Logistics, Costs, and GHG of Co-firing with 20% Biomass

May 23, 2013

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Technology Area Review: Heat and Power

Organization: PNNL, INL

Goal Statement & Project Overview

History: Biopower Technical Strategy Workshop held by the Bioenergy Technologies Office (BETO) on December 2-3, 2009

Priority RD&D and Analysis of Biopower identified:

- Pretreatment & conversion, Large-scale systems, Feedstocks for biopower

Priorities for Market transformation identified:

- Techno-economic analysis, Lifecycle analysis
- Comparative energy and environmental analysis

Goals: This collaborative project began in September 2011 to:

- Determine if co-firing biomass in utility-scale boilers can be cost and GHG emissions competitive with other sources of fossil and renewable energy (e.g., natural gas, wind and solar)
- Identify and analyze the feedstock logistics systems necessary to facilitate co-firing as an option to enable transition from coal to clean energy
- Add leverage to other BETO work in IBR (power block), depot concepts and densification

Supports MYPP Vision: "A viable, sustainable domestic biomass industry that: Produces renewable biofuels, bioproducts, and biopower… Provides environmental benefits, including reduced GHG emissions…"

http://www1.eere.energy.gov/biomass/pdfs/biopower_workshop_report_december_2010.pdf

Quad Chart Overview
10.1.1.1 (INL), 10.1.1.2 (PNNL)

Timeline

- Project start date: Sept 2011
- Project end date: Sept 2013
- Percent complete: 90%

Budget

- Total through FY13: $812K
- FY 2011: $175k (PNNL), $175k (INL)
- FY 2012: $231k (PNNL), $231k (INL)
- FY 2013: $0k
- ARRA Funding - none
- An average total of k/year: $271k

Barriers

- Barriers addressed
  - Ft-M. Overall Integration and Scale-Up
  - St-F. Systems Approach to Bioenergy Sustainability
  - At-C. Inaccessibility and Unavailability of Data

Partners & Roles

- INL – people from both biomass and fossil sectors
- PNNL - people from both biomass and fossil sectors
- Collaboration with Electric Power Research Institute (EPRI) – Luis Cerezo

1 - Approach

Technical

- Select feedstock collection distance, and use the Bioenergy Knowledge Discovery Framework (KDF) tool to establish county level feedstock supply amount/price
- Use Biomass Logistics Model (BLM) to compute feedstock price at Power Plant in-feed ("drop-in" to reactor throat/combustor)
- Calculate co-firing combustion efficiency, Levelized Cost of Electricity (LCOE), and Lifecycle Analysis (LCA) for CO_2 equivalent emissions
- Compare LCOE and LCA with wind, natural gas re-fueling, and natural gas combined cycle
- Complete torrefaction, leaching, and milling tests to evaluate assumptions and to calibrate BLM sub-models for unit operations

Project Management

- DOE goals driven statement of work, quarterly milestones, and quarterly-, annual-reports are described in the project management plan (PMP), managed by DOE
- Regular interface with multi-Lab/BETO sustainability activities via Office monthly team meetings, intra-Lab LCA working group, and milestone activities

