

Gasification in the Pulp and Paper Industry

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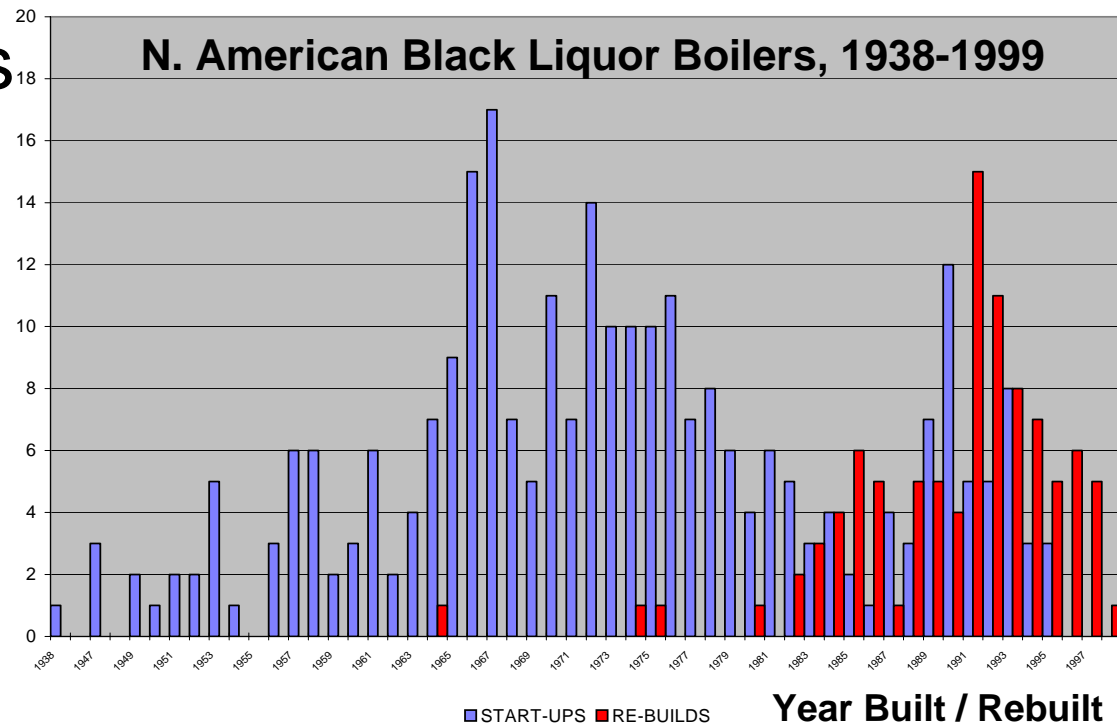
