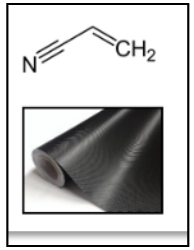


IEA Bioenergy eWorkshop 2020

IEA Bioenergy
Technology Collaboration Programme

RENEWABLE ACRYLONITRILE FOR CARBON FIBER PRODUCTION

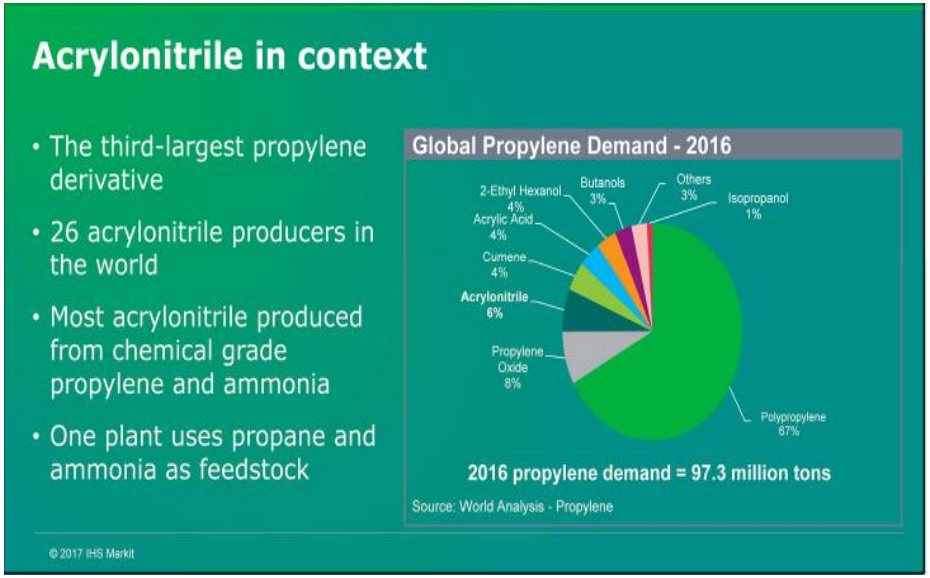
Amit Goyal
Director – Sustainable Chemistry and Catalysis
Southern Research

SOUTHERN RESEARCH

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

CYTEC SOLVAY GROUP

Market Perspective - Acrylonitrile



Total Production: 6.9 MMT/yr, CAGR of ~4-5%

ABS/SAN - Increasing at 5-6%
Acrylamide – increasing at 7-8%
Carbon fiber market (11-18%) is increasing rapidly

Major Producers: Ineos, Ashai Kasei Corporation, Mitsubishi Chemical Corp., and Ascend Performance Materials

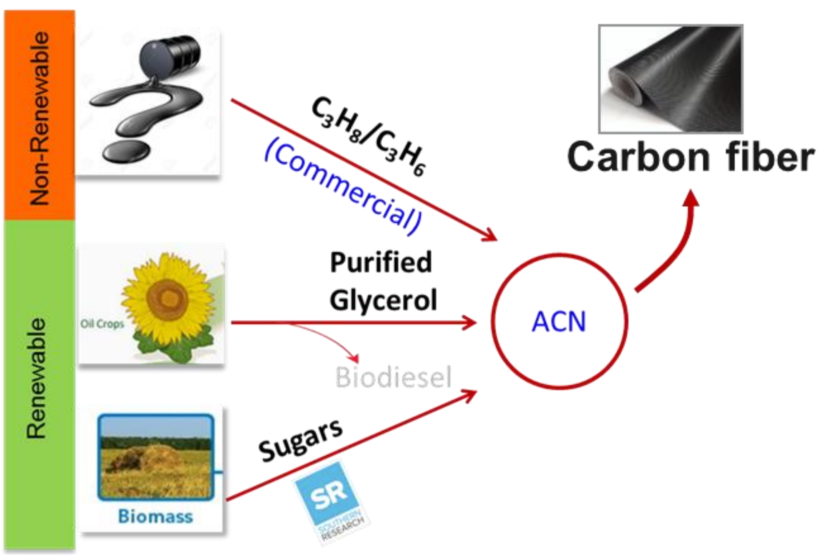
Scale of ACN Production

- Typical carbon fiber line produces 1000 MT/year
- A single line requires ~ 2200 to 2500 MT of Acrylonitrile
- 5000 MT ACN plant can supply 2 carbon fiber lines – most plants operate at this capacity at a single location
- Low capex for first of kind plants
- Requires ~ 100 MT biomass per day
- Sugar transportation easier than hazardous acrylonitrile

This is why small scale ACN production plants are important.

