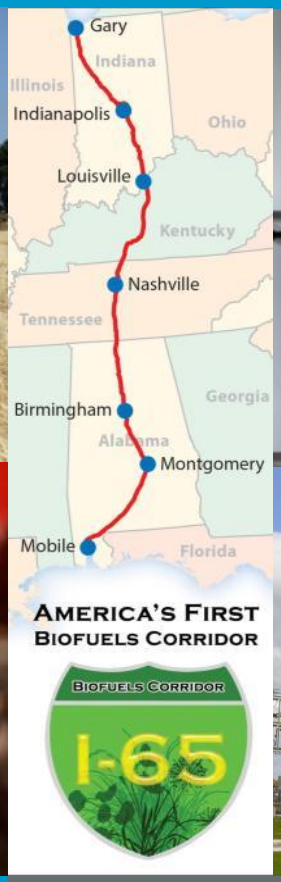
BIOENERGY TECHNOLOGIES OFFICE

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



ADO Workshop

December 12, 2017

Jonathan Male

Director

Bioenergy Technologies Office (BETO)

Outline

I. BETO Overview

II. FY18 Budget

III. BETO Consortia and Activities

IV. The Bioeconomy

V. Questions

Office of Energy Efficiency and Renewable Energy

Sustainable
TRANSPORTATION

Renewable
ELECTRICITY GENERATION

Energy Saving
HOMES, BUILDINGS, & MANUFACTURING

Mission-Critical Support
OPERATIONS

BETO's Mission & Vision

Vision

A thriving and sustainable bioeconomy fueled by innovative technologies

Mission

Developing transformative and revolutionary sustainable bioenergy technologies for a prosperous nation

Strategic Goals

Develop industrially relevant technologies to enable domestically produced biofuels and bioproducts without subsidies

BETO reduces technology uncertainty and costs 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 and 26% of emissions in the United States.

THE OPPORTUNITY

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

Biomass could displace **25%** of U.S. petroleum use annually by 2030, **keeping $260 billion in the United States**, adding **1.1 million direct jobs,** and reducing annual CO_2 emissions by 450 million tons or 7% of U.S. energy emissions**.

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

** 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

American Energy Dominance

How BETO activities tie into the White House's plan for 'Energy Dominance'

Unleashing American Energy

TREMENDOUS POTENTIAL

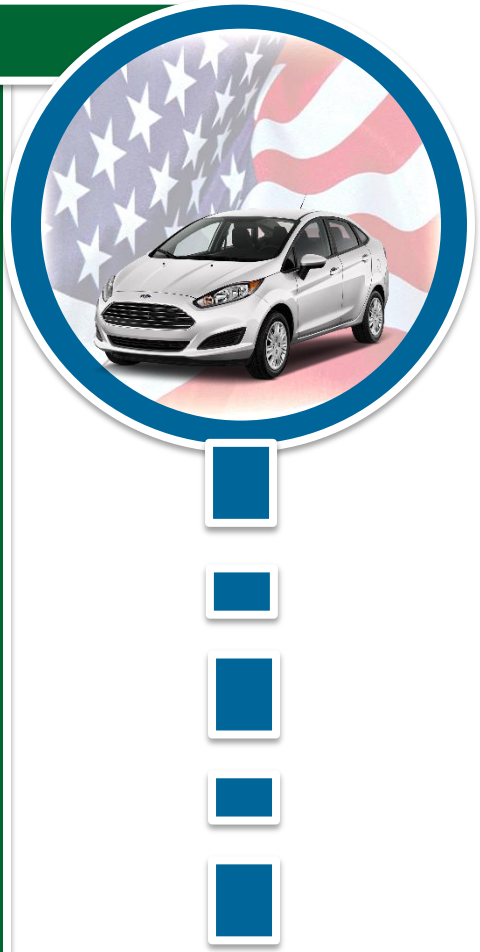
Achieving BETO goals will enable the U.S. bioeconomy, which has the potential to create 1.1 million U.S. jobs, 50 billion gallons of biofuels, and more than 50 billion pounds of biobased chemicals and products for domestic use or export.

BENEFITS U.S. COMPANIES

Additionally, it will create intellectual property for U.S. companies, enabling them to dominate the world market for biobased fuels and chemicals, while licensing these technologies worldwide.

SYNERGIES WITH FOSSIL ENERGY

BETO is closely coordinating with DOE's Office of Fossil Energy on strategies for the beneficial reuse of carbon dioxide emissions from power plants and petroleum refineries.



FY18 Budget Scenario Levels

Program Area	FY 2016 Enacted*	FY 2017 Enacted*	FY 2018 Request*	FY 2018 House Marks*	FY 2018 Senate Marks*
Advanced Algal Systems	0	30,000	5,000	5,000	30,000
Advanced Development & Optimization (Formally DMT)	75,100	54,041	6,000	8,000	50,000
Conversion Technologies	85,500	90,230	34,600	43,000	85,000
Feedstock Supply & Logistics	46,500	20,000	6,000	27,000	20,000
Strategic Analysis and Sustainability	11,000	10,729	5,000	7,000	5,000
NREL Site-Wide Facility Support	6,900	0	0	0	0
Total, Bioenergy Technologies	225,000	205,000	56,600	90,000	190,000

*Dollars in thousands

BETO Pillars

Feedstock-Conversion Interface Consortium
(FCIC)

Chemical Catalysis for Bioenergy
(ChemCatBio)

