METHANOL INSTITUTE

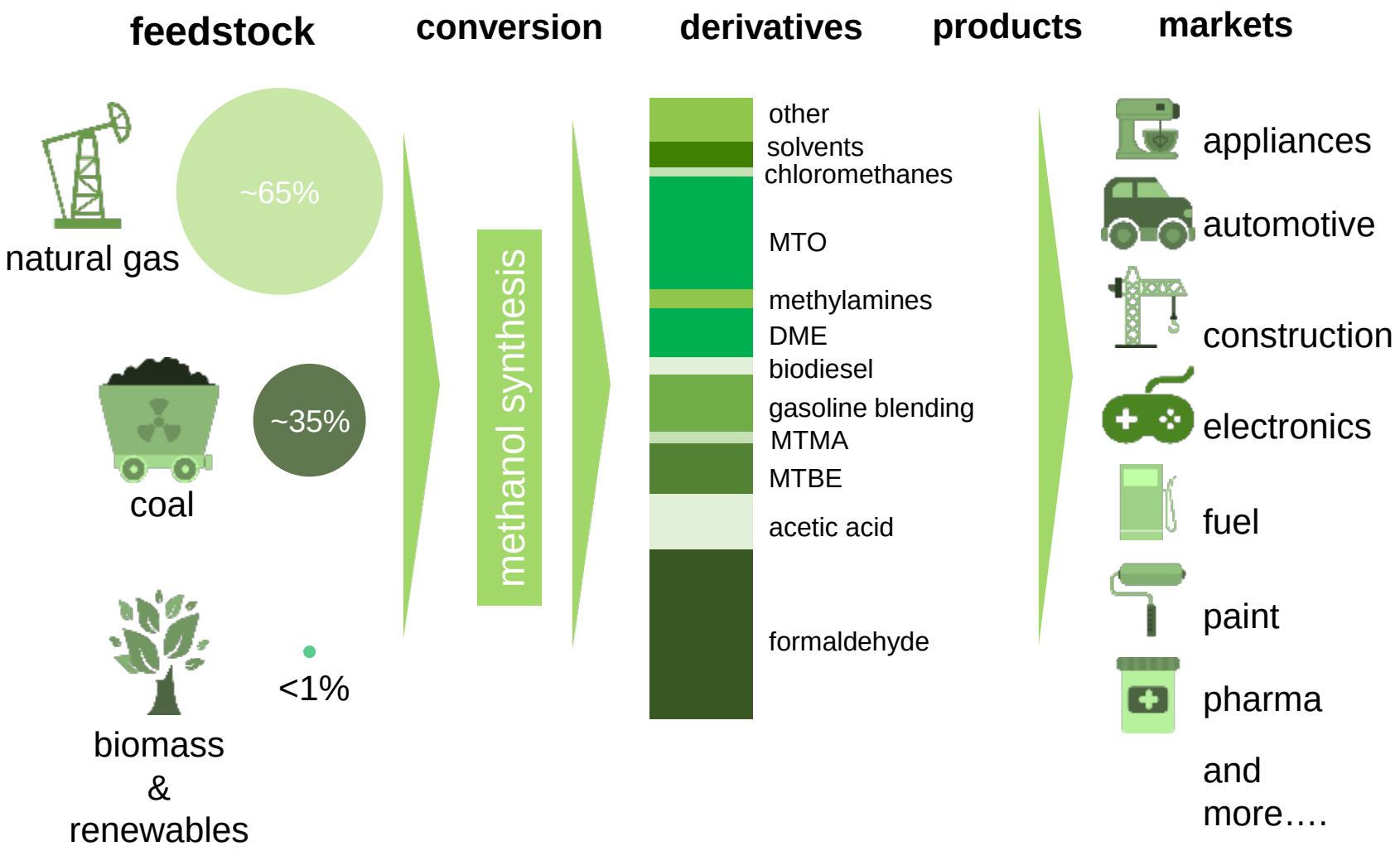
Overview of Global Methanol Fuel Blending

Gregory Dolan, CEO – Methanol Institute

Trinidad and Tobago Methanol Fuel Blending Forum

24 January 2019

Methanol: Broad Feedstocks and Markets



Methanol is a versatile fuel source

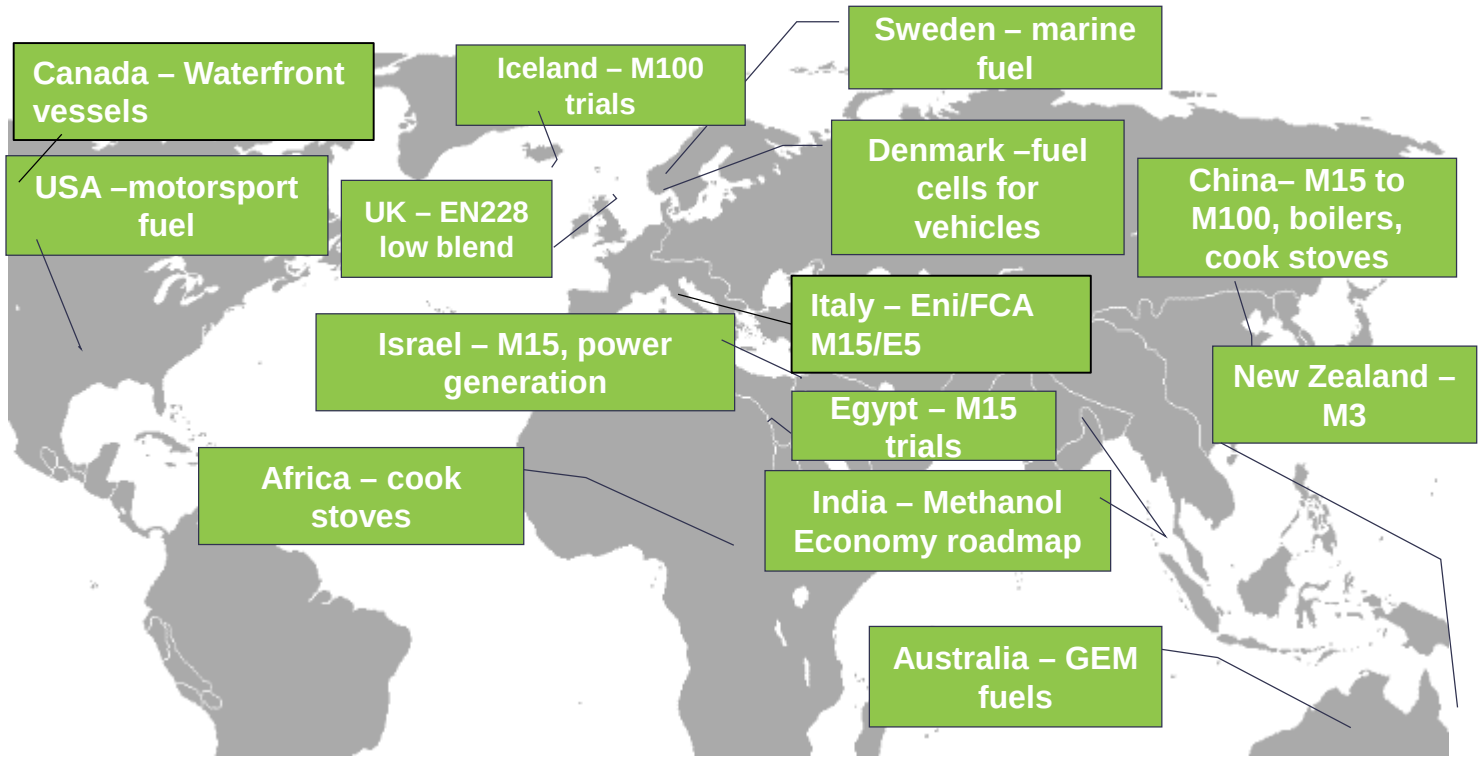
Out of the ~80 million metric tons of methanol sold globally in 2018, energy and fuel uses represent 40% of total demand

FUELS
- Neat fuel
- Low blends
- High blends
- GEM
- MTBE
- Biodiesel
- DME & OME
- MTG

TECHNOLOGIES
- SI & CI engines
- Turbines
- Fuel cells

SEGMENTS
- Road & non-road transportation
- Power & heat generation
- Marine

Global Methanol Fuel Examples



01 ROAD TRANSPORT

Solutions for gasoline and diesel engines

gasoline

- Low blends

- Mid level blends

- High blends

diesel

- FAME

- SI/CI HDVs

- DME/OME

Various Gasoline/Diesel Blend Options

M3 – M15

- EU allows M3 (EN228) *Blended a.o. in UK and NL*
- China uses M15 *Estimated 7 million metric tons*
- *~75% of cars built by international automakers*
- Israel standard for M15 gasoline blend

A20 – A30

- Automakers call for higher octane to facilitate greater engine efficiency *(higher compression, turbocharging, downsizing)*
- Methanol and ethanol alcohol fuels together at mid-level blends provide needed octane

M51-100

- ASTM D5797 standard revision
- M100 dedicated vehicles *(e.g. Geely)*
- Use of SI technologies in light duty vehicles
- Both SI and CI for heavy duty vehicles
- Few changes needed to existing vehicle technologies at low cost

40+ Years of Global Experiences with Methanol/Gasoline Blends

- **German Automakers and Oil Refiners conducted small vehicle fleet trials of methanol/gasoline fuels in mid-1970's**

- **Germans selected M15 as highest methanol content for use in vehicles with 1980's carburetor fuel systems and material compatibility**

- **Number of larger methanol/gasoline blend fleet trials conducted in late 1970's / early 1980's**

