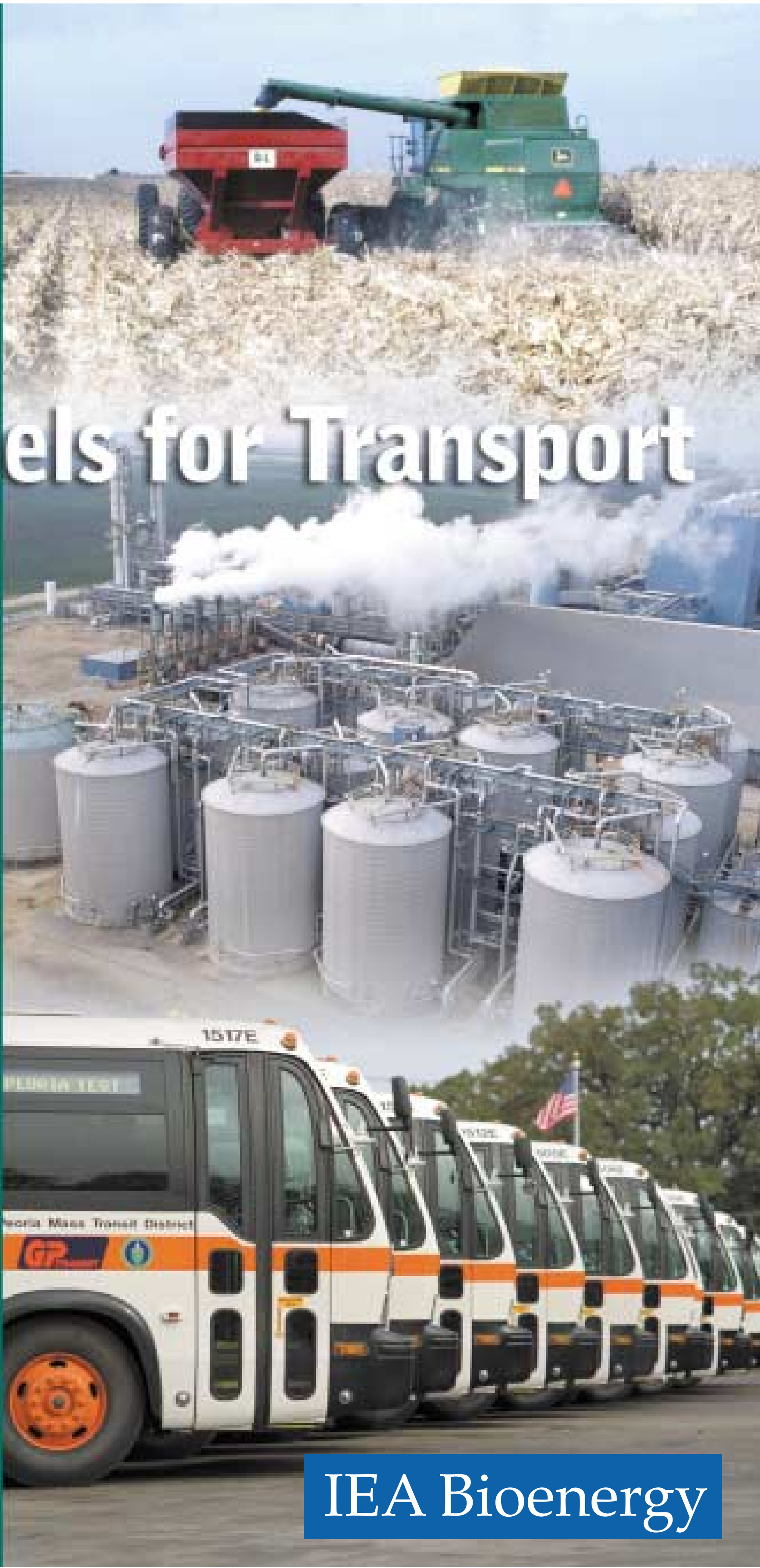
Biofuels for Transport



IEA Bioenergy

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Biofuels for Transport

This paper provides an overview of liquid biofuels. It was prepared by Dr Don Stevens, the Leader of Task 39 from 2001 to 2003, in conjunction with the participants in the Task. It draws on the work of the collaborating researchers in Austria, Canada, Denmark, Finland, Ireland, the Netherlands, Sweden, UK, USA, and the European Commission as well as associated networks.

