Liquid Fuels from Biomass

Robert L. McCormick
(with thanks to Michael A. Pacheco)

August 23, 2006

Biomass Strengths

Biomass is:

- Abundant
- Renewable
- Potentially carbon-neutral
- The only sustainable source of hydrocarbons.

Biomass can:

- Fill the gap between energy demand and petroleum availability in the near to mid term.
- Be a renewable source of hydrogen in the long term.

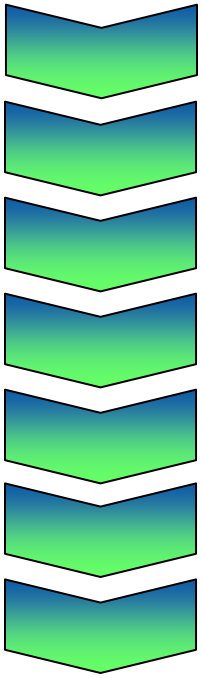
Leading Biofuel Technologies

Here Today

Ethanol – Produced from grain, used as blending component: E10 or E85

Biodiesel – Transesterified vegetable oils blended with diesel up to B20

Near Term



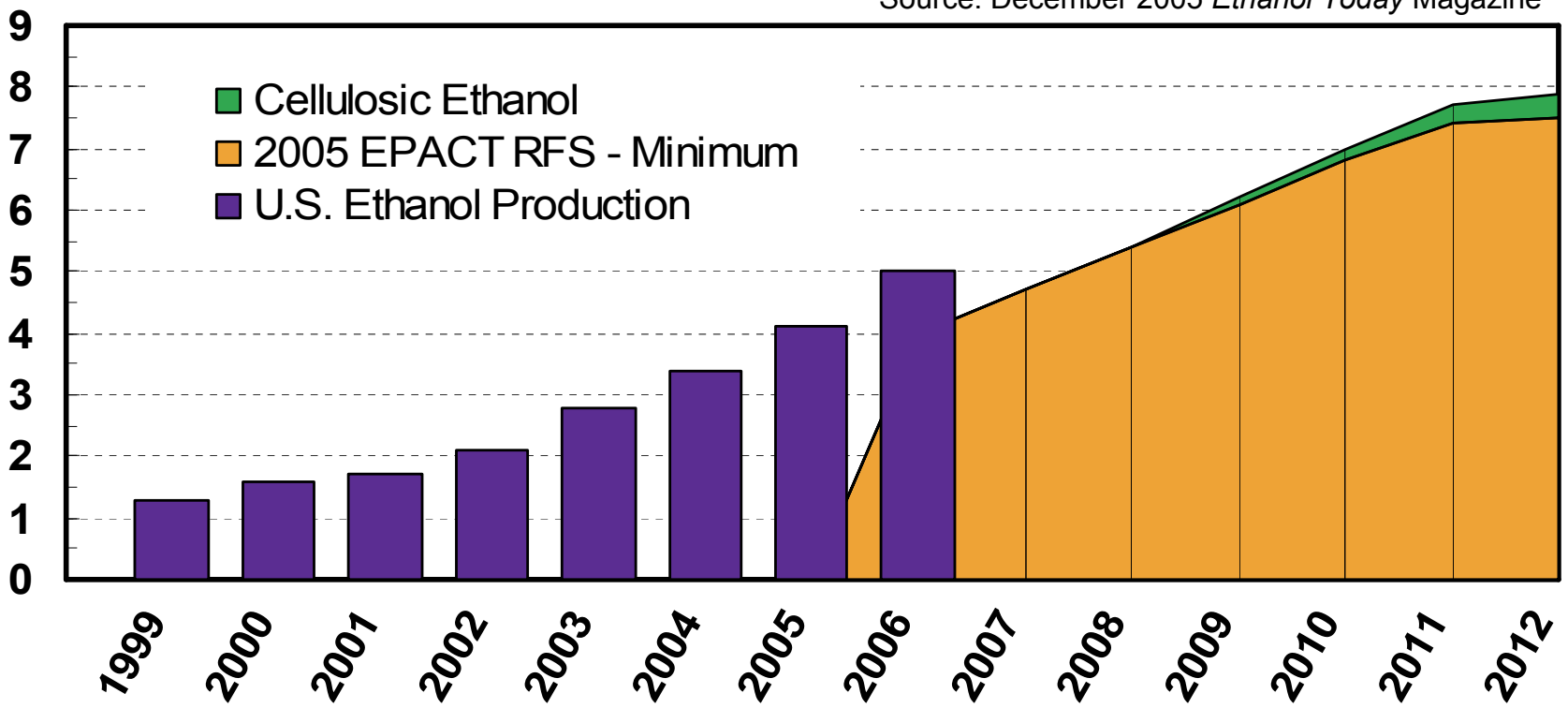
Long Term

Ethanol Production

Actual and Projected U.S. Ethanol Production 1999-2012

Billion Gallons of Production

Source: December 2005 *Ethanol Today* Magazine



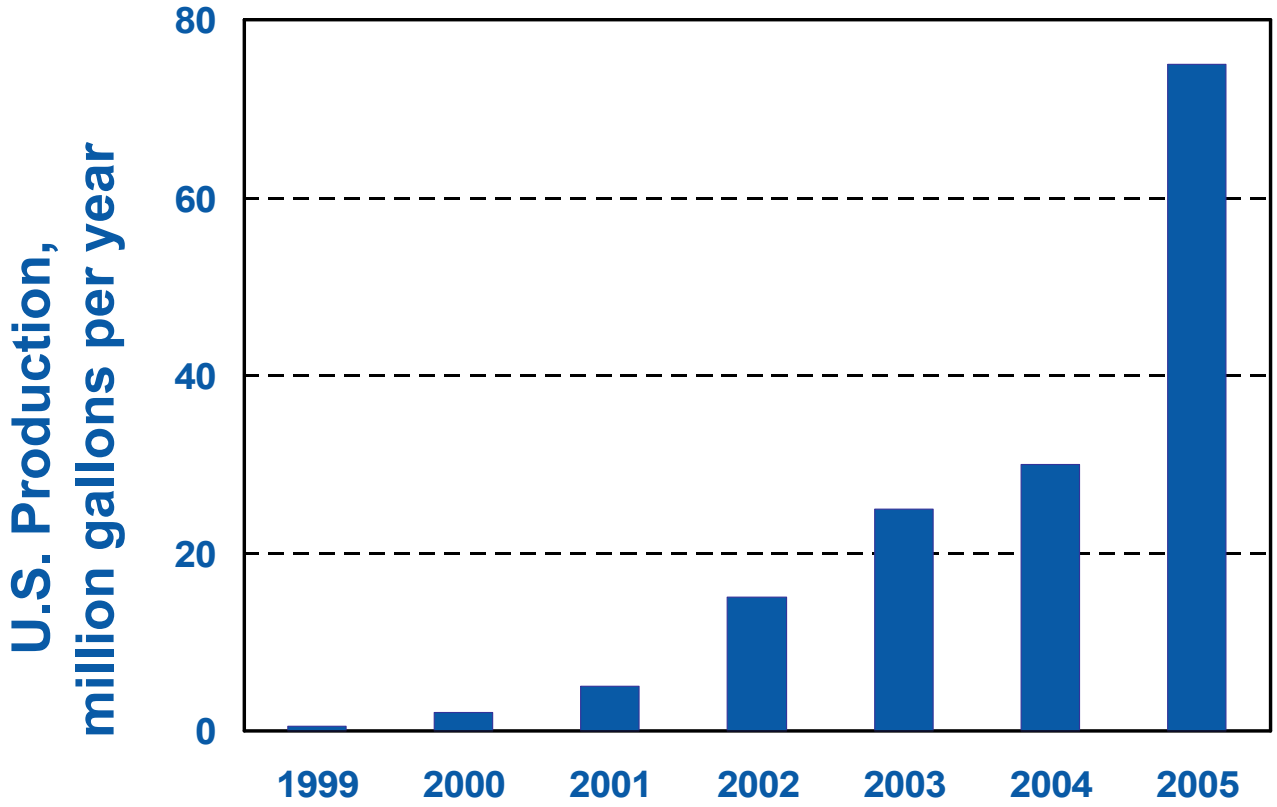
- Renewable Fuels Standard mandates 7.5 billion gallons by 2012
- Total US gasoline market ~140 billion annual gallons

