FLORIDA SOLAR ENERGY CENTER®

Creating Energy Independence

Sustainable production of hydrogen and synthetic hydrocarbon fuels for NASA's fleet from local biomass resources

Nazim Muradov, Ali T-Raissi

Amit Gujar, Jong Baik

Florida Solar Energy Center, UCF

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Objective

To assess technical and economic viability of production of hydrogen and synthetic liquid hydrocarbons (gasoline, diesel, jet fuel, kerosene) in Central Florida from locally available biomass feedstocks.

Atlas space vehicles currently use both types of fuels:

- kerosene in the main engine (RD-180)
- L-H_2 in the second stage engine (RL-10)

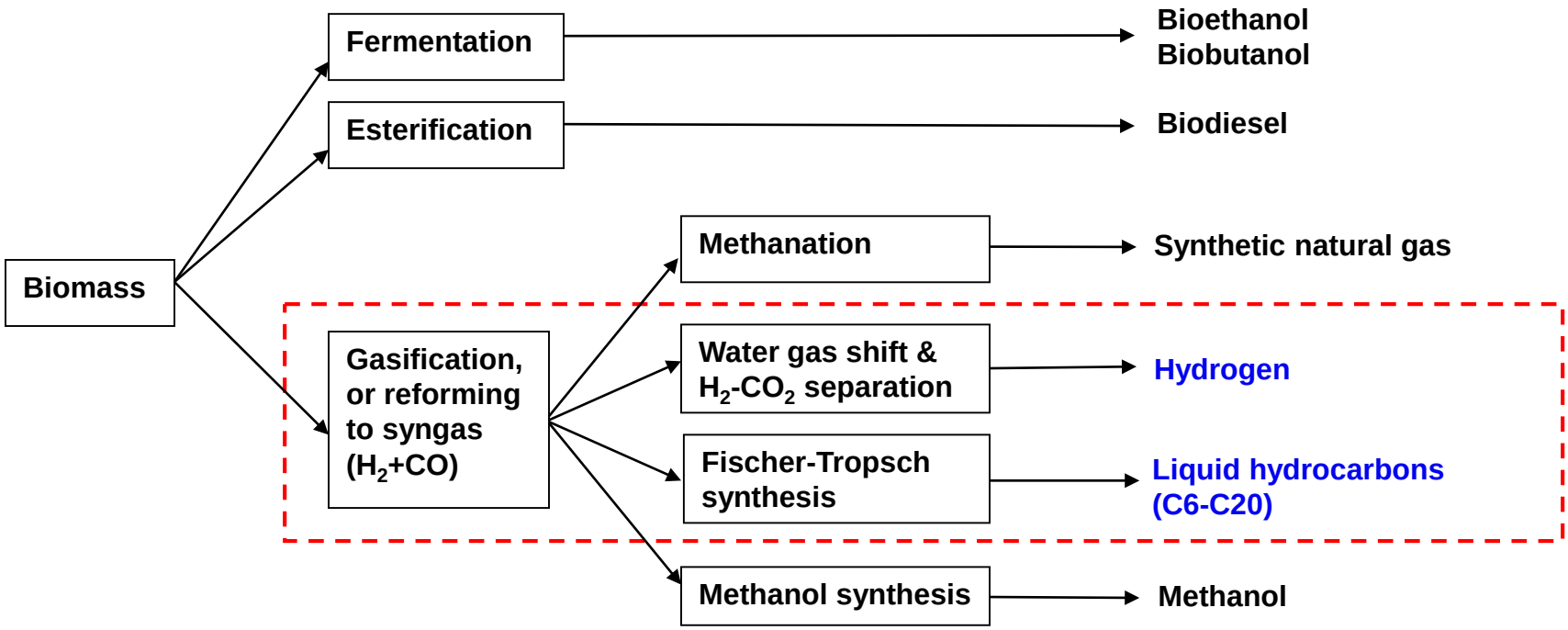
Why Biomass?

- Immense resources of biomass in Florida
- Carbon-neutral source
  - Citrus waste (CW) (~1 mln. t/yr)
  - Sugarcane bagasse
  - Forest residue, trees, grass
  - Energy crops
  - Urban wood waste, MCW

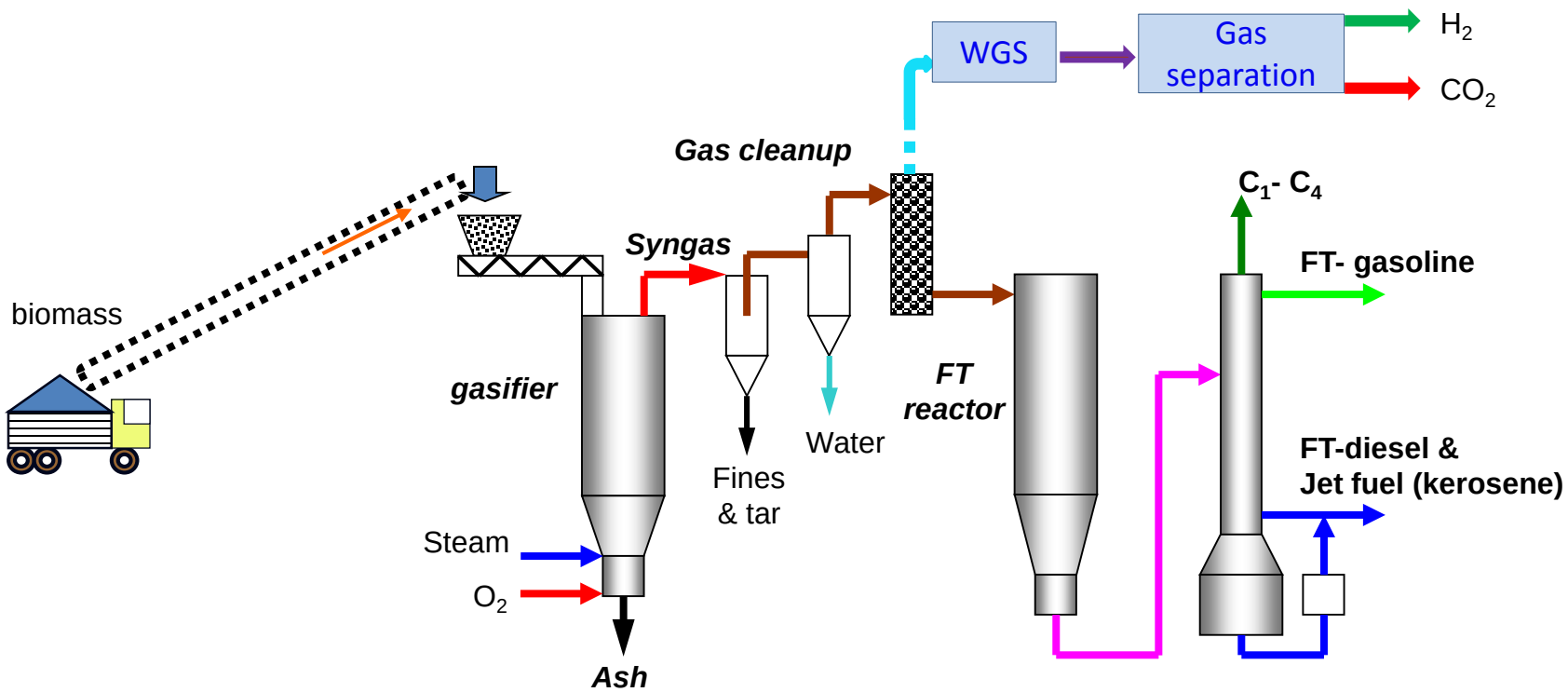
70,000 t/yr H_2 or 200,000 t/yr liquid hydrocarbon fuels can be produced from citrus waste in Florida

