The Future of Biofuels

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Washington state University and Aalborg University Copenhagen

WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

Pacific Northwest
NATIONAL LABORATORY

Content of Talk

- Mission of BSEL
- Forcast for world energy use
- Oil and need for oil substitutes
- Drop-in biofuels compared to bioethanol/biodiesel
- Substituting the whole barrel
- Diversification as a mean for risk reduction

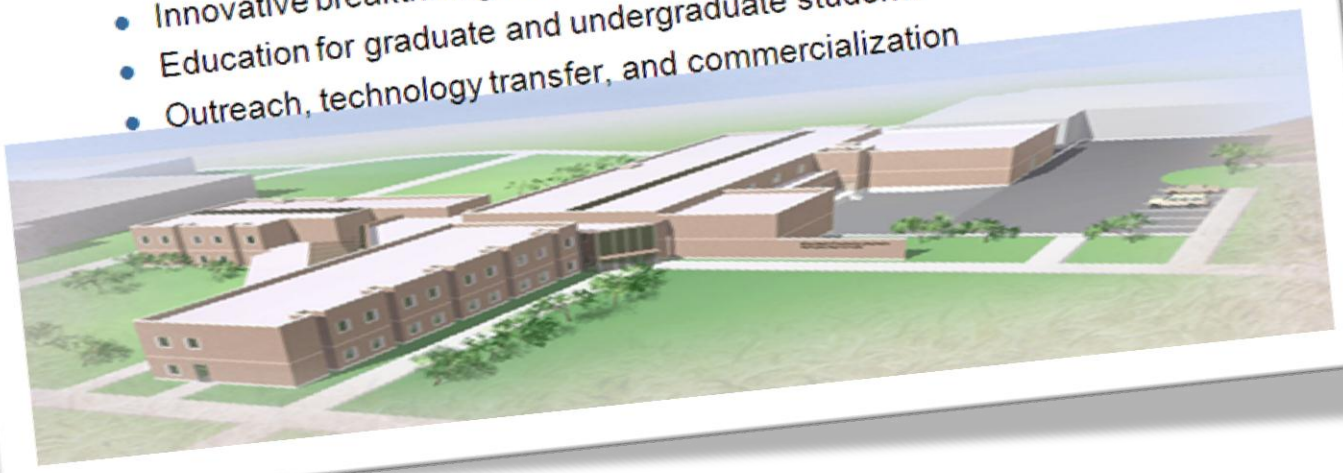
At the outset we provided this vision…

PNNL and WSU Collaboration
Our vision

To enable sustainable economic development in Washington and the Pacific Northwest based on bioproducts and biofuels using the world-class capabilities of Washington State University and Pacific Northwest National Laboratory.

This partnership will serve as a model for the nation and is based on:

- World-class science and engineering
- Innovative breakthrough technologies
- Education for graduate and undergraduate students
- Outreach, technology transfer, and commercialization

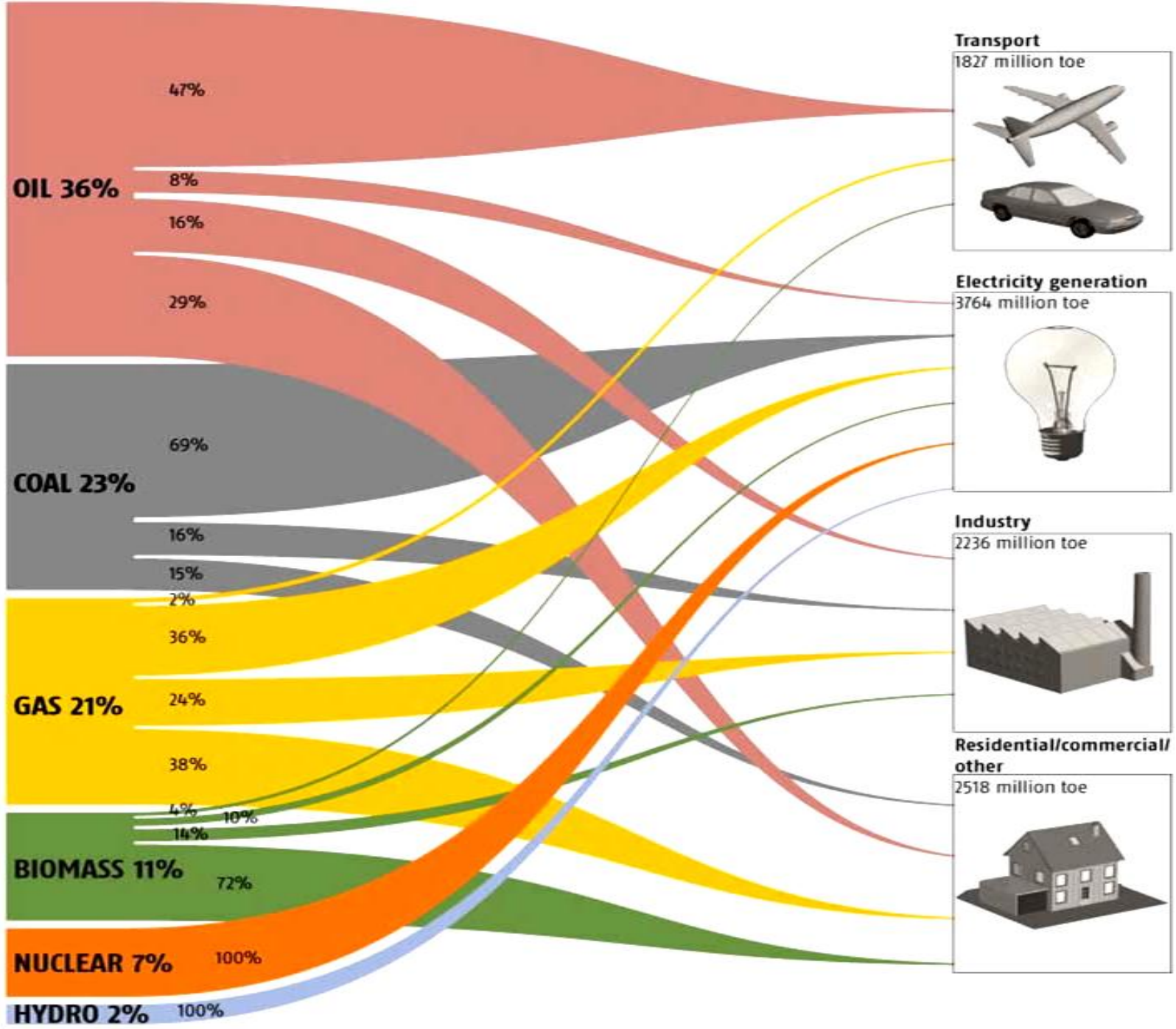


World-class Science and Engineering

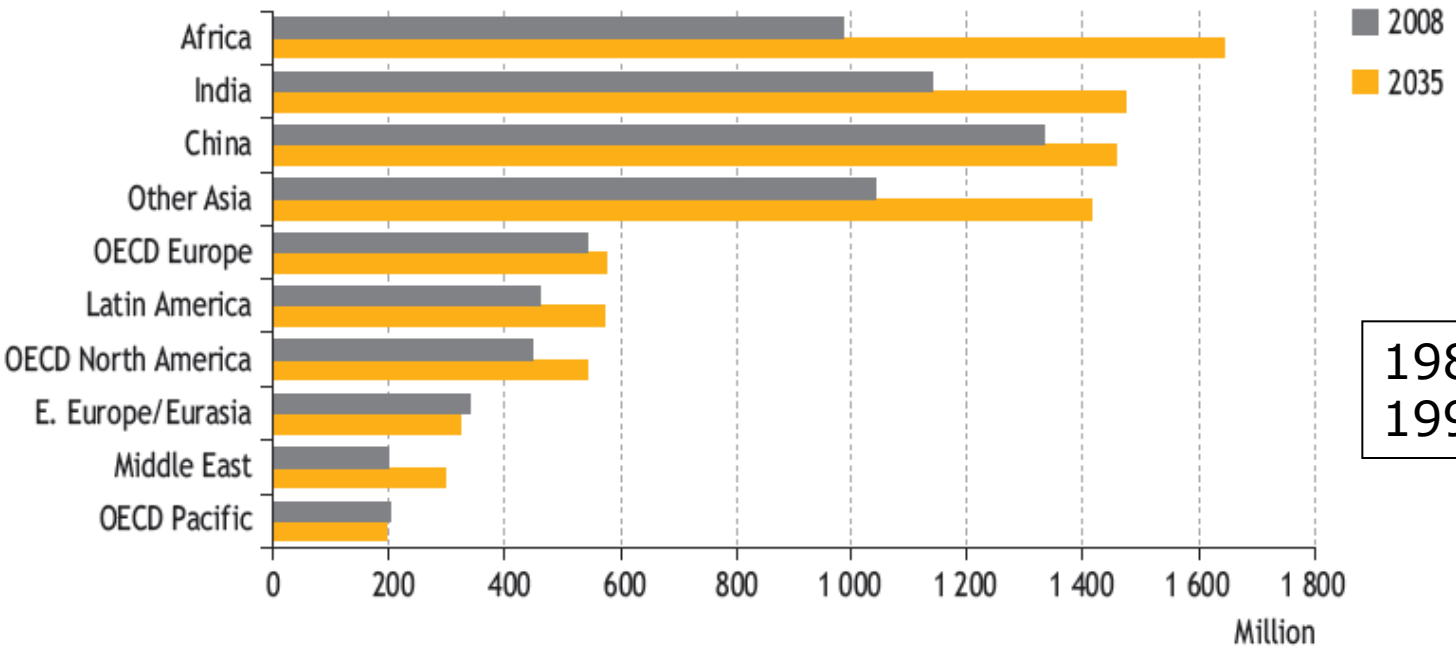
- BSEL is a $24 mio facility with equipment for over $20 mio:
  - Catalysis and biotechnology platforms to look at the challenges in a unique way
  - Uniting the power of a Department of Energy National Laboratory with the expertise of a Land Grant Institution
  - Integrating biomass production with biomass conversion working with WSU-Pullman, WSU-Prosser and USDA's Agriculture Research Center

GLOBAL ANNUAL ENERGY USE

10,345 million tonnes oil equivelent



Population Growth by Region



Sources: UNPD and World Bank databases; IEA analysis.

1980-2008: 1.5%
1990-2008: 1.3%

Population growth at 0.9% CAGR, in line with historical trends
Slows over period (1.1% to 2020, 0.7% from 2020-2035)
Urban population now greater than rural (2009)

Total Population (2008-2035): 6.7B to 8.5B

GDP Growth by Region

	1980-1990	1990-2008	2008-2020	2010-2015	2020-2035	2008-2035
OECD	**3.0%**	**2.5%**	**1.8%**	**2.4%**	**1.9%**	**1.8%**
North America	3.1%	2.8%	2.1%	2.7%	2.2%	2.2%
United States	*3.2%*	*2.8%*	*2.0%*	*2.4%*	*2.1%*	*2.1%*
Europe	2.4%	2.2%	1.5%	2.1%	1.8%	1.6%
Pacific	4.3%	2.1%	1.7%	2.6%	1.2%	1.5%
Japan	*3.9%*	*1.2%*	*1.0%*	*1.9%*	*1.0%*	*1.0%*
Non-OECD	**3.3%**	**4.7%**	**5.6%**	**6.7%**	**3.8%**	**4.6%**
E. Europe/Eurasia	4.0%	0.8%	3.0%	4.4%	3.1%	3.1%
Caspian	*n.a.*	*2.0%*	*4.6%*	*5.4%*	*3.2%*	*3.8%*
Russia	*n.a.*	*0.6%*	*2.9%*	*4.1%*	*3.1%*	*3.0%*
Asia	6.6%	7.4%	7.0%	8.3%	4.2%	5.4%
China	*9.0%*	*10.0%*	*7.9%*	*9.5%*	*3.9%*	*5.7%*
India	*5.6%*	*6.4%*	*7.4%*	*8.1%*	*5.6%*	*6.4%*
Middle East	-1.3%	3.9%	4.0%	4.3%	3.8%	3.9%
Africa	2.3%	3.8%	4.5%	5.5%	2.8%	3.5%
Latin America	1.2%	3.5%	3.3%	4.0%	2.7%	3.0%
Brazil	*1.5%*	*3.0%*	*3.6%*	*4.1%*	*3.1%*	*3.3%*
World	**3.1%**	**3.3%**	**3.6%**	**4.4%**	**2.9%**	**3.2%**
European Union	*n.a.*	*2.1%*	*1.4%*	*2.1%*	*1.7%*	*1.6%*

