Enabling Entrained-Flow Gasification of Blends of Coal, Biomass and Plastics

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Gasification of Mixtures of Coal, Biomass, Plastic

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COAL

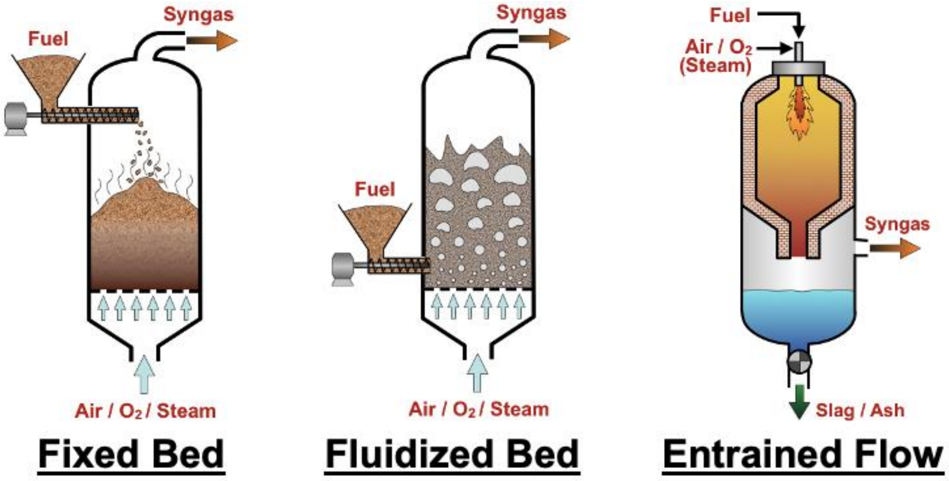
BIOMASS

WASTE PLASTIC

How to process mixtures of heterogeneous solid feedstocks?

- Coal
  - Low reactivity
  - High ash
  - Gasification well commercialized
- Biomass
  - High volatiles content
  - Relatively heterogeneous
  - Some commercial fixed/fluidized bed gasifiers
- Waste plastic
  - Very heterogenous
  - Difficult to size-reduce
  - Can be "dirty"
  - No gasification technology today

