Challenges and Lessons Learned in Commercial Biomass Gasification and Co-Gasification of Waste

Kevin J. Whitty

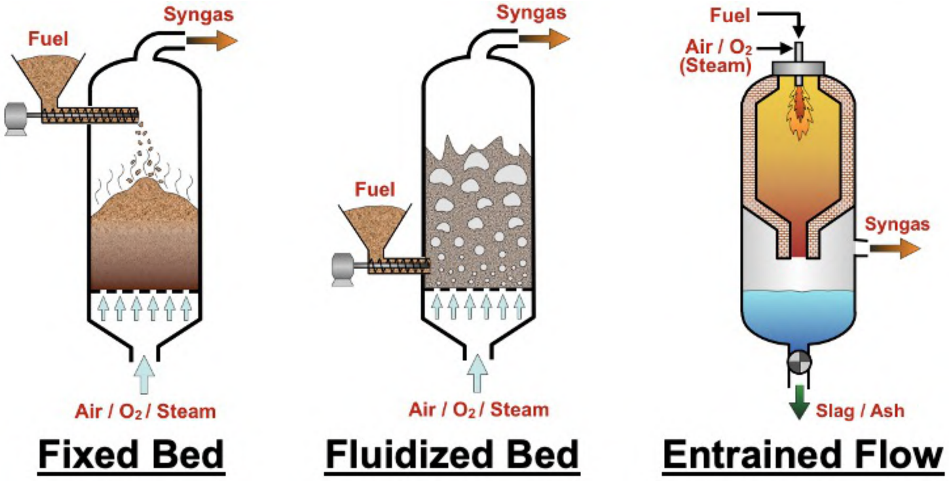
Department of Chemical Engineering
University of Utah

kevin.whitty@utah.edu

U.S. DOE Workshop
Gasification Technology Status and Pathways for Net-Zero Carbon Workshop

30 November 2022

General Gasifier Types

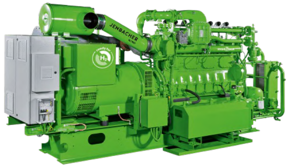


Property	Fixed Bed	Fluidized Bed	Entrained-Flow
Required feedstock properties	Solid 0.5-2 inch	Solid or liquid	Liquid (slurry) or powder (dry)
Pressurizing/process integration	Difficult	Difficult	"Easy"
Conversion to syngas	80-95%	80-95%	>98%
Syngas quality	Very messy	Quite messy	Comparatively clean

Primary Uses of Biomass Syngas

THE UNIVERSITY OF UTAH

- **Heat**
  - Co-fire or replacement for oil, natural gas, coal
- **Electricity**
  - Combust in IC engine + generator
  - Combust in gas turbine / IGCC
- **Transportation fuels**
  - Alcohol-based (methanol, ethanol) for automobiles
  - Fischer-Tropsch liquids for refining
  - Dimethyl ether
  - Substitute natural gas



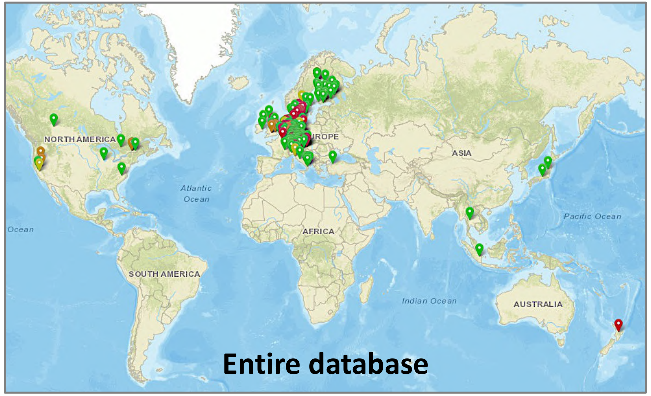
Innio Jenbacher gas engine (innio.com)

Vaskiluoto 140 MW CFB biomass gasifier (valmet.com)

