

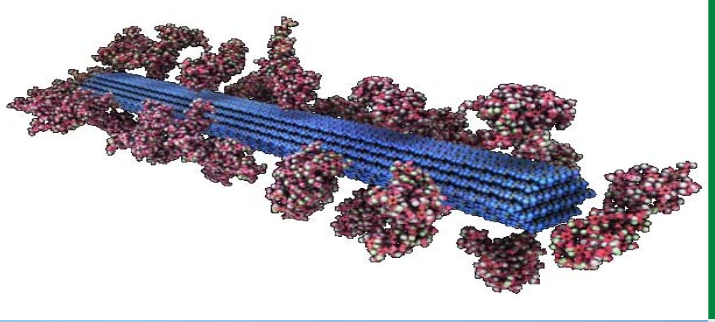
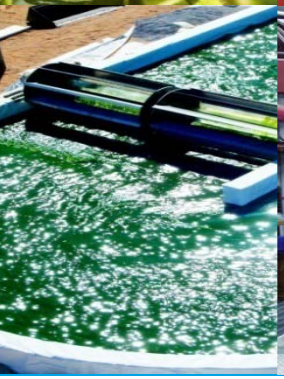



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

2017 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

Conversion Technologies Research & Development

Kevin Craig

Program Manager, Conversion R&D

March 6th, 2017

Outline

- Conversion Team Introduction
- Background
- Conversion R&D Organization and Metrics
- R&D Approach
- Recent Progress & Accomplishments
- Key Changes & Upcoming Events
- Budget and Review Structure
- Reviewer Introductions

Conversion R&D Team

Kevin Craig, Program Manager

DOE Staff	Conversion Support Contractors
David Babson	Josh Messner - AST, Manager
Jay Fitzgerald	Rafael Nieves – AST
Nichole Fitzgerald	Mark Philbrick – AST
Prasad Gupte	Jessica Phillips – AST
Beau Hoffman	Clayton Rohman - AST
Liz Moore	Trevor Smith - AST
Ian Rowe	Cynthia Tyler – AST
Andrea Bailey, ORISE Fellow	Robert Natelson – BCS, Inc.
Jeremy Leong, ORISE Fellow	Camryn Sorg – BCS, Inc.
Christine English – IPA (NREL)	
Michael Resch – M&O (NREL)	

Conversion R&D – Goals and Approaches

- **BETO Strategic Goal:** *Develop and demonstrate innovative and integrated value chains for biofuels, bioproducts, and biopower that can respond with agility to market factors while providing economic, environmental, and societal benefits.*
  - Biofuels and bioproducts offer a unique complement to other alternative energy technologies
  - Bioenergy enhances energy security and provides U.S. economic benefits
  - Bioenergy provides value for otherwise problematic waste streams
  - Bioenergy can enhance the environment with purpose-grown feedstocks.

- **Conversion R&D Goal:** *Develop commercially viable technologies for converting biomass feedstocks via biological and chemical routes into energy-dense, fungible, finished liquid transportation fuels such as renewable gasoline, diesel, and jet fuel, as well as bioproducts or chemical intermediates and biopower*.

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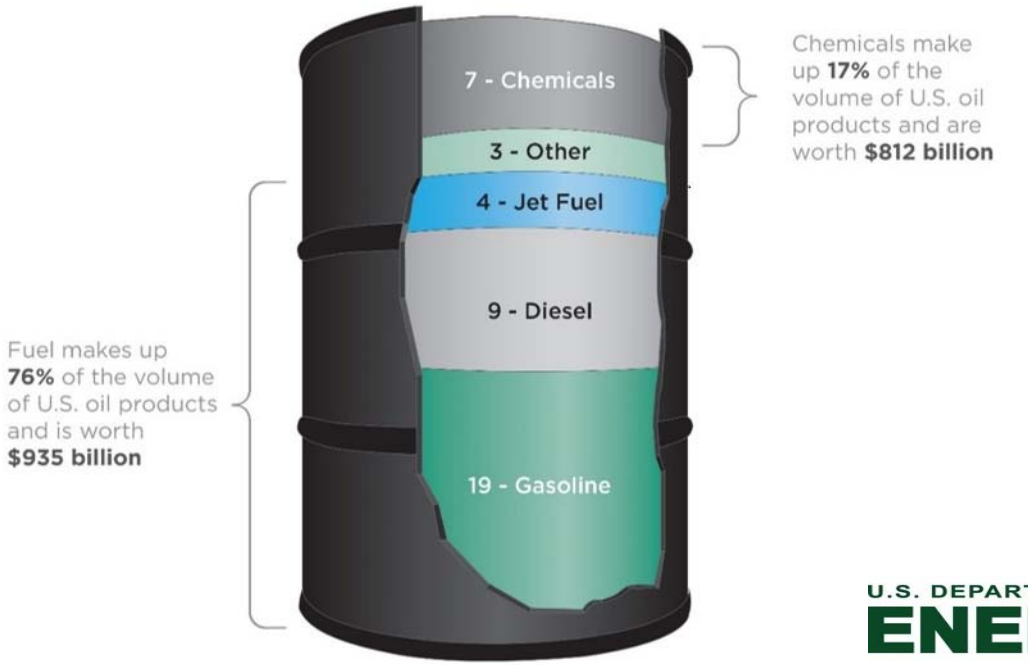
Replacing the Whole Barrel – A Shift Toward Drop-ins and Bioproducts

- Only ~40% of a barrel of crude oil is used to produce petroleum gasoline. Reducing oil dependence requires replacing **diesel, jet fuel, heavy distillates, and other products.**
- EERE successfully achieved modeled mature cost goals for cellulosic ethanol in 2012 and shifted its R&D to focus on **hydrocarbon "drop-in" biofuels, jet fuels, and bio-based products.**
- **Fuel makes up 76% of the** volume of U.S. oil products and is worth **$935B**.
- Products make up 17% of the volume of U.S. oil products and are worth **$812B**.



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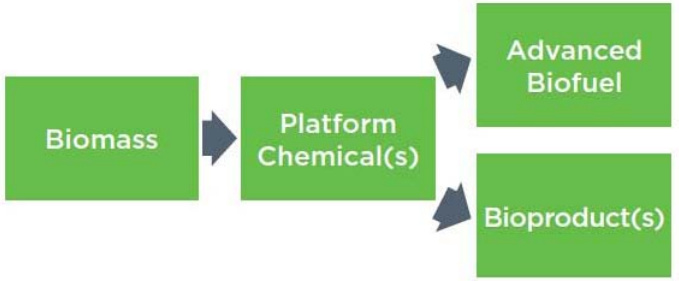
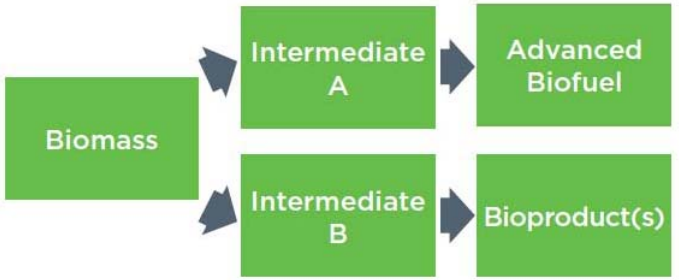
Potential Pathways of Interest to BETO

Fuel alone. Traditional approach which was highly successful for cellulosic ethanol

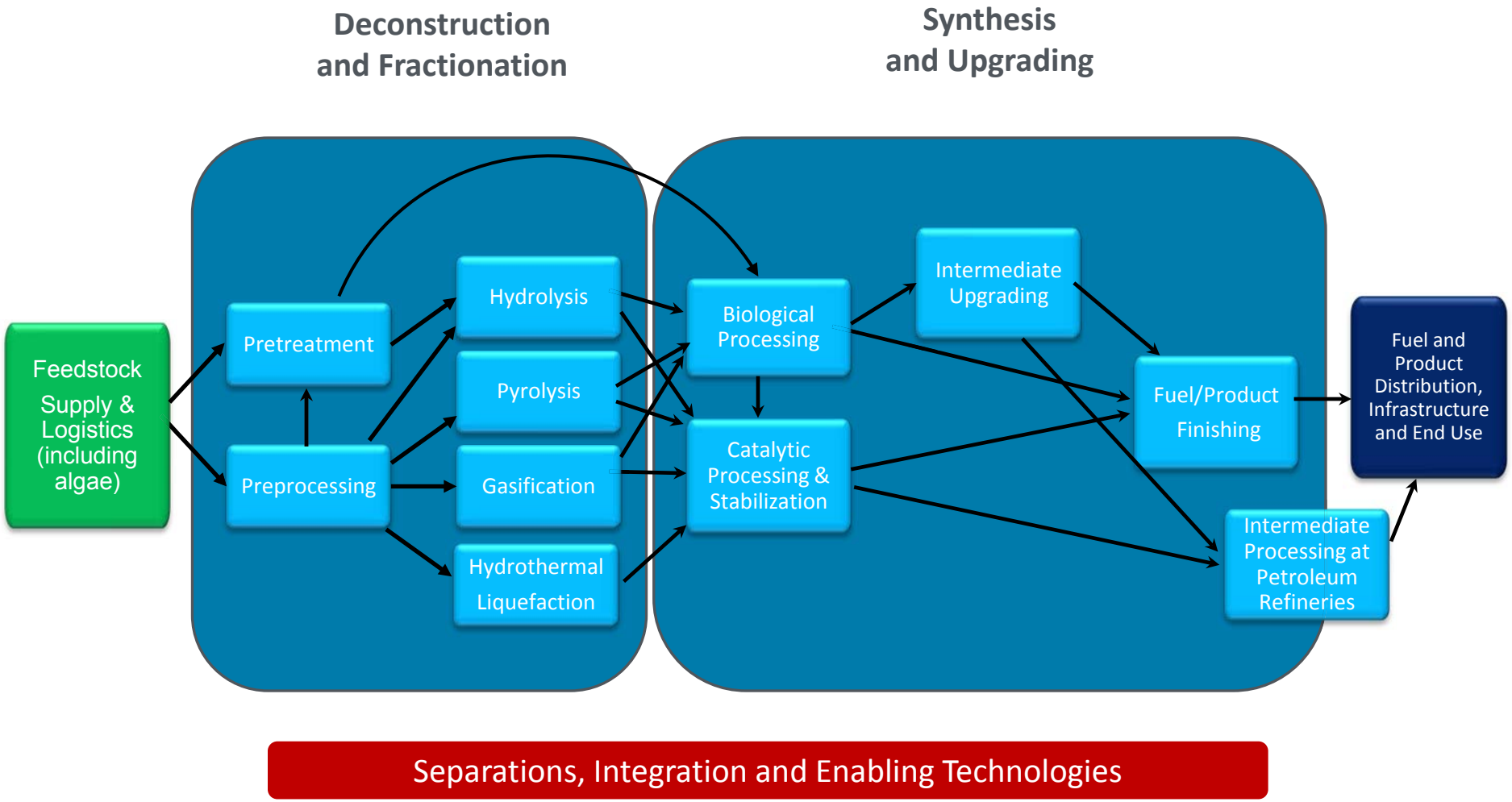


Platform chemical. (e.g. Vertimass EtOH to jet, levulinic acid)