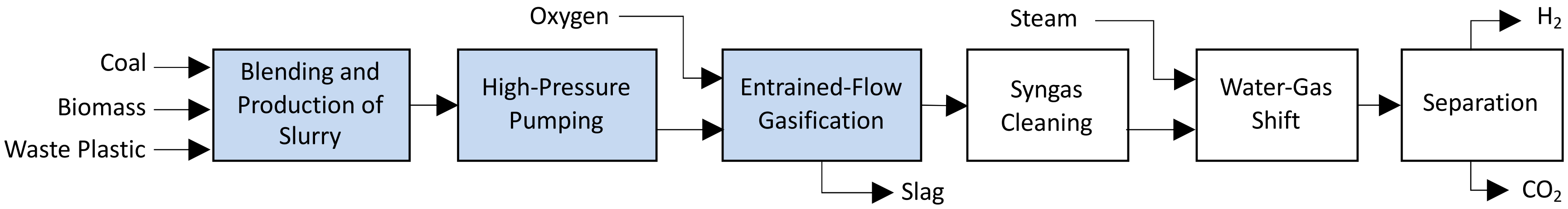
General Gasifier Types



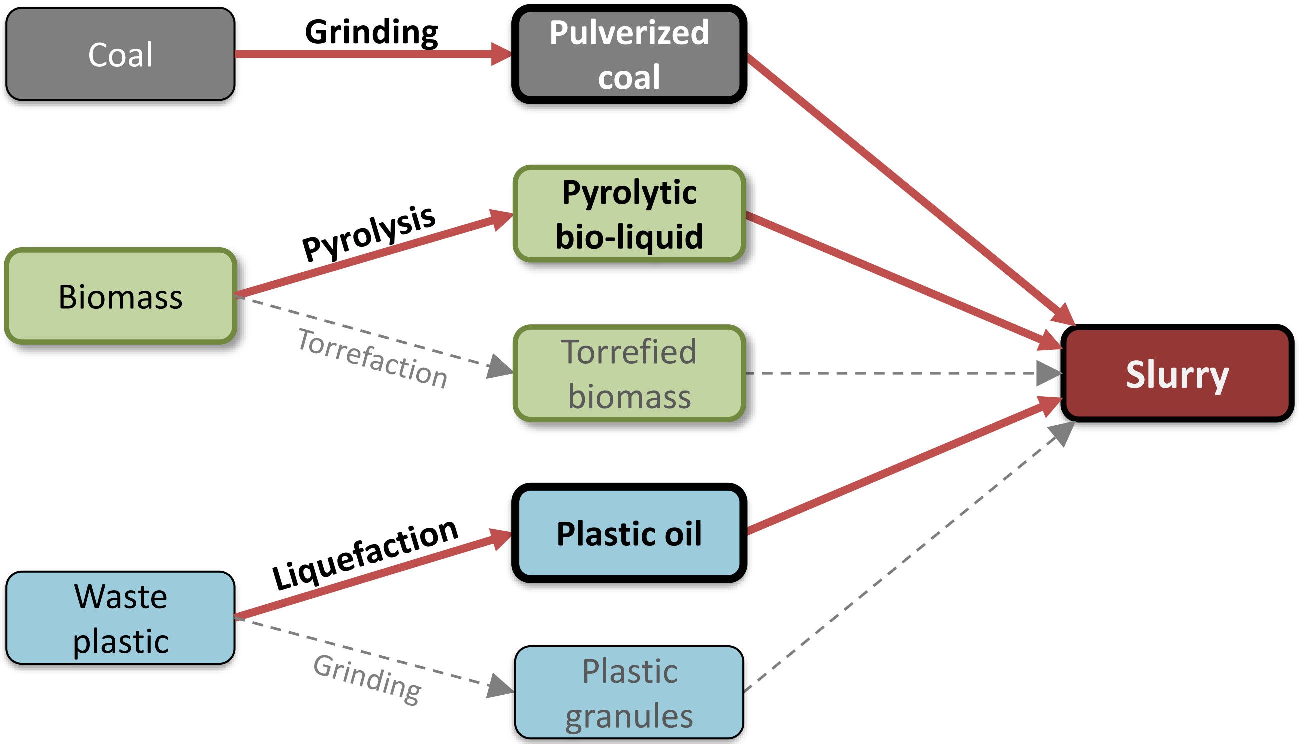
Property	Fixed Bed	Fluidized Bed	Entrained-Flow
Required feedstock properties	Solid 0.5-2 inch	Solid or liquid	Liquid (slurry) or powder (dry)
Pressurizing/process integration	Difficult	Difficult	"Easy"
Conversion to syngas	80-95%	80-95%	>98%
Syngas quality	Very messy	Quite messy	Comparatively clean

Technical Approach

- *High pressure, entrained-flow* gasification of blended fuel
  - EFG has proven track record
  - Should have good conversion, syngas quality
  - Can be used with existing coal gasification facilities
  - Integration with downstream synthesis is straightforward
- Biomass and plastic fed as *liquids*
  - Biomass as pyrolytic bio-liquid
  - Plastic as oil produced through thermal depolymerization



Technical Approach



Project Partners

- **University of Utah:**
  - Gasification R&D since 2001
  - Both lab-scale fundamentals and pilot-scale development
- **Eastman Chemical Co:**
  - Manufacturer of chemicals, plastics, advanced materials
  - Gasifying coal at Kingsport, TN facility since 1983
- **Ensyn Technologies**
  - Pyrolysis-based technology to turn biomass into liquid
  - Commercial process since 1980s
- **Renewlogy**
  - Salt Lake City-based company turning waste plastics into liquids
  - Commercial units approx 10 ton/day
- **Linde Inc**
  - Industrial Gas supplier
  - Has patented hot oxygen burner (HOB) technology

Project Objectives

- Overall objective: Demonstrate technical feasibility of gasifying blends of coal, biomass and mixed waste plastics in entrained-flow gasifier for production of H_2
- Specific objectives:
  1. Determine compositions of coal-biomass-plastic mixture that produce stable slurry suitable for pumping to high pressure
  2. Design and test novel burner to effectively atomize slurry in high pressure gasifier
  3. Acquire first-of-a-kind performance data for pressurized O_2-blown, entrained-flow gasification of slurried blends of coal, biomass and plastic waste

