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

Conversion Technologies II:

Bio-Oils, Sugar Intermediates, Precursors, Distributed Models, and Refinery Co-Processing

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Bryna Berendzen

Technology Manager

BETO Conversion Program

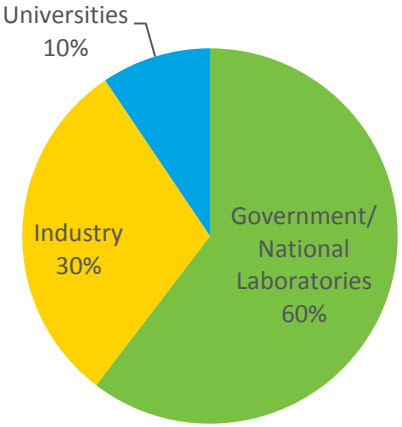
Conversion Program FY13/14 Workshops

- In the past year BETO has held 3 public workshops to engage stakeholders in discussions on the R&D needs within the various conversion technologies
- Biochemical:
  - PRINCE – Process Integration and Carbon Efficiencies - June 11-12, 2014
- Thermochemical:
  - GBTL – Natural Gas Biomass to Liquids - September 3, 2013
  - Bio-oil Co-processing Workshop – April 3, 2014

- No future FOAs are promised as a result of these workshops, these are stakeholder engagement activities that will all be considered for future program planning.