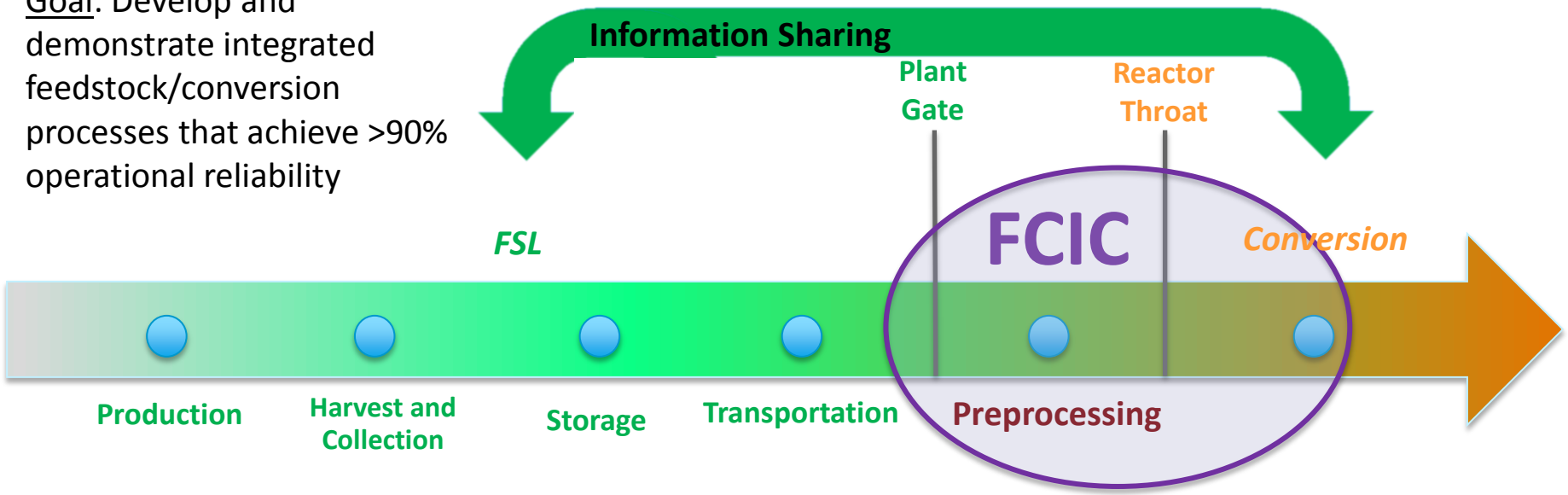
Agile BioFoundry
(ABF)

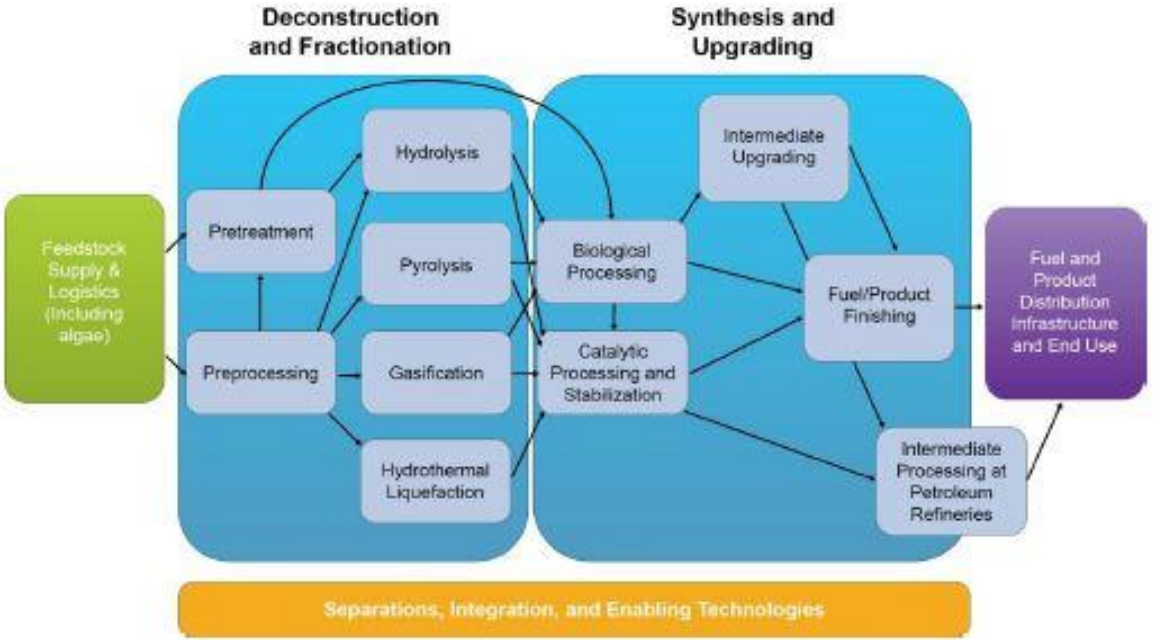
Bioprocessing Separations Consortium
(BioESep)

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

Feedstock-Conversion Interface Consortium (FCIC)

Goal: Develop and demonstrate integrated feedstock/conversion processes that achieve >90% operational reliability

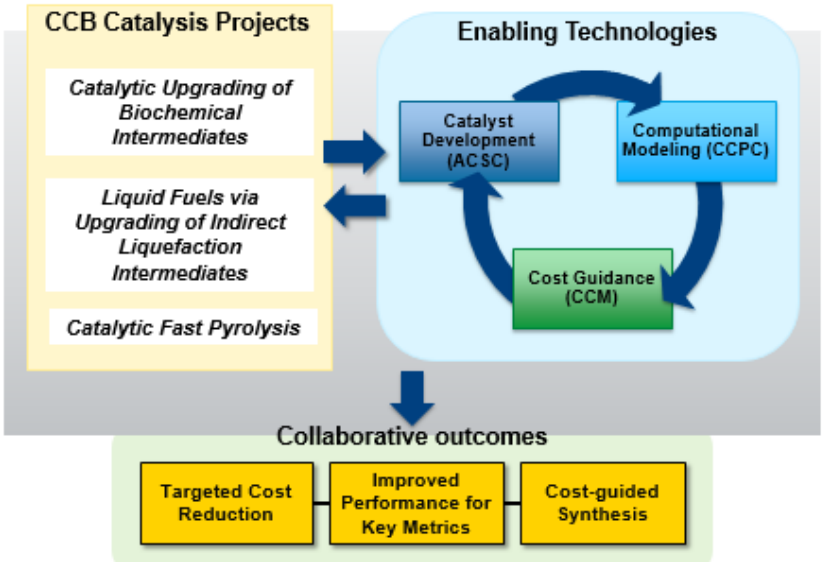




Guiding Principle: Feedstock chemical and physical characteristics are a primary consideration for process development, scale-up, and integration.

Why now? Early-stage applied research is currently the gap in enabling scalability and maximizing yields

ChemCatBio



Mission: ChemCatBio leverages unique US DOE national lab capabilities to address technical risks associated with accelerating the development of catalysts and related technologies for the commercialization of biomass-derived fuels and chemicals, leading to enhanced energy security and national leadership in the global bioeconomy.

