

Gasification-Based Biorefineries Integrated with Pulp Mills

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Gasification-Based Liquid Fuels

Fischer-Tropsch Liquids (FTL)

- Synthetic crude refinable to zero-sulfur, high-cetane, low-particulate diesel blendstock and gasoline blendstock.
- Explosion of global investment in gas-to-liquids GTL (e.g., Qatar, Nigeria)
- Growing investment in coal-to-liquids, CTL (China, USA).
- Initial commercial investment in biomass-to-liquids, BTL (Germany)

Dimethyl Ether (DME) (first cousin of methanol)

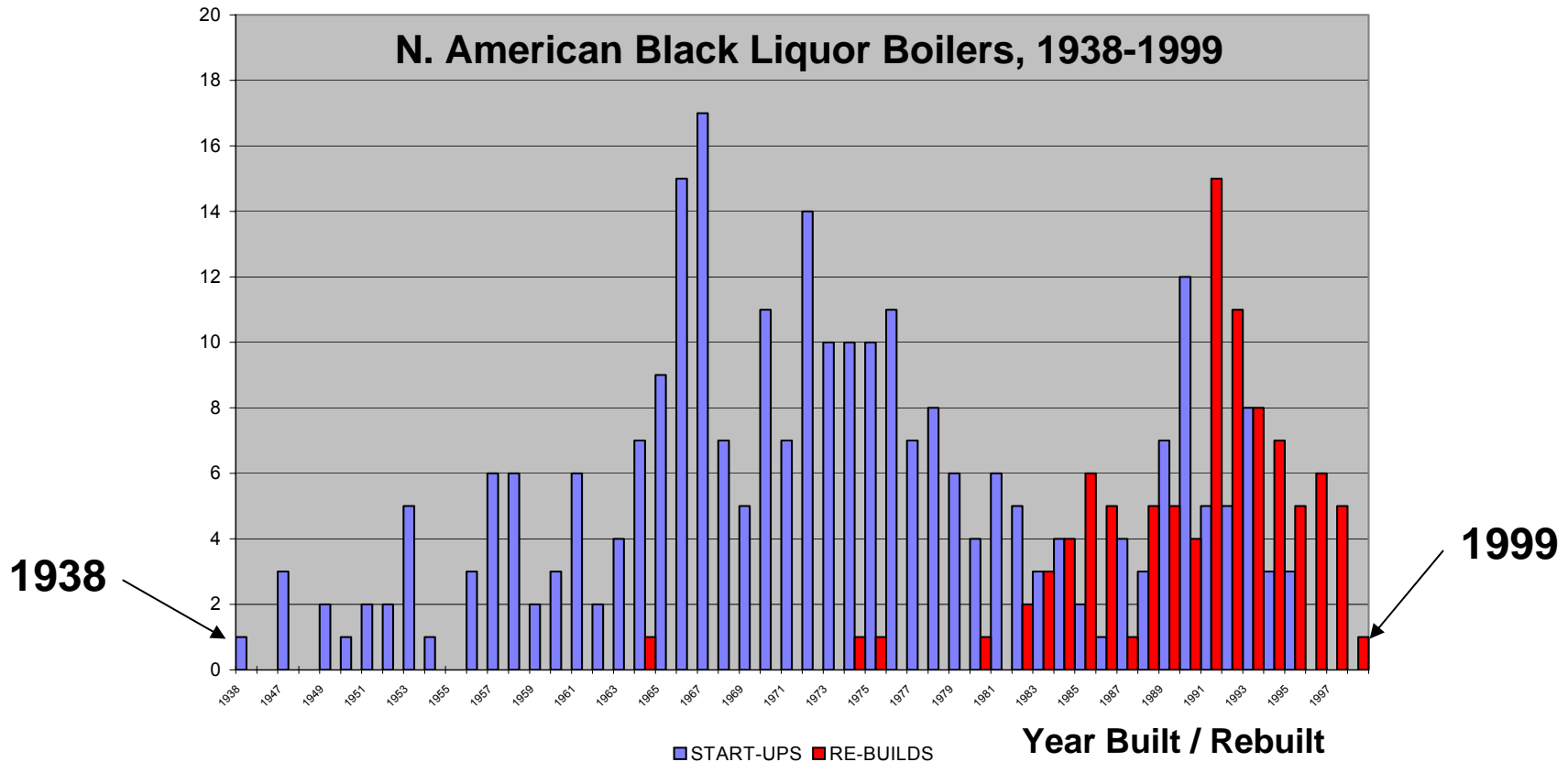
- Propane substitute/blendstock or zero-S, zero-PM, high-cetane diesel fuel.
- Exploding commercial investment in DME from coal in China;
- Long-standing methanol from coal production in China and USA;
- Growing investment in DME from gas in Iran, China, and (as buyer) Japan;
- Swedish interest in DME from biomass.

