DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Innovation and Optimization of the Szego Mill for Reliable, Efficient, and Successful Up- Scaling of the Deacetylation and Mechanical Refining (DMR) Process for Biofuel Production

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WBS 3.4.2.203

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Systems Development & Integration – Scale-Up Portfolio

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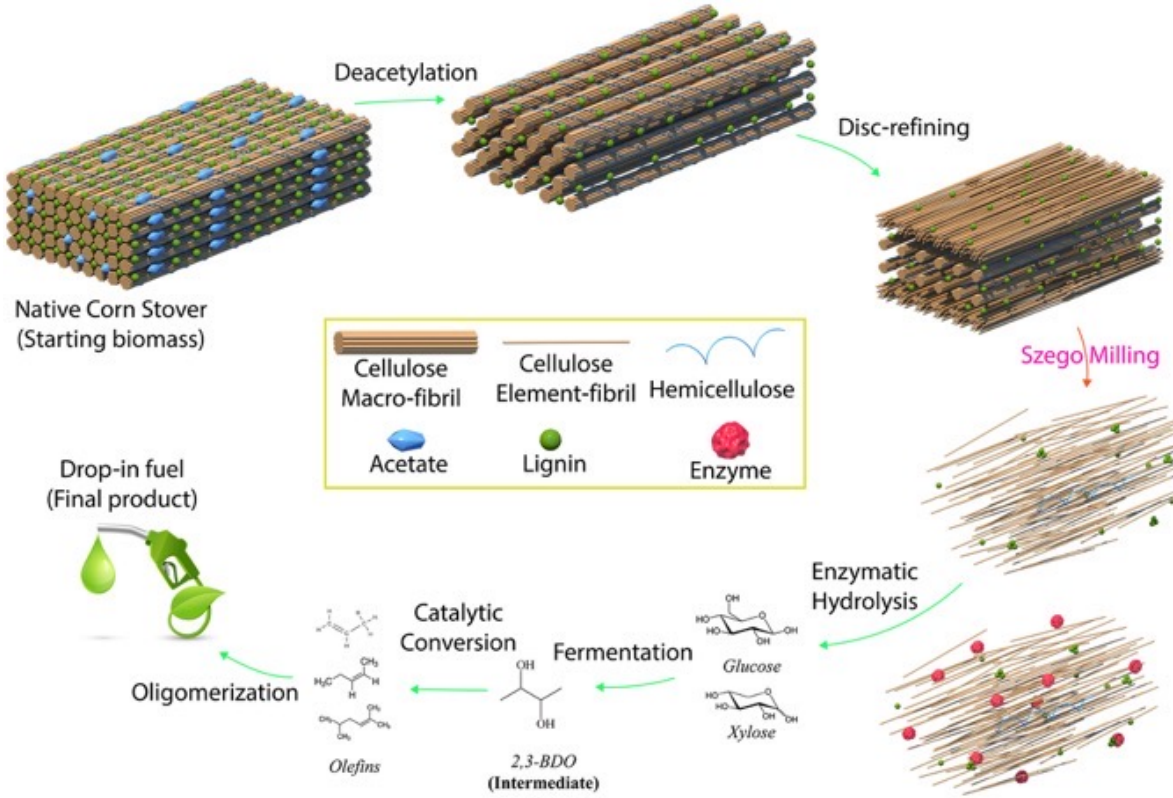
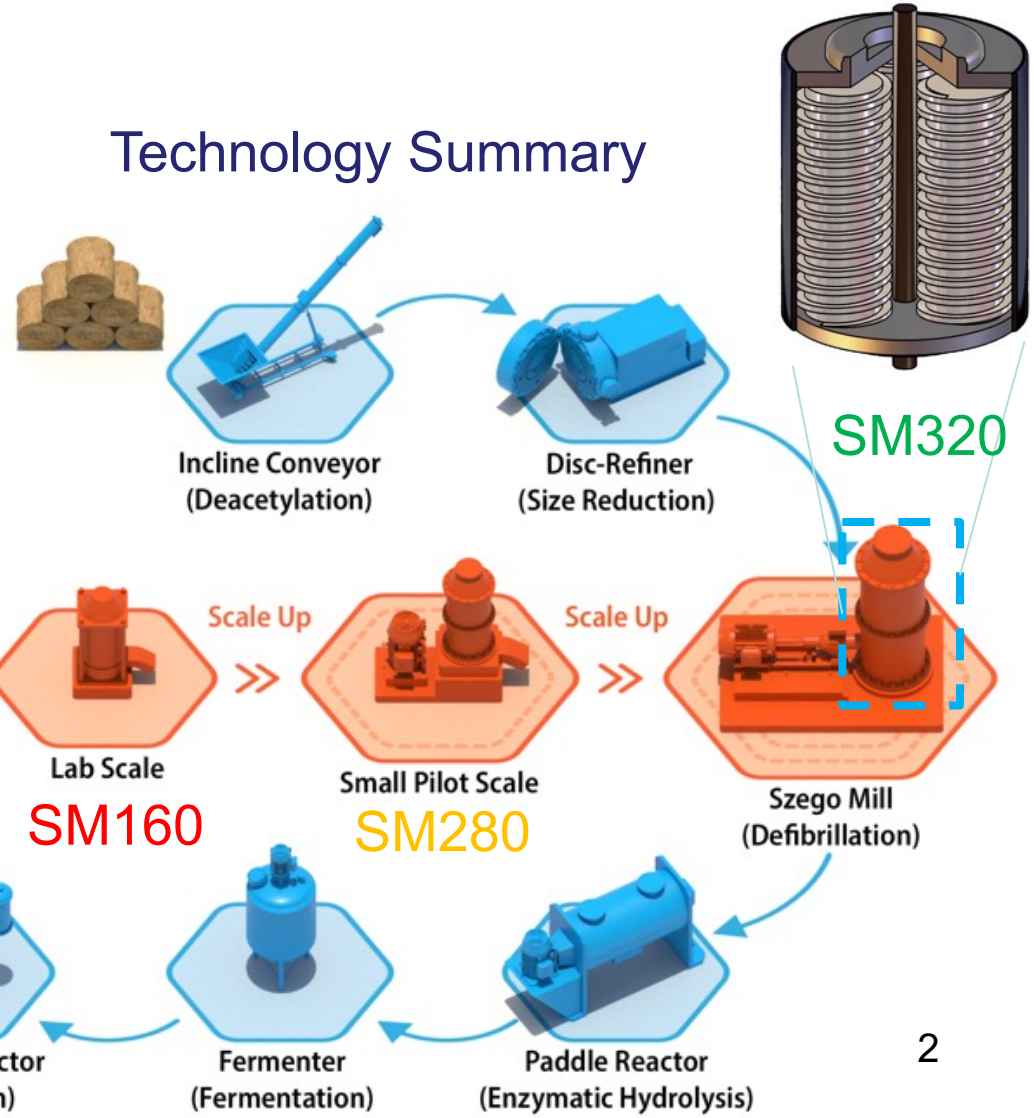
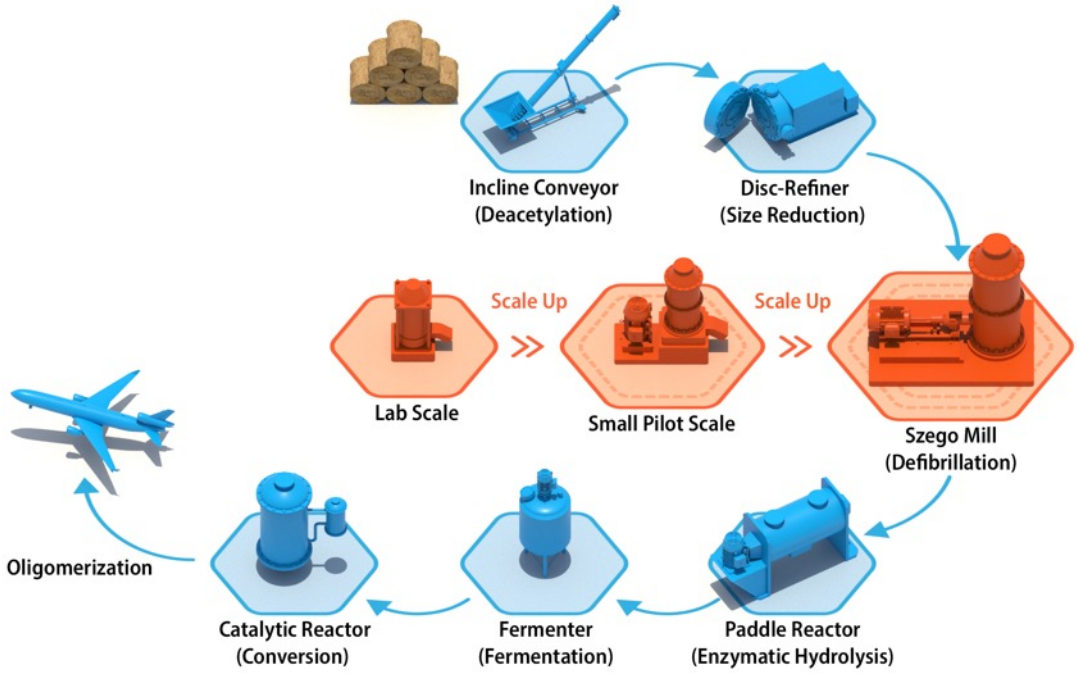


