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Methanol Institute

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Renewable Methanol Report

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EXECUTIVE SUMMARY: RENEWABLE METHANOL REPORT

Methanol (CH_3OH) is a liquid chemical used in thousands of everyday products, including plastics, paints, cosmetics and fuels. Liquid methanol is made from synthesis gas, a mix of hydrogen, carbon dioxide and carbon monoxide. These simple ingredients can be sourced from a wide range of feedstocks and using different technology approaches.

Renewable methanol is an ultra-low carbon chemical produced from sustainable biomass, often called bio-methanol, or from carbon dioxide and hydrogen produced from renewable electricity.

> *Renewable methanol is an ultra-low carbon chemical produced from sustainable biomass, often called bio-methanol, or from carbon dioxide and hydrogen produced from renewable electricity.*

Renewable methanol fuel drastically cuts greenhouse gas emissions

This includes reducing carbon dioxide (CO_2) by up to 95% and nitrogen oxide (NO_x) by up to 80%, and eliminating sulfur oxide (SO_x) and particulate matter (PM) emissions. Cutting emissions is essential in fighting climate change and improving public health through better air quality.

Creating value from unrecyclable waste

Biochemical company Enerkem is building a plant in Rotterdam that will turn 350,000 metric tons of waste, including unrecyclable plastic, into 270 million liters of bio-methanol every year. Up to 420 million metric tons of unrecyclable waste could be turned into biochemicals with Enerkem's technology. This is just one example. Other initiatives are also looking to create valuable commodities from non-food biomass resources.

Storing wind and solar power in renewable liquid e-fuels

Wind and solar photovoltaic (PV) are the world's fastest growing sources of energy, providing much-needed clean and affordable electricity to countries around the globe. However, wind and solar PV electricity must be dispatched as soon as it is produced, even if there is not enough demand for electricity. When this happens, operators have little choice but to disconnect the renewable source from the grid, leading to wasted energy and costs for governments and operators.

Instead, this energy could be harnessed to power the renewable methanol synthesis process. Then renewable methanol can be used as a source of energy for power plants, as an automotive or shipping fuel or as a chemical building block in thousands of everyday products.

Virtually unlimited renewable feedstock sources

Renewable methanol can be made from many plentiful sources which are available all over the world.

The necessary carbon molecules to make synthesis gas for methanol production can be obtained from CO_2 from industrial exhaust streams, or even captured from the air.

Synthesis gas also can be produced from the gasification of any carbon source, such as municipal solid waste or forestry residues. Biogas, obtained through fermentation, from landfills, wastewater treatment plants or animal wastes can also be used as a feedstock for methanol production.

Additionally, renewable energy can power the electrolysis process to generate clean hydrogen for the production of renewable methanol.

Given how abundant and widespread renewable methanol feedstocks are, renewable methanol can often be produced from locally available resources, increasing energy security for countries that are dependent on imported petroleum products and improving their fiscal balances by mitigating their reliance on oil imports.

Methanol is already a well-known chemical commodity

Methanol is the world's most commonly shipped chemical commodity and more than 95 billion liters are manufactured every year. It has been stored, transported and handled safely for over 100 years. Since it remains liquid at ambient temperature and pressure, the infrastructure required to deploy it as a fuel is largely in place: combustion engines, fuel cells and power blocks could quite easily and affordably be adapted to methanol.

BioMCN's renewable methanol plant

WHY CONSIDER RENEWABLE METHANOL?

Growing recognition of the threat posed by man-made climate change has spurred government institutions, industry and science to find clean fuels to power economic activity. In this context, renewable methanol has risen as a clean alternative to fossil fuels, offering a clear pathway to drastically cutting emissions in power generation, overland transportation, shipping and industry.

Compared to fossil fuels, renewable methanol reduces carbon emissions by 65 to 95% depending on the feedstock and conversion process. That's one of the highest potential reductions of any fuel currently being developed to displace gasoline, diesel, coal and methane.[1] Additionally, the combustion of pure methanol produces no sulfur oxides (SO_x), low nitrogen oxides (NO_x), and no particulate matter emissions.

Legislation drives change

Government legislation on emissions has created challenges for those who need to comply, opening new markets and opportunities for alternative fuels, including renewable methanol.

> *Compared to fossil fuels, renewable methanol reduces carbon emissions by 65 to 95 % depending on the feedstock and conversion process.*

Europe's first biofuel policy was introduced in 2003, setting blending targets for 2010. This policy was integrated in the Renewable Energy Directive (RED) in 2009, which set an obligation of 10% renewable energy in transport for 2020. In 2018 the European Parliament, Council and Commission agreed on the Renewable Energy Directive II (RED II), requiring 14% renewable energy to be used in transport by 2030.

RED II has created new markets for conventional biofuels like ethanol and biodiesel and for alternative biofuels such as renewable methanol, especially when made from wastes, residues or renewable electricity (Renewable Energy Directive II, Annex IX Part A).

Other European policies also impact the potential uptake of renewable methanol: the Fuel Quality Directive, the Alternative Fuel Infrastructure Directive, and the Air Quality Directive, among others.

The USA introduced the first biofuel policy in the form of the Energy Policy Act in 1992. Its objective was reducing dependence on oil imports, increasing energy security and improving sustainability.

In 2007, the United States introduced the Renewable Fuel Standard (RFS), requiring a minimum volume of biofuels to be used in the national transportation fuel supply each year. The total renewable fuel requirement is divided into four separate - but nested – categories. These are: total renewable fuels, advanced biofuels, biomass-based diesel, and cellulosic ethanol. Each has its own volume requirement. To qualify for the advanced biofuels category, a fuel must reduce lifecycle greenhouse gas emissions by 50%. To qualify for the cellulosic and agricultural waste-based biofuel subcategory, fuels must reduce lifecycle greenhouse gas emissions by at least 60%.

1 Methanolfuels.org

Other efforts to reduce greenhouse gas emissions in North America include the ongoing development of a Clean Fuel Standard by the Government of Canada (final regulations are expected in 2020) and the California Low Carbon Fuel Standard (LCFS), which has expanded into the Pacific Coast Collaborative, a regional agreement between California, Oregon and British Columbia, Canada to strategically align policies to reduce greenhouse gases.