Goal of CCB: ChemCatBio improves the Catalyst Value Factor for catalytic biomass conversion processes by improving productivity, increasing lifetime, and reducing catalyst cost. Significant increases in conversion efficiency.

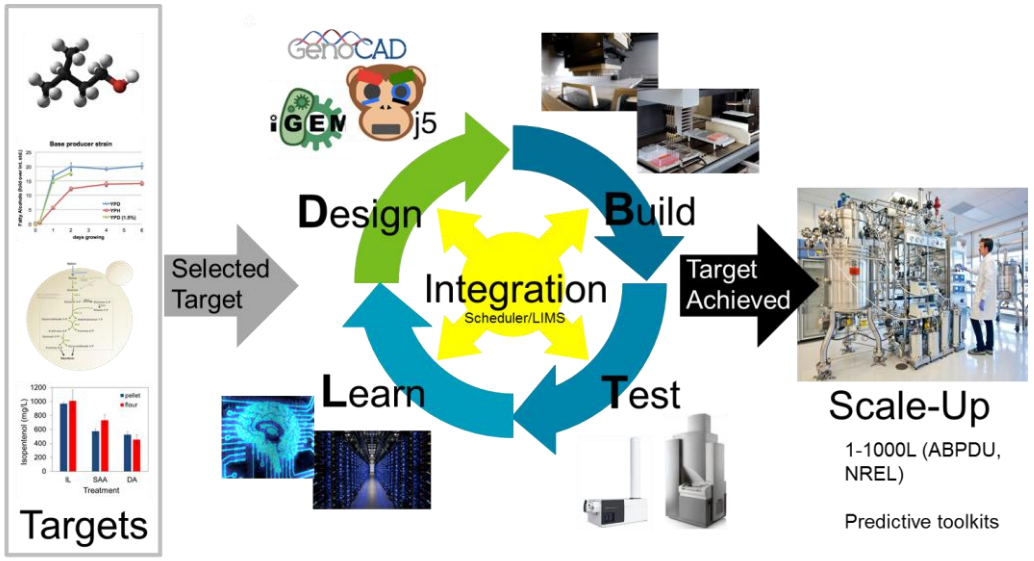
FY17 Achievements

- Launched ChemCatBio
- Two F2F consortium-wide meetings
- Regular technical updates/project re-orgs
- Website launched chemcatbio.org
- Capabilities tabulated, evaluated, and published
- Multi-lab CRADA and NDA negotiated and signed
- Industry listening day
- $4.3M awarded to 9 industry partnerships
- >60 publications

FY18 Highlights and Goals:

- ACS Symposium in March
- Launch Industrial Advisory Board
- Release publically available Catalyst Cost Model
- Determine the routes and process configuration best suited to achieving a MFSP (2014 $) of $3/gge when coupled with lignin co-product valorization (or $2/gge with diversion of a portion of sugars/biological intermediates to co-products) based on fuel properties and preliminary TEA projections for each upgrading route

Agile BioFoundry



Mission: The Agile BioFoundry will integrate industrially-relevant production microbes, advanced tools for biological engineering and data analysis, and robust processes for integrated biomanufacturing to enable industry to bring new chemicals and fuels to market, faster.

Goal: Enable a 50% reduction in the Design-Build-Test-Learn cycle time leading to a 50% reduction in time and cost to market compared to the average of ~10 years by establishing a distributed Agile BioFoundry that will productionize synthetic biology. Significant increases in conversion efficiency.

FY17 Achievements

- Launched Agile BioFoundry
- All-hands and Industry Advisory Board meeting
- Website launched: agilebiofoundry.org
- Designs built and tested for three target/host pairs
- Stood up Design-Build-Test-Learn (DBTL) infrastructure
- $5M awarded to 7 industry partnerships through successful directed funding opportunity
- >30 1:1 interviews with industry for feedback

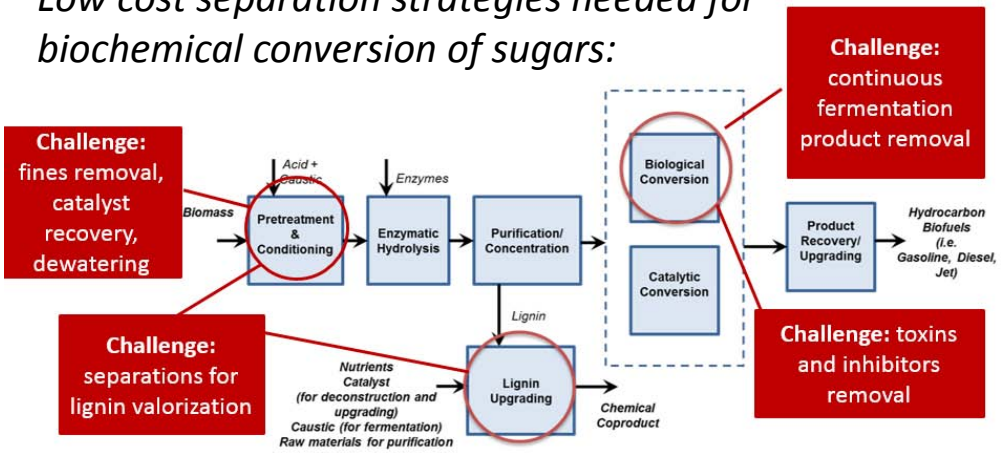
FY18 Highlights and Goals:

- Increase the DBTL throughput by 1.5-fold by initiating the cycle for 2 additional target/hosts
- Show process integration and scaling of one target molecule at >1g/L in a 2 L bioreactor in DMR-EH hydrolysate
- From a set of 5 target molecules, demonstrate successful production of 40% with titers >100mg/L
- Continue work on directed funding partnerships illustrating utility to industry
- Report TEA and LCA target cases on newly selected molecules

Bioprocessing Separations Consortium

BIOPROCESSING SEPARATIONS CONSORTIUM

Low cost separation strategies needed for biochemical conversion of sugars:



Goal: Move cost-effective, high-performing separations technology to market faster through coordinated separations research at the national laboratories that targets challenges relevant to BETO's priority pathways and industry.

Outcome: Biofuels and bioproducts industries will have new, high-performing, low-cost separations technologies available to them.