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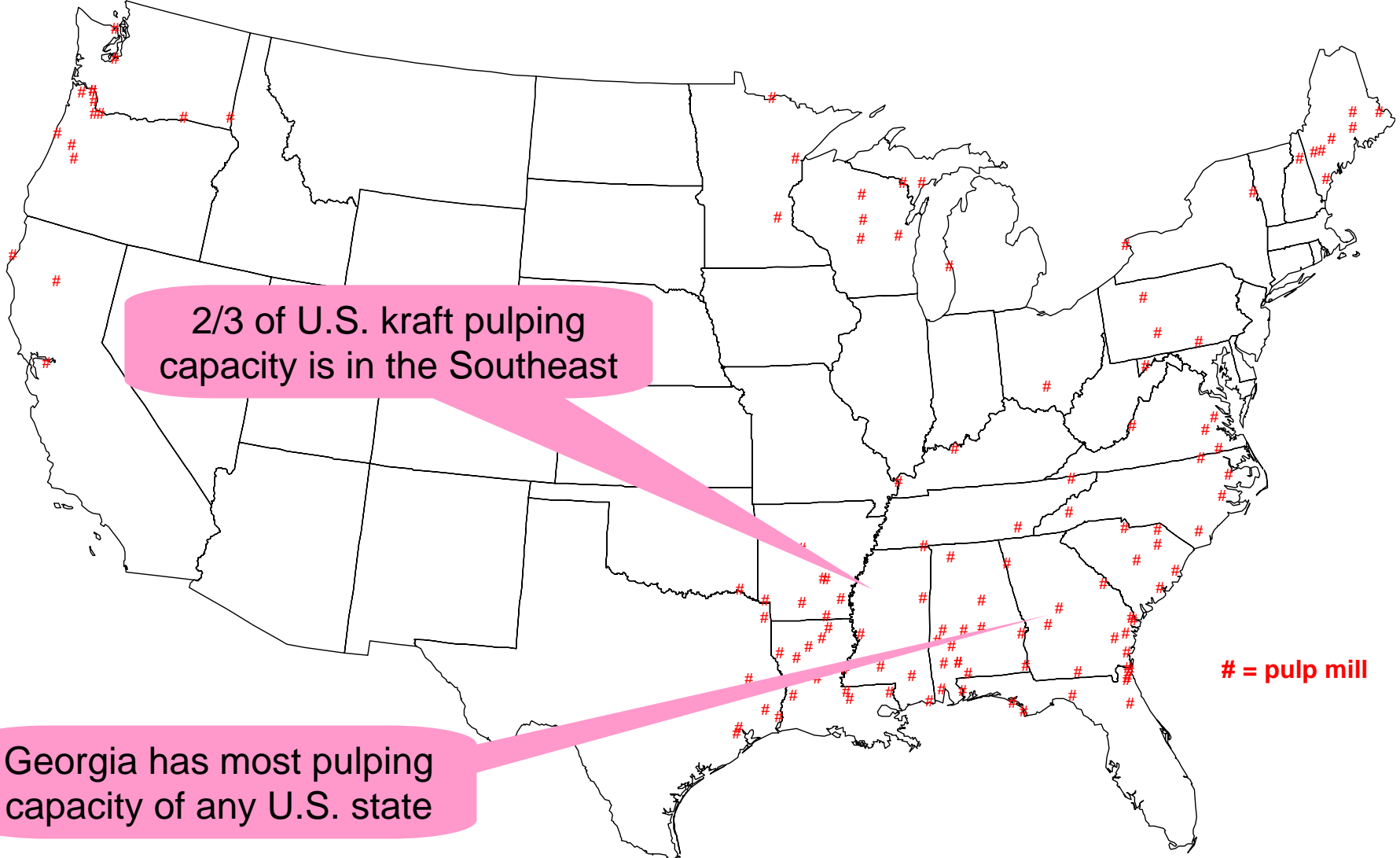
U.S. Kraft Pulp/Paper Industry

