Production of Electricity and/or Fuels from Biomass by Thermochemical Conversion

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Tasks 2 & 3: Conversion Technology

a. Power generation

b. Thermochemical fuels (TCFs)

c. Ethanol

d. Mobility chain analysis

e. Environment analysis

- Dartmouth: Lee Lynd, Mark Laser, Haiming Jin, Kemantha Jayawardhana, Charles Wyman
- Princeton: Eric Larson, Fuat Celik
- NREL: John Sheehan
- Argonne Lab: Michael Wang
- NRDC: Nathanael Greene, Dan Saccardi

Power, TCFs, and Ethanol: Overview

Objectives

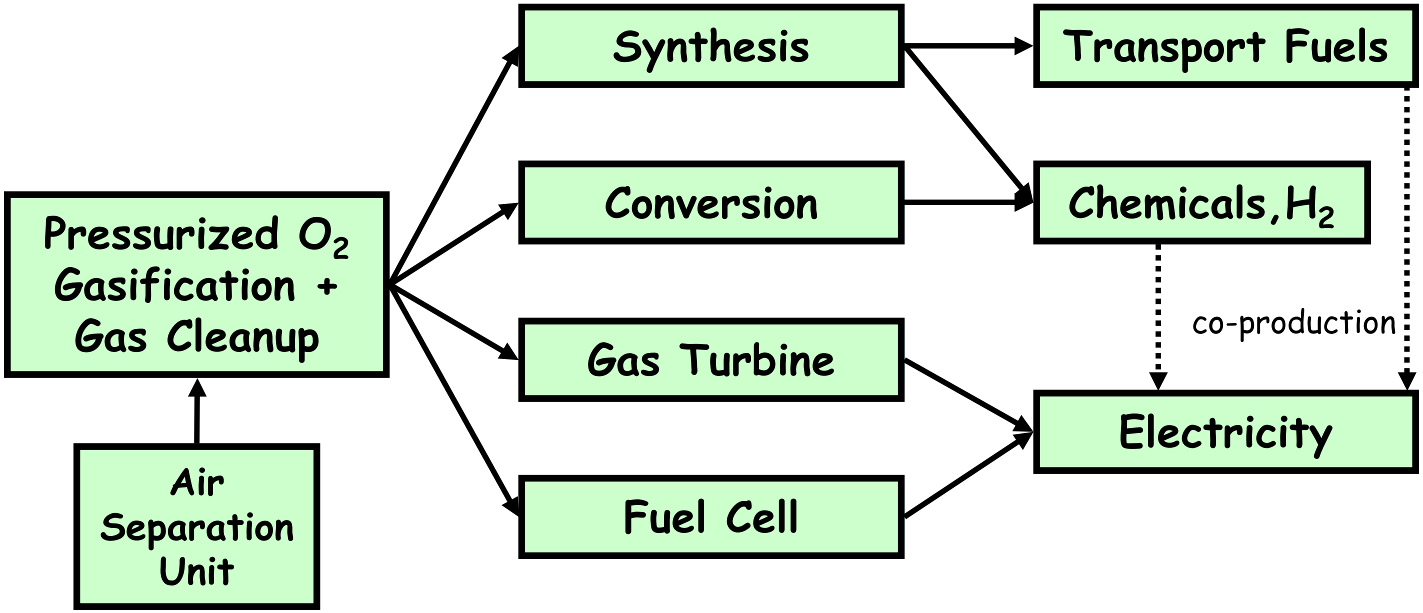
- Design self-consistent set of future, mature-technology processes for producing electricity and/or fuels (and chemicals, animal feed).
- Estimate performance and capital and operating costs.