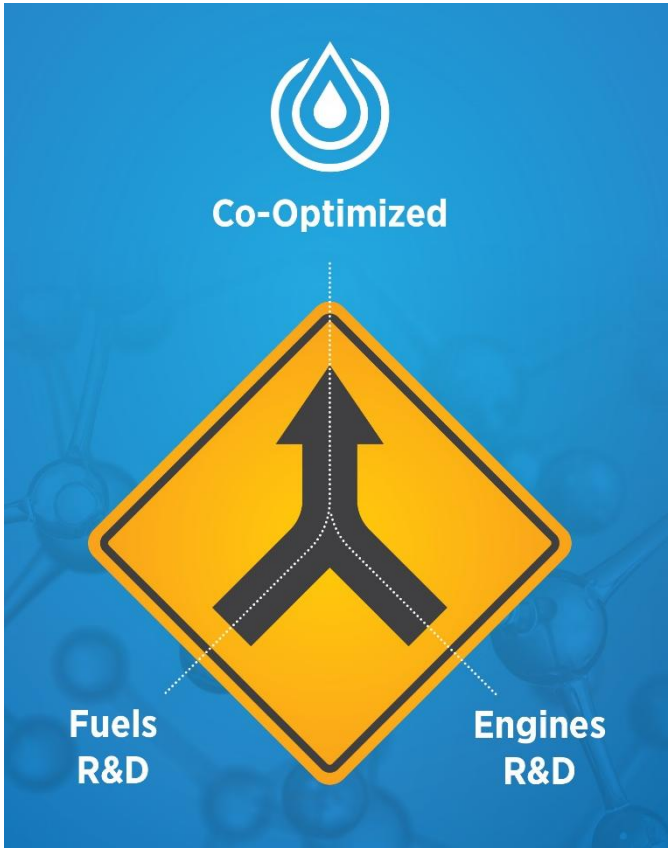
FY17 Achievements

- Launched Bioprocessing Separations Consortium
- Website launched bioEsep.org
- Industry listening day
- Industry advisory board established and providing feedback
- Identified separations challenges that will reduce biofuel production costs
- Quantified $/gge for each separations challenge

FY18 Highlights and Goals:

- Face to Face meeting with Industry Advisory Board
- From alkaline pretreated liquor (APL), recover/produce at least 20 wt% NaOH and 15 wt% organic acid streams separately using a new design of electrochemical membrane separation device and molecular-weight-based separations methods
- Show a separation efficiency at bench-scale as measured by 25% drop in total content of carbonyl species of a NREL woody (e.g., pine and oak) fast pyrolysis bio-oil. The technology applied to achieve this cut in carbonyl species content will be adsorbents (functional polymer or inorganic based).

Co-Optimization of Fuels and Engines



High performance, market-driven fuels enabling new high efficiency engines

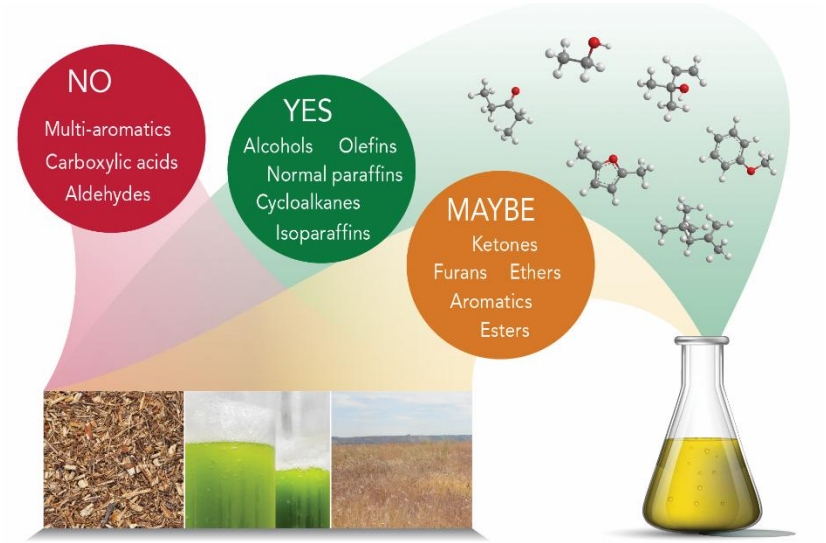
9 National Labs in Partnership with Stakeholders:

13 Light and heavy duty vehicle manufacturers

8 Biofuel companies

10 Oil companies/ Refiners and Retailers

2 End consumer organizations



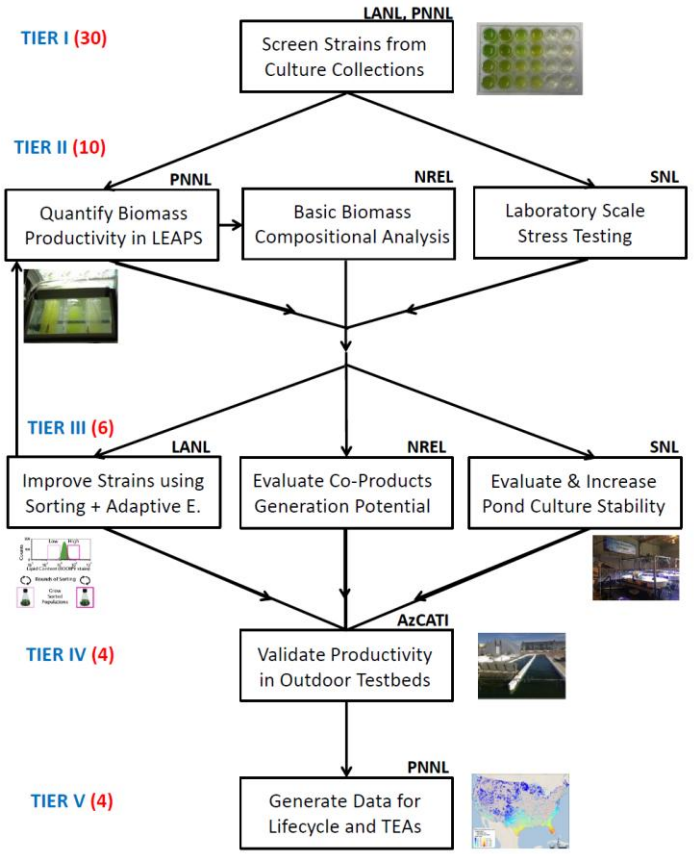
Additional 15% fuel economy improvement possible (50% total)

The Algae DISCOVR Consortium

Development of Integrated Screening, Cultivar Optimization, and Validation Research (DISCOVR)

Goals:

- **Reduce total microalgae biofuels production costs to $3/GGE** by 2030 by developing an **integrated screening platform** for the **rapid identification of high productivity strains with cellular composition suitable for biofuels and bioproducts for resilient, year-round outdoor cultivation** via crop rotation.
- **Overcome limitations of previous strain prospecting efforts,** such as low success rate and unrealistic laboratory test conditions.



