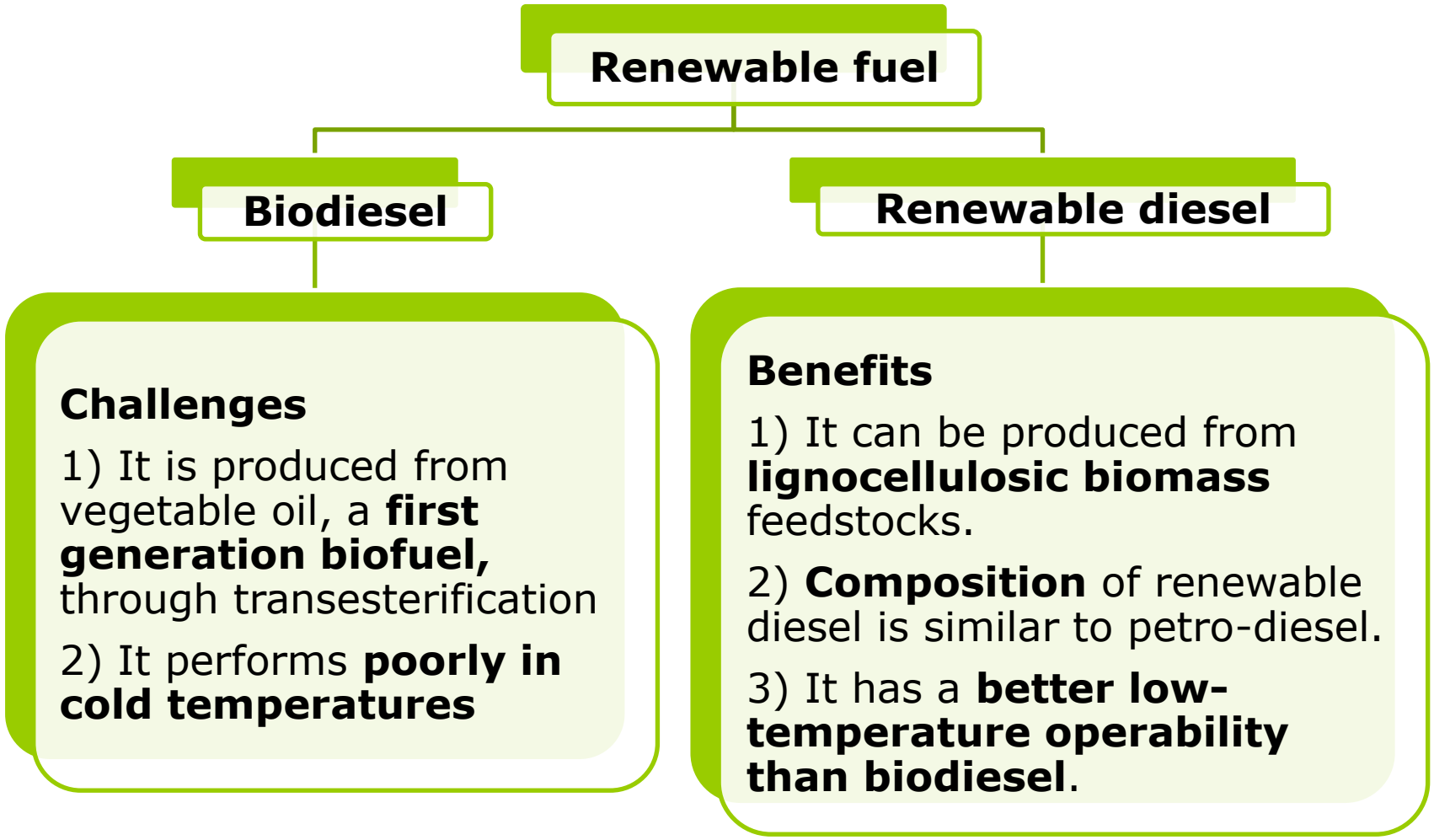
Comparative Experimental and Techno-economic Analysis of Production Cost of Renewable Diesel from Woody Biomass and Agricultural Residue

15th International Symposium on Bioplastics, Biocomposites and Biorefining (ISBBB 2018) July 24 - 27, 2018 , Guelph, ON, Canada

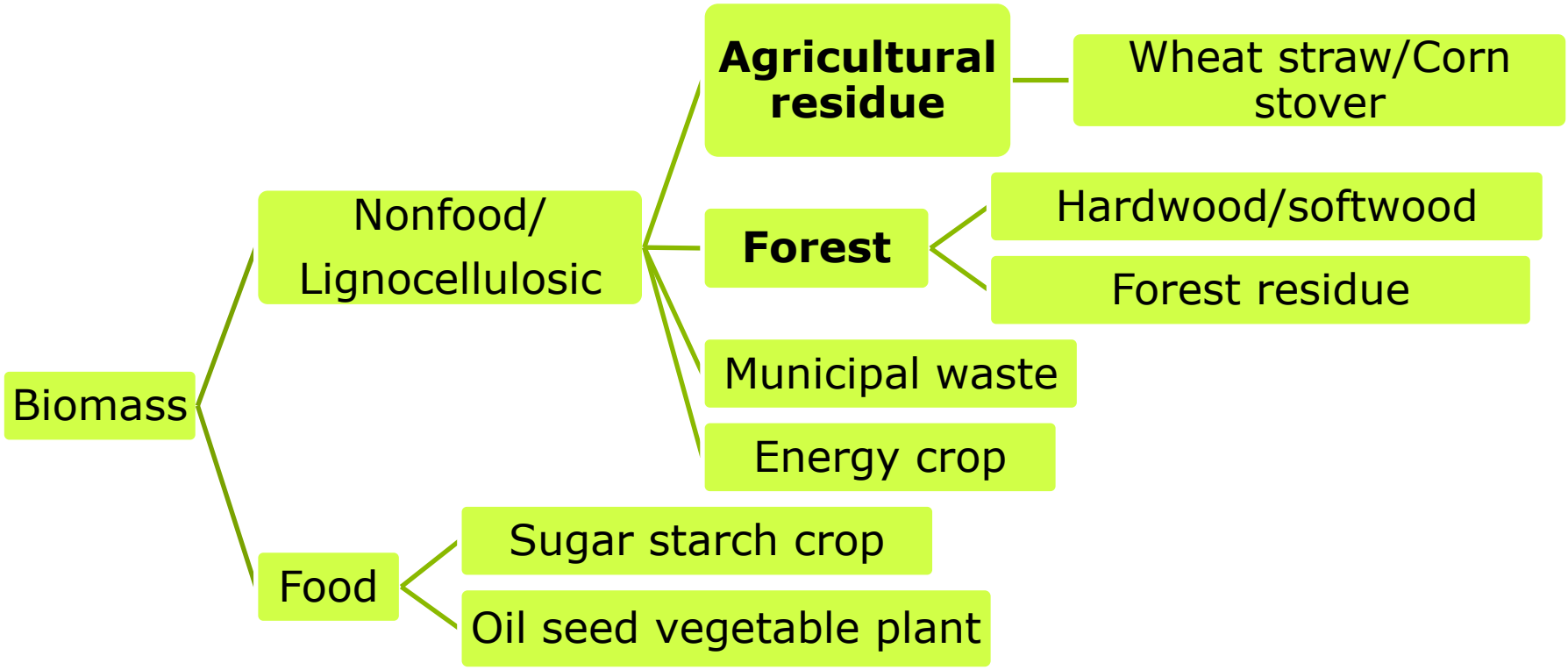
Madhumita Patel, Adetoyese Oyedun, Amit Kumar, Rajender Gupta

University of Alberta

Background

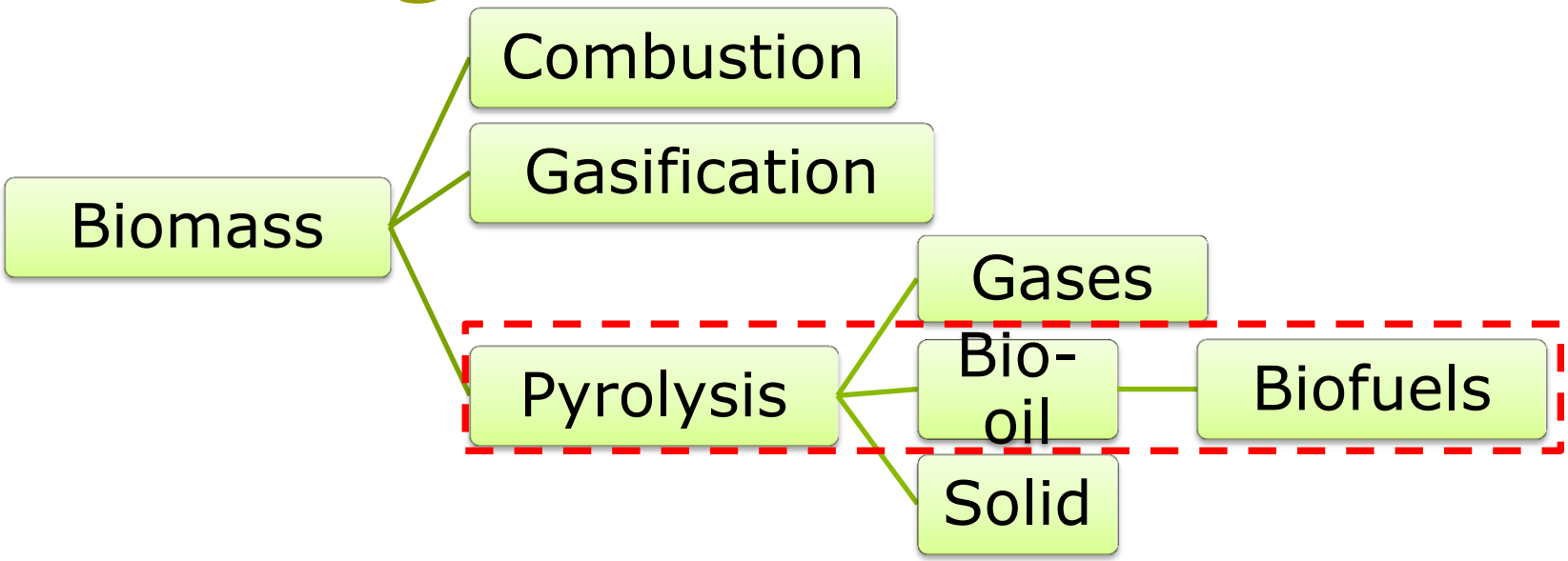

Renewable fuel
Biodiesel
Renewable diesel
Challenges
1) It is produced from vegetable oil, a **first generation biofuel,** through transesterification
2) It performs **poorly in cold temperatures**
Benefits
1) It can be produced from **lignocellulosic biomass** feedstocks.
2) **Composition** of renewable diesel is similar to petro-diesel.
3) It has a **better low-temperature operability than biodiesel**.

