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

2019 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

BETO Overview

March 4, 2019

Jonathan Male

Director

Outline

I. Welcome to BETO Peer Review

II. Overview

III. BETO Portfolio

IV. Response to the 2017 BETO Peer Review

Welcome!

2019 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

March 4-7, 2019, Hilton Denver City Center, Denver, CO

A Special Thanks To:

The 2019 Steering Committee	
Bill Crump (Committee Chair)	Leidos
Suzanne Lantz	DuPont
Kelsey McNeely	ExxonMobil
Stephen Costa	U.S. Department of Transportation - Volpe
John Sheehan	Colorado State University

and the 57 Reviewers from industry, government, academia and non-profits!

Bioenergy Technologies Office's Mission and Vision

Vision: A thriving and sustainable bioeconomy fueled by innovative technologies

Mission: Developing transformative and revolutionary sustainable bioenergy and bioproducts technologies for a prosperous nation

Strategic Goals: Develop industrially relevant technologies to enable domestically produced biofuels, biopower, and bioproducts

BETO Reduces Technology Uncertainties and Enables Affordability Through R&D

From Challenge to Opportunity

THE CHALLENGE

More than $215 million is spent **every day** on foreign oil **imports ($43/barrel/day in 2016*)**. Dependence on **foreign oil** can leave us vulnerable to disruptions in supplies and contributes significantly to our trade deficit.

Transportation accounts for 67% of petroleum consumption.

*Annual Energy Outlook 2017 with projections to 2050
eia.gov/outlooks/aeo/pdf/0383(2017).pdf

THE OPPORTUNITY

More than **1 billion tons of biomass** could be domestically converted into biofuels and products.

Biomass could displace up to **25%** of U.S. petroleum use annually by 2030, **keeping revenues in the United States**, adding **jobs,** and reducing annual CO_2 emissions**.

** Rogers et al. 2016, An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy.
onlinelibrary.wiley.com/doi/10.1002/bbb.1728/full

Bioenergy Technologies Office's Critical Program Areas

Production & Harvesting

Feedstock Supply & Logistics

Works to reduce the cost, improve the quality, and increase the volume of sustainable feedstocks available for delivery to a conversion process.

Advanced Algal Systems

Focuses on improving the productivity of algal biomass and enhancing the efficiency of cultivation and harvesting.

Conversion & Refining

Conversion

Develops technologies to convert non-food feedstocks into biofuels, bioproducts, and biopower.

Conducts feedstock blend testing, separations, materials compatibility evaluations, and techno-economic analyses to focus research on highest impacts.

Distribution & End Use

Advanced Development and Optimization

Aims to reduce technology uncertainty in bioenergy by integrating individual technologies into a system/process and provides vital knowledge fed back to research programs.

Crosscutting

Sustainability and Strategic Analysis

Supports program decision-making and develops science-based strategies to understand and enhance the economic and environmental benefits of advanced bioenergy.

FY 2017-FY 2019 BETO Budget

Program Area	FY 2017*	FY 2018*	FY 2019*
Advanced Algal Systems (AAS)	30,000	30,000	32,000
Feedstock Supply and Logistics (FSL)	20,000	29,000	30,500
Conversion Technologies	90,230	103,000	96,000
Advanced Development and Optimization (ADO)	54,041	54,545	57,500
Strategic Analysis and Sustainability	10,729	5,000	10,000
Total, Bioenergy Technologies	205,000	221,545	226,000

*Dollars in thousands

Selected Bioenergy Technologies Office's Consortia






Feedstock-Conversion Interface Consortium (FCIC)

Chemical Catalysis for Bioenergy (ChemCatBio)

Agile BioFoundry (ABF)

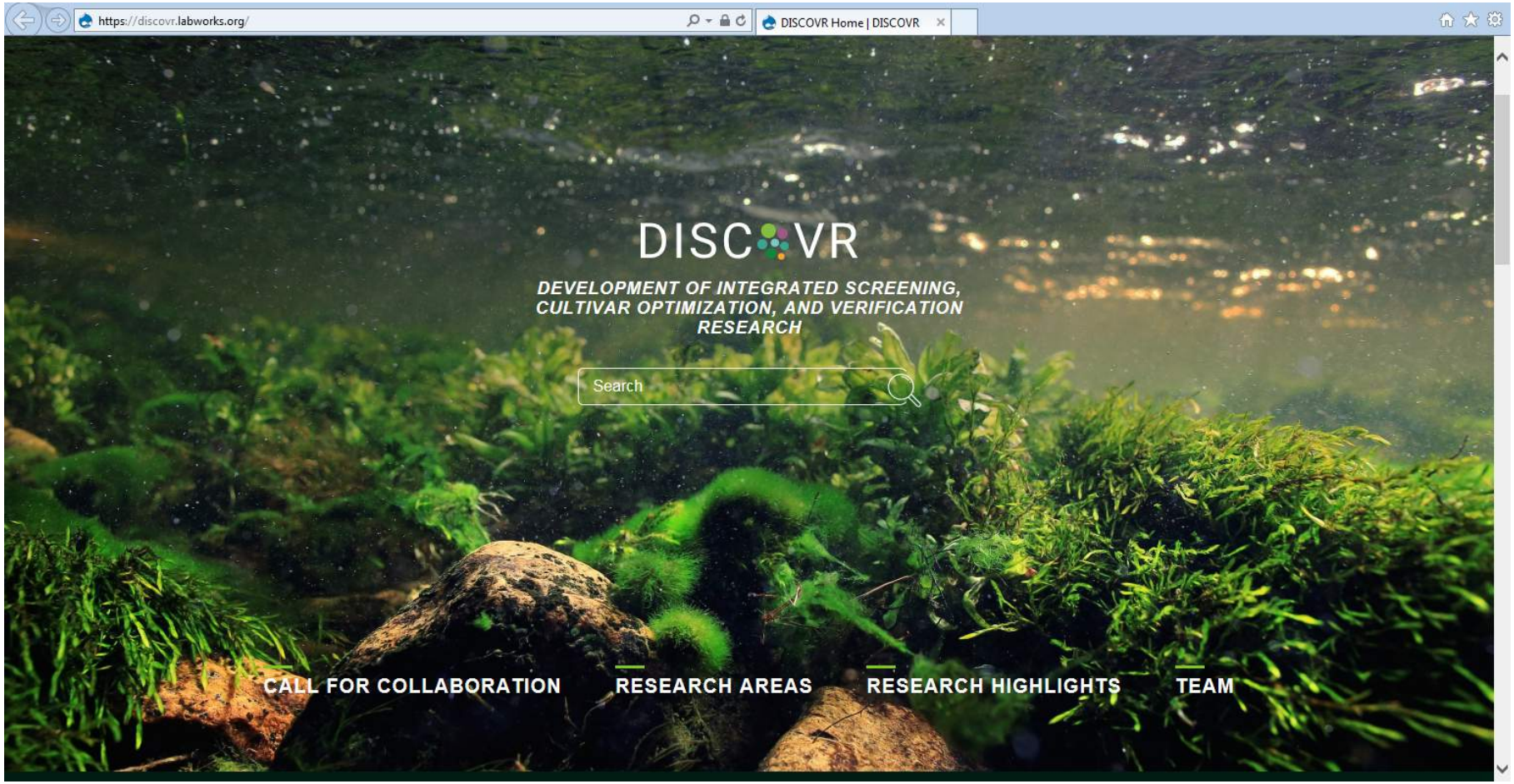
Bioprocess-ing Separations Consortium (BioESep)