Ethanol Utilization Issues

- Environmental issues (or perceived environmental issues) may cause state level air quality regulators to limit ethanol markets
- For E10:
  - Ethanol increases permeation through hoses and seals of older vehicles
    - Permeation of both ethanol and gasoline hydrocarbons
    - Significant increase in evaporative emissions, ~65%
    - California regulators view this as having already impacted air quality negatively
    - Additional testing required
  - Ethanol may increase NO_x – lack of definitive data
- For E85
  - Lack of recent emission data on modern hardware/FFVs
  - No information on commingling effect (blending to produce E20, E30, etc. in vehicle fuel tank)

U.S. Biodiesel Production

http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Graph_Slide.pdf (2-5-2006)



Predicted to top 150 million gallons in 2006

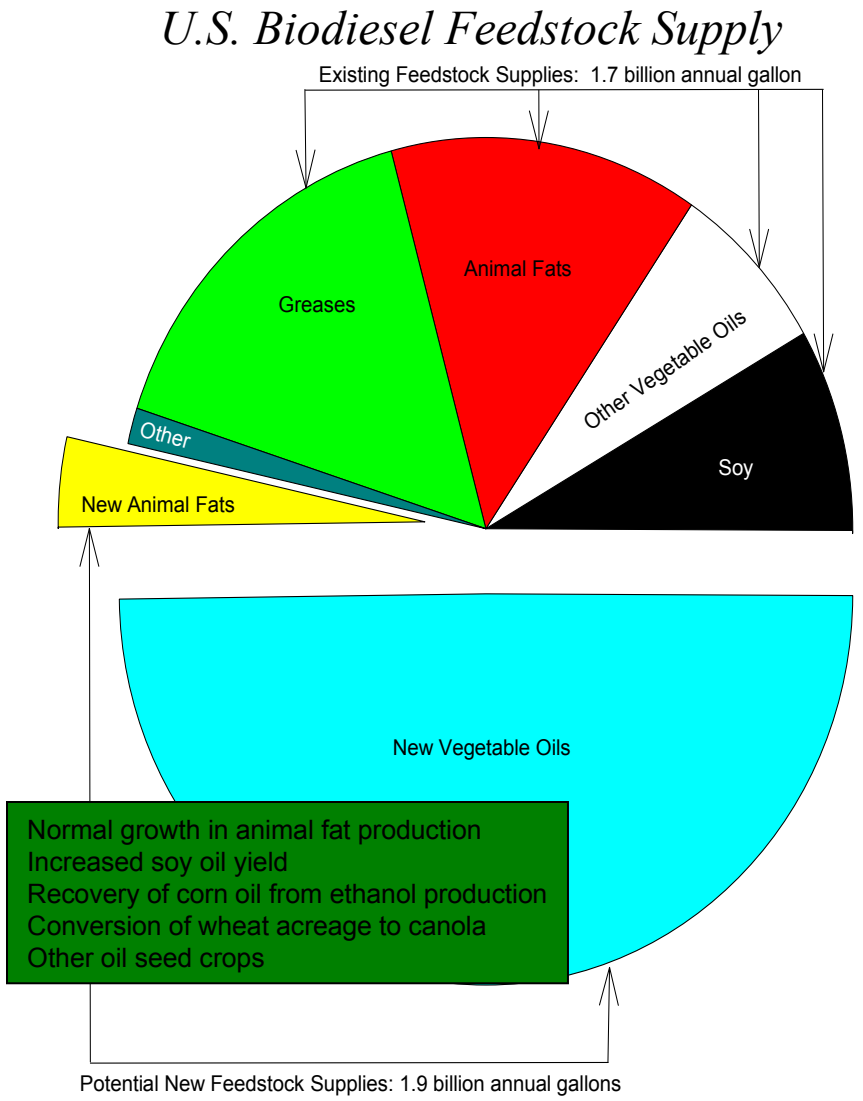
Installed production capacity over 400 million gallons, growing to over 900 million by end of 2007

Total US distillate fuels market is approximately 60 billion gallons/year

Biodiesel Resource

2004 DOE study concludes:

- 1.7 billion annual gallon resource
- 3.6 billion annual gallons by 2015
- Long-Term Potential: 10 billion annual gallons by 2030
- *Recent Biomass Program 30x30 workshop industry attendees put the 2030 resource size at 7.5 to 15 billion annual gallons*
- *Demand for biodiesel feedstock has begun to change vegetable oil markets*
  - *Increased crushing capacity*
  - *Crop contracts?*



NREL/TP-510-34796, June 2004

Biodiesel Utilization Issues

- Fuel Quality and Stability
  - Need ASTM specifications for biodiesel blends –oxidation stability
  - Industry needs to produce a consistent, high quality product
- Impact on engine durability and maintenance costs
  - Larger database on real-world durability and maintenance
  - Documented, controlled fleet and field studies
- Uncertainty over impact on NO_x emissions
  - Engine dyno studies show increase but chassis dyno tests show zero impact
- Unknown compatibility with 2007-2010 emission control systems
  - Initial data suggests good performance with DPF
  - Performance with NO_x control catalysts unknown

Leading Biofuel Technologies

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Ethanol – Produced from grain

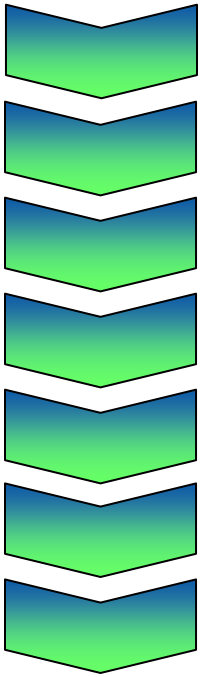
Biodiesel – Transesterified vegetable oils

Near Term

Ethanol – Produced from cellulosic material

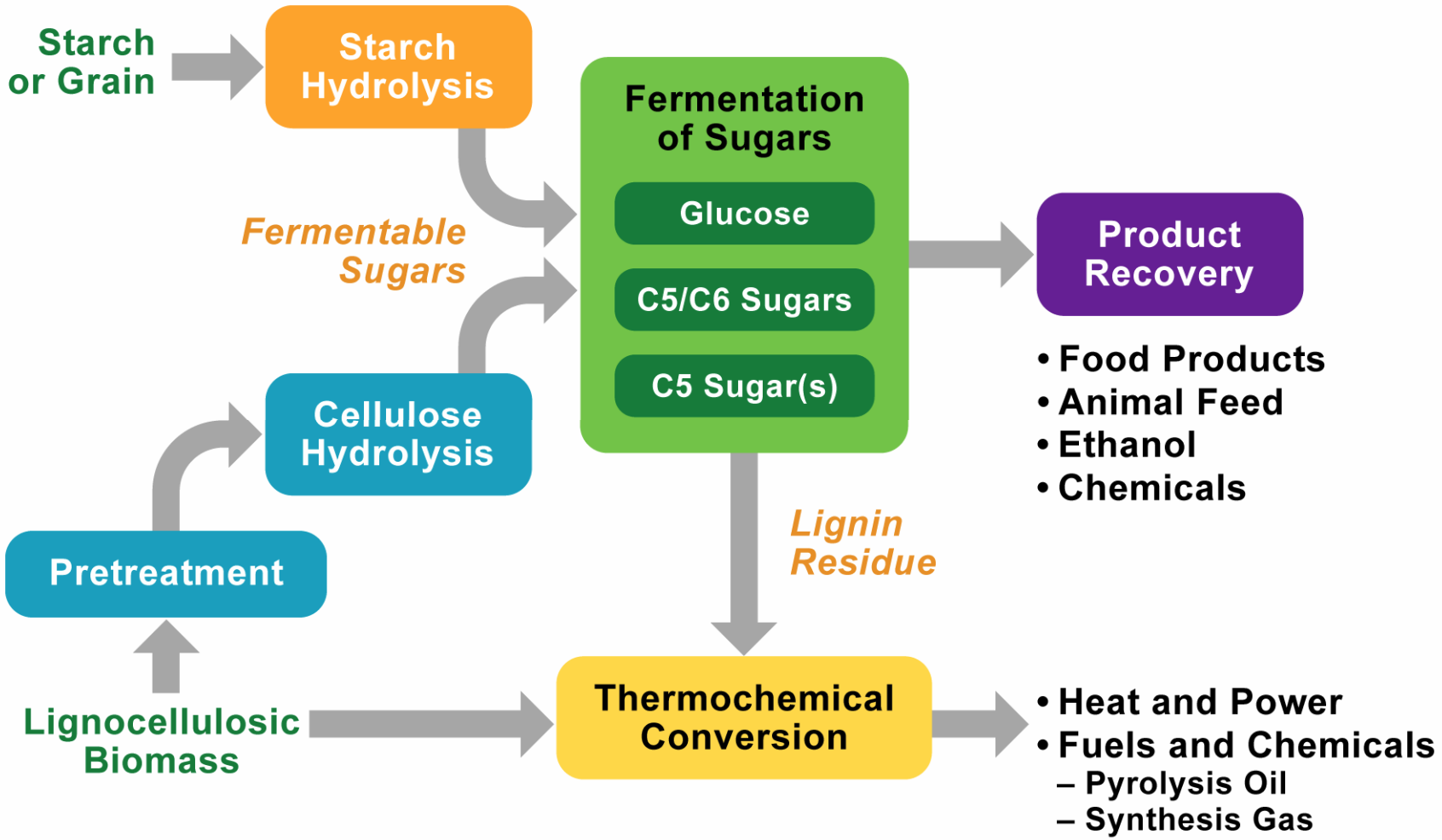
Butanol – Produced from grain or celluose

