SECOND GENERATION BIOFUELS
A REVIEW FROM A
MARKET BARRIER PERSPECTIVE

Prepared For:

IEA Bioenergy
Task 39
Liquid Biofuels from Biomass

Prepared By

(S&T)^2 Consultants Inc.
11657 Summit Crescent
Delta, BC
Canada, V4E 2Z2

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EXECUTIVE SUMMARY

IEA Bioenergy is an international collaborative agreement set up in 1978 by the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy RD&D programmes. The IEA Bioenergy Vision is "To realise the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, to provide a substantial contribution to meeting future energy demands."

The IEA Bioenergy aim is "To facilitate, co-ordinate and maintain bioenergy research, development and demonstration through international co-operation and information exchange, leading to the deployment and commercialization of environmentally sound, sustainable, efficient and cost-competitive bioenergy technologies."

Twenty countries plus the European Commission, take part in IEA Bioenergy: Australia, Austria, Belgium, Brazil, Canada, Croatia, Denmark, Finland, France, Ireland, Italy, Japan, The Netherlands, New Zealand, Norway, South Africa, Sweden, Switzerland, the United Kingdom, the USA and the European Commission. Work in IEA Bioenergy is carried out through a series of Tasks, each having a defined work programme.

One of the Tasks is Task 39, Liquid Fuels from Biomass. The objectives of this Task are to:

- Provide information and analyses on policy, regulatory and infrastructure issues that will help participants encourage the establishment of the infrastructure for biofuels as a replacement for fossil-based biofuels.
- Catalyze cooperative research and development projects that will help participants develop improved, cost-effective processes for converting lignocellulosic biomass to ethanol.
- Provide information and analyses on specialized topics relating to the production and implementation of biodiesel technologies.
- Provide for information dissemination, outreach to stakeholders, and coordination with other related groups.

As part of Task 39's ongoing program of promoting the commercialization of biofuels, the task has commissioned three reports that address specific market or policy barriers. These barriers have been identified by members of Task 39 and through analysis of independent reports.

First generation biofuels are generally accepted to include ethanol produced from sugar or starch feedstocks and biodiesel (methyl or ethyl esters produced from vegetable oils and animal fats). These fuels are being produced and marketed in many regions of the world.

Second generation biofuels can be produced from lower value feedstocks (ethanol from lignocellulosic materials), through different production processes (thermochemical conversion instead of biochemical pathways), or produce a liquid fuel other than an alcohol or an ester (Fischer Tropsch diesel or similar hydrocarbon). These new fuels or production processes are anticipated to offer some advantage over the existing fuel production pathways. The advantages may include improved environmental performance, lower production costs, greater production volumes, more attractive performance properties or other benefits.

While these fuels may offer some relative advantages in some areas, they may also have attributes that are less desirable. The objective of this work is to consider several of these second generation biofuels from the perspective of the "Market Barriers" that biofuels in general face and determine if these new fuels will reduce the barriers or could face new barriers as they are developed.

The specific objectives of this work are to:

- Identify the market barriers to the first generation biofuels in general,
- Assess the advantages and disadvantages that each of the new 2nd generation biofuels offers relative to the existing biofuels and the market barriers they face.
- Summarize the findings.

First generation biofuels, which are generally accepted to be ethanol produced from sugar or starch crops and biodiesel (methyl esters) made from vegetable oils and animal fats, have been introduced and used commercially as transportation fuels in a number of countries around the world. These first generation biofuels do provide some environmental benefits, have supported agriculture and rural economic development, and have diversified the transportation fuel supply system in many countries. These fuels have generally required some financial support from governments, adjustments to the fuel distribution system to allow their introduction, and in many regions there has been some resistance from the existing market participants to adopt these fuels.

There are other biofuel production processes that are being developed and promoted that may offer some advantages over the existing biofuels. These fuels have been called "2nd generation biofuels" and while there is no official definition, they are generally accepted to be any biofuels other than, ethanol produced from starch or sugar feedstocks, and biodiesel produced by the trans-esterification of vegetable oils and animal fats. It is claimed that these 2nd generation biofuels may offer even greater benefits in terms of environmental performance, better overall energy efficiency, the ability to use lower cost and more widely available feedstocks, and be more easily integrated into the existing fuel supply and distribution system.

The 2nd generation biofuels can describe ethanol produced from lignocellulosic feedstocks via either a biochemical production process or a thermochemical production process. The term has also been used to describe synthetic natural gas made from the gasification of biomass. There are other liquid fuels such as butanol that could be made from biomass via either biochemical or thermochemical pathways, or from sugar and starch, that have also recently been called 2nd generation biofuels. All of these pathways produce a fuel that is suitable for use in spark ignited engines.

For fuels for compression ignition engines there are a number of candidates that can be called 2nd generation biofuels. These include FT distillates that are produced from syngas produced from biomass. Bio-DME is promoted as a 2nd generation biofuel in some regions. All of the fuels mention so far are produced from lignocellulosic material but a process that converts the vegetable oils and animal fats into hydrocarbons via hydrotreating is also being classified as a 2nd generation biofuel by many industry observers.

The primary 2nd generation biofuels are briefly described with the significant advantages and disadvantages relative to the existing biofuels highlighted. Many of the developers of new technology do not divulge a great deal of information about their technologies so in many cases information can only be obtained from relatively general publications and statements, although more information on some technologies is available from public R&D sources this is not necessarily indicative of the status of individual process developers. The fuels have been grouped as fuels for spark ignited engines (gasoline) and fuels for compression ignited (diesel) engines.

The IEA reviewed 22 case studies of what they determined where successful energy market developments in IEA countries over the past twenty years. In studying the cases, the IEA considered three perspectives on deployment policymaking. These three perspectives have developed over the last quarter of a century.

- The Research, Development and Deployment Perspective, which focuses on the innovation process, industry strategies and the learning that is associated with new technologies;
- The Market Barriers Perspective, which characterizes the adoption of a new technology as a market process, focuses on decisions made by investors and consumers, and applies the analytical tools of the economist;
- The Market Transformation Perspective, which considers the distribution chain from producer to user, focuses on the role of the actors in this chain in developing markets for new energy technologies, and applies the tools of the management sciences.

The IEA concluded that the adoption of clean energy technologies would not be likely to succeed unless all three perspective were considered and that it is necessary to:

- Invest in niche markets and learning in order to improve technology cost and performance;
- Remove or reduce barriers to market development that are based on instances of market failure; and
- Use market transformation techniques that address stakeholders' concerns in adopting new technologies and help to overcome market inertia that can unduly prolong the use of less effective technologies.

The market barriers facing biofuels are quite similar for both ethanol and biodiesel. The two most significant barriers have been the price of biofuels compared to petroleum fuels and the difficulty marketing the product through the established fuel distribution companies.

New enterprises almost always face finance and business risk barriers during the start-up phase of the industry. In many countries ethanol and biodiesel projects have struggled with issues such as project financing, uncertainty with being able to design and construction facilities with new technology and dealing with the risk of commodity prices. In some countries these issues are mostly behind the industry as plants have been built and experience has been gained with dealing these issues. In other countries that are just beginning to develop their biofuels industries these are still issues that companies must face.

Ethanol and biodiesel have also faced less significant barriers in terms of price distortion and inefficient regulation. The industry has learned either how to deal with the issues or the removal of some of the other barriers, such as the competitive price issue, has also addressed or reduced the price distortion barrier.

Uncompetitive Price

The cost of producing biofuel is often higher than the cost of petroleum fuels, although the absolute value of the difference between the two is a function of commodity prices. In times of high crude oil prices and low agricultural prices, the gap can be small (or not exist at all) and when fossil energy prices are low, the gap can be large. In the regions of the world where biofuels have been used as a petroleum fuel blending component or fossil fuel substitute the gap has been eliminated through the use of tax incentives provided by governments. These tax incentives can be viewed as learning investments. The incentive mechanism itself can take many forms such as producer payments, payments to the biofuel blenders, or reduced consumer taxation. Governments have also invested in research and development in order to help to drive down the costs of production.

Inefficient Market Organization

Inefficient market organization applies when one firm or a small group of firms act in a similar manner and using the advantages of being the incumbent suppliers to resist the market penetration efforts of the new technology. In the case of transportation fuels, there are many end users of the fuel but they all purchase the product from a limited number of companies. These are also the companies that produce the competing product, gasoline or diesel fuel. In order for biofuels to penetrate the market and be available for the ultimate end user, they must be integrated into the existing distribution system.

Buyer's Risk

The Buyer's Risk could also be termed business risk and it is important to note that it is the perception of risk that may be more important that the actual risk. The gap between perception and actual risk is larger when an industry is new and one of the measures that reduced this gap and the buyer's risk for any venture is experience.

Perhaps the best descriptions of risk for fuel ethanol plants can be found in the prospectus' and managements discussion of results of ethanol plants that are public companies. The issues are quite similar in the reports of the different companies. Typical categories for the issues are:

- Risks related to equity financing
- Risks related to debt financing
- Construction and development risks
- Operation risks
- Ethanol production risks
- Organizational structure risks

Finance

A barrier that is somewhat related to Buyer's Risk is that of finance. Most projects are financed by a combination of equity and debt. Raising the debt portion can be challenging for a number of reasons including imperfections in market access to capital. Debt providers generally have no opportunity to participate in any project upside so they focus on ensuring that there are no downsides to their participation. They focus on the issues of what could go wrong.

Lenders have many opportunities presented to them and they chose those opportunities that provide them with their best returns or most limited risk. Many lenders also specialize in certain sectors of the economy. These are sectors which they understand the risks and rewards. New sectors require lenders to become comfortable with the risks or at least the perception of the risks. The first projects are therefore the most difficult to finance since there is no track record which lenders can rely on. It is extremely important that the first projects be successful. Problems or failures with early projects increase the difficulty in demonstrating that new projects won't have the same problems.

Note that in cases where there is imperfect access to capital, finance barriers could be considered a market failure barrier and increased government involvement may be warranted. The involvement could include special funding, third party financing options, loan guarantees or other approaches.

Price Distortion

Price distortion arises when some of the costs or benefits that arise from using a product are not reflected in the selling price. The most common example of this is the environmental costs that arise from using products that pollute the environment. These costs are real and are paid for by society through reduced crop production, increased maintenance costs and higher health costs. They are not generally included in the product cost.

In the case of biofuels, the lifecycle analysis indicates that there are greenhouse gas reductions from using the fuel and there are also reductions in the emissions of some of the tailpipe contaminants from using the fuel. These should have some value and could be used to offset the higher cost of the fuel.

Excessive/Inefficient Regulation

Regulations and standards are often prescriptive and not directly performance driven. This can be effective and efficient in cases where there is significant experience with a product and the performance can be controlled in a prescriptive manner. The system does not function particularly well when new products are introduced that may not have the wealth of experience associated with their use and may not behave in exactly the same manner as the incumbent technology.

2nd Generation Biofuels

The 2nd generation SI and CI biofuels have the potential to process lower cost and more abundant feedstocks. In the case of 1st generation biofuels, it has only been recently that concerns have been raised concerning the strain on resources that increased biofuels may cause. It must also be noted that feedstocks that are used for these 1st generation fuels have generally suffered from an imbalance in the supply and demand and that has been one of the drivers for biofuels, to try and bring the supply and demand back into a balance and hopefully raise farm income in the process. The availability of feedstocks has thus not been a barrier for the 1st generation biofuels to date.

For most of the 2nd generation biofuels the ability to use lower cost feedstocks does not currently result in lower cost biofuels. The feedstock cost savings are offset by higher chemical costs and much higher projected capital costs. Very large “learning investments” will be required to address the capital cost barriers that these fuels currently face. Considering the large investments involved plus the design, build, operate cycle (a minimum of three years) for these biofuels plants it will take 5 to 10 years of experience before there will be enough experience gained that will lead to a large enough reduction in capital costs for these plants to be financeable as commercial ventures.

The other benefits of the 2nd generation biofuels do not really lead to the significant reduction of the other market barriers that faced the 1st generation biofuels. While the development of the 2nd generation biofuel technology is important, these processes are not likely to replace the 1st generation biofuels for many years, if ever. The greatest potential for these fuels likely lies in their ability to process lower value, more abundant feedstocks and not in their ability to produce lower cost biofuels. It will be many years before the capital costs for the 2nd generation biofuels can be reduced to the point where the return on investment is comparable to that from 1st generation plants.

The real benefit of 2nd generation biofuels is in their ability to process a wider range of feedstocks than the 1st generation biofuels. In most regions of the world the 1st generation fuels have not yet reached a limit on market share due to feedstock availability and thus the need to switch to other processes is not yet a major driving force. Given the length of time that will be required to commercialize some the 2nd generation processes it is appropriate that governments support their development well before they are required by the marketplace.

The benefits of 2nd generation biofuels do not address most of the barriers that the 1st generation fuels have faced and in fact many of the 2nd generation fuels will face the same market barriers as the 1st generation fuels. It is important therefore that efforts to implement the production of 1st generation fuels not be reduced or postponed because of the promise of 2nd generation fuels. Doing so would only delay the eventual adoption of the 2nd generation biofuels. The use of 2nd generation biofuels needs to be viewed as a means to augment and not to replace the use of 1st generation biofuels.

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1. INTRODUCTION

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1.1 TASK 39 LIQUID BIOFUELS

One of the Tasks is Task 39, Liquid Fuels from Biomass. The objectives of this Task are to:

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As part of Task 39’s ongoing program of promoting the commercialization of biofuels, the task has commissioned three reports that address specific market or policy barriers. These barriers have been identified by members of Task 39 and through analysis of independent reports.

The objective of this work is to look at the second generation biofuels from the market barriers perspective and assess the advantages and disadvantages that each of the new biofuels possesses compared to the first generation biofuels of biodiesel (methyl esters) and ethanol (from sugar or starch feedstocks).

1.2 SCOPE OF WORK

First generation biofuels are generally accepted to include ethanol produced from sugar or starch feedstocks and biodiesel (methyl or ethyl esters produced from vegetable oils and animal fats). These fuels are being produced and marketed in many regions of the world.

Second generation biofuels can be produced from lower value feedstocks (ethanol from lignocellulosic materials), through different production processes (thermochemical conversion instead of biochemical pathways), or produce a liquid fuel other than an alcohol or an ester (Fischer Tropsch diesel or similar hydrocarbon). These new fuels or production processes are anticipated to offer some advantage over the existing fuel production pathways. The advantages may include improved environmental performance, lower production costs, greater production volumes, more attractive performance properties or other benefits.

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2. SECOND GENERATION BIOFUELS

First generation biofuels, which are generally accepted to be ethanol produced from sugar or starch crops and biodiesel (methyl esters) made from vegetable oils and animal fats, have been introduced and used commercially as transportation fuels in a number of countries around the world. These first generation biofuels do provide some environmental benefits, have supported agriculture and rural economic development, and have diversified the transportation fuel supply system in many countries. These fuels have generally required some financial support from governments, adjustments to the fuel distribution system to allow their introduction, and in many regions there has been some resistance from the existing market participants to adopt these fuels.

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The primary 2^{nd} generation biofuels are briefly described below with the significant advantages and disadvantages relative to the existing biofuels highlighted. Many of the developers of new technology do not divulge a great deal of information about their technologies so in many cases information can only be obtained from relatively general publications and statements, although more information on some technologies is available from public R&D sources this is not necessarily indicative of the status of individual process developers. The fuels have been grouped as fuels for spark ignited engines (gasoline) and fuels for compression ignited (diesel) engines.

2.1 SPARK IGNITION FUELS

Second generation biofuels are generally considered to include ethanol produced from lignocellulosic feedstocks. There are two families of technologies being developed and many variations within each family. These include the biochemical pathway whereby the cellulose component of the feedstock is converted to fermentable sugars and then to ethanol, and the thermochemical pathway, which involves the conversion of all of the lignocellulosic material to synthesis gas (primarily carbon monoxide and hydrogen) and then the production of ethanol (or other liquid fuel) from the synthesis gas.

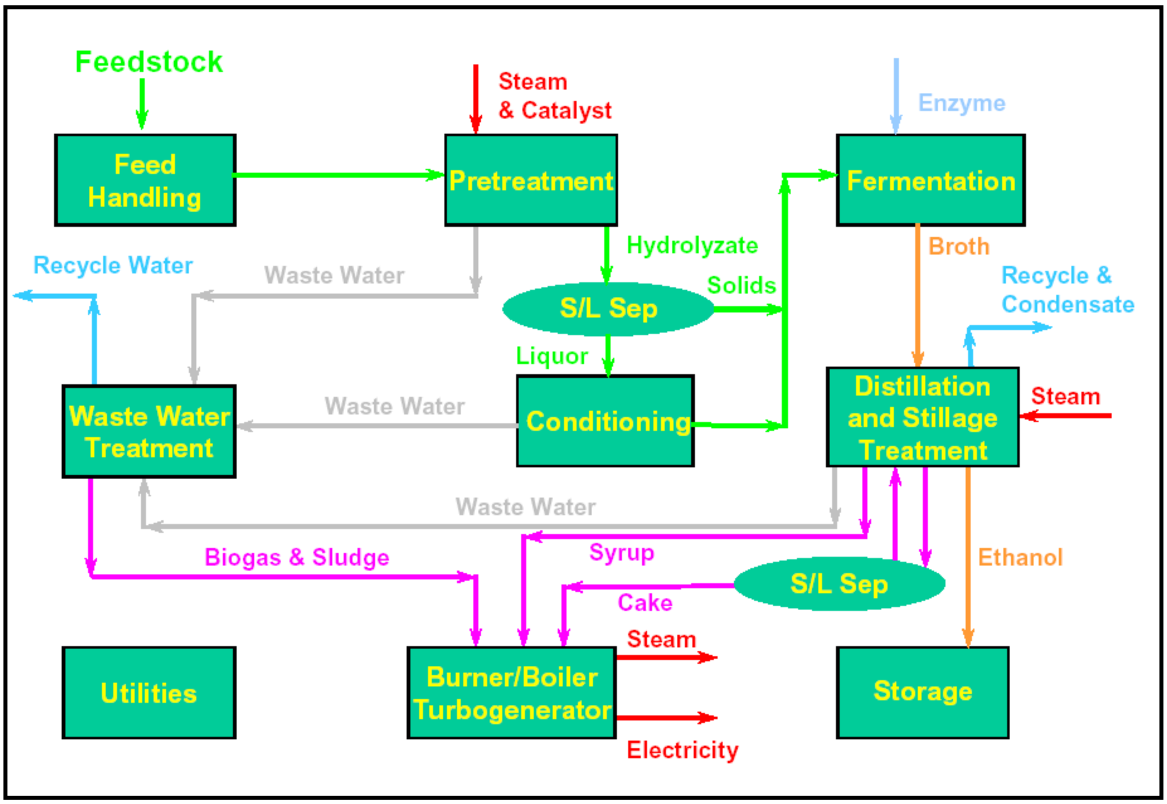
There are also thermochemical processes that can convert biomass to methane and biochemical and thermochemical processes that can produce higher alcohols that are sometimes mentioned as promising 2nd generation biofuels.

These pathways for producing fuels suitable for use in spark-ignited engines are described in more detail below along with their primary advantages and disadvantages.

2.1.1 Ethanol - Biochemical Routes

The production of ethanol from lignocellulosic materials is quite a complex process. There are many steps in the process and for each of the steps there are usually several options to consider. The generic process flow is shown in the following figure.

Figure 2-1 Generic Bioethanol Process Flow



The major steps in the process are pretreatment, hydrolysis, fermentation and distillation/separation. Only the distillation/separation step is relatively straightforward and able to draw directly on the existing fuel ethanol industry experience.

With so many individual process steps the processes are often characterized by the type of pretreatment employed and sometimes by the use of enzymes vs. acid for hydrolysis.

The goal of the pretreatment step is to separate the three components, lignin, cellulose and hemicellulose, so that the cellulose and hemicellulose can be hydrolyzed to produce fermentable sugars. It is a challenging step because there are many reactions that occur at different rates and it is possible to overshoot the desired end-point and produce degradation products rather than fermentable sugars. This is particularly true of hemicellulose where the hemicellulose is easier to hydrolyse than cellulose and therefore susceptible to the production of degradation products.

Modern pretreatment approaches have evolved from traditional thermochemical biomass hydrolysis processes that were developed prior to World War II. These processes typically employed cooking of biomass with an acid catalyst (often hydrochloric or sulphuric acid) in a pressurized reactor to hydrolyze the cellulose fraction of biomass to glucose. In such processes, yields of glucose are typically no higher than about 60%, as the harsh conditions required for cellulose hydrolysis result in a significant fraction of the released glucose being converted to non-fermentable sugar degradation products such as 5-hydroxymethylfurfural. In addition, single stage processes designed for cellulose hydrolysis resulted in the loss of carbohydrates from the hemicellulose fraction, which is primarily derived from a pentose sugar backbone in hardwoods, herbaceous plants, and typical agricultural residues.

The discovery of cellulase enzymes and the subsequent development of an industrial cellulase industry, coupled with the availability of efficient pentose-fermenting microorganisms, have dramatically altered the way in which the pretreatment of biomass is approached. Rather than requiring a thermochemical process to hydrolyze cellulose to glucose, the pretreatment step now needs to produce a solid substrate in which the cellulose can be efficiently digested by cellulase enzymes. It is also important that the hemicellulose-based fraction of biomass be converted at high yields to soluble pentose monomeric and/or oligomeric sugars, or minimally, be preserved as unconverted hemicellulose for subsequent enzymatic conversion, as more than one-third of the potentially available ethanol from the carbohydrates initially present in typical biomass feedstocks is hemicellulose-based.

The primary pretreatment technologies being evaluated by various researchers and commercial operations are shown in Table 2-1.