Technology Summary

- **Non-food** sugar to **acrylonitrile** (ACN)
- Renewable feedstock
- Three-step thermo-catalytic process



Routes to ACN

C_5 ✓
C_6 ✓

Feedstock flexibility
Validated using commercial sugar hydrolyzates and C_5/C_6 sugar mix

Process flexibility
Reduced dependency on oil/gas. H_2+NH_3 requirement ~7% of biomass.

High performance Catalysis
One step sugar to C_3,C_2 chemicals. ~100% selectivity to acrolein. High purity ACN via ammoxidation (No HCN, CO_2).

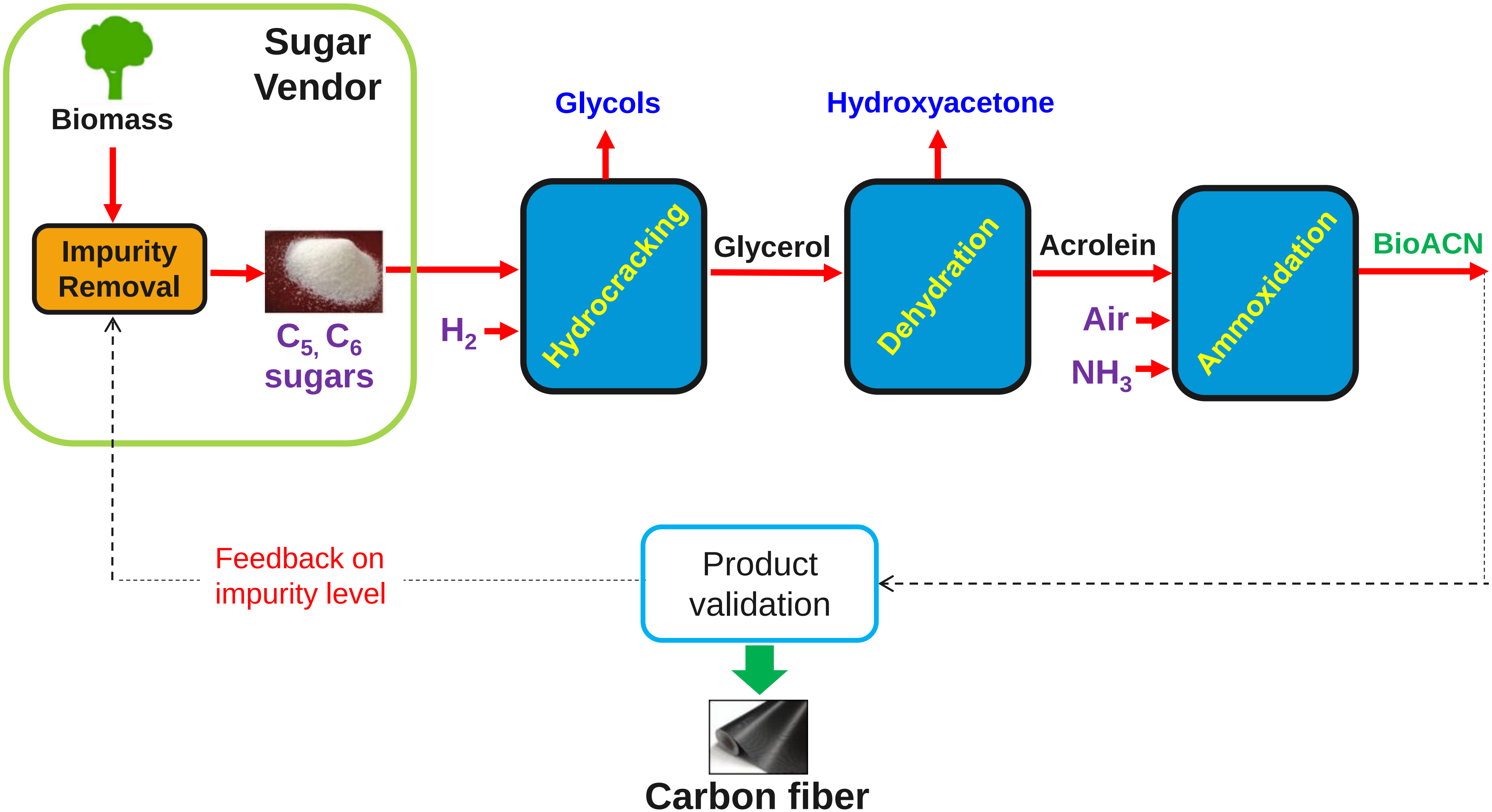
Cost and GHG reduction
<$1/lb ACN production cost. GHG 95% ↓

