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solutions that transform

R-GAS *Plus*: An Integrated Biomass Gasification and Reverse Water Gas Shift Approach for Maximal Biofuel Yields

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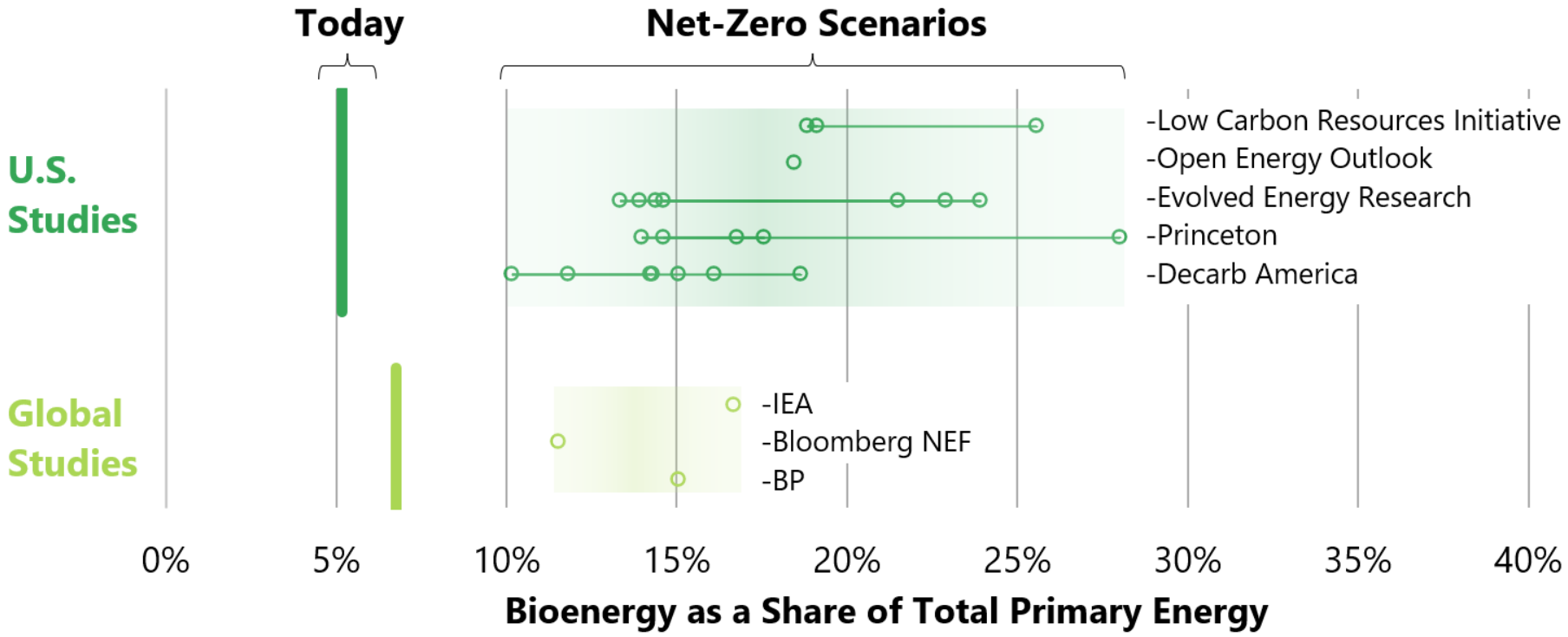
Bioenergy in Net-Zero Energy Systems

bioenergy use **increases** from today across economy-wide, net-zero studies



*US results adapted from Meta NZ: www.gti.energy/meta-nz/
*global results adapted from Global Energy Outlook: www.rff.org/publications/data-tools/global-energy-outlook/

GTI Energy Gasification Heritage

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Renewable Energy Transition

Syngas to Power
- Integrated-Gasification Combined Cycle
- Gasification to Direct Super-Critical CO2
- Partial Oxidation Turbine

