NARA

Production of 1,000 Gallons of Biojet in the NARA Consortium

R. J. Wooley[1], M. Wolcott[2], R. Cavalieri[2], J. Y. Zhu[3],
R. Gleisner[3], A. C. Hawkins[4], J. Ley[4], K. Evans[4],
G. Johnston[4], J. Gao[5], T. Spink[6], G. Marrs[7], J. Sessions[8]

NARA Final Meeting
Arlington, VA
November 17, 2016

[1]Biomass *ad infinitum*, LLC, [2]Washington State University, [3]Forest Products Laboratory,
[4]Gevo, Inc., [5]Weyerhaeuser, Inc., [6]TSI, Inc., [7]Gevan Marrs, LLC, [8]Oregon State University

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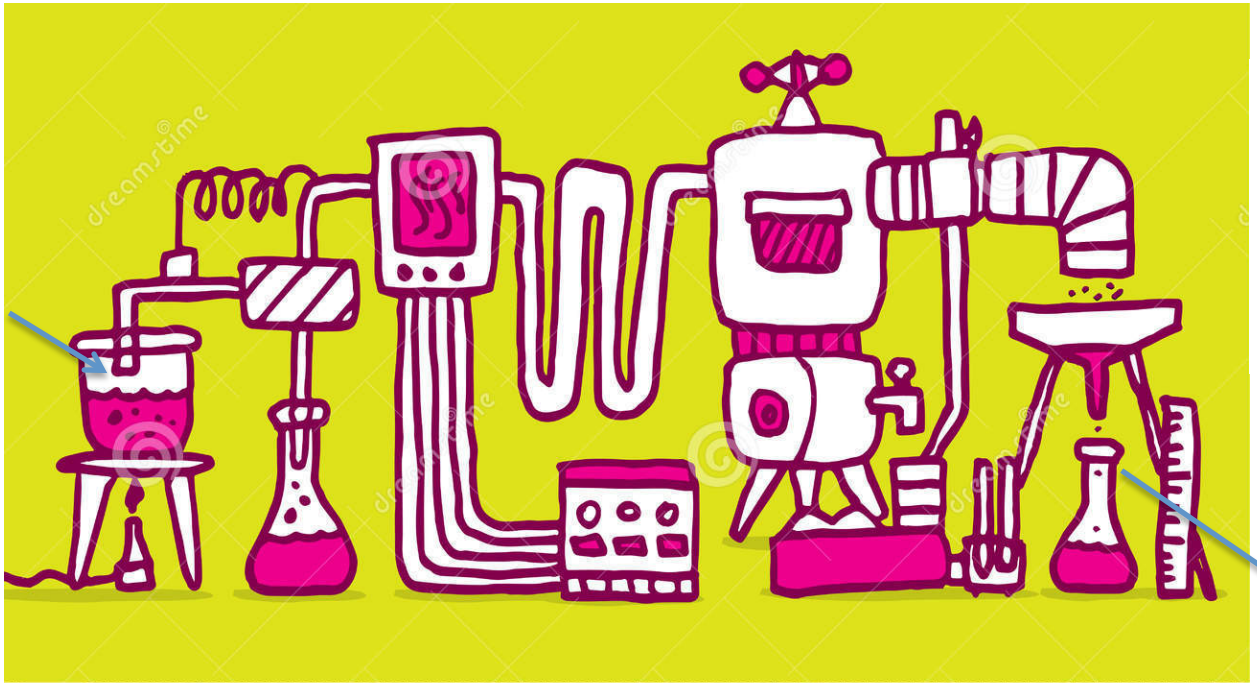
The Challenge!

- You have process in the lab/pilot plant

Wood Chips In

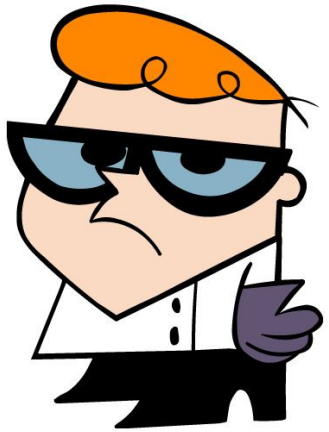


Jet Fuel Out

- You're able to validate the process & develop scale-up data
- You're able to supply quantities for analytical testing

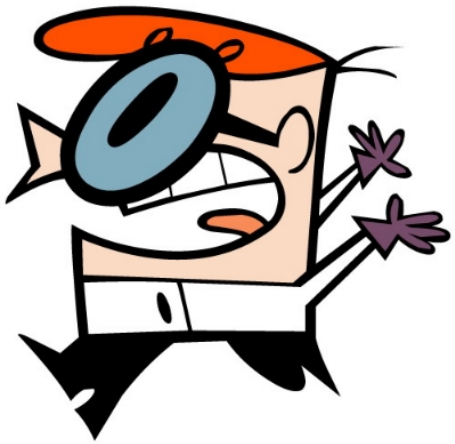
The Challenge!

- Then you realize that lab quantities are only going to get you so far



The Challenge!

- You need enough fuel product to demonstrate a commercial flight



1,000 Gallons of BioJet Fuel – Task Objective

Produce 1,000 gallons of jet fuel using the feedstock and process identified and researched by the USDA funded NARA project.

1,000 Gallons of BioJet Fuel – Task Objective

1. Utilize Key aspects from the NARA project in the production:
   - Feedstock: Softwood forest residues, primarily Douglas-fir and hemlock
   - Pretreatment: A mild bisulfite variant of the SPORL process as developed by USDA/FPL and Catchlight Energy
   - Enzymatic Saccharification: Utilizing commercial enzymes from Novozymes and as utilized by USDA/FPL and Gevo on this pretreated material
   - Isobutanol Production: Via fermentation using Gevo patented organisms and fermentation protocols
   - Jet Fuel Conversion: Via Gevo process

1,000 Gallons of BioJet Fuel – Task Objective (cont.)

