METHANOL INSTITUTE

Methanol: Renewable Hydrogen Carrier Fuel

Gregory Dolan, CEO – Methanol Institute

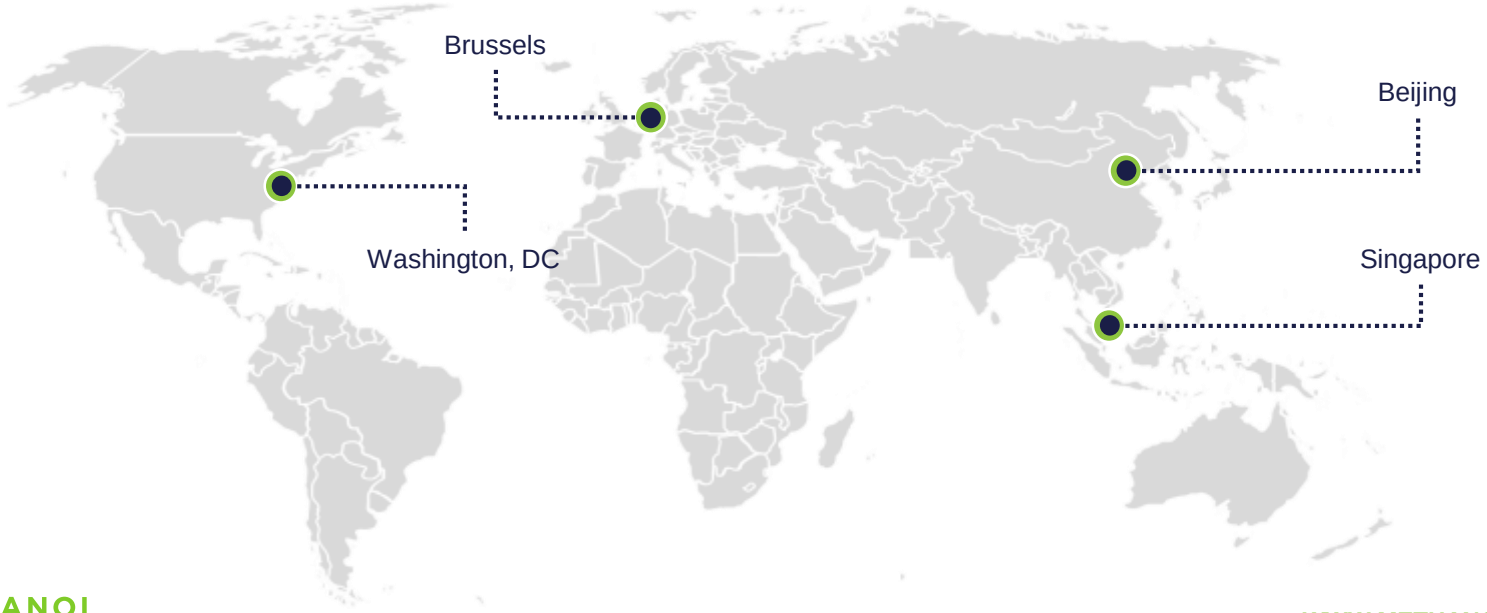
CaFCP Working Group Meeting

31 July 2019

01 WHO WE ARE

MI HISTORY

- The Methanol Institute (MI) was established in 1989
- 30 years later, MI recognized as the trade association for the global methanol industry
- Facilitating methanol's expansion from our Singapore headquarters and regional offices in Washington DC, Brussels, and Beijing



MI MEMBERSHIP

https://www.methanol.org/join-us/

Tier 1

MHTL – Methanol Holdings (Trinidad) Limited
methanex – the power of agility
سابك sabic
OCI

Tier 2

Qatar Fuel Additives Company Limited
MITSUBISHI GAS CHEMICAL AMERICA, INC.
ATLANTIC METHANOL
MITSUI & CO., LTD.
PETRONAS
Oman Methanol Company L.L.C.

Tier 3

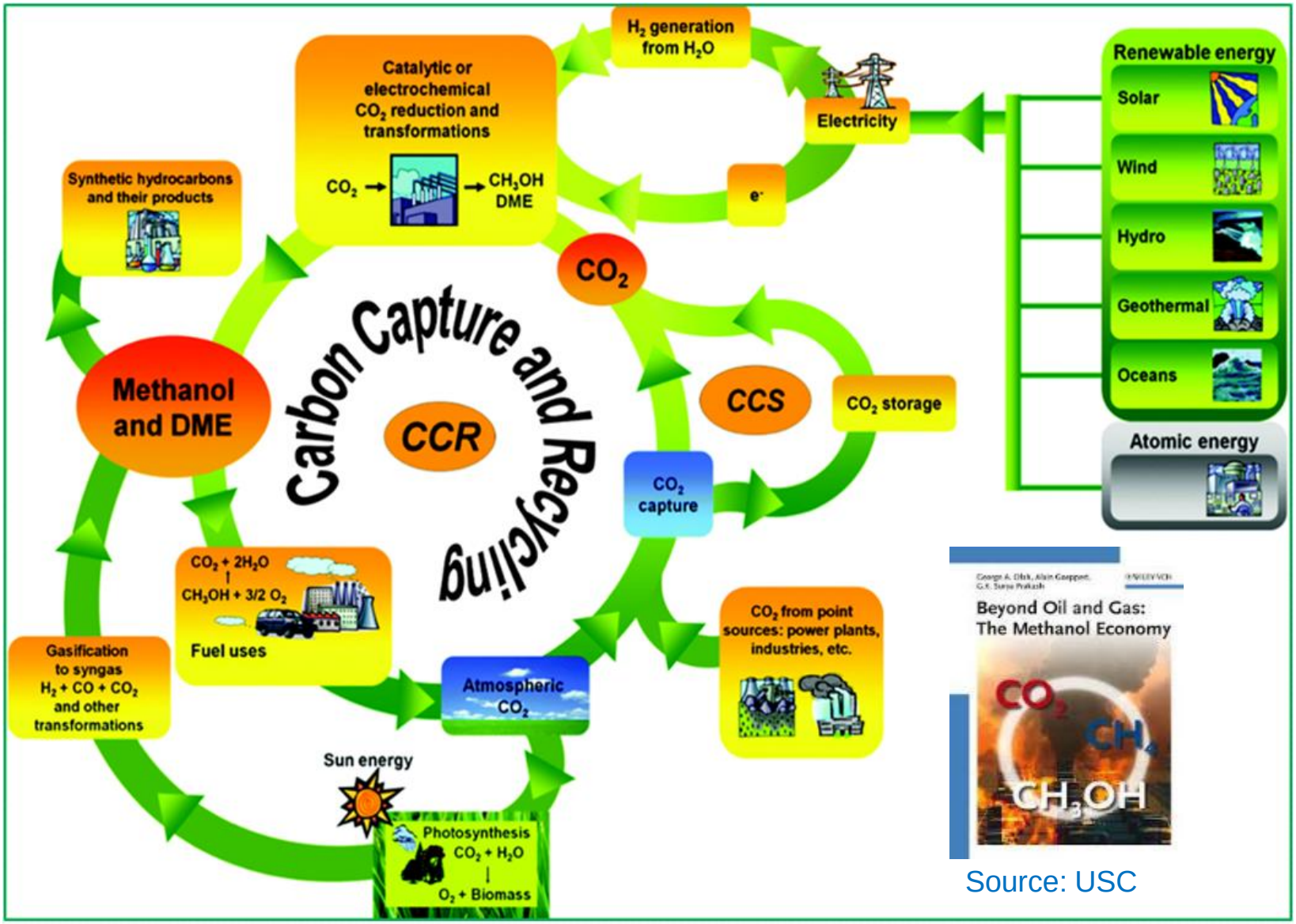
Eni Ecofuel
Sipchem – EXCELLENCE everywhere
GX G2XENERGY
JM Johnson Matthey – Inspiring science, enhancing life
Mitsubishi International Corporation

Tier 4

FiTech
Advent
HELM PROMAN METHANOL
azelis
MOL Mitsui O.S.K. Lines
Blue World Technologies
CARBON RECYCLING INTERNATIONAL
HALDOR TOPSOE
SCC Southern Chemical Corporation
bse engineering
YCI METHANOL ONE
FUEL FREEDOM – CHEAPER. CLEANER. AMERICAN-MADE.
GasTechno ENERGY AND FUELS
Palcan
IGPMethanol
Double Green Bridge NW INNOVATION WORKS
TRICON ENERGY
quantiam technologies inc.
IMTT – International-Matex Tank Terminals
NAKHODKA FERTILIZER PLANT
CLARIANT
CoogeeChemicals
OLAHMOTORS
VITUSA PRODUCTS™ INCORPORATED
solvadis we do chemistry
Nebraska Public Power District – Always there when you need us

