Enabling Small-Scale Biomass Gasification for Liquid Fuel Production

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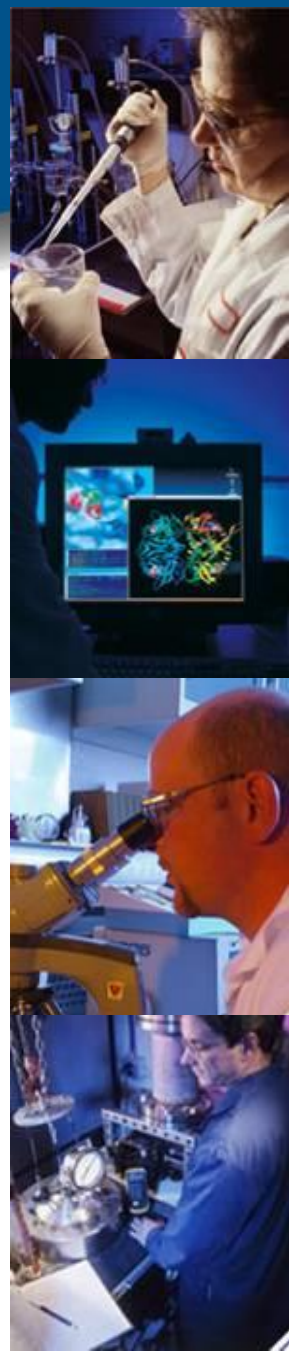
SOUTHERN RESEARCH INSTITUTE

Southern Research Institute

- Established in 1941 as an independent, not-for-profit (501-c-3) center for scientific research and development
- Headquartered in Birmingham, Alabama; 8 locations in Southeastern US; 500 employees
- Serves both Government and private industry clients
- Revenue ~$80 million from contract research/services and licensing of IP derived from internal technology development
- Research divisions:
  - Engineering
  - Drug Discovery
  - Drug Development



Environment and Energy Group
Durham, North Carolina

- Established in 2007 for alternative energy-related process research (biomass, coal, solar, waste heat) with a $30+ million investment
- Conducts lab, bench and pilot scale R&D/technology development
- Also provides contract services to private technology developers
- Capabilities include a 30,000 ft^2 high bay pilot plant, complete lab facility for process development, full interconnects, 50+ experienced PhD/MS/BS engineers and operators, 24/7 operations, Autocad and Aspen Modeling
- Pilot plant experience >30,000 hrs




Thermochemical Conversion via Gasification: Barriers and Continuing R&D Goals

- Large scale gasification and gas to liquids are commercialized for specific applications;
- Large scales don't match biomass availability, feedstock logistics, product usage
- For biofuels, can this be done at small scale?
- Focus R&D on:
  - Process Intensification
  - Reducing CAPEX and OPEX
  - Economic optimization for whole system (feedstock through product use)
  - Scale and technology that allows economic utilization of local feedstock and local product usage

Advantages and Barriers for Small Distributed Scale Gasification-FT Based Biorefineries

Advantages

- Low capital investment and associated risks
- Feed flexibility (e.g. biomass/coal/waste) and product flexibility
- Reduced feed transportation costs and infrastructure requirements
- Biomass gasifiers proven at small scales
- FT synthesis is leading/proven syngas conversion technology

Barriers Addressed by Projects at Southern Research

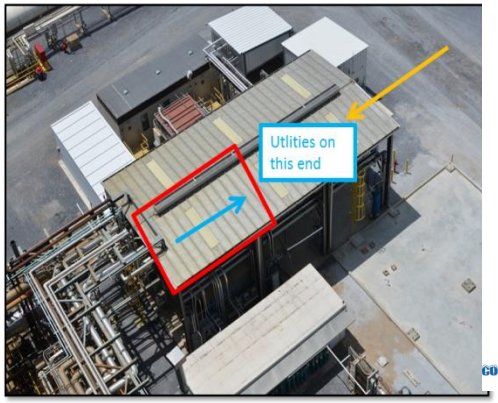
- Economy of scale—low cost gasifier, process intensification
- Mixed solid fuel feeding—piston plug high pressure feeder
- Syngas cleanup/upgrading—sulfur tolerant reforming catalyst
- Non-selective FT product slate—selective/active wax free catalyst