2. Efforts will be made to accommodate the production of representative co-products

3. Cost and availability of suitable demonstration scale equipment will dominate

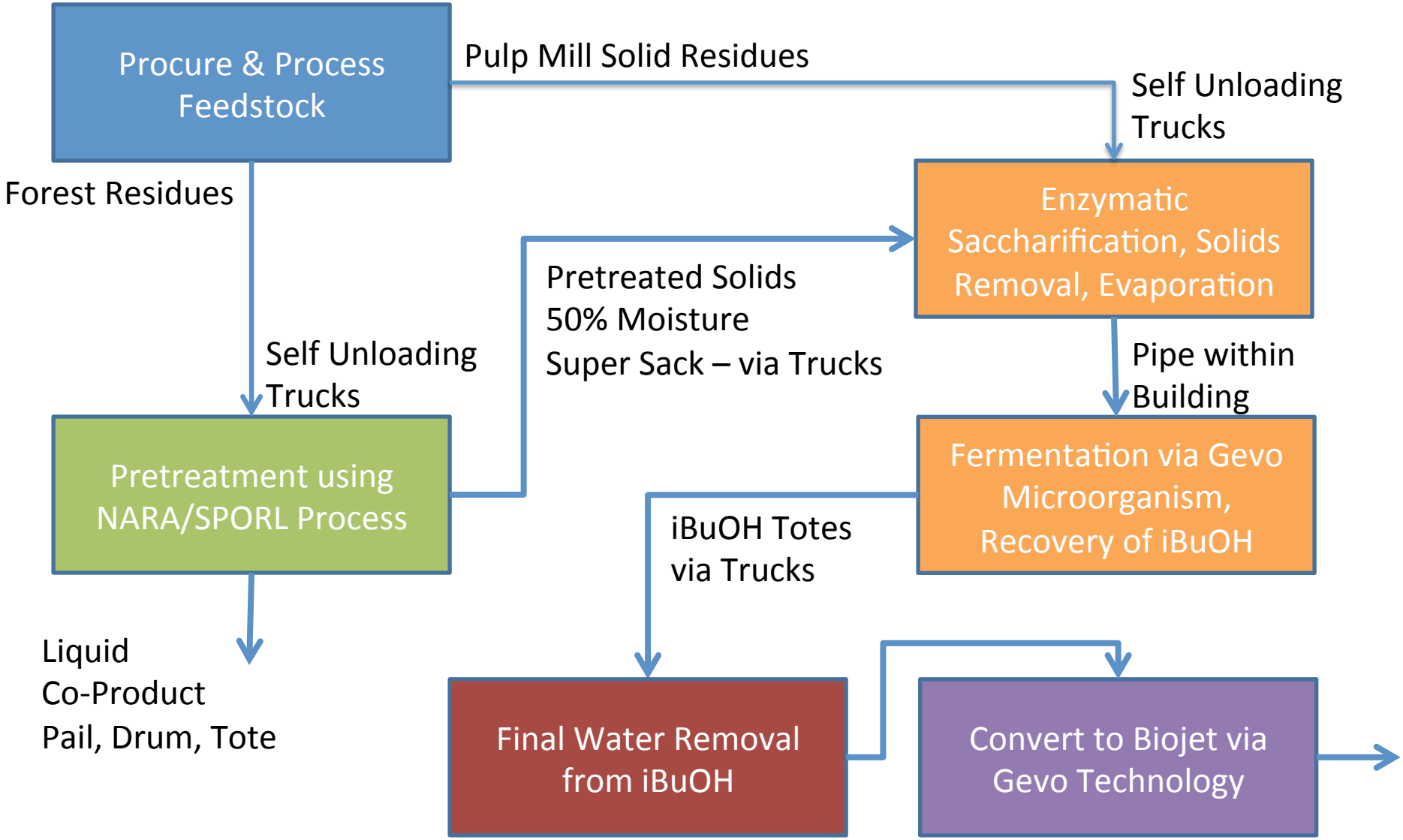
4. Efforts will be made to determine representative or scalable yields as opportunities present themselves

5. An overall optimized yield from wood to jet fuel is not expected

Determine Scale-up Requirements

- Identify & Investigate Potential Tolling Partners
- Determine additional testing needed by FPL and Gevo to scale to a continuous system that may require different process conditions than previously studied
- Discuss potential need for pre-trials with specific tolling equipment
- Requirements and procedures for shipping of intermediate materials – Will depend on toller capabilities and locations
  - Low pH of hydrolyzates
  - Moisture content of solids
  - Bio-stability of sugar containing materials
- Negotiate Contracts with Each Selected Partner

Overall Process Flow



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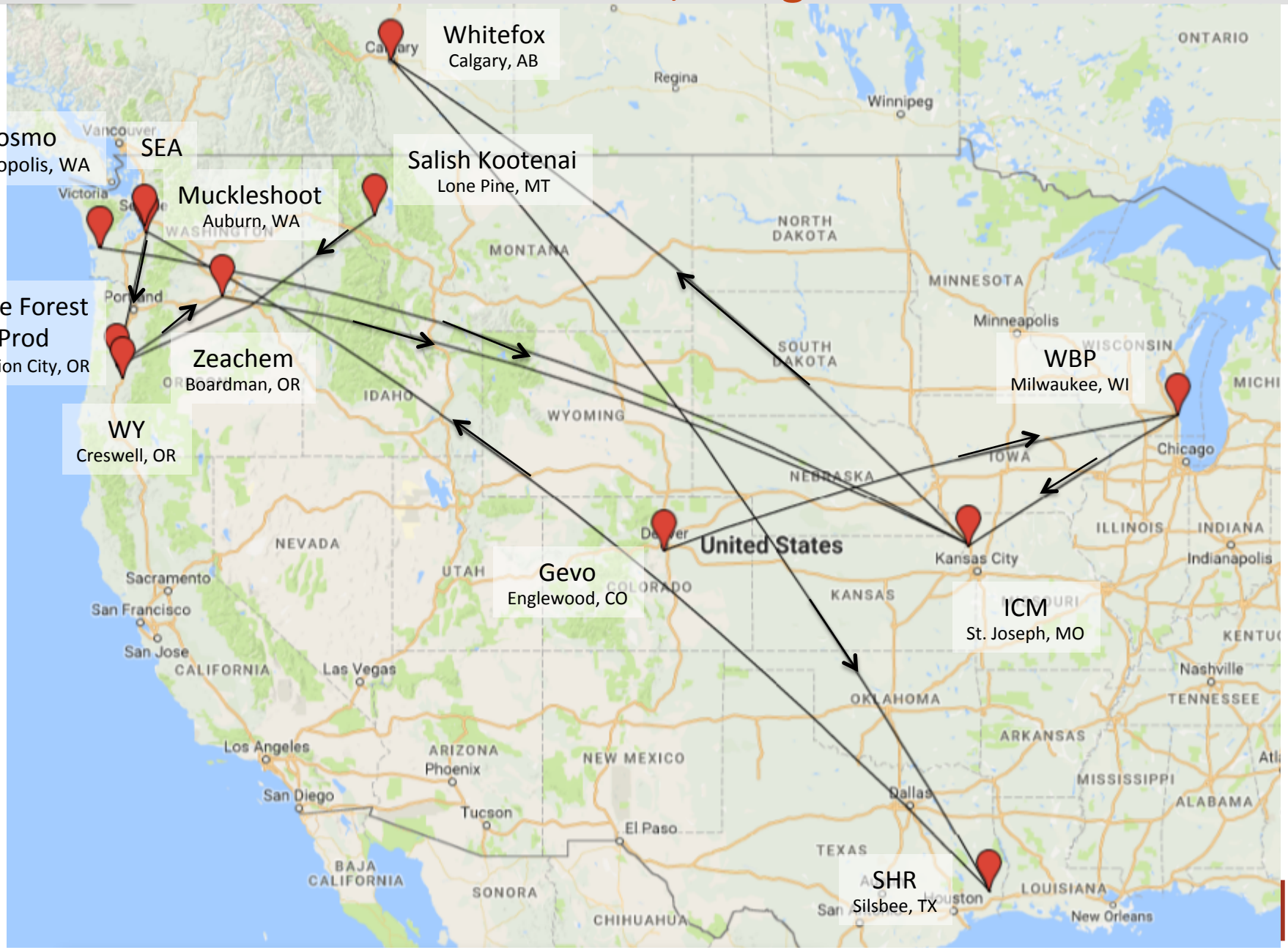
Potential Tolling Partners Evaluated

