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**EVOLUTIONARY TECHNOLOGICAL CHANGE:  
The Case of Fuel Ethanol in Developing Countries**

**Calestous Juma  
Science Policy Research Unit**

**Submitted in Partial Fulfilment of Requirements  
for the Degree of Doctor of Philosophy in Science and  
Technology Policy Studies**

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## **DECLARATION**

This thesis was written and submitted in accordance with the rules and regulations governing the award of Doctor of Philosophy Degree of the University of Sussex. I declare that the thesis has, neither in part nor in whole, been presented for examination at another university.

**CALESTOUS JUMA**  
Science Policy Research Unit

# **UNIVERSITY OF SUSSEX**

**CALESTOUS JUMA**

**DOCTOR OF PHILOSOPHY**

## **EVOLUTIONARY TECHNOLOGICAL CHANGE: The Case of Fuel Ethanol in Developing Countries**

### **SUMMARY**

This study suggests an evolutionary approach to the analysis of energy technology policy. The approach emphasizes economic fluctuations, technological change and institutional re-organization through time. The liquid fuel sub-sectors of Zimbabwe and Kenya constitute different technological systems adapted to the production and utilization of different energy forms. They represent different market niches in a techno-economic landscape. Gasoline occupies a central role in the energy budget. The 1973-74 oil crisis created major fluctuations which made it possible to introduce fuel ethanol as an alternative liquid fuel. The process of realizing the ethanol niche was largely dependent on the existence of technological options whose technical and financial characteristics allowed them to compete favourably with conventional liquid fuels. Niche realization also required the modification of the adoptive terrain to reduce the obstacles to the introduction of the new technological systems. The entire process takes an evolutionary perspective because it involves the generation, selection and retention of technological options under constantly changing conditions. Moreover, the technological systems continue to undergo or require incremental improvements after they have been installed. Such improvements require the generation of plant-level technical knowledge and often lead to the accumulation of local technological capacity. A glance at the evolutionary path reveals periods of gradual change, punctuated by moments of increased innovations which are often linked to periods of major fluctuations. The process is associated with a complex network of institutional arrangements which are also re-organized either in response to fluctuations or in anticipation of emerging niche opportunities. Institutions play a central role because the process is not random; it is purposive and based on socio-economic expectations. It is precisely this point that led to major differences in the process of niche realization in Zimbabwe and Kenya, although both countries were presented with the same technological options. The study draws a wide range of technology policy and research implications from these differences.

## INTRODUCTION

The 1973-74 oil crisis destabilized the world energy market and stimulated a search for alternative sources of energy. The use of biomass-based technologies started to receive renewed attention. The attempted transition towards more stable energy mixes brought forth the intricate linkages between energy, technology and socio-economic change. The energy transition involved the international transfer of machinery and know-how as well as the accumulation of related technological capacity.

This study attempts to unravel the major features of technological transition in the developing countries and contribute to policy studies by using the case of fuel ethanol development in Zimbabwe and Kenya as examples. There are several reasons why energy technology is an important source of insights on technological transition. The fact that no life can exist without energy flows makes this resource vital. However, there is a tendency among some energy researchers to subject all human activity to the physical laws governing energy, especially the entropy law, as has been done by Georgescu-Roegen.<sup>1</sup> The view in this study is that nothing is possible without energy, but energy is not everything. Entropic processes are an important consideration in energy matters but such approaches underestimate the role of materials, knowledge systems and technological innovation in the transition towards socio-economic complexity. It is precisely this evolutionary transition that makes energy important.

The first point to grasp is that energy does not exist in readily available forms but has to be extracted and utilized using technological devices. Energy transitions have tended to move from sources with lower to higher energy content as socio-economic conditions have evolved. These transitions were by no means Kuhnian shifts because various energy sources tended to co-exist over long periods. What is important is the fact that the

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1. "Casual observation suffices now to prove that *our whole economic life feeds on low entropy*, to wit, cloth, lumber, china, copper, etc., all of which are highly ordered structures," Georgescu-Roegen, *Entropy Law and the Economic Process*, pp. 277.

transition from one source of energy to another is often associated with major innovations, some of which have had profound economic consequences. This point can be illustrated by the case of the Industrial Revolution in Britain.<sup>2</sup>

Thomas has suggested an interpretation of the Industrial Revolution in which energy transition plays a central role.<sup>3</sup> He argues that wood shortage in the middle of the 18th century created ideal conditions for the use of relatively plentiful coal. However, the transition from wood to coal could not be made without the introduction of new technological systems which could enable pig iron to be refined into bar iron. The breakthrough came with the puddling and rolling process developed by Henry Cort in 1784. This innovation was part of a long history of efforts to use coal in iron refining. In the previous 25 years, there were at least 13 significant attempts to solve this problem.<sup>4</sup> The Cort process led to major innovations in machine tools and capital goods and subsequently revolutionized industrial production.<sup>5</sup> The Industrial Revolution (and the associated energy transition) was not an isolated phenomenon but a punctuation in which new technological systems associated with the widespread use of coal led to dramatic advances in socio-economic evolution.

This study emphasizes the interrelationships between socio-economic change, energy transition and technological innovations in a historical process. There are other advantages in studying energy transition as an indicator of long run socio-economic evolution. Energy sources tend to be distinct and fairly homogenous thereby limiting the range of production and utilization technologies. This is different in the case of other resources such

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2. "The Industrial Revolution...involved a...transition from reliance on renewable energy sources to dependence upon non-renewable fossil fuels. The coal-powered steam engine became the beating heart of industrialism. Its triumph was associated with other coal-based energy technologies, notably the use of coke for manufacturing iron," Layton, "The Industrial Evolution," pp. 249.

3. Thomas, "Energy Interpretation", pp. 1-15.

4. Morton *et al.*, "The Transition to Cort's Process", pp. 722-728.

5. For a similar view on the spread of the factory system in America, see Chandler, "Anthracite Coal", pp. 141-181. It should be noted that the use of coal as a source of energy was known for several centuries before the Industrial Revolution. What made the transition important, however, was the combination between this energy source, new innovations and general economic expansion. In other words, the Industrial Revolution was indeed a bifurcation in the long history of socio-economic evolution.

as food. There is a much wider range of carbohydrate sources than there are liquid fuels, a factor that restricts energy innovations along particular paths guided by fundamental physical and chemical laws as well as particular patterns of system configuration. The internal evolution of energy systems is therefore more confined within what Nelson and Winter have called "technological regimes".<sup>6</sup>

If these factors did not matter, it would still be important to examine alternative energy sources for purely economic reasons. The 1973-74 oil crisis worsened economic conditions in a large number of developing countries. The economic disruptions that followed the oil price increases made the search for alternative energy sources a worthwhile policy option. The share of foreign exchange earnings devoted to oil imports was large enough to warrant such policy interventions. The conventional view that energy consumption expanded in a linear way was brought to a sudden end by the re-organization of the world energy market.

But not all the vital lessons from these changes were learnt, especially those associated with efforts to introduce alternative energy technologies. Notions about the efficacy of "technical fixes" still dominate thinking in this field. It is often assumed that the problem is the lack of technological systems and not necessarily the complex socio-economic setting in which they are expected to operate. One of the most important realizations was the close link between energy, technology and economic change. Many analyses of energy transition over the post-1973 period were based on conventional economic models. But these models, as Clark has noted, are incapable of handling the long-term, dynamic, and uncertain characteristics of technical change.<sup>7</sup> Moreover, there is a large gap between economic theory and technology policy, a situation that has led Clark to suggest that economics, "with all its Cartesian and reductionist overtones, will have to be largely abandoned -- at least in so far as science and technology policy is concerned..."<sup>8</sup> These considerations are even more

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6. Nelson and Winter, *Evolutionary Theory*, pp. 258.

7. Clark, *Political Economy of Science*, pp. 229-230.

8. *Ibid.*, pp. 235.



important in issues that require major technological transitions from one energy source to another.

Marchetti notes that the "primary sources of energy, such as wood, coal, oil, gas and nuclear, form a sequence where the new sources slowly displace the old ones and finally replace them in the market".<sup>9</sup> The transition is usually towards energy sources with higher energy content as well as wider linkages into the techno-economic sphere. Barnett argues that the survival of new energy technologies depends on the physical, economic and social conditions prevailing in a particular market niche.<sup>10</sup> Both Marchetti and Barnett suggest (explicitly and implicitly) an evolutionary approach to the development of energy technology. Marchetti aims at building mathematical models for the diffusion of energy technologies in a manner analogous with the occupation of ecological niches by particular species. His hard modelling thus gives relatively smooth "Volterra curves".

Alternatively, the route identified by Barnett leads to an analysis which treats the energy market as an adaptive landscape which is constantly changing and which has strong selecting pressures. Technological systems are therefore not uniform entities with static internal characteristics. They constantly undergo incremental improvements due to internal as well as external pressures.<sup>11</sup> These changes (or technological drift) which occur in existing systems are not the only sources of structural re-organization. Major fluctuations in the techno-economic landscape may create favourable conditions for the introduction of new technological systems. This study is an illustration of such a process of technological change.

The liquid fuel sub-sectors of Zimbabwe and Kenya are conceived as landscapes in which different technological systems are adapted to the production and utilization of different energy forms and occupy different market niches. Gasoline occupies a central role in the energy budget. The 1973-74 oil crisis created major fluctuations which made it possible to introduce alternative liquid fuels. The process of realizing the new energy niches was largely dependent on the existence of technological options whose

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9. Marchetti, "Swings", pp. 13.

10. Barnett, "Rural Energy Needs", pp. 28.

11. This theme has been extensively explored in the "learning-by-doing" literature. See Fransman *et al.* (1984) for a sample of such studies.

technical and financial characteristics allowed them to compete favourably with existing energy sources. Niche realization also required the modification of the adoptive terrain to reduce the obstacles to the introduction of the new technological systems.

The entire process takes on an evolutionary perspective because it has a historical dimension and it involves the generation, selection and retention of technological options under constantly changing conditions. A glance at the evolutionary path reveals periods of gradual change (associated with technological drift), punctuated by moments of increased innovations (both novel and recombinant) which are often linked to periods of major fluctuations. The process is associated with a complex network of institutional arrangements which are also re-organized either in response to fluctuations or in anticipation of emerging niche opportunities. Institutions play a central role because the process is purposive and based on socio-economic expectations. It is through understanding the co-evolutionary dimensions of technology and institutions that we can have a clearer picture of policy issues. It is precisely this point that led to major differences in the process of niche realization in Zimbabwe and Kenya.

This study avoids some of the conventional aspects of fuel ethanol controversy. The debate over land-use, especially on the land competition between food and energy, is not discussed in this study. This is because the two projects do not seem to pose a problem of this nature since they rely on an agricultural base that is already devoted to sugarcane production. If a more general case were to be made against growing sugarcane in the first place, then such an argument would have to be extended to other non-food crops such as coffee, tea and tobacco as well. It is beyond the scope of this study to deal with the optimal choice of crops, especially in conditions where they already exist. However, if land was specifically brought under the plough to produce sugarcane for ethanol, then issues of land-use conflict would have to be considered.

There are other crucial questions relating to the rationale of investing in alcohol itself. The issue here would be to find out the opportunity cost of the project and determine the benefits that would accrue to the country from alternative ventures. As the study will show, the projects had their own

historical dynamics independent of what was the most suitable use of foreign exchange (in a hypothetical sense), and their potential social benefit to the two countries. Such a study, although useful, would illuminate a different set of issues from the ones that concern us most, the dynamics of technological change. The study will therefore deal specifically with the process of change using an evolutionary approach and not the comparison of statics. This will be done in eight chapters.

The first chapter will recapitulate the development of evolutionary views of socio-economic and technological change from Adam Smith to the present moment. This review will stress those developments which have contributed to our understanding of technological change, especially in the transition away from mechanistic concepts to evolutionary approaches. It will be argued that the influence of static and mechanistic concepts on conventional economics weakens its ability to deal with an inherently dynamic process such as technological change. A case will be made for an evolutionary approach.

The evolutionary view requires a different epistemological setting for conceptualizing the main issues and devising research methods. This will be the subject of Chapter 2. It will be argued that an evolutionary epistemology, insofar as it deals with dynamic realities, is one of the most suitable tools for examining technological change. In Chapter 3, the global resource market will be presented as an open system that undergoes constant fluctuations. The case of oil and sugar will be presented to illustrate how such shifts create conditions for internal re-organization through technological innovations. It will be argued that these fluctuations created favourable conditions for the potential introduction of fuel ethanol technological systems. This chapter also sets out the key factors which led to differences in policy approaches in the two countries.

The evolution of ethanol technological systems will be outlined in Chapter 4. It will be shown here that these systems evolved through a period of gradual transition punctuated by rapid innovation and the generation of a wide range of technological options which Zimbabwe and Kenya could choose from. The question of technology selection will be pursued in Chapter 5 in which the techno-economic landscape in the two countries will be mapped.

The notions of adaptive parameters and adoptive pre-conditions will be examined in detail in this chapter. Chapter 6 will compare the process of ethanol niche realization in the two countries and identify the main sources of differences in project implementation. It will be emphasized that the differences did not arise from the technological systems but from the process of implementation itself. The divergences between Zimbabwe and Kenya are further compared in Chapter 7. The last chapter will summarise the argument and identify the main policy and research implications of the study.

# **1. EVOLUTIONARY TECHNOLOGICAL CHANGE:**

## **A Theoretical Recapitulation**

### **Introduction**

This chapter examines the development of evolutionary approaches to the analysis of socio-economic and technological change. It argues that conventional economic approaches rely on Cartesian and Newtonian metaphors which are mechanistic and static and are therefore incapable of dealing with dynamic processes. The chapter outlines the major influences of the Cartesian and Newtonian views on economic thought, with specific reference to the analysis of technology transfer. The second section will examine the evolutionary views held by classical thinkers. It will deal only with those concepts which influenced the current theories of technological change. The third section covers the post-Marshallian era. In this section, the role of technical change in socio-economic evolution is emphasized. The fourth section deals with the dominant evolutionary theories of technological change. Finally, an alternative approach is offered for the analysis of emerging energy technologies in developing countries.

### **1.1 Conventional Thought and Technological Change**

The dominance of mechanistic thinking in economics and the purging of its organic content, prompted Veblen to ask: "Why is Economics not an Evolutionary Science?"<sup>1</sup> There are several reasons. First, biology was still embryonic at the time economics was consolidating itself. Darwin came to the scene a century after Adam Smith. Research in the biological sciences was largely devoted to classification rather than measurement and analysis.

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1. This was the title of his classic 1898 article. See Hamilton (1953) for a comparison between Newtonian and Darwinian approaches to economics.

But even more important were the efforts made in the 18th and 19th century to adopt the Cartesian-Newtonian world view and its Baconian methodology to economic analysis. The mechanistic content of economics cannot be understood without a glance at the growth of science in general.

The history of science can be summed up as a relentless search for what William James called "irreducible and stubborn facts".<sup>2</sup> Since the Greek days down to the Middle Ages, the search for irreducible and stubborn facts became a major subject of enquiry. This was brought to a head by Galileo whose tradition was continued by Newton. Galileo insisted that scientists should restrict themselves to those vital properties of material bodies that could be expressed in shapes, numbers, and movements.<sup>3</sup> The stage was set for the coming era of abstractions. And with the advent of Newtonian mechanics, biological notions (most of which were too dynamic to be subjected to the quantitative methods of the day) were banished to the periphery of mainstream science.<sup>4</sup>

The 17th century was the golden era of abstractions. Indeed, abstractions are a powerful analytical tool. By highlighting the essentials they improve understanding of social processes and help to rid society of numerous fallacies and misconceptions. But they pay little attention to the remainder of things. Insofar as the excluded things are significant, the abstractions may not necessarily be relevant to the totality from which they were initially abstracted. Narrow-mindedness inevitably steps in.<sup>5</sup>

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2. William James, quoted in Whitehead, *Science and the Modern World*, pp. 3.

3. The attachment to quantification was later refined to the Kelvin dictum: "When you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind," quoted in McCloskey, pp. 484. Hume expressed the same view: "When we run over libraries...what havoc must we make? If we take in our hand any volume -- of divinity or school metaphysics, for instance -- let us ask, *Does it contain any abstract reasoning concerning quantity or numbers?* No. *Does it contain any experimental reasoning concerning matter of fact and existence?* No. Commit it then to the flames, for it can contain nothing but sophistry and illusion," *ibid.*, pp. 485.

4. A detailed account of how the Cartesian-Newtonian paradigm has adversely influenced the sciences in general, and medicine in particular, is provided by Capra (1982).

5. As Whitehead says, the great thinkers who consolidated the modern scientific thought "applied the seventeenth century group of scientific abstractions to the analysis of the unbounded universe. Their triumph...was overwhelming; whatever did not fit into their scheme was ignored, derided, disbelieved," Whitehead, *Science and the World*, pp. 74.

Abstractions are usually instantaneous configurations of matter expressed in the context of time and space, appearing in simple location, as Whitehead puts it. He argues that this simple location has led to the error of mistaking the abstract for the concrete, the "fallacy of misplaced concreteness".<sup>6</sup> The simple location has therefore "no reference to any other times, past or future, it immediately follows that nature within any period does not refer to nature within any other period".<sup>7</sup> It is therefore clear that such abstractions cannot adequately deal with dynamic systems which have large numbers of interactions and change over time. The problem is compounded when such abstractions are translated into laws of economic activity and society is expected to behave accordingly; if it does not, it is often branded "irrational".

This is the 17th century tradition to which economists aspired; the tradition of hard sciences. The post-Smithian economics relied increasingly on abstractions; mathematicians endeavoured to make the discipline an exact science. This process reached a significant peak with the publication in 1874 of Walras' *Elements of Pure Economics* whose general equilibrium theory had strong mechanical underpinnings. To him "the pure theory of economics or the theory of exchange and value in exchange" was simply a "physico-mathematical science like mechanics or hydrodynamics".<sup>8</sup> The need to make economics an exact science was a strong drive during the period. Walras says that it is "perfectly clear that economics, like astronomy and mechanics, is both an empirical and rational science".<sup>9</sup> He complained that France produced mathematicians with no knowledge of economics and cultivated men of letters devoid of any notion of mathematics. This, in his view, led to the flourishing of bad mathematicians and bad pure economists. He said the 20th century would need to entrust the social sciences to men of general culture initiated into inductive and deductive thinking and who are familiar with reason and experience. "Then

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6. *Ibid.*, pp. 63.

7. *Ibid.*, pp. 64.

8. Walras, *Elements*, pp. 71.

9. *Ibid.*, pp. 47.

mathematical economics will rank with mathematical science of astronomy and mechanics; and in that way justice will have been done to our work."<sup>10</sup>

But the very discipline that set the pace for economics started changing its course in the last century leading to new physics. In the sub-atomic world there are no irreducible and stubborn facts but relationships, no isolated entities but systems. It can therefore be argued that conventional economics is well ahead of the other social sciences, but in a misleading direction; even the pace-setter, physics, has changed course.<sup>11</sup> Other sciences are changing course too. And as Veblen said, if "economics is to follow the lead or the analogy of the other sciences...the way is plain so far as the general direction in which the move will be made".<sup>12</sup> The evolutionary route. This route, however, was not taken. Instead, evolutionary concepts in the post-Marshallian period sought refuge in other theoretical camps and co-existed with Cartesian-Newtonian frameworks.

Much of Smith's equilibrium, laws of motion and scientific objectivity are drawn from Newtonian physics. The economic sphere was a microcosm of the celestial arena; forces of supply and demand, guided by the invisible hand, would generate a near-instantaneous balance, as market forces gravitated in the right direction. Newtonian concepts can also be traced in the economic formulation of human welfare. The ideal social welfare balance, like that of Newtonian celestial objects, could be realized through some form of Pareto optimality. And of course Ptolemy lives through the pages of mainstream economics -- the individual was, and still is, at the centre of the economic universe. The reification of the Newtonian model by economists has left the discipline a set of analytical tools which cannot adequately deal with the complex realities of economic processes.

Early studies on technology transfer to the developing countries were largely influenced by mechanistic thinking. This is partly because of the influence of both the concept of comparative advantage and that of the

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10. *Ibid.*, pp. 48.

11. Goergescu-Roegen says that "by the time Jevons and Walras began laying the cornerstones of modern economics, a spectacular revolution in physics had already brought down the mechanistic dogma both in the natural sciences and in philosophy. And the curious fact is that none of the architects of 'the mechanics of utility and self-interest' and even none of the latter-day model builders seem to have been aware at any time of this down fall," *op. cit.*, pp. 2-3.

12. Veblen, "Why is Economics not Evolutionary," pp. 388.



"dependency school". These two schools of thought carry strong mechanistic elements. The concept of comparative advantage assumes a world which is reversible and one where the values of each product are known in advance and their effects on the balance of trade can be established *a priori*. The international economic scene is viewed through the Heckscher-Ohlin model as a balanced system in which countries producing labour-intensive goods can mutually benefit from trade with those producing capital-intensive goods. This model assumes uniformity in technology and consumption patterns. It only allows for variations in factor endowment.

Similar Newtonian mechanisms dominate the "dependency theory". This theory, at least in its classical form, assumes a balance where economic growth in the industrialized countries is achieved at the expense of development in the peripheral countries. The economic system is seen as a constellation of economic spheres revolving around a centre; hence the centre-periphery relationships. Although this is a simplification of the theory, it captures the mechanistic content of its central themes. From these bases have sprung a series of theories of the transfer of technology to the developing countries. These theories assumed that technological systems were given units whose values were known or reducible to a few variables such as factor proportions.

A basic tenet of this study is that such approaches are incapable of dealing with the complex socio-economic and institutional relationships surrounding technological systems and the dynamics of social change. Moreover, they also ignore the fact that technological development is an evolutionary process associated with irreversible changes. To capture these dynamics, this study proposes to re-examine the literature and isolate those contributions which may help in the construction of an alternative analytical framework for studying dynamic technological processes.

## **1.2 Classical Antecedents**

Evolutionary views of socio-economic development in general, and technological change in particular, are to be found in the work of classical

economists. It is notable that Darwin's work was inspired by reading Malthus' *Essay on Population*.<sup>13</sup> The application of Darwin's theory to economic development was impeded by several factors. First, social change was not obviously gradualist and therefore the theory was not particularly consistent with the observations of social historians. Second, the rules of the hard sciences (especially Newtonian physics) combined with Cartesian philosophy which viewed natural phenomena as automata and the Baconian appeal to empirical rigour had become the most legitimate way of expressing reality. Economics readily adopted this mechanistic world view.

Classical economists recognized the dichotomy of static and dynamic systems although they were influenced more by mechanical dynamics than by organic evolution. It is in this context that the dynamics of Mill and Smith can be understood. Smith recognized the evolution of society through complexity and differentiation as exemplified by his assessment of the division of labour. But he drew a distinction between functional differentiation in zoological and social systems by stressing that unlike animals, human beings had specific attributes which enabled the division of labour to emerge; the ability to truck, barter, and exchange. These abilities could be brought into a common stock "where every man may purchase whatever part of the produce of the other men's talent he has occasion for".<sup>14</sup>

Species, Darwin came to show, were engaged in a constant struggle for survival. They also changed through gradual but chance variations. These were the cornerstones of his evolutionary theory, which got a mixed reception from his contemporaries. Marx's response was particularly interesting because he used the concept to enrich his Hegelian heritage but

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13. According to Schumpeter, "the terms static and dynamic were...introduced into economics by John Stuart Mill. Mill probably heard them from Comte, who, in turn tells us that he borrowed them from the zoologist de Brainville," *Theory of Economic Development*, pp. xi. These concepts, however, were originally obtained from classical physics.

14. Smith, *The Wealth of Nations*, pp. 121. "The strength of the mastiff is not...supported by either the swiftness of the greyhound, or by the sagacity of the spaniel, or by the docility of the shepherd's dog. The effects of those different geniuses and talents...cannot be brought into a common stock, and do not...contribute to the better accommodation and conveniency of the species," *ibid.*, pp. 21. See Houthakker (1956) for an extension of the view that Smith's analysis of the division of labour was akin to speciation.

severely attacked Darwin and his followers.<sup>15</sup> There are two main reasons for this hostility. First, the Malthusian content of the theory was inconsistent with Marx's own ideological position. He saw Malthusianism as an apologia for the establishment and Engels asserted that Darwinism was more scientific without its Malthusian content. Second, Marx and Engels contended that their conception of history as a series of class struggles was richer and deeper than the "weakly distinguished phrases of the struggle for existence".<sup>16</sup> Marx therefore rejected the application of Darwinian views to socio-economic evolution, preferring a Hegelian approach. However, he adapted Darwinian concepts to his analysis of technological change.<sup>17</sup>

Technology, according to Marx, evolves from crude designs to more refined systems that benefit from scientific disciplines:

The power loom was at first made...of wood; in its improved modern form it is made of iron... It is only after considerable development of the sciences of mechanics, and an accumulation of practical experience that, the form of a machine becomes settled entirely in accordance with mechanical principles, and emancipated from the traditional form of the tool from which it emerged.<sup>18</sup>

This occurs in a mutually-reinforcing socio-economic environment.<sup>19</sup> In this interactive process, the role of individuals adds only a little to the broader evolution. "A critical study of technology would show how little any of the inventions of the eighteenth century are the work of a single individual."<sup>20</sup> Marx equated the development of technology to that of biological organs. "Darwin has directed attention to the history of natural technology, i.e. the formation of the organs of plants and animals which

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15. When Marx first read Darwin's *Origin* in 1860, he wrote to Engels that "although it is developed in the crude English style, this is the book which contains the basis in natural history for our view," Meek, *Marx and Engels on Malthus*, pp. 172.

16. *Ibid.*, pp. 187.

17. See Harris (1934) for a discussion of dialectical and Darwinian economic evolution, and Colp (1982) for an exposition of the myth that Marx wanted to dedicate *Capital* to Darwin.

18. Marx, *Capital*, Vol. 1, pp. 505.

19. "Social relations are closely bound up with productive forces. In acquiring new productive forces men change their mode of production; and in changing their mode of production, in changing the way of earning their living, they change all their social relations. The handmill gives society with the feudal lord; the steam-mill, society with the industrial capitalist," Marx, *Poverty of Philosophy*, pp. 102.

20. Marx, *Capital*, Vol. 1, pp. 493.

serve as the instruments of production for sustaining their life. Does not the history of the productive organs of man in society, or organs that are the material basis of every particular organisation, deserve equal attention?"<sup>21</sup> As the tools evolve, they are adapted to the requirements of particular applications and professions.<sup>22</sup> This functional differentiation forms one of the material conditions for the existence of machinery. Here we see Darwin's law of variation applied to technical change.<sup>23</sup>

Marx recognized that technical change continued long after the machinery had been installed, a fact that underscores the evolutionary nature of technological progress. As noted elsewhere, he paid particular attention to the role of working experience, or the accumulation of disembodied technical change. Marx anticipated the modern studies of firm-level technical change in the capital goods sector. "When machinery is first introduced...new methods of reproducing it more cheaply follow blow by blow, and so do improvements which relate not only to individual parts and details of the machine, but also to its whole construction."<sup>24</sup> He was able to blend Darwin's notions with Hegelian dialectics to provide a methodological approach to technical change that is unparalleled among classical thinkers. Studies which have ignored this fact have missed the vital interactions and

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21. *Ibid.* Marx laments the absence of such a book. It still does not exist. Marx attempted to write such a history, which is still locked away in unpublished notebooks. See Colman, "Short Communications," pp. 234-235, for a list of the unpublished notebooks, dating mainly from 1863. Recent publications of Marx's work on technology are available in German by Müller (1981) and Wilkelmann (1982).

22. "In Birmingham alone 500 varieties of hammer are produced, and not only is each one adapted to a particular process, but several varieties often serve exclusively for the different operations in the same process. The manufacturing period simplifies, improves and multiplies the implements of labour by adapting them to the exclusive and specific functions of each kind of worker," Marx, *Capital*, Vol. 1, pp. 460-461.

23. "As long as the same part has to perform diversified work, we can perhaps see why it should remain variable, that is, why natural selection should not have preserved or rejected each little deviation of form so carefully as when the part has to serve for some one special purpose. In the same way that a knife which has to cut all sorts of things may be of almost any shape; whilst a tool for some particular purpose must be of some particular shape," Charles Darwin, *Origin of Species*, quoted in *ibid.*, pp. 461.

24. *Ibid.*, pp. 528.

feedbacks between technology and social change and have erroneously viewed Marx as a technological determinist.<sup>25</sup>

Marx's evolutionary notions were overshadowed by his appeal to revolutionary social change and therefore did not have any major influence on mainstream economics. It was Marshall who first attempted to bring the notions into mainstream economic thought.<sup>26</sup> To Marshall, the "Mecca of economics lies in economic biology rather economic dynamics."<sup>27</sup> He argued that economics was like biology because they both dealt with "a matter, of which the inner nature and constitution, as well as the outer form, are constantly changing".<sup>28</sup> For Marshall, the subject-matter of economics was "human beings who are impelled, for good or for evil, to change and progress".<sup>29</sup> Although he advocated the use of biological concepts, his own work paid only token allegiance to the approach, a mere pilgrimage to the Mecca of economics. Much of his *Principles of Economics* (1890) is non-evolutionary except for the sections which deal with industrial organisation and the division of labour. Marshall draws from the concepts of survival of the fittest and the physiological views of human behaviour. He sees large-scale industries as trees of the forest which grow, compete for light and water, lose vitality, grow old, and die; except for "vast joint-stock companies, which often stagnate, and do not readily die".<sup>30</sup>

Marshall's evolutionary views differed remarkably from Marx's because of his appeal to Darwinian gradualism: "Economic evolution is gradual. Its progress is sometimes arrested or reversed by political catastrophes; but its forward movements are never sudden; for even in the

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25. Studies on Marx's analysis of technology include Hansen (1921), Heilbroner (1967), Sweezy (1968), Rosenberg (1976), Shaw (1979), and McKenzie (1984).

26. For a review of Marshall's assertion that economics was a branch of biology, see Hirschleifer (1977). Hirschleifer (1982) has also tried to blend economics, law and evolutionary concepts. For an assessment of the use of economic models in ecology, see Rapport *et al.* (1977).

27. Marshall, *Principles of Economics*, pp. xii.

28. *Ibid.*, pp. 637.

29. *Ibid.*, pp. xlii. But not for all human beings because "economics is a study of...particular nations, of particular social strata; and it is only indirectly concerned with the lives of men of exceptional genius or exceptional wickedness," *ibid.*, pp. 697.

30. *Ibid.*, pp. 263. Marshall's analogy of the "trees of the forest" has been tested by Lloyd-Jones *et al.* (1982) in the case of the cotton industry in the 19th century and shown to be valid for the period.

Western world and in Japan it is based on habit, partly conscious, partly unconscious."<sup>31</sup> But like Marx, he admits that individuals add only little to the cumulative changes which have been in the making long before them.<sup>32</sup>

Marshall visualized some form of equilibrium in the growth of firms. He states that "a business firm grows and attains greater strength, and afterwards perhaps stagnates and decays; and at the turning point there is a balancing or equilibrium of the forces of life and decay..."<sup>33</sup> But although such balances appear dynamic, Marshall did not abandon the Cartesian-Newtonian world view. For the foundations of economics must "give a relatively large place to mechanical analogies".<sup>34</sup> The fragmentary statics were seen as a temporary feature. However, he offered an economic methodology under which mechanical analogies would be used in the early stages of economic evolution and biological explanations would take over in later stages.<sup>35</sup>

Marshall insisted on using mechanical analogies and mathematical abstractions. Mathematics was only useful to economics if it could throw "a bright light on some small part of the great economic movement rather than at representing its endless complexities."<sup>36</sup> As a result, the subject-matter would have to be reduced to steady-state entities that validate the use of mathematics. His tone was Newtonian in his view of the "stationary state". Like celestial bodies, parts change while the whole remains stationary: individuals grow old and die while the population remains stable; businesses rise and fall while firm population remains the same; grain prices fluctuate with every harvest but the average value of the grain remains stable.

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31. *Ibid.*, pp. xi.

32. Thus "...an inventor, or an organizer, or a financial genius may seem to have modified the economic structure of a people almost at a stroke; yet the part of his influence which has not been merely superficial and transitory, is found on inquiry to have done little more than bring to a head a broad constructive movement which has long been in preparation," *ibid.*, pp. xii.

33. *Ibid.*, pp. 269.

34. *Ibid.*, pp. 12.

35. "There is fairly a close analogy between the early stages of economic reasoning and the devices of physical statics... I think that in the later stages of economics better analogies are to be got from biology rather than from physics; and, consequently, that economic reasoning should start on methods analogous with those of physical statics, and should gradually become more biological in tone," Marshall, "Mechanical and Biological Analogies," pp. 314.

36. *Ibid.*, pp. 313.

To Marshall, the growing command of mankind over nature changed the character and magnitude of economic and social forces in a Newtonian way: "Our planetary system happens...to be a stable equilibrium; but a little change in circumstance might make it unstable; might for instance, after a time cause one of the planets to shoot away from the sun in a very long ellipse, and another to fall into it."<sup>37</sup> The law of supply and demand also takes, at an early stage, a Newtonian outlook: "In the earlier stages of economics, we think of demand and supply as crude forces pressing against one another, and tending towards a mechanical equilibrium; but in the later stages, the...equilibrium is conceived not as between crude mechanical forces, but as between the organic forces of life and decay."<sup>38</sup> Marshall's biological notions remained undeveloped as neo-classical thought took root.

### 1.3 Evolutionary Theories of Economic Change

Although post-Marshallian economic thought was dominated by mechanistic notions, efforts were made to inject some dynamic elements into its content.<sup>39</sup> One of these areas was market competition. Competition was viewed in conventional economics as analogous with Newtonian motions where resources "gravitated" towards their most optimal utility and prices were

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37. *Ibid.*, pp. 317.

38. *Ibid.*, pp. 318. Marshall was committed to the mechanical thinking of the day despite his appeal to biological analogies. All life is reducible to matter, the hard stuff that all things are supposedly made of. This could be understood through mechanical analogies. And since society is not an ordinary combination of inanimate material, we have to revert to some organic view of economic activity. This ambivalence is reflected in his analysis of competition, leading to some confusion over perfect and imperfect competition. His approach was later re-orientated by the neo-classical school, especially with the formulations of monopolistic competition and imperfect competition by Chamberlin (1933) and Robinson (1933). It is instructive that his biological views have been a subject of ridicule by neo-classical economists, for example by Samuelson: "All this prattle about the biological method in economics -- and the last decades' genuine progress in biology through the techniques of physics has confirmed my dictum...that talk about a unique biological method does represent prattle -- cannot change this fact: any price taker who can sell more at the going price than he is now selling and who has falling marginal cost will not be in equilibrium. Talk of birds and bees, giant trees in the forest, and declining entrepreneurial dynasties is all very well, but why blink at such an elementary point?" Samuelson, "The Monopolistic Competition," pp. 112.

39. See Spengler (1950) for a review of evolutionary thought in American economics since 1776.

"forced" to the lowest possible levels which could be sustained over the long-run. Competition therefore guaranteed order and stability in the market just as gravitation did among Newtonian bodies.<sup>40</sup> This view did not adequately account for the competitive *behaviour* of firms. Economic theory was bedeviled with the paradoxical concepts of monopoly and perfect competition; "both are situations in which the possibility of any competitive behaviour has been ruled out by definition".<sup>41</sup>

Chamberlin attempted to re-orientate economic theory by introducing dynamic concepts. Although he remained in the orthodox economic mainstream, his work carried elements of evolutionary thinking. His analysis sought to synthesize monopoly and competition in a way that was akin to chemical processes.<sup>42</sup> The chemical synthesis requires continuous movement and change, thereby taking an evolutionary outlook under which dynamic and static characteristics are clearly distinguished. Moreover, the dominant role of continuous product differentiation and the wide range of product possibilities suggests an implicit evolutionary content.

Although product variation plays a significant role in Chamberlin's model, it is not clear whether technology was to be held constant or not. But since he stressed product variation, it is reasonable to assume that innovation would play a significant role in the process. Indeed, he subsequently admitted that an entrepreneur would need to innovate to break away from the established order of things. "The appearance on the market of every new product creates pressure in some degree on the markets for others, and when products are variable and determined by profit maximization some of this pressure is bound to be exerted on quality in order to maintain prices which people can afford to pay."<sup>43</sup> Technical change

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40. McNulty (1968) has extended the physical analogy to equate the concept of perfect competition to a perfect vacuum; "not an 'ordering force' but rather an assumed 'state of affairs'", *ibid.*, pp. 643.

41. *Ibid.*, pp. 641.

42. Chamberlin, *Monopolistic Competition*, pp. 3.

43. Chamberlin, "Product as Variable," pp. 131. "Thus, in a world whose technology is constantly creating new products, it should not be surprising to find that a part of the whole process is the deterioration of other products in order to make room for the new ones at the mass market level where the population is concentrated," *ibid.*



therefore continues to unfold as firms adjust to emerging competitive conditions in the market environment.

Despite these dynamic aspects, Chamberlin did not seek to recast his theory on an explicit evolutionary forge. This was left to Alchian who sought to replace the notion of profit maximization with the biological concept of natural selection. "The suggested approach embodies the principles of biological evolution and natural selection by interpreting the economic system as an adoptive mechanism which chooses among exploratory actions generated by the adaptive pursuit of 'success' or 'profit'.<sup>44</sup> Competitive behaviour among firms, he argued, was not determined by the motive of profit maximization, but by "adaptive, imitative, and trial-and-error" behaviour in the search for profits. Success was influenced and reinforced by previous success, not motivation. The fact that successful firms were still in the market was not a result of their profit maximizing behaviour but because others had been eliminated. The situation is clearly Darwinian: "[T]hose who realize *positive profits* are the survivors; those who suffer losses disappear".<sup>45</sup> He rejects the efficacy of the entrepreneur because in a world of fools there would still be profits.<sup>46</sup>

Although Alchian gives a detailed assessment of the behaviour of firms in a competitive environment, he does not offer a convincing account of the role of technical change in economic natural selection. Part of the problem results from excessive emphasis on imitative behaviour to which much of the innovation is attributed. "Adapting behavior via imitation and venturesome innovation enlarges the model. Imperfect imitators provide opportunity for innovation, and the survival criterion of the economy determines the successful, possibly because imperfect, imitators."<sup>47</sup> But those who pioneer in innovating do so in response to changing market conditions.

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44. Alchian, "Uncertainty, Evolution, and Economic Theory," pp. 211. For an enlargement of Alchian's approach, see Enke (1951). Penrose (1952) has provided a critique of Alchian's model, emphasizing the purposive nature of the profit motive and the dangers of relying on biological metaphors.

45. *Ibid.*, pp. 213.

46. *Ibid.* "Also, the greater the uncertainties of the world, the greater is the possibility that profits would go to venturesome and lucky rather than to logical, careful, fact-gathering individuals," *ibid.*

47. *Ibid.*, pp. 219.

"Innovation is provided also by conscious wilful action, whatever the ultimate motivation may be, since drastic action is motivated by the hope of greater success as well as the desire to avoid impending failure."<sup>48</sup> This view ignores conditions under which innovation becomes a critical competitive tool; it sets in motion the imperatives for its constant improvement.

As in neo-classical approaches, Alchian treats technical change as exogenous to economic evolution. It is merely brought into play for purposes of adaptation to the changing market environment but does not necessarily shape those conditions. But in spite of the shortcomings, Alchian provides a useful starting point for incorporating innovation into the economic natural selection processes. Alchian did not seek to reframe all economic theory into an evolutionary outlook. He restricted his analysis to firm behaviour, especially on the irrelevance of the notion of profit maximization.<sup>49</sup>

Institutional economics, or institutionalism, provided one of the earliest bases for evolutionary concepts. Institutionalism was not itself a coherent package of analytical tools, but a diverse collection of critical ideas built on a theoretical and methodological rejection of conventional economics. It revolved around Veblen, Mitchell, and Commons.<sup>50</sup> They were dissatisfied with the neo-classical preoccupation with abstractions, demanded the integration of other social sciences into economic thought, and rejected the casual empiricism of conventional economics.

Veblen argued that economic activity evolved in an unfolding sequence, consistent with the the close-knit body of theory required for any evolutionary science. But conventional economics had remained at the stage where "the natural sciences passed through some time back".<sup>51</sup> The tools of economic analysis were still taxonomic. Veblen sought to reformulate the contextual setting of economics. "There is the economic life process still in

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48. *Ibid.*

49. Boulding attempted to restructure economics and bring it in line with ecological dynamics. In fact, he did not reconstruct economic theory but simply embellished it with an ecological canopy. He sought to defend economics as a hard science, a discipline based on abstractions. "It must never be forgotten that economics is an abstraction, useful and necessary as it is," Boulding, *A Reconstruction*, pp. 3. The main task of his work was "to improve the abstraction," *ibid.*, pp. 5.

50. See Blaug, *Economic Theory*, pp. 678. Spengler (1974) looks in detail at institutionalism since 1776. See also Boulding (1957) for a hostile assessment of institutional economics.

51. Veblen, *op. cit.*, pp. 384.

great measure awaiting theoretical formulation."<sup>52</sup> Industry and technology are the motive power behind this process. "The active material in which the economic process goes on is the human material of the industrial community. For the purpose of economic science the process of cumulative change that is to be accounted for is the sequence of change in the methods of doing things, -- the method of dealing with the material means of life."<sup>53</sup>

Veblen was writing at the turn of the century when the role of technological change in economic evolution had become apparent, but was largely unexplained. To him, everyone was intractably trapped in the evolutionary sweep of technological advancement. "Under the stress of modern technological exigencies, men's every-day habits of thought are falling into the lines that in the sciences constitute the evolutionary method; and knowledge which proceeds on a higher, more archaic plane is becoming alien and meaningless to them. The social and political sciences must follow the drift, for they are already caught in it."<sup>54</sup>

Veblen emphasized the role of technological change, broadly defined to include both hardware and know-how, but his work did not manifest a coherent analysis of the role of technological change in economic evolution. Moreover, he stressed industrial arts to a point that bordered on determinism. The adage, necessity is the mother of invention was reversed; invention had become the mother of necessity. Technological change was an inherent aspect of social evolution and still took place despite economic factors. This line of reasoning has recently been pursued by Gordon in an attempt to unify the various elements of institutional economics. To Gordon, "a new scientific discovery generally occurs because it is the next natural step in a technological sequence, not because someone wants to solve such

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52. *Ibid.*, pp. 387.

53. *Ibid.*

54. *Ibid.*, pp. 397. Veblen placed his evolutionary conception in an endogenous institutional context: "From what has been said it appears that an evolutionary economics must be the theory of a process of cultural growth as determined by the economic interest, a theory of a cumulative sequence of economic institutions stated in terms of the process itself," *ibid.*, pp. 393.

and such a problem and goes out and does it or because the profit motive called for a labour-saving rather than a capital-saving innovation."<sup>55</sup>

This view was based on John Dewey's instrumentalist philosophy and has become pervasive in some sections of institutional thinking in the United States. Latter-day advocates of this position include DeGregori who argues that there are no limits to growth as a "sustainable economy is one that continually evolves in the use of science and technology to create new resources".<sup>56</sup> This view is not held by all institutionalists. Ayres and his followers point out that social forces can arrest technological progress just as much as technological change can disrupt social institutions.<sup>57</sup>

Gordon obviously elevates Veblen's position to its absurdity, but that is a different problem. The issue at hand is the self-propelling dynamism that is accorded to technological change. There are several problems with this position. Firstly, such a view ignores the uneven distribution of the potential for technological change; why some societies develop particular technologies and others do not. Secondly, this kind of reasoning leads to some form of technological fatalism based on the assumed inevitability of cumulative change; because technological change is inevitable, there would be no need to do anything about it, except to wait helplessly for its emergence and consequences. Thirdly, and more fundamental, this view underestimates the role of external or environmental factors in technological evolution. In this view the external factors which shape the selection process and the unfolding cumulative sequence are excluded from analysis; the evolutionary context is therefore weakened. Veblen often suggested new directions for analysis but left them undeveloped. The role of technological change in the process of economic evolution had therefore to await the analysis of Schumpeter.

Schumpeter was a neo-classical thinker, yet his work contained both implicit and explicit evolutionary notions. He was admittedly influenced by

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55. Gordon, *Institutional Economics*, pp. 12. We are further told: "The cures for the common cold and for cancer will come at the appropriate stage in the evolution of our technology, but not because we are desperate for cures...and a squad of scientists has been assigned the task of finding these cures. If wishing and consciously diverting resources to the task could do the job, we would have had a cure for cancer long ago." *Ibid.*

56. DeGregori, "Technological Limits to Forecasts of Doom," pp. 1. This view is explored in detail in DeGregori, *Theory of Technology*.

57. Ayres, *The Theory of Economic Progress*.

Walras and Marx.<sup>58</sup> It is apparent that Schumpeter was influenced by both static and dynamic economic theories. By locating economic transition in the broader context of social change, Schumpeter adopted an evolutionary model in which technological change and the efficacy of the entrepreneur as an innovative agent played the most significant role.<sup>59</sup> However, because of his Walrasian influence, he used the notion of equilibrium as a theoretical norm.

The Schumpeterian economic system carried strong evolutionary notions. "The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process."<sup>60</sup> The capitalist system can never be stationary.<sup>61</sup> What then propels the evolutionary system of capitalism? "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new market, the new forms of industrial organization that capitalist enterprise creates."<sup>62</sup> The changes "illustrate the same process of industrial mutation -- if I may use that biological term -- that incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism."<sup>63</sup>

In his early work, Schumpeter analyzed not the process of evolution itself, but the dynamics which bring it about. "Not how the economic process developed historically to the state in which we actually find it, but the workings of its mechanism or organism at any given stage of development, is

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58. "Walras provided the foundations for his edifice, but Marx suggested to him the method for building on that foundation a structure that reflects his own 'vision'." Smithies, "Memorial," pp. 18.

59. Schumpeter's theory of innovation in his early work was slightly different from that presented in his later studies. See Sweezy, "Marx," pp. 117, and Freeman *et al.*, *Unemployment*, pp. 35-43, for details.

60. Schumpeter, *Capitalism*, pp. 82.

61. "And this evolutionary...process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change it alters the data of economic action; this fact is important and these changes (wars, revolutions and so on) often condition economic change, but they are not its prime movers. Nor is this evolutionary character due to a quasi-automatic increase in population and capital or to the vagaries of monetary systems of which exactly the same thing hold true," *ibid.*, pp. 82-83.

62. *Ibid.*, pp. 83.

63. *Ibid.*

what we are to analyse."<sup>64</sup> The influence of Walras and Marx can be noted at this metaphorical level in his reference to the mechanism or organism of the economic process. He attempts to blend the two. Schumpeter follows Marx's cue by rejecting the hasty generalizations arising from the Darwinian "postulate that a nation, a civilisation, or even the whole of mankind, must show some kind of uniform unilinear development".<sup>65</sup> He also rejects the Newtonian view of society by asserting that historical "changes constitute neither a circular process nor pendulum movements about a centre."<sup>66</sup>

There is a difference between Marx and Schumpeter which deserves mention. Marx started his analysis with socio-economic fluctuations and suggested that society would move towards equilibrium as classes disappear and institutions such as the state wither away. He thus collapsed into the Cartesian-Newtonian tradition. Schumpeter, on the other hand, started his analysis by assuming an equilibrium state but emphasized the manner in which the equilibrium was destabilized. Consequently, Marx was more interested in the abolition of capitalism while Schumpeter was interested in the sources and effects of instability in the economic system.

For Marx socialism would emerge from the collapse of capitalism while for Schumpeter it would result from the success of capitalism. Ironically, a Marxist position would lead to counter-evolutionary consequences as the sources of variability, competition, and selection are eliminated. This is a logical impossibility if the view that social systems are in constant flux is accepted. There is a tendency in the Schumpeterian system for the situation to return to a near-equilibrium state as investment opportunities shrink and the role of entrepreneurs becomes obsolete.

Schumpeter's theory of economic development emphasized the endogenous forces which bring about economic evolution. For economic development to occur, a society had to do more than just adapt to changing market conditions. If "the phenomenon that we call economic development is in practice simply founded upon the fact that the data change and that the economy continuously adapts itself to them, then we shall say that there is

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64. Schumpeter, *Theory of Development*, pp. 10.

65. *Ibid.*, pp. 57.

66. *Ibid.*, pp. 58.

no economic development".<sup>67</sup> In the Schumpeterian system, development is understood as "changes in economic life as are not forced upon it from without but arise by its own initiative, from within".<sup>68</sup> The transition is both cumulative and pre-conditional: "Every concrete process of development finally rests upon preceding development... Every process of development creates the prerequisites for the following".<sup>69</sup>

His evolutionary theory of development transcends the notions of circular economic flows and the tendency towards general equilibrium.<sup>70</sup> The changes in the circular flow and the destabilization of equilibrium result in the sphere of industry and commerce (on the supply side) not in the area of "wants of the consumers of final products" (on the demand side). The shift is not, by definition, minor; it is one "*which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps*. Add successively as many mail coaches as you please, you will never get a railway thereby".<sup>71</sup>

Schumpeter emphasizes further the evolutionary view of economic change in his *Business Cycles*: "[I]t is to physiology and zoology -- and not to mechanics -- that our science is indebted for an analogous distinction which is at the threshold of all clear thinking about economic matters".<sup>72</sup> He defines economic evolution as the "changes in the economic process brought about by innovation, together with all their effects, and the responses to them by the economic system".<sup>73</sup>

In his analysis, Schumpeter employs the same technique used by Marshall in which static abstractions form the theoretical norm:

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67. *Ibid.*, pp. 63.

68. *Ibid.*

69. *Ibid.*, pp. 64.

70. "It is spontaneous and discontinuous change in the channels of the flow, disturbance of equilibrium, which forever alters and displaces the equilibrium state previously existing. Our theory of development is nothing but a treatment of this phenomenon and the processes incident to it," *ibid.*

71. *Ibid.*

72. Schumpeter, *Business Cycles*, pp. 37.

73. *Ibid.*, pp. 86. Circular economic flows are viewed by Schumpeter as the circulation of blood in a dog, but the study of this circulation does not show how dogs come to exist at all. "Obviously, we have here a different process before us, involving different facts and concepts such as selection or mutation or, generally, evolution," *ibid.*, pp. 36.

For our present argument we may thus visualize an economic process which merely reproduces itself at constant rates: a given population, not changing in either numbers or age distribution, organized for purposes of consumption in households and for purposes of production and trade in firms, lives and works in an unchanging physical and social (institutional) environment.<sup>74</sup>

By holding such factors constant, various neo-classical tools could be applied. The production function was one of them. According to Schumpeter, the production function "tells us all we need to know for purposes of economic analysis about the technological process of production".<sup>75</sup> Innovation, the central force in the Schumpeterian system, is defined simply "as the setting up of a new production function".<sup>76</sup> More specifically, innovation is understood as "*a change in some production function which is of the first and not of the second or a still higher order of magnitude*".<sup>77</sup>

The disequilibrium caused by technical change necessitates difficult adaptations among firms to the changed environment. The situation starts to look ecological; the disruption of homeostasis in the ecosystem also opens up new opportunities for adaptation and flourishing of some species, niches for this matter. Schumpeter aptly calls this economic space.<sup>78</sup> The creation of

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74. *Ibid.*, pp. 38.

75. *Ibid.* See Atkinson and Stiglitz (1969) for a critique of the production function approach. The article stresses local learning, which is a critical aspect of the accumulation of firm-level technological capability.

76. *Ibid.*, pp. 87. "But what dominates the picture of capitalist life and is more than anything else responsible for our impression of a prevalence of decreasing cost, causing disequilibria, cutthroat competition and so on, is innovation, the intrusion into the system of new production functions which incessantly shift existing cost curves," *ibid.*, pp. 91.

77. *Ibid.*, pp. 94.

78. "For some of the 'old' firms new opportunities for expansion open up: the new methods or commodities create New Economic Space. But for others the emergence of the new methods means economic death; for still others, contraction and drifting into the background. Finally there are firms and industries which are forced to undergo a difficult and painful process of modernization, rationalization and reconstruction," *ibid.*, pp. 134. He adds: "It should be observed that these vital parts of the mechanism of economic evolution, which are readily seen to dominate many business situations and to produce results of fundamental importance, can never be revealed statistically by measuring variation in an index of production, or analyzed theoretically in terms of total output," *ibid.*



economic space or market niche leads to the swarming towards new innovations by imitators as the copying or modification of newly-introduced technologies become increasingly possible. In the Schumpeterian system such opportunities come in clusters and are unevenly distributed.<sup>79</sup> The changes which result from these disequilibria are not smooth as a Darwinian curve would tend to show, but they proceed in jerks and rushes. But it is still possible to locate their epicentre. "In every span of historic time it is easy to locate the ignition of the process and to associate it with certain industries and, within these industries, with certain firms, from which the disturbances then spread over the system."<sup>80</sup>

Schumpeter visualizes a situation where investment opportunities vanish and the entrepreneurial function becomes obsolete, forcing the economy into near-equilibrium socialist practice.<sup>81</sup> This was a glance into future based on emerging realities. "Technological progress is increasingly becoming the business of teams of trained specialists who turn out what is required and make it work in a predictable way. The romance of earlier commercial adventure is rapidly wearing away, because so many more things can be strictly calculated that had of old to be visualized in a flash of genius."<sup>82</sup> Finally Schumpeter delivers his ultimate prognosis: "Since capitalist enterprise, by its very achievements, tends to automatize progress, we conclude that it tends to make itself superfluous — to break to pieces under the pressure of its own success."<sup>83</sup>

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79. "First, the innovations do not remain isolated events, and are not evenly distributed in time, but...they tend to cluster, to come about in bunches, simply because some, and then most, firms follow in the wake of successful innovation; second, that innovations are not at any time distributed over the whole economic system at random, but tend to concentrate in certain sectors and their surroundings," *ibid.*, pp. 100-101.

80. *Ibid.*, pp. 102.

81. "A more or less stationary state would ensue. Capitalism, being essentially an evolutionary process, would become atrophic. There would be nothing for entrepreneurs to do. They would find themselves in much the same situation as generals would in a society perfectly sure of permanent peace. Profits and...the rate of interest would converge toward zero. The bourgeois strata that live on the profits and interest would tend to disappear. The management of industry and trade would become a matter of current administration, and the personnel would unavoidably acquire the characteristics of a bureaucracy," Schumpeter, *Capitalism*, pp. 131.

82. *Ibid.*, pp. 132.

83. *Ibid.*, pp. 134.

Although Schumpeter did not have much to say about institutionalism, he admitted that his system operated in an institutional context; "it must be emphasized once more that our model and its working is, of course, strongly institutional in character".<sup>84</sup> The model is therefore an abstraction built on observations in one moment in history and could easily vary as institutions evolve over time. "We must recognize...that we are dealing with a process subject to institutional change and therefore must, for every historical record, see whether or not our model, however faithfully copied from the history of other periods, still fits facts."<sup>85</sup> In this spirit, the crumbling walls of capitalism constitute both the obsolescence of the entrepreneurial function and the destruction of the prevailing institutional frameworks.

Schumpeter visualised an economic system that was flung far from equilibrium by innovation and one which returned to a stationary (near-equilibrium). The return of the economic system to a near-equilibrium state associated with socialist organization suggests that Schumpeter's break with the neo-classical tradition was not as radical as it appears. The appeal to stable or near-stable systems that characterized the post-17th century intellectual tradition influenced Schumpeter's thinking just it affected Marx's. Schumpeter's work, however, forms a significant starting point for the analysis of non-equilibrium economic systems.

#### **1.4 Evolutionary Approaches to Technical Change**

Schumpeter has brought us to a crucial turning point; from this vantage position we shall now delve into the gist of our assessment -- a look at the evolutionary theories of technological change. But to understand clearly technological evolution, we shall have first to review the theories of the growth of knowledge in general, and scientific knowledge in particular.

Kuhn introduced new ways of looking at the development of knowledge in general, and scientific knowledge in particular. Kuhn attacked the conventional view which attached a large measure of rationality to scientific

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84. Schumpeter, *Business Cycles*, pp. 144.

85. *Ibid.*, pp. 97.

practice and progress. He argued that scientific knowledge did not develop in a linear progression but in a series of historical stages of stability and disruption, taking a cyclical posture; all occurring in a socio-intellectual community. Before Kuhn, the development of scientific knowledge was often viewed as a "development-by-accumulation" process.<sup>86</sup> But this cumulative process makes it increasingly difficult for historians to account for discoveries which undermine the scientific edifice instead of adding to it.

