Cellulosic Biofuels in the USA: Progress and New Initiatives

Science Symposium on Next Generation Liquid Biofuels and Co-Products

Scion
Rotorua,
New Zealand

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

Current Situation

- Biofuels progress and drivers
- New initiatives
- RDD&D situation

NREL R&D Progress

- Biochemical cellulosic ethanol and mixed alcohols
- Improved piloting facilities
- R&D beyond cellulosic alcohols
  - National Advanced Biofuels Consortium (NABC)

Outlook and Final Thoughts

- On-going challenges and unresolved issues

Recent History of Advanced Biofuels

- 1995-2000: Demonstrate technical feasibility

  Focus on cellulosic ethanol

- 2000-2005: Show economic feasibility & scale potential

  Focus remains largely on cellulosic ethanol (BC route) and mixed alcohols (TC route)

- 2005-2010: Increase funding to accelerate biofuels RDD&D

  Expand product portfolio to encompass higher alcohols and hydrocarbon fuels

  Begin funding research to evaluate and prove out new concepts including hybrid BC/TC and algal pathways

Current Situation

Advanced biofuels R&D booming

- Many potential routes being rigorously studied (BC, TC, hybrid, algae, etc.)
- Major bioenergy research centers formed, actively engaged (BESC, JBEI, GLBRC, EBI, etc.)
- R&D community 100x larger

Commercialization starting

- Many dozens of companies pursuing technology development
- Cellulosic and algal biofuels production occurring, albeit at a pace much slower than planned or initially forecasted

Danish fueling station pump dispensing E5 gasoline-ethanol blend containing wheat straw-derived cellulosic ethanol

photo courtesy of Claus Felby (U. Copenhagen)

Drivers for Advanced Biofuels Remain Strong

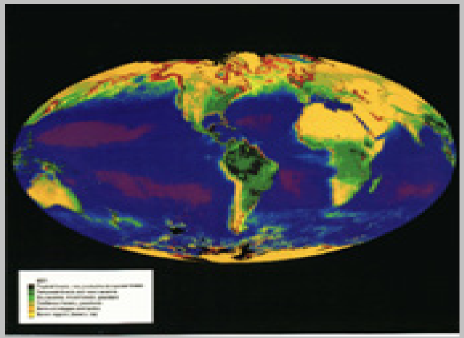
"Developing the next generation of biofuels is key to our effort to end our dependence on foreign oil and address the climate crisis – while creating millions of new jobs that can't be outsourced. With American investment and ingenuity – and resources grown right here at home – we can lead the way toward a new green energy economy."

– United States Secretary of Energy Steven Chu

Science and Discovery

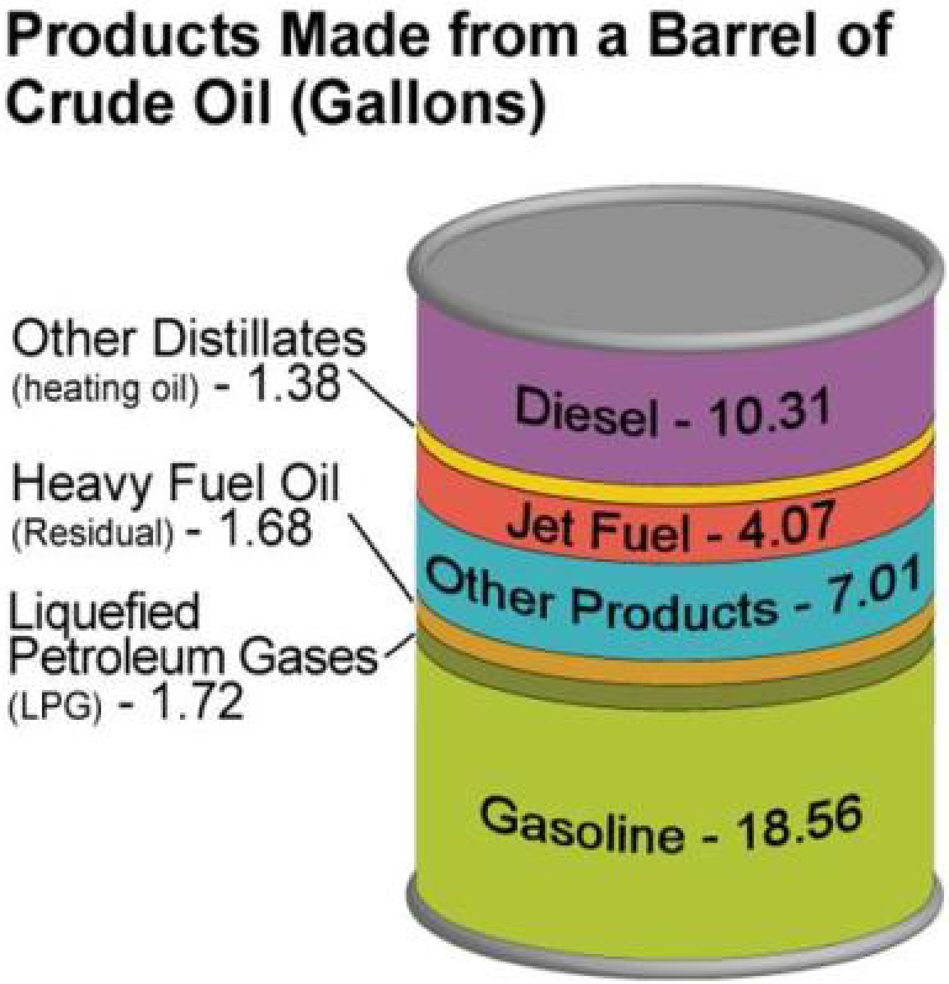
Economic Prosperity

Clean, Secure Energy



Climate Change

More Fuels Needed to Display Fossil Oil



- Advanced biofuels and products are needed to displace the entire barrel
  14.7 mbd = 225 bgy = ~850 bly
  70% of U.S. petroleum use

< Heavy duty/diesel and jet fuel substitutes required to displace several components
Diesel: 43 bgy = ~160 bly
Aviation fuel: 25 bgy = ~95 bly
Fuel oil for ships: 10 bgy = ~ 38 bly
Total: 78 bgy = ~ 295 bly
36% of transportation fuel

< Cellulosic ethanol displaces light duty gasoline fraction
140 bgy = ~ 530 bly
64% of transportation fuel

Source: Energy Information Administration, "Petroleum Explained" and AEO2009, Updated (post-ARRA), Reference Case.

Success Requires Functioning Supply Chain

The USDOE Biomass Program is working to advance biomass technologies in support of its mission to strengthen America's energy security, environmental quality, and economic vitality through:

Feedstocks

Developing lower cost feedstock logistics systems

Conversion technologies

Improving conversion efficiencies and costs

Integrated biorefineries

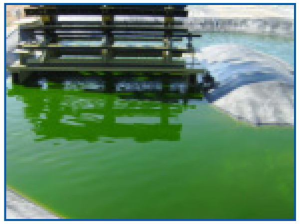
Systematically validating and deploying technology at first-of-a-kind facilities

Infrastructure

Evaluating vehicle emissions, performance, and deployment options

Biopower

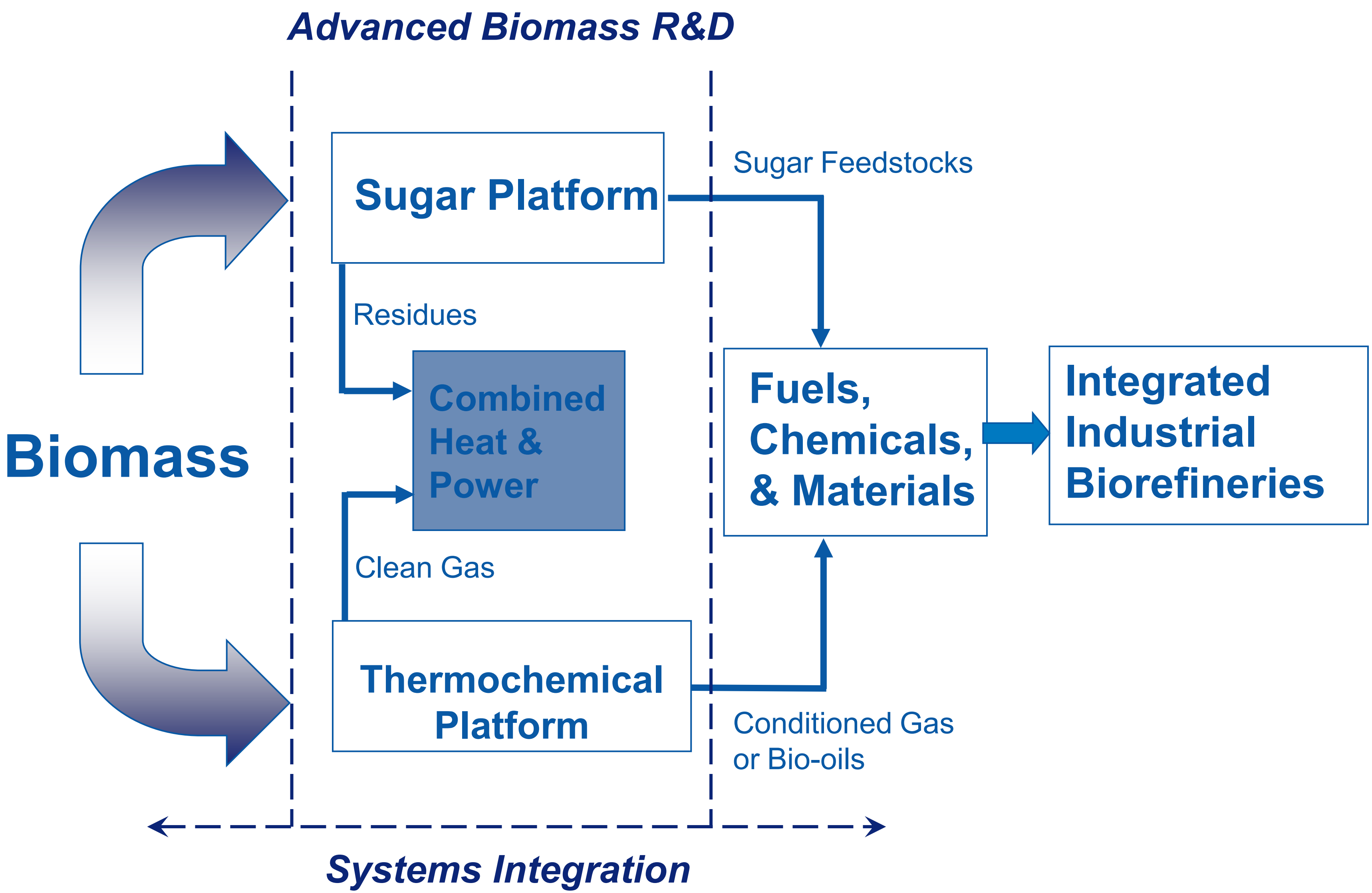
Providing a clean, domestic, dispatchable renewable source of power



