DOE Bioenergy Technologies Office (BETO)

2021 Project Peer Review

WBS 1.2.2.2 - Standardized Risk Assessment and Critical Property Analytics

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Feedstock Technologies Program

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INL/MIS-21-61455

Project Overview

- History:
  - FY08 Bioenergy Feedstock Library
  - Datasets capturing explainable variability in biomass resources

- Relevance:
  - Variability in biomass feedstock properties translates to risk for bio-project
  - Success of bio-economy depends on low cost of capital, which is currently high because of poor understanding and inconsistent assessment of risks

- **Current Project Objectives:**
  - **Facilitate "derisking" bio-project development by addressing biomass supply chain and technological risks**
    - develop systematic methodologies and frameworks for risk assessment
    - apply statistical approaches to identify and quantify biomass critical properties (CPs) associated with risk
- Challenges:
  - Industry buy-in and expert input and feedback are necessary for risk assessment success
  - Critical property statistical tools rely on reliable, meaningful datasets not collected by the project

1 – Management

Goal: *Facilitate "derisking" bio-project development by addressing biomass supply chain and technological risks*

Systematic Risk Assessment

- **Task 1.1** Biomass Supply Chain Risk Standards — **FY17-21**
- **Task 1.2** Quality by Design: Systematic Criticality Assessment Tool — FY21

Critical Property Analytics

- **Task 2** Critical Property Variability Quantification — **FY18-21**
- **Task 3** Critical Property Identification and Analysis — FY20-21
- **Task 4** Archival of samples and data from DOE FOAs — FY20-21

1 – Management

Task 1: Systematic Risk Assessment

Objective: Develop systematic methodologies and frameworks for risk assessment

Subtask 1.1: Biomass Supply Chain Risk Standards (BSCRS) Framework and Scoring Methodology

- **Communication Strategy:** Multiple webinars to and solicited feedback from industry stakeholder group (100+ members) and advisory board, weekly team meetings and BETO quarterly reporting

Subtask 1.2: Quality by Design Implementation: Systematic Criticality Assessment Tool

- **Joint subtask in FCIC Task X - Management**
- **Communication Strategy:** Subject area expert for specific process units evaluated, FCIC industry advisory board, weekly team meetings and BETO quarterly reporting

Risks: Success of these risk assessment frameworks require significant input from industry and subject area experts

- Frequent solicited feedback from relevant industry including financial institutions and a flexible subject area expert group.

Team (1.1)

Idaho National Laboratory
ECOSTRAT
Los Alamos National Laboratory EST. 1943

Industry Stakeholder Group (100+) and Advisory Board

Team (1.2)

Idaho National Laboratory
fcic

Subject Area Experts

1 – Management

Task 2 & 3: Critical Property Analytics

- **Objective:** Apply statistical approaches to identify and quantify biomass critical properties (CPs) associated with risk

Task 4: Archival of physical samples and characterization data from DOE FOAs

Team

- Multidiscipline/multi-department group of **data analysts**
- INLs Biomass National User Facility Research Projects

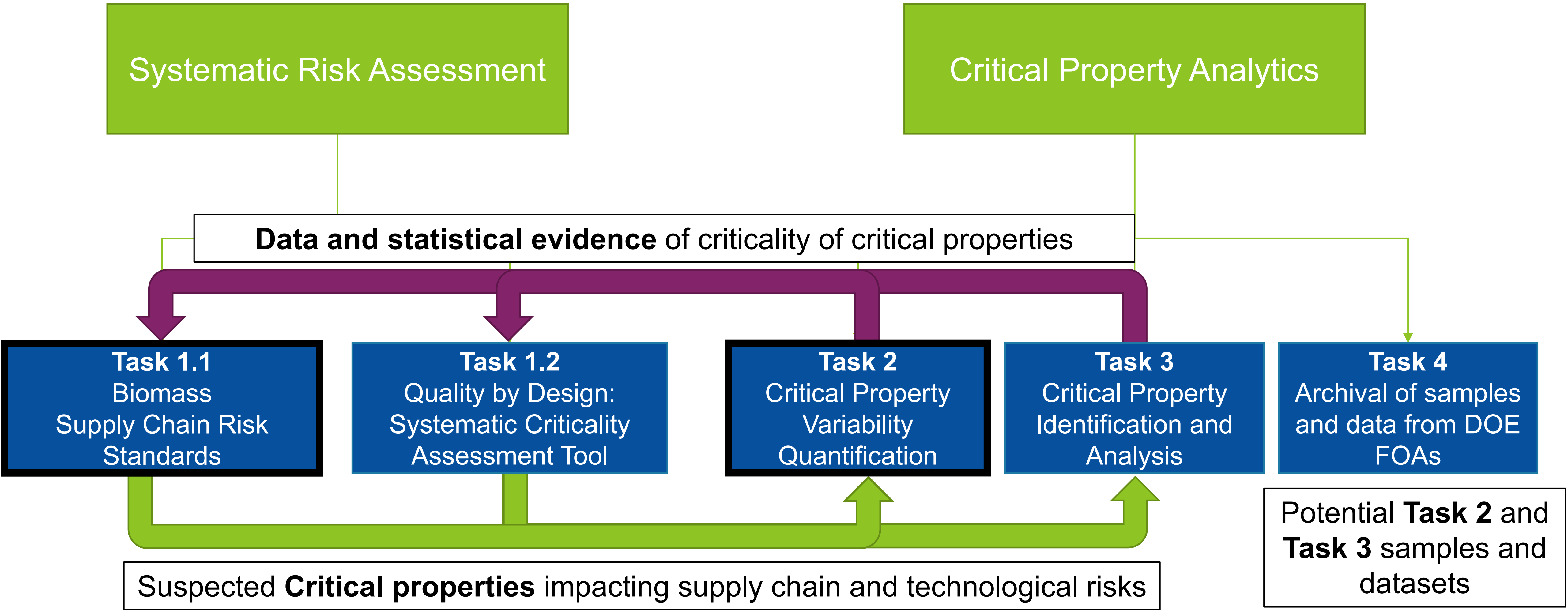
Communication Strategy:

- **Reporting:** BETO quarterly milestone reports
- **BETO project collaboration:** 1.1.1.2 Feedstock Supply Chain Logistics, 3.4.1.202 Biomass Feedstock National User Facility–Improving Bale Deconstruction and Material Flow
- **Task 4:** DOE FOA institution collaboration, alignment of datasets with ORNL through Knowledge Discovery Framework (KDF)

Risks: Critical property statistical tools rely on reliable, meaningful datasets not collected by the project

- Communication with experimental projects is critical for ensuring the generation of meaningful datasets

2 – Approach


Systematic Risk Assessment
Critical Property Analytics
Data and statistical evidence of criticality of critical properties
Task 1.1 Biomass Supply Chain Risk Standards
Task 1.2 Quality by Design: Systematic Criticality Assessment Tool
Task 2 Critical Property Variability Quantification
Task 3 Critical Property Identification and Analysis
Task 4 Archival of samples and data from DOE FOAs
Potential **Task 2** and **Task 3** samples and datasets
Suspected **Critical properties** impacting supply chain and technological risks

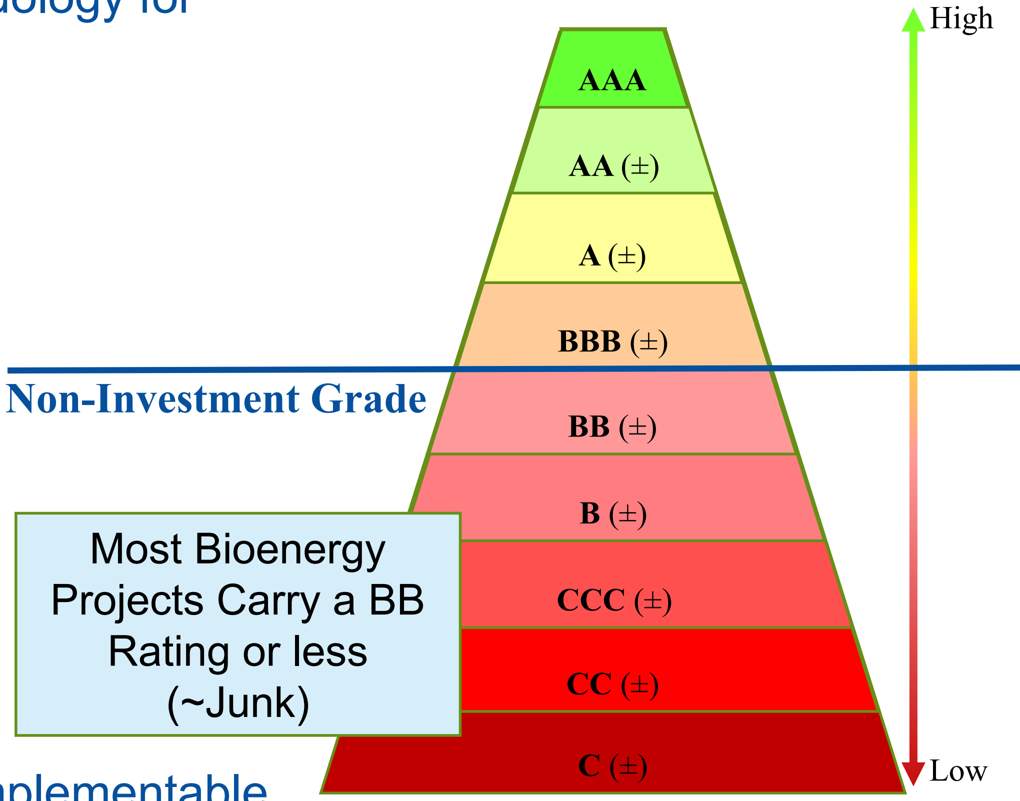
2 – Approach

> **"Lack of BSCR Standards is a material barrier to bio-project finance."**
> AGF, Stern Brothers, Raymond James, Jefferies Investment Banking

Task 1.1: Biomass Supply Chain Risk

Objective: Create draft of BSCRS framework and test scoring methodology for currently identified supply chain risk indicators.