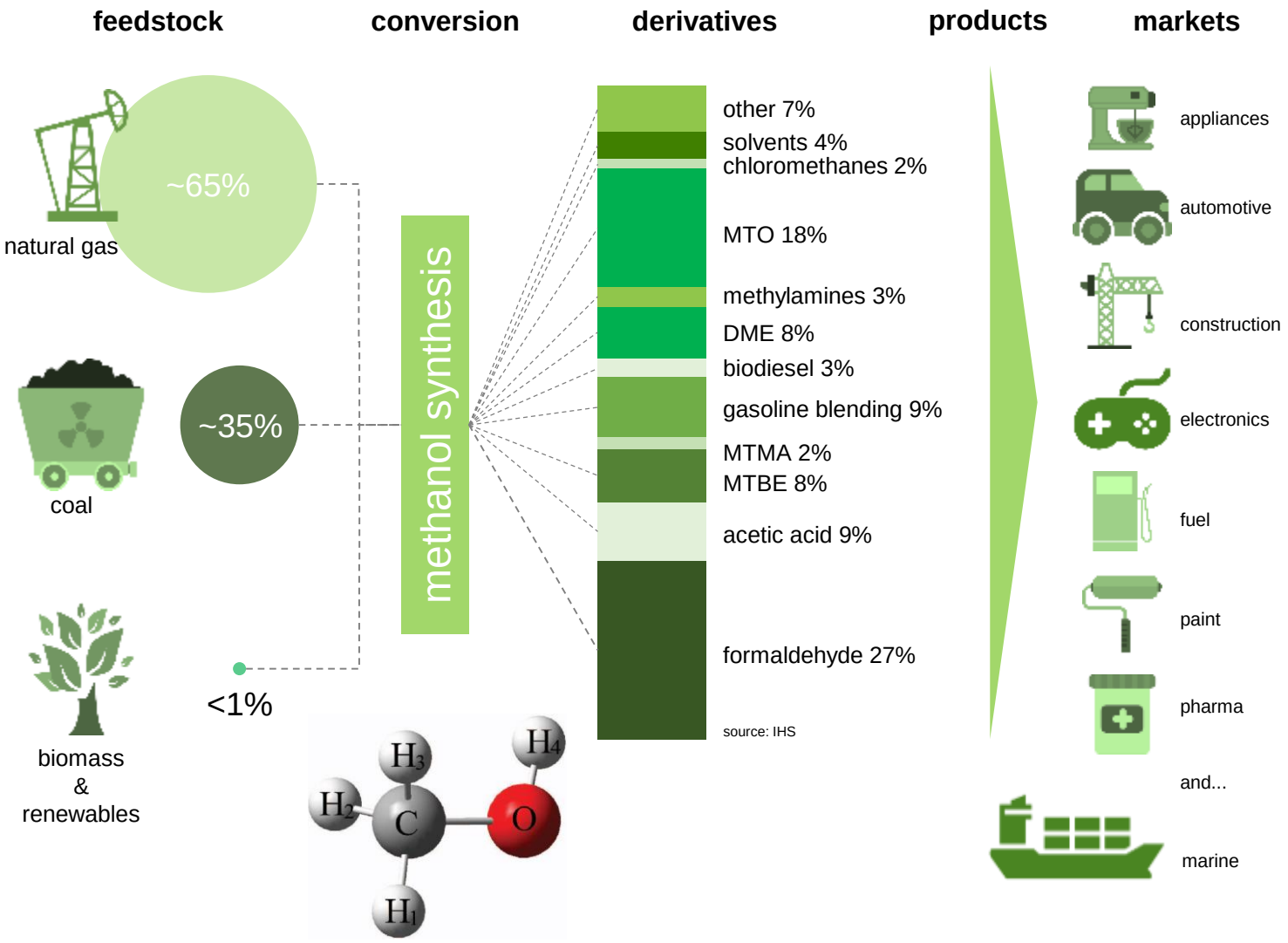
02 METHANOL ECONOMY

BEYOND OIL AND GAS: THE METHANOL ECONOMY

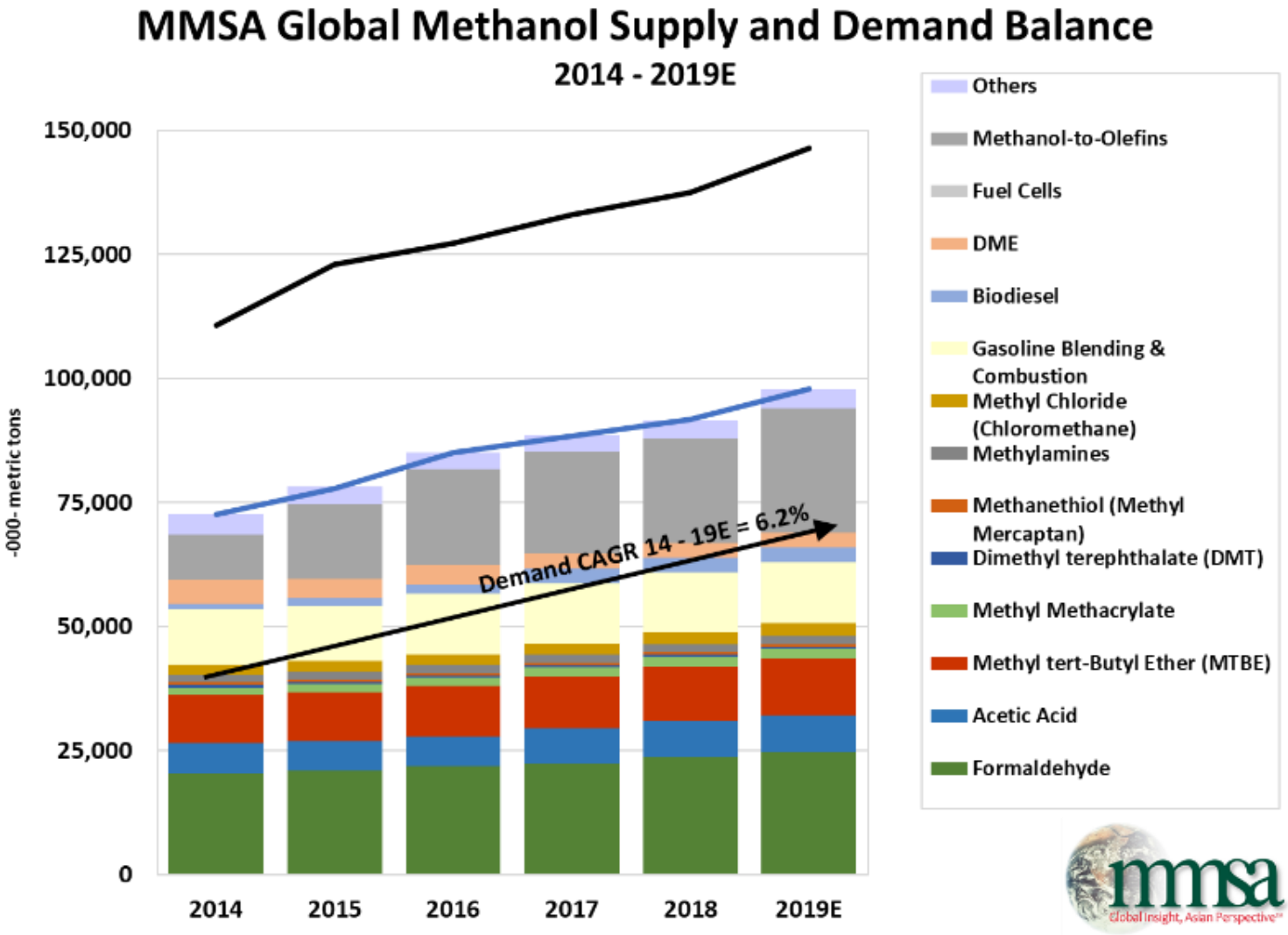


Source: USC

BROAD FEEDSTOCK RANGE, MANY APPLICATIONS

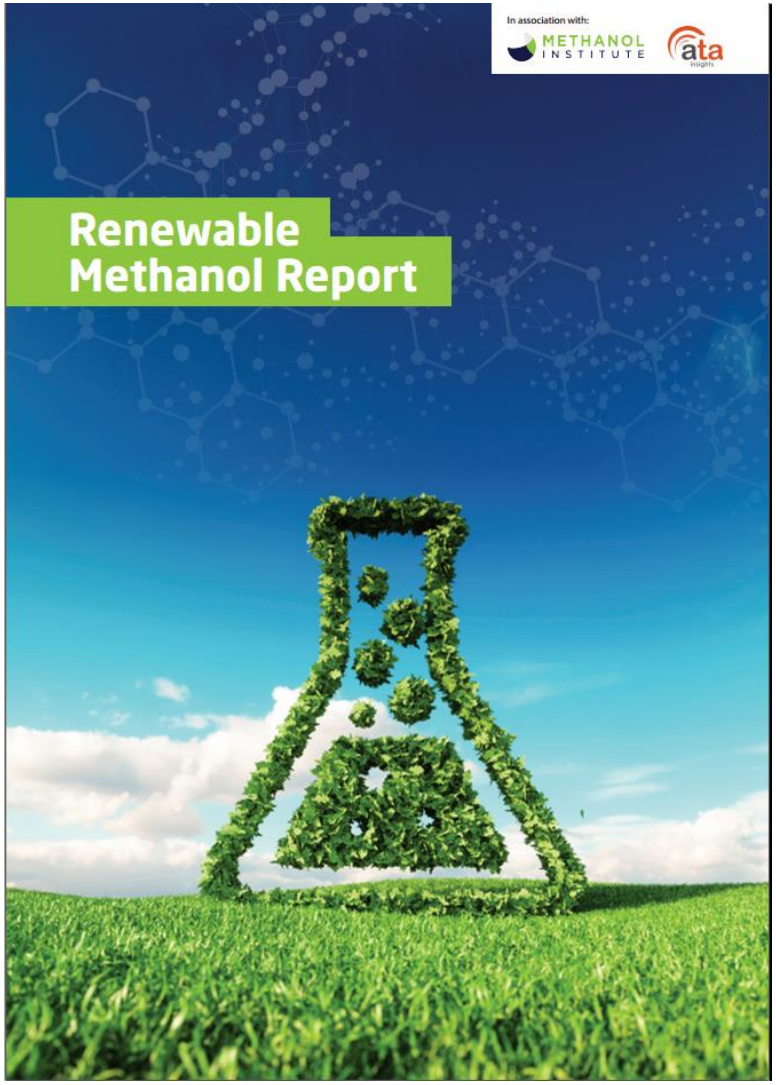


ENERGY & MTO DRIVING METHANOL GROWTH



GLOBAL METHANOL DEMAND NEARING 100 MILLION METRIC TONS = 33.3 BILLION GALLONS

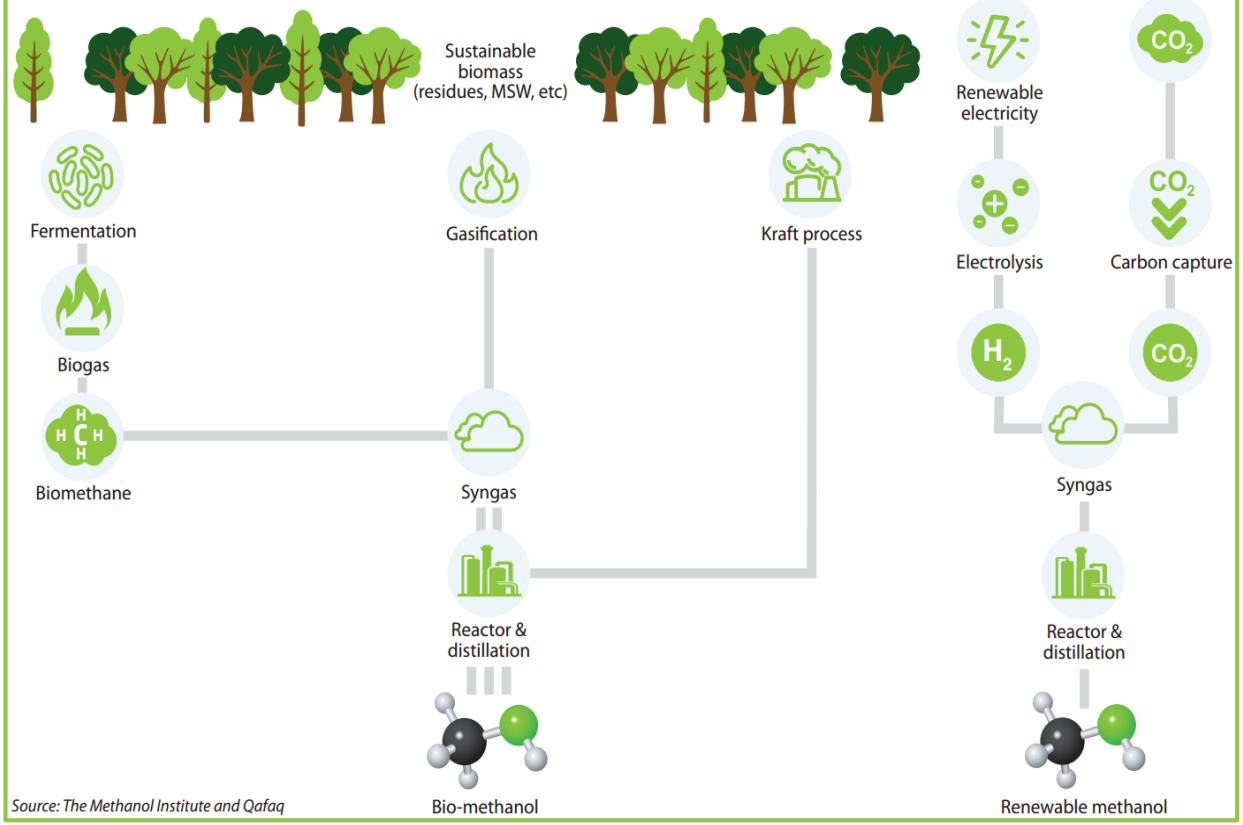
RENEWABLE METHANOL REPORT



- 2 February: MI releases ***Renewable Methanol Report*** prepared by ATA Insights
- Contents:
  - Executive summary
  - Why consider renewable methanol?
  - Renewable methanol production
  - Case Studies: CRI, Enerkem, BioMCN
  - Applications and uses of renewable methanol
  - Conclusions and how to find out more
- Free download here: http://bit.ly/2UeJpJp

RENEWABLE METHANOL REPORT