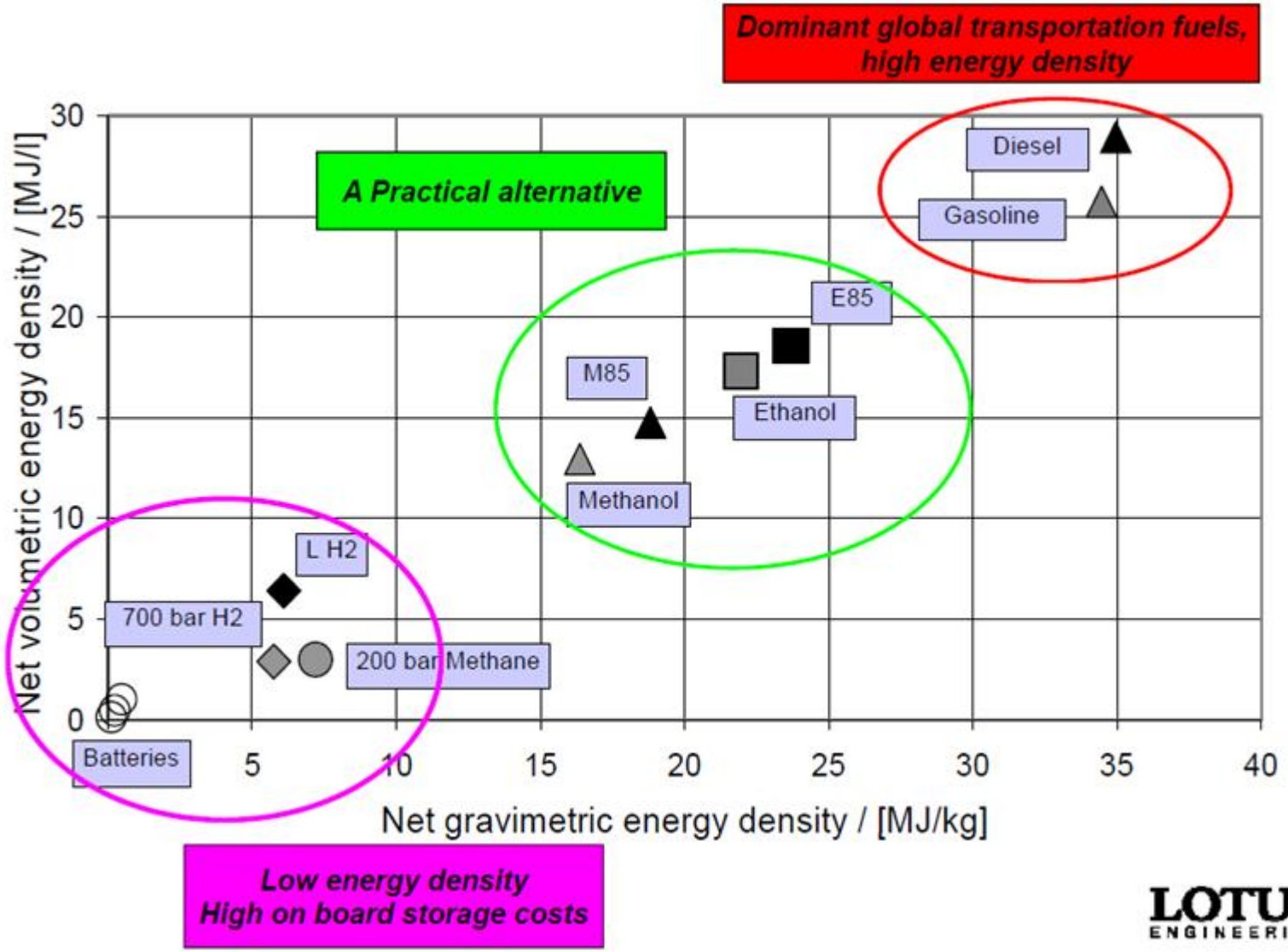
Germany	***~ 1,000 vehicles***
Sweden	***~ 1,000 vehicles***
New Zealand	***~ 950 vehicles***
China	***~ 500 vehicles***

Results: Methanol with corrosion inhibitors and co-solvent alcohols provided stable gasoline fuel, and protected fuel system metals in vehicles

- **The State of California managed extensive methanol/gasoline fuel programs in 1980's/1990's**

- **Some China Provinces initiated commercial M15 market trials in 2004**

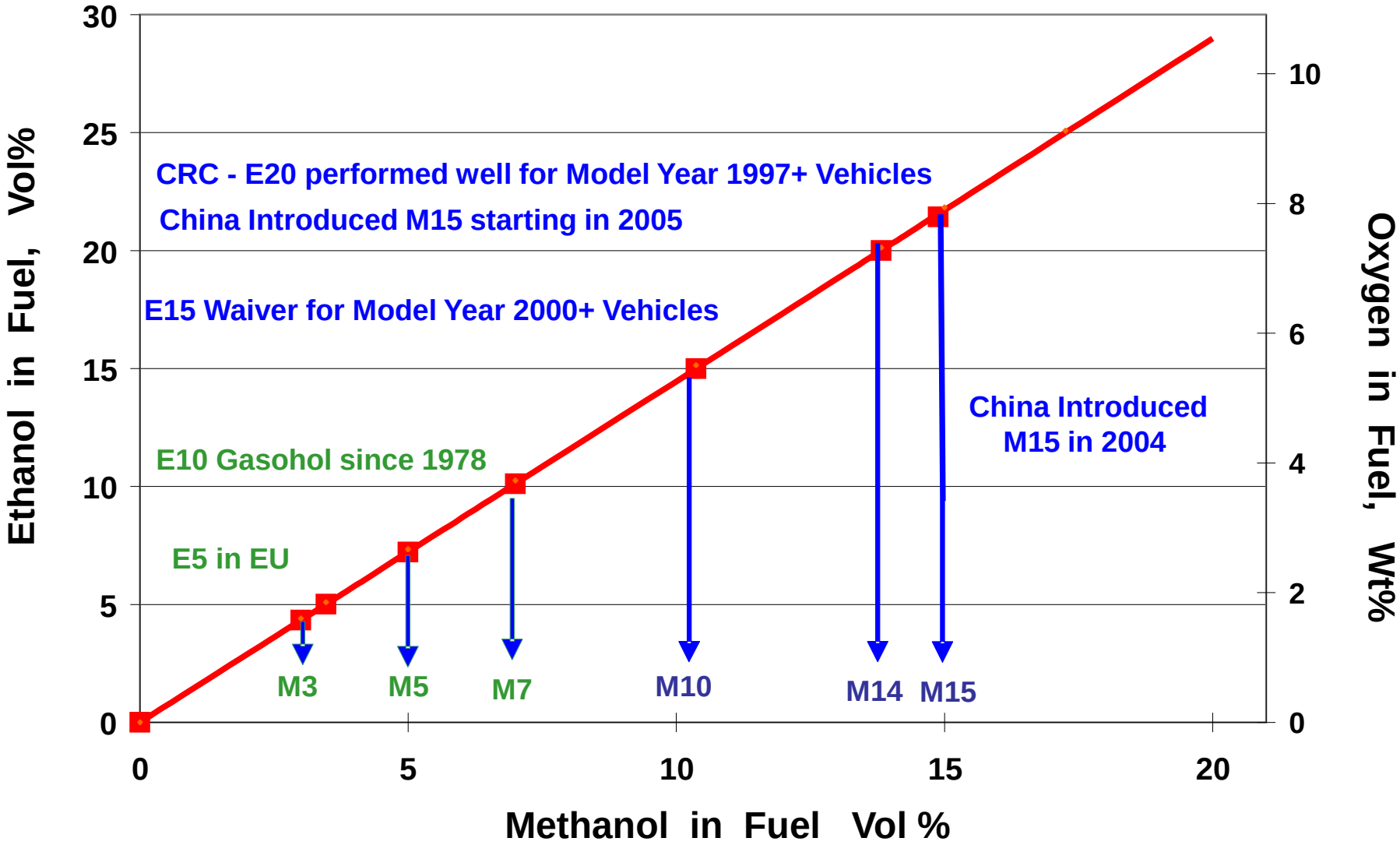
Methanol - Practical Liquid Fuel Alternative



LOTUS ENGINEERING

Newer Model Year Vehicles Can Manage Higher Alcohol Blends

Ethanol vs Methanol Gasoline Blend Vehicle Performance



Global Fuel Standards Allowable Methanol Content

- **Earlier commercial Fuel Standards started with nominal 3 vol % methanol in gasoline**

- **Higher methanol content in gasoline allowed as global automotive fuel system technology and materials continue to improve in global vehicle fleets**

Approved Methanol Gasoline Blends with Requirements for Co-solvent Alcohols and Additives						
Market Region		**Introduction Year**	**Maximum Volume % Methanol**	**Minimum Volume % Co-solvent**	**Maximum Wt % Oxygen**	**Corrosion Additives**
Europe	EC Directive	1985	3.0	≥ Methanol	3.7 %	
U.S.A	Sub Sim *	1979	2.75	≥ Methanol	2.0 %	
U.S.A	Fuel Waiver	1981	4.75	≥ Methanol	3.5 %	Required
U.S.A	Fuel Waiver	1986	5.0	2.5	3.7 %	Required
China, Shanxi	M15 Standard	2007	15.0	For Water Tolerance	~7.9 %	Required

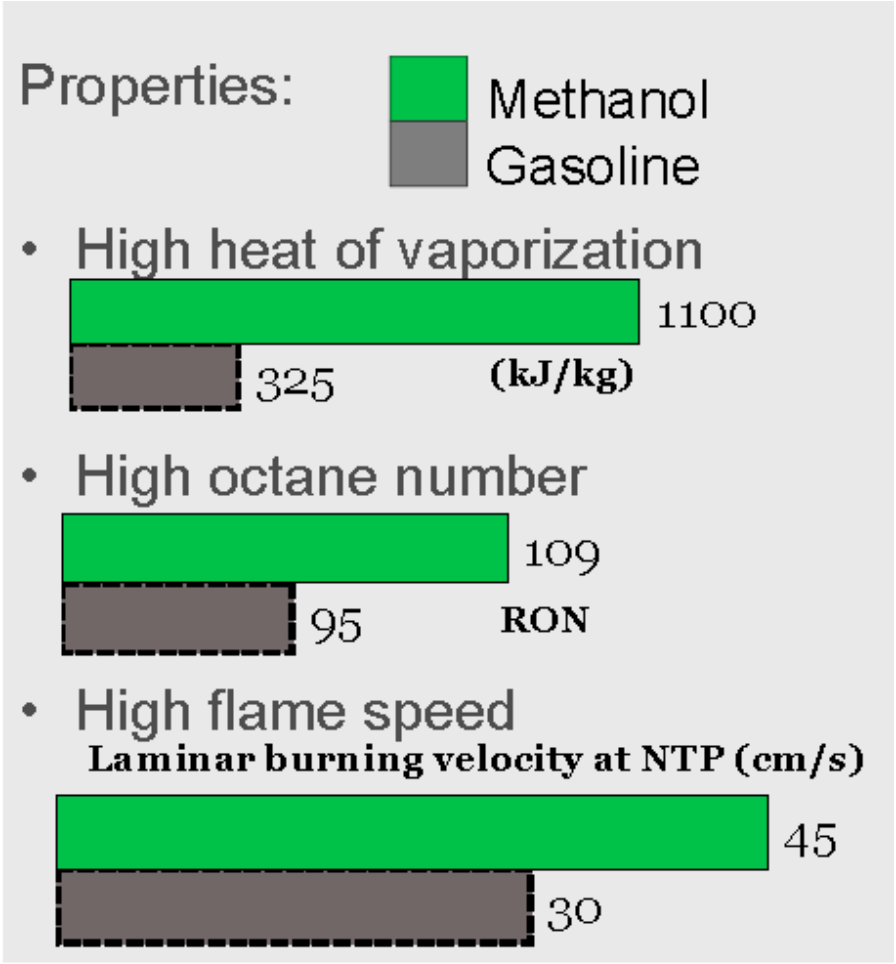
*** U.S. EPA's Substantially Similar Regulation for commercial gasoline**

Other countries evaluating introduction of methanol blending standards in gasoline: Egypt, Israel, Italy, New Zealand, Trinidad, Others

Methanol Blending Benefits

Ultra-high Efficiency Characteristics:

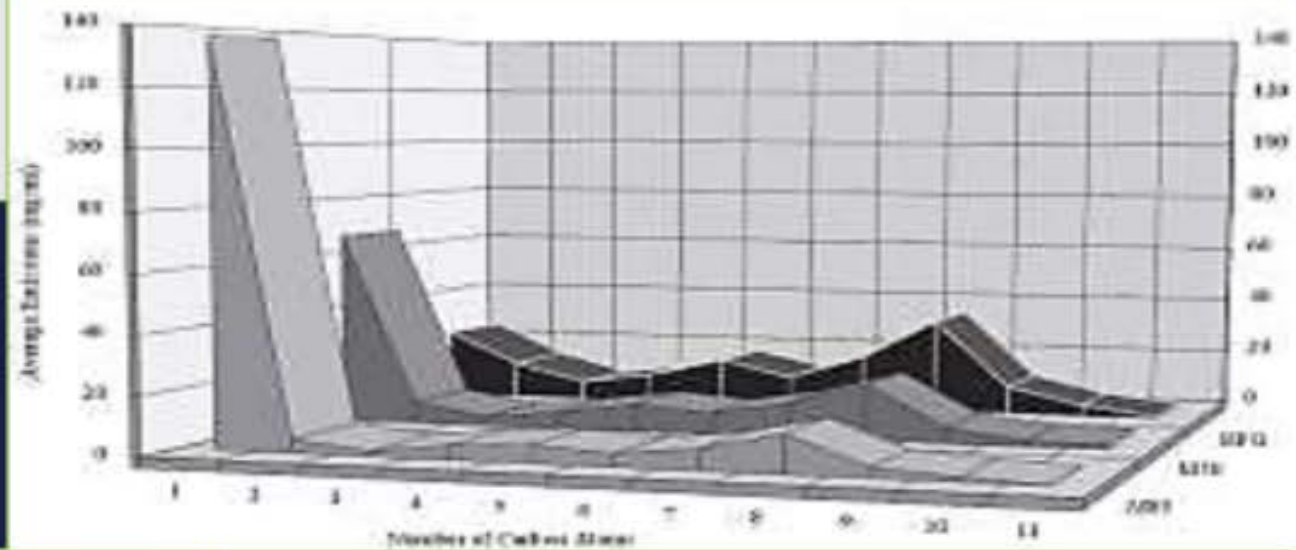
- Methanol use in spark ignition engines allows higher efficiencies by increasing the engine knock limit
- Methanol has much higher flame speed, which allows for tighter combustion control and more precise torque management
- Improving knock performance is important to help avoid undesired detonation while also allowing for highly effective recovery of energy from exhaust heat

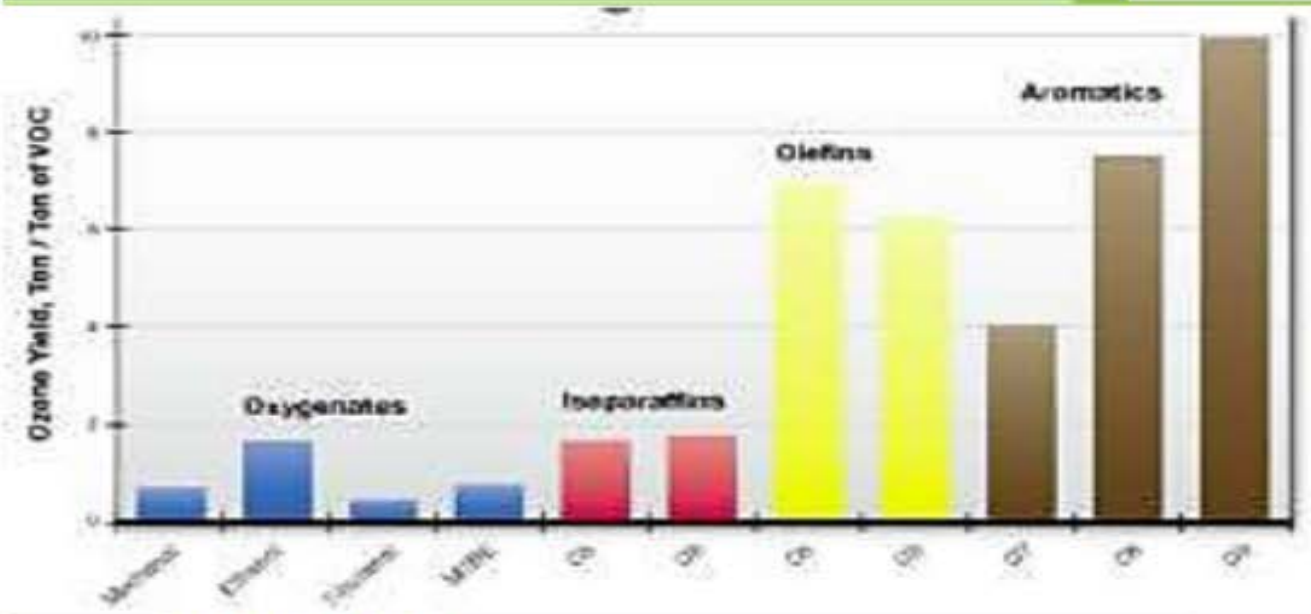


Methanol Air Quality & GHG Benefits

Inherently lower NOx and PM due to low temperature combustion properties;

C1 compounds in M85 compared to the much higher carbon content of reformulated gasoline





A lack of carbon-carbon bonds results in ultra-low particulate emissions;

The atmospheric reactivity of methanol is recognized to have lower ozone forming potential compared to the olefins and aromatics present in gasoline

The California Methanol Experience

Methanol Deployment in Light Duty Vehicles *Methanol Experience*

California Demonstrated Methanol as a Transportation Fuel in Light- and Heavy Duty Vehicles

mdj Research

THE CALIFORNIA & U.S. NATIONAL CONTEXT

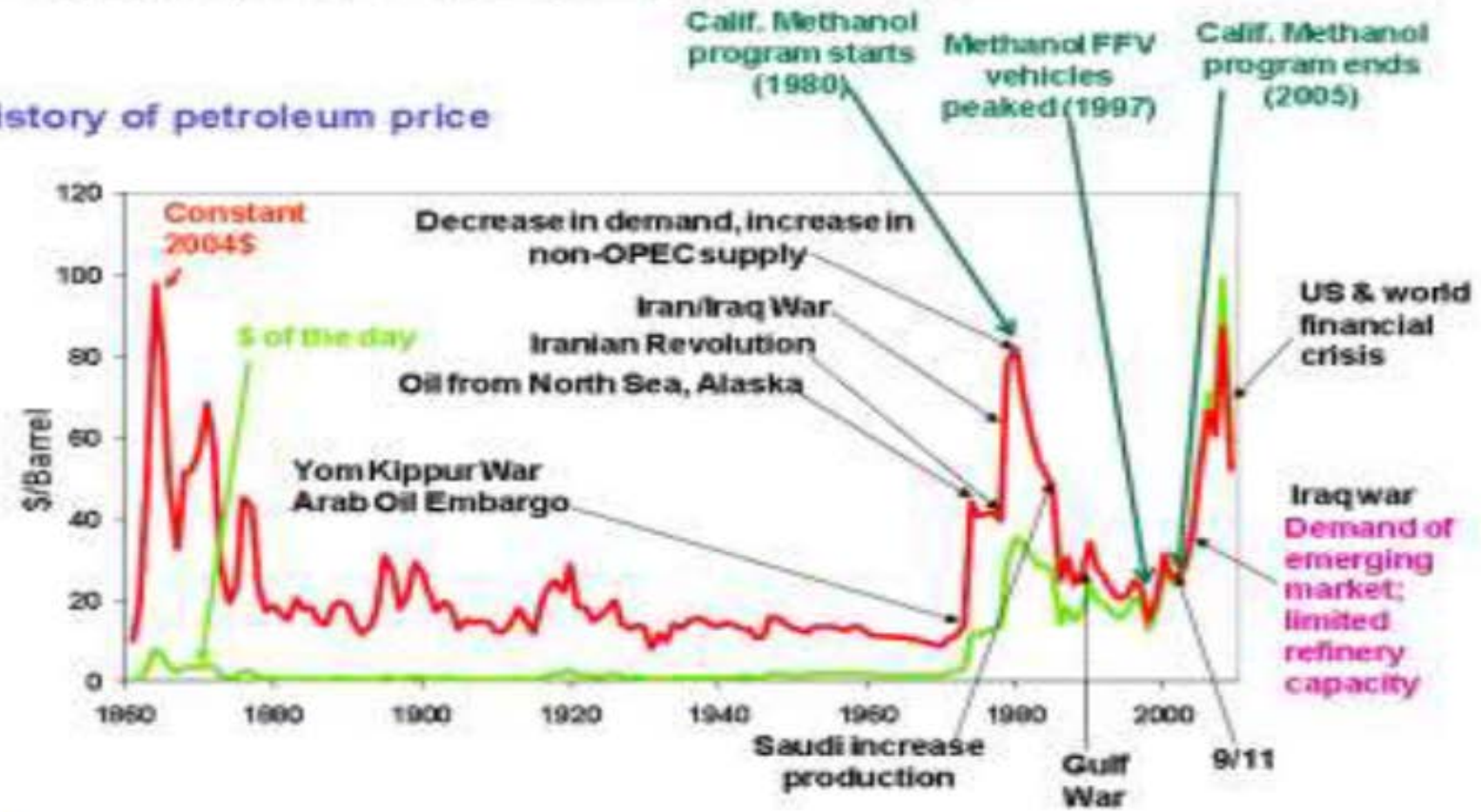
California Methanol Programs in the 1980s-90s, was fundamentally a technical success.

