NABC Webinar
18 November 2010

Tom Foust—Principle Investigator NABC
John Holladay—Scientific Officer
Kelly Ibsen—Operations Manager




Department of Energy Priorities and Goals

Advancing Presidential Objectives

Science & Discovery
- Connecting basic and applied bioscience
- Conducting breakthrough R&D

Economic Prosperity
- Creating jobs and reinvigorating rural economies
- Supporting the emerging U.S. bioenergy industry and market

Climate Change
- Reducing GHG emissions by 60% for cellulosic biofuels and 50% with advanced biofuels
- Validating and demonstrating low-carbon power generation technologies
- Influencing development of criteria and indicators for sustainable biofuel production

Clean, Secure Energy
- Developing & demonstrating advanced biofuels technologies

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National Advanced Biofuels Consortium

U.S. Transportation Fuel Needs

Gasoline (cars & trucks)

137 bgy

Diesel (on-road, rail)

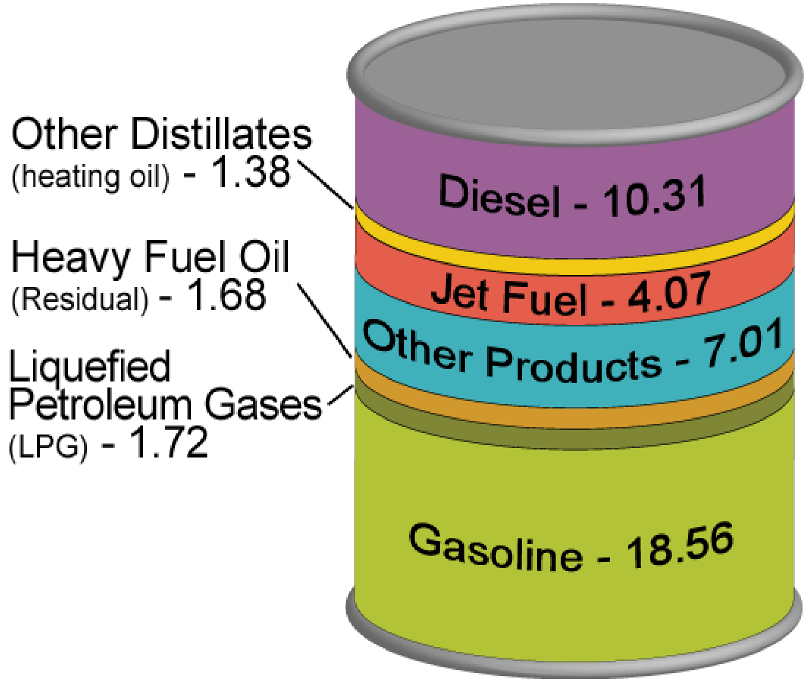
43 bgy

Aviation (jet fuel)

23 bgy

	2008	2030
Motor gasoline	137	126
Diesel	43	71
Jet fuel	23	30

Products in a Barrel of Crude (gal)



Source: Energy Information Agency

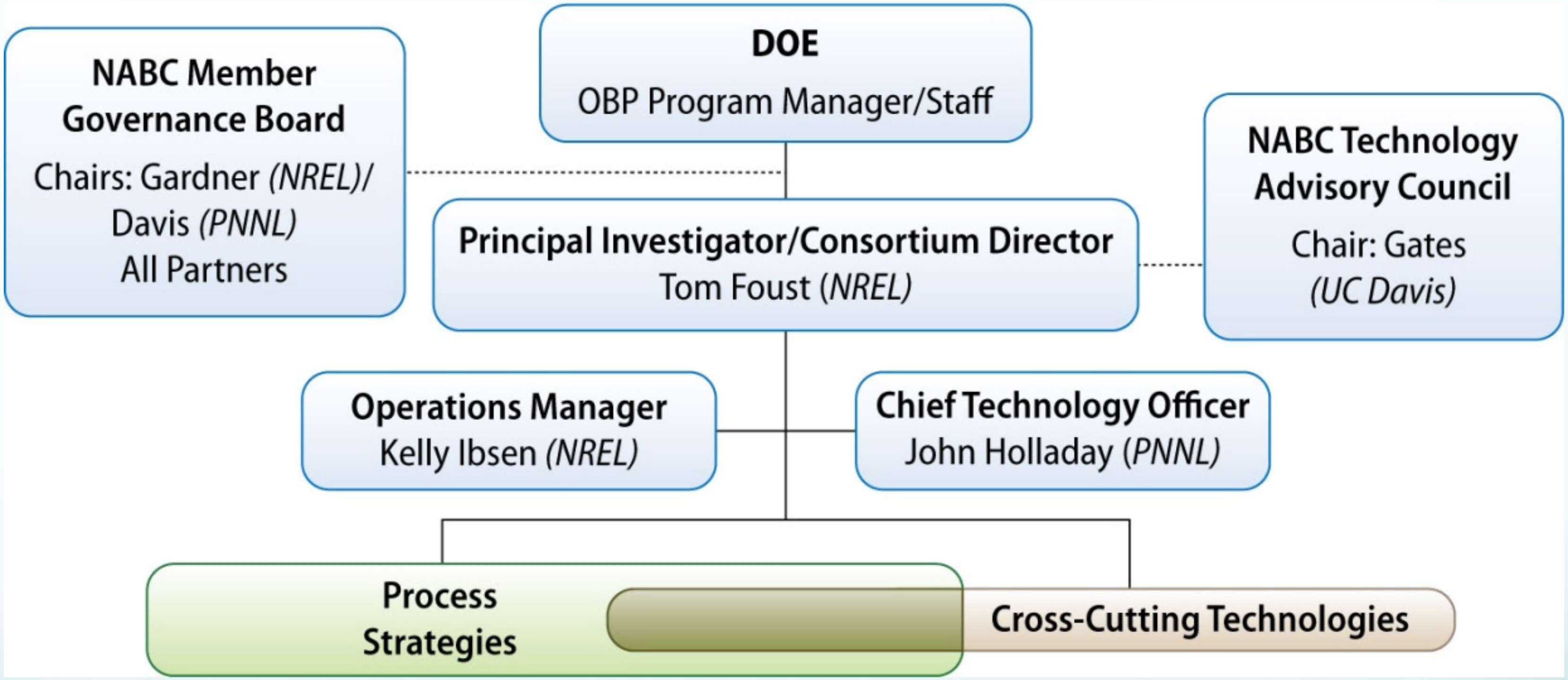
NABC Developing Technologies Towards Advanced Infrastructure

Consortium Leads
National Renewable Energy Laboratory
Pacific Northwest National Laboratory

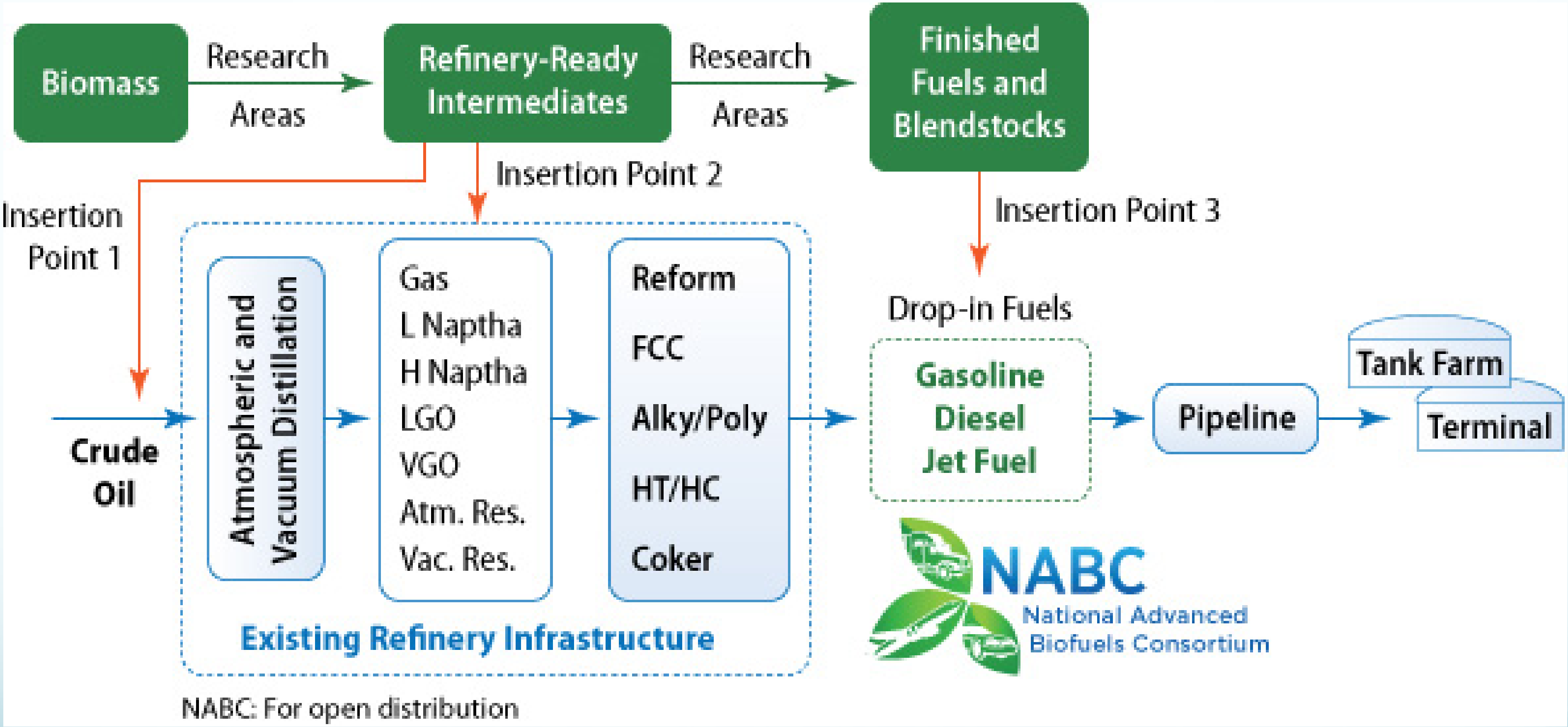
Consortium Partners
Albemarle Corporation
Amyris Biotechnologies
Argonne National Laboratory
BP Products North America Inc.
Catchlight Energy, LLC
Colorado School of Mines
Iowa State University
Los Alamos National Laboratory
Pall Corporation
RTI International
Tesoro Companies Inc.
University of California, Davis
UOP, LLC
Virent Energy Systems
Washington State University

Project Objective: to develop cost-effective technologies that supplement petroleum-derived fuels with advanced "drop-in" biofuels that are compatible with today's transportation infrastructure and are produced in a sustainable manner.

NABC Organization



How can biomass fit into the petroleum infrastructure?



- Three possible insertion points
- Develop new technologies that use today’s infrastructure

Crude Oil Refinery: Integral to Infrastructure Conversion

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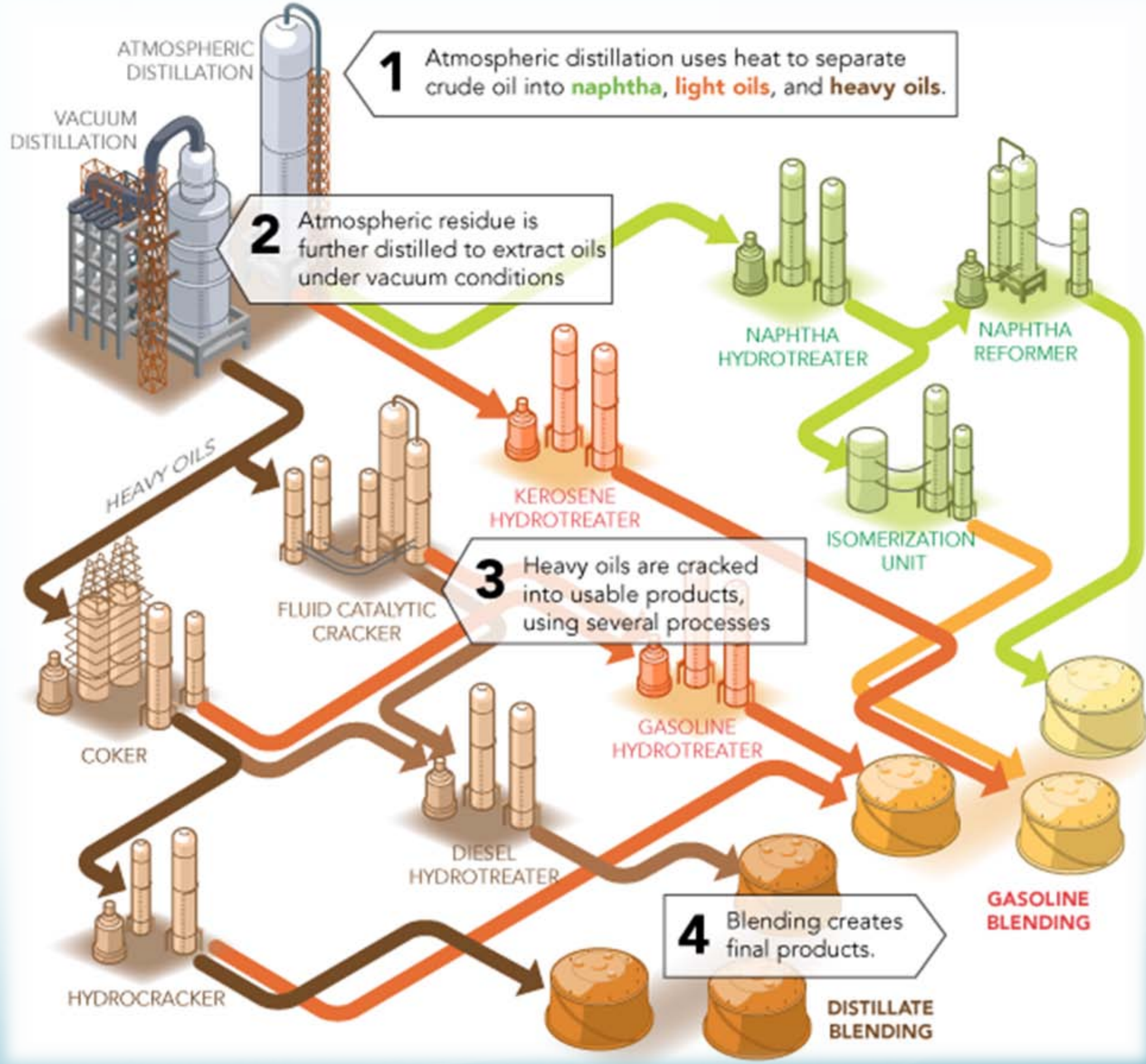
- Complex but efficient conversion processes
- ~100 years experience
- Refinery partners in NABC are helping identify how biomass may fit into this construct
- Analysis of materials and experimentation on how the materials may interact in the refinery



