NATIONAL ENERGY TECHNOLOGY LABORATORY

Contribution of Biomass to the LCI of Cofiring Power

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Why cofire coal and biomass for power generation?

- **Advantages**
  - Biomass provides a renewable and domestic resource with widespread public acceptance
  - Large installed capacity of coal-fired power plants with conventional pollution control equipment which are capable of burning biomass
  - Current Federal and state policies like Renewable Electricity Credits subsidize its use in support of the benefits above
- **Disadvantages**
  - Multiple uses compete for land resource
  - Higher cost feedstock relative to coal and natural gas
- **Utility's willingness to cofire with biomass hinges on a perceived environmental (CO_2) benefit to tip balance in favor of advantages**
  - CO_2 released during combustion was taken up during growth: carbon neutral fuel

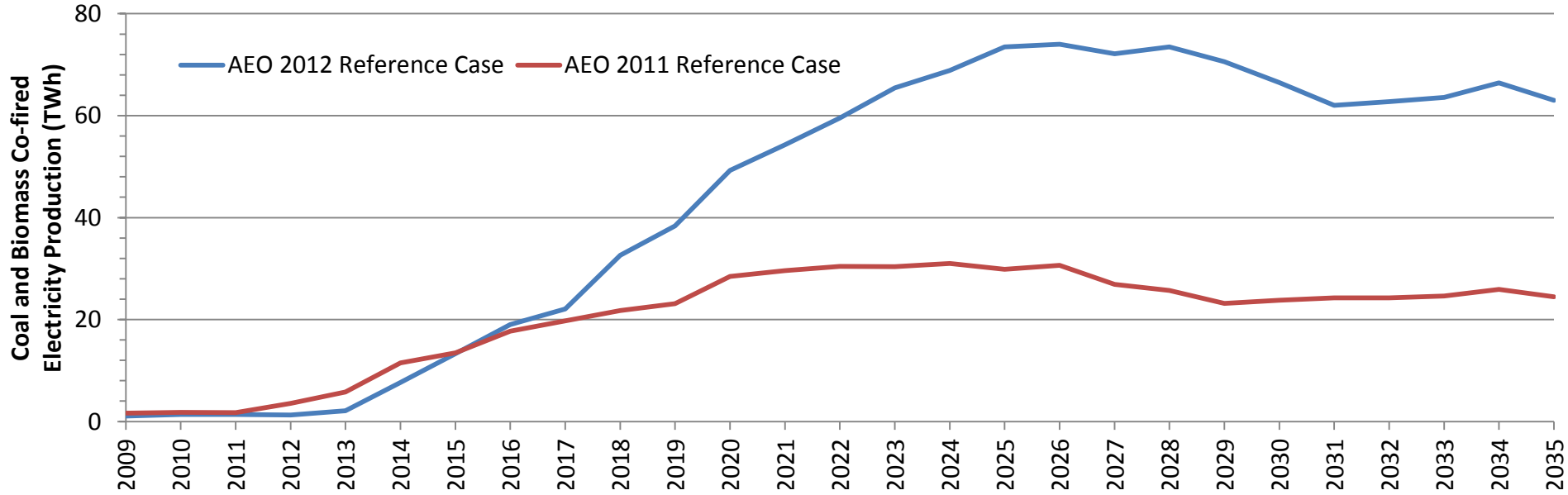
Source: USDA

Source: Freefoto.com

Current and Projected Cofiring Power Generation

Fuel	2010 Generation (TWh) (EIA, 2012)	
Coal	1,828	46.0%
Petroleum	34.7	0.9%
Natural gas	904	22.8%
Nuclear	807	20.3%
Hydro	253	6.4%
Geothermal	15.2	0.4%
MSW	16.4	0.4%
Biomass (Dedicated)	10.1	0.3%
Biomass (Cofiring)	**1.36**	**0.03%**
Solar	1.21	0.03%
Wind	94.6	2.4%

- **In 2010, the combustion of biomass accounted for 11.5 billion kWh of electricity generation (EIA, 2012)**
- **The co-firing of coal and biomass in the U.S. generated 1.36 billion kWh of electricity in 2010 (0.32% of the 430 billion kWh renewable electricity generation and 0.03% of the 3,998 billion kWh total electricity generation) (EIA, 2012)**
- **EIA's projected increase in biomass cofiring for electricity generation is driven by a combination of state RPS requirements and low cost of feedstocks**



3 Categories of Biomass Used in Cofiring

- **Agricultural residues**
  - Resource base of agricultural residues estimated by applying crop production statistics with residue-to-grain ratios (UTENN, 2010)
  - On a production basis, corn and wheat are largest crops in U.S. and have residue-to-grain ratios of 1 and 1.7, respectively (ORNL, 2011)
- **Forest residues and thinnings**
  - Most resources used by forest products industry, dominated by producers such as Georgia Pacific & Weyerhaeuser, plus thousands of small businesses that make paper & wood products
- **Herbaceous and woody energy crops**
  - Herbaceous Energy Crops: Switchgrass often used as benchmark for herbaceous perennial energy crops & has been focus of most research
  - Hybrid Poplar (HP): can be grown in areas currently in forestland or where herbaceous energy crops can be grown; poplar and willow are the two most prevalent SRWC

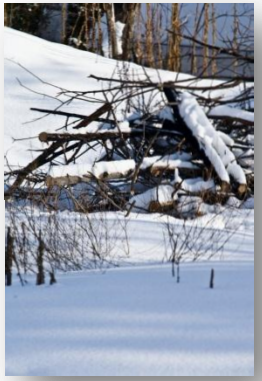
Hybrid Poplar

Source: USDA

Switchgrass

Source: © Aprescindere | Dreamstime.com

Forest Residue



Source: © Leloft1911 | Dreamstime.com

Corn Stover

Source: © Emily Jindra | Dreamstime.com

Potential for Cofiring Biomass in Existing Coal-fired Fleet

Exceeds Current Economic Limit for Existing Power Plants

(excluding significant boiler modifications & plant derating)

Percent of Coal-fired Power Supplied by Biomass	Annual Biomass Supply Requirement (million tons)	Annual Biomass Power (TWh)
0.5%	6	9
1%	13	18
2%	25	36
5%	64	90
10%	127	180
20%	255	360
30%	382	540
40%	510	720
50%	637	900
60%	765	1,079
70%	892	1,259
80%	1,020	1,439
90%	1,147	1,619
100%	1,275	1,799

Current Corn Market Size for Biomass Logistics

Exceeds EIA Projection of Biomass Cofire Growth from State Renewable Programs

(32 B kWh in year 2025)