Advanced biofuels

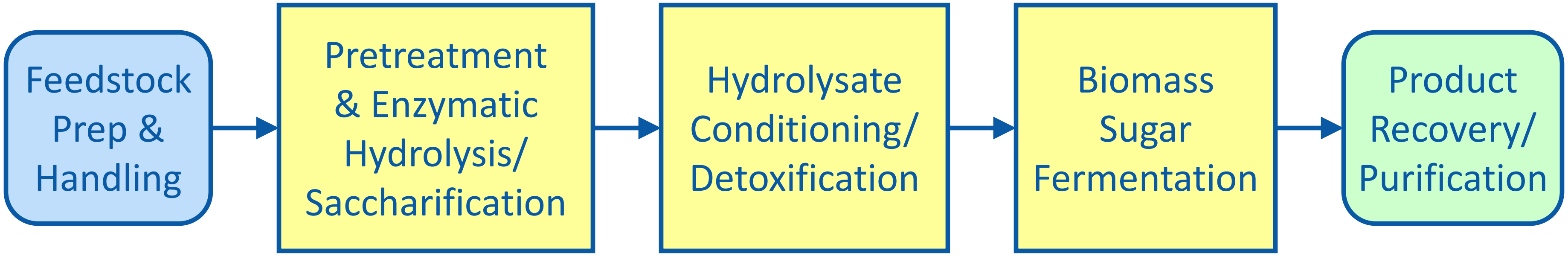
Expanding portfolio beyond cellulosic ethanol to hydrocarbon fuels

