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U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) 2017 Project Peer Review

Feedstock-Conversion Interface Consortium (FCIC)

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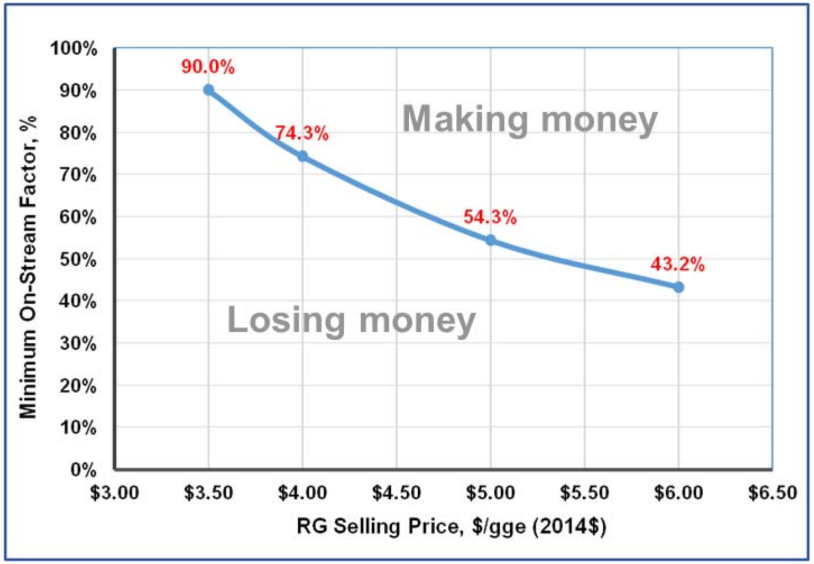
Observations from the Emerging Cellulosic Ethanol Market

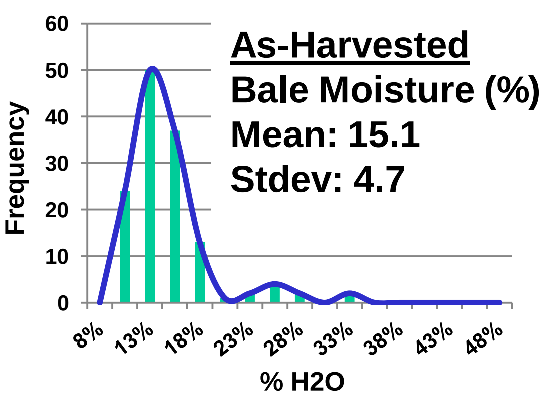
- In 2016, 4.0 million RINS generated from cellulosic ethanol
- ~7% of the total active 57.75 million gallons per year (MGY) of nameplate capacity
- “Feed handling” problems blamed for slow start-up
  - Grinding
  - Conveyance
  - Feeding
  - Solids handling up to and through conversion

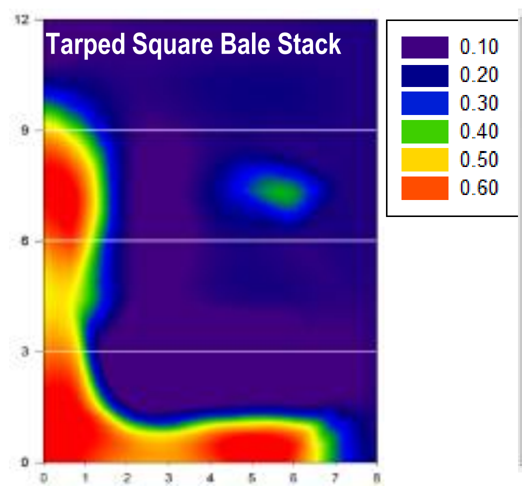


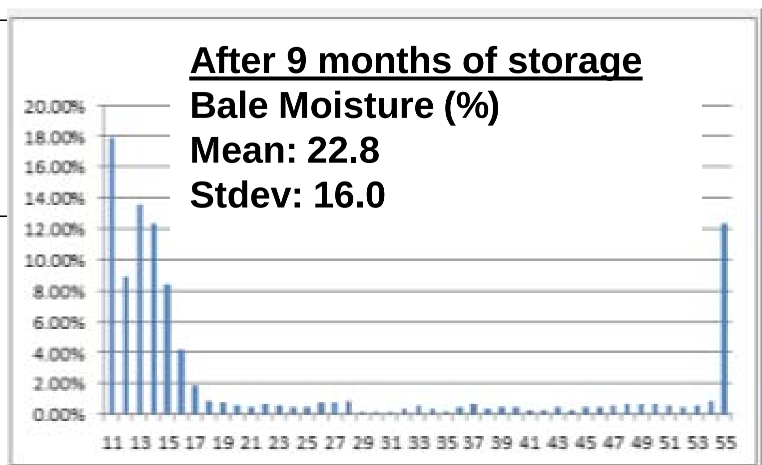
WBS 1.1.1.2

Understanding the Feed Handling Problem

- Bale-to-bale variability
  - Moisture
    - Hammermilling wet bales
    - Varying particle size distribution
  - Dimensional
  - Structural
- Equipment wear due to entrained soil
- Excessive fines
- Fires in grinders
- Flowability – plugging in surge bins & feed hoppers







