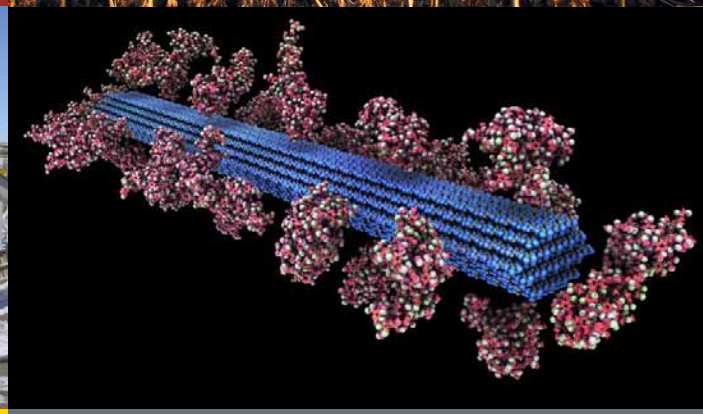
U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

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





BETO FY14 BC FOA Overview

Bryna Guriel
Biochemical Conversion Technology Manager
May 24, 2015

FY14 BC Conversion FOAs

- **Biological and Chemical Upgrading for Advanced Biofuels and Products (BCU)**

- **Renewable Carbon Fibers (RCF)**

BCU Overview – DE-FOA-0001085

- Sought diversification of the BETO portfolio to allow for biological, chemical and hybrid (multi step, chemical and biological) upgrading processes which will broadly encompass pathways found under the BETO Conversion - Biochemical Technology Area. Open to cellulosic sugars, lignocellulose derivatives, lignin, bio-solids and other biogasses as allowable biomass intermediates.

- FOA Released 4/15/14
- FOA Closed 6/13/14
- Selections Announced 10/9/14
  - Currently in negotiation – up to 13.4M

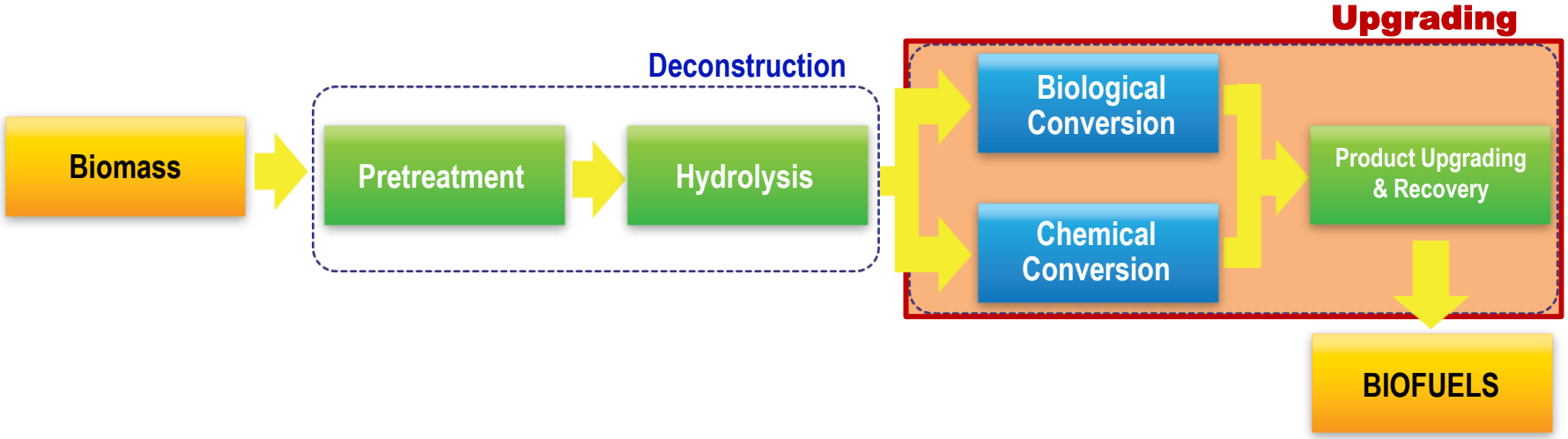
BCU Overview

- **Topic Area 1:** Process development and optimization of a ***single unit*** operation for the ***upgrading of biologically derived intermediates*** to ***fuels and products***. Single step biological or chemical upgrading processes will be the focus of this topic area.
  - NREL
  - Natureworks
  - Vertimass