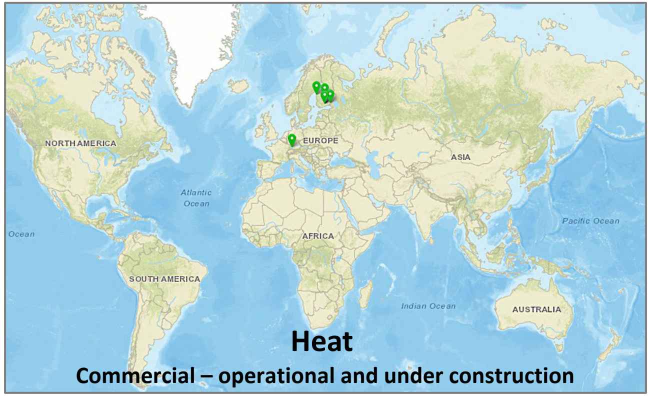
Gasification/DME pilot plant (ltu.se)

Biomass Gasification Activity Worldwide

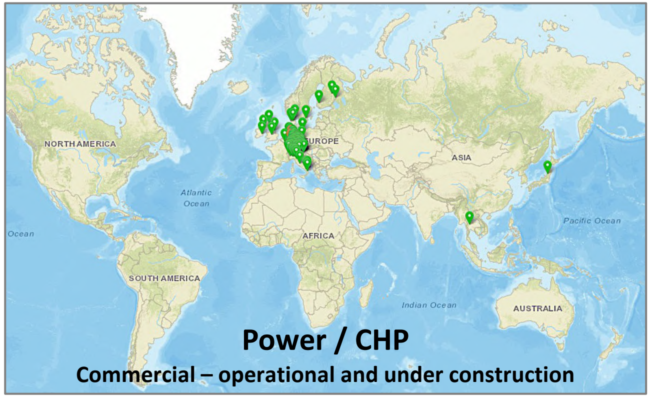
THE UNIVERSITY OF UTAH



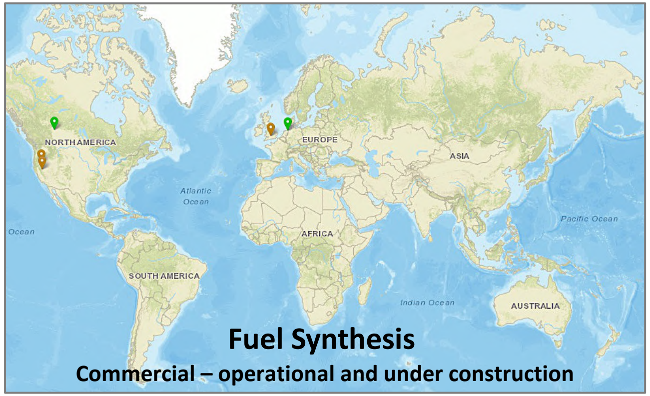
Entire database



Heat
Commercial – operational and under construction



Power / CHP
Commercial – operational and under construction

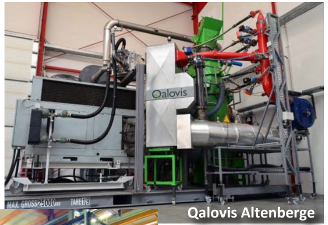


Fuel Synthesis
Commercial – operational and under construction

Data from IEA Bioenergy Task 33 Database (task33.ieabioenergy.com)

Successful Biomass Gasification

- Typically small scale
  - 5 to 100 ton/day
  - < 1 to 15 MW_{th}
- "Easy" feedstock
  - Relatively clean
  - Often pretreated
- Limited syngas cleaning
  - Oil scrubber
  - Particulate filter
- CHP application
  - Market for waste heat
  - Overall efficiencies approaching 90%


Qalovis Altenberge


Urbas


Güssing


Spanner Re²

- Power via IC engine
  - 0.2 to 3 MW_{el}
  - Robust, off-the-shelf
  - Tolerant of unclean gas
  - May have ORC on exhaust
  - Power efficiencies approaching 40%
- Tax incentives
  - Feed-in tariff
  - Critical for economics
- Standardized designs

