THE METHANOL PATHWAY TO HYDROGEN

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May 26, 2021, Wednesday

0800 HRS (PDT), 1600 HRS (CET), 2300 HRS (SGT)

Ardmore Shipping

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The Methanol to Hydrogen Pathway

Timothy Chan
Manager, Government and Public Affairs

May 26 2021

Singapore | Washington | Brussels | Beijing | Delhi

MI History

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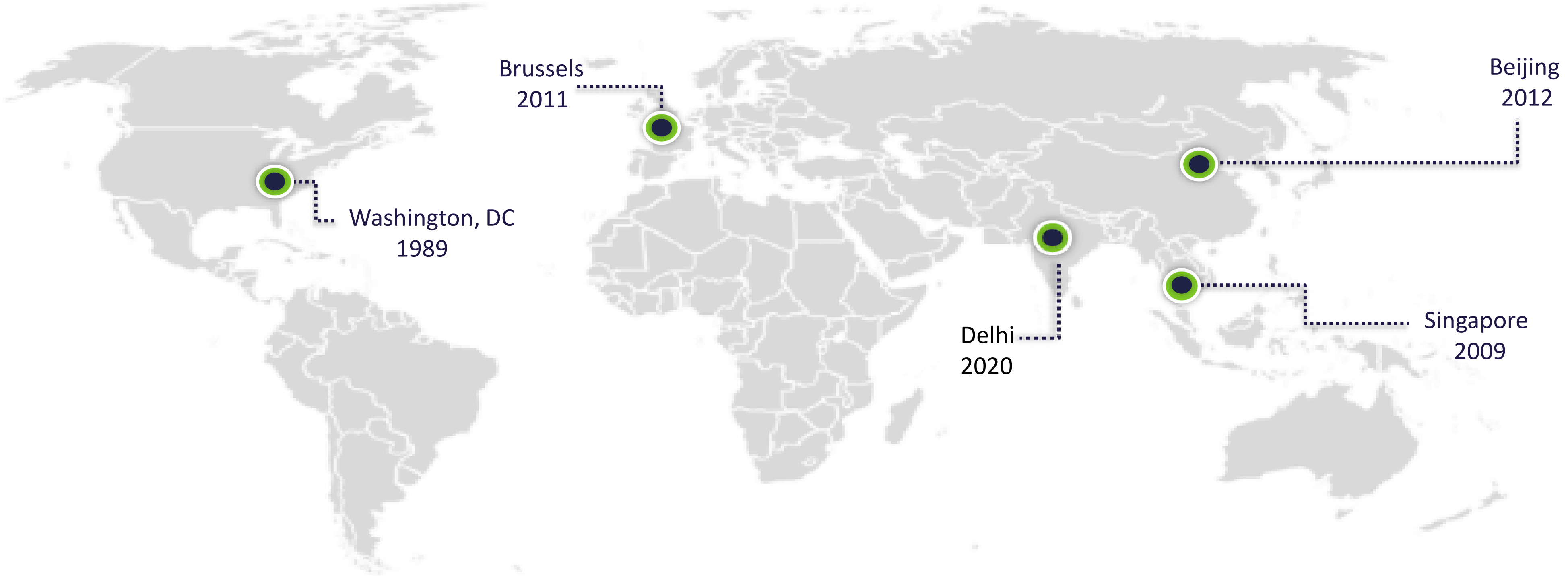
- The Methanol Institute (MI) was established in 1989
- Three decades later, MI is recognized as the trade association for the global methanol industry
- Facilitating methanol's expansion from our Singapore headquarters and regional offices in Washington DC, Brussels, Singapore, Beijing and Delhi.



Members

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Tier 1

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TRICON ENERGY · Stena Bulk · CLARIANT · RH2C Renewable Hydrogen Canada Corporation · Advanced Chemical Technologies Inc.

SOUTHERN GREEN GAS exporting Australia's sunshine · Nebraska Public Power District Always there when you need us · HALDOR TOPSØE · Liquid Wind

Our Committee Structure

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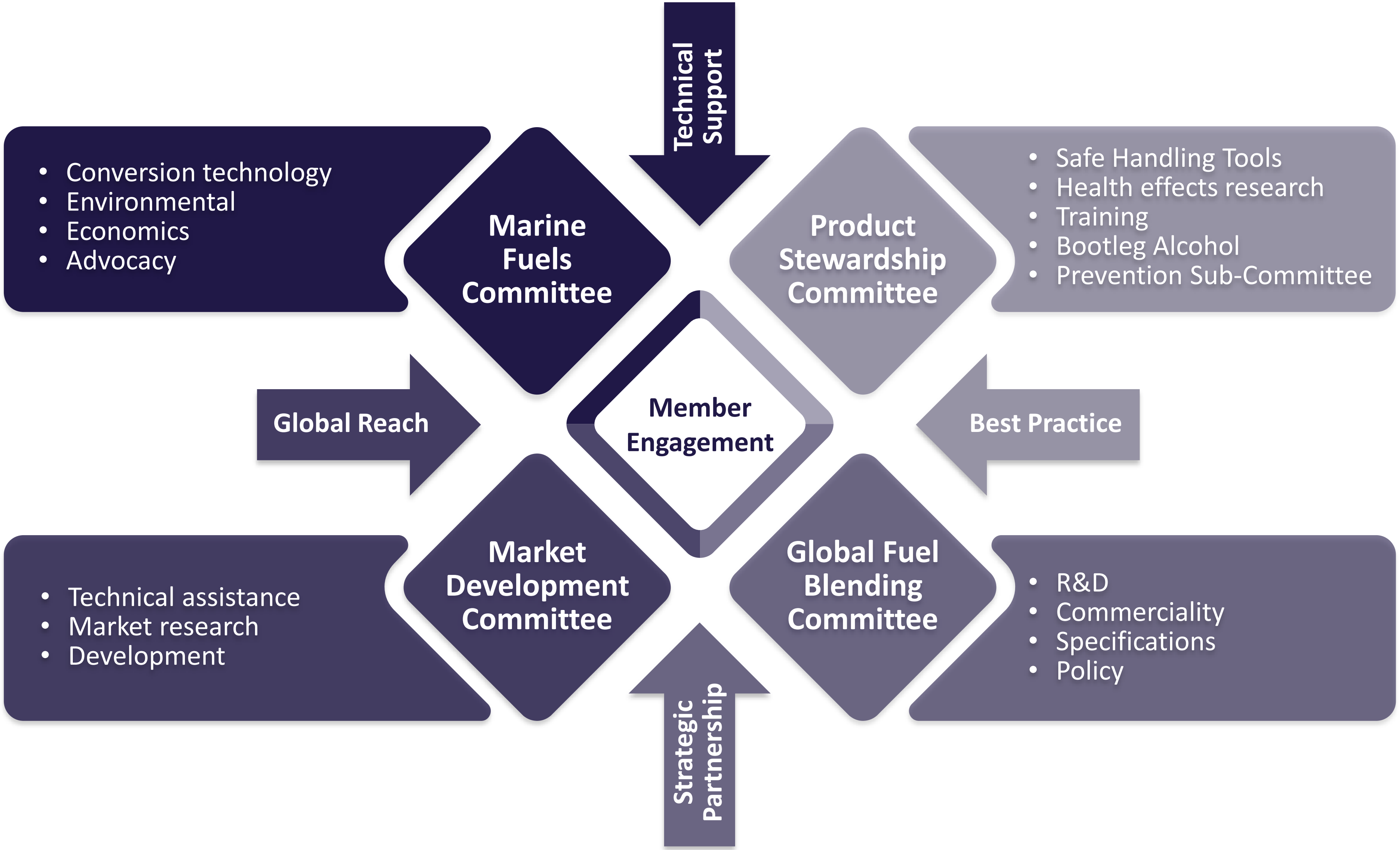

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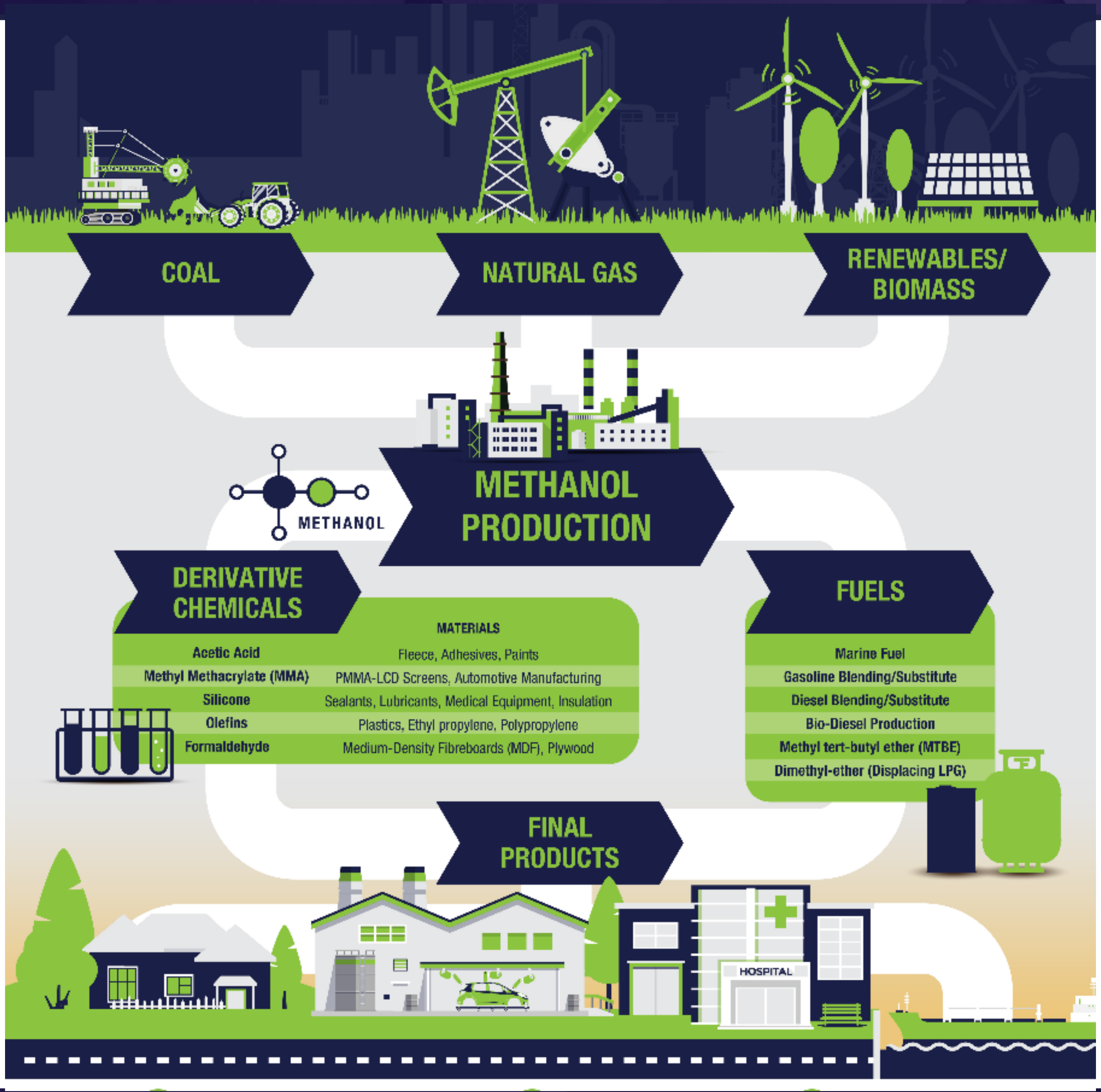
Methanol: A future proof hydrogen carrier fuel

Greg Dolan, CEO

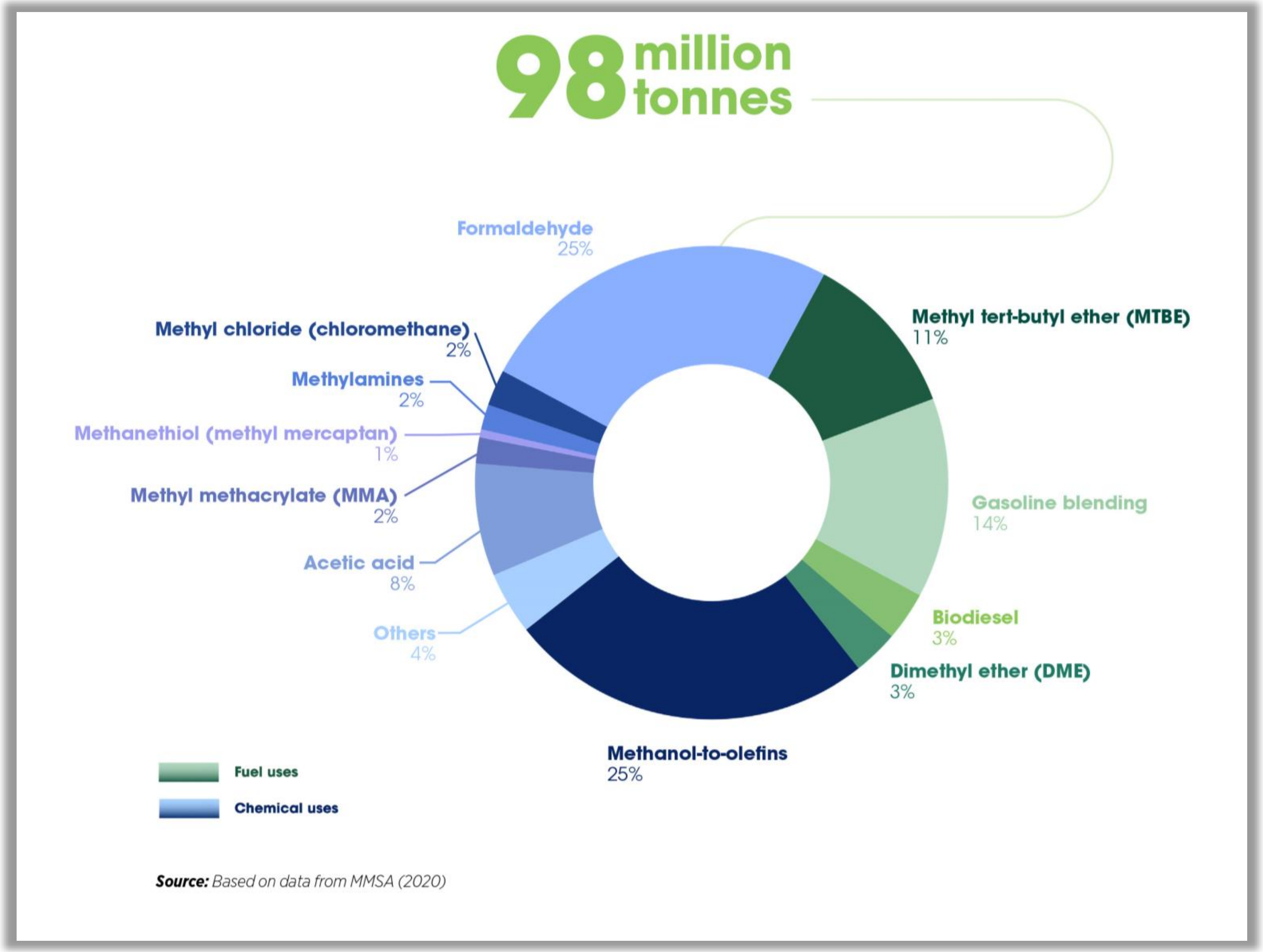
The Methanol Pathway to Hydrogen
26 May 2021

Singapore | Washington | Brussels | Beijing | Delhi

Essential Methanol



2020: Methanol Demand



Driven by China MTO

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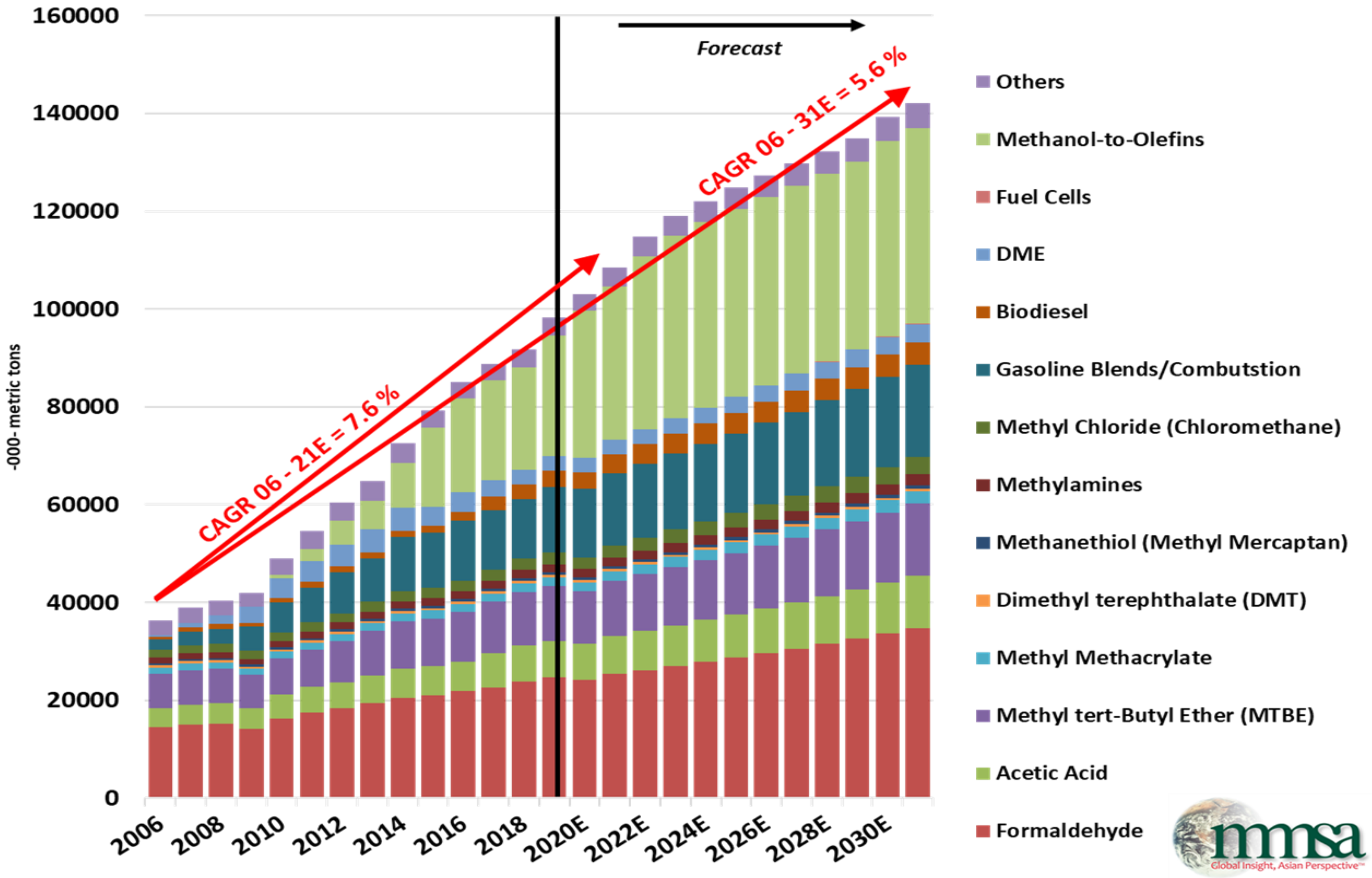