Lignocellulosic Biomass



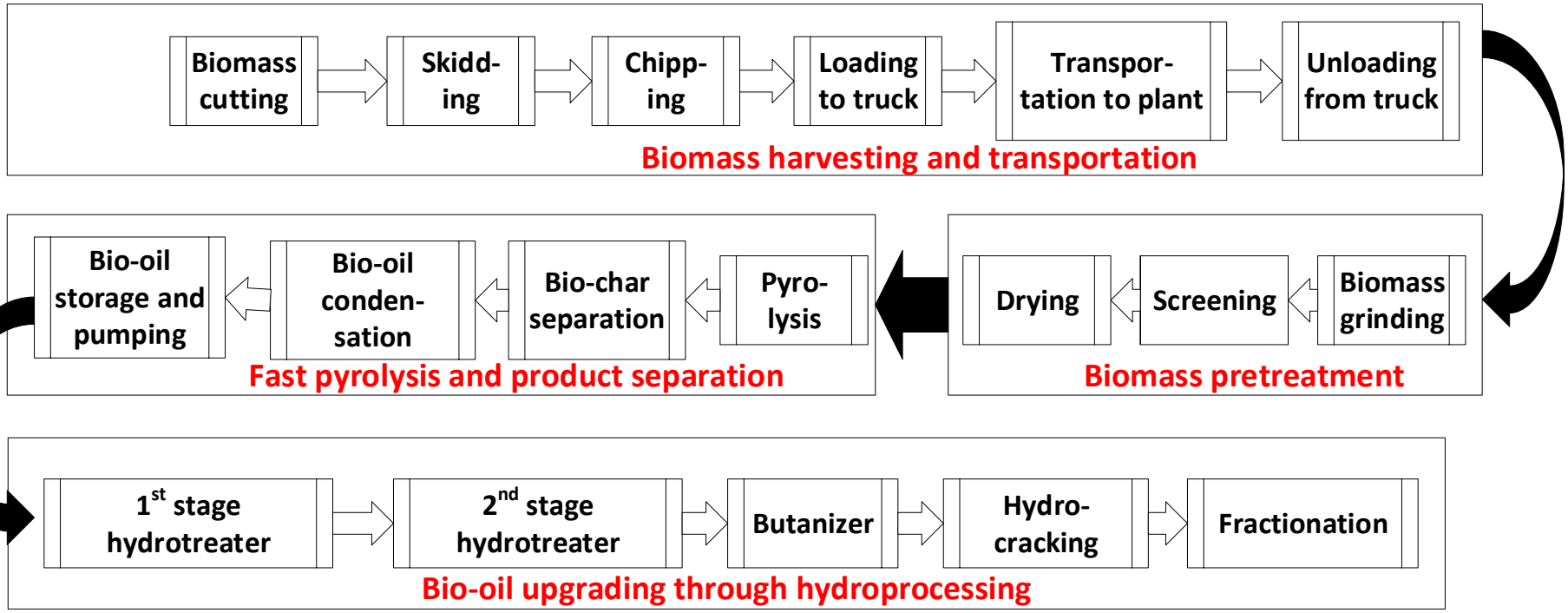
M. Patel, A. Kumar, Production of renewable diesel through the hydroprocessing of lignocellulosic biomass-derived bio-oil: A review, Renew Sust Energ Rev 58 (2016) 1293-1307.

Thermochemical Conversion Technologies

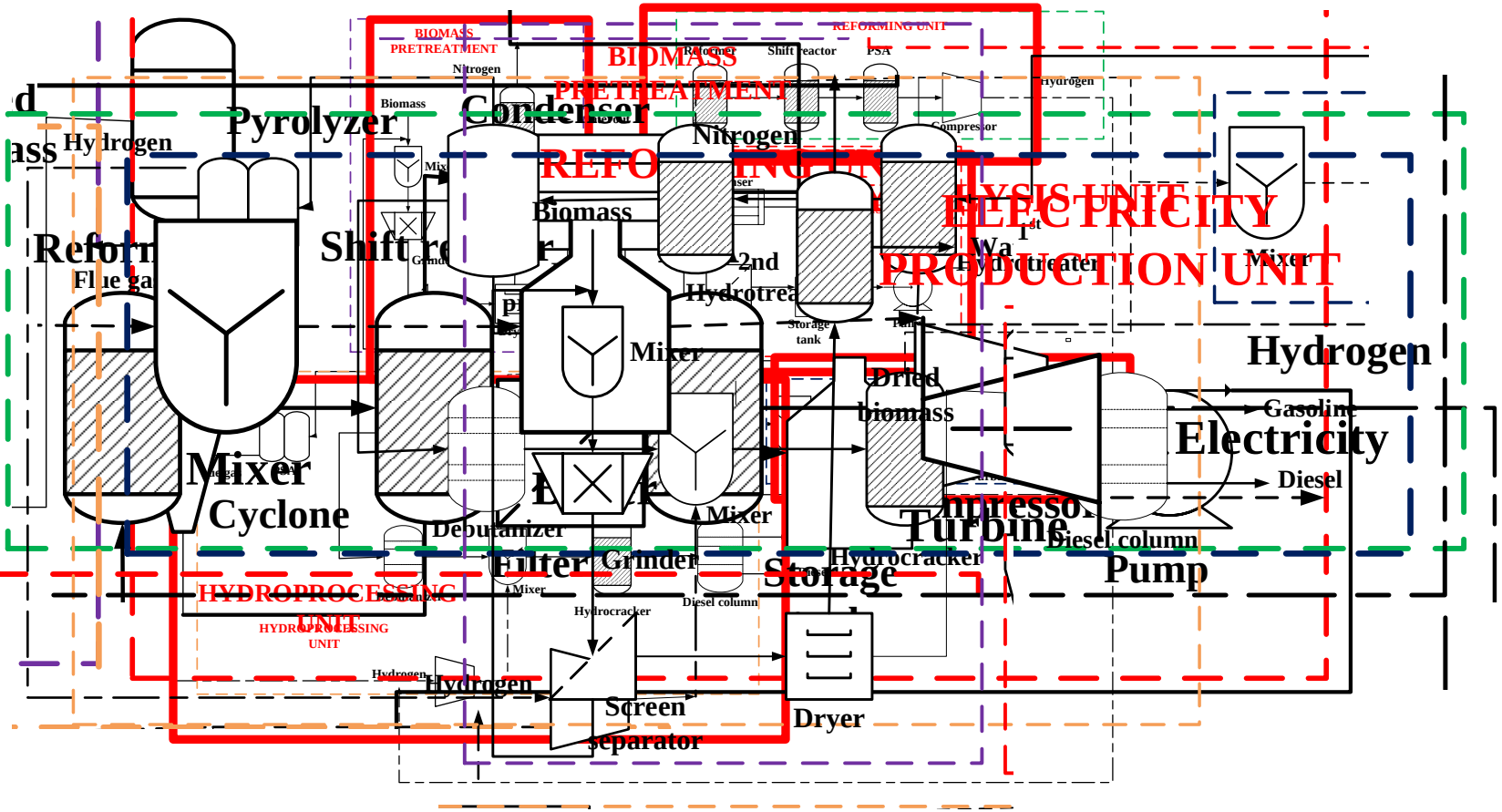


- **In absence of oxygen** to produce liquid bio-oil.
- Bio-oil is an **intermediate** for the production of renewable diesel.
- **Complex mixture of organic compounds** (high Oxygen content).
- **Polar, acidic, and immiscible with hydrocarbon**