Figure 1. Renewable methanol production processes from different feedstocks



Source: The Methanol Institute and Qafaq

> *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 Emission Reductions: CO2 by up to 95%; NOx by 80%; virtually eliminating SOx and Particulate Matter (PM)

RENEWABLE METHANOL REPORT

Methanol category	Commercial	Feasibility and R&D
Bio-methanol	■ BASF (GER) ■ BioMCN (NL) ■ Enerkem (CAN) ■ New Fuel (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)

GROWING GLOBAL PRESENCE

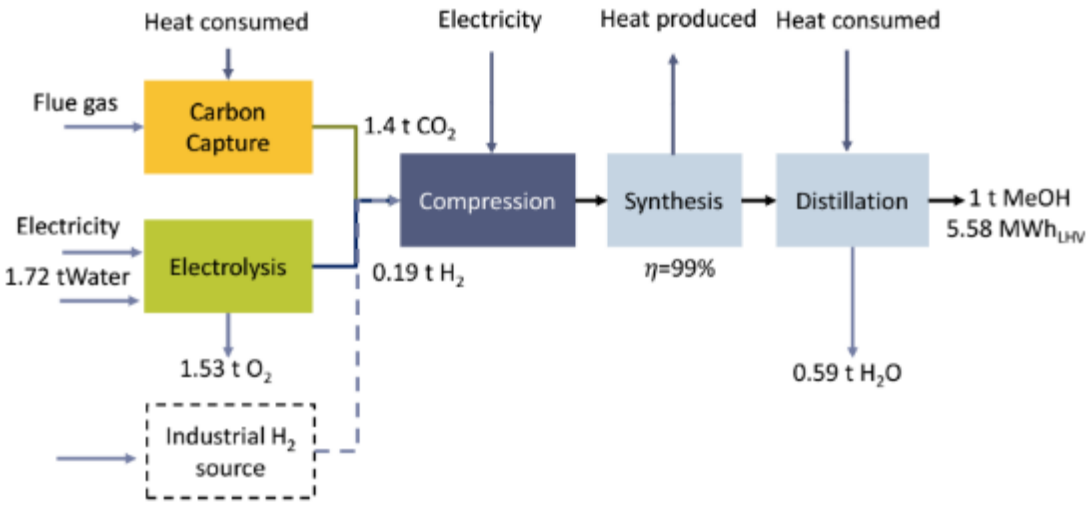
Power2Met Synthesis

Enerkem	BioMCN		BASF	New Fuel A/S	SÖDRA
Municipal waste	Biogas	Hydrogen synthesis	Biogas	Biogas	Wood waste

Source: Blue World Technologies

CARBON RECYCLING INTERNATIONAL

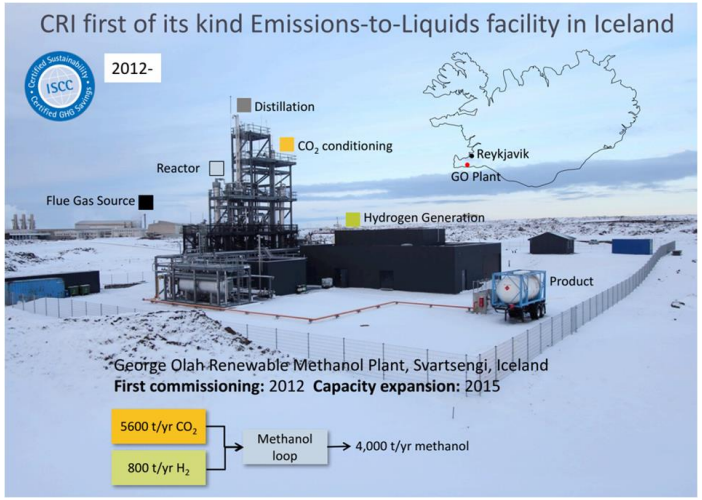
CRI direct CO2-to-methanol conversion technology