CYTEC SOLVAY GROUP

Product meets critical performance attributes (CPA) for ACN

SR

Process Development



Different Phases of Development

Phase I - Laboratory scale
Catalyst Development

Phase II (Pilot scale) –Process scale up

Reaction summary

Type of reaction	Feed	Pressure	Desired products	Productivity (g/L/hr)	Production scale up in phase II
Hydrocracking	Sugar,H_2	Pressurized	Glycols*, Glycerol	180	60 – 100x
Dehydration	Glycerol	Atmospheric	Acrolein, Hydroxyacetone	290	650 - 975x
Ammoxidation	Acrolein, NH_3, O_2	Atmospheric	Acrylonitrile	80-375	320 – 600x

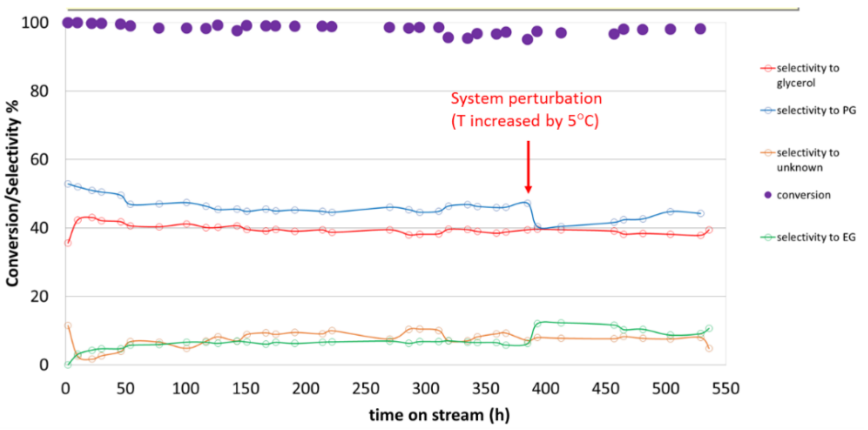
*Glycols are propylene glycol (PG) and Ethylene glycol (EG)

Phase II Footprint

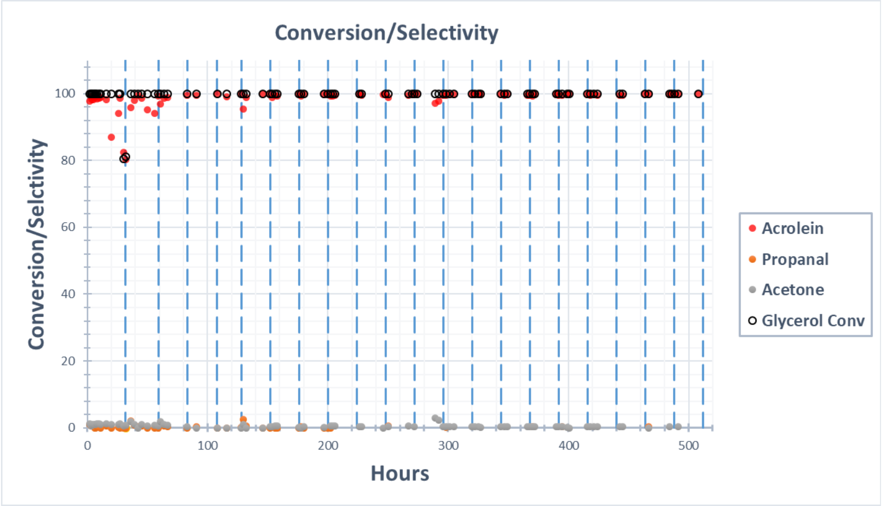
Decoupled pilot scale process with ~ 1kg/hr production capacity