Technical Background

Major Technological Routes for Converting Biomass to Fuels



Schematics of the Process



River algae

Duckweed

Citrus pulp pellets

Pine wood pellets

Pine charcoal pellets

Process Chemistry

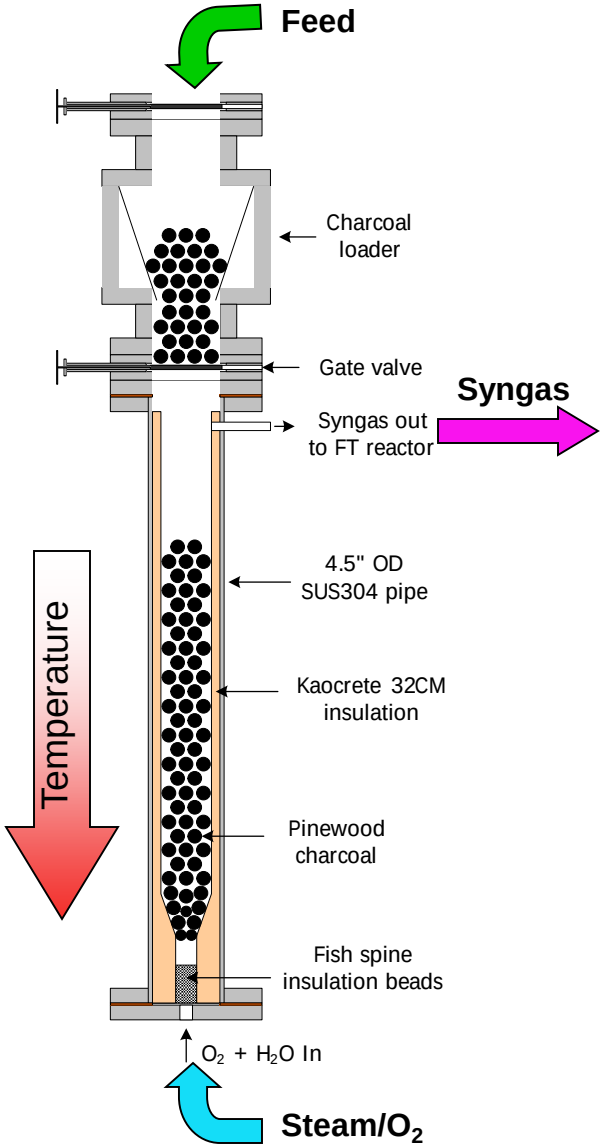
- **Generic biomass gasification reaction:**

$$CH_{1.4}O_{0.6} + 0.4\ O_2 \rightarrow 0.6\ H_2 + 0.7\ CO + 0.3\ CO_2 + 0.1\ H_2O$$

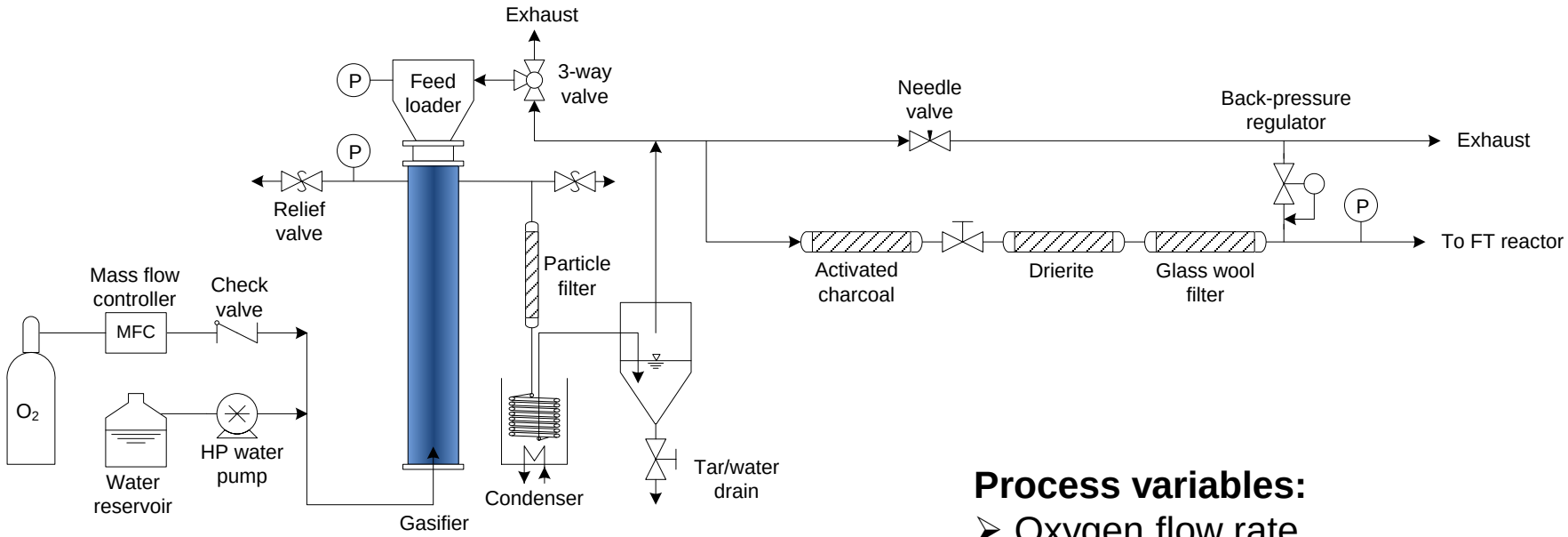
- **Fischer-Tropsch (FT) synthesis reaction:**