Mixed alcohols (MA)

- Mixture of ethanol and higher alcohols as a gasoline blendstock.
- No commercial synthesis technology available today.
- Demonstrated catalyst performance (modified methanol or modified FTL catalysts) does not yet approach MeOH or FTL catalyst performance.
- Interest exclusively in U.S.A., driven largely by policy emphasis on ethanol.

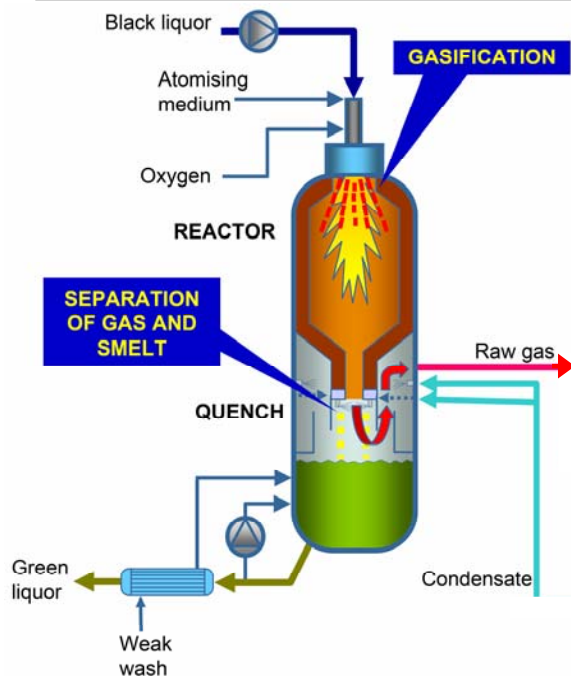
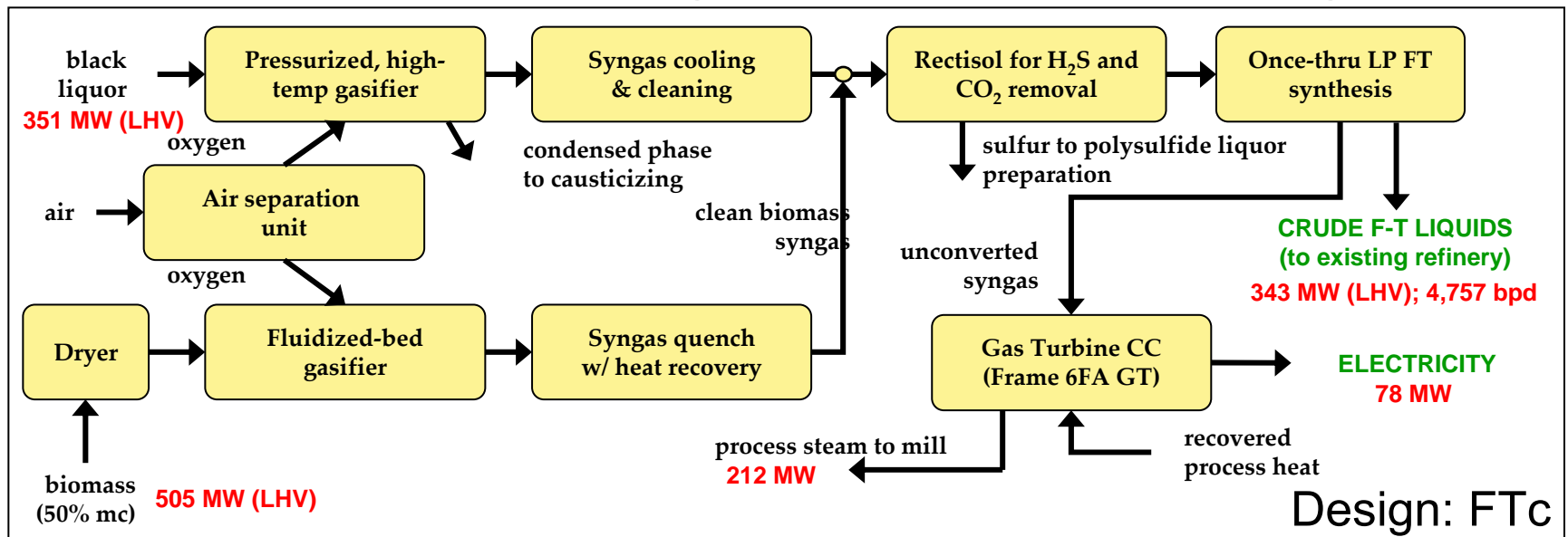
Bioenergy in the Kraft Pulp Industry