- **FY17/18:** Document and organize all identified sources of risk
- **FY19:** Develop Risk Scoring Method
- **FY20/21:** Verification of BSCRS using realistic case studies for existing bio-projects
  - **Go/No Go (FY20):** Develop case study to test application of potential BSCRS and Scoring Methodology.
  - **Go:** demonstrate **decrease in perceived** supply chain **project risk** score of **20%**.



Generic credit rating

- **Challenges**
  - Ensure stakeholders find BSCRS and scoring system easily implementable.
  - Obtaining buy-ins and adequate vetting by industry
  - Development of realistic case studies

2 – Approach

☆ New Subtask

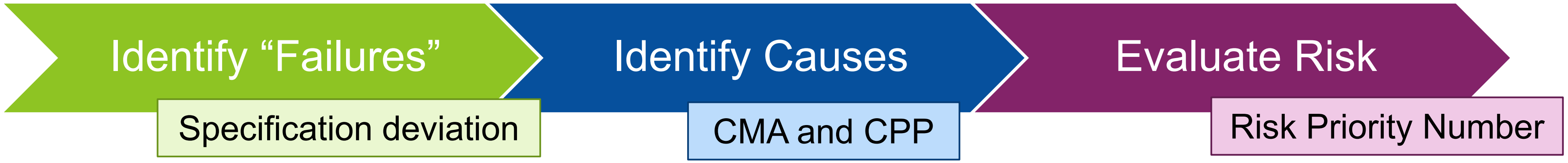
Task 1.2: Technological Risk

Objective: Develop systematic criticality assessment methodology by **adapting** a robust and well-accepted quantitative risk analysis approach:

Failure Modes Effect Analysis (FMEA) to calculate **Risk Priority Numbers (RPN)** for critical biomass properties: critical material attributes (**CMAs**), and critical process parameters (**CPPs**).

FY19 Reviewers' Comments:
BSCR Framework scope does not and cannot fully cover **technological risk**

- **FY21: Evaluate FMEA**
  - Create **adapted guidance scales** to calculate risk priority numbers for critical properties
  - Perform FMEA through interviews with **Subject Area Experts**
  - **Complete a proof-of-concept FMEA**



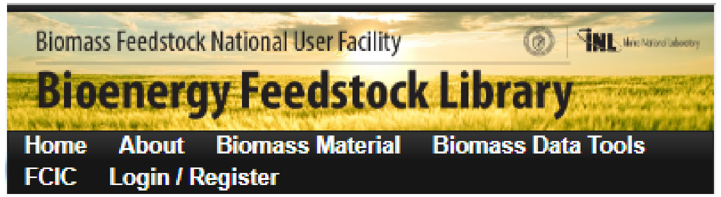
- **Benefits:** Qualitative and anecdotal information can be coupled with quantitative evidence.
- **Challenge:** Lack of data and/or experience for specific material/process units/product

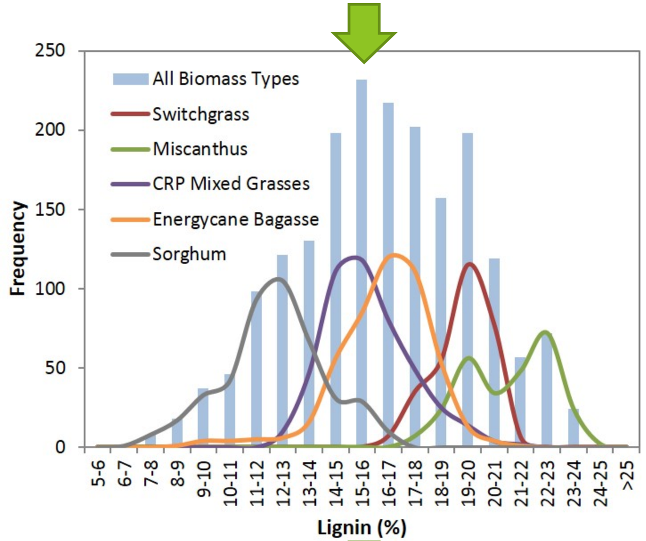
2 – Approach

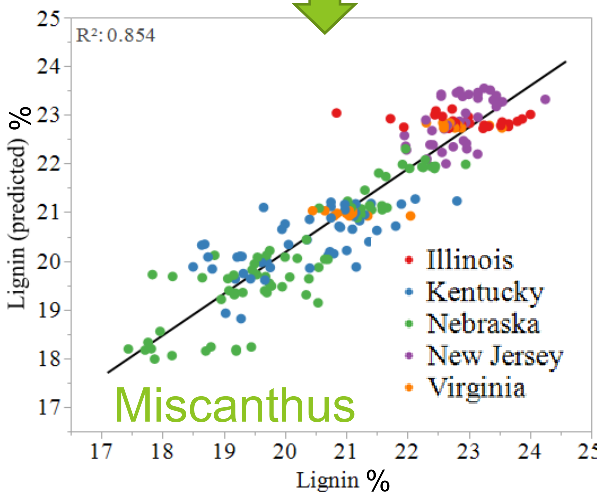
Task 2 and 3: Critical Property Analytics

