U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Bioenergy Technologies and Strategies:

A New Frontier

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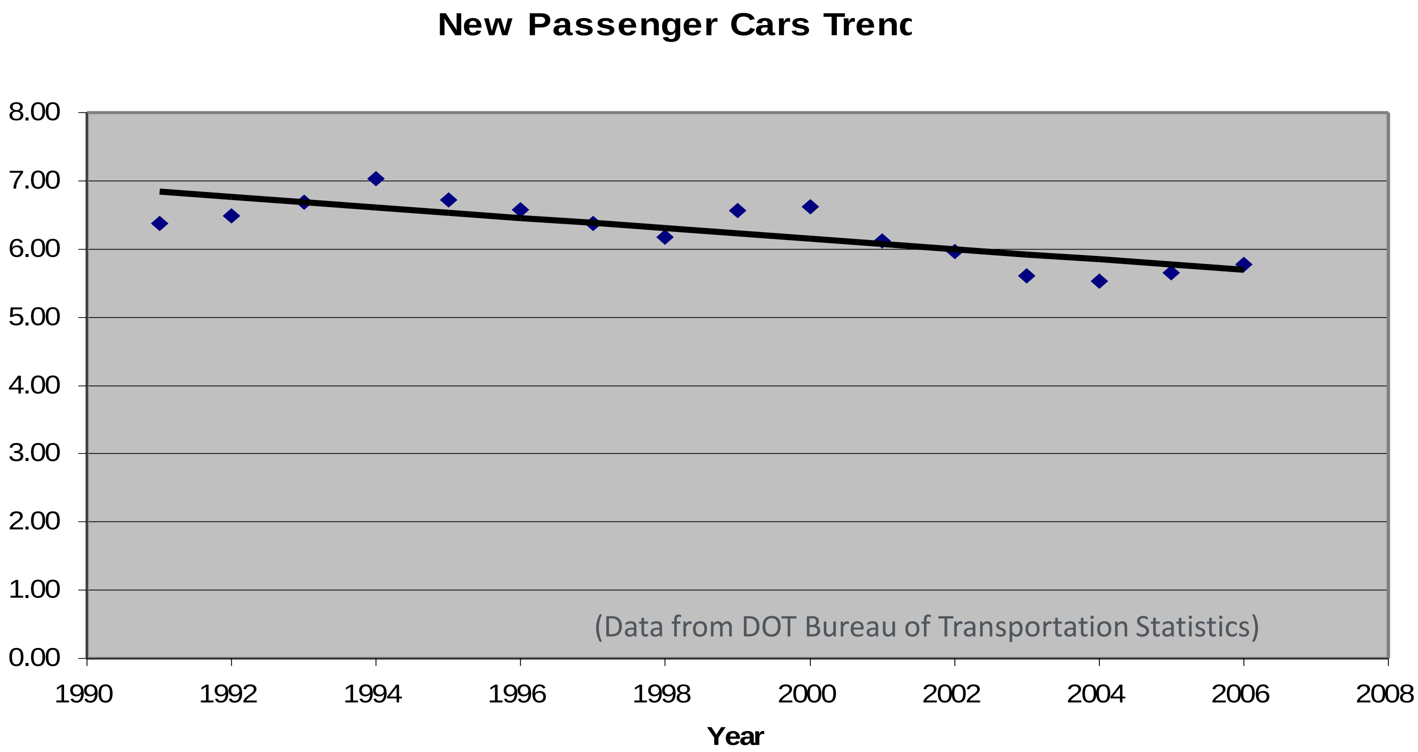
Why Biofuels: Energy Security and Diversity

Line at Gas Station in Maryland
(1979) US News and World Reports
Cause: Iranian Revolution (loss of imported oil)

Line at Gas Station in New Jersey
(2012) Christian Science Monitor
Cause: Hurricane Sandy (loss of electric power)

Transportation Infrastructure "Inelasticity"



- Number of cars constant (~132,000,000)
- 6.3% rate of fleet turnover per year
- 12 years to change over 50% of fleet; 30+ years for whole fleet

