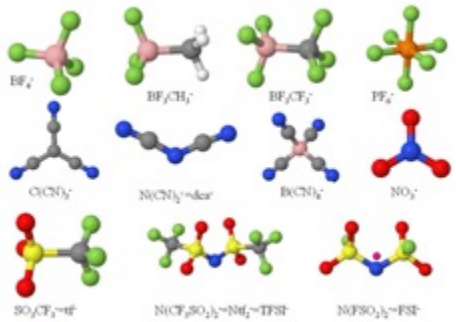
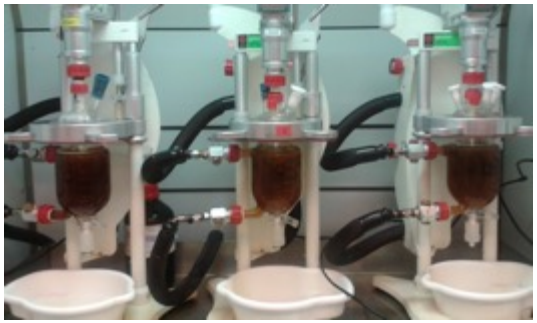
JBEI

Joint BioEnergy Institute

Driving the Future: Advanced Biomass Deconstruction and Conversion Technologies





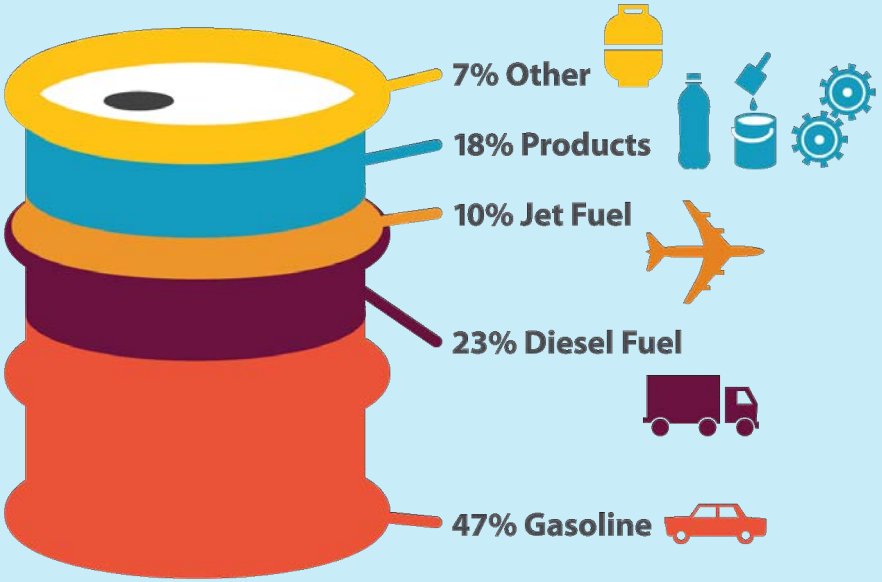
Joint meeting of the Alameda County Special District Association and the Contra Costa County Special District Association

Blake Simmons

July 12, 2021

Petroleum is the Primary Source for Transportation Fuels and Chemicals

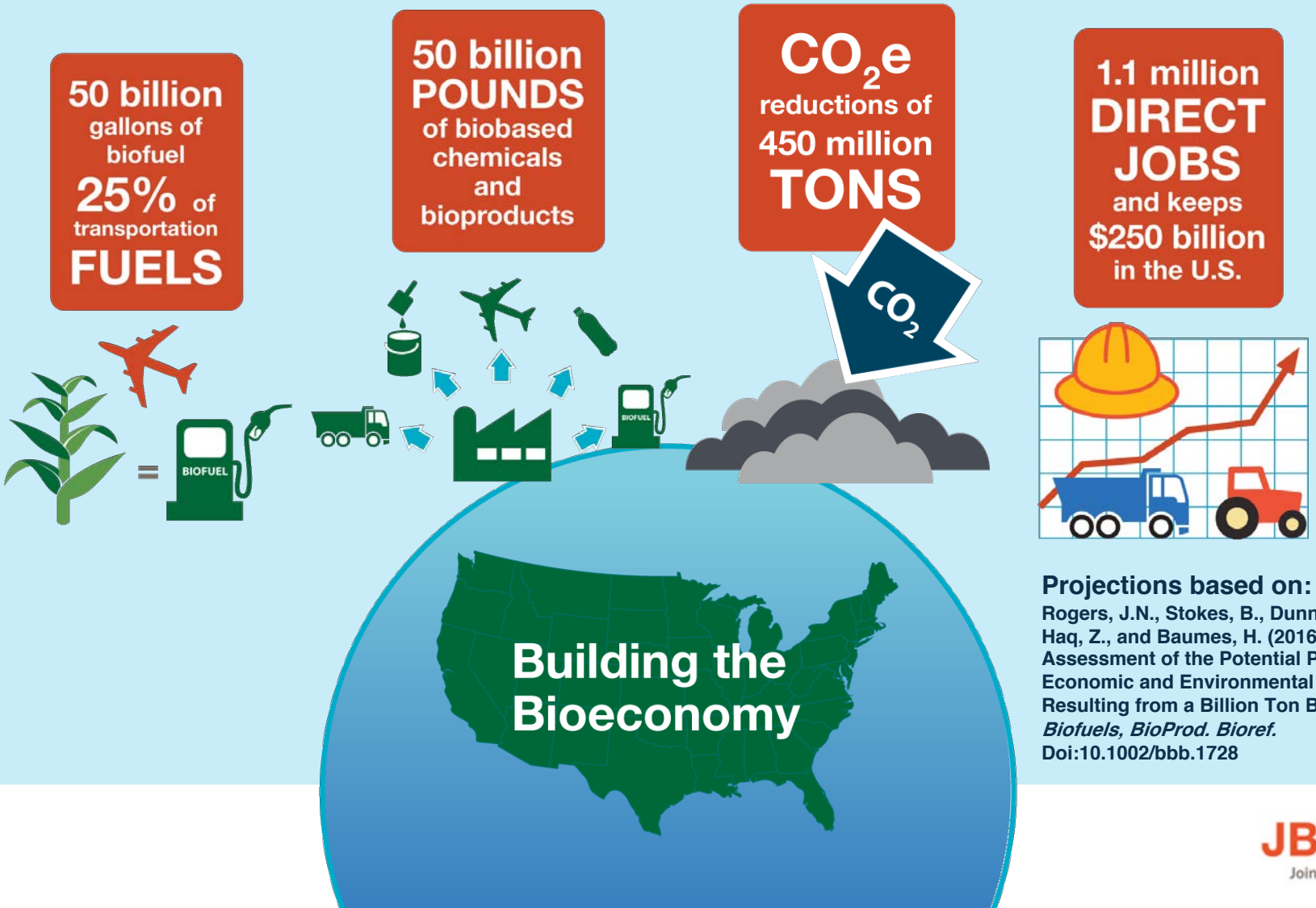
Petroleum products made from a barrel of crude oil