- Pretreatment
  - Andritz Pilot Facility, Springfield, OH
  - American Process (API) Pilot Plant, Thomaston, GA
  - Zeachem Development Plant, Boardman, OR
  - Cosmo Specialty Fiber, Cosmopolis, WA
  - Forest Products Lab (FPL), Madison, WI
  - ICM Corn & Cellulose Pilot Plant, St. Joseph, MO
  - NREL Biomass Pilot Plant, Golden, CO
  - University of Florida Pilot Plant, Perry, FL

- Enzymatic Saccharification, Fermentation, Purification
  - American Process (API) Pilot Plant, Thomason, GA
  - ICM, St. Joseph, MO
  - NREL Biomass Pilot Plant, Golden, CO

- iBuOH Conversion to Jet
  - South Hampton Resources, Silsbee, TX

Locations Involved to Produce 1,000 gallons



Feedstock

Feedstock Collection

- Weyerhaeuser Creswell, Oregon
- CSTK Lands near Lone Pine, Montana
- Muckleshoot Lands near Auburn, Washington

Feedstock Processing

- Lane Forest Products, Junction City, Oregon
- Forest Concepts, Auburn, Washington

Feedstock – Modified to fit Specific Toller

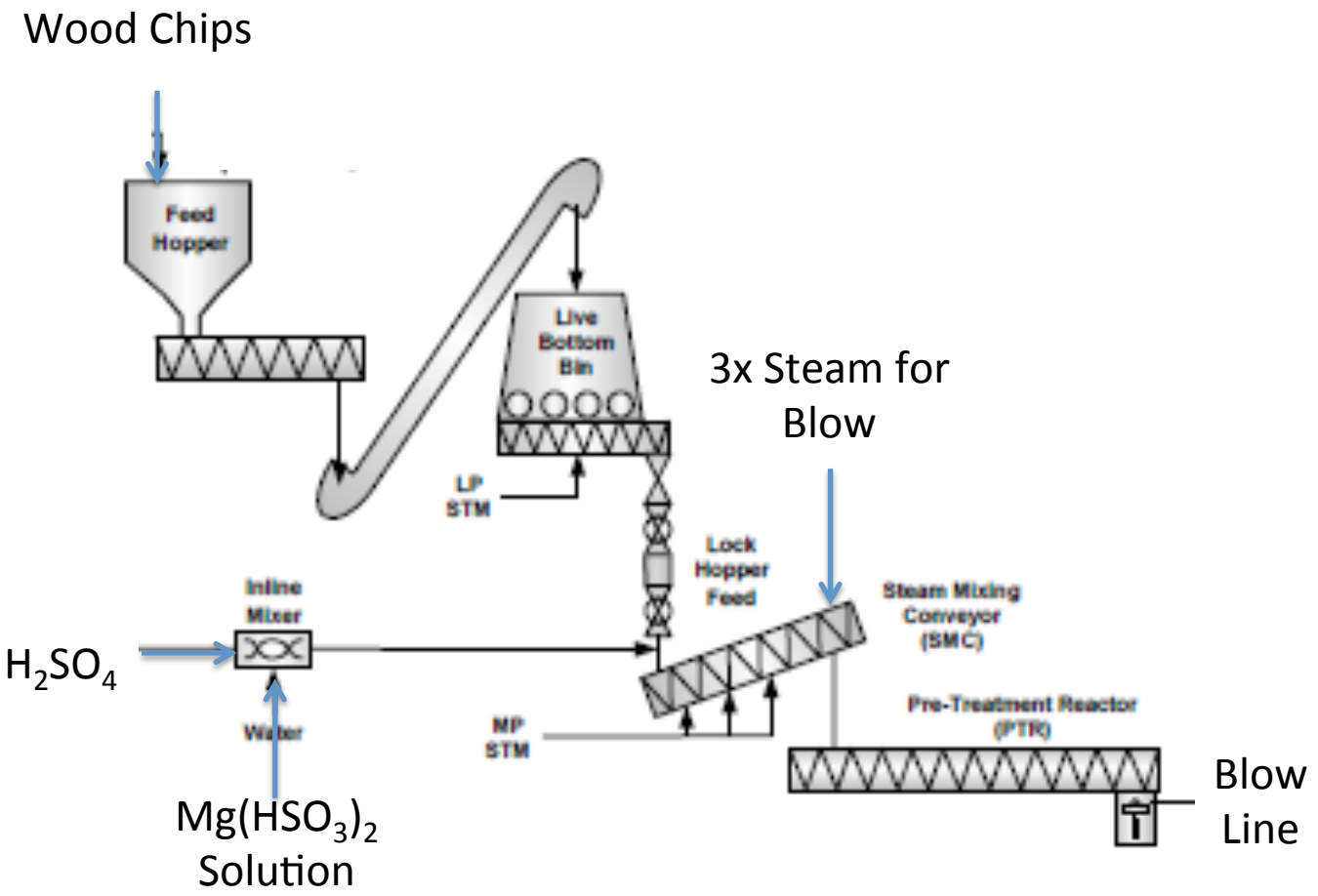
As Received at Lane Forest Products

Material Used at Zeachem

Zeachem Pretreatment Plant

- Zeachem – Boardman OR
  - Good Experience with pretreatment of wood for fuels and chemicals
  - Nominal 10 BDT/day
  - No SO_2 Handling Experience – Designs & Procedural Modifications
  - Andritz Designed and Supplied Equipment
    - Trial at Andritz Pilot (Springfield, OH)
    - Budget Quote for Andritz Commercial Plant for NARA
  - Refiner and High Pressure Blow will insure small particle size
  - Filter Press can produce 50% Solids, quite suitable for non-Hazmat Shipping
  - Highly motivated team at Zeachem

