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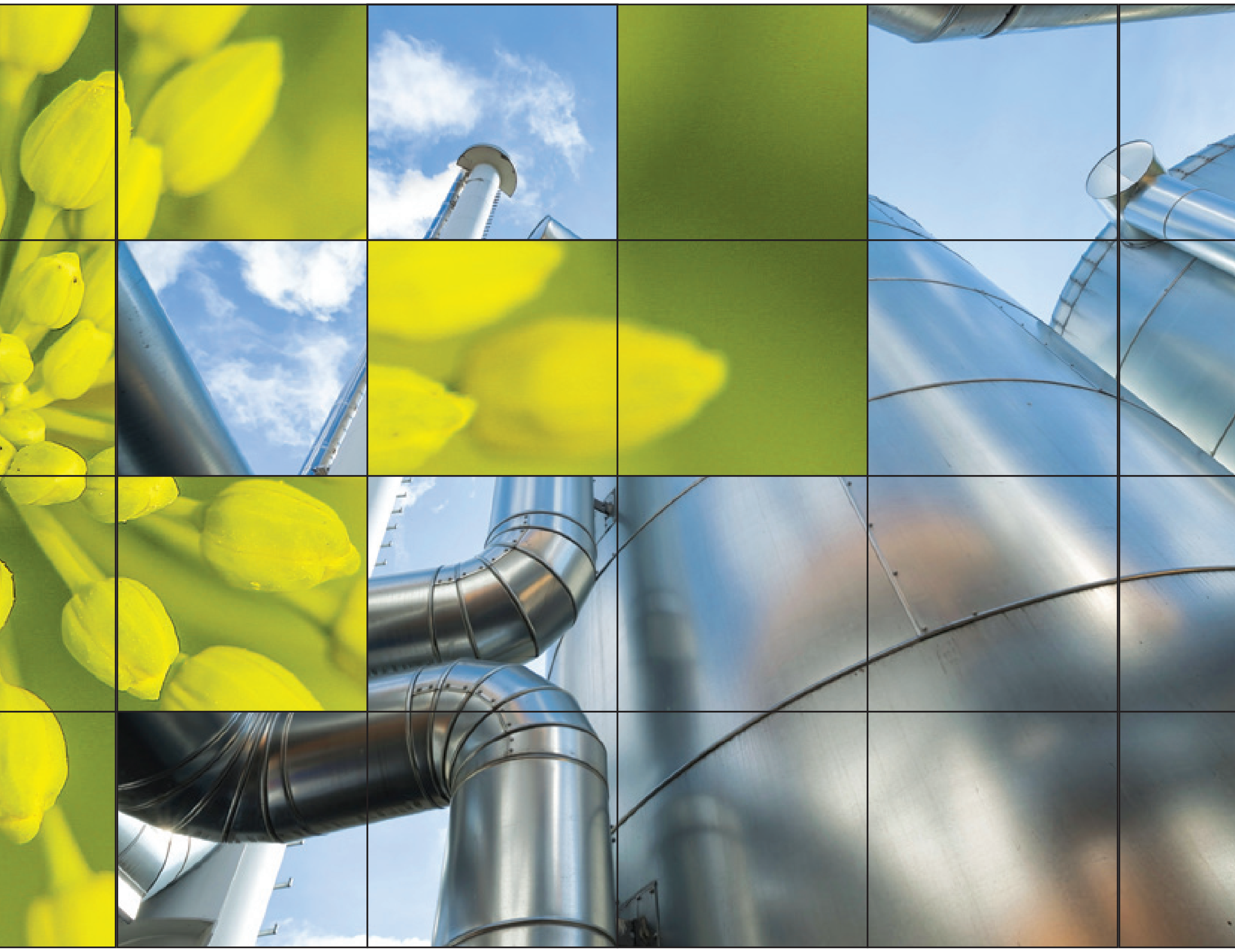
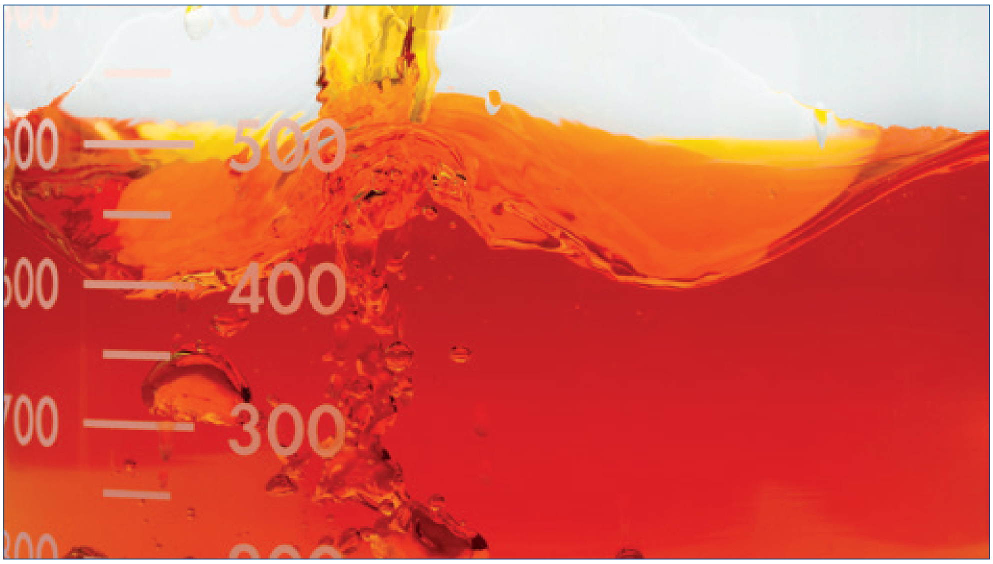
Low Carbon Technology Partnerships initiative



Low carbon transport fuels

Low carbon fuels are essential to achieving our environmental, social and economic goals



LCTPi
Led by wbcsd

CEO Statement

Efficient, reliable and cost-effective transportation solutions lie at the heart of the modern global economy. For 200 years we have relied almost exclusively on fossil energy to power an ever-greater movement of people and goods around the world. Today, the transportation sector faces a challenge and responsibility to drastically reduce greenhouse gas emissions.

We are dedicated to scaling the development and deployment of low carbon fuels. Currently, our technologies enable a greenhouse gas reduction of, at least, 50% compared to fossil fuels.

Low carbon fuels are essential to achieving our environmental, social and economic goals. The challenge is great; today, only 3% of transportation fuels are low carbon. According to the International Energy Agency, 10% of fuels must be low carbon by 2030 if we are to satisfy economic growth and meanwhile – along with other measures - limit global warming to below 2°C.

The economic opportunity is equally great; numerous low carbon fuel technologies, at various stages of development are integrated with other sectors—such as agriculture, forestry, waste, chemicals and biotechnology. Developing, deploying and expanding them will generate significant new growth opportunities across broad segments of the economy.

This is our call to action.

We represent 11 of the world's leading Low Carbon Fuel technology companies recognizing the need to accelerate the deployment of new fuel solutions now. We will continue to work to meet robust sustainability conditions and to drive down technology costs.

We will continue to highlight commercial deployment opportunities and synergies available today or in development. Harvesting these opportunities will depend on local circumstances and priorities. A 2°C world requires deployment of **all** available technologies that substantially reduce greenhouse gas emissions and, more generally, contribute to realizing the UN Sustainable Development Goals.

The huge size of the challenge in further industry investment and successful deployment will require a joint effort between the business community and governments at all levels. We recognize that this will not happen overnight. But the critical steps are identifying the right technologies for the right locations, taking technology maturity, feedstock availability and national contexts into account, and making these a priority for cooperation.

Public policies to support the transition to low carbon fuel technologies should promote:

- A market-based approach that allows the market to pick the best opportunities,
- Increased market demand for low carbon fuels,
- Investment and support for innovation and R&D,
- Clear standards for sustainability criteria based on emission reduction performance,
- Stable policies, including carbon pricing systems to reduce investor risk.

Our companies offer a ‘menu’ of low carbon technology options available for deployment today, and a guide to countries and regions where these technologies are already being deployed or can best be developed. Meanwhile, we present three Action Plans that will support this initiative in the short term:

1. We will promote R&D and commercial deployment of Low Carbon Transport Fuels (LCTF) and will drive forward construction of new facilities and supporting infrastructure,
2. We will support and promote cross industry engagement to create new markets and explore new technical synergies,
3. We will collaborate with Governments and other stakeholders around the world to raise awareness of LCTF solutions and explore opportunities to create new Public Private Partnerships.

As governments across the globe commit to their climate action pledges (“Intended Nationally Determined Contributions”) at COP21, they will be looking for solutions to deliver on them. We welcome the fact that several of these pledges already refer to the opportunity of low carbon fuels.

We present tangible scalable technologies that are ready for implementation in developed, emerging and developing countries, preferably through Public Private Partnerships initiatives. Our technologies have great potential to drive down carbon emissions. A strong and supportive policy environment is necessary to drive the continued decarbonisation of the transport fuel pool.

At the heart of our business is the belief that every molecule of CO_2 matters.

This is our call to action.

AUDI e-gas Betreibergesellschaft mbH
Hermann Pengg, CEO

Copersucar
Paulo Roberto de Souza, CEO

DSM
Feike Sijbesma, CEO

DuPont Industrial Biosciences
William F. Feehery, President

GranBio
Bernardo Gradin, CEO

Joule
Serge Tchuruk, CEO

LanzaTech
Jennifer Holmgren, CEO

Novozymes
Peder Holk Nielsen, CEO

Pannonia
Zoltan Reng, CEO

POET
Jeff Broin, CEO

SkyNRG
Maarten van Dijk, CEO

LCTPi

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Key to a sustainable economy

LOW CARBON TRANSPORT FUELS

Contents

What this report is about

➤ DECARBONIZING IS THIS SECTOR'S CORE BUSINESS

Decarbonizing the transport sector is indispensable for achieving the overall climate goal of staying below a 2°C rise of global temperature. Meanwhile, low carbon transport fuels have been widely acknowledged for their significant potential. Growth in this sector, however, must increase fivefold from today's levels within fifteen years.

