Design/Cost Study and Commercialization Analysis for Synthetic Jet Fuel Production at a Mississippi site from Lignite and Woody Biomass with CO_2 Capture and Storage via EOR

DOE/NETL Project #: DE-FE0023697
(under NETL Major Projects Division)

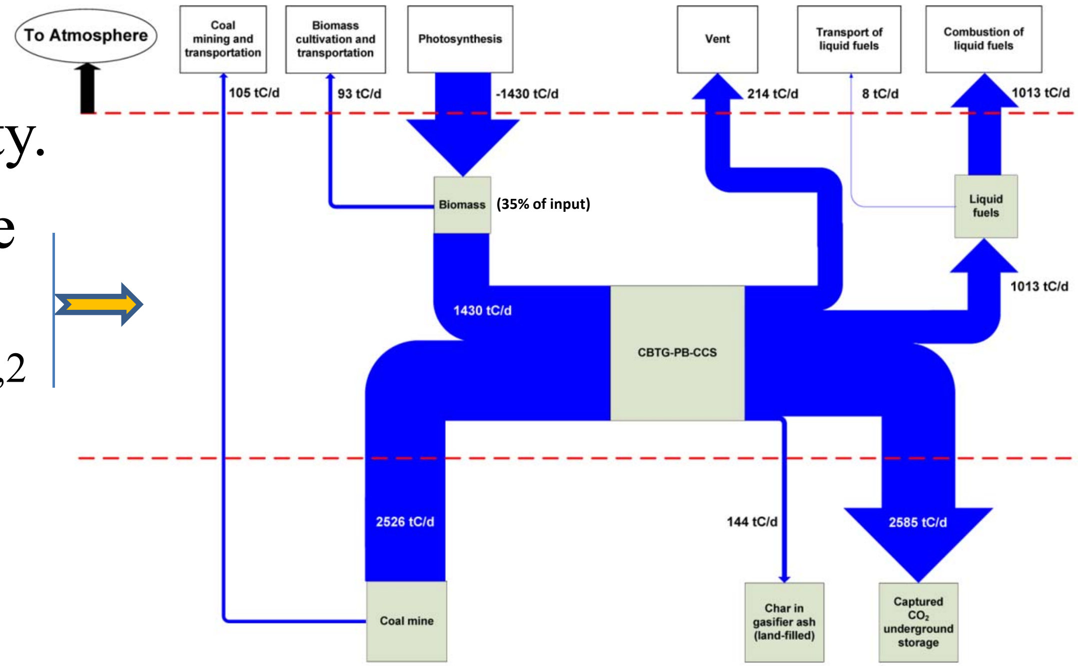
Eric Larson, PhD
(elarson@princeton.edu)
Project PI and Senior Research Engineer
Energy Systems Analysis Group
Andlinger Center for Energy and the Environment
Princeton University, Princeton, NJ

2015 Gasification Systems and Coal & Coal-Biomass to Liquids Workshop

Lakeview Conference Center, Morgantown, WV
10-11 August 2015

Project Motivation

- CBTL w/CCUS increases transportation energy security.
- Can achieve zero or negative GHG emissions (with less biomass than pure biofuel).[1,2]
- Economics improve with increasing GHG emission price.[1,2]



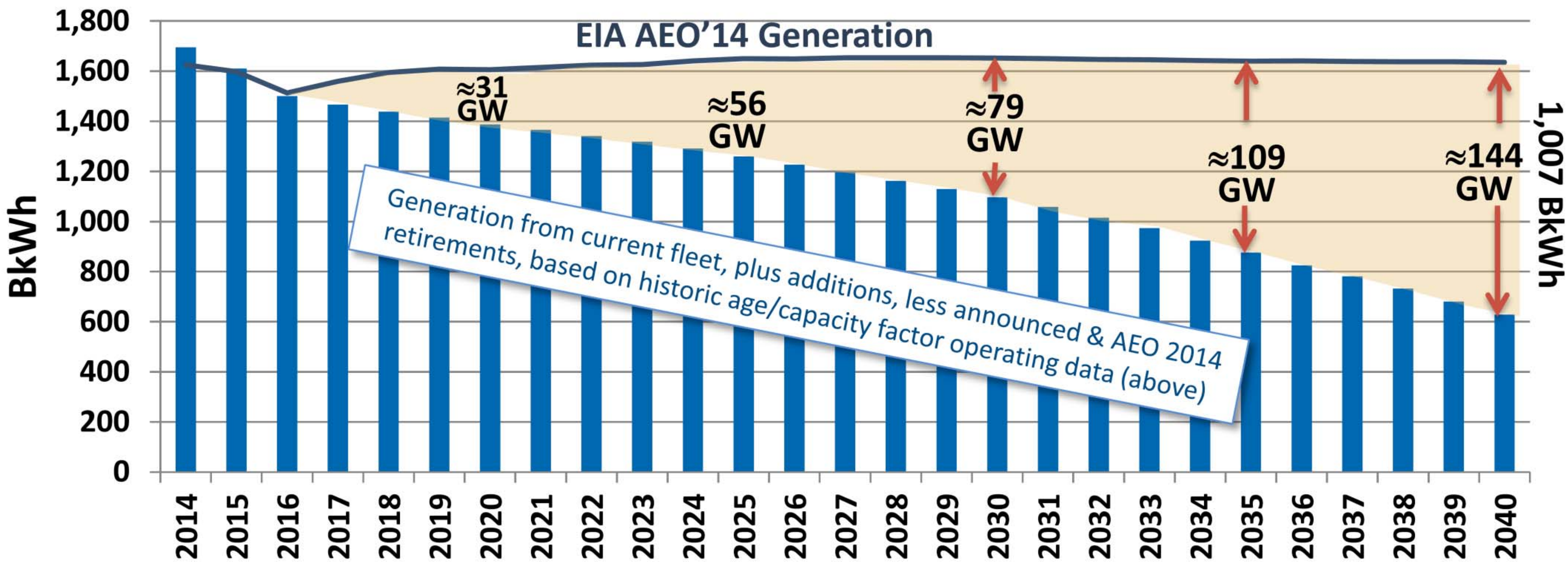
- Coproducing electricity with fuel (CBTLE-CCUS) can provide transportation fuel security and may provide an opportunity for coal to remain competitive in supplying the anticipated need for major new baseload capacity in a carbon-constrained world.[3]