Zeachem Flow Modified for Bisulfite

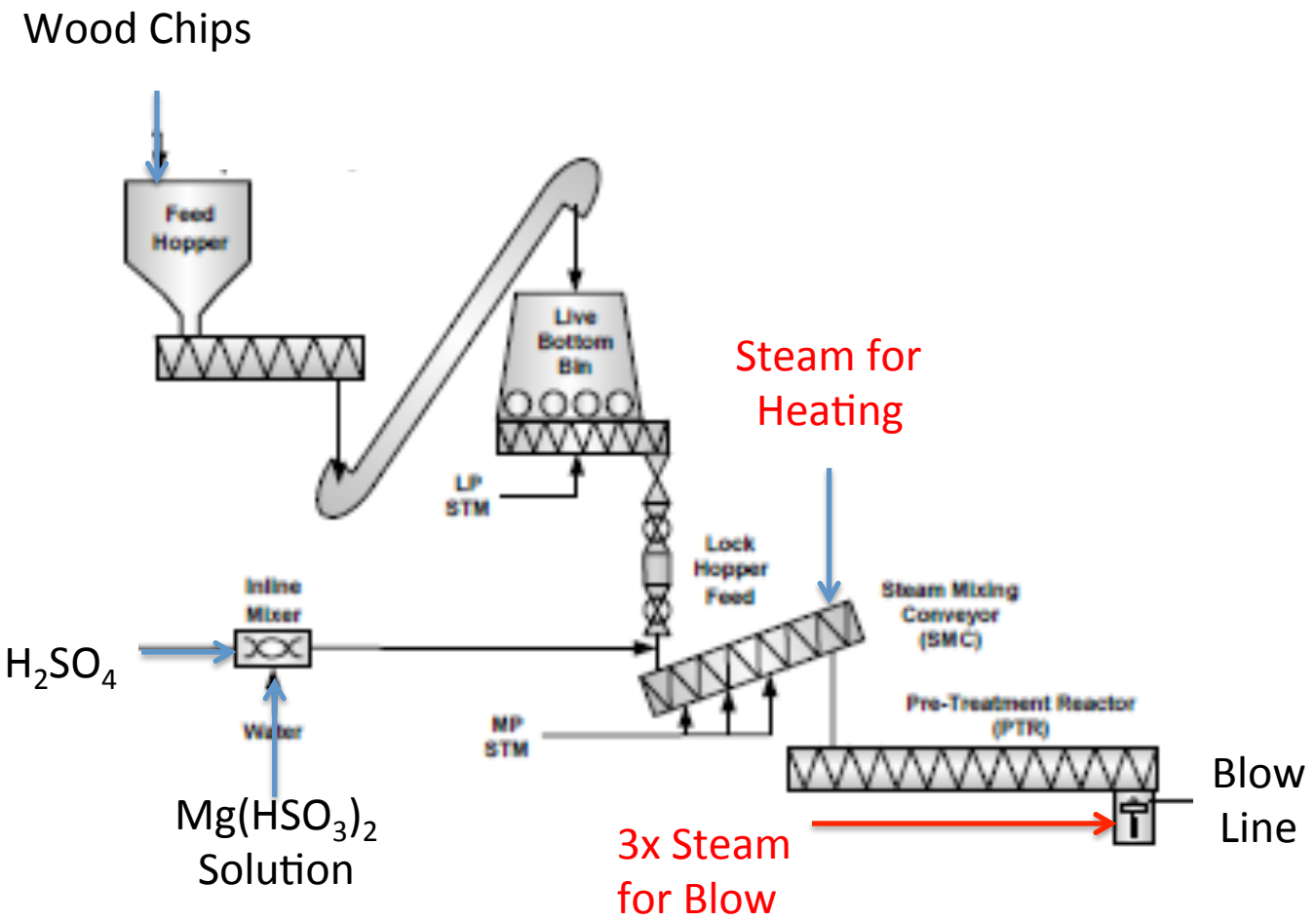


$$H_2SO_4 + Mg(HSO_3)_2 \rightarrow SO_2 + HSO_3^- + H^+ + Mg^{2+} + SO_4^{2-} + H_2O$$

$$2\ Ca(OH)_2 + 4\ SO_2 \rightarrow SO_2 + 3\ HSO_3^- + 2\ Ca^{2+} + H^+$$

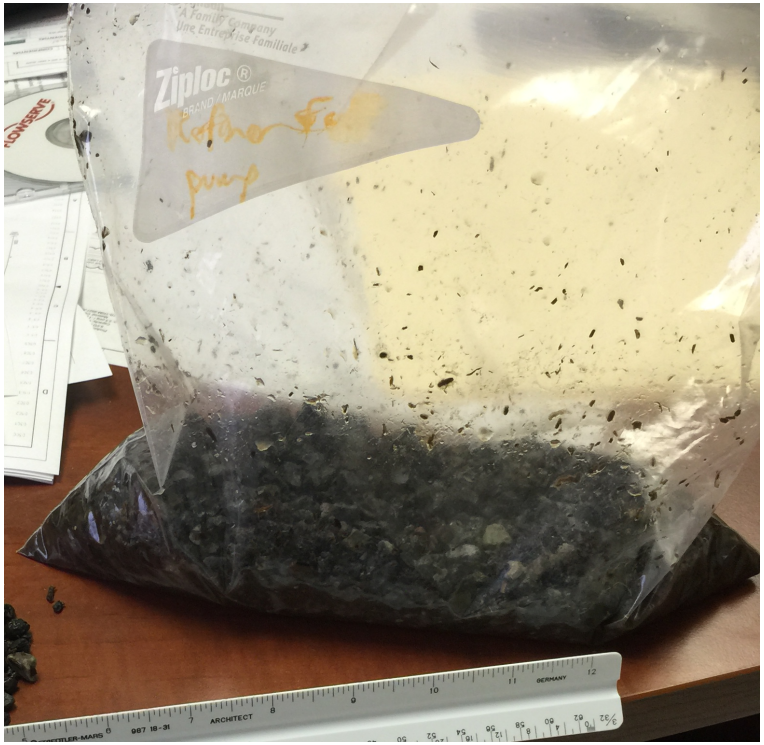
Zhu et al., Biores. Technol., 179 (2015) 390-397

Zeachem Solving Problem of Low SO2 Partial Pressure

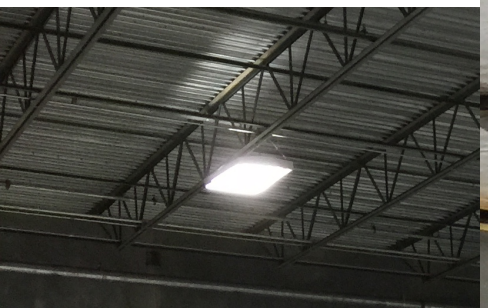


Zeachem Additional Processing Issues

- Rocks in the Feedstock!



