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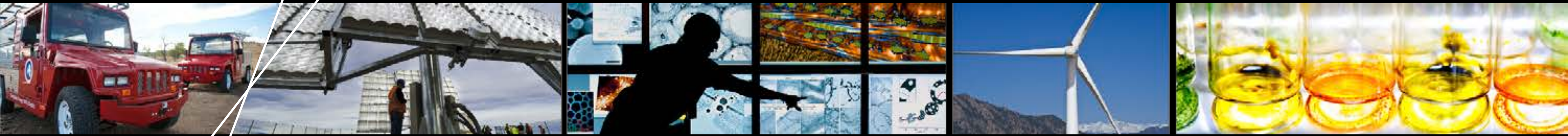
Field-to-fuel Performance Testing of Various Biomass Feedstocks



Production and catalytic upgrading of bio-oil to refinery blendstocks

Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products
September 2–5, 2014 • Denver, Colorado
TCS 2014

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September 4, 2014

NREL/PR-5100-62897

Intra-lab collaboration…

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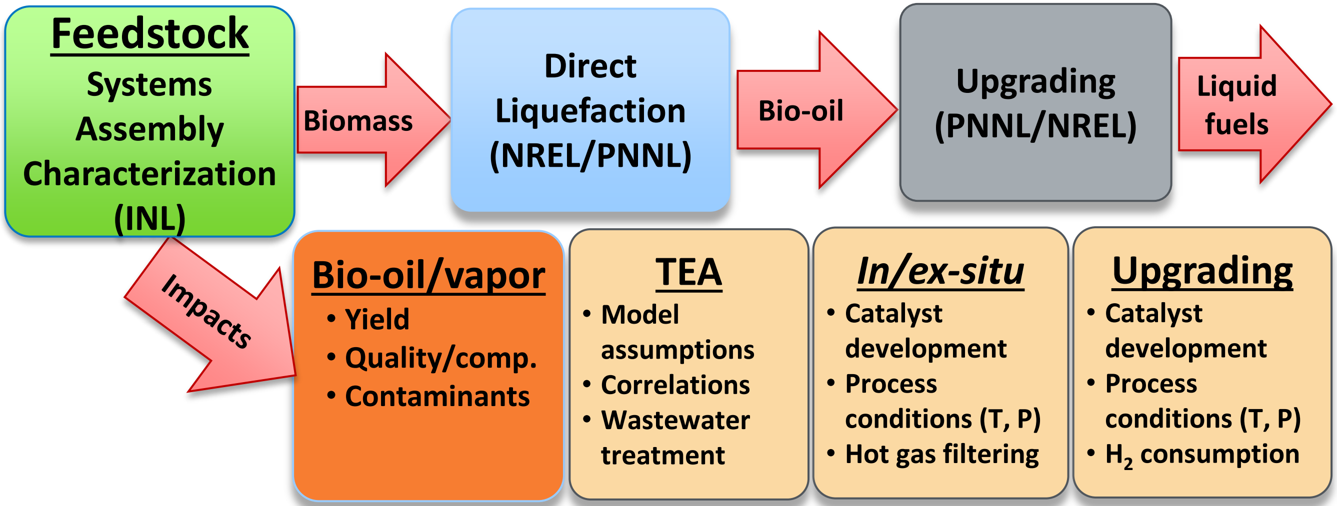


Feedstock Systems Assembly Characterization (INL)

Biomass

Direct Liquefaction (NREL/PNNL)

Bio-oil

Upgrading (PNNL/NREL)

Liquid fuels

Impacts

Bio-oil/vapor
- Yield
- Quality/comp.
- Contaminants

TEA
- Model assumptions
- Correlations
- Wastewater treatment

In/ex-situ
- Catalyst development
- Process conditions (T, P)
- Hot gas filtering

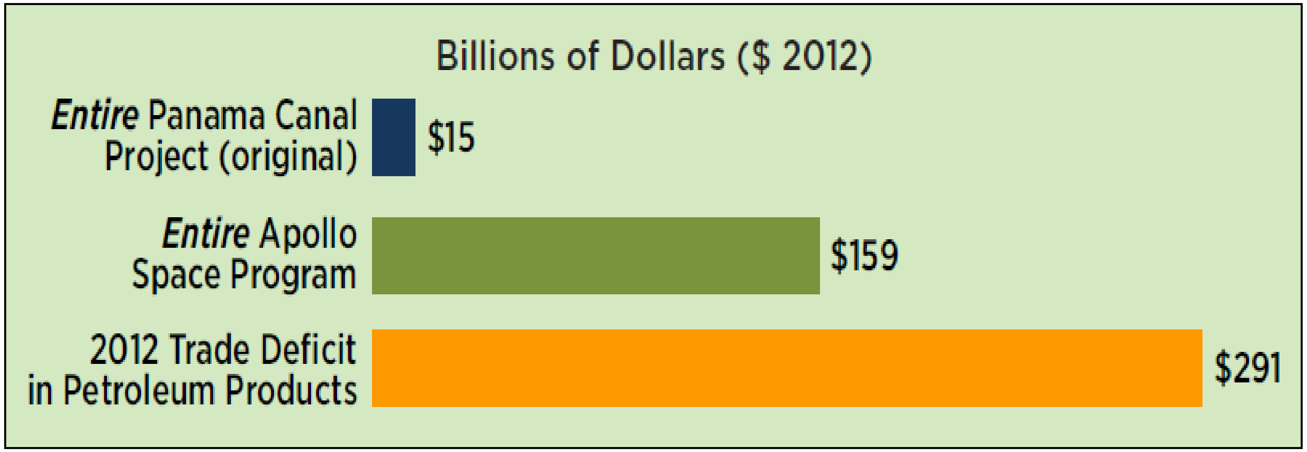
Upgrading
- Catalyst development
- Process conditions (T, P)
- H_2 consumption

Outline

- Background and Motivation
- Formulated Feedstocks
- Feedstock/Conversion Interface
- Bench-Scale Experiments
- Results
- Conclusions and Future Work

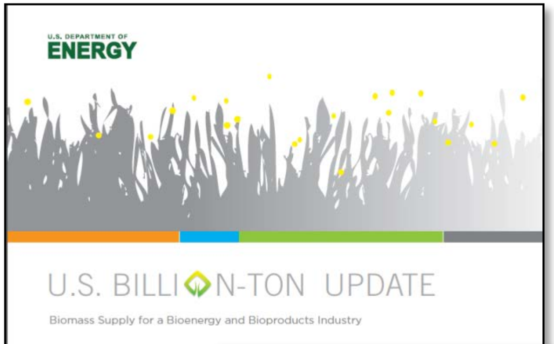
Motivation: EISA 2007

- Reduce greenhouse gas emissions and dependence on foreign fuels
- *Sustainably* produce 36 billion gallons of *infrastructure-compatible*, renewable fuels by 2022
- Minimum fuel selling price: $3.00/gallon gasoline equivalent (gge), competitive with ~$95/barrel oil



From: *Replacing the Whole Barrel* (BETO, July 2013)