This report highlights the efforts of a new, growing coalition of twelve companies and four partner organizations to delivering these growth rates. Within the framework of the Low Carbon Technology Partnerships initiative on transport fuels, they share a common goal in developing these markets and technologies. After all, decarbonizing the transportation sector is their core business.

But they cannot do this on their own. To secure this huge growth, the business community's efforts and investments need to be backed by effective and stable policies. Only with a consistent public-private collaboration, will the transportation sector meet the urgent need to contribute to mitigating climate change.

ABBI Associação Brasileira de Biotecnologia Industrial	Audi Vorsprung durch Technik	cgee Centro de Gestão e Estudos Estratégicos Ciência, Tecnologia e Inovação	CLARIANT
COPERSUCAR	DSM	DUPONT® The miracles of science™	GranBio
IATA	JOULE	LanzaTech	novozymes®
Pannonia Ethanol	POET	SkyNRG	SUSTAINABLE ENERGY FOR ALL

What are low carbon transport fuels?

Low carbon transport fuels are essentially liquid or gaseous fuels with a significantly better CO_2 performance (defined by this group as at least 50%) than conventional fossil transport fuels. Low carbon fuels can be based on biomass or other short-cycled carbon resources. Compared with fossil fuels, their life cycles of production and use lead to (much) lower CO_2 emissions. So-called (liquid) biofuels are the main group of low carbon fuels.

This partnership distinguishes two main groups of low carbon technologies:

Mature Technologies:

Conventional biofuel technologies include well-established processes that produce biofuels on a commercial scale. These biofuels, commonly referred to as 'first-generation', include sugar- and starch-based ethanol, and vegetable oil based biodiesel. Typical feedstocks presently used in these processes include sugarcane and sugar beet, grains like corn and wheat, oil crops like rape (canola), palm oil (see text box on sustainability later on in the report) and soybean, and waste streams like used cooking oil.

Early Stage technologies:

- Advanced biofuel technologies, commonly referred to as second- or third-generation, are still in the research and development (R&D), pilot or demonstration phase. They include biofuels based on lignocellulosic biomass, such as cellulosic-ethanol, biomass-to-liquids (BtL)-diesel and bio-synthetic gas (bio-SG). The category also includes novel technologies that are mainly in the R&D and pilot stage, such as waste gas fermentation, algae-based biofuels and the conversion of sugar into diesel-type biofuels using biological or chemical catalysts.
- Non-biomass based fuels are technologies that use non-biomass feedstock. Similar to advanced biofuels, these technologies are still in the research and development (R&D), pilot or demonstration phase. These technologies include biodiesel from algae, power-to-gas and power-to-fuel, so called electro fuels and fuels from engineered photosynthesis.

The section 'Low Carbon Fuel Technologies' of this report elaborates on these technologies. The graph below shows a number of biofuel technologies in different stages of development.

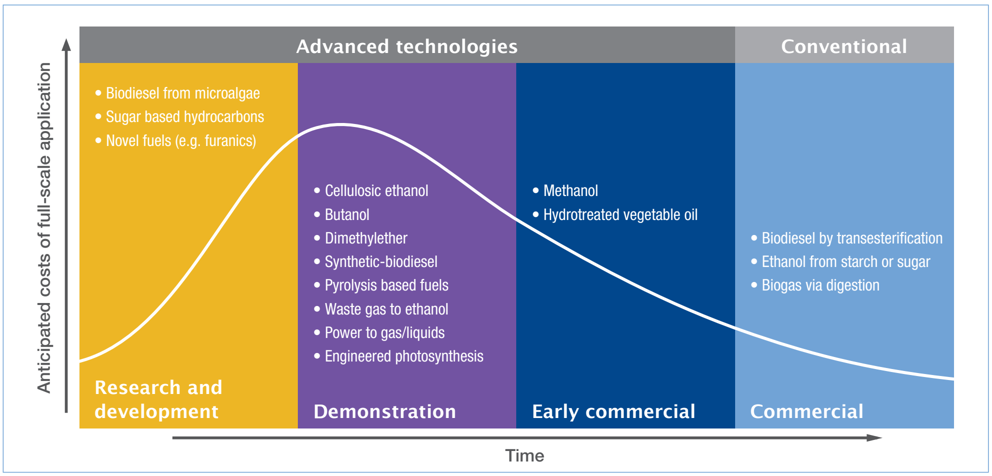


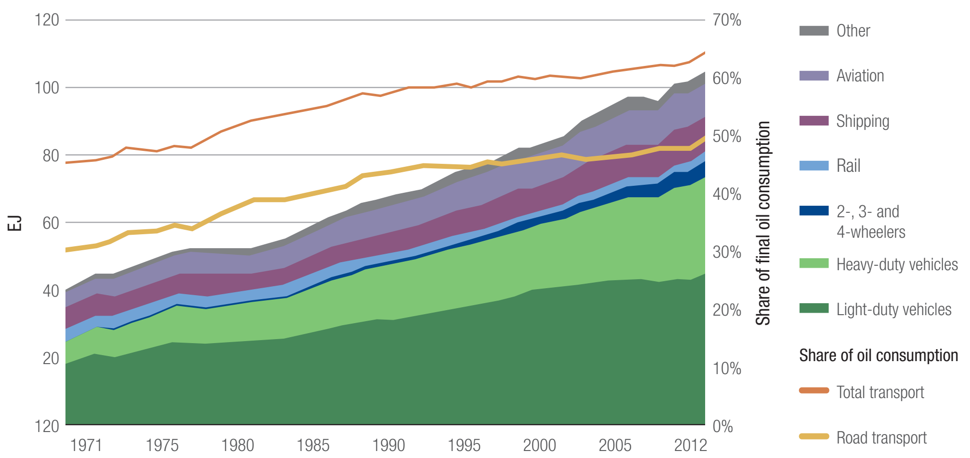
Figure 1
Commercialisation status of main Low Carbon Transport Fuel technologies

The present impact of transportation

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, particulates, NO_x and SO_x in the atmosphere have reached record highs. At present, transportation accounts for some 17% of all global greenhouse gas emissions (well-to-wheel).

Without further action, this growth in emissions will continue. By 2040, we expect to have 1 billion more people on the planet, with world energy demand expected to increase by up to 37% in the same timeframe. Without further measures, transportation greenhouse gas emissions will increase by some 35% by 2030 and almost double by 2050. This must not be allowed to happen and our sector has a mission to help stick to the 2°C pathway.

➤ OUR MISSION: CONTRIBUTE OUR SHARE IN FOLLOWING THE 2 DEGREES PATHWAY



Notes: Light-duty vehicles are cars and light trucks (up to 3.5 tonnes); heavy-duty vehicles are trucks and buses. Aviation and shipping includes international bungers, i.e. fuels user for international aviation and navigation.

Figure 2. Evolution of global energy consumption per transport mode since 1971.

Source: IEA Energy Technology Perspectives 2015.

How low carbon fuels can mitigate climate change

The Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency have indicated which pathways the global greenhouse emissions should follow in the next decades to keep the 2°C threshold within sight. Low carbon transport fuels are indicated as essential to meet this challenge, next to fuel efficiency improvement and volume reduction. According to the International Energy Agency, 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. This will lead to an effective reduction in greenhouse gas emissions of about 2 billion tons per year. In terms of replacing their fossil equivalents, this translates to some 800 million tons of oil equivalent per year.

Given the present status of low carbon fuels, the challenge is great. Today, only 3% of transportation fuels (including marine, road, rail and aviation fuels) can be called 'low carbon'. In some countries, specific low carbon biofuels have already reached mature status, leading to hundreds of facilities with a combined production of about 70 million tons of oil equivalent. For example, Brazil has reached a 27% share of low carbon fuels in transportation, the US a 10% share and the EU 5%. But such successes have not been easily replicated in other countries and regions. In most countries, development of low carbon transport fuel markets and technologies is lagging behind their technical potential.

Meeting the numbers mentioned above implies that the growth rate should accelerate to an average of 10% in the next fifteen years, and a somewhat lower growth rate between 2030 and 2050. In practice, this means that in the next ten to fifteen years the industry will have to increase investments to about $ 100 billion a year by 2035 and build hundreds of new production facilities. This figure is comparable to the current yearly investments in wind or solar energy production.

This growth must be met in a sustainable way with overall emissions minimized and other sustainability criteria met. Moreover, to achieve this, the world cannot afford to exclude any low carbon fuel options. In fact, ALL possible low carbon transport fuel options must be given equal opportunities to succeed. Starting now.

➤ **FOR A 2°C PATHWAY WE NEED ALL SOLUTIONS**

The main barriers to growth

The private sector can deliver the technologies that will help achieve the necessary emission reductions, but government policies and other issues influence the speed and levels of private investments. Technologies are diverse, at different stages of maturity and with different carbon-mitigation potential, and therefore require different strategy responses.

A number of barriers have caused limited growth in the sector in the last decades. The most important are mentioned in this section; possible solutions will be in the section 'Policy Asks'

Common barriers

➤ INCONSISTENCY AND LACK OF POLICIES ARE BARRIERS FOR FURTHER DEPLOYMENT OF EMERGING AND EXISTING TECHNOLOGIES

- Lack of stable policies (or in many countries a lack of policy) has proven to be the main barrier for successful deployment of many different types of low carbon fuel technologies. Stop-and-go policies, such as in the EU, are a large barrier for investors and in some cases even destroy viable business models. Countries which have "missing policies" have large potential but are still trying to find their position and cause insecurity to investors and banks about the return on their investments.
- Policies that focus on specific aspects of the production chain, for example prescribing feedstocks or conversion technologies rather than overall environmental performance, are also a barrier. This limits how the market itself can choose the best business cases available today and leads to unnecessary increases in costs.

Barriers to conventional technologies

- Limited awareness and poor perceived reputations in terms of sustainability of low carbon fuels (especially biofuels) exist with both policy makers and the public (see also text box). This has led to limited public support, which has created a barrier to creating incentives and maintaining policy stability.

Barriers to early stage technologies

- Developing emerging technologies up to a commercial scale can bring down the costs, but often needs large private investments. For instance, a technology pilot plant—which largely proves technological viability—will often need to be followed up by a demonstration plant, proving the viability on (pre-) commercial scale. The size is much bigger and requires large investments. Such investment is dependent on stable and long term policy security.

