National Advanced Biofuels Consortium

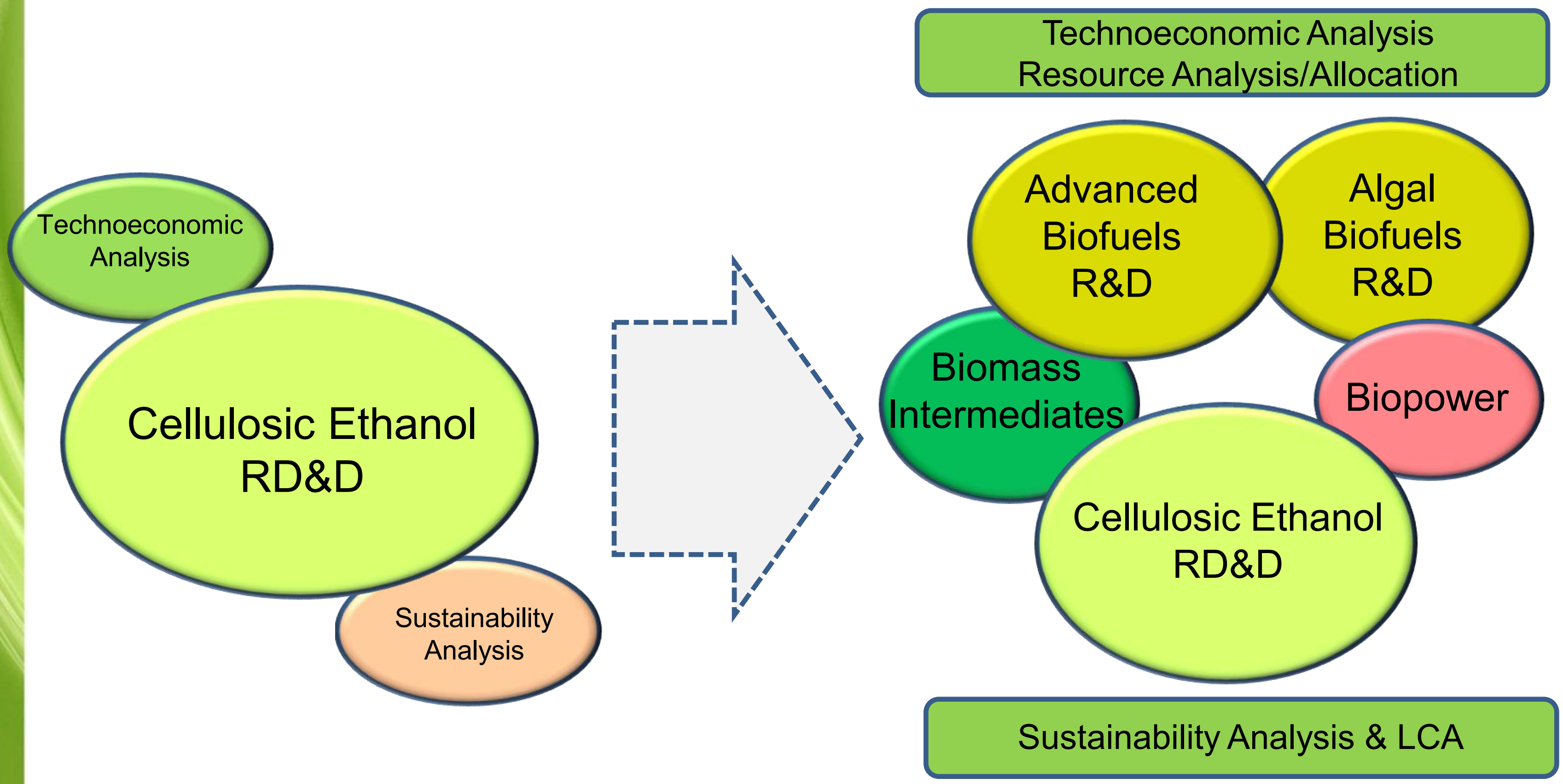
Virent Board of Directors

June 15, 2010

Biomass R&D Evolution

Prior Focus

Future Focus



2009 Solicitation
Advanced Fuels "Beyond Ethanol"

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Biofuels for Advancing America

- **Create a U.S. Advanced Biofuels Research Consortium to develop technologies and facilitate subsequent demonstration of infrastructure-compatible biofuels ($35 million)**

- **Create a U.S. Algal Biofuels Research Consortium to accelerate demonstration of algal biofuels ($50 million)**

FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

U.S. Department of Energy
Golden Field Office

Recovery Act: Development of Algal / Advanced Biofuels Consortia

Funding Opportunity Announcement Number: DE-FOA-0000123

Announcement Type: Initial

CFDA Number: 81.087

Issue Date:	July 15, 2009
Application Due Date:	September 14, 2009, 11:59 PM Eastern Time

E: Questions regarding the content of this announcement must be itted through FedConnect. Applicants must be registered in FedConnect omit or view Questions.