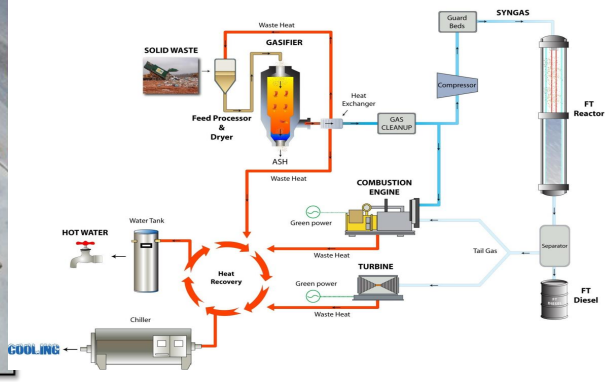
Example Projects

- **Lab-Scale Projects**
  - Solvent-based liquefaction of biomass
  - High temperature syngas reforming
  - Thermochemically-enabled solar energy storage
  - Hydrogen separation using membranes
- **Bench-Scale Projects**
  - Syngas cleaning
  - Coal and biomass feeding against high pressure without lockhoppers
  - Selective cobalt FT catalyst testing
  - Water cleanup from shale fracturing operations
- **Pilot-Scale Projects**
  - Conventional FT synthesis
  - Higher alcohol synthesis
  - Biomass gasification (gasifiers range from 2 to 4 ton/day, fixed and fluidized bed)
  - MSW gasification and conversion to power and liquid fuel
- **Field Demonstration Projects**
  - Thermal oxidizer- based microturbine for converting very low BTU gas to power
  - Solar-energy based adsorption chiller
  - Engine waste heat conversion to power using an organic Rankine cycle system

Gasification-Based Liquid Fuels Projects at Southern Research

- Support of pilot plant testing of Thermochem Recovery International's (TRI) fluid-bed reformer-based biorefinery
- Syngas upgrading and selective Fischer-Tropsch conversion to wax-free C_5-C_{20} hydrocarbon liquids
- Downdraft biomass gasification-based WTE system and micro-biorefinery





FT Synthesis Pilot Plant

- Three tube fixed bed catalytic reactor with commercial reactor length tubes
- Tube ID, residence time, space velocity and catalyst temperature identical to the commercial plant
- Results are directly scalable to the commercial FT reactors
- Operation on bottle gas or real syngas