WBS 1.2.1.2

Biomass Attributes Related to Feed Handling Problems

- Moisture
  - Grinder throughput
  - Particle size variability
  - Variation causes inconsistent mass and heat transfer in conversion
- Particle Size
  - Large particles (aka pin chips)
    - Cause plugging problems in bins, augers
    - Do not fully cook – plugging in downstream equipment, microbial contamination
  - Fine particles
    - High in ash
    - Dust – fire, explosion, and health hazards
    - Plugging of weep holes in digesters
    - Buffering capacity, increase chemical usage
  - Variation causes inconsistent mass and heat transfer in conversion
- Foreign material (dirt, metal)
  - Plugging, equipment wear

History repeats itself

- Rand Corporation study from 1980's showed that plants that process bulk solids typically operate at less than 50% of design capacity the first year of operation (Merrow 1985)
- Problems generally relate to an inadequate understanding of the behavior of particle systems (Bell 2005)

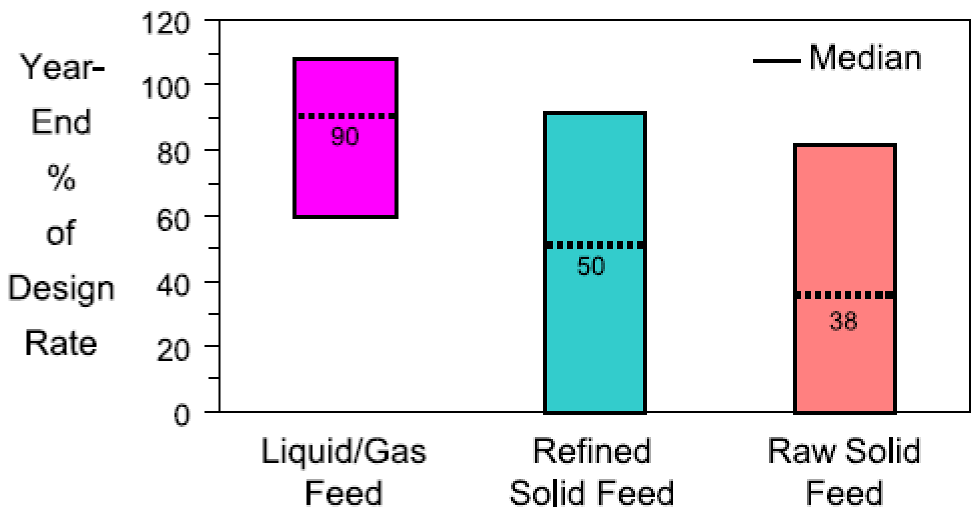


Image source: Merrow 1985

FCIC Focus

Focus: Science of scale-up and integration of feedstock and conversion technologies

FCIC

Biomass Resources → Preprocessing → Feedstocks → Integrated Pathways

Biomass Resources: What are the minimum acceptable characteristics of a biomass resource ***(QUALITY GRADES)*** to obtain acceptable feedstocks?

Preprocessing: What must be done to a specific biomass resource to produce an acceptable feedstock?

Feedstocks / Integrated Pathways: What are the ***ranges*** of impactful physical and chemical characteristics that a feedstock must meet ***(FEEDSTOCK SPECIFICATIONS)*** in order to perform adequately in a specific conversion pathway?

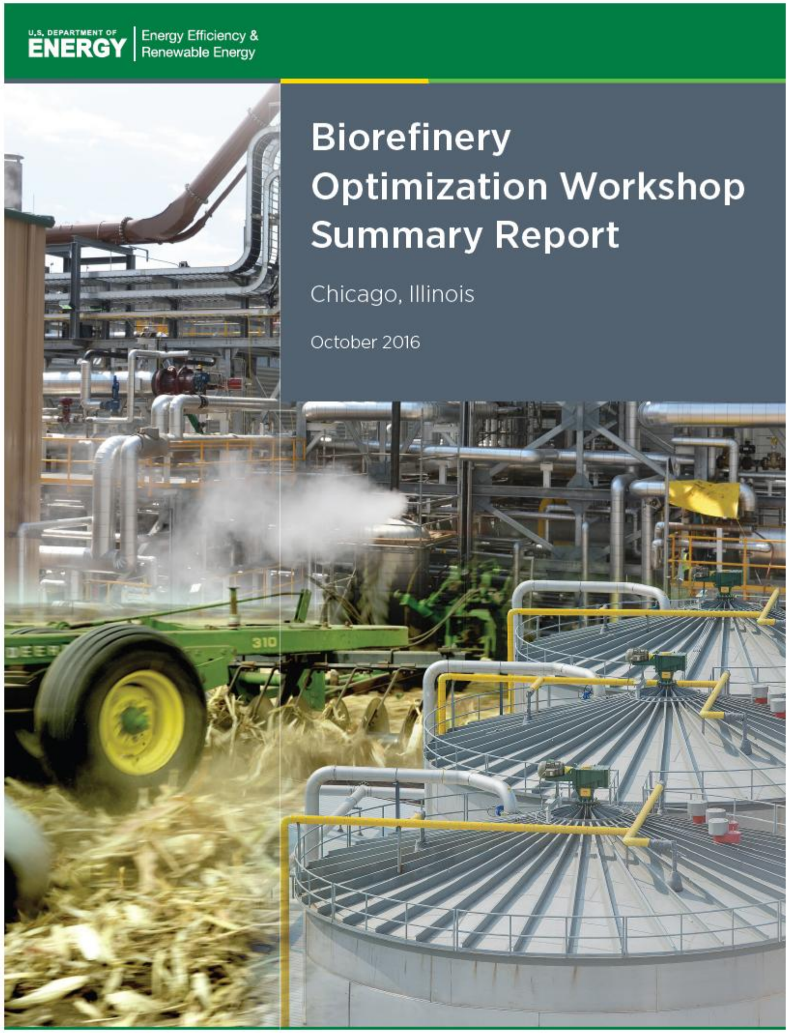
What are the most desirable characteristics of the most suitable feedstocks for a specific feedstock conversion pathway?