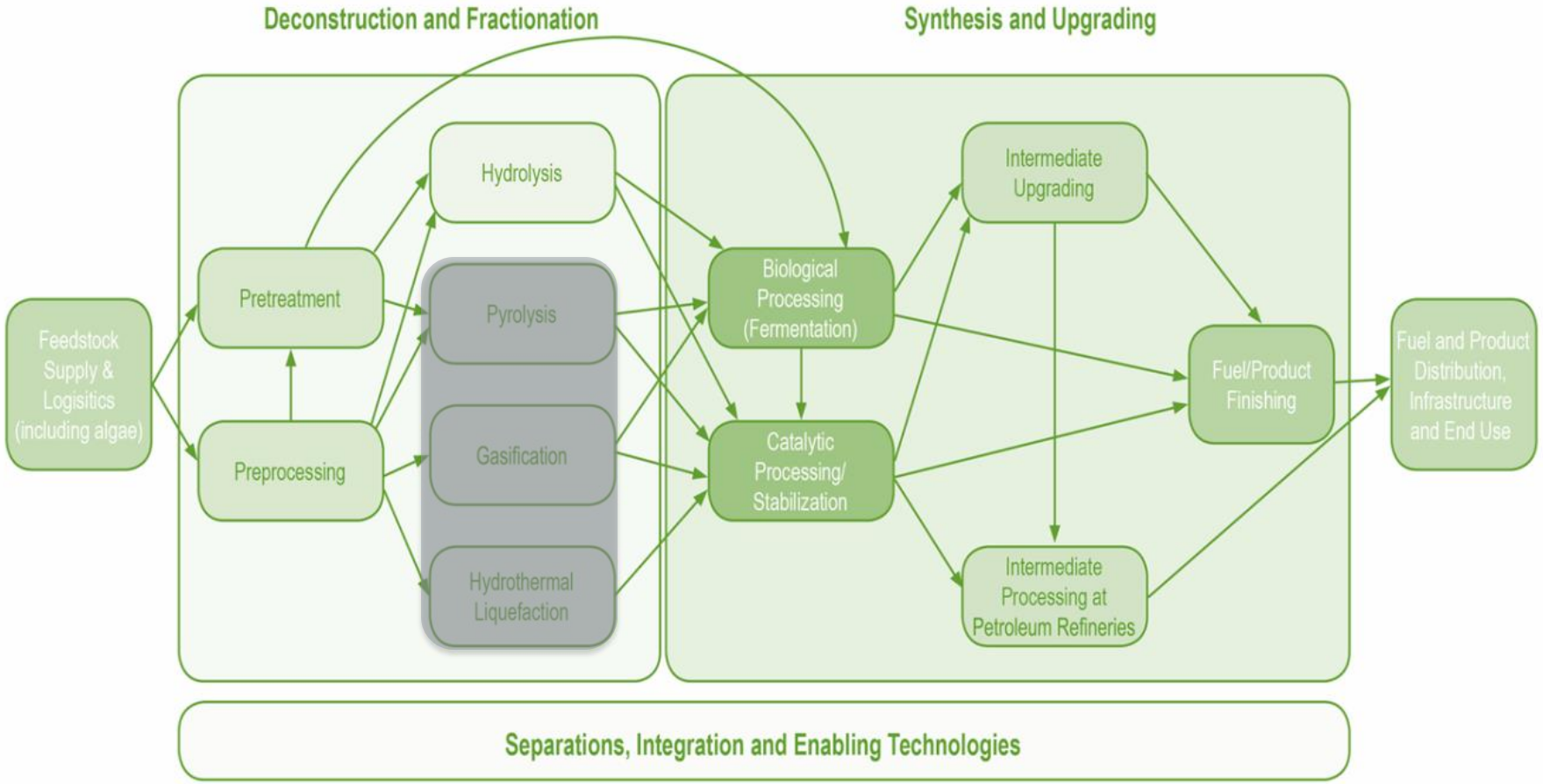
About the PRINCE Workshop

- The Process Intensification and Carbon Efficiency (PRINCE) workshop was held June 11-12, 2014 in Lakewood, CO
- Participants from industry, national labs, government and universities attended the workshop



- Focus of the workshop was to identify research gaps and technical barriers around Biochemical process integration, upgrading and separations technologies.

PRINCE - Technologies of Interest



PRINCE - Breakout Sessions

- Four breakout sessions were held. Participants were asked to address technologies in these topic areas;
  - Biological Conversion Technologies
  - Chemical Conversion Technologies
  - Process Integration and Separations Technologies
  - 'Other' – Necessary technologies not covered in other sessions
- Each breakout session was 2 hours long, during which participants were asked to identify applicable technologies and the metrics, barriers, and research and development needs associated with those technologies
- Participants were also asked to assess which technologies would have the greatest impact in the industry if successful

PRINCE - Biological Conversion Technologies

- Enzymatic Hydrolysis
  - Barriers: Lack of feedstock flexibility, enzyme loading, lack of fundamental process knowledge for newly-discovered enzymes
  - R&D Needs: Enzymatic hydrolysis tailored for specific processes, high-throughput discovery and characterization, development of modeling tools, understanding of process parameters, enzyme recycling
- Organisms for conversion of intermediates to fuels and chemicals
  - Barriers: Poor carbon/mass efficiency through metabolic pathways, organismal tolerance to inhibitors, few genetic tools for industrial organisms, few industrial organisms, extraction of product from organism/broth
  - R&D Needs: Better understanding of organisms and genetic tools, focus on industrially relevant organisms, use of real hydrolysate streams, understanding of process parameters, modeling tools for pathways, understanding economic drivers

PRINCE - Chemical and Catalytic Conversion Technologies

- Chemical Pretreatments
  - Barriers: Lack of feedstock flexibility, relatively low solids loading, pretreatments focused on five- and six-carbon sugars, carry-over of poisons to downstream processes
  - R&D Needs: Define feedstock input specifications, improved design of pretreatment reactors, recycling of reagents, development of integrated processes, matching process parameters (e.g. temperature, pressure)
- Catalytic upgrading of intermediates
  - Barriers: Short catalyst lifetimes, lack of multifunctional catalysts, high cost of catalysts, scale of catalyst development compared to hydrolysate produced
  - R&D Needs: Integration and use of real hydrolysate, better catalyst performance, better understanding of catalyst requirements, fundamental modeling, reactors for catalysis
- Lignin Utilization
  - Barriers: Depolymerization and repolymerization of lignin, lack of catalysts for depolymerization and for upgrading
  - R&D Needs: Catalyst development specific to lignin, better understanding of lignin and its degradation products, enzymes as an alternative to catalysts, understanding of products and techno-economics around lignin utilization alternatives