Syngas to Products
- Fuels
- Chemicals
- Synthetic Natural Gas

Feedstocks
- Coal
- Biomass

R-GAS™ Pilot Plant

R-GAS™ 800 tpd Demo

Shanxi - 2020

Advanced Gasification Test Facility

Flex Fuel Test Facility

Shanghai Plant - 1995

2020

2010

2000

1990

1980

1970

1960

1950

1941

RENUGAS Pilot Plant

U-GAS Pilot Plant

HYGAS Pilot Plant

Early PDU

IGT

gri

gti

GTI ENERGY

Skive - 2007 Zaozhuang - 2007

Lab Facility - 1947

Dr. James L. Johnson

Yima - 2012

SunGas RENEWABLES

HALDOR TOPSØE CATALYSING YOUR BUSINESS

AEROJET ROCKETDYNE

ANDRITZ

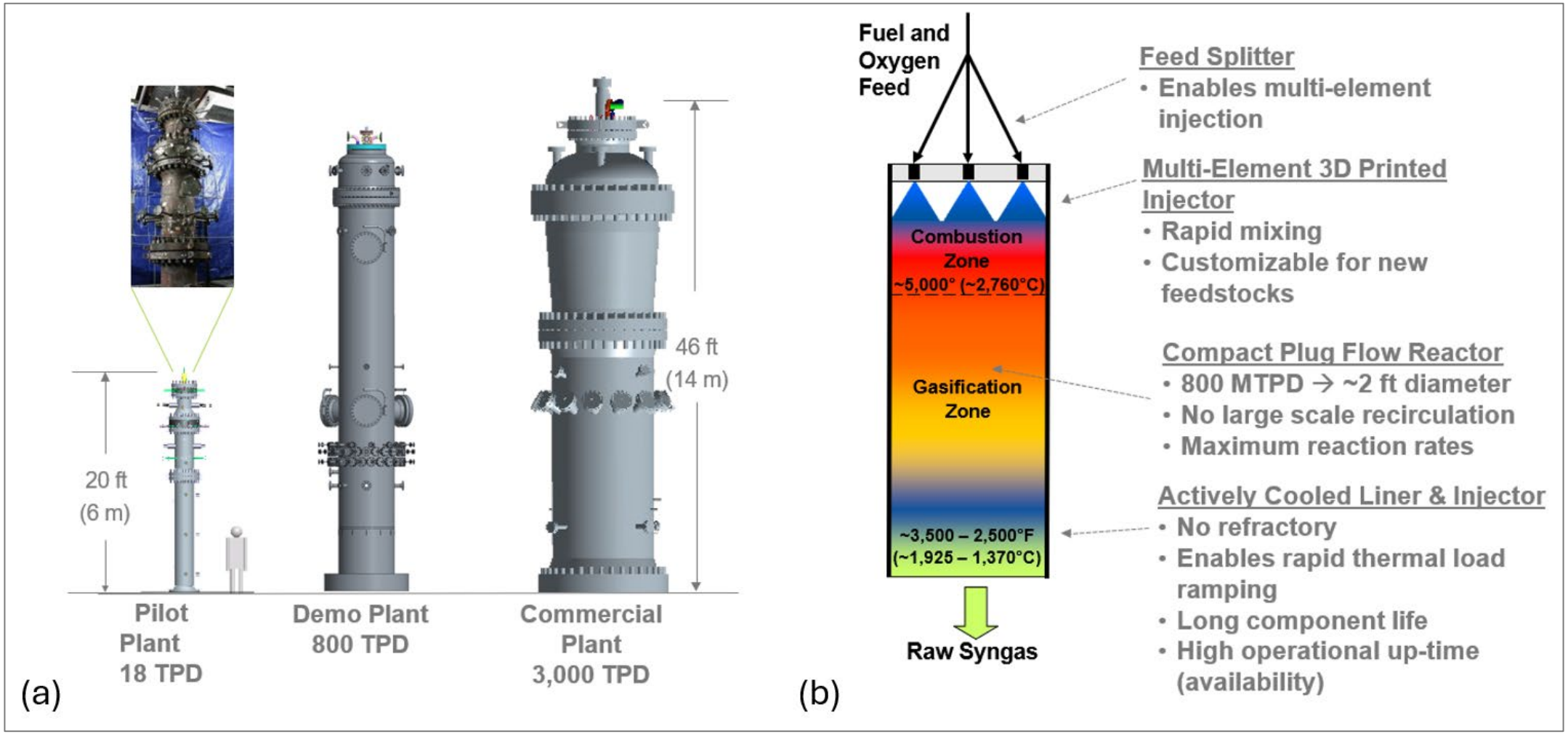
e·on

UPM

GreatPoint ENERGY

SES SYNTHESIS ENERGY SYSTEMS

R-GAS Technology Background



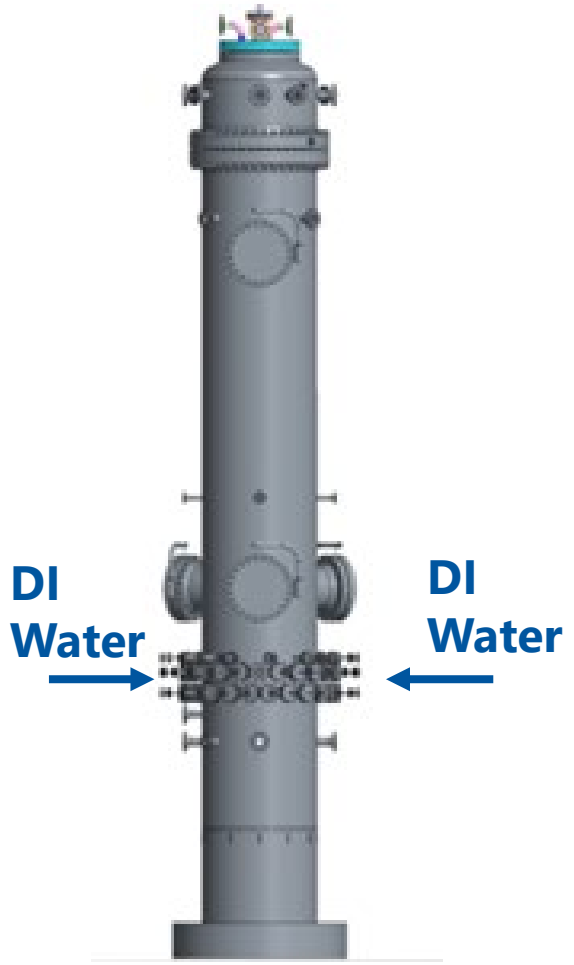
R-GAS Pilot Facility

- Rated for 18 TPD coal or biomass
- Flexible test facility to evaluate advanced gasification and syngas post-treatment technologies
- Fully integrated pilot plant to address the "real-world" aspects of gasification operations at relevant scale
- Full suite of instrumentation and analytical laboratory capability to provide detailed performance data