2- Technical Progress: 10.1.1.1 INL

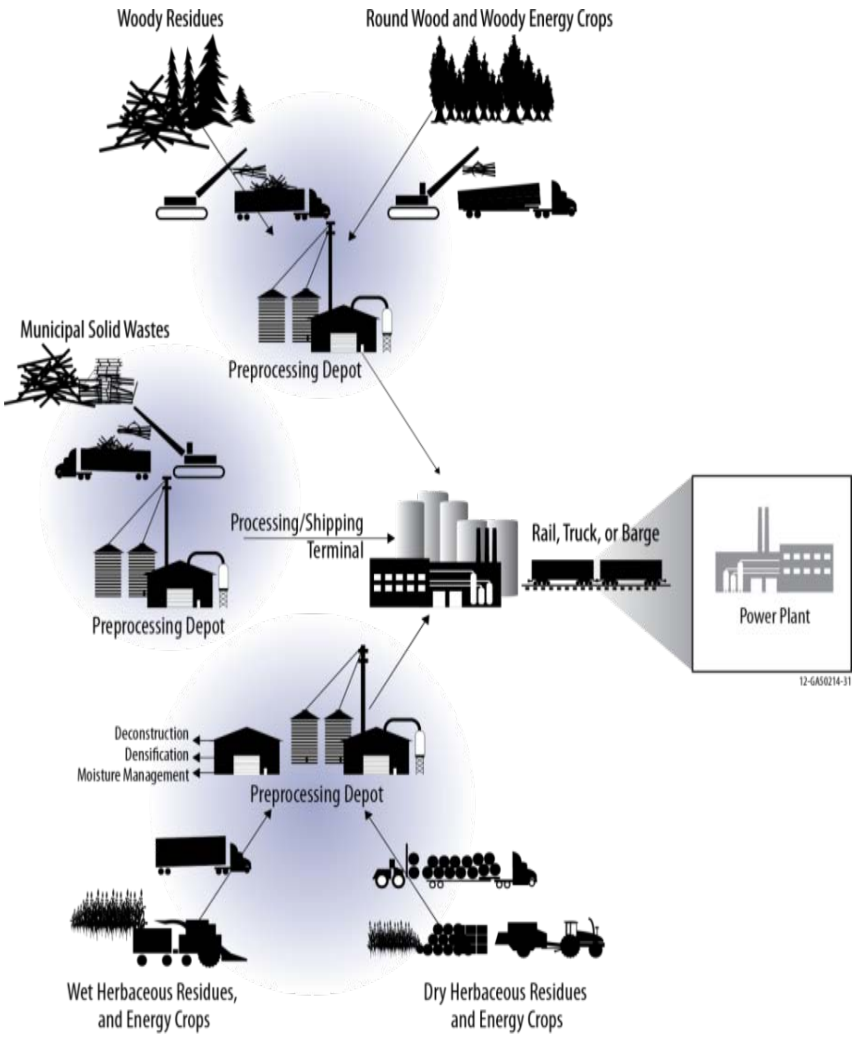
Milestone	Planned Completion Date	Completion
Kick-off meeting with report back to DOE	Jan, 2012	✓
Complete final cost and logistics modeling effort for all cases considered for feedstock supply in two regions.	Feb, 2012	✓
Support PNNL TEA development including feedstock costs and GHG emissions	Mar, 2012	✓
Develop initial report draft on INL biomass logistics and availability modeling efforts	July, 2012	✓
Incorporate PNNL data into draft of final report	Sep, 2013	✓
Report on preliminary TEA of co-firing 2 types of biomass (dried and torrefied) with coal was sent to external reviewers	Dec, 2013	✓
Incorporate external reviewer comments and resubmit report to DOE	Jun, 2013	Underway

2- Technical Progress: 10.1.1.2 PNNL

Milestone	Planned Completion Date	Completion
Kick-off meeting with report back to DOE	Jan, 2012	✓
Complete first data collection including cost data from INL	Feb, 2012	✓
Complete high level, preliminary TEA of co-firing of biomass	Mar, 2012	✓
Complete preliminary model of power generation facility using conventional pulverized coal combustion and co-firing with 1 biomass feedstock to examine cost and emissions impacts	Aug, 2012	✓
Complete report on preliminary TEA of co-firing 2 types of biomass (dried and torrefied) with coal	Sep, 2013	✓
Report on preliminary TEA of co-firing 2 types of biomass (dried and torrefied) with coal was sent to external reviewers	Dec, 2013	✓
Incorporate external reviewer comments and resubmit report to DOE	Jun, 2013	Underway

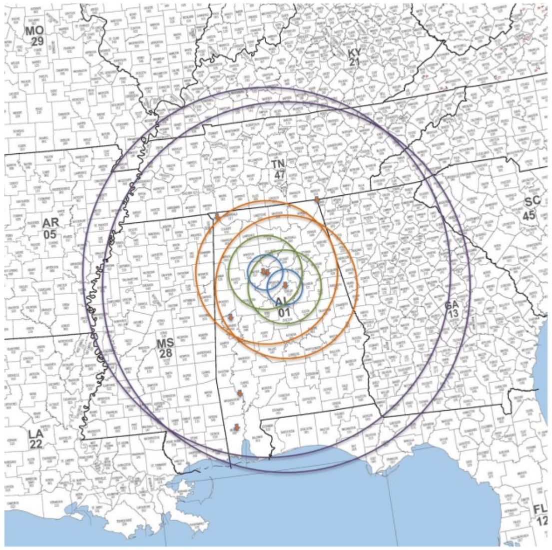
Technical Progress: Biomass Feedstock Logistics Overview