Goal: Streamline scale-up and accelerate start-up of integrated biorefineries

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

Scope of Integration and Scale-up

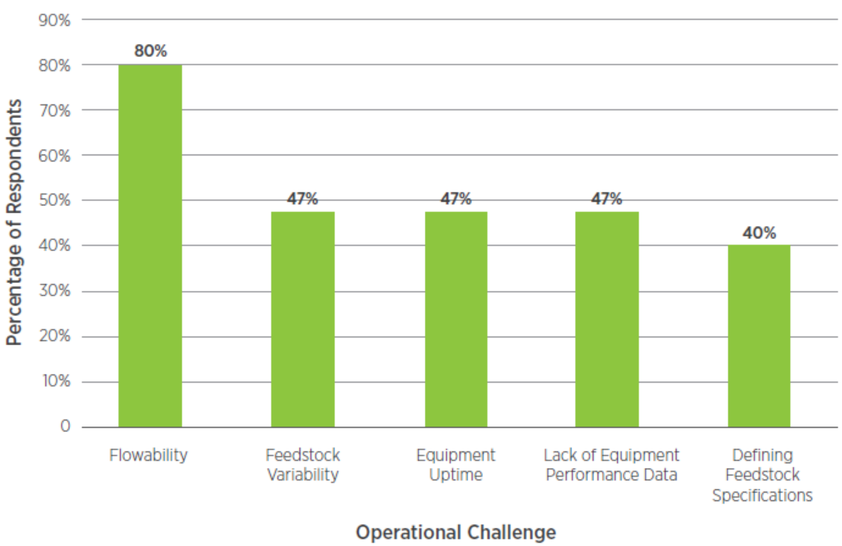
- Next 8 slides reflect input from bioenergy industry stakeholders at the Biorefinery Optimization Workshop
- Challenges, recommendations, and lessons learned from over 100 participants in 3 breakout sessions
  - Feedstock and Materials Handling
  - Process Scale-Up, Intensification, and Cost Reduction
  - Co-Product and Waste Stream Monetization



https://energy.gov/eere/bioenergy/downloads/biorefinery-optimization-workshop-summary-report

Top IBR Feedstock Operational Challenges

- Flowability
  - Study particle engineering approaches to reduce size of biomass material
  - Employ modern [computational] tools to guide the designs of related equipment
- Feedstock Variability
  - Perform additional characterization of non-pristine feedstocks
  - Assist IBRs with better understanding of their feedstock specifications
  - Design [equipment] on non-pristine material
- Equipment Uptime
  - Improve the incoming feedstock quality
  - Introduce improved control systems
- Lack of Equipment Performance Data
  - Collect continuous operational data at the pilot scale
- Defining Feedstock Specifications
  - Recognize the tradeoff between quality and affordability in feedstock



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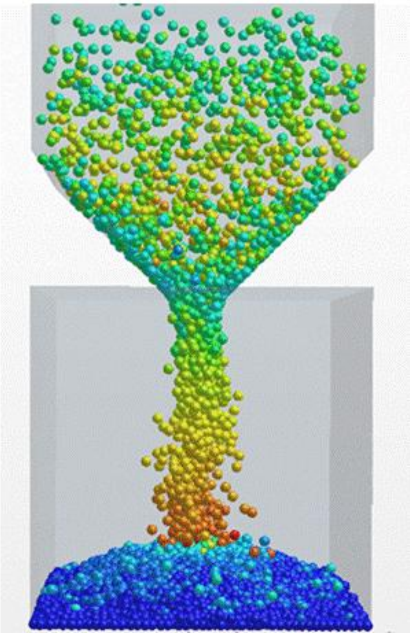
Future Directions in Feedstocks and Solids Handling

- Pilot and demonstration facilities
  - Develop an operational pilot-scale (or larger-scale) facility that is open to biorefinery project planners
- Modeling Tools
  - Develop modeling or simulation tools to allow directional guidance on materials and unit operations
  - Expand database for physical and mechanical properties of various feedstock
- Feedstock Quality Measurements and Standards
  - Expand the knowledge base on the subjects of solids handling
  - Enhance bulk solids measurement techniques
- Equipment Improvements
  - Publish an equipment engineering “handbook” for biomass materials. Identify correlations between biomass material properties and equipment design and performance parameters.

