Volume 6 • Issue 3 • Special issue on biofuels

Energy Security Insights

CONTENTS

Editor
Anomitro Chatterjee

The Energy and Resources Institute

www.teriin.org

Global energy security: are biofuels an answer?

Factors such as oil price spikes, the need for increased energy security, concern over greenhouse gas (GHG) emissions, dwindling levels of petroleum making the extraction of fossil fuels more difficult, and the limitations on future availability of fossil fuels, amongst others are driving the move towards sources of energy that are renewable, clean and more cost effective. Biofuels provide an alternative to fossil fuels that meet these criteria and are consequently garnering increased public and scientific attention.

Biofuel, as the term suggests, is a type of fuel whose energy is derived from biological carbon fixation. These include fuels derived from biomass conversion, as well as solid biomass, liquid fuels and various biogases. Even fossil fuels find their origin in ancient carbon fixation since they are the fossilized product of photosynthesis that took place billions of years ago. However, they cannot be considered to be biofuels since the carbon they contain has been out of the carbon cycle for a very long time.

Bioethanol production from carbohydrates produced from sugar or starch crops has already been commercialized in many parts of the globe. In Brazil, sugarcane is largely grown for bioethanol production and large refineries producing corn-based ethanol have been set up in the US. However, bioethanol production has also been subjected to criticism and debate. In particular, the "food versus fuel" debate has gathered momentum due to the rising prices of food commodities.

Microalgae have emerged as a major potential candidate for biofuel generation. It is widely accepted that algae, known to have high lipid content (as much as 70% under laboratory conditions), has the capacity to fulfill a large share of fuel requirements, without competing for the fertile soil resources, which are key for food production for an ever increasing population. However, the complex, energy intensive downstream process of harvesting, drying and extraction of micro-algal biomass to produce bio-diesel is low on energy efficiency, particularly the energy used in drying the high water content (almost 99%) of algae.

In 2010, worldwide biofuel production reached 105 billion litres, a 17% increase from 2009. Biofuels—largely made up of ethanol and bio-diesel—amounted to 2.7% of the world's fuel consumption for road transport. United States and Brazil top the list of world's producers accounting for 90% of global production. According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050.

The production of renewable energy sources is becoming increasingly important as potential reserves are gradually dwindling and people are becoming more aware of the adverse environmental consequences of fossil fuel combustion. Fuels developed from biomass have the potential to reduce dependency on petroleum resources, while at the same time reducing Greenhouse Gas (GHG) emissions. During the past few years many research agreements have been signed all over the world on biofuel technology development and production. Scientists are looking for alternate approaches of converting biomass—be it algae or agricultural residue—directly into energy through anaerobic digestion; converting biomass into methane fuel. Cellulosic biomass derived from non-food sources such as trees and agricultural residues are also being utilized. Hydrothermal liquefaction of wet organic biomass is also receiving renewed interest. Important research and development both of processes and end-products is still needed to take this technology from laboratories to full scale commercial implementation, particularly to overcome the main hurdle of high investment costs.

Dr Vibha Dhawan
Executive Director, Advanced Biotechnology
The Energy and Resources Institute, New Delhi

Second generation biofuels: global challenges and the road ahead

Sumit Bali
The Energy and Resources Institute, New Delhi

Introduction

The ever-increasing demand for energy and rapidly depleting natural resources have been instrumental in driving the development of technology for large-scale deployment of alternative energy. According to the International Energy Agency (IEA), emerging economies like China and India will drive global energy demands even higher (IEA 2010), causing the trends in energy generation and usage to become unsustainable on the economic, environmental as well as the social fronts (IEA 2011). Renewable energy resources not only offer the promise of delivering sustainable energy, but also hope to address greenhouse gas (GHG) mitigation and other energy policy issues. A number of renewable energy resources based on solar, wind, tidal, geothermal, biomass, and so on, are being researched and developed for providing sustainable clean energy for present and future needs. Biofuels derived from biomass are expected to emerge as one of the major contributors to this pool of alternative energy, especially in the transportation sector. Consequently, the demand for biofuels is expected to increase across the globe over time as predicted by the IEA Biofuels Technology Roadmap (Figure 1) (IEA 2011).

Many countries across the globe are developing, or have the potential to develop the technologies related to production and use of biofuels. Currently, USA and Brazil are leading producers of biofuels and the potential use of biomass for biofuels production is expected to increase considerably across the globe, in the future (Bain 2010). Biofuels can be produced from a number of varied feedstocks by using a number of different technological approaches for biomass conversion and processing. Conventional technologies include established processes that are already producing biofuels on a commercial scale. The biofuels produced from such technologies are commonly referred to as first-generation biofuels and include ethanol from sugars and starch, bio-diesel from oil-crop as well as vegetable oil and biogas from anaerobic biomass digestion. Typical feedstock used in these processes include sugarcane, grains like corn and wheat, oil crops like rape (canola), soybean and palm and also animal fats, used cooking oils and organic waste matter. On the other hand, advanced biofuel technologies are conversion technologies which are still at an early stage of research and development (R&D)—some even at the pilot or demonstration phase—but are not yet being exploited commercially for the production of biofuels. The biofuels from such technologies are commonly referred to as second (or higher-generation) biofuels and they include biofuels based on lignocelluloses, such as biomass-to-liquids (BTL) fuels (e.g., Fischer–Tropsch gasoline/jet fuel/diesel, methanol, ethanol, higher alcohols, dimethyl ether (DME), and so on), bio-synthetic gas (bio-syngas), bio-hydrogen for fuel cells, as well as hydro treated vegetable oil (HVO), and algae-based biofuels. Policies in favour of both first generation as well as second generation biofuels development are being driven primarily by energy security concerns as well as the desire to sustain the agricultural sector and strengthen the economy (Eisentraut 2010). However, lately, there has been a lot of debate amongst the various stakeholders regarding large-scale production and use of first generation biofuels, particularly focused around

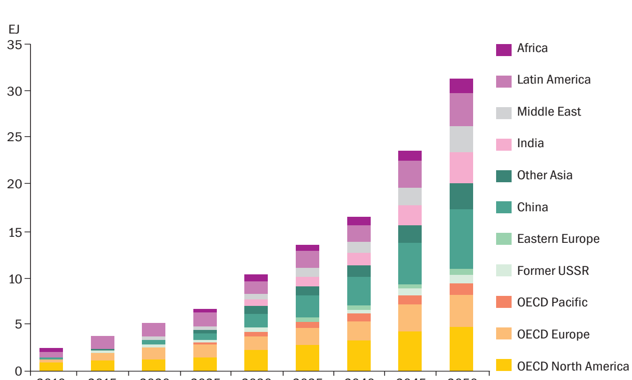


Figure 1 Biofuels demand across various regions for 2010–50
Source IEA 2011 Biofuels Technology Roadmap: biofuels for transport and Organization of Economic Co-operation and Development (OECD)

the land and food security issues and the GHG emissions associated with their use. Thus, effort is now being shifted and dedicated to development of second generation biofuels as they are expected to offer dramatically reduced life-cycle GHG emissions relative to first generation biofuels and also to fossil fuels, due to the higher energy yield per hectare, the possibility of using by-product plant waste for process energy and improvements on many other drawbacks being currently faced with first generation biofuels.

Transition from first-generation to second-generation biofuels

While most analyses indicate that first-generation biofuels do show some net benefits in terms of reduction in GHGs and energy balance, several drawbacks are still being associated with their production and use. These include contribution to increase in food prices due to competition with food crops, high production costs, and potential negative impacts on biodiversity caused by deforestation and competition with regard to water resources. Recently, it has also been perceived that these first-generation biofuels do not meet their claimed environmental benefits because the biomass feedstock used in many of these biofuels may not always be produced in a sustainable, eco-friendly manner and that these provide only limited GHG reduction benefits (apart from sugarcane ethanol). It is being debated (Aden 2009; Wang 2007) that GHG reduction associated with first-generation biofuels is only ~19%–28%, while that associated with the use of second (and higher) generation biofuels can be as high as ~86%. Consequently, more and more of the focus is now being shifted to development of second-generation biofuels, which can be produced from agricultural and crop residues as well as energy crops and organic waste. These fuels are expected to overcome the shortcomings associated with their first-generation counterparts and considerably reduce net GHG emissions, increase energy efficiency and reduce dependency on fossil fuels. However, second-generation biofuels are still relatively immature in terms of technological advancement although they are perceived to have immense potential. Some of the challenges presently being faced by second-generation biofuels in terms of their commercial development and deployment are discussed below.

