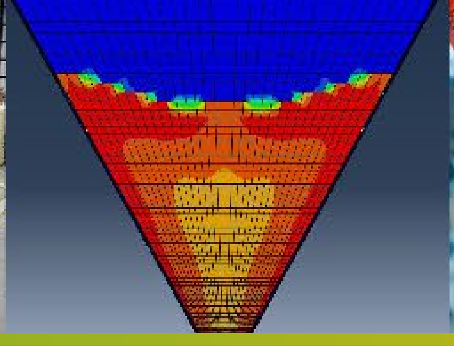


DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

FCIC DFO – Wonderful Company

"Rational design of robust reactor feeding systems for heterogeneous cellulosic and agricultural wastes based on biomass quality characteristics"

March 16, 2021
Feedstock Conversion Interface Consortium

Daniel Carpenter
NREL

fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

FCIC Task Organization

Feedstock → **Preprocessing** → **Conversion**

Feedstock Variability: Develop tools that quantify & **understand the sources of biomass resource and feedstock variability**

Preprocessing: Develop tools to enable technologies that **provide well-defined and homogeneous feedstock** from variable biomass resources

Conversion (High & Low-Temperature Pathways): Develop tools to enable technologies that **produce homogeneous intermediates** that can be converted into market-ready products

Materials Handling: Develop tools that enable continuous, steady, trouble free feed into reactors

Materials of Construction: Develop tools that **specify materials** that do not corrode, wear, or break at unacceptable rates.

Enabling Tasks

Data Integration: Ensure the data generated in the FCIC are **curated and stored** – FAIR guidelines

Crosscutting Analyses TEA/LCA: Works with other Tasks to **enable valuation** and intermediate streams and quantify impact of variability.

Background

NREL – National Renewable Energy Laboratory	Project lead, feeding and gasification tests, TEA/LCA
the Wonderful company™	Industry partner; biomass supply; engineering, finance, strategy, capital project support
INL – Idaho National Laboratory	Feedstock preprocessing, characterization, flow simulations

- The Wonderful Company is the world's largest almond & pistachio grower, generating 250,000 tons of nut waste/year (wood, hulls, shells); >5M tons/year industry wide
- Fewer outlets & new regulations, while nut production is projected to increase 25% over the next few years
- The industry is looking to turn these liabilities into carbon-negative revenue via reliable electricity and bio-char production

Jenike & Johanson – Science Engineering Design	Biomass flow testing, design and integration of feeding & handling system
VGRID	Industry partner; gasifier technology developer; potential host for extended test

Project Overview

Objectives: Understand the impacts of almond and pistachio waste attributes on conveyance and gasifier feeding and design a reliable system; generalize the methodology to other biomass feedstocks.

Current limitations: Biomass conveyance and feeding system design is often overlooked or adapted from other applications and based on empirically-derived guidelines not applicable to complex biomass feedstocks.

Relevance: (1) Reliable biorefinery preprocessing, conveyance, and feeding systems are crucial for economic viability – science-driven, flexible designs are needed; (2) Sustainable and economical solutions to agricultural waste accumulation are needed; (3) Supports BETO mission to "develop industrially relevant…bioenergy technologies…"

Risks: (1) Cost-effective preprocessing solutions that enable consistent material flow; (2) Capturing the full range of nut waste variability; (3) Scalability and broad applicability of results

Piles of hulls and removed almond trees (photos courtesy of TWC).