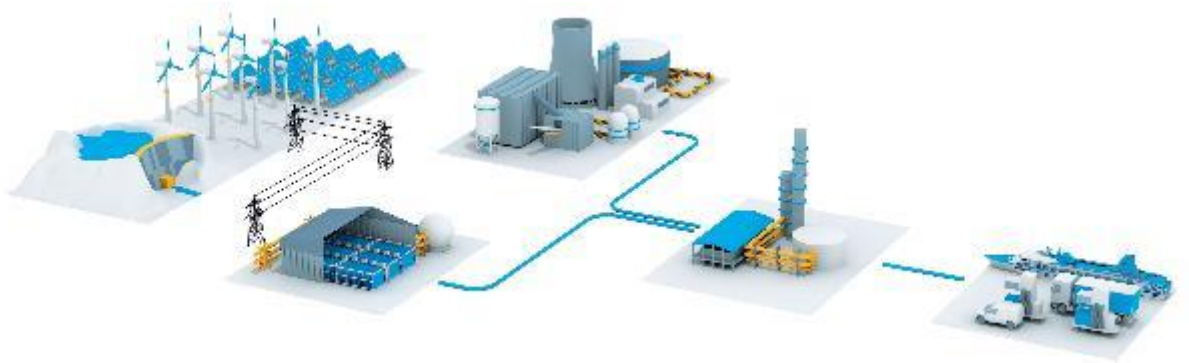
Reduction of life-cycle carbon footprint per MWh_{LHV}: 90-99%* with renewable electricity

*Compared to EU gasoline or diesel

Carbon Recycling International



THYSSENKRUPP GREEN METHANOL



- June 2019: thyssenkrup and Swiss Liquid Fuels announce technology for synthesizing green methanol from hydrogen and CO2 in small scale plants (10-200 tons per day)
- The hydrogen is produced by means of proprietary water electrolysis technology with CO2 recovered from biogas plants, flue gas or waste gas
- The power required for methanol production comes from renewable energy

RENEWABLE METHANOL AS AN ENERGY CARRIER IN SWEDEN

Welcome to:

Final Presentation

Liquid Wind

February 23, 2017

A 50 Mw plant could deliver…

- **Methanol Sales (40,000 tons)**
  - Sold at market price + **CO_2 benefit premium**
  - Market price (Feb 2017) 355 €/ton
  - **CO_2 benefit** 375 €/ton
  - Potential revenue: 29.200.000 €/year

How far can you go with 40,000t ReMe,

with an energy content of 220 GWh

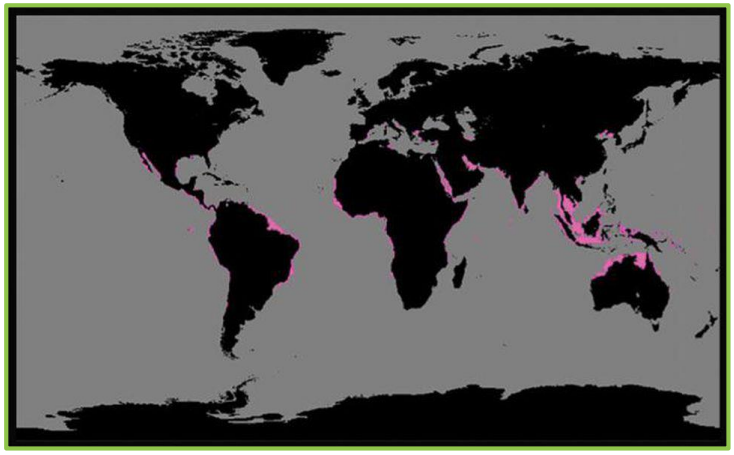
- A few comparisons
  - Stena Germanica to Kiel uses 100 t per return trip
    - So a total of 400 trips
  - One Geely methanol car would go 420,000,000 km
    - A total of 21,000 cars would go 2,000 Swe Mil/year
  - Boiler fuel for District energy
    - X % of Gbg energy peak load annually

Source:
file:///C:/Users/paulw/Downloads/liquid-wind-resultsclaes-fredriksson-20170223.pdf

Carbon Recycling International

SOLAR METHANOL ISLANDS

- Researchers from Norway and Switzerland have proposed using “solar methanol islands” as tool for reducing greenhouse gas emissions
- Use photovoltaic cells to convert solar energy into electricity, then powering hydrogen production and CO2 extraction from seawater to produce liquid methanol
- Requires wave height less than seven meters and water depth less than 600 meters
- 70 artificial islands cover one kilometer square
- 3.2 million floating islands would produce enough methanol to exceed total global emissions of fossil fuels



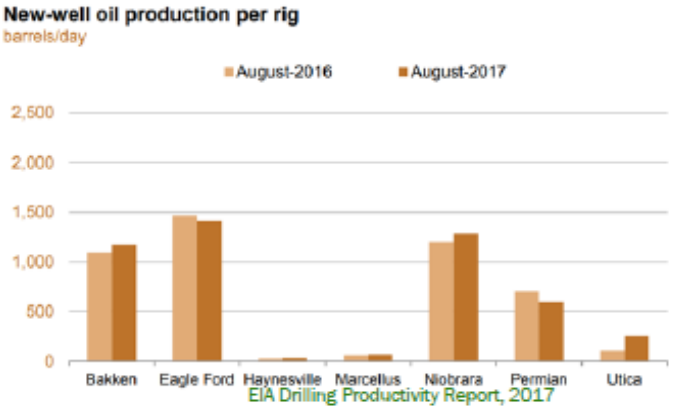
https://www.newsweek.com/giant-floating-islands-that-turn-atmospheric-co2-fuel-could-prevent-climate-change-scientists-say-1441793

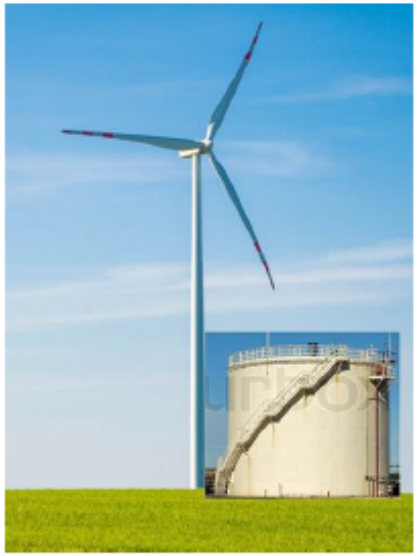
Sizing estimate for wind-to-fuel system

100 MW Wind Turbine to Methanol

Wind turbine power output	100 MW
Assumed electrolyzer efficiency	72% (54.6 kWh/kg)
H2 yield (100% availability)	**44,000 kg/day**
Water consumption	2800 bbl/day
Matching CO2 consumption (3H2 + CO2 → CH3OH + H2O)	320 tonne/day
MeOH yield	234 tonne/day
	1860 bbl/day

Oil well size comparison





- Small scale fuel synthesis plants matching distributed nature of renewable energy sources
- Fuel synthesis units directly integrated with the renewable H2 generation
- Economy of scale achieved by high volume manufacturing of standardized, automated units

Fuel farms replacing fuel wells

Cost estimates for renewable methanol

Estimated cost of H2 from PEM electrolysis (@6.88 c/kWh)	4.23 $/kg_H2	[1]
Fraction of electricity in H2 cost above	3.46 $/kg_H2	
Projected electricity cost from a wind farm	2.35 c/kWh	[2]
Estimate of H2 from PEM electrolysis with windfarm electricity	1.95 $/kg_H2	
Cost of H2 in MeOH (3H2 + CO2 → CH3OH + H2O)	**1.1 $/gal_MeOH**	[3]
Cost of captured CO2	40 $/MT = 0.04 $/kg_CO2	[4]
Cost of CO2 in MeOH (3H2 + CO2 → CH3OH + H2O)	**0.17 $/gal_MeOH**	[3]
Cost of Methanol synthesis (based on production from NG)		
Capital + Fixed O&M + Variable O&M	**0.50 $/gal_MeOH**	[5]
Total estimated cost of renewable MeOH	**1.8 $/gal_MeOH ($4 /gge)**	[6]