Integrated Biorefinery Conversion Platforms



Biomass Conversion to Fuels

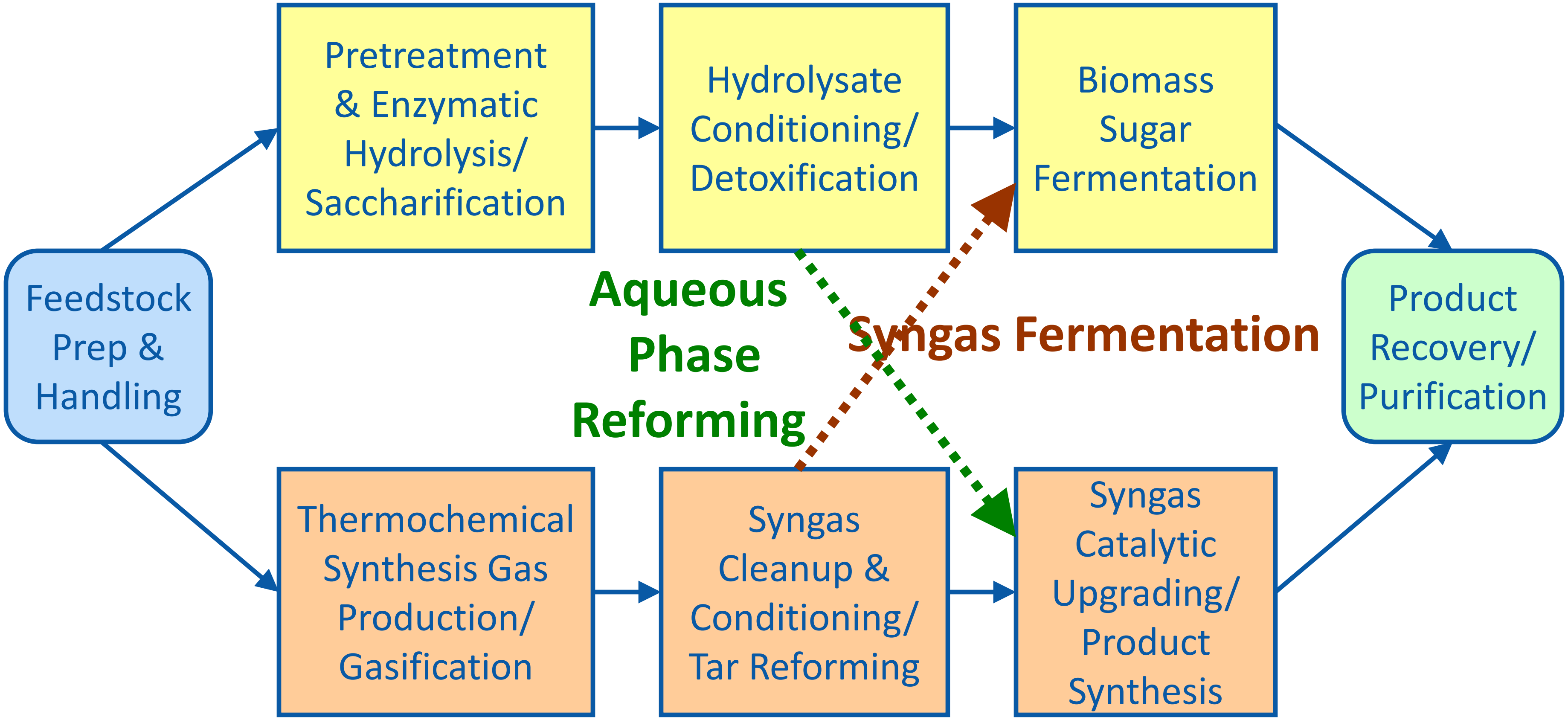
Major *Biochemical* Conversion Steps



Major *Thermochemical* Conversion Steps

Biomass Conversion to Fuels

Hybrid Approaches

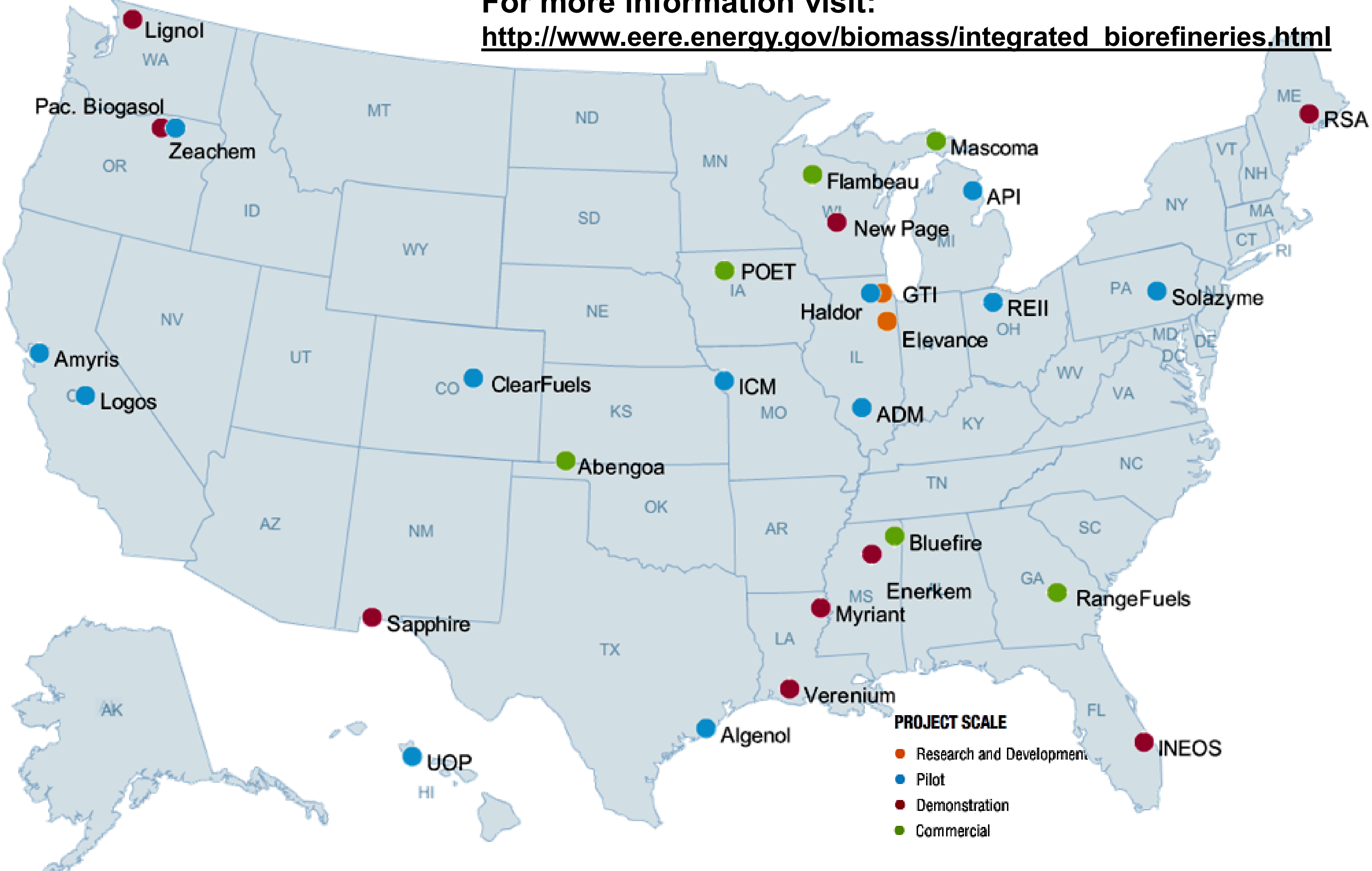


Integrated Biorefinery Projects

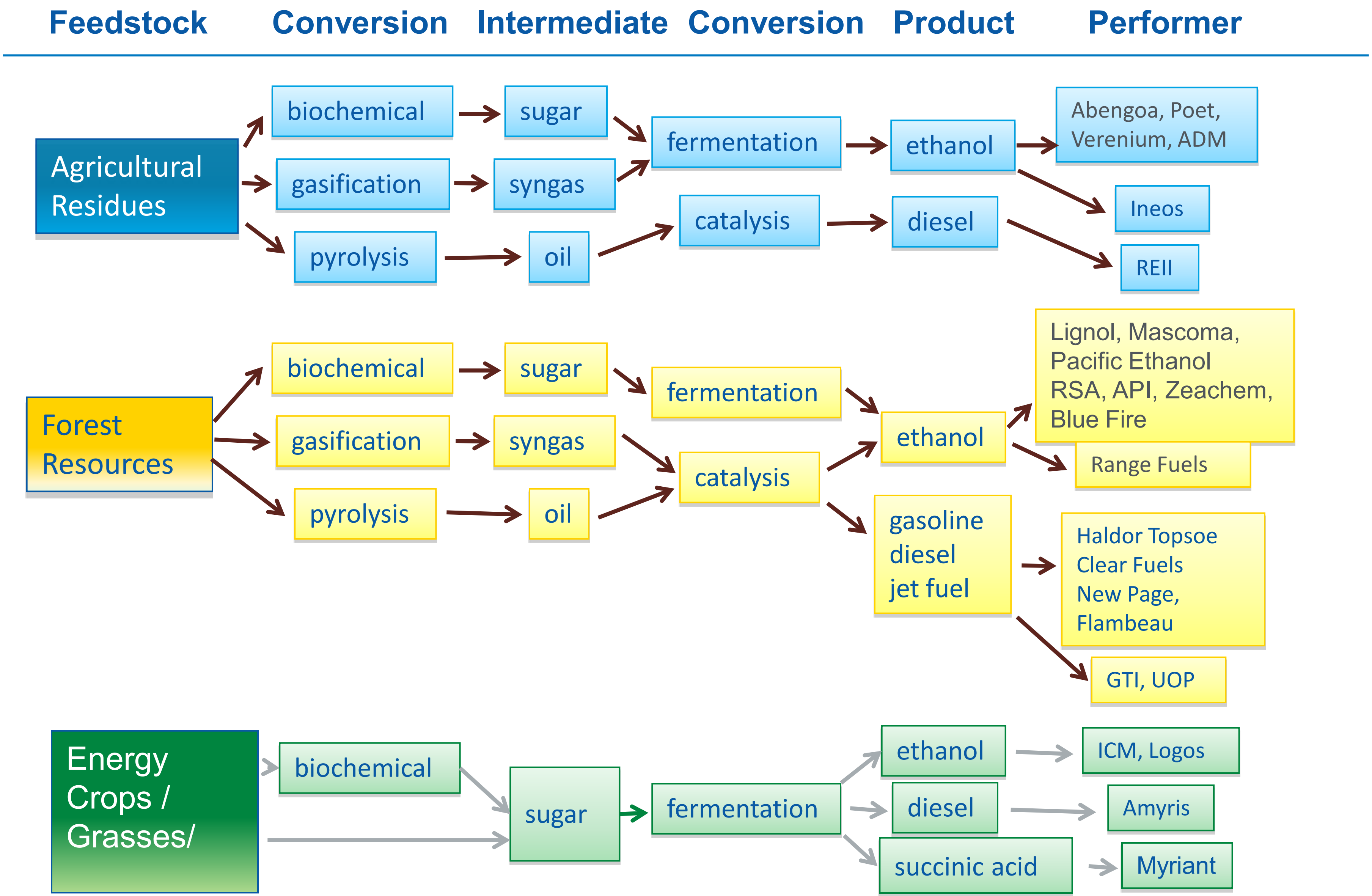
Scale	Description	Feedstocks	Fuel/Product
R&D 2 projects	Includes R&D and a preliminary engineering design	Poultry Fat, Woody Biomass, Ag Residue, Algal Oil	Renewable Fuels, Renewable Gasoline, Renewable Diesel
Pilot Scale 12 projects	Process a minimum of 1 dry ton per day biomass and verify integrated performance of the given suite of technologies from both a technical and an economic perspective for the first time	Algae, CO_2, Woody Biomass, Sweet Sorghum, Corn Stover, Switchgrass, Energy Sorghum, Ag and Forestry Residue, Hybrid Poplar	Ethanol, Cellulosic Ethanol, Renewable Diesel, Jet Fuel, Renewable Diesel
Demonstration Scale 9 projects	Validate process technology performance from both technical and an economic perspectives at a scale predictive of a commercial facility	Wheat Straw, Corn Stover, Poplar Residues, Woody Biomass, Algae, Mill Residues, MSW, Ag and Forestry Residue	Cellulosic Ethanol, Renewable Sulfur-free Diesel Fuel, Renewable Hydrocarbon-based Fuel, Renewable Gasoline, Renewable Diesel, Jet Fuel, Succinic Acid
Commercial Scale 6 projects	Process a minimum of 700 dry tons per day biomass in a a first-of-a-kind or “beta” commercial facility	Lignocellulosic Biomass, Corn Cobs, Woody Biomass, Mill Waste, Sorted MSW	Cellulosic Ethanol, Ethanol, Methanol

DOE's Integrated Biorefinery Project Map

For more information visit:
http://www.eere.energy.gov/biomass/integrated_biorefineries.html



Integrated Biorefinery Projects, cont'd.