Project Structure – Tasks

1. Project management and planning
2. Preparation and characterization of mixed feedstock slurries
   - 2.1 Procurement of feedstock materials
   - 2.2 Preparation of mixed feedstock slurries
   - 2.3 Physical and chemical characterization
3. Transport and atomization of mixed feedstock slurries
   - 3.1 High pressure pumping studies
   - 3.2 Design and construction of HOB gasifier burner
   - 3.3 Characterization of burner atomization
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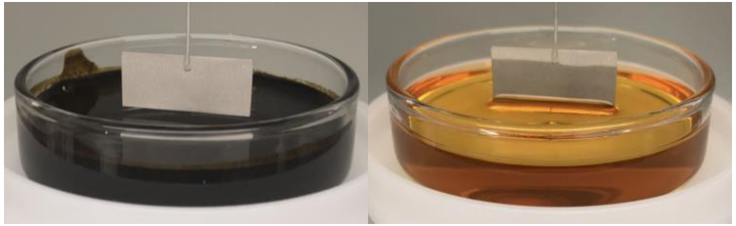
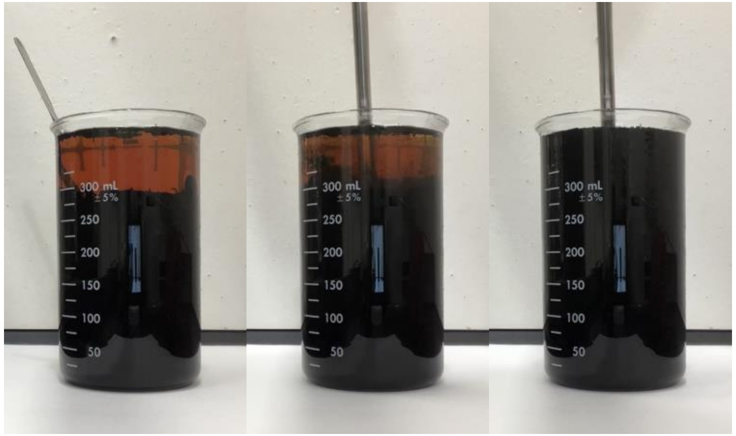
Feedstock Properties

- **Bio-liquid**
  - ~ 1200 kg/m^3
  - Similar in appearance to crude oil
  - High water, high oxygen content
  - Naturally stable emulsion
- **Plastic oil**
  - ~ 800 kg/m^3
  - Comparable to diesel

Feedstock	Illinois #6 coal	Bio-liquid	Plastic oil
Moisture (wt% as rec'd)	9.65	23.0	< 1.0
C (wt%, dry basis)	71.6	54.9	86.8
H (wt%, dry basis)	5.0	6.7	13.2
O (wt%, dry basis)	8.9	38.3	< 0.2
N (wt%, dry basis)	1.2	0.2	< 0.1
S (wt%, dry basis)	4.4	< 0.05	< 0.05
Ash (wt%, dry basis)	8.8	< 0.15	< 0.05
HHV (Btu/lb as received)	11,598	8,214	19,777



Bio-liquid Plastic oil



10% coal, 75% bio-liquid, and 15% plastic oil before, during, after mixing

Mixed Feedstock Slurries

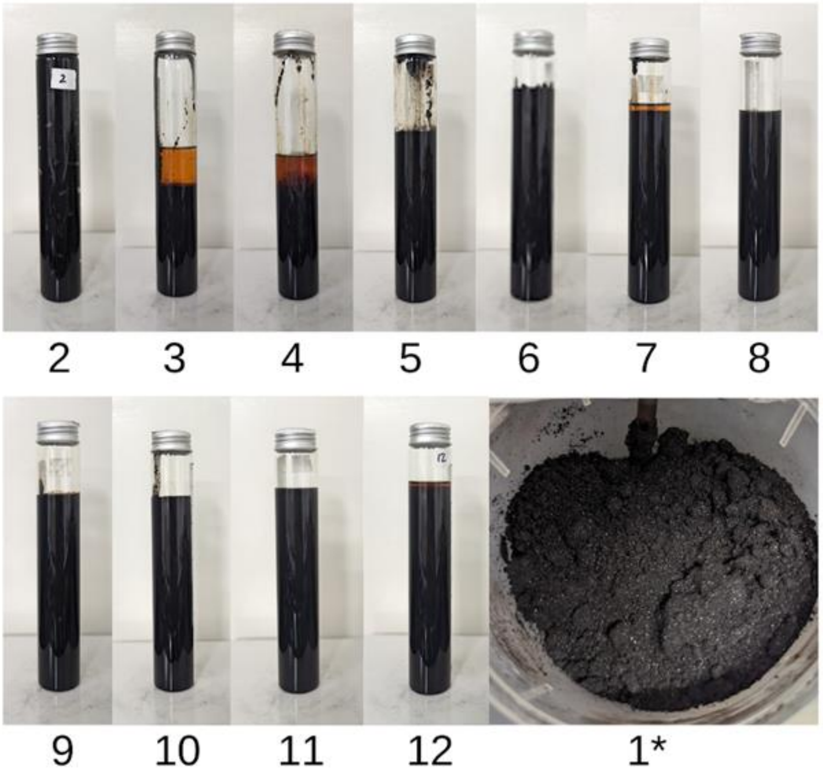
- Mixture requirements per FOA (HHV basis):
  - Biomass: 25, 40, 60%
  - Remainder: 25, 50, 75, 100% coal
- Result is 12 mixtures