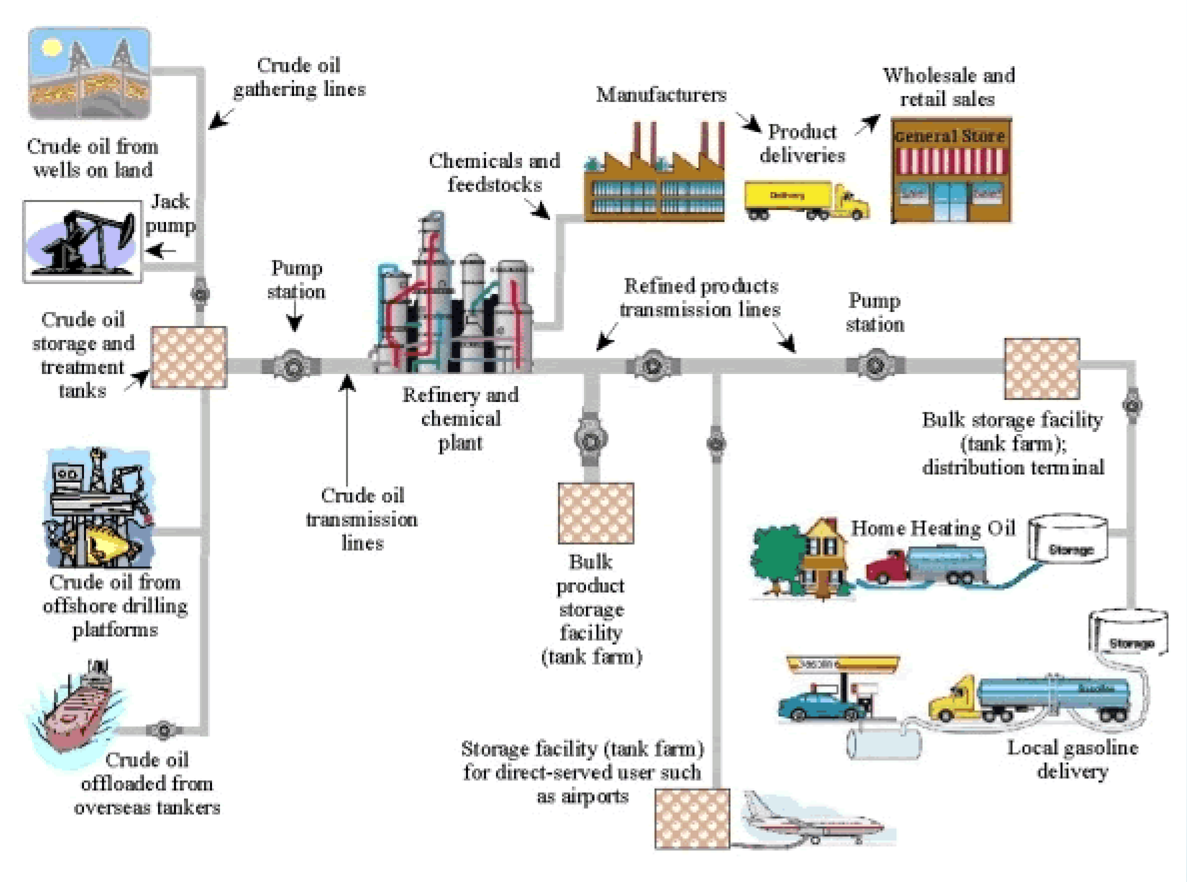
bp

TESORO

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

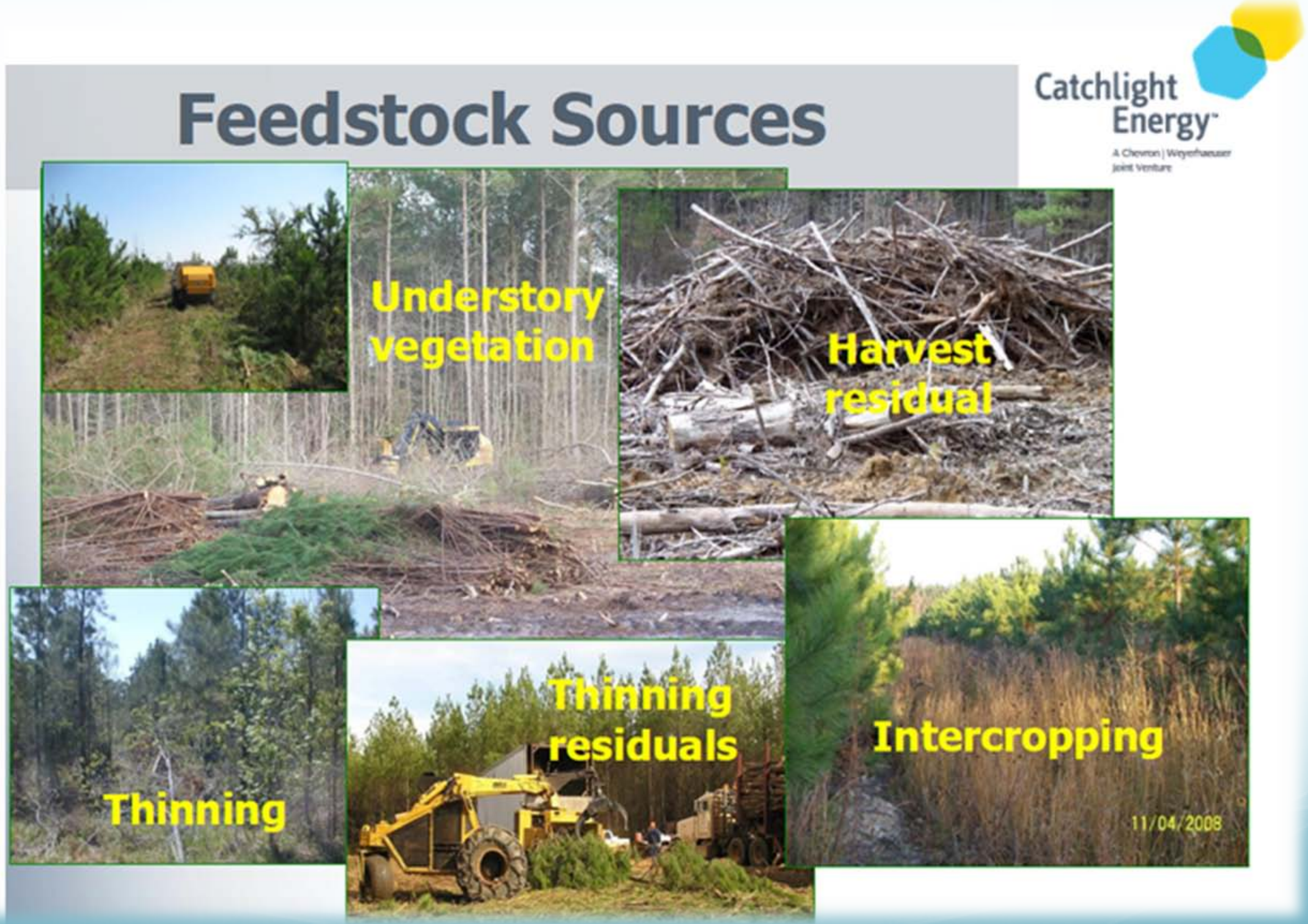
Hydrocarbon Fuel Delivery and Deployment System

- The U.S. has an extensive infrastructure to move crude oil to refineries and gasoline, diesel and jet fuel to end users
- Hydrocarbon-based biofuels can fit into the deployment and end use infrastructure (insertion point 3)



Picture courtesy of http://commons.wikimedia.org/wiki/File:Petroleum_Pipeline_Systems.gif

NABC utilizes full lignocellulosic feedstock base



Partners are addressing new ways to manage land

Intercropping of Dedicated Energy Crops

Catchlight Energy

- Grow strips of pine trees and an energy crop
- Energy crop harvested annually
- Trees managed for wood products and fiber

Catchlight Energy will provide intercropping information as part of our analysis

Harvest residues

- Under proper land management scenarios some amount of harvest residues could be available
- Feedstock logistics is one of the central research areas for DOE. NABC leverages that work.
- Corn stover may also provide a model for purpose-grown crops

Picture from http://green.autoblog.com/2008/07/15/purdue-study-says-corn-stover-better-cellulosic-ethanol-candidat/

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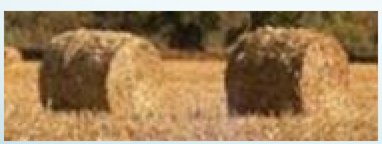
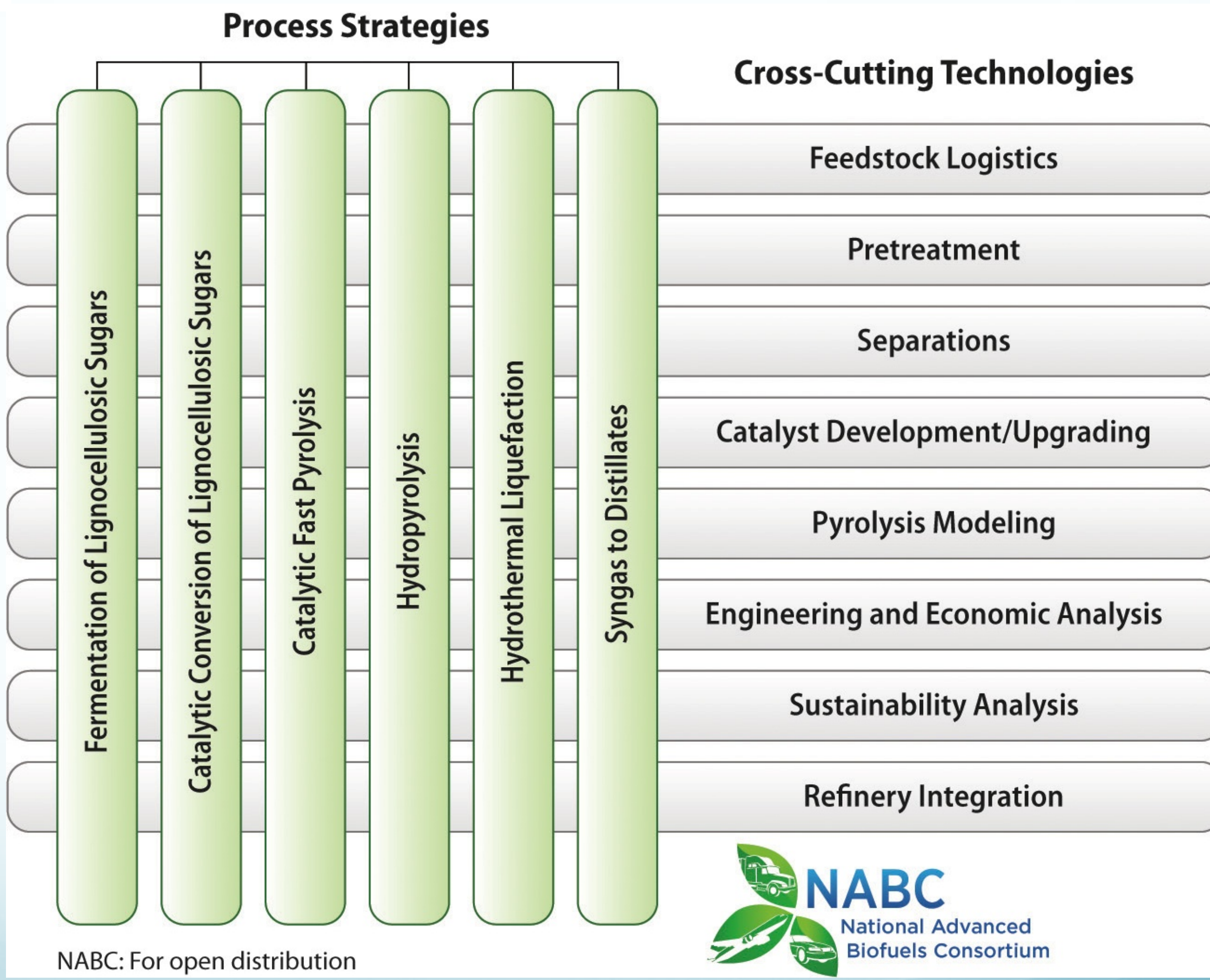
IOWA STATE UNIVERSITY

Strategies and Technologies

- Converting biomass into infrastructure-compatible materials





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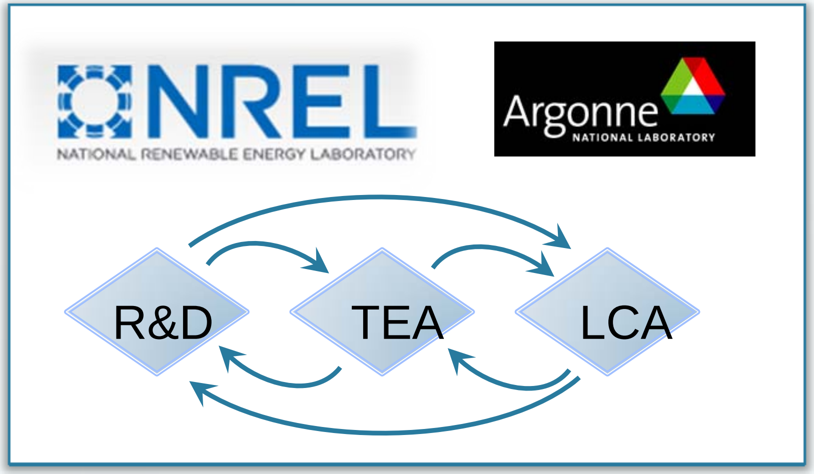
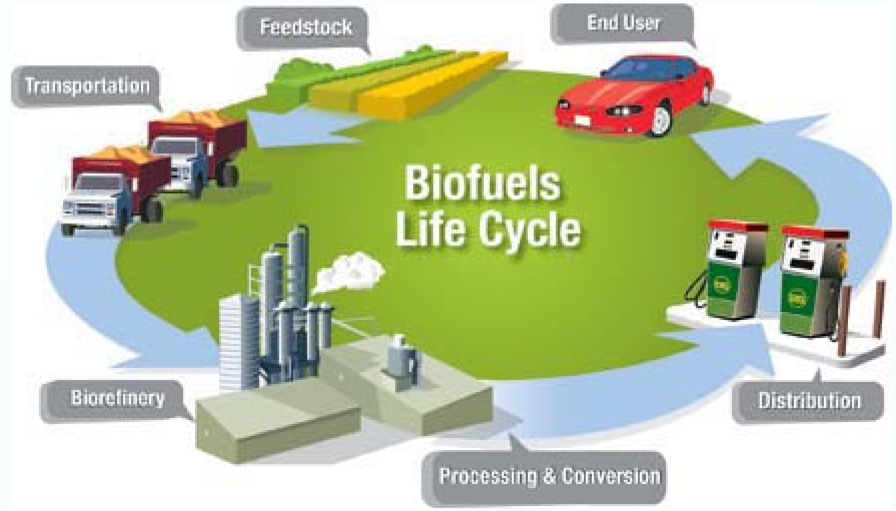
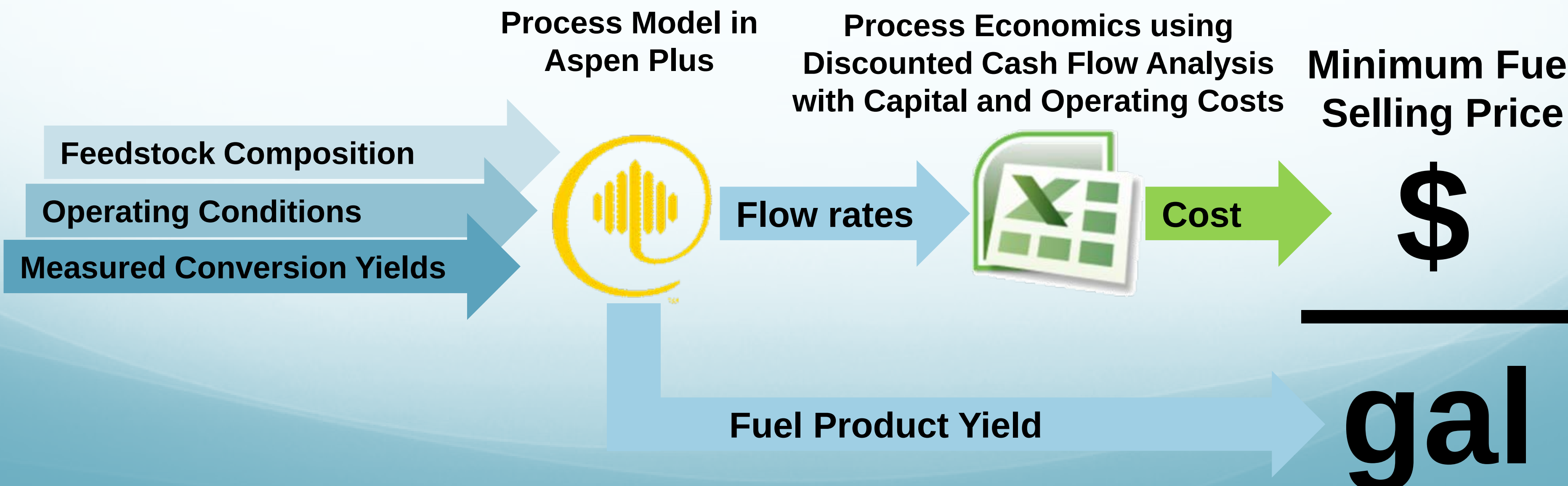
Analysis Team







