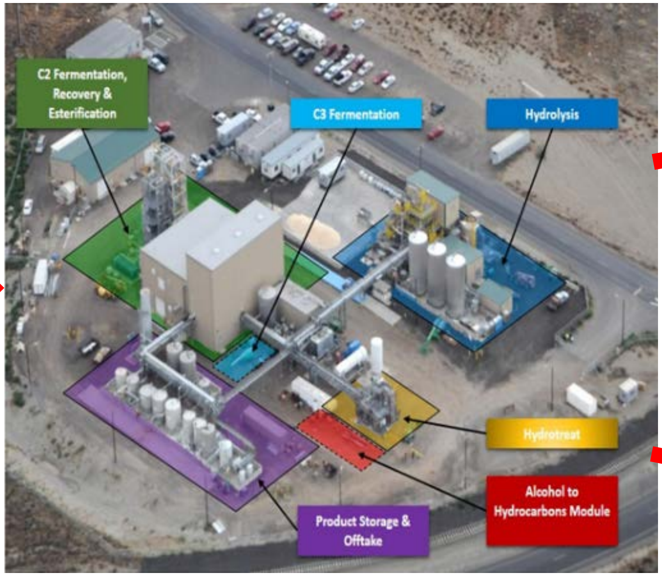
Production of Aviation Fuels and Chemicals from Poplar Feedstock



Rick Gustafson
School of Environmental and Forest Sciences

Advanced Hardwood Biofuels Northwest -
Laying the foundation for a PNW biofuels and bio based chemicals industry

WASHINGTON STATE UNIVERSITY

Oregon State UNIVERSITY OSU

AGRICULTURE CENTER *of Excellence*

UC DAVIS UNIVERSITY OF CALIFORNIA

University of Idaho

W UNIVERSITY *of* WASHINGTON

ZeaChem

NEW HOLLAND AGRICULTURE

ROCKY MOUNTAIN *Wildlife Institute*

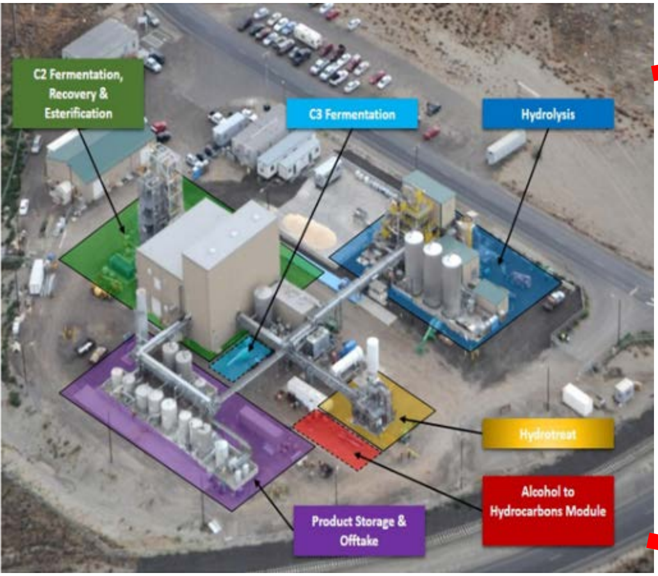
GREENWOOD RESOURCES
A Resource That Lasts Forever™

Advanced Hardwoods Northwest –
preparing PNW for bio based chemicals and biofuels industry

Sustainable energy tree farms growing optimized poplar feedstock

Flexible and efficient biorefineries

Chemical and transportation fuel products

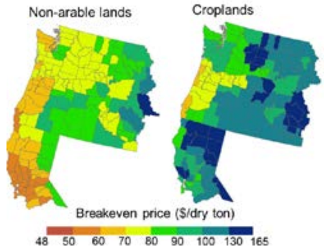


Laying the foundation for a renewable fuels and chemicals industry

Good science

Sound technologies

Thorough analyses



Community and policy support

Sustainable energy tree farms growing optimized poplar feedstock

Flexible and efficient biorefinery

Chemical and transportation fuel products

Well educated work force

Committed land owners

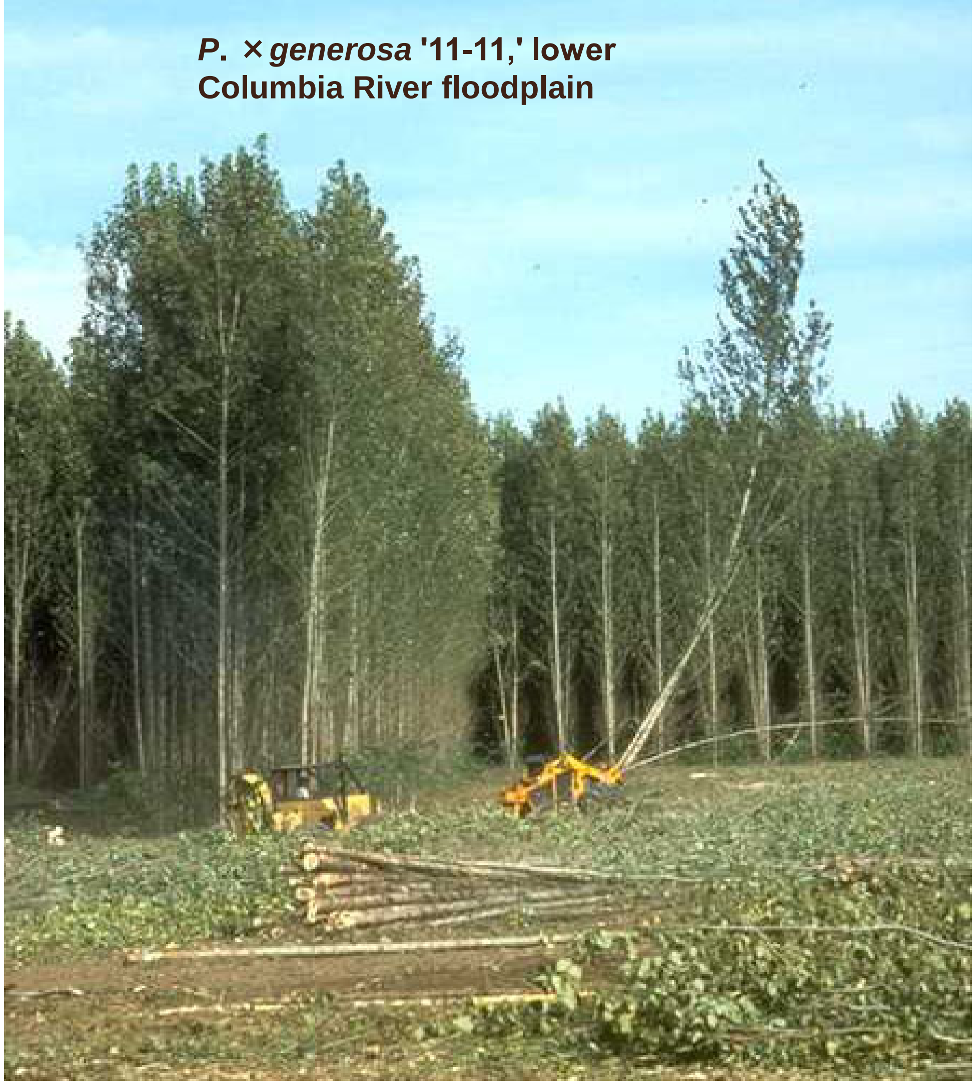
Agenda

- ☐ Feedstock
- ☐ Conversion
- ☐ Sustainability
- ☐ Education
- ☐ Extension

Feedstock production - growing poplar for bioenergy

Hybrid poplar for lumber, veneer, pulp chips

P. × *canadensis* 'OP-367,'
mid Columbia River basin



P. × *generosa* '11-11,' lower
Columbia River floodplain

Bioenergy silviculture

Stocking of 1,453 trees-per acre

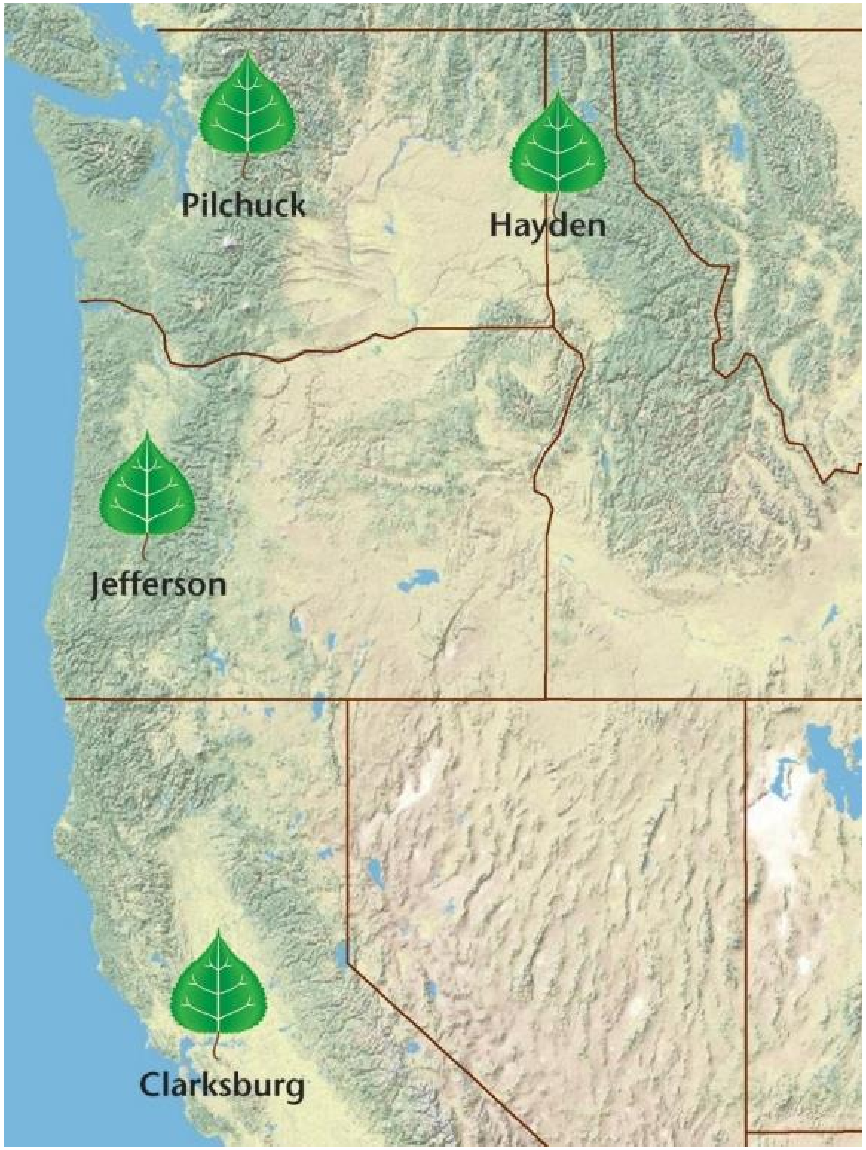
Single-pass harvest technology

Coppice regeneration

Five 3-year cutting cycles

Hybrid poplar demonstration farms

- ❑ Four farms, 50 to 100 acres each.
- ❑ Alluvial plains and Cascade range piedmont sites
- ❑ Sea level to 2300 feet elevation
- ❑ Level terrain up to 10% slope
- ❑ 18 to 45 inches precipitation
- ❑ Clay, clay loams, silty loams



