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

DOE Bioenergy Technologies Office Feedstock R&D – Addressing Feedstock Cost, Quality, and Quantity Challenges Facing the Biorefinery Industry

USDA S-1041 Meeting
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Washington DC

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From Challenge to Opportunity

THE CHALLENGE

More than $350 million is spent **every day** on foreign oil **imports**. Dependence on **foreign oil** can leave us vulnerable to disruptions in supplies and contributes significantly to our trade deficit.

Transportation accounts for 67% of petroleum consumption and 26% of emissions in the United States.

THE OPPORTUNITY

More than **1 billion tons of biomass** could be domestically converted into biofuels and products.

Biomass could displace **25%** of U.S. petroleum use annually by 2030, **keeping $260 billion in the United States**, adding **1.1 million direct jobs,** and reducing annual CO_2 emissions by 450 million tons or 7% of U.S. energy emissions.

BETO's Mission & Vision

Vision

A thriving and sustainable bioeconomy fueled by innovative technologies

Mission

Developing and demonstrating transformative and revolutionary sustainable bioenergy technologies for a prosperous nation

Strategic Goals

Develop industrially relevant technologies to enable domestically produced biofuels and bioproducts without subsidies

BETO reduces risks and costs to commercialization through RD&D.

BETO's Critical Program Areas

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Production & Harvesting

Feedstock Supply & Logistics
Works to reduce the cost, improve the quality, and increase the volume of sustainable feedstocks available for delivery to a biorefinery.

Advanced Algal Systems
Focuses on improving the productivity of algal biomass and enhancing the efficiency of cultivation and harvesting.

Conversion & Refining

Conversion
Develops technologies to convert non-food feedstocks into biofuels, bioproducts, and biopower.

Conversion
Intensification - at bench and pilot scale, conduct feedstock blend testing, separations, materials compatibility evaluations, and technoeconomic-driven verification tests

Distribution & End Use

Advanced Development and Optimization
Aims to conduct early stage R&D and related analysis to identify and evaluate the most promising biofuels, bioproducts, and biopower candidates and conduct performance prediction to enable bioeconomy and efficiency targets.

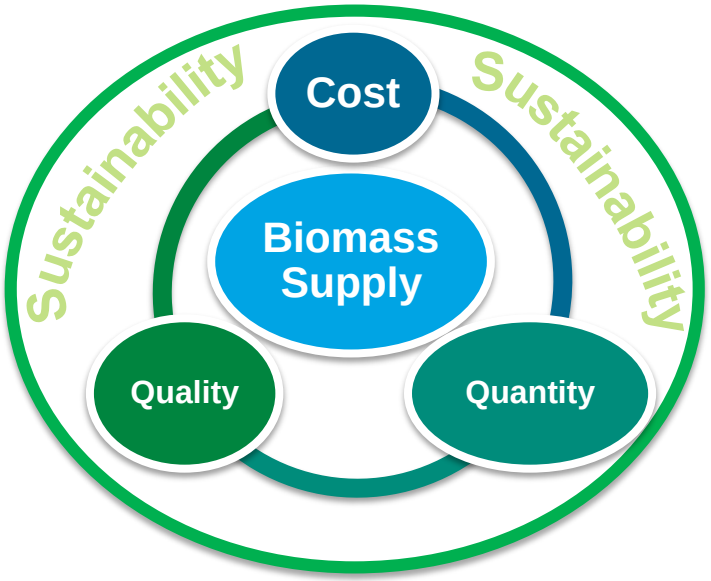
Crosscutting Areas: Sustainability, Strategic Analysis, & Communications

BETO works to address risks and reduce costs across the supply chain.

Feedstock Supply and Logistics

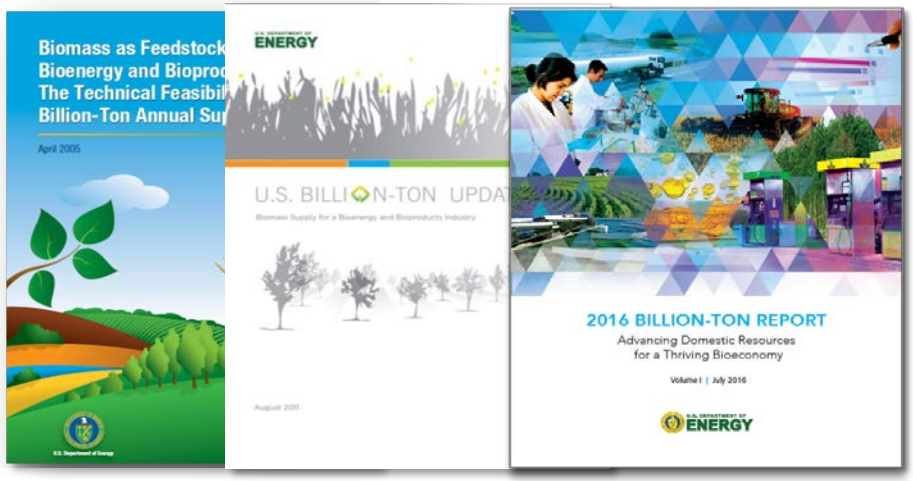
Focus

- Fully integrate feedstocks into supply chain (multiple interfaces).
- Reform raw biomass into high-quality feedstocks.
- Use innovative technologies to ensure sustainable supply and reduce costs.
- Reduce risks to enable industry expansion.



Approaches

- Use basic and applied science to understand, model, and manage.
- Provide nationally, but solve locally.
- Meet environmental performance targets and goals while assuring sustainability.
- Work with stakeholders and partners.



Addressing Feedstock Supply Challenges

- Reduce delivered cost and risks associated with feedstock quality and volume to accelerate widespread commercialization of sustainable biomass supply chains for a broad range of markets, in partnership with USDA and other key stakeholders. This goal corresponds to a cost and volume target:
  - By **2022**, verify at pilot or demonstration scale cellulosic feedstock supply and logistics systems that can economically and sustainably supply 285 million dry tons per year (excluding biopower) at a mature modeled delivered cost of $84/dry ton ($2014) to support a biorefining industry (i.e., multiple biorefineries) utilizing diverse biomass resources.

Billion Ton Studies – History and Accomplishments

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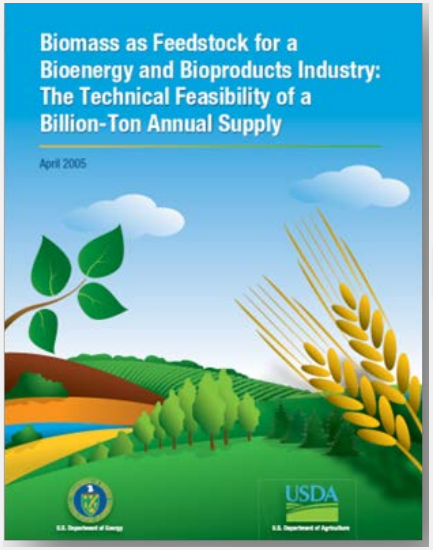
2005



Resource assessment

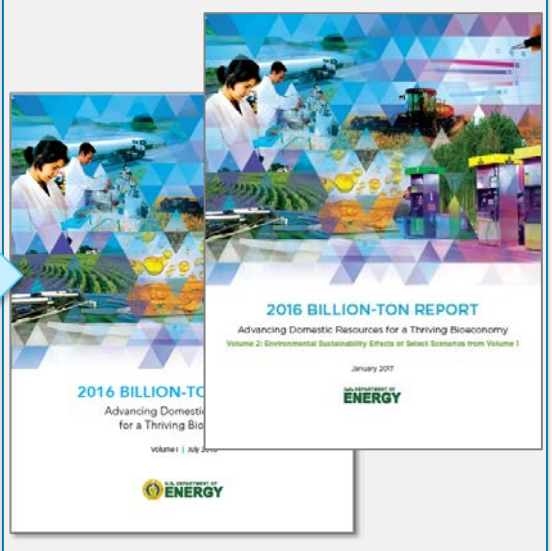
- How much biomass is available in the U.S.?
- Can we produce a sustainable supply of biomass that can displace 30% of the country's current petroleum consumption?