$$CO + 2\ H_2 \rightarrow (\text{-}CH_2\text{-}) + H_2O$$

Biomass Gasifier (Updraft)



Schematic of Experimental Setup



Process variables:

- Oxygen flow rate
- Steam/oxygen ratio

Output:

- Syngas flow rate
- Syngas composition
- Feed gasification rate

Control Volume for Equilibrium Calculations

Main Reactions in Gasifier

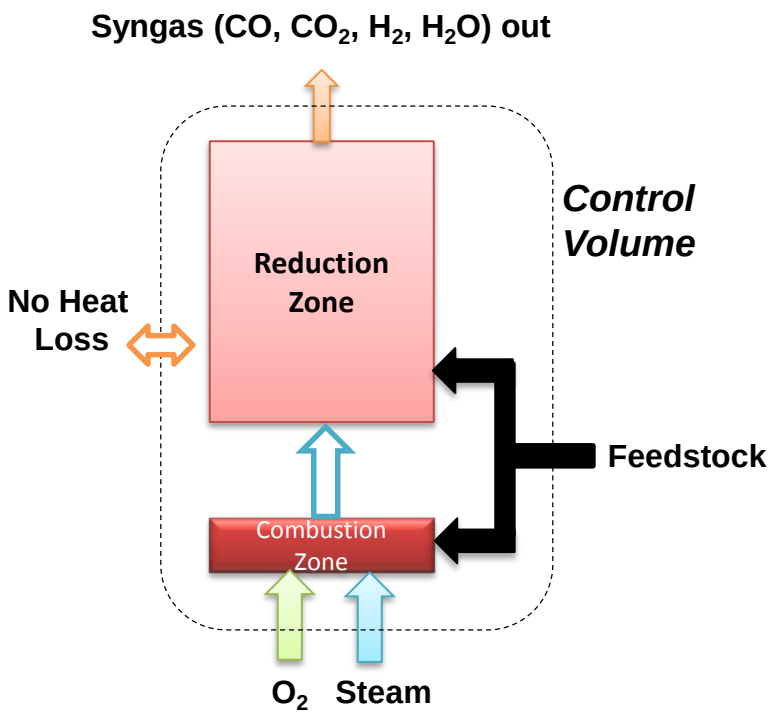
$C + H_2O \rightarrow CO + H_2$ (131 MJ/kmol)

$CO + H_2O \leftrightarrow CO_2 + H_2$ (-41 MJ/kmol)

$C + CO_2 \leftrightarrow 2CO$ (172 MJ/kmol)

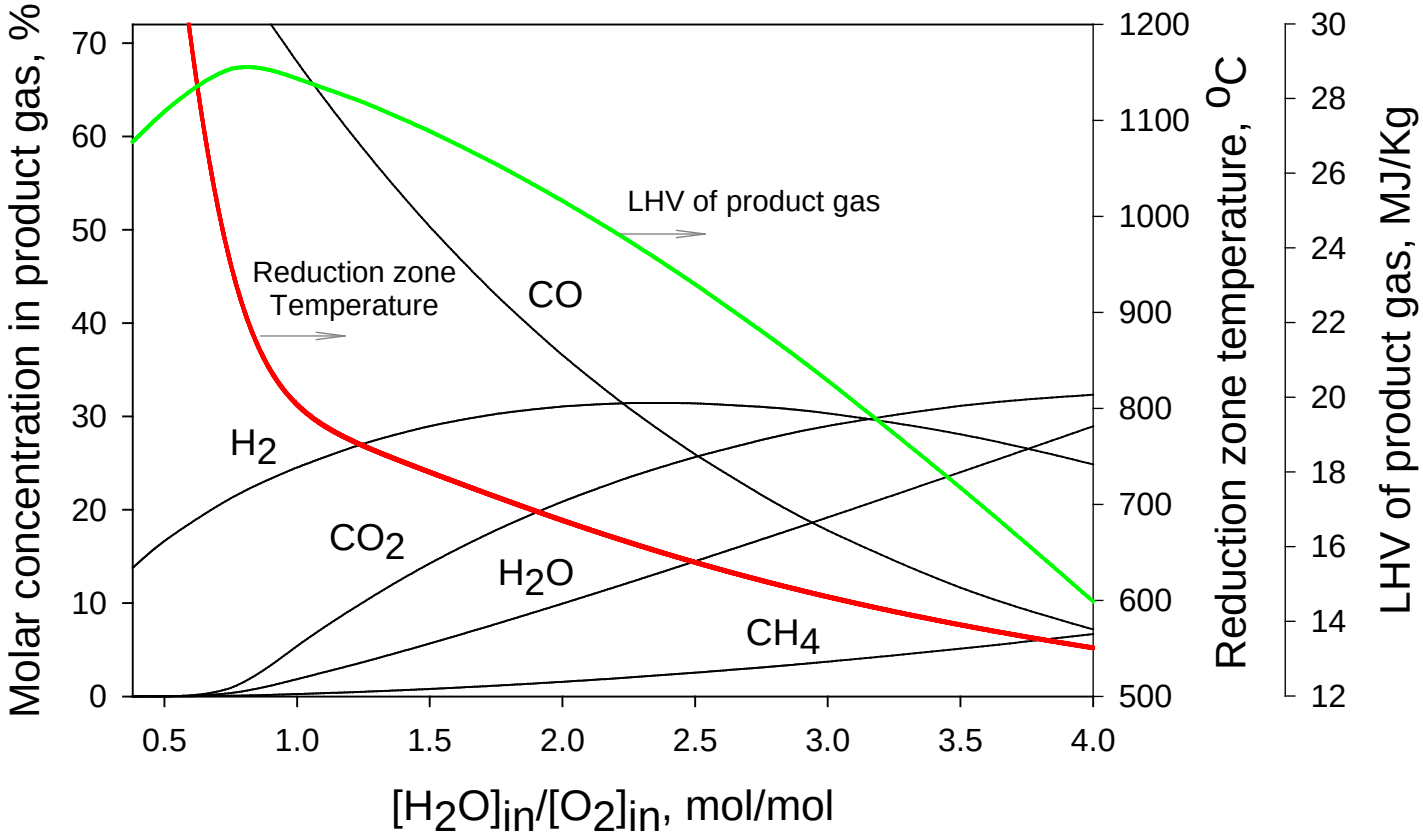
$C + O_2 \rightarrow CO_2$ (-394 MJ/kmol)