- Datasets
  - Bioenergy Feedstock Library
  - Collaboration with other BETO projects
- **Quantify ranges and sources of variability** for identified critical properties
  - Developing predictive models to explain variability in biomass chemical properties based on environmental factors
    - Large historical field studies, i.e., **Sun Grant Regional Feedstock Partnership**
    - **Task 4** - Affordable and Sustainable Energy Crops FOA
- **Quantify the impact of critical properties for preprocessing** technologies
  - **INL's Biomass National User Facility** experimental projects to identify analytical needs and develop datasets

- **Challenge:** Available data for addressing specific questions
- **Innovative** analytical method development, i.e., **Explainable Artificial Intelligence**







3 – Impact

"Lack of BSCR Standards is a material barrier to bio-project finance."

AGF, Stern Brothers, Raymond James, Jefferies Investment Banking

Systematic Risk Assessment

- **BSCRS** will provide a consistent framework and knowledge base to estimate these risks and lower the cost of capital of bioenergy projects.
- **FMEA** is one systematic approach to rank and quantify impacts of critical properties throughout preprocessing and conversion system to address technological risk.
- **BETO FY19 MYP Barrier OT-C** Risk of Financing Large-Scale Biorefineries

Lack of understanding of variability in biomass properties translates to risk for bio-projects

Critical Property Analytics

- Advanced analytic predictive models can provide
  - **Ranges** and **sources of variability** in these critical properties
  - **Which** and to what **extent** critical properties impact specific unit operations
- **BETO FY19 MYP Barrier FT-E** Feedstock Quality: Monitoring and Impact on Preprocessing and Conversion Performance

Dissemination: Conferences, publications (e.g., joint with Regional Feedstock Partnership members), publicly available datasets and model outputs hosted in Bioenergy Feedstock Library

4 – Progress and Outcomes

Task 1 Systematic Risk Assessment: Biomass Supply Chain

Impact
Provides and demonstrates the first established protocol for quantifying biomass supply chain risk

BSCRS Scoring Methodology

- Scoring methodology patterned after Moody's
- Weightings and rationale create feedstock resource specific adjustable framework
- Advisory board (AB) and Industry stakeholder group (ISG) feedback through multiple webinars and distribution

Scoring Process Overview

- Each indicator scored (Aaa-C) based on quantitative metrics
  - 127 indicators, 29 factors, 6 categories
- Calculate risk scores for Factors, Categories, and Project (whole) using Factor and Category feedstock resource specific weightings

Risk Category → Risk Factor (1) … Risk Factor (n) → Risk Indicator (1-1) … Risk Indicator (1-n)

Risk Category: Categories of risk necessary to consider for evaluating supply chain risk

Risk Factor: Pathways of risk within each Category

Risk Indicator: Markers of risk for each Factor

4: Feedstock Quality Risk | 4.1: Feedstock Quality | 4.1.5: Geographic location influence on feedstock quality variability →

Reporting Requirements:
Proponent shall **demonstrate understanding of geographic regions** from which feedstock will be sourced, and the **effect on feedstock quality**.

Current BSCRS Framework: https://bioenergylibrary.inl.gov/BSCR/RiskStandardsV2.aspx

4 – Progress and Outcomes

Task 1 Systematic Risk Assessment: Biomass Supply Chain

Case Studies

- 2 Complete Case Studies
  - Woody Resource for Biopower
  - Ag. Residue/By-products for Ethanol
- Successful completion of **Go/No-Go milestone (March FY20)**
- Advisory board and Industry stakeholder group feedback through multiple webinars and distribution
- Feedback from financial institution supporting approach and results

Impacts

- **Verification of BSCRS Framework** ability to quantify risk in standard, consistent manner
- Potentially **reduce perceived risk** of bio-projects

Go/No-Go Case Study Results

	Cat. Weight	Without BSCRS	With BSCRS
1.0 Supplier Risk	100	A	A
2.0 Competitor Risk	100	B	⇩ Baa
3.0 Supply Chain Rsik	95	Baa	Baa
4.0 Feedstock Quality	100	Baa	⇩ Aaa
5.0 Feedstock Scale-Up	25	A	⇩ Aaa
6.0 Internal Organization	75	C	⇩ Ba
Overall		**Ba**	⇩ **Baa**

Raw Score Conversion Table					
Aaa	A	Baa	Ba	B	C
Low Risk ←					High Risk

Case Study Overview

- **Decreased** project risk for Case Study **27%** (**Ba** to **Baa**)
- Primarily driven by increase in available and requested data between two scenarios used to develop scoring changes.

4 – Progress and Outcomes

☆ New Subtask

Task 1 Systematic Risk Assessment: Technological Risk

Failure Modes Effects Analysis Guidance Development

- Developed **initial guidance scales** for quantifying severity, occurrence, and detection associated with material/equipment TRL specific knowledge
- Formed groups of **subject area experts** for process areas
- Working towards first milestone to:

  "**Complete a proof-of-concept FMEA**…"

Impact
Standardized approach for quantifying risks for specific critical properties.