U.S. Biomass Resource Assessment



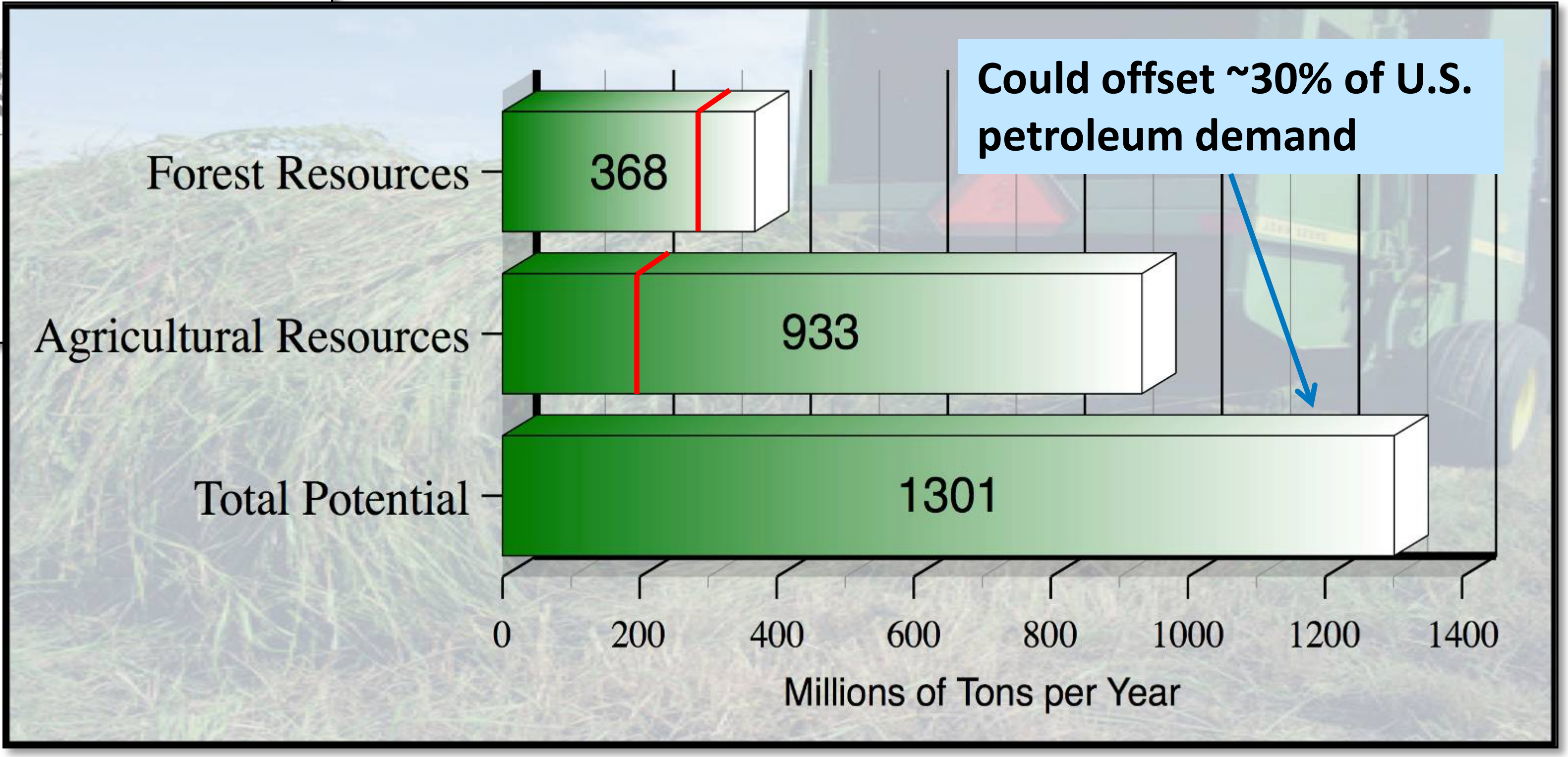
U.S. DEPARTMENT OF ENERGY

U.S. BILLION-TON UPDATE

Biomass Supply for a Bioenergy and Bioproducts Industry

August 2011

- BT2: updated August 2011
- Developed jointly by DOE and USDA
- Included supply-cost projections, county level estimates, sustainability



Could offset ~30% of U.S. petroleum demand

Example resources to meet RFS2

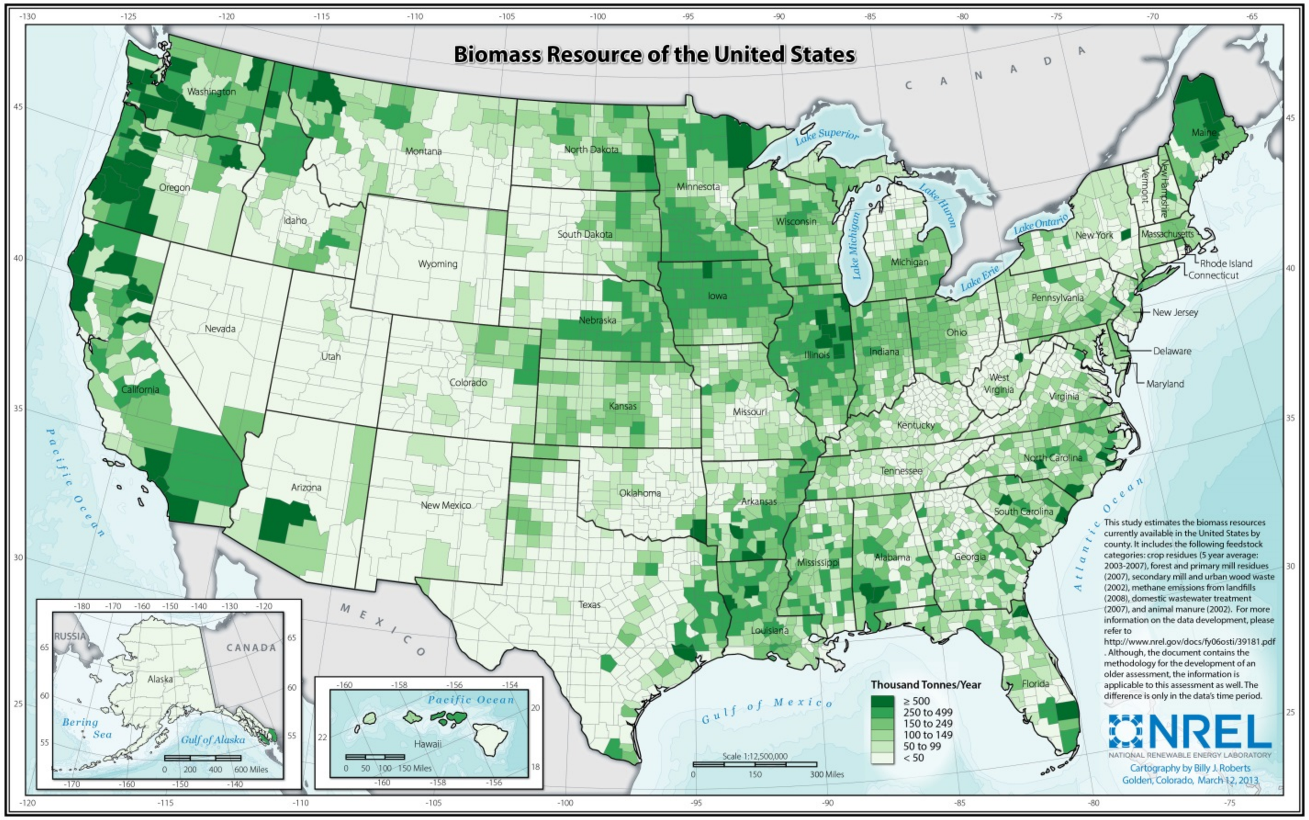
Target: Adequate U.S. Feedstock Supply Available
to Meet RFS and Other Demand for Bioenergy and Bioproducts
(Excludes Conventional Food/Feed/Fiber)

- Biomass from Forest Lands
  - Wood and Residue to Pulp & Paper and Forest Product Mills
  - Fuel Wood
  - Logging and Other Removal Residues
  - Fuel Treatments
- Biomass from Agricultural Lands
  - Grain Crops
  - Oil Crops
  - Agricultural Residues
  - Annual Grasses
  - Perennial Grasses
  - Woody Crops
- Other Secondary and Tertiary Biomass from Agricultural and Forest Lands
  - MSW and Urban Wood Waste
  - Animal Manures
  - Food Processing Wastes
- Biomass from Non-Terrestrial Sources
  - Microalgae
  - Macroalgae
  - Cyanobacteria

Currently Collected and Used: Wood and Residue to Pulp & Paper and Forest Product Mills; Fuel Wood; Grain Crops; Oil Crops