Mixture	Heating value basis			Mass basis (wt%)		
	Coal	Bio-liquid	Plastic oil	Coal	Bio-liquid	Plastic oil
1	75	25	0	68.0	32.0	0.0
2	56	25	19	54.6	34.4	10.9
3	37	25	38	39.1	37.3	23.7
4	19	25	56	21.8	40.4	37.8
5	60	40	0	51.5	48.5	0.0
6	45	40	15	40.8	51.2	8.0
7	30	40	30	28.8	54.2	17.0
8	15	40	45	15.3	57.6	27.1
9	40	60	0	32.1	67.9	0.0
10	30	60	10	24.9	70.2	4.9
11	20	60	23	16.9	71.6	11.5
12	10	60	30	8.9	75.4	15.7

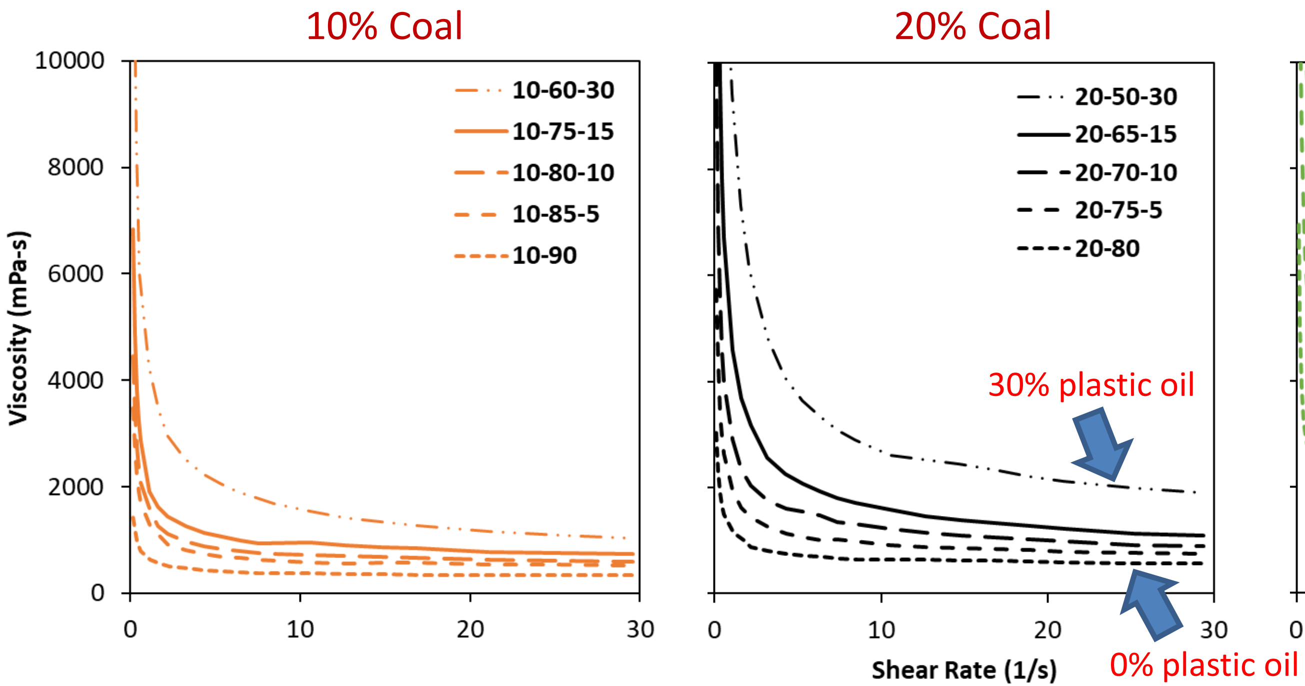
Best properties: less than 45 wt% coal, less than 20 wt% plastic oil

Mixed Feedstock Slurry Properties

Mixture	Mass basis (wt%)		
	Coal	Bio-liquid	Plastic oil
1	68	32	0
2	54	34	11
3	39	37	24
4	22	40	38
5	52	48	0
6	41	51	8
7	29	54	17
8	15	58	27
9	32	68	0
10	25	70	5
11	17	72	11
12	9	75	16