Table 2-1 Pretreatment Technologies

Pretreatment Category	Pretreatments	Reactor Configuration
Base-Catalyzed	AFEX/FIBEX	Batch/Continuous
	Ammonia	Percolation
	Lime	Batch
Non-Catalyzed	Hot Water	Batch, Percolation
	Hot Water-pH Neutral	Batch
	Nitric Acid	Batch
Acid-Catalyzed	Sulphur Dioxide	Batch or Continuous
	Sulphuric Acid	Continuous, Batch, Batch/Hot Wash Process
Solvent-Based	Organosolv (Clean Fractionation)	Batch
Chemical-Based	Peroxide	Percolation
	Wet Oxidation	

There are three primary approaches to hydrolysing the cellulose to fermentable sugars, dilute acid, concentrated acid and enzymatic hydrolysis. The acid processes are the approaches that have been used in the past commercially and there are still companies following these approaches. Most of the research effort however, is now focussed on the enzymatic approach.

The efforts by the US DOE with their partners Genecor and Novozyme have made some progress in reducing enzyme costs. Both companies have claimed that they have achieved a twenty fold reduction in enzyme costs (to about 30 cents per gallon) through their programs but more effort is required to reduce the enzyme costs to less than 10 cents per gallon of ethanol. Novozyme have publicly stated that they have reduced the enzyme costs to below 30 cpg and have received more funding from NREL to lower costs further (Novozyme). Genecor have stated that their costs are between 10 and 20 cpg of ethanol in NREL's cost model (Genecor).

The last step in the process is the fermentation of the sugar to ethanol. When the sugars are hexoses or C6 sugars the traditional ethanol industry yeasts are capable of converting the sugar to ethanol. When the sugars are pentoses, C5 sugars, the problem becomes more complex. Pentose sugars can make up a significant portion of the sugar produced from the hemicellulose of hardwoods and agricultural residues. They contribute a smaller portion of the sugars from softwoods but softwoods have a higher lignin content that makes those feedstocks more difficult to pretreat.

There has been work done on developing both yeasts and bacterial organisms for pentose fermentation over the past decade. There has been little commercial success.

2.1.1.1 Advantages and Disadvantages

There are not yet any commercial plants producing ethanol from lignocellulosic materials other than small plants that process waste sugar streams at sulphite pulp mills. There are some large demonstration plants and a number of companies are working on plans to build commercial plants within the next few years. These companies include Iogen, Abengoa, Dedini and many others. Most of these companies do not release any detailed information on their processes or their economics, the advantages and disadvantages are therefore somewhat speculative at this time.

As with most 2^{nd} generation biofuels the ability to process lignocellulosic feedstocks is a primary advantage of this 2^{nd} generation pathway. These feedstocks are abundant, geographically diverse, generally lower cost than starch or sugar feedstocks, and significant quantities are produced today that are currently wasted.

The yield of ethanol from the process can vary from about 250 to 350 litres/dry tonne of feedstock. This is lower than the ethanol yield from crops such as corn (460 litre/dry tonne) and wheat (425 litres/dry tonne). More feedstock must be transported and processed in the plant for a given ethanol production level compared to first generation technologies.

Most of the processes being developed utilize the lignin portion of the feedstock to produce the energy requirements for the processing facility and thus minimize the requirement for purchasing fossil fuels for the operations. This has two advantages; it improves the lifecycle greenhouse gas emissions for the process and lowers the operating costs by avoiding fossil fuel purchases.

It is sometimes stated that the energy balance of lignocellulosic processes is better than it is for first generation biofuels. Strictly speaking this is not correct. The total energy in (including the portion of the feedstock converted to energy) to total energy out is not as favourable for the current state of the art 2^{nd} generation plant, but the fossil energy balance is better than first generation processes that utilize fossil fuels. There are some first generation plants that are converting to biomass for their energy needs and their GHG emissions performance approaches that of the 2nd generation processes and their energy balances are far better ((S&T)², 2006b).

Detailed, independently verified information on the production costs of ethanol from 2nd generation plants is not available. It is generally accepted within the scientific community that the production costs have been reduced in recent years and they may now approach those of sugar or starch ethanol plants on a cash cost basis. The lower feedstock costs and lower energy costs are offset by high chemical and enzyme costs and higher labour needs.

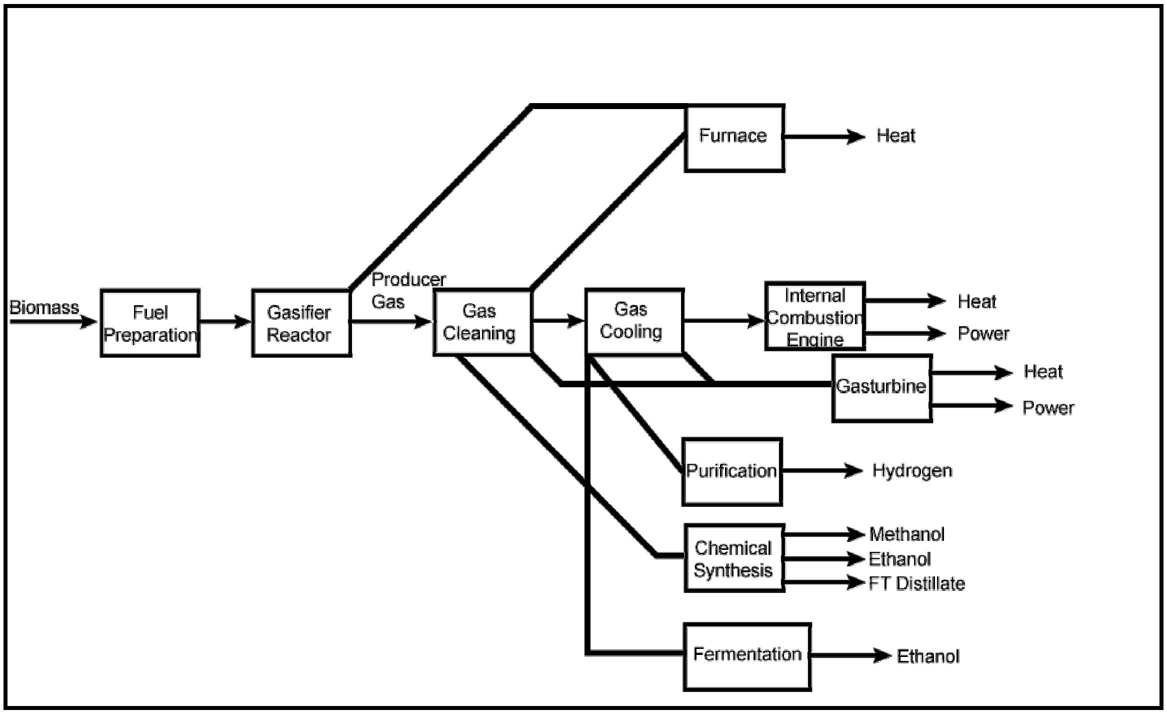
The capital costs of 2nd generation ethanol plants are much higher than they are for the first generation plants. Again, detailed information is not available but the best estimates for the capital costs are three to five times higher than for 1st generation technology plants ((S&T)², 2004). Some process configurations may be even higher. The high capital costs combined with the about the same operating costs currently makes these plants a less attractive investment than the 1st generation plants. Thus, for the same return on investment, these 2nd generation fuels are still more expensive than the existing ethanol production pathways.

Ethanol produced by the 2nd generation plants has the same physical and chemical properties as the 1st generation biofuels. Any barriers that exist for 1st generation ethanol because of these different properties also exist for 2nd generation ethanol.

2.1.2 Ethanol - Thermochemical Routes

If biomass is heated with limited oxygen (about one-third that needed for ideal combustion), it gasifies to a “syngas” composed mostly of hydrogen and carbon monoxide. This biomass gasification technology platform is one of the more versatile platforms in that in addition to the gas be combusted, it can be concentrated and purified to produce hydrogen or it can be used to produce a number of fuels and chemicals by reforming the hydrogen and carbon monoxide chemically or biologically. The possible pathways for this platform are shown in the following figure.

Figure 2-2 Syngas Platform Pathways

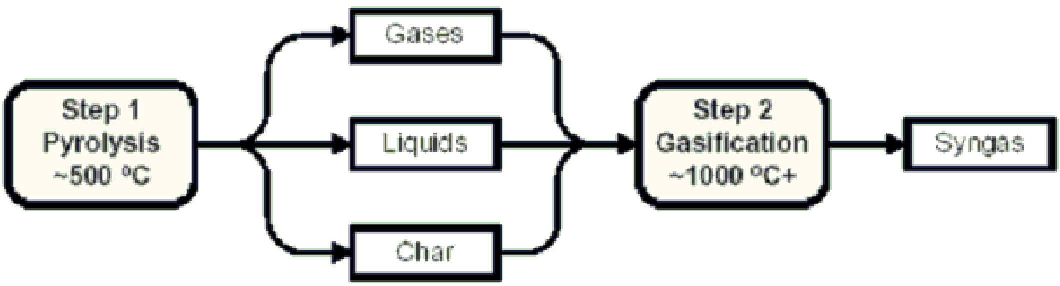


In a report prepared for the US DOE by E^2S (2002), biomass gasification technologies were benchmarked for the production of fuels, chemicals and hydrogen. The technologies employed in the main steps shown in the previous figure are summarized below and much of the description is derived from this report.

Biomass gasification is the conversion of biomass by partial oxidation into a gaseous product, synthesis gas or "syngas," consisting primarily of hydrogen (H_2) and carbon monoxide (CO), with lesser amounts of carbon dioxide (CO_2), water (H_2O), methane (CH_4), higher hydrocarbons (C_2+), and nitrogen (N_2). The reactions are carried out at elevated temperatures, 500-1400^oC, and atmospheric or elevated pressures up to 33 bar. The oxidant used can be air, pure oxygen, steam or a mixture of these gases. Air-based gasifiers typically produce a product gas containing a relatively high concentration of nitrogen with a low heating value between 4 and 6 MJ/m^3. Oxygen and steam-based gasifiers produce a product gas containing a relatively high concentration of hydrogen and CO with a heating value between 10 and 20 MJ/m^3. By comparison, natural gas has a heating value of about 40 MJ/m^3.

The chemistry of biomass gasification is complex. Biomass gasification proceeds primarily via a two-step process, pyrolysis followed by gasification as shown in the following figure. Pyrolysis is the decomposition of the biomass feedstock by heat. This step, also known as devolatilization, is endothermic (requires heat) and produces 75 to 90% volatile materials in the form of gaseous and liquid hydrocarbons. The remaining non-volatile material, containing mostly carbon, is referred to as char.

Figure 2-3 Gasification Steps



The volatile hydrocarbons and char are subsequently converted to syngas in the second step, gasification. A few of the major reactions involved in this step are listed below:

Exothermic Reactions:

(1) Combustion	{*biomass volatiles/char*} + $O_2 \rightarrow CO_2$
(2) Partial Oxidation	{*biomass volatiles/char*} + $O_2 \rightarrow CO$
(3) Methanation	{*biomass volatiles/char*} + $H_2 \rightarrow CH_4$
(4) Water-Gas Shift	$CO + H_2O \rightarrow CO_2 + H_2$
(5) CO Methanation	$CO + 3H_2 \rightarrow CH_4 + H_2O$

Endothermic Reactions:

(6) Steam-Carbon reaction	{*biomass volatiles/char*} + $H_2O \rightarrow CO + H_2$
(7) Boudouard reaction	{*biomass volatiles/char*} + $CO_2 \rightarrow 2CO$

Heat can be supplied directly or indirectly to satisfy the requirements of the endothermic reactions.

Directly heated gasification conducts the pyrolysis and gasification reactions in a single vessel. An oxidant, air or oxygen, combusts a portion of the biomass (Reactions 1 & 2) to provide the heat required for the endothermic reactions. Pyrolysis requires between 5 and 15% of the heat of combustion of the feed to raise the reaction temperature and vaporize the products. In these systems, the reactor temperature is controlled by the oxidant feed rate. If air is used as the oxidant, the product gas has a low heating value of 4 to 6 MJ/m^3 due to nitrogen dilution.

Indirectly heated gasification utilizes a bed of hot particles (for example, sand), which is fluidized using steam. Solids (sand and char) are separated from the syngas via a cyclone and then transported to a second fluidized bed reactor. The second bed is air blown and acts as a char combustor, generating a flue gas exhaust stream and a stream of hot particles. The hot (sand) particles are separated from the flue gas and recirculated to the gasifier to provide the heat required for pyrolysis. This approach separates the combustion Reaction 1 from the remaining gasification reactions, producing a product gas that is practically nitrogen free and has a heating value of 10-20 MJ/m^3. Reaction 2 is suppressed with almost all oxygen for the syngas originating in the feedstock or from steam (Reaction 6).

A variety of biomass gasifier types have been developed. They can be grouped into four major classifications: fixed-bed updraft, fixed-bed downdraft, bubbling fluidized-bed and circulating fluidized bed. Differentiation is based on the means of supporting the biomass in the reactor vessel, the direction of flow of both the biomass and oxidant, and the way heat is supplied to the reactor. The following table lists the most commonly used configurations.

Table 2-2 Gasifier Classification

Gasifier Type	Flow Direction		Support	Heat Source
	Fuel	Oxidant		
Updraft Fixed Bed	Down	Up	Grate	Combustion of Char
Downdraft Fixed Bed	Down	Down	Grate	Partial Combustion of Volatiles
Bubbling Fluidized Bed	Up	Up	None	Partial Combustion of Volatiles and Char
Circulating Fluidized Bed	Up	Up	None	Partial Combustion of Volatiles and Char

The synthesis gas produced by biomass gasification can contain one or more of the contaminants listed in the following table. The identity and amount of these contaminants depend on the gasification process and the type of biomass feedstock.

Tars are mostly polynuclear hydrocarbons (such as pyrene and anthracene) that can clog engine valves, cause deposition on turbine blades or fouling of a turbine system leading to decreased performance and increased maintenance. In addition, these heavy hydrocarbons interfere with synthesis of fuels and chemicals. Conventional scrubbing systems are generally the technology of choice for tar removal from the product syngas.

However, scrubbing cools the gas and produces an unwanted waste stream. Removal of the tars by catalytically cracking the larger hydrocarbons reduces or eliminates this waste stream, eliminates the cooling inefficiency of scrubbing, and enhances the product gas quality and quantity.

Table 2-3 Syngas Contaminants

Contaminant	Example	Potential Problem
Particles Ash	Char	Fluid bed material Erosion
Alkali Metals	Sodium and Potassium Compounds	Hot corrosion, catalyst poisoning
Nitrogen Compounds	NH_3 and HCN	Emissions
Tars	Refractive aromatics	Clogging of filters
Sulphur, Chlorine	H_2S and HCl	Corrosion, emissions, catalyst poisoning

Incompletely converted biomass and ash particulate removal is accomplished with cyclones, wet scrubbing, or high-temperature filters. A cyclone can provide primary particulate control, but is not adequate to meet gas turbine specifications. A high temperature ceramic filter system, such as one under development by Westinghouse, can be used to remove particulates to acceptable levels for gas turbine applications.

Since this filter can withstand temperatures in the 800°C range, the thermal losses associated with gas cooling and cleaning can be reduced.

Water scrubbing can remove up to 50% of the tar in the product gas, and when followed by a venturi scrubber, the potential to remove the remaining tars increases to 97%.

The wastewater from scrubbing can be cleaned using a combination of a settling chamber, sand filter and charcoal filter. This method is claimed to clean the wastewater discharge to within EPA drinking water standards but at the expense of increased capital cost.

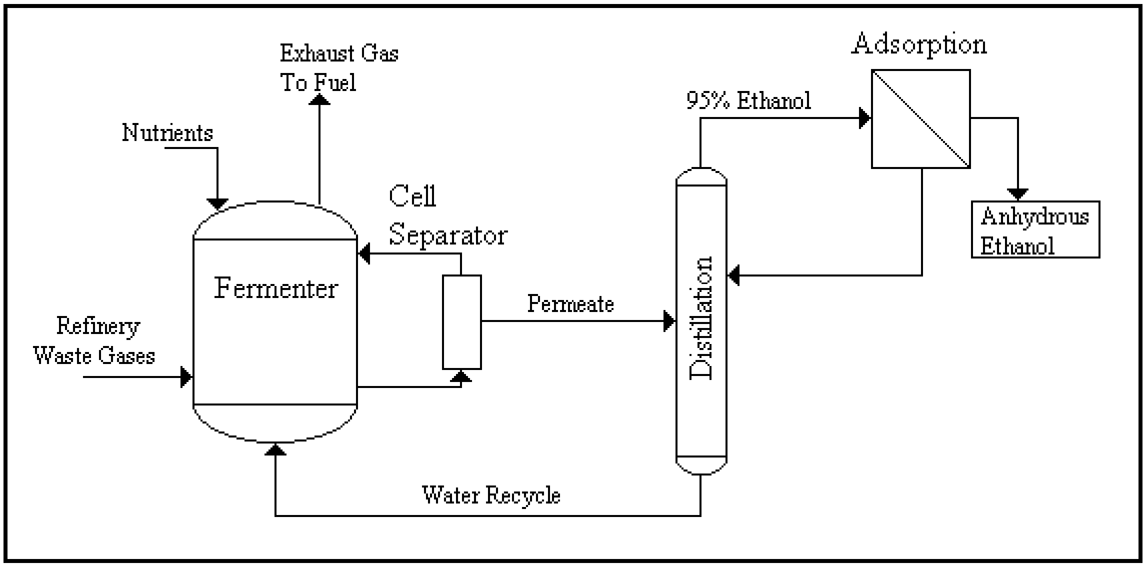
There are, however, a number of challenges with the application of gasification and the conversion technologies for biomass feedstocks. The biomass feedstock is non homogenous with varying moisture contents and chemical compositions. The composition of the gas that is produced is a function of the many competing chemical reactions that are happening in the process. The reactions are all temperature dependent and thus varying the moisture content of the feedstock can change the gas composition significantly. Another challenge is that of scaling the systems. Almost all of the systems have some temperature profile that varies from the edge of the system into the middle. That temperature profile determines the chemical reactions that are occurring in the system and thus the gas composition. If the size of the system is changed the temperature profile changes and so does the gas composition. This requires more engineering, development and operational fine-tuning of systems as larger and larger systems are built. This adds to the overall costs of the technology.

Ethanol can be produced from syngas but the catalysts that have been employed have not been particularly specific to ethanol and a mixture of alcohols from methanol to butanols is usually produced. There is work being undertaken to improve the ethanol selectivity and to improve the yield of the process (Syntec). The syngas from biomass gasification can be better suited to this process than syngas from natural gas because it has a lower hydrogen to carbon ratio and provides a higher yield of product as a result. Natural gas to mixed alcohol processes were investigated in the 1970's and 1980's but development was dropped in part because the processes couldn't achieve a realistic carbon balance. Mixed alcohol production accounted for less than 40% of the products and hydrogen accounted for most of the remainder ($(S\&T)^2$, 2004c).

The chemical synthesis of producer gas to ethanol can only be accomplished with the co-production of methanol, higher alcohols and hydrocarbons with currently know catalysts. Work is underway to increase the selectivity of the catalysts but detailed information on the yield and selectivity is not publicly available. The syngas will probably have to be clean and free of contaminants so as to not foul the catalysts. The ultimate product yields will also be dependent on the gas composition, which may vary with feedstock characteristics.

Several groups are working on a novel fermentation process that can convert carbon monoxide and hydrogen to ethanol (BRI Energy). The process was originally developed to deal with waste gases from the refining industry, the ethanol produced via this method would not be renewable but if the syngas were produced from biomass then the ethanol would come from renewable sources. The basic process flow is shown in the following figure.

Figure 2-4 Syngas Fermentation



The fermentation vessel operates at slightly above ambient temperatures (37°C) but at moderate pressure (3 bar) so that reaction rates are increased. The organism belongs to the clostridium family. It is claimed that the organism is stable and able to recover after a process upset. Ethanol is toxic to the culture so ethanol concentrations are kept below 3% v/v in the reactor. The organism consumes carbon monoxide, carbon dioxide, and hydrogen to produce ethanol and acetic acid. The acetic acid production is minimized by the recycle of distillation bottoms containing some acid back to the fermenter. It has been reported that the pathways are;

$$6CO + 3H_2O \rightarrow C_2H_5OH + 4CO_2 \text{ and}$$

$$6H_2 + 2CO_2 \rightarrow C_2H_5OH + 3H_2O$$

The reactions would indicate that carbon dioxide is also produced along with the ethanol. The fermenter will produce an excess of cell mass over time that will have to go either to a treatment plant or possibly, after de-watering, back to the gasifier. There may also be a small water stream that must be discharged to maintain the water balance.

For the syngas fermentation routes the organism used is a natural acetic acid producer and will only produce ethanol when stressed. This tends to make the fermentation system difficult to operate. The maximum ethanol concentration in the beer is between 2 and 3% with the existing technology, higher ethanol concentrations are toxic to the organism. There is usually waste heat available in the overall system that can be used for the concentration and distillation of the ethanol.

2.1.2.1 Advantages and Disadvantages

There are quite a few companies and research institutions around the world that are developing processes that produce ethanol via this thermochemical production pathway. Some companies have process development units but none have progressed to the point of having fully functioning integrated commercial demonstration plant. Some of the companies active with this pathway include BRI Energy, Pearson Technology, Syntec Biofuels, and many others.

There are several potential advantages of the thermochemical pathways for ethanol production. The pathways are not dependent on the carbohydrate composition of the feedstocks and can therefore convert the lignin as well as the cellulose and hemicellulose to ethanol. This could allow an even wider range of potential feedstocks being employed and higher yields depending on the conversion efficiencies of the process steps. The reaction times are potential shorter, especially for the all-chemical routes which could potentially lead to lower capital costs of the equipment.

Very little information is publicly available concerning the yield that can be achieved by these processes. While all of the biomass can be converted to syngas the efficiency of this gasification step is on the order of 60 to 70% and the chemical conversion of the syngas to ethanol is challenging as most catalysts have low conversion rates and low specificity to ethanol. The actual yield is therefore expected to be about 260 to 400 litre/dry tonne (NREL, 2005). This is in the same range as the biochemical processes.