This led Kuhn to formulate his sequential approach which starts with normal science and advances through anomaly, crisis and finally to scientific revolution. Kuhn's method combines both the dialectical approaches adopted by Marx and the evolutionary notions advanced by Darwin.<sup>87</sup> The Darwinian notions acquire specific significance only in the last stages of his sequential framework. Normal science is the stage where "research is firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice".<sup>88</sup> This is the stuff that is recounted in textbooks. Normal science is characterized by a dominant "paradigm" under which puzzle-solving is the mode of practice.

At this stage, the development of scientific knowledge is cumulative. But the emergence of unexpected discoveries causes anomalies in the paradigm, forcing the community to make some adaptations to the emerging view of reality. The persistence and penetration of anomaly leads to a crisis in the dominant paradigm. "Because it demands large-scale paradigm destruction and major shifts in the problems and techniques of normal science, the emergence of new theories is generally preceded by a period of pronounced professional insecurity which is generated by the persistent failure of the puzzles of normal science to come out as they should."<sup>89</sup> The

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86. "If science is the constellation of facts, theories, and methods collected in current texts, then scientists are the men who, successfully or not, have striven to contribute one or another element to that particular constellation. Scientific constellation becomes the piecemeal process by which these items have been added, singly and in combination, to the ever growing stockpile that constitutes scientific technique and knowledge," Kuhn, *Structure of Revolutions*, pp. 1-2.

87. Kuhn's approach resembles the punctuated equilibrium model of biological evolution developed by Eldredge and Gould (1972).

88. Kuhn, *op. cit.*, pp. 10.

89. *Ibid.*, pp. 97-98.

response to the crisis includes a series of modifications to existing theories to accommodate the anomaly. But the situation is ultimately resolved with the emergence of a new paradigm.<sup>90</sup> Paradigms are rejected only after alternative ones have been found, after which the situation returns to normal to start another paradigmatic cycle. Scientific revolutions or paradigm shifts are therefore major changes in the dominant world view.<sup>91</sup>

There are several problems with Kuhn's view. Although he admits that scientific knowledge develops in a socio-intellectual context, he does not examine the socio-economic context which shapes the emergence of particular paradigms. His approach is akin to Marx's concept of discontinuous change. In Marx, however, there is constant struggle which leads to the overthrow of one class by another. But in Kuhn, the period of normal science is relatively peaceful, with the scientific community subsumed in the intricacies of puzzle-solving. Despite the difference, the theory is largely dialectical; it bears apparent hallmarks of the materialistic conception of the development of knowledge.<sup>92</sup> Kuhn admits that he has "said nothing about the role of technological advances or of external social, economic, and intellectual conditions in the development of the sciences."<sup>93</sup> He only acknowledged the implications of external conditions, especially turning anomaly into a source of acute crisis.<sup>94</sup> The fact that Kuhn acknowledges these factors and leaves them unexplained does not vindicate him.

Kuhn emphasizes on the emergence of anomaly and the development of crises. This may be useful as an analytical tool, but it also downplays the evolutionary process that the development of scientific knowledge

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90. "Often a new paradigm emerges, at least in embryo, before a crisis has developed far or been explicitly recognized," *ibid.*, pp. 86.

91. This model has received a wide range of criticism, mainly from philosophical and epistemological standpoints. Kuhn has revised and, subsequently abandoned the term "paradigm", replacing it with the notion of "disciplinary matrix", *ibid.*, pp. 182. See Lakatos *et al.* (1970) for a collection of criticisms against Kuhn.

92. Cohen has argued that "Kuhn's essay is basically dialectical materialist, though Kuhn himself makes no such claims, and he apparently fails to see all the dialectical implications of the problem." Cohen, "Dialectics and Scientific Revolutions," pp. 327.

93. Kuhn, *op. cit.*, pp. x.

94. "The same example would illustrate the way in which conditions outside the sciences may influence the range of alternatives available to the man who seeks to end a crisis by proposing one or another revolutionary reform," *ibid.*

undergoes. As a result, the concept of selection becomes significant only as anomaly sets in and the crisis builds up. Adaptation occurs in the early periods of anomaly but selection has to await the emergence of alternative paradigms. The resolution of the crisis is merely the selection of the fittest way to conduct research. Here Kuhn takes the position of *revolutionary selection*, a dialectical method indeed.<sup>95</sup> This also implies that at any one moment there is only one dominant paradigm, a factor that underestimates the growth of diversity in theories and testing methods.

By emphasizing anomalies and revolutionary shifts, the Kuhnian framework does not reveal much about the cumulative changes which constitute technological evolution. This problem is more pronounced when dealing with technology, for technological systems either work or they do not; the triumph of one technological system over another is much more complicated than would be assumed in the case of scientific work. Many of the determining factors originate from outside the technical imperatives themselves. These external factors also influence the path and characteristics of puzzle-solving. Although Kuhn thought that the application of his method to technology would add an important analytical dimension for scientific evidence, not much has been done along these lines. An interesting attempt was made by Constant in his study of the turbojet using a model that "parallels Thomas Kuhn's model for science".<sup>96</sup>

Constant adopts the Kuhnian approach with minor modifications. He defines a technological paradigm as being more than "just a device or process, but like a scientific paradigm, is also rationale, practice, procedure, method, instrumentation, and a particular shared way of perceiving a set of technology".<sup>97</sup> Normal technology is viewed as the

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95. "The net result of a sequence of such revolutionary selections, separated by periods of normal research, is the wonderfully adapted set of instruments we call modern scientific knowledge. Successive stages in that developmental process are marked by an increase in articulation and specialization. And the entire process may have occurred, as we now suppose biological evolution did, without benefit of a set goal, a permanent fixed scientific truth...." *ibid.*, pp. 172-173.

96. Constant, "A Model for Technological Change," pp. 553. Other attempts to apply the paradigm concept to technical change include Freeman (1979), who argues that the demand-led innovations and technology-push changes are analogous with the Kuhnian concepts of normal science and paradigm shifts.

97. *Ibid.*, pp. 554.

articulation or application of technical change to conventional systems. Like in Kuhn, a paradigm shift is only significant in the limited area of practitioners "and has no connotation of social or economic magnitude".<sup>98</sup> Everything remains in the domain of practitioners.<sup>99</sup>

It is not clear when the revolution starts because what are considered as "tradition" and "significant minority" remain so vaguely defined that they provide no coherent meaning in the model. Part of the problem lies in the fact that Constant does not treat technological change as part and parcel of the socio-economic transition. He prefers to restrict his analysis to the community of practitioners as if the group operates in a socio-economic vacuum. As we have already argued, if technological change is the motive force behind economic evolution, then its dynamics would have to operate within the socio-economic setting. As a result of this inadequacy, the study is reduced to a description of what happened, without analysing how and why it did; its explanatory power has been undercut. Constant deals with a wide range of technological options along the historical path of the turbojet engine but the issue of selection is not seriously addressed.

The concepts of selection and cumulative change are vital in evolutionary theory. But they would be meaningless if they did not include perception, imitation, learning and thought; if they were not located in an epistemological context. Popper's work in epistemology manifests a strong evolutionary approach, which he claims developed independent of the post-Darwinian thinkers.<sup>100</sup> "[W]hat characterizes the empirical method is its manner of exposing to falsification, in every conceivable way, the system to be tested. Its aim is not to save the lives of untenable systems but, on the contrary, to select the one which is by comparison the fittest, by exposing

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98. *Ibid.*

99. "In technology, as in science, that revolution occurs when a significant portion of the relevant community shifts its professional commitment to a new paradigm and begins a new normal technology... Revolution occurs not when the new system is operational, not when its universally accepted, not when it first works, but when it is adopted as the foundation of a normal technological tradition by a significant minority of the relevant community." *ibid.*, pp. 556.

100. Popper, *Objective Knowledge.*, pp. 67. "My own approach has been somewhat independent of most of these influences, though I read with great interest not only Darwin...but also Lloyd Morgan and Jennings during the years before writing my first book... I laid great stress upon the distinction between two problems of knowledge: its genesis or history...and the problem of its truth, validity, and 'justification' on the other," *ibid.*

them all to the fiercest struggle for survival."<sup>101</sup> In Popper's world, theories are selected like species in a competitive environment.

The preference of a theory is not based on experimental justification or its logical reduction of the theory to reality, but on selection.<sup>102</sup> A theory which cannot be falsified is therefore not scientific. Popper's evolutionary epistemology undertakes to recapitulate the development of language from animal to human stages, on one hand, and to re-state the neo-Darwinian position of error-elimination, on the other.<sup>103</sup> This "error-elimination may proceed either by the complete elimination of unsuccessful forms (the killing-off of unsuccessful forms by natural selection) or by the (tentative) evolution of controls which modify or suppress unsuccessful organisms, or forms of behaviour, or hypotheses."<sup>104</sup>

Popper has thus offered a natural-selection epistemology embodying variation, selection and retention of adaptations which cover a hierarchy of knowledge processes, including thought, vision, imitation, language and scientific method. It may appear that Popper was only concerned with epistemology as it relates to science. This is not the case because he extended his analysis to cover what he called "exosomatic evolution", or technology for that matter. The evolutionary process and its knowledge content continues long after the evolution of organs has ceased.<sup>105</sup>

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101. Popper, *Logic of Scientific Discovery*, pp. 42.

102. "We choose the theory which best holds its own in competition with other theories; the one which, by natural selection, proves itself the fittest to survive. This will be the one which not only has hitherto stood up to the severest tests, but the one which is also testable in the most rigorous way. A theory is a tool which we test by applying it, and which we judge as to its fitness by the result of its application," *ibid.*, pp. 108. Popper (1963) expands this theme to include trial-and-error methods; or conjectures and refutations.

103. "And it consists of a certain view of evolution as a growing hierarchical system of plastic controls, and of a certain view of organisms as incorporating -- or in the case of man, evolving exosomatically -- this growing hierarchical system of plastic controls. The neo-Darwinian theory of evolution is assumed; but it is restated by pointing out that its 'mutations' may be interpreted as more or less accidental trial-and-error gambits, and 'natural selection' as one way of controlling them by error elimination," Popper, *Objective Knowledge*, pp. 242.

104. *Ibid.*

105. "*Animal evolution* proceeds largely, though not exclusively, by the modification of organs (or behaviour) or the emergence of new organs (or behaviour). *Human evolution* proceeds, largely, by developing new organs *outside our bodies or persons*: 'exosomatically'... These new organs are tools, or weapons, or machines, or houses." *ibid.*, 238. See Campbell (1974) for a detailed exposition of evolutionary epistemology.

This concept has profound implications for the process of technological evolution. Although the acquisition and accumulation of knowledge, as we shall see later, has come to be recognized as a vital aspect of technological evolution, epistemological theories are still alien to this field. This is partly because the study of technological change has largely been treated as a domain for economists while epistemology has remained a sub-set of philosophy or psychology.<sup>106</sup>

Recent approaches which take epistemological issues into consideration include Constant's work. Constant starts from the Popperian premise that technology "is knowledge, and as such is qualitatively no different from any other knowledge that is the property of any other entity".<sup>107</sup> From the simplest micro-organism to the height of human genius, knowledge is seen to be based on the mechanisms of random variation and selective retention. Although the behaviour of the organism is limited by the genetic coding, the selection of mutants (those which contain successful characteristics) is mediated by the environment. Constant builds his model on this analogy.

He retains the factors which characterize the Kuhnian normal science phase, but introduces the notion of selection. The articulation or application of a conventional system under new or more stringent conditions may lead to its failure. The selection of a solution to this functional failure depends on "ex post" competition among proposed alternatives".<sup>108</sup> The process of selecting a solution does not come from the community of practitioners, but from those acquainted with the technological tradition. This selection often

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106. Usher's classic *History of Mechanical Inventions* was one of the earliest attempts to examine technological change in an epistemological context. "The Gestalt analysis presents the achievements of great men as a special class of acts of insight, which involve synthesis of many items derived from other acts of insight. In its entirety, the social process of innovation thus consists of acts of insight of different degrees of importance and at many levels of perception and thought. These acts converge in the course of time toward massive syntheses," *ibid.*, pp. 61. See also Ruttan, "Usher and Schumpeter," pp. 602. See also Solo (1951) for a critique of the Schumpeterian distinction between invention and innovation.

107. Constant, *Origins of the Turbojet*, pp. 6. This Popperian view has been expanded by Campbell (1966; 1974) to constitute what he calls a nested hierarchy of selective-retention processes. Constant (1983) has also applied the Popperian concept of testability to technical change.

108. Constant, *Origins*, pp. 13.



relies on the co-evolution of similar devices. "Transported to technology, the concept of co-evolution implies that the development of one set of devices may be linked intimately to the development of other devices within the same macrosystem, and that the two sets of devices may exert powerful, mutually selective pressure on each other."<sup>109</sup>

In this model, economic factors are recognized as significant, but do not play a homogenous role in the selection of technological systems. "Economics acts as a direct selector both for entire macrosystems and for individual subsystems. Perceived economic factors operate as vicarious selectors during the process of technological change, and may serve in the first place to inspire efforts towards such change."<sup>110</sup> The role of economic factors as selectors tends to vary with time and in the hierarchical levels of technological practice. This partial emphasis on economic factors is a result of Constant's limited area of study; he restricts the formal unit of analysis to the community of practitioners.<sup>111</sup> This view ignores the complex interlinkages between technological, economic and institutional factors. To get away from this limited approach, we shall examine recent evolutionary theories of technical change from an economic viewpoint.

Recent efforts to explain technical change as an evolutionary process fall into four broad categories; those which examine innovation at firm-level, those which look at firm behaviour, those which emphasize long economic cycles, and those which view the market as a configuration of niches.<sup>112</sup> The first one emphasizes the concept of learning, while the second stresses search and selection mechanisms. The third approach is concerned with technology development and diffusion while the fourth one is concerned with the evolution and market penetration of technological systems. The schools reject the neo-classical production function as a tool for analysis. The "learning-by-doing" school has a long history built on the growing rejection of the production function, especially with the recognition

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109. *Ibid.*, pp. 14. See Constant (1978) for a detailed explanation of the co-evolutionary process.

110. *Ibid.*, pp. 27.

111. "It is men, not institutions or governments, who ramrod the development of what to others may seem an unlikely device to the point of community acceptance," *ibid.*, pp. 32.

112. These categories exclude studies which examine internal technical developments. See Sahal (1985) for a study which looks at the relationship between size and structure in technical evolution.

that productivity at firm-level could increase without changes in factor inputs; the so-called "Horndal effect".<sup>113</sup> The concept of learning has been extensively analyzed by David and has given rise to a series of studies in the developing countries, especially in relation to infant industries.<sup>114</sup>

David treats "technological progress as fundamentally *an historical evolutionary process*", under which "the future development of the system depends not only on its present state but also upon the way the present system was developed".<sup>115</sup> There is an element of historical indivisibility in this approach which enables one development to be linked to another. But the technical developments are local, neutral and stochastic: local because they are adaptive and incremental; neutral because they do not have any factor-saving bias; and stochastic because they do not manifest the Markovian processes which are drawn from classical mechanics. This process is not only endogenous but irreversible.<sup>116</sup>

David combined the Darwinian concepts of survival for the fittest with what he calls "the Mendelian principle of *heredity*".<sup>117</sup> This establishes a link between factor prices, choice of technique and the rate and direction of global technological change in a "fundamentally evolutionary character".<sup>118</sup> Moreover, the "drift of technological developments generated over time within a fairly stable economic environment needs to be viewed...as a distinctively *historical* phenomenon, inasmuch as it may arise through the myopic selections *past* producers made from among the different species of techniques with which they originally had to work."<sup>119</sup> This approach provides a useful starting point for examining firm-level technical change. However, it ignores the various extra-firm factors such as institutional mechanisms which influence selection. Furthermore, the selection

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113. The details are provided in Arrow (1962).

114. These studies are characterized by a stages-approach, as exemplified by Dahlman *et al.* (1981).

115. David, *Technical Choice*, pp. 76.

116. "As a result...previous economic configurations become *irrevocably* lost, and in trying to work backwards by entertaining counterfactual variations on the present, one cannot hope to exhibit the working of historical processes." *Ibid.*, pp. 15.

117. *Ibid.*, pp. 76.

118. *Ibid.*, pp. 61.

119. *Ibid.*

presupposes a search process that can only be understood by examining market characteristics and firm behaviour. For an evolutionary approach that includes both search and selection, we shall turn to Nelson and Winter.

Nelson and Winter reject the view that firms seek profit maximization and adopt the Alchian approach which stresses economic natural selection. Like Schumpeter, they discount the value of general equilibrium theory. But unlike Schumpeter, they discard the production function. Although the model is an attempt to break from neo-classical thinking, it still uses tools adopted from mechanical physics such as the Markov chain, a fact that has led David to argue that the model still "remains fundamentally neoclassical in spirit".<sup>120</sup> This claim is based on the assertion that since the Markov chain is built on the present and not past situations, it is ahistorical.<sup>121</sup> However, the notion of search and selection, which is central to the model, assumes the pre-existence of technological possibilities; it must assume a historical retroaction. The process of innovation therefore involves both creating and discovering; both of which need a historical basis to take an evolutionary posture. "In many technological histories the new is not just better than the old; in some sense the new evolves out of the old. One explanation for this is that the output of today's searches is not merely a new technology, but also enhances knowledge and forms the basis of new building blocks to be used tomorrow."<sup>122</sup>

The model rests on three basic concepts. First, firms have a set of organizational routines which set out what is to be done and how it is done. Routine is the genetic code of the firm; it carries the adaptive information required for competition and survival. The information in the genetic code changes over time as experiences are selected and retained. Second, firms undertake a search process which includes the evaluation of their routines for possible modification or replacement. Search routines stochastically generate innovations, or mutations for that matter. Third, there is the selection environment which includes all the factors which influence the well-being of the firm. This covers both the conditions prevailing outside the

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120. David, *op. cit.*, pp. 76.

121. For a defence of the Nelson-Winter model, see Elster, *Explaining Change*, pp. 156-157.

122. Nelson and Winter, *Evolutionary Theory*, pp. 255-256.

firm and the behaviour of other firms. "Differential growth plays much the same role in our theory as in biological theory; in particular, it is important to remember that it is ultimately the fates of populations or genotypes (routines) that are the focus of concern, not the fate of individuals."<sup>123</sup>

The model rejects the concept of profit maximization. It is suggested that firms adopt a satisficing behaviour because firms that are sufficiently profitable do not search for alternative techniques. "They simply attempt to preserve their existing routines, and are driven to consider alternatives only under the pressure of adversity."<sup>124</sup> The search process could either be local, concentrating on techniques close to the current ones; or imitative, looking to what other firms are doing. And at firm-level innovation tends to occur in a cumulative way following some natural trajectories which are defined by technical inter-relatedness.<sup>125</sup>

Nelson and Winter did not apply their model to any specific firm or technological system, except for computer simulations which validated some of their theories on technical change and competition. Dosi has attempted to apply a modified version of the approach to the study of the semiconductor sector. Dosi's work is interesting because it singles out those elements which are specific to technological change and synthesizes them with other theoretical frameworks to arrive at an analytical model that exposes the technological mechanisms which underly structural change. He combines the approach provided by Kuhn with the Rosenberg trajectories (which are modified in Nelson-Winter to become natural trajectories), and evolutionary concepts. The model reveals continuous progress along a defined technological trajectory which is triggered and pulled by the endogenous mechanisms of Schumpeterian competition. And this is associated with "the complementarities between different technologies and industries jointly with straightforward economic signals, such as changing relative prices, relative profitabilities and distributive shares".<sup>126</sup>

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123. *Ibid.*, pp. 401. The genetic analogy is explained in detail in Winter (1975).

124. *Ibid.*, pp. 211. See also Iwai (1984) for a neo-Schumpeterian model of innovation and imitation.

125. Nelson and Winter, "In Search of a Useful Theory," pp. 56-60.

126. Dosi, *Technical Change*, pp. 287. See Pasinetti (1981) for a macroeconomic model akin to Dosi's.

Major contributions to the neo-Schumpeterian tradition have been associated with the study of cycles in economic development. The cycles, according to Mensch, are associated with a cluster of basic innovations which establish new branches of industry. The resulting economic expansion reaches limits and consequently a technological stalemate is reached.<sup>127</sup> The stalemate or depression then induces innovations which come again in clusters and put the economy on another growth path. In Mensch's view new basic innovations are called upon during depression to replace those whose growth potential has been exhausted.

This view is rejected by Freeman *et al.*, who argue that the bunching of innovation associated with fundamental breakthroughs in science and technology lead to the availability of related families of technological systems. It is this swarming effect that leads to economic expansion, and not depression inducement.<sup>128</sup> While Mensch emphasizes the clustering of innovations, Freeman *et al.* stress the linking together of basic innovations to bring about new technological systems that contribute to a Kondratiev upswing. The escape from technological stalemate therefore depends on a combination of innovations made before and during the depression as well as during recovery. Depression, Freeman *et al.* admit, may bring about changes in the political and social climate which are favourable to the adoption of new technological systems.<sup>129</sup>

These neo-Schumpeterian studies, insofar as they emphasize evolutionary processes, assume technology as embodying known characteristics. They therefore do not engage with the process of innovation itself but emphasize its consequences. However, the market environment in which the innovations compete changes unevenly and therefore the prospects of entry are unevenly distributed over time and economic space, a view that casts doubts on the alleged periodicity of the Kondratiev long waves.

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127. Mensch, *Stalemate in Technology*, pp. xvii-xviii.

128. "Once swarming does start it has powerful multiplier effects in generating additional demand on the economy for capital goods (of new and old types), for materials, components, distribution facilities, and of course labour. This, in turn, induces a further wave of process and applications innovations. It is this combination of related and induced innovations which give rise to expansionary effects in the economy as a whole," Freeman *et al.*, *op. cit.*, pp. 65.

129. Piore and Sable (1984) have extended the role of institutions in the adoption of new technologies.

Moreover, the changing market environment requires products to adapt to the new conditions. The market therefore becomes a configuration of niches. Consequently, a product is designed to embody those characteristics that will enable it to adapt to a particular market niche. This is the message provided by Abernathy *et al.* in the model of technological de-maturity.

In this model, a product is a configuration of design concepts which are adapted to particular market conditions. But the introduction of another innovation may disrupt the market niche, making the existing capital equipment, labour skills, materials, components, management culture and organisations capabilities obsolete:

The stabilization of design concepts, in which industry maturity consists, makes productive units increasingly vulnerable to changes in technology, market preference, and relative prices. As does a biological species that has become perfectly adapted to a particular environmental niche, mature industries carry with them the implicit threat of extinction or, at least, catastrophe if environmental conditions should suddenly or radically shift.<sup>130</sup>

If the disruptions are non-trivial, then the firm can adapt by making incremental changes. But if they are substantial, then the firm is thrown back onto a new learning process. Such is the logic of de-maturity.<sup>131</sup> From this vantage point, the market can be conceived as an adaptive landscape where both products and the external environment (as well as the related institutions) constantly change.

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130. Abernathy *et al.*, *Industrial Renaissance*, pp. 28-29. Elsewhere, Abernathy *et al.* (1985) state: "As the product and process technologies evolve and develop, they become more robust in the way they accommodate the full range of variety in the existing environment. Like the trees that develop an extensive root system to weather the dry season it must occasionally face, management refines and perfects a product over time to better accommodate the range of variation in the market. Yet a product and process technology that becomes more highly organized and efficient...it also becomes more vulnerable to sudden and unanticipated variations in the environment. The highly productive, efficient and developed product unit is also more vulnerable to economic death," pp. 18.

131. The concept of market niches is also explored by Lloyd *et al.* (1975), Kvasnicka *et al.* (1983), and Busirano (1983).

## **1.5 Energy Markets as Adaptive Landscapes**

The previous sections have outlined some of the major contributions of evolutionary concepts to the economic as well as technical change literature. These contributions have gradually undermined the conventional approaches to technological change, especially those built on the mechanistic Cartesian-Newtonian world view. Conventional approaches, including those that appeal to evolutionary processes, do not adequately deal with the dynamics of technological change. This study offers an alternative approach where the energy market is seen as a techno-economic landscape in which different technological systems are adapted to the production and conversion of different energy forms. The landscape or terrain includes technical, economic, social, institutional and political *interrelationships*. The approach is therefore holistic.

### **1.5.1 The structural setting**

Operating technological systems occupy dynamic market niches which are maintained through technical, economic, social, political and institutional interactions. The niches are part of an open economic system. A techno-economic landscape is an adaptive zone in which the technological system and the external socio-economic environment (together with institutions) constantly undergo fluctuations. The changes result from innovations in the operating technical systems or from the introduction of new technological systems. Alternatively, disruptive fluctuations (such as the 1973 oil crisis) in the external environment may restructure the configuration of the niches and create suitable conditions for the introduction of new technological systems. The changes are mediated by political and economic interests which form the basis of socio-economic expectations.

The structure of the liquid fuels market, which constitutes the environment, defines the range of technologies that can be utilized. But the application of different technologies is pre-determined by both technical and socio-economic parameters. The techno-economic niche is therefore not a

static space in which a particular technology fits, but a result of changing technical and socio-economic configurations. The environment is not stable. It undergoes constant change. These changes can vary from the trivial to the drastic. Under trivial environmental change, various energy systems undergo efficiency and reliability improvements as well as cost reduction. These are simply continuous adaptations to changing conditions.

But there are situations which are marked by major surprises in the environment. These changes may come from within the system, like the introduction of a new technology. But other changes may come from outside the existing technological systems, as in the case of the 1973 oil crisis. Such changes, if drastic, will lead to the restructuring of the configuration of niches. Existing technological systems may be adapted to the new conditions, but the creating of new niche possibilities may also generate conditions for the introduction of new technological systems. The restructuring of the energy environment may lead to intense innovation efforts to take advantage of the emergent niches. This is the origin of a wide range of renewable energy technological systems. Whether these technologies take root or not depends on their ability to adapt to the environmental conditions, the alignment of various interest groups. Not only are they thought by the key actors to meet technical, financial and economic requirements, but their suitability would be extended to their social and ecological impacts.

An interesting phenomenon in this development relates to the sources of innovation. There are three main sources of innovation. First, there are those innovations which have hitherto been unknown and their invention is a result of the creation of new niches. Second, there are those energy technologies which have hitherto remained unexploited. Third, there are those innovations which are transferred from other sectors because the emerging conditions make them suitable. This last case is interesting because it calls into question changes in the adaptive mechanisms that were applied in the previous sector to fit the new conditions. Conditions may arise where the adaptive parameters introduced into the technological system do not enable it to compete with existing technology. If these limitations are largely technical, arising from the internal constraints of particular processes, then the system will be described as being in a *technological*



*stasis*. Such a situation is characterized by limited opportunities for process improvement and declining marginal gains from scale economies. A departure from this stasis may require a significant technical breakthrough or selection of alternative technological systems.

Political imperatives may make it difficult for people to abandon technological systems in stasis; their survival would therefore have to be guaranteed through subsidies and other forms of institutional support. This brings into our analysis the role of institutions in the generation, selection and retention of technological systems. The government may opt to underwrite the infant stages of the a particular technological system to a point where it has taken root. Alternatively, the government may simply remain a source of support for systems that are not adequately adapted to prevailing market conditions. By setting regulations, the government defines some of the criteria that the adaptive mechanisms of the technological systems and the adopting features of the environment must meet. Some governments define these parameters by giving entrepreneurs more opportunities to shape the market conditions.

The emergent niches create new chains of potential interrelationships. This implies that new energy systems that occupy the market-niches relate, at different levels, with existing technological systems in the economy in general, and in the energy sector in particular. This symbiotic relationship may take at least three different forms. In the first case, the special (technical, financial, economic, or ecological) features of the existing systems may be modified to provide support to the new technologies. This could lead to some losses in the existing systems if interventions such as cross-subsidies, partial protectionism, or controlled market entry are applied. Alternatively, the modes of intervention may be neutral (or even beneficial) to the existing technological systems. The annexing of fuel alcohol plants to existing sugar mills from which they draw surplus resources for their operations is a case of *technological symbiosis*.

The fact that the developing countries have to import technological systems complicates further the evolutionary process. First, the importing

countries need to search the international market for viable technologies.<sup>132</sup> Viability in this sense simply refers to those technologies which have adequate adaptive characteristics and which are likely to take root in the new environment. The search process involves the gathering and analysis of information on both the key adoptive conditions of the potential niche and the candidate technological system. Here the question of technical flexibility starts to acquire some significance. It is not possible to know in advance all the key factors in the niche, especially the combined effects of the known and unknown factors. Likewise, it is not possible to predict all the effects of the interaction between the candidate technological systems with the market.

The process of research and development (R&D) attempts to equip the technological system with key *adaptive parameters* which enable the technology to operate under particular conditions. The incorporation of these technical parameters into the design of the technological system presupposes some knowledge of the dominant features in the *adoptive terrain*, or the market zone in which the technological system is expected to operate. Apart from the technical parameters, the candidate technological systems also need to be equipped with non-technical adaptive requirements. These include factors such as capital cost and technology transfer conditions. The process of R&D is therefore not free of political and social values. The fact that the parameters of the adoptive terrain need to be known, at least partially, suggests that the process of innovation anticipates the external environment. Since the operating environment is social, the design of technological systems is largely a process of anticipating and planning social change.

The search process is therefore not just a way of minimizing costs, but also of establishing the wide range of parameters that are necessary for technological adoption. Knowledge of some key features in the adoptive terrain plays a significant part in the search and choice processes. The implementation process not only involves the introduction of the chosen technology, but also its continued operation (or retention). The improvement then becomes a learning process under which the useful

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<sup>132</sup>. It must be emphasized that the developing countries do not always search the international market. They often rely on the options presented to them by equipment suppliers.

aspects of the learning process are themselves retained in some cumulative form. This framework has profound implications for how we understand the process of policy formulation. It must be clear by now that the process of policy formulation and implementation goes hand in hand with the evolutionary process; it is in fact a constituent part of it.

### **1.5.2 Purpose and function in technological systems**

A technological system is a combination of several technological units which evolve at different rates. They are brought together to perform a certain function. This makes technological evolution a purposive and not a random process. The importance of the evolution of individual units is explained by the structure and function of the whole system. A technological system is therefore viewed as a convergence of co-existing functional units. The patterns of change among the units, both functional and allometric, is governed by the purposive imperative of the whole system, and not vice versa. This is mainly because the technological system is designed to fulfil certain pre-conceived goals which could be achieved by various technical configurations. The range of such technological systems is narrowed down through a selection process that attempts to match the adaptive parameters of the systems to the key features of the external techno-economic environment. The increased matching of these parametric sets may be viewed as an increase in techno-economic performance.

There is no technological system that is perfectly adapted to the environment or has the ultimate techno-economic performance. This is partly because of limitations in the internal structure of the systems themselves and the constant changes that occur in the external environment. What technological innovation does is to constantly improve the adaptive parameters of the system either by matching previously unmatched

environmental features, or by adapting to new changes.<sup>133</sup> This is the logic of increased techno-economic performance, which does not necessarily mean a perfect adaptive fit. This process of raising the techno-economic performance takes on a new phase if the environmental changes are radical and disruptive enough as to threaten the survival of hitherto existing systems. This may require radically new technological systems with new adaptive features. Alternatively, the discovery of either a technical unit or a system that has a higher techno-economic performance may threaten the existing system. The displacement of technological systems is often accompanied by periods of co-evolution.

If the design of a technological system is taken as the unit of selection, then conjectural technological variants are not generated through blind, random or unjustified variation. However, the variants still have to be further tested in the operating environment through the process of niche realization. This suggests that the process of error-elimination continues from the point of the conception of a particular technological possibility to the stage of niche realization and beyond. Moreover, shifts in the environment may require changes which can be achieved through incremental improvement and not necessarily by the scrapping of the technological system. Exogenous pressures as well as internal technical imperatives induce incremental innovations. The process of plant-level improvement involving incremental technical changes shall be referred to as *technical drift*.

The initial entry of a technological system into the market is therefore not the end of the story; the system will constantly be subjected to both internal and external pressures requiring constant innovation. This means that the system remains in a homeodynamic state of partial success until competing systems dislodge it. The rate at which systems are dislodged is complicated and depends on factors such as the size and characteristics of

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133. In other cases, firms may pre-empt the imperative to innovate by altering the external environment to suit their techno-economic performance and reduce competitive pressures. This can be done through a large number of protectionist measures. This view suggests that the environment is also subject to pressures from the firm. I conjecture that the firm constantly endeavours to create its own environment. This point will be illustrated in detail later under sections dealing with the modification of the adoptive terrain.

the market, the economics of scrapping, costs of research and market entry, perceived profits and production scale. What is important here is the process of the generation of conjectural technological variants, which is usually through research, development and demonstration.

Changes in the environment may also lead to the movement of technological systems from one niche to another without any form of distinctive divergence. Such divergence is a common aspect of technological evolution. For example, the Caterpillar farm tractor developed at Stockton, California in 1904 was later turned into the military tank and used in the First World War.<sup>134</sup> The two technological systems occupy different niches and continue to change in functional and systemic complexity by taking on new technical characteristics. What is interesting is not a taxonomy of technological systems and the associated dendrograms, but the mechanisms of technological variation, their selection and retention.

Apart from distinctive divergence, systems may also be moved from one niche to another without undergoing major internal changes. This may happen at times of major environmental changes which open up new opportunities for systems which could not otherwise have survived. The fuel ethanol example is an illustration of this. The technological system evolved in the beverage environment and although its energy potential was known, the dominance of petroleum made it uncompetitive in the energy environment. It was not until the oil shock that the potential for realizing the ethanol niche were enhanced. This made it possible to use on a large scale the technological systems from the beverage in the energy environment.<sup>135</sup>

### **1.5.3 The selection process**

A central feature of an evolutionary process is adaptation through variability and selection. To accommodate adaptation in this approach

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134. See Wik, "The American Farm Tractor," pp. 126. Technological speciation is characterized by purposive divergence and is different from product differentiation which is the biological equivalent of varieties, as exemplified by tractor or tank models. For a detailed exposition of the taxonomy, evolution and classification of organizational systems, see MacKelvey (1982).

135. This transfer, or spatial shift, will be examined in detail later.

technical evolution is viewed as the process through which a conjectural fit between a technological system and the market environment is improved. The adaptive relationship between technological systems and the changing market environment, referred herein as *verisimilitude*, is improved by incremental or radical technical changes in the main adaptive features of the technological system.<sup>136</sup> The selection process is bounded by the limitations of the technological system, both by physical and chemical laws as well as by the historical path of the design concepts. The selection process is also influenced by external factors such as patterns of corporate control. This means that issues that belong to the domain of political economy mark the wider technological regime within which the selection mechanisms operate.

The evolution of technological systems goes through different levels of verisimilitude, forming a hierarchy (of functional units, system configuration, and techno-economic performance). During the process of raising the techno-economic performance, incremental innovations reach limits which can be transcended through quantum shifts associated with marked punctuations in the evolutionary process. These shifts are accompanied by re-organizations in the industrial structure. The evolutionary process goes through variability and selection of the adaptive features. The hierarchy of verisimilitude starts with *functional units* which are core sections of a technological unit which fulfil a particular function. Technological systems, depending on their complexity, have varying numbers of functional unit.

Raising the verisimilitude at the level of functional units involves increasing efficiency, prolonging operating life, and reducing material and production costs. Research and development at this level is aimed at achieving an adaptive fit to a set of technical parameters. These parameters provide operative limits to the functional unit and therefore serve as selecting pressures. The list of parameters may not be exhaustive and new ones may even emerge during R&D. The parametric environment is therefore not static. A functional unit is designed to be adapted to as many selecting

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136. Verisimilitude implies an improvement relative to competing option. Conditions where the environment is modified to conform to a certain performance level does not constitute an improvement in verisimilitude.

parameters as possible. A technological system is usually a configuration of different functional units and the role of each unit is subject to the performance of the whole system. The raising of system verisimilitude is therefore a co-evolutionary development of different functional units. At this level, the verisimilitude becomes a matter of technical performance.

The third level of includes socio-economic parameters as selecting pressures. Socio-economic parameters will usually vary among different technological systems. In the case of energy technologies, new systems must be able to compete favourably with conventional technologies or their own variations. Socio-economic parameters usually feed back to the level of systems and functional units, forcing designers to search for more adaptive functional units or system configurations. This search involves diversity in functional units and system configurations. The selection process favours the systems which have higher techno-economic performance. At any one moment, the system is only conjectural, since it can be easily dislodged by others with higher verisimilitude. This displacement may occur through incremental innovations or radical shifts in functional units or system configurations.

Technologies which have low levels of verisimilitude (which are poorly adapted to actual conditions) may require non-market R&D support. This is partly to hedge against the uncertainties that may lead to failure. Related to this is the need to generate the variability from which functional or system concepts that promise improved verisimilitude may be selected. Public sector institutions may support the early stages of technological evolution until a competitive level of techno-economic performance is reached. This is usually marked by the steady creation of economic space or market niches. Product diffusion increases as variations of the technological system create new markets or compete in markets dominated by traditional technological systems.

The process of technical evolution is governed by both functional, system and economic uncertainties which need to be underwritten. Although the potential benefits from a technological system may be clearly visualized, the evolutionary route may be difficult to determine. The process of getting there is therefore one of conjecture and selection; one of purposive

and incessant trial and error. This necessarily requires an incessant generation of conjectural variability. One of the ways of dealing with the uncertainties is to enlist the support of the public sector.

#### **1.5.4 Institutional and policy considerations**

The fact that technological change is purposive and is associated with both hierarchical and non-hierarchical forms of organization requires an institutional setting which guides the evolutionary process. There are several reasons why technological change is closely associated with institutional change. In the first place, innovation is a social process which requires mechanisms for bringing different ideas, individual or groups of people together. The very act of creating such a network implies the necessity for institutional arrangements. Second, since the direction and consequences of any evolutionary path are difficult to determine in advance, institutional arrangements are required to provide a forum for identifying, selecting and retaining particular goals and tactical methods.

Since an evolutionary process requires the generation, selection and retention of options, patterns of policy formulation also take a similar outlook. Technology policy may hence be viewed as guidelines for the appraisal, search, generation, selection and retention of technological options. Since the process of implementation is associated with constant change, policies themselves get enriched by the implementation process because of cumulative learning. This would lead us to the partial conclusion that policy itself could be a result of the process of implementation just as implementation could arise from policy.

The process takes place in a holistic environment influenced by technical, economic and political factors. Policy formulation and implementation are articulated through institutional mechanisms. This, however, does not mean that the articulation is restricted to institutions alone. Far from it. This articulation is a complex interplay between a wide range of actors. We have identified institutions because they are specifically linked to the process of change and their patterns of change are directly related to the process of socio-economic evolution.



The very existence of uncertainty over the consequences of any evolutionary route leads to differences in expectations, strategies and tactics. This suggests that institutions are not homogenous and manifest extensive internal differences which may lead to conflicts. This is what gives institutions their political character. It is therefore not a coincidence that national politics (and its ideological underpinnings) is largely about the generation, selection and retention of broad development paths. Institutions such as the state which sit at the top of the hierarchy play a central role in the evolutionary process because they have the power (and occasionally the mandate) to overrule lower institutions in generation, selection and retention of options. The very existence of a nested hierarchy of institutions implies that the influences work in a complex way that cannot be determined by examining a unidirectional flow of authority.

The main advantage of this approach is that it enables us to deal directly with real events instead of mediating them through static abstractions. The appeal to realism makes the approach relevant for policy formulation and implementation. The normative references of the study lead to conclusions that cannot be easily reached using conventional approaches. Let us examine some of the general context in which the different conclusions are likely to emerge.

In the first place, the view that economies are non-equilibrium open systems enables us to appreciate the significance of fluctuations such as energy or resource price shifts and the uncertainties associated with the internal re-organization of economic systems. This view leads to conclusions and policies which emphasize *system-wide* changes. Alternatively, theories which conceive economies as closed systems will emphasize equilibrium notions. Policies which are informed by such views tend to pre-occupy themselves with the behaviour of economic systems in the neighbourhood of equilibrium. Instead of concerning themselves with the sources of change, they tend to aim their policy interventions at restoring the assumed equilibrium. Such policies may inhibit positive changes in the system. An evolutionary approach would instead focus on system-wide changes whose consequences depend on the degree of fluctuation and possibilities for major bifurcations within the system.

Second, the approach emphasizes the flow of events and resources through *time* and pays particular attention to the specific historical conditions surrounding investment projects. Long-term dynamics cannot be adequately analyzed without taking time into consideration. The notion of time brings into focus the concept of irreversibility. Policies which take into consideration irreversibility are likely to pay more attention to pre-investment planning and distribute the learning efforts over the entire life cycle of the project.

Third, by treating economic systems as *holistic*, the study will move away from the analysis of discrete units to the study of interrelationships. Whereas conventional approaches would tend to be reductionist, the evolutionary approach underscores complexity, diversity and variability. Such key characteristics of technological change cannot be adequately handled without taking a holistic approach. The notions of complexity, diversity and variability link the time dimension to the systems approach and enables us to study in detail how technological options are generated.

Fourth, the evolutionary approach treats both technology and institutions as *endogenous* to the process of economic change. This is precisely because the approach focusses on the sources and dynamics of change and re-organization within economic systems. An approach that treats technical change as endogenous to economic development will emphasize non-market support for R&D while other approaches would tend to use economic returns to R&D as a basis for funding.

Fifth, most conventional approaches tend to stress *linearity* in their analysis of economic events. The emphasis on linearity is also associated with an appeal to prediction. Alternatively, this study analyzes non-linear changes and does not concern itself with predictions. However, the approach lays emphasis on expectations and *anticipation*. Predictive approaches may lead to the formation of rigid institutional structures whereas an anticipatory world view may lead to institutional flexibility and adaptive behaviour. The policy implications of the two approaches are significantly different. On the whole, the evolutionary approach seems to be more suited to the analysis of dynamic processes than the conventional economic theories.

## **Conclusion**

This chapter has outlined some of the major contributions of evolutionary thought to the economic as well as technical change literature. It has examined how these contributions have gradually undermined the conventional approaches to technological change, especially those built on the mechanistic Cartesian-Newtonian world view. I have argued that conventional approaches, including those that appeal to evolutionary processes, do not adequately deal with the dynamics of technological change. The chapter has suggested a non-equilibrium approach in which the energy market is seen as a techno-economic landscape in which different technological systems are adapted to the production and conversion of different energy forms. The approach therefore emphasizes the relationship between technological systems on the one hand, and the economic as well as the institutional network on the other.

## 2. METHODOLOGICAL CONSIDERATIONS

### Introduction

The previous chapter presented an evolutionary approach to the analysis of techno-economic change. Such a research agenda requires an alternative philosophical basis for its methodological approaches. Methodological issues do not simply involve the various ways of doing research but encompass a certain epistemological outlook. This chapter sketches the main features of this alternative view. Understanding techno-economic change requires an evolutionary epistemology which can capture its internal and external dynamics. This chapter also discusses the research methodology and data base used for this study and their limitations.

### 2.1 Epistemological Setting

This study aims at identifying long-term *technology policy* issues under constantly changing international and national conditions. It is a study about economic re-organization under fluctuating conditions. The very fact that the external environment, technology and institutions constantly change as the economic system is re-organized imposes a different methodological approach from, say, that which could be used in the analysis of systems which are assumed to be determinate. Such a methodology has different epistemological underpinnings and conventional approaches would use reductionist methods. Conversely, this study appeals to *holism*, *irreversibility* and *realism*. Such an appeal presupposes a philosophical setting that is suited to the assessment of dynamic situations. We shall therefore offer an *evolutionary epistemology* as a methodological guide.

Evolutionary epistemology is largely about the changing inter-relationships between adaptive units and their environment as a function of knowledge and information flows. Apart from its ability to deal with change,

evolutionary epistemology allows us to deal with real situations, which is a significant pre-requisite for technology policy studies. The suitability of using evolutionary epistemology is underscored by the fact that technology is part of the human efforts to adapt to a constantly changing environment. The economic system can be conceived as a sophisticated ecological zone with extensive generation and use of exosomatic facilities. This, however, does not mean that all technology is about human survival. But the type of technologies that concern us, those which are important in socio-economic transition, are indeed part of human evolution. This makes evolutionary epistemology a suitable philosophical guide to such studies.

It is important also to emphasize that policies are key features of an evolutionary process and cannot be conceived outside the changing socio-economic conditions. With this in mind, the study treats technology policy as an institutional setting for the identification, generation, retention and evaluation of techno-economic options under changing conditions. This makes the evolutionary character of policy issues more explicit, although it does not mean that policy studies would be unnecessary under assumed stationary conditions. The richness of the evolutionary approach lies in the fact that it allows us to deal specifically with the dynamics of constant change as opposed to a tendency towards some equilibrium state.

The first main feature of an evolutionary approach is that it emphasized holism. Under reductionist approaches, the study would be required to state precisely its vantage point in a narrowly defined way. This would be difficult to do for several reasons. First, matters to do with technology policy tend to stretch across a wide range of disciplines. A *priori* selection of areas of focus reduces the ability to analyse the interactions of the key aspects of the subject-matter. This is a crucial point because this study treats technological change as a process that occurs within a socio-economic system comprising heterogenous sub-systems.

Second, this approach accords specific importance to *time*. By this we mean that past, current and future development are enfolded in a historical process where past actions and decisions influence future trends, and current decisions anticipate future developments. Technological change is therefore bounded in history. A reductionist approach would require us to

freeze time and extract instantaneous snapshots from the sequence of events for analysis. Although this would enable us to isolate the events according to the desired academic orientation it would also purge the process of its evolutionary content and undermine its usefulness as a policy guide. The link between holism and time is already apparent. What follows from this is the irreversibility question.

The fact that technological development is enfolded in time makes the process irreversible. This message has far-reaching consequences for policy. There are at least two ways of looking at irreversibility. First, irreversibility is associated with the arrow of time. It ascribes linearity to development processes. But this need not always be the case. Secondly, irreversibility is also associated with the re-organization of systems. Such non-linear irreversibility is fundamental to open systems which undergo constant change because of both internal and external factors.

The historical context of this study has two methodological facets. The first one is related to time and irreversibility. The second is linked to the fact that technological processes are evolutionary also because they are part of a larger process of biological evolution. The essence of evolutionary epistemology in this context is that technological change is part of human evolution and has a direct historical link with biological evolution. What we have therefore is an *argument by homology*. This point needs elaboration because the use of evolutionary approaches in the social sciences, especially in economics, evokes confusion over homology and analogy.

Evolutionary epistemology as presented by Popper and Campbell, appeals to the historical link between all organic forms through the gradual and cumulative development of knowledge as mediated by natural selection. Organic evolution is therefore a long historical process of problem-solving which is inevitably linked to the development of knowledge. Technological change is thus conceived as part of human exosomatic evolution. Homology therefore provides the historical context of this evolutionary process; from amoeba to Einstein, to use Popper's favourite example. Popper's view implies linearity as natural selection leads to higher organisms or theories.

In addition to Popperian selectionism, this study emphasizes the role of fluctuations and related non-linear re-organizations. Socio-economic

structures are indeed open systems which undergo re-organization due to internal and external factors. Adaptive tools such as knowledge systems equally undergo non-linear re-organization. The degree of fluctuation within the system influences the rate of the generation of adaptive tools, of which the generation of knowledge is paramount. Popperian selection is therefore more effective as an epistemological framework if viewed as operating within a system that undergoes non-linear re-organization but is still subject to irreversibility and the arrow of time.

A systems approach also allows for the analysis of localized knowledge and co-evolutionary processes. This is important for this study because the concept of techno-economic niches requires an understanding of the generation of localized knowledge within a larger system undergoing non-linear fluctuation. Some of the pressures generated by the re-organization of the system as a whole lead to local bifurcations which, in turn, re-organize the system. A purely selectionist approach would conceal such internal dynamics and confine us to tracing historical trajectories left by the selected theories or organisms. The selection processes themselves are part of the re-organization of the system and cannot be well understood without examining the dynamics of the system itself.

The potential of a bifurcation to have system-wide re-organizing effects is largely influenced by the degree of instability or fluctuation within the system. Localised bifurcations tend to have system-wide amplifications under conditions of extreme instability or rapid flux. For example, dramatic changes in the availability or prices of strategic resources may lead to the rapid generation and diffusion of knowledge about alternative resources. So long as systems undergo fluctuations (which is a key characteristic of open systems such as economies) major changes akin to Kuhnian paradigm shifts may result from localized bifurcations. For the purpose of this study, the positions held by Popper and Kuhn are complementary because they deal with two key features of an evolving system.

Critics of evolutionary approaches often perceive them simply as the application of biological analogies or metaphors to socio-economic processes. This perception carries a Cartesian dichotomy of human and non-human processes. The dichotomy can be made irrelevant by recognizing that

socio-economic and biological processes share homology. Whereas homology presupposes historical links or common descent, analogies develop because of exposure to similar circumstances. A more detailed discussion of these notions will show their potential uses and limitations.

One of the main criticisms of using analogies is that they can be fallacious. This is not a problem because we do not intend to crudely transfer known biological features to the workings of techno-economic systems. A more serious problem is that analogies can easily overshadow historical links. In constructing an analogous argument, for example, one is required to view technological change and biological evolution as parallel processes in similar circumstances which lead to similar results. Such a juxtaposition would not enable us to examine the evolutionary path, but the construct would be useful as a source of heuristics in identifying specific features of the evolutionary process. For example, allometrics would suggest the study of size and structure in technological systems. The analogy here arises from the fact that differential growth is a key feature of both internal technical change and organic development.

Homology requires that the study be a long argument in which history itself is allowed to tease out the main features of technological change.<sup>1</sup> This allows us to free ourselves from analogy as a methodological approach and to rely on the data. Therein lies our appeal to realism. By accepting homology, we do indeed have a certain view of biological evolution and expect to find some features of biological evolution in technological change. For example, both homology and analogy would predict variability, selection and retention in technological systems. These features are part of the *evolutionary logic*.

Evolutionary logic, however, differs from theories or basic laws because it enables us to cope with the causes and effects of change. It allows one to deal more comprehensively with technology policy matters because they are already contained in the process. The heuristics from homology and

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1. Arguments by homology have their dangers as well, especially under conditions of re-organization, morphogenesis, differentiation and hierarchical structures. Such changes tend to introduce new features or relationships which cannot be understood by homologous arguments. In such cases, similarities may result more from external conditions and therefore make analogous reasoning more relevant.



analogy lead to a resonant process where the theoretical base is constantly re-organized as research progresses. Simultaneously, the preliminary research findings also help to guide subsequent lines of analysis.

## **2.2 Data Sources and Research Methodology**

To build a clear picture of the sequence of events required extensive collection of relevant data over a specified historical period. The data base also had to allow us to examine the workings of socio-economic systems. Some sections of the study, especially those dealing with global trends, relied on readily available secondary data. The data were used mainly to illustrate the existence of fluctuations and not to analyse the causes of these fluctuations in detail. The secondary material available was therefore adequate for the purposes of this study.

The analysis of national trends relied on both secondary and primary data. These came from published materials, unpublished government studies, corporate reports, and interviews. The study also benefited from unpublished studies by international agencies. Those materials that could not be quoted were used as sources of background information and also provided the basis for further investigation. Because of the controversial nature of the projects, the research required that the details be well documented.

The case studies relied largely on primary data. The information was not concentrated in any one place and had to be collected virtually half-way around the world. The research process involved data collection in Kenya, Zimbabwe, Malawi, West Germany, Switzerland, Sweden, Britain, Brazil, Canada and the US. Most of the work was done in Kenya and Zimbabwe but some vital links in the sequence of events could not be made without specific pieces of information which were not available in these countries. Moreover, it was necessary to collect data on the supply side of the technology to get a comprehensive picture of the technological change process.

Successful data collection required knowledge of the key institutions and individuals involved in the investment projects. A study of the organizational structure of investment had to be done before the data on the

projects could be collected. Every project had a complex network of institutions from which data on various aspects of the investment could be obtained. The network changed over the project time. Some institutions that were associated with the project in the early stages were no longer involved in later periods. The links between technology and institutional change were imposed on this study at the pre-research stage.

By understanding this complex network, it was possible to identify those institutions which had certain types of information. In some cases, it was necessary to apply investigative techniques to collect information that was not otherwise easily available. This approach was necessary because very little published information was available on the projects and because the controversies surrounding them reinforced secrecy. Conventional sources such as newspaper clippings and Hansard were extremely deficient. The study did not rely on a pre-defined boundary within which data could be collected. The limits to data collection were implied in the extent of the information available on the projects. The aim was to produce a comprehensive, historical picture from which key trends could be identified.

The analysis and presentation of the data was guided by the need to identify key policy issues which could serve as a guide for long-term technological change. The analysis and presentation had therefore to rely on evolutionary epistemology, emphasizing observation so as to expose the dynamics of techno-economic transition. To give a holistic picture of the study, the relationships between the various aspects of the system studied had to be presented as they occurred. Explanations of parts of the system are presented in a manner that enables the links with the whole system to be established. This is precisely why the study emphasizes structure and function because they enable us to deal with the internal (hierarchical and non-hierarchical) organization of fluctuating systems. The analysis of various aspects of the study are only meaningful as part of the whole system. It is the nature of the system and its internal organization that dictates the method of explanation and not vice versa.

## 2.3 Research Limitations

This research project faced a number of obstacles: data availability, political sensitivity, official secrecy, limited institutional memory, and biases in information. Its study required that data of similar types be collected so as to allow comparisons to be made. The study also required that the unfolding sequence of events be as well-documented as possible. There are gaps in the study in both cases. The Zimbabwean case is well-documented in the early years but data on the construction period are fragmented. This is due to the war conditions that prevailed at that time. Government files were reportedly purged before the present government came to power and the study had to rely extensively on interviews for information on developments over this period.

Similarly, data on plant technical performance for Kenya were not available and it was not therefore possible to conduct comparative assessments of operating efficiency. Production figures are used as a proxy in the case of Kenya. The same problem also applies to data on energy balances. The study therefore carries inevitable imbalances with regard to the amount of information available at the various stages of the development of the project. These obstacles made it impossible to conduct a direct comparison of the two countries' projects. What is contained herein is therefore a study of fuel ethanol in Kenya against the backdrop of the Zimbabwean experience. The "backdrop comparison" is, however, adequate for the purposes of the study.

This study relied to a certain extent on interviews, especially given its historical nature. Although most of the key institutions and individuals involved in the Kenyan projects were identified, it became difficult in some cases to collect reliable information through interviews. This was mainly because of short *institutional memory*, partly resulting from the rapid mobility of staff in the civil service. This problem was worsened by the controversies surrounding the projects. In addition, the government wanted to retain a certain measure of credibility among international donors and therefore did not wish to release much relevant information.

This problem was compounded by the very nature of the institutional arrangements of the investments. The projects involved government equity to a scale that made them in effect parastatal organizations. This status subjected all information on the projects to the Official Secrets Act, which meant that the process of data collection had to be conducted largely through government channels, with considerable delay. The problem was to a certain extent lessened by the fact that some sections of the government were concerned about the long-term implications of Kenya's investment strategy and were therefore willing to provide the requested information. A new mood of self-criticism, which is so essential for institutional learning, was already emerging within the civil service. Despite these limitations, the data collected were comprehensive enough to provide the historical material needed to meet the methodological requirements of this study.

### **Conclusion**

This chapter has sketched the philosophical underpinnings of the methodology used in the study. It has also presented the research methods used, the state of the data base and its limitations. Evolutionary epistemology deals specifically with the dynamics of change under real world conditions, making it relevant to the policy analysis of techno-economic issues. Issues such as holism, interrelationships, fluctuations, adaptation and irreversibility which are central to this study can adequately be understood from the vantage point of evolutionary epistemology.

### **3. RESOURCE FLUCTUATIONS AND ECONOMIC RE-ORGANIZATION**

#### **Introduction**

This chapter will show that major fluctuations in the prices of oil and sugar created opportunities for the introduction of fuel ethanol technology. It will be argued that the introduction of fuel ethanol in Zimbabwe and Kenya was part of the re-organization of the economic system in response to the decline in sugar and molasses prices and rise in oil prices. The re-organization was influenced by the national socio-economic expectations and the institutional arrangements as well as policies formulated to guide the economy. It will be suggested that differences in the expectations of the two countries on the future of energy supply and prices largely influenced the patterns of institutional reform in the two countries.

#### **3.1 Fluctuations in Resource Prices**

##### **3.1.1 Disruptive shifts in oil prices**

The disruptive effects of fluctuations in oil prices depend largely on the share of this resource in the commercial energy budget. The share of oil in the world energy configuration (measured in energy units) rose from 13 per cent in 1925 to 45 per cent in 1970. The rise was linked to the economic upswing of the post-1945 period. However, the share and rates of increase had marked regional differences as shown in Table 3.1. The figures are based on the world consumption of oil, coal, natural gas and electricity but do not include wood and other non-conventional energy sources.

