# The Future of Liquid Transportation Fuels from Biomass

Stoichiometry, Energy & Economics

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# Primary Drivers & Assumptions (IMHO)

- Survival of humanity depends on:
  - Sustainable use of soil, sunlight & water for all purposes
  - Substantial reduction of net-GHG emissions
  - Solving the "non-renewables" problem (*e.g.*, metal ores, phosphate fertilizer, carbon for non-fuel products)
- All "energy" sectors must contribute to GHG reductions:
  - Transportation sector uses about 1/3 of total energy
  - Liquid fuels from crude oil dominate transportation sector
- Biomass is a critical resource:
  - <u>Traditional: </u>Food, Feed, Fiber, Construction, etc.
  - <u>New: </u>Organic Fuels & Materials
  - "Type" is irrelevant … in the end, it comes down to whatever "crop" makes best use of land & other inputs

# Context, Clarification, Etc.

- High-Value, **Non-Fuel** Products from Biomass:
  - Some are already economically viable
  - Their niche will grow as ag/bio-technology allows
  - They will **not** meaningfully impact GHG emissions
- Displacing Liquid Fuels from the Transportation Sector:
  - Will likely be significant in some cases:
    - Commuting (LDPV & First/Last Mile for Mass Transit)
    - Fleet Vehicles (Buses, Deliveries, Local Services)
  - Will probably not be significant in other applications:
    - Primary "family vehicle" in suburban & rural locales
    - Long-haul Freight & Passengers (Bus, Train, Truck, Barge, Ship)
    - **Air Travel!** (Jets & Prop Planes)

# Global Energy Consumption

| Energy Consumption (2013) | Quads / year | % of Total |
|---|---|---|
| Petroleum | 170 | 33 |
| Coal | 140 | 27 |
| Natural Gas | 100 | 20 |
| Nuclear | 20 | 4 |
| Biomass Fuels (Liq. BF=3 Quads) | 44 | 9 |
| All Other Renewables (Hydro=7; Geo=3; Wind=2; Solar=1) | 13 | 3 |

[redacted]

# Stoichiometry – 1

- Chemistry of Biomass:
  - **$C_1H_2O_1$ Sugar, Starch** (Typical "Biomass")
    **& (Hemi)Cellulose 65 – 75%**
  - **$C_1H_{1.5}O_{0.4}$ Lignin 25 – 35%**
  - **$C_1H_2O_{0.1}$ Vegetable Oils**

- Chemistry of Fuels & Chemicals:
  - **$C_1H_2$ Gasoline, Diesel & Jet Fuel (Paraffinic)**
  - **$C_1H_1$ Light Olefins**
  - **$C_1H_2$ Paraffins & Heavy Olefins**
  - **$C_1H_{1.0\text{-}1.3}$ Aromatic Fuels & Chemicals (BTX)**
  - **$C_1H_1O_{0.5\text{-}1.0}$ Organic Acids, Esters, Alcohols, etc.**