Hydrogenation-Derived Renewable Diesel/Gasoline – fats, waste oils, virgin oils processed pure or blended with crude oil and processed using petroleum refinery or similar operations

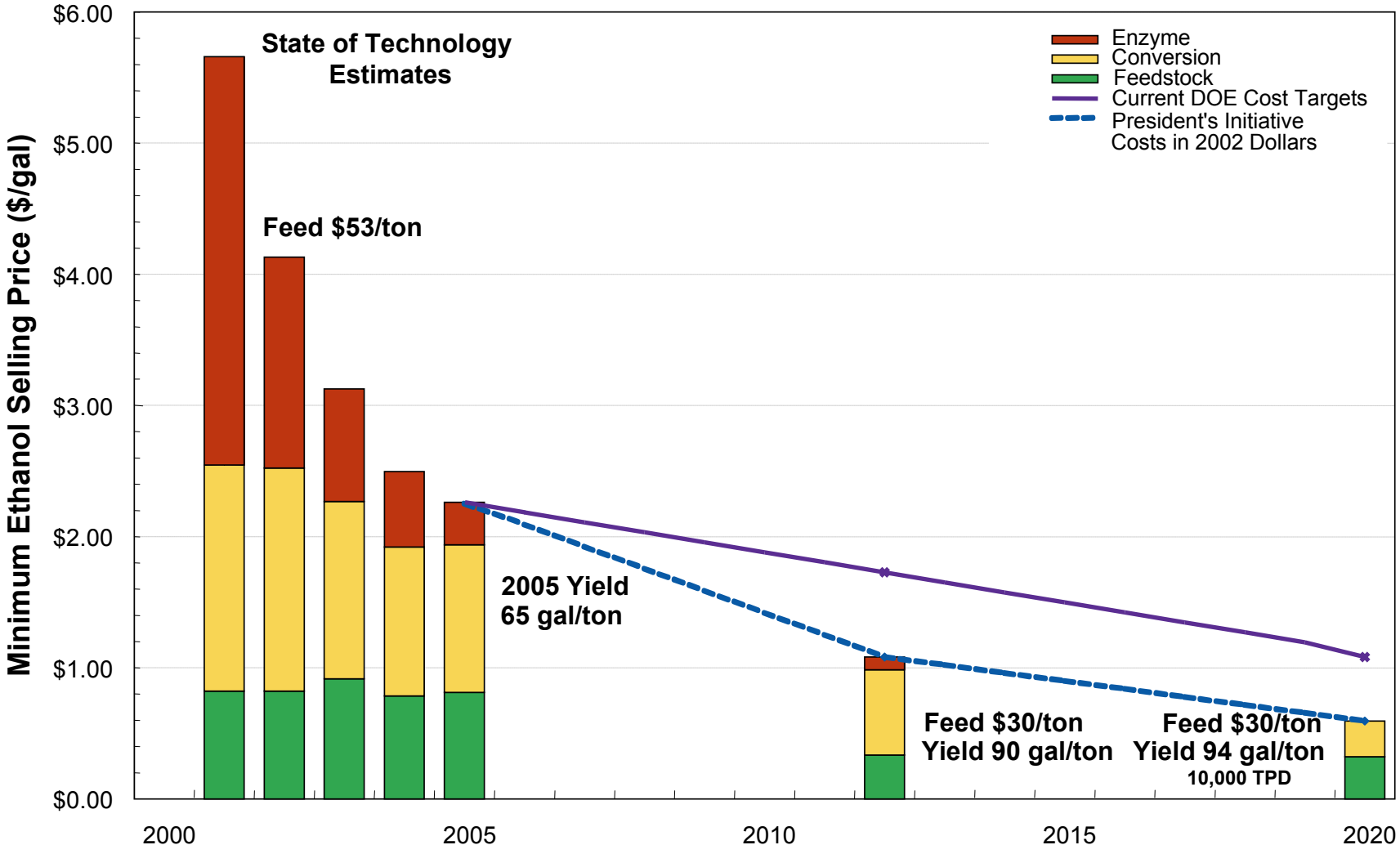


Long Term

Integrated Cellulosic Ethanol Biorefinery

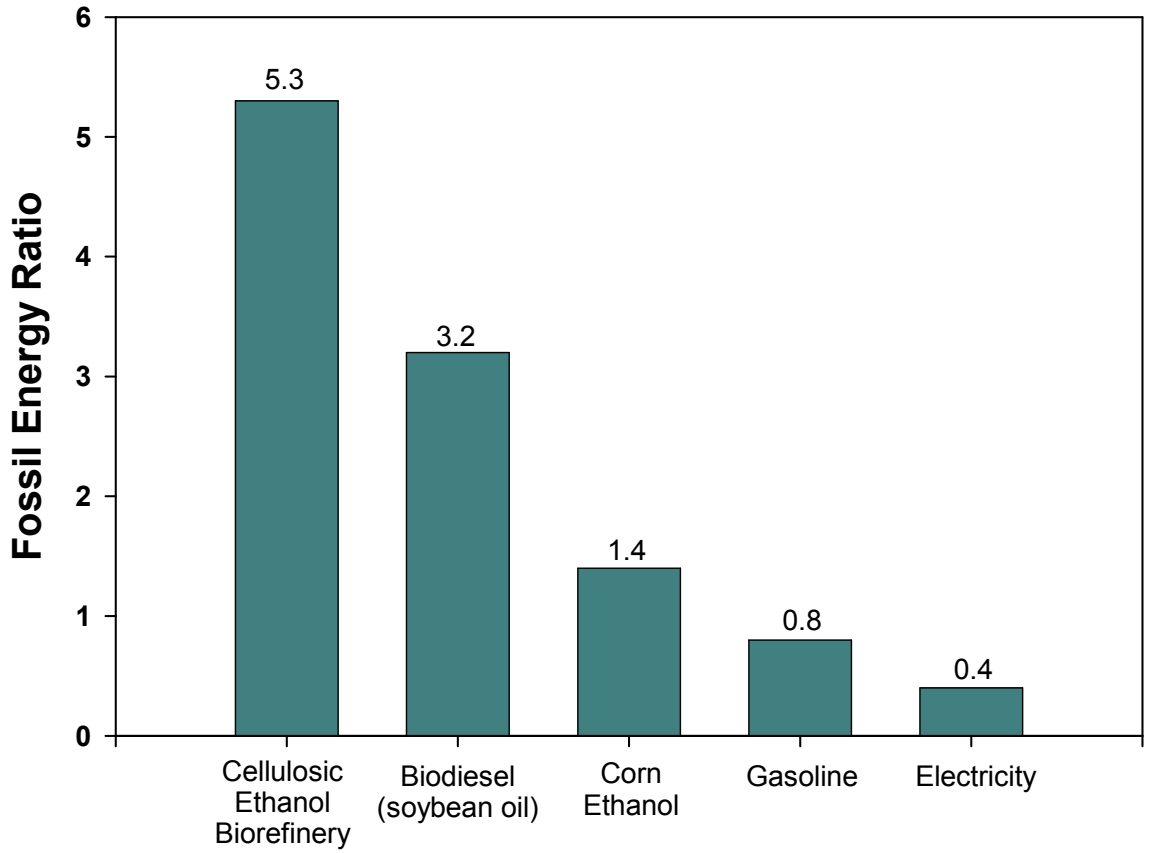