Technology Summary



Innovation and Optimization of the Szego Mill for Successful Up-Scaling of the (DMR) Process for Biofuel Production

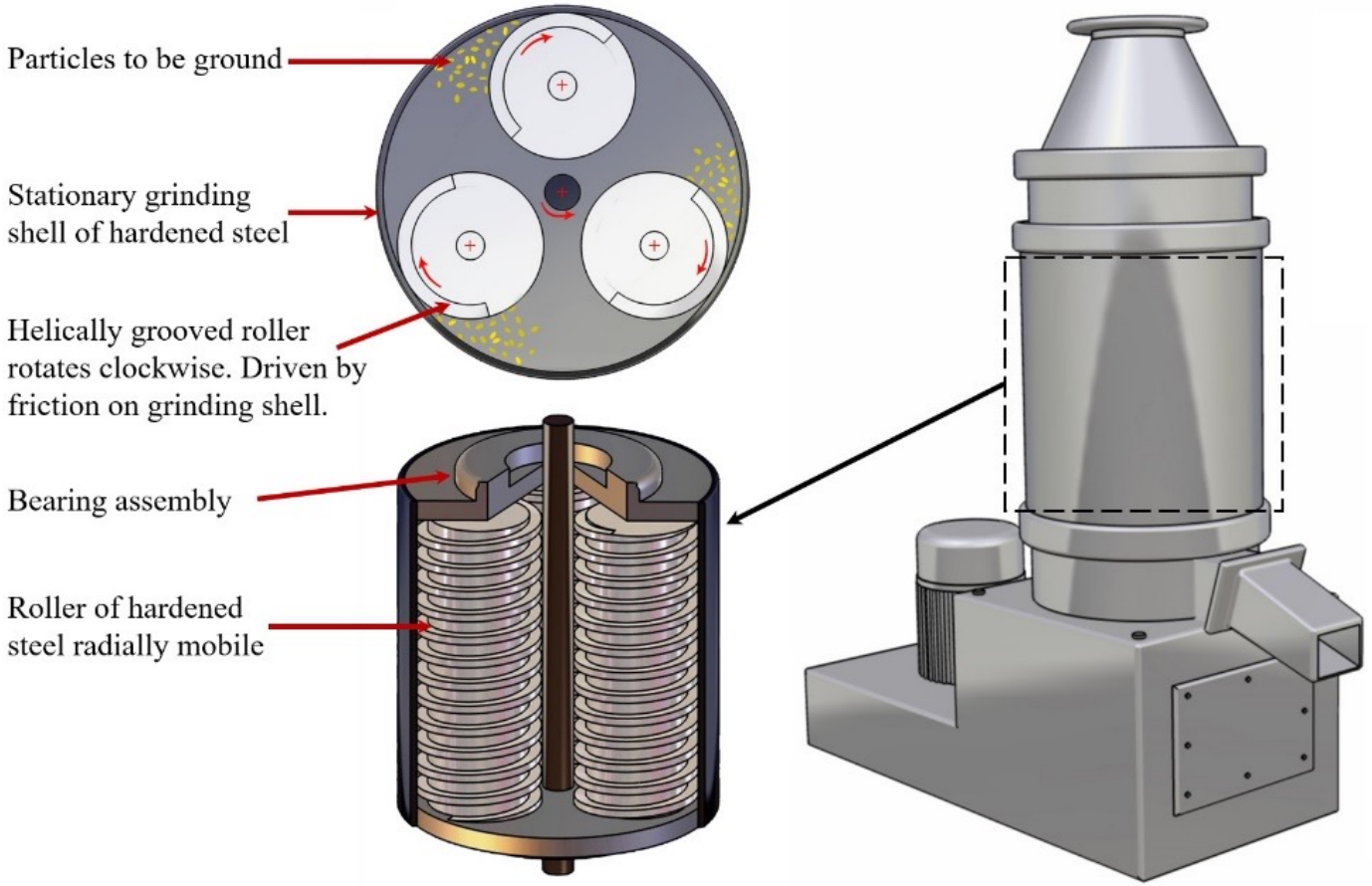
Technology Summary

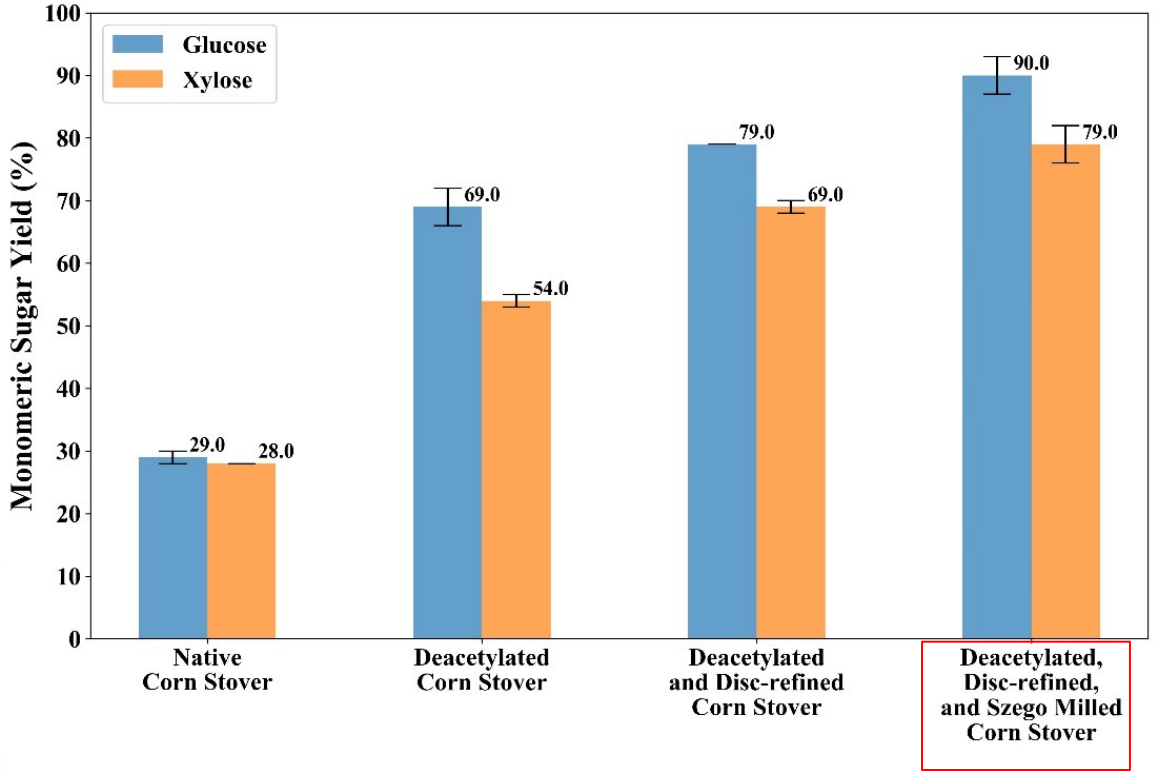


Project Goals

- Optimize design for roller geometries at multiple processing scales (0.5, 1 and 5 tonne/day) to improve biomass fibrillation and to reduce energy/water usage during Szego milling.
- Demonstration of 100 hours of continuous operation and 500 hours of cumulative operation of a large pilot scale Szego Mill (SM320X) integrated into DMR process with maintained, superior performance at a 1-5 tonne/day scale.
- Achieve ≥ 85% sugar yield using the produced DMR biomass from the 100-hour continuous operation by conversion of lignocellulosic biomass by enzymatic hydrolysis into final drop-in fuel via NREL's 2,3-BDO to drop-in fuel pathway.

What is Szego Milling and why do we need it?