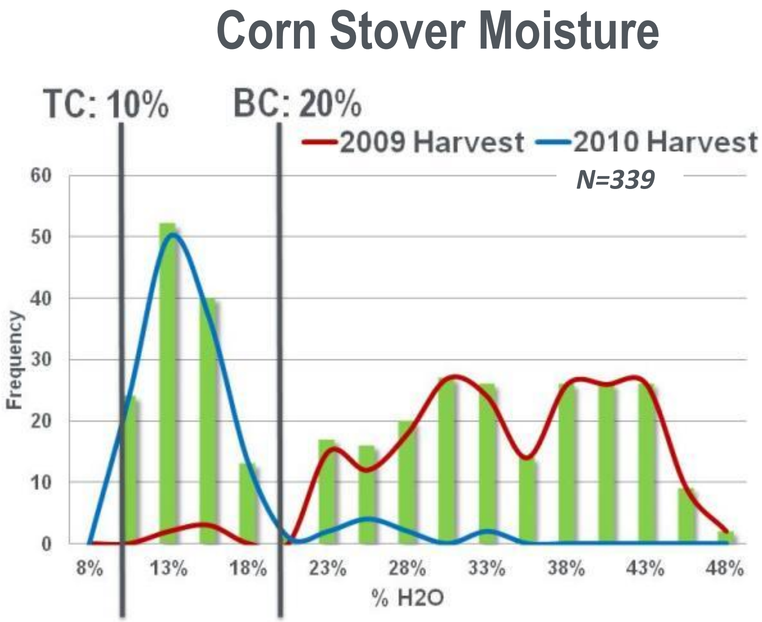
WBS 1.2.3.3



WBS 1.2.1.3

Feedstock and Materials Handling Lessons Learned

- Systems need to be designed with a full realization of moisture variability
- Robust control logic is necessary for integrated operation
- Well-designed sensors and control systems are very important
- There has been a lack of understanding of the feedstock characteristics and how that affects downstream operability
- Understand and study the effects that pre-processing steps can have on other downstream steps
- Handling systems need to be designed to be flexible enough to handle the [feedstock] variance



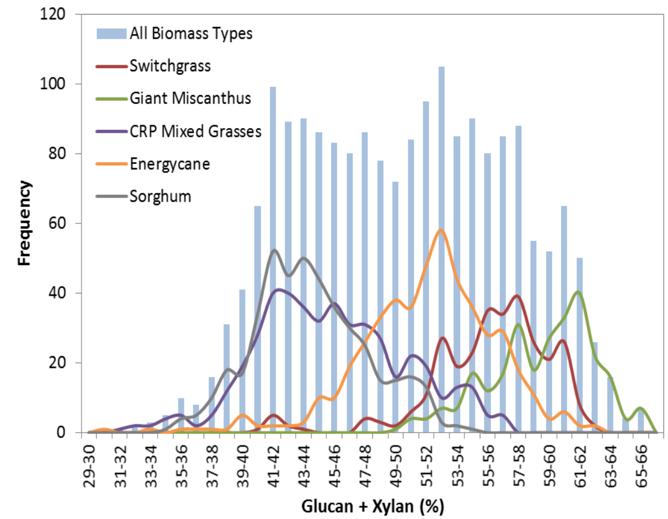
Midwest corn stover moisture for two consecutive years compared to thermochem (TC) and biochem (BC) design assumptions

Scale-up and Operation Challenges of IBRs

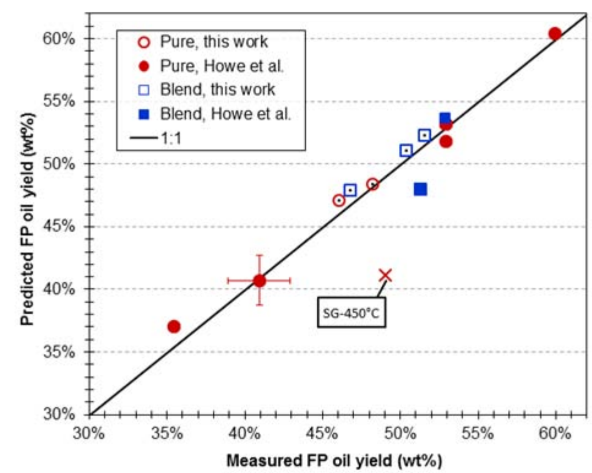
- Pilot-Scale Challenges
  - Dealing with improperly designed equipment based off of lab data
  - Inability to address feedstock variability and non-pristine feedstock
  - Working with realistic particle sizes and geometry
- Demonstration-Scale Challenges
  - Operating with insufficient data from improper piloting
  - Dealing with changes in conversion efficiency after scaling to demonstration scale
- Commercial-Scale Challenges
  - Handling solids at full commercial scale
  - Accurately estimating product yield
  - Determine whether the issues at existing commercial plants can be fixed or if they require going back to R&D