FMEA requires the ranking of Severity (S), Occurrence (O) and Detection (D) by Subject Area Experts to calculate Risk Priority Number (RPN).

RPN = S x O x D

Severity Guidance Table (initial)

Effect	Rank	TRLs			Criteria
Minor	1	A			None to minor disruption to production line. A small portion (much < 5%) of product may have to be reworked online.
…					
Very high	10	A	B	C	Major disruption to production line. Close to 100% of product may have to be scrapped. Process unreliable. Failure occurs without warning. Customer very dissatisfied. May endanger operator and/or equipment.

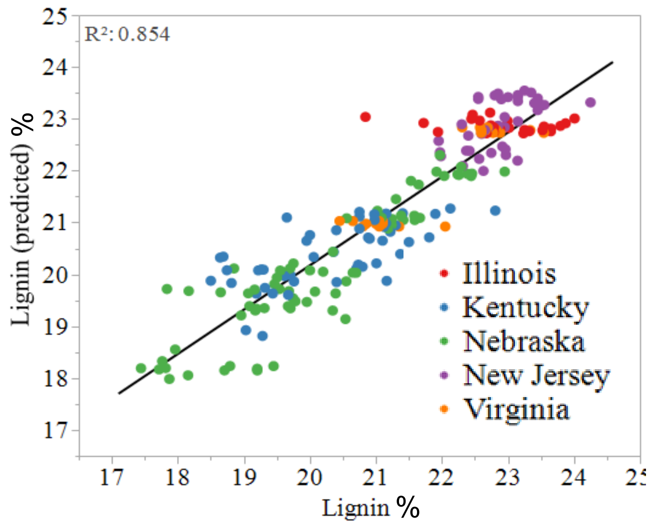
4 – Progress and Outcomes

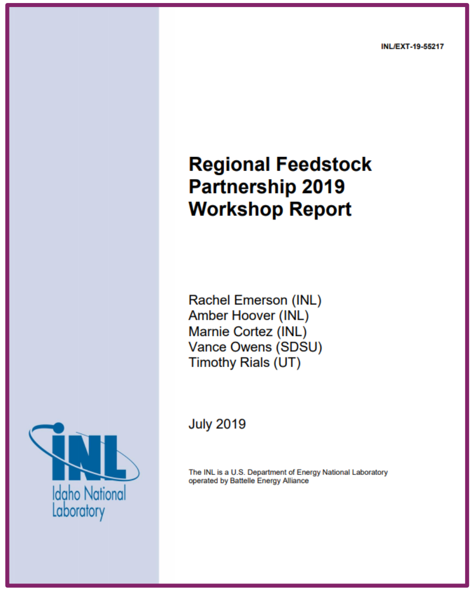
Task 2 Critical Property Variability Quantification

Environmental Material Attribute Prediction Models

- FY19 hosted workshop with Regional Feedstock Partnership (RFP) Field Study leads
- Developed multivariate models using location specific environmental, agronomic, and biomass genetic factors to predict specific chemical properties for RFP biomass
- Exploring use of **Explainable AI** to increase robustness of predictive models while retaining explainability

Miscanthus Lignin Environmental Model




INL/EXT-19-55217

Regional Feedstock Partnership 2019 Workshop Report

Rachel Emerson (INL)
Amber Hoover (INL)
Marnie Cortez (INL)
Vance Owens (SDSU)
Timothy Rials (UT)

July 2019

INL Idaho National Laboratory

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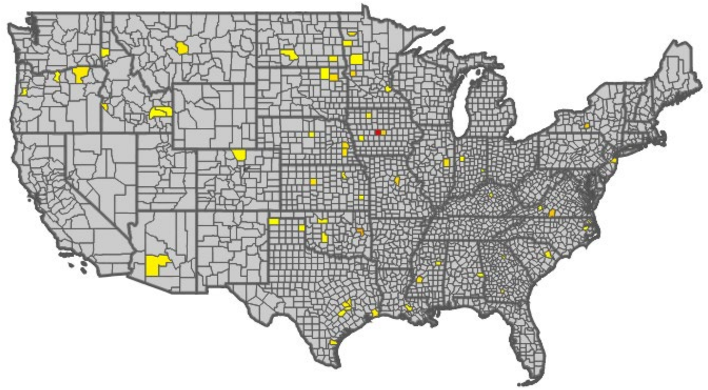
https://www.osti.gov/biblio/1558410

RFP Field Study Summary

RFP Biomass Resource	Data Set Summary
CRP Mixed Grasses	4 fields; 6 years; 3 N trt; 2 harvest times
Miscanthus	5 fields; 6 years; 3 N trt
Energycane	8 fields; 4 years; 5 genotypes
Sorghum	7 fields; 5 years; 6 genotypes
Switchgrass	5 field/cultivar; 6 years; 3 N trt
Corn Stover	22 field management trt; 4 years
Shrub Willow	12 fields; 35 genotypes; 1 rotation



Owens VN. Sun Grant/DOE Regional Feedstock Partnership: Final Technical Report. US; 2018. 10.2172/1463330