Enables evaluation and verification of operation with new feedstocks at relevant scale and conditions

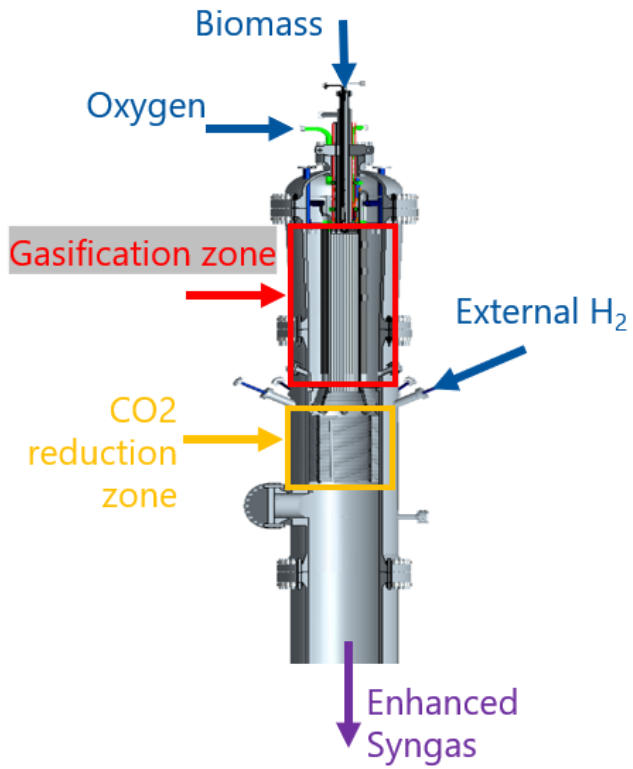
R-GAS Rapid Quench Shortcomings

- The R-GAS entrained flow technology can operate at very high temperatures (>2500C) thanks to its unique and sophisticated rapid-mixing and water-cooling schemes that are inspired from combustion and cooling techniques that are employed in rocket engine technologies → high carbon conversion efficiencies.
- The expected temperatures of the syngas exiting the gasification zone can be in the 1450C to 1550C range depending on the ash fusion temperature and need to be cooled quickly.
- Traditionally, we have implemented a 'rapid quench' system whereby deionized (DI) water is injected right at the gasification zone exit to quickly cool the syngas down to temperatures (<350C).
- 'Rapid quench' comes at the expense of the overall R-GAS island thermal efficiency, i.e., we are not optimally recovering the energy input to produce the significant quantities of O2 for the R-GAS high temperature operation.