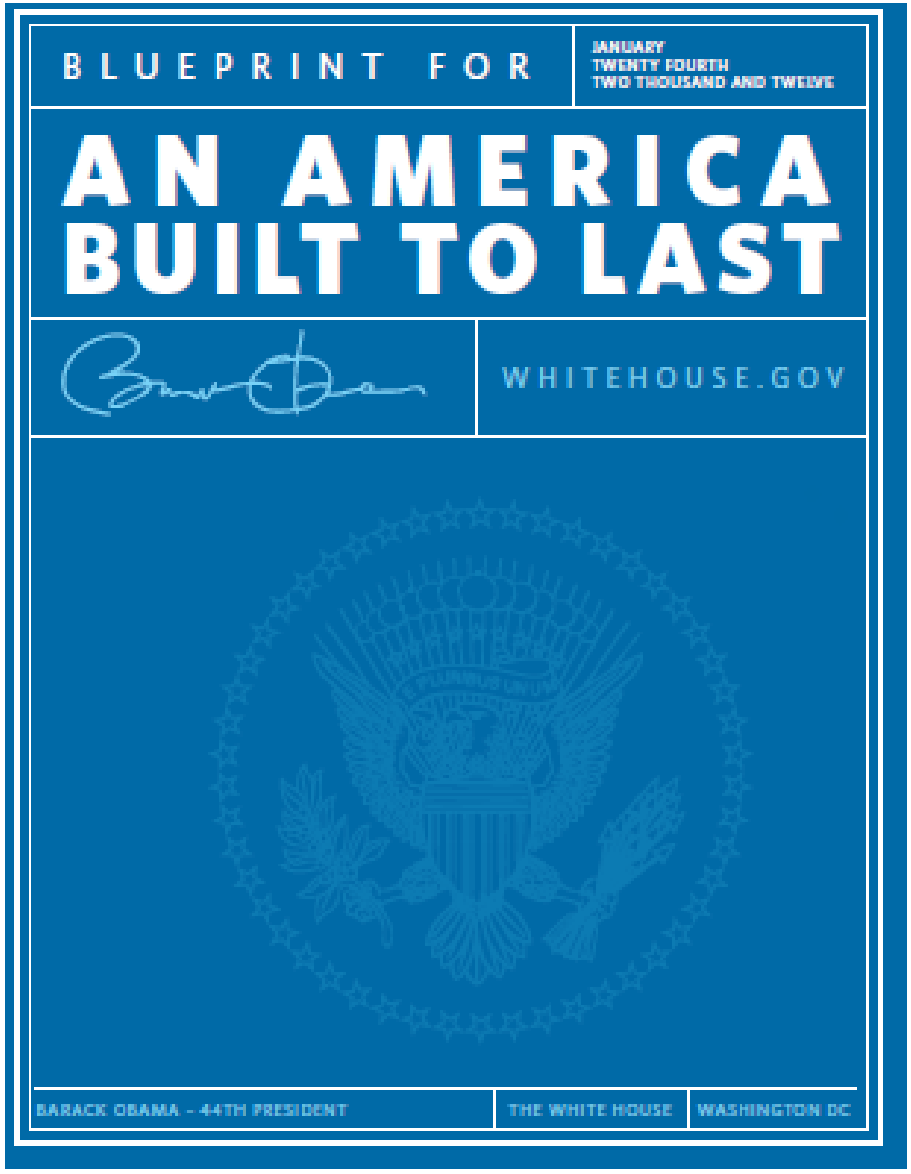
Note: Calculated based on GDP expressed in year-2009 dollars at constant purchasing power parity (PPP) terms.
Sources: IMF and World Bank databases; IEA databases and analysis.

Elasticity of Energy Demand

1980's: 0.64
1990's: 0.46
2000's: 0.67

- Growth in China expected to slow from ~10% to 4% beyond 2020.
- India overtakes China in 2020 as fastest growing region
- "Significant" growth to 2015 globally – 4.4% assumed
- OECD is 69% of global GDP in 2009
  - Declines to 52% by 2035

GDP growth to 2015 high, slowing in all regions beyond 2020


BLUEPRINT FOR
JANUARY
TWENTY FOURTH
TWO THOUSAND AND TWELVE
AN AMERICA BUILT TO LAST
WHITEHOUSE.GOV
BARACK OBAMA - 44TH PRESIDENT
THE WHITE HOUSE
WASHINGTON DC

Blueprint for Clean Energy

Create clean energy jobs in the United States: The President called on Congress to build on our success in positioning America to be the world's leading manufacturer in high-tech batteries and reiterated his call for action on clean energy tax credits and a national goal of moving toward clean sources of electricity by setting a standard for utility companies, so that by 2035, 80% of the nation's electricity will come from clean sources, including renewable energy sources like wind, solar, biomass, hydropower, nuclear power, efficient natural gas, and clean coal. Because Congress has not yet acted on this and other key steps to achieve a clean energy economy, the President announced that the Department of the Navy will make the largest renewable energy purchase in history – one gigawatt. In addition, the President is directing the Department of Interior to permit 10 gigawatts of renewables projects by the end of the year, enough to power three million homes.

Demand will continue to grow: China's desire to reach 'energy parity' will alone have a massive effect, not including other developing nations

U.S.

Population: 308 MM

GDP per capita: $47,100

Oil use: 19.2 MBD

Oil use (per 1,000): 62 bpd

Poland

Population: 38 MM

GDP per capita: $18,800

Oil use: 0.55 MBD

Oil use (per 1,000): 15 bpd

China

Population: 1,330 MM

GDP per capita: $7,500

Oil use: 8.3 MBD

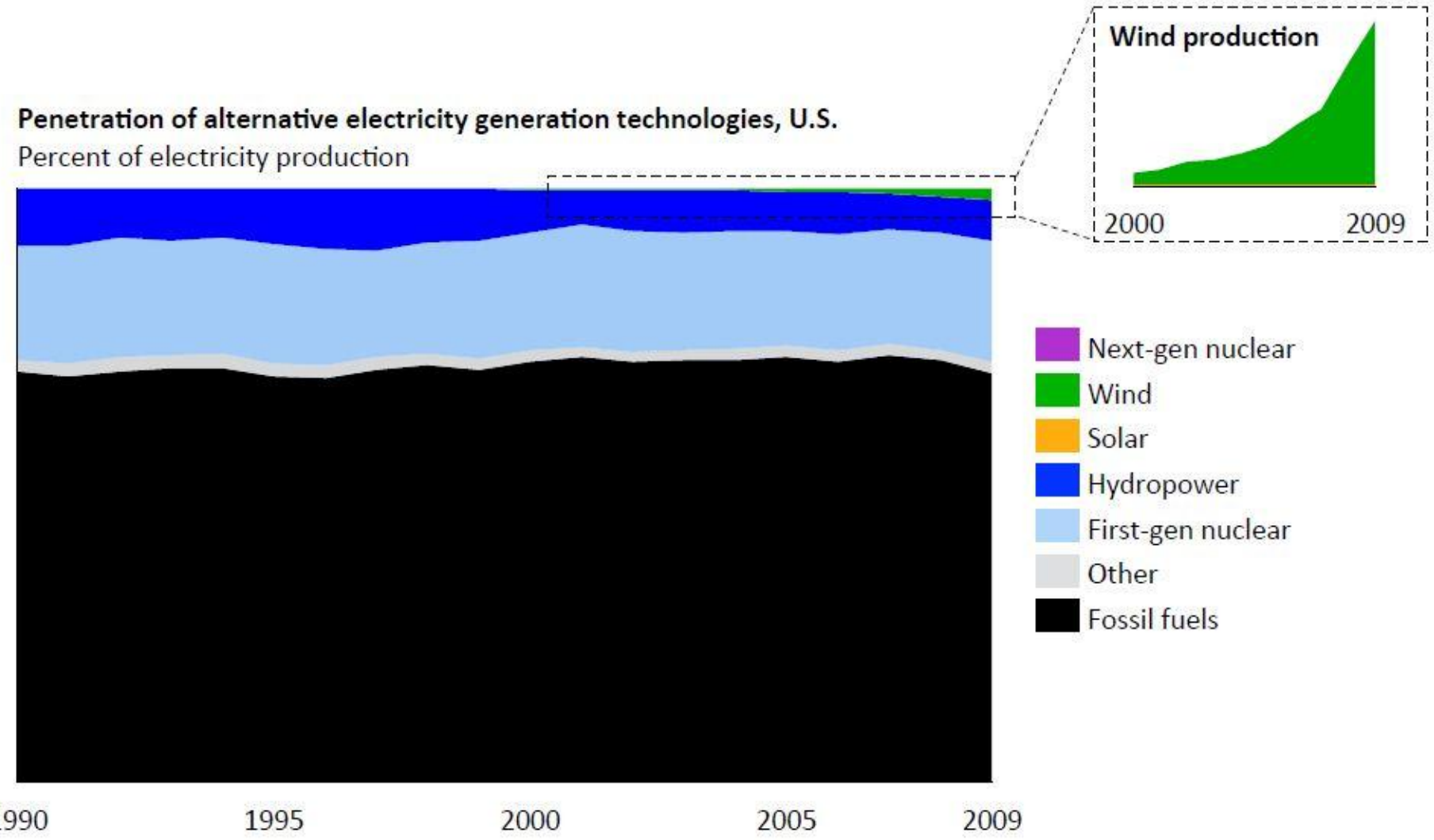
Oil use (per 1,000): 6.2 bpd

- If China aspires to be as "energy rich" as the U.S. by 2030, it will add 78.5 MBD
- If China aspires to be half as "energy rich" as the U.S. by 2030, it will add 35.1 MBD
- If China *only* aspires to be as "energy rich" as Poland* by 2030, it will still need to add 12.7 MBD (and still be the largest consumer of oil in the world)
- *When you factor in the significant demand growth from India, Russia, Brazil, and the Middle East, the effect will be highly disruptive to the world oil markets*

* Poland has the lowest energy use per capita of any country with a GDP per capita greater than $10,000

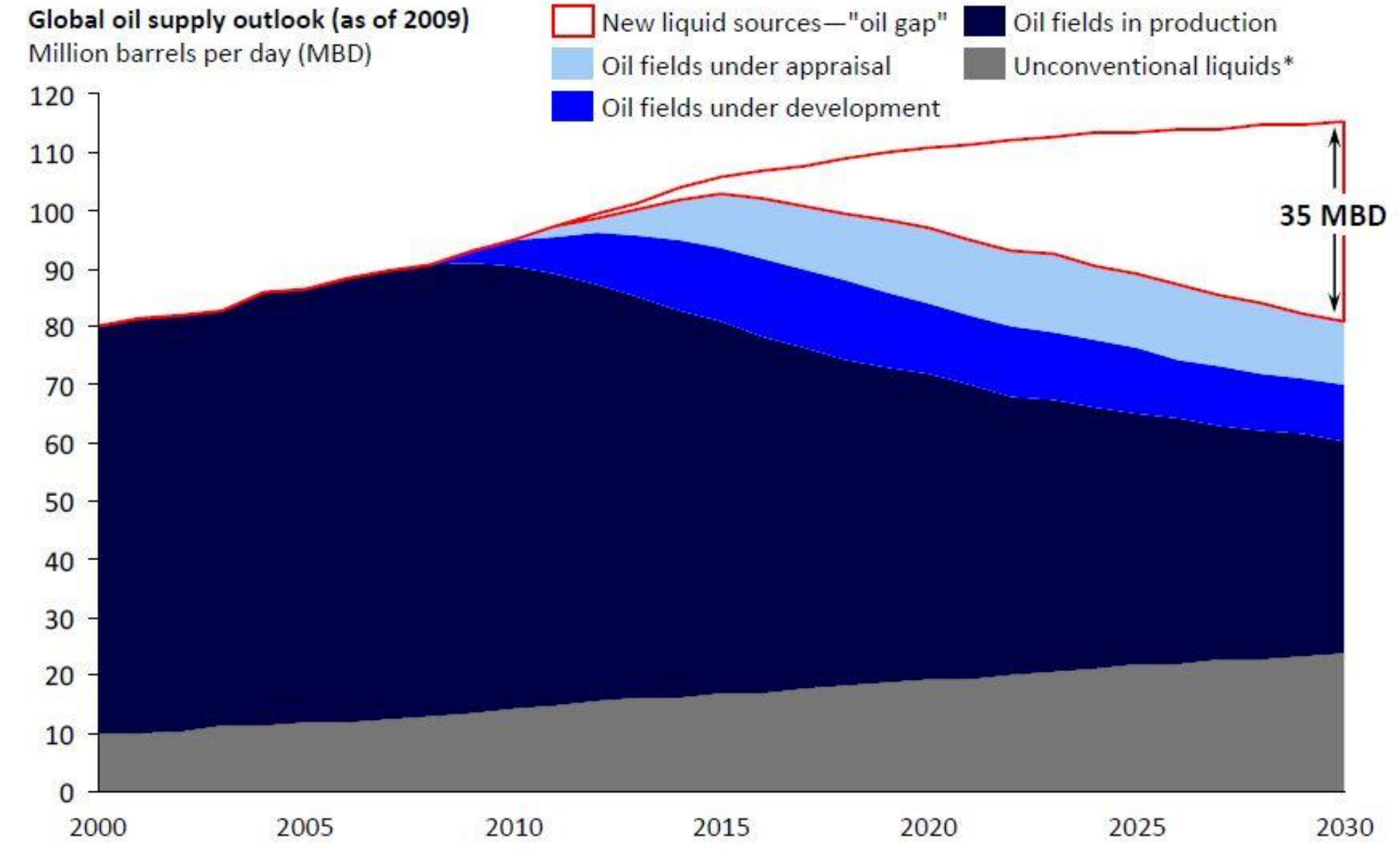
Note: Assumes population of China only grows to 1.4 billion by 2030