Reducing the Cost of Ethanol From Stover



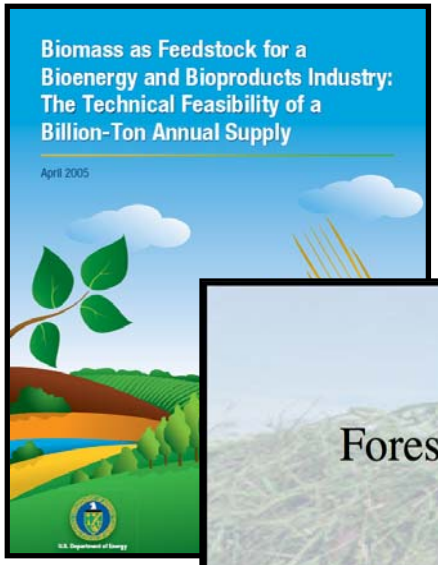
Fossil Energy Ratio

$$\text{Fossil Energy Ratio (FER)} = \frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$$

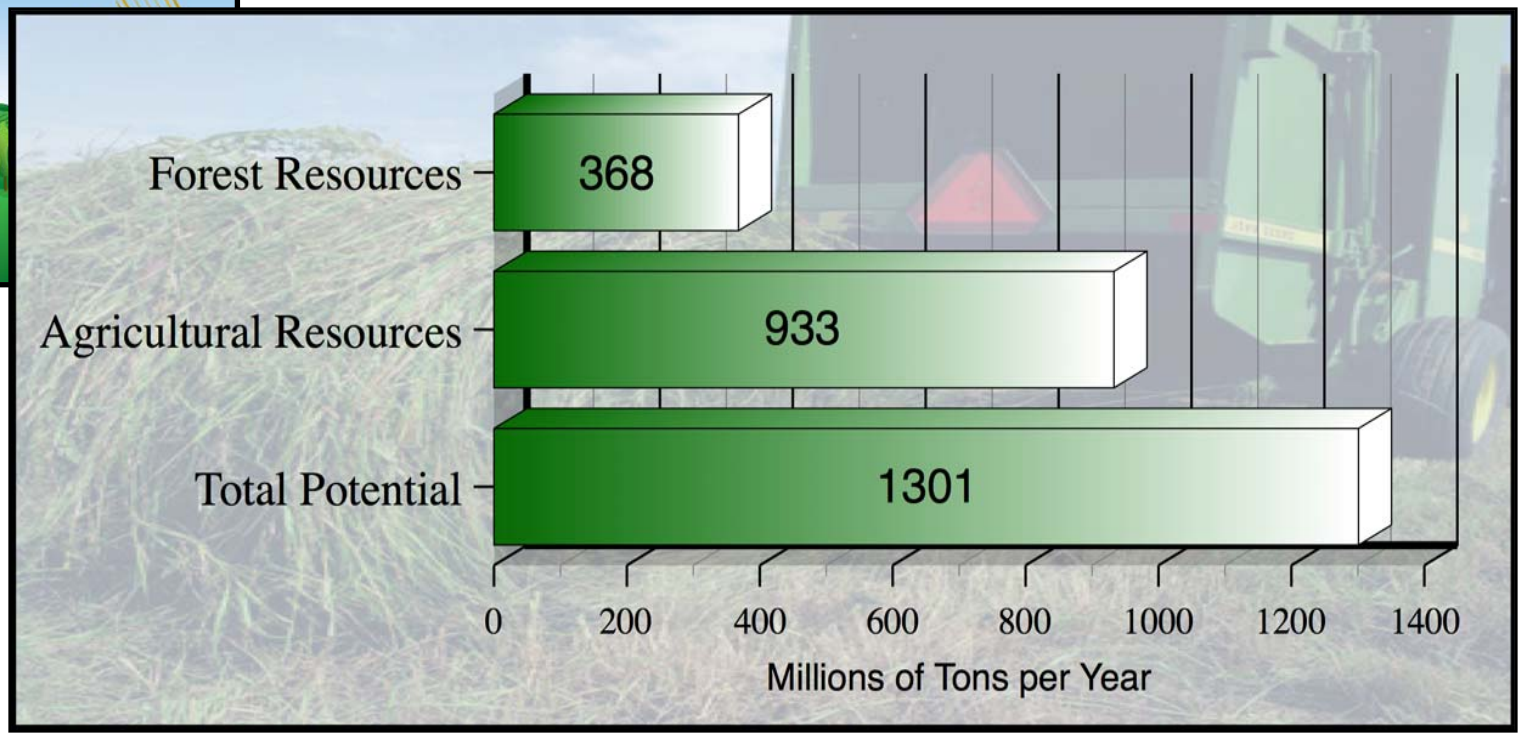


Source: J. Sheehan and M. Wang (2003)