2011

Resource assessment + Economic Analysis

- Timeline to 2030
- County-level biomass feedstock availability estimates
- Broad energy crop definitions and estimates
- Harvesting biomass only (not delivering biomass)

2016



Resource assessment + Economic Analysis + Environmental analysis

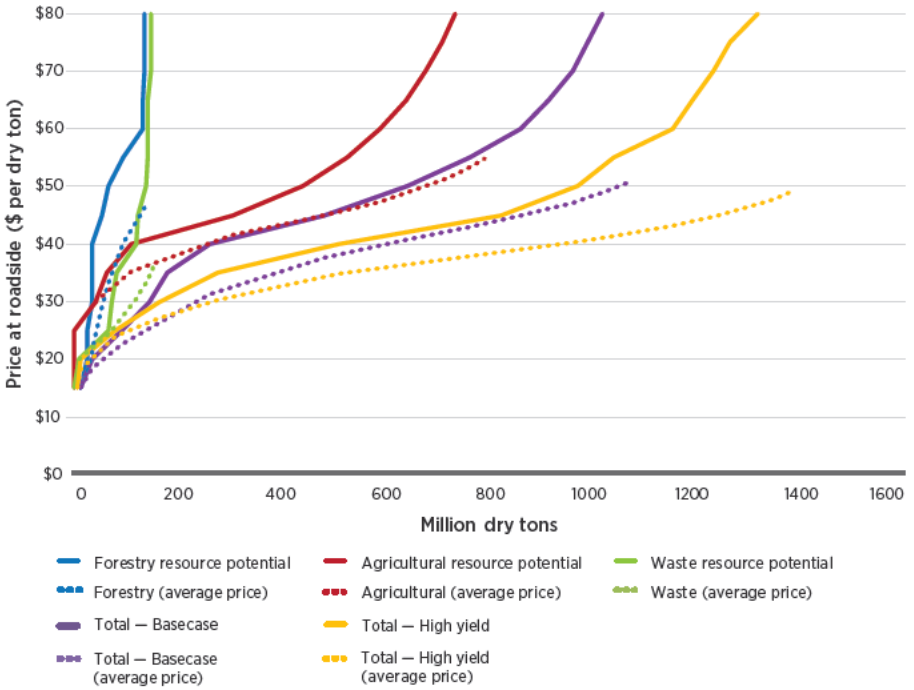
- Extended timeline
- Updated agricultural projections
- Detailed cost analysis
- Algae and energy crops
- Regional analysis
- Environmental sustainability analyses

Addressing Feedstock Availability Challenge

Summary of currently used and potential biomass available at $60/dry-ton under two scenario assumptions

Feedstock	Current used resource (MDT)	Total base-case scenario (MDT)	Total high-yield scenario (MDT)
Forestry resources	154	251	230
Agricultural resources	144	320	344
Waste resources	68	210	210
Energy crops	N/A	411	736
Total	365	1,192	1,520

MDT: Million Dry Tons



Potential forestry, agricultural, and waste biomass resources shown as a function of marginal and average prices at roadside in 2040.

A BILLION DRY TONS OF SUSTAINABLE BIOMASS

HAS THE POTENTIAL TO PRODUCE

1.1 MILLION Direct Jobs
and keeps about
$260 BILLION
in the U.S.
(direct contribution and inflation adjusted)

75 BILLION*
kWh of electricity
to power
7 MILLION
households. Plus
990 TRILLION BTUs
of thermal energy.

50 BILLION
gallons of biofuels
displacing almost
25%
of all transportation fuels.

50 BILLION POUNDS
of biobased chemicals and bio-products, replacing a significant portion of the chemical market.

450 MILLION TONS
of CO_2e reductions every year.

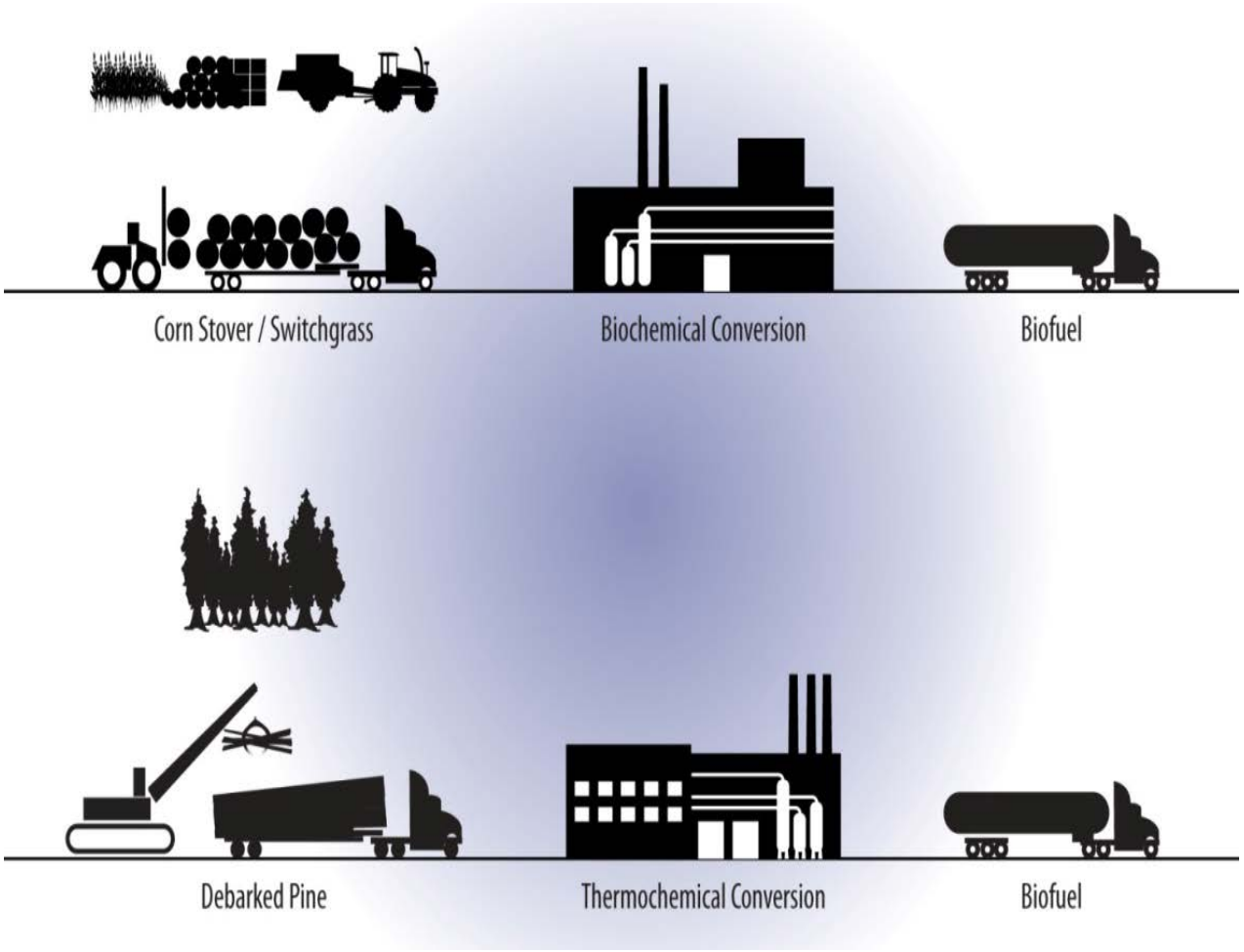
STEPS TO BUILDING THE BIOECONOMY

1. Accelerate research & technology development
2. Develop production, conversion and distribution infrastructure
3. Deploy technology
4. Create markets and delivery systems