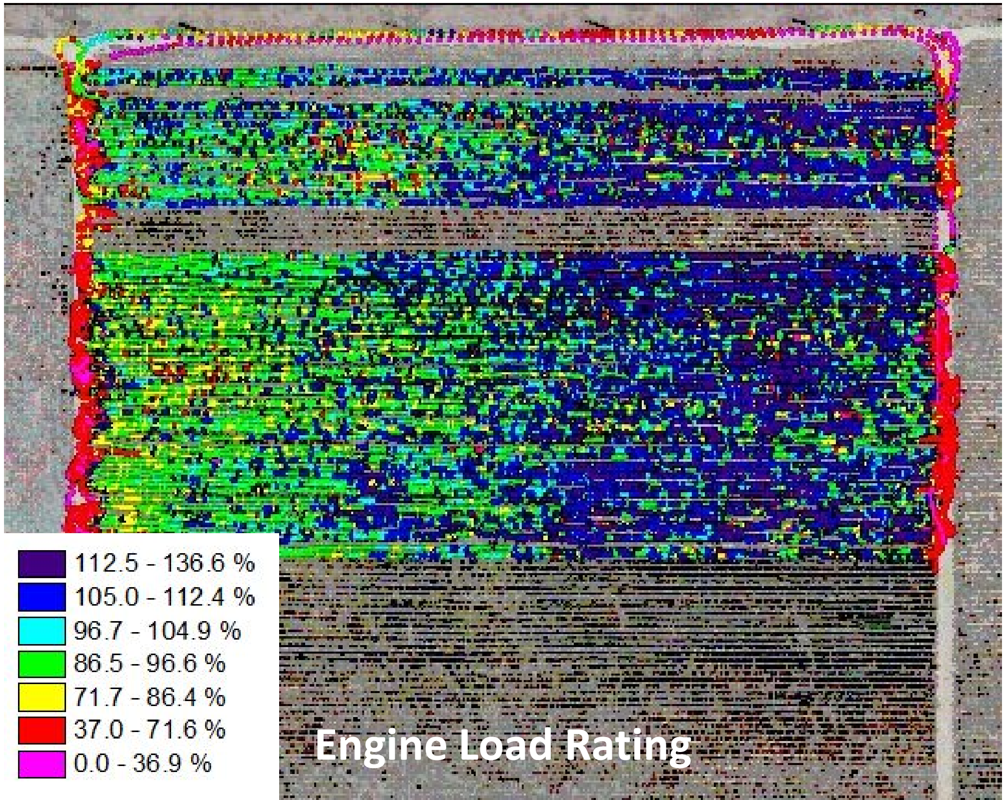
Jefferson OR – 2nd growing season after coppice

Biomass yields top varieties

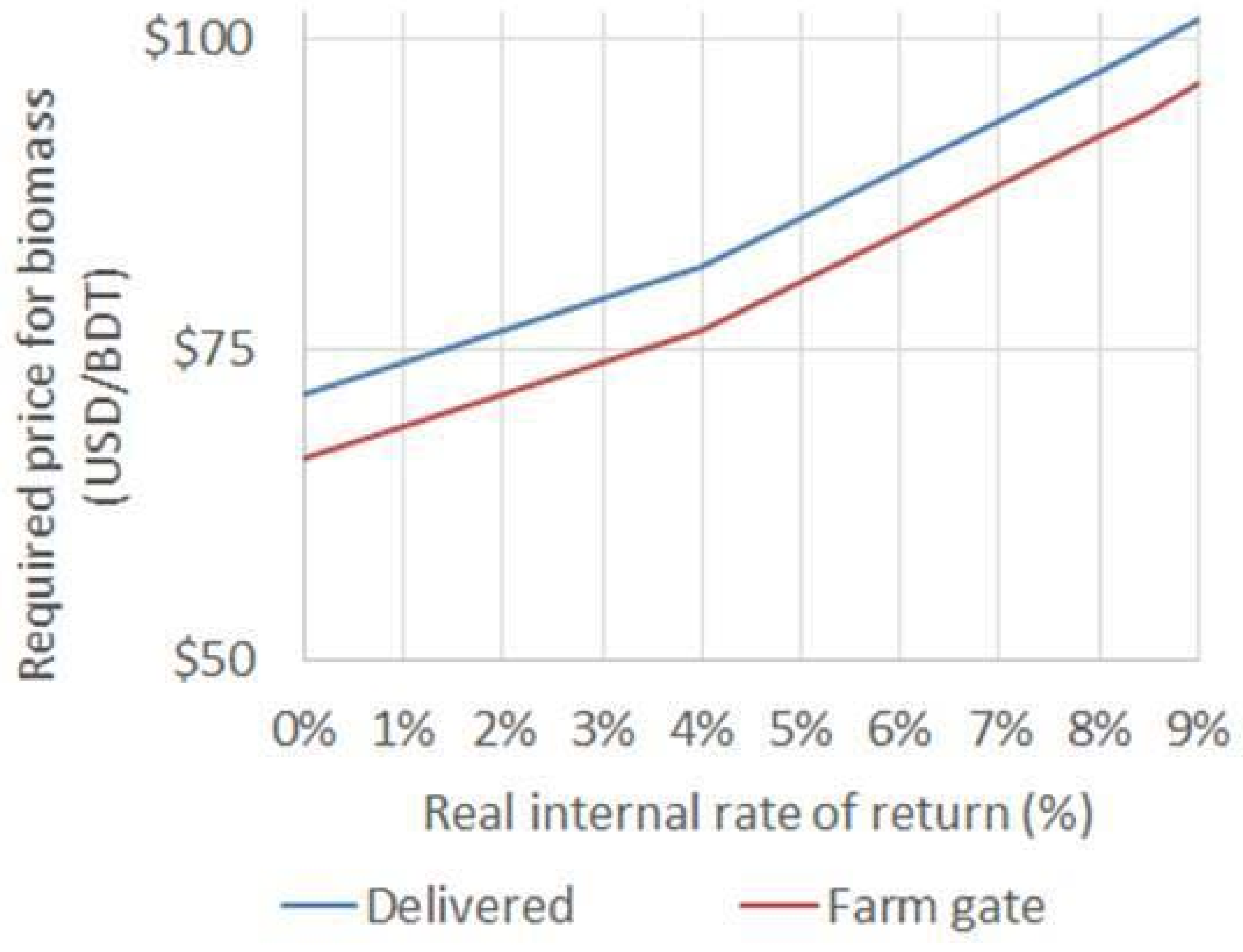
Site	1st Harvest: Two-Years from Planting	2nd Harvest: Three-Years from Coppicing	3rd Harvest: Three-Years from Coppicing
	BDT / acre / year		
Jefferson	5.0	7.0	7.0
Hayden	4.5	7.0	7.0
Clarksburg	5.0	8.7	8.7
Pilchuck	3.0	5.7	5.7
Mean	4.4	7.1	7.1

Inventory and Weight Tables

Harvesting efficiency

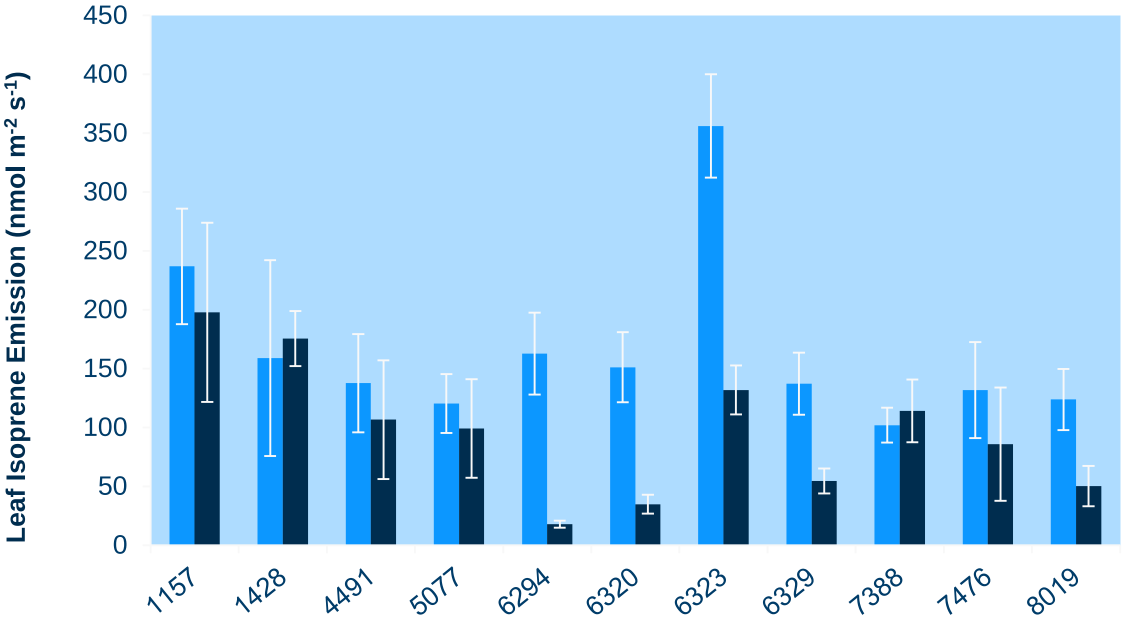


Economics analyses

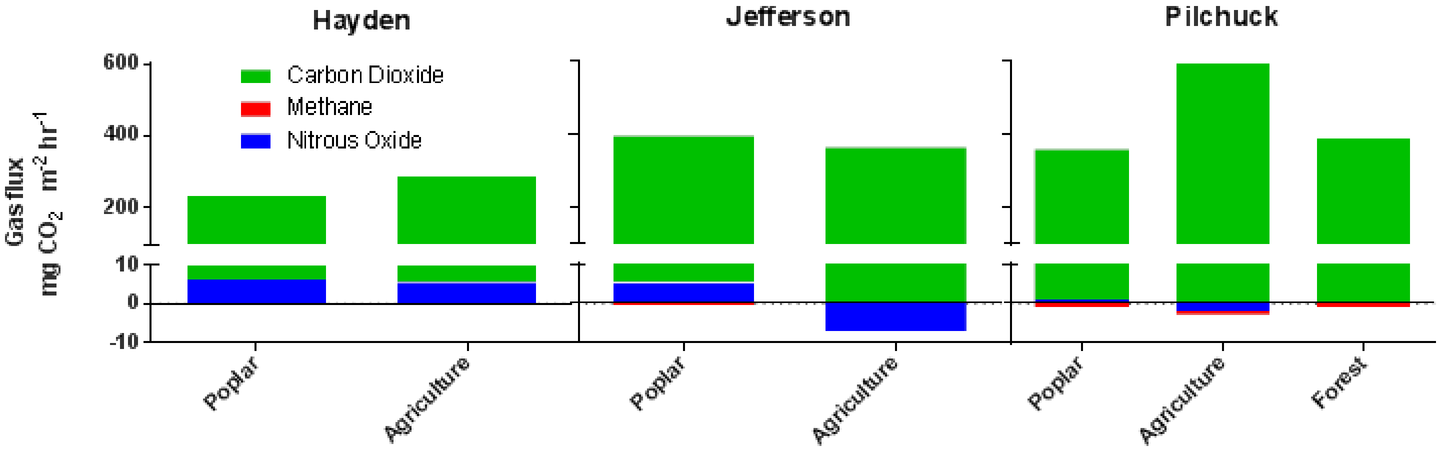


Agronomic sustainability

Leaf isoprene emission variation among hybrid variety for pre- and neo-formed leaves



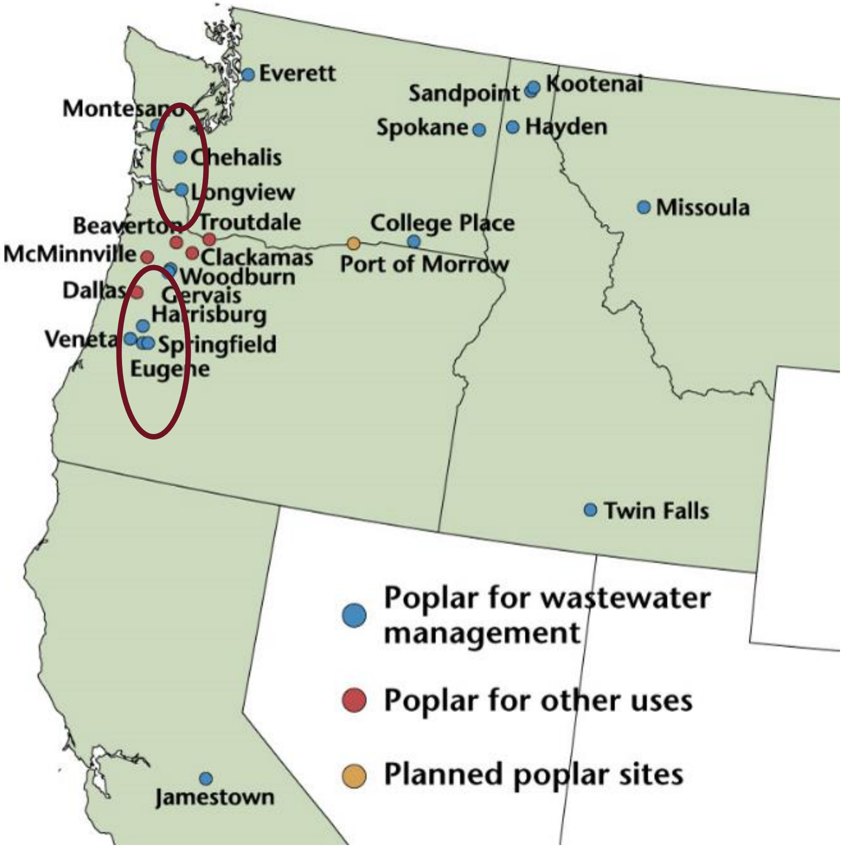
Greenhouse Gas Emissions in poplar and ag reference fields