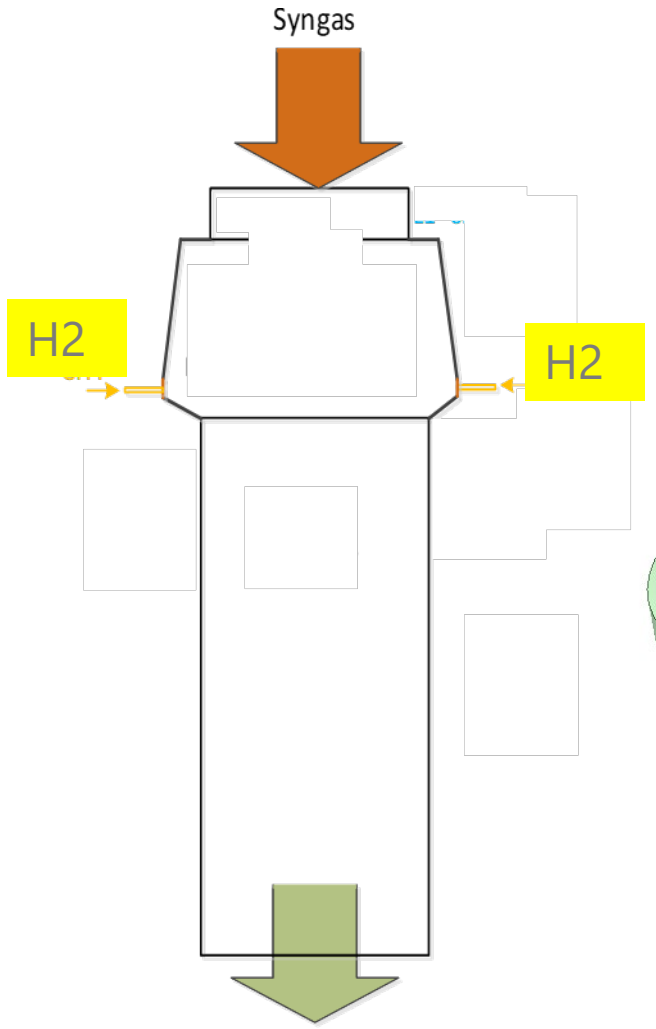


R-GAS *Plus* Syngas Enhancement Solution

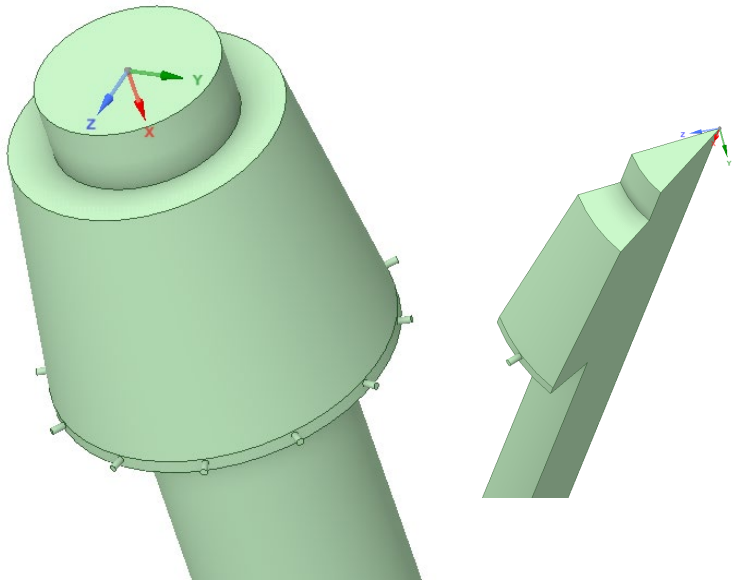
- The current R-GAS technology roadmap entails developing novel techniques that would utilize the heat in the syngas exiting the gasification zone to improve the final biofuel product yields and the overall thermal efficiency of the biorefinery.
- We have invented a new technique that relies on cooling the syngas through fast-reacting endothermic chemical reactions, namely reverse water gas shift (non-catalytic).
- Hydrogen can be indirectly heated by syngas and injected right at the R-GAS gasification zone exit to quickly react with the CO2 gasification products and endothermically cool the syngas down to temperatures in the ~1100-1150 degC range.
- This technique takes great advantage of the high heat content in the syngas to drive the fast endothermic reactions, significantly reducing the residence time for the conversion of CO2 into CO.