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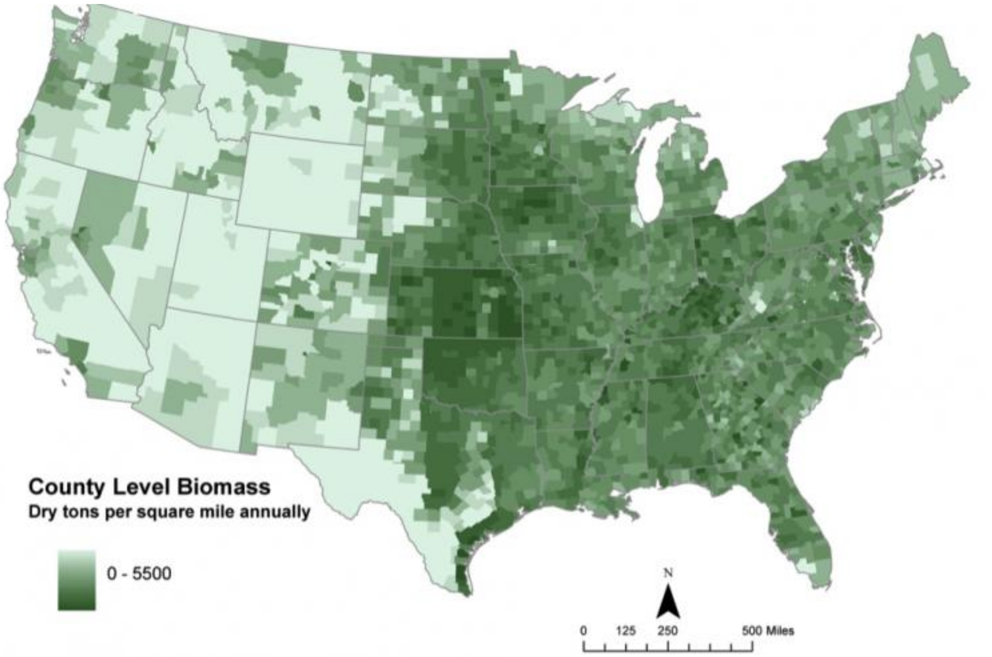
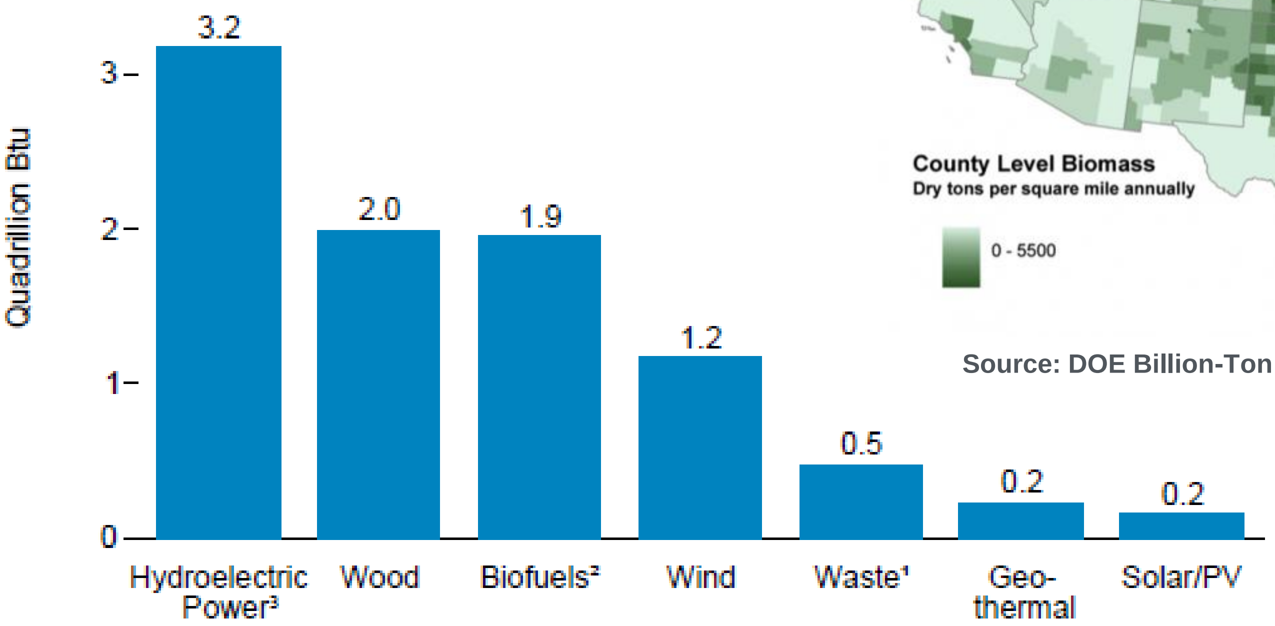
Biomass: A Strategic Clean Energy Resource

One Billion Tons of Biomass Sustainably Harvested Per Year
- Agricultural residues
- Woody biomass
- Energy crops



Source: DOE Billion-Ton Update, 2011



Annual U.S. Renewable Energy Consumption by Source
Source: EIA Annual Energy Review, 2011