Pacific Northwest NATIONAL LABORATORY

Los Alamos NATIONAL LABORATORY EST. 1943

Sandia National Laboratories

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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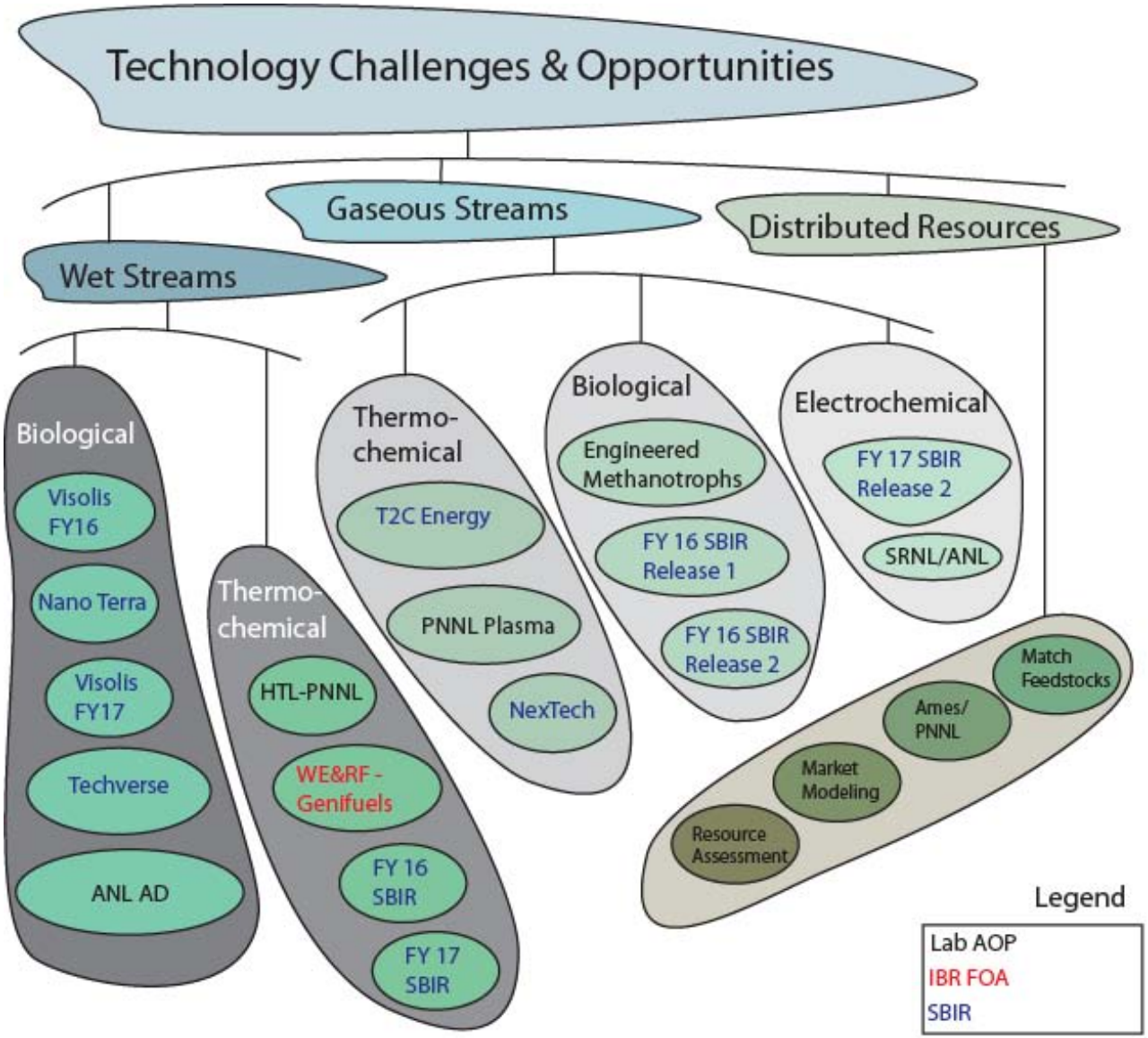
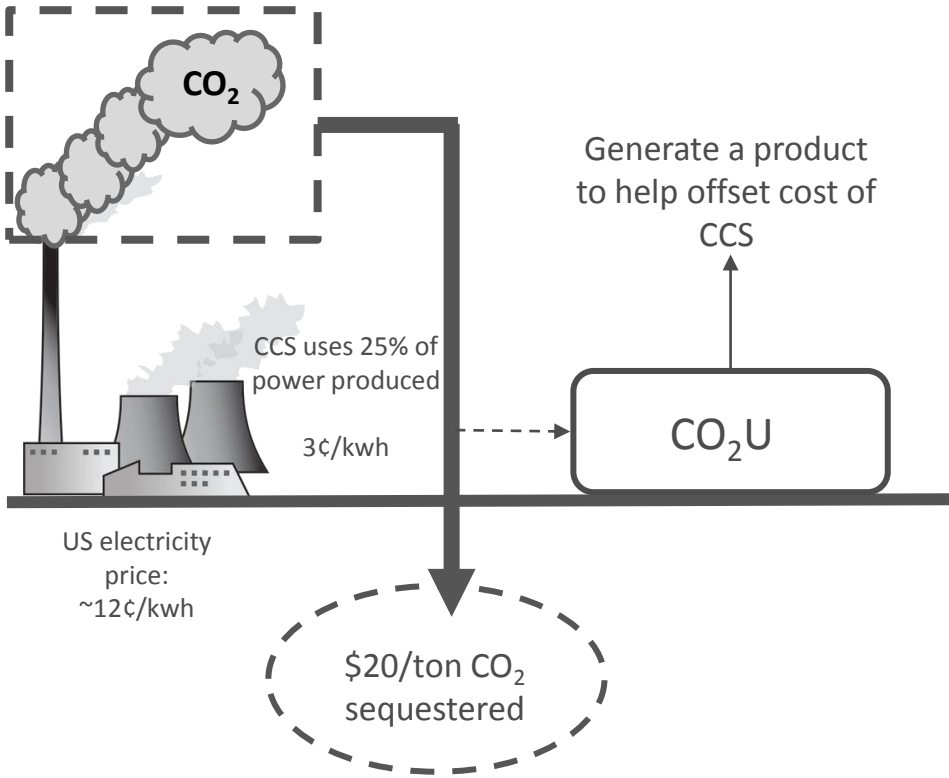
Alignment with Existing and Prospective Initiatives



