Breakthrough Hybrid CTL Process Integrating Advanced Technologies for Coal Gasification, NG Partial Oxidation, Warm Syngas Cleanup and Syngas-to-Jet Fuel

DOE/NETL Cooperative Agreement DE-FE0023592

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Jet Fuel from Coal and Natural Gas

The use of coal to generate jet fuel is beset by two key issues:

- the fundamental chemical difference between coal and the jet fuel it generates and
- the high equipment cost associated with the complicated conversion process.

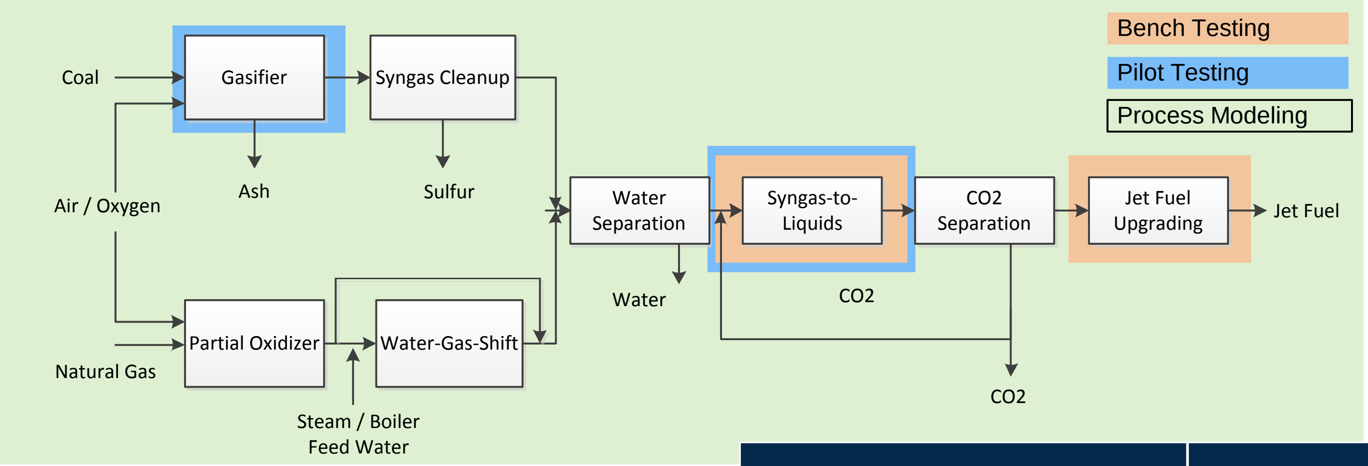
Conventional CTL plant requires ~84% of the non-fuel carbon to be captured to meet EISA 2007 §526 requirements.

- Conventional coal-to-liquid (CTL) processes generates an intermediate syngas high in CO and relatively low in H_2.
- Adjusting the H_2:CO requires reacting a significant portion of the CO within the coal-derived syngas with steam in a water-gas-shift conversion reactor to produce hydrogen.
- This imposes significant parasitic efficiency loss to the overall process while simultaneously generating CO_2 as a by-product.

An alternative is to use natural gas to generate a hydrogen-rich syngas that can subsequently be blended with the CO rich syngas obtained from coal gasification to achieve the desired H_2:CO ratio needed for jet fuel production.

Overview

Breakthrough hybrid coal-to-liquids process integrating several emerging technologies and adapting some commercially available technologies to produce cost-competitive jet fuel.

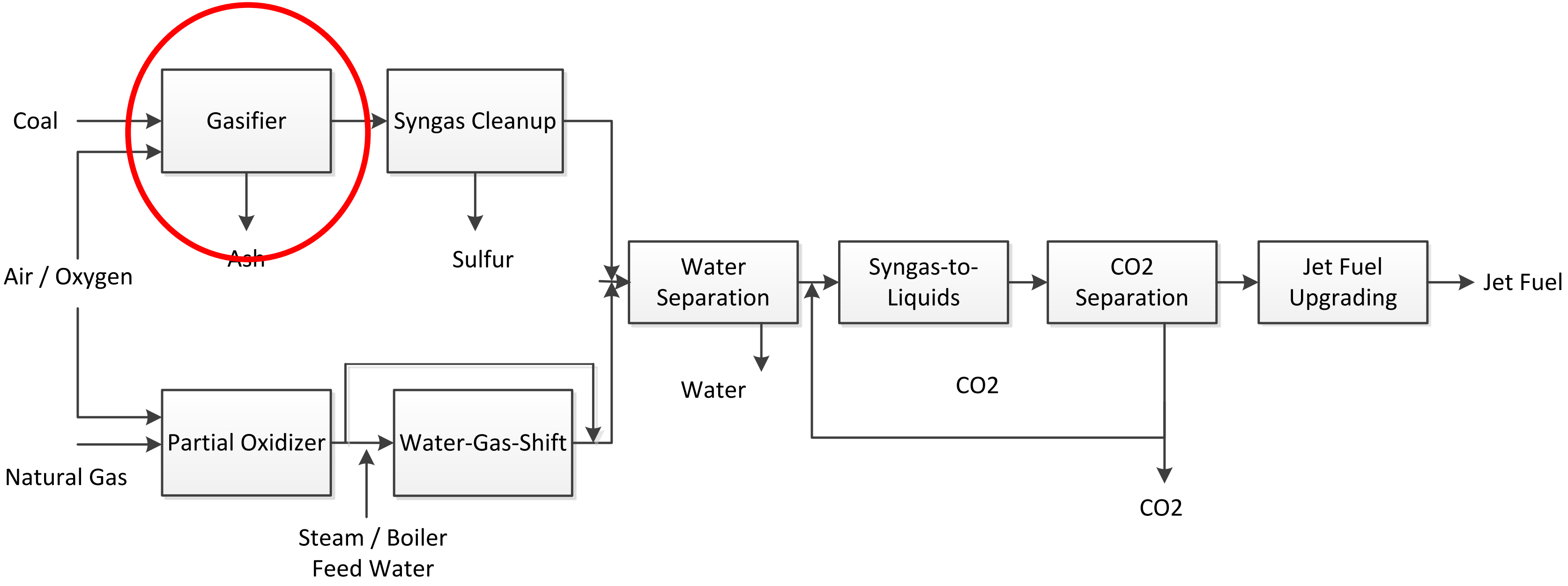


Development Team
- RTI International
- GTI

- GTI Compact Gasification System
- GTI Partial Oxidation Unit
- RTI Warm Syngas Cleanup
- Syngas-to-Liquid System
- Axens Hydroprocessing Technology

Technology	Benefits		
	Cost of Electricity Reduction	Thermal Efficiency Improvement	Capex Reduction
Advanced gasification with dry feed (AR)	>15%	7-10% (Cold gas)	23%
Warm syngas Cleanup (RTI)	5-10 %	>3% (HHV)	10-15%
Cumulative Impact	20-25%	7-8% (HHV)	33-38%