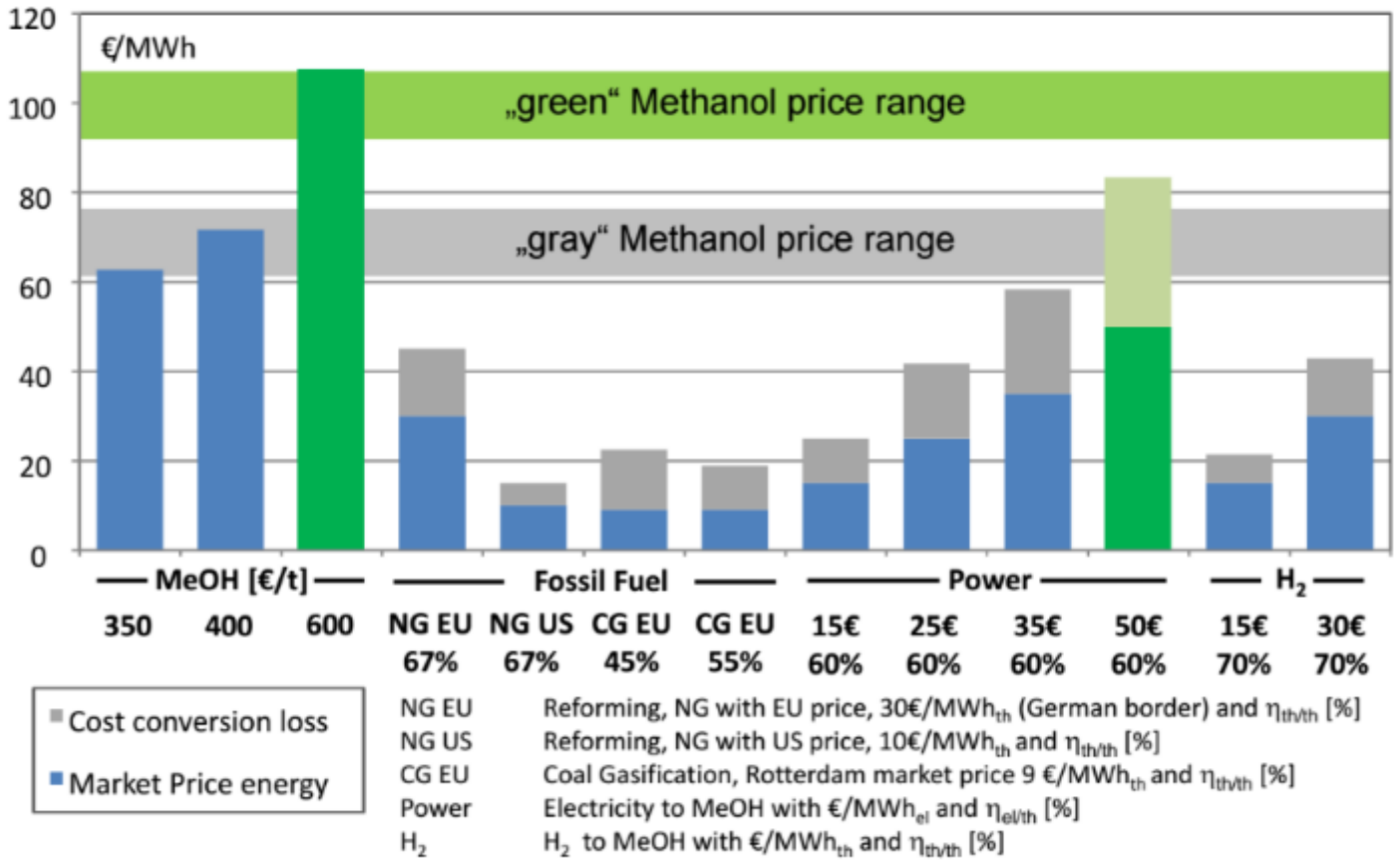
Max Lyubovsky, Journal of Energy Security, Oct 2017. www.ensec.org

- Cost of renewable methanol is in the range of the market prices
- Renewable H_2 production constitutes ~60% of the product cost
- Cost of CO_2 capture is a small fraction of the overall cost

1. DOE Hydrogen and Fuel Cells Program Record, forecourt future case https://www.hydrogen.energy.gov/pdfs/14004_h2_production_cost_pem_electrolysis.pdf
2. 2014 Wind Technologies Market Report, p 56 http://www.energy.gov/sites/prod/files/2015/08/f25/2014-Wind-Technologies-Market-Report-8.7.pdf
3. Assuming stoichiometric conversion
4. DOE Office of Fossil Energy projections to 2020-2025, http://www.energy.gov/fe/science-innovation/carbon-capture-and-storage-research/carbon-capture-rd
5. Baseline Analysis of Crude Methanol Production from Coal and Natural Gas, October 15, 2014, p.1 http://www.netl.doe.gov/energy-analyses/temp/BaselineAnalysisofCrudeMethanolProductionfromCoalandNaturalGas_101514.pdf
6. 116,000 BTU/gal LHV for gasoline vs. 57,250 BTU/gal LHV for methanol.

R&D to enable low-cost renewable H_2 is key to cost competitive synthetic fuel

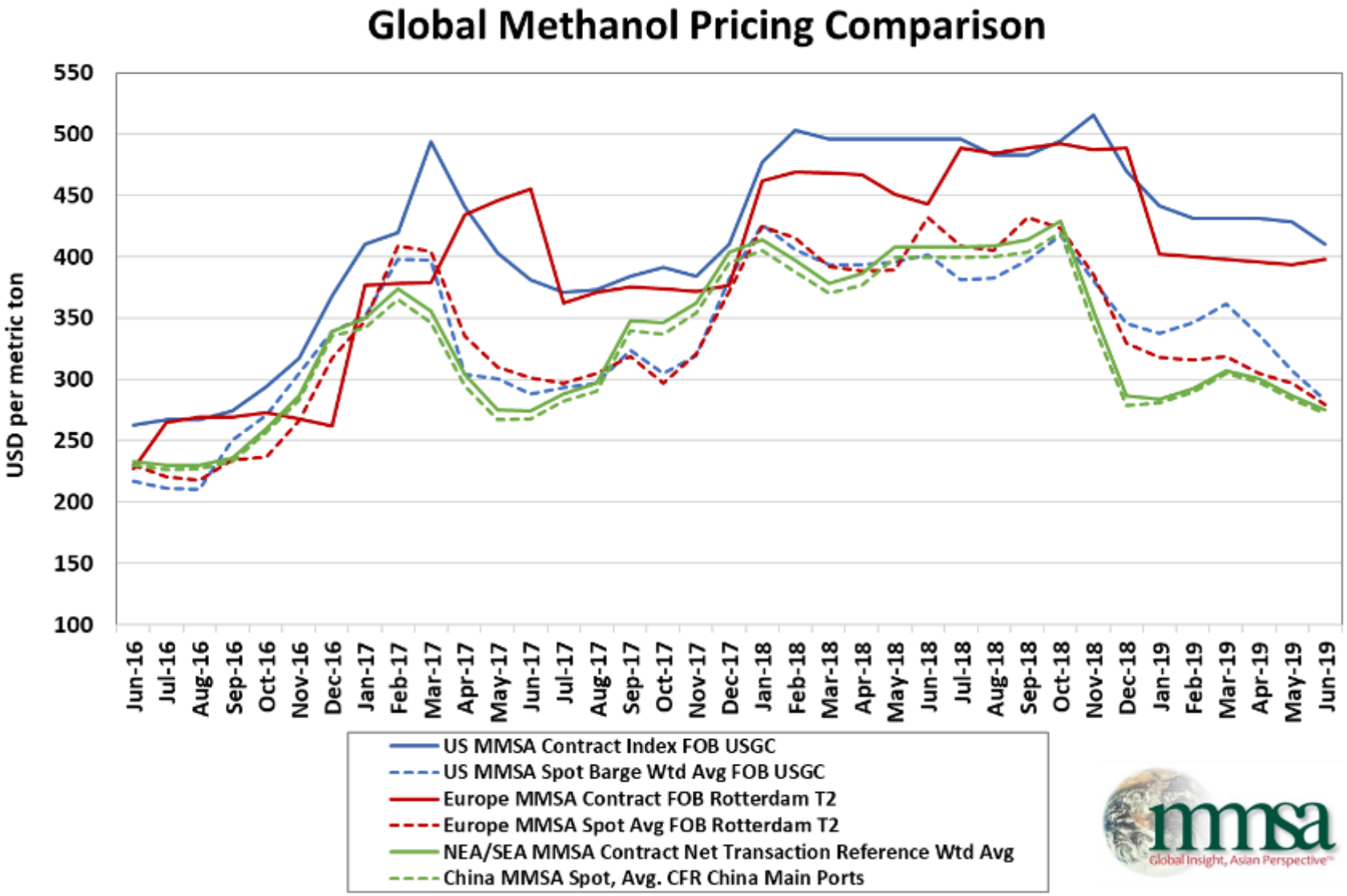
GREEN METHANOL COMPETITIVENESS CHALLENGE



Carbon Recycling International

Source: "Commercialization of Low Carbon Methanol", Christian Bergins, KC Tran, Esther Vox and Paul Wuebben, MTZ Extra, Fuels and Lubricants of the Future, Nov. 2016. https://www.springerprofessional.de/en/commercialization-of-low-carbon-methanol/7465464

