SOUTHERN RESEARCH

Conversion of Biomass and Coal to Liquid Transportation Fuels

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The Problem

- Total US Oil Consumption = 21 Mbpd, 12Mbpd imported, Transportation Fuels = 14 Mbpd
- Light duty vehicles use 9 Mbpd (138 billion gal/yr)
- Energy security, Risk of supply disruption, Finite petroleum resource
- Coal, most competitive alternative--abundantly available--increased use increases GHG emissions(CO_2) and mining operations
- EISA2007 mandates increasing renewable fuels from 4 to 36 billion gallons in 2022

Coal vs Biomass

- Coal
  - Abundantly available (>847 billion tons proven)>130 yrs
  - Good infrastructure / Price competitive
  - Coal to liquids not sustainable with out carbon capture and storage (CCS)
  - Social acceptance could be an issue
- Biomass
  - Food vs fuel debate for grainy biomass and vegetable oil
  - Cellulosic not abundant in a practical sense
  - "Cheap" is a misconception even for waste biomass
  - Poor to no infrastructure for large scale use
  - Nearly CO_2 neutral

Status of CTL and BTL

- CTL has been commercially available via the gasification/FT route for over 50 years
- No commercial plants in the US except Eastman's coal to chemicals complex in Kingsport
- Uncertainties and difficulties
  - Economics with respect to petroleum
  - Capital cost
  - Environmental and social acceptance
  - CO_2 storage not commercially proven
- No commercial BTL plants operating
- Government strongly promoting biomass development by co-funding numerous pilot and demo plants

Conversion Technologies

- Vegetable oil and animal grease
  - Esterification/Transesterification to biodiesel
  - Hydrotreating (limited to non-edible oils—eg camelina)
- Cellulosic biomass(wood, agricultural waste etc)
  - Thermochemical
    - Gasification/Fischer-Tropsch (FT) or syngas to methanol to gasoline (MTG) or ethanol
    - Pyrolysis/stabilization/hydrotreating
  - Biochemical
- Coal
  - Gasification/FT or MTG
  - Liquefaction

Simplified Gasification-FT Chemistry

- Gasification

  $C + H_2O = CO + H_2$ (Endothermic reaction)

  $C + O_2 = CO_2$ (Exothermic reaction)

- FT
  - Chain growth

    $CO + 2H_2 = -CH_2- + H_2O$

    $-CH_2-+ CO + 2H_2 = -C_2H_4- + H_2O$

    and so on
  - Chain termination to ethane and so on

    $-C_2H_4- + H_2 = C_2H_6$

The Potential

- Sustainable cellulosic biomass potential resource: 550 MMtons/y by 2020
- Biochemical route can produce up to 0.5 Mbpd by 2020 and 1.7 Mbpd by 2035
- BTL plants will require significant incentives for CO_2 reduction to make them competitive
- CTL plants can be commercially deployed but will not be until large scale CCS is demonstrated
- CBTL (60:40) can produce up to 4 Mbpd by 2020 at same CO_2 emission as petroleum

Comparison of $/bbl Gasoline Equivalent Cost

	Without CO_2price	With $50/tonne CO_2
CTL	65	120
CTL-CCS	70	90
Crude		
– $60/bbl	75	95
– $100/bbl	115	135
BTL	140	130
BTL-CCS	150	115
CBTL	95	120
CBTL-CCS	110	100
Cell. EtOH	115	110

Reference

Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts

America's Energy Future Panel on Alternative Liquid Transportation Fuels; National Academy of Sciences; National Academy of Engineering; National Research Council

ISBN: 0-309-13713-6, 388 pages, 8 x 10, (2009)

"A program of aggressive support for establishment of first-mover commercial coal-to-liquid transportation fuel plants and coal-and-biomass-to-liquid transportation-fuel plants with integrated geologic CO_2 storage will have to be undertaken immediately if commercial plants are to be deployed by 2020 to address U.S. energy security concerns and to provide fuels whose levels of greenhouse gas emissions are similar to or less than that of petroleum-based fuels."