The energy balance and GHG emissions should be similar to the biochemical route since the overall process yield is similar. Since there is little if any fossil energy used, the lifecycle GHG emissions should be very low and the fossil energy balance should be quite good. The lower ethanol yields than starch and sugar ethanol processes will still result in an overall energy balance that is slightly poorer.

Very little is known about the capital and operating costs of these plants. In theory the operating costs should be lower than for most of the biochemical processes because of the lack of enzymes and chemicals used and no outside energy being required but that will depend on the cost and life of the catalysts used in the process.

The capital costs will be higher than first generation biofuel plants since the processes are undertaken at elevated temperatures and pressures. None of the process developers has released capital cost estimates for their processes.

Ethanol produced by the 2nd generation plants has the same physical and chemical properties as the 1st generation biofuels. Any barriers that exist for 1st generation ethanol because of these different properties also exist for 2nd generation ethanol.

2.1.3 Other Liquid Fuels

There are other liquid fuels that could be produced from biomass and used in spark-ignited engines. Some of these include mixed alcohols or methanol produced through thermochemical processes, and butanol produced through fermentation. Other than methanol little is known about these pathways.

2.1.3.1 Advantages and Disadvantages

Butanol and mixed alcohols could be used in gasoline blends the same way that ethanol is. They may offer better performance in terms of water tolerance and vapour pressure performance but their octane values are lower than ethanol (and about the same as gasoline) and they have a lower oxygen content per volume (Taylor, et al). This would mean that more of the product is required to produce the same exhaust emission performance compared to ethanol and while some claim that this is an advantage, it may have negative implications for the overall fuel volatility curve and vehicle performance.

These fuels may have to go through a lengthy regulatory process before they can be sold in large volumes in some countries.

Little is known on the specific details of some of these processes. Butanol production through fermentation has been considered before but the conventional processes had low yields and were difficult to operate in an industrial environment.

2.1.4 Biogas

Methane can be produced through the anaerobic digestion of waste materials including lignocellulose. These biogas systems are usually used to produce heat and power but there is also the potential to concentrate the methane that is produced and produce pipeline quality natural gas. In some locations in Europe biogas systems are being fed with manure plus lignocellulosic materials to take advantage of attractive selling prices for renewable electricity. Other European systems operators are considering putting the biogas into the pipeline network after it has been cleaned and the methane concentrated.

Biogas systems are commercially available and in operations on a variety of feedstocks. Systems that process only lignocellulosic materials and use the produced gas for applications other than electric power are rare.

Natural gas is used as a transportation fuel in many regions of the world but it requires engines designed for the fuel or converted gasoline engines.

2.1.4.1 Advantages and Disadvantages

Biogas systems usually have a low requirement for external fossil energy so the overall GHG emissions performance and fossil energy balance are relatively good. Like all biological systems they can be difficult to operate at their most efficient state and some developers have experienced operational issues when very large systems have been built. Small systems will also negate the potential for economies of scale to be generated and the resulting benefits in terms of capital and operating costs.

The use of natural gas as a vehicle fuel requires a sequential decision process. First the user must decide to purchase a vehicle that is capable of using the fuel and then a fuel supplier must supply the infrastructure that is necessary to supply the fuel. These “chicken and egg” scenarios result in slow penetration rates since each decision maker waits for the other to commit first before they commit.

2.2 COMPRESSION IGNITION FUELS

There are at least three families of processes that produce a product that is used in a compression ignition engines and that are being labelled as 2nd generation biofuels. The first family of processes produces Fischer Tropsch distillate fuels via biomass gasification and synthesis gas reformation. The second family produces a hydrocarbon from feedstocks of the lipid family, vegetable oils and animal fats. The last pathway uses biomass gasification and synthesis of the produced gas to manufacture DME for use in engines. Each of the families is briefly discussed below.

2.2.1 Fischer Tropsch Routes

Gasifying any biomass material and then synthesizing a diesel type fuel using a Fischer-Tropsch synthesis step or the similar Shell Middle Distillate Synthesis technology can produce a compression ignition fuel. The fuel produced by these processes is a high cetane hydrocarbon that can be used as a diesel fuel component. The fuel has clean burning properties but does not contain any oxygen. Compared to conventional biodiesels, one advantage of this process is that the feedstock is not limited to oils and fats but can used agricultural residues such as straw or wood chips. While the synthesis step is employed commercially in South Africa and Malaysia, the feedstocks used have been coal and natural gas.

The technology has not yet been combined commercially with biomass gasification although some product has been produced in a pilot plant unit operated by the German company Choren (www.choren.de/). The process and the pilot plant are shown in the following two figures.

Figure 2-5 Choren Biomass to FT Distillate Process

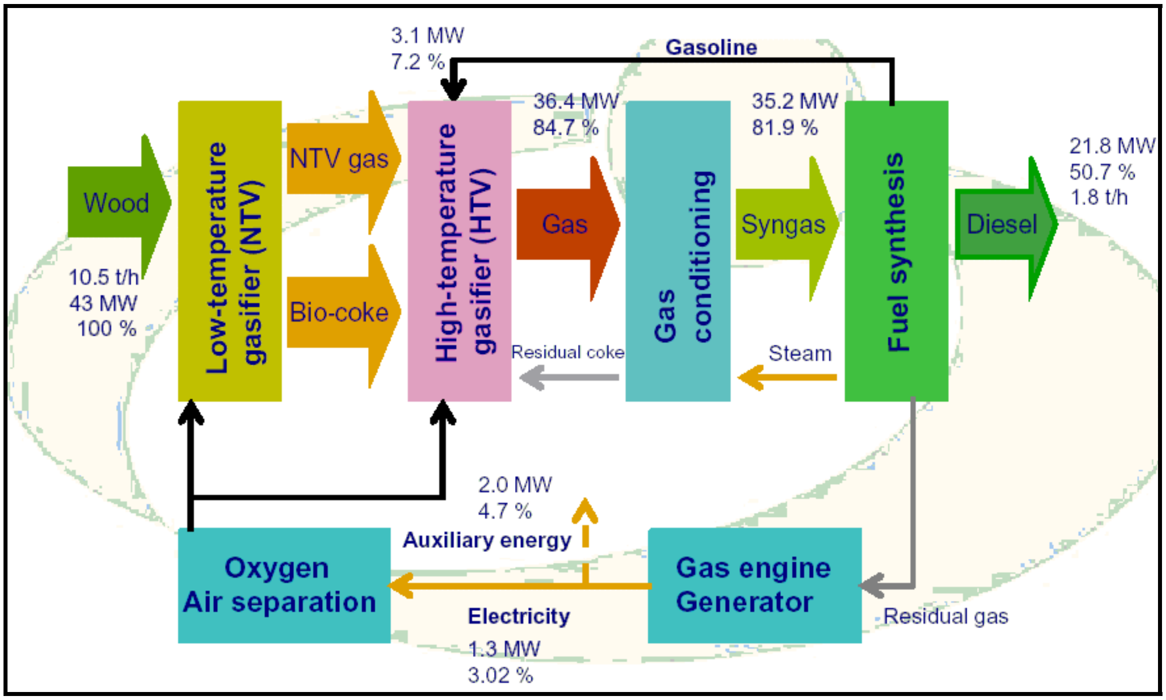


Figure 2-6 Choren Pilot Plant

There is interest in this pathway by Shell, Volkswagen and DaimlerChrysler for at least some parts of the world. Volkswagen has named the fuel Sunfuel® (www.sunfuel.de).

The advantages of this type of biodiesel claimed by Volkswagen Include:

- SunFuel® is a high-grade fuel consisting of hydrocarbons which contain no sulphur or aromatic compounds. This fuel has great potential for significantly reducing pollutant emissions produced by engines - in particular nitrogen oxides (NOx) and particles.
- The fuel properties can be chemically modified and adapted to meet the requirements of optimized combustion.
- SunFuel® uses the same infrastructure as conventional mineral oil fuels. It can be used as an alternative to diesel fossil fuel without having to tune the engine.
- Selectively adapting the properties of SunFuel® provides the possibility of optimizing future combustion processes and fuels. This opens up enormous potential for further reducing pollutant emissions, in particular particles.

A very similar concept has been studied by an alliance that includes ECN, Ecofys, Rabobank, Shell and Volkswagen. This concept is called BIG-FiT (Biomass Integrated Gasification – Fischer Tropsch).

The members have entered into an alliance with the main objective to investigate the demonstration of production of diesel and other climate neutral fuels via the route of biomass gasification and Fischer-Tropsch synthesis. They have completed a preliminary assessment that included a life cycle assessment, process design studies and costing studies (SDE). The general conclusions were that the next steps in the development of the concept should:

- Focus attention and resources on fundamental and industrial research aimed at addressing the key technical uncertainties of pressurized oxygen blown biomass gasification systems and syngas cleaning.
- Demonstrate market introduction of FT-diesel (out of natural gas) in addition to other means of promotional activities.

2.2.1.1 Advantages and Disadvantages

These FT diesel fuels are able to be produced from a range of feedstocks and are not limited to vegetable oils and animal fats like conventional biodiesel. The production potential is therefore much larger.

Like many of the 2nd generation biofuels there is not a lot of independently verified information available on these processes. The processes are believed to require between 4 and 6 kg of feedstock to produce 1 kg of FT distillate ((S&T)^2, 2004c). This compares to methyl esters that produce about 1 kg of fuel from 1 kg of oil and depending on the feedstock can produce 1 kg of oil from 2.5 kg of rapeseed or 5 kg of soybeans.

The energy efficiency of these processes can range from about 35 to 45% depending on the gasification and synthesis technologies employed. This is quite low compared to petroleum diesel fuels and 1st generation biofuels. Almost all of the energy required is derived from biomass so the GHG emissions profile is very good for these fuels.

Information on operating costs and capital costs is scarce. It has been suggested that the capital costs could be an order of magnitude higher than the capital costs for 1st generation biofuels plants of the same capacity (Hoffmann). While operating costs will not be dominated by the feedstock costs as they are in 1st generation plants, the high capital cost will have a severe impact on the potential investment returns.

The FT distillates do have the advantage that the products are fungible with the existing diesel fuels and thus distribution system issues are largely avoided by these products. The chemical composition of the products is also controllable, largely free of aromatic compounds, and essentially zero sulphur, making them excellent fuels from a combustion emissions perspective. It is the combustion properties that make them attractive to the automotive sector.

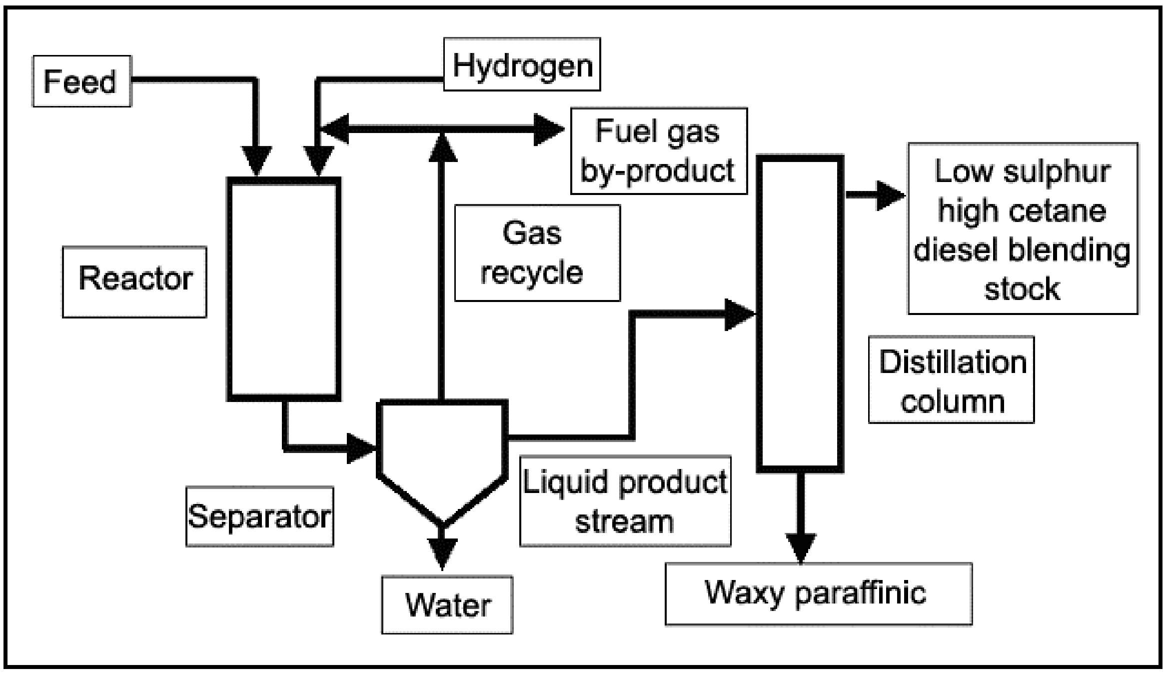
2.2.2 Other Thermochemical Distillates

Natural Resources Canada (NRCan, 2003) has developed a process that can process fats by hydrotreating them to produce paraffins. They call the product SuperCetane. The paraffins, which only contain carbon and hydrogen, can be used as a diesel fuel blending compound.

A number of feedstocks have been successfully processed using the technology including canola oil, soya oil, yellow grease, animal tallow and tall oil (a by-product of the Kraft pulping process). Yields of between 75 – 80% based on feedstock input have been achieved.

The process is shown in the following figure.

Figure 2-7 Super Cetane Process



Several reactions occur in the process, including: hydrocracking (breaking apart of large molecules), hydrotreating (removal of oxygen), and hydrogenation (saturation of double bonds). The catalyst employed by the process is a conventional commercial refinery hydrotreating catalyst. Hydrogen is the only other input.

The process has been successfully scaled up in a one-barrel/day hydrotreating pilot reactor using depitched tall oil as the feedstock. Approximately 3,800 litres of Super Cetane were produced for emission testing at Environment Canada labs in Ottawa, Ontario and for road tests with Canada Post in Vancouver, BC.

The main product generated by this process is a hydrocarbon liquid with the other co-products being a burner gas and water.

The hydrocarbon liquid product can then be distilled into three basic fractions: naphtha, middle distillate (super cetane) and waxy residues. In the production of this high cetane additive from yellow grease, animal tallow and vegetable oils, very little naphtha and waxy residues are produced. Most of the time, the fraction of naphtha is so small that it is not necessary to remove it from the Cetane Enhancer. The waxy residue, which is rich in paraffins, can be used as refinery feedstock or as power boiler fuel.

The middle distillate is the primary liquid product of the technology and product yields range from 70% - 80% for yellow grease and tallow.

A similar process has been developed by Fortum. This process has the additional step of isomerising the product to improve the cold weather performance of the fuel.

2.2.2.1 Advantages and Disadvantages

These hydrotreating processes have the same limitations on feedstock as the 1st generation biodiesel fuels since they both process lipids. The product yield from this process is about 20% less than the yield from the 1st generation fuel.

Most of the energy required for the process is provided from the co-products produced with the exception of the hydrogen required for the hydrotreating.

The GHG emissions are largely those resulting from the feedstock with the emissions from the hydrogen production also having a small contribution. When the hydrogen is produced from steam reforming natural gas the GHG emissions are about 10% higher than for the methyl ester process using the same feedstock ($(S\&T)^2$, 2006).

The capital cost of these plants should be higher than they are for a 1st generation plant since the process involves higher temperatures and pressures. The operating costs are probably also slightly higher given that hydrogen is usually a more costly input than methanol. The hydrogen costs will also vary widely depending on the location. If these plants are integrated inside a refinery then hydrogen costs will be lower.

Since this fuel is a hydrocarbon, some of the concern with methyl esters about compatibility with the fuel distribution system is not present. The fuel has a very high cetane but unless it is isomerised also has very poor cold weather properties. The emissions performance of this fuel may not be the same as the traditional biodiesels described earlier since there is no oxygen within the molecular structure. There should still be an emissions improvement since the fuel will be a high cetane and have a very low aromatic content and like the FT Distillate fuels the composition can be controlled.

2.2.3 Bio-DME

Dimethyl ether is a product that is currently manufactured from natural gas that has been promoted as a potentially attractive alternative fuel. The product has some attractive chemical and combustion properties that allow it to be used in compression ignition engines as well as being a possible hydrogen carrier for use in fuel cell applications. Its physical properties resemble those of LPG.

Like natural gas, the use of DME requires a sequential decision process as part of the market implementation. The vehicles must be built to use the fuel and the fuel infrastructure must be built to supply these vehicles.

DME can also be produced from the gasification of biomass to produce syngas and then the syngas is converted to DME. It is this biomass gasification process that results in DME being identified as a 2nd generation biofuel. The challenges and issues of DME production from biomass are similar to the other biofuel production pathways that rely on natural gas.

2.2.3.1 Advantages and Disadvantages

Like all of the gasification processes Bio-DME can utilize a wide range of feedstocks. The energy requirements for the process are supplied by the biomass with very little fossil fuel used in the lifecycle. The GHG emission performance is expected to be quite good. The natural gas to DME process is reported to have a relatively high conversion efficiency and it is expected that the Bio-DME would also have a good conversion efficiency compared to other biomass gasification pathways.

The biggest issue with DME is the sequential decision issue. How is a new application for the fuel introduced at the same time as a new fuel is introduced? The challenge for DME is even greater than it is for some of the other fuels since the chemical market demand for DME is also quite small and the current production for all uses is low. This may change in the future as DME may emerge as a fuel for power generation in some regions of the world.

Since DME has not been widely used as a fuel it will be required to move through a health, safety and environmental assessment in some countries before widespread adoption of the fuel is possible.

3. MARKET DEVELOPMENT PERSPECTIVES

3.1 APPROACHES TO MARKET DEVELOPMENT

The issue of creating markets for energy technologies has been the subject of considerable focus at the International Energy Agency over the past five years. In 2003, the IEA published a report "Creating Markets for Energy Technologies" that considered the process of market development.

> *The technological and market developments required to transform the energy system will be conceived and implemented largely in the private sector. But success in this endeavour will not be determined exclusively by market forces. Governments that value the wider benefits of cleaner and more efficient energy technologies will work in partnership with market actors to ensure there are real opportunities for technologies to make the difficult transition from laboratory to market. This book is about the design and implementation of policies and programs for that purpose.*
>
> *Governments are motivated to assist not only because they have a responsibility for the pursuit of long-term societal goals and stewardship of the planet, but also because they understand that their policy settings help to determine whether markets develop and operate efficiently. Policymakers must therefore understand the markets concerned and they must have a highly developed capacity to mount effective programs. In both cases, experience is the best teacher.*

The IEA reviewed 22 case studies of what they determined where successful energy market developments in IEA countries over the past twenty years. In studying the cases, the IEA considered three perspectives on deployment policymaking. These three perspectives have developed over the last quarter of a century.

- The Research, Development and Deployment Perspective, which focuses on the innovation process, industry strategies and the learning that is associated with new technologies;
- The Market Barriers Perspective, which characterizes the adoption of a new technology as a market process, focuses on decisions made by investors and consumers, and applies the analytical tools of the economist;
- The Market Transformation Perspective, which considers the distribution chain from producer to user, focuses on the role of the actors in this chain in developing markets for new energy technologies, and applies the tools of the management sciences.

In part, the three perspectives are three vocabularies for looking at the same issue but each adds something that the others are missing. The strength of the R&D plus Deployment concept is its vision of the future and its focus on the technology itself, its costs and performance and the process of market entry through niche markets. The market barriers approach uses economic analysis to improve the understanding of the barriers to market entry and provides some discipline to the analysis of market intervention measures that could be used as policy tools. The Market Transformation perspective encourages sensitivity to the practical aspects of crafting policies that produce the desired effects.

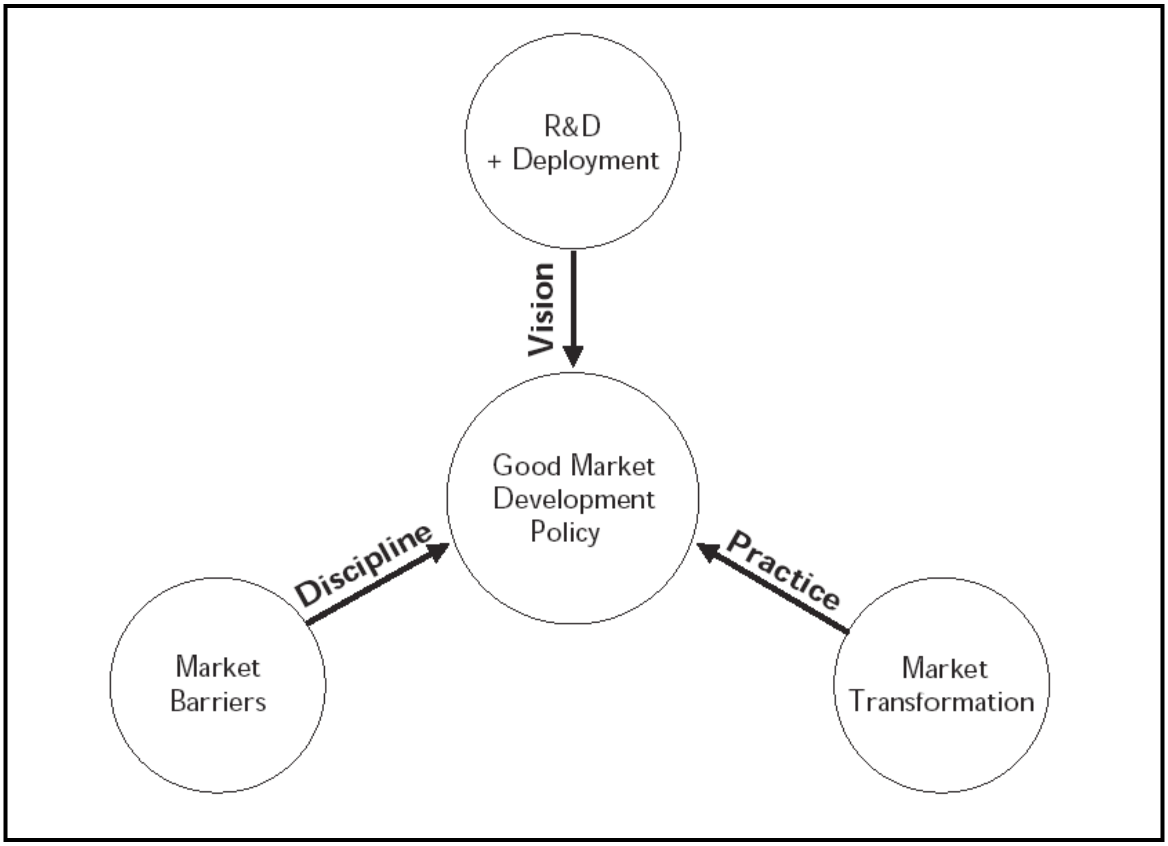
The IEA concluded that the adoption of clean energy technologies would not be likely to succeed unless all three perspective were considered and that it is necessary to:

- Invest in niche markets and learning in order to improve technology cost and performance;

- Remove or reduce barriers to market development that are based on instances of market failure; and
- Use market transformation techniques that address stakeholders' concerns in adopting new technologies and help to overcome market inertia that can unduly prolong the use of less effective technologies.