$C + ½ O_2 \rightarrow CO$ (-111 MJ/kmol)



FactSage™ program is used that minimizes Gibbs free energy for the control volume (CV) assuming no heat loss from CV.

Thermodynamic Analysis

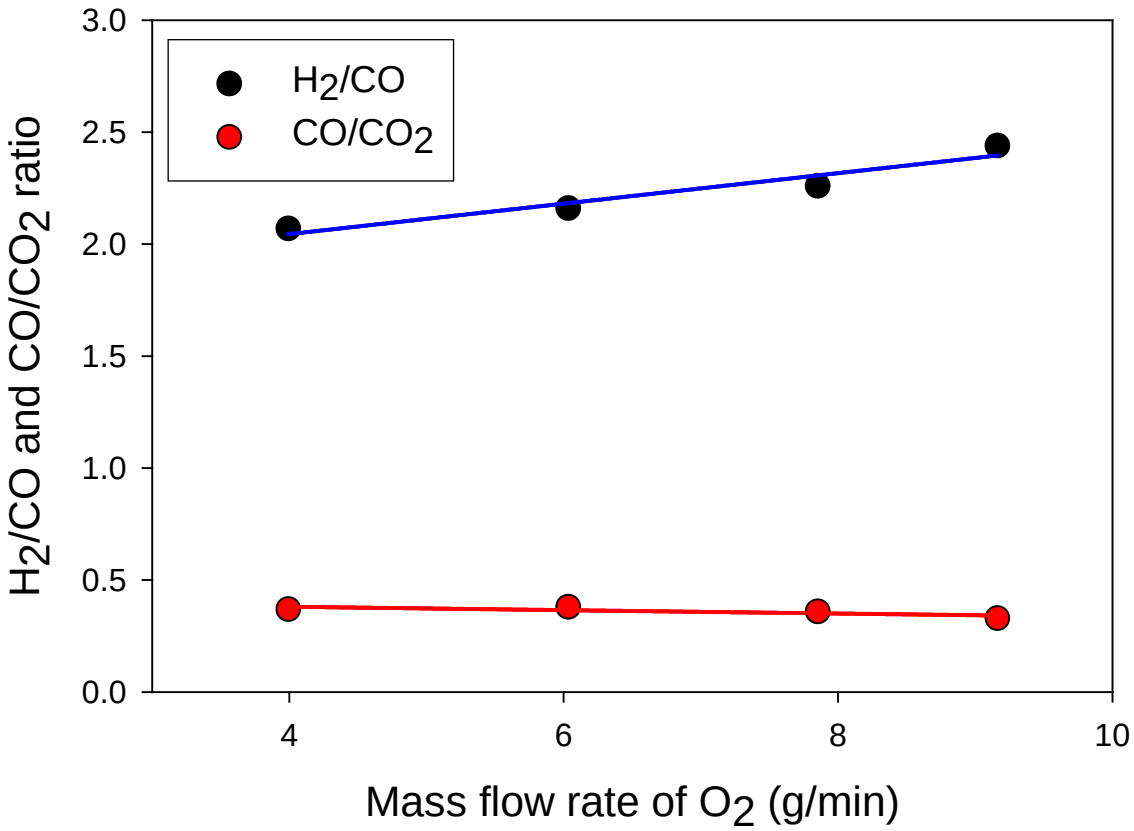


Material Balance for Gasifier

Pressure: 9.5 atm,
Temperature (reduction zone): 700-900°C

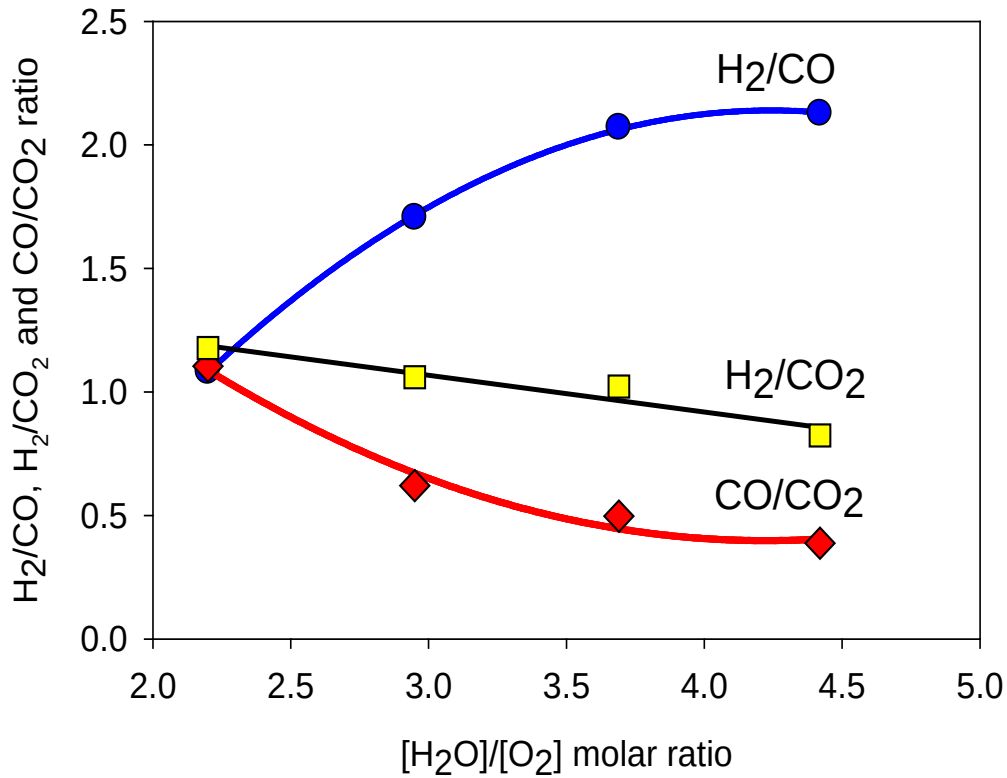
Material balance for the gasifier	Mass, kg
Feed stream	
Charcoal	7.60
Oxygen + Nitrogen (9.75 vol% of total flow)	5.59
Water	10.9
Total inflow	24.1
Exit stream	
Charcoal (unreacted)	0.522
Water + Tar	8.86
Ash	0.206
Gas	13.8
Total outflow	23.4
Mass balance (%)	97.1