For a full overview of barriers connected to possible solutions, see table 1 in the section 'Policy Asks'.

ADDRESSING SUSTAINABILITY ISSUES

Following rapid development of biofuels in the past decade, concerns have been raised about certain sustainability issues of low carbon fuels. Knowing that the starting position of these fuels is intrinsically more sustainable than their fossil equivalents, the industry supports even stronger sustainability requirements: regarding the performance in greenhouse gas emission reduction, preventing an impact on food security, and minimizing environmental impacts, e.g. at the feedstock production location.

One issue that has received much attention is the threat of Indirect Land Use Change (ILUC). Biofuels (and also other new biomaterials) produced from crops need increased production. At present, a large part of the biofuels on the market are the result of yield increases. But if additional agricultural land is created at the expense of tropical forests or peatland, as discussed within the framework of palm oil production, indirect carbon emissions can occur that may nullify the direct savings of low carbon fuels for many years.

Many organizations like the International Food Policy Research Institute IFPRI, the EU Joint Research Centre JRC and the UN Food and Agriculture Organization FAO have presented authoritative studies on the issue. At present, the industry focuses on growth options without causing ILUC, such as improving yields and supply chain efficiency, using degraded land, creating food-fuel synergy or pursuing non-biobased solutions.

Industry and policy makers should meet in setting sustainability requirements. While setting the general framework, policy makers should leave specific feedstock or technology choices to the industry. For instance, the EU has already set strict rules with regard to overall greenhouse gas emission savings. Also, using feedstock from land that was previously high in carbon or biodiversity should not be allowed.

Overcoming the barriers: policy asks

The low carbon fuels industry wants to invest in new markets, because it's our business. As a necessary counterpart, public policies should allow companies to increase their business, on reasonable terms and agreeable returns on investments, and thereby support the transition to low carbon fuel technologies.

Key policies could promote:

➤ STABLE AND TRANSPARENT POLICIES ARE NECESSARY TO REDUCE INVESTOR RISKS

Common Policies

- **Long-term stability.** Stable and transparent policies are necessary to reduce investor risks. Measures such as guaranteed market share and ambitious CO_2 emission reduction targets will tempt investors to increase their investments.
- **Market-based approaches.** Measures such as a defined carbon pricing system or feed-in tariff will allow the market to pick and develop the best opportunities, matching resources and technologies that are best suited to local circumstances.
- **Increased market demand for low carbon fuels.** For instance, mandatory blending ratios imply a secured market demand and thus will create security for investors in new production facilities.

Conventional Technologies policies

- **Clear standards for sustainability criteria.** For output, such criteria could be based on emission reduction performance. For input (resources) and processes criteria are needed to increase the overall performance of low carbon fuels compared with fossil. Both industry and government benefit from clarity on sustainability standards, as they will promote further innovation and emission reductions. They are also the foundation for broad public acceptance and policy support for low carbon fuels.

Early Stage Technologies policies

- **Investment and support for innovation and R&D**. As ALL low carbon fuel technologies are needed to follow a 2°C pathway, emerging and new technologies need to be deployed in addition to existing low carbon fuels. This will need innovation and R&D through public-private cooperation, bringing down the costs of transport fuels along the learning curve.

Table1 - Detailed Barriers and Policies Overview to Scale Deployment of LCTF Technologies. Sources: WBCSD "Innovation for green growth" 2007 & IEA's "Biofuels Roadmap", 2011

	Barriers	Policies	
		Domestic	International
General	Widely deployed incumbent technologies	Long-term stable policies that adopt standards and regulations, such as biofuels blending, and establish medium-term targets for low carbon transport fuel uptake. Clear energy intensity targets and carbon markets with sectoral approaches. Public procurement (off-take); market-based approach through technology neutrality.	
	Uncertainty of demand	Feed-in tariffs; fiscal incentives; renewable energy obligations; progressively eliminate subsidies on fossil fuels and tax carbon and polluting emissions; tax competing high carbon technologies; support assessment of sustainable land and feedstock potential.	
	Low Diesel and Gasoline Prices (fossil fuel)	Phase out fossil fuel subsidies	
	Non-inclusion of environmental externalities make fossil fuel alternatives price lower	Carbon pricing	
	Low-end use product differentiation (commodities)	Standards and regulations; low carbon fuels blending mandates; energy intensity targets; sectoral approaches; public procurement.	
	Trade Barriers	Further improve framework for international biomass and biofuel trade.	
		Consider appropriate tariffs and other barriers to enhance biomass and biofuel trade.	
Conventional Technology	Unclear Sustainability Criteria	Establish internationally agreed sustainability criteria and indicators (on both input and resources and on output).	
		Further alignment of different certification schemes between sectors and regions. Establish and harmonize targets for biofuel greenhouse gas and environmental performance. Adopt sound evidence-based land-use policies for biofuels, bioenergy and wider agriculture and forestry. Align biofuel sustainability policies with agricultural, forestry and rural development policies.	

<table>
<tr><th rowspan="2"></th><th rowspan="2">Barriers</th><th colspan="2">Policies</th></tr>
<tr><th>Domestic</th><th>International</th></tr>
<tr><td rowspan="6">Early Stage Technology</td><td rowspan="2">High up-front capital costs; Limited finance for demonstration</td><td colspan="2">Public investments in RD&D infrastructure; government funding of demonstration projects; direct subsidies to RD&D; government sponsored RD&D, national laboratories; promote collaborative RD&D, including PPP to share financial burden and risks; loan softening/loan guarantees.</td></tr>
<tr><td>RD&D tax credits; emerging technology reverse auction mechanism; national/state funded or run venture capitalists.</td><td></td></tr>
<tr><td>Public good nature of knowledge</td><td colspan="2">Public investments in RD&D infrastructure and IP protection; government sponsored RD&D; PPP to share finance, risk and management effort between public and private actors.</td></tr>
<tr><td>Limited first mover advantage</td><td colspan="2">Public subsidies to RD&D Knowledge Exchange between public and private institutions.
Public investment in human capital.</td></tr>
<tr><td>High complexity and technical risk of low carbon alternatives</td><td>Public investment in capacity building; promotion of collaborative RD&D, including PPP to share knowledge and risks; efficacy insurance with publicly guaranteed or funded reinsurance pools; off-take certainty (for limited periods); long term stable policies (such as feed-in tariffs).</td><td></td></tr>
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Country cases

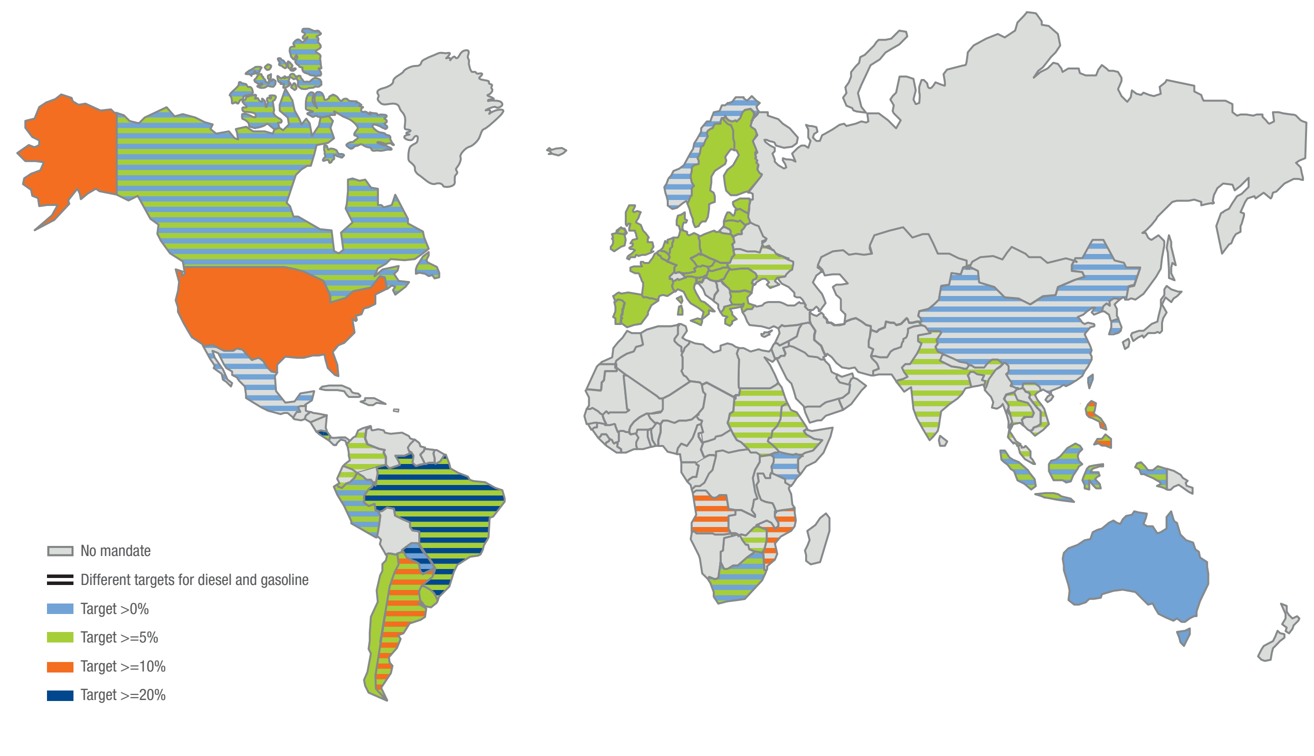


Figure 3. Low Carbon Transport Fuel mandates in different regions across the globe

The lighthouse country examples in this section show where there is high potential for deployment and/or where effective policies have led to the successful deployment of low carbon transport fuels globally.

Brazil has had biofuels policies in place for decades, and has a broad framework of legislation and regulations to shape biofuel production, trading and commercialization of biofuels:

- By mandate, gasoline contains between 18 and 27% ethanol;
- By mandate, diesel contains 7% biodiesel;
- These mandates have long term policy stability;
- Furthermore, taxes on biofuels are lower than on fossil fuels;
- Sustainability is enforced by laws on agricultural practices, ecological zoning, forest protection, industrial activities, etc.