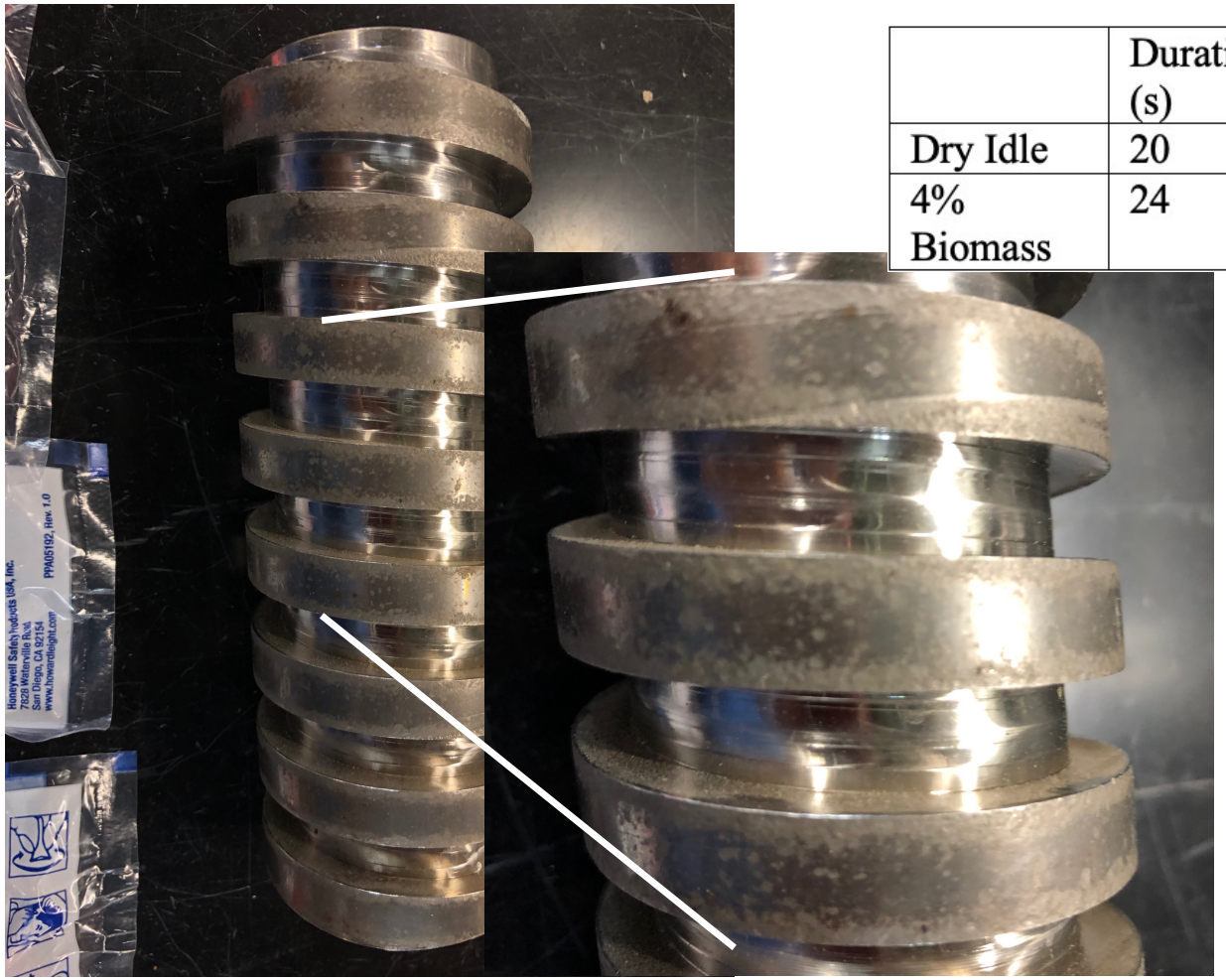




X. Chen, W. Wang, et al. , "Improving sugar yields and reducing enzyme loadings in the deacetylation and mechanical refining (DMR) process through multistage disk and Szego refining and corresponding techno-economic analysis", ACS Sustainable Chemistry & Engineering 4(1) (2016) 324-333.

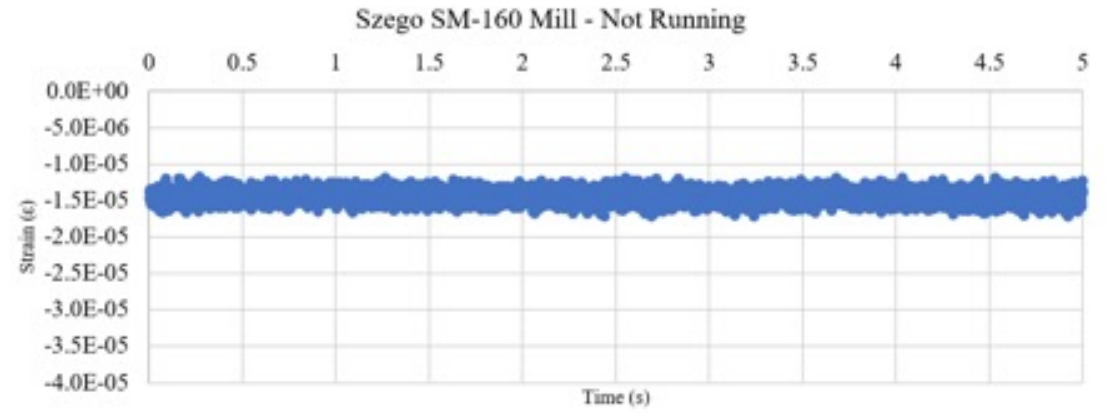
Szego Milling produces a 10% boost in monomeric sugar yield to the DMR process.

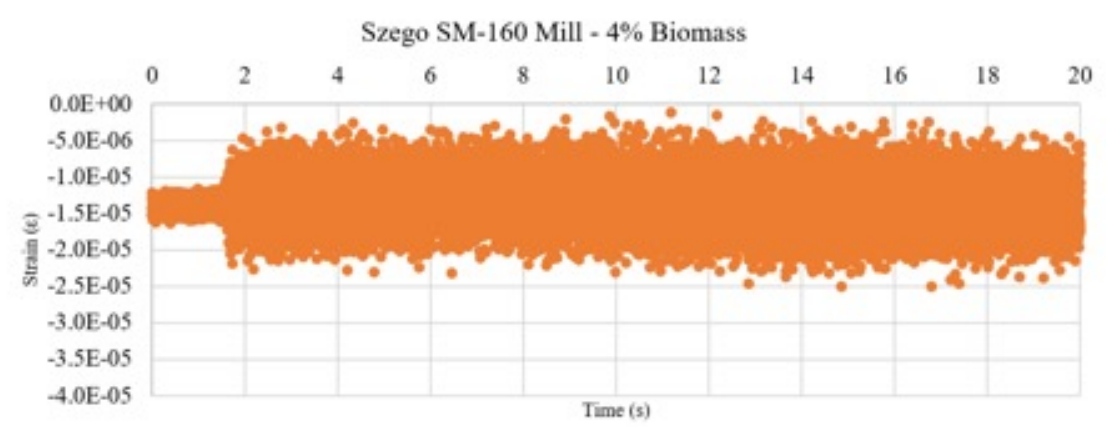
Current Szego Mill not robust enough for scaled-up process.



Photographs showing damage on austenitic stainless steel rollers for SM160

	Duration (s)	LA_{eq} (dB(A))	Max Level (dB)	TWA (dB(A))	Dose	Projected Dose
Dry Idle	20	117.9	119.6	86.3	136.2%	196105.1%
4% Biomass	24	116.4	118.2	85.7	117.2%	140612.8%





Need to scale up the technology to 1.5 tonnes per day (semi-continuous operations)
Right now excessive noise and vibration
Too much wear on rollers! How can we fix it?

What can we do to scale the process, enhance the robustness, and maintain the performance?

1. Better Materials
   - 52100 bearing steel – very hard but not corrosion resistant
   - 316 stainless steel – not hard enough, but corrosion resistant
   - How about martensitic stainless steels?

2. Innovative Surface Treatment Techniques
   - Laser peening for wear and fatigue resistance on contact surfaces
   - Cold spray deposition of wear resistance coatings

3. Better Mill Mechanical Design
   - Modify mechanical design to minimize vibration and wear
   - Optimize roller design specifically for biomass.