GTI Compact Gasification System



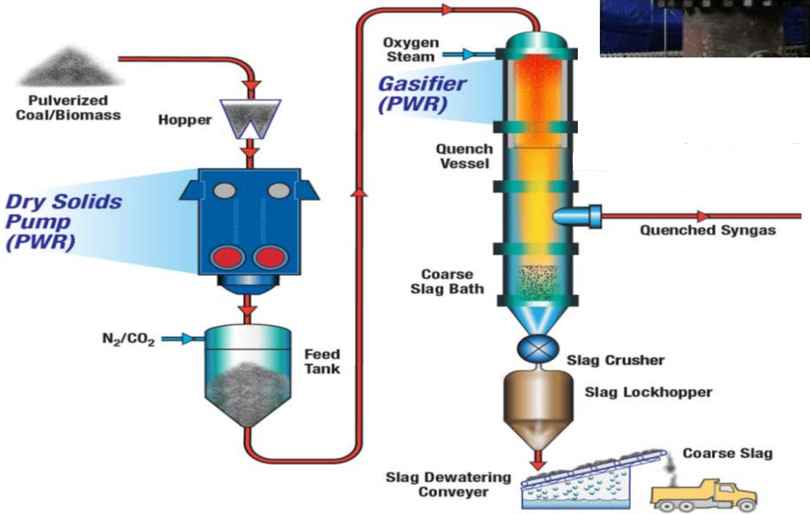
GTI Compact Gasification System

Compact Gasification System

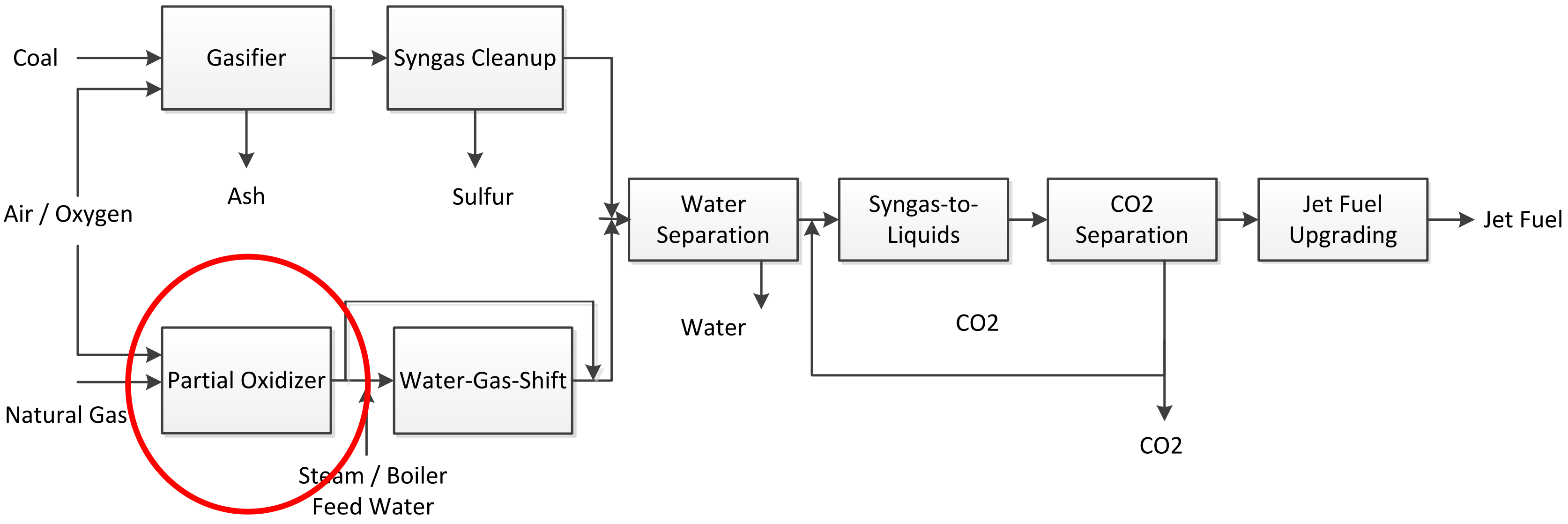
- 90% reduction in gasifier volume
- Cold gas efficiency improvements
  - 7% - 10% versus water slurry feeders
  - 2% - 4% versus dry feed systems
- Gasifier surface temperatures of 1000°F
  - >2 year life injectors (< 4 months GE injectors)
  - >10 year life cooling liner (1-3 year for refractory)
- Dry ash recovery eliminates black water collection system and waste water treatment requirements.
- >15% lower cost of electricity for IGGC
- >25% lower cost for hydrogen

PWR's Dry Solid Pump

- 32 GWh/y reduction in lock hopper power requirements (3000 tpd plant)
- Demonstrated performance with both coal and coal/biomass mixtures