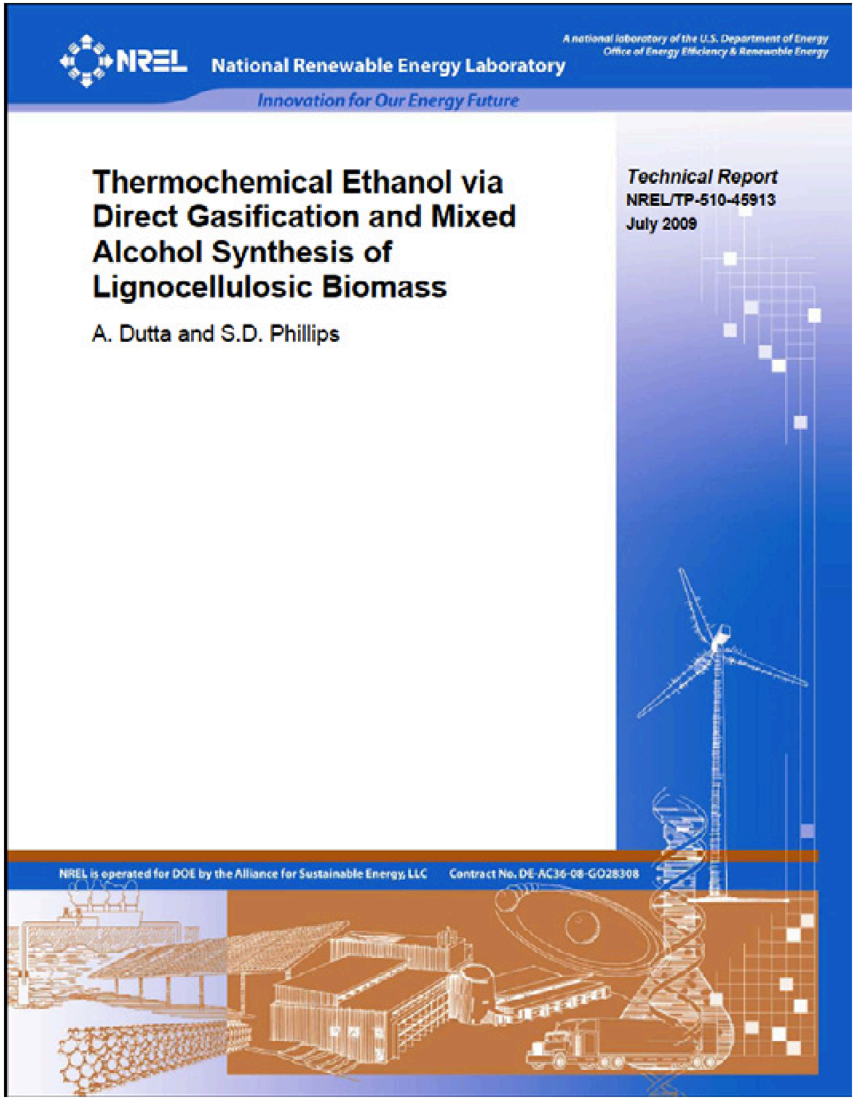
Progress at NREL

Cellulosic Ethanol/Mixed Alcohols Progressing

New Facilities Coming On-line (TCPDU and IBRF)

New Initiatives Underway (BESC and NABC)

NREL BC and TC Design Reports



BC: http://www.nrel.gov/biomass/pdfs/32438.pdf
TC: http://www.nrel.gov/biomass/pdfs/45913.pdf

- *Document probable BC and TC routes to cost-effective cellulosic ethanol/mixed alcohols*
  - ***Nominal 2012 "target" cases***
  - ***Updated BC design report will publish in 2011***
- *Establishes bases for comparison of other technology options (with clearly stated assumptions and referenced source data)*
- *Rigorous models to help quantify the R&D targets needed to achieve cost targets*
- *Enables impact of research progress to economic / cost goals to be quantified*
- *Transparency facilitates dialogue and collaboration with industry*
- *Have undergone extensive peer review by industry, academia and government*

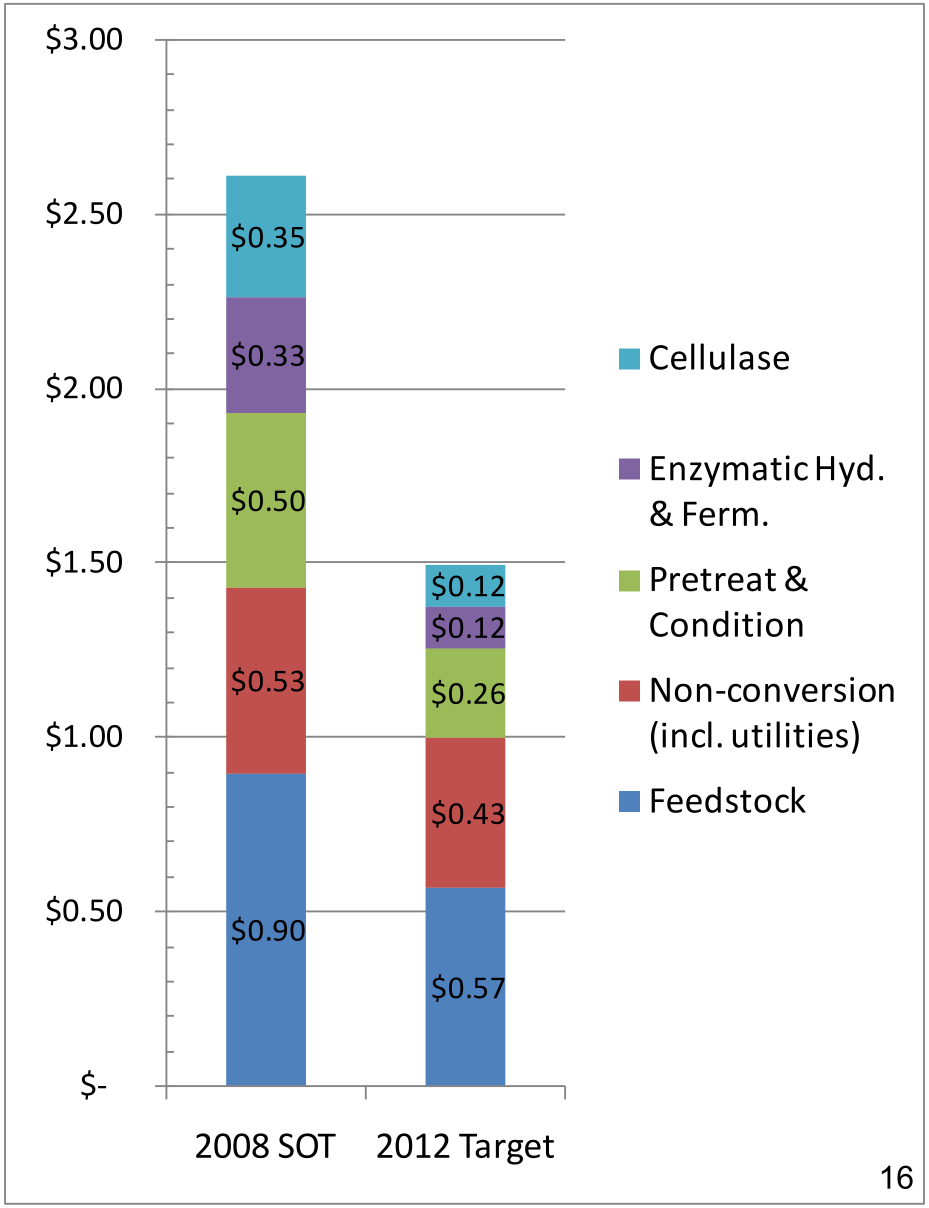
Achieving Economic Feasibility (BC)

Process cost drivers

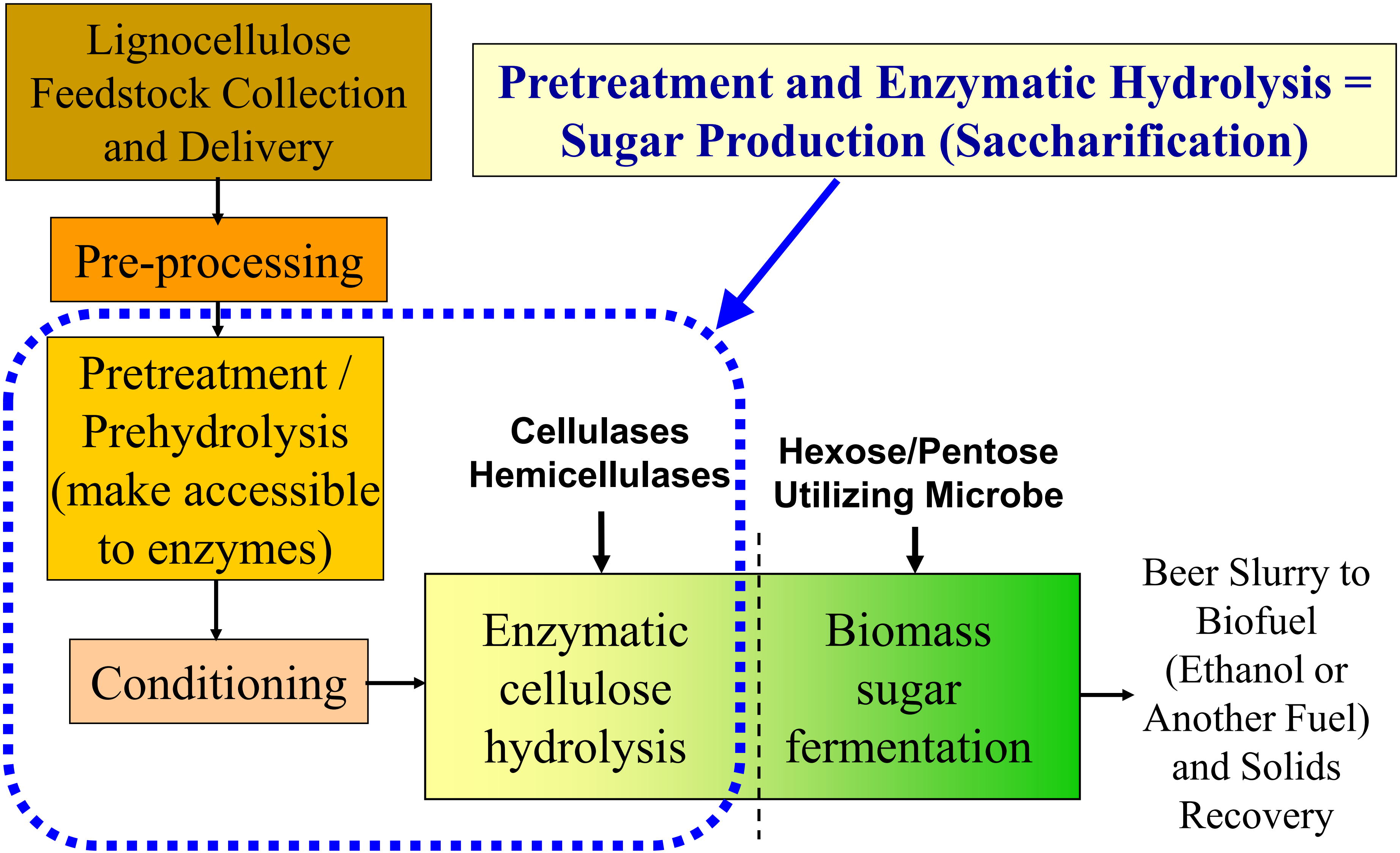
➔ Yield > Conc > Rate

- Feedstock
- Capital equipment
  - Pretreatment
  - Enzyme Production
  - Distillation
  - Boiler/CHP
- Operating cost
- Coproduct value

