Emerging Technologies for Second Generation of BIOFUELS

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Abstract

The global market for biofuels is expected to grow significantly in the coming decades. Most analysts are predicting particularly strong growth fostered by second generation biofuels. In February 2007, EU energy ministers agreed to increase the share of biofuels used in road transport to 10% by 2020. The strongest players at the fuel market are focused on crucial emerging second generation biofuels – those produced from non-food feedstocks such as residues from agriculture, from forestry or from waste. By using non-food feedstocks, such as woodchips and straw, second generation biofuels do not compete with food crops and they offer an efficient way to manage agricultural waste. They also offer greater CO_2 reduction benefits. It is expected that WTW CO_2 reduction can be reduced by 90 % when using biofuels at 100 % concentration. And – if produced on a commercial scale, biofuels have the potential to reach price parity with conventional gasoline and diesel. Significant commercial quantities of competitive biofuels are, however, still not expected to become available for the next 5 to 10 years.

Part I Biofuels for Otto engines

CELLULOSIC ETHANOL

Ethanol, today, is produced mostly from sugars or starches, obtained from fruits and grains. In contrast, cellulosic ethanol (also called lignocellulosic ethanol, or CeEtOH) is a type of biofuel produced from lignocellulose, a structural material that comprises much of the mass of plants, the main component of wood and straw. Since cellulose cannot be digested by humans, the production of cellulose does not compete with the production of food. The price per ton of the raw material is thus much cheaper than grains or fruits. Moreover, since cellulose is the main components of plants, the whole plant can be harvested. This results in much better yields per acre – up to 10 tons, instead of 4 or 5 tons for the best crops of grain.

Lignocellulose is composed mainly of cellulose, hemicellulose and lignin. Corn stover, switch grass, miscanthus and woodchip are some of the more popular cellulosic materials for ethanol production. Cellulosic ethanol is chemically identical to ethanol from other sources, such as corn starch or sugar, but has the advantage that the lignocellulose raw material is highly abundant and diverse. However, it differs in that it requires a greater amount of processing to make the sugar monomers available to the microorganisms that are typically used to produce ethanol by fermentation [1].

Switchgrass is the major biomass material being studied today, due to its high levels of cellulose. Cellulose, however, is contained in nearly every natural, free-growing plant, tree, and bush, in meadows, forests, and fields all over the world without agricultural effort or cost needed to make it grow. Whether distilled from agricultural crops such as corn, wheat, barley or created from cellulose, ethanol is ethyl alcohol. It is identical in chemical composition regardless of the source thus calling it cellulosic ethanol is initially misleading because it (cellulosic ethanol) is no different physically from corn ethanol or wheat ethanol. In essence, the term is used to describe the process for producing the alcohol rather than specifying a type of ethanol.

PRODUCTION METHODS

There are two broad ways of producing alcohol from cellulose:

- Hydrolysis breaks down the cellulose chains into sugar molecules that are then fermented and distilled
- Gasification transforms the lignocellulosic raw material into gaseous carbon monoxide and hydrogen that is then fed to a special kind of fermenter or to a catalyst bed (e.g. the Fischer-Tropsch process)

Hydrolysis processes

There are four or five stages in this process:

- A "pre-treatment" phase, to make the raw material such as wood or straw amenable to hydrolysis;
- Hydrolysis, to break down the molecules of cellulose into sugars;
- Separation of the sugar solution from the residual materials, notably lignin;
- Yeast fermentation of the sugar solution;
- Distillation to produce 99.5% pure alcohol.

Alternatively, instead of producing and recovering the enzymes to do the hydrolysis and fermentation separately, it is possible to use bacteria that does both. The cellulose molecules are composed of long chains of glucose molecules. In the hydrolysis process, these chains are broken down to "free" the sugar, before it is fermented for alcohol production. There are two major hydrolysis processes: a chemical reaction using acids, or an enzymatic reaction.

Chemical hydrolysis

In the traditional methods developed in the 19th century and at the beginning of the 20th century, hydrolysis is performed by attacking the cellulose with an acid. Diluted acid may be used under high heat and high pressure, or more concentrated acid can be used at lower temperatures and atmospheric pressure. A decrystalized cellulosic mixture of acid and sugars reacts in the presence of water to complete individual sugar molecules (hydrolysis). The product from this hydrolysis is then neutralized and yeast fermentation is used to produce ethanol. A significant obstacle to the diluted acid process is that the hydrolysis is so harsh that toxic degradation products are produced which is a hurdle for fermentation.

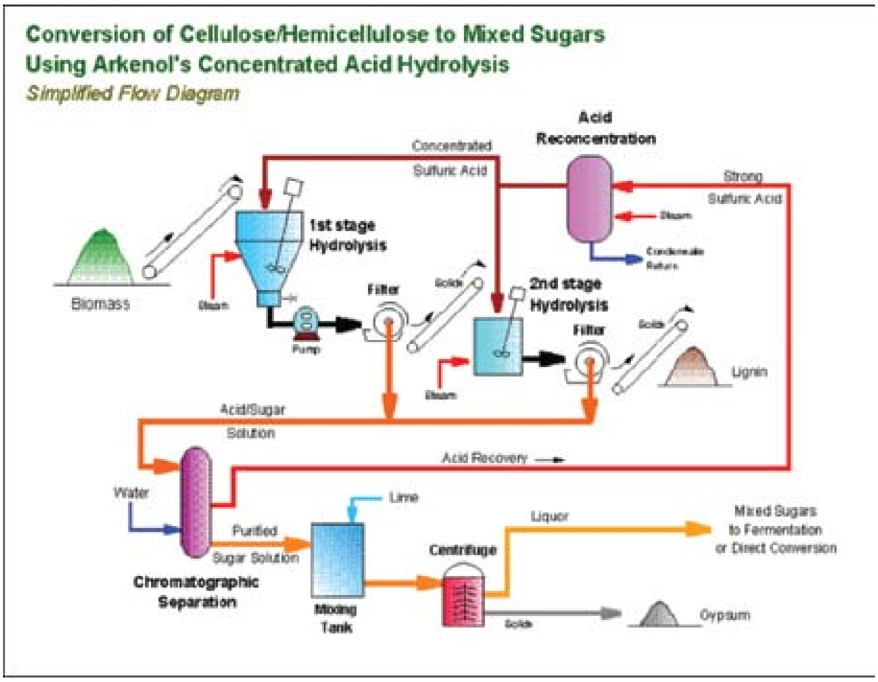

Figure 1. Cellulosic ethanol production via chemical (acid) hydrolysis

Concentrated acid must be separated from the sugar stream for recycle (simulated moving bed (SMB) chromatographic separation for example) to be commercially attractive.

