

# World Petroleum Council Guide

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## Biofuels

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# World Petroleum Council Guide

## Biofuels

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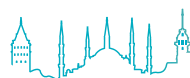
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The opinions and views expressed by the authors in this book are not necessarily those of WPC, its members or the publisher. While every care has been taken in the preparation of this book, they are not responsible for the opinions or any inaccuracies in the articles.

Unless otherwise stated, the dollar (\$) values given in the book refer to the US dollar.



# HAZARD OR FUEL?

Despite the fact that one single drop of oil can pollute 1,000 litres of water, thousands of tonnes of used cooking oil is poured away down household drains each year. MOL Group is committed to make use of this “waste material” to fuel mobility more sustainably. Since 2011, with the help of our customers we have collected 360 tonnes of used cooking oil and turned it into biodiesel. This is only our first step. We aspire to expand our biodiesel programme and make better use of other waste products that are hazardous to the environment.

SEE **USED COOKING OIL** OUR WAY

## Message from the Director General

As we move away from our dependence on fossil fuels, biofuels will play an ever-increasing role on a global level.



Dr Pierce Riemer, Director General, World Petroleum Council.

Biofuels are not new. Pioneers such as Henry Ford and Rudolf Diesel designed early engines to run on biofuels but petroleum-based fuels won out when cars started to go into mass production, largely for reasons of cost. Now the petroleum industry is faced with new challenges, such as the move towards a low-carbon global economy, the demand for more efficient fuels, oil-price volatility and the simple fact that fossil fuels are becoming less abundant.

The petroleum industry needs to embrace these challenges and view them as opportunities for diversification, sustainability, job creation, innovation and breaking into new markets.

It is essential for the petroleum industry to look ahead, to be at the forefront of new technologies and innovations and to not shy away from the role it can and should play in developing the fuels of the future. Biofuels are a renewable alternative to fossil fuels and a logical partner for fossil fuels.

To this end, the World Petroleum Council is proud to be part of this drive to look positively to the future and to play an important role in encouraging research and development in the biofuels sector. Our members have the potential to

be global leaders in ensuring energy security, improving energy efficiency and mitigating climate change by incorporating biofuel development into their businesses.

This guidebook has gathered experts to explain the technologies and processes that make biofuels viable. Practical examples of the work companies, governments and organisations are doing in the biofuel sector are essential for furthering our understanding and inspiring us all to be innovators. Modern-day Henry Fords and Rudolf Diesels are with us and will make the breakthroughs necessary to ensure the success of the biofuels sector.

I would like to thank J Luiz Orlandi, Director of ELO Energia e Logística in Brazil, who has worked closely with the WPC as the expert adviser on the *WPC Guide: Biofuels*. Luiz is a long-standing member of our Brazilian National Committee and brings a wealth of knowledge to this project.

The Education Series is now a substantial resource. It forms a solid collection and is proving popular in its electronic form with thousands of people on the WPC website. We are delighted to add a concise, easy-to-read resource on biofuels to the collection and look forward to many more.

# WPC vision, mission and values

The World Petroleum Council (WPC) is a non-advocacy, non-political organisation with charitable status in the UK and has accreditation as a non-governmental organisation (NGO) from the United Nations (UN). WPC is dedicated to the promotion of sustainable management and use of the world's petroleum resources for the benefit of all.

WPC conducts the triennial World Petroleum Congress, covering all aspects of the industry and its social, economic and environmental impact.

## Vision

An enhanced understanding and image of the oil and gas sector's contribution to sustainable development.

## Mission

WPC is the only organisation representing the global oil and gas community. WPC's

core value and purpose centres on sustaining and improving the lives of people around the world through:

- Enhanced understanding of issues and challenges.
- Networking opportunities in a global forum.
- Co-operation (partnerships) with other organisations.
- An opportunity to showcase the industry and demonstrate best practice.
- A forum for developing business opportunities.
- Information dissemination via congresses, reports, regional meetings and workshops.
- Initiatives for recruiting and retaining expertise and skills to the industry.
- Awareness of environmental issues, conservation of energy and sustainable solutions.

## Values

WPC values strongly:

- Respect for individuals and cultures worldwide.
- Unbiased and objective views.
- Integrity.
- Transparency.
- Good governance.
- A positive perception of energy from petroleum.
- Science and technology.
- The views of all stakeholders.

- The management of the world's petroleum resources for the benefit of all.

## Key strategic areas

- **World-class Congress** to deliver a quality, premier oil and gas congress.
- **Inter-congress activities** to organise forums for co-operation and other activities on specific topics; and to organise regional events of relevance to WPC members and all stakeholders.
- **Co-operation with other stakeholders** to add value by co-operating with other organisations to seek synergies and promote best practice.
- **Communication** to increase awareness of WPC's activities through enhanced communication, both internally and externally.
- **Global representation** to attract and retain worldwide involvement in WPC.
- **Youth and gender** engagement to increase the participation of young people and women in oil and gas issues, including the establishment of a dedicated Young Professionals Committee for the development of active networking opportunities with young people.
- **Legacy** to manage a central WPC legacy fund to benefit communities and individuals around the world based on WPC's mission.

## World Petroleum Congresses

### 2017 22nd WPC Istanbul

2014	21st WPC	Moscow	1979	10th WPC	Bucharest
2011	20th WPC	Doha	1975	9th WPC	Tokyo
2008	19th WPC	Madrid	1971	8th WPC	Moscow
2005	18th WPC	Johannesburg	1967	7th WPC	Mexico City
2002	17th WPC	Rio	1963	6th WPC	Frankfurt
2000	16th WPC	Calgary	1959	5th WPC	New York
1997	15th WPC	Beijing	1955	4th WPC	Rome
1994	14th WPC	Stavanger	1951	3rd WPC	The Hague
1991	13th WPC	Buenos Aires	1937	2nd WPC	Paris
1987	12th WPC	Houston	1933	1st WPC	London
1983	11th WPC	London			

## WPC overview

Since 1933, the World Petroleum Council has been the world's premier oil and gas forum and is the only international organisation representing all aspects of the petroleum sector.

World Petroleum Council (WPC) was established in 1933 to promote the management of the world's petroleum resources for the benefit of all. It is a non-advocacy, non-political organisation and has received accreditation as a non-governmental organisation (NGO) from the UN. WPC's prime function is to catalyse and facilitate dialogue among stakeholders, both internal and external to the petroleum industry, on key technical, social, environmental and management issues in order to contribute towards finding solutions to those issues.

Based in London, WPC includes 70 member countries from around the world representing more than 95% of global oil and gas production and consumption. WPC membership is unique, as it includes both OPEC and non-OPEC countries with high-level representation from national oil companies (NOCs) as well as international oil companies (IOCs). Each country has a national committee made up of representatives of the oil and gas industry, the service sector, academia, research institutions and government departments. The governing body of WPC is the Council consisting of representation from each of the national committees. Its global membership

elects the President and an Executive Committee every three years to develop and execute its strategy. The Council also selects the host country for the next World Petroleum Congress from the candidate countries.

Every three years, the Council organises the World Petroleum Congress hosted by one of its member countries. The triennial Congress is also known as the 'Olympics of the petroleum industry'. It covers all aspects of oil and gas from technological advances in conventional and unconventional upstream and downstream operations to the role of natural gas and renewables, management of the industry and its social, economic and environmental impact. In addition to industry leaders and experts, outside stakeholders such as governments, other industry sectors, NGOs and international institutions also join the dialogue. To ensure the scientific and topical quality of the event, the WPC Council elects a Congress Programme Committee whose members are responsible for delivering the high-level content for these events.

Istanbul will be the host of the 22nd World Petroleum Congress in 2017 ([www.22wpc.com](http://www.22wpc.com)).

Beyond the triennial Congress, WPC is regularly involved with a number of other meetings such as the WPC Youth Forum – the fifth edition of the Future Leaders Forum will be held in Rio in 2016, the WPC-UN Global Compact Best Practice Forum, joint WPC/OPEC workshops and other regional and topical events on important industry issues. Since 2015, a new event was added to the WPC programme when the Norwegian National Committee hosted the first WPC Leadership Conference on Responsibility, Co-operation & Sustainability in Tromsø, Norway.

### Legacy

As a not-for-profit organisation, WPC ensures that any surplus from the triennial Congresses and other meetings are directed into educational or charitable activities, thereby leaving a legacy.

WPC has set up a dedicated WPC Legacy Fund to spread the benefits beyond the host countries and its members and alleviate energy poverty through carefully selected projects.

The concept of leaving a legacy in the host country started in 1994 with the 14th World Petroleum Congress in Stavanger, Norway. After this Congress, the surplus funds were put towards the creation and building of the state-of-the-art Norwegian Petroleum Museum in Stavanger.

The 15th World Petroleum Congress in Beijing adopted the issue of young people as a key aspect of its theme: 'Technology and Globalisation – Leading the Petroleum Industry into the 21st Century'. To support the education and future involvement of young people in the petroleum industry, the Chinese National Committee donated all computer and video equipment used for the Congress to its Petroleum University.

Profits from the 16th Congress in Calgary were used to endow a fund that gives scholarships to

post-secondary students in several petroleum-related fields. The Canadian Government Millennium Scholarship Foundation matched the amount dollar-for-dollar, creating an endowment which supported more than 2,000 students until its conclusion in 2010.

The 17th World Petroleum Congress was the first to integrate the concept of sustainability throughout its event, taking responsibility for all the waste it generated. The Congress and the Rio Oil & Gas Expo 2002 generated 16 tonnes of recyclable waste – plastic, aluminium, paper and glass. All proceeds of the recycling activities were passed on to a residents' co-operative with 6,000 inhabitants located in the port area of Rio de Janeiro.

But the sustainability efforts did not stop there – an army of 250 volunteers collected 36 tonnes of rubbish in 10 days in a special community effort to clean up the Corcovado area before the Congress, donating all proceeds to the rubbish collectors, some of the poorest inhabitants of Rio.



Social Responsibility Global Village at the 2014 World Petroleum Congress in Moscow and its interactive World CSR Map.





The WPC legacy initiative started in 1994 when surplus funds from the 14th World Petroleum Congress were put towards the building of Stavanger's Norwegian Petroleum Museum.

The Finlândia Public School also received a new lick of paint from our volunteers. The surplus funds for the Congress were used to set up the WPC Educational Fund in Brazil, which was further increased in 2005 with tax initiatives added by the Brazilian government.

The 18th World Petroleum Congress also chose a sustainability focus for the first-ever WPC to be held in Africa – 'Shaping the Energy Future: Partners in Sustainable Solutions'. Education was the focus of the 18th World Petroleum Congress Legacy Trust, set up by the South African National Committee to provide financial assistance to needy young South Africans who wish to pursue a qualification in petroleum studies.

In 2008, with the 19th Congress in Madrid, the trend continued and the organisers selected a number of projects and foundations to receive

the surplus from the event for charitable and educational programmes in Spain and around the globe. The 19th Congress was the first one to offset all its carbon emissions and receive a certification as a sustainable event.

Qatar's 20th Congress also offset all of its carbon emissions and is establishing a gallery devoted exclusively to the country's oil and gas industry as an integral part of the future National Museum of Qatar (NMoQ). This gallery, dedicated to the story of oil and gas in Qatar, will educate Qataris and residents about the history of Qatar and the way the oil discovery shaped the nation since 1940, and in accordance with the legacy policy of the Congress will provide a project that serves the community.

Additionally, the most recently held 21st Congress in Moscow focused on the importance



WPC's first Youth Forum was held in Beijing in 2004.

of involving young people in the industry and managing the increasing talent gap. The WPC's Russian National established the 'Golden Legacy of WPC' Scholarship, which is aimed at identifying the most talented and successful students and young professionals from Russia with a special interest in the petroleum sector and assisting them with educational opportunities.

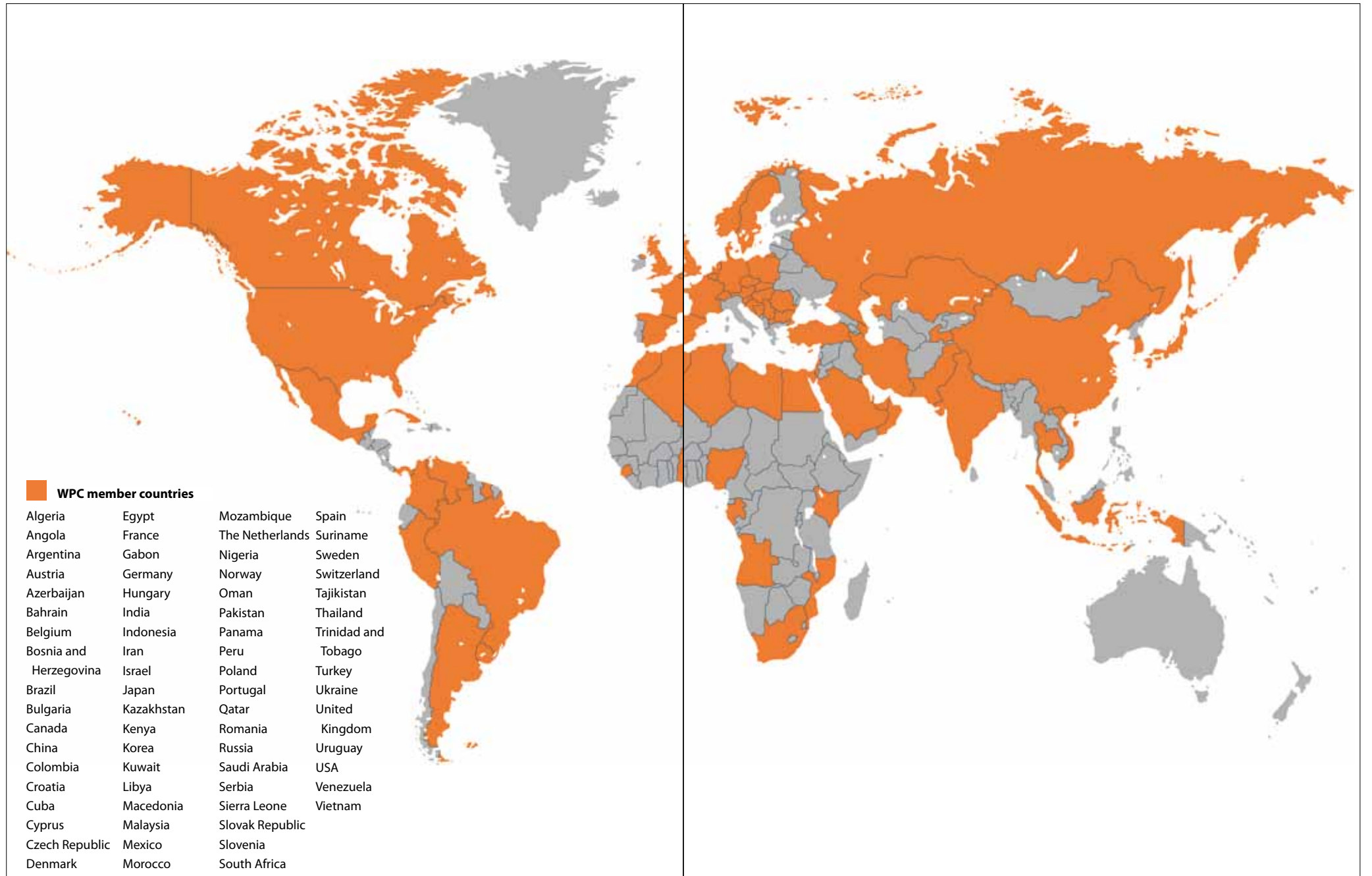
### Youth outreach

Youth is a critical factor in the sustainability of the oil and gas industry. Addressing and involving young people in the design of future energy solutions is therefore one of the major issues for WPC's 70 member countries. WPC recognises their significance to the future of the petroleum industry and the importance of giving the young generation scope to develop their own ideas,

talents and competencies to create viable solutions for the future of our world.

As part of its outreach to recruit and retain the next generation, WPC created its Youth Committee in 2006 to provide a channel through which young people have a direct involvement and say in the strategy and activities of the organisation. It aims to create and nurture a collaborative, global forum for young people to be heard, to champion new ideas within the petroleum industry, to promote a realistic image of the petroleum industry, its challenges and opportunities and to bridge the generation gap through mentorship networks.

In 2011, WPC launched a pilot Mentorship Programme to provide a bridge between international experts and the next generation of our industry. This programme is now in its third successful cycle and has already created 150 matches.





# Introduction to biofuels: part one

*By Jorge MT Camargo, Brazilian Petroleum, Gas and Biofuels Institute*

We are witnessing an energy transition, with biofuels central to the shift.

The history of humanity and civilisation's development were always related to energy. A crucial dilemma of our times is how to reconcile energy supply, preferably easily accessible and affordable – essential to human prosperity – with the equilibrium and preservation of the environment.

More than 7 billion people inhabit our planet, while 20% of this population hasn't access to the



Use of coal for power generation is in decline but fossil fuels are still likely to be the dominant power source by 2040.

basic comfort of electricity. According to the UN, by 2050 the world population will be 9 billion. In this scenario, we will need all forms of energy, or at least those minimally viable, to supply the growing demand, in particular the needs of billions of poor people who aspire, and rightly so, to a better life. This is only possible with access to affordable energy.

Life is made of choices. During COP 21 in Paris in 2015, 195 countries choose to reduce emissions of greenhouse gases (GHGs) and limit anthropogenic climate change. It is a choice that will have a profound impact on the global energy industry and our use of fossil fuels.

In its more conservative New Policies Scenario, the International Energy Association (IEA) forecast that by 2040, 74% of the energy demand would still be provided by oil, natural gas and coal. However, in the IEA's 450 Scenario, which considers the implementation of COP 21 policies and targets, the call on fossil fuels will be reduced to 60% of the global consumption, opening additional demand and opportunities for energy sources that produce lesser atmospheric impact.

Brazil had a protagonist presence at COP 21 and committed to reduce 37% of its GHG emissions by 2025. To deliver on this target, Brazil will need to reshape its energy matrix, expanding biofuels' share of the energy produced and consumed in the country.

The relevance of biofuels as an energy source is growing fast. Global production grew 9% in 2014. According to IEA's 450 Scenario, bioenergy may represent 16% of the energy matrix by 2040.

Currently, over 60 countries sponsor incentive programmes to progress biofuels consumption. The US and Brazil are the leading producers with 53.7 billion and 28.2 billion litres of annual production, respectively. As second-generation biofuels produced from biomass start to become economically viable, the scale of this market will raise to another level. Moreover, there is already



According to the International Energy Agency's 450 Scenario, which includes targets set out by the 2015 COP 21 climate conference, biofuels and bioenergy will represent 16% of the energy matrix by 2040. Soya beans, pictured, and sugar cane will be large contributors.

news of third-generation biofuels, the use of marine algae and other technological breakthroughs that may further strengthen biofuels as a vital source of renewable energy. Therefore, it is fundamental to make financial and human resources available to encourage technological research and development of biofuels.

Given its relevance as a leading biofuels producer and consumer, Brazil is probably the country that has more opportunities to offer and more to gain from the technological advances that will make biofuels production even more economic and efficient.

The climate agenda imposes itself as a decisive factor in the shaping of the future global energy matrix and markets. Clean-energy generation is now present in the energy planning agenda of the world's main economies, as a response to the clear and emphatic resolutions established by 195 governments during COP 21.

The future will become progressively less dependent on fossil fuels, as demanded by society and climate scientists, as the scale and economics

of renewable energy increases its share of the global-energy matrix.

We are living in times of transition. New attitudes, contexts, concepts and policies will transform the energy industry as we know it. Although it still represents a small fraction of global-energy consumption, the growth of renewable energies – and biofuels, in particular – will be one of the main drivers of change of the world's energy industry.

The Brazilian Petroleum, Gas and Biofuels Institute (IBP) applaud and is proud to take part in the World Petroleum Council's initiative to issue a book specially dedicated to biofuels, with contributions from the world's most qualified specialists, organised with competence and care by IBP's former director J Luiz Orlandi.

*Jorge MT Camargo is President of the Brazilian Petroleum, Gas and Biofuels Institute. He has worked with Petrobras for 27 years, including being a member of its Executive Board from 2000-03. From 2003-09, he worked for Statoil, initially as Senior Vice-President, later as President, Statoil Brazil.*

# Introduction to biofuels: part two

By J Luiz Orlandi,  
ELO Energia e Logistica

The COP 21 climate agreement has upped the urgency for renewables.

The importance of energy for economic development is clear, especially in modern society. In the fossil fuels versus alternative energies debate, petroleum is the main resource, however, the growing demand for energy also makes clear the importance of the use of other energy sources such as wind, solar, nuclear and biofuels.

There are cities that are beginning to produce biomethane from agricultural and animal waste. For example, Paris has been using the production

of this gas for residential heating systems. Biomethane, being a product with the same calorific value as natural gas, brings as a result not only the production of energy itself but also mitigates urban waste-treatment problems.

Pressure from environmental organisations to reduce CO<sub>2</sub> emissions has been an important factor to induce the gradual reduction of the use of fossil fuels. Global warming is attributed mainly to the excessive use of these fuels. The rise in average temperature of between 2-3°C in many regions has provoked sea-level rises, floods and melting icecaps, endangering agricultural crops and creating imbalances in the ecosystem.

In this context, we see the increasing use of biofuels. Global biofuels production increased 9% in 2014, reaching a record output of 127.7 billion litres of ethanol and biodiesel. Currently, more than 60 countries have programmes stimulating their use, mostly blended with gasoline or diesel.

The production of ethanol is an important economic activity in many countries, generating income and thousands of jobs. Currently the largest producer is the US (53.7 billion litres a year), followed by Brazil (28.8 billion), but there is huge potential for the development of the industry in many other countries. It would make sense for some African countries to become suppliers of large markets – especially to Europe. From a logistics point of view, they would be competitive.

Caribbean and Central American countries like Cuba, Jamaica and Costa Rica have enormous potential regarding quality of soil and climate for sugar-cane production. In Asia, countries such as China and Thailand have possibilities too.

It's important to note that second-generation, cellulosic ethanol, which uses raw materials such as sugar-cane bagasse, straw and woodchips, and the third generation, producing ethanol from algae, are realities that in the near future will mean a leap in terms of productivity, with a consequent reduction of costs.

Regarding biodiesel production, major producers are the US (4.8 billion litres a year), Germany (3.6 billion), Brazil (3.4 billion), Argentina (2.9 billion), Indonesia (3.3 billion) and France (2.1 billion), but since it's a fuel that uses diversified raw material in its production (soya-bean oil, animal fat, palm oil, rapeseed oil and others), the amount of countries that can produce it is even higher.

What the industry needs to grow in a safe and sustainable way are clear, stable policies. At the COP 21 climate conference in Paris in 2015, an agreement signed by 195 countries created deadlines for the reduction of greenhouse gases, as well as \$100bn a year for this purpose. The contribution that biofuels can make to reach climate-improvement goals is unquestionable.

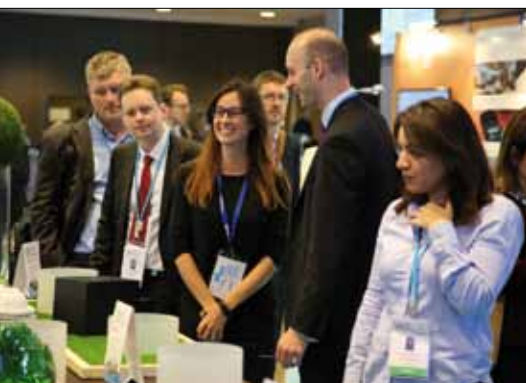
It is commonplace to say that we live in a globalised world. The misuse of the planet's resources charges a high price to everyone, regardless of nationality, race or economic status.

It has been my pleasure to co-ordinate the World Petroleum Council Guide: Biofuels and pro-

vide you with a balanced view of the issues. The focus of the guide is to improve the understanding of the biofuels industry and its contribution to generating income, creation of jobs and improving the environment.

I would like to thank the following people for their support during the development of this World Petroleum Council (WPC) guide: Dr József Toth, President of WPC; Dr Pierce Riemer, Director General of WPC; Jorge Camargo, President of the Brazilian Petroleum, Gas and Biofuels Institute (IBP); and Ernani Carvalho, Downstream Manager, IBP. Thanks also to WPC for inviting me to co-ordinate the biofuels guide. My thanks also to IBP for its support and I would especially like to thank the authors who lent their expertise.

Currently CEO of ELO Energia e Logistica, J Luiz Orlandi is also a member of the Brazilian National Committee for the World Petroleum Council. He is the former Director of Petroleo Ipiranga SA and former Vice-President of Infinity Bio-Energy SA.



The COP 21 meeting in Paris in 2015 was attended by 195 nations; an agreement was reached to limit global warming to below 2°C.



Jane Bustin of the UK National Physical Laboratory (right) moderates the Decarbonising Global Energy Supply panel at COP 21.



# First-generation biofuels

By Décio Luiz Gazzoni and Amélio Dall'Agnol, Embrapa

Since the 1970s, Brazil has been a beacon of biofuels progression.

Global energy consumption in 2013 was 13,541 Mtoe (million tonnes of oil equivalent), of which fossil fuels accounted for 81.4% and biofuels and other biomass energy 10.2%. Although use of biofuels dates back centuries, liquid biofuels occupied a prominent space when the oil crisis arose in 1973. High prices encouraged countries that were dependent on imported oil to invest in alternative energy sources. Biofuels are the most viable option to replace gasoline and diesel from a technical point of view but require improvements to optimise their performance.

Liquid biofuels can replace liquid fossil fuels with minimum or no changes to modern engines and use the same logistics for storage, distribution and sales. Due to this, several countries have invested in producing and using biofuels. Considering their higher cost compared to fossil fuels, policies were launched to encourage use.

A further stimulus was brought about by the awareness of fossil-fuel greenhouse gases (GHGs). Biofuels are renewables, with far less net GHG emissions. In 1992, there was willingness by several countries at the Earth Summit in Rio to develop biofuels production on a large scale.

## Production and consumption

Bioethanol production is concentrated in two major raw materials, sugar cane and corn. The US and Brazil are the largest producers, followed by China, Canada and Thailand. Sugar cane provides a lower cost per unit of bioethanol produced when compared to corn and a more favourable energy balance. Sugar cane typically yields 10 units of energy for each energy unit input to the system.

Production of biodiesel can use both vegetable oils and animal fats. The main producers are the US, Brazil, Germany, Indonesia, Argentina and Malaysia, with each favouring the most abundant raw material in its territory. The energy balance of biodiesel from palm oil in Malaysia, for example, is very favourable, sometimes up to 8:1.

## The Brazilian case

The first major project for the production and use of liquid biofuels was in Brazil. The Proálcool programme was created in 1975 and focused on the production of bioethanol using cassava, wood or sugar cane. Its objective was the progressive replacement of petroleum-derived gasoline.

Brazil's peak bioethanol market was 2009, when it represented 15.9% of the total energy supply. That year, bioethanol accounted for over 60% of total liquid fuels used by light vehicles. Today, the entire Brazilian production of bioethanol derives from sugar cane, where sugar-cane bagasse is harnessed to generate steam, mechanical power and bioelectricity.

The majority of biodiesel mandates lie between 2-5% blends. Brazil is an exception: a 7% biodiesel blend is the highest presently in place worldwide.

## Bioethanol use

There is no need to modify engines fuelled with bioethanol blends lower than 30% but to use proportions over that limit, adaptations are required, such as adjusting the compression ratio of an engine. When there is a ready supply of



At the UN Earth Summit held in Rio de Janeiro in 1992, environmental issues were tackled including the replacement of fossil fuels due to their links with global warming and pollution. A UN Framework Convention on Climate Change was negotiated and began two years later.

bioethanol, manufacturers can promote engine adjustments, making possible the use of any mix ratio. Flex-fuel cars can only grow in popularity.

## Cost considerations

Cheaper oil prices inhibit the production and consumption of biofuels, whose manufacturing cost is greater. Although biofuels rarely compete with fossil fuels from a financial point of view, their social and environmental benefits are higher.

Their use favours the creation of more jobs in the production of raw materials (three to four times more jobs than the chain of fossil fuels, according to Brazil's Ministry of Agrarian Development), as well as being renewable. In addition, they contribute to restricting rural exodus. For these reasons, expectations point to a larger share of renewable energy in the near future, including biofuels from all generations.

Décio Luiz Gazzoni is an agronomist and scientist at Embrapa, the Brazilian Agricultural Research

Corporation. He is also Chairman of the Steering Committee for Sustainable Energy at the International Council for Science. Amélio Dall'Agnol is an agronomist from the Universidade Federal de Pelotas, Brazil and has worked as a scientist with Embrapa since 1975.



Cassava, native to South America, was used in Brazil's pioneering Proálcool bioethanol initiative alongside sugar cane and wood.



# Second-generation biofuels

By Jaime Finguerut, Joaquim Henrique Cunha Filho and Natália Trombeta Calori, Centro de Tecnologia Canavieira

Brazil is a major ethanol producer but this is only the start of the journey.

In a context formed by urbanisation, population growth and increases in material wealth, the demand for food and energy has become a challenge to major production and consumption centres. In addition, new paradigms related to the mitigation of environmental impact, including the minimisation of emissions of greenhouse gases (GHGs), reinforce the need for obtaining alter-

## Mass of biomass (tonnes dry basis) in Brazil, 2015

Residual biomass	2015
<b>Total</b>	<b>829,152,477</b>
<b>Agricultural waste</b>	<b>738,545,302</b>
Soya bean	303,539,100
Corn	292,316,850
Sugar cane (straw)	92,218,252
Rice (straw)	50,471,100
<b>Agroindustrial waste</b>	<b>90,607,144</b>
Sugar cane (bagasse)	88,924,743
Rice (husk)	1,682,370
Bleach	21
Wood	10
<b>Energy forests</b>	<b>31</b>

Source: Estimated from PNE 2030 (2007) and Conab (2016).

Table 1.

native sources of clean and renewable energy. In this sense, the viability of other sources and forms of energy generation are opportune and increasing, highlighting the use of biomass for the production of electricity and biofuels.