# Stoichiometry – 2

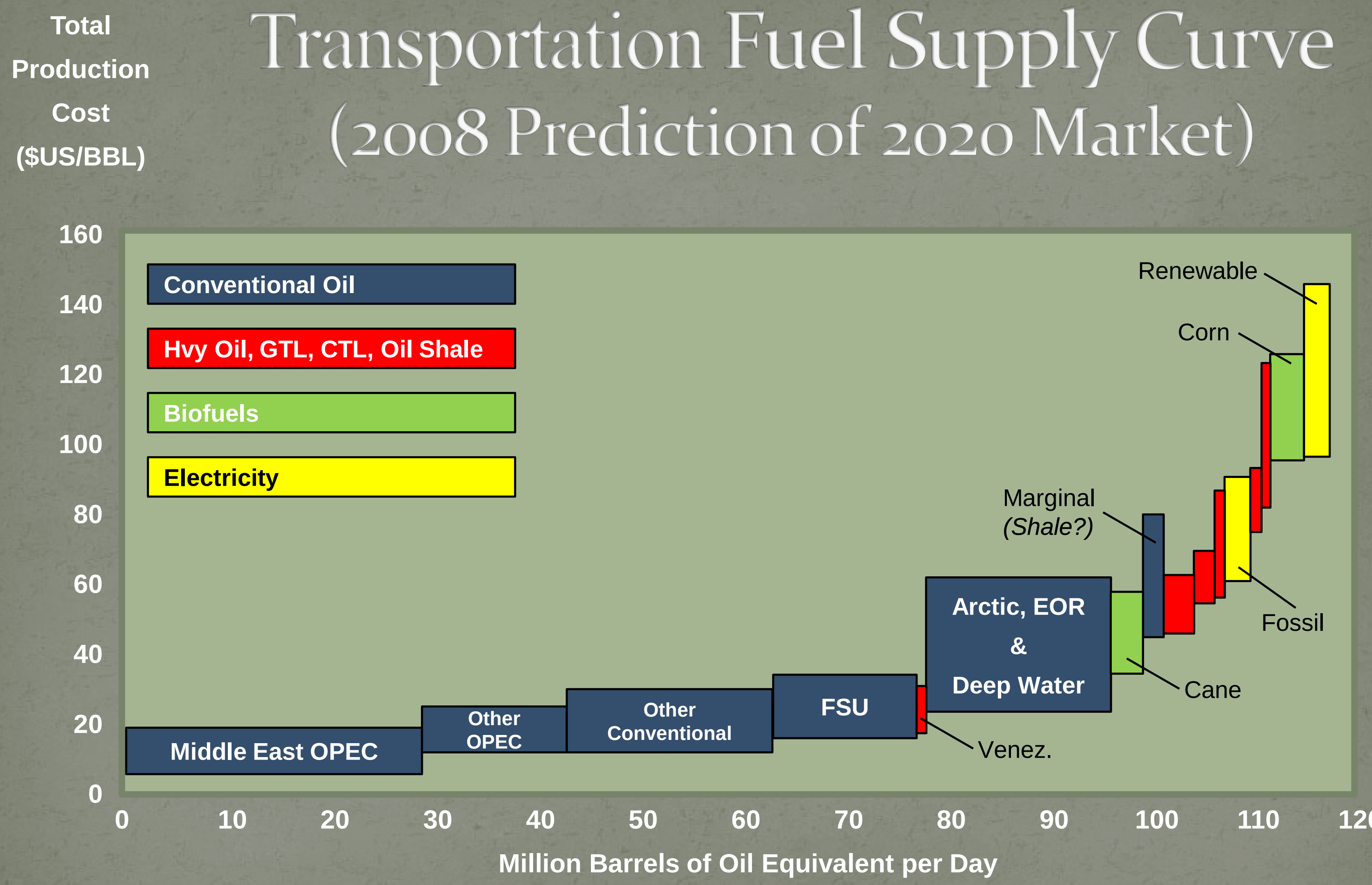
- Biomass contains oxygen; fuels ideally do not
- Some high-volume organic chemicals do contain oxygen, but these volumes are << fuels
- The only way to "get rid of" oxygen is as CO2 or H2O:
  - Paraffinic: $3CH_2O \rightarrow 2CH_2 + CO_2 + H_2O$
    (1 ton) (0.31 ton)
  - Aromatic: $5CH_2O \rightarrow 4CH + CO_2 + 3H_2O$
    (1 ton) (0.37 ton)
  - Ethanol: $6CH_2O \rightarrow 2C_2H_6O + 2CO_2$
    (1 ton) (0.51 ton)
  - Succinic Acid: $5CH_2O + 1.5O_2 \rightarrow C_4H_6O_4 + CO_2 + 2H_2O$
    (1 ton) (0.73 ton)

# Stoichiometry & Energy

- The maximum possible weight % yield of a product depends a great deal on the oxygen content of the product (and to a lesser extent on the hydrogen content)
- The maximum energy content (Btu, cal, kJ, etc.) of a product **does not** depend on the hydrogen or oxygen content (as long as the only other outputs are $CO_2$ & $H_2O$)
- The most efficient possible conversion process always results in the energy content of the feedstock being **entirely captured** in the energy content of the products
- Therefore, energy content is a better yardstick for comparison of various processes & products.

| Energy Source | Price (7/2016) | Conversion | $/MMBtu |
|---|---|---|---|
| Coal (fob PRB) | $8.70/ton | 8,800 Btu/lb | $ 0.50 |
| Coal (U.S. avg., delivered) | $41/ton | 10,400 Btu/lb | $ 2.00 |
| Nat. Gas (Henry Hub) | $2.80/MMBtu | -- -- -- | $ 2.80 |
| Corn Stover (plant gate, est.) | $80/ton | 7,500 Btu/lb | $ 5.35 |
| Wood Pellets (fob Rotterdam) | $113/tonne | 8,700 Btu/lb | $ 5.90 |
| Propane (USGC) | $0.52/gal | 89,200 Btu/gal | $ 5.45 |
| Crude Oil (WTI) | $42/BBL | 5.8 MMBtu/BBL | $ 7.20 |
| Diesel (U.S. Wholesale, ~Jet) | $1.25/gal | 137,630 Btu/gal | $ 9.10 |
| Gasoline (U.S. Wholesale) | $1.33/gal | 123,830 Btu/gal | $ 10.80 |
| Heating Oil (NY Harbor) | $1.20/gal | 115,000 Btu/gal | $ 10.45 |
| Corn Ethanol (CBOT) | $1.41/gal | 76,000 Btu/gal | $ 18.55 |
| p-Xylene (USGC) | $840/tonne | 18,650 Btu/lb | $ 20.40 |
| Butanol (n-/i-BuOH avg.) | $895/tonne | 15,500 Btu/lb | $ 26.10 |
| Electricity (U.S. avg.) | $0.106/kW-hr | 3412 Btu/W-hr | $ 31.00 |
| Cell. Ethanol (cobs, est.) | $3.55/gal | 76,000 Btu/gal | $ 41.20 |
| Succinic Acid | $1785/tonne | 5,745 Btu/lb | $ 140.60 |