Co-Optimization of Fuels and Engines (Co-Optima)

Consortium for Computa-tional Physics and Chemistry (CCPC)

DISCOVR: Development of Integrated Screening, Cultivar Optimization, and Verification Research

- DISCOVR Consortium achieved a relative **improvement in algae summer productivity of 28%** over baseline species, for a total average of 29.9 ± 3.1 $g/m^2/day$ (n = 20).
- Website and Call for Collaboration announced February 2019:



Demonstration Market Transformation becomes Advanced Development and Optimization

Potentially Untapped Carbon Resources

Leveraging DOE's National Laboratories expertise in polymer deconstruction in biomass and applying it to distributed sources of waste carbon to make molecular building blocks for fuels, products, and energy

Wet Wastes:
Biosolids, Food Wastes, Manures

Economically Advantageous Feedstocks

Gaseous Wastes:
CO and CO_2

Solid Wastes:
Sorted Municipal Solid Waste including Plastics

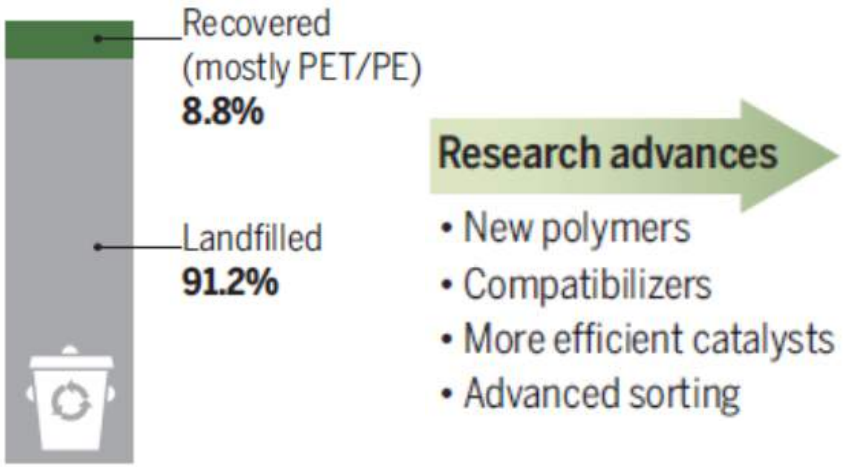
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

What is Needed: Better Plastics, Better Recycling

Moving beyond PET/PE recycling

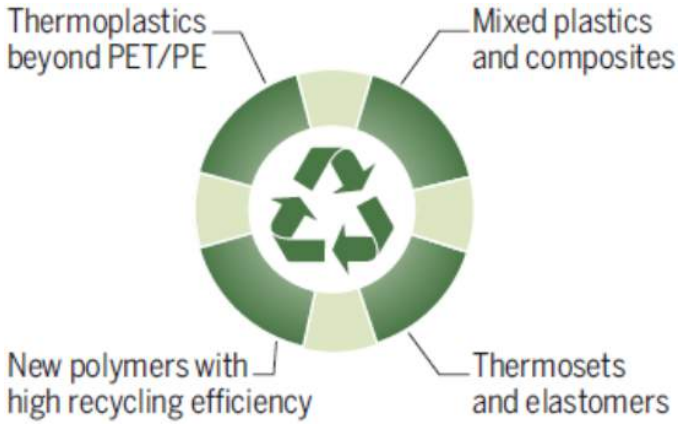
Most plastic waste is not currently recycled – New methodologies hold promise for recycling a wider range of plastics, including mixtures.

Current plastic waste treatment



BETO Opportunity Areas

Recycling of diverse polymers

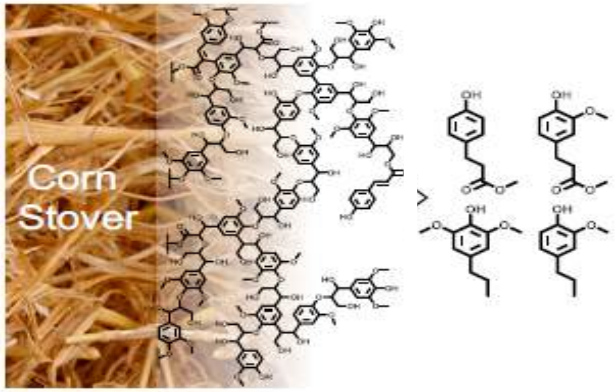


Garcia, J.M., Robertson, M.L. The Future of Plastics Recycling. *Science* 2017, 358 (6365), 870-872.