Exceeds Currently Available Biomass Supply without Dedicated Energy Crops
(assumes 100% of the available biomass can be used for cofiring)

LC Models of Cofire Power have Many Potential Scenarios

- Biomass type: Residues vs. cultivated crops
- Regionalization
- Inclusion of direct and indirect land use
- Transport type: Truck vs. rail
- Biomass/coal proportion: 0-100%
- Preparation: Dry and grind vs. torrefaction, pelletization
- Coal type: Bituminous vs. subbituminous
- Plant construction: greenfield vs. retrofit
- Combustion: boiler vs. CFB, super or sub-critical
- Carbon capture: Sequestration or EOR

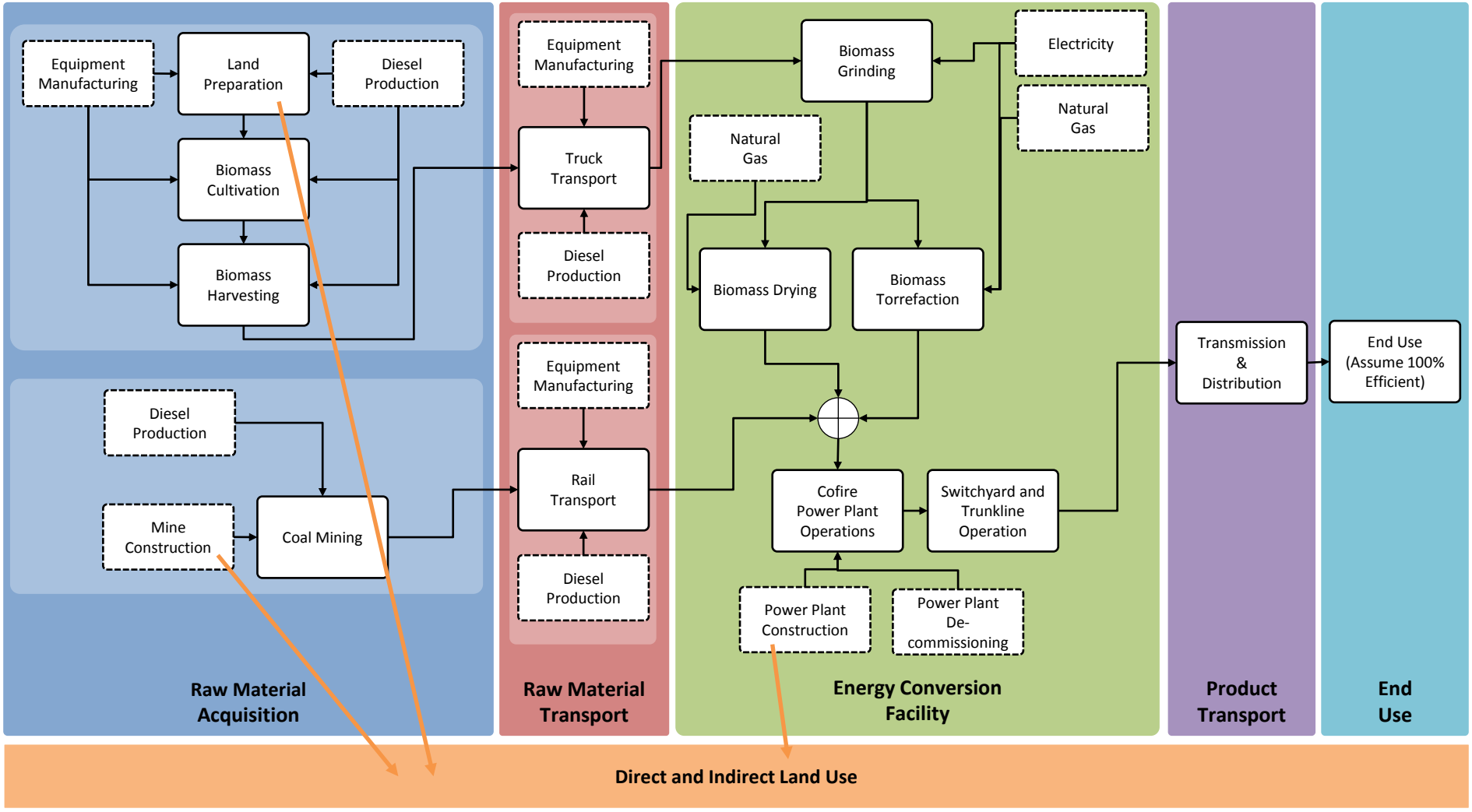
Results and project insights in this presentation are based on the following

- **DOE/NETL project results for co-utilization of coal and biomass**
  - Retrofit 550 MW subcritical PC plant with 10 or 20% of four different biomass types, with and without carbon capture
  - Supercritical Pulverized Coal Plant, 39% eff., New Construction
  - Integrated Gasification Combined Cycle (IGCC) Plant, 34% eff., New Construction, 13% biomass with and without capture
  - 550MW Circulating Fluidized Bed (CFB) Power Plant, 43% eff., New Construction, 30% Biomass, with and without CO_2 Capture

- **RAND biomass and cofire knowledge-base**
  - Detailed biomass uncertainty analysis modeling, industry cofire experience knowledge (based on operator interviews and site visits), and retrofit cost modeling

- **BAMF, BEAM Model**
  - National level biomass availability, acquisition cost, and environmental performance assessment for screening cofire (and other biomass utilization options) project feasibility

Life Cycle Process Flow for Cofire Power



Feedstock Modeling Parameters

Parameter	Hybrid Poplar			Switchgrass			Forest Residue			Corn Stover			Illinois No. 6		
	Low Value	Expected Value	High Value	Low Value	Expected Value	High Value	Low Value	Expected Value	High Value	Low Value	Expected Value	High Value	Low Value	Expected Value	High Value
Energy Content, Dry (Btu/lb)	8,438			7,787			8,438			7,152			11,666		
Annual Yield (tons/acre)	3.9	6.9	8.4	2.1	3.9	5.8	N/A			0.9	1.1	1.2	N/A		
Moisture Content, as Received, as Fed (%)	50%, 10%			15%, 5%			15%, 5%			50%, 10%			N/A		
Transport Distance (miles)	10	50	200	10	50	200	10	50	200	10	50	200	400		
Feedstock Cost ($/ton, $/MMBtu)	$81.6	$116.6	$151.6	$60.2	$86.0	$111.8	$21.5	$30.7	$40.0	$46.1	$65.9	$85.6	$26.8	$38.3	$49.7
	$4.8	$6.9	$9.0	$3.9	$5.5	$7.2	$1.3	$1.8	$2.4	$3.1	$4.4	$5.7	$1.2	$1.6	$2.1
Coal Methane Content (scf/ton)	N/A			N/A			N/A			N/A			360	422	500