GLOBAL METHANOL PRICING DYNAMICS



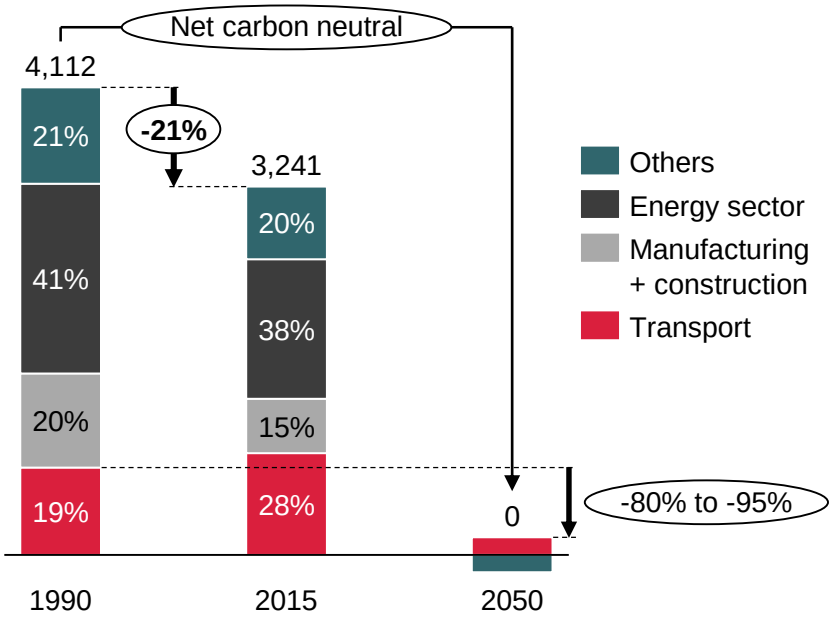
19 July 2019 US TX GC Spot = 71¢ per gallon or $236 per metric ton, Argus

03 EU E-FUELS/ POWER-TO-X

EU IS COMMITTED TO ESTABLISH A CARBON NEUTRAL ECONOMY BY 2050 – RENEWABLE ENERGY ACCOUNT FOR 95%

EUROPEAN COMMISSION GHG REDUCTION OBJECTIVES FOR 2050

CO_2 emission in the EU in million tons



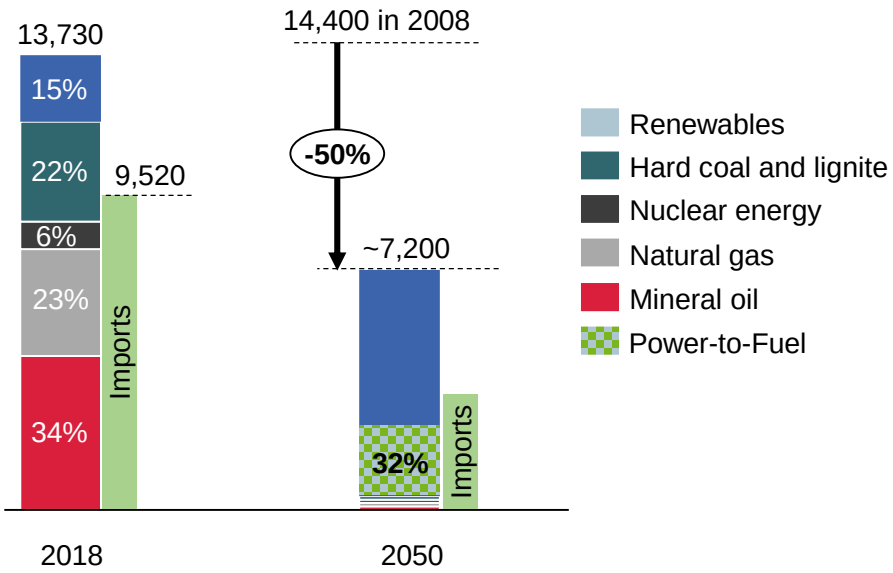
- It is assumed, the electricity generation achieves zero net emissions by 2050
- The transport sector target is less than for the overall economy
- The transport sector needs to cut its greenhouse gas emissions by 80% to 95% by 2050 compared to 1990

Source: European Commission, FEV

IN 2050 GERMANY WILL RELY ON IMPORTED CHEMICAL ENERGY CARRIERS – BUT THEY HAVE TO BE SYNTHESIZED FROM RENEWABLES

IMPORT OF SYNTHETIC FUELS IN 2050 EQUALS UP TO 50% OF TODAY'S MINERAL OIL IMPORTS

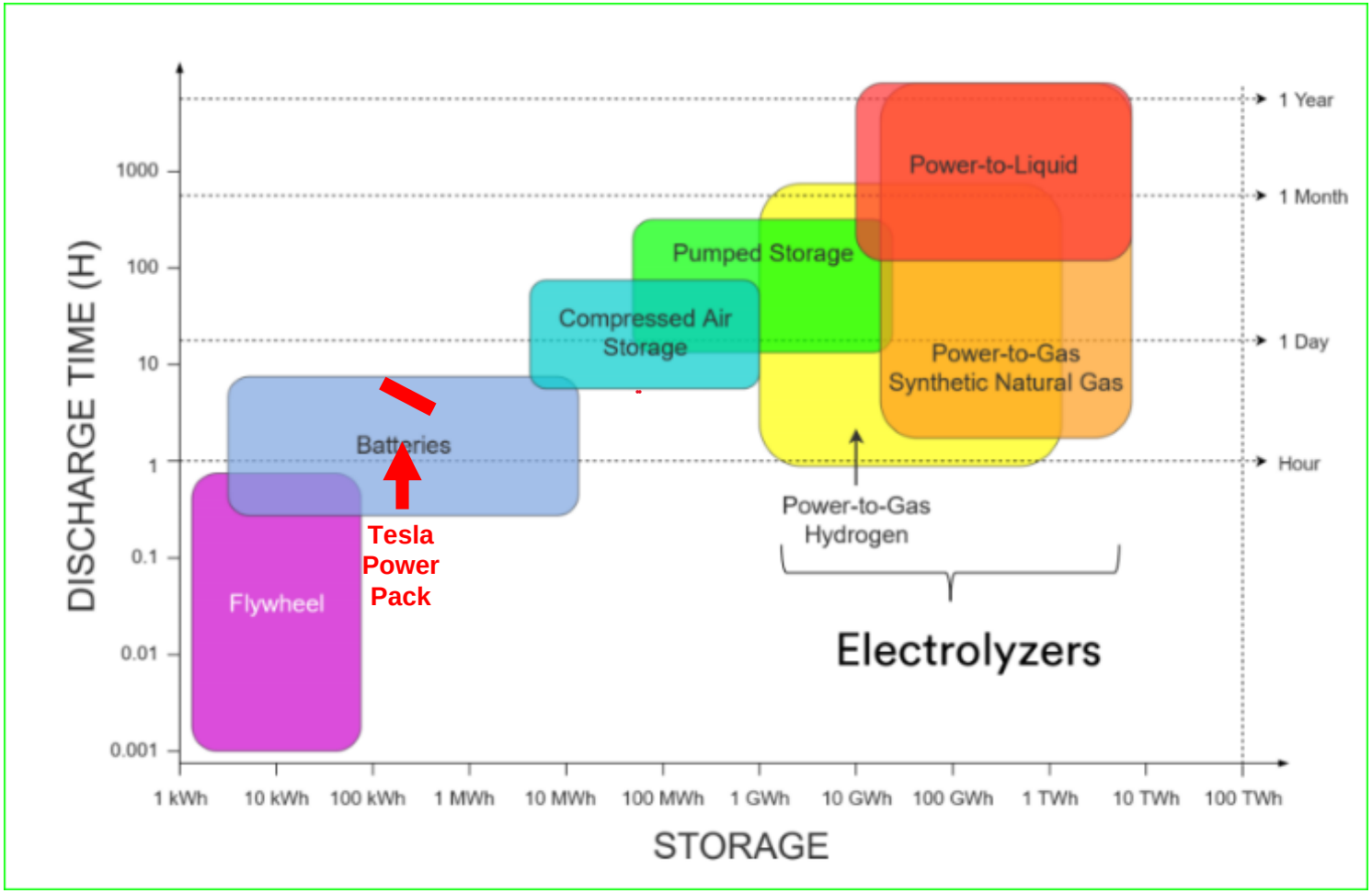
Primary energy carriers in PJ



- Primary energy use will be shortened by 50% compared to 2008
- Fossil fuels will provide only 5% of the total primary energy consumption
- Import of renewable electricity to Germany will increase
- ***Up to one third of the total energy consumption might be covered by Power-to-Fuels, thereof***
  - ***75% are imported from outside Europe***
  - ***17% are imported from inside Europe***

Source: European Commission, BMWi Energiedaten, AG Energiebilanzen, ewi gGmbH "Evolution scenario"