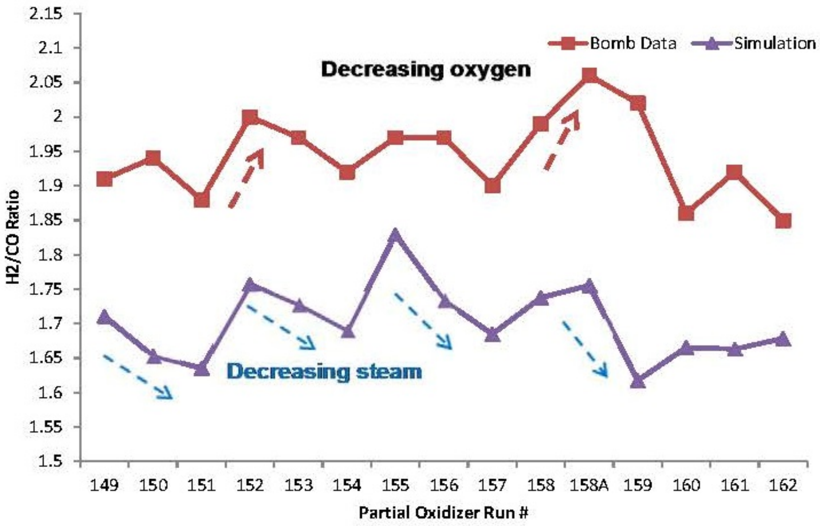


GTI Partial Oxidation Unit

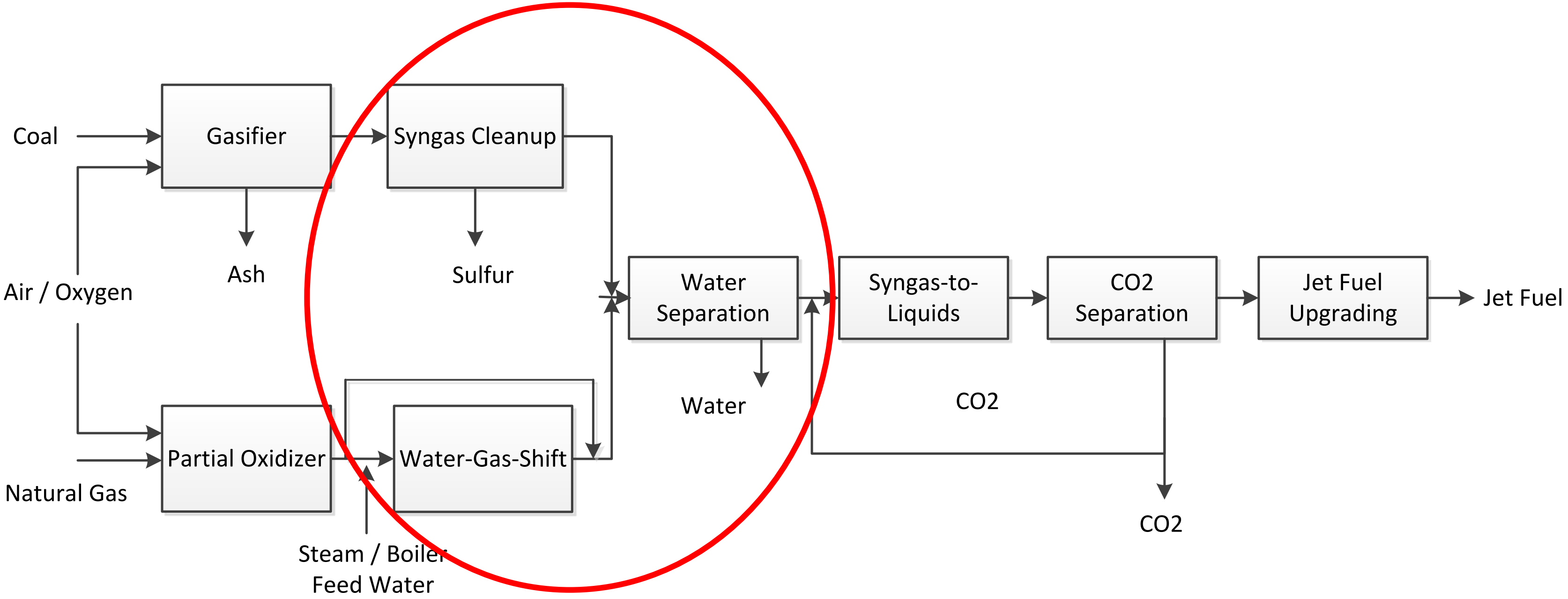


GTI Partial Oxidation Unit

- Developed with a focus on distributed gas-to-liquid production (~1,000 BPD)
- 80 hours of pilot scale (~450 MSCF/day NG feed) POX unit testing was performed in 2013
  - Validated performance and design approach
  - Demonstrated the ability to directly yield syngas with H_2:CO molar ratios near 2.0
  - Potential to eliminate the need for downstream water-gas-shift reactors
- Designed and fabricated a prototype POX unit
  - Incorporating burner element and cooled liner designs
  - Support testing of the POX unit with natural gas using either oxygen or air.
  - Designed to enable recycle of byproduct and/or wastewater streams to the unit
- POX technology offers the potential to reduce GTL plant capital cost by 10-15%.



RTI Warm Syngas Cleanup Technology Platform



RTI Warm Syngas Cleanup Technology Platform

RTI PILOT PLANT TEST UNITS AT EASTMAN COAL GASIFICATION PLANT

Sulfur
- Regenerable ZnO sorbents
- Transport reactor
- Direct Sulfur Recovery Process

Regenerable NH_3/HCN adsorbents

Hg adsorbents (disposable)

As adsorbents (disposable)

Se adsorbents (disposable)

HCl adsorbents (disposable)

Regenerable CO_2 sorbents

PRE-COMMERCIAL DEMO PROJECT w/CC UNDERWAY AT TAMPA ELECTRIC SITE

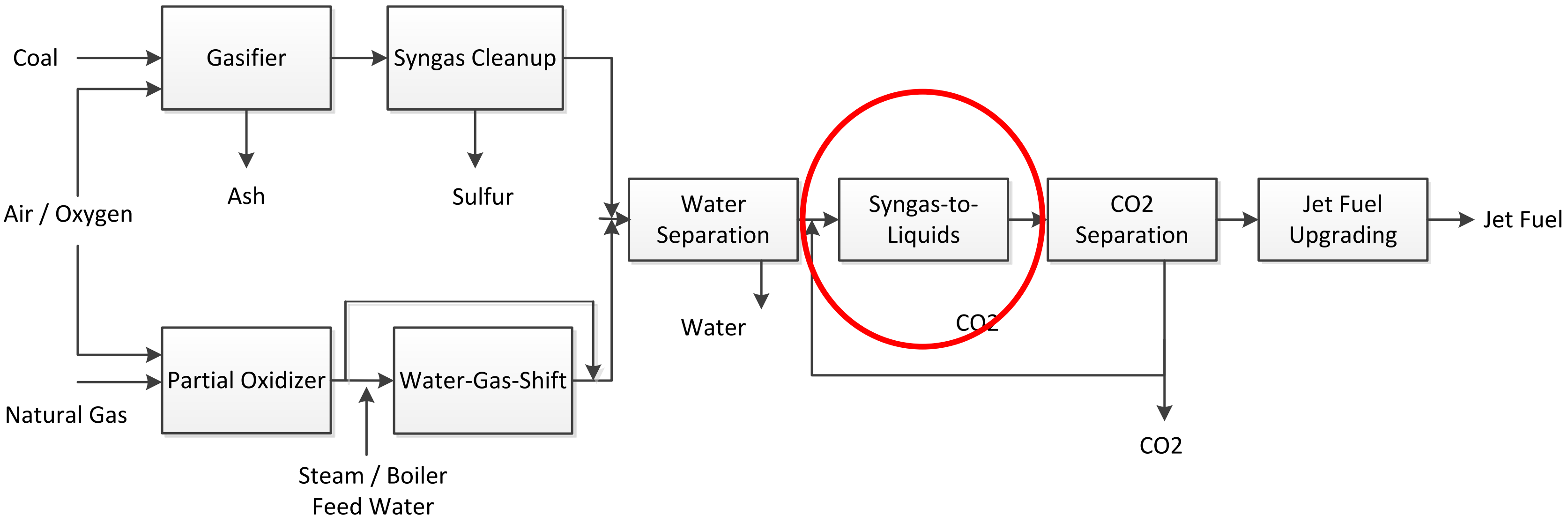
- Enhance overall process efficiency and lower costs by operating at temperatures of 250ºC to 600ºC with small footprints!
- Pressure independent
- Effective for all forms of sulfur
- Fully compatible with conventional and warm CO_2 capture

- Flexible modular approach meets:
  - New EPA electric power generation specifications
  - Industrial production specifications
- Systems tested on actual coal-based syngas
- 50-MWe demo project with carbon capture at Tampa Electric's Polk 1 IGCC site

RTI's Warm Syngas Desulfurization Process

- Construction was achieved on schedule and under budget.
- >500,000 total labor hours with no injury other than minor first aid.
- RTI WDP unit has consistently been able to reduce inlet total sulfur content from as much as 14,000 ppmv to ~10 ppmv (~99.9% total sulfur removal).
- Downstream clean syngas exiting the carbon capture block has consistently been < 0.5 ppmv (>99.99% total sulfur removal).
- Sorbent attrition rate has been in line with design expectations.
- Sorbent sulfur capacity has been steady - no sign of deactivation.
- Unit has successfully operated both below and above design rate.
- Achieved 3500+ total syngas operation hours
- Signed sorbent commercialization agreement with a global supplier
- **Casale SA and RTI have signed a global licensing and cooperation agreement**

