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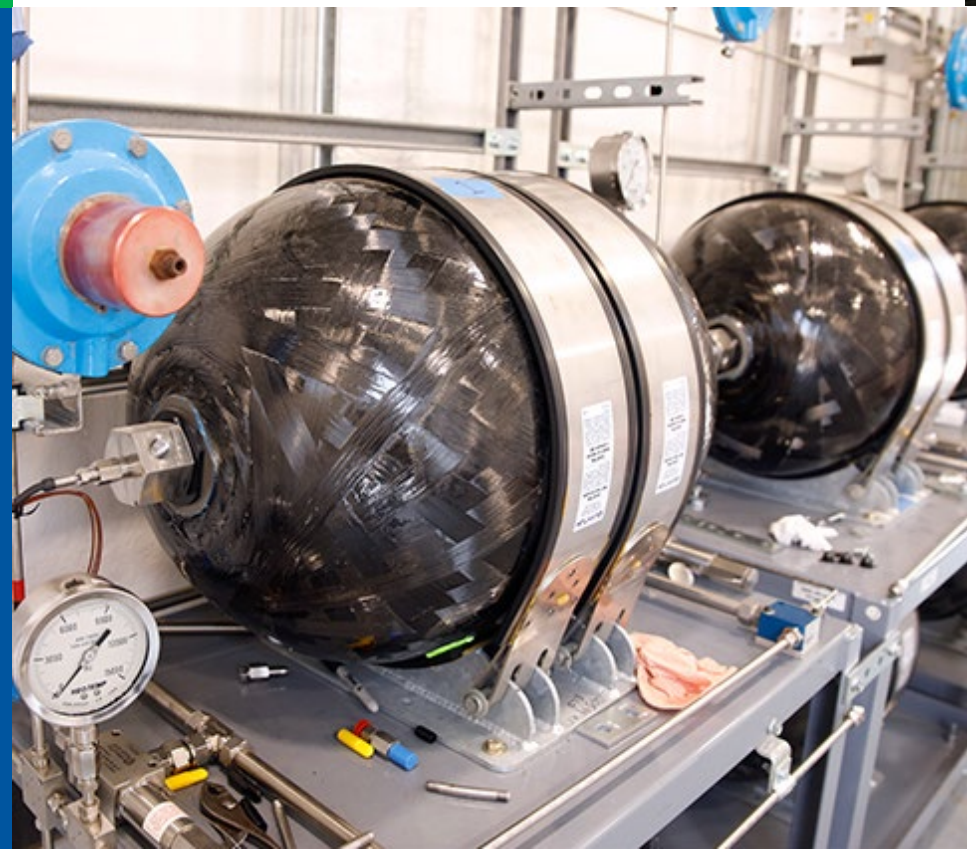

Challenges for Biomass Gasification to Fuels and Chemicals

Zach El Zahab, Ph.D. , *Gasification Program Manager*

US DOE - Gasification Technology Status and Pathways for Net-Zero Carbon Economy Workshop - 30-Nov-2022

Outline

- **GTI Energy Intro**
- **Biogenic Feedstock Technology Challenges**
- **Biogenic Feedstock Pre-processing Challenges**
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  - Pulverization of Biogenic Feedstocks
- **Biogenic Feedstocks Feeding Challenges**
  - Feedstock Low Density Issues
  - Feed Conduits Bridging & Clogging
- **Biogenic Feedstocks Gasification Challenges**
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  - Tar Formation and In-situ Cracking
  - Gasifier Operation Control
  - Alternative Oxygen Supply Methods
- **Syngas Clean-up and Heat Recovery**
  - Tar Removal Systems
  - Heat Recovery Challenges
- **Increasing Carbon Conversion to Biofuels and Chemicals**
- **Conclusions**

GTI Energy Intro (1)

80-year history of turning raw technology into practical energy solutions

Across the entire energy value chain

SOURCE | MAKE | MOVE | STORE | USE

450+ Employees

TOP WORK PLACES 2019 | TOP WORK PLACES 2021 | TOP WORK PLACES 2020 — Chicago Tribune