Based on the Brazilian National Energy Plan 2030 (PNE 2030) estimates, the biomass supply in Brazil in 2015 was 830 million tonnes on a dry basis, classed as agricultural waste, agroindustrial wastes and energy forests (Table 1). Regionally, this data focuses on the major agricultural production centres of Brazil, especially the midwest and southern regions, which traditionally produce grains, and the southeast, which has historically focused on sugar-cane production.

The amount of biomass in Brazil must be carefully analysed since its largest portion is not available for use in chemical-industrial processes such as the production of electricity, cellulosic ethanol or other biofuels. This scenario is set by a series of agricultural, technological, climatic and economic factors that render materials such as the plant waste of soya bean or corn, for example, unfeasible to be collected and properly processed for use in secondary proceedings other than fertilisation and soil protection or animal supplementation.

In Brazil, sugar-cane bagasse and straw are primarily used as raw materials for the production of electricity and/or cellulosic ethanol. Bagasse is obtained from the grinding of sugar cane.

It is important to emphasise the competitive advantage of the sugar sector in the use of biomass, since the spatial proximity between the supply of these materials and the thermal power plants/cellulosic-ethanol plants (ideally attached to sugar-cane plants) imply lower logistic costs.

In relation to the potential of second-generation ethanol production by biomass from sugar cane, Centro de Tecnologia Canavieira estimates that for every tonne of straw or bagasse (dry basis), considering the evolution of efficiency in hydrolysis, fermentation and distillation, it is pos-

sible to produce 300 litres of cellulosic ethanol. Using this estimate and considering the production of sugar cane in the 2015-16 crop, it would be possible, hypothetically, to produce 45 billion litres of second-generation ethanol. Discounting the use of biomass in the process of electricity generation for the plant's own use and the availability of straw (for agronomic handling and soil-conservation, it is recommended that at least 50% of the straw stay in the field), the production potential of cellulosic ethanol in the centre-south is currently 16 billion litres.

## Conclusion

Brazil is one of the world leaders in agriculture, with abundant sources of biomass. Only a small, but still a substantial amount, is available for non-food use. This biomass is derived from sugar cane, which is responsible for the production of first-generation ethanol fuel that, mixed with gasoline to be used in flex-fuel cars, represents 40-50% of the total Otto cycle fuels. The momentum of the sugar-cane and sugar-energy sector in Brazil gives the opportunity to demonstrate that the production of cellulosic ethanol is economically viable. The amount of sugar cane that is grown can be



Sugar-cane bagasse and straw are Brazil's prime raw materials for cellulosic-ethanol production and generation of electricity.

hugely increased, giving potential for sustainable biofuel production.

Jaime Finguerut is Technical Adviser at Centro de Tecnologia Canavieira (CTC) in Brazil, where he's involved in the development of cellulosic ethanol from sugar cane. Natália Trombeta Calori is a Business Analyst at CTC, having studied agronomy engineering and economics at the Universidade de São Paulo. Joaquim Henrique Cunha Filho is a Senior Business Analyst and Business Developer at CTC, with experience in economic research, business intelligence, trading and strategy in agribusiness and the sugar-cane industry.



In Brazil, thermal power plants and cellulosic ethanol plants are often built in close proximity to sugar-cane producers to lower costs.

# Third-generation biofuels

By Kira Schipper, Qatar University

Qatar University's research into algae-derived biofuels is a vision of a sustainable future.

In recent decades, biofuels have increased in popularity as a sustainable replacement for fossil fuels. Governments are including biofuels within their renewable-energy standards, mandating percentages of a country's energy to come from renewable sources. Biofuels have environmental benefits as well as reducing our dependency on finite fossil resources.

But how sustainable are biofuels? Popular biofuels, produced from food-crop feedstocks such as corn, sugar cane and soya bean, can have net energy losses, releasing more carbon in their production than is captured during growth. It is questionable whether these first-generation biofuels are a sustainable fossil-fuel replacement.

Second-generation biofuels are based on non-food crops such as wood, organic waste and other lignocellulosic biomass. Low productivities, the requirement for arable land and costly conversion technologies still make these biofuels challenging to implement. In an attempt to produce biofuels with greater sustainability, more focus is put on third-generation feedstocks: non-food biomass feedstocks that have high productivities and a net negative carbon return.

## Microalgae cultivation

Algae are organisms that grow in aquatic environments. Microalgae in particular, microscopic photosynthetic organisms, are a promising feedstock for biofuel production due to their high productivities (10-50 times higher than terrestrial plants) and short harvest cycles (1-10 days).

Production systems for microalgae consist of land-based artificial systems which are either open, raceway ponds or closed photobioreactors. The benefit of using artificial systems is they allow control of nutrient supply, salinity and CO<sub>2</sub> addition, as well as simplifying harvesting. These systems can be constructed on non-arable land.

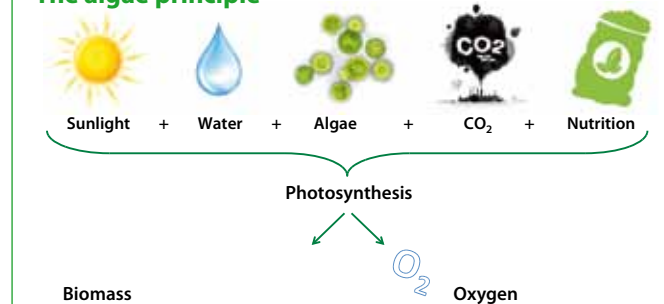
The algae strain is central to requirements and with an estimated number of species of between 200,000 and several million, there are plenty to choose from. With so much diversity, it is possible to select algae based on multiple criteria, ranging from productivity, application-specific biomass compositions and water source. In order to prevent the use of freshwater, it is more sustainable to focus on strains that can be cultivated in seawater or wastewater.

Another denominator for high productivity is climate. High temperatures and sunlight reduce the requirements for external temperature control and artificial light, thus increasing sustainability. Thirdly, CO<sub>2</sub> is of major importance for cultivation. For every 1kg of produced biomass, 1.8kg of CO<sub>2</sub> is required, which means that cultivation of algae can be a net carbon-negative process. To obtain high productivities, active CO<sub>2</sub> enrichment of algae cultures is a must. This can occur by the addition of pure CO<sub>2</sub> or incorporating industrial flue gas, which contains increased CO<sub>2</sub> concentrations, into the process.

## Biofuel production

Generally speaking, there are three types of liquid biofuels that can be produced from microalgae biomass: biodiesel, bioethanol and biocrude oil.

## The algae principle



Phototrophic algae growth requires the input of sunlight, water, CO<sub>2</sub> and nutrients, converting these into biomass and oxygen. Heat and sunlight make Qatar a prime location for algae production.

**Biodiesel** Biodiesel production from microalgae is based on the oily lipid component. The amount of lipids in the biomass is dependent on the algae strain, as well as the cultivation conditions and can reach up to 60% of the biomass dry weight. The lipid is extracted using chemical solvents. Using a transesterification process similar to that used for vegetable oil, this extract can be chemically converted into biodiesel.

**Bioethanol** Bioethanol production from microalgae focuses on a single, but different, component of the biomass: the sugars (carbohydrates). The carbohydrate content of microalgae can reach 70% of the biomass dry weight and consists of starch and cellulose, which are easily converted to ethanol. After extraction of these sugars, a microbial fermentation process converts the sugars to ethanol and carbon dioxide, after which distillation and purification are applied to acquire bioethanol, which can be used as a gasoline replacement.

**Biocrude oil** Hydrothermal liquefaction is a novel process in which the entire algae biomass is converted into an oil, chemically similar to light, sweet crude, with a complex mixture of light and heavy compounds, aromatics, phenolics, hetero-

cyclics and alkanes. This biocrude oil can be 'dropped in' to conventional refineries to create a variety of refined products.

## Algae in Qatar

Qatar is among the best places in the world for large-scale microalgae production. It has 3,200 hours of sunlight per year and an average temperature of 32°C. Furthermore, the availability of CO<sub>2</sub> from industrial flue gases, seawater, non-arable land and end users such as the aviation and livestock industries, make Qatar a prime location for algae production. With this in mind, a dedicated research group was established at Qatar University to develop algae-derived biofuel.

The establishment of an outdoor testing facility, with the capacity to grow 150,000 litres of microalgae biomass, enabled further development and scale-up, followed by demonstration at lab scale for analysis. Algae productivity was optimised for selected strains, showing promising results, up to 50% higher compared to Europe.

*Kira Schipper is a Research Associate with the Qatar University Algal Technologies Program, which works on developing algal technologies for sustainable applications, ranging from renewable energy to bioremediation and food security.*



Open raceway ponds at Qatar University; algae harvest cycles are just 1-10 days.

# Economics of biofuels feedstocks

By David Zilberman and Benjamin Gordon, University of California

We're still in the early stages of renewables but 'learning by doing' will increase profitability.

Historically, society relied on biomass to fuel transportation. Animal energy complemented human energy. Biofuels were initially used to power early engines, even including internal combustion engines. The discovery of petroleum changed everything and biofuels were relegated to a minor role in developed nations. However, concern about energy scarcity (reflected by the rising price of oil in the early 2000s), energy security and climate change have given rise to a renewed effort to introduce biofuels as a source of energy to replace transportation fuels, as well as primary energy production.

The economics of biofuels are rather simple. Their costs include feedstock production, processing, conversion and transportation. Our focus here is on the economics of feedstocks. Biofuels are profitable when the income generated through energy content and additional benefit from improved octane relative to fossil fuels are greater than overall costs. This calculus is also affected by subsidies and production may be increased by mandates. Furthermore, access to biofuels may be constrained by land-use restrictions and lack of infrastructure for biofuel intensive cars (e.g. E85).

But within a market economy, the economics of biofuels will improve as their cost of processing, conversion and transportation decline – this has been an area of much research. This section will emphasise the economics of feedstock production.

Feedstocks can be divided into three categories: food crops (corn in the US, wheat and sugar cane in Europe for gasoline, and soya bean, canola and palm oil for diesel), energy crops (switchgrass, miscanthus and wood) and algae. They are profitable if the revenue from production (price times yield) is greater than production costs (fertiliser, labour, cost of land, etc). The price received for feedstocks may reflect their value in production of biofuels as well as revenue gained from the value of residue products. For example, bagasse, the residual generated during the refining process of sugar cane, is used for power generation. In the case of corn, dried distillers' grain (DDGs) is used for animal feed. A major contributor that enhances the profitability of feedstocks is the ability to utilise residual products' profitability. One contributor to the profitability of corn ethanol is improvement in the utilisation of DDGs that may generate up to a third of the overall revenue.

Since the introduction of biofuels, the price has been highly correlated with the price of food and fuels. For biofuels based on food crops to be profitable, the price of biofuels relative to food needs to be sufficiently high. Biofuels producers in Brazil suffered when the price of fuel was capped around 2010.

Another key component for the profitability of feedstocks is yield. Corn productivity has increased drastically over the past 100 years – in the US, it has grown more than tenfold to up to 11 tonnes per hectare (10,000m<sup>2</sup>). However, the yield is about 5 tonnes per hectare in China and 1 tonne in Africa. This was a major contributor to the profitability of corn ethanol in the US. Similarly, the high yields of sugar cane in Brazil have contributed to the overall profitability of this sector. Fluctuations in yield

due to weather or ageing of the average crop have been contributors to the variability of profitability of biofuels. The inability of yield per acre has limited the profitability of wheat-based ethanol as well as biodiesel production from crops like soya beans and rapeseed. The survival of these crops is mostly because of government support or regulation. One biofuel feedstock that has the revenue potential to be profitable in production of biodiesel is palm oil, but its use in biofuels is limited due to high demand in the food market and environmental challenges associated with supply.

One of the major objections for using food crops for biofuel is the food/fuel tradeoff. The introduction of biofuels caused a significant price shock around 2008. But over time, its contribution to food-price increases has been quite modest. One impetus to the introduction of energy crops is that they do not seem to impact food supply.

There are several energy crops that are considered for production of gasoline substitutes in the US, including residues of food crops (corn stover), grasses (miscanthus and switchgrass) and fast-growing trees like poplar. Relative profitability and suitability of energy crops vary by location. Jatropha and other oil-rich crops have been promoted for biodiesel, especially in developing countries. For the most part though, energy crops have not been profitable without subsidies and mandates. Efforts to produce biofuels from algae (mostly biodiesel) show some promise. The profitability of the biofuel content by itself is limited, but profitability may occur if it is produced in conjunction with other higher value products.

Two forms of regulation – direct subsidies and mandates – have increased the production of biofuels but have received heavy criticism from economists on efficiency grounds. However, some biofuels reduce greenhouse-gas (GHG) emissions compared to the fuel they replace and their profitability should be enhanced if they are compensated for this effect. The GHG-reducing effect of

biofuels is the gain from sequestering carbon in crop production minus the energy required in production (including inputs), processing and transport. Another cost is the additional emissions due to indirect effects of biofuels, including land-use change and fuel use, which seems to be modest. Overall, sugar-cane ethanol and cellulosic ethanol may reduce GHG emissions by up to 70% compared to the gasoline they replace, while corn ethanol results in very modest savings.

Biofuels are still in the early stages. One feature of the biofuels sector is the continuous increase in profitability because of learning by doing. Their profitability is likely to improve as the cost of processing cellulosic ethanol declines and technology improves. Furthermore, studies have shown that sugar-cane biofuel production in Brazil could increase tenfold and bagasse could provide 14% of world transportation fuel demand. Production of feedstocks will expand even further if restrictions on genetically modified organisms are lessened along with the introduction of gene-editing technology to agriculture.

Biofuels are part of an ongoing effort to replace fossil fuels with renewable resources. It has already achieved a modest, yet significant, share in overall transportation fuel supply. While government policies have been essential to the introduction of biofuels, some segments of the sector are becoming economically self-sustainable. Its future depends on the capacity to increase production and processing and maximise biofuels' contribution to both social and environment efforts.

*David Zilberman is a professor whose expertise includes agricultural and environmental policy, water, marketing, risk management, the economics of innovation, natural resources, biotechnology and biofuels. Benjamin Gordon is a writer, editor and researcher at the University of California, Berkeley, focusing on agriculture and resource-management issues to drive change in policy and practice.*



# Alternative feedstocks for biofuels

By Marie-Hélène Labrie, Enerkem

Innovation is making waste material a sustainable biofuels business.

Sustainable business, once considered an empty buzzword that was introduced into the corporate landscape through environmentalism, has evolved into something that is part and parcel of doing business today. Sustainable business no longer means just 'green business', nor is it a select group of companies looking to offset negative environmental impacts. It represents enterprises that are committed to progress around issues of environment, community, society or economy – a business that strives to meet the bottom line.

Advanced biofuels play a significant role in sustainable business. More than 60 countries have blending mandates to increase renewable-fuel content and numerous corporations are integrating blended fuels. Ethanol represents more than three-quarters of global biofuels consumption, making it one of today's most proven alternative sources of energy.

There's more than one way to produce biofuels and more than one kind of feedstock. Interestingly, my company, Enerkem, takes the approach of leveraging an existing problem, on top of the already present demand for low-carbon transportation fuels, and transforms a feedstock into

something useful, affordable and sustainable. Our solution is waste, which can be your solution too.

According to the World Bank, global solid-waste generation is estimated to triple by 2100. By 2025, it is estimated to grow by 70%. The environmental cost of managing this is enormous. The financial cost is massive as well; the price of dealing with waste globally has grown steeply from \$205bn per year in 2010 and is on pace to cost \$375bn annually by 2025.

Enerkem has actualised what was once a revolutionary idea: manufacturing biofuels and renewable chemical products from non-recyclable urban waste. This is now a commercial reality in Edmonton, Canada, where the first full-scale facility to produce biomethanol from municipal solid waste is located, a partnership between Enerkem, the City of Edmonton and Alberta Innovates – Energy and Environment Solutions. It is a significant development in the waste and biorefinery sectors and one of the first commercial advanced biorefineries; second-generation ethanol production is also planned.

Ours is an innovative, sustainable solution for energy diversification, a more circular economy and better waste-management practices. It is built on the very foundation that defines sustainable business. Our technology uses municipal solid waste instead of petroleum to produce the lowest-cost liquid transportation fuels and chemicals relative to alternative-production methods. Each of our waste-to-biofuels and chemicals facilities bring value to communities and waste-generating industries, while offering a sustainable and economical alternative to landfill and incineration.

Our biorefinery process converts waste into a pure synthesis gas (syngas) and this syngas is then cleaned and converted into biofuels and other chemicals using catalysts. In less than five minutes, waste destined for landfill becomes transportation fuels or renewable chemicals, which can then be used to form other products.

The carbon contained in mixed waste undergoes a chemical recycling to be converted into methanol and ethanol – building blocks for olefins and acrylates and ideal additives for conventional fuel.

In addition to establishing partnerships and licensing technology, we provide modular equipment and handle assembly on-site. We are also developing processes to 'bolt-on' to current waste-to-chemicals equipment and oil-production facilities to offer a broader range of renewable chemicals and transportation fuels.

Demand for biofuels from the oil industry is rising, while solid-waste volumes are increasing, but change is possible. So as companies continue to grow and seek the most effective ways to run their business, solutions are available and can answer multiple problems at once, while biofuels that are anything but rubbish.

Marie-Hélène Labrie is Senior Vice President, Government Affairs and Communications at



The Enerkem Alberta Biofuels plant in Edmonton, Canada will increase the city's waste diversion rate from 50% to 90%.

Enerkem. Labrie is involved in numerous boards of directors such as the Canadian Renewable Fuels Association, Écotech Québec and the Conseil des Entreprises en Technologies Environnementales du Québec. She also represents Enerkem at the Advanced Biofuels Business Council.



The world's first full-scale waste-to-biofuels facility has a production capacity of 38 million litres of methanol a year; ethanol will follow.

# Biofuels and sustainability

By Artemis Kostareli, IPIECA

The strongest driver for renewables is a reduction of greenhouse-gas emissions, but careful and effective management is required.

Biofuels are an integral part of the road-transport fuel scene. Governments grant incentives and impose mandates, while research institutes and companies develop new technologies and pathways to convert biomass into substitutes for conventional fossil fuels such as gasoline and diesel.

These initiatives aim to capitalise on the positive effects that biofuels have on greenhouse-gas (GHG) reduction, energy security and rural development. However, large-scale introduction of biofuels can also have negative environmental and socio-economic effects, and these effects have spurred a worldwide debate on the sustainability of biofuels, including their effect on food prices.

All sections of society, including policymakers, the petroleum industry and those living on agricultural land have a role to play in ensuring that biofuels development is effectively regulated, so that the economic and environmental benefits may be realised in a sustainable manner.

The social benefits of biofuels for the transport sector depend on the ways in which biomass is grown and converted to biofuels, i.e. the biofuels system as a whole. Benefits can include improve-

ment of energy security, rural development and the reduction of GHG emissions.

Biomass is a renewable but limited resource which, even in optimistic scenarios, can only be expected to cover a fraction of the world's energy needs. If GHG reduction is the prime objective then governmental policy should ensure that biomass is used where it maximises GHG avoidance, or where it is the best available alternative to replace carbon-intensive energy products. This can only be achieved through assessing and comparing different ways to use the available bio resources. These may be different from country to country; this should be recognised when regional mandates for biofuel utilisation are considered.

## Drivers for biofuels development

### National or regional security of energy supply

The largest oil-consuming countries are increasingly aware of their dependency on oil-producing countries and seek to develop more diverse and secure supplies. Biofuels, particularly when grown domestically, but also when imported, can contribute to supply diversity and security. If security of supply is the main objective, actions should target those sectors that import energy.

In the US, this is primarily the transport sector, as most electricity and heat is generated from domestic coal, gas and other sources. In Europe, transport relies on imported energy and the heat and power sector is also dependent on imported gas. In such a case, using biomass to generate electricity or biogas for heating may also address the energy security issue.

### Supporting agriculture and rural development

For developing countries, biofuel programmes could be beneficial in supporting rural communities. Developing countries are often looking for suitable cash crops to support rural development and biofuel production is seen as a way to bring income to farmers through increased profits or, in



With energy security an increasing problem for large, oil-consuming countries, a diversification of fuel options can provide part of the answer. Biofuels also have benefits of reduced GHG emissions when compared to fossil fuels and provide rural jobs at the feedstock level.

cases where biofuels are not cost-competitive with fossil fuels, through government subsidies. The extent to which biofuels programmes can contribute to rural development is dependent on the characteristics of the industry (scale, modernity, integration) and whether it can become viable without direct government financial support.

As an example, the Brazilian ethanol model is based on agricultural production that includes:

- Many small-scale cane producers (but still large by developing-country standards).
- Large but not monopolistic mill/distillery complexes that generate electricity for themselves and for sale to the grid.
- A nationwide ethanol-supply system that is integrated with urban, social and industrial development. The Brazilian model also benefits from land area, sufficient water, favourable climatic conditions, low-cost labour and an efficient co-operative system with short raw-material transport distances. Duplicating this in other countries may be possible but will be a challenge.

### GHG emissions reduction

Reducing GHG emissions in order to mitigate climate change has become the strongest driver for biofuels. The GHG footprint of biofuels can, however, be very different depending on where, how and from what they are produced. The net GHG avoidance of ethanol produced in Europe can, for example, range from virtually 0% to more than 80% compared to fossil gasoline. The main factors affecting this balance are the crop and the conditions under which it is grown, the origin of the energy used in the biofuel manufacturing process and the fate of by-products.

### Biofuels and sustainability

Large-scale development of biofuels raises a number of concerns relating to competition with food and pressure on land resources, potentially leading to reduction in food availability, increased food prices and encroachment on sensitive land areas and forests. In some cases, when biofuels production causes clearing of high-carbon content land, substantial CO<sub>2</sub> emissions can be pro-





When farmers convert to production of biofuels feedstocks, assessments should be made on the effect of land-use change.

duced that may impact the GHG emission benefits of a biofuels system for decades.

There are two types of effects from land-use change. There is the direct effect: GHG gases can be released when converting land to certain crops (e.g. by releasing GHG gases such as methane,  $N_2O$  and  $CO_2$  from the soil or when biomass is burnt to clear land) and the indirect effects of land-use change which are derived by similar mechanisms but are much more complicated to estimate. Many of these effects can only be assessed by considering the performance of specific biofuels systems as well as effects from outside a biofuel system's boundaries.

Converting land to biofuels production will impact on the supply/demand balance of the crop previously produced. A decrease in production of a crop in one part of the world can lead to increased production elsewhere, and hence to land-use change. Currently, there is no consensus

on how to best calculate direct or indirect effects of land-use change. Without consensus, there can be no agreement on the size of this effect, which is why current estimates vary greatly.

Increased agricultural and biofuel production, if not carefully managed, has the potential to threaten global biological diversity. Biofuels crop production at industrial scale replaces the existing natural variation, which means that vegetation would be less varied and the ecosystem less resilient to support diverse fauna. Therefore, a land-use change impact assessment should be considered when introducing new crops.

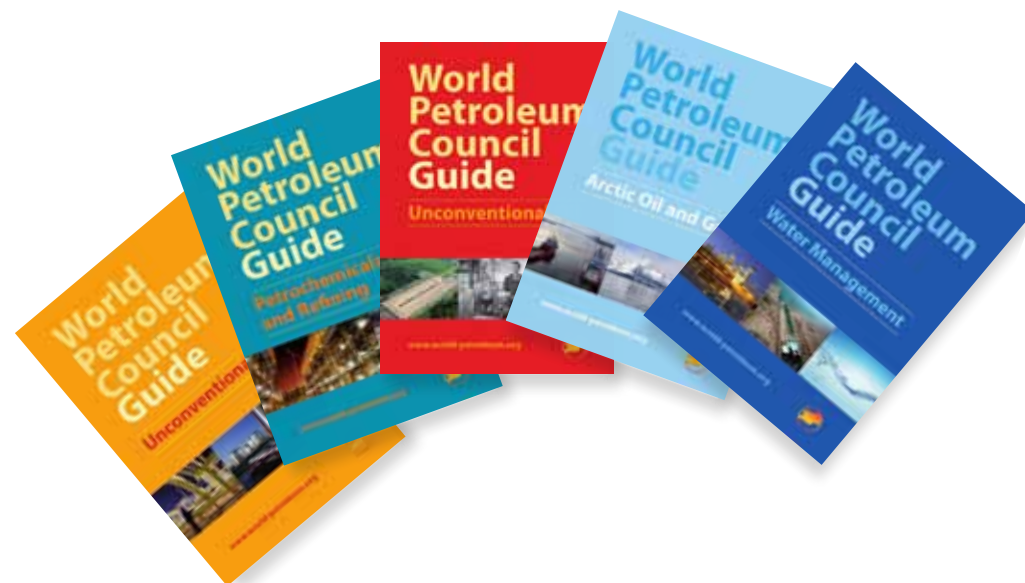
To effectively manage the impact of biofuels, an internationally recognised certification scheme is called for. Such a scheme should include an analysis of the GHG footprint of biofuels, an assurance on food competition and an assessment of the environmental and social issues associated with production. Only through this process can biofuels be properly judged for sustainability.

#### Next-generation biofuels

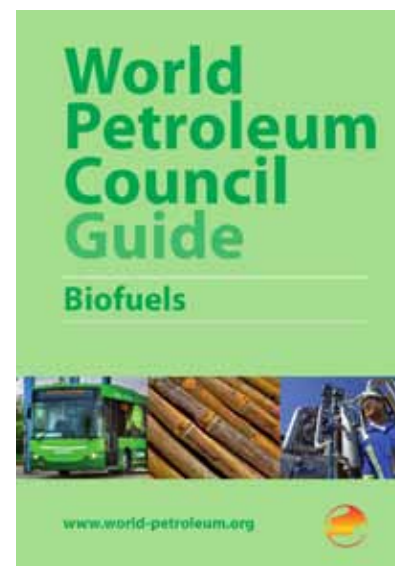
Biofuels' sustainability requires commercial viability. This means increasing the efficiency of the production, the supply chain and the availability of certified products. The oil and gas industry has the capabilities to overcome these challenges.

Oil and gas companies are already working with academic institutions, R&D centres and other business sectors in the development of next-generation biofuels, which includes cellulosic ethanol and biodiesel from algae. These advanced products are expected to overcome many of the trade-offs associated with today's biofuels, including deforestation and environmental destruction, and improve their sustainability.

*Artemis Kostareli is Manager of Fuels and Products, Supply Chain and Health at IPIECA. She has been with IPIECA, the oil and gas industry association for environmental and social issues, since 2012.*



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# Biofuels in transport

By Dina Bacovsky, Advanced Motor Fuels Technology Collaboration Programme

Renewables are with us for the long haul but fossil fuels will continue to share the fuel tank.

Since the creation of the internal combustion engine, liquid biomass fuels have been among the fuels considered. Nikolaus Otto used ethanol as fuel in 1860 and Rudolph Diesel first demonstrated the use of vegetable oil in 1900. However, with the availability of cheap petroleum products



The largest ethanol producer in the world is POET, based in the US. It makes corn-based and cellulosic ethanol from 27 plants.

from 1910, engine developers optimised their engines for gasoline and diesel.

Interest in alternatives rose during the world wars and later in the 1970s oil crisis. In 1975, Brazil established the National Alcohol Program (Proálcool) and pushed ethanol production and the implementation of vehicles that could operate on neat hydrous ethanol. In the US, the Energy Tax Act of 1978 enabled the first corn ethanol industry to grow. In South Africa, the process for the transesterification of vegetable oil to biodiesel was established in 1979 and in 1985, a pilot plant for biodiesel production started in Austria.

Drivers for biofuels are:

- New outlets for agricultural overproduction.
- Diversification for energy security reasons.
- Reduction of energy-related greenhouse-gas (GHG) emissions.

## Advanced biofuels

With the introduction of national mandates for biofuels in several countries, production of biodiesel and ethanol rose quickly in the early 2000s. For a while they were seen as the solution to several problems, reducing dependence on oil and lowering GHG emissions while also providing income to rural regions. Feedstock production for biofuels grew, as did international trade, and this created concern over environmental impacts. Reports of palm-oil plantations causing rainforest clearings in Indonesia and Malaysia, and about ethanol demand driving corn and, consequently, tortilla prices up in Mexico, caused opinion on biofuels to turn. The positive effects on the climate and for society were questioned, and to maintain support, positive effects had to be proven.

At this point, the EU and the US introduced minimum GHG-emissions savings which had to be proven for biofuels. The sustainability criteria introduced by the EU includes:

- A requirement to produce at least 35% less GHG emissions (increasing to 50% from 2017



In the early 2000s, assisted by mandates, biofuels production increased. To meet demand, feedstock production had to rise, with a wide variety of options proving useful, including (clockwise from top left) sugar beet, woodchips, straw, jatropha, rapeseed and sugar cane.

and 60% from 2018 for new installations) than their fossil equivalents.

- A prohibition on growing feedstock for biofuels on land with high carbon stock or high biodiversity, such as forests or grasslands. A cap of 7% has been placed on biofuels made from feedstock used for food and feed. Consequently, biofuels producers had to improve their installations to meet GHG-emission targets and feedstock had to be certified for sustainable production. Developers turned to residues and waste materials as feedstocks and aimed to develop their technologies accordingly.

The main biofuel production pathways that have emerged are cellulosic ethanol (made from agricultural residues such as corn cobs or wheat straw) and the gasification of woodchips or straw to produce a syngas from which a variety of synfuels can be produced. Products of the syngas route include methane, methanol, dimethyl ether (DME) and Fischer-Tropsch diesel.

Other routes include biodiesel from used cooking oil, the use of inedible oils for biodiesel production, the fermentation of sugars to hydrocarbons and the cultivation of microalgae.

## Non-road transport sectors

### Shipping

The shipping and aviation sectors represent about 10% of the global transport fuel demand, and both are investigating the use of biofuels.