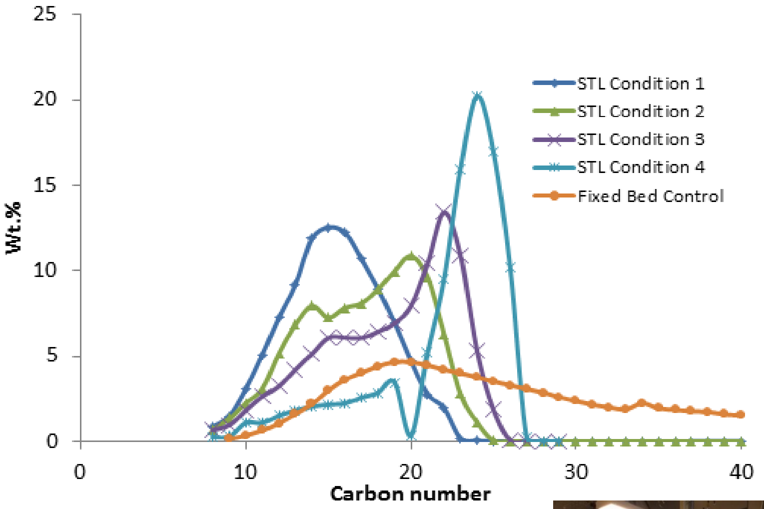
Syngas-to-Liquids System



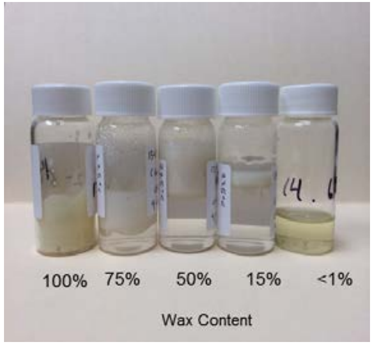
Syngas-to-Liquids System

RTI is developing an STL process with the following features:

- Produces a targeted narrow carbon range distributions of fuel products
- Achieves heat management through reduced reactant partial pressure
- Utilizes commercial and emerging F-T catalyst compositions



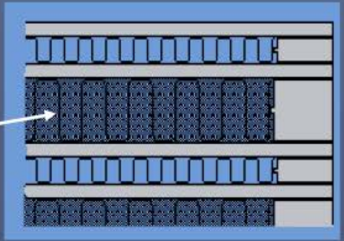
Single pass CO conversion efficiencies of over 60% with selectivity to C_8-C_{18} liquid products of 65% have been achieved.



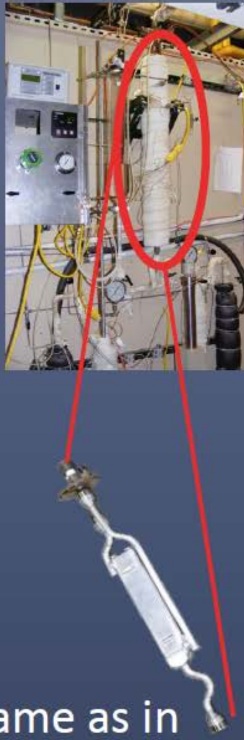
Compact/ Heat Exchange FT Reactor

EX: Compact FT Reactor

Reactant side (packed w/ cat)

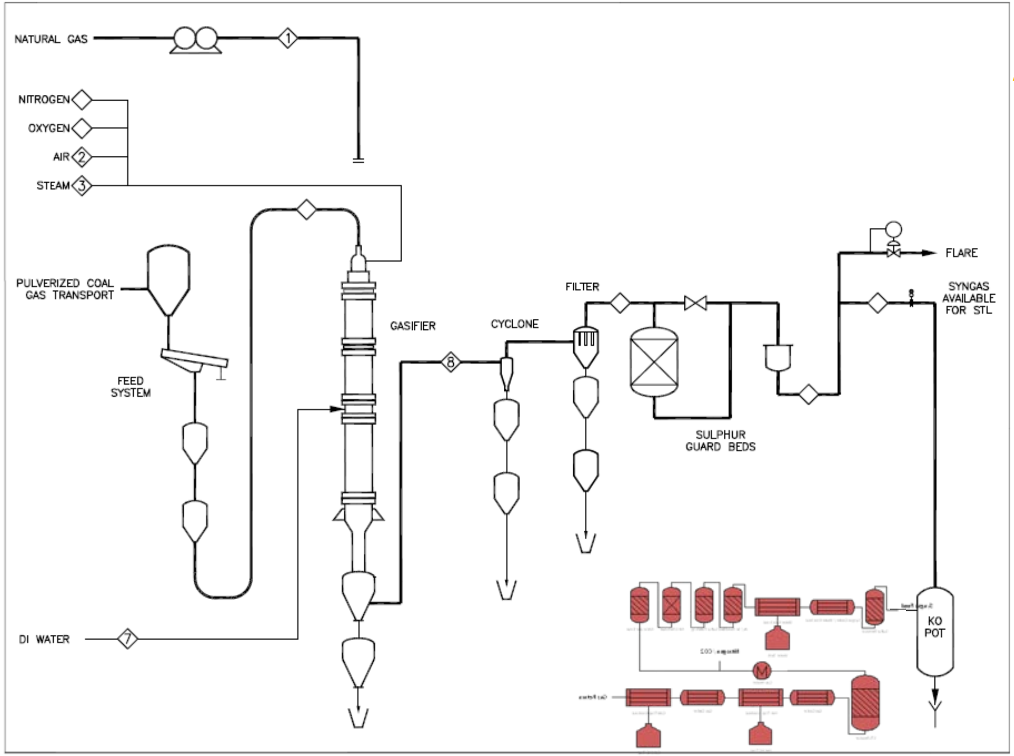


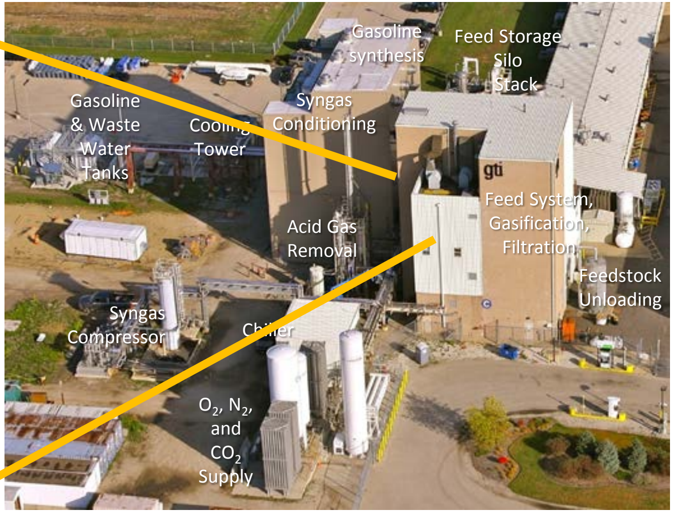
Coolant side



4 feet long reactor can reach the conversion same as in 40 feet long conventional tubular reactor

1 BPD Pilot Plant Testing with Syngas at GTI





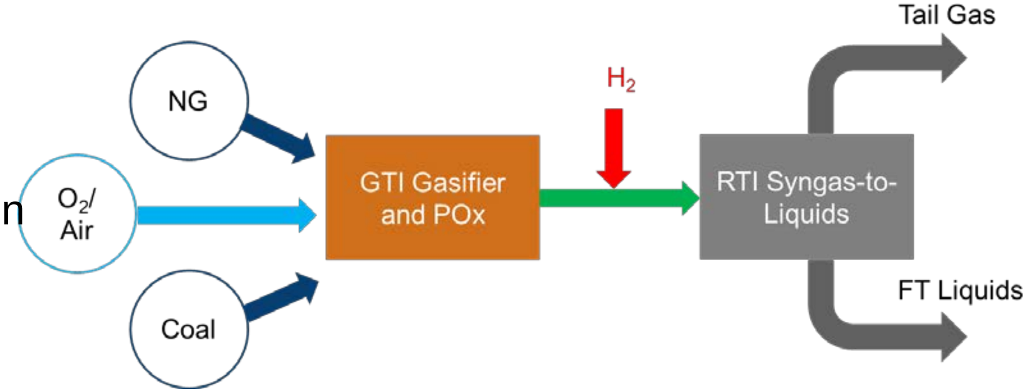
GTI's Gasification Pilot Plant

STL Pilot Demonstration at 1BPD

Syngas generated from natural gas or coal feed for testing STL skid.