2050: 5-Fold Demand Increase

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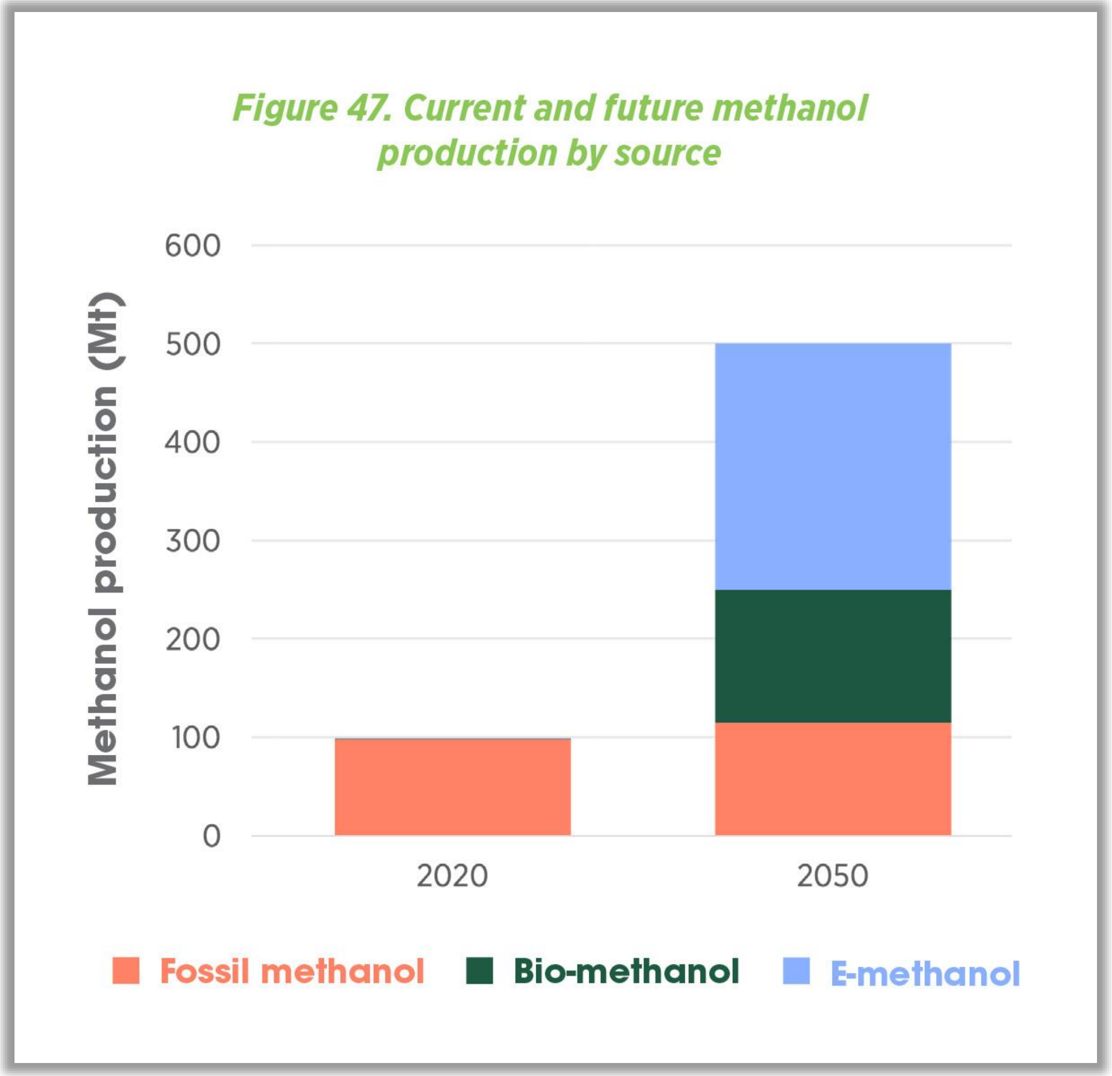
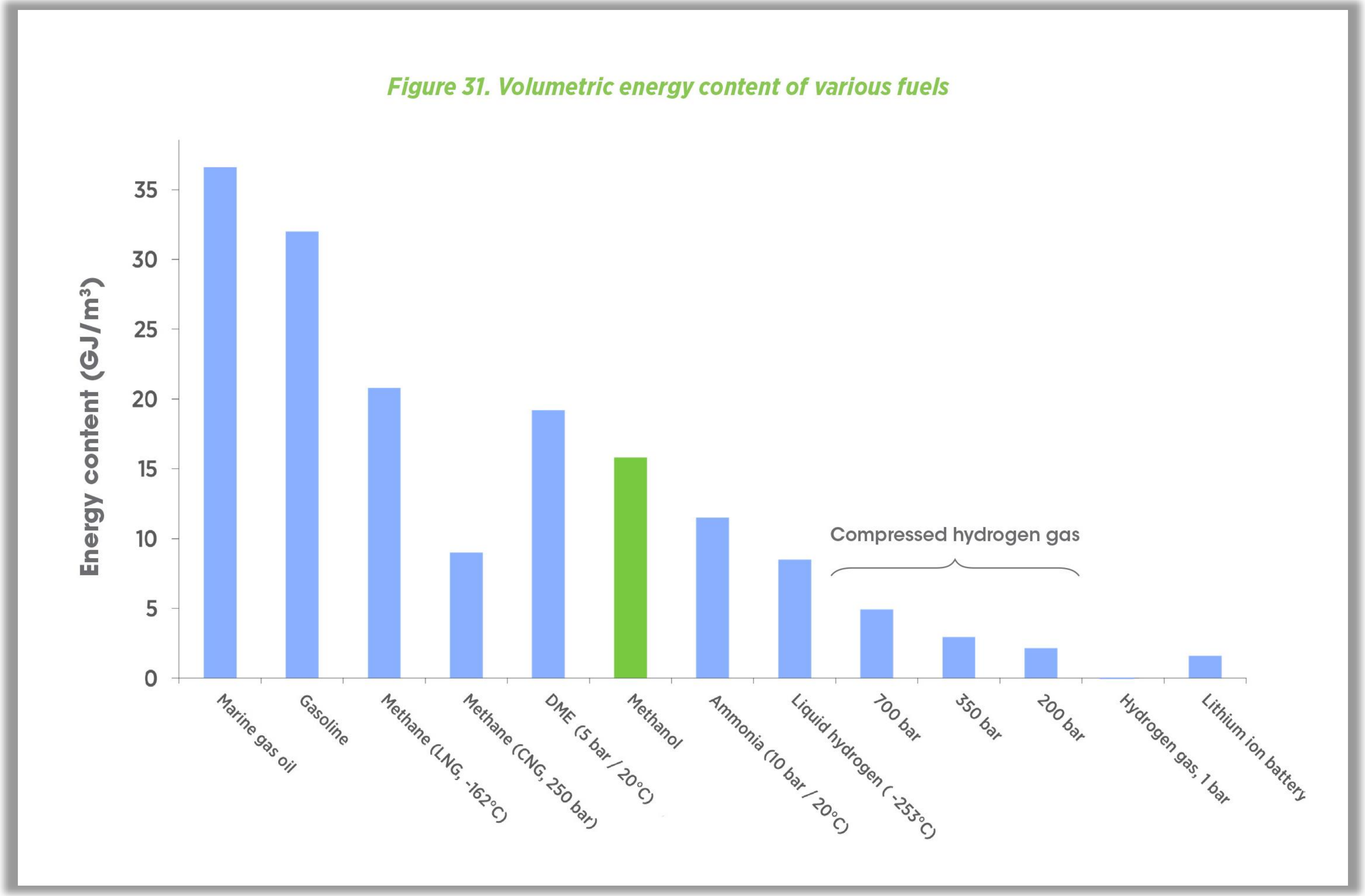
https://www.irena.org/publications/2021/Jan/Innovation-Outlook-Renewable-Methanol

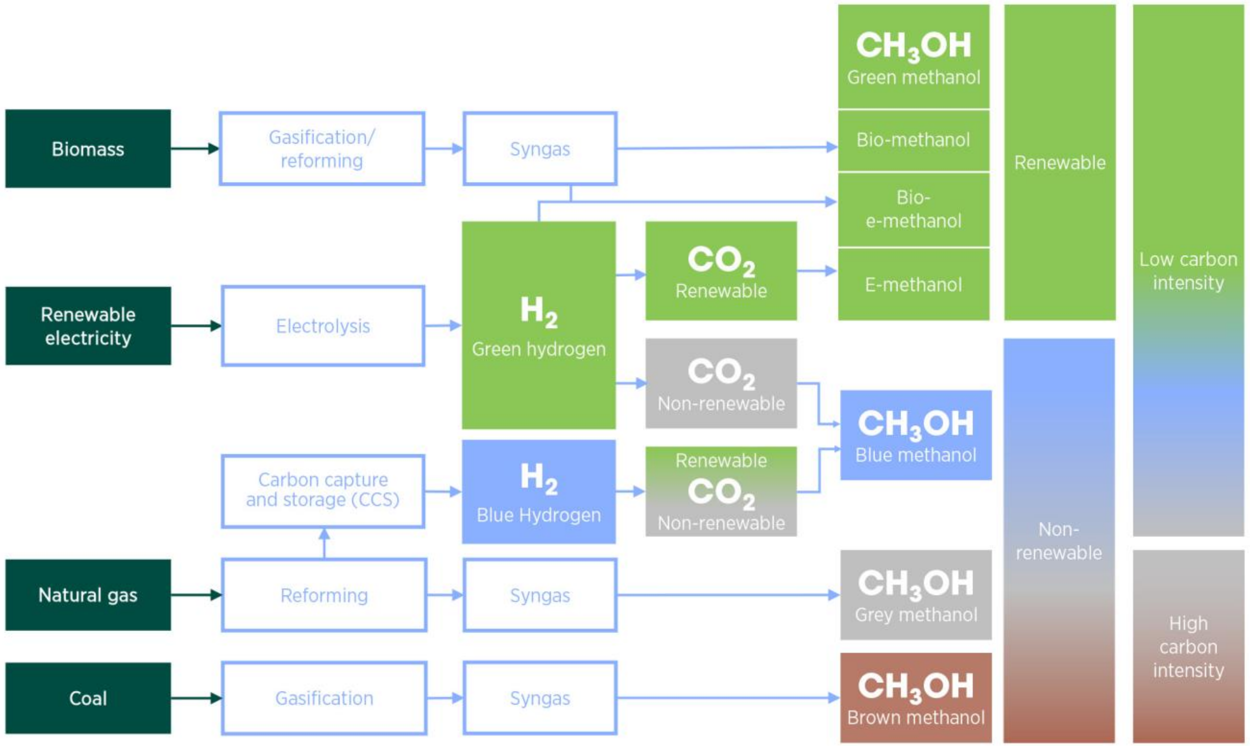


Fuel Comparison



Brown, Grey, Blue, Green

Figure 2. Principal methanol production routes



Renewable CO_2: *from bio-origin and through direct air capture (DAC)*

Non-renewable CO_2: *from fossil origin, industry*

While there is not a standard colour code for the different types of methanol production processes; this illustration of various types of methanol according to feedstock and energy sources is an initial proposition that is meant to be a basis for further discussion with stakeholders

Cost of Production

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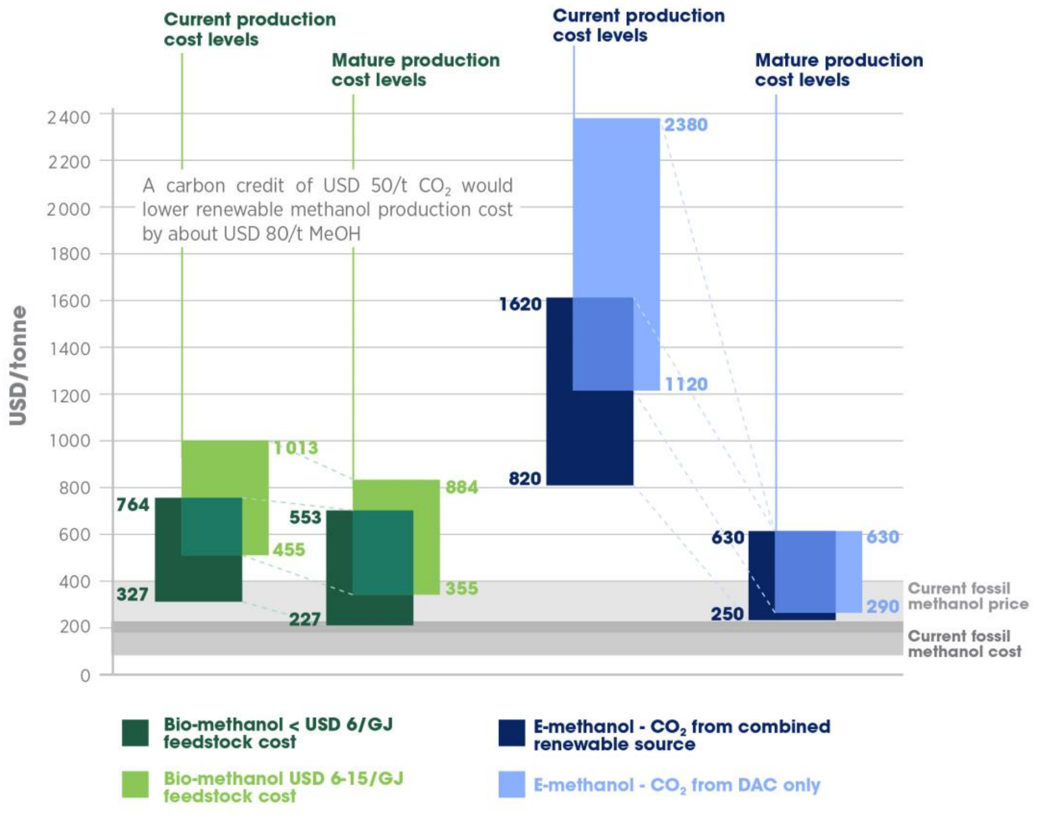
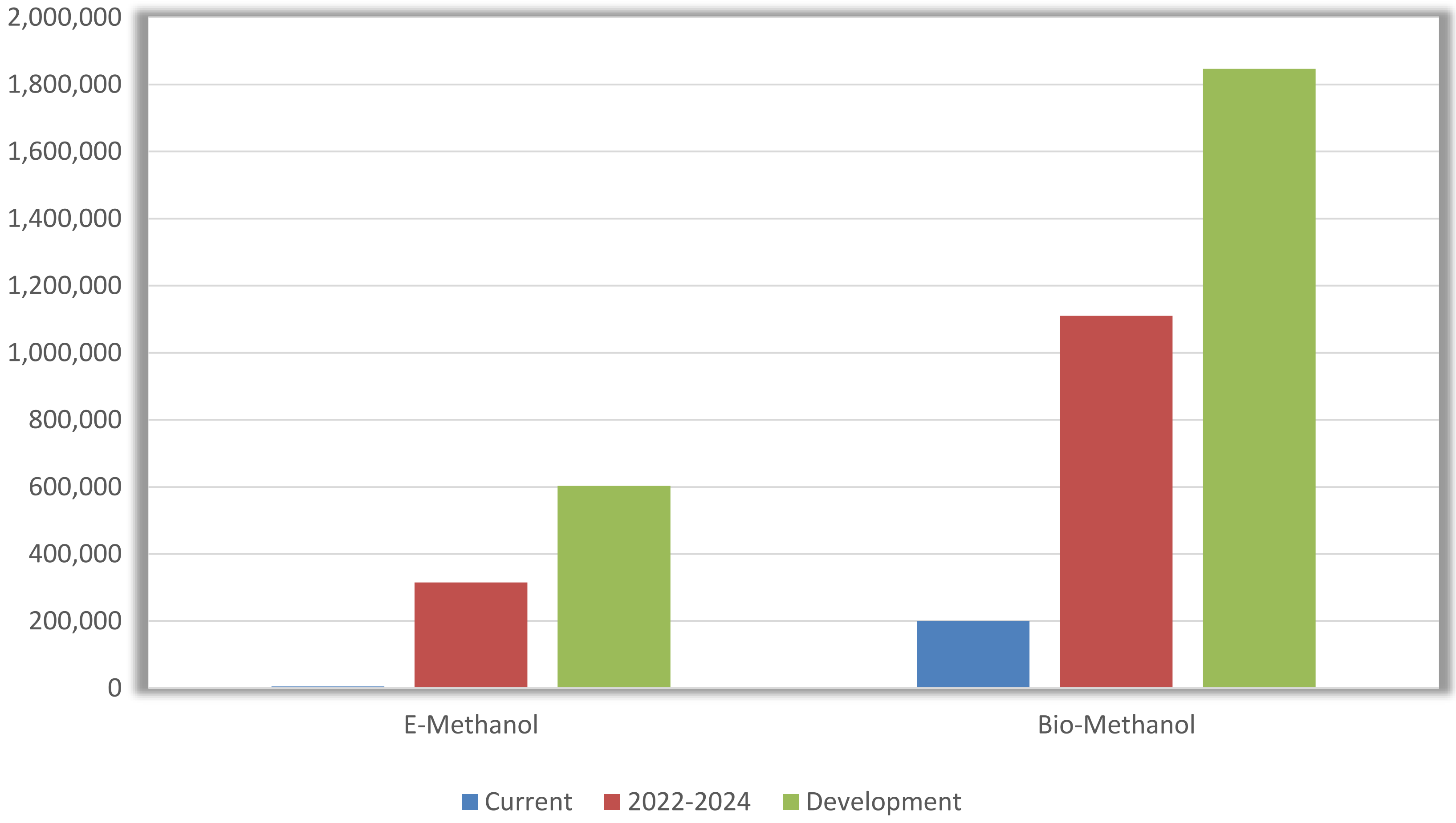
Figure 3. Current and future production costs of bio- and e-methanol