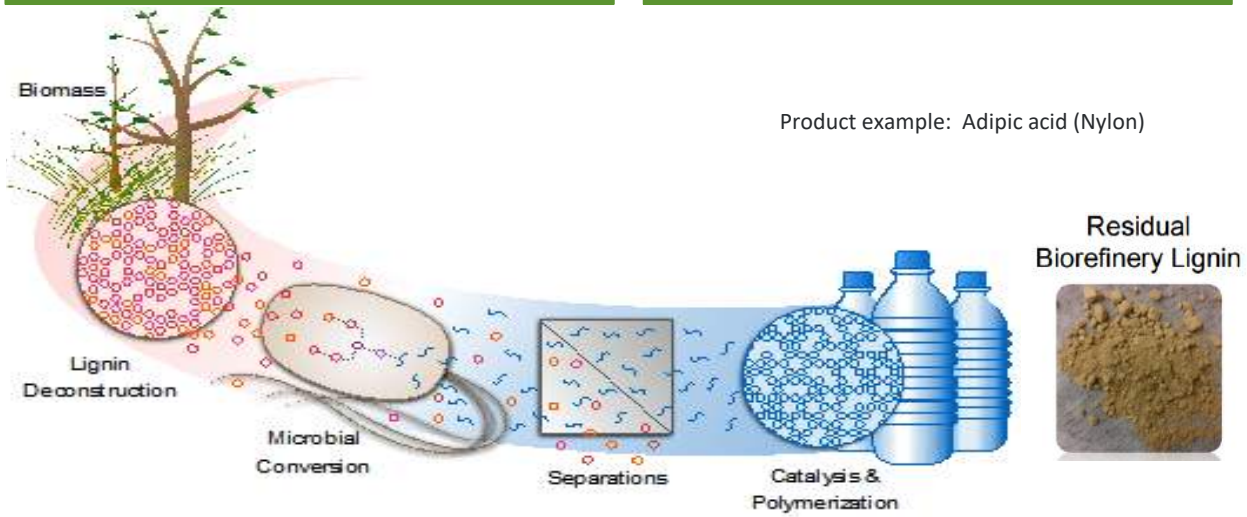
Today's Waste = Tomorrow's Untapped Resources

Lignin Valorization

Chemical Breakdown



Biological Funneling



Catalytic Upgrading

Product example: Adipic acid (Nylon)

Motivation: Lignin constitutes 15-40% of biomass carbon but it is currently considered a waste-stream in biorefineries, generally burned for heat and power.

Techno-economic modeling at NREL has indicated that lignin valorization to high-value products may reduce lignocellulosic biofuel cost by ~$1-2/gge.

FY18 FOA Selections on conversion of lignin to higher-value products:

- Two awards, $3.4 million
- Carbon fiber and spray insulation, thermoset polymers used for fiberglass and automotive applications

DOE/USDA Biomass Research and Development Initiative (BRDI) awarded and started to develop a solvent liquefaction process for feedstock deconstruction and lignin upgrading

2017 Peer Review Office Level Suggestions

What changes has BETO made based on the results of the 2017 Peer Review?

Lessons Learned on BETO Portfolio

Peer Review 2017 Comments & Programmatic Suggestions

"BRDi, DPA, TCF, and SBIR/STTR projects were not adequately covered in the 2017 Peer Review"

Actions to date

- **TCF and SBIR/STTR projects will be among those presenting in our first ever Peer Review Poster Session.**
  - **4:30-6:30PM Monday and Tuesday evening**
- **TCF and SBIR projects will be discussed in the "Industry Partnerships: Mechanisms, Opportunities, and Success Stories" plenary.**
  - **Tuesday morning**
- **Defense Production Act (DPA) projects are now being reviewed in the ADO session.**
  - **Tuesday afternoon**
- **BRDi projects will be presented in their respective parts of the portfolio review.**

Lessons Learned on BETO Portfolio

Peer Review 2017 Comments & Programmatic Suggestions

"The addition of industry oversight or formalized advisory positions for AOP projects may be advisable. One particular area that might benefit from this type of coordination is the development of products from lignin."

Actions to date

- **Direct Funding Opportunities (DFOs) have been utilized to fund Biopower, Agile BioFoundry and ChemCatBio projects.**
  - **DFOs encourage collaboration between industry and national labs.**
- **Consortia such as Co-Optima, Agile BioFoundry, and ChemCatBio continuously engage with industry to advance common needs.**
  - **The consortia employ a laboratory call process that enables working with industry and universities as well.**
- **Lignin projects initially utilize model compounds to understand mechanisms.**
  - **These transition to real world lignin or lignin derivative streams in order to increase relevance to industry.**

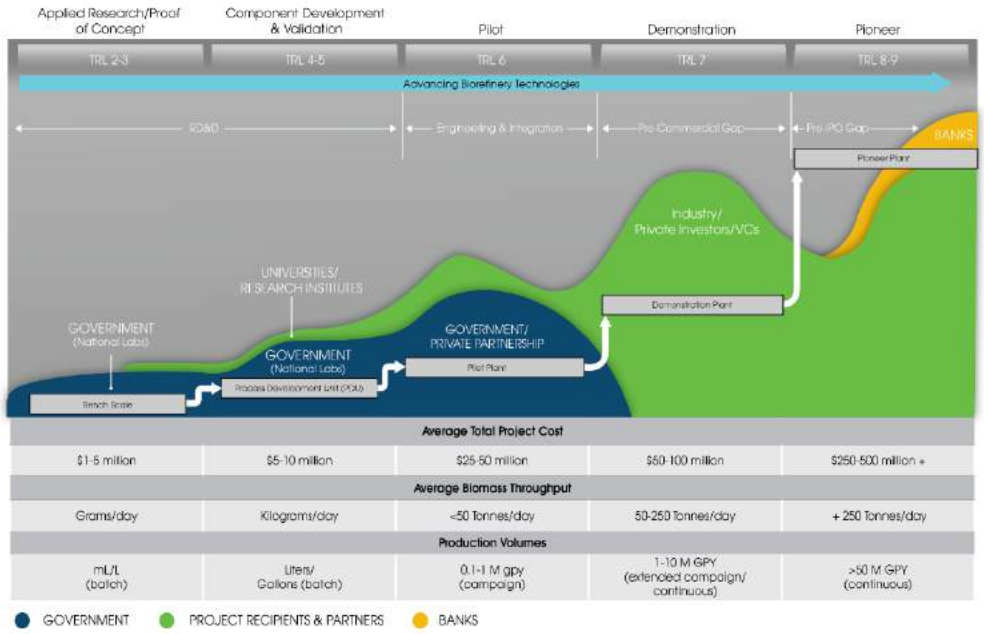
Lessons Learned on BETO Portfolio

Peer Review 2017 Comments & Programmatic Suggestions

"Investment in activities across the TRL spectrum is essential to leveraging innovations in bioenergy, with continued emphasis on commercial viability"

Actions to date

- **BETO has a rich pipeline of innovative ideas and has a mix of TRL levels from TRL 2-4 predominantly, but with some TRL 5 and TRL 6.**
  - **The higher TRL are in competitive awards with industry**
- **BETO continues to engage stakeholders to capture the latest thinking in rapidly evolving research areas**
- **BETO brought on a Deputy Director Detail, Carla Frisch, who helped foster additional novel thinking and perspectives**



Don Stevens

1949-2019

A notecard station has been set up to leave messages for his family.