Poplar at the Biocycle Farm

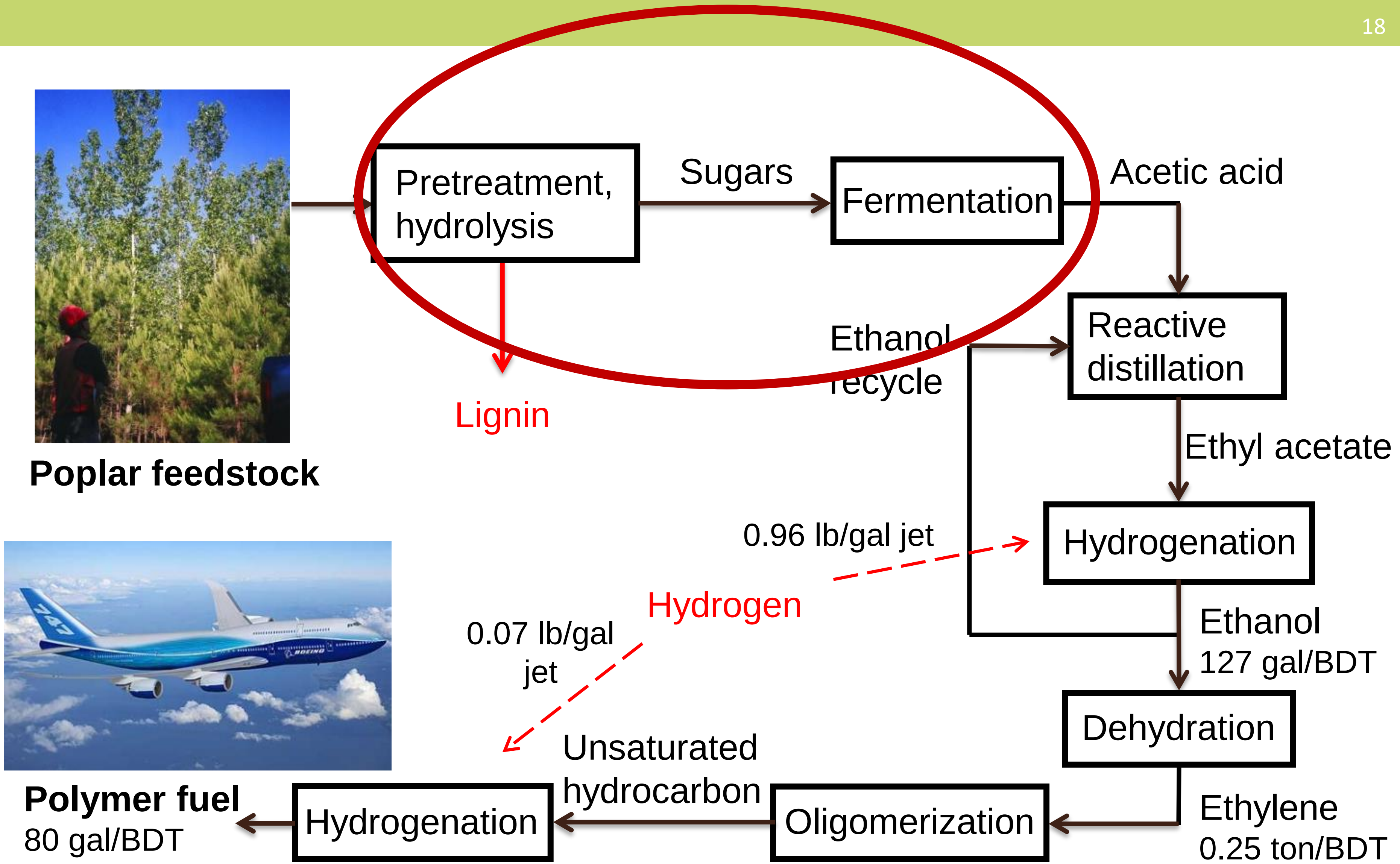
Poplar and Wastewater Management

Overlap with good biorefinery locations



Conversion -
turning trees into fuel and more valuable molecules

One way to make jet fuel from poplar wood



Poplar feedstock

Pretreatment, hydrolysis

Sugars

Fermentation

Lignin

Acetic acid

Reactive distillation

Ethanol recycle

Ethyl acetate

Hydrogenation

0.96 lb/gal jet

Hydrogen

0.07 lb/gal jet

Ethanol
127 gal/BDT

Dehydration

Ethylene
0.25 ton/BDT

Oligomerization

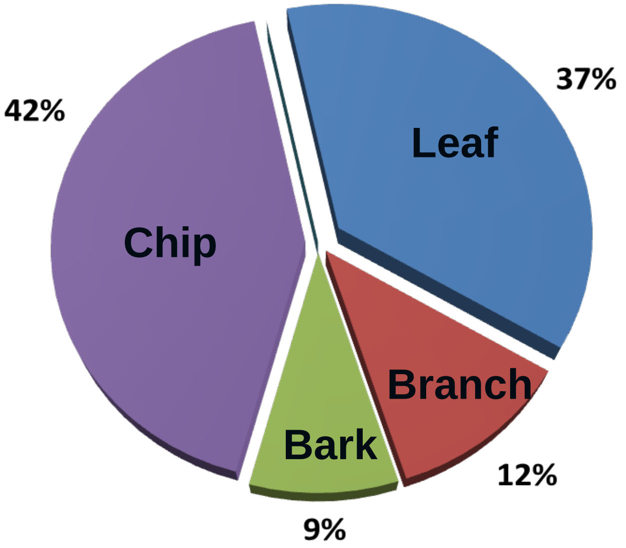
Unsaturated hydrocarbon

Hydrogenation

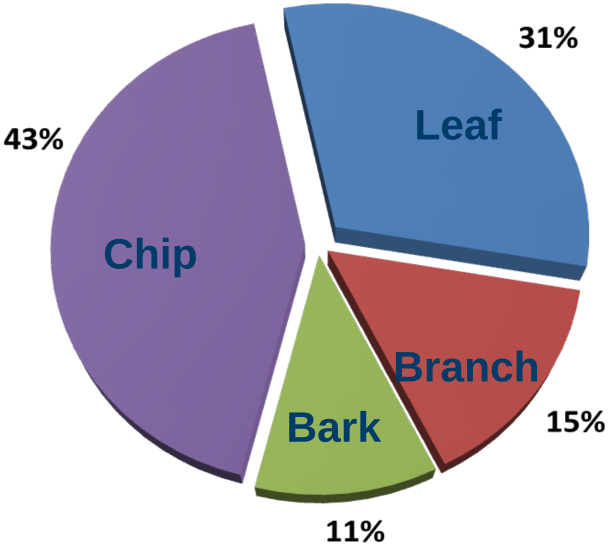
Polymer fuel
80 gal/BDT

Physical composition of 2-year-old hybrid poplar clones (w/w)