Recent large scale projects co-funded by DOE

- Coal: CCS driving Government funding
  - Future Gen 2: 1 billion $
    - Oxy-combustion plant generates CO_2
    - CO_2 piped to storage facility
    - Capacity >39 million tonnes CO_2
    - Sequester CO_2 from 200 MWe plant for 30 years)
- Biomass ($110-$140 million each)
  - Bioenergy International (biomass to succinic acid)
  - Enerkem (MSW and waste wood gasification)
  - Ineos (Gasification- syngas fermentation)
  - Sapphire (Algae to jet fuel and diesel)

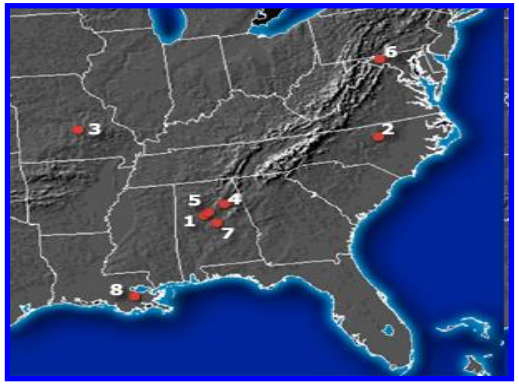
Some Important Technical Barriers that Southern Research is Addressing

- Lack of BTL and CBTL integrated demonstration
- Cost-effective feeder for coal-biomass mixtures
- High cost of syngas cleanup

SOUTHERN RESEARCH

Legendary Discoveries. Leading Innovation.

- SR Corporate
  - Since 1942
  - Eight locations
  - 600 staff, $81M revenue
  - Meaningful discoveries



- SR North Carolina
  - Established in 1991
  - 50+ staff
  - 42,000 ft^2 facility
    - Office, labs, process
  - Private & govt. clients
  - Internal RD&D