The U.S. has successfully developed and deployed alternative electricity methods, displacing more than 30% of fossil fuel use



* In the case of hybrids or electric vehicles

CERA estimates that by 2030, the world will demand 35 million barrels per day of liquids from unidentified sources—an "oil gap" that must be filled



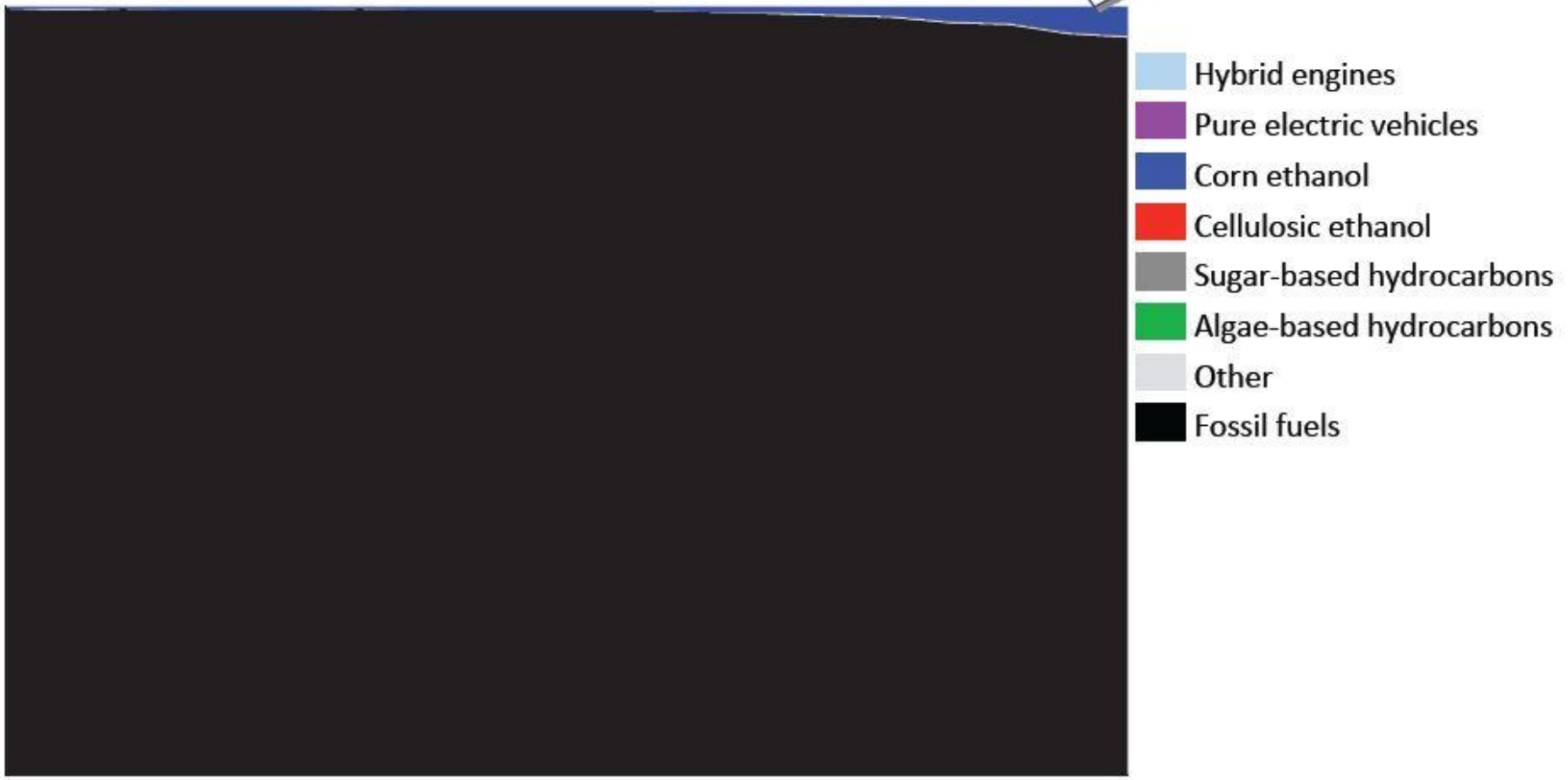
* Includes extra heavy oil, coal-to-liquids, gas-to-liquids, natural gas liquids, ethanol, biodiesel

Source: Cambridge Energy Research Associates "The Future of Global Oil Supply", 2009

Unlike electricity, there have been no meaningful alternatives developed to date to displace liquid petroleum

Penetration of alternative transportation fuel technologies
Percentage of fuel consumed (or saved*), oil equivalent

Corn ethanol accounts for less than 4% and is forecasted to stay at that level given mandates and farmland constraints



* In the case of hybrids or electric vehicles

All sources of non-fossil transportation fuel will be required, but some are better than others

Crude replacements

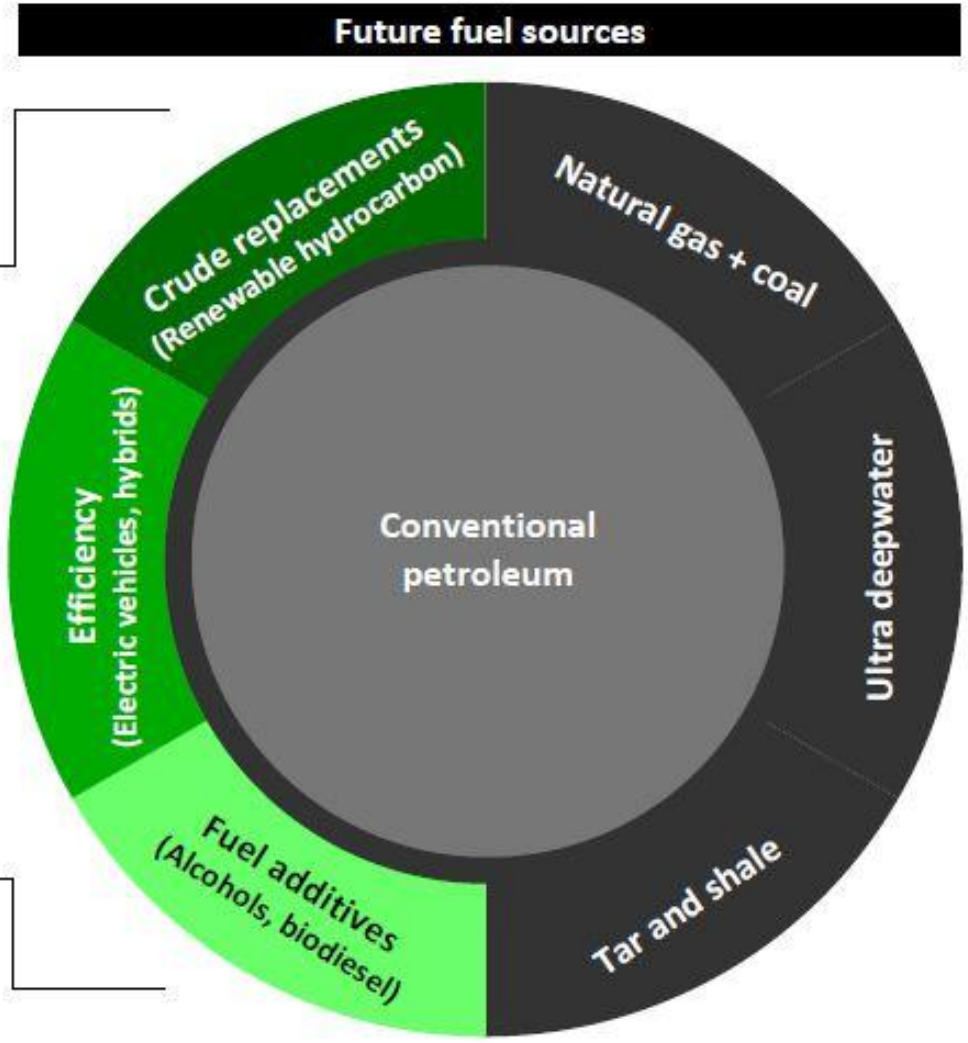
- Drop-in replacements, compatible with existing infrastructure
- Derived from either food or non-food photosynthetic feedstocks

Efficiency

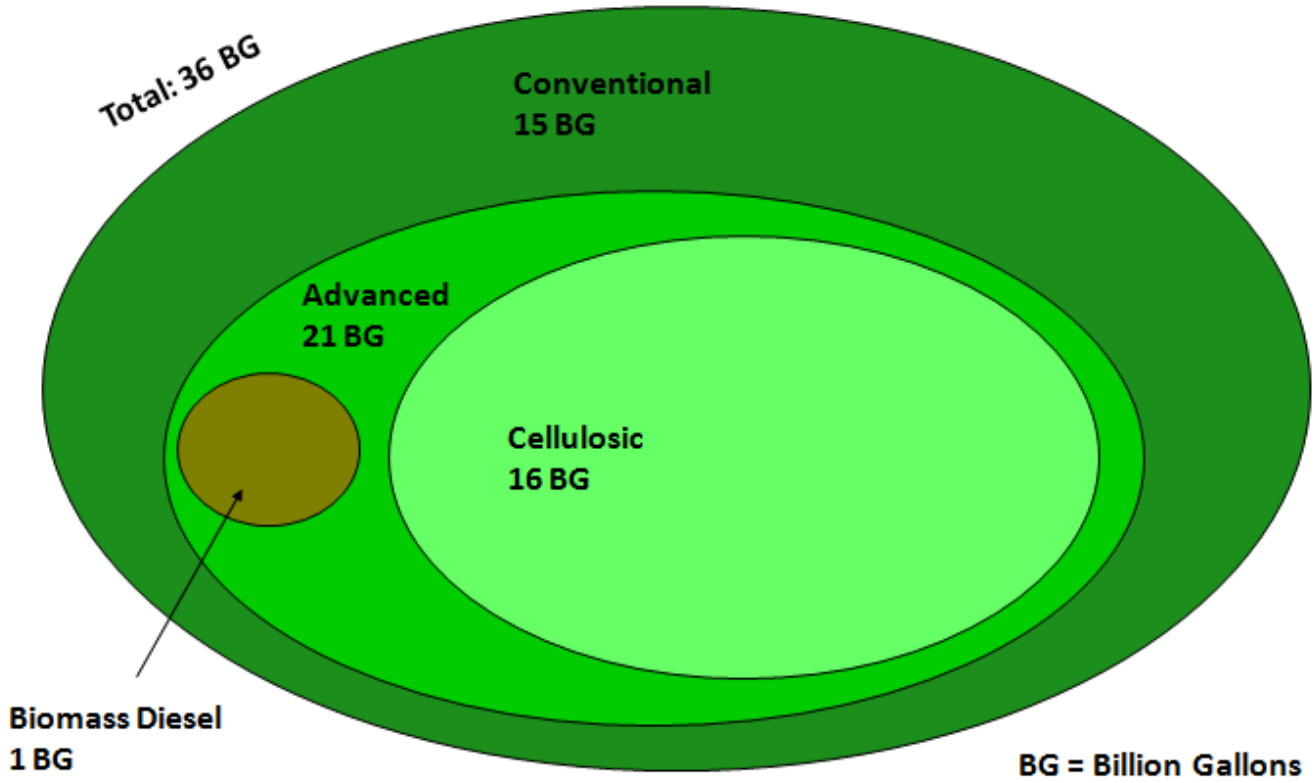
- Appropriate for limited light-duty vehicle and urban applications
- Cannot replace petrochemicals
- Infrastructure investment required