Appendix

Bioenergy Delivers Unique Value

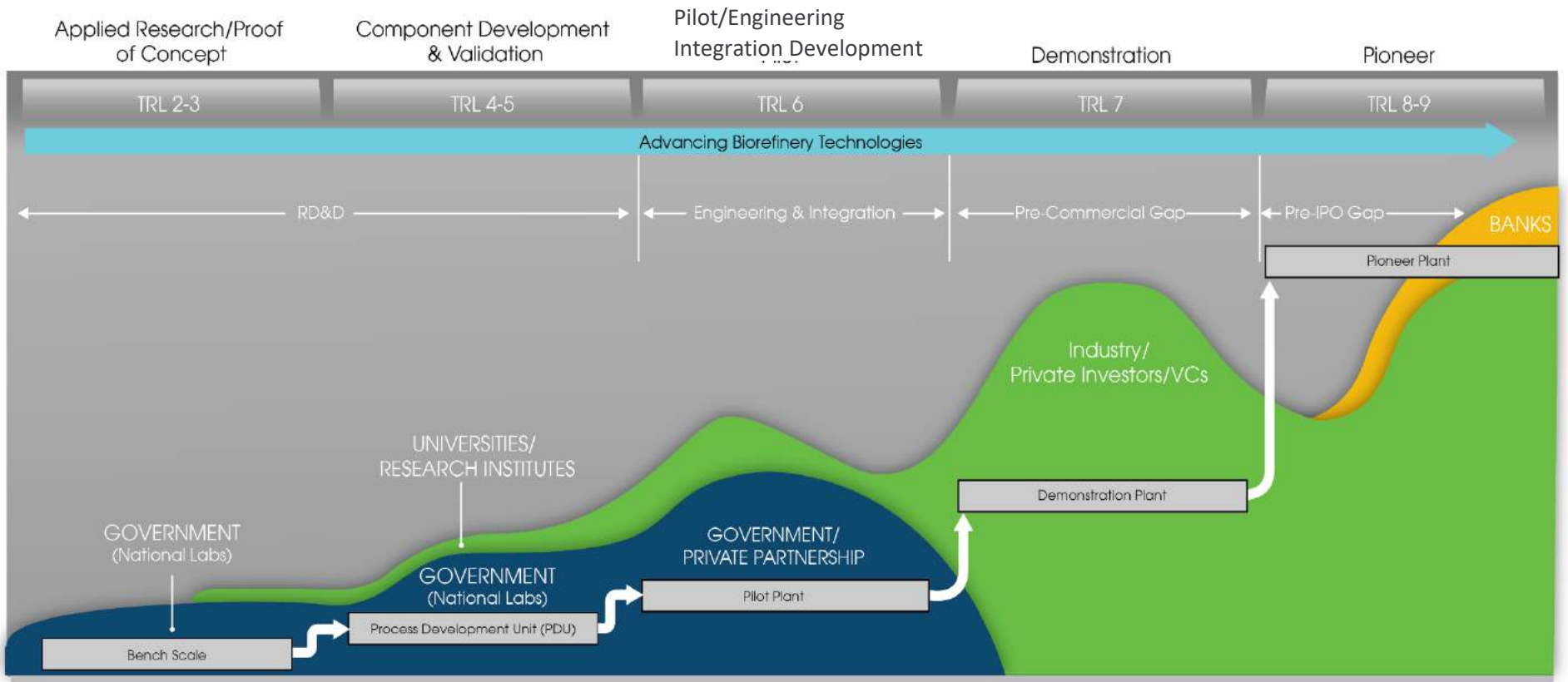
BETO funds research and development activities that reduce the price of production of biofuels, biopower, and bioproducts which enable:

- Increasing domestic bioenergy production to support America's ***national security*** interests
- Creating American ***jobs***, boosting ***economic growth***, and encouraging ***investment*** across the nation
- Advancing U.S. ***competitiveness*** in global energy and bioproduct markets
- Maximizing the use of America's abundant biomass ***resources***
- Improving the ***quality of life*** for Americans

America's Biomass Resources Could Provide Domestic Energy, Revenue, and Jobs

POET-DSM Project Liberty – Pioneer Commercial Plant

Moving to Earlier TRL Focus



Average Total Project Cost				
$1-5 million	$5-10 million	$25-50 million	$50-100 million	$250-500 million +
Average Biomass Throughput				
Grams/day	Kilograms/day	<50 Tonnes/day	50-250 Tonnes/day	+ 250 Tonnes/day
Production Volumes				
mL/L (batch)	Liters/ Gallons (batch)	0.1-1 M gpy (campaign)	1-10 M GPY (extended campaign/ continuous)	>50 M GPY (continuous)

GOVERNMENT PROJECT RECIPIENTS & PARTNERS BANKS

Feedstock Conversion Interface Consortium (FCIC)

Challenge: >70% of new pioneer biorefineries fail to achieve continuous profitable operations.