Impacts

- Quantitative understanding of **pre-harvest** factors impacting properties critical to both supply chain and technological risk
- Leveraged existing datasets in Bioenergy Feedstock Library (**Task 4: Archival of DOE FOA samples and data** actively building these datasets)

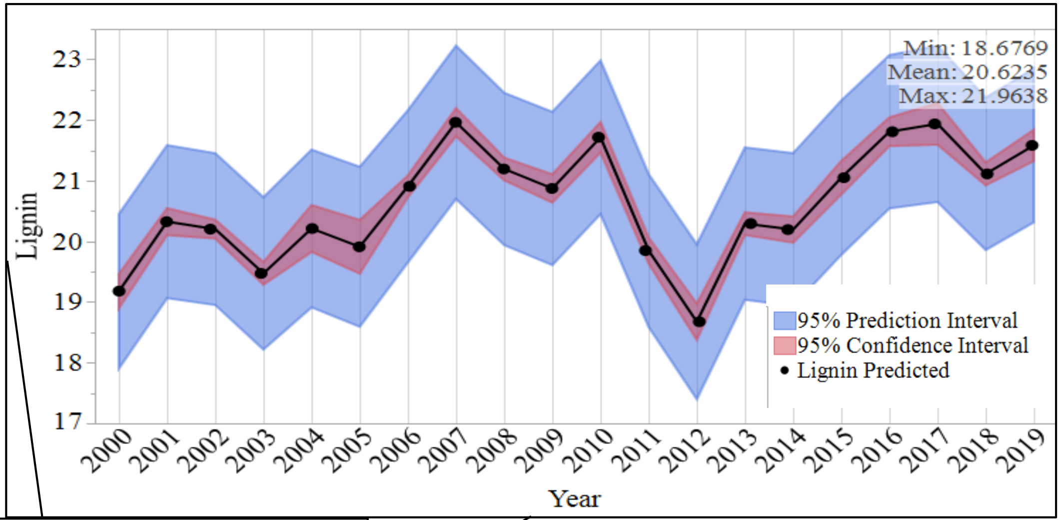
4 – Progress and Outcomes

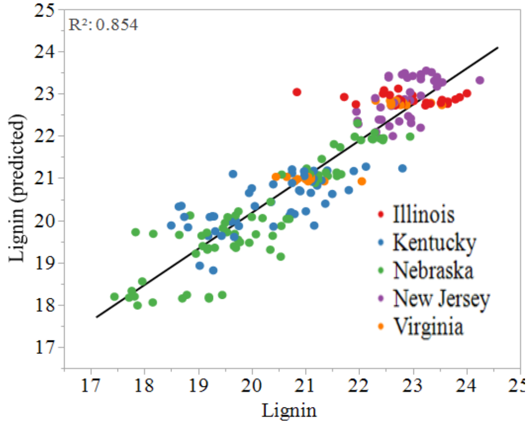
Task 2 Critical Property Variability Quantification

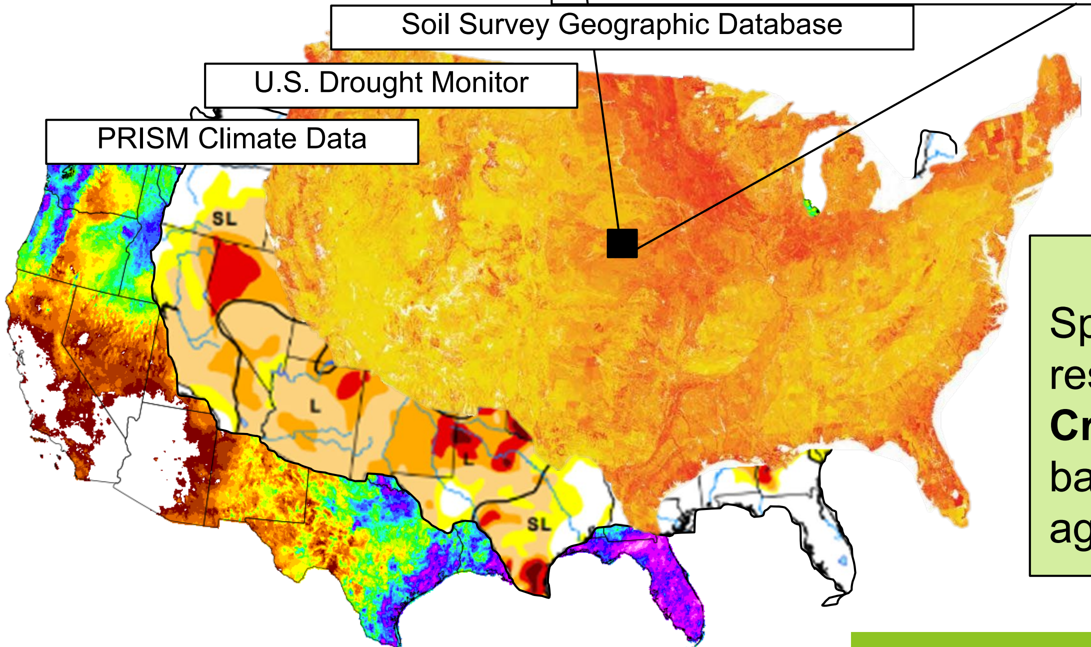
Environmental Material Attribute Prediction Models