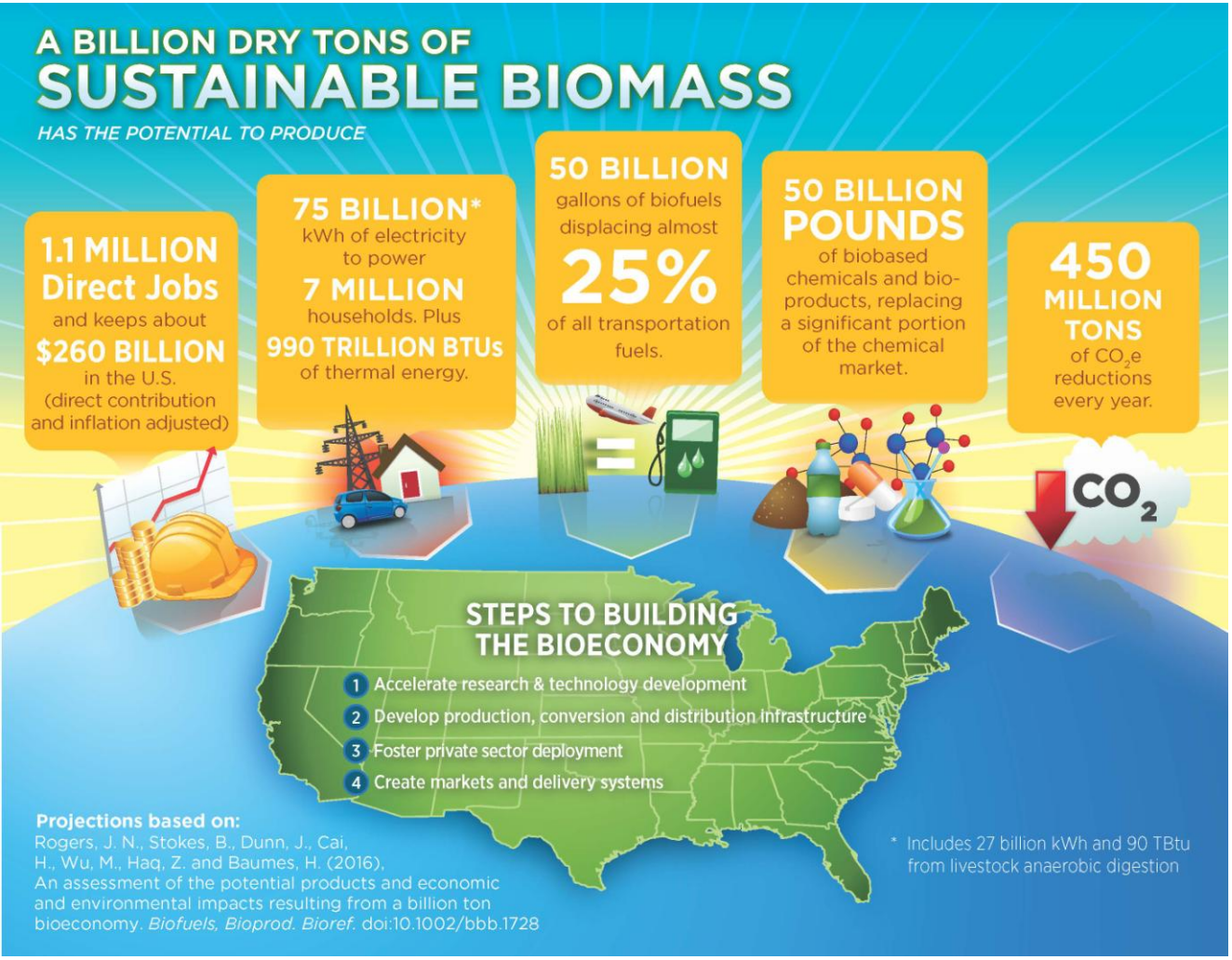
Carbon Reduction and Valorization Initiative

Implications & Benefits

- **Economic benefits**
  - Distributed manufacturing, resource utilization and job opportunities
- **Bioeconomy**
  - Land sparing implications
  - Parallel carbon and biomass supply chains
  - Increase effective land yield through enhanced carbon conversion efficiency
- **Power sector**
  - Grid reliability and stability
  - Energy storage
  - Promotion of CCU and CCS for legacy producers (see example)
- **Transportation sector**
  - Renewable power enabled decarbonization options
- **Fuel security**
  - Domestic sources of carbon based fuels without land and fossil resource dependencies



