NREL
NATIONAL RENEWABLE ENERGY LABORATORY





BioEngineering Advanced Materials and Chemicals

BioEnergy 2016 Conference

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National Renewable Energy Laboratory (NREL)

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NREL - National Asset with a Dedicated Mission

- Founded as Solar Energy Research Institute (SERI) - 1977
- Designated national laboratory in 1991 and renamed National Renewable Energy Laboratory
- Today managed by the Alliance for Sustainable Energy, LLC, for the U.S. Dept. of Energy
- Nearly 1,700 employees
- Campus is a model of sustainable energy

Integrated Approach to Market-Relevant Solutions

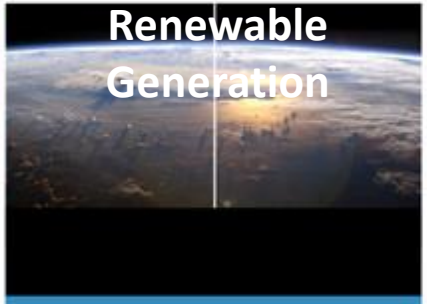
	Analysis & System Integration	Innovation & Application	Foundational Knowledge
Core Capabilities			
Market-Relevant Solutions	Systems Engineering & Integration Decision Science & Analysis	Chemical Engineering Mechanical Design & Engineering Power Systems & Electrical Engineering	Chemical and Molecular Science Biological/Bio-process Science & Engineering Materials Science & Engineering
Impact	Provides market insight and informs landscape	Responds to market challenges with solutions and identifies knowledge gaps	Scientific discovery that fills gaps and disrupts current-generation technology

“Analysis” driving “Applied R&D” which is informing “Foundational Science”

NREL Research Thrust Areas

Building Energy Efficiency

- Residential Buildings
- Commercial Buildings



Renewable Generation

- Solar
- Wind and Water
- Biomass
- Hydrogen
- Geothermal

Sustainable Transportation

- Advanced Biofuels
- Vehicle Components and Systems

Energy Systems Integration

- Grids of all Scales
- Renewable Integration & Storage
- System Design & Operation Tools
- Integrated Energy Planning

NREL BioEnergy Role in the Value Chain

Feedstock Supply and Logistics	Conversion * Technology Development	Integrated Biorefinery Deployment	Infrastructure and End-Use	Economic and * Sustainability Analysis
Developing commodity-scale feedstock supply and logistics systems	Improving conversion efficiencies, yields, and costs; demonstrating process integration	Systematically validating and deploying technology at first-of-a-kind facilities	Evaluating vehicle emissions, performance, and deployment options	Developing approaches to sustainability and providing public economic analyses

* *Major NREL Roles*

Past Example – Lab to Reality

Integrating Capabilities to Enable Cellulosic Ethanol

Integration to Impact

Partnered to develop, integrate and validate technologies that enabled first-of-a-kind commercialization of cellulosic ethanol in the U.S.

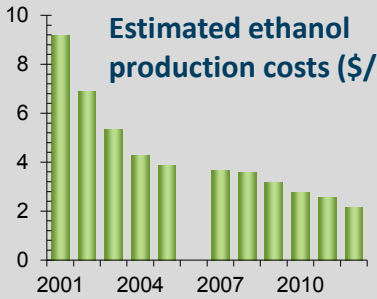
DUPONT

ABENGOA

POET

Innovation to Application

Used NREL pilot plant to integrate and scale technology advancements in pretreatment, enzymatic hydrolysis, and fermentation



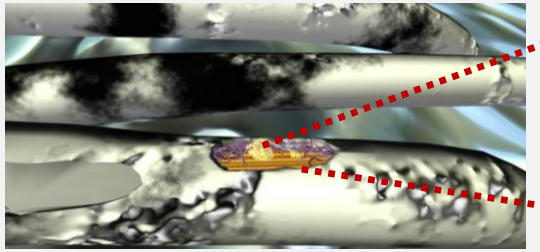
novozymes Rethink Tomorrow

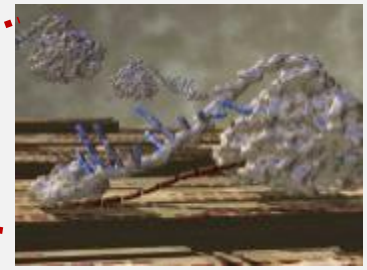
ANDRITZ

Cargill

Foundational *Knowledge*

Fundamental understanding of protein-substrate interactions allows for rational design of superior cellulase enzymes