---

1. Liu, Larson, Williams, Guo, "Gasoline from Coal and/or Biomass with CO2 Capture and Storage, 1. Process Designs and Performance Analysis and 2. Economic Analysis and Strategic Context," *Energy and Fuels*, Feb. 2015.
2. Liu, Larson, Williams, Kreutz, Guo, "Making Fischer−Tropsch Fuels and Electricity from Coal and Biomass: Performance and Cost Analysis," *Energy & Fuels,* January 2011.
3. Williams, "Coal/Biomass Coprocessing Strategy to Enable a Thriving Coal Industry in a Carbon-Constrained World," *Cornerstone Magazine*, 1(1): 51-59, 2013.

Need for New Baseload Capacity

Baseload coal power generation as projected by the EIA (line), and when accounting for coal-plant capacity factors declining with age (bars). Equivalent of 144 GW of new baseload capacity projected to be needed by 2040.*



Missing generation estimate 144 GW @80% average C.F. for new units to meet 2040 demand

NETL

* Source: K. Kern, "Coal Baseload Asset Aging: Evaluating Impacts on Capacity Factors," presented at Workshop on Coal Fleet Aging and Performance, EIA Post-Conference Meeting, Renaissance Hotel, Washington D.C., 16 June 2015.

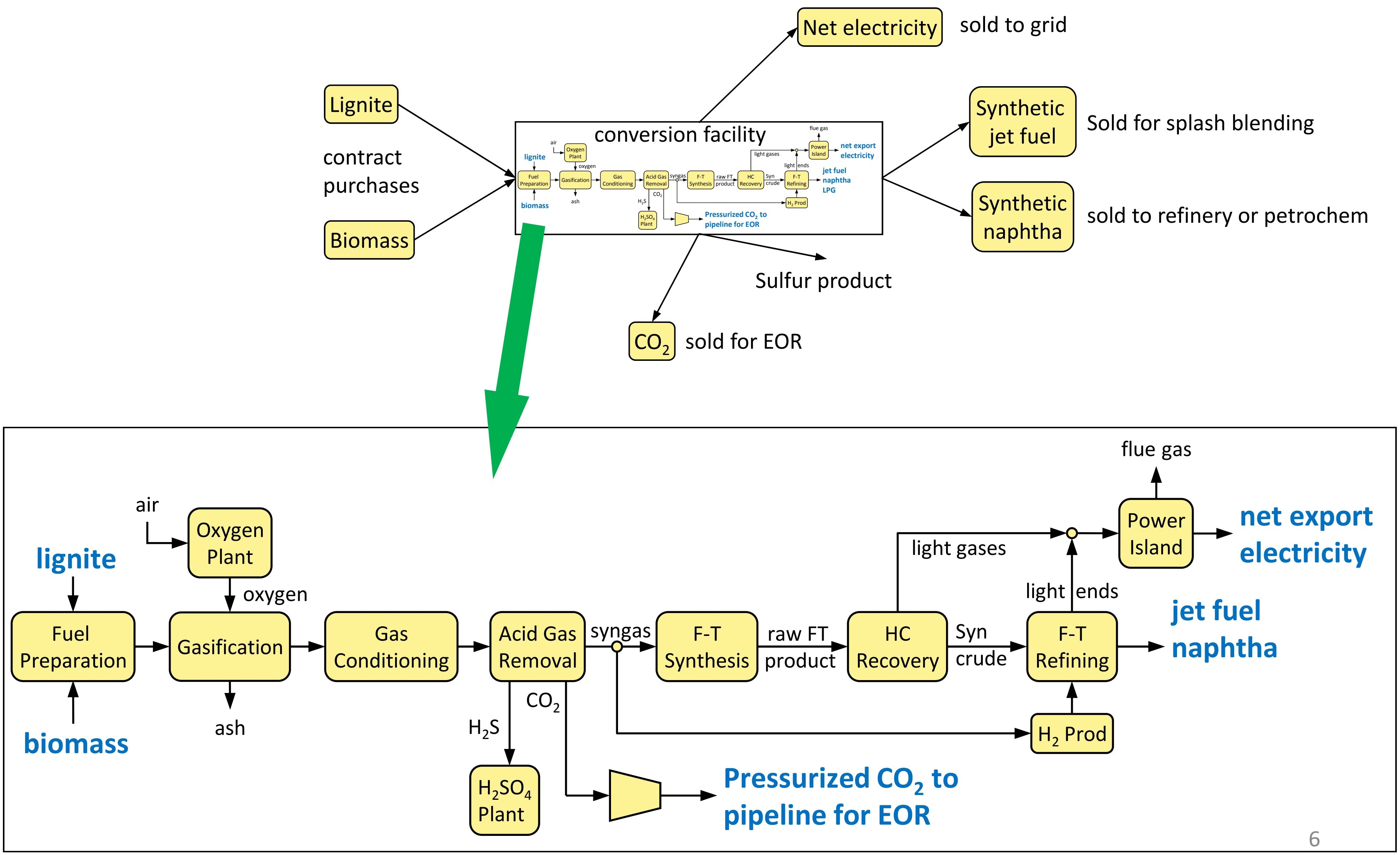
Project Objectives

- Design a first-of-a-kind (FOAK) plant co-gasifying lignite and woody biomass, with syngas conversion to F-T synthetic jet fuel suitable for 50/50 blending with petroleum jet fuel. Capture co-product CO_2 for EOR. Sell co-product naphtha and electricity.