Less-Successful Biomass Gasification

Generally larger-scale systems targeting IGCC or fuels production

- Biomass
  - Quality vs cost
  - Reliable source
- Feed systems
  - Plugging, inconsistency
  - Pretreatment costs
- Syngas quality
  - Tars
  - Alkali, particulate

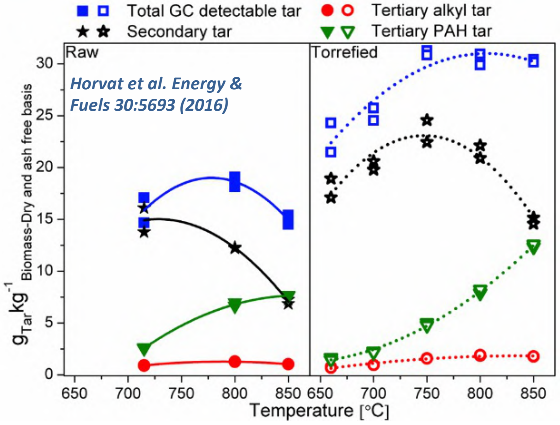

Battelle FERCO, Vermont

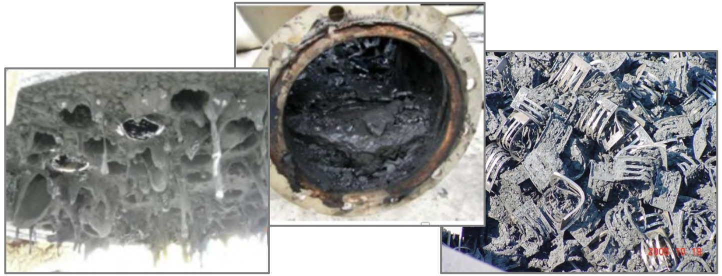

Värnamo, Sweden

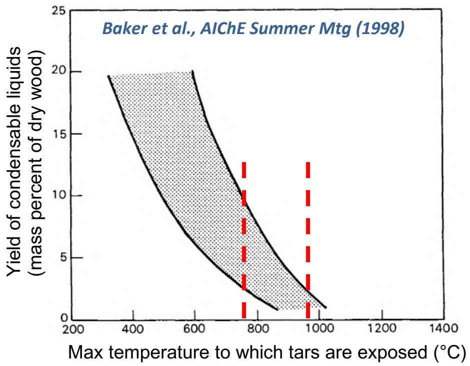
- System complexity
  - Advanced cycles
  - Many process units
  - Challenging startup
- Costs
  - High capital costs
  - Feedstock
  - Operators
  - Limited economy-of-scale

Tar Formation

- Natural result of biomass decomposition
- Formation most significant at 550-950°C
- Can range from 1 to 10% of feedstock carbon
- In-bed catalysts can reduce, but not eliminate tars
- Can foul downstream systems
- Loss of carbon otherwise converted to syngas
- Downstream cleaning systems necessary







An Observation

While a great deal of time and money has been spent on biomass gasification in the last two decades, there are very few truly commercial gasifiers, operating without government support or subsidies, day in, day out, generating useful gas from biomass. The typical project starts with new ideas, announcements at meetings, construction of the new gasifier. Then it is found that the gas contains 0.1-10% ‘tars.’ The rest of the time and money is spent trying to solve this problem. Most of the gasifier projects then quietly disappear.... Thus ‘tars’ can be considered the Achilles heel of biomass gasification.

- Tom Reed, 1998

Waste Gasification – MSW (RDF, SRF)

- Attractive due to potential for negative fuel cost
- Challenging due to
  - Heterogeneity of feedstock
    - requires sorting but will still contain small quantities of metal, glass, ceramic
    - day-to-day (hour-to-hour) variation
  - Physical properties (plastics, fluff, string) complicates feeding
  - Chemical impurities (chlorine, volatile metals)

Source: Grupo SPR

Source: srfpellets.com

Waste Gasification – Legacy coal

- Attractive due to
  - potential for "zero" fuel cost
  - opportunities for remediation
- Challenging due to
  - Low heating value
  - High moisture content
  - High ash (dirt) content
  - Powdery nature can complicate feeding
  - "New" pollutants when co-processing with biomass (Hg, As, etc.)