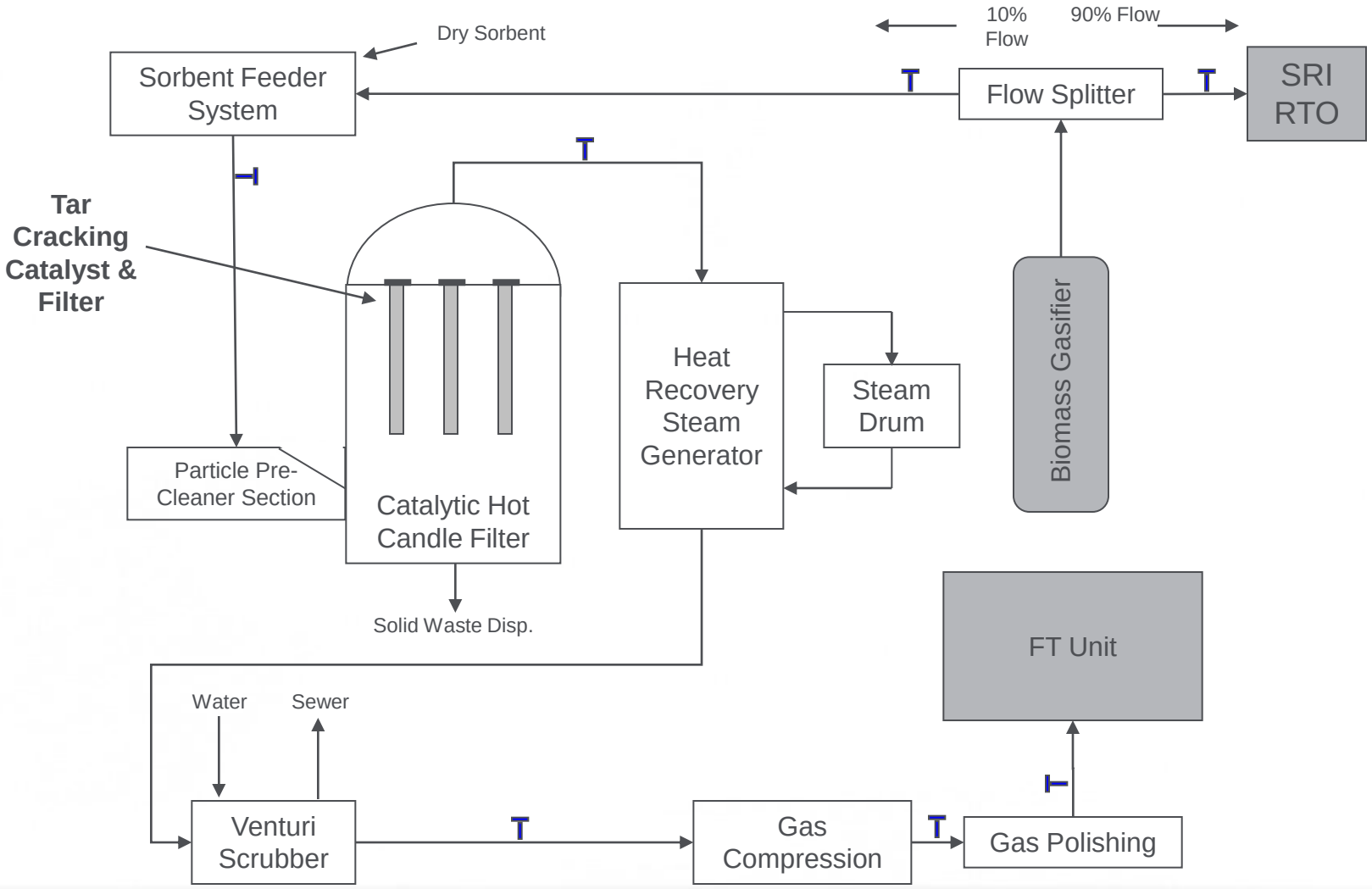
SR-NC Overview

- Main Business Areas
  - Energy & transport technology demonstrations
  - Advanced energy pilot plants
  - 3rd party performance testing & feasibility studies
  - Technology deployment strategy planning
- Energy and Transportation
  - Bioenergy, waste-to-energy, DE, DE-CHP
  - Transport fuels & devices
  - GHG control technology
    - Oil and gas distribution
    - Green buildings
    - Measurements systems
    - Others

Technologies Being Developed at SR

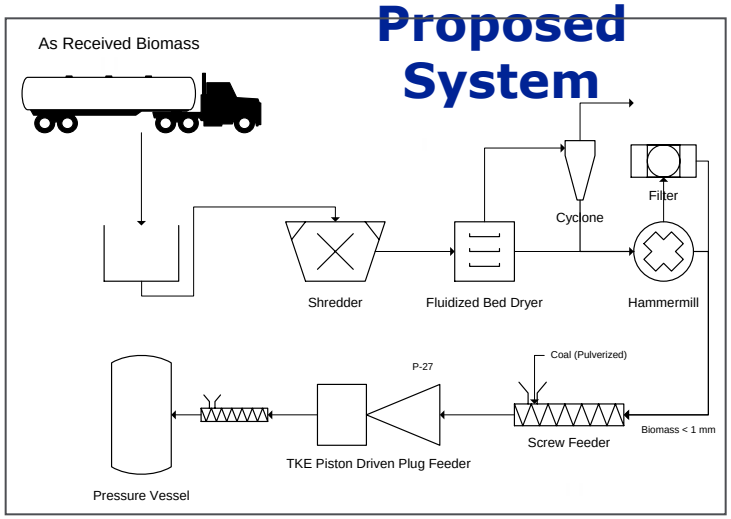
- Under development now in the process building
  - Thermochemical biorefinery - Biomass To liquids
  - Fuel prep and feeder for coal and biomass mixtures
  - Municipal solid waste to mixed Alcohols
  - Advanced syngas cleaning system
  - Molten metal gasification
  - Acid hydrolysis to industrial sugars
  - Small scale MSW to power and heating/cooling (IR&D)
- Field demonstrations
  - Landfill gas to power – Fort Benning
  - Solar thermal air conditioning – Parris Island
  - Mobile SCR – Durham city fleet
  - Marine vessel alternative fuels - USACE