- U.S. industry uses >1.5 quads/yr bioenergy, mostly **black liquor**.
- Aging **Tomlinson** black liquor boiler fleet.



- Tough global competition is spurring northern-hemisphere pulp industry interest in diversification, e.g., fuels/chemicals production.
- Window of opportunity for introducing gasification/biorefining.

Pulp Mill-Integrated Biorefining



Pressurized, high-temperature, O₂-blown (Chemrec) black liquor gasifier adopted in our biorefinery designs:

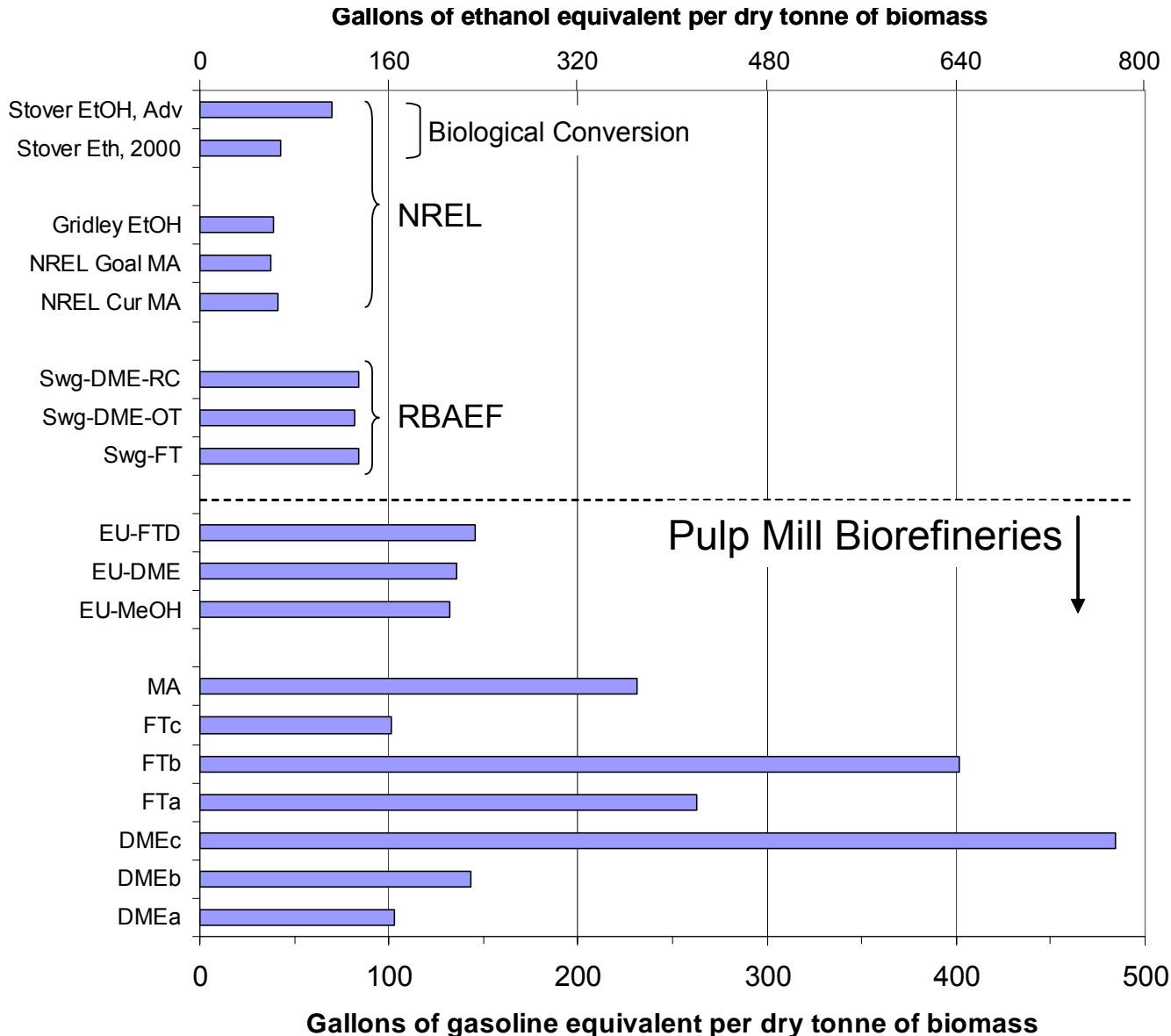
- Pilot-scale (20 tpd BLS) pressurized gasifier tests ongoing in Sweden since mid-2006.
- Commercial demo under planning for implementation by 2010 in Sweden.