Challenges associated with feed stocks

Ligno-cellulosic residues, such as forest residues and low cost crops, wood and the organic component of municipal solid waste are being explored for production of second-generation biofuels. Focus is also being diverted to short rotation forest crops as well as vegetative grasses like switch grass. The use of feedstocks grown on degraded and marginal land is also being explored to prevent the competition for land with food and forests. Dedicated and new varieties of energy crops are being researched using genetic modification and further improvement in existing crops is being explored by employing improved techniques, with the aim of increased productivity, better resistance and reduction in water as well as fertilizer needs. However, most of these technologies and approaches are in the developmental phase and need a lot of input in terms of investment and research to achieve the overall goal of reducing feedstock costs from production to delivery, a necessary step to ensure economic viability of any commercial biofuels project. Further, numerous state-of-the-art techno-economic analyses by the NREL for various second-generation biofuel technologies have estimated that at current state-of-the-art, biofuel plants need to operate at massive feedstock inputs of the order of several thousand tonnes per day to produce fuels that are cost competitive with fossil fuels. Thus, the treatment, transport, proper storage, and delivery of such large quantities of biomass incessantly to a biofuels production facility for sustainable output is still a big challenge.

Technological challenges

The synthesis of biofuels from ligno-cellulosic biomass is being explored via different processing pathways. The biochemical pathway uses enzymes and microbes for hydrolysis and conversion of biomass to biofuels (primarily ethanol), while the thermo chemical pathway involves thermal treatment via gasification/pyrolysis, followed by catalytic conversion of intermediates (syngas in case of gasification and bio-oil in case of pyrolysis), to a variety of fuels and chemicals or microbial treatment of syngas to alcohols. Dedicated R&D is being carried out across the globe for development of both these technologies. However, none has been demonstrated to produce biofuels at a commercial level, at a price comparable to the current price of fossil fuels. For the biochemical route, much is needed to be done in terms of improving feed stock characteristics, reducing pre-treatment costs, improving the efficacy of enzymes/microbes and lowering their production costs, and finally improving the overall integration of the process. The US Department of Energy (DOE/NREL), in collaboration with multiple partners in academia and industry, has focussed meticulously on enzyme biochemistry, cost, and specific activity by investigating in detail the biomass pre-treatment and enzymatic hydrolysis approach. They claim to have successfully achieved significant reductions in cost of enzymes for the process. However, considerable inputs are still required to improve the strain strength for it to be able to cater to varied feedstock and processes. Further, the separation and efficient use of the non-fermentable lignin component of biomass and efficient synergy of such process with the overall biochemical pathway still poses a big challenge. For the thermo chemical pathway, although there appear to be less technological hurdles since much of the technology is already proven, mostly with coal, concerns over availability of a large enough quantity of feedstock for an economical plant is a challenge. Also, considerable improvement is required in the gasification/pyrolysis of biomass reliably and economically and a large amount of capital as well as R&D is still required for integration of multiple conversion steps involved in the overall process (gasification/pyrolysis to fuel). Each of these steps in the overall pathway has to be skillfully perfected in itself before the fuels can be produced economically. In the present gasification to biofuels scenario, the high costs associated with syngas cleaning and conditioning by tar removal/reforming, adjustment of H_2:CO ratios for further chemical reactions, and subsequent use of multiple and better catalysts for different processes can be challenging in terms of combining multiple technologies efficiently. For the gasification followed by microbial route, though the syngas can be used for ethanol synthesis without much pre-conditioning, but the product yields obtained are too low and make the overall process uneconomic. For the pyrolysis to biofuels scenario, although pyrolysis to bio-oil is well established, subsequent bio-oil to fuels technology is still at a developmental stage. A lot of R&D is again required before such a route can be commercialized. Hence, both the biochemical and thermochemical technologies for biofuels production are under continual development and evaluation and have significant technical and environmental hurdles to overcome before their implementation on a commercial scale can be achieved for the production of second-generation biofuels.

Uncertainty in production costs: present and projected

The present production costs of second-generation biofuels at state-of-the-art facilities, as well as projected future costs for a commercial biofuels facility operating via both the biochemical as well as thermo chemical pathways are uncertain and highly unpredictable because they are highly dependent on parameters such as availability of feedstock, cost of feedstock (both in present scenario and in future), sudden improvements on the technological front, costs associated with land and labour, credit value of products generated along with the biofuels (heat, power, carbon, and so on), subsidies granted, food prices, and also the price of crude oil. Since there are not many large-scale plants in operation, the cost estimates are primarily dependent on simulation studies with small pilot plants as reference. A detailed periodic techno-economic monitoring of many actual large-scale demonstration projects is required. Often the data generated even for smaller pilot plants is not shared between multiple stakeholders effectively. This is required for the generation of accurate and comparative data for various competing technologies to better assess the price and also the future of various second-generation biofuels relative to each other, as well as to crude oil and other competing alternative fuel technologies, such as oil from oil sands/shale as well as coal to liquids and gas to liquids (CTL/BTL) technologies, some of which are already being exploited on a commercial scale.

Other challenges and the road ahead

The shortcomings associated with the production and use of first-generation biofuels has left a lot of scope for development of second-generation biofuels as sustainable and clean alternative fuels for the future. However, commercial production of second-generation biofuels is still a distant reality even after several decades of dedicated R&D as well as financial investment in several pilot-scale and demonstration projects across the globe. Further, due to volatile crude prices and recent global instability in the financial sector, there are lots of apprehensions towards investing in technologies related to production of second-generation biofuels as the commercial risks associated with such investments are still perceived to be high. Thus, considerable effort needs to put in by all stakeholders including government, non-government organizations, academia and industry, as well as various intergovernmental agencies to bring about a meaningful collaboration to make second-generation biofuels a viable option for meeting energy needs in a sustainable manner. There is a need to provide long-term targets to encourage and formulate policies that stimulate investment in such technologies so as to ensure that the second-generation biofuels can be produced on a commercial scale. Long-range funding opportunities are needed to be dedicated to research, development, demonstration, and deployment (RDD&D) of technologies that promote efficiency and promise financial profits for such biofuels. Technologies promoting maximum utilization of all components of biomass and producing high value co-products, along with biofuels, need to be developed to minimize production costs. Effective integration of various technologies producing biofuels via different routes (thermo chemical and biochemical) is required to optimize integrated bio-refineries as visualized by the NREL (Figure 2). These state-of-the-art bio-refineries are expected to provide pathways for use of biomass to its full potential and considerably improve efficiency and economics of biofuels production, thereby promoting investment, production, and use of such fuels and other high value co-products so obtained. Promotion of good practices in feedstock production, storage, transportation and utilization, as well as the integration of environmental and social issues related to production and use of second-generation biofuels in the support schemes initiated by the government and policy-makers is necessary to achieve sustainable second-generation biofuels production. Governments across the globe and various intergovernmental organizations need to set up minimum GHG emission targets that need to be met by specified time frames and also encourage an international collaboration in setting up markets for such biofuels across the globe in both developed as well as developing countries. There is a need to integrate and frame policies for coordinating action amongst various sectors that are involved in the development of second-generation biofuels and their use, including the agriculture, energy, environment, and transport sectors to stimulate investments to ensure that these biofuels reach the commercial stage of production.