Enzymatic Hydrolysis
Cellulose chains can be broken into glucose molecules by cellulase enzymes. This reaction occurs at body temperature in the stomach of ruminants such as cows and sheep, where the enzymes are produced by bacteria—there are actually at least three enzymes, used at various stages of this conversion. If the enzymatic hydrolysis process takes place with previously isolated enzymes, a steady supply of the cellulase enzymes is needed.

Neither process generates toxic emissions when it produces ethanol. According to US Department of Energy studies conducted by the Argonne Laboratories of the University of Chicago, one of the benefits of cellulosic ethanol is that it reduces greenhouse gas emissions (GHG) by 85% over reformulated gasoline. By contrast, starch ethanol (e.g., from corn), which uses most of the time natural gas to provide energy for the process, reduces GHG emissions by 18% to 29% over gasoline. Sugar ethanol, on the other hand, from sugarcane, reduces greenhouse gas emissions by as much as cellulosic ethanol because it uses sugarcane bagasse to provide the energy for the process and the excess to make electricity for the grid. Cellulosic ethanol production currently exists at "pilot" and "commercial demonstration" scale.

IOGEN PROCESS

In April 2004, Iogen Corporation, a Canadian biotechnology firm, became the first business to commercially sell cellulosic ethanol, though in very small quantities. The primary consumer thus far has been the Canadian government, which, along with the United States government (particularly the Department of Energy's National Renewable Energy Laboratory), has invested millions of dollars into assisting the commercialization of cellulosic ethanol. Iogen Corporation is promoting an enzymatic hydrolysis process that uses "specially engineered enzymes". The raw material (wood or straw) has to be pre-treated to make it amenable to hydrolysis [2].

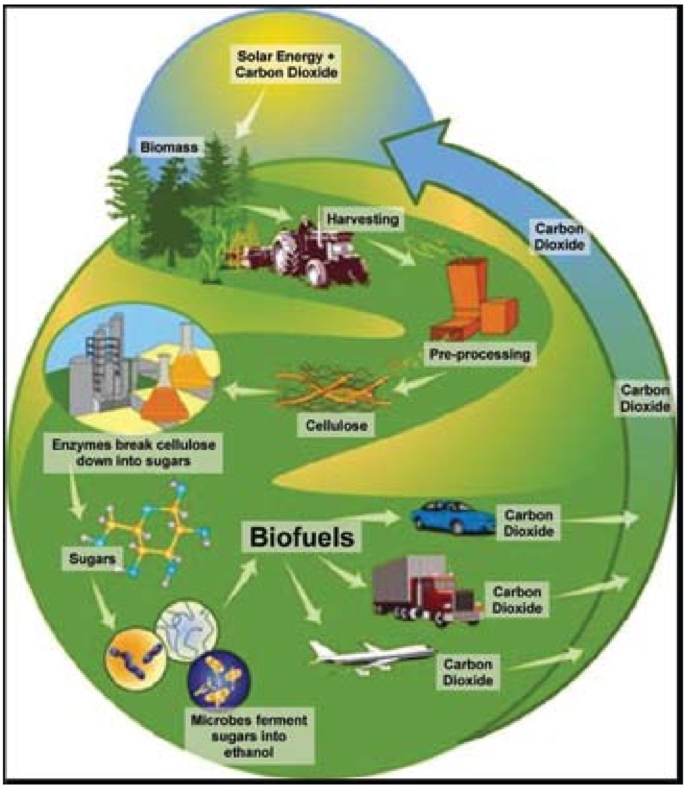

Figure 2. Second generation of biofuels production via enzymatic hydrolysis

Process Overview

Iogen technology makes it economically feasible to convert biomass into cellulose ethanol using a combination of thermal, chemical and biochemical techniques. The yield of cellulose ethanol is more than 340 litres per tonne of fibre. The lignin in the plant fibre is used to drive the process by generating steam and electricity, thus eliminating the need for fossil CO_2 sources such as coal or natural gas.

Pre-treatment
Iogen developed an efficient pretreatment method to increase the surface area and "accessibility" of the plant fibre to enzymes. It can be achieved through a modified steam explosion process. This improves ethanol yields, increases pretreatment efficiency, and reduces overall cost.

Enzyme Production
Iogen has a new, highly potent and efficient cellulase enzyme systems tailored to the specific pretreated feedstock. Iogen already has a worldwide business making enzymes for the pulp and paper, textiles and animal feed industries.

Enzymatic Hydrolysis
Iogen developed reactor systems that feature high productivity and high conversion of cellulose to glucose. This is accomplished through separate hydrolysis and fermentation using a multi-stage hydrolysis process.

Ethanol Fermentation
Iogen uses advanced microorganisms and fermentation systems that convert both C6 and C5 sugars into ethanol. The "beer" produced by fermentation is then distilled using conventional technology to produce cellulose ethanol for fuel grade applications.

Process Integration
Large-scale process designs include energy efficient heat integration, water recycling, and co-product production that make the overall process efficient and economical. Iogen has successfully validated these improvements within its demonstration scale cellulose ethanol facility.