Vision: Quantify, understand, and manage variability in biomass from field through downstream conversion and to understand how biomass composition, structure, and behavior impacts system performance

Provide First Principles based knowledge related to unit operations

Provide transfer functions to bridge scales from bench to pioneer biorefinery

Provide valuation of intermediate streams which can be commoditized

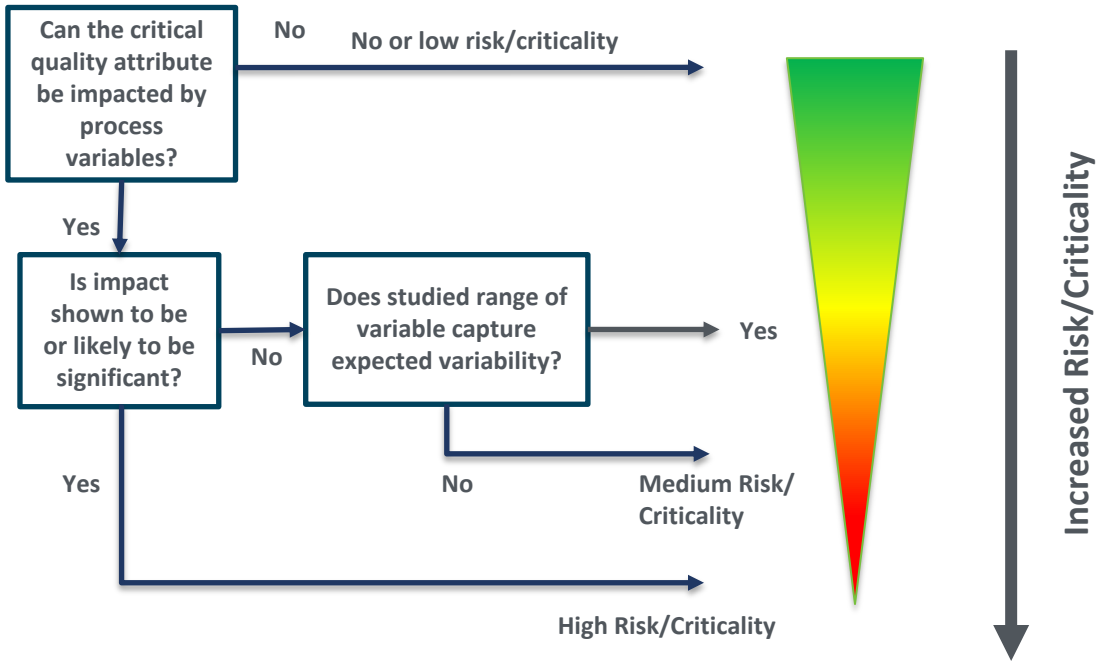
TOOLS FOR TECHNOLOGY DEVELOPERS AND BIOREFINERY DESIGNERS

Feedstock Conversion Interface Consortium (FCIC)

New Goals and Structure (2019 onwards):

- Shift in approach from “quality by testing” to “quality by design”
  - Disciplined methodology employed by the pharma industry to manage variability in processes

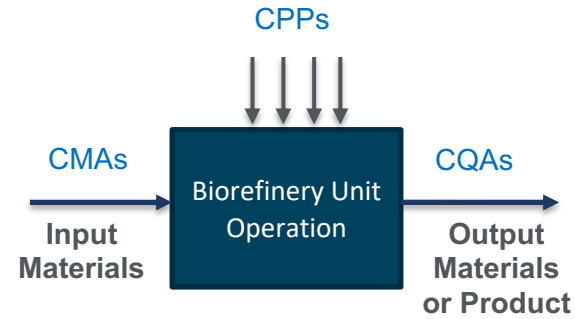
- 5 “processing” tasks: (feedstock variability, materials handling, preprocessing, low-temp conversion, high-temp conversion)
- 3 Enabling tasks: (materials of construction, crosscutting analysis, data integration)



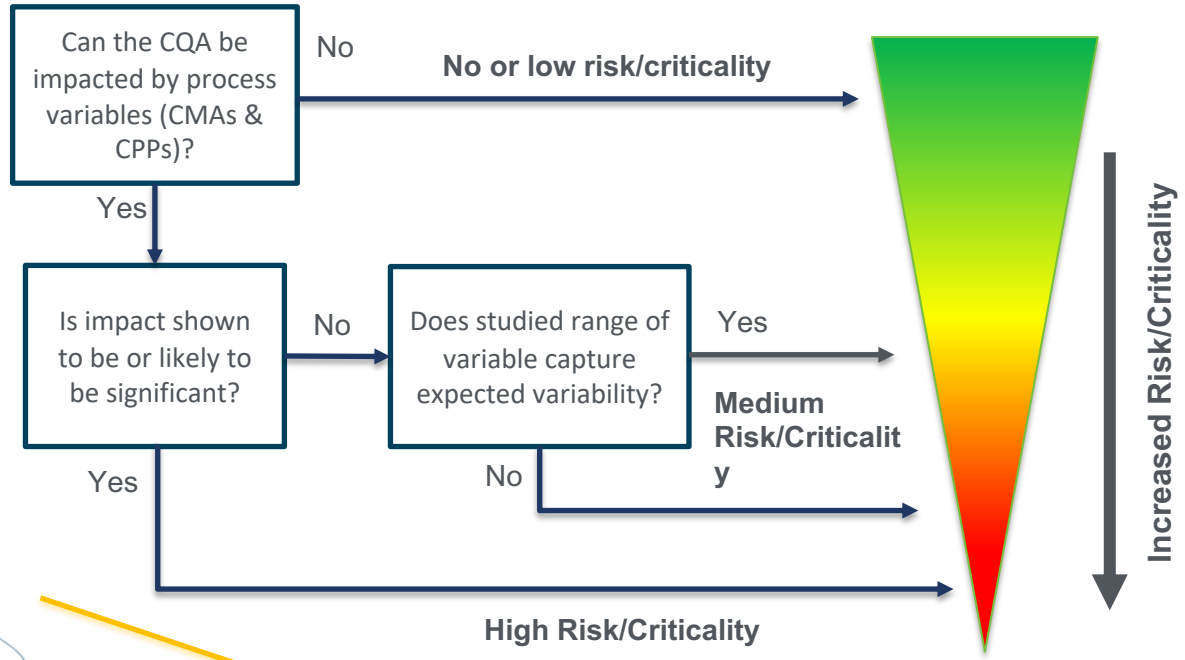
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Quality by Design: A framework for systematically managing variability

Schematic Flow Diagram for identification of CMAs/CPPs



$CQAs = f(CMA_1, CMA_2,\ldots, CPP_1, CPP_2,\ldots)$



Sandia National Laboratories · Argonne National Laboratory · Idaho National Laboratory · Pacific Northwest National Laboratory · Los Alamos National Laboratory · Oak Ridge National Laboratory · Berkeley Lab · NREL · National Energy Technology Laboratory