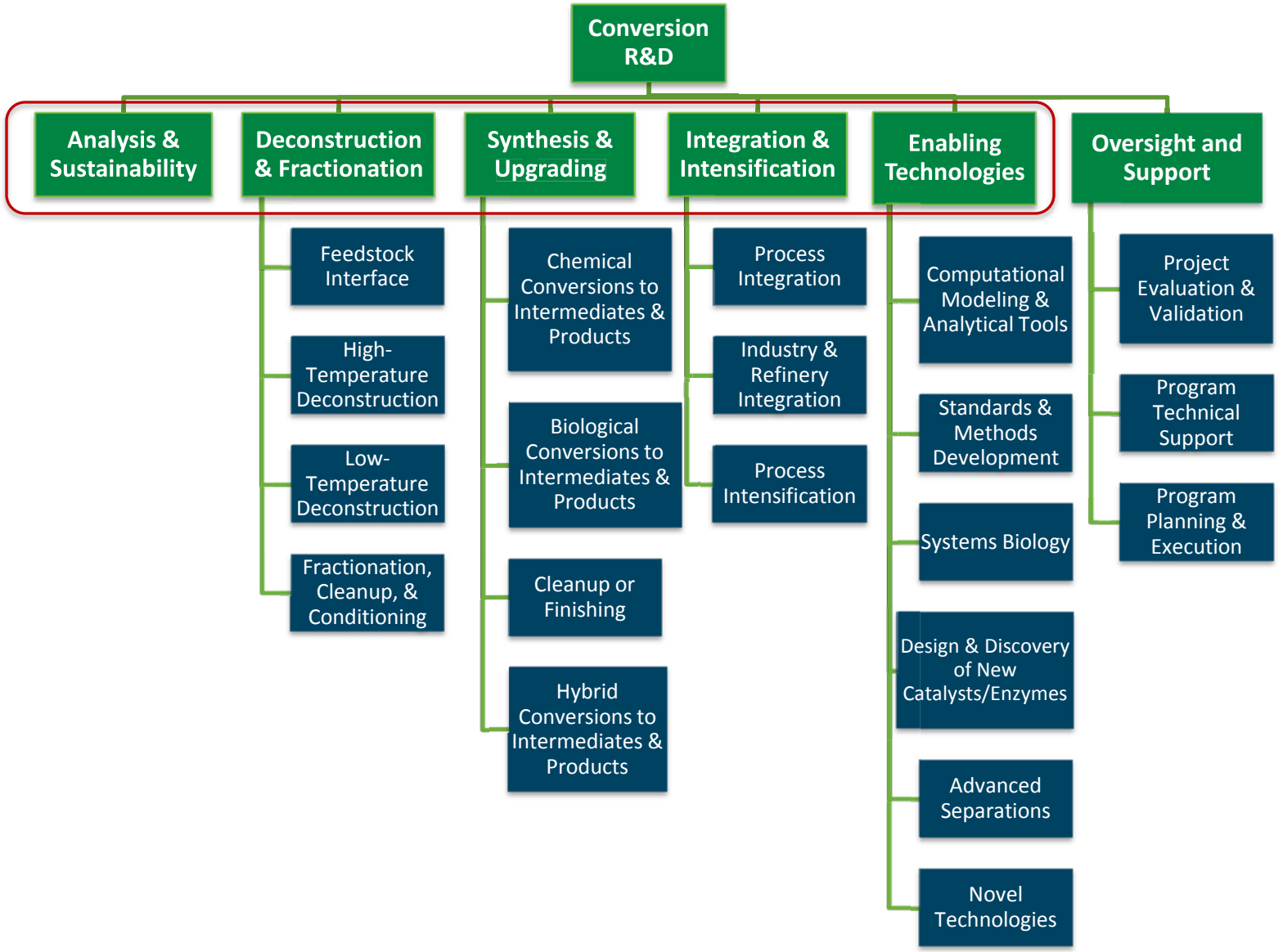
Coproduction. May utilize waste stream/slip stream conversion
(e.g. C5 to succinic, lignin utilization, starch ethanol, etc.)

Pathways are collections of technologies and interfaces



ORGANIZATION & METRICS

Conversion Portfolio - Work Breakdown Structure



Consortia

Deconstruction & Fractionation

- Feedstock Interface
- High-Temperature Deconstruction
- Low-Temperature Deconstruction
- Fractionation, Cleanup, & Conditioning

Feedstock Conversion Interface Consortium (FCIC)

Enabling Technologies

- Computational Modeling & Analytical Tools
- Standards & Methods Development
- Systems Biology
- Design & Discovery of New Catalysts/Enzymes
- Advanced Separations
- Novel Technologies

CCPC

Agile BioFoundry

BIOPROCESSING SEPARATIONS CONSORTIUM

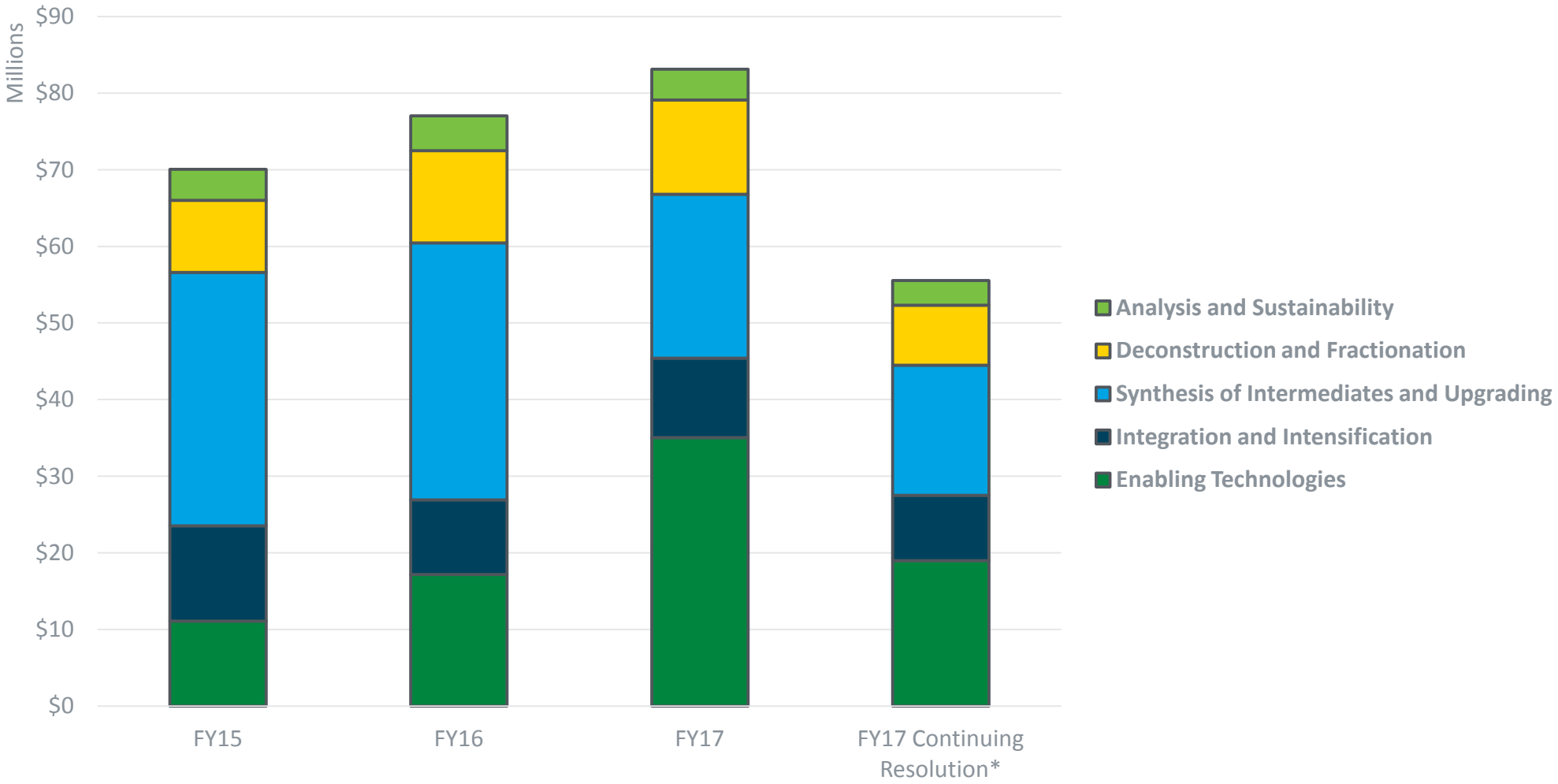
Synthesis & Upgrading

- Chemical Conversions to Intermediates & Products
- Biological Conversions to Intermediates & Products
- Cleanup or Finishing
- Hybrid Conversions to Intermediates & Products

ChemCatBio Chemical Catalysis for Bioenergy

Budget by WBS Area

($M appropriated, numbers rounded)

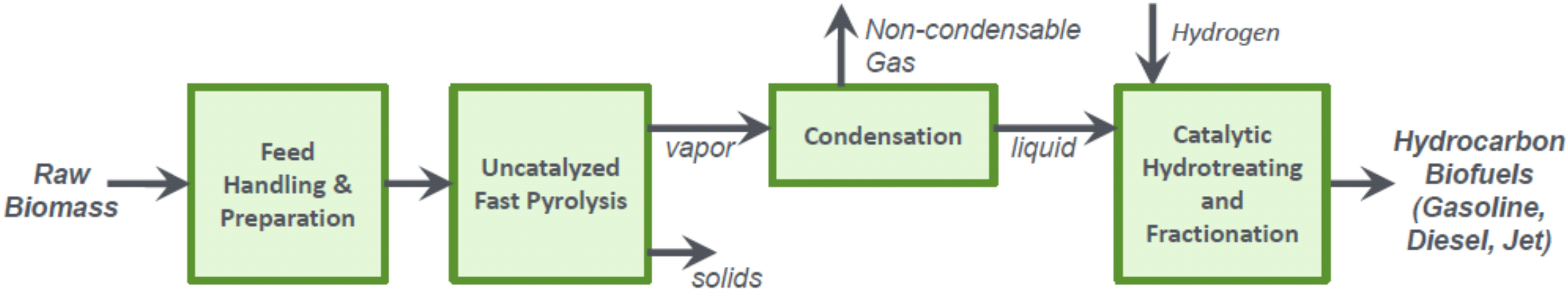


Conversion Design Cases and Benchmarking

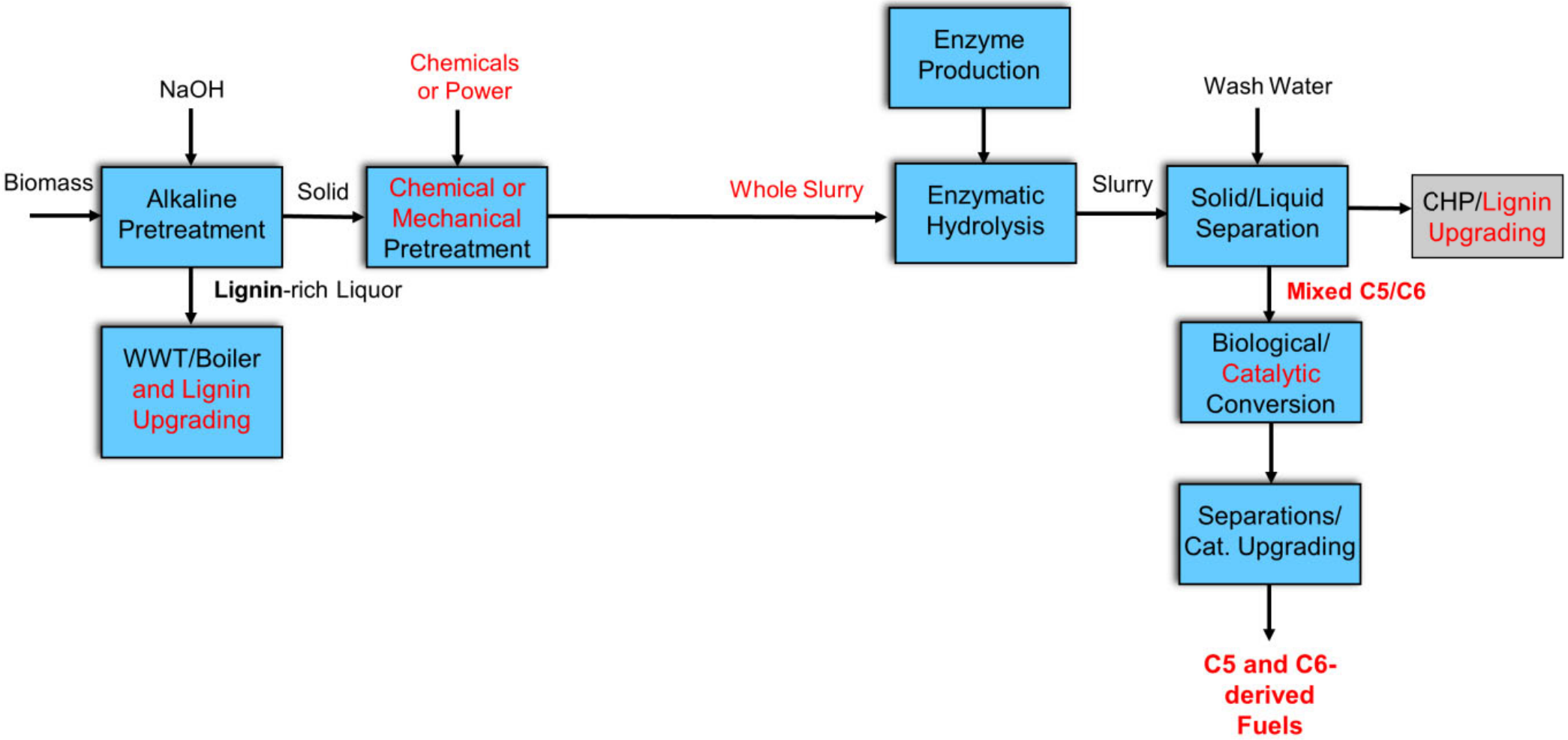
Category	Pathway
Low Temperature Conversion	Biological Conversion of Sugars to Hydrocarbons
	Catalytic Upgrading of Sugars to Hydrocarbons
Direct Liquefaction	Fast Pyrolysis and Upgrading
	Ex Situ Catalytic Pyrolysis
	In Situ Catalytic Pyrolysis
Indirect Liquefaction	Syngas Upgrading to Hydrocarbons

- Design cases help diversify R&D in recognition that ultimately industry will decide which pathways are the most viable
- Enable progress in one technology to have effects across multiple different pathways
  - A new preprocessing technology might enable cost reductions in all pathways
  - A new hydrolysis technology would enable multiple low-temperature deconstruction pathways
- Recognize that different pathways involve technologies at various levels of development (components with different TRLs)