NAABB
National Alliance For Advanced Biofuels and Bio-products

Development and Commercialization Value Chain

Other NAABB Partners: Pratt & Whitney, LiveFuels

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Biofuels for Advancing America

Project Objective – 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.

ARRA Funded:
- 3 year effort
- DOE Funding $35.0M
- Cost Share $12.5M

Total $47.5M

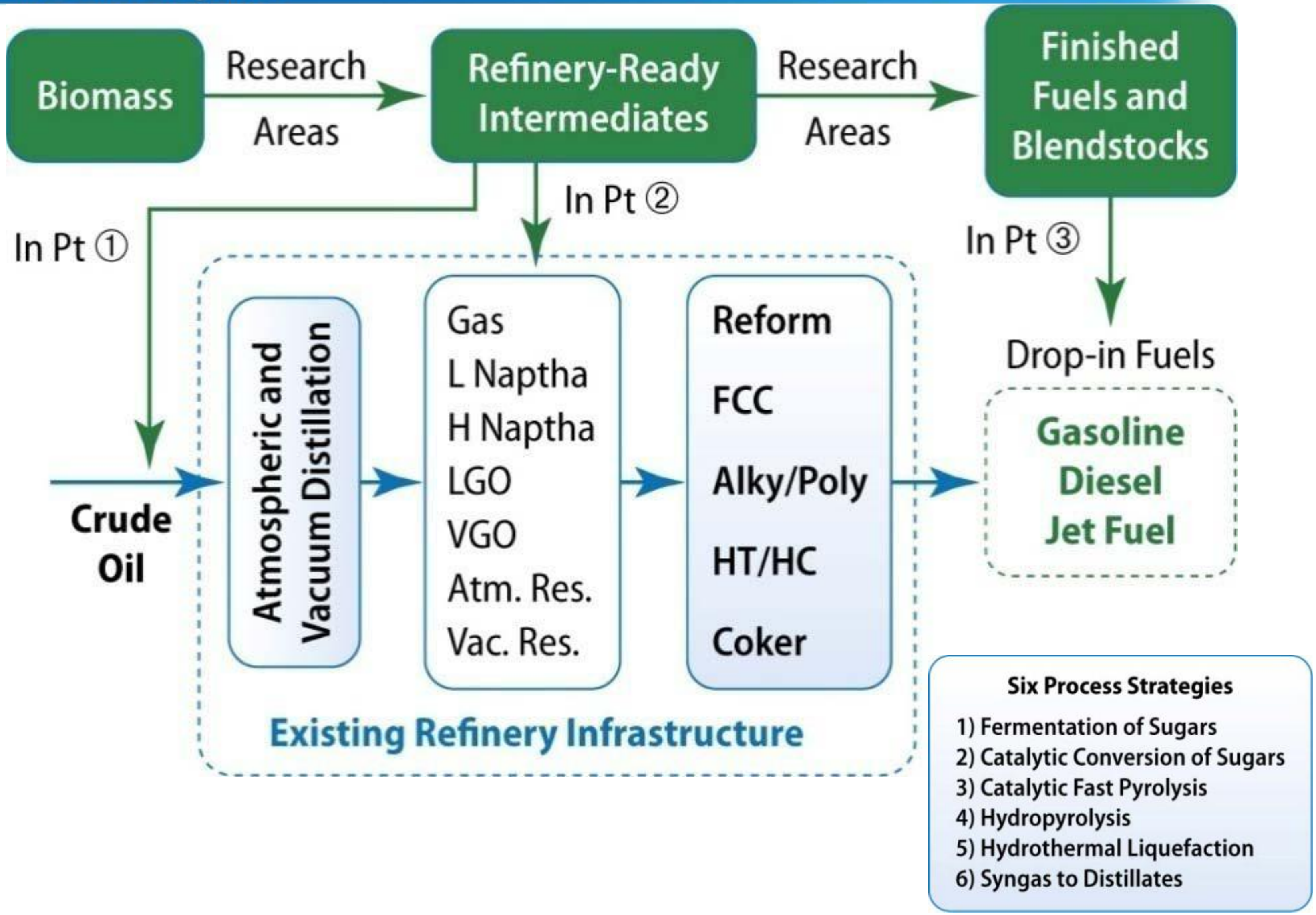
Consortium Leads

National Renewable Energy Laboratory
Pacific Northwest National Laboratory

Consortium Partners

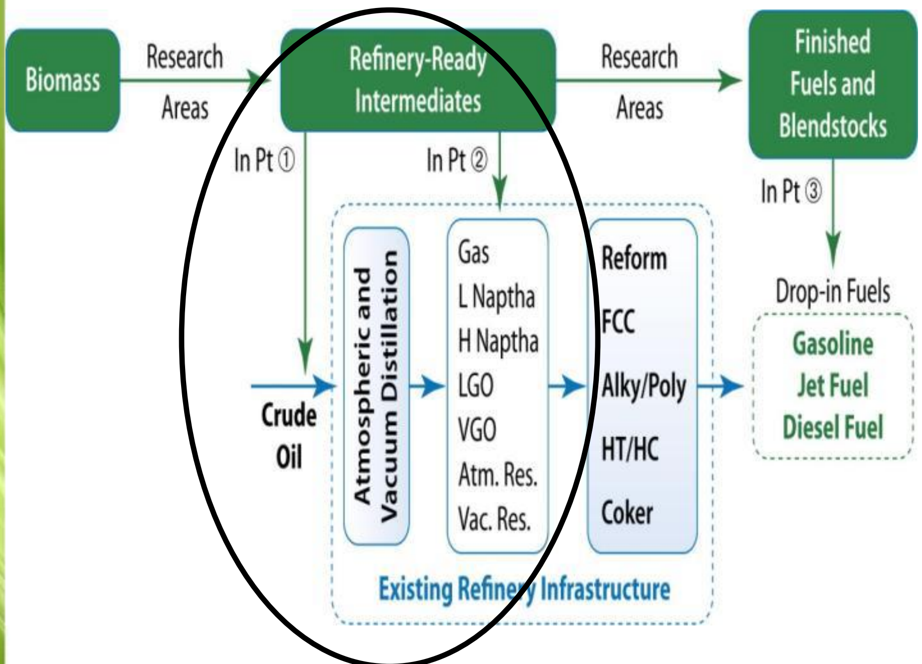
Albemarle Corporation
Amyris Biotechnologies
Argonne National Laboratory
BP Products North America Inc.
Catchlight Energy, LLC
Colorado School of Mines
Iowa State University
Los Alamos National Laboratory
Pall Corporation
RTI International
Tesoro Companies Inc.
University of California, Davis
UOP, LLC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

Infrastructure Compatibility Strategy



Insertion Points 1 & 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
- Fast Pyrolysis

Bio-oil must be miscible in crude or intermediate process stream

Significant processing and capital cost savings possible
- Base Case 1
  - $47/bbl* upgrading cost - raw pyrolysis oil to gasoline blend stock
  - >$300M capital cost – 2000 tpd greenfield plant
- Full Integration Case
  - Upgrading costs reduced by ~ 70% ($14/bbl vs. $47/bbl)
  - Significant capital cost savings – more research is need to quantify