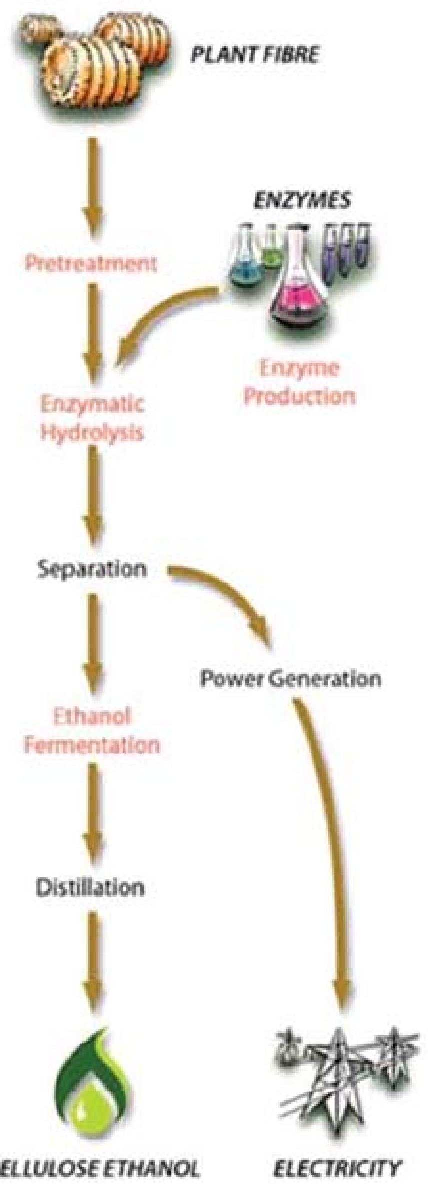

Figure 3. Iogen processing scheme

ABENGOA BIOENERGY PROCESS

Another company which appears to be nearing commercialization of cellulosic ethanol is Spain's Abengoa Bioenergy. Abengoa Bioenergy owns proprietary process technology to produce ethanol from cellulosic and lignocellulosic biomass. The core strategic activity of the company is to demonstrate at a commercial scale second generation biofuels. Abengoa Bioenergy have been consistently supported and awarded with funding from the European Union and the US Department of Energy (DOE) to demonstrate enzymatic hydrolysis technology. In March 2007, Abengoa Bioenergy were selected by the DOE to demonstrate proprietary enzymatic process technology for the production of ethanol and other renewable forms of energy through conversion of cellulosic and lignocellulosic materials at a commercial scale. This plant is under design and construction at this stage in Kansas, US. Abengoa Bioenergy is investing 500 million US dollars in the next 5 years in this technology. Abengoa Bioenergy has specific plans for biomass deployment through all existing assets worldwide, including this facility in Rotterdam [3].

Utilizing the process and pre-treatement technology from SunOpta Inc., Abengoa is building a 5 million gallon cellulosic ethanol facility in Spain and have recently entered into a strategic research and development agreement with Dyadic International, Inc. to create new and better enzyme mixtures which may be used to improve both the efficiencies and cost structure of producing cellulosic ethanol [4].

JOINT VENTURE COMPANY OF SUNOPTA INC. WITH GREENFIELD ETHANOL

In 2006, SunOpta Inc. announced a Joint Venture with GreenField Ethanol, Canada's largest ethanol producer. The joint venture will build a series of large-scale plants that will make ethanol from wood chips, with SunOpta and GreenField each taking 50% ownership. The first of these plants will be 10 million gallons per year, which appears to be the first true "commercial scale" cellulosic ethanol plant in the world. The SunOpta/ GreenField cellulosic ethanol plant is intended to demonstrate that large-scale cellulosic ethanol is commercially viable immediately. SunOpta Inc. markets a patented technology known as "Steam Explosion" to pre-treat cellulosic biomass, overcoming its "recalcitance" to make cellulose and hemicellulose accessible to enzymes for conversion into fermenatable sugars. SunOpta designs and engineers cellulosic ethanol biorefineries and its process technologies and equipment are in use in the first 3 commercial demonstration scale plants in the world [5].

OTHER COMPANIES' ACTIVITIES

A bio-plant in China engineered by SunOpta Inc. and owned and operated by China Resources Alcohol Corporation is currently producing cellulosic ethanol from corn stover (stalks and leaves) on a continuous, 24-hour per day basis [6].

Genencor and Novozymes are two other companies that have received United States government Department of Energy funding for research into reducing the cost of cellulase, a key enzyme in the production of cellulosic ethanol by enzymatic hydrolysis [7].

Other enzyme companies, such as Dyadic International, Inc. are developing genetically engineered fungi which would produce large volumes of cellulase, xylanase and hemicellulase enzymes which can be utilized to convert agricultural residues such as corn stover, distiller grains, wheat straw and sugar cane bagasse and energy crops such as switch grass into fermentable sugars which may be used to produce cellulosic ethanol.

Gasification process

Gasification process does not rely on chemical decomposition of the cellulose chain. Instead of breaking the cellulose into sugar molecules, the carbon in the raw material is converted into synthesis gas, using what amounts to partial combustion. The carbon monoxide, carbon dioxide and hydrogen may then be fed into a special kind of fermenter. Instead of yeast, which operates on sugar, this process uses a microorganism named "Clostridium ljungdahlii" [8]. This microorganism will ingest (eat) carbon monoxide, carbon dioxide and hydrogen and produce ethanol and water.

The process can thus be broken into three steps: [9].

Gasification – Complex carbon based molecules are broken apart to access the carbon as carbon monoxide, carbon dioxide and hydrogen are produced

Fermentation – Convert the carbon monoxide, carbon dioxide and hydrogen into ethanol using the Clostridium ljungdahlii organism

Distillation – Ethanol is separated from water

Figure 4. Fluidized Bed Gasifier in Güssing (Burgenland, Austria)

A recent study has found another Clostridium bacterium that seems to be twice as efficient in making ethanol from carbon monoxide as the one mentioned above [10].