- Predictive model extrapolation using **nationwide, publicly available databases** for environmental and agronomic factors
- Spatial (county level across U.S.) and temporal (20-year) variability in risk specific critical chemical properties
- Publications in process

Miscanthus Lignin content for Saunders County Nebraska 2000-2019







Impact

Spatially and temporally resolved predictions of **Critical Property variability** based on environmental and agronomic factors

Maps: PRISM Climate Data - Copyright © 2020, PRISM Climate Group, Oregon State University, (https://prism.oregonstate.edu/), Map created 7/15/2020; U.S. Drought Monitor -*The U.S. Drought Monitor is jointly produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. Map courtesy of NDMC; Soil Survey Geographic Database - Soil Database* - Credit: Martin, Madeline (Contractor) Thomas, USGS. Public domain.

4 – Progress and Outcomes

☆ New Subtask

Task 3 Critical Property Identification and Analysis

Critical Property Analysis of Preprocessing *Air Classification* Fractionation Equipment

- Multivariate linear regression to verify and quantify impacts of suspected critical processing parameters (**CPPs**) and critical material attributes (**CMAs**) on **separation efficiencies**
- Existing air classification data set collected as part of the FY22 Verification
- CMAs:
  - Particle size
  - Moisture
  - Particle shape*
- CPPs:
  - Air velocity

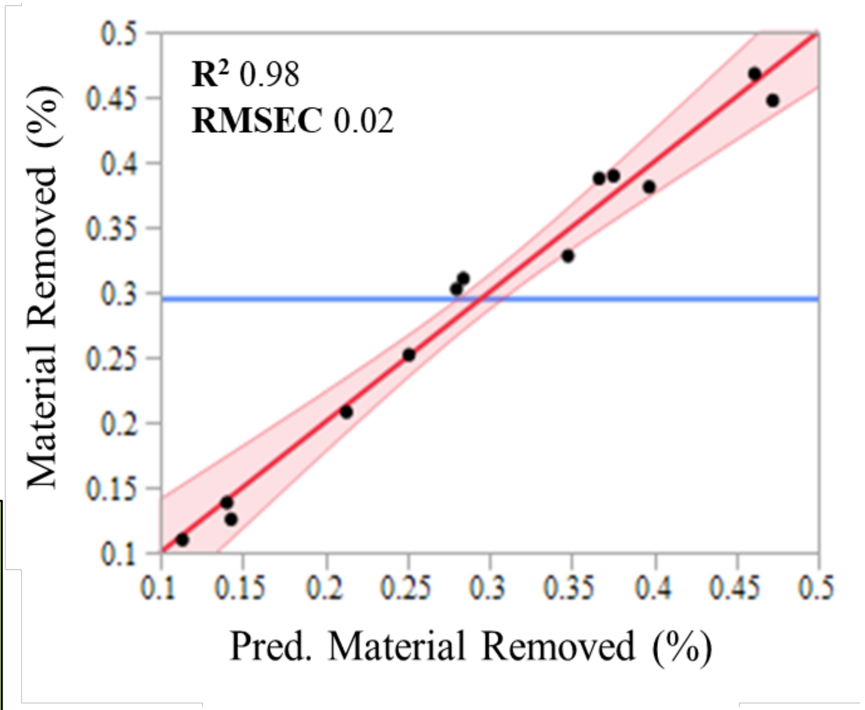
Decrease in rank

*currently being evaluated

Impacts

- Provide **quantitative evidence of criticality** for MA and PP
- Allows for **Quality by Design driven** future experiments supporting the FY22 verification

Pine Residue Critical Property Analysis Regression for Separation Efficiencies



Summary

- **Objective:** Facilitate “derisking” bio-project development by addressing biomass supply chain and technological risks

- **Progress:**
  - Significant progress **developing and verifying Biomass Supply Chain Risk Standards framework**
  - Introducing concept of **Failure Mode Effect Analysis for addressing technological risk**
  - Developed models to quantify environmental driven **variability of critical**, risk contributing, **properties** for lignocellulosic biomass

- **Relevance:**
  - Variability in biomass feedstock properties translates to risk for bio-projects
  - Poor and inconsistent understanding of risk associated with biomass feedstocks has resulted in high capital costs for bio-project financing

Quad Chart Overview

Timeline
- 10/1/2018
- 9/30/2021

	FY20	Active Project
DOE Funding	$1.21M	Total: $3.24M

Project Partners*
- Ecostrat, Inc. (subcontract)
- Los Alamos National Lab (subcontract)
- South Dakota State University (subcontract)
- Feedstock Conversion Interface Consortium Task X

Barriers addressed
Ft-E Feedstock Quality: Monitoring and Impact on Preprocessing and Conversion Performance: Task 2 efforts to develop predictive models to facilitate monitoring of identified CMAs based on environmental and agronomic factors to accurately predict critical properties prior to harvesting.