From BETO multi-year program plan, May 2013

Location, location, location

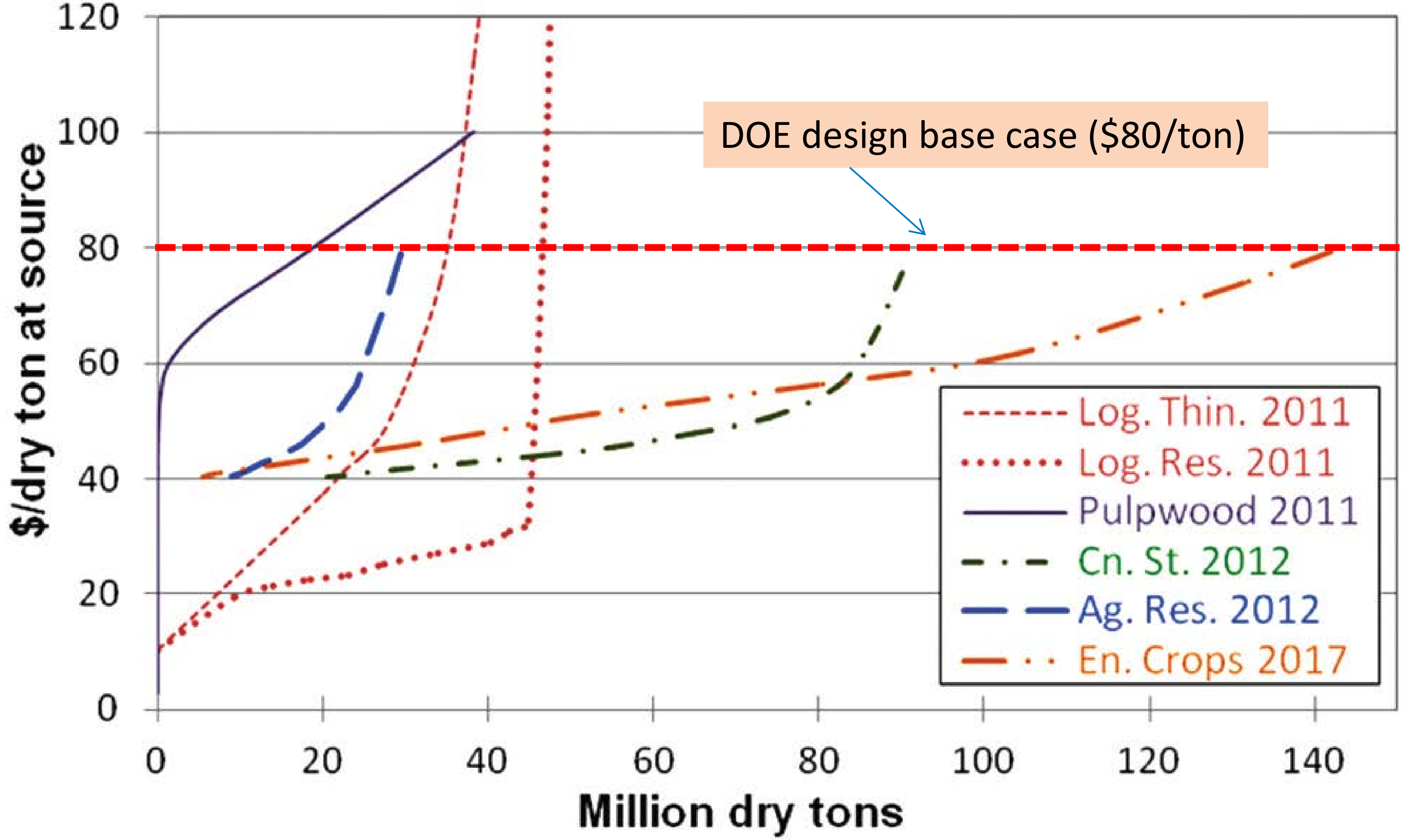


This study estimates the biomass resources currently available in the United States by county. It includes the following feedstock categories: crop residues (5 year average: 2003-2007), forest and primary mill residues (2007), secondary mill and urban wood waste (2002), methane emissions from landfills (2008), domestic wastewater treatment (2007), and animal manure (2002). For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf . Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.

Cartography by Billy J. Roberts
Golden, Colorado, March 12, 2013

- Need to expand the pool of available biomass
- What about quality?
- Formulated feedstocks?
- Seasonality?

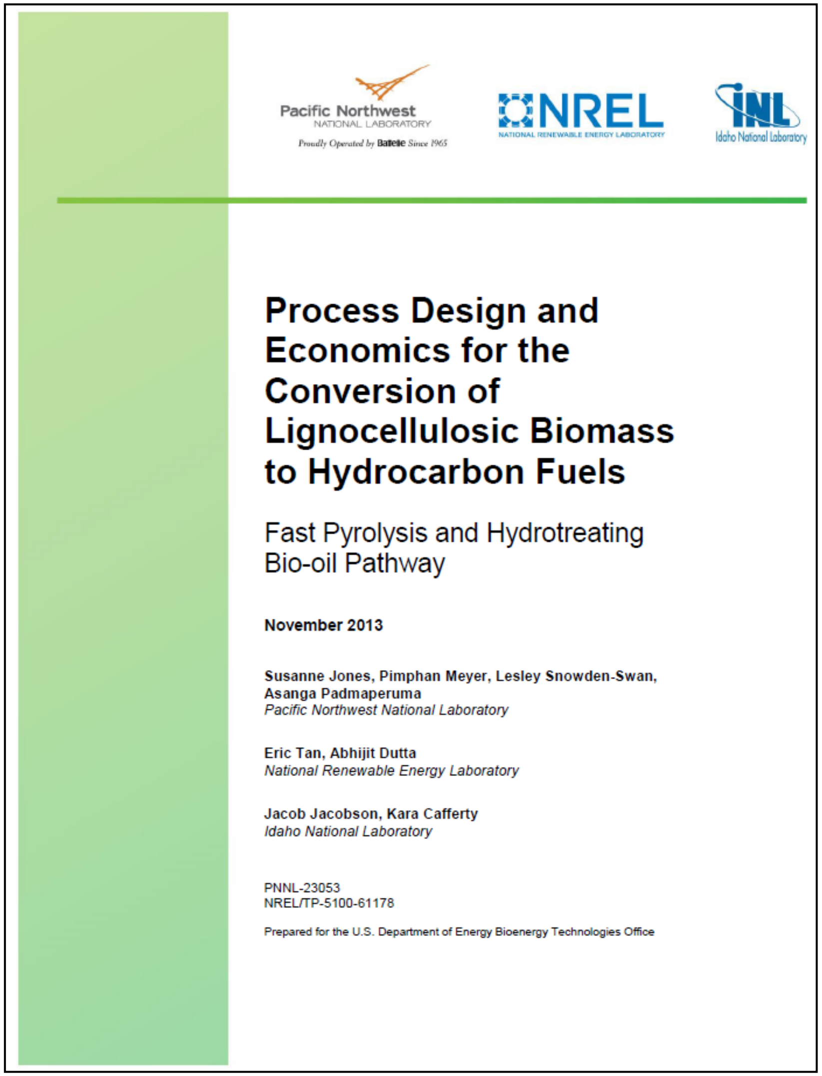
Supply-cost curves for key feedstocks (BT2)



DOE design base case ($80/ton)

Carpenter, Westover, Jablonski, Czernik, Green Chem., 2014, 16, 384, adapted from BT2

TEA design case for FP+HT (one of several pathways)



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INL
Idaho National Laboratory

Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels

Fast Pyrolysis and Hydrotreating
Bio-oil Pathway

November 2013

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PNNL-23053
NREL/TP-5100-61178

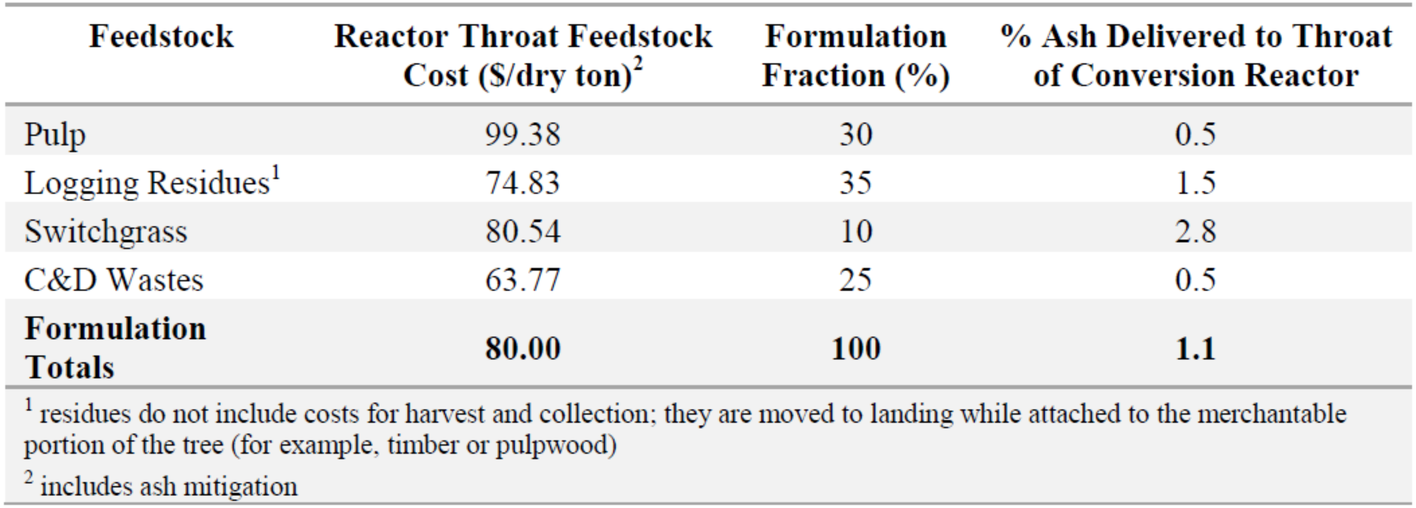
Prepared for the U.S. Department of Energy Bioenergy Technologies Office

- **Wood** Pyrolysis + Hydrotreating → HC fuels
- Allows sensitivity analysis of technical and market assumptions
- Assumes 64% oil yield and 44% HT product yield (dry basis)
- Yield = 84 gal/ton (gasoline+diesel blendstock)
- MFSP = \$3.39/gge (nth plant)
- **Biomass feedstock is projected to be the largest cost component (~40%) and is known to be one of the largest risk factors for biorefinery commercialization**
  - Need to understand feedstock effects on conversion process
  - Ash (total and elemental)
  - What about blends?