To summarize, unless there is a rapid shift in policies that favour the production and use of these

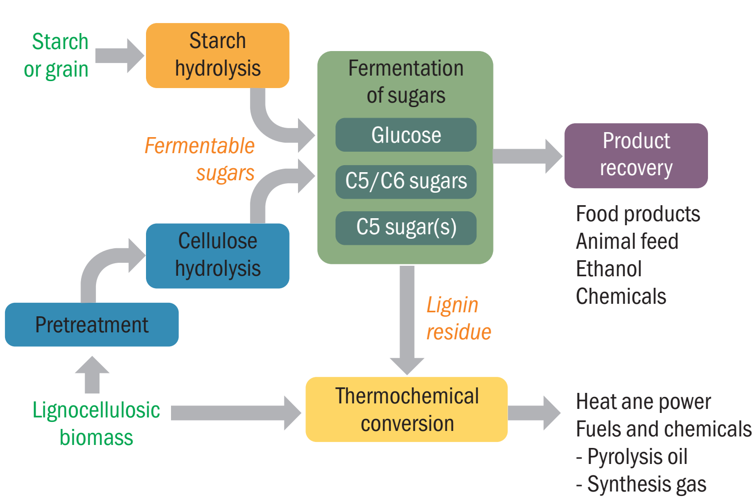


Figure 2 Concept of integrated bio-refineries for lowering overall production costs by maximum utilization of biomass potential
Source United States National Renewable Energy Lab

biofuels, coupled with a major breakthrough on the technological front in either the biochemical or thermo-chemical production pathway, which significantly lowers the production costs and accelerates investment and deployment, it can be reasonably concluded that it will take some more time before these fuels can be produced commercially and used at large scales for meeting the energy needs. During this period, demonstration and industrial-scale second-generation biofuels plants will be needed to improve on technology and economics so as to produce biofuels that can effectively compete with petroleum fuels, first-generation biofuels as well as other competing alternative fuel technologies.

References

Aden A. 2009. ***The current state of technology for cellulosic ethanol***. Golden, CO, USA: National Renewable Energy Lab (NREL).

Bain R. 2010. ***Hydrogen from biomass***. Golden, CO, USA: National Renewable Energy Lab (NREL).

Eisentraut A. 2010. **Sustainable production of second-generation biofuels potential and perspectives in major economies and developing countries**. IEA 2010.

IEA. 2010. ***World Energy Outlook 2010. Paris.*** International Energy agency.

IEA. 2011. ***Technology roadmap: biofuels for transport. Paris.*** International Energy Agency.

Michael Wang, May Wu, and Hong Huo. 2007. **Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types**. *Environ. Res. Lett.* **2** **(**024001).

Biofuel success in Brazil: lessons for India

Suani T Coelho, Patricia Guardabassi, and Renata Grisoli
The Brazilian Reference Center on Biomass (CENBIO) - Electrotechnics and Energy Institute / São Paulo University.

Introduction

The growth and development of ethanol derived from sugarcane in Brazil, to supply an expanding market as well as to export to other countries, has raised concerns over its sustainability, and environmental and social impacts. In particular, there are concerns that sugarcane production could compete with food production and increase pressure on native forests, such as the Amazon.

Such issues have been studied exhaustively and results indicate that when proper procedures (sustainability criteria) are applied, biofuels can be produced in a sustainable way, not only in Brazil, but also in other developing countries, such as India. However, it must be discussed that many of these criteria, particularly the ones established by the European Union, seem to be too strict for many developing countries, especially those in Africa and Asia.

Considering that most developing countries have a reduced internal market for biofuels, the export of biofuels to industrialized countries appears to be a significant economic issue for them. However, considering the lack of capacity building (including compliance with the sophisticated criteria mentioned above) and the need for adequate funding, it would be necessary to discuss the implementation of some kind of waiver, with adequate targets and time tables to allow poor developing countries to have enough time to attain these criteria. Such aspects are discussed in a detailed manner in UNCTAD (UNCTAD 2008), which calls attention to the fact that certification criteria should not be used as a way to protect European farmers.

In this scenario, this paper discusses lessons learned in Brazil on biofuels and how this experience could be transferred to other developing countries, including India. It is not only Brazil which has adequate overall conditions to produce biofuels; biofuels production can be maximized in an economically, environmentally, and socially sustainable way in other developing countries if the adequate conditions are in place.

Background

Transportation is an integrated and essential element of our modern lifestyle, but all over the world this sector is almost exclusively dependent on petroleum-based fuels and its use places a serious burden on the environment at the local, regional, and global levels. Currently, 13% of all GHG emissions come from the transportation sector and it represented 29% of total energy consumption in 2007 (Goldemberg, Coelho, and Guardabassi 2008).

Biofuels are one of the few practical alternatives to petroleum derivatives. Other technologies, particularly electrical or hybrid vehicles are still under development and will be commercially available only in 10–20 years. Existing commercialized liquid biofuels include bioethanol (to replace gasoline) and bio-diesel (to replace diesel oil).

Ethanol is a biofuel that replaces approximately 3% of the fossil-based gasoline consumed in the world today. It is produced through the fermentation of agricultural products, such as sugarcane, corn, and wheat among others. Technically speaking, ethanol from sugarcane is an attractive alternative to gasoline (Goldemberg, Coelho, and Guardabassi 2008). It is produced from agricultural products and does not have the impurities found in petroleum-based products, such as sulphur oxides, lead compounds, and particulates, which are the main sources of pollution in metropolitan areas.

The production of ethanol in Brazil was responsible for the creation of more than one million jobs, mainly in rural areas, and the introduction of mechanical harvesting of green sugarcane is upgrading the technical acumen of the workforce.

An interesting option for sugar producers in developing countries could be the transfer of the Brazilian experience to them, benefitting from the lessons learned during more than 30 years of the programme (Goldemberg and Moreira 1999).

Ethanol production in Brazil was initiated as a highly subsidized programme in 1975. However, over the intervening years, gains in technology and economies of scale have driven down the cost of production. By 2004, ethanol in Brazil became economically competitive with gasoline, even without subsidies. The advantages of this strategy were not only a reduction in oil imports, but also environmental and social benefits (Goldemberg, Coelho, Nastari, and Lucon 2004).

Worldwide, there are presently 110 countries growing sugarcane for sugar production. Of these, 39 are in Africa (FAO 2009). India also produces significant quantities of sugar from sugarcane. Such countries could produce sugarcane ethanol, not only for internal consumption, but also to export to industrialized countries, particularly to the European Union.

A brief overview of the Brazilian experience

The use of bio-energy in the Brazilian energy matrix has been a reality for a long time. Today, Brazil is the world's second largest producer of ethanol (and the largest one on sugarcane ethanol) with 28 billion litres, just behind the US, which produces ethanol from corn. In the last Brazilian harvesting season, there were 427 mills producing ethanol and sugar, in a planted area of 8.6 Mha of sugarcane. In 2010, the national average agricultural yield was close to 78 metric tonnes of sugarcane per hectare, with some regions reaching 100 tonnes per hectare (Brazilian Ministry of Agriculture, Livestock and Supply 2011).

The main advantage of sugarcane ethanol is its positive net energy balance in comparison to corn ethanol or ethanol from other crops. This energy balance is about 8.3 on average, with the best cases showing a balance of 10.2 (Macedo, Seabra, and Silva 2008).

Initially, ethanol was available for ethanol-dedicated engines (hydrated ethanol, 96% ethanol) or as an octane enhancer (anhydrous ethanol, 99.5%), replacing lead and methyl tertiary butyl ether (MTBE). There is a mandate from the federal government to blend anhydrous ethanol with gasoline in ranges from 20%–25%.

Nowadays, instead of ethanol-dedicated vehicles, hydrated ethanol is used in flex-fuel vehicles; more than 90% of all new cars sold in Brazil are flex-fuel, which can run on any blend of gasoline or ethanol, allowing drivers to make price-driven fuel choices (ANFAVEA 2010). In the domestic market, it replaces 41.5% of light duty transportation fuel in the country (DATAGRO 2010).

Bagasse, the residue from sugarcane crushing, is used for combined heat and power generation (cogeneration) in the mills, both for self-consumption and for the sale of electricity surplus to the grid. The installed capacity in 2010 was almost 6,000 MW (CONAB 2011).

In the 2009–10 harvesting season, total electricity production from sugarcane bagasse was 20,031 GWh. In this scenario, 28.2% of the mills sold their surplus to the grid (CONAB 2011).