Potential Impacts of a Billion-Ton Bioeconomy



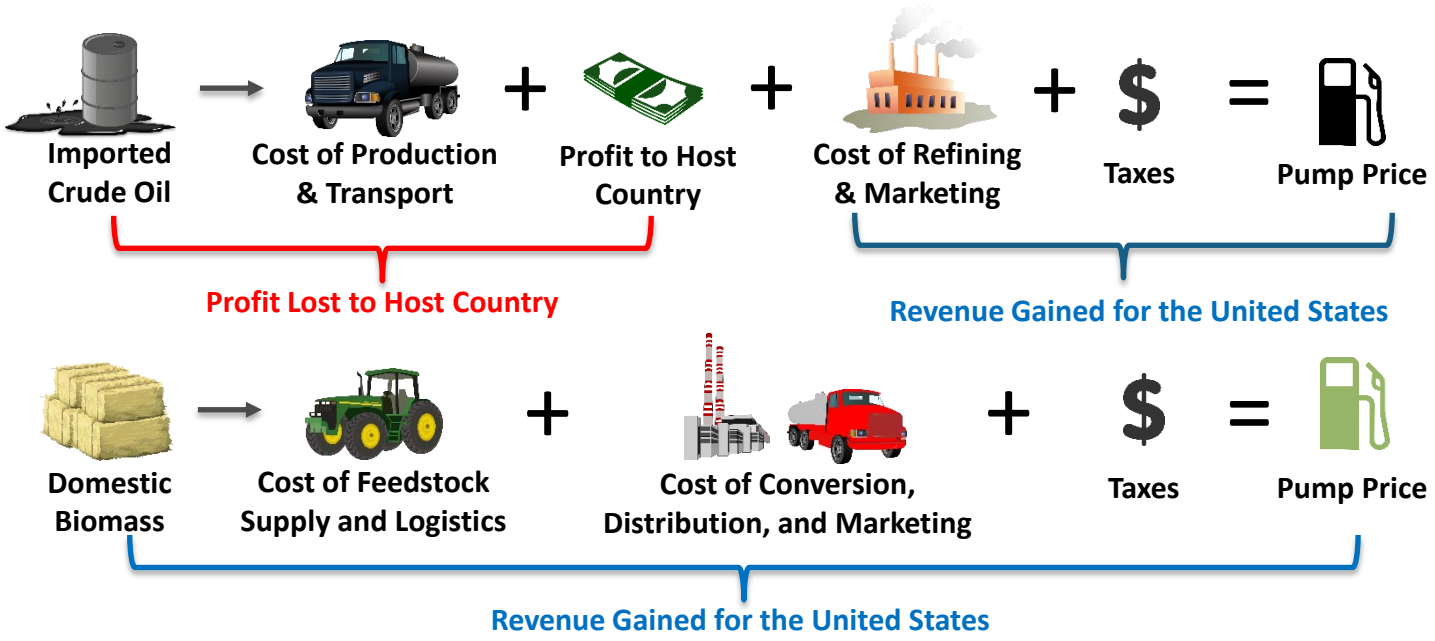
The **bioeconomy** is a global industrial transition of sustainably utilizing renewable aquatic and terrestrial biomass resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits.

1 billion tons of biomass could be sustainably produced in the United States.

Questions

Benefits of a Robust Domestic Bioeconomy

- **Job Creation and Balance of Trade** – Displacing oil imports offers a massive opportunity for domestic jobs creation, with virtually no consequent job destruction
- **Energy Security** – Domestic production decreases vulnerability to short-term economic disruption due to war, civil unrest, OPEC action, speculation, etc
- **Environmental Benefits** – Sustainable biomass production can reduce harmful emissions versus petroleum-based fuels on a life-cycle basis



Fuel from domestic biomass versus imported crude oil helps grow the US economy

BETO Impacts

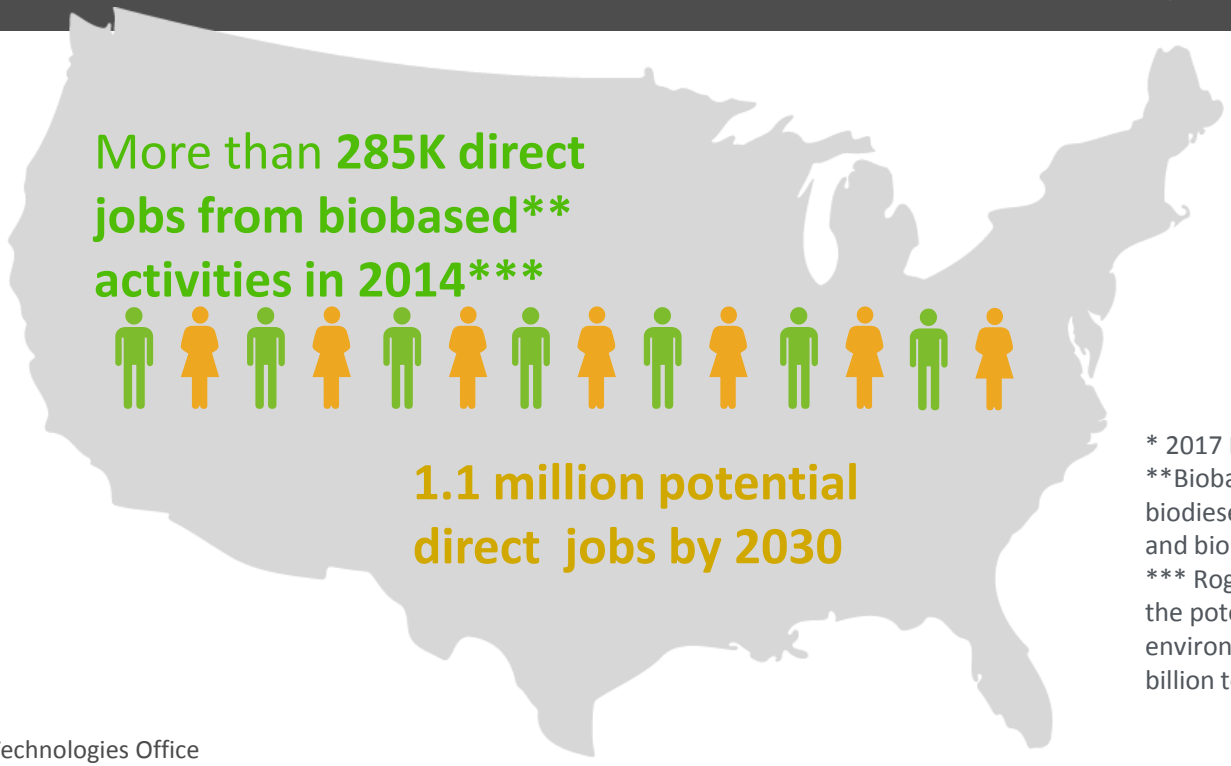
Since 2009 …

Lab Patents
261

Lab Publications
1,054

Lab Licenses
32

Biofuel Production
5,100,270* gallons of cellulosic biofuel



* 2017 Renewable Fuel Standard Data
**Biobased activities includes corn ethanol, biodiesel, cellulosic biofuels, bioproducts and biopower
*** Rogers et al. 2016, An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy

Bioenergy Delivers Unique Value

BETO funds research and development activities that reduce the price of production of biofuels 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.