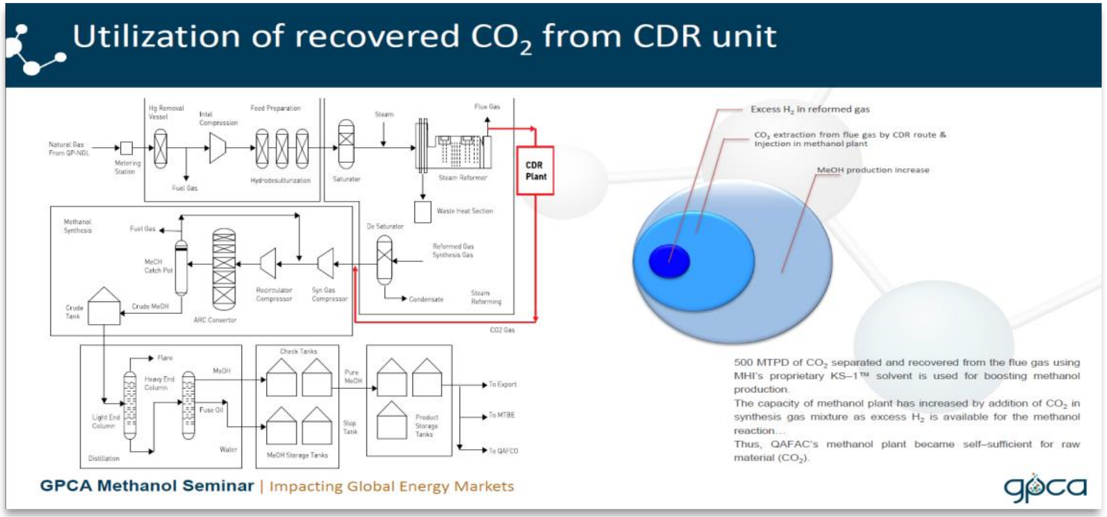
Notes: *MeOH = methanol. Costs do not incorporate any carbon credit that might be available. Current fossil methanol cost and price are from coal and natural gas feedstock in 2020. Exchange rate used in this figure is USD 1 = EUR 0.9.*

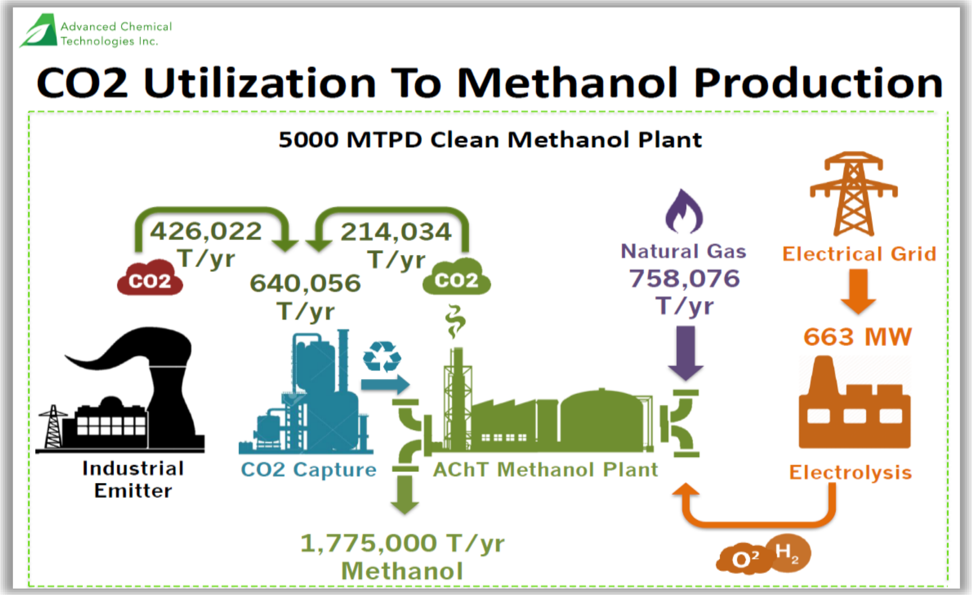
Green Methanol Plants and Projects

Commercial and Announced Renewable Methanol Projects



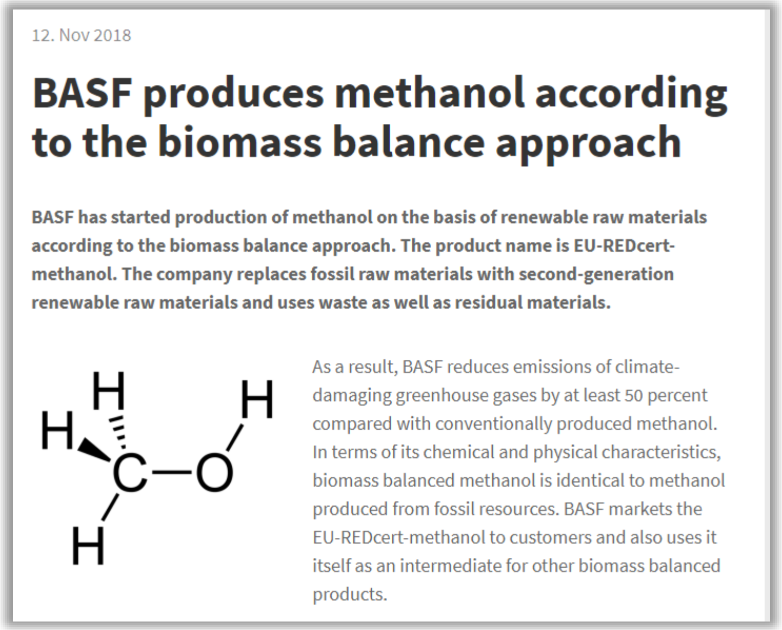
Blue Methanol





- To reduce the carbon intensity of methanol production from natural gas, a number of companies have developed low carbon or blue methanol processes
- Celanese and Mitsui will capture 60% of CO2 emissions from Fairway Methanol (US) to make sustainable methanol
- Methanex injects captured CO2 from a neighboring plant at Medicine Hat (Canada)
- Qatar Fuel Additives Company recovers CO2 from the reformer flue gas and re-injects to synthesis loop
- Baofeng Energy in China is building green hydrogen plant to feed into coal-based methanol plant to increase capacity and reduce CO2
- Advanced Chemical Technologies is planning a plant in Canada using waste CO2 from neighbor and 660 MW electrolyzer powered by hydroelectricity
- Johnson Matthey Leading Concept Methanol uses renewable electricity for all compressor drives, including ASU
- Haldor Topsoe is developing a compact fully electrified methane steam reformer

“Mass Balance” Bio-Methanol

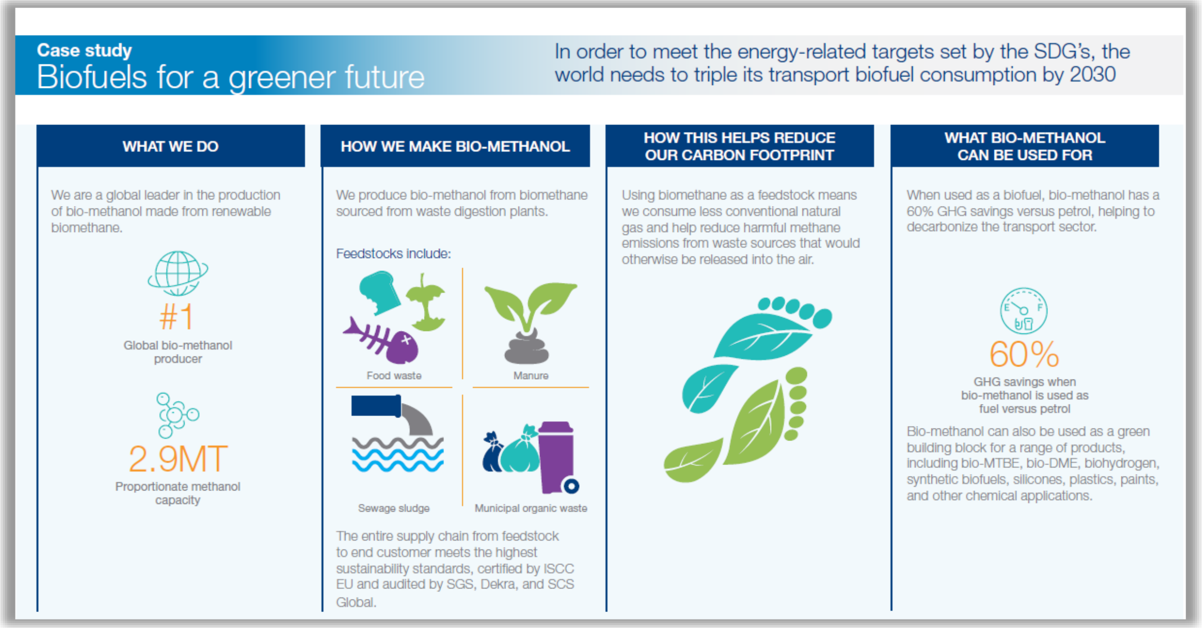


12. Nov 2018

BASF produces methanol according to the biomass balance approach

BASF has started production of methanol on the basis of renewable raw materials according to the biomass balance approach. The product name is EU-REDcert-methanol. The company replaces fossil raw materials with second-generation renewable raw materials and uses waste as well as residual materials.

As a result, BASF reduces emissions of climate-damaging greenhouse gases by at least 50 percent compared with conventionally produced methanol. In terms of its chemical and physical characteristics, biomass balanced methanol is identical to methanol produced from fossil resources. BASF markets the EU-REDcert-methanol to customers and also uses it itself as an intermediate for other biomass balanced products.



China e-Methanol Project

- 16-17 Oct 2020: 500 Chinese top scientists and leaders from renewable energy, fuels cells and methanol production industries attended Green Hydrogen and Liquid Sunshine Forum in Lanzhou organized by Dalian Institute of Chemical Physics.

- The forum celebrated opening of China and the world's first large-scale solar to methanol project producing 2,000 metric tones per year of methanol supplied by a 10 MW solar PV farm.

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Bio-Methanol Plants

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Table 12. Capital cost for bio-methanol plants

#	Project/ study	Status	Capacity (t/y)	Investment (million USD)	Investment (USD/t/y)	Investment (USD/kW)	Source
1	Trans World Energy (TWE), Florida (US)	FEED done, start-up Q2 2023	875 000	430	490	710	TWE
2	ENI Refinery, Livorno (IT)	Basic engineering ready Q3 2020	115 000	330	2900	4 280	NextChem
3	LowLand Methanol (NL)	Start-up early 2023	120 000	130	1 110	1 620	LowLand Methanol
4	Södra (SE)	Operational	5 000	11	2 220	3 230	Södra
5	Enerkem, Rotterdam (NL)	Engineering	215 000	580	2 690	3 840	Enerkem
6	Enerkem, Tarragona (ES)	Engineering	215 000	580	2 690	3 840	Enerkem
7	VTT	Detailed study	265 000	385	1 450	2 070	VTT
8	Chemrec, Domsjö (SE)	Preliminary engineering	147 000	390	2 640	3 400	Chemrec
9	Chemrec, nth plant	Concept	290 000	540/270*	1 880/930*	2 740/1 370*	Chemrec
10	New Hope Energy, Texas (US)	Investment decision Q4 2020	715 000	500	700	1 020	New Hope Energy

E-Methanol Facilities/Projects

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Table 7. Overview of existing or planned facilities and technology providers for e-methanol production

Country	Company	Start-up year	Capacity (t/y)	Product	Feedstock	Source
Iceland	CRI	2011	4 000	e-methanol (Vulcanol)	Geothermal CO_2 and H_2 from water electrolysis	CRI, 2020
China	Dalian Institute of Chemical Physics	2020	1 000	e-methanol	CO_2 and H_2 from water electrolysis (PV)	AAAS, 2020
Sweden	Liquid Wind	2023 (plan for 6 facilities by 2030)	45 000	e-methanol	Upcycled industrial CO_2 and H_2 from water electrolysis	Liquid Wind, 2020
Australia (Tasmania)	ABEL	2023	60 000	e-methanol	Biogenic CO_2 and H_2 from water electrolysis	ABEL Energy, 2020
China	Henan Shuncheng Group/CRI	2022	110 000	methanol[2]	CO_2 from limekiln and H_2 from coke oven gas	CRI, 2020
Norway	Swiss Liquid Future/ Thyssenkrupp	n/k	80 000	e-methanol	CO_2 from ferrosilicon plant and H_2 from water electrolysis (hydropower)	Swiss Liquid Future, 2020a, Swiss Liquid Future, 2020b
Norway	Consortium of companies/ CRI	2024	100 000	e-methanol	CO_2 and H_2 from water electrolysis	Stefánsson, 2019
Canada	Renewable Hydrogen Canada (RH_2C)	n/k	120 000	e-methanol	CO_2 and H_2 from water electrolysis (hydro)	RH_2C, 2020
Belgium	Consortium at the port of Antwerp	n/k	8 000	e-methanol	CO_2 and H_2 from water electrolysis	INOVYN, 2020
Belgium	Consortium at the port of Ghent	n/k	46 000-180 000	e-methanol	Industrial CO_2 and H_2 from water electrolysis	aet, 2019
The Netherlands	Consortium Nouryon/ Gasunie/ BioMCN and 3 others	n/k	15 000	e-methanol	CO_2 and H_2 from water electrolysis	Nouryon, 2020
Germany	Dow	n/k	- 200 000	e-methanol	CO_2 and H_2 from water electrolysis	Schmidt, 2020
Denmark	Consortium of companies	2023-2030	n/k	e-methanol	CO_2 from MSW and biomass. H_2 from water electrolysis (offshore wind). Up to 1.3 GW electrolyser capacity by 2030	Maersk, 2020
Germany	Consortium	n/k	n/k	e-methanol	CO_2 from cement plant and H_2 from water electrolysis (wind)	Westküste 100, 2020

E-Methanol Demo Plants

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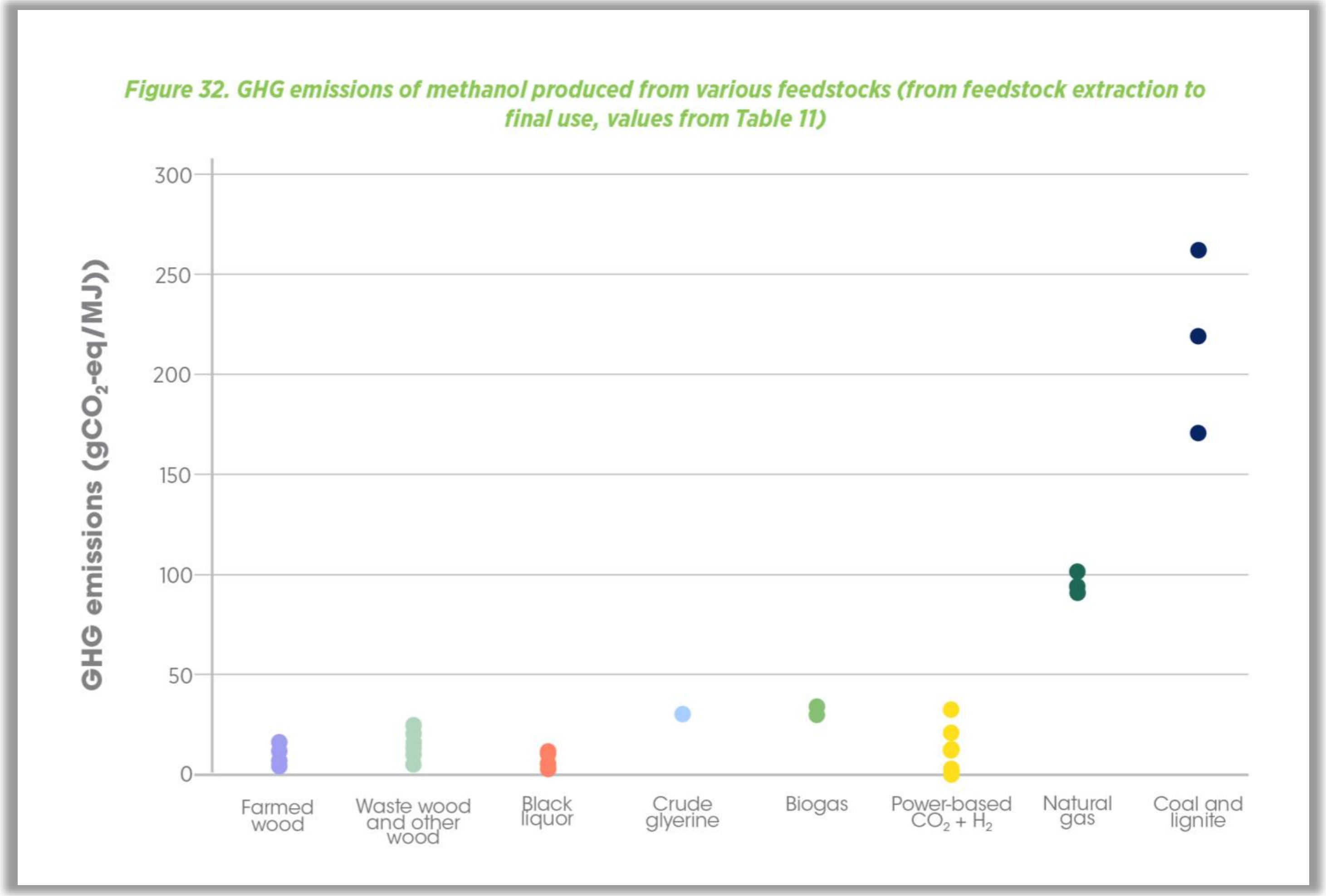
Technology demonstration plants (past and current)						
Country	**Company**	**Start-up year**	**Capacity**	**Product**	**Feedstock**	**Source**
Sweden	FreSMe	2019	1 t/d	e-methanol [(b)]	CO_2 and H_2 waste stream from steel manufacturing and H_2 from water electrolysis	FReSMe, 2020
Germany	$MefCO_2$	2019	1 t/d	e-methanol	Power plant flue gas CO_2 and H_2 from water electrolysis	$MefCO_2$, 2020
Denmark	Power2Met Danish Consortium	2019	800 L/d	e-methanol	CO_2 from biogas and H_2 from water electrolysis (wind and solar)	REintegrate, 2020
Germany	Carbon2Chem	2020	50 L/d	e-methanol [(b)]	CO_2/CO/H_2 from steel mill gases and H_2 from water electrolysis	Carbon2Chem, 2020
Germany	ALIGN-CCUS Project DME from CO_2	2020	50 L/d	e-DME	CO_2 from power plant flue gas and H_2 from water electrolysis	ALIGN-CCUS, 2020
Switzerland	Swiss Liquid Future	2012	75 L/d	e-methanol	CO_2 and H_2 from water electrolysis	Swiss Liquid Future, 2020a
Germany	Total/Sunfire e-CO_2Met project	2022	1.5 t/d	e-methanol	CO_2 from a refinery and H_2 from water electrolysis	Total, 2020
Germany	Bse Engineering / Institute for Renewable Energy Systems (IRES)	2020	28 L/d	e-methanol	CO_2 and H_2 from water electrolysis (wind)	bse Engineering, 2020
Japan	Mitsui	2009	100 t/y	e-methanol	CO_2 and H_2 from water electrolysis	Mitsui Chemicals, 2009, 2010
Korea	Korean Institute of Science and Technology (KIST) / CAMERE process	2004	100 kg/d	e-methanol	CO_2 from power plant flue gas and H_2 from water electrolysis	Joo, 2004

Selected technology providers						
Iceland	CRI	Technology provider	50 000-100 000	e-methanol	CO_2 and H_2 from water electrolysis	CRI, 2020
Germany	Thyssenkrupp/ Uhde/Swiss Liquid Future	Technology provider	3 600-72 000	e-methanol	CO_2 and H_2 from water electrolysis	Thyssenkrupp, 2020a
Germany	Bse Engineering / BASF	Technology provider	8 200-16 400	e-methanol	CO_2 and H_2 from water electrolysis	bse Engineering, 2020
Denmark	Haldor Topsoe	Technology provider	Variable	e-methanol	CO_2 and H_2 from water electrolysis	HT, 2019a
United Kingdom	Johnson Matthey	Technology provider	Variable 100 000-1 700 000	e-methanol	CO_2 and H_2 from water electrolysis	JM, 2020

Notes: *(a) Hydrogen obtained from coke oven gas and not from water electrolysis.*
(b) Part of the hydrogen obtained from the waste stream of steel manufacturing.
n/k = not known.