Selecting and Using Better Steels

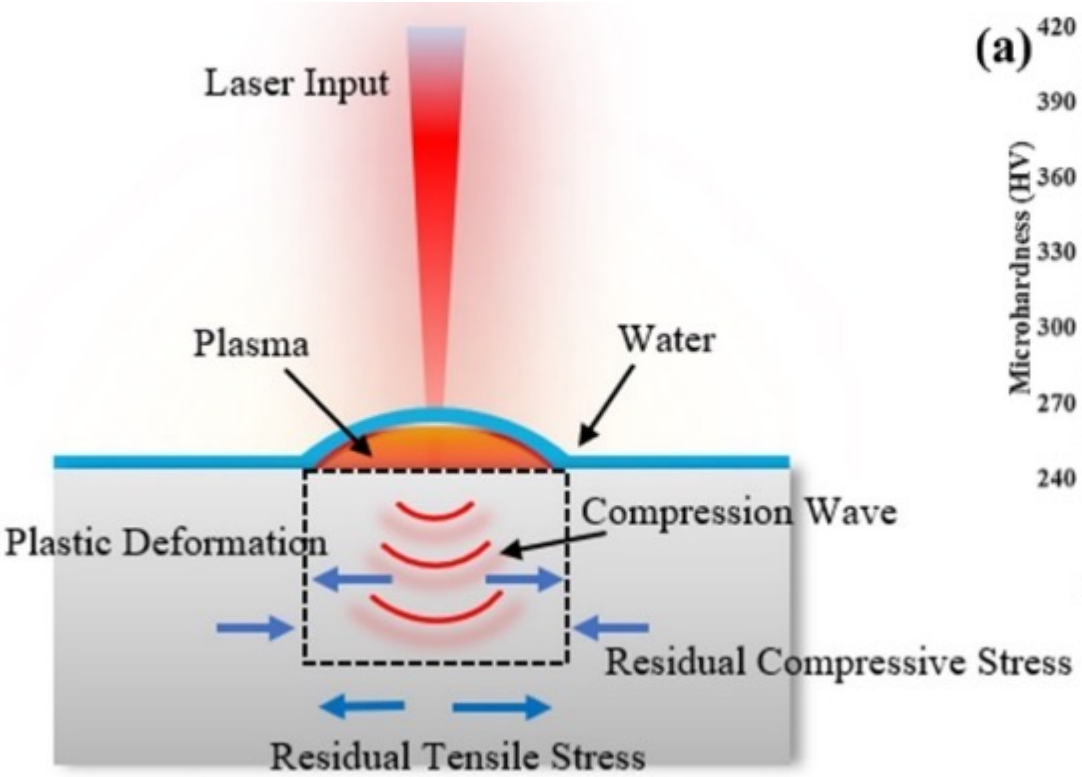
Current steels used by NREL for Szego Mill

- 52100 bearing steel – very hard but not corrosion resistant
- 316 stainless steel – not hard enough, but corrosion resistant

Steel	Hardness (HRB/HRC)	Note
52100	61 HRC	Bearing steel used in current Szego Mill
316 stainless steel	79 HRB	Austenitic stainless steel used in previous NREL experiments
410	95 HRB	Martensitic stainless steel
420	52 HRC	Martensitic stainless steel
440C	57 HRC	Martensitic stainless steel
17-4PH	32 HRC	Precipitation hardened stainless steel

Apparent rust on 52100 roller after only 12 hours of use in biomass milling.

Laser Peening for Enhanced Mechanical Reliability



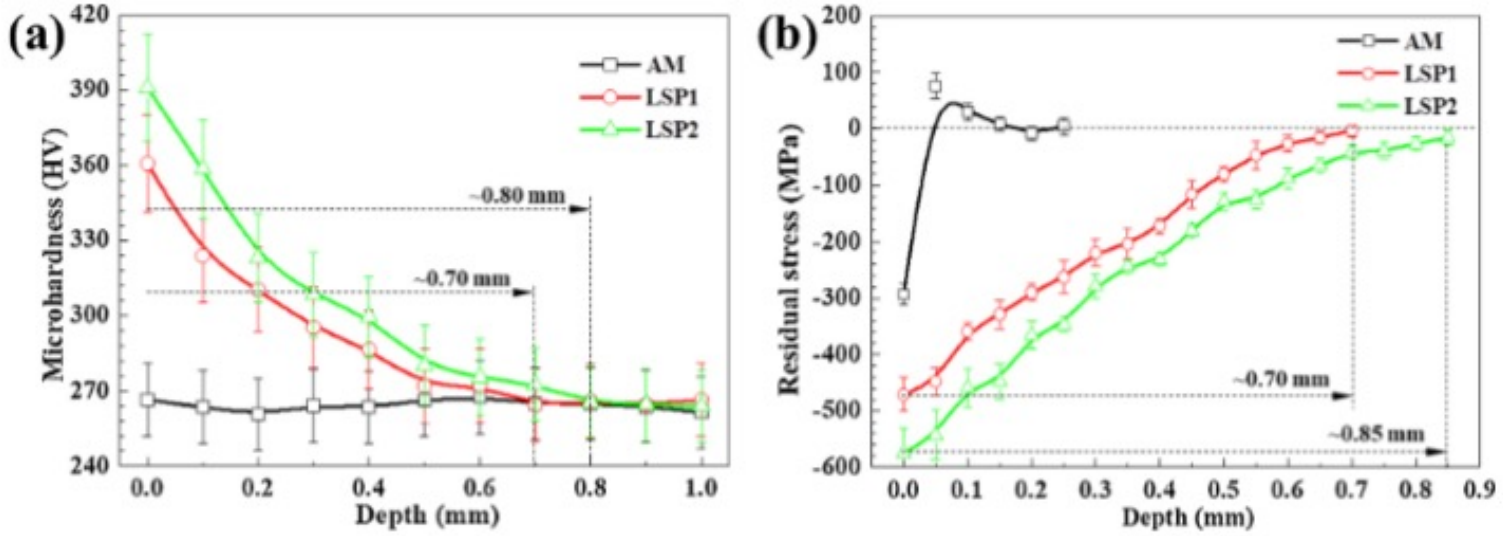
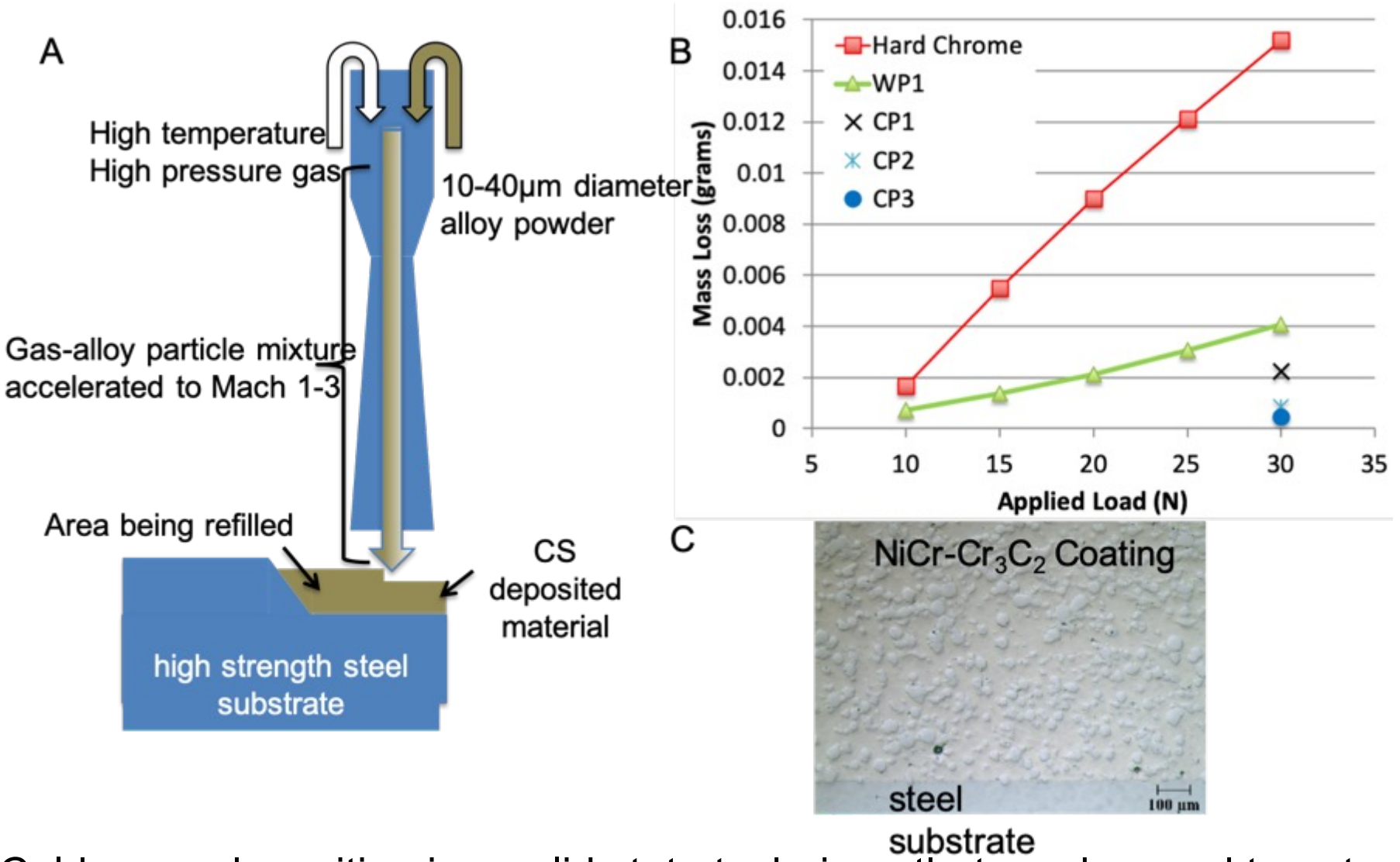


Fig. 2. In-depth (a) micro-hardness curves and (b) residual stress distributions of the AM, LSP1 and LSP2 samples.