BETO Consortia Activities

Chemical Catalysis for Biofuels (ChemCatBio)

ChemCatBio is a research and development consortium dedicated to identifying and overcoming catalysis challenges for biomass conversion processes. It leverages unique capabilities such as surface analysis, computational chemistry, and catalyst synthesis and characterization at U.S. Department of Energy (DOE) national laboratories. CCB is working with industry to rapidly transition R&D discoveries into commercial processes by improving catalyst effectiveness and selectivity to dramatically improve carbon efficiency to desired end-products fuels and chemicals.

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

Co-Optima is working to identify new fuel components that can be blended with petroleum to improve efficiency and performance by providing key properties required to optimize advanced internal combustion engines in both light and heavy duty vehicles. The fuel property-based, technology neutral approach allows for market-driven, industry-led solutions.

Agile BioFoundry (ABF) and APBDU

The Agile BioFoundry connects distributed capabilities across multiple National Laboratories to develop Design-Build-Test-Learn synthetic biology processes that will enable predictable design by establishing a robust biomanufacturing set of principles. These capabilities and techniques are currently only available to a small number of well-funded companies and utilize and apply only to a small number of organisms and product molecules. The ABF will enable a large number of companies of all sizes to rapidly engineer a wide variety of organisms to produce a diverse set of fuels and chemicals.

Feedstock Conversion Interface Consortium (FCIC)

Plants processing bulk solids typically operate at <50% of design capacity the first year of operation. The overall goal of the FCIC is to develop integrated feedstock supply-preprocessing-conversion processes that achieve >90% operational reliability (i.e., time-on-stream) so that today's integrated cellulosic ethanol biorefineries can improve their profitability and resiliency.

Feedstock-Conversion Interface Challenges

Challenges have persisted for at least 30 years

- Plants processing bulk solids typically operate at <50% of design capacity the first year of operation (Merrow, 1985). Much lower than for plants processing liquids or gases.
- Problems generally relate to an inadequate understanding of the behavior of particle systems (Bell, 2005).

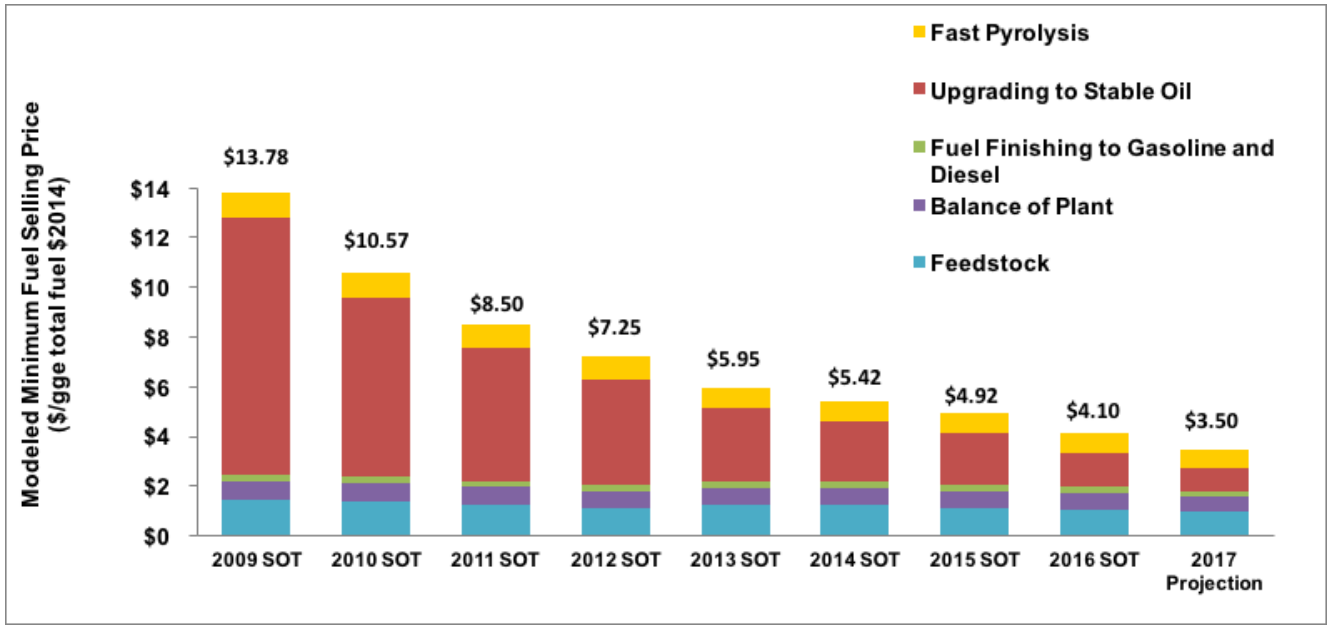
Top 5 Feedstock Handling Challenges (see BETO's Biorefinery Optimization Workshop Summary Report, 2016)

1. Inadequate flowability
2. Unpredictable feedstock variability
3. Inconsistent equipment up-time
4. Lack of equipment performance data
5. Undefined feedstock specifications

Opportunities

- Quantify the ranges of & the interaction between
  - Physical Properties (feedstock & intermediates)
  - Chemical Properties (feedstock & intermediates)
  - Mechanical System Performance
- Necessary to achieve sustainable integrated biorefinery operations

Trajectory to Cost-Competitive Gasoline & Diesel Blendstock Fuel



- Biomass derived liquid transportation fuels have the potential to be competitive—without subsidies—with their fossil derived equivalents
- The pathway presented here (the conversion of biomass into infrastructure-compatible hydrocarbon fuels via fast pyrolysis) represents a goal case targeting performance potentially available between now and 2017
- Based on this design case, a total potential cost reduction of 75% can be achieved between 2009 and 2017 with continued funding of R&D activities
- In FY17/18, BETO will initiate analysis on R&D needed to enable price competitive biofuels ($2.0/gge)

BETO R&D plays a crucial role reducing the costs of biofuels without subsidies.

*EIA Annual Energy Outlook 2016 Reference Case BETO Multi-Year Program Plan