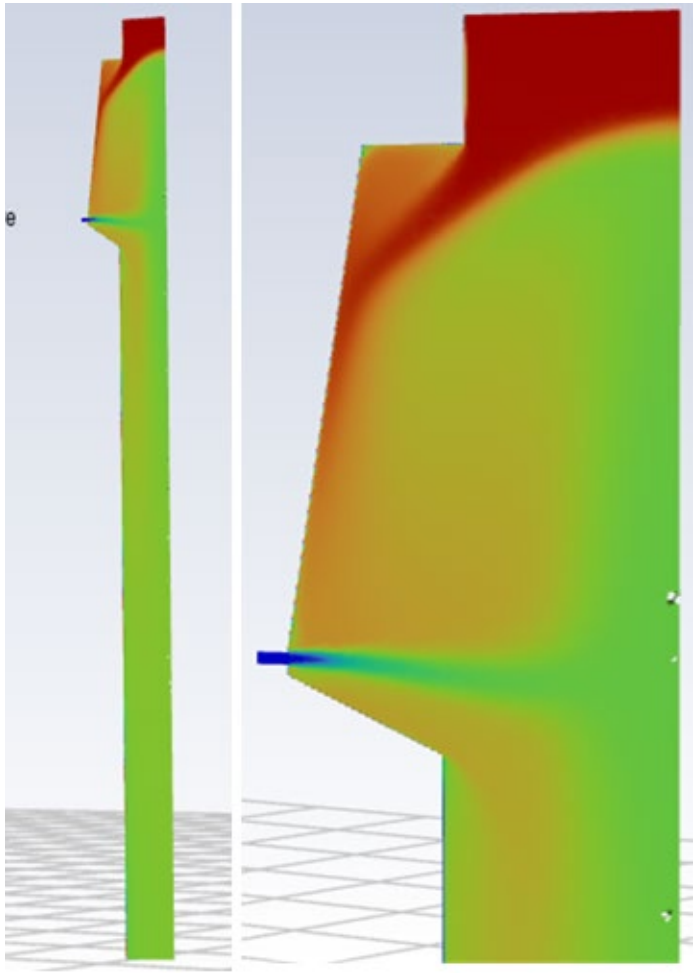
H2 Injection Simulation



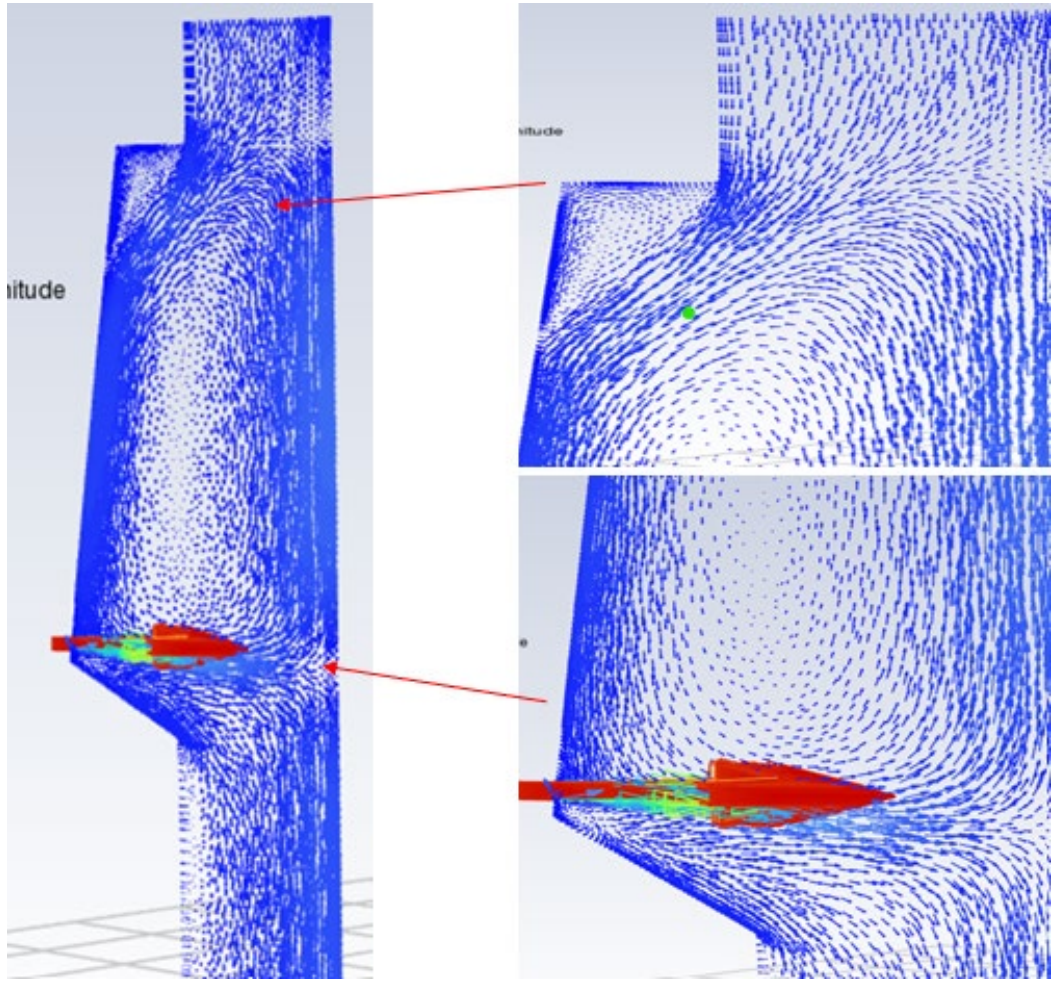
Total H2 injection nozzles at the end of the cone. 1/12th of the domain is simulated due to symmetry