The shipping sector is driven by new legislation that defines emission-control areas in which ships have to use lower-sulphur fuels or sulphur-oxide exhaust scrubbers. Fossil-fuel options are ultra-low-sulphur diesel, marine diesel oil, marine gas oil, methanol, DME, liquid propane gas (LPG) and liquefied natural gas (LNG). Biofuels include vegetable oil, biodiesel, hydrotreated vegetable oil (HVO), pyrolysis oil, biomethanol, bio-DME and biomethane. Several shipbuilders and operators have recently turned to methanol or LNG. Biofuels are technically feasible but not yet substantially used in shipping.

### Aviation

Although currently there is no regulation in place to cut GHG emissions from aviation, this is seen as a challenge to face. Aircraft manufacturers have expressed interest in biofuels. Specifications for aviation fuels are very stringent but biofuels are



Biofuels are yet to be embraced by shipping operators. With strict emissions regulations on the seas, liquified natural gas is an option.

being tested by airlines and air forces, and they have also been used in commercial flights.

### Fuels derived from natural gas

Natural gas can be used either as compressed natural gas (CNG) or liquefied natural gas (LNG, more common for shipping). In Otto engines, natural gas can be used either stoichiometric or lean-burn. The lean-burn concept is more energy efficient, whereas the stoichiometric engine efficiently controls emissions with a three-way catalyst. Another concept – used in diesel engines – is dual-fuel technology, which uses diesel fuel to ignite the natural-gas/air mixture. All natural-gas engines deliver low particulate matter emissions.

Most countries limit the amount of methanol allowed in transport fuel but in China, methanol is

used in blends with gasoline from 5% to neat. Methanol can be used in Otto engines and, similar to ethanol, it reduces emissions of hydrocarbons, carbon monoxide and nitrogen oxides.

### Electric drivetrains

Electrification and hybridisation of drivetrains have recently received much attention for their ability to reduce regulated vehicle-exhaust and GHG emissions. In 2015, 1 million electric vehicles were on the road worldwide.

Despite all efforts, market penetration of electric vehicles is still slow, and thus internal combustion engines and electric drivetrains will be in place next to each other for some time.

Biofuels, natural gas-derived fuels, advanced internal combustion engine technologies and electric vehicles all have benefits to offer exhaust- and GHG-emission reductions and should be part of a comprehensive mix of fuels and drivetrains. Both biofuels and modern engine technology can offer GHG-emission reductions and reduced exhaust emissions for all transport sectors.

*Dina Bacovsky is Secretary of the Advanced Motor Fuels Technology Collaboration Programme and the Austrian delegate to IEA Bioenergy Task 39 (Liquid Biofuels). For more details see [www.iea-amf.org](http://www.iea-amf.org), [www.task39.org](http://www.task39.org) and [www.demoplants.bioenergy2020.eu](http://www.demoplants.bioenergy2020.eu)*



A number of airlines have trialled biofuels on commercial flights, while the US Air Force has been flying F-16s on 50/50 blends.

## Upwards and onwards: Etihad Airways and BIOjet Abu Dhabi

**BIOjet Abu Dhabi's** long-term aim is the sustainable production of aviation biofuels in the United Arab Emirates, from the supply of feedstocks to biorefining and distribution.

**Richard Hill, Chief Operations Officer at Etihad Airways**, explains his airline's commitment.

### WPC: Why did Etihad Airways become involved with BIOjet Abu Dhabi?

**Richard Hill:** We acknowledge the role that alternative fuels will play in the sustainability of the airline industry. Etihad Airways sees partnership as essential to ensuring change and this strategy is applied extensively in the airline's commitment to alternative sustainable fuels. There are two main initiatives that Etihad is engaged with; firstly, in ensuring extensive stakeholder collaboration to set the map for a viable alternative aviation fuels industry; and secondly, to identify locally produced sustainable feedstocks in a desert environment.

### What is Etihad's role in the partnership?

While Etihad Airways' support for alternative fuels started in 2009, it was in 2014 that BIOjet Abu Dhabi was announced. It's a collaboration between Etihad Airways, Boeing, the Masdar Institute, Takreer and Total. Etihad Airways is wholly committed, confirmed through its \$2m contribution to the Sustainable Bioenergy Research Consortium (SBRC) and its leadership role in BIOjet Abu Dhabi.

### What are the feedstocks and processes involved?

Led by the Masdar Institute, with funding partners including Etihad Airways, Boeing, Takreer, Safran and General Electric, the SBRC is pioneering the Seawater Energy and Agriculture System [SEAS]. SEAS is an effort to develop a novel form of agriculture, producing food and fuel on traditionally non-arable desert land irrigated with seawater. There are three integrated

production systems of SEAS that leverage each other's co-products for sustainable operations. There are aquaculture ponds, isolated from coastal waters in which shrimp or fish are grown, partly fed by meal from halophytes [salt-tolerant plants]. Then there are fields of halophytic plants that are irrigated by nutrient-rich discharge water from aquaculture ponds, producing oil and biomass fuel feedstocks, animal feed and high-value chemicals – transforming an aquaculture pollution problem into a fuel, chemical and fertiliser resource. And there are also created mangroves that eliminate nearly all remaining nutrients before the water is discharged into coastal waters, and can provide biomass from coppiced trees.

### What are the advantages of aviation biofuels?

Sustainably produced aviation biofuel reduces carbon emissions by 50-80% through its lifecycle.

### Do you view BIOjet Abu Dhabi as an investment in Etihad's future?

Absolutely. The project is a great example of public-private collaborations that we believe are essential to stimulating innovation and driving change within the transportation industry.

### What is the future for aviation fuel?

The airline sector is committed to reducing its greenhouse-gas emissions and has set a target of carbon-neutral growth from 2020. The use of these fuels will significantly contribute towards achieving that target. Aviation is one of the strongest-growing transport sectors and this trend will continue. In the period up to 2030, aviation is expected to grow by 5% annually. The demand for aviation fuels is expected to increase by 1.5-3% per year. Renewable jet fuels derived from biomass offer the largest opportunity to reduce emissions while ensuring fuel security. **LG**



# Biomass for power generation

By Lee Gale, ISC

In the UK, Drax Power Station's upgrade from coal to compressed-wood pellets is cutting emissions.

Despite the industrial ravages of the 1980s, the landscape of Doncaster in England's unfeasibly flat north-east is still one of railway sidings, chimneys and canals. There is, however, a recent exclusion from the horizon. Colliery winding gear, so long a feature of the terrain, has vanished, although from

the window of a Hull-bound train you'll still see the odd slagheap, sprawling like an oversized, fast-asleep Labrador. Coal, which powered the industrial revolution and the engines of the British Empire, is no longer mined in Yorkshire. In 1984, there were 56 pits in the region but the 2015 closure of Hatfield and Kellingley collieries brought to an end an industry that had been active since Roman times.

The one-time abundance of Yorkshire mining encouraged the arrival of major power stations, the largest of which, Drax, was opened in 1974. Despite sharing a name with a James Bond villain, the power station takes its title from a nearby settlement. In fact, the power station has a larger workforce (around 1,000) than the village of Drax has inhabitants (488).

In the lowland triangle between Doncaster, Selby and Goole, the 4,000MW power station is viewed in a positive light, not least because it is a large employer in an area that has struggled with job security for decades. Stray beyond the boundary and Drax's perception dips. It is a known poll-

uter; in 2007, it produced over 22 million tonnes of CO<sub>2</sub>, a fact Drax's Chief Executive Dorothy Thompson was uneasy about: "We were the centre for a lot of protests and actually we were not comfortable with it ourselves," Thompson voiced.

Once inside the perimeter fence, the enormity of the dozen 114-metre-high, natural-draft cooling towers and the 259-metre-high reinforced-concrete chimney – the highest industrial chimney in the world when built – is overwhelming. Drax produces 7-8% of the UK's electricity but in an attempt to reduce emissions, a huge decarbonisation project was initiated. In 2004, the power station trialled the burning of biomass and hasn't stopped. Three of Drax's six units have been upgraded to run on biomass instead of coal, which has led to a halving of its carbon footprint in five years. Currently, two are 100% biomass and the third is using approximately 85% biomass, with a full conversion planned if the power station can gain state-aid approval. Upgrading turbines has further reduced Drax's CO<sub>2</sub> emissions by a million tonnes a year.

The essential differences of coal and compressed-wood biomass are instantly apparent as you wander into the interior of the site. Coal is stored in the open, beneath grey Yorkshire cloud mass, but biomass pellets are useless when damp so are housed in four purpose-built, 50-metre-high domes, each capable of holding 80,000 tonnes. Typically, pellets are made up of compacted treetops from logging operations and sawmill waste; they smell a little like hamster food. Drax consumes 7 million tonnes of pellets a year. To put this into perspective, the US produces 93 million tonnes of biomass waste annually.

Pellets give off a fine dust and because of this, are highly prone to spontaneous combustion. Drax treats biomass as if it's gunpowder, which is why nitrogen is pumped into the domes to avert the sort of freak blazes seen in recent years at the UK's Tilbury and Ironbridge power stations. Nothing is left to chance.



A turbine stands waiting to be installed in the power station's turbine hall; upgrading turbines greatly reduces emissions.

On average, 17 biomass trains arrive at Drax each day, six days a week, from the Port of Tyne, Immingham, Hull or Liverpool, packed with pellets sourced from around the world, but predominantly from the US and Canada. Unfortunately, as we viewed a drop-off, the DB Schenker Class 66 locomotive on the front was having mechanical issues – a rare occurrence – but it allowed close inspection of Drax's massive stainless-steel bio-



An assignment of pellets that originated from Portugal arrives during our site visit. Each of Drax's hoppers carries 72 tonnes.



Specially-made, nitrogen-filled biomass domes house Drax Power Station's supply of biomass pellets, while coal lies open to the elements.





Note the large springs: once the biomass is jettisoned from the rail wagons, these shake the biomass onto a conveyor belt.

mass wagons. At 18.9 metres long and capable of carrying 71.6 tonnes of pellets, they are 30% bigger than any other freight wagon in the UK; 200 are in operation.

Whether coal or biomass, power stations mostly burn dust. To achieve this at Drax, raw material is ground to smithereens by 10 large ball bearings inside a Babcock & Wilcox pulverising mill. The powder is then blasted into one of six 15-storey-high, 4,000-tonne boilers. A pellet, or what remains of it, will last under a second in the furnace. Roughly twice the amount of biomass is needed than coal to produce the same amount of power.

Drax sources its wood pellets from sustainable forests – what it calls ‘good biomass’ (‘bad’ being from unsustainable sources). Before a consignment is shipped to Yorkshire, suppliers must pass strenuous screening and sustainability audits, conducted by independent bodies. Rigid requirements are written into contracts and if there is evidence that strict standards are not being met, Drax will terminate the contract and find alternative sources. It also complies with sustainability standards set out by the British independent regulator Ofgem. Since upgrading to biomass, Drax has reported an 86% carbon saving compared to coal and with plans to go fully biomass if it can attain government support, the carbon saving will further increase.

Roused by R&D, power-generation technology forges ahead with an ingenuity that we would hardly have believed possible at the turn of the century. As the International Energy Agency has recently stated, “In the 2°C scenario, almost 30% of direct industrial CO<sub>2</sub> emissions reductions by 2050 hinge on processes that are in development or demonstration today.” It’s easy to assume that Drax, frequently labelled a ‘dinosaur’ due to its previous pollution figures, will ultimately face the same extinction as the nearby collieries that once



Drax has four biomass domes on site, fed by 102 trains a week. Burning biomass has led to an 86% carbon saving compared to coal.

supplied it. More likely, biomass and coal will continue to play their part among an ever-widening array of power-generating options in the UK, with natural gas leading the pack. Of course, there are still emissions caused by transportation, but if Drax’s primary fuel source makes use of waste from certifiably sustainable timber in a programme that

increasingly strives for carbon neutrality, it’s a difficult proposition to ignore.

**For tours of Drax Power Station in Yorkshire, visit [www.drax.com/education/visit-drax](http://www.drax.com/education/visit-drax)**

*Lee Gale is Managing Editor at International Systems and Communications.*

## Bright sparks: building a 21MW biomass plant in just over a year

*By Mark Wickham, Managing Director and founder, HRS Energy*

*In the UK, HRS Energy’s new 21MW biomass plant near Hull will heighten efficiency for renewable-electricity generation.*

Biomass is one of the most important forms of renewable energy, playing an essential role in efforts to move to less carbon-intensive power generation. It’s a clean source of energy that, unlike solar and wind, is not at the mercy of the elements. Of course, some fuel sources are more sustainable than others, which is why we’ve gone to great lengths to source a recycled-wood supplier to power our new 21MW biomass power plant at Tansterne near Hull.

For the Tansterne project, HRS Energy is responsible for the whole package, from design to the building and installation of the power plant. With enough carbon-neutral, clean energy to power 11,000 homes, Tansterne will make a considerable contribution to the renewables provision in the region. With our standardised modular design, the plant will be operational and generating electricity by March 2017.

In simple terms, the Tansterne plant will take in recycled wood and convert it into heat to fire a boiler. This, in turn, generates steam that drives a turbine to produce electricity. The two-stage combustion process takes place on a fluidised bed of finely sieved sand, limestone or ash; the fluidity is provided by a stream of high-pressure air. The behaviour of the bed is similar to boiling liquid, with vigorous movement and mixing. This air, fuel and bed material creates rapid heat

transfer, efficient combustion and low emissions. With this, and flue gas-condensing technology, we can convert a wide range of biomass products into power at a cycle efficiency of around 35%.

We use a ‘black-box’ approach to generating power. This means that all the equipment necessary fits into a single, compact module, with a much smaller footprint than traditional biomass plants. Furthermore, the shorter interconnecting ducts, pipes and cables mean the cost is reduced.

Using HRS technology, biomass projects like Tansterne are a viable investment. A 21MW biomass power plant can be ready to use in 15 months at a cost of around £75/MWh, which is similar to new combined cycle gas turbines (the cheapest form of new generation). In this way, our plants address each aspect of the energy trilemma – affordability, security of supply and environmental sustainability. Whichever way you look at it, biomass makes sense.

*Mark Wickham founded HRS Energy in 2008 after holding a number of senior roles with other energy firms. Wickham has led HRS (Heat Recovery Solutions) to year-on-year growth and the company’s innovative designs are now found in countries around the world. A qualified mechanical and civil engineer, Wickham has developed several patents for gas-turbine heat recovery and power plants. A 21MW biomass power plant in northern England is the company’s latest project and provides an interesting snapshot into how this form of renewable energy is being pushed forward.*

# Ethanol

By Bliss Baker,  
Global Renewable Fuels Alliance

Sustainable and with production rising exponentially, ethanol is a key part of the global fuel complex.

Ethanol, or ethyl alcohol, is produced from starch and sugar-based feedstocks like corn and wheat grain, sugar cane and sugar beet, as well as cellulosic feedstocks, such as woodchips or crop residues. In recent years, global ethanol production has hit record levels, with consistent growth expected. Rapid expansion of use since the 1980s has been driven mostly from ethanol-blended fuel.

Fuel ethanol is currently produced in more than 50 countries from a variety of feedstocks and its production has increased more than threefold from



Thirteen of the 20 most-polluted cities are in India but Scania's ethanol Green Bus has recently been introduced in the country.



A wide range of feedstocks can be used in the production of ethanol, including woodchips, straw and crop residue.

2004-14 to over 90 million litres. It is expected that ethanol production will exceed 145 million litres by 2030, even with a conservative annual growth rate of 2.8%.

According to a report by the International Energy Agency, sustainable biofuels, like ethanol, could provide 27% of the world's total transport fuel by 2050 and avoid around 2.1 gigatonnes of CO<sub>2</sub> emissions per year, with biofuels eventually providing 20% of total emission savings in the transport sector.

Around the world, public-transit systems are increasingly adopting ethanol-fuelled vehicles as part of the global drive to reduce greenhouse-gas (GHG) emissions from transport fuel. It is estimated that emissions savings from ethanol use in the transport sector could rise from 168.9 million tonnes per year in 2014 to 264 million tonnes CO<sub>2</sub> equivalent in 2030. This represents a 56% increase in GHG emissions reductions in that time.

With consumer demand for alternative-fuel vehicles, manufacturers are working to produce more flex-fuel vehicles (FFVs), which are capable of operating on E85 (85% ethanol and 15% gasoline), regular gasoline, or any combination of the two.

FFVs contain a fuel sensor that detects the ethanol/gasoline ratio. A number of other parts on the FFVs fuel-delivery system are also modified so that they are ethanol compatible. The fuel tank, fuel lines, fuel injectors, computer system and

anti-siphon device have been modified slightly from gasoline-only vehicles.

In addition to its GHG-reduction benefits, ethanol has an octane rating of 113. When ethanol is added to gasoline, it boosts the octane level of the resulting blended fuel. For example, low-octane gasoline can be blended with 10% ethanol to attain the standard 87-octane requirement. At higher concentrations, ethanol will produce 89, 91 and 94 octane ratings when blended with gasoline.

As a result, ethanol has become established as a proven performance fuel. It is the fuel of choice for NASCAR, Indycar, American Le Mans and the US National Boat Racing Association. The Ferrari Formula 1 team uses a blend that contains ethanol.

The high-octane rating of ethanol also makes it ideal for use in smaller and lighter engines that require a higher energy content than is available from gasoline alone. It has been utilised in all engine types, including off-road engines (two-stroke and four-stroke), marine engines and motorcycles as a safe and desirable alternative to straight gasoline because it burns cooler and cleaner.



In 2010, Ferrari started using an ethanol blend in its Formula 1 race fuel. The ethanol, produced by Shell, is derived from straw.

Since the 1990s, small-engine manufacturers have also made modifications to fuel systems to be compatible with ethanol-blended fuels. This category of non-automotive equipment includes recreational equipment such as snowmobiles, all-terrain vehicles, watercraft, as well as lawnmowers.

All mainstream manufacturers of power equipment and snowmobiles permit the use of gasoline blended with up to 10% ethanol in their products. Tests completed on lawnmowers, chainsaws, weed trimmers and blower vacs with ethanol fuels



An ethanol storage facility in Brazil; annual ethanol production in the country is over 30 billion litres, second-only to the US (56 billion litres).





Ethanol has many uses away from transport fuel; hand-sanitiser gels, medical wipes and cosmetics all rely on its properties.

showed no engine failures, no unscheduled maintenance and good performance.

Ethanol is also the oxygenate of choice in some water-recreation areas because of its clean-air and clean-water benefits. Major marine manufacturers including Honda, Kawasaki and Mercury Marine allow the use of gasoline containing up to 10% ethanol (E10) in their products.

### Beverage and industrial uses of ethanol

In addition to its use as a fuel, significant volumes of renewable ethanol are produced for the beverage and industrial markets from agricultural feedstock, such as grains and sugar beet. Renewable ethanol produced for these industries differs from ethanol for fuel only in its strength, which can vary between 96-99.9% in its purity.



When producing ethanol from corn, only the starch is required; the residue of protein, fat and fibre then goes into animal feed.

Ethanol used as an intermediary product by the chemical, pharmaceutical or cosmetics industry is of the highest and purest possible quality. It has many useful properties that allow it to be used by a range of industries in the production of:

- **Alcoholic beverages:** Neutral alcohol is mixed with water, aromas and flavourings.
- **Food and non-alcoholic beverages:** Ethanol is used as a natural product to extract and concentrate flavours and aromas, which are then used by the food and drink industry. No alcohol is contained in the final products.
- **Chemicals:** It is also a widely used solvent and is increasingly used as a renewable alternative to fossil-based chemicals for creating a large range of products, such as bioplastics.
- **Cosmetics:** It is contained in perfumes, deodorants and other cosmetics.
- **Pharmaceutical:** It is used in medicines, medical wipes and as an antiseptic in most antibacterial hand-sanitiser gels.

### Co-products

The production of ethanol from starch or sugar-based feedstocks is among man's earliest ventures into value-added processing. While the basic steps remain the same, the process has been considerably refined in recent years. A host of new technologies allow ethanol producers to add corn oil, recoverable CO<sub>2</sub>, corn syrup, bio-based chemicals and other co-products to their traditional output of feed and fuel.

Ethanol production requires only the starch portion of a corn kernel. The remaining protein, fat, fibre and other nutrients are returned to the global livestock and poultry feed markets. One-third of every bushel of grain that enters the ethanol process is enhanced and returned to the feed market, most often in the form of distillers' grains, corn gluten feed and corn gluten meal. Every bushel of corn processed by an ethanol plant produces approximately 7.7kg of animal feed.

Over the past decade, the ethanol industry has also emerged as a major producer of corn-distillers' oil (CDO), which is used as an animal-feed ingredient or feedstock for biodiesel production. In 2015, approximately 85% of dry mills in the US were extracting oil and it is estimated that more than 1.2 million tonnes of CDO were produced.

### Ethanol use will keep growing

It is clear that demand for ethanol will grow with a long and widening list of uses. While the value add of ethanol production is substantial, there is still room for significant growth in the sector, particularly with the commercialisation of next-

generation technologies. What is needed to achieve this potential is the political will to introduce ethanol-friendly policies that will maximise the advantages of ethanol technologies that are demonstrated to be effective, affordable and immediately available.

*Bliss Baker is President of the Global Renewable Fuels Alliance (GRFA). The GRFA is a non-profit organisation dedicated to promoting biofuel-friendly policies internationally. Through the development of new technologies and best practices, members are committed to producing renewable fuels with the smallest possible footprint.*

### Racing lines: Sunoco's ethanol blends

In the US, Sunoco's ethanol blends are the official fuel of Indycar and the top three NASCAR race series. **Rob Marro, Vice President of Sunoco's Race Fuels division**, talks corn and consistency.

**WPC:** *In motor racing, does ethanol-blend fuel give a comparable performance to gasoline?*

**Rob Marro:** Yes, it's similar to traditional fuels if the engine is properly tuned to take advantage of ethanol. Ethanol contains oxygen, so more engine tuning is required as the ethanol level increases.

**NASCAR uses Sunoco Green E15, while Indycar races with E85. Are we headed for pure biofuels in motor racing?**

Conventionally sourced fuels and components will be a key part of racing for a long time and Sunoco will be there to provide the most advanced formulas. More than 50 racing sanctions use our fuel.

**Do you work closely with teams when supplying racing fuel?**

We work closely with sanctioning bodies and teams whenever there is a new requirement or a new fuel, but once teams tune their

machines to the new fuel, they don't generally require assistance.

**What feedstocks are used for your ethanol?**

Corn; 100% of our ethanol is produced at our Sunoco Ethanol facility in Fulton, New York.

**Motor racing has loyal support. What message does the use of biofuels send out?**

The message it sends is that we make every fuel that racers and consumers demand and will do so at the highest of quality standards.

**How does Sunoco get these prestigious contracts?**

Largely due to our record of high quality and consistency; our racing heritage goes back more than 50 years. Racers depend on consistent high performance from their fuel and that's what Sunoco does best. Having one facility that manufactures all performance fuels allows us to ensure quality and consistency of our racing fuels. For NASCAR, our premier race-fuels team has been stewarding the quality of our fuel and its delivery for more than a decade, fuelling millions of miles of NASCAR races with zero defects. That is a record our company is extremely proud of. **LG**



# Biodiesel

By Donnell Rehagen,  
National Biodiesel Board

Whether used in vehicles or home heating, Americans are increasingly turning to this diverse renewable.

From humble beginnings, the US biodiesel industry has risen to a 7.6 billion litre annual market. And, as the industry continues to grow, biodiesel is becoming an important tool in helping diversify the country's transportation fuel mix with a cleaner-burning, low-carbon option.

Biodiesel is a renewable fuel used in diesel engines that is reducing America's sole dependence on petroleum, diversifying our diesel fuel pool, creating jobs and improving the environment. Made from a mix of feedstocks including vegetable oils, recycled cooking oil and animal fats, it is the first and only advanced biofuel designated by the US Environmental Protection Agency (EPA) that is in commercial-scale production across the country.

From the early 1990s into the early 2000s, biodiesel was a niche market. Since the mid-2000s, biodiesel has grown exponentially and is currently produced at refineries in every part of the country, and from any fat or natural oil, through the chemical process transesterification.

While soya-bean oil is the largest feedstock currently used in the US, producers use locally available feedstocks. In heavily populated areas, biodiesel producers put to use recycled cooking oil retrieved as waste from restaurants and food-service operations. In areas with significant livestock industries, biodiesel production provides a new market for the animal fats collected

from rendering plants. In the cooler climates of North America and Europe, canola or rapeseed is a leading vegetable-oil source.

Not only is biodiesel a diverse fuel, it is one of the most-tested fuels. Biodiesel is the only alternative fuel to have completed the health-effects testing requirements of the 1990 Clean Air Act amendments. It is simple to use, biodegradable and essentially free of sulphur and aromatics. Commercially produced biodiesel must meet the standards set by ASTM International. It can be used in existing diesel engines without modification and has support across all diesel applications because it is easy to use with existing infrastructure.

The 7.6 billion litre market represents a growing component of the annual US on-road diesel market, which is currently 133 billion to 151 billion litres a year. Consistent with projected feedstock availability, the industry has established a goal of producing 10% of the diesel transportation market by 2022, or doubling to 15 billion litres.

Meanwhile, the biodiesel industry's growth has boosted the US economy, not just by creating jobs but reducing our dependence on unstable oil markets. There are more than 200 US biodiesel plants with total registered capacity to produce 11.4 billion litres annually. The industry supports 62,000 jobs in a variety of sectors, from manufacturing to transportation, agriculture and service. The industry's economic impact is poised to grow with continued production increases, generating billions of dollars in gross domestic product, household income and tax revenues, while expanding the US's refining capacity.

## Advanced biofuels help reach carbon goals

The EPA has recognised biodiesel's environmental benefits by classifying it as an advanced biofuel, making biodiesel the only commercial-scale US fuel produced to meet the agency's advanced criteria. According to the EPA, biodiesel reduces greenhouse-gas emissions by at least 50% and up to 85% when



By 2022, it is expected that biodiesel will make up 10% of the American diesel transportation market, a figure of 15 billion litres.

compared to petroleum diesel, making it one of the most practical ways to address carbon mitigation. In addition to lifecycle emissions, biodiesel can greatly reduce major exhaust pollutants from petroleum diesel, particularly in older diesel vehicles. This is important because health agencies consistently cite diesel exhaust – primarily from older vehicles – as a dangerous pollutant.

The EPA administers America's most important and effective transportation energy policy, the Renewable Fuel Standard (RFS). Created under President George W Bush with overwhelming bipartisan congressional support, the RFS requires increasing volumes of renewable fuels to be blended into the nation's fuel supplies. The RFS has been functioning for a decade, replacing 10% of our fuel supplies with clean, American-made renewables. From the 7.9 billion litres of biodiesel used in the US in 2015, there was a reduction of more than 18 million tonnes of carbon, or the equivalent of removing 3.8 million cars from American roadways.

## Biodiesel benefits the world food supply

While carbon reduction is propelling policies that promote low-carbon fuels, biodiesel also has a major benefit to the world food supply. The US



The Renewable Energy Group operates 12 biorefineries in the US, including the Grays Harbor biodiesel plant in Washington state.

industry is proud of its careful approach to growth and a strong focus on sustainability. In the early 1990s, Midwestern soya-bean farmers set out to find an industrial market for excess soya-bean oil in order to solve a problem in the economics of the food supply. When soya beans are processed for protein to be used in food for livestock and human consumption, oil is co-produced and used in numerous applications. The abundant excess oil was a drag on soya-bean prices and forced protein meal to carry the full value of the beans.

Today, all US feedstocks used to make biodiesel are byproducts of protein production. Producing protein co-produces more fat than humans can consume. By using the extra fat produced when we make healthy protein, that protein becomes less expensive by having the fat absorb the economic value of the feedstock. And that is important to feed a growing population as we pay more for protein than any other macronutrient.

### Fleets and OEMs support biodiesel

Because of biodiesel's carbon-reduction benefits and ease of use, it recently ranked as the No.1 alternative-fuel choice among North American fleet managers. The 2016 Fleet Purchasing Outlook study conducted by NTEA – The Association for the Work Truck Industry also found that more fleets planned to acquire or continue using biodiesel than any other alternative fuel.

Detroit's 'big-three', Ford, General Motors and Fiat Chrysler, support high biodiesel blends. Although vehicle manufacturers don't warranty fuel, rather just their own parts and workmanship, nearly all manufacturers supplying diesel vehicles in the US now support blends of 20% biodiesel (B20). More than 78% of diesel vehicles coming off production lines cite biodiesel use in their owner's manuals. In the US, vehicles from medium- and heavy-duty truck manufacturers use more than 92% of on-road diesel. And of those manufacturers, 90% support the use of B20 and higher blends.

### Future biodiesel market growth

Beyond our success in diversifying the vehicle fuel sector, the biodiesel industry continues to explore new feedstocks for production. Researchers continue to make progress in developing economical processes for biodiesel feedstocks like algae, pennycress and brown grease. And the biodiesel industry sees rail and marine transport as markets with potential for tremendous growth.

Already, we have made progress in other off-road markets that can serve as a template for growth in the success of the oilheat industry. In 2004, the National Biodiesel Board began developing the Bioheat brand for heating homes and businesses. Biodiesel can be blended safely with all types of heating oil and is a perfect complement as the industry transitions to ultra-low sulphur fuels.

In 2015, ASTM International developed a separate standard specifically designed for Bioheat home-heating oil blends up to B20 to assure consumers that the fuel will operate as intended. As the heating-oil industry continues to move to low-carbon fuels, biodiesel will play a key role. The National Oilheat Research Alliance has even set a long-term goal of transitioning the entire home-heating industry to 100% biodiesel in the future.

The success of the biodiesel industry is a direct result of the diverse, united coalition we have built – large, publicly traded corporations and small businesses, entrepreneurs and farmers. These partnerships have afforded the industry to do more than any of us could have done individually. Our industry goals couldn't be achieved without the relentless, diverse, unified, collective voice of an industry standing together. And together we are diversifying our energy supply and achieving carbon-reduction goals with home-grown advanced biofuels.