Example pathway – Fast Pyrolysis



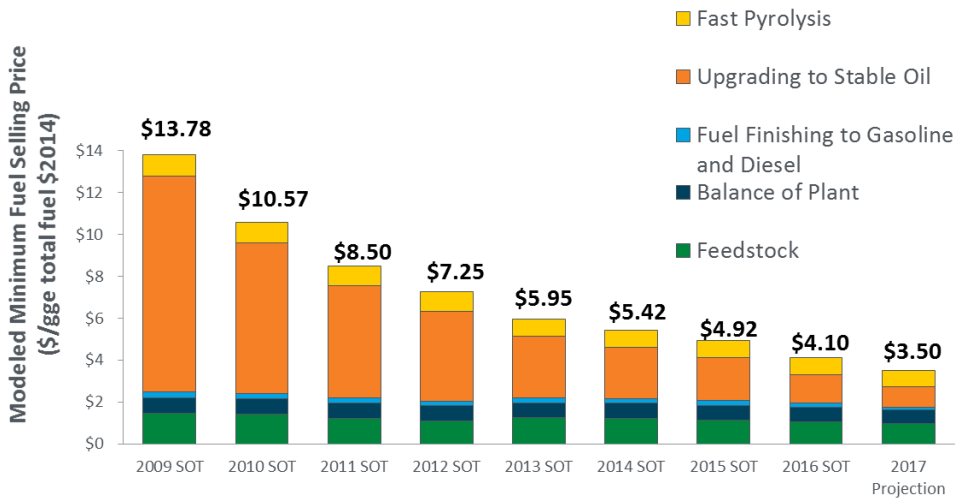
Example Pathway – Biological Upgrading of Sugars

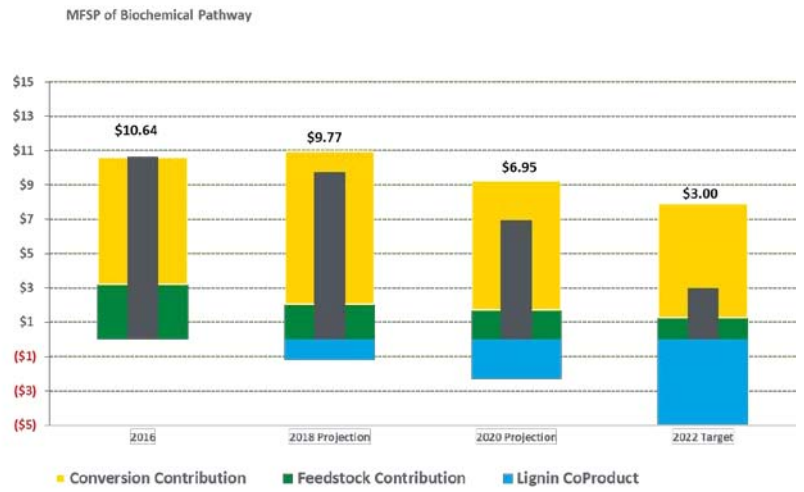


Conversion R&D Program Technical Progress Metrics

- By 2017, verify an nth plant modeled minimum fuel selling price (MFSP) of $3/GGE (2014$) via a conversion pathway to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel.

- By 2022, verify an nth plant modeled MFSP of $3/GGE (2014$) for two additional conversion pathways to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel.





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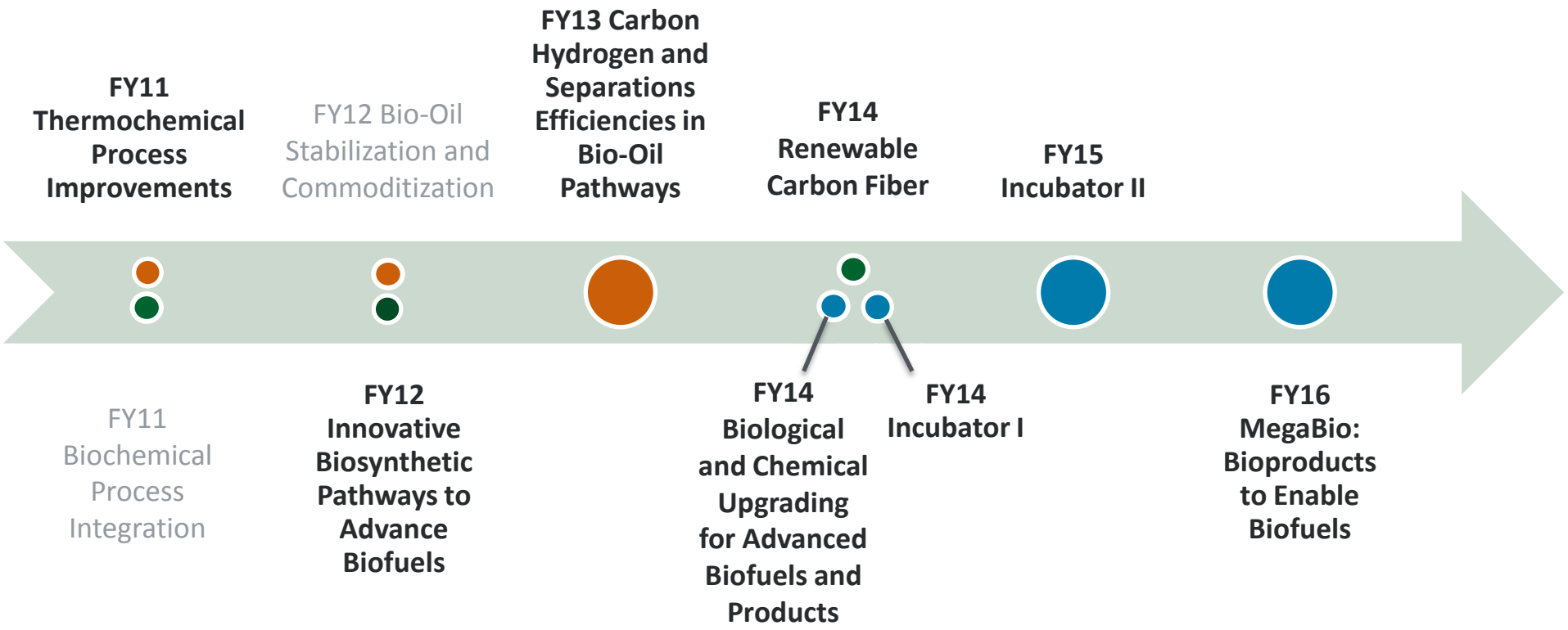
APPROACH

Competitive FOAs

FOAs with active projects at this review

BETO Run Opportunities (thermochem, biochem, hybrid)



Joint Funding Opportunities with USDA

APPROACH

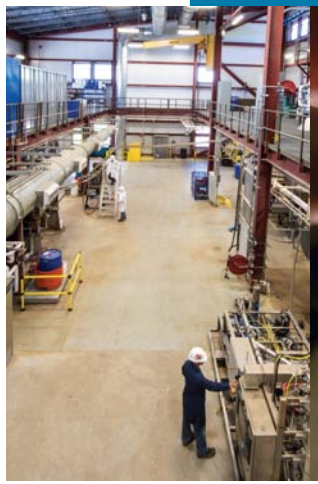
Lab AOPs

AOP process overview

- All National Lab projects undergo an external merit review every 3 years
- Concept papers -> Full proposals -> Merit review
- Selected projects enter a three year cycle.
  - Go/No Go Milestone after first 15-18 months
  - Annual Milestones
  - Year 3 milestone = BHAG
  - Projects may continue
    - Impactful accomplishments
    - Clear need for additional work
    - Successful merit review
- If a project has run its course, PIs are asked to propose new work

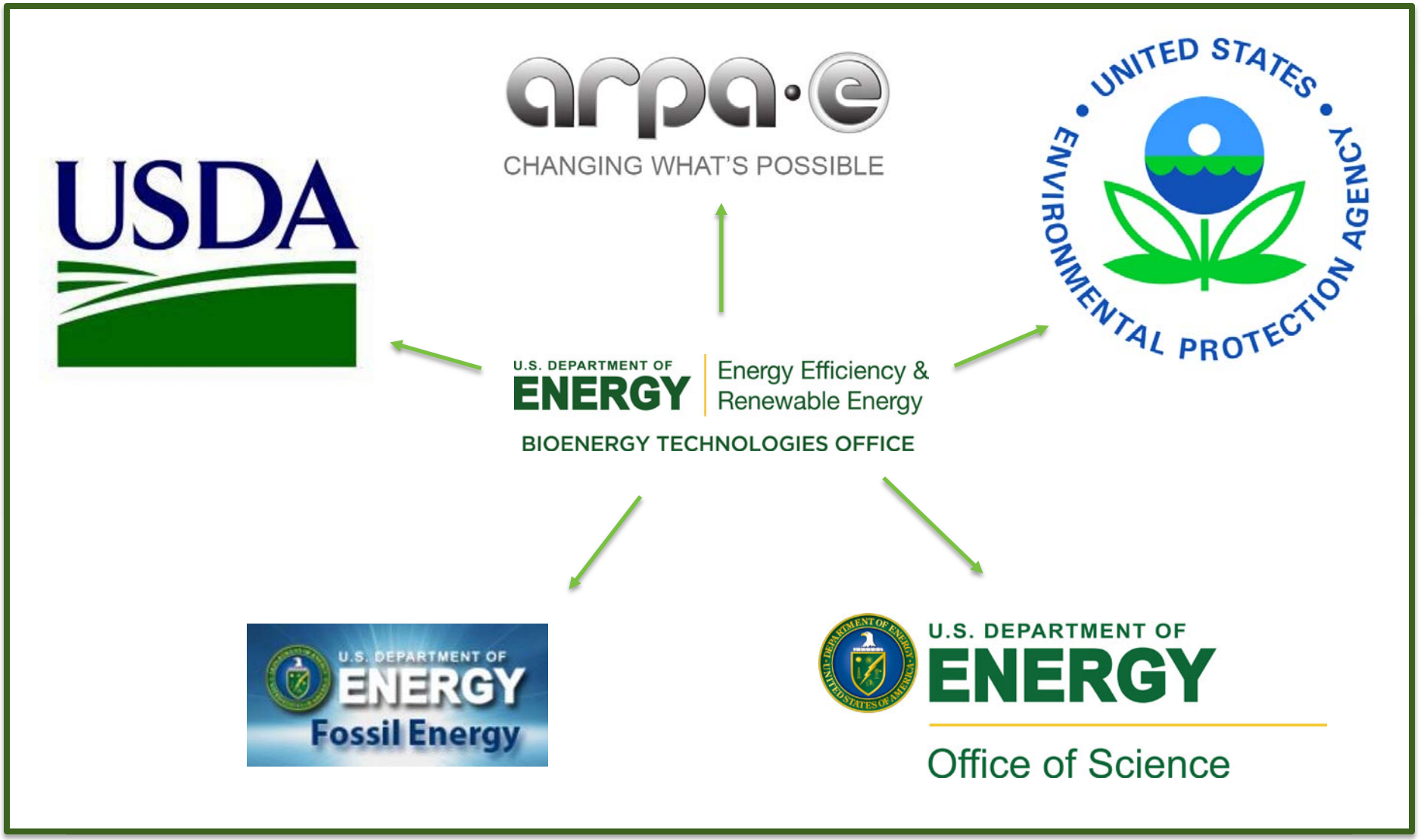
APPROACH

Additional Collaborations





Interagency Work



ARPA-e spin outs

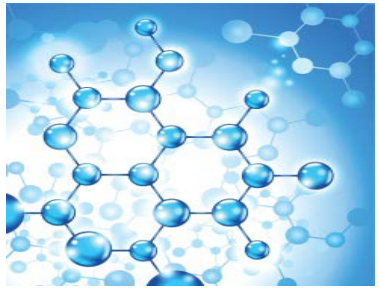
Plants Engineered To Replace Oil (PETRO)

Targets the production of fuel molecules, such as oils and hydrocarbons, directly in the plant through metabolic engineering

Yield10 Bioscience

(Incubator 1 FOA)

Reducing Emissions using Methanotrophic Organisms for Transportation Energy (REMOTE)



Targets the development of new methane bioconversion strategies for small scale, low CapEx gas-to-liquids processing

LanzaTech

(Incubator 2 FOA)

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

(BCU FOA)

NatureWorks
CALYSTA ENERGY

(BCU FOA)