- ✓ Sixty retail fuelling stations
- ✓ 17,500 M85-compatible vehicles - first large scale production of Flexible Fuel Vehicles
- ✓ Over 200 million miles of successful vehicle operating experience along with a zero-incident health & safety record

However, despite the establishment of a California Fuel Methanol Reserve (CFMR), the low oil price during that period presented major competitive challenges…

US experience with Methanol

- Methanol succumbed to decreasing oil prices and lack of advocacy, replaced by MTBE (now banned) and ethanol



NOT ALL WAS LOST…

…Extensive technical literacy gained in the following areas

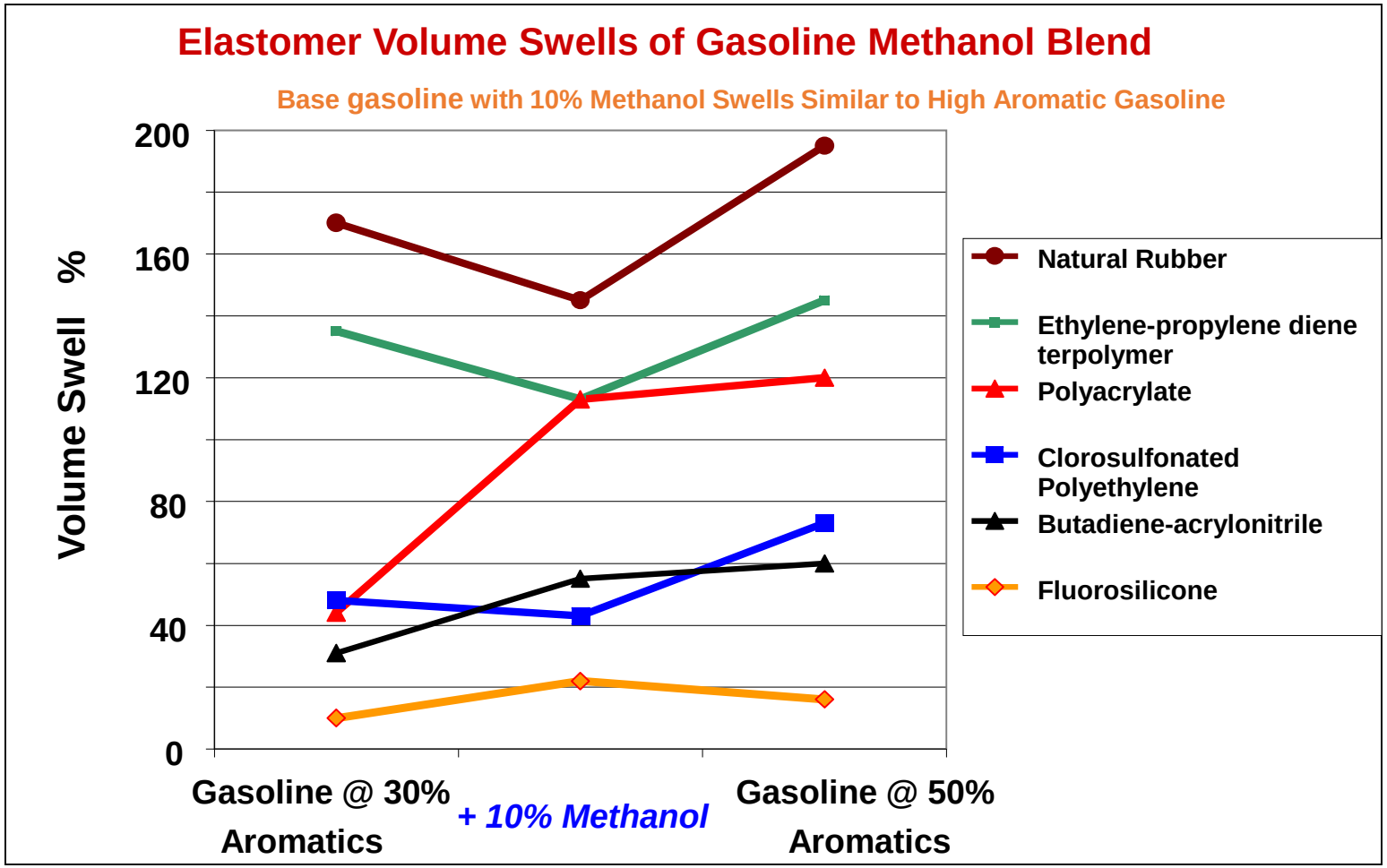
POSITIVE OUTCOMES

+ Distillation Properties
+ Water Solubility
+ Material Compatibility in
+ FFVs
+ Vehicle Emission Impacts *(e.g., HCHO standard adopted and easily complied with via close coupled catalysts)*
+ Octane Effects
+ Blending Vapor Pressure
+ Toxicity of Vapors
+ Risk Mitigation *(e.g., flame arrestors, anti-siphoning devices)*

Material Compatibility With Methanol Blends Well Understood

- **Elastomer Compatibility with Methanol Blends well studied in the 1980's**

- ***Society of Automotive Engineers (SAE) Compatibility Guidelines established M15 as fuel standard for selecting materials used in vehicle fuel systems starting 1993***



Neat Methanol Material Compatibility [1, 2, 3]

Material	Compatibility	Material	Compatibility
304 stainless steel	A-Excellent	Hypalonr	A-Excellent
316 stainless steel	A-Excellent	Hytrelr	B-Good
Acetal (Delrinr)	A-Excellent	Kalrez	A-Excellent
Aluminum	A[1]-Excellent	Kel-Fr	A[1]-Excellent
Brass	A-Excellent	LDPE	A[1]-Excellent
Bronze	A-Excellent	Natural rubber	A-Excellent
Buna N (Nitrile)	A-Excellent	Neoprene	A-Excellent
Carbon graphite	A-Excellent	NORYLr	A-Excellent
Carbon Steel	A-Excellent	Nylon	B[1]-Good
Carpenter 20	A-Excellent	Polycarbonate	B[1]-Good
Cast iron	A-Excellent	Polyetherether Ketone (PEEK)	A-Excellent
Ceramic Al203	A-Excellent	Polypropylene	A[2]-Excellent
Ceramic magnet	A-Excellent	PPS (Ryton®)	A-Excellent
ChemRaz (FFKM)	A-Excellent	PTFE	A-Excellent
Copper	B[1]-Good	PVC	A[1]-Excellent
CPVC	A-Excellent	PVDF (Kynar®)	A-Excellent
EPDM	A-Excellent	Silicone	A-Excellent
Epoxy	B[1]-Good	Titanium	B-Good
Fluorocarbon (FKM)	C-Fair	Tygonr	A[1]-Excellent
Hastelloy-Cr	A-Excellent	Vitonr	C-Fair

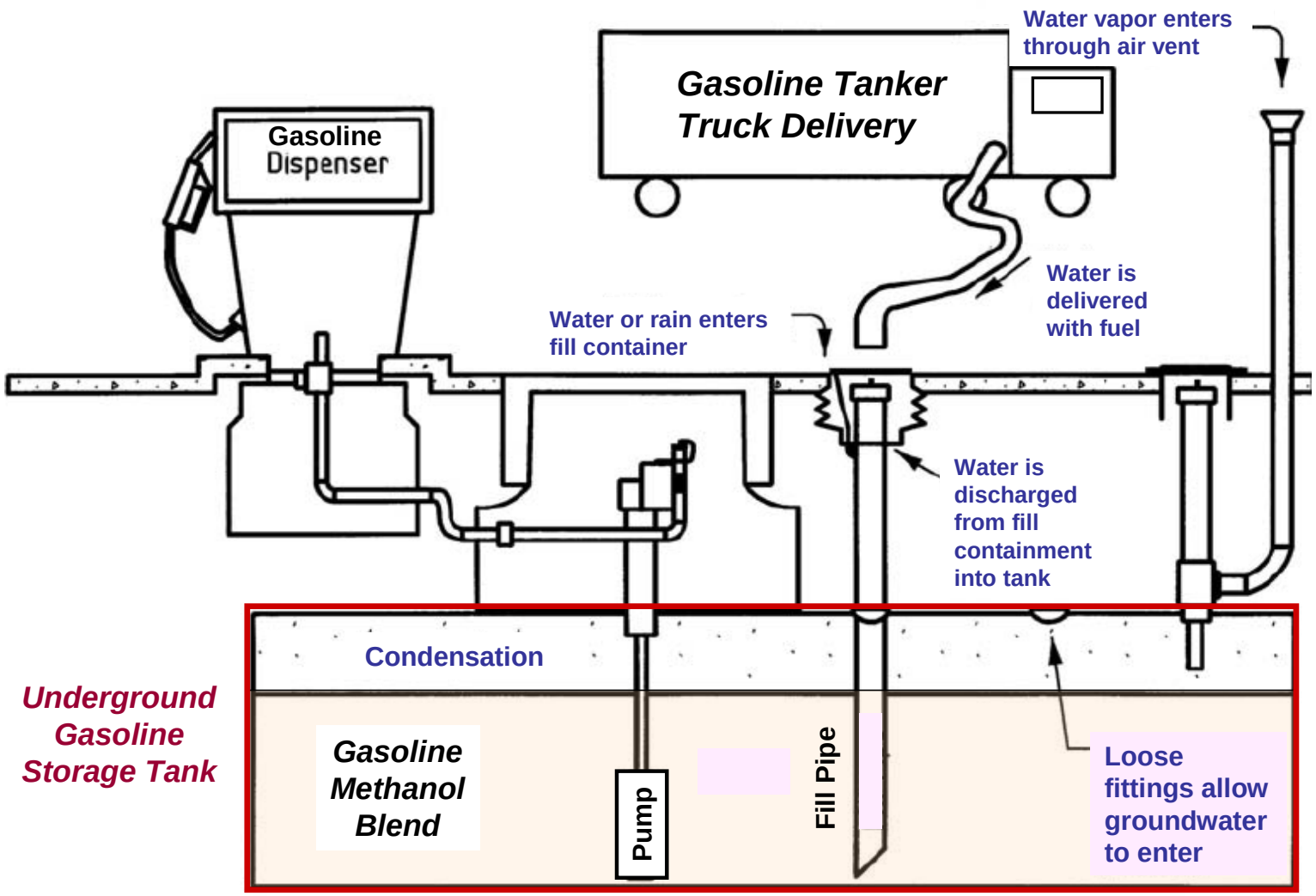
Footnotes for Previous Table:

1. Source: http://www.coleparmer.com/techinfo/chencompresults.asp
2. *Explanation of Footnotes*
   1. Satisfactory to 72°F (22° C)
   2. Satisfactory to 120°F (48° C)

   Ratings – Chemical Effect
   A = Excellent.
   B = Good -- Minor Effect, slight corrosion or discoloration.
   C = Fair -- Moderate Effect, not recommended for continuous use. Softening, loss of strength, swelling may occur.
   D = Severe Effect, not recommended for **ANY** use.
   N/A = Information Not Available.
3. The only severe defect (level D) noted were for ABS plastic and polyurethane. However, neither of these materials is likely used in fuel wetted parts in vehicles, since aromatic compounds such as benzene, toluene and xylene each have an equivalent rating of severe defect level D for both ABS plastic and polyurethane. Thus, these specific material incompatibilities have no practical significance in the context of low level methanol blended transportation fuels.