In total, 66 countries have put targets or mandates in place. Besides the EU-27, 14 countries in the Americas, 12 countries in Asia Pacific, 11 in Africa and 2 in non-EU countries in Europe all have implemented biofuels adoption policies, some as high as 15 to 27%[2].

Beyond national policies, some industries – such as the marine sector - have also introduced their own mandates. The International Maritime Organization (IMO) introduced so-called Emission Control Areas to significantly reduce SO_x and NO_x emissions. In 2018 the IMO also announced it aims to reduce CO_2 emissions from the sector by 50% by 2050.

> *To qualify for the advanced biofuels category, a fuel must reduce lifecycle greenhouse gas emissions by 50%. To qualify for the cellulosic and agricultural waste-based biofuel subcategory, fuels must reduce lifecycle greenhouse gas emissions by at least 60%.*

Report structure

The first chapter shows how methanol can be made sustainably from renewable feedstocks which are abundant worldwide. These include CO_2 from industry or captured from the atmosphere, or sustainable biomass such as agricultural residue and municipal solid waste.

The report then explores the connection between renewable energy and renewable methanol, both as an input in methanol production and as a means to store excess power from variable renewables such as wind and PV.

Subsequent chapters describe three successful examples of large-scale commercial renewable methanol production: BioMCN, Carbon Recycling International (CRI) and Enerkem.

Finally, the report offers an overview of renewable methanol applications in power generation, heating, road transportation, and shipping.

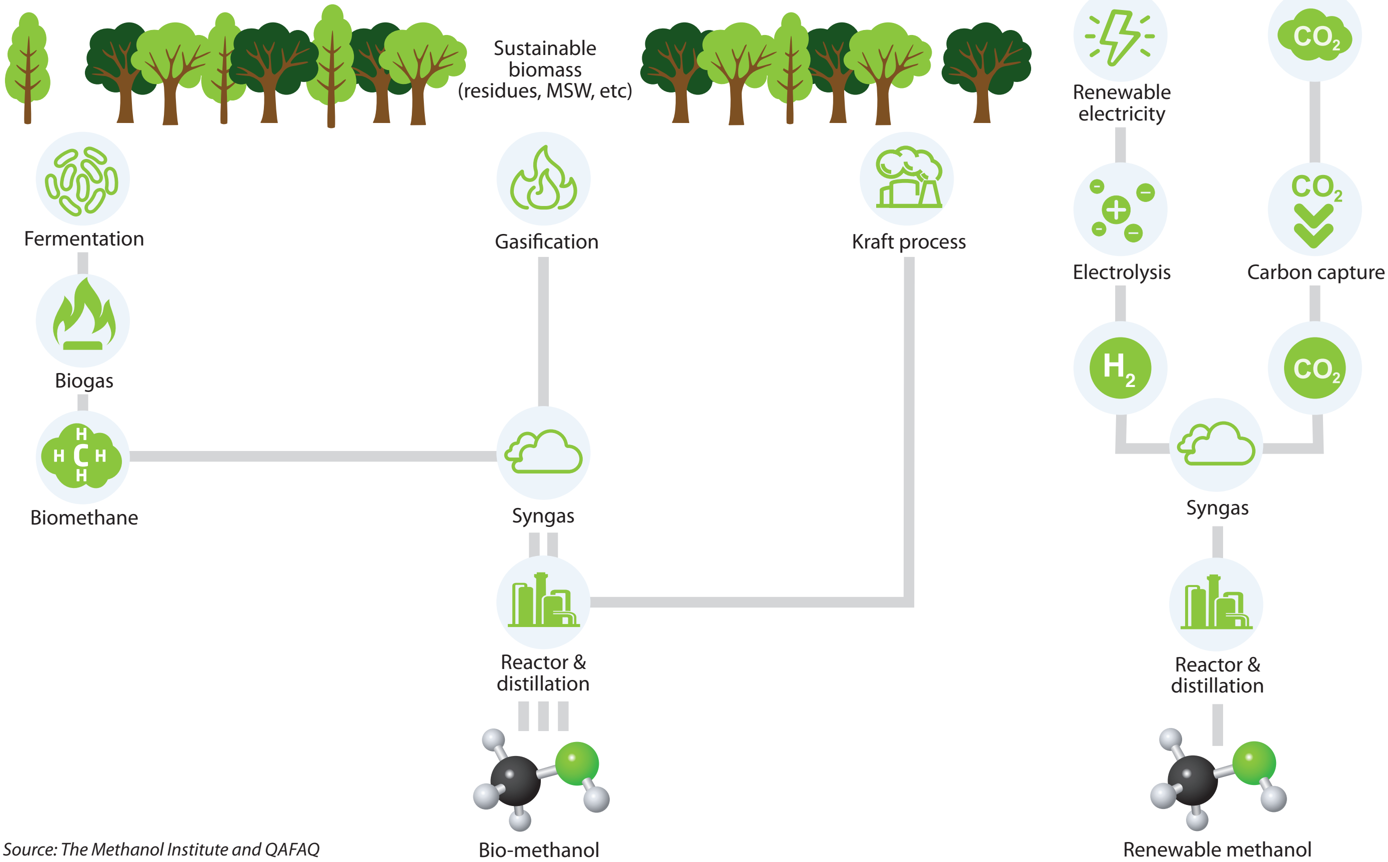
2 LANE, Jim (a): https://www.biofuelsdigest.com/bdigest/2018/01/01/biofuels-mandates-around-the-world-2018/

RENEWABLE METHANOL PRODUCTION

Methanol (CH_3OH) is a liquid chemical used in thousands of everyday products, including plastics, paints, cosmetics and fuels. More than 95 billion liters are produced worldwide, and methanol is the world's most-shipped chemical commodity[3]. Renewable methanol is an ultra-low carbon chemical produced from sustainable biomass, often called bio-methanol, or from CO_2 and hydrogen produced from renewable electricity.

Renewable methanol synthesis

Figure 1. Renewable methanol production processes from different feedstocks



Source: The Methanol Institute and QAFAQ

There are several pathways to renewable methanol.

In the electro-fuel pathway, renewable electricity is used to extract hydrogen from water by electrolysis. Hydrogen is then reacted with carbon dioxide captured from point sources (e.g. industrial exhaust streams) or from the atmosphere.