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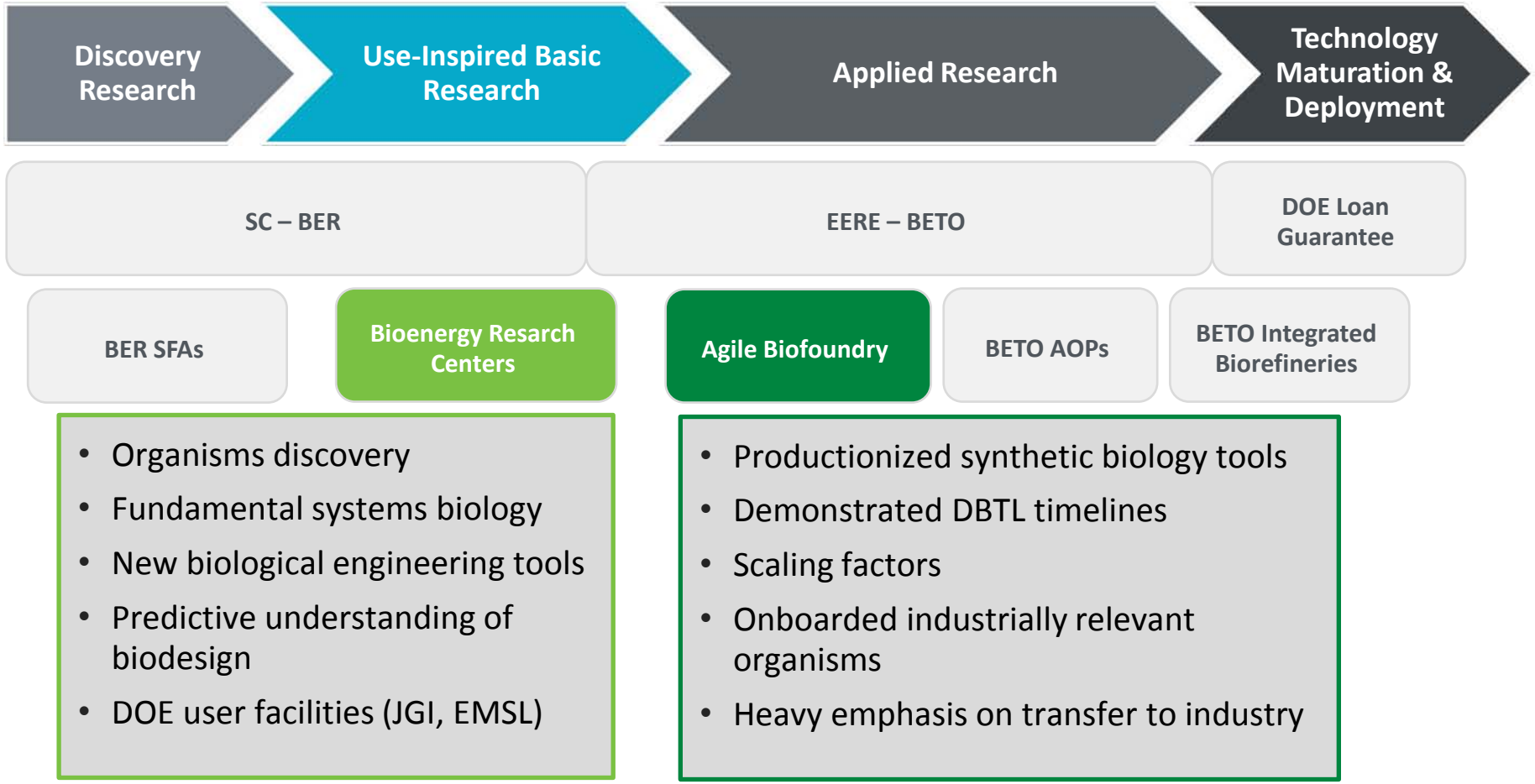
Agile BioFoundry - Coordinated BioDesign Research across BER and BETO



PROGRESS

Technical Accomplishments

- By 2017, verify an nth plant modeled minimum fuel selling price (MFSP) of $3/GGE (2014$) via a conversion pathway to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel.

Commercial Partnerships

- **LBNL partnered with over 20 small businesses to assist with the scale-up and commercialization** of processes to produce bioproducts and biofuels
  - *The LBNL Advanced Biofuels Process Demonstration Unit which works on most of these partnerships will present on Wednesday at 10:15 a.m. in the Biochem session*

Technical Accomplishments

Commercial Partnerships

- **PNNL licensed HTL technology to Genifuel**
  - For the conversion of sewage into biofuels
  - Eliminates the previous cost-prohibitive energy-intense need to dry the sewage
  - *PNNL will present on their HTL technology on Tuesday at 11:15 a.m. in the Waste to Energy Session.*

- **Vertimass and ORNL** continued work on their **low-energy process for the conversion of ethanol to hydrocarbon fuels and products**.
  - Process has the potential to increase the profitability of biorefineries and provides method for overcoming the ethanol blendwall
  - Vertimass licensed the technology from ORNL in 2014
  - **ORNL received an R&D 100 award for this work in 2015**
  - *Vertimass will present on Wednesday at 3:45 p.m. in the Thermochemical session.*

Technical Accomplishments

Progress from former FOA Awardees

- **Genomatica** (FY11 Biochemical Process Improvements)
  - Developed an organism and better process steps to **convert cellulosic sugars to the renewable chemical 1,4-butanediol**
  - **Process licensed by BASF**
- **Lygos** (FY12 SynBio)
  - Awarded **$300K in a Small Business Voucher Pilot to scale up processes funded under BETO award**
  - Will fund large fermentation vessels to validate their **biobased production of malonic acid**
  - *Lygos will present Thursday at 11:25 a.m. in the Biochem session*
- **Novozymes** (FY12 SynBio)
  - Advanced cellulases and hemicellulase enzyme cocktails have resulted in **1.4x reductions to the cost of hydrolyzed sugars**
  - *Novozymes will present Thursday at 11:05 a.m. in the Biochem session*

Technical Accomplishments

Jet Fuels and Aviation

- **PNNL**, working with Imperium Aviation Fuels and **LanzaTech** developed process to produce **jet fuel from alcohols**
  - Liter quantities produced in 2015
  - Process advantageous as ethanol more plentiful and less expensive to produce than other precursors
- **LanzaTech** announced the **production of 1,500 gallons of renewable jet fuel from industrial waste gases**
  - Same partnership as above
  - Will be used by Virgin Atlantic
  - Carbon savings of 65% compared to conventional jet fuel.
  - *LanzaTech will present on a portion of this work Thursday at 9:30 a.m. in the Thermochem session*

Technical and Programmatic Accomplishments

Coprocessing – NREL/PetroBras

- *PyOil coprocessing in a refinery FCC is economically feasible today (5wt% substitution).*
- *Co-processing pathway approval by EPA (Part 79) and CARB*
- *1-2 billion gallons of biofuel per year potential is US*
- *The NREL-Petrobras CRADA will present Wednesday at 10:15 a.m. in the Thermochem session*

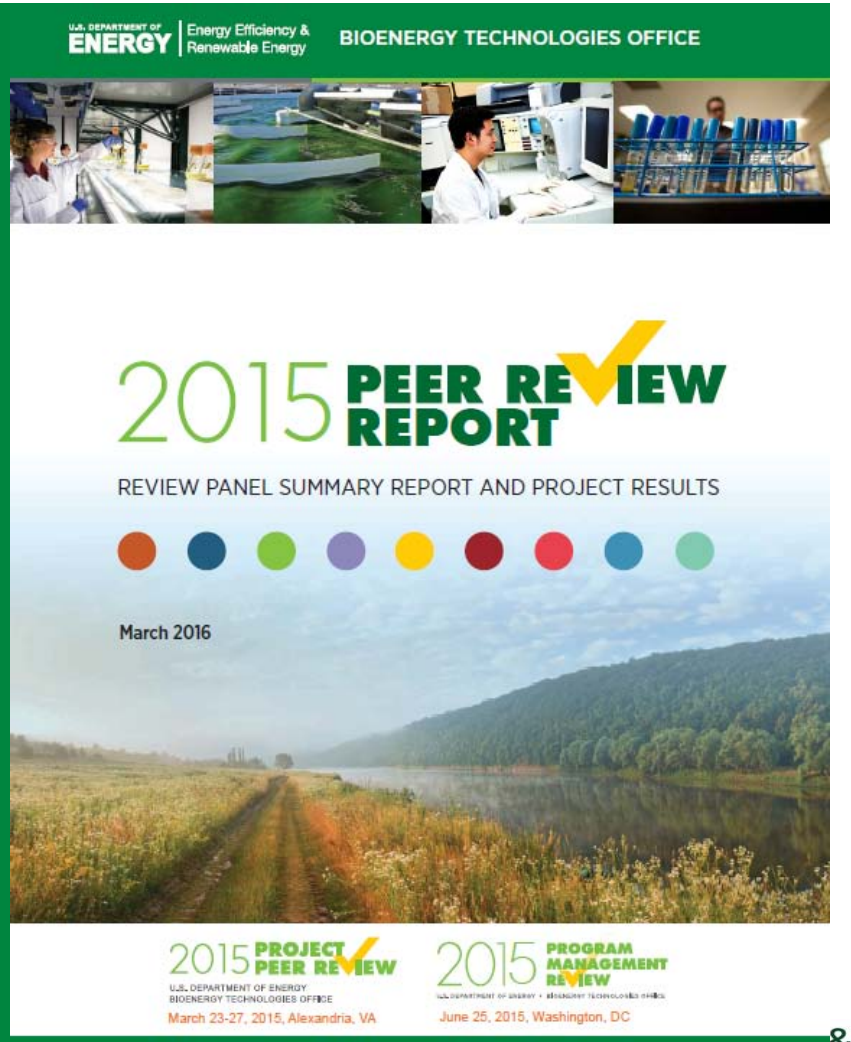
- **Tesoro Refining and Marketing Company** will acquire **Virent**,
  - Support the **scale up and commercialization of Virent's BioForming® technology**
  - *Virent will present on their BETO-funded work on hydrothermal liquefaction on Wednesday at 2:00 p.m. and their work on catalytic upgrading on Thursday at 9:50 a.m. both in the Thermochem session*)

Database of Cellulosic Sugars and Lignin sources

- Addresses industry need for suppliers/partners
  - Responses available online (feedstock, process, and. capacity/quantity available)
  - Additional responses may still be submitted to **sugarandlignin@ee.doe.gov**

Key Changes Since 2015 Peer Review

- Completed R&D Organization around broad barrier areas
- Expanded use of validations for FOA projects
- Implemented 3-year AOPs with external review
- Developed consortia increase collaboration, leverage capabilities and reduce overlap
- Wet Waste to Energy – opportunity feedstock
- Implemented bioproduct strategy to help jump-start the bioeconomy



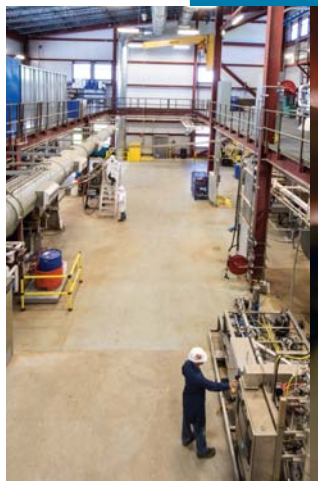
Upcoming Workshops and Listening Days

- Carbon Capture and Utilization
  - Coordinating with BETO's Algae program and DOE Office of Fossil Energy
- Biofuels and Bioproducts from Wet and Gaseous Waste Streams: Market Barriers & Opportunities
- Moving Beyond Drop-In Replacements: Performance Advantaged Bio-Based Chemicals (June 1, Denver CO)
- Non-photosynthetic Reduction of CO_2
- Cell-Free Synthetic Biology
- Industry Listening Day for Chemical Catalysis for Bioenergy