Fuel additives

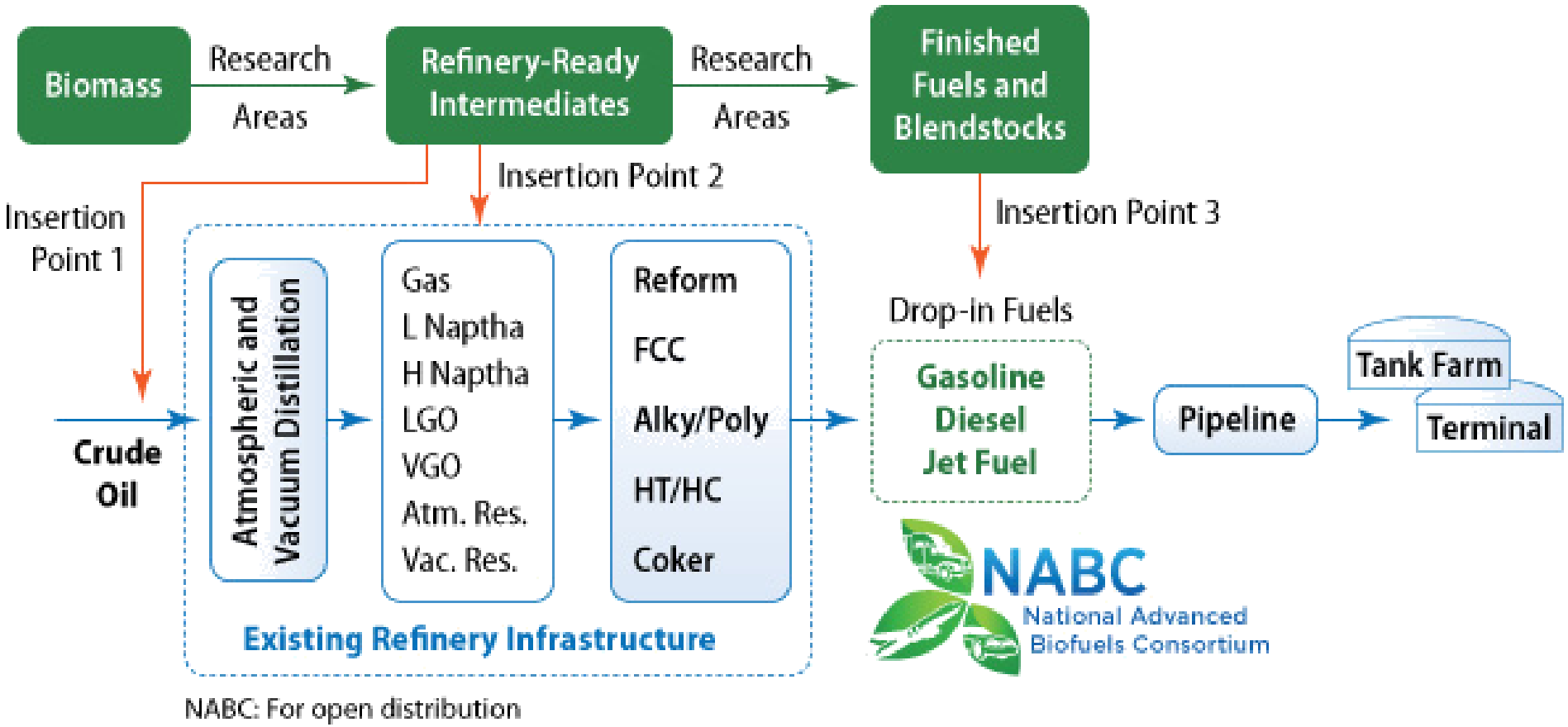
- Most feedstocks compete for agricultural resources; not massively scalable
- Infrastructure investment required because they are not drop-in fuels



Renewable Fuel Standard
RFS2

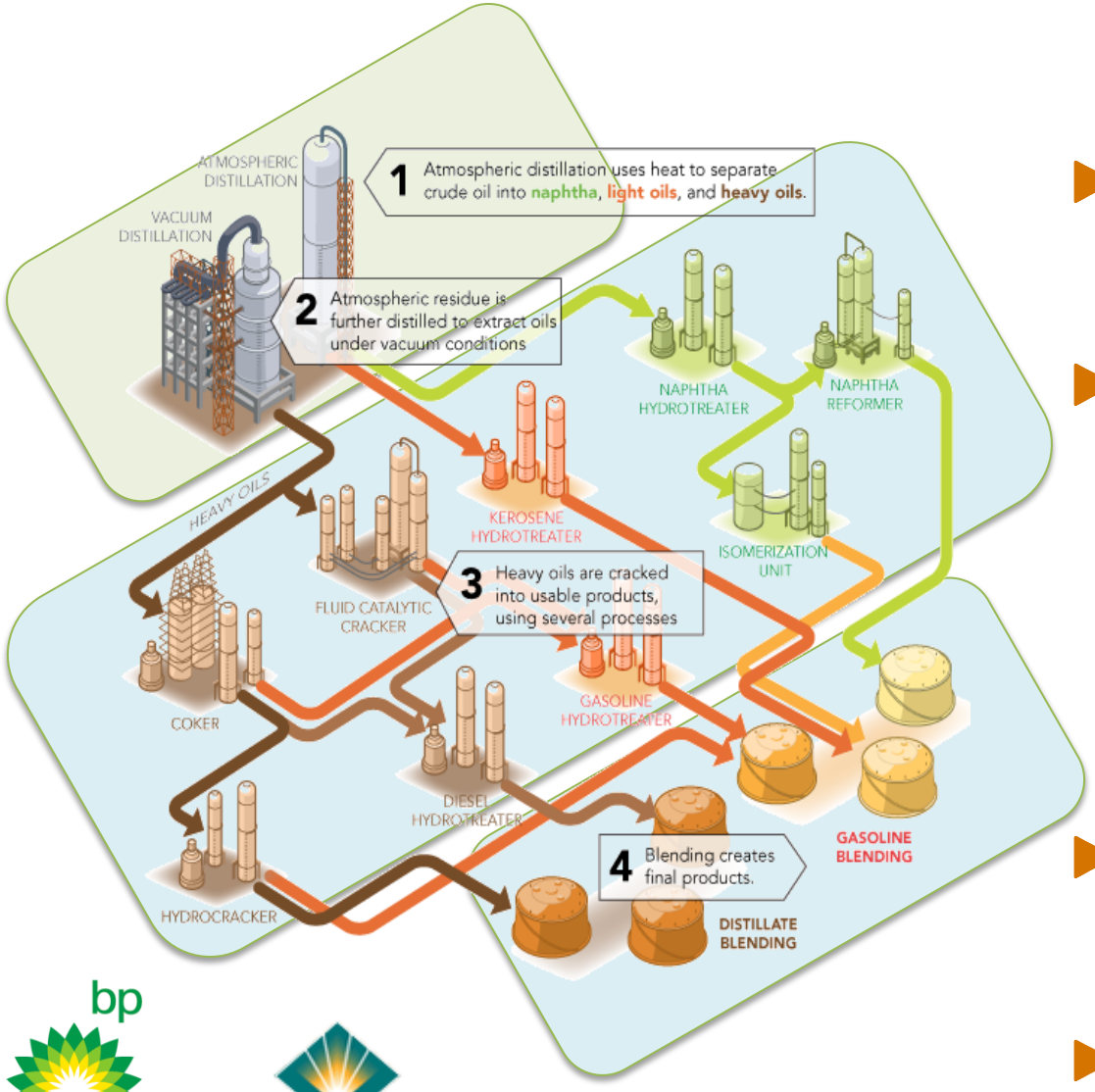


NABC Utilized Refinery Integration Strategy/Insertion Point Concept



Insertion Point 1 – added to crude oil
Insertion Point 2 – can be co-processed with conventional refinery stream(s)
Insertion Point 3 – near-finished fuel or blendstock

Refined Understanding of Insertion Points



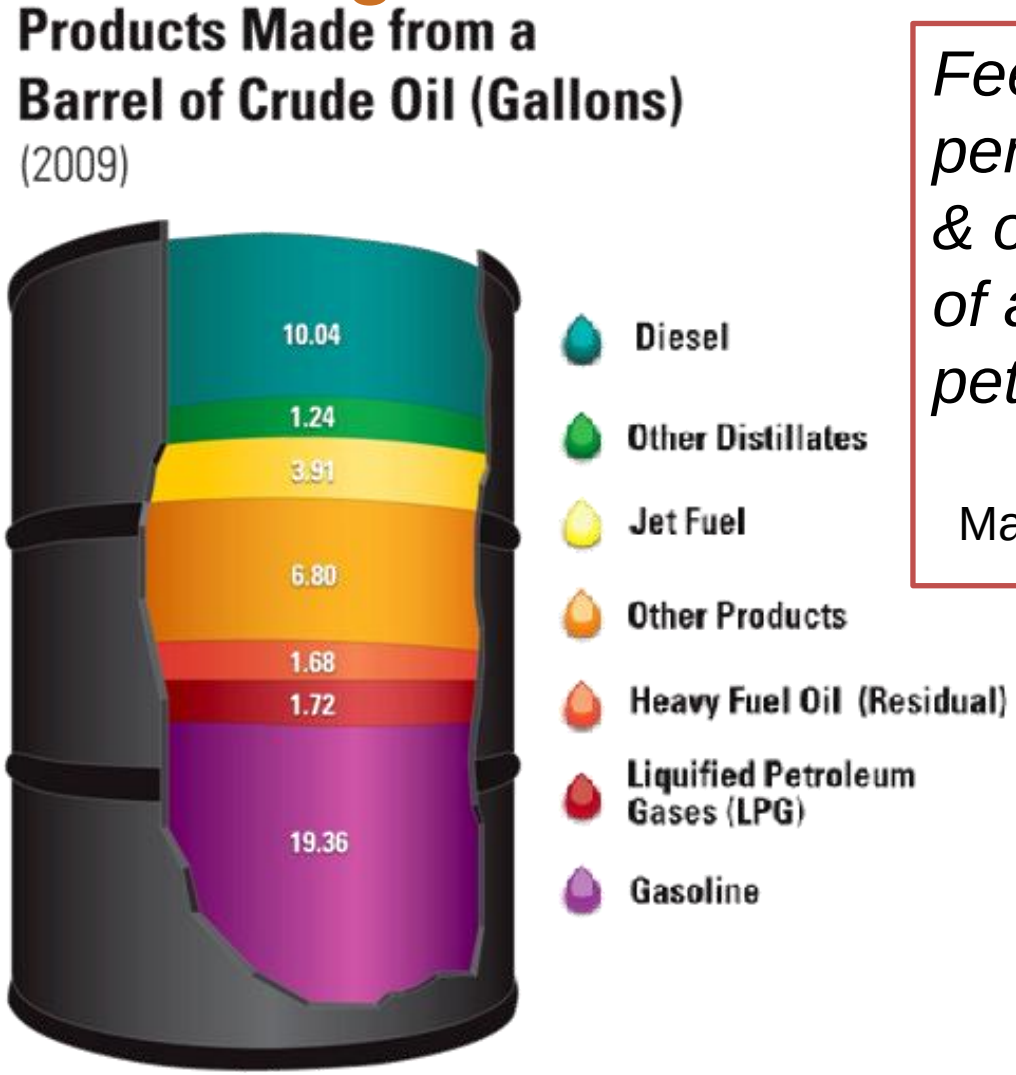
- Rule out Insertion Point 1
  - Crude units do not chemically alter material
- Insertion Point 2
  - Underused capacity
  - Definition on unit ops (tightly engineered)
  - H_2 load and corrosivity
  - Policy changes needed (RFS2)
- Insertion Point 3
  - Preference to do blending at refinery
- Continuum between Points 2 and 3

Picture courtesy of http://www.bantrel.com/markets/downstream.aspx

Biorefineries

THE CASE FOR PRODUCTS

What is done with petroleum? Is this something that could be learned?

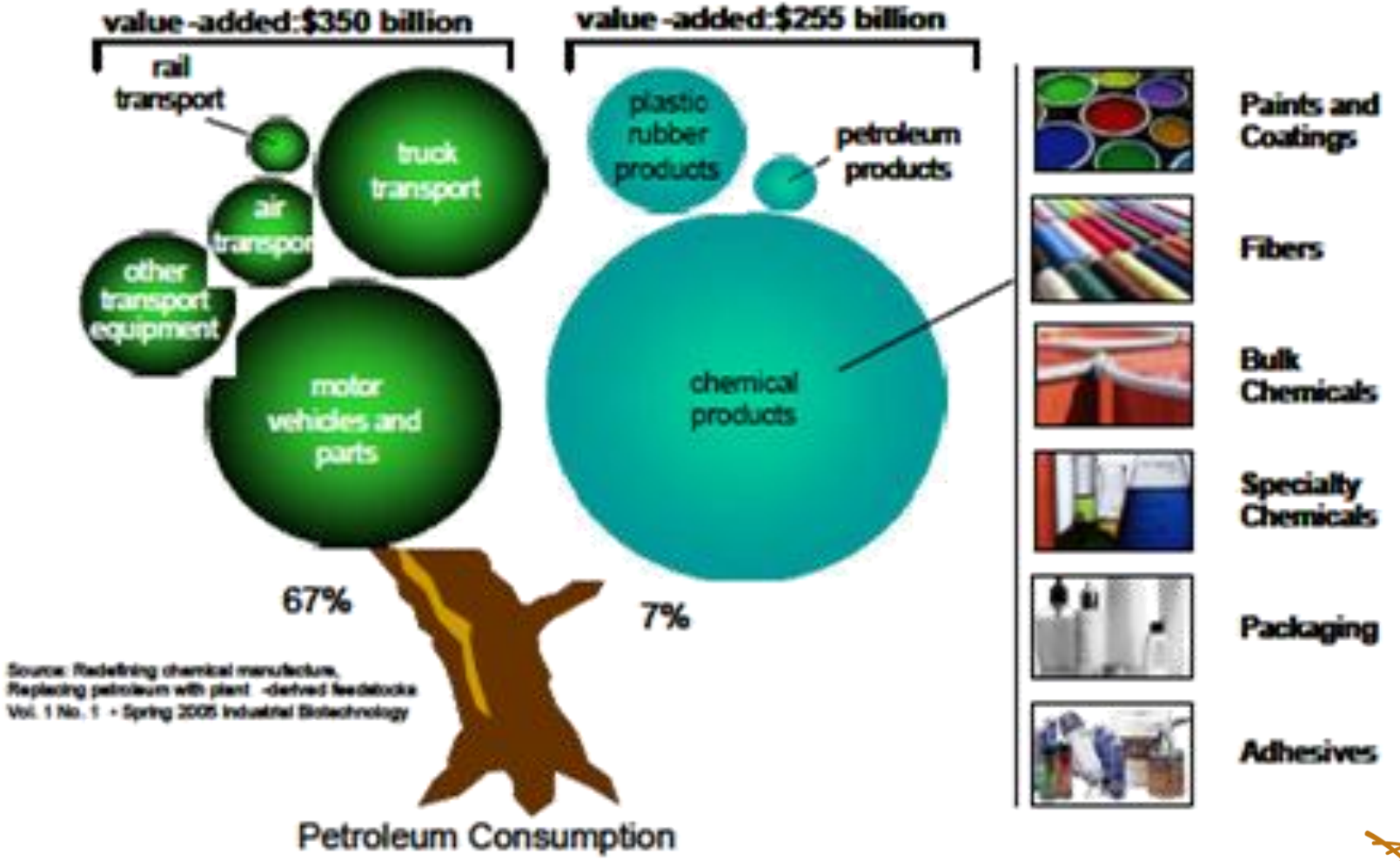


Feedstocks like naphtha, pen-hex, BTX, light paraffins & olefins help form the basis of a ~$375 billion petrochemical industry.