Hybrid Poplar

Source: USDA

Switchgrass

Source: © Aprescindere | Dreamstime.com

Forest Residue

Source: © Leloft1911 | Dreamstime.com

Corn Stover

Source: © Emily Jindra | Dreamstime.com

Coal

Source: Freefoto.com

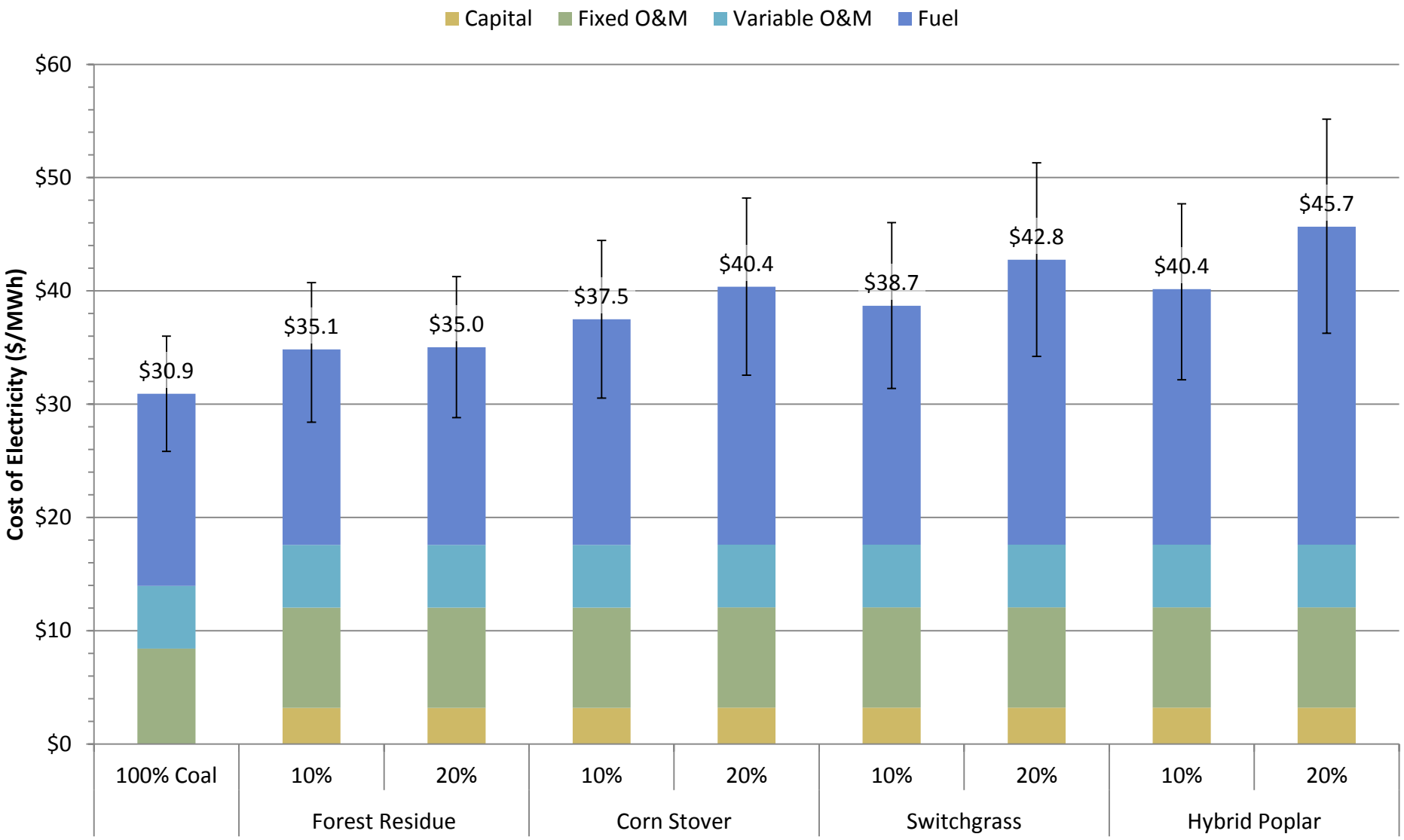
Power Plant Modeling Parameters

Power Plant Parameter	Coal Only		Cofire		
Technology Retrofit	Cofire Only	Carbon Capture	Cofire Only	Carbon Capture	CofireOnly
Biomass Share by Energy (%)	0%		10%		20%
Net Capacity (MW)	550	370	550	370	550
Capacity Factor (%)	85%		85%		
Plant Life (Years)	30		30		
Coal Feed Rate (tons/hr)	207		188		167
Biomass Feed Rate (tons/hr)	0		29		58
Heat Rate (Btu/kWh)	10,340	15,370	10,412	15,530	10,418
Efficiency (%)	33.0%	22.2%	32.8%	22.0%	32.8%
Capital ($/kW)	$0	$1,760	$230	$1,990	$230
Fixed O&M ($/kW-year)	$87	$133	$91	$137	$91
Variable O&M ($/MWh)	$8	$11	$8	$11	$8
Transmission Loss (%)	7%		7%		