Biofuels are widespread in Brazil, as is illustrated by the vehicle fleet: about 90% of sales of new cars in Brazil are flexfuel vehicles, and pure ethanol can be used by 24 million Brazilian vehicles. Following the Brazilian example, biofuels are very popular in South America, and mandates have been introduced in several neighbouring countries.

The US Renewable Fuel Standard (RFS) specifies a minimum volume of biofuels that should be used in the national transportation fuel supply. The total volumetric amount of biofuels is to increase from nearly 13 billion US gallons in 2010 to 36 billion US gallons in 2022. Most biofuels, including corn-starch ethanol, fall into this category and must meet a lifecycle greenhouse gas emission reduction of 20%. But the RFS also specifies smaller subcategories of better performing biofuels, stimulating the production of biofuels from cellulosic feedstock, waste and residues. Next to federal laws, several States have introduced regulations, tax breaks and grants to spur the deployment of alternative fuels, such as the often cited Californian Low Carbon Fuel Standard, calling for a reduction of at least 10% in the carbon intensity of California's transportation fuels by 2020.

China has a 15% overall biofuels target for 2020. Current deployment is supported by investment grants and tax breaks. Between 2003 and 2008, ten Chinese provinces installed a 10% ethanol blend mandate. In the long run, China aims to produce cellulosic ethanol from agriculture waste such as corn stover and straw. Following concerns over increasing livestock feed prices and the supply of edible grains for human consumption, grain-based fuel ethanol projects were stopped by the National Development and Reform Commission (NDRC). Now, only new plants that use non-grain feedstocks such as sugar cane, sweet sorghum, cassava and sweet potatoes will be approved by the government.

South Africa has had a National Biofuels Strategy since 2007. The regulatory framework provides financial support to biofuel manufacturers via a general fuel levy, however this has not been enough to encourage production. Mandatory blending regulations for B5, E2 and E10 were targeted to start in October 2015. However, in August 2015 the South African government announced that the biofuel funding incentive is being revamped over concerns that it is unaffordable after the drop in global crude oil prices over the past year.

Indonesia has a huge feedstock base in the form of palm oil. The biodiesel production capacity was large and focused on export. However, the low petroleum prices are slowing Indonesian biodiesel exports. Within Indonesia, biofuels use has been small and fluctuating over the past years. In April 2015, the government increased the biodiesel mandate to 15%, shifting the biodiesel economy from export heavy to one driven by domestic demand. The mandate concerns biodiesel blending in gasoil used by the transport, household, commercial and industrial sectors. Next to this, Indonesia has a 3% blending mandate for ethanol in gasoline, but in reality, the use of ethanol is negligible.

Indonesia is the largest producer of palm oil, often at the cost of deforestation and peatland oxidation, in turn causing large carbon emissions. Palm oil biodiesel can only be sustainable, if additional palm oil production is developed on low carbon stock land, or within existing plantations.

India has a 5% mandate for the blending of ethanol in gasoline, likely to increase to 10% soon. Very recently, the Ministry of New and Renewable Energy proposed a national biofuels policy with a target of 20% blending of transportation fuels — diesel and petrol (gasoline) — with bio-diesel and bio-ethanol by 2017. One of the reasons for the steep increase of the ethanol mandate is to create new opportunities for the sinking sugar industry. Currently deployment of biofuels is still hindered by infrastructure and inter-state trade hurdles.

On the diesel side, much is expected from the cultivation and processing of Jatropha plant seeds, for example through the introduction of community based production schemes.

Europe has installed an obligation of 10% renewable energy in transport by 2020. This obligation is administrative, as some forms of biofuels count double and electricity in road transport counts five times. Following concerns about indirect land use change induced carbon impacts, the Renewable Energy Directive and the Fuel Quality Directive were amended in 2015. The amendment introduced a cap of 7% on the contribution of biofuels produced from 'food' crops, and some emphasis on the production of advanced biofuels from waste feedstocks, through an indicative target of 0.5%. The cap on conventional biofuels and the policy uncertainty beyond 2020 has stalled investments. Even investment decisions for advanced biofuels production facilities that have received considerable subsidies, are now being put on ice because demand beyond 2020 is uncertain.

Hungary passed a national biofuel law in 2010 and its corresponding regulations have been implemented and enacted. The policy framework supporting biofuels in Hungary includes:

- Mandate of 4.9% of transport fuels demand (calculated on an energy basis) needs to be met by biofuels;
- A tax rebate on E85 excise duty.

The biofuel targets set by Hungary have so far been met. Sustainability of biofuels is enforced by European legislation (Renewable Energy Directive).

Bioport Holland is an existing initiative centred around the main Dutch (air)ports, involving key aviation and bio jet fuel stakeholders, with a strong link to a broader European setting through RenJet (supported by Climate KIC). The stakeholders aim to create a structural bio jet fuel supply and demand hub for Western Europe. Current partners are: KLM NV, Schiphol Airport, SkyNRG, Port of Rotterdam, Neste, the Dutch Ministries of Economic Affairs (EZ) and Infrastructure and Environment (I&M).

In the short term (2014-2018), partners have a strong focus on getting a bio jet fuel supply chain up and running to supply significant quantities of sustainable jet fuel to Schiphol Airport. For 2015-2016 the main efforts are:

- Setting up the physical supply chain;
- Ensuring enough volumes of sustainable feedstock;
- Developing financing mechanisms for project development financing and to overcome the initial price premium.

Finland is a pioneer in the bioeconomy. By 2020 in the transport sector, the country aims to cut use of imported oil by 50%. Finland will also increase the share of renewable transport fuels to 40% by 2030 (compared to 20% by 2020) and decrease GHG emissions from transport by 30 to 40%. The main measures to promote biorefinery and biofuel development in Finland have been

- Enhancing the development of biofuels markets through a biofuel obligation and through structural changes to energy taxes on transport;
- Funding on R&D in the area of biorefining and biofuels;
- Investment aid to demonstration of biorefinery concepts.

Italy was the first country in the EU to adopt a binding target for advanced biofuels. On 10/10/2014 the government adopted a decree establishing a binding ramped up target for advanced biofuels for the next 8 years. With the overall goal to achieve the target of 10% renewable energy in transport by 2020 advanced biofuels will have to be blended in increasing shares: 0.6% from 2018, 0.8% in 2020, 1% from 2022.

In July 2015, France adopted its new Energy Transition Law which specifies that France aims to reduce the use of fossil fuels by 30% (primary energy consumption) by 2030. The new Law includes a 15% share of renewables in transport objective to be achieved by 2030 (vs 10% in 2020). This 15% will be met with a mix of conventional biofuels, advanced biofuels and renewable electricity used in electric vehicles. The separate advanced biofuels objectives will be settled in the multi-annual programming (defined every 5 years).

The way forward

Starting point: commitment to partnering

Given the potential of low carbon fuels, the perspectives of climate change mitigation and the barriers above, the first step in overcoming these barriers is this partnership. This collaboration is unique and first-of-a-kind in covering the whole field of low carbon fuels. Individual companies will have their own preferences in investing in new and increased markets and will, in a sense, be competing. In the few first months of existence, however, every company in the partnership has recognized common ground and shared interests.

➤ THIS COLLABORATION RECOGNIZES A STRONG COMMON INTEREST IN THE DIVERSE FIELD OF LOW CARBON TRANSPORT FUELS

Unequivocally exploring low carbon fuel markets and co-operating with other stakeholders (governments, NGOs, manufacturers of cars, trucks, planes and ships, etc.) will help each company strengthen its business. Our commitment to keep this collaboration strong well beyond the Paris Climate Summit, is a significant starting point.

The potential

Already, many low carbon fuel solutions have successfully entered the global market, while new and emerging technologies are ready for commercial deployment immediately or in the near term. This report highlights the technologies that can contribute to fuel production targets and the policies that would be supportive to their growth.

The technology factsheets in this reports show numerous low carbon fuel technologies, at various stages of development and integration with other economic sectors - such as agriculture, forestry, waste, chemicals and biotechnology. They show their development, deployment and expansion and how they will generate new and significant economic opportunities throughout broad segments of the economy.

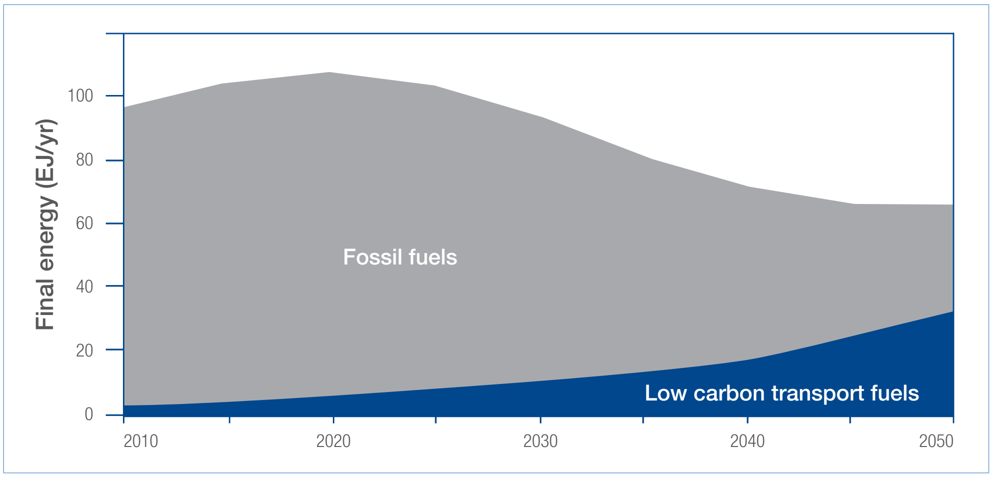


Figure 4. Final global energy supply for transport split by fossil fuels and low carbon transport fuels. Fuel efficiency and low carbon fuels are both necessary for staying on the 2°C pathway. If a decreasing demand scenario (e.g. WWF/Ecofys 2011 The energy Report) is combined with an increasing supply of low carbon fuels, (IEA 2013 Biofuels roadmaps 2011, OECD/IEA Paris), the share could even exceed 30%.