Marshall *New Scientist*, **2007**, 28-31

Source: Energy Information Administration, "Oil: Crude Oil and Petroleum Products Explained" and AEO2009, Updated February 2010, Reference Case.

Value from Fuels and Products



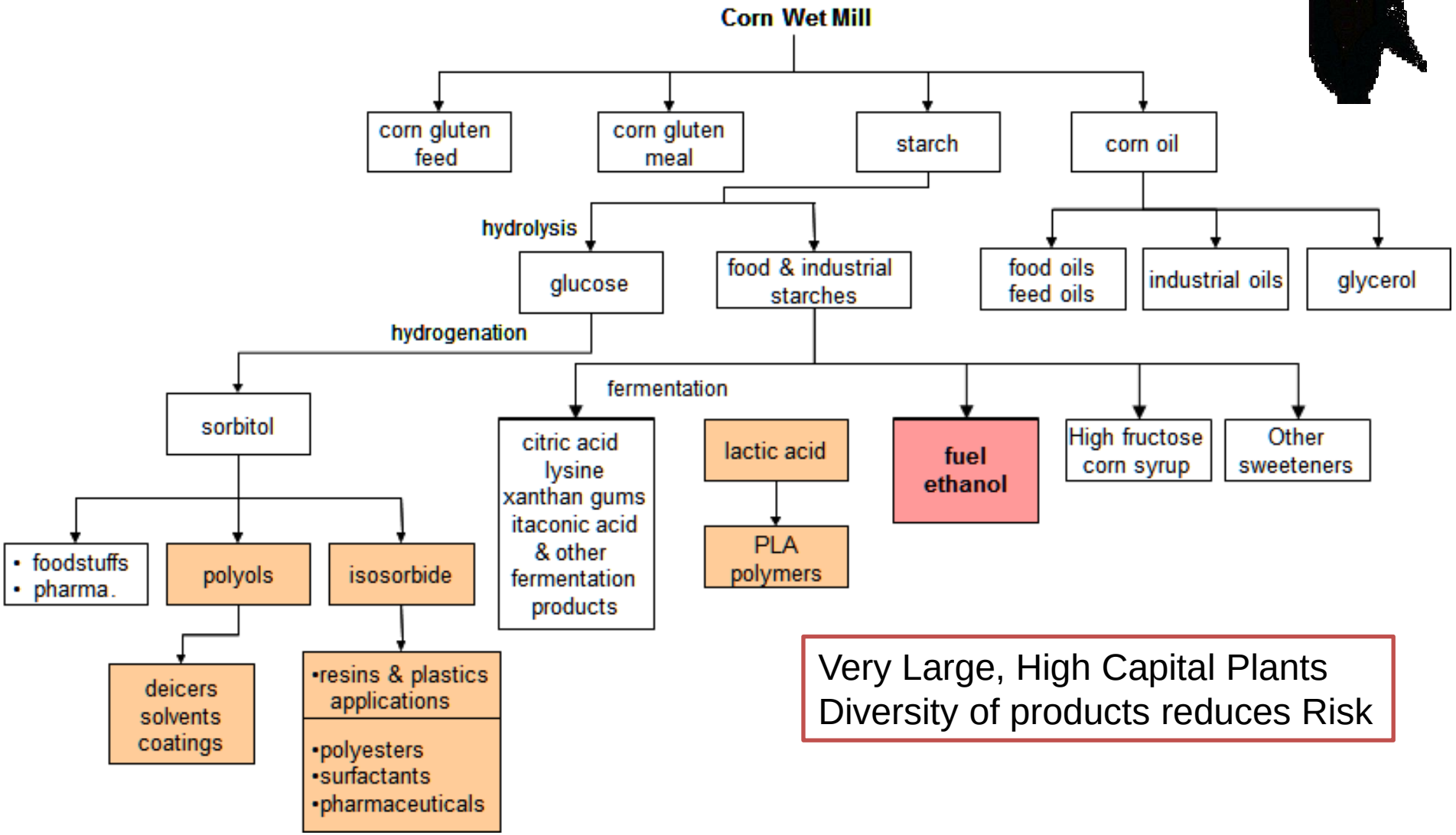
Source: Redefining chemical manufacture. Replacing petroleum with plant -derived feedstocks Vol. 1 No. 1 • Spring 2005 Industrial Biotechnology

Paul Bloom, ADM

Biorefineries

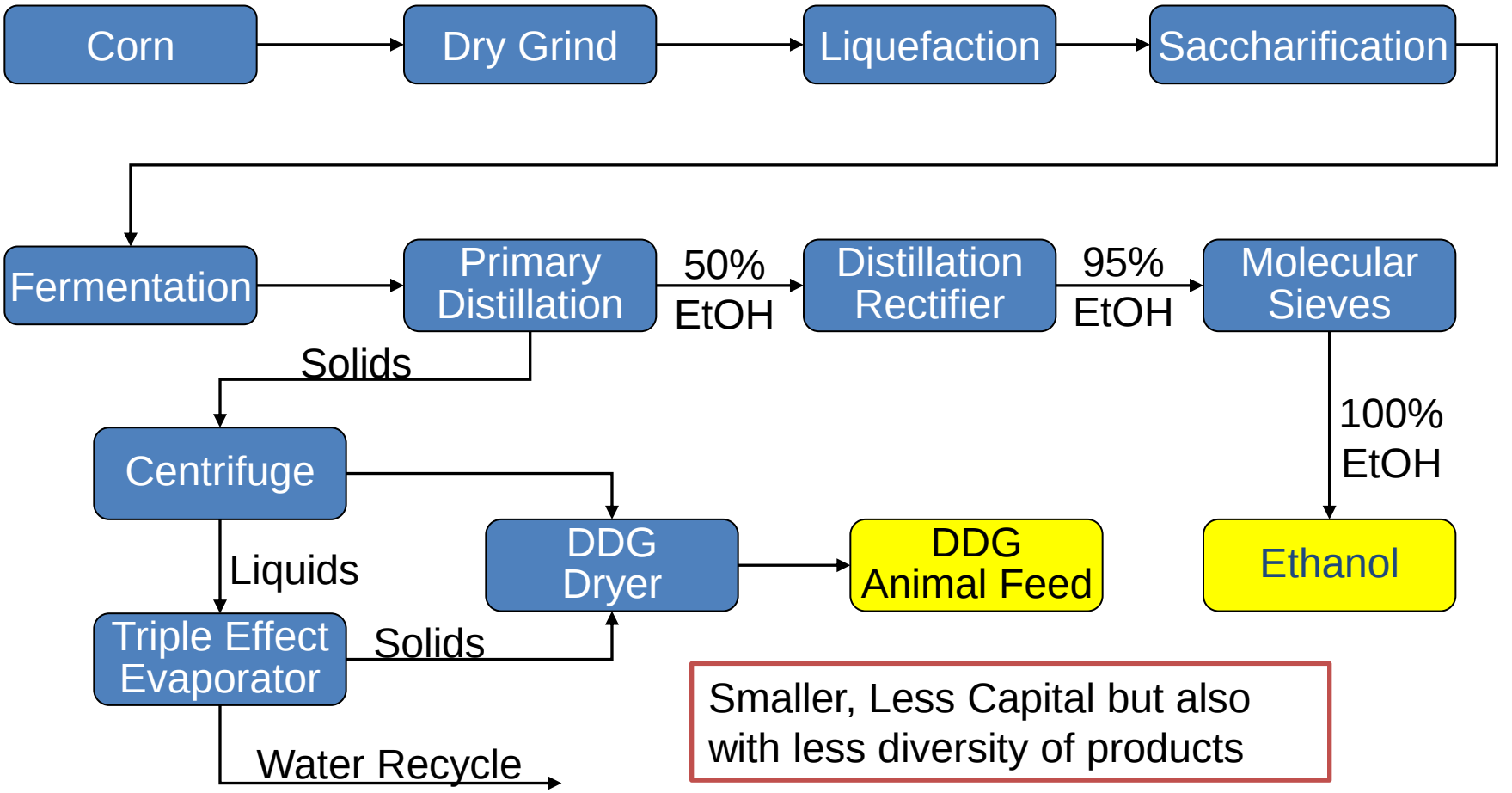
PRODUCT DIVERSITY-RISK (ECONOMIC PERFORMANCE)

An Example of a Current Biorefinery

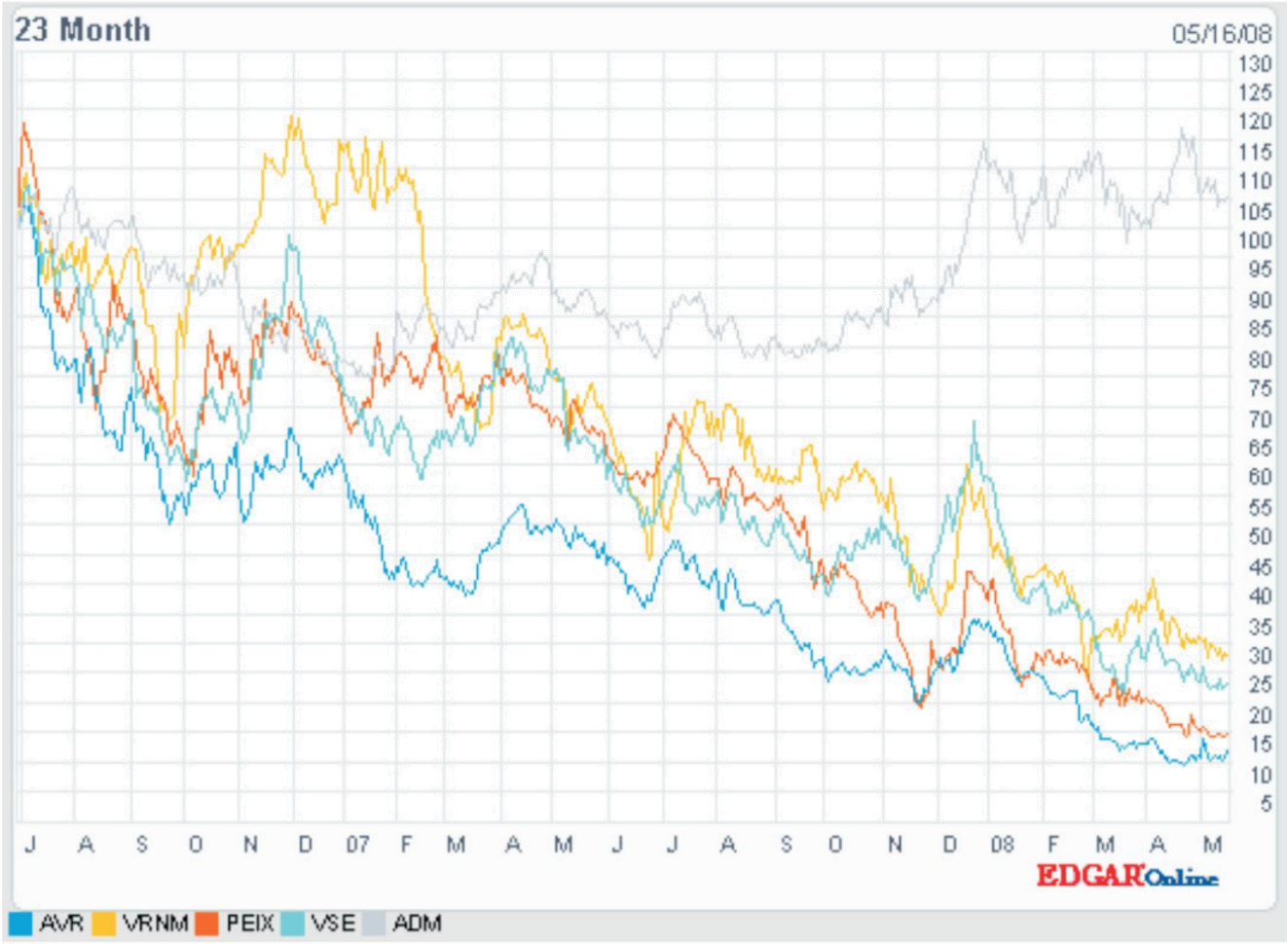


Very Large, High Capital Plants
Diversity of products reduces Risk

Dry Mill Ethanol Process—Only 2 Products



2006-2008 Stock Prices for Publically Traded Ethanol Producers



AVR - Aventine Bioenergy
VRNM - Verenium
PEIX - Pacific Ethanol
VSE - VeraSun
ADM - Archer Daniels Midland