Proposed Activities in FY17

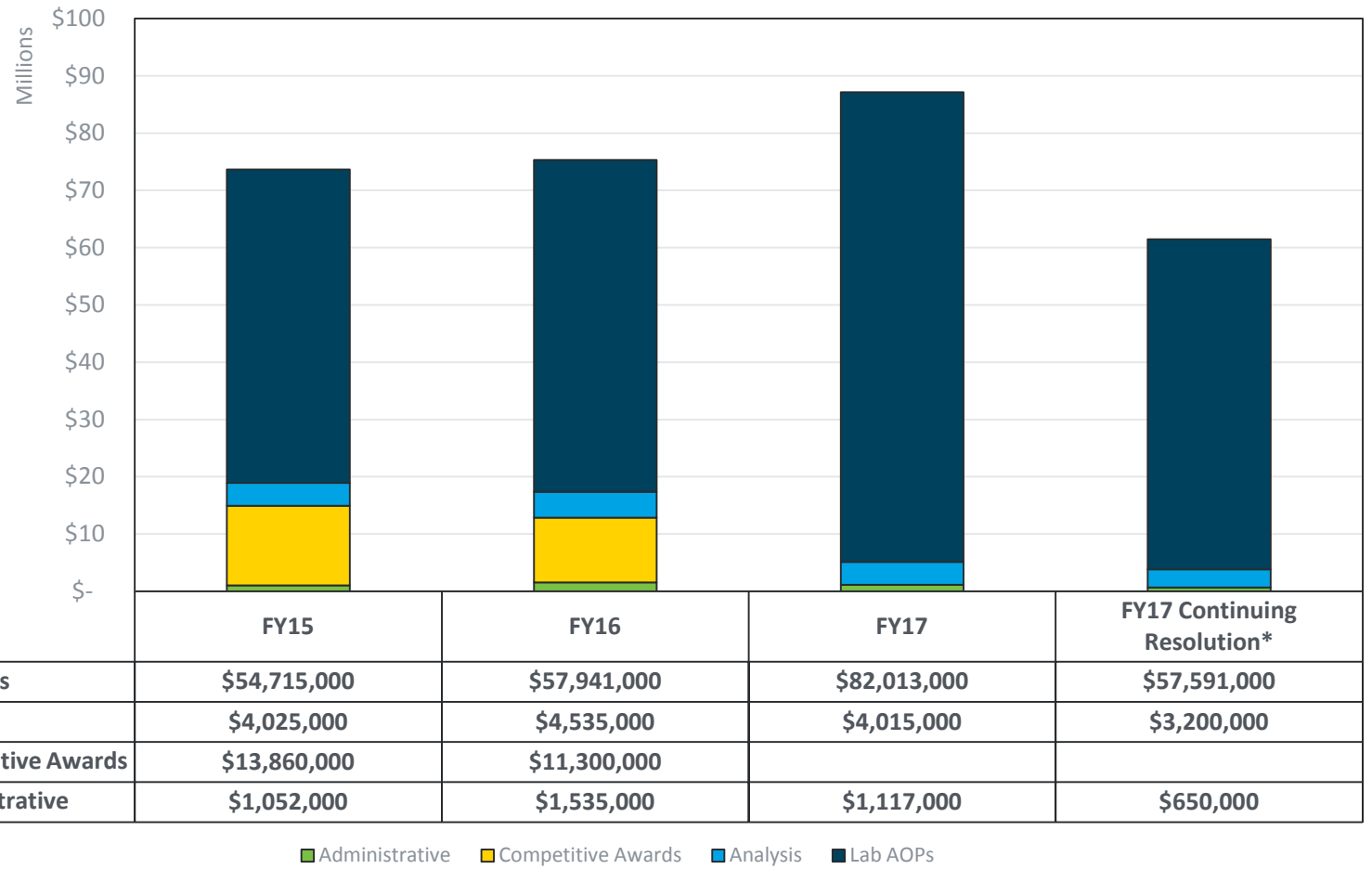
- Verify at pilot scale at least one technology pathway for hydrocarbon biofuel production demonstrating a mature modeled cost of $3/gge with GHG emissions reduction of 50% or more.
- National Laboratory consortia will continue strategic research that brings BETO closer to its goals by reducing costs and improving performance throughout the bioenergy value chain, and validating technology and reducing risk in order to encourage technology development and commercialization.
- Define organism chassis and target molecules as targets for the Agile BioFoundry consortium.
- Through competitive awards with industry (MEGA-BIO FOA), continue progress on technologies for bio-products to improve biorefinery economics.
- Conduct workshops to engage industry and define R&D directions:
  - ChemCatBio technical symposium and industry listening day
  - Waste to Energy – June 2017
  - Functional Replacements to Enable the Bioeconomy – June 2017
  - Cell-Free Synthetic Biology Workshop – July 2017

PORTFOLIO STRUCTURE AND BUDGET




Budget

Budget breakdown by spending area ($M appropriated, numbers rounded)



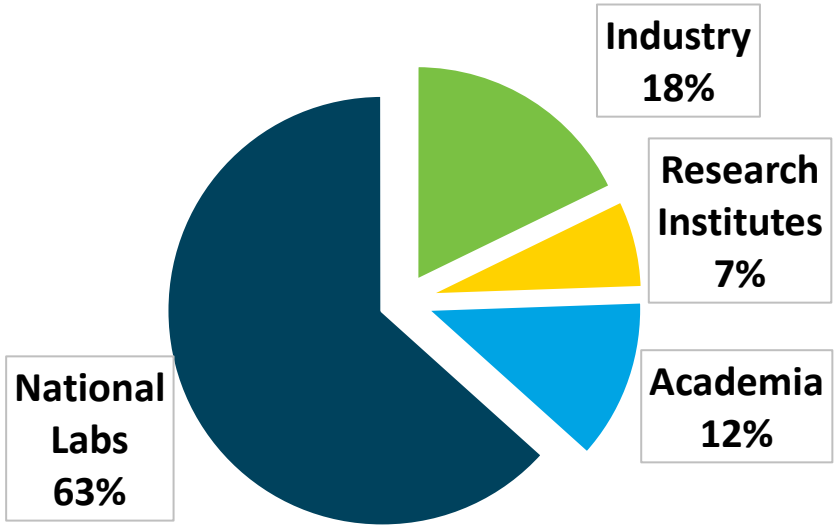
	FY15	FY16	FY17	FY17 Continuing Resolution*
Lab AOPs	$54,715,000	$57,941,000	$82,013,000	$57,591,000
Analysis	$4,025,000	$4,535,000	$4,015,000	$3,200,000
Competitive Awards	$13,860,000	$11,300,000		
Administrative	$1,052,000	$1,535,000	$1,117,000	$650,000

*Under the current continuing resolution which is in place until the end of April, National Lab projects have been instructed to spend on average 20% less than their original budget request for 2017

Portfolio Structure

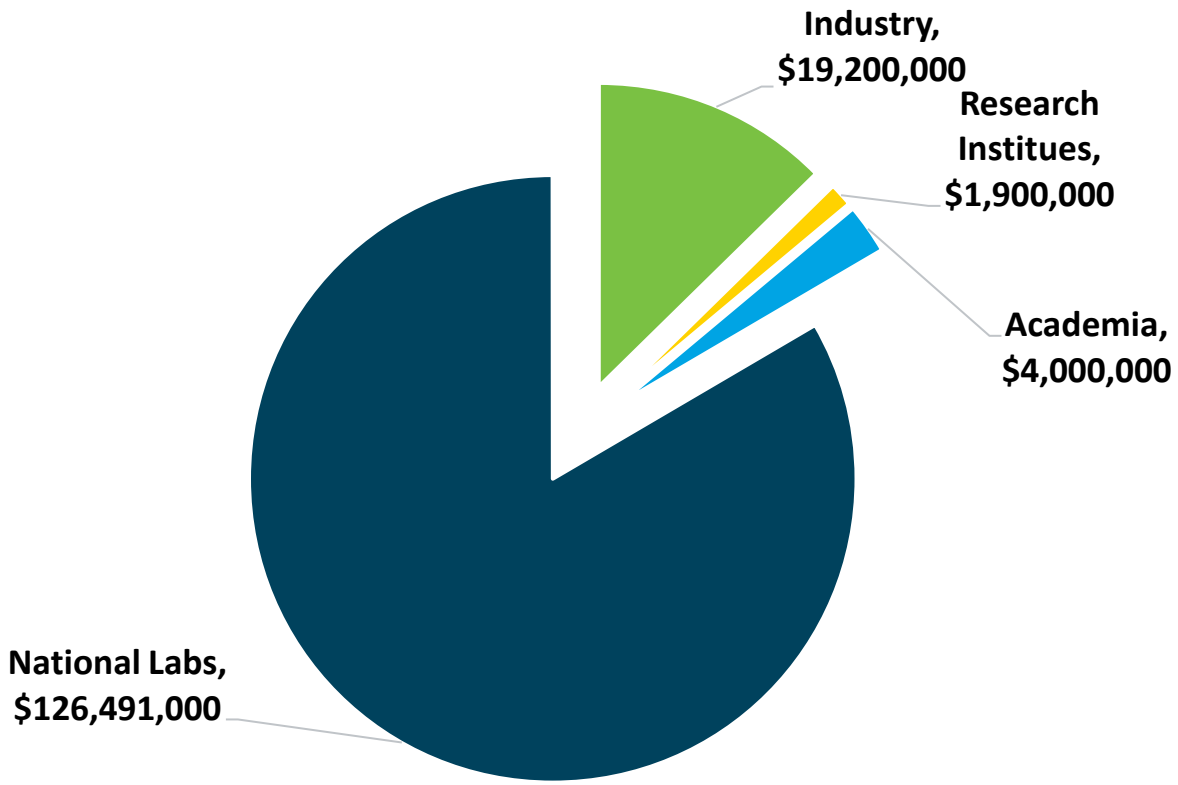
90 total Conversion portfolio projects to be reviewed over the next four days:

- 39 in the Biochemical Review Session
- 33 in the Thermochemical Review Session
- 11 in the Waste to Energy (WTE) Session
- 7 in the Conversion/Feedstock Interface Session (6 additional projects from the Feedstocks portfolio will also be reviewed)



Portfolio Structure and Budget

Amount Appropriated During Review Period (FY15-16) by Recipient Type (numbers rounded)



Introduction - Conversion Reviewers

Thermochemical
- Shawn Freitas,* TRI, Inc.
- Lorenz (Larry) Bauer, Independent Consultant
- Tim Brandvold, Abbott Molecular
- Jeffrey Scheibel, Independent Consultant
- Niels Udengaard, Independent Consultant

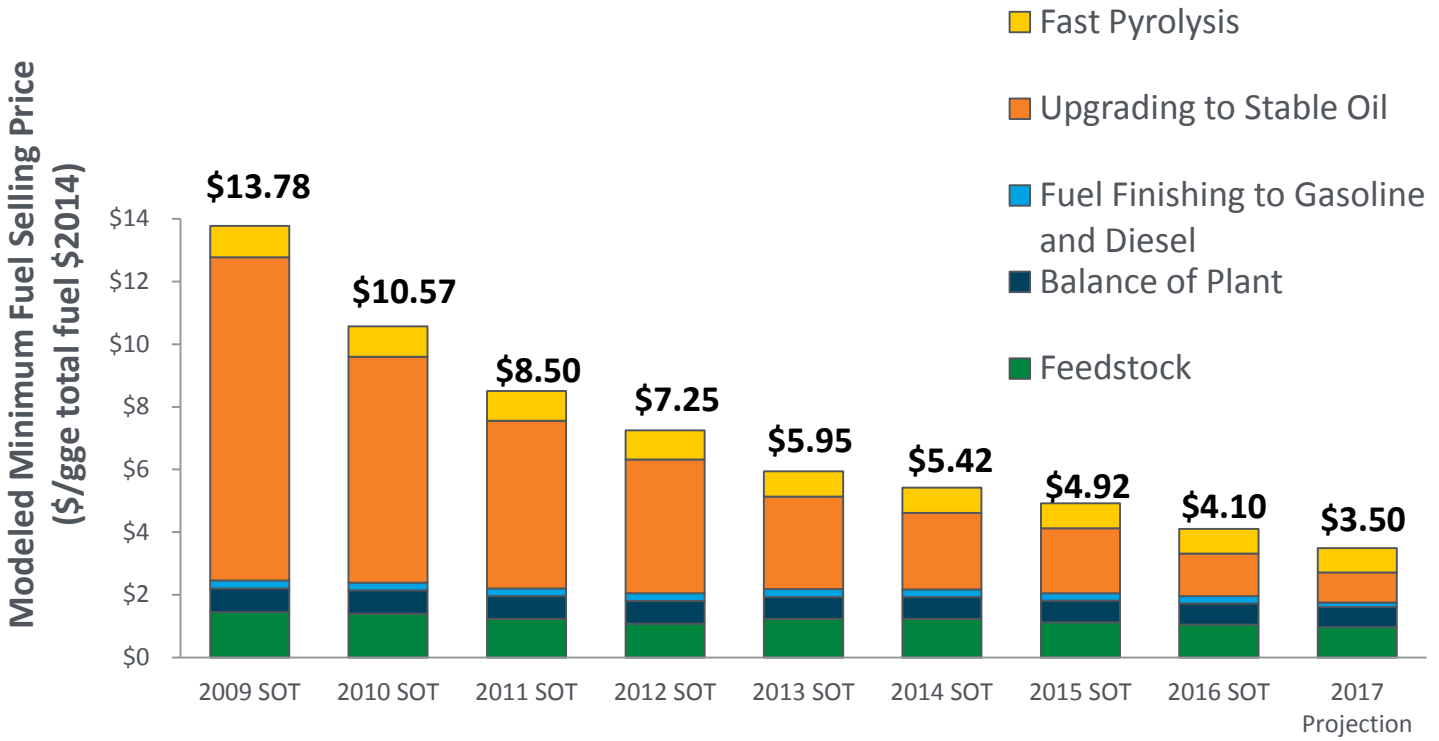
Biochemical
- Suzanne Lantz*, Dupont
- Joseph Bozell, University of Tennessee
- Yoram Barak, BASF
- Jamie Ryding, Corvia Biotechnology Group
- Steve Van Dien, Genomatica

Waste to Energy
- Luca Zullo,* Verde Nero
- Brandon Emme, ICM, Inc.
- Jeremy Guest, UIUC
- Phil Marrone, Leidos