Additional LCC Parameters

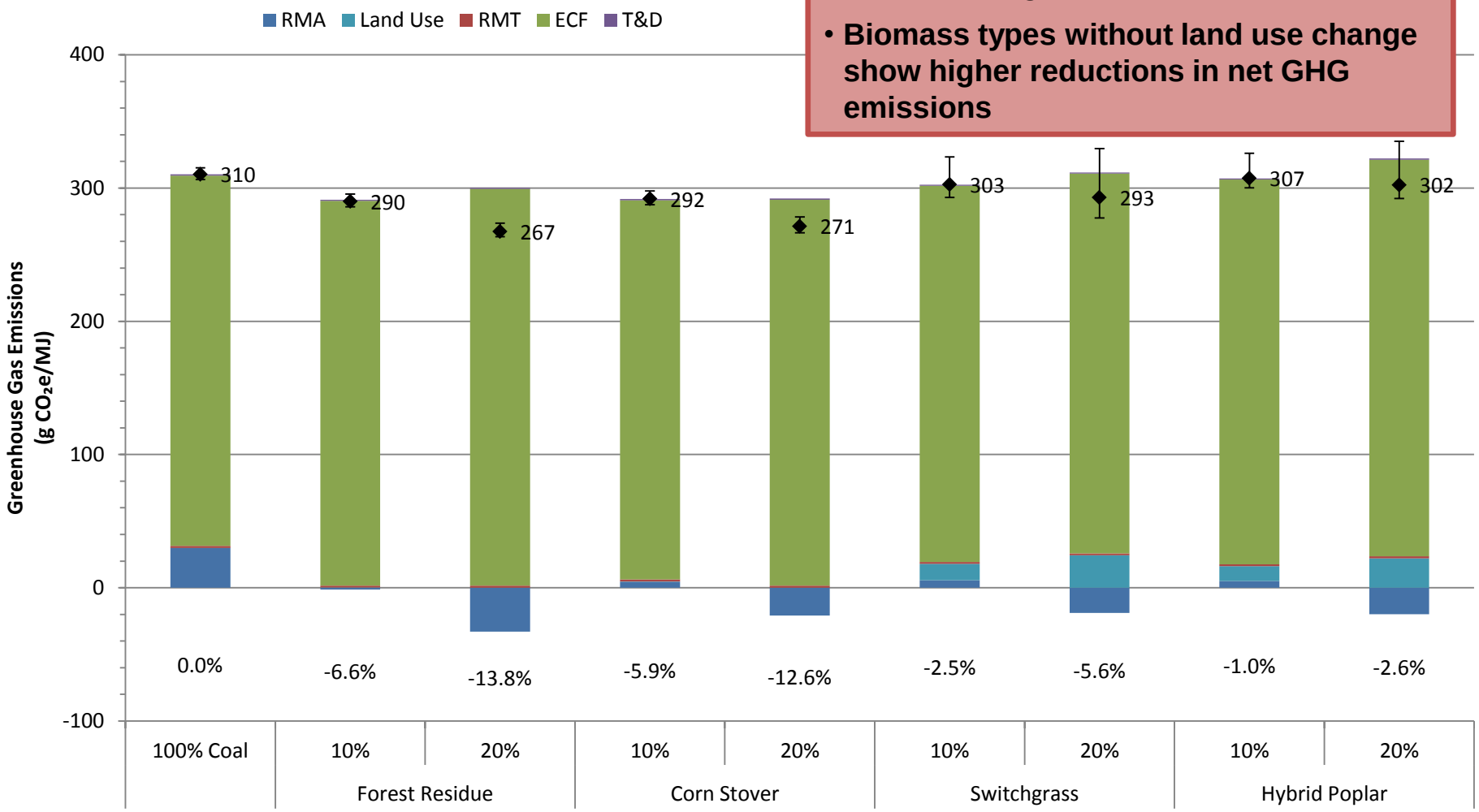
- Low risk investor-owned utility
- 50/50 debt/equity ratio with IRROE of 12%
- 4.5% interest rate
- 38% total tax rate, 20 yr MACRS depreciation
- 30 year plant life, O&M costs escalating 3.0% annually
- Costs are 2007$ (first year of capital expenditures)
- Startup year is 2008 (1 year of construction for retrofit)

Cofire Retrofit Power Plant Options: COE

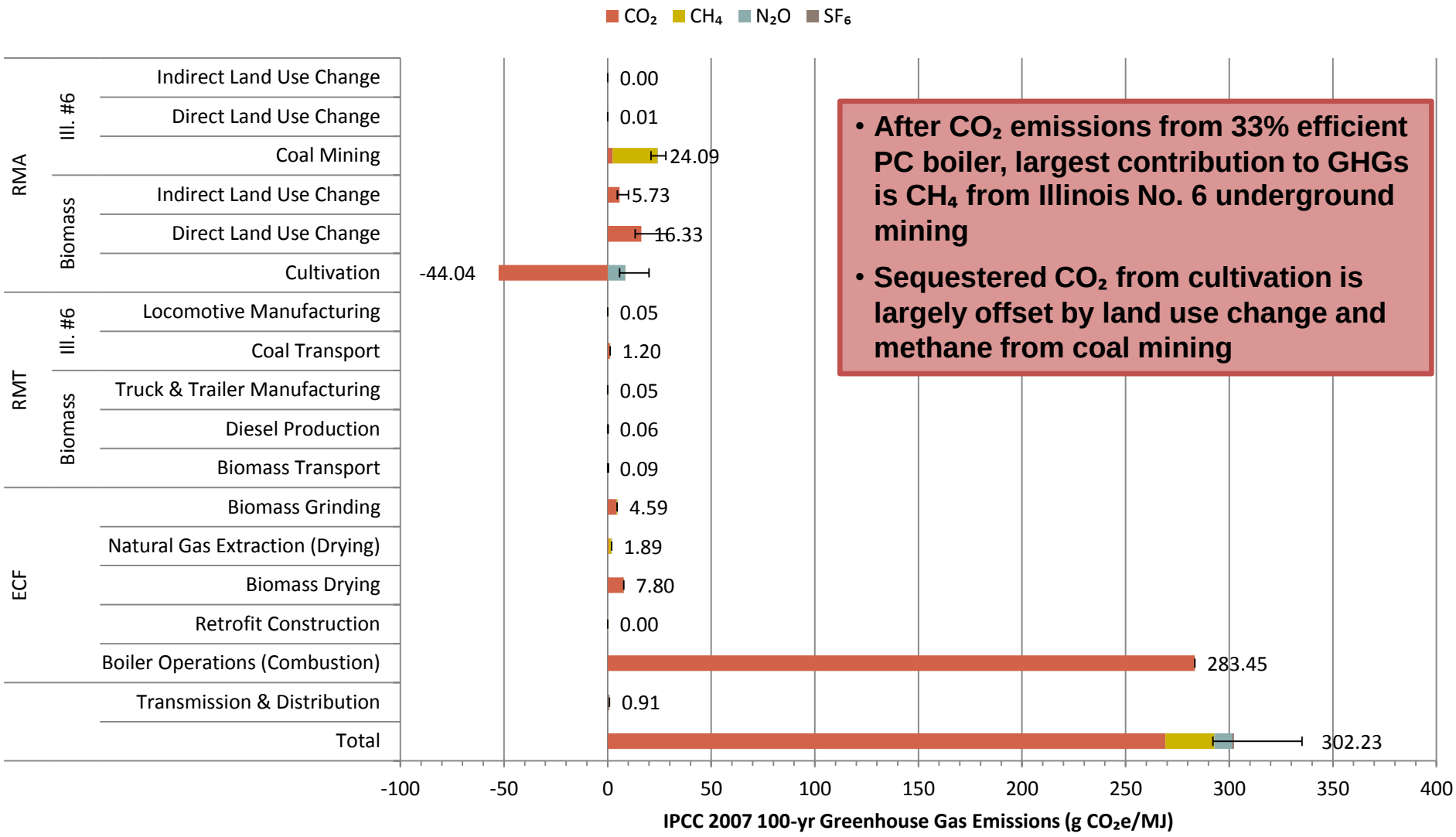


Cofire Retrofit Power Plant Options: LC GHG Emissions
(Illinois No. 6 Coal, Various Biomass Types)