Projections based on:
Rogers, J. N., Stokes, B., Dunn, J., Cai, H., Wu, M., Haq, Z. and Baumes, H. (2016), An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy. *Biofuels, Bioprod. Bioref.* doi:10.1002/bbb.1728

* Includes 27 billion kWh and 90 TBtu from livestock anaerobic digestion

Today: Conventional Feedstock Supply Systems

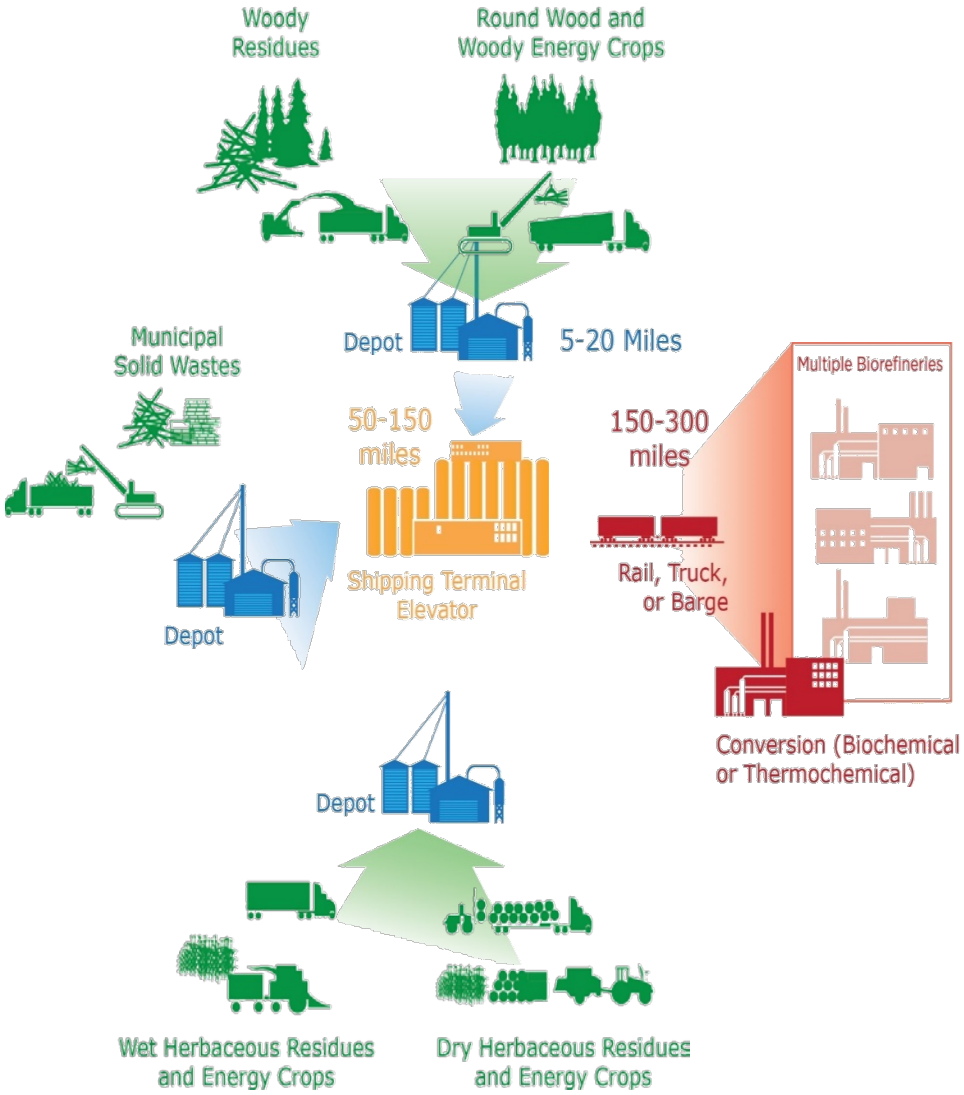


Problems with CFSS

- Inconsistent quality of feedstock
  - Variation in bale properties (ash, moisture content, dimensions)
  - Does not meet conversion specs
- High dry matter loss in storage
- Low bulk density and poor flowability
- Integration of preprocessing with conversion lowers the reliability of the biorefinery

All these problems have led to lengthy start-up periods and low throughput of pioneer biorefineries

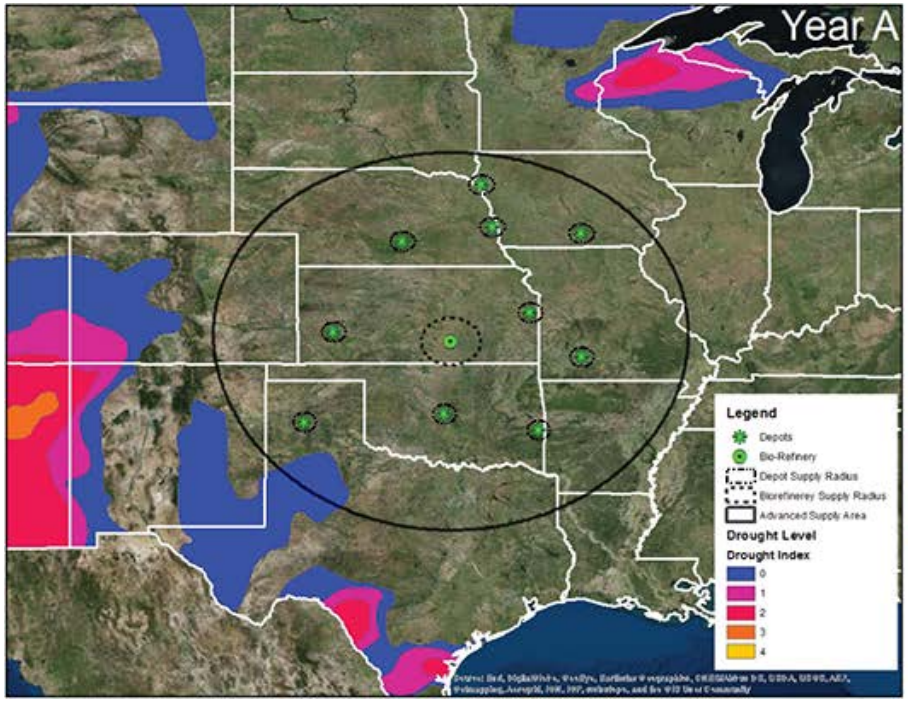
Tomorrow: Advanced Feedstock Supply System

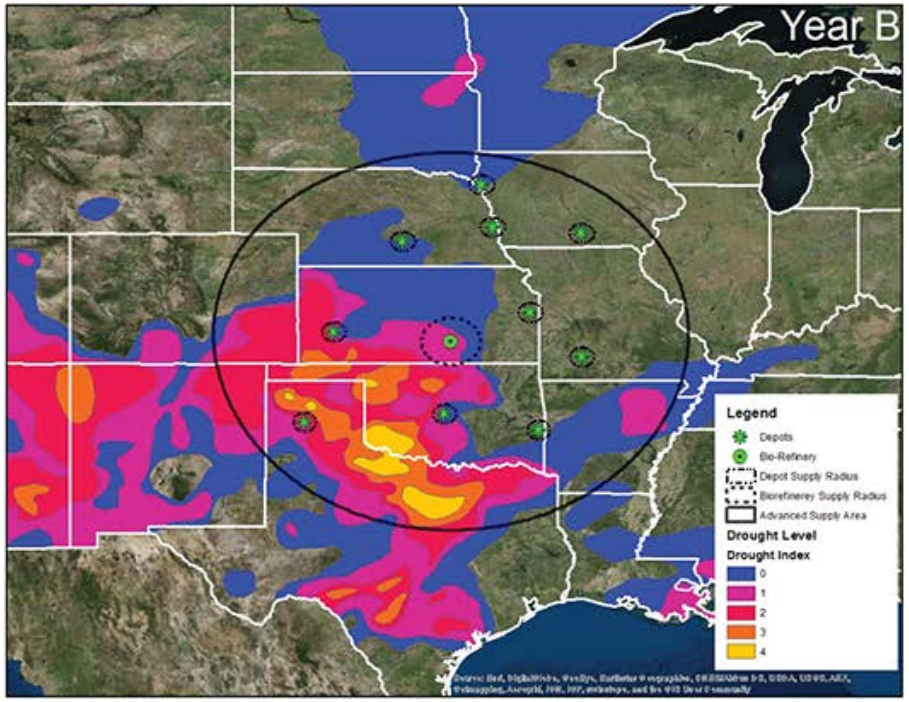


Distributed depot system provides the following benefits:

- **Enhanced quality**
  - Meets conversion specs, thereby enhancing conversion yield
- **Reduced Supply Risk**
  - Decoupled from biorefinery;
  - increases supply radius and improves reliability of the biorefinery;
  - enables larger biorefineries
- **Densification (pellets, briquettes)**
  - Increased efficiency in transport (weight limited versus volume limited)
  - Enhanced flowability allows better movement in bulk systems; uniform
  - Enhanced Stability with no significant dry matter loss (1-2 year shelf life)
- **Product grades**
  - Standardized material classified into quality “grades” of expected characteristics

CFSS vs AFSS: Challenges and Opportunities





Impact of drought levels (from 0:low to 4:very high) on an example biorefinery sourcing radius in a conventional (dotted circle) and advanced supply system (wider circle including depot operations) over two years.

Biofuels, Bioproducts and Biorefining
Volume 9, Issue 6, pages 648-660, 20 AUG 2015 DOI: 10.1002/bbb.1575
http://onlinelibrary.wiley.com/doi/10.1002/bbb.1575/full#bbb1575-fig-0003

Near-term strategies for transition to AFSS

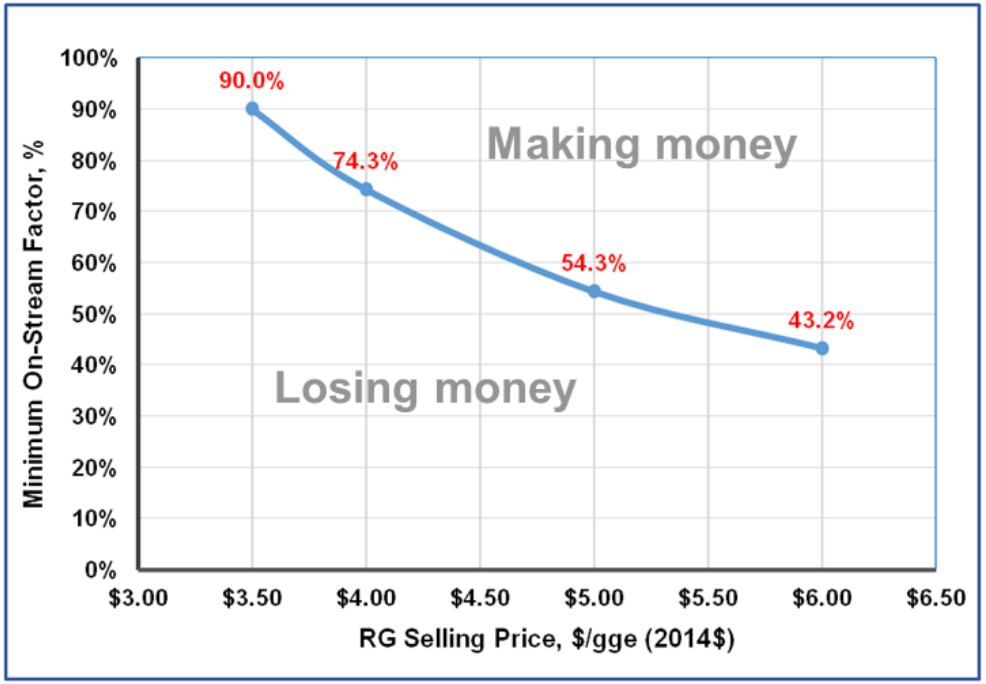
- Decouple biomass preprocessing from conversion
- Develop in-line sensors for moisture and dirt
- Reduce the ash content in bales
- Remove ash from biomass using multiple steps as necessary
- Select appropriate equipment for processing high-moisture bales
- Densify feedstock (where applicable) to improve handling
- Collaborate with leading conversion technology developers to understand their feedstock specifications

Plugged hammer mill screen

Damaged screw conveyor

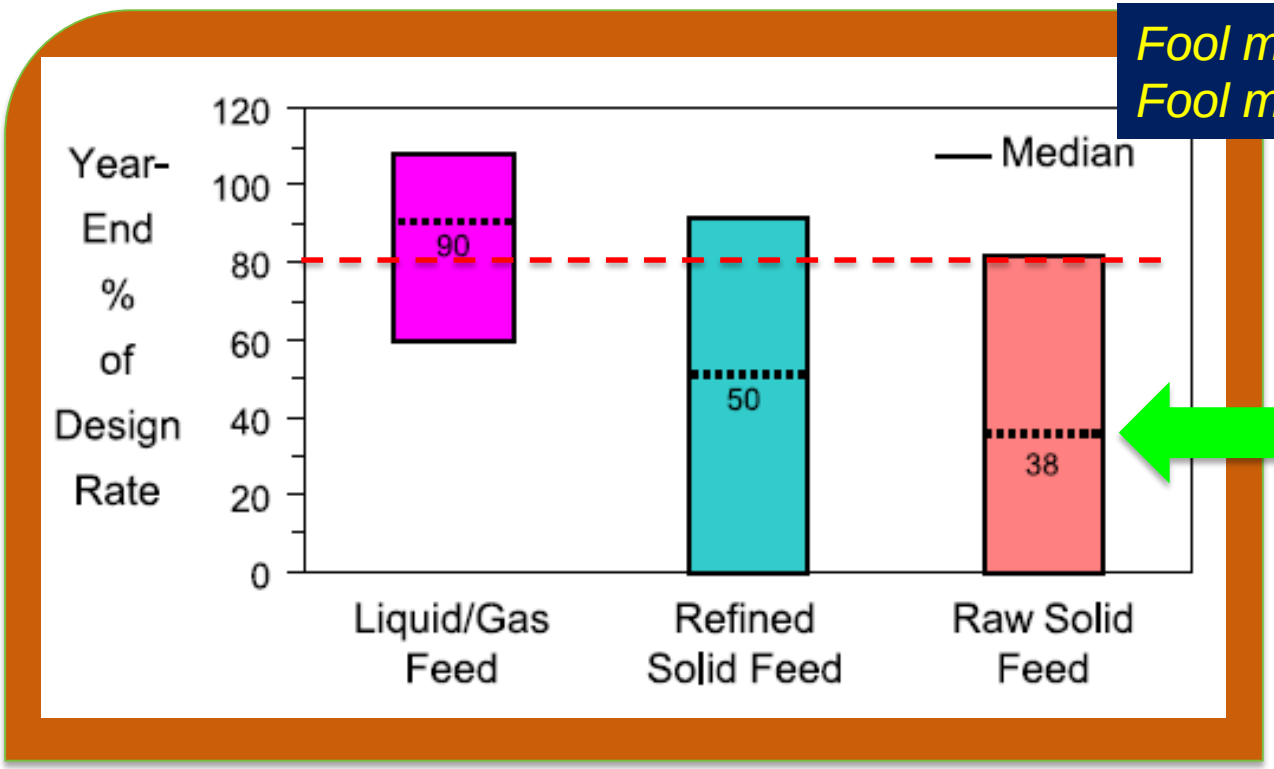
Observations from the Emerging Cellulosic Ethanol Market