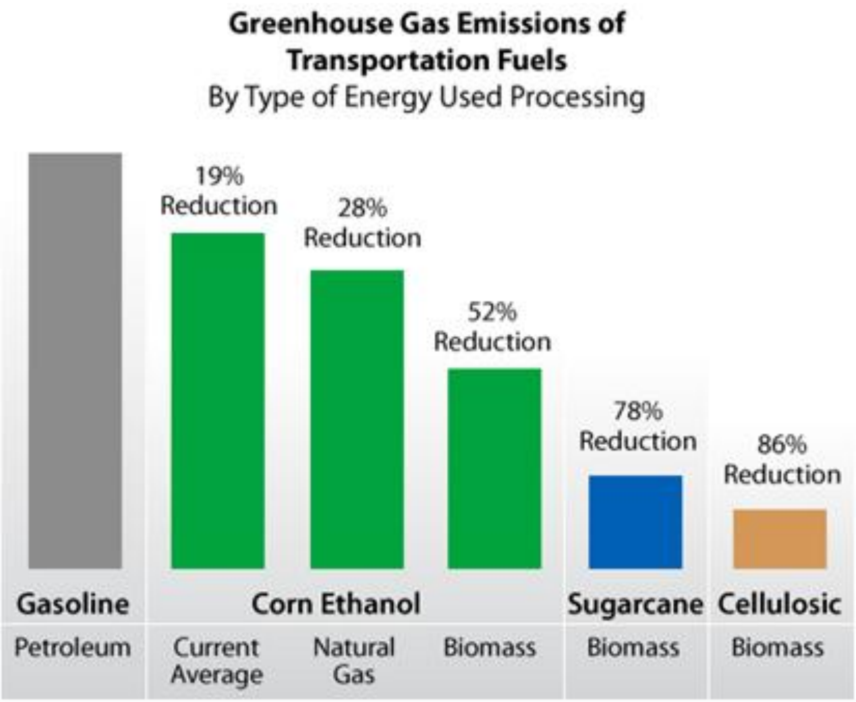
Biomass is the **largest** renewable energy source consumed in the United States

Cellulosics: Improving the Environmental Benefits

Water Consumption of Transportation Fuel

	Net Water consumed	Key Variability Factors
Corn ethanol	10-324 L/L ethanol	Regional differences in irrigation
Switchgrass ethanol	2-10 L/L ethanol	Fuel production technology
Gasoline (US conventional crude)	3-7 L/L gasoline	Age of oil well, production technology and degree of recycling
Gasoline (Canadian oil sands)	3-6 L/L gasoline	Geological formation, production technology

Source: Wu et al. Environmental Management (2009)



Source: Wang et al. Environmental Research Letters (2007)

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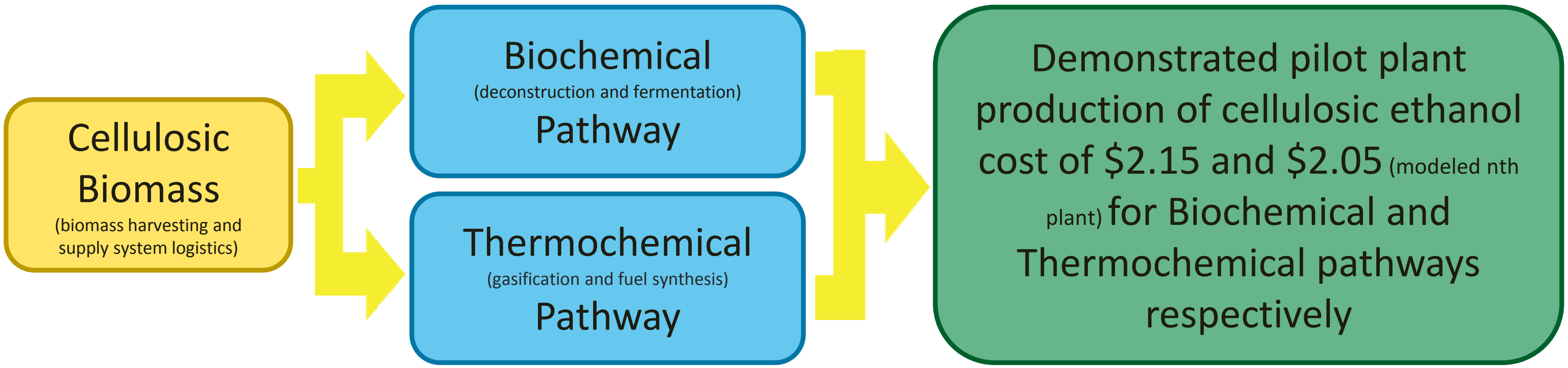
Cellulosic Ethanol R&D Accomplishment

In September 2012, scientists at DOE's National Laboratories successfully demonstrated feedstock and conversion processes resulting in production of cellulosic ethanol at a price of $2.15 or less per gallon.