Methanol GHG Emissions



GHG Emissions

Table 11. GHG emissions of methanol from various sources, ordered by feedstock type

Resource type	Feedstock	Original system boundaries	Raw material to final use GHG emitted in g CO_2eq/MJ*	Source
Biomass-based	Farmed wood	(A)	12	Majer and Gröngröft, 2010
	Farmed wood	(A)	16.5	RED II, Annex V, 2018 (EU, 2018)
	Farmed wood (current to near term)	(A)	7.3	Chaplin, 2013
	Farmed wood (novel medium term)	(A)	4.6	Chaplin, 2013
	Waste wood	(A)	10	Majer and Gröngröft, 2010
	Waste wood	(A)	13.5	RED II, Annex V, 2018 (EU, 2018)
	Waste wood	(A)	16.1	Rönsch et al., 2014
	Waste wood	(A)	22.6	BLE, 2017
	Waste wood	(A)	5.3	Chaplin, 2013
	Waste wood	(A)	18.3	Ellis and Svanberg, 2018
	Wood	(D)	25	Kajaste et al., 2018
	Wood chips	(B)	20.91	Ecoinvent, 2019
	Black liquor	(A)	10.4	RED II, Annex V, 2018 (EU, 2018)
	Black liquor	(B)	12	Lundgren et al., 2017
	Black liquor	(A)	3	Chaplin, 2013
	Black liquor	(A)	5.7	Ellis and Svanberg, 2018
	Crude glycerine	(A)	30.6	Chaplin, 2013
	Biogas	(A)	34.4	Chaplin, 2013
	Biogas (manure, crops)	(A)	30	Majer and Gröngröft, 2010
Power-based	Renewable electricity, flue gas from biomass plant	(B)	3.23	Buddenberg et al., 2016
	Renewable electricity, CO_2 from ethanol plant	(A)	13	Matzen and Demirel, 2016
	Renewable electricity, CO_2 from biogas process	(B)	0.5	Hoppe et al., 2018
	Renewable electricity, CO_2 from ethanol plant	(D)	21.3	Kajaste et al., 2018
	Renewable electricity, CO_2 captured from coal power plant	(D)	33.1	Kajaste et al., 2018
	Renewable electricity, flue gas (geothermal energy plant)	(A)	12.1	CRI, 2020
	Renewable electricity, flue gas from biomass plant	(A)	1.74	Chaplin, 2013
Fossil-based	Natural gas	(B)	101.6	Ecoinvent, 2019
	Natural gas	(C)	94	Kajaste et al., 2018
	Natural gas	(A)	91	Ellis and Svanberg, 2018
	Natural gas	(A)	94.4	Chaplin, 2013
	Hard coal	(B)	262	Ecoinvent, 2019
	Hard coal	(C)	219	Kajaste et al., 2018
	Lignite	(A)	170.8	Rönsch et al., 2014

** Raw material to final use GHGs in g CO_2-eq/MJ calculated from the original system boundary:*

(A) From raw material extraction until use phase; no correction needed.

(B) From raw material extraction until methanol production gate; add the RED II default value of 2.0 g CO_2-eq/MJ for transport and distribution of MeOH.

(C) From raw material extraction until methanol production gate; add the RED II default value of 2.0 g CO_2-eq/MJ for transport and distribution and the combustion emission of MeOH of 69 g CO_2-eq/MJ.

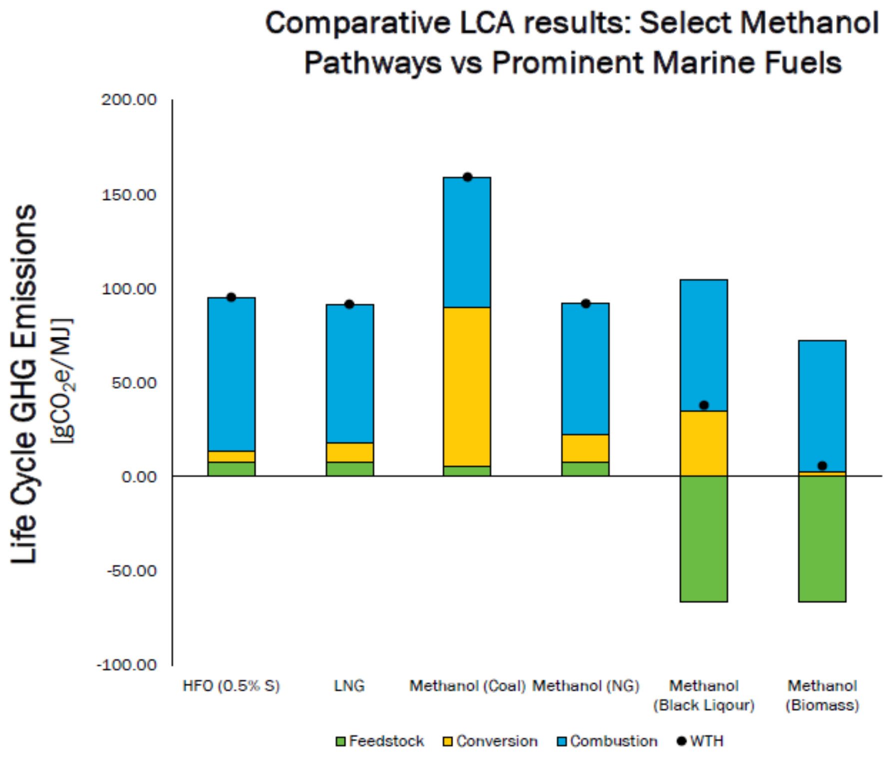
(D) From raw material extraction until methanol production gate; corrected for CO2 emitted during methanol use 69 g CO_2-eq/MJ; add the RED II default value of 2.0 g CO_2-eq/MJ for transport and distribution of MeOH.

GREET Model

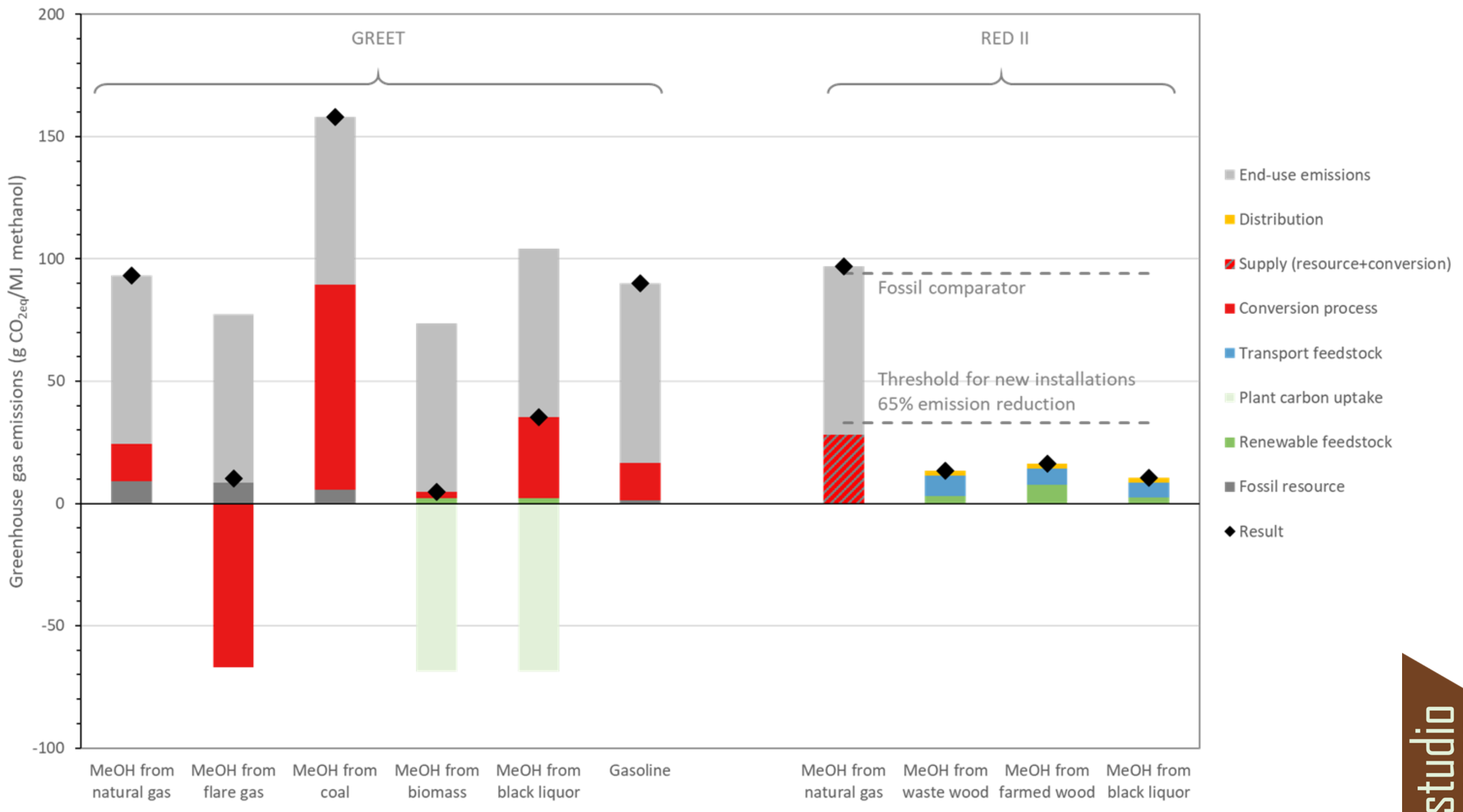
Argonne GREET: Marine Methanol Pathways

GREET Marine Methanol Pathways:

1. Methanol from Coal
2. Methanol from Natural Gas
3. Methanol from Flare Gas
4. Methanol from Renewable Natural Gas
5. Methanol from Black Liquor
6. Methanol from Biomass



GREET & RED II



GREET
RED II
200
150
100
50
0
-50
-100
Greenhouse gas emissions (g CO_{2eq}/MJ methanol)
Fossil comparator
Threshold for new installations
65% emission reduction
MeOH from natural gas
MeOH from flare gas
MeOH from coal
MeOH from biomass
MeOH from black liquor
Gasoline
MeOH from natural gas
MeOH from waste wood
MeOH from farmed wood
MeOH from black liquor
End-use emissions
Distribution
Supply (resource+conversion)
Conversion process
Transport feedstock
Plant carbon uptake
Renewable feedstock
Fossil resource
Result

GREET

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Pathway	Emissions (gCO_{2eq}/MJ final product)		Data sources for proces steps
Methanol from natural gas *(66.5 – 71% process efficiency)*	Feedstock	9.1	• Wang 2007
	Processing	15.3	
	Combustion	68.8	
Methanol from flared gas (66.5-71% process efficiency)	Feedstock	8.5	• Wang 2007
	Processing	-67.1	
	Combustion	68.8	
Methanol from coal (43 – 58% process efficiency)	Feedstock	5.6	• Wang 2007
	Processing	83.8	
	Combustion	68.8	
Methanol from biomass *(31 – 58% process efficiency)*	Feedstock	-66.5	• Wu 2005
	Processing	2.5	
	Combustion	68.8	
Methanol from black liquor *(64.8% process efficiency)*	Feedstock	-66.5	• None
	Processing	33.0	
	Combustion	68.8	

- Wang M, Wu Y and Elgowainy A, 2007, Operating manual for GREET Version 1.7 revised ANL/ESD/05-3, Argonne National Laboratory.
- Wu M, Wu Y and Wang M, 2005. Mobility Chains Analysis of Technologies for Passenger Cars and Light-Duty Vehicles Fueled with Biofuels: Application of the GREET Model to the Role of Biomass in America's Energy Future (RBAEF) Project.
- ANL GREET research leader Mr. Michael Wang: "***No thorough research was conducted to examine key input assumptions for the methanol pathways***"

RED II

[EC JRC 2017 Definition of input data to assess GHG default emissions from biofuels in EU legislation]

Pathway	Emissions (gCO_{2eq}/MJ final product)		Data sources for proces steps
Methanol from natural gas (as input in FAME production)	Supply Combustion	28.2 68.9	• Larsen 1998
Methanol from waste wood *(70% process efficiency)*	Cultivation Transport feedstock Processing Transport/distribution final	3.1 8.4 0.0 2.0	• Katofsky, 1993 • Dreier 1998 • Paisley 2001 • Atrax 1999
Methanol from farmed wood *(51% process efficiency)*	Cultivation Transport feedstock Processing Transport and distribution	7.6 6.6 0.0 2.0	• Same as for waste wood
Methanol from black liquor *(74% process efficiency from pulp)*	Cultivation Transport feedstock Processing Transport and distribution	2.5 5.9 0.0 2.0	• Berglin 1999 • Landälv 2007 • Ekbom 2005

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Methanol-to-Hydrogen Generators

May 26, 2021

Dave Edlund, Ph.D.
CEO and Founder
Dave@e1na.com

Scalable.
Reliable.
Affordable.

Energy-Efficient Process

$CH_3OH + H_2O + heat \rightarrow 3\ H_2 + CO_2$

Ideal reaction—in reality, also get some CO (requires hydrogen purification)

- Unlike water electrolysis, very little electricity is required for methanol reforming to hydrogen
  - Water electrolysis consumes 50 to 55 kWhr electricity/kg hydrogen
  - Methanol reforming consumes <0.04 kWhr electricity/kg hydrogen
- Energy for methanol/water vaporization and reforming is supplied by combustion of waste-gas stream
  - 7.5 kWhr thermal energy yields 1.0 kg hydrogen
- High energy efficiency (84% LHV) is achieved in practice

Three Product Families

Compatible with any Low-Temperature PEM Fuel Cell

All hydrogen generators are fully automated

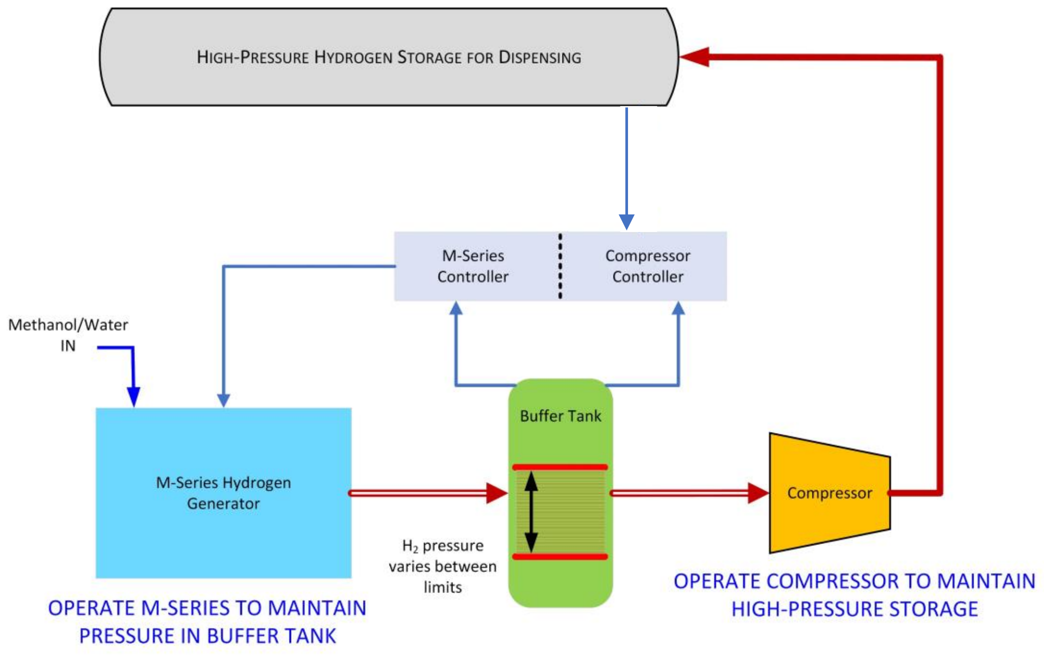
S-Series (small stationary)
Up to 0.7 kg H_2/hr
demonstrated

M-Series (mobility)

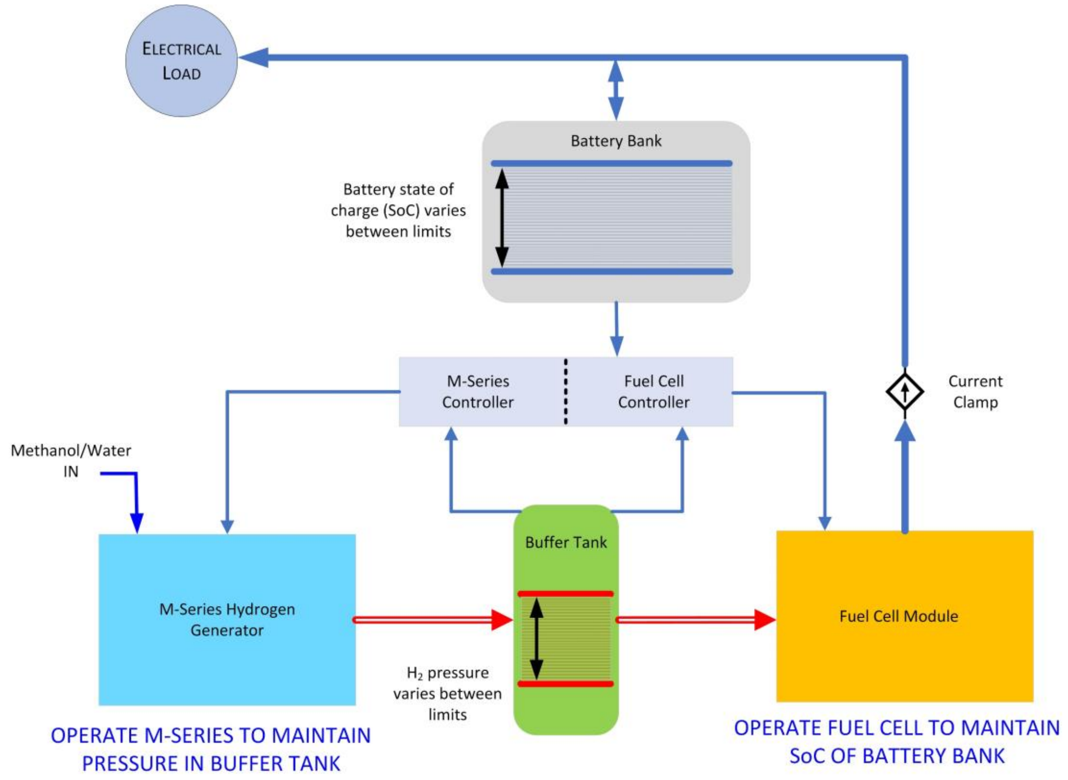
L-Series (large stationary)