PRINCE - Process Integration and Separations

- Separations
  - Barriers: Particle size, high energy requirements, water usage, residual solids through processing, efficiency of recovery, lack of knowledge for appropriate solvents, emulsion formation, lack of materials and materials understanding, poor selectivity, and fouling
  - R&D Needs: Integration within an entire process, tailoring technologies for a process, defining process requirements, use of real process streams, better analytical tools, handling impurities, development of catalytic membranes, *in situ* recovery, reactor design, predictable scaling, engagement with manufacturers
- Process Integration
  - Barriers: Limited information in public literature, lack of scaled down and flexible systems, handling of fouling agents, no standards or specifications
  - R&D Needs: Outlining specifications and parameters for integration, online monitoring, analytical tools, engagement with manufacturers, predictable scaling

PRINCE - Other topics

- Feedstocks - Development, Logistics, and Handling
  - Barriers: Compositional variability, ash content, water usage, supply chain stability, impact of blending on downstream processes, storage, transportation
  - R&D Needs: Genetically engineered feedstocks, field trials to understand temporal and spatial variability, analytical tools, appropriate logistics
- Anaerobic Digestion
  - Barriers: Use of biogas as a feedstock, lack of microbial tolerance to inhibitors, presence of ammonia and nitrogen in feedstock, lack of TEAs and LCAs
  - R&D Needs: Engineering organisms to produce molecules other than methane, understanding microbial consortia for AD, feedstock pretreatment, empirical data for performing TEAs and LCAs
- Consolidated Bioprocessing
  - Barriers: Lack of understanding of fundamental aspects of the technology
  - R&D Needs: Development of organisms, enzymes, and cellulosomes, understanding process conditions, comparative TEAs and LCAs

PRINCE - Market Drivers and Considerations

- Must insure that potential fuels and chemicals will be acceptable to industry
  - While fuels may be positioned as direct replacements, trace impurities will be different than those in petroleum fuels and have different impacts on engines
- TEAs and LCAs will be critical for understanding the path to commercialization for bio-based fuels and chemicals
- Biomass-derived intermediates contain oxygen, much of which must be lost during processing to hydrocarbon fuels, lowering overall mass efficiency
  - Perhaps a better use of biomass is for specialty and commodity chemicals that contain oxygen, allowing for utilization of maximum biomass input and increased potential commercial impact

PRINCE - Conclusions & Path Forward

- R&D needs for biological and chemical conversion processes generally encompass development of efficient unit operations, understanding integration of unit operations for an end-to-end process, and developing the techno-economic and life cycle data to enable focused development and commercialization

- The draft report has been provided to workshop participants for comment as of 7/28/14.
  - Comments are due back to the program no later than

- Workshop summary report will be available on the workshop website by the end of summer

http://www.energy.gov/eere/bioenergy/process-integration-and-carbon-efficiency-workshop

GBTL - Natural Gas-Biomass to Liquids Workshop

- Coordinated between the Bioenergy Technologies Office, Office of Fossil Energy, and the National Energy Technology Laboratory

- Held September 3, 2013 in Chicago, IL in conjunction with tcbiomass2013

- Follow-up webinar entitled “The Potential for Natural Gas to Enhance Biomass Technologies” conducted on February 6, 2014

- Materials available on BETO website (http://www.energy.gov/eere/bioenergy/aviation-fuels)

GBTL - Motivation for the Workshop

- The recent development of the increased availability of low cost natural gas has increased opportunities to consider the use of natural gas as a feedstock for conversion into liquid hydrocarbons (GTL).
- Co-conversion of natural gas with biomass (GBTL) has the potential of increasing yield of liquid product while also having lower greenhouse gas emissions relative to petroleum.
- DOE is interested in further understanding how the use of natural gas and biomass may be optimized and integrated into a conversion process to produce liquid fuels.
  - Office of Energy Efficiency and Renewable Energy
    - Bioenergy Technologies Office
  - Office of Fossil Energy
  - ARPA-E

GBTL - Workshop Objectives

- The objective of the workshop was to obtain input from industry, research establishments, and other experts to identify the pre-competitive R&D and scale-up challenges to commercializing GBTL.
  - Focus ***more*** on more clearly defining the ***problems***
  - Focus ***less*** on potential ***solutions***