The raw material is plentiful. Cellulose is present in every plant: straw, grass, wood. Most of these "bio-mass" products are currently discarded.

Transforming them into ethanol using efficient and cost effective hemi (cellulase) enzymes or other processes might provide as much as 30% of the current fuel consumption in the US—and probably similar figures in other oil-importing regions like China or Europe. Moreover, even land marginal for agriculture could be planted with cellulose producing crops like switch grass, resulting in enough production to substitute for all the current oil imports [1].

COST OF PRODUCING CELLULOSIC ETHANOL

In June 2006, a U.S. Senate hearing was told that the current cost of producing cellulosic ethanol is US $2.25 per US gallon (US $0.59/litre). This is primarily due to the current poor conversion efficiency. At that price it would cost about $120 to substitute a barrel of oil (42 gallons), taking into account the lower energy content of ethanol. The same Senate hearing was told that the research target was to reduce the cost of production to US $1.07 per US gallon (US $0.28/litre) by 2012 [1].

BIOBUTANOL – A NOVEL BIOFUEL

Biobutanol (C4H10O) is a four-carbon alcohol that can be used as an automotive fuel either compatibly blended with gasoline in any ratio in unmodified engines or in some cases be used directly as fuel without mixing. The next graph compare butanol´s energy density with other biofuels and petroleum based fuels [11-14].

With a Reid Vapor Pressure (RVP) of 2.3 kPa, compared to gasoline at 31.0 and ethanol at 13.8, butanol is safer to handle than either. Also, with its high Flash Point (FP) of 37°C, butanol is a very safe fuel to use in high temperature environments. In a gasoline engine, it uses an air/fuel ratio that is close to that of gasoline. Butanol also is less corrosive as ethanol.

Butanol also has a higher cetane number (25), than ethanol (9), relative to required cetane number of over 40 for diesel fuels. This allows butanol potentially to be blended with petrodiesel (where it also reduces the gel temperature point and the viscosity) to produce an improved biodiesel with some positive environmental effects. Consequently, butanol is a very versatile fuel and fuel extender for both gasoline and diesel engines.

There are several possibilities of industrial production of bio-butanol:

- ABE fermentation
- New two-step process developed by EEI, USA
- Sangi process
- C.Beijerinckii – Based Fermentation
- BP – DuPont – British Sugar joint process

DIMETHYLFURAN (DMF) AND ITS POTENTIAL

In 2007 some research centers in the USA started their R&D activities with dimethylfuran (DMF). DMF has a number of attractions as a biofuel. It has an energy density 40% greater than ethanol, making it comparable to gasoline (petrol). It is also chemically stable and, being insoluble in water, does not absorb moisture from the atmosphere. Evaporating dimethylfuran during the production process also requires around one third less energy than the evaporation of ethanol, although it has a boiling point some 14 °C higher, at 92 °C, compared to 78 °C

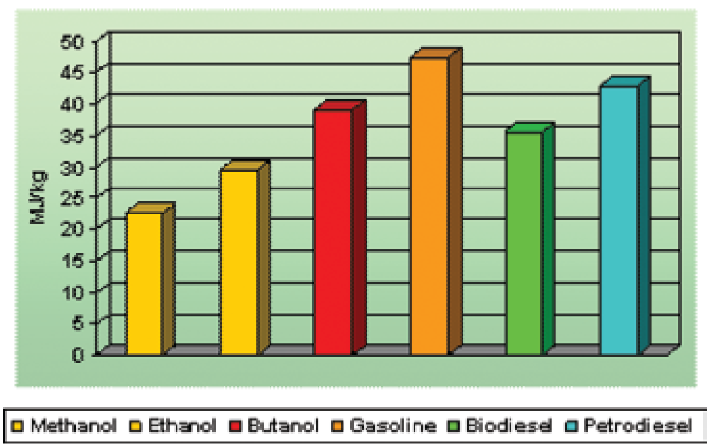

Figure 5. Comparison of Biofuels and Fossil fuels energy content (HHV)

for ethanol. The ability to efficiently and rapidly produce dimethylfuran from fructose, found in fruit and some root vegetables, or from glucose, which can be derived from starch and cellulose – all widely available in nature – is likely to add to the attraction of dimethylfuran once safety issues have been examined [15].

Part II Biofuels for diesel engine

NEXBTL TECHNOLOGY BY NESTE OIL

NExBTL diesel is produced in a patented vegetable oil refining process. Chemically, it entails direct catalytic hydrogenation of plant oil, which is triglyceride, into the corresponding alkane. The glycerol chain of the triglyceride is hydrogenated to the corresponding C3 alkane, propane – there is no glycerol sidestream. This process removes oxygen from the oil; the diesel is not an oxygenate like traditional transesteried biodiesel. Unlike the yellow transesterified biodiesel, the product is a clear and colorless paraffin, with a good cetane number (85 to 99) and better properties than even petrodiesel. As it is chemically identical to ideal conventional diesel, it requires no modification or special precautions for the engine [16-17].

As NExBTL is a hydrocarbon, traditional biodiesel esters components may be added to blends

Simpilfied NExBTL Process Flow Scheme

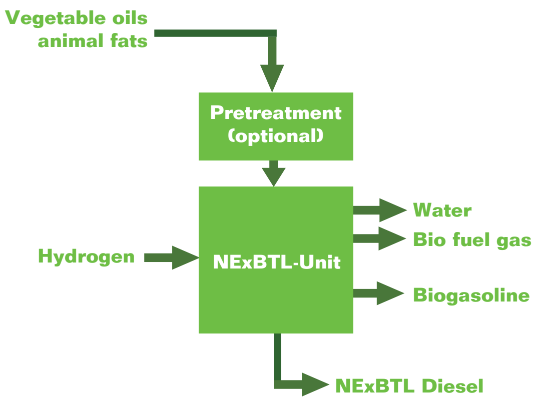

Figure 6. NExBTL process

containing NExBTL to increase the overall renewability of diesel fuel.