Air-blown system simulated with nitrogen addition.

Syngas composition adjusted with hydrogen addition.



Syngas Composition

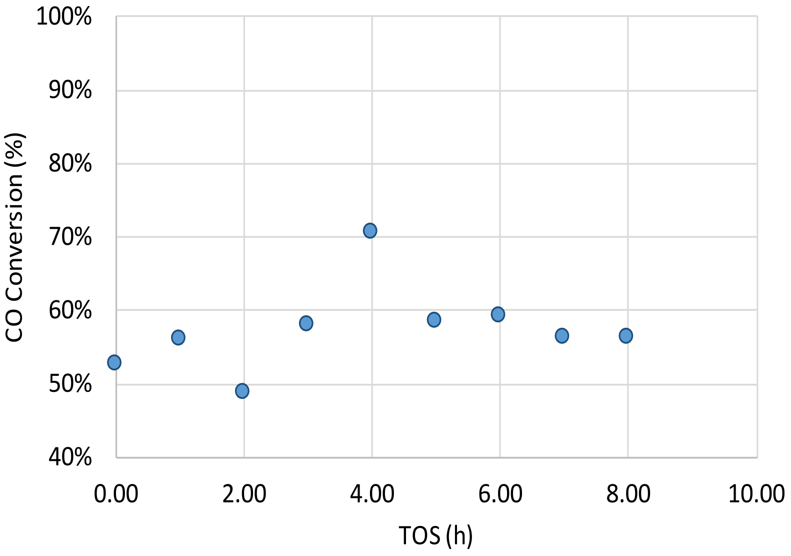
$H_2/CO = 2.1$ $CO_2 = 2.0$ vol.% $N_2 = 10$ to 60 vol.%

Data Acquisition Point #	Feed Flow (scfh)	N_2 Dilution	STL Temp. (C)	STL Press. (psig)	Space Velocity
DAP 1: O_2-blown POx	2500	No	230	300-330	Low
DAP 2: Air- blown POx	2500	Yes	220	300	Low
DAP 3: Increased Space Velocity	2500	Yes	218	300	High
DAP 4: Sim. Air-Blown PRB coal	2500	Yes	214	300	High
DAP 5: O_2-Blown PRB coal	2500	No	218	300	High

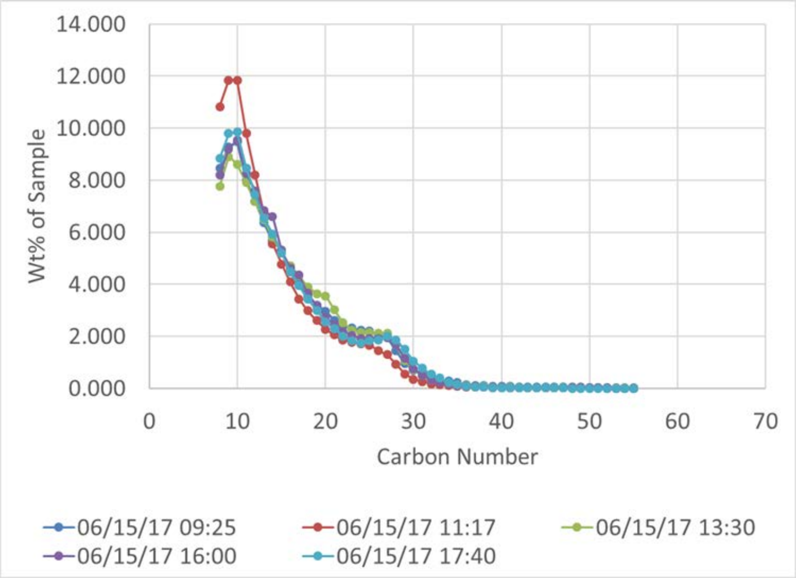
STL Pilot Demonstration at 1BPD - Results

STL skid was tested over two test campaigns at GTI's Flex Fuel Facility.

- ~80 gallons product
- CO conversion : 50-70% (Single Pass)



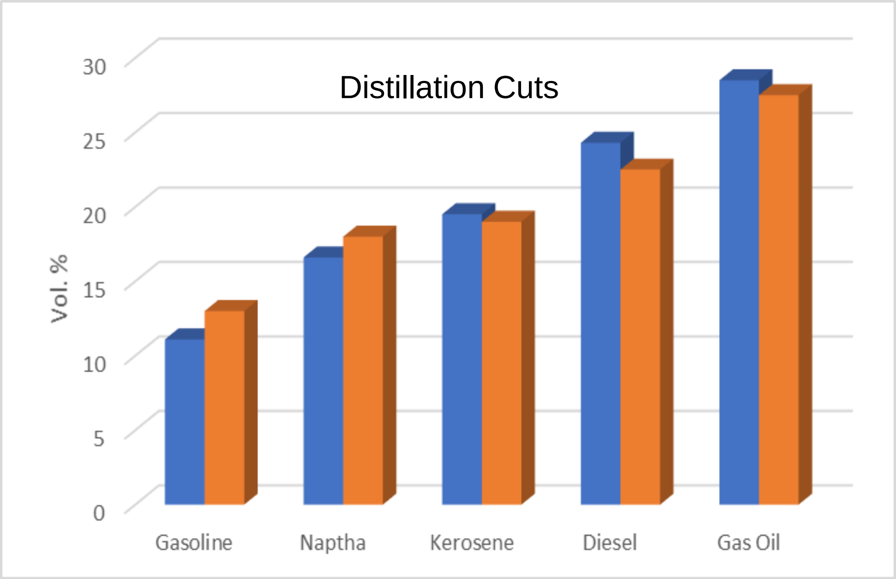
Example conversion data from 1 data period