Further steps

This report will be a guide for taking further steps, today and tomorrow, in investigating deployment of low carbon technology options and contributing to an emerging global bio-economy. Through the WBCSD LCTP initiative, this Low Carbon Transport Fuels Report already shows tangible scalable projects that have partners and stakeholders ready to lead. It demonstrates that the private sector has clear options for the future and that public support is required to ensure these options materialise. In parallel, we believe that the 2°C threshold should not be exceeded. If barriers are addressed, the industry is committed to making the $100billion/year investments necessary to stay below a 2°C temperature rise.

This partnership, established in mid-2015 is ready to make meaningful progress.

The companies that endorse this report are committed to:

- **Elaborate** on this first report and explore issues in markets, technologies, sustainability and policies in more detail;
- Continue to **invest** in Low Carbon Transport Fuels (LCTF) through R&D, new facilities and infrastructure as well as encourage others to do so;
- **Engage** with further companies across industries and vehicle/ engine manufacturers to create new markets (supply/demand) and explore new synergies. Engaging with other organisations such as like SE4ALL and the LCTPi on Freight will be further explored;
- **Collaborate** with governments, NGOs and other stakeholders around the world to raise awareness of solutions and explore opportunities to create new Public Private Partnerships.

The partnership will continue to develop plans beyond the Paris Climate Summit and fully intend to formulate concrete plans for actions, focussing on solving specific issues and barriers that are experienced by the industry.

LCTPi
Led by wbcsd

Technologies

LOW CARBON TRANSPORT FUELS

Contents

TECHNOLOGIES

Characteristics of transportation sectors

Transportation is responsible for about 17% of global greenhouse gas emissions: about half from light road transport, a quarter from heavy road transport, and smaller equal shares (about 10%) from shipping and aviation.

Cars

Passenger transport can be seen as the most diversified group within the entire transportation sector. Growth has been continuous in the last decades, and with no dedicated policies, road travel is likely to double by 2050, with most growth occurring in developing countries. According to the IEA Energy Technology Perspectives, more than 2 billion light duty vehicles are expected to be on the roads in 2050 (today approximately 900 million).

Although Diesel and Otto engines running on diesel, petrol (gasoline) or natural gas are predominant in cars, this sector has broad experience in experimenting with other types of motors and fuels. This allows for innovation in both fuel efficiency and in low carbon fuel use. Conventional motors already allow for limited blends of (bio) ethanol (up to 20 to 30%) with gasoline, but with further adjustments cars can run on 100% biofuels.

Low carbon options in this sector cover a broad spectrum, from electric vehicles to biodiesel and bio-ethanol. The car market is very competitive and many manufacturers have taken the initiative to work with low carbon fuel developers. Meanwhile, fuel infrastructure and specifications are partially locked-in to conventional fuels. Opening up this infrastructure for alternatives is the challenge here.

Road Freight

Heavy road transport, representing about a quarter of all greenhouse gas emissions in transportation, is also expected to grow considerably, resulting in double the emissions from a business-as-usual scenario. A 10% reduction by 2050 would be needed to stay on the 2°C track. Trucks mostly run on diesel engines, which could run on very high fractions of biodiesel or ethanol with only minor engine adjustments. Drop-in low carbon transport fuels are also being developed, which global truck manufacturers are experimenting with.

The way in which freight transport is organized is expected to be a good breeding ground for innovation. As opposed to cars where individual ownership is predominant globally, trucks are often owned by fleet owners. This could lead to effective cooperation and efficient implementation of new low carbon technologies with agreeable costs.

Shipping

At present, shipping represents about 10% of the total energy demand in transportation and is among the fastest growing transportation modes. There are two principle options for reducing the greenhouse gas emissions from shipping: increasing the energy efficiency of shipping or decreasing the carbon intensity of shipping propulsion. The last one may be the decisive option for emissions reduction, as efficiency improvement is limited. Furthermore, low carbon transport fuels are sulphur free and assist the shipping sector's challenge to strongly decrease sulphur emissions.

There are many types of ships, from small to cargo and container ships, mostly running on diesel engines, and in some cases gas-fired engines. Current marine fuels are mostly very cheap. They are carbon-intensive fuels produced from crude oil (like heavy fuel oil) or liquefied natural gas (a small fraction). Trucks, inland vessels or piping systems transport the fuel to the wall bunker station in port areas, where it is stored until further use. Blending with lower carbon fuels is possible.

The shipping sector is still in an early stage of orientation towards biofuels. Several R&D projects and tests with biodiesel and bio LNG are known, but not broadly shared and replicated. The international dimension is a barrier for common policies for shipping, although harbours may apply measures to reduce emissions.

Aviation

The aviation sector is a relatively small sector in transportation (10% of energy use) but it is the fastest growing, with a projected demand growth of 4.5% annually up to 2050. Without further measures, greenhouse gas emissions could more than double by 2050. However, reductions can be accomplished by improved efficiency, improved operations and infrastructure, and alternative fuels. IATA identified that over half of emissions reductions should come from the deployment of low carbon transport fuels.

Kerosene, a liquid fossil fuel, fuels most aircrafts in the world. It is mainly transported in trucks and stored at airports and airfields. New low-carbon fuels have been officially approved with additional fuels going through the rigorous approval process. The production of these fuels represents still only a small share in total demand.

The aviation sector is a global sector that does not easily allow for unilateral or national policies and measures. One example is that it is virtually impossible to establish national (carbon) taxes to kerosene; moreover, the fuel is in most cases exempted from local fuel taxes. Similarly, it appeared impossible to include aviation into the EU system of emissions trading. By 2013, all aviation companies flying into and from EU Member States had to comply with EU ETS rules, but international objections led to the adjustment of this ruling. EU ETS coverage is now limited to domestic EU flights only, with any international measure for reducing emissions from transcontinental flights yet to be enforced.

The main parties leading the transformation to a low carbon future are the International Aviation Association IATA, some plane manufacturers and several of the larger individual aviation companies such as KLM, Lufthansa and British Airways. IATA has formulated far reaching targets to drive down greenhouse gas emissions.

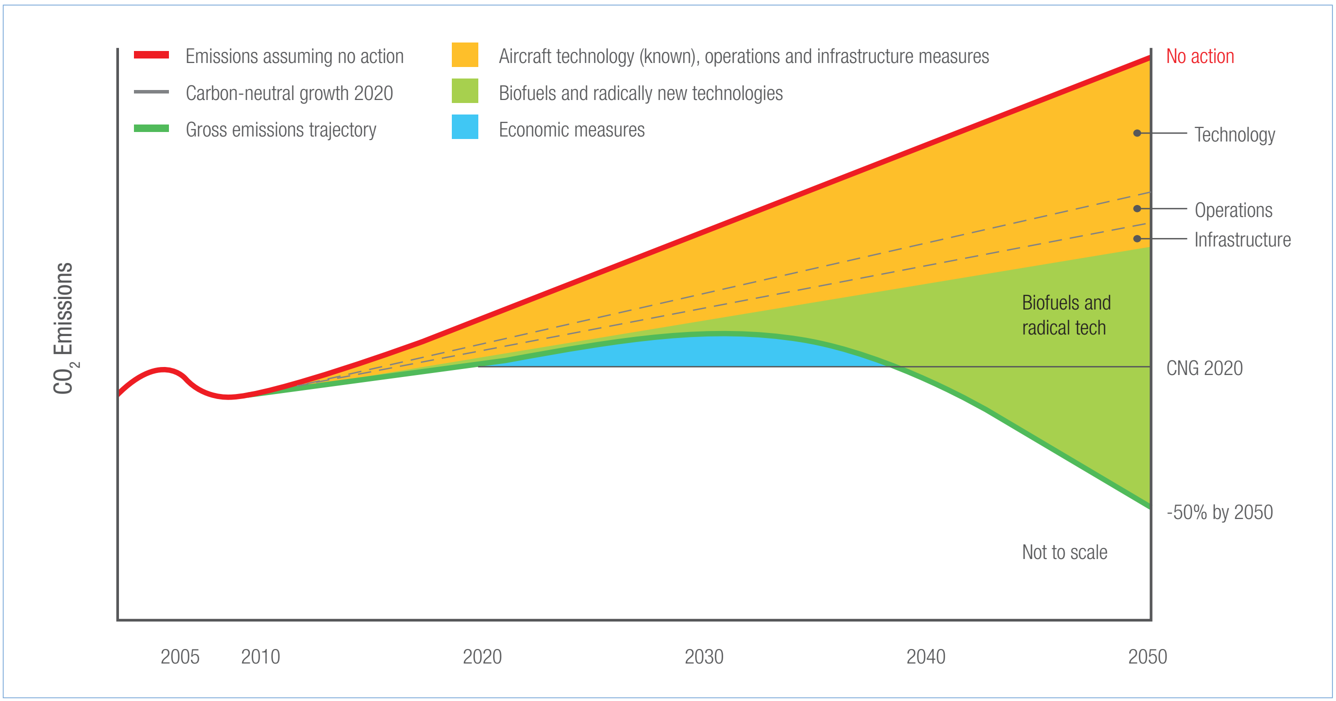


Figure 5. Carbon abatement potential of biofuels and other technologies in the aviation sector (source IATA Technology Roadmap).

Technology showcase

This section highlights seven existing categories of low carbon transport fuels technologies, in different stages of maturity and development. Each technology category hosts a number of cases within the portfolio of the eleven parties within this partnership. Together, they represent the wide range of technologies that are already on the market, or being prepared to enter the market.

Every technology description shows basic characteristics including potential greenhouse gas emissions reduction compared with fossil equivalents. They also include an estimate of potential for substitution of global fuel consumption in the transport sector, in million tons of oil equivalent. These last estimates are ball park figures and not based on sophisticated modelling. Global realisable potentials depend strongly on the timeframe considered, as well as on a large set of technical and economic assumptions. For these estimates we have assumed long-term potentials at technology maturity and with no limitations in the availability of capital.