In the biomass pathway, organic matter undergoes fermentation or gasification (subjecting the biomass to high temperature in the absence of air) to produce synthesis gas (syngas) that is processed in a reactor and formed into bio-methanol.

3 ANDERSSON, Karin (2015)

Hybrid bio-methanol uses a combination of the two methods, combining biogenic syngas with hydrogen from electrolysis.

Feedstocks

Renewable methanol can be produced from a wide range of renewable feedstocks available worldwide. This section considers the availability of five main sources of feedstocks: municipal solid waste (MSW), agricultural waste, forestry residues, carbon dioxide (CO_2) and renewable hydrogen. These are some of the largest sources but not the only ones.

> *Using MSW to produce renewable methanol creates value from unrecyclable garbage and relieves pressure on landfill sites.*

Agricultural Waste

Agricultural activity yields a great deal of biomass that can be converted into bio-methanol without interfering with food prices or availability or encroaching on agricultural land.

It has been estimated that around 998 million metric tons of agricultural waste is produced every year[4]. In Europe, estimates say that up to 132.4 million metric tons of dry agricultural residues could be collected from the EU-27 states, with the potential to generate 639 TWh of energy[5]. The DOE Billion Ton Report (2016) estimates that there will be 94.1 dry tons of forest biomass available by 2020 in the USA, assuming a cost of USD 60 per dry ton to roadside[6].

Forestry Residues

A large amount of residual biomass, such as leaves, branches, needles and woodchip, is produced in the process of harvesting trees. These by-products can be used as a feedstock for producing biochemicals such as renewable methanol.

Forestry biomass resources have been estimated at around 140 million metric tons in the USA[7]. In the European Union, it has been estimated that total forest biomass amounts to 716 million m^3 annually[8].

Swedish company Södra is building a plant that will produce bio-methanol from the raw methanol resulting from their pulp mill manufacturing. The company claims this is part of a sustainable circular process that uses all parts of forest raw materials to the best possible effect. Once completed, the plant will produce 5,000 metric tons of bio-methanol every year. According to Södra, their bio-methanol reduces CO_2 emissions by 99% compared to fossil fuels[9].

Municipal Solid Waste (MSW)

Using MSW to produce renewable methanol creates value from unrecyclable garbage and relieves pressure on landfill sites.

4 OBI, UGWUISHIWU and NWAKAIRE: https://www.ajol.info/index.php/njt/article/viewFile/145674/135199
5 In the original study different units were used, amount of residues: 146,000 kt/year, potential energy: 2,300 PJ/year. Source: MONFORTI, LUGATO, MOTOLA, BODIS, SCARLAT, DALLEMAND https://www.sciencedirect.com/science/article/pii/S1364032114010855
6 US Department of Energy (DOE): See page 39. https://bioenergykdf.net/sites/default/files/BillionTonDownloads/BillionTon_Report_2016_Chapter3.pdf
7 HAN, CHUNG, WELLS AND ANDERSON: https://doi.org/10.3390/f9030121
8 ANTTILA, Pertu and ASIKAINEN, Antti: http://www.metla.fi/julkaisut/workingpapers/2014/mwp289-4.pdf
9 SÖDRA: https://www.sodra.com/en/about-sodra/press/press-releases/2658273/

> Instead of being wastefully curtailed, , renewable electricity could be harnessed to generate renewable methanol, which could in turn be used to generate clean power or as a renewable fuel for cars and ships.

Every year 1.3 billion metric tons of MSW are produced globally and this is expected to increase to 2.2 billion metric tons by 2025.[10] Managing such volumes of waste poses great challenges for municipalities and governments.

Two thirds of MSW are either dumped in landfills or incinerated. A significant portion of this waste could be diverted towards producing sustainable chemicals, including renewable methanol.

Biochemical company Enerkem estimates that up to 420 million metric tons of unrecyclable waste could be turned into biochemicals, using their technology[11]. Enerkem is building a plant in Rotterdam which will turn 350,000 metric tons of waste, including plastic matter, into 270 million liters of bio-methanol every year[12].

Carbon dioxide (CO_2)

Around 32.5 billion metric tons of CO_2 were released into the atmosphere in 2017 alone[13], rising 1.4% from 2016. This rise is the equivalent of having 170 million new cars on the roads.

With current technology, it is possible to capture CO_2 from the atmosphere and from industrial exhaust streams. Power plants, steel and cement factories, and distilleries, among others, produce carbon dioxide that could be used as a source to produce methanol.

Carbon Recycling International takes 5,600 metric tons of carbon dioxide every year which is reacted with renewable hydrogen to synthesize 4,000 metric tons of renewable methanol (see CRI case study.)

Renewable hydrogen: harnessing renewable energy for electrolysis

As shown in Figure 1, renewable electricity is used to obtain hydrogen from water by electrolysis.

In recent years, solar PV, hydro and wind have grown to account for a significant part of the energy mix in many parts of the world. These resources provide clean and affordable electricity, but maximum electric yield might not match peak demand. A wind power plant might peak at 3 am, when the wind blows strongly but there is little need for electricity. In this case, supply could outstrip demand and threaten to overload the electric grid.

When this happens, the transmission system operator (TSO) tends to disconnect the renewable resource to safeguard the integrity of the grid. As a result, renewable energy is wasted. In the energy industry, this is known as curtailment.

Curtailment costs can escalate. TenneT, a TSO, paid close to 1 billion euros in 2017 to wind energy

10 World Bank: Urban Development Series – Knowledge Papers, Chapter 3 Waste Generation 2016 https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap3.pdf (Last Accessed on 12 Sept 2018)