- 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 against pressure gradients
  - Solids handling up to and through conversion



History Repeats Itself

- 32 year old Rand Corp. study 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).**

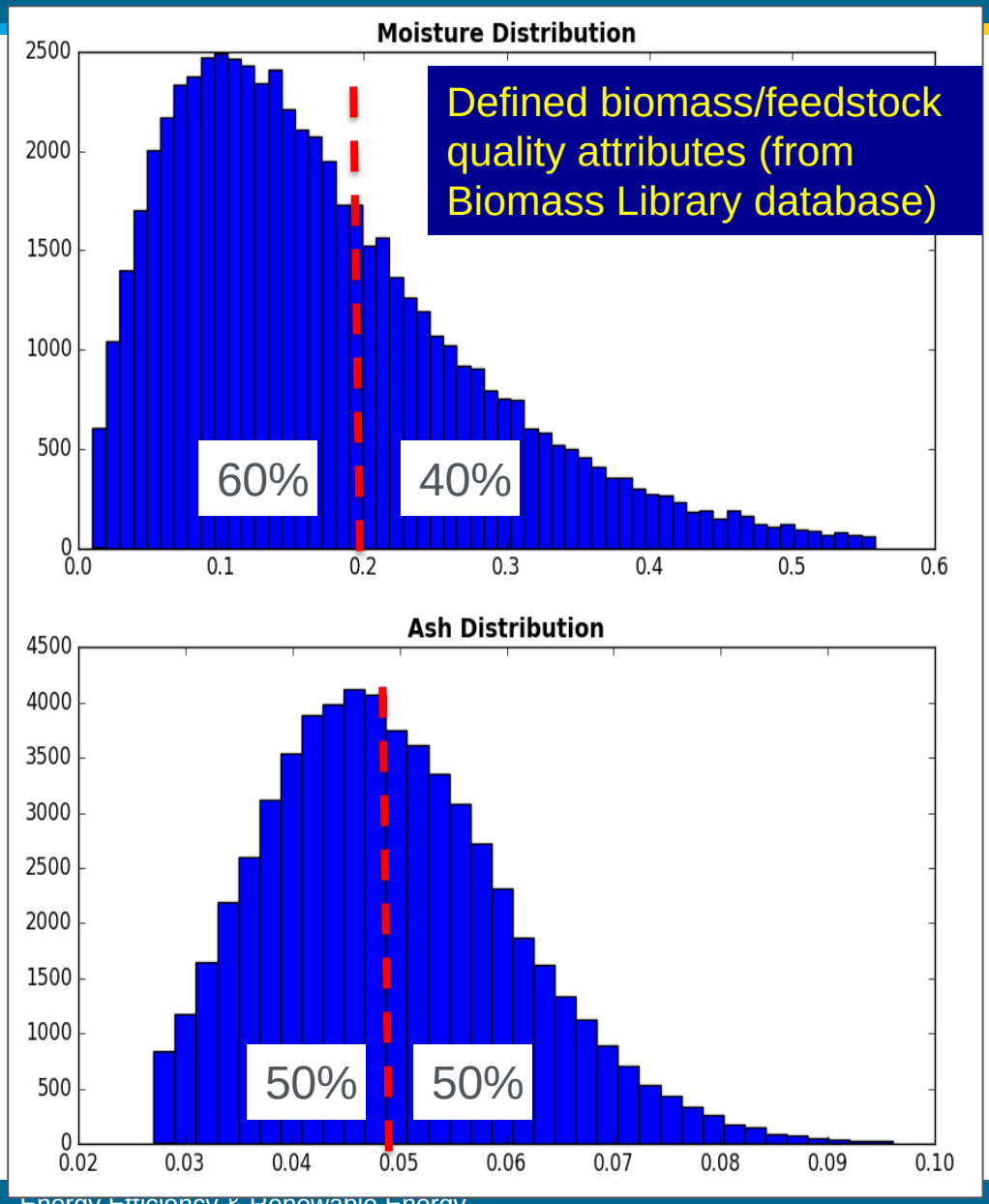


Fool me once, shame on you.
Fool me twice, shame on me.

Biomass Attributes Affecting Feed Handling & Conversion Problems

- **Moisture content**
  - Stability in storage; risk of spontaneous combustion
  - Grinder throughput; energy usage; plugging screens
  - Fragmentation characteristics change, resulting in particle size variability/distribution
- **Particle size distribution**
  - Large particles (aka “pin chips”, “overs”)
    - Cause plugging problems in bins, augers, heat exchangers, distillation columns, etc.
    - Do not fully cook –
      - plugging in downstream equipment; microbial contamination; excess residual solids; etc.
  - Fine particles
    - Plugging of weep holes in feeders/digesters
    - Overcooking, resulting in excess char formation
    - Dust – fire, explosion, and health hazard risks
    - High in ash (buffering capacity; increased chemical usage; catalyst fouling, equipment wear)
  - Variation results in inconsistent mass and heat transfer in Conversion making performance targets difficult to achieve (i.e., profitability, sustainability)
- **Foreign material (soil, plastic bale wrap, tramp metal)**
  - Plugging, fouling, equipment wear

Consequences of Conventional Feedstock Supply Systems

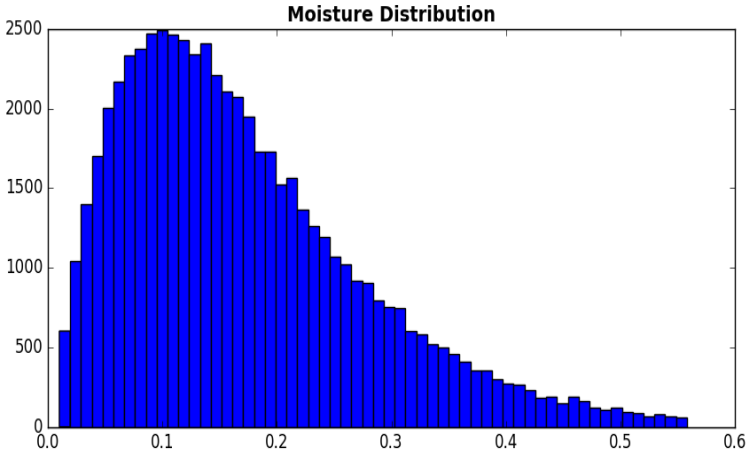


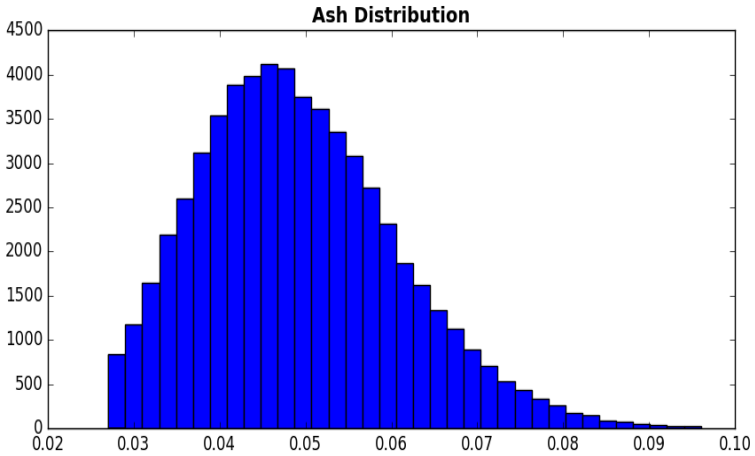
- Biochem spec
  - 20% moisture
  - 5% ash
  - 59% CHO
  - ¼-inch minus
- Independent variables
  - 0.6 * 0.5 = 0.3
  - CHO constraint
  - PSD constraint
- Fast pyrolysis spec
  - <10% moisture
  - 1% ash
  - 2 mm particle size