Introduction

"Biofuels" is a term used to describe raw biomass processed into a more convenient form to be used as a fuel. It is most commonly applied to liquid biofuels for transport but could also refer to gaseous fuels and solid fuels such as wood pellets and briquettes. This paper focuses on liquid biofuels for transport.

The use of biofuels is increasing in many regions throughout the world. At present, a total of approximately 30 billion (30 x 10^9) litres of biofuels are used annually in Europe, North America, and South America. This figure is expected to grow significantly as the demand for sustainable transportation fuels increases.

Benefits of Biofuels

The market for biofuels is expanding because these fuels address key policy needs. While the relative importance of these policy drivers varies, countries and regions that successfully implement the use of biofuels enjoy benefits in the following areas:

- Environment
- Energy security
- Economic development.

Cover picture Harvesting of corn for ethanol feedstock, ethanol processing plant based on corn fibre and a bus fleet fuelled by ethanol. (Courtesy DOE/NREL, David and Associates and W. Gretz)

Environment

Local sources of biofuel provides security of supply in Brazil - the world's leading producer of ethanol. (Courtesy J. Domac, Croatia)

Biofuels have environmental benefits that are a major driving force for their introduction. Using biofuels instead of fossil fuels reduces net emissions of carbon dioxide, which are associated with global climate change. Biofuels are produced from renewable plant resources that "recycle" the carbon dioxide created when biofuels are consumed. Life-cycle analyses consistently show that using biofuels produced in modern facilities results in net reductions of carbon emissions compared to using petroleum equivalents. These life-cycle analyses include the energy requirements for the farming and production of the biomass resource, as well as harvesting, conversion and utilization. Biofuels therefore help nations achieve their goals of reducing carbon emissions. Biofuels also typically burn cleanly in vehicle engines and reduce emissions of unwanted products, particularly unburned hydrocarbons and carbon monoxide. These characteristics contribute to improvements in local air quality.

Energy Security

Biofuels help provide energy security for the countries that use them. When produced from local and regional biomass resources, biofuels are relatively isolated from the uncertainties of international political disruptions. Domestically produced biofuels also enhance national security by reducing net imports of petroleum and helping reduce international trade imbalances sometimes associated with oil imports.

Economic Development

Biofuels create local and regional economic development opportunities. Such developments frequently occur in rural areas where other options are very limited. The use of biofuels allows energy and agricultural policies to be coupled to provide benefits in both areas.

Biofuels are also practical. The compatibility of biofuels with modern vehicles provides an option for replacing petroleum in transportation. Current motor vehicles use fuel management technologies that permit a range of biofuel blends to be used by consumers. Most new vehicles today can readily accommodate biofuel blends up to about 20%, and flexible-fuel or dedicated-fuel vehicles for high-concentration blends or neat biofuel are also commercially available. As a result, consumers have a variety of vehicle options available that will readily use biofuels.

Transport of sugar cane to the Barra Grande alcohol and sugar mill. (Courtesy J. G. Darcie, Zillo Lorenzetti Group of Copersucar, Brazil)

Biofuels Today

Ethanol pilot plant based on corn fibre and other cellulosic material, New Energy Company of Indiana, USA. (Courtesy DOE/NREL and W. Gretz)

Three biofuels account for almost all consumption in the transport sector at present:

- Ethanol (and ETBE made from ethanol)
- Biodiesel
- Biogas.