- Net GHG change relative to coal only case, at 310 g CO_2e/MJ
- Biomass types without land use change show higher reductions in net GHG emissions



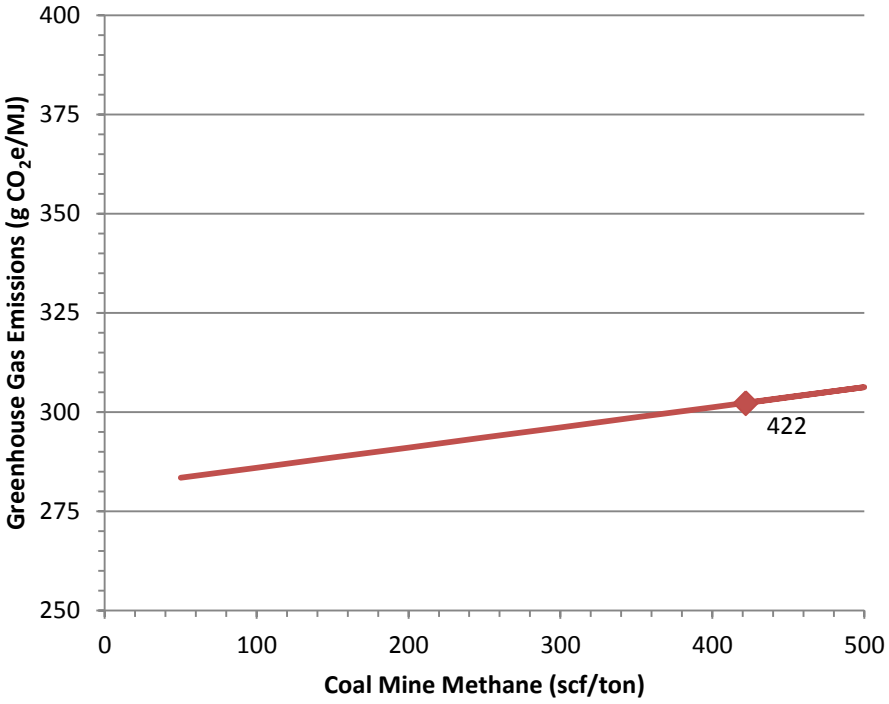
GHG Drilldown: 20% Hybrid Poplar Cofire

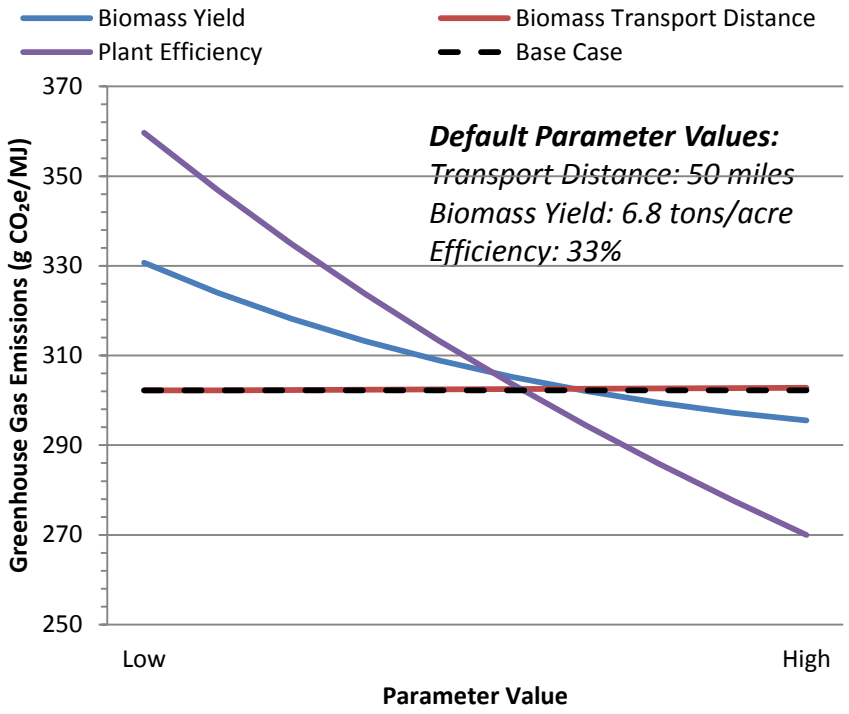


- After CO_2 emissions from 33% efficient PC boiler, largest contribution to GHGs is CH_4 from Illinois No. 6 underground mining
- Sequestered CO_2 from cultivation is largely offset by land use change and methane from coal mining

LC GHG Parameter Sensitivity

(20% Hybrid Poplar, 80% Illinois No. 6 Case)