* $4 – 12/bbl for crude oil upgrading

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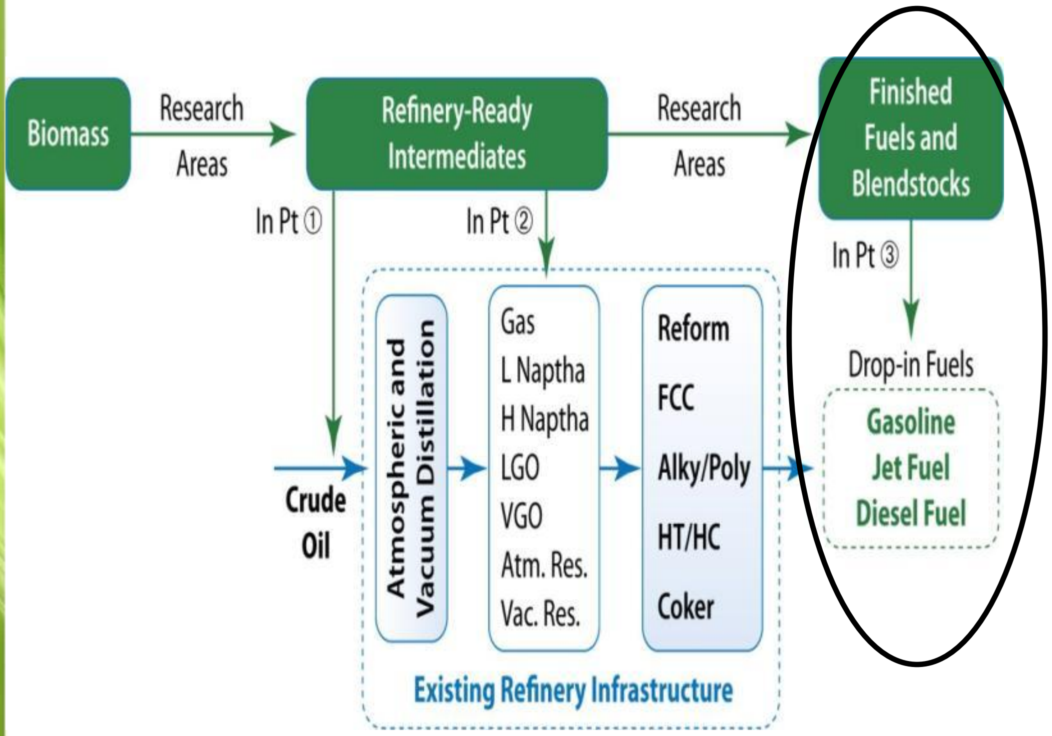
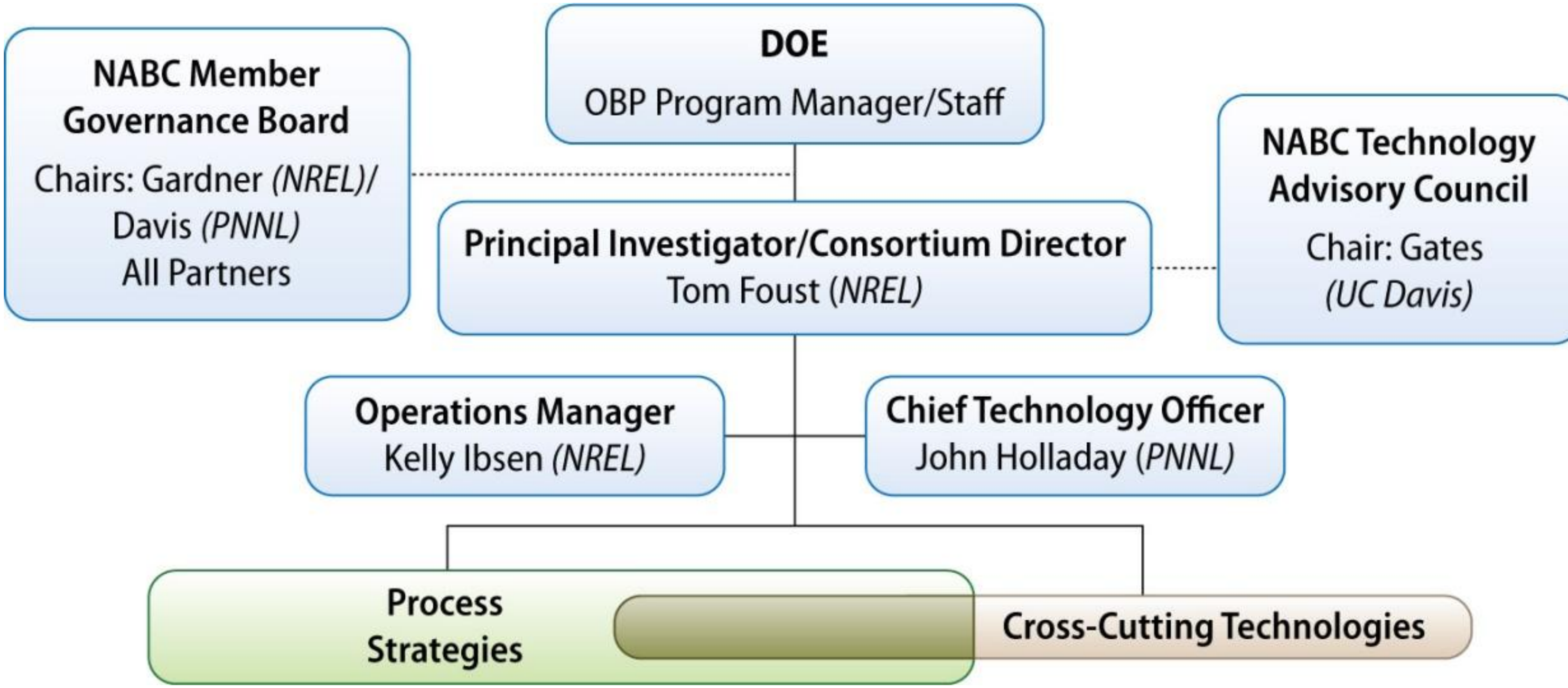
Insertion Point 3