- Uses >1.5 quads/yr bioenergy, mostly black liquor.
- Needs new technology to stay globally competitive.
- Aging black liquor boiler fleet provides window of opportunity for introducing gasification.
- USA, Sweden efforts to commercialize BL gasification.
- USDOE and US forest products industry supporting gasification-based “biorefining”.



Assess Pulpmills as Gasification-Based Liquid Fuels and/or Electricity Producers

- Multi-year effort; DOE and AF&PA funding; Industry, government, academia steering group; Analysis team includes Princeton, Politecnico di Milano, Navigant, IPST

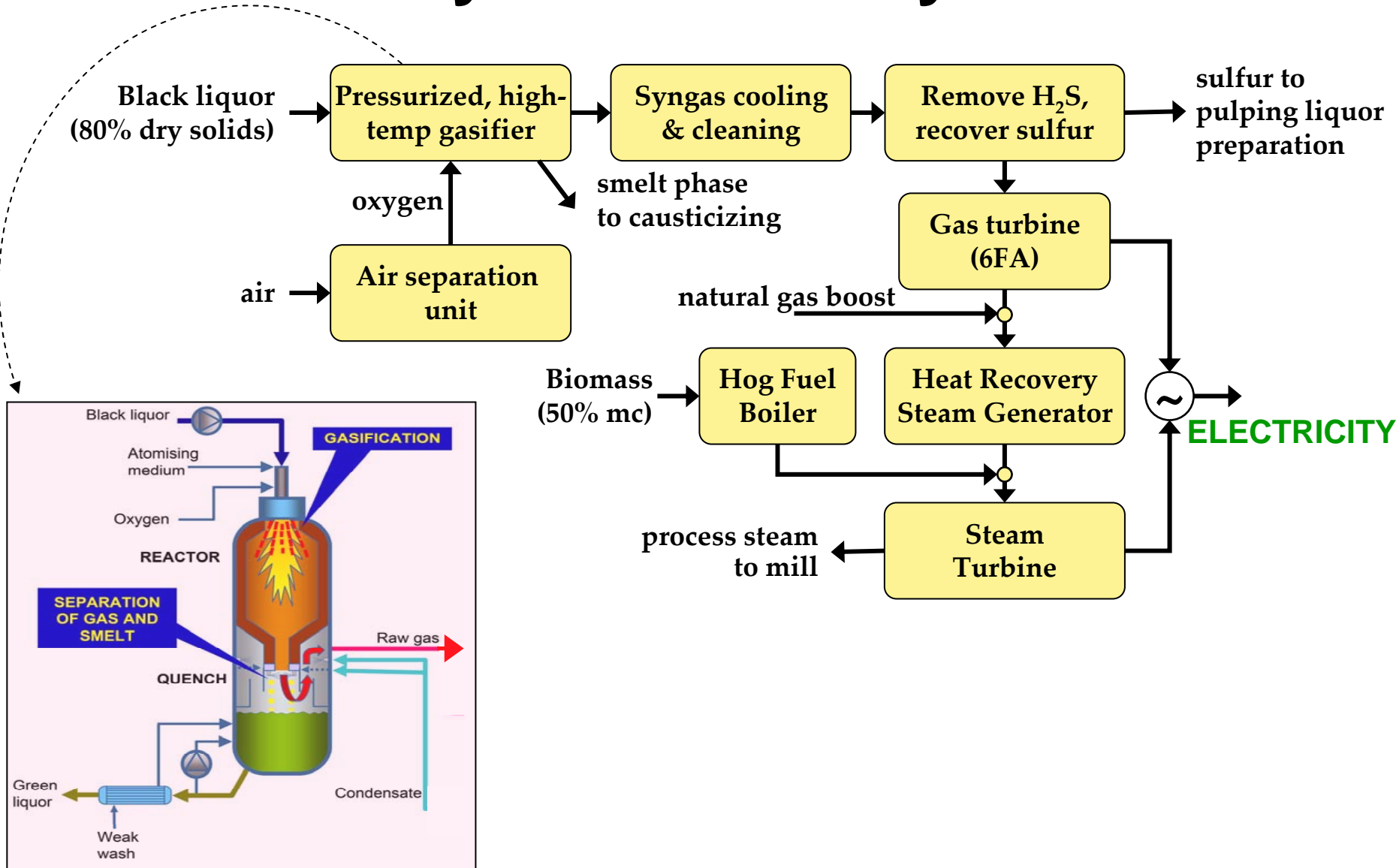


2/3 of U.S. kraft pulping capacity is in the Southeast