Over the next 10 years, in the best scenario (considering higher pressure boilers installed—99 bar, in all mills, for a sugarcane production of 1.04 billion of tonnes), electricity production from sugarcane bagasse is expected to increase up to 68,730 GWh (CONAB 2011).

As far as bio-diesel is concerned, Brazil is the world's second largest producer. By the end of 2010, production was at 2.3 billion litres and there were 68 plants registered with an installed capacity of 6.2 billion litres (ANP 2011). Soy is the main feedstock used for bio-diesel production (accounting for 80%), followed by animal fat (almost 13%), and others, including vegetable oils.

The domestic market of bio-diesel is guided by the blending mandate of 5% bio-diesel (B5) in all diesel sold in the country. In 2010, the use of B5 was anticipated from the scheduled year of 2014 and there was a significant increase in the production of bio-diesel.

The use of soy as the most important vegetable oil in the country is due to the fact that this oil is the byproduct of the soy (protein) export for animal feed in other countries. The increasing use of animal fat is because of the huge amount of cattle heads in the country, mainly to fuel the meat export industry.

Existing policies and regulations (including the agro-economic environmental zoning)

Green harvesting

Harvesting and burning practices, which result in immense air pollution, are being phased out, resulting in energy benefits of mechanization due to higher surplus of electricity that can be produced from sugarcane byproducts, corresponding to 30% more in terms of biomass availability (State Law 11, 241/2002). Also, harvesting and burning practices are controlled / authorized by São Paulo State Secretary for the Environment according to atmospheric conditions.

In 2007, the São Paulo Secretariat for the Environment and UNICA—the sugarcane agro-industry association—signed a voluntary environmental agreement, which aims at rewarding good practices in the sugarcane sector. In 2011, most ethanol plants have adhered to it, corresponding to more than 90% of total cane crushing in the state. One of the main guidelines of this agreement is to anticipate the timetable for sugarcane burning phase-out. Following the Protocol timetable, in 2010, 60% of the sugarcane was harvested green in the state of São Paulo, and until 2014, the use of fire is to be banished in areas that can be mechanized.

Despite the high investment costs—each harvesting machine costs about R$1 million ($ 600,000)—the operational costs are reduced and productivity gains obtained.

Mechanical harvesting will prevent the release of 3.9 thousand tonnes of particulates (~28% of emissions from diesel vehicles in the Sao Paulo Metropolitan Region or SPMR); 45.3 thousand tonnes of carbon monoxide (12% of diesel emissions in SPMR); and 6.5 thousand tonnes of hydrocarbons (11% of diesel in SPMR). Riparian forests, delineated for protection, were close to 400 thousand hectares (~10% of cultivated land). Results are verifiable through satellite images.

Other initiatives have also been taken for the banning of sugarcane burning in many states. Furthermore, the Brazilian sugarcane zoning laws establish national targets and timetables for the phase-out of this activity.

Environmental zoning of sugarcane

Due to the expansion of sugarcane production in the recent years, concerns about the direct impacts of land use change led federal and state governments to adopt policies for determining suitable areas for this crop.

The state of Minas Gerais was the pioneer in this process and launched economic-environmental zoning in the year 2007. The zoning is based on social, economic, and environmental information that shows regional characteristics, potentialities, and vulnerabilities.

In the state of São Paulo, the agro-environmental zoning, launched in September 2008, was conducted by the State Secretariat for the Environment, based on studies related to soil and climate restrictions, topography, water availability, air quality, existence of protected areas, and biodiversity conservation areas, identified by the Biota Program/Fapesp (Joly, Rodrigues, Metzger *et al.* 2010).

Another decisive new step was the agreement mentioned in the above section. The text stipulates a set of measures to be followed, anticipating the legal deadlines for the elimination of sugarcane harvest burning and immediately halting burning practices in any sugarcane harvests located in expansion areas. Furthermore, it targets the protection and recovery of riparian forests and water springs in sugarcane farms, controls erosion and content water runoffs, implements water conservation plans, stipulates the proper management of agrochemicals, and encourages reduction in air pollution and solid wastes from industrial processes.

The Federal Government launched national agro-ecological zoning for sugarcane in September 2009 and oil palm in 2010.

This zoning identified the areas where sugarcane crop expansion could take place. The zoning forbids sugarcane cultivation in 92.5% of national territory, including the Amazon Forest, the Pantanal wetlands, and other native biomes. It identified 64 million hectares that comply with environmental and productivity requirements.

The Federal zoning was an intense programme led by *Embrapa Solos*, involving dozens of institutions and researchers working on agricultural and environmental issues. In this process, maps were produced showing soils, climate and rainfall, and topography.

According to these studies, about 650,000 square kilometres of land are available for sugarcane and 300,000 square kilometres for oil palm in Brazil, for cultivation without undesirable impacts. On the *Embrapa Solos* website, a number of reports, maps, and methodological issues can be easily accessed. Unfortunately, all relevant documents are available in Portuguese only.

Nowadays, other states like MatoGrosso do Sul launched their environmental economic zoning not only for sugarcane, but also for eucalyptus plantations for pulp and charcoal production, mainly in degraded areas previously used for cattle rearing.

Perspectives for replication in India and other developing countries

Until recently, the use of biofuels was limited to local markets and played a marginal role in the global energy mix. However, today biofuels have acquired a global dimension with the potential to grow even more, without negative environmental or social impacts.

In general, developing countries have a larger potential to produce biomass than industrialized countries due to better climatic conditions and lower labour costs. Under this assumption, international trade in biofuels and/or feed stocks from developing to developed countries is expected to increase with significant positive implications for development (UNCTAD 2009).

Through the production and use of biofuels, energy security can be improved, power access enhanced (Sub-Saharan African countries have an average of only 15% energy access), rural development aided, and employment can be generated and accelerated.

Since biomass as a resource is more equitably distributed than other energy sources and can be procured locally from a variety of sources, it addresses energy security, especially in a country like India, with huge urban-rural disparity in terms of access to commercial forms of energy. Bio-energy contributes to nearly 90% of energy used in rural households and about 40% of energy used in urban households[1].

In all these regions, land availability is crucial to achieving high production levels. Higher agricultural productivity in biomass crops could allow Africa to supply about 30% of world production for most of the model horizon (sugarcane agricultural yield is less than 1/3 of the Brazilian agricultural scenario[2], but in India, in 2009, the agricultural yield was 64.5 tonnes per hectare (FAOSTAT 2009).

India, together with some Asian and African countries, has seen substantial developments in its agricultural sector. Government support (adequate financial and policy instruments) allowed improved seeds and fertilizer use. Africa's continued growth in bio-energy production is mainly attributed to the Northern and Western regions, with the Southern and Middle countries still falling well below the average growth rate. However, the prospect of growth in these regions does exist.

Among the 39 countries already producing sugarcane in Africa, there are many countries in southern Africa, which have large potential for growing biofuel feedstock. Angola, Mozambique, Zambia, and Tanzania have low population densities and favourable soils and climate. So far, commercial biofuel production in the region is limited. However, this is about to change as many southern African countries are planning to produce biofuels and have already started to grow feed stock with the purpose of producing ethanol, mainly from sugarcane and bio-diesel from Jatropha[3].

India is already a large producer of sugarcane (the production in 2009 was 285 million tonnes) and sugar (FAOSTAT 2009). Hence, it can use molasses (byproduct of sugar production) to produce ethanol, as is now being evaluated in African countries[4]. India already has in place a strong technical capacity building programme and several Indian specialists are now working in African countries; also Indian companies are manufacturing and conducting operation and maintenance in biomass cogeneration plants in African countries.

---

[1] Global Network on Energy for Sustainable Development, Bioenergy Theme, 2010.www.gnesd.org
[2] Field visit to West Kenya sugar mills by Suani Coelho on April 2011, from AFREPREN (http://www.afrepren.org/cogen/index.htm)
[3] Global Network on Energy for Sustainable Development, Bioenergy Theme, 2010. www.gnesd.org
[4] Field visit to West Kenya sugar mills by Suani Coelho on April 2011, from AFREPREN (http://www.afrepren.org/cogen/index.htm)

In this context, for India, the most significant learnings from the Brazilian experience include the adequate choice for biofuels crops, through environmental-economic zoning, to define the best areas for food and fuel production, allowing food security, and contributing to rural development, not only through the creation of jobs in rural areas, but also through the increase of energy access from sugarcane bagasse, as is already being done in the country (Goldemberg 2009).