*The National Biodiesel Board (NBB) is the single trade association for the biodiesel industry in the US. Donnell Rehagen has been COO since 2004.*

### Beer necessities: Brewtroleum

New Zealand takes its beer drinking seriously, and now, with **DB Export Brewtroleum** – a 10% ethanol blend made from the waste of beer brewing – it's taking alternative fuel seriously too. **Ulrik Olsen, Commercial Manager of Gull**, speaks about a local biofuel sensation.

#### WPC: How do you make fuel from beer waste?

**Ulrik Olsen:** The process of creating ethanol for DB Export Brewtroleum is basically the same as making alcohol for human consumption. Once the ethanol is up to our stringent specification, we take it and blend it with premium petrol to make the highest-quality and highest-octane bio-petrol on the New Zealand market.

#### What was your role in the biofuel's creation?

Gull, as the fuel retailer, facilitates the link between concept and actually selling Brewtroleum to the New Zealand motoring public. We made Brewtroleum available at all our 98-octane retail outlets and people loved it. The idea that you can do your bit for a cleaner environment by doing something you enjoy, i.e. drink beer, struck a chord with our customers.



Gull's beer-derived Brewtroleum E10 blend was a quick seller in New Zealand; expect further deliveries in the near future.

#### What were the initial challenges when creating Brewtroleum?

As with any new concept on this scale, it takes a lot of people to pull on the same rope to make it all come together seamlessly. But thanks to a huge amount of perseverance and great planning by everyone, from the DB Export brewers and distillers to the service-station owners, we managed to be the first in the world to retail Brewtroleum.

#### Is the ethanol extracted when making alcohol-free beer or is it from somewhere else in the process?

The ethanol is extracted from the yeast that is left over – yeast slurry; a beer by-product – after the beer-fermentation process when making the DB Export range of beer.

#### Is Brewtroleum basically an E10 blend, and did you experiment with larger amounts of ethanol?

Brewtroleum is an E10 blend made from 10% DB Export ethanol and 90% Gull premium petrol. We're not planning to experiment with higher levels of ethanol at this stage as we don't have enough ethanol, even at 10%, so we need more people to drink DB Export to make a bigger difference.

#### Gull is something of a biofuels trailblazer. Can we expect more novel biofuels from you in the future?

We're always looking for new ways to make the energy we sell more sustainable and that includes looking at new ways of making ethanol for petrol and biodiesel for diesel cars.

#### It appears that Brewtroleum is currently unavailable. Is this due to the fuel's popularity?

We simply couldn't get enough ethanol to meet demand but keep checking online because we're on the verge of a Brewtroleum return. **LG**

[gull.nz/dbexportbrewtroleum](http://gull.nz/dbexportbrewtroleum)

# Biomass as a fuel source

By Luiz Augusto Horta Nogueira,  
University of Campinas (Unicamp)

Diverse feedstocks and a variety of conversion paths are powering biofuels' rapid growth.

In many ways, bioenergy and fossil hydrocarbons are partners. In recent centuries, surpassing the demand for traditional bioenergy, reservoirs of bioenergy fossilised in coal, oil and natural gas were crucial in the construction of our society. Now, bioenergy is back in the energy scenario and able to mitigate environmental problems, bringing a new dynamic to the agroindustrial sector and supplying an option in the transition to a more sustainable energy mix.



Sugar cane is a perennial crop cultivated in tropical countries. This is sugar-cane bagasse which will be transformed into ethanol.

## Fundamentals of bioenergy

Biomass production essentially depends on solar radiation and the presence of water and carbon dioxide (CO<sub>2</sub>), combined in plant cells according to complex cycles that can be defined by the following formula, where water and CO<sub>2</sub> are combined to form glucose, a simple sugar and oxygen.



Among these production elements, CO<sub>2</sub> is widely distributed in the atmosphere. In recent decades, its concentration has grown, which has been associated with the intensive use of fossil fuels. Biofuels reduce these carbon emissions.

Regions of South America and Africa are good areas for the expansion of bioenergy production, due to availability of water and sunlight. Extensive areas have been identified, currently occupied with pastures of low productivity, which could be cultivated in harmony with existing forests and agriculture. It's estimated that up to 2 million km<sup>2</sup> (770,000 miles<sup>2</sup>) could be used for bioenergy production, equivalent to 45 million to 90 million barrels of oil per day. It's a significant potential option to meet the global energy demand.

Biomass energy can be obtained by direct combustion or converted into bioenergy vectors,



Oilseed rape is a familiar sight in Europe and is the continent's preferred raw material (80%) for biodiesel production.

which are more elaborate and suitable for end use. Bioenergy can be found in several forms: wood and waste from sawmills, charcoal and biogas, as well as liquid biofuels such as ethanol, biodiesel and aviation biofuels, and bioelectricity generated from burning bagasse and wood.

Liquid biofuels have been developed to meet the energy needs of transportation and adhere to the strict specifications for modern engines and gas turbines of high efficiency and low emissions. In addition, second-generation biofuels have been developed, utilising innovative technologies of low-cost raw materials such as lignocellulosic waste, using biochemical and thermochemical routes, with a high production potential and reduced environmental impact. Studies to raise the productivity of raw materials are being developed, as in 'cane energy', which eventually doubles the production of ethanol per square kilometre, and by growing and processing algae as a raw material for biofuel production.

## Current situation and perspectives

Overall, the production of liquid biofuels is equivalent to 1.9 million barrels of oil per day, 3% of the energy consumption for transportation, and is mainly ethanol (72%) and biodiesel (28%). The area occupied for this production is 130,000 km<sup>2</sup> (50,000 miles<sup>2</sup>), around 1.3% of the planet's cultivated area. There is a wide range of productivity per unit area for the raw materials; 7,200 litres of cane ethanol per hectare (10,000m<sup>2</sup>) and 600 litres of biodiesel per hectare.



Sawmill waste can be converted to fuel by thermochemical pathways.

The role of biofuels is not only as a renewable and sustainable alternative to meet the energy needs of modern society but also represents the demand to address the challenge associated with maintaining the quality of life on our planet. It is possible to observe synergies between the oil and biofuel industries, reducing emissions and competitively adjusting the specifications of conventional fuels. Increasingly, these industries co-operate, develop and support each other.

Luiz Augusto Horta Nogueira is an Associate Researcher at the Interdisciplinary Group of Energy Planning, Universidade de Campinas, Brazil and a consultant for the UN and governmental agencies.

## Future scenarios for the global demand for biofuels

Scenario	References	Demand for biofuels in 2030
Trend: Biofuels represent about 5% of the energy used for transportation.	BP, 2015 WEC, 2011	2.9 million barrels of oil equivalent per day
Required: Biofuels cover 11% of transport consumption, to stabilise the climate change.	IPCC, 2011	7.2 million barrels of oil equivalent per day



# Biofuels in China: a work in progress

By Robert Earley, MotionECO

Ethanol production and use is increasing but biodiesel is yet to receive policy support.

In the late 1990s, China watched as the rest of the world geared up its biofuel industries through renewable-fuel obligations and likewise decided that it would investigate how to follow this trend. It was found that China had corn and wheat that was not being utilised every year and that with this excess, bioethanol could be manufactured.

In 2002, pilot projects were established for the production of bioethanol – invested by state-owned enterprises – and biodiesel made from used cooking oil (UCO) became a target of private-sector investment.

Since the early 2000s, the biofuel industry has grown and is becoming increasingly diversified. Yet the industry faces stiff challenges – lack of policy support, challenges in ensuring that biofuel feedstocks are not competing with the human food supply and a lack of trust on the behalf of the industry – meaning that while opportunity abounds, the industry is always on the verge of stagnancy.

With recent low oil prices, policy and technological innovation are more important than ever for biofuels, and this is no less true in China than anywhere else.

## China's ethanol rules

In 2002, China began its first bioethanol pilot project, creating a supportive policy that resulted in the creation of the Henan Tianguan bioethanol company – along with a policy for gasoline in Henan to be blended with 10% ethanol (E10). China's ethanol plants are primarily fed with corn and wheat, and seeing that ethanol as fuel helped to support grain prices and created employment opportunities in the rural sector, support for these fuels grew, resulting in optimism in the industry.

The sector grew quickly until 2008, when scientists discovered that biofuel production was having indirect impacts on food and land markets. When many proposed bioethanol projects ground to a halt and the era of significant growth in first-generation bioethanol tapered off quickly, government began to demand that biofuel development meet three criteria:

- Does not compete with humans for food.
- Does not compete with food production for land.
- Does not harm ecosystems.

With the issuing of these three criteria, the focus of biofuel development shifted to advanced, next-generation biofuels such as cellulosic fuels and algal biodiesel but because of technological challenges, these could not be scaled up immediately. This policy, however, does not seem hard set as towards the end of 2015, China had excess, unused and mouldy corn stock of over 30 million tonnes, and in 2016 announced that it may auction 10 million tonnes of corn suitable for ethanol production.

## Development policies

While policy for biofuel development is not aggressive in China, the government has taken some measures to encourage the industry at times when it was seen as important for employment and economic development. When the industry was starting up from 2004-10, grain-based (first-

generation) ethanol was offered a 100% VAT tax exemption along with a 0% excise tax rate. However, after 2010, the VAT exemption on first-generation ethanol was gradually decreased to 0% in 2015, while the excise tax was gradually increased to 5% so as to discourage unbridled development of the industry. Meanwhile, fuels judged to be more sustainable, including '1.5'- and second-generation bioethanol continue to enjoy a 100% VAT exemption and excise tax waiver. Furthermore, 1.5-generation fuels (derived from non-grain feedstocks such as sorghum and cassava) enjoy a RMB 750 (\$115) per-tonne subsidy, and second-generation fuels enjoy an RMB 800 (\$123) per-tonne subsidy.

With both domestic and international aviation set to be integrated into China's national carbon-emissions trading scheme, there is opportunity for biojet fuel demand to grow as long as methodologies are integrated into the scheme to account for fuel carbon intensity. If China's biodiesel supply is any indicator, biojet fuel could potentially also be made from used cooking oil in China, creating a very low-carbon alternative to conventional jet fuel. It is important to note that virtually no production capacity for biojet fuel exists in China.

China promotes bioethanol particularly in provinces where feedstock is available, such as in the grain-growing north-east central China and the cassava-growing south. There are six provinces supporting a 10% fuel-ethanol standard – Heilongjiang, Jilin, Liaoning, Henan, Anhui and Guangxi – and more than 30 E10 pilot cities. While Hainan island has a 5% biodiesel blending standard, the primary biodiesel supplier CNOOC New Energy has shuttered its plant after years of losses, leaving the island with a supply gap.

## Bioethanol

Bioethanol as a fuel has been produced in China since 2001, when the Chinese government discovered several conditions: first, that energy

security was becoming a major national concern as the country undertook its huge leap in economic development, and at the same time, excess grains such as corn, wheat and sorghum were available and offered an economic development opportunity. The National Standard of Denatured Fuel Ethanol and National Standard of Vehicle Bioethanol were produced, and a RMB 5bn (\$760m) pilot project was started in 2002 to drive the consumption of bioethanol produced in five plants across China, starting in Henan province, and expanded to Heilongjiang, Jilin and Anhui. The fuel bioethanol industry is tightly controlled, where



The LanzaTech-operated BaoSteel Mill in Shanghai is a waste-gas-to-fuel (ethanol) demonstration plant, using flue gas in its process.



LanzaTech's second waste-gas-to-fuel demonstration plant in China currently has an output of 300 tonnes of ethanol a year.

only companies approved by the National Development and Reform Commission may produce fuel ethanol. Furthermore, there are no official imports of fuel ethanol. All imports of denatured ethanol are to be used in the industrial sector and non-denatured ethanol would be used in the beverage sector.

Another company, Hainan Yedao, in a joint venture with Sinopec, received approval in 2014 to construct a cassava-based ethanol plant and produce 100,000 tonnes of fuel ethanol in phase one and 200,000 tonnes in phase two. News reports indicate production could begin in 2017.

LanzaTech, a company that has invented a microorganism that ferments flue gas from steel

plants and other facilities that produce carbon monoxide now operates two pilot projects in mainland China, each producing about 300 tonnes of ethanol per year. The outlook for this technology in mainland China is unknown, but the company has signed a commercial-sized deal in the city of Kaohsiung, Taiwan.

The USDA projects that the production of fuel ethanol will probably rise slightly after 2020, taking up a larger component of total gasoline production in China, with a consumption of 3.9 billion litres of fuel ethanol by 2025.

While ethanol was being imported at record volumes in 2015, this ethanol was likely not for the transport sector. Furthermore, with China's old corn stock rising to about 200 million tonnes in 2016, it is expected that China may begin producing more of its own corn-based bioethanol.

### Biodiesel in China

Biodiesel does not receive nearly the same type of policy support as ethanol in China. Biodiesel is not accepted by CNPC or Sinopec for sales in their refuelling stations – which have over 90% of the market – meaning that biodiesel needs to be sold directly to commercial clients or more likely into the agricultural sector or small riverboat fleets for very low prices.

Many want to use biodiesel due to its low price and as a result, biodiesel producers can't sell at

even market prices for regular diesel. Large companies including CNOOC New Energy, which operated a large facility in Hainan, have pulled out of the market, as has Gushan, a NYSE-listed company, which was the largest biodiesel producer in China due to the poor market conditions. While it is believed there are more than 50 facilities producing biodiesel in China, many of them sit idle during long periods of the year, with only 27% of capacity operating at any one time.

Anecdotal evidence suggests that high prices for used-cooking-oil biodiesel in Europe have created opportunities for China to export used cooking oil, further constraining the domestic market. Biojet fuel producer SkyNRG, based in the Netherlands, uses gutter oil imported from China to create low-carbon jet fuels, valuable in the European aviation sector which is required to purchase emission credits on the EU Emissions Trading System. The European Renewable Fuels Directive also rewards fuel providers for using waste-based diesel in the on-road market.

Nonetheless, it is estimated that 150 billion litres of biodiesel were used in the transport sector in China, accounting for 0.2% of total on-road diesel use.

A note on trade in biodiesel: in 2013-14, China experienced a leap in the import of 'biodiesel' when a RMB 0.8/litre tax (\$0.12) was eliminated on biodiesel imports. Between 2012-13, imports leapt from 101,000 litres to 2.5 million litres but have since normalised.

### Conclusion

Biofuel is in an uncertain state in China, particularly biodiesel. While fuel ethanol has found a stable market with slow growth (constrained by policies and limited subsidies), biodiesel faces a difficult domestic market, with competition domestically and internationally, and a limited audience. Future technologies are under development but a conservative national government means that progress is slow and risk exists that current scale-up can't meet the demands of the future.

*Robert Earley is a Beijing-based Canadian advocate for cleaner transportation and energy sources in Asia. He has served numerous Chinese and international environmental NGOs and is now a consultant as well as the Chief Operating Officer of MotionECO, a company dedicated to providing clean transportation solutions for China.*

### The main companies licensed to produce fuel ethanol from 2004-14

Producer	Capacity (1,000 tonnes)	Feedstock	Ownership
COFCO ZhaoDong	450	Corn, wheat	COFCO
Jilin Fuel Ethanol	750	Corn, wheat	COFCO & CNPC
COFCO Guangxi	400	Cassava	COFCO
ZTE Energy	80	Sweet sorghum stalks	ZTE
Shandong Longlive	80	Corn cob (cellulosic)	Publicly traded
Henan Tianguan	750	Corn, wheat, cassava,	ShouGang Group
COFCO Anhui	700	Corn, cassava	COFCO
<b>Total</b>	<b>3,210</b>		

### Biofuel generations in China

China generally regulates fuels according to the generation of their technology. This table describes the three generations of fuels generally available in China.

Fuel type	Main product	Main feedstock	Status
First-generation biofuel	Grain-based ethanol	Corn, wheat	Industrialised (2004-) by state-owned sector
	Waste-oil biodiesel	Waste cooking oil (frier oil, gutter oil, brown grease, etc)	Industrialised (2006-) primarily by private sector
1.5-generation biofuel	Non-grain, but sugar or starch-based ethanol	Cassava, sweet sorghum	Industrialised (2008-)
	Non-edible oil-based biodiesel/ biojet fuel	Jatropha	Demonstration (2010-)
Second-generation biofuel	Cellulosic ethanol	Corn cob; corn stalk	
	Waste-gas ethanol and other biochemical	Waste flue gas	Demonstration (2012-)
	Biomass to liquid	Agricultural residue	Research stage

Source: Kang, 2014 and author

# The dawn of Sunliquid technology

By Martin Mitchell, Clariant Group

Clariant's cellulosic ethanol from agricultural waste is technically and economically viable.

As one of the leading specialist chemical companies worldwide, Clariant contributes to value creation with innovative and sustainable solutions for customers from many industries. The key theme of 'driving innovation through sustainability' is a strategic pillar of the corporate business strategy at Clariant. Clariant drives innovations to increase energy and process efficiency, as well as foster the substitution of fossil resources with renewable resources, to address customers' needs in the 21st-century sustainable economy.



Sugar-cane bagasse is just one of a number of non-food feedstocks used by Clariant to produce cellulosic ethanol.

Since 2006, Clariant has leveraged many of its innovative R&D efforts to sustainability via the formation of Clariant Group Biotechnology to commercialise innovative technology using industrial biotechnology from renewable and sustainable raw materials, such as cellulosic ethanol-conversion. Clariant has set itself the goal of efficient use of natural resources; sustainability within Clariant is regarded as all-embracing. The new Clariant Bio-tech & Renewables Center in Munich is the cornerstone of our strategy.

A perfect example of this implementation is Sunliquid technology. Sunliquid uses non-food biomass such as wheat straw, sugar-cane bagasse, corn stover and rice straw to produce cellulosic ethanol and other bio-based chemicals with high greenhouse-gas (GHG) savings and no land-use competition. With Sunliquid, Clariant is providing the world with technology that delivers the lowest carbon solution for fuels and chemicals.

Sunliquid technology is both technically and economically viable for the commercial-scale production of cellulosic ethanol. The technology delivers cellulosic ethanol to the market that is the most cost competitive against other lignocellulosic technology providers. This is a competitive integrated technology package of:

**1 Chemical-free pretreatment**, which drives down costs compared to chemical pretreatment solutions that also have environmental concerns associated with them. Clariant opted to utilise existing commercial pretreatment technology from the paper and pulp industry and optimised the enzymes to work with this pretreatment solution, as opposed to other conversion technologies that opted to develop new pretreatment technology due to the limited number of commercial enzyme suppliers worldwide.

**2 Process-integrated enzyme production**, which is the most efficient method to produce enzymes for cellulosic ethanol, driving the total cost contribution of enzymes for cellulosic



Clariant's Sunliquid technology was in the pre-commercial phase for four years, based at the Straubing demonstration plant in Germany.

ethanol production from 30% to approximately 10%. This is made possible because the Clariant enzymes are manufactured on site and process-integrated using a small percentage of the pretreated biomass as the raw material.

**3 Feedstock-specific enzymes**, which maximise the amount of sugars that can be released from the lignocellulosic biomass. By developing feedstock-specific enzymes, Clariant is able to achieve higher yields. All sugars are released from the biomass as opposed to other non-optimised commercial enzyme solutions which cannot efficiently release the sugars in the biomass.

**4 Optimised fermentation organism** simultaneously converts C5 and C6 sugars into cellulosic ethanol, increasing ethanol output by 50%. Energy efficient ethanol separation and thorough energy integration have succeeded in an entirely energy self-sufficient process: all energy demand can be generated from the byproducts of the technology. No fossil-based energy sources are used, thus making Sunliquid almost carbon neutral with GHG savings of up to 95% and reaching up to 130% with CO<sub>2</sub> captured.

Beyond the technology advantages of Sunliquid technology, Clariant has brought the commercial product validation of cellulosic ethanol to the market via a number of partnerships worldwide. These important partnerships have included:

- Clariant, Haltermann and Mercedes-Benz partnered in a fleet test to bring cellulosic ethanol to the road as an E20 blend. The fuel was tested in Mercedes-Benz vehicles and showed good performance and sustainability.
- Clariant and Werner & Mertz collaborated to produce Frosch Bio-Spirit Multisurface-Cleaner made from cellulosic ethanol with Sunliquid technology.
- Clariant and Scania partnered in a fleet test using a 95% cellulosic ethanol-blend fuel in Scania Ecotrucks, which demonstrated a significant reduction in CO<sub>2</sub> emissions compared to petroleum-derived diesel fuel.

Sunliquid technology is ready for deployment. After four years of demonstration at the pre-commercial plant in Straubing, Germany, Clariant is ready to deliver a robust technology licensing package to the market for commercial-scale production of cellulosic ethanol. The Sunliquid Process Design Package is complete and provides a technological blueprint for commercial facilities between 75 million and 225 million litres of cellulosic-ethanol production per year.

*Martin Mitchell is Business Development Manager Americas for Clariant Group Biotechnology. He is responsible for the commercial development and technology licensing of Sunliquid technology.*



# India: beyond fossil fuels

By Divakar Rao,  
agribusiness consultant

The state of Karnataka in India has a strategy for biofuel development that offers a template for other Asian and African nations.

The energy sector in India is in for a major churn. The colonial-era mindset of ignoring our own inherent strengths and interests and taking the easy way out to the undue advantage of far-off nations may be changing at last, over six decades after attaining independence. The farmer-centric bioenergy model with a strong rural orientation

developed in the state of Karnataka in India has captured the imagination of planners at national and international levels. If planned and implemented judiciously, it will transform India by enhancing the availability of clean, competitively priced energy to rural areas and to the transport sector all over the nation. The resultant higher agri-productivity, access to rural energy and higher rural incomes will make Indian villages more liveable and could decelerate urban migration. Availability of transport and industrial fuels blended with green biofuels at significant ratios will improve the quality of the environment and reduce petroleum import bills. The ingredients for a successful transformation are already there; with the right kind of political will, India has the potential to be self-sufficient in meeting its energy needs and even become an energy exporter in the long run.

India has 1.5 million km<sup>2</sup> (600,000 miles<sup>2</sup>) of arable land of which 600,000km<sup>2</sup> (230,000 miles<sup>2</sup>) are irrigated. India has a significant base in crop and animal agriculture, industrial manufacture, nuclear and space technology and a youthful workforce that is up to taking on any new



The Karnataka State Biofuel Demonstration and Information Centre has a small-scale transesterification plant for biodiesel production.

challenge. India occupies 2.4% of the world's land and supports 16% of the world's population. Economic growth has exceeded 7% a year for over a decade. However, the GDP growth has not come without a cost. Although India has brought many benefits through rapid economic growth in the past decade, the environment has suffered. It has led to a degraded environment with issues like air

and water pollution. Paradoxically, India's per capita power consumption of 1,010 kWh is among the lowest in the world. China has a per capita consumption of 4,000 kWh, with developed nations averaging around 15,000 kWh per capita.

Table 1 illustrates the dismal energy scenario in India even in comparison with other BRICS nations (Brazil, Russia, India, China and South Africa):

## Energy development index for Brazil, India, China and South Africa (normalised variables)

Country	Rank	EDI	Household-level energy access				Community level energy access		
			Access to electricity indicator		Access to clean cooking facilities indicator		Household-level indicator		
			Electrification rate	Per-capita residential electricity consumption	Electricity access indicator	Share of modern fuels in residential total final consumption	Per-capita electricity consumption	Share of economic energy uses in total final consumption	Community level indicator
India	41	0.30	0.75	0.11	0.29	0.14	0.22	0.06	0.38
China	26	0.49	1.00	0.33	0.57	0.19	0.38	0.34	0.85
South Africa	14	0.65	0.76	0.72	0.74	0.04	0.39	0.97	0.84
Brazil	11	0.68	0.99	0.48	0.69	0.46	0.57	0.59	0.99

Source: IEA (2012).

Table 1.

## Final commercial energy consumption (in Mtoe) in India by sector

Sector	1980/81	1985/86	1990/91	1995/96	2000/01	2005/06	2010/11	2011/12
Agriculture	1.6 (2.3%)	2.4 (2.6%)	4.9 (3.9%)	8.4 (5.3%)	15.2 (7.9%)	15.1 (6.9%)	23.14 (7.3%)	18.70 (5.9%)
Industry	36.9 (53.7%)	49.2 (53%)	62.9 (50.4%)	77.5 (48.6%)	77.4 (40.4%)	96.2 (44.4%)	137.98 (46.6%)	146.72 (46.7%)
Transport	17.4 (25.3%)	21.7 (23.4%)	28 (22.4%)	37.2 (23.4%)	33.5 (17.5%)	36.5 (16.8%)	55.34 (17.5%)	63.39 (20.2%)
Residential and commercial	5.6 (8.1%)	8.9 (9.6%)	12.6 (10.1%)	15.3 (9.6%)	24.1 (12.6%)	32.6 (15.1%)	43.43 (13.73%)	44.09 (14%)
Other energy uses	1.9 (2.8%)	2.7 (2.9%)	3.9 (3.1%)	6.8 (4.3%)	13.4 (7.0%)	18.7 (8.6%)	30.25 (9.56%)	14.33 (4.6%)
Non-energy uses	5.3 (7.7%)	7.9 (8.5%)	12.6 (10.9%)	14.1 (8.8%)	28 (14.6%)	17.5 (8.1%)	26.15 (8.27%)	27.17 (8.6%)
Total	68.7 (100%)	92.8 (100%)	124.9 (100%)	159.3 (100%)	191.6 (100%)	216.6 (100%)	316.29 (100%)	314.4 (100%)

Note: Figures in parentheses indicate the percentage share of each sector.

Sources: TERI, India (various years); CEA, Gol (2011); MoPNG, Gol (2011); MoP, Gol (2012).

Table 2.



Seeds of the mahua, a tree native to India, has shown potential for biodiesel production. In the past, seeds have been left to rot.

Table 2 gives an idea of the energy consumption by different sectors in India over the past 30 years:

The new biofuel strategy of India must, therefore, make use of all the strengths and avoid the known pitfalls to transform the nation into a much better place to live in the coming decades.

### Sources of energy

India has several sources of energy, like hydro-electricity, electricity from coal, coal, firewood, nuclear energy, LPG, CNG, gasoline, diesel, kerosene and aviation fuel. There are also renewable sources like solar photovoltaics, solar thermal, wind and biofuels. However, renewables are a small fraction of the total energy. In the following account, only coal and petroleum fuels will be considered and compared with biofuels.

### Challenges in India: energy and related sectors

While India has been fortunate in terms of availability of agricultural land and water resources, the same cannot be said about its coal and petroleum deposits. The quality of available coal is poor in terms of calorific value and purity, and petroleum and natural-gas resources are limited and inadequate. It has to resort to large-scale imports

of crude oil and other related products in order to keep the nation going. In spite of being self-sufficient in food production, the agriproductivity is low due to small land holdings, sub-optimal management of soil and water resources, inadequate energy supply for agri-operations and lack of affordability of agri-inputs for a majority of farmers. These conditions in India also bring to the forefront the food-versus-fuel debate whenever there is even an intention of using agricultural land for production of biofuels. Also, the fact that India is a major importer of cooking oils makes it difficult to justify diversion of cooking oils for biodiesel manufacture like in Europe and the US.

Some of the major issues pertaining to the energy sector that needed to be addressed in India at the turn of the millennium were as follows:

- Reduce dependence on imported petroleum to improve energy security and reduce outflow of foreign exchange.
- Reduce dependence on coal and petroleum fuels by switching to sustainable and renewable energy and reduce pollution.
- Enhance tree cover in the country and derive maximum environmental benefits from it.
- Reduce poverty by accelerating rural development, giving special attention to agriproductivity and farmers' income since 60% of India's population is directly dependent on agriculture. This is to be achieved by improving availability of energy in rural areas for timely irrigation and agri-operations and improving soil health with biofertilisers.
- Create newer opportunities for farmers to get additional income by new business opportunities, thereby creating value for their existing farming operations, agri-residues and wastelands.

### Development strategy for biofuels in India: work already done

Considerable amounts of work have been done in India on biofuels in the past few decades. The

pioneering field trials conducted by Karnataka State Road Transport Corporation, Bangalore on a small fleet of its buses using diesel mixed with biodiesel and later diesel mixed with ethanol generated a great deal of data and public interest. A biofuel park was developed by the University of Agricultural Sciences, Bangalore in the Hassan district of Karnataka a few years ago. Another project worth highlighting is the rural development work done by the Application of Science and Technology for Rural Areas programme of the Indian Institute of Science in the mid-1990s, creating biofuels using non-edible tree-borne oilseeds (TBOs) and using them to power various agricultural and rural development activities near Kunigal in the Tumkur district of Karnataka state.

In 2003, the Planning Commission of the government of India started the National Bio-diesel Mission, in which an attempt was made to promote cultivation of the jatropha species as the preferred source of biofuel. Also, a decision was taken to blend ethanol up to 5% in gasoline sold by oil-marketing companies which was to be increased in stages to 20% by 2017. However, by 2008, it was obvious that jatropha was unable to live up to its expectations under Indian conditions and had to be shelved. The ethanol-blending programme was also languishing due to several reasons.

### The Karnataka strategy and model

In the meantime, the Karnataka state came up with a different method. It formed a task force in 2008 for a holistic, yet focused, approach for biofuel development in the state. This task force, after a study of the situation in the country, produced a framework for a development model. It also came up with a set of recommendations that included a comprehensive policy for biofuel development for Karnataka. As a result, the Karnataka State Bio-energy Development Board was constituted in 2010 to implement this policy and carry forward



Seeds from the simarouba glauca contain 60% oil. The species was brought to India from South America in the 1960s and grows rapidly.

the momentum created by the task force. The board went about its job with missionary zeal and evolved a model, the key features of which are:

- Focus on using wasteland for energy plantations; agroforestry model for agricultural lands; the idea is to ensure that biofuel programmes will not attract the food-vs-fuel debate.



Pongamia is a tree-borne oilseed that has shown huge potential for biofuel production in India; seeds contain up to 40% oil.



Seeds of the *calophyllum inophyllum* tree contain up to 70% oil, a green liquid which is also used in India for medicinal purposes.