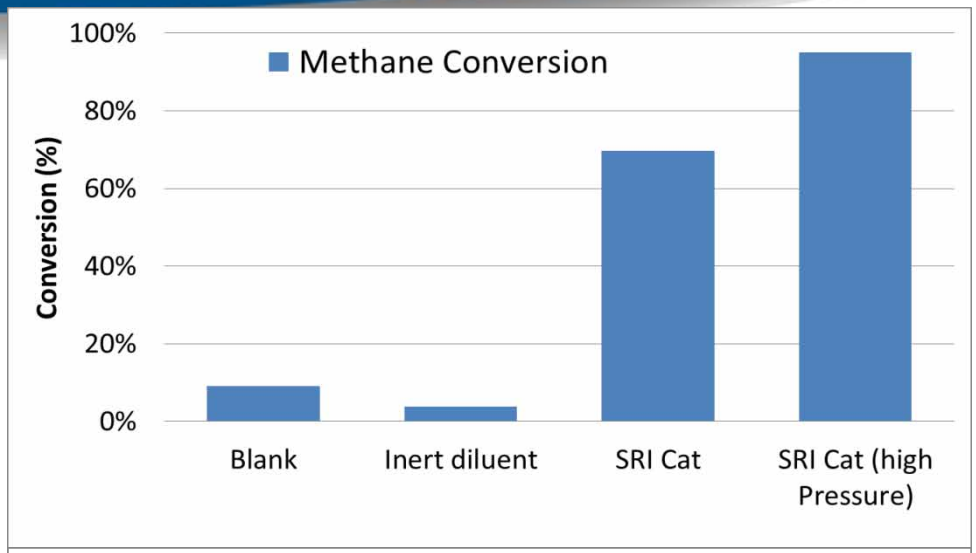
Syngas Cleaning and Upgrading

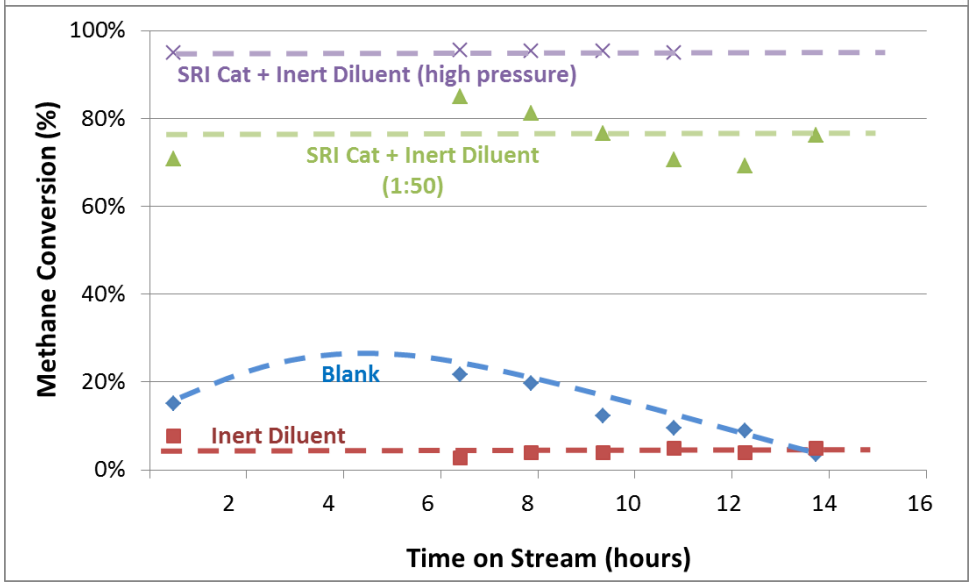
- Gas cleanup technology still costly
- Efficiency issues when using FT (cool gas, then reheat and compress)
- Potential significant water and waste issues
- Evaluating potential solutions:
  - Develop optimized sulfur-tolerant high temperature steam reforming catalyst
  - Convert tars, light hydrocarbons, and ammonia in one step
  - Increase H_2/CO ratio and concentrations
  - Promising catalyst candidates have been prepared and tested
  - Parametric tests using simulated raw syngas are underway

Syngas Upgrading Results

Simulated Syngas feed Composition (Vol %)