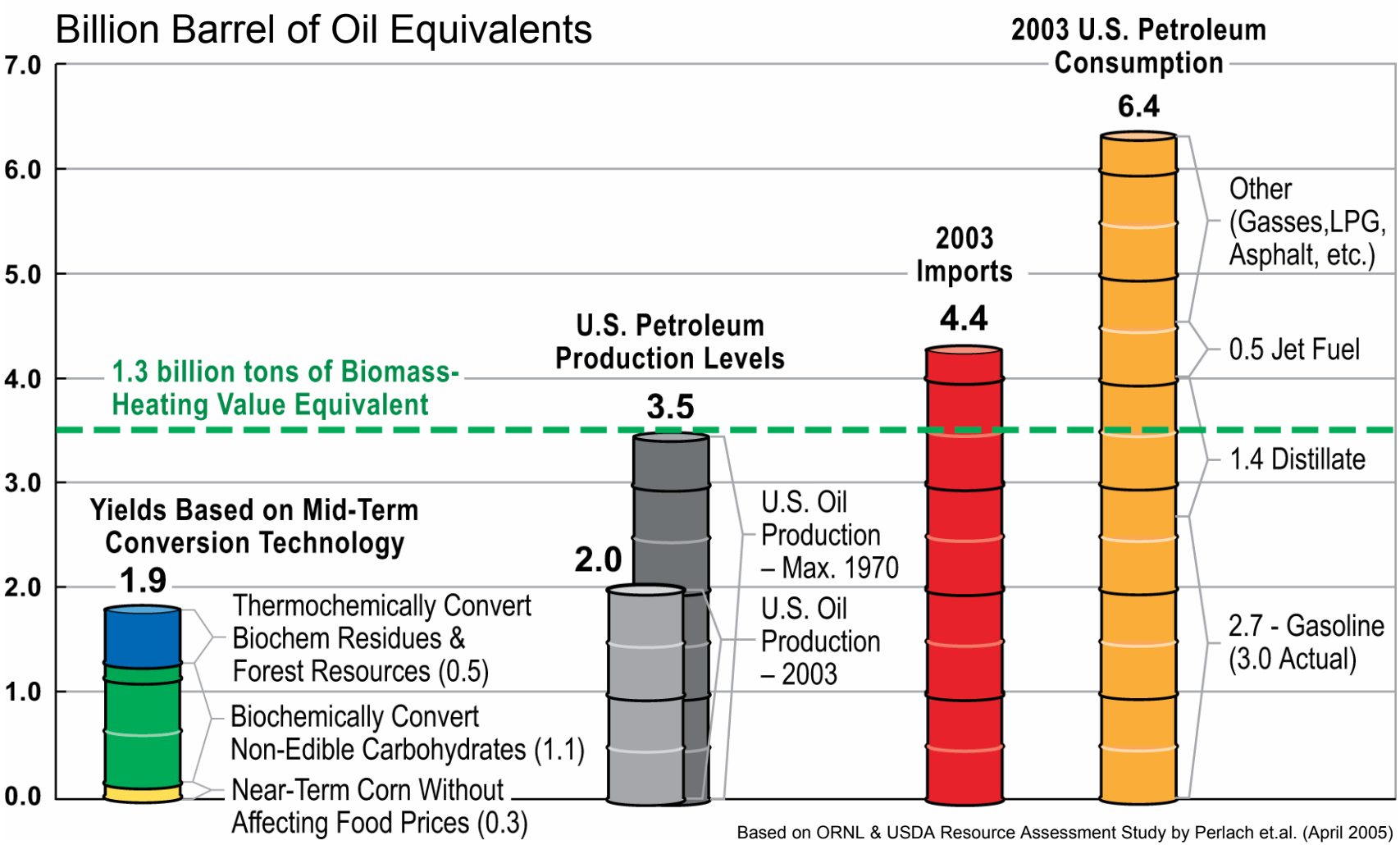
U.S. Biomass Resource Assessment



- Updated resource assessment - April 2005
- Jointly developed by USDOE and USDA
- Referred to as the "Billion Ton Study"

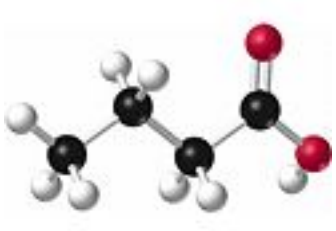


The 1.3 Billion Ton Biomass Scenario



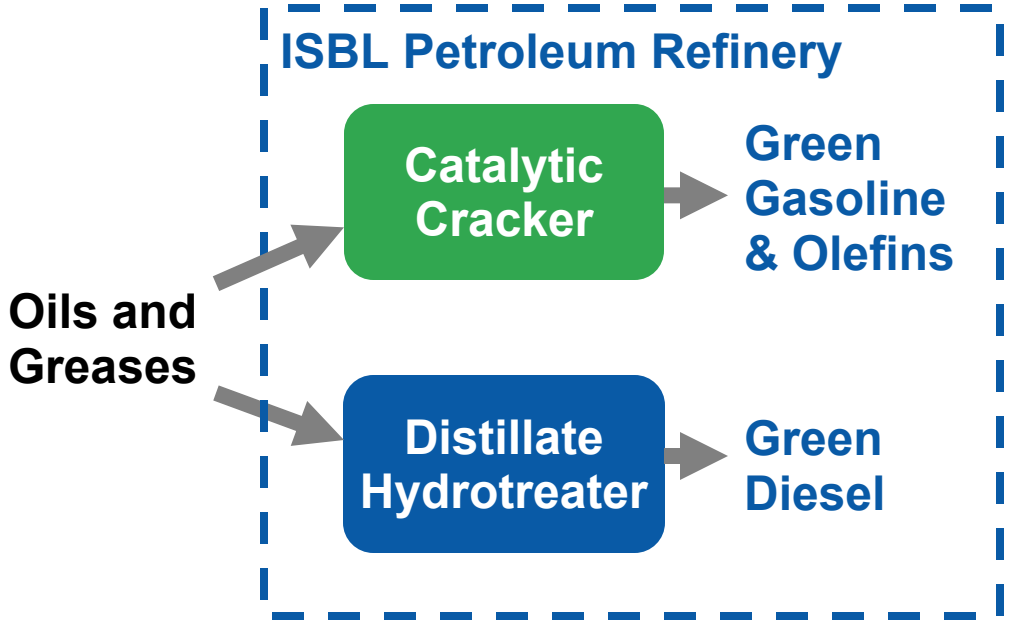
Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Butanol



- Butanol is produced by fermenting the same sugar used to make corn-derived ethanol
  - But using *Clostridia* (a bacterium) rather than yeast
  - New processes may ferment cellulose derived sugars
- BP and DuPont have announced plan to produce butanol for sale as a fuel by fermentation (sugar beets) in UK in 2007
- Retrofitting of ethanol plants to produce butanol is claimed to be economical
- Claimed to be competitive without subsidy at $30-$40/bbl petroleum
- Properties more similar to gasoline, may be possible to transport gasoline/butanol blends by pipeline

Oils, Fats & Greases as Bio-renewable Petroleum Refinery Feedstocks: Hydrogenation-Derived Renewable Diesel (HDRD) or Gasoline



- **Co-processing of oils and greases with petroleum fractions**
- **Utilize existing refinery process capacity**
- **Also stand alone processes**
- **High quality diesel blending component**
- **G/D flexibility**

Based on Presentations at 1st International Biorefinery Workshop, Washington DC, July 20-21, 2005

- ***Future Energy for Mobility***, James Simnick, **BP**
- ***From Bioblending to Biorefining***, Veronique Hervouet, **Total**
- ***Opportunities for Biorenewables in Petroleum Refineries***, Jennifer Holmgren, **UOP**

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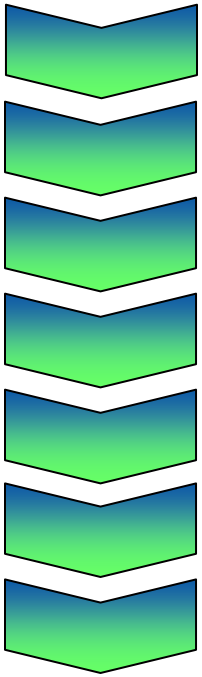


Fuels From Synthesis Gas – for conversion to Fischer Tropsch liquids, MeOH/DME, or mixed alcohols