Proposed Paths Forward to Address Biorefinery Challenges

- Stakeholder Collaboration
  - Encourage industry and academy to understand the scale-up mechanisms
  - Disseminate lessons learned from prior IBRs to industry and national laboratories
- Data Modeling
  - Define the data that is required to generate a reliable data set for the commercial facility
  - Develop better models that are tailored to biomass systems
  - Provide access to pilot-scale data that was used to scale-up the process
  - Develop robust simulation models and life-cycle analyses that take uncertainty into consideration



WBS 2.2.1.501



WBS 2.2.1.301, 2.2.1.304, 2.2.1.305

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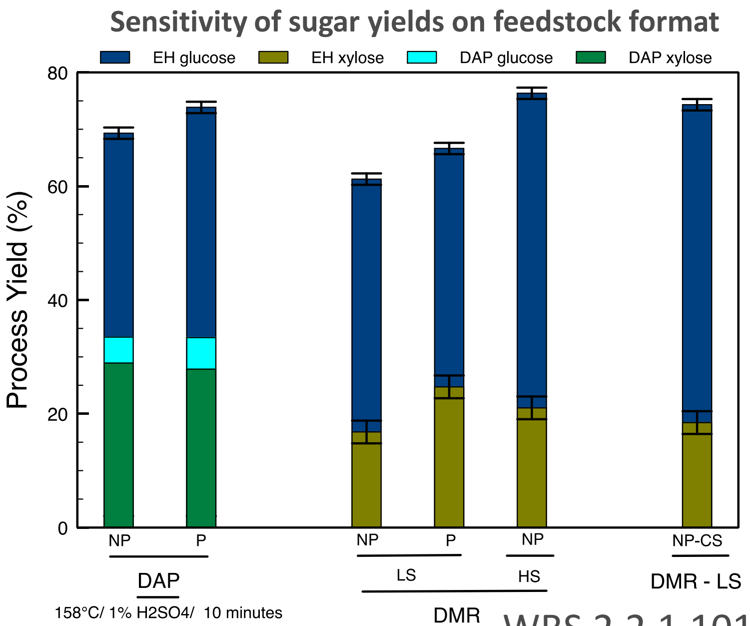
Challenges in Process Integration

- Engineering Processes
  - Understanding process sensitivities
  - Understanding the effect of feedstock soil content impact on process design and projected maintenance
- Quality Assurance and Control
  - Ensuring reliable feedstock pre-processing at high volumes and low cost
  - Understanding design safety and standards, particularly for feedstock size reduction and dust removal
- Data Collection
  - Validating process models and simulations at demonstration and commercial scales

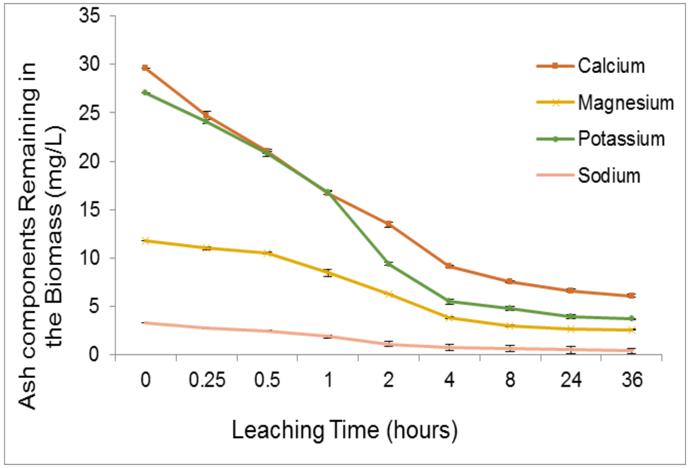


WBS 2.2.1.101

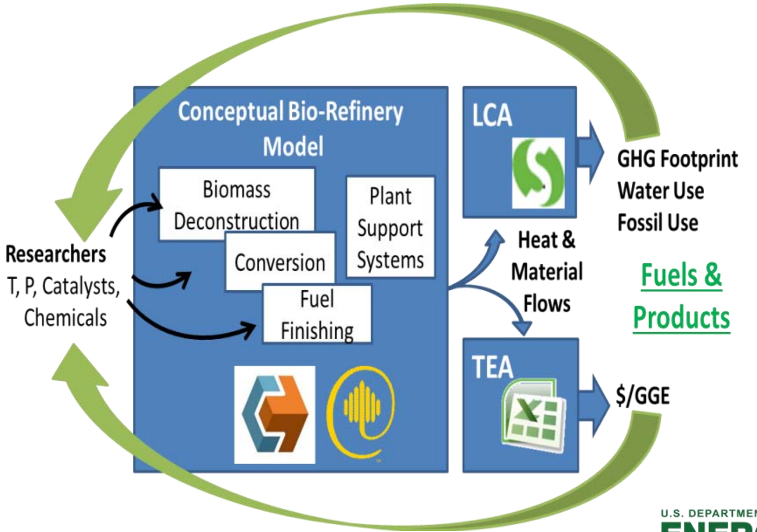
WBS 3.1.3.2

Challenges in Conversion Pathways

- Engineering Processes
  - Removing biomass contaminants that can deactivate biological catalysts or produce a contaminated co-product
  - Inability to maintain design process condition
- Equipment
  - Dealing with the erosion and corrosion of reactor vessels, heat exchangers, and valves
- Business Decisions
  - Understanding the balance between the economic feasibility and environmental impact