We work collaboratively to address critical energy challenges

- OTD Operations Technology Development
- UTD Utilization Technology Development
- ETP Emerging Technology Program
- LCRI Low-Carbon Resources Initiative

GTI Energy Intro (2)

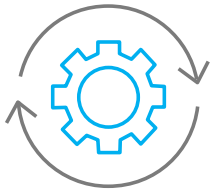
Working across the energy value chain

Source

Expanding supplies of affordable, clean energy

- Subsurface production of hydrogen
- Enhanced geothermal systems
- Unconventional natural gas and oil production
- Geologic modeling and reservoir characterization
- Hydraulic fracturing diagnostics and optimization
- Hydraulic fracturing and reservoir flow modelling
- Enhanced recovery
- Liquefied natural gas (LNG)

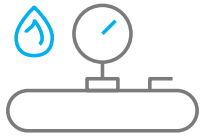
Make



Transforming natural resources into clean energy

- Hydrogen production
- Integrated biofuels technology R&D
- Syngas generation and processing
- Carbon management
- CO_2 capture and utilization
- Chemical research and process development
- Renewable natural gas and gas quality
- Gasification process development

Move & Store



Ensuring safe and reliable energy infrastructure

- Methane emissions, monitoring, mitigation, and reduction
- Data integrity and risk management
- Infrastructure rehabilitation and improvements
- Environmental matters, enabling renewable gas, and gas quality
- Smart utility information technology tools
- Materials and analytical testing
- CO_2, H_2, and natural gas underground storage

Use

Delivering solutions for efficient and environmentally responsible energy use

- Residential/commercial appliances, equipment, and building systems
- Industrial process heat and steam
- Power generation and combined heat and power
- Alternative transportation fuels
- Natural gas-solar thermal hybrid equipment
- CO_2 capture and utilization

Biogenic Feedstocks Technology Challenges

Courtesy of INL

Courtesy of TNO/Synova

Biogenic Feedstock Pre-processing Challenges

- MSW Sorting
- Pulverization of Biogenic Feedstocks

Biogenic Feedstocks Feeding Challenges

- Feedstock Low Density Issues
- Feed Conduits Bridging & Clogging

Biogenic Feedstocks Gasification Challenges

- Lack of Kinetics & Mineral Data
- Tar Formation and In-situ Cracking
- Gasifier Operation Control
- Alternative Oxygen Supply Methods

Syngas Cleanup and Heat Recovery

- Tar Removal Systems
- Heat Recovery Challenges

Enable low carbon intensity fuels, chemicals, and power

Pre-processing: **MSW Sorting**

- Technical Challenge: Variability of the non-recyclable MSW (NMSW) chemical composition (both organics and inorganics) → unsteady gasifier performance → Unreliable biofuel/chemicals production
- GTI Energy Current Effort (DE-EE0010298): 1) Characterize chemical properties of NMSW using advanced infrared (IR) sensors and ASTM methods to build the database, 2) Develop a predictive model using AI and machine learning to correlate NMSW components to proximate and ultimate analysis and high heating value, 4) Develop a gasifier control algorithm that targets a feedstock HHV range of [18-20.7] MJ/kg, chlorine levels <1000 ppm, and inorganic (Na, Mg, Fe) content <2% and Ca content <10% of overall feed using pre-processing methods such as blending, booster stream addition, fractionation, and decontamination. **Timeline is 2.5 years**.
- GTI Energy Future Efforts: Live pilot scale demonstration in which the gasifier is integrated with the IR sensors and AI sorting system.