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Fundamentals

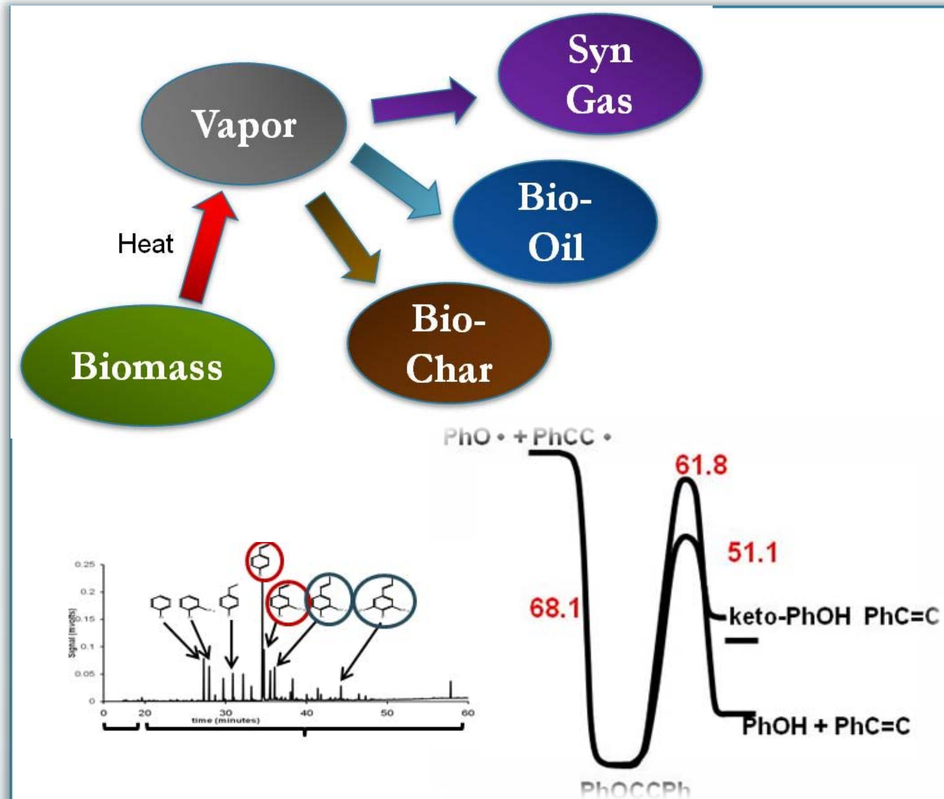
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Los Alamos NATIONAL LABORATORY EST. 1943

IOWA STATE UNIVERSITY

COLORADO SCHOOL OF MINES EARTH ENERGY ENVIRONMENT

NORTHWESTERN UNIVERSITY



<u>Objective</u>

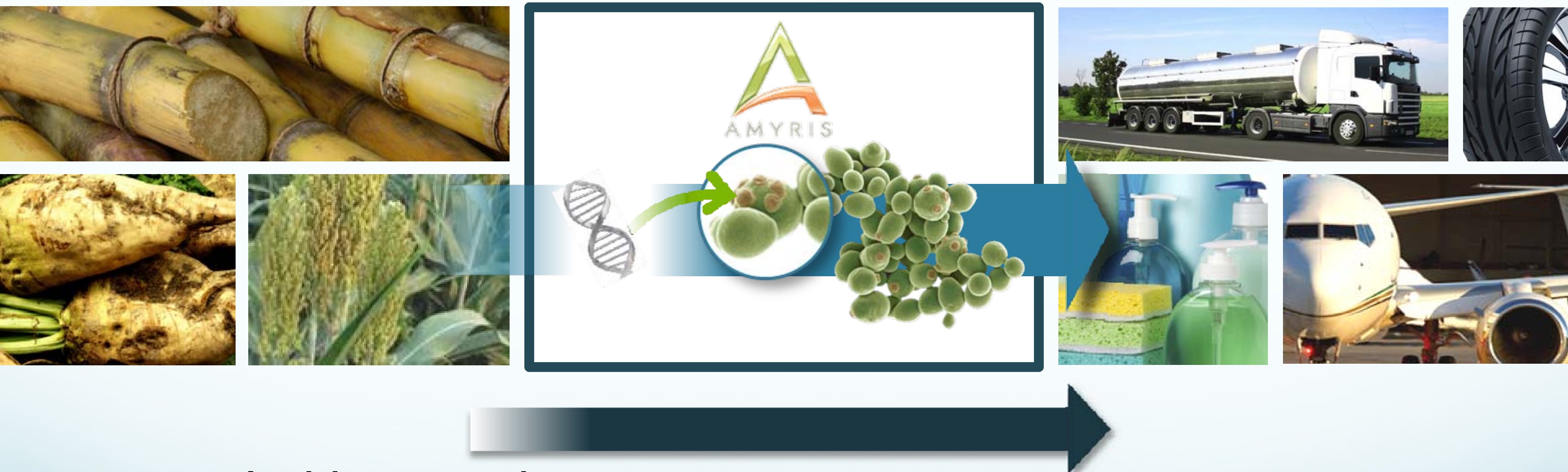
Combine fundamental and applied studies to develop improved predictive kinetic/mechanistic models for thermal pyrolysis

Fermentation of Lignocellulosic Sugars

ANY FEEDSTOCK

INDUSTRIAL SYNTHETIC BIOLOGY PLATFORM

RENEWABLE CHEMICALS AND FUELS



- Team led by Amyris

AMYRIS

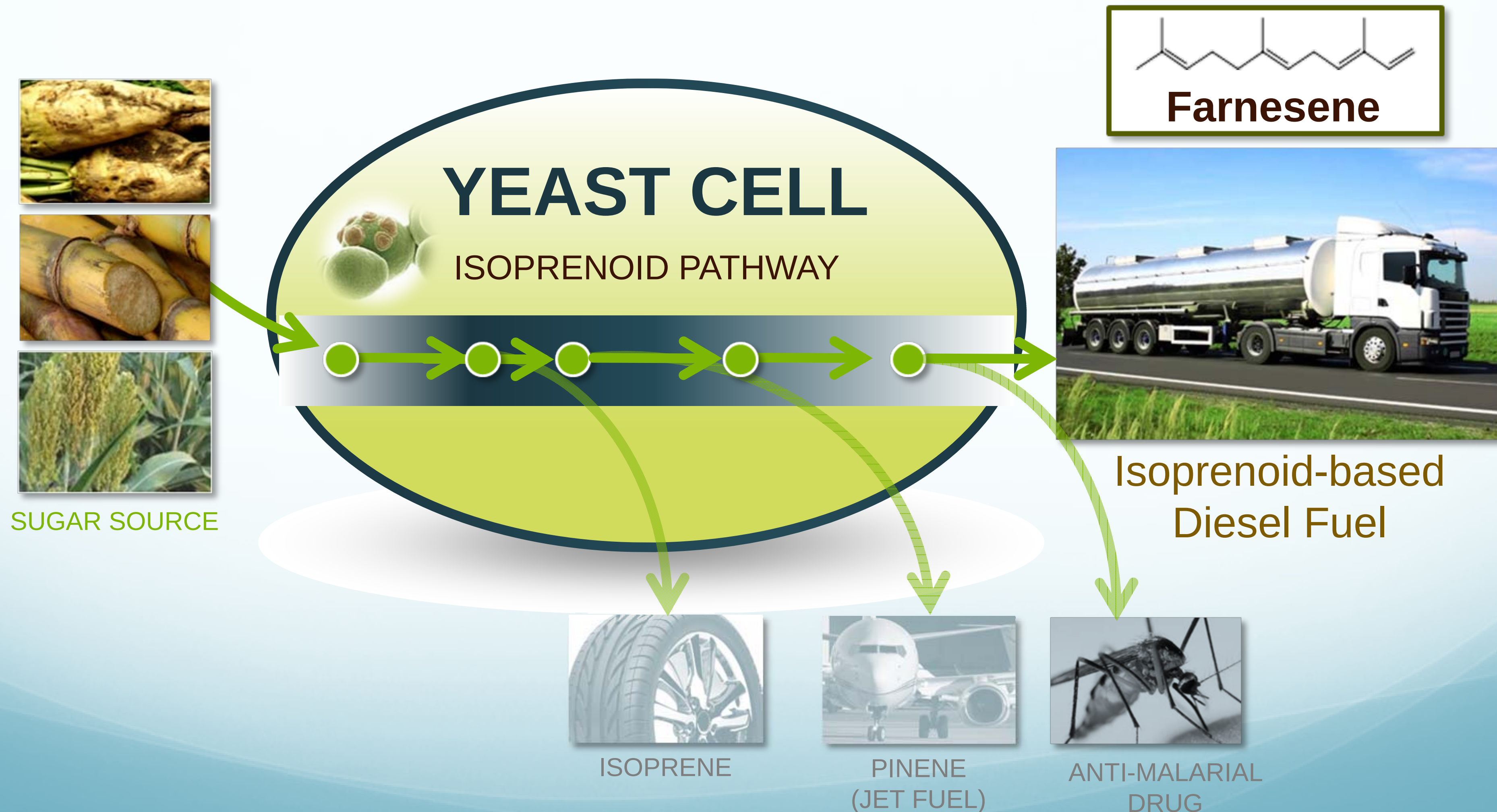
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

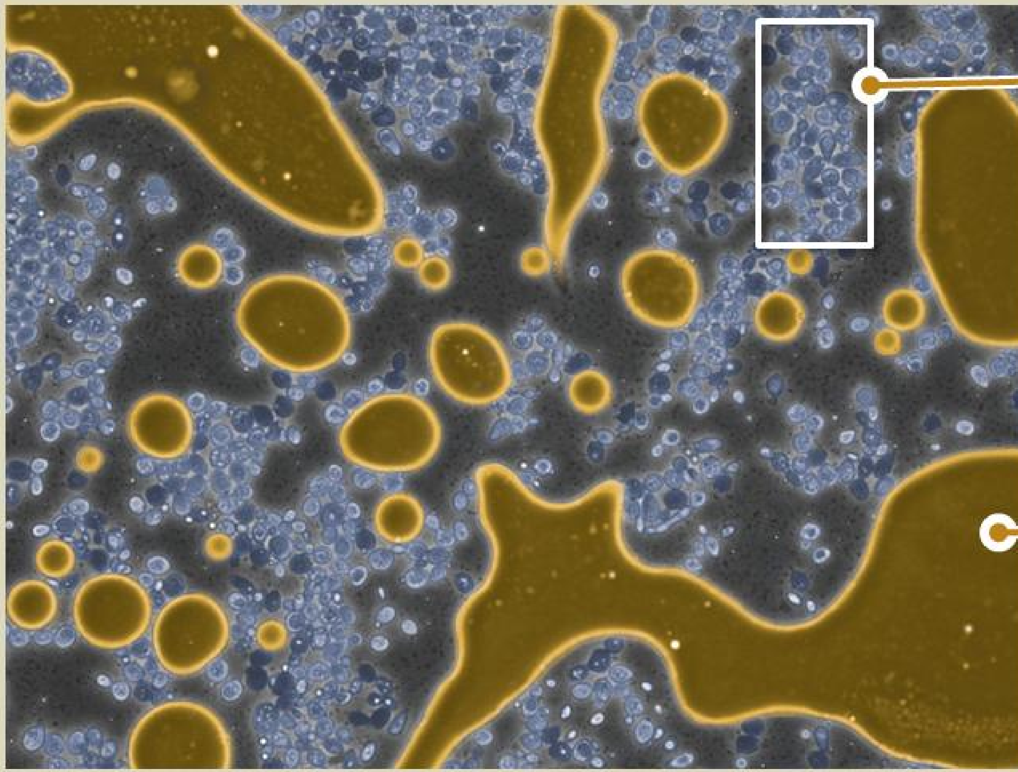
PALL Pall Corporation

TESORO

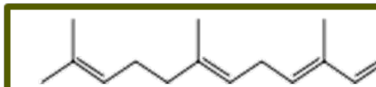
Modified yeast to produce diesel fuel



Yeast excretes farnesene, a diesel fuel precursor



Phase-Contrast Micrograph of Amyris Engineered Microbes Producing Farnesene



Farnesene

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State of Technology

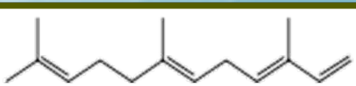
- Pilot process based on cane juice
- Scaled to 60,000 L fermentor (simple sugars)
- Fuel registered by EPA for a 35% Blend

