IOWA STATE UNIVERSITY

Biofuels: Challenges and Opportunities*

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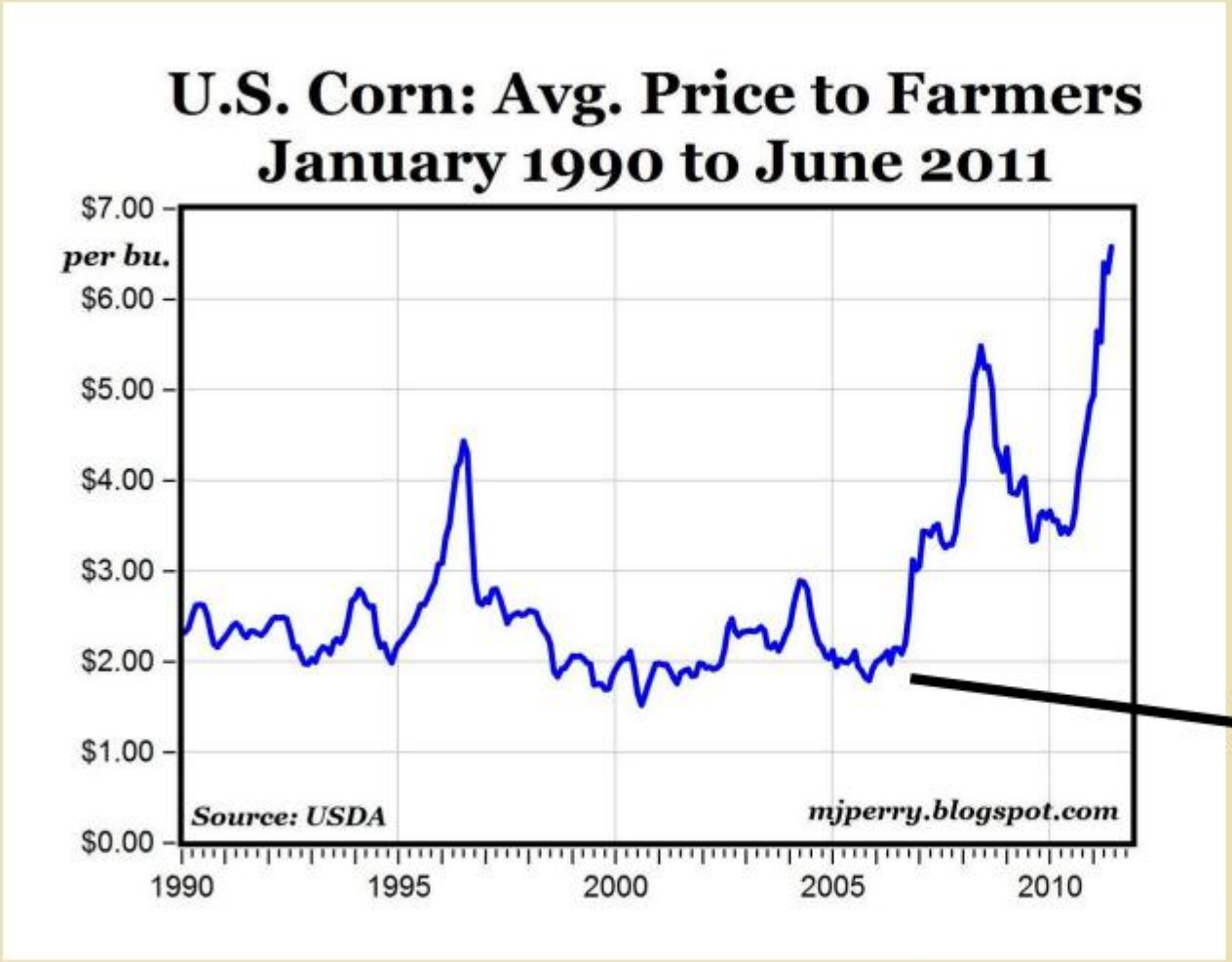
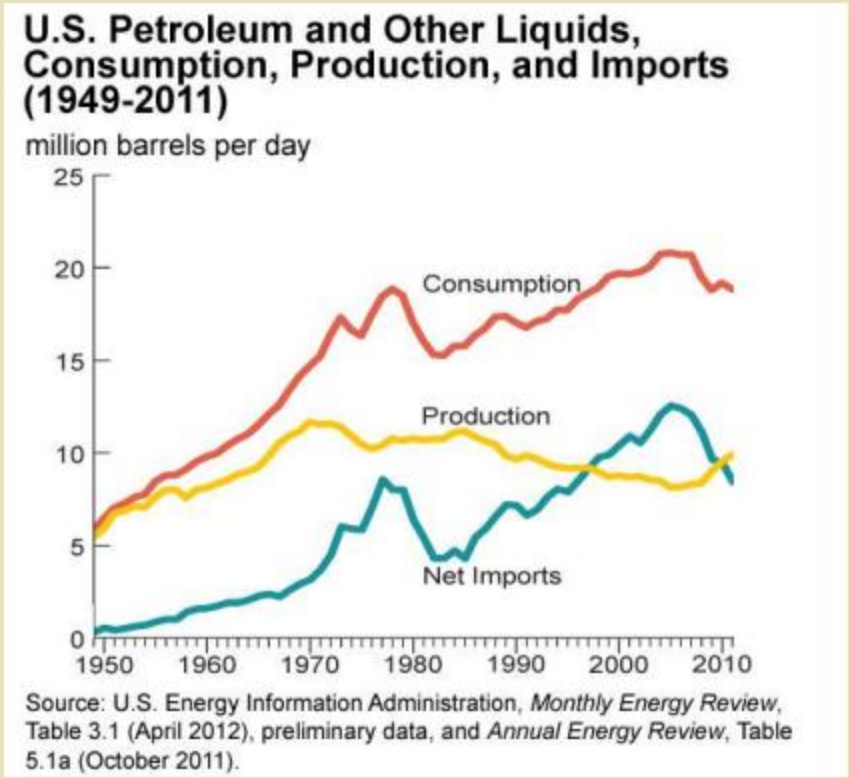
* Disclaimer: opinions expressed are those of the speaker