***Lead Reviewer**

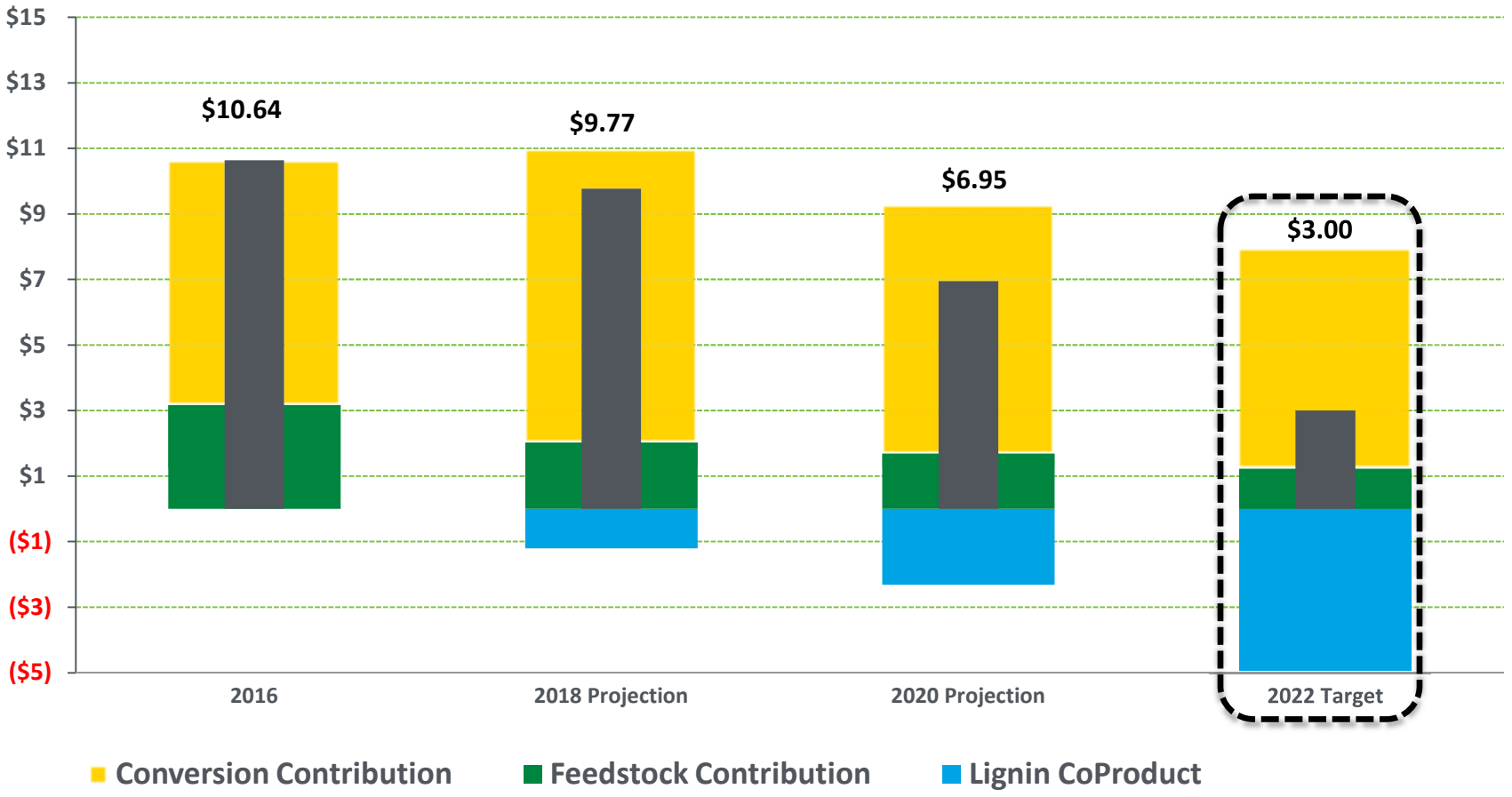
Thank you!

2017 Pathway Validation: Fast Pyrolysis



	2014 SOT	2015 SOT	2016 SOT	2017 Target
Minimum Fuel Selling Price ($/GGE, 2014$)	$5.42	$4.92	$4.10	$3.50
Feedstock Contribution ($/GGE, 2014$)	$1.23	$1.12	$1.05	$0.97
Conversion Contribution ($/GGE, 2014$)	**$4.19**	**$3.80**	**$3.05**	**$2.53**

MFSP of Biochemical Pathway



Current and Past FOA overview

Biochemical Focused FOAs (projects in bold will present at this review)

Biochemical Processing Improvements

FY2011 ($36M)

- Process integration and development of deconstruction and upgrading technologies
- Texas Engineering Experiment Station, Genomatica, Michigan Biotechnology Institute (MBI), Virent, HCL Cleantech (Virdia), General Atomics

Innovative Biosynthetic Pathways to Advance Biofuels (Synbio)

FY2012 ($10M)

- Development of processes that use innovative synthetic biological and chemical techniques to convert biomass into processable sugars.
- **J Craig Venter Institute, Lygos, Novozymes,** PNNL, **Texas Agrilife**

Renewable Carbon Fiber (RCF)

FY2014 ($11M)

- Production of cost-competitive, high-performance carbon fiber material from renewable, non-food-based feedstocks.
- **Southern Research Institute, NREL**

Current and Past FOA overview

Thermochemical Focused FOAs (projects in bold will present at this review)

Thermochemical Intermediates Upgrading FY2011 ($12M)	• Funding to advance drop-in biofuel production, efficiency, and cost effectiveness • **LanzaTech, Virent Energy Systems, Inc., Research Triangle Institute**
Bio-Oil Stabilization and Commoditization (BOSC) FY2012 ($12M)	• Focused on creating bio-oils capable of blending within existing petroleum refineries to produce drop-in fuel. • PNNL, Gas Technology Institute, Southern Research Institute, Stevens Institute of Technology, Idaho National Lab, Sapphire Energy, Iowa State University, University of Georgia
Carbon Hydrogen and Separations Efficiencies in Bio-Oil Pathways (CHASE) FY2013 ($12M) *$6M in alternates in FY2014)*	• Addreeses three barriers to biofuel production: carbon efficiency hydrogen efficiency, and separations efficiency. • **Virent Inc., University of Oklahoma, Ceramatec Inc., Oak Ridge National Lab, Research Triangle Institute**

Current and Past FOA overview

Hybrid Approach FOAs (projects in bold will present at this review)

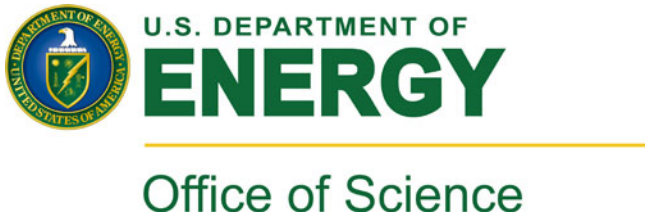
Biological and Chemical Upgrading for Advanced Biofuels and Products (BCU) FY2014 ($13M) *$4M in alternates in FY2015*	• Focused on the integration and development of upgrading and separations in advanced biofuel production systems. • **American Process Inc ‡, Vertimass LLC†, NREL*, NatureWorks LLC*, University of Wisconsin†, Ohio University*, Texas A&M ‡**
Incubator I/II ($10M in FY2014, $10M in FY2015)	• Focused on the addition of novel technologies not represented elsewhere in the portfolio. • I: **Metabolix‡, Ohio State University‡, University of California Riverside†,** Cargill**, Kiverdi Inc.‡, Gas Technology Institute †** • II: **Duke‡, LanzaTech‡, Lygos‡, White Dog Labs‡**
MEGABio: Bioproducts to Enable Biofuels FY2016 ($11M)	• Focused on enabling cost-effective biofuel production through coproduction of bio-based chemicals and products. • **DOW‡, Research Triangle Institute†, Amyris‡**

†project will present in the Thermochemical session
‡project will present in the Biochemical session
**project will present in the Waste to Energy session*

Current and Past FOA overview

Other Solicitations

- **Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR)**
  - Run through the Office of Science, managed by BETO, targeted at small businesses



- **Biomass Research and Development Initiative (BRDI)**
  - Joint solicitation run with USDA in FY12 and FY15 in an effort to coordinate federal research efforts on bioenergy and bioproducts.

Small Business Vouchers (SBV) Pilot Program - Bioenergy

- **Purpose:** To help small businesses bring clean energy technologies to market faster by enabling access to national lab expertise and tools *easily* and *affordably.*
- SBV (www.sbv.org) is a pilot program coordinated by EERE that matches selected clean energy small businesses with experts from the national labs and awards the businesses vouchers valued at $50K to $300K that they can exchange for national lab technical assistance.
  - 5 lead national laboratories (ORNL, NREL, LBNL, PNNL, and Sandia)
  - All DOE national laboratories are eligible to participate

Round 1 Awardees: Lygos & Visolis

Round 2 Awardees: ZymoChem, HelioBio Sys, Virent, Mango Materials, and Avatar Sustainable Technologies

Recent Funding Opportunity Announcements

Incubator 2

- Up to **$10 million** in funding announced May, 2016 to **advance the production of advanced biofuels**, substitutes for petroleum-based feedstocks, and **bioproducts** made from renewable, **non-food-based biomass**, such as algae, agricultural residues, and woody biomass.
- **Goal:** To make **drop-in biofuels** more **accessible** and **affordable** and meet the **cost target equivalent** of **$3 per gallon of gasoline by 2022**.
- **Funding was awarded to:**
  - **Arizona State University (2 projects)**
  - **Duke University**
  - **Lygos, Inc.**
  - **White Dog Labs**
  - **LanzaTech, Inc.**

Recent Funding Opportunity Announcements

MEGA-BIO Projects: Bioproducts To Enable Biofuels

- On August 2, 2016, BETO announced **$11.3 million** for three projects that support the **development of biomass-to-hydrocarbon biofuels conversion pathways** that can produce variable amounts **of fuels and/or products** based on external factors, such as market demand.
- Funding was awarded to:
  - **The Dow Chemical Company**
  - **Amyris, Inc.**
  - **Research Triangle Institute**

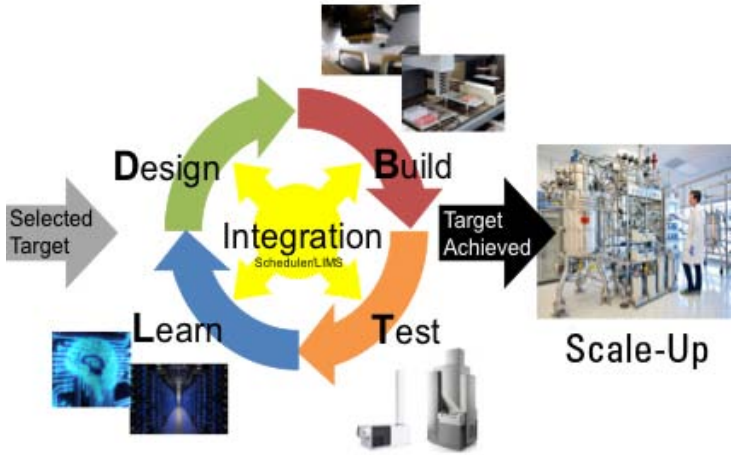
Recent Funding Opportunity Announcements

FY15 DOE BRDI Selections

- **Announced on May 9, 2016; total DOE funding of $3M.**
- The Biomass Research & Development Initiative (BRDI) is a **joint program through the Energy Department and the Department of Agriculture**. Projects funded through the initiative focus on the development of diverse cost-effective technologies for the use of **cellulosic biomass in the production of biofuels, bioenergy, as well as a range of biobased products (including chemicals, animal feeds, and power) that potentially can increase the economic feasibility of fuel production in a biorefinery**.
- Funding was awarded to:
  - **The Ohio State University (OSU)**
  - **Massachusetts Institute of Technology (MIT)**

Agile BioFoundry

Mission	The Agile BioFoundry will apply advanced synthetic biology tools to the biomanufacturing of fuels and chemicals. This will lead to new bioproducts getting to market in half the time and with half the cost of traditional bioproducts as well as >50% GHG reductions vs petroleum-derived products.
Key Players	Berkeley Lab, Idaho National Laboratory, Argonne National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, NREL, Ames Laboratory, Oak Ridge National Laboratory, Los Alamos National Laboratory
Website	agilebio.lbl.gov/



Impact: *The National Lab consortium, in partnership with academia and industry, aims to:*

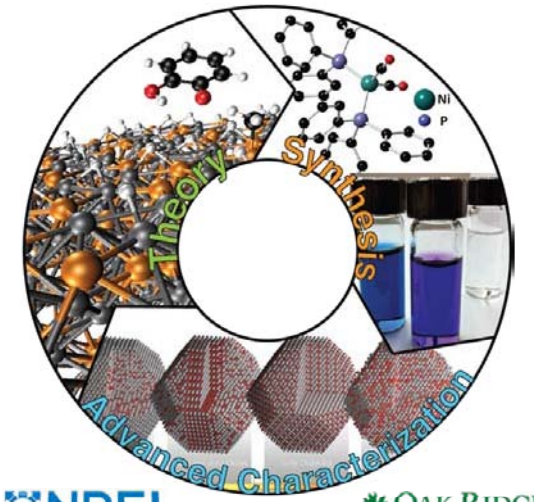
- Decrease the energy intensity of current manufacturing processes by 40% over status quo
- Decrease the carbon intensity of current manufacturing processes by 60% over status quo
- Increase biomanufacturing cycle efficiency (cost, time) >40%
- Develop new manufacturing technologies, increase US industry competitiveness, and create new opportunities for private sector growth

Chemical Catalysis for Bioenergy Consortium (ChemCatBio)

*ChemCatBio will bring new catalytic materials to commercial bioenergy applications at least **two times faster** and at **half the cost** by leveraging unique capabilities and experts within the DOE National Laboratories*

ChemCatBio
Chemical Catalysis for Bioenergy

Coordinated resource network with a suite of capabilities for advanced materials R&D working to solve critical technical bioenergy challenges



- Addresses that catalytic materials significantly contribute to the cost of making advanced biofuels
- Consists of technical capabilities experts, technology transfer/agreement experts, and data experts from seven DOE national laboratories
- Streamlined processes for accelerated technological advances
- Builds off the successes of the CCPC and Catalysis Working Group

Energy Materials Network
U.S. Department of Energy

NREL
National Renewable Energy Laboratory

Oak Ridge National Laboratory

Pacific Northwest National Laboratory

Argonne National Laboratory

Los Alamos National Laboratory

New Material Innovations for Clean Energy 2X Faster and 2X Cheaper

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

Consortium for Computational Physics and Chemistry (CCPC)

Mission: To utilize core computational capabilities across the US DOE national laboratory system to enable and accelerate the development of new materials and optimize process scale-up to advance the bioenergy economy.