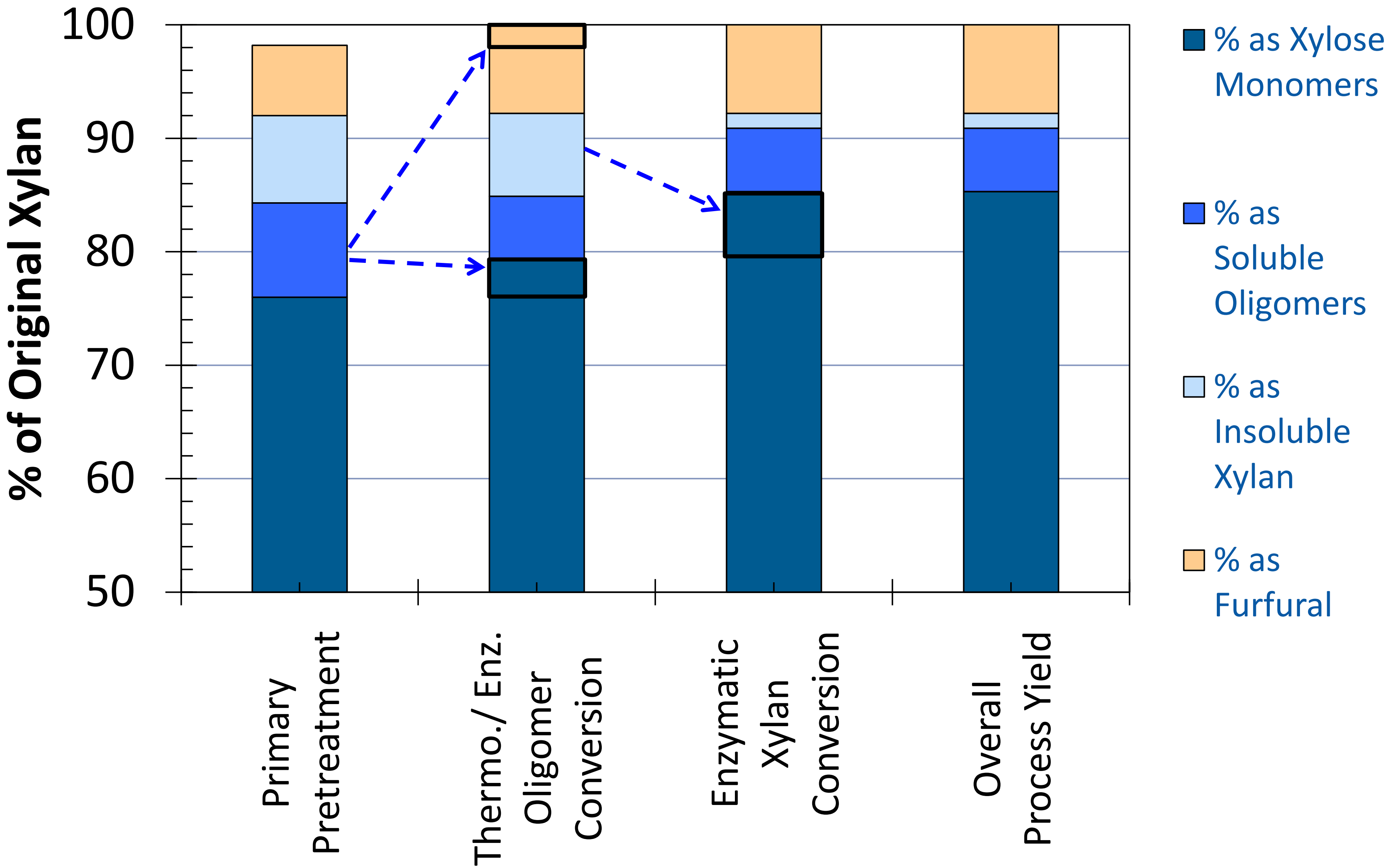
➔ Reduce CAPEX through co-location and process intensification