WBS 1.2.2.1



WBS 2.1.0.100, 2.1.0.301, 2.1.0.302

Recommendations and Lessons Learned

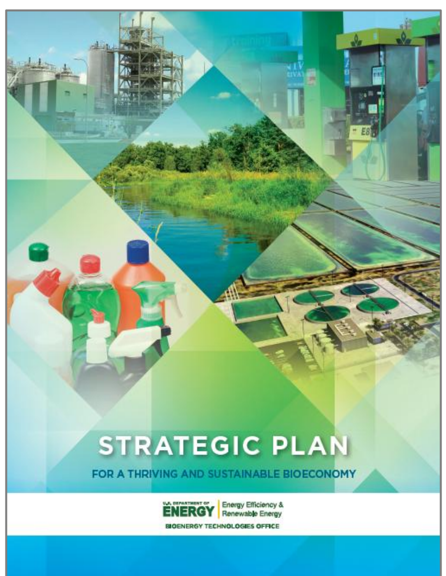
WBS 1.2.1.3

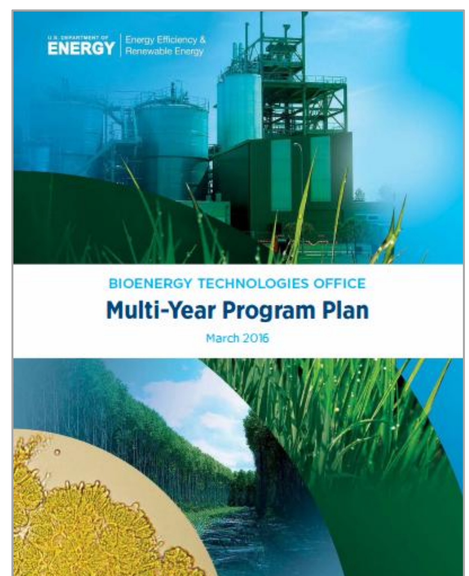
- Methods for Reducing Capital and Operational Expenditures
  - Use the same feedstock(s) as a planned feedstock at the commercial scale for a robust process during scale-up
- Lessons Learned in Process Scale-Up, Intensification, and Cost Reduction
  - If process intensification opportunities are missed, the process may be far less likely to succeed commercially
  - People tend to use a "standardized/ideal" feedstock early in process development,
  - Sufficient length of piloting with real feedstock
  - Robust data collection during operations that can be "mined" to develop process understanding and to solve problems
  - Project teams should consist of both scientists that developed the technologies, as well as the engineers who will be operating it at scale

Particle morphology

FCIC Strategies

1. Improve biorefinery operation and reliability
2. Improve the efficiency and success of technology scale-up
3. Develop a knowledge network on process integration at all scales
4. Develop science and engineering-based solutions to industrial problems
5. Develop a formal mechanism to identify industry needs and challenges and incorporate these into FCIC RD&D portfolio

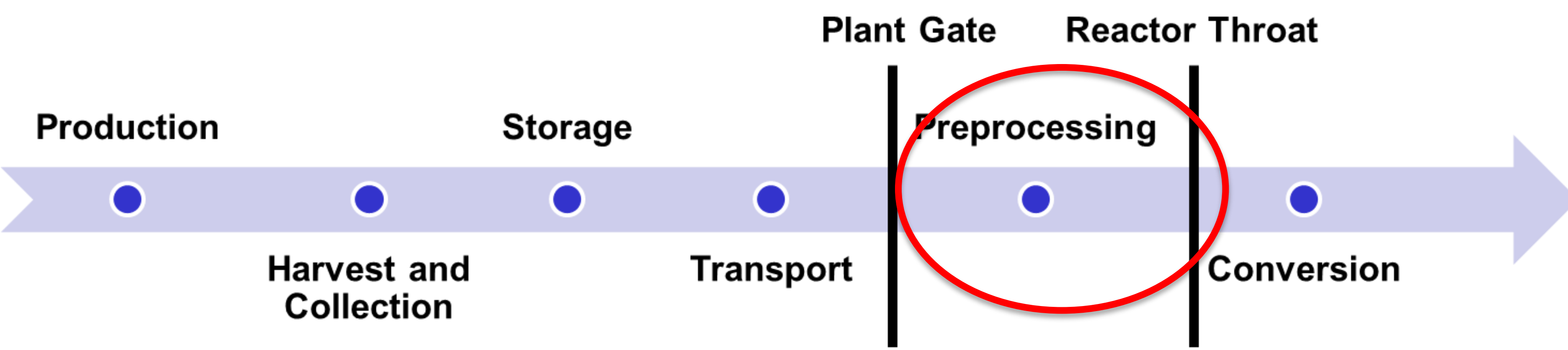




FCIC Strategies & Objectives

Strategy 1: Improve biorefinery operation and reliability

- Develop preprocessing technologies to produce consistent, conversion-ready feedstocks
- Develop control logic & systems to improve the robustness and flexibility of integrated preprocessing and feeding systems
- Develop reactor feeding / solids handling tools and technologies