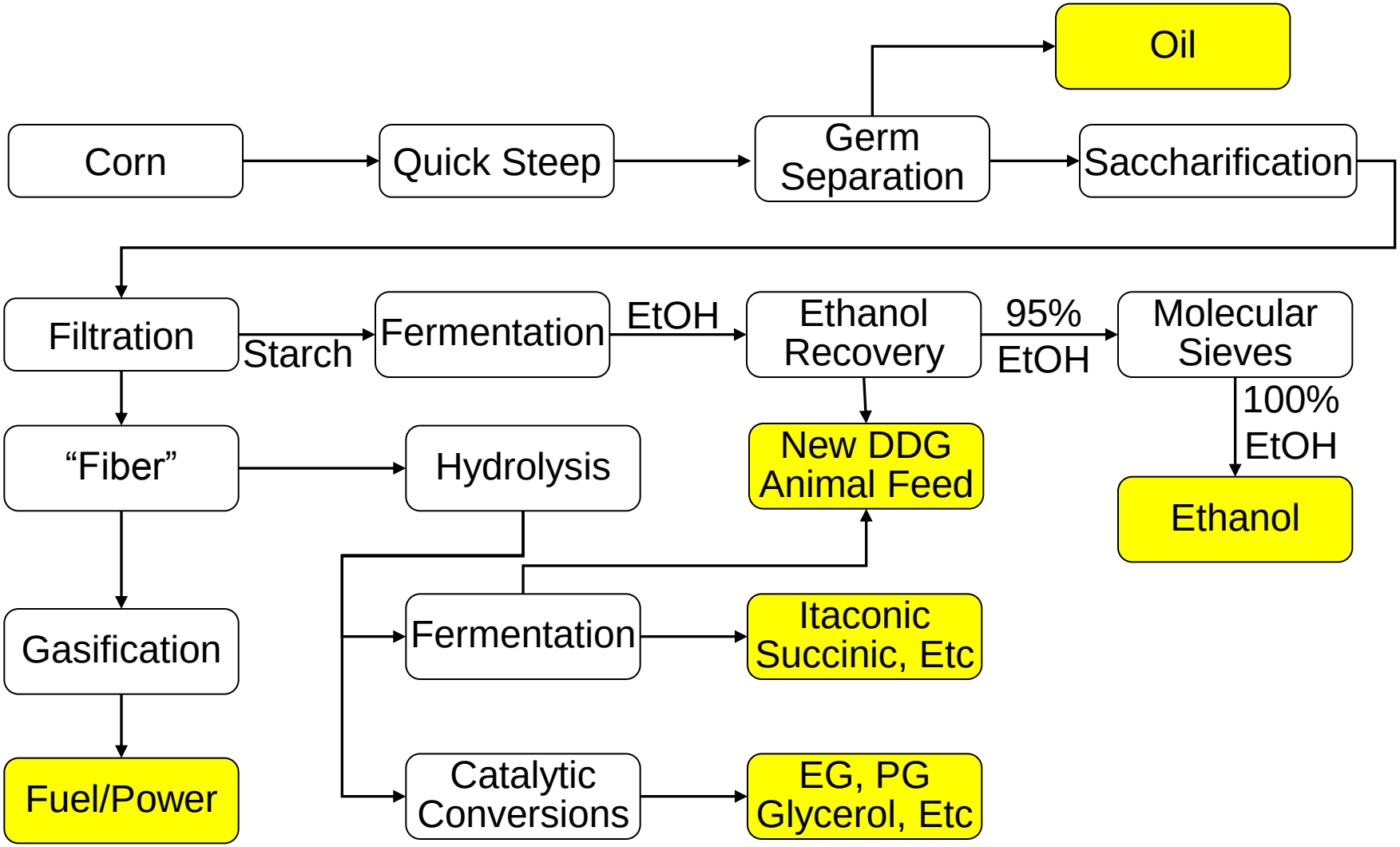
Current Status of Ethanol Dry Mills

- Economics are difficult
  - Current ethanol facilities limited to only two products, ethanol and DDG
  - Economics are highly dependent of value of the co-product DDG
  - Significant energy costs are associated with the drying of DDG
  - Markets for DDG are not always favorable and will deteriorate as additional ethanol facilities come on line

Strategies for Creating Additional Value

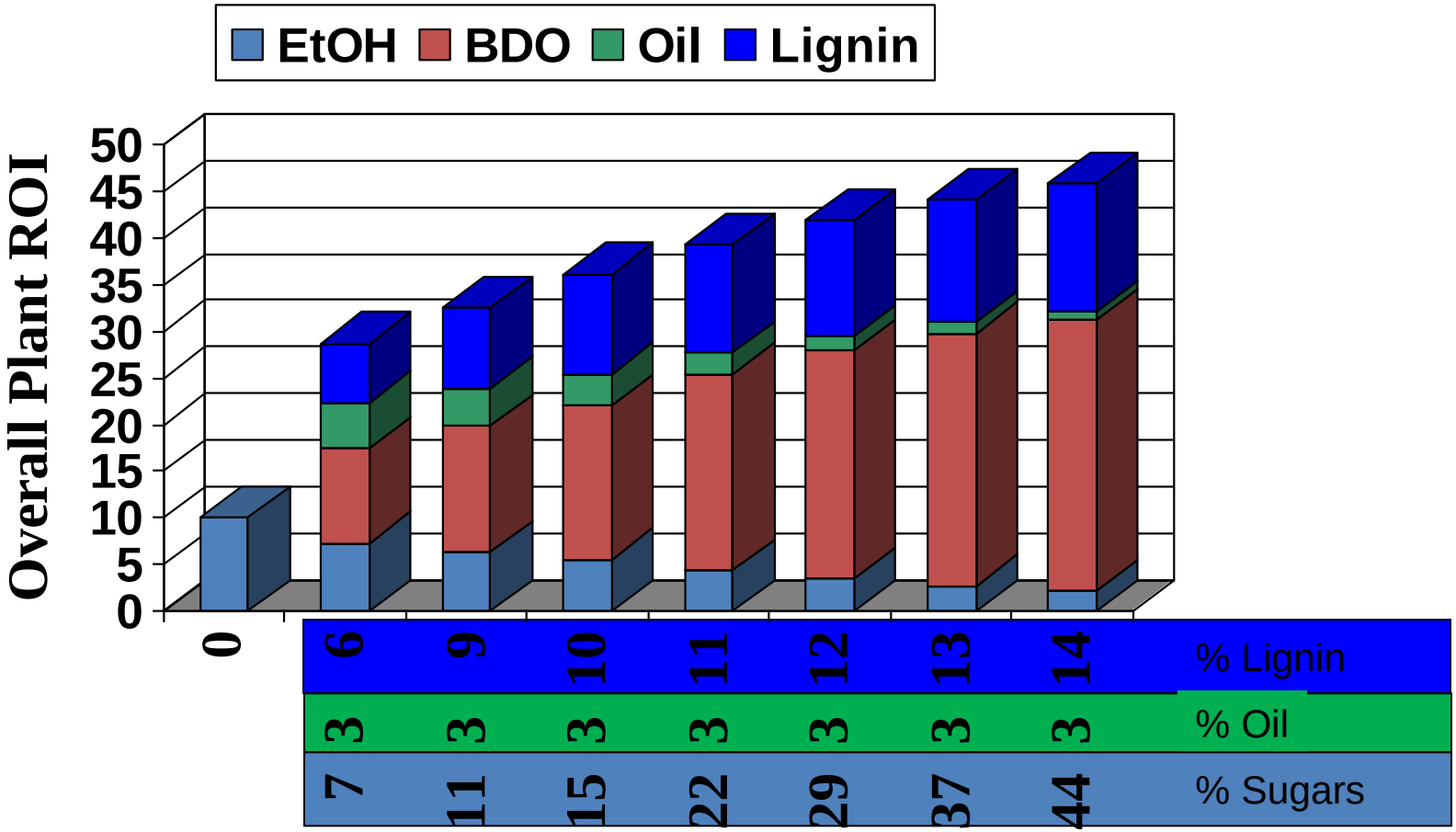
- Modify dry mills to include a quick steeping process that allows germ recovery
- Add an intermediate filtration process to recovery non-starch derived sugars (hemicellulose)
- Develop new fermentations for utilization of five carbon sugars (itaconic acid, succinic acid, etc)
- Develop new chemistry to produce value added products from hemi-cellulose (sugar alcohols, polyols)
- Include an energy component-gasify “DDG or modified DDG” to produce fuel gas

The Holistic Ethanol Facility



Integrated Biorefinery
"Back of the Envelope Economics"
EtOH, BDO, Oil, Lignin

2122 Tons/Day
$30/Dry Ton
BDO @ $0.60/lb



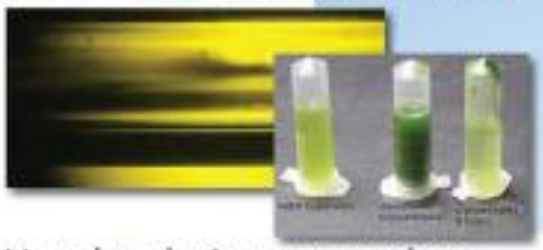
Percent Feedstock (Sugars, Oil and Lignin) Utilized for Chemicals

Algal Biology

Greater space-time lipid/algae yields

Cultivation

Harvesting and Extraction



Novel techniques to reduce cost and environmental impact

Valuable Coproducts

Livestock feed

Direct energy production

Chemicals for industry use

Fuel Conversion

High energy-density fungible fuels

CO_2

Water

Land

Nutrients

Algal biorefineries *MUST* have high value co-products to succeed

Biorefineries (Case Studies)

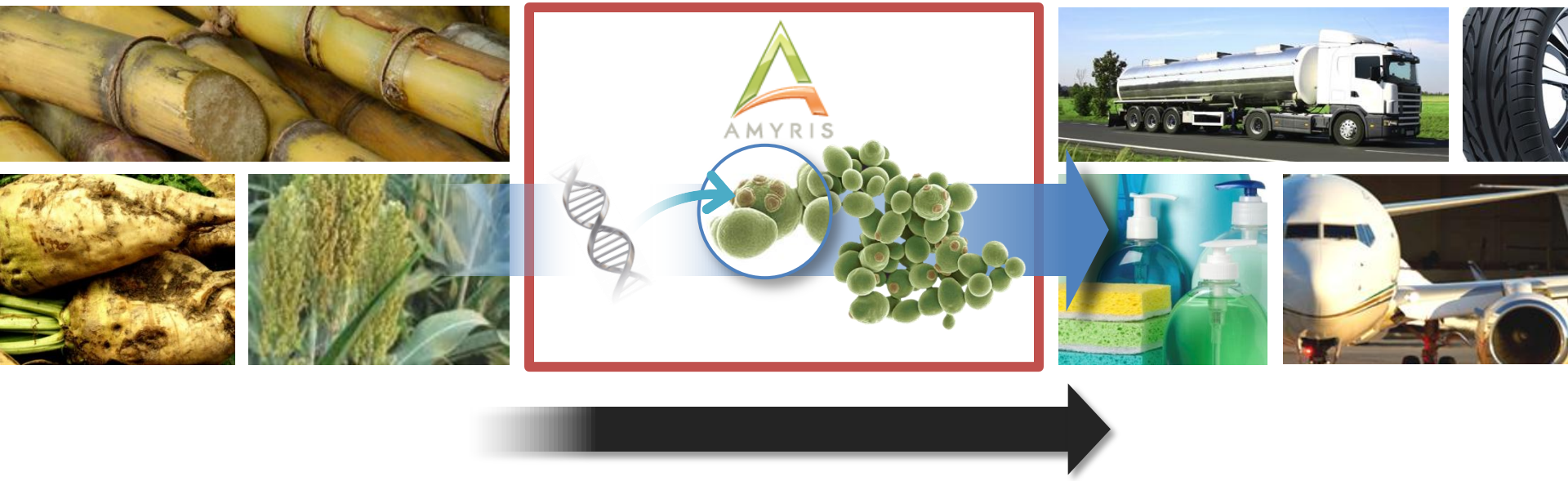
AMYRIS
VIRENT
GEVO
CLEANVANTAGE/WSU

Case Study 1:
Amyris Technology Platform

ANY FEEDSTOCK

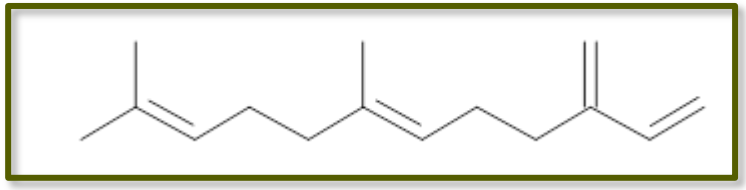
INDUSTRIAL SYNTHETIC BIOLOGY PLATFORM

RENEWABLE CHEMICALS AND FUELS



Farnesene Building Block (Fermentation Tech)