The share of oil in the commercial sectors of the developing countries expanded rapidly over the post-World War II period from nearly 14 per cent in 1950 to about 60 per cent in 1970. This dominance made the economies more vulnerable to price fluctuations and access restrictions. The uneven

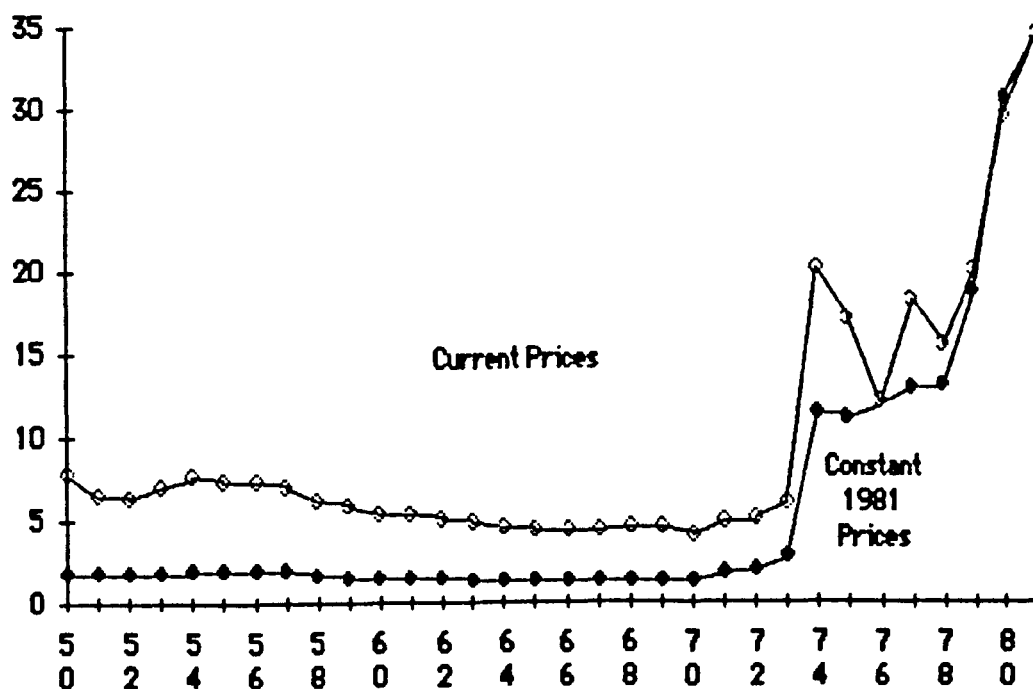
distribution of this resource worsened the risks of disruption. The risks were outweighed by the fact that oil was becoming relatively cheaper than coal, was easy to use and allowed for flexibility in end-uses. Joint government and industry interventions were used to keep the price of oil low in relation to coal to facilitate the transition to oil use.<sup>1</sup> The developing countries therefore easily joined the oil-based industrial growth.

TABLE 3.1: *Percentage Share of Oil in Commercial Energy (BTUs)*

Region	1925	1950	1970
US and Canada	19	39	44
Western Europe	3	14	56
Japan	4	6	69
Communist areas	11	14	25
Others	12	40	59

Source: Griffin *et al.* (1980).

FIGURE 3.1: *Trends in Oil Prices (US Dollars per Barrel)\**



\*Weighted average OPEC crude prices

1. Griffin *et al.*, *Energy Economics*, pp. 16-17.

Moreover, the fact that these countries relied on oil-based capital stock from the industrial countries made the use of oil almost inevitable. The switch to oil was helped by cost reductions from improved production technology and economies of scale in transportation. The discovery of more oil fields made oil easily available at cheap prices and helped to facilitate the diffusion of oil-using technologies. The discovery of new oil fields in the Middle East in the 1930s helped keep prices even lower. As a result of low entry barriers (to both producers and consumers) in the oil market and technological advancement, real oil prices fell in the 1950s and 1960s, providing producers with the incentive to set up a cartel to raise prices. The Organization of Petroleum Exporting Countries (OPEC) was established in 1962 but did not have any significant impact on oil prices until the 1973 oil embargo. Figure 3.1 shows the changes in oil prices between 1950 and 1981.

The 1973-74 oil shock, which was sparked off by geopolitical factors and led to the realization of OPEC's long-standing policies on higher oil prices, raised questions concerning the exhaustibility of this resource. It was not just an issue of price increases but also a matter of resource management. The effects of the price increases were different in the various importing countries. Petroleum was so firmly tied into the economic process that immediate adjustments to price shocks were difficult to make. Various countries tended to adjust consumer prices, reduce imports and cut back on some economic activities. Many of the developing countries turned to external borrowing as a short-term measure to ease the impact of high oil price on their balance of payments.<sup>2</sup>

The oil shock found the developing countries already tied into a global economic system with worsening terms of trade.<sup>3</sup> This problem was coupled

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2. The loans also served as a way of recycling the rapidly-accumulating oil revenues although the bulk of the funds went to a few countries, the so-called newly-industrializing countries (NICs).

3. The declining terms of trade was already a major concern among developing country economists and the United Nations in the 1950s. Using an index of 100 for 1950, the developing countries' terms of trade declined to 86 in 1961 *vis-à-vis* the industrialized countries, according to Hallwood *et al.*, *Oil, Debt and Development*, pp. 10-11. Concern over the falling terms of trade led to two major international initiatives. First, the UN launched the First Development Decade aimed at redressing the imbalance through an accelerated GNP growth rate (of no less than 5.0 per cent). Second, trade and development negotiations were launched through the UN Conference on Trade and Development (UNCTAD), which later became a permanent UN body concerned largely with global trade imbalances.

with the fact that as many as 64 of the 92 oil-importing developing countries depended on oil for over 75 per cent of their commercial energy.<sup>4</sup> This meant that any slight shift in the prices or availability of oil would have far-reaching effect on the economies of these countries. Between 1972 and 1974 alone, the oil import bill of the oil importing developing countries rose by 450 per cent to reach US\$21.5 billion.<sup>5</sup> The disruption caused by these shifts were reflected in deteriorating current account deficits particularly with OPEC and industrialized countries.

Moreover, economic growth (as measured in GDP) dropped in most developing countries over the post-1973 period. The average annual rate of growth in GDP in the oil importing developing countries over the 1967-1972 period was 6.1 per cent. It rose to 7.3 per cent in 1973 but declined to 5.3 per cent in 1974, and 4.1 per cent in 1975.<sup>6</sup> This decline was also associated with economic recession in the industrialized countries. These changes worsened the debt problem although the increase in borrowing was not specific to the oil crisis. Indeed, international borrowing among developing countries was already significant in the post-1945 period.

Medium and long-term borrowing rose at an average annual rate (at current prices) of 14.8 per cent in the 1955-1960 period and 16.5 per cent over the 1960-1965 period. The figure rose to 16.8 per cent over the 1967-1972 period and 21.0 per cent over the 1972-1976 period.<sup>7</sup> The borrowing which started in the 1950s was facilitated and expanded by the oil shock. It is notable that concern over the rising debt burden had become a matter of concern in the late 1960s, prompting the Pearson Commission to note that the debts already contracted by the developing countries "cast a pall over the short- and long-term management of their economies".<sup>8</sup>

The oil-importing developing countries tried to reduce the effects of higher oil prices and keep their borrowing level by drawing from their foreign exchange reserves which had accumulated from SDR15 billion in 1960

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4. World Bank, *Energy in Developing Countries*, pp. 4.

5. Hallwood, *op. cit.*, pp. 79.

6. *Ibid.*, pp. 164.

7. *Ibid.*, pp. 75.

8. Pearson Commission, *Partners in Development*, pp. 74. The debt contracted in the 1950s was largely government-to-government borrowing. However, much of the borrowing in the post-1973 period was through private financial institutions.



to SDR33 billion in 1973.<sup>9</sup> These reserves were reduced by about 25 per cent in the first two years following the oil shock. It should be noted, however, that the worsening balance of payments did not result from oil price increases alone. Price shifts were associated also with other fluctuations in the exports and imports of these countries, as well as changes in the terms of trade with the industrialized countries.

The effects of the high oil prices were reflected in higher consumer prices, limitations on employment and a general economic slow-down in the oil-importing developing countries. Some of the effects were articulated at the political level, leading to political upheavals in various African countries. Long-standing problems of income inequality were aggravated by real or anticipated effects of the high oil prices. The effects, both economic and political, were irreversible. Existing oil importation patterns and practices had to be reconsidered. Most of the developing countries had no energy policies or contingency measures to deal with such dramatic shifts.

The energy crisis led to the search for short-term adjustment mechanisms. Whereas some countries responded with short-term price adjustment and import cut-backs, others considered long-term solutions and the search for different demand patterns. These included intensified oil exploration, diversified sourcing of petroleum and a search for alternative energy sources. This latter option is interesting because it required a shift away from conventional approaches which sought for solutions within the oil sector itself. As pointed out earlier, the range of substitution in the energy sector is usually very limited. And where alternatives exist, the transition entails the introduction of new technological systems.

The range of technological options or diversity in the liquid fuels sub-sector was limited to a few sources, mainly methanol and ethanol fuels. Of these, ethanol was the easiest to select and implement because of at least three reasons. First, it could be blended with gasoline up to 20 per cent without requiring engine modification. Second, the technology for producing it could be transferred easily from the beverage sector and incremental adaptation could also be easily undertaken. Third, the conventional raw materials for producing fuel ethanol, sugar and molasses, were undergoing

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9. Hallwood *et al.*, *Oil*, pp. 81.

dramatic price reductions at that time and hence could be diverted to fuel production with minimal opportunity costs and political acceptability. The next section looks at the recent trends in the world sugar market to show the convergence of factors in commodity prices which created the opportunity for the development of fuel ethanol niches in some developing countries.

### **3.1.2 Trends in world sugar prices**

The previous section underscored the fact that rising prices of oil opened up opportunities for structural re-organization in the world economy, of which the production of fuel ethanol was one. It was also noted that the production of fuel ethanol was facilitated by declining sugar prices, a feedstock for ethanol production. The history of sugar is different from that of oil. The main differences are summarized in Table 3.2. Apart from the basic differences, the future of sugar is also currently being threatened by a wide range of artificial and natural sweeteners. Over the years, sugar prices have tended to fall while at the same time leaving excessive oversupply. These two trends have created favourable conditions for the introduction of fuel ethanol as an alternative outlet for sugar.

The world sugar economy has been associated with dramatic fluctuations and uncertainties, forcing the governments of producing countries to introduce measures to stabilize the situation. One of the earliest effort were undertaken in Brazil with the formation of the Institute for Sugar and Alcohol (IAA) in 1933. Among other things, this institute aimed at converting some of the surplus sugar to fuel ethanol as a way of maintaining artificial scarcity and therefore stabilizing prices. The formation of IAA was not an isolated act, but a realization of cumulative efforts that had been initiated in the previous century to stabilize the world market for sugar, especially with the advent of new challenges from sugar beet in Europe. The volatility of the world sugar market is therefore not a

recent phenomenon but a long-standing problem.<sup>10</sup> More recent trends in the production, trade and prices of sugar have been even more dramatic.

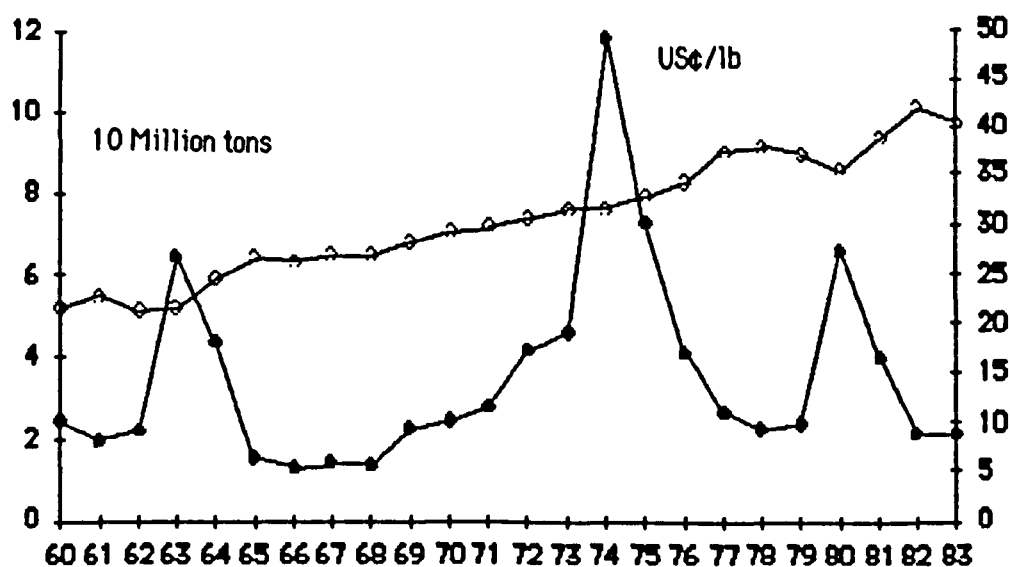
TABLE 3.2: *Main Characteristics of Sugar and Oil*

Characteristic	Sugar	Oil
Importance to importers	Non-strategic	strategic to all economic sectors
Composition of producers	Numerous and small	Few and large
Composition of middlemen	Numerous	Few
Range of substitutes	Numerous	Few
Market structure	Tied to long-term agreements	Concentrated in industrialized countries
Demand feature	Falling	Rising
Income elasticity of demand	Low	High

World sugar production has nearly doubled since 1960, rising from 52 million tons to 101 million tons in 1982 (Figure 3.2). Over that period, there were only seven years that saw reductions in output and these were caused by crop failure. Prices tended to rise dramatically in response to these failure-induced deficits. As a result of these price rises, major investments were undertaken to benefit from a seemingly recovering industry. The investments, which represented massive private and government financial, material and human inputs, added more sugar to an already flooded market. Over this period, there was no major increase in sugar consumption, except that which could be accounted for by population growth. It appears from these trends that national policies on investment in the sugar industry in the developing countries were not influenced by a close examination of the behaviour of the world sugar market.

10. See Nunberg (1978) and Gordon-Ashworth (1980) on the role of the state in the Brazilian sugar industry.

FIGURE 3.2: *Trends in World Sugar Output and Prices (1982 Prices)*



Protectionist measures such as price guarantees, import duties as well as import quotas weakened the efforts to stabilize the international sugar market. The European Economic Community (EEC) for example, maintained high price guarantees as well as an export restitution system under which producers were refunded the difference between world export prices and the guaranteed prices to EEC farmers. This system was stopped in 1981.<sup>11</sup> The refund operated only for export quantities that fell within the range of production quotas, set at 110–115 per cent of consumption.

However, exports outside quota limits were still profitable and as a result EEC sugar production rose from 9.0 million tons in 1970 to 15.0 million tons in 1982, adding some 5.0 to world production capacity. Considerations of resource self-sufficiency in the EEC following the OPEC oil shock influenced production policies, as reflected in the raising of EEC quota levels by over 20 per cent. This output was also associated with major technological advances which raised beet productivity and the range of

11. FAO, *Sugar*, pp. 4.

varieties, a direct threat to developing countries which had relied for a long time on sugar as a major source of foreign exchange.

In the meantime, developing countries embarked on sugar expansion programmes, especially following the 1973-74 sugar price increase. It was assumed in the industrialized countries then that prices of commodities were generally going to rise and therefore an increasing number of developing countries initiated major investment projects in this sector. Inter-governmental lending agencies were equally willing to fund new sugar projects or revamp existing ones. The high sugar prices in the 1973-74 period led to a reduction in consumption in 1975, which then rose again in 1976 as sugar prices dropped. Meanwhile, production continued until bad weather hit again in 1979/80 -- tripling real prices. This was reduced by half the following year and since then sugar prices have remained lower than production costs. And this is happening in a sector where world output is well in excess of demand. The 1984 consumption level was about 95 million tons, leaving a surplus of about 6.0 million tons. The production capacity is far larger than the current output. Moreover, the response period is also very short. For example, following the 1980 price increases, the world was able to add some 17 million tons of sugar to the market in just 24 months.

Sugar is traded under two different market forms. In the first place some 25-30 per cent of the traded sugar is handled under special arrangements like the Sugar Protocol of the Lomé Convention, Commonwealth Sugar Agreements and other arrangements among the socialist economies. The second type is the free market which accounts for the rest of the sugar trade. Ironically, the free market is a residual forum because it only handles the sugar that has not been bought under the special arrangements or consumed locally. Out of the 90 million tons produced in the early 1980s, about 70-75 million tons were consumed locally. Some 15-17 million tons were traded on the free market and 3-4 million tons traded through preferential transactions. The international sugar market is influenced by extensive political considerations which govern policy formulation, preferential arrangements, licensing systems, control devices and other aspects of the industry. The free market exists only insofar as prices are

not administered. But efforts have been initiated to keep prices within certain ceilings, especially under the International Sugar Agreement.<sup>12</sup>

TABLE 3.3: *World HFCS Production ('000 tonnes, dry basis)*

Country/Region	1980	1981	1982	1983	1984	1985
USA	2045	2540	2900	3385	3800	4100
Canada	42	85	110	140	165	190
EEC	185	192	187	185	185	185
Other West Europe	60	85	85	95	110	120
East Europe	15	30	45	75	80	100
Japan	365	525	590	625	660	690
South Korea	16	55	92	95	115	140
Other Asia	1	5	8	10	40	100
Latin America	40	45	50	65	80	110
Africa	--	--	--	--	20	40
World total	2765	3562	4067	4675	5255	5775

Source: Thomas (1985).

It is not just the decline of sugar prices that threatens the industry. Alternative sweeteners are also slowly penetrating the market. Interestingly enough, the entry of some of the sweeteners has been made possible by the efforts to maintain high sugar prices. One of the alternatives is the conversion of glucose contained in corn to high fructose corn syrup (HFCS). This is produced by the enzyme isomerase which yields a liquid sweetener of the equivalent of 60 per cent sucrose in water. The world output of HFCS rose from 136,000 tons in 1974 to 500,000 in 1975 and was expected to account for about 2.5 per cent of the world sugar production by 1980.<sup>13</sup> The global sale for HFCS for 1980 was estimated at 2.8 million tons. It rose to 4.7 million tons in 1983 and 5.8 million tones in 1985 (Table 3.3). By 1980, the price of HFCS was about 47 per cent less than that of sucrose in the US and Japan.<sup>14</sup> As a result, companies such as Coca Cola and Pepsi Cola have switched from sugar to HFCS for some of their products.<sup>15</sup>

Another technical possibility which has increased the potential use of HFCS is the combined production of ethanol and HFCS in the same wet milling

12. UNCTAD, *Studies in the Processing of Commodities*, pp. 4-5.

13. Withers, "The Trade and Technology of Sugar", pp. 144.

14. Vuilleumeir, "World Outlook for Syrups", pp. 34.

15. *Ibid.*

process. Furthermore, innovation in enzyme technology has helped reduce HFCS production costs. The industry has increased the application of immobilized enzymes which have high isomerization, are more permeable, flow better and result in higher conversion efficiency. The substitute is being used in industrial sectors where sugar has been dominant; beverages accounted for over 60 per cent of the 1985 output, baking 12 per cent, canning 12 per cent, food processing 8.0 per cent, dairy products 6.0 per cent and rest going to confections. Over 50 per cent of the sweeteners used in the beverage industry are now accounted for by HFCS. The penetration of HFCS is likely to have profound effects on the sugar market given the number of countries that are increasing or planning production. They include the US, Canada, Mexico, Argentina, Uruguay, Brazil, Peru, Venezuela, Spain, Portugal, Hungary, Yugoslavia, Bulgaria, Soviet Union, Egypt, Morocco, Sudan, Japan, Korea, Pakistan, China, Indonesia and Malaysia.

There are other threats to sugar. A wide range of natural sweeteners are now being discovered and considered for large-scale production. The "sweetness gene" of the West African plant *Thaumatococcus daniellii*, which is over 1,600 times sweeter than sucrose, has been inserted in bacteria, making it possible to produce natural sweeteners in conventional vats. Thaumatin is now being marketed as a sugar blendstock by Tate and Lyle in Britain under the trade name of Talin and is used in candies, chewing gum, pickles, jellies, soups and other products. This is not the only candidate. The so-called miracle fruit (*Synsepalum dulcificum*) from West Africa is a protein-based candidate that might lead to a new range of non-fattening sweeteners. The berry contains no calories.<sup>16</sup>

Also from West Africa is the Serendipity berry (*Dioscoreophyllum cumminsii*) which is 3,000 times sweeter than sucrose. From Paraguay is *Stevia rebaudiana* whose leaves are 300 times sweeter than sucrose; it is already being marketed in Japan. A Chinese fruit, *Momordica grosvenori*, which is sold in southern China and Hong Kong is a potential candidate for large-scale sweetener production. The new hunt for natural sweeteners has also led to the re-discovery of *Lippia dulcis*, which the indigenous South

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16. Myers, *Wealth of Wild Species*, pp. 166.

Americans reportedly enjoyed chewing at the time of the conquest of the Aztecs. This candidate is 1,000 times sweeter than sucrose.<sup>17</sup>

So far the penetration of natural sweeteners has been limited to a few products and their impact is yet to be felt on a large scale. However, there are several factors which indicate that they will pose long-term challenges to the sugar industry. In the first place, the natural sweeteners do not have uniform taste so they will offer diversity in the food industry, whose growth is largely influenced by product differentiation. Secondly, the use of genetic engineering makes it possible to extract the relevant genes from the plant and insert them in another organism, thereby freeing production from the complicated agricultural process that is associated with cane or beet production. Thirdly, with the very high levels of sweetness, even extremely low conversion efficiencies would yield substantive amounts of sweetener. Fourthly, the discovery of protein-based sweeteners is likely to create a new market for those concerned with the health effects of sucrose or saccharin. And of course the search for new varieties opens up more possibilities for the discovery of more suitable substitutes.

The previous two sections have illustrated some of the resource changes that have unfolded in the world in recent decades. First was the rising prices of oil which caused a wide range of disruptive effects in the oil-importing developing countries. Second was the falling prices of sugar and the entry of various substitutes in the sweetener market. These trends have weakened the position of sugar as a foreign exchange earner and strengthened the position of oil as a foreign exchange consumer. A possible reconciliation of the two divergent trends has resulted from the fact that sugar can be used as raw material for producing fuel ethanol to meet some of the energy needs of the oil-importing countries while at the same time finding a new market for sugar.

### **3.1.3 The molasses resource base**

The production of fuel ethanol in the post-1973 period was linked to the availability and relative cost of raw materials, molasses for this matter, at

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17. Vietmeyer, "How Sweet", pp. 28.



the national level. This section examines the major trends in the production and availability of this resource as a feedstock for fuel ethanol production. It will be shown that the availability of molasses created an independent resource-based search for possible end-uses which only became important for ethanol because of the changes in the energy environment.

The production of sugar leaves large amounts of residual molasses which has a high sugar content. The range of optional uses for molasses depends largely on the composition of the raw material, which varies according to cane variety, climate, soil type, agricultural inputs and farming techniques. However, molasses generally comprises 75 per cent water and 25 per cent solids. Nearly one half of the solids constitutes fibrous material and the rest is soluble solids (12 per cent). About 10.5 per cent of molasses is accounted for by sugar and the rest of the soluble solids include non-sugar substances such as proteins, amino-acids, carboxylic acids, starch, wax, fats, phosphatides, gums, minerals and unidentified substances.<sup>18</sup> Molasses (from beet and cane) has a wide range of end-uses which fall into five main categories: animal feed; desugarization; fermentation; human consumption and technical applications.

In animal feed, molasses is used as a source of nutritional energy. Desugarized liquids are usually prepared for the recovery of glutamic acid, betain, potash and amino acids. The category of fermentation yields a wide range of products including baker's yeast, food and feed yeast, fat yeast, ethyl alcohol, rum, acetic acid, citric acid, lactic acid, glutamic acid, itoconic acid, aconitic acid, fumaric acid, malic acid, butyric acid, propionic acid, gluconic acid oxalic acid, butanol, acetone, 2.3-butylene glycol and glycerol. The range of human uses of molasses include caramel and edible colours, coffee surrogate, edible molasses, mycelial protein, pharmaceutical products, production of arrak and sake.

Molasses is also used as bleaching agents (activated carbon), binders for insulating materials, blackening agents (iron and steel), briquetting agents (coal dust, coke slack, sawdust), denaturants (cattle salt), fertilizers, binders in foundry work, fuels (direct combustion), granulating agents in mineral fertilizer, sealing compounds, wood seasoning agents, and

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18. Rüter, *Molasses Utilization*, pp. 2.

soil structure stabilizers. This range of end-products illustrates the variety of market niches that can be opened up by molasses.

The process, however, is determined largely by the relative costs of production and the competitiveness of the products. The creation of market niches requires a recognition of the production possibilities associated with a particular resource. Both Zimbabwe and Kenya exported large shares of their molasses. But changes in the world molasses price led to the search for local niches for molasses products. The search for alternative end-uses for molasses in Zimbabwe started long before energy became a major concern. Changes in the traditional export market for Zimbabwe forced the country to examine the local market as an outlet for new products.

It was the view of the government, as expressed in a Ministerial report on molasses in October 1964, that export of surplus molasses brought little benefit to the economy and high transportation costs at times of depressed prices undercut any gains from exports.<sup>19</sup> This concern prompted the government to look into the possibilities of downstream molasses processing. "It is...desired to see whether by upgrading molasses into some other form, these difficulties might be overcome and, if possible, to interest an overseas company in establishing a processing plant in Rhodesia."<sup>20</sup> It is notable that this view was expressed in a government report, which illustrates that the state joined the private sector in the search for possible market niches.

The government's view was also based on an understanding of changes in the international molasses market. For example, the government suggests that the rising utilization of molasses as animal feed had led to higher prices, which in turn had "caused a switch from fermentation to the petroleum chemical route in the manufacture of a number of chemicals".<sup>21</sup> The knowledge of the international market and resource trends led the government to conclude that the availability of cheap petroleum reduced the competitiveness of molasses in making similar products.

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19. See chapter 5 for pre-1964 efforts to utilize molasses.

20. Ministry of Trade, Industry and Development, *Possible Disposal of Molasses*, pp. ii.

21. *Ibid.*

The fact that the Ministry of Trade, Industry and Development produced a report on this issue may give a misleading impression that the search for alternative markets for molasses was mainly a government endeavour. The initiatives were supported by the private sector through the Rhodesia Sugar Association (RSA). This was indeed a small group of people with converging interests. Two estates, Triangle and Hippo Valley, produced virtually all of Zimbabwe's sugar. The detailed information that the government used in the preparation of the molasses report was provided by the RSA. It is notable that this information was compiled to enable a Ministerial delegation visiting Britain to negotiate with industrialists interested in setting up a plant. "Their visit provides an opportunity for discussions with industrialists who might be able to advise on, or...be interested in establishing a plant...with the object of securing a long term supply of rectified spirits, or some other product."<sup>22</sup>

Concern over the future of molasses markets was based on projected surplus. Although Zimbabwe exported large quantities, it was felt that the country would in the short-run have large surpluses if new local market were not found. The export contract was expected to expire in 1968, leaving the country with nearly 100,000 tonnes of surplus molasses (Table 3.4). Already, the country was using part of its molasses for industrial and potable spirits production, yeast manufacture, and animal feed.

TABLE 3.4: *Zimbabwe Molasses Export and Surplus ('000 Tonnes)*

Year	Export	Surplus
1965	22,200	35,000
1966	33,800	40,000
1967	48,300	43,000
1968	52,000	45,650
1969	--	100,000

Source: Ministry of Trade Industry and Development (1964).

The chances of securing export markets for Zimbabwe's molasses were reduced by the trade sanctions which followed the Unilateral Declaration of Independence (UDI). This not only reduced possible external

22. *Ibid.*, pp. 4.

Investment in the molasses market, but they also reduced the chances of selling molasses itself. Moreover, the war and its effects on transport routes through Mozambique forced the country to rely on South African ports for exports. The costs of shipping molasses through South Africa became increasingly prohibitive and the molasses producers were forced to dump it. Consequently, the search for local markets became even more urgent.

Over the period, Kenya exported most of its molasses until the combined effects of transportation costs and declining world prices changed export prospects. Most of Kenya's molasses was produced from four sugar mills in western Kenya. The yield varied according to the recovery efficiency of the various sugar mills in the country (Table 3.5). These variations were partly influenced by the age of the mills. Older mills were less efficient in the recovery of sugar and therefore left molasses with higher sugar content. Other factors such as production scale and operating efficiency also influenced the recovery of both sugar and molasses. Kenya exported its molasses mainly to Europe, the US, and Canada. Exports rose steadily over the 1967-1977 period while export prices were marked by sudden variations (Table 3.6). Although average prices rose over the 10-year period, transportation costs steadily reduced the net income, subsequently making it increasingly necessary to look for local uses for molasses.

The local demand for molasses is difficult to estimate. The Kenya Sugar Authority (KSA), an advisory parastatal wing of the government, uses a residual approach under which the exported quantities are subtracted from the reported factory output. The residual value is taken to represent local consumption, most of which is allocated to animal feed. This approach may be misleading because it does not take into account unreported uses such as the production of local rum or gin, which is a common economic activity in the sugarbelt. Moreover, the main sugarbelt is located near the Uganda border and it is not known how much molasses is smuggled across the border. A survey by the Industrial Survey and Promotion Centre (ISPC) of the Ministry of Commerce and Industry reported that some 10-19 per cent of molasses produced in Kenya in the mid-1970s was used as animal feed. This represented an annual average consumption of 12,000 tonnes. The absence of

data on this end-use led to policy conflicts between the Ministry of Livestock Development and the promoters of fuel ethanol in the late 1970s.

TABLE 3.5: *Sugar and Molasses Recovery in Kenya (1980)\**

Mill	Commisioned	Capacity (t/d)	Sugar yield (%)	Molasses yield (%)
Miwani	1920s	1,200	7.0	3.40
Ramisi	1920s	1,530	7.5	3.75
Muhoroni	1966	1,800	9.3	3.75
Chemelil	1968	2,235	9.4	3.30
Mumias	1973	7,000	11.0	2.97
Nzoia	1980	2,000	11.2	2.58
Sony	1980	2,000	10.6	3.77

\*The figures are based on interviews with the management of the sugar mills and the Kenya Sugar Authority, Nairobi, September 1984. The molasses yield figures are based on a six-year average.

TABLE 3.6: *Kenya Molasses Production, Export and Surplus*

Year	Production ('000 t)	Export ('000 t)	Price (KShs./t f.o.b)
1967	24.2	14.6	NA
1968	32.6	17.4	NA
1969	46.2	25.3	NA
1970	50.1	34.2	85
1971	49.6	25.0	100
1972	36.9	21.5	138
1973	55.2	31.0	273
1974	65.8	28.5	354
1975	63.8	41.9	258
1976	55.0	36.4	365
1977	56.0	34.0	330
1978	75.8	40.4	248
1979	97.9	62.9	466
1980	132.9	68.6	580
1981	120.2	67.1	657

Sources: Kenya Sugar Authority, Nairobi; East African Storage Company, Mombasa.

The Ministry of Livestock Development identified molasses as a strategic feed in national plans to boost livestock production. The Ministry estimated that animal feed was claiming some 30,400 tonnes of molasses in 1980, nearly half the exported quantity, and would need to rise at the rate of 7.0 per cent per year in order to meet the country's livestock

development targets. The basis for these estimates could not be justified, either on the current or projected livestock nutrition patterns. KSA, on the other hand, estimated a growth rate of 3.0 per cent in the livestock demand for molasses.<sup>23</sup> But if the required molasses were available, distribution and transportation costs would still limit the extent of utilization.

The only major industrial use of molasses was the Miwani Distillery which used about 4,800–5,000 tonnes a year. The distillery produced spirits estimated to have about 40 per cent ethanol (on a volume basis). The annual output ranged from 336,722 litres to 362,279 litres over the 1971–1976 period. The distillery also produced industrial spirits for the local market and exported small quantities. On the whole, the search for local markets started much earlier in Zimbabwe than in Kenya. This was partly because of the differences in socio-economic expectations between the two countries. The next section will show that not only did the differences in expectations influence perceptions on resource utilization, but they also affected the patterns of institutional re-organization, especially in relation to energy.

### **3.2 Socio-economic Expectations and Institutional Change**

#### **3.2.1 The formative years**

This section will examine the institutional background which subsequently accompanied the process of niche realization in the two countries. It will be stressed that although Zimbabwe and Kenya had some basic similarities in their historical development, the institutional settings under which their energy strategies were formulated were different. The Kenyan development plans were characterized by expectations based on assumed normalcy in international trade while the Zimbabwean approach relied on presumed shortfalls in the supply and prices of liquid fuels. These differences led to variations in policies and administrative interventions.

Understanding the configuration of energy niches in Zimbabwe and Kenya in the post-1960 period requires a more detailed understanding of the

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23. Interviews, Kenya Sugar Authority, Nairobi, September 1984.

sources of socio-economic expectations and institutional reform. Kenya inherited an economic structure which had been designed to emphasize agricultural production. This feature moulded the patterns of commercial energy use. The early 1960s were marked by rapid growth in international trade and the developing countries hoped to increase their foreign earnings by expanding the export of their raw materials. The post-colonial policies in Kenya were therefore aimed at first maintaining the existing institutional structure while at the same time raising agricultural production and increasing industrial output. Not only were the traditional export markets maintained, but efforts were made to find new ones. The expectations also shaped the political outlook and became part of the ruling ideology. Those who suggested major reforms in the economic base were ejected from their political positions while those who proposed minor changes were absorbed in the main political party; a development that made Kenya a *de facto* one-party state soon after independence.<sup>24</sup>

This first decade also saw rapid economic growth. As an indicator, total GDP rose at an annual average rate of 6.6 per cent over the 1963-1973 period. While agriculture grew at 4.7 per cent over the period, manufacturing rose at 8.4 per cent per year.<sup>25</sup> These high growth rates resulted from land redistribution, rapid hybrid maize diffusion, and small holder agricultural expansion. They also influenced industrial output. The increased agricultural incomes generated demand for industrial goods. As a result, the government liberalized foreign direct investment policies, provided protection for the locally produced goods, and participated in joint ventures with the private sector. All these institutional changes were based on the assumption that the high growth rates would continue.

The situation in Zimbabwe was different. The imposition of sanctions against the country by the United Nations led to the inference that the country would face difficulties in the supply of raw materials. Disruptions in the economic sphere were expected and therefore the government introduced a wide range of measures to guarantee local self-sufficiency in strategic

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24. The country remained a *de jure* one-party state until 1982 when efforts to form another political party aspiring to different socio-economic expectations forced the government to amend the constitution and legitimize the *de facto* status.

25. World Bank, *Kenya: Growth and Structural Change*, pp. 1-3.

industrial inputs. The policies formulated and the institutions set up to devise policies to realize the policies clearly indicate that the government was concerned about the possible economic disruptions. The new measures and institutions represented a set of adaptive features geared towards coping with uncertainty. The major responsibilities for this institutional and policy adjustment lay in the Ministry of Commerce and Industry. The ultimate goal of the government was to maintain political and economic stability which would guarantee increased private enterprise participation.

However, the looming uncertainties increased state intervention. The Minister for Commerce and Industry summed up the situation thus: "Here in Rhodesia we have seen the stultifying effects of political uncertainties and we know that unless businessmen have confidence in a country...that Government will not forget that its first duty is to govern, to maintain law and order; then no amount of physical development or financial incentives will induce them to invest".<sup>26</sup> The most critical challenge to the government was to intervene in industrial development without necessarily having excessive control over its operations. The aim was to pave the way for private interests. It was felt that some degree of government control was necessary, but the proclaimed tendency was "to control as little as possible and to remove these controls if the need for them has passed."<sup>27</sup>

Before UDI, the government supported industrial development through the Customs and Excise Tariff as well as tax concessions. The level of protection was limited to competing imported goods. Moreover, tariff relaxations were also extended to the use of local materials, thereby stimulating demand for local industrial output. But following UDI, new elements were added to the customs and tariff regulations. The most important of these was the net foreign exchange benefit of industrial projects. This requirement was based on the presumed shortfalls in the availability of foreign exchange to the country due to sanctions.

These expectations were converted into policies and implemented through new institutional frameworks. In 1964, for example, the National Export Council was set up to assist exporters in finding markets for their

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26. Mussett, "Government's Industrial Policies", pp. 7.

27. *Ibid.*, pp. 7.



products. The search process involved the Ministry of Commerce and Industry and was operated in liaison with the country's diplomatic missions abroad. This followed the formation of the Industrial Development Corporation (IDC) the year before. IDC was set up by an Act of Parliament "to facilitate, promote, guide and assist in the financing of new and existing industries and industrial undertakings".<sup>28</sup>

The post-UDI industrial policies were heavily protectionist. However, they still required the investments to operate under competitive conditions. The import control policies were therefore subject to constant review. Again the Minister for Commerce and Industry stressed that "it would make no economic sense for Government to encourage the development of new industries which would only survive under the permanent umbrella of import control. It would not be in the national interest to permit the entrenchment of unsound and inefficient enterprises".<sup>29</sup> One of the ways of ensuring that government control did not lead to inefficiency was to use customs tariffs.

The choice was different from Kenya where equity participation and subsidies were common modes of state involvement. Moreover, Kenya introduced regulations which facilitated the use of imported machinery to meet the growing local demand for industrial goods. Like Zimbabwe, Kenya used customs and tariffs to ensure control. However, the policies applied were different. While Zimbabwe emphasized the use of local materials and foreign exchange saving, Kenya introduced policies which were inimical to the use of the local industrial base, local raw materials and the saving of foreign exchange. For example, whole machinery would be allowed in at lower duty (or even duty-free) than the semi-processed materials required for local machinery production. The imported machinery, on the other hand, was often not obtained through competitive means such as open tender and therefore had high chances of being overvalued.

Indeed, there was no immediate reason for Kenya to worry about foreign exchange because the country showed high growth rates in its foreign reserves and there were no indicators that any shortfalls would in the medium-run (defined as operating with the tenure of the current development

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28. *Ibid.* pp. 9.

29. *Ibid.* pp. 12.

plan) emerge in the foreign reserve base. The assumptive normalcy that obtained in Kenya led to the formation of institutions similar to those in Zimbabwe but operating on different expectations and using different policies with different outcomes.

A look at the expectations which shaped the industrial strategies and the relevant institutional and policy frameworks reveals more complex adaptive dynamics. The expectations which influenced industrial policies also applied in more or less similar ways to the energy sector. There are at least two important reasons for this. First, energy (especially imported petroleum) was an important industrial input. Second, energy could not be considered in isolation without the relevant conversion technological systems. The policies which governed industrial activities also applied to energy investment and technology acquisition strategies.

### **3.2.2 Energy and socio-economic expectations**

The high growth rates in the Kenyan economy in the 1960s were closely associated with increases in the consumption of commercial energy sources. Of the various commercial energy needs, transportation emerged as the largest consumer of commercial energy resources and the country built a refinery to meet local and export markets. The refinery was in itself part of the import substitution strategy which was combined with meeting the needs of the neighbouring countries, especially Uganda which imported most of its products. The refinery's contribution to the economy was partly reflected in its post-investment expansion. It was initially built to handle 1.8 million tonnes of crude oil a year but was expanded in 1969 to refine 2.5-4.8 million tonnes. The building of the refinery added another link in the interlocking web between energy and economic development. Not only was the refinery providing energy inputs into socio-economic activities, but it became a source of foreign exchange. The introduction of the refinery in the energy environment not only consolidated the gasoline niche but also made it difficult to introduce alternative liquid fuels.

Like Kenya, Zimbabwe built the Feruka refinery (in 1964) to meet local demand and export requirements, especially to Zambia. However, the refinery was closed down after a year of operation due to the international sanctions. It was owned by oil firms, none of which controlled more than 20 per cent of the shares. The closing down of the refinery was a major source of concern over future liquid fuel supplies. The uncertainty was compounded by the fact that the country was land-locked. Not only did Zimbabwe rely heavily on South African refineries, but it also made efforts to beat the international sanctions. The country is well endowed with indigenous supplies of coal and has considerable hydro-power supplies.

However, neither of these energy resources could serve as a ready substitute for imported liquid fuels. This situation generated a search for alternatives. Attempts were made to obtain liquid fuels from coal as well as to develop electric vehicles.<sup>30</sup> These responses suggested that the policy makers had already institutionalized their expectations over possible disruptions and geared the economy towards the generation of alternative energy technological systems. None of these efforts led to major commercial application and the country continued to depend on imported liquid fuels for its transportation sector. Although the expected disruptions induced the search for alternatives, petroleum was already too tightly inter-locked with economic activities.

Many of the options that were proposed failed largely because they could not meet the criteria set up by the government for all investment projects. The 1973 oil crisis had profound disruptive effects on both Kenya and Zimbabwe. Zimbabwe had already introduced a large number of institutional measures aimed at coping with shortfalls or disruptions but the situation in Kenya was different. The country had lived over a decade on

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30. Zimbabwe's efforts to produce liquid fuels from coal failed largely because there was no proven technology that could be adapted to the local conditions. "Direct hydrogenation is not just an indifferent performer on our coals. It is definitely the wrong type of technology to thrust upon countries with limited industrial capability. The development of these routes has tested the engineering and process skills of the top industrialised countries to their utmost, yet in the US, for instance, none of the projects coming falteringly into commercial operation (and deemed worthy of finance by the government) is a direct hydrogenation plant. These are still regarded as too risky to merit the big bucks," Hollaway, "Rhodesia's Search for Synthetic Fuels," pp. 35.

assumptive normalcy and did not have at hand any operating mechanisms aimed at dealing with disruptions in strategic resources such as oil.

### **3.2.3 Oil crisis and institutional responses**

The oil crisis was a surprise to both Kenya and Zimbabwe. But the Zimbabwean economy had already instituted policies which dealt with disruptions in oil supplies. As pointed out earlier, the use of local materials was now coupled with the maximization of foreign exchange savings as a fundamental aspect of the industrial development strategy. But in Kenya the developments were built on the assumptions that economic growth would expand without major interruptions.

Kenya's economy was particularly vulnerable to fluctuations in oil prices, not because it was not prepared for it, but because of its high dependence on the international market for its major products, to changes in international trade. The oil crisis in this case represented a major shift in the international economic scene. The effects of the high oil prices were reflected first in changes in the average growth rate of GDP, which had expanded by 6.5 per cent over the 1963-1972 period and was reduced to less than 1.0 per cent over the 1973-1975 period. It also increased the rate of inflation and recession, forcing the government to freeze employment and promotions. Changes in the supply and demand patterns of petroleum products over the 1974-84 period are presented in Table 3.7.

Before the oil crisis, Kenya registered marginal net expenditures on oil imports. This was mainly because of the value of refined products exported to the neighbouring countries. By 1972 the net import of petroleum and petroleum products accounted for only K£0.6 million. This rose to K£35.1 million in 1974 and K£200.1 million in 1981. Net oil imports accounted for only 0.3 per cent of the total foreign exchange earnings (or 0.6 per cent of non-oil foreign exchange earnings) of the country by 1972. This rose to 20.9 per cent in 1977 and 65.6 per cent in 1981. The changes in the allocation of foreign earnings led to balance of payments difficulties. But as pointed out earlier, the export of refined products helped to balance out the expenditure

on imported petroleum. In the meantime, the share of exported petroleum products dropped as that of local consumption increased. It is notable that oil represented over 85 per cent of the commercial energy used in Kenya, with 12 per cent from electricity and the rest from coal and coke.

TABLE 3.7: *Kenya's Petroleum Supply and Demand Balance ('000 Tonnes)*

	1974	1976	1978	1980	1982	1984
<b>DEMAND</b>						
LPG	12.2	14.7	17.6	21.5	20.9	21.6
Motor spirit	225.7	241.0	290.5	300.8	269.3	257.7
Aviation spirit	5.6	5.7	6.5	5.6	6.1	5.6
Jet/turbo fuel	238.9	305.2	328.0	347.9	281.8	259.4
Illuminating kerosine	53.1	53.2	78.0	85.6	82.2	81.4
Power kerosine	1.5	0.2	0.2	0.1	--	--
Light diesel oil	250.1	288.3	244.2	408.5	373.1	420.1
Heavy diesel oil	40.4	44.7	29.0	38.9	27.6	25.2
Fuel oil	412.0	503.3	463.9	462.1	428.3	411.4
TOTAL	1,238.6	1,456.5	1,537.9	1,671.0	1,489.3	1,482.4
Refinery usage	114.1	107.0	122.0	97.2	84.0	71.1
TOTAL LOCAL DEMAND	1,352.7	1,567.5	1,659.9	1,768.2	1,573.3	1,553.5
Petroleum fuels export	1,588.7	1,472.0	1,173.3	1,581.8	868.0	685.3
<b>TOTAL DEMAND</b>	<b>2,941.4</b>	<b>2,935.5</b>	<b>2,832.2</b>	<b>3,350.0</b>	<b>2,441.3</b>	<b>2,238.8</b>
<b>SUPPLY</b>						
Crude oil import	2,902.9	2,496.7	2,369.2	3,075.5	2,162.5	1,874.3
Petroleum fuels import	129.9	47.7	258.3	166.5	101.6	100.6
TOTAL	3,032.8	2,544.4	2,627.5	3,242.0	2,264.1	1,974.9
Adjustment*	-91.4	391.1	205.7	108.0	177.2	263.9
<b>TOTAL SUPPLY</b>	<b>2,941.4</b>	<b>2,935.5</b>	<b>2,833.2</b>	<b>3,350.0</b>	<b>2,441.3</b>	<b>2,238.8</b>

\*Adjustment due to production losses and inventory changes

Source: Central Bureau of Statistics, Nairobi.

Changes in the availability of wood fuels such as charcoal and fuelwood increased the use of petroleum products. For example, extensive shortages of charcoal in 1977-78 for urban use led to increased use of kerosine. The demand for illuminating kerosine was 53,000 tonnes in 1974. It remained more or less unchanged in the following two years. However, charcoal shortages increased its demand to 78,000 tonnes in 1978 and 89,300 tonnes in 1979. The charcoal shortages were felt mainly in the urban areas. It is not known to what extent the current rate of deforestation in the country and

the related shortage of fuelwood has contributed to the shift towards kerosine use. Such changes contributed to the growing imbalance between supply and demand for petroleum products. By 1980, the demand for motive fuels, kerosine and LPG outstripped local supply and the refinery had to be supplemented by imports.<sup>31</sup>

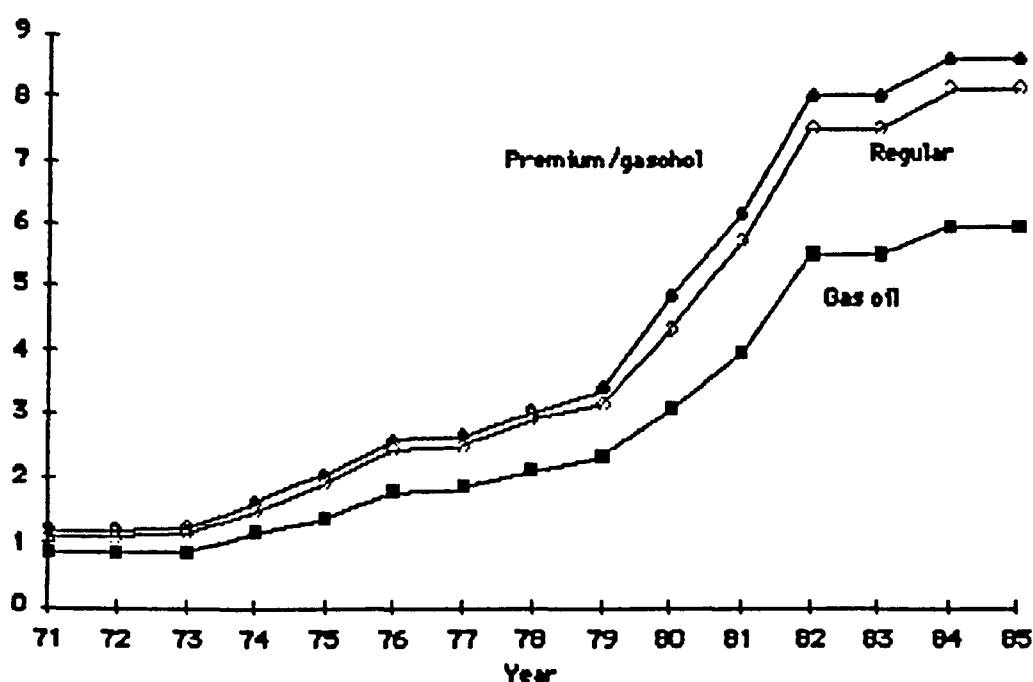
But even more disruptive were the indirect effects of the high oil prices on the Kenyan economy. These effects were largely associated with the country's high dependence on external trade. First, the high oil prices led to increases in the prices of goods manufactured in the industrialized countries. Kenya depended largely on imported machinery whose prices had risen due to high manufacturing costs resulting from high oil prices. This dependence was a result of the import-substitution strategy which favoured the importation of intermediate and capital goods. In the meantime, the prices of raw materials occasionally declined, reducing the country's foreign exchange earnings. Trends in Kenya's exports of coffee and tea were uneven during the post-1973 period. Fortuitous upswings in the prices of tea and coffee in the 1976-1977 period eased the pressure on the country's foreign reserves. As a result, the country did not take the issue of petroleum seriously before 1979 when the second oil crisis led to a major reduction in the country's foreign reserves.

The 1973 crisis did not induce any major changes in oil consumption. The growth of GDP and oil consumption showed a one-to-one correspondence between 1972 and 1976 when the effects of high oil prices started to affect the economy. The oil crisis came at a time when Kenya was recording high growth rates and the expansionary trends required even higher amounts of petroleum. Some of the growth that occurred over the period was aimed at increasing export earnings as a way of coping with the foreign exchange problem. Yet this itself required higher oil consumption. This situation continued until 1976 when the country showed a reduction in the consumption of energy which was not directly associated with corresponding changes in GDP growth. The reduction in oil consumption could be explained by the delayed effects of the high retail prices which had been effected since 1973 (Figure 3.3).

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31. O'Keefe, *et al.*, *Energy and Development in Kenya*, pp. 51.

FIGURE 3.3: *Changes in Retail Petroleum Prices in Kenya (KShs./litre)*



Concern over petroleum as a strategic form of energy was first reflected in the country's development strategy in the late 1970s. Before that matters pertaining to energy policy had been articulated through an inter-ministerial committee operating through the National Council for Science and Technology. The Council was an advisory body under the Office of the President. The fact that energy matters were treated by an inter-ministerial committee indicated that the issue went beyond the boundaries of existing ministries. However, the fact that energy was for several years handled by a committee under a council without direct ministerial backing suggested that the issue was not yet a matter of major concern. It was not until November 1979 that the Ministry of Energy was formed. Meanwhile, the oil sector was relatively inflexible and major reductions in consumption could not be achieved without adverse effects on industrial output.

Investment in the energy sector may serve as an indicator of concern over the various sources of energy. Most of the investment was in electricity generation. The investment in the oil sub-sector was concentrated on oil exploration, refinery construction and expansion, as well as the building of a pipeline to transport refined products. Between 1959 and 1978, private firms

managed to sink 12 wells at the cost of K£12 million, none of which showed any prospective results. The refinery was built in the early 1960s at the cost K£25.4 million. The energy sector as a whole registered low levels of capital formation. Energy investment over the 1972-1979 period accounted for less than 10 per cent of total investments. Over the period, energy investment as a percentage of GDP rose at the rate of 2.9 per cent.

Prior to the 1979 oil price increases, Kenya continued investing largely in the electrical power sub-sector. The country invest in large dams and also diversified into electricity generation using geothermal resources. The only significant oil-related investment over the period was the construction of the 300-mile Mombasa-Nairobi pipeline at an initial cost of K£40 million. This did not alter the uncertainties surrounding the availability of this resource. The pipeline is managed by the Kenya Pipeline Company (KPC), which is wholly-owned by the government through the Ministry of Finance and the Ministry of Energy. It operates as a service, charging the oil companies for the products delivered. It handles about 1.2 million tonnes of refined petroleum products per year; its pumps operate on electricity.

The situation in Zimbabwe was different. The responses to the energy crisis were influenced largely by the expected fluctuations in prices and availability of liquid fuels. In the first place, the closure of the Feruka refinery forced Zimbabwe to import refined products. This change tended to conform with the constantly changing patterns of liquid fuel use in the country. Moreover, the importation of refined products gave the country more flexibility in changing the patterns of use through policy interventions. While Kenya maintained almost the same liquid fuel composition over the post-1964 period, Zimbabwe's consumption patterns changed considerably both as a result of policy interventions as well as changing patterns of demand (Table 3.8). For example, policy interventions encouraged the use of diesel. As a result, the use of diesel in Zimbabwe rose from 1,121,000 barrels in 1964 to 2,289,000 in 1980.

Over the same period, the use of petrol rose from 1,310,000 to 1,597,000 barrels; a marginal increase compared to that of diesel. The demand for aviation fuel dropped from 294,000 barrels in 1964 to 94,000 barrels in 1966 largely because of the effects of international sanctions.



However, the demand for the fuel rose again reaching 616,000 barrels in 1978. This rise was largely accounted for by the military use of this fuel. Such shifts could not have been met by the refinery and would have still required additional imports. The country's total import of oil products rose from 2,999,000 barrels in 1964 to 4,608,000 in 1980. The total import bill rose from Z\$9.0 million in 1964 to Z\$166.0 million in 1980, a rise of about 1800 per cent. The share of imported fuels rose from 10 per cent of total imports in the mid-1960s to over 25 per cent in the late 1970s.

TABLE 3.8: *Zimbabwe's Petroleum Imports (Current Prices)*

Year	Total barrels	Cost (Z\$ million)	Z\$/barrel
1964	2,999	9.0	2.99
1965	1,229	3.9	3.17
1966	2,183	15.5	7.11
1967	3,101	12.8	4.12
1968	3,167	11.6	3.68
1969	3,394	11.4	3.35
1970	3,446	11.5	3.34
1971	3,829	13.7	3.58
1972	4,508	17.7	3.49
1973	5,013	18.9	3.76
1974	4,374	38.1	8.72
1975	5,389	59.2	10.98
1976	4,754	66.1	13.91
1977	4,698	71.8	15.29
1978	4,864	76.2	15.67
1979	4,204	144.3	34.32
1980	4,608	166.8	36.20

Source: Ministry of Trade and Commerce, Harare.

Unlike Kenya, Zimbabwe was less integrated into the international market for its inputs and products. A wide range of policy measures were introduced to enhance economic self-reliance. The import-substitution strategy and the administrative rationing of imports reduced the indirect effects of high energy prices that are embodied in imported intermediate and capital goods. The overall strategy was to optimize the use of foreign exchange. This policy was effective in the non-fuel sectors because of higher substitution elasticities. However, efforts were initiated not only to undertake fuel switching, but also to look for alternative sources of fuel. The country is well endowed with hydro power resources and has substantial

coal reserves. End-uses that had earlier been met by petroleum products and could now be met with either coal or electricity were converted. Railway electrification and the use of coal-fired engines was one of the conversions. Factor substitution was also noted in the mining, agriculture, manufacturing and construction sectors; oil had to some extent been replaced by labour, which had subsequently been replaced by electricity.<sup>32</sup>

Although the costs of oil did not seem to have put much stress on the Zimbabwean economy, it was seen as a strategic resource. The country mobilized its research institutes to look into possible alternatives to imported oil products. This was in recognition of the long-term effects of disruptive fluctuations in the supply and prices of oil products. Energy-related issues were handled at the level of the Prime Minister's Office with the help of a technical advisor. Various technological systems were designed and tried. The generation of these options was guided by the need for import-substitution and were therefore based on the use of local resources.

The search for alternative sources of energy was a joint endeavour of the the private sector, the government and research institutes. It also involved external support, especially in the provision of technical assistance in the evaluation of various technological options. In all these efforts, the government maintained that the market should be the ultimate selecting mechanism although the existence of regulatory institutions provided the direction along which the economy was to follow, depending on the dominant expectations. The initiatives were therefore conducted through IDC which had a team working on alternative transport fuels.