Effect of O_2 Flowrate



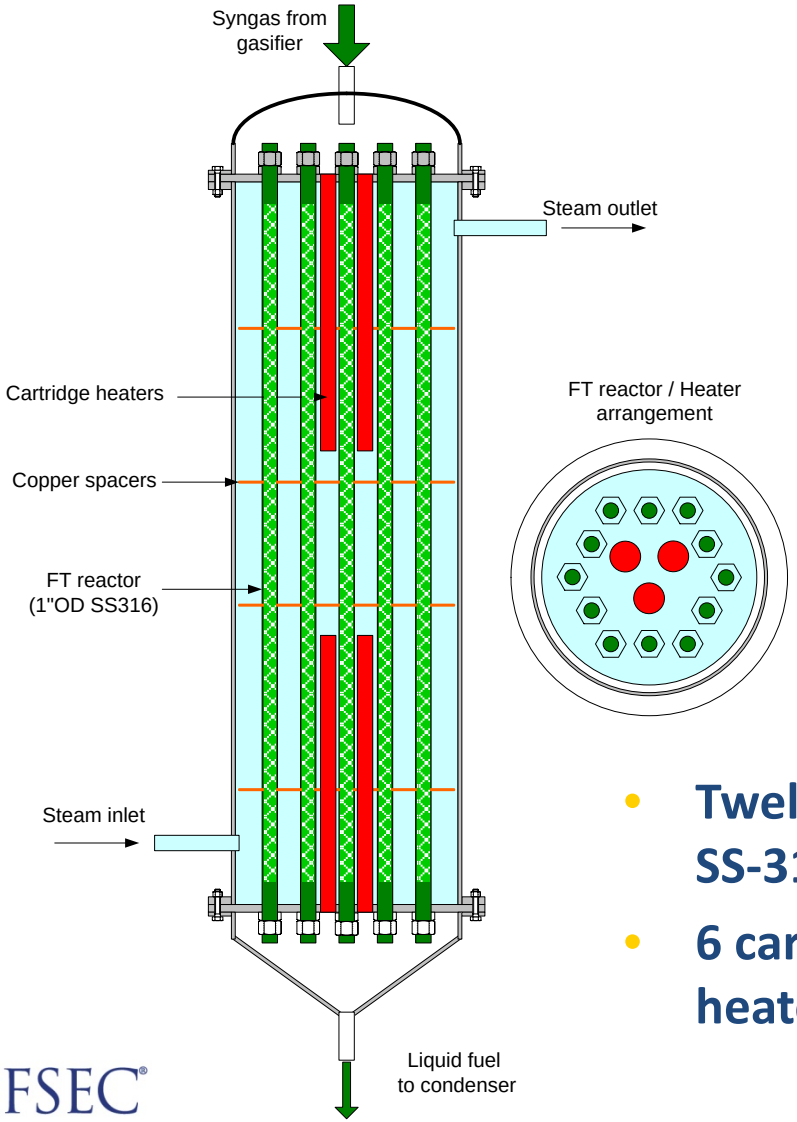
Effect of oxygen flow rate on the H_2/CO and CO/CO_2 ratios in the syngas

Effect of H_2O/O_2 Ratio in the Feed



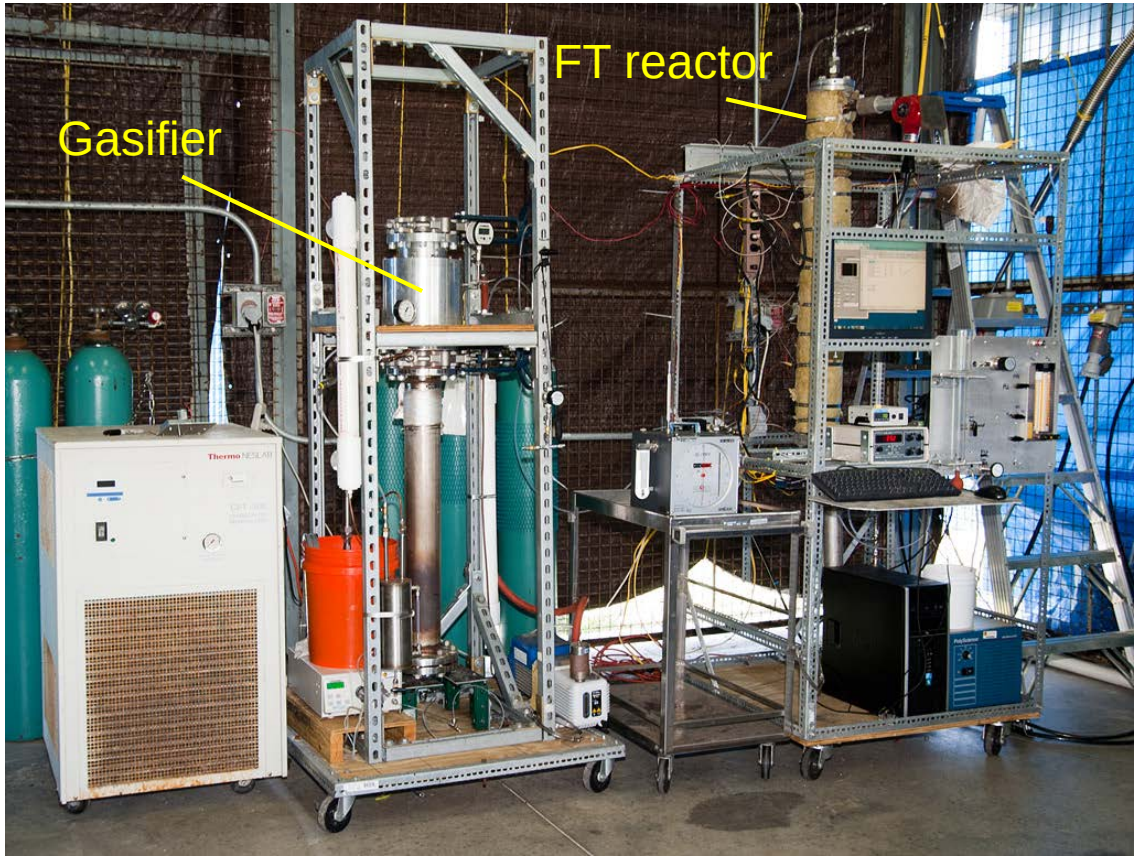
Effect of the inlet steam/oxygen molar ratio on the H_2/CO, H_2/CO_2 and CO/CO_2 ratios in the syngas