Ot-C Risk of Financing Large-Scale Biorefineries: Tasks 1 and 3 contribute to the FSL 2022 R&D annual milestone for work building systematic risk assessment frameworks supporting consistent and quantitative risk assessment necessary for informed financing.

Project Goal
Facilitate "derisking" bio-project development by addressing biomass supply chain and technological risks:
- develop systematic methodologies and frameworks for risk assessment
- apply statistical approaches to identify and quantify biomass critical properties (CPs) associated with risk

End of Project Milestone
(1) Perform FMEA exercise on 3 of the best understood (i.e., highest TRL) combinations of material/process unit/product, (2) perform FMEA on air classification unit using CPs identified in Q1 to compare FMEA and statistical approaches for CP impact quantification and identification, (3) integrate at least 3 pieces of new PDU 2.0 equipment into the QbD framework

Funding Mechanism
AOP

Additional Slides

Responses to Previous Reviewers' Comments

- **Reviewers Comment**: "…Success will only provide access to lower cost financing for projects that also have no technological risk as well. Technological risk will also require "expensive" capital or remain in junk rating status until that risk is addressed with other market financing tools such as efficacy insurance."
  - This comment represents multiple similar comments regarding the limitations of the Biomass Supply Chain Risk Standards to address additional risks that a bio-project might experience. Technological risk is a large multifaceted problem. In response this project has implemented an additional subtask to develop a systematic approach for addressing technology-based risks using FMEA.

- **Go/No-Go Review:** Biomass Supply Chain Risk Standards was able to demonstrate a 27% decrease (*Go Criteria 20%*) in project supply chain risk proving that the BSCRS framework and scoring methodology could in theory allow for lower risk evaluation leading to lower capital costs for emerging bio-projects.
  - A review of the Go/No-Go Case Study evaluation by a financial institution apart of our Industry Stakeholder Group gave this feedback:
    - "My confidence in the overall approval is clearly higher. I am now more comfortable that the feedstock risks were actually assessed...."
    - "I think this is a great tool and would be beneficial for lenders and investors as they explore opportunities in the biomass industry. I wish we had access to this on our prior projects."

Publications, Patents, Presentations, Awards, and Commercialization

- Publications

Hoover, A.; Emerson, R.; Ray, A.; Stevens, D.; Morgan, S.; Cortez, M.; et. al., Impact of Drought on Chemical Composition and Sugar Yields From Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Miscanthus, a Tall Fescue Mixture, and Switchgrass. *Front Energy Res* **2018**, 6 (54).

Hoover, A.; Emerson, R.; Hansen, J.; Hartley, D.; Ray, A., Drought Impacts on Bioenergy Supply System Risk and Biomass Composition. In *Drought (Aridity)*, Online First ed.; Ondrasek, G., Ed. IntechOpen: 2019.

Emerson, R., Hoover, A., Cortez, M., Owens, V. (SDSU), Rials, T. (UT). July 2019. *Regional Feedstock Partnership 2019 Workshop Report.* Report ID: INL/EXT-19-55217. Idaho National Laboratory, Idaho Falls, ID 2019.

Hoover, A.; Emerson, R.; Williams, C. L.; Ramirez-Corredores, M. M.; Ray, A.; Schaller, K.; Hernandez, S.; Li, C.; Walton, M., Grading Herbaceous Biomass for Biorefineries: a Case Study Based on Chemical Composition and Biochemical Conversion. *BioEnergy Research* **2019**, 12 (4), 977-991.

- Presentations

Solomon, J., *New US National Standards for Biomass Supply Chain Risk: Driving Growth by Decreasing Bio-Product Financing Costs,* In Advanced Bioenergy Leadership Conference, Washington, DC, February, 2018.

Solomon J.; Nair, S. K., *U.S. National Standards for Biomass Supply Chain Risk,* Feedstock Sourcing Track at the 18th Annual Conference of BioCycle REFOR18, Raleigh, NC, October 16, 2018.

Nair, S. K., Emerson, R. M., *1.2.2.2 Potential Biomass Supply Chain Risk Standards (BSCRS),* 2019 DOE Project Peer Review, Denver, CO, March 2019.

Solomon, J., *Decreasing Barriers to Private-Sector Investments in Biomass: Supply Chain Risk Ratings,* 2019 Advanced Bioeconomy Leadership Conference, Washington, DC. April 3, 2019.

Hoover, A., I*mpact of Environmental Factors on Herbaceous Biomass Chemical Composition and Bioconversion*. Switchgrass V International Conference hosted by the University of Illinois at Urbana-Champaign, Champaign, IL. July 24, 2019.

Lewandoski, M.; Nair, S.; Solomon, J., *U.S Biomass Supply Chain Risk Standards (Industry Stakeholders Group).* DOE-BETO Biomass Supply Chain Risk and Material Analytics Project, Webinar. February 12, 2020.

Lewandoski M.; Nair, S.; Solomon, J., *U.S Biomass Supply Chain Risk Standards (Advisory Board).* DOE-BETO Biomass Supply Chain Risk and Material Analytics Project, Webinar. January 24, 2020.

- Technology Transfer:

Software Disclosure Request in place for BSCRS scoring methodology