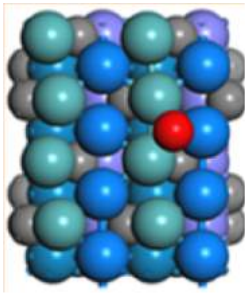
fcic Feedstock-Conversion Interface Consortium

U.S. Department of Energy | Energy Efficiency & Renewable Energy

Consortium for Computational Physics and Chemistry (CCPC)

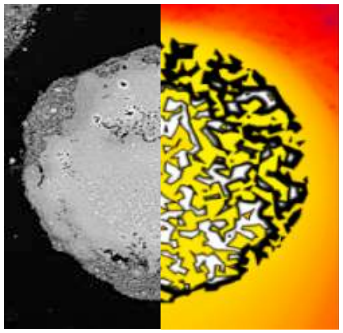
A multi-scale problem … A multi-lab solution

Atomic Scale Catalysis Modeling



Accelerating ChemCatBio catalyst development *by investigating novel catalyst material combinations and understanding surface chemistry phenomena to guide experimentalists*

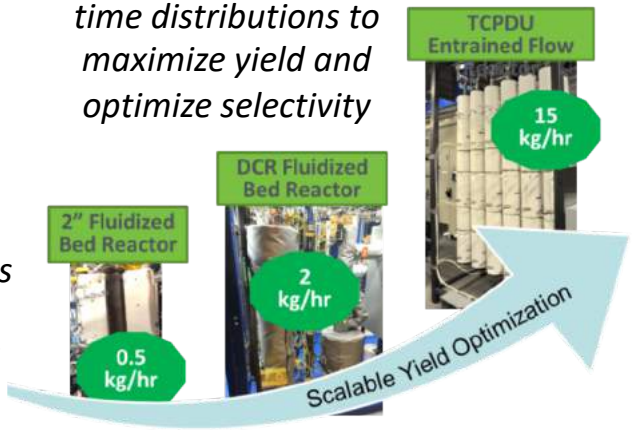
Meso Scale Particle Modeling



Addressing bio-complexity challenges *by understanding mass transport of reactants/products, reaction kinetics, and coking and deactivation processes*

Process Scale Reactor Modeling

Enabling scalability of ChemCatBio technology *via process residence time distributions to maximize yield and optimize selectivity*



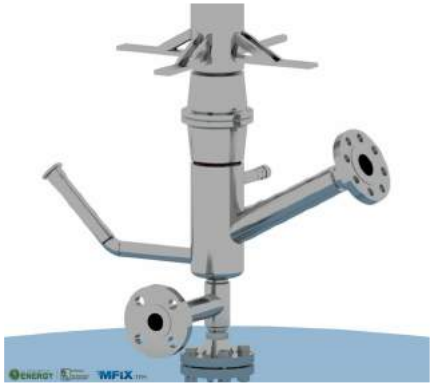
ChemCatBio Enabling Projects

CCPC
www.cpcbiomass.org

ACSC
Advanced Catalyst Synthesis & Characterization

CCM
Catalyst Cost Model

ChemCatBio
Chemical Catalysis for Bioenergy



Oak Ridge National Laboratory · NREL National Renewable Energy Laboratory · National Energy Technology Laboratory · Argonne National Laboratory · Pacific Northwest National Laboratory

U.S. Department of Energy | Energy Efficiency & Renewable Energy

Re-Evaluating the Value of CO_2 as a Resource

- BETO-supported National Academies of Sciences study on "Developing a research agenda for utilization of gaseous carbon waste streams"

- CO_2 Valorization via Rewiring Carbon Metabolic Network in bacterial cells
  - NREL tailored bacteria as a model for direct biochemical CO_2 utilization, reaching 150 mg/L titer of 3-hydroxybutyrate (3-HB, a polyester precursor) and developing CRISPR-Cas9 gene editing tools

- Three FY18 FOAs awarded in Topic Area 5: Rewiring Carbon Utilization

LanzaTech | Montana State University | Johns Hopkins University

- Formate Lab Call – new AOPs in early stage R&D for biological platforms capable of upgrading formate, which can be efficiently generated from CO_2
  - NREL – Improving formate upgrading via bacterial conversion
  - NREL – Enhancing CO_2 conversion to value-added products via formate
  - NREL/LBNL – Synthetic cycle for electrosynthesis of products and fuels from formate

BETO has a Role in Mixed Plastics and Composites

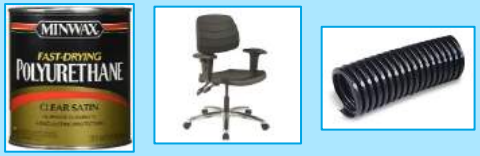
Materials: C-C Plastics

Challenges:
- C-C bond linkages
- Crystallinity
- Contamination
- Breakdown rate

Materials: Polyesters
PET

Challenges:
- Selective C-O chemistry
- Contamination/mixed streams
- Breakdown rate/extent
- Crystallinity

Materials: Textiles & Foam
Nylons, lactams, polyamides, polyurethanes



Challenges:
- Selective C-O, C-N chemistry
- Contamination/mixed streams
- Breakdown rate/extent

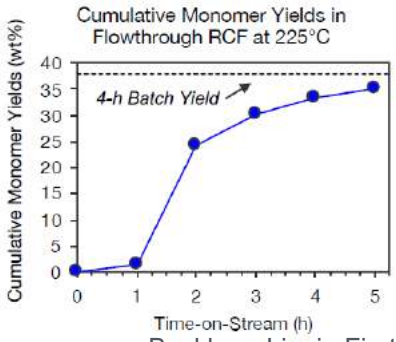
Basic Science Opportunity (Crosscut with NSF, BES)
- C-C bond breaking catalysts
- "Wax worm" type biology

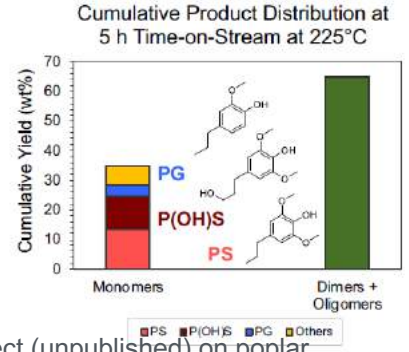
Applied Opportunity (Crosscut with AMO)
- Enzymatic cocktails for mixed plastic degradation
- Applied opportunity should add some inorganic catalysis
- Organic contamination less problematic for biology
- Enzyme engineering is a BETO strength
- Crystalline cellulose/crystalline plastics have similarities