Source: U.S. Department of Energy

The Alternative: Biomass and the Bioeconomy

A billion dry tons of sustainable biomass has the potential to produce …



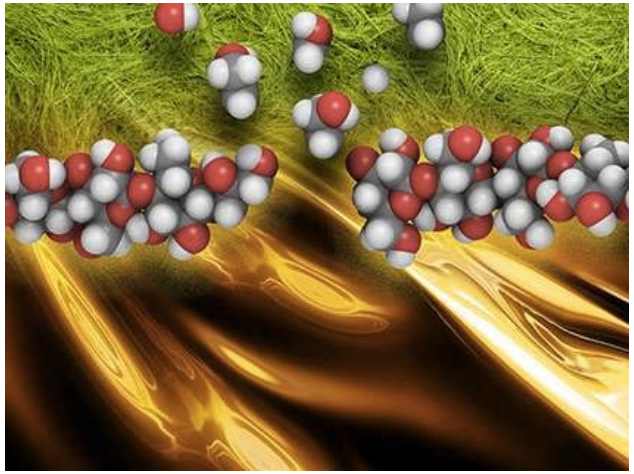
Projections based on:

Rogers, J.N., Stokes, B., Dunn, J., Cai, H., 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

JBEI
Joint BioEnergy Institute

The Challenges

- Lack of scalable and sustainable bioenergy crops
- Difficulty in deconstructing and separating bioenergy crops into targeted intermediates
- Lack of a robust pretreatment technology
- Expensive depolymerization enzymes
- Lack of efficient and affordable microbial routes to drop-in biofuels and bioproducts



JBEI
Joint BioEnergy Institute

JBEI Snapshot

BERKELEY LAB

Sandia National Laboratories

BROOKHAVEN NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

Lawrence Livermore National Laboratory

UCSB UNIVERSITY OF CALIFORNIA SANTA BARBARA

Berkeley UNIVERSITY OF CALIFORNIA

UC San Diego

UC DAVIS UNIVERSITY OF CALIFORNIA

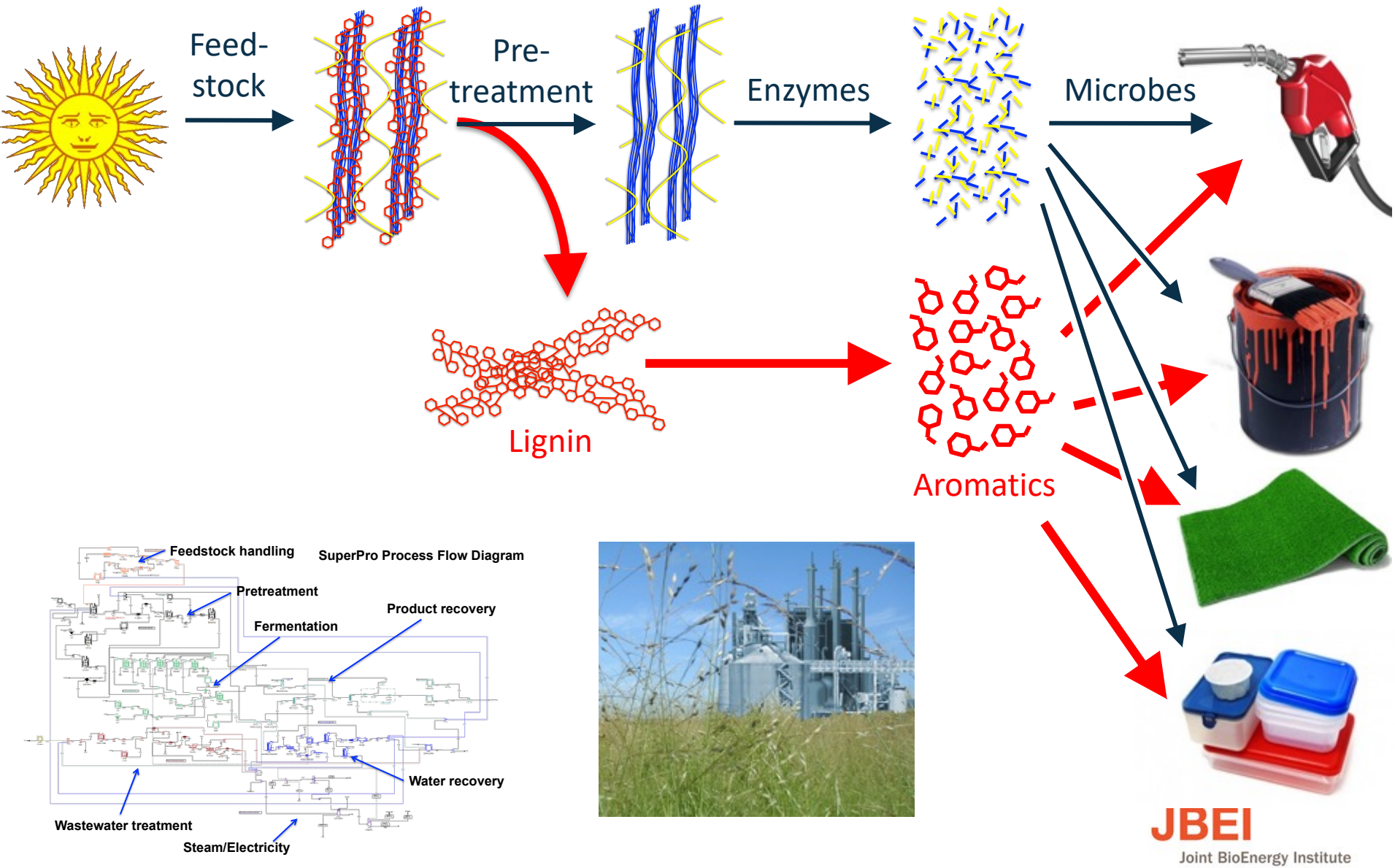
University of California Agriculture and Natural Resources