- **Topic Area 2:** Process development and optimization of ***multiple unit operations*** for the ***upgrading and separations*** of biologically derived intermediates to ***fuels and products***. Hybrid chemical and biological upgrading processes with the integration of separation steps will be the focus of this topic area
  - University of Wisconsin
  - American Process, Inc.

Performance Goal:

- By 2017, achieve an nth plant modeled conversion cost of $3.30/gge utilizing formatted biomass via a biochemical conversion pathway. This contributes to a minimum fuel selling price (MFSP) of $5.10/gge in 2011 dollars, an interim target on the path to $3/gge fuels.
- By 2022, achieve an nth plant modeled MFSP of $3/gge, utilizing formatted biomass via a biochemical conversion pathway.



Biogas Valorization: Development of a Biogas-to-Muconic Acid Bioprocess

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Prime Recipient: **National Renewable Energy Laboratory**
Principal Investigator: Dr. Michael T. Guarnieri
Project Partners: Farmatic Inc., Metabolon Inc., University of Washington, and North Carolina State University
Topic Area 1- Single step biological/chemical upgrading processes
Federal Funds Requested: **$2,500,000** Cost Share: **$629,999** Total Budget:**$3,129,999**

Project Goal and Proposed Research Summary:

- Development of a conversion process to demonstrate the production of muconic acid from renewable biogas
- Research thrusts include: strain engineering, metabolic flux analysis, bioreactor design, anaerobic digestion, and techno-economic analysis

Muconic Acid

Adipic Acid

Project Impacts:

- Expansion of BETO's feedstock and waste-to-energy portfolios beyond lignocellulosic and algal biomass
- Muconic acid is readily catalyzed to an array of industrially relevant bioproducts such as fuels, plasticizers, and lubricants
- Proof of concept for the production of adipic acid
- Bioprocess aims to replace a high-volume petrochemical responsible for approximately 10% of global N_2O emissions

Lactic Acid Producing Methanotrophic Bacteria (LPMB) for Biological Upgrading of Biomethane

Prime Recipient: **NatureWorks LLC**
Principal Investigator: Ken Williams
Project Partners: Calysta
Topic Area 1- Single step biological/chemical upgrading processes
Federal Funds Requested: **$2,500,000** Cost Share: **$8,735,869** Total Budget:**$11,235,869**

Project Goal and Proposed Research Summary:

- Develop and optimize a disruptive fermentation process using biomethane from biogas and engineered methanotropic bacteria for the production of lactic acid (HLA)
- Produce metabolic models to better understand the impact of biogas impurities on cellular metabolism
- Assess biogas to understand the impact on lactic acid production
- Develop reliable, fast analytical assays for the detection of lacitc acid

Project Impacts:

- Work can be leveraged for the development of the technological infrastructure for commercializing biomethane to fungible liquid transportation fuels in the U.S.
- Production of a commercially viable strain to produce lactic acid from biomethane
- Further understanding of biogas impurities and their impact on fermentation

One-Step High-Yield Production of Fungible Gasoline, Diesel, and Jet Fuel Blend Stocks from Ethanol without Added Hydrogen

Prime Recipient: **Vertimass LLC**
Principal Investigator: John R. Hannon, PhD
Project Partners: Technip Stone & Webster Process Technology, ORNL
Topic Area 1- Single step biological/chemical upgrading processes
Federal Funds Requested: **$2,000,000** Cost Share: **$1,000,000** Total Budget:**$3,000,000**

Project Goal and Proposed Research Summary:

- Conduct laboratory and initial scale-up research to further advance the novel catalyst technology to convert ethanol into diesel fuel, gasoline, and jet fuel blend stocks compatible with the current transportation fuel infrastructure
- Work includes development of industrial robust catalyst, catalyst optimization efforts, closing mass and energy balances, and refining techno economic modeling of process

Project Impacts:

- Potentially eliminate the existing “blend wall” limiting current ethanol markets by converting excess ethanol to other fungible fuels

Catalytic Processes for Production of α,ω-diols from Lignocellulosic Biomass

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Prime Recipient: **University of Wisconsin**
Principal Investigator: George Huber
Project Partners: University of Minnesota, Argonne National Lab
Topic Area 2- Hybrid chemical and biological upgrading processes with integration of separations
Federal Funds Requested: **$3,287,577** Cost Share: **$821,684** Total Budget:**$4,109,260**

Project Goal and Proposed Research Summary:

- Develop an integrated and efficient process to produce high value chemicals, namely 1,5-pentanediol (1,5-PDO) and 1,6-hexanediol (1,6-HDO), from lignocellulosic biomass
- Separation of lignocellulosic biomass into its constituents and their conversion into platform molecules suitable for hydrodeoxygenation reactions
- Conversion of these platform molecules into target products
- Laboratory integration with focus on separation

Project Impacts:

- Demonstration of continuous production of furfural from hemicellulose
- Development of a highly active and selective catalytic process to convert furfural to 1,5-PDO in a continuous reactor
- Development of a process to convert cellulose to 1,6-HDO

Continuous Membrane Assisted IBE Fermentation from AVAP® Cellulosic Sugars

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Prime Recipient: **American Process Inc.**
Principal Investigator: Vesa Pylkkanen
Project Partners: University of Maine, Toray Industries, Inc.
Topic Area 2- Hybrid chemical and biological upgrading processes with integration of separations
Federal Funds Requested: **$3,088,632** Cost Share: **$1,948,879** Total Budget:**$5,037,511**

Project Goal and Proposed Research Summary:

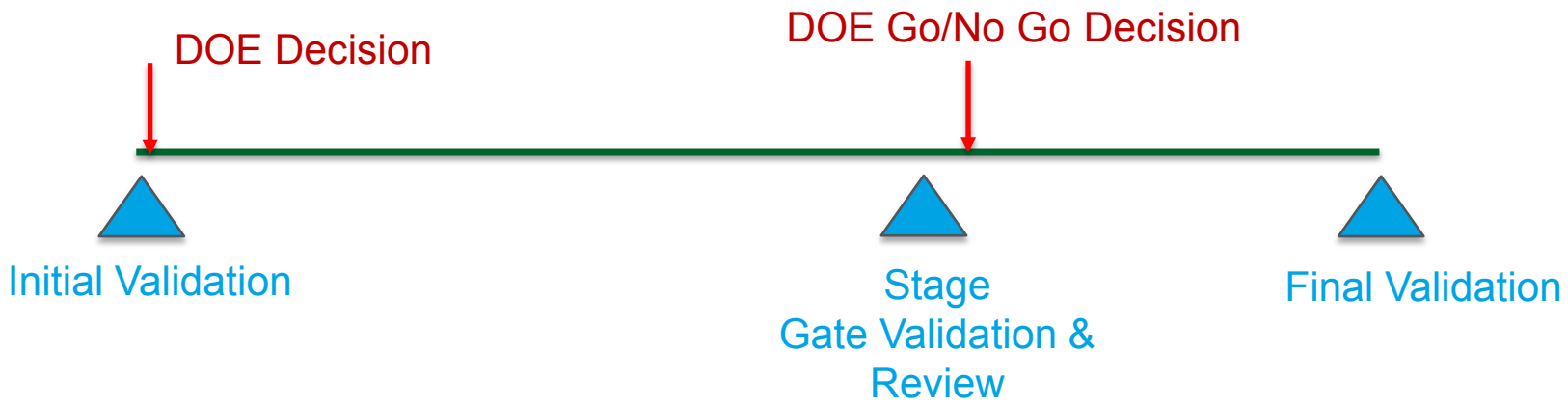
- Development of a process to continuously ferment lignocellulosic biomass to produce isopropanol, n-butanol, and ethanol (IBE)
- The project will seek to demonstrate a recycle of bacteria through membranes
- Research will target reduced energy inputs for a novel liquid/liquid extraction and reactive distillation method for purifying butanol