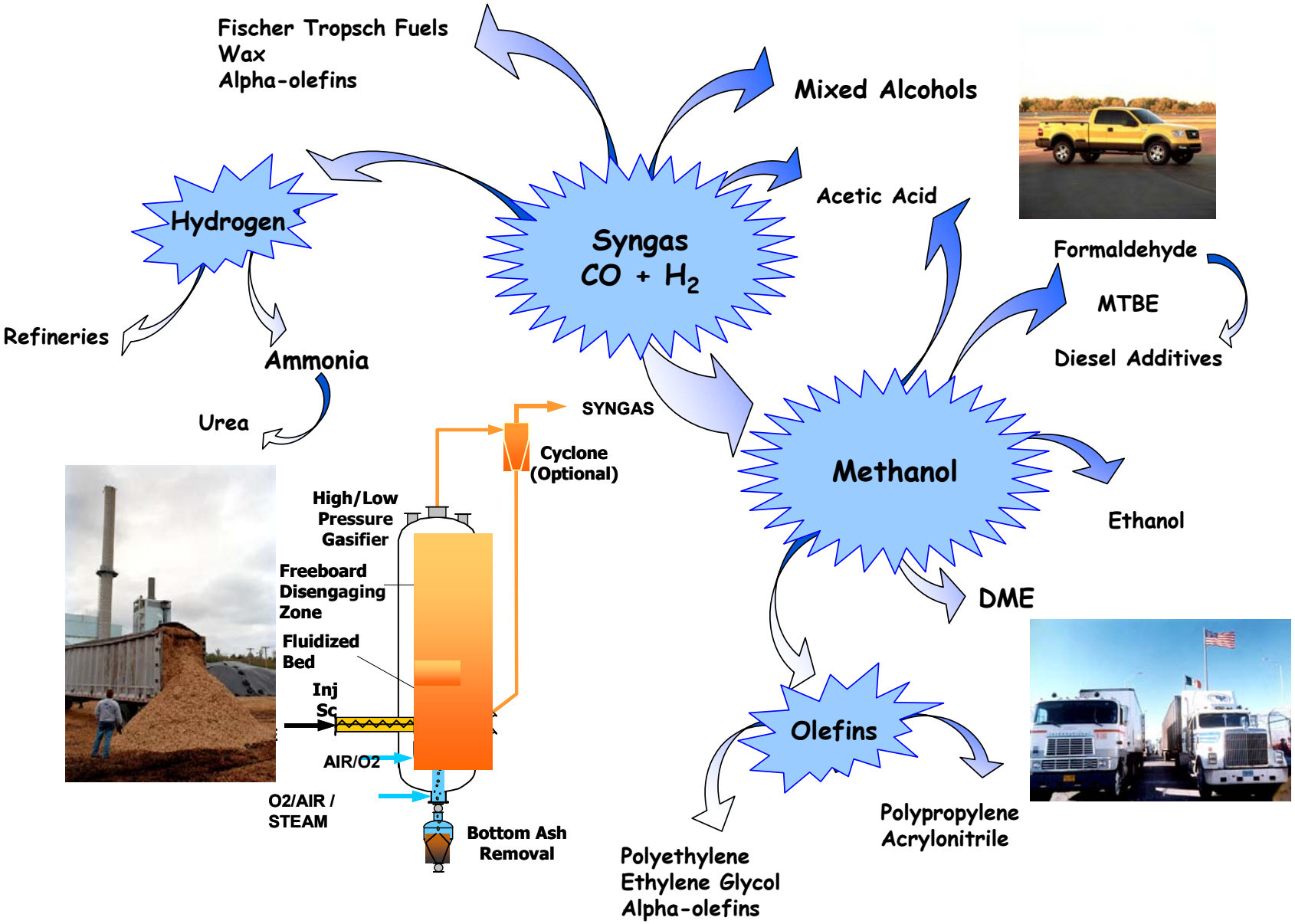
Pyrolysis Liquids – as a boiler fuel or an alternative feedstock to petroleum refinery or gasification facility, also a future source of aromatics and/or phenols

Algae – as alternative source of triglycerides for biodiesel or green diesel

Long Term

Alkanes – from hydrogenation of carbohydrates, lignin, or triglycerides

Fuels from Syngas



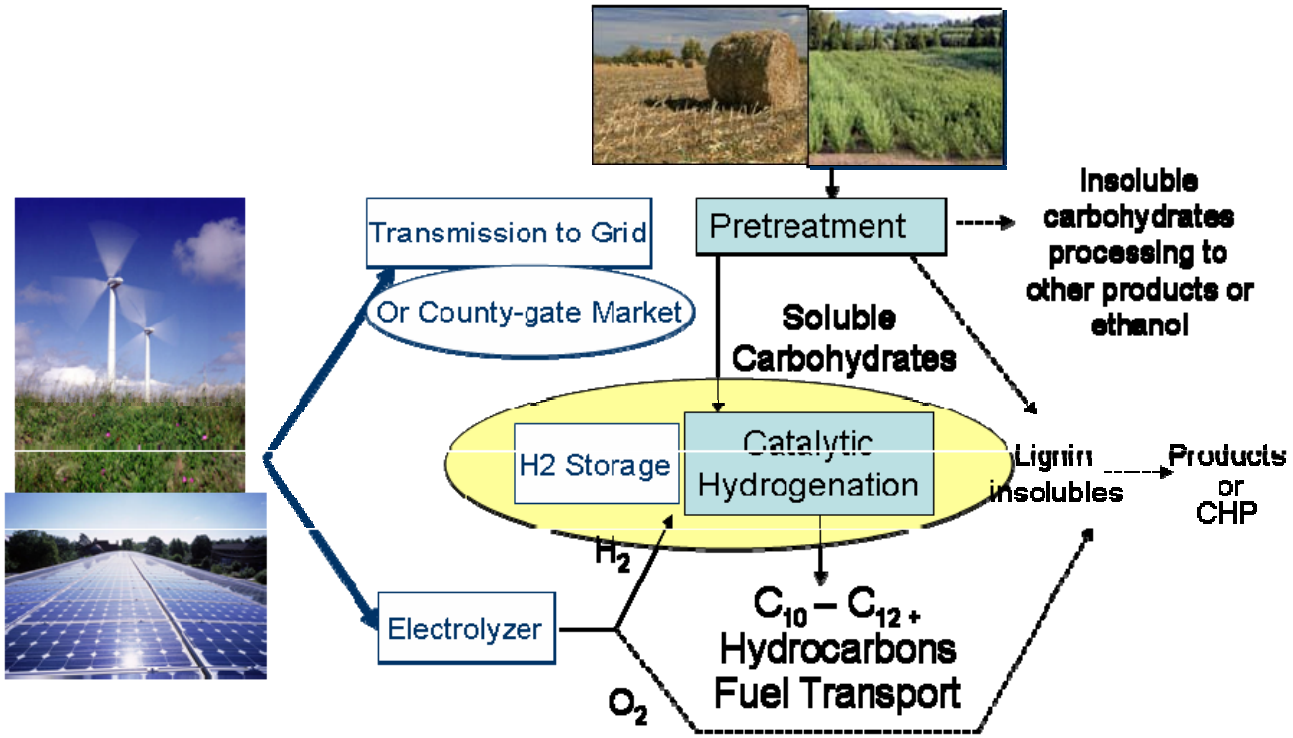
Fast Pyrolysis Bio-oil

Bio-oil is water miscible and is comprised of many oxygenated organic chemicals.

- **Dark brown mobile liquid,**
- **Combustible,**
- **Not miscible with hydrocarbons,**
- **Heating value ~ 17 MJ/kg,**
- **Density ~ 1.2 kg/l,**
- **Acid, pH ~ 2.5,**
- **Pungent odor,**
- **Ages - viscosity increases with time**

Potential feedstock for HDRD/G or other processes

R&D on Hydrogenation of Carbohydrates



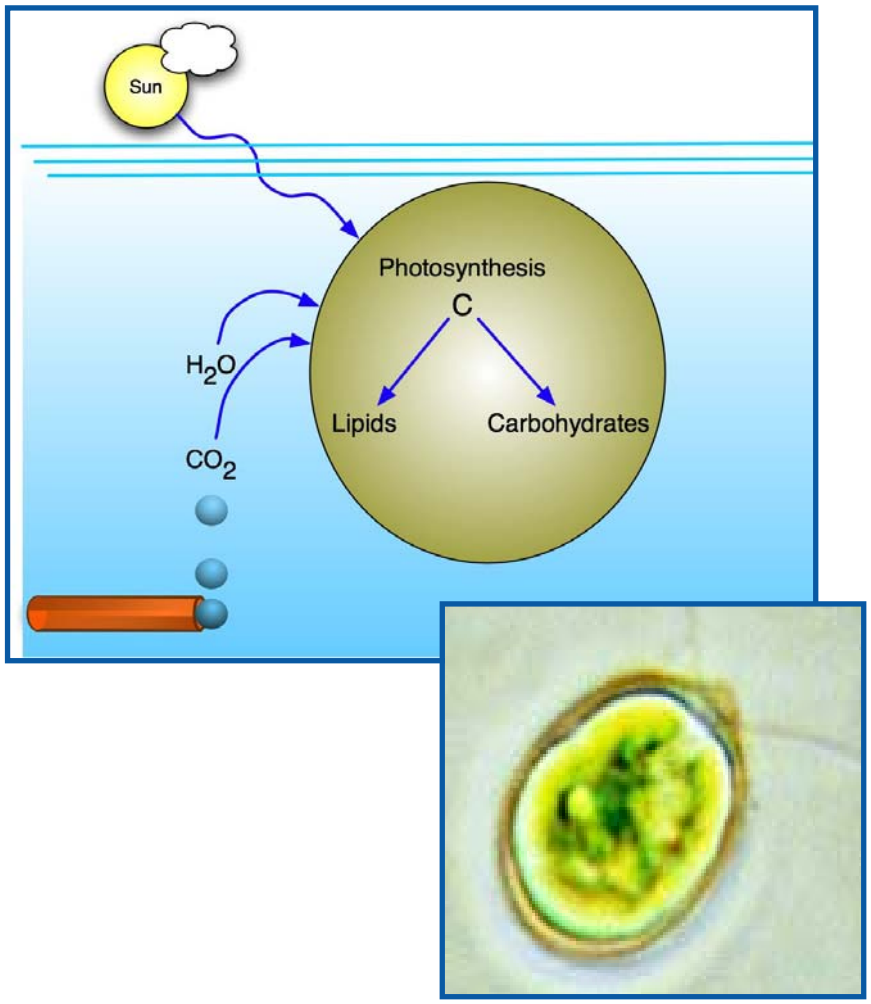
New H_2 Storage Concept and
integration of intermittent Renewables with Biomass