Formulated feedstocks

Move toward formulated feedstocks…*to mitigate variability and reduce cost, commoditize feedstocks for biofuels production, establish composition-based specifications (precedence for this is coal and animal feed industries)*

Example blend *(from Jones, et al design report):*



Feedstock	Reactor Throat Feedstock Cost ($/dry ton)[2]	Formulation Fraction (%)	% Ash Delivered to Throat of Conversion Reactor
Pulp	99.38	30	0.5
Logging Residues[1]	74.83	35	1.5
Switchgrass	80.54	10	2.8
C&D Wastes	63.77	25	0.5
Formulation Totals	**80.00**	**100**	**1.1**

[1] residues do not include costs for harvest and collection; they are moved to landing while attached to the merchantable portion of the tree (for example, timber or pulpwood)

[2] includes ash mitigation

How will the process tolerate different feedstocks? Process optimization and feedstock development need to be closely-coupled!

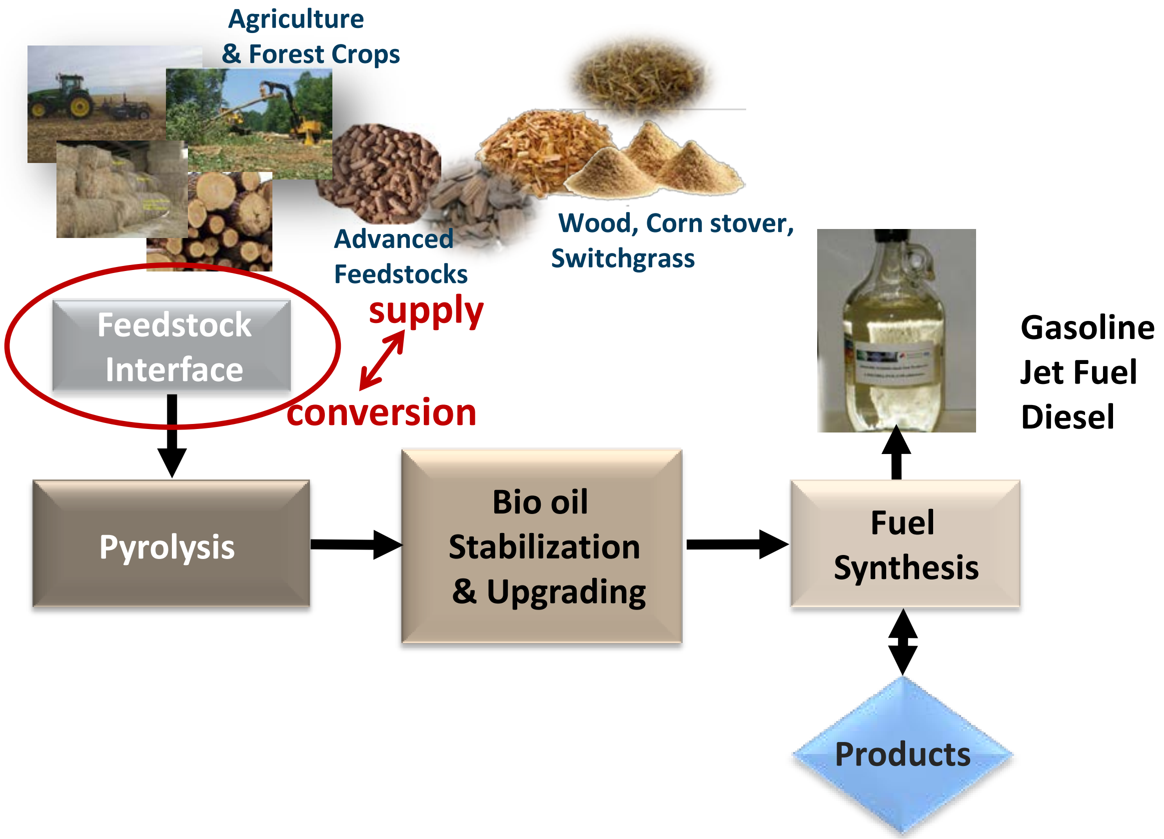
Joint feedstock-process interface project

Process requirements impact feedstock choice ↔ feedstock properties drive R&D decisions

- Goals: **minimize** cost of delivered feedstock, **improve** value and consistency of fuel intermediates, **establish** composition-based specifications

Research Focus/Roles:

- Identify, procure, and characterize feedstock specifications (INL)
- Evaluate TC conversion performance (NREL)
- Input and link data in Biomass Resource Library (INL)
- Develop rapid analysis screening tools (NREL/INL)



Experimental: feedstocks used

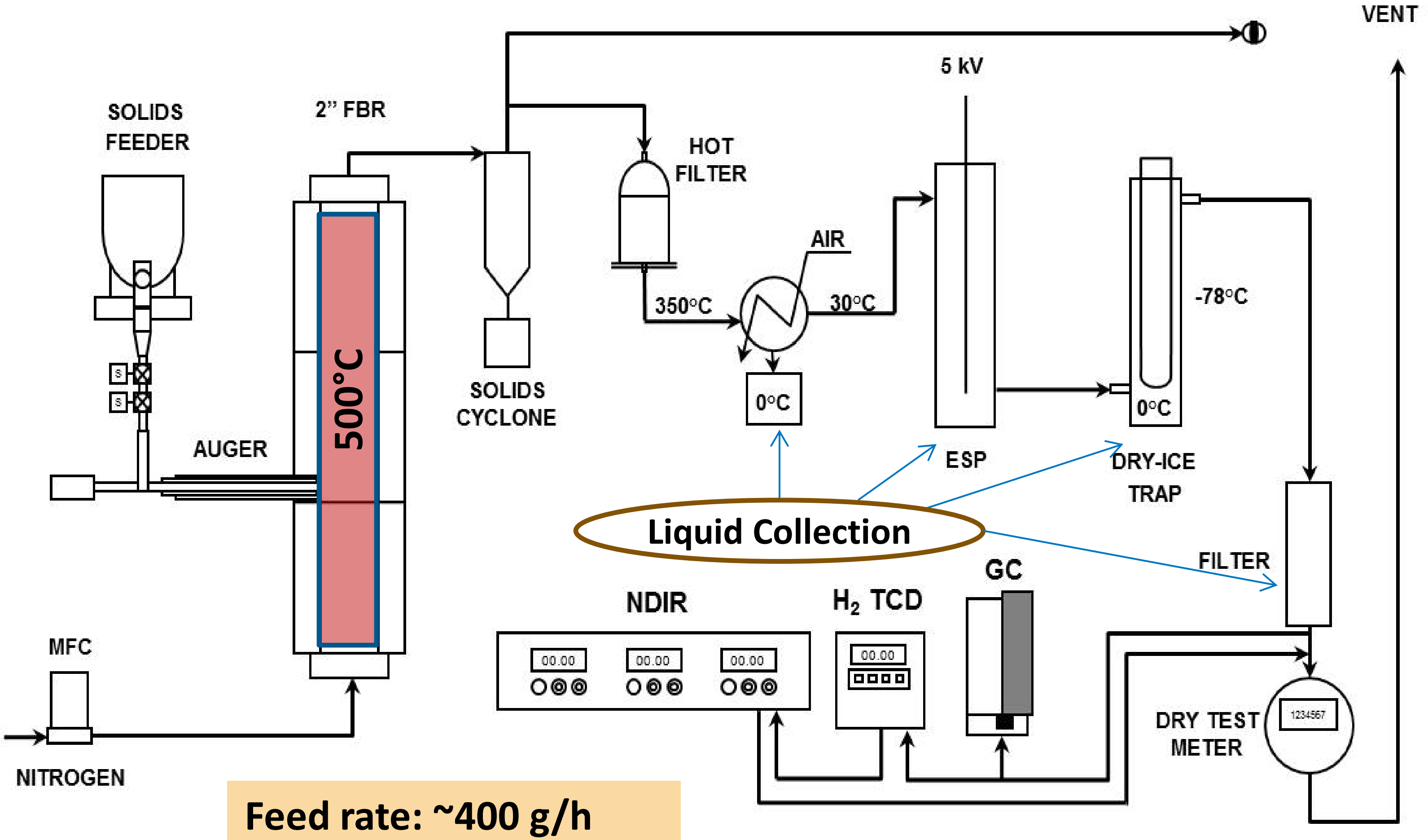
- **Could be blended at a projected cost of $80/ton**
- **Available at ~50 million tons/year combined**
- **“Commercial-type” materials used (i.e. harvested & ground in amounts of >1000 kg)**
- **Blend #1 = 1:1:1 TP:SG:WP**
- **Blend #2 = 1:1:1 CP:HP:WP**