5077



8019



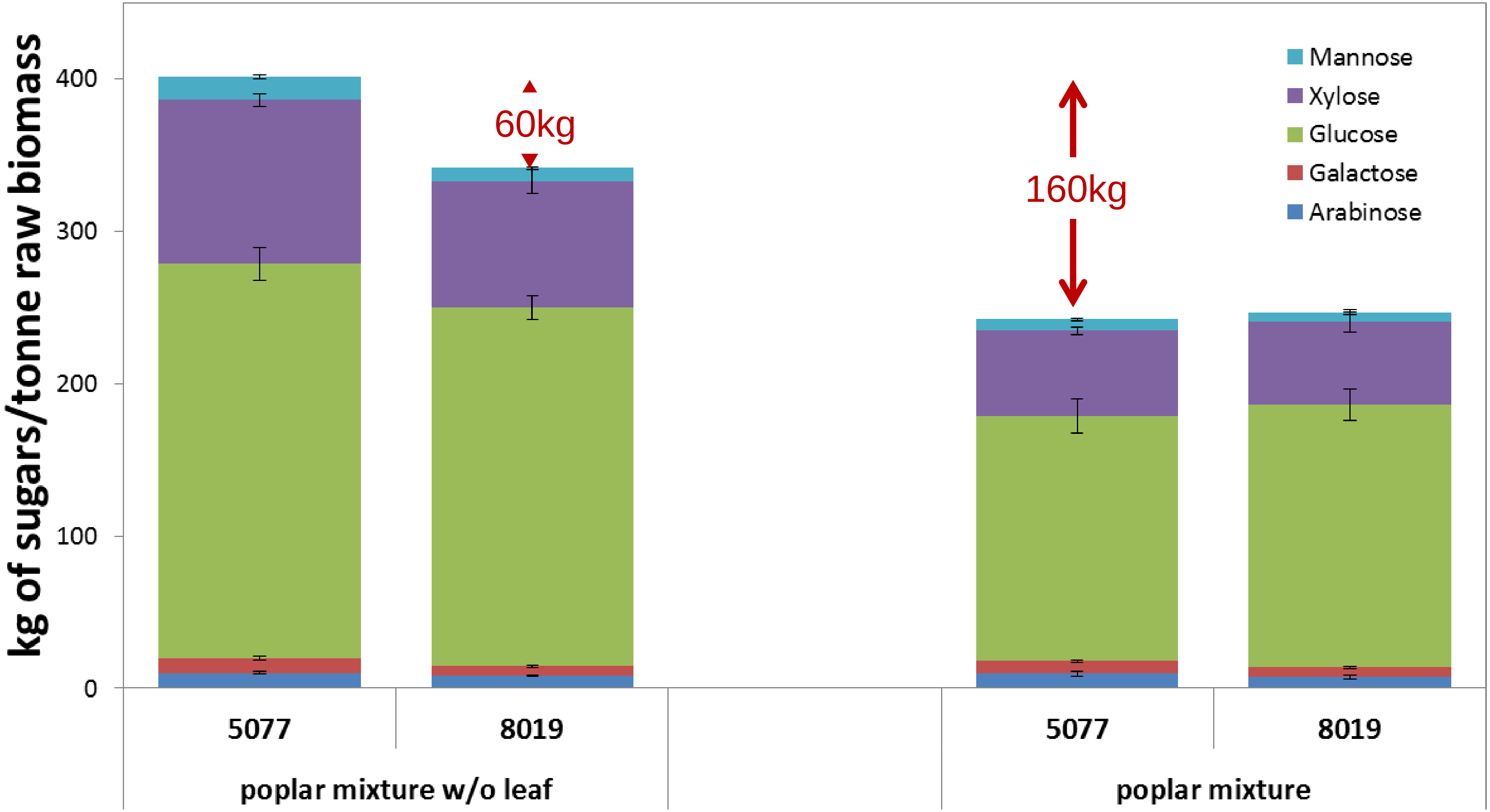
Leaf

Bark

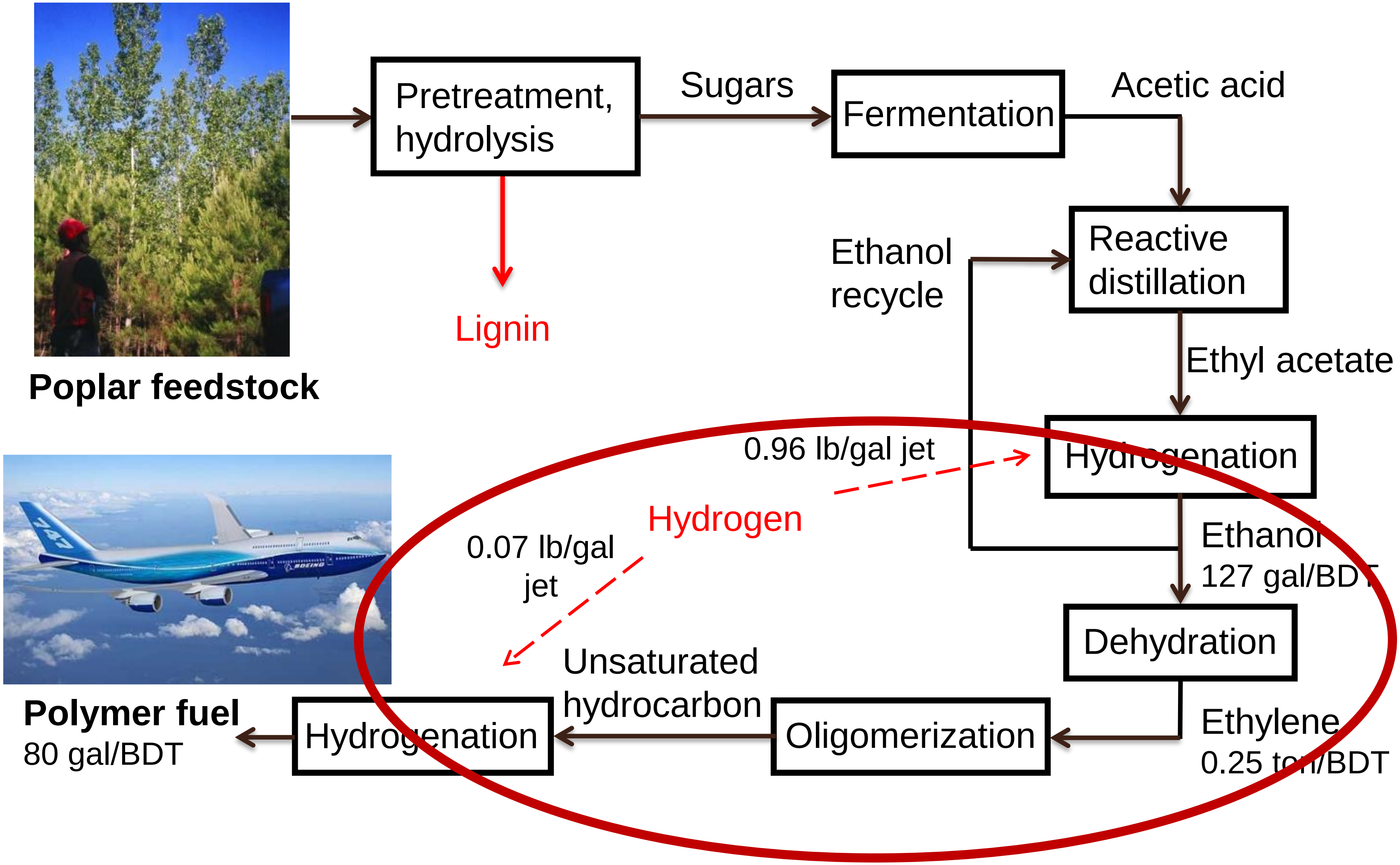
Branch

Chip

Overall monomeric sugars recovery after pretreatment and hydrolysis (kg/tonne)



One way to make jet fuel from poplar wood



Poplar feedstock

Pretreatment, hydrolysis

Sugars

Fermentation

Acetic acid

Reactive distillation

Ethanol recycle

Ethyl acetate

Lignin

Hydrogenation

0.96 lb/gal jet

Hydrogen

0.07 lb/gal jet

Ethanol
127 gal/BDT

Dehydration

Ethylene
0.25 ton/BDT

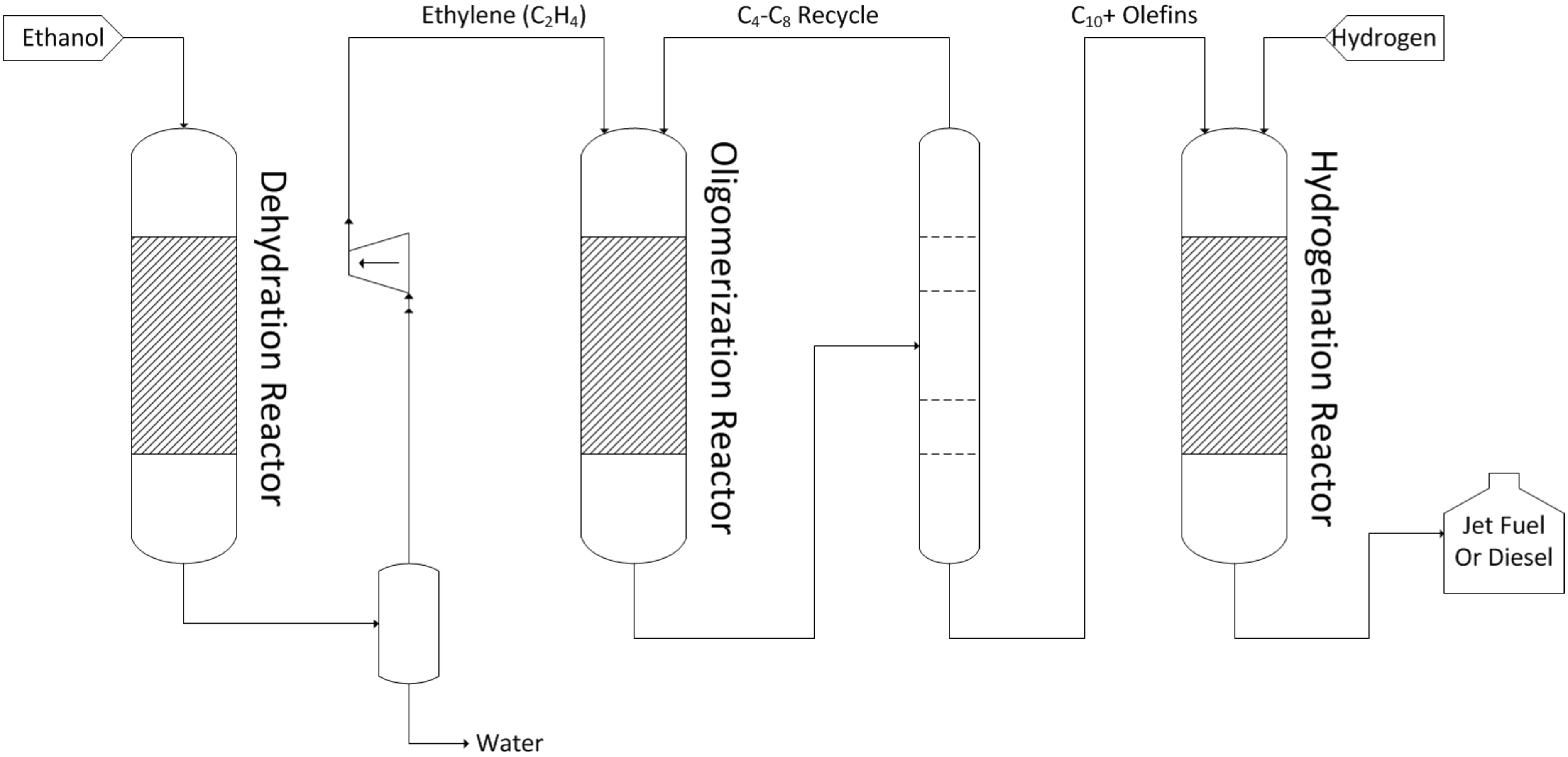
Oligomerization

Unsaturated hydrocarbon

Hydrogenation

Polymer fuel
80 gal/BDT

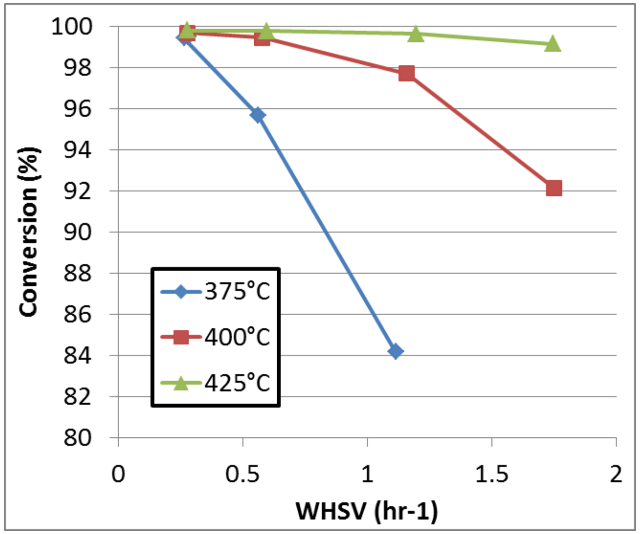
Process flow diagram



Dehydration of Alcohols

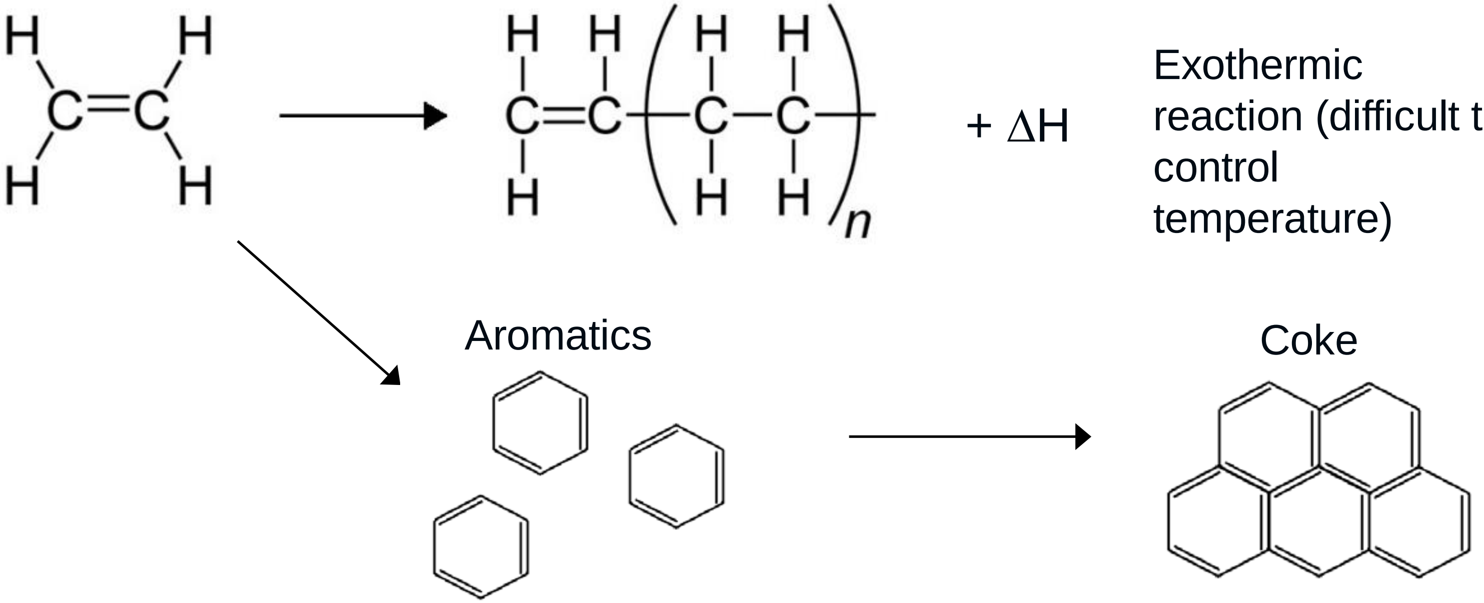
$$C_2H_5OH \rightarrow C_2H_4 + H_2O$$

- Ethanol dehydration experiments completed
  - Commercial alumina catalyst (inexpensive, readily available)
  - Conversion and selectivity to ethylene > 99.5% achieved
- Propanol dehydration experiments completed
  - Same catalyst, similar results



Fresh catalyst **After 310 hrs**

Oligomerization of ethylene



ethylene

oligomers

+ ΔH

Exothermic reaction (difficult to control temperature)