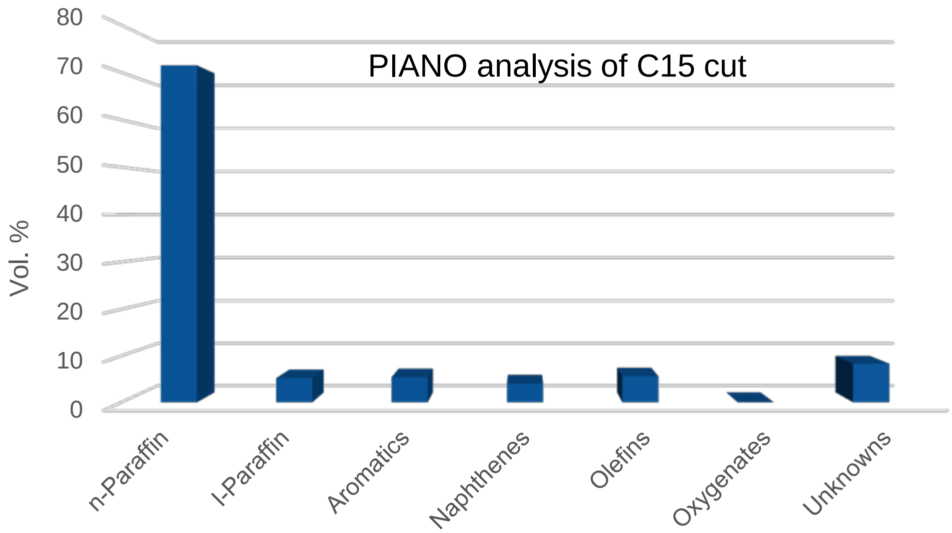


Example liquid product from 1 data period

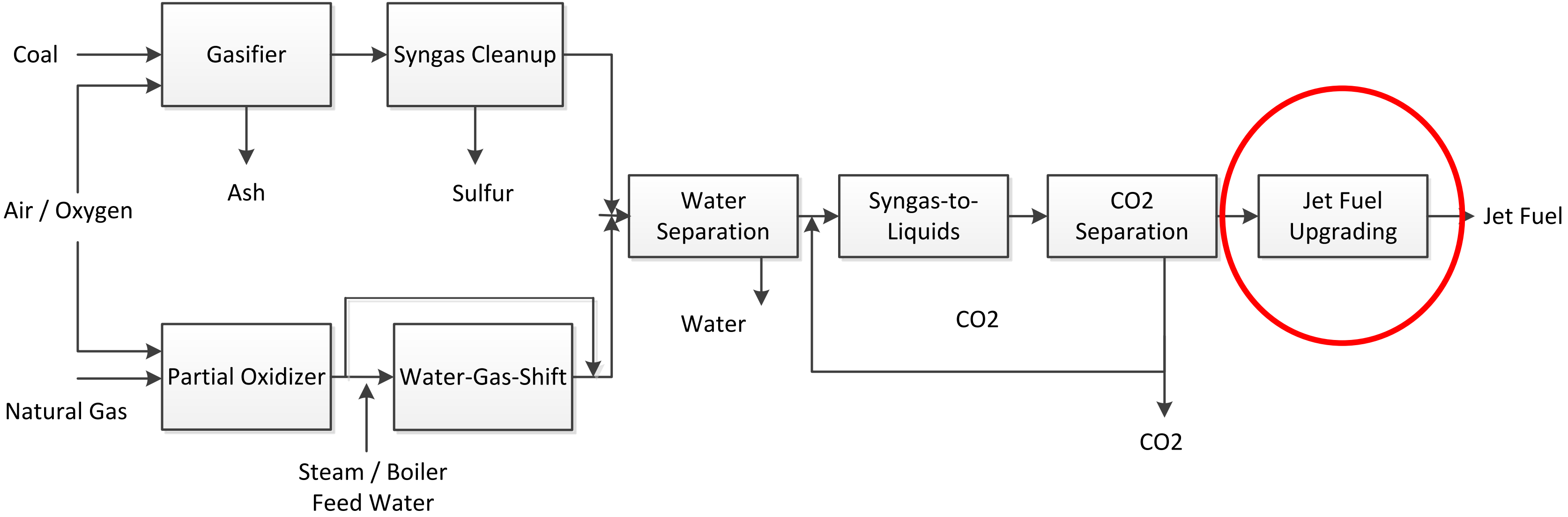
STL Pilot Demonstration at 1BPD - Liquid Product Characterization

FT-crude produced from advanced STL process is low wax product, ready for simple upgrading to finished fuels.





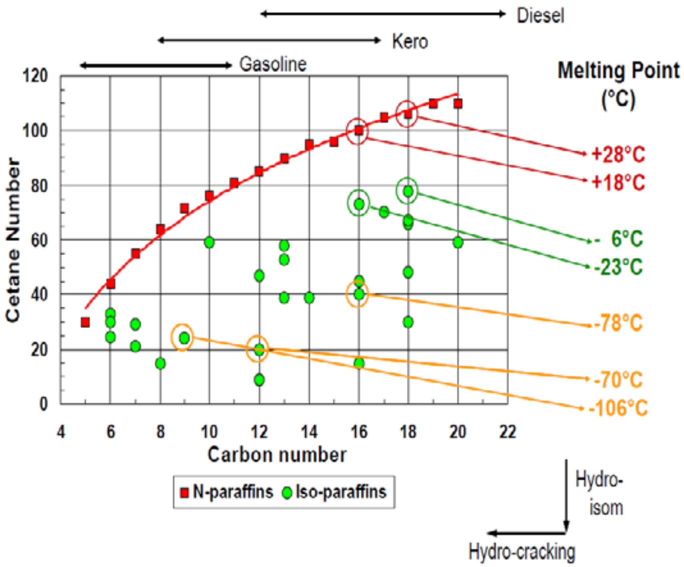
Axens Hydroprocessing Technology



Axens Hydroprocessing Technology

Initial upgrading assessment of the produced FT liquid was performed by Axens.

- All properties indicate suitability for upgrading to fuel with emphasis on jet fuel
- Lower than average oxygenates reduce H_2 demand
- Higher than average aromatic content adds some uncertainty to the modeling



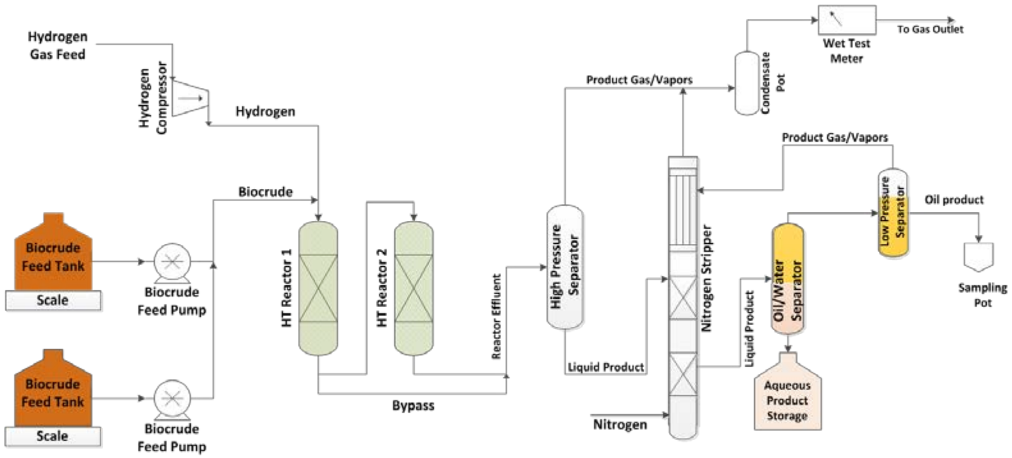
Property	Typical Vegan Jet Product
Density, kg/m3	766
D86 T10, ºC	169
D86 FBP ºC	272
Freezing point ºC	-57
Flash point ºC	68

Axens' technologies have been developed to ensure:

- Minimum production costs by careful balancing of the hydrotreatment reaction pathway (hydro-isomerization vs hydro-cracking).
- Minimum impact of CO/CO_2 inhibition
- Fine tuning of product cold flow properties
- Superior fuel stability in operation

RTI Hydroprocessing Capabilities

Bench-scale testing is being used to validate commercial catalyst performance with the produced FT product.