Biochemical Conversion of Corn Stover: A Decade of Improvements

Source: NREL

Biomass Supply → Feedstock Logistics → Pretreatment /Conditioning → Enzymatic Hydrolysis → Fermentation → Ethanol

Production Cost Improvements: (2001 = $9.16; 2012 = $2.15)

Biomass Supply	Feedstock Logistics	Pretreatment /Conditioning	Enzymatic Hydrolysis	Fermentation	Ethanol
2001 = $1.25/gal (combined)		2001 = $1.37/gal	2001 = $4.05/gal	2001 = $0.60/gal	2001 = $1.90/gal
2012 = $0.34/gal	2012 = $0.49/gal	2012 = $0.27/gal	2012 = $0.39/gal	2012 = $0.15/gal	2012 = $0.51/gal (Balance of Plant)

Technology Improvements:

Improved Biomass Supply Analysis

- economic availability of feedstocks
- feedstock prices specified by quantity and year
- Incorporation of sustainability metrics
- Development of four yield scenarios
- Spatial distribution

Better Collection Efficiency
- *43% to 75%*

Higher Bale Density
- *9.2% to 12.3%*

Lower Storage Losses
- *7.9% to 6%*

Higher Grinder Capacity
- *17.6 to 31.2 ton/hr*

Better Xylan to Xylose Yields
- *63% to 81%*

Lower Degradation Product Formation
- *13% to 5%*

Lower Acid Usage
- *3% to 0.3%*

Reduced Sugar Losses
- *13 to <1%*

Reduced Ammonia Loading
- *decreased by >70%*

Enzyme Cost Reductions
- *$3.45 to $0.36/gal*

Enzyme loading Reductions
- *60 to 19 mg/g*

Higher Cellulose to Glucose Yields
- *64% to 78%*

Process Efficiency Improvements
- *washed solids to whole slurry mode of hydrolysis*

Improved Overall Ethanol Yield
- *52% to 96%*

Better Xylose to Ethanol Yields
- *0% to 93%*

Better Arabinose to Ethanol Yields
- *0% to 54%*

Improved Ethanol Tolerance
- *36 to 72 g/L titers*

Scale Improvements:

- National to county-level detail
- Model Estimates to Field/Pilot Demonstration
- Bench (1L batch) to Pilot (1 ton/day, continuous)
- Bench (1 L batch) to Pilot (1 ton/day, continuous)
- Bench (1L) to Pilot (8000L)

First Commercial Cellulosic Ethanol Production in US

Ineos Bio's Indian River Bioenergy Center, Vero Beach, FL

Source: Ineos Bio Website

THE WALL STREET JOURNAL.

The news was a milestone for the renewable fuels … If INEOS Bio can sustain production at the Florida plant, it would offer the promise of a new industry producing fuel out of everything from grass to garbage.

(Ryan Tracy, July 31, 2013)

U.S. Commercial Scale* IBR's Based on Cellulosic Feedstocks

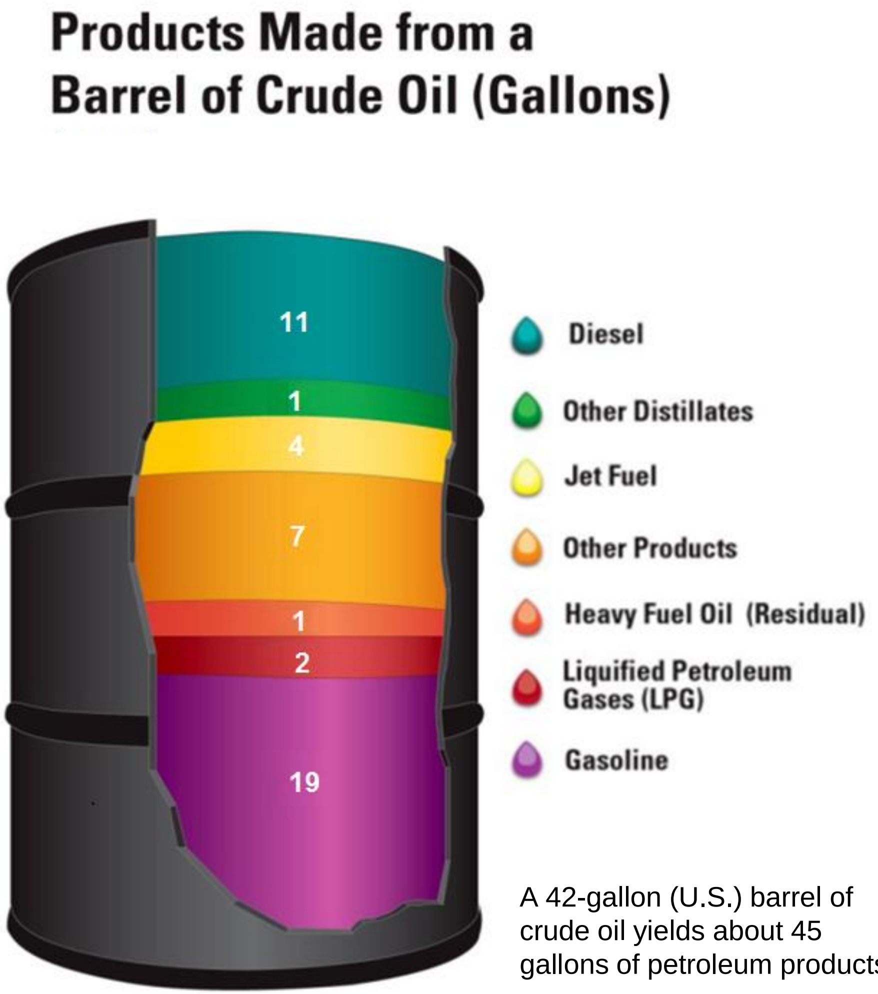
	Ground Broke	Target Product	Location	DOE Role
DuPont	Q4, 2012	Cellulosic ethanol	Nevada, Iowa	R&D
POET-DSM	Q1, 2012	Cellulosic ethanol	Emmetsburg, Iowa	R&D, IBR
Abengoa	Q4, 2011	Cellulosic ethanol	Hugoton, Kansas	IBR
KiOR	Q2, 2011	Cellulosic gasoline, diesel and jet	Columbus, Mississippi	none
Ineos-Bio	Q1, 2011	Cellulosic ethanol	Vero Beach, Florida	R&D, IBR