Catalytic Syngas Cleaning System



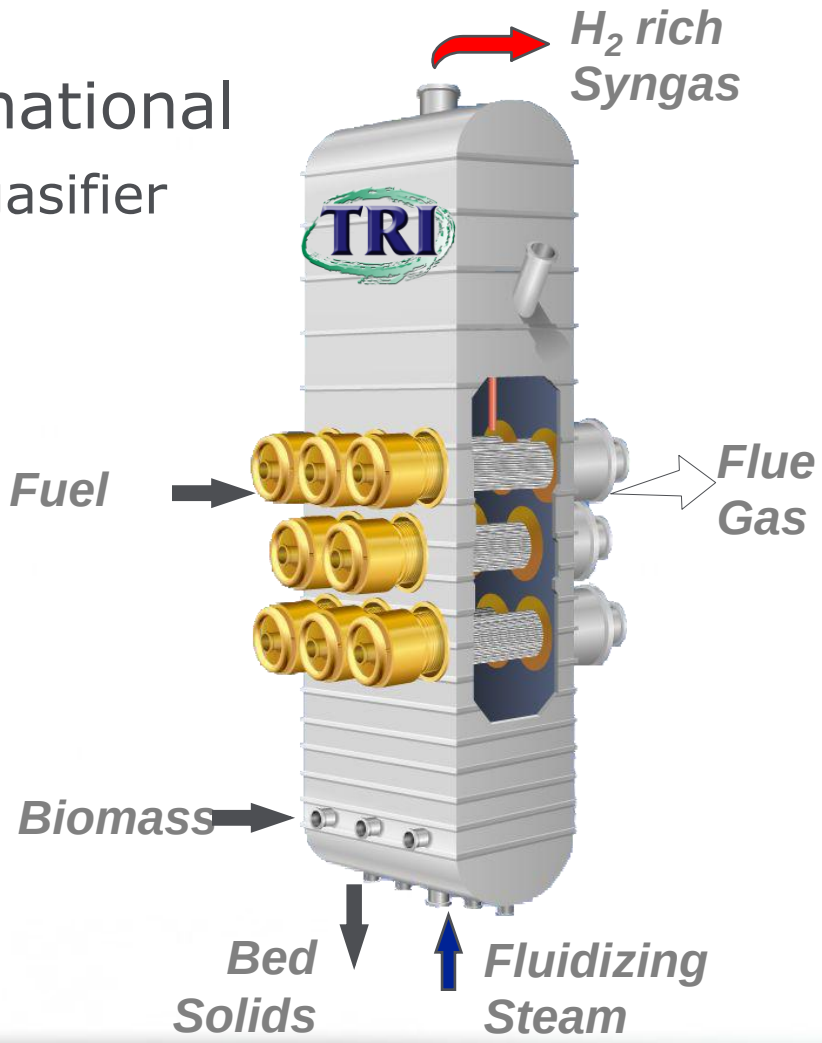
Erect and Demonstrate a Coal/Biomass Feeder for CBTL Plants

- DOE NETL & European Partner
  - TKE Energie - feeder partner
  - Piston driven plug feed system
  - PDU feed rate 7-8 TPD
- Scope of Work
  - Erect, modify and demonstrate feeder for entrained flow gasifiers
  - Shred, dry, mill stover, wood, and grass; mix with pulverized lignite, sub-bituminous or bituminous
  - Feed 70/30 & 50/50 mixtures to gasifier simulator
  - Evaluate the engineering and economic viability