- Eventual Goal: Uniform format commodity feedstock
- The current effort evaluates woody and herbacious feedstocks under 3 scenarios specific to the southern, and northern midwest U.S.
  - Scenario 1: state of the art - 10% co-firing with raw biomass
  - Scenario 2: 20% co-firing - feedstock preprocessing on site
  - Scenario 3: 20% co-firing - feedstock preprocessing at distributed depots



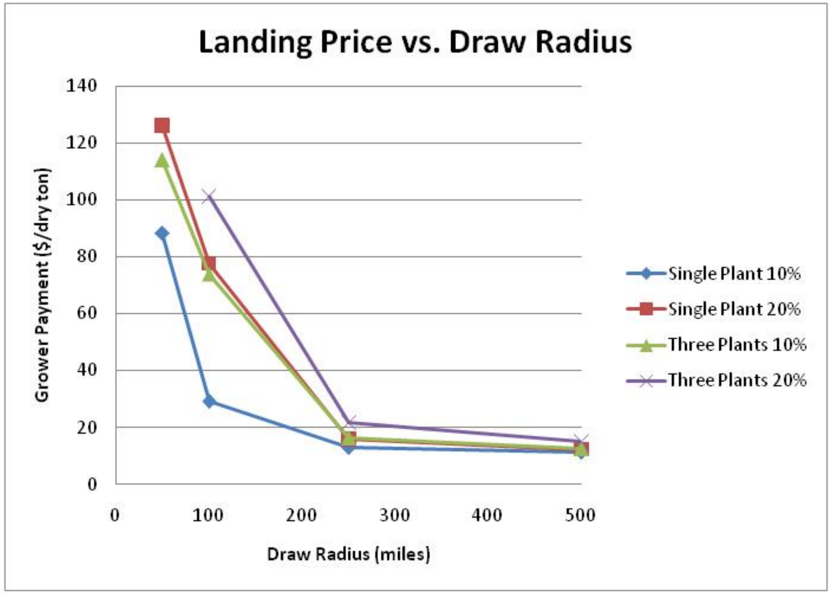
Source: “Commodity-Scale Production of an Infrastructure-Compatible Bulk Solid from Herbaceous Lignocellulosic Biomass” *Uniform-Format Bioenergy Feedstock Supply System Design Report* Series April, 2009 – INL/EXT-09-17527

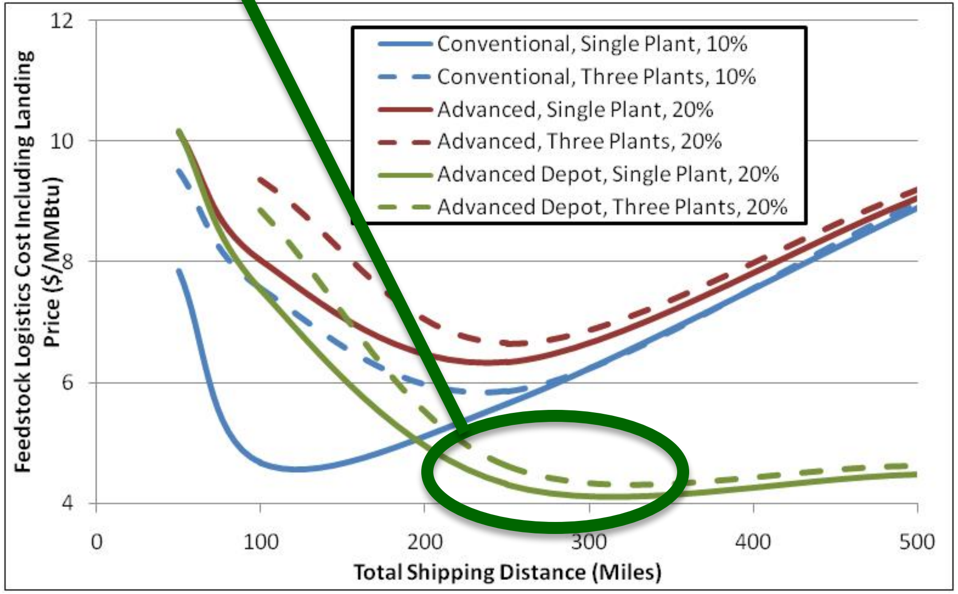
2 - Technical Accomplishments: Alabama Woody Biomass Landing Price