Catalyst Performance

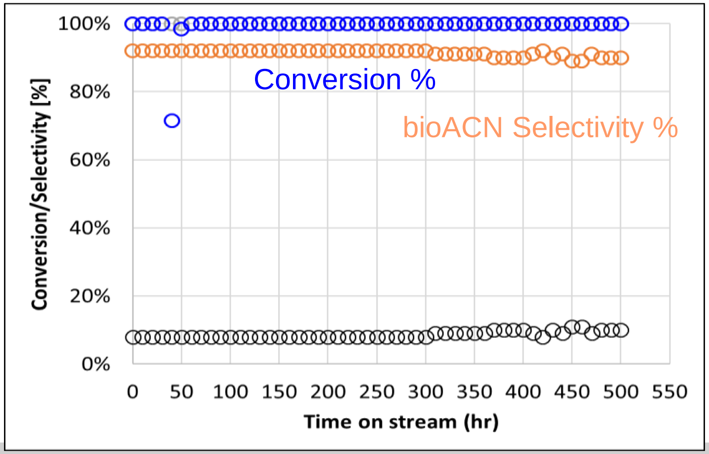
1. Hydrocracking



2. Dehydration



3. Ammoxidation –



Pilot scale results– All impurities present in the sugar hydrolyzate

Stable catalyst operation continuously for all reaction steps > 500 hours

Importance of Chemical Purity

≥ 99.2% ACN

+

Balance acetonitrile, propionitrile and water. No detectable metal.

SR produced BioACN

Impact of Impurities on BioACN Properties

Impact of Impurities

Water	Propionitrile	Acetonitrile	Acrolein
High Concern	Low Concern	Insignificant	Insignificant
Conversion (Detrimental)	Conversion (Low Concern)	Conversion (Insignificant)	Conversion (Insignificant)
Polymer Concentration (Detrimental)	Polymer Concentration (Insignificant)	Polymer Concentration (Insignificant)	Polymer Concentration (Insignificant)
Molecular Weight (Insignificant)	Molecular Weight (Insignificant)	Molecular Weight (Insignificant)	Molecular Weight (Insignificant)
Polydispersity (Insignificant)	Polydispersity (Insignificant)	Polydispersity (Insignificant)	Polydispersity (Insignificant)
Rheology (Low Concern)	Rheology (Insignificant)	Rheology (Insignificant)	Rheology (Insignificant)

- Detrimental: Causes significant deviation from baseline process*
- High Concern: Causes some deviation from some baseline properties*
- Low Concern: May cause minor deviation from baseline properties*
- Insignificant: No deviation from baseline properties can be detected*