Visually the IEA summarize the three perspectives as shown in the following figure.

Figure 3-1 Overall Perspective on Technology Market Development



Around this central theme, a close reading of the IEA case studies revealed more detailed messages about the nature of successful policy-making. Some key points are:

- *Deployment policy and programs are critical for the rapid development of cleaner, more sustainable energy technologies and markets. While technology and market development is driven by the private sector, government has a key role to play in sending clear signals to the market about the public good outcomes it wishes to achieve.*
- *Programs to assist in building new markets and transforming existing markets must engage stakeholders. Policy designers must understand the interests of those involved in the market concerned and there must be clear and continuous two-way communication between policy designers and all stakeholders. This calls for the assignment of adequate priorities and resources for this function by governments wishing to develop successful deployment initiatives. Programs must dare to set*

targets that take account of learning effects; i.e., go beyond what stakeholders focused on the here-and now may consider possible.

- *The measures that make up a program must be coherent and harmonized both among themselves and with policies for industrial development, environmental control, taxation and other areas of government activity.*
- *Programs should stimulate learning investments from private sources and contain procedures for phasing out eventual government subsidies as technology improves and is picked up by the market.*
- *There is great potential for saving energy hidden in small-scale purchases, and therefore the gathering and focusing of purchasing power is important.*
- *Most consumers have little interest in energy issues per se, but would gladly respond to energy efficiency measures or use renewable fuels as part of a package with features they do care about.*

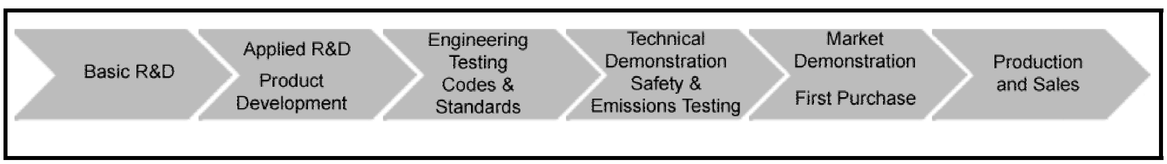
The three perspectives from the IEA have been considered here so that the issues that impede market development for biofuels and that require addressing from a policy perspective can be identified and addressed.

In the rest of this chapter, the individual perspective is described in more detail and then the market development issues for biofuels are assessed from that perspective. The description of the different perspectives draws heavily on the IEA report but the tools found in each of the perspectives have been applied to the specific application of biofuel market development.

3.2 Research and Development + Deployment

Many groups consider product or technology development as a linear process which moves from research and development through to the end market as shown in the following figure, which is adapted from an Industry Canada discussion of the process.

Figure 3-2 Stages of Development



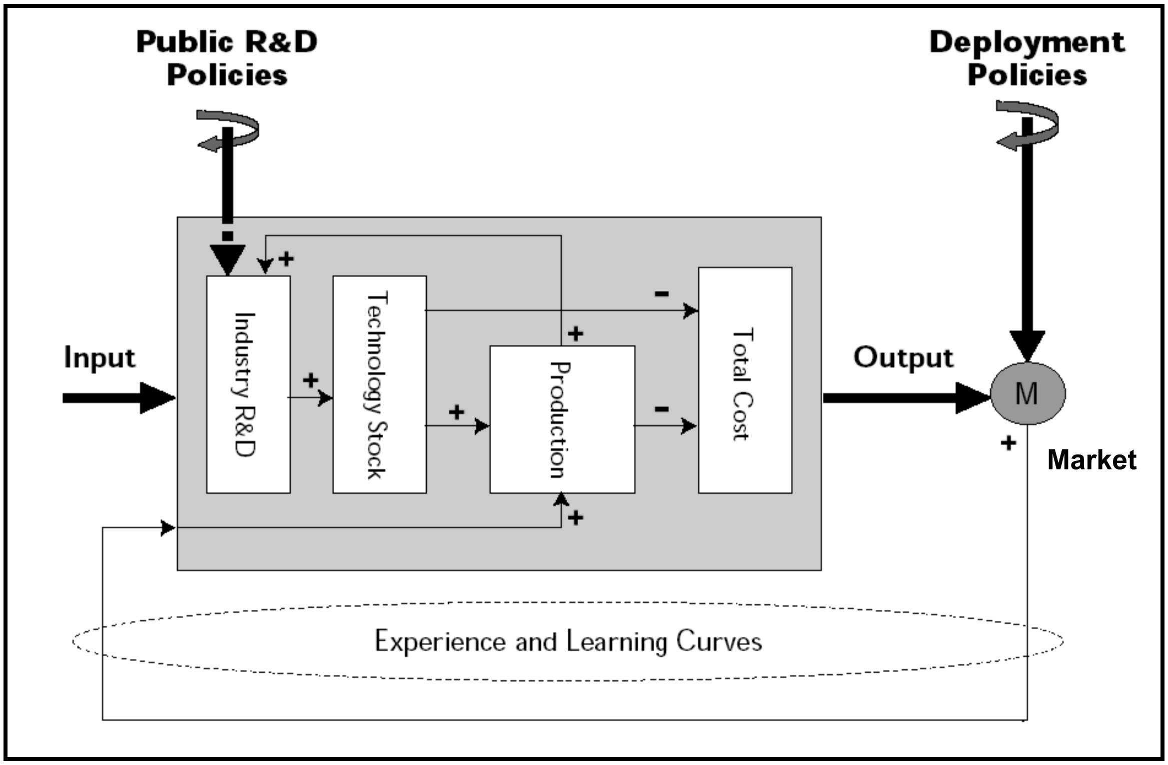
In practice, the technology development process is cyclic in nature rather than linear with decisions being made at each stage having an influence on any eventual market success and in the later stages feedback between the market experiences and further technology development are very important. It is this feedback between deployment and R&D that is critical for success and that is why the IEA called this perspective Research & Development + Deployment.

The market uptake of new bioenergy technologies has two positive effects. First, there is the *physical effect* of using renewable energy and the reductions in greenhouse gas emissions that would accompany this and the second effect is the *learning effect* of how to produce new energy sources less expensively and more effectively. It is the combined effect that produces the real impact for new technologies.

In the case studies that the IEA considered they found that many government sponsored deployment programs defined success in terms of sales growth and market penetration. They found that this was too narrow a view and it neglected the link between the programs and private sector investment decisions. Decision makers in industry often consider the initial costs of market learning too high and too risky. Governments on the other hand have scarce public resources and can't bear the total cost of moving a new technology to market. However, in many of the case studies early government involvement in the deployment process played a crucial role in encouraging private sector involvement and in activating the learning process among the market participants.

The IEA describes the process of the interaction between the governments and the private sector as shown in the following figure.

Figure 3-3 Influences on the Learning Process from Public Policies



The figure summarizes how public sector and industry R&D interact to produce a 'virtuous cycle' in which government support encourages corporations to try out new technologies in genuine market settings. The two vertical arrows represent the encouragement for industry R&D and production with a new technology brought about by government policies. Expanded output and sales stimulate the 'plus' cycle in the diagram: industry R&D increases further, which enhances the technology stock, which in turn further stimulates production. The production increases also stimulate the learning process and the 'minus' cycle in the diagram, resulting in reductions in the cost of production. This further stimulates sales and the cycle reinforces itself. The figure also indicates the role of experience and learning curves, which will be discussed next in this section. They provide a quantitative measure of market learning and the efficiency of the feed-back from market experience ("M") to production and industry R&D, which leads to cost reductions and improved technology.

The figure also provides a powerful argument in favour of government support for technology deployment, if government is supporting research it should also be supporting deployment. This argument has also made by many industry stakeholders in many different countries. This gap between R&D funding and commercial funding is often described as the "Valley of

Death" and many technology developers state that it is the largest barrier that new technology must overcome on the path to commercialization. The "Valley of Death" is not a phenomenon that is unique to a specific country or product as references to it can be found in the literature of all of the developed countries.

3.2.1 Experience Curves

There is overwhelming empirical evidence that deploying new technologies in *competitive markets* leads to *technology learning*, in which the cost of using a new technology falls and its technical performance improves as sales and operational experience accumulate. Experience and learning curves, which summarise the paths of falling technology costs and improving technical performance respectively, provide a robust and simple tool for analysing technology learning.

Viewed from the Research, Development and Deployment (R&D + D) perspective, the curves provide a method to set targets and monitor programs; this includes a way of estimating program costs and providing a guide to phasing out programs as technologies mature and no longer require the support of deployment measures.

The shape of the curves indicates that improvements follow a simple power law. This implies that relative improvements in price and technical performance remain the same over each doubling of cumulative sales or operational experience. As an example, the following figure shows that the prices of photovoltaic modules declined by more than 20 percent as each doubling of sales occurred during the period between 1976 and 1992 (IEA, 2000). Furthermore, the relationship remains the same over three orders of magnitude of sales.

The experience curve is described mathematically as:

$$\text{Price at year t} = P_0 * X^{-E}$$

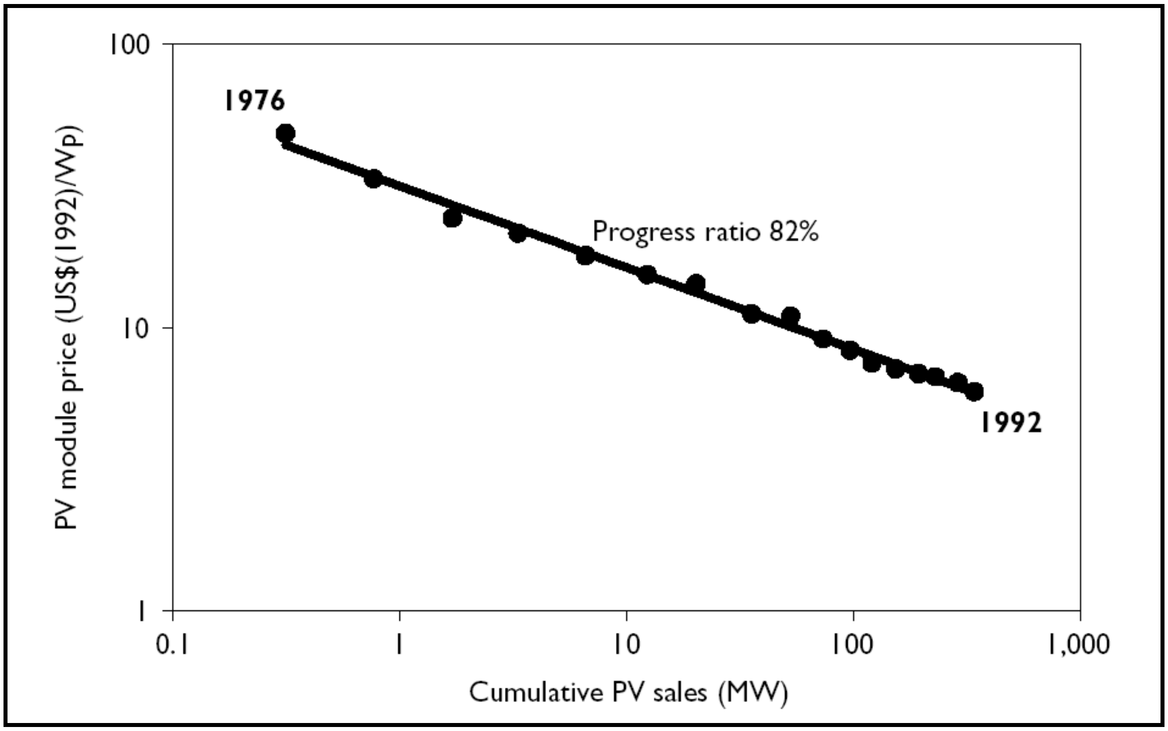
where:

- P_0 = the price at one unit of cumulative production.
- X = the cumulative production of energy, sales, or a similar surrogate for the experience gained with the technology in year t.
- E = the experience parameter which characterizes the slope of the trend line when plotted on a log-log scale.

Progress in the reduction in energy price as technology travels down the experience curve is commonly reported in terms of the progress ratio, or PR. The PR is the energy price after double the cumulative production, as a fraction of the starting price at any point on the line and is calculated from the experience parameter (E) using the equation: $PR = 2^{-E}$.

The Progress Ratio is usually presented as a percentage and in the PV case shown below, the progress ratio is 82%.

Figure 3-4 Photovoltaic Experience Curve



The straight line captures a very important feature of the experience curve. Anywhere along the line, an increase by a fixed percentage of the cumulative production gives a consistent percentage reduction in price. This means that for technologies having the same progress ratio, the same absolute increase in installed capacity will yield a greater cost decrease for young technologies (i.e., they learn faster) than old technologies. This also means that the same absolute increase in cumulative production will have more a dramatic effect at the beginning of a technology's deployment than it will later on. For well-established technology, such as oil refineries using conventional technology, the volume required to double cumulative sales may be of the order of 100 million bbls/day, so the experience effect will hardly be noticeable in stable markets.

There is a significant amount of information on experience curves in the literature for many different technologies. Figure 3-5 shows the distribution of Progress Ratios for 108 case studies for a range of different products in the manufacturing sector (IEA, 2000). The average value of the progress ratio over these case studies was 82%. The consistency of the Progress Ratios over so many different technologies and products means that the approach can be used confidently, with some care, as a policy analysis tool for a range of technologies.

In the energy sector, experience curves have been prepared for many electricity production technologies in the European Union and that data is shown in Figure 3-6. The dominant incumbent technologies have the lowest cost but interestingly the lowest progress ratios. This would suggest that over time, with the learning that arises from increased deployment and increased R&D that is driven by higher sales some of the new technologies will be able to challenge the incumbent fossil technologies on the basis of price while at the same time providing environmental benefits.

Figure 3-5 Distribution of Progress Ratios for 108 Case Studies in the Manufacturing Sector

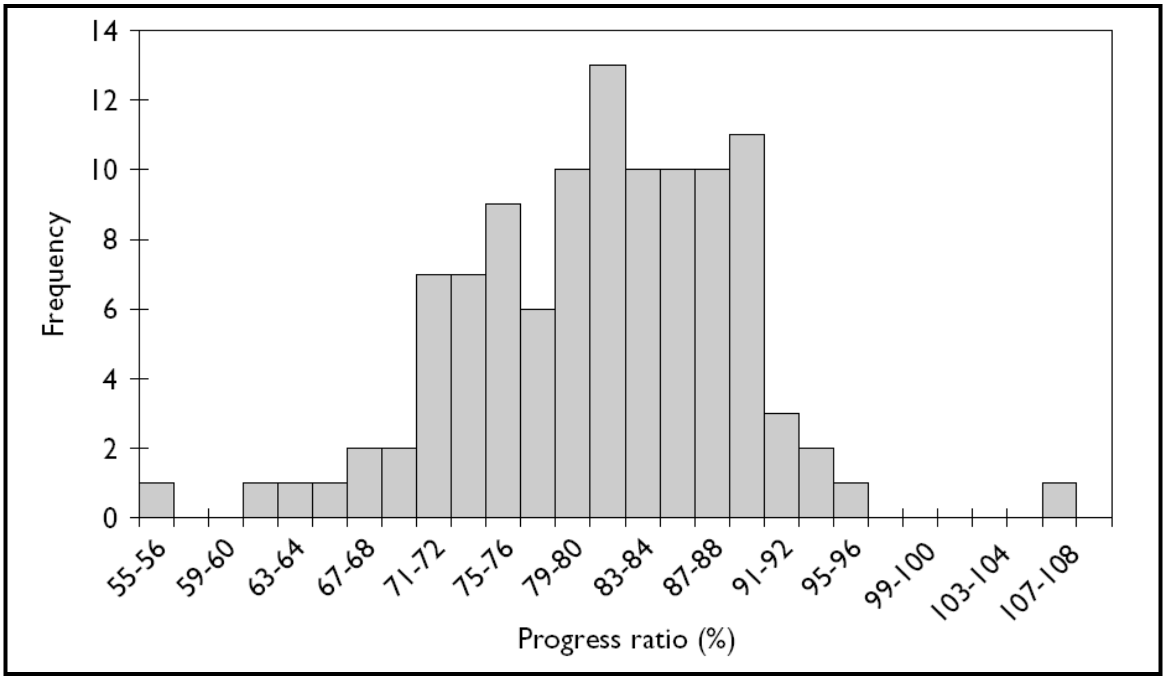
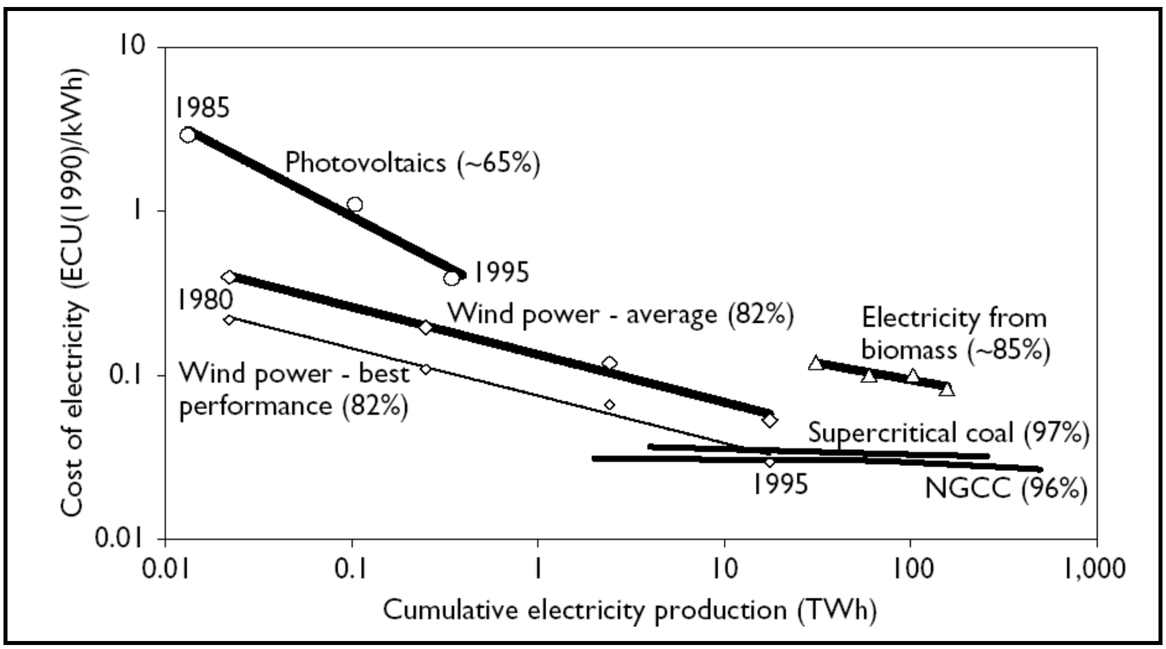


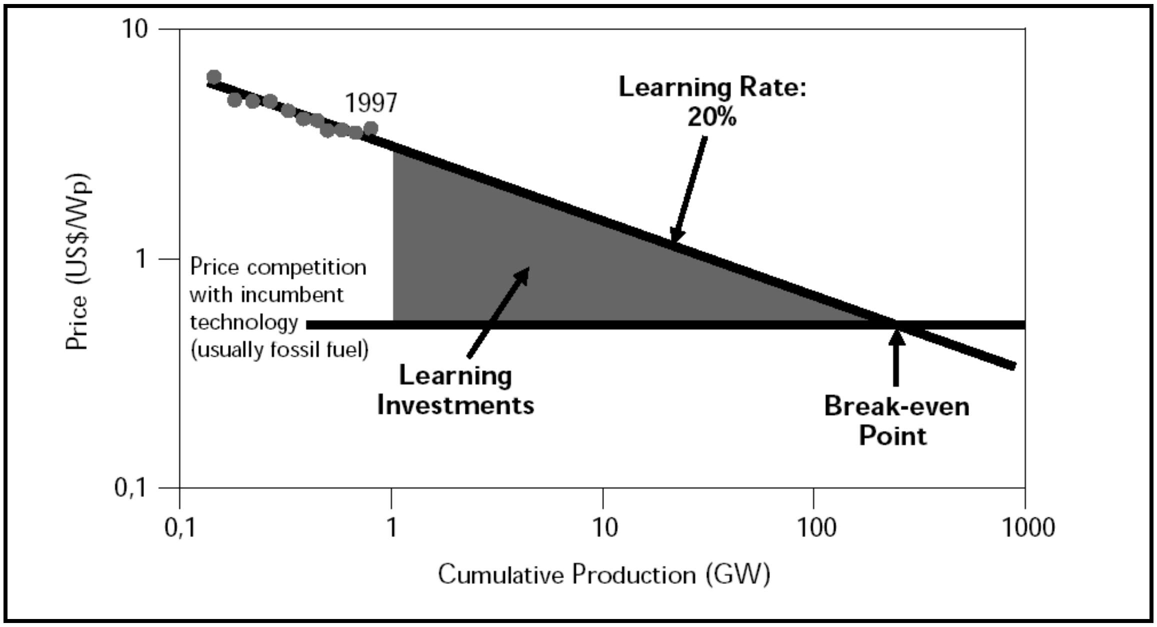
Figure 3-6 Electric Technologies in the EU, 1980-1995



Note that Figure 3-4 uses the installed capacity of photovoltaic technologies for the quantity measure and Figure 3-6 uses the amount of electricity produced as the measure. The experience curves can be applied to both capital cost and the cost of production. The two measures may have different Progress Ratios, as there are costs other than capital (feedstock, operating costs, etc.) that influence the total production cost.