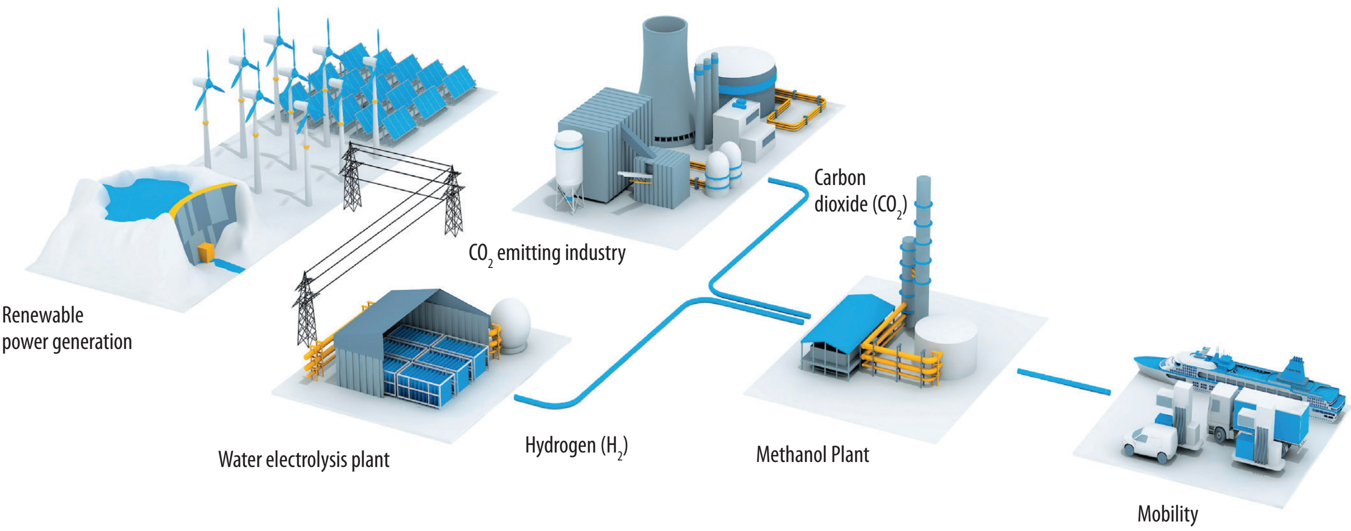
11 Enerkem Inc: https://enerkem.com/waste-diversion/waste-challenge/

12 METHA, Angeli: https://www.chemistryworld.com/news/outline-for-europes-first-waste-to-methanol-plant/3008729.article

13 International Energy Agency: https://www.iea.org/publications/freepublications/publication/GECO2017.pdf

Figure 2. thyssenkrupp's concept of using renewable energy and waste CO_2 to make renewable methanol

A number of companies are exploring the idea of harnessing excess renewable energy to obtain clean hydrogen from electrolysis. One of them is thyssenkrupp, which is also sourcing excess CO_2 from industrial sources to create renewable methanol.



operators as compensation for curtailment in the area it serves in Germany[14]. In California, the grid operator states that, although only about 1% of solar energy is curtailed in the state, "during certain times of the year, it's not unusual to curtail 20 to 30% of solar capacity"[15].

Instead of being wastefully curtailed, this electricity could be harnessed to generate renewable methanol, which could in turn be used to generate clean power or as a renewable fuel for cars and ships.

The price of electricity is one of the main cost drivers of renewable methanol[16], and excess renewable energy tends to command low prices because it is dispatched when demand is at its lowest.

A number of companies are exploring the idea of harnessing excess renewable energy to obtain clean hydrogen from electrolysis. One of them is thyssenkrupp, which is also sourcing excess CO_2 from industrial sources to create renewable methanol[17].

Commercial methanol production

Several companies and institutions across the world are producing renewable methanol or bio-methanol. Many others are in research and development.

14 TenneT: http://files.smart.pr/4d/76b0d038cf11e8b28c2defbda27260/20180405-Market-Review-2017.pdf
15 California ISO: https://www.caiso.com/documents/curtailmentfastfacts.pdf
16 Liquid Wind: https://www.innovatum.se/wp-content/uploads/2017/05/final-final-liquid-wind-report-may-2017.pd
17 Thyssenkrupp: https://www.thyssenkrupp.com/en/carbon2chem/#421127

Figure 3. Institutions involved in the production of Bio-methanol or Renewable Methanol

Methanol category	Commercial	Feasibility and R&D
Bio-methanol	■ BASF (GER) ■ BioMCN (NL) ■ Enerkem (CAN) ■ New Fuel (DEN) ■ Nordic Green (DEN)	■ Biogo (GER) ■ Enerkem (NL) ■ LowLands Methanol Heveskes Energy (NL) ■ NREL (USA) ■ Origin Materials (USA) ■ Södra (SE)
Renewable methanol	■ CRI (IC) ■ Innogy (GER)	■ Advanced Chemical Technologies (CAN) ■ Asahi Kasei (JPN) ■ Blue Fuel Energy (CAN) ■ bse Engineering (GER) ■ Catalytic Innovations (USA) ■ CRI (CN/GER) ■ Gensoric (GER) ■ Infraserv (GER) ■ Liquid Wind (SE) ■ MefCO2 (GER) ■ Neo-H2 (USA) ■ Port of Antwerp (BE) ■ Quantiam Technologies (CAN) ■ STEAG (GER) ■ Swiss Liquid Future (CH) ■ thyssenkrupp (GER) ■ USC (USA) ■ ZASt (GER)
Low carbon methanol	■ GPIC (BAH) ■ Methanex (CAN) ■ QAFAC (QAT) ■ SABIC (KSA)	■ Carbon2Chem (GER) ■ FRESME (SE) ■ GasTechno (USA) ■ Haldor Topsoe (DEN) ■ Maverick Synfuels (USA) ■ NCF (CN) ■ OPTIMeoH (GER)

Chinese automaker Geely, in partnership with Carbon Recycling International, has conducted long-term tests on methanol powered cars.

Low Carbon Methanol

In recent years, several companies have developed technologies that reduce the carbon intensity of methanol produced from natural gas. This is called Low Carbon Methanol (LCM).

Methanex Corporation produces LCM in its Medicine Hat (Canada) plant by injecting sequestered CO_2 from a neighboring industrial facility into the methanol synthesis loop. This process significantly reduces GHG emissions when the LCM is utilized as a fuel. According to Methanex, a car that relies entirely on low carbon methanol would emit 30% less CO_2 per kilometer, from well to wheel, compared to a gasoline-powered car.

Other methanol producers, such as Qatar Fuel Additives Company Limited (QAFAC), have implemented carbon dioxide recovery plants to extract the CO_2 from their flue gas (exhaustion gas) and re-inject it into the methanol production, reducing GHG emissions and water consumption.