Recent Wins in Lignin

Chemical

New flow system gives >35% yield of upgradable monomers with >90% enzymatic hydrolysis yields for monomers



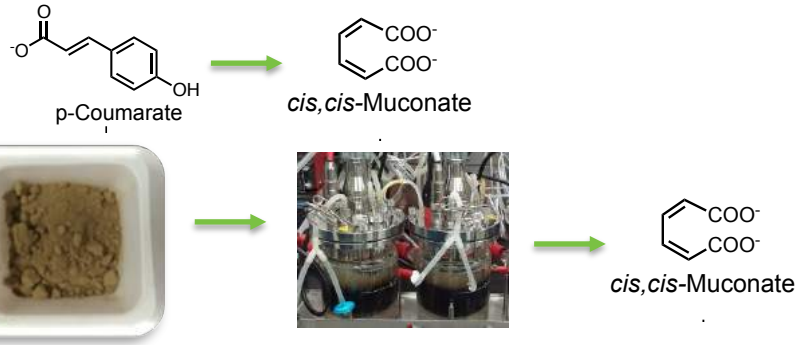


Beckham Lignin First project (unpublished) on poplar

Biological

Model feed: 50 g/L titer, 100% yield, 0.5g/L/hr productivity

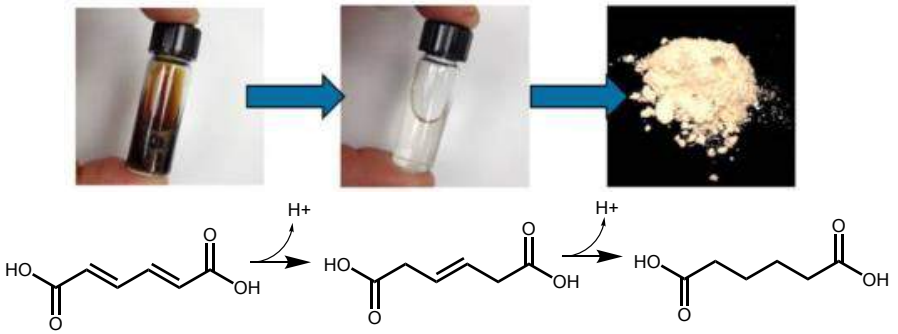
Real Lignin Baseline First Test: 4 g/L, 15% yield by mass (137% yield from 2 major monomers in stream)



Biological Lignin Valorization Davinia Salvachua

Catalytic

>99% yield of adipic acid from biologically produced muconic acid in flow system



Derek Vardon

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

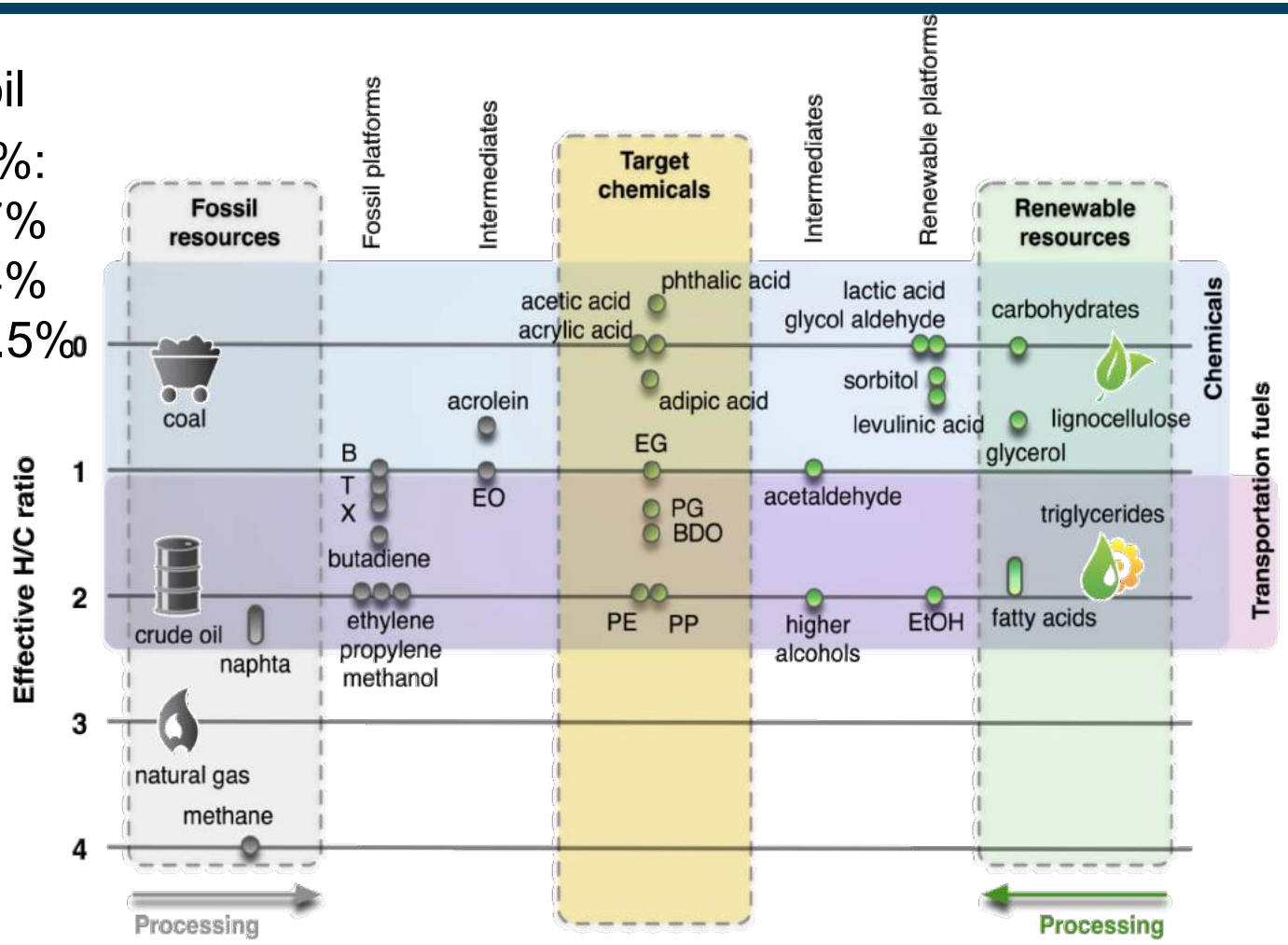
Why is BETO Interested in Biobased Products?