U.S. Pilot Plant

Emeryville, CA Site

Brazil Demo Facility

São Martinho Site

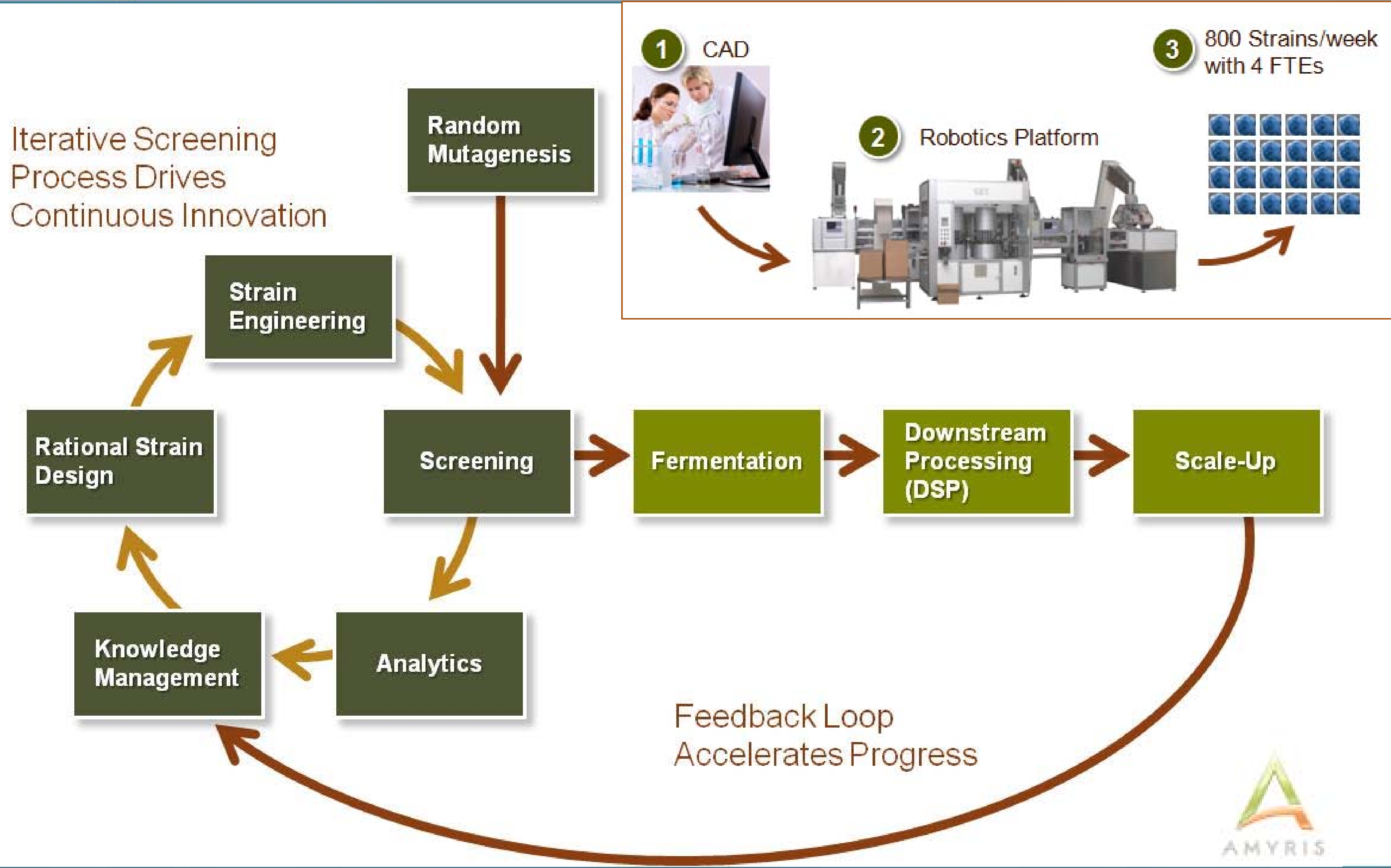


Farnesene

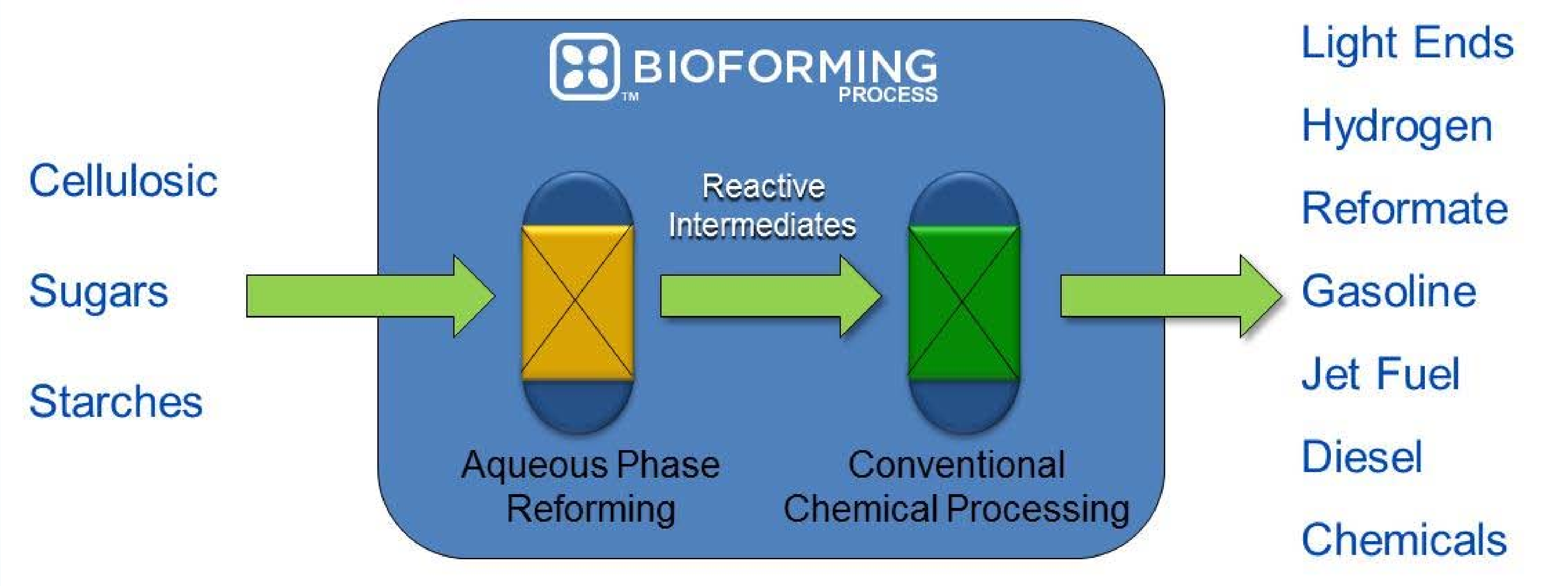
Challenge for NABC

- Develop technology that can use complex sugars from lignocellulosics (woody biomass or corn stover)
- Effective, low cost process to provide sugar stream from biomass—called hydrolysate
- Robust organism that does not suffer from inhibitors present in biomass hydrolysate
- Organism must be able to use both five carbon sugars and six carbon sugars found in hydrolysates
- New integrated process must be cost competitive with current simple sugar-based process

Scientific Process



Catalysis of Lignocellulosic Sugars

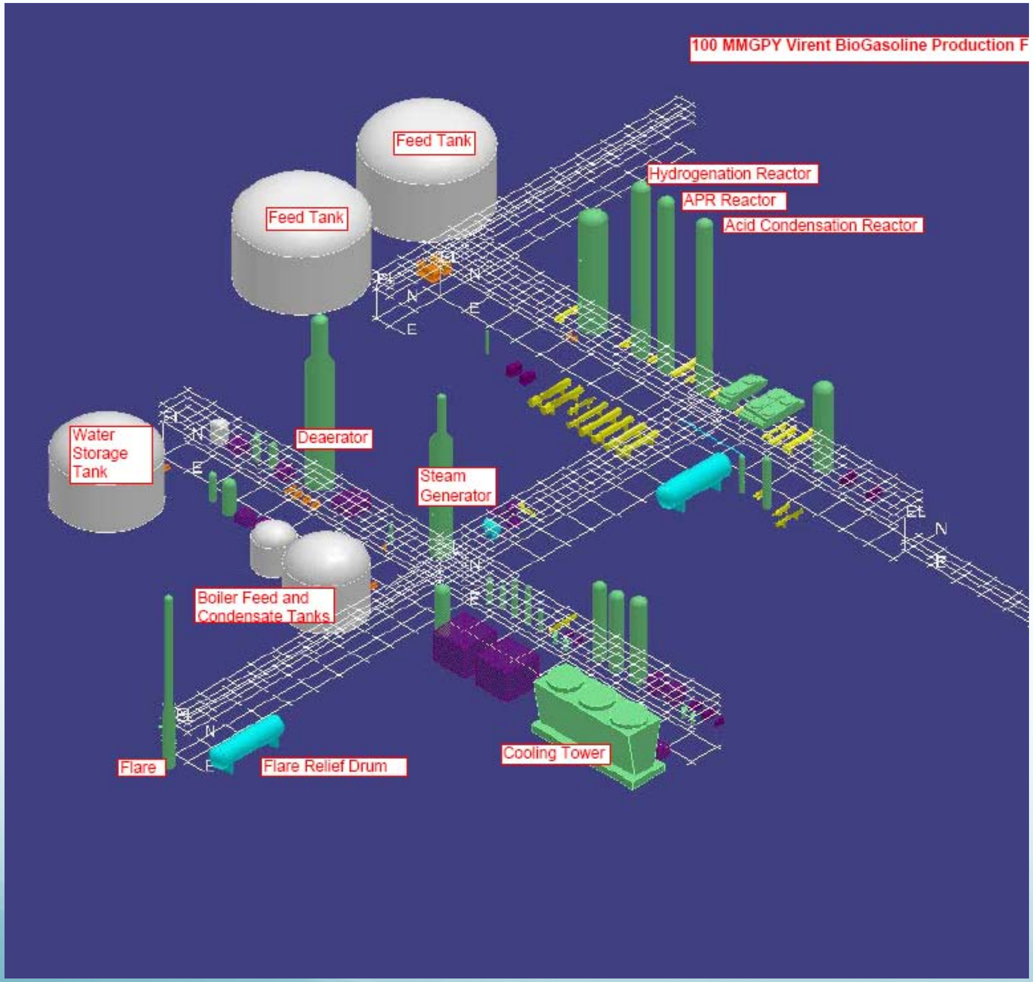


- Team led by Virent

VIRENT, NREL National Renewable Energy Laboratory, Washington State University World Class. Face to Face., PALL Pall Corporation, Pacific Northwest National Laboratory, bp, TESORO

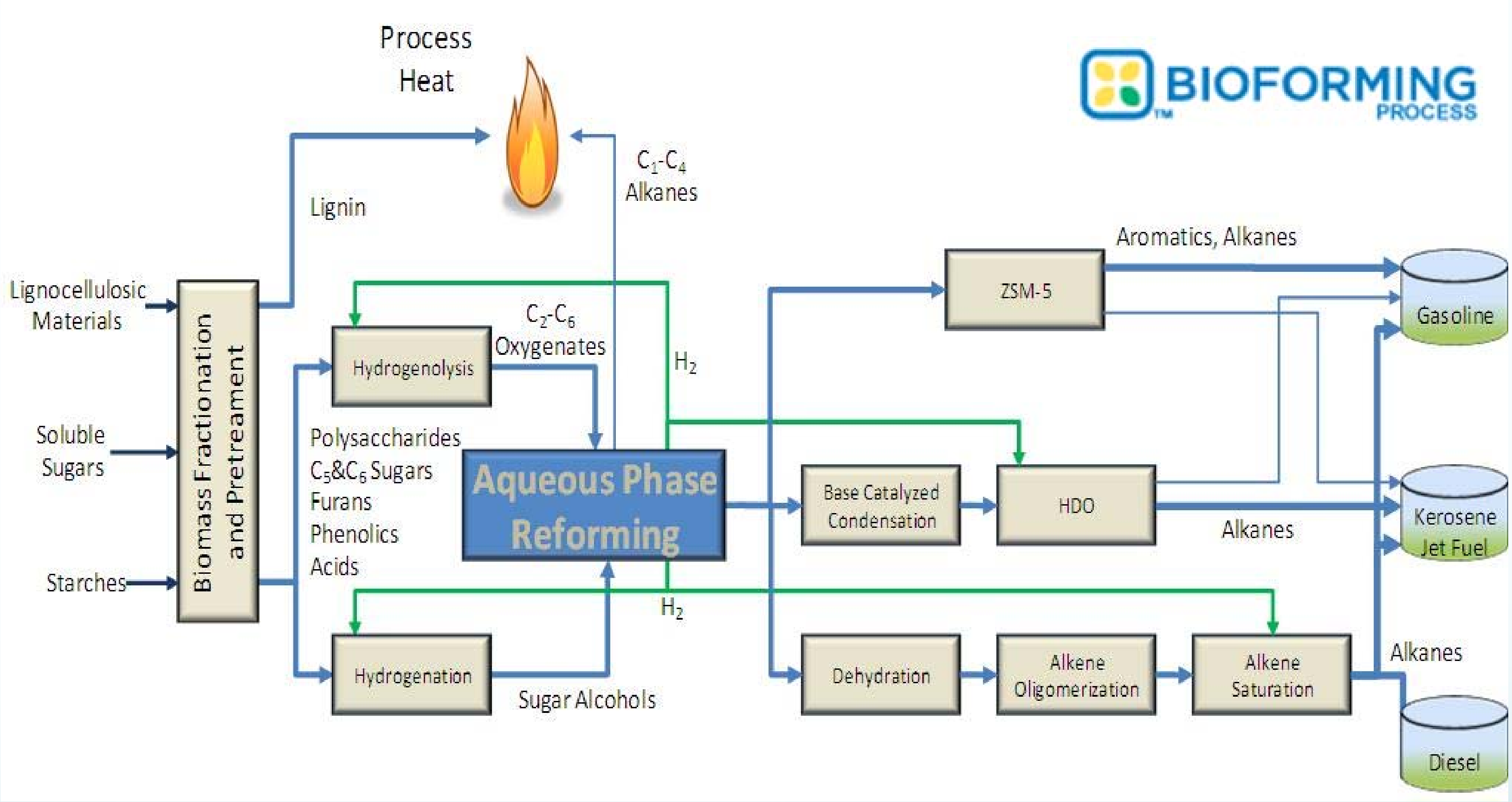
Virent's BioForming® Technology

A Catalytic Route to Renewable Hydrocarbon Fuels and Chemicals



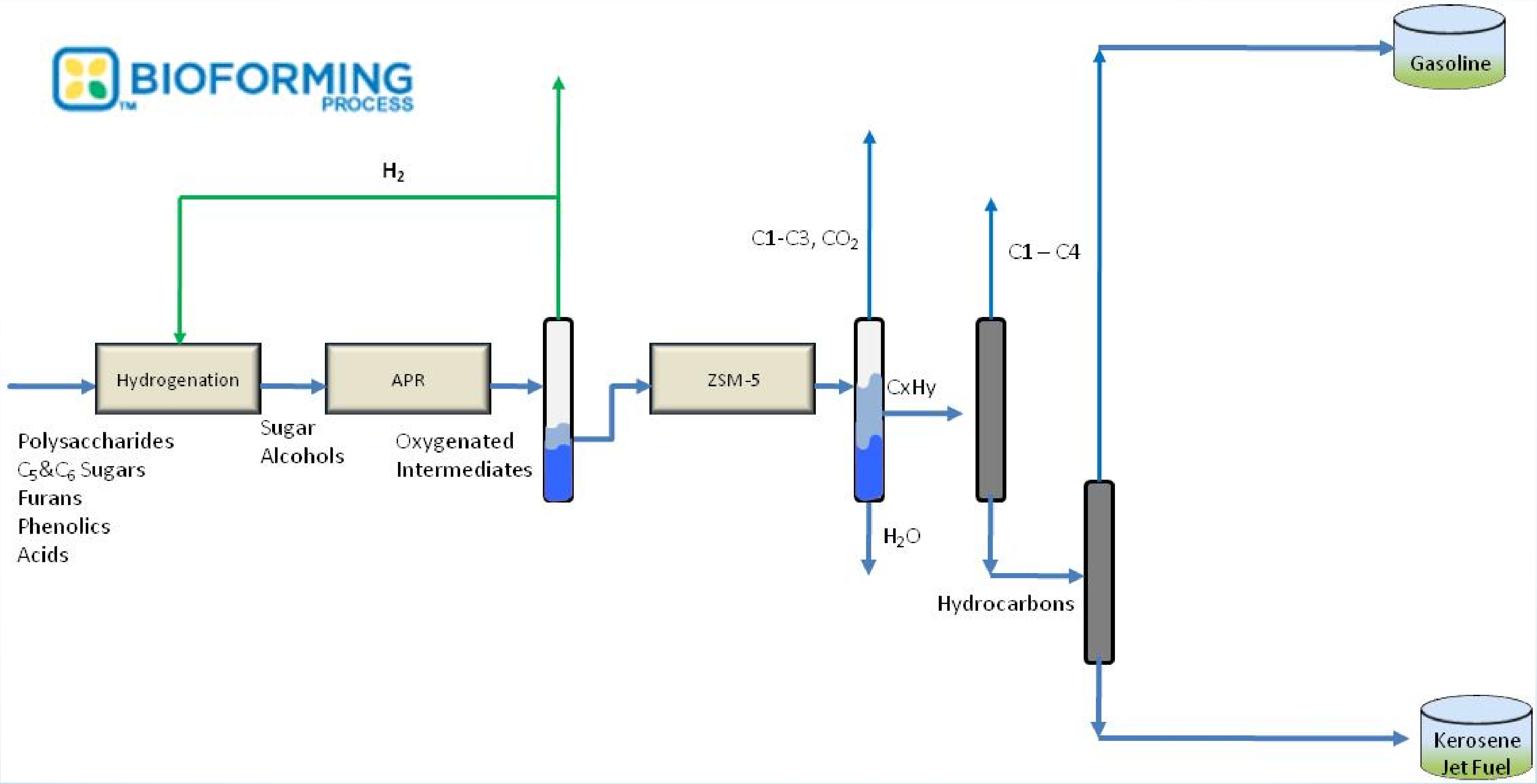
- Fast and Robust
  - Inorganic Catalysts
  - Industry Proven Scalability
- Energy Efficient
  - Low Energy Separation
  - Low Carbon Footprint
- Premium Drop-in Products
  - Tunable Platform
  - Infrastructure Compatible
- Feedstock Flexible
  - Conventional Sugars
  - Non-Food Sugars