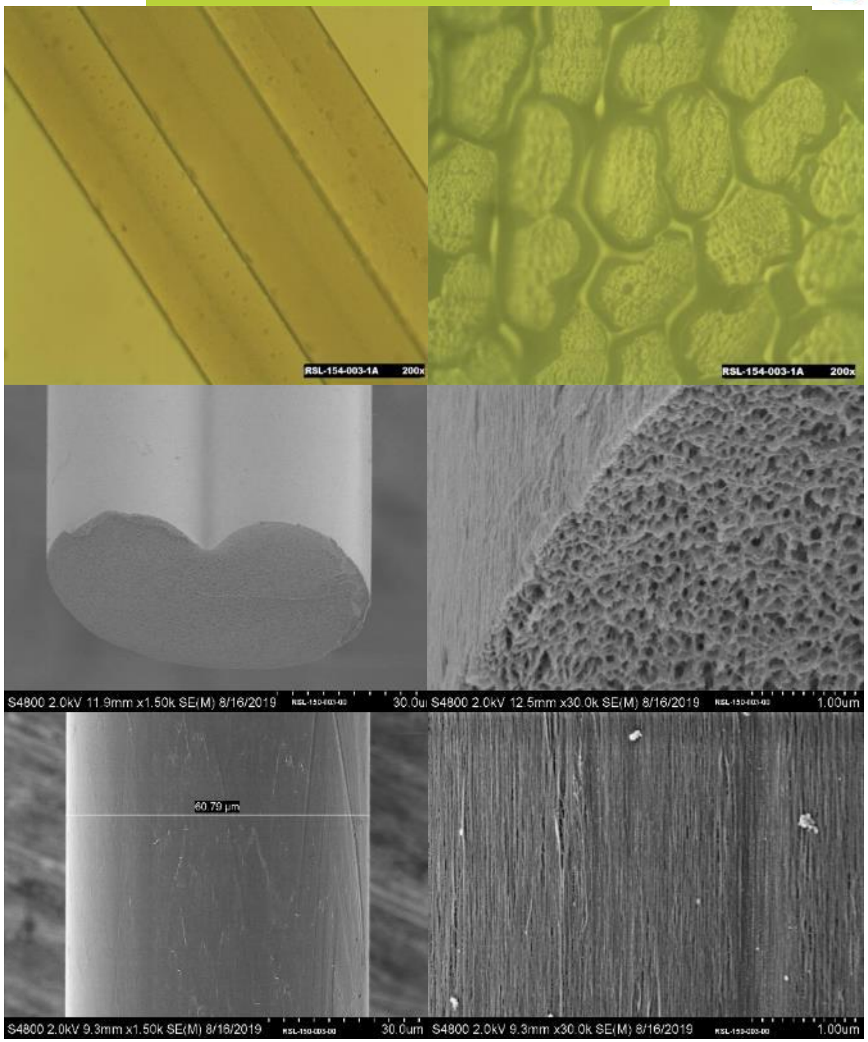
*Above undisclosed concentrations

CYTEC SOLVAY GROUP

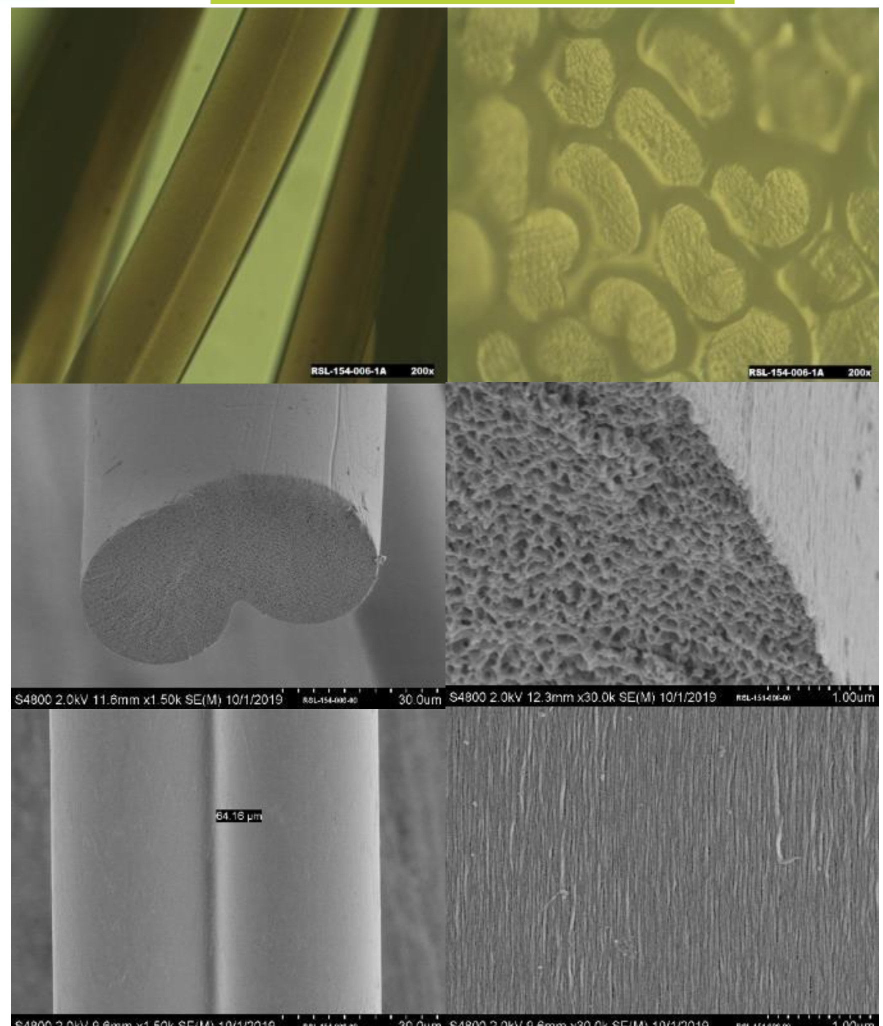
SR

Fiber Morphology Comparison

Control Fiber



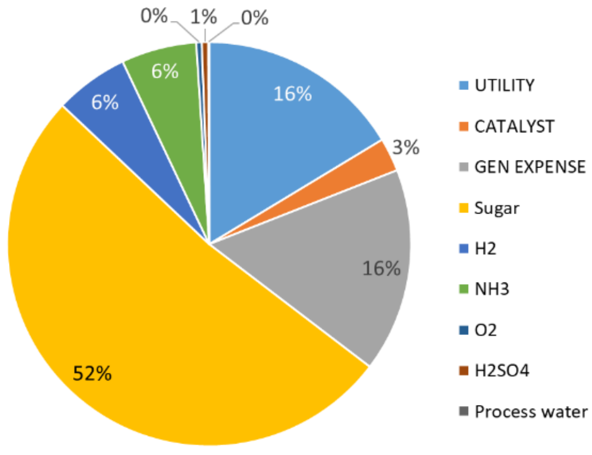
Bio-Mass PAN

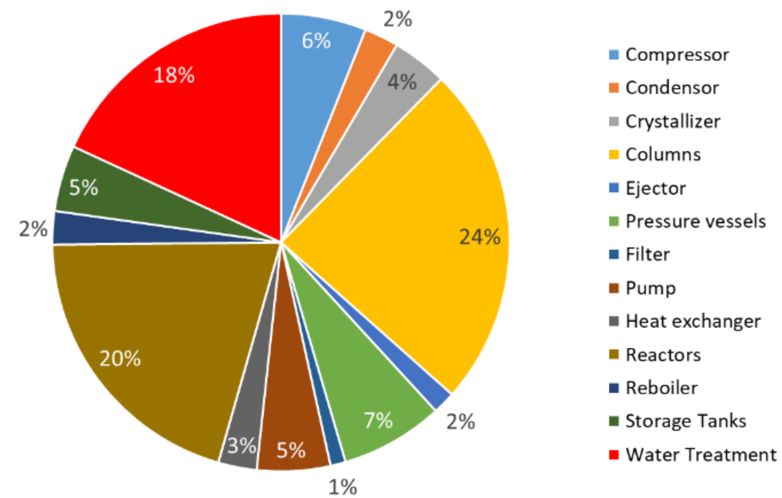


No observable differences in fiber shape and structure