There are also other large-scale technologies for producing LCM from natural gas that yield similar emission reductions. Johnson Matthey, a technology licensing company, has developed a process called Advanced Combining Reforming that produces LCM by utilizing renewable electricity.

These are examples of existing technologies that can be implemented to produce LCM from natural gas, while still leading to GHG reductions.

Low Carbon Manufacturing Plant in Medicine Hat, Canada (Methanex)

CASE STUDY: CARBON RECYCLING INTERNATIONAL

Renewable production of methanol at Carbon Recycling International's George Olah plant in Iceland

Carbon Recycling International (CRI) has successfully established a renewable methanol plant near Iceland's Blue Lagoon. The famous lagoon's water flows from the nearby Svartsengi geothermal power station: CRI's methanol plant harnesses a portion of Svartsengi's waste carbon dioxide and uses renewable energy from the Icelandic grid to produce hydrogen from the electrolysis of water.

The CRI plant is named after Nobel prize-winning chemist George A. Olah (1927-2017) who pioneered the idea of the methanol economy. His vision inspires the CRI plant, which uses 5,600 metric tons of carbon dioxide piped from Svartsengi every year.

The Icelandic grid, powered by hydro and geothermal energy, provides green electricity for the process of splitting water into hydrogen and oxygen. 4,000 metric tons of synthesized methanol (CRI calls it Vulcanol) are produced annually.

Vulcanol is a clean burning, high octane fuel. It can used directly as a vehicle fuel or blended with gasoline. It can also be used as a feedstock for producing bio-diesel or fuel ethers and as a hydrocarbon feedstock for further production of synthetic materials. CRI supplies it to companies in Iceland, Sweden, the Netherlands, the UK and China.

Unlike biofuels, CRI's renewable methanol doesn't use any fossil fuel inputs or agricultural resources as feedstocks.

According to CRI, "Vulcanol from our current production plant reduces carbon emissions by more than 90% compared to fossil fuels, in the complete product life-cycle, from extraction, production to end use. The process is certified by SGS Germany according to the ISCC Plus system, based on standard ISCC EU methodology for calculation of GHG [greenhouse gas] emissions in the product life-cycle."[18]

CRI's George Olah Renewable Methanol Plant is the largest carbon dioxide methanol plant in the world. The company is ranked among the fastest growing technology companies in Europe[19], with turnover up 440% between 2013 and 2017. CRI has partnered with Geely Holdings and Zixin Industrial Co to promote and establish renewable methanol production facilities in China.

Geely and CRI, in collaboration with local companies, have also conducted a long-term fleet test of Geely's 100% methanol powered cars in Iceland running on Vulcanol. The cars were driven over 150,000 kilometers during an 18-month period, and study participants reported virtually no difference in driving experience compared to regular gasoline or diesel fueled cars.

> “
> *The Icelandic grid, powered by hydro and geothermal energy, provides green electricity for the process of splitting water into hydrogen and oxygen.*

18 Carbon Recycling International: http://carbonrecycling.is/vulcanol/ accessed 11/07/18
19 Deloitte

CASE STUDY: ENERKEM

Producing renewable methanol from solid waste

Based in Montreal, Canada, Enerkem is a cleantech company that produces clean transportation fuels and renewable chemicals from municipal solid waste (MSW). The firm was founded in 2000 with the aim of further developing and contributing to a strong circular economy. It provides an innovative and sustainable solution to the increasingly pressing environmental issues of waste management and supporting energy diversification through biofuels.

The company's first flagship, commercial scale waste-to-biofuels facility is in Alberta, Canada, where it helps the City of Edmonton increase its waste diversion goal from 50% to 90%. The plant began producing methanol in 2015, using the city's non-recyclable and non-compostable waste. The plant is designed to process over 100,000 metric tons per year of unrecoverable waste otherwise destined for landfill[20] into methanol[21].

Enerkem's facility was certified in accordance with the International Sustainability and Carbon Certification (ISCC) system in 2016.

> *The company's first flagship, commercial scale waste-to-biofuels facility is in Alberta, Canada, where it helps the City of Edmonton increase its waste diversion goal from 50% to 90%.*

Figure 4. Transitioning to a circular economy with Enerkem's MSW to methanol model

Source: Enerkem

20 Enerkem Inc https://enerkem.com/facilities/enerkem-alberta-biofuels/

21 LANE, Jim: http://www.biofuelsdigest.com/bdigest/2018/01/24/the-rise-rise-rise-of-bio-methanol-for-fuels-and-chemical-markets/ accessed 16th July 2018

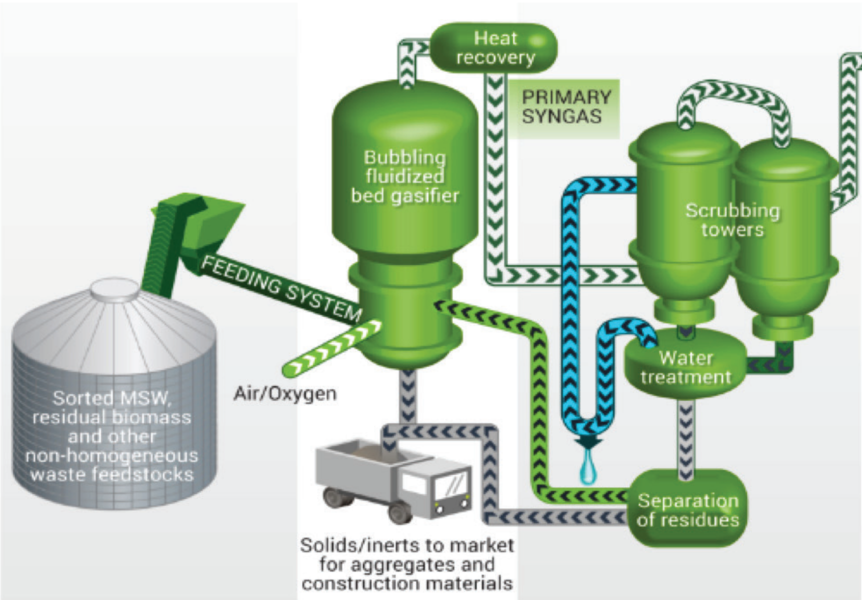
Figure 5. Enerkem's four step thermochemical process

Feedstock preparation
Sorting, shredding, drying (if required) and feeding

Gasification
Conversion of carbon-rich residues into synthesis gas

Cleaning and conditioning process
Primary syngas purification

Catalytic synthesis and product purification
Conversion of chemical-grade syngas into final renewable products



Source: Enerkem

Enerkem has developed and patented its technology to chemically extract and reuse the carbon in non-recyclable waste. First, the feedstock of waste is sorted and treated. A thermochemical gasification process converts the carbon-rich residues into a synthesis gas (syngas) which is purified, then treated with catalysts to produce biofuels and commercial chemicals.