POTENTIAL TO STORE EXCESS RENEWABLE POWER



Sources: *Laura Nereng, 3M, 2017;*
Tesla July 2017 announcement extrapolation

04 HYDROGEN CARRIER FUEL - INFRASTRUCTURE

2002: CaFCP OPENS METHANOL STATION

- April 24, 2002: California Fuel Cell Partnership opens methanol fueling station in Sacramento.
- 2,000-gallon above-ground tank and dispenser just $45,000.
- Features spill-free methanol fueling nozzle.
- June 2002: Daimler's NECAR 5 drives San Francisco to Washington, DC – 16 days and 3262 miles

2004: JAPAN HYDROGEN FUEL CELL VEHICLE PROGRAM 50 NM3/H FUELING STATION BASED ON MGC - MH TECHNOLOGY

Managed by Japan Air Gases Ltd in Kawasaki City, Japan

THE NEXT GENERATION: ELEMENT 1

L-Series Hydrogen Generator

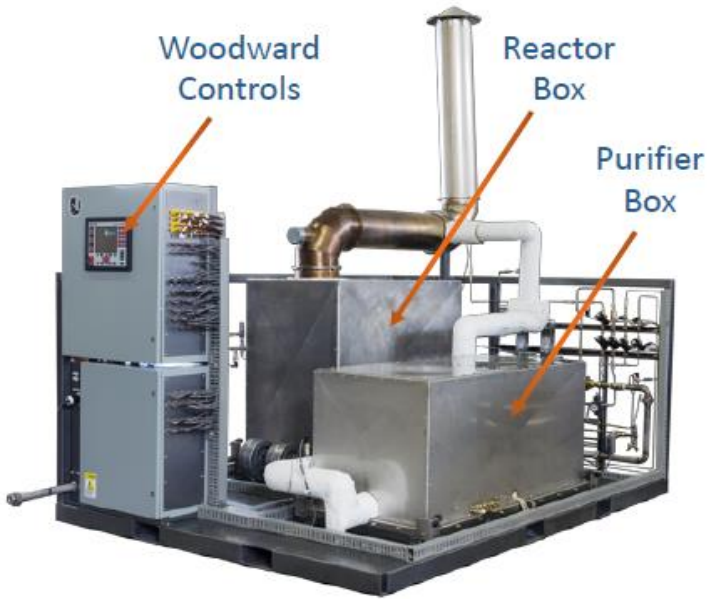
Large-Scale, On-Demand Hydrogen Generator

Overview

- **L-Series:** Was designed to displace expensive electrolyzers and deliver the lowest total cost of hydrogen for refueling applications
- **Feedstock:** Methanol & DI water feedstock
- **Product Hydrogen:** >99.97% with <0.2 ppm CO and <0.2 ppm CO_2
- **Target uses:** Buses, cargo vans, delivery trucks, lift trucks, and trains

Key Advantages

- **Lowest total cost of hydrogen:** 40% less than competing solutions
- **Lowest initial cost of equipment:** 70% less than competing solutions
- **Scalable hydrogen production:** from 50 kg/d to 500 kg/d
- **Minimal power requirements:** (<2 kW for L100)
- **Compact design**
- **State of the art Controls:** Woodward Flex 500



H_2 BULK TRANSPORT REALITIES: 7 X LARGER TRUCK FLEET NEEDED COMPARED TO METHANOL

Gaseous H_2:

40 ton transport tanker truck

500 kg H2 delivered @ 200 bar

H_2 as methanol:

40 ton transport tanker truck

3,600 kg of H2 delivered at STP

Carbon Recycling International

METHANOL ALREADY ESTABLISHED PLATFORM MOLECULE FOR THE CHEMICAL INDUSTRY/ FUEL PRODUCTION AND AN EXCELLENT FUEL!

METHANOL IS A PROBABLE SOLUTION TO IMPORT RENEWABLE ENERGY TO GERMANY/EUROPE

MeOH is used as fuel already

- First series production M100 truck, claiming 18% costs savings/year
- Methanol is used from M5 to M100
- Applications range from PC to HD

Source: bigwheels.my

MeOH is promising alternative for SI and commercial engines

- Methanol is cheap to produce
- Established product and building-block (chemical industry)
- Handling and infrastructure is considered to be more complex
- Available applications very limited (EN228 limits MeOH to 3% v/v, but push from Asia)

	Fuel costs	Availability	Technology Readiness Level	Fuel distribution	Compatibility with existing vehicles
Methanol	**+/o**	**o**	**+/o**	**o**	**o/–**

Methanol utilization in transport will significantly rise

INFRASTRUCTURE COSTS

- **Vehicle Capital Cost Savings**
  - Methanol: $100 Δ for FFVs / *PEM FCVs under development*
  - H_2FCVs: $30,000 to $50,000 first cost
- **Infrastructure Capital Cost Savings**
  - **Current "H_2 Stations" may be considered "Nano-Stations"**
    - **Only 50 – 300 kg per day**
  - Methanol: **$100,000 +/- $50,000**
    - **Gasoline station-equivalent throughput: 1,000 to 2,000 kg per hour**
  - Hydrogen: **$60 to $80 million**
    - ***Equivalent throughput of a conventional gasoline station***

- **Methanol Volumetric H_2 density: *Higher* than LH_2!**
  - Methanol: 100 g/l
  - Hydrogen: 71 g/l

Carbon Recycling International

STATION TO STATION

COMPARATIVE INFRASTRUCTURE CAPEX

	Liquid Fuels	Electricity	Hydrogen
Daily Miles Enabled by Typical Current Station*	500,000	4,800	9,000
Stations Needed to Achieve Energy Equivalent Throughput Capacity	1	104	56
Cost Per Current Station	$200,000	$80,000	$2,500,000
Cost Per Equivalent Station	$200,000	$8.3 million	$139 million
Cost for 10,000 Station National Network	$2 billion	$83 billion	$1.4 trillion

** Gasoline Benchmark: 600,000 gallons / month, average 25 mpg*
** Level 3 EV Recharging Benchmark: 200 miles / EV; 1.5 hours for full charge; 2 plugs per station; 24 cars per day*
** Hydrogen "Nano-Station" Benchmark: 150 kg/day; 60 miles / kg.*

** Gasoline Benchmark: 600,000 gallons / month, average 25 mpg; equivalent to 1,000 kg/hour*
** Level 3 EV Recharging Benchmark: 200 miles / EV; 1.5 hours for full charge; 2 plugs per station; 24 cars per day*
** Hydrogen "Nano-Station" Benchmark: 150 kg/day; 60 miles / kg.*
** Hydrogen Gasoline-Equivalent Station: 1,000 kg/hour capacity; either 35' high above ground storage or 50+ MW on-site electrolysis. The permiting of either of these options in congested urban areas is highly doubtful if not impossible.*

05 HYDROGEN CARRIER FUEL - APPLICATIONS

METHANOL A HYDROGEN CARRIER FOR FUEL CELLS

- Blue World Technologies (Denmark)
- Palcan (China)
- Horizon Energy Systems (Singapore)
- Oneberry (Singapore)
- Altergy (USA)
- Serenegy (Denmark)
- SFC Energy (Germany)
- Toshiba (Japan)
- Ultracell (USA)

COMMERCIAL OFFERINGS REFORMED METHANOL FUEL CELLS FOR STATIONARY POWER

METHANOL FUEL CELL EV RANGE EXTENDER

- 2015: Denmark opens EU's first methanol fuel pump
- Cars/vans use Serenergy RMFC technology as range extender and CRI methanol as fuel
- Increasing range of battery powered vehicles from 200 to 800 kilometers
- April 2019, Beijing Auto Show: AIWays unveils Gumpert RG Nathalie methanol fuel cell electric supercar with a 1,200 km range and a top speed of 300

DENMARK'S BLUE WORLD TECHNOLOGIES AND CHINA'S PALCAN

MANUFACTURING PLANTS: 50,000 UNITS/YEAR – 5 kw RMFC

Blue World

Launch Reception: Blue World Technologies presenting plans for large-scale manufacturing facility

Blue World Technologies today presents plans for the world's largest methanol fuel cell factory located at the Port of Aalborg ready for global export of clean energy technology. Methanol fuel cell components will be produced in high volume enabling electric vehicles to have a 1000km range with 3 minutes refuelling time.

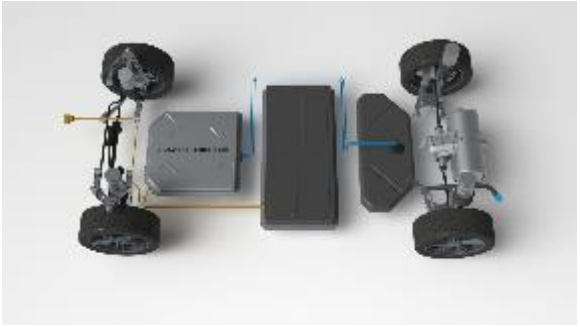
Blue World technology is newly founded but has ambitious goals from the start by targeting the most potential markets in form of automotive and electric mobility. The challenge is daunting, but also the possibility to really make a difference in the world.