Techno-Economic Assessment (TEA)

Cost distribution

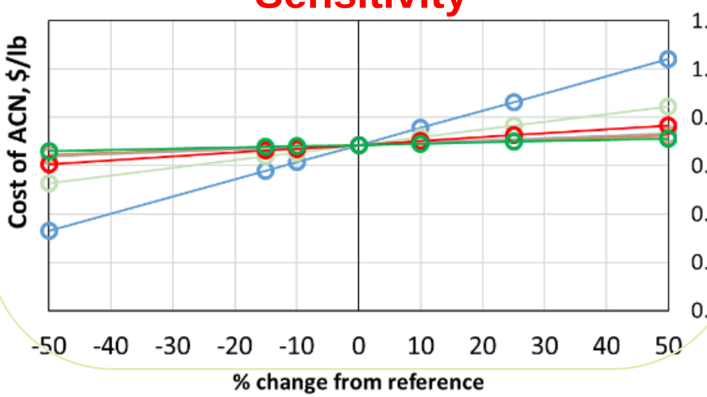




Variable cost analysis

Equipment cost analysis

Sensitivity



Production (MT/year)	Capital Investment
5000 ACN + 5800 PG	$ 15 – 19 million (verified by independent contractor)

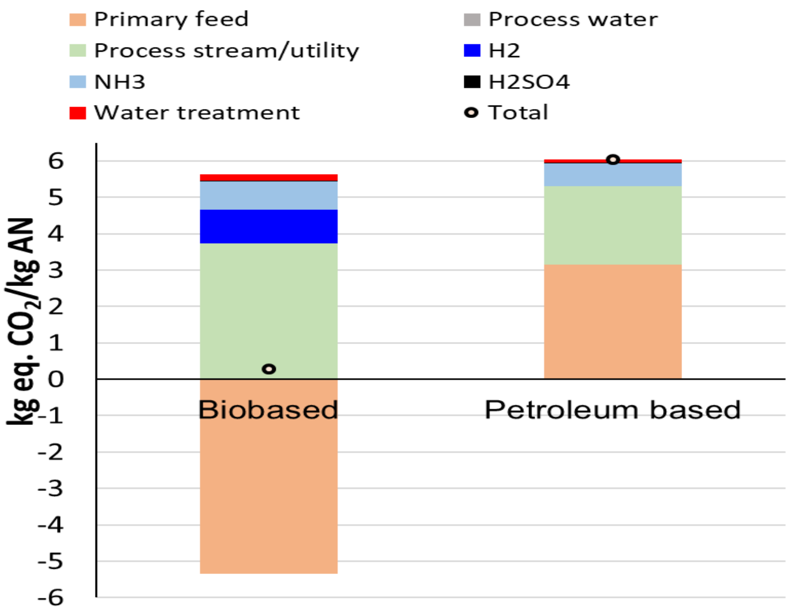
Sugar key cost driver

SR

Life-Cycle Assessment (LCA)