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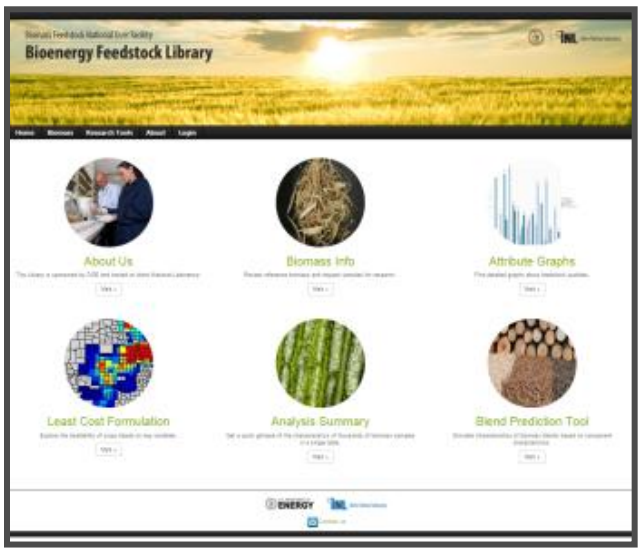
FCIC Strategies & Objectives

Strategy 2: Improve the efficiency and success of technology scale-up

- Assemble a comprehensive database of biomass chemical and physical properties
- Develop models that use characterization data to inform the proper selection, design, and integration of feedstocks and conversion technologies
- Develop the transfer functions between pristine and industrial feedstocks to support development of robust conversion processes



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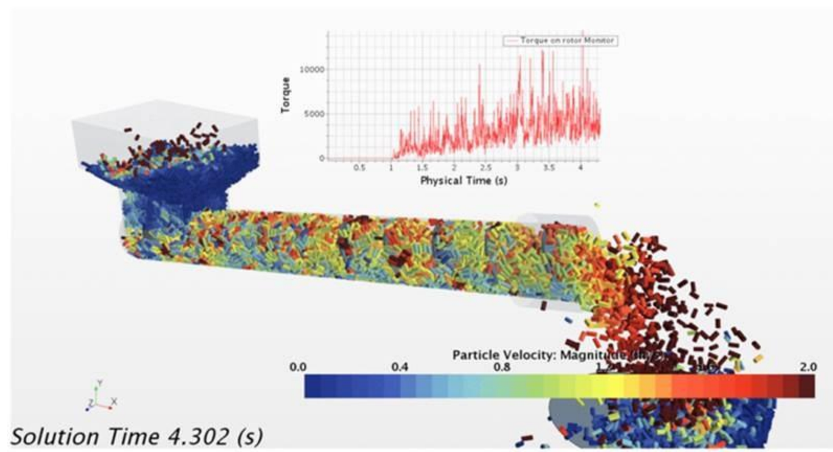
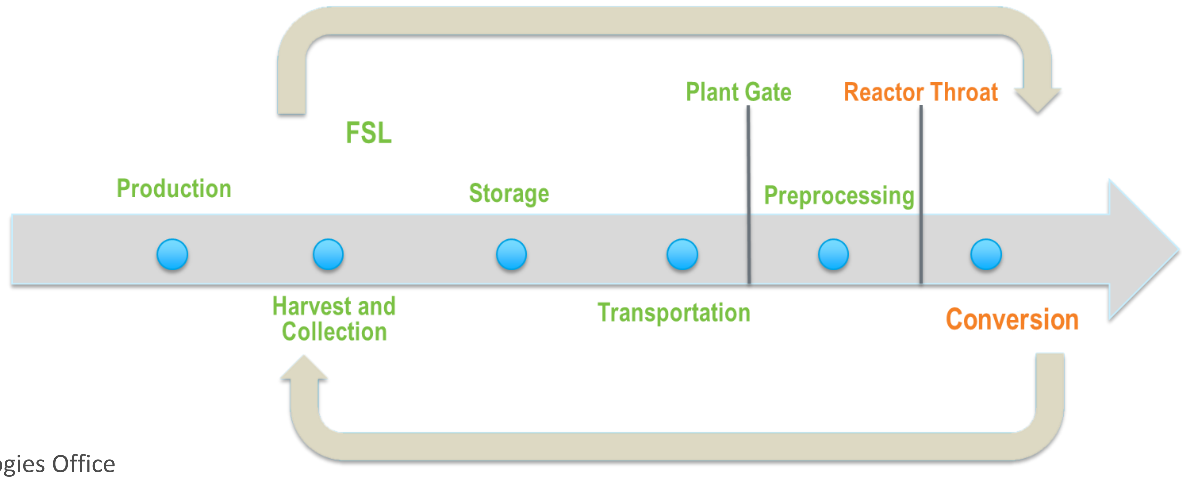


Pellets fed through hopper into an auger system.
Source: Recent INL simulation, WBS 1.2.1.3

FCIC Strategies & Objectives

Strategy 3: Develop a knowledge network on process integration at all scales

- Integrate feedstock supply chain and conversion pathway analysis models to evaluate design sensitivities, tradeoffs, and optimization
- Develop feedstock specifications for integrated biorefinery pathways
- Investigate and develop process intensification strategies from the laboratory scale for
  - feedstocks supply chains,
  - conversion pathways,
  - and integrated bioenergy value chains