- Multi-species approach; this ensures that the failure of a single species does not significantly affect the programme; also, farmers get choice for different agro-climatic zones.
- Work done on all types of biofuels, solid, gaseous and liquid; this ensures a holistic development both from farmers' and environmental angles.
- Farmer-centric approach resulting in rural prosperity and overall nation-building.
- Energy security in India, energy to rural areas, enhanced food security through locally available agri-inputs such as de-oiled cakes and timely irrigation.
- Tailor-made institutional infrastructure to cater to the needs of all stages of the biofuel value chain.
- Programmes/schemes designed to ensure fair returns to farmers, energy security and environmental benefits; also to ensure optimal usage of existing government schemes.
- Working with funding institutions like India's National Bank for Agriculture and Rural Development for successful commercialisation of these ideas.

- Emphasis on R&D in bioenergy and the involvement of young people in matters of bioenergy, environment and self-reliance.

The wholesomeness of this strategy and the schemes and institutional mechanism that were used to implement it attracted national and international admiration. The government of India is currently working out the modalities of biofuel development at the national level and the Karnataka model is expected to play an important role in it. The International Fund for Agricultural Development and the International Center for Research in Agroforestry, after a thorough study and a gap analysis, have concluded that this would be an ideal model for many developing nations in Asia and Africa.

#### Developmental strategy at the national level

The government of India is presently working on a comprehensive strategy for the development of biofuels in India. A new Renewable Energy Act has been finalised and is being brought before parliament by the Ministry of New and Renewable Energy (MNRE), in which biofuels would play a vital role. The Ministry of Petroleum and Natural Gas (MoPNG) is taking up a lead role by constituting a working group which is proactively looking at accelerating the blending of biofuels in diesel and gasoline sold by the oil-marketing companies. Thanks to the efforts of MoPNG, many bottlenecks in the blending programmes are being removed and the pace of blending is improving.

MNRE and the Ministry of Rural Development are working together to find an inter-ministerial, multipronged approach to large-scale planting of TBO species on wasteland. The Ministry of Agriculture will also have to pitch in to popularise the agroforestry model of TBO plantings on borders of agricultural lands as a standard practice. Looking at the vast potential of this sector as shown in Table 3 (above right), these efforts would be worth it in the medium to long run.

### Biofuel scenario and potential in India at a glance

Type of biofuel	Raw materials available/possible to produce	Annual potential (conservative estimates)	Remarks
Solid biofuels like logs, woodchips, sawdust, briquettes and pellets	Agri-horticultural crop residues, forestry byproducts, etc.	300 million tonnes of briquettes/pellets.	Will be useful as sources of cheap fuels in rural India for cooking.
Gaseous biofuels like biogas (58% methane)	Household and hotel solid wastes, municipal sewage, industrial effluents, food and agro-processing wastes, etc.	25,000 million metres <sup>3</sup> of 95% pure methane.	Will be useful in meeting demands of gas for cooking at home and in restaurants in rural and urban India.
Bioethanol	For first-generation ethanol: sugary substances like cane sugar, molasses, sugar-cane juice, starchy materials like grains and tubers (presently only molasses are used in India to avoid the food-versus-fuel debate). For second-generation: cellulosic agri-residues, agroindustry wastes, etc.	50 billion litres of ethanol.	Since the demand for gasoline in India is only 10% of diesel, the excess production can have a good export market.
Straight vegetable oil (SVO)/biodiesel	Non-edible tree oilseeds from species like pongamia, simarouba, neem, jatropha, etc (edible oilseeds are avoided to prevent food-versus-fuel debate).	75 million tonnes of oil or 65 billion litres of biodiesel.	SVO with minimal processing can easily be blended with petrodiesel in low RPM and stationary applications. Diesel can be substituted by biodiesel up to 100%.

Table 3.

#### Time to act

Most experts agree that existing and known reserves of petroleum will be exhausted by 2050. While environmentalists may not consider this bad news, this should serve as a wake-up call for planners. The transport sector at present is heavily dependent on liquid fuels derived from petroleum and is looking at alternatives like electric vehicles, CNG, hydrogen fuel cells and biofuels. The generation of electricity is another concern. Power generation using coal is one of our most polluting industrial activities. However, there are excellent methods of generating electricity using solid biomass, either directly or through the biogas/gasification route. Natural gas, being a non-renewable energy, will also run out at some point beyond 2050. Our coal reserves will last much longer, but this is poor consolation from an environmental point of view.

As a rational species, it is our obligation to future generations to find simple logical and environmentally friendly solutions to our energy and environmental crisis. Becoming complacent

in striving for this goal just because a handful of petroleum-producing countries decide to manipulate the prices of petroleum is not only foolish but can have serious consequences for the continued survival of the human race.

Biofuels are one of the best alternatives since they reduce pollution, are renewable and can be grown abundantly on land and water. This is also the most practical way of aiding the completion of the carbon-dioxide cycle as nature intended it. In countries like India, it also provides an opportunity for marginal farmers to have access to another channel of livelihood and energy.

*Divakar Rao is an agribusiness specialist active in several life-sciences sector initiatives. He is qualified in agriculture, animal husbandry and food technology and has experience in dairy development, rural development, agriculture, dairy and food technology, biotechnology and bioenergy. He lives in Bangalore, India and advises governments, industry and other organisations on matters related to the life-sciences sector.*



# Palm oil: Malaysia's golden crop

By Tian Ching Long, Vance Bioenergy

Managing the most efficient oil-bearing crop in the world.

The oil palm is considered Malaysia's 'golden crop' and this reflects not just the colour of the oil that it produces but also the immense importance it plays in Malaysia's economic development.

The palm industry is a major contributor to Malaysia's external trade and accounts for 5% of Malaysia's exports with a value of \$20bn a year. The industry is also a large employer, involving 600,000 people across an array of jobs. The industry's effects and spin-off activities are extensive, creating economic benefits to numerous adjacent industries such as marine transport, logistics, equipment supply, food processing and packaging.

As such, the oil palm has come a long way since its introduction into Malaysia by the British in the 1870s as an ornamental plant. In the 1960s, the Malaysian government introduced land-settlement schemes for planting oil palm as a crop to eradicate poverty for landless farmers and smallholders, as well as to diversify the economy away from its then dependence on tin and rubber.

Today, about 56,000km<sup>2</sup> (21,600 miles<sup>2</sup>) of land in Malaysia is used for oil-palm cultivation, producing about 20 million tonnes of palm oil a year. This makes Malaysia one of the largest producers

and exporters of palm oil, accounting for 39% of world palm-oil production and 44% of world palm-oil exports. Malaysia also currently accounts for 12% of the world's total oils and fats production and 27% of the world's export trade of oils and fats. Major destinations of Malaysian palm oil are India, the EU, China, Pakistan and the US.

## The sustainability of palm

Being one of the biggest producers and exporters of palm oil and its derivative products, Malaysia plays an important role in fulfilling the growing global need for oils and fats sustainably. The Malaysian palm-oil industry is highly regulated, governed by more than 15 laws and regulations.

In Malaysia, palm-oil trees are mainly of the tenera variety, a hybrid between the dura and pisifera. The tenera yields 4-5 tonnes of crude palm oil (CPO) and 1 tonne of palm kernels per hectare (10,000m<sup>2</sup>) of land per year, over an economic life-span of 25-30 years. This compares favourably against other commercially grown oil-bearing crops such as soya bean, sunflower and rapeseed, which yield less than 0.7 tonnes of oil per hectare of planted land per year. In short, the oil palm's productivity is at least six times that of other oil-bearing crops in respect to land-use intensity. The oil palm is the most efficient oil-bearing crop in the world.

In fact, oil palms contribute approximately 33% of the world's production output of fats and oils (among the 10 major oilseed crops such as soya bean, rapeseed and sunflower) but use only 5.5% of the world's total planted agricultural area. This makes palm oil one of the most sustainable solutions when it comes to meeting the food, fuel and chemical needs of the growing world population.

## An important and flexible oil and fat

While the oleochemicals (chemicals derived from plant and animal fats) industry has been well-established in Malaysia since the early 1990s, the

biodiesel industry came into being only in the mid-2000s. Nevertheless, the hype surrounding biodiesel during that period catalysed an accelerated build-up of biodiesel production capacity in Malaysia that soon eclipsed oleochemicals production capacity. In Malaysia, there are currently 19 oleochemical plants with a total production capacity of 2.7 million tonnes compared to an estimated 40 biodiesel plants with a total production capacity in excess of 4 million tonnes. Having said that, a majority of these biodiesel plants are inactive. Excess capacity coupled with poor export demand has resulted in overall capacity utilisation of about 10%, compared with oleochemicals capacity utilisation of about 80%.

## National Biofuel Policy

Malaysia's National Biofuel Policy was released in 2006 by the Ministry of Plantation Industries and Commodities. It encourages the use of biofuels in line with Malaysia's Five-Fuel Diversification Strategy introduced in 1999 and contains a comprehensive framework in line with the objectives of the United Nations Framework Convention on Climate Change, to which Malaysia is a party.

The National Biofuel Policy envisions:

- The use of environmentally friendly, sustainable and viable sources of energy to reduce the dependency on depleting fossil fuels.
- The enhanced prosperity and wellbeing of all the stakeholders in the agriculture and commodity based industries through stable and remunerative prices. And this biofuel policy is underpinned by five strategic thrusts involving the use of palm biodiesel in transport and industry, its export, its research and development and its use for a cleaner environment.

## Palm biodiesel

Palm-based biodiesel has been on the developmental map of the Malaysian Palm Oil Board (MPOB), the government agency responsible for the pro-

motion and development of the palm-oil industry in Malaysia, since the 1980s. From 1990-95, the MPOB and Mercedes-Benz conducted an extensive trial involving 30 Mercedes-Benz buses with OM 352 engines. The buses covered distances of up to 351,000km (218,000 miles) each. Mercedes-Benz concluded, "The test showed that OF 1313 buses with OM 352 engines, which have been designed for operation with diesel fuel, can just as well be operated with palm biodiesel or a blend of palm biodiesel and petroleum diesel. This applies both to the engine performance and long-term operation. The results of the engine performance for the OM 352 engines can be translated to other direct-injection engines."

Studies have shown that the cultivation and processing of oil palm requires less input of fertilisers, pesticides and fuel energy to produce each tonne of oil relative to other oil-bearing crops. Furthermore, palm biodiesel typically contributes to greenhouse-gas (GHG) emission savings of 50% compared to petroleum diesel. With increasing numbers of palm-oil mills implementing methane capture, GHG emissions savings rise beyond 70%.

The depletion of fossil fuels, coupled with the increasing awareness of environmental protection,



Harvesting the hybrid tenera palm-oil tree in Malaysia: for every hectare (10,000m<sup>2</sup>), 5 tonnes of crude palm oil can be produced.

have led to concerted and escalating efforts in the search and use of renewable and environmentally friendly sources. Palm biodiesel can be, and should be, a major contributor to this spectrum of friendly alternative energy sources.

### Malaysian biodiesel industry: exports and local mandate

The Malaysian biodiesel industry grew rapidly in the mid-2000s on the back of the promise of relatively low palm-oil prices and anticipated strong demand from the EU and the US, which were then embarking on ambitious biodiesel programmes. The Malaysian government approved 91 biodiesel production licences and it is speculated that these licences cumulatively represented up to 10 million tonnes of potential production capacity. A much smaller number of these plants were eventually constructed and an even smaller number are actually in operation today.

Prior to 2011, the Malaysian biodiesel industry was solely focused on the export market, with the EU and the US being the major destinations. Exports of Malaysian biodiesel grew from 2006-09 but were severely compromised from 2010 onwards because of sharp price competition from Indonesian producers. As can be seen in the table (right), exports fell dramatically from 2010-12.

Since 2010, Indonesia has put in place a Differential Export Tax on its palm-oil products which essentially imposes a significantly higher export duty on CPO relative to processed palm-oil products such as biodiesel. This essentially caused CPO to be cheaper in the domestic Indonesian market than the international markets, providing Indonesian biodiesel producers with a significant economic advantage to compete aggressively against Malaysian producers. The bleak situation for Malaysian biodiesel producers reversed slightly from 2013-15 when fossil-fuel prices became a lot more expensive relative to CPO and that gave Malaysian producers some breathing room to

export. Nevertheless, Malaysia's export quantities remained low relative to installed capacity.

In 2007, the Malaysian Biofuel Policy Act was passed. This facilitated the development of the biodiesel industry in Malaysia and contained a provision to mandate blending of biodiesel into the domestic diesel pool. In 2010, following the collapse of commodities prices, the government announced plans for the implementation of the B5 biodiesel mandate.

The following year, the B5 mandate was rolled out in phases across regions to ensure a smooth and successful implementation. In 2014, the B5 programme graduated into the B7 programme. At the time of writing, the B10 programme is undergoing final stages of evaluation.

The Malaysian Biodiesel Association (MBA) has been working closely with the government at every step of the mandate implementation. In its latest initiative to promote the B10 mandate, it organised an expedition to the Malaysia highlands (1,500m above sea level), where temperatures fall to the low-teens Celsius, as a demonstration of the effective use of higher palm biodiesel blends in cooler climates. Members of the MBA drove various vehicle makes and successfully used blends of palm biodiesel from B10 to B100.

In 2015, it is estimated that half a million tonnes of palm biodiesel was utilised under the national biodiesel mandate. This translates to a proven

### Palm biodiesel exports from Malaysia

Year	Export (tonnes)	Export revenue
2008	182,108	NA
2009	227,457	\$155m
2010	89,609	\$68m
2011	49,999	\$46m
2012	28,983	\$25m
2013	175,032	\$129m
2014	87,356	\$66m
2015	178,942	\$124m

Source: Malaysian Palm Oil Board.



A Malaysian plantation used by Vance Bioenergy. Vegetable oil can be extracted from the red-coloured edible palm fruit and the kernel.

track record of 39 million km (24 million miles) of driving distance by Malaysian motorists with no known complaints relating to the biodiesel used.

### Malaysian Biodiesel Association

The MBA was established in 2008 and consists of members with commissioned biodiesel production facilities. It works closely with the government in the implementation of the domestic biodiesel mandate and represents the industry in regular government dialogues, forums and committees.

The current members of the MBA are essentially the biodiesel companies that have continued to sustain their business through the years, notwithstanding the dismal export outlook. The 20 members in the MBA represent an installed capacity of 2.4 million tonnes with total investment value of about RM2.2bn (\$600m).

Members of the MBA are capable of producing palm biodiesel that meets global specifications such as the EU, US and Malaysian standards.

### In conclusion

The Malaysian biodiesel industry is highly volatile due, in large part, to the vagaries of the export market for biodiesel. Nevertheless, the domestic biodiesel mandate has contributed to a synergistic effect among the biodiesel industry, the palm-oil industry, the country and the environment. The use of palm biodiesel in Malaysia has far-reaching benefits to the economy, in terms of a cleaner and greener environment, energy security and support for CPO demand. This consequently has an effect on a significant portion of the Malaysian population and a positive effect on GDP.

*Tian Ching Long is a Director with Vance Bioenergy, Malaysia's leading biodiesel exporter. The company is a pioneer in the Malaysian biodiesel industry and has one of the most advanced biodiesel analytical laboratories in the industry. Vance Bioenergy has been a full member of the Roundtable on Sustainable Palm Oil since 2006.*

# Hydrothermal processing

By James R Oyler,  
Genifuel Corporation

The science behind a pilot system that is creating high-quality crude oil and methane gas from wet organic waste material.

The National Alliance for Advanced Biofuels and Bioproducts (NAABB) was formed in 2009 by the US Department of Energy (DOE) to explore the potential for biomass to contribute to the supply of US transportation fuels. Genifuel Corporation was one of the original participants in NAABB. One of Genifuel's NAABB goals was to fabricate

and demonstrate a pilot-scale system to convert biomass into fuels. The purpose was to show that processes previously developed in the laboratory could be scaled up to a pre-commercial level, and show the ultimate viability and cost of biofuels.

## Evolution of the pilot system

The pilot system's size and capabilities evolved during the programme but eventually came to include the capability to produce biocrude oil and methane gas using hydrothermal processing (HTP). Genifuel's HTP process was initially developed by the DOE at its Pacific Northwest National Laboratory (PNNL) and is licensed to Genifuel, which has continued to advance the technology jointly with PNNL.

When HTP is configured to produce biocrude oil it is known as hydrothermal liquefaction (HTL), and when producing gas it is known as catalytic hydrothermal gasification (CHG). The conversion process is similar to the formation of fossil fuels, in which organic matter settles into shallow water or swamps and over time is subjected to temperature and pressure in the presence of water. HTP

achieves similar thermochemical conditions with any wet organic material using temperatures of 350°C and pressure of 200 bar for 45 minutes. The process converts 80% of the carbon of the wet material into oil and gas, which are chemically and physically similar to their fossil counterparts.

While the process works with any wet organic material, the particular focus of NAABB was to process algae. One of the consortium members, Reliance Industries, was interested in growing algae and using HTP to convert it into a refinery feedstock to process either separately or together with fossil crude. Reliance became a partner in the project to implement the pilot system, grow the algae and test the pilot system output in its refinery. The project became known as the Hydrothermal Processing Pilot System, or HPPS.

## System description

The size selected for the pilot system was 1,500 litres a day of algae slurry containing 20% solids, or 300kg a day dry weight of biomass. It was planned to be a HTL-CHG system, though the two processes would run separately. Since the owner of HPPS was Reliance, the system would ultimately be installed in India near their refinery.

The design was a skid-mount system which could go into containers for shipment from the US to India. The design was developed by Genifuel in consultation with PNNL, with detailed design and engineering by Merrick & Company, and fabrication by Springs Fabrication Inc. The system is now in India and being integrated into the algae-growing operation in preparation for processing algae feedstock on a continuous basis.

## System specifications

A number of samples of oil and water were taken. The tests showed that HPPS performance and oil production were similar to the performance and oil production reported by PNNL from many bench-scale tests with a variety of samples. The

## HPPS system specifications

Item	Measure
Operating pressure	207 bar (3000 psi)
Operating temperature	350°C (662°F)
Flow rate range (wet slurry)	1,000 to 2,000 L/d (264 to 528 GPD)
Flow rate as tested	1,500 L/d (396 GPD)
Size (total of both skids)	2m x 10m x 3.5m
Weight (total of both skids)	13,000kg

process scaled successfully by a factor of 40x and produced high-quality outputs.

## Conclusion

The results of the HPPS project are highly positive for the commercialisation of hydrothermal processing. The system scales well and the process works well with a wide variety of wet feedstocks, including wastewater solids, animal wastes, food-processing wastes, organic chemical wastes, wood, agricultural wastes and many others. The HTP biocrude is more similar to fossil crude than other bio-oils which have been tested. Tests of the biocrude for refining show that if the oil is subjected to preliminary hydrotreating it will upgrade to light sweet crude similar to a high-quality fossil crude and can then be refined like petroleum.

*Formed in 2006, Genifuel Corporation develops and manufactures hydrothermal processing systems to produce biofuels from wet organic materials, especially wet wastes. This allows the company to 'solve three problems at once' by producing renewable fuels, cleanly disposing of difficult wastes and producing clean water. Outputs may be either biocrude oil, natural gas or both. James R Oyler holds more than 20 patents issued or pending, as well as exclusive licences to other patents for hydrothermal processing. Genifuel has recently commissioned a pilot-scale facility to convert algae to fuel and is also working with a number of other projects using wet wastes as feedstocks.*



The skid-mount design of Genifuel Corporation's Hydrothermal Processing System means it can easily fit in a container for transportation.



# Global biofuels market

By Tammy Klein, fuel and transport consultant

A low-carbon transport future: should we stay or should we go?

Despite a prolonged period of low crude-oil prices that may continue for a while, citizens and policymakers in many countries have never been more committed to combatting climate change in all sectors, including transport. Transport currently contributes 25% of energy-related green-

house gas (GHG) emissions and 20% of energy use and is expected to double by 2030, according to the International Energy Agency. Passenger transport accounts for nearly 60% of total transport-energy demand and 60% of this is in member countries of the Organisation for Economic Co-operation and Development. In 2012, oil products accounted for 93% of final energy consumption. The question is, what can we do about this? What can we do to combat transport-related climate change and ensure personal mobility?

The answers have revolved around promoting tougher fuel-efficiency standards in light- and heavy-duty vehicles and increasing renewable energy in transport. Policymakers in countries such as the US, Canada, Japan, China, India, South Korea, Mexico and the EU are pushing tough new fuel-efficiency standards for gasoline- and diesel-fuelled vehicles. For renewable energy in transport, the top options encouraged by governments and favoured by some citizens are electric or hydrogen fuel-celled vehicles and biofuels. As battery prices fall, electric-vehicle sales are pro-

jected to take off with some studies bullishly stating they will represent 35% of all new global car sales by 2040. Hydrogen fuel-cell vehicle sales are expected to grow slowly, representing not even 1% of new sales by 2020. While the GHG-emission reductions are substantial, the challenges with these two options are the cost of the technologies used, consumer interest and acceptance, and importantly, fuelling infrastructure. Also, in the case of hydrogen, the GHGs produced in making hydrogen and the subsequent energy loss when looking at the combustion and thermodynamic cycle need to be considered.

That leaves biofuels, which are arguably the only true viable renewable energy transport pathway right now that is compatible with existing fuelling infrastructure. Recognising this, a 'biofuels gold rush' erupted in 2004 as policymakers began to see biofuels as a way to kill many birds with one stone. They could reduce harmful air pollutants, combat GHGs, enhance energy security, support their agricultural industries and provide jobs. Some countries were still phasing out lead and saw the addition of ethanol as a viable octane replacement.

Many governments moved quickly to require biofuels blending in gasoline and diesel, setting ambitious targets, and consumption grew. Some countries experienced a massive build out and scaleup of biofuels production over a short period of time. Other countries, faced with the reality of moving from aspiration to implementation, struggled and as a result, targets were delayed.

Further complicating implementation in some countries were concerns about sustainability. Since the mid-2000s, biofuels have been dogged by questions about whether they really reduce GHGs and thus whether it makes sense to grow biofuels feedstocks over food or clear forests and other carbon sinks for fuel. Mainly these questions concerned first-generation biofuels made with food crops such as corn, sugar cane, soya beans and palm oil. Conflicting analyses and methodologies



While conventional oil accounts for 93% of energy consumption, biofuels mandates will help meet GHG-reduction commitments.

used to investigate the environmental impacts of biofuels have caused some policymakers to question the wisdom of biofuels programmes. This produced an environment of regulatory and investment uncertainty for those producers and blenders (generally refiners) charged with complying with biofuels mandates and programmes, and which had invested billions in scaling up production, distribution and storage of biofuels. Some first-generation biofuels producers responded by making aspects of their production processes and feedstock sourcing more efficient.

Despite regulatory uncertainty and concerns over sustainability, biofuels consumption is increasing. Between 2014-25 and 2025-40, biofuels consumption is expected to grow 38% and 48%, representing 4% of total energy demand by 2025, according to ExxonMobil. Many countries have or plan to use biofuels as a GHG-mitigation strategy as part of their COP 21 commitments.

Meanwhile, different R&D efforts from government, academia and industry began to show that biofuels could be commercialised using non-food feedstocks that would reduce even further GHG emissions, depending on the production process used. These second-generation or 'advanced' biofuels show enormous promise in reducing or even eliminating these sustainability concerns. But for



Biodiesel production at Embrapa in Brazil. The country has an ambitious blending mandate assisted by its sugar-cane heritage.



A soya-bean harvest in the US; in the mid-2000s, there was environmental uncertainty about the production of first-generation biofuels.

the most part, production scaleup has been slow. Many companies promised that advanced biofuels would be commercialised by now and be price competitive with gasoline and diesel but that has not happened – not yet, anyway.

Biofuels programmes such as the US Renewable Fuels Standard were created in part to support the large-scale penetration of advanced-generation biofuels into the gasoline and diesel pool to reduce GHG emissions and enhance energy security. More than 260 billion litres were required under the statute in 2016; however, only a fraction of that was produced in 2015. Technical barriers and constraints have proven larger than expected. These constraints – lack of commercial production, fallout from the sustainability debate and the lack of clear, long-term policy signals and support from the US, EU and other countries – created a climate of investment uncertainty.

As a result, some companies shut down as capital dried up, which only generated further negative impacts for the industry. In fact, the industry association Biotechnology Innovation Organization has estimated the lack of regulatory certainty has cost the industry \$13.7bn in investment over the past several years. Current oil prices have only

worsened the situation. Ironically, this has happened at a time when some companies are making real progress.

With such a challenging outlook, should we give up and call it a day? Should we focus on other strategies? Does it matter to society whether advanced biofuels are really commercialised? It depends on your frame of reference. If you believe that climate change is an issue and accept the statistic about transport's contribution to it, then the answer is yes. That brings us back to the low-carbon options. The reality is that a combination of these strategies will be needed to reduce transport GHG emissions but their development and commercialisation are at different stages. First-generation and advanced biofuels are important, and in fact, some studies have shown that it is difficult to near impossible to achieve a low-carbon transport future without their use. Staying the course may be the most responsible option.

*Tammy Klein is a strategic adviser to global-automotive and oil-industry clients, as well as governments on fuels-policy issues, with 20 years' experience on conventional-fuels, biofuels and alternative-fuels policy and market issues.*



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# Global perspective on ethanol production

By Luiz Carlos Corrêa Carvalho, Canaplan

Leaders of the new-energy scenario.

As a geopolitical topic, the consequences of the COP 21 meeting on climate in 2015 have been key to the future of production, marketing and use of energy. This implies, on the one hand, challenges to producers of fossil fuel, but on the other hand opportunities for a new world with these same producers seeking new technologies.

After a cycle of high commodity prices, there has been a low cycle since 2015 in commodity and energy prices. Low prices often encourage demand but a lower supply of energy. The slow growth of the world economy pressured by oil surplus creates great opportunities.

In this new energy scenario, Brazil differs from other economies, especially when its energy matrix and emissions are compared to OECD countries and the rest of the world (see table, below).

## Domestic energy supply 2014

Region/country	Renewable weight (%)	CO <sub>2</sub> emissions (tCO <sub>2</sub> /tep)
Brazil	39.4	1.59
OECD	10	2.31
World	14	2.37

Source: Resenha Energética Brasileira 2015, MME.

The main factors to explain these differences in Brazil are the by-products of sugar cane and hydroelectricity in the energy matrix. In Brazil, 74.6% comes from renewable sources against 23.6% in the world average and 23.1% in the OECD. The products of sugar cane (bagasse and ethanol) in Brazil account for 57% of the biomass and 15.7% of the energy matrix. In 2014, the share of bioenergy (ethanol and biodiesel) in the transportation sector was 17.6% against 3.6% in OECD countries and 0.4% in other countries.

The US and Brazil are the main ethanol producers. In Brazil, ethanol is almost entirely from sugar cane; 29 billion litres were made in the 2015/16 harvest. In the US, the supply is much higher, with formidable growth and corn as the raw material (57.8 billion litres in 2015).

## The international market for ethanol

Recently, the global ethanol market has shown a slight contraction, with a global production of 116 billion litres. While the US, Brazil and EU have reduced production by 1.2 billion litres, China is increasing its supply by 400 million litres and has replaced the EU as the third-largest producer, with 8.2 billion litres. There has been a stagnation of international ethanol trade between 7-8 billion litres and a concentration of supply on the US, Brazil, EU and China. For a global supply of fuel ethanol of 96.2 billion litres and a consumption of 92.9 billion litres, small business and product difficulties of becoming a 'commodity' can be noted.

## Public policies in major producing countries

Ethanol prices from country to country show differences given internal policies. Mandatory use laws in the US and EU that, years ago, were attractive, have now reached a supply ceiling.

## Scenarios

International oil prices are clearly a major factor for the viability and scale of ethanol. Sometimes

pressured by inadequate public policies, even in previous years with high oil prices, the supply of ethanol moved forward at a slow pace.

New energy resources and technological tools are becoming available. However, little work has been done to create a clear map of the energy and geopolitical nexus. This is especially true in the US, which is reappearing as a major oil producer and exporter. How and when to move this power forward, intervening in energy markets or otherwise, will be a difficult decision that will require an analysis of complex elements that change rapidly.

With an estimated global demand for gasoline in 2025 of 1.7 trillion litres, a supply of 205 billion litres of additive ethanol to replace only 10% of the world's demand for gasoline would be needed. A new development called 'sugar-cane energy' should generate agricultural productivities over twice the current amount and second-generation ethanol will allow a huge supply of renewable fuel from agricultural and forestry production, in addition to waste transformed into clean energy.

The prospect of an increase in energy consumption is explained by emerging countries. Low oil prices show an opportunity for public policy as characterised by US economist Lawrence Summers, a professor at Charles W Eliot University and President Emeritus at Harvard: "The recent steep fall in oil prices has become an opportunity. There is room for debate about the size of the tax and about how the resources should be deployed. Defending a carbon tax is not some kind of government planning argument – it is the logic of the market: that which is not paid for is overused."

Luiz Carlos Corrêa Carvalho is Director of Canaplan, a company that specialises in projects for the sugar and ethanol sector. He is also Director of the Alto Alegre Group, President of ABAG (Brazilian Agribusiness Association), a member of the Superior Council for Agribusiness FIESP, President of SNA (National Agriculture Society) and a member of the board at both UDOP (Union of Biofuel Producers) and Unica (Sugarcane Industry Association, Brazil).



The vast majority of Brazil's ethanol is derived from its sugar-cane harvest and most of its fuel ethanol is used in the home market.



# Biofuel management in an oil company

By Anna Wysok and Csaba Zsótér, MOL Group

It's time to build renewables strategies and look beyond 2020.

Current biofuel blending targets may seem easy to achieve, but in a company like MOL Group, with operations in over 40 countries, operating four refineries, two petrochemical plants and owning over 1,750 service stations, this 'few per cent of obligation' amounts to 500,000 tonnes of biofuel per year, blended in our own refineries or depots. It's little wonder that a biofuel management and dedicated Biofuels Trading Team is key to tackling challenges and opportunities in the bio-world.