1 – Management

Subtask	Lead(s)	Major Responsibilities
1. Waste Preprocessing Optimization	INL	Characterization of waste material; preprocessing optimization; sample production
2. Bulk Flow Testing and System Design	Jenike & Johanson	Bulk flow measurements; Engineering reviews and conceptual design
3. Bench-Scale Feeding and Gasification Tests	NREL	Micro-scale conversion screening; Bench-scale feeding and gasification testing
4. Commercial System Integration and Testing	NREL, TWC, V-Grid	Design and operational improvements to commercial conveyance and gasifier systems; Carry out extended testing
5. Economic and Sustainability Analysis	NREL	Technoeconomic Analysis (TEA) and Life Cycle Assessments (LCA)
6. Method Generalization	NREL	Apply learnings and attribute-based design principles to other feedstocks
7. Project & Data Management	NREL	Oversee work, coordination, reporting, budget, data management

- **Risks:** Risks are captured in the Annual Operating Plan and discussed/mitigated with the project team, industry advisors, FCIC PI/PM, and BETO
- **Communication strategy:** Bi-weekly project team meetings; site visits; regular communication with industry partners; regular briefings with BETO

2 – Approach

Technical Approach: (1) Analytical sampling and detailed characterization of TWC waste material, including bulk solids flow measurements; (2) Iterative preprocessing development; (3) Lab-scale devolatilization tests; (4) Bench-scale feeding and gasification trials; (5) Long-term commercial gasifier demonstration; (6) Technoeconomic and life cycle assessments to track cost and carbon cycle tradeoffs

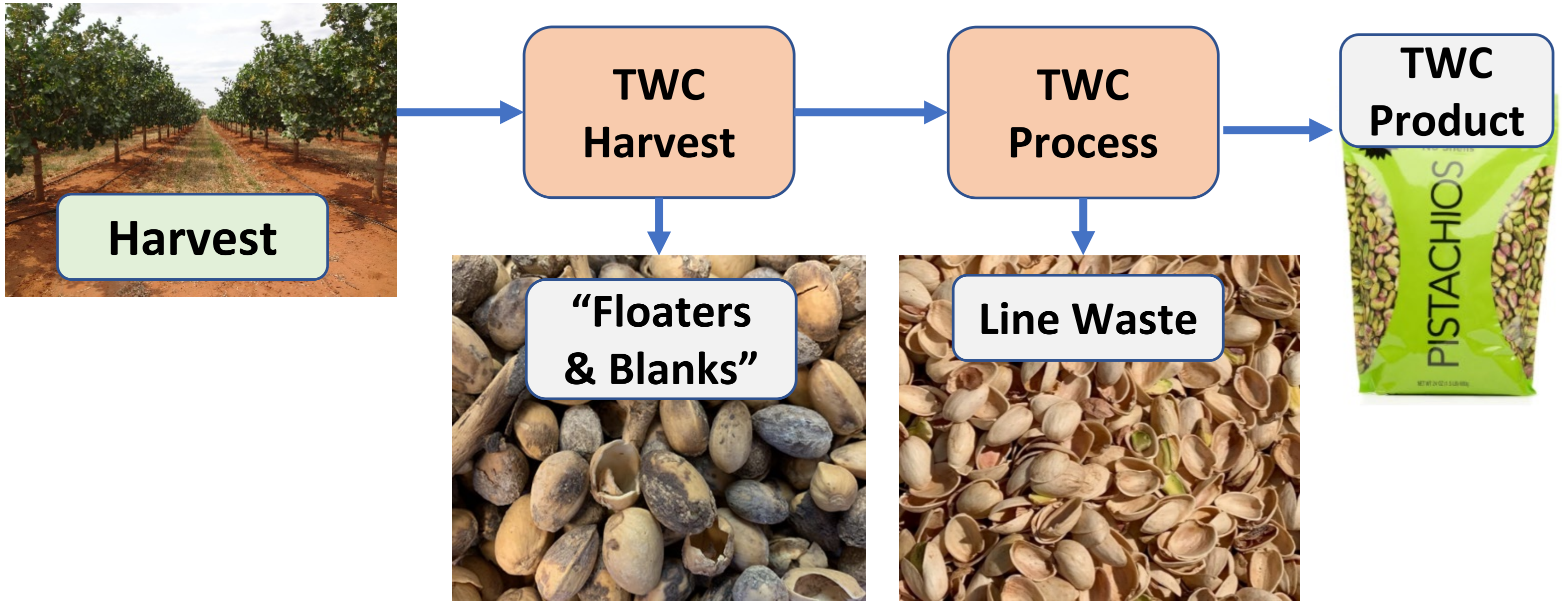
Challenges:

- Capturing the range of variability in waste materials and ensuring these can be cost-effectively preprocessed to achieve consistent flow behavior
- Design principles derived from small scale preprocessing and conversion tests that are relevant to commercial scale

Metrics:

- Successful long-term gasifier feeding trials that demonstrate robust feed handling and gasifier operation with variable feedstocks (i.e., increase in on-stream factor and lower electricity production costs - $/kWh)
- System design methodology developed for almond and pistachio waste is applicable to other feedstocks and can be validated with forest residues

Understand the feed and conversion technology

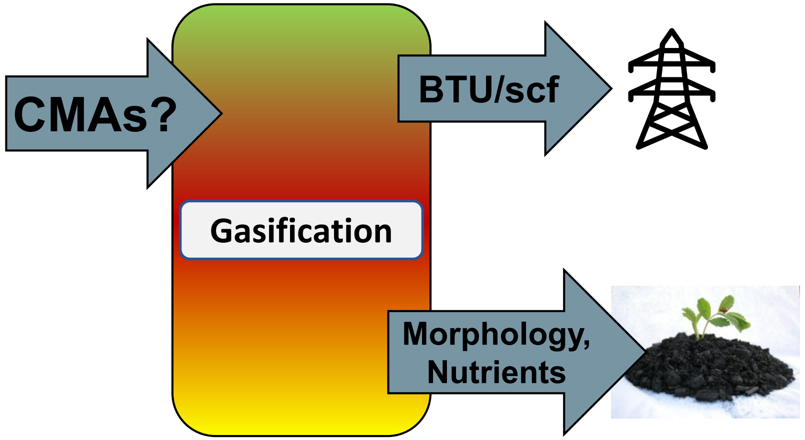


Two primary waste sources

- Harvest Waste: blank shells, inedible meats, sticks, leaves, dirt, adhering hulls, other debris
- Process line waste: half shells, residual meats

Presumed gasifier critical material attributes (CMAs)

- Particle size distribution (depends on design, need to remove < 6 mm and large debris – sticks, plastic contaminates, etc.)
- Moisture content (flowability, heat balance)
- Inorganics (speciation, ash melting, hulls?, roasted & salted?)
- High protein = high tars (meats)

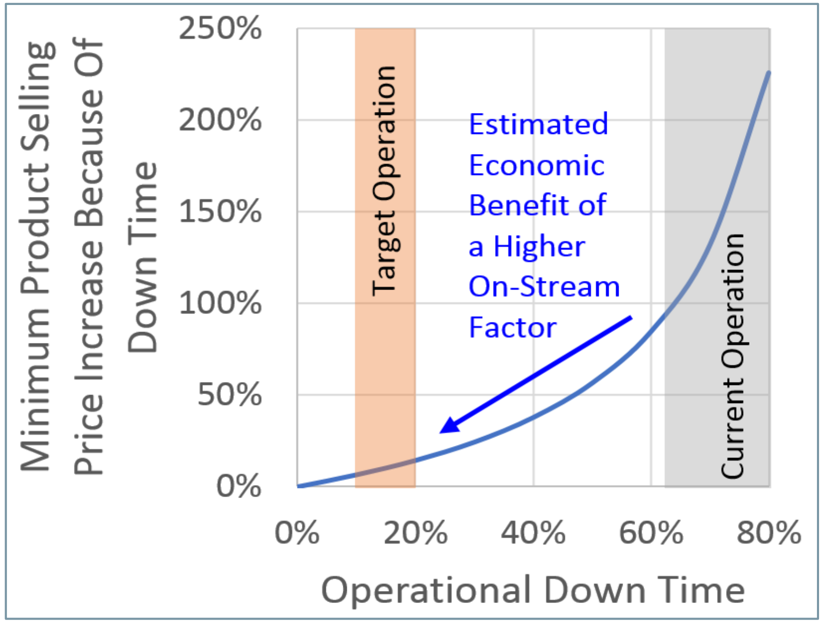


3 – Impact

Impact:

- Connecting feedstock attributes to preprocessing, handling, and reactor feeding performance will enable predictable and robust system performance for variable material properties
- Optimizing cost-effective feedstock quality control steps (preprocessing) will enable higher on-stream factors and will be applicable to other difficult-to-handle biomass feedstocks
- Successful conveyance and reactor feed design would help the industry turn large agricultural waste liability into usable, profitable energy source

Dissemination: Technical reports, process models, engineering designs, etc. shared on Box site. Results will be published/presented as appropriate. Material offtake agreements are possible.



Effect of process downtime on production costs for conceptual biomass-to-gasoline process.

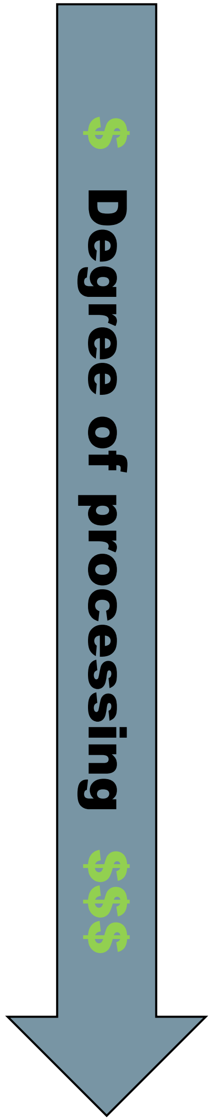
Understanding TWC's Waste

Characterization

- 16 super sacks collected and shipped to INL (spanned several sources, locations, and years)
- Composition is typical of other agricultural residues and grasses
- Moisture holding capacity relatively low (<10%, good for gasification)
- Inorganics = 2.3%-13.7%; K = 0.7%-1.1%; N = 0.9%-2.0%; S = 75-1770 ppm
- High P and K could cause slagging at high gasifier temperatures (>800°C)

Preprocessing

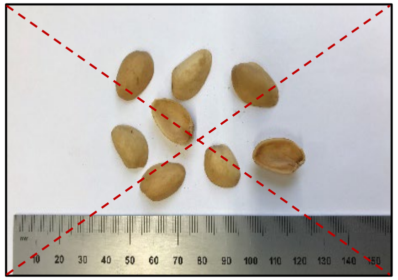
- Sieving, air classification, grinding, washing
- Modeled costs range from $2-37 per ton
- Pelletizing of fines (up to 40 wt% in some samples); $10/ton



Harvest waste (as received from piles)

Mechanical sieving (remove fines, overs)

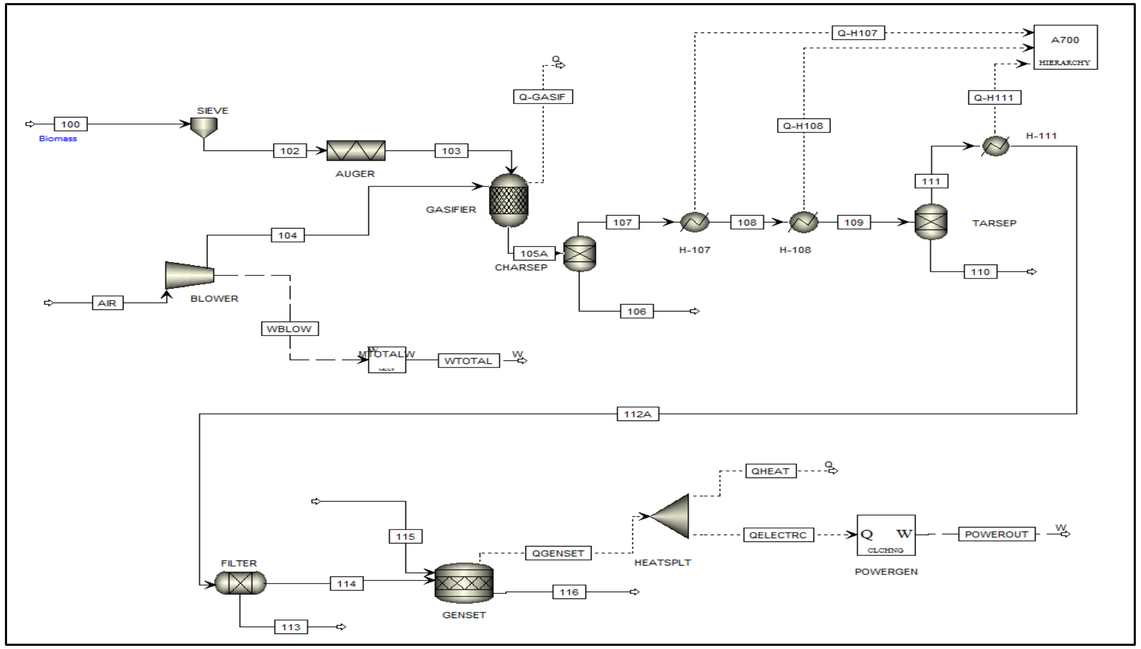
Air classification (remove meats)