	Proximate (% dry basis)						Ultimate (% dry basis)			
Sample	Moisture	Volatile	Ash	Fixed Carbon	HHV (MJ/kg)		H	C	N	O[a]
Cl. Pine	2.16	79.3	0.7	17.9	8428		5.9	49.6	0.2	44.4
Wh. Pine	1.99	78.4	0.7	18.9	8883		5.9	50.2	0.2	43.4
Hy. Poplar	3.73	79.8	0.9	15.6	8250		6.0	48.1	0.2	45.0
Tu. Poplar	3.79	80.9	0.4	14.9	8202		6.0	47.4	0.2	46.4
Sw. Grass	3.84	73.5	4.0	18.6	7768		5.9	45.4	0.5	44.7
Cn. Stover	5.38	73.0	4.0	17.6	7567		6.0	46.1	0.7	43.5
Blend #1	3.64	77.7	1.7	17.0	8179		6.0	47.5	0.3	45.1
Blend #2	3.73	77.8	0.6	17.9	8551		6.1	48.5	0.2	45.4

Ash composition (ppm in whole biomass, dry basis)

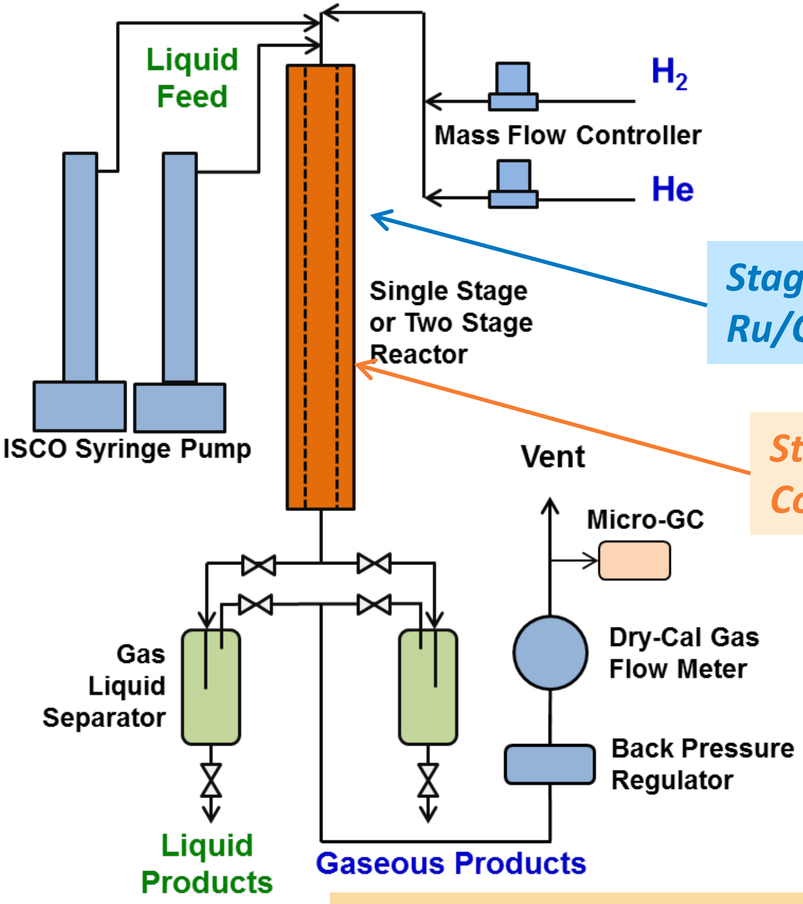
	Ash%	Al	Ca	Fe	Mg	Mn	P	K	Si	Na	S	Ti
Cl. Pine	0.73	199	942	290	265	68	75	758	1,557	51	68	13
Wh. Pine	0.74	184	1,096	415	291	72	93	756	1,300	54	73	9
Hy. Poplar	0.86	76	1,702	143	377	7	252	1,956	523	79	107	7
Tu. Poplar	0.47	39	944	62	261	35	70	822	568	23	70	3
Sw. Grass	4.29	59	2,312	537	2,579	66	831	6,097	10,843	506	466	5
Cn. Stover	4.24	63	2,815	356	1,601	33	551	9,338	10,055	25	387	3
Blend #1	0.62	107	1,162	144	295	48	134	1,137	673	49	79	6
Blend #2	1.66	90	1,366	383	934	58	319	2,505	3,632	182	181	6

Experimental: Fast pyrolysis reactor



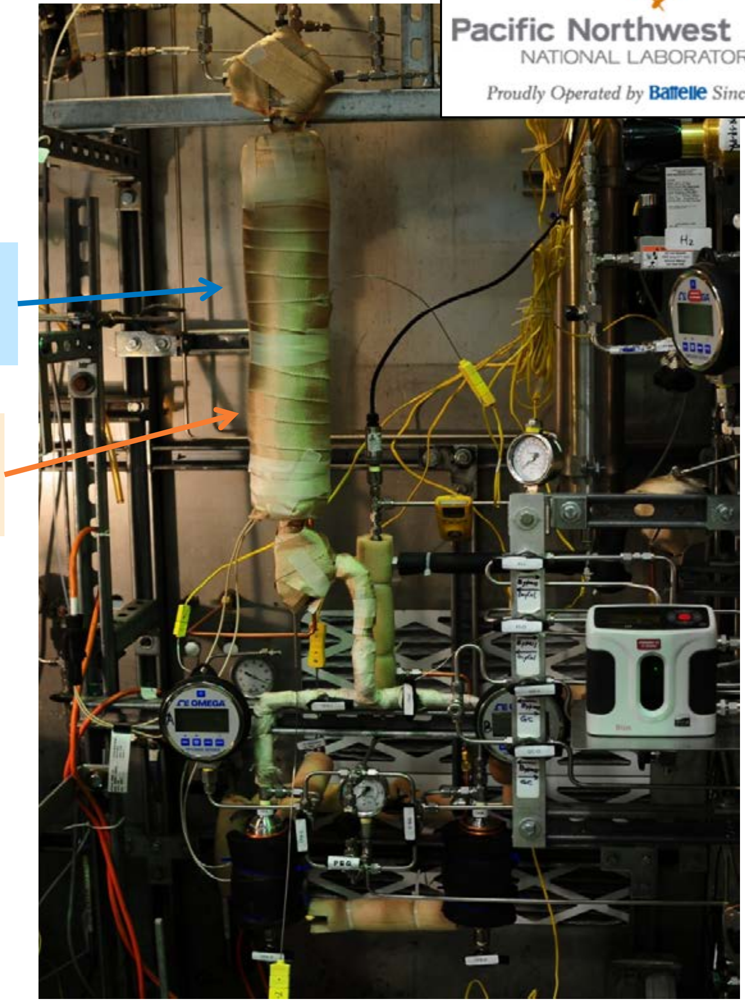
Feed rate: ~400 g/h
Reactor: 5.0 cm ID
Fluidizing N_2: 14 slm
Residence time: ~2 sec.