## The real exposure: be faster than the others

Biofuels play a significant role in the EU's sustainable development. The Renewable Energy Directive imposed a biofuel blending target for states, which is increasing each year, while the Fuel Quality Directive commits fuel suppliers to lower greenhouse-gas (GHG) emissions by 10% between 2011 and 2020. For oil companies, it means selling biofuel at the price of conventional fuel, which is usually loss-making. However, loss can be minimised. Since everybody is facing the same problem, a good strategy can turn a burden into a competitive advantage.

## Biofuel playground: know your tools

It is important to follow the changes of the non-liquid biofuel market and take advantage of short-term opportunities. There are a few ways to optimise biofuel component blending based on current prices but it is possible only in countries where the law does not set the precise amount of biofuel to be blended. The first choice is between ethanol and fatty acid methyl ester (FAME). Usually ethanol is the cheapest option and it is blended to the blending wall, then the remaining part of the obligation is fulfilled with FAME. In the case of biodiesel, the supplier can decide on either a single- or double-counting (waste-based) type. The second one is more expensive, but can be counted double towards the energy target and bring real savings to the company.

In countries where national legislation allows yearly basis reporting, there is room to allocate the volumes within a year, especially when there is a big difference between the prices of winter- and summer-quality biofuel. Profit can also be made out of storage shortage in the market via contango deals by bringing a position forward, cheaper.

Quick reacting can show good results but thinking in mid- and long-term gives greater opportunities. The first typical strategic question is: make or buy? Ownership of a biofuel production site brings flexibility and lowers dependence on external companies but it moves a traditional oil company out of its comfort zone and puts part of its exposure on the feedstock side.

While planning the 2020 GHG emission-reduction target fulfilment, it is worth mentioning upstream emission reductions. It is possible to account for GHG-emission reduction from the upstream side to the downstream target and lower the amount of blended biofuel, if appropriate audits are performed.

Being proactive and changing something which does not work or could work better should be a priority. Active advocacy on the national and

EU level ensures being up-to-date and creating a better environment for business activities.

The list of biofuel components is getting longer, slowly turning to waste-based products. Besides bioethanol and FAME, a fuel supplier can blend used cooking oil methyl ester, hydrotreated vegetable oil or second-generation ethanol.

Changing the blending limits in gasoline and diesel standards is expected, especially on the ethanol side. Many countries already allow E10 gasoline with 10% ethanol, however, high blends such as B30, B100 (diesel with 30% or 100% biodiesel) and E85 can be sold as a fuel for heavy vehicles if it is allowed by national regulations.

## Main challenges: be aware of them

Blending limits are becoming too low when considered against the rising biofuels obligation. However, car manufacturers and customers are mostly against increasing the allowed biofuel percentage, and most of the car fleet in Eastern Europe is old and unsuitable for such an increase. A solution is 'drop-in' biofuels (e.g. HVO). Its chemical composition is similar to diesel so it can be used without any limits.

Each country has its own regulatory environment. Those variations, together with hectic changes and lobbying, put an operational burden on wholesalers. Only moving towards a unified system of pricing can change this.

Unclear legislation and differences between countries leave opportunities for grey market activities, which can have an impact on legal and fair business. National governments should not create more regulations but rather provide wiser control on already existing ones.

## The future is around the corner

Even though nothing is carved in stone, it is time to start analysing the opportunities for post-2020 and prepare for different rules. One thing is for sure: the EU is turning towards waste-based



MOL Group owns and operates two petrochemical plants and four refineries, blending 500,000 tonnes of biofuels a year.

blending. In the centre of difficulties lie opportunities. If the company is an international corporation or a small player, everybody at some point will have to deal with biofuels. Do you hide from the storm or build a suitable boat to survive?

Anna Wysok joined MOL Group in 2015 under the GROWWW post-graduate programme. She is responsible for EU and national-level biofuel-related regulations. Csaba Zsótér is Product & Renewables Trading Manager in MOL Group. He manages MOL Group trading activities in relation to oil products, biofuels and other renewables.



The blend limits for gasoline and diesel will have to increase in the coming years to meet rising biofuels obligations.

# The petroleum industry vision on biofuels

By Mario Lindenhayn, BP Biofuels

With biofuels becoming a significant component of the road-transport fuel mix, there are challenges and choices ahead.

The energy trilemma – accessing secure, low-carbon and affordable energy – is particularly challenging in the transport sector. Transport accounts for 23% of energy related CO<sub>2</sub> emissions, with 80% coming from road transport. It is a sector where greenhouse-gas (GHG) emission

reductions will be required if progress towards COP 21 is to be made.

Transport is predominately reliant on oil (94%), with road transport comprising over a billion vehicles globally. It is also a sector that exacts demanding requirements of both vehicle and fuel technology in terms of safety, cost, performance, range and reliability. In addition, fleet turnover occurs slowly with new vehicle technologies taking approximately 15 years to fully penetrate. Lastly, and crucially, liquid fuels have higher energy densities and are easier to transport and store when compared with the alternatives.

## Biofuels: current state of play

Biofuels have already made a significant penetration into road-transport fuels. Globally, biofuels account for 1.4 million barrels of oil equivalent per day (boe/d) or around 2.5% of total transport demand. The fact that they are liquid and have an energy density comparable to their fossil equivalents, gasoline and diesel, can be blended and are largely compatible with vehicles and the supply infrastructure, has meant that the use of

biofuels has outpaced other alternative fuels such as compressed natural gas (CNG) or liquid petroleum gas (LPG).

## Challenges: supply and demand

This growth has not come without concerns. Biofuel policies have been criticised by policy-makers, academics, NGOs and others for driving up food prices, contributing to hunger, climate-change impacts, deforestation, loss of biodiversity and increasing pump prices.

Not all biofuels are equal in terms of carbon impact and sustainability. Crops such as grains and oilseeds are highly intensive to cultivate and relatively low yielding; this is because of the biological energy required to manufacture the starch, proteins, etc. The yield, or more technically net primary productivity, is often correlated with many of the sustainability dimensions at stake, including carbon impacts, water use and biodiversity impacts. While biofuels produced from intensively cultivated food crops have a role to play in terms of providing an initial entry platform, they have clear limitations.

The ultimate goal is to move to biofuels produced from high-yielding crops that require low agricultural inputs and do not require prime land. Agricultural wastes and residues are an additional and complementary supply source.

Sugar cane is a good example; yields range from 21-25.5 dry tonnes per hectare (10,000m<sup>2</sup>), up to three times higher than US corn yields. Sugar cane's high yield allows it not only to produce significant amounts of ethanol, but the non-sucrose portion of the crop, the bagasse, is recovered and used as feedstock for the sugar-cane mill's cogeneration unit, providing steam and power for the mill as well as for export to the grid. In addition, sugar cane is highly efficient in terms of water use. As well as irrigation being primarily rain-fed, the water removed from the field in the form of the crop is returned back from mills as



BP's Brazilian biofuels production is now fully mechanised. Sugar cane is transported to one of three mills for conversion to ethanol and electricity.

vinasse, a nutrient-rich recycled water stream. This return flow acts both as supplemental irrigation and crop nutrition, reducing fertiliser requirements.

The result is that sugar cane supplies 16% of Brazil's energy mix from 97,000km<sup>2</sup> (37,500 miles<sup>2</sup>) of land under cane cultivation – which is 4% of Brazil's productive arable land. The challenge is how to replicate this elsewhere. Basic climatic differences mean that other crops will need to be used, namely fast-growing energy grasses such as miscanthus, napier grass and wood feedstocks. To turn these into biofuels requires the development and deployment of advanced cellulosic conversion technologies. Progress is occurring, with six commercial-scale cellulosic biofuel plants now coming on line in the US, Brazil and Europe.



Slow turnover of the global vehicle fleet means that new technologies can take 15 years to spread.

There are challenges on the demand side. The primary one is the so-called 'blendwall' – ethanol and biodiesel specification blending limits due to vehicle and fuel-delivery system compatibility and tailpipe pollutants caps. The most well-known instance of this is in the US, where meeting biofuel targets would require ethanol to be blended into gasoline above the current 10% volume limit.

While a number of approaches are being pursued to address the blendwall issue, the challenge is the slow turnover of the existing vehicle fleet and the introduction of new fuel-supply infrastructure, coupled with warranty issues with the existing vehicles and fuel-dispensing equipment.

### The prize

While the introduction of electrification into road transport is likely, the size and rate of turnover of the existing global car fleet means that over 90% of cars will still be reliant on the liquid-fuelled internal combustion engine in 2030.

The use of biofuels produced from high-yielding, low-input crops such as sugar cane have an important role in complementing the GHG-emission reductions achieved through increasing vehicle efficiency. A hybrid, fuelled with a high percentage blend of a sustainable, low-carbon biofuel could offer similar lifecycle CO<sub>2</sub> reduction as electric vehicles using low-carbon grid electricity, or fuel-cell vehicles using low-carbon hydrogen, at a substantially reduced cost to the motorist, without major changes to the infrastructure.

This might sound like a compelling story but the supply of land is finite and given all the other pressures, is there enough availability of land and/or biomass to form a sustainable supply base?

The UK Energy Research Centre has conducted probably the most comprehensive review of all the studies in this field. It concludes that by 2050, at the most conservative end of the scale, 100 EJ (exajoule; 1 quintillion joules) of biomass would

be potentially available, with some projections ranging up to 300 EJ, which is 25 million boe/d, to 75 million boe/d respectively. It's a significant resource when compared with today's global road-transport demand of 41 million boe/d.

There are, however, caveats: clearly this bio-mass resource potential is not dedicated for liquid fuels and can be utilised for other energy applications, namely biopower, heat and biochemicals. More importantly, it is dependent on advances in crop technology, agricultural techniques and conversion processes. Also, careful selection of land, crop-management technologies and uses are all required. The choice of crop must balance high yield with low inputs, be low impact on the environment and have a positive climate impact.

To explore this further, BP has been working with MIT to use its emissions-prediction and policy analysis model to investigate what a large-scale bioenergy sector might look like. The project indicates that a carbon price of \$99/CO<sub>2</sub> tonnes equivalent by 2050 would be sufficient to stimulate a global bioenergy sector of 150 EJ (one of comparable size to today's oil sector) utilising up to 2.6 million km<sup>2</sup> (1 million miles<sup>2</sup>) of land, equivalent to 27% of the US total land area, and well within estimates of up to 13 million km<sup>2</sup> (5 million miles<sup>2</sup>) of abandoned/underutilised arable land globally. The work demonstrates that the impact on food prices would be an increase of 3% versus business as usual. In addition, the modelling demonstrates that the potential impacts of a large bioenergy system on natural forests could be managed with dedicated land-use policies, including a price on land carbon, although both may be challenging to implement.

### BP activities

So how is BP responding? BP has the largest-operated renewables business among our oil and gas peers, consisting of our US wind business and our Brazilian biofuels business, where we operate



Heavy goods vehicles will most probably remain powered by the internal combustion engine using biofuel blends for the foreseeable future. Hybrids and 'trolleytrucks' could be interesting propositions for battery power with the right conditions in place.

three sugar-cane mills producing ethanol and sugar and exporting power to the grid.

We're also developing biobutanol with DuPont. Biobutanol can be made from the same feedstocks as ethanol, but has improved fuel properties so it can be blended with gasoline at higher proportions, providing a blendwall solution.

Increasingly, biofuels are becoming an integral part of BP's businesses. As a fuels supplier, BP has been procuring and blending biofuels in a range of markets in response to biofuel targets. Recently, Air BP has started the first commercial supply of biojet fuel via an airport's existing fuel hydrant system, at Oslo Airport in Norway.

### Conclusion

Biofuels that are low cost, sustainable and low carbon have a key role to play in reducing GHG emissions from the transport sector as well as improving energy security. Biofuels produced from relatively low-yield, resource-intensive crops are a starting point, a platform for further

development, but cannot form the meaningful global resource base at the scale required. However, the expertise, capabilities, operational know-how, and, in some cases, physical asset bases should be leveraged to deploy technologies based off advanced higher-yield energy crops.

There is no silver bullet that will deliver the desired de-carbonisation of the transport sector. It will require a combination of technologies on the vehicle and fuel side. Sensible policy should recognise this and seek to compliment the improvements in vehicle efficiency, hybridisation and other vehicle-side technological developments with those on the fuel side, including low-cost, low-carbon biofuels.

*Mario Lindenhayn is the CEO of BP Biofuels. As the senior BP biofuels representative, he has overseen the company's expanding sugar-cane ethanol production. On top of the Brazilian portfolio, Lindenhayn has also assumed responsibility for global businesses including Butamax and DuPont.*



# Food vs fuel: part one

By Jeremy Martin,  
*Institute of the Americas*

Sufficient land exists for biofuels production. With correct management, food security is not an issue.

For years, a debate has raged over the efficacy and merit of utilising and converting crops such as corn and sugar cane into transportation fuels. The benefits of reduced fossil-fuel use and lower greenhouse-gas (GHG) emissions on one side were pitted against the impact on availability and prices of food sources. This battle was particularly acute in the developing world and nations where

even slight effects on the cost and supply of food have dire consequences. In many ways, the intensity of the debate has declined of late with the downward spiral of oil prices.

But the ebbing of the discussion also stems from the fact that a verdict is in: food vs fuel is not a zero-sum choice. That is to say, with appropriate market-based policies, renewable-fuel mandates and increased usage of crop-based biofuels can co-exist with agricultural production without jeopardising food security. This is particularly so when proper consideration is given to sustainability criteria of crop selection for renewable fuels.

## Emissions reduction

The historic COP 21 meeting in Paris in 2015 and resultant agreement on climate change furthered those who advocated the upside for emissions reduction brought by boosting renewable-fuels production and consumption. The science has demonstrated the validity of increased usage of renewable fuels to reduce GHG. According to the US Renewable Fuels Association, transportation-related emissions trended downward following adoption of the US Renewable Fuel Standard and

current levels are 10% below 2005 levels. It is also important to note the caveat that GHG-emission reductions are at different levels depending upon the feedstock. The least effective, corn ethanol, produces 34-44% less GHG emissions than gasoline, while sugar cane reduces GHG emissions by up to 50%. But the most efficient and producing the largest reduction is cellulosic ethanol, which in some cases is a carbon-neutral source with no net GHG emissions.

## Growth of mandates

Contributing to the intensity of the debate was the increased embrace by policymakers and legislators of targets for percentages of renewable fuel blends in transportation fuels. Indeed, strong opposition to mandates produced advocacy campaigns such as Mandating Hunger.

Over 60 countries have biofuels targets and varying forms of mandates including 27 European nations through the Renewable Energy Directive. Interestingly, and in an effort to defuse its critics, the European Union put in place a 7% cap on 'food-based' biofuel used as transportation fuels.

In Latin America, countries such as Brazil have long been pioneers and figured prominently in policies aimed at renewable-fuel usage. Brazil has a minimum ethanol content of 27%. Other countries in Latin America have objectives to include different types of biofuels as minimum content. Colombia has E8 ethanol, Chile E5 and B20 biodiesel and Mexico E2 (initially a regional target but will eventually expand). Paraguay has a 25% mandate but is looking to boost its target along the lines of Brazil. Argentina's government has announced a plan to increase the renewable-fuel standard from 10% to 12%. Ecuador, Peru, Uruguay and Central American countries have already committed to achieve biofuels targets to also make regular fuels more competitive.

Perhaps most indicative is to understand where renewable-fuel standards fit as part of countries'



A recent Brazilian report suggests that crops grown for conversion to biofuel also safeguard crops used for human consumption

Nationally Determined Contributions (NDCs) under the Paris climate agreement: almost 30 out of 128 nations at COP 21 feature biofuels policy measures as part of their climate-action plans.

## Food security and agricultural implications

Since 1975, the International Food Policy Research Institute has been looking for policy solutions aimed at reducing poverty, hunger and malnutrition in a sustainable way. Their latest report issued in 2016, *Green Energy: Fueling the Path to Food Security*, notes that energy is vital to ensure food security and achieve a strong global food system but stresses that countries around the world need to look for sustainable and green paths to decelerate climate change.

A landmark study released in 2015, *Bioenergy & Sustainability*, produced by researchers from the São Paulo Research Foundation in Brazil, set forth findings to counter the argument that increased production and consumption of renewable fuels would cause food insecurity. To the contrary, the report strongly emphasised that it 'helped improve food security by optimising land productivity and agricultural management'.

## The sustainability factor

There is little disagreement that altering land use has impacted biodiversity, hydrology, climate and



European Union rules on biofuel production from food crops, such as sugar beet, mean that only 7% can be directed for fuel use.



The reality is that a third of the world's food goes to waste, rising to 40% in the US; stringent food management needs to be introduced.

weather patterns. Science has long demonstrated that biodiversity is key to a healthy ecosystem.

There is no doubt that part of ensuring the continued balance between renewable fuels and food security has to do with policies that emphasise and guarantee best practices for sustainable production. Turning again to the *Bioenergy & Sustainability* report, one of its principal conclusions is that the world does have sufficient land to dedicate greater areas to biofuels production without threatening global food security, but that most of this land is in Africa or Latin America. Indeed, Brazil has spare arable land available, roughly 700,000km<sup>2</sup> (270,000 miles<sup>2</sup>), in which sugar and other crops can expand without tapping any rainforest land or competing with land for food production.

While several analyses point to an equitable and sustainable balance, continued assessment of any pertinent land-use changes linked to biofuel production must be a political and policy priority.

This is particularly so in the largest-producing markets in Latin America, principally Brazil.

### Conclusion

Based upon several different studies, experts point to trends that will see an increase in acreage devoted to sugar cane and cellulosic biofuels. At the same time, corn-based biofuels that are less efficient and with fewer GHG benefits will be grown almost exclusively for food and livestock feed.

As with most policy debates, striking the proper balance will be essential. Here the challenge lies in reconciling what crops and land are devoted to fuel production versus food production.

*The Institute of the Americas is a think tank based at the University of California, San Diego. Its Energy Program works to foster a deeper understanding of critical energy issues. Jeremy Martin is Director of the Energy Program and spends his time following energy trends and policy issues across the Americas.*

## Food vs fuel: part two

By Dr Eric Sievers, *Ethanol Europe*

Grain ethanol production is a net contributor of protein to the food chain.

Feeding 9-10 billion people by the middle of the century and preventing dangerous climate change are two great challenges facing humanity. Embedded carbon released through burning fossil fuels is a major cause of climate change. Biofuels produced from crops also release CO<sub>2</sub> but in Europe these emissions are on average 60% lower than those of fossil fuels. Indeed, biofuel blends have become a significant mechanism to reduce greenhouse-gas (GHG) emissions globally. However, concerns have developed that fuel produced from crops could impact negatively on food security.

The two most cited negative impacts of biofuel production are food security and indirect land use change (iLUC). The first suggests food-price increases caused by biofuels lead to hunger. The second suggests that biofuel production displaces some food production onto new farmland carved out of forests, thus resulting in additional CO<sub>2</sub> emissions. The two are linked in that iLUC is expected to occur if prices of crop commodities incentivise use of new farmland.

This analysis of the debate focuses on the EU ethanol pathway; with food-chain impacts, price impacts and food-quantity aspects considered.

### Food-chain impacts

White corn or sweetcorn, what most people think of as the corn they eat, is not used in ethanol. Production uses feed corn that has almost no market as food but is purchased for animal feed and industrial uses (plastics, paper, chemicals, etc). Most ethanol produced today is from such corn and most of the remainder is from sugar cane, sugar beets and feed wheat. The uses of feed wheat are similar to feed corn in that there has never been any large amount consumed by people. Indeed, these crops have always been for 'fuel' in that these are the crops that fed horses and livestock before the ascendance of the internal combustion engine.

Ethanol uses low-nutritional-value components from corn or wheat. The ethanol pathway process uses only starch. Starch is of low nutritional and market value. Starch does not add nutritional value to foods other than calories; it offers no protein, fat, vitamins or minerals. Whether used in a human body or an ethanol plant, the starch is converted to simple sugars by enzymes.

Accordingly, in grain ethanol production, everything but sugar goes back into the food chain. The nutrients are not removed but remain in the food chain in the form of high-protein animal feed.



Crop-based biofuels can meet 10% of global transport energy by 2030 without any adverse effects on food security.





Ethanol uses feed corn that has little market value as food but is bought for animal feed or industrial use. White/sweet corn is not used.

Indeed, more than 'everything' goes into this feed; some of the starch is upgraded to protein in the form of large quantities of brewer's yeast, meaning that in a world short of protein (and the world is indeed long on starch and short on protein), grain ethanol production is a net contributor of protein.

A modern grain ethanol plant produces equal quantities of ethanol and animal feed, known as distillers' grain (DGS). DGS contains three times more protein, fat and fibre than corn.

### Price increases

The food security concern is that price increases lead to a reduction in the quantity or quality of food consumed. There is a disconnect between ethanol production and food price inflation. While ethanol production in the US has grown, food inflation has fallen. It's identical in Europe.

With regard to food security, food prices (not commodity prices) are what matters. Food prices are impacted by the global prices of sugar, wheat and corn but are not determined by the prices of

these commodities. This is because local food prices are often disconnected from commodity prices in trading hubs and it is also because commodity inputs are often far less than half the price of finished food products. Indeed, in many cases, the portion of food price that is set by feed commodity prices is too small even to quantify.

Studies have conflated feed commodity prices and food prices. Yet, biofuel feedstock prices have gone up less than those of any other group of commodities. The price of corn in the US dropped by half in 2015, becoming the same as it was in 2008. Bioethanol production doubled in the same period, making the disconnection of corn price from corn-ethanol production all the more salient.

Agricultural commodity prices are linked to oil price. They have been, in contrast, only weakly linked to ethanol. The UN Food and Agriculture Organization (FAO), the World Bank and the International Energy Agency (IEA) have identified the relationship between oil prices and food prices. The 2013 World Bank report *Long-term Drivers of Food Prices* concluded that higher oil prices caused two-thirds of the price increases in feed commodities used for biofuel production. It also concluded that the impact of biofuels on the price of these commodities was negligible. The recent fall in crude-oil prices has been mirrored in the collapse in the global food-price index, reinforcing the link between food prices and the price of oil. To drive the point home, 2015 was a record year for global ethanol production.

Commodity costs are usually a small component of final food-production costs and final food-product price. The OECD estimates that in developed countries, agricultural commodity prices constitute less than 35% of final food prices. Processing, packaging, distribution and marketing costs are unrelated to crop commodity prices. Thus, even though biofuel production has had a low-level impact on commodity prices, impacts on food prices are even lower.

### Food quantity

With the global population approaching 9 billion in the next few decades, it is asserted that there is a need for 70-100% more food. The FAO calculates that the world produced 13 quadrillion calories of food in 2010, which amounts to more than twice the recommended average dietary intake of about 2,400 kcal per person per day. It seems there is no global food quantity problem, yet, food is not available for all. Food security is not directly linked to global food production but rather is determined by many important drivers, such as smallholders versus large-scale farms, distributional issues, or inefficient food usage.

Today people are getting more calories. Food calorie intake per capita is 20% higher globally than 50 years ago. Roughly 30% of food is lost to waste; up to 40% of food in the US goes uneaten.

Recent developments show that bioethanol production has played a negligible adverse role in global food insecurity. Other factors, such as structural elements in the global agricultural trade system, or inadequate infrastructure and policy in the developing world play a dominant role.

Indeed, to the extent that bioethanol production increases the income levels of farmers, the industry may have a net positive food security impact. As all recent analyses of food security observe, the true solution lies not in making food cheaper but in increasing the incomes of those who are most food insecure.

Bioethanol has grown strongly in volume over the past decade and if major global food-security problems were to ensue, facts should have reflected them by now. It just has not happened. In contrast, climate, social and economic benefits have been brought globally by bioethanol production.

It would, of course, be irresponsible to push for biofuels volumes that overstretch the productive capacity of farming systems but it would be equally irresponsible to fail to promote biofuels only because there is a limit to how much oil can



Biofuels have had negligible impact on commodity prices and an even lower impact on food prices.

sustainably be displaced by biofuels. From current information, it appears certain that 10% of global transport sector energy can be supplied by crop-based biofuels in a gradually increasing production arc to 2030 without adversely impacting global food security or causing iLUC.

### Food and fuel

Today, 2% of transportation fuels are low carbon. According to the IEA, 10% of fuels must be low carbon by 2030 if we are to satisfy economic growth and limit global warming. Decarbonising the transport sector is indispensable for achieving this goal. Sustainable crop-based ethanol is one of a range of low-carbon transport fuel solutions that can make a significant contribution. And it facilitates more food production at the same time.

*Dr Eric Sievers is Director – Investments at Ethanol Europe. He is helping to commercialise new bio-based technologies associated with Europe's largest ethanol production facility, Pannonia Ethanol.*



# COP 21

By Alex Forbes, industry writer  
and trend analyst

The Paris Agreement on climate change presents opportunities and challenges for all energy industries.

The historic climate agreement reached in Paris in 2015 at the 21st Conference of the Parties to the UN Framework Convention on Climate Change (COP 21) was a triumph of diplomacy. Now, as the 195 countries that are signatories grapple with ratification and implementation, what are the Paris Agreement's implications for the energy industry?

The strength of COP 21, in terms of the mitigation of climate change, was that the negotiators were able to agree a single, unambiguous target: to limit anthropogenic climate change to 'well below 2°C above pre-industrial levels'.

This is the limit beyond which the effects of climate change are likely to be catastrophic. This number will affect the prospects for all sources of energy for the rest of this century.

## Good news, bad news

It is good news for renewable-energy sources and nuclear. It is unquestionably bad news for coal, which, though it currently has a huge share of electricity generation, faces decline unless carbon capture and storage becomes an economic reality. It is also bad news for oil, though its role in transportation will take a long time to usurp.

## A brief history of climate talks

The UN Framework Convention on Climate Change (UNFCCC) treaty was established at the Earth Summit in 1992. It led in 1997 to the adoption of the Kyoto Protocol, which bound developed countries to emissions-reduction targets.

The drawback of the Kyoto Protocol was the concept that countries could be neatly divided into 'developed' and 'developing', with only developed countries having to take action on global warming. Today, such a binary approach would sound ludicrous, as developing nations are among the largest emitters of GHGs.

The next milestone was COP 15 in Copenhagen in 2009. Hopes were high that a global agreement on the mitigation of climate change would be the eventual outcome. It turned out to be a political shambles. That said, lessons were learnt – lessons that have contributed to the success of COP 21.

Prior to Copenhagen, a number of countries and regions made pledges to mitigate climate change in the hope that such pledges would help catalyse a successful outcome. This concept of countries making voluntary pledges was enshrined in the non-binding Copenhagen Accord that resulted from COP 15. By 2010, nearly 100 parties had filed submissions with the UN secretariat.

As part of the process that led to COP 21, countries were asked to submit climate-action pledges in advance. The importance of these Nationally Determined Contributions (NDCs) cannot be overstated. Anyone disappointed at the lack of specifics in the Paris Agreement will find plenty in the 190 or so NDCs submitted to the UNFCCC.

## The impact of NDCs

Together, the NDCs as pledged so far put us on a trajectory to 2.7°C of global warming. Some of the most intense negotiations in Paris focused on how ambition could be ramped up and the processes needed to do so. It was agreed that there would be a five-yearly 'stocktake' to assess

progress, thus providing a basis for the ratcheting up of ambition. The first is due in 2023. In their current form, NDCs are a big improvement on the 4.8°C of global warming that business-as-usual would lead to, and, if implemented as pledged, would have major impacts on all forms of energy.

## Enormous opportunities

Energy production and use account for two-thirds of GHG emissions so energy will be central to achieving reductions. According to the UNFCCC report on the aggregate effect of NDCs, to have a 50% chance of limiting global warming to 2°C, we now have a 'budget' of CO<sub>2</sub> that can be emitted after 2011 of 1,300 gigatonnes.

Of the possible ways of staying within this limit, the most obvious is to use energy that emits no carbon. But to meet growing demand for energy with zero-carbon sources will not be possible for some time so other choices will have to be made. One of the most effective ways of reducing carbon emissions is to substitute a carbon-intensive fuel such as coal with one that is less carbon-intensive, such as biofuels or natural gas. Indeed, the argument has been accepted by a number of economies, notably the US with its Clean Power Plan, and the UK, which proposes to phase out coal-fired electricity generation by 2025.

## NDC scenarios

So how likely it is that NDCs will be implemented in their present form? The following are possible:

- The pledges end up becoming mere good intentions, leaving the world on a trajectory to global warming of 2.7-4.8°C.
- The NDCs are implemented, putting the world on a 2.7°C trajectory.
- Ambition is ramped up in five-yearly NDC cycles sufficiently to meet the 2°C target of 450 parts per million (ppm) of GHGs in the atmosphere. This is the scenario that the IEA has been advocating in its 450 Scenario.



The COP 21 agreement will lead to the decline of coal and oil use. Now is the time for renewable industries to point the way forward.

- One of the surprises of COP 21 is that, alongside the agreed limit of 'well-below 2°C', there is the aspiration to keep warming below 1.5°C; it is one of several compromises that were necessary for agreement to be reached.

The emphasis to ramp up ambition beyond the NDCs suggests that anything less in terms of implementation would be judged as failure. On the other hand, the IEA states that even the 2°C target will be challenging. The likely outcome is a scenario that falls between points two and three.

Claims that COP 21 marked the end of the fossil-fuel era are nonsense. The world will still be dependent on coal, oil and gas by 2050, although coal and oil will decline. How that will develop will depend on NDC pledges. It will also depend on how successful the industry is in persuading policymakers that it is a vital part of solving the climate-change challenge. The renewables industries need to get their act together.

Alex Forbes is an independent journalist and consultant who has been reporting on energy developments and analysing trends for 30 years.

# Global warming and biofuels: part one

By Clare Wenner,  
Renewable Energy Association

Why biofuels needs to gather pace.

Climate change does not hit the headlines in the way that it used to. The media focus has shifted and more immediate topics have come to occupy our minds. But climate change has not gone away – it is an increasingly urgent issue that still needs dealing with. It is the subject of serious scientific research in response to observed changes in the world around us.