The project narrowed down the proposed technologies to ethanol , coal liquefaction, vegetable oils, diesel-ethanol blends, gasoline-ethanol blends, and electrical vehicles. Much of the work was to monitor international trends in these fields while at the same time establishing technical contact with experienced firms and research establishments in the industrialized countries. In addition to Zimbabwe's own efforts in technical monitoring, much information was also obtained through South Africa, with which various firms had technical agreements. The monitoring was based on the view that the oil crisis was not just an ephemeral problem but a

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32. Suckling, *Energy Prices*, pp. 95-97.

disruption which had long-term effects. It was because of this that IDC started monitoring the use of electric vehicles although this technology was still far from market realization. The main aim was to identify technologies that could occupy isolated techno-economic niches; it was a search for technologies that would be feasible alternatives in selected areas.<sup>33</sup>

The late 1970s saw increased participation of research institutes in the generation and testing of a range of candidate technological systems. The Department of Research and Specialist Services of the Institute of Agricultural Engineering played a significant role in the search of alternative motive power. Apart from working on different ways of extending conventional liquid fuels with ethanol and vegetable oil, the department also embarked on a project to "show the feasibility of converting a standard diesel powered tractor to a solid fuel fired steam engine".<sup>34</sup> These links underscored the co-evolutionary nature of technological imperatives and institutional re-organization.

This project aimed at using the country's coal resources as a source of thermal energy to run tractors that had previously been fuelled by diesel. A complementary project was designed to "investigate the feasibility of using vegetable oil such as sunflower oil, soya-bean oil and cottonseed oil as a fuel for diesel engines under practical operating conditions".<sup>35</sup> These projects were discontinued after independence and the institute reverted to monitoring international developments. Kenya did not have any such initiatives. Although energy-related institutional frameworks emerged in the late 1970s, they did not have any specific R&D agenda. The differences in Kenya and Zimbabwe came to play important roles in shaping the realization of ethanol niches in those countries.

## Conclusion

This chapter has suggested that the major fluctuations in the prices of oil and sugar created opportunities for the application of fuel ethanol

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33. IDC, *Electric Vehicles*, pp. 2.

34. Institute of Agricultural Engineering, *Annual Report 1978-79*, pp. 65.

35. *Ibid.*, pp. 67.

technology in Zimbabwe and Kenya. It has argued that the introduction of fuel ethanol was part of a re-organization of the economic structure in response to the decline in sugar prices and rise in oil prices. However, the re-organization was influenced by the socio-economic expectations of the countries and the institutional arrangements as well as by policies which emerged as a guide to economic paths. It was suggested that differences in the expectations of the two countries on the future of oil supply and prices largely influenced the patterns of institutional reform in the two countries. The ethanol option, however, could not be pursued without the existence of the relevant technological systems. The next chapter looks at the evolution of ethanol technological systems.

## **4. EVOLUTION OF ETHANOL TECHNOLOGICAL SYSTEMS**

### **Introduction**

The previous chapter showed that the drastic changes in the international oil prices disrupted the configuration of the energy niches and forced the two countries to look for alternative sources of liquid fuels. These same disruptions also stimulated renewed innovation in the field of fuel ethanol production as a candidate for realizing the potential niche. This chapter identifies the major features of the evolutionary path followed by ethanol technological systems. The systems first originated in the beverage sector and were later relocated in the energy market. It shows that the development of the ethanol technological systems proceeded with minor incremental changes. But the changes in the energy environment created new conditions to which it could not effectively adapt without major technical changes. The process of innovation, supported by the private and public sector, generated a wide range of conjectural technological variants while at the same time improving the ability of the existing technological systems to adapt to the changed market conditions.

### **4.1 Ethanol as a fuel option**

Ethanol, also known ethyl alcohol, has been on mankind's list of beverages for time immemorial. Babylonian records reveal a 6,000-year history; and historians have pushed the European record back to the period after the third ice age, some 10,000 years ago. The commercialization of this liquid was started in Europe by monks around AD 800. But it was not until the 19th and 20th century that alcohol was produced on a large commercial scale. Ethanol is conventionally obtained by breaking down simple sugars with an enzyme (zymase) contained in yeast (usually *Saccharomyces cerevisiae*). The process also releases carbon dioxide and heat.

The type and complexity of the production process depends on the feedstock used. In the case of sugarcane or molasses, the process is shown in Appendix 1. The cane is cleaned and crushed and the juice is extracted. This may be done through conventional crushing or by diffuser technology. The juice or molasses resulting from sugar production is then pre-treated for fermentation and the resulting beer is distilled and dehydrated (if anhydrous ethanol is required). The fermentation is done using yeast grown for separate batches or recovered from fermented beer depending on the type of process used. The process therefore goes through the stages of feedstock preparation, fermentation, distillation, and dehydration.

TABLE 4.1: *Physical Properties of Selected Fuels*

Property	Ethanol	Gasoline	Diesel
Formula	CH <sub>3</sub> CH <sub>2</sub> OH	C <sub>4</sub> to C <sub>12</sub>	C <sub>14</sub> to C <sub>19</sub>
Energy content (MJ/kg)	26.60	43.80	42.80
Energy content (MJ/l)	21.00	32.00	36.40
Specific gravity	0.79	0.73	0.85
Research Octane Number	106-111	79-98	NA
Motor Octane Number	89-100	71-90	NA
Cetane Number	0-5	5-10	45-55
Molecular weight	46.10	100-105	240.00
Autoignition temperature	423.00	257.00	—
Flash point °C	13.00	-43	38.00

NA: Not Applicable

Source: World Bank (1980).

The use of ethanol as a fuel is as old as the internal combustion engine itself. When Nikolas Otto designed his first internal combustion engine, he tried it on ethanol, not gasoline. Numerous studies were conducted on the use of fuel ethanol at the turn of the 20th century. Henry Ford described ethanol as the "fuel of the future" and designed his Model A to run on ethanol, gasoline or a combination thereof. Its physical characteristics make it a suitable fuel for use in internal combustion engines. Various countries have used fuel ethanol at one stage or another. It was the discovery of oil and its spread that stalled the development and application of ethanol as a fuel.

One of the most important features of any liquid fuel is the amount of energy it contains by volume or weight. This is important because the weight

and space occupied by various components of mobile systems such as vehicles is significant in its efficiency. As Table 4.1 shows, a kilogramme of ethanol contains 26.6 megajoules (MJ) as compared with 43.8 MJ in gasoline and 42.8 MJ in diesel. Although it would appear that there is a large differential between ethanol and the other fuels, the gap narrows when the fuels are compared by volume. These differences, however, imply that fuel ethanol has less energy content than the other fuels.

Because of its low calorific value, ethanol has an unfavourable fuel economy compared to diesel and gasoline. However, ethanol burns with a slightly higher thermal efficiency which partially off-sets the calorific differential. Moreover, the higher octane value of ethanol can help in improving the fuel economy. At normal compression ratios, ethanol delivers about 5.0 per cent more power than gasoline. This can be raised to 15 per cent by increasing compression ratios from 8:1 to 14:1. Such engines have already been designed and are operating in Brazil where over 2.2 million cars now run on neat hydrous ethanol. Ethanol can be used in blended fuels partly to boost the octane rating and partly to replace the lead that is conventionally used to eliminate engine knocking.

Ethanol is completely soluble in these fuels so long as there is no water in the system. This enables ethanol to be blended with these fuels (to varying degrees of ignitability and combustibility). But if water is present in the system, the blend separates into two phases, one rich in gasoline and the other mainly an ethanol-water mixture. Ethanol has an infinite miscibility with water. The ethanol-water phase would stall the engine and can cause considerable corrosion to engine parts. Phase separation is a critical problem in case of engine mismanagement. Evidence from Brazil indicates that most petrol tanks contain small amounts of water which do not pose any phase separation problems.

Ethanol requires more heat for vaporization than gasoline. This makes starting difficult, especially in temperatures below 10°C. The Brazilian ethanol cars are fitted with small gasoline tanks which are used for cold start. For additional pre-heating, the exhaust manifold of the engine is

placed in contact with the intake manifold. This ensures that the intake air is pre-heated by the exhaust air without any additional fuel cost.<sup>1</sup>

One of the significant advantages of fuel ethanol is that it is based on biological materials which are renewable and relies on global energy flows as opposed to energy stocks. Moreover the entropic implications of using renewable biomass resources are lower than those of relying on non-renewable resources. Simple sugars can be obtained directly or indirectly from a wide range of biological materials. Where simple sugars are not readily available, starch can be converted to simple sugars and then fermented to produce ethanol (Table 4.2).

TABLE 4.2: *Ethanol Yield from Biomass Resources*

Crop	Yield (tonne/ha/yr)	Ethanol	
		Litres/tonne	Litres/ha/yr
Sugarcane	50-90	70-90	3,500-8,000
Sweet sorghum	45-80	60-80	1,750-5,300
Sugar beet	15-50	90-100	1,350-5,500
Fodder beet	100-200	90-100	4,400-9,350
Wheat	1.5-2.1	340	510-714
Barley	1.2-2.5	250	300-625
Rice	2.5	430	1,075-2,150
Maize	1.7-5.4	360	600-1,944
Sorghum	1.0-3.7	350	350-1,295
Irish potatoes	10-25	110	1,110-2,750
Cassava	10-65	170	1,700-11,050
Sweet potatoes	8-50	167	1,336-8,350
Grapes	10-25	130	1,300-8,000
Molasses	--	245	--

Source: National Academy of Sciences, Washington, DC.

As can be seen from the table, large amounts of ethanol can be obtained from various crops. However, sugarcane is suitable because it is readily available and is an established crop in a large number of countries. However, hypothetical availability cannot turn the resource readily into ethanol. Economic considerations such as the opportunity cost of switching to other products need to be considered. It is the context of rising oil prices

1. Details on innovation in ethanol engines are based on interviews with car and truck manufacturers in São Paulo, Brazil in February-April, 1985.



and falling sugar prices that the switch to ethanol might be justified. The use of this fuel is therefore a result of the structural re-organization of the relative position of oil and sugar in the international economy.

## 4.2 The Origins of Ethanol Technological Systems

The significant functional units of the ethanol technological system used in the field of energy originated in the beverage environment where development was marked by a series of incremental innovations, largely in response to external selecting pressures such as competition, regulation, taxation and other institutional interventions.<sup>2</sup> The external pressures on brewing not only constituted quantifiable market mechanisms but also included factors such as taste and habit among consumers which tended to stall the tempo of technical change as the system settled into particular design configurations and practices associated with consumer taste.

Significant developments in brewing occurred long before organized scientific research became a major input into industrial production. In a detailed study of the industry in England over the 1700-1830 period, Mathias concluded that the industrial transformation of brewing relied on traditional techniques and "occurred in a generation unhelped by a major invention".<sup>3</sup> Fermentation, the most important biochemical process in brewing, was extensively used but its scientific aspects remained unknown for a long time.

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2. To illustrate this point we shall limit our analysis to the fermentation stage of the process. This analytical boundary is based on various reasons. First, fermentation is the stage that has seen most innovations. Second, it is the core part of the whole process; it is at this stage that ethanol is actually produced. The process of ethanol production stretches from agricultural production to waste treatment (with the intermediate stages of feedstock production, fermentation, distillation and dehydration). This section includes feedstock preparation in the fermentation process. Subsequent sections, however, will look at innovation in all the major stages of ethanol production.

3. Mathias, *The Brewing Industry in England*, pp. 63. "But industrial success of this order itself induced the search for, and application of, new techniques. When conditions are propitious, the virus of economy and efficiency is an infectious one, as much as the sickness of inertia when they are not; and men touched with the hope of gain by reorganizing their breweries had their wits sharpened in the search for profit by other means. Moreover, the problems of success, as well as its opportunities, stimulated activity towards preserving the conditions which allowed it, making the role of innovation a cumulative one," *ibid.*

Ironically, the growth of fermentation knowledge was partly retarded by institutional rigidity in the scientific community as influential scientists believed in false concepts. The leading German chemist Leibig believed that fermentation was caused by the motion set up in the liquid by some decomposing substance. The theory by the Frenchman Cagniard de La Tour and German chemists Knetzing and Turpin in the late 1830 that yeast was a vegetable organism that caused fermentation by its own development was strongly opposed by Leibig for over 20 years. It was Louis Pasteur who, in 1860, showed that yeast was indeed a living organism whose natural changes led to alcoholic fermentation. Brewing continued without much scientific input although British chemists were calling on brewers to take advantage of the systematic knowledge that was accumulating among chemists.<sup>4</sup>

However, the increased availability of technological knowledge and the changing economic as well as legal pressures gradually led to the application of scientific knowledge to brewing. It is notable that although scientific knowledge relevant for some aspects of brewing was available, it was not applied to brewing until changes in the external environment generated pressures which required the use of available innovation. This is consistent with the adaptive landscape approach in that the changes in the external environment created suitable conditions for the application of particular innovations originated in other sectors of the techno-economic field and which were then relocated in the brewing sector.

The first significant innovations were the introduction of the thermometer and saccharometers, both of which were associated with quality control and regularity. The innovations were adopted by the industry from other fields; the saccharometer was merely a hydrometer which had been calibrated to measure the specific gravity of beer. With the thermometer the mashes ceased to be measured in terms of 'blood heat', or 'milk heat' or the 'temperature which the elbow may just tolerate', or 'whereat the surface of the liquid...gives a perfect, still reflection when just about to steam'.<sup>5</sup> The thermometer eliminated these vague estimates of the temperature and enabled the brewers to determine the right

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4. *Ibid.*, pp. 64-65.

5. *Ibid.*, pp. 65-66.

temperatures. The hydrometer, on the other hand, provided accurate measurements of both beer and distilled alcohols.

The application of scientific knowledge to brewing did not occur in a smooth way but advanced unevenly in association with changes in the external pressures which led to competition among different instruments. The external pressures set selection criteria and at the same time stimulated competition among instrument makers. This process of instrument selection was bound up with institutional issues, especially in relation to the legitimization of particular instruments through legal endorsement. Legalization became important because most of the pressures on brewers originated from the government and were related to state regulation. The innovation process, as will be seen later, became largely a series of incessant attempts by brewers to find technical ways to circumvent the legal process. It is because of this that scientific knowledge was imparted to (as well as generated from) brewing.

The use of the hydrometer in the gauging of spirits in England, especially for excise duty collection was itself an interesting case of "technological falsification". Following their selection by the authorities in the late 1750s, disputes arose over the accuracy of the two instruments used. Modifications were introduced in one of the instruments, ostensibly to raise their accuracy or verisimilitude. It took up to 1803 for a selection to be made among the competing hydrometers, even though efforts continued to challenge the selected instrument for another 15 years when the choice was legally confirmed by the Hydrometer Act of 1818. Subsequent inventions in Scotland were more accurate and challenged those used in England. The degree of accuracy in hydrometers was important because minor deviations could lead to loss of profit among producers.

The instruments provided valuable information which was later applied to the costing of various inputs and the setting of product prices. Since the operative unit in feedstocks was the amount of fermentable substances, as expressed in the form of sugar, the saccharometer became useful in establishing the value of the raw material. With the thermometer, it became possible to control brewing temperatures and therefore keep the industry going in summer as well. The proposal for this sort of innovation first went

to the naval brewhouses, which often faced unexpected fleet arrivals in summer, forcing them to brew under unfavourable temperature regimes. With the piped circulation of water at controlled temperatures, it became possible to brew beer in summer. While the instruments allowed for quality control and enabled production efficiencies to improve, they also freed the industry from dependence on suitable weather and climatic conditions. Moreover, instrumentation increased the ability to control fermentation and consequently reduce losses arising from contamination.

Major advances occurred in the industry as a result of state fiscal policies, many of which were aimed at reducing the export of Scottish alcohol to England.<sup>6</sup> For example, increased taxation in the 1780s based on the quantity of malt forced Scottish distillers to increase the amount of raw grain. This showed the lack of scientific knowledge in the field of enzymatic hydrolysis. The authorities did not know that the amount of diastase in the malt (even if it accounted for only 20 per cent of the entire feedstock) was enough to turn the starch in the raw grain into fermentable sugars.

On discovering this innovative response among distillers, the authorities moved to impose duty on the wash. It was thus assumed that each unit of the wash yielded the same amount of alcohol. In response, the distillers raised the concentration of fermentables in the feedstock by adding sugar and treacle. Subsequently duty was determined by hydrometers as in England. The advances made both in innovation and policies illustrate the co-evolutionary re-organization that resulted from the interactions between technology and institutions. Because technological practice advanced faster than the related scientific knowledge, institutional changes had to await the latest developments. Moreover, there was no way of telling in advance which innovations were likely to result from new administrative pressures.

A 1788 legislation in Scotland led to significant improvements in distillation. It restricted and based the levy on the size of the stills used. Distillers responded to this by raising the pace of distillation and consequently increasing throughput. One way was to make the stills shallower and thereby increase the rate of distillation. James Watt, after finding out that liquids boiled at lower temperatures under reduced

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6. See Clow *et al.*, *The Chemical Revolution*, pp. 551-568, for details.

pressure, tried the technique on stills but there was no widespread use at the time. Shallow distillation led to new problems such as saturated carbon dioxide which caused froth in the still. Soap was added to the still to eliminate this problem. These innovations were incremental and did not alter the basic design concepts of the process. All sub-processes were operated in batches. Flows and controls had not been introduced in the system on a large scale. Although the production process appeared disjointed, it constituted a technological system. The various processes from feedstock preparation to distillation constituted a purposive structure whose individual units could only be explained by the workings of the whole system.

As production expanded, the need for alternative sources of power to replace horses became more pressing, especially for pumping and milling. Unlike in other sectors such as the woollen industry, steam-engines could be easily adapted to the industry without much internal re-adjustment or delay. A large engine could be easily fitted to an existing horse-mill. But the engine had to be made rotative, to fit the technical needs of the breweries. The rotative design had to be tested against the then operative plans of eight horses; its triumph in this test led to widespread interest among brewers. The diffusion of the steam-engine was so rapid that by 1800 all the major operations of brewing had been mechanised and production scales which had not hitherto been envisaged were reached.

As suggested earlier, the scientific details on fermentation remained unknown until Pasteur's work. Even after his discovery, it took 23 years before the knowledge was turned into technological practice. The cultivation of pure yeast was first successfully applied by Hansen at the Carlsberg brewery in Copenhagen. This was a significant advancement because artificial selection was applied to yeast for the first time. Hansen admittedly introduced into brewing the technique of artificial selection which was being widely used in agriculture. This not only eliminated the wild yeast varieties that caused contamination but also guaranteed that a robust strain could be propagated and used on a large-scale resulting in increased culture uniformity and higher possibilities for controlled fermentation. But the technique required lower fermentation temperatures, preferably achieved by artificial refrigeration, a factor which was partly used to explain the initial

resistance among British brewers, where plants operated at higher temperatures (12°C-13°C) than on the continent (5°C-6°C).<sup>7</sup> Lower temperatures were also required for storage. But the elimination of wild yeasts would also have removed the distinct flavours of the British beers, on which part of the demand was based.

The Hansen approach was also in response to problems arising from brewing practice. The approach constituted a recombination of existing pieces of knowledge. On the one hand, the fact that fermentation was caused by a wide variety of living organisms was central to the innovation. Second, the fact that these organisms could be isolated and propagated on a large-scale enabled him to suggest a way of eliminating the contamination problem. The innovation was a recombination of scientific knowledge originating from brewing as well as from the agricultural sector.

Thus much of what constitutes ethanol production is based on the convergence of different functional units introduced over 100 years ago. The changes which have since been introduced into the system have been adaptive and incremental. Most of them did not originate in the sector itself but were adopted from other uses. The system is built around fermentation and distillation processes. The feedstock phase of the process has drawn technological inputs from the agricultural sector while chemical engineering has enriched the distillation and purification phase. But the convergence of these different technical units is governed by the inner logic of the structure of the ethanol production system viewed as a whole.

These developments, which firmly established ethanol production technology in the beverage environment also prepared the ground for its relocation to the energy environment. This is mainly because the technical characteristics of ethanol made it a candidate source of liquid fuel. But the beverage sector had slightly different selecting pressures than the energy environment. Whereas the technological system was relatively established in its beverage environment, a shift to the energy environment would mean a

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7. Teich, "Fermentation Theory and Practice", pp. 130. See also Sigsworth, "Science and the Brewing Industry", pp. 536-550, for a rejection of the notion that scientific advance had any revolutionary impact on British brewing; and Cochran, *The Pabst Brewing Company*, pp. 102-128, on the role of science in American brewing. Glamann, "The Scientific Brewer", pp. 186-198, gives an account of the role of science in the rise of the modern brewing industry.

whole new process of niche realization under which both the technological system and the environment would be transformed in unpredictable ways.

The next section looks at the relocation of this technology to the energy sector. It will be noted that raising the verisimilitude of the technological system required major innovations superior to the incremental changes in the earlier evolutionary stages. Some of the innovations constituted major changes in the system through recombinant innovation and the application of scientific knowledge. These major innovations were largely influenced by the fluctuations in the energy environment.

### **4.3 Technological Relocation**

The previous section traced the evolution of ethanol technological systems and their adaptation to changes in the beverage sector. This section will examine the application of the technological system in the energy environment. It will be shown that the development of the technological system in the new environment was subject to new pressures which required changes in its internal structure. These pressures resulted from the prices and types of inputs, energy balances, ethanol prices, and ecological considerations. However, the initial relocation was not associated with any major changes in the ethanol technological system.

Ethanol as a source of energy was used in isolated niches protected from market competition. It is equally important to identify the different reasons for producing fuel ethanol. Its production (and use) in Brazil in the 1920s and 1930s was largely aimed at reducing surplus sugar and stabilizing the international sugar market. The operations were not conducted with any competitive considerations in mind. For example, the cost of ethanol was not viewed in relation to alternative sources of liquid fuels. As a result, there were no major external pressures on the manufacturers to improve the efficiency of ethanol production. Moreover, production was conducted by the government. Since the purpose of the technological systems was to reduce surplus sugar, the directors of the programme argued that the efficiency of the plants be assessed in those terms and not in terms of economic efficiency

or the competitiveness of the by-product, ethanol.<sup>8</sup> This purpose could be achieved without any improvements in the technological systems.

The case of Brazil in the 1930s indicates that the relocation of ethanol technological systems was not a major shift towards the creation of a new energy niche although the ethanol was used as fuel. The programme was aimed at normalizing the sugar market. As a result, there were no strong internal or external pressures influencing the internal evolution of the technological systems. The system remained uncompetitive with gasoline and relied on the same techniques applied in the beverage environment; it was a batch process with long fermentation periods. The system also relied on conventional sources of raw materials as used in the beverage environment. Further still, the use of the systems was not associated with a lobby of scientists and technologists who wanted it institutionalized. For such a development, we turn to the historical and institutional efforts to establish a more permanent ethanol niche in the US in the 1930s as an illustrative case.

These efforts were associated with the Farm Chemurgic Council which flourished between 1935 and 1939, sponsored by the Chemical Foundation. The council believed in the efficacy of scientific knowledge, especially chemistry, to revolutionize agricultural production and raise the US economy from depression. The council believed that "modern science has placed new tools in the hands of man which enable a variety of surplus products of the soil to be transformed through organic chemistry into raw materials usable in industry".<sup>9</sup> This was based on the view that a bundle of scientific knowledge was available which could be used to transform agricultural surpluses into industrial chemicals and may have been influenced by the

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8. See Nunberg, *State Intervention in the Sugar Sector in Brazil*, for a detailed review of ethanol production in Brazil over this period and the institutional forces that shaped the utilization of ethanol then.

9. Chemical Foundation, "Declaration of Dependence", pp. 32. The signing of the declaration was adorned by symbolic political paraphernalia: a replica of the Hall of Independence which Henry Ford as host to the conference erected at his outdoor museum; a replica of the inkstand used in Philadelphia on July 4, 1776; a desk that belonged to Thomas Jefferson; a table and chairs that were once owned by Abraham Lincoln. Henry Ford supported the declaration because of his interest in alternative automotive fuels following fuel shortages during the war. He was also interested in producing plastics from agricultural resources. See Wik, "Henry Ford's Science and Technology for Rural America", for an assessment of Henry Ford's interests in agricultural development.



success of chemists following the extensive use of the products of this discipline in World War I.<sup>10</sup>

The Chemical Foundation obtained finance from nearly 5,000 German chemical patents seized by the US federal government from Germany during World War I, many of which belonged to the I.G. Farben complex.<sup>11</sup> The patents were sold to the Chemical Foundation by the Alien Property Custodian, who later resigned from the government and became the President of the Foundation. Government action brought against the Foundation in the Supreme Court was defeated. Not only did the US chemical industry exploit the patents, but the government also imposed a protective tariff against the products of a reviving German chemical trust. The 1922 tariff system remained intact until the 1964 Kennedy round of tariff negotiations.<sup>12</sup>

The Farm Chemurgic Council provided a framework for the application of the existing stock of scientific and technical knowledge to the generation of a permanent source of energy. This stock of knowledge had accumulated during World War I when fuel shortages stimulated interest in this source. The fear of further shortages in the post-war period served as an impetus in both innovation and institutional reform. Legislation was introduced which distinguished industrial alcohols from alcoholic beverages. Efforts to expand the use of ethanol in the 1920s failed because of technical problems such as corrosion as well as the discovery of more oil fields, technical advances in petrol refining and the use of tetra-ethyl lead as an octane booster. Attempts to enlist institutional support for fuel ethanol were overwhelmed by counteracting advances in the petroleum sector.

Most of the ethanol produced in the US after World War I was obtained from fermenting blackstrap molasses. This was relatively easy because molasses contains readily fermentable sugars. But the 1930s were associated with surplus corn which was not readily fermentable. This required changes in the molasses-based ethanol technological systems to incorporate a section for the hydrolysis of starch into simple sugars. The technology for doing so was already available and had been used in the

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10. See Pursell, "The Farm Chemurgic Council", pp. 307-310 for details.

11. Borkin, *Crime and Punishment of I.G. Farben*, pp. 150-153.

12. Pursell, *op. cit.*, pp. 308.

beverage environment for a long time. What was needed was recombinant innovation to adapt a hydrolysing unit onto the existing molasses-based technological system. This process represented a departure from the previous *ad hoc* projects to a more systematic approach to ethanol production which required some institutional reform to legitimize the realization of ethanol niches in the corn-growing states such as Illinois, Iowa, Indiana and Nebraska.

The introduction of such reforms required changes in the criteria used to evaluate fuel ethanol; it was no longer an issue of reducing farm surplus but a technological intervention whose economic viability had to be judged against other options. Since the production of corn had already incurred high costs, especially through energy inputs, the production of ethanol had to account for these costs.<sup>13</sup> As a result of criticism, the legislative reform efforts were defeated. It is important to note that the Department of Agriculture was not in favour of using agricultural surplus for industrial products but preferred restrictions of acreage.<sup>14</sup> Although studies had identified a wide range of raw materials that could be used for producing ethanol, the Department of Agriculture was unwilling to support any ethanol project.<sup>15</sup> Deprived of any support the Chemical Foundation decided to go it alone, setting up the first ethanol plant at Atchison, Kansas in 1936.

The plant was based on a variety of raw materials obtained in the region. It encountered enormous legal and raw material supply problems in its first six months. It came on stream in 1937 and produced ethanol at a cost five times higher than the refinery price of gasoline. Although ethanol from the plant was widely marketed, the council had to subsidise its production. The foundation withdrew its support for the council in 1937 due to the running out of its German patents and therefore signalled the end of

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13. Giebelhaus, "Farming for Fuel", pp. 179.

14. Pursell, *op cit.*, pp. 309-310.

15. The decision was largely influenced by political differences between government officials and the promoters of fuel ethanol, especially on agricultural policy. It appears that while the government was unwilling to move immediately into large-scale agro-industrial projects such as fuel ethanol, they indeed considered them as an option that needed to be pursued more carefully. In the meantime, the New Deal supporters managed to have their approach accepted more readily. The choice of technological options was therefore influenced by broader political issues pertaining to the direction of socio-economic evolution.

the project.<sup>16</sup> The plant was finally shut down in 1938 after the Foundation had invested US\$600,000. Subsequent efforts to revive the plant failed because the management could not raise the US\$125,000 needed to match a loan from the Reconstruction Finance Corporation. The failure of the project became an issue of political conflict in the state, involving claims and counter-claims against the oil industry.<sup>17</sup>

The collapse of the Atchison plant was linked to a wider conflict between government policies (as enshrined in the New Deal) and the appeal to the role of science in reducing agricultural surpluses and increasing farm incomes. While the government favoured financial payments to farmers, the chemurgic movement advocated the use of chemical knowledge to turn agricultural surpluses into industrial products. The issue became a political conflict between the government and the council on whose board well known critics of the New Deal served. The government defused these conflicts by establishing four research laboratories devoted to the utilization of farm surpluses in 1938.

Although the government refused to subsidise the Atchison plant, the project had demonstrated the technical feasibility of fuel ethanol application. Interestingly, the government was more willing to pursue the ethanol option as an experimental project and not as a commercial venture. The US Department of Agriculture decided to build a small ethanol plant at its Peoria laboratory producing 300-500 gallons a day for experimental purposes under the 1938 Agricultural Adjustment Act. And indeed, the government subsidized ethanol production during World War II. The Atchison plant went into production again during this period but not for the energy market but as an industrial feedstock. The ethanol was used for munitions manufacture and synthetic rubber production. Again the World War II period demonstrates that ethanol was drawn into the industrial sphere to solve anomalies generated in other economic sectors. These conditions did not provide major incentives for the internal evolution of the ethanol technology. The Atchison plant showed that a technological system that could provide an

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16. The alcohol movement lost the support of the Foundation's President Francis Garvan when he died in 1937, a year after the patents he sold to the Foundation run out.

17. Giebelhaus, *op cit.*, pp. 182.

alternative energy source was available. But this system could not compete with conventional sources of liquid fuel.

Moreover, the economic boom that followed World War II and the related rise in employment, combined with the rise of physics (following the success of nuclear detonations) as the new frontier for scientific and industrial advancement, made the chemurgic movement less relevant. And so were the innovations that it sought to promote such as fuel ethanol. The innovations that came later to be applied in ethanol technological systems had emerged in other disciplines. Many of these applications had to await the market opportunities created by the 1973 oil crisis. Over the 1930-1973 period, the technological system changed only marginally. There were no major environmental pressures that could have facilitated technical advances or induced system-specific innovations. The main feature of the system remained its batch configuration.

#### **4.4 Technical Change and Corporate Restructuring**

The structure of the technology market remained heterogenous with established suppliers of traditional batch systems still playing a large role. Most of the large engineering firms possess the capacity to design and build ethanol plants. There is no distinct ethanol technology market except for some specialist firms that have for a long time supplied distilleries to the beverage sector. Some of these firms are subsidiaries of large engineering corporations. But these firms did not play a significant role in the supply of technology to the developing countries in the 1970s. This was largely because the main market for ethanol technology was Brazil. The supply of ethanol technology to the energy sector was therefore dominated by Brazilian firms such as Codistil (a subsidiary of Dedini), Zanini and Conger.

At the time of the oil crisis, these firms had established themselves as major suppliers of ethanol technology but mainly for the beverage sector. The crisis simply necessitated the relocation of their supply to a different market without any major changes in their technological capacity or management techniques. The largest five ethanol technology suppliers in Brazil had the capability to produce more than 128 distilleries per year

producing up to 120,000 litres each in the early 1980s (Table 4.3). Codistil alone could supply about 60 per cent of this output. This meant that the real market structure of ethanol technology was dominated by Brazilian firms.

TABLE 4.3: *Distillery Production Capacity of Brazilian Firms (1980)\**

Firm	Capacity	Share (%)
Dedini	75	59
Conger	20	16
Zanini	18	14
Fives Lille	10	8
Piratininga	5	3

\*Estimated capacity of 120,000 litres per day.

Source: Sercovich (1983).

TABLE 4.4: *Change in Codistil's Plant and Capacity Production*

Year	Plants Sold	Average Capacity (Litres per day)
1973	2	50,000
1974	16	86,000
1975	24	68,000
1976	33	87,000
1977	46	89,000
1978	58	85,000
1979	33	105,000
1980	47	123,000
1981	46	117,000
1982	25	97,000
1983	37	117,000
1984	30	109,000

The Brazilian firms increased their production capacity by large margins (measured in ethanol output per day) over the post-1973 decade. Codistil, for example, increased the average capacity of its output from 86,000 litres per day 1974 to 109,000 litres a day in 1984. As shown in Table 4.4, the capacity rose to 123,000 litres per day in 1980 and then declined thereafter. Much of the decline is accounted for by the diversification into smaller distilleries as well as the sale of experimental plants producing 5,000 litres a day. Over the period, the design configurations changed only marginally to incorporate scale expansion. Codistil started selling 120,000-

litres-a-day plants in 1974 for the first time. Plants with the capacity of 220,000 litres a day were first sold in 1976 and those producing 240,000 litres a day were first supplied by Codistil in 1981. By 1983, Codistil started supplying plants with the capacity to produce 300,000 litres a day.

Brazilian firms increased their capacity to export ethanol plants in the 1970s. This was based on the experience gained in the supply of technology to the diverse Brazilian conditions. Whereas Codistil exported only one plant (to Bolivia) in the 1960s, its export in the 1970s and 1980s increased to include destinations such as Venezuela, Costa Rica, Paraguay, Bolivia, Cuba, Peru, Haiti and Pakistan. In addition, Conger and Zanini also exported plants to Peru, Venezuela and Kenya. The size of the Brazilian market and the export potential led a number of firms in the industrialized countries to establish offices in Brazil. Without such linkages, the technological potential among industrialized country firms to manufacture ethanol technology could not be adequately utilized.

Brazilian firms also established links with some firms in the industrialized countries with the aim of getting access to emerging technologies as well as supplying technologies to the industrialized countries. For example, Zanini entered joint ventures and technical co-operation agreements with Zahnraederfabrik Renk A.G. of West Germany and Foster-Wheeler of the US. The Foster-Wheeler deal included the supply of distilleries to the US market. Conger, on the other hand, took up 5.0 per cent shareholding in Vogelbusch of Austria in order to have access to stillage-reducing technology. Conger acquired the know-how but did not market the process as widely as had been expected.

It is notable that the suppliers of ethanol technology such as Codistil also had the capacity within their industrial complex to supply other technologies related to sugarcane production. The complex design configuration of various technical units and scientific knowledge associated with ethanol technological systems made it relatively difficult for new small firms to emerge in this sector. Much of the relevant know-how in the early stages had already been embodied in capital goods and operating skills associated with batch processes. But the new design configurations with potentially higher performance embodied knowledge that was possessed by

firms that already existed in different sectors. Moreover, some of the established firms supported university research, especially in the US by allowing researchers to patent their innovations while the financiers retained the right to license the technology.

The post-1973 trends did not see major market restructuring with any significant concentrations like those witnessed in photovoltaics.<sup>18</sup> This is partly because no large markets were envisaged and the radical innovations could not be easily brought to commercial application. Moreover, ethanol technological systems constituted a large number of distinct units whose design control was distributed over a relatively large number of firms. Even more important was the fact that no major market niches were perceived outside the Brazilian energy environment. It was expected that the Brazilian market would be an open terrain in which new technological systems would be tested and adopted. However, the country relied on locally-produced batch processes as part of its policy to protect the local industry.<sup>19</sup>

The firms that brought their expertise to ethanol R&D or initiated new R&D efforts included chemical and pharmaceutical firms, engineering companies, food and drink corporations, biotechnology-dedicated companies and oil corporations. Firms such as Novo Industri (Denmark) and Gist-Brocades (Netherlands) which had long-standing capability in enzyme production could bring their expertise to the ethanol sector, especially in the prospective area of enzymatic hydrolysis. With capability in enzymology and process engineering, Novo Industri designed a continuous fermentation process but did not find a market for it. Diamond Shamrock entered the ethanol market by building an experimental plant in the US, while at the same time funding research at the University of Arizona. Their entry into the market was clearly to acquire some competence in the field while at the same time passing on some of the R&D work to university scientists. Again, this illustrates the fact that corporate strategies were not built on instant enthusiasm over the immediate expansion of ethanol niches. The support for university research was mainly aimed at widening the range of potential

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18. Juma, *Photovoltaics in Developing Countries*, pp. 22-34.

19. Efforts to open up the Brazilian market for foreign technology under a World Bank project failed as local firms won most of the bids. This was expected since the competition was largely based on capital costs, a factor which gave the Brazilian firms a competitive edge over foreign suppliers.

technological variants in ethanol production systems. Other chemical firms involved in ethanol production include W.R. Grace and Union Carbide.<sup>20</sup>

Market restructuring also resulted in interesting corporate recombinations. The engineering firm UHDE GmbH joined expertise with the chemical firm Hoechst to develop an innovative continuous process based on tower fermentation, one of the simplest and advanced ethanol technological systems unveiled in the post-1973 era. Pilot plants are operating in West Germany, Brazil and an imitation of it has been developed by the Brazilian firm Zanini with additional scientific input, especially in dense yeast selection done at a Brazilian agricultural university.<sup>21</sup> This process had been designed for the US market but was later transferred to Brazil.

Another form of corporate restructuring involves the formation of Swedish AC Biotechnics by Alfa-Laval and Cardo of Sweden. AC Biotechnics is responsible for marketing, among other biotechnology process, the Biostil process. AC Biotechnics obtained resources and expertise on genetic engineering, fermentation and other bio-processing techniques from Alfa Laval and Cardo. It also inherited experience in process design, engineering, equipment and plant construction and has now turned to marketing the process outside Brazil. Other engineering firms have bought out small traditional ethanol technology suppliers. For example, the German firm Krupp has acquired Hermann Buckau/Wolf which established the first ethanol plant in Africa.

Oil firms also registered their interest in ethanol technology by funding university research. Atlantic Richland Company (ARCO) for example, supported the research at Arkansas University on enzymatic fermentation. The involvement of ARCO and Texaco was largely to acquire expertise in the field while at the same time funding university research. This strategy enables them to stay on the forefront of scientific advancement without necessarily committing massive financial resources and building in-house capability on technological systems whose prospects are still uncertain.

The corporate restructuring that followed the 1973 oil crisis did not result in many major increases in the use of ethanol technology. This is

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20. UNCTAD, *Renewable Energy Technology*, pp. 11.

21. Interviews, Conger, Piracicaba, Brazil, March 1985.



partly because there were no significant market prospects outside Brazil. Furthermore, technological innovations were restricted to process optimization and there were no major departures from the already established functional units. The competition was largely over the marketing strategies of various firms and their links in countries where potential niches existed. By the late 1970s, the competing systems were mainly batch although semi-continuous processes were starting to enter the market.

#### **4.5 Technological Diversity and Complexity**

The oil crisis represented a significant turning point in the evolution of ethanol technological systems. First, it opened up opportunities for the extended diffusion of the systems in the energy environment. The rising oil prices changed the relative competitiveness of fuel ethanol. Production costs which were previously considered too high were brought into a reasonably competitive range with imported gasoline. But even more significant was the possible emergence of ethanol niche opportunities in areas that had been dominated by oil. This had four main effects. First, it stimulated recombinant innovations to improve the performance of ethanol technological systems using existing know-how. Second, it set in motion new R&D efforts. Third, new institutional arrangements were made in various countries to support these research efforts. Finally, the shifts led to a restructuring of the international market for ethanol technology.

All these changes were underpinned by two main features. First, innovation was directed at improving the performance of ethanol technological systems in a relatively new environment (with added selection criteria such as ecological and energetic considerations). Second, the process of technological evolution was marked by increased diversity in technological variants. Given the uncertainties surrounding the technology and the lack of a favourable track record in niche realization, the diversity tended to widen the scope for selection and adaptive prospects for technological systems.

One of the most significant parameters in the energy sector was the cost of fuel ethanol. As indicated earlier, ethanol had been used in niches

which were protected from competition with gasoline or with other alternative liquid fuels such as methanol. But for it to operate within acceptable competitive limits, ways of reducing the production costs of ethanol had to be identified. This set in motion a wide range of efforts to rationalize the efficiencies of the various functional units which constituted the technological systems. One of the areas which received much R&D interest was improving fermentation. Whereas the history of the ethanol system had been dominated by batch fermentation systems, the post-1973 efforts were directed at generating technological variants using continuous processes with higher volumetric efficiencies. Research was also directed at improving the conventional batch processes. The variants that have so far been operated or tested fall into three broad categories: improved batch, semi-continuous (or cascade) and continuous fermentation processes.

The batch process involves the repeated emptying, cleaning, sterilizing and refilling of the tank. The fermentation cycle in this process takes 36-48 hours under temperatures held at 20°C-30°C with an initial pH of 4.5. The conversion efficiency falls in the 90-95 per cent range and yields ethanol concentrations of 10-16 per cent (weight/volume). The yeast used in batch processes is grown separately and inoculated into every tank. Batch processes are easy to use and require little highly skilled labour. Moreover, the risks of yield loss are low because the fermentation process is distributed in several tanks. But the low fermentation productivity due to long down-times represents an obstacle to improved process efficiency. One of the first improvements on this process involved the recycling of yeast. This does not increase the fermentation efficiency but it reduces the time needed to grow yeast for each batch.

Cascade systems embody improvements over the batch process. Tanks similar to the ones used in batch processes are connected in series allowing the substrate to be fed into the first tank constantly while at the same rate being withdrawn from the last tank. This process uses the same number of tanks as in batch systems but it takes less fermentation time because of the cascading flow of the substrate through the process. Not only does it save down-time, but it also reduces the chances of infection by allowing air contact between ambient and internal fermenter surfaces. Such

systems may also use yeast recycle units. Substrate flow in the process is done either with the use of gravity or pumping. The cascade process was developed through modifications on the batch process on the basis of available engineering concepts on volume-control and flow regulation.

Improvements on the cascade design have led to the concept of continuous fermentation in which both the substrate and yeast are recycled. This process has resulted also in a large number of variants which have reached different stages of development. The change from batch to continuous fermentation has been mainly to reduce down-time and increase volumetric efficiency. It has also contributed to savings in the time and substrate needed for growing fresh yeast for every batch per unit of output. Because of higher volumetric efficiency, the systems employ less capital equipment and space. But on the other hand, the systems are more sophisticated and require skilled operators. The use of centrifuges, for example, raises the capital cost of the technology in comparison to the batch process. It was not just production efficiency that called for improvement. Issues related to feedstock availability generated new pressures.

Raw material costs and availability played a significant role in the viability of fuel ethanol. It has been stressed that most of the early ethanol programmes were aimed at reducing surplus agricultural products such as sugarcane or corn. The latter resource led to the introduction of starch-based fermentation processes in the energy field. But for the technological system to establish a long-term niche, raw material supply had to be guaranteed. The use of corn or any other grain raised questions related to possible competition between food and energy despite the fact that many of the early projects were based on surplus agricultural yield or residues. Guaranteeing long-term raw material availability required either intensified agricultural yield in the traditional supplies or diversification into new areas, especially where resource conflicts are minimal. One such area is the use of starch or cellulosic material such as agricultural residue or municipal solid waste (MSW) for ethanol production. These resources often have a low opportunity cost and might therefore be economically turned into ethanol. But this required improvements and modifications in the technological systems to enable them to convert cellulosic material to

fermentable sugars. The field of cellulosic fermentation generated a range of novel technological variants.

Starch-based plants have been attractive in the industrialized countries because they provide a way of getting rid of surplus grain. One of the main problems in starch-based plants has been the low energy balance because of the absence of fibrous residues such as bagasse for steam generation. This problem has been overcome by advances in process energy optimization and recent plants now operate at positive energy ratios. Firms such as Buckau-Wolf (formerly Gebr. Hermann Buckau Walther) are now supplying energy-efficient starch-based plants. Similarly energy-efficient plants are now operating in the US. For example, the Staley Manufacturing Company plant at Loudon (Tennessee) uses only 21,000 BTUs for a gallon of ethanol produced, more than 20 per cent less than in conventional plants. The plant produces 40 million gallons of anhydrous ethanol a year from corn, making it the second largest ethanol plant in the US.<sup>22</sup>

Concern over other uses for surplus grain led to research on cellulosic materials as another ethanol feedstock. Although cellulose is the most abundant renewable resource available for conversion to fuel, it is also one of the most difficult to break down into fermentable constituents. Cellulose occurs as a crystalline form that is reinforced by a lignin-hemicellulose complex. Various ways of degrading it include biological, chemical, mechanical, and thermal methods. Any of these methods would lead to a slightly different system configuration whose techno-economic performance at any stage can only be established through testing.

The use of weak acid to degrade cellulose was not a new technique. Dilute and concentrated acids had been used in cellulose degradation during World War I. The conjectural technological variants that were being developed at various US universities included the application of new scientific knowledge and technical advances to this established concept. The key technical problem in the acid hydrolysis include low sugar recovery, corrosion, and unfavourable economics even in the long-run. As a result, the R&D efforts have not been able to bring the pilot plants to commercial application although research still continues.

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22. Morris, "Huge Plant for Ethanol".

A significant achievement in continuous fermentation was made by Alfa-Laval engineers who designed a process that utilizes concentrated feedstock. This system was designed to reduce the amount of stillage released during ethanol production. Instead of the 11-15 litres of stillage normally released for every litre of ethanol produced in batch process, the Biostil process releases 0.8-4 litres depending on the concentration of the substrate (Table 4.5). The process was designed to deal with the environmental problems associated with ethanol production. The process differs considerably from other techniques. The ethanol is continuously stripped from the fermenter broth at low concentration thereby eliminating the need to dilute the substrate with massive amounts of water. The dilution is required to protect the yeast from poisoning.

TABLE 4.5: *Comparison of Biostil and Conventional Plant in Brazil*

Parameter	Biostil	Conventional
Yield (% of theoretical limit)	94.5	87.0
Stillage (litre/litre of ethanol)	0.8	11.0
Personnel requirement	3.0	7.0
Space requirements (cubic meters)	350.0	1350.0

The figures are based on plants producing 150,000 litres a day.

Source: Alfa-Laval, São Paulo, Brazil.

The Biostil process had another adaptive parameter which most other continuous processes did not have. Most other continuous processes ran the risk of ethanol loss through contamination. The Biostil process was designed to reduce the risk of contamination. First, the internal design of the process allows the yeast to undergo pasteurization thereby killing off the bacteria. Second, the feedstock is subjected to high osmotic pressure, low sugar concentration, 4.5-5.0 per cent ethanol, and high yeast concentration in the fermenter. These conditions do not favour the growth of bacteria.<sup>23</sup>

The technology was targeted for the Brazil but several factors hindered its widespread use. First, the process was about 20 per cent more

23. Garlick, "Fermentation of Molasses", pp. 15.

expensive than the conventional batch processes and there was no pressure on Brazilian producers to invest in efficient systems. Second, the process required carefully controlled operating conditions and relied on skilled personnel and therefore had high labour costs. Third, Brazil gradually increased the use of stillage as fertilizer and therefore undermined one of the most important attributes of the Biostil process. As a result, the process has not had the expected rate of commercial application in Brazil.<sup>24</sup>

TABLE 4.6: *Production Cost of Ethanol by Enzymatic Hydrolysis*

Component	Annual Cost (\$M)	Cents/Gallon	US\$/tonne
Raw materials	30,838	61.68	206.50
Utilities	10,279	20.58	68.85
Operating costs	9,799	19.60	65.67
Overhead expenses	9,980	19.96	66.83
By-product credit	-12,208	-24.42	-18.75
Cash cost of production	48,688	97.38	326.03
Depreciation	33,080	--	--
Net cost of production	81,768	163.54	547.54
Sales price at 15% DCF	--	212.60	711.80

These 1982 cost estimates are for a plant producing 50 million gallons a year (149,335 tonnes) with a total fixed inventory of US\$193.6 million.

Source: Isaacs (1984).

According to Alfa-Laval officials, the firm had turned down offers from Brazilians they suspected would replicate the plant and introduce cheaper versions on the market. Alternatively some Brazilian distillery manufacturers contended that the Biostil process was too sophisticated for Brazil and there would be no need for replication. It is interesting to note that the Brazilian government, through the Secretaria de Tecnologia Industrial (STI) funded the development of the Flashfern process to a pilot scale. The core concepts of the Flashfern were similar to Biostil's.<sup>25</sup> The development of local versions of the Biostil process could have retarded its diffusion as potential adopters waited for the new variants which were likely to be cheaper and more appropriate to the Brazilian conditions.

24. Interviews, Alfa-Laval, São Paulo, Brazil, March 1985.

25. Another version of the Biostil concept, the Engenho Novo process was supported by the Financiadora de Estudos e Projetos (FINEP), which also co-sponsored the Biostil plant at São Luiz.

One of the most innovative variants in ethanol production has been the application of genetic engineering to the cellulose degradation. Studies on cellulosic degradation in the US originated in the military, especially in trying to reduce rotting among military supplies in the tropics during World War II. A research programme at the US Army Natick Development Centre set out to investigate "the causal organisms, their mechanism of action, and the development of methods of control not requiring the use of pesticides".<sup>26</sup> This led to major advances in enzymatic hydrolysis which were later applied to ethanol production, especially using the soil fungus *Trichoderma*. This area has also attracted the use of carefully selected and genetically engineered organisms to produce energy.<sup>27</sup>

TABLE 4.7: *Typical Energy Balance for Ethanol Production*

		Energy (Mcal/hectare/year)					
		Energy Input			Energy Output		
	Crop Yield (t/ha/yr)	Ethanol Produced (l/ha/yr)	Agricultural	Industrial	Ethanol	Residue	Balance
Sugarcane	54.0	3,564	4,138	10,814	18,747	17,500	+21,345
Cassava	14.5	2,523	2,573	8,883	13,271	--	+1,815
Sweet sorghum	62.5	5,165	8,021	16,500	27,168	19,110	+21,757

Source: Da Silva *et al.* (1978).

This approach not only represents a change in the source of raw materials but also in the methods and disciplines applied to ethanol production. Many of these innovations have remained at laboratory level. The main obstacles to the commercial application of these processes has been high capital costs. By 1981 the capital cost estimates were in the range of US\$3.5-US\$5.5 per annual gallon of capacity. Then the figure for corn-to-

26. Reese, "History of the Cellulose Program". pp. 9.

27. See White (1983) for a description of the various acid and enzymatic processes funded by the US government and their status. Work is also underway to improve yields from *Saccharomyces*, especially through immobilization. The Japan Gas Company (JGC) has developed a continuous process which uses immobilized yeast. The process allows fermentation to be completed in five hours and achieves 11.0% alcohol concentration, *Biomass Digest*, Vol. 6, No. 1, pp. 1, January 1984.

ethanol was US\$2.5.<sup>28</sup> A large share of the cost was accounted for by high feedstock prices (Table 4.6). The feedstock costs could be reduced by further research into more efficient ways of reducing cellulose.

TABLE 4.8: *Energy and Capital Costs for Separation Units*

Unit Type	Concentration (wt%)	Energy Requirement (Btu/gal)*	Installed Capital Cost [\$M (10 <sup>6</sup> gal/yr)]
Conventional distillation	10-99.9	27,000	1.6 (25)
Vapour re-use distillation	10-99.9	18,000	2.0 (25)
Cantrell/Petrek (Diffusion carrier gas)	10-85	9,900 (39000)	--
Intertechnology/Solar/Science Applications, Inc. (Solvent extraction)	30-99.9	2350 7200 (10-30)**	-- --
Georgia Tech (Solvent extraction)	26-98	12,600 (2,600) 5,000 (10-26)**	3.7 (27)
Hydrocarbon Research Inc. (Ethanol selective adsorption)	15-99.9	25,000 (12,600)	--
Purdue (Ethanol selective absorption)	91-99.9	2000-3000	--
Shock Hydrodynamics (Ethanol selection absorption)	--	--	--
Southern Research Institute (Ethanol selective membranes)	--	--	--
GKSS (Membrane dehydration system)	8-99.5	13,200	--

\*The number in parentheses represent the thermal equivalent of the electric energy required with the a heat-to-electricity efficiency of 0.33.

\*\*Approximate energy requirement to concentrate ethanol from 10 wt % to the concentration shown.

Source: Douglas *et al.* (1983).



Apart from the the development of new variants, research efforts were also directed at reducing the energy used in the production of ethanol. Ethanol production typically showed positive energy balances (Table 4.7). However, the question of energetics became significant as critics of ethanol programmes argued that it was irrational to use more energy in producing a unit of fuel than was contained in the unit itself. The notion of net energy balance is broad and accounts for the ratio between all the energy used in ethanol production to that contained in the final ethanol and by-products; it therefore covers agricultural production as well. The case for "energetic determinism" has its own limitations.

The central question is not the production of energy as measured in standard units, but involves the economic costs of substituting one form of energy for another. Energetic determinism ignores the fact that the range of energy resources that can be used in the same conversion system is so limited that it can be justified to convert, for example, solid biomass into liquid fuels since particular technologies will only use the latter. This, however, is not a vindication of inefficient energy conversion and use. The concern over energy balance was therefore important in identifying areas which potential energy savings in the ethanol technological systems.

Innovations in this field concentrated on distillation (or separation), which accounted for 25-50 per cent of the energy used in ethanol production. Innovation in separation units took three routes. First, existing technology was improved through incremental modifications. Second, technical advances made in other engineering fields were introduced in ethanol technological systems.<sup>29</sup> Third, radically new technological variants were proposed. These fell into two main categories; distillation and non-distillation. The non-distillation variants represented a departure from conventional distillation techniques. The new approaches used solvent extraction, adsorption/absorption, membrane, and diffusion techniques (Table 4.8).<sup>30</sup> Although their energy requirements were less than those of conventional distillation, the installed capital equipment remained relatively

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29. Essien *et al.*, "Energy Conservation in Ethanol Production", pp. 31.

30. For a detailed technical review of these techniques, see Douglas *et al.*, *Evaluation of Ethanol Separation Processes*, pp. 11-27.

higher. But some of these systems, especially solvent extraction and grain adsorption, have reached competitive levels and additional improvements would enable them to displace conventional techniques.

The increasing complexity of ethanol technological units and pressures for systems control have led to the increased application of information technology in fermentation. As pointed out earlier a technological system functions as a whole under the pressure of functional imperatives. Rationalizing this process requires the ability to process, transmit and control various pieces of operative information. This requirement has led to the increased use of computers in ethanol technological systems.

This use of computers is largely a continuation of the instrumentation and control process that started with the introduction of saccharometers and hydrometers. While the instruments measure isolated variables, computers can handle combinations of variables and system performance. With computers, advanced system configurations can be designed and the fermentation process can be closely monitored, controlled and adjusted to maintain optimal performance. Many of the computer-aided fermentation (CAF) techniques have been relocated from the pharmaceutical environment which, for example, has applied the approach in the production of penicillin. The early applications of CAF were in experimental and pilot plant levels.<sup>31</sup>

#### **4.6 Technological Imperatives and Institutional Reform**

The introduction of a new technological system is usually associated with a process of socializing knowledge and providing a framework within which options can be generated, selected and retained. Furthermore, such an institutional framework provides also a forum for the continued assessment of the external environment so as to give direction to the evolutionary process. This makes institutions endogenous to the process of technological change. The demands or imperatives of the ethanol technological systems made it necessary to reform existing institutions or create new ones as well as establishing new forms of institutional alignment.

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31. Cooney, "Computer Applications in Fermentation", pp. 2.

The early stages of renewed generation for ethanol technological variants was characterized by institutional support. This was partly to underwrite the high costs of variant generation and the losses that might result due to the uncertainties inherent in new technological systems. Public sector support varied from direct support for increasing production capacity as in the case of Brazil to support for R&D programmes such as in the case of the US and other industrialized countries. These differences, however, were not mutually exclusive. Brazil, for example, mobilized its civilian and military research institutes into R&D, especially on the end-use side. New engines that utilized hydrated ethanol were designed and marketed largely through the collaboration of local research institutes (mainly the air force) and the private sector.<sup>32</sup> The US, on the other hand, concentrated its support on the generation of new ethanol production systems.

The US biomass fuels programme had long-term objectives with specific targets to the year 2000. These targets embodied the need to raise the performance of the conjectural technological variants and also specified the desired size of the ethanol niche. For example, the cost target for 1.0 million BTUs was set at no more than US\$3.5 (at 1977) prices for the year 2000. To achieve the objectives, the plan emphasized the technological co-evolution of different units. It was envisaged that this approach, coupled with the extensive generation of conjectural variants, would offer a higher chance of bringing some of the emerging technological systems to the commercial stage. Indeed, the approach was aimed at raising total system performance; the subsystems or units were only significant in relation to the whole system. It is notable that the support for ethanol technological systems was not an isolated development but part of a larger programme aimed at increasing the role of biomass in general in the energy environment.<sup>33</sup> Support for fuel ethanol was given by both federal and state governments, leading to significant R&D advances.