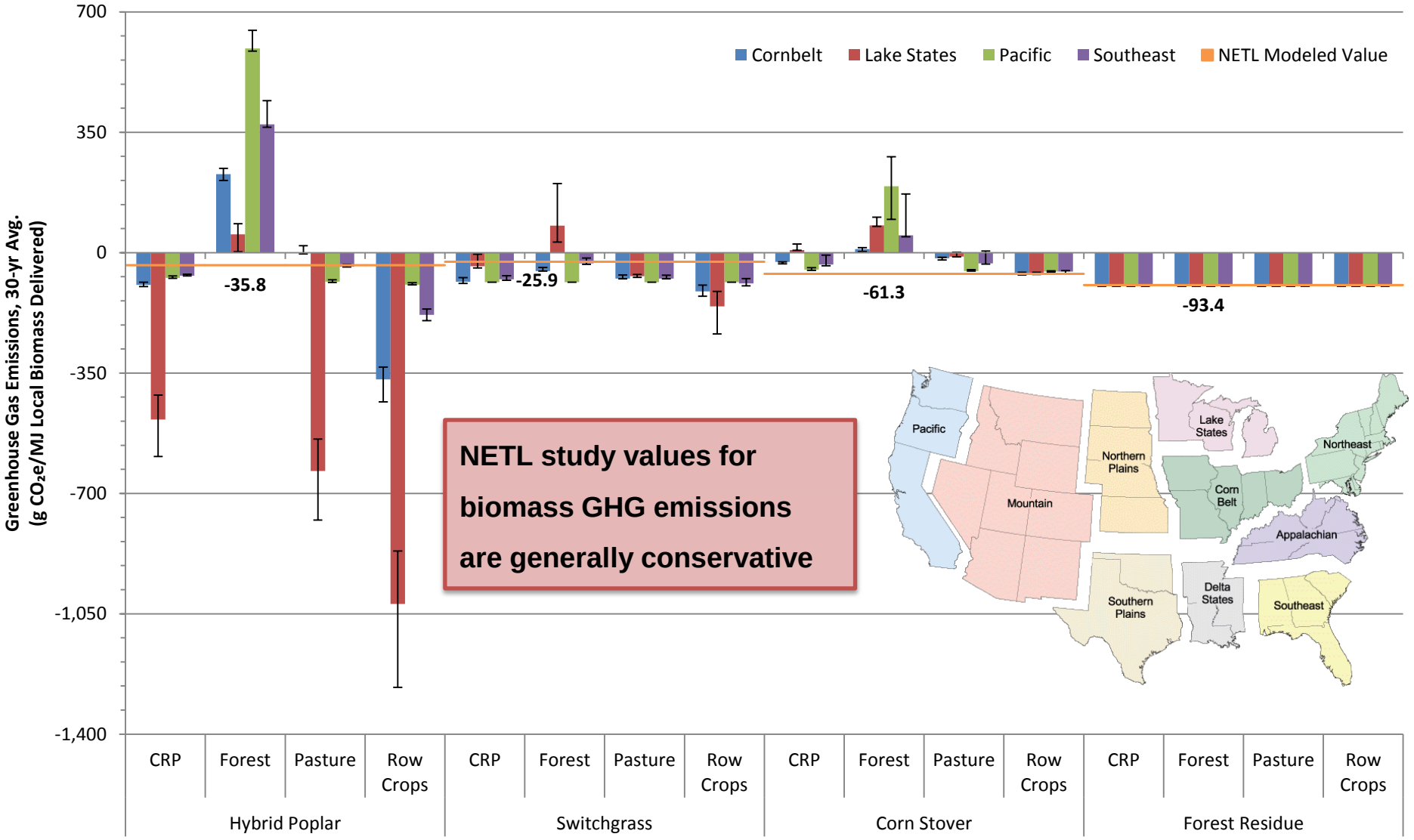
Coal Mine Methane: 50 – 500 scf/ton

Biomass Yield: 3.9 – 8.4 ton/acre

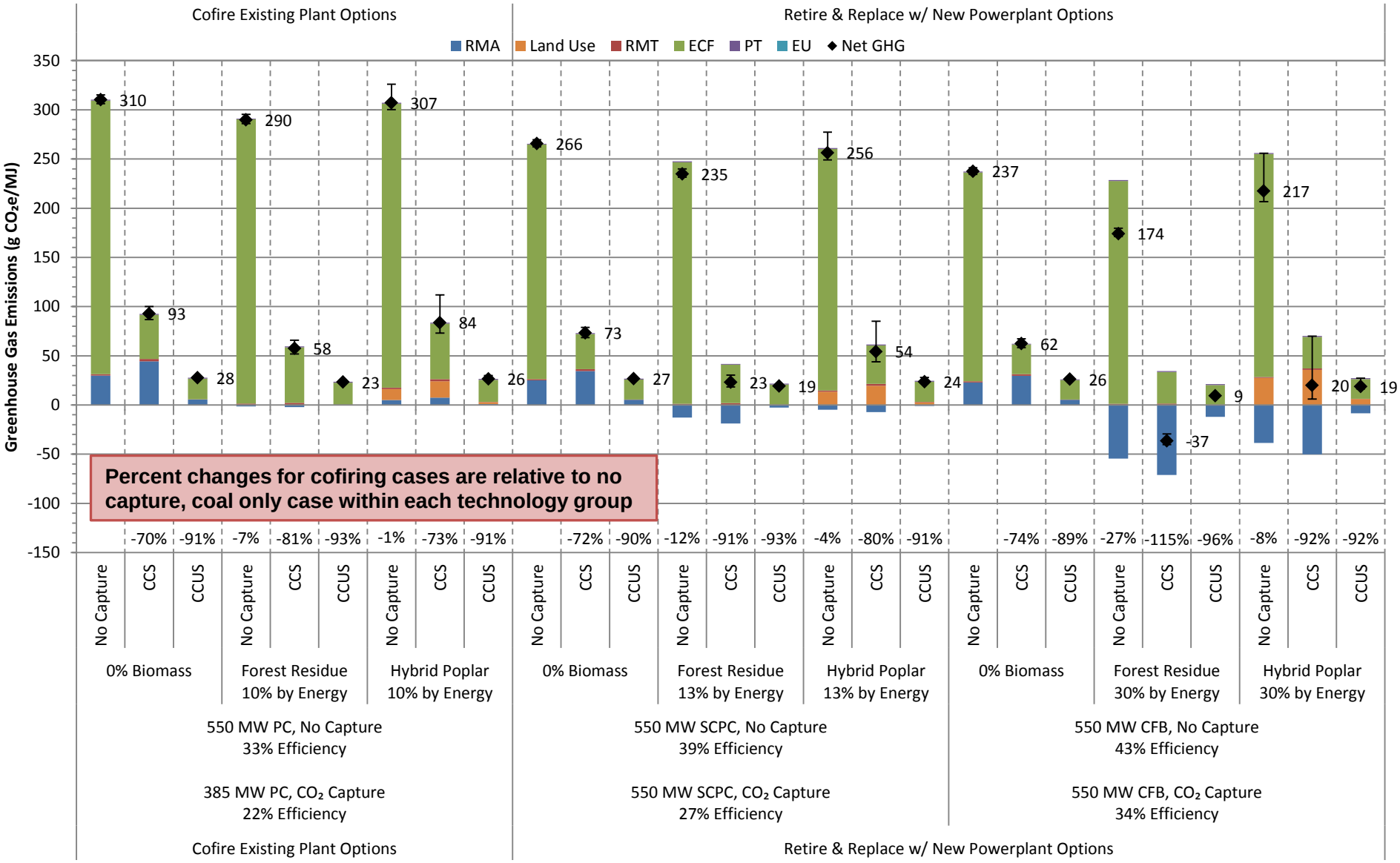