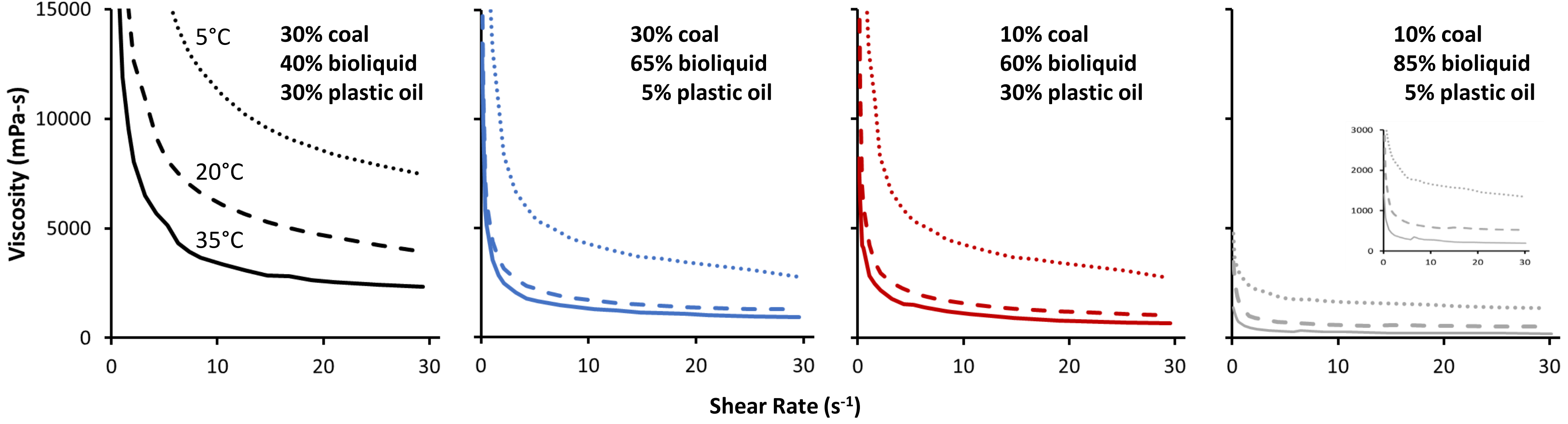
Influence of Coal and Plastic Oil on Viscosity



Influence of plastic oil and coal is predictable

Viscosities roughly double as coal increases from 10 → 20% and then from 20 → 30%

Influence of Temperature on Viscosity



- Significant reduction in viscosity with increased temperature
- Heating required in the case of low ambient temperatures
- Startup conditions must be carefully considered (i.e. very low shear during pump startup)

See Logan's poster during Wed evening reception

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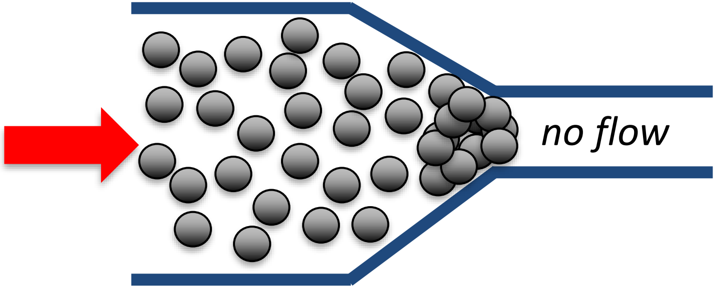
Slurry Pumping Studies

- Test various pump designs for reliability
  - Progressive cavity
  - Positive displacement gear pump
- Test flow through small passages
  - Tubing
  - Injector internals
- Test both at low and high pressure
- Challenges
  - Incompatibility between bio-liquid and some elastomer materials
  - Plugging if passage is too small
- Avoid passages less than approx 3/32 inch