Biomass products blended into near finished fuel



- Biomass is converted to a near-finished fuel or blendstock
- Must meet all applicable standards (ASTM) for finished fuel
- Allows tailoring processes to unique properties of biomass

NABC Organization



Research Strategies

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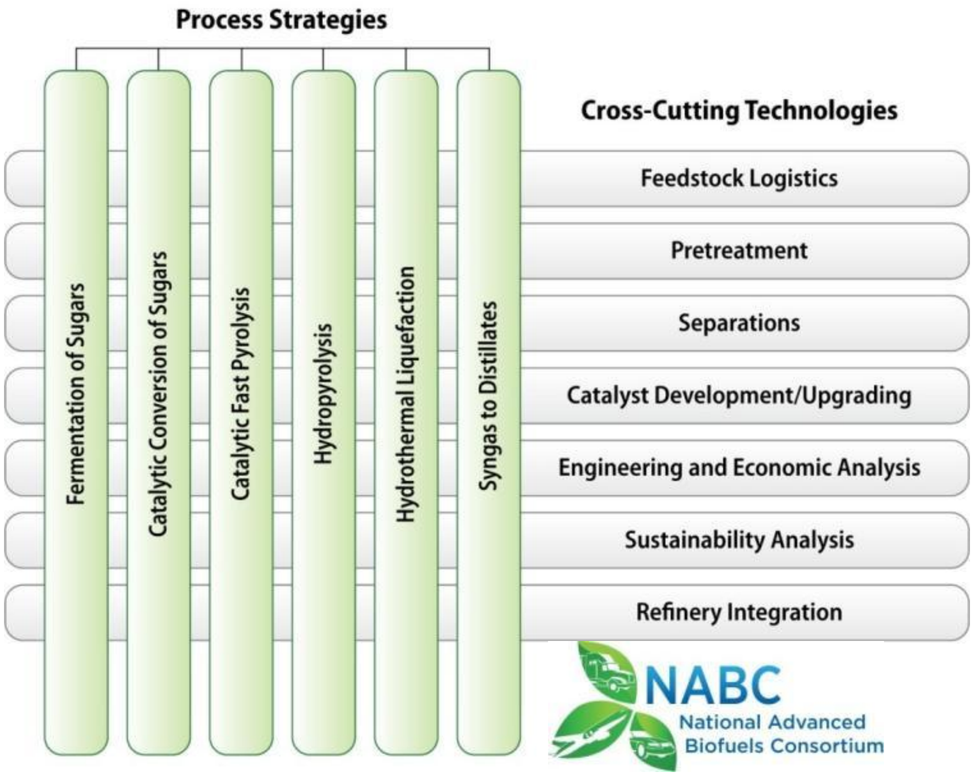
NABC matrix of technology and strategy teams will ensure development of complete integrated processes.



Stage 1: Selection of Technologies via Feasibility Study
Stage 2: R&D and Engineering on Selected Technologies (1 -3 down-selected process strategies)