  - (Future) construction and operation of the plant should demonstrate technical feasibility of the concept and provide data to improve performance and reduce costs for future commercial-scale plants.
- The FOAK plant should produce jet fuel with lifecycle GHG emissions lower than for petroleum jet fuel. (Stepping stone to zero-emission CBTLE plants.)
- Prepare design documentation to support a detailed capital cost estimate for the FOAK plant.
- Assess economics of FOAK plant and examine cost-reduction potential for mature-technology plants.
- Project duration: October 2014 – September 2016.

Project Team

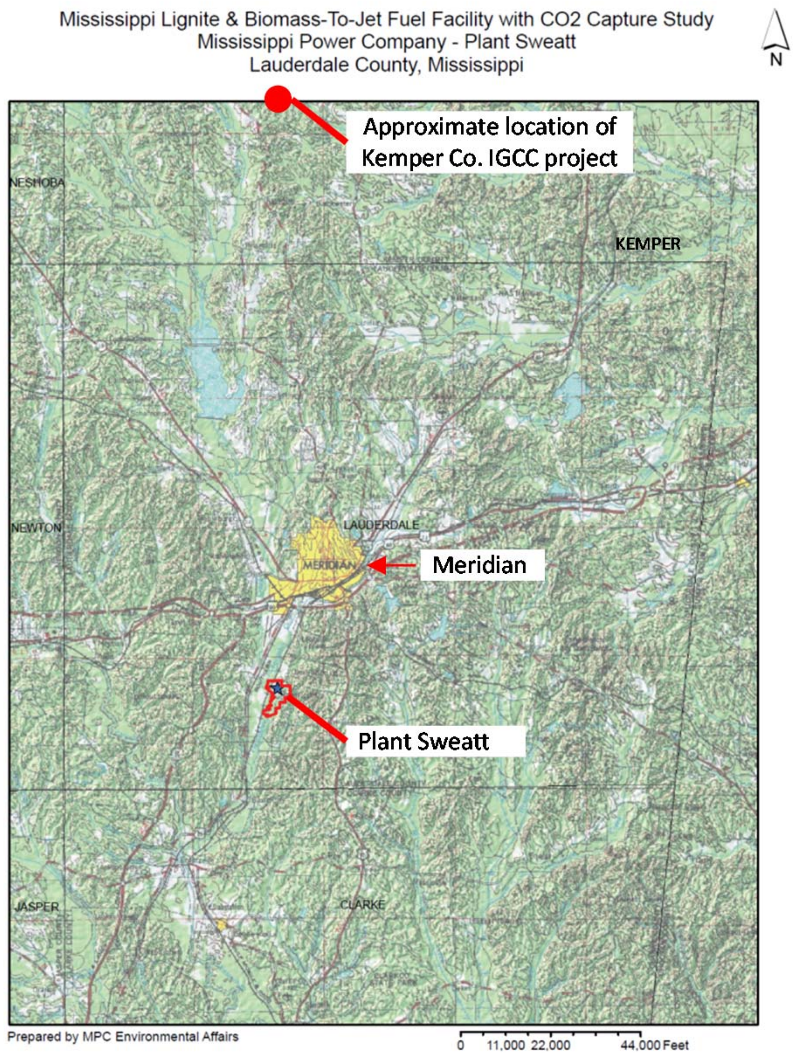
- Energy Systems Analysis Group, Princeton University
  - *Eric Larson, Tom Kreutz, Hans Meerman, Robert Williams*
- University of Queensland Energy Initiative, Australia (cost-share contributor)
  - *Chris Greig (formerly CEO of Australia's ZeroGen Project)*
- Southern Company Services (cost-share contributor)
  - *Providing inputs relating to gasifier technology and Mississippi project site*
- Consultants
  - *Emanuele Martelli (Politecnico di Milano) on process heat integration, Antares Group (biomass supply and biogenic carbon emissions accounting)*
- Technology providers:
  - *KBR (TRIG gasifier), Emerging Fuels Technology (FT island), Siemens (GT), others*
- Engineering services: WorleyParsons
  - *Harvey Goldstein, Lora Pinkerton, Erich Mace, Qinhua Xie*

Plant Concept
Lignite + Biomass to Jet Fuel ("LBJ")