Renewable Diesel Production Pathway



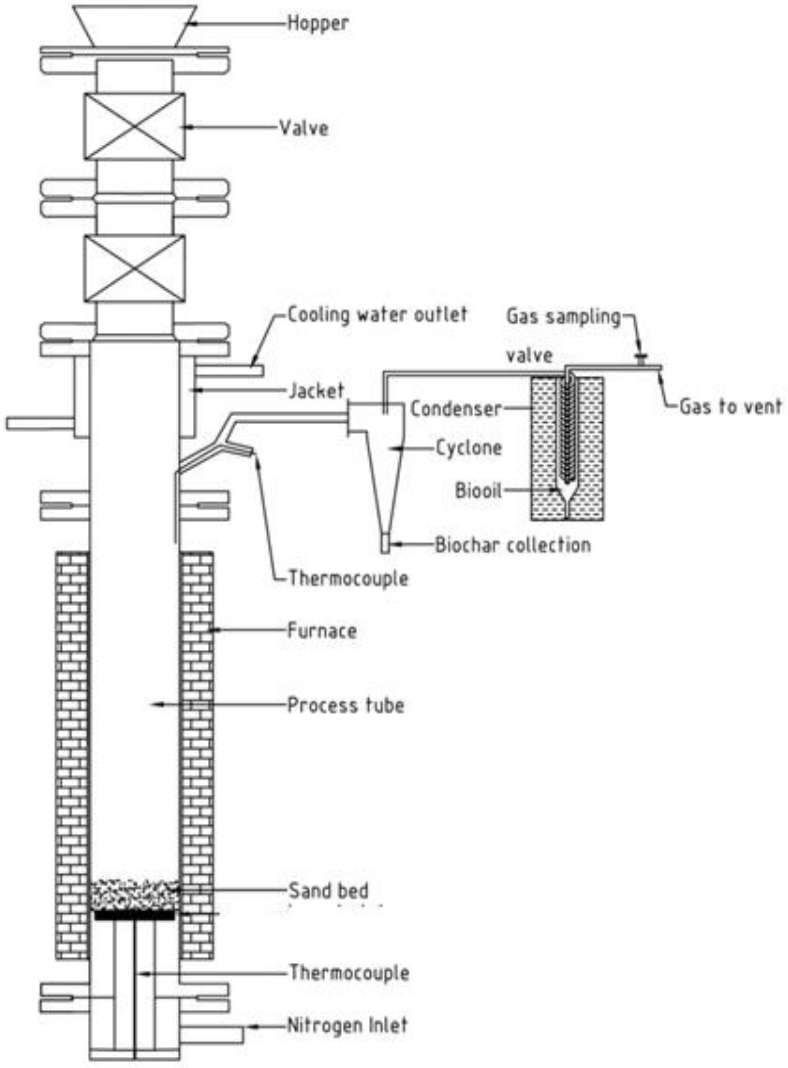
Developed Process Model



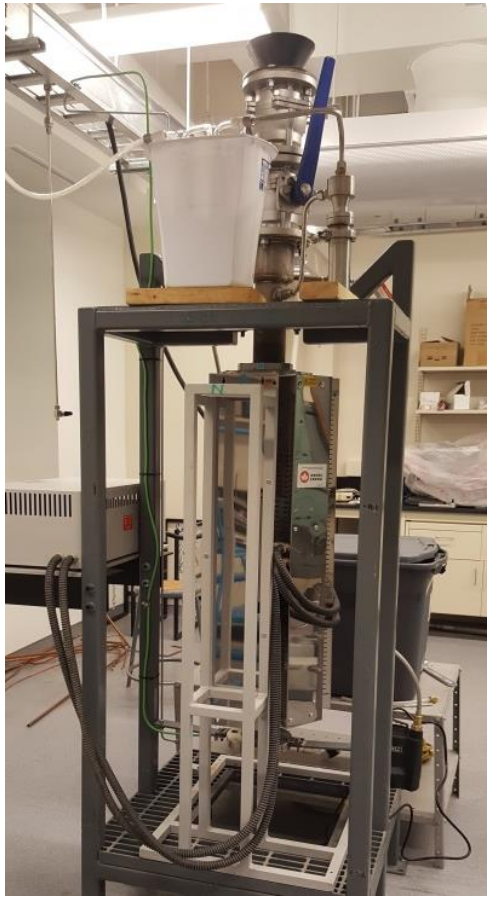
Input Data Required for the Model

- **Physical and chemical properties** of the lignocellulosic biomass
- **Operating conditions of the pyrolyzer** in terms of particle size of biomass, temperature and nitrogen flow rate to obtain maximum bio-oil
- **Bio-oil and un-condensed gases composition** from different lignocellulosic biomass
- **Process condition and catalyst type** for hydrotreating, hydrocracking unit, fractionation column, electricity production unit and hydrogen production unit

Experimental Set-up







Experimental Conditions

- Pressure: 1 atm
- Temperature: 380-520 °C
- Particle size: 0.125-0.425, 0.425 -1 mm and 1-2 mm
- Fluidizing medium: Sand
- Fluidizing gas: Nitrogen
- Condensing medium: ice and water
- Biomass weight: 50 gm
- Sand weight: 250 gm



Proximate and Ultimate Analysis

	Wheat straw	Corn stover	Spruce softwood
Proximate analysis (dry basis)			
Ash	**6.3**	**6.06**	**0.45**
Volatile	75.4	76.32	79.5
Moisture	4.1	6.15	3.9
Fixed carbon	18.3	17.62	16.15
Ultimate analysis (dry basis)			
Nitrogen	0.76	1.2	0.18
Carbon	42.24	41.5	47.48
Hydrogen	5.69	5.6	6.44
Sulfur	**0.03**	**0.05**	**0**
Oxygen	**51.08**	**50.25**	**45.9**

Development of Techno-economic Model



Experimental Data
- **Bio-oil**
- **Biomass**
- **Gases**

Delivery Costs
- **Harvesting**
- **Collection**
- **Transportation**

Financial parameters
- **Life time of plant**
- **Inflation**
- **Internal rate of return**
- **Plant capacity factor**

$/L

Revenues
- ***Renewable diesel***
- ***Gasoline***
- ***Biochar***

Capital Costs
- **Biomass pretreatment and pyrolysis plant**
- **Hydroprocessing plant**
- ***Steam generation plant***
- ***Reforming plant***

Operating Costs
- **Energy**
- **Labor**
- **Catalyst**
- **Hydrogen**

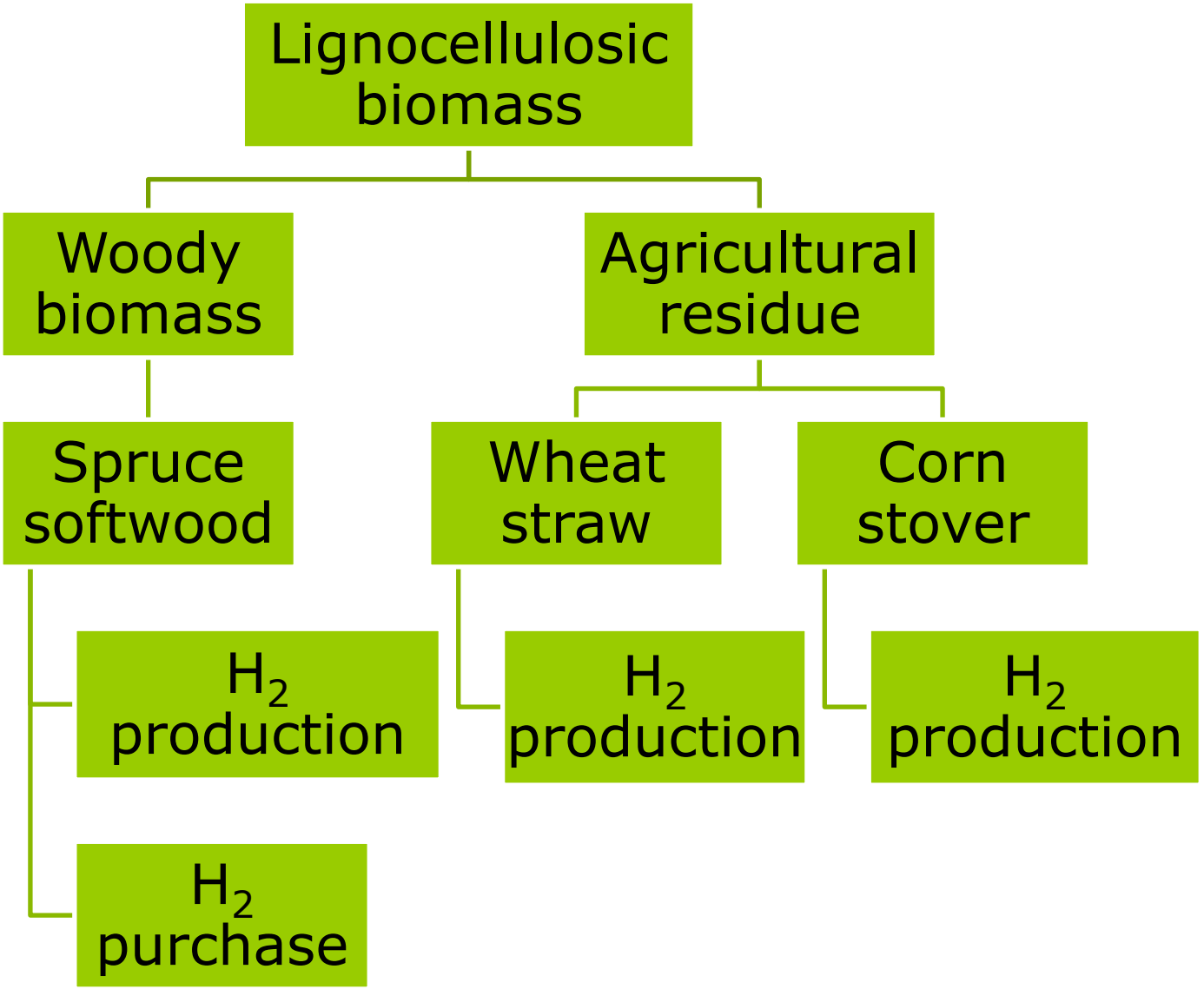
Techno-economic Assumption

Parameter	Value
Plant lifetime (y)	20
Plant capacity	2000 dry tonne/day
Escalation rate	
General & administrative	3.5%
Project capital	5%
Products	5%
Raw material	3.5%
Operating and maintenance labor	3%
IRR	10%
Dollar used	US 2016
Plant startup factor	
Year 0	0.7
year 1	0.8
Year 2+	0.85
Spread of construction cost	
Year -3	20%
Year -2	35%
Year -1	45%