Technology in Our Biorefinery Designs

Technology		Status*	FTa	FTb	FTc	DMEa	DMEb	DMEc	MA
Black Liquor Gasification Island	Entrained flow gasifier	Pilot	◆	◆	◆	◆	◆	◆	◆
	Quench	Pilot	◆	◆	◆	◆	◆	◆	◆
	O ₂ feed	Com	◆	◆	◆	◆	◆	◆	◆
Woody Biomass Conversion	Fluid-bed gasifier	Pilot	◆	◆	◆		◆	◆	◆
	Syngas cooler	Pilot	◆	◆		◆	◆	◆	
	Hot gas filter	Pilot	◆	◆			◆	◆	
	Quench cleanup	Com			◆				◆
	O ₂ feed	Com	◆	◆	◆		◆	◆	◆
Boiler	Com				◆				
H ₂ S Capture and Recovery	Rectisol®	Com	◆	◆	◆	◆	◆	◆	
	Selexol®	Com							◆
	Claus/SCOT	Com	◆	◆	◆	◆	◆	◆	◆
Fuel Synthesis Island	Slurry bed reactor	Com	◆	◆	◆	◆	◆	◆	
	Fixed-bed reactor	Lab							◆
	Syngas recycle	Com				◆	◆		◆
Power Island	Gas turbine	Com	◆	◆	◆		◆	◆	◆
	Back pressure ST	Com	◆			◆	◆	◆	◆
	Condensing ST	Com		◆	◆				◆

* Com = commercially-offered; Pilot = Demonstrated at pilot scale; Lab = Demonstrated in Laboratory