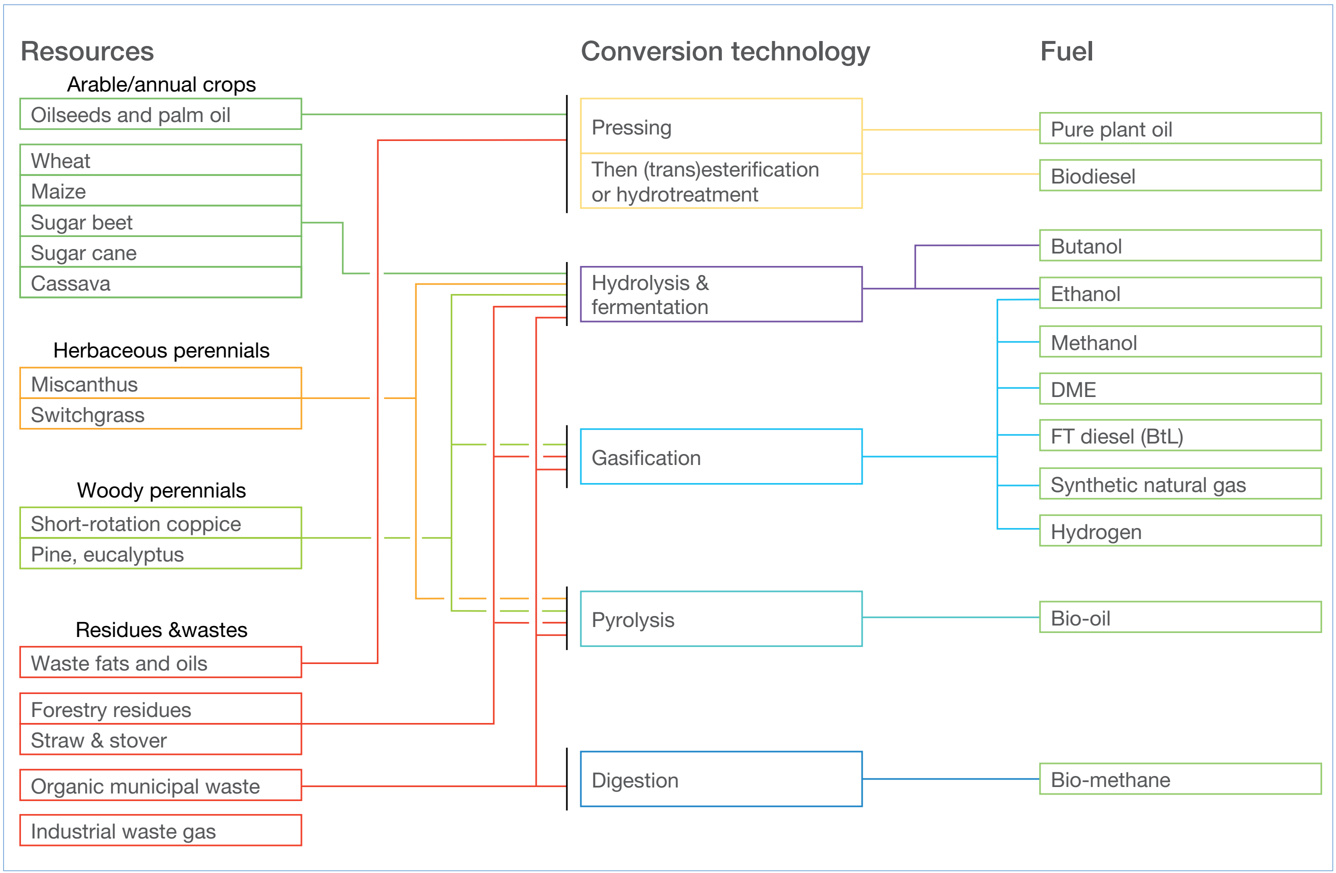


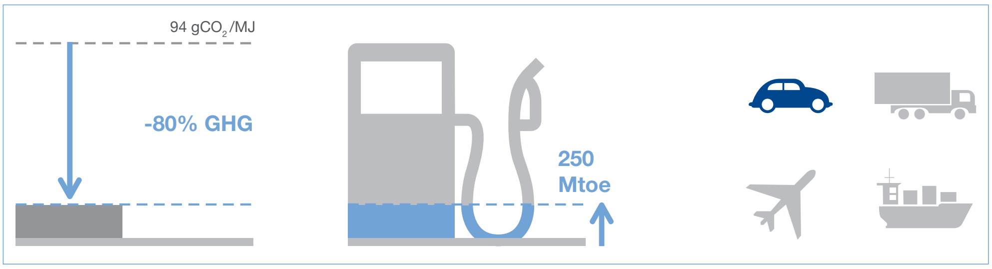
Figure 6. Low Carbon Transport Fuels pathway (adapted WBCSD, Biofuels – issue brief, 2007)

Conventional ethanol

How does it work?

Sugar or starch
(Cane, beets,
Corn, wheat, etc.) → Fermentation → Ethanol

GHG MITIGATION POTENTIAL



MAP OF INITIATIVES

TECHNICAL DESCRIPTION

Bioethanol obtained from sugar cane, corn, sugar beet, wheat or other crops with high sugar or starch contents is the most widespread biofuel and the largest renewable contribution in the transport sector. The bioethanol production process is technically mature and deployed at commercial scale in several regions of the world.

The production of bioethanol from crops high in sugar or starch is often referred to as a biological conversion route. A yeast is used to convert the sugar or starch into ethanol in a process called alcoholic fermentation.

Bioethanol can be blended with gasoline in different proportions and can be used by both conventional and flex-fuel vehicles.

CASE STUDIES

COPERSUCAR

Copersucar is the largest Brazilian sugar and ethanol commercial production operation, with global leadership in the market of these products. Its unique business model combines the large-scale supply of high quality products with an integrated system of logistics, transportation, storage and commercialization to serve the domestic and global markets. The Company has exclusivity in the sale of sugar and ethanol volumes produced by 37 Partner Producing Units, located in the States of São Paulo, Paraná, Minas Gerais and Goiás. In addition, it commercializes under a non-exclusive plan, with sugar and ethanol production at around 50 non-partner producing units. Copersucar leads the sale of sugar and ethanol in Brazil. In the 2013/2014 Crop Year, it was responsible for 22% share of both products in the Brazilian market, it exported 6.9 million tons of sugar and 1.0 billion litres of ethanol, as well as acting in the United States biofuel market through Eco-Energy, its subsidiary.

Pannonia Ethanol

Pannonia Ethanol is located in Dunaföldvár, Tolna County, Hungary. The facility currently utilizes roughly 1,000,000 tons of corn annually, producing up to 450 million litres of ethanol, and 330,000 tons of Dried Distillers Grains with Solubles (DDGS), a high protein animal feed. It also produces 10,000 tons of corn oil, an animal feed ingredient. Based on EU methodology, the produced ethanol saves 65% GHG emissions compared to fossil fuels, amounting to an emission reduction equivalent to the yearly emission of 100,000 cars.

Pannonia was set up due to the initial stable policy the EU offered in the Renewable Energy Directive. Further investor plans for additional plants in the whole of EU were cancelled due to rapid policy change.

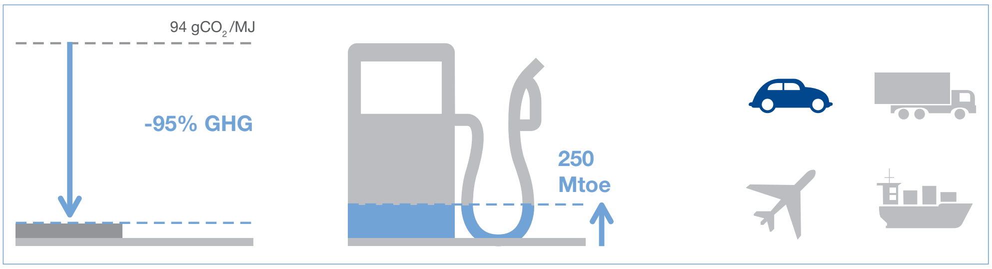
POET

POET has 27 ethanol plants operating in 7 states in the USA. The first plant came online in 1989 in Scotland, South Dakota. The plants primarily use corn to produce ethanol and a wide variety of other products. Much of POET's future expansion of ethanol production will likely be through co-location with the cellulosic ethanol industry as well as continued expansion of co-product. See for example the co-operation with DSM which is discussed in the lignocellulosic ethanol factsheet.

Lignocellulosic ethanol

How does it work?

GHG MITIGATION POTENTIAL



MAP OF INITIATIVES

TECHNICAL DESCRIPTION

Ethanol is commonly produced by fermentation of sugar or starch (see section on Conventional Ethanol). Plant biomass, such as from wood, straw and grass, contains cellulose, hemicellulose and lignin, of which the former two components are effectively polymers of sugars. It is possible to hydrolyse the cellulose and hemicellulose into sugars, and to subsequently ferment these sugars into ethanol.

Over the past decade, different technologies have been developed and demonstrated in pilot and demonstration plants. There is much interest in this technology because it can extend the scale of conventional ethanol production. Thanks to this technology, ethanol producers in Brazil, which are currently only using the sugar fraction, can also use a large part of the co-produced bagasse. Also, corn ethanol production (in Europe and the US) can increase if stover (leaves and stalks) can also be converted. Straw from many agricultural crops, as well as fast-growing energy crops (miscanthus, switchgrass, poplar, eucalyptus) can also be used.

CASE STUDIES

In Crescentino, Italy, the world's first commercial scale lignocellulosic ethanol facility has been in operation since October 2013. It produces 50 million litres of ethanol per year from a variety of feedstocks including agricultural waste such as wheat and rice straw, as well as energy crops like Arundo donax (giant cane). The facility is the result of the combined skills of three committed market leaders: Novozymes supplies market-leading enzymes, Beta Renewables licenses the Proesa™ process technology for conversion of biomass to sugar, and Chemtex supplies the basic engineering and key equipment.