Catalysis of Lignocellulosic Sugars



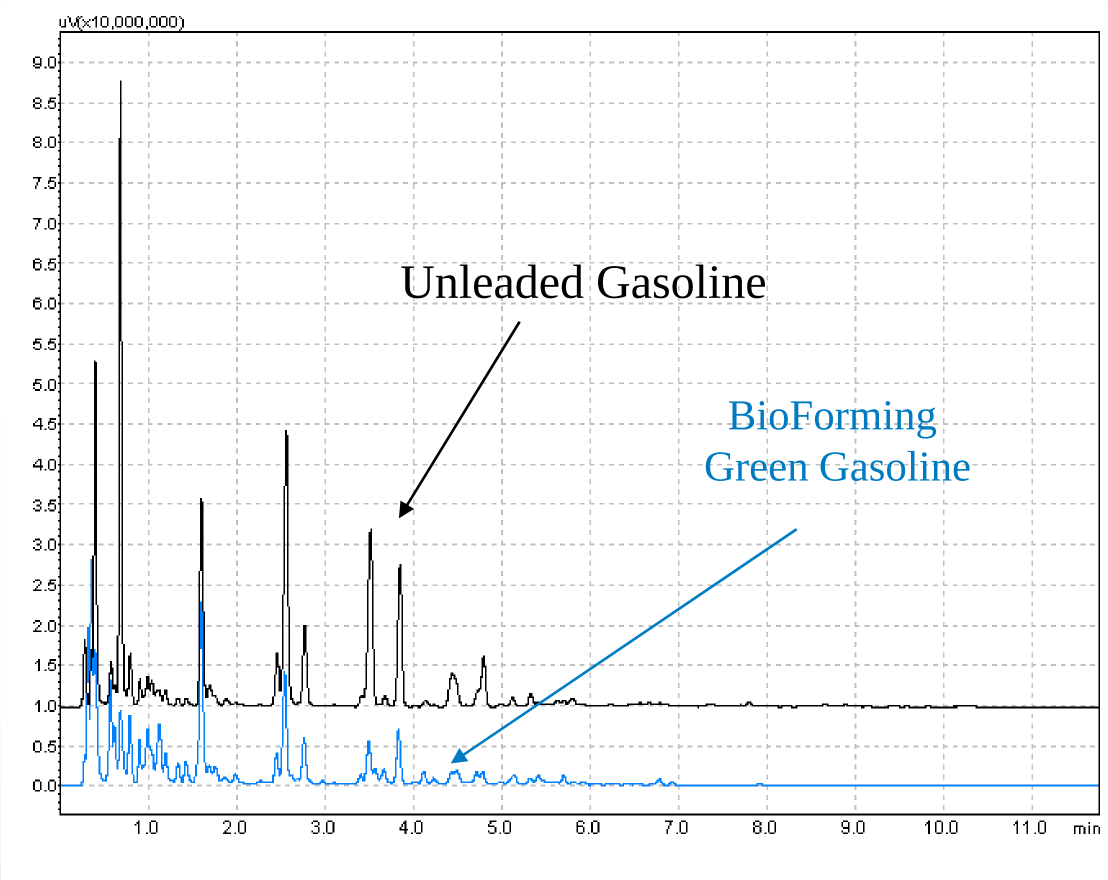
- Many options for producing gasoline, diesel and jet fuels

Catalysis of Lignocellulosic Sugars



- APR is done under moderate temperatures and pressures (ca. 175 – 300 C and 150 - 1300 psi) to give oxygen containing compounds (alcohols)
- Conventional processing (dehydration/condensation) is done in a second step

Biogasoline Product



Unleaded Gasoline
115,000 BTUs/Gal

BioForming BioGasoline
+120,000 BTUs/Gal

Ethanol
76,000 BTUs/Gal

~ 20 liters of sugar derived gasoline from Virent's BioForming process.

- Gasoline produced by the Virent Process is a high quality, premium hydrocarbon fuel

Biogasoline Product

Virent BioGasoline blended in Scuderia Ferrari race fuel

Fleet testing is also being done working with Shell

State of Technology

- Piloted process based on beet sugar
- Multiple week performance data at Eagle Pilot Plant (beet sugar) 10,000 gal/y scale (37,000 L/y)
- Full length reactor and commercial scale catalyst
- Product volumes for registration and fleet testing

Eagle Pilot Plant
Madison, WI

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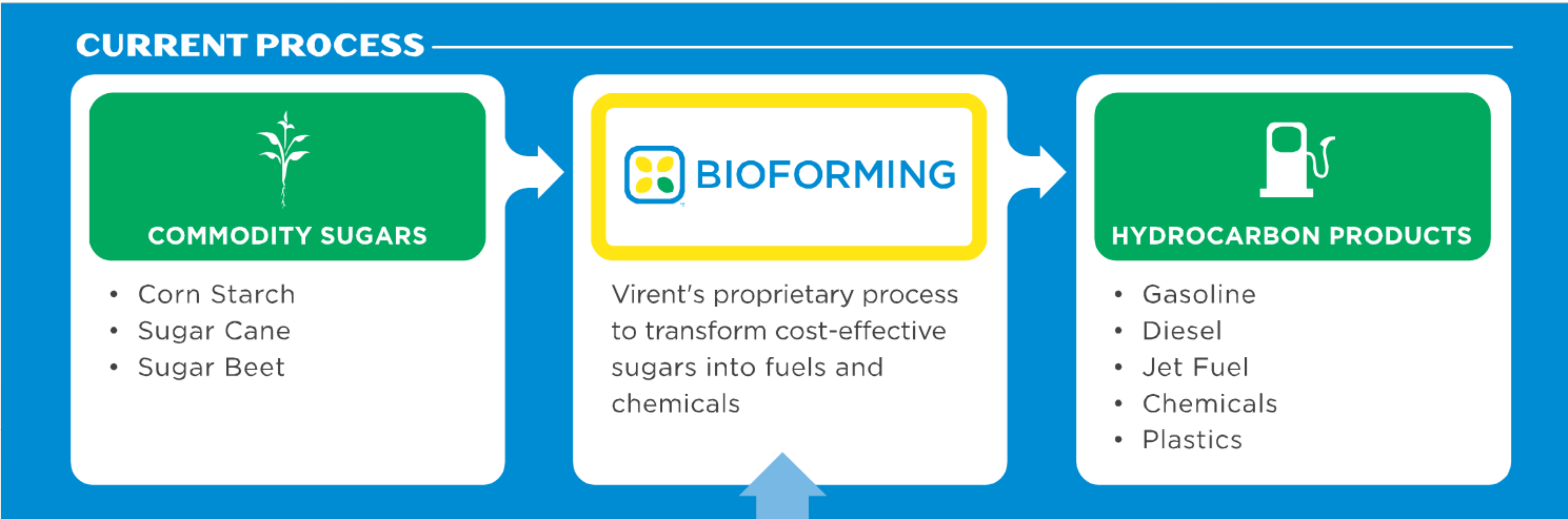
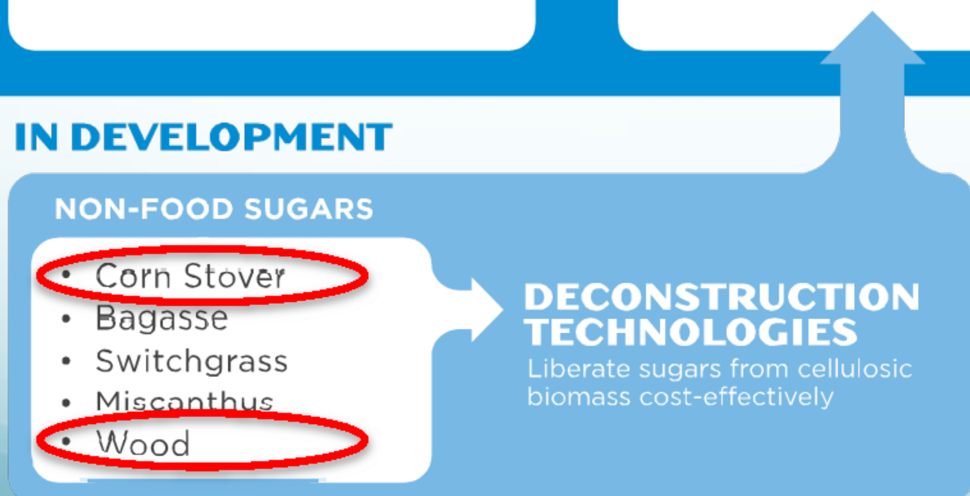
Catalysis of Lignocellulosic Sugars





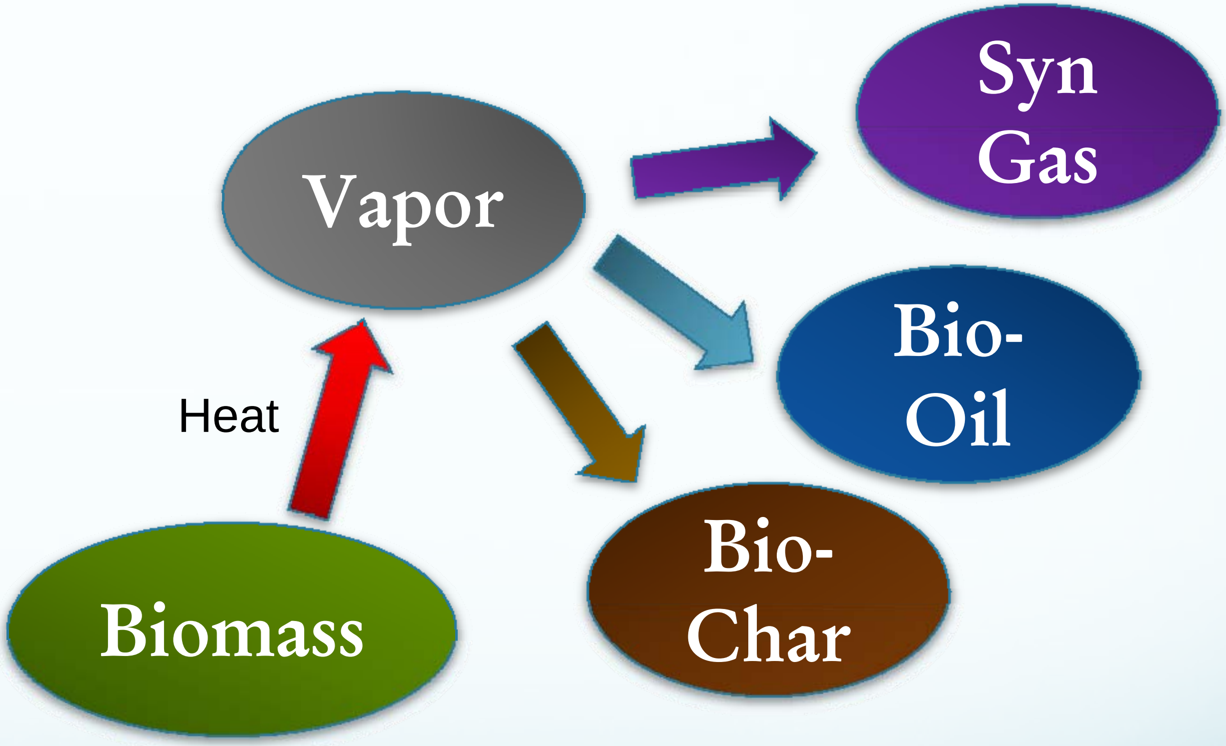
- BioForming technology validated with commercial sugars
- NABC focus on lignocellulosic feedstocks, including wood and corn stover

Challenge for NABC

- Develop technology that can use complex sugars from lignocellulosics (woody biomass or corn stover)
- Effective, low cost process to provide an input stream for the APR process
  - The stream can contain soluble sugar oligomers and even sugar-derived products that are inhibitors to fermentations
  - Sulfur and nitrogen from biomass can poison the catalyst
- Robust catalyst that does not suffer from inhibitors present in biomass hydrolysate
- New integrated process must be cost competitive with current simple sugar-based process

Heating biomass can give a bio-oil or synthesis gas

- The first two technologies use biomass hydrolysates (sugars portion from biomass)
- Other four technologies use whole biomass with various heat treatments

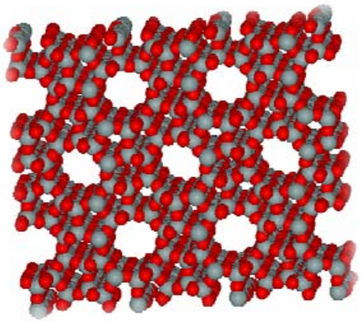


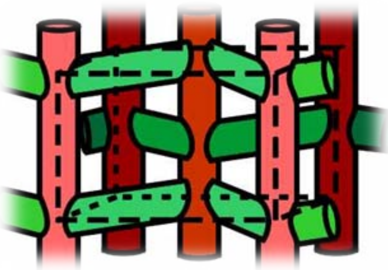
Thermal Processes

- Fast pyrolysis
- Background

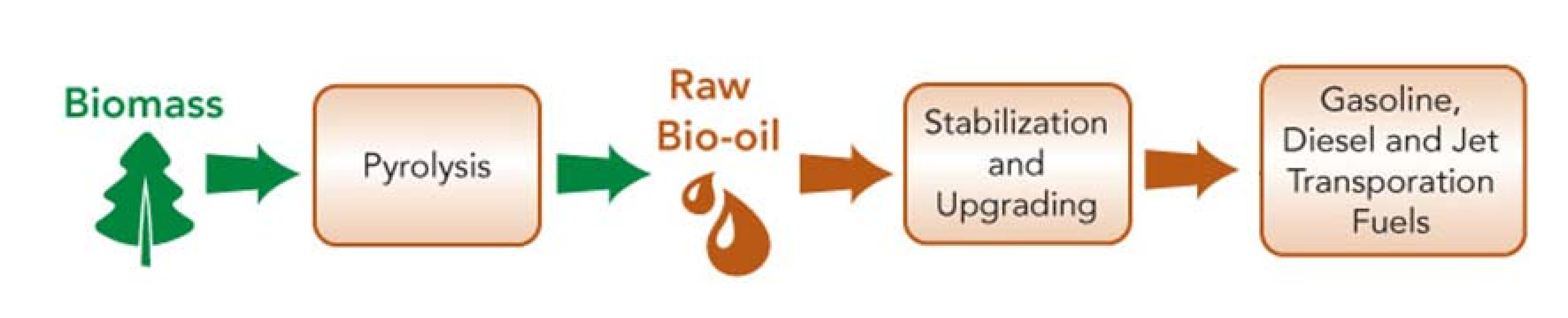
- Catalytic Fast Pyrolysis
- Hydropyrolysis
- Hydrothermal liquefaction
- Part of NABC