Some Historical Context



IEA Recent Report*

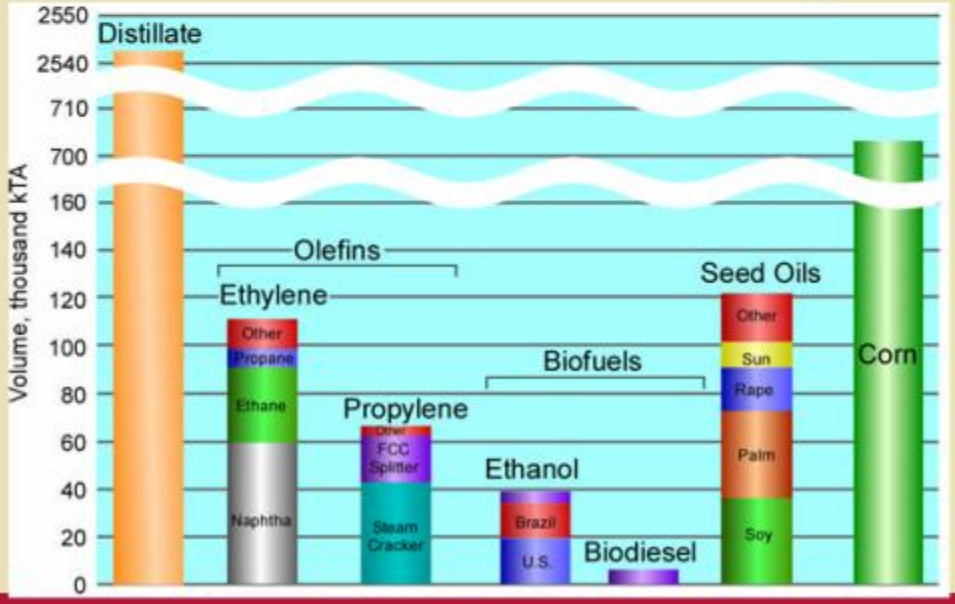
- **2011 – only 45% crude oil imported**
- **2020 – U.S. only importing from Canada, U.S. world's largest oil producer***
- **2030 – U.S. net oil exporter***