* "Commercial-scale" defined by expected profitability and not nameplate capacity

Replacing the Whole Barrel

Greater focus needed on RDD&D for a range of technologies to displace the *entire* barrel of petroleum crude

- Ethanol can only displace the portion of the barrel that is made into gasoline.
- Reducing our dependence on oil also requires replacing diesel, jet fuel, heavy distillates, and a range of other chemicals and products that are currently derived from crude oil.

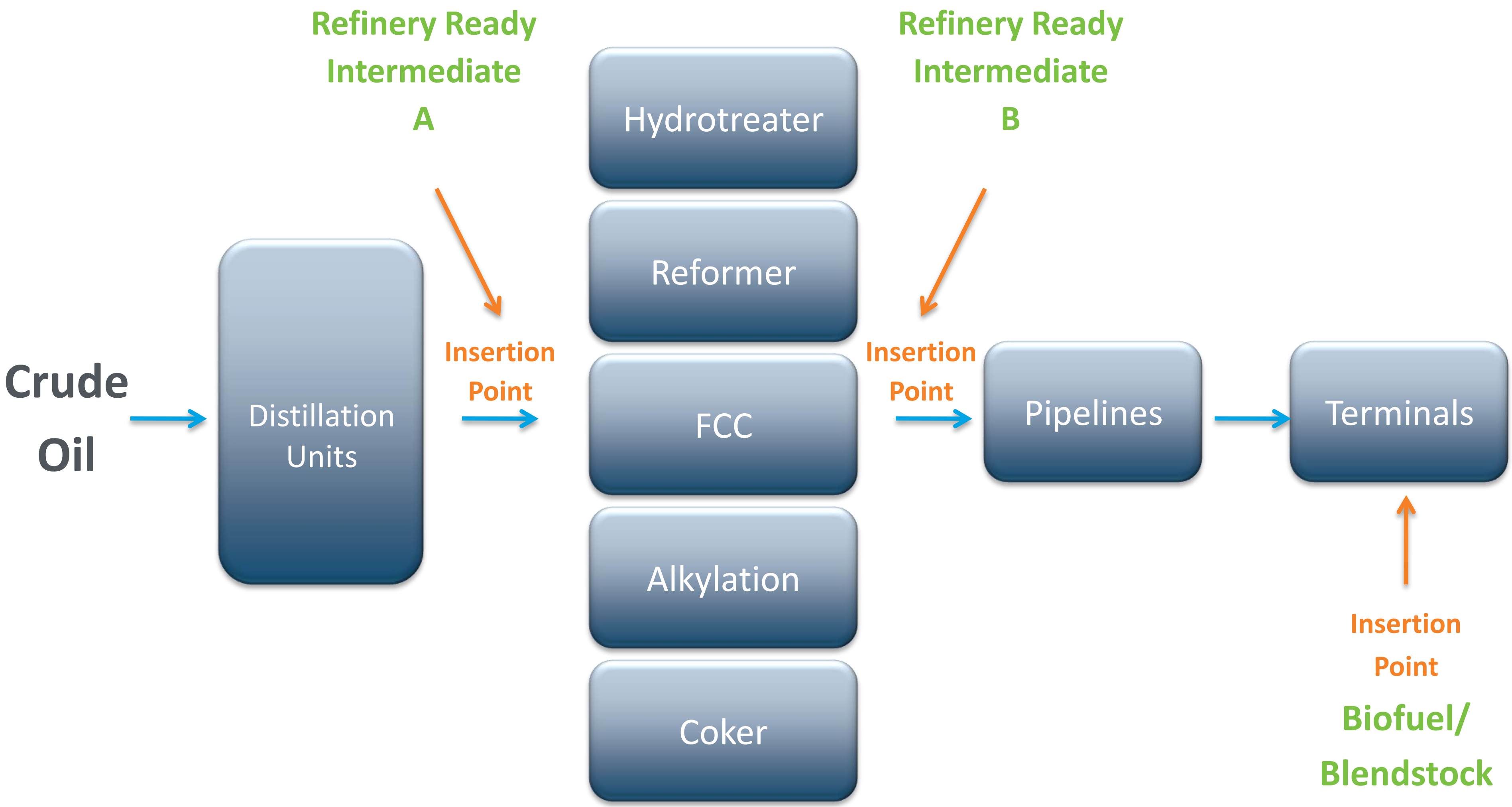


A 42-gallon (U.S.) barrel of crude oil yields about 45 gallons of petroleum products.

Source: Energy Information Administration (2011)

*American Petroleum Institute

Adapting to Refinery Infrastructure: Save on CAPEX

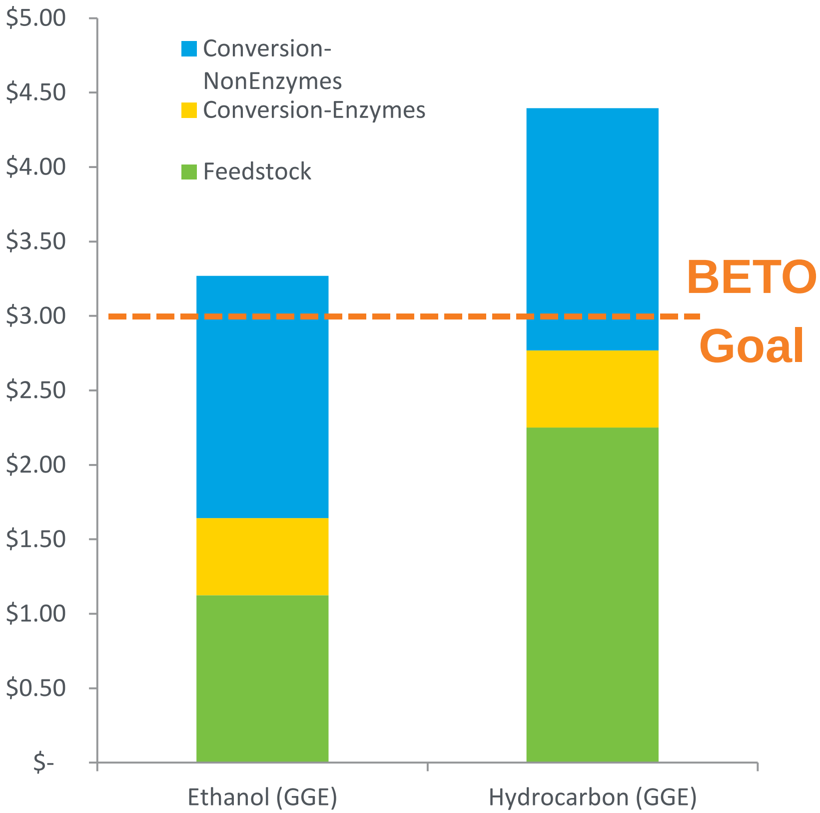


Adapted from the National Advanced Biofuels Consortium Website

Hydrocarbon Strategy and Implications

	Crude Oil (>80C:1O)	Biomass (1C:1O)
Elemental Composition of Feedstock (weight %)	C = 83 - 87% H = 10 – 14% N = 0.1 – 2% O = 0.05 – 1.5%	C = 44 – 51% H = 5.5 – 6.7% N = 0.12 – 0.6% O = 41 – 50 %
Elemental Composition of Ethanol Product (C_2H_6O)	C = 52% H = 13% O = 35%	C = 52% H = 13% O = 35%
Elemental Composition of Hydrocarbon Product (50% C_8H_{18}) (50% $C_{12}H_{23}$)	C = 85.3% H = 14.7% N = 0% O = 0%	C = 85.3% H = 14.7% N = 0% O = 0%

Strategic Options



- Data from modeled nth plant cellulosic ethanol NREL Design Case (Humbird, 2011) transposed to generating hydrocarbon fuels using "same" technologies but accounting for 50% loss of feedstock
  1. Even if same technology breakthroughs were achieved for hydrocarbon fuel from biochem processing, we will miss our $3/GGE goal
  2. Strategy *must* include:

  A. Non-fuel products, which are *enriched in oxygen* from biomass

  - or -

  B. Shrink the conversion costs to < $1.00

  - or -

  C. Derive higher value from lignin

  -or –

  D. Better use of feedstocks

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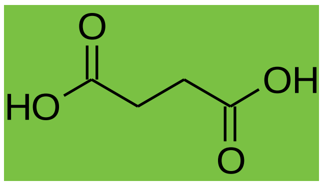
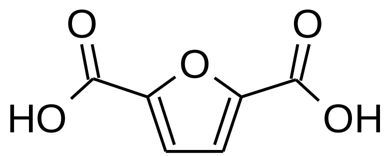
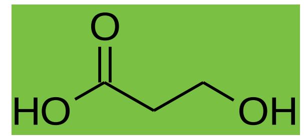
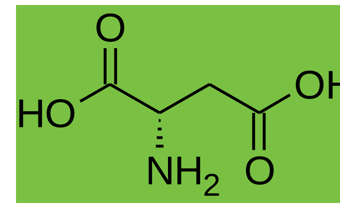
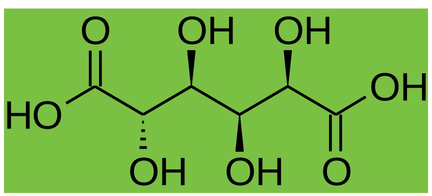
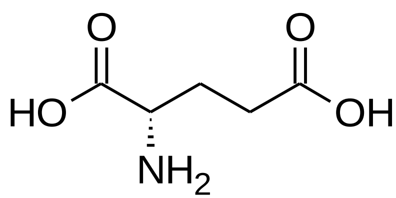
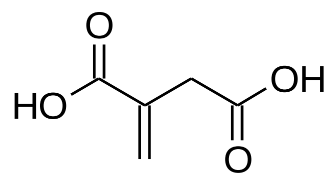
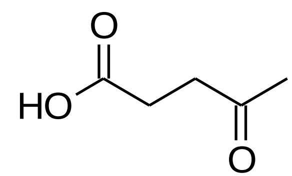
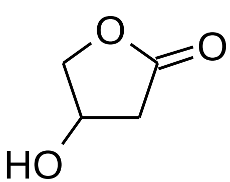
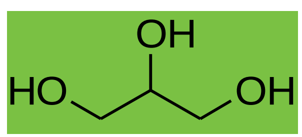
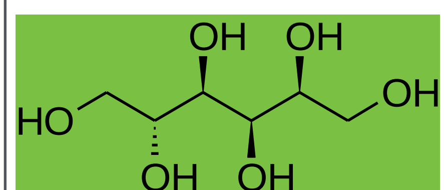
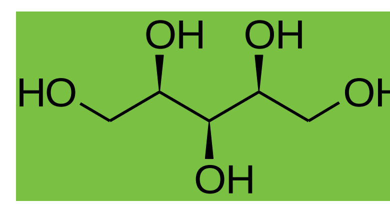
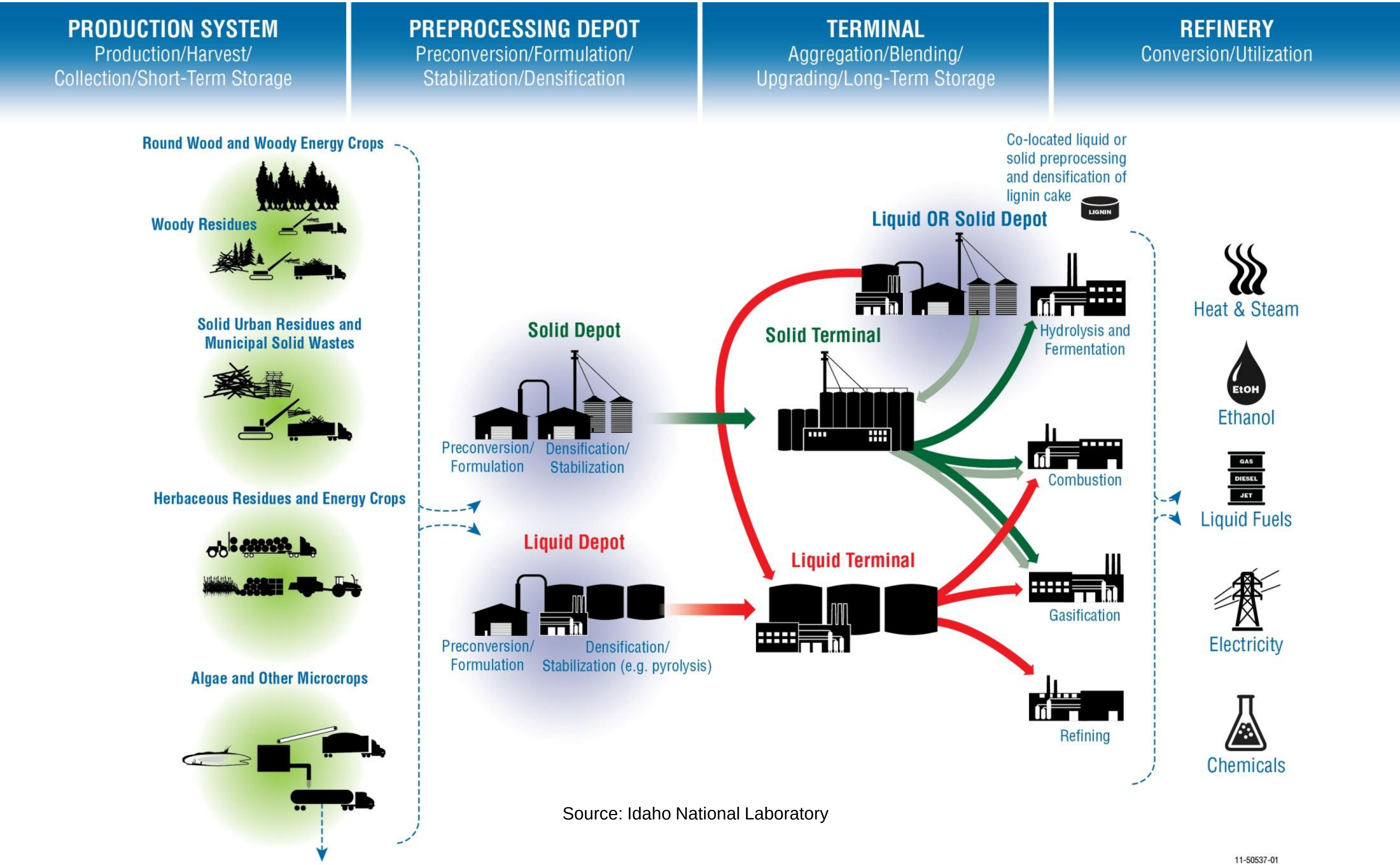
Value-Added Building Blocks From Sugars: 1C : 1O Candidates