Zeachem 52 BDT of Pretreated Solids Shipped to ICM

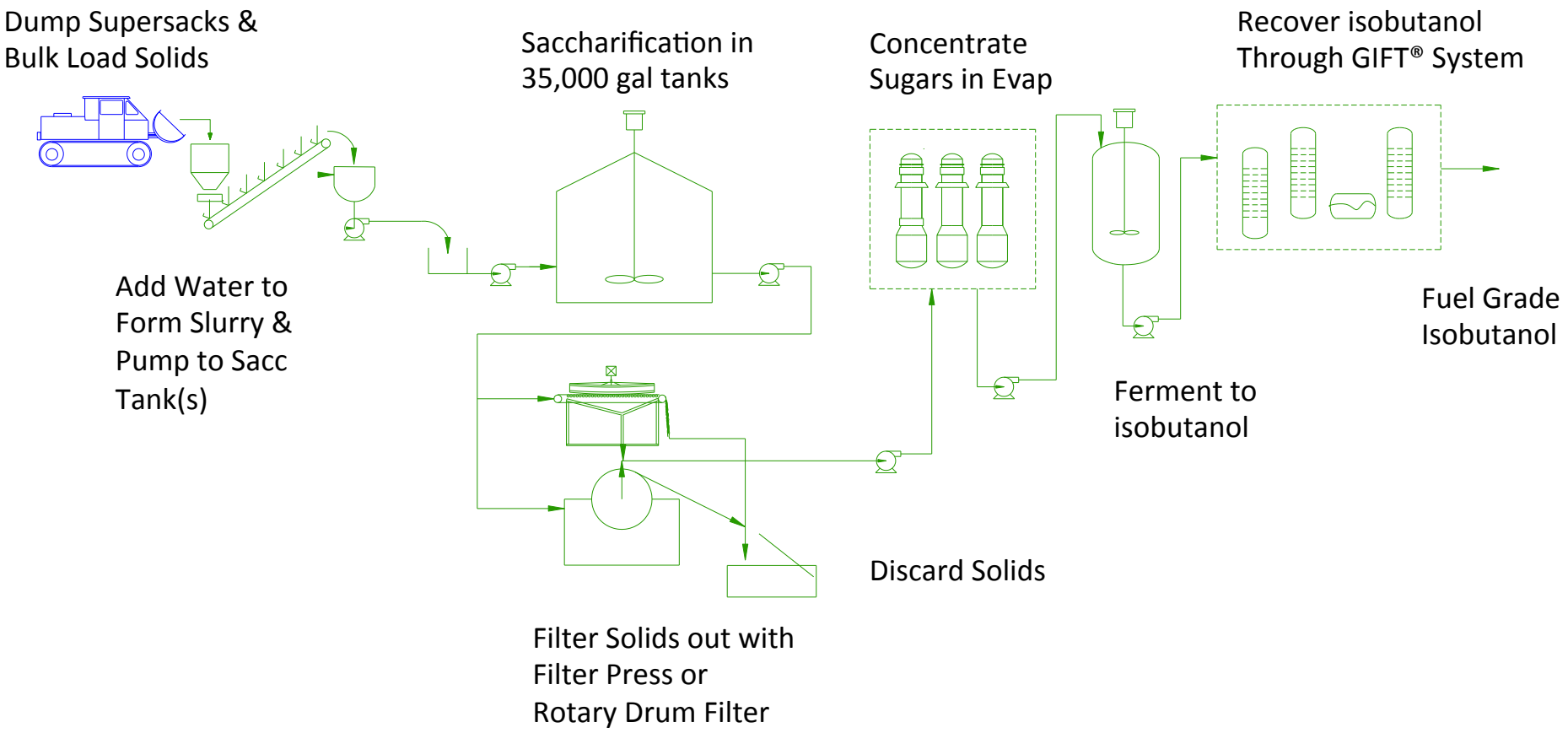


216,000 lb wet
52 Dry tons
265 Supersacks

ICM – St. Joseph, MO Site

- ICM – St. Joseph, MO
  - Considerable experience with:
    - Biomass Saccharification
    - Isobutanol Fermentation, Recovery and Purification using Gevo Technology
  - Existing, 35,000 gallon enzyme saccharification tanks
  - Filter Press with washing capability to remove solids after Saccharification
  - Evaporation to concentrate sugars to 150 g/l for fermentation
  - 3 Existing 6,000 gallon sterile fermenters that can be used in parallel
  - Existing pilot unit using the Gevo GIFT technology for high efficiency of isobutanol recovery from Fermentation