FT Reactor Design



- **Twelve (12) 1" SS-316 tubes**
- **6 cartridge heaters**

Integrated Gasifier-FT Reactor Unit



Fisher Tropsch Synthesis Products

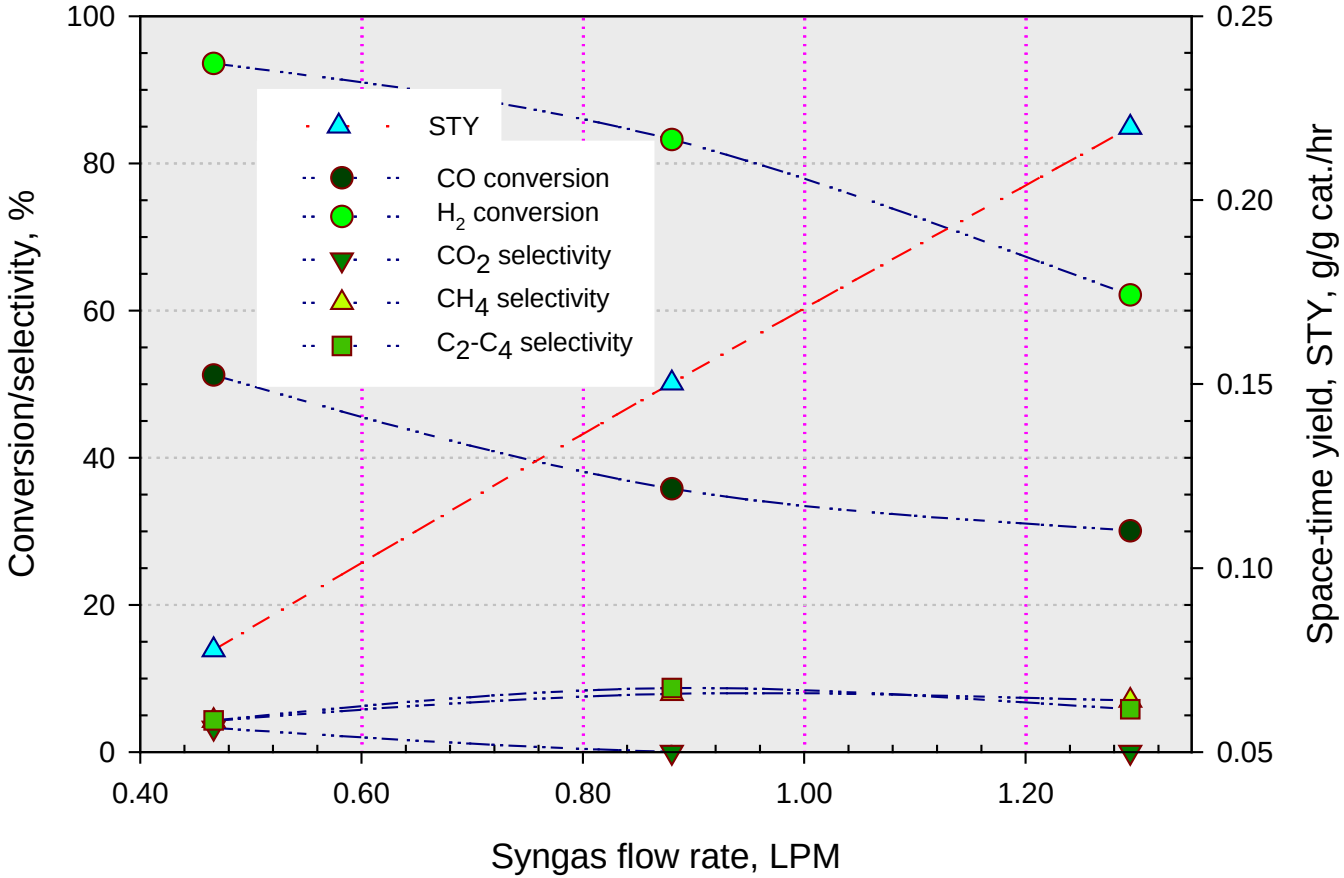
Raw FT Synthesis Product

- **Co/SiO_2 catalyst, T=250°C, P=200 psig**

FT Products After Purification