Alkali washing (remove adhered hulls)

Benchmark technoeconomic analysis

- Visited V-Grid gasifier installation at Firebaugh, CA pistachio processing site
- Developed Aspen Plus process model* based on V-Grid system (mass, energy balance)

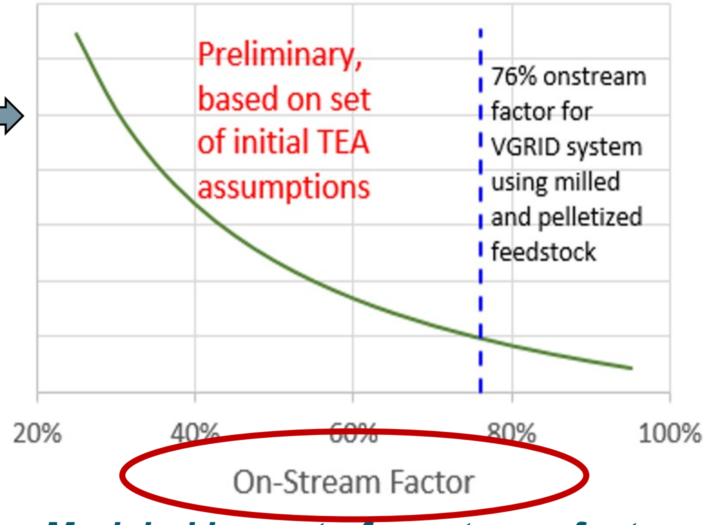


V-Grid gasifier skid installed at Firebaugh, CA pistachio processing site

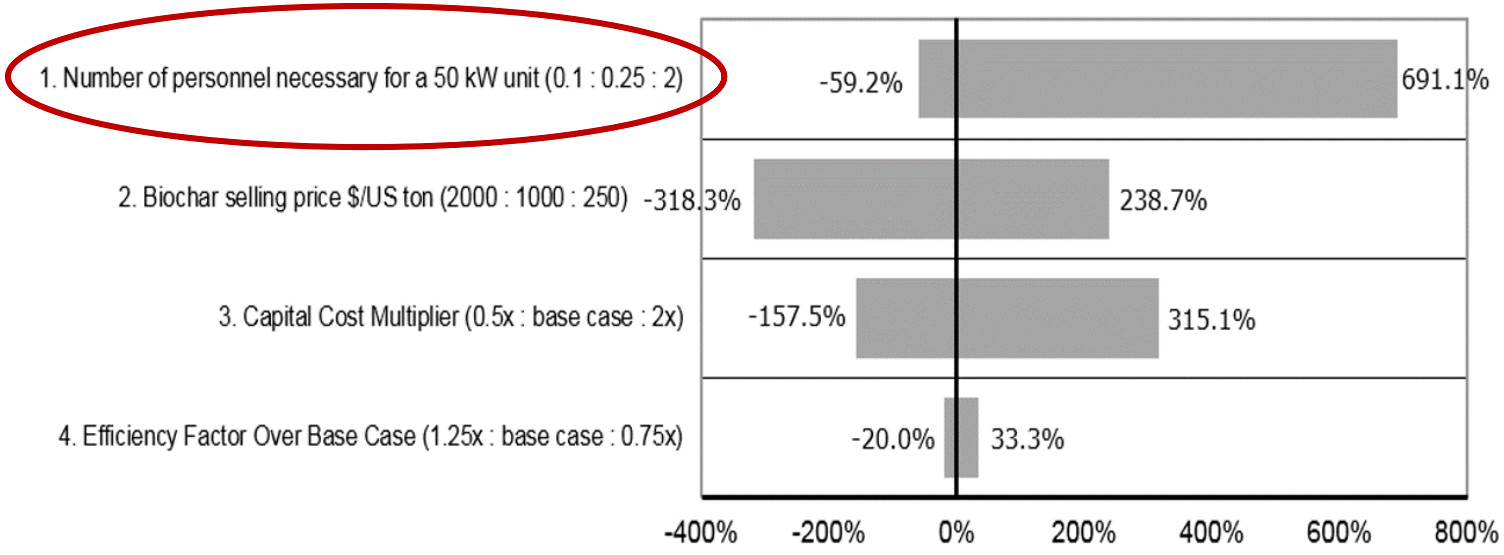
Benchmark TEA (cont.)

Minimum electricity selling price is highly dependent on staffing requirements, bio-char selling price, and gasifier on-stream factor

10x $/kWh