African and Asian countries have the potential to produce the necessary raw material and manufacture ethanol and bio-diesel, and the exploitation of such resources could be expedited through technology transfer. However, for this process to be successful, two main steps are needed—adequate incentive policies and foreign financing for the projects.

Moreover, recent studies show that food and biofuels can be produced in a sustainable way, without any serious impact on food security (Egeskog 2011). This study concludes that dairy farmers, in regions where cattle are being replaced by sugarcane crops, can increase their income through an integrated system. The increased total output and higher land-use efficiency in dairy production may even counteract possible indirect land-use changes.

It should be pointed out here that, when discussing the best regions for each crop, *Jatropha curcas*, used in large-scale plantation should be carefully evaluated, since there are not enough varieties to ensure minimal impact of disease and losses in the plantation, according to The Brazilian Agricultural Research Corporation (Sato 2009).

Recently, a mission of CENBIO (The Brazilian Reference Center on Biomass)[5] in Mozambique concluded that with adequate action, one can achieve sustainable production of biofuels in Africa, with technologies that have already been commercialized. Also, an existing project from GEF/UNEP to implement cogeneration from biomass, including sugarcane-bagasse, shows the interesting perspectives of using bio-energy to increase energy access in African countries[6].

Considering all these issues, the following three preconditions should be met.

- Sugarcane agro-ecological zoning to identify producing areas
- Economic development and development of markets through a blending mandate of 10% ethanol in all gasoline sold
- Rural development, building industries, generating jobs and incomes, and reducing poverty

References

UNCTAD. 2008. **Making certification work for sustainable development: the case of biofuels**.

Goldemberg J, Coelho S T, and Guardabassi P. 2008. **The sustainability of ethanol production from sugarcane**. *Energy Policy* **36**: 2086–2097.

Goldemberg J and Moreira J R. 1999. **The alcohol program**. *Energy Policy* **27**: 229–245.

Goldemberg J, Coelho S T, Nastari P M, and Lucon O d. 2004. **Ethanol learning curve - the Brazilian experience**. *Biomass and Bioenergy* **26**: 301–304.

FAOSTAT. 2009. Crops. Sugarcane. Data from 2009. Details available at http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor.

Brazilian Ministry of Agriculture, Livestock, and Supply. 2011. Sugarcane. Details available at: http://www.agricultura.gov.br/vegetal/estatisticas.

Macedo I C, Seabra J E, and Silva J E. 2008. **Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: the 2005/2006 averages and a prediction for 2020**. *Biomass and Bioenergy* **32**: 582–595.

ANFAVEA-Official Brazilian Automotive and Autoparts Industry Guide. 2010. **Brazil Automotive Industry Yearbook**. Details available at http://www.anfavea.com.br/anuario.html.

DATAGRO. 2010. **Bulletin**. Details available at: http://www.datagro.com.br.

CONAB-National Company of Food Supply. 2011. **Thermoelectric Generation with Sugar Cane Bagasse in Brazil - Performance Analysis of 2009-2010 harvest**. Available at: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/11_05_05_15_45_40_geracao_termo_baixa_res.pdf.

ANP-National Petroleum Agency. 2011. **National biodiesel production (B100)**. Details available at: http://www.anp.gov.br/?id=472.

[5] http://cenbio.iee.usp.br
[6] http://www.afrepren.org/cogen/index.htm

Joly C A, Rodrigues R R, Metzger J P, Haddad C F, Verdade L M, Oliveira M C, *et al*. 2010. **Biodiversity Conservation Research, Training, and Policy in São Paulo**. *Science* **328**: 1358–1359.

SMA. 2008. **Zoneamento Agroambiental**. Details available at http://www.ambiente.sp.gov.br/etanolverde/zoneamentoAgroambiental.php, last accessed 12 March 2011.

UNCTAD. 2009. ***The Biofuels Market: current situation and alternative scenarios***.

Goldemberg J. 2009. **The Brazilian Experience with Biofuels**. *Innovations Journal* **4**: 91–107.

Egeskog A, Berndes G, Freitas F, Gustafsson S, Sparovek G. 2011. **Integrating bioenergy and food production— A case study of combined ethanol and dairy production in Pontal, Brazil**. *Energy for Sustainable Development* **15**: 8–16.

Sato M, Bueno O, Esperancini M, Pires F E. 2009. **A Cultura do Pinhão-Manso (*JATROPHA CURCAS L.*): Uso para fins combustíveis e descrição agronômica. EMBRAPA.** *Revista Varia Scientiav* **07** (13): 47–62. Details available at http://e-revista.unioeste.br/index.php/variascientia/article/download/2523/1947.

IPCC. 2007. ***Climate Change 2007: Synthesis Report***. *Contribution of Working Groups I,II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (R. K. Pachauri, Ed.) Geneva, Switzerland.

Nassar A M, Rudorff B F, Antoniazzi L B, Aguiar D A, Bacchi M R, and Adami M. 2008. **Prospects of the sugarcane expansion in Brazil: impacts on direct and indirect land use changes**. In P. Zuurbier, & J. van de Vooren (Eds.), *Sugarcane ethanol - Contributions to climate change mitigation and environment* (pp. 63–93). Wageningen Academic Publishers.

Zhang Z, Lohr L, Escalante C, and Wetzstein M. 2010. **Food versus fuel: What do prices tell us?** *Energy Policy* **38**: 445–451.

Algae: fuelling the technology which will fuel our future

Mayank Dwivedi
Biotech Consortium India Limited, New Delhi

Dr Vibha Dhawan
The Energy and Resources Institute, New Delhi

Introduction

Microalgae are autotrophic microorganisms that contain chlorophyll—the most vital pigment responsible for photosynthesis. Microalgae usually exist in various shapes, sizes and colours, with over 30,000 identified species. Algae can grow in almost any environment owing to their high adaptability (ranging from marine to freshwater and hyper-saline environments, with some strains even forming symbiotic associations with other organisms).

The term algae can refer to microalgae, cyanobacteria (the so called "blue-green algae"), and macroalgae (or seaweed). Some strains of microalgae accumulate significant amounts of lipids (more than 50% of their ash-free cell dry weight). Under certain conditions, this characteristic provides excellent potential for their utilization as high energy density lipids. Lipids can also be produced using other algal feedstock and intermediates, including starches and sugars from cyanobacteria and macroalgae. In addition to lipids, a variety of different biofuels and other products can be generated using algal precursors. Therefore, algae as feedstock for bio-energy refer to a diverse group of organisms. Understanding, managing, and exploiting the biology of algal strains selected for use in production systems are the foundations for processing feedstock into fuels and products.

Several advantages of algal biofuel production have precipitated the interest of researchers and entrepreneurs around the world. These advantages include:

- High per-acre productivity
- Non-food-based feedstock resources
- Use of otherwise non-productive, non-arable land
- Utilization of a wide variety of water sources (fresh, brackish, saline, marine and wastewater)
- Production of both biofuels and valuable co-products
- Potential recycling of CO_2 and other nutrient waste streams

Understanding cultivation and harvesting

Microalgae and cyanobacteria can be cultivated by photoautotrophic methods (where algae require light to grow and create new biomass) in open or closed ponds or by heterotrophic methods (where algae are grown without light and are fed a carbon source, such as sugars, to generate biomass). Macroalgae has different cultivation needs that typically require open off-shore or coastal facilities.

Designing an optimum cultivation system involves leveraging the biology of the algal strain used and integrating it with the best suited downstream processing options. Choice of the cultivation system is key to the affordability, scalability, and sustainability of algae to biofuel systems. The different concepts for algal cultivation have been clearly depicted in Figure 1.