LCA Assumptions:

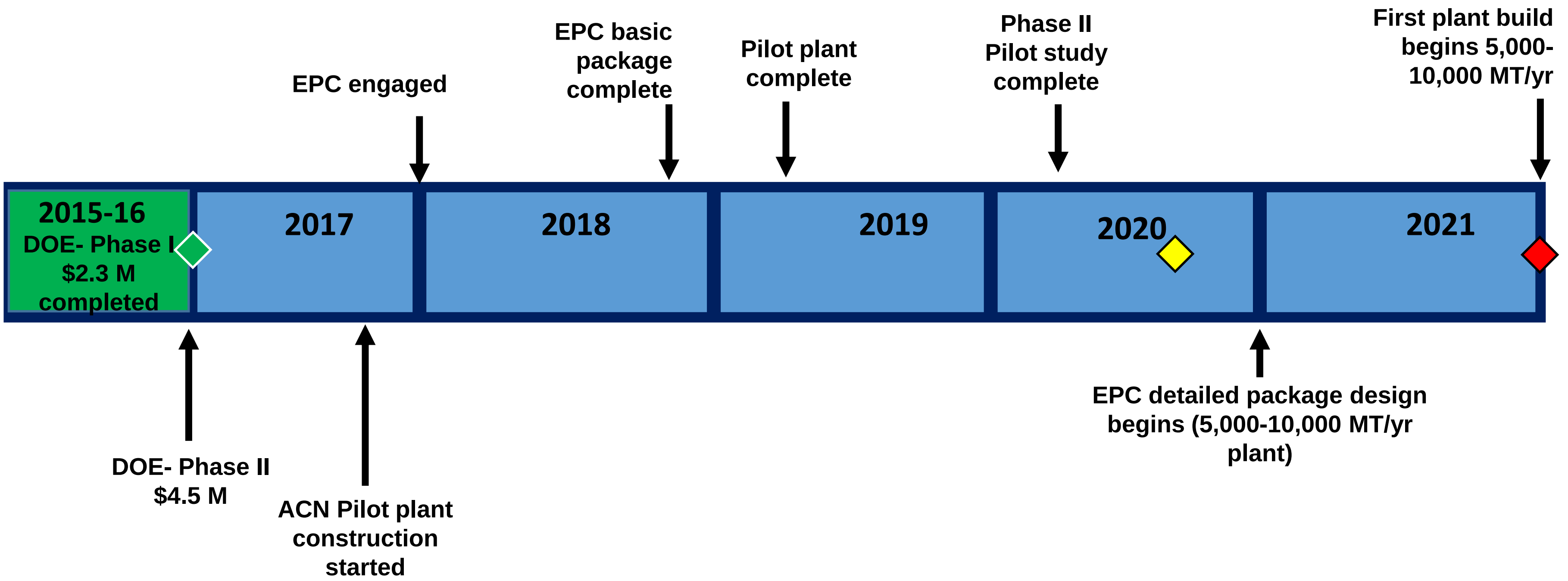
- Biomass source: Corn Stover with 20% bulk moisture content
- Biomass to sugar yield: 1 kg sugar (C_5+C_6) produced from 2.35 kg biomass



Individual GHG

Biomass to ACN results in significantly less CO_2 footprint than **Crude to ACN** (0.29 versus 6.05 kg eq. CO_2/ kg of product)

Commercialization Timeline



Major Milestones

- DOE funding received
- First commercial investment
- First plant commercialization build begins

Acknowledgements

US Department of Energy

Partners

BETO Project officer: Mark Shmorhun

Southern Research
Amit Goyal (PI)
Jadid Samad

Cytec Solvay
Jeremy Moskowitz (Technical Lead)
Billy Harmon

NJIT
Zafar Iqbal (Lead)