Project Impacts:

- The product stream will have a higher total product value by producing isopropanol instead of acetone as a product
- The recycle of bacteria will increase fermentation efficiency while simultaneously reducing capital costs
- The project will take advantage of AVAP® derived cellulosic sugars from a variety of sustainable feedstocks including wood, agricultural residue, and perennial grasses

BCU Validation Process

- All BCU awards will participate in the BC validation process:
  - Initial validation – within 2-3 months of the start of the award
  - Stage Gate validation – just prior to the end of BP1 and the Stage Gate review meeting
  - Final validation – just prior to the end of the award



- The primary purpose(s) are two fold;
  - Verify the data provided within the original application accurately represented the project's starting point/baseline
    - The data to be validated is required to be presented in the application, following a uniform
  - Allow DOE to clearly track technical and economic progress throughout the project and the meeting (or not) of milestones.
- Validations will be conducted by a 3rd party (NREL SI/ANL) in conjunction with DOE & CNJV

Main Objective:

- Identify and develop a cost-competitive technology pathway to high performance carbon fibers using biomass as a starting raw feedstock and bio-acrylonitrile (or bio-ACN) as a target product, and
- Engage with industrial manufacturers of polyacrylonitrile that will benchmark and validate the bio-ACN with respect to the key technical performance attributes important for manufacturing lightweight automotive structural components.

Focus:

Converting raw biomass sugars, algal oils, or lignin, to high quality acrylonitrile in two phases:

- The first phase of the project will be focused on establishing the critical functions of the prototype system at bench scale (TRL3)

- The second phase of the project will be focused on validating the prototype performance at a larger scale (TRL6)

  - ❖ FOA Posted: 2/4/14
  - ❖ FOA Closed: 4/11/14
  - ❖ Selections Announced: 7/30/14
  - ❖ Up to 11.3M for 2 awards:
    SRI
    NREL

RCF Overview

Cellulosic Sugars or Lignin

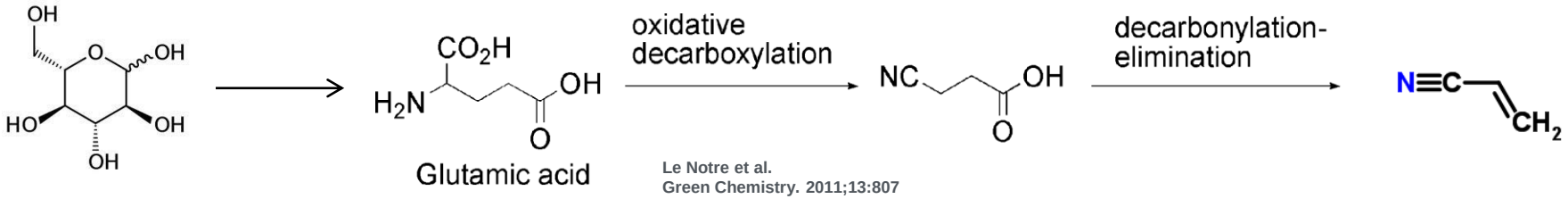
Microbial Conversion

Acrylonitrile precursor (e.g. amino acids, glycerol)

Inorganic Catalytic Conversion

Manufacturing Validations

"CF-Ready" Acrylonitrile (Bio-ACN)