CFD Simulation Results - 1

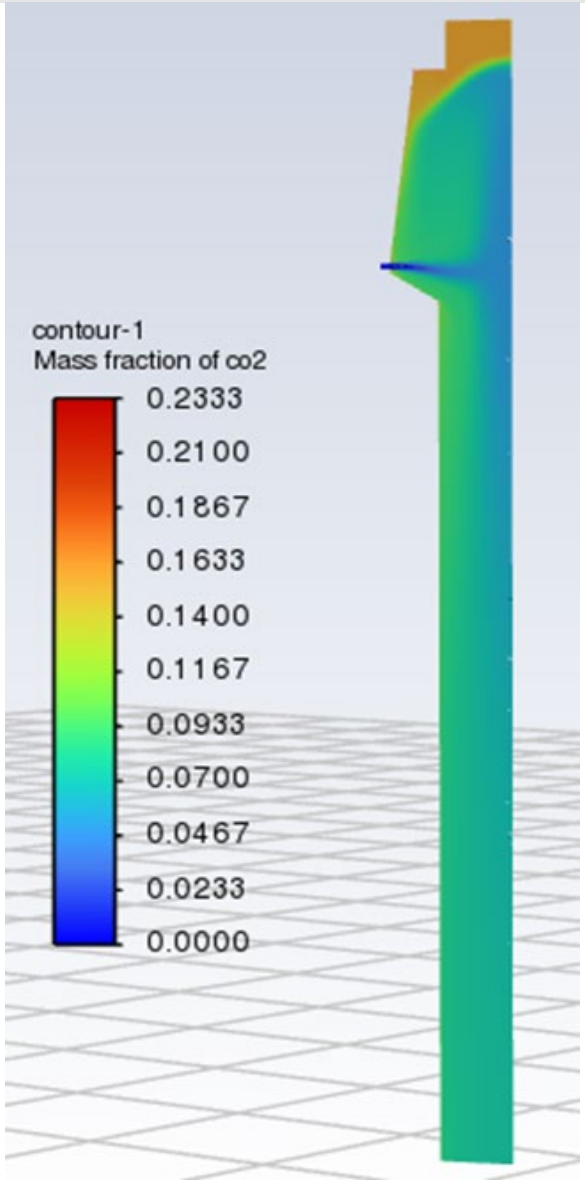


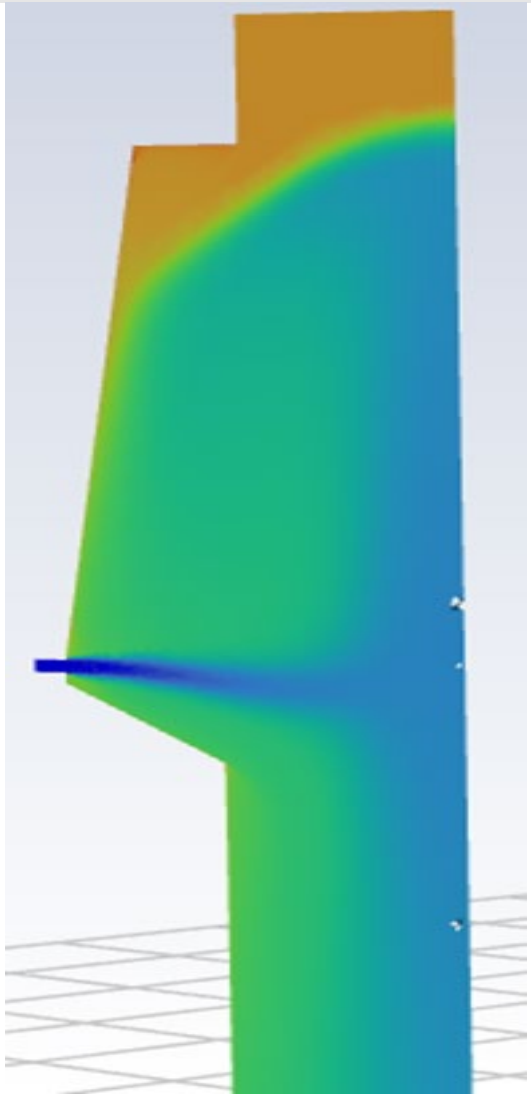
Temperature profile resulting from H2 injection and RWGS reactions