Minimum channel diameter impacts burner design

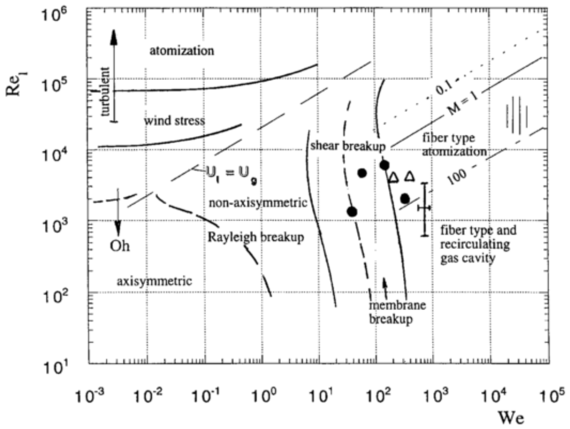
High pressure progressive cavity pump

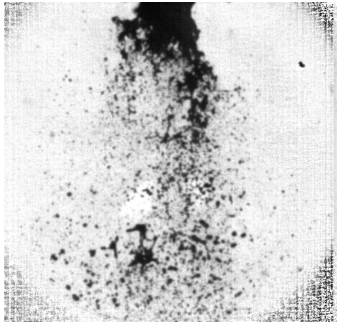


Plugging occurs if channel diameter is too small

Liquid Feedstock Atomization

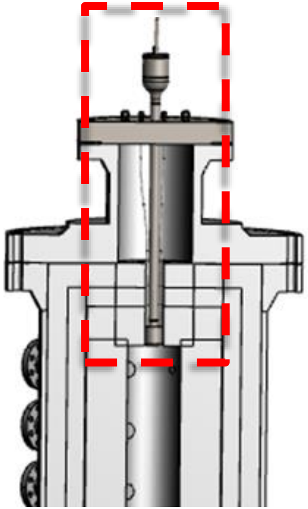
- Challenges with gas-based atomization:
  - O_2 only (no N_2) – 80% less compared to air
  - Approx 1/3 of stoichiometric
  - High pressure = low velocity (momentum)
- Solution: Hot oxygen burner