Source: Wyoming Mining Association

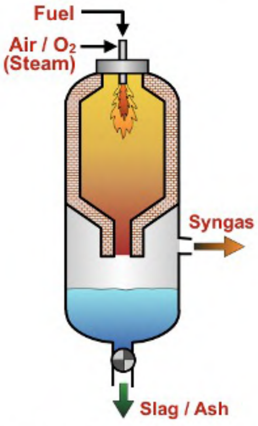
Source: Wikipedia

Lessons Learned – Fixed and Fluidized Beds

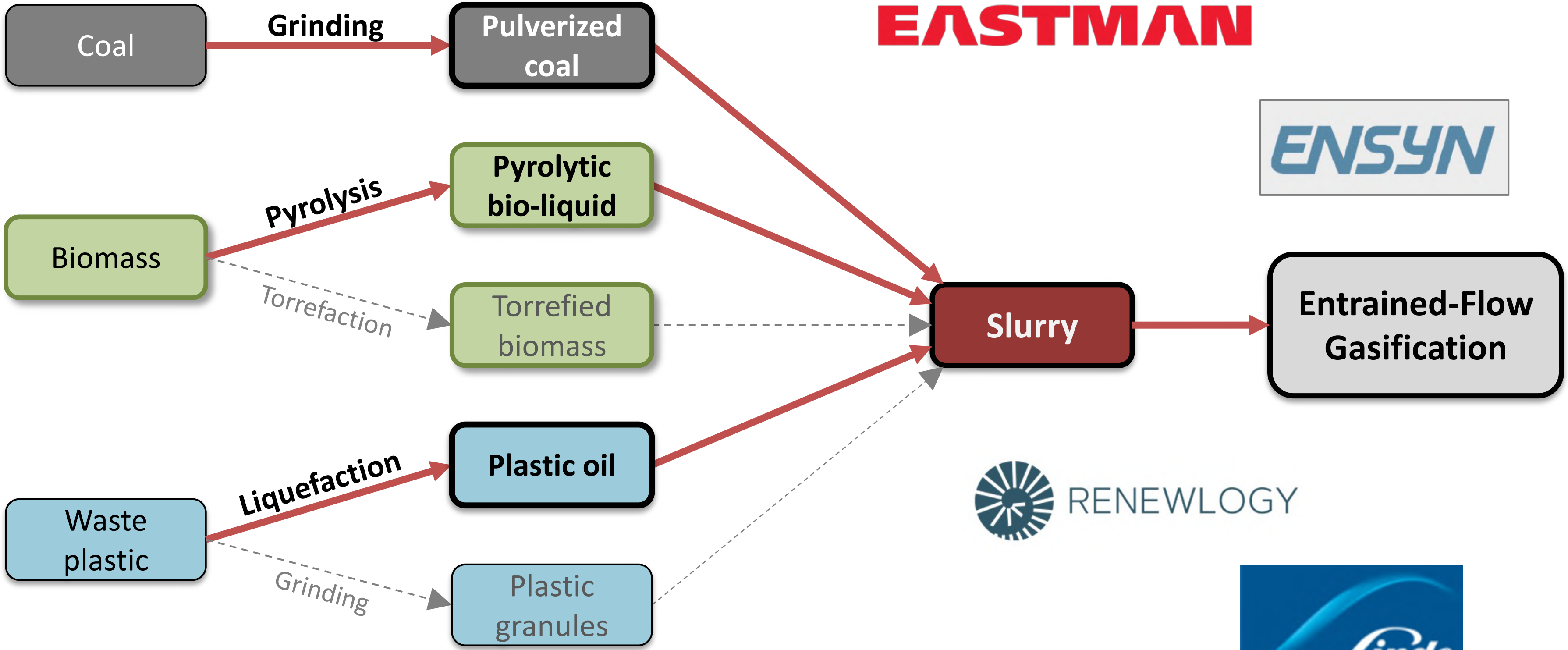
- Simple IC engine-based CHP systems can be successful
  - ...yet still depend on incentives, tax credits
- Complex configurations add cost and more opportunities for failure
  - Gas turbine-based power generation
  - Catalytic fuels/chemicals synthesis
- Tars remain a problem for most systems
  - Gas cleaning is still a major focus
- Feedstock availability and quality is critical
- Waste offers interesting opportunities, but adds challenges
- Stand-alone systems difficult to make successful
- Economics still rule the day