OAK RIDGE National Laboratory

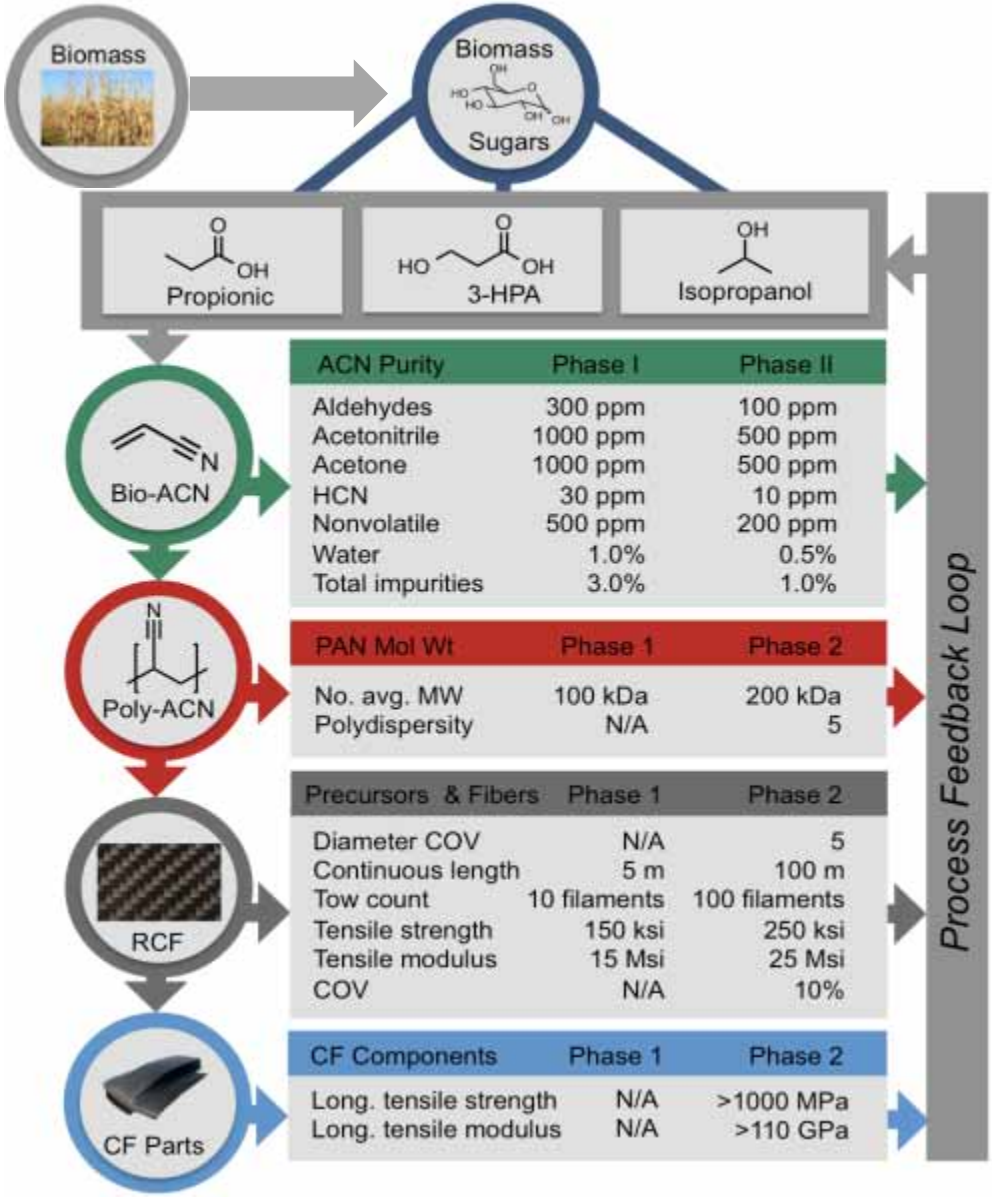
INL Idaho National Laboratory

Pacific Northwest NATIONAL LABORATORY

BESC BioEnergy Science Center

Current Endeavor – Renewable Carbon Fiber

Renewable Carbon Fiber Consortium (RCFC)