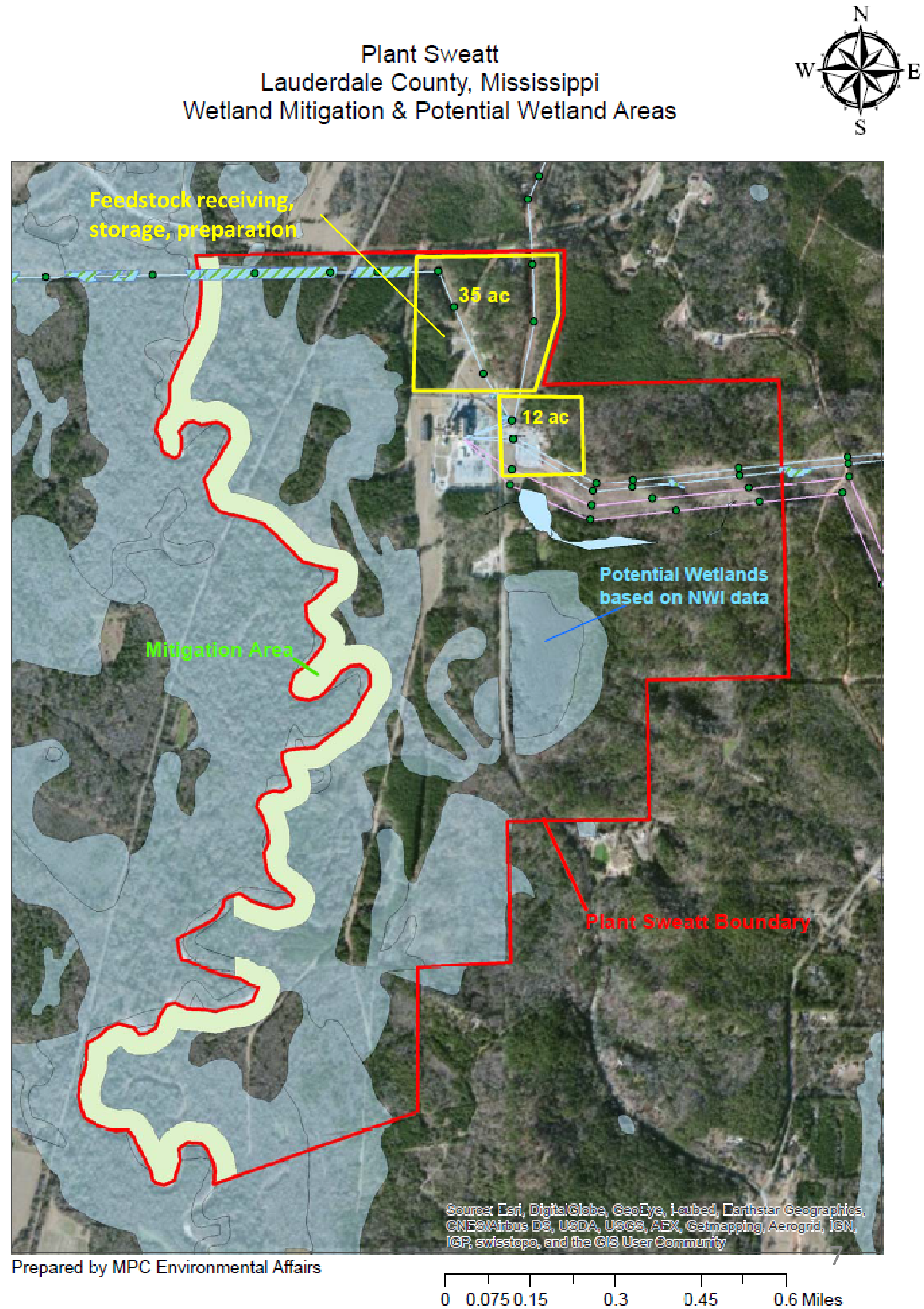


LBJ site: Mississippi Power Plant Sweatt (30 mi south of Kemper Co. IGCC-CCS)

Mississippi Lignite & Biomass-To-Jet Fuel Facility with CO2 Capture Study
Mississippi Power Company - Plant Sweatt
Lauderdale County, Mississippi



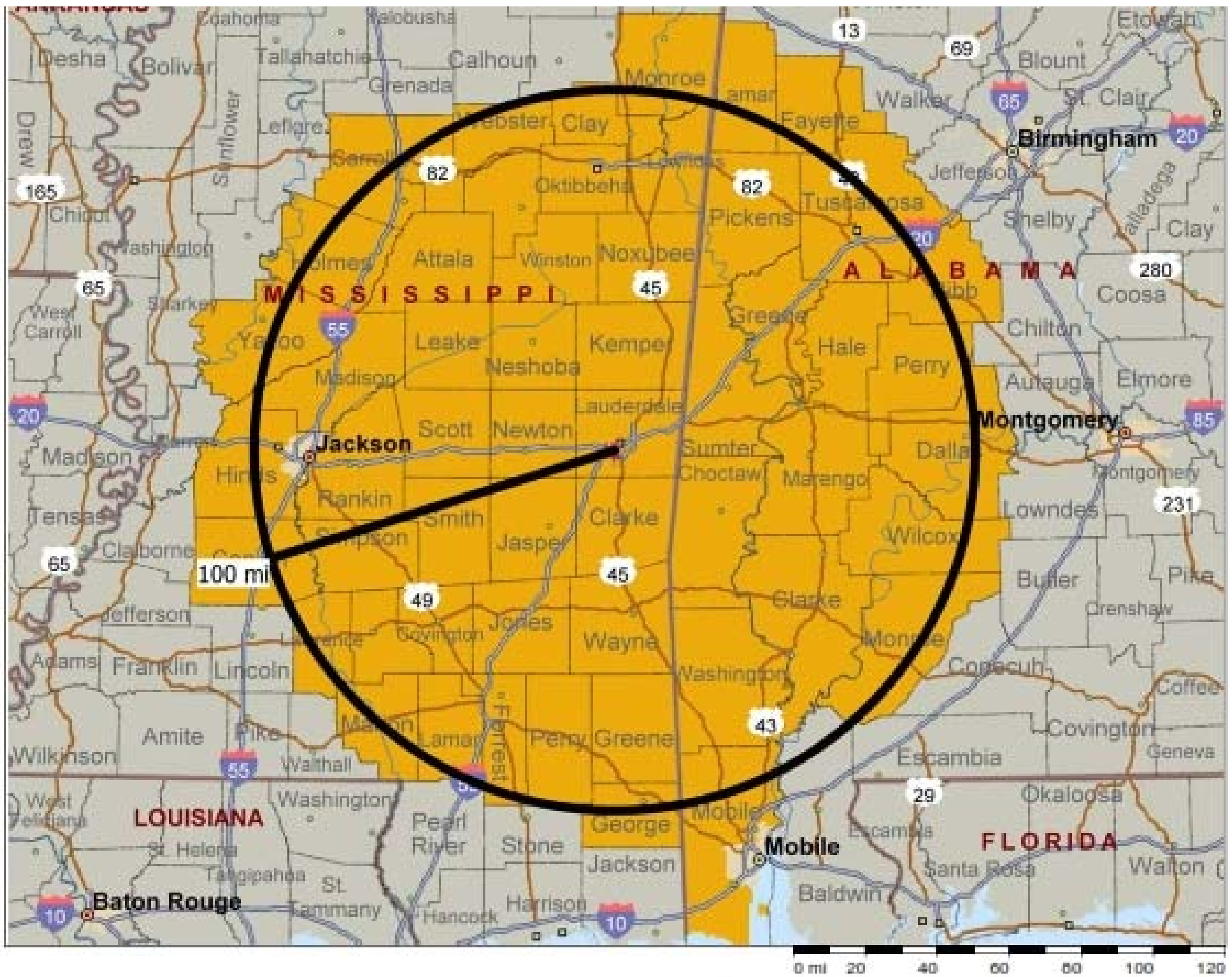
Plant Sweatt
Lauderdale County, Mississippi
Wetland Mitigation & Potential Wetland Areas