Today the mayor of Aalborg; Mr. Thomas Kastrup Larsen is attending the launch reception of Blue World Technologies on the Port of Aalborg. Furthermore, plans for the world largest methanol fuel cell manufacturing facility will be presented.

1 - Blue World Technologies - fuel cell factory visualisation

Volume production of methanol fuel cells

Blue World Technologies will establish a state-of-the-art manufacturing plant for a unique fuel cell technology platform utilizing methanol as a fuel. The plant will be highly specialized in the production of materials and components for the fuel cell and stack which can be compared to the engine block of a car. The overall effort will require several hundreds of new employees for both development and operations. The factory will be built and have initial manufacturing activity during 2019.



Palcan

Our Development Plan Ⅱ

"Build a 50,000 sets of fuel cell module production base (2018)"

►Industrial Base: Cixi, Zhejiang province
►Total investment of 100 million
►Achieve 50,000 sets of fuel cell module production capacity.

►Market target：Electric logistics vehicle, mobile charging vehicle, communication backup power supply, civil-military integration.

CHINA FUEL CELL PIVOT

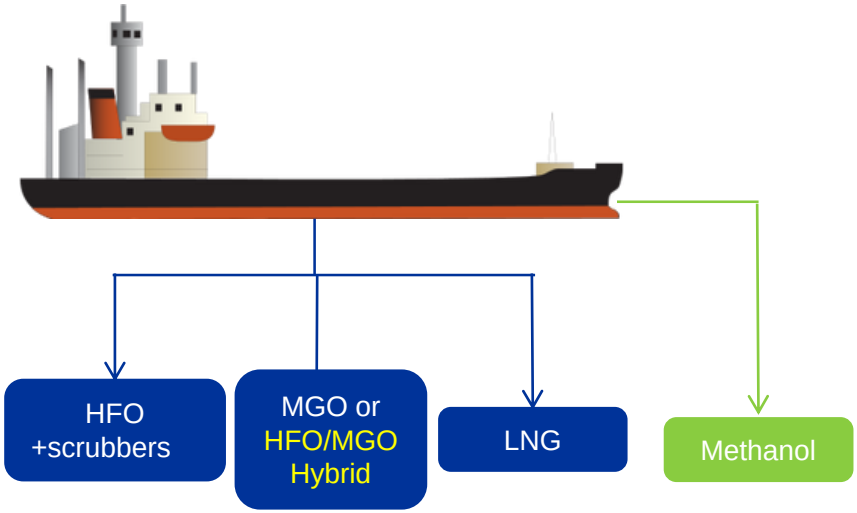
- China now has just 1,500 FCVs and 23 hydrogen fuelling stations
- March 2018: MIIT releases plans for hydrogen fuel cell promotion as “new energy vehicles”
- Targets: 2020 – 5,000 FCVs; 2025 – 50,000 FCVs; 2030 – 1 millon FCVs
- Pivot away from EV subsidies and moving support to hydrogen fuel cells
- Emphasis on commercial vehicles: buses and trucks, long-haul
- ***October 2019: MI and MIIT holding methanol seminar in Chongqing***

CHINA M100

- Dec 2018: MIIT completes acceptance of all methanol pilot demonstration programs
- ***March 2019: MIIT and 7 other ministries announce methanol policy paper for M100***
- MI issues press release and briefing report
- "Paper 61" encourages commercial introduction of M100 vehicles; empowers Provinces; ***supports methanol hybrid and fuel cell vehicles***
- Currently over 10,000 methanol-fueled taxis operation for total of 1.2 *billion* kilometers
- Approval of 32 product models from 9 methanol vehicle manufacturers

06 MARINE FUELS

OPTIONS AVAILABLE TO SHIP OWNERS



www.methanol.org/marine-fuel

METHANOL VESSELS ON THE WATER

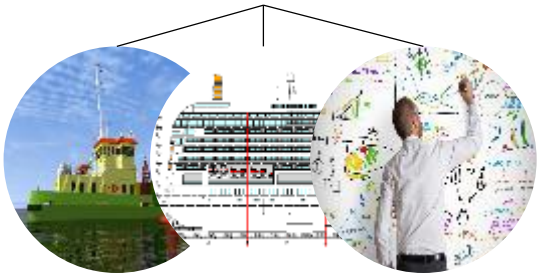
DUAL FUEL

7x - +4	1x	1x	1x
chemical tankers	ROPAX ferry	Pilot boat	dry bulk
MOL, WL, Marinvest	Stena Line	MI/SMA ScandiNaos	Jiang Long
2 stroke MAN	4 stroke Wärtsila	high speed Scania, Weichai	DMCC Yuchai
new build	retrofit	retrofit	new build

FUEL CELL

2x	1x
Tourist Boat propulsion	Ferry hotel load
Innogy HTWG Konstanz	Viking Line
SerEnergy fuel cells	
retrofit	retrofit

PROJECT and R&D



Cruise ships, fishing boat, barge, dredge, a.o.

SUMMETH/MARTEC, Lean Ships, Methaship, Billion Miles, FiTech, India, PCG Product Vessel, NTU Test Port of Rotterdam Barge, **Green Maritime Methanol, FastWater**

SI hybrid, dual fuel, fuel cells

new build & retrofit

METHANOL BUNKERING EASY & CLEAN

- Liquid at atmospheric pressure
- Available in many ports around the world and along rivers
- Low infrastucture cost
- Flexible, modular system
- Environmentaly friendly as it's **biodegradable**

07 CONTACTS

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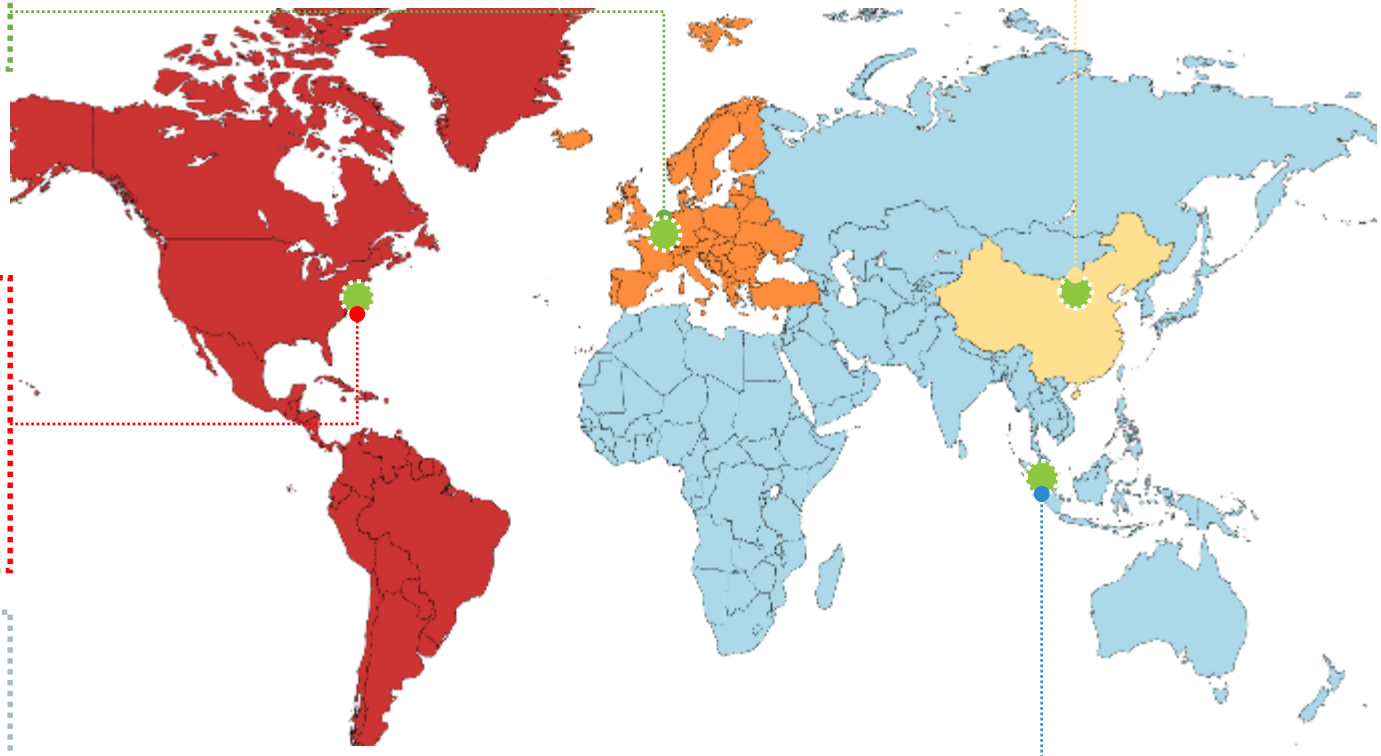

www.methanol.org www.methanolfuels.org