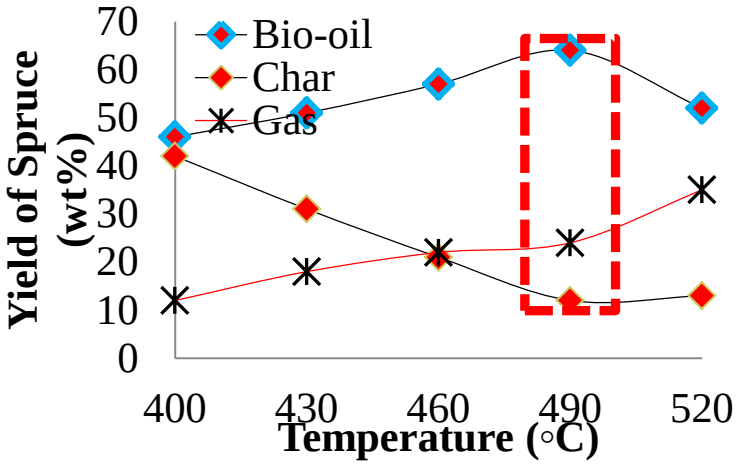
Parameter	Value
Total purchase equipment cost (TPEC)	100% TPEC
Total installed cost (TIC)	302% TPEC
Indirect cost (IC)	89% TPEC
Total direct and indirect cost (TDIC)	TIC + IC
Contingency	20% TDIC
Fixed capital investment (FCI)	TDIC + Contingency
Location factor (LF)	10% FCI
Total capital cost	FCI + LF

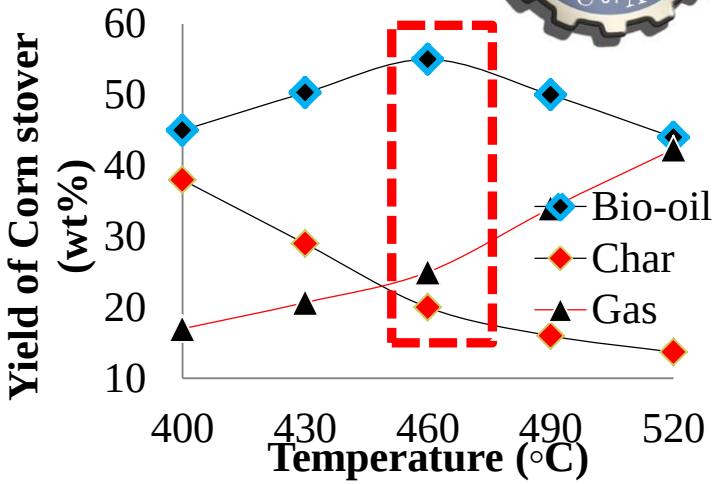
Results and Discussion

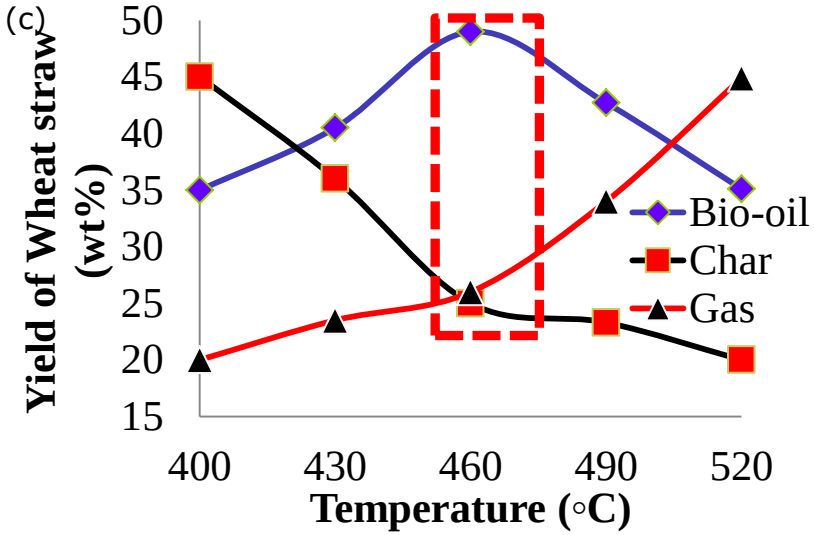
Result: Scenarios Analyzed



Experimental Results

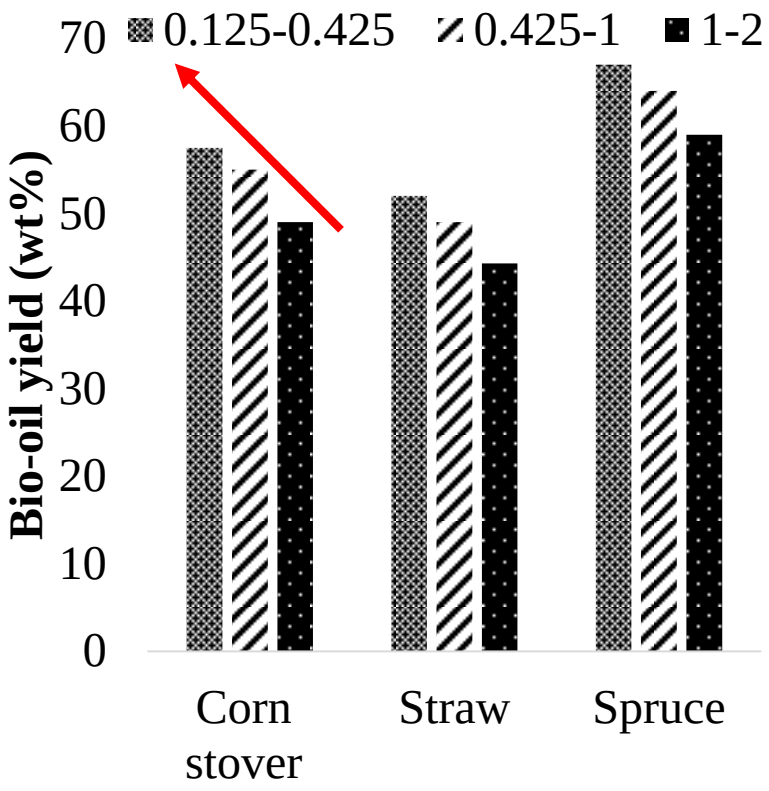


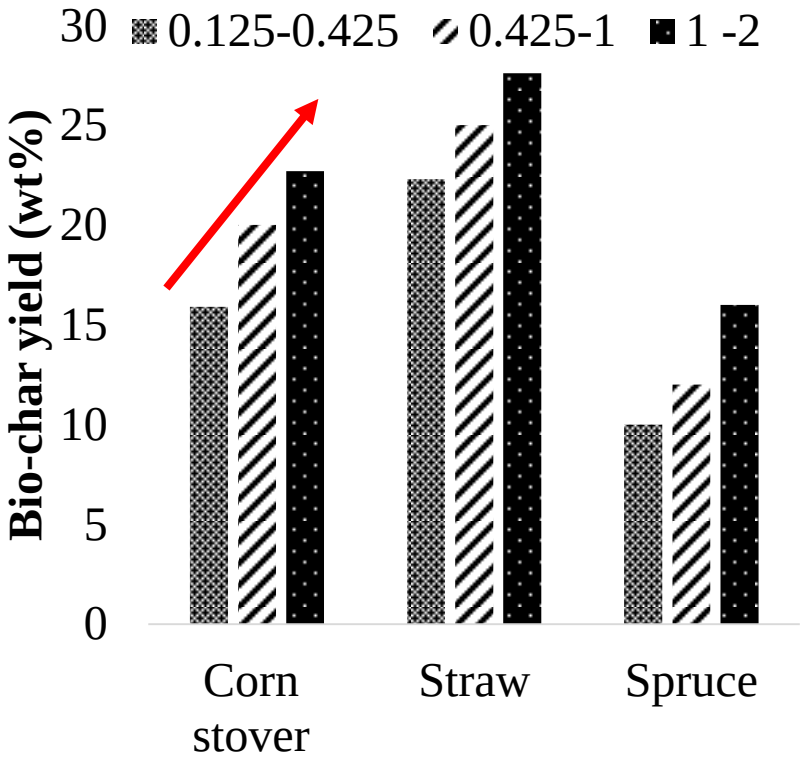




Effects of temperature on product distribution for fast pyrolysis of biomass with (a) spruce, (b) wheat straw, and (c) corn stover

Experimental Results





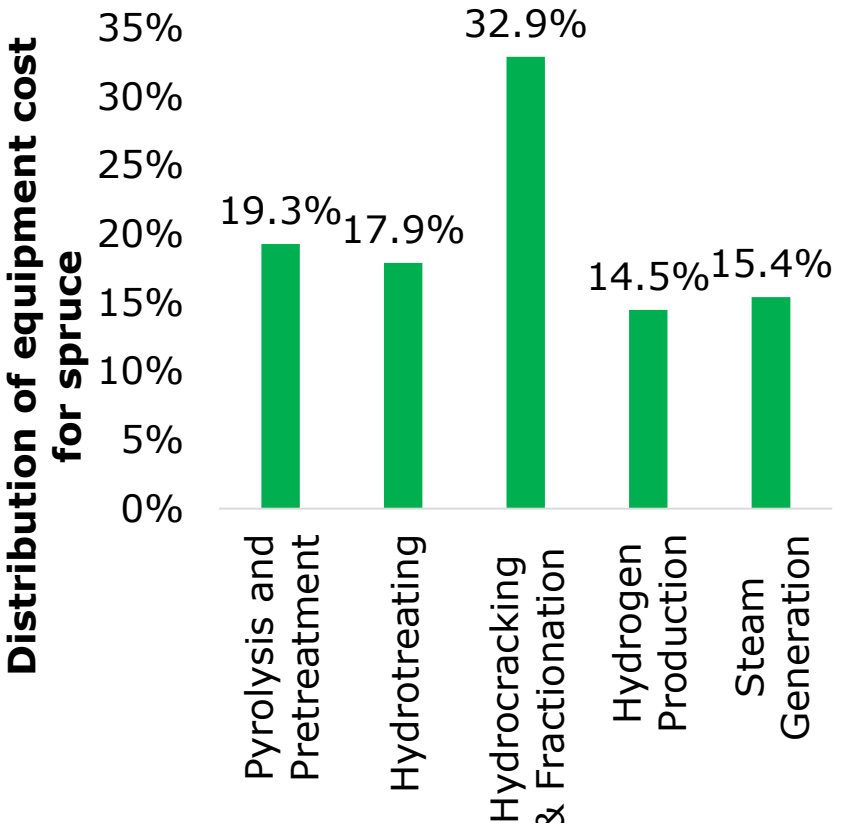
Effects of particle size distribution on bio-oil and biochar yield at 460°C for corn stover and wheat straw and at 490°C for spruce in an inert nitrogen atmosphere