Ethanol is the most common biofuel, accounting for more than 90% of the total usage. It is currently produced by fermentation of the 6-carbon sugars from grain or sugar crops. Conversion facilities are typically large-scale, sophisticated "biorefineries", which efficiently process biomass into a range of products such as chemicals and animal feed in addition to fuels, providing several revenue streams.

Ethanol is most frequently used in low-concentration blends with petroleum gasoline. In North America and parts of Europe, blends of 5-10% (E-5 to E-10) are common, and selected filling stations in a few major metropolitan areas sell E-85 for "flexible fuel" vehicles. In Brazil, motor gasoline by law contains a minimum of 22% ethanol. The warm climate of Brazil also makes feasible the use of E-95 (denatured, hydrous ethanol), and an increasing number of vehicles capable of using that fuel are being sold. ETBE (ethyl tertiary–butyl ether), produced by reacting ethanol with butylene, is used in low-concentration gasoline blends up to about 8-10% in fuels in parts of Europe, particularly France and Spain.

The growth of ethanol as a motor fuel in the United States is illustrated in Figure 1. Ethanol use began in the early 1980s and has increased substantially in the past few years. In 2003, an estimated 10 billion litres of ethanol were used in motor fuels.

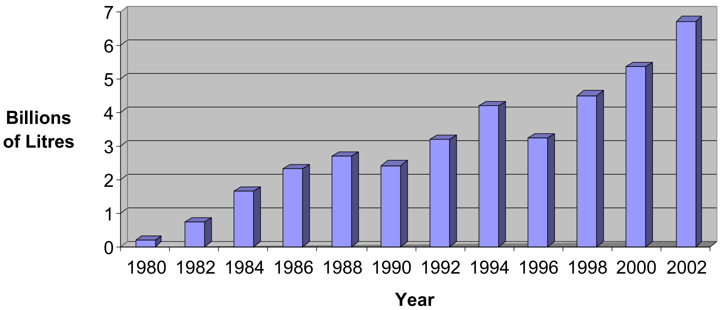

Figure 1: Ethanol use in USA motor fuels. Source: US Department of Energy, Energy Information Agency

Biodiesel is produced by the chemical esterification of oils from oilseed crops such as soy, rape, mustard, or from other sources such as waste cooking oil. The esterification step involves a simple chemical reaction of the oil with methanol. Biodiesel is the biofuel with the most rapid rate of market growth. It's use has grown rapidly from essentially zero in 1995 to a total of about 1.5 billion (1.5 x 10^9) litres per annum worldwide in 2003. The rapid increase of biodiesel use in Germany is shown in Figure 2; it is used in Germany not only as a transportation fuel but also as a fuel for heat and power generation in some locations.

Rapeseed oil is an important raw material for biodiesel. (Courtesy ORNL, USA)

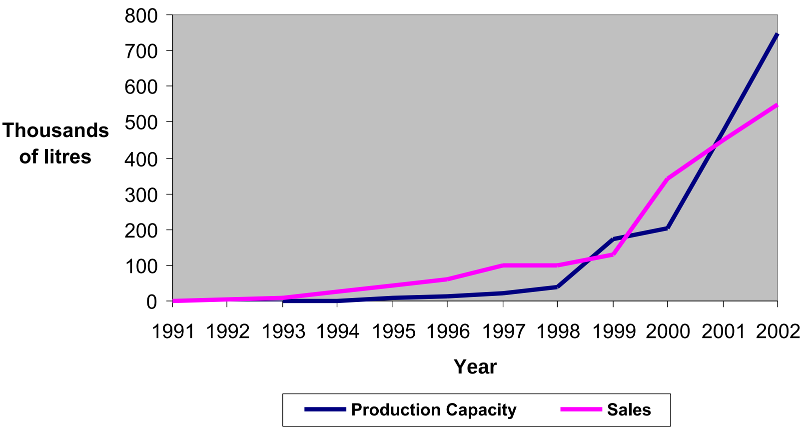

Figure 2: Biodiesel production capacity and sales in Germany. Source: S&T Squared Consultants, Inc.