Approach

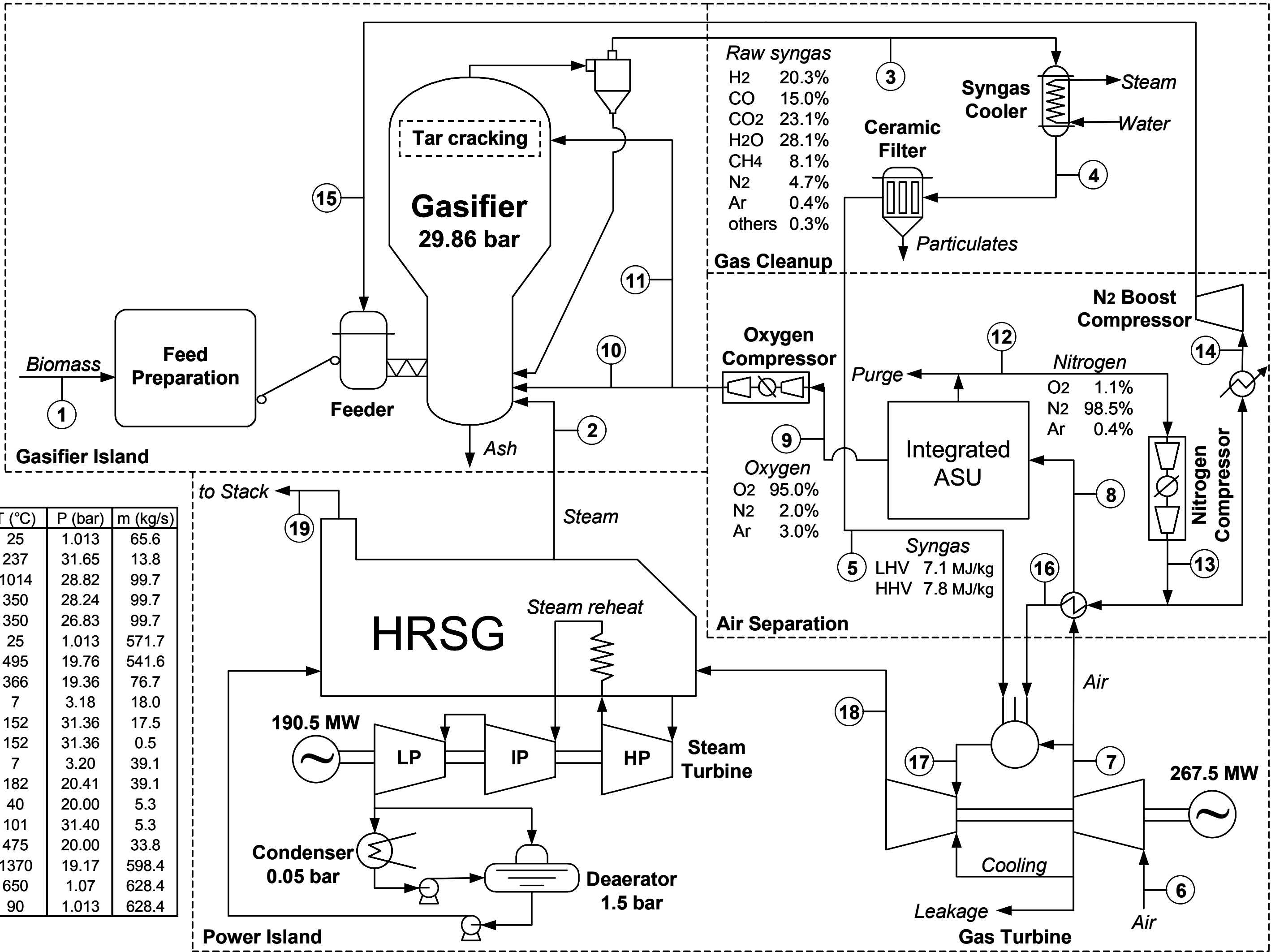
- Integrated effort between Dartmouth (biological) and Princeton (thermochemical)
- Design/simulation of heat and mass balances using Aspen$^+$, with design parameter values from literature and experts.
  - RBAEF hypothesis: future mature biomass facilities will be relatively large (~5000 dry tons per day feed, or ~1000 MW_{th})
- Capital and operating cost estimates based on careful review of literature, own prior work, extensive discussion with industry experts, NREL cost database.
- Consistent financial parameters and accounting framework for economic analysis.
- Substantial effort: 20-25 Aspen$^+$ simulations in all !