Clariant has developed the fully integrated sunliquid® process which uses a chemical-free pre-treatment process with integrated enzyme production followed by enzymatic hydrolysis and fermentation. This process converts both C5 & C6 sugars efficiently and sustainably to cellulosic ethanol from agricultural residues such as wheat straw, corn stover or sugarcane bagasse. Since July 2012 Clariant's pre-commercial plant in Straubing, Germany, has been in operation, confirming the viability of the sunliquid® technology on an industrial scale using various feedstocks within established and well characterized equipment. With an annual capacity of 1,000 tons (1.25 million liters), the plant converts approximately 4,500 tons of lignocellulosic feedstock per year.

GranBio started operation of its commercial scale cellulosic bioethanol plant in São Miguel dos Campos-AL (Brazil) in 2014. The plant has the capacity to produce 82 million litres of bioethanol per year using sugarcane straw as a main feedstock, although the plant can operate with other feedstocks. The facility uses technology provided by Novozymes.

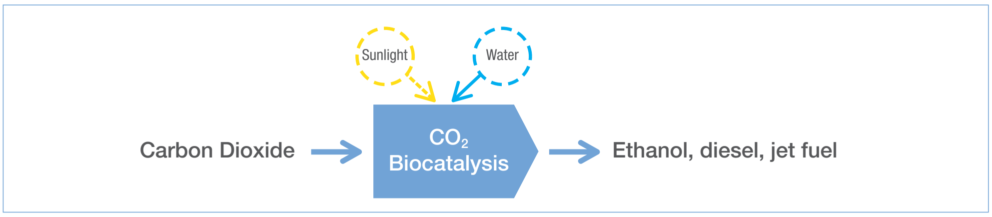
Project LIBERTY is a cellulosic biofuel plant that is using crop residue—corn cobs, leaves, husk, and some stalk—to produce 20 million gallons of bioethanol per year, later ramping up to 25 million gallons per year. POET-DSM Advanced Biofuels intends to globally license an integrated technology package converting corn crop residue to cellulosic bio-ethanol, as well as use it in 26 existing corn ethanol plants in POET's network. LIBERTY is co-located in Emmetsburg, Iowa, next to the existing grain ethanol plant, POET Bio-refining Emmetsburg.

In Piracicaba, São Paulo, Brazil, Raízen's Costa Pinto facility has produced lignocellulosic ethanol since 2014. Annually, it converts agricultural waste that is left over from sugarcane harvesting and processing operations (sugarcane bagasse and sugarcane tops/leaves) into 40 million litres of ethanol. It is co-located with Raízen's Costa Pinto sugarcane processing mill, which enables substantial integration opportunities. The facility uses technology provided by Iogen Corporation from Canada and Novozymes. Raizen is a joint venture of oil major Shell and cane ethanol major Cosan.

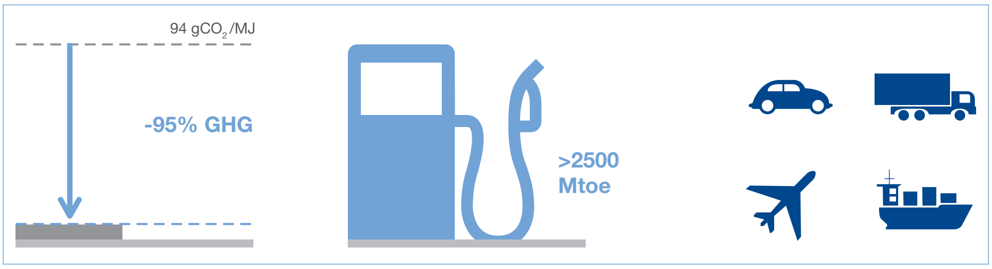
DuPont Industrial Biosciences opened its cellulosic ethanol plant in Nevada, Iowa on October 30, 2015. DuPont will use corn stover biomass collected from farms within a 30-mile radius around the facility as the feedstock for the biorefinery. The operation will produce 113 million Litres (30 million gallons) of cellulosic ethanol per year, a biofuel that offers up to 90 percent fewer greenhouse gas emissions as compared to petroleum. DuPont started developing the cellulosic ethanol technology a decade ago and since 2009 we have operated a demonstration facility in eastern Tennessee producing cellulosic ethanol from both corn stover and switchgrass. In Iowa, DuPont has worked closely with farmers, equipment makers and others for three years of large-scale corn stover harvest trials to demonstrate the ability to manage a cost-effective cellulose supply chain. DuPont plans to license the cellulosic ethanol technology package including access to plant specific vendors and proprietary equipment, technical support during construction and operations, enzyme biocatalyst supply and feedstock supply consulting.

Engineered photosynthesis

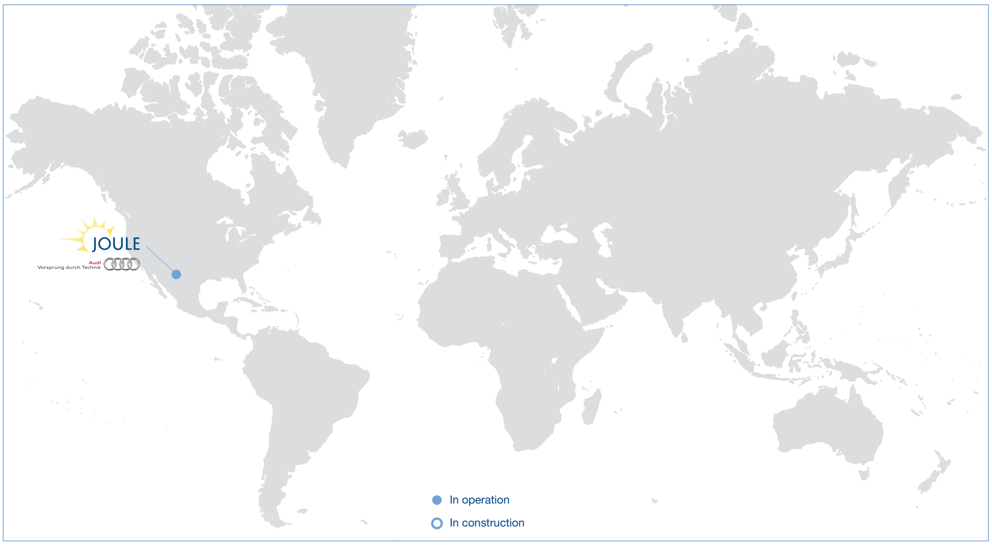
How does it work?



GHG MITIGATION POTENTIAL



MAP OF INITIATIVES



TECHNICAL DESCRIPTION

Engineered photosynthesis technologies convert carbon dioxide from industrial waste into fuels. The inputs are CO_2, sunlight, and (non-potable) water. At the heart of this process are photosynthetic micro-organisms. When fed with CO_2, instead of using photosynthesis to produce new cells, these modified microorganisms continually produce fuel. Potential sources of CO_2 include the steel and cement industry, power generation plants, oil & gas processing plants, refineries, etc. With this technology ethanol, diesel fuel or even jet fuel can be produced. A key environmental advantage of this technology is that it does not need arable land. Therefore no agricultural land is needed, nor clean drinking water.

From a technological and economic standpoint its modularity and scalability are also a potential advantage for future market deployment and large scale expansion. The process is relatively simple: Liquid fuels are produced from CO_2 and process water with the help of solar energy. At the heart of this process are photosynthetic microorganisms, each one with a diameter of about three thousandths of a millimeter. Instead of using photosynthesis to produce new cells, however, these microorganisms continually produce fuel. In the process, they utilize sunlight, saltwater or wastewater and CO_2 from industrial waste gases. There is no need to use agricultural land or clean drinking water.

From this technology, Audi e-diesel and Audi e-ethanol are produced. The e-ethanol project delivers a product that has the same chemical properties as conventional bioethanol; its decisive advantage is that it is produced without biomass. For vehicles that can use E85 fuel, it may be used as an admixture to fossil-fuel gasoline at percentages of up to 85 percent. Audi e-diesel will function without any problems with existing clean diesel systems, and it does not pose any other challenges to engine development.

CASE STUDIES

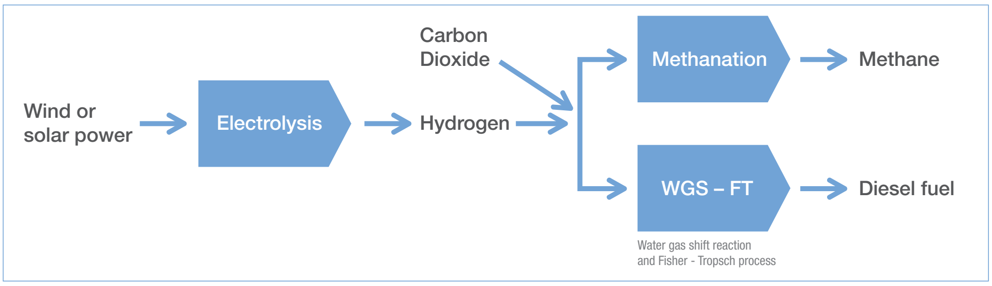
Joule and Audi are operating a ‘first of a kind’ research and demonstration engineered photosynthesis plant in New Mexico. Yield at technology maturity of the CO_2 biocatalysis process could deliver 25,000 gallons of ethanol / acre / year. The resulting ethanol has the same chemical properties as conventional bioethanol. For vehicles that can use E85 fuel, it may be used as an admixture to fossil-fuel gasoline at percentages of up to 85 percent.

At full-scale commercialization, a 10,000 acre Joule plant will represent a reserve value of 50 million barrels of solar-derived fuel, equivalent to a medium-sized oil field.

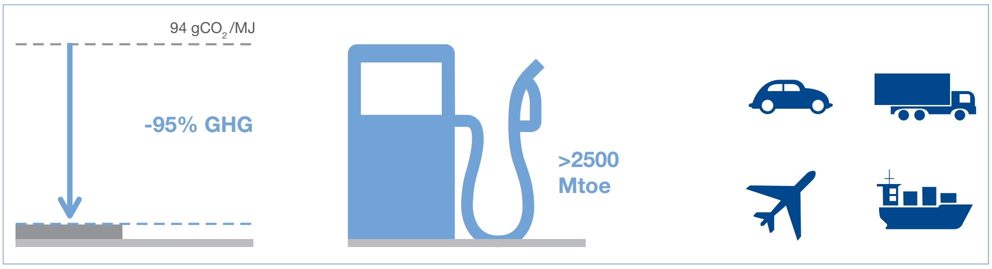
Along with the development of the ethanol project, Joule and Audi are also working to produce sustainable diesel fuel. One of the great strengths of e-diesel is its purity. The “drop in” fuel does not contain any sulphur or aromatics – unlike petroleum diesel which is a mix of many different hydrocarbon compounds. Moreover, the fuel ignites very easily due to its high cetane number. Its chemical composition permits unlimited blending with fossil diesel.