LSP study on 420 martensitic stainless steel by C. Wang et. Al. 2020

- Laser shock peening (LSP) can be used to impart compressive residual stresses on the surface of materials to improve component reliability, in particular fatigue life.
- Surface hardness can also be increased to a lesser extent.
- LSP data is only available in the literature on 2 of 6 steels considered in this project.

Cold Spray Deposition for Enhanced Wear and Corrosion Resistance



- Cold spray deposition is a solid state technique that can be used to put wear resistance coatings on components surfaces.
- Previous research shows success with NiCr-chromium carbide coatings on steel.

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Program Technical Approach

Analyze current base-line performance of lab-scale mill (SM160)

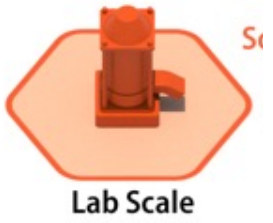
Select steels with better performance characteristics for the DMR environment (hardened and corrosion resistant).

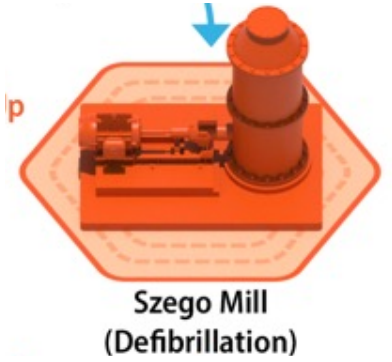
Assess potential for surface modification approaches that will lead to enhanced performance and robustness, i.e. laser peening and cold spray deposition.

Optimize the geometric and mechanical design to enhance biomass comminution and mechanical performance (low vibrations, high robustness).

Prototype and test changes in small pilot scale mill (SM280)

Prototype, test, and demonstrate performance in DMR process line with large scale pilot mill (SM320X)





Program Technical Approach

- Failure analysis
- Materials selection
- Process evaluation
- Mechanical Design
- Biomass Comminution

Biomass Comminution

Design Data

GCI

- Biomass Comminution
- Mechanical Design
- Szego Mill Production

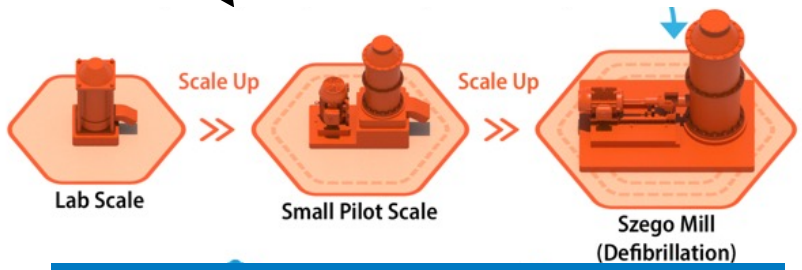
Baseline data

Design Input

Szego Mill Performance

Design Input

Szego Mill Performance



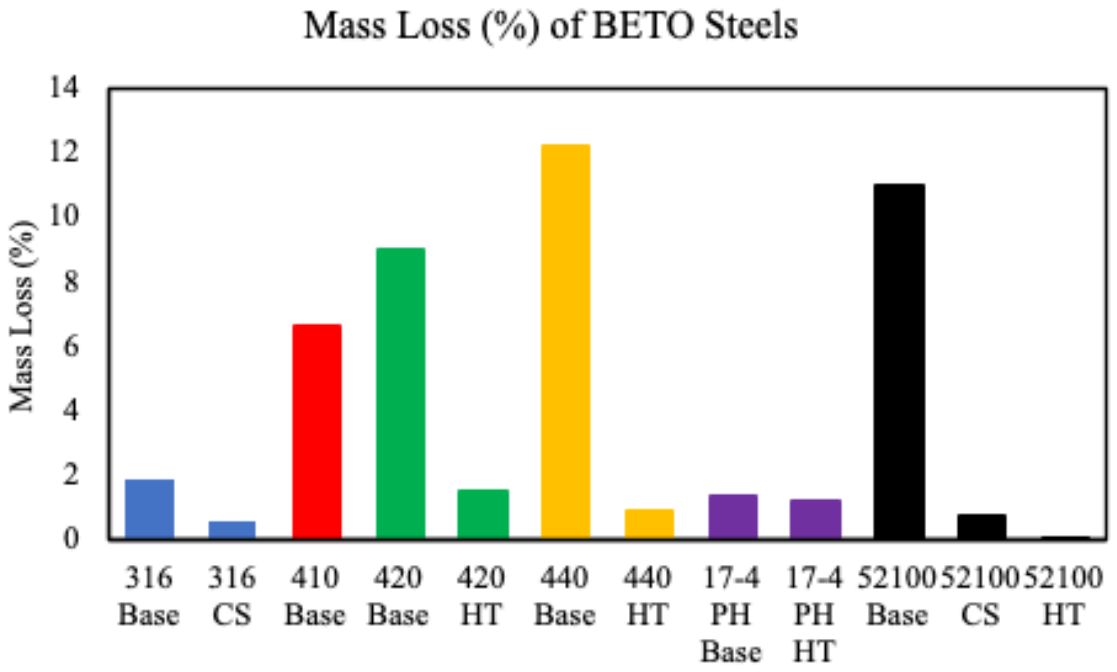
NREL
Transforming ENERGY

- Szego Mill Testing
- DMR Process Owner
- Final Customer

2 – Progress and Outcomes

- We have identified promising options for Szego Mill materials: 420SS, 17-4 PH, and 410SS
- A complete consideration of reliability for the scale-up of the Szego Mill should consider wear and other important factors: e.g. corrosion, contact fatigue, etc.
- Combinations of these steels, cold spray deposition and laser peening can improve the overall reliability and performance of the Szego Mill:
- Comminution modelling shows good potential for biomass-specific roller design
- SM 280 installed at UA and ready for use

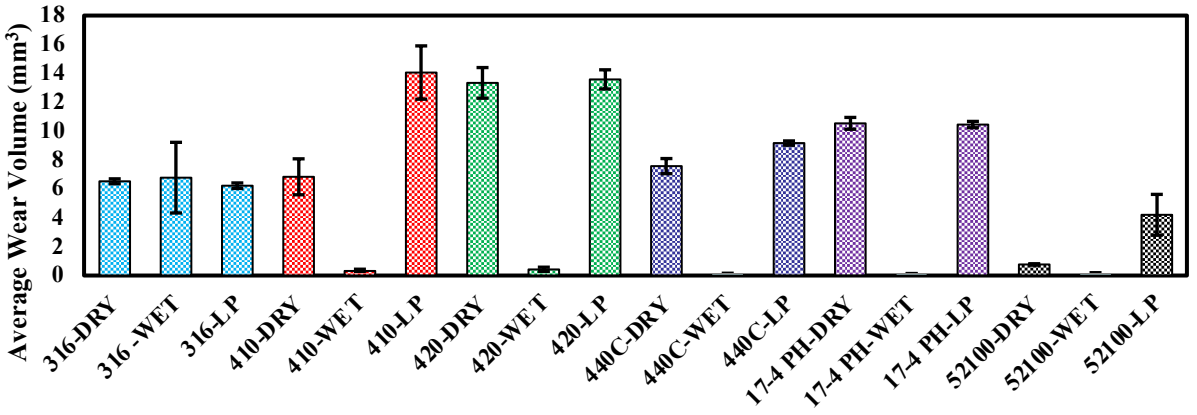
420 and 17-4 PH Stainless Steels Will Enable Successful Scale-Up of the Szego Mill



- Propose moving forward with 410, 420, 17-4 PH, and 52100 steels.
- 52100 is the top performer in terms of wear resistance, but its corrosion performance is not good and will be a concern in terms of biomass contamination and reliability.
- Heat treated 420 and 17-4PH have good wear and corrosion resistance.