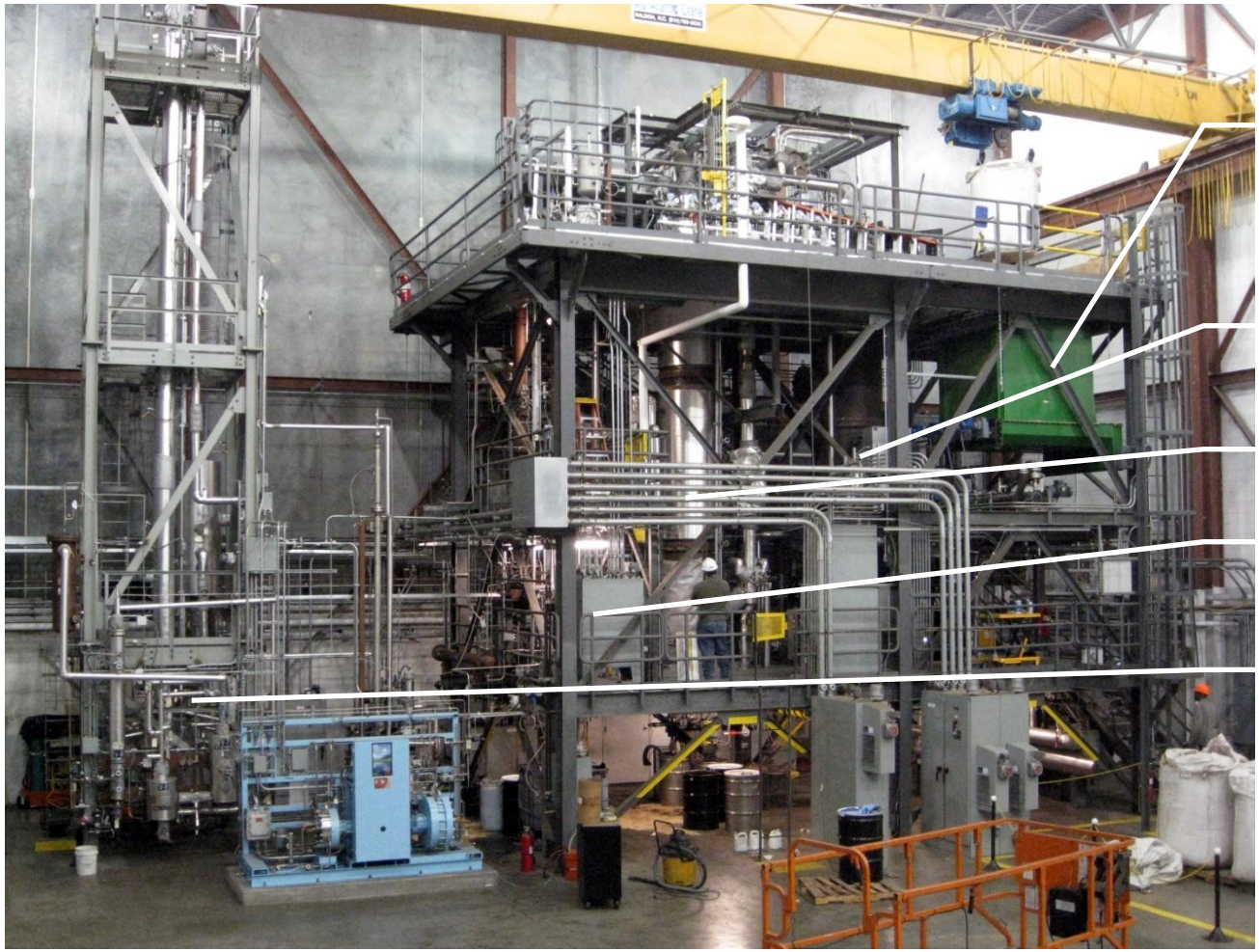


Biomass Gasification System

- Thermochem Recovery International
  - Steam reforming fluidized bed gasifier
  - PDU feed rate 4 bone dry TPD
- Scope of Work
  - Commission, run trials with various feed materials
  - Integrate & demonstrate an integrated (bio-refinery)
  - Scale-up and optimize system (new commercial plants in process now)



The TRI PDU


Biomass Feed System
Steam Reformer
Carbon Trim Cell
Gas Clean Up System
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