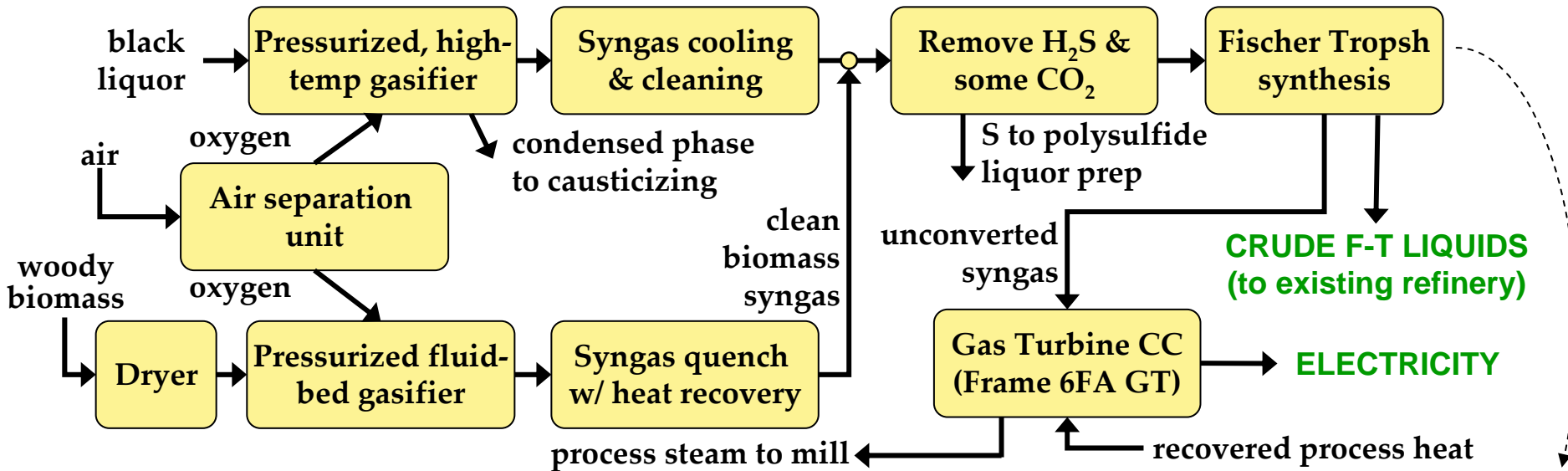
Georgia has most pulping capacity of any U.S. state

= pulp mill

BLGCC: Black Liquor Gasification Combined Cycle Electricity Production

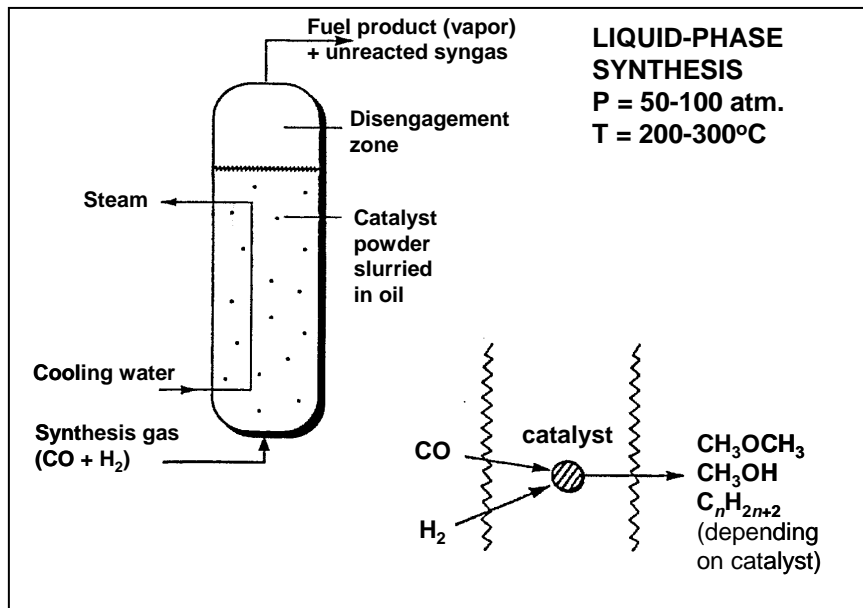


Biorefinery Co-Producing Liquid Fuels and Electricity



Some Synthetic Liquid Fuels from CO + H₂

- **Fischer-Tropsch Liquids (FTL)**
 - Synthetic crude refinable to zero-sulfur, high-cetane, low-particulate diesel and gasoline blendstocks
- **Dimethyl Ether (DME)**
 - Propane substitute
 - No-sulfur, no-particulate, high-cetane diesel fuel.
 - Strong commercial interest in Asia and Europe
- **Mixed alcohols**
 - Mixture of ethanol and higher alcohols
 - Gasoline additive/substitute