IOWA STATE UNIVERSITY

- Funded by DOE
- Started in 2007
- Renewed in 2012
- Renewed in 2017

JBEI
Joint BioEnergy Institute

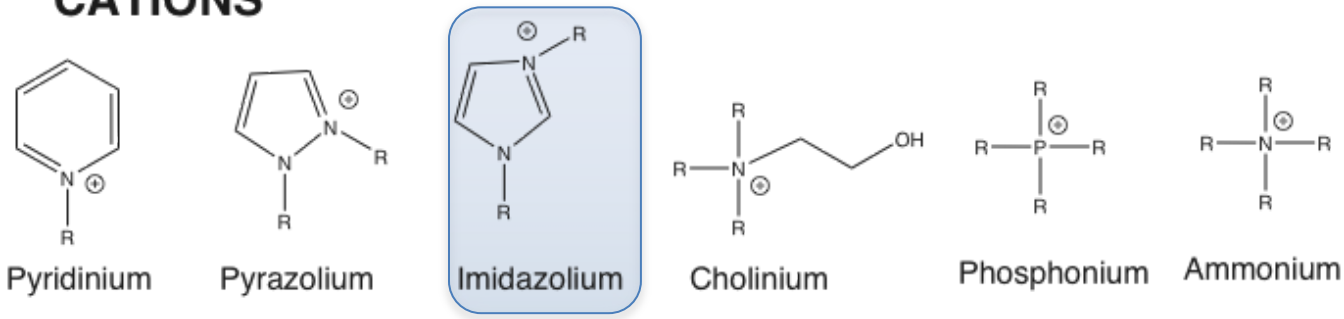
Replacing the Whole Barrel of Oil



Ionic Liquids as Pretreatment Solvents

Room Temperature, Molten Salts

CATIONS



Cation determines:
- stability
- properties

Water immiscible ⟹ Water miscible

ANIONS

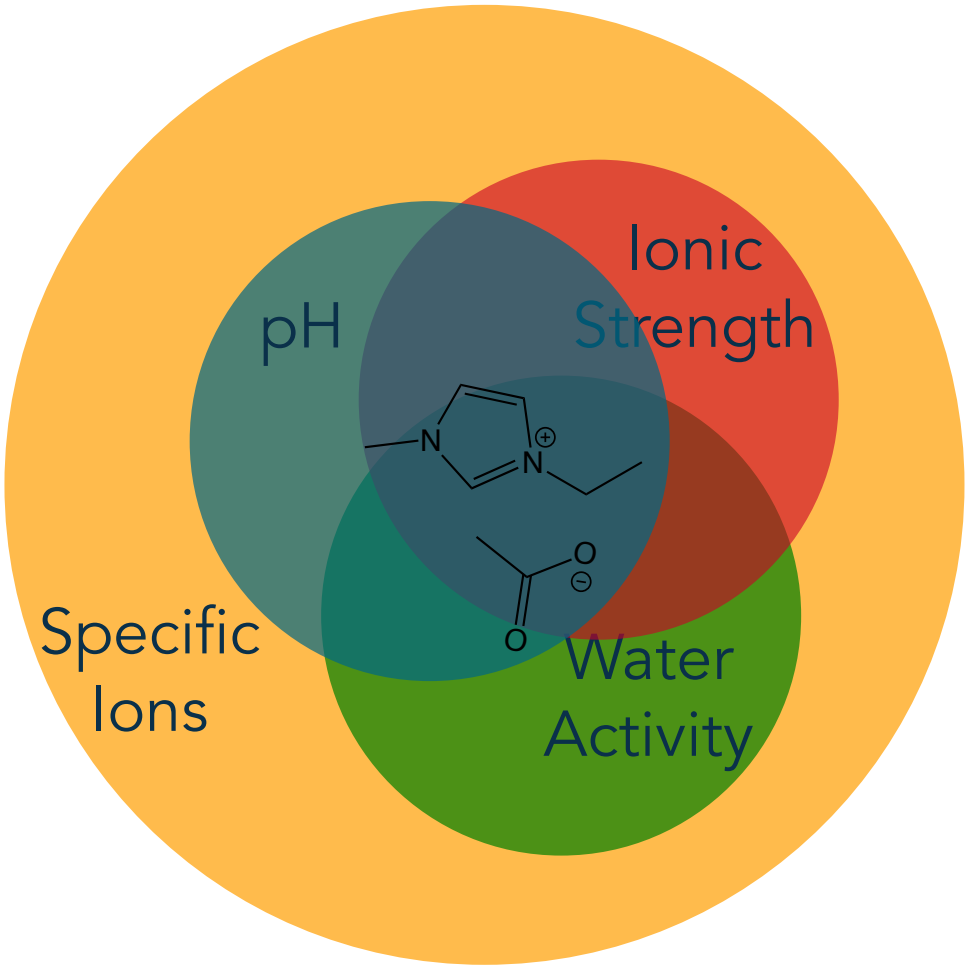
Anion determines:
- chemistry
- functionality

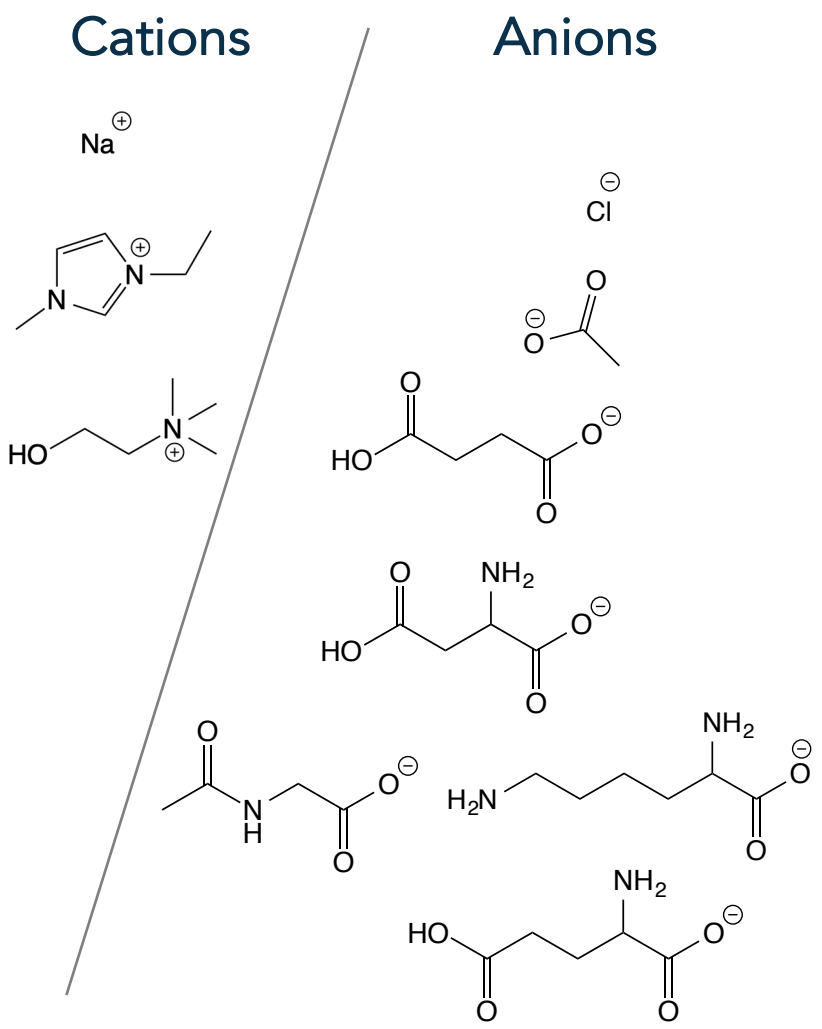
1-ethyl-3-methylimidazolium acetate, abbreviated as $[C_2mim][OAc]$, dissolves > 20 wt% cellulose