Potential Advantages:

- Compatibility of alkanes with petroleum fuels
- Up to 50% increase in liquid fuel per unit of biomass
- Effective utilization of biomass as hydrogen carrier
- H2 storage/carrier for intermittent sources: solar PV, wind, or photo biology

Based on research of Dumesic and coworkers. G. W. Huber; R. D. Cortright; J. A. Dumesic, "Renewable Alkanes by Aqueous Phase Reforming of Biomass Derived Oxygenates", *Angew. Chem. Int. Ed.* **2004**, *43*, 1549 and discussions with NREL staff.

Algae as a Source of Biofuels



- Source of biodiesel or HDRD/G from lipids, other fuels from carbohydrates
- Produced in ponds or bioreactors
- Complements terrestrial biomass production
  - Reduces pressure on land use
  - Option to utilize large waste CO_2 resource (e.g. Coal-fired Power plants, or Ethanol plants)
- Outstanding productivity
  - Up to 50 times more productive than traditional oilseed crops
  - Very large resource potential for producing additional biodiesel
- A new resource

Summary & Conclusions

✓ Biomass is the only domestic & renewable option for liquid transportation fuels.

✓ U.S. resource base sufficient to supply a large fraction of U.S. demand, with good potential to increase the resource base

✓ A sustainable solution to meet the supply-demand "gap" expected to be caused by peaking world oil production and rising demand

✓ On-going R&D will create many opportunities that go beyond today's biopower, ethanol, and biodiesel facilities

Backup Slides

Non-Edible Constituents of Biomass

Lignin: 15%–25%

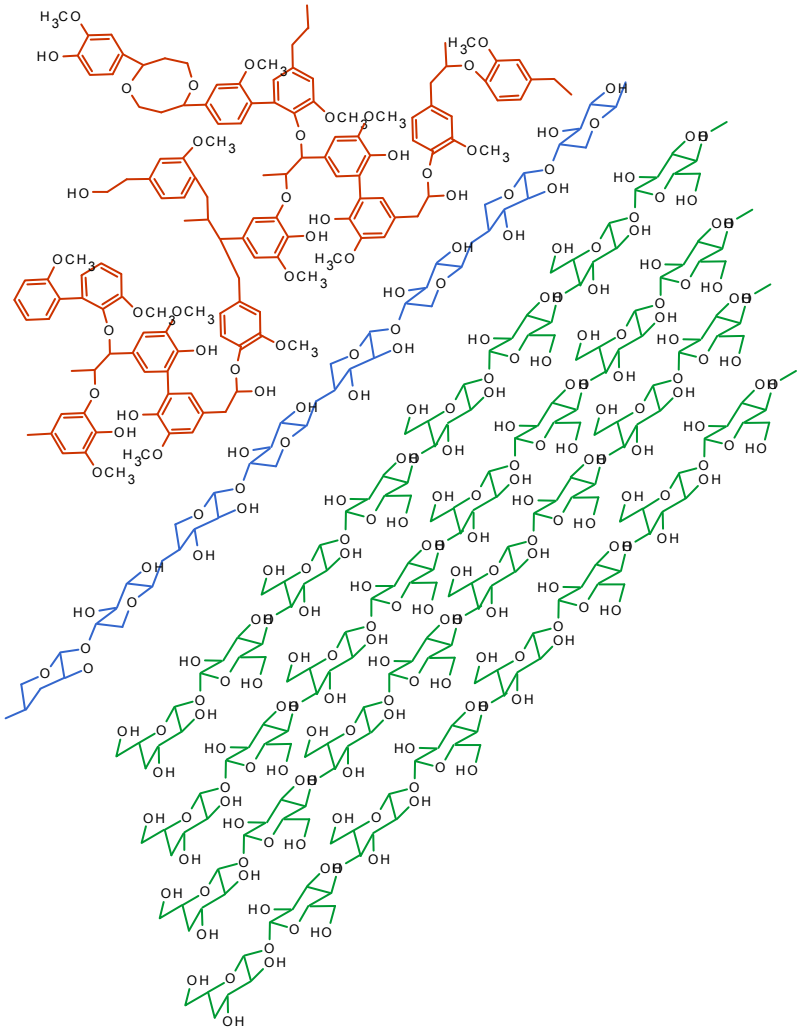
- Complex aromatic structure
- Very high energy content
- Resists biochemical conversion

Hemicellulose: 23%–32%

- Xylose is the second most abundant sugar in the biosphere
- Polymer of 5- and 6-carbon sugars, marginal biochemical feed