Up to 9.8 kg H_2/hr demonstrated. Plan to scale-up at least 2x

Stationary Applications



Compressed –Hydrogen Fueling Station



Primary or Backup Stationary Power System

Low-pressure buffer tank simplifies interface to the compressor or fuel-cell

Onboard Hydrogen Generation

Compressed H_2 vs. Methanol/Water Mix

- Composite cylinders for hydrogen supply (80 kg H_2)
- At 7.5 miles/kg H_2, range is 600 miles (max., no reserve)
- Time to drive 600 miles is estimated to be 11 hours
- In 11 hours, M13 will deliver 77 kg H_2
- Consume 1,070 L methanol/water mix (283 gal)
  - 62.5wt% methanol (≈70% methanol by volume)
- In low mfg. volume, M13 will cost ≈ 50% price of composite cylinders for high-pressure hydrogen

Location of composite cylinders for hydrogen supply (80 kg H_2)

Estimated weight is 1,100 kg

M-Series Hydrogen Generator

Estimated weight is 900 kg

Generate Onboard Heavy-Duty Vehicle

Eliminates Need for High Pressure Hydrogen

- Onboard hydrogen generation beats compressed hydrogen on:
  - Capital cost
  - Size
  - Cost of hydrogen
  - Range

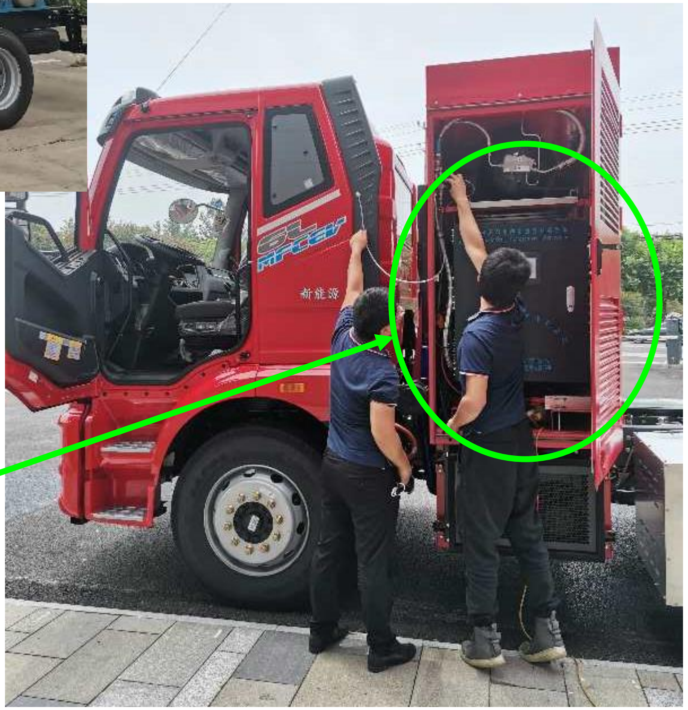
M-Series Hydrogen Generator

- Three operating states: ON, OFF, and HOT STANDBY
- HOT STANDBY to ON is achieved in one to two minutes
- Fuel cell should be sized to meet the average load demand
- Battery bank provides instantaneous power and peaking power

Commercial Opportunities

- Hydrogen fueling stations
- Hydrogen generation onboard heavy vehicles
  - Trucks
  - Trains
  - Ships and boats
- Auxiliary power in maritime applications
- Distributed generation
  - Backup
  - Microgrids

Road Testing by FAW Liberty in Changchun, China (2020)



M-Series Hydrogen Generator (Gen2)

Element 1
Powering Innovation

Thank you

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Methanol Institute

Hydrogen Carriers

Q221

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- **Independent Research**
  - Market Research
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  - Capital Connections & Private M&A
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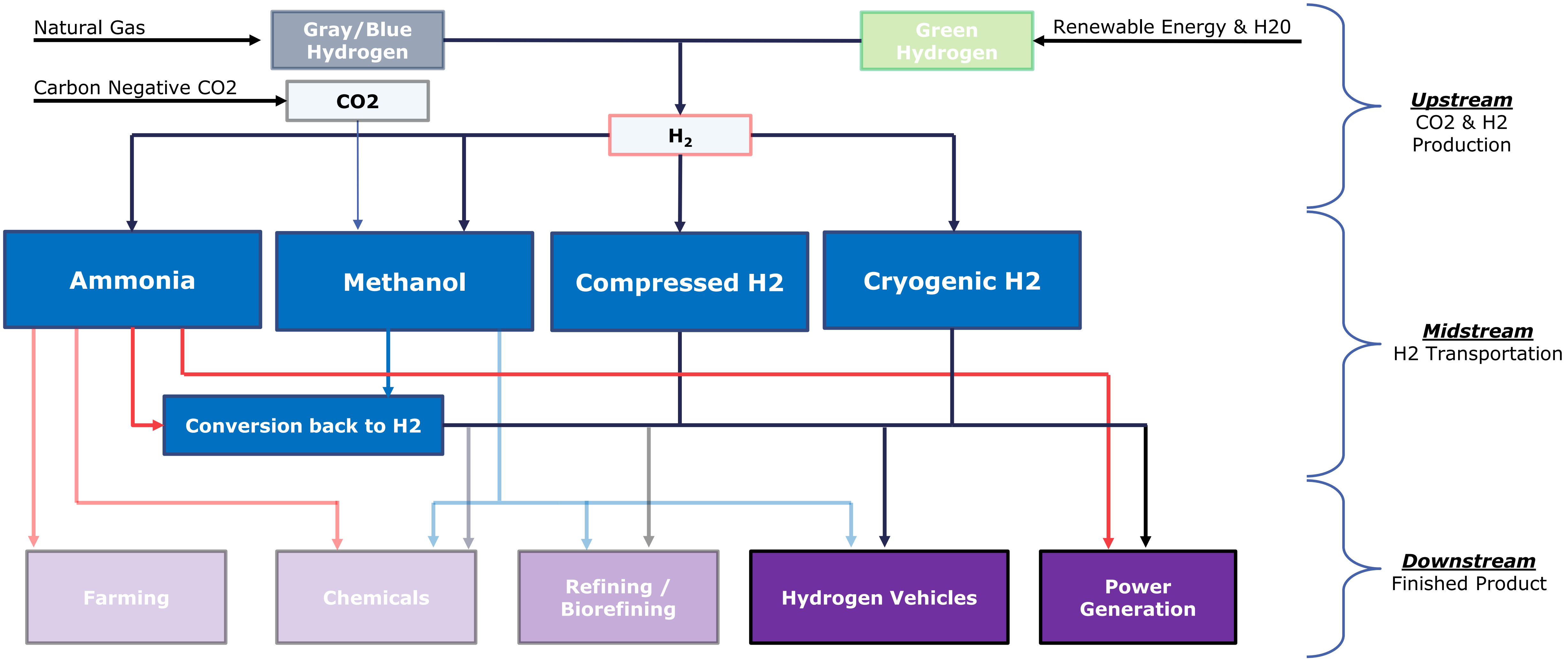
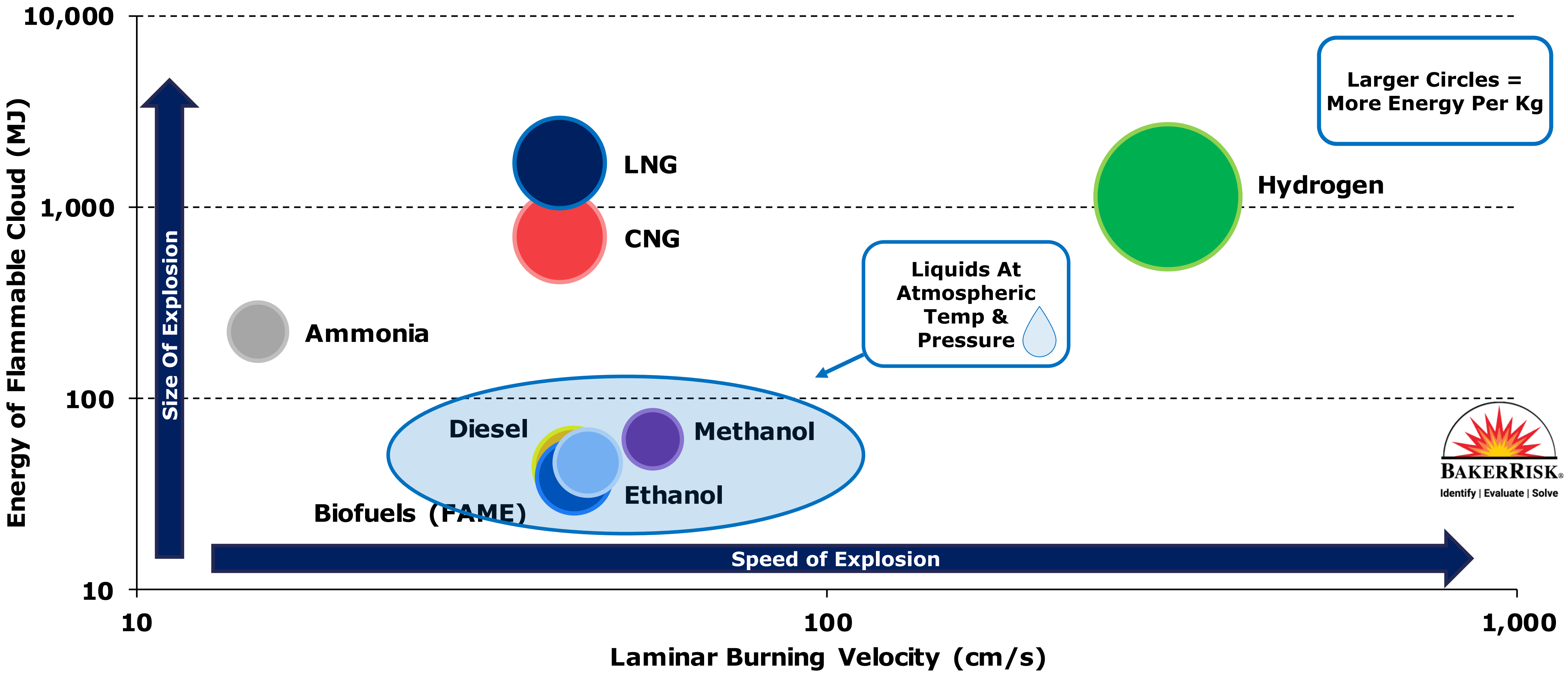
Hydrogen Carriers: Hydrogen’s Midstream



Hydrogen Vehicle’s Midstream Fuel Supply Pathways.

Fuel Safety Analysis From Baker Risk



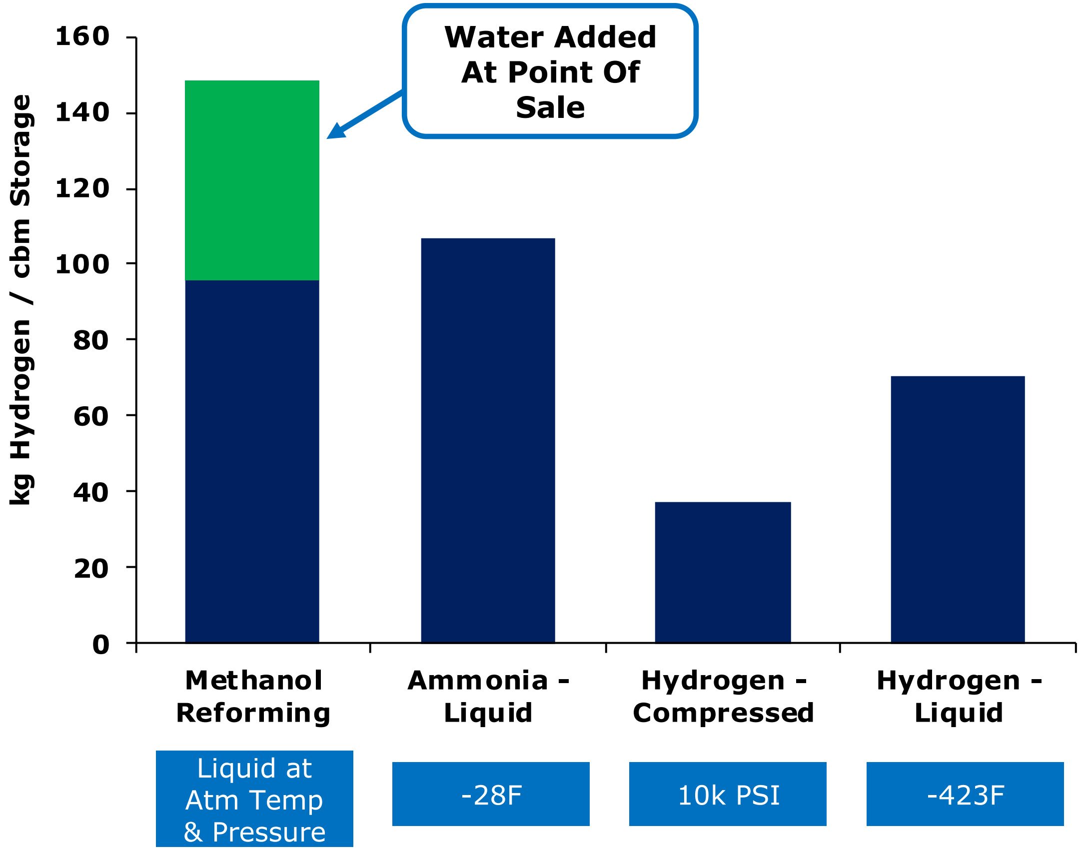
Methanol Has Many Of The Same Physical Properties Of Gasoline And Diesel.

1) Conditions for these fuels include: Methanol – 70F, 15psi, Ethanol – 70F, 15psi, Biodiesel – 70F, 15psi, Diesel – 70F, 15psi, Hydrogen – 70F, 250bar, Ammonia – 70F, 20psi, CNG – 70F, 250bar, LNG - -300F, 75psi
Source: Company & Regulatory Filings, W|EPC Analysis

Logistics Overview

- **H2 Sold By Kilogram, Not Gallon:** H2 sales price at the pump is determined by its weight and not volume.
- **Why Does This Matter:** To reduce H2's midstream costs, the focus should be on getting the most kg of H2 to the end user in 1 transport.
- **Methanol As A Carrier:** Methanol combines with water at the point of sale to generate 30-40% more hydrogen than Methanol carries.
- **Storage Considerations:** Process facilities weigh logistics in the design of their on-site storage capacities. Below is a brief comparison of CAPEX vs Hydrogen Capacity:
  - **Methanol: ~$7/kg H2**
  - **Ammonia:** ~$23/kg H2
  - **Cryogenic H2:** ~$162/kg H2
  - **Compressed H2:** ~$900/kg H2

Hydrogen Logistics

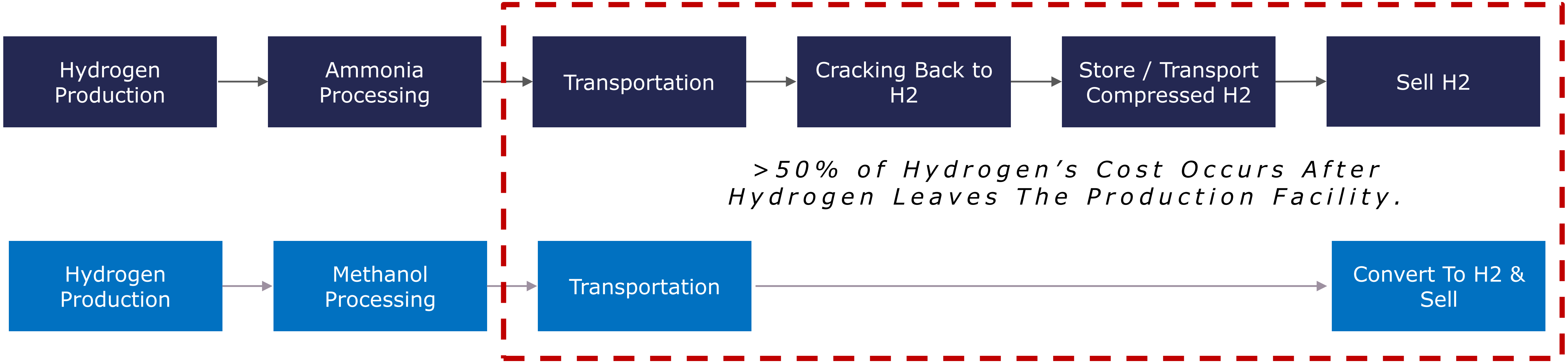


A 10,000 Gallon Tanker Truck Of Pure Methanol Produces ~5,000kg Of Hydrogen.

Source: Company & Regulatory, DOE Storage Costs, W|EPC Analysis

Hydrogen Carriers: Methanol Vs. Ammonia

Ammonia – Converting Ammonia to Hydrogen requires higher heat (600C to 900C = Outside Heat Source), more expensive equipment, and large centralized facilities for Hydrogen distribution to end users. Public spaces cannot currently convert Ammonia to Hydrogen without high costs and/or public safety risk.