Transport Distance: 10 – 200 miles

Plant Efficiency: 27.5 – 36.7%

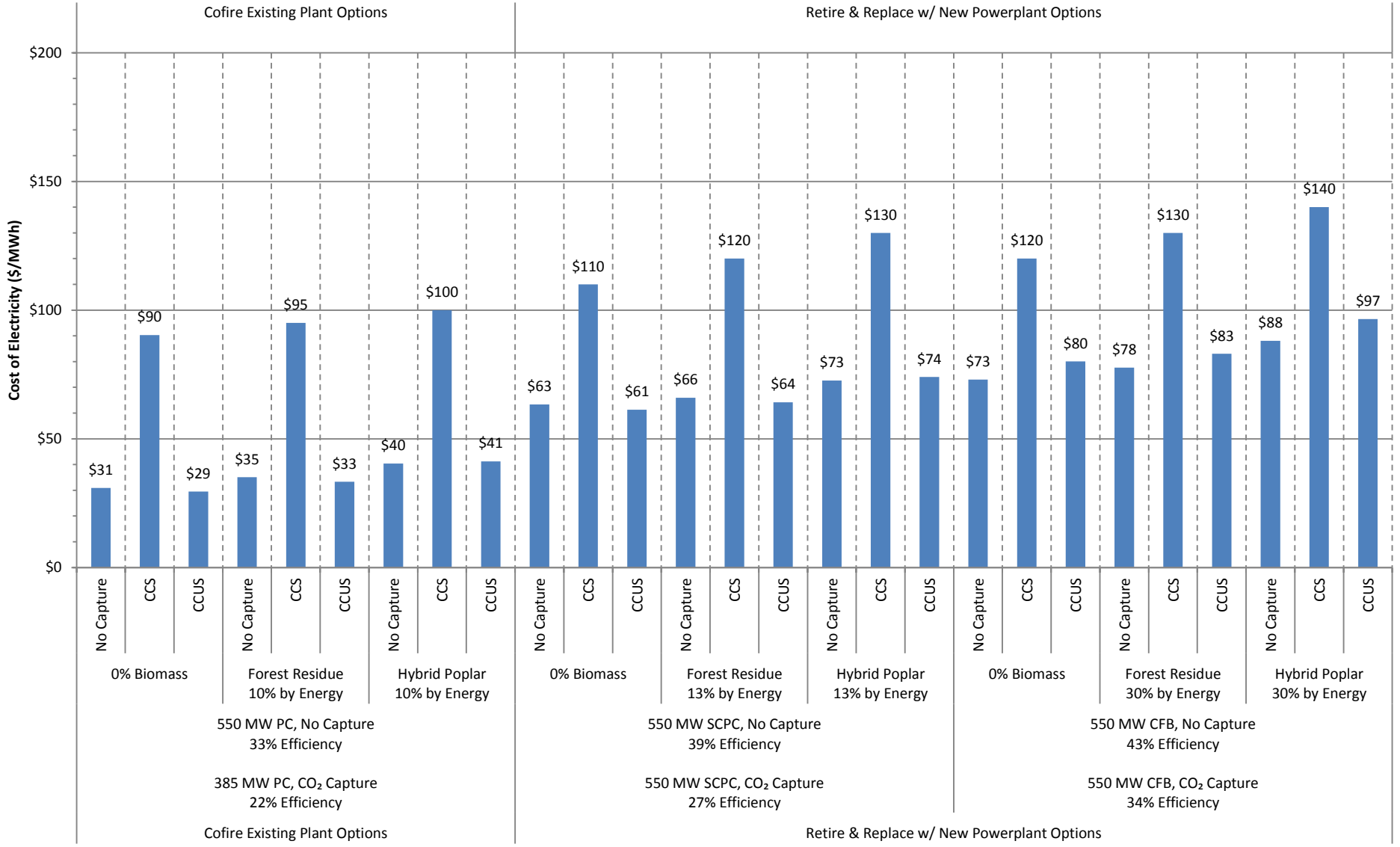
Biomass GHG Profiles Vary with Type, Region, Ecosystem