Experimental: Hydrotreating reactor



Stage 1: 220°C
Ru/C, 30-60 mesh

Stage II: 400°C
CoMo/Al_2O_3



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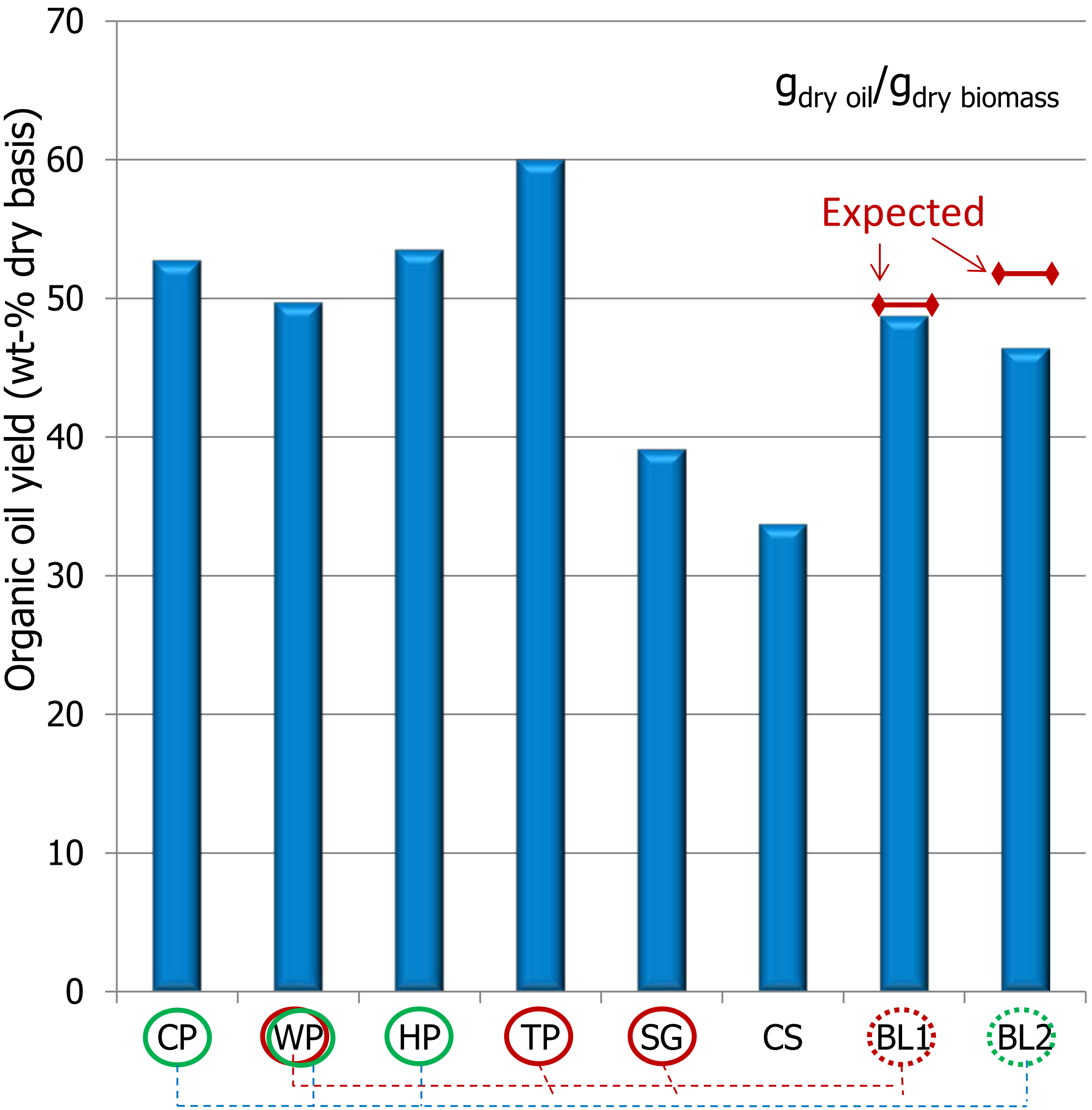
Reactor: 1.3 cm ID, 63.5 cm long
Feed rate: 48 mL/hr
Pressure: 1550 psi

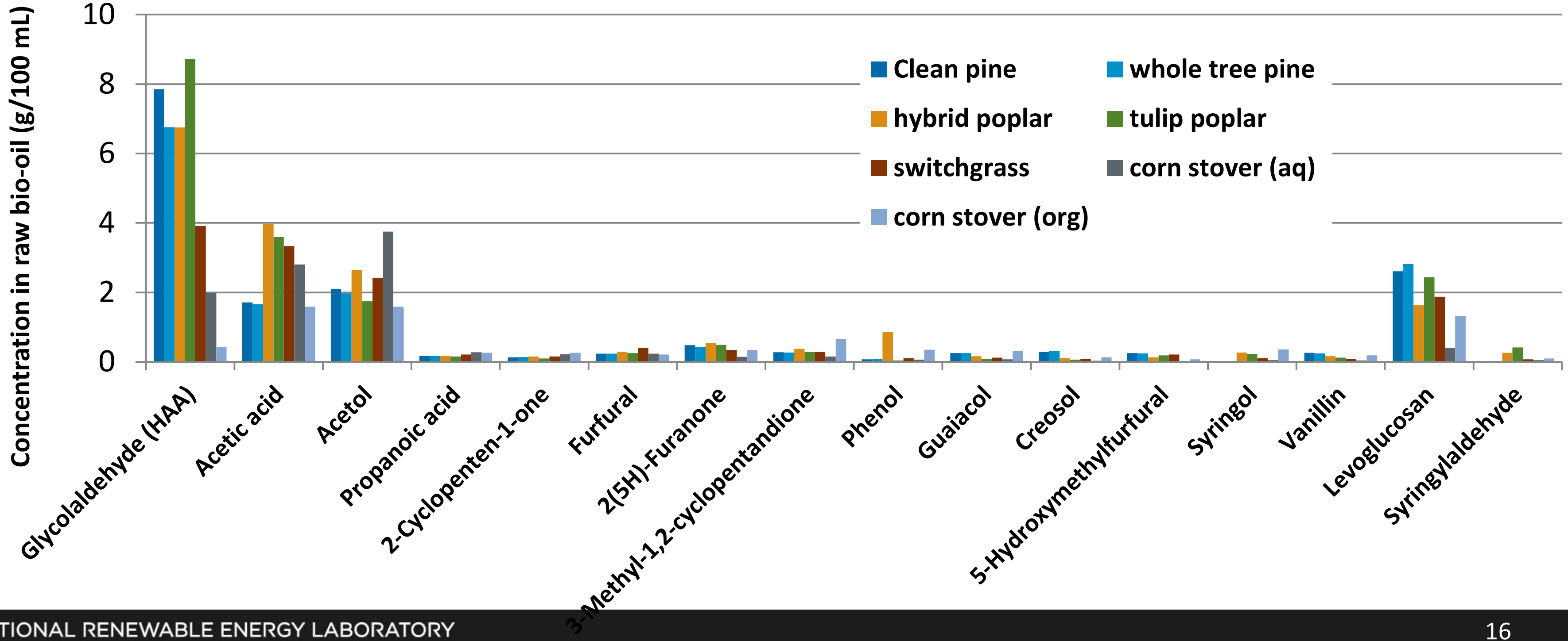
Fast pyrolysis results: product distributions

- Total liquid yields
  52-71 wt%
- Water in bio-oil
  18-37 wt%
- Char yields
  9-19 wt%
- Gas yields
  14-22 wt%
- Carbon conversion
  45(CS)-70(TP) wt% of feed
- Average mass balance
  94% (87% for C)