Le Notre et al.
Green Chemistry. 2011;13:807

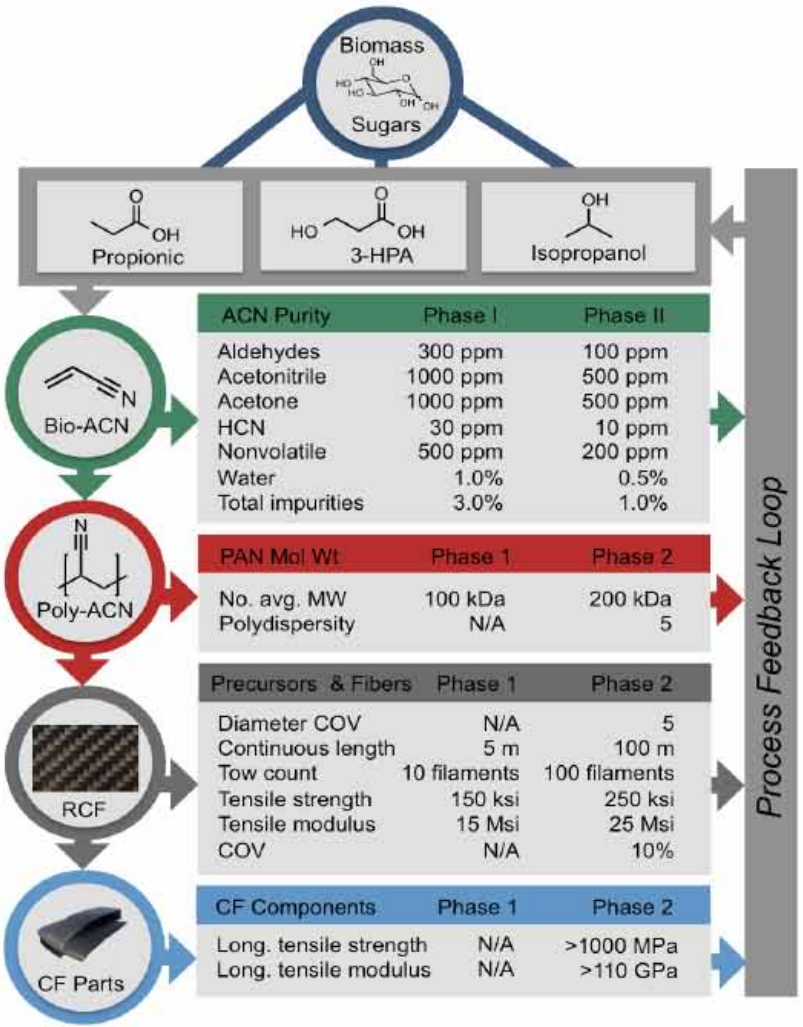
FOA GOALS:

- > 1 g/L/h precursor productivity
  - 6 g/L/h glutamic acid productivity achieved by commercially by Ajinomoto and others
- > 50% bio-ACN yield
  - 10% yield documented (LeNotre, 2011)
- $1/lb functionally equivalent bio-ACN
  - CF manufacturers feedback on specification

IMPACTS, IF COMMERCIAL:

- > 5 BGY of fuel saved (avoid financing 50-100 biorefineries)
- >$57B new revenue in supply chain

Renewable Carbon Fiber Consortium (RCFC)



ACN Purity	Phase I	Phase II
Aldehydes	300 ppm	100 ppm
Acetonitrile	1000 ppm	500 ppm
Acetone	1000 ppm	500 ppm
HCN	30 ppm	10 ppm
Nonvolatile	500 ppm	200 ppm
Water	1.0%	0.5%
Total impurities	3.0%	1.0%

PAN Mol Wt	Phase 1	Phase 2
No. avg. MW	100 kDa	200 kDa
Polydispersity	N/A	5

Precursors & Fibers	Phase 1	Phase 2
Diameter COV	N/A	5
Continuous length	5 m	100 m
Tow count	10 filaments	100 filaments
Tensile strength	150 ksi	250 ksi
Tensile modulus	15 Msi	25 Msi
COV	N/A	10%

CF Components	Phase 1	Phase 2
Long. tensile strength	N/A	>1000 MPa
Long. tensile modulus	N/A	>110 GPa