However, these technological advances did not immediately reach the market and as a result most of the technological systems used in ethanol

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32. Brazil established the most elaborate institutional network on fuel ethanol. For a description of the network, see World Bank, *Brazil*.

33. US ERDA, *Program Plans*, pp. 1-3.

production before and after 1973 were predominantly of the batch process type. The largest market for such technologies was Brazil, which launched its national ethanol programme in 1975 using traditional batch systems manufactured in the country. The prospects for extended market niches brought on to the scene a new form of market restructuring in which firms with relevant scientific and technological know-how increased their R&D on generating technological variants.

TABLE 4.9: *DoE's Renewable Energy Budget, 1981-1985 (Million US\$)*

	Carter Request 1/1981	Reagan Request 9/1981	Budget Authority 1982	Budget Authority 1983	Budget Authority 1984	Reagan Request 1985
Photovoltaics	161.60	54.1	75.0	58.00	50.4	47.5
Solar Thermal	149.80	57.5	76.0	61.10	60.3	46.3
Biomass Energy Systems	55.50	18.0	20.5	16.00	--	28.1*
Alcohol Fuels	32.60	8.8	10.0	5.00	28.4	--
Wind Energy Systems	73.60	18.3	34.4	31.40	26.5	23.3
Ocean Energy Systems	36.80	--	20.8	10.50	5.5	3.5
Renewable Energy Infor.	12.70	3.5	6.7	3.00	3.3	6.0
Renewable Energy Inter.	13.00	8.8	4.0	10.00	0.5	0.5
Programme Support	--	--	3.5	1.00	0.8	0.5
Solar Reserve Account	--	--	12.3	--	--	--
Programme Direction	6.90	4.0	4.0	5.80	6.0	4.9
Total	558.96	170.1	268.2	201.94	181.7	163.6

\*Amount includes funds for alcohol fuels.

Source: Kraft *et al.* (1984).

The development of ethanol technological systems in the US in the 1980s were also influenced by fluctuations in the institutional climate. Much of the R&D and other tax incentives to stimulate the application of the technology were started during the Carter Administration, which was more favourable to alternative energy options. Government support under Reagan has dwindled and many of the new research routes that had been earlier perceived fruitful have now been abandoned (Table 4.9). This change in the institutional climate was not directly related to changes in oil prices but to perceptions about the role of government in alternative energy sources.

On the whole, the evolution of ethanol technological systems was marked by increased complexity, adaptive flexibility and system diversity. The drift towards complexity and flexibility was helped or retarded by the public sector and other institutions. Although efforts were undertaken to introduce radically new process recombinations, the international market was still dominated by batch processes in the late 1970s and early 1980s. Some of the new R&D routes that had been initiated in the 1970s were abandoned or curtailed as oil prices started to fall in the 1980s.

## **Conclusion**

This chapter has outlined the major features of the evolution of ethanol technological systems. It has showed that the technological system, as a purposive configuration of various technical units, advanced through incremental improvements and recombination of technological units that had co-evolved in other sectors. The 1973 oil crisis created prospective conditions for the diffusion of technological systems into new market niches. In response, a wide range of technological variants were introduced as technical change drifted towards complexity and higher techno-economic performance. These changes were also associated with institutional as well as corporate restructuring. However, the commercially-viable technological options were dominated by batch processes in the 1970s. It is against this background of fluctuation and limited diversity in conjectural technological systems that Zimbabwe and Kenya embarked on their fuel ethanol programmes.

## **5. MAPPING THE TECHNO-ECONOMIC LANDSCAPE**

### **Introduction**

The previous chapter examined the evolution of ethanol technological systems and pointed out that the systems went through long periods of incremental and recombinant innovations. However, the 1973 oil shock stimulated new innovations which resulted in a limited range of commercially-viable technological variants in the 1970s. This chapter maps the key features of the techno-economic landscape which were significant for the realization of ethanol niches in Zimbabwe and Kenya. These features are divided into two categories; adoptive pre-conditions and adaptive parameters. It will be shown that the techno-economic landscape is constituted not only by technological and economic factors, but it also includes institutional variables.

### **5.1 The Adoptive Terrain**

#### **5.1.1 Initial niche exploration**

The availability of surplus molasses and the identification of potential niches in the energy market led to efforts to ascertain the techno-economic feasibility of fuel ethanol as a pre-condition for the realization of these niches. The earliest explorations to ascertain the techno-economic feasibility of fuel ethanol were made in Zimbabwe. The fact that the process was first initiated in Zimbabwe illustrates the fluctuations in molasses trends and energy availability as shown in chapter 3. The use of molasses to manufacture ethanol was identified in a 1963 government survey of industrial opportunities as a potential feedstock for industrial applications and energy

source.<sup>1</sup> The UDI necessitated the search for alternative liquid fuels due to the expected disruptions and shortfalls following the imposition of trade sanctions.

Following a Zimbabwean ministerial trade mission to Britain in 1964, the Alcohol Company of London expressed interest in buying 750,000 gallons or 3,000 tonnes of rectified cane spirit annually from Zimbabwe. But the British proposal was pre-empted by a decision by African Distillers company (ADC) to undertake the large-scale production of rectified spirits. Following this decision, the Ministry of Commerce and Industry decided to stop promoting the production of ethanol. But because of ADC inaction, the ministry decided to resume work on ethanol with new priorities in mind. In 1965, the ministry clearly stressed the potential strategic importance of ethanol as a fuel: "In view of the sanctions which have been imposed on oil supplies...it is now necessary to consider the project and its priority from the strategic point of view as well as economic point of view."<sup>2</sup>

The ministry suggested two possible ways of producing fuel ethanol. First, they considered turning surplus molasses to fuel. The country had some 37,400 tonnes of surplus molasses in 1966 which could yield only about 1,850,000 gallons (8.42 million litres) of ethanol. This amounted to about 3.86 per cent of national gasoline requirements. It was recognized by the government that this quantity had little strategic importance although it had potential economic benefits. "While the establishment of a factory to produce this quantity of alcohol would have little strategic importance, the industry in normal times could bring about a useful economic contribution to the country if it could export alcohol."<sup>3</sup> But this was overly optimistic and contradicted the general view that export markets were likely to shrink.

Another suggestion was to replace 25 per cent of the gasoline demand, which is the technical limit that could be reached without requiring any modifications in motor engines. This option required about 10 million gallons of fuel ethanol. To produce this quantity would have taken all the surplus molasses and additional cane juice processed from about 565,000 tonnes of

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1. Federal Ministry of Commerce, *Opportunities for Industry*, pp. 57-60.

2. Ministry of Commerce and Industry, *Power Alcohol*, pp. 1.

3. *Ibid.*, pp. 2.

cane. This diversion of cane would have led to a reduction in foreign exchange earnings from sugar. It was estimated by the government that the substitution of refinery gasoline with locally-produced ethanol would save about Z\$302,000. Its export could have earned the country Z\$700,000 in foreign exchange. The price of a tonne of sugar (ex-refinery) was about Z\$20 and the 565,000 tonnes of cane would produce about 70,000 tonnes of sugar. The project would have cost the Treasury about Z\$54,000 annually in foregone excise duty on gasoline. The recovery of fermentation by-products such as potassium sulphate and potassium chloride were considered but there was no evidence that it was economical and would improve the overall economics of ethanol production.

This option did not look viable from the start because it required the government to forego taxes and excise duty in lieu of direct subsidy. Already at this moment, the Universal Oil Products (UOP) of South Africa had submitted a proposal to the government which was conditional to the removal of excise duty, subsidized rail rates for ethanol transportation, and the availability of finance for pre-investment work such as feasibility study preparation. Alternatively, UOP suggested to drop the demand for waived excise duty if ethanol were to be sold at the price of gasoline.<sup>4</sup> The government could not meet any of these conditions and the UOP proposal was passed on to IDC for further evaluation.

The second option looked attractive as a strategic consideration but could not be justified on economic grounds. The government estimated that the Treasury would lose about Z\$800,000 annually from foregone excise duty and the retail price would be almost twice that of gasoline. It was estimated by the government that the capital cost of building the plant was about Z\$1.4 million. The Projects Committee of the Ministry of Commerce and Industry decided that the large-scale option should not be pursued "because the economic costs far outweighed the strategic benefits".<sup>5</sup> It was decided that work on small-scale ethanol production be investigated by IDC. The decision by the government to pass on the responsibility for further evaluation to IDC was influenced by two factors. First, the initial proposals required

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4. *Ibid.*, pp. 7.

5. Projects Committee, *Minutes of the Second Meeting*, pp. 3.



government financial input and other administrative interventions which would have caused conflict with other interested parties. For example, the decision against special rail rates for the UOP proposal was partly based on the view that the management of the railways would not accept to offer special rates.<sup>6</sup> Second, much of the pre-investment work at the time was being done at IDC which had been set up partly to liaise between the government and the private sector.

The government in this case was providing a regulatory framework within which the ethanol niche could be realized. The conditions prevailing in Zimbabwe then created conditions which enabled those with adoptive skills to make proposals. The UOP proposal, for example, was built of expertise which had been gained at the National Chemical Industries (NCI) of South Africa. The founder of UOP had worked in NCI on ethanol-related activities and had therefore gained experience required in the production of fuel ethanol. It is notable that UOP did not intend to be fully involved in the venture but only to offer management expertise while leaving the economic risks to borne by other investors.

As soon as the prospects for fuel ethanol emerged, Hippo Valley conducted technical studies on the feasibility of using ethanol-gasoline blends. This was possible because Hippo Valley already operated a small distillery for potable ethanol. The results were communicated to the oil companies who were getting interested in the use of fuel ethanol. The evaluation of the technical feasibility of fuel ethanol was continued by the oil companies, especially after the Feruka refinery was shut down because of disruption in the supplies of crude oil. It was on the basis of the technical feasibility of the fuel that the oil companies (BP, Caltex, Mobil, Shell and Total) confirmed to the government that they would accept to blend ethanol in gasoline. The assurance given by the oil companies on marketing ethanol was conditional. First, they could not give long term guarantees. It was felt that long-term guarantees would have mainly helped the sugar industry find a local market for its produce.

Moreover, the oil companies did not want to foreclose the option of returning to full gasoline utilization in case the situation returned to

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6. Ministry of Commerce, *Potable Alcohol*, op. cit., pp. 7.

normal.<sup>7</sup> Indeed, the companies, some of whom had shares in the refinery, reminded the government of the Refinery Agreement which gave the refinery the full mandate to supply the petroleum products needed by the country whenever it was able to do so. Second, they insisted that the price of ethanol be equal to the ex-refinery gasoline delivered to mixing depots. Finally, they required that the additional costs of tankage and blending facilities be borne by the government.<sup>8</sup>

The declaration of intent by the oil companies was prompted by a Ministry of Commerce and Industry request on the position of the oil companies on the matter. The Ministry, however, was also responding to a suggestion by IDC that it would stop working on the promotion of fuel ethanol unless a market was guaranteed, preferential rail costs provided and excise duty waived. These, indeed, were the same demands put forward by potential investors in ethanol production. The IDC position was reached after their own evaluation which showed that ethanol could not be competitive unless it received some form of financial support. The government, however, was unwilling to lose revenue. All they did was to seek assurances from the oil companies on the possibilities of marketing ethanol.

At this stage the government was considering yet another proposal submitted in February 1966 by Lepage, Urbain & Cie of France through Hall, Longmore and Company of South Africa. This proposal offered a turn-key plant to produce 36,400 litres a day at a capital cost of Z\$324,000. The proposal included supplier's credit terms of five years and proposed to sell ethanol on par with gasoline. Most discussions on the project were done by Hall on behalf of Lepage, Urbain & Cie and the government took an active role in discussing the project with other sectors of the industry, especially the oil companies. Although the project generated much interest in government and private circles, it did not receive much support from Hippo Valley where

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7. A letter to the Ministry of Commerce and Industry dated April 27, 1966 signed by the oil companies states: "Members of the Oil Industry would like to make it clear that during any period of uncertainty surrounding oil supplies and whilst the Feruka Refinery is at a standstill due to lack of crude oil supplies, they would extend all possible co-operation in order to absorb the production of Absolute Ethanol in Motor Spirit. However, it appears as if the sugar producing companies are looking to the Industry for long term assurances and this we are afraid we cannot give," pp. 1.

8. Stuckey and Juma, *Power Alcohol in Kenya and Zimbabwe*, pp. 37.

it was likely to be located. Hippo Valley objected to Lepage's labour cost estimates and questioned the proposed effluent disposal method.

No major decisions were taken on ethanol development either by the Ministry of Commerce and Industry or IDC during the rest of 1966. It is notable, however, that the submission of the Lepage proposal and the insistence of IDC on a market guarantee created conditions which in the long run reduced possible conflicts between the oil companies and the sugar industry. Moreover, the problems of niche realization were now limited to the technical and economic issues related to ethanol production since the institutional obstacles of market entry had been reduced. In the meantime, IDC continued to conduct studies to ascertain the most probable costs and benefits of fuel ethanol.

A report in February 1967 by IDC put an end to the initial efforts to test the prospects of realizing the fuel ethanol niche. It noted that the ex-refinery cost of gasoline was 21.3 pennies per gallon and a parity price of ethanol would only be reached with subsidies of 12.8-40.3 pennies per gallon depending on the raw material types and production techniques used. The report stressed that fuel ethanol had no strategic importance since it contributed only about 20 per cent of the gasoline demand. While the by-products of ethanol production had no viable markets, the large-scale utilization of cane for ethanol would lead to a subsidy of Z£16 per tonne of sugar. The subsidies would be difficult to revoke as they would still apply even if the sugar market returned to normal.<sup>9</sup>

The IDC study pre-empted the consideration of several other proposals. For example, J. Dupont and Company of South Africa proposed in March 1967 to supply a turn-key plant with a capacity of 10,000 tonnes (2.75 million gallons) per year. The proposal required that several conditions be met by the government. First, the company required the right to supply up to 20 per cent of motor spirit and legal assurance that the oil companies would be compelled to blend a maximum of 20 per cent ethanol in their motor spirit even after the trade boycott of the country was lifted. Second, the company asked for land to be made available next to an existing sugar mill which would also provide process steam to the distillery. Third, they required the

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9. Cambitzis, *Ethyl Alcohol from Sugar*, pp. 6.

government to issue an import licence for the plant and equipment. But despite the support of sections of the Ministry of Commerce and Industry, this proposal was shelved.<sup>10</sup>

The decision to shelve the idea of fuel ethanol was partly based on the short-term economics of ethanol production. However, there were long-term considerations as well. There was the view that any investment in fuel ethanol would face political uncertainties which would affect the long term returns on the investment. For example, the removal of the trade embargo would suddenly change the economics of ethanol production. It was from this understanding that J. Dupont insisted on the legal right to continue the supply of fuel ethanol even if the embargo was lifted. It is notable that most of the proposals presented to the government in the feasibility exploration stage were external turn-key projects. Then, there was not much local knowledge on the large-scale production of ethanol.

The IDC report coincided with a memorandum by the South African Cane Growers' Association (SACGA) urging the government to support a fuel ethanol programme under which each of the 20 sugar factories in South Africa would be supplied (at government expense) with a standard-size distillery producing 5,000 gallons of ethanol a day at the capital cost of R500,000. The total output of the distilleries could provide about 3.0 per cent of the country's gasoline demand. The memorandum suggested that an increase in the number of distilleries, depending on the milling capacity, be included in the second phase of the project.<sup>11</sup> The SACGA proposal to the South African government tended to heighten the suspicion held in sections of the Zimbabwean Ministry of Commerce that South African sugar producers were not interested in seeing a low-cost ethanol industry developed in Zimbabwe.<sup>12</sup>

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10. Walker, *Proposal from J. Dupont*, pp. 1. J. Dupont were already in the molasses business in South Africa and made other proposals to import some of Zimbabwe's surplus molasses.

11. SACGA, *The Production of Power Alcohol*, pp. 7.

12. These suggestions are recorded in a progress report prepared by the Ministry of Commerce and Industry on April 16, 1966. It subscribes in part to the "view-point that the South African alcohol producers...are not anxious to see a low-cost producer develop in Rhodesia", pp. 2. It is ironical that the SACGA memorandum was used in 1973 in Zimbabwe to justify the production of fuel ethanol.

At the end of this phase, a number of issues crucial to ethanol niche realization had been identified. Moreover, the period was marked by an extensive search of the local market for potential molasses uses. With potential market niches already identified, subsequent periods were dominated by more focussed approaches, concentrating mainly on reducing the economic costs of producing fuel ethanol. This period also enabled the sugarcane producers to start building firm-level ethanol-related capability. Hippo Valley already had a distillery and firm-level expertise in ethanol production. Triangle started looking into the feasibility of building a distillery during this period although they did not present any proposal to the government.

Kenya went through this similar process but with marked differences. As indicated elsewhere, proposals to produce ethanol were presented to the government as early as 1973. Kenya did not review the early initiatives as carefully and in detail as the Zimbabweans did. This is partly because the molasses problem was not acute and therefore the country still relied on the international market as a disposal medium. The first major study to look at molasses with the intention to produce ethanol was conducted by Tate & Lyle Technical Services in 1975. This study built its case for ethanol, not only on the basis of export earnings but on the fact that Kenya's molasses contained large amounts of sugar which could be better used through the local manufacture of by-products.

The study led to the submission of a pre-feasibility study to the government in July 1975, thereby prompting the government to look into potential local markets for molasses by-products. At that time the disposal of molasses was starting to acquire importance. One of the earliest government studies on the feasibility of utilizing molasses linked the issues of molasses disposal to energy. "This study is...intended to assist the Government in taking informed decisions on the economic utilization of molasses which is an important effluent in the sugar industry and is also a potential source of energy."<sup>13</sup> This is not surprising since the Tate & Lyle study was completed a couple of years after the oil crisis and coincided with the international publicity over the launching of the Brazilian programme.

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13. ISPC, *Pre-Feasibility Study on Molasses*, pp. 2.

The government identified various derivatives of ethanol which could be manufactured locally. It was thought that molasses could form a basis for an organic chemical industry. Molasses, the government argued, created a serious problem of disposal and environmental pollution. "But this problem can be easily solved and wasted molasses can be effectively put to profitable uses by making it a base for an organic chemical industry in the country and an important foreign exchange saver."<sup>14</sup> The production of fuel ethanol was identified by the Kenya government as an initial step in the development of a broader organic chemical industry. The view of the government was largely influenced by the Tate & Lyle study on which the government relied heavily for technical data. However, the Tate & Lyle proposal did not get much attention in the government and officials claim that this was because of limited follow-up by Tate & Lyle.<sup>15</sup> This view, however, tends to ignore the fact that the Tate & Lyle proposal was soon followed by other proposals which were more ambitious and much larger.

The ethanol proposals presented to the Kenya government in the early and mid-1970s were not associated with a consistent policy to look for alternative molasses uses. Government activities were merely responsive to private sector initiatives. The capacity to assess the viability of the proposals was so limited that the pre-feasibility studies were often the very source of data that were reproduced in subsequent evaluations. Moreover, technical possibility was often mistaken for economic feasibility. For example, all the by-products that could technically be recovered from molasses were treated as if their production was economically viable. It is this assumption which led to the ambitious view that fuel ethanol could be an interim by-product of molasses "till the various industries...are able to fully absorb the locally produced alcohol".<sup>16</sup>

On the basis of mere technical possibility and private sector interest, the government made clear its support for fuel ethanol, promising to promote viable proposals. "The Government would promote any viable proposal for the industrial utilization of molasses. It would in particular

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14. *Ibid.*, pp. 3.

15. Interviews, Industrial Survey and Promotion Centre, Nairobi, September 1984.

16. ISPC, *op. cit.*, pp. 4.

encourage a working relationship between the sugar mill and the oil companies which may be interested in participating in the manufacture of power alcohol in the country."<sup>17</sup> It is notable that the government extended its support for the manufacture of molasses by-products including those which were not being commercially produced anywhere in the world. Here Kenya differed remarkably from Zimbabwe because the latter had considerable commercial and technical links with South Africa and had information on technical possibility as well as economic viability.

Moreover, government records reflect extensive knowledge of technological trends in other countries. For example, the Ministry of Commerce and Industry was aware of attempts in India to produce fertilizer from molasses by-products and the problems associated with the process. Kenya, on the other hand, thought that this was a possible way of improving the economics of molasses utilization. Unlike Kenya, there was a more critical review of proposals in Zimbabwe. And as will be shown later, the ready willingness of the Kenya government to invest in new projects complicated the evaluation process. The critical evaluation of projects in Zimbabwe served as a vicarious mechanism for selection. Costly errors were eliminated during the pre-investment phase of niche testing or exploration.

The identification of molasses uses in Kenya was conducted in isolation of other industrial activities although they were governed by broad government policies on import substitution. These policies were not associated with the active search of the local market for alternative uses as was the case in Zimbabwe. In Kenya the search was conducted by both local and foreign entrepreneurs without promotion work by the government. This was the case despite the fact that the Kenya government had set up the Industrial Survey and Promotion Centre (ISPC) whose main functions included market identification. Although ISPC did its own internal surveys, most of their work was in response to initiatives by potential investors.

The approach taken in Zimbabwe was slightly different. Market identification and promotion work was given much priority and involved the highest levels of the institutional hierarchy. Some of the senior government

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17. *Ibid.*, pp. 14.

officials and even ministers in charge of commerce, trade and industry had some business background and not only maintained links with the private sector but were themselves aware of the intricacies of business practice. It was therefore not a surprise that B.H. Mussett, who had been in business for more than 10 years, was appointed Minister for Commerce and Industry in 1965. The links between the private sector and government officials made communication much easier and decision-making faster.

The borderline between business and government in Zimbabwe was difficult to distinguish because of the intense interaction between the two sections of the society.<sup>18</sup> Most of the top bureaucrats in the Kenyan government in the early and mid-1970s were career civil servants who had been trained mainly in bureaucratic administration. And ministerial positions were not necessarily held by people with any relevant skills although it was a tradition in Kenya for the President to appoint people with an economics background to hold the finance and economic planning portfolios.<sup>19</sup>

Zimbabwe also engaged independent consultants who regularly reported to the government (through IDC) on potential market niches. The consultants emphasized the use of local resources and explored the local industrial potential in the manufacture of various products. This is exemplified by the work of the London-based consulting chemical engineers, Cremer and Warner who looked at the potential for the local manufacture of nitrogen fertilizer. They were later asked to undertake similar exploratory work on the possibilities for the local manufacture of ethanol plants. Armed with such independent studies, the government was in a better position to judge the possible success of proposed investments and therefore to make more informed decisions. There were no comparative efforts in Kenya to search the local economy for manufacturing capability.

It appears that the process of niche realization started with initial exploration which was usually characterized by pre-feasibility studies with limited technical and financial data. Since this phase was highly conjectural (and involved large margins of uncertainty), it was not associated with large

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18. E.M. Seward, Former IDC Director, Personal communication, Harare, September 1983.

19. Interviews, Office of the President, Nairobi, September 1984. As shown earlier, links between the business community and the government were weakened by the distinct differences between some bureaucratic practice and business entrepreneurship.



financial and technical inputs. This is partly why those who already had technical and economic knowledge of the field were the first to make exploratory proposals. Those with other relevant resources such as production technology, finance, or raw materials tended to follow with their proposals, basing their judgement on the initial exploration. Here the role of knowledge flows becomes crucial in the process of niche realization.

Two interesting difference between Zimbabwe and Kenya emerge from this understanding. In Zimbabwe the exploration stage was followed by a period of reduced activity in the field of fuel ethanol. The files were seemingly closed until the 1973 oil crisis led to new initiatives characterized by robust proposals. The lessons learned in the exploration phase were incorporated into subsequent activities. In Kenya, however, the exploration period was soon followed by robust proposals. This rapid transition meant that the problems which could have been eliminated at the exploration stage (through more careful evaluations) were embodied in robust proposals and subsequently incorporated into the investment projects themselves. As we shall see later, the elimination of some of these errors could only be done through the removal of the investments themselves, with massive financial and credibility costs.

Equally important in the exploration stage was the re-arrangement of adoptive interrelations to make the realization of the niche relatively easier. In the case of Zimbabwe, the exploration phase helped to identify those key problems and constraints that needed to be solved or removed before fuel ethanol could be introduced. Not only were these requirements identified, but some of them were fulfilled as in the case of assurances from oil companies. It is notable that some potential ethanol investors asked for legal reforms to legitimize the ethanol niche. Similar institutional re-arrangements did not occur in the case of Kenya and the exploration phase passed without any major efforts to identify the potential obstacles to fuel ethanol production and utilization. Niche exploration did not necessarily need to be followed by a long period of inaction. What was important was the identification of the possible obstacles to niche realization and the related market and institutional re-organization in view of the overall national development strategy. This could only be done with the generation of

knowledge specific to the process of niche realization. The next section will look at the relationship between the initial exploration stage and that of robust proposals.

### **5.1.2 Robust proposals**

The previous section looked mainly at the initial exploration for potential niches and isolated the main differences between Zimbabwe and Kenya. This section will look at the stage of robust proposals, which is usually associated with detailed financial, economic and technical feasibility studies of proposed projects. This stage was different from the exploration phase in many respects. First, it was marked by confidence in the feasibility of financial benefit on the part of the investors (not necessarily project success as will be shown later). Second, it involved financial commitment, especially in the preparation of the feasibility study; a factor which underscores the level of confidence in potential financial gains. Third, the stage included the most elaborate corporate and institutional arrangements required for the attainment of the implicit goals of the investors. Fourth, robust proposals were initiated mainly by those who controlled the strategic resources in the realization of particular niches, molasses or gasoline distribution in this case.

It is important to note that the explicit goals, as embodied in feasibility studies and public declarations were not necessarily the main motive behind investment strategies. The real motives of some of the investors were different from their explicit declarations. Some investors, as will be shown later, were mainly interested in the benefits from the sale of machinery and not from the long-term viability of the project. Such motives can be discerned by a careful examination of the corporate arrangements surrounding a specific project and the conditions to be met by other investors (in case of joint ventures) or the government.

The emergence of robust proposals in Zimbabwe was associated with the 1973 oil crisis which forced the government to re-consider ethanol in view of the changed conditions in the energy environment. This period was marked by increased activity in this field and spread to include other

resources. Not only did the government and the private sector consider the cane-based options, but studies were also conducted on the possibility of producing ethanol from maize.<sup>20</sup> The turn to maize was partly based on the fact that the records of the sugar industry did not show any ample surplus molasses at the time of the oil crisis to justify large-scale ethanol production. The government relied on the previous evaluations to determine the prevailing possibilities. Previous studies, especially the 1967 IDC report were updated with information requested from the sugar industry.

This renewed government attempt to promote fuel ethanol did not meet with much success as the private sector had already found local markets for surplus molasses. The cotton industry, for example, was already using about 9,000 tonnes of molasses a year and a large share was being devoted to animal feed. Hippo Valley claimed that their long-term availability of molasses had been prejudiced by a proposal from a French firm to set up a plant to produce 3.3 million gallon of potable spirits for export. When the government enquired on the possibility for producing molasses with high sugar content (which simply meant the mills would produce less refined sugar), the sugar industry rejected the idea. However, Hippo Valley was willing to turn cane juice directly into fuel ethanol but suggested that the juice be valued at the market price of refined sugar.

Triangle, on the other hand, said they did not anticipate any surplus molasses in the next five years. These obstacles, now on the raw material side, put an end to the second attempt to produce fuel ethanol and the government was left with no option but to pursue the maize alternative. Complementary work was subsequently initiated to produce vegetable oils to replace diesel. It appears from the sequence of events that the sugar

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20. Although the details of the starch-based ethanol project will not be discussed in this study, the proposal illustrates the seriousness with which the government approached the liquid fuels problem. Much of the work on maize-based ethanol was done by the National Foods Ltd., at Bulawayo which sought technology from H.L.S. of Israel. The proposed acid hydrolysis plant was estimated to cost R\$5.0 million at a production capacity of 60 million litres a year. National Foods estimated that they could have saved about 20 per cent of the foreign exchange costs if some of the components were fabricated locally. The Israeli technology was going to be based on American patents. This plant was planned to produce enzymes as well. Obtaining ethanol from corn starch is more expensive than fermenting molasses or cane juice because of the extra capital investment required to convert starch to simple sugars.

Industry was interested in producing ethanol only if it undertook the task itself. If this view is correct, then it was in its interest to delay the introduction of ethanol until it was itself in a position to undertake production. This view can be supported by the fact that only a few years after Hippo Valley and Triangle had told the government that they could not guarantee surplus molasses for fuel ethanol production, they presented proposals to the government.

The proposals were not the exploration-type that dominated the earlier phases but were robust and carefully worked out to include all the major pre-conditions for the application of fuel ethanol. At this time, further technical tests as well as economic evaluations had been carried out by the oil industry to establish the key factors which influenced the use of fuel ethanol under Zimbabwean conditions. Although the technical review was positive on the feasibility of using ethanol, the oil industry was negative about its economics. A position paper by Shell, for example, had earlier concluded that the loss of revenue to the country coupled with negligible return on molasses and refining made the proposition seem not worthwhile.<sup>21</sup>

Triangle, which was known to be working on possible ethanol production presented a proposal to the government in 1975. This was the first robust proposal to be submitted to the government from the sugar industry. The proposal, however, was not favourably received by the government as it was believed then that the most viable alternative for the country was grain ethanol. Moreover, the previous insistence by the sugar industry that there was not enough molasses in the country could not be easily reconciled with the submission of a proposal to produce ethanol from molasses. This proposal was subsequently rejected by the government on economic grounds. The following year, Hippo Valley, a subsidiary of the South African conglomerate, Anglo-American, and a rival of Triangle in sugar production, submitted their proposal to the government.

Hippo Valley proposed to produce about 12 million litres of absolute ethanol and another 3 million litres of potable and industrial ethanol to be sold to the African Distillers who were already operating a small distillery annexed to their sugar mill. The project was estimated to cost Z\$3.25

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21. Shell Ltd., *Summary of Current Position Concerning Power Alcohol*, pp. 3.

million (without working capital) of which about Z\$1.25 million was estimated to be in foreign exchange. The firm was prepared to enter a 20-year contract (subject to a five-year review) with the government on the supply of fuel ethanol. Because the project was seen to be sensitive to the price of delivered coal for steam generation, Hippo Valley suggested that the price of ethanol be fixed at 16.5 cents but raised by 0.12 cents for each Z\$1.00 increase in delivered coal prices. The suggestion was to accommodate possible fluctuations in coal prices.

The price was also sensitive to capital costs and the proposal required an increase or decrease of 0.15 cents for a corresponding movement of Z\$100,000 in the ultimate cost of the project. Then, the average landed cost of gasoline was about 13 cents per litre. It was estimated on the basis of calorific differences that ethanol was 5.5 cents more expensive than gasoline. The figures assumed that the government was prepared to waive excise duty of 3.853 cents per litre of motor spirit. This option seemed attractive to the government provided the foreign content of the project could be obtained and there were no technical problems in marketing the blend.<sup>22</sup> Following a detailed internal government review, the proposal was rejected, largely on the basis of low potential foreign exchange savings.

The post-1975 period was significant because the source of feasibility studies had been narrowed down to Triangle and Hippo Valley who controlled nearly all the molasses produced in the country. This indicated that the two firms had also accumulated enough knowledge about the feasibility of fuel ethanol and had considerable confidence about their proposals. The two firms also competed to submit the most attractive option to the government. The preparation of feasibility studies at this stage involved technical input from the mother firms in South Africa. While Hippo Valley drew expertise from Anglo-American, Triangle worked in close collaboration with Hulett's. There were two dimensions to these links. In the first place the links were part of the normal arrangements on technical services between Zimbabwean and South African firms. Second, Zimbabwe had developed extensive links with South Africa as part of their strategic response to the UN sanctions.<sup>23</sup>

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22. Walker, *Power Alcohol from Molasses*, pp. 1-2.

23. Interviews, Triangle Ltd., Triangle, December 1984.

The early period of robust proposals was not successful. However, it was associated with the competitive improvement of the proposals.

Kenya did not not go through this lengthy period in their transition from initial exploration to robust proposals. Following the Tate & Lyle study, the government received robust proposals from local entrepreneurs who had worked closely with the foreign machinery suppliers. The three robust proposals which were later to realize (with one failed attempt) the ethanol niches in the two countries were all submitted in 1977-78 period. In Zimbabwe, the successful proposal was presented to the government by Triangle while in Kenya the two proposals were submitted by two groups, Madhvani and Mehta. Both groups were managed by local Asian families who had long-standing experience in the sugar industry in East Africa. Madhvani's activities had previously been concentrated in Uganda. They moved to Kenya after the expulsion of Asians by President Idi Amin in the early 1970s. The Mehta group controlled the East African Sugar Industries (EASI) and the South Nyanza Sugar Company (SONY) through management and equity investment.<sup>24</sup>

The roots of the divergent paths that were subsequently taken by the two countries are partly embedded in the context of the proposals. The process of doing the main feasibility study presupposes a partial establishment of the main actors in the investment project and the relationship between the project and the broader issues of macro-economic policy. This is important because feasibility studies are usually judged on the basis of some explicit or implicit policy guidelines. In some cases such guidelines may be distorted or ignored by decision-makers due to vested or

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24. It is tempting to explain the entry of the two firms into ethanol production in terms of the traditional rivalry between these two families. Indeed, a Mehta group manager claimed that a member of the Madhvani family got the idea of developing fuel alcohol from a pre-feasibility study which happened to be lying on the table at the Mehta home. The Madhvani family member was allegedly staying with the Mehtas after being expelled from Uganda. He then quickly moved to propose the project in order to pre-empt the Mehtas. This family anecdote adds some flavour to the intrigue of entrepreneurship but does not reveal the fundamental dynamics of technological evolution. The World Bank recommended to Uganda, where the Madvanis were the dominant sugar producers, to look into the possibilities of producing fuel ethanol as far back as 1961 following an economic survey mission, World Bank, *Economic Development of Uganda*, pp. 281.

personal interests. Decision-making institutions do not usually act in accordance with the laid down guidelines.

The Triangle proposal represented a culmination of the cumulative efforts that had started in the early 1960s to produce fuel ethanol. At this time, the price of oil had risen to levels where ethanol was starting to look increasingly favourable. Moreover, the hope that the political situation would return to normal was slowly sinking and the strategic importance of ethanol was rising. A look at the institutional context of the preparation of the feasibility study shows significant configuration of interests which gave the proposal the robustness that was later to see it accepted by the government.

In the first place, the feasibility study was conducted by a local engineering firm, Jager and Associates (J&A) who understood the local engineering base and could establish with reasonable accuracy the potential for the local manufacture of the various components of the plant. The firm had built up consulting expertise in the field of petroleum technology and was well-equipped to deal with fuel ethanol technology. In Kenya, the feasibility studies were conducted in conjunction with foreign firms. While Madhvani collaborated with a Switzerland-based firm, Process Engineering Company (PEC), the Mehta group's feasibility study was conducted by Vogelbusch, a subsidiary of the Austrian state-controlled engineering firm, Vereinigte Edelstahlwerke AG (VEW).

The J&A feasibility study was conducted in collaboration with Hulett's R&D, a division of Hulett's of South Africa which not only controlled Triangle, but also provided technical support to the mills. The J&A study dealt with process technology, market acceptability, pricing, capital investment, operating costs and the interaction of ethanol with Triangle's other activities. The study looked at the various possibilities of using molasses under different economic and political conditions before drawing its conclusions.<sup>25</sup> The J&A study shows that Triangle had accumulated considerable knowledge of the market environment before deciding to produce fuel ethanol. In Kenya, Madhvani proposed to produce fuel ethanol, citric acid, baker's yeast and vinegar while Mehta opted for fuel ethanol and

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25. Jager and Associates, *Alcohol Plant*, pp. 1.

baker's yeast. The choice of products became a significant aspect in the implementation of these projects, especially in relation to market availability and capital investment.

Both Metha and Triangle remained modest in their objectives, concentrating on financial returns but Madhvani presented grandiose promises which included major foreign exchange savings through export earnings and import substitution, employment increases, domestic subcontracting and on-the-job fabrication, stimulation of the economy through technology diffusion, employment for Kenyan specialists, improvement in food and nutritional situation, and superior products for local consumption.<sup>26</sup> While the Mehta and Triangle proposals were based on certain guarantees of the availability of molasses, Madhvani could not make such an assurance and they did not own any sugar mill. Indeed, they relied on the possible supply of molasses from existing sugar mills but could not secure long-term supply arrangements. This problem later became a major source of commercial and institutional conflict.

The Triangle and Mehta proposals were technically superior to the Madhvani feasibility study. Madhvani used assumptions which did not seem to be based on technical studies. While Triangle and Mehta based their estimates on laboratory tests and were therefore more reliable, Madhvani sent samples for analysis after the proposal had been submitted to the government and agreed upon. Even more crucial were the aggregations used in the Madhvani proposal. Whereas the other two proposals provided a detailed break-down of the the various items involved in the entire project with their estimates, Madhvani's proposal subsumed all the items in broad categories such as plant and facilities, purchase and preparation of land, erection and start-up, training, water treatment and buildings.<sup>27</sup> This approach made independent evaluations or comparisons difficult to undertake.

Furthermore, the estimates made on the price of molasses were too low compared to the prevailing export prices. Similarly, long-term projections in the price of molasses tended to downplay possible up-turns in

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26. Madhvani Group, *Final Proposals*, pp. 4

27. *Ibid.*, pp. 2.



the world molasses market. Indeed, this period was marked by increases in molasses prices. What was equally ignored was the fact that if molasses prices were not fixed (which was the case then), the mere introduction of new sources of demand would tend to raise the price above the previously assumed levels. But Madhvani hoped to overcome such problems through state intervention since the government was the majority shareholder in the joint venture.

### **5.1.3 The finance-technology nexus**

The choice of technology in the two countries was largely influenced by the existing institutional arrangements governing financial matters. The choice of technology was therefore not a simple instantaneous decision but a complex process that was linked to both finance policies and subsequent project implementation. Triangle's technology choice process was largely influenced by the government policy which required that all investment projects recover their foreign exchange component in one year. This had far-reaching implications for the design of industrial projects. Feasibility studies were required to include a search of the local market to identify the possible sources of local inputs which might reduce foreign exchange costs.

Although the government guaranteed some foreign loans through local banks, the repayment of the loans had to be met by the savings made by the borrowing firm. The guarantee was therefore made against expected foreign exchange savings. By restricting the foreign exchange content of projects, the government reduced the level of guarantee and therefore took minimal risks. Triangle operated under these constraints and had to rely on local inputs for most of the components of the plant and imported only critical parts. The potential technology supplier had to take into consideration the financial limits of Triangle and be willing to supply the know-how without insisting on the supply of hardware. The search team, which included Triangle staff and J&A visited various European countries, the US and Brazil and finally settled for a Herrman-Buckau Walther (West Germany) technology.

This search process was not merely to identify potential technology suppliers but it was also a learning process. The team carefully studied the technologies offered and made their decision on the basis of their capacity to fabricate the chosen option. Matters pertaining to quality standard were discussed and negotiations were carried out on the technical specifications of the materials to be used in fabrication. This was important because Triangle was going to rely largely on local technological capability and Herrman-Buckau were concerned about their technical specifications on which their reputation was based. But even more important was the fact that the search team carefully studied the various fabrication techniques used in the firms they visited and made choices on the basis of their local availability.<sup>28</sup>

TABLE 5.1: *Original Finance Structure*

	Source of Finance	US\$ million	Per cent
<b>MADHVANI</b>			
Equity	Kenya Government	12.0	19.9
	Madhvani Group	3.0	5.0
	Chemap Group	5.0	8.3
Loans	Ex-Switzerland	24.7	40.8
	Ex-Austria	14.8	24.4
	Commercial	1.0	1.6
Total		60.5	100.0
<b>MEHTA</b>			
Equity	Kenya Government	5.3	26.3
	East African Sugar Industries	0.7	3.3
	Mehta Group and Associates	0.7	3.3
Suppliers' credit		10.6	52.8
Government loan		2.5	12.3
Bank facilities		0.4	2.0
Total		20.2	100.0

Source: Industrial Survey and Promotion Centre, Nairobi.

28. Interviews, Triangle Ltd., Triangle, Zimbabwe. The search process was conducted under disguise because of the international sanctions against the country. While Triangle files on the trip to West Germany were marked "Brazil", the records of Hermann-Buckau refer to the project as "Durban II", supposedly destined for Hulett's in South Africa.

The institutional imperatives of finance operated differently in Kenya. The country's technology-related policies, especially those on machinery importation, were designed to facilitate the importation of whole plants under the import substitution strategy pursued in the 1970s. These policies allowed low or no import taxes on machinery while they placed heavy taxes on engineering raw materials. This distortion encouraged the importation of turn-key plants while at the same time inhibiting the local fabrication of such machinery or their spare parts. Under such conditions, investment projects most likely contained a high foreign exchange content. As a result industrial projects tended to rely on borrowed finance and the government often offered to guarantee the foreign loans.

The import licensing system was divided into three major categories of schedules and was managed by the Trade and Supplies section of the Ministry of Commerce and Industry. Goods under Schedule I were considered priority imports and automatically received licence and foreign exchange. The category included industrial raw materials, capital goods and spare parts. The second category (Schedule IIa) included industrial and agricultural goods of middle priority. The third category (Schedule IIb) included consumer goods and luxury items. The tariff schedules also favoured the importation of finished capital goods. For example, the tariff on steel was 40 per cent while the rate on wind mechanical systems was only 20 per cent. In this case, there would be little incentive to import steel and manufacture windmills locally. Instead, it would be cheaper to import finished product.<sup>29</sup>

This arrangement was compounded by the financial participation of the government in projects, often through equity investment and joint ventures (Table 5.1). The Mehta and Madhvani projects were joint ventures under which the government guaranteed their foreign loans. The foreign exchange was obtained through contact with Swiss and Austrian businessmen who made arrangements with their respective local banks on condition that they supplied the technology. About 82 per cent of the foreign funds for the Mehta project came from Girozentrale und Bank der Österreichischen Sparkassen Aktiengesellschaft of Vienna. As a result Mehta involved Vogelbusch in

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29. Interviews, Kenya Association of Manufacturers, Nairobi, November 1984.

preparing the feasibility study because of the finance and technology link.<sup>30</sup> Madhvani on the other hand involved PEC due to the Swiss finance. The loans for the Madhvani project initially came from the Union Bank of Switzerland in Zürich and PEC. But while Vogelbusch had its own technology, PEC had to import technology from the Brazilian firm, Conger and ship it to Kenya.<sup>31</sup>

It appears from the evidence available that while Triangle chose technology on the basis of financial limitations, Mehta and Madhvani chose a techno-financial package which restricted their technological choices. This underscores the fact that technology choice is intricately linked with finance and bound up in institutional frameworks which shape the direction of search and choice. While Triangle invested in learning, both Mehta and Madhvani went for options which did not require much learning effort at this early stage. The route taken by Kenya led to project choices which included tied commercial loans. The large sums of money involved required government guarantees.

#### **5.1.4 Location and infrastructure**

One of the crucial pre-conditions for ethanol production is the location of the plant and the availability of infrastructure required for the distribution of the product. The question of location is important because of the sensitivity of ethanol production to raw material costs and the issues which may arise from energy balances. Long distance transportation of raw materials may adversely affect the final costs of ethanol. Moreover, the location of the market may also add to the costs of transporting ethanol. In this respect, the choice of location is an important consideration in the realization of ethanol niches.

It was noted in the previous section that the robustness of the three proposals was partly accounted for by the control over the production of raw materials. In this respect, the robustness of the Madhvani project was greatly weakened by the fact that they did not have direct access to raw materials while Mehta and Triangle controlled mills and therefore had

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30. See Vogelbusch, *Feasibility Study*.

31. Interviews, Conger, Piracicaba, Brazil, March, 1985.

access to molasses production. This was an important consideration because one of the options for reducing the transportation costs was to annex the ethanol plants to existing sugar mills from which molasses and steam could be drawn. This was the strategy adopted by Triangle and Mehta.

Mehta decided to annex the plant to their mill at Muhoroni in western Kenya. The mill was to provide about 30 per cent of their molasses needs and the rest could be bought from other mills in the sugarcane belt. The mill's surplus steam could be pumped to provide process energy to the plant. Triangle took the same approach and annexed the plant to their sugar mill. Although these arrangements look similar, there were some differences in the way the two groups organized their management. Triangle subsumed the operations of the plant into the management of the mill thereby reducing overhead costs. Mehta, on the other hand, entered a joint venture with the government and VEW and formed a separate firm, Agro-Chemical and Food Company (ACFC) to manage the project. By doing so, the symbiotic synergy between the mill and the plant was reduced.

Madhvani, like Mehta formed the Kenya Chemical and Food Company (KCFC) which entered a joint venture with the Kenya Government, PEC, Chemfood Investment Corporation (Switzerland), Advait International (Luxembourg), and Eximcorp (Panama). Madhvani decided to locate the plant on the outskirts of Kisumu town on the shores of Lake Victoria some 80 kilometres away from Mumias sugar mill which was expected to be the main source of molasses. Madhvani claimed that the location was chosen after "having carried out an exact study relating to the supply of molasses and transportation, water availability, waste water treatment, storage of raw materials and finished products".<sup>32</sup> Other considerations allegedly included accessibility to road and rail transport as well as cheap labour in Kisumu, the third largest town in the country.

What is even more interesting in Madhvani's choice of location is the view that "[b]lending and transportation of gasoline and alcohol, as well as the distribution, does not present any problems...considering direct access

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32. Madhvani Group, *Final Proposals, op cit.*, pp. 18. It will be argued later that this location had political underpinnings.

to road and railway".<sup>33</sup> This statement implied (and is supported by a diagram of the plant layout) that the blending of ethanol with gasoline would be done at Kisumu. This was indeed an untenable proposition because the oil refinery is located at the coast to the east of the country while the main market was Nairobi somewhere between the refinery and the plant. Considering that the plant was going to meet about 10 per cent of the country's liquid fuel needs, some 75 per cent of all the refinery output would have to be transported all way across the country to Kisumu to be blended with ethanol before being shipped back to Nairobi. It appeared more logical to send the additive to the main blendstock instead of doing it vice versa. This may seem like logistic idiocy but it masked more complex strategic interests.

The view at Madhvani was that they could only guarantee that blending took place if they themselves did it. It was clear from the very beginning that Madhvani did not take seriously the question of blending and the related infrastructure. Mehta did not consider the issues either and hoped that Madhvani, who was pioneering the path, would help establish the pattern of distribution and they would simply follow suit.<sup>34</sup> In Zimbabwe, Triangle and the government finalized all the key aspects of distribution and the related infrastructure before the plant was built.

Issues related to the disposal of stillage or waste from ethanol production became another major problem of consideration. Here the three projects pursued different alternatives. Triangle, on the basis of studies conducted in Brazil, decided to use the stillage as fertilizer by settling it in lagoons, mixing it with irrigation water and finally returning it to the canefields. Mehta incorporated an effluent-treatment component in the project while Madhvani proposed to install the Anamet waste treatment unit sold by Sorigona (Cardo Group) of Sweden. The Anamet unit was designed to recover some by-products such as ammonia and methane from stillage. There was little information about the suitability of the Anamet process since it had only been commercially operated since 1977. Triangle went for a much

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33. *Ibid.*, pp. 19.

34. Interviews, Agro-Chemical and Food Co., Muhoroni, September 1983.

cheaper option and later attempted to use concentrated molasses stillage (CMS) as animal feed.

This section has examined some of the main features of the adoptive terrain which influenced the development of fuel ethanol in the two countries. It was argued that Zimbabwe instituted a series of measures to smooth the terrain and make possible the successful introduction of the technology. These measures were part of an overall strategy to cope with expected disruptive socio-economic fluctuations. Kenya, on the other hand, continued to pursue policies which assumed a surprise-free world. The next section looks at the main adaptive variables and how they shaped the technology acquisition process.

## **5.2 Adaptive Parameters**

### **5.2.1 Technology supply issues**

The adoptive requirements outlined above are necessary but they do not constitute sufficient conditions for niche realization. Since this process entails the entry of a technological system into a techno-economic landscape, the key variables which make this process necessary need to be spelt out. They include the technical parameters, capital investment and pricing structure.

One of the key aspects of niche realization is the type of technology chosen. The previous chapter showed that the development of fuel ethanol has gone through three main stages; batch, semi-continuous, and continuous. Batch and semi-continuous systems co-existed at the period of choice of technique and the three countries had the option of choosing any of their variants. Any technological variant retains the key characteristics which are associated with its dominant functions and configuration. Although the dominant features may remain the same, there may be wide differences resulting from the fact that a particular technological system is an embodiment of different functional units with different operating parameters and morphology.

The functional and morphological features of a particular technological system may also be influenced by adoptive pre-conditions such as finance availability, ecological considerations and labour availability. A technological system is therefore not a fixed unit with pre-determined characteristics; it is constitutive of purposive imperatives. This view illustrates the fact that the ability of a technological system to adapt to new market environments entails more than just capital, labour and skill requirements. Fuel ethanol technological systems also involve liquid flows rather than the movement of mechanical parts thereby lowering the labour-capital ratio or raising the capital intensity of the operation.

After a detailed examination of the international technology market, Zimbabwe opted for a batch process with a rated capacity of 120,000 litres per day. The plant was a conventional process which was well established and fairly stable. By choosing an established technology, the management had more access to related process know-how and could therefore rise up the learning curve relatively faster than would have been the case if they had opted for a new process. This is partly because the process know-how of new technologies had not been widely diffused or protected to maintain corporate monopoly.

Triangle had another consideration as well. They hoped that they would improve the technology whenever foreign exchange was available and therefore they chose a technological system that was flexible and more amenable to modification. A batch system is more flexible in this respect than a continuous process because the functional units of the latter are more tightly linked together to achieve high system efficiency. Moreover, continuous processes rely on centrifuges which cost about US\$100,000 each. As far as this condition was concerned, batch systems were therefore more adaptive to the Zimbabwean conditions because they met the conditions needed to realize Triangle long-term strategy.

Kenya, on the other, opted for different systems. As suggested above, the choice of technology by Madhvani and Mehta was foreclosed by the choice of finance and therefore the decision lay in the offices of Vogelbusch and PEC. Vogelbusch had then developed a cascade process which had not been widely tried. Madhvani, on the other hand, accepted the batch process



fabricated by Conger, which was, ironically, partly based on Austrian technology transferred to Brazil in the 1930s.<sup>35</sup> This process had undergone minor improvements over time and was adapted to Brazilian conditions. The feasibility study, however, promised that PEC would supply a continuous process.<sup>36</sup>

Given the fact that Triangle did not have experience in ethanol plant management, it was logical for them to go for a process that they could master as quickly as possible. Furthermore, they could not justify paying additional management fees in foreign exchange. This was not part of the Kenyan agenda because the payment of management fees to foreign firms was such an attractive proposition that some local entrepreneurs were associated with management firms registered in foreign countries. It was therefore not a surprise that the joint ventures were managed by firms registered in Panama and Bermuda. It appears that the adoptive pre-conditions of the acquiring end puts selective pressures on the adaptive side and therefore limits the number of suppliers that may meet the requirements. In the case of Triangle, the choices were narrowed down to a handful of technological systems of which the Herrman-Buckau Walther technology was the most suitable option.

There were other pre-conditions as well. Triangle was looking for a supplier who would forgo the supply of hardware and sell only the know-how in the form of drawings and other disembodied technological knowledge. The supply side therefore had to make a decision on the basis of its corporate strategy as part of its adaptive response to changing market conditions. Herrman-Buckau had a long-term strategy to enter the African market at a time when oil prices were projected to rise. A successful plant in Zimbabwe was likely to give the firm high visibility and therefore create possible market opportunities. Indeed, this vision paid off because the ethanol plant erected in Malawi in 1982 is a Herrman-Buckau process.<sup>37</sup> The vision of

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35. Interviews, Conger, Piracicaba, March 1985.

36. Madhvani Group, *Final Proposals*, pp. 43-44.

37. Richard Jager, Jager and Associates, Personal Communication, Blantyre, Malawi, January 1985. The Malawi plant was executed by J&A, building largely on the knowledge gained during the Triangle operation.

future plant sales made the suppliers insist on stringent quality control to ensure the successful operation of the plant.

The three plants did not differ much in their release of stillage. Their output was 12-15 litres of stillage per litre of ethanol produced. At the time of technology choice, there were no low-cost, non-polluting ways of disposing of the stillage. It was also the time when firms such as Alfa-Laval were working on new stillage reducing technologies such as the Biostil process. However, options such as molasses evaporation existed. Indeed, the Vogelbusch process was equipped with a facility to evaporate stillage to 65 per cent solid concentration before lagoon disposal. The decision to include this waste treatment unit was influenced by the Kenyan laws on water quality control.

The other technical consideration was the net energy balance of the processes. This was not a major consideration at the time partly because sugar-based ethanol plants do show positive energy balances. The energy balance of the Madhvani project, however, was expected to be negative because the location did not allow them to use surplus bagasse for steam generation. They planned to use petroleum products for this purpose.

### **5.2.2 Capital investment**

The adaptability of a particular technology is linked with its capital costs. This is partly because the capital invested is eventually reflected in the production costs thereby affecting the competitiveness of the fuel with conventional sources of energy. Triangle's capital costs were relatively lower than the other projects at US\$6.4 million for a plant producing 42 million litres a year (Table 5.2). In their initial proposals, Madhvani and Mehta planned to spend US\$60.4 million and US\$18.3 million respectively on their projects (Table 5.3). These figures are misleading because they include the manufacture of other products. The capital costs given by Madhvani and Mehta were not independently evaluated before they were approved by the government. A study conducted by ISPC in 1978 argued that the project had been overcapitalized, suggesting on the basis of Brazilian

experience that a figure of US\$30 million would have been reasonable.<sup>38</sup> But this was too late since the decision had already been taken.

TABLE 5.2: *Capital Cost of the Triangle Plant*

Item	Cost (US\$ '000)
Site preparation and foundations	264
Buildings and structures	536
Vats and tanks	864
Pumps and blowers	330
Heat exchangers	305
Distillation columns	453
Piping and installation	910
Valves	205
Electricals and installations	244
Instrumentation and installation	169
Paint and insulation	213
Stillage disposal	233
Molasses stillage concentrators	221
Engineering fees	523
Project charges	149
Interest	154
Miscellaneous	635
Total	6,408

Source: Triangle Limited, Triangle.

At the time the Madhvani project had been planned to produce 9.24 million litres of ethanol, 1,000 tonnes of baker's yeast, 2,200 tonnes of citric acid, and 1.7 million litres of vinegar a year. Mehta, on the other hand, planned to produce 18 million litres of ethanol and 1,154 tonnes of baker's yeast annually. These production capacities were not determined by the country's gasoline consumption patterns and their choice was not guided by any policy guidelines on the development of fuel ethanol. It is most likely that the choice of capacity was largely influenced by the technologies already available on the market and could be easily obtained with minimal capital expenditure by the suppliers (PEC and Vogelbusch for this matter).

38. ISPC, *Evaluation of Utilisation of Molasses in Kenya*.

TABLE 5.3: *Original Capital Cost Structure (US\$)*

Item	Mehta	Madhvani
Land	720	--
Site preparation	132,320	250,000
Buildings (civil)		1,700,000
Production and yeast	664,940	--
Others	156,670	--
Residential buildings	460,510	--
Machinery and equipment		45,400,000
Yeast plant	3,642,740	--
Alcohol plant	4,968,510	--
Evaporation plant	710,700	--
Service and safety units		
Energy supply	360,190	--
Water supply	390,110	200,000
Storage tanks	480,000	--
Others	50,000	--
Effluent treatment	197,140	--
Training	--	250,000
Pre-start-up-interest	--	2,000,000
Furniture, fixtures and vehicles	100,000	1,500,000
Total	12,344,550	51,300,000
Overhead and design costs		
Construction and design	2,444,700	2,000,000
Sales tax and FEAL fee	1,173,090	4,994,000
Freight, insurance and other charges	1,500,000	400,000
TOTAL CAPITAL COSTS	17,462,340	58,694,000
Contingencies	873,120	1,716,000
GRAND TOTAL	18,335,460	60,410,000

Source: Industrial Survey and Promotion Centre, Nairobi.