Simmons, B. et al., Ionic Liquid Pretreatment, *Chem Eng Prog,* 2010, 3, 50-55

JBEI
Joint BioEnergy Institute

Ionic Liquids alter Solution Conditions

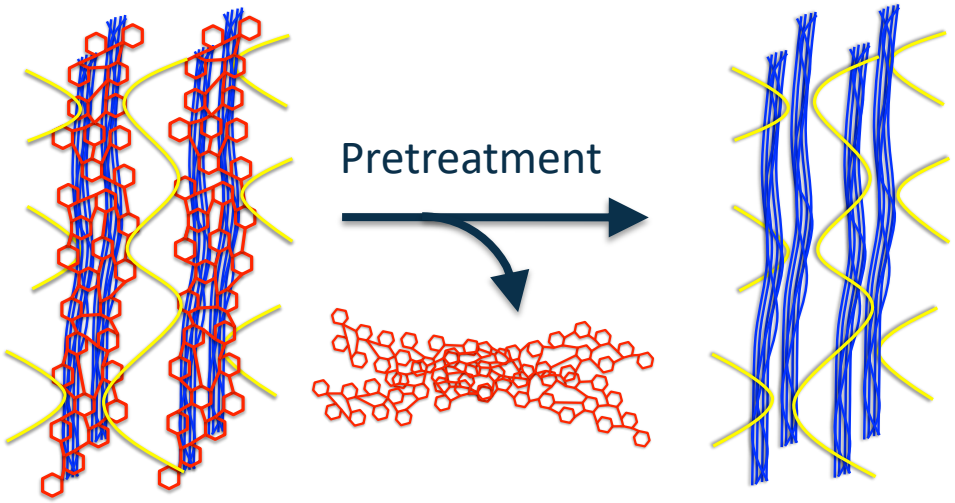




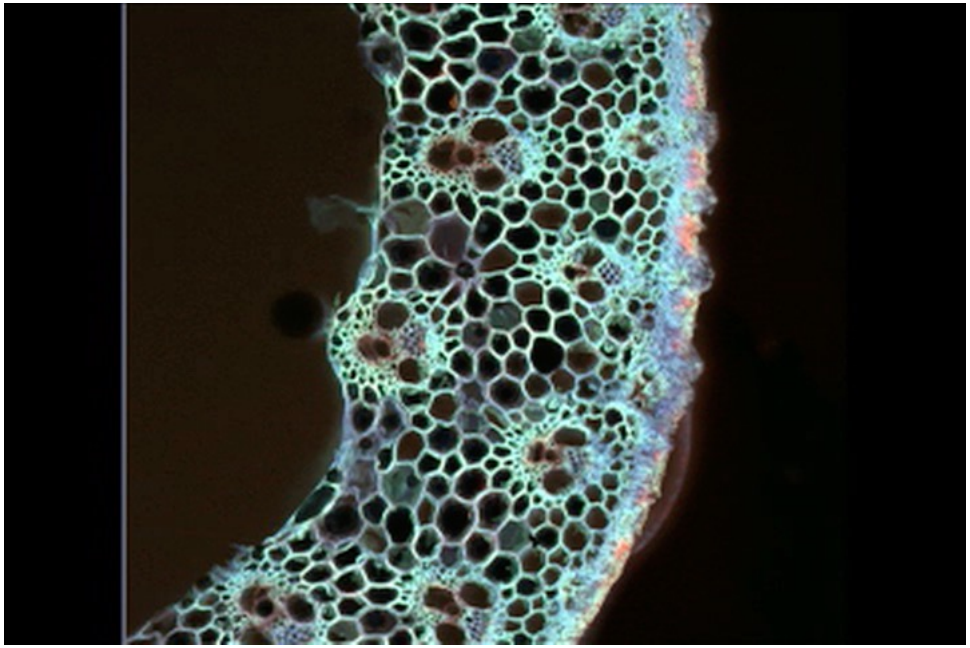
We have been investigating pretreatment efficacy, enzyme stability/activity, and microbial viability as a function of defined solvent conditions

JBEI
Joint BioEnergy Institute

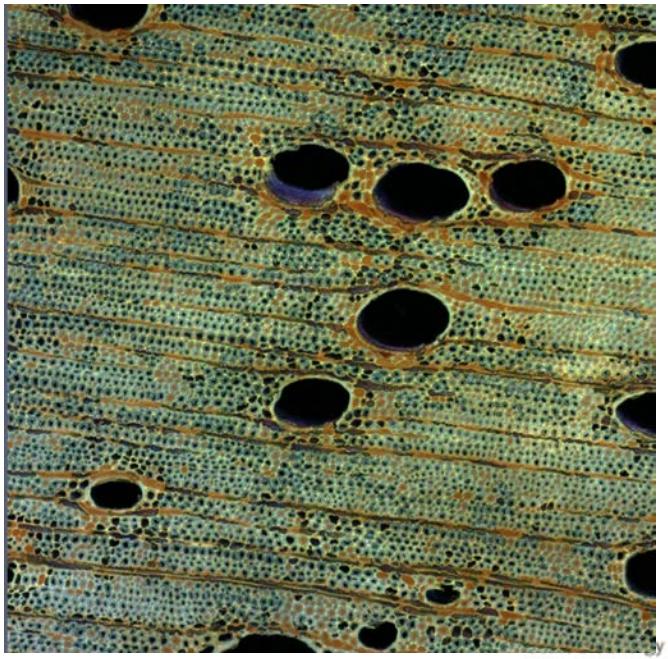
Certain ILs Significantly Perturb Wide Range of Plant Cell Walls



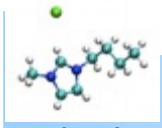
Switchgrass



Eucalyptus



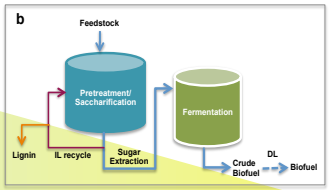
IL Technology Progression at JBEI



Imidazolium pretreatment

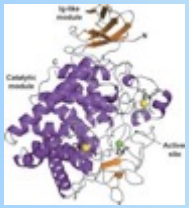
IL-water separations

Mixed feedstock processing

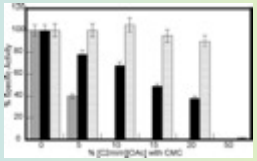


Consolidated pretreatment & saccharification

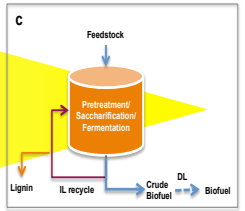
Bionic liquids



IL-enzyme screening & modeling



IL tolerant enzyme mixtures



One-pot conversion

Compost and Rain Forest screening

IL Tolerant Enzymes

IL Tolerant Microbes

IL Pumps

2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

Joint BioEnergy Institute

Lignocellulose Conversion using a One-Pot Process

Step 1

a: IL PT [Ch][Lys] @ 30- 20 wt% solid, 1-3h, 120-140 °C, 60 rpm
b: pH Adjustment (4.8-5)

atm pressure

Step 2

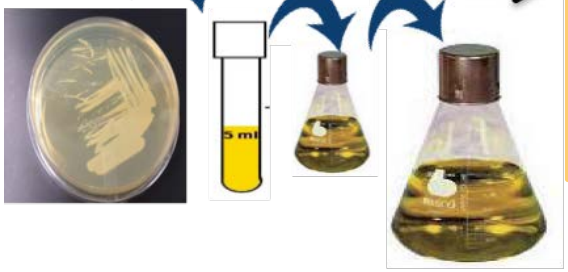
Enzymatic Hydrolysis

20-10 wt% solid, CTec3Htec3,
10 mg/ g biomass 50 °C, 24-48h

➢ **One-Pot Process: Hinges on Biocompatable ILs**

Bioproduct

Microbe propagation



Step 3

Fermentation

20-10 wt% solid, (microbe cells)
37 °C, 24- h

JBEI
Joint BioEnergy Institute

One-Pot Scale-up Project Overview

- **Mission: scale-up JBEI technology on biomass deconstruction and conversion and demonstrate biofuel production on hydrolysates generated with Aemetis**
- **Biofuel targets: cellulosic ethanol and isopentenol**
- **Scale-up target: conversion of 600L of hydrolysate**
- **Feedstocks: mix of CA woody biomass (pine, almond, walnut; 20:40:40 ratio)**