Modeling Feed Handling Problems

Modeled effects of biomass/feedstock attributes on biorefinery feed handling operations

Defined biomass/feedstock quality attributes (from Library data)





Also included particle size distribution from grinding

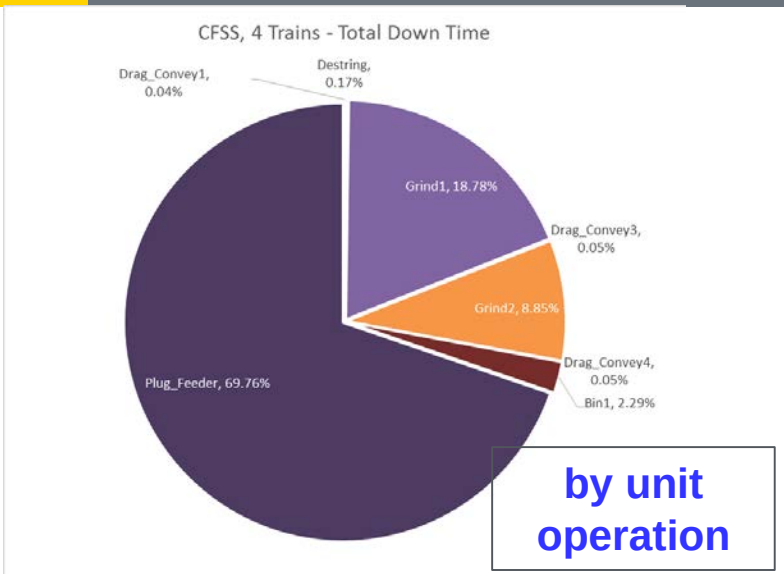
Defined equipment performance and reliability

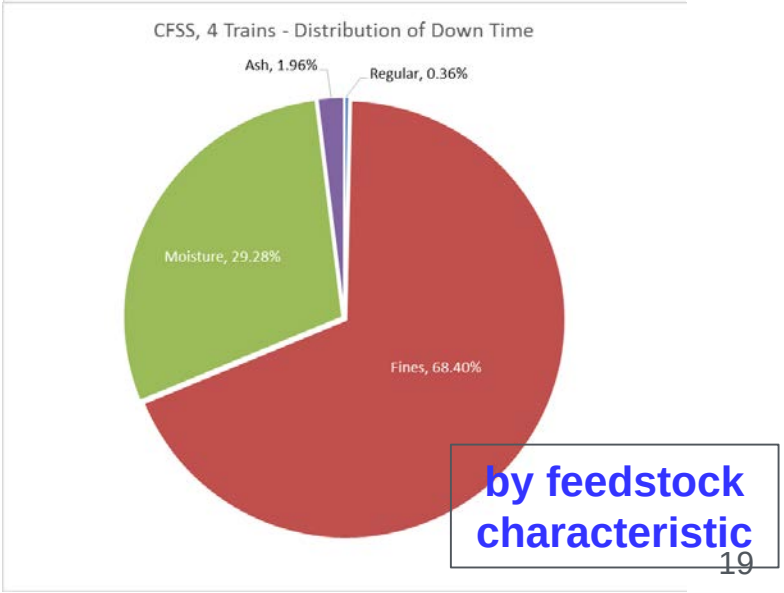
First Stage Grinder	
Regular Failure	
Mean time to failure	6 months
Mean repair time	2 hours
Repair time standard deviation	30 minutes
Ash Caused Failure	
Cumulative ash processed	500 tons
Mean repair time	6 hours
Repair time standard deviation	2 hours
Moisture Caused Failure	
Maximum moisture content	35%
Mean repair time	30 minutes
Repair time standard deviation	15 minutes

Plug Screw Feeder	
Ash Caused Failure	
Cumulative ash processed	6,426 tons
Mean repair time	2 days
Repair time standard deviation	12 hours
Fines Caused Failure	
Cumulative fines processed	2,240 tons
Mean repair time	2 days
Repair time standard deviation	12 hours

CFSS

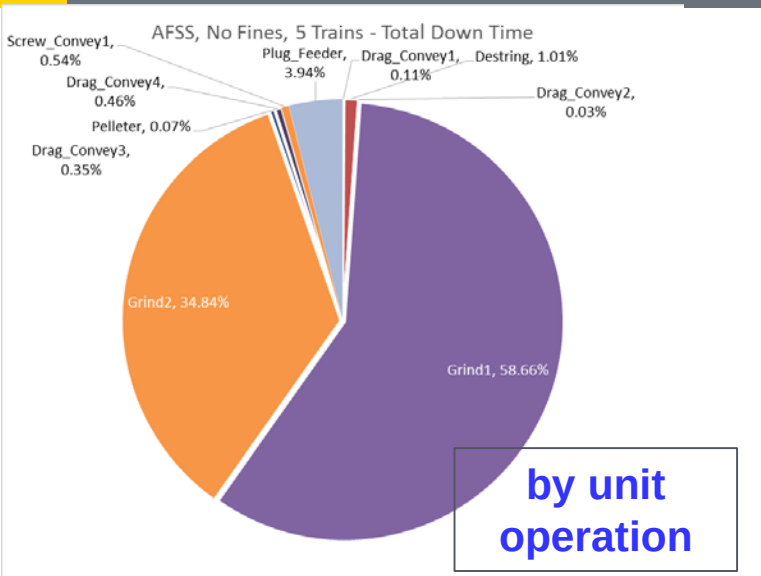
- Design
  - 800K tonnes/year design
  - Operating at 90% of design throughput
  - 4 preprocessing lines (trains)
- Preprocessing
  - No active quality controls for moisture, particle size, or ash
  - Two-stage grinding
- Performance
  - 27% of design throughput (4 preprocessing lines)
  - Max throughput of 45% (94 preprocessing lines)
  - >90% of design throughput with 11 lines if reject >50% of biomass infeed
  - Does not meet conversion specs