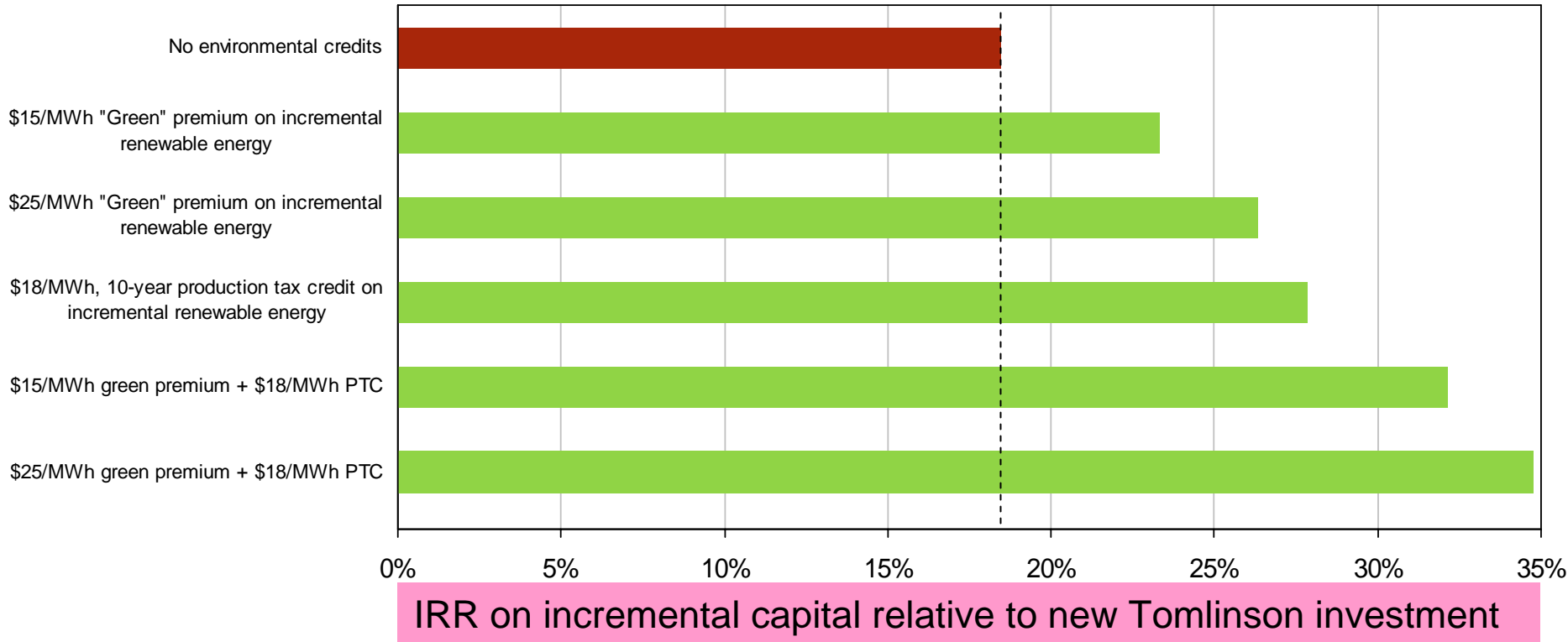
Nth Plant Performance and Cost Comparisons

	Tomlinson ¹	BLGCC ¹	FTL ²	DME ²
Energy inputs (MW, lower heating value)				
Black liquor	393	351	351	351
Woody biomass	58	54	505	250
Natural gas	0	61	0	0
Energy outputs (MW, lower heating value)				
Liquid fuel	0	0	343	168
Electricity (for pulp mill or export)	64	115	78	88
Process steam (for pulpmill)	212	200	200	200
Overall efficiency (LHV)	61	68	73	76
Installed capital cost (Million \$, mid-2005\$)	136	217	443	395

1. Source: E.D. Larson, S. Consonni, and R. Katofsky, *A Cost-Benefit Assessment of Biomass Gasification Power Generation in the Pulp and Paper Industry, Final Report*, October 8, 2003 (downloadable via <http://www.princeton.edu/~energy>).
2. Preliminary results from work in progress.