It is interesting to note that the two countries took different approaches to the question of capital investment. The fact that there were no overall policy guidelines controlling foreign exchange expenditure on investment projects accounted for part of the laxity in the level of capital investment. This argument applies only to the Mehta project which, however, had been rated to be more reasonably costed than the Madhvani project. A more serious problem is the fact that the design of the Madhvani project carried implicit attempts to make the capital investment as high as possible. From the evidence available, it appears that the Madhvani proposal was partly aimed at making profit on the sale of machinery. One of the ways for

doing so was to keep the capital costs as high as possible. The failure of this investment had its roots in the design of the project itself. Although the Mehta costs were relatively high compared to other projects elsewhere, its capital costs were lower than Madhvani's and the details of the proposals show intent to carry the project through successfully.

The Project Implementation and Management Agreement (PIMA) entered between KCFC and Eximcorp stipulated that the management should be paid 5.0 per cent of all capital expenditure on the project (excluding the cost of land which was to be leased to the company for 99 years) in US dollars upon the completion of the project.<sup>39</sup> In addition, Eximcorp was to be paid a net fixed fee of US\$150,000 annually by a US dollar draft on the London (Berkley Square) branch of Morgan Guarantee Trust Company of New York. Another 2.0 per cent of sales based on packed ex-factory floor prices net of discounts was to be paid monthly in US dollars. Finally, the company had to pay Eximcorp 3.0 per cent of its annual profits which was to be calculated before interest and tax deductions but after deduction for the depreciation schedule allowable by the Income Tax Act.

It appears from this contractual agreement that the management of the company had an interest in higher capital investment because it enabled them to earn correspondingly higher management fees. This suggestion is supported by the evidence collected from Conger in Brazil where PEC asked for technical specifications which added to the capital costs. For example, Conger included expensive stainless steel parts in places where cheaper materials would normally be used. Moreover, the support structure of the distillery was built to withstand earthquakes measuring 6.0 on the Richter scale.<sup>40</sup> Triangle abandoned steel support structures altogether and used concrete instead. These seemingly superfluous additions to the capital costs indicate that the project was partly designed to maximize on machinery-related payments such as pre-start-up management fees.<sup>41</sup> It appears

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39. The 99-year land lease was itself questionable because the project did not have such a lifespan. Moreover, the land was on the outskirts of a rapidly expanding urban area. The request for land was based on artistic impressions and not detailed land evaluations.

40. Interviews, Ministry of Commerce and Industry, September 1984, Nairobi; Conger, Piriacicaba, Brazil, March 1985.

41. More evidence of this will be given in subsequent chapters on the implementation of the project, especially on sections dealing with cost overruns.

therefore then while Triangle planned to minimize its capital expenditure, Madhvani planned to do exactly the opposite; to maximize on capital expenditure so as to earn high management fees.

The actual capital costs of the Madhvani project were much higher than the given figures because the Joint Venture Agreement (JVA) committed the government to providing other capital-embodying infrastructural facilities. The JVA stated that the government shall procure or cause to be procured at no cost to the company the provision of a wide range of facilities and services. These included electric power (6.0 MVA), water (1,000,000 gallons per day), effluent disposal (225,000 gallons per day), road, water supply, electricity connection, telephone, rail access, effluent disposal facilities and the relevant government licenses. The government was also expected to provide permits, authorizations, approvals and licenses required for the operations of the joint venture, as well as port facilities for imports and exports of materials and products related to the investment project. These requirements constituted a subsidy and if costed, they would have added enormously to the already high capital costs.

Other hidden capital costs were included in the JVA stipulation that the government undertake all the necessary measures to guarantee the availability of raw materials at reasonable prices and arrange for the sale of fuel ethanol to the oil companies. This requirement put the burden of acquiring blending facilities and the related capital costs on the government. Apart from capital expenditure, the government was also going to lose revenue due to the requirements of the agreement. For example, the JVA listed a wide range of imports for which import duties were to be waived. The very terms of the agreement meant that a large number of government officials would be deployed to ensure that the project was implemented on schedule. The fact that the assumptions on which the feasibility study was based were themselves shaky meant that the government had to virtually push the project through the implementation phase before it was subjected to the selecting pressures of the external environment. At this stage, the benefits of vicarious selection had been foreclosed and the selection pressures were to act directly on the project itself.

### 5.2.3 Pricing structure

Prices play a crucial role in determining the competitive level of new products. They also serve as an indicator of the relative adaptation of a product in the market environment. In other words, prices are an important factor in the techno-economic landscape because they reflect to a certain extent the adaptive relationship between a new technological system and traditional ones. It is in this context, and not necessarily in the supply-demand relationship, that prices attain their importance. In these countries, ethanol prices, either hypothetical or real, had no relationship to supply and demand factors. But even more interesting was the fact that both Madhvani and Mehta avoided the issue of pricing in their feasibility studies except in calculating the expected production costs. It is notable that both countries avoided the economics of pricing and opted for either technical valuations or political approaches.

J&A developed for Triangle a technical value of ethanol based on the fact that ethanol was not just a source of motive power but an octane booster. It was argued that premium gasoline was valued higher than regular gasoline because of the higher octane value. Since octane numbers were influenced by altitude, J&A put the normal octane requirements some 5 points lower than those required at sea level. On the basis of this and other technical parameters, J&A developed the following formula for pricing ethanol:

$$E = \frac{E_o - R_o}{P_o - R_o} (P - R) + R$$

where E, P, R are values in cents per litre of ethanol, and the blending components  $E_o$ ,  $P_o$  and  $R_o$  are the octane ratings of ethanol, blended gasoline and other blended fuels.

According to this equation, the technical value of ethanol was shown to be higher than that of gasoline. For example, if it is assumed that regular gasoline of octane rating 87 is blended with ethanol, showing a blending

octane number of 120, to premium gasoline with an octane rating of 93 and the import parity prices for regular and premium are 14 and 15 cents per litre respectively, then the equivalent value of ethanol would be 19.5 cents per litre. This formula shows a high price for ethanol as an octane booster which would be comparable to the production costs.

This formula is only relevant in cases where only refined products are imported. The situation is more complex in Kenya because of the presence of an oil refinery. The technical value of ethanol in such cases would depend on whether there is a balance between the products refined from imported crude oil and the demand patterns. In most cases, refineries produce less "white products" from imported gasoline thereby leaving uneconomical "black products". In some of such cases, white products are added to the crude to enhance the balance. Apart from the "spiking", lead is added to the process to raise the octane rating. Under such conditions, the technical value of ethanol would be equivalent to the backed out spiking component, imported lead and the related conversion yield changes. Such a value is usually arrived at with a refinery linear programme.

Given such complexities, both Madhvani and Mehta did not consider seriously the price of ethanol. While Madhvani relied on the government to fix the price of ethanol as suggested in the JVA, Mehta took a slightly different approach. They hoped that the government would fix the price on the basis of the Madhvani production costs (which were expected to be much higher than the landed cost of gasoline). This would then have given Mehta a higher profit margin because their capital costs were lower than Madhvani's. It appears therefore that although Mehta did not argue initially for prices on the basis of production costs, they intended to raise their profit margins by relying on differences in production costs.<sup>42</sup>

To arrive at any price depended largely on the relationship between oil companies and ethanol producers because the new product was intended to displace petroleum products and possibly reduce the earnings of petroleum importers, refiners and distributors. This problem was not severe in Zimbabwe because the oil companies had agreed to market ethanol and the refinery was not operational. In Kenya, the oil companies issued no

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42. Interviews, Agro-Chemical and Food Company, Muhoroni, September 1983.



statement of intent and were operating a refinery in which the government had 50 per cent of the shares. The matter would not only bring about conflicts between ethanol and gasoline producers, but the various government departments responsible for the promotion of the two fuels would also enter into conflict.

There was another element of the pricing that was not considered which impinged not just on the economic viability of the projects, but also on the ability of the projects to meet their foreign loan obligations. The price fixed had to take into account the debt payment schedule. Since the government had guaranteed the foreign loans, it was in its interest to grant a price that enabled the projects to survive while at the same time be able to re-pay the foreign debts. This requirement meant that the prices had to be fixed at relatively high margins due to the high foreign exchange content of the projects.<sup>43</sup>

The pre-adaptive changes in the techno-economic landscape already illustrate some of the basic differences between Zimbabwe and Kenya. In the first place, Kenya did not develop the kind of overall policy guidelines and institutional behaviour that could ensure the emergence of more adaptive business practices. Secondly, the institutional climate provided ideal conditions for the introduction of ill-suited technological systems. But even in cases where there were no problems with the technological systems themselves, the evidence suggests that the possibilities for project failure were higher in Kenya than they were in Zimbabwe. This is largely because the institutional reforms and learning necessary for modifying the adoptive terrain took place much earlier in Zimbabwe than they did in Kenya.

These conclusions tend to overturn the general view that developing countries need first to formulate policies on technology transfer, develop guidelines and then outline tactical approaches before they can move into technology acquisition. The evidence here, which will be reinforced in subsequent chapters, tends to suggest that the process may follow a reverse pattern where policy guidelines are drawn from project implementation and fed into subsequent stages in the evolutionary process as new knowledge and experiences get incorporated into the economic management tradition.

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43. Details on the price conflicts will be given in subsequent chapters.

## **Conclusion**

This chapter has mapped the key features of the techno-economic landscape which were significant for the realization of ethanol niches in the two countries. These features were divided into two categories; adoptive pre-conditions which dealt with developments at the technology acquiring end, and adaptive parameters which concentrated on variables on the supply side of the technology. It was shown that the techno-economic landscape constituted not only technological and economic factors, but it also covered institutional variables as well. The next chapter will deal with the efforts to realize the ethanol niche in the two countries.

## **6. THE PROCESS OF NICHE REALIZATION**

### **Introduction**

The previous chapter mapped the techno-economic landscape for fuel ethanol and identified the major adaptive and adoptive pre-conditions for the successful implementation of the ethanol technological system. This chapter will examine the process of niche realization in Zimbabwe and Kenya. The chapter stresses the interactions between adaptive and adoptive parameters and shows how they affected the development of fuel ethanol in the two countries.

### **6.1 Project Implementation**

At the time of plant construction, the Mehta and Triangle projects remained the same while Madhvani had changed the composition of the project in various important aspects (Table 6.1). The changes suggest lack of appreciation for the need to attempt matching adaptive parameters to adoptive pre-conditions. These changes were made after the JVA had been signed. The expanded project included units for the production of oxygen and sulphuric acid. The most important change was an increase in the capacity of the ethanol unit from 9.2 million litres a year to 16 litres tonnes a year. This increase was done without any corresponding increases in capital costs, thereby indicating that the plant had been over-costed in the first place.

The capacity increase made production costs look much better than in the previous case. But there was another reason why the capacity was increased. Mehta had been working on a fuel ethanol proposal since 1975 but did not submit it when Madhvani did. They waited for about six months after the signing of the JVA in July 1977 before submitting it. It is remarkable that

the Madhvani proposal was approved by the government in less than two months after submission. It is not clear whether the government was convinced that the project was sound or whether the haste was partly aimed at pre-empting possible opposition to the venture. Comments and suggested amendments by the Attorney General's Chambers, the legal advisor to the government, were not incorporated in the proposed venture.<sup>1</sup>

TABLE 6.1: *Changes in the Madhvani Product Composition*

Product	Original (May 1977)	Revised (March 1978)
Fuel ethanol	9.2 million litres	16 million litres
Citric acid	2,200 tonnes	3,000 tonnes
Dry baker's yeast	1,200 tonnes	1,000 tonnes
Fresh baker's yeast	1.7 million litres	3,000 tonnes
Vinegar	1.7 million litres	2.2 million litres
Sulphuric acid	--	7,500 tonnes
Ammonium sulphate	--	2,000 tonnes
Oxygen	--	6,800 tonnes
Methane	--	60 billion BTUs

Source: Kenya Chemical and Food Corporation, Nairobi.

Other sections of the government had analysed the proposal and indicated that the joint venture was over-costed. For example, the Industrial Development Bank (IDB) showed in a 1977 study that the venture would produce alcohol at KShs.3.87 per litre while gasoline cost KShs.1.54. This was based on the original (1977) capital cost. The same study concluded that waiving import duty and sales tax would lead to a KShs.90.7 million loss to the Treasury. But if the government was to charge duty and sales tax on purchases, the project was bound to lose some KShs.45.2 million annually. IDB, which lends to the private sector on the basis of economic viability,

1. Not all the sections of the JVA were given to the Attorney General's Chambers for review as is normally done. For example, the Technical Engineering Agreement (TEA) was not available to the Chambers for comments before the signing of the JVA.

concluded that the project was not viable without subsidies. The study was not used by the Treasury when the joint venture was approved.<sup>2</sup>

Concern over the high capital costs of the project was also expressed at a higher institutional level by the Centre for Industrial Development (CID) of the European Economic Community (EEC) and the African, Caribbean and Pacific (ACP) countries based in Brussels. CID informed the Kenya government in July 1977 that a plant of such capacity should cost US\$18-24 million as opposed to the proposed US\$60.5 million. This advice could not be used by the government as the JVA had already been signed.

It appears that the decision to increase the capacity of the plant was influenced by the Mehta proposal. The expansion of the project raised the demand for molasses, thereby making it difficult for the government to justify other molasses-based projects. The original project had been designed to utilize some 55,000 tonnes of molasses annually but the revised version required 110,000 tonnes of molasses a year.<sup>3</sup> It is therefore not a coincidence that the Mehta proposal was submitted in February 1978 and the revision of the Madhvani proposal was done in March 1978. It can be argued from the sequence of events that the decision by Madhvani to expand the project was a pre-emptive move to maintain monopoly in the ethanol industry by cornering the raw material base. What is not clear is why the government approved the Mehta proposal in July 1978 when it appeared that the two projects were likely to compete for molasses.

Ethanol and yeast were not the only products planned by Madhvani. In addition, they intended to recover 6,000 tonnes of gypsum and 9,000 tonnes of carbon dioxide. The economics of producing these products was questionable. But even more important was the fact that there was no evidence of available local or export markets for these products, especially at the proposed production capacity. For products such as sulphuric acid,

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2. Interviews, Industrial Development Bank, Nairobi, October 1984. IDB was then reputed for the competence of its technical staff and was one of the few parastatal institutions that operated largely as a private business. The competence of their studies allowed them to avoid some of the risks involved in public enterprises.

3. Interviews, Kenya Sugar Authority, October 1984, Nairobi. More details on molasses availability will be given later.

the capacity already existed in the country and increased demand could have been readily achieved through the expansion of existing facilities.<sup>4</sup>

The local market for citric acid was estimated at 400-500 tonnes per year in the early 1980s while the Madhvani capacity was 3,000 tonnes. About 70 per cent of the demand was in soft drinks, with Coca Cola importing about 150 tonnes. The consumption of baker's yeast was 332.8 tonnes in 1976 which declined to 268.3 in 1977, and 207.9 tonnes in 1978. The decline was partly attributed to price changes over that period from US\$1.98 per tonne in 1976 to US\$2.73 in 1977. A total production capacity of 4,000 tonnes could not be justified unless there was an export market that would absorb the remaining 3,700 tonnes. The mismatch between production and market availability suggests that Madhvani had other reasons for expanding production capacity. These reasons include raising the project's capital costs and locking most of the national supply of molasses into their production processes as a way of pre-empting the entry of other molasses-based industries.

The choice of products in this case was influenced by restrictive control over the availability of strategic inputs on the one hand, and raising capital investment to increase earnings from management fees, on the other. The increase in plant capacity seems therefore to have also been aimed at increasing the earnings from the supply of machinery. The allocation of capital in the revised proposal illustrates the point (Table 6.2).

Although Triangle maintained flexibility in their project to accommodate further capacity expansion, they did not make any major changes in the proposed project. This is partly because of possible disruptions in the pre-start-up learning which was crucial to the eventual implementation of the project. The proposal, which was a revision of a 1975 proposal, was submitted in early 1978 and approved in November, 1978. After the approval, construction did not start until July 1979. During this period, Triangle and J&A undertook a series of measures to ensure the successful completion of the project. The technical drawings that had been

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4. Interviews, Ministry of Commerce and Industry, Nairobi, August 1984.

obtained from West Germany had now to be converted into an operating plant.<sup>5</sup>

TABLE 6.2: *Madhvaní Capital Allocation (KShs. '000)*

Item	Original	Revised
Land and preparation	2,125	10,702
Buildings	14,450	17,849
Machinery and equipment	385,900	564,619
Oxygen plant	--	13,478
Sulphuric acid plant	--	6,584
Fire fighting equipment	--	3,750
Factory equipment	--	6,640
Incoming water system	--	5,082
FEAL	3,859	4,755
Sales tax	38,590	59,649
Clearing, freight and insurance	3,400	21,747
Erection and commissioning	17,000	40,126
Training	2,125	2,142
Furniture and fixture	--	2,677
Water treatment	1,700	--
Vehicles	12,750	10,711
Pre-start expenses	17,000	114,897

Source: Kenya Chemical and Food Corporation, Nairobi.

Herrman-Buckau had agreed that only the design would be bought and all construction would be done in Zimbabwe. However, they insisted on providing a construction supervisor to oversee the fabrication of the distillation columns. The pre-commissioning checks and tests as well as the commissioning itself were to be done by a Herrman-Buckau team. The construction was done under a Project Team composed of Triangle, Hulett's, J&A, and Herrman-Buckau personnel. The equipment that was not available in Zimbabwe was imported mainly from South Africa. This included plate heat exchangers, air blowers, special pumps as well as instruments. Other imports included stainless steel plates, special pipes and valves.

After the approval of the project, Triangle and J&A undertook another search of the local market for fabricating capability. This was not a general process of capability identification, but a detailed review of the existing

5. This period is the least documented in the history of ethanol development in Zimbabwe partly due to the intensity of war in the country. The rest of the details are based on interviews with Triangle management.

capability to fabricate specific components. The search was carried out with the help of samples obtained from Herrman-Buckau. The samples were compared with copies made by local manufacturers and were checked against Herrman-Buckau specifications and requirements as part of the agreement entered into between the two parties.

This phase of sample-tendering was followed by the development of specific fabrication capability. This was mainly because much of the fabrication had to be done on site, especially because the process involved large tanks which could not be easily transported across the country. To acquire this capability, Triangle set up a special on-site school at which special fabrication techniques were taught to a carefully selected cadre of technicians. The process involved a wide range of incentives and created a hierarchical structure among the trainees. It should be noted that the trainees were already skilled in related aspects of plant fabrication and the training equipped them with specific skills required for the fabrication of ethanol plants.

The training involved the production of samples which were checked by experts assembled by J&A using equipment such as X-ray detection. Those who produced sub-standard samples were asked to re-do the job or undergo re-training. But those who produced high quality samples were given bonuses in addition to their normal pay. At the end of the training, the successful candidates were given special certificates of competence. The training programme was conducted in two weeks after which the fabrication of the plant started.

The fabrication of the plant proceeded in a hierarchical manner as well, starting with non-critical parts such as pipes and rising to more critical components such as distillation columns. This approach helped to match the possibilities of error with their costs. It was based on the fact that the error chances are reduced as one rises up the learning curve and accumulates experience. The chances of error were likely to be higher at the early stages of the fabrication process. If this stage was devoted to the fabrication of non-critical parts, then the cost of errors made during the process would be relatively non-critical as well. But as work continued and experience accumulated so did the chances of error diminish. However, this



experience curve approach to fabrication only eliminates error possibility but not the seriousness of any one error made. For example, the cumulative errors made during the welding of pipes may be less critical than one error made in the fabrication of distillation columns.

The workers had special numbers which enabled the management to identify the producer of a particular part. This had two effects. First, it enabled the management to maintain control over the production process. Second, the workers identified themselves with the sections they built and therefore attempted to maintain a high level of fabrication quality. This was the most critical phase in the whole process and was overseen by a South African management team of engineers with experience in this field. Those components which could only be manufactured under special factory conditions were fabricated in the industrial town of Bulawayo and transported to Triangle.

The most critical aspect of the process was fabricating the distillation columns. The columns were 2.0 metres wide and 30.0 metres high and contained 55 internally-supported perforated trays. The trays had to maintain specific levelness and symmetry which could only be achieved through high quality fabrication. To ensure this, the fabrication process was continuously controlled by a Local Inspection Authority. The standards were set by a Herrman-Buckau construction supervisor.

The fabrication of the Triangle plant illustrates the links between the initial search and the final implementation of the project. The choice of the Herrman-Buckau process was made partly because of its ease of local fabrication. The choice was made on the basis of a general survey of the local industrial base and not on identified specialized skills. These skills were developed during the implementation process. It appears therefore that the level of sophistication of the industrial base and diversity of activities makes it more possible to recombine or re-train existing expertise for specialized operations. The capacity to fabricate stainless steel existed in Kenya but the approach taken by Triangle was precluded by the technology policies operating in the country and the financing structure of the projects.

It is notable that Triangle maintained a record of the workers and used it as a reference base for specialized operations. New industrial projects

which required such skills requested Triangle for details of the workers who were then contracted for short-term jobs. Even more important is the fact that Triangle needed to maintain the list for their own subsequent work either in maintenance or in new projects. As indicated, the plant was built to allow capacity expansion which would necessarily need on-site fabrication. In this case, Triangle would recall the workers from their respective positions. The construction of the Triangle plant was completed in June 1980, several months ahead of schedule.<sup>6</sup>

As noted elsewhere, there was no local search in Kenya to establish the potential contribution of the industry to the project. The Kenyan metal fabrication sector is well developed and has served to supply engineering equipment to the Eastern African countries. Kenyan firms such as Dynamics Engineering (Nairobi), Scope Engineering (Mombasa), Metal Equipment (Nairobi), Hartz and Bell (Nairobi) and Industrial Plant (Nairobi) specialize in metal working. Two of these firms, Dynamics Engineering and Industrial Plant specialize in stainless steel. Industrial Plant has been involved in stainless steel work since its inception in 1960. The company has accumulated brewing-related technology from its work in Kenya, Uganda, Malawi and Zambia. Industrial Plant's sister company, Airduct, was established in 1975 to specialize in mild steel and concentrates on product research, design and development. Ironically, Industrial Plant has built a brewery at Kisumu involving stainless steel fabrication.<sup>7</sup>

It can be argued that fabricating distillation columns requires more skilled expertise than is needed for fermentation tanks. This argument can be countered in two different ways. First, if such expertise did not exist, then the Kenyans would have still been better off utilizing at least the tank fabrication skills they already had. Second, the expertise to fabricate distillation columns existed and local firms had indeed fabricated plants which were more sophisticated than distillation columns. Dynamics

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6. The only major concern during the construction period was security against guerilla attacks. After discussions between the government and Triangle, the government suggested that the plant could be painted in colours which made it less visible. An earth wall less than 30 feet high was built around the plant, which is located in a plain surrounded by hills and towers several hundred feet above the ground.

7. Interviews, Industrial Plant Limited, Nairobi, September 1985.

Engineering, for example, fabricated all the key components for the phase II of the Olkaria geothermal plant at Naivasha for the Kenya Power Company, a state-owned company.<sup>8</sup> The project involved high pressure steam and was therefore more critical than distillation columns. The welds were X-ray tested and found to have no flaws at all. Dynamics Engineering has an annual turnover of US\$3.0 million and has links with firms in the UK, West Germany, France and the US. It is clear therefore that the capacity to fabricate major sections of ethanol plants existed in the country but was not utilized.

The Madhvani project was hit by problems from the start. The first major problem was related to its location. Because of limited co-ordination and collaboration among the various government departments, the provision of facilities and services as stipulated in the JVA could not be accomplished in time. For example, the government could not release the promised land for the siting of the plant in time. Some of the departments in charge of this issue felt that the amount of land required by the company as well as the terms of the lease (99 years) was beyond the requirements of the project. Even at a more technical level, there was concern over the fact that the requirement for land was not based on competent valuation but on an artist's impression of the layout of the industrial complex. The firm expected the government to release the land by June 1978. By March 1979, only 60 acres had been released out of the requested 245 acres. The remainder of the land was not given until December 1979.<sup>9</sup>

KCFC engaged Epcil (Kenya) to undertake civil engineering work from June 1979. The firm withdrew from the project in January 1980 for allegedly

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8. Interviews, Kenya Power Company, Nairobi; Dynamics Engineering, Nairobi, September 1985. The Kenya Power Company has a consistent policy of building its own internal technological capability and relying extensively on local expertise. The steel components for the plant were imported from Japan but the fabrication was done by Kenyans. The development of geothermal energy required the accumulation of scientific knowledge on local geological and ecological conditions. This was done over a long period and the company is now providing consulting expertise on geothermal development to neighbouring countries such as Ethiopia which have geothermal potential. This case is different because tapping geothermal energy cannot be done without site-specific knowledge.

9. Shiv Sharma, Project Manager, KCFC, quoted in *Kenya Engineer*, "Building Troubles Beset Kenya's Power Alcohol Projects", pp. 10. The provision of the land was partly delayed because of legal problems with its transfer. The Ministry of Land had to compensate KCFC for the delay but even after that the previous owners of some of the land refused to let KCFC use the land.

failing to meet the required turnover.<sup>10</sup> The breach of contract by Epcil was compensated out of court in fear that a court case would delay construction for at least six months. The task was re-tendered and the Israeli firm, Solel Boneh won the bid. Solel Boneh's work, jointly with Coastal Kenya Enterprises, was to prepare the ground for the erection process which was to be handled by the Indian firm, Deweto International under a PEC sub-contract. It is notable here that even construction work did not involve much local participation as most of the functions, including architectural work and quantity survey work, were sub-contracted to foreign firms.

During this period, some of the deals entered by KCFC with contractors had no fixed figures and the contractors kept asking for more funds. This raised the capital expenses. Such practices were, either by default or by design, in the interest of the management because they raised the pre-start-up capital costs and therefore earned them more money. The management agreement was written in such a way that delays in construction benefitted the management since the incurred expenses added to the capital investment. Numerous reasons were evoked by KCFC to explain delays, many of which were related to the obligations of the government. In response to the inability of the government to meet all these obligations, the other shareholders (CIC and Advait) resolved at one time to withhold the disbursement of their equity. This was aimed at putting pressure on the government to provide the subsidies required to complete the construction of the plant.

## 6.2 Corporate Conflicts

One of the most important features of a fuel ethanol programme is that it involves a large number of other sectors of the economy. The range of activities spans the entire spectrum of development planning from agriculture to transportation. Some of the key actors in these fields are usually long-standing and well established firms which are intricately linked

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10. Epcil was subsequently reported to have gone bankrupt. See *Weekly Review*, "Molasses Plant: Another Crisis", pp. 29-30.

into the country's institutional and political networks. The introduction of fuel ethanol often faces a large number of entrenched interests. The most crucial areas in this process relate to the availability of raw materials and the distribution of fuel ethanol. Subsumed in these two areas are issues related to prices.

The Triangle plant was built after guarantees on the distribution of fuel ethanol had been made by the oil companies. The main issue of concern at the time of project design was the availability of raw materials (Table 6.3). To guarantee that feedstock would be available, Triangle designed the plant to operate on both molasses and cane juice or a combination thereof. Their strategy was to use cane juice in case there was no market for sugar. The flexibility therefore enabled them to link the plant to the rest of the sugar production process. This was not the case with either the Madhvani or Mehta projects. The two plants were planned to operate on molasses alone.<sup>11</sup>

TABLE 6.3: *Sugar and Molasses Production in Zimbabwe*

Year	Sugar ('000 tonnes)	Molasses ('000 tonnes)
1975	280.0	75.6
1976	292.6	79.0
1977	284.4	76.8
1978	301.4	81.4
1979	309.5	83.6
1980	299.2	80.8
1981	427.5	115.4

The molasses figures are based on a yield of 0.27 tonnes per tonne of sugar.

Since the mill and the plant were owned by the same firm, the two activities were integrated to maximize returns on the total investment and not on the separate operations. As a result, Triangle adjusted the output of either molasses or sugar to suit the profitability of the total operation. For example, the content of fermentable sugars in molasses could be raised at the expense of sugar production depending on market prices. Triangle also entered an agreement with Hippo Valley for the supply of molasses at Z\$50

<sup>11</sup> The switch from molasses to sugar does not require any changes in the basic technology but only in feedstock preparation.

per tonne. This arrangement was made easier by the fact that Hippo Valley and Triangle had become part of the Anglo-American complex.<sup>12</sup> This integration and flexibility were precluded in the Madhvani and Mehta projects because of corporate project ownership and management.

The first main conflict involving the Madhvani Group was the price and availability of molasses. The JVA had stipulated that the government would enable KCFC to obtain molasses at reasonable prices. The figures used in the feasibility study assumed that the price of molasses would remain at KSh. 160 per tonne. The justification for ethanol production from molasses was partly based on the declining export prices. However, the prices started to pick up in the mid-1970s partly because of Brazil's decision to use its output in ethanol production. The prices were therefore likely to rise and therefore increase the production costs of ethanol. Indeed, the cost of ethanol was highly sensitive to molasses prices (Table 6.4).

TABLE 6.4: *Ethanol Sensitivity to Molasses Prices in Kenya*  
(KShs./litre 1981 Prices)

Case	Molasses (KShs./tonne)	Ethanol Wholesale Price	Ethanol Pump Price	Blend Price (10% Ethanol)
1	400	7.77	10.90	6.63
2	350	7.50	10.63	6.60
3	300	7.23	10.31	6.57
4	250	6.96	10.09	6.54
5	200	6.68	9.81	6.52
6	150	6.41	9.54	6.49

Source: Ministry of Energy and Regional Development, Nairobi.

It appears from the sensitivity analysis that even at the low price of KShs.150 per tonne of molasses, ethanol would still not be competitive with the 1981 pump price of premium gasoline of KShs.6.35 per litre. Then, the Kenya Sugar Authority had set a minimum price of KShs.160 per tonne for sale to farmers (supposedly as animal feed) while the rest of the molasses was sold according to market demand and its price therefore fluctuated

12. Triangle has on occasions imported molasses. For example, in September-October 1980, Triangle imported 8,804.24 tonnes of molasses "C" containing 4,004.934 tonnes of total fermentables as sucrose (TFAS) from Zambia.

accordingly. Over the same period, the average net earning from molasses exports was over KShs.300 per tonne. These conditions made it difficult for Madhvani to acquire molasses at favourable prices. Their claim that molasses had a zero opportunity cost was countered by the sugar industry whose representatives asserted that a resource that had effective demand could not have a zero opportunity cost.<sup>13</sup>

The conflict over molasses pricing became a major issue of concern and the government arranged a series of meetings between the sugar industry and Madhvani aimed at finding a compromise over the issue. Madhvani asked for a ban on the export of molasses and a fixed price for molasses sold to their industrial complex. This request was resisted by the sugar industry whose representatives preferred to sell the resource on the most competitive market available. This view was strengthened by the fact that the world molasses prices had started showing an upturn. Compromises such as imposing an export duty on molasses to encourage local utilization were resisted by the sugar industry. The government's view was that the two parties should start negotiations to establish procurement procedures and fix prices.

Despite efforts by KCFC to secure long-term assurances on molasses prices which would enable the project to show favourable returns, the sugar industry insisted that the price of molasses be determined by market forces. This dispute was compounded by the fact that some molasses producers were also consumers. For example, Miwani sugar mills operated a potable ethanol distillery and could not give long-term guarantees on molasses availability on the grounds that they planned to increase the capacity of their distillery. A similar reason had been given in Zimbabwe by Hippo Valley partly to prevent another firm from using the surplus molasses. Miwani had reasons to worry because Madhvani had the potential to sell different types of ethanol in markets that were either under Miwani's control or had been identified for future entry.

While molasses prices were being discussed, new concerns over the availability of the resource emerged. In the early period of the project, it had been assumed that there would be enough molasses to meet all the needs

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13. Interviews, Kenya Sugar Authority, Nairobi, October 1984.

of the complex. This view, however, was invalidated by the approval of the Mehta proposal and the subsequent doubling of the capacity of the Madhvani project. The government did not seem to have had reliable data on the availability of molasses in the country at the time of the signing of the JVA. This is supported by the fact that the sugar industry received requests for data on their molasses output from the government a few days after the signing of the JVA. The industry had not been officially consulted on the matter before.

Estimates of actual production and projections from different sources varied widely. Even figures from the same agency (as in the case of the Kenya Sugar Authority) varied from time to time thereby making the decision-making process more difficult. What was even more crucial was the fact that discussions were often based on quantities of molasses measured in either volume or weight. The different sugar mills in the country had different recovery efficiencies and therefore the value of molasses depended largely on the content of fermentable sugars.<sup>14</sup> These technical requirements did not feature prominently at the early stages of the discussions.

The figures provided by the KSA in 1980 for the projected availability of molasses showed that there would be deficits in the molasses output if the two projects went on stream as planned (Table 6.5). These projections were based on the assumption that sugar production would generally expand and that the growth rate in the demand for animal feeds and other non-specified uses would expand at the rate of 2.5 per cent per year. At the time, the sugar mills were operating below capacity and it was felt that if capacity utilization improved, there would be enough molasses to meet the needs of the two projects. If for example, capacity utilization for 1979 was raised from an estimated 60 per cent to 90 per cent, then molasses output would rise from 97,200 tonnes to 145,639 tonnes. Such calculations, however, ignored the economic, technical and managerial sources of low capacity utilization.

The molasses question was not resolved because the sugar industry was unwilling to bow to either political or bureaucratic pressure to sell

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14. See chapter 3 for a discussion of molasses recovery efficiencies.



molasses to Madhvani at preferential prices. Moreover, various sections of the government did not support the idea and suggested that all arguments take into consideration prevailing export prices for molasses. The molasses question became more critical as construction approached completion. By the beginning of 1981, about 75 per cent of the complex had been completed but the availability and price of molasses had not been guaranteed.

TABLE 6.5: *Projected Molasses Production and Use ('000 Tonnes)*

	1979	1980	1981	1982	1983	1984	1985
<b>PRODUCTION</b>	<b>(Actual)</b>						
Miwani	12.9	14.0	18.0	20.0	22.0	23.0	23.0
Chemelil	15.7	17.0	17.0	17.0	17.0	18.0	21.0
Muhoroni	20.6	17.8	20.2	24.0	24.0	26.0	26.0
Mumias	27.7	48.0	48.0	48.0	48.0	48.0	48.0
Nzola	12.9	11.0	16.7	19.5	20.0	24.0	24.0
Ramisi	6.9	8.5	10.5	12.1	13.0	15.0	17.0
Sony	--	14.4	16.0	20.0	24.0	24.0	24.0
Others	0.5	1.0	1.5	2.0	2.0	2.0	2.0
<b>TOTAL</b>	<b>97.2</b>	<b>131.7</b>	<b>147.9</b>	<b>162.6</b>	<b>170.0</b>	<b>180.0</b>	<b>187.0</b>
<b>UTILIZATION</b>							
Miwani Distillery	5.7	6.0	6.0	6.0	6.0	6.0	6.0
Exports	74.6	60.3	0.7	--	--	--	--
Animal feed	29.6	30.4	31.2	32.1	32.8	33.7	34.6
KCFC	--	35.0	110.0	110.0	110.0	110.0	110.0
ACFC	--	--	--	50.4	63.0	63.0	63.0
<b>TOTAL</b>	<b>109.0</b>	<b>131.7</b>	<b>147.9</b>	<b>198.5</b>	<b>221.8</b>	<b>212.7</b>	<b>213.6</b>
<b>BALANCE</b>	<b>--</b>	<b>--</b>	<b>--</b>	<b>(35.9)</b>	<b>(41.8)</b>	<b>(32.7)</b>	<b>(26.6)</b>

Source: Kenya Sugar Authority, Nairobi.

One of the options suggested by the Ministry of Energy was to switch from molasses to cane juice as a feedstock. Irrigated sugarcane was growing 60 kilometres from the plant under a National Irrigation Board (NIB) project. The West Kano canefield lay equidistant to the Madhvani plant and Miwani sugar mill. The growers were having problems transporting cane to Miwani and consequently much of their yield was rotting in the field. The re-direction of the cane to Madhvani would have helped solve both the molasses question and the farmers' problems. This shift required additional

investment to instal crushing equipment. The KCFC management objected to this suggestion claiming that the plant had been designed to use molasses and not cane juice.<sup>15</sup> This claim was erroneous because the Conger process could easily use cane juice with minor changes in the feedstock preparation stage.<sup>16</sup>

While the molasses question remained unresolved, the oil industry introduced new issues such as blending and distribution. As mentioned earlier, Madhvani originally planned to have gasoline transported to Kisumu for blending and then shipped back to the oil companies in Nairobi for distribution. This view did not take into consideration the political strength of the oil companies, not to mention the logistic problems and costs associated with such an operation. Like the sugar industry, the oil companies expressed their interest to participate in the project but put forward their own conditions. However, while the sugar industry appealed to market mechanisms as a regulator of molasses prices, the oil industry took the more tedious and time-consuming strategy of calling for formal agreements, quality standards and other technical requirements which were in fact legal and even desirable. In most instances, the oil companies called upon KCFC to do what should have been done before the JVA was signed.<sup>17</sup>

In the first place, the oil companies insisted that any pricing formula must take into consideration the effects of introducing ethanol on the operations of the refinery, especially given its rigidity in product configuration (Figure 6.1). This was an important technical issue which had previously been ignored. While Zimbabwe could easily produce ethanol and replace a volume of gasoline with an equal volume of ethanol, Kenya could not do so because any litre of gasoline replaced would mean that other refinery products contained in the same barrel would have to be imported. The foreign exchange saving formula used in earlier calculations assumed that the displacement was one-to-one as in Zimbabwe and therefore did not include the other costs of producing ethanol. Moreover, the oil companies

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15. Interviews, Ministry of Energy and Regional Development, Nairobi, October 1984.

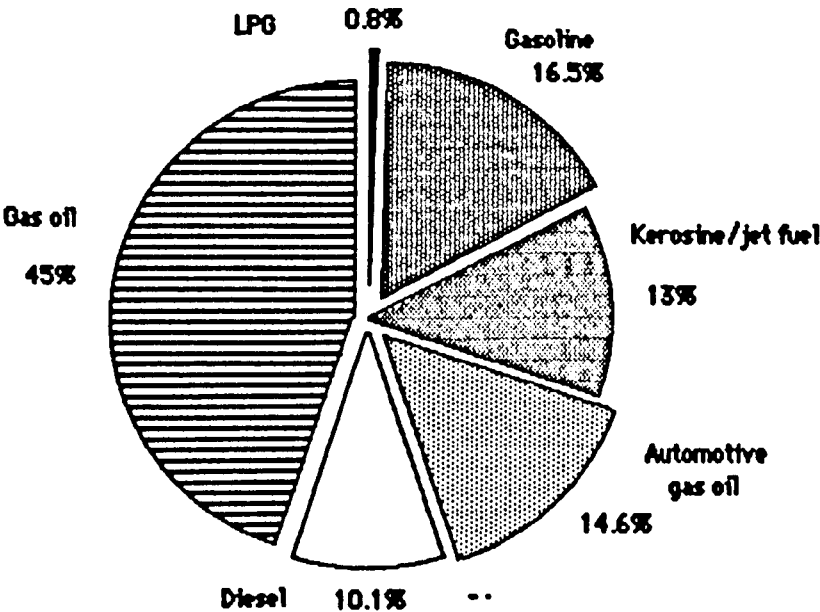
16. Interviews, Conger, Piracicaba, Brazil, March 1985.

17. The appeal appeared like a genuine interest in smoothing the terrain for the introduction of ethanol. The difference was that the companies were standing firmly in KCFC's way.

stressed they did not want any blend that would require them to make modifications in the refinery.

The oil industry also insisted on conducting road tests to ascertain the suitability of using fuel ethanol. The industry's approach was to ensure that KCFC took all the responsibility for the effects of fuel ethanol and also accepted the risks involved. KCFC was asked to indemnify the industry from legal liability arising from the use, blending, handling, storage, sales, supply and distribution of ethanol. The oil industry demanded that blending be done in their depots but KCFC take the responsibility to ensure that quality standards and delivery schedules were met. Moreover, the industry was willing to undertake all the modifications required for the introduction of ethanol at the expense of KCFC. All consumer education and legal matters required for the industry to be involved had to be paid for by KCFC. In the process, the industry and KCFC continued to discuss in great detail a series of draft agreements which were never ratified.

FIGURE 6.1: *Refined Fractions from Arabian Light Crude Oil*



Differences emerged between KCFC and the oil industry on the pricing formula with each side trying to maximize its gains. The oil companies suggested that in order to achieve optimal fuel performance, the blend would

need to contain 60 per cent premium gasoline, 27.5 per cent regular gasoline and 12.5 per cent ethanol. In addition to this, the oil companies proposed that KCFC should sell to them ethanol at a price equivalent to the wholesale price of premium gasoline in bond at Nairobi less a mutually agreed discount. The offered price was KShs.3,003 per 1,000 litres. This price was nearly half the KCFC production costs and was therefore not acceptable.

This offer also concealed the fact that if the ethanol was sold at the price of regular and then blended to include the premium gasoline and sold at the price of gasoline, then the oil companies would retain revenue from the difference between regular and premium gasoline. At that time the difference was KSh. 640 per kilolitre. In this case, the pricing formula suggested by the oil companies would have enabled them to earn some KSh. 176 per kilolitre of blended premium gasoline sold. Moreover, the oil companies would have used ethanol as a substitute for tetra-ethyl lead as an octane booster without including refinery savings in the price of ethanol. As in the case of molasses, KCFC did not enter into any significant arrangements with the oil industry, making the process of niche realization less prospective.

### **6.3 Public Knowledge and Institutional Learning**

Concern over the KCFC project reached the public arena through a series of Press investigations over loss of government funds through questionable joint ventures with the private sector. The approval of the Mehta project raised questions concerning the availability of raw materials. The KSA, which had informed the Press about possible molasses shortfalls, released new figures in May 1979 showing that the country had enough molasses for two or even three alcohol plants. This was possibly to justify the approval of the Mehta plant. At this moment, the Press started questioning the costs of the projects. Owing to the lack of comparative figures for ethanol capital costs, the Press initiated research on the issue

but did not get much information until the World Bank released comparative data the same year.<sup>18</sup>

The Press was the only sector in Kenya that publicly questioned the viability of this project. The government, which was the majority shareholder in the project, did not participate in the debate or issue any public statements on the matter. It was left to KCFC who issued statements arguing that it was not legitimate to compare the industrial complex with any other plant and that the World Bank did not have experience in the implementation of fuel ethanol projects.<sup>19</sup> During the debate, some of the local politicians attacked the Press claiming that the critics of the project were in the pay of foreign firms which were opposed to the development of the local industrial base.<sup>20</sup> KCFC maintained close links with local politicians and used their influence to seek government support. The politicians, on the other hand, evoked nationalistic sentiments claiming that this was the first project of its kind in Africa and needed full government backing. The prospects of employment at KCFC was a possible source of political capital for them, especially during elections.

The main gist of KCFC defence was that the project could not be compared with any other plant in the world because it was unique in complexity and product mix. However, in the same Press release they provided figures of production costs in Brazil and the US to show that their costs were comparable. While they did not want comparisons at the level of capital investment, they evoked production costs because this made their investment look more attractive. The Press was alleged to be "divisive and malicious".<sup>21</sup> The management also sought political support by appealing to

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18. A review of the role of the Press is summarized in *Weekly Review*, "Industry: Press Power", pp. 22-25.

19. KCFC, *Press Release*, stated: "Comparisons to World Bank and UNIDO sources...have no credibility as neither of these international institutions have promoted or financed anywhere in the world a project that in any sense resembles the KCFC's complex", pp. 3. A UNIDO representative was involved in the 1978 ISPC evaluations which showed that the project was over-priced.

20. *Ibid.*, pp. 25. We shall return to the conflict between the World Bank and KCFC investors later.

21. *Ibid.*, pp. 5.

the import substitution policy and Presidential statements.<sup>22</sup> As mentioned above, the export markets for these products had not been identified and the JVA required the government to help find these export options.

As the Press increased its coverage of the project, so did the intensity of counter-reports increase. By 1982, the Madhvani group was already buying advertising space in the local newspapers to answer fully their critics. The replies appealed to the complexity of the project, its relevance and benefits to the country. Issues such as cost escalation were justified in terms of the risks of being pioneers in a new venture. They compared their project, inadvertently, with the development of nuclear energy and space satellites in the US whose final costs were usually higher than the original estimates. "For Kenya, whose economy is at a very different stage of development, new and complex high-technology investments such as the one in Kisumu are liable to even higher cost escalation."<sup>23</sup> This reasoning, however, ignores the fact that Kenya did not have the same amount of financial resources as the US and that is exactly why they could not afford high cost overruns. Zimbabwe built its plant largely on a strategy aimed at reducing such losses.

The level of public debate on the project was limited by the availability of information on the investment projects. The fact that the government was the majority shareholder (over 51 per cent) in the investment made the project a parastatal undertaking. By virtue of this, all the information pertaining to the project was governed by the Official Secrets Act. And since some of the crucial aspects of the project were being questioned, it was not in the interest of the government or the private investors to release any information that might be used by critics. This arrangement undermined the requirements for public accountability in government decisions that involved tax-payers' funds.

But as the construction of the project continued, more information started reaching the public. Matters such as cost overruns and construction

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22. "KCFC represents a dynamic approach to industrialisation in which more than 80% of the financing has been provided from external sources. In addition, at a time when...the President has called upon Kenyan industry to realize fully Kenya's export potential, no mention has been made of KCFC's export orientation for citric acid and baker's yeast," *ibid.*

23. Madhvani Group, "The Challenges of Complexity", pp. 18.

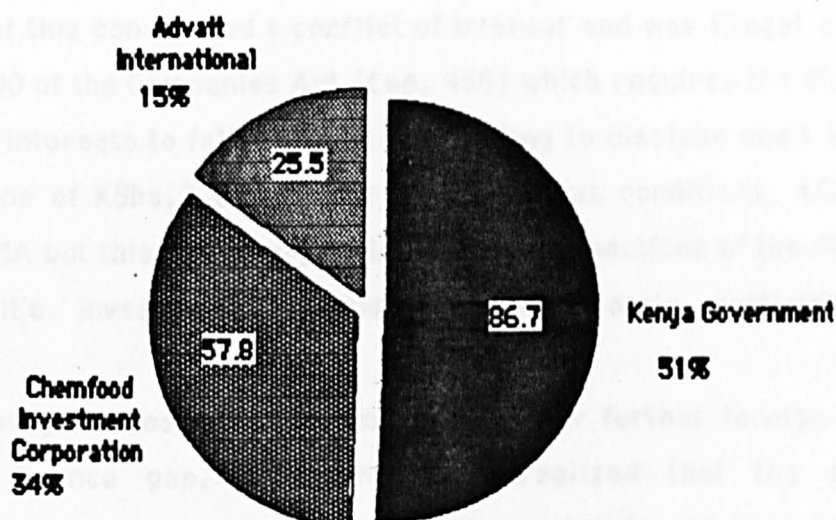
stoppages could not be kept away from the public, especially when they involved the largest joint venture the country had hitherto entered. Debates continued among government departments and even spilled over to involve the World Bank. Intra-governmental conflicts arose when the Ministry of Finance and Planning, which was instrumental in the approval of the JVA, started calling upon the other ministries to help implement the project. Several inter-ministerial committees were set up to look into the various aspects of project implementation.

The fact that some of the ministries had not been consulted before the signing of the JVA became a source of disagreement and even withdrawal from implementation efforts. For example, on May 16, 1979, the Minister for Power and Communications instructed members of his ministry through his Permanent Secretary not to participate on any of the committees formed to look into ways of implementing the projects. Although the Minister expressed his respect for the business acumen of Madhvani and Mehta, he remained sceptical about the success of the projects. His view was that the government should have solicited studies from industrial experts on the viability of the projects instead of moving in such haste to sign the joint ventures. The Minister's main concern was that his Ministry, which was charged with dealing with energy matters, should have been properly consulted before such heavy financial commitments were made. As a matter of principle, he wanted to go on record as having dissociated himself from the two projects. Which he did.

The criticism emerging from various government departments led to the formation of a Working Party on KCFC to examine the history of the project, indicate and evaluate progress on implementation, and undertake economic, financial and technical revaluation of the joint venture. The findings would be used in the possible restructuring of the project. The Working Party was formed on July 24, 1980 under the chairmanship of the Office of the Vice President and the Ministry of Finance. The Working Party, which was composed of representatives from the Ministries of Energy, Agriculture, Industry, and Economic Planning and Development, was required to produce a Cabinet paper in 10 days. Concern over the project was for the first time going to be discussed at the Cabinet level. By that time a

large number of issues had emerged which raised not only economic and financial matters, but also legal issues, especially on the constitution of the project.

FIGURE 6.2: *Original Shareholding Structure (KShs. Million)*



One of the key techno-legal issues was the interlocking partnership in the project. For example, CIC, which was one of the key contributors of equity would only participate in the venture on condition that KCFC signed the Technical Engineering Agreement (TEA) which allowed PEC to become the supplier of machinery and equipment. Similarly, Advait's investment in the project was conditional to the acceptance of Eximcorp as project managers. In the JVA, PEC and CIC were represented by the same signatory indicating that they were actively related while Advait and KCFC had the same signatory, who happened to be Nittin Madhvani, the organizer of the venture. The signatures confirm the link between KCFC and Madhvani. But Madhvani was also the principal investor in Advait and participated actively in Eximcorp.<sup>24</sup>

24. This view is confirmed in a published statement by Madhvani Group, *The Kisumu Project*: "The foreign investors -- Chemfood Investment Corporation, S.A., and Advait International, S.A. -- have contributed K.shs. 83.3 million... -- or 49% -- of the equity capital. The Madhvani Group was the initial organizer of the venture, is the major investor in Advait International, and participates actively in Eximcorp, the management agency." pp. 1.



CIC and PEC shared the same office, telephone, and address at Männedorf, on the outskirts of Zürich, Switzerland. In other words, the main actors in the project were the Kenya government and a handful of investors interlocked in a manner that allowed them to benefit at the expense of the government's participation, mainly through machinery supply and management fees.

This interlocking ownership raised questions concerning conflict of interest. One of the directors of KCFC was also a director of Eximcorp. The view was that this constituted a conflict of interest and was illegal according to section 200 of the Companies Act (Cap. 486) which requires the director to disclose his interests to fellow directors. Failing to disclose one's interests carried a fine of KShs.2,000. Under more serious conditions, KCFC could avoid the PIMA but this had been precluded by other sections of the JVA which made Advait's investment conditional to Eximcorp's participation as managers.

Following the cost overruns and the need for further foreign loans to bridge the finance gap, the government realized that the risks of implementing the project rested largely in its own hands. As a consequence, the government sought the re-negotiation of the JVA to ensure that the other shareholders, CIC and Advait, counter-guaranteed the loans. Before this, the previous loans had been guaranteed by the Kenya Commercial Bank (KCB) on behalf of the government. KCB was later (December 1979) to produce an update of the Madhvani feasibility study in which it argued that the government had put so much money into the project that it would not be wise to abandon it.<sup>25</sup> The government's decision to call upon shareholders to counter-guarantee foreign loans was an indicator that the government was starting to learn from the project and was reviewing its own policies on foreign loans.

The government also proposed other measures which would have strengthened its influence on the project. For example, the government would seek the right to approve the appointments of the general manager of KCFC as well as the heads of departments. But doing so required an amendment of the PIMA. This agreement had other curious clauses that came to light during the review. Take the case of force majeure. Even if the

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25. Kenya Commercial Bank, *Update Feasibility Study*.

project were terminated because of industrial disputes, war, civil disturbances, order of any public authority such as nationalization or expropriation, fire, natural catastrophe or other disasters, the management would still be paid no less than US\$500,000 in foreign exchange.

At its second meeting held on August 5, 1980, the Working Party considered a number of options including rescinding the agreements if overpricing in machinery and equipment could be established through agencies such as the United Nations Industrial Development Organization (UNIDO). Then a UNIDO representative, who had earlier been involved in the 1978 ISPC study, was still based in the Ministry of Industry and participated on the Working Party. But establishing fraud would have been difficult because the government did not have any reliable way of knowing what was included in the TEA. This was compounded by the fact that a Swiss firm, General Superintendence, had been appointed to certify that the machinery and equipment paid for was the same as that delivered. The firm had no mandate to compare prices. Further still, even if the government rescinded the agreements, they would have had to repay the guaranteed loans right away.

The debate over the Madhvani project took an international outlook when the World Bank, at the request of the Kenya government, started preparing for a mission to Kenya to review the ethanol sub-sector.<sup>26</sup> The government was then already looking for possible sources of bridge funding for the project. The World Bank concluded that only the Mehta project seemed financially and economically favourable. This was at a critical time when Madhvani was seeking funds to cover the cost overruns and would not appreciate critical reports from an influential institution such as the World Bank.

The Bank's own analysis relied on conventional approaches and assumed that the Mehta project would be implemented as planned. The main conclusions and recommendations of the study focussed on the need to take sugar and oil price projections into consideration before embarking on ethanol projects. Although valid, the recommendations did not take into consideration the fact that issues relating to technology acquisition and project implementation could easily bring down a project that appeared

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26. World Bank, *Kenya: Biomass Alcohol Sub-Sector*, pp. 23.

viable when examined in the narrow context of financial analysis. The adaptive terrain in which the project had to survive contained a wide range of other financial, economic technological and institutional issues whose effect on project implementation required a view that transcended the conventional approach.

In anticipation of the World Bank's criticism, KCFC commissioned the Schnader, Harrison, Segal & Lewis law firm of Philadelphia and Washington, DC to prepare a report whose release coincided with the World Bank mission to Kenya. The report included sections by an executive vice president of the Equator Bank, a former World Bank economist, and a former executive of ESSO. Their analysis relied on data provided by KCFC. The report expectedly concluded that the project was viable and required three main steps to be fully implemented. First, the closing of the financial gap created by cost overruns, arrangements for the supply of molasses at reasonable prices, and satisfactory plans for the blending, distribution and sale of gasohol.<sup>27</sup>

The fact that the government had guaranteed the foreign loans and could be called upon by the lenders in case the project failed, forced the government to look into possible ways of making the project work. But the project could not work without additional knowledge on fuel ethanol operations. As a result, government officials visited Brazil in May-June 1980 to acquaint themselves with fuel ethanol production. The trip enabled the officials to obtain comparative data on turn-key projects exported by Brazilian distillery producers such as Codistil and Zanini. This post-investment knowledge search enabled the officials to re-evaluate the project on the basis of experiences elsewhere. The officials, for example, found out that Codistil had exported a distillery producing 240,000 litres a day (more than four times the Madhvani capacity) to Costa Rica in 1978 at the cost of US\$13 million (KShs. 92.2 million).<sup>28</sup>

In August 1981, another team of government officials as well as Shell and KCFC representatives visited Zimbabwe to learn from their experiences.

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27. KCFC, *The Agro-Chemical Complex*, pp. 80. The report was printed in the US and copies shipped to Kenya. It was believed in the Ministry of Energy that KCFC had engaged a firm in Washington, DC to lobby against the World Bank report. This may or may not be the same firm that prepared the KCFC report.

28. Interviews, Codistil, Piracicaba, Brazil, March 1985.

While the first group concentrated on the economics of ethanol production, the second group was more interested in the introduction of ethanol, especially blending techniques. It is clear that all these concerns should have been considered before the signing of the JVA and not after. The effective use of the knowledge acquired during these trips had been precluded by the developments which had already occurred in project implementation.

This knowledge later became a major source of policy reform in the government. The process was cumulative, starting with other project failures such as the Ken-Ren fertilizer venture which collapsed while the machinery was on the high seas. Indeed, it was during Press investigations over Ken-Ren that details on the Madhvani project came to light. Evidence was starting to build up indicating that existing government policies gave room for corporate as well as bureaucratic malpractices in investment projects. The Madhvani project was the largest and latest of such industrial projects. The political visibility that the investors intended to use for financial benefits became a liability for the whole country and also a source of insitutional learning.

The process of institutional learning had two main sources; internal and external. Internally, the government had to deal with a large number of inefficient public sector investments. This coincided with the World Bank and International Monetary Fund's initiatives on reductions in government expenditure. In February 1979, the President appointed a committee to review all parastatal bodies. The committee reported in May that "there was clear evidence of prolonged inefficiency, financial mismanagement, waste and malpractices... A confused situation of this sort can be exploited in many ways, e.g. to resist public accountability and to engage in corruption and nepotism".<sup>29</sup> At the time of the review, the problems of KCFC were just emerging.