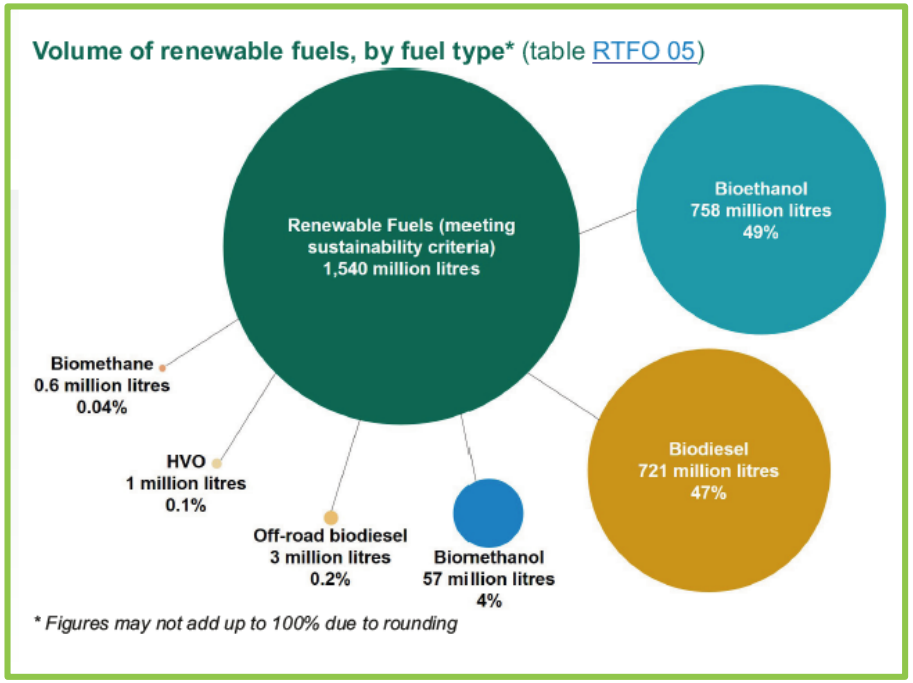
Monitoring For Water Maintains Quality / Stability of Methanol Blends

- **Good operating practices in gasoline distribution system maintain quality gasoline**



UK BioMethanol Blending

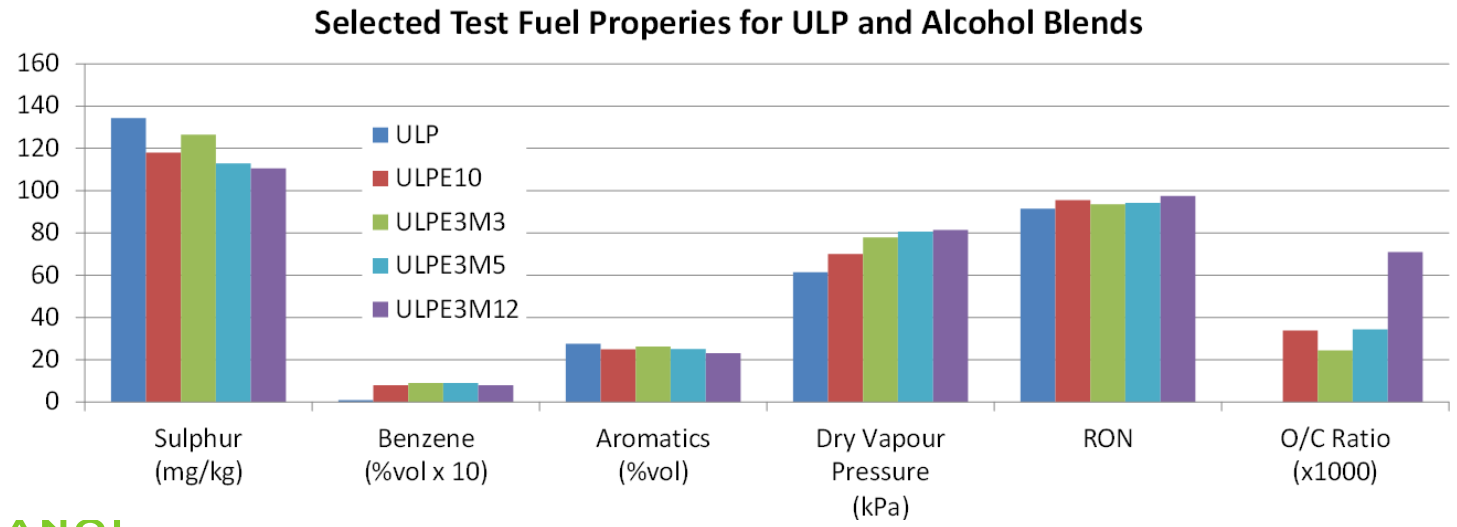
- UK Department of Transport: Renewable Transport Fuel Obligation Report – 1 February 2018
- Averages 1% methanol in summer, and 1.5% in winter
- Biomethanol 57 Million liters, or 4% of UK total renewable fuel use
- “The supply of biomethanol has been increasing in recent years to an all-time high in 2016/2017.”



https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/681174/rtfo-year-9-report-6-revised.pdf

Australia Methanol Fuel Blending

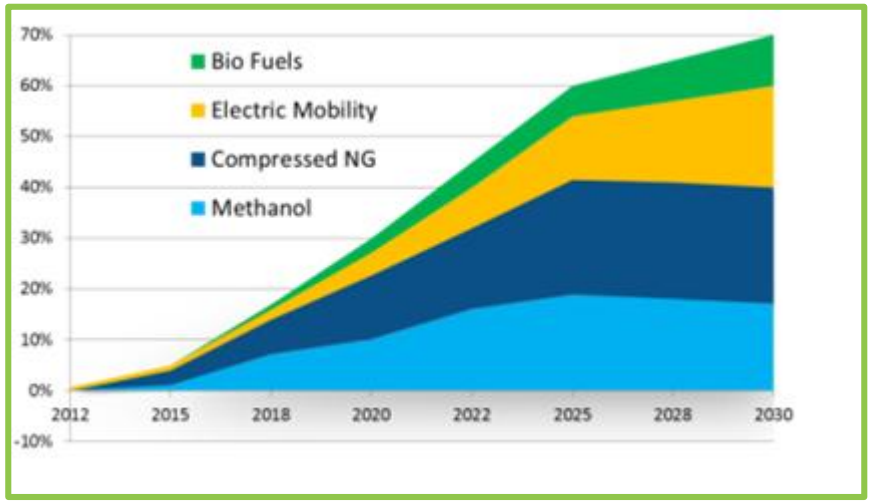
- Methanol Fuels being commercialized in Australia
  - Project led by Coogee. Methanex is a partner
  - Methanol excise tax free status for 10 years (~A38c/litre)
  - Successful road trials and testing programs completed
  - **Commercial roll out of GEM 8 (M5/E3) on hold pending methanol plant restart: GEM15 & GEM56 in the future**



Driven by the pure power of methanol

Israel Methanol Fuels Demonstrations

- Prime Minister Netanyahu established Fuel Choices Initiative
- Driven 1,000,000 kms on M15 fuels with improved power and torque
- In 2016, Israel adopted national standard for M15 fuels
- Fiat marketing M15 car in Israel, and Dor Chemicals has introduced M15 retails pumps



Italy M15/E5 Blending

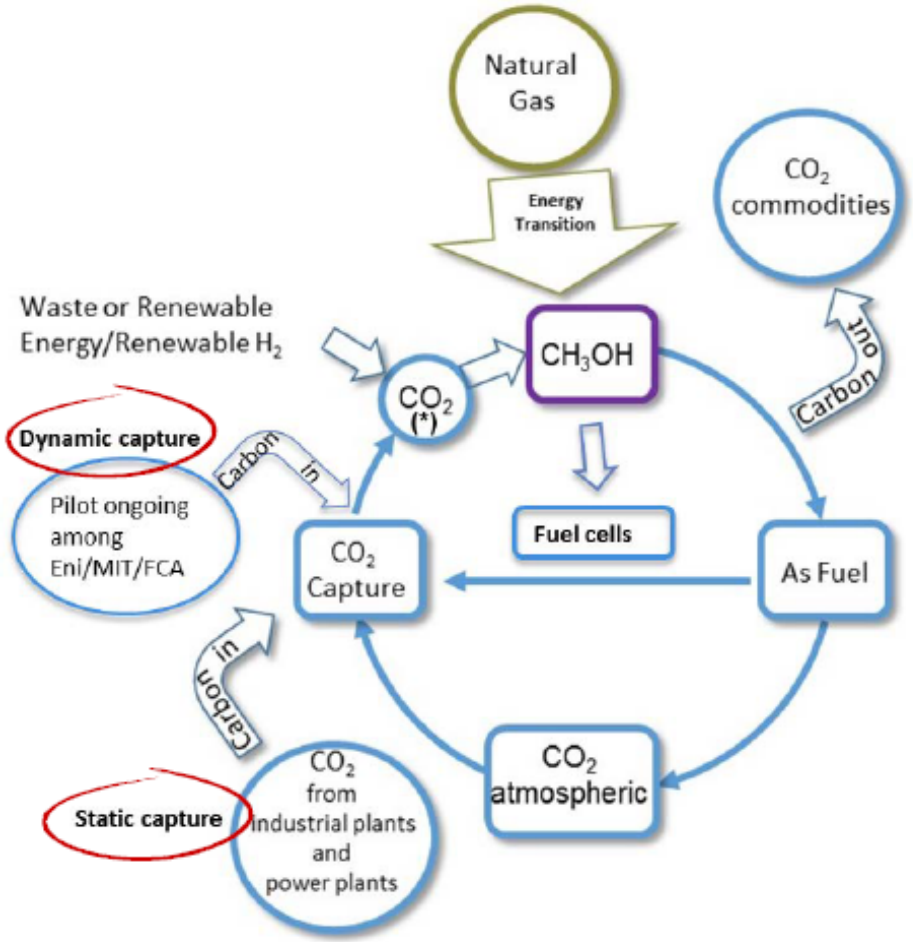
- 21 November 2017: With Italian Prime Minister, the CEOs of Eni and Fiat Chrysler Automobile sign MOU for joint development of technology reducing CO2 of road transport vehicles
- Eni had developed an “A20” fuel blend of 15% methanol and 5% bioethanol
- New blend being demonstrated in 5 FCA Fiat 500 vehicles in Eni’s Enjoy car-sharing fleet

Joint press release

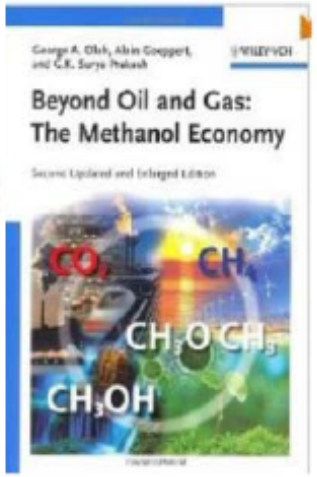
Eni and FCA sign research agreement for joint projects to significantly reduce CO_2 emissions produced by road transport vehicles

https://www.eni.com/en_IT/media/2017/11/eni-and-fca-sign-research-agreement-for-joint-projects-to-significantly-reduce-co2-emissions-produced-by-road-transport-vehicles

Gas-to-Liquids: The Methanol Circular Economy



(*) CO_2 as current main environmental issue transformed into a resource



2006: G. Olah and the Methanol Economy

- Effective energy storage and gas into liquid conversion
- Existing infrastructure utilization
- As for ICE, alcohols already have a consolidated usage as a fuel
- Rapid go to market, **blending methanol with gasoline to create the basis for the Methanol Economy**

Density	0.792 g/cm³
Boiling point	64.7 °C
Vapour pressure	13.02 kPa (at 20 °C)
Octane Number	130
Acidity (pK_a)	15.3
Solubility in water	Miscible

A20: a New Methanol-based Alternative Fuel

15% MeOH

5% bio-EtOH

80% Gasoline

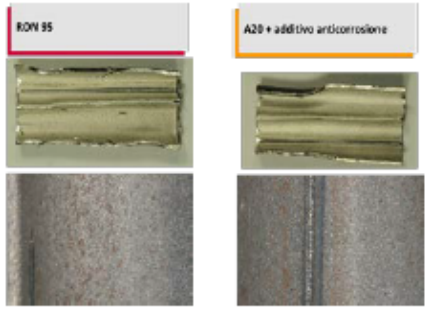
- Formula Cost Reduction
- "Transparent" to all the E10 car vehicles
- No-chemical corrosion problems
- No-phase separation (in the car tank and gas-station)

CUNA specification (NC 627-02 July 2018)

Property	Units	Limits MIN – MAX	
Research octane number, RON		100	
Motor octane number, MON		86	
Lead content	mg/l		5.0
Density (at 15 °C)	kg/m³	720.0	775.0
Sulfur content	mg/kg		10.0
Manganese content	mg/l		2.0
Nitrogen content	ppm		100
Oxidation stability	minutes	360	
Existent gum content (solvent washed)	mg/100 ml		5
Water content	% (m/m)		0.2
Oxygen content	%(m/m)		10.0
Methanol	%(V/V)	12.0	16.0
Ethanol + other Alcohols (C3-C4)	%(V/V)	4.0	6.0
Ethers (5 or more C atoms) other oxygenates	Volume blending of these components is restricted to 10.0 % (m/m) maximum oxygen content including methanol oxygen.		