CALIFORNIA ENERGY COMMISSION — **Funding agency**

AEMETIS — **Industry partner**

JBEI — **Core technology development**

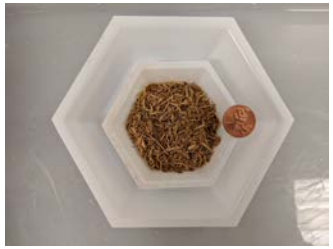
AB PDU — **Process development and scale-up**

novozymes — **Industrial C5/C6 utilizing yeast**

Woody Biomass Feedstocks

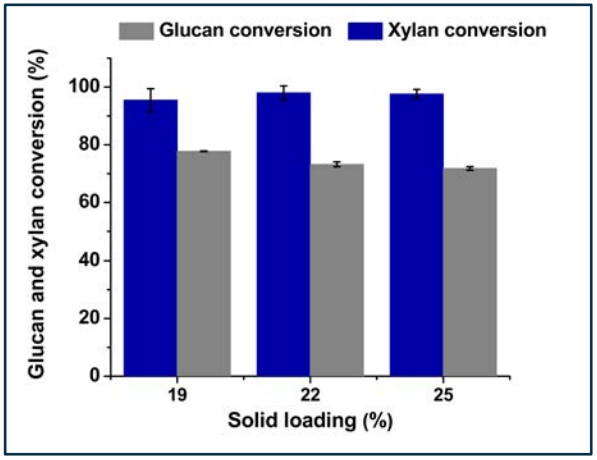
- Central Valley woody biomass feedstocks
- Agricultural and forestry residues
- Biomass milled to 6mm mesh

	Almond	Walnut	Pine
Extractives (%)	15.94 ± 0.30	12.42 ± 1.10	7.12 ± 0.34
Glucan (%)	38.54 ± 0.311	26.29 ± 0.704	29.82 ± 0.566
Xylan (%)	16.056 ± 0.115	9.921 ± 0.268	13.48 ± 0.281
Klason Lignin (%)	21.63 ± 0,145	17.63 ± 0.951	24.74 ± 0.072
Ash (%)	8.13 ± 1.207	19.23 ± 2.304	0.0 ± 0.07

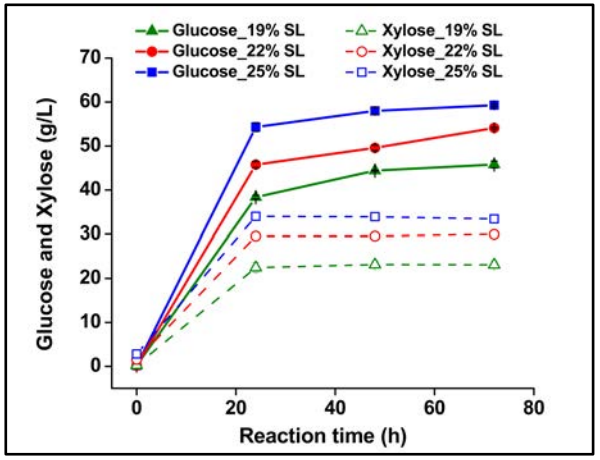


Deconstruction Process Scale-up

- Process scale up to 210L Andritz vessel



- Glucan conversion drops at higher solids loading
- Higher concentrations increase downstream toxicity



- Hydrolysis nearly complete after 24 hours

Fermentation Process Scale-up

Feedstock:
- 630L composite hydrolysate
- 42 g/L glucose, 17 g/L xylose post-inoculation

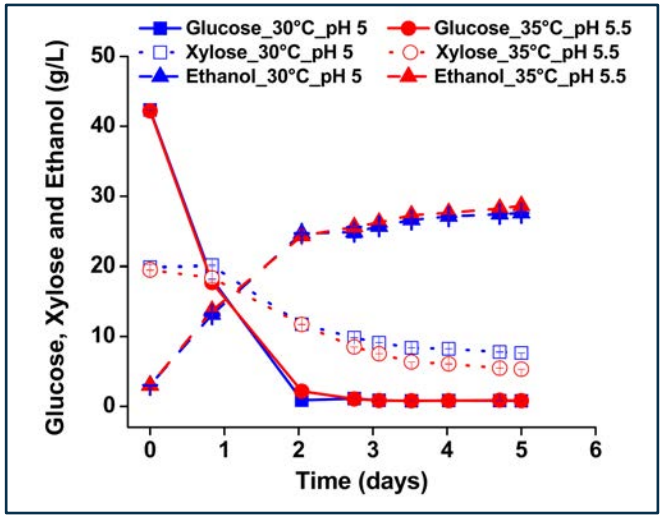
Seed 1:
- YPD media
- 7L shake flask culture

Seed 2:
- 50% YPD / 50% hydrolysate
- 150L aerated fermentor

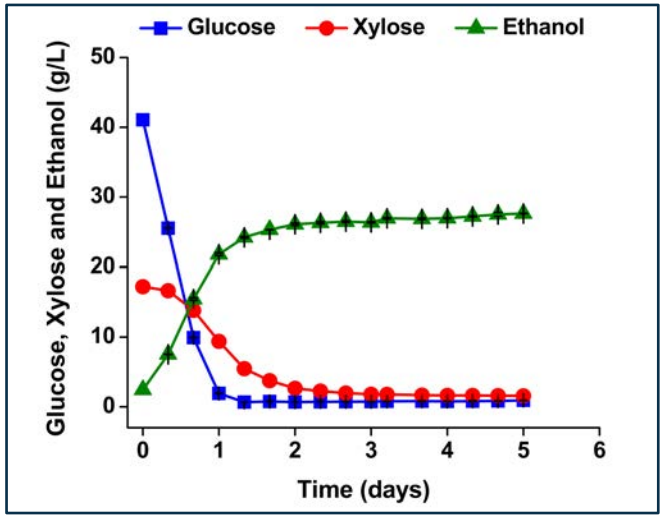
Main fermentation:
- Unfiltered hydrolysate
- 1500L agitated fermentor

