Advanced BiCRS Process for H_2 Production with High-Negative Carbon Efficiency – BioVac H_2™

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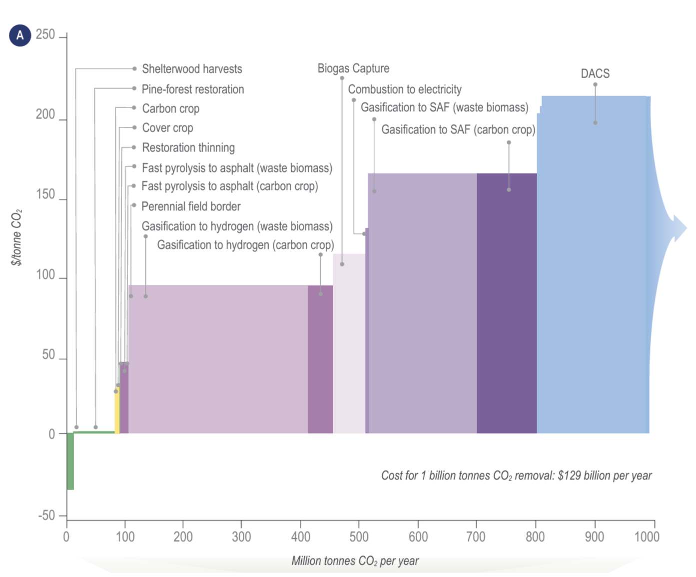
Motivation and Vision

- BiCRS is a key element of the carbon removal strategy. BiCRS approaches have been evaluated and found to offer a significant potential to meet CO_2 removal (LLNL Roads to Removal, Chapter 6) targets
- Higher C capture and sequestration and higher C negativity are important aspects of a BiCRS process. The BioVac H_2 approach has exceptional performance on this metric along with favorable economics based on early TEA work.

Benefits and Value

- Removal of CO_2 from the atmosphere while producing energy or chemicals is an important part of global climate strategy.
- This technology can significantly reduce the carbon emissions of BiCRS processes
- Gasification of biomass to H_2 using waste biomass is a large contributor to the low-cost tier of options for CO_2 removal to meet targets
- BiCRS can contribute 350 million tons: per year of needed CO_2 removal

CO_2 Capture Supply Curve



Business Concept

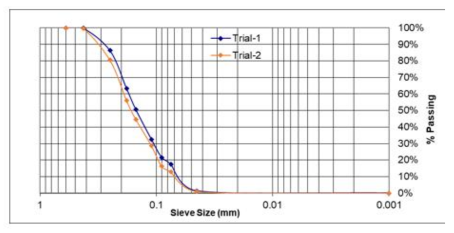
- Develop new BiCRS process, BioVac-H2 using advanced emerging processes

Technical Solution

- Key features/process
  - Feedstock Pre-processing*
  - GTI Energy's R-Gas Gasification of Torrefied/Pulverized Ag Wastes*
  - Water Gas Shift
  - GTI Energy/Uhde GmbH Morphysorb* AGR solvent – CO_2 Removal and Capture*
  - Oxy-torrefaction*
  - Pressure Swing Absorption
  - Power Block – H_2 Combustion/Turbine
  - CO_2 Compression
- *Developmental Technology

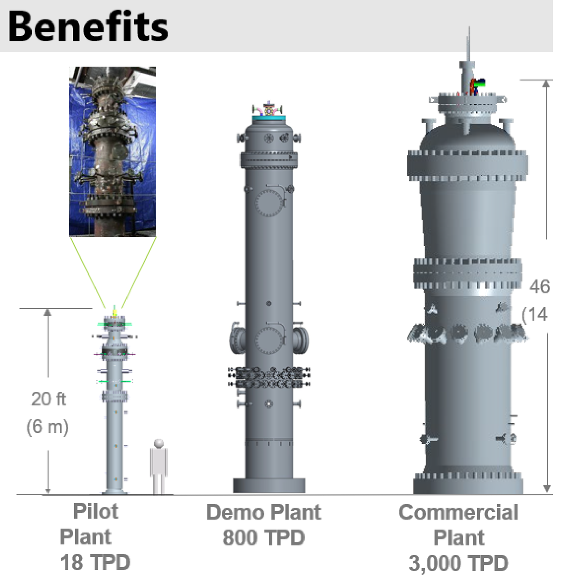
Feedstock Pre-processing

- Corn Stove (CS) bales are deconstructed and then pelletized.
- The CS pellet torrefaction then go through a torrefaction process at ~245 degC temperature and a residence time of about 30 minutes until the pellet color turns into 'dark brown' inside-and-out with very minimal fibrous materials.
- The feedstock mass loss through the torrefaction process ranges between 10% and 20%.
- The torrefied pellets are then pulverized to achieve a particle size distribution with a median size of about 150 micron.