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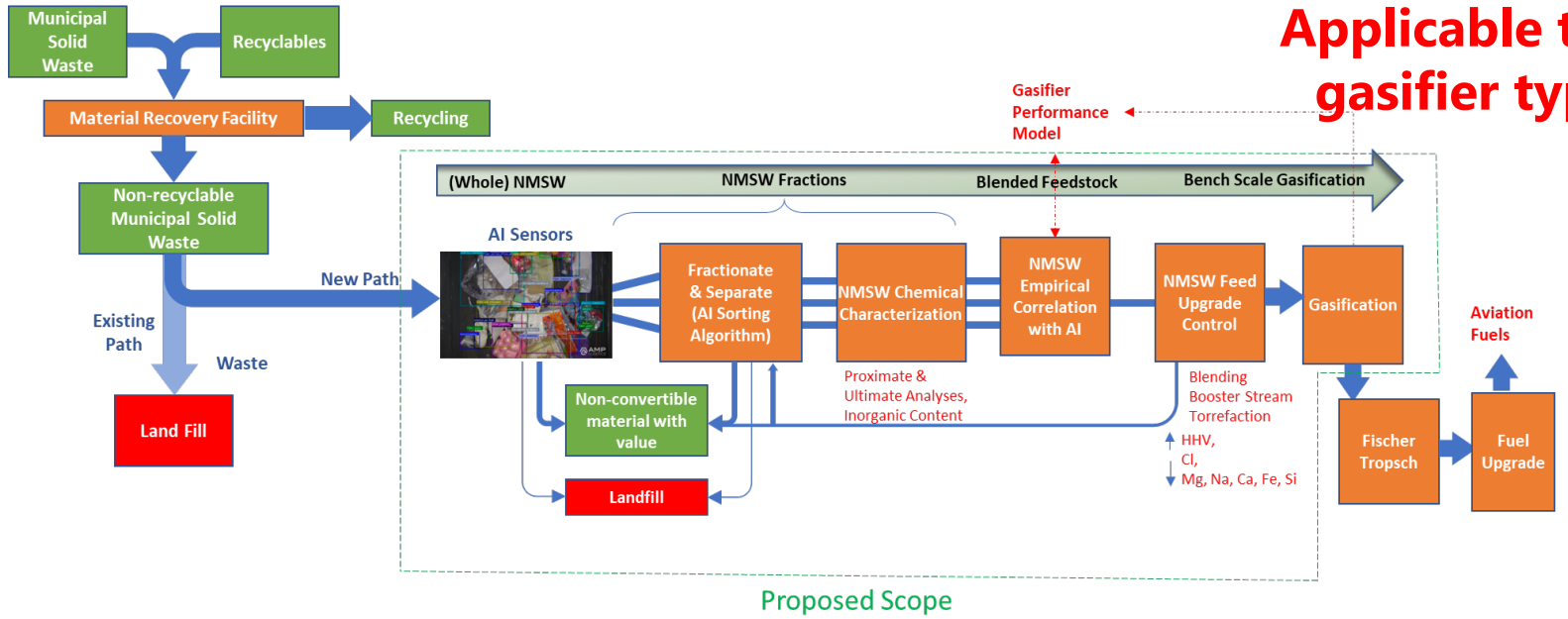

Pre-processing:
Pulverization of Biogenic Feedstocks

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Torrefied Biomass

Pulverization

Non-thermal drying

Pulverization

- Technical Challenge: Difficulty to pulverize biogenic feedstocks to particle size distribution (PSD) that enables high carbon conversion during the gasification process.
- GTI Current Effort (DE-EE0009755): Pre-process corn stover using torrefaction, steam-explosion, and non-thermal drying and sorted MSW using non-thermal drying. Pulverize pre-processed feedstocks to PSD < 1000-micron and <200-micron **End by 2-2023**.
- GTI Future Efforts: Pre-process and pulverize a wide range of biogenic feedstocks and build a database that houses the pulverization properties of each biogenic feedstock type. **Timeline 2023-2028**.