Crude oil

Avg. wt%:
C 83-87%
H 10-14%
O 0.1-1.5%

Biomass

Avg. wt%:
C 36-53%,
H 5-7%,
O 31-48%



Consider the Oxidation State of Chemicals – Retain What Nature Provides

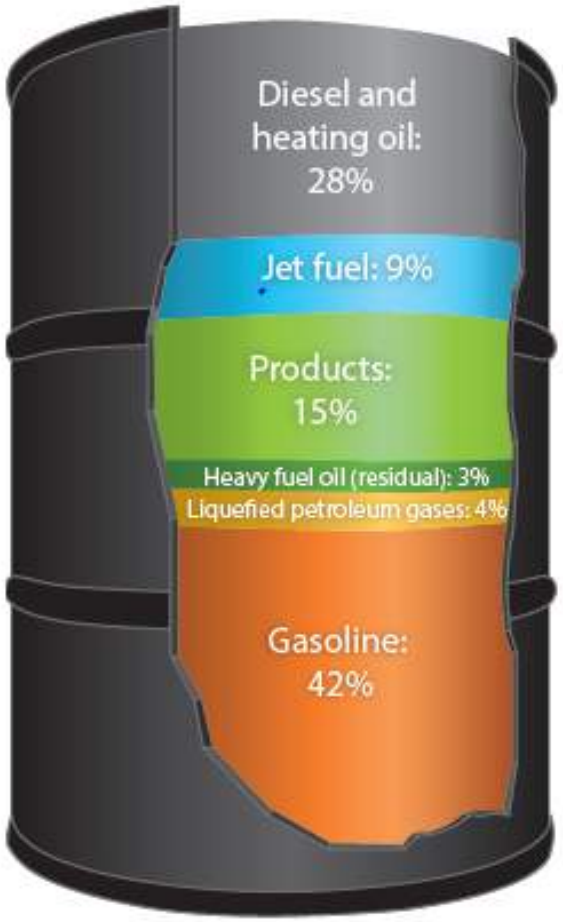
Vennestrøm, P.N. R. *et al Angew. Chem. Int. Ed.* **2011**, *50*, 10502-10509

Shen, J. *et al Energy Conversion and Management* **2010**, *51*, 983–987

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

Replacing the Whole Barrel – Fuels & Products

- Enhancing U.S. security requires producing fuels and bioproducts from our large supply of biomass.
- Supporting U.S. Farmers rather than buying foreign oil.
- EERE R&D focuses on **"drop-in" hydrocarbon** biofuels, and **bio-based products.**
- "Drop-in" hydrocarbon fuels will be fully compatible with existing infrastructure and equipment, including diesel and jet engines.
- **Products**
  - Fuels makes up 76% of the volume of U.S. oil products and is worth $935B.
  - Chemicals make up 17% of the volume of U.S. oil products and worth $812B.
- Maximizing biofuels production in conjunction with the development of chemical intermediates will drive down the cost per gallon.



DISCOVR Call for Collaboration

DISCOVR Focus Areas

- Develop and implement a pipeline as a standardized and validated strain characterization process
  - *Purpose*: Evaluate algae strains for their potential as future algae biomass/biofuels/bioproducts production strains
- Facilitate the execution of BETO's annual Algae State of Technology (SOT) experimental effort
  - Purpose: Demonstrate progress towards outyear biomass productivity goals as outlined in the BETO MYPP

We recognize that the algae industry and research communities are also continuously developing new strains and cultivation methods, which are important for driving progress of the field as a whole.

Goal

- Offer an opportunity for DISCOVR and the algae community to work together to incorporate the best algae strains, operational/cultivation strategies, and crop protection strategies into DISCOVR and the SOT

Approach

- Release a Call for Collaboration to solicit strains, tools, and techniques to help achieve BETO's aggressive technical and economic targets for algae bioenergy production

Outcome

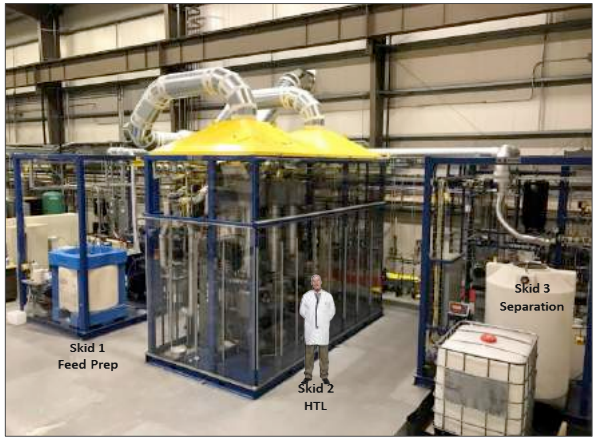
- To accelerate the development and implementation of "the best of the best" algae technologies to foster the growth of the bioeconomy and facilitate the realization of cost effective algae biofuels and bioproducts

Waste-To-Energy

- PNNL published the wet waste design case, Conceptual Biorefinery Design and Research Targeted for 2022: Hydrothermal Liquefaction Processing of Wet Waste to Fuels
- PNNL/NREL developed systematic characterization of over 15,000 publically owned wastewater treatment plants
  - Assesses strategies to recover 170 trillion BTU energy potential from wastewater, including site-specific blending with MSW organic waste
- Report to Congress on Waste-to-Energy from Municipal Solid Wastes - submitted to OMB in December

Hydrothermal Liquefaction of Wet Waste

- HTL is a process that uses heat and pressure to convert biological materials to biocrude oil in about 15 minutes, using the same principles that nature transforms biological materials to crude oil over centuries
- The crude oil from waste water is rich in diesel-range hydrocarbons and has high cetane



Wet biological material (waste water, algae, wood) → Stable biocrude oil (up to 60% yield) → Hydrocarbon fuels (95%+ yield)