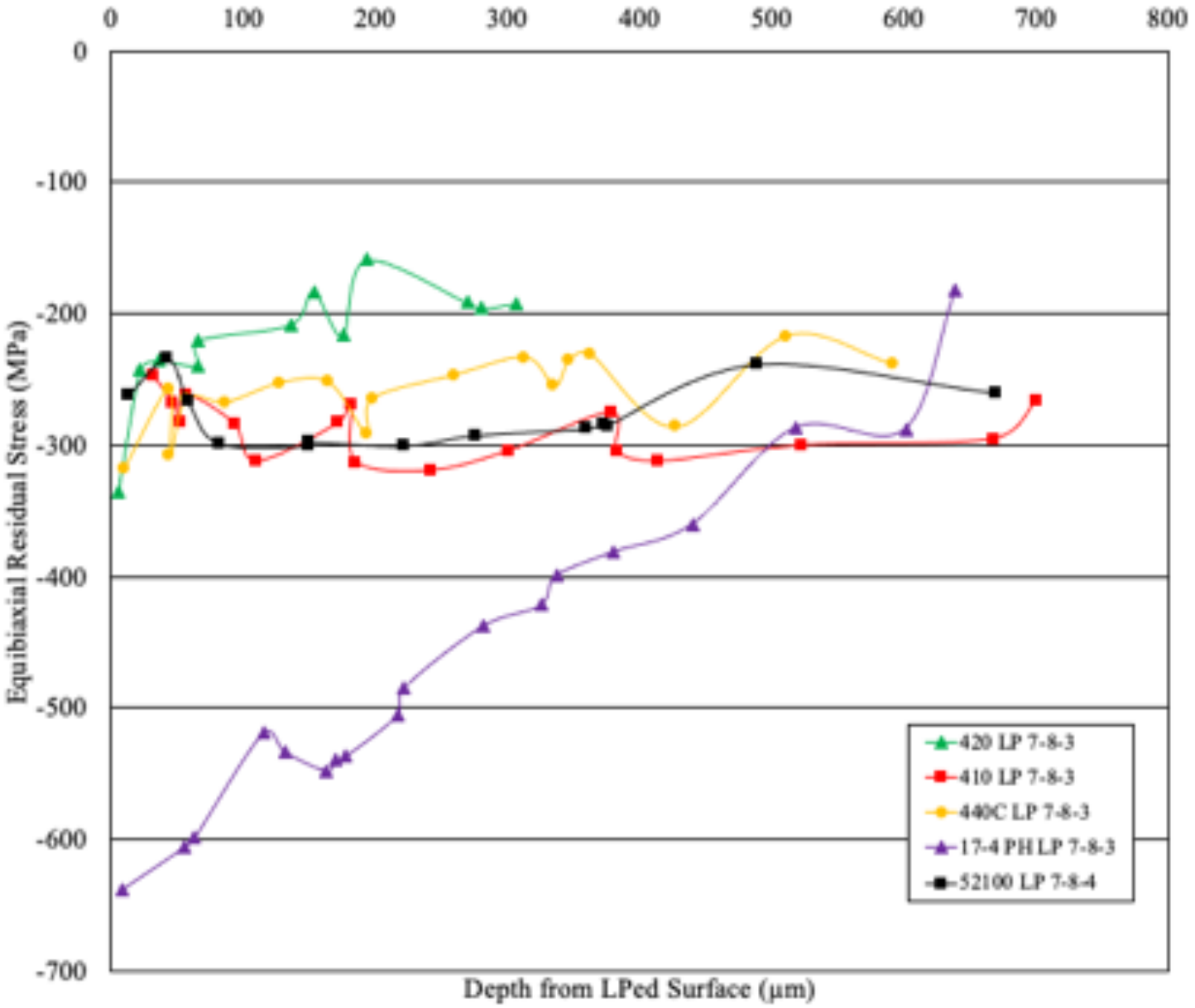
Mass loss testing performed at UA. (CS indicates steel coated with Ni-WC cermet deposit)

Laser Peening Provides Compressive Residual Stresses But Not Improved Wear Resistance.



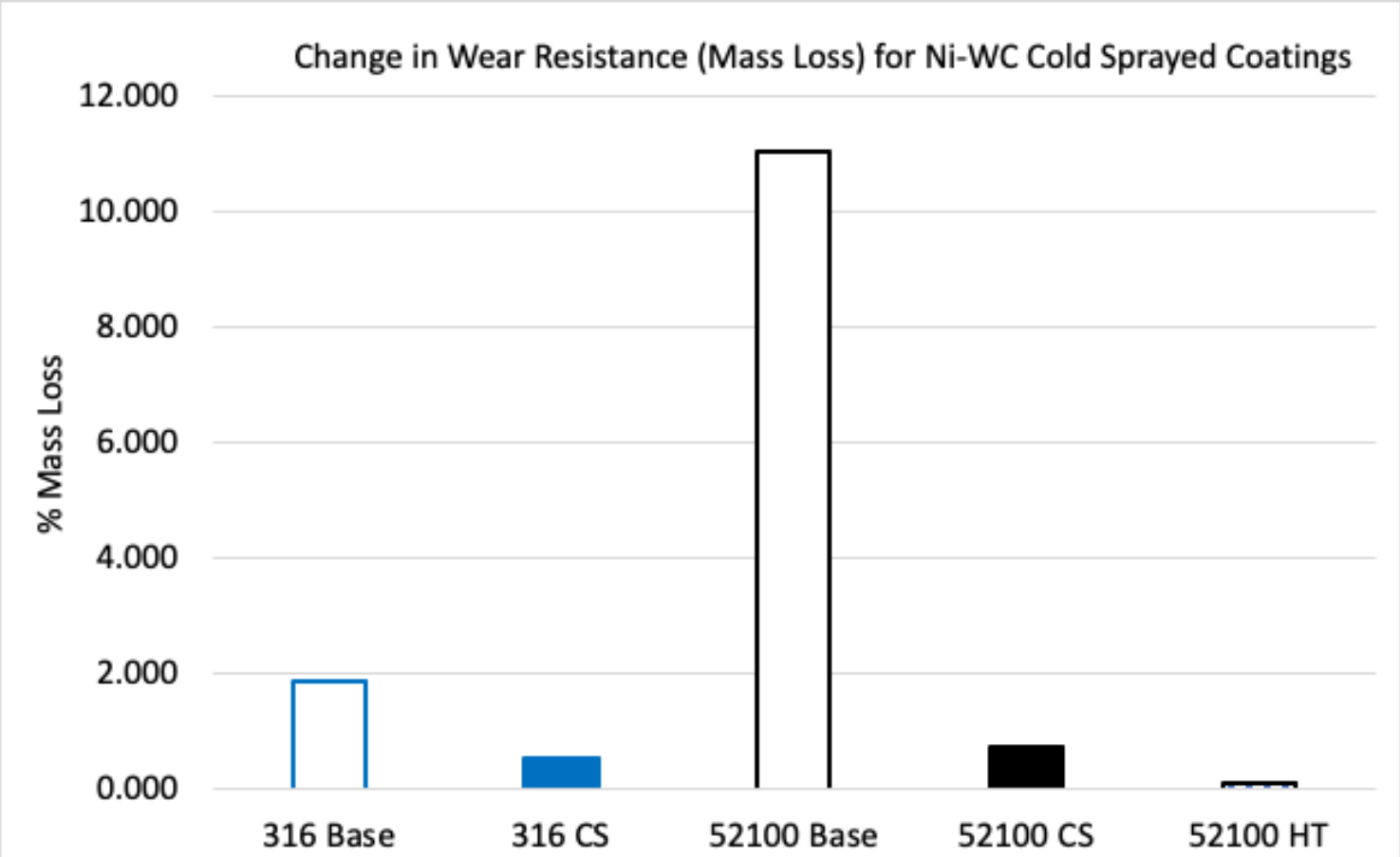
- Laser shock peening (LSP) did not increase wear resistance for any of the stainless steels.
- LSP reduced the wear resistance for 410SS, 440, and 52100 steels
- These measurements were made on annealed steels using the dry contact condition.
- What would happen if LSP were applied to heat treated steels in the wet condition?

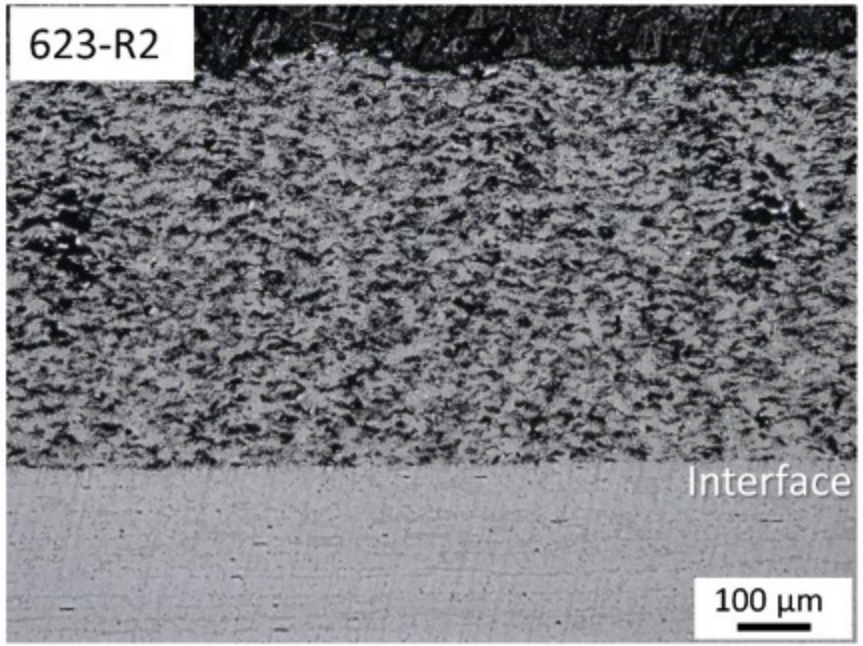
Laser Peening Provides Compressive Residual Stresses But Not Improved Wear Resistance.