Enable entrained flow gasification

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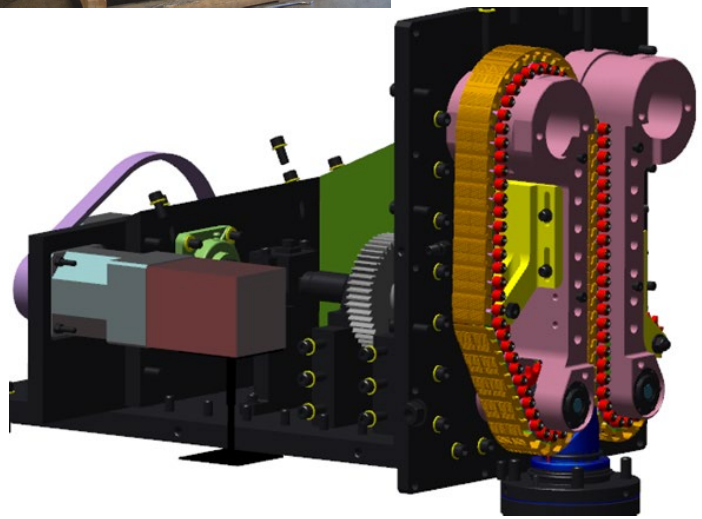
Feeding:
Feedstock Low Density Issues



Challenge: Biogenic feedstocks tend to have lower densities compared to coal and there are currently no reliable analytical models to predict their flow dynamics through feed systems:

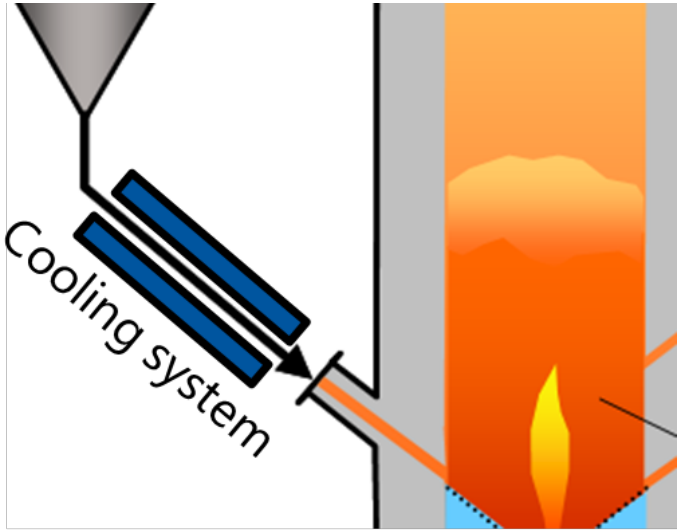
→ Larger size lock-hopper / feeder-hopper are needed → Higher CAPEX and limitation by building codes & regulations

→ More pressurization gases are needed → Larger OPEX and higher GHG emissions

Current Effort (DE-EE0009265): The focus of the upcoming third and final budget period of BETO Project DE-EE0009265, "Decontamination of Non-recyclable MSW and Preprocessing for Conversion to Diesel", will be to fabricate and test a bench-scale DSP specifically designed to feed NMSW into a pressure vessel, building on past GTI experience with the DSP in coal applications.

Future Efforts: Pending successful current efforts, next steps should include further scaling up the bench-scale design to feed a pilot gasifier at steady state, for example the GTI U-GAS pilot in Des Plaines, followed by additional scale-up to demonstration size. Pilot testing could commence as soon as 2024 after current bench-scale efforts are complete.

Feeding:
Feed Conduits Bridging & Clogging (1)



Cooling system for the U-GAS feed pipe

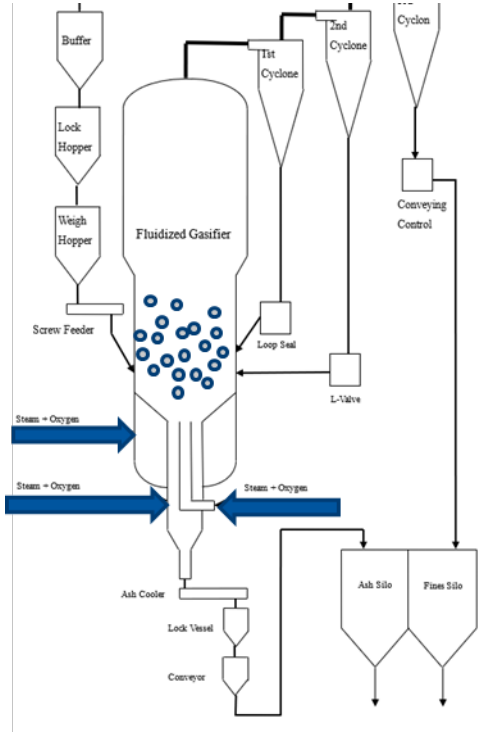
- Technical Challenge (1): Feed conduits narrowing and clogging due to plastics sticking to metals as result of the relatively low plastic melting point in the case of biogenic feedstock blends containing significant amount of plastics
- GTI Current Effort (DE-FE0032176): Pilot feed system flowability testing (*both for the pneumatic and screw-feed configurations*) in the presence of a heat source that simulate the radiation from the gasification flame → Set the design basis of a cooling system. Design, implement, and test the cooling system. **End by 12/2024**.
- GTI Future Efforts: Run pilot scale gasification to test the effectiveness of the feed pipe cooling system at pressure and under real heat conditions → possibly refine its design. **Timeline ~ 2024-2025**.