1,4-Diacids 	2,5-Furan-dicarboxylic acid 	3-Hydroxy-propionic acid 	Aspartic acid 
Glucaric acid 	Glutamic acid 	Itaconic acid 	Levulinic acid 
3-Hydroxy-butyrolactone 	Glycerol 	Sorbitol 	Xylitol/Arabitol 

www.pnl.gov/main/publications/external/technical.../PNNL-14808.pdf

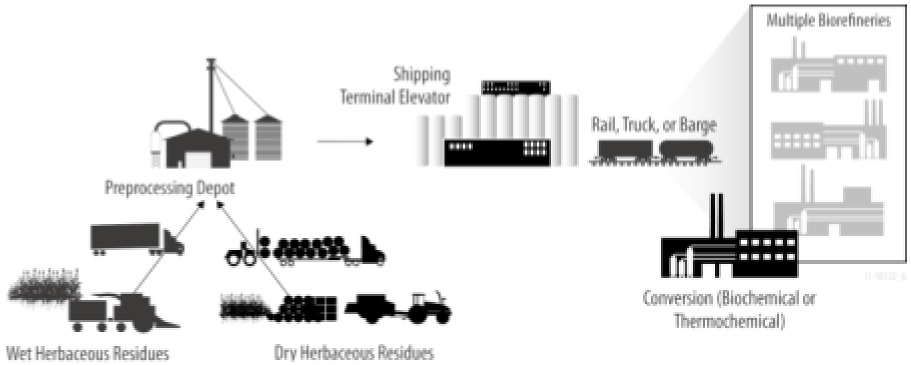
The Commoditized Biomass Feedstocks Vision



Source: Idaho National Laboratory

Commoditization Benefits

1. Density and Stability



1. Infrastructure Compatible (16 lbs/ft^3 in field to >48 lbs/ft^3 in supply system)
2. Long-term stability in supply system (years, like grain or coal)

2. Conversion Performance

Grade A Feedstock

(Material the conversion process was developed around)

Commodity Attributes

- On-spec quality
- Uniform density
- Consistent format
- Stable
- Reliable supply
- Infrastructure compatible

Upgrade

Manage

- Moisture content
- Ash
- Sugar

Field Run Biomass

Diverse

- Format
- Density
- Compositional properties (does not meet conversion spec)

Source: Idaho National Laboratory

Other Opportunities: Energy Efficiency Innovation

Renewable Materials: Energy Efficiency Impact

Cars are heavy!
(each car weighs 4,000 lbs)

Reducing vehicle weight by 10% will result in a 4-5% reduction in fuel use in passenger cars
(Pagerit et al., 2006. Fuel Economy Sensitivity to Vehicle Mass for Advanced Vehicle Powertrains. Society of Automotive Engineers. 2006-01-0665)

Carbon fiber has the highest strength to weight ratio (super light weight material)

Assuming 8.8 million barrels of oil consumption by passenger cars per day, a 10% weight reduction will results in an annual saving of ~ 5 billion gallons of gasoline in the United States alone

THANK YOU FOR YOUR ATTENTION!

Questions? Please email:

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