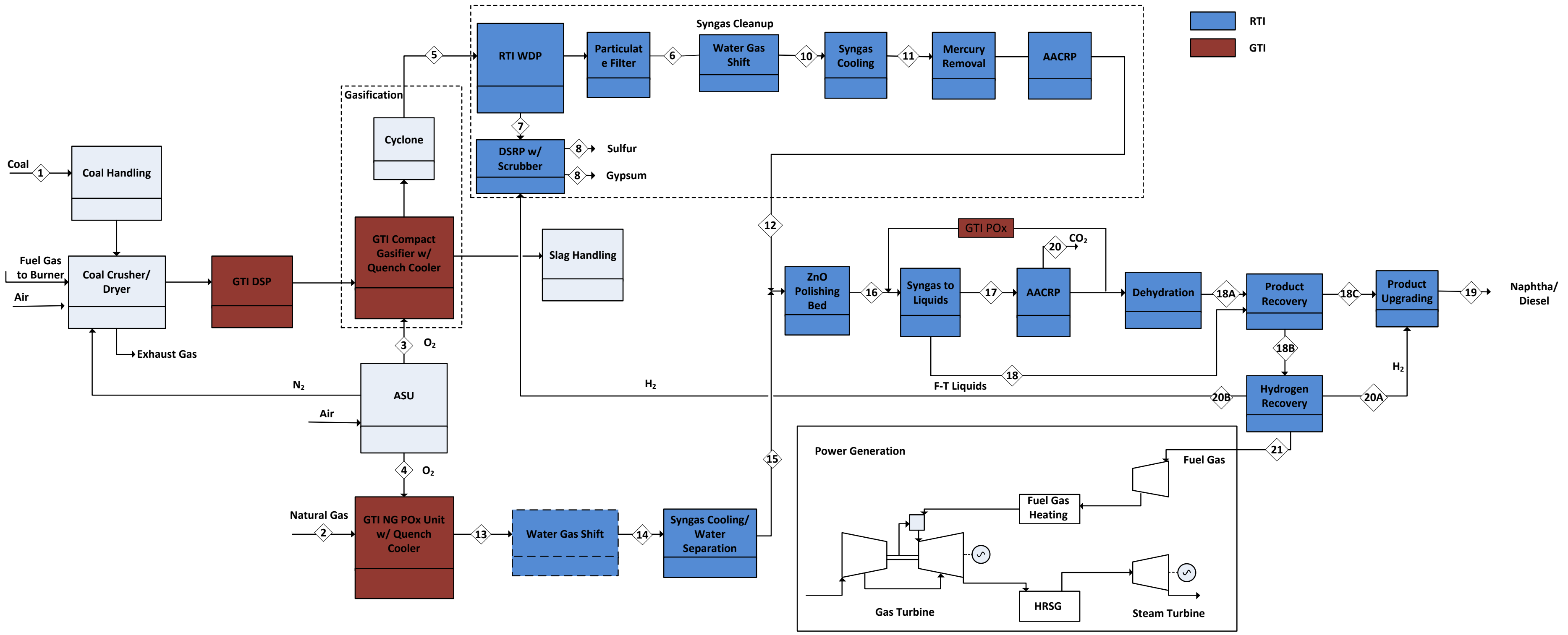


Simplified HDT Unit Process flow Diagram

Unit Details

- Reactor volume - 350 mL
- Catalyst volume - 20 to 250 mL
- LHSV - 0.1 to 1.0
- Flow rates - 50 to 250 mL/h
- N_2 is used as the stripping agent
- Maximum design pressure of 3000 psig
- Maximum design temperature of 450° C

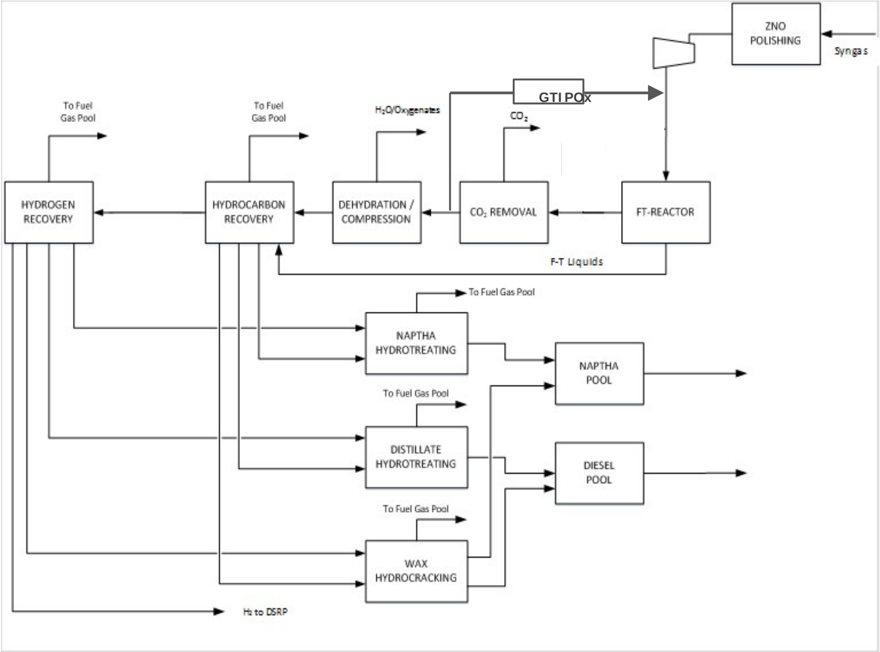
Updated TEA – Revised PFD of the CTL Process



Fischer Tropsch Process Modeling based on Pilot Testing Results

- Pilot testing data was used to model the FT process

Reaction Conditions	Pilot Performance Data
Temperature- 218°C Pressure- 300 psig Feed H_2/CO- 2.11 Pressure Drop- 1.5 bar	CO Conversion- 72.7% Product Selectivity CO_2 Selectivity- 4.3% CH_4 Selectivity-20.1% C_2 Selectivity-1.4% C_3 Selectivity-1.0% C_4 Selectivity-0.8% C_5 Selectivity-0.9% C_{5+} Selectivity-71.7%



- The FT-liquids collected in the product fractionator were separated into three liquid streams:

Naphtha	C_5 saturates to 350°F (177°C)
Middle Distillate	350°F - 650°F (177°C - 343°C)
Wax	Greater than 650°F (343°C)