An Alternative – Entrained-Flow Gasification

- Advantages
  - Relatively feedstock agnostic
  - High conversion
  - Low tar
  - Reduced syngas cleaning requirements
  - High pressure operation
- EFG also has challenges
  - Cost for oxygen production
  - Reactor materials (refractories)
- Coal/petcoke gasification has gravitated to EFG
  - Over 1,000 gasifiers today
- Some EFG biomass gasifiers exist today
  - Chemrec process for black liquor
  - KIT BioLiq process

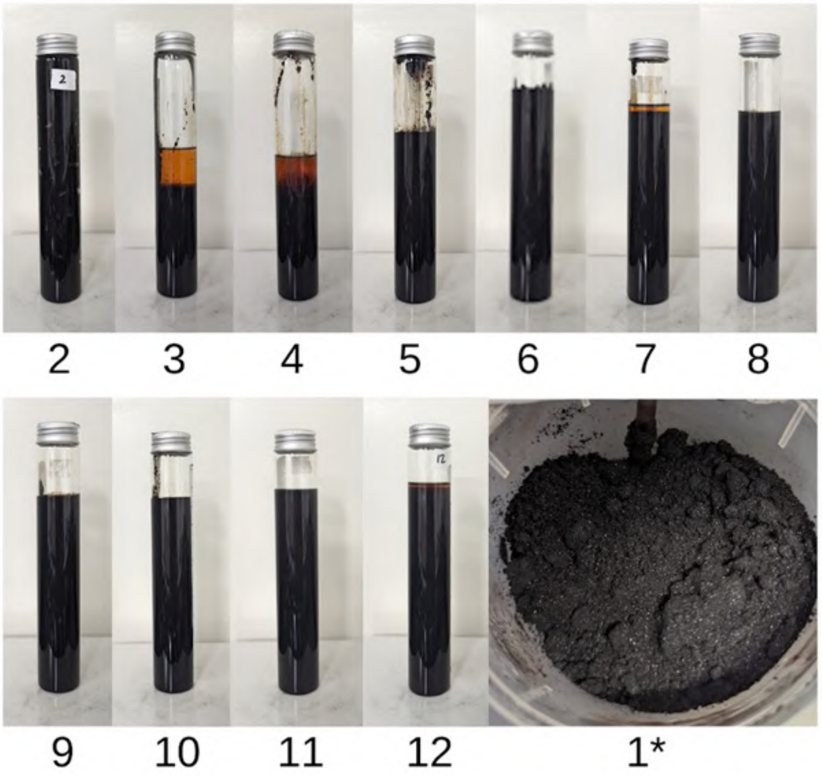


Approach


Coal
Grinding
Pulverized coal
Biomass
Pyrolysis
Pyrolytic bio-liquid
Torrefaction
Torrefied biomass
Waste plastic
Liquefaction
Plastic oil
Grinding
Plastic granules
Slurry
Entrained-Flow Gasification

Mixed Feedstock Slurries

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



Conclusions

- Biomass gasification has had some commercial success
  - Primarily small-scale CHP systems
  - Some larger-scale systems for heat, power
  - But still no large commercial plants for IGCC, FT liquids
- Historical challenges continue
  - Feedstock
  - Tars
  - Economics
- Many interesting opportunities, both in terms of fuels (waste materials) and products (H_2, carbon-negative CO_2 sequestration)
- Entrained-flow gasification is a promising alternative

Acknowledgements

- Portions of this material is based upon work supported by the U.S. Department of Energy under award number DE-FE0032042
- University of Utah Industrial Energy Systems Lab

DISCLAIMER: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise docs not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.