Experimental Results

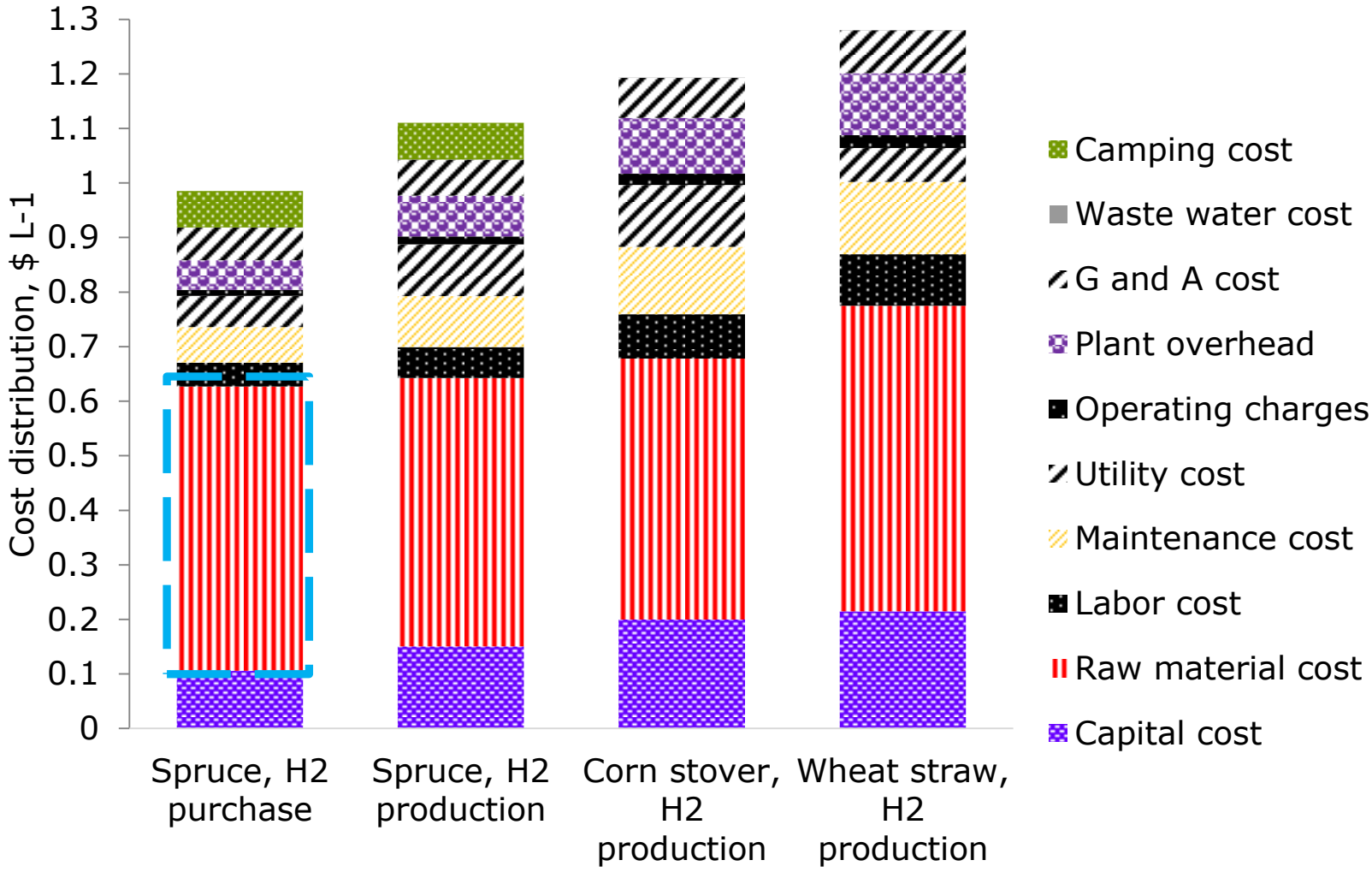
Spruce	Wt%	Corn stover	Wt%	Wheat straw	Wt%
1,3-Cyclopentanedione	4.46%	Cyclohexanone	1.28%	Guaiacol	7.24%
3-Hexanone	0.92%	1,2 Cyclohexane dimethanol	2.76%	P-cresol	0.95%
2,5-Piperazinedione	2.95%	Phenol	4.85%	2-ethyl-2-hexenal	1.27%
Phenol, 2-methoxy-	6.55%	2-cyclopentone, 2,3 dimethyl	5.80%	4-methyl-2-methoxyphenol	1.64%
Maltol	1.59%	Mequinol	7.02%	5-ethylguaiacol	1.60%
Phenol, 2-methoxy-4-methyl-	5.10%	**2-ethyl phenol**	1.15%	**2-Methoxy-4-vinylphenol**	2.24%
Phenol, 4-ethyl-2-methoxy-	2.79%	Benzofuran 2,3 dihydro	7.76%	Syringol	4.27%
Eugenol	2.06%	1,2 benzenediol 3-methoxy	1.62%	Vanillin	2.19%
Vanillin	5.40%	Benzene	2.87%	Phenol	3.36%
Phenol, 2-methoxy-4-(1-propenyl)-,	4.55%	Octanoic acid	0.94%	2-ethylbiphenyl	1.15%
Homovanillyl alcohol	2.85%	Vanillin	1.96%	1,2,4-trimethoxybenzene	1.47%
Ethanone, 1-(4-hydroxy-3-methoxyphenyl	1.83%	Acetic acid	1.89%	Benzaldehyde	1.25%
Benzoic acid, 4-hydroxy-3-methoxy-	1.13%	Ethanone	1.21%	1-monobenzyl glycerol	2.25%
Acetic acid	3.11%	Diphenyl	0.88%	Acetic acid	3.20%
3-Acetyl-6-methoxybenzaldehyde	8.71%				

Key Results: Techno-economic Assessment of A 2000 Dry t d^{-1} Plant

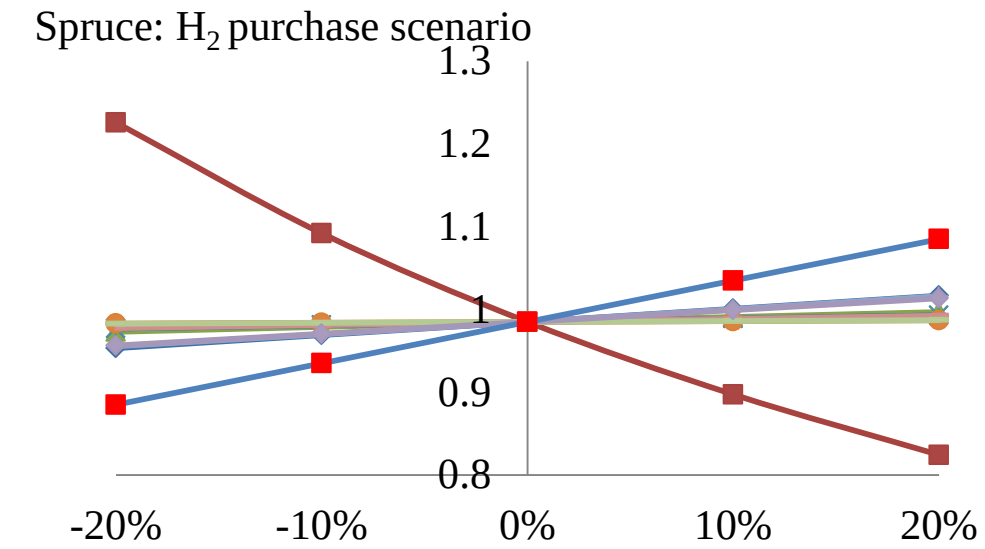
	Spruce		Corn stover	Wheat straw
Parameter	Merch-ant H_2	H_2 produ-ction	H_2 produ-ction	H_2 produ-ction
Installed capital cost (M$)	**247.3**	**347.8**	**322.7**	**300.6**
Total project investment cost (M$)	422.6	594.5	551.5	513.8
Annual operating cost (M$ y^{-1})	157.3	170.6	133.0	123.4
Cost of renewable diesel ($ L^{-1})	**0.98**	**1.11**	**1.19**	**1.27**
Cost of gasoline ($ L^{-1})	0.93	1.06	1.14	1.22