Modeled impact of on-stream factor on minimum electricity selling price (MESP)



Sensitivity analysis showing effect of key factors and uncertainties at 90% on-stream factor

- **Preprocessing ($)?**
- **Conveyance?**
- **Gasifier feeding, operation?**

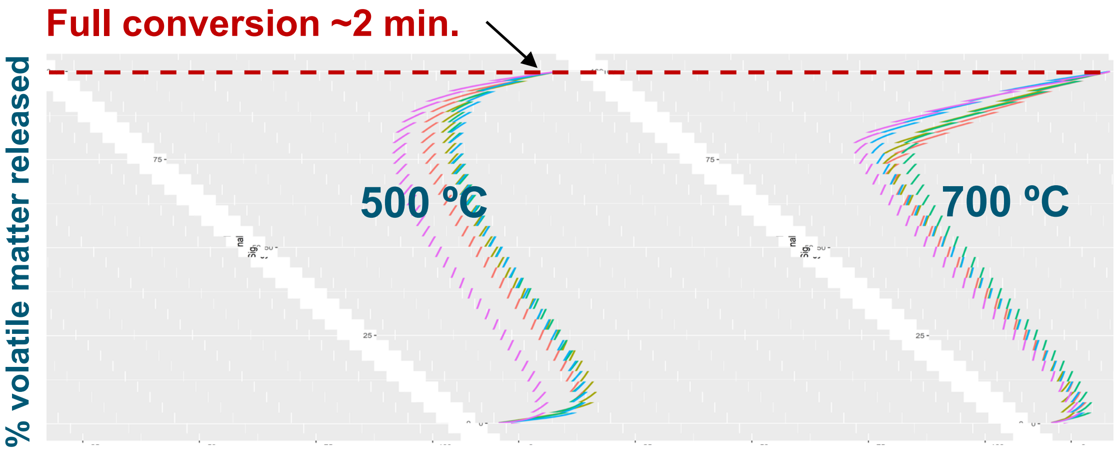
Connecting the feed and conversion tech

- As-received material is free flowing (high fines and moisture can cause issues)
- Size reduction not needed (gasifier res. time ~30 min)
- Particle size distribution is critical
- Feed format (shells vs. chips) is critical