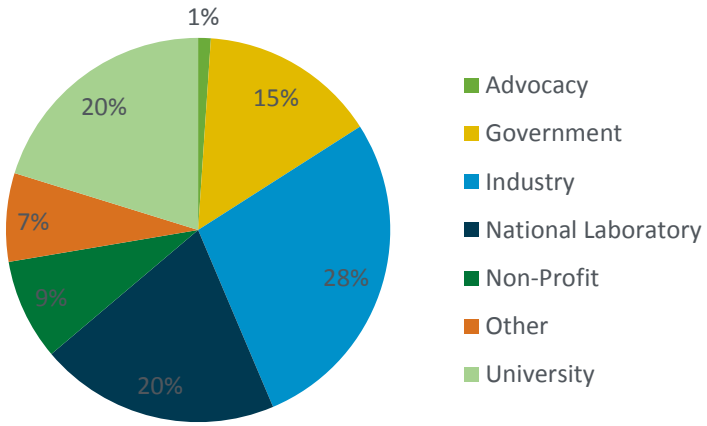
- To enable networking and collaboration for stakeholders in this emerging area

GBTL – Key Discussion Topics

- Standardization of methodology to determine GHG reductions is needed
- May be ideal for distributed or seasonal situations such as biomass available after natural disasters or stranded natural gas resources
- Catalyst improvements may be applicable to both technologies
- Ability of technologies to switch between biomass and natural gas blends may reduce economic risk
- Potential to reduce capital costs may benefit both technologies

Bio-Oil Co-Processing Workshop

- Held April 3, 2014 in conjunction with the AIChE Spring Meeting in New Orleans, LA
- Opening Presentations:
  - Initial Perspectives on Biomass and Bio-Oils in Existing Infrastructure, Corinne Drennan, Pacific Northwest National Laboratory (PNNL)
  - Back to the Well – Repurposing Refining Expertise, Liz Moore, Bioenergy Technologies Office
  - The Prospect of Shared Value from Biomass-Derived Hydrocarbons, Michael Talmadge, National Renewable Energy Laboratory (NREL)
- Participants represented all points in the supply chain