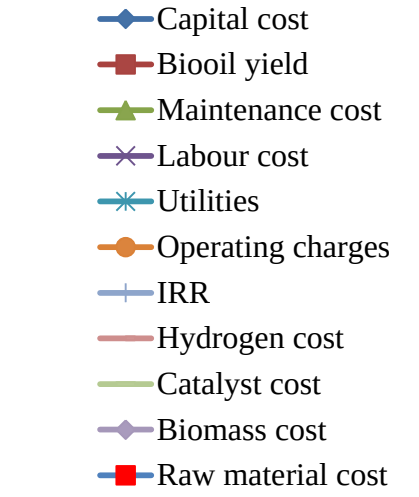


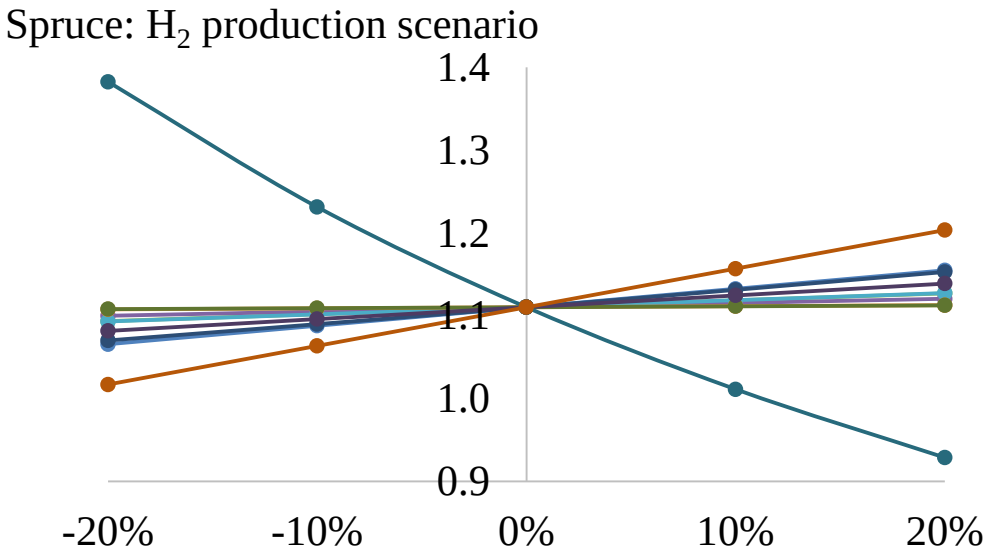
Cost Distribution of A 2000 Dry t d^{-1} Plant

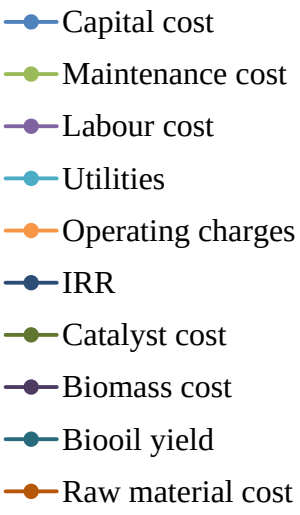


Sensitivity Analysis

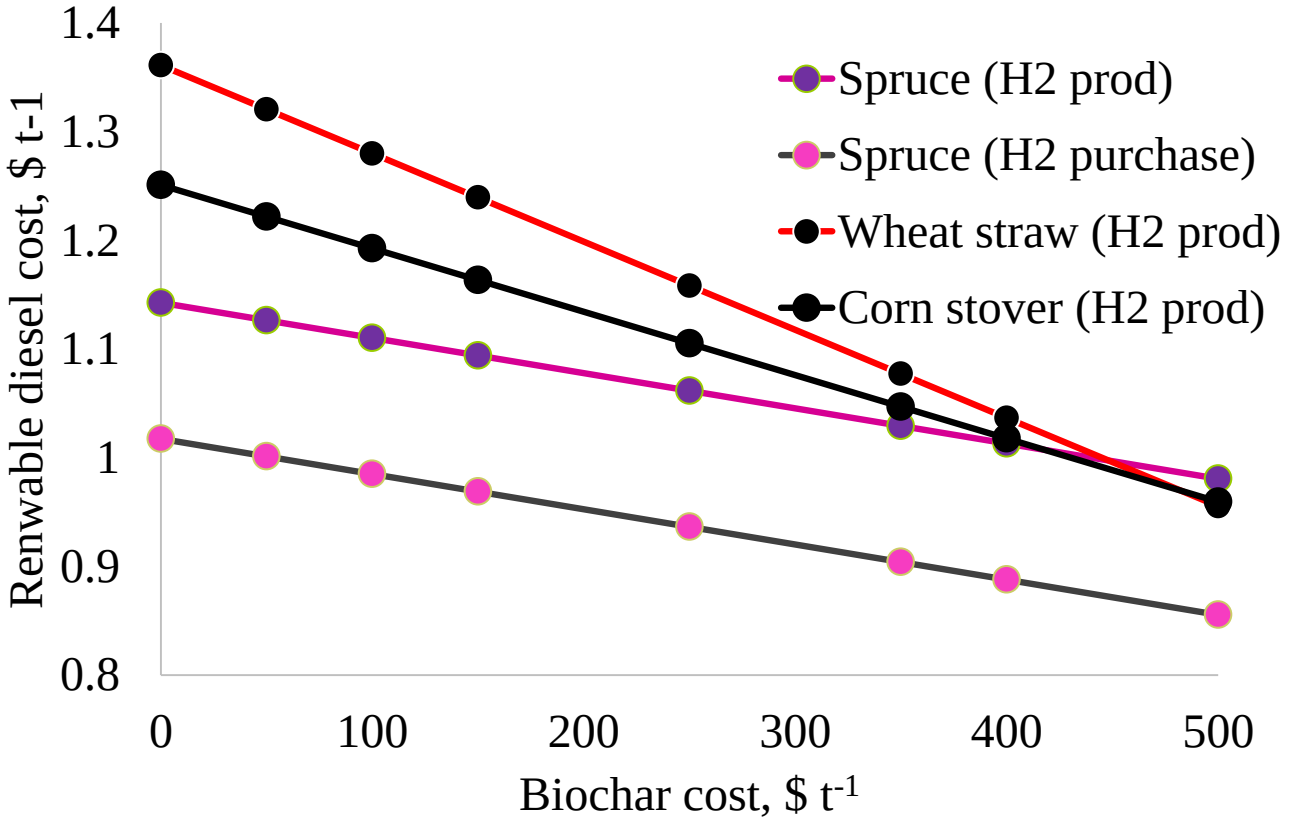








Effect of Byproduct Selling Price on Renewable Diesel Cost



Key Observations

- Renewable diesel production cost is lowest for woody biomass due to high yield of bio-oil compare to agricultural residues. This number lies between 1 to 1.3 $\$L^{-1}$
- Bio-oil yield followed by raw material cost and IRR are the most sensitive parameters to renewable diesel production cost with variations of ±20%.
- Reactor type, reactor conditions and particle size of the biomass play an important role in determining the yield of bio-oil.
- Byproduct selling price has a significant effect on renewable diesel production cost. .

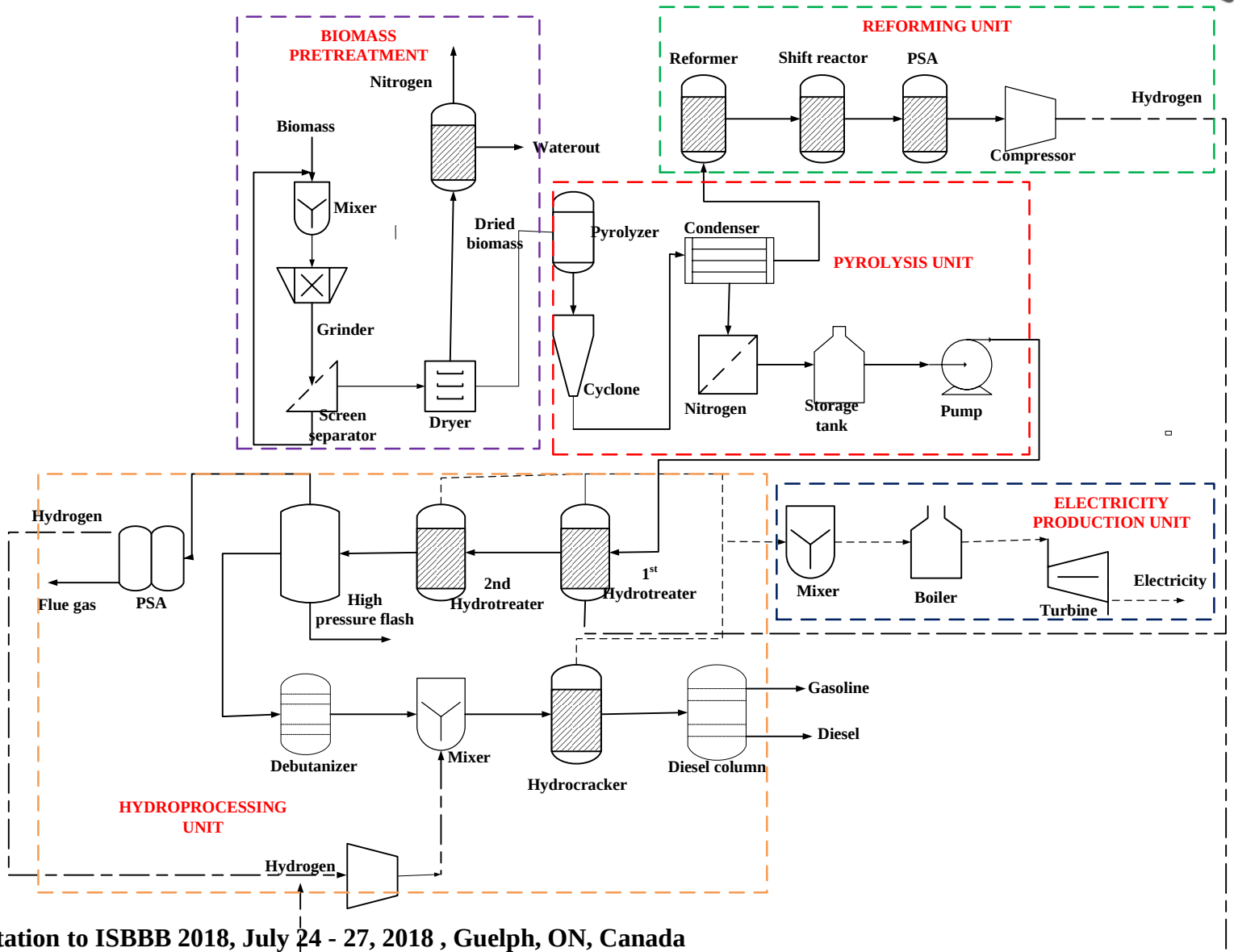
Acknowledgement

- The authors are grateful to Northwest Upgrading (NWU) and Natural Sciences and Engineering Research Council of Canada (NSERC) for financial support.