Process line waste with fines

Potential issues…

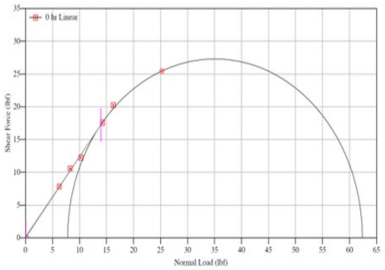
- Throughput of 1st screen (overs) during unloading of trucks
- Fines removal (and usage)
- Tar, char, solids buildup/plugging in gasifier
- Handling of char (smoldering)
- Jamming of augers with wood chips

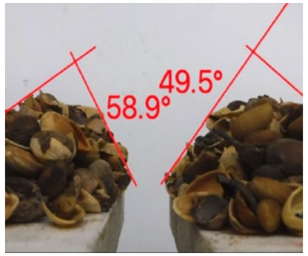


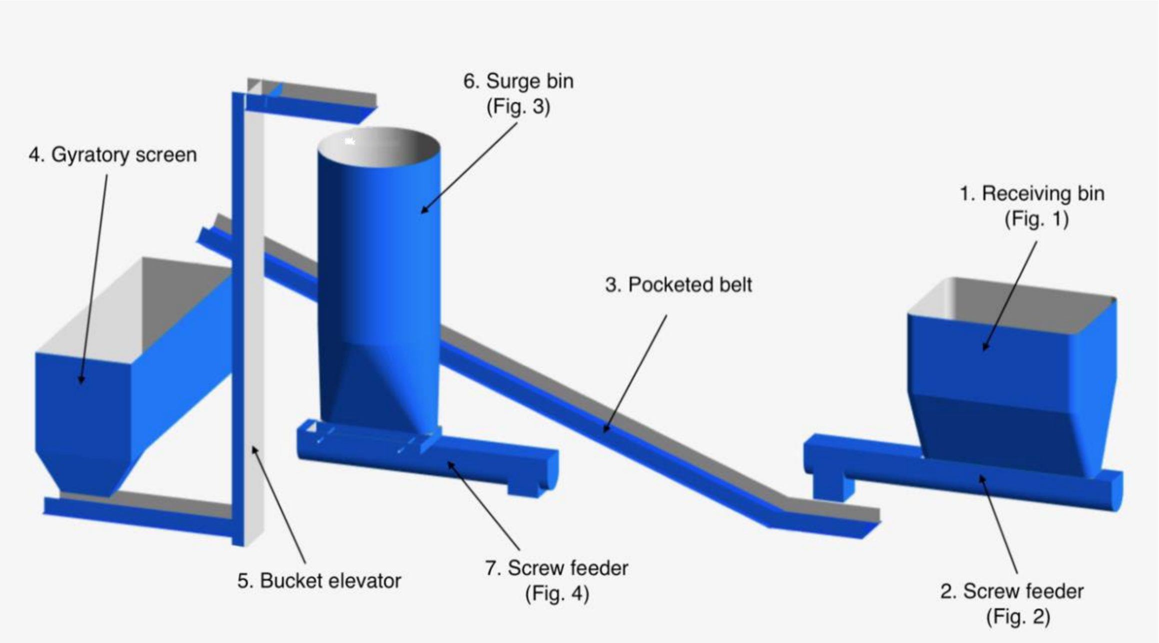
Pistachio shell conversion vs. time for various particle sizes

Engineering design & recommendations

- Completed bulk flow material testing, conceptual design, and engineering cost estimate (Jenike & Johanson)
- Project Team submitted recommendations for preprocessing, material handling, and gasifier system modifications, e.g.:
  - Remove fines before storage + pelletize
  - Review cyclone and hot packed bed inlet design
  - Char passivation methods
  - Catalytic reforming or partial oxidation step
  - Mechanical agitation to break up agglomerates