Comparing Effective Liquid Fuel Yields



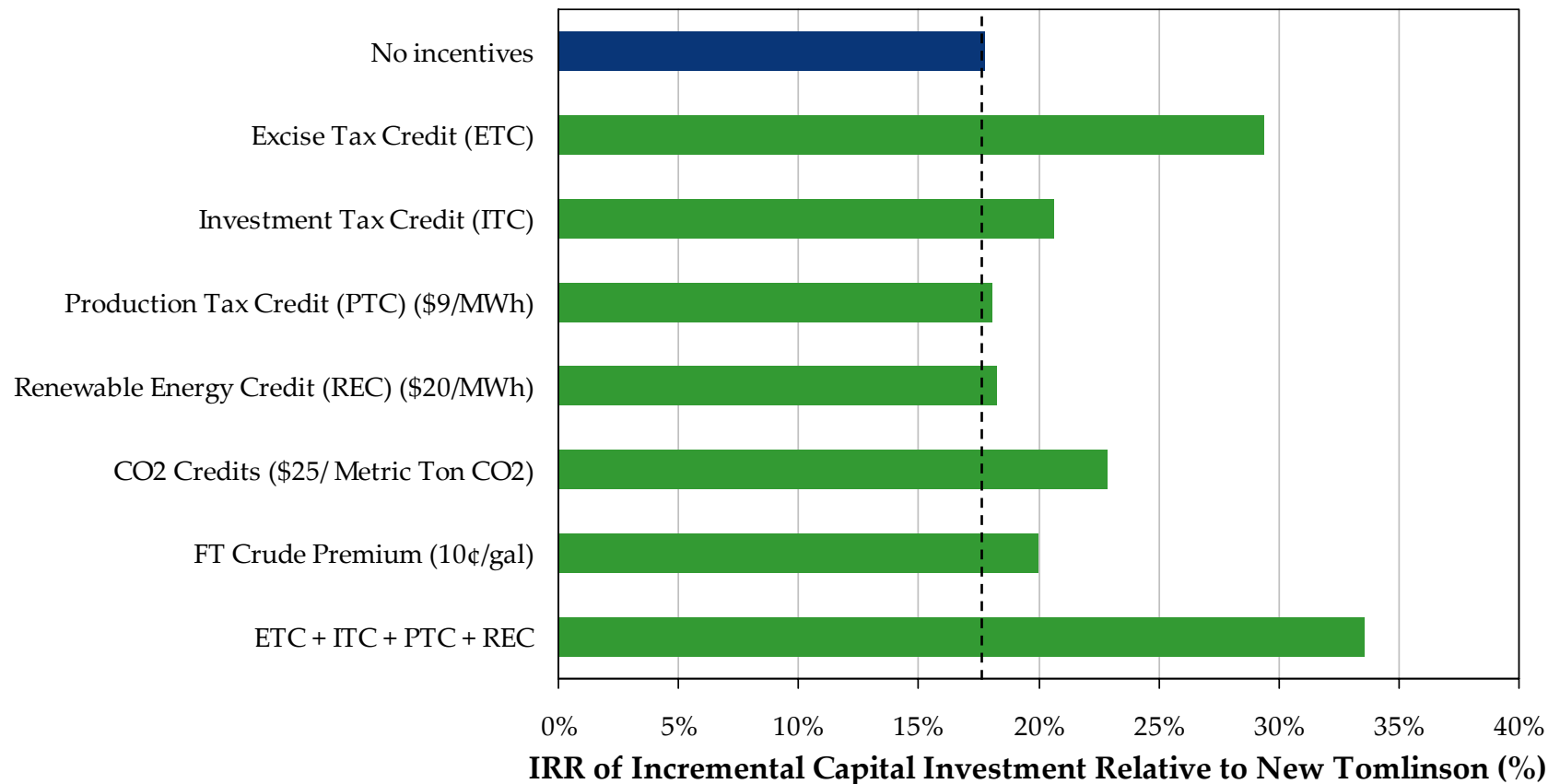
- A biorefinery integrated with a pulp mill effectively requires much less biomass per unit of liquid fuel produced vs. “stand-alone” biofuel production
- The reason is that black liquor (and some biomass) are charged against services provided to the mill (chemical recovery, process steam and power) – not against liquid fuel.

“Nth Plant” Installed Capital Costs

- New Tomlinson boiler system: ~\$140 million.
- New gasification-based biorefinery: \$250-500 million.