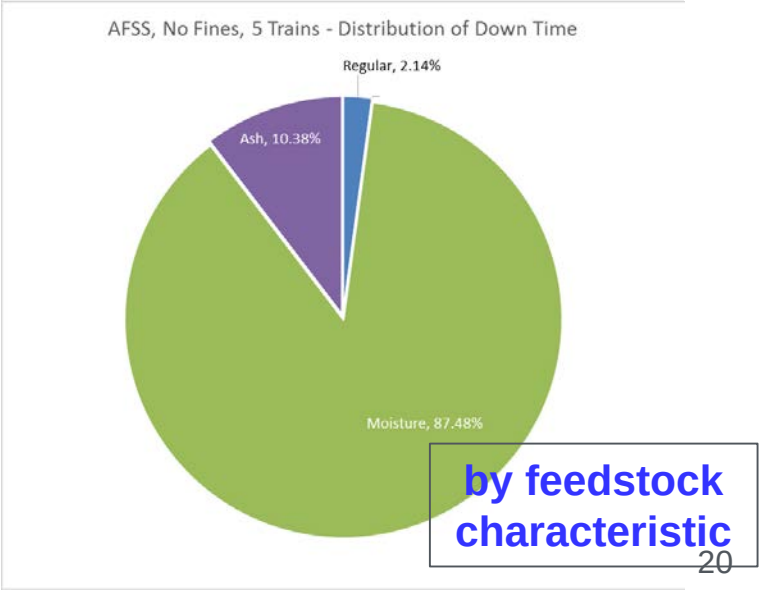




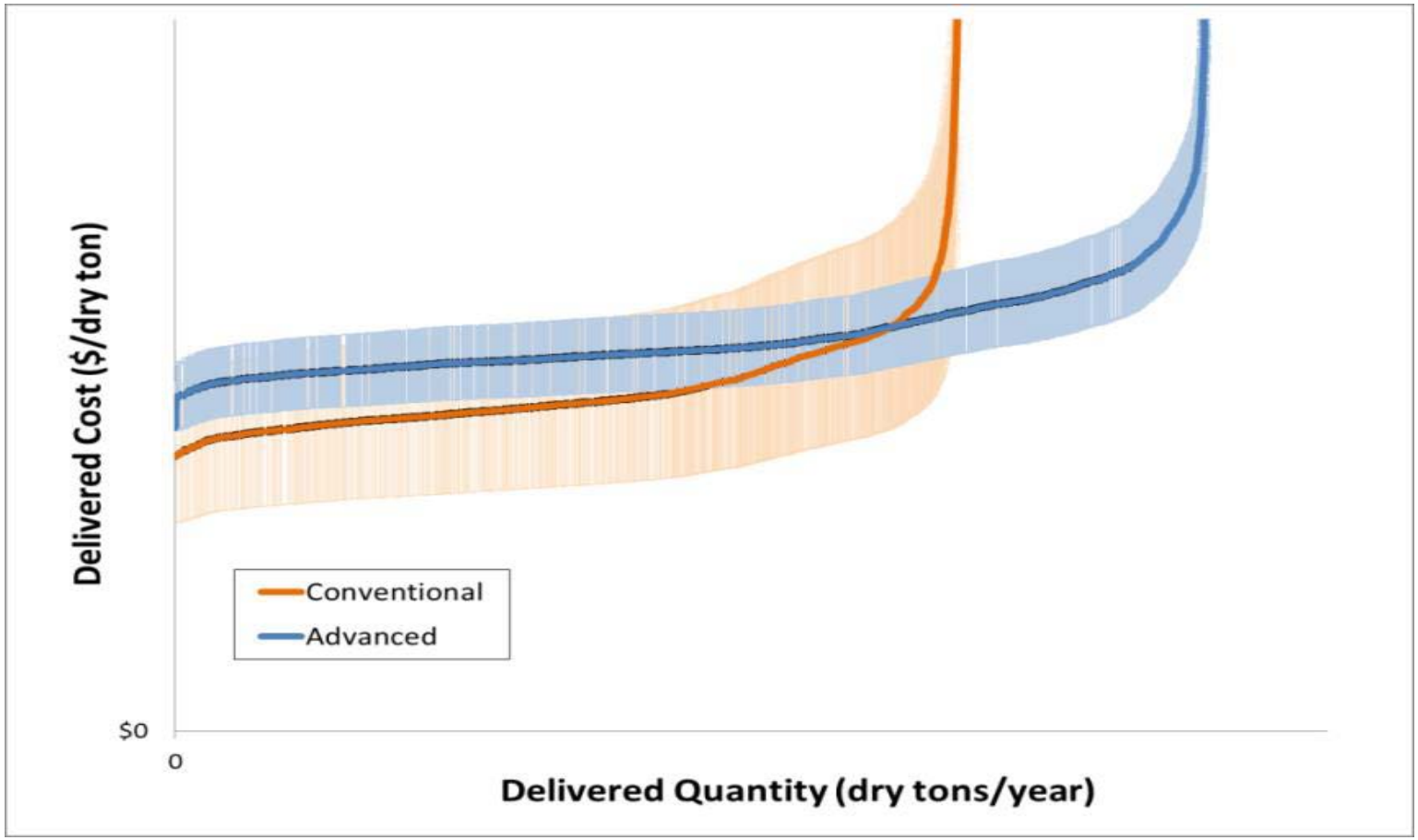
AFSS

- Design
  - 800K tonnes/year feedstock required
  - Operating at 90% of design throughput
  - 5 preprocessing lines (trains)
    - 4 at plant, 1 at depot
  - Decoupled from pretreatment reactor
- Preprocessing
  - Active quality controls – feedstock moisture and fines
  - Fractional milling
  - Wet densification
  - Cross-flow dryer
- Performance
  - 41% of design throughput (4 preprocessing lines)
  - Max throughput of 90% (17 preprocessing lines)
  - Meet all conversion specs except ash spec





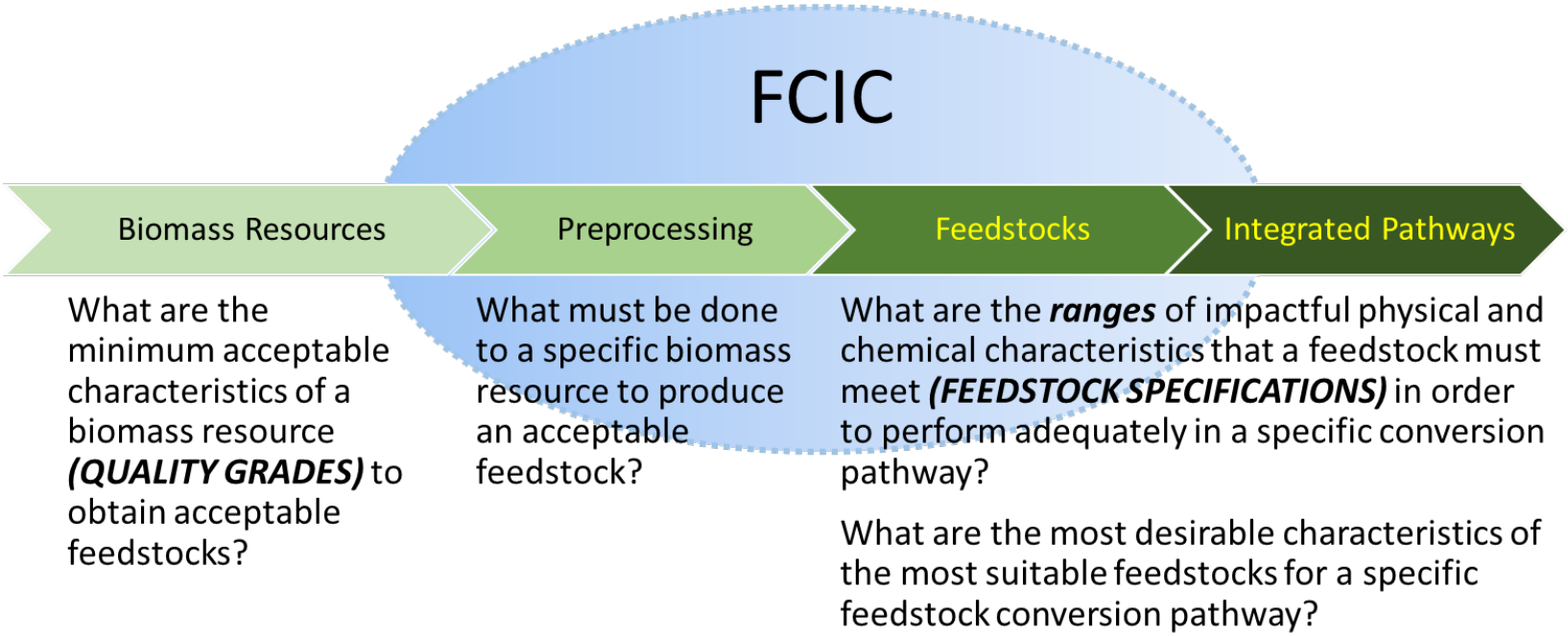
AFSS Can Access Much More Biomass if Cost Gap is Closed with CFSS



Advanced feedstock supply systems can reduce the costs and risks associated with delivering biomass of sufficient quality to meet the 21 billion gallons of advanced biofuels RFS2 target.