GTI Energy's R-Gas Gasifier - Benefits

- High temperature operation enables gasification of high ash fusion temperature and high ash coals
- Efficiency (cold-gas, HHV)
  - ~2-4% higher than other dry feed
  - ~7-9% higher than slurry
- 15-25% lower CAPEX & OPEX
- Reduced water usage
- 90% smaller reactor volume allows for factory integration, reduce efforts on transportability and maintainability



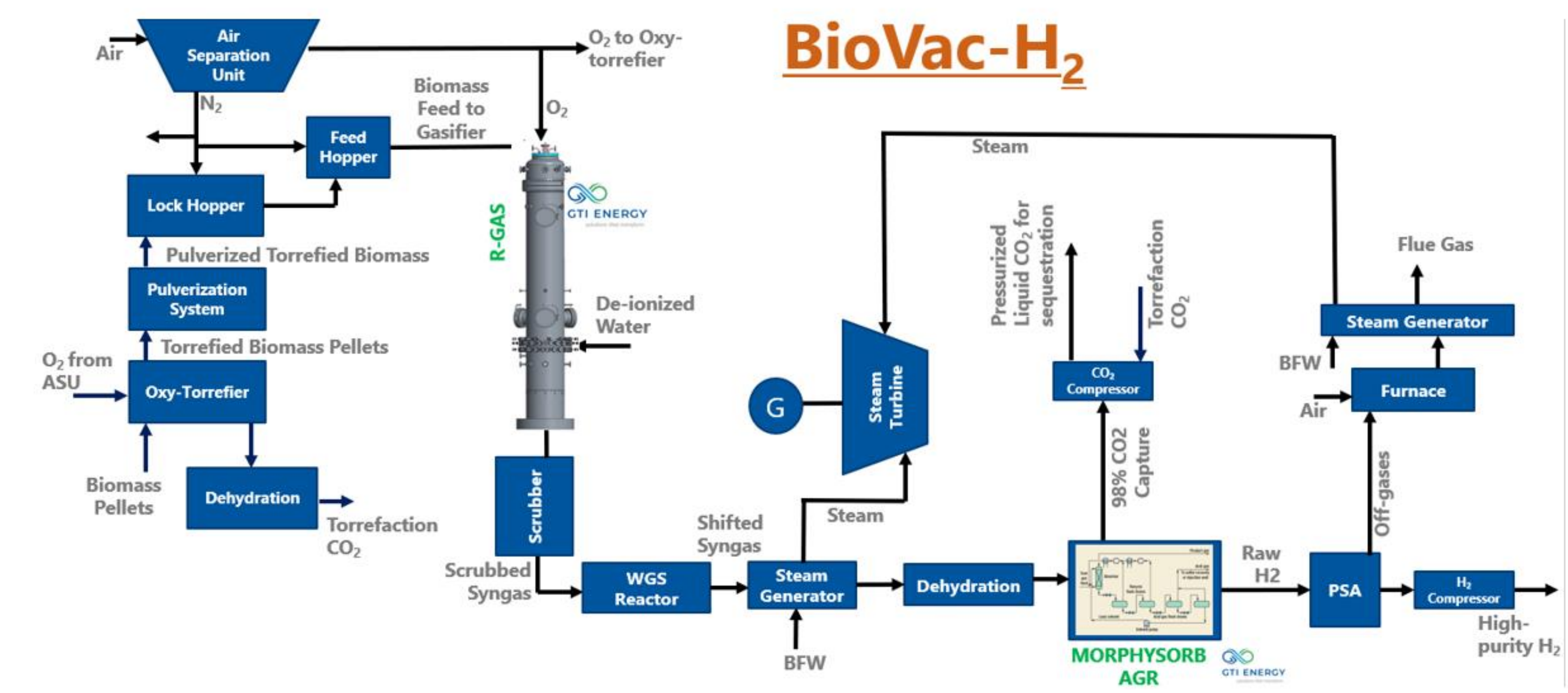
Acid Gas Removal – Morphysorb® Process

- Solvent process to remove mainly H_2S and CO_2 from scrubbed syngas.
- Regeneration of rich solvent via flashing with mild heating (if needed.) Lower energy than amine processes.
- Physical solvent – works best at pressure, moderate temperatures (but >50 °F), and in the absence of heavy hydrocarbons
- Tested and developed with natural gas, commercialized for bulk removal of H_2S and CO_2 (~40 - 50 vol% in total) at ~1,000 psi at 450 MMSCFD.
- Tested in GTI Energy pilot unit (1 MMSCFD) with syngas from fluidized bed gasification of 20 TPD wood in the U-GAS process at ~900 psig.
- Excellent Results in Biomass syngas service (Ref. Acid Gas and Trace Contaminant Removal from Synthesis Gas produced by fluidized bed gasification of wood using the Morphysorb® Process in the GTI Flex Fuel Pilot Plant, D. Leppin, TCBiomass2013, Chicago IL, April 2013)

Conclusions and Next Steps

- The proposed conceptual process, BioVacH2™, uses advanced biomass feed processing, gasification (R-Gas™), and acid gas treating technology (Morphysorb®) along with state-of-the art CO_2 compression, oxy-torrefaction and power generation equipment (H_2-capable gas turbines, when available) to convert suitable biomass feedstocks to H_2 or optionally carbon-negative power. Very high pre-combustion CO_2 recovery indicates a very high negative C result for this process.
- Pathway to net-negative H_2 at $1/kg is REALIZABLE as long as there is a carbon offset market that pays ~$90/tonne for CO_2 removal.
- GTI Energy will endeavor to continue development of the process depending on available funding. GTI has many of the pilot plant scale equipment modules needed for an integrated test of the concept if the evaluation going forward continues to be favorable.