The evidence from experience curves draws attention to the need to provide ***learning opportunities*** for new technologies in markets for energy services. That typically means that a supplier of energy services will have to incur costs that are greater than those incurred when incumbent technologies are used. Figure 3-7 illustrates the point with the experience curve for photovoltaic modules.

Figure 3-7 Projection of Break Even Points



In this example, for photovoltaic systems to compete against currently used technologies in central power stations, the cost of modules has to be brought down to 0.5 US$/Wp, indicated by the horizontal line marked 'Price competition with incumbent technology' in the diagram. The experience curve represents the price necessary for a producer of PV modules to cover the cost of production; however, in markets dominated by the incumbent technologies the producer will not obtain this price. Thus, the shaded triangle represents the extra cost, the *learning investments*, that will have to be covered from other sources if the market for PV-electricity is to expand and the cost of production with PV is to fall to the level of the current market price – the breakeven point in the diagram.

While not all technologies will require the same amount of money needed to reach the break-even point for PV, it is clear that large sums of money are needed to finance learning investments. Should they come from investors in the private sector or government? The answer is probably both. The important point here is to be aware of the issues involved in efforts by government to activate private funding of learning investments and shorten the time horizon within which a technology will be considered a commercial endeavour.

The magnitude of the learning investment may also be influenced by the economies of scale. For many of the conversion technologies where the capital cost of the infrastructure is a significant part of the overall product cost, large plants, with their inherent economies of scale, will have a lower required total learning investment than multiple small plants. This requires the development of large markets at the same time, feats that are not easy to synchronize for new products and new technologies. Note also that large is a relative term and different technologies may have different thresholds for large. A large biodiesel plant may produce less energy than a large ethanol plant for example.

The IEA Creating Markets paper concludes its discussion of providing opportunities for technology learning with the following discussion of the role of private and public investments in deployment programs.

> *As a matter of course, the private sector finances investment in some new technologies that have not yet reached the break-even point (for example, through venture capital). This can be understood by recognising the implications of the experience curve continuing to the right of the break-even point. The expectation is that the cost of using a new technology will fall below the current market price. Since incumbent technologies may still account for the larger market share, they will determine the market price for the energy service produced and the new technology will begin earning net profit that recovers the learning investments. However, existing firms tend to prefer incumbent technologies. Even if they are aware of opportunities for technology learning, they will often be cautious about investing in them and possibly for good reasons from their viewpoint. They may view the learning rate and the associated time path of learning benefits as too uncertain; and any given company may face the risk that some or all of the benefits of its learning investments can end up being captured by its competitors. Thus, if they make learning investments independently at all, they are likely to choose technologies that have already progressed substantially down the learning curve (though exceptions to this are plausible, such as in cases where new technologies have been developed through in-house R&D).*
>
> *Government deployment programs that provide assistance or incentives for private investment can thus make a crucial difference for major new technologies in the energy sector. Furthermore, the tendency towards inertia on the part of market actors creates a classic case for action from government – an instance of what economists refer to as positive externalities. If private investors are not forthcoming to undertake learning investments in a technology that is judged to be market-ready, society will benefit if government (which may have a different risk profile and lower costs of capital) puts resources into encouraging and facilitating the investment in technology learning. For practical reasons governments are not in the habit of responding to this argument for just any technology, but in the case of new energy technologies that help to achieve the governmental goals of improving energy security and reducing greenhouse gas emissions, the case for action becomes very strong.*
>
> *This argument of course raises complex questions about 'picking winners' and about how much cost governments should incur when it is not clear how large the future benefits will be and to whom they will accrue. This is a large subject and an exploration of it is beyond the scope of this book. As already noted, the case study project was focused on the design and implementation of successful deployment programs and was not intended to cover the process leading to decisions to establish programs in the first place. However, it is worth noting here that empirically-observed learning effects are helpful when benefit-cost analysis is used to establish whether there is a rationale for a specific deployment program. Some benefit-cost analyses neglect dynamic effects of this sort, in which case these analyses will be biased towards locking in existing technologies and their variants. As well, changes in a technology and organizational learning effects can bring about changes in the nature of an energy service, which means that price and cost observations for the new form of the service may not be directly comparable to prices and costs of the old form of the service. This can lead to inaccurate conclusions about the relative efficiencies of new and old technologies and could affect benefit-cost*

calculations. Qualitative changes of this sort are also of interest because they can provide the basis for 'niche markets.

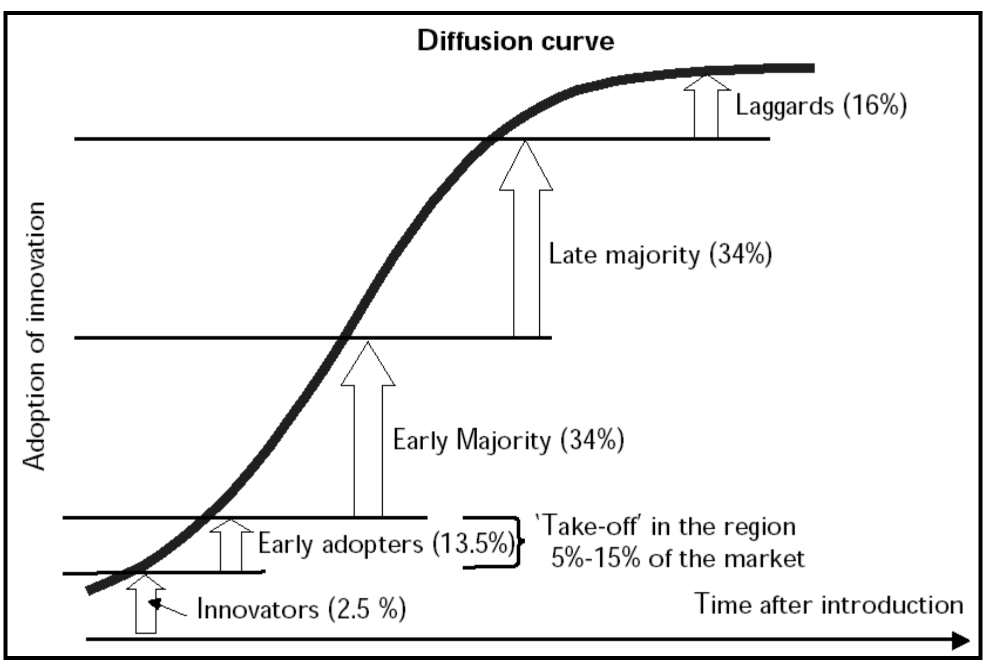
As noted earlier it is important to consider that experience curves can be applied to different aspects of new technologies. One could consider the capital cost of the new technologies and how they might change as more plants are built or one could consider the cost of the energy product itself. This gives some insight in bioenergy opportunities because not all aspects of bioenergy are new. The biomass feedstock has generally been produced for many years and we are a long way down the learning curve for the production, harvesting and transportation of grain, straw, waste wood, or animal fats from renderers have been practiced for years. This is not to say that further cost reductions are not possible but they will likely be slower than experienced with the conversion technology. With other feedstocks such as new industrial oilseed crops there are still opportunities for learning for the production of these materials. Not all of the conversion technologies have reached the same stage of development so some have more potential for cost reductions than others do.

The key point is that for emerging technologies the costs can change quite rapidly as the technology is developed. The current costs are not the same as the future costs. Given that the incumbent technologies have a much larger base, the rate of improvement in those technologies is slower than it is for new technologies and the price gap will be reduced over time.

3.2.2 Technology Diffusion

Closely connected with the study of experience curves is the subject of technology diffusion, how new products and services move into the market place. There has been a significant amount of research and a number of publications concerning this subject in the past quarter century as well. The idea that the adoption of successful new products by buyers throughout an economy grows according to an S-shaped curve has long been used in the study of innovation. This S-Curve is illustrated in Figure 3-8.

Figure 3-8 S Curves



The determination of the actual shape of the S curve is quite complex. There are four main elements to the diffusion process. There is the innovation itself, the communication of the innovation, time and the social system that is attempting to adopt the new technology. Each element is critical to the successful diffusion of innovation or technology and is discussed briefly below.

Innovations

The characteristics of the technology, as perceived by the potential user, help to determine the rate at which the new technology is taken up. There are five important considerations to the adoption of new technology. The five factors are:

- the relative advantage of the new product,
- the degree to which it is consistent with the existing social values,
- the complexity of the innovation,
- the observability of the new product or system, and
- the ease with which the new system can be tried by potential users (trialability).

The relative advantage of a biofuel is the degree to which biofuel is *perceived* to be better than the fuel it replaces. The degree of advantage can be measured in economic terms, but other factors such as social prestige, convenience and satisfaction also play a role in determining the perceived relative advantage. The true objective advantage is not as important as the perceived advantage. It is recognized and important to note that the expected continued improvement in existing technology presents a moving target for new bioenergy technologies and makes a relative advantage of an alternative technology more difficult to achieve and demonstrate. An example of this is the move to ultra low sulphur diesel fuel and the introduction of cleaner diesel engines later this decade. The relative advantage does and will change over time.

Successful innovations must be consistent with the existing values, past experiences, and needs of potential adopters. Technologies that require changes with the values and norms of a society take much longer to adopt. The adoption of these incompatible innovations requires the prior adoption of a new value system. For example, concern for the environment is a value that is becoming part of society's value system, but it is still a relatively small component of determining the relative advantage of a new technology.

Innovations that are easy to understand by most members of society will be adopted quicker than difficult and complex technologies. For example, liquid biofuels fuels that can be handled like gasoline and diesel are easier for the public to comprehend than gaseous biofuel.

Observability is another quality that influences the rate of adoption of new technologies. The easier it is for individuals to see the results of an innovation the more likely it is that they will adopt it.

It is important for people to be able to try new things without making a permanent commitment. Innovations that are trialable generally are adopted quicker than those that are not. Bioenergy systems that are new and unproven will be slow to be adopted because of the high cost and high risk of a trial.

These five qualities, relative advantage (real or perceived), compatibility, complexity, observability, and trialability have been identified by past diffusion research as the most important characteristics of innovations that determine their rate of adoption. Biofuels generally rate high on most of these qualities.

Communications

Communication is the process by which participants create and share information with one another in order to reach a mutual understanding. The essence of the diffusion process is the communication of a new idea from one individual to another. A communication channel is the means by which messages get from one participant to another. Mass media channels are effective at creating awareness of a new idea but interpersonal channels involving face to face exchanges are more effective at persuading individuals to accept a new idea.

Research into the diffusion process has indicated that most individuals do not evaluate an innovation on the basis of scientific studies of its consequences. Instead, most people depend mainly upon a subjective evaluation of an innovation that is conveyed to them from other individuals like themselves who have previously adopted the innovation. This dependence on the experience of near peers suggests that the heart of the diffusion to potential adopters consists of modelling and imitation of those who have adopted previously. Therefore, diffusion is a very social process.

Effective communications also has a financial component. Mass media awareness and interpersonal communications are expensive to implement but effective programs can be developed given sufficient financial resources. Biofuels such as biodiesel and ethanol will require a very large number of people to become aware of the product and its relative advantages.

The challenge of information dissemination was mentioned by many stakeholders as being a real issue and identified as a potential role for government to play. Interestingly those stakeholders involved with biodiesel (products that will require mass communications) did not perceive this as a major barrier.

Time

Time is a third element in the diffusion process and a very important element. The time dimension is involved in diffusion in three ways:

- In the innovation decision process by which an individual passes from first knowledge of an innovation through its adoption or rejection,
- in the relative earliness/lateness with which an innovation is adopted, and
- in an innovations rate of adoption in a system.

The innovation decision process is the process through which an individual passes from first knowledge of innovation to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation and use of the new idea, and to confirmation of this decision. There are therefore five main steps in the innovation decision process:

- knowledge,
- persuasion,
- decision,
- implementation, and
- confirmation.

These five steps usually occur in time ordered sequence. There can be exceptions to the order such as when the decision that is taken before persuasion.

Not all individuals proceed through the decision process at the same rate. An individual can be more or less innovative than another person. Individuals can be ranked in order of their innovativeness using the following five classes:

- innovators,
- early adopters,
- early majority,
- late majority, and
- laggards.

Individuals within each class of innovators will have much in common. It is important to note that each class of innovator will rank the relative advantages of attributes differently, to the relative importance of mass media communications vs. interpersonal communication and whether they are active or passive information seekers.

It should also be recognized that it is extremely difficult develop innovations that appeal to the majority if the innovation does not also have some (but not necessarily the same) appeal to the innovators and early adopters. The sequential and social nature of the process makes it difficult and extremely unlikely that steps can be skipped to save time.

Time is also an important parameter of the learning and experience curves. It is also an important aspect of the political and policy process but unfortunately, the time horizons of the diffusion process do not always align with the horizons of the political and policy process. This lack of alignment increases the complexity of the development process.

Social System

The social system is the fourth element of the diffusion process. The members of the social system are engaged in joint problem solving to accomplish a common goal. The members may be individuals, informal groups, or organizations. The most innovative members are not always influential in the decision making process as they often have low credibility due to their willingness to try all new things. Opinion leaders and change agents, people who are able to persuade others to change are the most influential members in the social system. New technologies will not be adopted without these members.

The social system has another important influence on the diffusion of new ideas. Innovations can be accepted or rejected by one individual or by the entire system by a collective or authoritative decision. The individual optional innovative decisions are made independent of other members. These decisions are the classical means by which new ideas have spread through society. Collective decisions are made by consensus of the members of a group. The establishment of car pools would be an example of a collective decision. Authority decisions are those made by a few individuals who have the power, status, or technical expertise to make decisions for all members of the society. Individuals have little or no influence on the decision. Relevant examples would be the establishment of new standards for fuels or vehicle fuel economy, or the use of biodiesel blends in a companies diesel fuel products. The fourth type of decision is contingent decision, this is a sequential decision of two or more of the other types of decisions. This type can be made only after another decision has been made. They tend to have long implementation times. They are also typical of the type found with alternative fuels that require both new fuels and vehicles to be introduced at the same time.

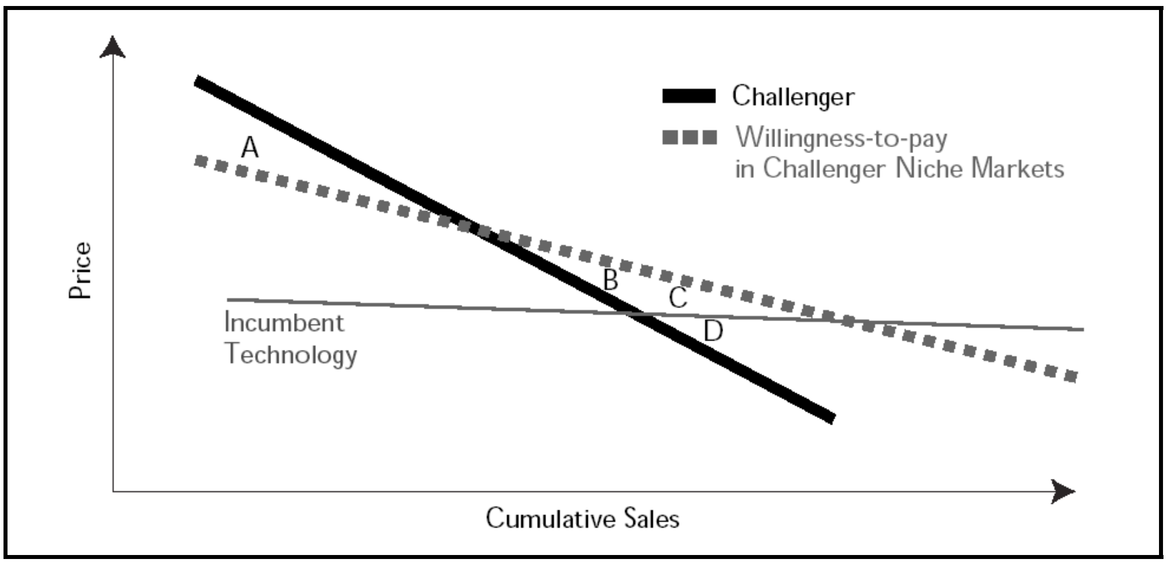
Specific characteristics of new technologies can add value that makes potential buyers with special needs ready to pay extra for energy services produced with them instead of with incumbent technologies. Examples of characteristics (relative advantages) that may provide the basis for a niche market are low emissions, modularity and compatibility of a new power source with electricity load patterns on the grid. These early buyers are often called innovators or early adopters as shown in the figure.

The niche markets may be small relative to the total potential for a technology, but they can be important from the viewpoint of providing learning opportunities. Making use of them in deployment programs can help both to shorten the time before a new technology will be viewed as a viable commercial endeavour and provide a source of business funding for learning investments. Market leaders often use a niche market in developing a ‘challenger’ to an existing technology, viewing it as a stepping stone towards a mass market. The fact that these early adopters are willing to pay more for products that meets their needs means that less money must be invested in the “learning investments” by governments and industry.

Ideally, there is a match between the size of the niche market and a commercial production facility. This allows one or more facilities to be constructed to satisfy just the niche market. In many cases, this is not possible and the niche market opportunity can absorb only a small portion of a commercial plant output and little benefit can be gained from the niche. This is more of a problem in countries with small geographically diverse markets such as Canada, than it is in the United States or Europe with their much larger markets, although even in a unified market such as Europe there can be distortions between countries. A 50 million litre per plant in the United States represents 0.02% of the US distillate market but 0.2% of the Canadian market.

Figure 3-9 illustrates how a niche market can lead to earlier commercialization of a technology and that the bill for learning investments can be split between public and private sources.

Figure 3-9 Experience Curves and Niche Markets



Consider the following scenario. In the situation marked by ‘A’, the cost of the challenger-technology is still higher than the willingness to pay in the niche market. A financial incentive can provide the difference between the actual cost and the price in the niche market. As demand at the upper end of the niche market is satisfied, the price on the niche market is reduced, but learning has also reduced the cost of providing the product. In situation 'B’, cost is below the willingness-to-pay in the niche market and no public money is needed to finance learning investments, though it may still be necessary to assist with indirect support (e.g., labelling schemes and other information devices). In situations ‘C’ and ‘D’, the market leader may be in the enviable position of being able both to brand his products for a niche market that is very profitable (C) and to let one of his lesser brands feature a low-price version of the product that competes with the incumbent technology (D).

The characteristics of the actors in the diffusion curve shown above are summarized in the following table. It is the innovators and early adopter characteristics that are of particular interest since those are the proponents that are willing to pay more and can help to drive the experience curve.

Table 3-1 Consumer Characteristics

Adopter Type	Characteristic	Role And Size
Innovators • enthusiast	Venturesome; Enjoys the risk of being on the cutting edge; Demands technology.	Market drivers. Want more technology, better performance.
Early Adopters • visionaries	Well connected; Integrated in the main-stream of social system; Project oriented; Risk takers; Willing to experiment; Self-sufficient; Horizontally connected and acts as their peers.	
Large Difference between groups above and below.		
Early majority • pragmatists	Deliberate; Process oriented; Risk averse; Want proven applications; May need significant support; Vertically connected and acts as their superiors.	Followers of the market. Want solutions and convenience.
Late majority • conservatives	Sceptical; Does not like change in general. Changes under ‘pressure‘ from the majority.	
Laggards • sceptics	Traditional; Point of reference is ‘the good old days‘; Actively resists innovations.	Economic/ power interest different from status quo?

Creating and exploiting niche markets is an efficient strategy for a deployment program, both to provide learning investments from private sources and to stimulate organisational learning among market actors.

3.2.3 Biofuel Market Development from a R&D + D Perspective

The development of a biofuel “market” can be evaluated from the R&D + D perspective. The issues with respect to experience curves and technology diffusion are discussed below briefly.

3.2.3.1 Experience Curves

Feedstock costs are one of the most significant cost items for the 1st generation biofuels and almost all of the 2nd generation biofuels process less costly feedstocks. It is this ability to lower feedstock costs that is in fact driving much of the development of these new production pathways. The ability to process less costly inputs does come at a cost, and all of the 2nd generation systems have much higher capital costs than the 1st generation biofuels.

Part of the higher cost is fundamentally inherent in the more extensive process required for the 2nd generation fuels but part of the high cost is a function of the state of development of the new technologies and the lack of learning experience with the new fuels.

As shown earlier, the potential for learning experiences should be considered from several perspectives including plant capital, plant operating costs, feedstock costs, and revenue enhancement.

When one considers the advantages to be gained through the learning curve perspective it is important to recognize that the competition, the 1st generation biofuels, will also be benefiting from learning experiences at the same time as the 2nd generation fuels are learning. In effect the goal posts for the 2nd generation fuels are moving as they gain experience and become more competitive. With 2nd generation biofuels the competition is not only the fossil fuels gasoline and diesel fuel but also the 1st generation biofuels. Whereas gasoline and diesel fuels are gaining experience very slowly because of the vast experience gained in the past, the 1st generation biofuels have much less experience and the costs of making these fuels is still being visible reduced.