When compared with emissions from the "clean" European sulphur-free EN-590 diesel, NExBTL Renewable Synthetic Diesel shows:

- Life cycle greenhouse gas emissions are reduced by over 60%
- NOx emissions are reduced by over 15%
- Particulate matter emissions are reduced by over 25%
- Hydrocarbon emissions are reduced by over 20%
- Carbon monoxide emissions are reduced by over 5%

Neste Oil's NExBTL product is referred to as a "Renewable Synthetic Diesel" to distinguish it from the traditional "biodiesel esters", which are commercially available today. In fact, the feedstock for both fossil-diesel substitutes is the same – natural organic acids contained in animal fat and vegetable oil. The difference is in the processing and chemical nature of the end products. In the NExBTL Renewable Syntehtic Diesel process technology, they fatty acid feedstock is "hydrotreated"; that is, it is reacted with hydrogen. The product is a hydrocarbon product, free of oxygen and aromatic compounds. This "hand-crafted" product is what gives NExBTL its superior fuel and emission properties. Side products include propane and gasoline – premium fuels which have also been produced from the renewable, biological feedstock. [18].

Simplified NExBTL Process Chemistry

In 2005, Neste Oil started to build a NExBTL Renewable Synthetic Diesel production plant at its (200,000 bbl/day) Porvoo oil refinery. Costing some €100 million, the plant is capable of producing 170,000 metric tonnes per year (60 million USG/year). Enough to fuel 100,000 vehicles for a year. NExBTL is made from renewable biomass sources – namely fatty acids from vegetable oils and animal fats. With only 2-3% (by mass) addition of hydrogen, NExBTL is 97-98% renewable. Neste Oil also plans to invest approximately €550 million in building a plant in Singapore to produce NExBTL Renewable Diesel. NExBTL technology is the first commercial new-generation renewable diesel production process, and can use any vegetable oil or animal fat as its input. [19].

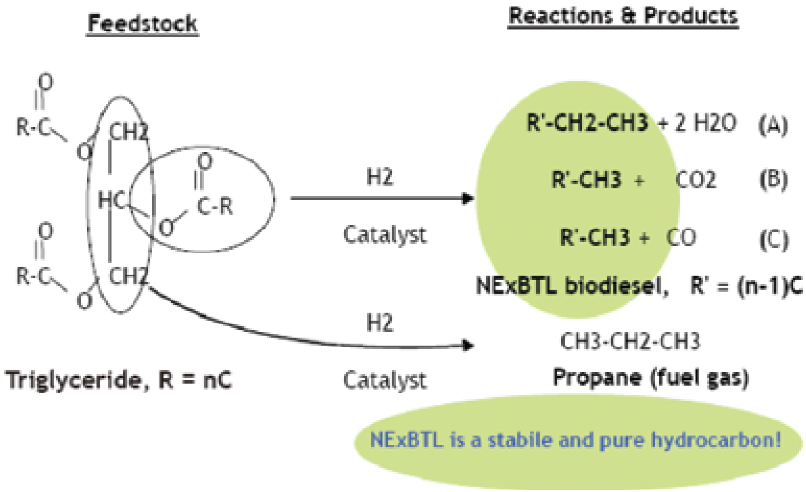

Figure 7. The Neste Oil's NExBTL Renewable Synthetic Diesel Technology to produce a second generation renewable diesel.

CHOREN INDUSTRIES

The Key Element in the Technology: the Carbo-V® Process

The Carbo-V® Process is a three-stage gasification process involving the following sub-processes [20]:

- low temperature gasification
- high temperature gasification
- endothermic entrained bed gasification

During the first stage of the process, the biomass (with a water content of 15 – 20 %) is continually carbonized through partial oxidation (low temperature pyrolysis) with air or oxygen at temperatures between 400 and 500 °C, i.e. it is broken down into a gas containing tar (volatile parts) and solid carbon (char).

During the second stage of the process, the gas containing tar is post-oxidized hypo-stoichiometrically using air and/or oxygen in a combustion chamber operating above the melting point of the fuel's ash to turn it into a hot gasification medium.

During the third stage of the process, the char is ground down into pulverized fuel and is blown into the hot gasification medium. The pulverized fuel and the gasification medium react endothermically in the gasification reactor and are converted into a raw synthesis gas. Once this has been treated in the appropriate manner, it can be used as a combustible gas for generating electricity, steam and heat or as a synthesis gas for producing SunDiesel [21].

Figure 8.