H_2	29.2
CO	34.3
CO_2	13.6
CH_4	2.5
H_2O	18.9
NH_3	0.28
Tar	0.1
H_2S	35 ppm

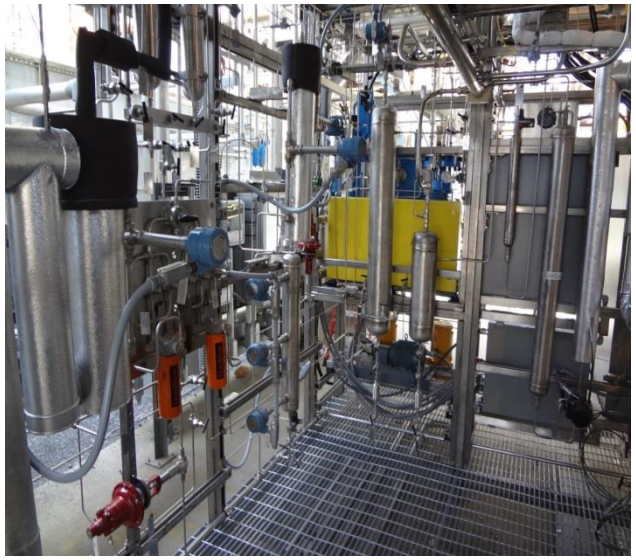


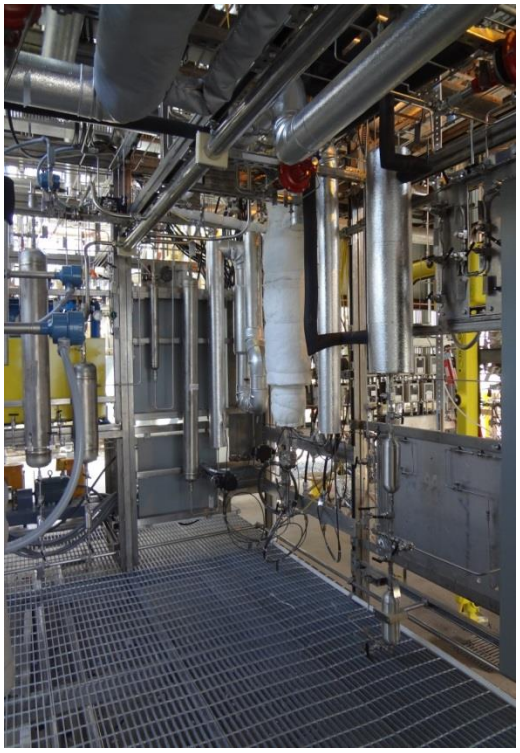


Selective FT Conversion to Liquid Fuels

- Project:
  - Slip stream conversion of coal/wood-derived syngas from transport reactor integrated gasifier (TRIG) at the National carbon Capture Center (NCCC)
  - Efficient heat exchange reactor system designed and commissioned
  - High liquid fuel selectivity/activity wax-free Chevron cobalt-zeolite hybrid catalyst
  - Initial testing carried out in April; further testing planned in October
  - Techno-economic analysis and LCA
- Advantages:
  - C_5-C_{20} liquid product in high yield with >70 % carbon selectivity
  - No wax production, handling and upgrading needed
  - CAPEX and OPEX reductions

Southern Research FT System Installed at NCCC Transport Gasifier Facility





- Skid mounted FT reactor system at NCCC
- 80 % PRB coal, 20% hard wood
- 5 lb/h slip stream, 350 psig, 24/7 operation
- Integrated gas cleanup system
- Designed for 4 liters/day liquids production

Fischer-Tropsch Synthesis Performance of a Chevron Co-Zeolite Hybrid Liquid Selective Catalyst

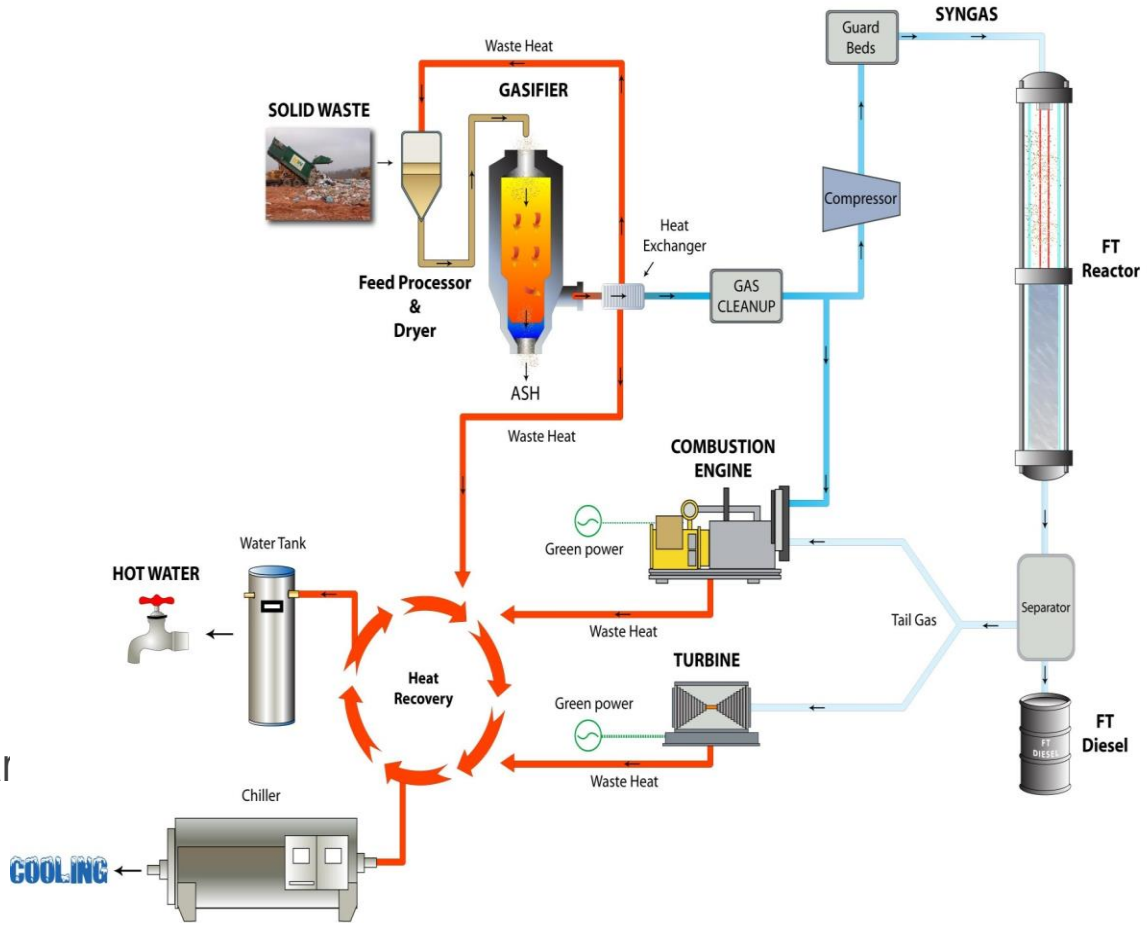
Time on stream (h)	254	326	419	440
Pressure (atm)	10	10	15	20
CO conversion (%)	35.1	34.5	38.4	41.7
CH_4 selectivity (%)	12.6	12.6	12.3	11.9
C_2 selectivity (%)	1.7	1.7	1.7	1.4
C_3-C_4 selectivity (%)	10.8	11.1	8.9	7.9
C_5-C_{20} selectivty (%)	74.9	74.6	77.4	79.0
C_{21} + selectivity (%)	2	0	0	0