- Laser shock peening (LSP) produced considerable compressive residual stresses in most steels.
- 17-4 PH responded particularly well to this treatment.
- Compressive residual stresses can really help prevent fatigue and contact fatigue failures (under cyclic loading)

Cold Spray of Wear Resistant Coatings Shows Potential for Enhanced Szego Mill Performance





- Cold spray of Ni-WC coatings is effective at reducing wear rate (dry contact).
- What kind of corrosion protection does this coating provide? (NiCr-Cr_3C_2 is also sprayable)
- Could cold sprayed Ni-WC coatings allow softer/annealed (easier to manufacture) steels to be used in the Szego Mill?
- Cold spray could be used to repair worn rollers/shells in a service environment.

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Preparing for Combined Experimental and Computational Optimization of Biomass-Specific Comminution Designs.

Modification of particle breakage models for biomass comminution.
We will extend and refine the fluid mechanics and contact mechanics models used for predicting particle breakage during the comminution of lignocellulosic biomass, specifically.

Dr. Olev Trass (GCI) is revisiting the dynamic wet-grinding dynamics for the Szego Mill. He recently reviewed the state-of-the art and showed preliminary analyses at the Clearwater Clean Energy Conference (July 2022).

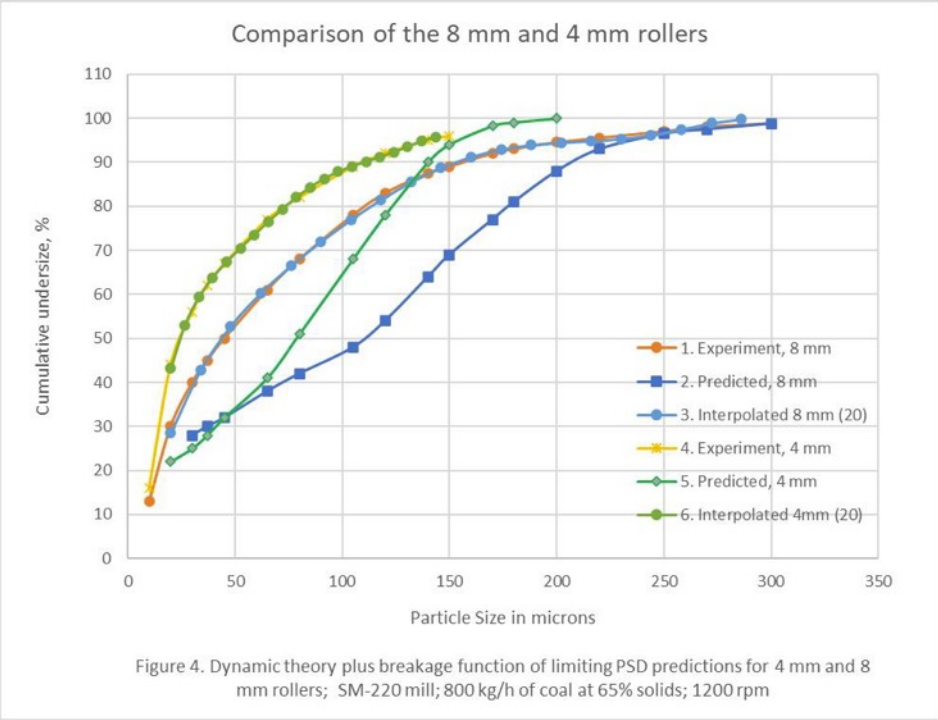


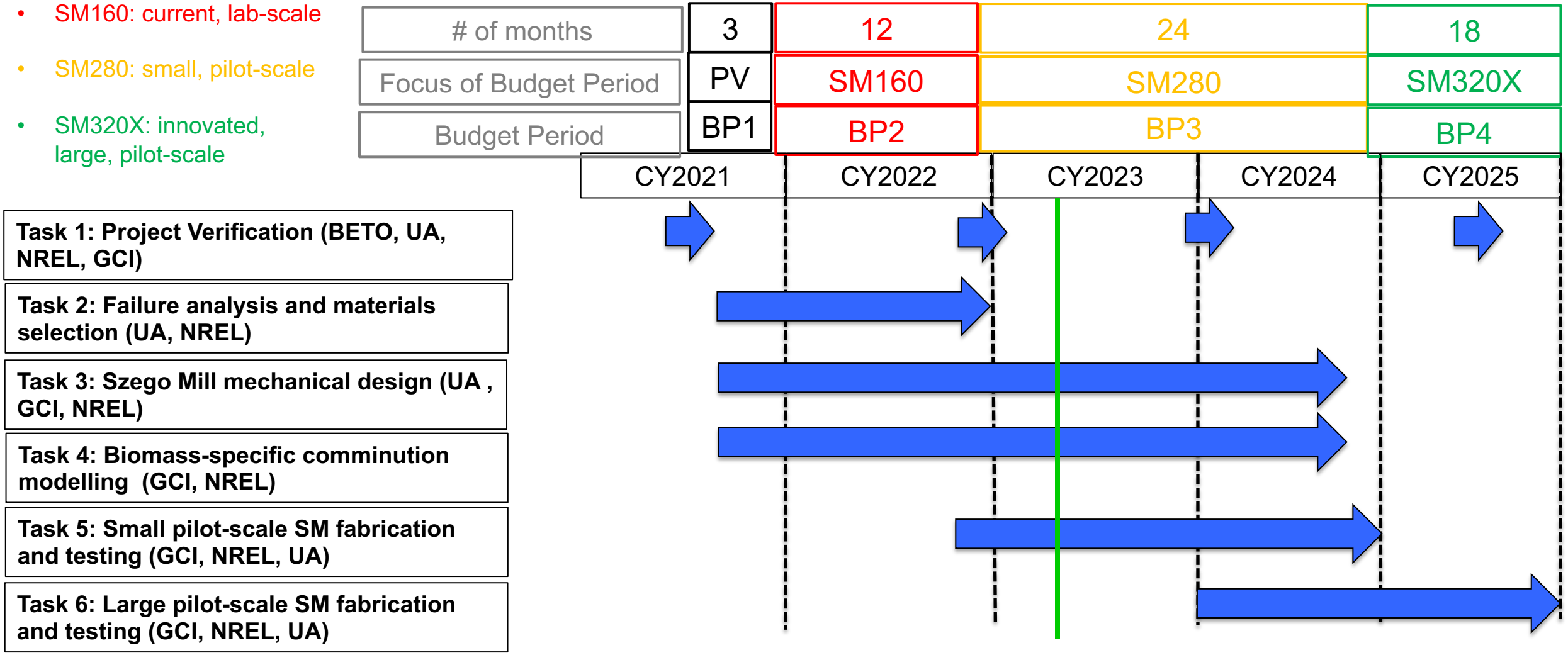
Figure 4. Dynamic theory plus breakage function of limiting PSD predictions for 4 mm and 8 mm rollers; SM-220 mill; 800 kg/h of coal at 65% solids; 1200 rpm

Introduction of particle breakage model for coal-water slurries (65% by weight coal) using 1200 RPM roller rotational speed.

This particle breakage model will be adapted to biomass slurries.

The model will be informed and validated by experiments at UA.

- SM160: current, lab-scale
- SM280: small, pilot-scale
- SM320X: innovated, large, pilot-scale



Current project timeline (April 2023)

We have finished the deliverables for BP2.
Waiting for approval to begin BP3.