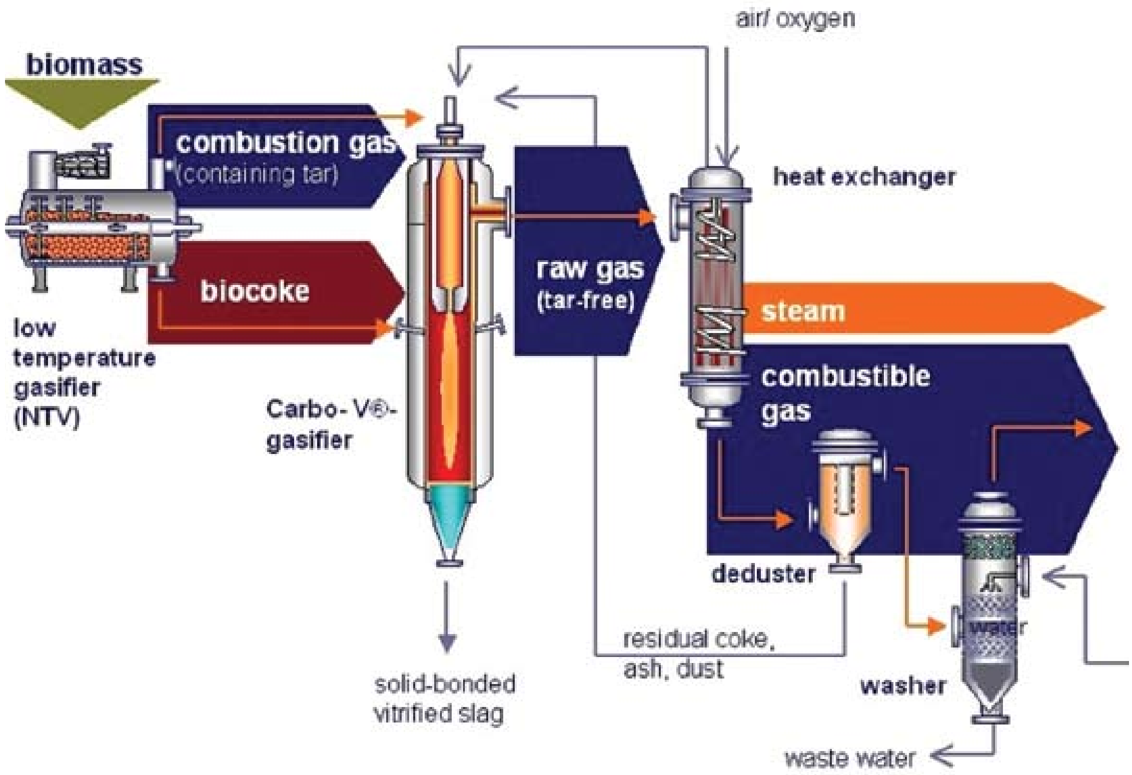

Figure 9. Carbo-V® Process for Producing of SunDiesel

ADVANTAGES OF THE CARBO-V® PROCESS

Because of its unique multi-phase approach, the Carbo-V® Process has the following advantages:

- A wide range of feed materials can be used
- A high-quality gas with tar content below minimum detection limits and a very low concentration of methane (< 0.5 % at 5 bar)
- Complete exploitation of the feed material used
- Numerous fields of application (electricity, heat, cold, methanol, synthetic automotive fuels, waxes etc.)
- Conversion efficiency for gasification (cold gas efficiency) > 80 %
- Electrical energy efficiency levels of up to 35 %
- Low emission levels
- The ash is converted into a solid bonded slag granulate suitable for building purposes

ADVANTAGES OF SUNDIESEL®

High-quality synthetic automotive fuels (Gas-to Liquids or GtL) are obtained from a synthesis gas. When this synthesis gas is obtained from biomass, we refer to the fuel as BtL (Biomass-to-Liquid) or SunFuel. The make-up and especially the purity of the synthesis gas are able to meet the highest quality standards. Fischer-Tropsch (FT) synthesis is used to convert the synthesis gas into an automotive fuel. During this process, the reactive parts of the synthesis gas (CO and H_2) interact with a catalyst to form hydrocarbons. FT synthesis was developed in Germany in the 1920s and it is particularly used in South Africa on a large scale to produce automotive fuels from coal. In order to maximize the output of diesel (SunDiesel®), the waxes formed during the FT synthesis process are further processed using hydrocracking techniques, a standard proRenewable, synthetic automotive fuels will guarantee future mobility.

SUNDIESEL®

- has a high cetane number and therefore much better ignition performance than conventional diesel fuel,
- has no aromatics or sulphur content and significantly reduces pollutants from exhaust emissions,
- can be used without any adjustment to existing infrastructure or engine systems,
- is largely CO_2-neutral [22].

THE CENTIA™ TECHNOLOGY [23]

New biofuels technology developed by North Carolina State University engineers has the potential to turn virtually any fat source – vegetable oils, oils from animal fat and even oils from algae – into fuel to power jet airplanes. The technology – called Centia™, which is derived from "crudus potentia," or "green power" in Latin – is "100 percent green," as no petroleum-derived products are added to the process. Centia™ can also be used to make additives for cold-weather biodiesel fuels and holds the potential to fuel automobiles that currently run on gasoline. NC State received provisional patents to use the process to convert fats into jet fuel or additives for cold-weather biodiesel fuels. The technology has been licensed by Diversified Energy Corp., a privately held Arizona company specializing in the development of advanced alternative and renewable energy technologies and projects. The fuel created by the new process also burns cleaner, so it's better for the environment.

E-DIESEL – OXYGENATED DIESEL [24]

E-Diesel is well positioned to play a role in the evolution of cleaner diesel systems. In order to make use of existing infrastructure for liquid fuels Pure Energy has combined diesel's positive attributes with cleaner burning renewable ethanol to run in unmodified diesel engines. The fuel is a liquid blend of low-sulphur No.2 diesel fuel, 15% ethanol and a small amount of a proprietary additive designed to stabilize the fuel and improve performance. The presence of ethanol improves the emissions profile substantially when compared to regular neat diesel.
Oxi-Diesel

Oxi-Diesel is a tailored mixture of linear oligomers (poly-oxy-methylene structure) produced via proprietary process from Natural Gas/ ethanol. Recently Snamprogetti and ENI have concentrated the attention to a new oxygenate that appears to be very promising as concerns characteristics, effects and cost: [25]. Oxi-Diesel includes the Ethanol derivatives obtainable from bio-ethanol. Oxi-Diesel produced from EtOH has characteristics better than biodiesel or EtOH/diesel blends:

- very good cold properties (CFPP ca. -30 / -35°C),
- higher flash point,
- excellent properties/more distributed distillation curve.