RCFC Objective and Summary

The objective of the RCFC is to demonstrate cost-effective production of renewable carbon fibers from lignocellulosic biomass-derived acrylonitrile (bio-ACN)

Federal funds:	$ 5.8M
Cost-share:	$ 2.1M
Total budget:	**$ 7.9M**

Period of performance: 40 months

Key Milestones and Deliverables

Phase I : Produce 50 g of ACN at 0.5 g/L/hr and a yield of 20% of theoretical max that meets targeted specifications via an optimal pathway

Phase II : Produce 50 kg of ACN at 2.0 g/L/hr and a yield of 50% of theoretical max that meets targeted specifications at $1/lb ACN

Project Impact

DOE's interest in this area has enabled the assembly of a diverse team of R&D experts across biomass deconstruction, conversion and carbon fiber production. The RCFC has the potential to enable significant technical advances and economic benefits in the carbon fiber and vehicle efficiency markets.

Southern Research Institute - SRI

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Applicant Name: Southern Research Institute

Project Title: Biomass conversion to acrylonitrile monomer-precursor for carbon fiber production

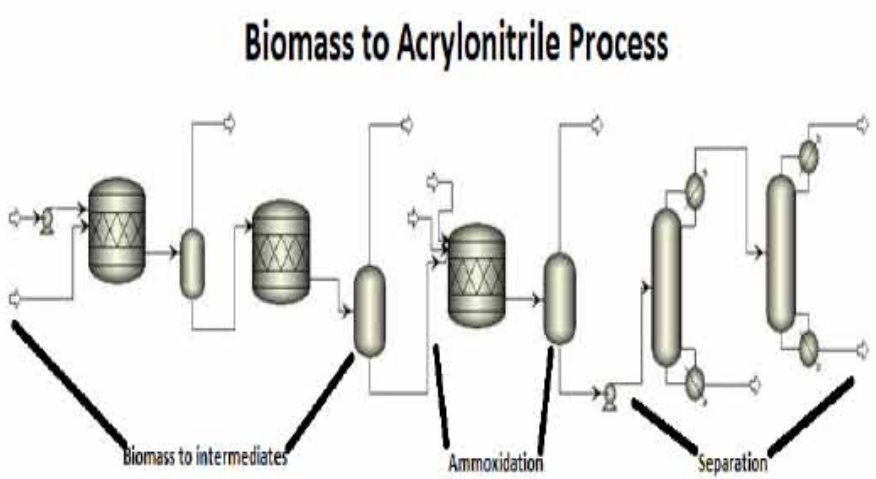
Principal Investigator: Dr. Amit Goyal

Key Partners: Cytec Carbon Fiber, LLC and
New Jersey Institute of Technology

Proposed Total Project Cost: $6,815,879
- Requested DOE funds/Share %: $5,981,713/87.75%
- Proposed Applicant Funds/Share %: $834,166/12.24%

Proposed Project Duration: 40 months

Key Graphics :



Technology Summary: A multi-step fixed bed catalytic process is proposed for conversion of sugars from non-food biomass to acrylonitrile at mild conditions. Process utilizes known pretreatment methods for recovery of sugars from any type of biomass. In the first reaction step, sugars are converted to oxygenates using a novel multi-functional catalyst, oxygenates are then converted to a gas phase intermediate followed by conversion of the intermediate to acrylonitrile.
Description of the Technology's Impact: ~56% reduction in greenhouse gas emissions as compared to conventional propylene ammoxidation route for ACN production, with 22% reduction in cost. The produced acrylonitrile will be carbon fiber ready material and validated by industrial partners.

Proposed Project Objectives/Goals:
1. To produce biomass based acrylonitrile at < $1.00/lb
2. Reduce GHG emissions by <50% as compared to petroleum ACN
3. Validate quality of monomer precursor to be carbon fiber ready material

Project's Key Idea/Takeaway: This technology enables use of non-food biomass conversion to acrylonitrile. Proposed method leverages on two known technologies and contributes two innovative multi-functional catalysts to increase the yield, separation and thereby, lower capital costs with scalability for production of bio-ACN.