Vision: To create computational toolsets that facilitate the modeling of biomass industrial processes from atomic to commercial scale.

Objectives:

- Provide predictive simulation tools to enable BETO experimental teams to maximize yield and fuel chemistry based on reactor design, operational parameters, feedstock type, and feedstock particle size distributions during pilot scale verification.
- Simulations of reactor scale up effects and predictive impact on linkage of BETO bench and pilot scale results to full plant TEA.
- In conjunction with ChemCatBio, more rapid advancements in catalyst formulation and design that result in experimentally observed improvements (yield, selectivity, durability, lifetime, cost).

Energy Materials Network
U.S. Department of Energy

ChemCatBio
Chemical Catalysis for Bioenergy

CCPC

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

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

Bioprocessing Separations Consortium

Motivation

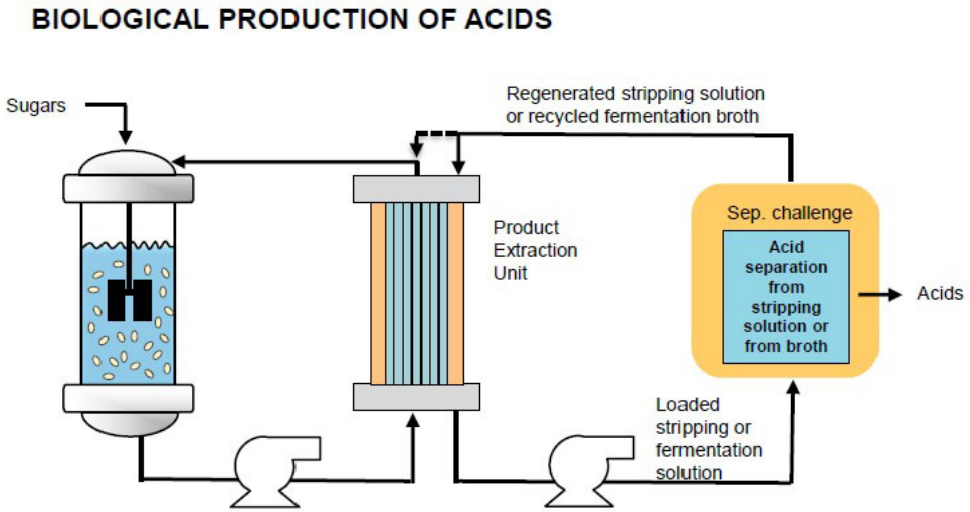
Stakeholder input has highlighted the need for cost-effective separations technologies. Currently, separations can represent up to 70% of biomass processing costs.

Approach

Interlab consortium working together to develop new technologies for to meet cost goals and improve process robustness of biofuel pathways. Supported by industrial advisory board that reviews progress and development in project.

Objective

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.



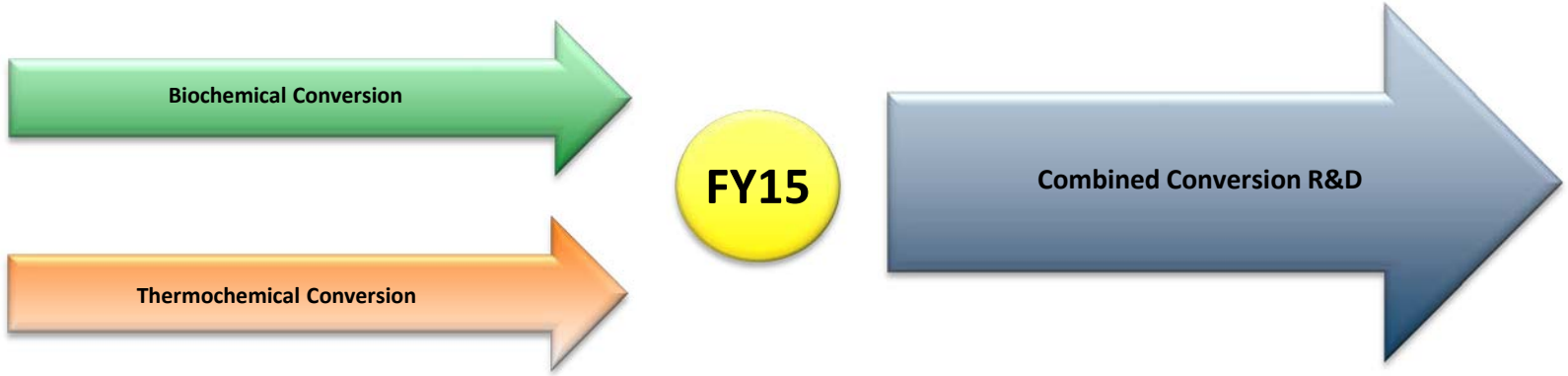
BIOPROCESSING SEPARATIONS CONSORTIUM

BERKELEY LAB · INL Idaho National Laboratory · Argonne National Laboratory · Pacific Northwest National Laboratory · Sandia National Laboratories · NREL · Oak Ridge National Laboratory · Los Alamos National Laboratory

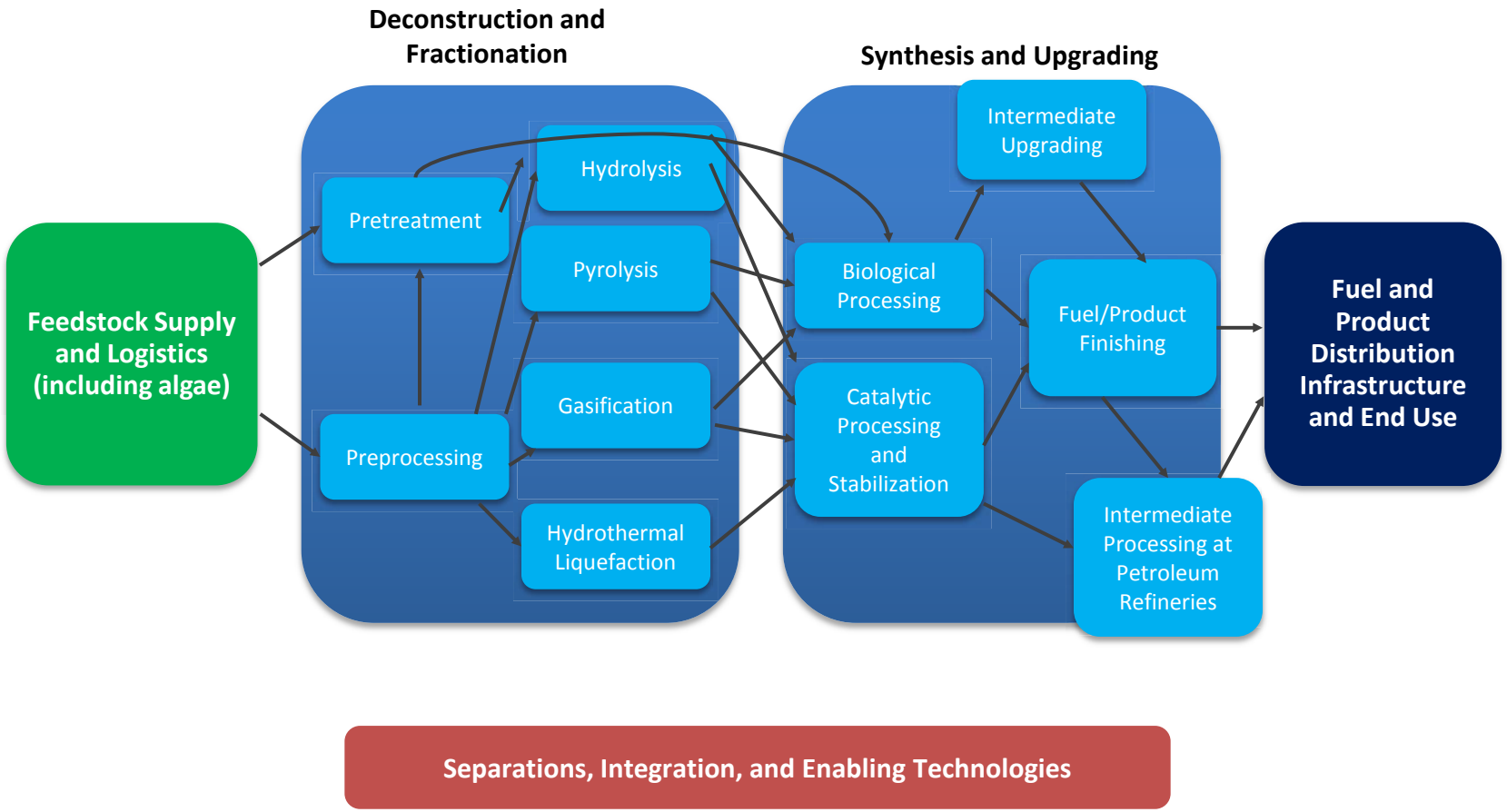
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Combined Conversion R&D

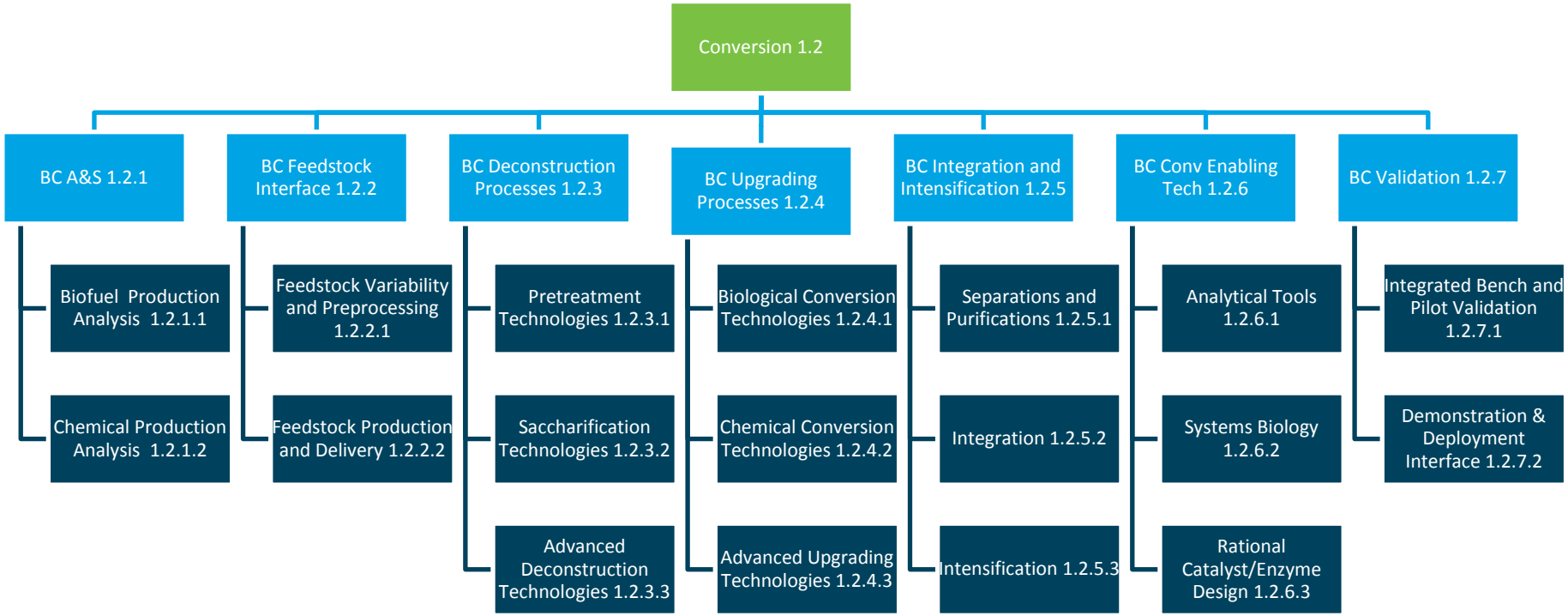
- Prior to FY15, projects were divided as thermochemical or biochemical conversion based on the following definitions
  - **Biochemical conversion** technologies involve pathways that use sugars and lignin intermediates.
  - **Thermochemical conversion** technologies involve pathways that use bio-oil and gaseous intermediates.
- BETO has now shifted to a combined conversion platform that better addresses existing barriers and encompasses existing technologies by focusing on combining stepwise processes to move from deconstructed feedstock to finished fuels and products that may include both biochemical and thermochemical elements