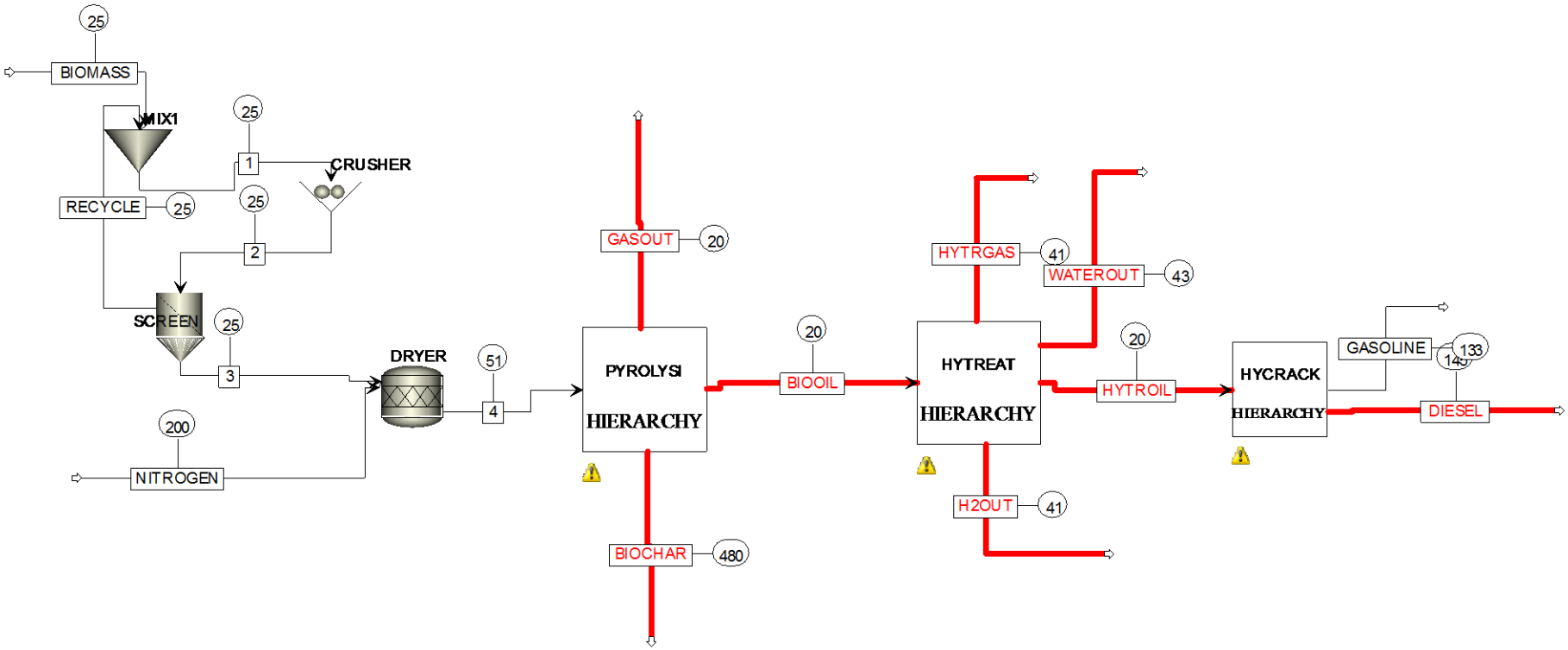
- The authors also thank Bob Rimes of Agri-Food Discovery Place (AFDP) and Terry Kemp of NWU for their valuable inputs on this work.


THANK
YOU

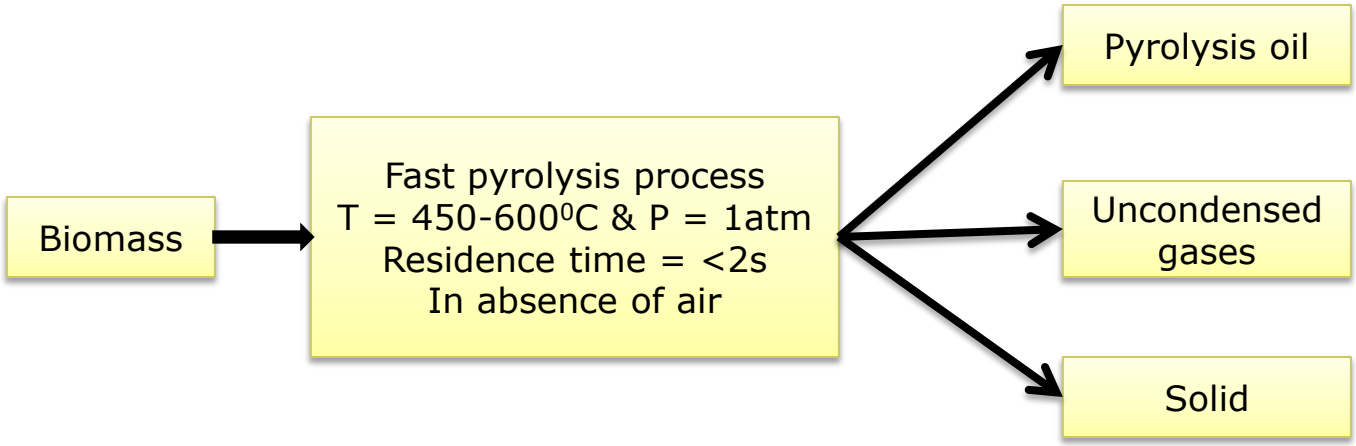

ENGINEERING
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BIOMASS PRETREATMENT
Nitrogen
Biomass
Waterout
Mixer
Dried biomass
Grinder
Screen separator
Dryer
REFORMING UNIT
Reformer
Shift reactor
PSA
Hydrogen
Compressor
Pyrolyzer
Condenser
PYROLYSIS UNIT
Cyclone
Nitrogen
Storage tank
Pump
ELECTRICITY PRODUCTION UNIT
Mixer
Boiler
Electricity
Turbine
Hydrogen
Flue gas
PSA
High pressure flash
2nd Hydrotreater
1st Hydrotreater
Debutanizer
Mixer
Hydrocracker
Diesel column
Gasoline
Diesel
HYDROPROCESSING UNIT
Hydrogen