hydrolysate



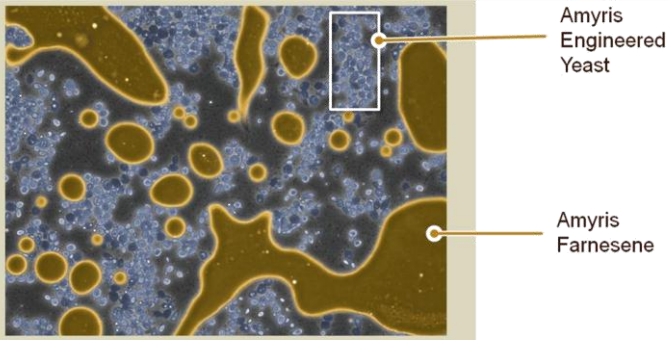
Farnesene

YEAST CELL

Mevalonate Pathway

Farnesene Synthase

Diesel & Chemical Precursor



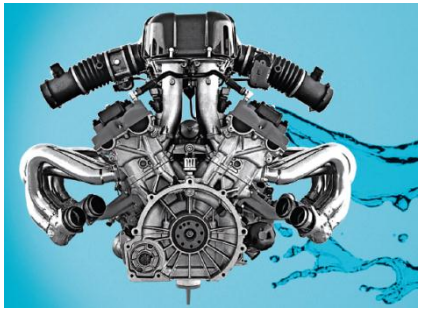
Phase-Contrast Micrograph of Amyris Engineered Microbes Producing Farnesene

[1] Cane juice
[2] Fermentation broth
[3] Separations
[4] Purification

Farnesene Biosynthesis Technology Provides opportunities for many applications

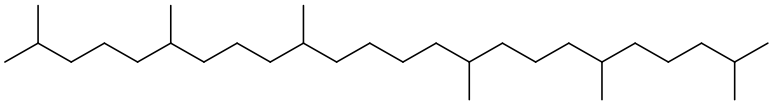
Lubricants (Novvi SA)

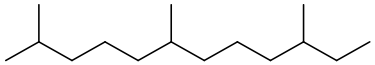
- Hydraulic fluids
- Compressor/turbine oils
- Food grade lubricants
- Gear Lubricants
- Greases
- Transmission Fluids
- 2-Cycle Engine oils
- Engine Oils

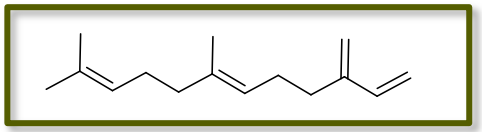


Fuels

- Diesel
- Jet







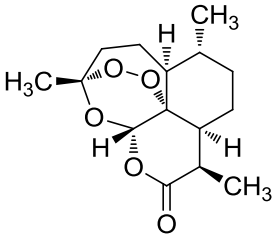
Farnesene

Personal Care

- Squalane (Soliance)
- Flavors
- Fragrances

Therapeutic

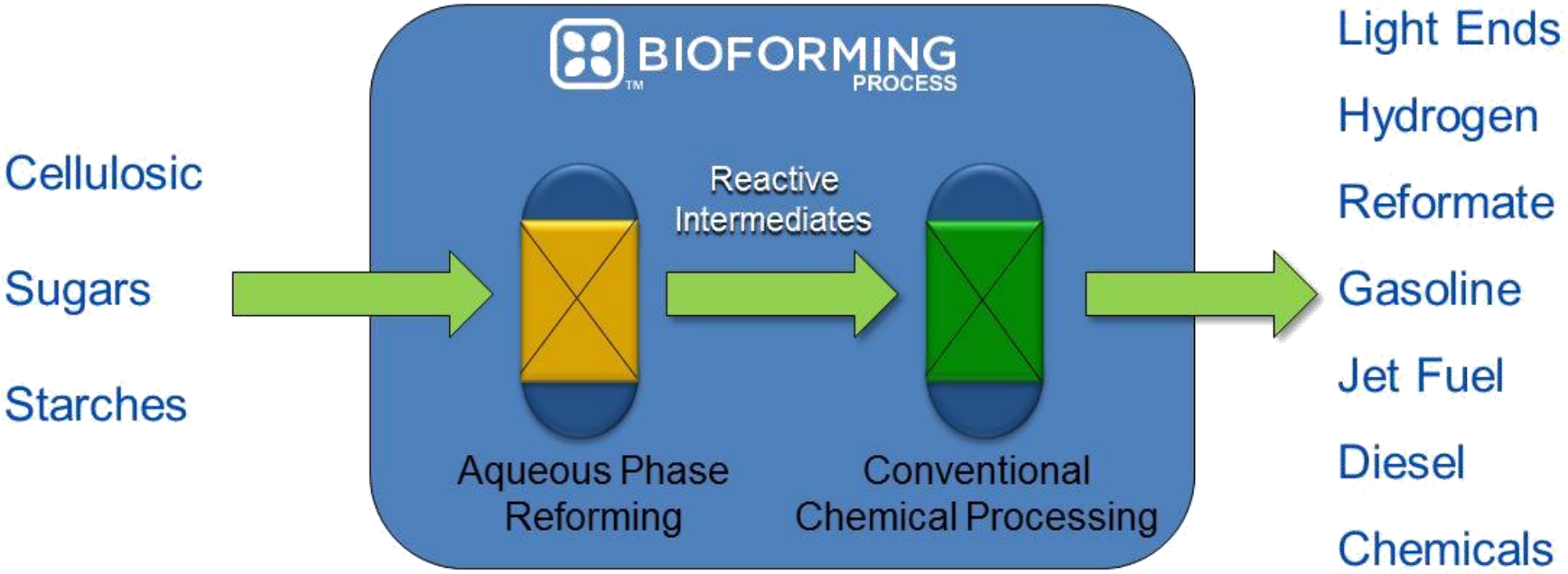
- Artemisinin (from artemisinic acid)
- (antimalarial)



Polymer Applications (M&G)

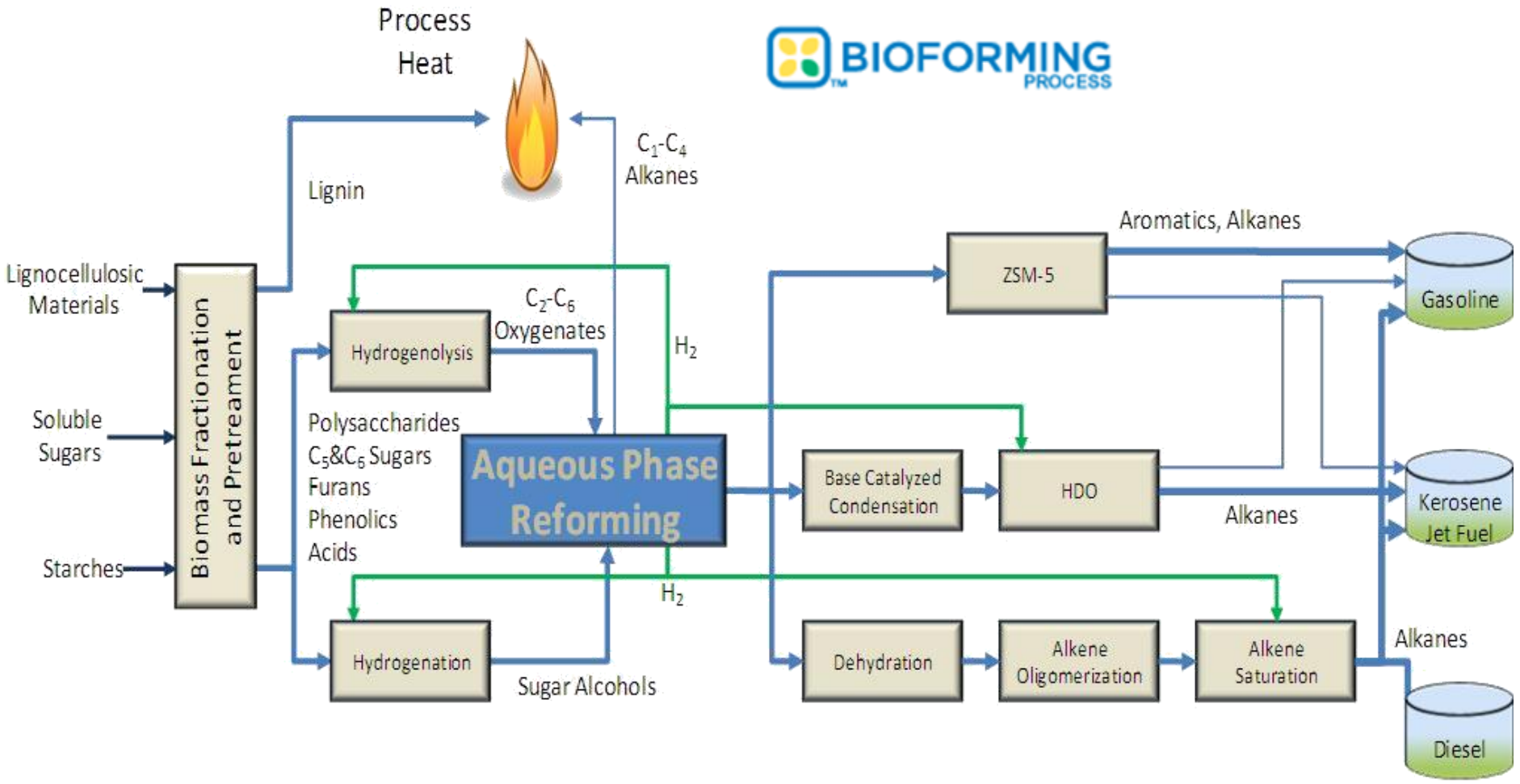
- Ingredients for PET
- Plasticizers
- Adhesives
- Plastics
- Packaging

Case Study 2:
Virent Catalysis Technology

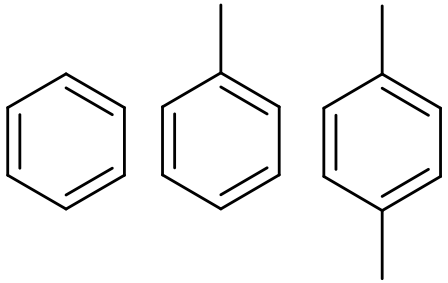


The message on their website is—we are a refinery capable of making numerous products

Multiple Pathways (catalysis)

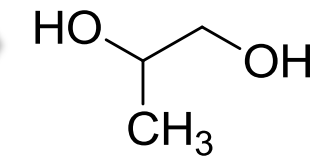


Aromatics and paraffins from biomass

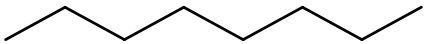


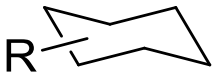
Benzene Toluene Xylene (BTX)