More Context

- **Petroleum at $90/bbl**
  - **Gasoline, wholesale & untaxed ~$2.70/gal**
  - **Diesel, wholesale & untaxed ~$3.00/gal**
  - **Grain Ethanol, corn at $3 & $6.50/bu $2.40 & $3.80/gge**

Usage *(in billions of bushels)*	2002/03	2007/08	2012/13
Ethanol	**1.10**	**3.00**	**5.00**
Returned from ethanol to feed	0.36	1.00	1.66
Feed, export, residual, other	8.40	9.80	9.79
Total available for other uses	**8.76**	**10.80**	**11.45**



Biofuels Digest, May 11, 2012

Mark Jones, Dow 2011

Technology Comparison*

- Requires consistent capital cost and evaluation bases
- Comparative economics, not business-case economics
- Considered commercial or "near-commercial" technology where possible
- Material and energy balances by Aspen Plus, generally
- Location U.S. Gulf Coast, 2011 $
- Biomass at $5.4/GJ (limit 1 million t/yr/plant)
- Coal at $2/GJ
- Estimates for N^{th} of a kind plants (N = 5-7)
- Stand-alone plant: Feedstock in; Finished fuels out
- Comparisons are based on best available data; design basis and data are often not very complete

* *Jim Katzer (ExxonMobil retired, Iowa State University)*

Technology Platforms

- **Thermochemical**
  - **Gasification followed by synthesis to fuels (biomass and/or coal)**
  - **Pyrolysis followed by upgrading to fuels (biomass)**
- **Biochemical (biomass)**
  - **Fermentation of sugars (grain ethanol)**
  - **Lignocellulose deconstruction/fermentation**
  - **Algal (lipid) route**
- **Catalytic conversion of bio-products**
  - **Catalytic conversion of sugars or other compounds**
  - **Plant oil-based (soybean or palm oil) routes**

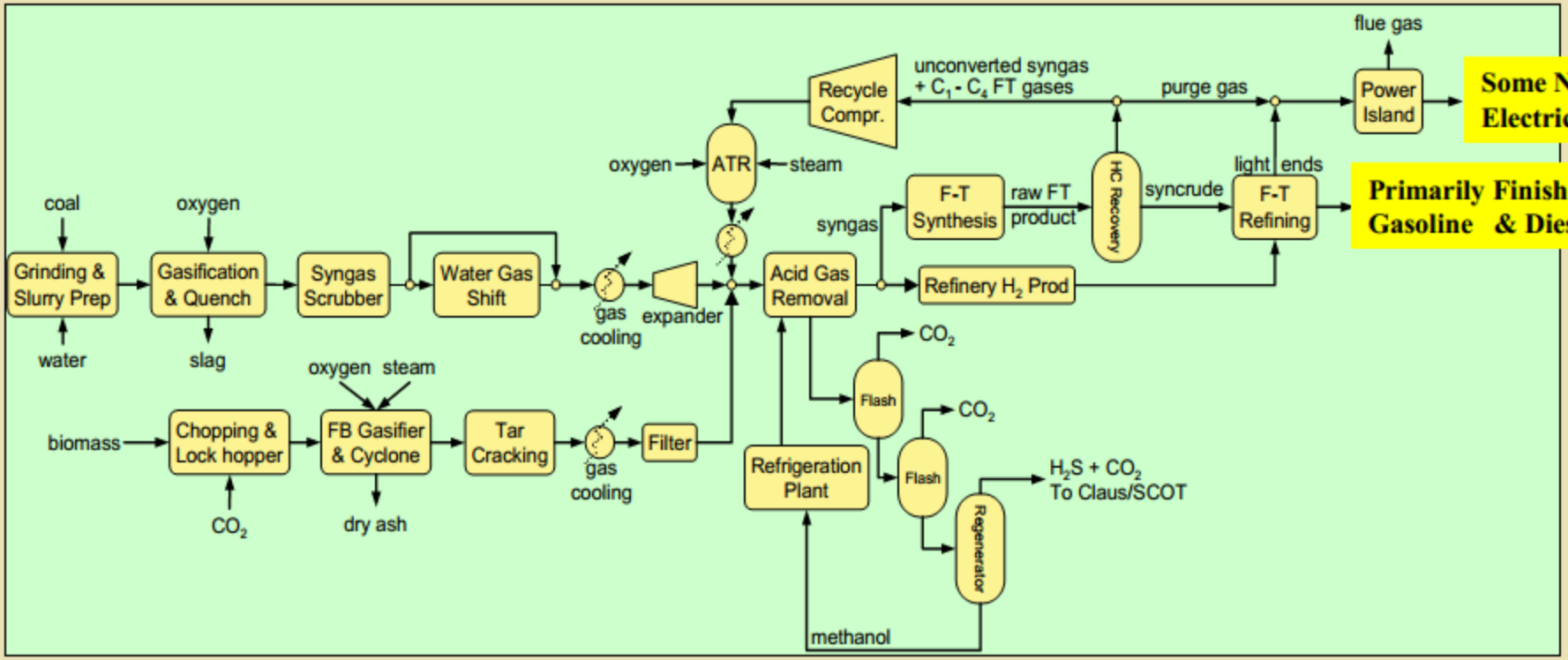
Biomass Properties & Fuel Cost Component