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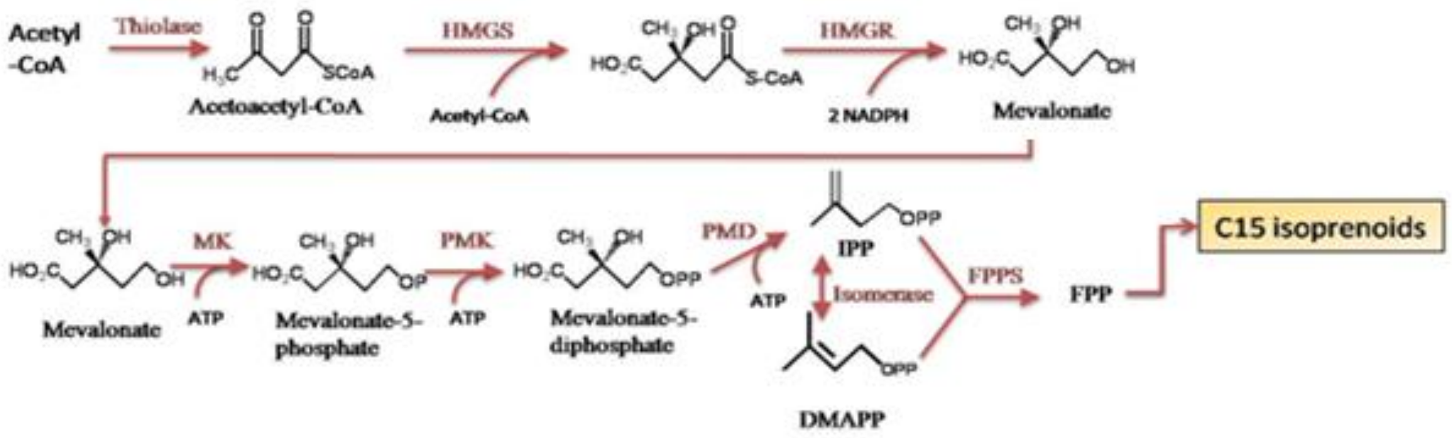
Fermentation of Sugars

- The fermentation technology builds on a class of compounds called isoprenoids. The primary (5-carbon) building block for these isoprenoids is isopentenyl pyrophosphate (IPP).

- In the mevalonate pathway Acetyl-CoA is converted into C15 isoprenoids.

- Will be looking at organism development for C5 sugar utilization and biomass hydrolysate compatibility.



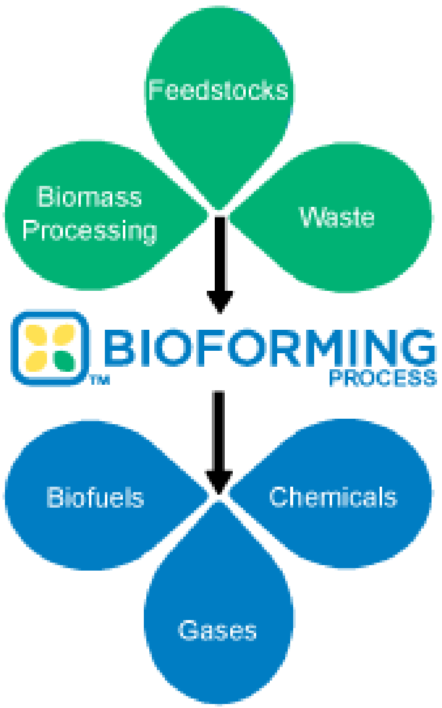
Mevalonate pathway for diesel fermentation intermediate production (Amyris)

Catalytic Conversion of Sugars

- Catalytic conversion of sugar via aqueous phase reforming (APR) combined with catalytic processing generates hydrocarbon fuel blending components .
- Uses heterogeneously-catalyzed reactions at moderate temperatures and pressures (ca. 175-300 °C and 150-1300 psi).

- The APR reactions include reforming, dehydrogenation, hydrogenations, de-oxygenations, and cyclizations. The catalytic processes involve acid and base-catalysed condensations and oligomerizations.

- A catalytic process will be developed that can handle complex sugars from lignocellulosic biomass

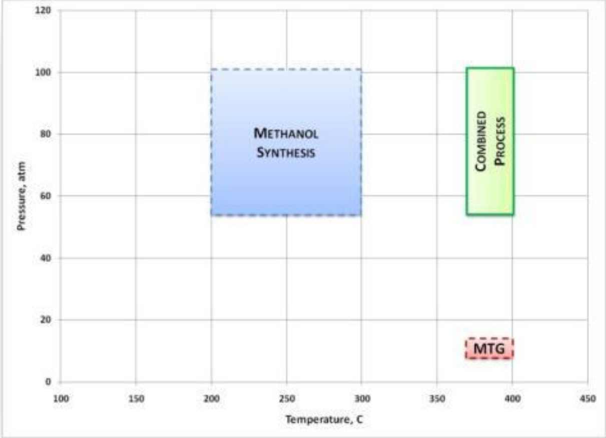


Syngas to Distillates

- Will integrate and combine the various necessary unit operations along with catalyst improvements to develop an efficient technology capable of producing gasoline and diesel.

- A key element to overall process simplification is the elimination of the methanol to DME reactor and the durene removal steps.