Economic Sugar Production Remains Biggest Challenge for BC Route

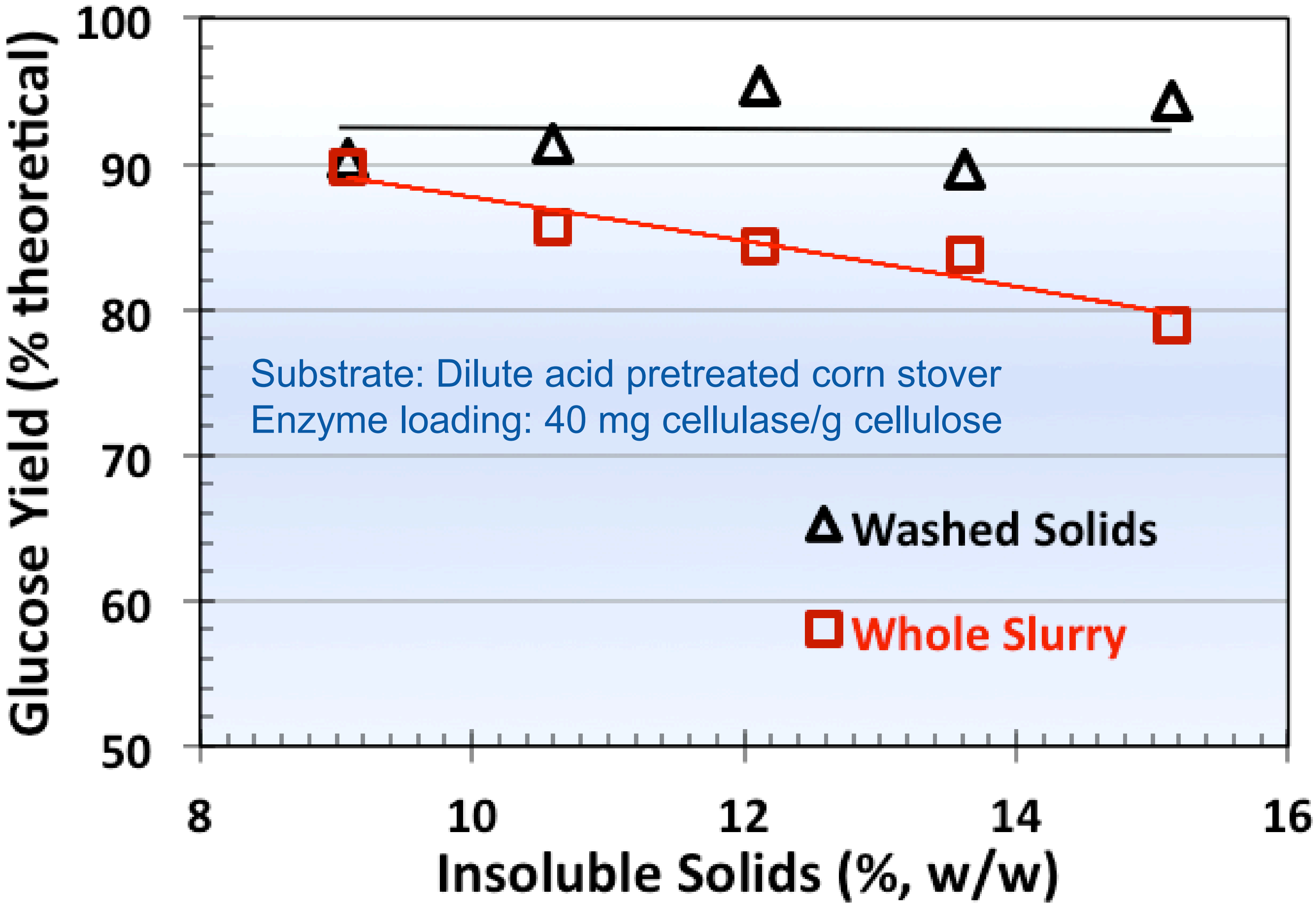


Increasing Monomeric Xylose Yields



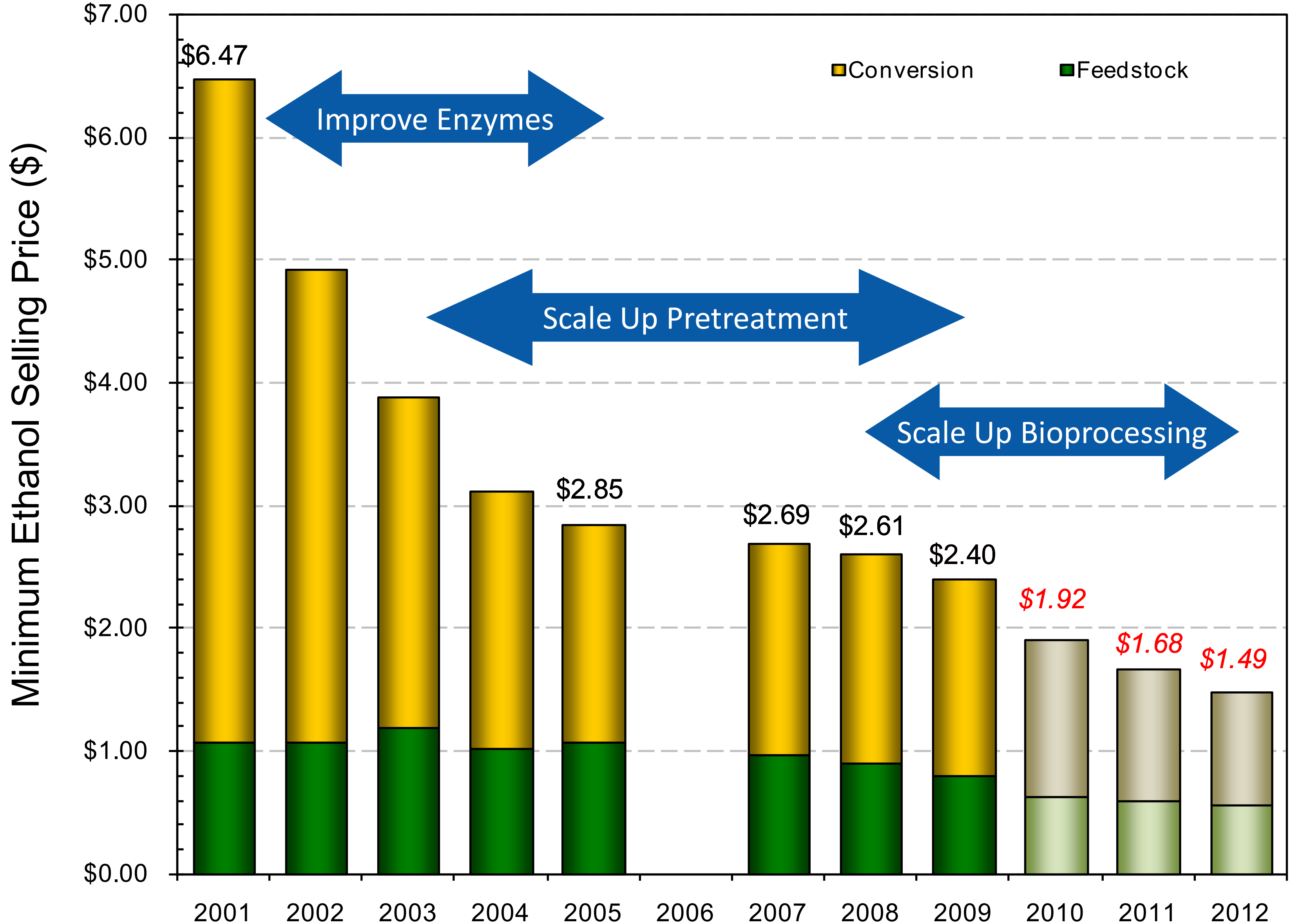
Source: Rick Elander (NREL)

Intensifying Enzymatic Hydrolysis



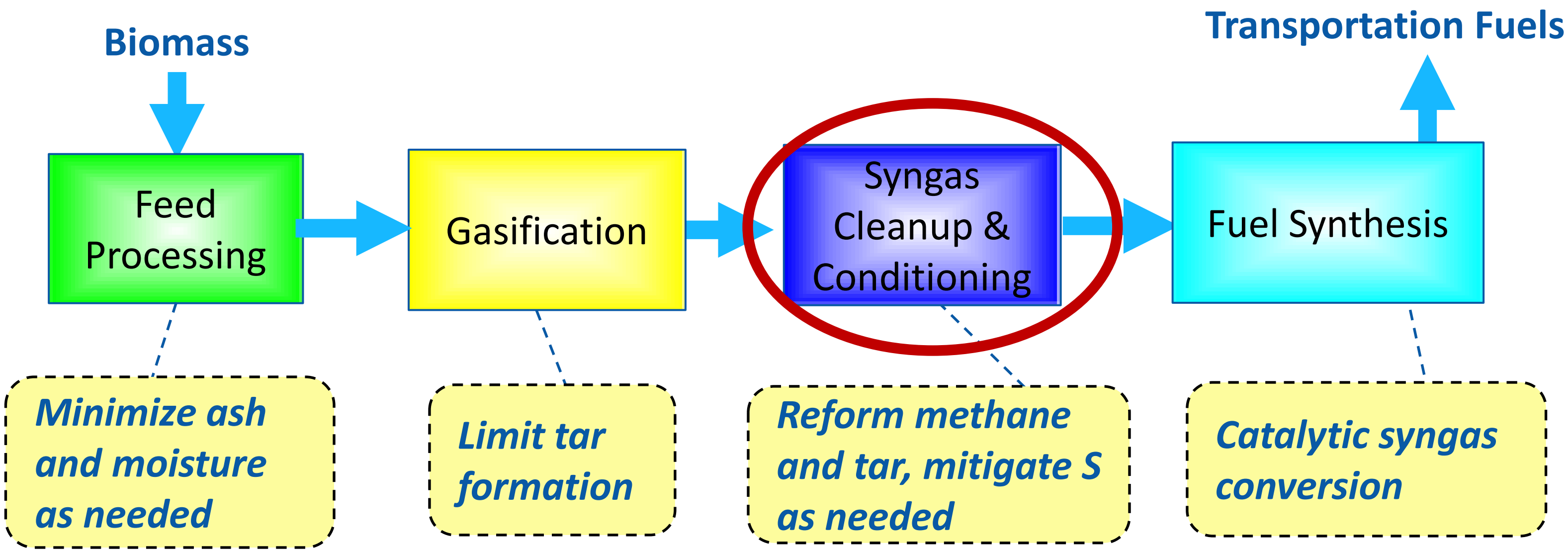
Source: Dan Schell (NREL)

Biochemical Technology Progress (2007$)



Source: Humbird and Aden. 2009. NREL/TP-510-46214.

TC Focus: Clean Up and Conditioning

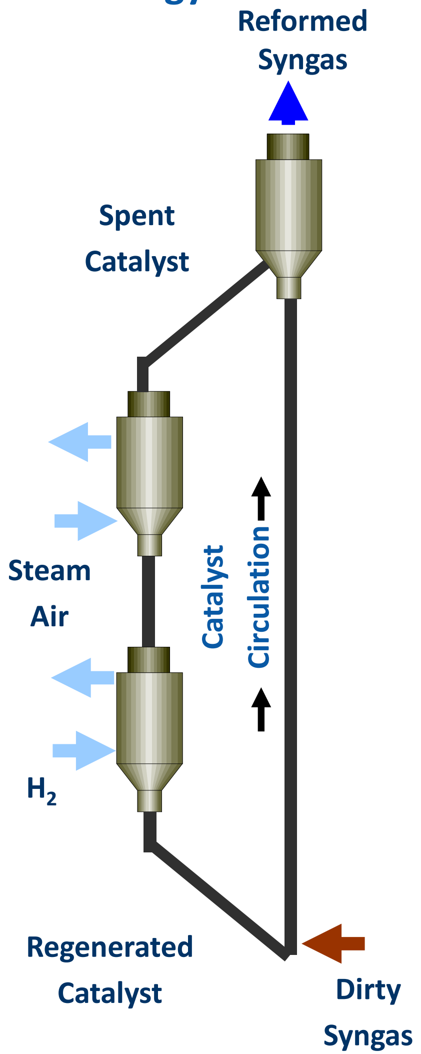


Pathway to 2012 Cost Target:

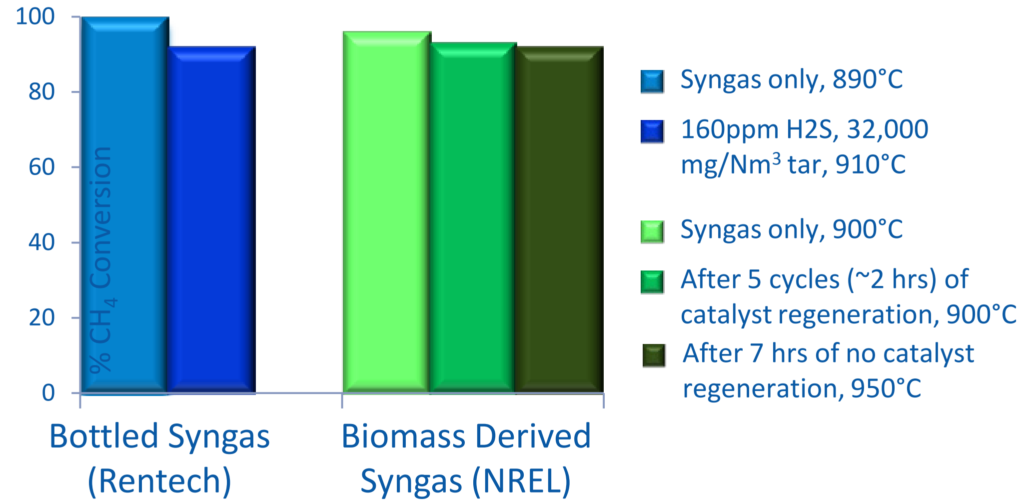
- **Demonstrate continuous CH_4 reforming at >80% conversion**
- Improve catalyst performance by 10-20% – productivity and/or selectivity
- Better use of waste heat for drying of biomass
- Rigorous optimization of fuels synthesis operating conditions