The use of 100% biodiesel (B100) is common in some European countries such as Germany. Biodiesel is also blended with petroleum diesel at concentrations of 5 to 25% (B5 – B25) throughout North America and Europe. More biodiesel is used in Europe than North America, in large part because Europe has a much higher percentage of diesel-fuel vehicles. Quality standards have been established for biodiesel that help ensure the compatibility of this fuel with most vehicles.

In addition to these liquid biofuels, biogas is available commercially in a few areas, primarily in Europe. Biogas is composed mainly of methane and carbon dioxide and is

Biogas vehicle. (Courtesy Task 37 and A. Wellinger, Switzerland)

produced by the anaerobic digestion of organic material. At present, the biomass sold commercially is usually collected from municipal waste landfills. The gas is compressed and used in vehicles equipped for natural gas. Biogas at present has a very small market share, but its use could increase as the number of vehicles using gaseous fuels increases and filling stations become more readily available.

Biofuels in the Future

While biofuels already contribute significantly to the needs of the transportation sector, their use is expected to grow markedly in the future. These increases are expected to result from the ongoing need to address environmental, energy security, and economic issues. The increasing use of biofuels will require changes in both the feedstocks and the conversion technologies used to produce these fuels.

Although grain, sugar, and oil crops will continue to be important biomass resources, the use of lignocellulosic biomass is essential in the longer term. Lignocellulosic materials include such feedstocks as woody biomass, corn stover (dried leaves and stems), or other energy crops. A variety of lignocellulosic feedstocks are available, enabling biomass to be grown in a wide range of climatic conditions.

These feedstocks substantially expand the supply of biomass available for conversion and will help reduce the potential for food/fuel conflicts. In Europe, for example, the land available for grain and sugar production is not sufficient to fully support a very large ethanol industry. While North America can increase grain production significantly, even there the long-term availability of biofuels would be limited unless lignocellulosic crops can also successfully be utilized. The transition from grain- and oil-based crops to lignocellulosic feedstocks will be gradual, but the lignocellulosic materials are critical to the longer-term expansion of the biofuels industry.

The characteristics of lignocellulosic biomass are different from those of grain and sugar crops, and so the technologies for converting them to biofuels must be modified appropriately. The sugars and starch from sugar/grain crops are relatively easy to ferment into ethanol, and the oils from oil-seed crops are easily converted to biodiesel. By comparison, the major building blocks of lignocellulosic biomass are more difficult to convert to liquid biofuels. The major building blocks of lignocellulosic feedstocks are 6-carbon sugars stored as cellulose, 5-carbon sugars stored as hemicellulose, and lignin, a complex phenolic material. Technologies must be able to effectively utilize these components for efficient biofuels production.

Ethanol from lignocellulosic feedstocks

Over the past three decades, extensive RD&D has been conducted on the biological conversion of lignocellulosic biomass to ethanol in a variety of countries. The focus of this research is to produce fermentable 5- and 6-carbon sugars that can subsequently be converted to ethanol. Basic processing steps include pretreatment that both disrupts the structure of the woody biomass and releases 5-carbon sugars from hemicellulose, hydrolysis of the cellulose to form 6-carbon sugars, and the fermentation of the sugars to ethanol.

Ethanol fuel pump for refueling vehicles. (Courtesy DOE/NREL and W. Gretz)

The pretreatment step, while relatively well understood, remains a significant technical challenge due to the heterogeneous nature of lignocellulosic feedstocks. Several different types of processes, including steam explosion, ammonia steam explosion, dilute acid and concentrated acid treatments, have been studied extensively for application to agricultural residues, but these are less well understood when applied to forest residues. The forest materials typically have lignin contents that inhibit subsequent hydrolysis. To provide better conversion of these feedstocks, newer pretreatment approaches including enzymatic pretreatment and others are being examined.