This report was followed in January 1982 by the appointment of a Working Party by the President to look into ways of containing government expenditure within the limits of government revenue receipts. The working party dealt with a wide range of matters but identified the management of

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29. Republic of Kenya, *Review of Statutory Boards*, pp. 4.

government investments as a major source of financial waste. It recommended reductions in public investment and withdrawal from guaranteeing foreign loans for joint ventures. It also recommended that a task force be set up to help the government divest itself of investments in non-strategic activities which included, among others, fuel ethanol.<sup>30</sup>

Concurrent initiatives were also being taken by the Ministry of Economic Planning and Development which launched an intensive programme aimed at strengthening existing procedures and where possible "instituting new procedures which would ensure that the implementation of development projects is properly scheduled and regularly monitored".<sup>31</sup> The initiatives, which were contained in a circular to all the other ministries, emphasized the costs of project delays and tied-up government funds, increased project costs and delayed receipt of foreign exchange from externally-financed projects.

The initiatives were followed by detailed guidelines on the preparation, appraisal and approval of new public sector investment projects. The guidelines included those specific issues which had arisen from the Madhvaní project. This was not surprising because the project had become a major source of knowledge on project implementation as government officials prepared detailed reports on all the aspects of the venture for the numerous meetings that were held to try to resolve the situation. According to the guidelines, government "equity contributions, loans or loan guarantees to enterprises will as a rule be restricted to economic activities fundamental to development and will be subject to detailed financial and economic analysis...there will...be no import duty concessions...exclusive technology licensing arrangements will be time-limited".<sup>32</sup> The guidelines applied to all investments in which the government provided financial inputs in the form of equity, loans or loan guarantees. Apart from the normal

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30. Republic of Kenya, *Report and Recommendations of the Working Party*, pp. 42-43. This report, known popularly as the Ndegwa Report (Philip Ndegwa, chairman of the working party and has been a long-standing advocate of economic and government efficiency), later became the basis for the 1983-88 Development Plan and source of policy guidance on other economic planning matters.

31. Ministry of Economic Planning and Development, *Implementation of Development Projects*.

32. Republic of Kenya, *Guidelines*, pp. 5-6.

matters of financial and economic analysis, the guidelines included project location and environmental effects as significant considerations. These issues directly resulted from the the controversy over the Madhvani project.

One of the major areas of concern in the JVA was the number of concessions that the government made to the project. The new guidelines sought to close this loophole by emphasizing that no special concessions would be provided by the government. However, those seeking such concessions would be required to give full costing details to help the government establish the level of support or subsidy. Other requirements such as duty and tax exemption or remission on inputs would be calculated at the amount which would be collected with no exemption or remission.<sup>33</sup>

To ascertain the foreign exchange savings of new projects, the guidelines required foreign and local costs to be separated. Moreover, the issue of local manufacture of some of the inputs was starting to enter policy guidelines. "Where a project input is locally supplied, is a significant part of total annual cost, and contains a high import content, project sponsors should examine at least the last stage of domestic production of that input to determine its local and import components."<sup>34</sup> The issue here was not to encourage local manufacturing but to establish the level of foreign content as a tool for quantification.

One of the problems with the Madhvani project was that the foreign investors made their participation conditional on the acceptance of PEC as the suppliers of technology. The new guidelines now required that the sourcing of inputs be subjected to open local and international tender together with estimates of the percentage by which the project costs were higher than competitive prices. Details of differences in the quality of inputs were also required. The Madhvani project used arbitrary figures in their estimates and the new guidelines now require that "all sources of information and bases of estimates should be documented".<sup>35</sup>

On the whole, it appears from the details of the new guidelines that the government had learned the significant lessons of the Madhvani project and

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33. *Ibid.*, pp. 14.

34. *Ibid.*, pp. 16.

35. *Ibid.*, pp. 17.

was willing to guard against similar projects by devising relevant policy approaches. This again reinforces the view that policy formulation may result from project implementation as new realities emerge from practice. The guidelines form the criteria for project selection and are associated with institutional reform. In this case, the reforms included the strengthening of the Project Appraisal and Monitoring Division of the Ministry of Economic Planning and Development.

The reforms, however, still remained in the traditional mould of financial analysis and did not take into consideration some of the main lessons relating to technology acquisition. By emphasizing financial issues, the reforms relied on improving some of the short-term elements of project implementation such as prices. Long-term considerations remained unexamined. For example, there was no systematic examination of the relationship between technology acquisition and the utilization as well as development of local technological capability. The reforms therefore did not have any major influences on broader issues of technology policy although most of the problems that faced the ethanol programme related directly to long-term technological issues.

These reforms and institutional re-organization legitimized a procedure of incremental policy reform that was already underway. The government had already stopped guaranteeing large foreign loans in 1981, indicating that the lessons of the Madhvani project were being incorporated into policy practice. The first venture to face the consequences of this policy change was another fuel ethanol project proposed by a consortium of Kenyan and French investors. This autonomous ethanol project was to be located at Riana in western Kenya. It was planned to produce 45 million litres of ethanol a year from cane juice and was costed at US\$76 million (excluding the development of 10,000 hectares of land for cane production).

The project was similar in structure to the Madhvani investment. It was based on a turn-key technology to be supplied by the French firms Société d'Etudes et de Construction pour les Industries Agricoles SA (SODECIA) and Five-Cail Babcock (FCB). The project was to be managed by another French firm, SUDE and consulting work was done by OTH International of Paris. The project was promoted by a local engineering firm, J.T.

Cottingham & Partners who hoped to get local loans from the Industrial Development Bank (IDB) and foreign loans from French banks led by Banque de Paris et des Pays-Bas. The foreign loans were expected to be guaranteed by the government whose proposed equity participation was 51 per cent, thereby creating another parastatal body.

Unlike the Madhvani project, the Riana venture involved the French government who intended to include the loans as part of their Protocol aid on condition that the Kenyans acquired French equipment. The French protocol long term credit was estimated at Fr.300 million and carried a low weighted interest rate of 5.8 per cent. The project involved Total Oil (France) and Birlas Company (India) and was supported by the Ministry of Energy. The Kenya government was expected to participate in the project through the Industrial Development Bank (IDB) and the Kenya Pipeline Company (KPC).

TABLE 6.6: *Revised Capital Costs for the Riana Project (1980)*

Item	US\$ ('000)
Plant infrastructure	6,240
Buildings	4,289
Machinery (milling, distillery, briquetting plant)	43,764
Tractors and transport	518
Furniture	138
Professional fees	2,854
Contingencies	2,419
Working capital	1,709
Preliminary expenses	287
Pre-start-up interest	3,259
TOTAL	65,339

Source: Industrial Development Bank, Nairobi.

The Riana proposal was thoroughly discussed and evaluated mainly against the background of the Madhvani project. Some of the loopholes which led to cost escalation in the Madhvani project were sealed and the New Project Committee of the government approved it in March 1981. However, the approval was made on condition that the government would not be asked to subscribe equity or guarantee any loans. The government remained firm on this condition and the project was finally shelved. Attempts were subsequently made to change the concept from ethanol energy production to



resins manufacture in the hope that the government would possibly consider participating in the manufacture of plastics. The collapse of Riana indicated that the government was going through a learning phase by eliminating some of the sources of financial loss inherent in the industrial policies.<sup>36</sup>

At this moment the government's energy policy had not been spelled out. The first attempt to produce a policy document on energy made clear the concerns of the government over investment in ethanol projects. The policy document, prepared by the Ministry of Energy which had earlier been supportive of ethanol projects, stated that the government would not increase its investment in alcohol programmes although they did not discourage private initiatives.<sup>37</sup> Given this background in institutional reform and learning, it was therefore difficult for the Madhvani project to survive given its failure to incorporate suitable adaptive parameters and at the same time smooth the adoptive terrain.

#### **6.4 The Madhvani Collapse**

The implementation of the Madhvani project started with a series of problems, many of which could have been anticipated. Indeed, sections of the government felt at the very beginning that the project was likely to face serious problems. The previous sections have shown that the main features of the techno-economic landscape which required to be changed to accommodate the project were not modified. But even more important is the fact that the internal parameters of the project were counter-adaptive. Not

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36. It is notable that the changes in government policy over this period were associated with political changes in the country. Jomo Kenyatta had died and President Daniel arap Moi had become a champion of administrative efficiency and justice. He strongly spoke against corruption and made major changes in the bureaucratic machinery. This period was also marked by severe foreign exchange constraints. The era of profligacy which followed the 1977 coffee boom had ended and a new mood of rationalization was setting in. This transition in policy learning has now become a major component of current (1985-86) economic practice and guidelines for future policies.

37. Interviews, Ministry of Energy and Regional Development, Nairobi, October, 1984. It is interesting to note that the 1984-88 Development Plan avoids the issue of fuel ethanol altogether.

only was the total capital investment too high, but the project was designed in a manner that made its ultimate failure almost inevitable. This section looks at the adaptive features and how they influenced the implementation of the project.

TABLE 6.7: *The Madhvani Project Escalation (KShs. '000)*

Item	1977	1980	Increase
Land and site preparation	2,102	17,849	15,747
Buildings	12,297	78,112	63,815
Machinery and equipment			
Swiss equipment and services	385,165	564,619	179,454
Oxygen plant	--	13,478	13,478
Sulphuric acid plant	--	6,587	6,587
Factory equipment	--	6,420	6,420
Fire fighting equipment	--	3,750	3,750
Incoming water system	1,682	5,082	3,400
FEAL	3,852	4,755	903
Sales tax	38,517	59,649	21,132
Clearing, freight and insurance	3,364	21,747	18,383
Erection and commissioning	25,229	40,126	14,897
Training	2,102	2,142	40
Furniture and fittings	--	2,677	2,677
Vehicles	12,615	10,711	(1,904)
Pre-production expenses			
Formation and stamp duty expenses	--	1,192	1,192
Contingency and deferred expenses	10,697	34,959	24,262
Pre-start-up finance costs	16,819	78,746	61,927
TOTAL	516,441	952,598	436,157

Source: Kenya Chemical and Food Corporation, Nairobi.

The possibility for cost overruns was built into the JVA under a large number of clauses, the most obvious being the terms of the management fees. It was indeed in the interest of the management for cost overruns to occur because this would increase the total capital investment and therefore enlarge their management earnings. By 1980, the project costs had risen from the original KShs.516,441,000 to KShs.952,598,000, escalations of about 80 per cent (Table 6.7).<sup>38</sup> This cost escalation did not only require more equity injection, but also needed additional foreign exchange which could only be obtained through borrowing and further government guarantees.

38. The figures for the original proposal given in Table 6.2 differ slightly from those given in Table 6.7. The differences have been presented as provided in KCFC documentation.

Several reasons accounted for the escalation of the costs. In the first place, the foreign contributions to the project were valued in Swiss francs. This included the equipment supplied by Waagner-Biro of Austria and Sorigona of Sweden. As the value of the Swiss franc appreciated over the 1977-1980 period, the relative value of the Kenya shilling declined, thereby leading to cost escalation. In 1977, SFr.1.0 was equal to KShs.3.36. By 1980, the rate was KShs.4.50, an increase of nearly 34 per cent in three years. This appreciation alone added another KShs.100 million to the cost of the project by 1980. This, and the related inflationary trends, were the only sources of cost escalation exogenous to the project. The other two sources of escalation included increased project capacity and delays in construction.

TABLE 6.8: *KCFC's Financial Gap (1980)*

Item		KShs. million
<b>TOTAL FUNDING REQUIRED</b>		
Project cost		955.00
Net working capital		49.00
Contingency fund		14.00
<b>TOTAL</b>		<b>1,018.00</b>
<b>AVAILABLE FINANCES</b>		
Equity share capital		170.00
Kenya Government	86.7	
Advait International	25.5	
Chemfood Corporation	57.8	
Outstanding loans		580.00
Union Bank of Switzerland	438.0	
Process Engineering Company	52.0	
BEDCO-Eurodollar loan	90.0	
<b>TOTAL</b>		<b>750.00</b>
<b>TOTAL FINANCIAL GAP</b>		<b>268.00</b>

Source: Kenya Chemical and Food Company, Nairobi.

Other delays resulted from sections of the political arena such as the Parliament. The Swiss loan agreement which included the purchase of equipment was signed in November 1977 but the necessary sessional papers were not presented to Parliament until June 1978. The papers were withdrawn from Parliament only to be re-introduced several days later.

Because of the delay, KCFC missed the deadline for the tendered price of the TEA and had therefore to start new negotiations at escalated prices. This delay reportedly led to an increase of KShs.18 million (US\$2.4 million).<sup>39</sup> The provision of electricity was not done in time because the East African Power and Lighting Company insisted on down payment for all its services which included the installation of step-down transformers. KCFC had to install a temporary generator to power its activities.<sup>40</sup> By the end of 1980, a substantive financial gap of KShs.268 million had emerged which needed to be bridged before the project could be completed (Table 6.8).

To fill the gap, KCFC proposed a wide range of measures which required more contributions from the government. These measures included additional equity (KShs.30 million) by the shareholders, conversion of the KShs.31 million owed to the government as sales tax on machinery to a loan, payment of the deferred credit agreement of KShs.5 million owed for the sulphuric acid plant, and the provision of KShs.22 million as working capital cash credit. These measures still left a gap of KShs.180 million (US\$24 million) which had to be filled through loans. The rising costs of the project led to increased search for solutions and the government included the possibility of scrapping it altogether.

By the end of 1980, the cost of the project was approaching KShs.1.0 billion, twice the original estimate. The capital intensity of the project was illustrated by the fact that it took KShs.1.5 million to generate one job, an estimate that does not take into account the fact that the number of experts working on the project far exceeded the normal requirement. The project had by that time become a subject for intense Cabinet discussions. The government had guaranteed about KShs.600 million in loans and there was no sign that the project would become operational soon or even realize any profits in the first nine years of operation.

The government was at this time faced with three main options. First, the project could be terminated. Second, it could be reconstituted (both technically and legally). Third, the government could opt for a major re-negotiation of the various agreements in order to minimize government

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39. This escalation alone was equivalent to the amount paid to Conger for the distillery.

40. KCFC, *The Agro-Chemical Energy*, op. cit., pp. 34.

risks. The first option was ruled out because the government would be called upon to honour the loans immediately and a whole set of legal actions would be initiated involving shareholders and creditors.

The second option was only feasible if the project could be made economically viable in another form. This option too, required the government to repay the foreign loans. At least in principle, the government's position was to initiate a series of negotiations aimed at reconstituting the project. In the meantime, the costs of the project continued to rise thereby making the case for liquidation even stronger. Attempts were made to search for bridging loans from different sources. These loans, which were usually small compared with the total requirements, were supplemented by additional equity, but the gap remained.

In April 1981, the government decided that they would guarantee loans to meet outstanding expenses but stressed that any future loans would be guaranteed equitably with the other shareholders. In response, the shareholders issued a memorandum under which their equity contribution (KShs. 15 million) would only be made if the government agreed to guarantee a foreign loan of US\$24 million from Blyth Eastman. The shareholders also asked that the government reimburse them all the expenses incurred by KCFC as a result of delays caused by the Treasury's refusal to honour the terms of the JVA. Other demands included the provision of facilities such as electricity, land allotment and reimbursement of land expenses, construction of rail siding and other items.

At this moment, the first repayment of foreign loans by KCFC was approaching and they demanded that the government issue a letter of support for their request to reschedule the loans borrowed from the Union Bank of Switzerland and PEC. These demands amounted to pressure on the government to honour the JVA at a time when it was calling for re-negotiation. The government was then still committed to the completion of the project. This was partly because of local political lobbying and concern over Kenya's record and credibility among the lender and donor community. The government therefore remained firm on its position.

By the end of 1981, the government was already looking into the consequences of continuing with the project. Government estimates in early 1982 showed that the country would lose some KShs.135 million annually in the next 10 years if the project was completed. This subsidy would have to be met by increasing general taxation, raising taxes on petroleum and reducing government expenditure in other areas. But if the project was stopped then, the government had to meet loan obligations which then amounted to KShs.780 million. If the government repayed the loans under the existing terms of borrowing, the country was expected to spend an average of KShs.120 million annually for next 10 years.

In the meantime, efforts by KCFC to secure foreign loans became increasingly difficult as reports on the problems of the project reached the international banking community. Syndication arrangements through Blyth Eastman failed largely because the bank was aware of reports suggesting that the project was on the verge of collapse and KCFC did not have enough operating funds. Blyth Eastman contacted some 30 banks in the US, United Kingdom, Belgium, France, Canada, Italy, Switzerland and the Arab countries but there were no positive responses. The banks required an assurance that the government fully supported the project either through Parliamentary approval or the Treasury.

Pressure on KCFC was increased by action from local creditors. The most critical was the decision in May 1982 by the East African Power and Lighting Company to disconnect power supplies due to non-payment of KShs.58,000. Solel Boneh had ceased to do construction work in December of 1981 due to non-payment. In April 1982, PEC notified KCFC that they were going to demobilize their operations since Deweto could not undertake further erection work as the civil contractor had stopped working. PEC demanded the payment of SFr.1.1 million as demobilization fees.

By this time the total capital expenditure on the project had reached US\$125 million (Table 6.9). According to KCFC figures, 39.8 per cent of the capital expenditure was accounted for by the citric acid plant while the yeast component claimed some US\$29.5 million. Fuel ethanol accounted for only 18.4 per cent. This distribution of capital expenditure was aimed at showing that the ethanol component was not as high as had been claimed and was in

fact comparable to the Mehta's capital cost of US\$27 million. But by doing this, a large sum of money was allocated to facilities which were not the original justification for the project. Energy had been marginalized and products for which there was no readily available market to absorb all the output had acquired central positions in the complex.

TABLE 6.9: *Capital Allocation of the Madhvani Complex (1982)*

Unit	US\$ million	Percentage
Citric acid	49.7	39.8
Yeast	36.9	29.5
Ethanol	23.0	18.4
Anaerobic water treatment	7.6	6.0
Vinegar	4.1	3.3
Oxygen	2.6	2.0
Sulphuric acid	1.2	1.0
TOTAL	125.0	100.0

Source: Kenya Chemical and Food Corporation, Nairobi.

It was obvious by then that there would be molasses shortfalls and the demand for the Madhvani plant alone would consume some 94,000 tonnes a year, while available molasses in the sugarcane belt was estimated at 86,000 tonnes a year in 1981. This figure excluded the requirement for the Miwani distillery. It was clear then that the commissioning of the Mehta plant would definitely lead to molasses shortages in the area even without considering the requirements for animal feed. The government had just formed the Ministry for Livestock Development which was at this time considering molasses as one of the main sources of animal feed for an expanded livestock production programme.

But even if molasses were readily available from the nearby sugar mills, the cost of transportation was becoming increasingly prohibitive. The alcohol plant alone would require about 226 tonnes a day at the haulage cost of KShs. 120 per tonne or KShs. 27,120 per day. This added enormously to the final cost of delivered molasses. For example, at an ex-factory price of KShs. 200 per tonne for molasses, transportation alone added another 60 per cent, bringing the delivered cost to KShs. 72,320. These changes would also be reflected in the price of ethanol (Table 6.10).

TABLE 6.10: *Madhvani's Cost of Molasses per Litre of Ethanol*

Price (KShs./tonne)	Total Cost	Cost per Litre	
		Without Hauling	With Hauling
150	33,900	0.57	1.02
200	45,200	0.75	1.20
250	56,500	0.94	1.39

Source: Kenya Chemical and Food Corporation, Nairobi.

The location of the project also affected the energy requirements of the plant. Because of the lack of access to surplus bagasse, the plant was designed to rely on bunker fuel for its energy requirements. The complex included the Anamet unit which was to produce methane. But this accounted for only 30 per cent of the total energy requirements of the complex. The alcohol plant required about 300 tonnes of steam a day generated from burning 24 tonnes of bunker fuel a day. The delivered cost of bunker fuel was KShs.3,500 per tonne. An additional 15,360 Kwh of electricity was required per day. The two sources of energy accounted for KShs.91,680 per day. At a production level of 60,000 litres per day, the energy costs alone accounted for KShs.1.53 per litre, which was over twice the Mehta costs of KShs.0.61 per litre. The costs of inputs thus started to show high production costs which raised questions concerning the viability of ethanol as a substitute for gasoline.

All these developments were compounded by the demand of Union Bank of Switzerland and other lenders for loan re-payments. The government took no action on the project and the situation worsened. This silence brought KCFC to its knees, as creditors sought legal redress and workers went without pay. In August 1982, Eximcorp resigned from its directorship because of the non-payment of due management fees. In effect, the KCFC was insolvent but had not been declared bankrupt. Efforts by the management to push the government through local politicians did not yield any results as the government made no decisions on the project. For all practical purposes the project had collapsed. The situation thereafter was summarized by the World Bank thus: "[The government] has not initiated a formal review although the



debacle of the KCFC investment is clearly now the subject of cabinet discussions regarded by the civil service as highly sensitive and confidential.<sup>41</sup>

The collapse of the Madhvani venture illustrates clearly the importance of the linkages between the adaptive parameters and the adoptive terrain in project implementation. The approach, which was counter-adaptive, contrasts sharply with the Triangle experience where most of the major adaptive and adoptive factors influencing fuel ethanol projects were studied in detail and incorporated into a learning process which eliminated most of the major risks. The Madhvani debacle left Kenya with the Mehta project which had to introduce modifications in the adoptive terrain during the implementation process in order to survive.

### **Conclusion**

This chapter examined the the process of project implementation in Zimbabwe and Kenya and stressed the importance of the interaction between adaptive and adoptive parameters in the introduction of technological systems. It was shown that the successful introduction of the ethanol in Zimbabwe depended on a long history of changes in the adoptive terrain which offered conducive conditions for project implementation. The failure to link adaptive parameters to the adoptive pre-conditions led to the elimination of the Madhvani project. Unlike Zimbabwe where the selecting pressures were tested vicariously through a series of studies and evaluations (followed by gradual terrain modification), the Madhvani project was directly planted in an unmodified terrain with grave consequences. The next chapter will examine further developments in the Mehta and Triangle projects.

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41. World Bank, *Kenya: Energy Assessment*, pp. 5.

## **7. DIVERGENT TECHNOLOGICAL EVOLUTION**

### **Introduction**

The previous chapter examined the process of niche realization and identified the main features of the techno-economic landscape that influenced the different approaches in Zimbabwe and Kenya. It showed that the mismatch between the adoptive pre-conditions and adaptive parameters of the Madhvani project made it difficult for the joint venture to succeed. All the errors embodied in the project could not be eliminated without the collapse of the venture itself. It was noted that the Mehta project had more favourable adaptive conditions. This chapter looks at the performance of the Triangle and Mehta projects and stresses that the differences in their performance record was largely influenced by the same factors identified in the previous chapters. It will be shown that over time, Kenya attempted to guarantee the survival of the project by modifying the adoptive terrain.

### **7.1 Project Timing**

The rise and fall of the Madhvani project in Kenya directly affected the Mehta project in various ways, especially in its timing. Mehta decided to follow Madhvani into the market instead of taking the lead. The possibility for Mehta to commission their plant before Madhvani arose from the delays of the latter. But it was in the interest of Mehta to come second. By following the trail of Madhvani, Mehta did not have to incur the costs of smoothing the techno-economic terrain to enable the technological system to take root. Indeed, the adaptive parameters of the project did not require as much terrain modification as the Madhvani project did.

By taking second position, Mehta had the advantage of learning from the challenges and opportunities Madhvani faced. The Mehta group, together with Vogelbusch, closely studied the unfolding of events and made the

necessary adjustments to their project. For example, efforts were made to ensure that their project did not undergo the kind of cost overruns that were bringing down the Madhvani project. Much of the institutional and legal matters required to bring ethanol to the market were being undertaken by Madhvani and Mehta did not have to incur the costs of lobbying for the changes. In a sense, some of the costs incurred by Madhvani related to the creation of institutional arrangements for ethanol development and should have been shared by Mehta as well. However, since Madhvani decided to take an early lead in the market, they had to bear all the costs while subsequent entrants benefitted from the initial efforts.

There were other reasons why the Mehta group and their associates had to study the Madhvani developments closely and internalise the lessons. Madhvani attempted to pre-empt the Mehta entry through the expansion of their project to use most of the molasses produced in the country. In response, Mehta had to use a survival strategy which included making their project appear more viable than Madhvani's. This was done through reductions in capital costs as well as ex-factory prices. For example, the revised Madhvani proposal gave the local price of baker's yeast as US\$3,750 per tonne while Mehta valued it at US\$2,200. Madhvani was caught in a situation where they could only justify the high capital costs of the project by allocating high prices to their products so as to show favourable cash flows. But by doing so, they exposed themselves to competition from those who could offer projects with lower capital costs and ex-factory prices (among other adaptive parameters). Mehta did exactly that.

The lessons of the Madhvani project on management arrangements were also incorporated into the Mehta deal. Instead of fixing the management fee as a percentage of the total capital invested, Mehta fixed an annual fee of KShs.600,000 to be paid in Swiss francs. The Mehta management contract was for five years while the Madhvani one was for 10 years. The duration of the Madhvani contract became a matter of government concern and Mehta did not want to face the resulting problems which included re-negotiation to reduce the duration.

Such problems were not experienced in Zimbabwe for two reasons. First, most of the institutional requirements for the introduction of ethanol

were met before the ethanol was introduced. Second, the fact that Zimbabwe had only one plant did not provide opportunity to learn from the experiences of others. The risks involved in the learning process in Kenya were so high as to include possible project collapse. In Zimbabwe, these risks were eliminated by the knowledge acquisition and retention which took place in the pre-commissioning period. Apart from the adoptive changes which enabled Triangle to implement the project with relative ease, the adaptive parameters of the plant were stripped of almost all the possible sources of risk. Unlike the Madhvani plant, which was largely baroque, Triangle introduced a system that produced ethanol alone. Additional processes such as the recovery of carbon dioxide were added after the ethanol plant was shown to be working satisfactorily.

The timing of the Triangle plant was also fortuitous. The plant was constructed during the last days of UDI and came on stream soon after the government of Robert Mugabe came to power. It was the first industrial project to be officially commissioned by the Prime Minister. This gesture signalled approval and interest on the part of the government in the project. This type of political support, symbolic as it may be, was virtually lacking in the Kenyan case. Government officials did not want to publicly associate themselves with the projects. The controversies that surrounded the Madhvani project right from the start limited the level of public support for the project, except from local politicians.

## **7.2 Start-up Performance**

As indicated above, the timing of the Mehta project was partly influenced by the progress of the Madhvani venture. The time lag between the two projects had to be long enough to enable Mehta to internalise the lessons from Madhvani's implementation process. However, it also had to be short enough to enable Mehta to benefit from changes in the adoptive terrain resulting from Madhvani's early entry. But the collapse of Madhvani forced Mehta to facilitate the construction process while at the same time taking over the challenges of modifying the terrain for smooth ethanol introduction. The construction of the plant started in April 1981 and was completed in May

1982. Trial runs were conducted in June 1982 and commercial production was expected to start in July 1982.<sup>1</sup> It did not start because the price of ethanol had not been settled and there were no facilities for blending ethanol with gasoline. The two requirements proved to be more difficult to implement than had been expected; they became a major obstacle to the completion of the final stages of niche realization.

The issue of pricing and blending now brought Mehta into direct conflict with the oil companies, with the government attempting to find a solution amid its own internal conflicts as reflected by the differing positions of the various ministries and even departments within ministries. As early as January 1982, the government had decided that an inter-ministerial committee under the chairmanship of the Ministry of Energy would be formed to review the price of molasses and ethanol. While the Ministry was collecting data on ethanol-related issues to establish a pricing formula, the oil companies submitted detailed information on the technical and financial impact of the introduction fuel ethanol on their operations.

TABLE 7.1: *Cost Saving for a Litre of Ethanol (1982)*

Item	White Oil Rule Applied		White Oil Rule Waived	
	Litres	Cost (KShs./l)	Litres	Cost(KShs./l)
Crude reduction	1.9530	4.646	6.752	16.063
Surplus naphtha revenue	0.7110	0.768		
LPG Import Cost	0.0023	(0.075)	0.078	(0.254)
Distillates Import	0.6880	(2.294)	2.379	(7.934)
Less residue export	0.8620	(1.364)	2.982	(4.718)
Foreign exchange saving		1.681		3.157

Source: Mobil Oil Kenya Limited, Nairobi.

It is notable that not all the oil companies shared the same views on the issue. Most members of the group preferred to retain the "white oil rule" while others suggested that it should be waived to facilitate the introduction of ethanol (Table 7.1). Under the rule, the oil industry was required to

1. ACFC, *Gasohol Programme in Kenya*, pp. 4.

process sufficient crude oil to meet the total demand for white oil products. Waiving the rule would mean the country would import enough crude oil to meet the demand for gasoline alone and the rest of the fractions would be imported. Under the rule, the introduction of ethanol would leave the country with about 20,000 tonnes of gasoline blendstocks a year which would have to be exported. Handling the export would reduce the foreign exchange savings from the introduction of ethanol. However, the oil refiners resisted efforts to waive the rule.

After detailed discussions with the various ministries, the Ministry of Finance recommended that ethanol be sold at KShs.5.60 per litre in bond. This price included the transportation costs of about KShs.0.35 per litre from the plant (Muhoroni) to Nairobi. This meant that the ex-factory price of ethanol was valued by the Ministry of Finance at KShs.5.25 per litre. But ACFC argued that such a price would be uneconomical for the plant and would not enable them to meet their foreign loan obligations. This figure was much lower than the price requested by ACFC in March 1983 based on the cost of production. The ACFC argued that a more realistic way of arriving at the price was to either use the cost of production method or a cash break-even approach that would take into account the requirements for debt servicing.

A cost of production approach worked out at KShs.5.18 per litre (Table 7.2). In addition, ACFC wanted a guaranteed 15 per cent return on investment which raised the ex-factory price to KShs.5.64 per litre and excluded dividends to shareholders. This figure was based on a molasses price of KShs.175 per tonne and a minimum capacity utilization of 85 per cent. A cash break-even approach required another KShs.0.51 per litre to finance loan repayments, bringing the ex-factory price to KShs.5.76 per litre. Another KShs.0.35 was needed to meet transportation costs, bringing the Nairobi price to KShs.6.11 per litre. In anticipation of resistance from the oil companies, ACFC requested a lower ex-factory price of KShs.5.64 per litre. This was suggested by ACFC to be the minimum price required to enable the project to survive.

The ACFC figures, however, carried biases which reflected a much higher cost of production. For example, their price application to the government was based on a production capacity of 12.6 million litres per

year instead of the rated capacity. The plant maintenance were based on full capacity utilization and used a deferred period (1985) as the base year. The pre-paid expenses were calculated for four years (1982-1985) yet they had been amortized over the economic life span of the project. The pricing structure included questionable expenses such as marketing whereas the oil companies were expected to undertake this function. The ex-factory price of ethanol suggested by ACFC was considerably higher and the fact that ACFC was willing to settle for a lower figure than the requested price tends to strengthen the view that the fuel was over-priced.

TABLE 7.2: *Cost of Ethanol Production at ACFC (1982)*

Item	Cost (KShs./litre)
1. Variable Costs	
Molasses (at KShs.175 per tonne)	0.604
Labour, energy and other materials	1.907
Sub-total	2.511
2. Semi-variable and Fixed Costs	
Salaries, wages and benefits	0.197
Plant maintenance	0.525
Depreciation	0.512
Marketing and administration	0.418
Amortization and pre-production costs	0.197
Sub-total	1.849
3. Interest and Finance Charges	0.820
TOTAL	5.180
4. 15% return on equity	0.460
5. Ex-factory price	5.640

Source: Agro-Chemical and Food Company, Nairobi.

Ironically, the question of foreign exchange savings did not enter the discussions. This was partly because of the complexity of the calculations involved and the variations in the prices of key items, especially molasses. Simple calculations show that the project had a positive impact on the foreign exchange savings. At full capacity utilization, the plant was expected to displace the crude oil equivalent of US\$13.7 million. However, a total of US\$23.7 million had to be spent on importing displaced fractions. The foreign loan obligation of ACFC amounted to US\$1.5 million, leaving a balance of

US\$8.5 million. The foreign exchange earnings from the 62,100 tonnes of molasses required for the plant was US\$2.5 million. The net saving therefore worked out to US\$6.0 million or US\$0.33 per litre.

This figure excludes foreign expenditure on spare parts, inputs, dividends to foreign investors and other related expenses. It also assumes that the import for crude oil based on the requirement for gasoline alone and the other white products are met through the import of refined products. However, if enough crude oil is imported to meet all the requirements for white products, then the foreign exchange savings would be eroded. Moreover, the calculations do not take into consideration the fact that Kenya exports refined products to neighbouring countries thereby adding foreign exchange value to the imported crude oil.

In the absence of a consensus on the price of ethanol, especially from the oil companies, the government could not make a decision. This delay had several effects on the viability of the project. Already, a devaluation of the Kenya shilling in December 1982 had increased the interest and loan repayment liabilities to Girozentrale und Bank by 15 per cent. The Austrian foreign loan of AShs.250.75 million (KShs.190.3 million) accounted for 82 per cent of the total ACFC foreign borrowing. Over the period, ACFC required higher working capital to meet their inventory costs. The total cost to ACFC due to the prolonged closure was estimated at KShs.3.0 million per month. The closure meant that any further prices would have to take into consideration the accumulated interest requirements as well as other additional costs. Consequently, delays in fixing the price required even higher ex-factory prices.

Because of shut-down and other reasons, the cost of the project escalated from KShs.259,582,000 estimated in October 1980 to KShs.300,208,000 in January 1983. Nearly 90 per cent of the cost escalation was due to exchange rate fluctuations. The Kenya shilling was effectively devalued by 20 per cent in 1981 and 15 per cent in 1982. The rest of the costs were accounted for by the high pre-production expenses resulting from delays in the commercialization of ethanol. Unlike the Madhvani project, the plant and machinery was supplied under a fixed price contract and therefore did not undergo unnecessary cost increases. The liquidity of ACFC was



drastically drained during the closure and the company relied on overdrafts to meet essential payments.

Even more serious was the fact that the company was not able to repay its first loan installment of of KShs.7.517 million to Girozentrale und Bank due in December 1982. In order to put pressure on the government to facilitate the introduction of fuel ethanol, ACFC asked the government, which had guaranteed the loan, to repay the outstanding amount and any further default interest. The money would then be converted to a long term loan to be repaid by ACFC when their liquidity conditions improved. As a result an application was made to the bank to reschedule the loan.

Efforts to re-start production were undertaken by the company, the Mehta group and sections of the various ministries. As early as October 1982, the Austrian embassy in Nairobi had contacted the government on the matter. The issue was part of the agenda for discussion between the Austrian Ambassador to Kenya with senior government officials on bilateral issues. The Austrian mission in Nairobi expressed its concern over the closure of the plant and possible ACFC default. The view of the Ministry of Energy was that ACFC was to blame for the delay because they went ahead with construction without making the necessary pricing and blending arrangements.<sup>2</sup> The Austrian embassy was concerned because VEW, an Austrian state-controlled firm, was a shareholder in the venture.

In January 1983 the Ministry of Energy fixed the ex-factory price of ethanol at KShs.5.60 per litre net in bond as had been suggested by the Ministry of Finance (Table 7.3). The retail price for the ethanol blend was put on par with premium gasoline. By doing so, the government had to forego taxes on ethanol, which was another form of subsidy. This price was considered even less favourable to ACFC than it appeared before because the closure of the plant had worsened the liquidity position of the firm. Instead, ACFC suggested that a price of KShs.6.85 per litre in bond would be adequate for loan obligations.

The price build-up maintained the same retailer's margin for premium and gasohol but did not include a city delivery allowance for ethanol. Although the government taxed ethanol, the Treasury lost KShs.13.1 million

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2. Interviews, Ministry of Energy and Regional Development, Nairobi, October 1984.

annually due to the forfeit of import duty on alcohol and the differential in tax between regular and premium gasoline. The oil companies lost a total of KShs.5.9 million in the foregone sales of premium and the price differential between gasoline and ethanol. Possible ways of reducing losses to the Treasury included lowering the ex-factory price of ethanol or raising the pump price of all the fuel types and thereby shifting the costs to consumers.

TABLE 7.3: *Liquid Fuel Price Build-up in Kenya in 1983 (KShs./l)*

	Premium	Regular	Ethanol	Gasohol
Ex-factory	4.042	3.863	5.600	4.117
KPC Fee	0.254	0.254	0.300	0.259
Government tax	3.369	3.078	3.300	3.289
Depot price (Nairobi)	7.665	7.195	9.200	7.665
City delivery	0.030	0.030	--	0.030
Retail margin	0.305	0.295	--	0.305
Pump price	8.000	7.520	9.200	8.000

Source: Ministry of Energy and Regional Development, Nairobi.

In the meantime, ACFC was facing other technical challenges, mainly on the installation of blenders. The Kenya Pipeline Company (KPC), wholly-owned by the government through the Treasury and Ministry of Energy, had accepted to store ethanol at a fee and supply it to the oil companies for blending. An agreement was signed between KPC and ACFC for ethanol storage in March 1983. This was the only formal agreement entered into all through the history of ethanol development in Kenya. KPC also undertook to purchase blending facilities to be installed on the premises of the oil companies.

The choice of the blend and the technical facilities were largely influenced by the conflicting interests over the introduction of fuel ethanol. The government did not relax the octane limits of 93-94 and therefore the blend had to meet these requirements. To achieve this, a three-part blend of 65 per cent premium, 25 per cent regular and 10 per cent ethanol was the most optimal combination. The other option was a two part blend (regular and ethanol) but the octane rating of regular gasoline had to be raised from 84 to 87 and the vapour pressure lowered. KPC preferred a two-part blend partly because they were going to bear the costs of the operation and

preferred a cheaper option. However, the oil companies preferred a three-part blend.

The three-part blend was chosen and it was decided that the blenders, imported from West Germany, would be located at the depots of oil companies. The storage and blending facilities cost KPC some KShs.25 million of which KShs.15 million was in revalued idle capacity and the rest was additional capital equipment, mainly blenders. The blenders earned KPC a fee of KShs.0.03 per litre of ethanol. After the blenders were installed, the government instructed the oil companies to start taking ethanol despite the fact that no formal agreement had been entered into between the parties involved. There were several outstanding issues such as the ownership of ethanol while in transit or storage and indemnity for losses or contamination. The ownership of ethanol during transit was critical because the government planned to tax any lost ethanol at the rate of potable alcohol.

While the debates continued, the government forced the fuel into the market. A notice was issued to the oil companies in March 1983 giving them four days to run down their stocks and prepare to receive ethanol for blending from KPC. The notice also took into consideration the need for government procurement in enabling the fuel to sell. The oil companies were asked to give priority to bulk consumers such as parastatal bodies and government agencies in the conversion process. The refinery was requested to maintain its specifications since the blend was to maintain an octane rating of 93. The consumers were not informed about the introduction. On the morning of April 16, motorists in Nairobi found a new fuel on the market.

The decree was issued by the Ministry of Energy which was handling most of the work related to the introduction of ethanol. The decree overrode the Traffic Act, Chapter 403, Section 51 (1) which states that "no fuel shall be used in any motor vehicle except that specified in the vehicle licence in respect of such vehicle or, in case of a motor vehicle the motor unit which is a compression ignition engine, light amber mineral oil". This offence carries a fine not exceeding KShs.10,000, a maximum three-year prison term, or both. In addition, the vehicle is liable to be forfeited. The Ministry of Transport and Communication drew the attention of the Ministry of Energy to

this section of the Act but the proposed amendments were not carried further than inter-ministerial exchanges.

Different views emerged on the legality of fuel ethanol with the Attorney General's Chambers suggesting that the product should be treated as an additive (such as tetra-ethyl lead) therefore avoiding the introduction of a new Parliamentary bill on the blend. But the Ministry of Energy suggested that the Act be amended to include gasoline substitutes approved by the government. The Ministry of Energy had an interest in having ethanol treated as a new fuel and not an additive. If ethanol was classified as an additive, the central role played by the Ministry of Energy in this matter would be challenged by other ministries.

In the meantime, ACFC entered another trying period; the ethanol niche was effectively blocked and the first two years of their operations were devoted to unlocking the niche from constraints in the adoptive terrain. These constraints not only weakened the liquidity of the firm, but they nearly brought ACFC to collapse. Unlike the Madhvani project, ACFC were able to come on stream in time and the economics of their project looked more favourable. The government was therefore more willing to help open up the niche. It already carried the burden of re-paying the Madhvani loan and did not wish to see another project collapse.

TABLE 7.4: *Production Cost of Ethanol at Triangle*

Cost item	1980/81	1982/83	1983/84
Raw materials	10,439,837	15,070,192	13,127,126
Salaries and wages	107,084	89,423	88,893
Depreciation	223,384	187,500	230,985
Insurance	30,242	33,653	22,561
Utilities	196,010	518,269	744,235
Maintenance	162,804	185,576	106,381
Miscellaneous	36,764	--	--
Total	11,548,618	16,084,613	14,320,181
Ethanol output	30,400,000	40,000,000	36,630,000
Production cost (US\$/l)	0.38	0.40	0.39

Source: Triangle Limited, Triangle.

The introduction of ethanol in Zimbabwe did not go through these challenges. The pricing formula agreed upon by the government and Triangle

allowed for all the production costs and a 5.0 per cent return on investment. Because this was agreed before commissioning, there was no delay in the marketing of fuel ethanol. In keeping with the original goal, the operation showed a saving of foreign exchange in its first years of operation. The savings, however, were dependent on the world market for sugar.

The average production cost over the 1980-83 period was US\$0.35 per litre or US\$16.28 per GJ. Over the same period, the landed cost of gasoline (at Triangle) was US\$0.50 or US\$14.66 per GJ. This means that the cost of producing ethanol was 11.0 per cent more expensive than imported gasoline. This favourable margin was accounted for by low initial capital investment in the plant and the manner in which it had been designed. The fact that the pricing formula guaranteed a return on capital investment allowed additional gains to be made through plant-level improvement.

The foreign exchange saving of producing ethanol at Triangle was dependent on international sugar prices. The plant was designed to respond to these variations. Not much foreign exchange was saved in the first two years of the plant's operation because of the repayment of the foreign exchange component of the project. However, foreign exchange savings were reflected in the 1983/84 production period. From 7.72 tonnes of sugarcane, the plant could either produce 1.0 tonnes of sugar or 623 litres of ethanol. Given the 1984 landed cost of gasoline of US\$0.70 per litre, the foreign exchange saving from ethanol production was US\$436.10. At the world sugar price (New York) of US\$130 per tonne (with US\$55 per tonne for transportation through South Africa) the net foreign exchange saving was US\$175 per tonne.<sup>3</sup>

### **7.3 Progress in a Constricted Niche**

The fact that the adoptive terrain in Kenya had not been adequately prepared for the introduction of ethanol resulted in a constricted niche. The installation of the blenders was not the end of ACFC's problems. As soon as production resumed new problems emerged, this time from the distribution side. The first problem related to the functioning of the blenders. Sales

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3. Lewis, "Some Aspects of Production of Ethanol," pp. 391.

dropped in the months of May and June because one of the main blenders was broken and a dispute arose on who should meet maintenance costs. It emerged then that there was a logistic imbalance between the location, ownership and strategic importance of the blenders for the three parties involved. Malfunction in the blenders strongly favoured the oil companies because they then sold their traditional products and left ethanol stocks to accumulate at KPC and ACFC depots. Although KPC lost revenue, the effects were not as drastic as those suffered by ACFC.

The problem was worsened by the limited storage capacity for ethanol. While ACFC had only 13 days' storage capacity, KPC had about 50 days' capacity, making a total of 63 days. With this level of storage capacity, production became sensitive to sales. Reductions in sales did not only reduce revenue, but they also added to working capital as stocks accumulated. Reductions in sales therefore affected production levels since stocks could not go beyond the 63 day storage limit.

KPC realised after repeated mechanical problems that the costs of maintaining the facilities were much higher than anticipated and suspicion over possible industrial sabotage emerged.<sup>4</sup> This allegation was difficult to prove and much of the discussions were concerned with maintenance liabilities and not proving sabotage. KPC demanded assurances from the oil companies that the blenders would not break again; an assurance that the oil companies could not give. Attempts to pass on the maintenance costs to the oil companies were unsuccessful since the blenders were a KPC investment. While the debate was underway, ACFC attempted to undertake the repair themselves but were denied access to the blenders by the oil companies. Later KPC attempted to sell the blenders to the oil companies but the offer was rejected outright and KPC had to continue maintaining them.

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4. Interviews, Kenya Pipeline Company, Nairobi, October 1984.

TABLE 7.5: *Ethanol Production and Sales (Litres)*

Month	Opening Stock	Production	Sales	Closing Stock
1982				
September	388,603	254,303	--	642,906
October	642,906	--	--	642,906
November	642,906	--	--	642,906
December	642,906	--	--	579,675
1983				
January	579,675	--	--	579,675
February	579,675	--	--	541,382
March	541,382	879,155	65	1,346,626
April	1,346,626	883,795	--	2,230,991
May	2,230,991	395,502	271,200	2,354,287
June	2,354,287	762,885	555,400	2,561,203
July	2,561,203	393,069	543,524	2,410,368
August	2,410,368	--	586,600	1,792,598
September	1,792,598	872,937	572,540	2,093,226
October	2,093,226	446,489	545,700	2,060,046
November	2,060,046	717,817	640,700	2,137,114
December	2,137,114	694,019	592,800	2,190,542
1984				
January	2,190,542	777,910	548,300	2,419,054
February	2,419,054	488,921	660,900	2,261,036
March	2,261,036	347,445	677,100	1,927,681
April	1,927,681	592,663	621,100	1,895,144
May	1,895,144	716,552	505,700	2,082,313
June	2,080,927	513,829	318,700	2,269,749
July	2,269,749	667,672	368,700	2,568,656
August	2,566,608	445,842	531,200	2,481,260
September	2,485,197	765,649	564,127	2,686,766
October	2,694,029	1,212,686	591,400	3,307,372
November	3,307,372	533,144	497,700	3,370,607

Source: Agro-Chemical and Food Company, Nairobi.

But even after the blenders were repaired, ACFC was not able to sell more than a daily average of 42 per cent of its production capacity. Various reasons were given for the constriction of the niche. It was suggested that consumers had switched to regular gasoline which was not blended with ethanol.<sup>5</sup> Since ethanol was being marketed in Nairobi alone, it was thought that consumers were obtaining their supplies on the periphery of the city where the blend was not being sold. Interestingly enough, the use of the

5. This period also coincided with a government decision to restrict the movement of government vehicles, whose effect on ethanol consumption was considered marginal.

blend was not mandatory and various institutions such as the United Nations Environment Programme (UNEP), the State House and sections of the army sought exemption. In addition, the oil companies continued to sell premium gasoline to some consumers. The combined effect of these constraints contributed to the low capacity utilization of the plant. This level of sales could not enable the firm to meet its loan obligations. More pressure was therefore put on the government to stabilize the niche.

Several options emerged for ensuring that the plant realized its full capacity of 45,000 litres a day (Table 7.6). One of the options was to expand the area served by ethanol to cover the whole country. But according to oil company sales figures such an expansion would absorb only 24,000 litres of ethanol a day, accounting for about 53 per cent of the rated capacity of the plant. The extension of the blend zone would also require additional capital investment for new blenders, meters, piping and associated piping. These costs were relatively high for a minor increase in the overall consumption.

Another alternative was to increase the ratio of ethanol in the blend from 10 per cent to 15 per cent (with 44 per cent premium gasoline and 41 per cent regular gasoline). This option could be implemented in less than a month in Nairobi, compared to six months required to market ethanol throughout the country. The only major technical needs were adjustments in the blenders estimated to cost KShs.5,000 and road test expenses. The ratio could only raise sales to 28,500 litres per day, or 63 per cent of capacity utilization. This option could have led consumers to switch to regular gasoline and therefore reduce the consumption of ethanol. The increase of ethanol in the blend ratio would also have necessitated a KShs.0.10 increase in pump price from KShs.8.61 to KShs.8.71, thereby reducing the loss of revenue to the Treasury from ethanol.

The oil companies objected to a blend with 15 per cent ethanol in January 1984 on the grounds that the price structure could not support it and they stood to lose in the process. They demanded a price adjustment that could compensate them for the reduced earnings. Instead they proposed a long-term strategy which included working out the legal agreements, effective blender maintenance, centralizing blenders at the KPC terminal and then introducing a regular-ethanol blend. Most of the suggestions were



either time-intensive or required additional capital outlay and constituted delays which worsened the survival chances of the ethanol project.

The oil companies were interested in getting rid of the blenders altogether because the Customs Department insisted on charging any "lost" ethanol as potable alcohol. Some of the losses allegedly arose from blending errors. Any differences in the tank arising from disproportionate blendings was charged at the rate of KShs.162 per litre (29 times the ex-factory price). Since there was no agreement between the oil companies, KPC and ACFC on ownership of ethanol at various stages, the Customs Department applied existing regulations and the blending losses were charged to the oil companies. It was therefore in the interest of the oil companies to shift the burden to KPC or any other interested party.

TABLE 7.6: *Additional Losses to the Treasury*

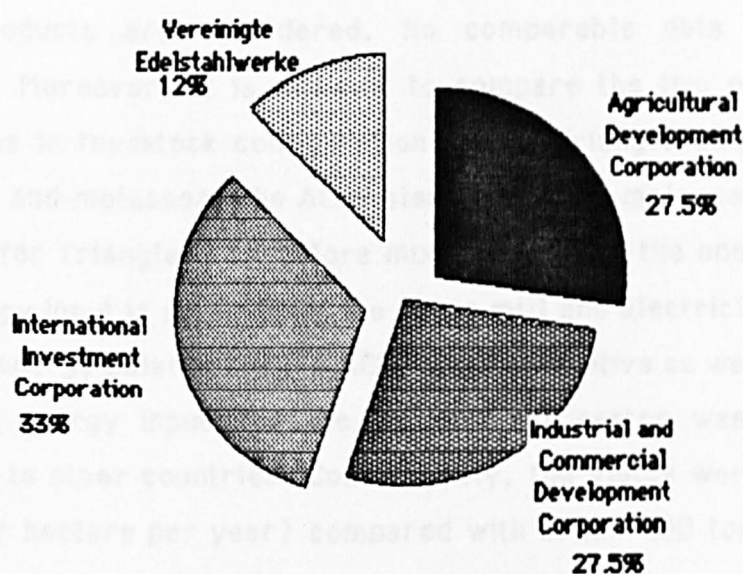
Sales Option	Ethanol (litres/day)	Blend (litres/day)	Loss of Revenue (KShs.)
Target capacity utilized	45,000	300,000	13,100,000
Extended up-country	36,000	240,000	8,640,000
15% ethanol blend	28,500	190,000	6,840,000
Multiple blend	45,000	450,000	5,616,000

Another option for extending the blend zone included a combination of the existing arrangement, with the rest of unsold ethanol blended with regular gasoline. This multiple-blend option could bring the operation of the plant to full capacity. The last option was to get rid of premium gasoline altogether and introduce a mono-grade regular gasoline for blending with ethanol. After a long period of deliberation, the government decided in 1985 that all gasoline shall be blended with ethanol to allow the ACFC plant to operate at full capacity. This was the option taken by Zimbabwe right from the beginning. This option has opened up the ethanol niche and renewed interest in rehabilitating the Madhvan plant as well.<sup>6</sup>

6. This enthusiasm is expected to decline due to the 1986 fall in oil prices. Moreover, any decisions to produce ethanol will have to consider the current oil exploration efforts in the country. More recent developments include a proposal by Mumias Sugar Company to produce fuel ethanol. Mumias has been the proposed site for the relocation of the ethanol plant at Kisumu. An independent proposal by Mumias would most likely pre-empt or complicate current efforts to transfer the plant.

The opening up of the ethanol niche resulted from pressure from the producers, bringing sections of the government into conflict with one another. The government is the main shareholder in the project, accounting for 56 per cent of the equity through parastatals. The government also controls 50 per cent of the refineries; it also guaranteed the foreign loans. The parastatal shareholders have previously withheld equity subscription to ACFC as a way of putting pressure on the government to make favourable decisions on matters such as price increases or market zone expansion.

FIGURE 7.1: *Equity Subscription in the ACFC Venture*



The introduction of ethanol in Zimbabwe was simplified by the agreement reached by all the relevant actors on the basic issues; it was relatively easier to work out the logistics of blending and distribution. The range of conflicting interests was narrower. The fact that both Hippo Valley and Triangle were later owned by Anglo-American made agreements on molasses easier to reach. Moreover, the oil companies were willing to distribute the fuel and there were no refinery vested interested to influence the price structure or technical specification of the fuel.

Even more important was the fact that in Zimbabwe all the liquid fuels were procured by a government agency which resold the products to the oil companies for distribution. This arrangement did not exist in Kenya because

KPC's role was only to transport and store the liquid fuels and not to trade in the products. This was why the blending facilities had to be operated by the oil companies because KPC had no legal right to handle any distribution related aspects. By doing the blending, KPC would also have had to accept responsibility for losses, contamination and any other resulting costs.

#### **7.4 Energy Balance**

Energy balance is a key issue in ethanol projects. A study of Triangle by Lewis showed that the net energy ratio of the plant is 1.15 if ethanol is treated as the only output.<sup>7</sup> The ratio, however, was given as 1.52 if all the major products are considered. No comparable data on Kenya were available. Moreover, it is difficult to compare the two plants because of differences in feedstock configuration. While Triangle was designed to use both juice and molasses, the ACFC plant uses only molasses. The analytical boundary for Triangle is therefore much wider than the one for ACFC whose main energy input is steam from the sugar mill and electricity from the grid. A partial energy balance for the ACFC plant is positive as well.

The energy input into the agricultural sector was relatively high compared to other countries. Consequently, the yields were also high (112 tonnes per hectare per year) compared with Brazil (60 tonnes per hectare per year) and Mauritius (78 tonnes per hectare per year). While cane production at Triangle was done under irrigation, non-irrigated cane growing was dominant in other countries. The energy input into non-irrigated cane production was equally lower. Most of the sugarcane grown in Kenya is rainfed and the energy inputs were possibly lower than Zimbabwe.

An approximation of the energy picture of the ACFC plant shows a favourable energy balance. The ethanol component of the plant requires 82,476 tonnes of steam a year. Producing 1.0 million litres of prima spirit requires 13,362,494 MJ of steam (calculated at 2,904.8 MJ per tonne of steam at 10 bars). In addition, 120 MWh or 432,000 MJ of electricity was needed, amounting to 13.79 million MJ or 13.79 MJ per litre. The plant

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7. Lewis, "Some Aspects of the Production of Ethanol," pp. 379-382.

generated about 176,100 tonnes of slops a year from the distillery which was treated at the cost of 107.14 million MJ. For 1.0 million litres, the energy requirement for evaporation was 5.95 million MJ.

TABLE 7.7: *Energy Input into Sugarcane Production at Triangle\**

Input	(GJ/ha/yr)
Fertilizer	
Ammonium nitrate	38.50
Single super phosphate	3.30
Potash	1.00
Herbicides	0.21
Insecticides	0.03
Seed	1.31
Labour	2.37
Fuels and lubricants	4.16
Electricity	10.51
Maintenance and repairs	13.20**
TOTAL	74.60

\*Sugarcane field cover 12,200 hectares.

\*\*The annual energy used in manufacturing, commerce and transport is 2,171,000 tonnes of oil equivalent while the value of gross domestic output from the sectors is \$1295 million. Thus the energy value of expenditure in these sectors is  $(2171 \times 10^6 \text{ kg} \times 42 \text{ MJ/kg}) / \$1295 \times 10^6 = 70.4 \text{ MJ per dollar}$ .

Source: Lewis (1984).

TABLE 7.8: *Energy Input into Sugarcane Processing at Triangle*

Input	(GJ/ha/yr)
Electricity	23.61
Coal*	83.93
Maintenance and repairs	9.81
Labour	0.02
TOTAL	117.37
Total energy into processed sugarcane for ethanol production**	87.84

\*Bagasse from fuels for boilers for 9 months a year and coal is used during the rest of the year.

\*\*The total sugar processed is 1,360,060 tonnes. Input into the plant is 35,276 tonnes of invert from molasses plus 21,960 tonnes of invert from juice, amounting to 57,236 tonnes of invert in sugarcane equivalent (15% invert in sugarcane). The area required to produce sugarcane for ethanol is  $(381.573 / 360.060 \times 12,200 \text{ ha})$  3,423 hectares. Invert production (juice and molasses) consumes 20% about 20 per cent of energy in sugar processing. The energy input into the processing of invert is 0.20/0.28 that of the total figure for the sugar processing plant (expressed as GJ/ha/yr).

Source: Lewis (1984).

TABLE 7.9: *Energy Inputs into Industrial Process for Ethanol Production\**

Input	(GJ/litre/yr)
Fermentation	353.43
Distillation	42.41
Chemicals and additives	
Diamonium phosphate	79.39
Urea	27.04
Sulphuric acid	150.00
Benzene	146.80
Labour	0.41
Maintenance and repairs	115.13
Total	914.61
Total (in GJ per hectare per year)**	8.12

\*The units apply to a litre of ethanol produced (out of a total output of 30.4 million litres).