Material:	Grain (corn)	Corn Stover	Wood (poplar)
Starch, wt %	72.0	n/m	n/m
Cellulose, wt %	2.4	36	40
Hemicellulose, wt %	5.5	26	22
Lignin, wt %	0.2	19	24
Ash, wt %	1.4	12	0.6
Bio-Conversion:			
Typical Yields: gge/dry tonne	72	48	50
Thermal-Conversion:			
Gasification Yield, gge/dry tonne	-	67	72
Pyrolysis Yield, gge/dry tonne	-	55	60
Feedstock Cost, $/dry tonne:	255	95	80
Feedstock Cost Component:			
Bioconversion, $/gge	3.50*	$2.00	$1.60
Gasification, $/gge	-	$1.40	$1.10
Fast Pyrolysis, $/gge	-	$1.75	$1.30

Red numbers are first-cut indicator of feedstock cost contribution to product cost

* For Corn at $6.50/bu, DDGS netback reduces this to ~$2.60/gge

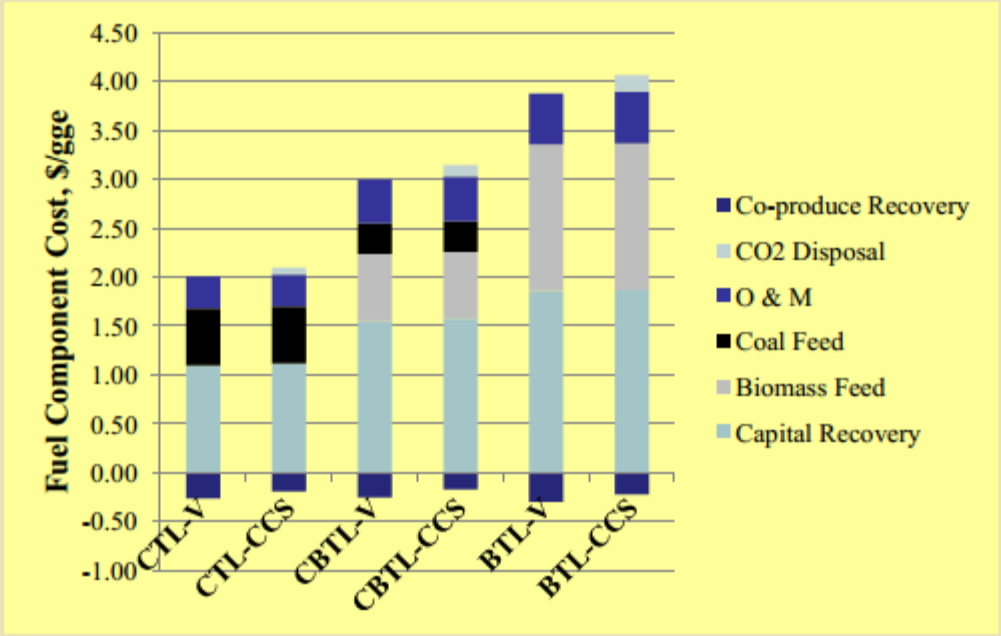
Thermochemical: Gasification



- **Coal: all components are commercially robust**
- **Biomass gasification is "essentially commercial"**
- **Gasification leads to very low criteria emissions, similar to NGCC**
- **Multiple design and operational options to meet specific objectives**
- **In place of FT, use methanol synthesis followed by MTG to produce mainly gasoline**