Fermentation Results

5L tech transfer



670L pilot fermentation



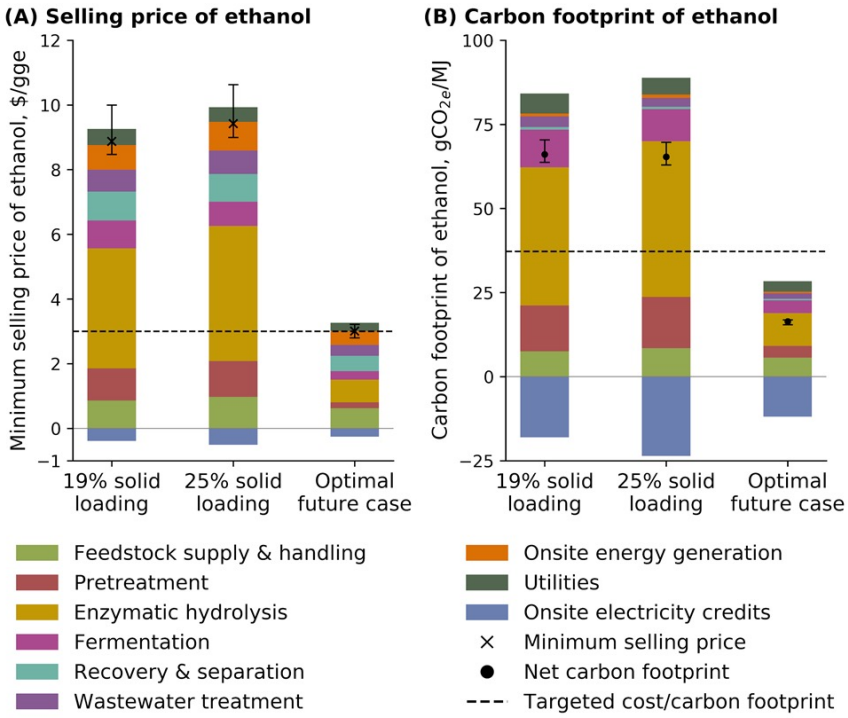
Critical adjustments:

- Reduced pasteurization intensity
- Improved seed train timing
- Final titer 27.7 g/L

11L distilled ethanol

JBEI
Joint BioEnergy Institute

Process Economics at Scale

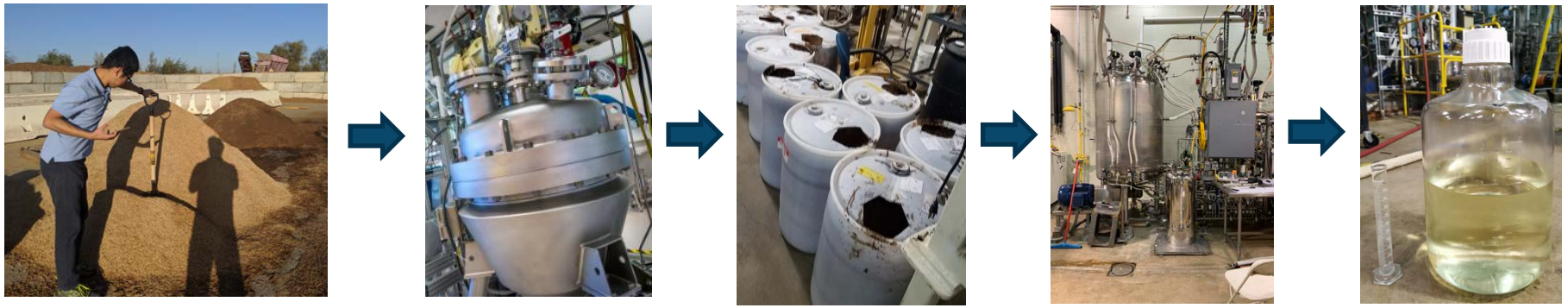


	Current case	*Optimal future case*
Solids loading in pretreatment	19%	25%
Enzyme loading (mg protein/g biomass)	30 mg/g	10 mg/g
Deconstruction efficiency	83%	95%
Fermentation efficiency	93.3%	95%
Carbon footprint (gCO_{2e}/MJ)	**65.3**	**16.4**
Ethanol selling price ($/GGE)	**$8.80**	**$3.00**

JBEI
Joint BioEnergy Institute

Key Results

- Full integration from feedstock to purified ethanol
- No intermediate separations
- >80% deconstruction efficiency
- >90% C5/C6 fermentation efficiency
- >80% ethanol recovery via distillation
- Up to 30 g/L ethanol from California woody biomass
- Scaled to 110L pretreatment and 670L fermentation



JBEI
Joint BioEnergy Institute

Acknowledgments

LBNL
Blake Simmons
Eric Sundstrom
Carolina Barcelos
Jipeng Yan
Asun Oka
Take Soon Lee
Justin Heady
Tosveena Thomas

SNL
Ezinne Achinivu
Lalitendu Das
Harsha Magurudeniya
John Gladden

Aemetis
Jeff Welch
Eric McAfee
Goutham Vemuri

CALIFORNIA ENERGY COMMISSION — **Funding agency**

AEMETIS — **Industry partner**

JBEI — **Core technology development**

AB PDU — **Process development and scale-up**

novozymes — **Industrial C5/C6 utilizing yeast**

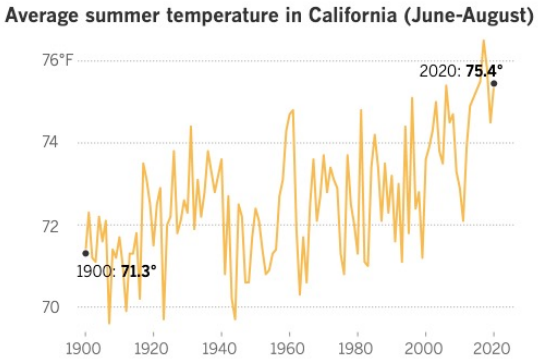
Mobile Biorefineries

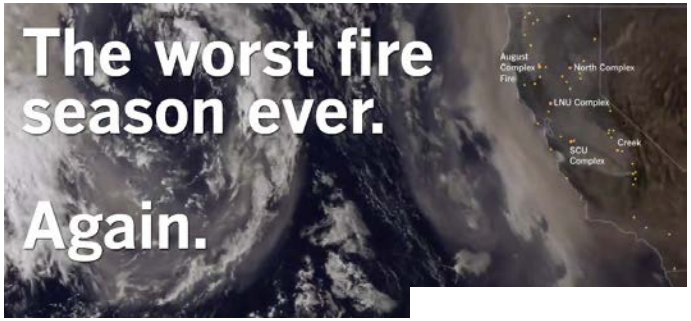
A Distributed Approach to Reduce Wildfire Risk and Boost the CA Economy

JBEI
Joint BioEnergy Institute

The Problem

- Some California forests have 500-800 trees per acre, compared with 60-100 prior to pre-Gold Rush. *https://www.latimes.com/environment/story/2020-09-13/150-million-dead-trees-wildfires-sierra-nevada.
- With temperatures rising, intensifying drought, our forests are now a powder keg.
- 11 million Californians live in the wildland-urban interface.





https://www.latimes.com/projects/california-fires-damage-climate-change-analysis/

- In 2020, five of the six largest wildfires in California history were burning -- at the same time.
- 4% of the land of the state burned.