R&D+D is still a very important perspective for the 2nd generation biofuels since almost all of them are still at relatively early stages of technical development. The companies developing these technologies still need support for the R&D and many are now at the stage where they are developing the plans for their first plant and therefore need support for the deployment of the technologies.

3.2.3.2 Technology Diffusion

The critical first component of the development of the market penetration curve is the identification of the early adopter group. These consumers are targeted for their willingness to pay more or to switch their purchasing habits to lead the market development effort. The step of moving beyond the early adopters is really the critical one for most new technologies. In most cases, the costs at this stage need to be competitive with the incumbent for significant market development to occur.

The 1st generation biofuels, ethanol and biodiesel, have some different properties than gasoline and diesel fuels that require changes in how the blended fuels are handled. Some of the 2nd generation biofuels have properties that are essentially fungible with the existing petroleum products. This has the advantage of reducing the technical barriers to the implementation of the new fuels but may have the disadvantage of reducing the perceived relative advantages of the fuels and thus reduce their appeal to the early adopters. If the new 2nd generation biofuels offer no perceived relative advantages to attract the early adopters they must have lower prices than the 1st generation fuels to gain a market advantage.

Some 2nd generation biofuels such as Fischer Tropsch fuels may have some relative advantages over traditional diesel fuel but have fewer advantages over natural gas based FT diesel fuel. The relative advantages can thus change over time making deployment strategies move difficult to plan and implement. The 2nd generation biofuels do have an advantage over traditional fuels in terms of environmental benefits but the environmental benefits of one fuel over another are often more difficult to communicate because of the lack of observability of some environmental benefits such as lifecycle greenhouse gas emissions.

Not all 2nd generation biofuels offer advantages in terms of yield, energy balance or GHG emissions profiles compared to first generation biofuels. The environmental performance of 1st generation biofuels can also be improved to rival that of the best 2nd generation processes through substituting bioenergy for their fossil energy inputs.

3.3 MARKET BARRIERS PERSPECTIVE

The Market Barriers perspective views the adoption of new technologies as a market process and focuses on the frameworks within which decisions are made by investors and consumers. Anything that slows down the rate of adoption can be referred to as a market barrier. The emphasis on this perspective to market development should be on understanding the barriers and in what role the government may play to reduce those barriers. The Research and Development and Deployment perspective focussed on the innovation and its relative advantages, the Market Barriers perspective considers more of the social systems and communications issues with respect to diffusion of the technology.

Inertia is likely to be found in well-established markets based on conventional energy technologies that have been around for many decades. For a variety of reasons – such as ingrained consumer attitudes combined with the large expense involved in trying to change them or the advantages that existing sellers have if their technologies are based on costly capital infrastructure that has been paid for in the past – the market system may be sluggish when it comes to welcoming new products. In the past several decades, many proponents of energy conservation and diversification believed that normal market processes were far too slow at bringing about the widespread use of new energy technologies that were urgently needed to enhance energy security and the environment. They suggested that this was due to various barriers in the way of the rapid market penetration of technologies that were obviously superior in their view and they advocated government action to reduce or eliminate them. This view has created some debate about the proper role of government in addressing the barriers with the incumbent energy producers and many economists on one side and energy technology developers and environmentalists on the other side.

Out of this debate came what the IEA are calling the Market Barriers perspective, a view that focuses on the desirability of facilitating the adoption of cleaner and more efficient energy technologies, but by way of policies consistent with the underlying objectives and constraints of a market system. The objective of promoting energy conservation is still there, but subject to the constraint that the policy measures used to pursue that goal are economically efficient. Put another way, it is the perspective that results when the barriers that tend to slow the rate of adoption of new technologies are identified and subjected to analysis within the framework of neoclassical economics.

The various market barriers that are viewed as important are well known. The following table provides a summary list, along with some typical measures that are taken to alleviate the barriers. Note that a list of this sort is not comprehensive and is not meant to suggest that the individual barriers are tight categories. The barriers overlap and there is interaction between them and their effects on decisions to invest in new technologies.

Table 3-2 Types of Market Barriers

Barrier	Key Characteristics	Typical Measures
Uncompetitive market price	• Scale economies and learning benefits have not yet been realized.	• Learning investments • Additional technical development
Price distortion	• Costs associated with incumbent technologies may not be included in their prices; incumbent technologies may be subsidized.	• Regulation to internalize 'externalities' or remove subsidies • Special offsetting taxes or levies • Removal of subsidies
Information	• Availability and nature of a product must be understood at the time of investment.	• Standardization • Labelling • Reliable independent information sources • Convenient & transparent calculation methods for decision making
Transactions costs	• Costs of administering a decision to purchase and use equipment (overlaps with "Information" above).	
Buyer's risk	• Perception of risk may differ from actual risk (e.g., 'pay-back gap') • Difficulty in forecasting over an appropriate time period.	• Demonstration • Routines to make life-cycle cost calculations easy
Finance	• Initial cost may be high threshold • Imperfections in market access to funds.	• Third party financing options • Special funding • Adjust financial structure
Inefficient market organization in relation to new technologies	• Incentives inappropriately split owner/designer/user not the same. • Traditional business boundaries may be inappropriate • Established companies may have market power to guard their positions.	• Restructure markets • Market liberalization could force market participants to find new solutions
Excessive/ inefficient regulation	• Regulation based on industry tradition laid down in standards and codes not in pace with development.	• Regulatory reform • Performance based regulation
Capital Stock Turnover Rates	• Sunk costs, tax rules that require long depreciation & inertia.	• Adjust tax rules • Capital subsidies
Technology-specific barriers	• Often related to existing infrastructures in regard to hardware and the institutional skill to handle it.	• Focus on system aspects in use of technology • Connect measures to other important business issues (productivity, environment)

Not all of these barriers apply to bioenergy in general or to biofuels specifically. In the following table, the market barriers are assessed for bioenergy in general and some other energy technologies (IEA, 1995). It is apparent from the table that the barriers that bioenergy faces are not that different from the barriers facing other forms of renewable energy or even new forms of fossil energy.

Table 3-3 Summary of Market Barriers by Technology

Barrier	Small-scale Hydro	Windpower	Clean Coal	Bioenergy
Cost	0	0	++	++
Price Distortion	++	++	++	++
Informational	+	+	+	++
Risk	+	++	++	++
Financial Barrier	++	+	++	+
Market Organization	++	*	+	*
Regulatory Processes	++	++	++	++
Equipment Turnover Rate	+	+	++	+
Technology Specific Barriers	none	Systems integration	Infrastructure complexities	none
Environmental	++	++	++	++

0 For some applications costs are close to competitive with established technologies
+ Weak barrier, not a key constraint
++ Strong barrier, primary focus of sector participants
* Not obviously applicable

According to the principles of market economics, governments should intervene in the economy only in a situation in which the market fails to allocate resources efficiently and where the intervention will improve net social welfare. In the 'strong' form of this view, barriers in the way of the adoption of new technologies should be dealt with by government action only if they involve *market failure*. In those cases, government should intervene to correct the market failure (again, subject to the intervention increasing net social welfare). Once this has been done, according to the market barriers perspective, government should leave decisions on the purchase of new technologies to the private sector. Therefore, one should consider to what extent the barriers identified involve market failure and whether there are any qualifications to the market failure argument. It is critical to note that not all market barriers involve market failure.

Some of the market barriers shown in Table 3-2, such as higher product costs, the risk of product failure, the high cost of finance for small borrowers, and others included in the table, are normal and inherent aspects of the operation of most markets and they should be allowed to influence decisions in energy markets just as they influence decisions in all other markets. These barriers do not usually satisfy the market failure criterion because they involve necessary costs that have to be covered for all goods and services; the existence of the barriers themselves does not provide a reason for favouring new energy technologies, which (in the classical economists view) should have to compete for investment dollars with everything else of value if resources are to be allocated efficiently.

Most instances of market failure involve *externalities,* which occur in a market transaction if any of the costs or benefits involved in it is not accounted for in the price paid for the product that is sold. If there are costs that are external to the market (i.e., the buyer does not pay some of the costs incurred in producing the product), a negative externality occurs. If there are external benefits, a positive externality occurs.

An example of a classic market barrier that can involve market failure is the cost and inconvenience to consumers of finding and analyzing information about energy-saving equipment (the communications issue of technology diffusion). Consumers require small amounts of technical knowledge to become aware that a useful new energy-efficient product is available and to evaluate the claims of competing brands. Given the administrative costs involved in large numbers of small market transactions, it is hard to imagine that such an information service would be offered exclusively by private firms through individual market transactions. Neither would potential suppliers of such information be very interested in such a market because they would know that the consumer who buys such information could so easily pass it on to others. Thus too little of this kind of information service would be provided relative to the benefit of it to consumers. These factors rationalize the involvement of government agencies in disseminating information on energy efficiency.

Certain aspects of a market's structure may lead to inefficiency. For instance, a firm with monopoly power may be able to fend off competition from a new technology. In some countries or local markets, suppliers of financial services may not face much competition and this can result in unnecessarily high interest costs for financing purchases of energy-saving equipment.

The equipment turnover barrier may be high for those technologies that address markets that are not growing fast and are served by a few dominant players that fight for market share. The transportation fuels market would be a classic case. Bioenergy technologies that try to penetrate this market could be termed disruptive technologies. They must fight with the incumbent technology for the relatively scarce market. Markets that are growing fast and served by many participants are generally easier to penetrate and the technologies that will address these markets could be considered incremental technologies. The incremental technologies will have lower market barriers.

One can see that government action may be warranted in the case of some market barriers and not in others. In some situations, dealing with barriers in a pragmatic way can be a matter of making sure that normal aspects of market infrastructure (e.g., consumer protection laws, laws of contract) are working well in markets for energy technologies. Table 3-4 classifies the barriers identified in Table 3-2 as normal barriers or market failure barriers.

Table 3-4 Classification of Market Barriers

Barrier	Barrier Type
Uncompetitive Market Price	Normal
Price Distortion	Market Failure
Information	Market Failure
Transactions Costs	Market Failure
Buyer's Risk	Normal
Finance	Normal
Inefficient Market Organization	Market Failure
Excessive/ Inefficient Regulation	Market Failure
Capital Stock Turnover Rates	Market Failure
Technology Specific Barriers	Normal

3.3.1 Biofuel Development from a Market Barriers Perspective

Each of the identified barriers for new energy technologies will be evaluated to determine its applicability to 2nd generation biofuel market development.

3.3.1.1 Normal Market Barriers

There are four types of normal market barriers identified, uncompetitive market price, buyer's risk, finance, and the potential for technology specific barriers. These are discussed below.

Uncompetitive Price

The cost of producing biofuel is often higher than the cost of petroleum fuels, although the absolute value of the difference between the two is a function of commodity prices. In times of high crude oil prices and low agricultural prices, the gap can be small (or not exist at all) and when fossil energy prices are low, the gap can be large. In the regions of the world where biofuels have been used as a petroleum fuel blending component or fossil fuel substitute the gap has been eliminated through the use of tax incentives provided by governments. These tax incentives can be viewed as learning investments. Governments have also invested in research and development in order to help to drive down the costs of production.

Even where there is an incentive there is concern on the part of some lenders, developers and marketers that the incentives could be removed in the future making their investments in biodiesel production and marketing unprofitable.

Biofuels also face the problem of commodity price volatility. The changes of a few cents per litre in the selling margins could have a large impact on profitability. This is one of the drivers for the 2nd generation biofuels that process lower value biomass and should therefore face less price volatility.

Biofuels require either fiscal incentives to overcome the unattractive price and the price volatility issue or a complicated support program that is flexible and responsive to changing market conditions that will ensure that the biofuel price is competitive with petroleum fuels but that the programs that yield the competitive price are not too costly.

Buyer's Risk

The Buyer's Risk could also be termed business risk and it is important to note that it is the perception of risk that may be more important that the actual risk. The gap between perception and actual risk is larger when an industry is new and one of the measures that reduced this gap and the buyer's risk for any venture is experience.

The business risks for biofuel operations are not untypical of those for other agricultural processing industries. Typical categories for the risks are:

- Risks related to equity financing
    - The idea for a biofuel plant development may originate with a small group of individuals who then undertake to raise equity for the project. There is no guarantee that the process can be successfully completed once it is started. In most cases, the investments made by individuals are placed in trust until certain thresholds are met and are returned if the equity drive fails, the original proponents may still lose their initial investment.
    - Individual equity drives can have additional specific risks such as restrictions on locations of participants, the presence or lack of brokers, the lack of a secondary market to sell shares in the future, no guarantees that future sales of units will not dilute the original shareholders.
    - These risks are generally reduced or eliminated once the equity drive has been successful.
- Risks related to debt financing
    - There are no guarantees that after the equity is raised that sufficient debt will be available to complete the project. The project may be abandoned and some of the invested money lost.

    - Lenders may place restrictions on the corporate activities that reduce the rights and flexibility of the operation and the equity holders.
    - The inability to generate sufficient revenue from the operation to support the debt may reduce the value of the equity raised.

- Construction and development risks

    - The owners are not generally experts in construction and design and must rely on third party specialists to carry out this work. Much of the ultimate operating success of the facility may be dependent on the performance of the contractors and the quality of their work.
    - The equity and debt is often raised before definitive agreements for construction are in place. There is a risk that there could be increases in cost and reductions in performance at this stage.
    - In some cases in the US, the contractors and designers are taking equity positions in plants, which can lead to conflicts of interest.
    - There may be unforeseen issues arise during construction.
    - The plant may not perform as expected or it may cost more than expected. Generally, increased costs must be covered by equity injections.

- Operation risks

    - A Board of Directors often controls the operation and there may be some conflicts of interest between the Board and shareholders in general.
    - In the case of new operations, the company often has no experience with biofuels, and co-products production and marketing and relies on third parties for some functions that are critical for success.
    - Demand for the products is generally driven by factors outside of the influence of the owners.
    - In some cases, new unproven technologies are being considered for adoption or demonstration. These carry high levels of risk. This is particularly true for 2nd generation biofuels.

- Biofuel production risks

    - The actual production of biofuel is dependent on the supply of the raw materials, which fluctuate in price and quality. Higher input costs cannot always be recovered in the selling prices.
    - Profitability is also dependent on the existence of production and tax incentives, which are not usually guaranteed.
    - The industry may be competitive and they may be more competitive operations, which can produce and sell biodiesel at lower costs.
    - Successful operations require skilled operating personnel. These may be difficult to obtain and retain in some locations.
    - Plants are subject to environmental regulations, which may change over time.

- Corporate structure risks

    - Depending on the corporate structure chosen there may be additional risks for investors. In a partnership, the distributions of cash may not be sufficient to cover the investors tax liability.
    - Cash distributions are not guaranteed and may fluctuate with plant performance and market conditions.

It can be seen that the Buyer's risk generally is reduced as a project proceeds through fundraising and construction. There are methods of reducing some of these risks through insurance, bonding and structural approaches but these generally add cost to a project. In general, the more successful projects that there are, the lower the perception of risk becomes.

Once a plant is operating and has demonstrated that it meets the design criteria then the risks tend to be mostly commodity risks. In some cases, it may be possible to hedge and offset these risks but these programs can be expensive and they may not be available to all producers.

The types of policy measures that can be considered to address this barrier are investments in demonstration projects, programs to reduce commodity risks, and assurances that there will not be changes in government programs that would negatively impact performance.

Finance

A barrier that is somewhat related to Buyer's Risk is that of finance. Most projects are financed by a combination of equity and debt. Raising the debt portion can be challenging for a number of reasons including imperfections in market access to capital. Debt providers generally have no opportunity to participate in any project upside so they focus on ensuring that there are no downsides to their participation. They focus on the issues of what could go wrong.

Lenders have many opportunities presented to them and they chose those opportunities that provide them with their best returns or most limited risk. Many lenders also specialize in certain sectors of the economy. These are sectors which they understand the risks and rewards. New sectors require lenders to become comfortable with the risks or at least the perception of the risks. The first projects are therefore the most difficult to finance since there is no track record which lenders can rely on. It is extremely important that the first projects be successful. Problems or failures with early projects increase the difficulty in demonstrating that new projects won't have the same problems.

Note that in cases where there is imperfect access to capital, finance barriers could be considered a market failure barrier and increased government involvement may be warranted. The involvement could include special funding, third party financing options, loan guarantees or other approaches.

Technology Specific Barriers

There can be technology specific barriers to the creation of a biofuel market. One example is the issues raised by adding biodiesel to diesel fuel. The process increases the blends propensity to gel in cold weather conditions. In the existing diesel fuel distribution infrastructure, this creates the need to handle the product in a different manner. This need for special handling creates additional costs but they can be overcome as shown by the widespread use of biodiesel in Europe where many of the same issues have been addressed.

Technology specific barriers can also be related to the skills necessary to handle the differences between new systems and the existing infrastructure. Programs to overcome these barriers generally focus on increasing knowledge and promoting a full systems approach to dealing with issues.

3.3.1.2 *Market Failure Barriers*

Market failure type barriers are more difficult for individuals to overcome since they are systems related. A stronger case can be made for government intervention to address these barriers. The five categories of market failure barriers are discussed below and whether or not they are barriers to the development of a biodiesel market.

Price Distortion

Price distortion arises when some of the costs or benefits that arise from using a product are not reflected in the selling price. The most common example of this is the environmental costs that arise from using products that pollute the environment. These costs are real and are paid for by society through reduced crop production, increased maintenance costs and higher health costs. They are not generally included in the product cost.

Governments can and have taken action to remove these price distortions. One example with transportation fuels was the tax differential applied to leaded gasoline by the Canadian federal government and some of the provinces prior to the ban on the use of leaded gasoline. That additional tax, which removed the financial incentive for using lower cost leaded gasoline, was very effective at accelerating the switch from leaded to unleaded gasoline.

In the case of biofuels, the lifecycle analysis indicates that there are greenhouse gas reductions from using the fuel and there are also reductions in the emissions of some of the tailpipe contaminants from using the fuel. These should have some value and could be used to offset the higher cost of the fuel.

The magnitude of the price distortion caused by transportation fuels has been declining in recent years as regulations that require cleaner fuels and cleaner vehicles are adopted by many countries. New vehicles have emission rates that are more than 95% less than uncontrolled vehicles in most cases. The price distortion between the modern petroleum fuels and the new biofuels is therefore much less than it has been in the past and the importance of this barrier is therefore lower than it has been previously ($(S\&T)^2$, 2005).

Information

Markets work best when all participants have the information required to make informed decisions. The time and effort required to gather and analyze the information about new products can act as a serious impediment to their adoption. It was shown earlier that the communication of information about innovations is a very social process and one that can take considerable time, effort and financial resources. Proponents of new energy technologies often do not have the necessary resources to make this happen.

Policy options that can be used to address the issue of insufficient information include providing reliable independent information, standardization and labelling activities.

Transaction Costs

Closely aligned with the issue of information is the issue of the cost of making decisions. Large numbers of small purchases are costly and can overwhelm the benefits of choosing cleaner energy technologies. If consumers had to make a separate purchase for the biofuel portion of their fuel purchase the added inconvenience and cost of the transaction would make many buyers and sellers think twice about the purchase.

This is not likely to be a barrier for transportation biofuels since the transaction for the biofuel is likely to be upstream of the point of consumer purchase and be a transaction between the biofuel plant and the fuel marketer. Downstream of this transaction, all subsequent transactions should be transparent. Transaction costs are not likely to be a significant barrier to the development of a biofuel market.

Inefficient Market Organization

Inefficient market organization applies when one firm or a small group of firms act in a similar manner and using the advantages of being the incumbent suppliers to resist the market penetration efforts of the new technology. In the case of transportation fuels, there are many end users of the fuel but they all purchase the product from a limited number of companies. These are also the companies that produce the competing product, gasoline or diesel fuel. In order for biofuels to penetrate the market and be available for the ultimate end user, they must be integrated into the existing distribution system.

Excessive/Inefficient Regulation

Regulations and standards are often prescriptive and not directly performance driven. This can be effective and efficient in cases where there is significant experience with a product and the performance can be controlled in a prescriptive manner. The system does not function particularly well when new products are introduced that may not have the wealth of experience associated with their use and may not behave in exactly the same manner as the incumbent technology.

In many countries, regulations are developed through a consensus process involving producers, consumers, and regulators. In most cases, the producers are the most knowledgeable members of the panels and exert a strong influence on the outcome. In the case of new products, the incumbent producers can use this dominance to resist change to the specifications that might favour a new product.

Some of the 2nd generation biofuels, like DME, butanol, and mixed alcohols are new products that have not previously been used as a transportation fuel before. These products may have to go through a lengthy regulatory review before they can be widely used as a commercial fuel.

Capital Stock Turnover

The petroleum industry has invested significant money in the construction of refineries to convert crude oil into gasoline and diesel fuel. The addition of a fuel component produced outside of this existing infrastructure has the potential to reduce refinery throughput, which has a negative impact on the economics of refining. If the volume of additional product supplied to the system is large enough, it could result in marginal refineries being closed and written off.

In some countries the turnover of refinery stock should not be a real barrier to increased biodiesel use. Increased demand for diesel fuel, and refinery closures provide opportunities to include biodiesel in the diesel pool without rolling back refinery production.

3.4 Market Transformation

The term *market transformation* refers to a significant or even radical change in the distribution of products in a given market. A *market transformation program* refers to actions taken by government (or sometimes by some other entity acting in the public interest) to facilitate the market transformation process. In effect, the long-term objective of most such initiatives is to make a new efficient or low impact technology or product-type the preferred 'norm' in a market place.