BIODIESEL MADE OF JATROPHA CURCAS

Jatropha curcas named also as a biodiesel "miracle tree" is becoming a poster child among some proponents of renewable energy and appropriate technology, especially as an oil-bearing, "drought resistant" tree for marginal lands for small farmers. Unrefined Jatropha oil can only be used in certain types of diesel engines, such as Lister-type engines. The trans-esterification of jatropha is a normal chemical process. During the process, methanol is used. Jatropha biodiesel emits about two-thirds less in unburned hydrocarbons and almost half as much carbon monoxide and particulate matter as conventional diesel. It contains no sulphur and so emits none. From the point of view of global warming, it is neutral in its net addition to greenhouse gasses because the carbon dioxide released in combustion was sequestered when growing the crop (this claim is questionable, since CO_2 released would soon equate the CO_2 sequestered by the plants after a relative short time [26].

The UK-based company, D1 Oils plc [27], has put itself at the forefront of efforts to replace the edible oils for biodiesel production by Jatropha oil. Jatropha grows quickly, is hardy, establishes itself easily even in arid land, and is drought-tolerant, requiring only 300mm of annual rainfall. It grows especially well in South and West Africa, and South East Asia. Jatropha can even be grown on semi-arid land using waste water, making it a useful tool in the prevention of desertification. Each Jatropha tree can produce an average of 3.5 kilos of beans each year depending on irrigation levels. According to D1's estimates, if 2,200 Jatropha trees are planted per hectare, each hectare could yield up to 7 tonnes of beans per annum.

Figure 10. Jatropha plantation: Jatropha grows also in vast areas where deserts approach, where no other plant can grow

Jatropha beans can produce oil yields of up to 40% and D1 expects each hectare to deliver about 3,000 litres of biodiesel. In the established process for refining biodiesel, the vegetable oil is esterified, reacted with methanol and sodium hydroxide, to produce diesel and glycerine. D1 has adapted this method to create its own proprietary process producing biodiesel from Jatropha and various other feedstocks. The Jatropha biodiesel meets the European EN14214 standard for use as a pure or blended automotive fuel for diesel engines. D1 has already secured plantation agreements in Burkina

Figure 11. Jatropha seeds

Faso, Ghana and the Philippines totalling 37,000 hectares, and has the option to extend planting to approximately 990,000 further hectares of land in Burkina Faso and 5 million hectares of land in India. The company recently raised L13 million in a London Stock Exchange flotation to fund these initiatives.

BIODIESEL FROM ALGAE – ALGACULTURE

From 1978 to 1996, the U.S. National Renewable Energy Laboratory experimented with using algae as a biodiesel source in the "Aquatic Species Program". Michael Briggs, at the UNH Biodiesel Group, offers in his article estimates for the realistic replacement of all vehicular fuel with biodiesel by utilizing algae that have a natural oil content greater than 50%, which Briggs suggests can be grown on algae ponds at wastewater treatment plants. This oil – rich algae can then be extracted from the system and processed into biodiesel, with the dried remainder further reprocessed to create ethanol. The production of algae to harvest oil for biodiesel has not yet been undertaken on a commercial scale, but feasibility studies have been conducted to arrive at the above yield estimate. In addition to its projected high yield, alga culture – unlike crop-based biofuels - does not entail a decrease in food production, since it requires neither farmland nor fresh water. Some companies are pursuing algae bio-reactors for various purposes, including biodiesel production. In 2006 the Aquaflow Bionomic Corporation in Marlborough, New Zealand announced that it had produced its first sample of bio-diesel fuel made from algae found in sewage ponds. Unlike previous attempts, the algae were naturally grown in pond discharge from the Marlborough District Council's sewage treatment works. The Department of Environmental Science at Ateneo de Manila University in the Philippines, is working on producing biofuel from algae, using a local species of algae.

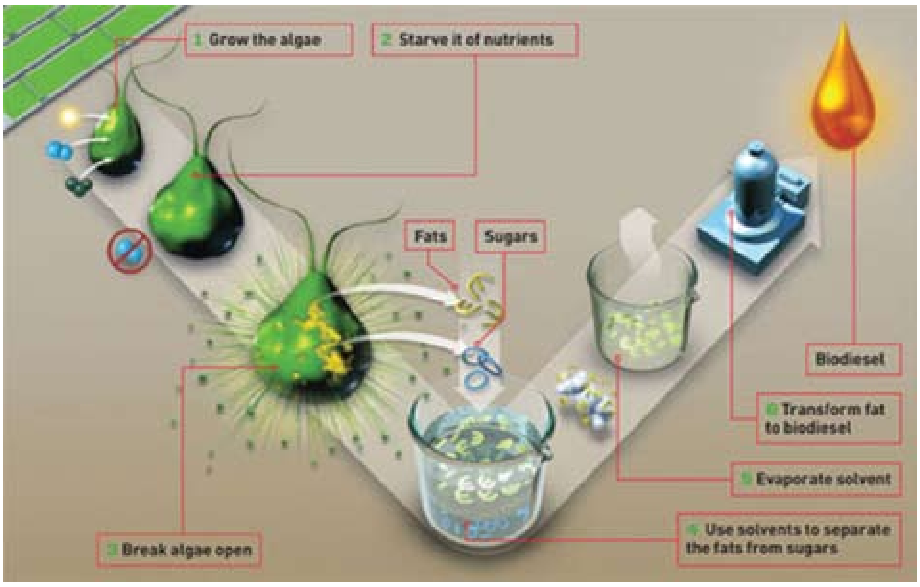

Figure 12. Schematic utilization of Algae for biodiesel production

Figure 13. Vision of a biorefinery with algae cultivation for biodiesel production

Currently most research into efficient algal-oil production is being done in the private sector, but if predictions from small scale production experiments bear out then using algae to produce biodiesel, bioethanol and biobutanol may be the only viable method by which to produce enough automotive fuel to displace current world gasoline usage.