Plentiful supplies of woody biomass within a 100 mile radius of Meridian, MS

Total encircled area is about 25 million acres, 19 million of which are forested.

More than 90% of the forested land is privately owned, and much of it is pine plantations.



Key Guiding Principles for Plant Design

Plant scale:

- Capital investment **no more than about $2 billion**.
- Liquid fuel production **capacity > 1,000 bbl/day**.
- **Non-negligible biomass fraction** co-fed with lignite.

Plant life:

- 20 year design life; operate long enough (5 to 10 years) to demonstrate technical viability and provide data for future plants; operate beyond 5-10 years as long as economics allow.

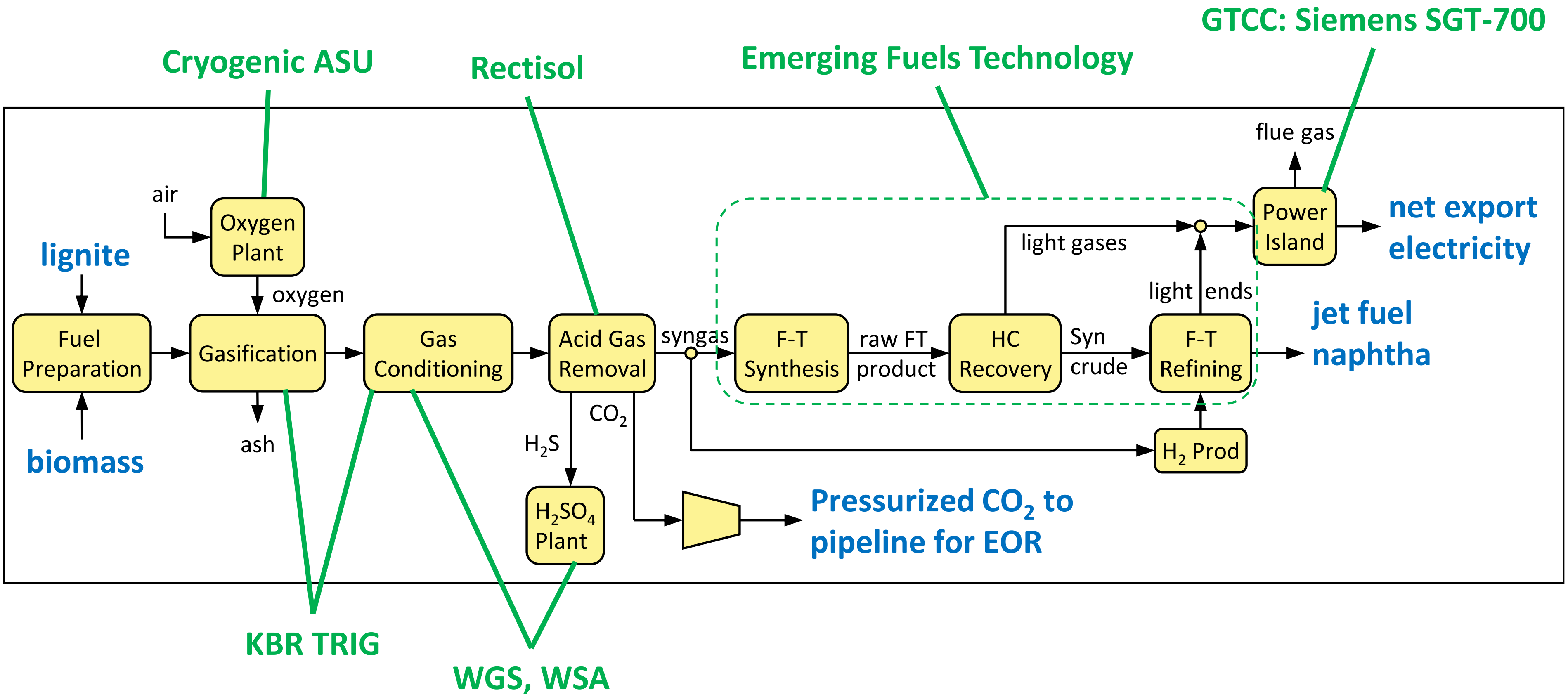
Primary Products:

- **Synthetic jet fuel satisfying EISA Section 526 (fuel-cycle GHG emissions less than for petroleum-derived jet)** and designed for 50/50 splash-blending with petroleum jet fuel to meet ASTM Standard D1655-14 for commercial aviation.
- **Non-negligible electricity export fraction** using off-gas fired GTCC power island.