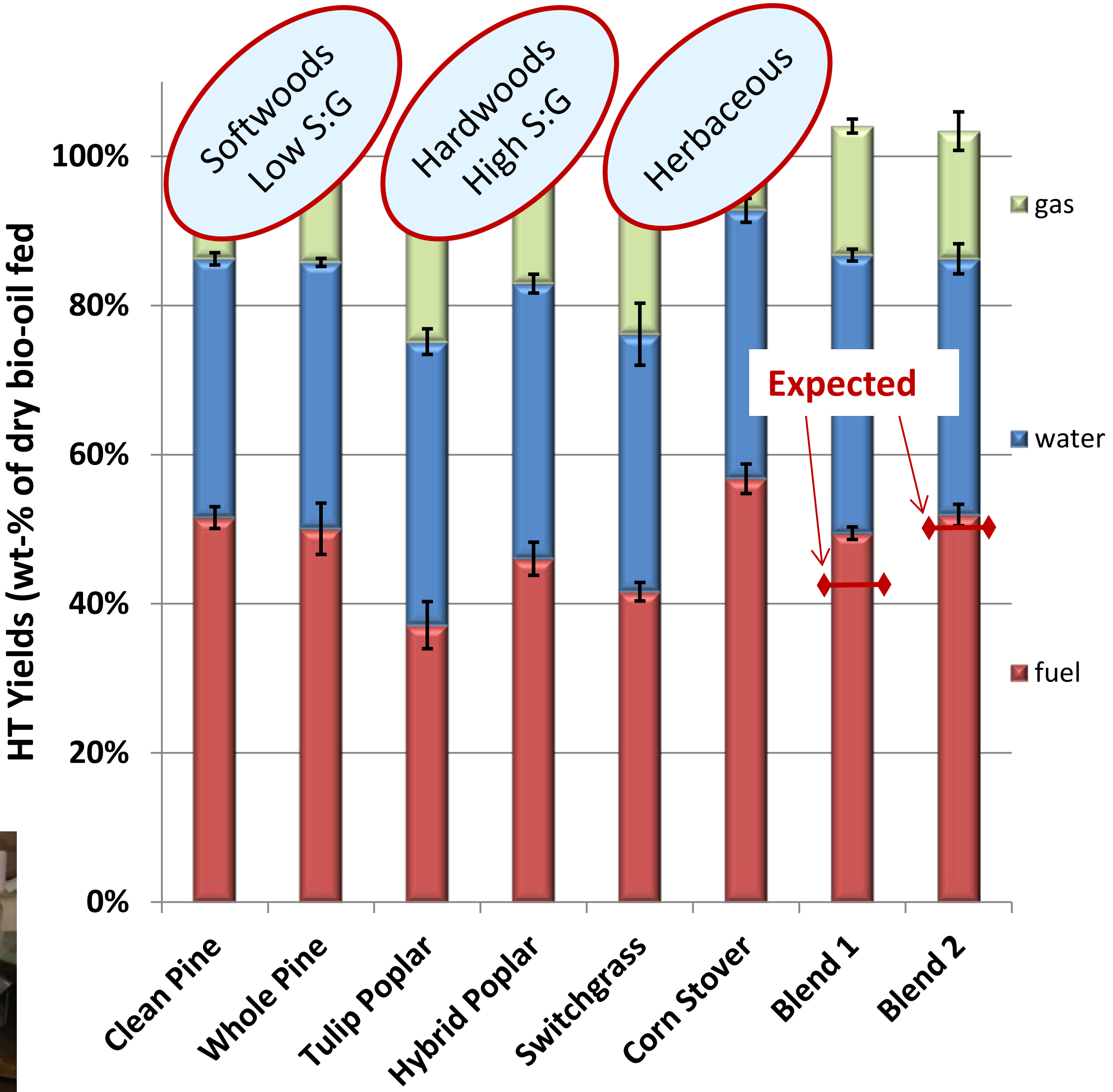
Fast pyrolysis results: bio-oil properties

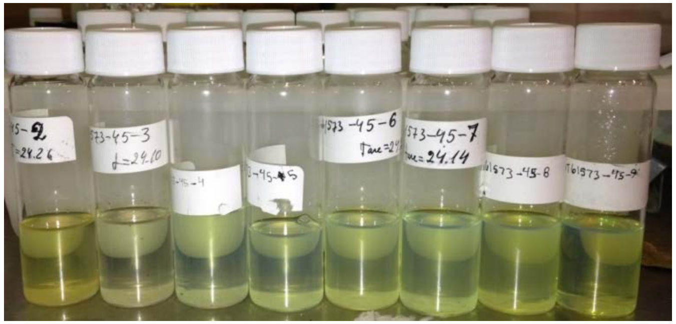
	Clean pine	Whole tree pine	Hybrid poplar	Switchgrass	Corn stover $(48_{aq}/52_{org})$	Tulip poplar	Blend #1	Blend #2
C (wt% as rec'd)	45	45	46	35	14/59	45	40	43
H (wt% as rec'd)	8	8	8	9	11/8	7.7	8.5	8
N (wt% as rec'd)	0.08	0.09	0.08	0.36	0.16/1.29	0.08	0.19	0.09
O (by diff.)	47	47	46	55	76/32	47	50	48
S (wt% as rec'd)	0.06	0.06	0.06	0.1	0.08/0.12	0.06	0.08	0.07
Water (KF-wt%)	21	23	21	37	72/10	19	27	26
TAN (mg/g KOH)	40	38	66	104	41/46	71	72	47
Viscosity (cP, 25°C)	83	92	60	17	2/773	101	39	44



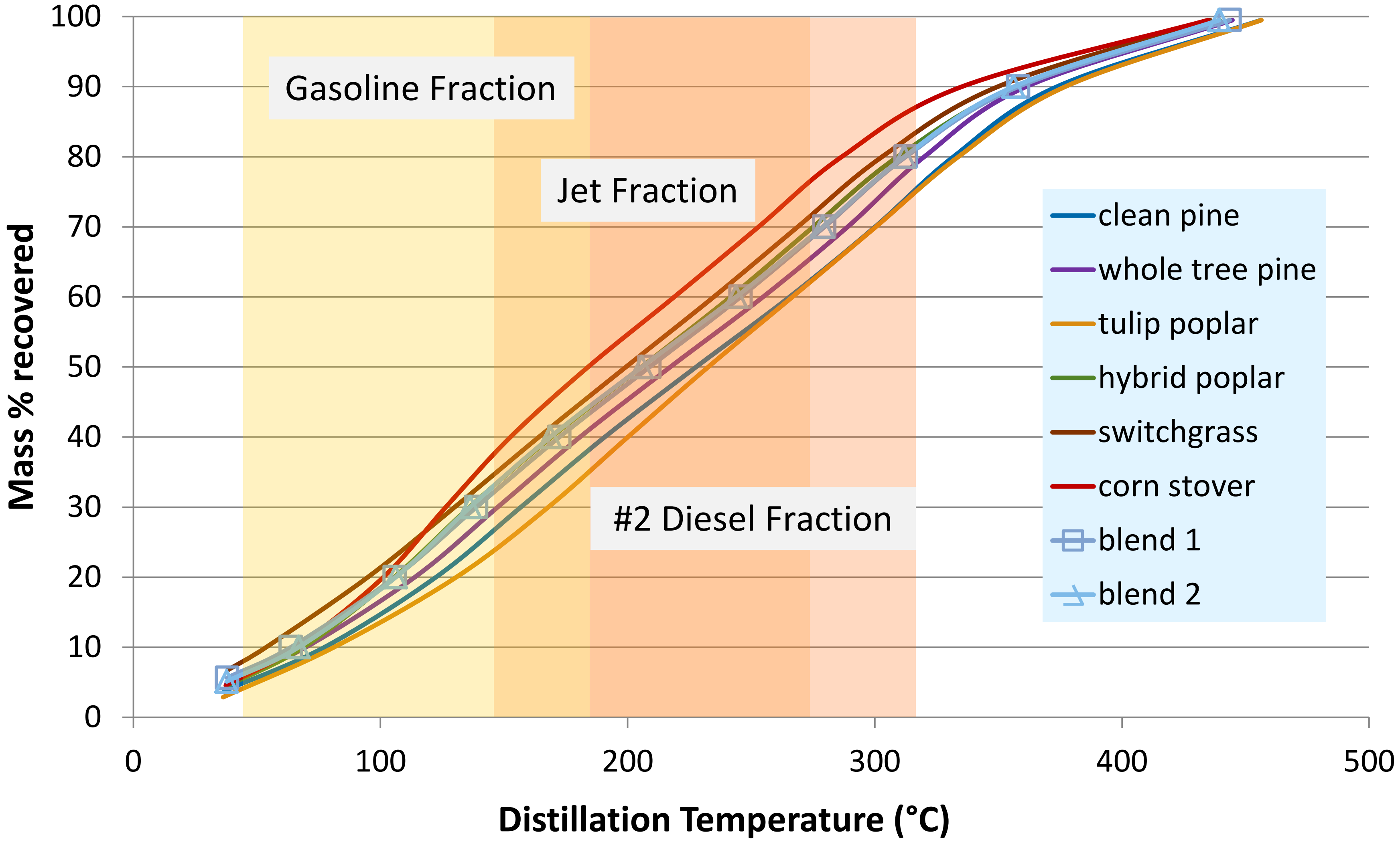
Catalytic hydrotreating results

- Fuel yields
  37.2-56.8 (g/g dry oil)
- Water produced
  34.3-39.8 g/g dry oil
- Gas yield
  14.1-21.0 g/g dry oil
- H_2 consumption
  53(CS)-70(CP) mg/g dry oil