THOUSAND 2005\$	Power/Steam ^a		Biorefinery -- Power/Steam/Liquid Fuel						
	Tomlin.	BLGCC	DMEa	DMEb	DMEc	FTa	FTb	FTc	MA
Recovery boiler	125,018	0	0	0	0	0	0	0	0
Steam system modifications ^b	11,136	0	3,000	0	0	0	0	0	0
Air separation unit (ASU)	0	42,628	43,053	61,561	52,933	55,001	72,762	77,823	54,080
ASU increment for O ₂ delig. ^c	0	1,118	1,061	879	954	933	805	776	948
BL gasifier & green liquor filter ^d	0	63,720	63,720	63,720	63,720	63,720	63,720	63,720	63,720
Nitrogen compressor	0	0	0	1,188	810	1,071	1,757	2,013	5,181
Acid gas removal & sulfur recovery	0	19,003	37,732	37,732	27,321	27,321	27,321	42,164	24,529
Synthesis island	0	0	49,344	49,344	16,287	22,019	22,019	38,767	83,548
Combined cycle power island	0	89,243	0	105,303	100,091	90,018	171,895	104,300	90,348
Wood yard expansion ^e			867	2,697	789	1,303	4,832	5,788	1,077
Biomass dryer, including RTO ^f	0	0	0	50,295	32,523	37,286	72,507	45,558	31,383
Biomass gasifier & tar cracker	0	0	0	28,354	18,320	20,867	41,365	47,063	22,949
Biomass syngas cooler & filter	0	0	0	8,484	4,998	5,666	11,372	0	0
Biomass syngas cooler & wash	0	0	0	0	0	0	0	34,425	16,092
Biomass syngas expander	0	0	0	3,778	2,661	2,670	9,410	0	0
Hog fuel boiler	0	0	50,736	0	0	0	0	0	0
Other ^g	0	2,359	2,359	2,359	2,359	2,359	2,359	2,359	2,359
Overnight Installed Capital Cost	136,154	218,072	251,873	415,695	323,766	330,234	502,125	464,755	396,215
Annual non-fuel O&M cost^h	5,446	8,723	10,075	16,628	12,951	13,209	20,085	18,590	15,849