Feeding:
Feed Conduits Bridging & Clogging (2)

Test facility for the feed system

- Technical Challenge (2): When pulverized for entrained-flow gasifier applications, biogenic feedstocks tend to be cohesive and do not flow easily → cause bridging issues within lock-hoppers & feeder-hoppers as well as clogging issue within feeding conduits
- GTI Current Effort (DE-EE0009755): Pulverized biogenic feedstocks (dried and torrefied) flowability testing through the pilot-scale lock-hopper system, feeder hopper system, and ultra dense phase (UDP) feedline system. **End by 4/23**.
- GTI Future Efforts: Implement and test the UDP system with torrefied biomass for a commercial demonstration scale gasification plant based on the lessons learned from the DE-EE0009755pilot scale project. **Timeline is 2025-2026**.

Gasification:
Tar Formation from Biogenic Feedstocks



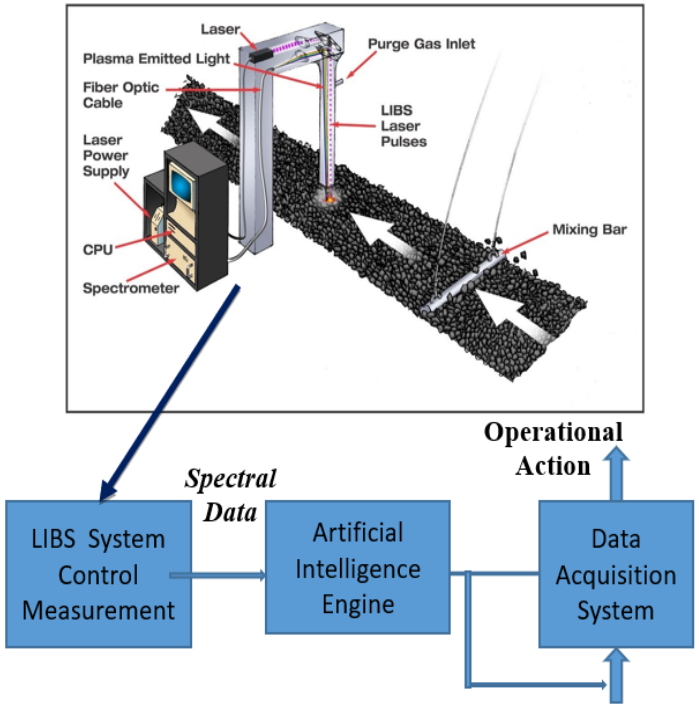
- Technical Gap #1: Formation of tars within fluidized bed (FB) gasifiers that run <1000 degC
- Current Effort (GTI Internal R&D): TGA and Bench scale FB gasification testing for in-situ heavy tar cracking with commercially available alumina bed materials.
- Future Efforts: **Timeline 2023-2025**
  - Run further bench scale tests with a customized alumina bed materials that with optimal thermal and catalytic tar cracking effects.
  - Run pilot scale gasification tests and optimize performance and the selection of the alumina bed materials.
  - Develop a fluidized bed multiphase CFD model (anchored based on the pilot testing) to understand the temperature distribution in the presence of bed materials.