Some processes for the conversion of algae to liquid transportation fuels require pre-processing steps, such as harvesting and dewatering. Algal cultures are mainly grown in water and may require process steps to concentrate harvested algal biomass prior to extraction and conversion.

Major components extracted from algal biomass are:

1) Lipids (including triglycerides and fatty acids)
2) Carbohydrates
3) Proteins
4) Pigments and carotenoids (like β-carotene, Astaxanthin)

Spirulina, a nutritional supplement for humans and animals is commercially produced in countries

		Advantages	Challenges
Photoautotrophic cultivation	Closed photobioreactors	• Less loss of water than open ponds • Superior long-term culture maintenance • Higher surface to volume ratio can support higher volumetric cell densities	• Scalability problems • Require temperature maintenance as they do not have evaporative cooling • May require periodic cleaning due to biofilm formation • Need maximum light exposure
	Open ponds	• Evaporative cooling maintains temperature • Lower capital costs	• Subject to daily and seasonal changes in temperature and humidity • Inherently difficult to maintain monocultures
Heterotrophic cultivation		• Easier to maintain optimal conditions for production and contamination prevention • Opportunity to utilize inexpensive lignocellulosic sugars for growth • Achieves high biomass concentrations	• Cost and availability of suitable feedstocks such as lignocellulosic sugars • Competes for feedstocks with other biofuel technologies

Figure 1 Comparison between photoautotrophic and heterotrophic algal cultivation
Source NREL, Algal Biofuel Technology Roadmap

like USA, India, Chile, Thailand and so on. Apart from the above mentioned components, algae have also been used in the production of a wide range of pharmaceuticals and nutraceuticals. Recent studies suggest that mass cultivation of algae can also yield the following:

Antimicrobial, Antivirals, and Antifungals—*Ochromonas sp.*, has been reported to have many pharmaceutical applications (Katircioglu *et al.* 2006). Similarly, Phaeophyceae has been found to have high anti-microbial activity (Noemi *et al*. 2007).

Neuroprotective agents and human therapeutic proteins are also derived from *Spirulina platensis* (Zhang *et al.* 2007) and *Chlamydomonas reinhardtii* (Mayfield *et al*. 2007), respectively, although these possibilities are being explored at lab scale. With the extent of interest expressed by the pharmaceutical industries in algae, this knowledge might be enhanced to a commercial scale in the recent future.

While lipids and carbohydrates are fuel precursors (e.g., gasoline, bio-diesel and jet fuel), proteins can be used for co-products (e.g., animal/fish feeds). Most challenges in extraction are associated with the industrial scale-up of integrated extraction systems. Some algal biomass production processes are investigating options to bypass extraction, though these are also subject to a number of unique scale-up challenges.

Along with all positive aspects, there are also numerous engineering and research hurdles facing scaling up of this technology, which can be listed as follows.

1 Algae requires nutrient media for growth with specific salt, pH and temperature requirements, be it raceway pond or photobioreactor. To avert risk of contamination from bacteria and fungi the nutrient media must be changed after every few cycles (the number varies depending on the season and location) adding to the overall cost of the operations.
2 To bring down the cost of biomass production, researchers are exploring various options of reutilization of the nutrient media for multiple growth cycles of microalgae through an automated monitoring and buffering system to precisely measure the level of individual ions in nutrient media and buffering it with only the requisite quantities of salt. Reutilization brings down the cost of production, but such an automation system is in itself an expensive addition to the overall budget.
3 Further, certain toxins are released in the media by the algal cells, which inhibits further growth.
4 It is known that different algal strains have different illumination requirements, both in terms of duration and intensity. Depending on the species to be mass cultivated, daylight is maneuvered (either reduced by obstructing incident light or by supplementing light from artificial sources). Artificial source of light to extend day length for optimizing growth conditions of a specific strain

appears promising, but it is an energy intensive exercise. Hence, finding energy-efficient ways to provide light is also a challenge.

5 The metabolic functions in algae are impacted by the abiotic factors. Thus, a strain selected in a particular location may not perform similarly in another region and sometimes might not even grow as efficiently as expected at the same location during different seasons.

The need for precise monitoring at all stages of growth makes scaling up a difficult and tedious exercise.

Conversion into fuels and end uses

Conversion of algae into fuels and products is predicated on a basic process decision point at which one of the three methods below is adopted.

1) Lipid extraction from algae
2) Processing of algal biomass for other metabolites; or
3) Drawing out algal secretions

Conversion technology options include chemical, biochemical, and thermochemical processes, or a combination of these approaches as shown in Figure 2. The end products vary depending on the conversion technology utilized. Focusing on biofuels as the end-product poses challenges due to the high volumes and relatively low values associated with bulk commodities like gasoline and diesel fuels.

Many venture capitalists believe that processing algae for fuel through one route alone will not only be uneconomical, but will pose major problems with regard to waste generation. Hence, an approach to develop an Algal Biorefinery should be promoted as it caters to all the processing alternative measures as shown in Figure 3.

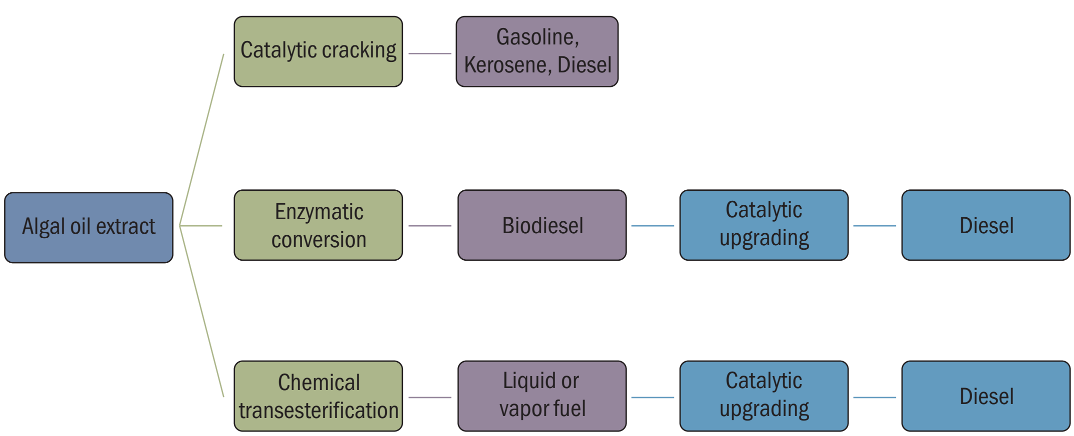


Figure 2 Showing various routes to convert algal oil extracts into liquid fuels

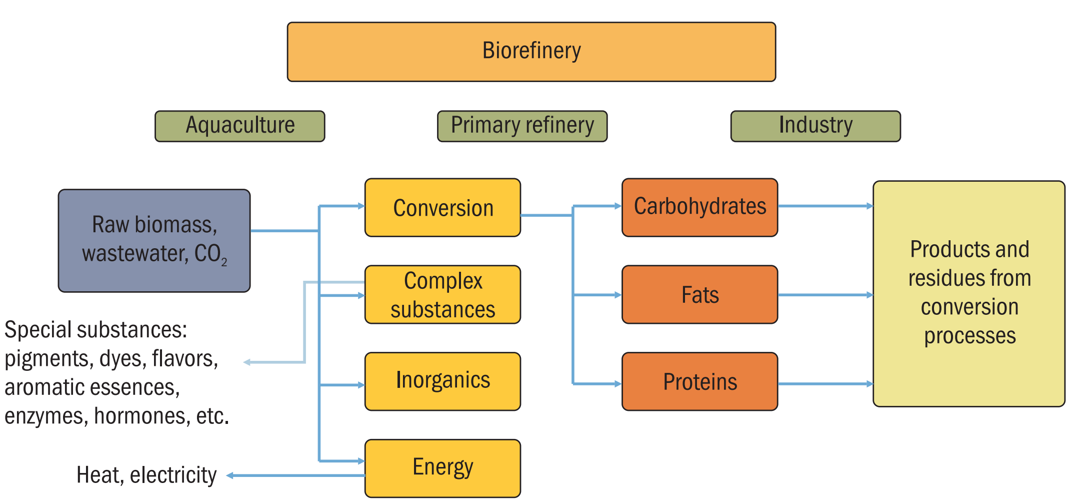


Figure 3 Biorefinery concept flowchart
Source NREL, Algal Biofuel Technology Roadmap

Potential of algal biofuel

Some of the facts mentioned in the national policy on biofuels, formulated by the MNRE are as follows.