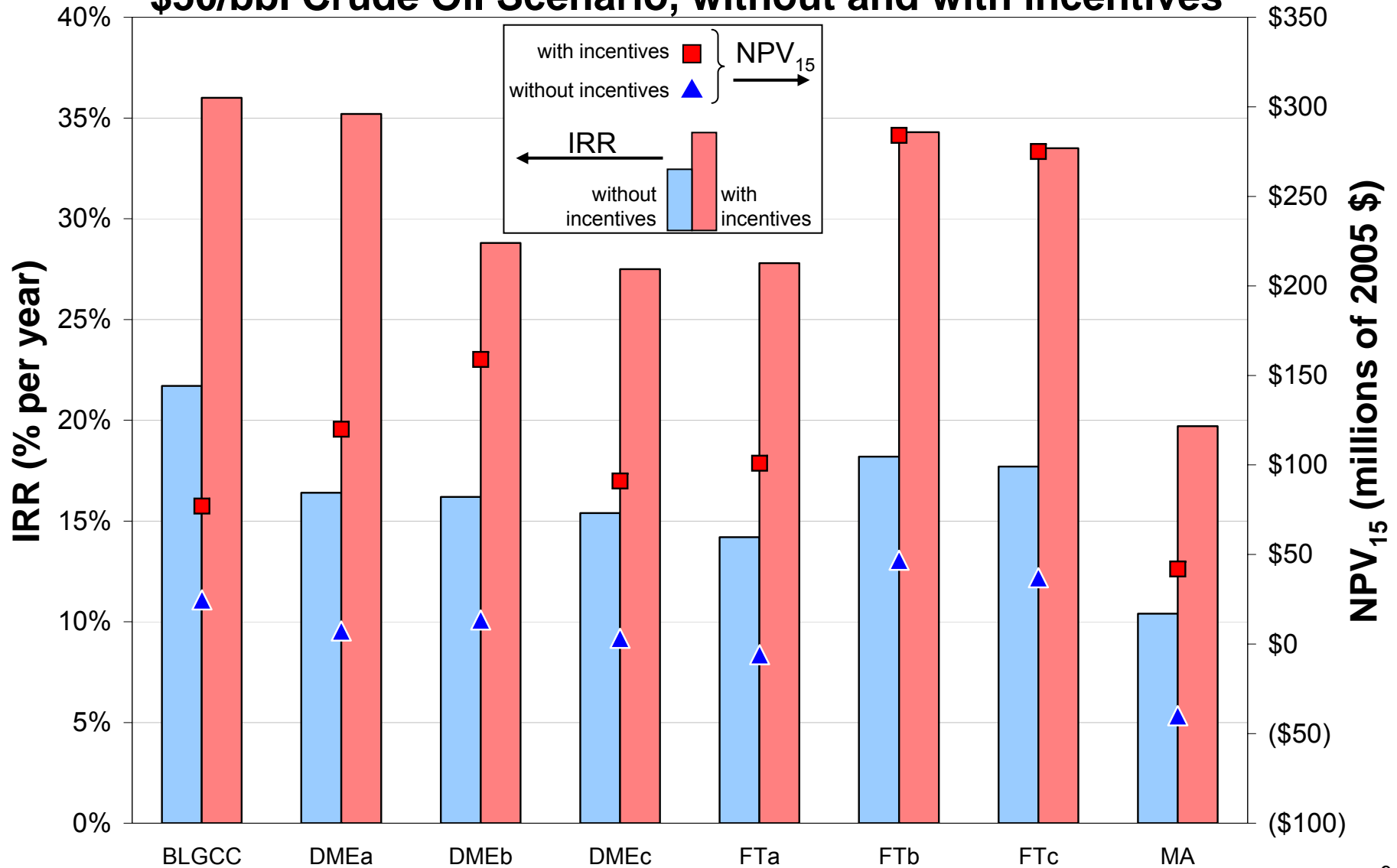
Internal Rate of Return Analysis: FTc



- \$330 million incremental capital investment
- \$50/bbl Crude Oil Scenario (AEO '06 Reference Projection)
- Electricity sale price: 5.3 c/kWh (without incentives)
- Incentives examined:
 - Excise Tax Credit (ETC): Equivalent to existing \$0.51/gal for ethanol on energy basis.
 - Investment Tax Credit (ITC): 20% gasification tax credit (under EPAct 2005).
 - Production Tax Credit (PTC): \$9/MWh for 10 years (on incremental electricity relative to Tomlinson).
 - Renewable Energy Credit (REC): \$20/MWh (e.g., under RPS or green credits). Applies only to incremental electricity.
 - CO₂ Credits: \$25/tCO₂ applied to net reductions (including grid offsets and petroleum displaced)
 - FT Crude Premium: \$4.2/bbl for superior performance

Pulpmill Biorefinery Financial Performance

\$50/bbl Crude Oil Scenario, without and with incentives



Final Comments

- Pulpmill-integrated gasification biorefinery economics are much better than stand-alone biorefinery due to capital cost-sharing with pulp mill and low effective feedstock costs.
- But the pulp industry is conservative and technology risk-averse → pulp mill operation requires >95% on-stream time for black liquor chemical recovery system.
- Pulp industry needs energy-industry partners to help manage risk and contribute know-how to move forward with biorefining.
- Woody biomass gasification (for IGCC-electricity and/or liquid fuels) could be a way to minimize initial risks.

www.princeton.edu/~energy

1. Larson, Consonni, Katofsky, Lisa, and Frederick, “A Cost-Benefit Assessment of Gasification-Based Biorefining in the Kraft Pulp and Paper Industry,” final report (in 4 volumes) to U.S. Department of Energy and the American Forest & Paper Association, DOE contract DE-FG26-04NT42260, December 2006.
2. Larson, Consonni, Katofsky, “A Cost-Benefit Assessment of Biomass Gasification Power Generation in the Pulp and Paper Industry,” final report to U.S. Department of Energy, October 2003.

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