Design decisions:

- Maximize likelihood of technical success (not necessarily lowest cost).
- Minimize novel or not-yet-commercial equipment; off-the-shelf packages preferred over custom equipment; shop-fabricated modules preferred over field fabricated.

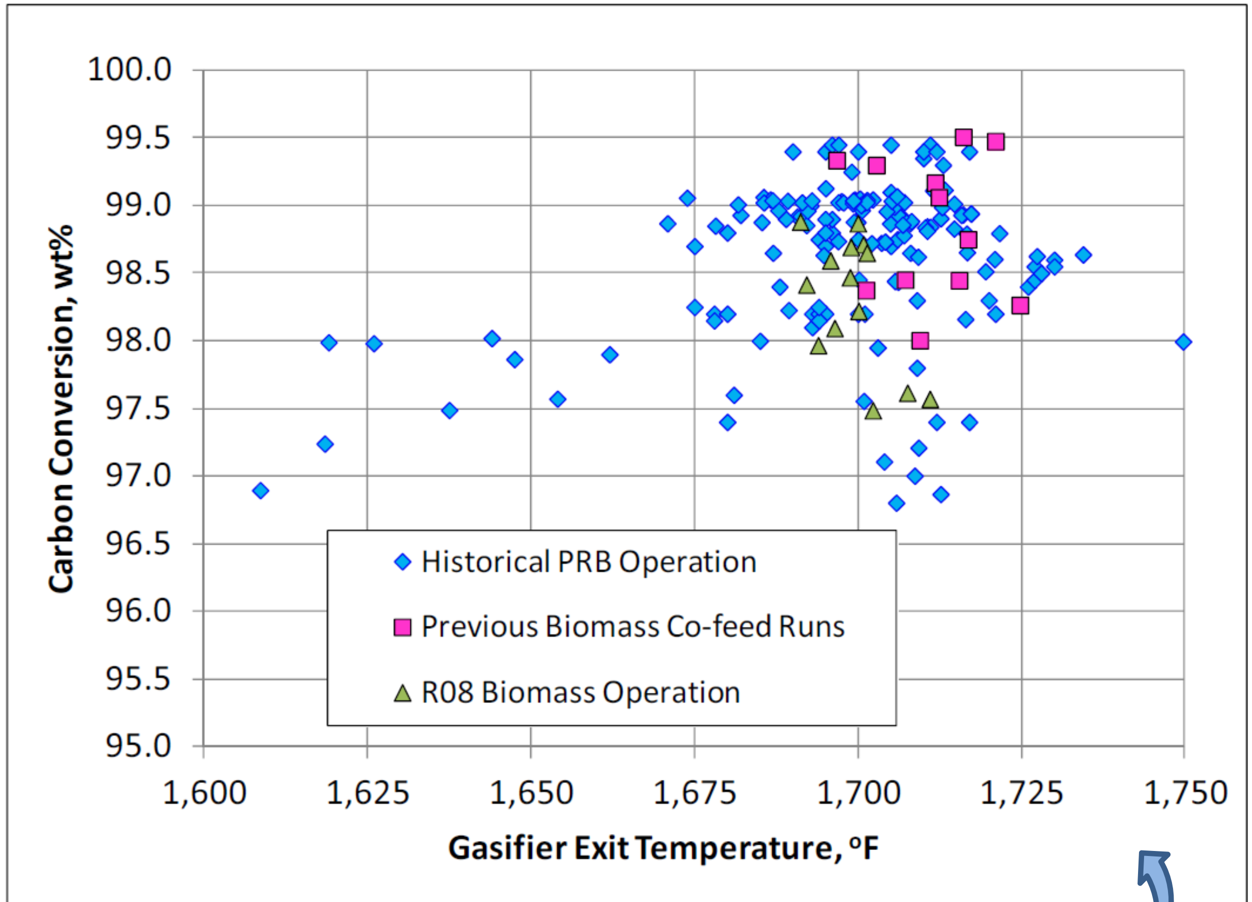
LBJ Technologies



Liquids off-take: Jet fuel into Plantation Pipeline via Meridian pumping station. Naphtha to local refinery: , e.g., Hunt (Tuscaloosa, AL, 75k bbl/d) or Chevron (Pascagoula, MS, 330k bbl/d).