The objective of a market transformation program is to make changes that are both substantial and sustainable. An isolated instance in which a government supports the introduction of a new energy technology does not constitute a market transformation program. Market transformation is about creating substantial change in the market for a particular class of products: changes in the behaviour of consumers so that they choose to buy more efficient goods or services; changes in the behaviour of producers, so that they bring to the market only efficient (or at least more efficient) models; changes in the behaviour of wholesalers and retailers in regard to what they make available to final buyers; and changes in the capabilities of suppliers in related markets to provide whatever ancillary goods and services are needed (e.g., suppliers of equipment parts and other intermediate goods, installers, repair companies). When the process is completed, a successful market transformation program will have had a lasting and significant effect.

This perspective thus also addresses the social aspects of technology diffusion but in a different way from the Market Barriers perspective. It focuses more (but not exclusively) on the end use of the technology or the market rather than on the whole supply chain.

In the work of the IEA on creating markets, the idea of a market transformation perspective is further expanded. It considers the market transformation perspective as fitting into a larger picture of what can be done by governments to help build markets for new energy technologies. The RD&D and the market barriers perspectives are useful, however these perspectives do not address an important additional process affecting market deployment. The RD&D perspective deals primarily with the implications of learning and the interactions between R&D and market development, particularly for the cost and performance of new technologies. The market barriers perspective identifies obstacles in the way of new technologies and suggests ways to deal with them that conform to the constraints of market economics, but does not deal in depth with how to implement change. Although economic analysis is rich in insights about problems in existing markets, it does not say very much about the steps needed to create new markets out of the entrepreneurial process. Correspondingly, the IEA focuses the market transformation perspective on the outcome to be achieved and then runs the logic back through all the factors that would be necessary to attain that outcome: improving technology cost and performance and removing barriers, but also actively creating the conditions that facilitate the rapid market uptake of new more efficient products.

The idea at the centre of the market transformation perspective is that people involved in technology deployment policy should think about what is needed to encourage the adoption of new products in the same way that private-sector suppliers think about it. That is, they have to understand in depth what makes the market for a new product take off, and then use that understanding to identify aspects of market structure and behaviour that affect product acceptance and also happen to be determined or affected by government actions. The idea is to apply the kind of expertise used by business to develop markets in pursuing the objectives of government policy in the energy sector. Unlike a business, however, the designer of a market transformation strategy is consciously pursuing a public policy objective; and therefore needs to exercise great care not to usurp the proper role of the market in 'picking winners' (and losers).

Market transformation programs involve governments in influencing market decisions, but an important aspect of the market transformation perspective has come to be an emphasis on designing that influence so as to interfere with normal market processes as little as possible. The objective is to affect private energy-related decisions by reducing market barriers, changing incentive structures, providing public information, and encouraging competition in the aspects of products that determine energy efficiency and emissions. Good market transformation programs are about raising the profile of energy variables in market activities and making once-only adjustments to the background infrastructure in which markets operate; and doing that in ways that are consistent with a public-good approach to policy making in a dynamic economy. It is not about regulatory tribunals, price controls and other forms of intervention that have been overly used and therefore discredited.

The actual process of transforming markets is described by the IEA as follows:

> *Developing effective market transformation policies is straight forward in principle, but far from easy in practice. The straight forward principle is first to develop an understanding of the buyer-relevant characteristics (both positive and negative) of the technologies being promoted and the workings of the markets that will potentially be transformed; and then to identify strategies that would help to boost the positive attributes (including high energy efficiency) and overcome the negative ones (e.g., high purchase costs, a lack of a proven track record, etc.). The practice is far from easy because products and markets differ in ways that might be well understood by suppliers but will not be easily grasped by policy practitioners who arrive on the scene with quite different backgrounds. Furthermore, as noted above, care must be taken not to interfere with the normally efficient aspects of market-based resource allocation.*
>
> *In large part this challenge is dealt with through diligent and open minded interaction with people involved in the target markets and by an openness to a variety of expertise. Market transformation practitioners need to be wide-ranging and eclectic in regard to the bodies of knowledge they draw upon. A variety of disciplines are relevant, such as marketing, economics, psychology, management science and engineering; and experience in the target market is obviously a big plus when it comes to qualifying for a job on a market transformation project.*
>
> *The starting point for the development of market transformation programs is to identify the technologies and the markets to be worked upon. Central to this is an evaluation of the potential for increasing societal welfare through government action. In the present context this means exploiting a potential for improving energy efficiency in a way that generates net benefit but would not be brought about by normal market processes, at least not as quickly.*
>
> *Such unexploited potential may exist for various reasons. For instance, the technology to improve the energy efficiency of a given type of household appliance might be available but not yet incorporated to a significant degree into widely marketed models. Suppliers in that market might find their current range of models to be quite profitable; they might be aware of the possibility of improving energy efficiency without adding greatly to their production costs, but may not view its incorporation into their products as a high-priority option in their overall marketing strategies. This might involve a belief that consumers are more likely to focus on initial purchase costs and non-energy aspects of performance than to take account of energy costs over the product's life cycle. Indeed energy might contribute a relatively small portion to total life-cycle costs. In such a situation, a range of market transformation actions can be effective in tilting supplier strategies towards introducing the new technology. In a market with several suppliers it can be possible to do this by taking action that will focus competition on energy efficiency; for instance, with a combination of actions that reinforce each other, such as by working with suppliers through a procurement program while at the same time enhancing the likelihood that buyers will pay attention to the energy-using characteristics of the appliance by way of an energy labelling system combined with advertising and sales training programs. In other types of markets it may be necessary to intervene more aggressively to set the transformation in motion; for instance, by amending mandatory product standards.*
>
> *In practice the market transformation practitioner has to deal with many complications because target markets can be very complex. Many energy services can be provided in more than one way and markets interact with each other and often disaggregate into*

systems of sub-markets. Thus even the initial step of specifying the market to be worked on has to be understood as an open process with feedback loops – all of the areas to be worked on may not become clear until after the work has begun.

A key aspect of the Market Transformation process is to identify all of the important decision makers according to the different roles they play. In the technology diffusion process, the importance of these key influencers in promoting the uptake of new technology is well understood. The following table illustrates that the number of different market players can be large and varied. While some of the roles played by market actors overlap and many actors have multiple roles, the table indicates that consulting with stakeholders, and involving some of them in the transformation process in other ways, is a large job. It is nevertheless a centrepiece of most market transformation programs. The chances of having a performance enhancement or a new product accepted can be greatly increased through the involvement of important market players, especially when the changes are technically complex and currently accepted products are well established.

Table 3-5 Types of Market Actors Involved in Case Study Projects

Typical Role	Market Actor
Buyer	Facility operators
Buyer & seller	Distributors, wholesalers, retailers, purchasers, contractors, service companies, utilities, energy distributors
Development	Planners, architects
Development – manufacturing	Manufacturing companies, parts suppliers
Financing	Funding brokers & other financial institutions
Information dissemination	Energy agencies, mass media companies & agencies, individual investors
Policy & funding	Government agencies, other public institutions
Policy – formulation & decisions	Politicians, regulatory agencies & other public authorities
Represent special interests	Trade associations, consumer associations, other NGOs
Basic research	Universities
Research & development	Research institutes, corporate research labs
Seller	Equipment installers, energy distributors
Special tasks (e.g., policy analysis)	Consultants
Technology user	Homeowners, consumers, customers, end-users

Working with stakeholders can be done by tapping into existing networks, such as trade associations and consumer groups, or by building new networks of contacts. For instance, in technology procurement programs developing cooperative networks among buyer-groups is important. Industry associations may develop their own networks to work together on building the foundations for the offering of a new product. Some, but not all, of these strategies are applicable to some of the biomass energy opportunities

Three broadly based models that are often used in market transformation programs are:

- Procurement Actions
- Strategic Niche Management
- Business Concept Innovation.

3.4.1 Procurement Actions

Procurement processes are natural vehicles for encouraging technology market development – they offer an entry point for influencing industry decisions in a framework that governments know well. In the market transformation perspective, a procurement specification list provides a useful pathway for program designers to get into the details of market operations.

Technology procurement can be viewed as a tool that can influence the whole chain of innovation and commercialization. One strength of the procurement model is that it allows policy designers to address issues such as how do you entice consumers to buy energy-efficient equipment when the cost of energy is only a small component of its total cost and the consumer is much more interested in characteristics of the equipment other than its energy efficiency? The answer is to entice equipment producers to embed energy-efficient technologies in products designed with other characteristics that consumers think are important. This is not high-level R&D, but it is an important bit of common sense. In the new products that resulted from the procurement programs in the case studies, equipment suppliers were able to make improvements quite easily. However, prior to being nudged by the procurement programs, they had little incentive to develop improved versions of their products that would substitute for existing versions that were already profitable.

Procurement programs arouse a latent potential and encourage new thinking that results in both technical and commercial development. In many respects, this is addressing the relative advantage of the new technologies. What is important is to consider all aspects of the new technology and not just what may seem to be the key aspects.

There is great potential for variety in the design of procurement programs. The IEA identifies several different approaches that could be taken with procurement programs.

- *Components vs. systems:* The target technology may vary from specific components of a technical system to a whole system or facility. A single component may be a generic technology and widely applicable, whereas a system may have local features. A system may involve more flexibility and leave room for different approaches, whereas a component-approach is often tied to a certain technology. Risk and complexity increase when going from a single component to a system.
- *National vs. international programs:* Procurement programs are usually arranged nationally but made open to competition from international manufacturers through national regulation and trade agreements. International procurement processes increase the purchasing power of buyer groups and more strict criteria can be applied.
- *Single-stage vs. multi-stage programs:* Most programs are single projects based on one product specification. An interesting innovation would be to introduce a multi-stage process that builds on the strengths of a particular procurement approach. Some examples: the first stage might be national and the second stage international in order to multiply the effects of the program and its appeal to suppliers; the first stage might involve a system component and the second the whole system; or the first stage might focus on working with manufacturers and the second with consumers.
- *Externally-led vs. self-organized programs:* Technology procurement must be highly organized and carefully managed to be successful, which means that leadership is important. But some versions of the procurement model can take shape spontaneously. For example, it could arise when an established network of buyers comes to a voluntary consensus that a tendering procedure would benefit all members of the group. The Internet is a tool that might be effectively used to collect buyers and build purchasing power.

- *Technology-focused vs. ordinary procurement programs:* The typical market transformation procurement program has involved a strong focus on the technical characteristics of a relatively new product that requires some development to respond better to competition from established products. In an ordinary procurement program, the focus may be on creating more purchasing power to reduce the price of better-than-average products.

Focused procurement programs may also be associated with other market transformation actions that affect the market concerned. For instance, new information dissemination programs and an energy labelling system might be timed to interact with the results of a procurement effort. Similarly, the development of buyer-groups might be timed contingently to follow the successful completion of the technical development aspect of the procurement arrangement. This kind of staged approach relates to the next model of Market Transformation.

Procurement programs are ineffective where the volume of product represented by the purchasers is not sufficient to cause the creation of production economies of scale. In general, the more capital intensive the production process, the less likely that procurement actions will be a useful tool for market development.

3.4.2 Strategic Niche Management

A technology niche market is one that offers sellers some limited level of protection against competition from existing products and therefore provides some room for experimentation, trial and error, and product modifications. At the same time, the new technology is embedded in a wider market. This provides the opportunity for a different kind of market transformation strategy.

Niche markets help to set important processes of change in motion: interactive learning, institutional adaptation, networking and technical development efforts that are necessary for the wider implementation of a niche technology. Thus a market transformation program could accelerate this process by focusing on aspects of change that depend on government actions (such as adjustments to standards and codes, public information, etc.) and providing leadership in bringing users, suppliers and other market actors together in an interactive learning process. This sort of approach to market transformation programs involves more risk, but could be important in areas that require difficult changes in market infrastructure.

When trying to create the market niche in which such a strategy may be applied, it would be important to require a good fit between the technology being launched and the expectations of the market. This requires close consideration of market characteristics by the market transformation practitioner in ways that parallel the approach of the firms launching the new product. For instance, it is important to choose a niche that takes full advantage of the merits of the new technology, to concentrate initially on a limited number of applications and work first in small geographical areas. Working with forms of the technology that have the potential for scale economies increases the chances of success and it is helpful to focus on customers and users who are demanding and likely to lead the market in adopting new products.

3.4.3 Business Concept Innovation

An innovative business strategy may also provide a framework for market transformation policies of a different kind. In some parts of the energy sector traditional business models have involved little emphasis on innovation as a tool for creating competitive advantage; this can also be said about some other sectors of the economy in which large amounts of energy are consumed; e.g., the construction sector. An example in the energy sector is the traditional electric or natural gas utility, which in the past focused strongly on its core business.

Regulatory regimes created a static environment that was not conducive to innovations in the products and services put on the market by these companies. Regulatory reform has changed that. In a more competitive environment, companies find that they have to pay attention not only to production efficiency and cost, but also to the specific needs of their target customer groups and to the more subtle characteristics of how they deliver their services. Thus, an electricity company may find that it can attract end-use customers by offering a variety of services. E.g., household consumers may respond to the offer of maintenance services, information technology devices that improve household management or reduce energy costs, and 'green energy' packages. Industrial customers respond to time-of-use pricing, energy performance contracting or options to be involved in distributed generation facilities.

This suggests that there are situations in which market transformation techniques can be fit into or coordinated with regulatory reform. While the reform may be primarily motivated by other objectives, opportunities to achieve technology deployment objectives by encouraging new business concepts may take shape as part of the process of competitive change that is set in motion. A Finnish project on the use of diesel engines for combined-cycle power generation showed that the scope for government-industry cooperation on business concept development is not limited to areas of regulatory reform. It involved support for the development of compact and modular combined heat and power systems by a major diesel equipment producer. Leading users and several providers of finance joined together to undertake a full-scale demonstration project. New ways of providing competitive energy solutions and total energy service concepts were developed. These have proven successful and have led to increased sales.

The cluster concept where the output from one operation is used as the feedstock for another operation is an example of a business concept innovation that is used for market transformation. In Europe there are now some community anaerobic digesters than produce heat and power from the manure from a number of farms, this is an innovative business concept. Partnering firms with feedstock resources, production expertise, with market developers who will explore and create new bioenergy markets but who lack the operational expertise would be an excellent example of Business Concept Innovation.

The idea of a market transformation perspective is in the early stages of its development relative to the other two perspectives discussed. It is a compendium of ideas that have taken shape out of the experience of policy practitioners and it is still evolving. It is nevertheless an important part of the discussion because it is about the details of getting the job of deployment policy done. There exist many opportunities to release the potential for cleaner and more efficient energy use.

4. MARKET BARRIERS DISCUSSION AND CONCLUSION

Having briefly considered the attributes of 2nd generation biofuels and the issues of market development it is worthwhile to consider the issues that the 1st generation biofuels have faced from a market development perspective. These can change from country to country but previous work on the identification of the barriers facing biofuels in Canada, Europe and South America have found an high degree of similarity of the issues in different regions ((S&T)^2, 2004, 2004b, 2005, 2006).

4.1 MARKET BARRIERS FOR 1ST GENERATION BIOFUELS

The market barriers for ethanol and biodiesel are summarized in the following sections. These summaries are derived from the work undertaken for Natural Resources Canada in 2004. Once these barriers are identified then the attributes of the 2nd generation biofuels can be considered to see if they help to address the barriers and thus their introduction would speed the biofuels implementation process or whether the either do not address the barrier or make it worse, in which case the market prospects for the 2nd generation fuel is less attractive than the 1st generation fuels.

4.1.1 Ethanol from Sugar and Starch

For the normal market barriers, the category of uncompetitive prices is rated as being a low to high market barrier. The range is created by the different tax incentives for ethanol available in different regions and the restrictive nature of some of those incentives. In regions where there is no government support for fuel ethanol, the issue of price competitiveness for ethanol will be high. Since the issue of price competitiveness is a relative one, commodity prices have a large impact on the magnitude of the barrier.

There is a range in terms of buyers risk, which also ranges from low to high depending on the technology and the feedstock being processed. The risk should be lowest for corn and sugar ethanol plants, slightly higher but still manageable for wheat ethanol plants, higher still for barley ethanol plants and highest for the cellulose technology (a 2nd generation fuel).

The financing risk is rated medium to high. Even the 1st generation facilities are difficult to finance because they are still relatively new and do not have a long successful track record. The producers are dependent on the tax incentives for their profitability and the markets for the products are not well developed. In many cases, the types of financial institutions (banks with a primary focus on agricultural activities) that have financed ethanol plants in the United States do not exist in all regions.

For the use of ethanol, there is considerable know-how in the United States and Brazil with respect to the distribution and use of ethanol that is directly transferable to other regions of the world and the technology related barriers are ranked low.

In the cases of the market failure type barriers, the use of ethanol provides some reductions in greenhouse gas emissions and reductions in some of the criteria air contaminants from automobiles, in most regions these benefits are not factored into the price of the product and thus there exists some price distortion.

There is some level of knowledge about ethanol blended gasoline in the market place in most regions and in many there is an overwhelming view that more ethanol gasoline blends should be sold. There is always still an opportunity to increase consumer knowledge about the fuel so the information barrier is ranked low to medium.

Transaction costs are not expected to be a barrier to increased ethanol use.

In most regions the market organization is inefficient related to ethanol. The distribution of the ethanol from the producer to the final user is essentially controlled by a small group of oil companies. This group has been reluctant to embrace ethanol even in regions where governments have made moves to legally require some ethanol in gasoline. This group has used the argument of reduced refinery throughput and stranded assets in the past as justification for not using ethanol. Under current market conditions of refinery closures, increased demand, and the elimination of alternative octane sources these arguments are weak.

The incumbent gasoline marketers have used the inefficient standards and regulatory system as a means to slow the development of appropriate standards for ethanol blended gasoline and in doing so have decreased ethanol's value to refiners and thus the return that ethanol producers could expect to receive.

The market barriers identified for ethanol are summarized in the following table.

Table 4-1 Summary Market Barriers – 1st Generation Ethanol

Barrier	Ethanol from Starch and Sugar
Normal Market Barriers	
Uncompetitive market price	Low to High
Buyer's risk	Low to Medium
Finance	Medium
Technology-specific barriers	Low
Market Failure Barriers	
Price distortion	Low to Medium
Information	Low to Medium
Transactions costs	Low
Inefficient market organization in relation to new technologies	High
Excessive/ inefficient regulation	Medium
Capital Stock Turnover Rates	Low

4.1.2 Biodiesel

For the normal market barriers, the category of uncompetitive prices is rated as being a medium to high market barrier for biodiesel. The range is created by the different feedstock costs and of course by different support regimes in different regions.

The buyers risk is primarily influence by the relative lack of experience with the design, construction and operation of these plants in countries that are first adopting biodiesel. Countries that have experience with biodiesel production have low risk in this category.

The financing risk is rated medium to high. These facilities are difficult to finance because they are still relatively new and do not have a long successful track record. The producers are dependent on the tax incentives for their profitability and the markets for the products are not well developed in most regions. In many cases, the types of financial institutions (banks with a primary focus on agricultural activities) that have financed biodiesel plants may not exist in some countries.

For the use of biodiesel, there is considerable know-how in Europe with respect to the distribution and use of that is directly transferable to other regions and the technology related barriers are ranked low. There have also been generally good experiences with the many demonstration projects that have been undertaken in Canada and the United States.

In the cases of the market failure type barriers, the use of biodiesel provides some reductions in greenhouse gas emissions and reductions in some of the criteria air contaminants from vehicles, these benefits are not factored into the price of the product and thus there exists some price distortion.

There is always an opportunity to increase consumer knowledge about the fuel so the information barrier is ranked low to medium.

Transaction costs are not expected to be a barrier to increased biodiesel use.

The market organization is inefficient related to biodiesel. The distribution of biodiesel from the producer to the final user is essentially controlled by a small group of integrated oil companies. This group has been reluctant to embrace alternative fuels. This group has used the argument of reduced refinery throughput and stranded assets in the past as justification for not using these alternatives. Under current market conditions of refinery closures, and increased demand these arguments are weak.

The incumbent fuel marketers have used the inefficient standards and regulatory system as a means to slow the development of appropriate standards for biodiesel. The lack of appropriate standards will slow the market development of the higher percentage biodiesel blends.

The market barriers identified for biodiesel are summarized in the following table.

Table 4-2 Summary Market Barriers - Biodiesel

Barrier	Biodiesel from Animal Fat	Biodiesel from Vegetable Oil
Normal Market Barriers		
Uncompetitive market price	Medium	High
Buyer's risk	Medium	Medium
Finance	Medium-High	Medium-High
Technology-specific barriers	Medium	Low
Market Failure Barriers		
Price distortion	Low	Low
Information	Medium	Medium
Transactions costs	Low	Low
Inefficient market organization in relation to new technologies	High	High
Excessive/ inefficient regulation	Medium	Medium
Capital Stock Turnover Rates	Low	Low

4.1.3 Summary 1st Generation Biofuels Market Barriers

The market barriers facing the 1st generation biofuels are quite similar for both ethanol and biodiesel. The two most significant barriers have been the price of biofuels compared to petroleum fuels and the difficulty marketing the product through the established fuel distribution companies.

New enterprises almost always face finance and business risk barriers during the start-up phase of the industry. In many countries ethanol and biodiesel projects have struggled with issues such as project financing, uncertainty with being able to design and construction facilities with new technology and dealing with the risk of commodity prices. In some countries these issues are mostly behind the industry as plants have been built and experience has been gained with dealing these issues. In other countries that are just beginning to develop their biofuels industries these are still issues that companies must face.

Ethanol and biodiesel have also faced less significant barriers in terms of price distortion and inefficient regulation. The industry has learned either how to deal with the issues or the removal of some of the other barriers, such as the competitive price issue, has also addressed or reduced the price distortion barrier.

These six barriers, uncompetitive price, inefficient market organization, finance risk, business risk, price distortion and inefficient regulation are now considered for the 2nd generation biofuels to determine where they might have advantages and where they face even larger barriers.