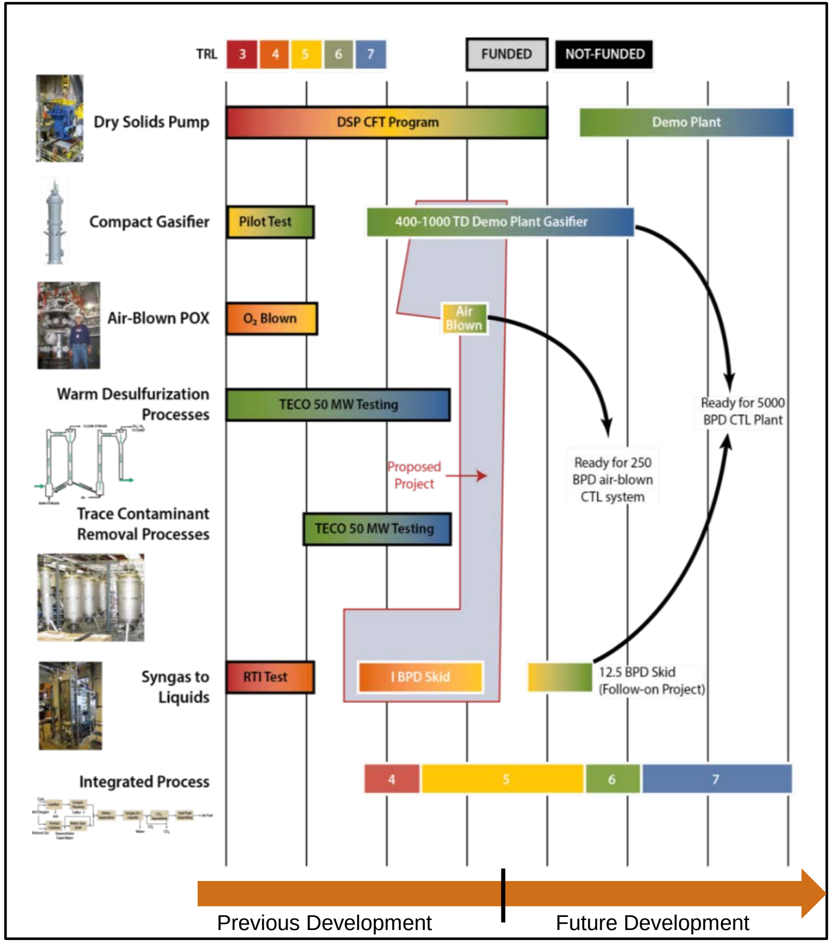
- Commercial partners will provide the capital costs estimates and performance data for the product upgrading block.

Comparison of Technology Cases

	Reference Plant[1]	Advanced Plant
Syngas Generation		
Shell Gasifier with lock-hopper-based feed system	✓	
GTI Compact Gasifier with a Dry Solids pump		✓
Natural Gas POx		✓
Gas Cleanup		
Rectisol	✓	
RTI WDP with AACRP		✓
Water Gas Shift		
Sour Shift	✓	
Advanced RTI Sweet Shift		✓
Fischer-Tropsch Synthesis		
Commercially available technology	✓	
RTI Advanced STL technology		✓

[1] "Cost and Performance Baseline for Fossil Energy Plants, Volume 4: Coal-to-Liquids via Fischer-Tropsch Synthesis," DOE/NETL-2011/1477, Oct 2014

Path to Commercialization

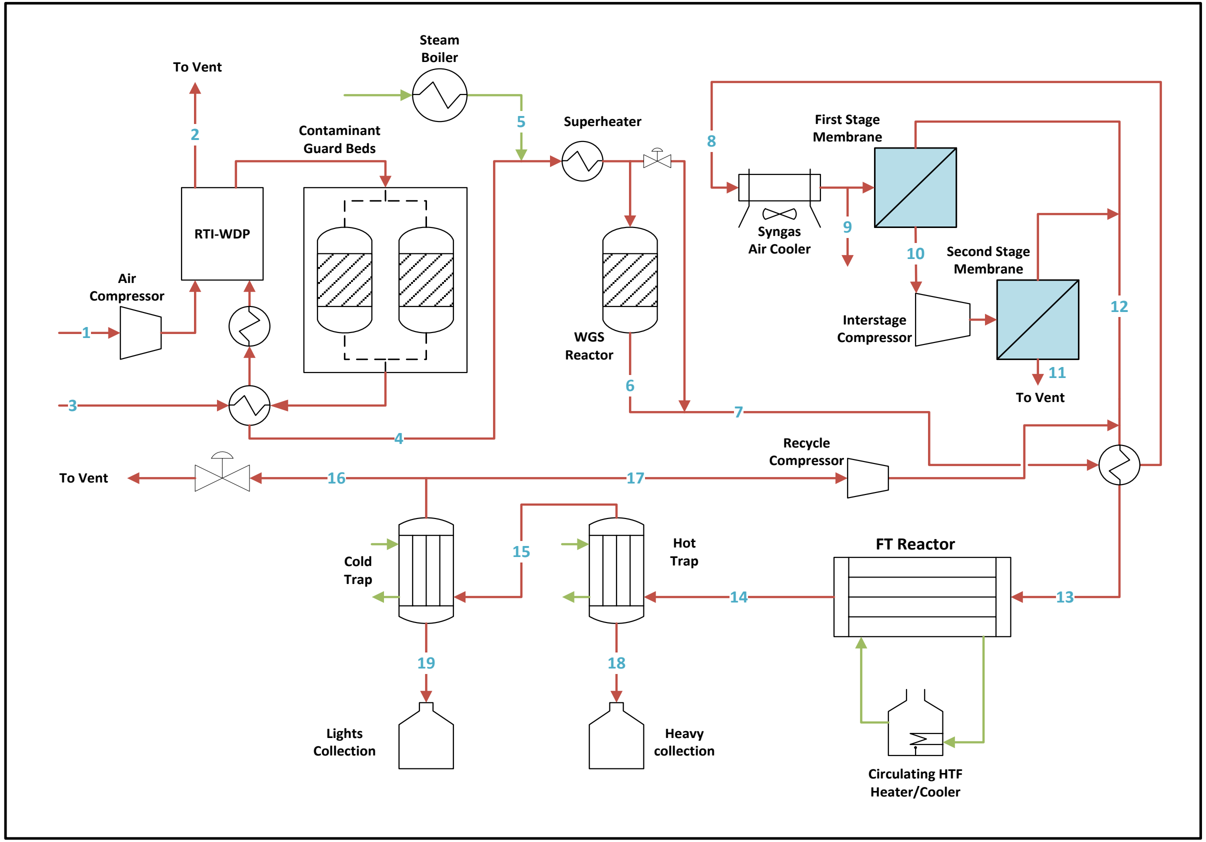


- Developing a commercialization plan for the deployment of the hybrid CTL process within the next 5 to 15 years
- One of the key activities is developing a plan for the design, construction, and operation of a 12.5 BPD commercial-scale modular STL reactor
  - Leverages existing gasifier equipment to complete approximately 30 days of testing
  - Develop a budgetary estimate to implement this plan
- Develop plans for the demonstration of the hybrid CTL technology at >250 BPD

12.5 BPD Commercial-Scale Modular STL Reactor

- Developed testing objective for the 12.5 BPD unit
- Completed detailed design of the commercial-scale unit
- Obtained budgetary estimate for the detailed engineering, fabrication, and construction of the STL unit
- Estimated 50 week of completion

	Syngas Composition, vol%	
	Dry	Wet
H_2	23.7	12.3
CO	41.6	21.7
CO_2	16.4	8.5
CH_4	0.15	0.08
COS	0.03	0.02
H_2S	0.21	0.11
N_2	18.0	9.4
H_2O	-	47.9



Technology Status

- Leveraging advanced technologies drive down production cost of fuel from coal and natural gas feedstocks.
  - Demonstrated STL at 1 BPD and verifying upgrading
  - Refining economic cost models for technology integration
- GTI currently seeking commercialization opportunities for the compact gasifier and POx technology platforms.
- RTI WDP technology commercially available through licensing agreement with Casale SA.
- Technologies provide potential for smaller-scale systems and opportunities for small-scale applications are sought.

Acknowledgements

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