Methanol Economy Concept

- The late Dr. George Olah, Nobel Prize laureate, 1994, and his co-authors: “Beyond Oil and Gas: the Methanol Economy”, 2006.

- Key features of methanol economy as envisioned by Dr. Olah
  - Methanol is the primary energy carrier, instead of oil
  - It is liquid, versatile and low cost
  - Can be synthesized via a number of routes, including from CO₂.
  - It is reactive. A number of products can be made from it.
  - Can address GHG as part of “CO₂ looping”. Methanol is burned, CO₂ is captured and made into methanol.

- 50,000 liter/yr (< 1 bpd) pilot plant in Iceland, using geothermal energy.

- Methanol is substituting crude oil and products from crude in some applications.
Past Feedstock Prices
(constant 2017 dollars)

- Coal, bituminous averaged
- Gas, Citigate (to 1996) and Electric Power Price
- WTI Cushing
- Propane
- Methanol
- RBOB

Demand Substitution
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- When oil (and downstream products from it, like gasoline, diesel, plastics, fibers, functional fluids) is high-priced, it experiences higher rates of substitution by alternatives:
  - Power-generation fuel mix (coal, NG, renewables, nuclear) via electric cars, plug-in hybrids, even telecommuting.
  - Compressed natural gas in CNG vehicles
  - Biofuels: bioethanol, biodiesel, renewable diesel
  - Commuting in electrically powered light rail
  - Even walking or biking to work.

- More relevant to industries using gasification and syngas technologies (chemicals, fertilizers, power)
  - Ethylene and propylene production from natural gas liquids instead of naphtha.
  - Wax and lubricants from plant-based, Fischer-Tropsch and ethylene-based feedstocks.
  - Methanol and derivatives from natural gas and coal instead of naphtha
  - Fertilizers from natural gas and coal instead of naphtha.
Methanol Already Big Part of Economy
Substitution by Methanol

- LPG – Dimethyl Ether
- Ethylene, Propylene via MTO
- Gasoline
  - Methyl Tertiary Butyl Ether (MTBE)
  - Direct blending into gasoline
  - Drop-in gasoline via MTG processes
  - Ethanol via methanol carbonylation
- Diesel
  - Methanol ~ 15% of biobiesel
  - DME – diesel substitute
- Bunker fuel – methanol bunkering on few pilot vessels
Substitution by Methanol

- We estimate as of end of 2016:
  - Methanol demand approximately 74 MM tpy
  - ~ 55% of methanol use is in traditional chemical applications. ~ 45% is in oil substitute applications.
  - Methanol substitution of oil is approximately ~ 0.55% of global oil market.
  - Or equivalent to ~ 32% of oil demand growth 2009 - 2017
Will Substitution by Methanol Continue?

Primary Products Prices Energy Basis
(constant 2017 dollars)

- Methanol
- Methanol Blended on Volume Basis
- Methanol Blended on Energy Basis
- Methanol Cash Cost
- Gasoline
Recent Progress in Fuel Substitution

- In 2015, United Kingdom lowered fuel taxes on methanol blended into gasoline
- Australia - Coogee demonstration project completed and regulations in place for methanol fuels
- New Zealand – In Dec. 2016, announced it would allow 3% methanol in updated fuel specifications (mid-2017)
- Israel – national standard approved for M15 in late 2016 (market potential~450kta); testing higher blends. Vehicle partner - Fiat Chrysler
# Developing Methanol Economy

<table>
<thead>
<tr>
<th>Large Volume Product</th>
<th>Process from crude</th>
<th>Process from methanol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ethylene, propylene</strong></td>
<td>Naphtha refining → Steam cracking</td>
<td>UOP/Hydro MTO, Lummus/SYN DMTO, Sinopec S-MTO Lurgi MTP, Sinopec S-MTP, Tsinghua FMPT</td>
</tr>
<tr>
<td><strong>LPG</strong></td>
<td>Distillation Cracking → Distillation</td>
<td>DME via Haldor Topsoe, Lurgi, Uhde, others’ DME processes</td>
</tr>
<tr>
<td><strong>Ethylene glycol</strong></td>
<td>Naphtha refining → Steam cracking → Oxidation</td>
<td>Eastman/JM formaldehyde to EG, No commercial plants. Process via glycolic acid formerly practiced.</td>
</tr>
<tr>
<td><strong>1-butene, isobutylene, butadiene</strong></td>
<td>Naphtha refining → Steam cracking</td>
<td>Not commercial, co-production with MTO/MTP is possible</td>
</tr>
<tr>
<td><strong>Isoprene</strong></td>
<td>Naphtha refining → Steam cracking → Separation</td>
<td>Formaldehyde + isobutylene, commercial, possibly practiced</td>
</tr>
<tr>
<td><strong>Gasoline</strong></td>
<td>Naphtha refining → Blending</td>
<td>Direct blending</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ExxonMobil MTG, Haldor Topsoe TIGAS™</td>
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<tr>
<td></td>
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<td>Ethanol via Celanese TCX ®, Enerkem</td>
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<td>Methanol component of MTBE</td>
</tr>
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<td>Large Volume Product</td>
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</tr>
<tr>
<td>------------------------------------------</td>
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</tr>
<tr>
<td>Naphtha-range paraffin solvents and fluids</td>
<td>Naphtha refining $\rightarrow$ hydrogenation</td>
<td>None known</td>
</tr>
<tr>
<td>BTX</td>
<td>Naphtha Refining $\rightarrow$ reforming $\rightarrow$ Separation</td>
<td>Developments in China and ExxonMobil. Successful pilot.</td>
</tr>
<tr>
<td>Kerosene/Jet fuel</td>
<td>Refining $\rightarrow$ blending</td>
<td>None known</td>
</tr>
<tr>
<td>n-Paraffins</td>
<td>Refining $\rightarrow$ separation</td>
<td>MeOH $\rightarrow$ MTO $\rightarrow$ Alpha-olefins, n-paraffin substitute</td>
</tr>
<tr>
<td>Diesel</td>
<td>Refining $\rightarrow$ blending</td>
<td>DME via Haldor Topsoe, Lurgi, Uhde, others. Diesel substitution by DME is in trials Methanol in FAME “Drop-in” – none known</td>
</tr>
<tr>
<td>White Oils</td>
<td>Refining $\rightarrow$ hydroprocessing</td>
<td>None known</td>
</tr>
<tr>
<td>Lubricants</td>
<td>Refining $\rightarrow$ hydroprocessing</td>
<td>MeOH $\rightarrow$ MTO $\rightarrow$ Alpha-olefins $\rightarrow$ PolyAlphaOlefins, synthetic substitutes</td>
</tr>
<tr>
<td>Bunker fuel</td>
<td>Refining</td>
<td>Direct substitution by methanol is being piloted</td>
</tr>
</tbody>
</table>
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