Thermochemical: Gasification

Feedstock	Mode	Fuel Price, $/gge
– Coal (CTL)	Vent CO_2	1.75
– Coal	CCS	1.90
– Coal/Biomass (40%) (CBTL)	Vent CO_2	2.75
– Coal/Biomass (40%)	CCS	3.00
– Biomass (BTL)	vent CO_2	3.60
– Biomass	CCS	3.85



Fuel Component Cost

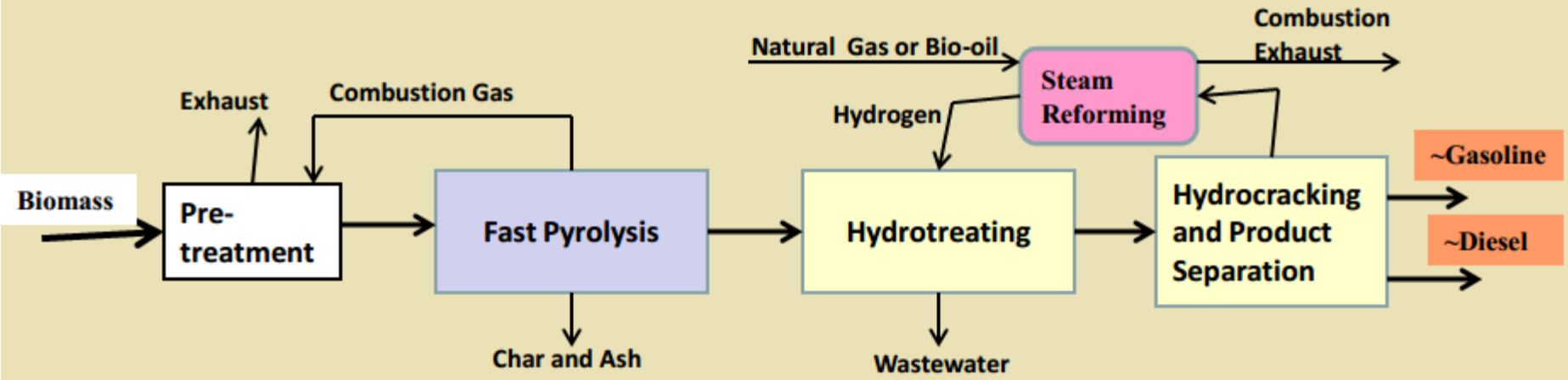
Thermochemical: Pyrolysis

- Pyrolysis is "pre-commercial" requiring much further R&D and demonstration
- Approach includes "fast pyrolysis", "fast catalytic pyrolysis", and "hydropyrolysis"
- Being aggressively pursued because of its potential for lower fuel costs
- Lack of demonstration- or commercial-scale data means higher estimate uncertainty
- Biomass $\xrightarrow{\text{HEAT}}$ Bio-oil (~40 % O) $\xrightarrow{\text{Hydrogen, Catalyst}}$ Fuel (~0 % O) + Water
- Typical yields: bio-oil (60-70 wt % which typically contains 10-15 % water); char (12-15 %), and light gases (13-25 %)
- Bio-oil: density of 1.2 kg/l; acidic with pH of 2.5: ages, ~ 40% O; needs upgrading.

KIOR Fast Catalytic Pyrolysis, 50 ton/day

ENSYN 40 tonne/day fast pyrolysis

Thermochemical: Fast Pyrolysis



- Biomass to liquid fuel energy conversion efficiency is about 37% vs. 47% for gasification
- Estimated capital cost is about 35 % lower than for gasification
- Estimated fuel cost is $3.40 per gallon gasoline equivalent vs. $3.60 for gasification
- Largest factors affecting fuel cost are: fuel yield (wt % of bio-oil), biomass cost, and bio-oil yield (wt % of the feed).