CUNA NC 627-02 include also the evaporative class parameters to prepare A20 grade for summer, winter and transition period

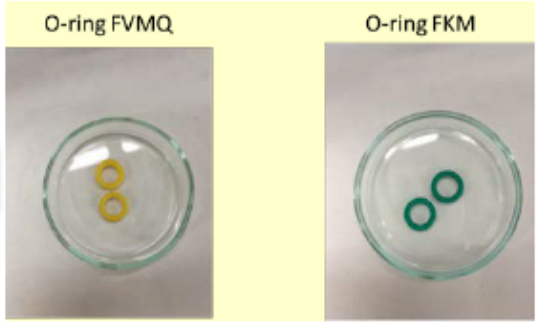
A20: Overall Transparency



After 1000 hours of test No evidence of corrosion-related criticalities for A20.

Metal tube

O-ring

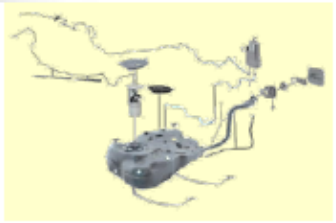


All o-ring test shows No compatibility issue with A20

Plastic tube

For all types of tube tested, the ageing of A20 fuel does not lead to criticality in the mechanical behavior of the materials

Fuel system



Vehicle	Engine calibration	Air volume washed	Canister weight difference after cycle	Hot Soak	Day 1	Day 2	P. Factor	TOT
500 1.2 8v	4M10FVCS	231 L	34,1 g	HC 0,068 g	HC 0,598 g	HC 0,486 g	HC 2x0,120 g	HC 1,392 g

Vehicle test target : 2 g /test

A20 has positively passed the evaporative emission test

The results of the tests carried out so far confirm the compatibility of the fuel with FCA vehicles compliant with E10

Next step: On going process to check the compatibility to other carmakers and motorcycle manufacturers

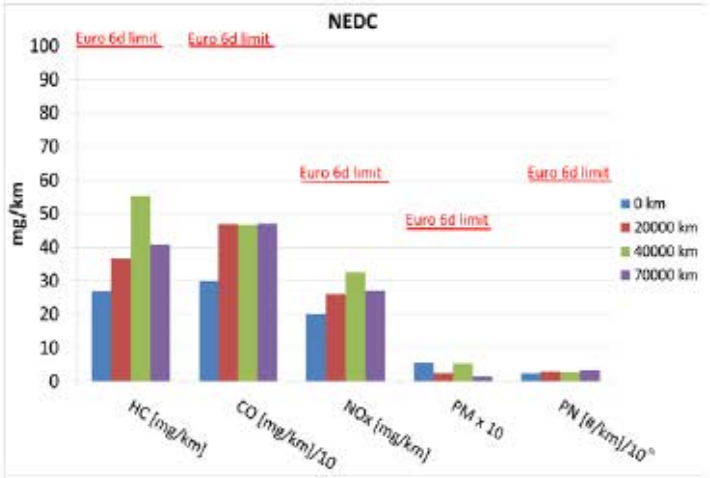
Fleet Test is On-going in Milan

Eni got approval from Italian Ministers to use A20 fuel for fleet tests as first step for selling into Italian market

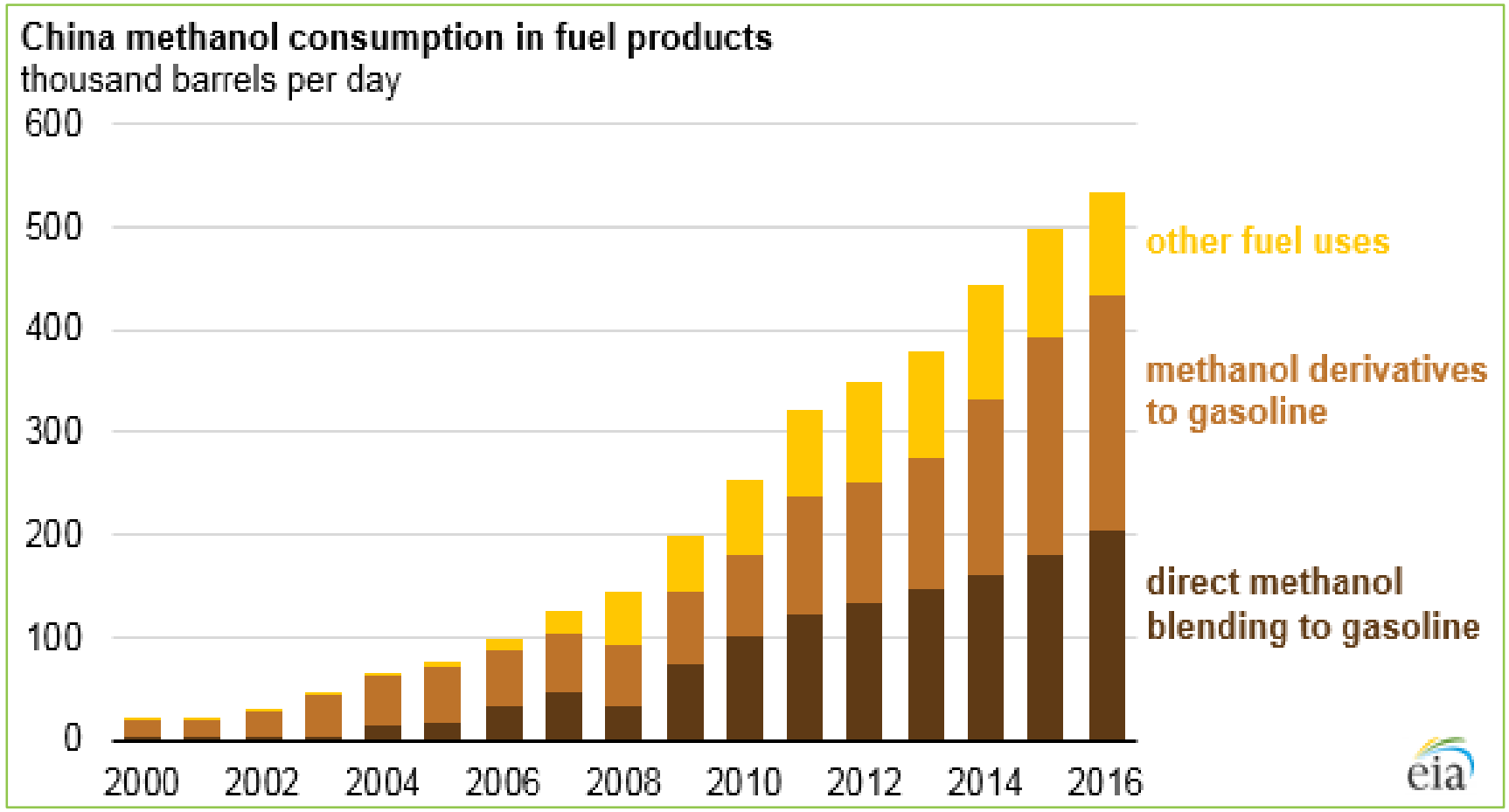
In November 2017 the fleet tests started on Enjoy car sharing vehicles (n.5 Fiat 500) constantly monitored and refueled by the Enjoy team on a Eni station c/o Milan

Endurance test

- The car subjected to accumulation has run 100,000 km. All the controls (emissions, etc.) have been successful



China Leading World in Methanol Fuel Use



https://www.eia.gov/todayinenergy/detail.php?id=30072

China Methanol Fuel Status

2009

China adopted national standards for M85 and M100

2012

MIIT "high proportion" methanol demonstration to serve as the basis for M85 vehicle standards in Shanxi, Shaanxi, and Shanghai, and has expanded to other provinces and cities.

2014

7 million tons (2.3 billion gallons/8.7 billion liters) of methanol blended with gasoline, against total gasoline consumption of 2.25 million barrels per day or 34.5 billion gallons/130 billion liters

180,000

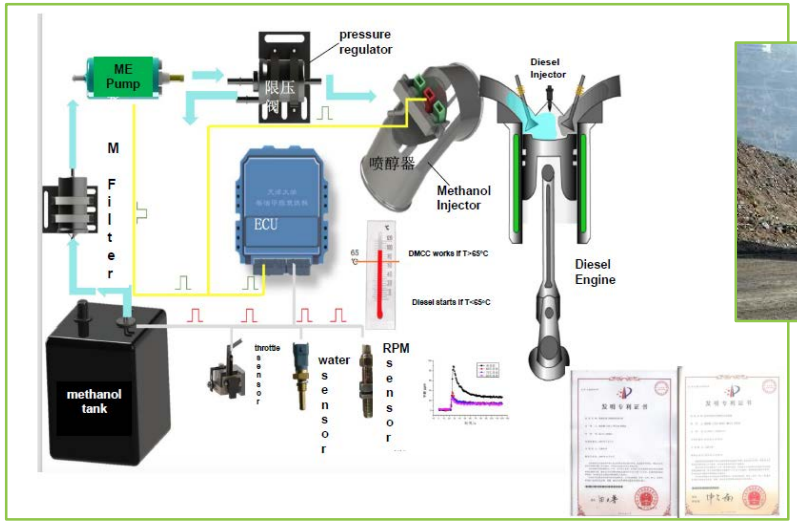
Vehicles converted to methanol fuel, mostly taxis.