Internal Rate of Return on Incremental Investment in BLGCC

(without and with “green” credits)



Financial assumptions

- 50/50 debt/equity financing
- 8% cost of debt
- 40% federal + state taxes
- 2% property tax & insurance
- 95% capacity factor
- 25 year economic life
- 4.0 to 4.3 ¢/kWh electricity value
- Levelized woody-residues price, \$1.5/MBtu
- Levelized natural-gas price, \$3.8/MBtu

Relative Air Emissions for BLGCC

(L = low, M = moderate, H = high)

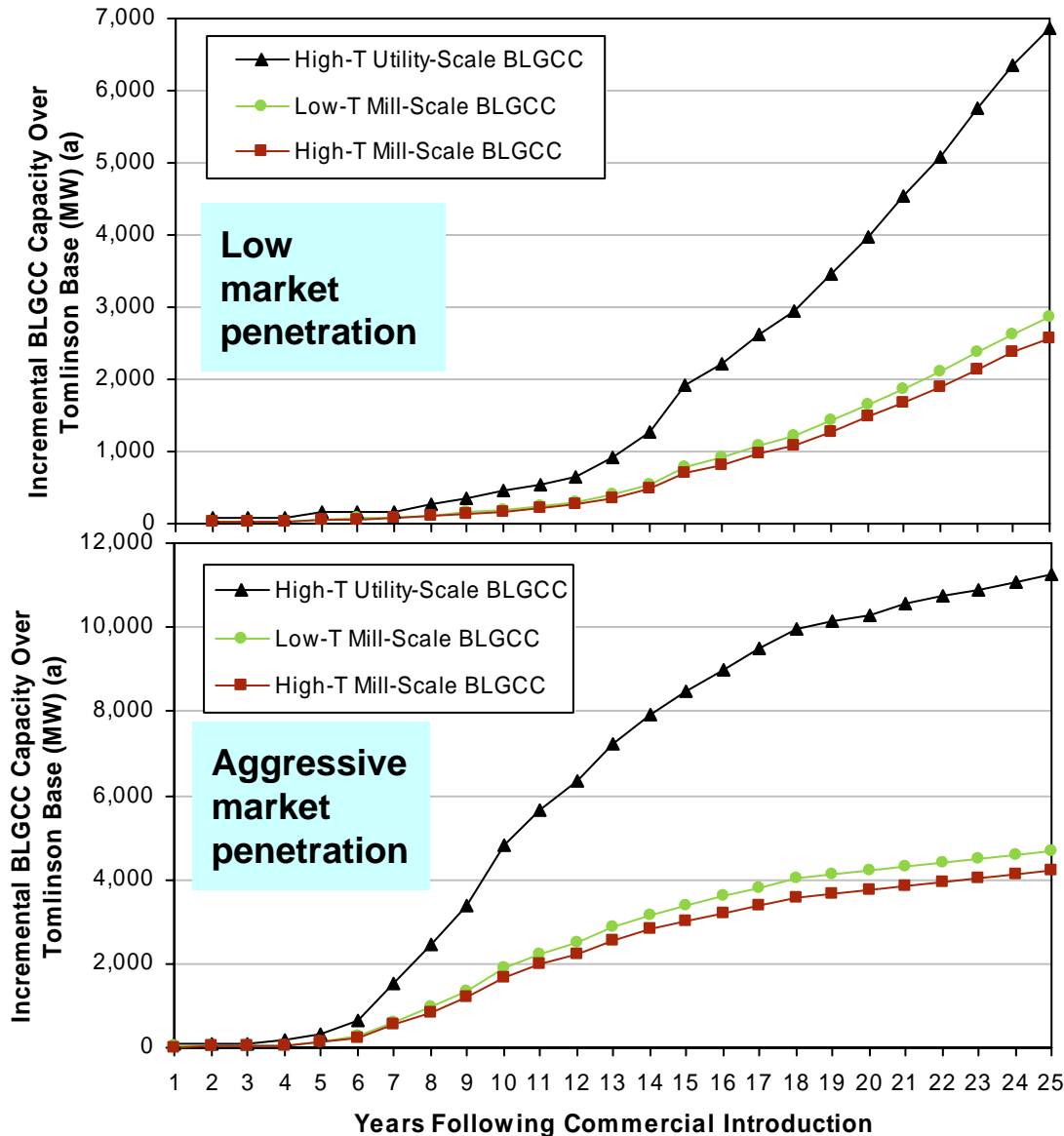
Pollutant	Relative Environmental Impact of Pollutant ¹	Relative Emissions Rates from Tomlinson Furnaces (uncontrolled)	Relative Emissions Rates with Controls on Tomlinson	Relative Emissions Rates with BLGCC Technology
SO ₂	H	L	L (not required)	L
NO _x	H	M	M ³	L
CO	L	M (can be highly variable)	M ³	L
VOCs	H	L	L ³	L
PM	H	H ²	L-M	L
CH ₄	L	L	L ³	L
HAPs (metals)	M	L ²	L ²	L
TRS	L	L	L ³	L