- Combine the MTG/MOGD conversions efficiently into a single reactor along with effective catalyst regeneration.



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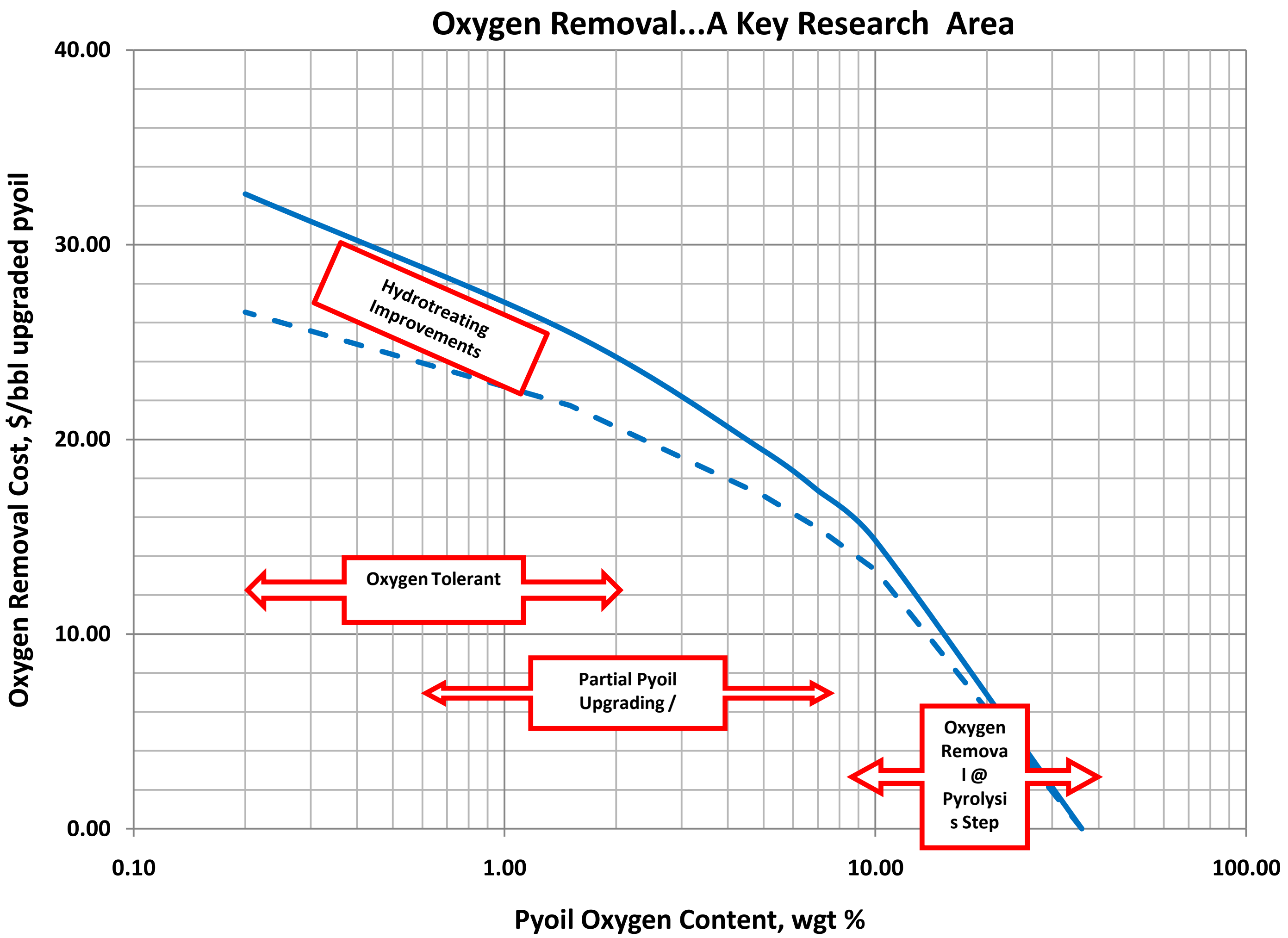
Insertion Points 1 &2 Strategies