Thermochemical Conversion

High temperature (900-1000°C) gasification of biomass to make "synthesis gas" that subsequently is converted into electricity and/or fuels, chemicals, heat.



Pressurized-Gasifier Combined Cycle



	T (°C)	P (bar)	m (kg/s)
1	25	1.013	65.6
2	237	31.65	13.8
3	1014	28.82	99.7
4	350	28.24	99.7
5	350	26.83	99.7
6	25	1.013	571.7
7	495	19.76	541.6
8	366	19.36	76.7
9	7	3.18	18.0
10	152	31.36	17.5
11	152	31.36	0.5
12	7	3.20	39.1
13	182	20.41	39.1
14	40	20.00	5.3
15	101	31.40	5.3
16	475	20.00	33.8
17	1370	19.17	598.4
18	650	1.07	628.4
19	90	1.013	628.4

Switchgrass input = 983 MW_{hhv}

Net electric output = 443 MW_e

Efficiency (HHV) = 45.1%

Switchgrass input, MW_{th}	Higher heating value (HHV)	983.2
	Lower heating value (LHV)	886.8
Internal power use, MW_e	ASU power[a]	-6.4
	O2 compressor power	5.3
	N2 compressor power	10.8
	N2 boost compressor power	0.33
	Steam cycle pumps, total	3.5
	Fuel handling	0.66
	Lock hopper/Feeder	0.52
	Total on-site use	14.8
Gross power output, MW_e	Gas turbine output	267.5
	Steam turbine gross output	190.3
	Total gross output	457.8
Net Power, MW_e		443.0
Electricity efficiency, %	Higher heating value (HHV)	45.1%
	Lower heating value (LHV)	50.0%

Key Technical Features Assumed for Mature Electricity Plants

- Reliable biomass feeding to pressurized gasifier.
- High reliability commercial gasifier operation.
- Acceptable extent of tar cracking.
- Warm-gas cleanup of particulates, alkali, trace contaminants and (for solid-oxide fuel cell) sulfur.
- Commercially reliable air separation unit integrated with gas turbine.
- Targeted solid-oxide fuel cell performance.

Thermochemical Fuels (TCF)

Fischer-Tropsch Liquids
(straight-chain C_nH_{2n}, C_nH_{2n+2})

- F-T fuels are commercially made from natural gas and (in S. Africa) from coal.
- F-T process dates to 1930s, but technology has improved significantly.
- Commercial fuel interest today is primarily in the middle distillate fraction, a high-cetane, no-sulfur diesel fuel substitute.
- The process also gives a naphtha fraction (chemical feedstock) and heavy waxes (high-value, small market).

Dimethyl Ether
(CH_3OCH_3)

- Ozone-safe aerosol propellant, chemical feedstock.
- Current global production < 150,000 tons/year by drying methanol (CH_3OH).
- Similar to LPG – mild pressurization needed to keep as liquid.
- Good diesel-engine fuel: high cetane #, no sulfur, lower NO_x, no C-C bonds ➔ no soot.
- Growing interest (especially in Japan, China, Sweden) for using DME

Hydrogen
(H_2)

- Intense H_2 interest today.
- Preferred fuel for a fuel cell vehicle.
- Low or no tailpipe emissions of criteria pollutants or CO_2.
- Low volumetric energy density presents challenge for on-board storage.