Reference: Kibby C. L., Jothimurugesan K., Das T., Saxton; R. J., Burton, Jr. A. W., US Patent Application 20110144219 (2011)

Production of wax free liquids

Southern Research Small Scale Biomass and Waste to Energy Platform

- Distributed application for local feedstocks and local product offtake
- 3 systems envisioned
  - **1-3 tpd WTE system**
    - U.S. DoD FOBs
    - Other small generators
  - **10-50 tpd WTE system**
    - U.S. DoD domestic base
    - Universities, Hospitals,
    - Municipal landfills
  - **100-200 tpd Bio-refinery**
    - Power, fuels, hot water, char
- Initial gasification trials completed with wood, rice hulls, MSW/RDF



Addressing Economy of Scale for Small Plants

- Feedstock Preparation
  - Minimal sorting, no pelletization, low-cost drying
- Gasifier
  - Simple, inexpensive, commercially proven and scalable (1 to 50 tpd) downdraft system
  - Agreement with manufacturer for development of fully integrated systems by Southern Research
  - High efficiency and extremely low tar make
  - Handles wide variety and sizes of very low to high density feeds
  - Automated char removal system accommodates clinker formation up to 1 inch
- Syngas cleanup
  - Novel dry syngas cleaning system
- Fischer-Tropsch synthesis
  - Novel selective catalyst maximizes liquids (C_5-C_{20}) and produces no wax

Preliminary Economic Analysis for a 200 Ton/Day Plant

Assumptions		Results	
Plant Availability	67% Yr1; 90% Yr2	Plant Capacity (20 % moisture)	200 tpd
Delivered biomass cost	$34 per dry ton	Installed Capital Cost	$38 million
FT Catalyst Replacement	2 yrs	Operating Cost	$6.4 million/year
Fuel price	$3.61/gal	Gross Revenue	$11 million/year
Inflation	2.4 %	IRR at 4% Interest	16.8 %
Equity	25%	IRR at 7.2% Interest	11.2 %
Loan term	15 Yrs		

Summary

- Gasification/FT is a preferred and flexible technology for biomass to liquid fuels
- Large scale systems have significant technical, logistics, and economic challenges
- Small-scale biomass plants (200 tpd) and medium scale coal/biomass plants (500-1000 tpd) have the potential to overcome these challenges through technical advances for reducing capital cost:
  - Low cost modular gasifiers
  - Process intensified syngas upgrading/cleanup
  - Selective FT synthesis
    - High activity and selectivity for C5 to C20 hydrocarbons
    - Elimination of wax formation, handling, and hydrotreating
- Projects are underway at Southern Research addressing these technical advances

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