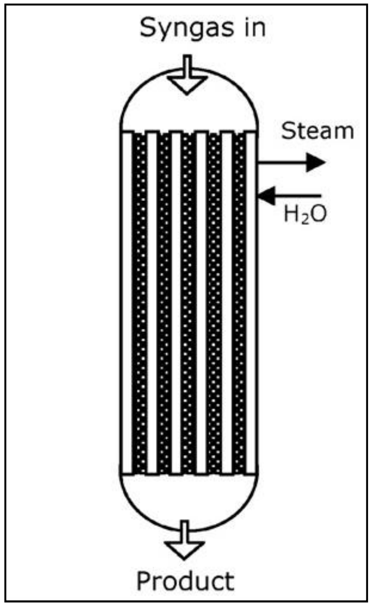
CO_2 off-take : Deliver to Kemper IGCC pipeline to Jackson Dome or sell at plant gate (e.g., to Denbury)

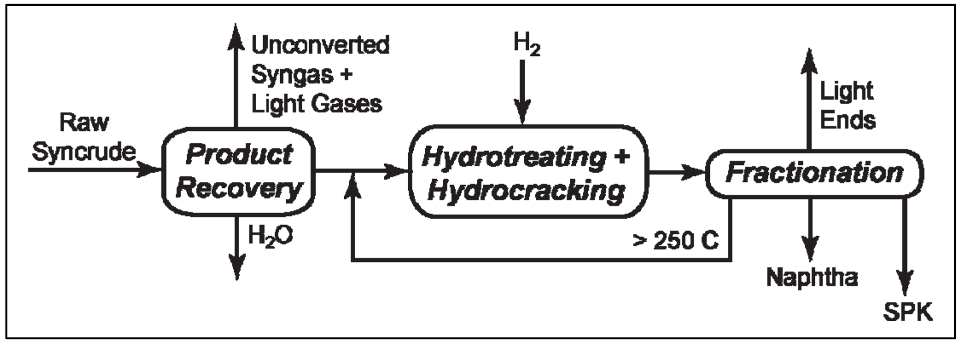
Wilsonville Power Systems Development Facility tests



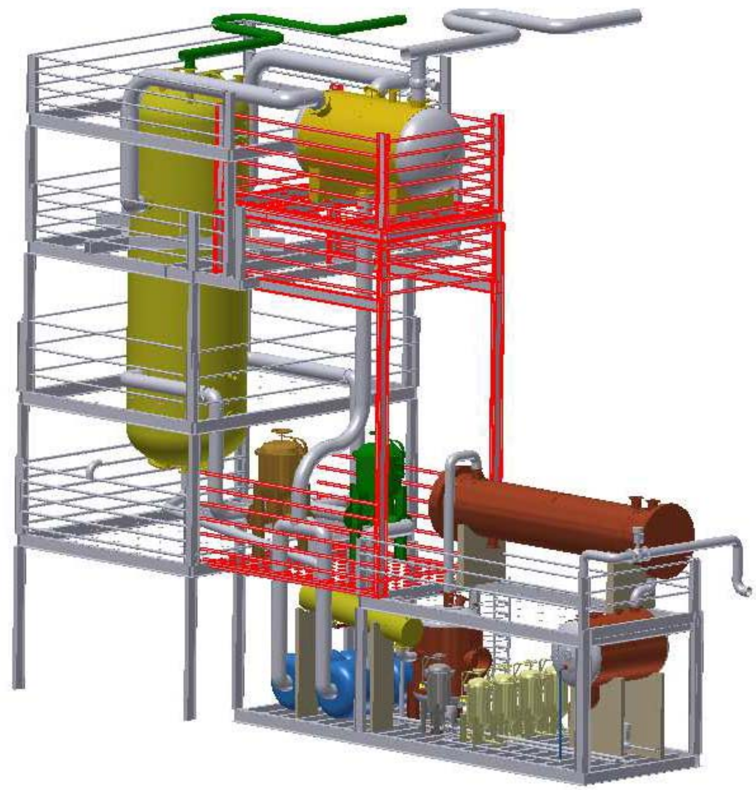
- PSDF TRIG success with up to 30 wt% woody biomass co-feed with PRB coal in both air and in O_2.
- No significant preparation or feeding issues.
- Negligible effect on carbon conversion or syngas heating value with biomass co-feed.
- No evidence of agglomeration or deposition in gasifier solids.
- No indication of excessive tar generation.
- Particulate filtration device (PCD) performance remained stable – consistent pressure drop and low particulate loading in outlet syngas (<0.1 ppm)

FT Island Design (Emerging Fuels Technology)