Process Flow for Enzyme Sacc & Fermentation at ICM



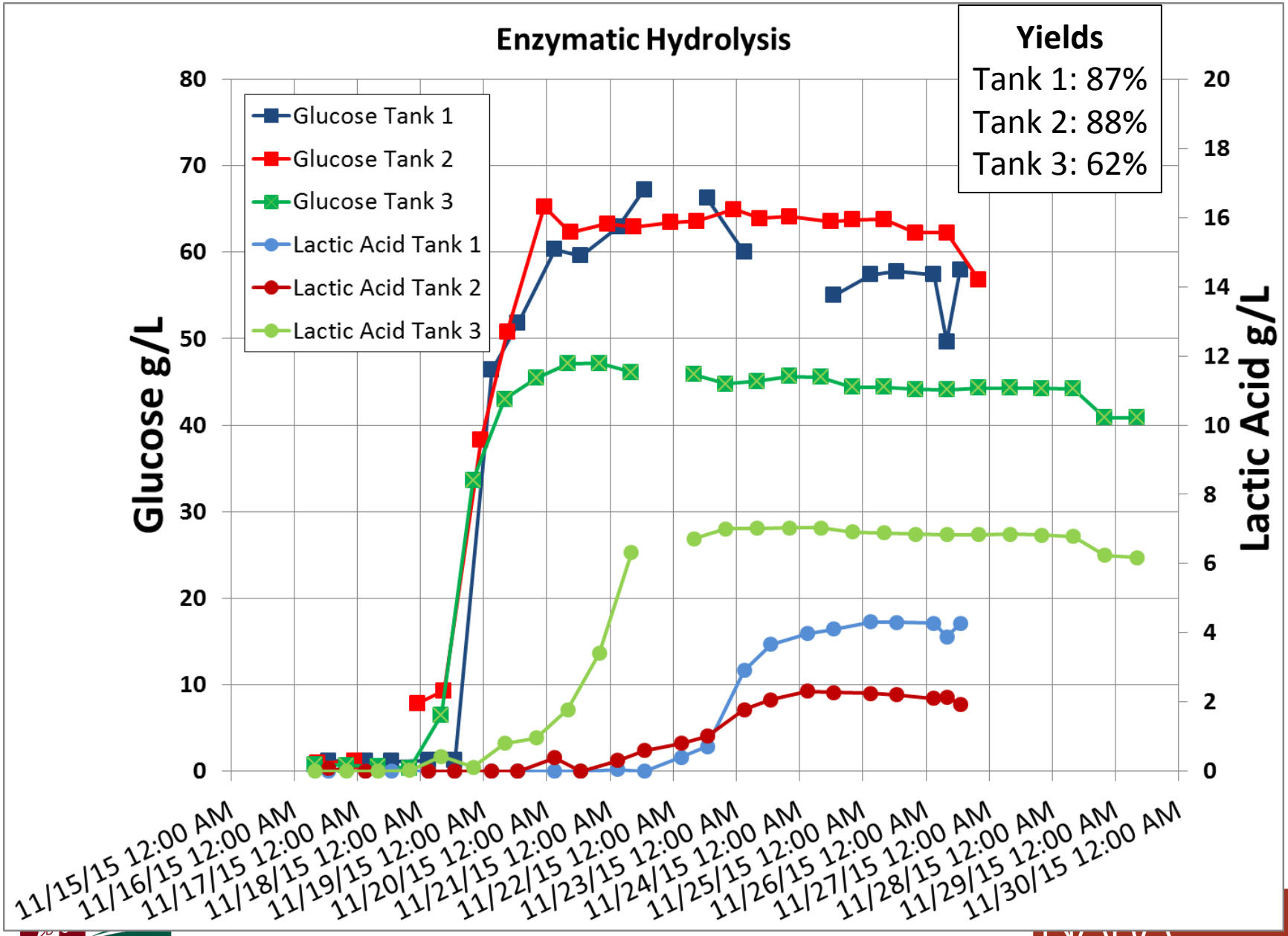
Loading the Solids

Supersacks being Dumped and Scooped

Slurry That Was Pumped

Loading Cosmo

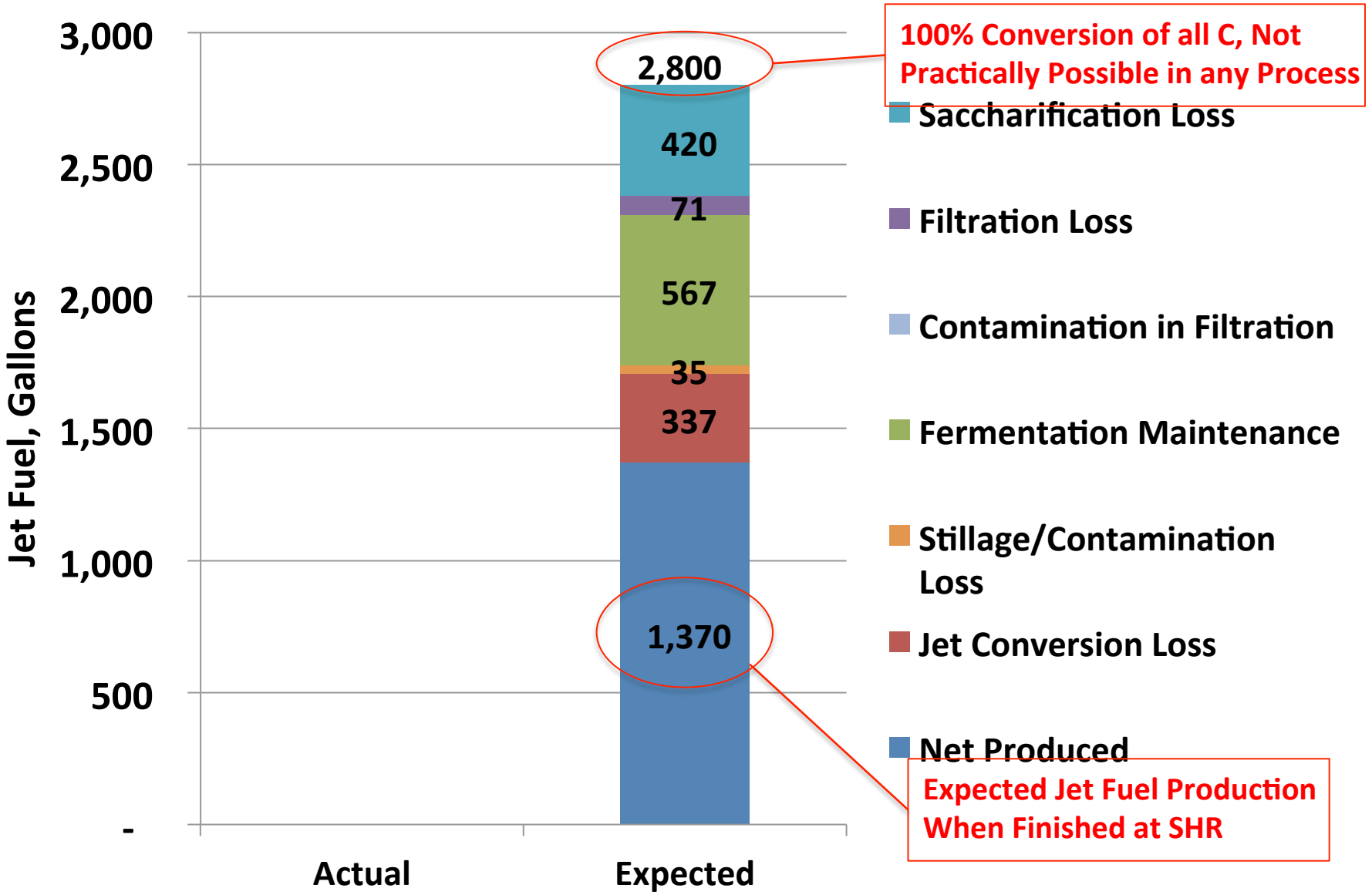
Enzymatic Hydrolysis Excellent, but …



Major Processing Issues at ICM

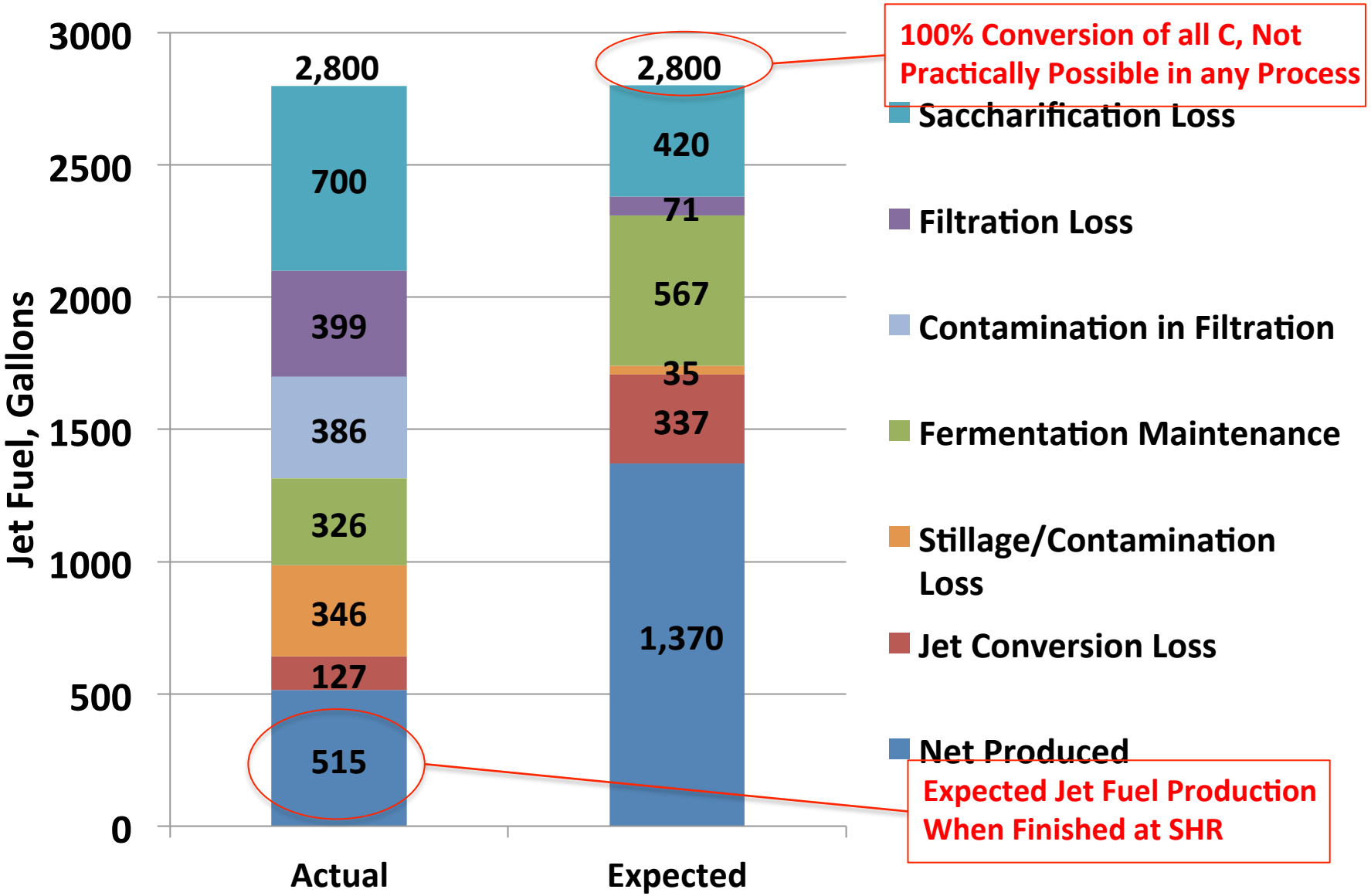
- Filtration of Post Saccharification Solids
  - Testing immediately before run indicated there might be issues
  - Filter Press Filter Rate was much slower than expected
  - Rotary Drum Filter was much slower than expected
  - Sugar losses were much greater than 10% expected
- Led to Long Storage of Sugar
  - Stored at high temperature to avoid contamination
- GIFT system could not maintain design pressure
- Distillation upsets led to contamination of product

Expectation going into ICM as Potential for Jet Fuel



Losses in Ferm & Jet Conv are based on % of material, so design is based on larger amounts coming into those areas