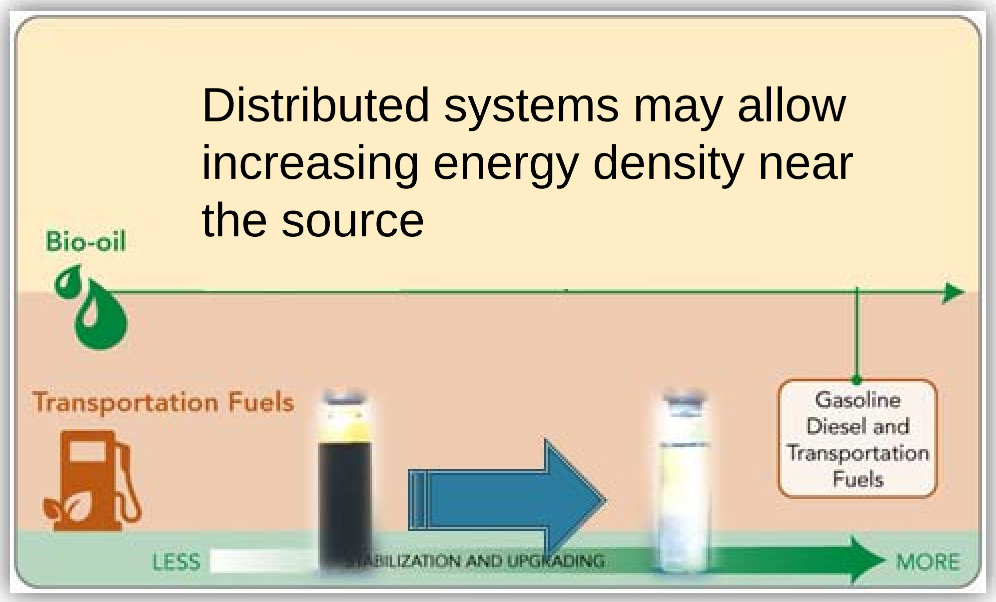
Catalysis is central to our research

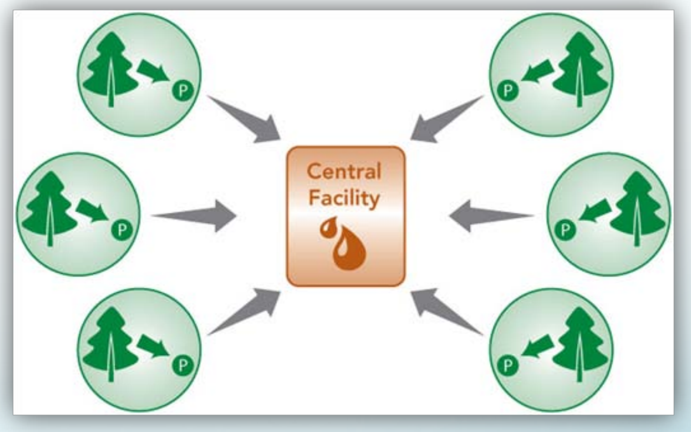




Pyrolysis allows a way to make bio-crude in a distributed manner







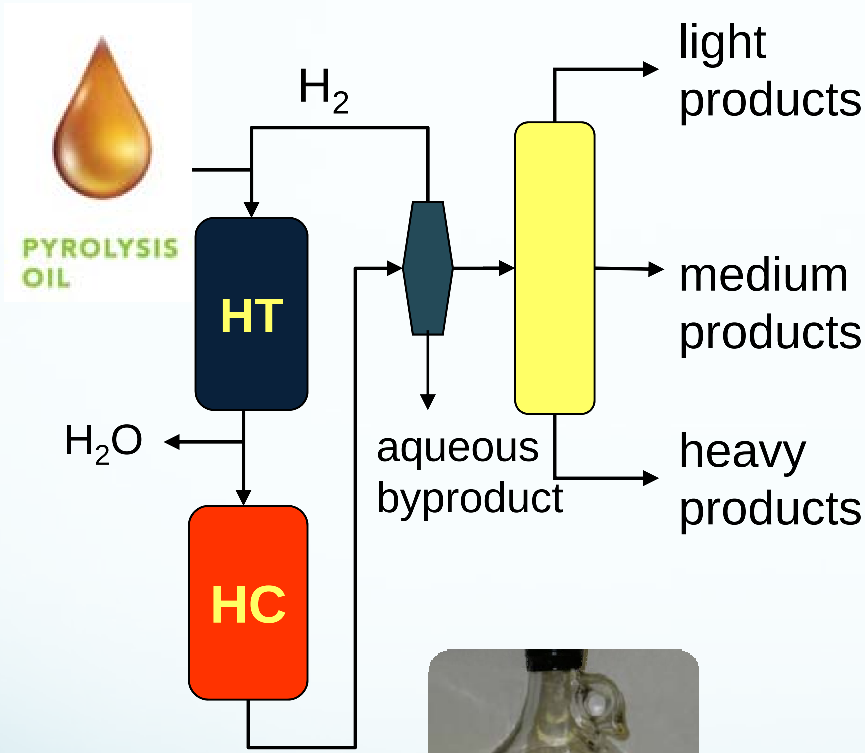
Fast Pyrolysis Oil

http://www.envergenttech.com/index.php

- Process:
  - 500 ºC atm, dry, finely divided, < 1 sec
  - Inert atmosphere
  - Non-catalytic
- Product:
  - Medium Btu oil (8,000 Btu/lb)
  - High water content and acidity
  - Not miscible with hydrocarbons
  - Low thermal stability

Biomass Material	Yield (wt%)	Gross Caloric Value (MJ/kg)	Higher Heating Value (Btu/lb)
Hardwood	70-75	17.2 - 19.1	7,400 - 8,000
Softwood	70-80	17.0 - 18.6	7,300 - 8,000
Hardwood Bark	60-65	16.7 - 20.2	7,180 - 8,680
Softwood Bark	55-65	16.7 - 19.8	7,180 - 8,500
Corn Fiber	65-75	17.6 - 20.2	7,570 - 8,680
Bagasse	70-75	18.9 - 19.1	8,100 - 8,200
Waste Paper	60-80	17.0 - 17.2	7,300 - 7,400

Fast pyrolysis oil is converted to fuels in a 2-step process

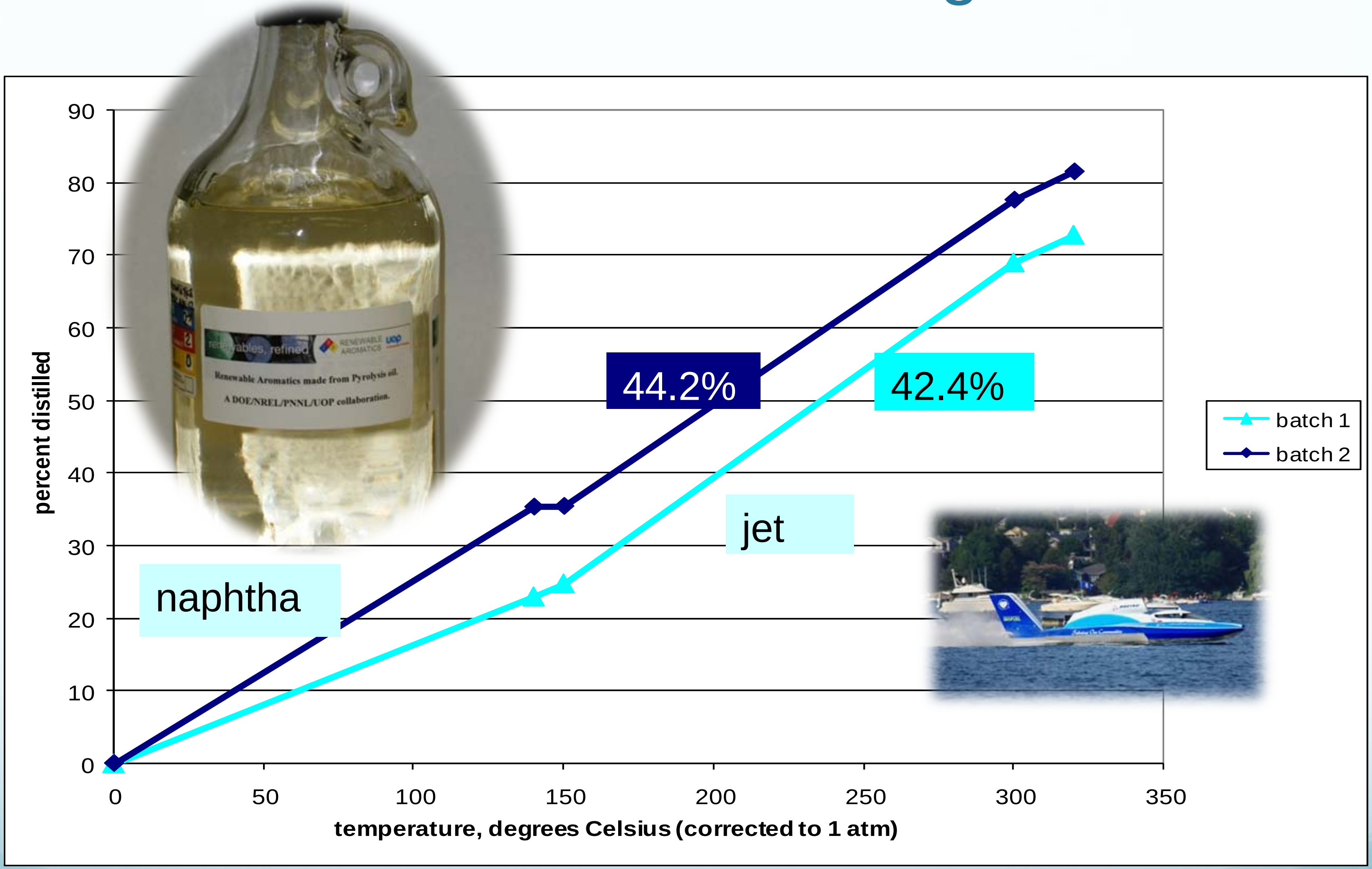


	Hydroprocessed Bio-oil (from Mixed Wood)		Petroleum Gasoline
	Min	Max	Typical
Paraffin, wt%	5.2	9.5	44.2
Iso-Paraffin, wt%	16.7	24.9	
Olefin, wt%	0.6	0.9	4.1
Naphthene, wt%	39.6	55.0	6.9
Aromatic, wt%	9.9	34.6	37.7
Oxygenate, wt%		0.8	

The carbon recovery based on bio-oil was about 50%

Holmgren, J. et al. NPRA national meeting, San Diego, March 2008.

Hydroprocessed Bio-oil makes jet fuel range fuels



Goal of NABC is to Improve the Fast Pyrolysis Process with Catalysts…

- Make a higher quality bio-oil:
  - That is thermally stable
  - With a reduced demand for hydrogen
  - Can be fully deoxygenated in one step to make fuels
  - Can be integrated into refinery

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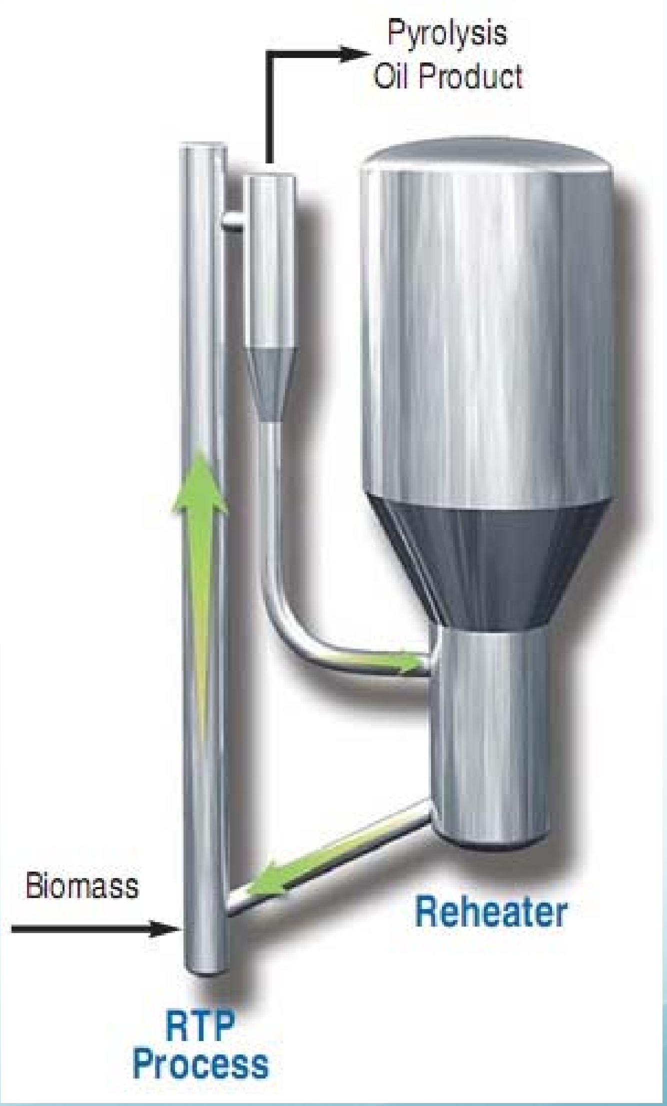
Catalytic Fast Pyrolysis

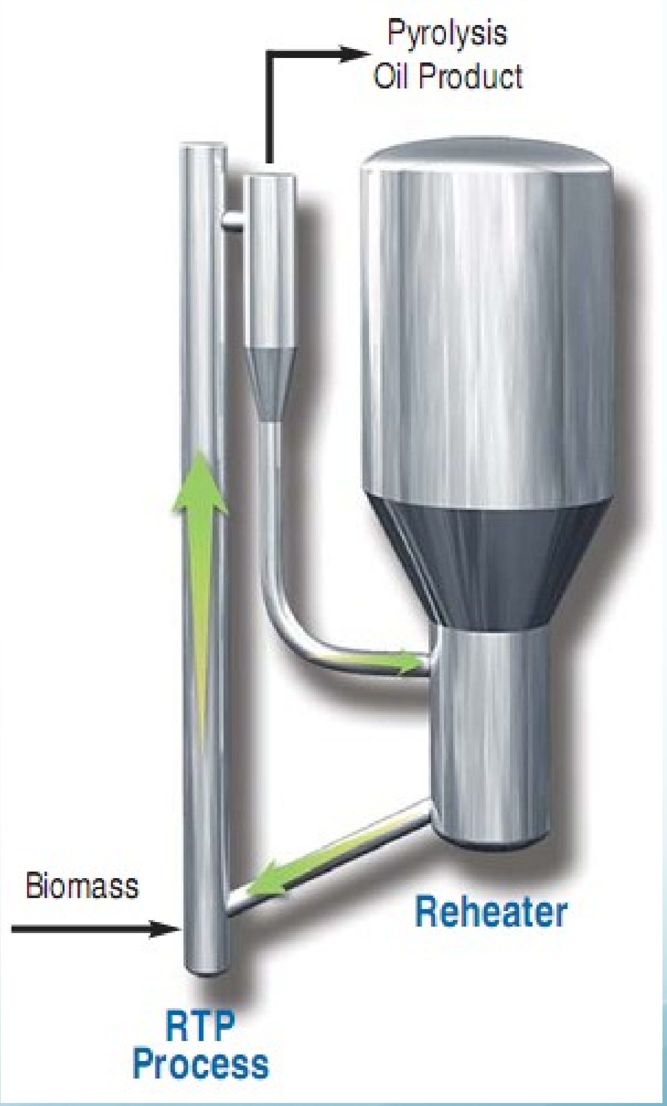
- UOP leads the team

UOP A Honeywell Company
Envergent Technologies A Honeywell Company
USDA
ALBEMARLE®
NREL National Renewable Energy Laboratory
TESORO
Pacific Northwest National Laboratory
bp
PALL Pall Corporation
Argonne National Laboratory