# Transportation Fuel Supply Curve (2008 Prediction of 2020 Market)




(Source: "The Future of Alternative Transportation Fuels" – Booz & Co. Study (2008))

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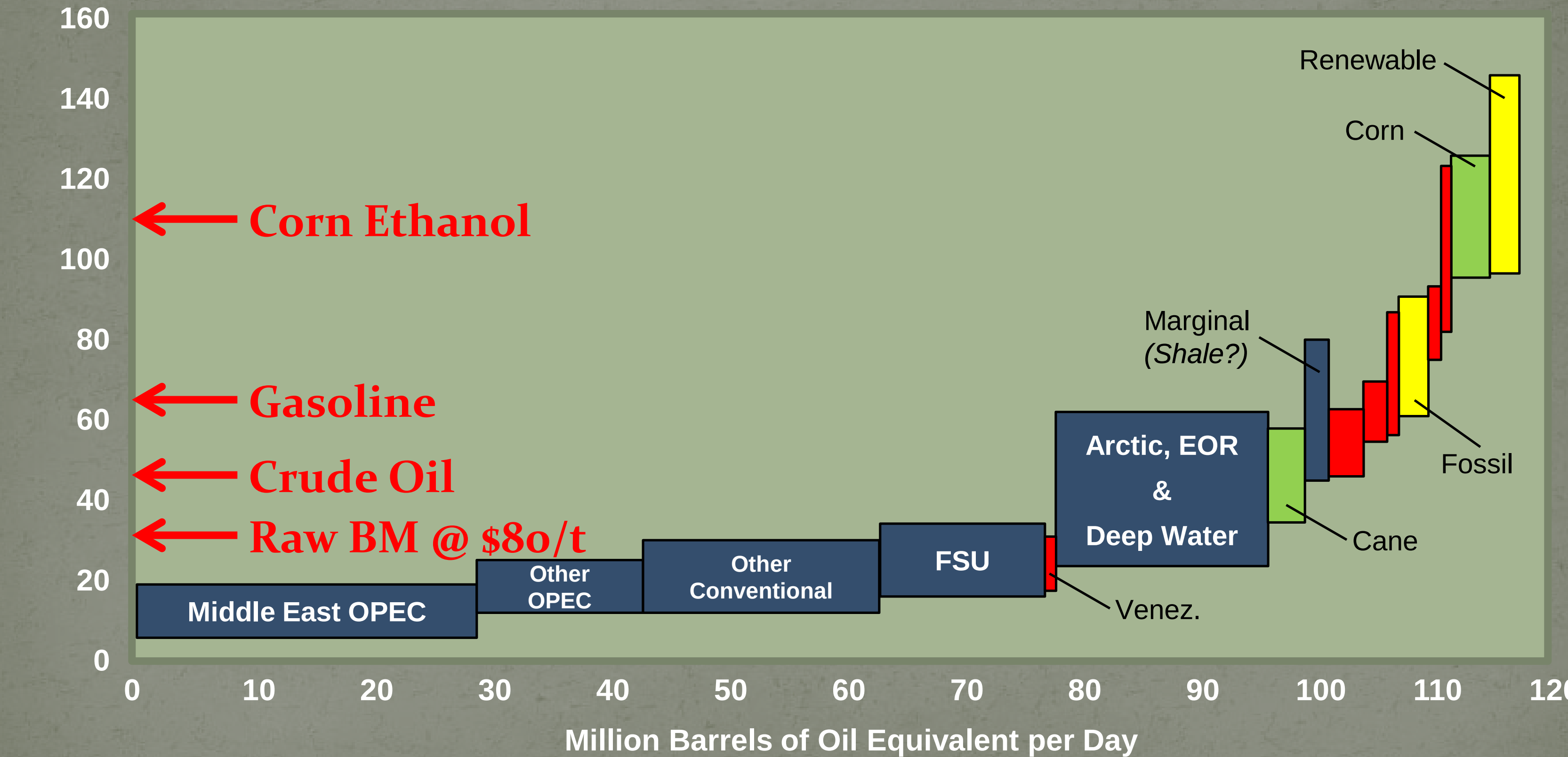
## (2008 Prediction of 2020 Market)

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# Conclusions

- Liquid fuels will be needed in large volumes for the foreseeable future
- Biomass is the only promising source of renewable, sustainable liquid fuels
- Biofuels cannot compete with fossil fuels on an economic basis without a GHG-emissions penalty
- Non-food biomass is currently a much more costly source of fermentable sugars than sugars & starches
- Lignin makes up a substantial portion of the energy content of non-food biomass

# Implications for Biomass Feedstocks

- GHG-emissions penalty is essential
- Lignin utilization will be important for fuels and other low-value products
- Crops & processes should focus on:
  - Maximizing energy capture and GHG reduction
  - Minimization / recycle of inputs (water, N, P, K)
  - Maintenance of soil health
- Likely future:
  - Fermentation, mainly of sugar / starch crops, for high-value products, with integrated CAFO + AD + nutrient recycle
  - Thermochemical conversion of whole biomass for fuels and other low-value products

# Thank You!