Lead: *NREL*

Partners: *INL, Biochemtex, Johnson Matthey, CU-Boulder, Colorado School of Mines, ORNL, MATRIC, DowAksa, Ford, Michigan State University*

Objective: *Cost effective production of renewable carbon fibers from ligno-cellulosic biomass*

Strategy:

- *Deconstruction of biomass to sugars*
- *Biological production of strategic intermediates*
- *Chemical catalysis to acrylonitrile (ACN)*
- *Polymerization of ACN to Carbon Fiber for industrial testing and validation*

Deconstruction of Biomass to Sugars

Goal:

- Production of biomass derived sugars from wheat straw (Biochemtex) and corn stover (NREL/INL)

Metric:

- Suitable for downstream conversion operations at a modeled cost of approximately $0.10-0.15 per lb

Status

- >10 kg hydrolyzate delivered to ACN production team from both NREL and BioChemtex pilot plants
- Propionic acid fermentation performance very good on both sugar streams
- 2nd batches being produced for studies at higher sugar concentrations for fermentation optimization

Pretreatment and Enzymatic Hydrolysis sections in the BioChemtex PROESA™ pilot plant

NREL's Integrated BioRefinery Research Facility (Pilot Scale)

Biological Production of Strategic Intermediates

Goal:

- Production of Propionic Acid from fermentation of biomass derived sugars

Metric:

- Productivity of 0.5 g/L/hr in Phase I
- Productivity of 2.0 g/L/hr in Phase II

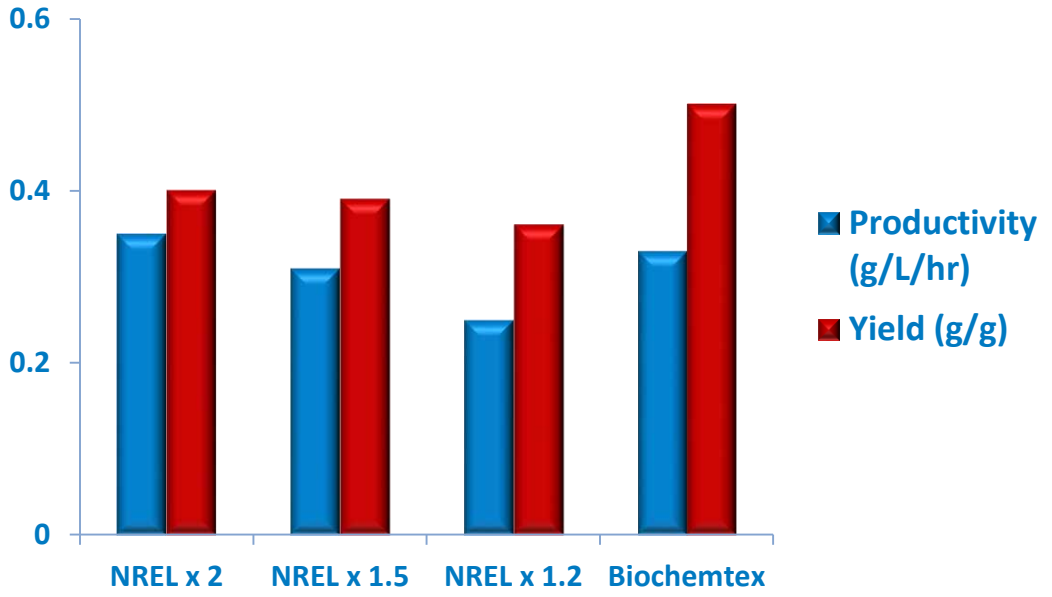
Status

- Good initial utilization of all sugars even with real hydrolysate
- Batch productivities ~0.25-0.35 g/L/hr and titers ~30g/L
- Fed-Batch strategies being explored to improve both