Gasification:
Lack of Kinetics and Mineral Data

Bench scale fluidized bed gasifier at GTI Energy

- Technical Challenges: Lack of kinetics data, lack of data on conversion yields, lack of syngas data, and lack of info on the trace elements from biogenic feedstocks.
- GTI's Current Effort (DE-FE0032176): TGA and bench scale gasification testing where 29 different permutations test runs with various feedstock and operating temperatures. Anchor existing models to bench scale data. **End by 12/2023**.
- GTI's Future Efforts: Run U-GAS pilot scale gasification tests and refine the kinetic/mineral models (analytical and CFD) based on the bench-scale tests. Establish mitigation strategies to protect the metallurgy of downstream components from MSW contaminants → TRL 6. **Timeline is 1 year**. Further bench-scale testing for various types of biogenic feedstocks. **Timeline 2023-2028**.

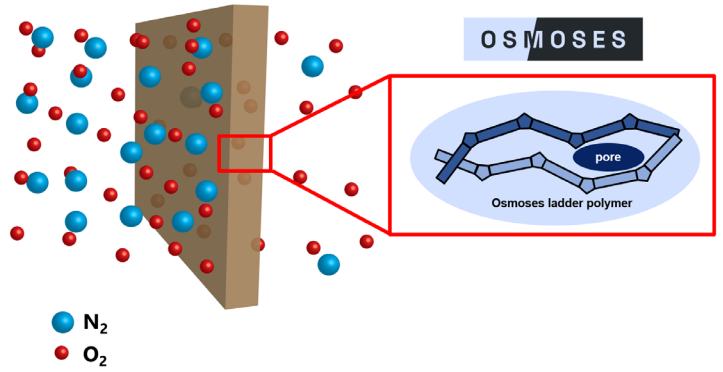
Gasification:
Active Control of Gasification Operation



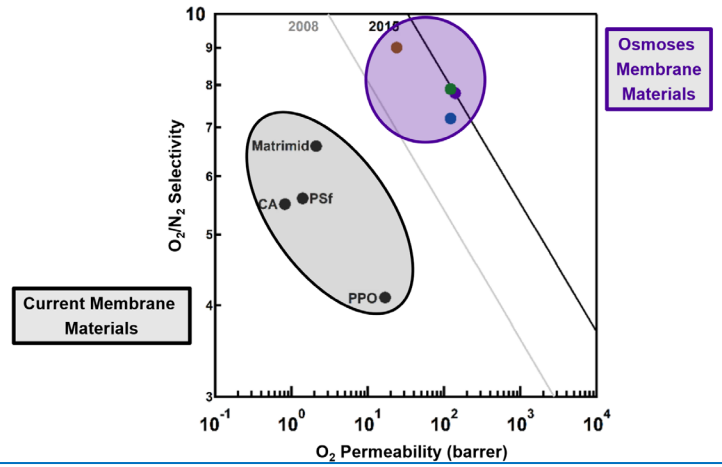
- Technical challenges: Gasifier unstable operation due to constant variation in feedstock mixtures especially in the case of MSW.
- Current Effort (DE-FE0032177):
  - Design and assemble a safe and reliable Laser Induced Breakdown Spectroscopy (**LIBS**) system for detection and quantification of mixed waste material samples.
  - Develop and validate Machine Learning (ML) algorithms for LIBS data processing to ultimately reduce future feedstock sampling and analysis requirements.
  - Perform an analysis to assess the benefit of incorporating the proposed system on upgraded operational protocols and control schemes of gasifiers for hydrogen production.
- Future Efforts: Run pilot scale demonstration for the integration of gasification and LIBS. **Timeline is 2025-2027**.

Gasification:
Alternative Oxygen Supply Methods

Osmoses is developing polymer membranes for industrial scale gas separations



Osmoses polymers have record permeabilities and selectivities that can easily be tuned for air separations



Challenge: Incorporation of traditional cryogenic air separation units presents an economical challenge for small modular biogenic feedstocks gasification systems → Need alternative economical oxygen production methods.

Technology Description:

- ✓ Osmoses polymer membranes have the highest known combinations of permeability and selectivity for any material in their class.
- ✓ Compared to other technologies such as VPSA, Osmoses membranes operate continuously simplifying operational complexity and process design.
- ✓ Ultrahigh flux and selectivity enables membrane module miniaturization and fewer stages compared to traditional membranes.