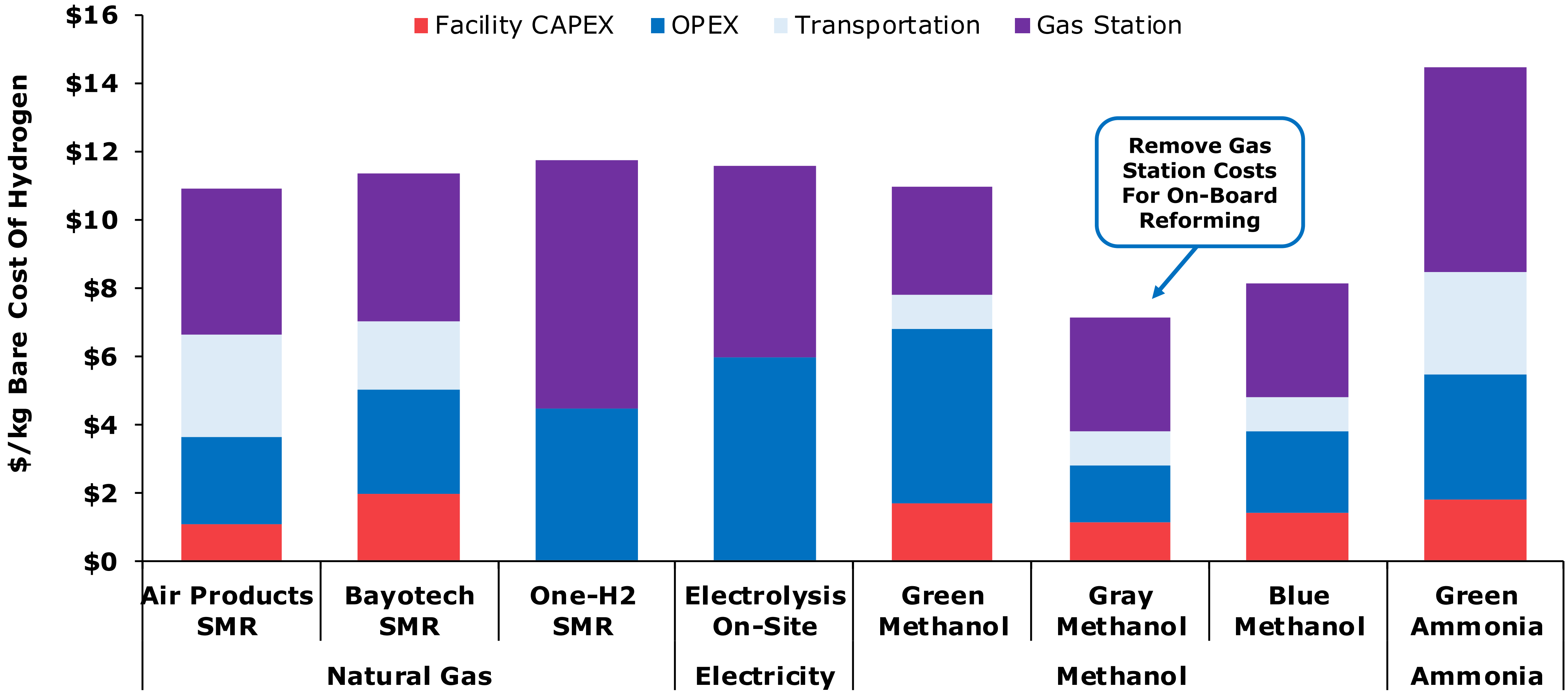


Methanol – Methanol can convert to Hydrogen at lower temperatures (300C to 450C). Methanol also leverages existing liquids infrastructure and converts to Hydrogen with proven technology that is less expensive, safer, and with a limited footprint.

Methanol Can Utilize Gas Station Storage With Existing Safety Measures.

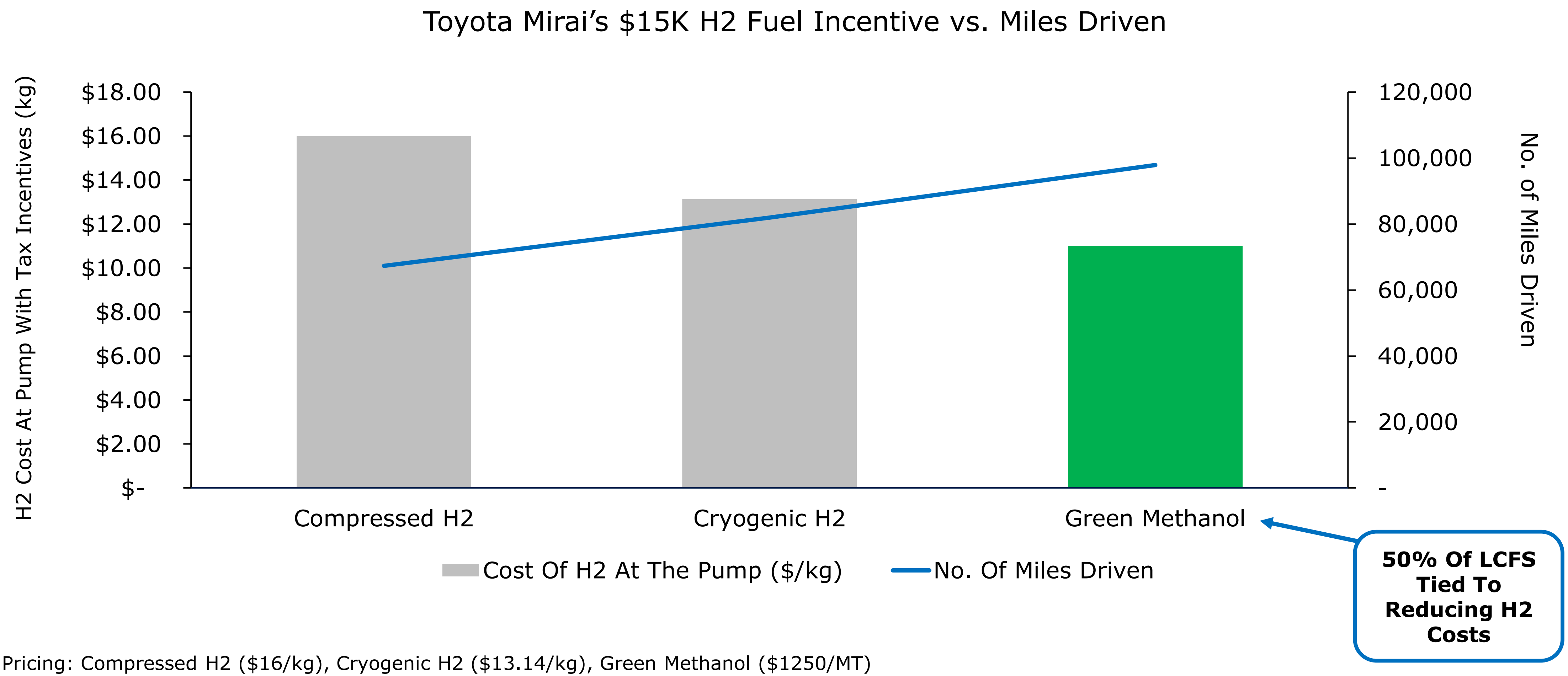
Source: Company & Regulatory Filings, W|EPC Analysis

Hydrogen Carriers: Build-Up Costs (No Tax Incentives)



Methanol Provides A Great H2 Solution Due To Storage, Transportation, And Low Conversion Costs.

Source: Company & Regulatory Filings, W|EPC Analysis

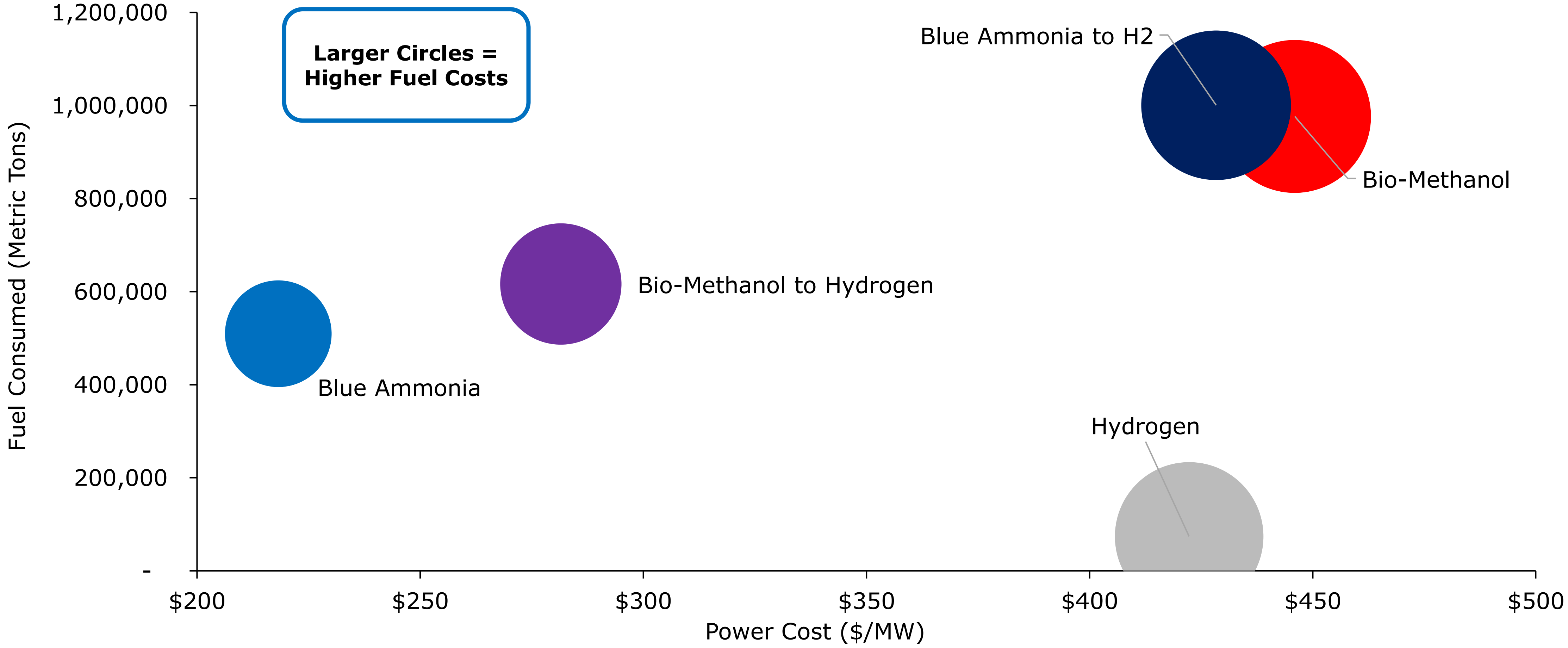


Pricing: Compressed H2 ($16/kg), Cryogenic H2 ($13.14/kg), Green Methanol ($1250/MT)

Green Methanol Decreases Costs & Emissions While Increasing Miles Driven By >40%.

Source: Company & Regulatory Filings, W|EPC Analysis

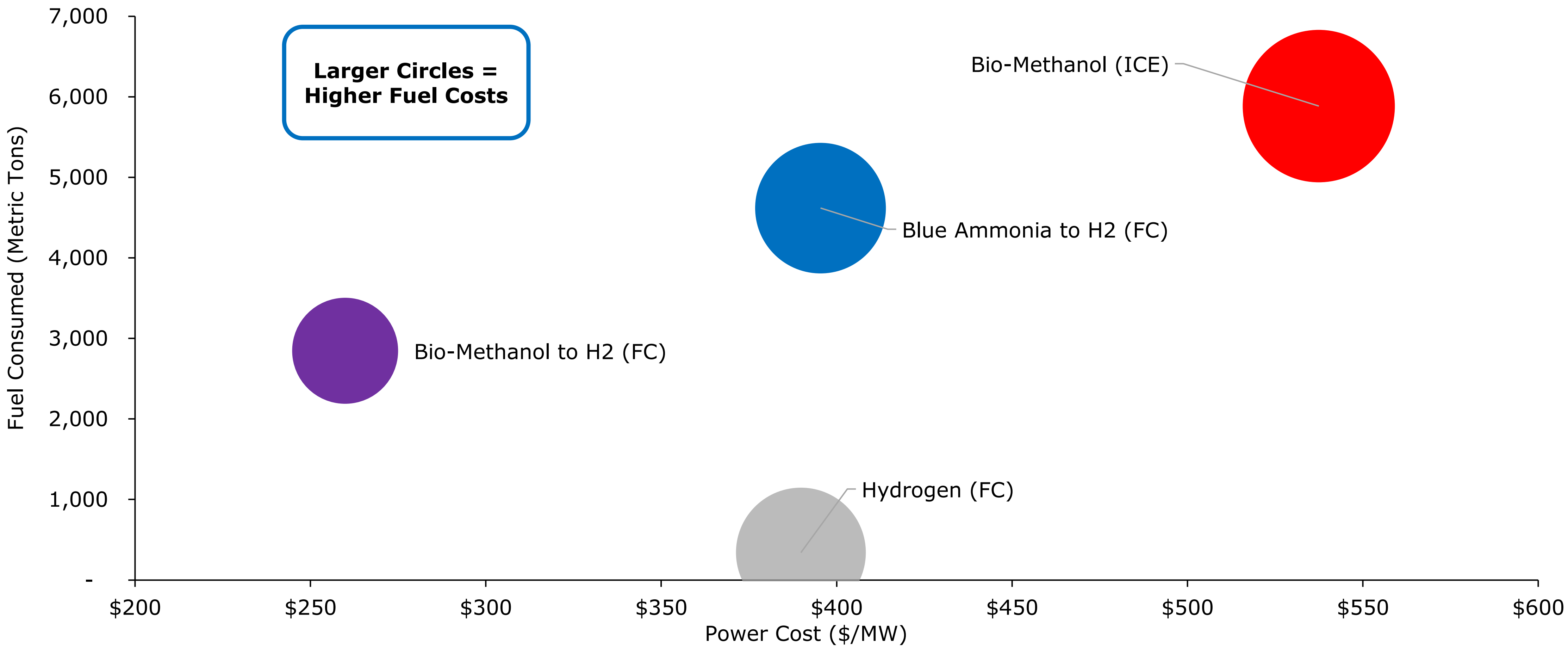
Hydrogen Carriers: Low Carbon Energy Comps (Turbines: 200MW for 1 Year)



Pricing: Blue Ammonia ($750/MT), Bio-Methanol ($800/MT), Hydrogen ($10/kg)

Blue Ammonia's Use In Large Scale Turbine Systems Make It A Good Fit For Power Generation.

Source: Company & Regulatory Filings, W|EPC Analysis



Pricing: Blue Ammonia ($750/MT), Bio-Methanol ($800/MT), Hydrogen ($10/kg)

Methanol Provides The Best Mid-Scale Power Benefits Using Fuel Cells.

Source: Company & Regulatory Filings, W|EPC Analysis

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BALLARD

The role of fuel cell technology in the decarbonization of heavy duty motility

Nicolas Pocard

Vice-President Marketing

May 2021


BALLARD
Fuel Cell Innovators for Over 40 Years

BALLARD

We deliver fuel cell power for a sustainable planet

Heavy-Duty Motive

Focusing where fuel cells deliver the strongest value proposition

Growth

in regions supported by decarbonization policies

Leadership

in technology and cost reduction

Hydrogen is most competitive in heavy duty motive applications

Buses & Coaches

Trucks

Trains

Vessels

Our focus is on applications where hydrogen fuel cells have a clear advantage

BALLARD

Why medium- and heavy-duty motive applications?

Strong
value proposition

Centralized
depot refueling

Disproportionate
emissions from
hard-to-abate mobility

The advantages of fuel cells over battery electric vehicles

Only fuel cell vehicles can directly replace diesel, route for route

All weather performance

Range and payload

Refueling time

BALLARD

Ballard by the Numbers

42
YEARS

900
employees

1,400
patents & applications

26 years Nasdaq
28 years TSX
publicly listed Company

WEICHAI
AngloAmerican
NISSHINBO
大洋电机 BROAD-OCEAN
4
strategic shareholders

1,300+
transit buses

2,200+
trucks

6 TRAIN
projects on track

8 SHIPS
in development

HIGH-POWER DENSITY
stack development program

850 MW
fuel cell products delivered

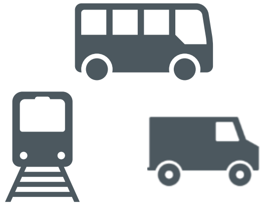
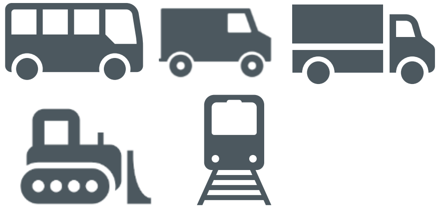
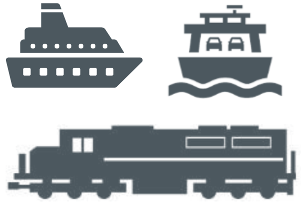
>6.5million MEAs
produced

>88 million
kilometers in operation

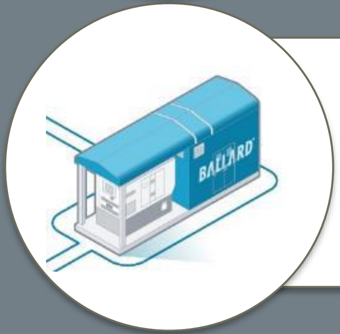
>35,000hours
operation of fuel cell stack

2030
commitment to carbon neutrality

Ballard's current fuel cell module offering for HD mobility

		Power Level	Features	Applications
	FCveloCity®	30, 85 & 100kW Legacy Mobility Platform (7th generation)	▪ >1,500 modules produced ▪ 15,000hrs ▪ IP 55 ▪ Separate air and cooling kits	
	FCmove™	70 & 100 kW HD Mobility Engines (8th generation)	▪ >25,000hrs ▪ Freeze start (-25 °C) ▪ Engine bay and roof top ▪ IP6K9K	
	FCwave™	200kW HD Power System Marine & Rail	▪ >25,000hrs ▪ Marine certified ▪ Cabinet configuration ▪ Stand alone or containerized ▪ Multiple modules to MWs	

Ballard's current fuel cell system offering for stationary

		Power Level	Features	Applications
	FCgen® – H2PM	1.7 & 5kW Backup Power for critical infrastructure	▪ 7,000hrs ▪ Systems can be coupled to 60kW ▪ High reliability	
	FCwave™	200 kW Modular Stationary Power System	▪ >25,000hrs ▪ Cabinet configuration ▪ Stand alone or containerized ▪ From 200kW to 1MW	
	ClearGen™ II	1.5 MW Large Scale Stationary	▪ Containerized system ▪ High durability ▪ Compact system footprint ▪ MW's power plant	

We are powering thousands of heavy-duty vehicles globally.