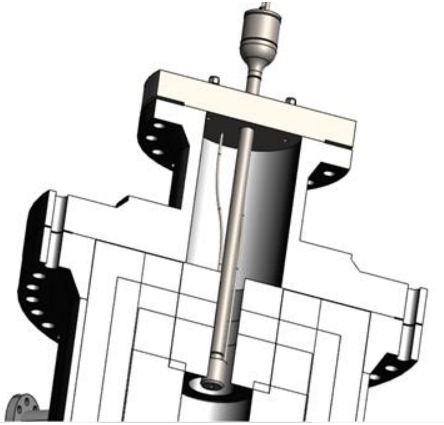




Water

Silicone Oil

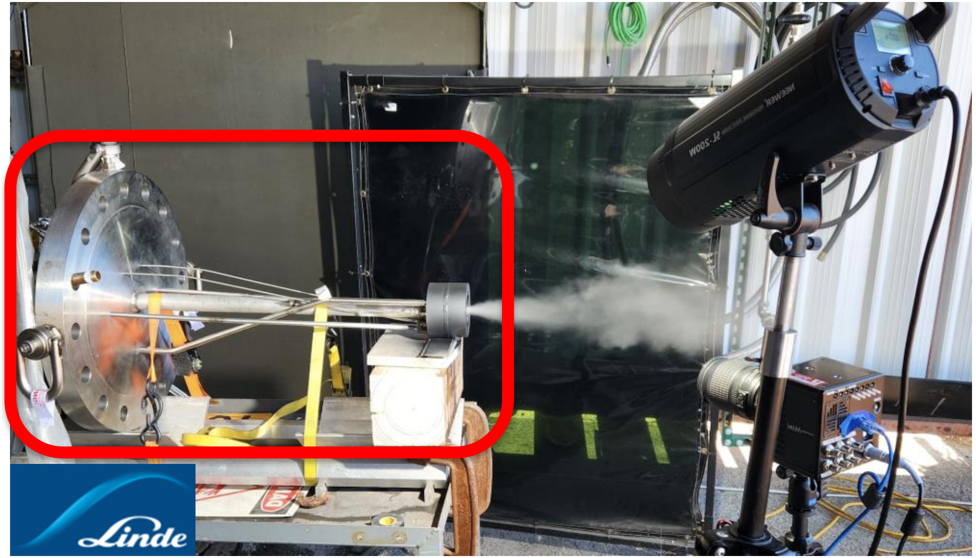




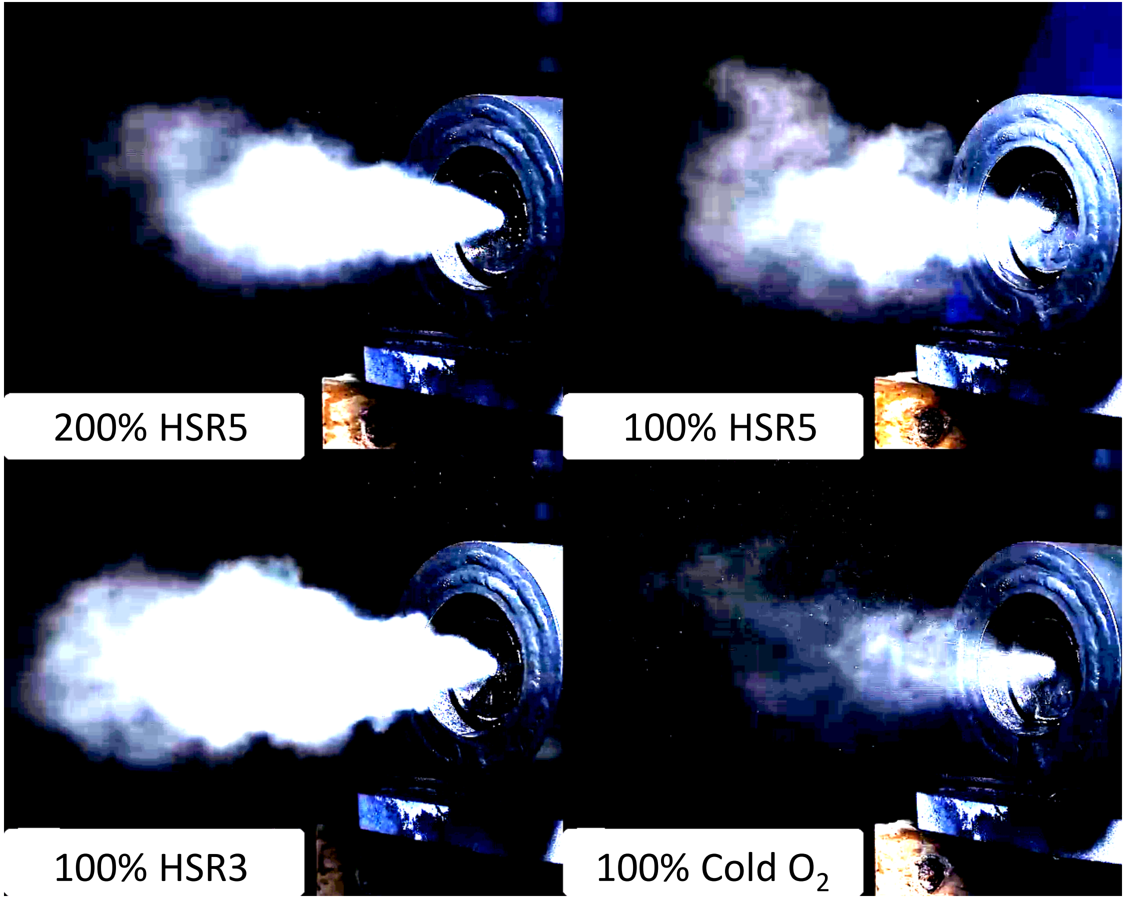
Waind, T.; Effect of atomizer scale and fluid properties on atomization mechanisms and spray characteristics. (2015), Doctoral Dissertation, The University of Utah, Dept. of Chemical Engineering

Hot Oxygen Burner (HOB)

- Burner design
  - Based on established Linde HOB
  - Custom design for Utah gasifier
  - Preheat oxygen to achieve high velocity and reactivity
  - Also allow for natural gas feed, simplifying operation
  - Enables use as a warmup burner
- Atomization tests
  - Water instead of slurry
  - Atmospheric pressure
  - Scaled to match expected performance under pressurized conditions
  - Examine overall spray pattern plus high-speed imaging



HOB Burner Testing



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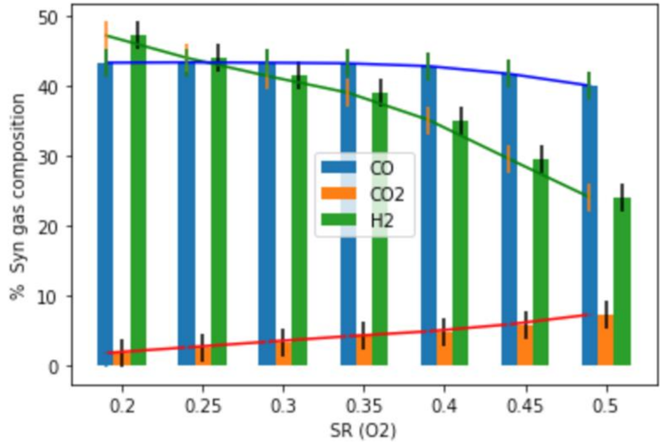
Entrained Flow Gasification Modeling