The hydrolysis step is essential in converting the cellulose and hemicellulose components to fermentable sugars. The hydrolysis of the components from lignocellulosic materials is more difficult than processing starch from grain, and the hydrolysis step produces a wider range of simple sugars because the feedstock is not as homogeneous. Research and development activities have been conducted on both chemical and enzymatic conversion processes, and either can be effective in producing fermentable sugars. Ongoing RD&D, such as the identification of better and lower cost enzymes, is being conducted to improve the efficiency and process economics of these approaches.

The fermentation step for lignocellulosic biomass also faces unique challenges. While the 6-carbon sugars are readily fermentable by commercially available micro-organisms, those organisms typically don't convert 5-carbon sugars. R&D activities have created organisms capable of generating ethanol from either the 5-carbon or 6-carbon sugars. However, the lignocellulosic materials contain a greater range of sugars and other products, some of which can inhibit the fermentation reaction. Engineering advances are being made to reduce these inhibitory effects. Advances have also been made that allow hydrolysis and fermentation steps to be better integrated, leading to improved yields and potential cost reductions for the ethanol production process.

At various stages throughout the process, fractionation or separation of the chemical components of lignocellulosics is important. Improvements in separation processes and product recovery are helping to improve process efficiencies. Improved fractionation technology will provide industry with the ability to utilize more variable biomass sources of lignocellulosics, including urban waste, agricultural and mill residues, as well as traditional agriculture and forest crops and residues.

Process Development Unit for biomass to ethanol, 9000 litre fermenters, Golden, Colorado, USA. (Courtesy DOE/NREL and W. Gretz)

Additional RD&D activities are being conducted to develop bio-based products from ethanol-based processes. Bio-based products provide additional revenue streams to help support biorefineries economically. Like the grain-based facilities of today, the lignocellulosic-based facilities of the future will also require a variety of products to provide adequate economic return.

Successful implementation of the advanced technologies is expected to lead to significant reductions in the cost of producing ethanol. The National Renewable Energy Laboratory estimates that the selling price of ethanol from lignocellulosic biomass could be reduced to less than $0.25/litre with appropriate technical progress. As a result of the RD&D progress over the past several years, several pilot- or demonstration-scale facilities are being planned or built by industry. These initial facilities are typically utilizing agricultural biomass resources. For example, the Iogen facility in Ottawa, Canada, has a design capacity of about 40 tons of agricultural biomass per day.

Fermentor in Iogen agricultural biomass-to-ethanol demonstration facility. (Courtesy Iogen, Canada)

In addition to the interest in biological conversion of lignocellulosic biomass, there is also substantial current interest in the thermal conversion of this resource to ethanol. Thermal conversion technologies offer the potential of high conversion efficiencies because they utilize all the major components of the lignocellulosic resource. In the thermochemical conversion process, biomass would be gasified to form a synthesis gas composed primarily of carbon monoxide and hydrogen. Biomass thermal gasification technologies for synthesis gas have been under development for several years, and several demonstration facilities are operating. The synthesis gas produced by biomass gasification would subsequently be used to produce ethanol, using either a catalytic or biological process, or a combination of both. The catalytic process would be similar to those used in the petrochemical industry to produce chemicals such as methanol. As an alternative, the synthesis gas could potentially be converted to ethanol using micro-organisms. Basic research is being conducted on biological conversion of synthesis gases at several locations. Several small-scale proof-of-concept facilities relating to thermal ethanol production are being built or are operating in North America and Europe.

Corn and stover, Colorado, USA. (Courtesy DOE/NREL and W. Gretz)

Biodiesel

While biodiesel technologies are well defined and will continue to use oil-based crops, future improvements are expected as the new industry matures. Opportunities for better catalytic conversion approaches are being examined, and R&D activities are examining ways to increase oil yields in selected plants. Because biodiesel can directly replace petroleum diesel and because the market is so new, the prospects are good for substantial growth of biodiesel use.