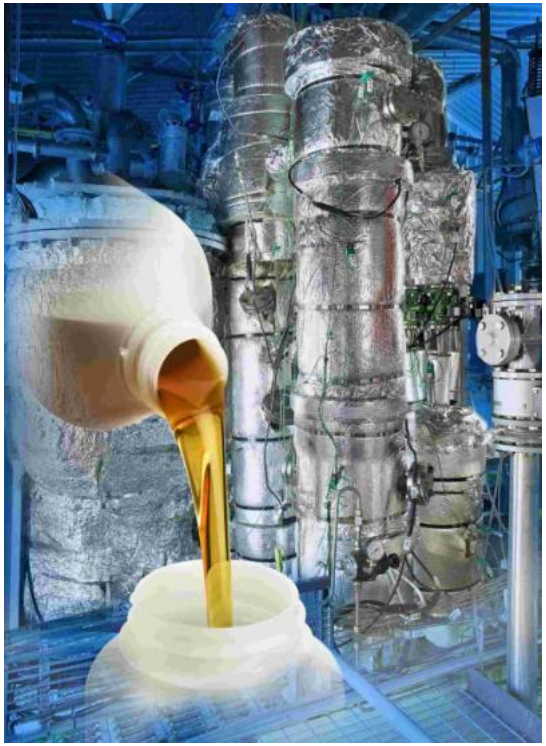
NABC: For Open Distribution

Catalytic Fast Pyrolysis

- Pyrolysis occurs at ambient pressure and temperatures between 400 and 600 °C at reaction times approaching 0.5s.

- Gives relatively high oil yields approaching 70% by weight.

- Fast pyrolysis oil however has many undesirable properties:
  - High water content: 15-30%
  - High O content: 35-40%
  - High acidity; pH = 2.5, TAN > 100 mg KOH/g oil
  - Unstable (phase separation, reactions)
  - Low HHV: 16-19 MJ/kg



- Will be looking at catalytic methods to produce improved bio-oils for insertion into the refinery.

Hydropyrolysis

- Hydropyrolysis, (pyrolysis in the presence of hydrogen and added catalyst) is carried out at pressures that are substantially higher than those employed for fast pyrolysis (c.a. 250–500 psi).

- Produces an oil-like product that has much of the oxygen removed and is more suitable for co-processing in a petroleum refinery or for upgrading to finished fuels.

- In this project we will investigate methods to reduce hydrogen demand.

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Hydrothermal Liquefaction

- Hydrothermal liquefaction occurs in liquid-phase media at temperatures between 300-400 °C and at the vapor pressure of the media.

- For biomass with water as the media temperature is 374 °C with pressure between 2500-3000 psi.

- Catalysts are employed to speed the hydrogen transfer reactions.

- Product oils have low water content and are lower in oxygen (c.a. <10%). but have other undesirable physico-chemical properties such as a relatively high viscosity.

- The focus will be on new reaction media and catalysts that reduce process severity while maintaining high reaction rates and low oxygen content of the oil.

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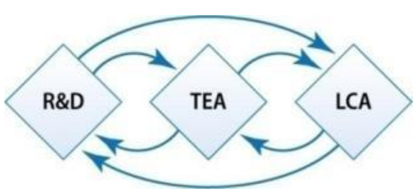
Sustainability and GHG Analysis

GHG Reduction Potential of Advanced Biofuels based on preliminary data

Feedstock	Process Technology	Fuel Products	GHG Reduction vs. Conventional Fuels	Source
Corn stover	Fast Pyrolysis with refinery hydroprocessing	Gasoline and Diesel	62% vs. conventional (gasoline + diesel)	NREL/UOP analysis
Corn Stover	Hydrolysis plus aqueous reforming of sugars	Gasoline	94% vs. conventional gasoline	Virent analysis using GREET
Energy Cane	Hydrolysis plus fermentation to hydrocarbons	Diesel	>90% vs. US diesel	Amyris analysis

The overall sustainability of biofuels includes elements of economic and environmental sustainability, as well as societal benefits. There are many metrics for environmental sustainability, including GHG emissions, air toxics, water quality, and water use. LCA has become an increasingly vital aspect of the biofuels industry.

LCA modelers will have two tools available for quantifying land use change:



- Global Trade Analysis Project (GTAP) model, being incorporated into GREET by ANL.
- Systems dynamic land use change model developed by John Sheehan (University of Minnesota) and Nathaniel Greene (NRDC).

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Process Efficiencies

Comparison of Liquid Fuel Yields

Fuel Production Technology	Process Energy Efficiency
Conventional Petroleum Refining to Gasoline	85%
Conventional Petroleum Refining to Low-S Diesel	87%
Biomass Gasification / Fischer-Tropsch	41%
Fast pyrolysis (with HDO)	77%
Hydropyrolysis	82%

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