Average temperatures at the Poles are rising at double the rate of the rest of the planet; by 2100, sea level could be a metre higher.

The icecaps are melting and extreme weather events are increasing. The debate about our responsibility for climate change rumbles on but the Paris Agreement in 2015 marked a turning point in the global recognition that whatever the cause, the solutions are in our hands and are urgently needed. Keeping the global average temperature rise to 2°C or under is a massive task.

As individuals, we may have aspirations to cut our own carbon emissions but this is not easy to do. We can switch lights off and put a few more clothes on but do we really believe we are making a difference? Is it not easier to leave it to the power companies, to other countries and not take personal responsibility? And if that is how we view our electricity and heat use, how much more so is it the case when it comes to getting around?

The car is a central part of our lives and we place huge value on personal mobility. Public transport rarely competes and our low-carbon dreams vanish when the kids have to be collected from school or a relative needs visiting in hospital. Car usage dropped off a bit when the oil price hit \$140 a barrel, but with the oil price slump in 2016, we are back to our old habits and adding to carbon emissions. The effects of vehicle pollution on our air quality appears more in our headlines than it used to but this is still perceived as an urban phenomenon and is always trumped by our need to get there and get there as quickly as possible.

There is nothing like high energy costs to stimulate innovation and the price rises of the early 2000s prompted not only the use of some new technologies but a low-carbon vision of the future. Significantly, not just small techno-enthusiasts but big oil companies began to look at the opportunities that low-carbon options offered. Among these was the development of biofuels. When Shell and BP began to invest in biofuels they created real, feasible options for decarbonising the fossil fuels that power our cars. Policy-makers introduced mandates for renewable trans-

port fuels and it began to look as if transport could make a real contribution to a low-carbon future.

The emergence of commercial interests and private-sector investment in low-carbon fuels provoked a backlash among those who had so strongly demanded action on climate change. The concept of indirect land-use change (iLUC) provided the catalyst for activists to demand that biofuels be banned. Their argument was derived from the felling of forests in South-east Asia to make way for further plantations of palm oil.

In the UK, carbon emissions from transport dropped a little during the recession but, according to the Committee on Climate Change, are now only 2.5% lower than in 1990 and transport carbon emissions have increased by 1.1% since 2013, while emissions in all other sectors of the economy have decreased by between 16% and 73%.

So, do biofuels have a role to play in combatting climate change? To answer this, we need to unpick the arguments ranged against them. Firstly, do biofuels emit more carbon than they save? Undoubtedly, if peatlands are drained to make way for palm-oil plantations. Thankfully, the UK biofuels industry does not use palm oil to produce biodiesel. But global use of palm oil has greatly increased to feed other habits, including a vast array of foodstuffs and health-care products. The activists have rightly drawn our attention to the environmental damage that can be caused by palm-oil production and, whatever the end use, better agricultural practises must be encouraged and paid for and consumers made more aware of the consequences of their shopping choices.

In addition to not using palm oil as an input, UK fuel suppliers' imports of palm oil-based biodiesel have dropped from 84% to 0% since 2008. Even when iLUC is taken into account, biofuels still reduce carbon emissions. Emissions from bio-ethanol, for example from feed wheat, are 50% lower than fossil gasoline. It is not biofuel use that is causing our increased carbon emissions.



A warmer climate will increase the intensity of unusual weather, giving more severe storms, heatwaves, drought and flooding.

And this takes us to the next line of argument – that land should not be used to make biofuels, that crops from that land should go to the food and feed chains and not into fuels for our cars, and that biofuels push up the cost of global food and cause global hunger. These somewhat lurid arguments ignore the fact that wheat ethanol supplies as much high protein animal feed as low-carbon liquid fuel, which derails arguments that pit the



When the price of oil peaked in 2008, oil consumption dipped but with depressed prices, consumers are taking to the road again.



UK imports of palm-oil derived biodiesel has recently fallen to zero.

production of food and fuel against each other; that a third of the food produced globally is wasted, a stark and shocking misuse of land; and that biofuel production provides much-needed investment into agricultural productivity.

Where productivity goes up, hunger can go down and if we don't invest in agriculture we'll never be able to feed a world population of 9 billion people. It has been acknowledged that the global commodity price hike of 2008 could not have been due to the emerging use of biofuels but rather to just the kind of weather events that are caused by climate change, market speculation and not least to the high oil price at the time. Significantly, the production of biofuels has increased since then, while commodity prices have tumbled.

The truth is that decarbonising fossil fuels is a complicated business. We have developed some useful renewable fuel options but we're only at the beginning of the story. Transport emissions are growing as more and more cities take to the internal combustion engine. While this remains the case, fossil fuels will continue to be used for decades to come. In more developed economies

we can move to electric and other low-emission vehicles but this will be a slow process and does not come for nothing – vehicles will still only be as low carbon as the electricity that powers them.

We should be smarter about our low-carbon fuel solutions and we need to transit technologically from first-generation biofuels based on crops to advanced biofuels based on waste. This can only be done incrementally and with the necessary investment in more challenging and therefore more expensive technologies. We can't make progress if policy is stop-start, which has been happening. Investors will not put up with it. It is only with the commitment of private-sector investment that we can develop low-carbon fuels at a sufficient scale to make a change in transport fuel use.

There is no reason why this can't go hand in hand with further development into transport electrification. Indeed, with transport emissions rising, we need to deploy all solutions. Biofuels never were the silver bullet to decarbonise transport but they have shown the way to better land use, they provide food and fuel, they have given agricultural investment a vital boost, they have provided technological transition to more imaginative uses of waste and have allowed us as consumers to consider alternative ways of satisfying our craving for personal mobility.

Without the biofuels debate, would innovative thinking have emerged that has led to more creative vehicle solutions with the potential to solve carbon and air pollution at a stroke and a range of different car-ownership models? Biofuels have led the way out of total dependence on fossil fuels and will have a role to play for years to come.

*Clare Wenner is Head of Renewable Transport at the Renewable Energy Association. For over ten years, Wenner has championed the renewable transport fuels policy and has also been closely involved with the implementation of the EU Renewable Energy and Fuel Quality Directives.*

## Global warming and biofuels: part two

*By Suzana Kahn, Universidade Federal do Rio de Janeiro*

**Policymakers should prioritise R&D.**

Our impulse to use biofuels is due to one of the greatest challenges of the 21st century: confronting climate change. International studies, notably reports by the Intergovernmental Panel on Climate Change (IPCC), show the rising recognition of the human contribution to global warming. The average temperature of the planet has been increasing and its relationship with human activities is highly probable. This scientific evidence, together with the advance of climate negotiations most recently with COP 21 in 2015, make the potential 'decarbonisation' of the energy mix a world relevance.

The measures that are planned will involve the alteration of energy mixes. As 80% of greenhouse-gas (GHG) emissions are due to burning fossil fuels, the issue of global warming becomes an energy problem. Therefore, biofuels produced from renewable biomass can contribute to decarbonisation.

Biofuels' CO<sub>2</sub> emissions, the gas mainly responsible for global warming, are practically annulled when the biomass grows, producing the same amount of negative CO<sub>2</sub> contained in the atmosphere.

Biofuels can be obtained through a variety of technologies, with characteristics similar to traditional fossil fuels. The liquid biofuel widely used is

alcohol, and this has many raw material sources such as sugar cane, corn and beet. Biodiesel is another alternative that also presents a number of raw-material options, mainly oilseeds. Ligno-cellulosic ethanol, algae and other micro-organisms are the technological routes that, nowadays, seem to be more promising for the increase of biofuel production.

However, there are still environmental and economic issues associated with land use for biofuels, such as competition with food, water usage and loss of biodiversity that need to be solved. In relation to the GHG-emissions balance, biofuels present great advantages in relation to fossil fuel but this balance is not zero since during the planting, harvesting, transporting and processing of biofuels, fossil fuel is consumed and this generates GHG emissions. Thus, each fuel, depending on its raw material and production process, will have a different emission balance.

The case of Brazilian ethanol is particularly positive as it uses biomass energy in the industrial process; and often during the agricultural process, biofuel can be used too. It is still necessary to



It's possible for biofuels to be carbon-neutral but fossil fuel is often used during cultivation, harvesting and transportation.





Seeds of oilseed rape contain around 45% oil and due to this, the crop is widely used as a feedstock for biodiesel production; the remaining 55% of the seed is used as high-protein animal feed. Oilseed rape was previously used as a break crop to improve soil quality.

consider the emissions associated with the use of fertilisers and land-use change. Evidently, if the use of energy crops implies direct or indirect deforestation, the emission balance will be highly negative for the biofuel. The issue of indirect emissions caused by energy crops has been a target of intense debate due to the evaluation difficulty about land-use change. It is something that can't

be disregarded when ascertaining the net balance of emissions. It is also important to emphasise the recurring debate around the competition of bio-fuel production with other uses of biomass and the land; mainly food.

Another impact is the loss of soil quality due to monoculture. However, technologies that increase productivity are evolving.



NASA has been conducting flight tests using jet biofuel blends; it confirmed that jet biofuel exhaust contains 50% less soot emissions.



Central London has long struggled with pollution; meanwhile, road transportation in developing countries is expected to rise.

In relation to the use of biofuels, the transport sector deserves focus. Transport activity is almost entirely powered by the internal combustion engine. As such, alternatives to diesel and gasoline are of extreme importance and urgency.

This is the fastest-growing sector in terms of energy use. It is expected that during the coming decades, the use of energy in the transport sector in developing countries will represent almost 40% of world energy consumption. There are also initiatives to transform biomass into aircraft fuel, so-called aviation biokerosene, from a variety of feedstocks (read about NASA's tests on page 108). The production cost is still prohibitively high, but there are plans to install biorefineries in Brazil with this purpose in mind. For electricity generation, the country has, so far, not given too much attention to biomass as a strategy.

Biofuels are not expected to replace oil products in their entirety but will certainly be a significant part of the energy mix, mainly in the

transport sector. Brazil has enormous comparative advantages with its availability of agricultural land, water resources and favourable climate. However, investment and responsible and competent management are necessary for these advantages to become competitive. In other words, the careless production of biofuels can also represent soil depletion, concentration of wealth, food culture dislocation and larger emissions.

The necessity of decarbonising the economy imposed by global warming makes the efforts of producing biofuels an attractive alternative for power generation and needs to become a priority in energy policy and research and development areas.

*A professor at UFRJ in Rio, Brazil, Suzana Khan is also President of the Scientific Committee at the university's Brazilian Panel on Climate Change.*



# Reducing CO<sub>2</sub> emissions and climate change: the impact of biofuels

By Isaias C Macedo,  
Universidade de Campinas

Bioenergy and the road to 2050.

The quantification of greenhouse-gas (GHG) emissions on climate change is well documented; it is possible today to estimate consequences for representative emissions scenarios. Today, 63% of all anthropogenic CO<sub>2</sub> emissions originate from fossil fuels, and biofuels – emitting less GHG than equivalent fossil fuels – are an essential component in any mitigation scenario.



Limiting climate change is a global necessity. Biofuel production, such as ethanol conversion from bagasse, will play a central role.

GHG emissions from biofuels production vary, with biomass type, cultivation technologies, land-use change, industrial conversion and end use, and their quantification needs a comprehensive assessment. This helps to select and design processes to reduce biofuels' own emissions, and also to find sustainable agriculture where much larger areas used for crops and pasture will increase productivity, soil carbon stocks and quality, while decreasing direct and indirect land-use change (dLUC and iLUC) emissions and reduce conflicts between food and bioenergy production.

## Evaluation of GHG emissions in biofuels

The Intergovernmental Panel on Climate Change (IPCC) guidelines for GHG inventories are the basis for many protocols and analyses for biofuels GHG emissions. There are methodological differences, such as how to consider co-products and there is still high uncertainty around some of the parameters and the potential iLUC effects.

In general, for biofuels:

- Agricultural production and industrial conversion have good regional databases.
- dLUC estimation is dependent on IPCC default values, with some advances. Uncertainties in the soil carbon stocks are high.
- iLUC emissions are still in discussion due to inadequate modelling and data. From 2008-15, values attributed to ethanol dropped from 110 to close to 10gCO<sub>2</sub> equivalent MJ (megajoules).

The evaluation of average GHG emissions for a biofuel must consider all the pertinent fluxes (biomass production, conversion, transportation and end use) and use adequate and large databases including different production plants, agricultural practises and regions. They should also report separately dLUC emissions where large uncertainty exists and register the local parameters – environmental legislation, use of residues and pasture intensification, as they can lead to net carbon sequestration from LUC.



Table 1 (below) shows results for biofuels based on reliable databases. For second-generation biofuels using residues, no suitable data is available; projected results for cellulosic ethanol indicate low emissions.

## Land use: 2050 scenarios

Global land use for food production is very inefficient, with productivity gaps and the potential for intensifying pastures being much larger than it is for crops. Intensification of cropland and pasture is essential for the sustainable development of food and biofuels production. Using areas liberated by pasture intensification for crops or sugar cane led to higher carbon soil stocks and lower, even negative, LUC emissions.

Bioenergy contribution in five low-carbon scenarios for 2050 (IPCC; IEA 2Ds; GEA Efficiency; Greenpeace ER; ECOFYS/WWF) averages 138 EJ (80-180 EJ); this corresponds to 24.9% of 2050's energy supply. A scenario for bioenergy supply in 2050 – bioheat, power and transportation – of 200 EJ/year estimates that the area needed for biomass production will be 1.5% of global land supply.

## Summary

Reducing GHG emissions to limit climate change is an important global objective and bioenergy has an essential role to play in accomplishing this.



Biomass cultivation for transportation, bioheat and electricity will need vast space by 2050, around 1.5% of the world's land surface.

The experience with selected biofuels shows good GHG mitigation, considering production/conversion emissions. By reducing productivity gaps for agriculture and pasture and with the right environmental policies, biofuels emissions from LUC will be much smaller, even negative.

In this context, land availability for bioenergy will be far beyond the needs of low-carbon scenarios considered to 2050.

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## GHG average emissions for commercial biofuels; no LUC

	Average GHG emissions <sup>a</sup>	Uncertainty range	GHG mitigation (% fossil fuel)
Commercial liquid biofuels	gCO <sub>2</sub> e/MJ	gCO <sub>2</sub> e/MJ	
Sugar-cane ethanol, Brazil <sup>b</sup>	21.3	15-32 <sup>a</sup>	76
Corn ethanol, USA <sup>c</sup>	52.6	42-71 <sup>a</sup>	42
Rapeseed biodiesel, EU <sup>d</sup>	53.8	45-58 <sup>b</sup>	40
Solid biomass (power >10 MWe) <sup>e</sup>	gCO <sub>2</sub> e/kWh	gCO <sub>2</sub> e/kWh	
Wood waste, forest residues, SR woody crops	26-48 <sup>f</sup>		> 93

a No LUC; includes co-products credits (displacement); b Seabra, *et al* (2011); c Wang *et al* (2012); d Edwards *et al* (2013); e Warner, *et al* (2013); commercial biopower generation technologies; f Electrical efficiency = 31.5%; g 10th and 90th percentiles; h Maximum and minimum values.

Table 1.



# Income generation and employment

By Robert Spišák,  
Envien International

Farmer, scientist, construction worker, engineer and sales are just some of the jobs in biofuels.

The biofuels sector represents a substantial stimulus for the global economy due, in particular, to its socioeconomic impacts. Biofuels provide the prospect of new employment opportunities for people with various professional backgrounds both in urban and rural areas. Moreover, comparisons in different countries have suggested that biofuel feedstock production can be a more lucrative activity for farmers than crop cultivation for food purposes. Therefore, production of biofuels



For farmers, biofuels cultivation can be more lucrative than food. Large-scale production also generates considerable employment.

improves financial stability and supports income generation of farmers who supply biofuel plants with their key feedstocks.

However, the effect of biofuel production on employment and agricultural income generation depends, to a great extent, on the type of feedstock production system adopted and its institutional context. There is significant debate about which of the two production schemes – large scale or smallholder – can contribute most to employment and agricultural income generation, especially in developing countries.

If smallholders in developing countries start producing feedstock for biofuels on a small scale, they usually make use of their own land. If the workload becomes heavier, more family members have to work, but smallholders do not usually employ other people. In such cases, one could speak about the creation of additional income but not about additional job creation. With regard to large-scale biofuels projects, investors either have to prepare the land and hire staff to work on it or contract larger scale farming entities. Should the economics of scale and often lower transaction costs for accessing markets be considered, income generation in such business models is more apparent compared to small-scale conditions. What is perhaps even more important, especially from the macroeconomic perspective, is the fact that large-scale biofuel production schemes generate considerable employment opportunities for agriculture.

Apart from jobs created in the agricultural sector, there are further working possibilities created in the conversion process from feedstock to biofuels as this process generally takes place close to where the feedstock is produced. Direct jobs in biofuel production are usually created through processing activities (land preparation for the factory, building and running of the factory, etc). Furthermore, various indirect jobs are generated within the economy as a result of

expenditure related to the previously mentioned direct jobs.

Scientists and engineers are sought in research and development, as are construction workers for building plants and infrastructure. Agricultural forces are in demand to grow and harvest feedstocks, plant workers to process feedstocks into fuel. There are also sales workers required in order to sell biofuels. Therefore, it is no surprise that the biofuels industry today represents a considerable labour market, accounting for nearly 1.8 million jobs worldwide. The biofuels industry is the second-largest employer within the overall renewable-energy sector, after solar photovoltaics.

According to a report by the International Renewable Energy Agency, Brazil has the largest workforce in the liquid-biofuels industry, with 845,000 employed. Among other countries, the United States has 282,000 jobs, the EU 98,000, China 71,000 and India 35,000.

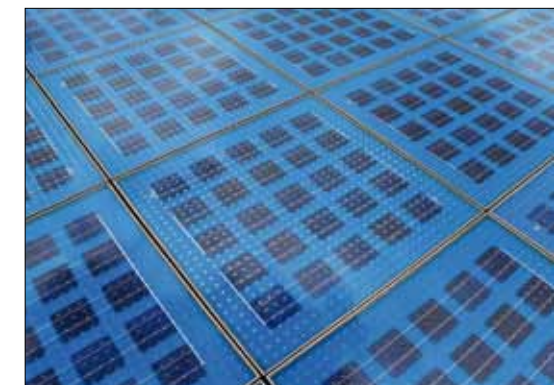
The onward potential of employment in the worldwide biofuels industry is highly influenced by the viability of advanced biofuels. A study partially related to employment in the advanced-biofuels industry that was commissioned by Danish biotech company Novozymes and processed by Bloomberg New Energy Finance (*Moving Towards a Next Generation Ethanol Economy*), estimates that within the period 2011-30, up to 8.2 million man years of employment could be created by the advanced biofuels industry in the most important biofuel producing countries. This figure also includes jobs to be created in the agricultural-residue supply chain.

It is projected that China, USA, the EU, Brazil, Mexico, India, Australia and Argentina will create 8.2 million man years of employment in the advanced biofuels industry by 2030. China itself will create the most employment possibilities among selected countries whereby its 2.9 million man years will be an even higher figure than the aggregated contribution of USA and the EU.

## The biofuels industry: key facts

- The biofuels sector is a vital stimulus for the global economy.
- The biofuels sector supports financial stability of farming entities and stimulates their income generation.
- The biofuels sector currently creates 1.8 million employment opportunities around the world.
- While Brazil and the United States dominate, the European Union, China and India contribute noticeably as well.
- It is projected that the advanced-biofuels sector will create at least 8.2 million man years of employment by 2030.

*Robert Spišák's academic achievements and experience in the fields of economics, law and energy have resulted in his career covering numerous executive and honorary positions. He is Chairman of the Board for a group of companies based in Central and Eastern Europe. Among these, Spišák is the Executive Director at Envien International, a biofuels specialist. Spišák is a member, contributor and speaker with various associations in the private and public sectors.*



While the biofuels industry employs almost 2 million people globally, the solar photovoltaic sector is larger, with 2.8 million.



# Biofuels: future governmental policies

By João Carlos de Souza Meirelles,  
São Paulo state

Policymakers should follow Brazil's lead and plan for flex-fuel.

In the coming years, petroleum will still be the main natural source of fuels. Being a fossil resource, government bodies around the world are studying ways to tailor the use of oil and its derivatives in a greener manner. Since 1975, Brazil has been an example of success in the use of biofuels thanks to sugar-cane ethanol and oleaginous biofuel. The

introduction of flex-fuel vehicles powered by ethanol, gasoline or a combination of both in any proportion was a milestone for the introduction of green fuel and since then, the Brazilian government has given the consumer the choice of which fuel to use in their vehicle.

Governments, especially in developed countries, need to introduce this technology through public policies. Currently, 94% of vehicles produced in Brazil are flex-fuel. The automotive industry is working towards the development of a flex-fuel engine that can be used globally.

In Brazil, gasoline-C – the gasoline blend available at Brazilian service stations – contains 27% ethanol and the country recently approved a 10% biodiesel addition to diesel marketed until 2019. But this must reach other countries. Ethanol is not a substitute for gasoline; it is a complement. Bio-fuel's mission is to replace anti-knock additives such as methyl tert-butyl ether (MTBE) and ethyl tert-butyl ether (ETBE). But it is not enough to have a great octane fuel with low CO<sub>2</sub> emissions if governments do not prepare laws, industry and population for this new era.



Today, 80% of cars made in Brazil are flex-fuel, meaning the engine can run on gasoline, ethanol blends or 100% ethanol (E100).

Soon, leading countries will use high-octane gasoline with 25-40% ethanol. But to mix ethanol with gasoline, it is necessary to have a global CO<sub>2</sub> emission-control policy.

High-tech agriculture in Brazil, especially in the sugar-cane and corn industries, can transfer to countries with the appropriate climate. Second-generation ethanol is a reality in Brazil. Besides its cost being high, technology is being developed to lower costs. In Africa, there is an opportunity for ethanol production. It has all the necessary factors of space, soil quality, weather, workforce and it is near the consumer centres of Europe and Asia.

Biofuel research can bring improvements in the agriculture, transportation and equipment sectors. Developed countries should give special attention to the transportation sector. Countries that do not have transportation via railways or waterways

have a very high road modal participation. In the future, vehicles will need engines capable of receiving more than one type of fuel.

The COP 21 agreement has set far-reaching goals. Biofuel is the way to go and Brazil is in an excellent starting position.

*João Carlos de Souza Meirelles is the Secretary of Energy, Department of Energy and Mining, São Paulo state in Brazil. Previously, he was Secretary of Agriculture and Economic Development, as well as Special Adviser for Strategic Affairs, São Paulo state. Meirelles has also been President of the Amazon Business Association, President of the National Council of Beef Cattle, Co-ordinator of the Productive Chain of Bovine Livestock Mercosur Forum, Vice-President of the International Meat Secretariat (IMS) and Director of the Fronteira Norte Engenharia de Desenvolvimento.*

## Global biofuels mandates

Biofuels mandates have been set up in over 60 countries. Many are EU nations, who have signed up to a directive of 20% final energy consumption by 2020 and 27% by 2030. But it is South America that leads the way. Here are global examples:

Country	Ethanol	Biodiesel	Country	Ethanol	Biodiesel
Angola	10%	-	Mexico	2% (regional)	-
Argentina	12%	10%	Mozambique	10%	-
Australia (New South Wales)	4%	2%	Norway	5%	3.5%
Brazil	27%	8%	Panama	10%	-
Canada	5%	2%	Paraguay	25%	1%
China (9 provinces)	10%	-	Peru	7.8%	2%
Colombia	8%	-	Philippines	10%	5%
Costa Rica	7%	20%	South Africa	2%	5%
Ecuador	5%	-	South Korea	-	2.5%
Ethiopia	5%	-	Sudan	5%	-
EU	7%	7%	Taiwan	-	1%
India	5%	-	Thailand	-	3%
Indonesia	3%	10%	USA	*	*
Jamaica	10%	-	Uruguay	5%	2%
Kenya (regional)	10%	-	Vietnam	5%	-
Malawi	10%	-	Zimbabwe	10%	-
Malaysia	-	5%			

Mandates correct at June 2016.

\* Uses a total volumetric system; by 2022, a mandated 136 billion litres of biofuel will be used, which is estimated as 7% of the expected annual US transportation fuel consumption.

# Biofuels: advances in technology

By Melissa Stark, Accenture Energy

The progress of commercial-scale lignocellulosic biofuels has been slower than expected due to cost and access to feedstocks.

Conventional biofuels are a significant part of our fuels market and can provide greenhouse-gas (GHG) and air-quality benefits over fossil fuels. Biofuels is a diverse market and the size of the GHG and air-quality benefits differ depending on the feedstock and technical process. In the gasoline market, ethanol, produced from sugar cane (in Brazil) or corn (US) through a yeast-fermentation process, is primarily blended with gasoline as E10 or used as the primary fuel in gasoline engines as E85.

In the diesel market, biodiesel, produced from vegetable oil or waste oils and fats in a transesterification process, is blended at varying levels with diesel (B5 to B20). An alternative is renewable diesel, produced primarily through hydro-treated vegetable oil (HVO), a very different thermochemical process. HVO uses vegetable oil or waste oils and fats as feedstock. Renewable diesel can be blended at virtually any level and has even been used as a bio-jet fuel.

There are a number of different biofuels pathways being developed to produce gasoline and diesel substitutes. This article is largely taken from the technology and biofuels chapters of the US

National Petroleum Council's 2012 report, *Advancing Technology for America's Transportation Future*. We will focus on what the National Petroleum Council viewed as the two most promising pathways to convert lignocellulosic biomass to gasoline and diesel, biochemical (or enzymatic) hydrolysis followed by fermentation and pyrolysis.

A key challenge for the biofuels industry is to move beyond food-based feedstocks. Lignocellulosic biofuels are liquid fuels derived from biomass such as stover, switchgrass, miscanthus, bagasse and other agricultural waste. Lignocellulosic biofuels offer the potential for expanding the feedstock supply and providing greater GHG reduction. There are significant quantities of biomass available, which if converted to biofuels, could increase the volume of available biofuels several-fold from today's levels. It has been a challenge to commercialise the technologies that can use lignocellulosic feedstocks. Two technologies being developed are biochemical (enzymatic) hydrolysis and pyrolysis. However, the logistics of using lignocellulosic feedstock is a challenge that is common to both technologies.

## Lignocellulose logistics and densification

Biomass is a relatively low-density product and this is especially the case for crop residues, forestry residue and grasses. Feedstock logistics can be a significant portion of production cost and also limits the size of a centralised plant.

High cost and inefficient delivery of the feedstock to centralised plants has placed severe limitations on the economies of scale of biomass-conversion plants. Storage of biomass is also a problem because of losses to the biomass of up to 15% over a season due to natural decomposition. Additionally, a very large footprint is required to store low-density biomass for delivery to a large central plant (e.g. baled corn stover requires seven to eight times the volume of storage as corn grain per unit mass).

## Biochemical hydrolysis and fermentation

### Biochemical hydrolysis

Hydrolysis is the process of using enzymes on pretreated lignocellulosic materials to break down cellulose, hemicellulose and lignin into component sugars that can then be further processed. The volume and type of enzymes used depends on the pre-treatment and the feedstock. The cost of cellulose converting enzymes is still significantly higher than the cost of the enzymes used to convert starch in the corn ethanol process.

In its simplest embodiment, enzymatic hydrolysis takes place in a separate process step between pretreatment and fermentation, a configuration known as separate hydrolysis and fermentation (SHF). The major advantage of separating hydrolysis and fermentation is that each process can be run at its respective optimum conditions. The enzyme dose required to achieve a given cellulose conversion level is important in determining the overall cost of the enzymatic hydrolysis unit process, and in turn the minimum ethanol selling price. The main drawback of SHF is that the concentrations of cellobiose and glucose products build up during the course of the batch process and inhibit cellulases and thus limit yields.

In simultaneous saccharification and fermentation (SSF), enzymatic hydrolysis and fermentation is concurrent in a single vessel to which both enzymes and fermentation organisms have been added. With SSF, cellobiose and glucose concentrations remain low because they are consumed by fermentation organisms and no longer inhibit cellulases. A second advantage is capital cost reduction since hydrolysis and fermentation occur in one vessel. However, optimal temperatures for fermentation do not coincide with optimal temperatures for hydrolysis, at least for the fermentation of sugars to ethanol by *saccharomyces cerevisiae*. Commercial preparations for biomass hydrolysis are most effective at 50°C, which is too high for most relevant fermentation organisms.



Finding alternatives to food crops has been a challenge for the biofuels industry. Miscanthus is high yielding and grows quickly.

Hybrid hydrolysis and fermentation represents a third approach in which hydrolysis is started under optimal conditions for hydrolysis. After a set time period, the temperature is lowered and fermentation organisms are added, but hydrolysis is allowed to continue under these non-optimal conditions.

High solids loading during enzymatic hydrolysis is important because the presence of water as a diluent increases processing costs. In particular, the energy needed to distil ethanol from the fermentation of beer is a strong function of ethanol concentration, which in turn is directly related to the sugar concentration in the hydrolysate. However, conversion efficiency decreases nearly linearly with solids concentration. The primary impact of solids loading on conversion is the result of the interference with enzyme adsorption to solid substrates byproducts.

In addition, enzymatic-hydrolysis performance is closely related to the type and severity of pre-treatment. A trade-off often exists between pre-treatment cost and enzymatic-hydrolysis cost. Pretreatments that are more effective in removing lignin and in opening the lignocellulosic structure typically use more chemicals, higher temperatures and higher pressures, and are therefore more

expensive. But as a result of improved pretreatment, lower enzyme doses can be used.

### Fermentation of C5 and C6 sugars

After the lignocellulose has been broken down into its component sugars using hydrolysis, these sugars need to be fermented.