- 5% blending of ethanol with gasoline has already been taken up by the oil marketing companies in 20 states and 4 Union Territories.
- 10% mandatory blending of ethanol with gasoline has become effective from October 2008.
- An indicative target of 20% blending by 2017 is proposed.
- To overcome the cost parameters, a comparative study on land and water footprint has been conducted. The algal route to producing biofuels has higher potential than any other bio-diesel source. The comparative study reveals the difference in land footprint as shown in Table 1. The land requirement for getting bio-diesel from algae is far less compared to the land required for *Jatropha* cultivation, which would yield the same volume of bio-diesel.

The average water footprint for *Jatropha* is less than algae for the same volume of bio-diesel, but it has been observed during studies that water used for supporting algal growth can be acquired from sewage, runoffs, and so on, and also in a closed system (Photobioreactor) water can be reused for many cycles of algal growth, hence, bringing down the overall water footprint for algal bio-diesel.

CO_2 mitigation

Microalgae generally have a high photosynthetic efficiency compared to most other plants. They often reach light-to-biomass conversion efficiencies of 1%–4%, as opposed to ~1% conversion rates, which is normally observed in other plants and food crops, with sugarcane being an exception at 8% (Stephens *et al.* 2010). Aresta *et al.* (2005) states that aquatic biomass on average has an efficiency of 6%–12% compared to the average of close to 2% in terrestrial photosynthetic varieties. These numbers all describe naturally occurring efficiencies, and could be improved further through various means. Photosynthetic efficiency is one of the factors that determine how good an agent the organism is in fixating carbon dioxide into biomass. Microalgae take CO_2 in the dissolved form from the water in which they grow. Different strains of microlage are known to have varying CO_2 tolerance as depicted in Table 2.

Table 1 Land footprint comparison

Planning Commission: Biofuel Mission Report					*Jatropha cultivation	*Algae
Year	Diesel demand (MMT)	Bio-diesel (@5%) (MMT)	Bio-diesel (@10%) (MMT)	Bio-diesel (@20%) (MMT) (A)	Land requirement for (A)(MHa)	Land requirement for (A)(Ha)
2001–02	39.81	1.99	3.98	7.96	6.66	30,153.07
2006–07	52.33	2.62	5.23	10.47	8.75	39,636.02
2011–12	66.90	3.35	6.69	13.38	11.19	50,671.69

*Source MBD Energy Ltd. Details available on http://www.mbdenergy.com/catalogue/c5/p280/cp4

Table 2 Showing difference in CO_2 tolerance (*currently being scaled up at TERI)

Species	Maximum CO_2 Conc.	References
Cyanidium celdanum	100%	Seckbach *et al.* 1971
**Scenedesmus sp.*	80%	Hanagta *et al.* 1992
Chlorococcum littorale	60%	Kodama *et al.* 1993
Synechococcus elongates	60%	Miyairi 1997
Euglena gracilis	45%	Nakano *et al.* 1996
**Chlorella sp.*	40%	Hanagta *et al.* 1992
Eudorine spp.	20%	Hanagta *et al.* 1992
**Dunaliella tertiolecta*	15%	Nagase *et al.* 1998
**Nannochloris sp.*	15%	Yoshihara *et al.* 1996
**Chlamydomonas sp.*	15%	Miura *et al.* 1993
Tetroselmis sp.	14%	Matsumoto *et al.* 1995

Current status

Most of the institutes/companies are at the stage of pilot-scale demonstration and, thus, rescind any request for technology exchange. It might be interpreted that the technology is either not perfected or they are unwilling to share till it is protected properly through IPRs. There are also a few cases where the pilot plant was established, but was later shut down due to high costs of operation.

It can partly be due to climatic conditions that are not favourable for algal growth (algae requires temperature in the range of 28 °C–35 °C, light intensities of 11,000 lux and long day lengths). Further, many of them have gone for over sophistication, resulting in high infrastructure and maintenance cost. Government organizations and corporate giants like the Department of Energy (US), BP, Ford Motors and Exxon Mobil Corporation are investing heavily on making this technology the power source of the future. The key edge for Indian research groups and scientists is that this country is blessed with plenty of sunshine round the year, and has temperatures conducive to algal growth.

Several billion dollars have been invested into biofuels over the last 10 years. The major players in this booming sector include Solazyme, British Petroleum, Shell, HR Biopetroleum, Exxon Mobil, Department of Energy (NREL), US Airforce Division (DARPA), Ford Motors and Chevron. Such participation is aimed at harvesting the huge potential of algal bio-energy.

Figure 4 Crude oil price trends
Source *Energy Information Administration (US Dept. of Energy, 20/10/2011)*

Oil price trend vs biofuel prices

The world has witnessed an overall increasing trend in crude oil prices (shown in Figure 4) and with burgeoning demand and limited supply of fossil fuels, there is an inevitable need to explore alternative fuels and also build capacity to take these advancements from the lab to the commercial arena.

World primary energy consumption grew by 45% over the past 20 years, and is likely to grow by 39% over the next 20 years. The fastest growing fuels are renewables (including biofuels), which are expected to grow at 8.2% per annum (2010–30) (shown in Figure 5).

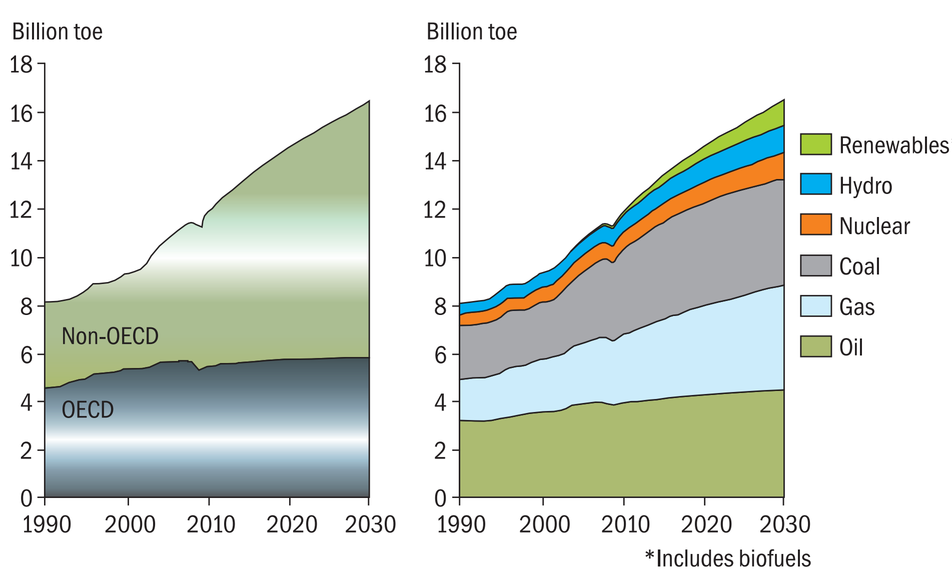


Figure 5 Forecasted dependence on various energy sources
Source BP Energy Outlook, 2011

Biofuels production is expected to exceed 6.5 Mb/d by 2030, up from 1.8 Mb/d in 2010—contributing 30% of global supply growth over the next 20 years as shown in Figure 6.

The pilot-scale plants installed at several institutes and organizations have helped NREL to forecast price trends and cost breakdown of algal biofuel, which is depicted in graphs 1 and 2.

To better understand the extent of projected decrease in the price of algal biofuel with respect to technological advancements, NREL has given a silhouette of cost components of algal biofuel, which when worked upon in an efficient manner, will bring down the cost substantially.

Making biofuels more cost-effective

Currently, the main components, which add up to the production cost of biofuels include the following.