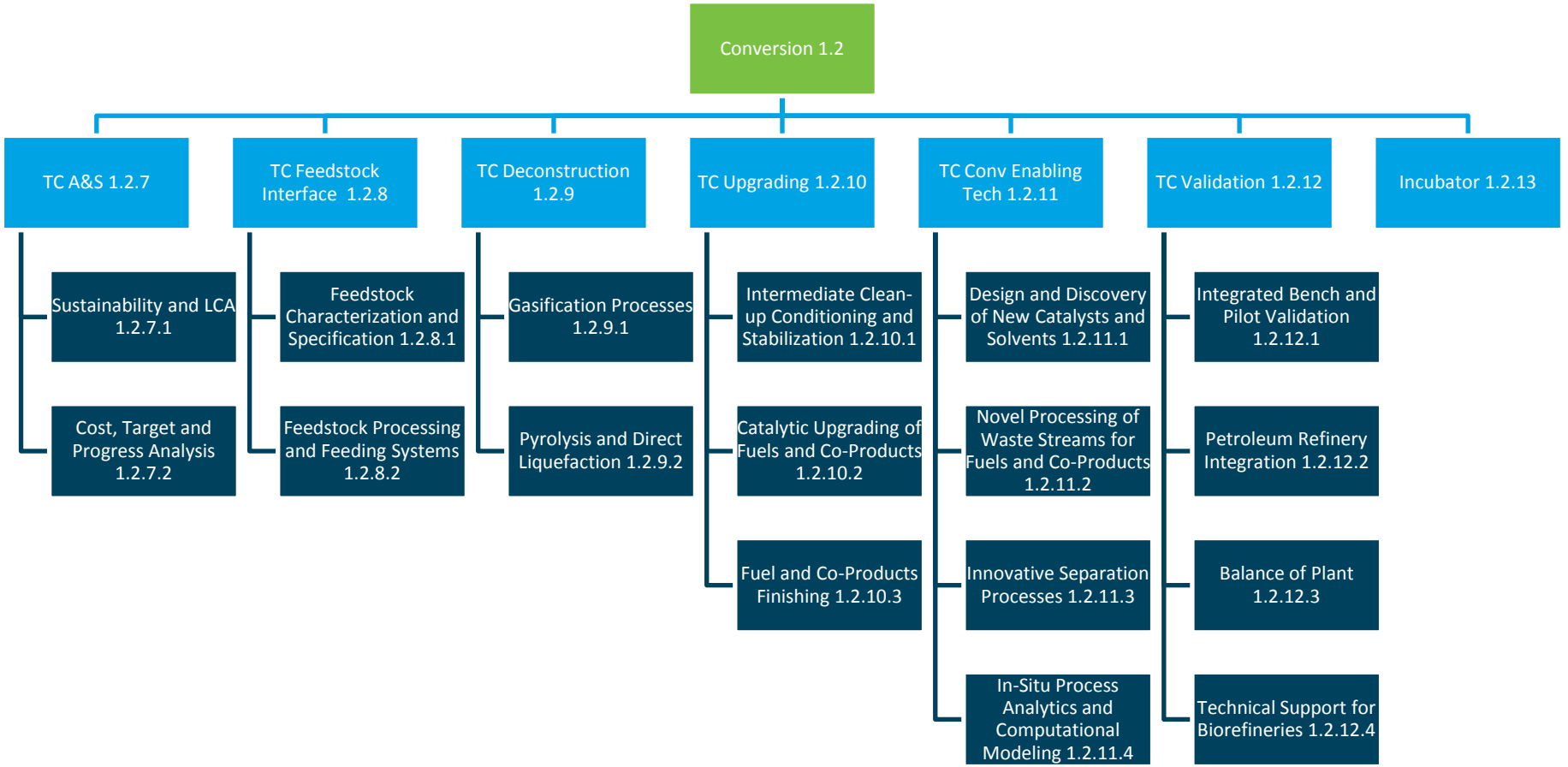
Conversion Portfolio Structure



Work Breakdown Prior to FY15

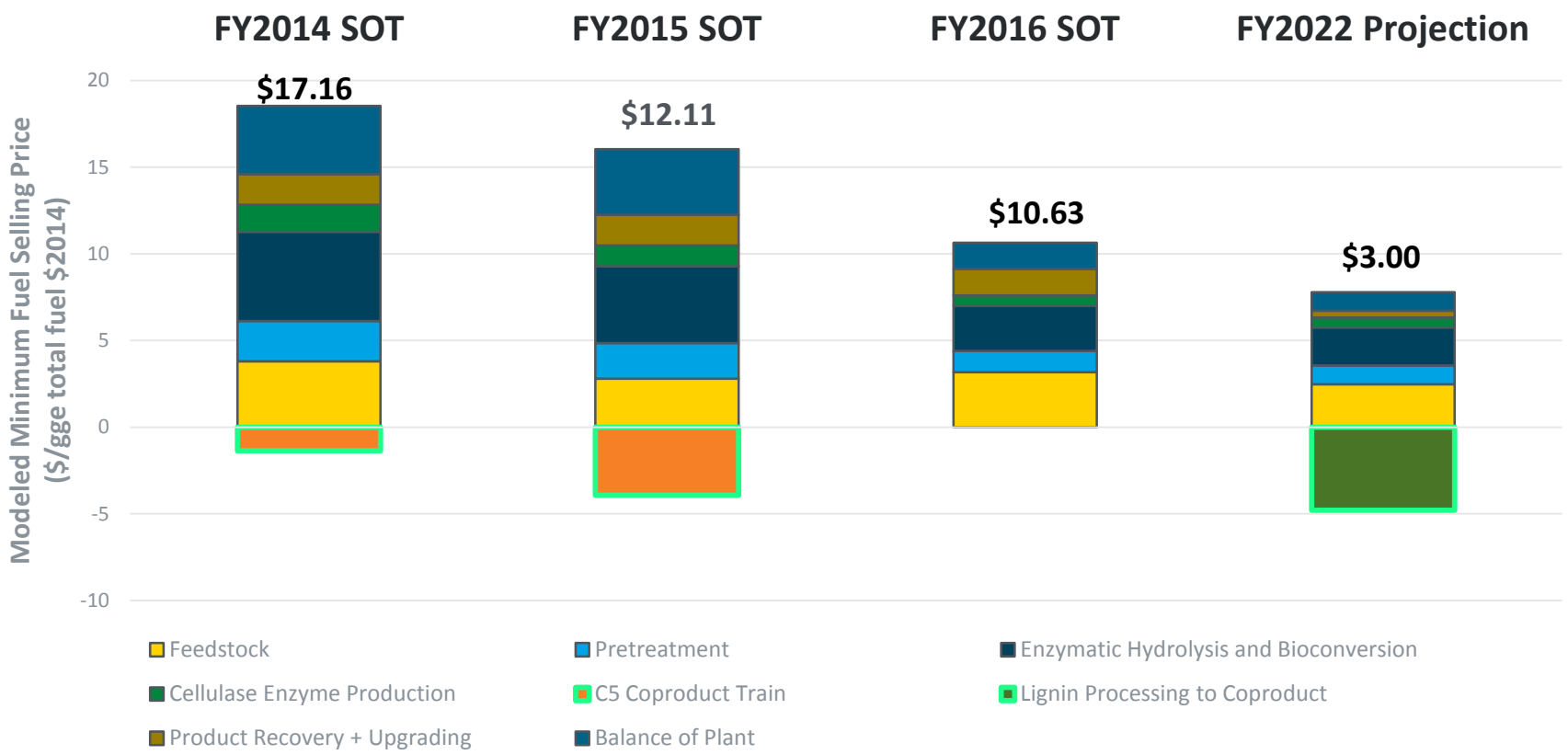


Work Breakdown Prior to FY15



MEASURE: Validate an nth plant modeled minimum fuel selling price (MFSP) of $3/GGE ($2014) via a conversion pathway to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel during FY2017. Two additional pathways should be validated by FY2022.

2022 Pathway Validation: Biological Upgrading of Sugars



	2014 SOT	2015 SOT	2016 SOT	2022 Target
Minimum Fuel Selling Price ($/GGE, 2014$)	$17.16	$12.11	$10.63	$3.00
Feedstock Contribution ($/GGE, 2014$)	$3.80	$2.79	$3.17	$2.47
Conversion Contribution ($/GGE, 2014$)	$14.73	$11.19	$7.46	$5.32
Co-Product Contribution	-$1.37	-$3.92	-	-$4.80

2015 Review Feedback and Responses

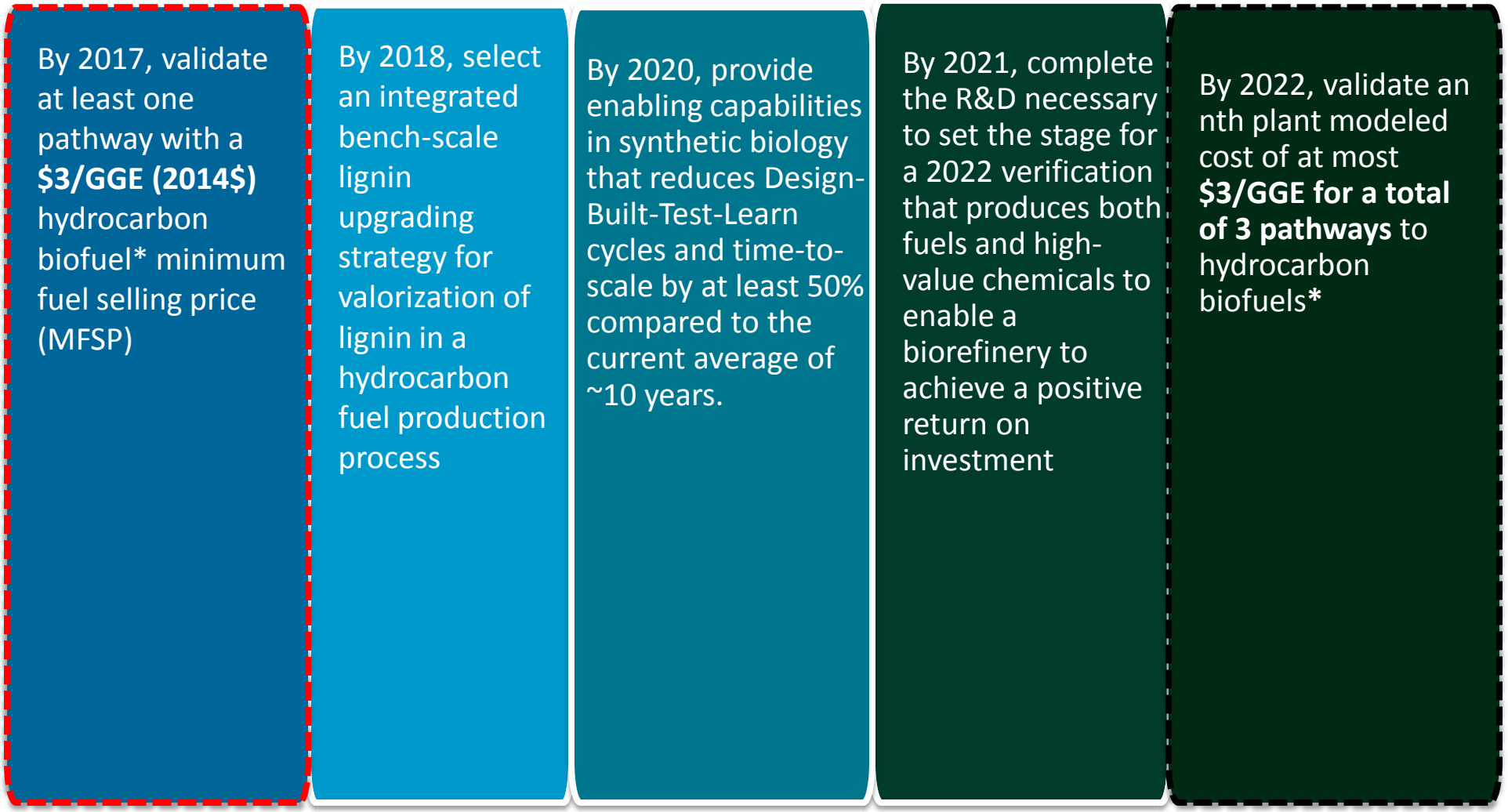
2015 Thermochem Panel Top Three Recommendations

1. Establish clear, specific technical and economic targets for all projects to measure success
2. Establish an "Experimental Catalysis Consortium" and perhaps others
3. Increase the number of innovative projects with potential for significant breakthroughs

2015 Biochem Panel Top Three Recommendations

1. BETO could look to provide a template TEA at project outset or as part of the application process for all projects, including seed projects and National Laboratory projects.
2. Technical Area validation process/model should be captured for posterity.
3. Projects should be required to show historic progress towards goals/targets over the project lifetime and provide a specific Lessons Learned Summary over that history.

Conversion R&D Interim Objectives FY17-FY22



***with GHG emissions reduction of >50% compared to petroleum-derived fuel**