100+
Advanced biofuels facilities built in China by 2035

This process minimizes environmental impact because it uses relatively low pressures and temperatures. This cuts the demand for energy and keeps costs down, making it scalable and commercially viable.

Methanol produced by Enerkem's Alberta plant has many applications. It's directly used in adhesives and solvents, polyester fabrics and drinks bottles. It's further processed to create ethanol, acrylic acid, n-Propanol, n-Butanol, olefins and acetic anhydride, chemicals that are used to make thousands of industrial and consumer products.

Enerkem's unique technology is leading to partnerships around the world, as municipalities, waste management and petrochemical groups develop commercial models to reduce landfill waste while creating clean fuels and renewable chemicals that will help meet carbon reduction targets.

The company is working in Quebec and Rotterdam to develop biorefineries and has signed an agreement in China to license equipment and technologies to be used in a joint venture that could see over 100 advanced biofuels facilities built in China by 2035.

CASE STUDY: BIOMCN

Renewable methanol from biogas

Netherlands-based BioMCN has chosen to produce renewable methanol by replacing conventional natural gas with biogas as a feedstock in its production process. The company uses biogas from numerous different sources, including municipal solid waste landfills and anaerobic digestion plants, which has been upgraded to pipeline quality and injected into the Dutch national gas grid.

BioMCN operates two methanol production lines with a combined capacity of 900,000 tons at its plant located in Delfzijl in the northeastern part of the Netherlands. The plant was originally constructed in 1974 but was later mothballed in 2005 due to the high cost of natural gas. In 2006, BioMCN was founded and acquired the plant with the aim of producing renewable methanol from glycerin. In 2015, BioMCN was acquired by OCI N.V. and continued producing renewable methanol from biogas.

During 2017, BioMCN produced nearly 60,000 tons of renewable methanol which was primarily sold as a biofuel in the European transportation sector.

In response to global climate change concerns, the Netherlands has chosen to impose tighter environmental regulations on carbon emissions and has actively encouraged the use of anaerobic digestion plants to process organic wastes into biogas. Digester plants reduce greenhouse gas emissions through methane recovery and are operated by waste companies, industrial firms and farmers processing numerous different types of municipal, industrial and agricultural wastes. BioMCN has become a vital market participant in this new green economy by utilizing this biogas to produce renewable methanol.

Today, BioMCN consumes more than half of all the biogas produced in the Netherlands and has begun to source biogas from neighboring EU countries. As the number of digesters and availability of biogas grows in the future, BioMCN expects its production of renewable methanol will grow and its reliance on conventional natural gas will decrease.

"We strongly believe that BioMCN and bio-methanol derived from waste sources can play an important role in the circular green economy of the future and help the decarbonization of transportation," said Paul Compagne, Operations Director at BioMCN.[22]

During 2017, BioMCN produced nearly 60,000 tons of renewable methanol which was primarily sold as a biofuel in the European transportation sector.

22 Biomethanol Chemie Nederland B.V. (BioMCN) https://www.biomcn.eu/biomcns-10-year-anniversary-2006-2016/

APPLICATIONS AND USES OF RENEWABLE METHANOL

Renewable methanol in action

Growing environmental and political pressure to reduce greenhouse gas emissions is putting renewable methanol on the mainstream agenda as a viable alternative to fossil fuels commonly used in passenger and goods transport and haulage at sea.

Methanol has been tested in a number of countries as a transportation fuel and is widely used in China.

25.8%

European transport sector contribution of total greenhouse gas emissions in 2015.

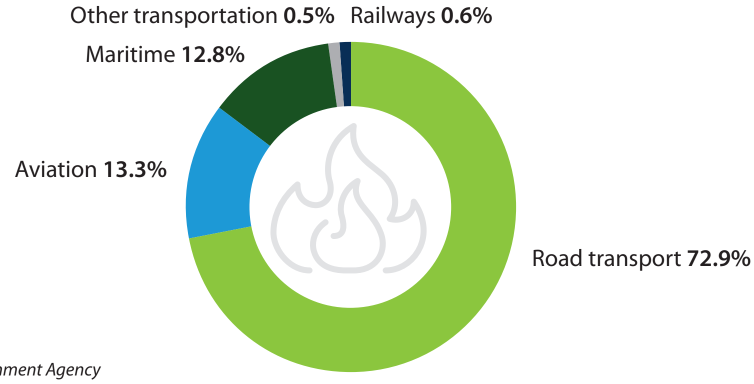
Benefits to human health

The World Health Organization (WHO) states that reducing emissions of greenhouse gases through better transport, food and energy-use choices can result in improved health. The WHO estimates that climate change, driven mainly by man-made greenhouse gas emissions, will cause 250,000 additional deaths per year worldwide between 2030 and 2050, because malnutrition, diarrhea, malaria and heat stress will all increase. In the US alone, the WHO estimates that the direct cost of damage to health will be $2-4 billion annually by 2030[23], excluding increased costs in agriculture, water and sanitation supply networks. Making and using renewable methanol doesn't only reduce carbon dioxide emissions, it also reduces other harmful air pollutants including nitrogen and sulfur oxides (NO_x and SO_x), volatile organic compounds (VOCs), particulate matter and other toxic pollutants.