Future Efforts:

- ○ Scale-up membrane systems to demonstrate performance at pilot scale.
- ○ Optimize membrane separation scheme to capture maximum value for gasification.
- ○ Integrate membranes with gasification process.

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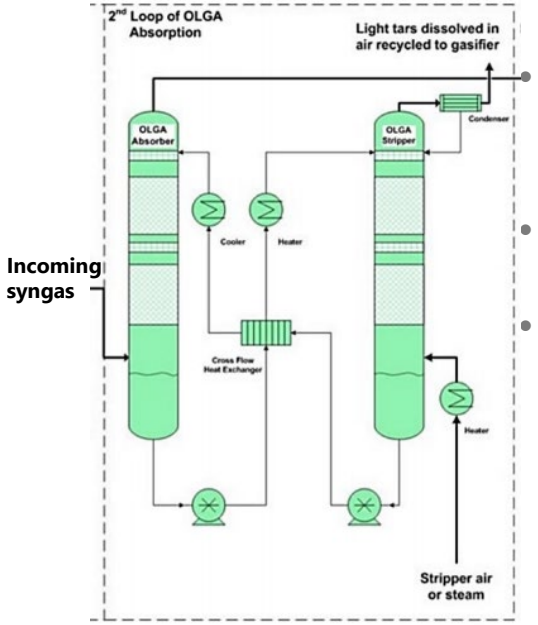
Syngas Cleanup & Heat Recovery:
Tar Formation from Biogenic Feedstocks



Technical challenges: Presence of light tars in the syngas products of (FB) gasifiers that run <1000 degC after in-situ cracking of heavy tars

Current Effort: None.

Future Efforts:

- Conduct a feasibility study for the integration of a compact high-pressure version OLGA with U-GAS → leading to lower CAPEX when compared to the current hot oxygen burning system.
- OLGA unit comprises a scrubber to wash the tars from the gas with oil and a stripper to regenerate the washing liquid. The gas inlet temperature of OLGA must be higher than the tar dew point. The gas outlet temperature is kept above the water dew point to avoid mixing of condensed water and scrubbing liquid

- Develop and test high-pressure OLGA system and demonstrate light tar removal at a pilot scale - **Timeline is 2024-2026**.

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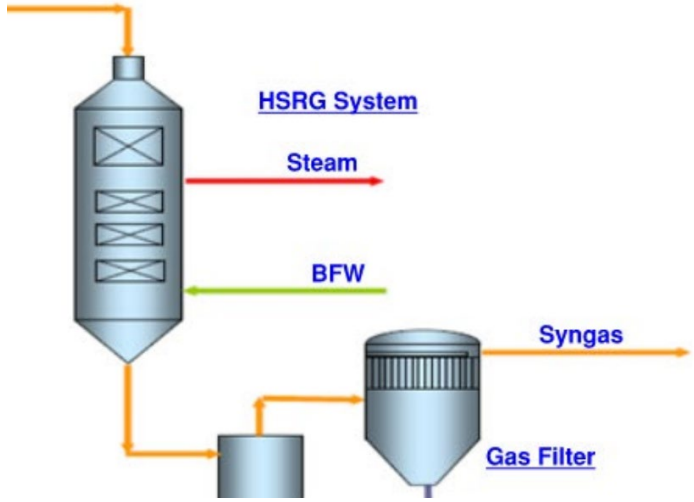
SYNOVA