Feedstock-Conversion Interface Consortium (FCIC)

Focus: Science of scaling and integration of feedstock and conversion technologies



Goal: Develop and demonstrate integrated feedstock/conversion processes that achieve >90% operational reliability (i.e., time-on-stream)

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

Funding Opportunities

- FY17 Biomass Research and Development Initiative (BRDI)
  - Joint USDA and DOE program, $9 million in funding
  - Three technical areas: Feedstock Development, Biofuels and Biobased Products Development, and Biofuels Development Analysis.
  - Concept papers due by July 7, 2017
  - Full applications due by Sept 22, 2017.

Upcoming Conference - Bioeconomy 2017

On **July 11–12**, BETO will host its tenth annual conference—*Bioeconomy 2017: Domestic Resources for a Vibrant Future*.

Each year, approximately 600 participants attend the conference, including key stakeholders from the bioenergy industry, Congress, national laboratories, academia, and the financial community.

Sheraton Pentagon City

900 South Orme Street

Arlington, VA 22204

Upcoming Activities - 2017 Program Management Review

On **July 13**, BETO will host it's 2017 Program Management Review.

Results of the Project Peer Review will be presented by Lead Reviewers, along with an overall assessment of BETO's portfolio presented by the Steering Committee.

Sheraton Pentagon City

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Thank you!

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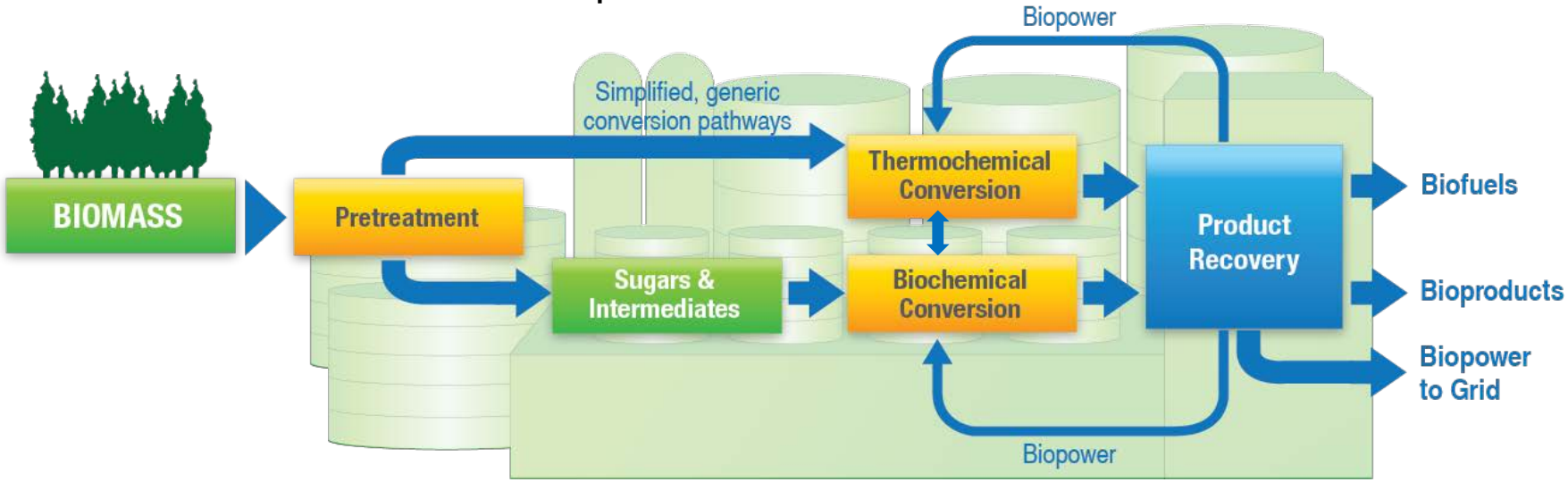
Key Challenge for Innovation – Lowering Risks

De-risking technologies is central to R&D through **demonstration** with greater **integration** and **scale**. BETO focuses on:

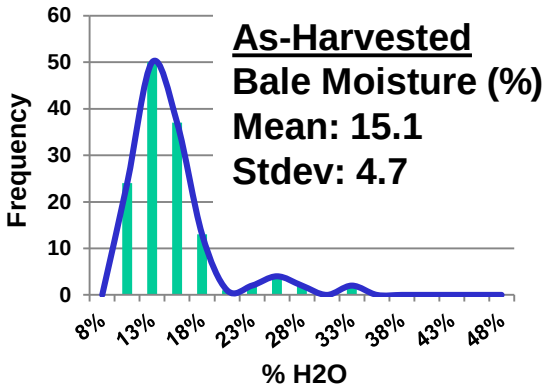
- Advancing renewable gasoline, diesel, and jet fuels technologies
- Technical, construction, operational and financial/market risk reduction

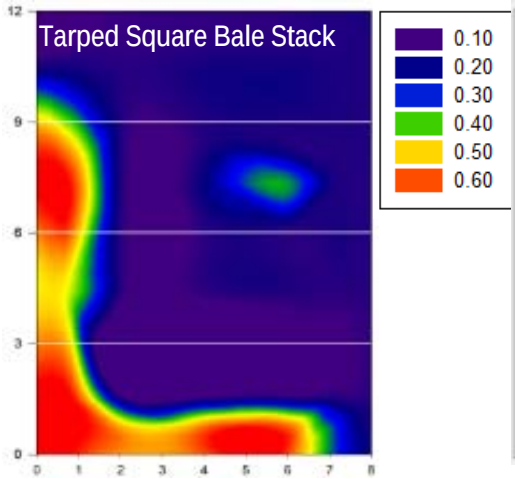


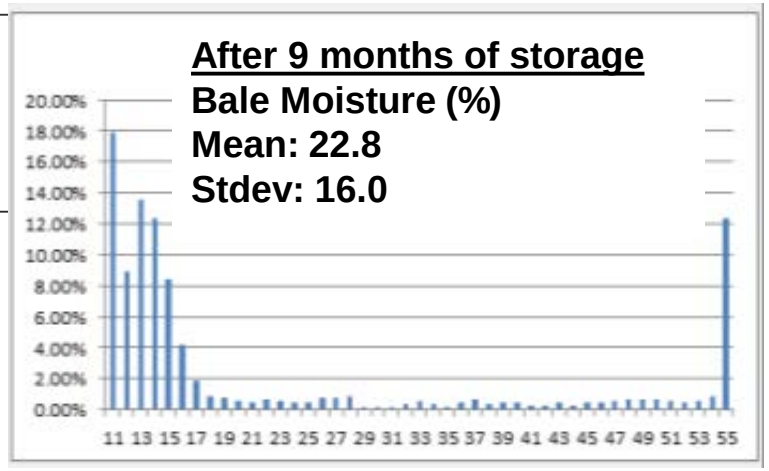
Key Challenges			
Biomass	**Pretreatment**	**Conversion**	**Product**
• Reliable supply • Consistent quality • Affordable delivery	• Biomass feeding, sizing and moisture • Solids handling • Construction materials	• Product Yields • Construction materials • Catalysts • Fermentation organisms	• Separations • Catalytic upgrading • Recycle loops

Understanding the Feed Handling Problem

- Bale-to-bale variability
  - Moisture
    - Hammer milling 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







The Value of AFSS

Adding value to biomass

- Preprocessing can produce uniform feedstocks of specific quality, thereby adding value to the biomass.

Mitigating Risk

- Provide "active" processes necessary to mitigate feedstock supply system risks for current biorefineries (e.g., fire, quality, weather, etc.)
- Stabilize and ensure supply to end users

Developing feedstock into a commodity

- "Mobilize" biomass resources into the market place and produce value-add merchandisable biomass intermediates
- A commodity-scale resource will create market pull within the cellulosic biorefining industry for intermediate blends and beyond.