BALLARD PARTNERS WITH

NEW FLYER

Ballard-powered New Flyer buses are ready to deliver zero-emission transit throughout North America

New Flyer offers a 40-foot and 60-foot Altoona-tested fuel cell electric buses

FCveloCity®-HD

BALLARD PROJECT WITH

KENWORTH

Class 8 drayage truck in operation at Ports of LA and Long Beach in California

FCveloCity®-HD

BALLARD PROJECT WITH

DONGFENG

Deployment of 500 fuel cell trucks now delivering goods throughout Shanghai

Ballard fuel cell stacks manufactured in China and integrated by Re-Fire into the fuel cell engine

BALLARD POWERS

UPS TRUCKS

Ballard fuel cell modules power California UPS trucks in CARB-funded clean energy project

30kW range extender boosts driving range to provide certainty of service

BALLARD POWERS

AZETEC PROJECT

Ballard modules power 2 tractor-trailer trucks as part of the Alberta Zero-Emissions Truck Electrification Collaboration project

Trucks will move freight year-round between Edmonton and Calgary

FCveloCity®-HD

BALLARD POWERS

MINING TRUCKS

Ballard modules power an ultra heavy duty mining truck for Anglo, the world’s largest platinum group metals mining company

Anglo expects to deploy more trucks, each with MW scale fuel cell power, at other operations around the world

BALLARD POWERS

FIRST COMMERCIAL TRAM LINE

Ballard modules power five trams built by CRRC Qingdao Sifang for operation in Foshan, China

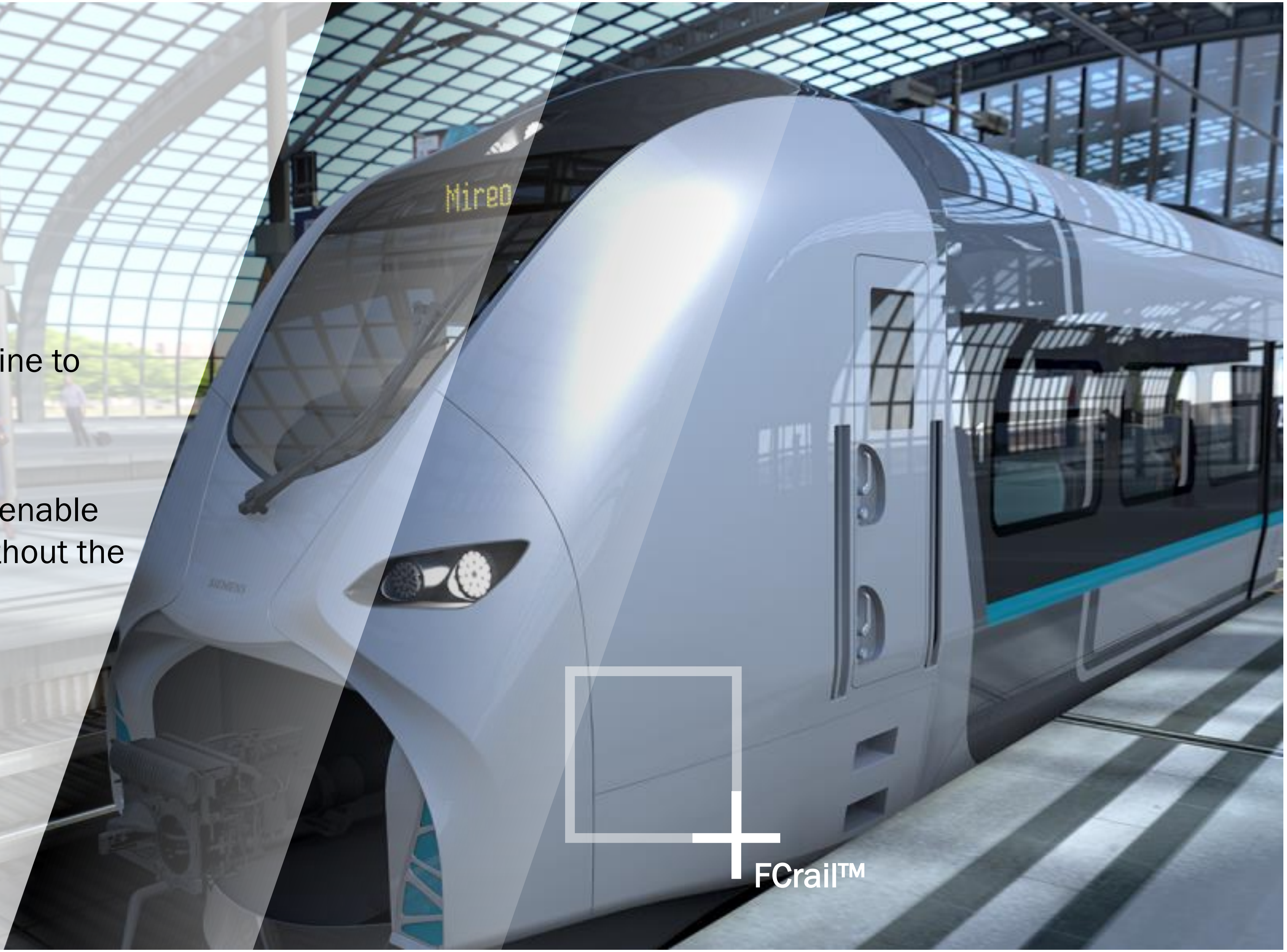
The tram has a maximum range of 125 kilometers and has operated over 102,800 kilometers in service since Dec-2019

BALLARD PARTNERS WITH

SIEMENS

Development of fuel cell engine to power Mireo commuter train

In this application, fuel cells enable electrification with range, without the need for costly catenary wire infrastructure



BALLARD POWERS

HYDROFLEX TRAIN

Ballard modules power the U.K.'s first fully sized hydrogen demonstrator train

Ballard also provides system controls development, mechanical integration of sub-systems and other components

BALLARD POWERS

CP RAIL locomotive

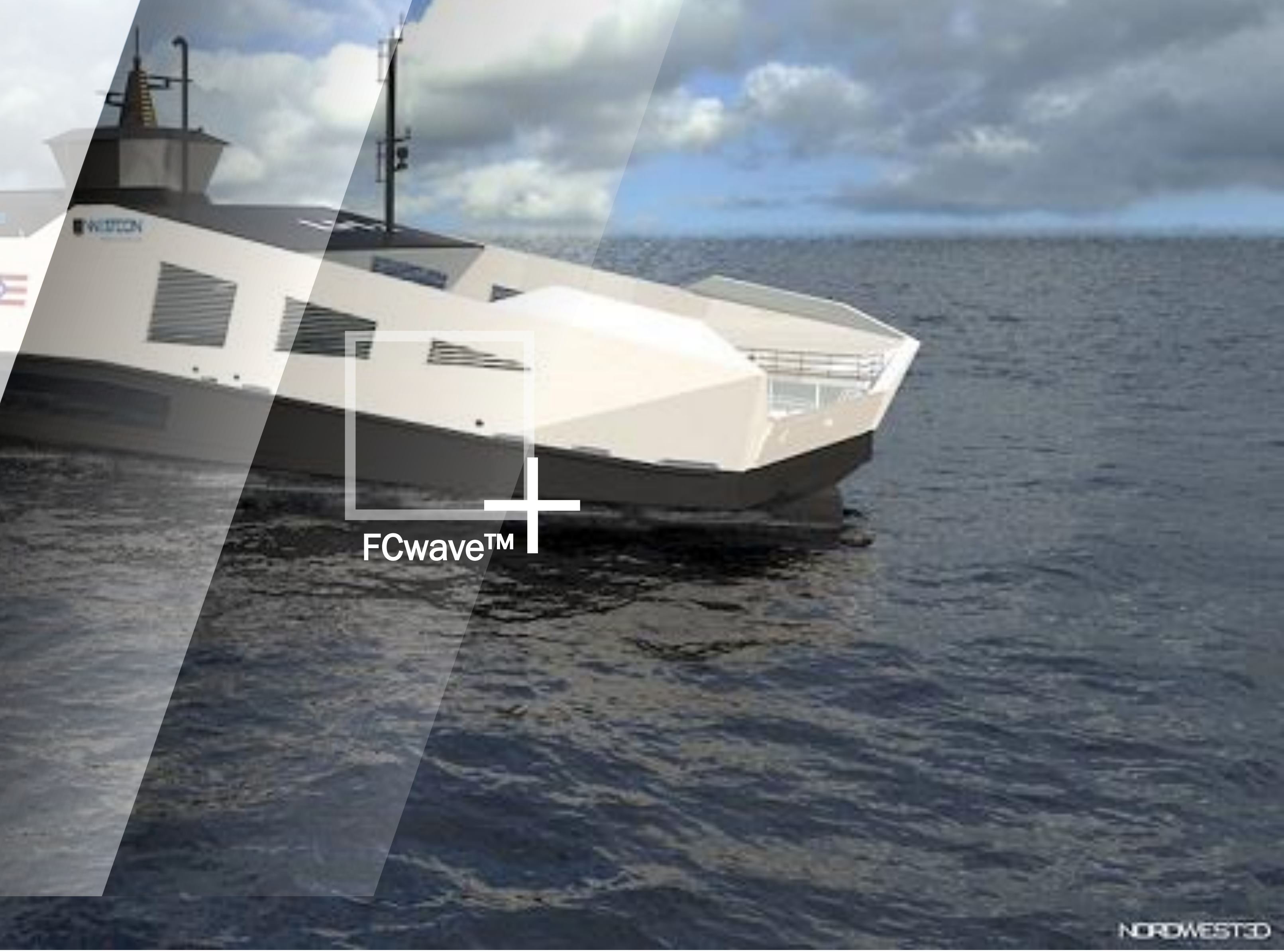
Through its Hydrogen Locomotive Program, CP will develop North America's first hydrogen-powered line-haul freight locomotive by retrofitting a formerly diesel-powered locomotive with Ballard hydrogen fuel cells.

BALLARD POWERS

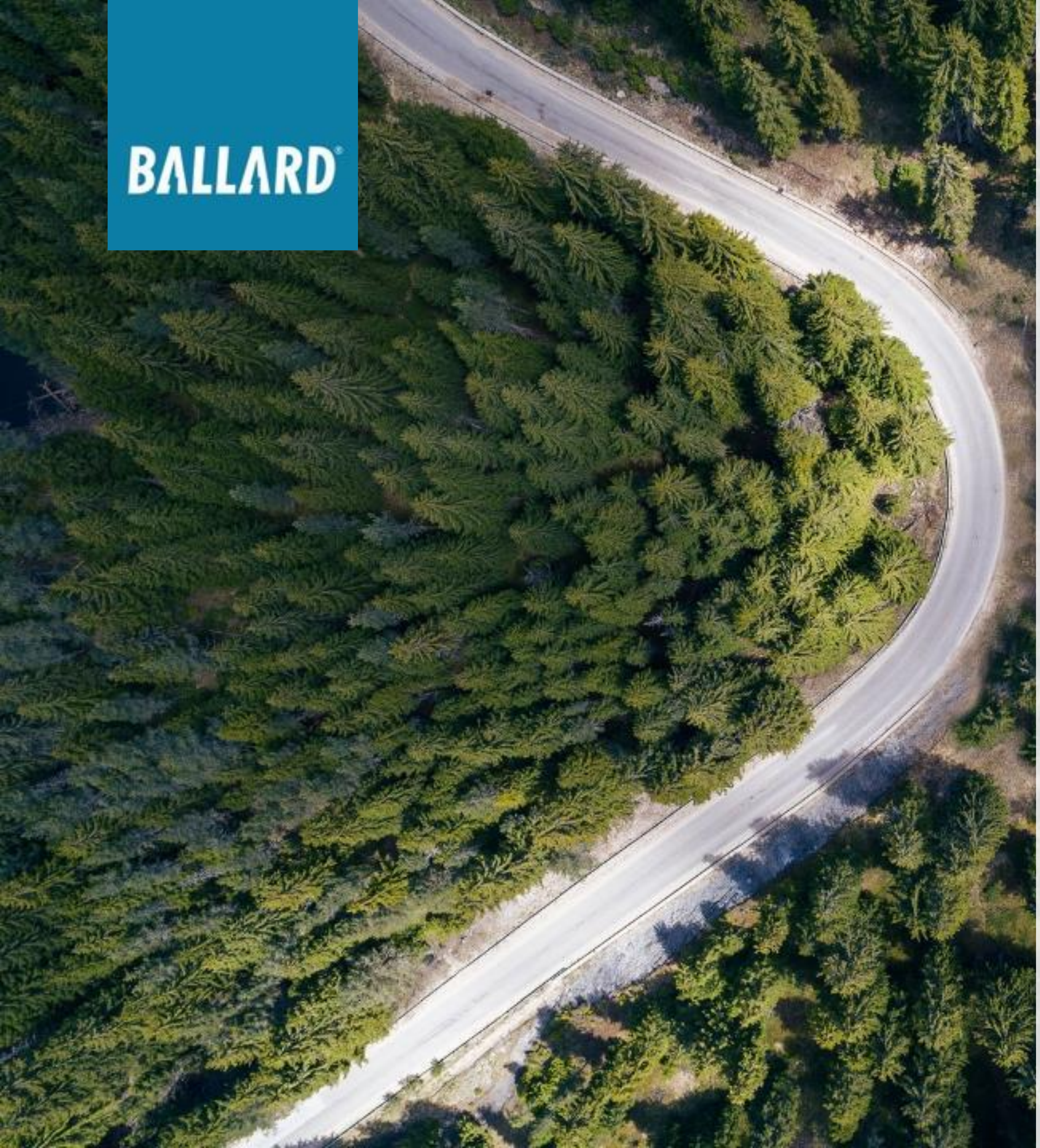
Norled Ferry

Ballard will power the world's first operational liquid hydrogen powered ferry, which will transport both cars and passengers in Norway

"We believe that hydrogen will play a significant role in the future of zero-emission ships," said Heidi Wolden, CEO of Norled.



LMG MARIN



BALLARD®

Power to Change the World®

Thank You


Marine
Getting hydrogen to work
Stuart Crawford
scrawford@e1marine.com

e1 Marine

Who we are

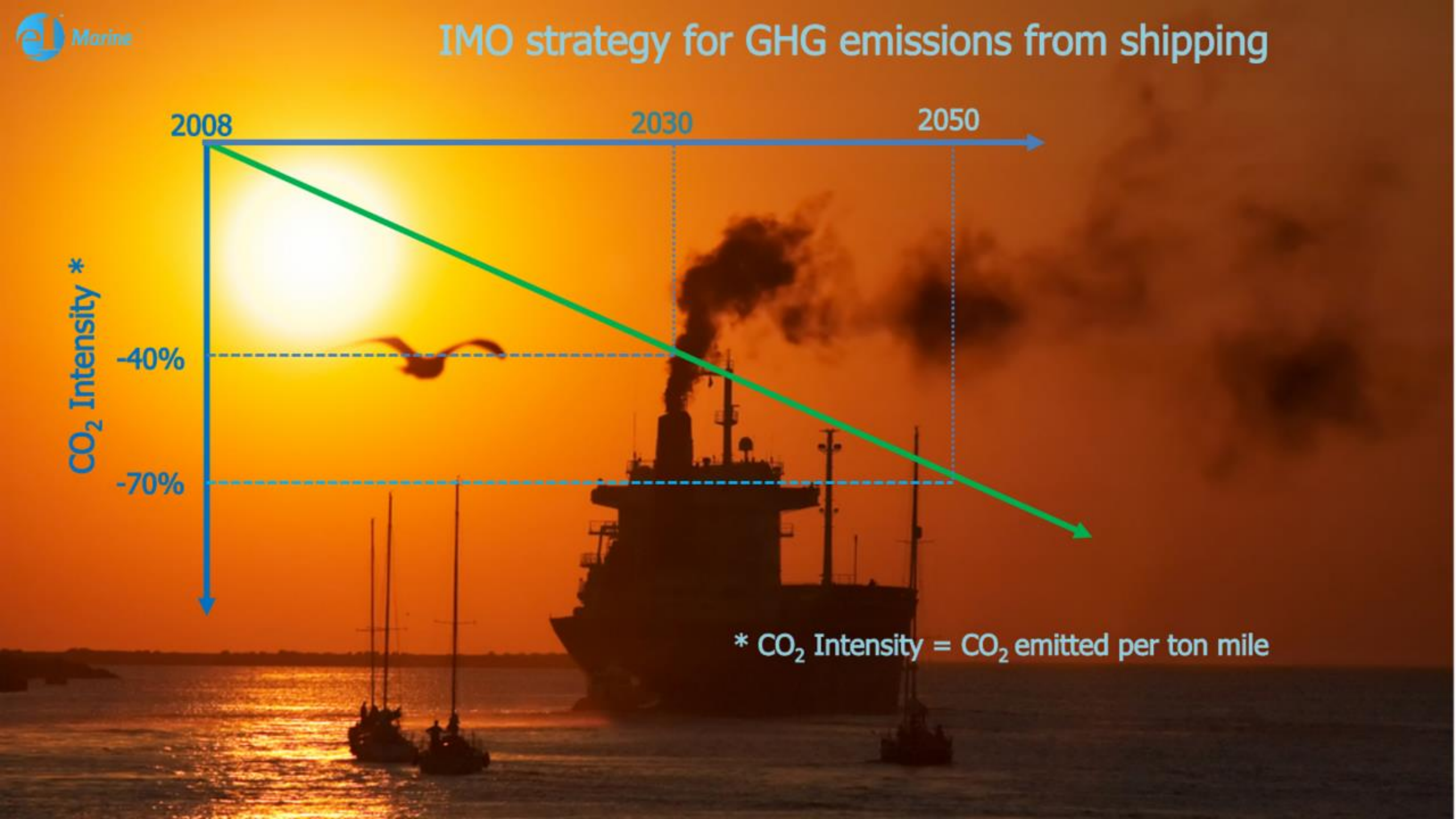
Ardmore Shipping Corporation

MP

Element 1

e1 Marine

- → 3 visionary joint venture partners driven to change the face of shipping by bringing an innovative hydrogen generation solution to the maritime industry
- → e1 Marine is tasked with bringing the vision to fruition



IMO strategy for GHG emissions from shipping
2008
2030
2050
CO_2 Intensity *
-40%
-70%
* CO_2 Intensity = CO_2 emitted per ton mile

Marine

Hydrogen is the solution.

Methanol/water mix is the most effective hydrogen carrier.

The Methanol reformer solves the Hydrogen delivery, energy density and safety issues.

Direct onboard generation of hydrogen enables fuel cell technology to be adopted into the marine industry.