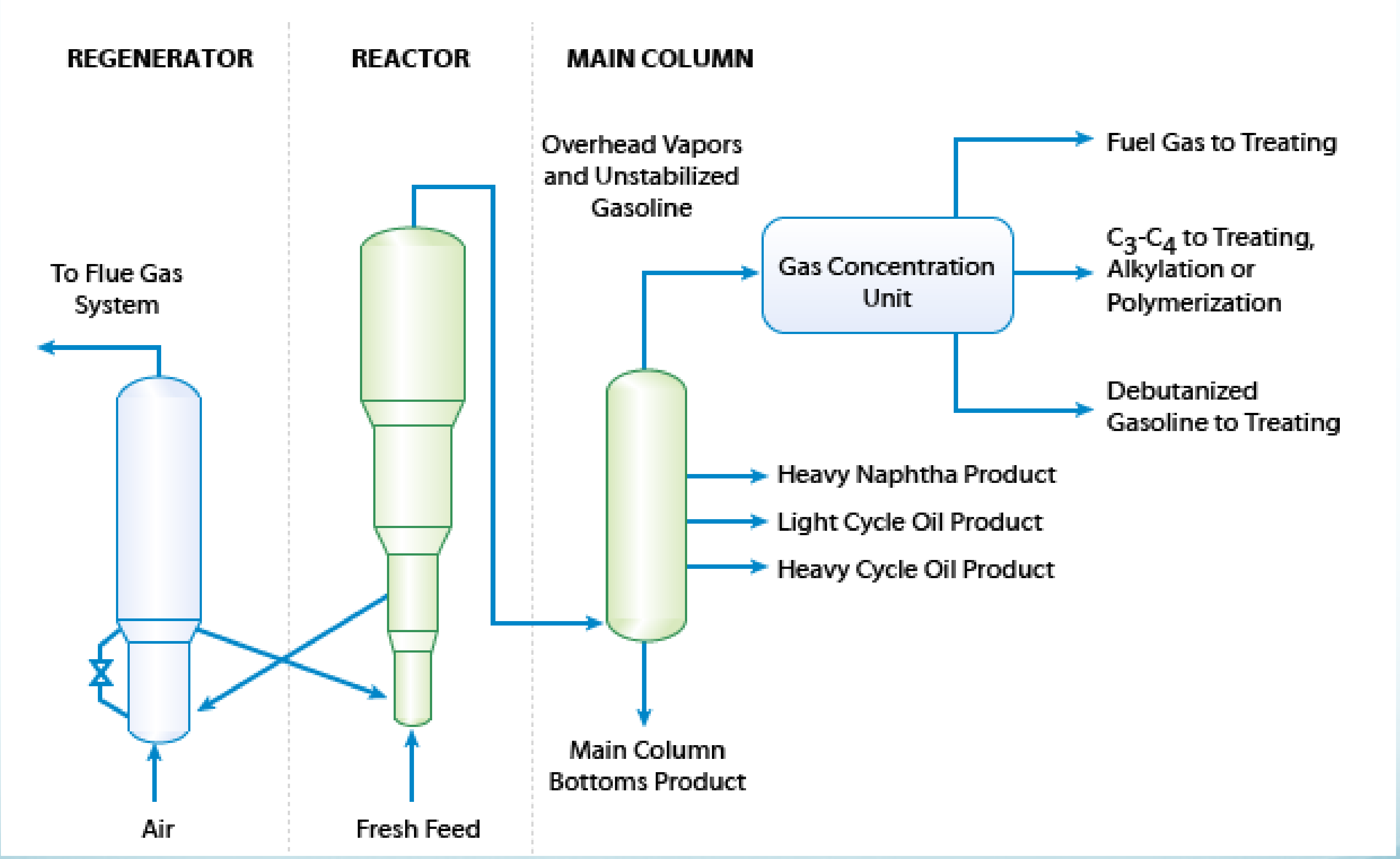


Catalytic Fast Pyrolysis

- Ensyn Rapid Thermal Processing (RTP) technology uses an inert fluidized media such as sand
- The sand is the medium to add heat to the biomass
- In NABC research the sand is replaced with catalyst (such as zeolite)
- Catalyst converts oxygen containing compounds to hydrocarbons
- Can give aromatic rich fuel precursors and reduce oxygen in the oil (including the carboxylic acids that lead to low pH)



Fluid Catalytic Cracking Petroleum Technology



UOP is the world leading expert in FCC Petroleum Technology

Challenge for Catalytic Fast Pyrolysis Team

- Identify multi-functional catalysts for deoxygenation and upgrading to reduce pyrolysis oil acidity and minimize hydrogen demand during the final pyrolysis oil upgrading
- Use techno-economic analysis to choose between degree of carbon loss to CO_2 and hydrogen demand for direct hydrodeoxygenation in the upgrading step
- Select catalyst candidates based on performance and develop sufficiently attrition-resistant formulations for the FCC operation, keeping in mind that reactor design and process development are codependent
- Examine up to 10 cycles of process/regeneration to confirm no catastrophic catalyst deactivation in performance nor catalyst property change
- Upgrade selected pyrolysis oil products to determine final product quality and to obtain data for techno-economic analysis and process modeling.

Hydropyrolysis

- RTI—Team Lead

RTI INTERNATIONAL

ALBEMARLE®

NREL NATIONAL RENEWABLE ENERGY LABORATORY

TESORO

Pacific Northwest NATIONAL LABORATORY

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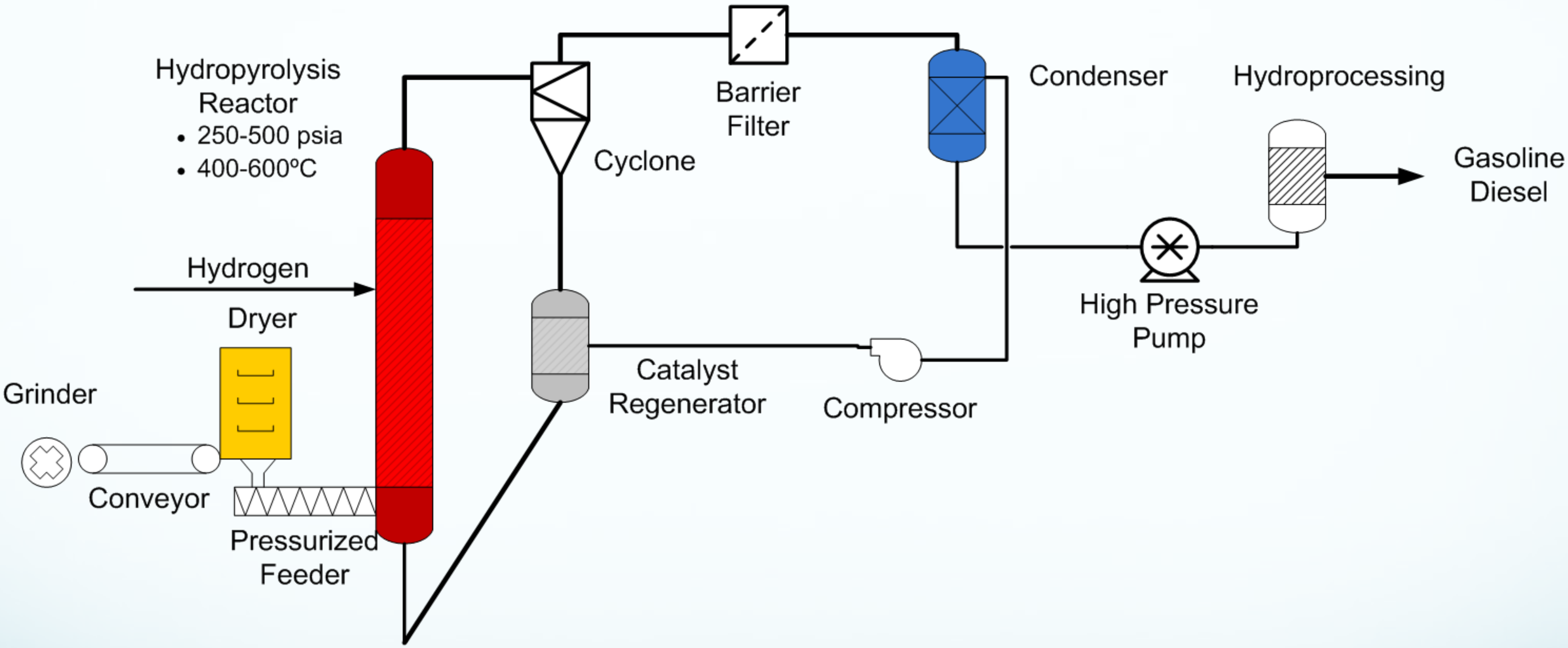
PALL Pall Corporation

RTI's Transport Reactor System

Hydropyrolysis - Technology

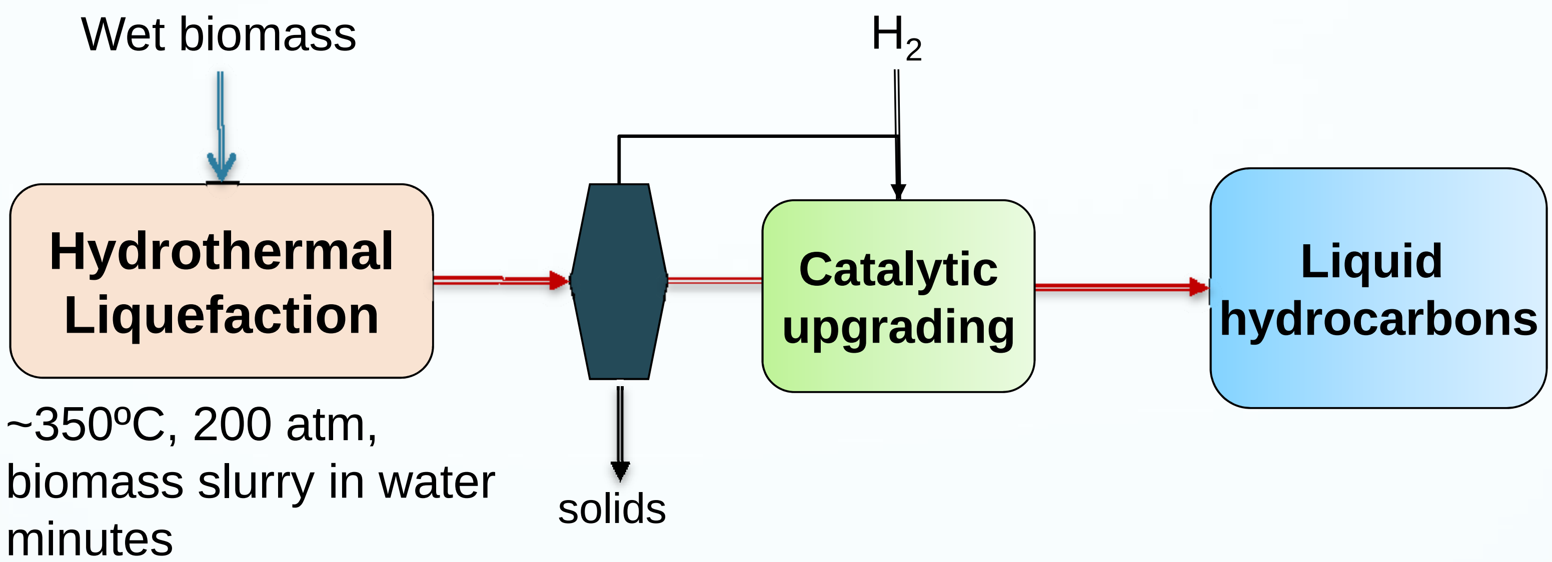


- The addition of a reactive gas may lead to significantly better quality oil
- Builds on expertise at partners, including coal-based technologies at RTI and PNNL and catalyst expertise at Albemarle

Challenge for Hydropyrolysis Team

- Use a reactive gas to cap the reactive intermediates formed in pyrolysis vapor to produce a quality bio-oil for refinery integration
- Adapt catalyst formulations in attrition-resistant materials for circulating fluid bed applications analogous to fluid catalytic cracking technology
- Evaluate long-term catalyst performance and robustness during continuous regeneration cycles and the effect of impurities—such as sulfur, chlorine, and potassium—as catalyst poisons
- Use process modeling to explore commercial concepts, evaluating the potential for integrating this technology into existing refineries or developing stand-alone processing and upgrading facilities

Hydrothermal Liquefaction



- PNNL—Team Lead

Comparison of Oils

- Based on early work in Europe
- Leverages PNNL algal work
- Produces a thermally stable oil

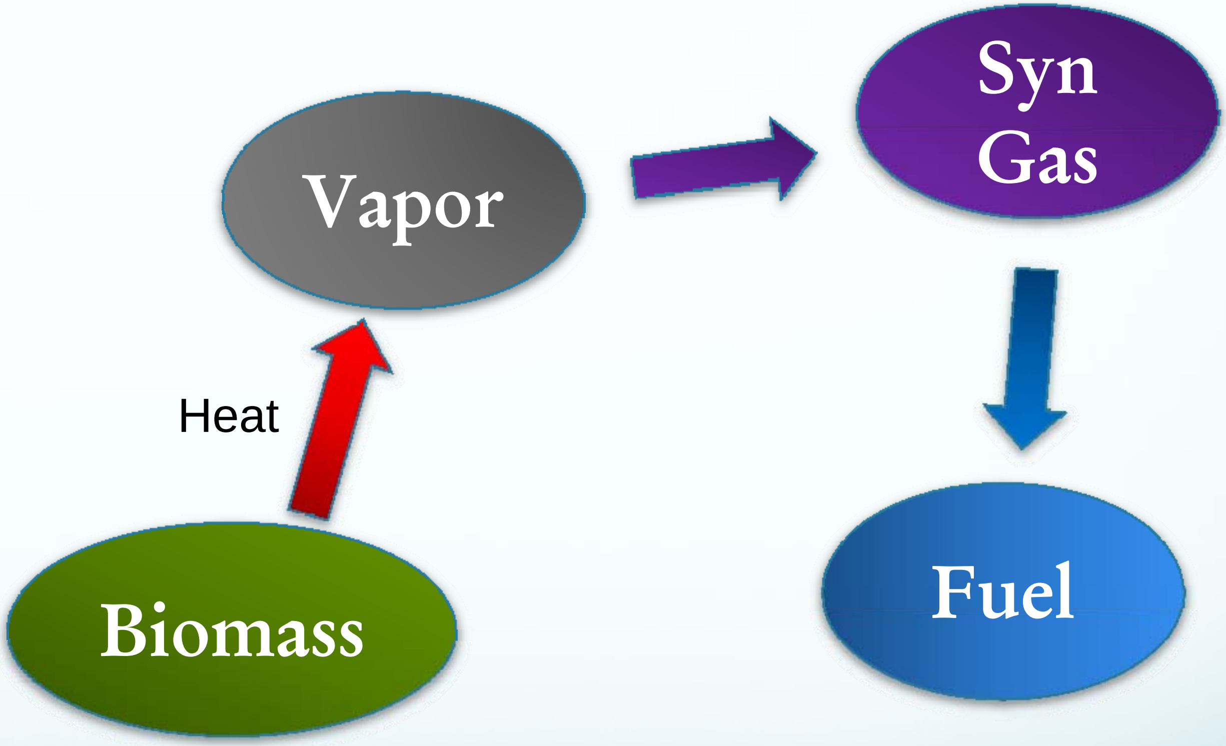
Characteristic	Fast Pyrolysis Bio-oil	Hydrothermal Bio-oil
Water content, wt%	15-25	3-5
Insoluble solids, %	0.5-0.8	1
Carbon, %	39.5	72.6-74.8
Hydrogen, %	7.5	8.0
Oxygen, %	52.6	16.3-16.6
Nitrogen, %	<0.1	<0.1
Sulfur, %	<0.05	<0.05
Ash	0.2-0.3	0.3-0.5
HHV, MJ/kg	17	30
Density, g/ml	1.23	1.10
Viscosity, cp	10-150@50ºC	3,000-17,000 @ 60ºC