\*\*The area of land required to produce sugarcane for input into ethanol plant is 3423 hectares (381,573/1,360,060) x 12,200 hectares). Effective ethanol yield is thus 8881 litres per hectare.

Source: Lewis (1984).

TABLE 7.10: *Energy Output from the Triangle Plant\**

Output	(GJ/ha/yr)
Ethanol	190.94
Stillage	62.71
Fusel oils	0.29
Aldehydes	1.74
TOTAL	255.68

\*The effective area of land is taken to be 3423 hectares.

Source: Lewis (1984).

Despite the fact that the energy balances of Triangle and ACFC cannot be compared, it appears that there are differences in the way matters pertaining to energy use were conceived. For example, the decision by Triangle to use stillage for irrigation was partly influenced by the need to cut down on energy expenditure on waste treatment. It was also shown that decisions on energy use affected the milling process. The ACFC plant, on the other hand, incorporated an evaporation unit which accounted for over 20 per

cent of the total energy input. Possible shortages of energy became a matter of concern while construction was underway and attempts to burn stillage and recycle the steam failed because of lack of funds to import the equipment. The ACFC plant could not return the stillage to the canefields because they do not use irrigation.

TABLE 7.11: *Partial Energy Balance of the ACFC Plant*

Item	Quantity	MJ
INPUT		
Production		
Steam	4,600 tonnes	13,362,494
Electricity	120 MWh	432,000
Evaporation steam	3,049 tonnes	5,952,248
Total		19,746,742
OUTPUT		
Ethanol	1.0 million litres	21,500,000
BALANCE		1,753,258

## 7.5 Plant Performance and Technical Drift

In the previous chapter it was argued that the Triangle project was designed to enable the management to undertake plant improvement and process rationalization. The Mehta project, on the other hand, relied on technical expertise from the suppliers under a technical agreement. The choice of the Triangle process was done under conditions of foreign exchange constraint and therefore some of the technical advances in ethanol production could not be incorporated in the original project design. Instead, provisions were made to enable the incorporation to be undertaken in the post-start-up period. Apart from these dynamic changes, provisions were also made for static changes such as capacity expansion through additional tanks.

These provisions were made in anticipation of changes in the external environment such as improvement in the foreign exchange situation or potential expansion of the size of the ethanol market. However, technical pressures originating from the production process itself led to attempted technical changes at various stages of the process. These pressures were expected because some technical specifications had been lowered because of foreign exchange problems. The plant had therefore to be monitored closely so as to identify and solve various resulting problems. Additional pressure to improve the process resulted from the fact that higher conversion efficiencies reduced the demand for sugar for fermentation and therefore left an exportable surplus. This reduced the intensity of competition between export and energy requirements for sugar.

Fermentation feedstock could be collected at different boiling stages of the milling process. This could vary from the stage immediately after juice extraction or down the line to the molasses stage. Normally molasses "B" is further processed to leave molasses "C" which has lower sugar content. Laboratory tests showed that the third boiling (which left molasses "C") considerably reduced the amount of fermentable sugars. Triangle therefore decided to abandon this last stage and collect juice before evaporation. The decision also led to energy savings (almost equivalent to the energy required for distillation or 25 per cent of all the energy required for ethanol production). It was no longer necessary to build additional boilers as low pressure steam could be obtained from the installed power station.

The first critical point during the post-start-up period was a shortfall of 3,000 tonnes of molasses due to unreliable measurement. Hitherto, Triangle had normally measured the inflow of molasses in volume and then converted the units into tonnes using an average number. This method had several shortcomings. Errors in measurement could easily distort expected yields. The most serious problem was that it did not give reliable information on fermentation yields. This information was necessary both for process improvement and decision-making because the amount of ethanol expected from a unit of molasses was dependent on its content of fermentable sugars.

These pressures required the generation of site-specific technical knowledge on which improvements could be based. The management decided to hire a biochemist to monitor the plant and make the necessary improvements. The first major challenge to the plant was instrumentation, especially for measuring the various constituents of molasses and cane juice. A choice had to be made between the widely used gas liquid chromatography (GLC) and high pressure liquid chromatography (HPLC) techniques. The two techniques are fundamentally similar because they involve separating the components of interest from other substances in the analytical sample for quantification.

However, there are practical differences. In GLC, volatile materials in a stream of inert gas are separated by passing them over a stationary liquid phase of low volatility. But since sugars are not volatile, they must first be converted into volatile derivatives before they can be subjected to GLC. In HPLC, the moving phase is a liquid and the stationary phase is a solid. Since sugar is soluble in water, HPLC can be used without having to prepare sugar derivatives. Sample preparation in HPLC is limited to filtration. Triangle chose HPLC because it was easier and faster to use than GLC. The equipment was bought from Waters (USA) at Z\$18,000.

TABLE 7.12: *Comparison of Classical and HPLC Methods\**

Substrate	Purity (%)**	Ethanol yield (l/kg of Fermentables)	
		Classical methods	HPLC
Juice	8.55	6.06	6.11
Syrup	8.48	6.05	6.07
"A" molasses	6.91	5.83	6.13
"B" molasses	5.28	5.64	5.91
"C" molasses	3.72	4.98	5.95

\*The results are means of five determinations for each case.

\*\*Purity is calculate as a percentage of sucrose over total dissolved solids.

Source: Triangle Limited, Triangle, Zimbabwe.

Other considerations were included in the choice. HPLC is relatively cheaper to use and has lower operating costs. In addition, the results are



available within 15-20 minutes of samples being taken and quantification of all the substances of interest (sucrose, glucose, fructose, ethanol and glycerol) is done in one sample. Because of its simplicity of use, HPLC does not require specific skills among users. The introduction of HPLC at Triangle did not only influence the technical aspects of the plant, but also gave the management more flexibility in decision-making. For example, data on the completeness of fermentation could be obtained in 15-20 minutes and therefore the management could decide either to stop or continue fermentation in time and with relative certainty.<sup>8</sup>

The introduction, however, was not done without resistance, especially from the technicians and the associate laboratories of Hullet's. The technicians viewed the introduction largely in the context of their specialist knowledge of the use of GLC equipment. HPLC made their skills almost redundant because the new method could be used by any worker at the plant with minimal training. Hullet's, on the other hand, was concerned with conformity in data collection since their other operations used classical methods such as GLC. The resistance, however, took a technical outlook with arguments on the reliability of HPLC. A series of tests were conducted to establish the reproducibility of the results. Mean reproducibility tests over May-July 1983 showed standard deviations of 0.67 per cent for sucrose, 1.12 per cent for glucose, 0.80 per cent for fructose and 0.97 per cent for sucrose, showing relatively high reliability.<sup>9</sup>

With the help of HPLC, Triangle was able to initiate a number of experiments aimed at improving the process. The changes were in fact similar to those already included in the advanced plants available on the market. The planned improvements constituted efforts to re-trace the innovation path followed by ethanol technological systems. The choice of the improvement path, however, was determined by internal imperatives of the plant. The first experiment involved the recycling of yeast by using a centrifuge borrowed from a local firm. The objective of the experiment was to find ways of saving on the sugar used in the growing of fermentation yeast.

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8. Tannock, "The Application of High Pressure Liquid Chromatograph," pp. 77-77.

9. *Ibid.*, pp. 74.

The novelty of this experiment included the partial conversion of the process from batch to semi-continuous.

The experiment showed that recycling yeast saved about 3.0 per cent of the sugar used in ethanol production. This experiment had strategic considerations as well. Triangle envisaged possible increases in ethanol consumption. Such demand could easily be met by making the process continuous instead of batch by adding centrifuges for recycling yeast. Centrifugation could increase the residence time of fermentation by 50 per cent thereby raising the volumetric efficiency of the plant. By January 1985, the management estimated that an investment of Z\$180,000 in an Alfa-Laval FESX 512S centrifuge could be repayed in six months. Apart from ethanol-specific knowledge on yeast, Triangle attempted to use the plant as a base for generating and diffusing knowledge on yeast. This was envisaged as a training project for firms with yeast-related activities in the country.

TABLE 7.13: *Effects of Stillage Recycling on Fermentation*

Stillage content (%)**	Time for Complete Fermentation (hrs)	Ethanol Yield (1/100 kg TFAS)*	Dissolved Solids in Stillage
0	36-40	57.9	7.9
10	28-34	57.7	9.9
20	30-36	57.9	10.6
30	34-38	57.2	11.1
40	34-38	57.5	14.7

\*Total fermentables sugars expressed as sucrose (TFAS).

\*\*Dissolved solids were determined by daily composite stillage sample analysis.

Source: Triangle Limited, Triangle, Zimbabwe.

The second experiment undertaken by Triangle involved stillage recycling. The need to recycle stillage resulted from two main concerns. The first was the waste disposal problem which forced Triangle to look into different options. The second was the need to raise the solids content of stillage for the production of concentrated molasses stillage (CMS) for animal feed. The alternative was to use additional energy to evaporate the stillage. One of the ways of achieving the two objectives was to return

stillage into the mash, which also reduced the demand for dilution water. But the recycling of stillage required knowledge on its effects on fermentation.

A series of experiments established that the share of stillage in the mash could be raised to 40 per cent without adverse effects on the fermentation process. However, high solid levels increased corrosion in evaporators and scaling of distillation columns. The latter problem was solved by washing the stripping reboiler with caustic every 6-8 weeks. Even after the CMS venture stopped, Triangle continued to recycle stillage as a way of raising fermentation temperatures in winter. The average winter temperature at Triangle is 23°C while 30-35°C is required for optimal fermentation. In this case, stillage which is normally 96°C on outflow, is used to raise the temperature of the mash to required levels.

Another innovation Triangle introduced involved stillage disposal. So far it had been shown that the production of CMS and the recycling of stillage partly alleviated the waste disposal problem. However, the plant still released vast quantities of stillage that had to be disposed of. After considering various options, it was decided that the most suitable option was to dilute each litre of stillage with 40 litres of water and irrigate the cane with the mixture. This approach helped to improve cane yields in the stillage-irrigated areas by about 7.0 per cent. However, the long-term effects of this process were not known and the management continued to search for an alternative disposal technique. The worry sprang over the fact that the stillage contained compounds collected from over 34,000 hectares and returned to less than 10 per cent that surface area. The long-term effects of mineral concentrations on microbial flora and their potential effects on sugarcane productivity were not known.

One of the alternative approaches considered by Triangle was to incorporate some of the components of the Alfa-Laval's Biostil process into the plant thereby changing it to a high brix fermenter. This option was initially rejected because the raw materials at Triangle were available in the form of molasses or cane juice which would have to be further concentrated before being fermented under the high brix requirements of the Biostil process. Furthermore, Triangle did not foreclose the option of extending the area under stillage irrigation.

Other projects under consideration at Triangle include investigations into ways of cutting down on the consumption of various nutrients in fermentation, especially urea and diamonium phosphate (DAP). One of the drawbacks of DAP is that it leaves solid residues in the fermentation tanks. Alternatives to DAP include phosphoric acid which is a liquid and leaves no solid residues. Such changes require controlled studies to establish their effects on ethanol yields.

All these experiments enhance the adaptive parameters of the plant while at the same time enabling the management to acquire technical knowledge necessary for the improvement of the plant or the potential expansion of the ethanol niche. Triangle has therefore become a vital node in the network of knowledge systems related to ethanol production in particular and other aspects of bio-processing. The experiments at the plant also represent efforts to respond to internal technical pressures by building a stock of knowledge that would enable them to respond favourably to changes in the external environment.

It is notable that the search of the international market for potential contributions to the adaptive parameters has become part of the regular operations of the Triangle management. Trade magazines and technical journals are constantly monitored for technical advances. The potential contribution of new equipment to the improvement of the plant is part of the management routine. The knowledge search and accumulation process is part of the learning process of the firm and is guided by both short-term and long-term considerations. In the short-term, the firm requires a certain stock of knowledge with which to respond to technical problems.

Since the source of such problems is unpredictable, the stock of knowledge must be broad enough to cover all the critical areas. These short-term considerations are associated with repair and maintenance. However, these are not normal activities because the original design of the project embodied relatively high break-down probability due to the deviation from the design specifications. The long-term considerations include major changes in the process either through static expansions or dynamic innovations which embody more advanced functional units such as centrifuges for yeast recycling or even high brix fermentation units. These latter

considerations are strategic in that they equip the firm with the capability to respond favourably to external changes.

The efforts at Triangle to generate plant-specific technological knowledge contrasts sharply with the ACFC approach to technical improvements. In the first place, the low level of capacity utilization of the ACFC made it difficult for any reliable data on plant performance to be obtained in the first two years. Secondly, a technical agreement with the suppliers promised that any technical advances in the process would be provided to the plant by the technology suppliers. As a result, ACFC relied either on the agreement or on new equipment supply for plant modifications.

The firm has a training programme which has a dual mandate. First, it is aimed at phasing out expatriates and replacing them with Kenyans in accordance with government requirements. Second, the programme plans to use training as a way to "increase the efficiency and productivity to ensure a smooth and trouble free running of the plant so that all the products are manufactured at a most economical and profitable cost of production".<sup>10</sup> Despite this assertion, the training programme concentrates on the Kenyanization of the staff and there is no clear strategy to accumulate plant-level technological knowledge. The ACFC management argue that they could not invest in long-term training and accumulation of technological knowledge because the employees could easily leave them for other jobs. As a result, the training programme was designed to cater for medium-term operating requirements and not long-term plant-level capability accumulation.<sup>11</sup>

As pointed out in the case of Triangle, the generation of plant-level knowledge could not be effectively undertaken without adequate instrumentation. The ACFC plant started operations with inadequate instrumentation and called on the suppliers to carry out repairs or replace some of them. These problems affected key instruments such as the research centrifuge, Abbe refractometer (which was supplied without an instruction manual), electric crucible furnaces (which were not operating at

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10. ACFC, *Training Programme*, pp. 1.

11. Interviews, Agro-Chemical and Food Company, Muhoroni, September 1983. This view is also reflected in the training programme document: "It is probable that some of the trained personnel will leave the company for other industries... It is proposed, therefore, to have certain flexibility to cater for such eventualities," *ibid.*, pp. ii.

the required temperature) and heating mantles. Without these instruments the laboratory team could not carry out the required tests adequately, leave alone initiate new experiments.

TABLE 7.14: *Changes in Ethanol Yield at Triangle*

Total fermentables	1980	1981	1982	1983	1984
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Fermentables input (tonnes)					
Molasses	32,807	49,124	54,850	69,154	77,786
Juice	20,854	21,843	16,987	3,637	799
Total	53,661	70,967	71,834	72,791	78,585
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Molasses as percent of total	61	69	76	95	99
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Yield	562	539	534	504	509
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Source: Triangle Limited, Triangle, Zimbabwe.

Whereas at Triangle the generation of plant-level knowledge was viewed as a way of saving on capital outlays, the ACFC management relied on capital availability as a source of improvement. This was partly encouraged by the investment climate in the country which inhibited the local supply of technological inputs. The technical agreement also provided for the continued dependence on the suppliers for technical expertise. Under the agreement, the cost of some of the repairs was charged to the suppliers thereby pre-empting the need for plant-level skills.

Over the first five years of the operation of the Triangle plant, the fermentation yield of the the plant steadily declined. The decline in fermentation yield is related to changes in feedstock composition. In 1980 molasses accounted for 61 per cent of the total feedstock. This share increased to 76 per cent in 1982 and 99 per cent in 1984. Over the same period, ethanol yield per tonne of sucrose declined from 562 litres in 1980 to 534 litres in 1982 and 509 litres in 1984 (Table 7.14).

## **Conclusion**

This chapter has examined the process of niche realization and identified some of the main features of the techno-economic landscape which influenced the post-start-up development of ethanol projects in Zimbabwe and Kenya. It examined the record of the Triangle and Mehta projects and stressed that the differences in their performance was largely influenced by the same factors identified in the previous chapters. It was shown that over time, Kenya attempted to improve the adoptive terrain for ethanol by making modifications in the techno-economic landscape, thereby preventing the Mehta project from collapsing as well. While much of the time in Kenya was spent on bringing the plant to full capacity utilization, Triangle moved smoothly through the start-up period and introduced a programme to improve the performance of the plant through the accumulation of plant-level technological knowledge.

## **8. CONCLUSIONS AND CONJECTURES**

### **Introduction**

This study has come to a close. The previous chapters presented an evolutionary picture of the development of fuel ethanol technology in Zimbabwe and Kenya. This chapter will summarise the central arguments of the study, examine the policy implications of the findings and make a plea for further research using evolutionary approaches. The policy considerations will relate to both national economic strategies as well as patterns of technological development. It will also be pointed out that the evolutionary approach taken in this study is part of an emerging world view that is gradually permeating the natural and social sciences.

### **8.1 Retrospect**

This study has shown that fluctuations in the energy techno-economic landscape created favourable conditions for the introduction of new technological systems. The opportunities, however, could only be realized through an implementation process under which the adaptive parameters of the candidate technological systems were matched with the adoptive pre-conditions. The cases of fuel ethanol development in Zimbabwe and Kenya illustrated this point. The evolutionary picture that emerged represented both gradual and major changes in the patterns of resource use as well as in the development of ethanol technological systems.

The liquid fuel sub-sectors of Zimbabwe and Kenya were viewed as landscapes in which different technological systems were adapted to the production and utilization of different energy forms and occupied different market niches. Gasoline occupied a central role as a motive fuel in the energy balances of these countries. The 1973-74 oil crisis ushered in major



fluctuations which created favourable conditions for the introduction of alternative liquid fuels. The process of niche realization largely depended on the availability of technological options whose technical and financial features allowed them to compete favourably with conventional energy sources. This was aided by the decline in molasses prices which made its local use as an ethanol feedstock possible. The niche realization also necessitated the modification of the adoptive terrain to facilitate the introduction of the new technological systems.

The process took an evolutionary perspective because it involved the generation, selection and retention of technological options under constantly changing conditions. The evolutionary trail reveals periods of gradual change (associated with technological drift), punctuated by moments of increased innovations (both novel and recombinant) which were often linked to periods of major fluctuation. The process was associated with a complex network of institutional arrangements which were also reformed either in response to the changes or in anticipation of emerging niche opportunities. Institutions played a central role because the process was not random; it was purposive and based on socio-economic expectations. Variations in expectation and purposive action resulted in different forms of institutional organization. It was precisely this point that led to major differences in the process of niche realization in Zimbabwe and Kenya.

This study has presented a long trail of events in a historical perspective and attempted to unravel the logic underlying long run technological change. It has attempted to show that long run transition manifests an internal evolutionary logic which can be isolated on close examination, especially when attention is given to detail. The study has also dealt with a process that is irreversible. As pointed out in the study, the problem of irreversibility is taken for granted in conventional thinking since the notion of equilibrium is timeless. The comparison of statics also assumes that change through time does not influence the events being compared.

The economic structure has been presented as an open system which undergoes fluctuations and internal re-organization through innovations. The ethanol niche is but a small section of a much wider system that is in

constant flux. As Prigogine *et al.* have argued, fluctuations are the main source of re-organization in open and non-equilibrium systems.<sup>1</sup> It is my view that such an evolutionary logic enables us to see technological systems as constantly changing entities with no fixed initial conditions. They are, however, products of purposive action based on socio-economic expectations.<sup>2</sup>

## **8.2 Policy Considerations and Conjectures**

The findings of this study cannot be generalized to other technologies or be used for formulating definitive energy or economic policies. There are limits to what one can learn from case studies. However, there are conjectural policy lessons which can be drawn from the studies. Two sets of policy considerations have emerged in the course of this study. The first relates to the organization of economic systems and role of energy diversity in reducing vulnerability to fluctuations. The second set pertains to technology policy. More generally, they pertain to technological change as part of a broader development strategy.

### **8.2.1 Energy diversity and economic stability**

One of the most significant policy lessons of the 1970s was the economic vulnerability of the developing countries to fluctuations in strategic resources such as oil. Their heavy dependence on oil imports developed over a period which was marked by the absence of major price fluctuations or disruptions in supply. Such conditions led to the assumption that trends in oil prices would continue along past patterns and would be fairly predictable. This linear view resulted in policies and institutions which

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1. Prigogine *et al.*, *Order Out of Chaos*, pp. 177-209.

2. Although the process of innovation is purposive, its final outcome is stochastic. New innovations introduced into the economic system lead to unpredictable effects. This co-existence between purposive and stochastic processes has major policy implications that will be discussed in the next section.

pre-occupied themselves simply with oil procurement and payment procedures. The basic procedures became part of business practice and were not added to governments' agenda of critical issues. The steady supply and stable prices that marked the supply side, together with the procurement routines which evolved in the developing countries combined to form a fairly reliable oil trade. The oil crisis changed all this of course.

The assumed reliability was also reflected in the view that increases in energy consumption corresponded with similar rises in economic growth as measured in GDP. This piece of numerology was shattered by the post-1973 growth patterns in various countries as wider gaps started to emerge in growth indices of GDP and energy consumption. The dependence on imported oil and the assumed stability of prices and supply also carried the seeds of vulnerability. There were no immediate reasons to allocate financial and institutional resources to the search for alternative sources of energy. Most countries were therefore ill-equipped to deal with major fluctuations in the prices and availability of oil. This point illustrates the extent to which institutions and technological or resource patterns co-evolve.

It was not just the dependence on imports that led to vulnerability. The fact that these countries relied heavily on petroleum as a motive fuel made the economies vulnerable to disruptions in its supply. But such a problem would still occur even if oil was locally produced. What is needed is therefore *diversity* as a basis for reducing the sources and effects of fluctuations. Diversity in this case introduces an element of flexibility and stability in the economic system. The case for diversity almost immediately runs contrary to the absolutist view of the world in which only one economically viable form of energy becomes the dominant source. This view is supported by arguments such as economies of scale and production efficiency. It is indeed a powerful argument in a world that attempts to adhere to certain principles of absolutist rationality.

Most conventional cost-benefit analyses tend to operate against the need for diversity because they seek to establish one viable option of doing things. The case for diversity can be established through more comprehensive cost-benefit approaches which take into consideration the need for economic stability. This may be done at the cost of economic

efficiency and that is why economic arguments become the basis on which the decisions are judged. The choice to sacrifice economic efficiency for the sake of diversity is largely a political one because it includes the redistribution of costs, benefits and risks in the economic system.

Brazil is an example of this. While the fuel ethanol programme can be argued to be uneconomical in strict economic terms, the economy has over the last decade introduced diversity and possible stability in the energy environment. The diversity that the programme introduced goes beyond the energy environment. The wide range of technological projects initiated through the programme are likely to spread to other sections of the agricultural sector. On a smaller scale, the Zimbabwean plant has become a source of knowledge on fermentation-related technology for other industries. The introduction of energy diversity adds to the general technological stock of the country in ways that cannot be ascertained by arguing for single options.

The development of fuel ethanol in the developing countries suggests that one of the ways of dealing with economic crises which result from dependence on single strategic resources is to introduce a certain degree of diversity by generating alternatives. This seems to be a logical imperative which suggests that the effects of fluctuations in strategic resources could be minimized by the planned introduction of diversity. What crises seemingly do is to bring to the forefront special cases which call for diversity. The cases are special because they relate to particular resources and specific periods in history. What is needed is a more comprehensive strategy to strengthen the economic base through diversity.

The oil crisis did not just highlight the problems related to liquid fuels, it created the need for diversity in the energy environment in general. One of the ways to introduce energy diversity and reduce dependence on exhaustible resources was to develop the so-called renewable sources of energy.<sup>3</sup> These resources are numerous and vary widely in their characteristics. They range from science-intensive technologies such as

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3. The notion of renewability relates both to the use of solar influx and resource management. The long-term renewable potential can only be realized through resource management. Renewability does not apply to cases such as forest depletion.

photovoltaics to incremental innovations such as efficient wood-burning stoves. One renewable resource base that has received increased attention is biomass.

Biomass is one of the most abundant resources on earth and can be used as a source of energy in various forms such as charcoal, methane and fuel ethanol. Its versatility already suggests that it could contribute to energy diversity. The fact that the resource is renewable makes it a suitable source of stability because it can be managed to maintain a balance between productivity and harvesting. But the degree to which any of the various sources of biomass energy can be introduced depends on the structure of the economy, income patterns, end-use characteristics and the available conversion technologies. This suggests that policies to introduce diversity in the energy environment also imply changes in social organization and the related institutional arrangements. This re-affirms the view that these changes have far-reaching social and political implications which have to be considered when formulating energy-related policies. It is therefore not a surprise that the introduction of fuel ethanol in Zimbabwe and Kenya needed political goodwill and bureaucratic support.

As noted elsewhere, politics is largely about choices between variations in anticipated social changes. Political considerations are often presented in different ideological outlooks which provide a context through which the future can be anticipated. The role of anticipation is even more crucial if one considers that the outcome of various actions is stochastic and irreversible. Politics then becomes a process of making choices about the future under conditions of uncertainty. The element of uncertainty is usually heightened under a crisis and may lead to intense and differentiated political activity. It is precisely this point that makes political considerations an important aspect in the introduction of diversity in economic systems.

Biomass availability is necessary for the introduction of diversity in the energy environment. However, the introduction is largely related to the ability to generate or acquire the required conversion technology. This shifts policy considerations to the general need to establish diversity in the economic systems to more detailed aspects of technological development. It is through technical and institutional innovations that economic systems can

be re-organized to achieve short-term crisis management goals and introduce diversity as a potential source of long-term stability.<sup>4</sup>

### 8.2.2 Technological and institutional considerations

The case studies present a large number of conjectural policy lessons on the acquisition and development of technological capability. These lessons fall into two broad categories; those pertaining to economic policies that facilitate the accumulation of technological capability, and those which relate to operational approaches. We shall refer to the first category of issues as *strategic*, and the second as *tactical*. These two categories do not suggest a dichotomy because strategic and tactical issues interact intimately in the process of project implementation and influence each other over time. This is precisely because project implementation as a *learning process* influences overall national policies and is in turn influenced by them.

The study showed that the Zimbabwean project was implemented more successfully than the Kenyan one. This comparison evoked institutional and historical reasons to explain the differences in policy formulation and implementation. It can be counter-argued that the policy approaches were specific to the different countries and cannot therefore be compared. Indeed, an approach that takes a conventional political economy approach would suggest that there were no alternatives for Kenya given the class structure and links between the local business community and foreign firms, especially transnational corporations. But this view cannot explain the fact

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<sup>4</sup> The concept of diversity attains even more operative value if one considers that social advancement occurs partly through a series of experiments whose results articulate themselves through the economic system by selection and imitation. This view suggests that the degree of diversity within the system and a certain measure of autonomy would allow more experiments to be performed and therefore avail a larger number of possible options for articulation. This makes diversity a pre-condition for social re-organization. The very notion of re-organization presupposes the existence of a range of options which can only be enhanced through diversity. The size of the experiments also matters. An appeal to diversity carried an element of decentralization. There is, however, a danger in advocating diversity as an end in itself because all sorts of undesirable social experiments could be performed under the banner of diversity. We are of course assuming that a country has a political framework that provides adequate criteria for the choice of social experiments and accepts the principle of public accountability. Diversity should therefore not be confused with anarchy.

that over the same period, Kenyans were developing geothermal energy resources using strategies that were similar to Zimbabwe's. The development of geothermal energy in Kenya also undermines the view that the state is a homogenous unit that represents particular class interests. This kind of analysis has very little policy value and underestimates the variability in socio-economic expectations and these are reflected in government circles.

There are clear differences in the way the two governments related to investment projects in general. The behaviour of the Zimbabwean government was guided by principles of self-reliance in industrial development. The Zimbabwean government did not invest in projects; that was left to the private sector. All they did was to regulate the patterns of investment to ensure that they conformed to the long term economic objectives. The goals were clearly stated and government institutes were organized to reflect the related overall strategies. Policies pertaining to the use of local resources for industrial production were effectively implemented and had a long history going back to the 1940s. These kind of policy guidelines were not unique to Zimbabwe. Indeed, Kenya is currently attempting to introduce similar guidelines as a measure to improve efficiency in local industrial production.

While Zimbabwean policies governing imports favoured the use of local resources (both raw materials and industrial capacity), those in Kenya were largely inimical to the full capacity utilization of the industrial base. They retarded its expansion and diversification. Over the 1970s, Kenya's industrial sector experienced low capacity utilization and declining trends in gross fixed capital formation. The foundries used only 23 per cent of their capacity while the metal engineering workshops utilized only 34 per cent of the capacity in the 1980s.<sup>5</sup> Over the 1976-1982 period, gross capital formation in machinery and equipment declined from K£102.67 million to K£95.16 million in 1982 (at constant 1976 prices).<sup>6</sup> Part of the decline was accounted for by the collapse of the East African Community and the closure of the Kenya-Tanzania border in 1977. The two events reduced the demand for Kenya's industrial output. The economy was not effectively re-organized in

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5. Coughlin, *Converting Crisis to Boom*, pp. 2-3.

6. Republic of Kenya, *Statistical Abstract*, pp. 43-44.

response to the changed external conditions. No systematic efforts were undertaken to search for local markets for the idle production capacity of the industrial sector.

The policies introduced in Zimbabwe may appear to have been influenced by the war situation and international sanctions and therefore may not be applicable to the Kenyan conditions.<sup>7</sup> While this may be the case, the policies related specifically to economic disruptions and can therefore be applied to other countries with similar economic constraints. Indeed, the oil crisis created similar economic conditions. The saving of foreign exchange through the use of local industrial resources was not a problem unique to Zimbabwe under UDI. What the sanctions did was to make such policies the only viable option open to the country.

One of the main concerns of the government which seems to have prevailed all through the implementation of the Triangle project was the need to find a balance between *strategic* and *economic* considerations. The choice of projects in Zimbabwe was done both on strategic and economic benefits. This selection process was influenced by the need to save on the available resources such as foreign exchange. For over a decade, the ethanol project could not be justified both on strategic and economic grounds. But when the economic gains seemed substantial, the government gave its approval. In Kenya, much of the controversy concerned both the strategic and economic value of the projects in relation to the level of investment. It is notable that Zimbabwe was concerned with strategic issues even though the government had no plans to invest in the project.

Strategic considerations bring us back to the theme of diversity. Whereas in Kenya the ethanol projects were independent industrial investments, Zimbabwe pursued other alternatives under a wider *energy programme* to reduce vulnerability. This was indeed an attempt to introduce diversity in the energy environment. Various government departments as well as research institutes collaborated with the private sector in this endeavour. No similar efforts were initiated in Kenya and the ethanol projects represented isolated investment ventures.

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7. The re-organization of the Zimbabwean industrial structure to rely on more heavily on domestic markets started with the break-up of the Federation of Rhodesia and Nyasaland.



The overall strategic guidelines are not themselves ultimate laws which do not change. It has been argued elsewhere that one of the problems with conventional thinking is that it tends to ignore the flow of time and the related changes in economic organization. The situation is even more serious where government policies do not undergo *constant review* in light of changing economic conditions. Policy guidelines are usually abstractions from specific historical periods and do not necessarily relate to reality at other moments. It is however assumed that the guidelines are rational and would help establish a set of desirable economic practices. But the constant re-organization of the economic system brings about new developments which necessitate a review of existing policy guidelines.

The review of government policies was constantly done in Zimbabwe whereas in Kenya government technology-related policies remained almost unchanged all through the 1970s. Constant policy review would enable the country to identify emerging trends and formulate relevant strategies. Without the benefit of policy review, the ability of the country to reform its institutions in view of the changing conditions would be very much limited. But undertaking policy reform requires a certain measure of confidence and appreciation for self-criticism. These are crucial elements in the ability of a system to change because it implies questioning or even abandoning established practices in view of new realities and *experimenting* with new ones whose effectiveness is uncertain.

This leads us to the role of institutions as sources of change. Institutions perform three basic functions which are crucial to long term social change. In the first place, they serve as a basis for the generation and legitimization of development options. Secondly, they are involved in the selection of desirable options. Thirdly, they are given the mandate to realize the agreed goals. The first and third roles impose on institutions conflicting patterns of practice. On the one hand, institutions must be flexible and open enough to generate new option. But on the other, they must retain the selected option and implement them through time. The latter implies a certain degree of routine which may come with a measure of resistance to change. The hierarchical existence of such varied institutions may retard change due to the inability to find compromises.

This partly explains the differences in the links between the government, private sector and research institutes in the two countries. In Kenya, a tight hierarchy prevailed and government institutions continued their activities on the basis of established patterns, ignoring the research that was being conducted independently in academic institutes. But a *non-hierarchical network* between the government, private sector and research institutes was established to facilitate the search for alternative sources in Zimbabwe. The Industrial Development Corporation was set up partly to provide a link between the different institutions while retaining its legal mandate as a parastatal body. Similar bodies existed in Kenya but they related to the research and private institutions in a hierarchical way thereby diminishing the degree of mutual collaboration. Moreover, the hierarchical structure robbed the institutions of the autonomy and relative freedom necessary for the generation of alternative options.

It appears that the links between institutions operate effectively in a non-hierarchical way if they are associated with specific functions and the types of knowledge required. For example, research on fuel ethanol in Zimbabwe brought together different types of institutions and networks from those required for hydrogenation research. What was important was that each participating institution in the network possessed particular types of knowledge that were crucial in the realization of the proposed goal. The participant's position in the network was therefore as important as the others. The existence of networks does not invalidate hierarchies. What is different is that the structure of the network is shaped by the functional imperatives of the goals to be achieved and not the other way round.

One of the points illustrated in the study are the links between *finance and technology*. These links operate at two related levels. In the first place, overall economic policies on foreign exchange influence the patterns of technology acquisition. This point is illustrated by the policy introduced in Zimbabwe under which investors were required to recover the foreign exchange component of their projects in a year or less. This forced the investors to search the local market for inputs so as to minimize the foreign component of their proposed projects.

But for such a policy to be effective, there must be an industrial base capable of providing some of the key technological requirements for industrial projects. A certain degree of diversity must exist in the industrial sector to provide the requirements directly or through the recombination of existing industrial capability or skills. Such a policy enables the economy to place pressure on the industrial sector to expand both in gross output and in complexity. Moreover, the local search helps to identify those industrial inputs which are in demand and therefore lead to the generation of new branches of industrial specialization.

But there is another effect which relates to the use of industrial skills without necessarily forming new industrial branches. This was exemplified by the training of skilled welders for the *local fabrication* of the Triangle plant. What existed prior to the construction of the plant was a skill pool that could be re-trained to undertake specialized tasks without necessarily setting up new firms or importing specialized welders from other countries as the Kenyans did. This local "skill wheeling" also guarantees that the re-trained people are available in the country and can be called upon for similar or related tasks. This form of investment in human resources is much cheaper than the setting up of new industrial branches.

The other link between finance and technology relates to the supply of equipment. The case of Kenya shows that where local technological inputs are not mandatory in project design, there is a tendency to borrow from foreign sources so as to import the required technology. Links between the source of finance and technology are established early enough to foreclose the open tender system. The source of finance would tend to determine the source of technology. This arrangement does not involve much choice because there are no genuine options presented to the importer of the technology. The very act of going for turn-key projects suggests that a decision has been made not to include major local inputs into the project.

Such decisions have long-term implications for the performance of the project. They may involve equity subscription from the suppliers of the technology and even more stringent contractual agreements. It is also through financial collaboration (in the form of joint ventures for example) that further technical inputs and spare parts can be fully guaranteed. This,

however, is not the only way. But it is certainly a soft option for those who do not want to invest in learning or accumulation of technological capability. Such cases emerge partly because there is very little *negotiation* between technology importers and suppliers. Often the two are in league and the contractual arrangements are entered to maximize their benefits at the expense of other shareholders who simply subscribe equity but do not participate actively in project design and management.

Also related to this is the issue of *loan guarantees*. The Kenya government guaranteed the foreign loans for the projects. This was a major disincentive for effective project implementation because the managers knew that if the projects failed, the government would be called upon to bail them out. The guarantees, as we have shown, weakened the ability of the government to introduce new measures that would have shifted some of the risks to the other shareholders. In Zimbabwe, the guarantee was made against the projected earnings of the venture. Moreover, the amounts involved were so small that they did not pose a major problem to the government. It would be unwise to argue against all forms of government guarantees for foreign loans. What is needed is a system that would provide an effective criteria for selecting strategic projects which cannot be supported by the private sector but are crucial to long-term economic development.

Apart from the guarantees, the Kenya government also invested excessively in the projects through equity participation and it was in its interest to make the projects work. Both the guarantee of the loans and the excessive equity participation seem to have been undesirable and even could have contributed to complacency among the managers. Considering the scale of government support for the Madhvani project, it is doubtful that any investors would have gone ahead with a project with such risks without government participation. It is therefore not a surprise that the Riana project collapsed partly because the government was unwilling to put in equity.

The early stages of the development of the two projects were associated with differences in the capacity to carry out reliable *evaluations* and to *search* the market for technology. This study has shown that these

two types of technological capability were vital in the design and implementation of the Triangle project. The evaluations conducted in Zimbabwe, especially during the period of niche exploration, had at least three important characteristics. First, they were linked to more general industrial evaluations that were being conducted to find local avenues for local industrial expansion and self-reliance. Second, the evaluation process was supplemented by independent consultants whose views were taken into consideration when selecting projects. Independent evaluations helped rid the projects of institutional and corporate biases. Third, the evaluations contributed to a knowledge pool on particular projects and maintained a certain measure of continuity in the available information. There was indeed a high level of *institutional memory* maintained on particular projects.

The evaluations also helped generate *resource information* on which government and corporate decisions could be reliably based. In the case of Kenya, we have shown how resource information was manipulated to justify particular decisions. Indeed, the projects were approved by the government before a comprehensive data base on the availability of molasses was compiled. While construction was underway, debates continued on whether the country had enough molasses to meet the requirements of the projects. The Kenya Sugar Authority, which was supposed to advise the government on policy issues pertaining to sugar and sugar products, continued to release conflicting data on the availability of molasses.

The capability to search both local and international markets was crucial given the limitations placed upon potential investors by government policies. The search for the technology on the international market had to be done with some knowledge of the local industrial potential to fabricate the chosen option. Conversely, knowledge of the local industrial base influenced the search and choice of technology. This required the search to be a process of active learning and took the search team from negotiating tables to workshops. The local search was helped by the existence of local consulting firms such as Jager and Associates (J&A) whose knowledge of the local industrial base provided information on the extent of its diversity.

It should be noted that J&A had *international contacts* with other firms in South Africa, Europe and the US which contributed to the flow of

knowledge on the available technological options. The international dimension is important because of the need to know the dominant trends in technology. This also required constant monitoring of trends in the international market for technology as well as R&D. The study pointed to the confusion over technical feasibility and economic viability over the choice of products at the Madhvani plant. Knowledge on commercially viable options can be acquired through an international technology search. But the need to search the market does not arise if the supply of the technology is directly linked to the source of finance and the open tender system is precluded.

Most of these policies relate to situations where the designers of a project are interested in the long-term viability of their venture. We have argued elsewhere that the Madhvani project seemed to have been designed to maximize the gains from the sale of machinery and not from long-term operation.<sup>8</sup> This should have been noticed at the early stages of project design if the Joint Venture Agreement (JVA) had been subjected to independent evaluation. Alternatively, a political system that adheres to the need for public accountability would have found it difficult to justify a project which carried such excessive risks.

The contractual arrangements of the Madhvani project made independent evaluations almost impossible to perform. Without such evaluations, it was difficult to decide on whether to stop the project as a result of the massive cost overruns. We have shown how independent evaluations by the World Bank met with opposition from the management who often made it look as if a criticism of the project was a direct attack on government policy. It was obvious from the start that the Madhvani project should have been abandoned. But such a decision was already precluded by the JVA. The need for independent evaluations was indeed expressed in a section of the government but it was difficult to do so at the time.<sup>9</sup>

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8. See Enos, "Choice of Technique," for an interesting study of how the choice of beneficiaries distorts the patterns of technology acquisition in developing countries.

9. "The difficulty of abandoning a project after several million dollars have already been committed...tends to prevent objective review and recosting. For this reason...an independent management team...should do the recosting and, if possible, the entire review. When the technology...is new to the company but already in use elsewhere, it is always worthwhile to try to bring in a strong, outside technical management team well-versed in the technology to undertake this study," Davis, "New Projects," pp. 110.

There are other policy considerations which relate to project *location, operational flexibility and infrastructure*. Triangle and Mehta annexed their plants on existing sugar mills from which they planned to draw molasses, steam and management expertise. This was not the case with Madhvani. The important lesson here is that the Triangle project was designed to minimize all costs and introduce flexibility in the industrial operations so as to use cane juice or molasses. But Madhvani maintained corporate inflexibility and was unwilling to use cane juice as an alternative to molasses. The Kenyan projects were set up as separate ventures with additional overhead costs which were finally reflected in the price of ethanol.

The establishment of vital infrastructure such as blending facilities seemed to have been ignored in Kenya until the Mehta project was completed. The delay in installing blenders and agreeing on the pricing structure suggested that such vital issues should have been settled before the project was started. We can learn here from the experience of Malawi where nine legal agreements had to be signed before the financiers could disburse any funds.<sup>10</sup> The *legal aspects* of the Kenyan projects have since been a matter of detailed discussions between the various conflicting interests.

One of the most important aspects of the Triangle project was the explicit efforts to build plant-level technological capability and carry out a series of experiments to improve the process. The spirit of *experimentation* confirms further that Triangle had a long-term view of the project and considered the acquisition of the plant as part of a learning process. No such elaborate plans were incorporated into the Mehta and Madhvani projects. As noted elsewhere, the knowledge that is generated at Triangle is used for plant improvement and also shared with other fermentation-related industries in the country. The plant also offers a link with academic research at the University of Zimbabwe through internships.

As pointed out elsewhere, the generation of plant-level knowledge was part of the Triangle management from the start. It is also reflected in the way the manpower of the plant was organized. The integration of the plant into the overall management structure of the company enabled the

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10. Interviews, Ethanol Company of Malawi, Blantyre, January 1985.

experience accumulated in running the sugar mill to be adapted to the plant. There was, however, an interesting twist to the learning process. The use of existing management resources enabled Triangle to hire additional people specifically to conduct experiments and accumulate technical knowledge. This implies that there was conscious effort to create the basis for adaptive changes in the development of the project. This was in sharp contrast with the Mehta and Madhvani projects where the manpower of the plant was largely devoted to management and administrative tasks.

The learning that is occurring at the Triangle plant involves constant monitoring of the production process through the use of reliable instrumentation. The information generated from the monitoring process is used both for management purposes as well as for plans to introduce modifications in the plant. Technical drift cannot occur without changes in the knowledge base.<sup>11</sup> It is also through the learning process that Triangle constantly evaluates the possibilities for adapting new production units instead of relying on technical drift as the main source of change. In other words, the learning process allows the firm to determine when to make a discontinuity in the current production practices and move to a new level.

The case studies illustrate a few fundamental aspects of technical drift which relate to the various types of learning that have been identified by Bell.<sup>12</sup> These include learning through plant operation, plant modification, hiring, training and searching. The fact that constant changes occur both in the adoptive terrain and in the technological system requires the generation of new knowledge that allows the plant to operate within the limits of the adaptive peak without falling far below its design specification. Technical drift also allows for the solution of routine operating problems as well as the improvement of the plant to achieve higher performance.

It should be borne in mind that technical drift as represented by incremental technical change only relates to selection pressures that affect particular aspects of the functional units but are not compelling enough to

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11. Such changes in the knowledge base and the associated flow of information do not occur automatically. "The learning from such flows of information thus is not effortless; nor is it without cost. Costless learning-by-doing thus has limited relevance for the accumulation of technological capability," Bell *et al.*, *Assessing Infant Industries*, pp. 32.

12. Bell, "Learning' and the Accumulation of Industrial Capacity," pp. 187-200.



lead to a new selection phase. In other words, technical drift allows for change within existing technological systems and does not require the introduction of alternative designs to replace existing ones. The shift to new vintages is largely a function of the age structure of a particular generation of technological systems. This point is illustrated by the Brazilian case where existing batch processes cannot be scrapped over the short-run and give way to new designs. At least the economic reasons are not strong enough to justify moving into a new selection phase before the end of the lifespan of existing processes. Incremental innovations will therefore tend to dominate the changes in the adaptive terrain.<sup>13</sup>

The study has shown how the Zimbabweans relied heavily on the benefits of technical drift in the search and choice of technology. They chose a process that allowed for subsequent improvement either through incremental technical change or through *technical grafting*. With grafting we mean the replacement of whole functional units without scrapping the entire system. As indicated, one possibility was to introduce the Biostil solid fermentation unit from Alfa-Laval while leaving most of the other units intact. Such a decision could only have been made on the basis of plant-level experiments. Indeed, the experiments to recycle stillage were partly aimed at getting information that would help in subsequent technical grafting.

This process gives us a picture of both continuity and discontinuity. Every step in the process of incremental improvement is both cumulative and gradual. But the very fact that it is cumulative also means that it advances

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13. This view is consistent with World Bank policies on the Brazilian programme. The World Bank has suggested a rationalization project for the next phase of their support for the programme. This phase emphasizes technical and institutional improvement instead of quantitative expansion. The proposed measures fall under the broad category of programme rationalization and involve increased data collection, project monitoring and R&D. Discussions on this shift were underway long before the recent fall in oil prices which have led the government to freeze the programme. It would appear that both institutional pressure and reductions in oil prices will impose new conditions on the programme and create conditions which require increased incremental innovation. The possibilities for increasing ethanol yield tend to lie more in the agricultural sector rather than in the industrial processing phases. The possibilities for technical improvement in fermentation or distillation in existing process are limited. The other option is of course the introduction of radically new technological systems with comparable capital costs but more efficient than the existing processes. But for a system to be widely adapted will depend on its overall benefits and the age structure of the existing plants. It appears therefore that the current processes are likely to dominate the Brazilian market in the short and medium term.

towards some bifurcation point that is difficult to predict in advance. The bifurcation point is reached when a discontinuity occurs and a new selection stage is reached. There are several sources of bifurcation. The most fundamental is at the level of R&D where new technological variants are generated. But incremental improvements can also lead to new breakthroughs which result in new technological variants. We do not, however, expect such a process to occur in places where only one plant is operating. The chances for such a process to occur is partly a function of diversity.

What is important is the role of analogy and homology in the search process. The process of experimentation not only creates new types of knowledge, but it also helps in the identification of areas of ignorance. Whenever difficult problems emerge from the plant-level experimentation or monitoring, it gives an indicator of where to search for solutions. If for example, the problem is in the fermentation process, the search would be directed in those areas with related expertise. This is a search by analogy because the problem is a result of exposure to similar pressures. In other cases, the search would be directed in areas with similar functional units because of common origins or phyletic links. For example, solutions to distillation problems may be sought in the oil refining industry.

This should not be a surprise since we have argued elsewhere that technological evolution occurs largely through recombinant innovation. Almost every technological variant is both a result of divergence and convergence. Divergence occurs as particular design concepts in use find other end-uses. On the other hand, the recombination of separate functional units to serve a particular function is an act of convergence. The recombination of design concepts to achieve new technological systems is a fundamental process of technological evolution. But limits to recombinant innovation which are placed on system builders by physical, chemical and biological laws. Moreover, the way the recombination is done is largely influenced by non-technical factors.

The findings of this study emphasize the role of purposive action in structural re-organization, a factor which underscores the role of institutions in socio-economic evolution. The domain of policy formulation

and implementation is therefore part of the process of technological evolution and not a separate set of guidelines for action. Policies are only significant if viewed as part of the process of change. The study has so far illustrated the role of institutional learning in the process of project implementation. To the contrary, conventional wisdom tends to offer policy guidelines as rules which assume perfect knowledge of the current and expected behaviour of particular parameters of the implementation process.

From this understanding, it is meaningless to study projects in the context of their success or failure, which are only important if viewed as part of a more general process of socio-economic transition. As the case studies illustrate, the failure of the Madhvani project was the beginning of new approaches to project implementation. Policy formulation is therefore a form of institutional learning in which key lessons become guideposts or reference points for further action. The manner in which the lessons are incorporated into the general policy guidelines depends very much on the ability of the existing institutional structures to undergo the required reforms and take on new practices. There are of course other obstacles to policy reform, especially from various interest groups. Such interest groups often have access to political power and can undermine attempts to reform policies or introduce new practices.

The tempo of policy learning also varies depending on whether a system has stabilized along an organizational path or is undergoing major fluctuations. In the case of the former, as was the situation in Kenya in the 1970s, existing policies became a dominant source of practice. Government departments settled into routine behaviour guided by linear thinking. Aberrations within the systems could easily be contained through minor adjustments. Under such conditions it was difficult to introduce new ideas. When the socio-economic system is settled in such organizational patterns, new ideas are easily eliminated or are simply ignored.

The situation is different under conditions of major fluctuation. Here the diffusion of new policies is made more likely, partly because the failure of existing policies makes the system more open to new ideas. Moreover, fluctuations are likely to send institutions and individuals searching for alternative options. Such a climate increases the receptive and retentive

capacity of institutions. It also creates favourable conditions for the emergence of new institutional arrangements. Just as fluctuations create favourable conditions for the introduction of new technological systems, so do they make it possible for concomitant institutions and policies to emerge. Under suitable conditions, technological change, policy formulation and institutional reforms tend to co-evolve. The alternative is a fragmented and haphazard response to fluctuations which may be counter-adaptive.

Conventional thinking tends to treat policy guidelines as rules which govern movement along Newtonian trajectories. Investment projects are expected to obey fundamental laws of economics. The situation is also thought to be deterministic so long as market forces are allowed to operate freely. This study, however, shows that vital knowledge concerning project implementation is generated during the implementation process itself. The unfolding of events generates the required knowledge and policies are changed accordingly. This suggests that policies must be able to create suitable conditions for the generation of new knowledge for use in anticipating or adapting to changing conditions.

The ability of a country to formulate relevant policies is also influenced by its own historical development and institutional organization. Policies are subjected to selection pressures in the organizational arena and the selection process is guided by the socio-economic expectations of the country as embodied in overall economic goals. Fluctuations in the technoeconomic landscape tend to invalidate existing policies. The re-organization of the system in response to fluctuations is guided by new policy interventions as well as institutional support.

The fact that socio-economic systems tend to evolve towards complexity suggests that at any one moment, the process brings about new interrelationships which were hitherto unknown. The effects of such developments are difficult to determine in advance. This implies that policies are not only responses to emerging circumstances, but they also anticipate particular developments. This is illustrated by the case of Zimbabwe where decisions on future actions were embodied in preceding practices. The selection of technology was not just a reflection of prevailing circumstances, but also took into consideration anticipated developments.

Although the implementation process appears to have been done in stages, the process itself was time-bound; the past, present and future were treated holistically.

The view that an evolutionary process involves learning suggests that policies and institutions must maintain a certain measure of flexibility otherwise institutional rigidity would be counter-adaptive. Ironically, regulatory institutions tend often to be less flexible in relation to the imperatives of technological change. This is partly because higher-level institutions are more concerned with the retention of an already selected option and are removed from the sources of change or the generation of new options. Fluctuations in the socio-economic system are felt more readily at the firm level. A wide communication gap between firms and state institutions tends to limit the rate of adaptive responses and anticipatory planning.

A suitable arrangement seems to be one of co-evolution between state institutions and the techno-economic sphere with a greater degree of flexibility, positive feedbacks and mutual interaction. Whereas the structure in such an arrangement would remain hierarchical, its functioning would take the form of an interactive network guided by socio-economic expectations. Such a co-evolutionary approach to policy formulation and implementation requires a certain level of decentralized power and responsibility and would require new forms of non-hierarchical co-ordination.

### **8.3 Research Prospects**

An evolutionary approach is a powerful framework for analyzing policy-related issues because it deals specifically with the process of change itself. The elegance of abstract modelling may be lost in the complexity of real events. But that loss is not regretted because the concern here is to unravel the central features of long run technological change and not to engage in abstract puzzle-solving. Moreover, an evolutionary approach provides the opportunity to bridge the gap between theory and policy by appealing to the process of change itself.

It has been suggested that a new world view is gradually permeating the research establishment, especially within the natural sciences. The traditional approaches built on the works of Descartes and Newton are giving way to a more holistic and dynamic world view. In essence, scientists have traditionally engaged in pulling things apart. There seems to be a change under which emphasis is being placed on putting things together again; it is a tide against reductionism. The new world view has profound implications for those social sciences which deal with volatile and constantly changing systems.

This study suggests new directions for research. At an epistemological level, there is an urgent need to build alternative theories of knowledge which would equip us more adequately to deal with constant change and major fluctuations. Already Popper and Campbell have provided a start with their evolutionary epistemology. Their approach stresses the role of homology in understanding evolutionary processes. But argument by homology has one fundamental limitation. The fact that evolutionary processes tend to advance towards complexity implies that new factors and relationship emerge which did not exist at previous stages.

But there is yet another major limitation in the current state of evolutionary epistemology. It understates the systemic nature of evolutionary processes and places excessive emphasis on randomness. There is a need to undertake further research on the *evolution of complex systems* and how they re-organize themselves in response to internal and external influences. Such an understanding requires the fusing of the epistemological roots of general systems theory and evolutionary approaches. All these issues fall in the field of macro-evolution. There are other levels which require further research. The re-organization of socio-economic systems involves the interplay between human creativity, fluctuations and resources. This meso-evolutionary level also involves institutional change and policy formulation. Much has been written on the separate components of this level but their modes of interaction still remain unexplored.

At an even lower level we are confronted with problems of how technological systems themselves emerge and evolve. Most of the existing

studies which use evolutionary approaches admit that innovation is endogenous to socio-economic transition just as Schumpeter did. Already work on internal technical change as well as the numerous case studies on indigenous technical change have suggested some of the internal imperatives which determine the direction of innovation. This line of analysis needs to be pursued with greater emphasis because it will enrich our understanding of the internal evolution of technological systems. It would be advisable to start constructing taxonomies of technology in order to isolate the phyletic links between various systems and the range of recombination.

But to get a more comprehensive picture of the process of technological evolution, research will have to be directed at the interface between human perception and the design of technological units. This may sound far-fetched but the core of socio-economic evolution is the re-organization of knowledge systems. It is through the application of knowledge that purposive re-organization can be achieved in a fluctuating system. A more detailed understanding of knowledge systems will also give us more insights into the nature and structure of institutions, which exist largely as frameworks for the socialization of information.

This view raises other questions related to the application of information technology to the process of socio-economic change. It is now possible to create extensive knowledge systems and networks by using information technology. This implies that the structure and nature of institutions are also changing. The organizational gains of such changes are enormous but their policy implications are difficult to establish. What is clear, however, is that the application of information technology may allow extensive institutional flexibility and therefore facilitate the process of change. Even more important is the fact that information technology can be used in vicarious learning and therefore introduce efficiency into the evolutionary process. More research on information technology may reveal new aspects of the evolutionary process that may strengthen our understanding on how socio-economic systems change.

One final area that requires research is the role of energy and energy technology in socio-economic evolution. Conventional thinking treats energy as any other resource. It was suggested at the beginning of this study that

energy is a special resource both because of its importance in life processes and because of its technological implications. The history of energy in the transition of different societies may provide us with useful policy lessons, especially given the variations in current development patterns.

On the whole, the policy implications of the process of project implementation suggest a closer examination of the adaptive landscape as the arena for economic re-organization. It is here that all the crucial technical, social, economic and political factors interact. The process of niche realization, as has been argued in detail, requires the careful modification of the adoptive terrain to facilitate the introduction of new technological systems. The technologies themselves are equipped with adaptive parameters which need to be matched with the adoptive conditions. This evolutionary process is *knowledge-intensive*.

## Conclusion

This chapter has summed up the central argument of the study, examined its policy implications and made a plea for further research. It is noted that the evolutionary approach used in this study is part of an emerging world view that is gradually permeating the natural sciences. The fact that this approach deals specifically with the process of change makes it more relevant for the social sciences, which have for a long time been dominated by Cartesian and Newtonian reductionist as well as static concepts. It appears that a cognitive shift in our world view is underway and the social sciences need therefore to re-examine their vantage positions. This study did not attempt to bypass conventional thinking, but to transcend it. One may risk the suggestion that if the social sciences do not adopt the emerging non-equilibrium systems approach, those who will in the future take over the analysis of socio-economic change will come from the natural sciences, especially as barriers between the disciplines succumb to the pressures of the emerging holistic principles.



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APPENDIX 1: Fuel Ethanol from Cane Juice and Molasses