TNO innovation for life

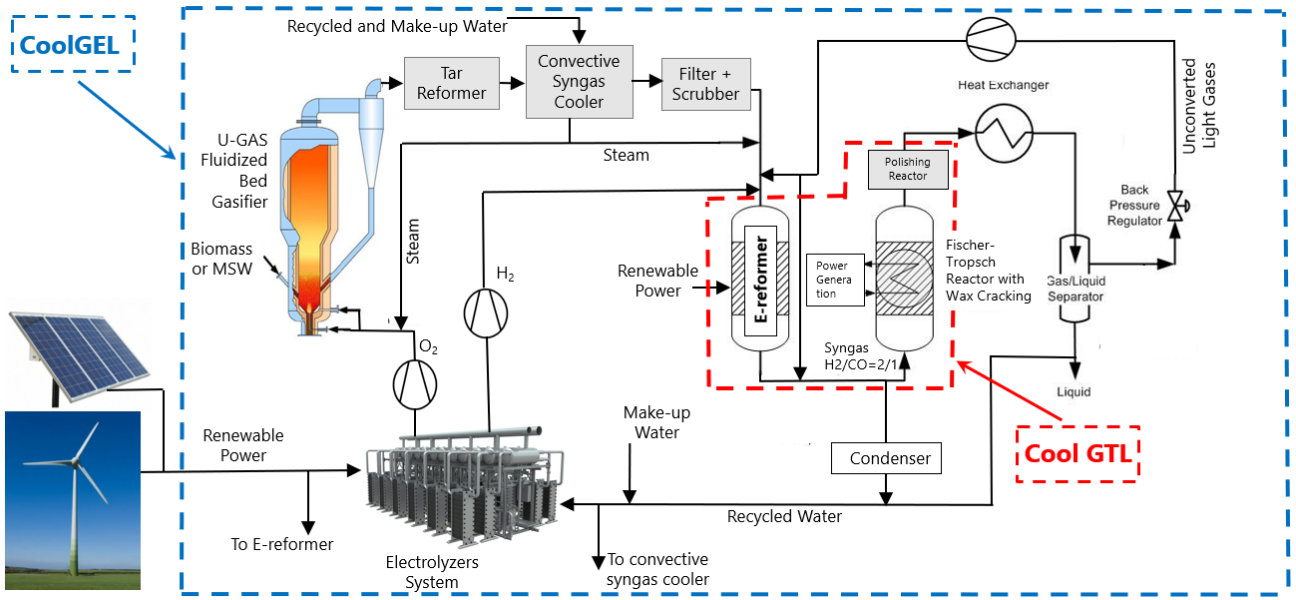
Syngas Cleanup & Heat Recovery:
Heat Recovery Challenges

Incoming syngas with ash fines not captured by upstream cyclones



- Technical challenges: ash fines deposition and fouling on the heat recovery steam generator tubes → reduced heat transfer and erosion issues → compromised gasification island thermal efficiency and possible plant unavailability. *Also, few HRSG manufacturers exist for high-pressure syngas cooling → very high CAPEX. More manufacturers are needed in the market to balance the current equipment prices*.
- Current Effort: GTI is developing a proprietary approach that can remove sub-micron particle size.
- Future Efforts: GTI would like to test it proprietary approach on a pilot scale - **Timeline is 2024-2027**.

Increasing Carbon Conversion to Biofuels & Chemicals



USPTO Patent no. 10,882,800

- Technical challenges: Traditional biomass/MSW gasification pathways have low feedstock carbon conversion (32-35%) → low biofuel yields (60-65 gal/dry ton biomass)
- Current Effort: Feasibility studies for Cool GEL concept → 85% carbon conversion is possible → 160-170 gal / dry ton biomass.
- Future Efforts: Pilot-scale integration (1000 gal/day) of the U-GAS pilot, with electrolysis and the novel Cool GTL technology at the GTI campus in Des Plaines, IL. Develop a PDP for a first of kind commercial demonstration plant to be located at site where there's an abundance of woody biomass and renewable energy. **Timeline is 4 years**.

Conclusions

- Biogenic feedstocks gasification continues to face several technical challenges that need to be **urgently** resolved in the next ~7 years → Those solutions cannot wait beyond 2030 if our goal is to be 50% carbon neutral by 2030!
- All solutions need to be proven and matured on a commercial scale → promote more funding opportunities for commercial demonstration projects to propel gasification technologies from TRL 7 to TRL 9 and help mature technologies that have just achieved TRL 9.
- GTI Energy is eager to maintain a key role in developing solutions for the current gasification challenges → continue to build a wider network of technology partners.