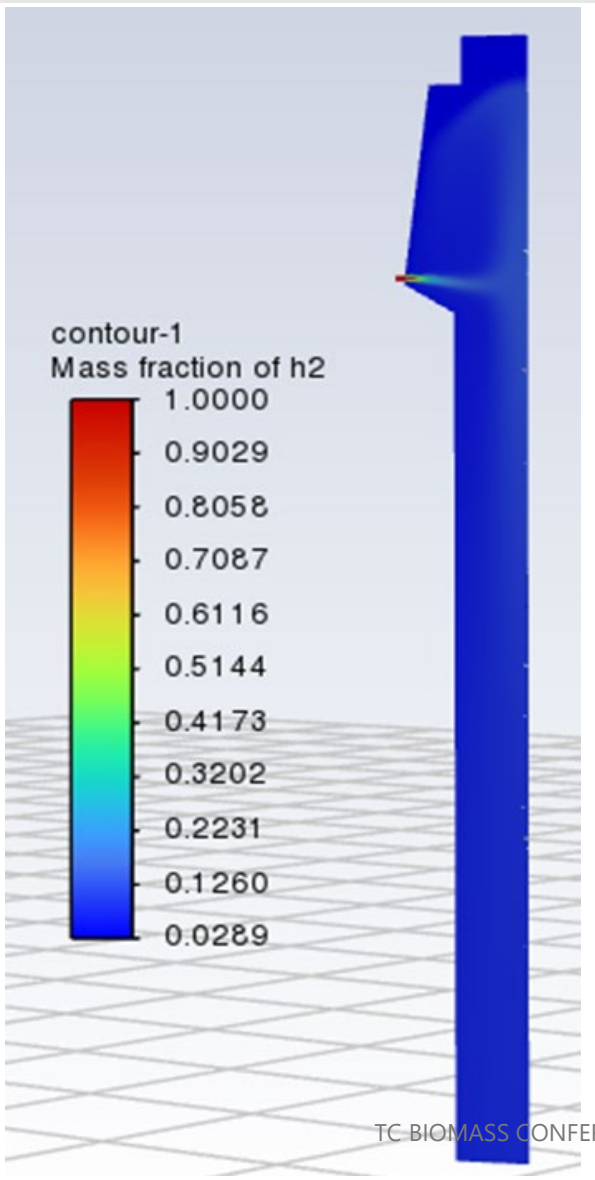


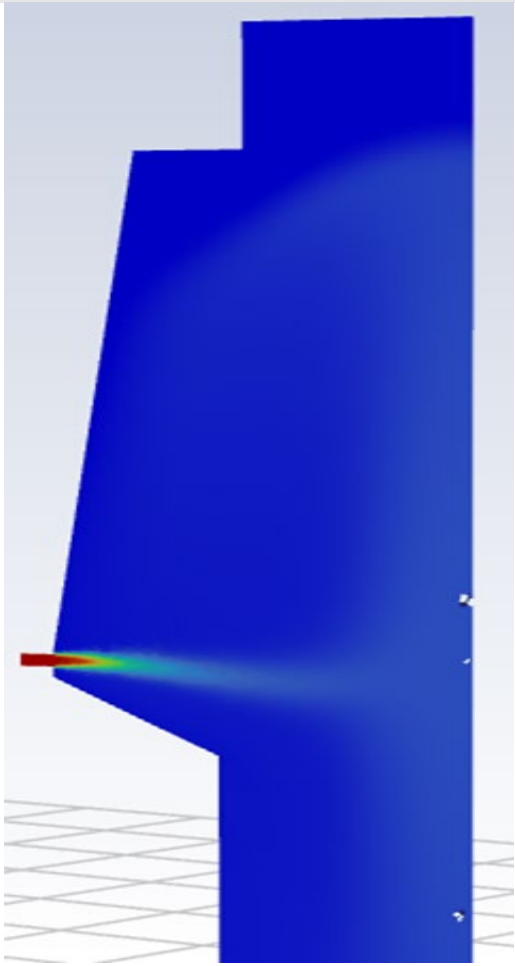
Field velocity vectors

CFD Simulation Results - 2



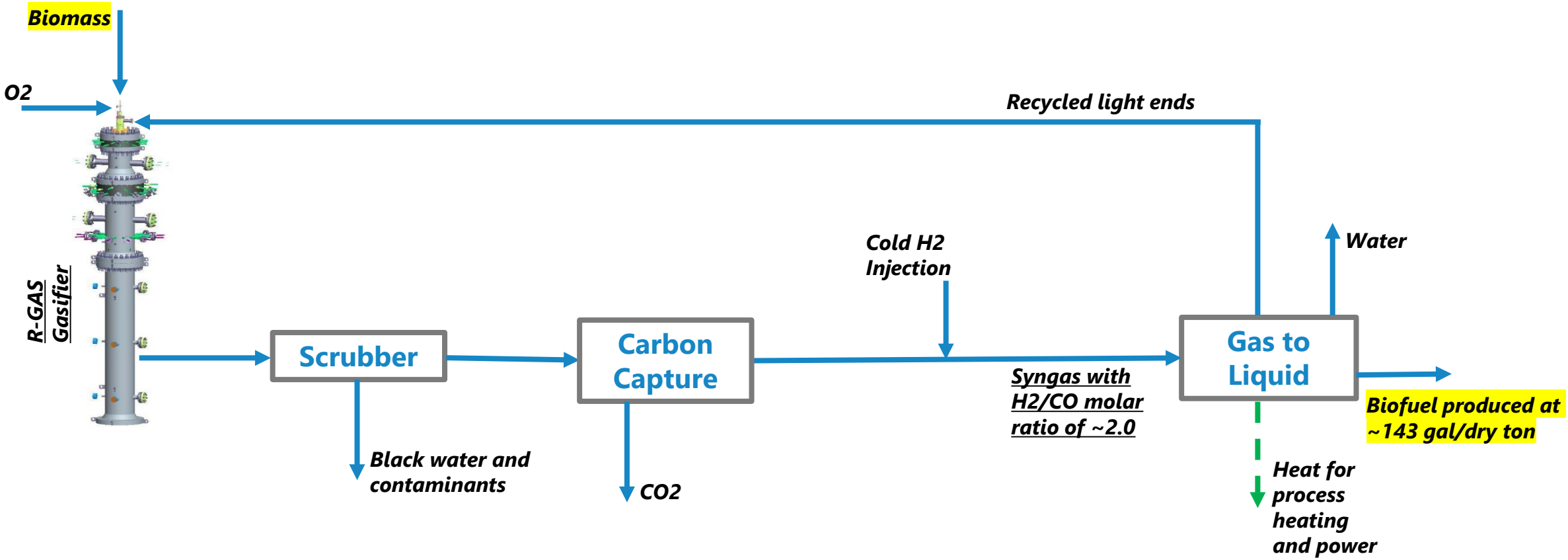






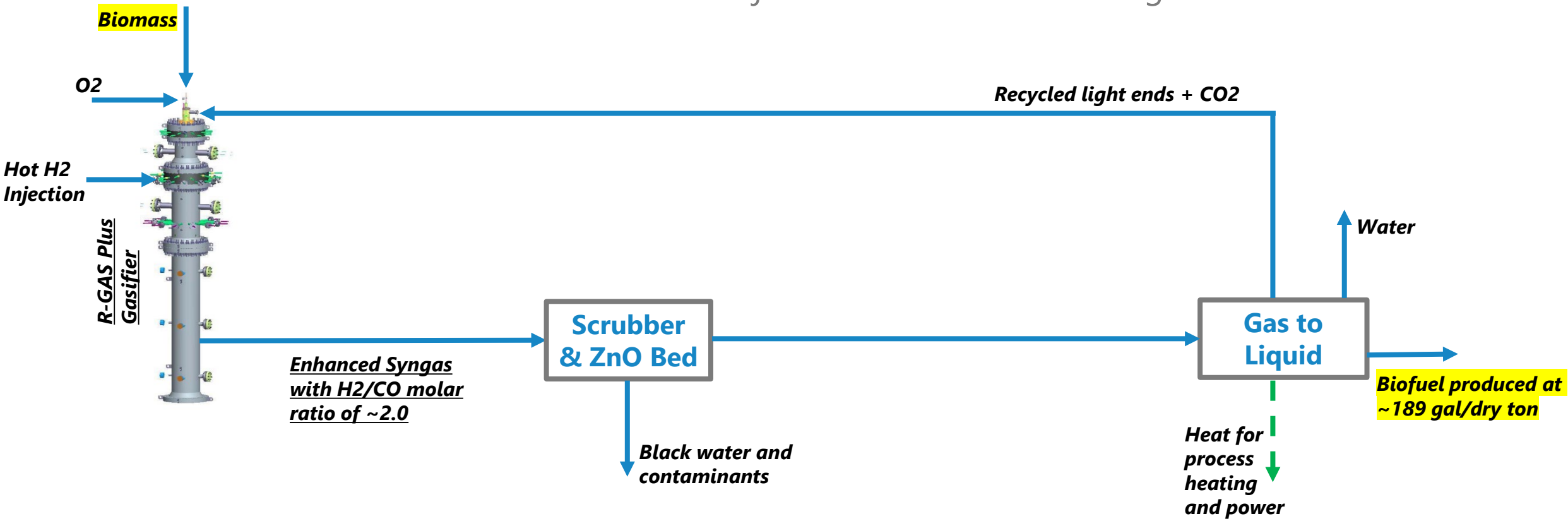
Biorefinery Performance: Standard Gasification + GTL Route

- H2 can be easily injected in front of the Gas to Liquid (GTL) block to adjust the H2/CO molar ratio as needed for the synthesis process.



Biorefinery Performance: Enhanced Gasification + GTL Route (R-GAS *Plus*)

- Process intensification by eliminating the Carbon Capture block → Lower CAPEX per barrel.
- FT light ends are recycled directly to the gasifier where they get reformed.
- The gasification process CO2 is reduced inside the gasifier vessel through non-catalytic RWGS reactions with hot H2 that is injected downstream of the gasification zone.



R-GAS *Plus* Economical Benefits

H2 @ $2/kg

R-GAS Standard

Raw biomass cost per ton	$	70.00
Installed Capacity (BPD)		2623
Total Installed Cost	$	716,091,784
TIC per BBL installed	$	273,014
Capital Charge factor		11.00%
Capacity Factor		90%
CAPEX per BBL	$	91.42
Total Opex Cost	$	106,677,254
OPEX per BBL produced	$	123.81
$/BBL produced	$	215.23
$/gallon produced	**$**	**5.12**
$/tonne produced	$	1,683

10.8% cost reduction

R-GAS *Plus*

Raw biomass cost per ton	$	70.00
Installed Capacity (BPD)		3475
Total Installed Cost	$	723,718,199
TIC per BBL installed	$	208,235
Capital Charge factor		11.00%
Capacity Factor		90%