3 – Impact

Impact on BETO's biomass → jet fuel initiative (SAF grand challenge)

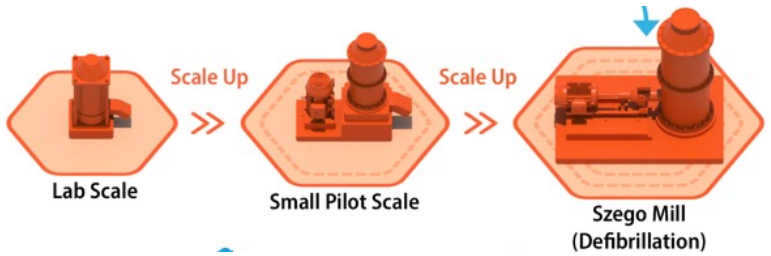
- *Using corn stover biomass as an acceptable biomass feedstock.*
- *Reducing the scale-up uncertainty and risk of the NREL's integrated biorefinery pathway by focusing on engineering solutions for the highest risk unit operation (Szego Milling) in the DMR pretreatment process.*
- *Having plenty of verifiable lab-scale work on the Szego milling and the DMR pretreatment process. The success of the DMR pretreatment for biofuel production at lab-scale justifies further development to engineering-scale.*
- *The technologies developed in this program could be readily used for other biomass harvesting and processing equipment such as disk grinders, arbors, fermentation equipment, etc.*

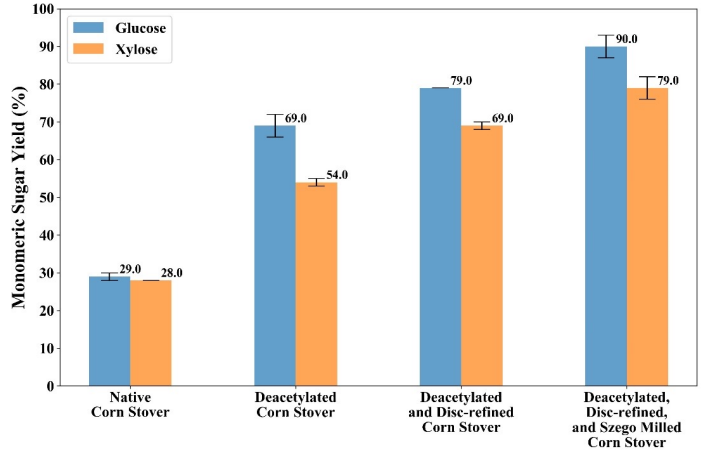
Impact on DOE future workforce and academic knowledge

- *Program is supporting three doctoral students*
- *Is producing publicly available knowledge: 1 conference presentation given and 1 journal article in preparation thus far.*

Summary

- *Szego Mill provides secondary refinement which boosts sugar yield on corn stover feed stock in the DMR process by at least 10%*
- *Current technology needs to be scaled-up and made more robust without sacrificing sugar yield.*
- *Technology approach is selecting and utilizing better steels, implementing surface treatments, and optimizing mill design specifically for corn stover biomass.*
- *The first two budget periods have shown that corrosion is just as important as wear and the commercial materials are available for successful scale-up.*
- *Laser shock peening and cold spray deposition show promise for enhancing mill reliability and could be used on other machinery for biomass production.*





Quad Chart Overview

Timeline

- *10/1/2020*
- *9/30/2025*

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022)* *$390,880*	*(negotiated total federal share)* *$3,053,043*
Project Cost Share *	$103,631	$763,059

Project Goal

The project will optimize and scale-up the Szego Mill for large scale implementation in the DMR process by innovating on the mechanical and comminution design of the rollers and as well as on the materials and the fabrication processes used for the mill`s construction.

End of Project Milestone

Demonstrate 100 hours continuous run time, and 500 hours of cumulative run time of the SM320X or equivalent producing intermediates that show >85% sugar yield and ≥85% 2,3-BDO yield in down stream enzymatic hydrolysis and BDO fermentation and with >10% improvement in ≥ 2 of the following compared with the baseline performance: wear rate, vibration, noise, or energy consumption.

Funding Mechanism

DE-FOA-0002203 (2020)

Topic Area: SCale Up of Bench Applications (SCUBA)

TRL at Project Start: 4

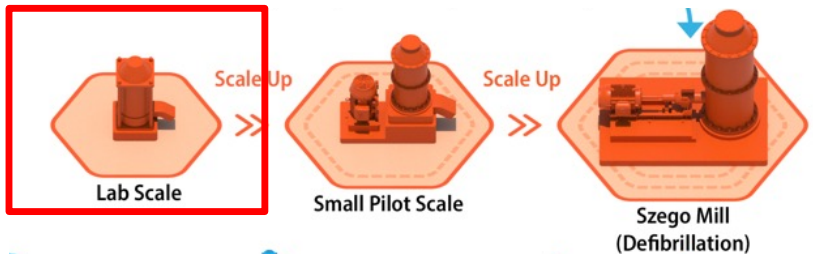
TRL at Project End: 6

Project Partners

- NREL (D. Xiaowen Chen)
- General Comminution Inc. (Dr. Olev Trass)

Additional Slides

Program Structure



Task 1: Project Verification (BETO, UA, NREL, GCI)

Go-No Go based on independent engineering evaluation between each budget period.

Task 2: Failure analysis and materials selection (UA, NREL)

Milestone 2.1.1 from Task 2.1. Baseline levels of vibrational characteristics, stress in shell component, noise levels, and energy consumption will be measured for the current Szego Mill at NREL. (milestone due April 1, 2022)

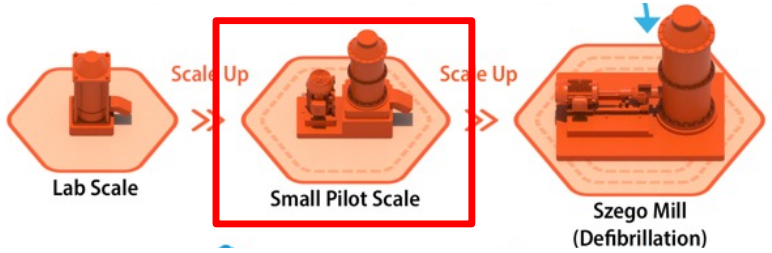
Milestone 2.2.1 (SMART) from Task 2.2. Four steels selected based upon > 5% improvement on wear characteristics compared with baseline steel in SM160 or equivalent. (Milestone due September 2022)

Milestone 2.2.2 (SMART) from Task 2.2. Demonstrate that at least two combinations of new materials and/or fabrication processes show > 10% improvement on wear characteristics compared with baseline Szego Mill roller materials. (Milestone due September 2022)

Milestone 2.3.1 (SMART) from Task 2.3. Demonstrate > 10% improvement on wear characteristics from laser peening of steel compared with baseline Szego Mill roller materials.

Milestone 2.4.1 (SMART) from Task 2.4. Demonstrate > 10% improvement on wear characteristics from cold spray coatings on steel compared with baseline Szego Mill roller materials.

Program Structure



Task 3: Szego Mill mechanical design (UA , GCI, NREL)

Task 4: Biomass-specific comminution modelling (GCI, NREL)

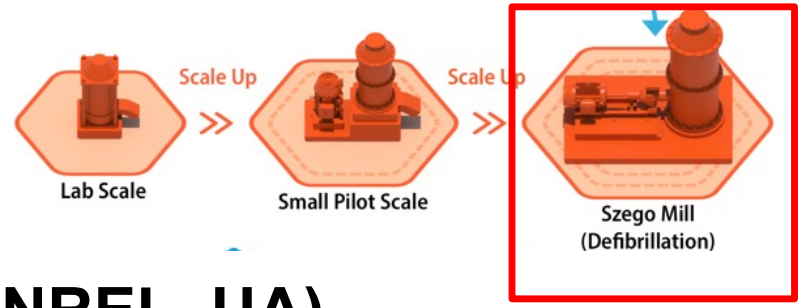
Milestone 4.2.1 (SMART) from Task 4.2. Three new SM280 roller ridge/groove designs based on the biomass specific dynamic model predicts >5% increase in sugar yield with <20% increase in energy consumption compared to the SM160 or equivalent baseline.

Task 5: Small pilot-scale SM fabrication and testing (GCI, NREL, UA)

Milestone 5.3.1 (SMART) from Task 5.3. DMR processed corn stover using SM280 or equivalent shows >2% yield increase than without Szego Milling (DDR process) in converting corn stover to sugar and BDO in the enzymatic hydrolysis and BDO fermentation, respectively.

Milestone 5.3.2 (SMART) from Task 5.3. Demonstrate >10% reduction of at least two of the following compared with the baseline performance of SM160 or equivalent: wear rate, vibration, noise or energy consumption.

Program Structure



Task 6: Large pilot-scale SM fabrication and testing (GCI, NREL, UA)

Milestone 6.3.1 (SMART) from Task 6.3. Demonstrate 100 hours continuous run of the SM320X or equivalent producing intermediates shows >85% sugar yield and ≥85% 2,3-BDO yield in down stream enzymatic hydrolysis and BDO fermentation.

Milestone 6.3.2 (SMART) from Task 6.3. Demonstrate 500 hours cumulative run on SM320X or equivalent with >10% improvement in ≥ 2 of the following compared with the baseline performance of the SM160 or equivalent: wear rate, vibration, noise, or energy consumption

Milestone 6.4.1 (SMART) from Task 6.4. DMR processed corn stover using SM320X or equivalent shows >5% yield increase than without Szego Milling (DDR process) in converting corn stover to sugar and BDO in the enzymatic hydrolysis and BDO fermentation, respectively.

Publications, Patents, Presentations, Awards, and Commercialization

Presentations:

- Dr. Olev Trass (GCI), “Szego Mill Scale-Up for Biomass Processing”, Clearwater Clean Energy Conference (July 2022).

Publications:

- N. Brooks, X. Chen, Y. Li, K. Ziska, A. Beheshti, L.N. Brewer, K. Davami, “Tribocorrosion Behavior of Fe-Cr Alloys for Mechanical Refinement in a Corn Stover Environment,” in preparation for *Tribology International,* 2023.