Transport fuel

In Europe, the transport sector contributed 25.8% of total greenhouse gas emissions in 2015. 72.9% of these were caused by road transport. 44.5% came from passenger cars and 18.8% from heavy vehicles. Transport emissions were more than 23% above 1990 levels in 2015 and will need to fall by 68% by 2050 to meet emissions targets.[24]

Figure 6. Share of transport greenhouse gas emissions 2015*



**European Environment Agency*

23 World Health Organization: http://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

24 European Environment Agency https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-10

Figure 7. Well-to-wheel CO_2 emission - from Danish Department of Energy, Alternative Drivetrains 2014*

Type	Current status	Green scenario
Diesel	132g/km	100g/km
Gasoline	176g/km	123g/km
Hybrid	142g/km	80g/km
Battery electric	98g/km	2g/km
Hydrogen	178g/km	3g/km
Methanol	**83g/km**	**2g/km**

**JENSEN, Mads Friis*

> *Widespread adoption of vehicles powered by renewable methanol would dramatically lower CO_2 emissions in transportation.*

Since road transport makes up almost two thirds of overall transport emissions, widespread adoption of vehicles powered by renewable methanol would dramatically lower CO_2 emissions in transportation, as shown in Figure 7.

Geely Auto Group is a leading Chinese car manufacturer which also owns automotive brands Volvo, Lotus and Proton, and is the largest shareholder in Daimler. It has been operating methanol in automotive engines since 2005. Through China's successful Methanol Vehicle Pilot Program, in Shanxi Province alone methanol vehicles travelled more than 21.4 million kilometers (12.84 million miles) over three years. The firm has also deployed fleets of methanol-fueled taxis all over the country. In 2017 Chinese Vice Premier Liu Yandong noted in a visit to Geely's Methanol Car manufacturing plant that "methanol automobiles have low operating costs and good emissions."

Acting as a liquid hydrogen carrier for fuel cells is another way that renewable methanol can help lower transport industry emissions. Danish company SerEnergy produces methanol fuel cell range extenders to increase electric cars' range, allowing them to reach 800 km in total. These also power the MS Innogy (Lake Baldeneysee, Germany) a converted diesel tour boat operating on renewable methanol produced using CO_2 from the surrounding air, and green electricity and water.

Chinese firm Palcan produces methanol fuel cell electric trucks and delivery vans, and German-Chinese partnership AIWAYS Gumpert has announced the Gumpert RG Nathalie, a methanol fuel cell powered electric supercar with a 1,200 km (745 mile) range and a top speed of 300 km/h (186 mph).

In the USA, an early methanol research program tested dedicated methanol vehicles throughout the 1980s, and flexible fuel vehicles in the 1990s. The success of the program and investment in local methanol fuel infrastructure meant that major manufacturers including Ford, GM and Chrysler produced methanol-fueled versions of popular cars priced the same as their gasoline equivalents. By 1997 there were 15,000 methanol vehicles on the road and 100 refueling stations in California alone. Market conditions led to the decline of the program and its eventual cancellation: gasoline prices fell, making it more affordable than methanol fuel. However, the 200 million plus miles driven in methanol vehicles proved the viability of methanol cars for use by ordinary consumers as well as government departments and rental fleets. Now, gasoline and diesel prices have risen, so methanol is once again an affordable alternative road vehicle fuel.

Shipping fuel

There's a huge global demand for marine fuels, with recent estimates of consumption at around 298 million metric tons per year.[25] Fleet numbers and volumes of goods shipped are increasing year on year. The international world trade fleet of ships increased 1.5% from 2013-15: transport supply of chemical tankers and general cargo ships grew by 15%, cruise ships by 11% and container ships by 9%.[26]

1.5%

Increase of international world trade fleet of ships from 2013-15.

Figure 8. Properties of methanol vs other shipping fuels*

Properties	Methanol	Methane	LNG	Diesel fuel
Molecular formula	CH_3OH	CH_4	C_nH_m; 90-99% CH_4	$C_nH_{1.8n}$; C_8-C_{20}
Carbon contents (wt%)	37.49	74.84	≈75	86.88
Density at 16˚C (kg/m^3)	794.6	422.5[a]	431 to 464[a]	833 to 881
Boiling point at 101.3kPa(˚C)[b]	64.5	-161.5	-160 (-161)	163 to 399
Net heating value (MJ/kg)	20	50	49	42.5
Net heating value (GJ/m^3)	16		22	35
Auto-ignition temperature (˚C)	464	537	580	257
Flashpoint (˚C)[c]	11		-136	52 to 96
Cetane rating	5		0	>40
Flammability limits (vol % in air)	6.72 to 36.5	1.4 to 7.6	4.2 to 16.0	1.0 to 5.0
Water solubility	Complete	No		No
Sulfur content (%)	0	0	<0.06	Varies, <0.5 or <0.1

a for methane / LNG at boiling point
b to convert kpa to psi, multiply by 0.145
c the lowest temperature at which it can vaporize to form ignitable mixture in air
**ANDERSSON, Karin (2015)*

Because of the volume of shipping fuel in demand, renewable methanol fuel substitution for heavy fuel oils could have great potential to reduce greenhouse gas emissions. Supply infrastructure is often in place for methanol, as it is already available and shipped through many ports around the world. Although methanol is less energy dense than traditional fuels, requiring more storage space on board, it's a liquid fuel, so it can be stored in ballast and "slop" tanks. This is in contrast to liquefied natural gas (LNG) which demands a large cryogenic tank, absorbing substantial on-board space.

The Stena Germanica is one of the world's largest ferries: a 24 MW roll-on, roll-off passenger (ROPAX) vessel that can take 300 cars and 1,300 passengers. It was converted to run on methanol in 2015, as

25 OLMER, COMER, ROY, MAO and RUTHERFORD: https://www.theicct.org/sites/default/files/publications/Global-shipping-GHG-emissions-2013-2015_ICCT-Report_17102017_vF.pdf
26 Idem

a way of meeting new, lowered sulfur emission regulations. Stena oversaw the conversion of four medium-speed, four-stroke marine engines to methanol operation, as well as the fuel storage and distribution systems. The company, one of the world's largest ferry operators, with a fleet of 35 ferries and over 1,000 vessels, recognizes the potential for "enormous" environmental gains in the future through the use of methanol as a shipping fuel.[27]

40%

Of the Waterfront Shipping fleet will be methanol-powered by 2019.

Canada's Waterfront Shipping (a subsidiary of Methanex, the world's largest methanol producer and distributor) was awarded the Lloyd's List 2018 Best Fuel Solution Award for their seven methanol dual fuel tanker vessels using slow speed two-stroke marine engines. The award recognizes improvements in fuel efficiency and environmental performance, including efforts to bring forward low emission sustainable fuel technology to the market. Following the safe and successful operation of these vessels since 2016, four more have been commissioned. This means that 40% of the Waterfront Shipping fleet will be methanol-powered by 2019.