Achieving Methane Reforming Targets

Catalyst Regeneration Strategy



Methane Conversion During Continuous Regeneration



- 2009 - Industrial collaborator demonstrated > 92% CH_4 conversion under regenerating conditions after 100 hrs using spiked bottled syngas
- 2010 - NREL demonstrated > 90% CH_4 conversion after multiple regeneration cycles (~2 hrs) and >90% CH_4 conversion with no regeneration (~7hrs) - 2010
- 2011-2012
  Determine optimum regeneration strategy at scale
  Test tar reforming catalysts from 3 industrial partners
  - Johnson-Matthey, NexTech and Sud Chemie

Integrated Biorefinery Research Facility(IBRF)

NREL’s Expanded BC Pilot Plant (IBRF)

- State of the art cellulosic biofuels piloting facility
- Two (2) parallel processing trains for pretreatment and primary enzymatic liquefaction
- Accelerate cost reduction focused R&D
- Provide multiple biomass pretreatment/feedstock options for RD&D support (unparalleled flexibility)
- Greatly improve industry partnering capabilities to speed scale up and commercial deployment
- DOE’S prime facility for future pilot scale pretreatment and enzymatic saccharification R&D

Early March 2010

Integrated Biorefinery Research Facility

June 2010

Inside View of IBRF Operations Level

National Advanced Biofuels Consortium (NABC)

National Advanced Biofuels Consortium

NABC National Advanced Biofuels Consortium

Biofuels for Advancing America

Project Objective – Develop cost-effective technologies to supplement petroleum-derived fuels with sustainable advanced "drop-in" biofuels compatible with today's transportation infrastructure.

ARRA Funded:

- 3 year effort
- DOE Funding $35.0M
- Cost Share $15.1M

Total $50.1M

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

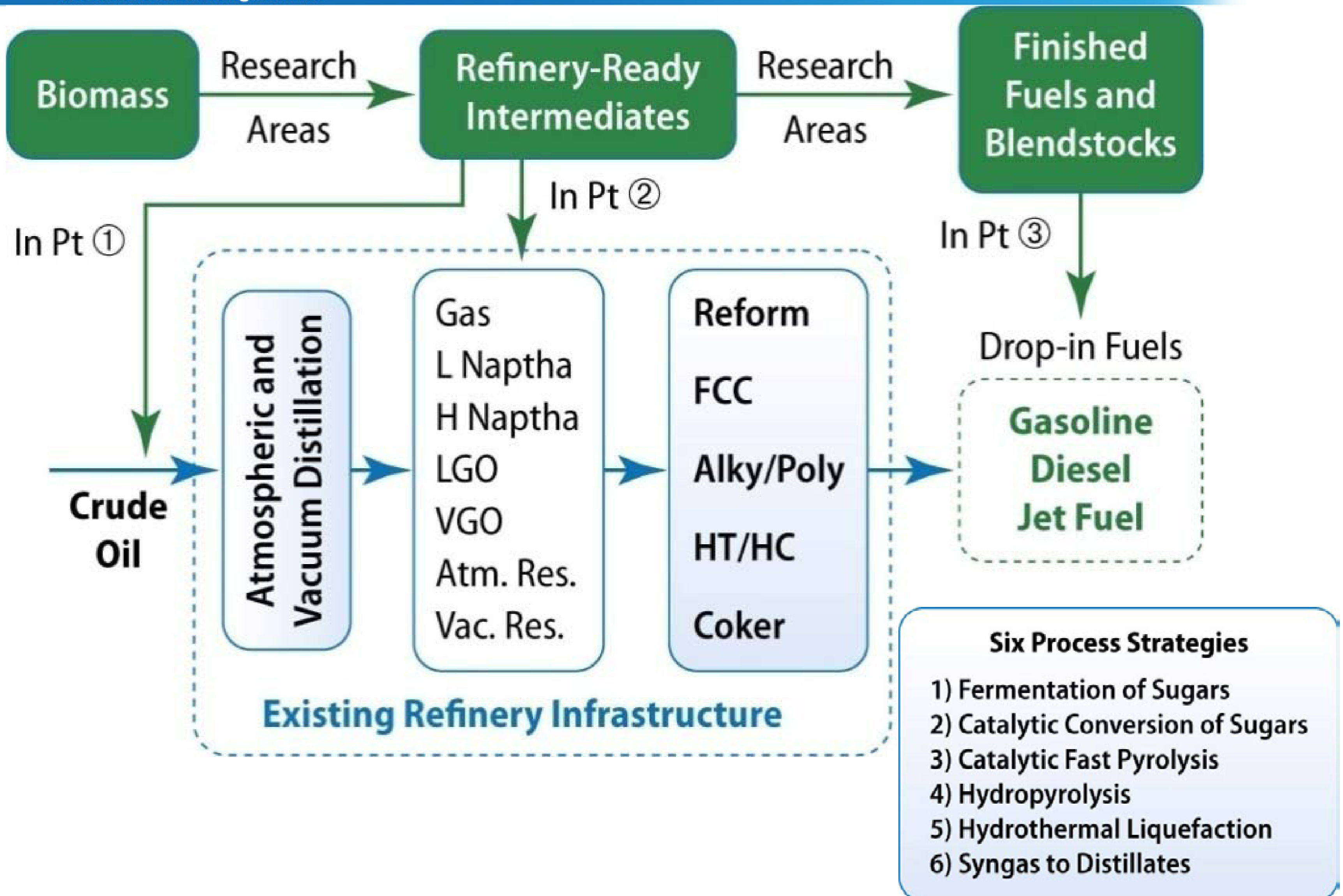
UOP, LLC

Virent Energy Systems

Washington State University

NABC
National Advanced Biofuels Consortium
Biofuels for Advancing America

Infrastructure Compatibility Strategy



NABC: For Open Distribution

Outlook and Final Thoughts

Outlook for 2011-2015

- 1990-2000: Demonstrate technical feasibility
  Focus on cellulosic ethanol
- 2001-2005: Show economic feasibility & scale potential
  Focus remains largely on cellulosic ethanol
- 2006-2010: Increase funding to accelerate biofuels RDD&D
  Expand RDD&D portfolio to higher alcohols and hydrocarbons
  Begin funding new concepts including hybrid BC/TC and algal pathways
- 2011-2015: Prove out and winnow advanced biofuels options
  Bring first large scale demonstrations on line

Leverage Past Learnings to Succeed in Commercialization Efforts

➔***Key to success at scale is accurately estimating cost and performance at smaller scales!***

Plant cost growth strongly correlated with:

- Process understanding (***integration issues***)
- Project definition (***estimate inclusiveness***)