Marine

Marine

https://www.e1marine.com/

The Methanol Pathway to Hydrogen Webinar

May 26th, 2021

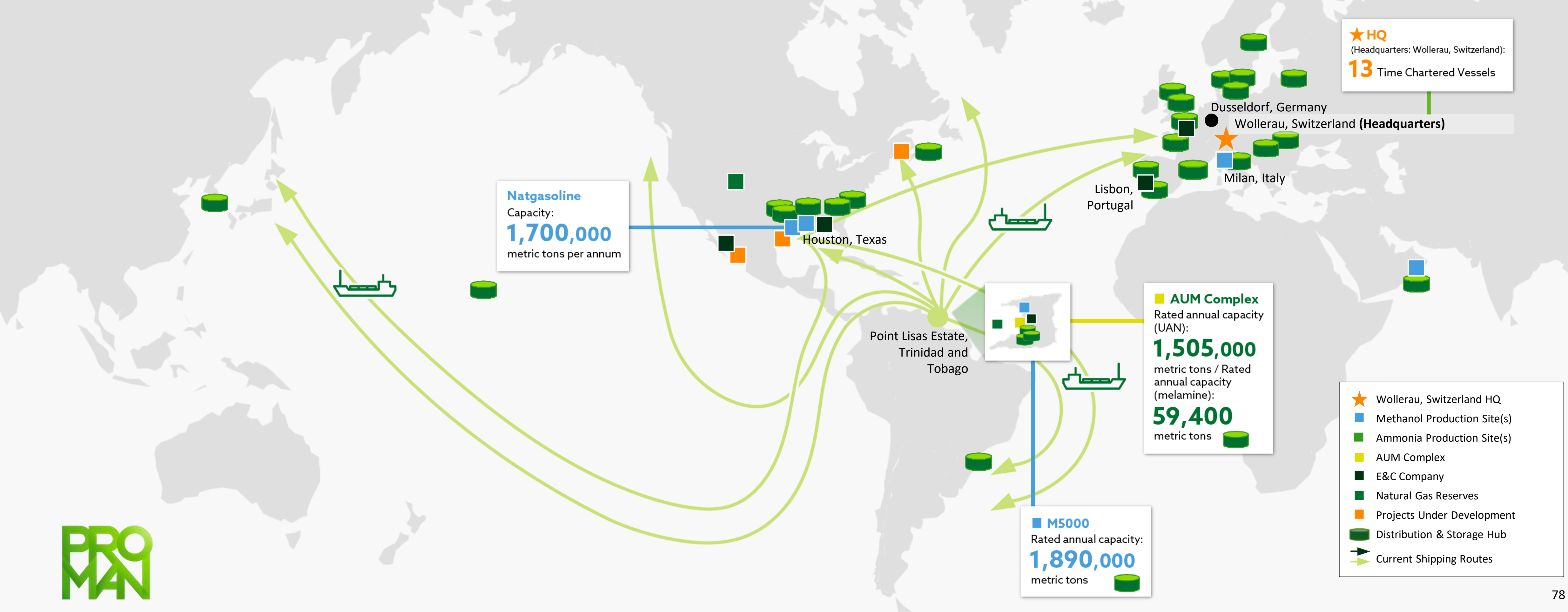
Key Facts and Figures

- Headquartered in Wollerau, Switzerland
- 30+ years operating in Trinidad and Tobago
- 1,600 employees operating in four continents
- 17 petrochemical plants worldwide
- 10,000,000 MT/y production capacity
- EPC experience with over 15 plants built
- Fleet of 13 time-chartered vessels comprised of 9 zinc-coated, 3 epoxy-coated chemical tankers and 1 marine-line coated tanker, with an additional 4 newbuildings on order owned by Proman and Proman Stena Bulk

We have a large global footprint

Our global footprint allows us to leverage our wide range of in-house expertise, geographic positioning and local knowledge to optimise our assets and best serve our customers

- **2nd** Largest Producer of Methanol Globally
- **4th** Leading Fertilizer Producer in North America
- **$6 +** Billion Dollars in Assets
- **27** Storage Locations Across 5 Continents
- **7** E&C Company Offices Worldwide



Proman is Committed to a "Greener" Future

Proman is committed to **investing in new, innovative clean energy technologies** around the world

We are **adopting non-fossil fuel production of our core products** and developing new products demanded by a clean energy economy

As a **top producer of** methanol and ammonia, both **hydrogen carriers**, Proman is positioned to lead and drive adoption of both commodities as clean energy fuels

We are actively **leveraging** our **operational expertise** and **deep industrial knowledge** to capitalize on the transition to a greener economy

Our production of low emission methanol in Trinidad & Tobago **recycles CO_2** from nearby fertilizer plants

We continue to **study ways to reduce the environmental impact** of our existing assets

PROMAN

5

Thought Leadership

- **Innovation**
- **Technology Improvement**
- **Investment**
- **Implementation**

Strategic Partnerships

- **Government**
- **Communities**
- **Academic Institutions**
- **Private Sector**

Sustainable Future

PROMAN

We are already investing in the energy future

Varennes Carbon Recycling Project

- One of the world's largest renewable hydrogen and oxygen production facilities with an 87MW electrolyzer leveraging Quebec's green electricity
- Conversion of more than 200,000 tons of non-recyclable waste and wood waste into an annual production of nearly 125 million liters of biofuels
- Contribution to greenhouse gas reduction equivalent to taking close to 50,000 vehicles off the road annually

Malta Energy Storage System

- Malta's electro-thermal energy storage system is a new grid-scale technology that collects and stores energy for long durations
- Energy can be stored from any power generation source in any location enabling reliable and predictable operation of the grid, which will support increasing penetration of intermittent, renewable generation

Proman – Stena Bulk Joint Venture

- Landmark investment promoting use of methanol as a clean, low-carbon marine fuel alternative with significantly lower emissions than traditional fossil fuels
- Proman – Stena vessels eliminate SOx and particulate matter, reduce NOx by 60%, and, if using bio methanol, reduce CO_2 emissions by up to 95%

PROMAN

Why methanol?

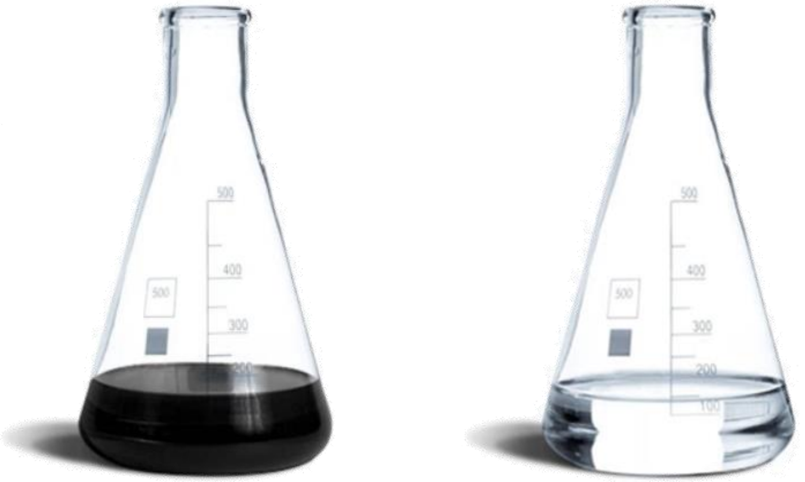
- Methanol is a clean burning fuel with significantly lower emissions than traditional fuels
- It eliminates SO_x and Particulate Matter, and cuts NO_x
- Grey methanol also brings an immediate 10-15% CO_2 reduction, which increases to >90% with Green methanol

- Grey methanol is cost competitive as a fuel now and future proof
- Long term pricing visible to market, global cost curve not oil based

- Methanol is safe to handle, and part of a tested and established infrastructure
- It is available in 122 ports worldwide, including all major bunkering hubs, with relatively low infrastructure costs

- Methanol runs well in existing engine technology with few modifications and significantly lower CAPEX when compared to other available alternative fuels. It also shows great promise in stationary power, mobility and marine fuel cell applications.
- Significant operating history already available

- Methanol is fully biodegradable, reducing lasting environmental harm and complying with the latest environmental regulations

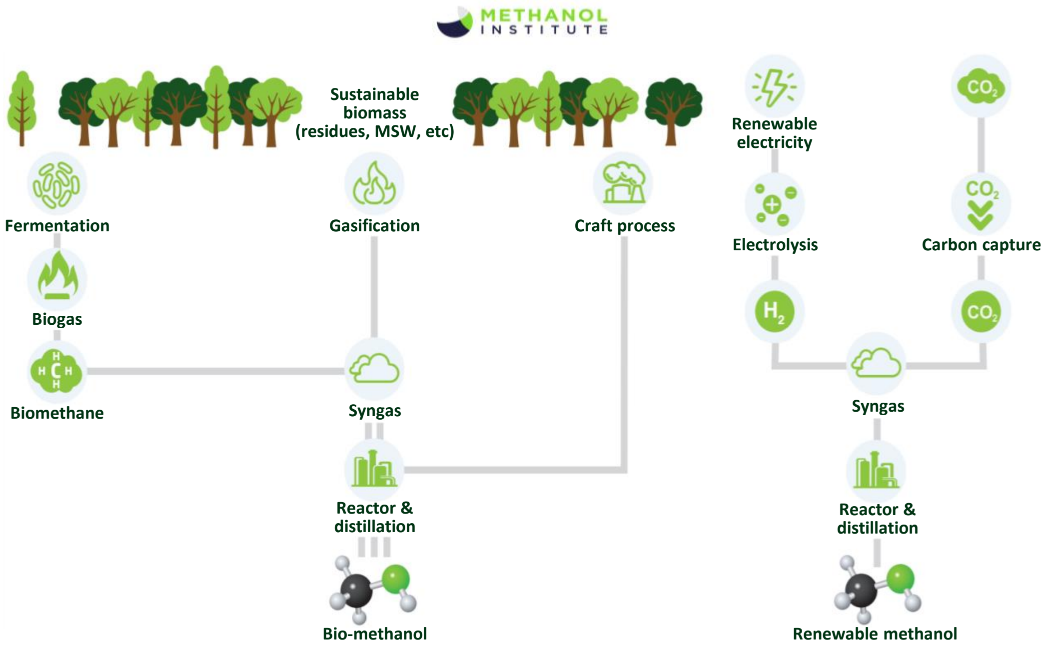


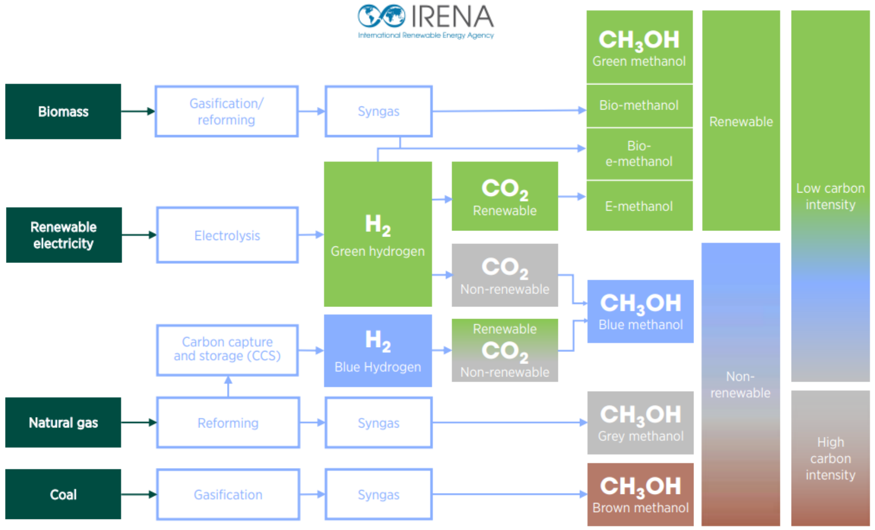
GASOLINE

METHANOL

Methanol is a carbon neutral, and potentially carbon negative, hydrogen carrier

- Effective energy carrier: rich in hydrogen
- Easy to manage, inexpensive to store and transport
- Large Scale Production Potential vs Other Fuels
  - Grey methanol is a low carbon pathway fuel
  - Blue methanol (natural gas-based with carbon capture) can be an intermediary, easy to implement and cost-effective solution to bridge the price gap
  - Green e-methanol is produced from renewable power, water and recycled CO_2
  - Green Bio-methanol can be produced from a variety of biomass sources, including municipal waste





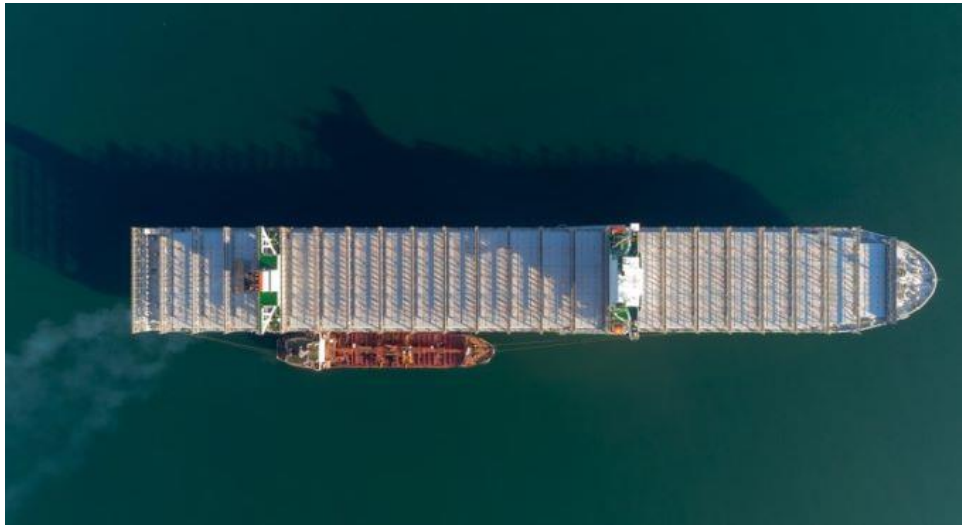
Why Proman decided to use methanol-powered ships

- Proman is a global leader in the production of natural gas derived products & services
  - Number 2 global producer of methanol with ~7m tons of low-carbon Grey methanol production capacity
- Proman transports methanol to all major shipping bunkering ports already
  - Exploring methanol bunkering solutions as part of industry initiative with close partners
- Significant sustainability commitment with:
  - Current low carbon methanol in Trinidad and the United States
  - Green methanol Projects in development and construction in Canada and Belgium and in development in other global locations
  - Vessel replacement programme in JV with Stena Bulk to build three methanol- fuelled vessels
- Ability to provide low carbon methanol as a marine fuel today, with a clear and invested pathway to reducing current carbon intensity as we blend Blue and Green methanol with Grey methanol

- **IMO safety guidelines -> Interim ships safety guidelines formally approved**
- **OEMS have improved their promotion of methanol engines, with over 30 vessels on the water or on order**
- **Solution for NO_x Tier 3 already available with water mixture**
- **Dual fuel designs are available across the vessel spectrum (drybulk, container, tanker)**

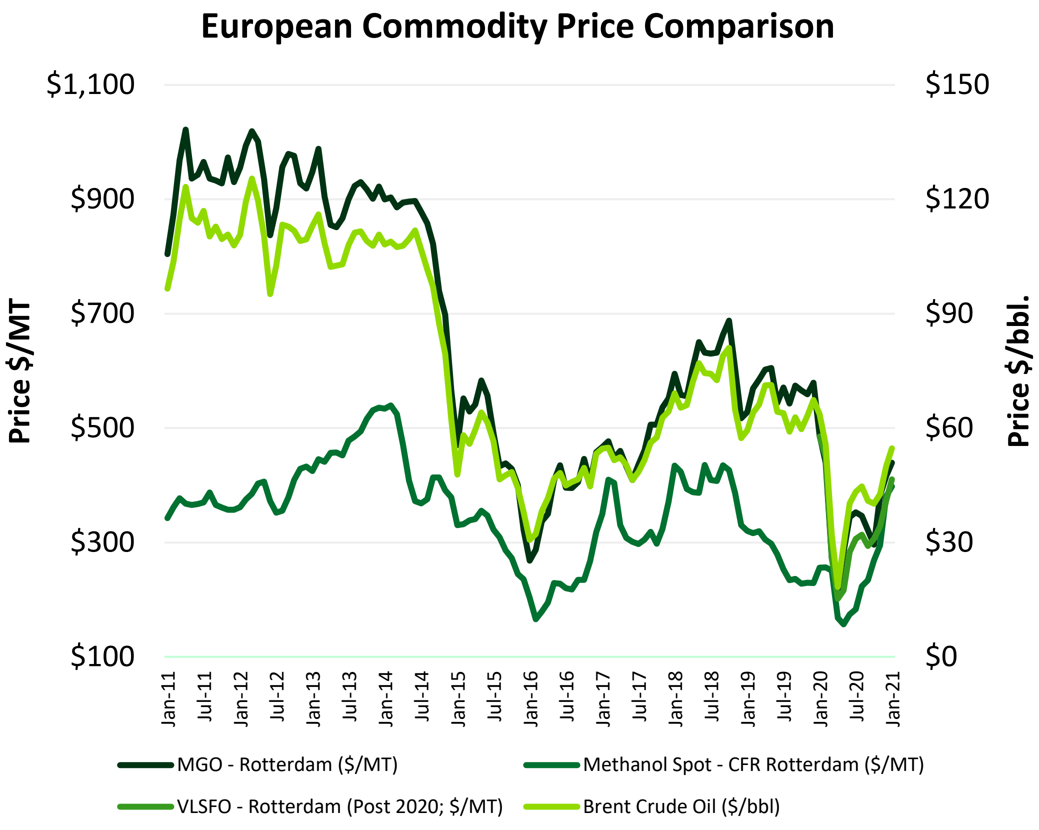
Methanol Bunkering considerations vs Hydrogen

- Safety procedures for handling methanol are well known and practiced all over the world
- Methanol molecule remains stable through ambient temperatures. It handles easily like existing fuels, with reduced “spill implications”
- Bunkering companies are supportive of methanol due to ease of handling for their existing operations, with minor alteration to infrastructure expected
- Methanol readiness evaluations already taking place in major ports
  - Methanex successfully completed a bunkering demonstration at the Port of Rotterdam on May 10th, 2021
- Proman is prepared to perform the work required to ensure methanol deliveries support ship bunkering globally
  - Secure/support necessary approvals with the Port, local authorities and setting up the necessary bunkering infrastructure



General Pricing for and Economic Considerations for Marine Applications

- Methanol is an attractive and competitive alternative from the point of view of fuel storage and bunkering infrastructure costs
- The capital costs of marine methanol are significantly lower than the equivalent costs of marine LNG, a competing fuel that also is compliant with SOx and NOx reductions regulations (LNG infrastructure requires scale to become economic)
- Additionally, methanol allows shipping companies to start with relatively modest investments and build up gradually as more ships convert to the fuel
- As a fuel, methanol has been cost-competitive with MGO
- Methanol is also competitive when compared with emissions abatement measures such as scrubbers and catalysts, as the latter also add to operational costs
- A dual fuel engine can also be installed to allow the use of VLSFO/MGO as well as methanol, enabling a ship to switch between fuels to operate cost-effectively whilst remaining compliant with environmental regulations



Maersk estimate that a doubling of fuel costs would only add 6c to the price of $100 trainers

Maersk Sustainability Report 2020

Thank you

- Panel Discussion -

- Q&A -