Top 20 Largest California Wildfires

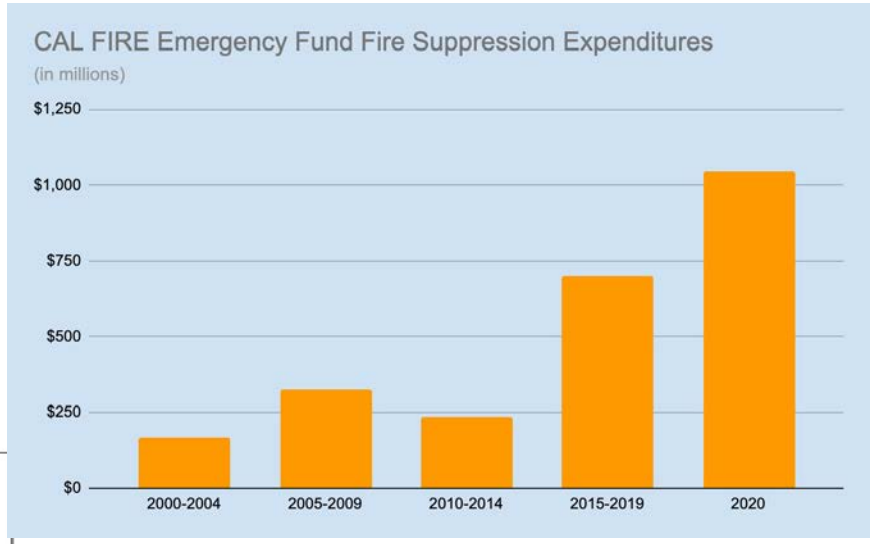
	FIRE NAME (CAUSE)	DATE	COUNTY	ACRES	STRUCTURES	DEATHS
1	**AUGUST COMPLEX** *(Under Investigation)**	August 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, & Colusa	**1,032,649**	935	1
2	**MENDOCINO COMPLEX** *(Under Investigation)*	July 2018	Colusa, Lake, Mendocino & Glenn	**459,123**	280	1
3	**SCU LIGHTNING COMPLEX** *(Under Investigation)**	August 2020	Stanislaus, Santa Clara, Alameda, Contra Costa, & San Joaquin	**396,624**	222	0
4	**CREEK FIRE** *(Under Investigation)**	September 2020	Fresno & Madera	**377,693**	853	0
5	**LNU LIGHTNING COMPLEX** *(Under Investigation)**	August 2020	Sonoma, Lake, Napa, Yolo & Solano	**363,220**	1,491	6
6	**NORTH COMPLEX** *(Under Investigation)**	August 2020	Butte, Plumas & Yuba	**318,930**	2,352	15

https://www.fire.ca.gov/media/4jandlhh/top20_acres.pdf

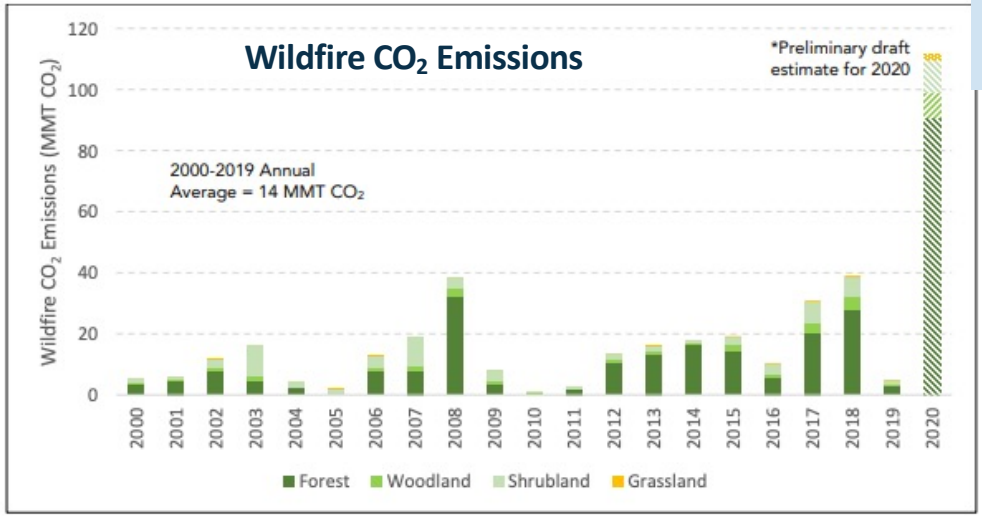
JBEI
Joint BioEnergy Institute

The Carbon and Economic Costs are Enormous

Economic damages
- 2018: ~$120-140B
- 2020: ~$130-150B



https://www.fire.ca.gov/media/px5lnaaw/suppressioncostsonepage1.pdf



https://ww3.arb.ca.gov/cc/inventory/pubs/ca_ghg_wildfire_forestmanagement.pdf

JBEI
Joint BioEnergy Institute

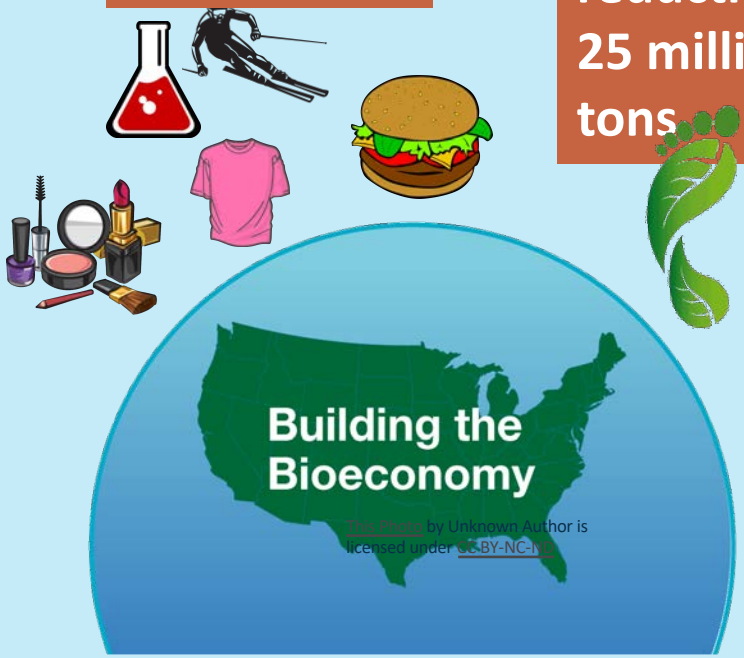
For California … What 56 million tons of sustainable biomass could mean ---

2.5 billion gallons of **jet fuel** (60%+ of current California jet consumption)

2.5 billion pounds of **bioproducts**

C02e reduction of **25 million tons**

61,600 direct jobs

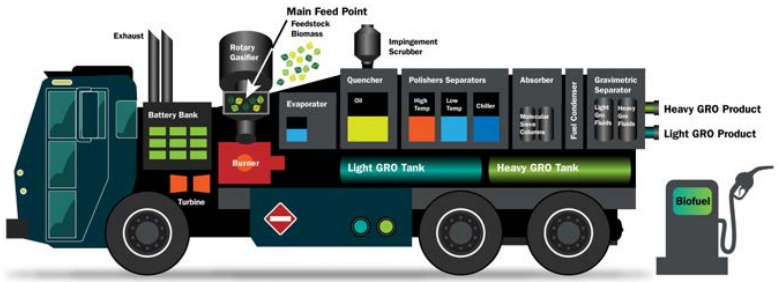


JBEI
Joint BioEnergy Institute

CARIBOU Conversion Approach

Forestry thinnings/residues

CARIBOU Platform



Benefits

- Generate local electricity for vehicles and equipment.
- Generate fuel that can be transported and sold.
- Efficient conversion of forestry thinnings on site.
- Support remote fire crew operations.