Power to fuels (gas and liquids)

How does it work?



GHG MITIGATION POTENTIAL



MAP OF INITIATIVES

TECHNICAL DESCRIPTION

Low carbon liquid or gaseous fuels can be obtained by using (renewable) electricity to power a chemical synthesis process. These processes are called power-to-gas and power-to-liquids. In both cases the first step is to obtain hydrogen from water by means of electrolysis.

In the case of power-to-gas technologies, hydrogen is then mixed with CO_2 to obtain synthetic methane gas. Chemically, it is nearly identical to fossil-based natural gas, so it can be compressed (Compressed Natural Gas -> CNG) and distributed over the natural gas grid to filling stations and be used to refuel vehicles. The energy conversion efficiency of this process can be above 70%.

In the case of power to liquid technologies, diesel fuel is synthesided from CO_2 and hydrogen by means of a reverse watergas shift reaction and the well-known and established catalytic Fischer-Tropsch (FT) process.

The energy conversion efficiency of both processes is around 70 percent. An additional advantage of these processes based on electrolysis is that they can be used flexibly to store (cheap) renewable energy power when production peaks and power prices are lower.

CASE STUDIES

Audi
Vorsprung durch Technik

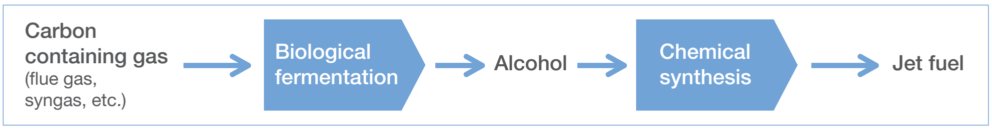
An industrial scale power to gas plant has been running since the end of 2013 in Werlte, Emsland (Germany). Audi built this facility in cooperation with ETOGAS. The plant has an installed capacity of 6 MW distributed in three 2 MW electrolysers for the production of hydrogen. The carbon dioxide used by the plant comes from the exhaust flow of a biomethane plant in the immediate vicinity which is operated by an energy utility.

The output of the facility is 1,000 metric tons of CNG per year (equivalent to 15,000 kilometres of CO_2-neutral driving). The gas is fed into the existing natural gas network and distributed to more than 600 filling stations. Audi is commercialising several car models adapted to run on CNG.

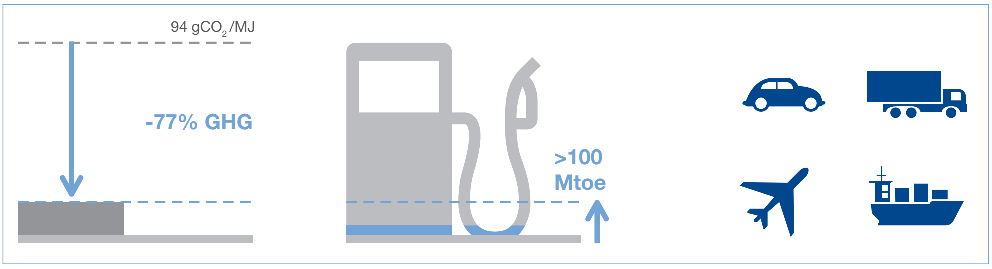
Audi is also operating a research power-to-liquid facility in Dresden (Germany). Energy technology corporation Sunfire is Audi's project partner. The plant uses electrical power to produce a liquid fuel. The only raw materials are water and carbon dioxide. The CO_2 used is currently supplied by a biogas facility. In addition, an initial portion of the CO_2 needed is extracted from the ambient air by means of direct air capturing, a technology of Audi's Zurich-based partner Climeworks.

Waste gas to fuels

How does it work?



GHG MITIGATION POTENTIAL



MAP OF INITIATIVES

TECHNICAL DESCRIPTION

Waste gas streams from certain industrial processes can be used as feedstocks to produce low carbon fuels. This can be achieved by converting relatively simple gases (usually mixes of carbon monoxide, carbon dioxide and hydrogen) into more complex compounds, including ethanol, jet fuel or commodity chemicals.

The core process is a biological fermentation of these gas molecules, followed by separation, distillation and product recovery. The fermentation is done by microbes that are able to recycle a wide variety of carbon rich gases. The conversion of waste gas to fuel can substantially reduce carbon emissions compared with the usual combustion of these waste gases to produce electricity. Third party analysis of the resulting fuel ethanol has shown a GHG reduction of over 70% compared to fossil alternatives.

The biological fermentation process can be applied to a wide variety of gases, including industrial flue gas, gases obtained from the gasification of biomass as well as other societal or industrial residues, such as gasified Municipal Solid Waste (MSW).

CASE STUDIES

LanzaTech

LanzaTech has operated four demonstration facilities in New Zealand, China and Taiwan, integrated with active steel mills and used the waste gases to produce ethanol. Two of these demonstration plants at the 400,000 litres per annum scale were constructed in China by joint ventures with Baosteel and with Shougang; both exceeded their technology demonstration targets. LanzaTech now has multiple commercial projects in development with steel partners in China, Taiwan and Europe. Projects are expected to come online in 2017. Typical capacities for future commercial steel gas to ethanol projects will range from 40 to 150 million litres per annum, depending on gas availability at a given mill.

ArcelorMittal LanzaTech

ArcelorMittal, LanzaTech, and steel technical partner Primetals Technologies, announced in July 2015 their agreement to construct Europe's first-ever commercial scale production facility to create bioethanol from waste gases produced during the steelmaking process.

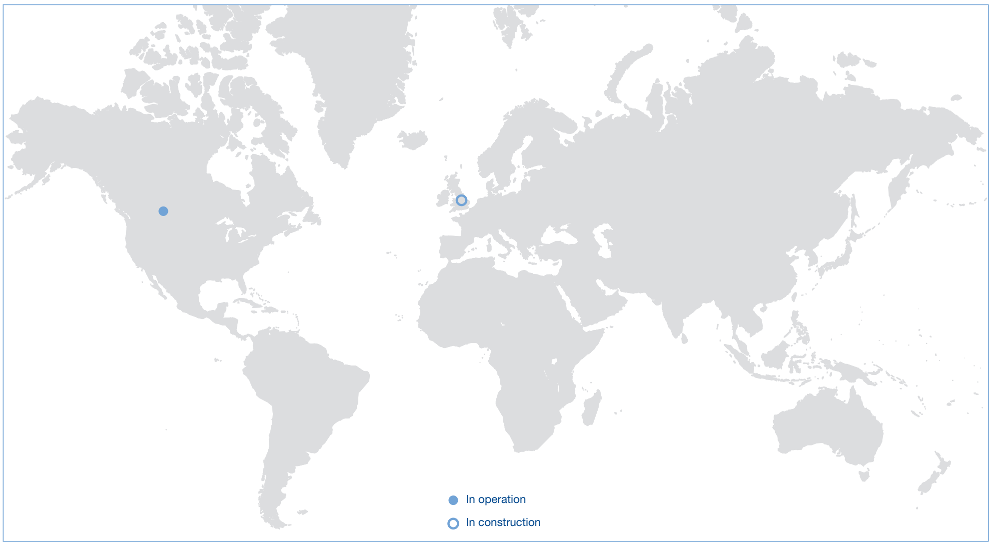
The installation, which will be located at ArcelorMittal's steel plant in Ghent (Belgium) will have a total cost of €87 million and the capacity to produce 47,000 ton ethanol/annum. Bioethanol production is expected to start in mid-2017.

Municipal solid waste to fuels

How does it work?

Municipal solid waste → Gasification → Synthesis gas → Catalytic synthesis → Ethanol

MAP OF INITIATIVES



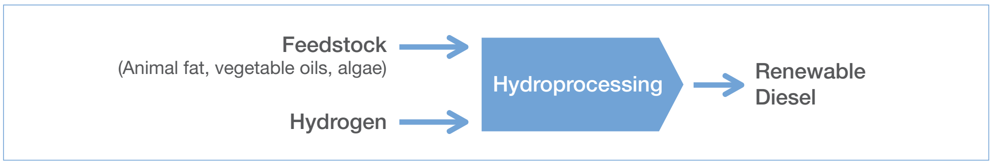
TECHNICAL DESCRIPTION

Municipal solid waste can be converted into low carbon fuels via the well-known and established catalytic chemical process called Fischer-Tropsch (FT) synthesis. The process starts with the gasification of the organic fraction of the waste under high temperatures. This breaks down the waste molecules into more simple gas molecules. After this gas is cooled down and cleaned, the catalytic synthesis process reforms the gas into more complex molecules, including liquid transportation hydrocarbon fuels and other useful compounds.

Synthetic fuels produced via the Fischer-Tropsch technology have been used for years, mostly using coal as feedstock. However, using landfill waste for production of clean fuel is a solution to produce low-carbon fuels, contributing to solving global environmental challenges. The feedstock is available near urban centres and can use existing value chain and transport infrastructure.

Hydrogenated organic oil

How does it work?



MAP OF INITIATIVES

TECHNICAL DESCRIPTION

Hydrogenated vegetable oil, can be obtained by refining vegetable oils through a hydro-treatment process.

There are two processing routes for converting vegetable oil to diesel fuel. The conventional processing route for diesel fuel production is via esterification with methanol to produce Fatty-Acid Methyl Ester (FAME-biodiesel) with glycerol as a by-product. Instead, the hydro-treatment route uses hydrogen to remove oxygen from the triglyceride molecules in the vegetable oil, tree oil (tall oil) or animal fat. Possible feedstocks include soybean, palm oil, canola, or rapeseed oil, vegetable oil waste or other vegetable oils.

Hydro-processing can be carried out with existing technology, which is widely deployed in conventional refineries.

Acknowledgements
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