- Providing artificial light
- Providing adequate aeration
- Extraction of algal biomass (the present method of extraction through centrifugation is one of the most expensive steps in the production process)
- Maintaining asepsis

Prospects for reduction of these costs exist. Incorporation as well as further exploration of technology to lower the cost of operation of photo-biotic reactors (PBRs) has been initiated. In place of light, light emitting diodes (LEDs) are being tested. LED consumes much less electricity and has shown promising growth conditions for algae.

Sparging of CO_2 mixed with air takes care of aeration and mixing requirements, which can then be easily provided using normal pumps, which could be solar-powered.

Milking of algae (a process in which a chemical stress forces algae to ooze out lipid) can make the level of dependence on centrifuge almost negligible. Another possibility is to introduce membrane technology designed specifically for getting algal biomass.

Using selected strains with high salt tolerance supports the growth of microalgae free from any contamination. The high salt concentration makes it difficult for any other organism to co-exist with flourishing algae and the media containing these salts can be reutilized after milking of algae for lipids.

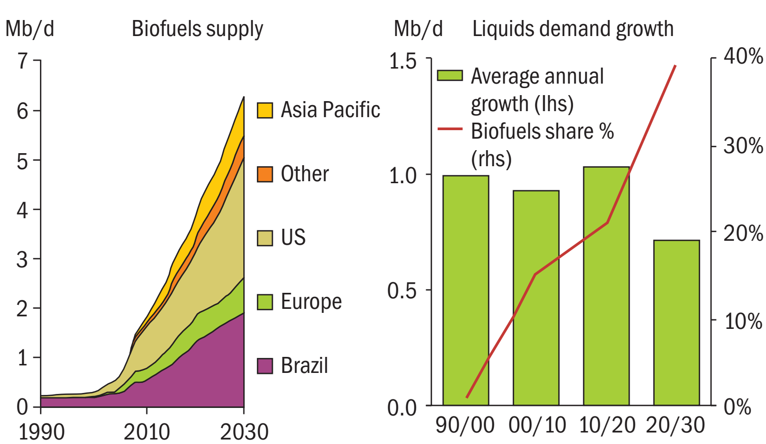
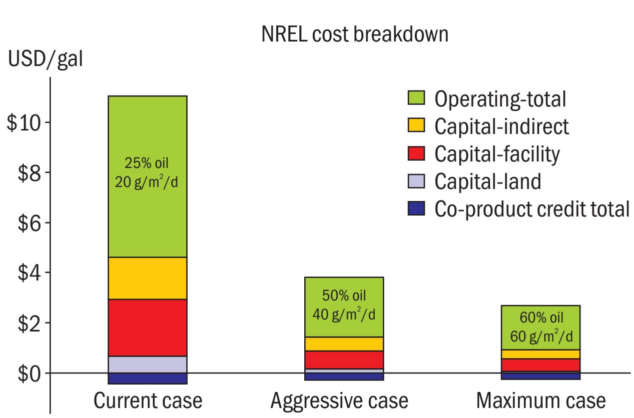


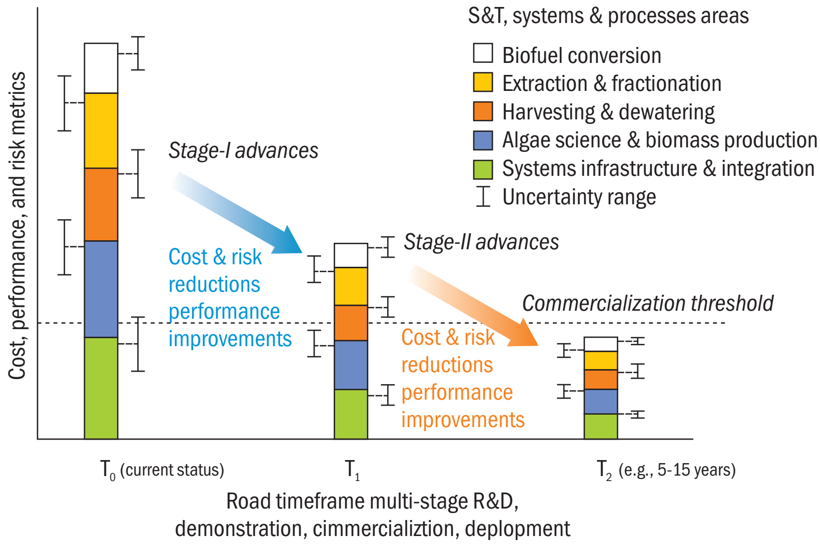
Figure 6 Comparison between demand and supply of liquid fuels
Source BP Energy Outlook, 2011



Graph 1 Price of algal biofuel (Historical Overview of Algal Biofuel Technoeconomic Analyses, DOE, Algal Biofuels Workshop, December 2008, Philip T Peinkos, NREL)

Conclusion

Owing to great benefits and promising technological advancements, researchers and entrepreneurs are providing more and more intellectual and monetary inputs to providing an economical and green solution to the current fuel price and fossil fuel depletion dilemma. The shift of interest from second generation to third generation biofuels is largely due to high prospects offered by the algal system, since it offers more lipids and, hence, more biofuel. It is supposedly most efficient in mitigation of CO_2 due to higher photosynthetic efficiency (Maria 2011) and has lower land and water (on account of water reusability) footprint. A number of new organizations have come



Graph 2 Research inputs forecast for commercialization of algal biofuel (National Algal Biofuels Technology Roadmap, May 2010)

up recently which are broadening the horizons of study of algal biofuels. People around the globe are investing time and effort to come up with innovative ways to increase mass awareness about renewable sources of energy, in which algal bio-energy is a forerunner. This particular source is being given impetus through the involvement of more and more technologically proficient experts and professionals. Although algal biofuel is a complex concept, appropriate exploration of this technology can meet a huge share of global energy requirement.

References

Katircioglu H, Beyatli Y, Aslim B, Yüksekdag Z, and Atici T. **Screening for Antimicrobial Agent Production of Some Microalgae in Freshwater**. *The Internet Journal of Microbiology*. 2006 Volume 2 Number 2.

Mayfield S P, Manuell A L, Chen S, Wu J, Tran M, Siefker D, Muto M, and Marin-Navarro J. 2007. ***Chlamydomonas reinhardtii* chloroplasts as protein factories**. *Curr Opin Biotechnol.* doi:10.1016/j.copbio.2007.02.001.

Salvador N, Garrete A G, Lavelli L, and Ribera M A. 2007. **Antimicrobial activity of Iberian macroalgae**. *SCIENTIA MARINA* **71**(1):101–113, Barcelona (Spain) ISSN: 0214-8358.

Zhang X, Xie W, Qu S, Pan T, Wang X, and Le W. 2005. **Neuroprotection by iron chelator against proteasome inhibitor-induced nigral degeneration**. *Biochem. Biophys. Res. Commun.* **333**: 544–549.

Centre for Research on Energy Security

Centre for Research on Energy Security (CeRES) was set up on 31 May 2005. The objective of the Centre is to conduct research and provide analysis, information, and direction on issues related to energy security in India. It aims to track global energy demands, supply, prices, and technological research/breakthroughs – both in the present and for the future – and analyse their implications for global as well as India's energy security, and in relation to the energy needs of the poor. Its mission is also to engage in international, regional, and national dialogues on energy security issues, form strategic partnerships with various countries, and take initiatives that would be in India's and the region's long-term energy interest. *Energy Security Insights* is a quarterly bulletin of CeRES that seeks to establish a multistakeholder dialogue on these issues.

Previous issues of this newsletter are available at <http://www.teriin.org/div_inside.php?id=41&m=3>.

Steering Committee

For inclusion in mailing list, contact

M K Bineesan
Centre for Research on Energy Security
T E R I, Darbari Seth Block
I H C Complex, Lodhi Road
New Delhi – 110 003

Tel. 2468 2100 or 4150 4900
Fax 2468 2144 or 2468 2145
India +91 • Delhi (0)11
E-mail bineesan@teri.res.in

Printed and published by Dr R K Pachauri on behalf of The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi – 110 003 and printed by him at Innovative Designers and Printers and published at New Delhi.