Conceptual design for 4000 lb/h pistachio shells to gasifier conveyance system

Future Work

1. **Extended gasifier field trials** to show (1) increased uptime from system modifications (conveyance, feeding, gasifier); (2) system robustness and product quality (syngas, char) with respect to feedstock variability
2. Final **TEA** (reduction in modeled $/kWh) and **Life Cycle Assessment** (net carbon impacts)
3. **Generalize learnings** to other feedstocks
   - Document methodology and workflow
   - Connect feedstock attributes to system performance and how these impact specific design parameters (e.g., preprocessing, bulk handling design insights from Jenike for wood vs. shells)

Summary

Management: Multidisciplinary industry/national lab project team; annual operating plan defines work breakdown, milestones, risks, and mitigation strategies; bi-weekly meetings

Technical Approach: Characterize material attributes, variability, and conversion behavior of nut waste; optimize preprocessing; design material handling system; long term testing to demonstrate improved on-stream factor

Impact: Biomass attribute-based design principles and optimization of preprocessing, conveyance, and conversion; utilization of an agricultural waste stream

Progress: Bulk waste material sampled and characterized; developed baseline technoeconomic analysis; preliminary gasification tests; conveyance system design complete

FCIC – Wonderful DFO Team

NREL – National Renewable Energy Laboratory

- Daniel Carpenter (Lead)
- Dan Dupuis
- Abhijit Dutta
- Rebecca Jackson
- Steven Rowland
- Stephen Tifft

The Wonderful Company

- Ilia Florentin
- Mike Leone
- Mike O'Banion

INL – Idaho National Laboratory

- Sergio Hernandez
- Jaya Tumuluru

Jenike & Johanson – Science Engineering Design

- Carrie Hartford
- Jayant Khambekar
- Herman Purutyan

VGRID

- Greg Campbell

Quad Chart Overview

Timeline

February 2, 2019 – August 9, 2021

	FY20 Costed	Total Award
DOE Funding	$221K-NREL $64K-INL	$675K-NREL $165K-INL $840K total
Project Cost Share		$300K cash $84K in-kind $384K total

Project Partners

- The Wonderful Company
- Idaho National Laboratory
- Jenike & Johanson
- V-Grid Energy Systems

Project Goals

Understand the impacts of TWC waste material variability on the performance of preprocessing, conveying, and reactor feeding systems

Design a conveyance system and gasifier feeder for this material

Demonstrate consistent and reliable preprocessing and reactor feeding into a gasification process, resulting in an increased on-stream factor and modeled biomass-to-electricity costs.

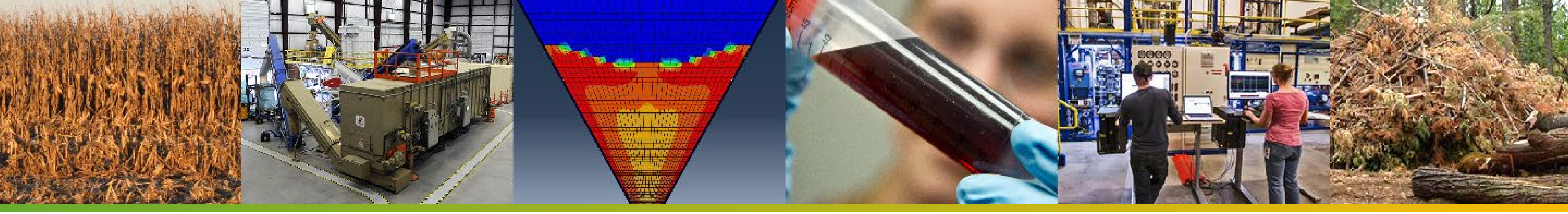
End of Project Milestones

Develop a generalized methodology for designing robust biomass handling and high-temperature in-feed systems (determine the feedstock physical, chemical, and mechanical attributes driving these design decisions)

Deliver an engineering design package for such a system to The Wonderful Company for conversion of pistachio waste products to syngas and validate the approach with forest residues.

Funding Mechanism

2018 FCIC Directed Funding Opportunity, Topic Area 2: “Biomass Preprocessing, Feed-Handling, and Conversion Process Integration”



Thank you

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