Ethanol is the primary target for many of the companies proposing to produce cellulosic biofuels. *Saccharomyces cerevisiae* is a yeast used extensively in industrial fermentation processes. Relatively speaking, yeasts are robust and can tolerate high titres of ethanol as well as other inhibitory substances in the hydrolysate. Another advantage of yeasts is that they ferment at low pH values, which minimises the possibility of infection by micro-organisms. The familiarity with yeast in existing corn ethanol plants is another advantage in using this organism for cellulosic ethanol fermentations. The major drawback of *saccharomyces cerevisiae* is that it is not naturally capable of fermenting pentose sugars such as xylose and arabinose. Fermentation of pentose sugars to a fuel product is critical to the economic viability of a cellulosic biofuel plant.

Several researchers have genetically transformed yeast to allow utilisation of xylose (usually the dominant pentose sugar in lignocellulosic substrates).

There are a few commercial plants that produce ethanol from lignocellulosic biomass using biochemical hydrolysis followed by fermentation. For example:

- Beta Renewables/Crescentino: 51 million litres a year, from 2012 (straw).
- POET-DSM/Liberty: 76 million litres a year, from 2014 (corn stover).
- DuPont: 114 million litres a year, from 2015 (corn stover).
- Granbio: 83 million litres a year, from 2014 (bagasse).
- Raizen: 61 million litres a year, from 2014 (bagasse).

However, most are not operating at full capacity. Second-generation fuel has to compete with first-generation (corn and sugar cane) ethanol, and using lignocellulosic feedstock is still much more expensive. Also, ethanol above E10 has to compete with gasoline. In recent years, corn-based ethanol was less expensive than gasoline but the recent fall in oil price has resulted in ethanol trading above gasoline. Finally, the market for ethanol has not grown as consumers have chosen to stick with E10 versus moving to E15 or E85. E15 has been challenged because vehicle warranties are for E10. For E85, although many vehicles now are flex-fuel and can operate on gasoline and E85, the E85 refuelling infrastructure is still limited.

### Pyrolysis

In pyrolysis, lignocellulosic feedstock is converted through a thermochemical process into a bio-oil that can then be transported and further processed in a refinery. Biomass-pyrolysis technology is commercially available but has not been applied to commercial-scale fuel production. Bio-oil chemical composition is not suitable for direct biofuel production without further processing. It has high oxygen content, is corrosive (low pH) and thermally unstable (does not re-vaporise completely).

Pyrolysis, in its simplest form, consists of rapidly heating biomass to 600°C and flashing off the volatiles which are then condensed to produce bio-oil. Yields of up to 80% of feedstock are possible. Since biomass is made up of three major components, hemicellulose, cellulose and lignin – each of which have their own optimal pyrolysis temperature – simple pyrolysis technology is a compromise in producing bio-oil products. Bio-oil produced in conventional pyrolysis is a mixture of low molecular weight acids, hydroxy acid and hydroxyl aldehydes as well as more upgradable components such as furans and phenolic compounds. This mixture poses problems for simple upgrading schemes. Current research to solve this

issue is focusing on fractionation of simple pyrolysis products for more appropriate upgrading, or adopting catalytic pyrolysis methods to produce a larger fraction of components more amenable to upgrading.

Bio-oil can be upgraded at the source prior to full production or after the formation of the liquid product. The two most popular methods in post-production upgrading are adapted from hydrocarbon processing. These are bio-oil cracking over solid acid catalysts and hydrotreating in the presence of a hydrodesulphurisation catalyst and high-pressure hydrogen. Although both processes have the potential to bring down the oxygen content, both cracking and hydrotreating are accompanied by the loss of hydrogen (as H<sub>2</sub>O) and carbon (as CO<sub>2</sub> or CO) from the bio-oil.

The impact of bio-oil quality and stability on hydroprocessing catalyst performance needs to be validated at the pilot and commercial scales. Raw bio-oil contains potential impurities such as alkali metal, chlorine, nitrogen and sulphur that could poison hydrotreating catalysts and limit long-term activity. Thermal stability of the bio-oil or biocrude intermediate will have a major impact on coke formation during upgrading and hence overall carbon efficiency. Catalytic pyrolysis processes under development may produce intermediates that have better thermal stability. Additionally, any oxygen removed before the upgrading step will lower the H<sub>2</sub> demand of biofuel production and potentially improve process economics. Producing a finished fuel in a stand-alone biorefinery is not as cost effective as developing a biomass (catalytic) pyrolysis process that can be integrated within a petroleum refinery to utilise existing capital assets and infrastructure.

The development and upgrading of higher-quality pyrolysis oil is getting to demonstration scale. Hydrotreating raw bio-oil is feasible using existing refining technology (catalysts and process conditions). Processing includes a mild hydro-



There has been stagnation in the fuel ethanol market as motorists are reluctant to move from E10 to E15 or E85, despite flex-fuel cars.

treating step followed by hydroprocessing to finished fuel. Yields are low, carbon efficiency is poor because of extensive coke formation and hydrogen demand is high. All of this challenges the economics of pyrolysis oil to biofuels. Processing the hydrocarbon intermediates in a petroleum refinery improves process economics.

### Conclusion

Corn-, sugar cane- and vegetable oil- (or even waste oils- and fats-) based biofuels are a permanent part of our fuels infrastructure. A key challenge for the industry is to use lignocellulosic biomass. Progress has been made but has been slower than many expected with the challenges often not in the science but in the engineering and scaleup. Biofuels face competition with electric and natural gas in the quest to replace gasoline and diesel.

*Melissa Stark, Managing Director Energy at Accenture Energy, was Assistant Chair of Technology for the US National Petroleum Council's study 'Advancing Technology for America's Transportation Future'. Stark led the development of New Energy, Unconventionals and now LNG practices for Accenture.*



# Gas fermentation

By Dr Jennifer Holmgren, LanzaTech

Liquid fuels and chemicals need a source of carbon. Capturing carbon from industrial off-gases and recycling it is already underway.

Population and economic growth have been the two main drivers for increasing transportation needs over the last century. As this growth has occurred, the amounts of greenhouse gases (GHGs), particulates, NO<sub>x</sub> and SO<sub>x</sub> in the atmosphere have

reached record highs. At present, transportation accounts for 17% of GHG emissions (well to wheel). Without action, transportation emissions will double by 2050. Even with rapid electrification, it will take 40 years to substitute Europe's existing 250 million fleet. In addition, shipping and aviation will continue to need liquid transport fuels until problems like payload, speed, power generation and storage density are addressed.

Institutions like the Intergovernmental Panel on Climate Change and the International Energy Agency (IEA) have indicated that low-carbon fuel solutions will be required to meet this challenge, as well as improvements in fuel-efficiency and volume reduction. Low-carbon fuels are those with a better CO<sub>2</sub> performance (at least 50%) than fossil transport fuels, that release CO<sub>2</sub> stored for millions of years back to the atmosphere.

According to the IEA, if we are to satisfy economic growth and limit global warming to below 2°C, 10% of all transport fuels must be low carbon by 2030 and 30% by 2050. In real terms,

this translates to an effective reduction in GHG emissions of about 4 billion tonnes or replacing around 800 million tonnes of oil equivalent.

Today, 2% of transport fuels (including marine, road, train and aviation fuels) are low carbon and growth in low-carbon fuels has been 2% a year. If we keep moving at that pace, the penetration of low-carbon fuels may increase to 4% by 2050, which is not enough to follow the 2°C pathway.

To accelerate the growth to 10% means that the industry will have to increase investments. The world can't exclude any low-carbon options.

## Liquid fuels need carbon

Energy can be carbon-free (wind, solar and hydro) but you need a source of carbon to make liquid fuels and chemicals. Carbon-rich off-gases, high in toxins and particulates, are available as a byproduct of power generation as CO<sub>2</sub> and the chemistry of manufacturing processes (e.g. steel) as carbon monoxide. Today, there is an abundance of carbon in all the wrong places. We recycle metals, plastics and paper, so why not carbon? Why not take carbon from the source of its production and convert it into useful products?

Waste carbonaceous feedstocks such as carbon monoxide in industrial off-gas, municipal solid waste and biomass residue contain carbon and energy, which enables recycling and upgrading to higher-value products such as fuels. Carbon in the form of CO<sub>2</sub>, however, contains carbon but no energy, and thus has had little value until we recognise the negative externalities of climate change. Adding value and recycling CO<sub>2</sub> requires energy input from low-carbon sources, such as H<sub>2</sub>, sunlight or electricity and today, technologies exist that can capture CO<sub>2</sub>-rich gases before they are emitted and convert them into products.

## CO<sub>2</sub> as a resource

Photosynthetic organisms like algae 'consume' CO<sub>2</sub> and use sunlight as the source of energy as they



The LanzaTech Steelanol project in collaboration with ArcelorMittal in Belgium will recycle gas from steel production for ethanol fuel.

grow. They store the carbon in their biomass and/or oils, which are converted into a variety of end products from food to feed to fuels. Four litres of algae crude oil takes in around 20kg of CO<sub>2</sub>. Companies such as Sapphire and Algenol are nearing commercialisation. Algenol has a facility in Florida and has started operations in India with Reliance Industries.

Algenol's process converts a tonne of CO<sub>2</sub> into 545 litres of fuel while recycling CO<sub>2</sub> from industrial processes and converting 85% of the CO<sub>2</sub> used into ethanol and renewable biocrude. According to a 2016 US Department of Energy study, the potential for algae carbon capture using existing technology is over 200 million tonnes per year of CO<sub>2</sub>.

In the US, Liquid Light is also developing a technology that can convert industrial CO<sub>2</sub> into over 60 chemicals, with ethylene glycol the first commercial target. Estimates from Liquid Light show that using CO<sub>2</sub> as a feedstock is up to 80% cheaper than using petroleum-derived feedstocks commonly used for ethylene-glycol production. With such a strong economic story, the technology is another reminder that environment and wealth need not be mutually exclusive.



Algenol's algae technology platform for producing renewable transportation fuels consumes CO<sub>2</sub> from industrial sources

Finally, at an earlier stage of development, electrotrophic microbes, as pioneered by Dr Derek Lovley at the University of Massachusetts, use electricity and CO<sub>2</sub> to upgrade to fuels and chemicals. This technology directs electric current as the energy source and combines CO<sub>2</sub> and H<sub>2</sub>O to produce fuels, in essence a 'reverse combustion reaction'.

### CarbonSmart: LanzaTech case study

Gas-fermentation platforms, for example that of LanzaTech, use microbes to biologically convert carbon monoxide containing gases into fuels and chemicals. It works like a brewery but instead of sugars and yeasts, it uses gases and microbes. Substitute beer for fuel-grade ethanol.

LanzaTech's gas-fermentation technology has been taken from the lab through pilot testing and demonstrated at scale. The process has been robust, with 40,000 hours of run time. LanzaTech is in the process of building its first commercial-scale units in China with Capital Steel, in Taiwan with China Steel and with the world's largest steel producer, ArcelorMittal in Belgium.

### Conclusion

Decarbonising the transportation sector will play a key role in staying within a 2°C temperature rise. Technologies exist that can help us meet the task of increasing the low-carbon fuel supply over the next 30 years. It is critical that all low-carbon technologies be allowed to contribute to this future fuel pool, with all receiving equal support in the form of investment, subsidies or tax credits regardless of technology profile or feedstock. Advances in carbon recycling together with first- and second-generation technologies will help meet that goal.

*Dr Jennifer Holmgren, Chief Executive Officer at LanzaTech, has over 20 years' experience in the energy sector, working in the development and commercialisation of chemicals technologies.*

## Anaerobic-digestion plants

**Tropical Power chairman Mike Mason** tells us of his plans to power Africa by copying a cow's stomach.

We may regard animals like lions and eagles in royal reverence but when it comes to majestic power, the cow has been overlooked. Don't be fooled by the dewy-eyed gazes across five-bar gates, for it is the cow – or rather, its digestive tract – that holds the secret to abundant, inexpensive energy.

A cow's stomach is a highly efficient anaerobic-digestion (AD) unit, a fact understood by Mike Mason who leads research programmes at Oxford University on AD technology, as well as energy crops for semi-arid regions and hybrid AD/solar systems. In 2013, Mason founded Tropical Power and associate companies Biojoule and Solarjoule in order to construct AD and solar plants in Ghana and Kenya. The Tropical Power-built 2.8MW Gorge Farm site at Naivasha in Kenya is the largest AD power plant in Africa – and more are planned.

### WPC: Gorge Farm is the largest plant of its kind in Africa. How is that working out?

**Mike Mason:** It took us a long time to secure the power-purchase agreement, and because it was the first of its kind on that scale, we had all sorts of issues with things like bringing in the right skills and building large concrete structures. But effectively, it's all done and it all works.

### Do you have plans to build more in Africa?

We have an ambition to do more. We're still sorting out a few issues with the first plant. There are always teething problems, biology problems, and so on. We're building up our feedstocks and waiting for new features to come on board. When we've got it up to full power, we'll set up the next.

### What feedstocks are you using?

Agricultural waste. At present, there isn't as much as we'd like, so we're building the feedstocks up.



The largest anaerobic-digestion plant in Africa is Tropical Power's 2.8MW Gorge Farm in Kenya. Access to local feedstock has proved problematic but the facility is based near a fresh-produce exporter and now receives 150 tonnes of waste vegetation every day.

### We understand that your long-term aim is to make an AD plant work as efficiently as a cow's digestive system.

AD plants use bacteria that are similar to, or the same as, those from cows. But a cow does the rate-limiting step, breaking down cellulose, up to 30 times faster than an anaerobic-digestion plant. What we've built is conventional technology. My research is to emulate the high speed of the cow.

### Why can't we do that now?

I don't know yet. We've got strong clues as to how it might be working and we've got laboratory tests going on, a proof of concept trial to see if we've got the right idea. There's probably a few years of work in it but we'll see if we can make it happen.

### What will that mean once you get to that point?

It will dramatically reduce the cost of anaerobic digestion as a source of renewable energy.

### Where do you see Tropical Power in 20 years?

My research has two components. One is getting the cost of anaerobic digestion down. The second is developing new, hyper-water-efficient crops that we can grow on semi-arid land, where we're not competing with food and not competing with wildlife. We are focused on working with a photo-synthetic mechanism called crassulacean acid

metabolism. This can be up to ten times as water efficient as mechanisms used by ordinary crops. Put those two things together and you have a proposition that is cost-competitive with coal.

### Do you think there's enough time and effort being put into renewables?

No. I think what we lack is a sense of urgency and focus about dealing with the solutions. We need to put these things on a wartime footing and say, "We have to solve these problems." The more we spend on research the less we have to spend on subsidising things that are uneconomic. **LG**

### What is anaerobic digestion?

AD biogas – roughly 60% methane, 40% carbon dioxide – is created through the digestion and decomposition of organic matter by micro-organisms in the absence of oxygen. Feedstocks can include crop waste, food waste and manure. The biogas that is made, when combusted in a gas engine, can be used to generate electricity and heat; alternatively, pure methane can be injected into the mains gas grid or used for transport. The remaining nutrient-rich digestate can be used as a fertiliser.

# AAFEX-II: the search for alternative aviation fuel

NASA's Bruce Anderson discusses his biofuels research and how animal tallow and camelina oil could help reduce global warming.

In 2011, an article by Ulrike Burkhardt and Bernd Kärcher at DLR, Germany's aeronautics and space-research centre, revealed that aviation contrails – the lines of cirrus cloud created by aircraft – were the largest constituent of aviation-induced global warming. Studying 2002's air-traffic inventory, the report went on to state that our current climate is more affected by contrail-induced cloudiness than by all the carbon dioxide emitted by every aircraft that has ever flown.



NASA's contrail tests involved flying behind a DC-8 airliner at altitude and manoeuvring the trailing aircraft to capture particle samples.

Prior to the paper's release, NASA had tested non-petroleum jet fuel as part of its Alternative Aviation Fuel Experiment (AAFEX). AAFEX had two primary tasks: reducing dependence on foreign oil and finding less-polluting aviation fuel, but as the experiment unfolded, it became clear that actual testing on contrails was needed. AAFEX-II, with NASA partnering DLR, took place above California in 2011. Although it was a bumpy ride, emissions readings were taken from engines powered by exotic biofuel blends. We speak to Bruce Anderson, AAFEX-II's lead scientist, about his findings.

## WPC: Should we be giving more thought to alternative aviation fuel?

**Bruce Anderson:** Regular jet fuel creates CO<sub>2</sub> and other pollutants and it has double the aromatic hydrocarbon content of biofuel, leading to soot formation, which is also bad for air quality. Alternative fuels burn cleaner and can be produced from renewable feedstocks. Some of the fuel we used in the AAFEX-II experiments was made from animal fat – chicken and beef tallow – and we also tested fuel made from camelina oil [a plant oil]. These fuels create less CO<sub>2</sub> and less greenhouse gases.

## Why are contrails bad?

Contrails probably contribute more to atmospheric warming than CO<sub>2</sub> from aviation. Some say that contrails are 3-5% of the total radiative forcing and it's particularly noticeable where there's a lot of aircraft traffic, like here on the US east coast. We get contrails that completely paint the sky.

## When testing, you flew behind NASA's DC-8 aircraft. Isn't there a turbulence hazard flying behind an aircraft?

There was concern that when we were chasing a DC-8 with a small aircraft, we would get caught up in wake turbulence, which would damage our aircraft or cause us to have an engine flame out. One of our rules was that we had to be within gliding distance of an airport. And then we couldn't enter the exhaust wake of the DC-8 further back than 300 metres. From 300 metres to 14 nautical miles behind the DC-8, we weren't supposed to fly in the contrails because the turbulence would be so intense.

## Did you go into the wake?

Yes. A typical flight plan was to rendezvous with the DC-8, then alternately move the top of our aircraft into the exhaust of the left and right port engines. We had instruments on top of our aircraft where we drew in exhaust samples and measured the soot quantity. We also had an ice-particle probe that counted the number and measured the size of ice particles. There's a lot of turbulence shed at the tips of aircraft wings, so-called 'wing vortices'. You'll have seen four-engine aircraft fly overhead. Initially, there'll be four contrails but 500 metres behind the plane, there'll be two. What happens is, the exhaust from the engines is caught up in the wingtip vortices, which are little horizontal tornadoes. They can cause catastrophic failure to planes.

## What was your experience in the wake?

In the States, we have lots of gravel roads. It's like riding over washboard gravel – with those ripples

in the road, real bumpy. In the experiment, we had forward video camera and displays in front of the instrument operators' seats. I was in the back of the plane, so I could watch the video and see where we were and had a good situational awareness. I didn't get sick or feel bad. DLR, who were our partners in the experiment, had a similar aircraft but the people in the back of theirs didn't have displays and didn't know what was going on, so they just experienced periodic turbulence and wing roll out. There were people getting sick on their plane. It can be rough.

## Did you find that fewer contrails were created when burning biofuels?

The blended fuel produced 40-60% fewer soot particles and less soot mass. There's a significant reduction in soot when you burn cleaner fuel. But a large fraction of the water that condenses in the contrail is from the background atmosphere, not aircraft exhaust. With very cold days, when the atmosphere is dry, a contrail will form and quickly evaporate. Around this 50-mile racetrack over California that we were flying, there were variable amounts of water vapour, large fluctuations, so we didn't have homogeneous conditions to see if exhaust soot was controlling the contrail density. It's a tough experiment.

## Are further experiments planned?

We're hoping to repeat it with the Germans.

## Is working for NASA as much fun as it sounds?

I've been here for 25 years and enjoy it very much. We have lots of world-class assets and aircraft that we can put instruments on. We have expensive, unique tools that we can access to take on important experiments. It's a good environment to do science in. I'm within a few years of retirement but we've got some young people coming in to continue the work. They're very hard working and I think we're going to make progress. **LG**



# Glossary of terms

**Algae** Single cell or multicell photosynthetic plants that grow quickly and are able to live in freshwater, seawater or oils. Numerous species can be used to produce biofuels.

**Anaerobic digestion** Breakdown of organic microbes without the presence of oxygen in an enclosed environment; the result is methane and CO<sub>2</sub> which can be used for a variety of energy options.

**Bagasse** The dry, fibrous, pulpy waste of sugar cane or sorghum once sugar has been extracted during factory processes. It can be converted to ethanol or burned to generate electricity.

**Biobutanol** A second-generation alcohol fuel made from the fermentation of biomass. It is chemically similar to gasoline and can be used, unmodified, in gasoline-fuelled engines.

**Biodiesel** Renewable diesel fuel produced through the transesterification of organically derived oils and fats. Biodiesel is usually blended with regular diesel.

**Biofuel** Fuel for transportation, power or heating that is made from biomass or its derivatives after processing. Biofuels include ethanol and biodiesel.

**Biogas** A mixture of methane and CO<sub>2</sub> created by the breakdown of organic matter through anaerobic digestion in the absence of oxygen.

**Biomass** Plant matter such as wood, grasses, crops, crop waste, aquatic plants and any other biological material.

**Biomass pellet** Capsule of fuel made from compressed organic matter.

**Camelina** A flowering plant related to flax that produces oil-bearing seeds. Camelina oil has been used in jet-fuel tests.

**Carbon negative, neutral, positive** A product or process that, during its lifetime, causes a net decrease, increase or no net increase/decrease in atmospheric carbon levels.

**Cassava** A woody, tropical shrub with a starch-rich root that can be used for the production of ethanol.

**Cellulose** Structural component in the cell wall of green plants that is used in several biofuel production processes.

**Cellulosic biofuel** Biofuel made from the inedible, cellulose-rich parts of plants.

**Contrails** Narrow clouds or vapour trails produced by aircraft engine exhaust.

**Corn** A grain that is a source of ethanol feedstock, especially in the US.

**COP 21** United Nations Climate Change Conference held in Paris in 2015.

**Crude palm oil (CPO)** Edible, red-coloured oil extracted from the pulp of oil palm fruit.

**Crassulacean acid metabolism** A carbon fixation pathway in some plants as a response to dry conditions, where the stomata in the leaves is closed during daytime to reduce evapotranspiration but open at night to collect CO<sub>2</sub>.

**Direct/indirect land-use change (dLUC/iLUC)** The human impact on a given area of land and how that change of land use will affect greenhouse-gas emissions.

**Distillers' grains (DDGs)** Nutrient-rich co-product of dry milled ethanol production; popular feed ingredient for livestock and poultry.

**Electrotrophic micro-organisms** Microbes that can directly accept electrons from electrodes.

**Ethanol** A clean-burning, colourless, high-octane, renewable fuel made primarily from sugar cane and corn residues.

**Exajoule (EJ)** Equal to one quintillion (10<sup>18</sup>) joules.

**Fatty acid methyl ester (FAME)** A fatty acid ester that is derived by transesterification with methanol, with characteristics close to fossil diesel.

**Feedstock** The raw material from which fuel is produced; in the case of biofuels this is a plant or algae.

**Fischer-Tropsch process** A collection of chemical reactions that converts a mixture of carbon monoxide and hydrogen into liquid hydrocarbons. It was developed in 1925 in Germany by Franz Fischer and Hans Tropsch.

**Flex-fuel vehicle** A vehicle that can run on varying blends of ethanol.

**Fossil fuel** Petroleum, coal or natural gas, formed by the decomposition, over thousands or millions of years, of biomass.

**Furan** Chemical compound composed of one oxygen atom and four carbon atoms in a ring structure.

**Gasoline (petrol)** A volatile mixture of flammable liquid hydrocarbons derived mainly from crude petroleum and principally used as a fuel.

**Greenhouse gas (GHG)** Any gas that traps heat in the Earth's atmosphere, leading to global warming.

**Hemicellulose** Random, amorphous structure found in most plant cell walls.

**Hybrid hydrolysis** Combination of separate hydrolysis and fermentation (SHF) and simultaneous saccharification and fermentation (SSF) processes.

**Hydrodesulphurisation catalyst** Chemical catalyst to remove sulphur from natural gas and refined petroleum products.

**Hydrolysate** Any substance produced by hydrolysis.

**Hydrolysis** The breaking of large molecules using water: splitting by water.

**Hydrothermal liquefaction (HTL)/processing (HTP)** Conversion of wet biomass through elevated temperature and pressure to crude bio-oil.

**Hydrotreated vegetable oil** Renewable diesel produced from a wide range of vegetable oils and fats.

**Jatropha** A flowering plant grown in tropical regions, often on marginal land. Oil from its seeds can be used to produce biodiesel.

**Joule** Standard unit of electrical, mechanical and thermal energy.

**Lifecycle analysis** The environmental impact of an activity through all its stages, from raw material extraction to production, use and disposal.

**Lignin** Polymers that form structural material in plants and algae; assists water through plant stem.

**Lignocellulose** Dry plant matter; biomass.

**Methanol** A simple, toxic alcohol that burns with an invisible flame and is biodegradable; it can be blended at 3% with gasoline and used in a conventional engine.

**Miscanthus** Fast-growing (up to 3m tall), low-maintenance, high-yield grass that can be used for ethanol production.

**Municipal solid waste** Refuse, rubbish, trash, garbage, waste.

**Napier grass** Robust, potentially invasive tropical grass which can be used as a cellulosic biofuel feedstock or biogas feedstock.

**Net energy balance** The difference between the energy produced and the energy it takes to produce it, e.g. corn ethanol in the US has a net energy balance of 1.3 to 1; sugar cane 8 to 1.

**Octane rating** The standard measure of a fuel's performance. The higher the number, the slower the fuel burns, and the less likely your engine will 'knock' (when a separate pocket of air-fuel mixture ignites after the spark has ignited).

**Oleaginous** Oily, or produces oil.

**Palm oil** Mostly grown in South-east Asia, an edible vegetable oil derived from oil-palm trees, which can be used to produce biodiesel.

**Petrol** See gasoline.

**Petroleum** A thin or thick, flammable mixture of gaseous liquid and solid hydrocarbons occurring naturally beneath the Earth's surface.

**Phenols** Similar to alcohol but with higher acidity; compounds are produced by plants and micro-organisms.

**Pyrolysis** Decomposition of organic material through high temperatures.

**Raceway pond** Shallow, man-made pond used to cultivate algae.

**Saccharomyces cerevisiae** A yeast used extensively in industrial fermentation processes.

**Separate hydrolysis and fermentation (SHF)** Conversion of cellulose to ethanol performed sequentially.

**Simultaneous saccharification and fermentation (SSF)** Process for conversion of lignocellulosic biomass to alcohol/ethanol in a single reaction vessel.

**Soya bean** A legume used primarily as food, but which also has limited application in biofuel production.

**Stover** Leaves and stalks of a crop after it has been harvested.

**Sugar cane** Perennial grass that is rich in sucrose, providing 70% of the world's sugar. Sugar cane and its by-products are the primary source of ethanol production in Brazil.

**Switchgrass** A perennial bunchgrass native to North America that is drought and flood tolerant and can be used in ethanol and biobutanol production. It can also be pressed into pellets for power-station use.

**Syngas** A mixture of mainly carbon monoxide and hydrogen that can be used for electricity generation or to produce synthetic petroleum.

**Titre** The concentration of a solution as determined by titration.

**Transesterification** The process of converting vegetable and plant oils into biodiesel fuel by exchanging the organic group of an ester with the organic group of an alcohol.

**Vinasse** Waste liquor from the processing of sugar cane or sugar beet that is a source of methane, which can be used to generate heat or electricity.

**Wells-to-wheels** Emissions total that includes well-to-pump and pump-to-wheels, thus including feedstock recovery, production and transportation of the fuel.

**Wet waste** Leftover organic material such as food, flowers or leaves that is heavy in weight due to dampness.

**Xylose** Sugar that occurs widely in plants; can be isolated from wood hence its other name 'wood sugar'.

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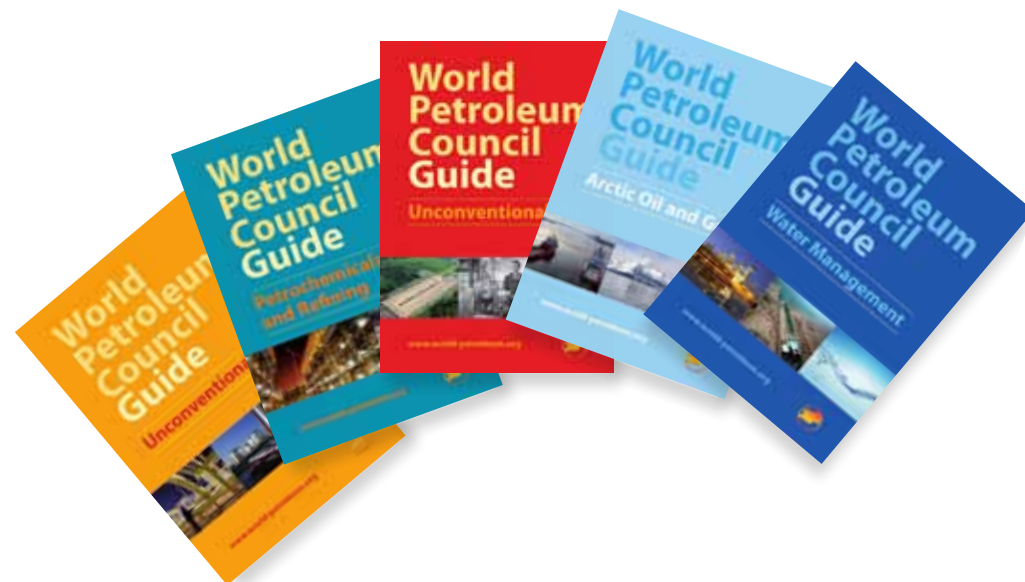
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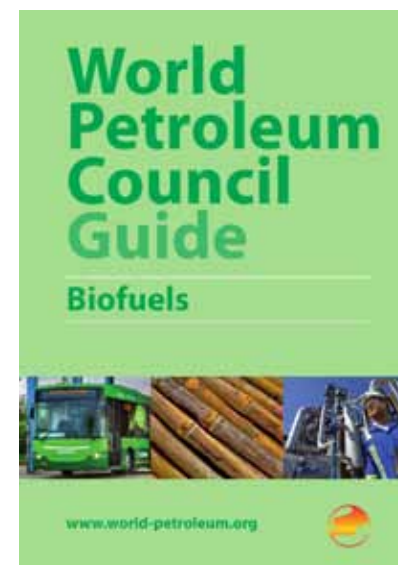
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