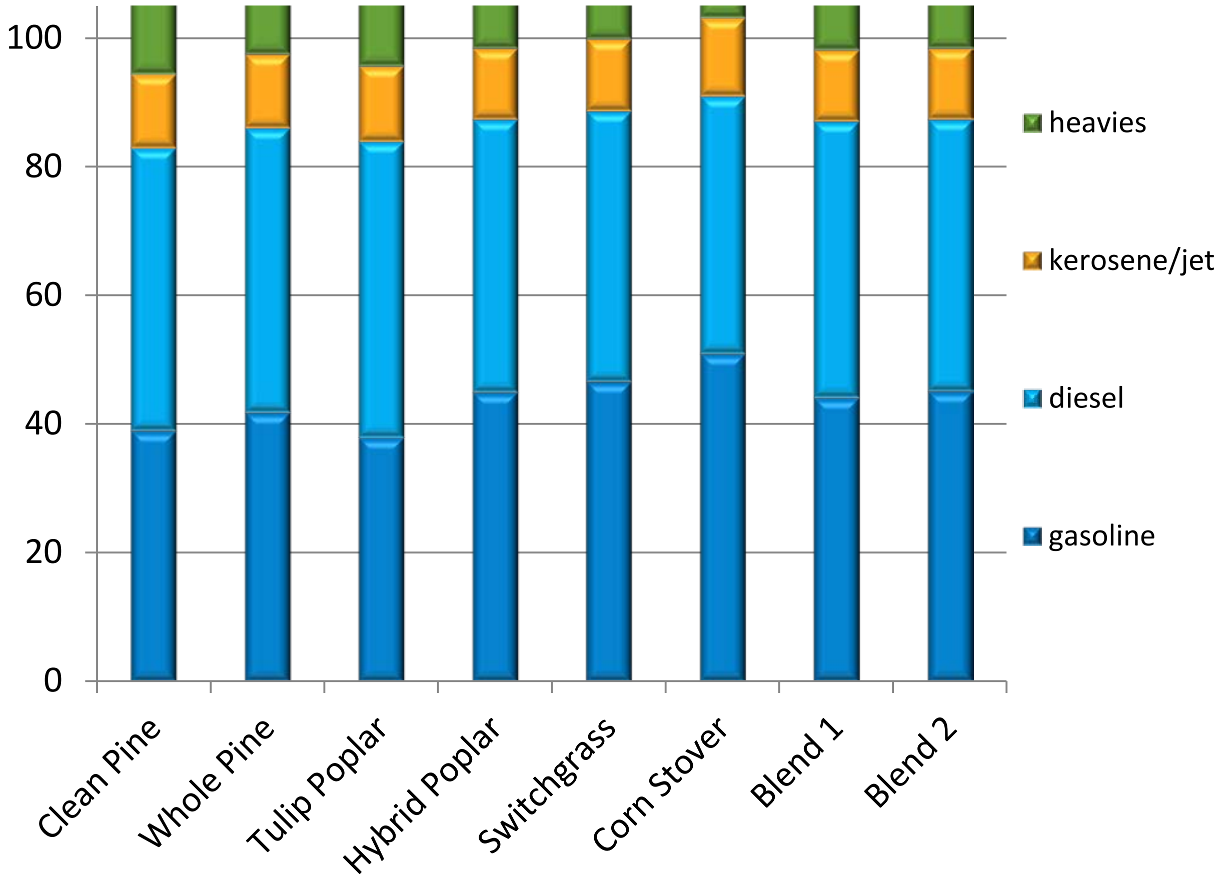
SimDis of final fuel blendstocks



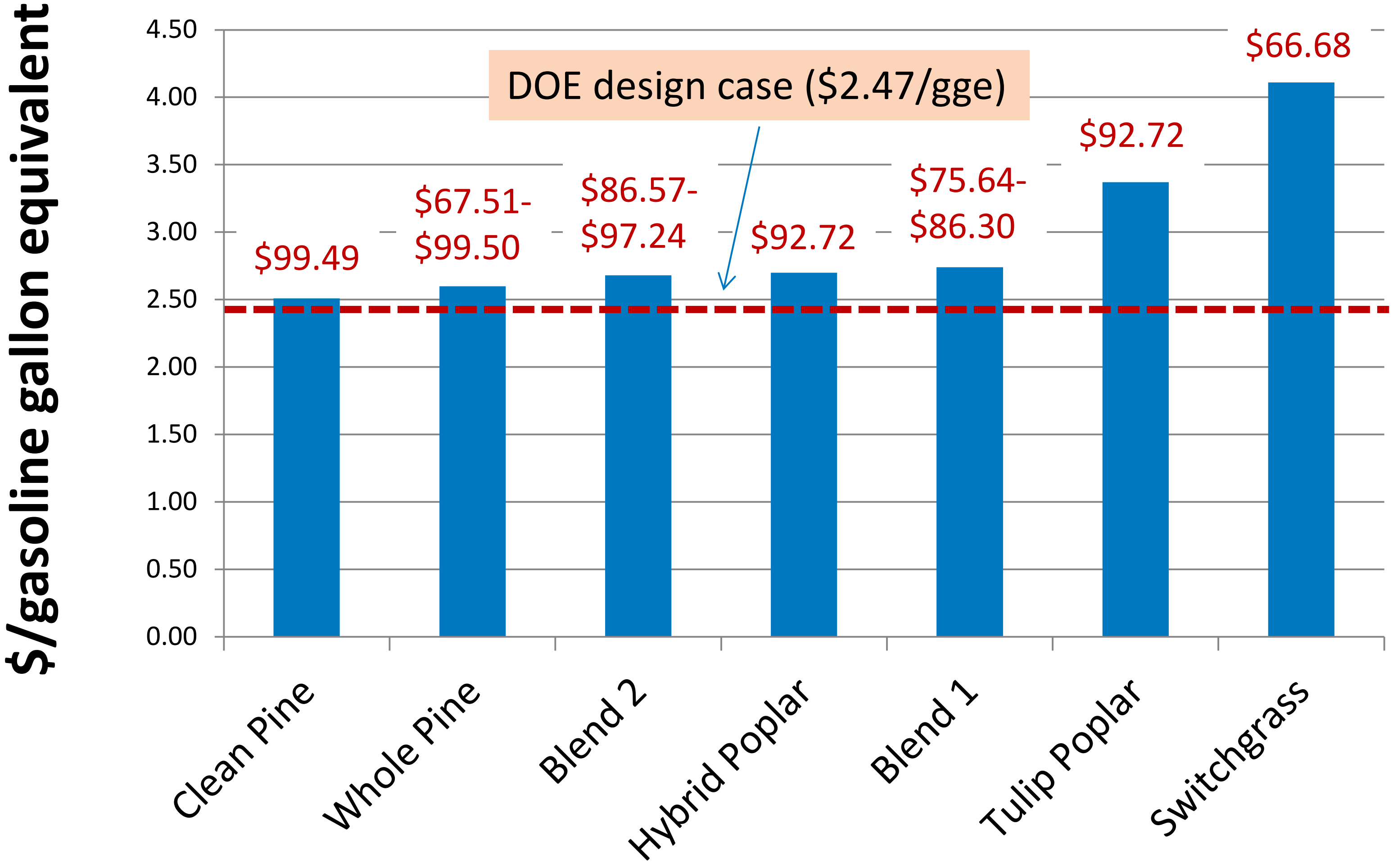
Hydrotreating summary

Biomass Feedstock	Field-to-Fleet Yield
	(g fuel oil/ g biomass)
Clean Pine	27.2%
Whole Pine	24.9%
Tulip Poplar	22.3%
Hybrid Poplar	24.6%
Switchgrass	16.3%
Corn stover	19.3%
Blend 1	24.1%
Blend 2	24.1%

Fuel composition



Preliminary Modeled Conversion Costs (excludes feedstock cost)



Summary

- Feedstock affects everything downstream:
  - FP yields
  - Bio-oil composition
  - HT yields
  - Selectivity to fuel products
- S:G ratio may have negative effect on hydrotreating
- Blends aren't bad, demonstrated same performance for less $

Future work

- Develop PLS model to predict bio-oil/fuel yields based on feedstock composition (INL)
- Test more blended materials (include other high-volume feedstocks: MSW, C&D waste, yard waste)

Thank you for your attention!

Acknowledgements:

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