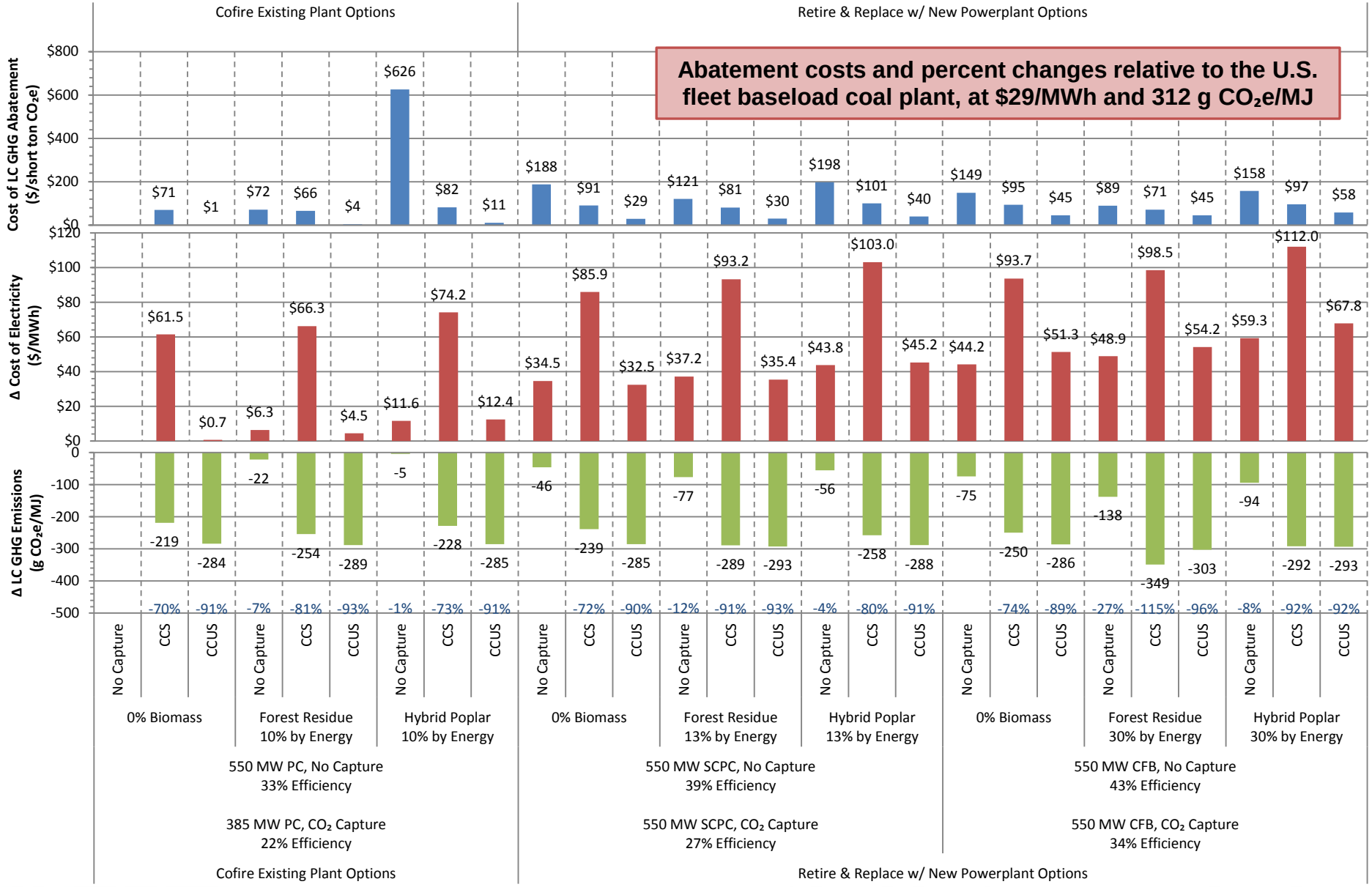
Life Cycle Greenhouse Gas Emissions



Cofire Power Options: Cost of Electricity

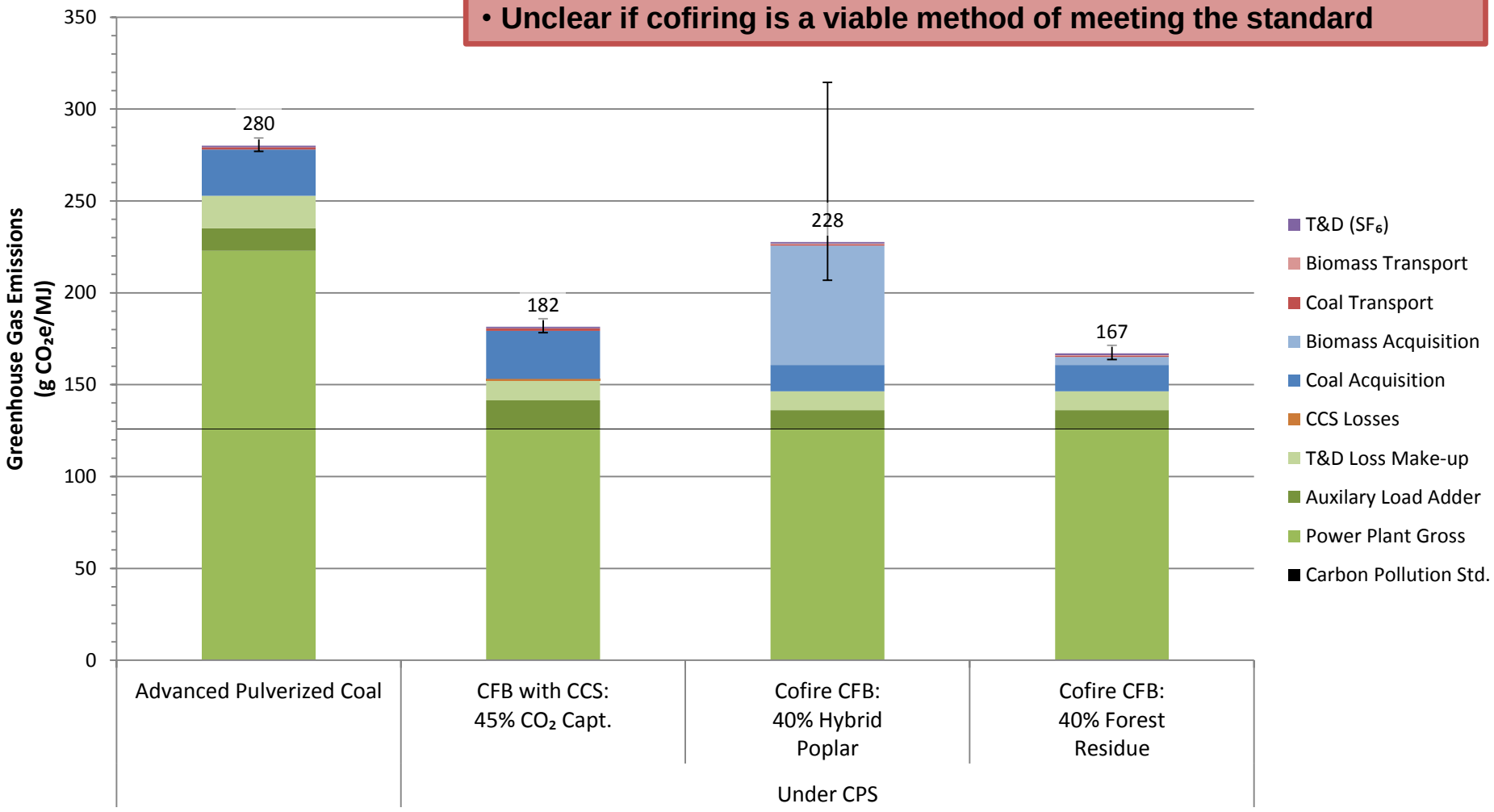


Cost of Improving the Existing Coal Fleet



Options for Meeting the Federal Carbon Pollution Standard

- New Source Performance Standard under the Clean Air Act limits new power plants >25MW to 1,000 lbs CO_2/MWh over 30 years
- Unclear if cofiring is a viable method of meeting the standard



Conclusions

- **Some biomass can be used to lower carbon footprint of power plants**
  - Depends heavily on the type of biomass and assumptions regarding yield and direct and indirect land use
- **Power plant technology is a much bigger driver of GHG reductions**
  - Advanced power plants have increased efficiency from current fleet
- **Post-combustion CO_2 capture is an even larger driver of reductions**
  - This comes at a significant cost, for which enhance oil recovery is a potential mitigating use for the CO_2
- **Need for research to reduce the uncertainty surrounding biomass challenges**

Reports & Tools: *www.netl.doe.gov/energy-analysis*

Unit Process Data: *www.netl.doe.gov/LCA*

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