1. In general, not specifically for the P&P industry.

2. Current MACTII rules are expected to result in about a 10% reduction of HAPs and a modest reduction in PM.

3. Not generally practiced other than by maintaining good combustion efficiency.

Key BLGCC Impacts, Southeast U.S.



- Within 25 years, BLGCC could add generating capacity of 2,500-7,000 MW_e (low) to 4,000-11,000 MW_e (aggressive).
- Within 12 years BLGCC could contribute up to 44% of required new renewable power under an RPS that mandates 5% of all new electricity be renewable.
- With utility-scale BLGCC, cumulative (25-year) CO₂ emission reductions could be up to 344 million tons (~7.5% of otherwise expected increase in grid emissions).

Biorefining: Potential DME Markets

Blending with LPG

- 20% of current LPG fuel market in USA is ~8 million tonnes/yr of DME.

75 large pulpmill biorefineries

	fuel	feedstock	total
Residential	0.57	0	0.57
Commercial	0.10	0	0.10
Transport	0.01	0	0.01
Industry	0.41	1.76	2.17
Total	1.09	1.76	2.85

Centrally-Refueled Diesel Fleet Vehicles

Vehicle Type	Total Number	# Centrally-Refueled	Annual diesel million gal/y (quads/yr)	DME million t/yr
Total of below 3 types	4,718,419	3,844,857	6,329 (0.922)	35
Urban transit buses ¹	76,190	73,904	656 (0.096)	4
School buses ²	458,229	426,153	913 (0.133)	5
Light/delivery trucks ³	4,184,000	3,344,800	4,760 (0.693)	26

¹Avg of 3.6 MPG at 31,932 mi/yr ²Avg of 7.0 MPG at 15,000 mi/yr ³Avg of 17.6 MPG at 24,960 mi/yr

330 large pulpmill biorefineries

Biorefining Potential

		FTL ⇔ motor diesel			DME ⇔ propane		
		Million gallons/year		GA pulpmill prod as % of use	Million gallons/year		GA pulpmill prod as % of use
Pulpmill BL Solids (10 ⁶ tds/yr)	Pulpmill FTL (diesel eq)	Diesel Use (2004)	Pulpmill DME (prop. eq)		Propane Use (2004)		
US 77.1	6,775	47,186	2%	5,178	13,758	5%	
SE 52.2	4,585	12,905	7%	3,505	2,640	25%	
GA 10.0	878	1,767	50%	671	260	258%	

- This scenario (for all U.S.) requires ~1.2 Quads/year more biomass than the biomass currently used for energy at pulp/paper mills.
 - “Billion ton” study by USDOE/USDA* indicates potential long-term biomass energy supplies in U.S. (currently unused biomass) of about 22 Quads/yr.
- ➔ Biomass supplies are sufficient to build a biorefinery industry on the pulp and paper industry and to expand biorefining substantially beyond this.

* Source: Perlack, Wright, Turhollow, Graham, Stokes, and Erbach, *Biomass as Feedstocks for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-Ton Annual Supply*, jointly sponsored by USDOE and USDA, Oak Ridge National Lab, April 2005.