APR Oxygenates



Propylene Glycol

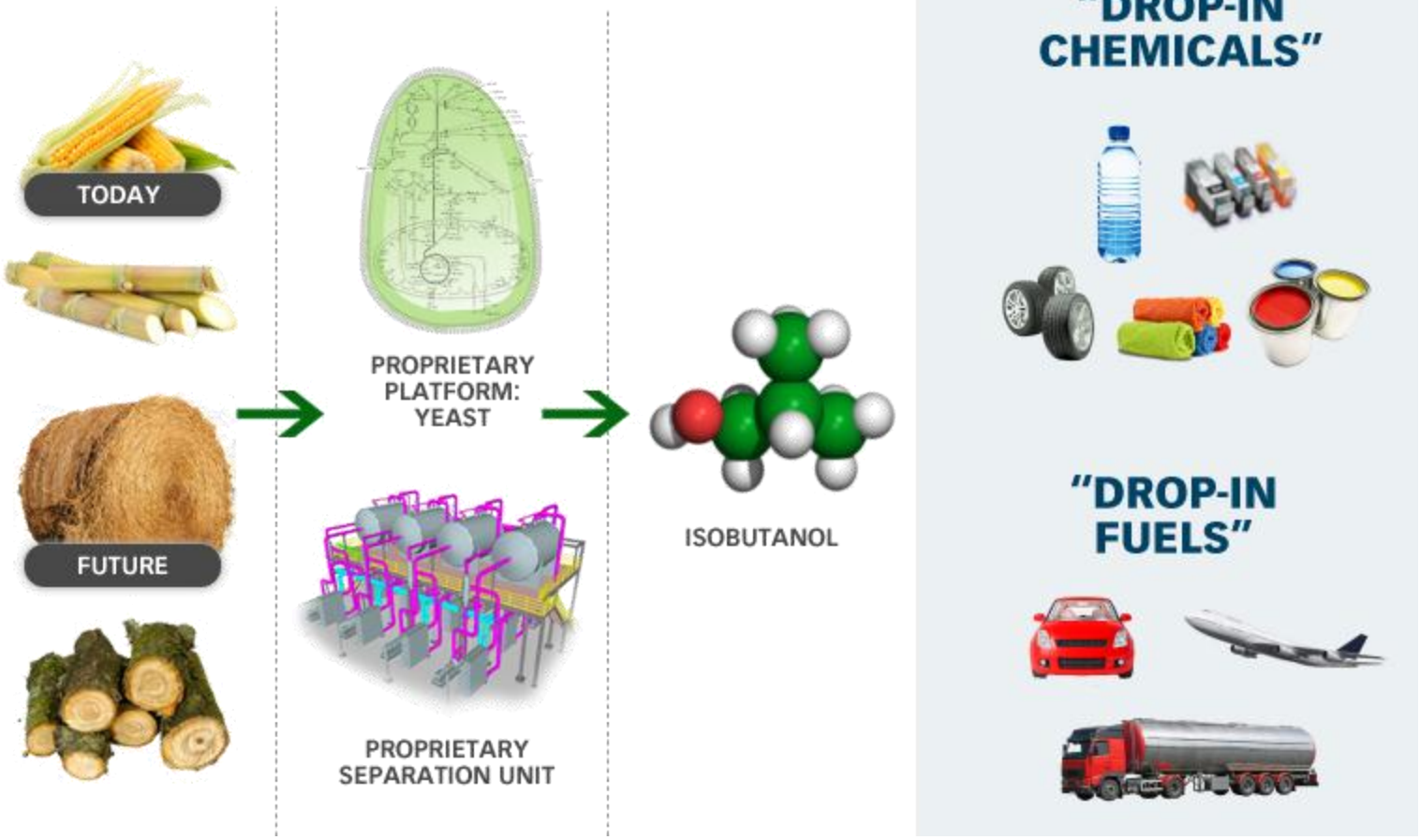




Cyclic and straight chain paraffins

Precursors that go into polymer building-blocks and wide-ranging uses in solvents, dyes, food preservatives, detergents and pharmaceuticals.

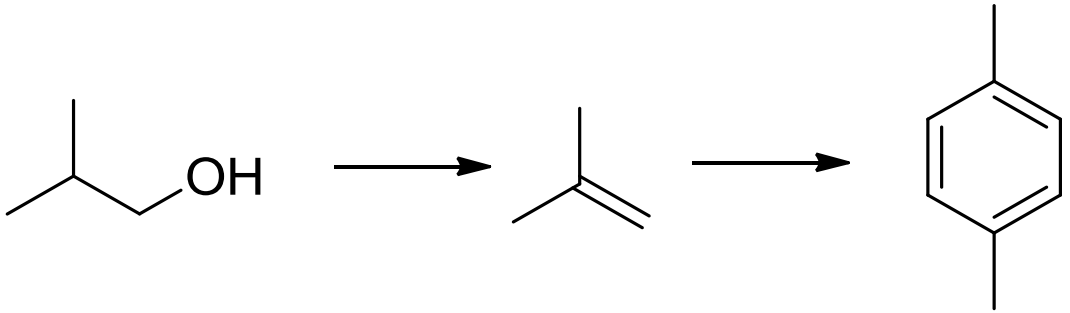
Case Study 3:
Gevo Yeast Fermentation



Website message: we make drop in chemicals too! (not just fuels)

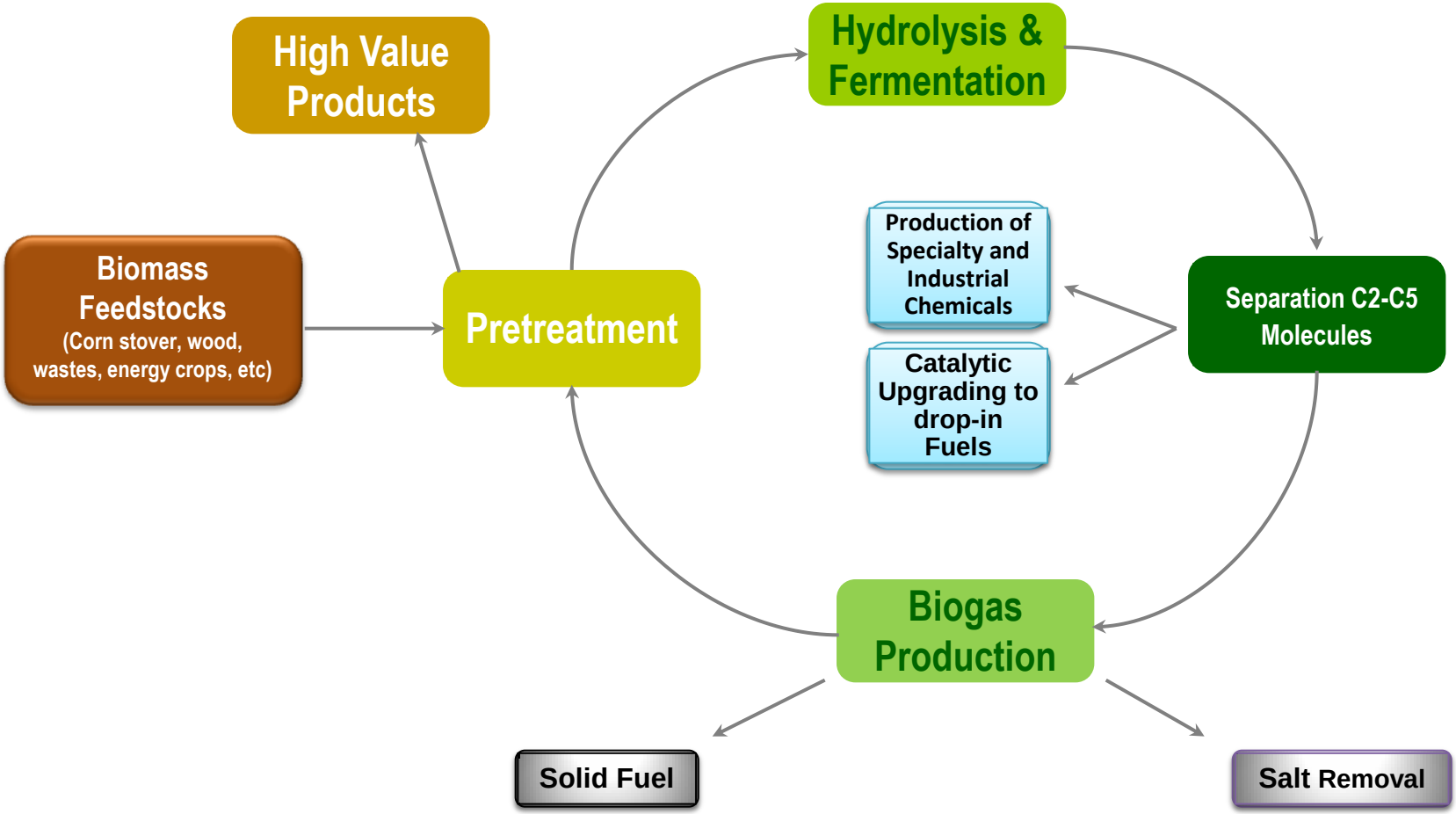
Isobutanol Platform

Isobutanol can be dehydrated with well-known processes to produce butenes which are building blocks for the production of materials such as lubricants, synthetic rubber, poly(methyl methacrylate), propylene, xylene and PET.



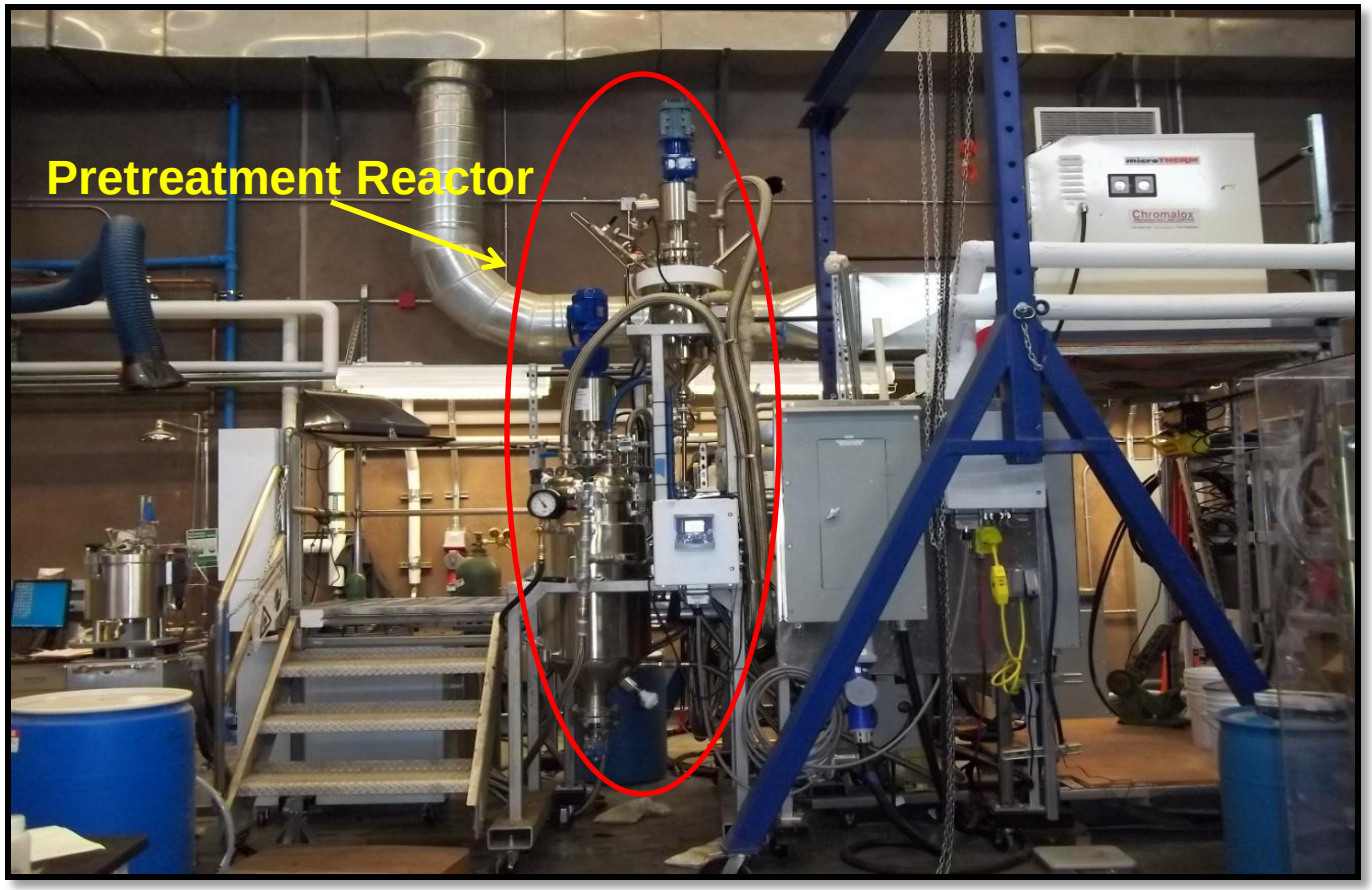
- **Solvents:** Sasol has signed a non-binding Letter of Intent to purchase isobutanol for sale and distribution to its global customer base.
- **Materials, Plastics and Fibers:** Toray has signed a non -binding letter of interest related to the future supply of isobutanol for the production of para-xylene for the production of plastics and other performance materials.

Case Study 4: CleanVantage/WSU



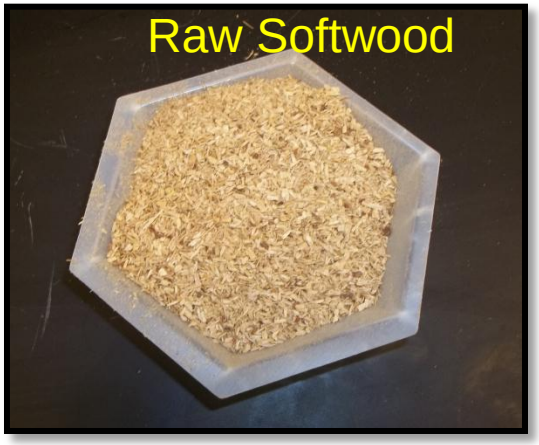
The BioChemCat Process

WSU Biomass Pretreatment System



Softwood to hydrolysate and sugars

Milling



Pretreatment

Special thanks to my group and collegues at BSEL

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Questions ?