4.2 2ND GENERATION SPARK IGNITION FUELS

The 2nd generation biofuels that have been discussed as being possible fuels for spark ignited engines are ethanol produced from lignocellulosic feedstocks via either a biochemical pathway or a thermochemical pathway, higher alcohols that could be produced from lignocellulosics via the same two general pathways as ethanol, higher alcohols such as butanol produced from sugar or starch are also a possible 2nd generation fuels, and methane produced from biomass. The relative order of the state of development of these pathways is subject to debate but it is probably in the same order as they have been presented here. These pathways are now considered from the perspective of their ability to address the barriers that the 1st generation biofuel, ethanol from starch or sugar, has faced.

4.2.1 Uncompetitive Price

The biggest issue that the 1st generation biofuels have traditionally faced is that of being price competitive with gasoline. This barrier has usually been addressed through government support in the form of lower taxes or producer payments. More recently, with higher crude oil prices, the magnitude of this issue has been reduced and even eliminated in some jurisdictions but oil prices are historically volatile and there remains concern that oil prices may fall and the price gap may again become a larger issue. In the following table are comments about the individual pathway and its ability to address the price issue.

Table 4-3 2nd Generation SI Biofuels and Uncompetitive Price

Pathway	Comment
Ethanol – Biochemical Routes	Lower cost feedstock and reduced purchase of fossil energy is offset by higher chemical costs and much higher capital cost. Cash production costs may be close to 1st generation biofuels but they are not yet capable of providing equivalent or better financial returns compared to 1st generation technology. Large learning investments still required to lower capital costs.
Ethanol – Thermochemical Routes	Business case is not as well developed as the biochemical route but lower cost feedstock and reduced purchase of fossil energy is offset by higher capital costs and possibly catalyst costs. Probably not yet capable of providing equivalent or better financial returns compared to 1st generation technology. Large learning investments still required.
Higher Alcohols - Biochemical	First applications are likely to use the same feedstocks as 1st generation fuels and therefore unlikely to have a lower production costs.
Higher Alcohols - Thermochemical	Lower cost feedstock and reduced purchase of fossil energy is offset by higher capital costs and possibly catalyst costs. Maybe lower cost than producing ethanol from the same feedstock due to less complicated fuel production processes.
Biogas	This pathway is not as well defined as most of the other 2nd generation SI fuels. It is difficult to assess the overall economics of the pathway.

The 2nd generation SI biofuels do not yet offer any advantages over the 1st generation biofuels in terms of being able to be produced at a lower cost when the issue of capital is also included. Some specific processes offer some interesting potential for lower costs but very large "learning investments" will be required to prove out the potential. Commercial success (better financial returns than 1st generation processes) is still likely 5 to 10 years away even with aggressive government supported deployment programs and success is not guaranteed.

Some 2nd generation biofuel proponents make the claim that costs will be lower because they can achieve higher yields resulting from the ability to process all of the feedstock rather than just the carbohydrate portion. Performance data from some of these processes does not support this claim as lower conversion efficiency offsets being able to convert the whole plant.

4.2.2 Inefficient Market Organization

The 1st generation biofuels have had difficulty gaining market access in most countries where they have been introduced. The biofuels are generally used blended with the traditional fuel. Without the cooperation of the incumbent distributors biofuels have a difficult time moving to market. Some of the reluctance of the existing market participants to adopt biofuels stem from the different fuel properties and the additional precautions that must be taken to accommodate higher vapour pressure, reduced water tolerance and some materials compatibility issues. The ability of the 2nd generation fuels to address these issues is summarized below.

Table 4-4 2nd Generation SI Biofuels and Inefficient Market Organization

Pathway	Comment
Ethanol – Biochemical Routes	No real difference, the same product. Some companies have a lower resistance to ethanol if the feedstock is not also a potential food product.
Ethanol – Thermochemical Routes	No real difference, the same product. Some companies have a lower resistance to ethanol if the feedstock is not also a potential food product.
Higher Alcohols - Biochemical	Higher alcohols have properties that are closer to gasoline and may be easier to integrate into the existing system. Other properties such as octane are less attractive than the 1st generation biofuels.
Higher Alcohols - Thermochemical	Higher alcohols have properties that are closer to gasoline and may be easier to integrate into the existing system. Other properties such as octane are less attractive than the 1st generation biofuels. Some processes will co-produce methanol as part of higher alcohol blend. These will be less attractive to some stakeholders.
Biogas	Biogas will require a sequential decision process to successfully penetrate the market. That is both a vehicle and fuel purchase decision will be required. These kinds of decisions are more difficult to deploy. Therefore there is little advantage over the first generation biofuels.

Some of the 2nd generation biofuels may have some advantage over the use of ethanol but they will also have some less attractive properties. It must be noted that many regions have successfully deployed the first generation biofuels with little difficulty and thus the costs and benefits of the higher alcohols must be weighed against the measures taken and the benefits derived from the 1st generation fuels.

4.2.3 Finance Risk

New industries always face a barrier in financing the first operations. This is due to uncertainty in terms of construction and operating success. The risks and rewards that new ventures offer are not always apparent to the financial institutions and usually in their view the new investment opportunities are less attractive than industries and situations that they understand better.

Table 4-5 2nd Generation SI Biofuels and Finance Risk

Pathway	Comment
Ethanol – Biochemical Routes	Higher capital costs, lower returns, and new technical approaches with uncertain results make these pathways currently less attractive to financial institutions than 1st generation fuels.
Ethanol – Thermochemical Routes	Higher capital costs, lower returns, and new technical approaches with uncertain results make these pathways currently less attractive to financial institutions than 1st generation fuels.
Higher Alcohols - Biochemical	New technical approaches with uncertain results make these pathways currently less attractive to financial institutions than 1st generation fuels.
Higher Alcohols - Thermochemical	New technical approaches with uncertain results make these pathways less currently attractive to financial institutions than 1st generation fuels.
Biogas	The technology risk for some processes may be low but the uncertain market outlook (because of the sequential decision process) will be a concern to lenders.

The 2nd generation biofuels currently offer no advantages over the 1st generation fuels in terms of offering a lower financial risk profile. In fact because of the uncertainty that the application of new technology introduces the 2nd generation fuels have a higher finance barrier than the 1st generation fuels.

4.2.4 Business Risk

Business risk covers a wide range of issues that face new ventures including risks related to equity financing, construction and development risks, operational risks, production risks and corporate structure risks. These are commented on below.

Table 4-6 2nd Generation SI Biofuels and Business Risk

Pathway	Comment
Ethanol – Biochemical Routes	Very high construction and development risks related to the stage of development. Operationally will be more challenging than 1st generation fuels.
Ethanol – Thermochemical Routes	High development risks. The gasification of biomass process does not scale as easily as some other chemical processes. Many unknowns concerning the catalytic conversion of syngas to ethanol.
Higher Alcohols - Biochemical	Employs bacterium fermentation processes which are more difficult to operate than fungal fermentations.
Higher Alcohols - Thermochemical	High development risks. The gasification of biomass process does not scale as easily as some other chemical processes.
Biogas	Some pathways are technically less challenging than the other 2nd generation fuels.

None of the 2nd generation biofuels offer less business risk that the 1st generation fuels. This is not only a function of the stage of development but also the fact that all of the production processes employed to produce the new fuels are more complex than the 1st generation processes. Some involve higher temperatures and pressures, and others have a narrower operating range where optimum performance can be achieved.

4.2.5 Price Distortion

Price distortion is a relatively minor barrier for the 1st generation biofuels in that resolving the uncompetitive price situation usually also addresses the issues of price distortion caused by not including the environmental benefits in the economic decision making process. The largest difference between the 1st and 2nd generation fuels are likely to be the GHG emission performance since in most cases the product is the same as the 1st generation fuel and there will be no difference in the environmental performance of using the fuel, only in making it.

Table 4-7 2nd Generation SI Biofuels and Price Distortion

Pathway	Comment
Ethanol – Biochemical Routes	May offer larger environmental benefits depending on the exact process used.
Ethanol – Thermochemical Routes	May offer larger environmental benefits depending on the exact process used.
Higher Alcohols - Biochemical	Environmental benefits are uncertain and will depend on the exact process used. There may be an impact from the fuel use as well.
Higher Alcohols - Thermochemical	May offer larger environmental benefits depending on the exact process used. There may be an impact from the fuel use as well.
Biogas	Environmental benefits are uncertain and will depend on the exact process used.

The environmental benefits of the 2nd generation biofuels will depend on exactly how the processes are deployed. For those processes that use less fossil fuel, the GHG emission performance may be enhanced but there are also real possibilities of improving the GHG performance of the 1st generation fuels as well.

4.2.6 Inefficient/Excessive Regulation

In some countries 1st generation biofuels faced regulatory issues since they had performance characteristics that were different than traditional fuels and when regulations were prescriptive rather than performance driven this created issues. In most countries these regulatory issues with 1st generation biofuels have been addressed over time so that any remaining barrier in this area is very small.

Table 4-8 2^{nd} Generation SI Biofuels and Regulation

Pathway	Comment
Ethanol – Biochemical Routes	Same as 1^{st} generation.
Ethanol – Thermochemical Routes	Same as 1^{st} generation.
Higher Alcohols - Biochemical	New fuel so the regulatory burden may be higher than for the existing 1^{st} generation biofuels.
Higher Alcohols - Thermochemical	New fuel so the regulatory burden may be higher than for the existing 1^{st} generation biofuels.
Biogas	Same as for fossil natural gas.

The 2^{nd} generation biofuels do not appear to offer any advantages over the 1^{st} generation biofuels in terms of reduced regulatory barriers.

4.2.7 Summary 2nd Generation SI Biofuels Market Barriers

The 2^{nd} generation SI biofuels have the potential to process lower cost and more abundant feedstocks. In the case of 1^{st} generation biofuels, it has only been recently that concerns have been raised concerning the strain on resources that increased biofuels may cause. It must also be noted that feedstocks that are used for these 1^{st} generation fuels have generally suffered from an imbalance in the supply and demand and that has been one of the drivers for biofuels, to try and bring the supply and demand back into a balance and hopefully raise farm income in the process. The availability of feedstocks has thus not been a barrier for the 1^{st} generation biofuels to date.

For most of the 2^{nd} generation SI biofuels the ability to use lower cost feedstocks does not currently result in lower cost biofuels. The feedstock cost savings are offset by higher chemical costs and much higher projected capital costs. Very large “learning investments” will be required to address the capital cost barriers that these fuels currently face. Considering the large investments involved plus the design, build, operate cycle (a minimum of three years) for these biofuels plants it will take 5 to 10 years of experience before there will be enough experience gained that will lead to a large enough reduction in capital costs for these plants to be financeable as commercial ventures.

The other benefits of the 2^{nd} generation SI biofuels do not really lead to the significant reduction of the other market barriers that faced the 1^{st} generation biofuels. While the development of the 2^{nd} generation biofuel technology is important, these processes are not likely to replace the 1^{st} generation biofuels for many years, if ever. The greatest potential for these fuels likely lies in their ability to process lower value, more abundant feedstocks and not in their ability to produce lower cost biofuels. It will be many years before the capital costs for the 2^{nd} generation biofuels can be reduced to the point where the return on investment is comparable to that from 1^{st} generation plants.

4.3 2^{ND} GENERATION COMPRESSION IGNITION FUELS

The 2^{nd} generation biofuels for compression ignition engines that have been discussed as are Fisher Tropsch distillates produced from lignocellulosic feedstocks via a thermochemical pathway, hydrocarbons that could be produced from vegetable oils and animal fats via hydrotreating, and bio-DME that would be produced via gasification of lignocellulosic feedstocks and reforming of the syngas. The relative order of the state of development of these pathways is subject to debate but the hydrotreating pathway is likely to be the first that is commercialized followed by the FT distillate process. These pathways are now considered from the perspective of their ability to address the barriers that the 1st generation biofuel, biodiesel from vegetable oils and animal fats, has faced.

4.3.1 Uncompetitive Price

One of the biggest barriers that biodiesel has faced has been the relative price between petroleum diesel and biodiesel. The high biodiesel price has primarily been a function of the feedstock price as the other operating costs and the capital costs for the facilities are relatively modest in comparison. Two of the pathways attempt to resolve this by processing a lower cost feedstock, lignocellulosic material.

Table 4-9 2nd Generation CI Biofuels and Uncompetitive Price

Pathway	Comment
FT Routes	Lower cost feedstock, but lower yield and much higher capital cost offset the feedstock advantage.
Other Thermochemical Routes	Same feedstock as 1st generation fuel. Capital and operating costs are likely higher than the fist generation fuels and the yield is lower.
Bio-DME	Lower feedstock cost and higher capital costs compared to 1st generation biofuels.

These 2nd generation biofuels have the potential of processing more abundant lower cost feedstocks but much development work needs to be accomplished before the promise can be realized. The capital costs of these plants may be an order of magnitude higher than the cost of a 1st generation biodiesel plant. In some regions of the world the biodiesel production capacity outstrips the ability of local producers to supply feedstock and so the 2nd generation biofuels may offer an attractive alternative when the technology can be demonstrated and proven in a commercial environment.

4.3.2 Inefficient Market Organization

Biodiesel has been used both as a 100% fuel and as a blending agent in petroleum diesel. The current trend is towards higher use as a blending agent as there is some concern with respect to compatibility with new engine technologies that are being introduced around the world. The use in low level blends requires the support of the existing petroleum distributors and in some cases these companies have resisted the use of biodiesel because of concerns about the ability of the product to perform in all weather conditions. Two of the pathways produce a hydrocarbon product rather than an ester and these products are fungible with the existing petroleum product distribution system.

Table 4-10 2nd Generation CI Biofuels and Inefficient Market Organization

Pathway	Comment
FT Routes	Should address concerns about the 1st generation biodiesel. Some oil companies are involved with the product and process development.
Other Thermochemical Routes	Should address concerns about the 1st generation biodiesel. Some oil companies are involved with the product and process development.
Bio-DME	This product will require a sequential decision process. Both new vehicles and new fuelling infrastructure need to be introduced at the same time.

Two of the 2nd generation pathways have support from major oil companies, which should lead to an easier market acceptance for the product. The two hydrocarbon liquid fuels are fully fungible with the existing petroleum diesel fuels and that should also lower resistance to the new product if the costs can become competitive.

4.3.3 Finance Risk

New industries always face a barrier in financing the first operations. This is due to uncertainty in terms of construction and operating success. The risks and rewards that new ventures offer are not always apparent to the financial institutions and usually in their view the new investment opportunities are less attractive than industries and situations that they understand better.

Table 4-11 2nd Generation CI Biofuels and Finance Risk

Pathway	Comment
FT Routes	Very high capital cost. The FT part of the process is well known and established with feedstocks such as coal and natural gas. This may lower the finance barrier.
Other Thermochemical Routes	Will probably employed inside existing refineries and may not need to be financed on a project basis, greatly reducing the barrier.
Bio-DME	The sequential decision process will be a concern to lenders. There will be uncertainty regarding the small size of the non-fuel DME markets.

4.3.4 Business Risk

Business risk covers a wide range of issues that face new ventures including risks related to equity financing, construction and development risks, operational risks, production risks and corporate structure risks. These are commented on below.

Table 4-12 2nd Generation CI Biofuels and Business Risk

Pathway	Comment
FT Routes	Very high construction and development risks related to the stage of development. Operationally will be more challenging than 1st generation fuels.
Other Thermochemical Routes	Probably the lowest risk of the 2nd generation fuel options.
Bio-DME	Very high construction and development risks related to the stage of development. Operationally will be more challenging than 1st generation fuels.

4.3.5 Price Distortion

Price distortion is a relatively minor barrier for the 1st generation biofuels in that resolving the uncompetitive price situation usually also addresses the issues of price distortion caused by not including the environmental benefits in the economic decision making process. The largest difference between the 1st and 2nd generation fuels is likely to be the GHG emission performance.

Table 4-13 2nd Generation CI Biofuels and Price Distortion

Pathway	Comment
FT Routes	Should be good GHG emissions performance if no fossil fuels are used in the production process. The FT distillates have attractive combustion performance.
Other Thermochemical Routes	Not as attractive from a GHG emissions performance compared to 1st generation biofuels.
Bio-DME	Should be good GHG emissions performance if no fossil fuels are used in the production process.

The environmental benefits of the 2nd generation biofuels will depend on exactly how the processes are deployed. For those processes that use less fossil fuel, the GHG emission performance may be enhanced

4.3.6 Inefficient/Excessive Regulation

In some countries 1st generation biofuels faced regulatory issues since they had performance characteristics that were different than traditional fuels and when regulations were prescriptive rather than performance driven this created issues. In most countries these regulatory issues with 1st generation biofuels have been addressed over time so that any remaining barrier in this area is very small.

Table 4-14 2^{nd} Generation CI Biofuels and Regulation

Pathway	Comment
FT Routes	FT distillates produced from coal and natural gas are being used in the marketplace. Should be no issues with biofuels.
Other Thermochemical Routes	Similar to existing fossil fuels. Should be no issues with biofuels.
Bio-DME	DME has not been commercially used as a transportation fuel. There will likely be regulatory issues in many jurisdictions.

4.3.7 Summary 2nd Generation CI Biofuels Market Barriers

The 2^{nd} generation CI biofuels have the potential to process lower cost and more abundant feedstocks. In the case of 1^{st} generation biofuels, it has only been recently that concerns have been raised concerning the strain on resources that increased biofuels may cause. It must also be noted that feedstocks that are used for these 1^{st} generation fuels have generally suffered from an imbalance in the supply and demand and that has been one of the drivers for biofuels, to try and bring the supply and demand back into a balance and hopefully raise farm income in the process. The availability of feedstocks has thus not been a barrier for the 1^{st} generation biofuels to date.

For most of the 2^{nd} generation CI biofuels the ability to use lower cost feedstocks does not currently result in lower cost biofuels. The feedstock cost savings are offset by much higher projected capital costs. Very large “learning investments” will be required to address the capital cost barriers that these fuels currently face. Considering the large investments involved plus the design, build, operate cycle (a minimum of three years) for these biofuels plants it will take 5 to 10 years of experience before there will be enough experience gained that will lead to a large enough reduction in capital costs for these plants to be financeable as commercial ventures.

The other benefits of the 2^{nd} generation CI biofuels do not really lead to the significant reduction of the other market barriers that faced the 1^{st} generation biofuels. While the development of the 2^{nd} generation biofuel technology is important, these processes are not likely to replace the 1^{st} generation biofuels for many years, if ever. The greatest potential for these fuels likely lies in their ability to process lower value, more abundant feedstocks and not in their ability to produce lower cost biofuels. It will be many years before the capital costs for the 2^{nd} generation biofuels can be reduced to the point where the return on investment is comparable to that from 1^{st} generation plants.

4.4 Summary and Conclusions 2^{ND} Generation Fuels Market Development

This section of the report has considered the development of 2^{nd} generation biofuels production and marketing from a market development perspective using the IEA developed template for creating markets. The focus has been on the Market Barrier perspective but some conclusions can be drawn from the other perspectives as well. When the biofuels are considered from the R&D+D perspective several issues become apparent:

1. Most of the proponents of 2^{nd} generation biofuels are pursuing very large plants to take advantage of economies of scale.

2. Few of the proponents would appear to have incorporated the issue of the learning experience in determining the optimum size of the first several plants.
3. Some of the 2nd generation biofuels are more fungible than the existing biofuels and while this offers some advantages in reduced barriers to market development it may have reduced the perceived relative advantages of the products compared to traditional fuels. This could make them less attractive to early adopters.
4. Not all 2nd generation biofuels offer advantages in terms of yield, energy balance or GHG emissions profiles compared to first generation biofuels. The environmental performance of 1st generation biofuels can also be improved to rival that of the best 2nd generation processes through substituting bioenergy for their fossil energy inputs.

The 2nd generation biofuel development is being promoted from a more traditional perspective than the market transformation perspective encourages. The plants being envisioned are large plants to achieve the economies of scale. It is not clear that the scale is totally appropriate for the feedstock and the products being produced and in a few cases the concept of a hub and spoke production scheme is being developed. In this concept a number of small pre-processing plants would be distributed around a region close to the source of feedstock. The material would be partially processed to increase the energy density of the material and then shipped to a large central processing plant where it would be transformed into the final transportation fuel.

When the new biofuels are considered from the Market Barriers perspective the fuels the primary barriers that the fuels face are not that dissimilar to the first generation biofuels.

1. High biofuels price. While 2nd generation biofuels often employ lower cost feedstocks, the capital costs of the plants are usually higher and the processing costs may also be higher negating some or all of the feedstock advantages.
2. Inefficient market organization. Some of the 2nd generation biofuels are fungible with existing petroleum products and may therefore face less resistance from the existing product distributors. Other issues with respect to displacing the existing products from their marketplace remain.
3. Finance risk. The high capital cost and the high degree of risk that new unproven technologies face will generally increase this market barrier.
4. Business risk. The new technologies face considerable business risk with new production processes that must be proven in a commercial environment.

The real benefit of 2nd generation biofuels is in their ability to process a wider range of feedstocks than the 1st generation biofuels. In most regions of the world the 1st generation fuels have not yet reached a limit on market share due to feedstock availability and thus the need to switch to other processes is not yet a major driving force. Given the length of time that will be required to commercialize some the 2nd generation processes it is appropriate that governments support their development well before they are required by the marketplace.

The benefits of 2nd generation biofuels do not address most of the barriers that the 1st generation fuels have faced and in fact many of the 2nd generation fuels will face the same market barriers as the 1st generation fuels. It is important therefore that efforts to implement the production of 1st generation fuels not be reduced or postponed because of the promise of 2nd generation fuels. Doing so would only delay the eventual adoption of the 2nd generation biofuels. The use of 2nd generation biofuels needs to be viewed as a means to augment and not to replace the use of 1st generation biofuels.

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