Expectation going into ICM and Result as Potential for Jet Fuel



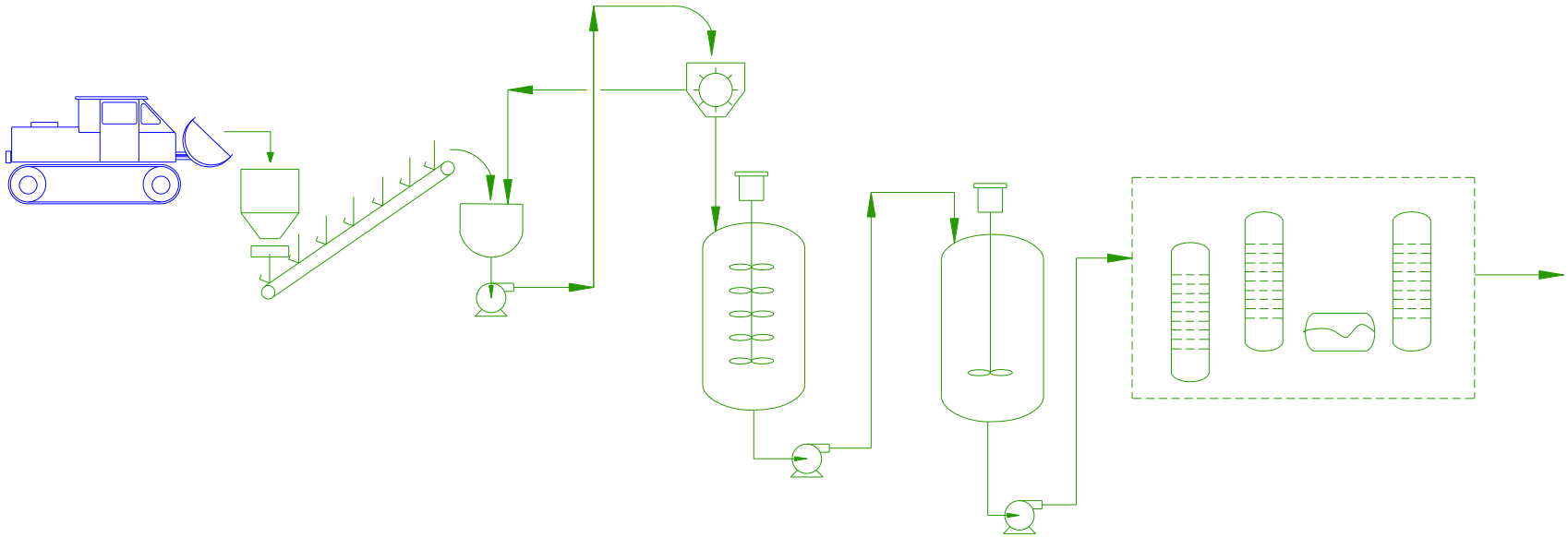
Losses in Ferm & Jet Conv are based on % of material, so design is based on larger amounts coming into those areas

What to Do?

- Pretreated Feedstock Exhausted
- Additional Cosmo Specialty Fibers Material Reject Pulp Might be Available
- Rejected Pulp from Cosmo Specialty Fibers
  - Cosmo material was part of the ICM run
    - ~ 10,000 lb was evaluated in 1st Phase
  - Process is Bisulfite & Similar to NARA/SPORL
  - Feedstock is Hemlock from the NorthWest
  - Retrofitting a Mill or utilizing residues is a design consideration of NARA

Reconfigure at ICM, focus on Lessons Learned

- Process Material through Fermentation without Filtering
  - More like a NARA envisioned Commercial Process
  - Requires more Dilute Fermentations
  - Solids could be an issue in fermenters and GIFT

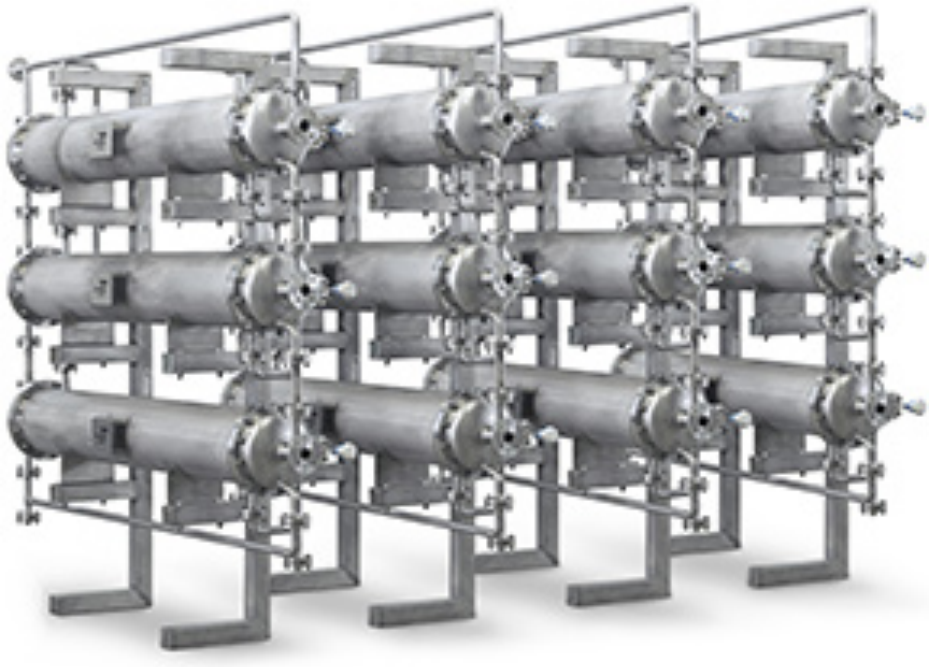


Results with Cosmo Reject Pulp

- After a rough start & initial contaminated saccharification
- 4 Successful Fermentations
- Volume of iBuOH sufficient to produce 1,000 gallons of Biojet.
- Final removal of water before producing Jet

Final Water Removal

- Distillation System at ICM was insufficient to remove Final Water
- Membrane Option was available from Whitefox Technologies
- iBuOH was shipped to Calgary, Alberta for final processing.



Lessons Learned

- Trial as many operations in Toller Equipment as Possible
- Don't Push ahead with Unit Operations Until you are sure the next Unit will Perform as Expected
  - Especially if there could be issues with storing the intermediate
  - This Occurred when we had all solids enzymatically hydrolyzed or in process before we knew how the solids separation would perform
- Avoid storing intermediates which are subject to degradation
  - Moderate concentration sugar streams which are subject to contamination under some conditions and degradation under other conditions
- Make sure there is a strong cost control plan at the toller
  - Fixed Price Might be Best
  - Fixed Rates for tons fed possibly

Biojet Toller

- South Hampton Resources, Silsbee, TX
  - Biojet Production
    - Only pilot facility already set-up to produce BioJet from isobutanol
    - Facility has been running nearly continuously producing Biojet from isobutanol since late 2011 for Gevo