Aromatics

Coke

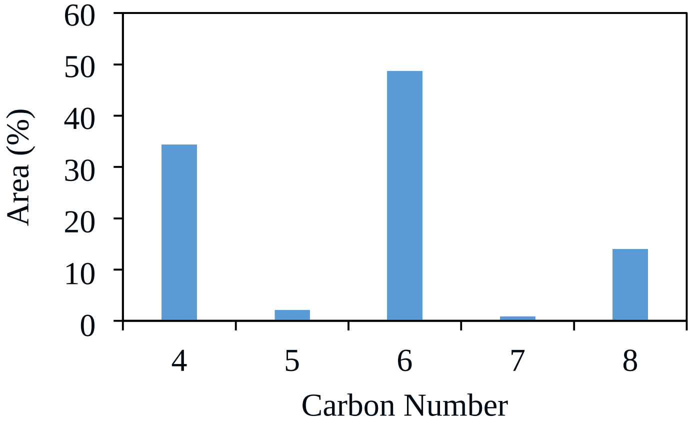
Deactivates catalyst

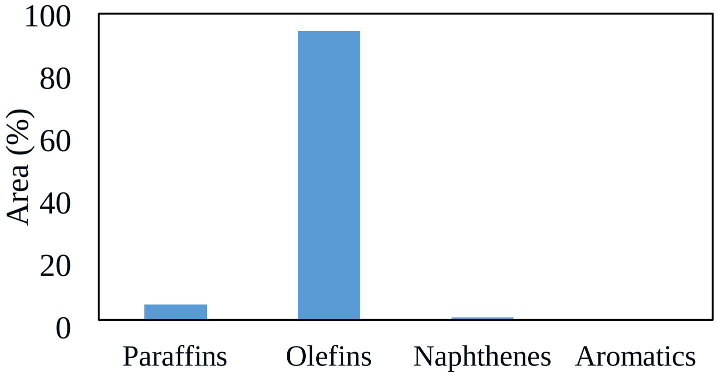
Unclean combustion (smoke and char)
Benzene is carcinogenic (limit 0.8 wt %)
Maximum 20 wt % in gasoline

Hydrocarbons Composition – Ni-Al-MCM-41

190° C, 510 psig, with 5 wt.% nickel at a WHSV of 3.50 hr^{-1}. Liquid yield:24.58 wt.%

Ni-MCM-41 Preparation



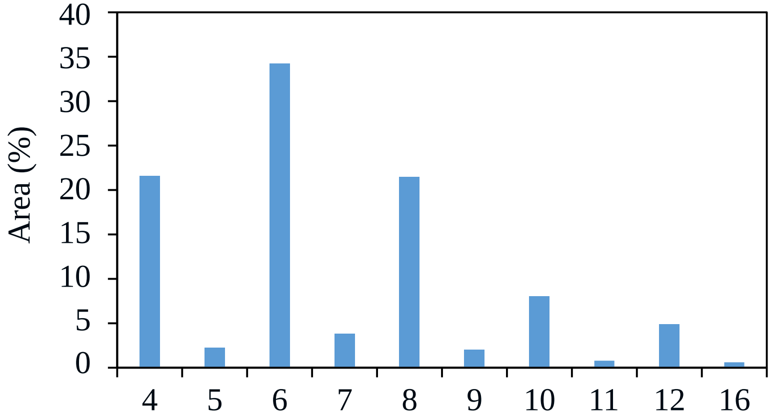


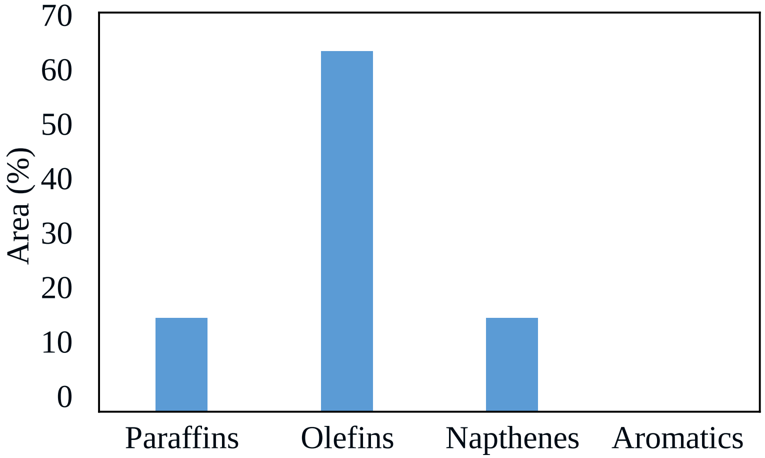
Liquid Product

Hydrocarbons Compostion - Ni-Hβ

120° C, 520 psig, 5 wt.% nickel at a WHSV of 2.08 hr^{-1}. Liquid yield: 8.03 wt.%

Catalyst Preparation





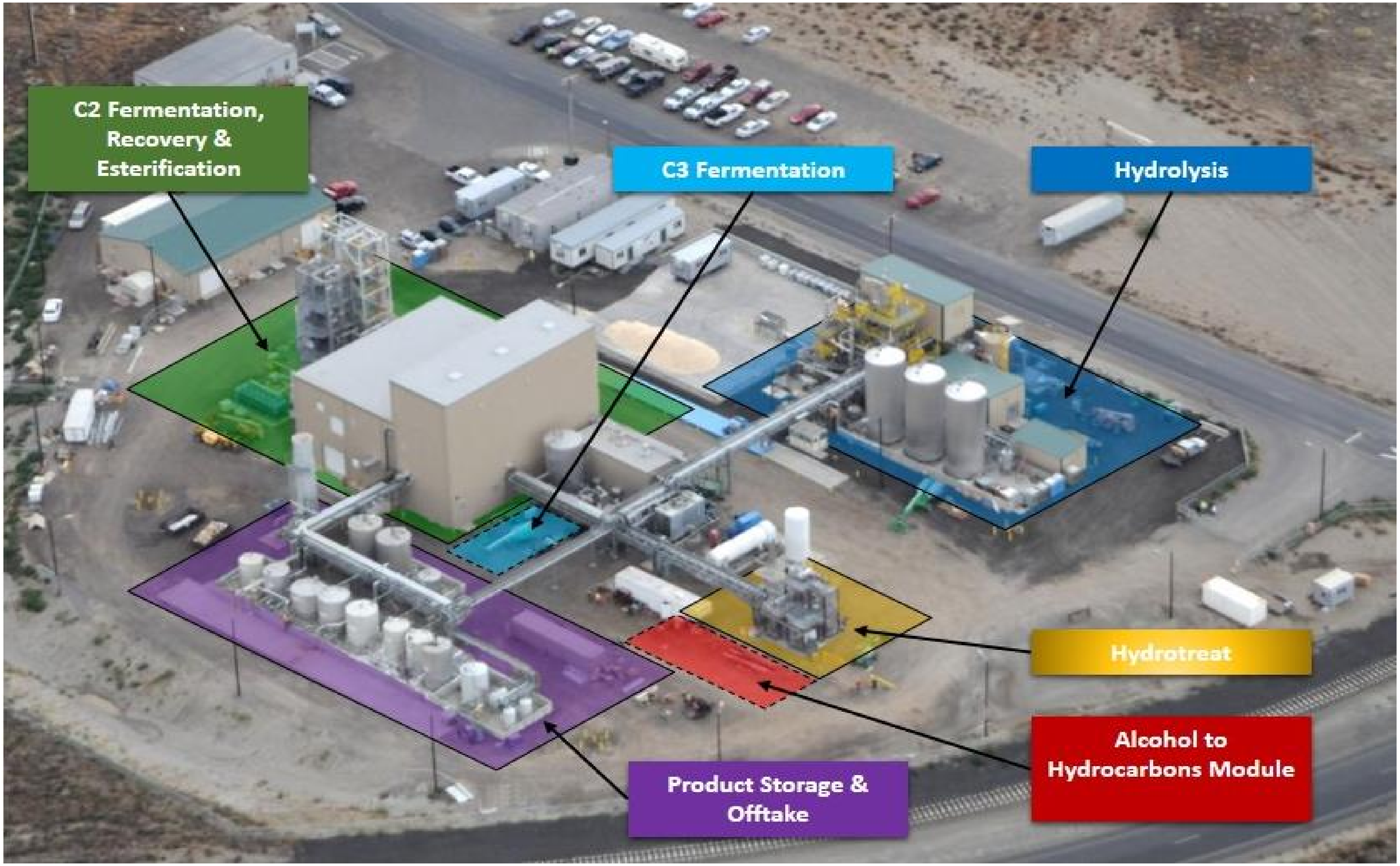
Liquid Product

2016/2017 research

- Optimize catalyst and reactor performance
- Produce hydrocarbon fuel at kgs scale
- Begin ASTM certification process

ASTM
INTERNATIONAL
Standards Worldwide

ZeaChem's Boardman demonstration-scale refinery



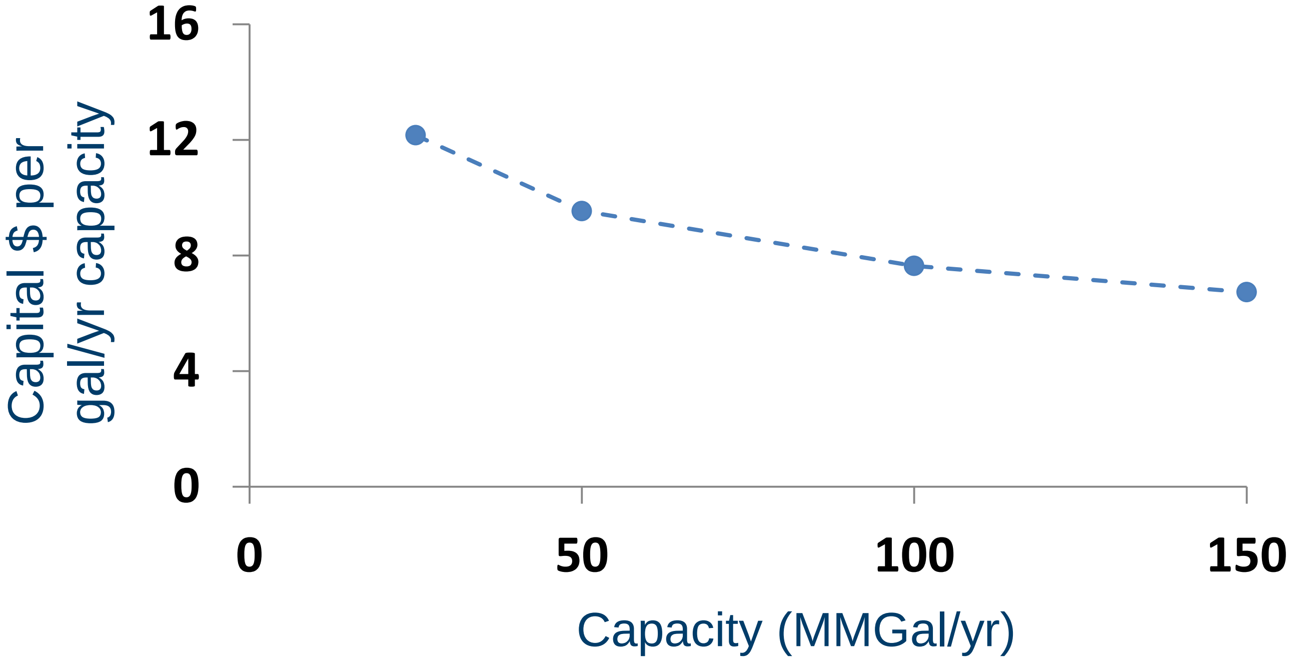
ZeaChem Commercial Update

Sustainability - performance metrics

Capital costs for 100 MMgal/yr plant

(Fixed capital, $ million)	
Feedstock through ethanol	502
Alcohol to hydrocarbon	113
Steam plant and natural gas reforming	149
Total	**$764**

Capital economies of scale



($ million)	25	50	100	150
Fixed capital	$304	477	764	1,010

Operating expenses

Operating cost	Dollars per gallon
	Base case, 100MMGAL
Feedstock	0.88
Cellulase enzymes	0.50
Fermentation nutrients	0.09
Other raw materials	0.29
Waste disposal	0.04
Electricity (6¢/kWh)	-0.01
Reforming O&M	0.04
Natural gas	0.34
Fixed costs	0.45
Total cash cost	**$2.62**
Minimum selling price, 7% discount	**$3.44**
Minimum selling price, 15% discount	**$4.11**