Hydrolysate Composition

Dilution	Total sugars (g/L)	Glucose (g/L)	Xylose (g/L)	Arabinose (g/L)	Acetate (g/L)	Furfural (g/L)
NREL x 1.2	130.5	75.0	48.8	6.7	2.93	0.35
NREL x 1.5	107.4	61.8	40.1	5.5	2.35	0.28
NREL x 2	76.8	44.5	28.3	3.9	1.76	0.21
Biochemtex	77.2	37.3	37.3	2.6	3.1	0.0

Productivity and Yield



Chemical Catalysis to Acrylonitrile (ACN)

Goal:

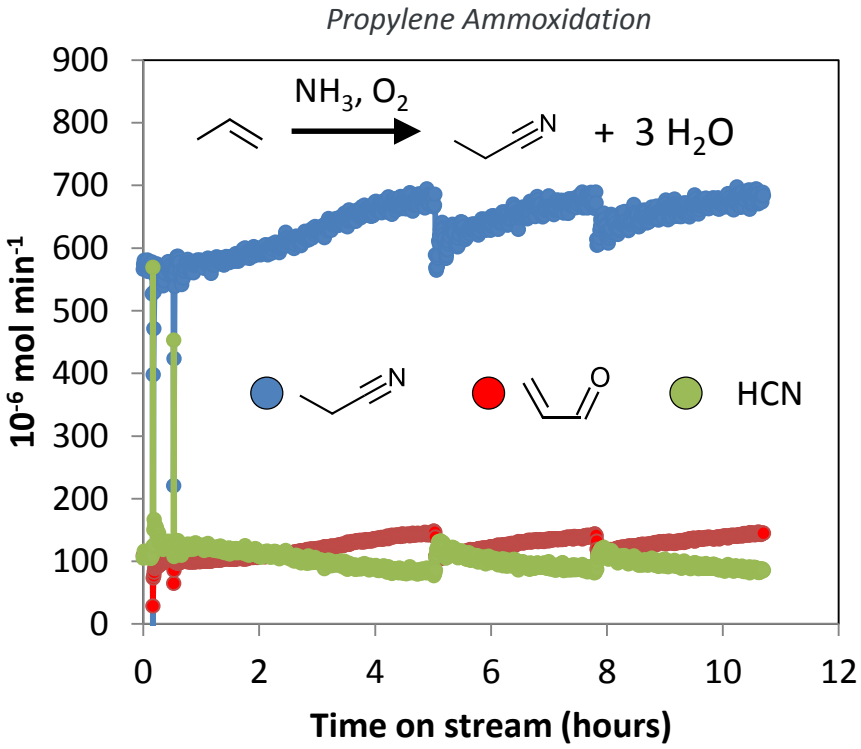
- Production of Acrylonitrile (ACN) from biomass derived intermediate

Metric:

- "high conversion yields" that enable the total biomass to ACN yield targets (20% and 50% respectively)
- Ultimate cost of ACN production modeled at $1/lb

Status

- Produced ~20g of ACN from each of the pathways for polymerization studies
- Propylene ammoxidation yields consistent with industrial single pass yields
- Novel catalytic strategy from non-propylene intermediates demonstrated >90% yields



Polymerization to PAN and Carbon Fiber

Goal:

- Production of poly-acrylonitrile (PAN) and Carbon Fiber from bio-ACN

Metric:

- PAN MWw >200,000
- Polydispersity Index (PDI) <5

Status

- ACN purification strategies being pursued
- Model ACN polymerization promising (95% yield, <2 PDI, 65,000 MWw) with strategies to improve
- NREL bio-ACN samples in hand and are informing purification and polymerizaton strategies.

Carbon Fiber Technology Facility at Oak Ridge National Laboratory

Questions?

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