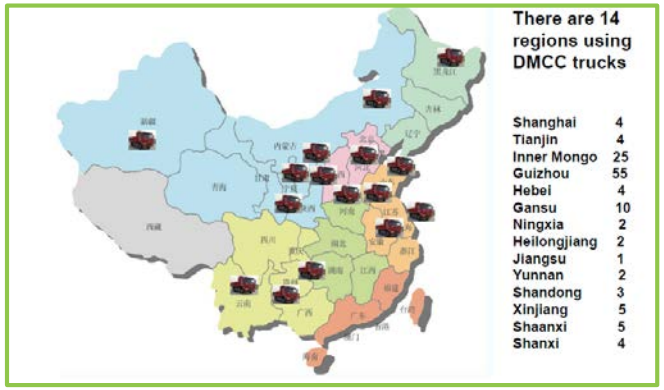
Geely M100 Vehicles

- China's Geely Automotive Holdings is global leader in the commercialization of M100 vehicles
- Geely has two methanol engine and five methanol vehicle manufacturing bases, with an annual methanol vehicle production capacity of 300,000 - 500,000 cars
- Now introduced M100 bus, long-haul truck and medium-duty truck

Tianjin University - DMCC

- Prof. Chunde Yao of Tianjin University has developed Diesel Methanol Compound Combustion (DMCC) technology.
- Fine-tuned diesel combustion by adjusting methanol/diesel ratio at intake manifold.
- Diesel operation for start-up and low load, and homogeneous diesel methanol operation for medium/high load.
- Retain diesel fuel system and EGR, add 2nd fuel tank for methanol, port fuel injection system, and revisions to ECU.
- No NOx aftertreatment, 5% more efficient than today's diesel engines, up to 40% diesel substitution





EU Rally Racing with GEM Fuels

- **Methanol Institute, Methanex and OCI NV (Natgasoline) sponsored GEM fuels in 2013, 2014, and 2015 World Rally Championship.**
- **GEM Fuels: 37% Gasoline; 21% Ethanol; 42% Bio-Methanol**
- **2013 Junior WRC and 2014 Fiesta Trophy Results:**
  - 24 young drivers in 10 Rally Race events across Europe drove 16,000 km
  - Consumed 38,000 liters of GEM fuels
  - Saved 66,000 kilograms of CO2

METHANEX ABENGOA natgasoline MH ePURE GEM FUEL

India: Roadmap to Methanol Economy

- September 2015, NITI Aayog formed Methanol Economy Expert Group
- September 2016, MI jointly organized Methanol Economy International Seminar held in Delhi
- M15 rollout in January 2019
- Working towards M100 and MD95 fuel blending, demonstrations for cook stoves, marine fuels, railways, coal-based methanol production

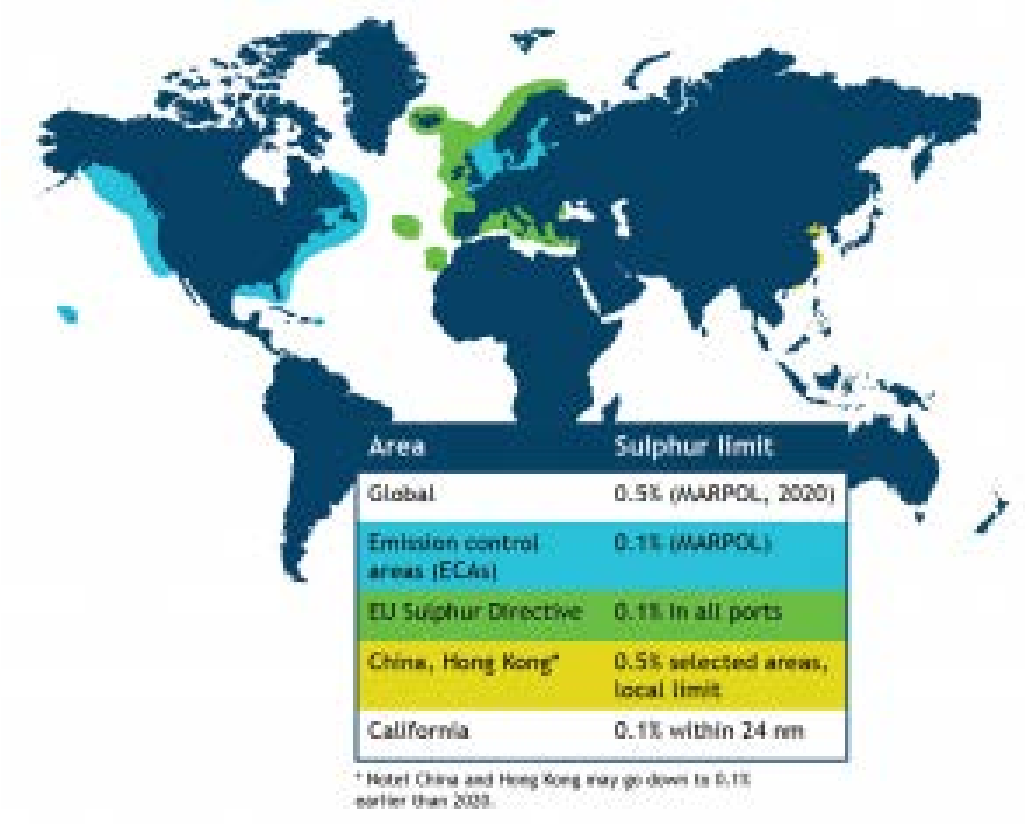
Denmark: Methanol Fuel Cell EV Range Extender

- Green Methanol Infrastructure consortium opened the first methanol fuel pump in Europe
- 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
- Serenergy fuel cells also in 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)

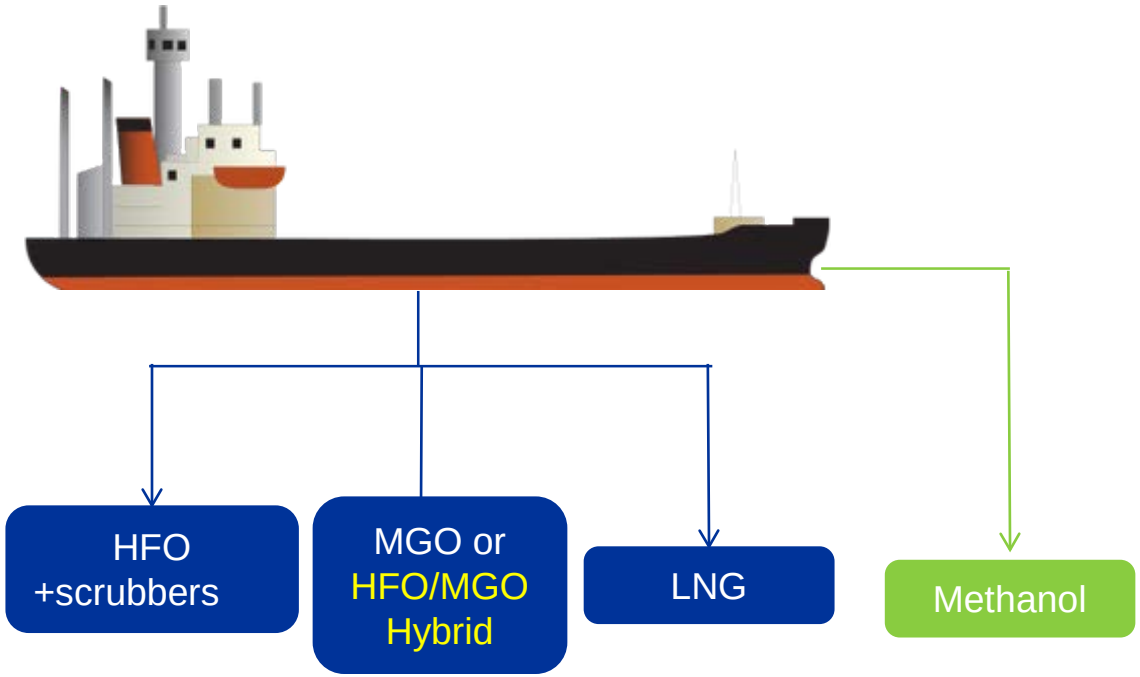
02 MARINE FUELS

Emissions regulations driving market

- The International Maritime Organization has adopted emission regulations transforming the shipping industry
- In 2020, global SOx reductions take effect
- By 2050, greenhouse gas emissions must be cut in half