- Used FactSage™ thermodynamic modeling software
- Used compositions of coal, biomass, plastic to determine compositions of mixtures
- Baseline – gasification with 35% of stoichiometric O_2
- Calculate flame temperature and equilibrium gas composition

Slurry Mixture	Temperature (°F)	Syngas Composition					
		CO (%)	H_2 (%)	H_2O (%)	CO_2 (%)	CH_4 (%)	H_2S (%)
1	2432	57.31	33.03	5.09	2.96	0.20	1.00
2	2452	55.33	35.59	5.16	2.65	0.21	0.75
3	2481	53.29	38.12	5.28	2.29	0.20	0.50
4	2502	51.33	40.63	5.31	2.13	0.21	0.26
5	2256	53.33	34.13	6.84	4.14	0.45	0.78
6	2271	51.87	35.99	6.99	3.85	0.46	0.59
7	2286	50.39	37.89	7.11	3.57	0.46	0.39
8	2301	48.88	39.83	7.22	3.30	0.46	0.20
9	2084	48.26	34.89	9.20	5.80	1.11	0.50
10	2092	47.37	36.03	9.35	5.56	1.12	0.38
11	2114	46.68	37.45	9.31	5.13	1.05	0.25
12	2109	45.56	38.36	9.66	5.10	1.10	0.13



U.Utah Pressurized Entrained Flow Gasifier

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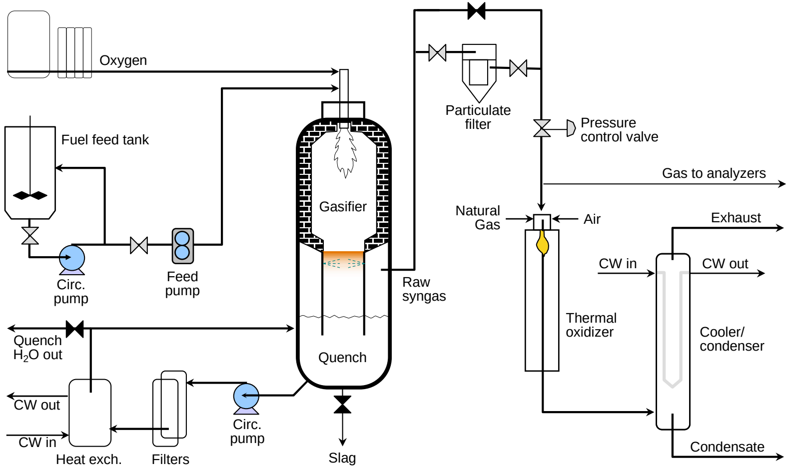
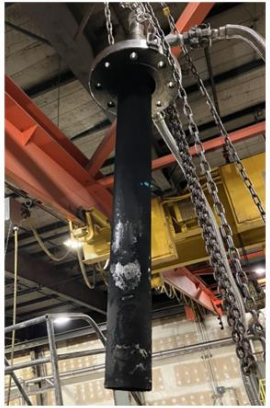
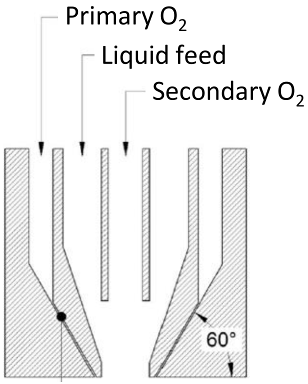
- 1-1.5 ton/day
- Max 500 kW thermal input
- Liquid or slurry-fed
- O_2 available at 450 psi
- Maximum pressure 400 psi (28 atm)
  - Typical 250-300 psi (18-21 atm)
- Maximum temperature 3000°F (1650°C)
- Has been operated with coal-water and petcoke-water slurries, diesel, IPA
- Night/weekend standby on natural gas

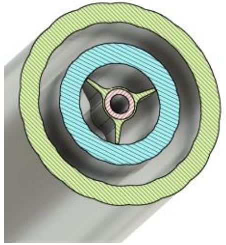


Preliminary Gasification Tests

- Initial testing with "easy" feedstock
  - High bioliquid, low coal
- Refine startup procedure
- Confirm reliability of pumping and slurry transport
- Tested at pressures to 265 psi, temperatures to 3000°F
- Used existing conventional 3-stream gasification injector/burner
  - Significant soot observed
  - Lower conversion than desired due to relatively poor atomization
- Improved burner with higher O_2 momentum in construction
- Gasification using HOB in coming months







Acknowledgements

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- University of Utah Industrial Energy Systems Lab
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    - Ensyn Technologies
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