Marine engine manufacturers including MAN and Wärtsilä have played a key role in the design and build of these vessels and continue to research and evolve engine technology to support potential renewable methanol fuel adoption.

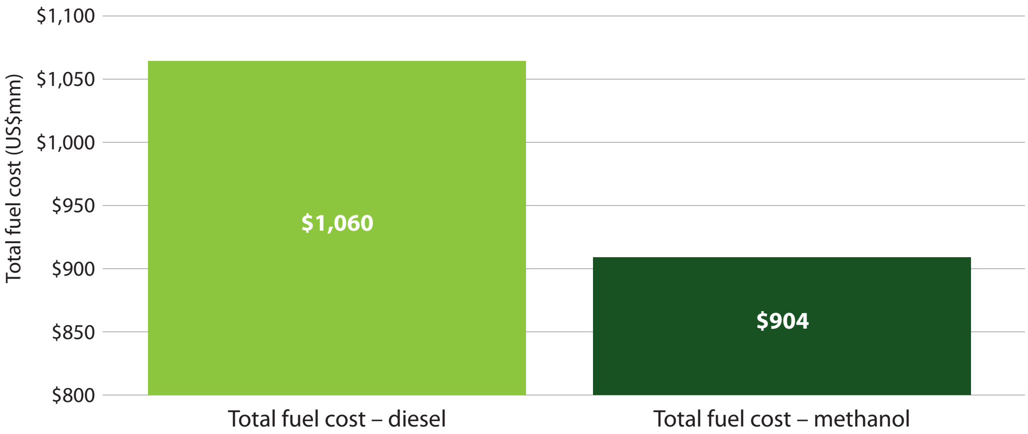
27 Stena Line Group: https://www.stenaline.com/en-GB-corp/corporate/environment/supergreen-en/fuel-of-the-future

Figure 9. Stena Germanica plies the Kiel-Gothenburg route

Source: Cruisemapper

Figure 10. Cost savings from switching a 100 MW power plant from diesel to methanol

10 year total fuel costs – methanol vs. diesel (2006-2015, per 100MW of power generation)



Over the past decade, a hypothetical 100MW power plant in the Caribbean, operating on methanol vs diesel, would have saved ~US$156 million in fuel costs.

Sources: Methanex, public data from Anguilla, St Lucia and Grenada eletricity generation utilities

Power generation

Much of the electricity generated around the world is still powered by highly polluting fossil fuels such as coal, diesel and fuel-oil. Renewable methanol is a readily available fuel that would drastically reduce harmful emissions.

In Israel, a 50 MW plant that was converted from light fuel oil to methanol has completely eliminated sulfur oxide emissions, and reduced nitrogen oxide and particulate matter emissions by 85% and by 90% respectively. The conversion, which took place in 2014 and cost US$ 5 million, enabled the Israel Electric Company to comply with newly introduced stringent air pollution regulations. These regulations allowed the plant to operate only 300 hours a year whilst running on light fuel oil; once converted to methanol, it could operate without restrictions, improving the economic performance of the plant[28].

Island nations, which often rely heavily on diesel generators, could save money by switching to conventional methanol. According to Methanex, an 100 MW power plant operating in the Caribbean could have saved US$ 156 million in fuel costs between 2006 and 2015[29].

As wind and solar prices drop, they are often cheaper than diesel, offering islands an opportunity to enjoy lower energy costs, reduce dependence on imported energy, and mitigate their impact on the environment.

> *As wind and solar prices drop, they are often cheaper than diesel, offering islands an opportunity to enjoy lower energy costs, reduce dependence on imported energy, and mitigate their impact on the environment.*

However, wind and solar are variable and might not be available when most needed, so islands need

28 DAY, William: http://www.methanol.org/wp-content/uploads/2016/12/Methanol-Nov-Dec-2016-GTW-.pdf
29 Methanex Corporation: https://www.methanex.com/sites/default/files/about-methanol/methanol-and-energy/Methanex_PowerBrochure.pdf

to retain some back-up capacity in the form of batteries and diesel generators. These generators can easily be converted to run on both methanol and diesel, providing flexibility and making the system more robust.

These arrangements have previously relied on conventional rather than renewable methanol. The principles remain the same. Adopting methanol as part of the energy mix would reduce harmful emissions, much more so if methanol is renewable.

Renewable methanol could also play a key role in providing grid stability, by drawing excess renewable electricity from the system to power electrolysis, one of the key processes in the manufacture of renewable methanol. The resulting renewable methanol could then be used as a clean power plant fuel that can be dispatched to provide energy whenever it is required.

Enerkem's biofuels plant in Alberta, Canada.

CONCLUSION AND HOW TO FIND OUT MORE

Industrial scale production of ultra-low carbon renewable methanol is already happening in Europe and North America. In Asia, the potential for methanol fuel is widely understood by governments and industry, with methanol-powered automotive fleets established in China and a clear determination to explore renewable methanol sources and implement them at scale.

Methanol has many applications, both as fuel and as a chemical feedstock to other vital industrial production and manufacturing processes. With a wealth of available renewable feedstocks, from biomass municipal waste to exhaust carbon and power from renewable sources, methanol has shown itself to be a versatile, affordable and stable energy source that's well suited to use in transportation and industry. It has clear potential to help reduce greenhouse gas emissions if it's adopted in place of fossil fuels.

There's no magic bullet when it comes to renewable energy. A range of solutions will be needed to meet different consumer, industrial and geographic demands for fuel, heat and power. For example, electrification is an excellent solution to many light-duty, land-based energy demands, but for heavy vehicles and in industries like shipping and aviation, the technology and infrastructure does not currently exist to make this possible. They will continue to require liquid fuels: renewable methanol is one of the most sustainable and cleanest options.

The diverse and successful trials in both production and application, along with substantial worldwide commercial investment in renewable methanol technologies, give a clear indicator that renewable methanol will play a significant role in transportation and chemical production in the coming decades.

Visit methanol.org to discover more about methanol's production and application or to get in contact with a sector expert.

www.methanol.org/energy/
www.methanol.org/renewable-methanol/

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