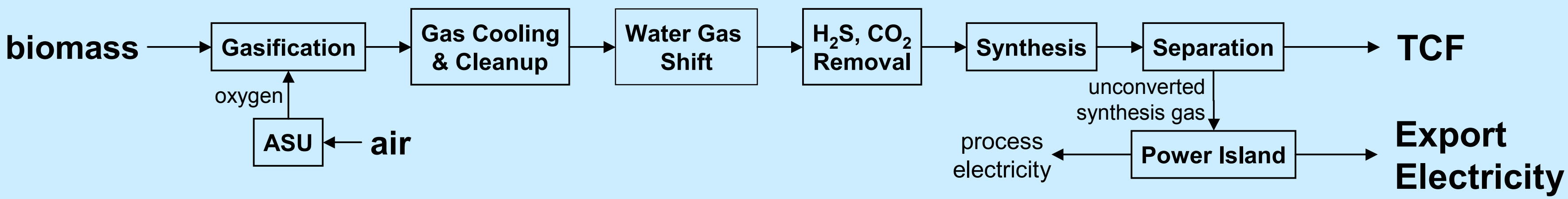
Methanol
(CH_3OH)

- Fuel cell vehicle fuel via onboard reforming.
- Health concerns as fuel.
- Chemical feedstock.

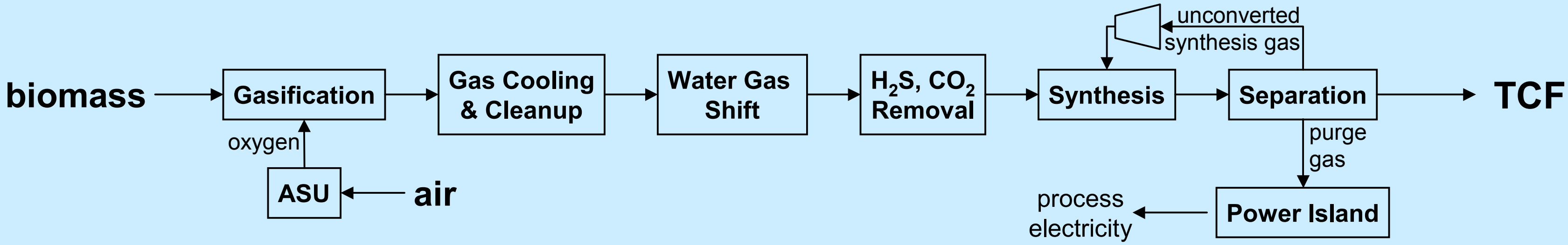
Biomass Thermochemical Fuels (TCF)

- No commercial TCF production from biomass conversion today, but components are commercial or near commercially-ready.

Design with "Once-Through" Synthesis



Design with "Recycle" Synthesis



Status of Process Simulations

GASIFIER DESIGN →	Indirect, Atm-Pressure (BCL)	Pressurized Oxygen (GTI)
Gas turbine/steam turbine combined cycle	●	●
Solid-oxide fuel cell/gas turbine hybrid	×	●
Fischer-Tropsch Fuels	×	○
Fischer-Tropsch Fuels / Electricity	×	○
Dimethyl Ether *	×	◖
Dimethyl ether / Electricity *	×	◖
Hydrogen *	×	○
Hydrogen / Electricity *	×	○
Methanol	×	◖
Methanol / Electricity	×	◖
Reference Rankine cycle	●	

* Relatively pure stream of CO_2 is available as a byproduct in these cases, but the possibility of capture/storage of CO_2 as GHG emissions reduction option is not being considered in this project.

Status of Cost Estimates

GASIFIER DESIGN →	Indirect, Atm-Pressure (BCL)	Pressurized Oxygen (GTI)
Gas turbine/steam turbine combined cycle	●	●
Solid-oxide fuel cell/gas turbine hybrid	✕	?
Fischer-Tropsch Fuels	✕	○
Fischer-Tropsch Fuels / Electricity	✕	○
Dimethyl Ether *	✕	◖
Dimethyl ether / Electricity *	✕	◖
Hydrogen *	✕	○
Hydrogen / Electricity *	✕	○
Methanol	✕	◖
Methanol / Electricity	✕	◖
Reference Rankine cycle	●	

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