Aspen Plus Flow Sheet



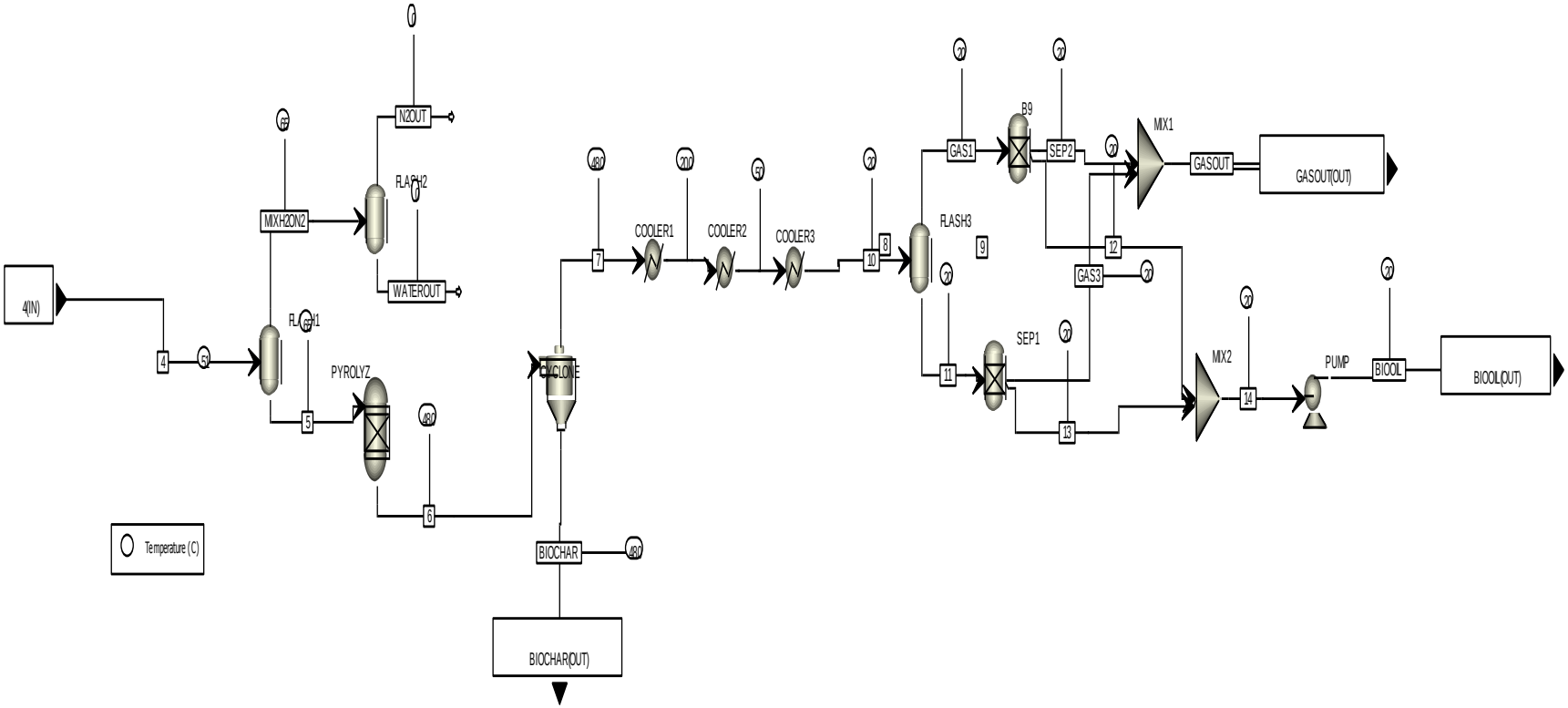
Fast Pyrolysis Technology



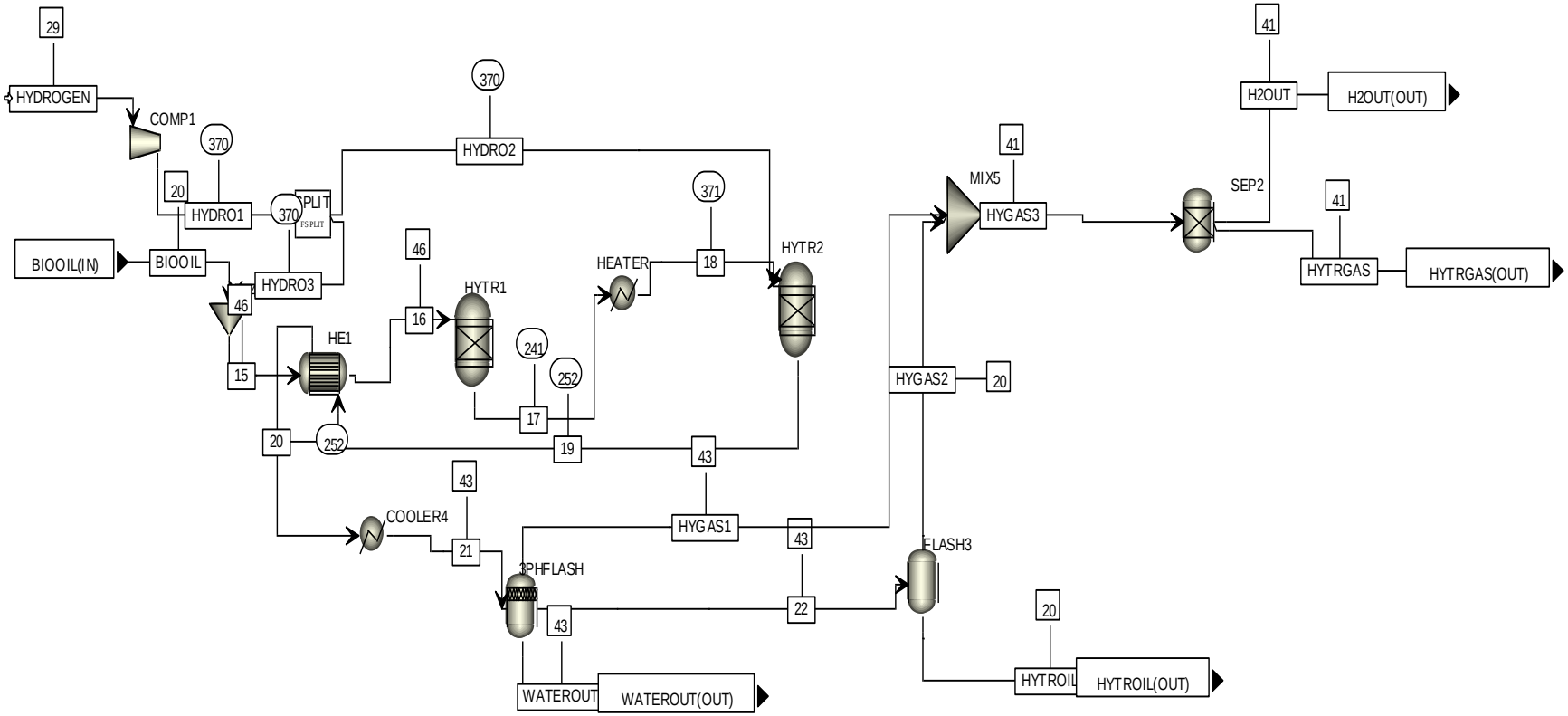
Characteristics of fast pyrolysis oil

- ✓Complex mixture of organic compounds
- ✓Oxygen content around 30-50 wt%
- ✓ Polar, acidic and immiscible with hydrocarbons
- ✓ Low energy density, low thermal and chemical stability
- ✓ Highly viscous, corrosive and limited storage stability

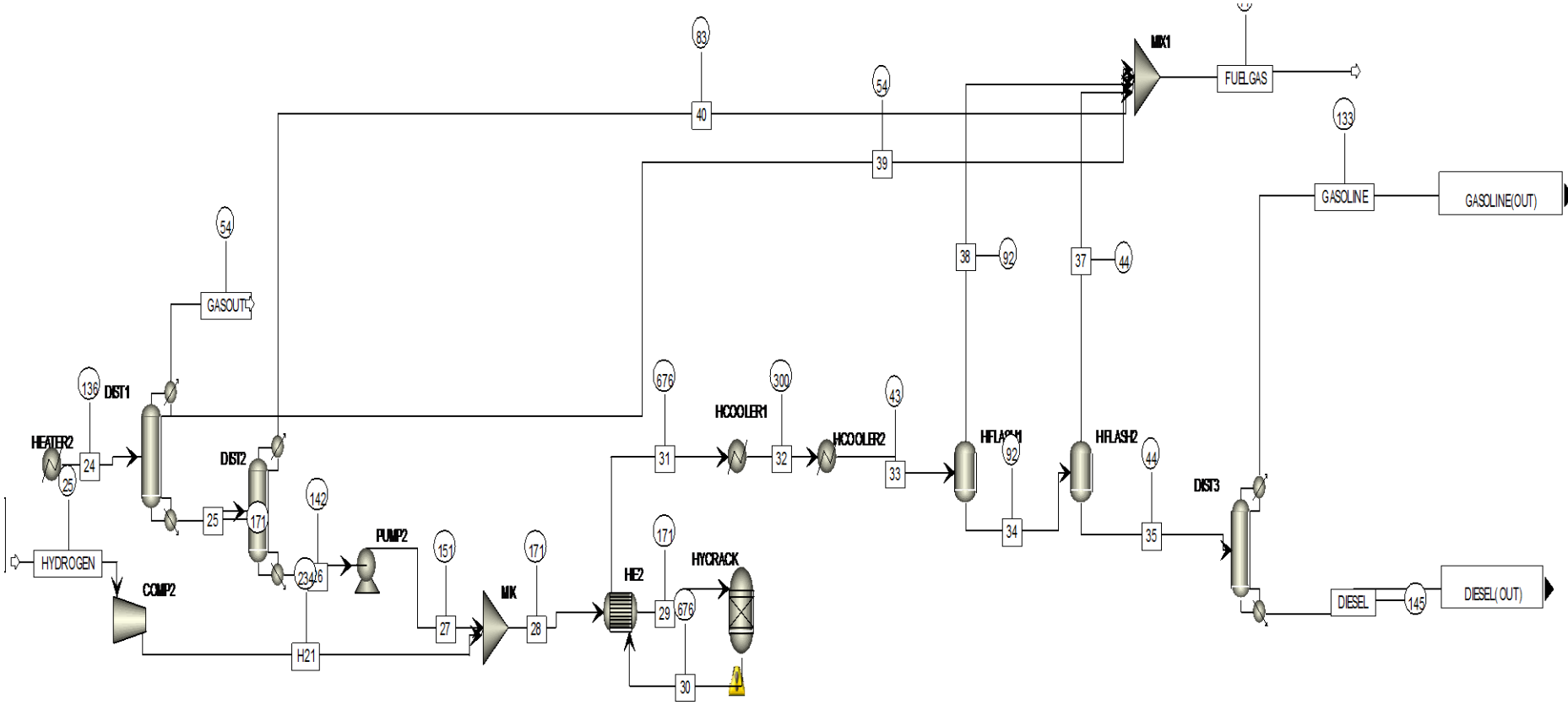
Fast Pyrolysis



Hydrotreating Unit



Hydrocracking Unit



Property	Biodiesel	Renewable diesel	Petro-diesel
Density (g/ml)	0.885-0.9	0.77-0.83	0.85
Sulfur (ppmwt)	0 – 0.012	<10	12
Cetane number	45 -72.7	80 – 99	54.57
Flash point (^{0}C)	96-188	68-120	52-136
Net heating value (MJ/kg)	37.1-40.4	42-44	44.97
CFPP (^{0}C)	(-13)-15	>20	-6
Cloud point (^{0}C)	(-3) – 17	(-25) – 30	-5
Pour point (^{0}C)	(-15) -16	(-3) – 29	-21
Kinematic viscosity (mm^2)	1.9 – 6.0 (@ 40^{0}C)	1.9 – 4.1(@ 40 ^{0}C)	1.9 – 4.1(@ 40 ^{0}C)

http://advancedbiofuelsusa.info/wp-content/uploads/2011/03/11-0307-Biodiesel-vs-Renewable_Final-_3_-JJY-formatting-FINAL.pdf