Operating expenses

Operating cost	Dollars per gallon	
	Base case, 100MMGAL	2015 Facility*
Feedstock	0.88	1.01
Cellulase enzymes	0.50	0.97
Fermentation nutrients	0.09	0.09
Other raw materials	0.29	0.35
Waste disposal	0.04	0.04
Electricity (6¢/kWh)	-0.01	-0.01
Reforming O&M	0.04	0.05
Natural gas	0.34	0.35
Fixed costs	0.45	0.78
Total cash cost	**$2.62**	**$3.63**
Minimum selling price, 7% discount	**$3.44**	**$5.78**
Minimum selling price, 15% discount	**$4.11**	**$7.06**

- 25MMGAL capacity
- $80/BDT feedstock
- 20mg enzymes/g cellulose @ $10/kg enzymes
- 40% equity with 5% loan rate

Alternative products

	Annual capacity at 100% production	Selling price	Annual revenue at 100% production
Acetic acid	730,000 tons	$600/ton	$438 million
Ethyl acetate	523,000 tons	$1000/ton	$523 million
Ethylene	314,000 tons	$1000/ton	$314 million
Ethanol	160 MMGal	$1.40/gal	$224 million
Jet fuel	100 MMGal	$1.00/gal	$100 million

E85
85% Ethanol

plantbottle™

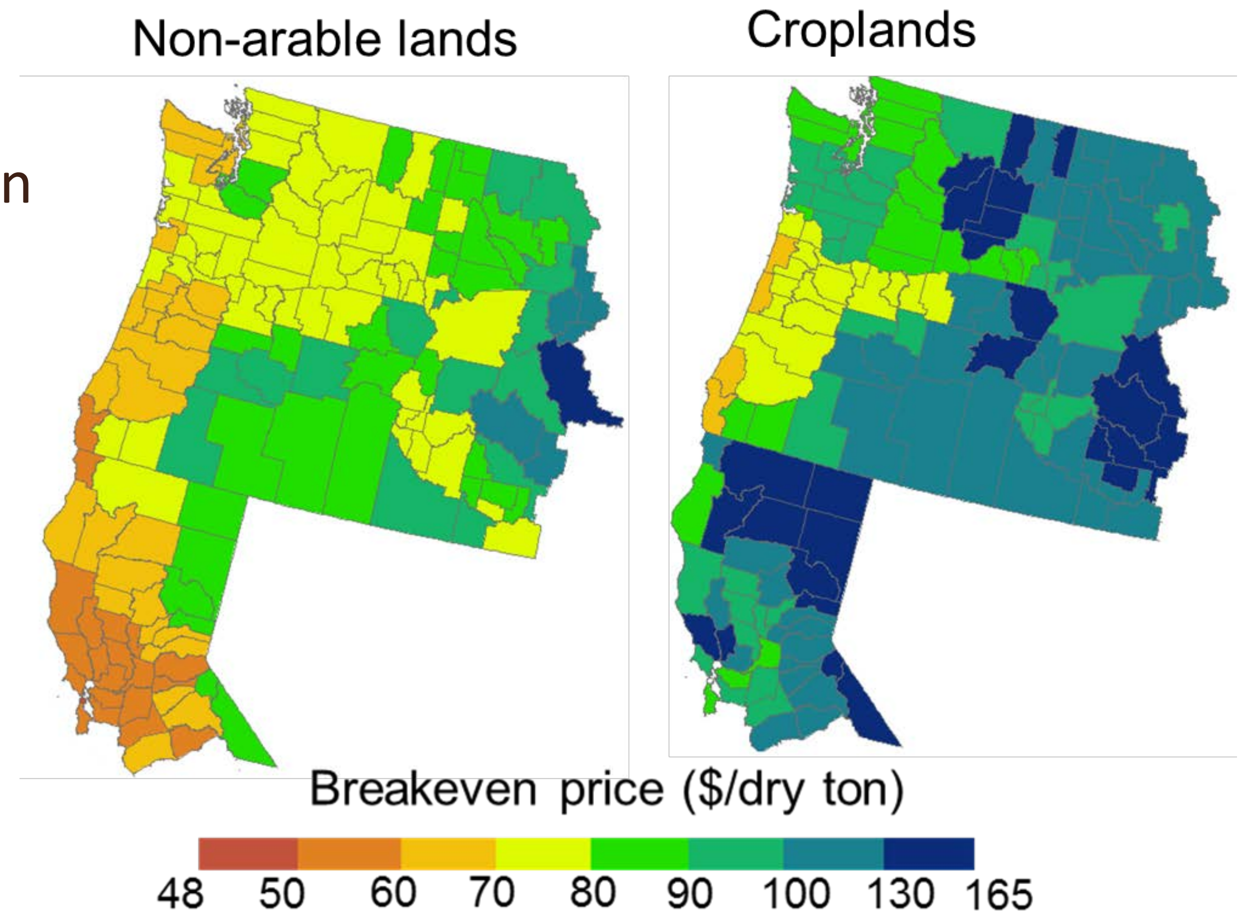
Land suitability for growing poplar - suitable acres by state and suitability class

State	Suitability Class	Acres
California	Without Irrigation	7,300,000
California	With Irrigation, Water Available	4,000,000
California	With Irrigation, Water Unavailable	12,000,000
Montana	Without Irrigation	35,000,000
Montana	With Irrigation, Water Available	450,000
Montana	With Irrigation, Water Unavailable	7,200,000
Oregon	Without Irrigation	9,300,000
Oregon	With Irrigation, Water Available	830,000
Oregon	With Irrigation, Water Unavailable	8,200,000
Washington	Without Irrigation	7,700,000
Washington	With Irrigation, Water Available	1,200,000
Washington	With Irrigation, Water Unavailable	5,000,000

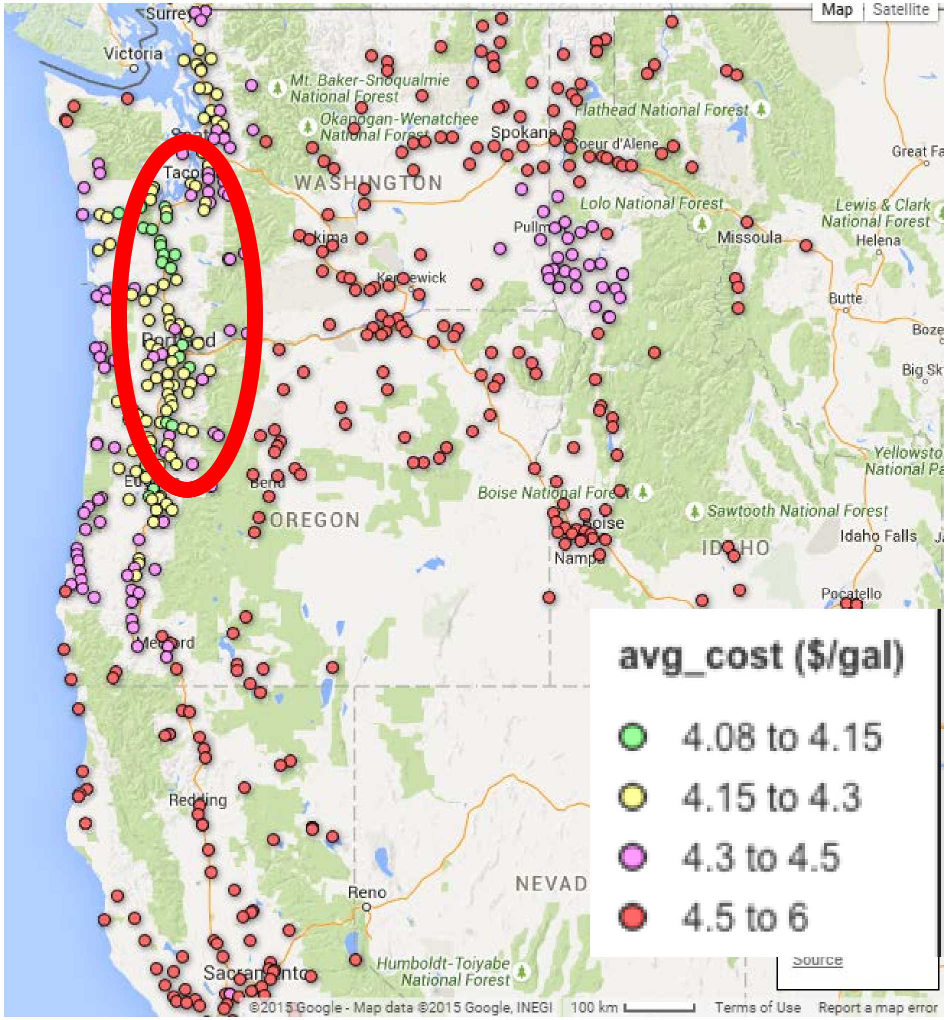
Regional poplar budgets

- Breakeven price for poplar ranges from \$48--\$160 depends on region, type of land and management.

- Breakeven prices are higher for croplands due to higher land rents and irrigation costs.