FCIC Strategies & Objectives

Strategy 4: Develop science and engineering-based solutions to industrial problems

- Expand pilot testing utilizing the collection of Process Demonstration Units across the National Lab network
- Develop "virtual scale-up teams*" from National Lab researchers which can be made available to companies looking to scale up their technology

Biomass Feedstock PDU (INL)

Integrated Biorefinery PDU (NREL)

Advanced Biofuels PDU (LBNL)

*Neil A. Belson, biofuelsdigest.com/bdigest/2016/10/24/derisking-a-strategy-for-growing-the-biobased-economy/

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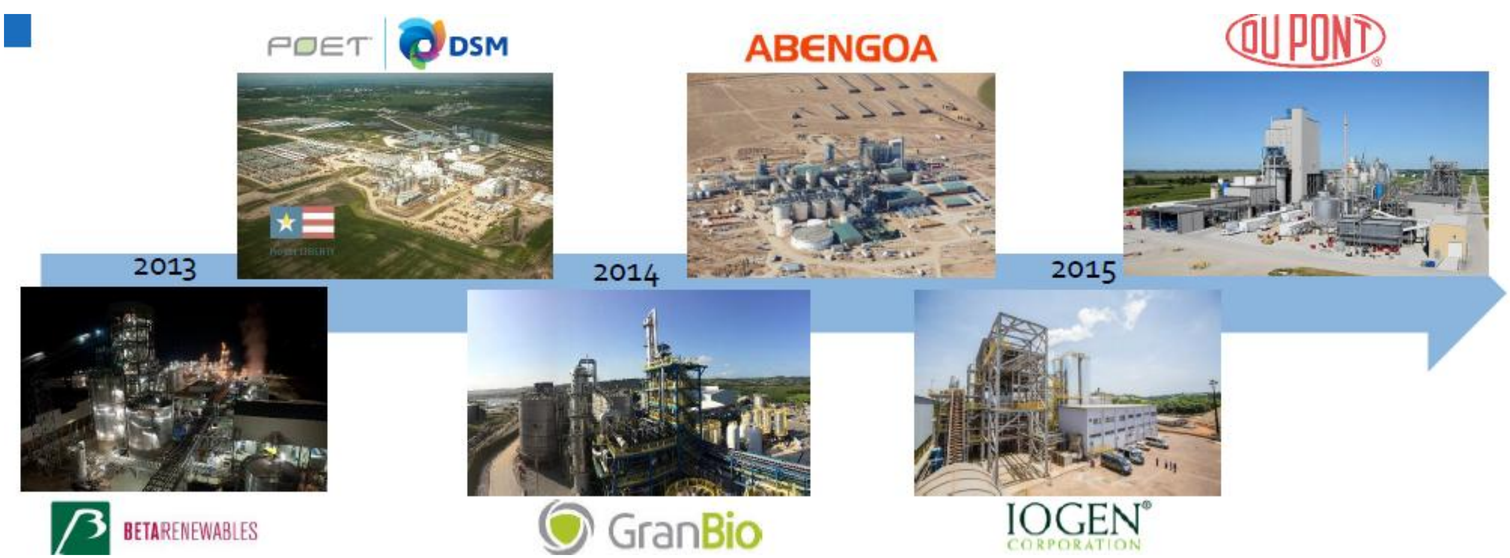
FCIC Strategies & Objectives

Strategy 5: Develop a formal mechanism to identify industry needs and challenges and incorporate these into FCIC RD&D portfolio

- Collect market intelligence from Lab outreach, lessons learned from PDU collaborations, and other tech-to-market activities
- Establish an Industry Advisory Board
- Convene an annual Industry Listening Day



Defining Success in FY17 and Beyond

FY17

- Finalize strategic plan with input from BETO leadership and Lab PIs, and Advisory Board
- Convene the initial meeting of the Industry Advisory Board
- Identify two specific short-term, industrially-relevant research needs that the FCIC will address in FY18
- Reorganize existing FCIC portfolio to align with strategic plan

FY18

- Work to address two specific industry needs
- Define a prioritizing mechanism t hat transparently assigns priority to problems and issues collected from publically held rounds of industry listening meetings
- Complete realignment of FCIC portfolio

Long Term:

- Coordinate feedstock qualification metrics that consider both FSL and conversion priorities and technical targets
- Track industry engagement through the involvement of and advice provided by the Industrial Advisory Board, and through participation by the larger group of industry stakeholders in “listening days” open to the public.

Feedback Requested

- Focus: Science of scale-up and integration of feedstock and conversion technologies
- Goal: Streamline scale-up and accelerate start-up of integrated biorefineries
- Strategies
  1. Improve biorefinery operation and reliability
  2. Improve the efficiency and success of technology scale-up
  3. Develop a knowledge network on process integration at all scales
  4. Develop science and engineering-based solutions to industrial problems
  5. Develop a formal mechanism to identify industry needs and challenges and incorporate these into FCIC RD&D portfolio

Thank you for your attention!

Advisory Board members wanted. If interested, please contact kevin.kenney@inl.gov or ed.wolfrum@nrel.gov