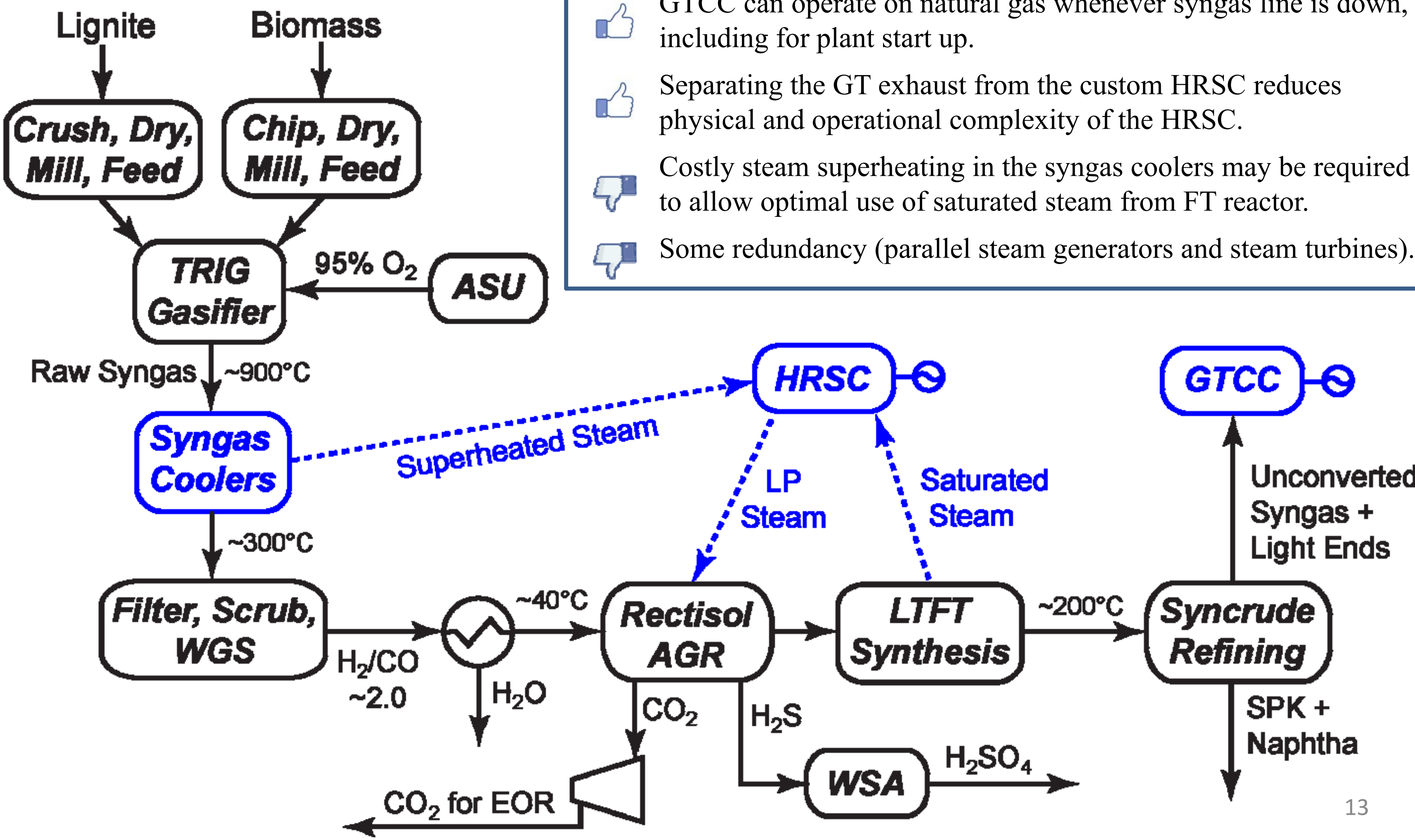
- Tubular, fixed-bed, low-temperature Co catalyst FT reactor, with ~90% CO conversion. No external recycle.
- Simple refining to make SPK, refinery-grade naphtha, and off-gas.
- FT reactor modules are standardized at nominal 500 barrel/day to reduce manufacturing and erection costs.



Power Island Design

Off-gas fired GTCC + process waste heat recovery steam cycle (HRSC).

- 👍 Use of off-the-shelf GTCC for good GTCC performance.
- 👍 High CH_4 from TRIG + refinery off-gases for GT fuel.
- 👍 GTCC can operate on natural gas whenever syngas line is down, including for plant start up.
- 👍 Separating the GT exhaust from the custom HRSC reduces physical and operational complexity of the HRSC.
- 👎 Costly steam superheating in the syngas coolers may be required to allow optimal use of saturated steam from FT reactor.
- 👎 Some redundancy (parallel steam generators and steam turbines).



Early LBJ Plant Estimates

PRELIMINARY – DO NOT QUOTE !

Total feedstock input, MW HHV	311
Biomass % of feedstock HHV input	**25%**
Lignite input, t/d A.R. (45.5% mc)	1,683
Biomass input, t/d (dry)	333
Biomass input, kt/year (dry) (90% CF)	109,252
Jet fuel, MW LHV	82
Naphtha, MW LHV	12
Jet fuel, barrels/day	1,388
Naphtha, barrels/day	228
Total liquids production, barrels/day	**1,616**
GTCC (SGT-700) gross output, MWe	44
Process heat steam cycle, gross MWe	30
On-site electricity use, MWe	25
Net electricity output, MWe	**49**
Electricity, % of energy outputs, LHV	34%
First law efficiency (LHV)	49%
CO_2 captured, metric tCO_2/hr	69
CO_2 stored, million t/y (100% CF)	0.6

Feedstocks

Red Hills Mississippi Lignite (Kemper Public Design Report)

Weight %	*Dry*	*AF*	*AR*
Carbon	57.84	45.13	31.53
Hydrogen	3.63	2.83	1.98
Nitrogen	0.88	0.69	0.48
Chlorine	0.02	0.02	0.01
Sulfur	1.82	1.42	0.99
Oxygen	13.89	10.83	7.57
Ash	21.92	17.10	11.95
Moisture		**22.00**	45.50
Sum	100.0	100.0	100.0
HHV, MJ/kg	22.58	17.61	12.30
LHV, MJ/kg	21.79	16.46	10.76

Southern Pine (NETL, 2014)

Weight %	*Dry*	*AF*	*AR*
Carbon	53.89	45.81	30.56
Hydrogen	5.33	4.53	3.02
Nitrogen	0.41	0.34	0.23
Chlorine	0.00	0.00	0.00
Sulfur	0.04	0.03	0.02
Oxygen	39.25	33.36	22.25
Ash	1.09	0.93	0.62
Moisture		**15.00**	43.30
Sum	100.0	100.0	100.0
HHV, MJ/kg	20.19	17.17	11.45
LHV, MJ/kg	19.03	15.81	9.73

Project Timeline

- Process design done: Q4, 2015.
- Detailed capital cost estimate and associated documentation done: Q2, 2016.
- Final design report, including financial analysis and commercialization analysis, done: Q3, 2016.