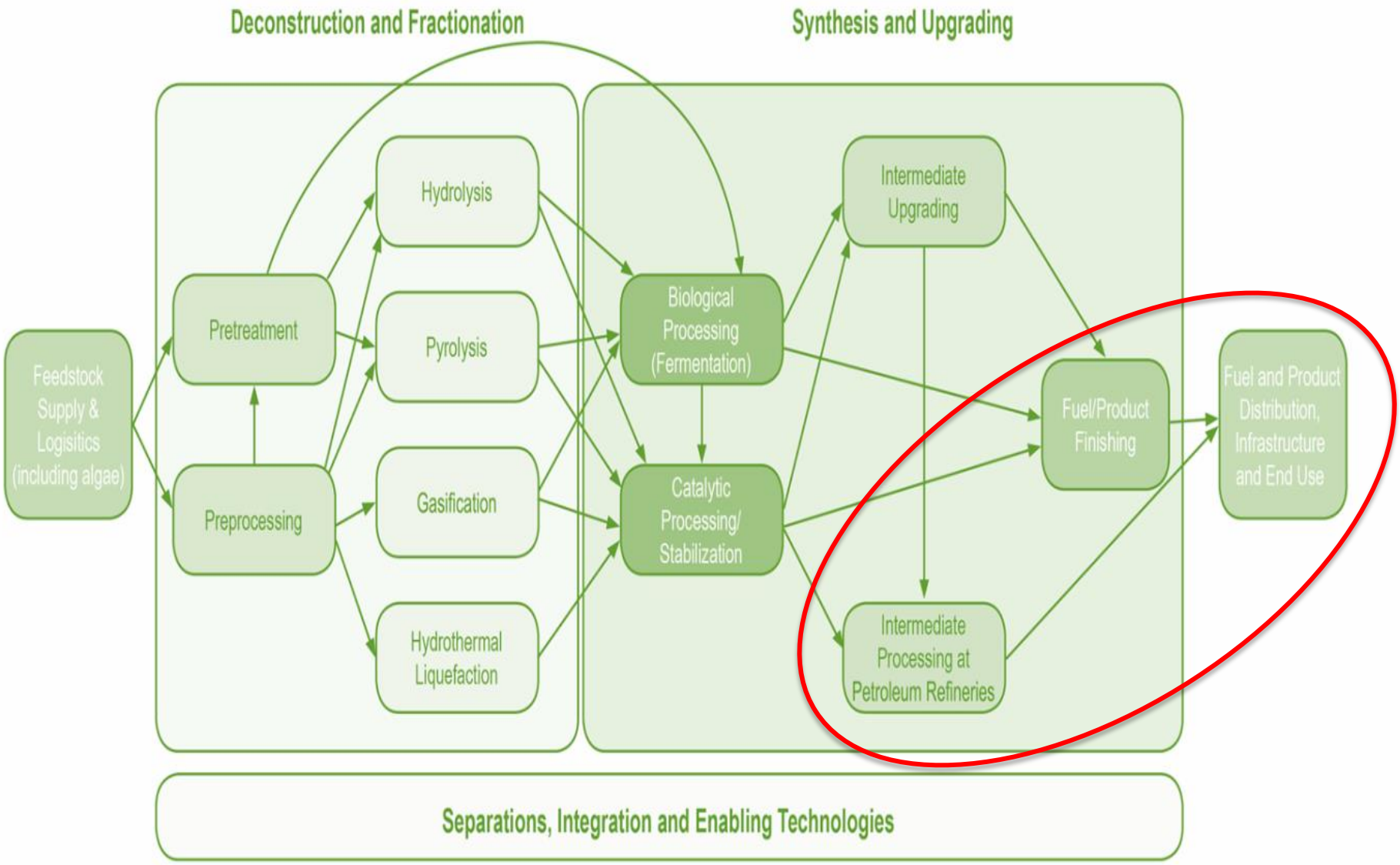


Bio-Oil Co-Processing Workshop Goals

- Participants were asked to:
  - Explore the resource expansion potential for conventional refineries by considering biomass-derived oils as a supplemental feedstock.
  - Identify the next step(s) in gathering information about the physiochemical properties, reactivities, and compatibilities of intermediates to petroleum refineries.
  - Understand and specify bio-oil intermediate requirements for use in petroleum refineries and the distribution infrastructure.

Bio-Oil Co-Processing Workshop Outcomes – Remaining R&D Needs

- Standards and Methods Development
  - Bio-Oil specifications and analytical methods
- Computational Modeling and Analytical Tools
  - Online monitoring of bio-oil quality and predictive modeling tools
- Process Intensification
  - Determining ideal scale for bio-oil production in relation to existing refining infrastructure
- Industry and Refinery Integration
  - Understanding potential economic benefits for existing petroleum refineries
- Fractionation, Clean-Up, and Conditioning
  - Impacts of trace contaminants (CA, K, Na, Mg, Cl) on bio-oil quality
- Feedstock Interface
  - Effects of feedstock pre-treatment


Deconstruction and Fractionation
Synthesis and Upgrading
Feedstock Supply & Logisitics (including algae)
Pretreatment
Preprocessing
Hydrolysis
Pyrolysis
Gasification
Hydrothermal Liquefaction
Biological Processing (Fermentation)
Catalytic Processing/ Stabilization
Intermediate Upgrading
Intermediate Processing at Petroleum Refineries
Fuel/Product Finishing
Fuel and Product Distribution, Infrastructure and End Use
Separations, Integration and Enabling Technologies

Conversion Technologies II:

- **Bio-Oils, Sugar Intermediates, Precursors, Distributed Models, and Refinery Co-Processing**

  - *This session will highlight successful business models and the resources needed for realizing the potential compatibility of biologically, chemically, and thermochemically derived fuels and fuel intermediates with existing markets. Panelists will focus on how to strategically leverage innovative technological and financial solutions in order to meet the challenges faced by this emerging market.*

Co-Processing and Repurposing Technologies

- The Bioenergy Technologies Office recognizes the value in technologies that have been developed by other industries
- Recent program activities have explored the potential in applying these technologies to further advance the production of renewable fuels and products
- Workshops encourage stakeholder involvement to identify future R&D needs
  - Process Intensification and Carbon Efficiency (PRINCE)
  - Natural Gas-Biomass to Liquids (GBTL) Workshop
  - Bio-Oil Co-Processing Workshop