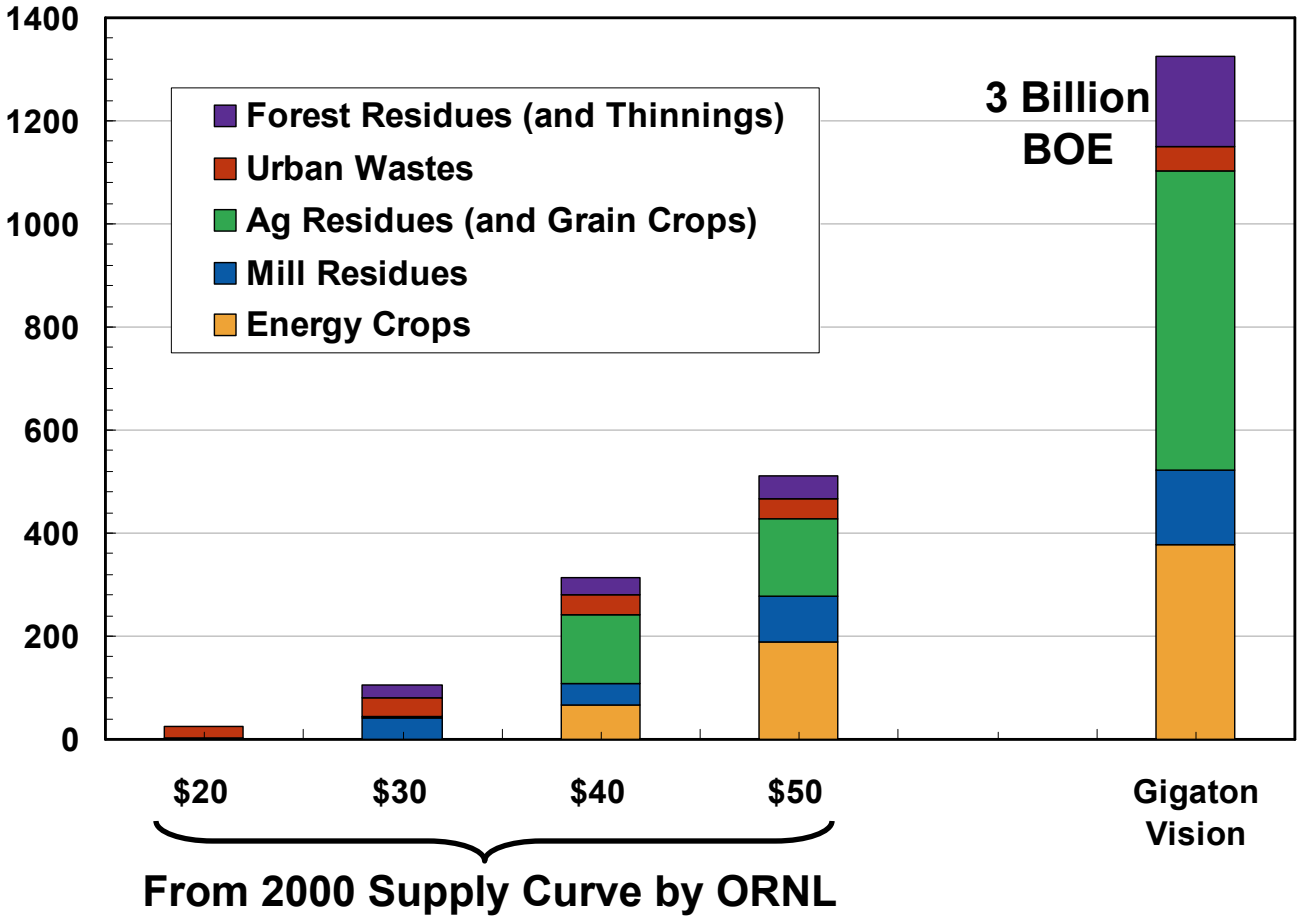
Cellulose: 38%–50%

- Most abundant form of carbon in biosphere
- Polymer of glucose, good biochemical feedstock



U.S. Biomass Resource Potential

Million Dry Tons per Year



Butanol Fuel Properties

- Much higher volumetric energy content than ethanol
- Does not suffer from separation caused by water
- Gasoline-butanol blends appear more compatible with pipeline system – needs to be verified
- Gasoline containing butanol (up to 2.7% oxygen) is already "approved" by EPA
- May not suffer from non-ideal vapor pressure (vapor pressure bump) like ethanol, may lower vapor pressure of ethanol blends
- Many fuel-engine compatibility, ASTM specification, and environmental issues remain to be resolved

	Ethanol	*Butanol*
Boiling Point, F	173	181
RVP, psi	2.8	2.7
Heat of Combustion, btu/gal	76,000	93,000
Heat of Vaporization, btu/gal	2600	1700
RON	111	113

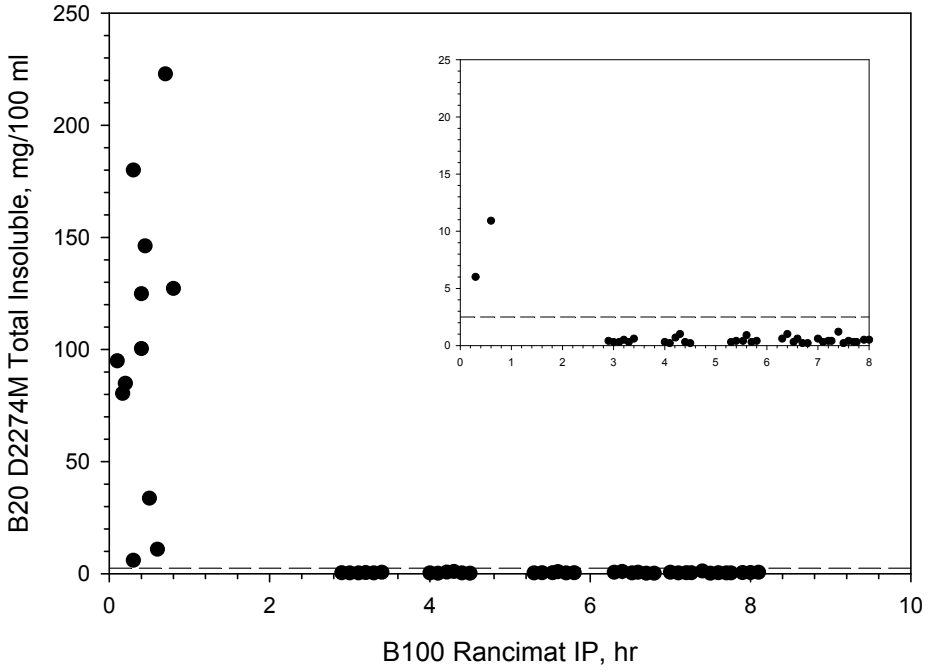
B20 Vehicle Testing Summary

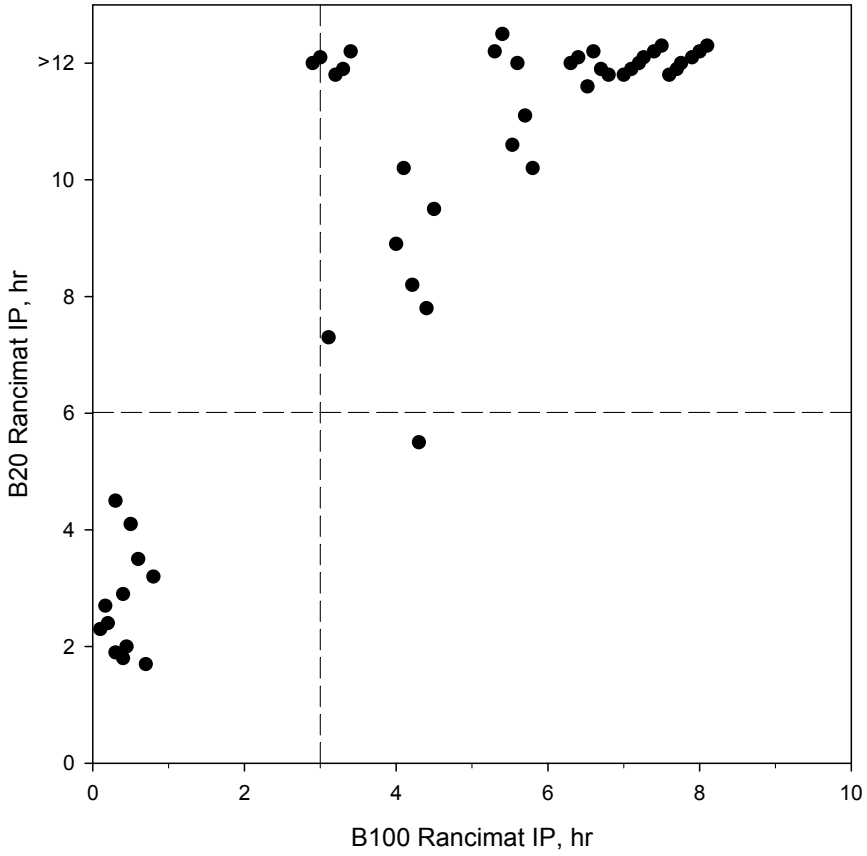
- Average change in NO_x for B20 use is -0.6%
  - Not statistically significant
  - Versus +2% in EPA analysis
- Magnitude and direction of NO_x impact is cycle dependent
- Average change in PM for B20 use is -23%
  - Versus -12% in EPA analysis
- Two additional HD vehicles being tested this FY
  - Class 8 Truck (2000) and School Bus (2005)
  - Report details by Sept 30
- Working to understand why engine test is not predictive of vehicle results

Vehicle	Engine		MY	Cycle	NOx % Change	PM % Change
1	Cummins ISM	Transit Bus	2000	CSHVC	-3.8	-17.4
2	Cummins ISM	Transit Bus	2000	CSHVC	-6.2	-49.3
3	Cummins ISM	Transit Bus	2000	CSHVC	-4.1	-22
4	Cummins ISM	Class 8	2005	CSHVC	0.0	-28
4	Cummins ISM	Class 8	2005	WVU Interstate	2.0	-35
5	International Green Diesel	School Bus	2005	RUCSBC	1.5	0*
5	International Green Diesel	School Bus	2005	CSHVC	-1.0	0*
6	Cummins ISB	Motorcoach	2003	CSHVC	2.8	-28.1
6	Cummins ISB	Motorcoach	2003	UDDS	3.4	-30

*Vehicle equipped with diesel particle filter

Can B100 Stability Ensure B20 Stability?





Yes, B100 stability appears to be an excellent predictor of blend stability, 3 hour Rancimat ensures low deposits and 6 hr Rancimat in the blend (with one exception out of 48 samples)