Biodiesel production site in Mureck, Austria. (Courtesy M. Scheuer, Croatia)

Biomass-based diesel can also potentially be produced by the thermochemical conversion of biomass utilizing gasification technologies. As described above, the biomass feedstock would be gasified to produce a synthesis gas composed primarily of hydrogen and carbon monoxide. The synthesis gas would then be converted to hydrocarbon products in the diesel range using catalysts based on the existing Fischer-Tropsch process. The product, while different from that made from vegetable oils, would directly replace petroleum diesel. Analyses are being conducted in several locations to determine the feasibility of this approach.

Other biofuels

The shift to lignocellulosic biomass feedstocks and more efficient conversion pathways provides the opportunity to consider "next-generation" biofuels. These fuels would be produced by efficient processes that could be based on biological or thermochemical pathways, or a combination of both. Highly efficient processes would produce more biofuel per quantity of biomass resource, therefore reducing the land area requirements for these fuels. Such fuels might include methanol, dimethyl ether (DME), methyl-tetrahydrofuran (MTHF), fuels based on biomass pyrolysis, or others. Methanol is of interest because of its potential for powering fuel cells, and DME production has recently been evaluated in Europe. Studies of pyrolysis-derived motor fuels are also under way.

Biomass is a potential source of hydrogen for fuel-cell powered vehicles. Hydrogen is viewed by many as an important transportation fuel in the future, and biomass resources provide a renewable feedstock for its production. Biomass provides the flexibility to address both the near-term needs of the transportation sector and the longer-term opportunities for new fuels.

Forest residues are an important potential lignocellulosic feedstock for biofuel production. (Courtesy A. Timperi, Timberjack, Finland and J. Tustin)

The Role of Policies

Countries and regions that recognise the value of biofuels have enacted policies and regulations to encourage their use. These policies are very important for the implementation of biofuels and for their long-term growth.

At present, the costs of biofuels are greater than their petroleum equivalents. The wholesale prices of ethanol and biodiesel for large quantities, without excise taxes, at the plant gate are shown for the USA in early 2004 in Table 1 below. These should be considered approximate since the production processes of both the petroleum and biofuels have varied significantly over the past few years. Further, the costs are compared on a volumetric basis and are not adjusted for energy content.

Table 1: USA wholesale prices of ethanol and biodiesel at the plant gate.

Fuel	Spot Price, US$/litre*
Ethanol from grain	$ 0.35
Mid-grade gasoline	$ 0.28
Biodiesel	$ 0.55
Petroleum diesel	$ 0.27

*January 2004

The price differential is expected, given the maturity of the petroleum industry and the establishment of international policies over many decades to ensure availability of inexpensive petroleum.

The current price differential means policies and regulations are crucial for biofuels to compete economically in the marketplace. While many different types of biofuels policies exist, they are generally based on one of three approaches:

- Taxation-based policies
- Agriculture-based policies
- Fuel mandates.

Taxation-based Policies

Taxation-based policies typically involve reductions in motor fuel excise taxes. Blended or undiluted biofuels are taxed at lower rates than their petroleum counterparts, and the tax reduction allows biofuels to be sold at the pump to consumers at the same or lower prices. Taxation-based policies have been very effective at increasing the use of ethanol in North America and at increasing the use of biodiesel in Germany. These policies can help keep the price of biofuels paid by the consumer low, but they typically result in reduced Government revenues.

The effect of taxation-based policies on biodiesel in Germany is shown in Figure 3. Biodiesel used as B100 in Germany has a 100% tax exemption, which allows the price consumers pay at the pump to be less for biodiesel than petroleum diesel. This policy has led to very rapid growth of biodiesel over the past few years. Germany now has over 1500 filling stations with B100.