Challenge for Hydrothermal Liquefaction Team

- Capture higher quantity of carbon in oil (avoid loss in water)
  - Higher slurry feed concentrations
  - Low cost pretreatment
  - Improved recycle systems
- Reduce processing conditions (pressure) at pressure
  - Alternative feedstock slurry media
  - Reactor parameters
- Improve oil quality
  - Reduction chemistry
- Understand relative value vs. other technologies

NABC is looking at one technology based on syn gas

- We just reviewed NABC efforts in bio-oils
- Gasification is a process where biomass is broken into its simplest molecules of carbon monoxide and hydrogen (syn gas)



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Syngas to Distillates

- PNNL—Team Lead

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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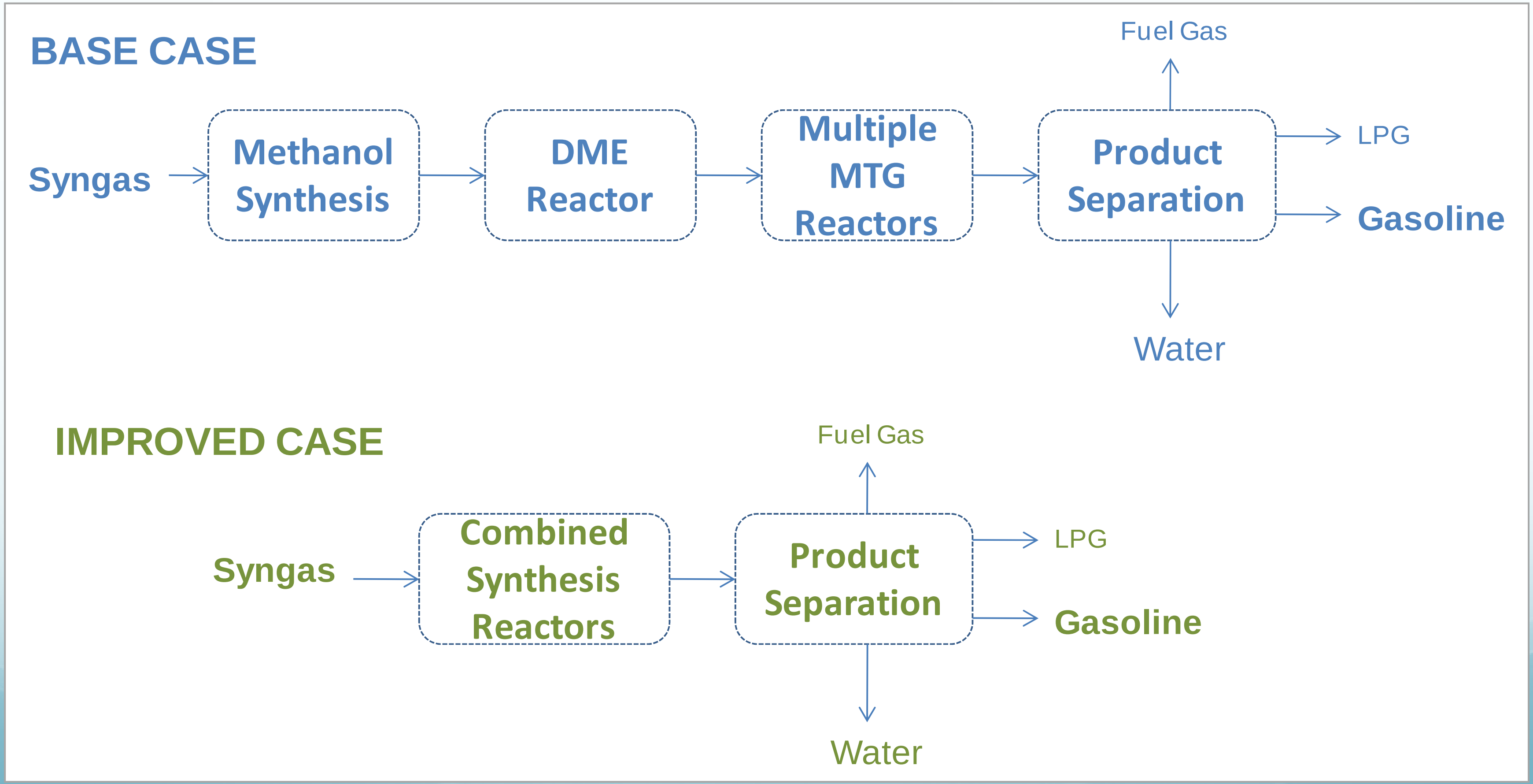
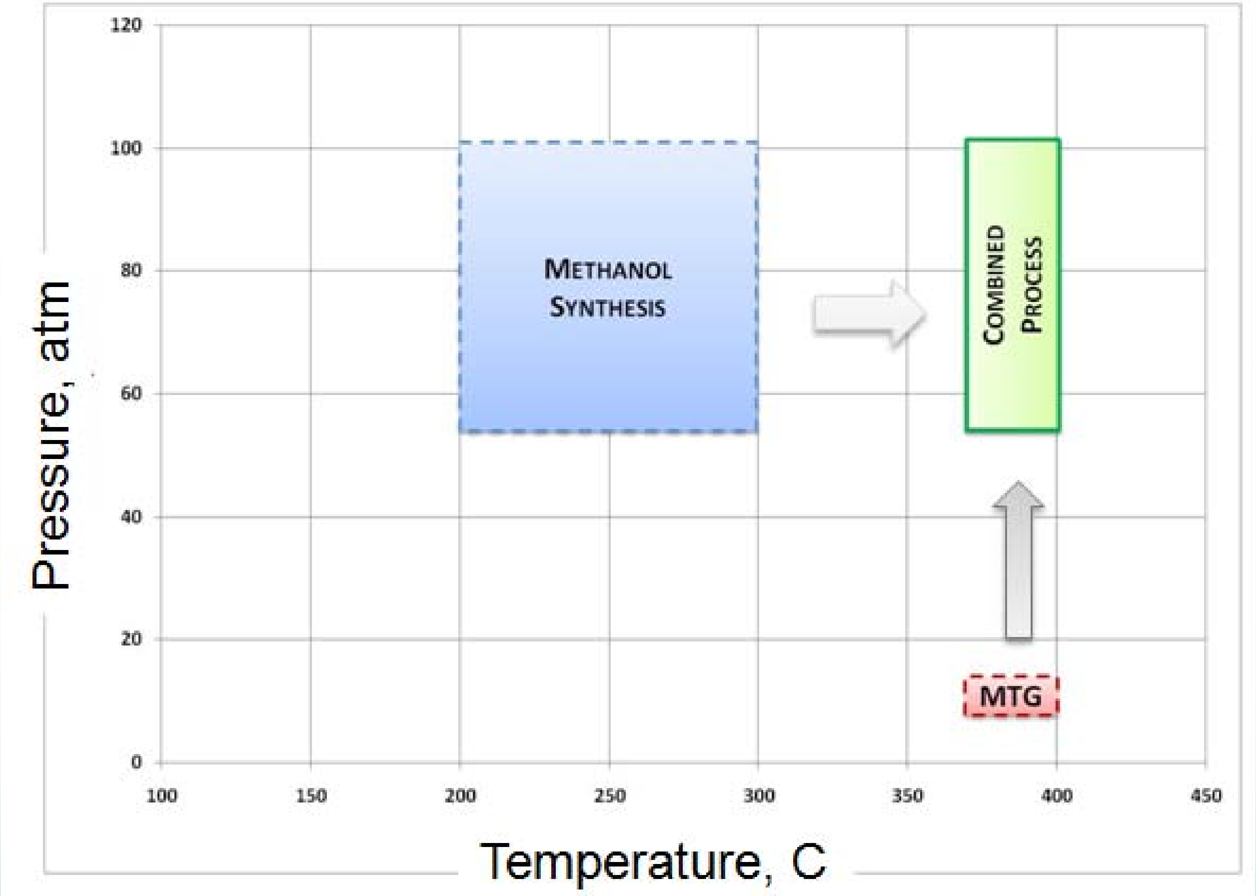
Process Simplification

Base case = standard MTG process
Improved case = proposed S2D process



Combining Methanol synthesis with conversion to fuels

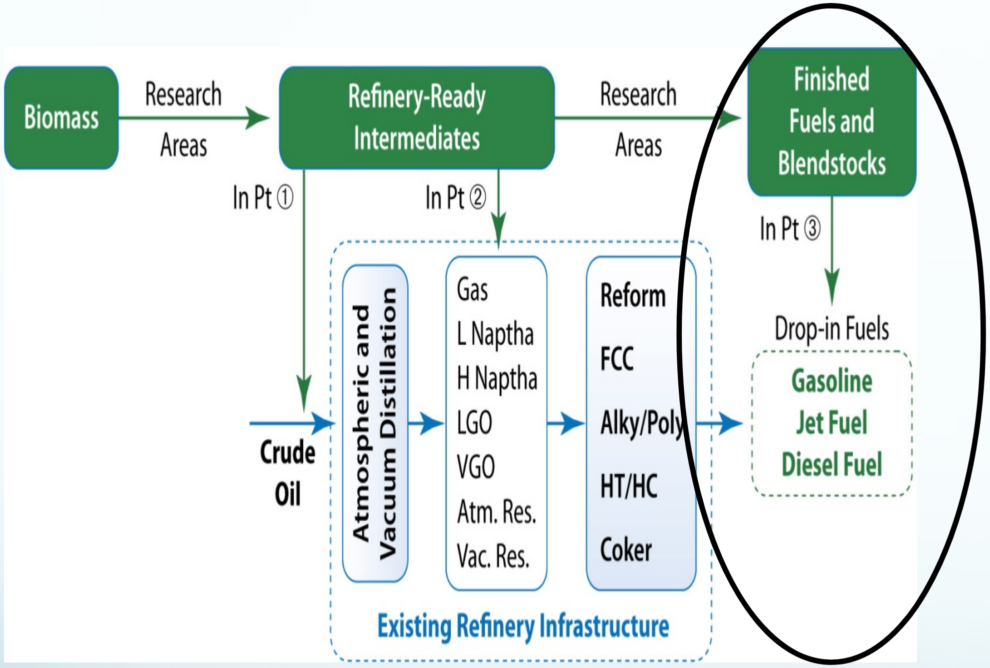


Challenge for the Syn Gas to Distillates Team

- Revise models to understand potential savings versus current multi-step methanol-to-gasoline processes
- Understand product quality
- Understand catalyst stability
  - Precious metal methanol production catalysts operating at high temperatures
  - Zeolite catalyst operating under hydrothermal conditions

Conclusion: Insertion Points 3

Biomass products blended into near finished fuel

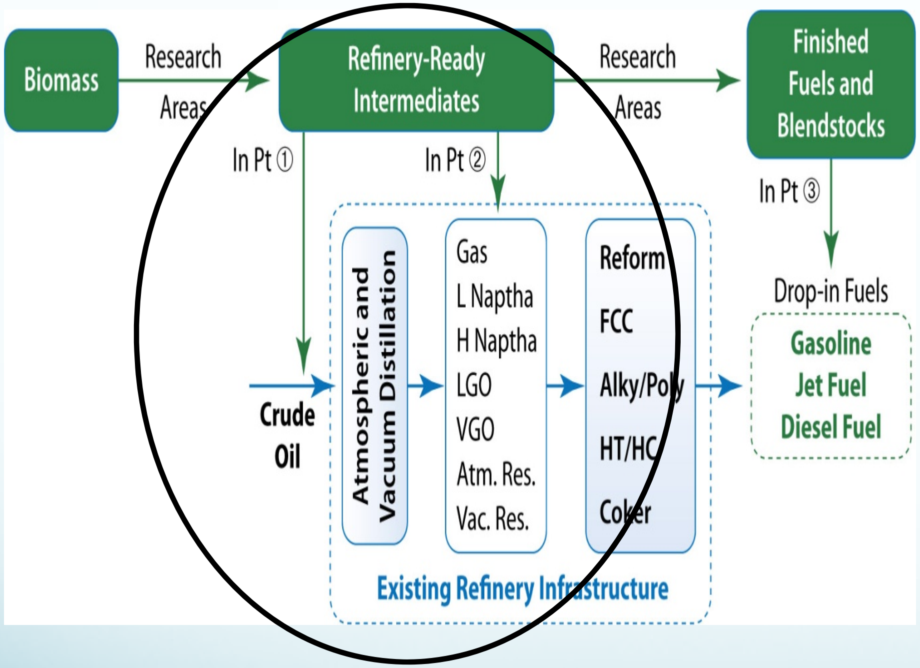


- Biomass is converted to a near-finished fuel or blendstock
- Lower risk but less leveraging of existing infrastructure
- Uses "downstream" infrastructure
- Allows tailoring processes to unique properties of biomass

Picture courtesy of http://memrieconomicblog.org/bin/content.cgi?news=2897

Conclusion: Insertion Points 1 and 2

Biomass intermediate is fed into front end or midstream of refinery



1 Jones, S., Valkenburg, C., Walton, C., Elliott, D., Holladay, J., Stevens, D., "Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking", Feb 2009

- Biomass is converted to a bio-oil that can be co-processed with conventional crude
- Bio-oil must be miscible in crude or intermediate process stream
- Significant processing and capital cost savings possible

General Conclusion

- The NABC represents a change of thinking on what fuels we should be making from biomass—gasoline, diesel and jet fuels, and how we can use the infrastructure in place to make and deliver those fuels into our vehicle fleet today
- Six technologies are being examined, up to three will be continued in years 2 and 3
- Pilot ready technology will be delivered at the conclusion

Questions?

- The National Advanced Biofuels Consortium (NABC) is a collaboration among U.S. Department of Energy national laboratories, universities, and private industry that is developing technologies to produce infrastructure-compatible, biomass-based hydrocarbon fuels.

- The consortium, led by the National Renewable Energy Laboratory and Pacific Northwest National Laboratory, is funded by the U.S. Department of Energy under the American Recovery and Reinvestment Act and by NABC partners.