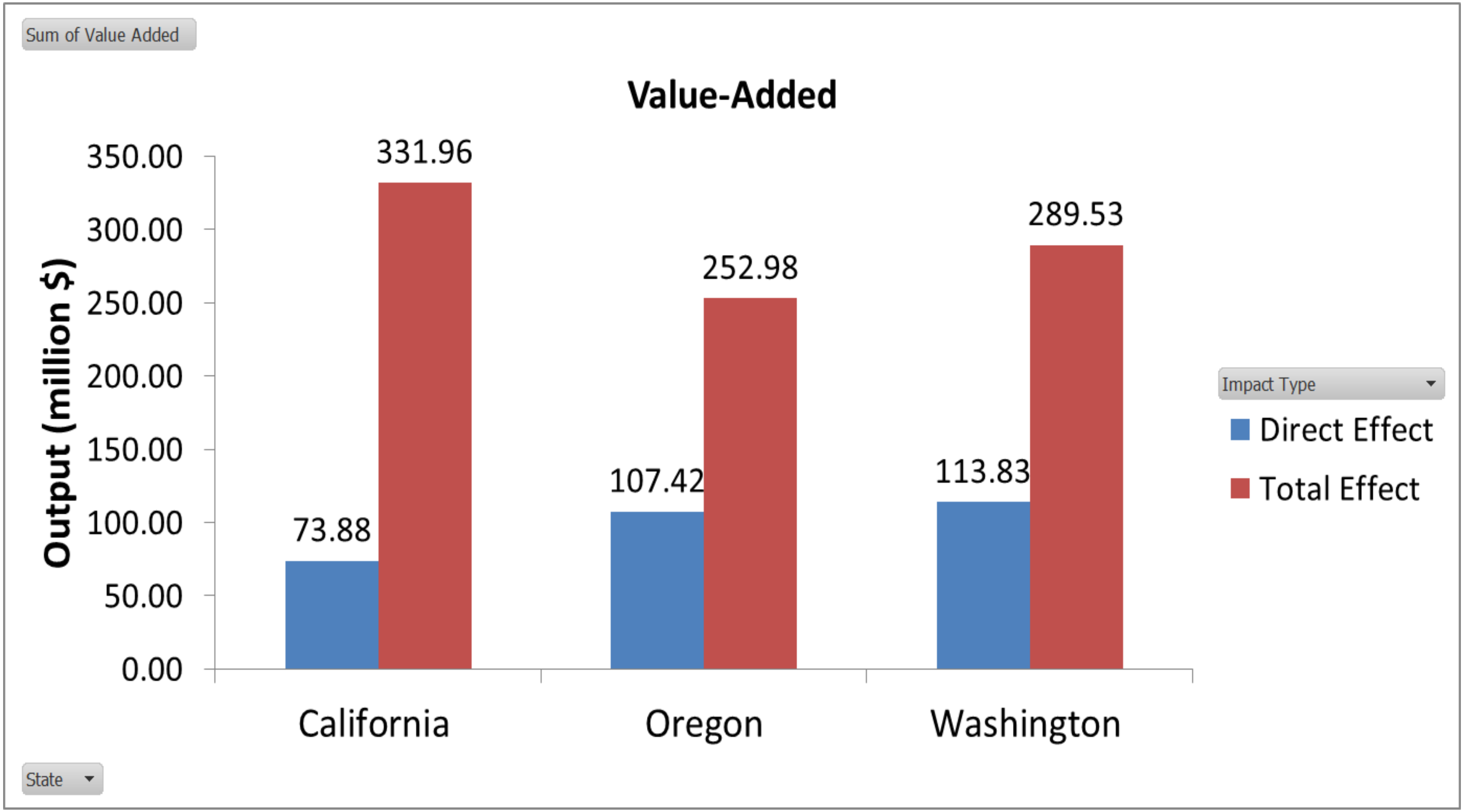


Analysis of jet fuel biorefineries – 1,250,000 tons biomass/year

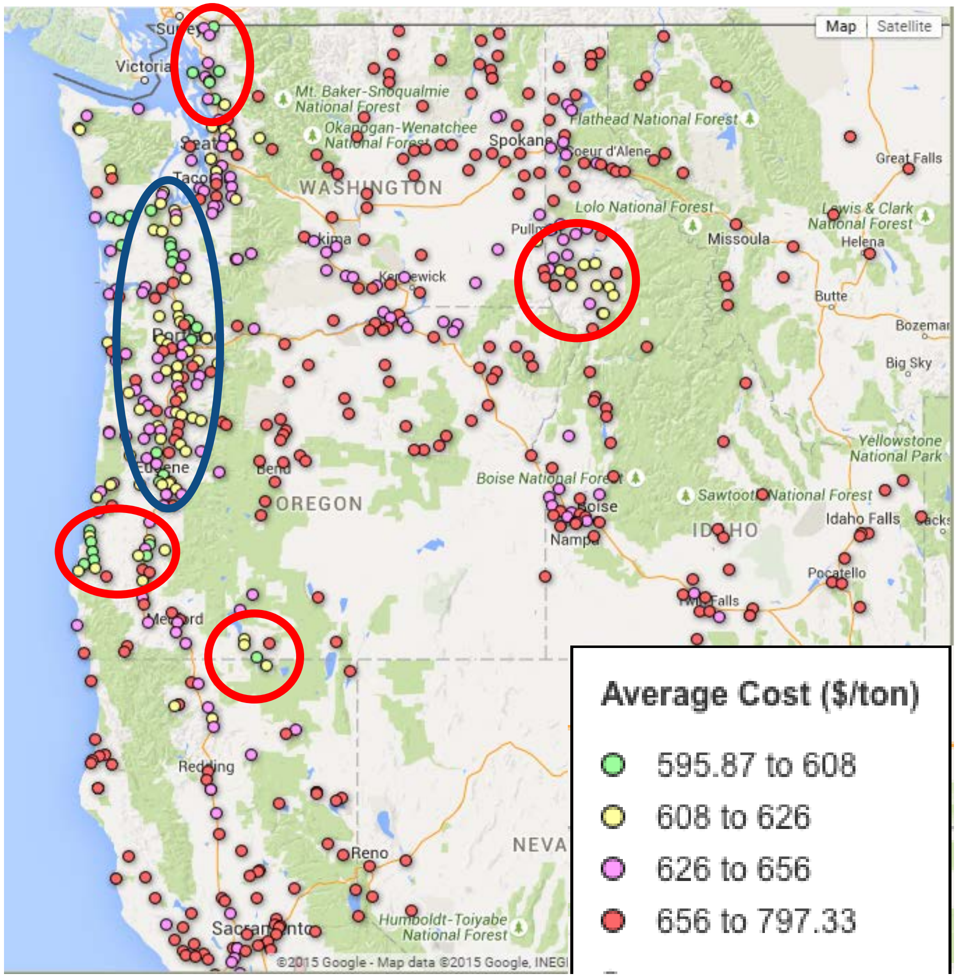


- Best sites in western WA and OR
- Most sites have costs >$4.5/gal
- Challenges in aggregating enough low cost poplar

Value-added from the operation of a biorefinery



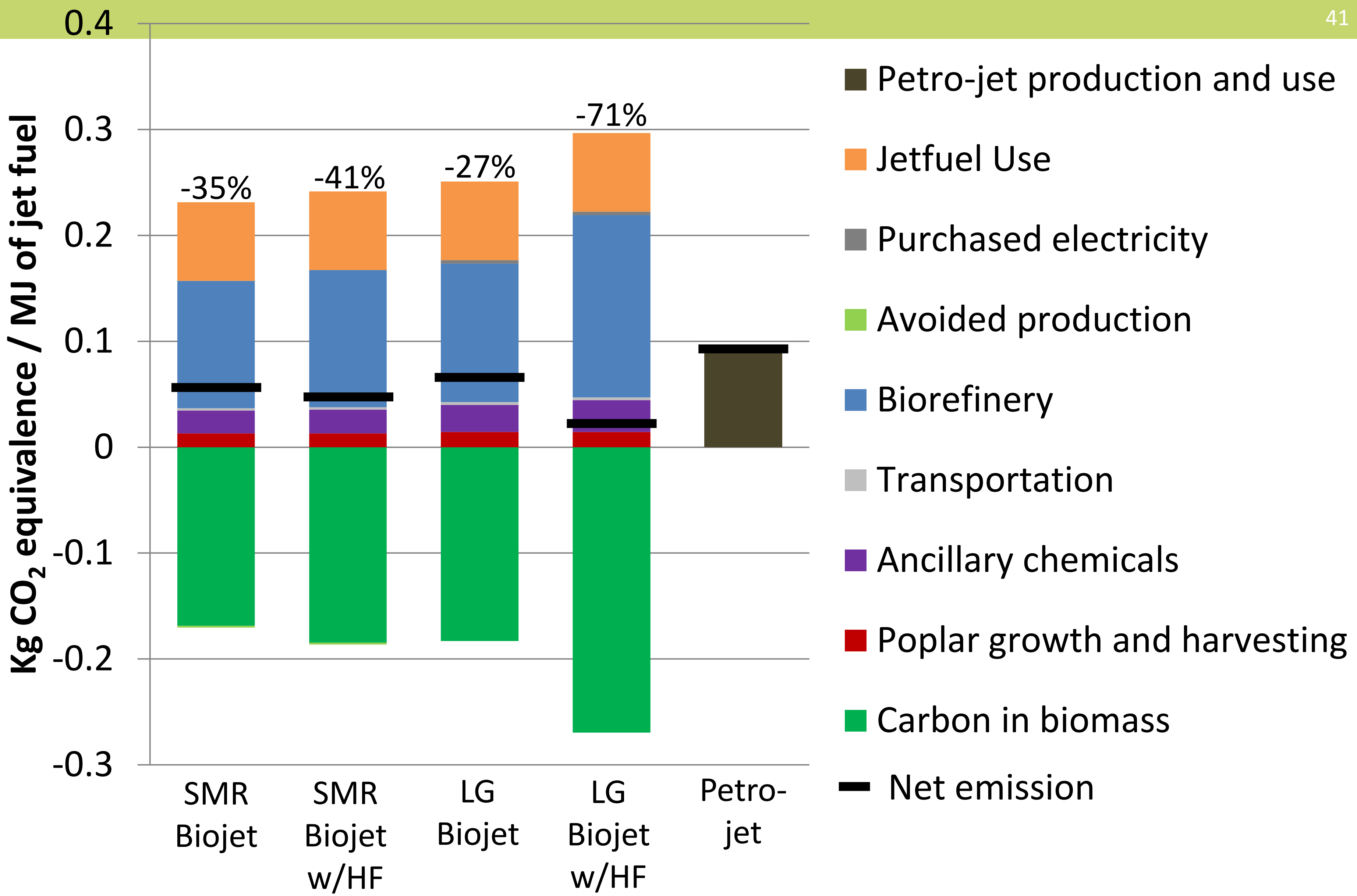
Analysis of acetic acid biorefineries – 250,000 tons biomass/year



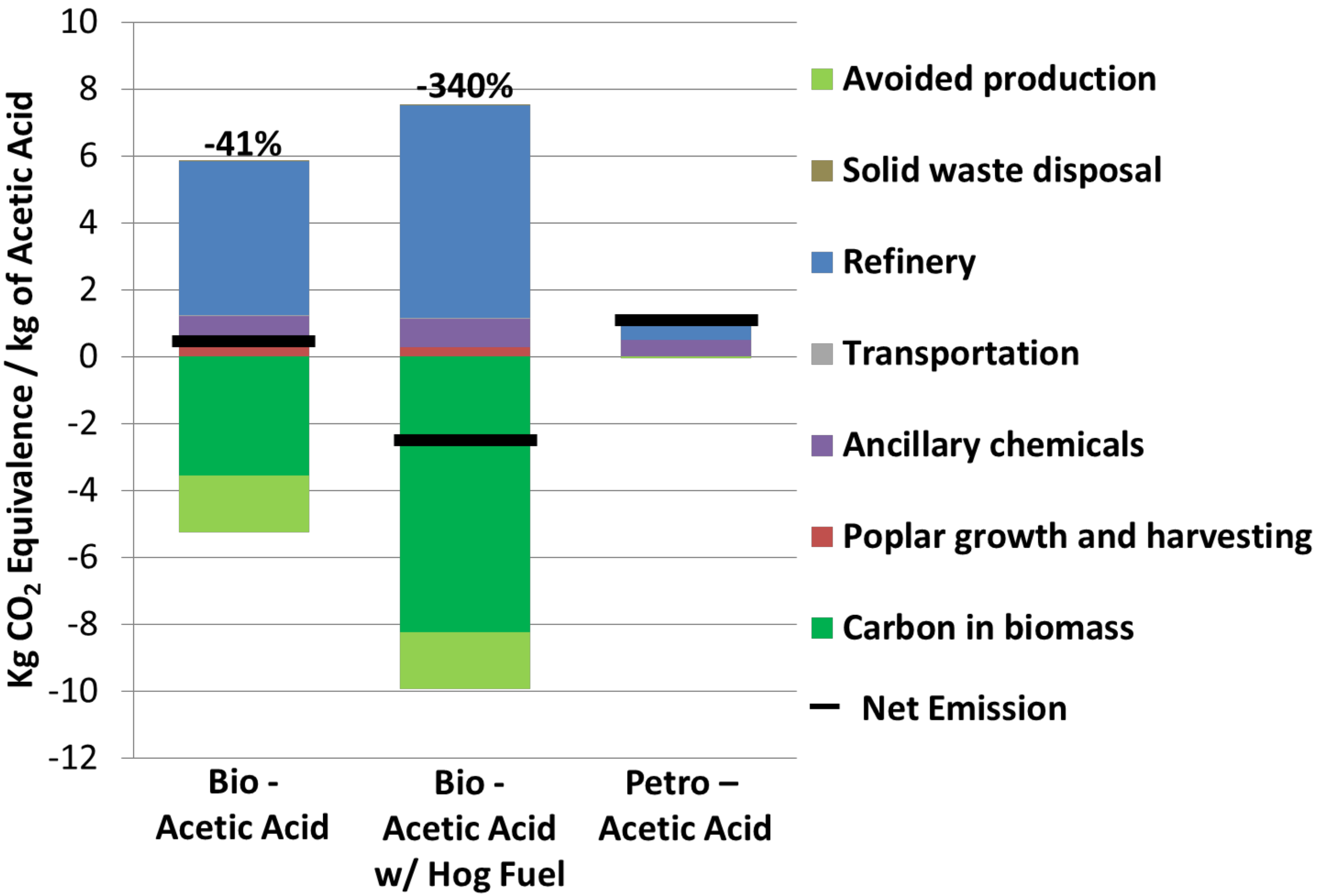
- ❑ Larger set of good sites
- ❑ Production costs of $600/ton - $650/ton

~$500-$550/ton with novel recovery process!!