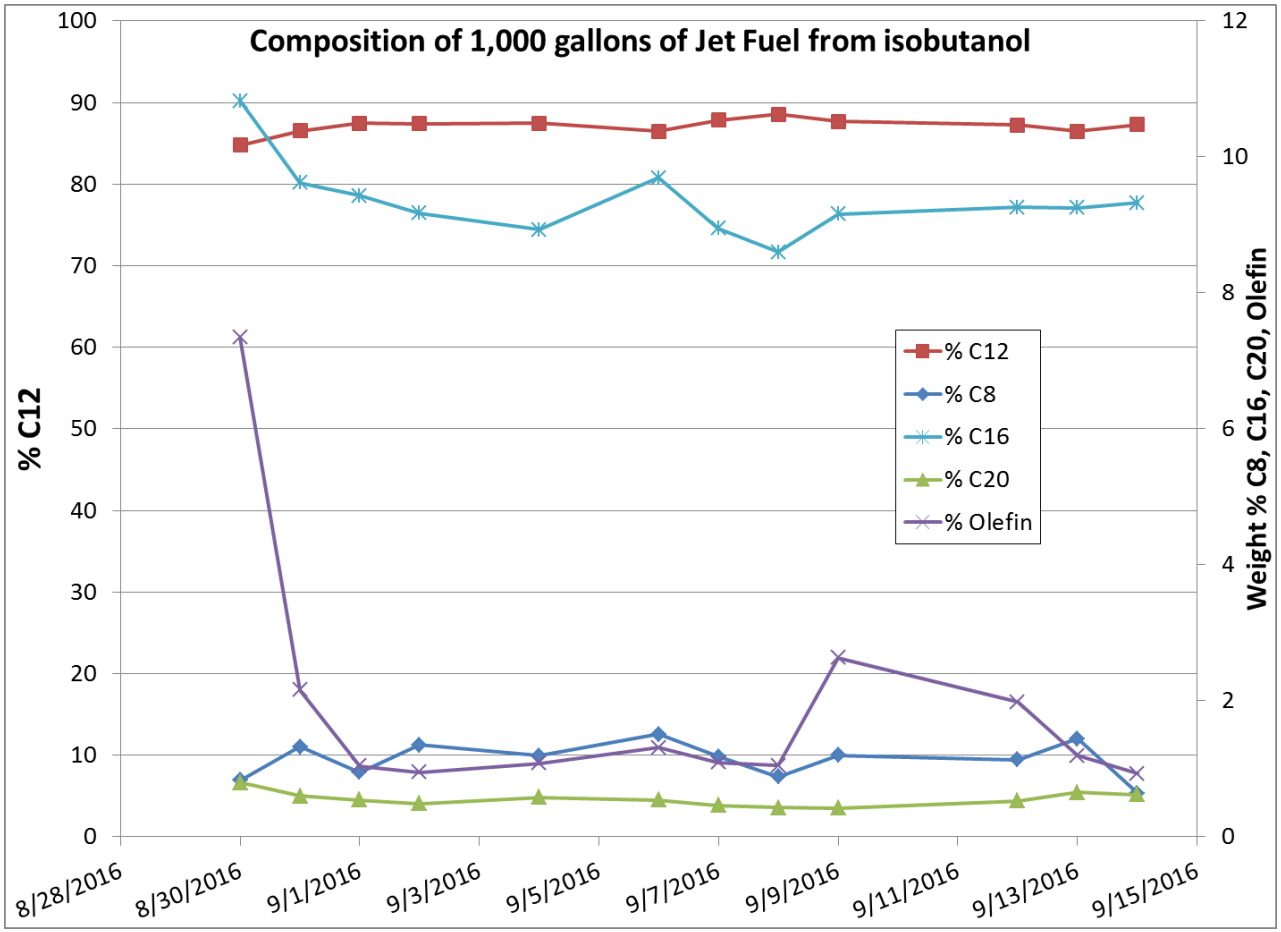
Gevo's Biojet Facility at South Hampton Resources

Biojet Demonstration Plant
South Hampton Resources
Silsbee, Texas

South Hampton Resources
An Independent, Petrochemical Manufacturer in Southeast Texas

Flawless Operation at South Hampton

- Conversion from isobutanol took about 15 days to complete



Final Analysis of Jet Fuel

IAC Port Arthur
6175 Highway 347
Beaumont, Texas 77705-7657 United States of America
T: 409-212 9322
F: 409-212-9327

Certificate of Analysis

INSPECTORATE

Vessel / Shore Tank :	**Submitted Sample**	**Sample Submitted By :**	**South Hampton Refining -- S**
Product :	**BioJet**	**Analysis Performed By :**	**IAC Port Arthur**
Client Reference :		**Date Sampled :**	**15-Sep-2016**
Terminal / Port / Office:	**South Hampton Refining -- Silsbee, TX**	**Date Reported :**	**04-Oct-2016**
Job ID :	**577508-16-0041472**	**Submission ID :**	**008-1603881**
Comments :	**Serial# 244585, 244614 ,& 244601 (Lot# F02SF40001)**		

		Submitted		
	Sample Number	008-1603881-01-006		
Method	**Test**	**Result**	**Specification**	**Pass-Fail**
ASTM D3242	Acid Number , mg KOH/g	0.000	0.015 Max.	Passed
ASTM D86	Observed Barometric Pressure , mm Hg / kPa	760 / 101.3		
	Initial Boiling Point , °C	163.2		
	5% Recovered , °C	175.8		
	10% Recovered , °C	176.4	205 Max.	Passed
	20% Recovered , °C	177.3		

Final 1,000 Gallons of Fuel Passed the Specification Established in ASTM D7566

ASTM D7566 was adopted by the Aviation Industry through great leadership efforts of NARA partner - Gevo

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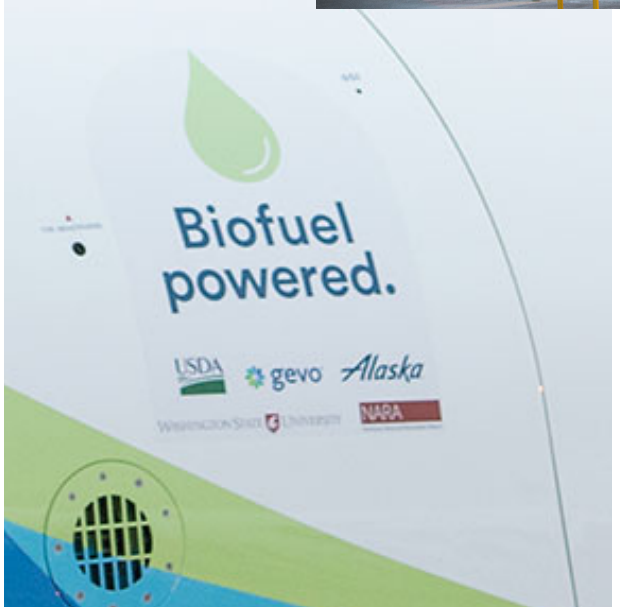
Blending the fuel

Fueling the Alaskan Airline 737 at Seattle Airport
Monday Morning November 14th



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Acknowledgments

The Project was Funded by the U.S. Department of Agriculture's National Institute for Food and Agriculture Program, Award No. 2011-68005-30416.

Novozymes Generously Contributed the Cellic® CTec3 Used for the Enzymatic Saccharification

Hard work and dedication of the Engineers and Technicians at Lane, Zeachem, ICM, Whitefox, SHR and the NARA 1,000 Gallon Task Team

Commercial Demonstration

gevo™

Gevo has made possible these flights by leading the effort to obtain the ASTM Certification of this fuel