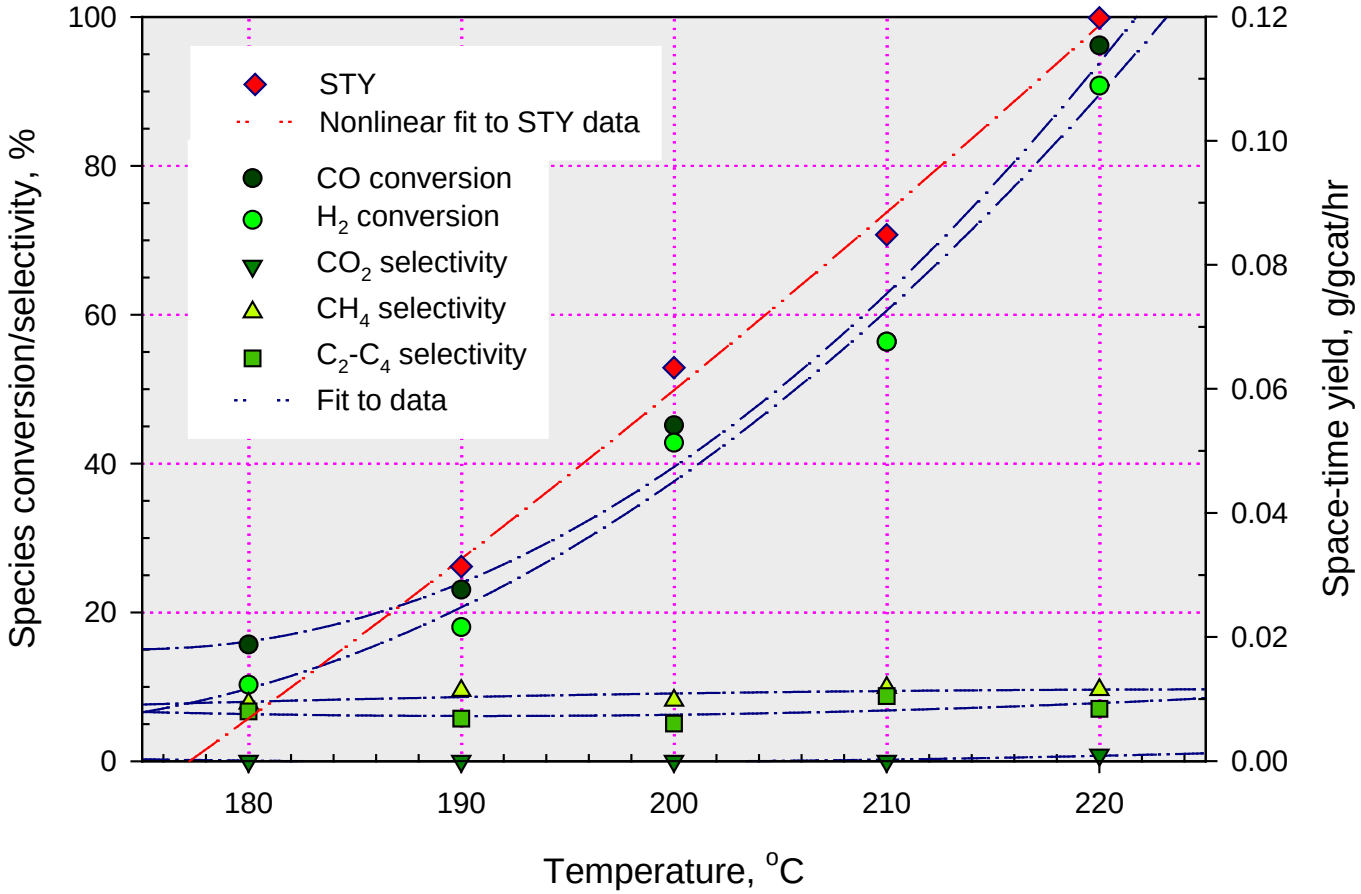
Gasoline range (C_5-C_{10})	48.98 wt%
Kerosene/jet fuel range (C_{11}-C_{12})	15.08
Diesel range (C_{13}-C_{16})	21.10
Lube oil and wax range (C_{17}-C_{26})	14.84

Effect of Operational Parameters



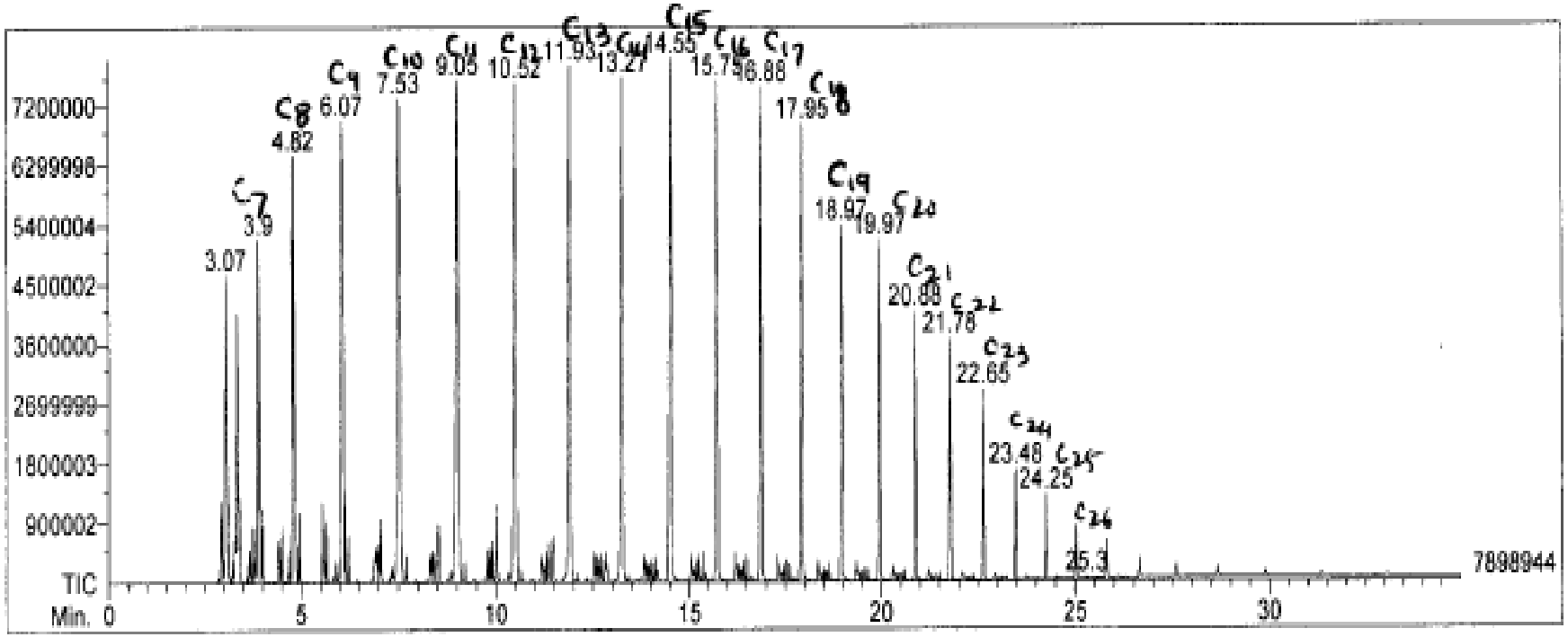
Effect of space velocity (230°C, H_2:CO= 1:1)