Microalgae have much faster growth-rates than terrestrial crops. The oil yield per unit area of algae is estimated to be 5,000 to 20,000 gallons per acre, per year (4.6 to 18.4 l/m^2 per year); this is 7 to 30 times greater than the next best crop, Chinese tallow (699 gallons). The difficulties in efficient biodiesel production from algae lie in finding an algal strain with a high lipid content and fast growth rate that isn't too difficult to harvest, and a cost-effective cultivation system (ie., type of photobioreactor) that is best suited to that strain. Additionally, a cost-effective way to extract the oil must be found.

Research into algae for the mass-production of oil is mainly focused on microalgae; organisms capable of photosynthesis that are less than 2 mm in diameter, including the diatoms and cyanobacteria; as opposed to macroalgae, e.g. seaweed. This preference towards microalgae is due largely to its less complex structure, fast growth rate, and high oil content (for some species). Some commercial interests into large scale algal-cultivation systems are looking to tie in to existing infrastructures, such as coal power plants or sewage treatment facilities. This approach not only provides the raw materials for the system, such as CO_2 and nutrients; but it changes those wastes into resources [28].

Royal Dutch Shell Plc. and HR Biopetroleum formed a joint venture company, called Cellana and announced the construction of a pilot facility (Hawaii) to grow marine algae and produce vegetable oil for conversion into biofuel. Algae hold great promise because they grow very rapidly, are rich in vegetable oil and can be cultivated in ponds of seawater, minimising the use of fertile land and fresh water. The site is near existing commercial algae enterprises, primarily serving the pharmaceutical and nutrition industries. The facility will grow only non-modified, marine microalgae species in open-air ponds using proprietary technology. Algae strains used will be indigenous to Hawaii or approved by the Hawaii Department of Agriculture. Once the algae are harvested, the vegetable oil will be extracted. An

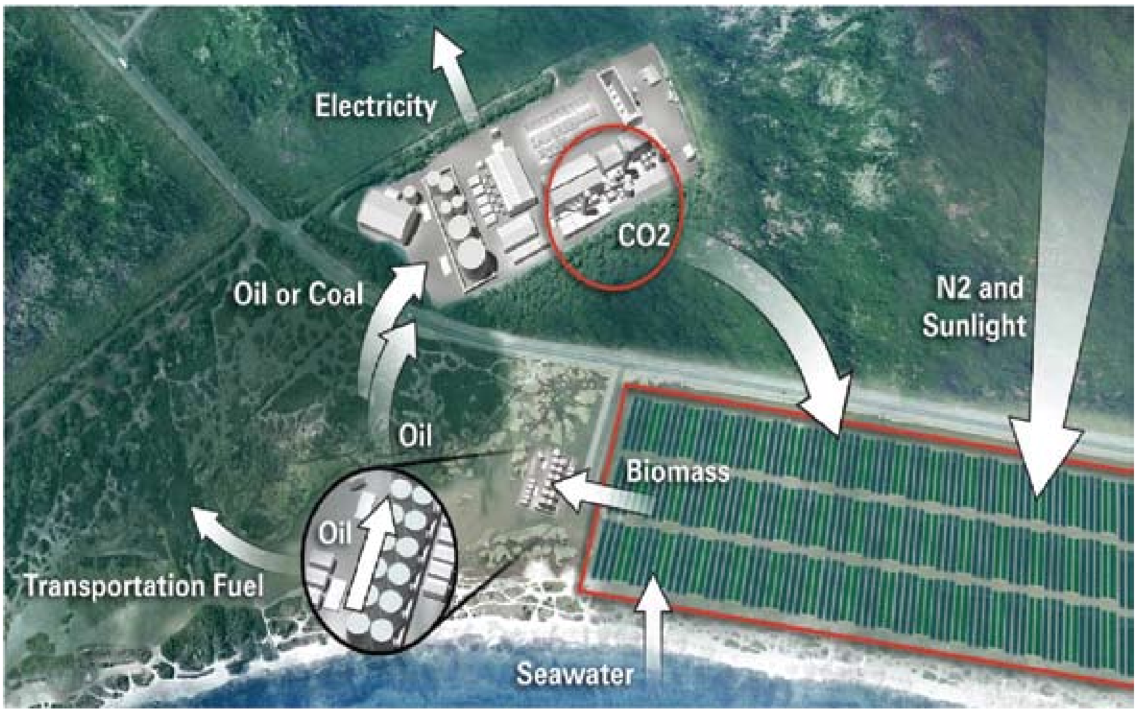

Figure 14. Vision of industrial cultivation and processing of algae for biodiesel

academic research programme will support the project, screening natural microalgae species to determine which ones produce the highest yields and the most vegetable oil. The programme will include scientists from the Universities of Hawaii, Southern Mississippi and Dalhousie, in Nova Scotia, Canada. An advantage of algae is their rapid growth. They can double their mass several times a day and produce at least 15 times more oil per hectare than alternatives such as rape, palm soya or jatropha. Moreover, facilities can be built on coastal land unsuitable for conventional agriculture. Over the long term, algae cultivation facilities also have the potential to absorb or 'capture' waste CO2 directly from industrial facilities such as power plants. The Cellana demonstration will use bottled CO2 to explore this potential. [29].

Summary

The utilization of biomass as well as algae for production of second generation of biofuels will need direct commitments between agriculture as the producer and industry as the processer of renewable feedstock. This practise will ensure the conditions of sustainable development while the processing of the domestic renewable sources and will provide self-sufficiency in feedstock supply, more effectively utilization of land reserves with lower land valuation. Algae itself offer a much higher productivity potential than crop-based biofuels.

The research of the second generation of biofuels also permits an application of the results of biological sciences at work – which is named as biologicalization of national economy. It will be supported the development of biotechnology and will boost the creation of bioeconomics. And the last but not least it will help to integrate scientific, research, technological, educational, economical, social and environment aspects of countries development. It would be ideal if the producers of motor fuels as well as automobile manufacturers were integrated into the process.

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