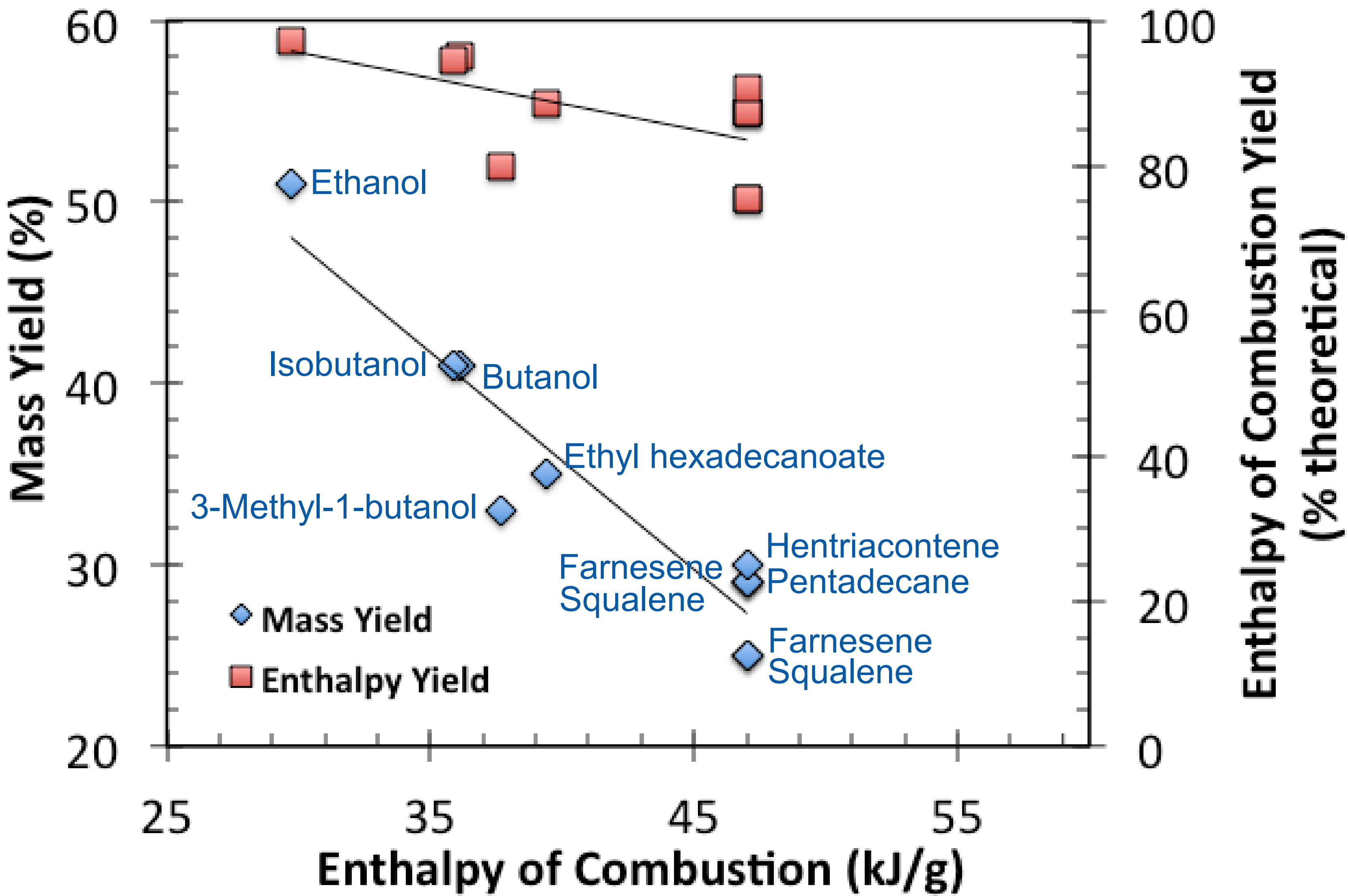
Plant performance strongly correlated with:

- Number of new steps
- Percent of heat and mass balances based on data
- Difficulty of waste handling
- Need to process primarily solid feedstocks

➔ **These issues all apply to lignocellulose processing using new technologies. We must directly tackle them!**

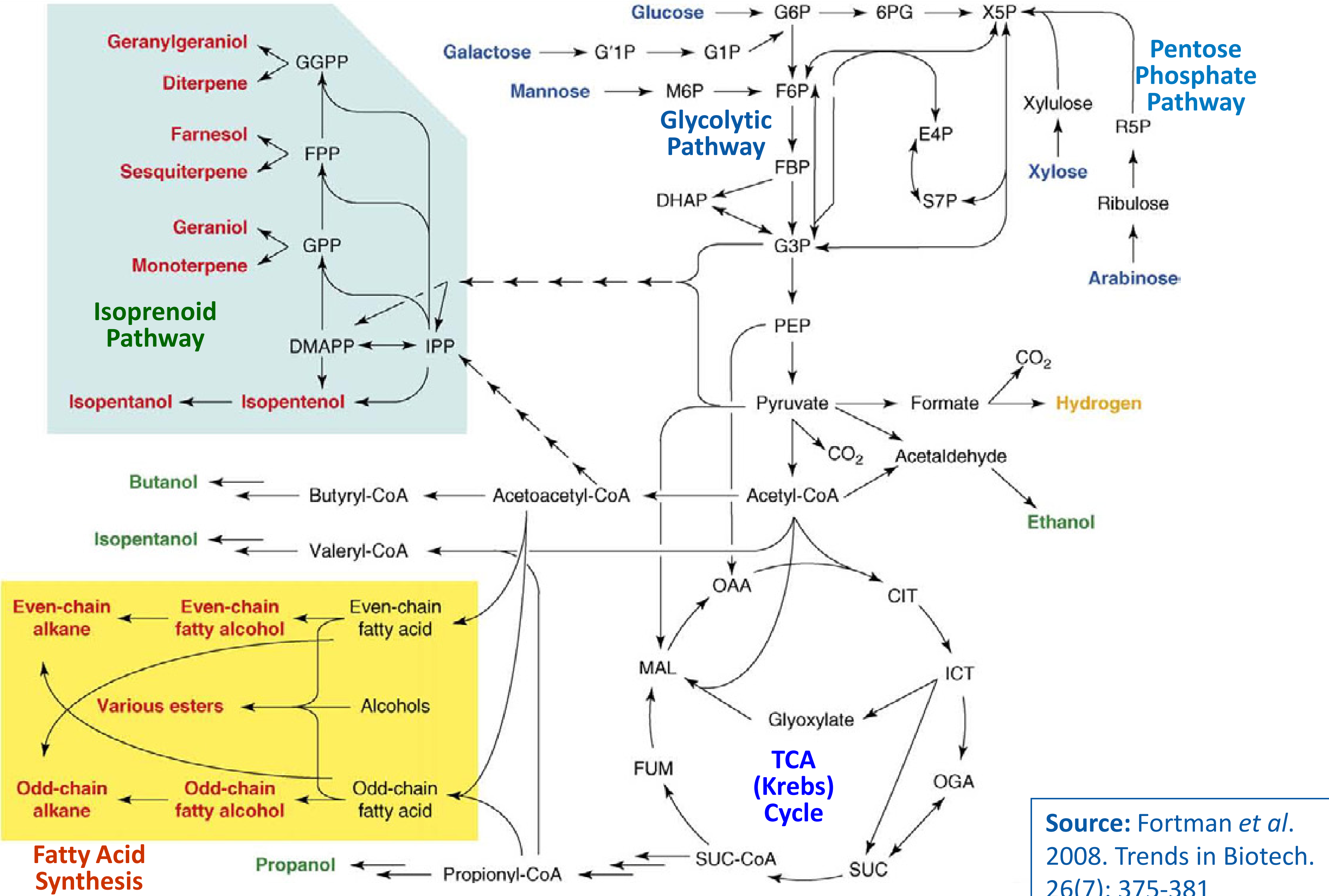
1981. Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants. 1981. Rand (for USDOE).
1985. Linking R&D to Problems Experienced in Solids Processing. Chemical Engineering Progress (May).
1988. Estimating Startup Times for Solids Processing Plants. Chemical Engineering (October).

Energy Density vs. Mass and Enthalpy Yields



Theoretical yield calculations from: Rude and Schirmer. 2009. Current Opinions in Microbiology, **12**:274-281.

Anabolic vs. Catabolic Product Pathways



Source: Fortman *et al*. 2008. Trends in Biotech. 26(7): 375-381

Final Thoughts

Lots of progress happening. Many process and product options being advanced and scaled up to pilot and demonstration scales. Commercialization beginning.

Solids handling issues and compositional analysis accuracy and throughput remain challenging technical issues limiting the pace of advanced biofuels RDD&D

Factors in play for cellulosic biofuels include:

- What pretreatment and enzymatic hydrolysis (saccharification) schemes will prove out?
- How much and how quickly will catalysts, hydrolytic enzymes and biofuels production strains be improved?
- How quickly will higher alcohols and hydrocarbons be proven at scale?

Potential game changers include:

- Price on (net) carbon, GHG emissions mitigation
- Competition for feedstocks (biopower, bioproducts)
- Production of higher value coproducts
- Price of petroleum & ethanol blend limit for non-FFVs

Acknowledgments

- USDOE’s EERE’s Office of the Biomass Program – Funding and selected slides on USDOE’s strategy and investments
- NREL’s Mark Davis – Slides on TC conversion progress
- NREL’s Dan Schell, Alex Chapeaux, Nancy Dowe Farmer and Andrew Lowell – Data on enzymatic hydrolysis glucose yields = f[insoluble solids]

More Information

National Renewable Energy Laboratory

www.nrel.gov

DOE's Biomass Program

www.eere.energy.gov/biomass/

DOE-USDA Biomass R&D Initiative

www.brdisolutions.com

Alternative Fuels

www.afdc.doe.gov

USA BioEnergy Atlas

http://maps.nrel.gov/bioenergyatlas

Built into Google Maps, BioEnergy Atlas includes two interactive maps, BioPower and BioFuels. These maps allow you to compare and analyze biomass feedstocks, biopower and biofuels data from the U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), and the U.S. Department of Agriculture.

BioFuels Launch

BioFuels Atlas is an interactive map for comparing biomass feedstocks and biofuels by location. This tool helps users select from and apply biomass data layers to a map as well as query and download biofuels and feedstock data. The state zoom function summarizes state energy use and infrastructure for traditional and bioenergy power, fuels, and resources. The tool also calculates the biofuels potential for a given area.

BioFuels Atlas was developed by the **National Renewable Energy Laboratory** with funding from the **DOE Biomass Program**.

BioPower Launch

BioPower is an interactive map for comparing biomass feedstocks and biopower by location. This tool helps users select from and apply biomass data layers to a map as well as query and download biopower and feedstock data. The analysis function offers common conversion factors that allow users to determine the potential biopower production for a selected feedstock in a specific area.

BioPower was developed by the **National Renewable Energy Laboratory** with funding from the **EPA Blue Skyways Collaborative**.

Thanks for Your Attention!
Questions?