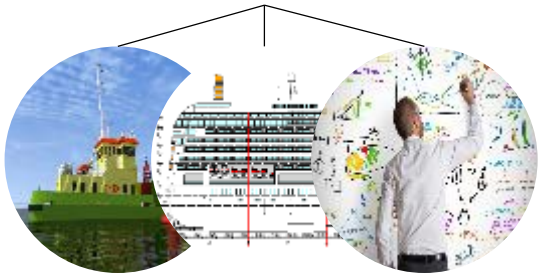


Options available to ship owners

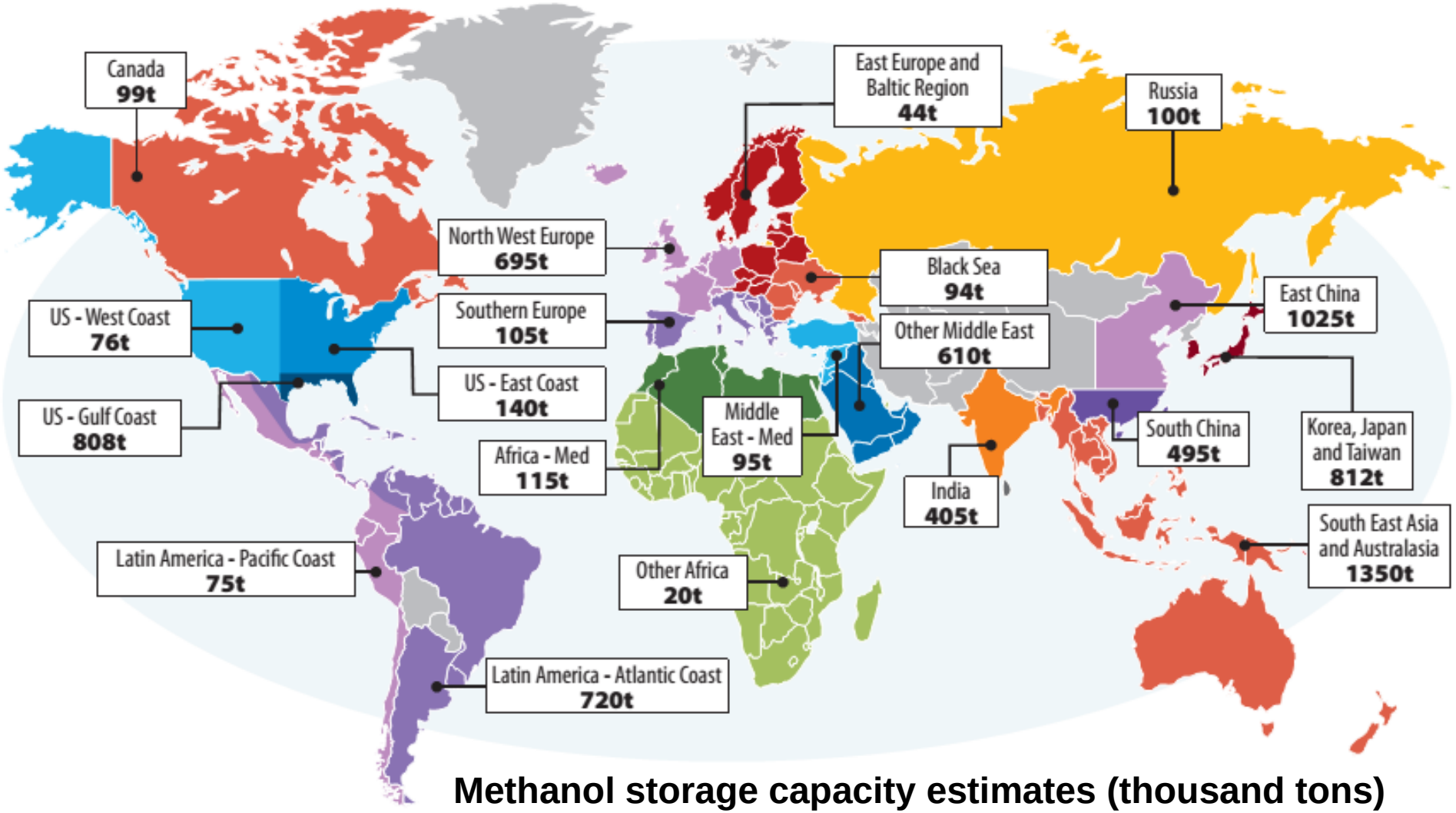


https://www.methanol.org/marine-fuel/

Examples of vessels running on methanol

DUAL FUEL			FUEL CELL		PROJECT and R&D
					
7x - **+4**	1x	1x	2x	1x	
chemical tankers	ROPAX ferry	Pilot boat	Tourist boat	Ferry	Cruise ships, fishing boat, barge, dredge, a.o.
MOL, WL, Marinvest	Stena Line	MI/SMA ScandiNaos	Innogy HTWG Konstanz	Viking Line	SUMMETH/MARTEC, Lean Ships, Methaship, Billion Miles, FiTech, India, PCG Product Vessel, NTU Test Bed Port of Rotterdam Barge
2 stroke MAN	4 stroke Wärtsila	high speed Scania, Weichai	Serenergy fuel cell stacks		SI hybrid, dual fuel, etc.
new build	retrofit	retrofit	retrofit	retrofit	new build & retrofit

Available in many ports around the world



Methanol storage capacity estimates (thousand tons)

Methanol bunkering easy and 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**

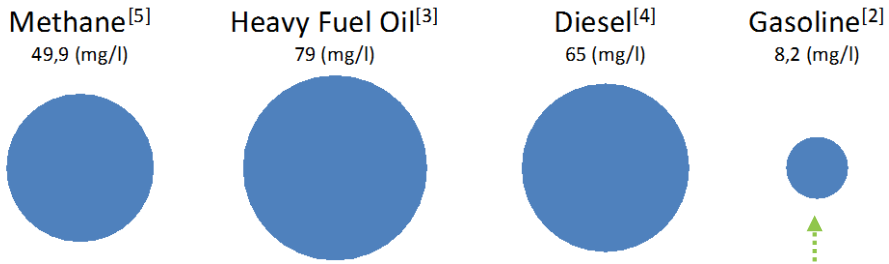
SAFER FOR THE ENVIRONMENT

Methanol[1]
15,400 (mg/l)

LC50, LC = LETHAL CONCENTRATION

Concentration in water, at which half the population died within specified test duration

Safer than Diesel by a factor of 240 times



Safer than Gasoline by a factor of 1900 times

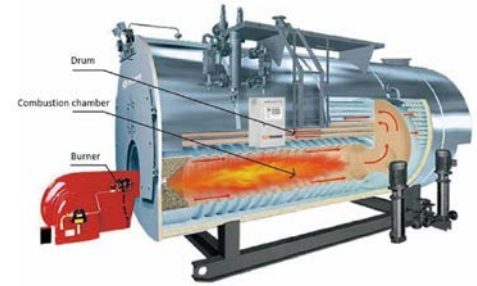
[1] ECHA, European Chemicals Agency, registration dossier Methanol
[2] Petrobras/Statoil ASA, Safety Data Sheet, ECHA registration dossier Gasoline
[3] GKG/ A/S Dansk Shell, Safety Data Sheet
[4] ECHA, European Chemicals Agency, registration dossier Diesel
[5] ECHA, European Chemicals Agency, registration dossier Methane

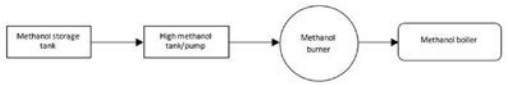
Additional Source: Meyer-Werft

03 OTHER MARKETS

Methanol Industrial Boilers in China

- Industrial boilers are widely used for heating and industrial stream
- Many cities in China prohibiting use of coal and diesel fuels
- Capacity ranged from 1 to 20 ton/hour
- One steam ton capacity consumes 110 kg of methanol, and runs 24/7
- Methanol fuel is used neat or as blend with diesel fuel
- Standards developed with MI and Methanex support
- ***Estimated more than 1000 units, consuming over 2 MMTs methanol in 2017***
- ***Growing to 5 MMT in 5 years***



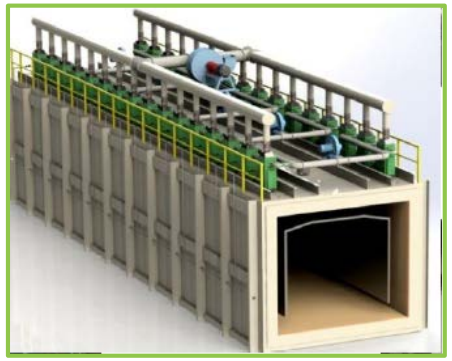


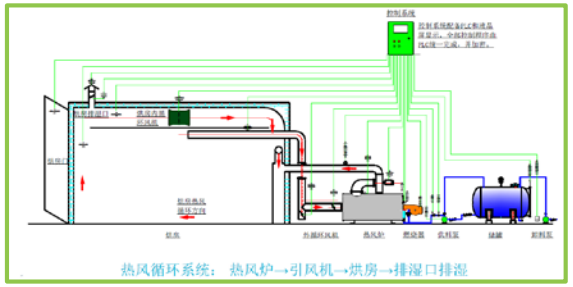
https://www.methanol.org/energy/boiler-cookstoves/

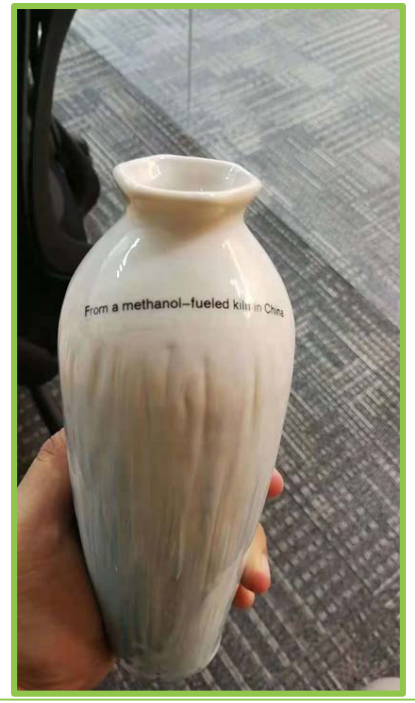
Methanol Cook Stoves in China

- **Different types methanol cook stoves:** Single heating, stir fry, steaming
- Widely used in restaurants, central kitchens, mainly cost-driven
- Simple storage and transportation, filling the gap of pipeline NG supply
- Fuel: 100% methanol to methanol blends usually with water
- ***Market for Cooking Application estimated over 5 MMTs in China in 2017***
- ***Growing to 7-8 MMT in 5 years***

Glass/Ceramic Kilns and Tobacco Drying







- China also developing other new markets for the use of methanol:
  - Glass/ceramic kilns – China produced 60% of world's glass products; methanol uses less air intake and produces cleaner flue gas for superior finish
  - Tobacco drying – One in every 3 cigarettes smoked in the world are smoked in China

Methanol a Hydrogen Carrier for Fuel Cells

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

04 CONTACTS

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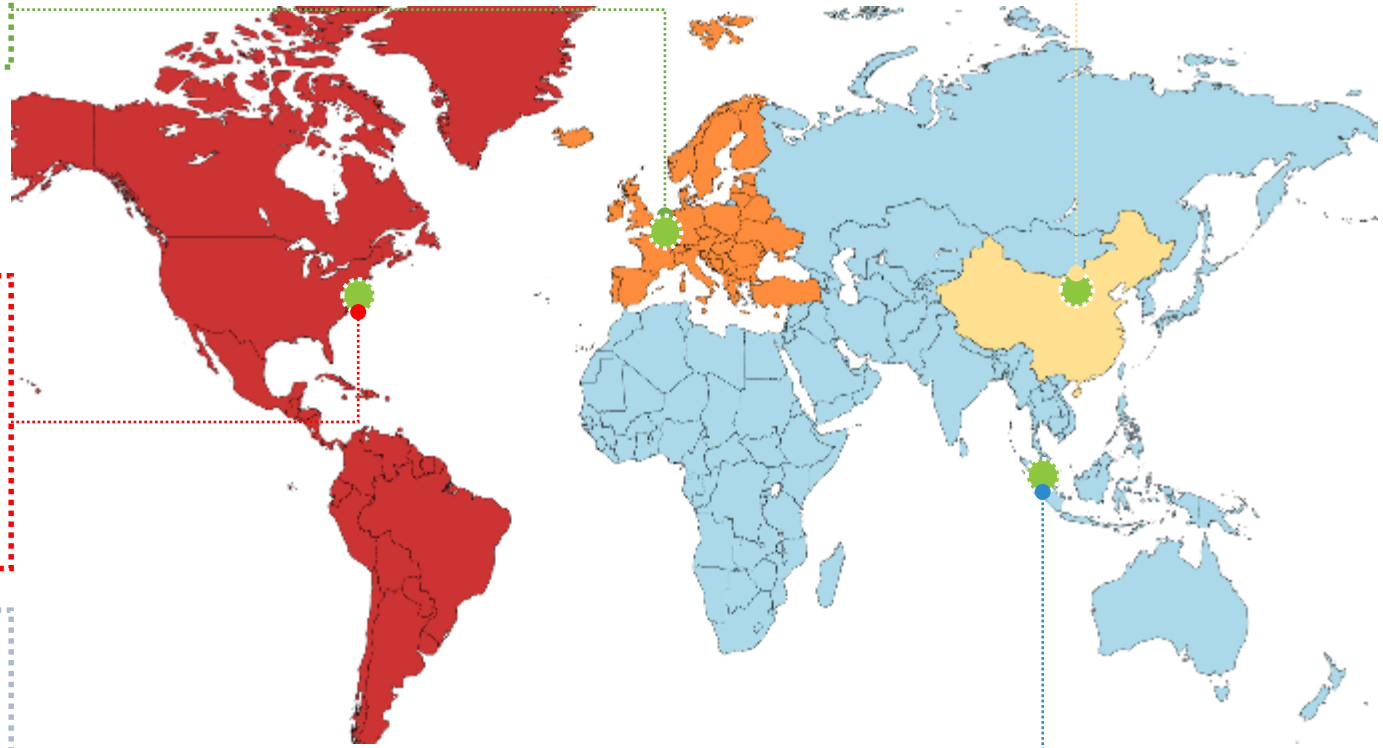

www.methanol.org www.methanolfuels.org