Jet fuel LCA global warming potential



Acetic acid LCA global warming potential: cradle to biorefinery gate



Education and Extension

Community college workforce development

- Provide relevant practical technical training to build the workforce for bioenergy and other production/process related industries
- Train participants for well-paying rural jobs at the nexus of agriculture, water and energy production
- Pair new applied science and engineering courses with existing electrical curriculum

New Degrees:

AAAS Plant Operations

AAS-T (applied science transfer degree)

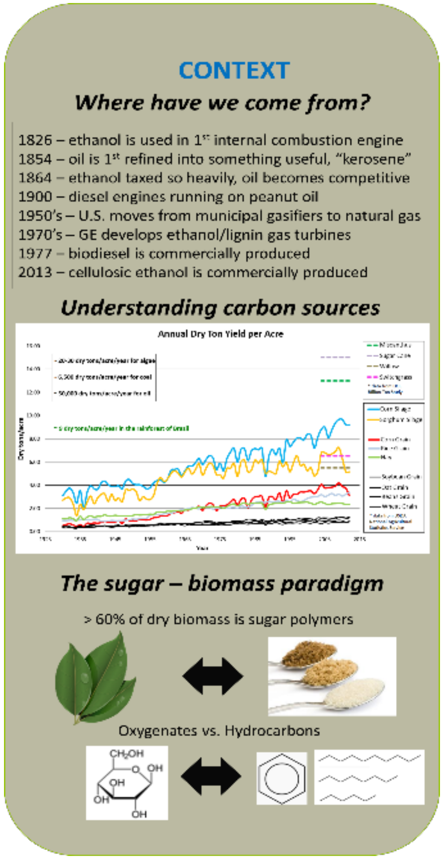
Both plug-in to applied degrees: Electrical, HVACR, Wind, Millwright

New Certificates:

Industrial Maintenance, Biomass Feedstock Management, Plant Operations

Short Certificate in Bioproducts *(in progress)*

Bioenergy YouTube channel is operational!



CONTEXT

Where have we come from?

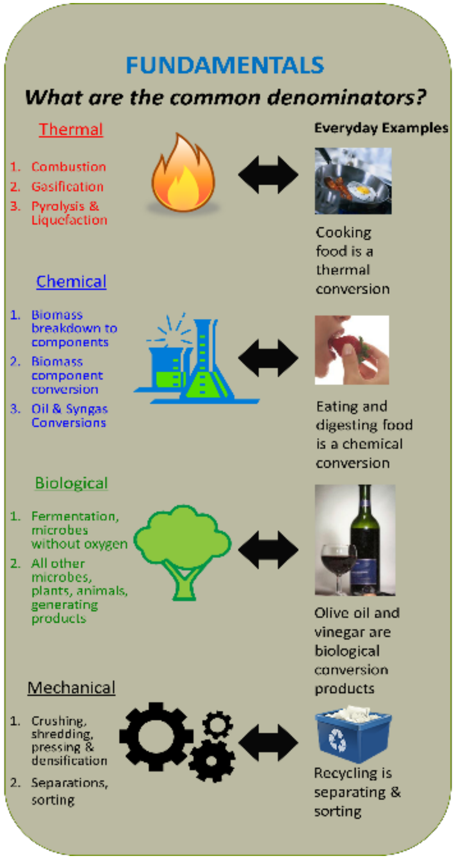
1826 – ethanol is used in 1st internal combustion engine
1854 – oil is 1st refined into something useful, "kerosene"
1864 – ethanol taxed so heavily, oil becomes competitive
1900 – diesel engines running on peanut oil
1950's – U.S. moves from municipal gasifiers to natural gas
1970's – GE develops ethanol/lignin gas turbines
1977 – biodiesel is commercially produced
2013 – cellulosic ethanol is commercially produced

Understanding carbon sources

The sugar – biomass paradigm

> 60% of dry biomass is sugar polymers

Oxygenates vs. Hydrocarbons



FUNDAMENTALS

What are the common denominators?

Everyday Examples

Thermal
1. Combustion
2. Gasification
3. Pyrolysis & Liquefaction

Cooking food is a thermal conversion

Chemical
1. Biomass breakdown to components
2. Biomass component conversion
3. Oil & Syngas Conversions

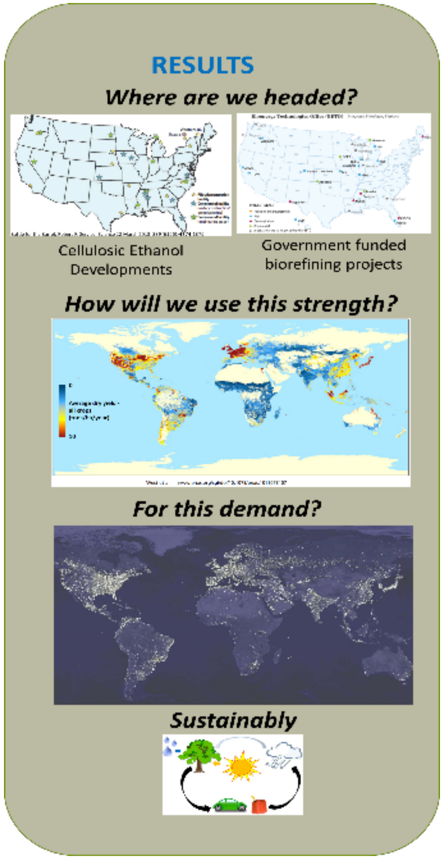
Eating and digesting food is a chemical conversion

Biological
1. Fermentation, microbes without oxygen
2. All other microbes, plants, animals, generating products

Olive oil and vinegar are biological conversion products

Mechanical
1. Crushing, shredding, pressing & densification
2. Separations, sorting

Recycling is separating & sorting



RESULTS

Where are we headed?

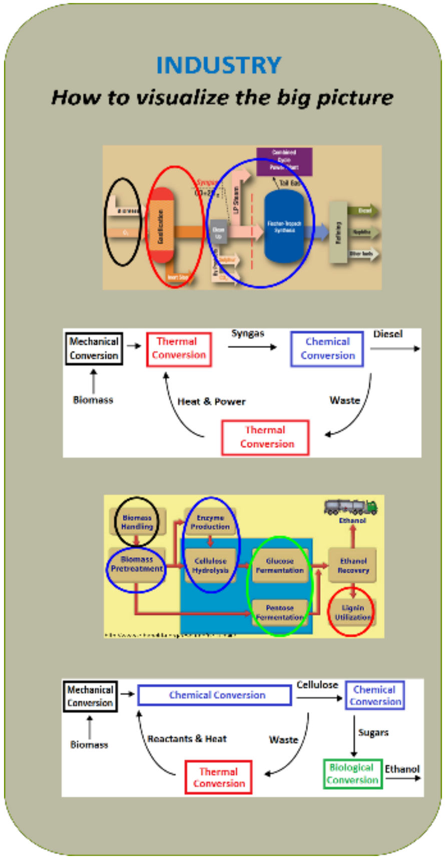
Cellulosic Ethanol Developments

Government funded biorefining projects

How will we use this strength?

For this demand?

Sustainably



INDUSTRY

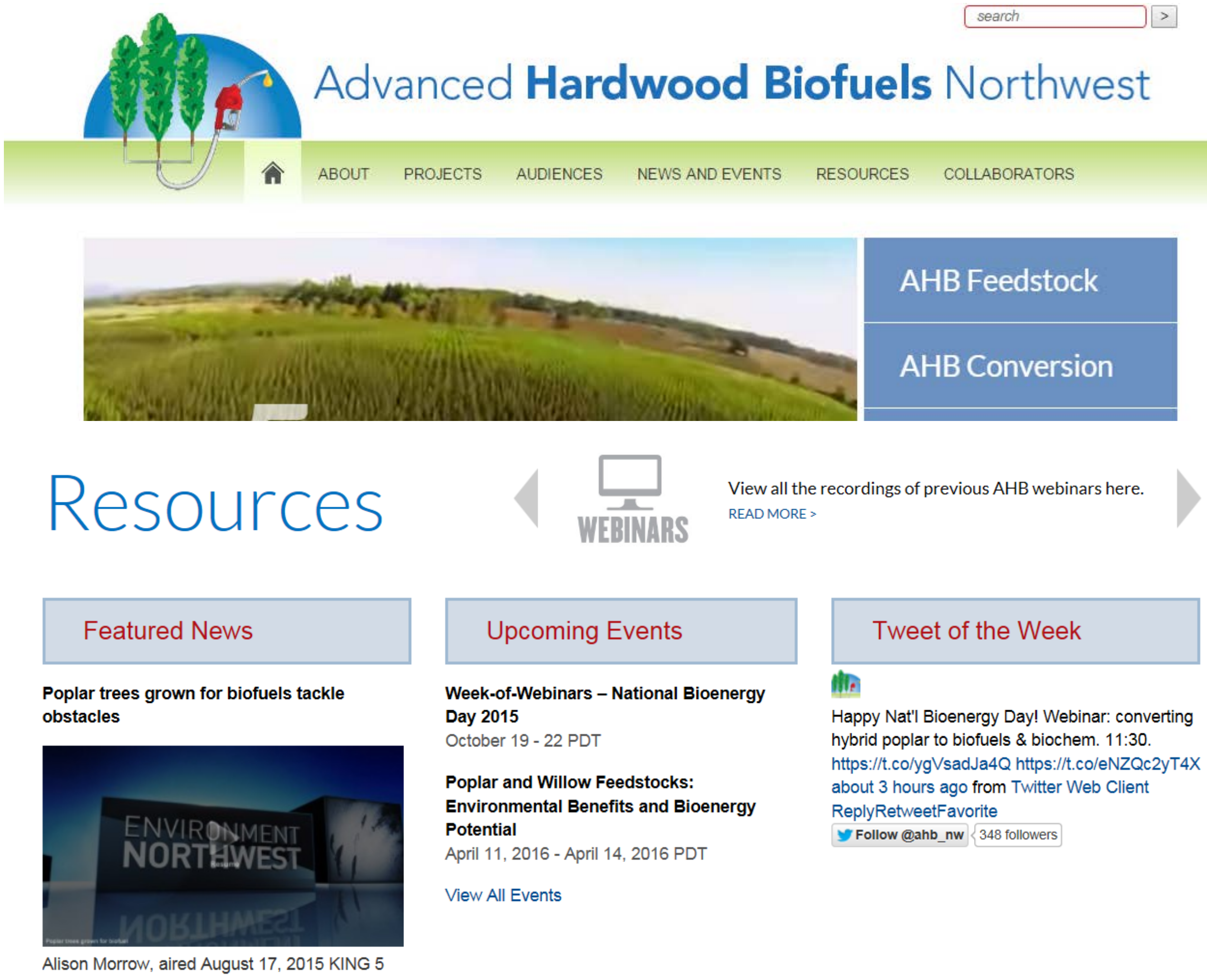
How to visualize the big picture

Expand bioenergy community:

- Generate open source knowledge available to everyone.
- Support K-12, community college & industry education.

AHB Website

- Over 7000 unique visitors since 2013
- Web traffic is up 38% from 2014
- Consistently over 50% new visitors
- Over 300 pages of content



Advanced **Hardwood Biofuels** Northwest

Resources

View all the recordings of previous AHB webinars here.
READ MORE >

Featured News

Poplar trees grown for biofuels tackle obstacles

Alison Morrow, aired August 17, 2015 KING 5

Upcoming Events

Week-of-Webinars – National Bioenergy Day 2015
October 19 - 22 PDT

Poplar and Willow Feedstocks: Environmental Benefits and Bioenergy Potential
April 11, 2016 - April 14, 2016 PDT

View All Events

Tweet of the Week

Happy Nat'l Bioenergy Day! Webinar: converting hybrid poplar to biofuels & biochem. 11:30. https://t.co/ygVsadJa4Q https://t.co/eNZQc2yT4X
about 3 hours ago from Twitter Web Client
ReplyRetweetFavorite
Follow @ahb_nw 348 followers

Conclusions

- ☐ Poplar is a viable feedstock for production of renewable fuels and chemicals
- ☐ Producing aviation fuel from biomass is challenging with current petroleum pricing
    - ☐ Production of high value chemicals can increase revenue
    - ☐ Monetizing of ecosystem services can also add value
- ☐ Commercialization of a biorefinery in the PNW is forthcoming
- ☐ Production of fuels and chemicals from poplar feedstock is sustainable and provides substantial rural economic benefits
- ☐ Multi-dimensional, integrated research programs are needed for comprehensive development and assessment of large scale bioresource enterprises

The AHB project is supported by Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30407 from the USDA National Institute of Food and Agriculture

USDA NIFA