CAPEX per BBL	$	69.73
Total Opex Cost	$	141,142,399
OPEX per BBL produced	$	123.63
$/BBL produced	$	193.35
$/gallon produced	**$**	**4.60**
$/tonne produced	$	1,512

H2 @ $1/kg

R-GAS Standard

Raw biomass cost per ton	$	70.00
Installed Capacity (BPD)		2623
Total Installed Cost	$	716,091,784
TIC per BBL installed	$	273,014
Capital Charge factor		11.00%
Capacity Factor		90%
CAPEX per BBL	$	91.42
Total Opex Cost	$	78,285,554
OPEX per BBL produced	$	90.86
$/BBL produced	$	182.28
$/gallon produced	**$**	**4.34**
$/tonne produced	$	1,425

15.5% cost reduction

R-GAS *Plus*

Raw biomass cost per ton	$	70.00
Installed Capacity (BPD)		3475
Total Installed Cost	$	723,718,199
TIC per BBL installed	$	208,235
Capital Charge factor		11.00%
Capacity Factor		90%
CAPEX per BBL	$	69.73
Total Opex Cost	$	96,192,153
OPEX per BBL produced	$	84.25
$/BBL produced	$	153.98
$/gallon produced	**$**	**3.67**
$/tonne produced	$	1,204

Development Needs for the R-GAS *Plus* Gasification Approach

- Refine commercial scale TEA.
- Build a cold flow model to physically simulate the H2 injection.
- Implement specialized injection lances and retrofit the existing R-GAS pilot reactor to enable H2 injections right at the exit of the gasification zone.
- Conduct a 500-hours pilot demonstration of the gasifier with H2 injections according to a very carefully developed test plan.

GTI Energy develops innovative solutions that transform lives, economies, and the environment