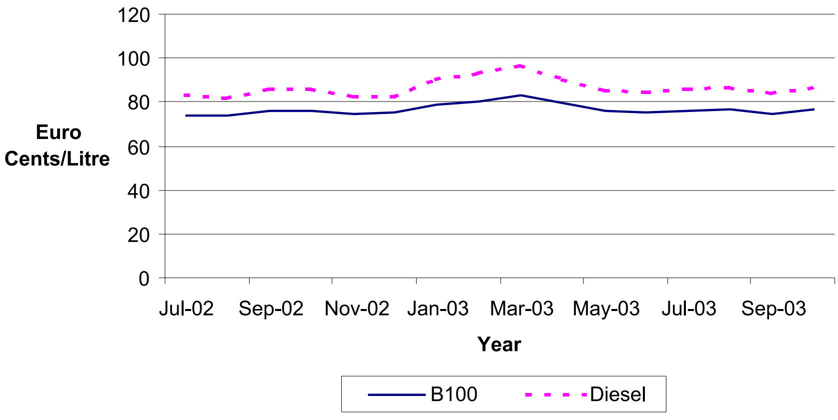

Figure 3: Comparison of German retail prices for biodiesel B100 and petroleum diesel at the pump. Source: S&T Squared Consultants, Inc.

Agriculture-based Policies

Agriculture-based policies have also been used in some areas to help implement use of biofuels. In those areas, farming credits are provided for using biomass grown on set-aside lands that are unavailable for food production. The policies have the effect of reducing the cost of the biomass feedstock and therefore lowering the cost of the resulting biofuels. Agriculture-based policies have been used in Europe to encourage production of ethanol for conversion to ETBE. Like the taxation-based policies, agriculture-based polices help keep the pump prices of biofuels low but typically reduce Government revenues.

Fuel Mandates

Fuel mandates that require that motor fuels contain minimum percentages of biofuels can also be helpful with implementation. Brazil, for example, requires motor gasoline to contain at least 22% ethanol. The European Union has also adopted policies that encourage minimum levels of biofuels in the motor fuel mix, and fuel mandates are being considered in many other locations including North America. Fuel mandates provide a simple, direct method to achieve biofuels implementation. This approach generally preserves Government revenues based on motor fuel taxes, but consumers may pay higher pump prices to cover any differential cost of biofuels.

These and other possible approaches provide a variety of ways for Governments to help implement use of biofuels. The selection of such policies and regulations can be customised to meet the needs of individual Governments, but the policies remain an essential part of biofuels implementation.

Ethanol distillation towers at the Pekin Energy Company, Illinois, USA. (Courtesy DOE/NREL and W. Gretz)

Conclusion

Biofuels are an increasingly important part of the motor fuel mix in many countries, with a total of about 30 billion litres used annually. These fuels are successfully used in a variety of vehicles and across a range of climates and conditions. Policies and regulations have been essential in the implementation of use of biofuels and will continue to be important in the future. These policies allow the Governments that adopt them to achieve benefits in the areas of environment, energy security, and economic development.

For further information, readers should visit Task 39 at www.forestry.ubc.ca/task39 or the IEA Bioenergy website at www.ieabioenergy.com .

Short-rotation forest crops are a potential source of lignocellulosic feedstocks, 6-year-old hybrid Eucalyptus spp. *(Courtesy International Paper, Brazil)*

Key Contacts in Task 39

From January 2004, Canada is the Operating Agent for the Task with Jack Saddler the Task Leader. The management structure of the Task in each triennium is shown below.

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2. Sub-Task Leader *Implementation issues*	Don Stevens	Eric van den Heuvel
3. Sub-Task Leader *Specialized biodiesel topics*	Manfred Wörgetter	Manfred Wörgetter
4. Newsletter Editor/Webmaster	David Gregg	David Gregg

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Ireland	Pearse Buckley	Sustainable Energy Ireland
The Netherlands	Eric van den Heuvel	NOVEM
Sweden	Ann Segerborg-Fick	Swedish Energy Administration
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IEA Bioenergy

IEA Bioenergy Task 39

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