Technology can scale in a mobile platform to 500-5000 lbs/hr (bone dry basis)

JBEI
Joint BioEnergy Institute

Birth of the Technology

Generate electrical power from raw wet waste on Forward Operating Bases (FOB)

Reduce JP-8 (diesel) fuel consumption

- Fuel deliveries require military escort
- Estimated delivered cost to FOB $350 to $800 per gallon

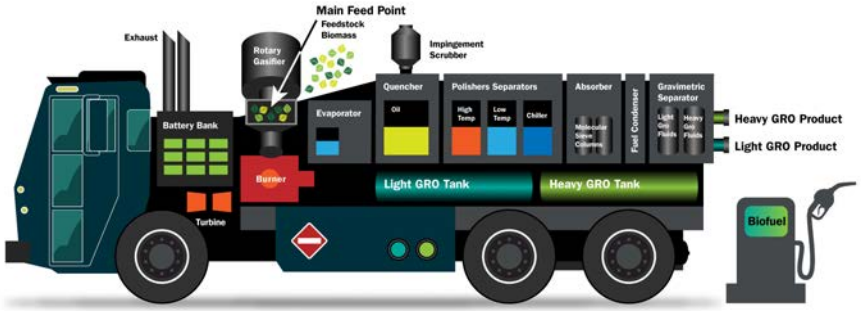
Eliminate burn pits

- Smoke and pollutants
- Health risks

Image: JULIANNE SHOWALTER/U.S. AIR FORCE
HTTP://WWW.STRIPES.COM/NEWS/FEDERAL-COURT-TO-WEIGH-LAWSUIT-ALLEGING-LUNG-DISEASES-FROM-IRAQ-AFGHANISTAN-BURN-PITS-1.386711 -

Compact and Flexible System

- Low parasitic load
- Simple and light weight
- Small reactor and process vessels
- Minimal or no feedstock preparation
- Process dripping wet feedstock
- Able to process soil, stones, glass, and metals mixed with feedstock
- Safe (low hydrogen production)
- High energy syngas from cracking heavy oil into gasoline and diesel.



JBEI
Joint BioEnergy Institute

Feedstock Flexible

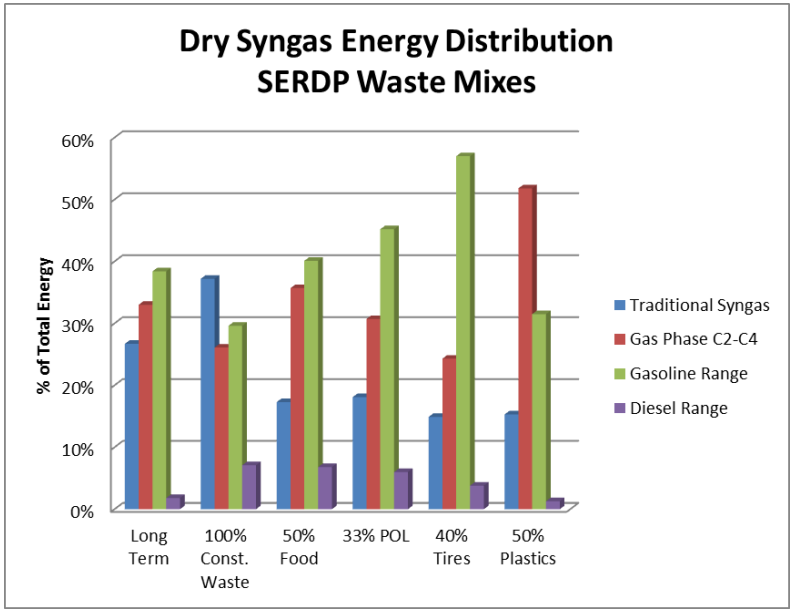
- Able to process dripping wet feedstock
- Cardboard (flat and corrugated)
- Wood (pallets, crates, demolition, etc.)
- Plastics (film, tarps, containers, etc.)
- Clothing (cotton, polyester, canvas, etc.)
- Food (bread, produce, meat, vegetables, etc.)
- Rubber (tires, hose, belts, etc.)
- Used lubricants (crankcase oil, gear lube, grease, c
  spec fuel, etc.)
- Ag wastes (manure, refusals, hay, grass, etc.)
- Trimmings (branches, leaves, cuttings, etc.)

The inclined rotary gasifier developed at SCU (source: SCU).

JBEI
Joint BioEnergy Institute

Choice of Liquid or Gaseous Biofuel Outputs

- Produces a liquid fuel similar to gasoline or a clean syngas
- No biofuel blend wall limit
- Can be extended to produce sustainable aviation fuels
- Simple thermal process
- De-volatilization – NOT incineration
- Accelerates what naturally occurs in the earth over thousands of years to less than 20 minutes



JBEI
Joint BioEnergy Institute

CARIBOU deployment scenarios

- Core technology can be scaled to fit mobile and centralized processing units
  - Best of both worlds in terms of flexible technology development
- Future incarnations of CARIBOU could integrate biopower and biofuel/bioproduct generation
  - Syngas fermentation
  - Sugar production and conversion
- Can be scaled and deployed in multiple locations
  - MSW/mixed feedstock conversion in urban areas
  - Ag residue/forestry thinning/feedlot runoff conversion in rural areas

Next Steps

- Conducting tests on prototype system on CA woody biomass
- Mobile unit optimized for woody biomass is currently being designed
- Scheduled for procurement and delivery late CY21/early CY22
- Validation and remote operations (most likely in Tahoe Basin) in Spring 2022

Summary

- Providing a solution that can scale in both a centralized and a distributed way is essential to accessing the true potential of distributed carbon.
- Improved social, economic and environmental justice in rural and historically disadvantaged communities.
- Mobility – go to where the biomass is.
- Vast opportunities for robust public private partnerships.
- The state/agency/industry defines the equipment and rules.
- Revenue generated will allow for significant scale up and employment opportunities.

Thanks to …

The JBEI Team

www.jbei.org

U.S. DEPARTMENT OF ENERGY | Office of Science

ABPDU

AEMETIS

CALIFORNIA ENERGY COMMISSION

basimmons@lbl.gov

JBEI
Joint BioEnergy Institute