BioVac-H2 Block Flow Diagram



Key Process Advantages

- Torrefaction/ Feed Pre-processing
  - Enables use of various biomass feedstocks with minimal feeding and heavy liquids issues
  - Enables use of entrained flow gasifier with high efficiency, low footprint
- Oxy-torrefaction
  - Torrefaction off-gases combusted at high-temperature in an oxy-combustion system
  - Enables additional CO_2 capture without expensive, massive CO_2 removal from flue gas process
- Gas Turbine
  - Efficient power production with only water vapor emissions. 100% H_2 capable turbines to be available from Siemens and GE around 2030.
- High Efficiency AGR Solvent
  - High CO2 Recovery, Low regeneration energy (solvent flashing only)

Key Process Performance Ratios

Parameter	Value
O_2 to C in feed ratio*	1.17
Sales H_2 to C in feed ratio	0.19
CO_2 sequestered, lb/lb C in feed, %	94.7
Net renewable power required, MWe	18

900 tons of biomass per day → 79 tons of high-purity H2 per day → CI < -20 kg CO2e / kg H2

900 tons of biomass per day → 1,917 tons of CO2 removal per day

*Combined O_2 to Gasification and Oxy-torrefaction
Feed: Corn Stover
**Additional CO_2 generated from overall process from biomass feed transportation, construction activities – LCA not performed at this time.

TEA

Capital Costs	
Bare Erected Cost (BEC):	$ 291,857,396
ASU	$57,156,697
Biomass Handling and Torrefaction	$52,097,128
Power Generation	$ 7,000,000
Gasification Island	$71,337,088
PSA	$ 6,266,482
WGS + CO2 Capture	$60,000,000
CO2 Compressor	$38,000,000
Other direct cost (balance of plant)	$34,731,030
Indirect Costs (EPCM, spare parts, commissioning etc.)	$40,860,035
Contingency (15%)	$55,117,269
Total Plant cost (TPC)	$422,565,731
Operating Costs	
Biomass ($70/tonne delivered to site)	$20,713,896
Hydrogen Revenue ($1/kg)	$ (30,763,339)
Chemicals, Catalyst etc.	$2,000,000
Renewable Power Cost (6 cents/kWh)	$ 8,798,544
Fixed Annual Cost (Staffing, insurance, maintenance etc.)	$11,451,315
Total operation cost	**$12,200,415**
CO2 removal cost ($/tonne)	**$ 88.95**

Removal cost is ~$89/tonne while producing high-purity H2 at $1/kg