Effect of Operational Parameters

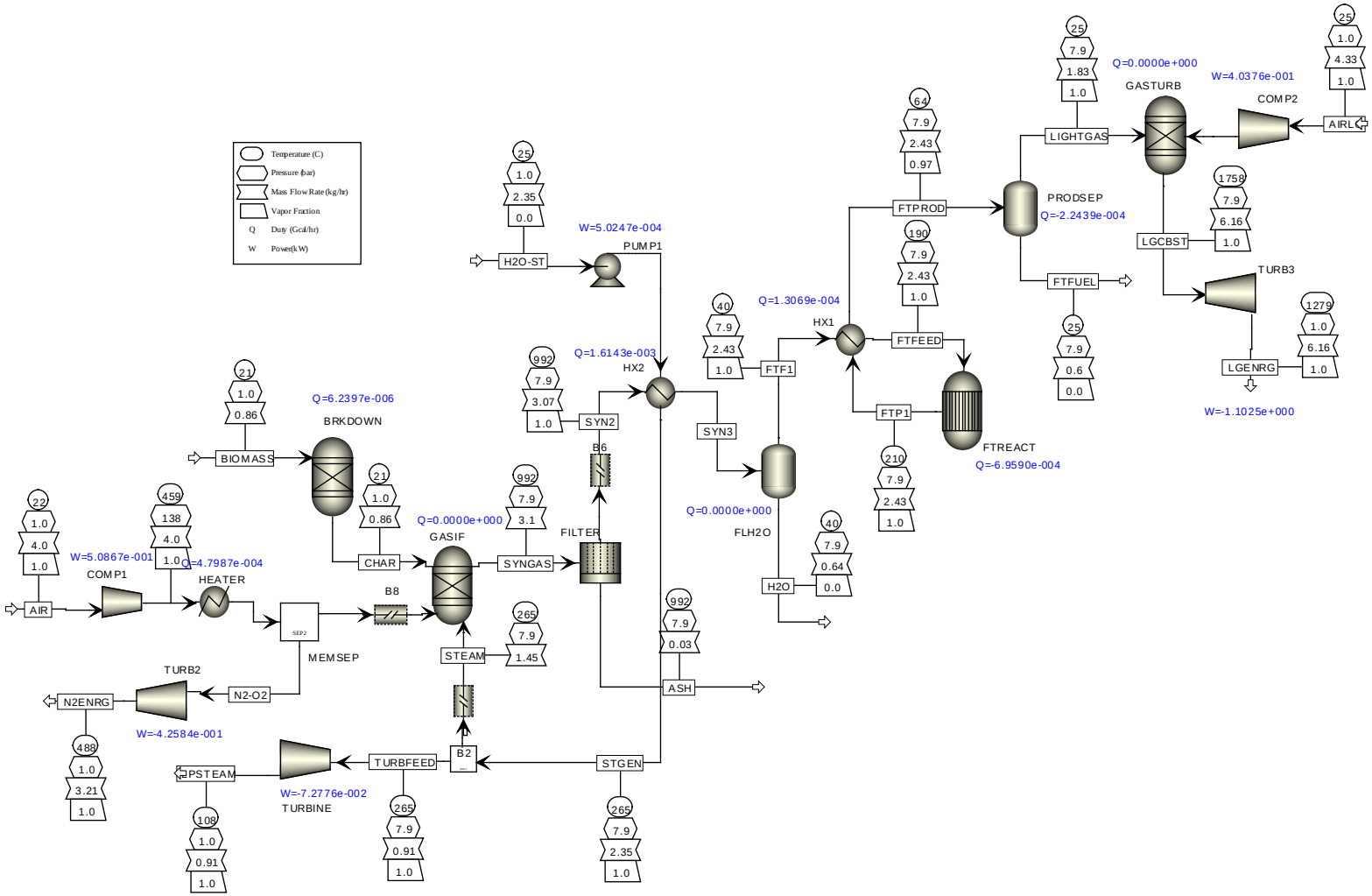


Temperature effect (H_2:CO=2:1, 450 mL/min flow)

GC-MS of FT Product



AspenPlus Chemical Simulation



Economics of the Process

Economic Assessment of Biomass to FT fuel process

Cost Component	Cost: $/kg of FT product	% of total cost
Capital costs	0.81	39.3%
Fixed O & M	0.18	8.6%
Feedstock	1.12	54.4%
Other raw materials	0.06	3.0%
Byproduct credits - electricity generation	-0.13	-6.5%
Other variable costs	0.02	1.2%
Total	$2.06	Per kg FT fuel (diesel)
	$7.00	Per gal FT fuel (diesel)

Summary

- Thermochemical process for converting biomass feedstock to hydrogen and petroleum-equivalent fuels (gasoline, kerosene, diesel) has been developed and performance-tested.

- The effect of operational parameters (temperature, pressure, reactor throughput, catalyst) on products yields have been determined.

- The developed process appears to be technologically and economically feasible:
  - overall process efficiency of 41% can be achieved based on the tri-generation of fuel, heat and power
  - FT diesel fuel can be produced at a cost of approximately $7 per gallon. The cost could be further reduced through the process optimization and reduction in the cost of biomass feedstock.

Acknowledgments

Florida Energy Systems Consortium

Thank you