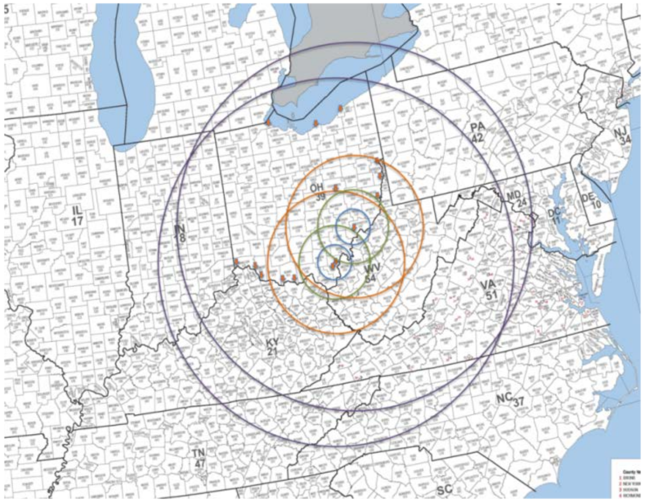
- Collection distances considered: 50, 100, 250, and 500 miles
- 1 plant (2.7 GWe; 20% HHV ≅ 6,000 tons BM/day)
- 3 plants (5.7 GWe; 20% HHV ≅ 12,000 tons BM/day)

Advanced depot outperforms all options at shipping distances >200 miles





2 - Technical Accomplishments: Ohio Herbaceous Biomass Landing Price



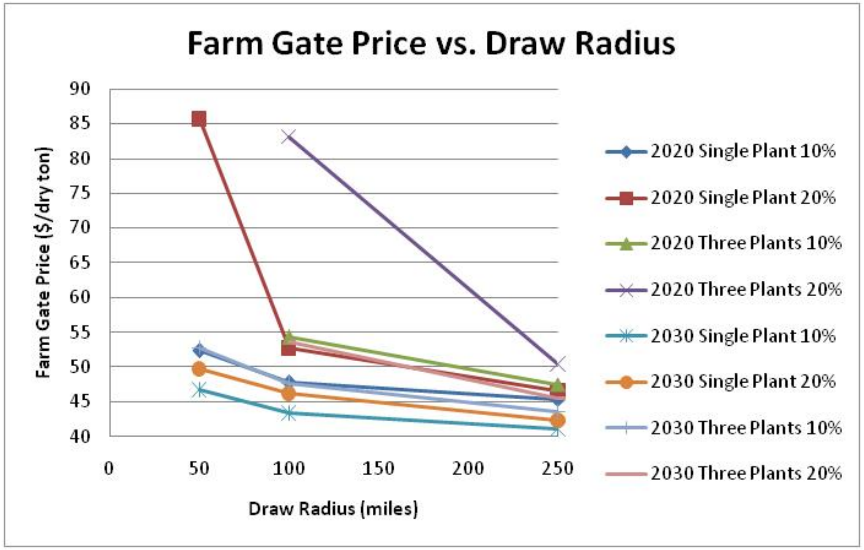
County level switchgrass cost and availability

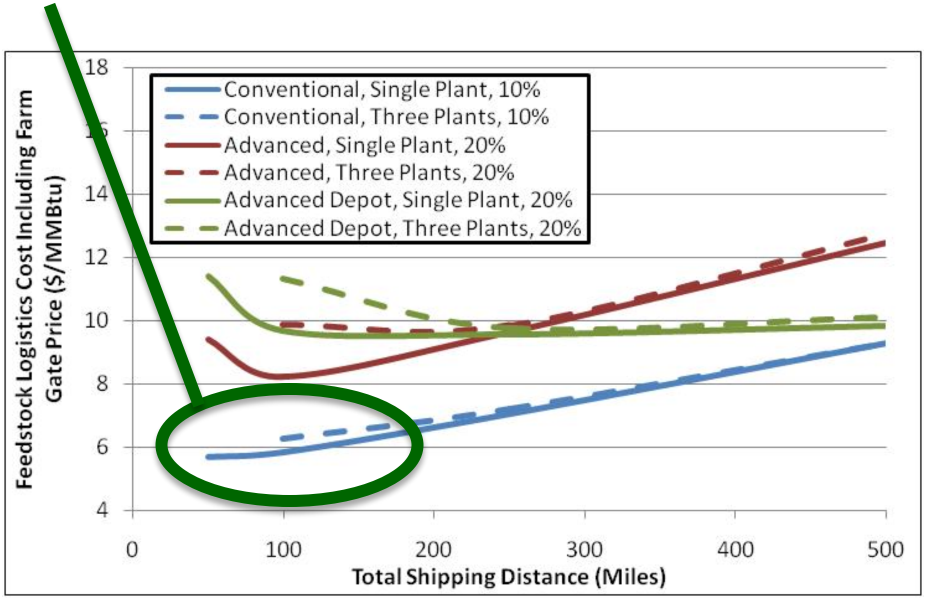
Based on projections for 2020 and 2030 for:

50, 100, 250, 500 miles

- 1 plant (1.5 GWe; 20% HHV ≃ 3,200 tons BM /day)
- 3 plants (4.2 GWe; 20% HHV ≃ 11,000 tonsBM /day)

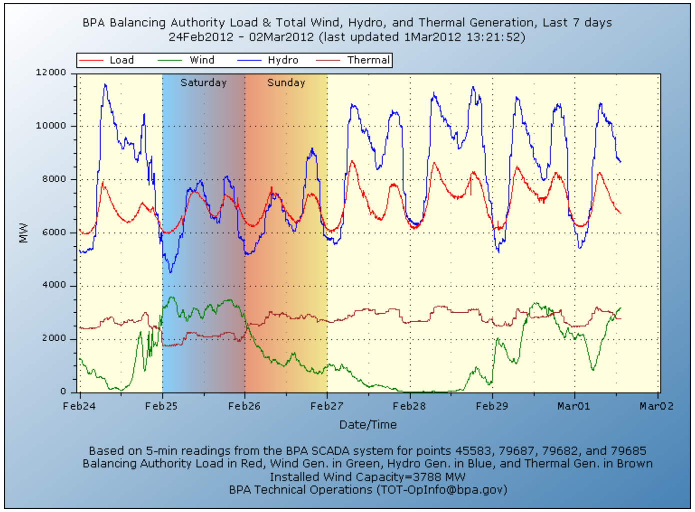
Conventional outperforms all – due to low yield during torrefaction of biomass





2 - Technical Accomplishments: Wind and Solar Power Generation

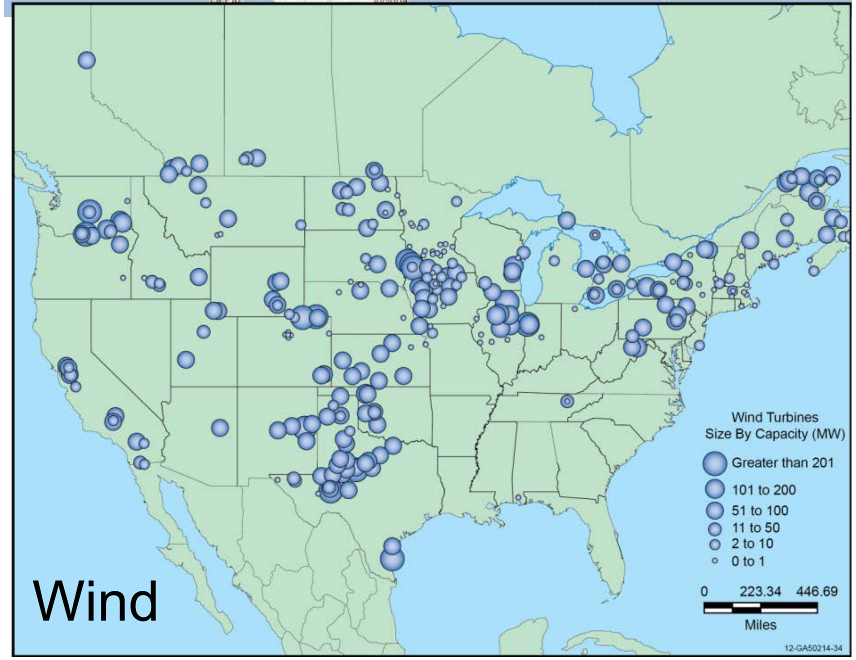
- Other Renewable Resources Considered
  - Wind
  - Solar
- Limitations:
  - Production Capacity versus Demand
    - Day/night and seasons
  - Resources are not typically located with demand



BPA Balancing Authority Load & Total Wind, Hydro, and Thermal Generation, Last 7 days
24Feb2012 - 02Mar2012 (last updated 1Mar2012 13:21:52)

Based on 5-min readings from the BPA SCADA system for points 45583, 79687, 79682, and 79685
Balancing Authority Load in Red, Wind Gen. in Green, Hydro Gen. in Blue, and Thermal Gen. in Brown
Installed Wind Capacity=3788 MW
BPA Technical Operations (TOT-OpInfo@bpa.gov)

Week long utility load (BPA 2012)

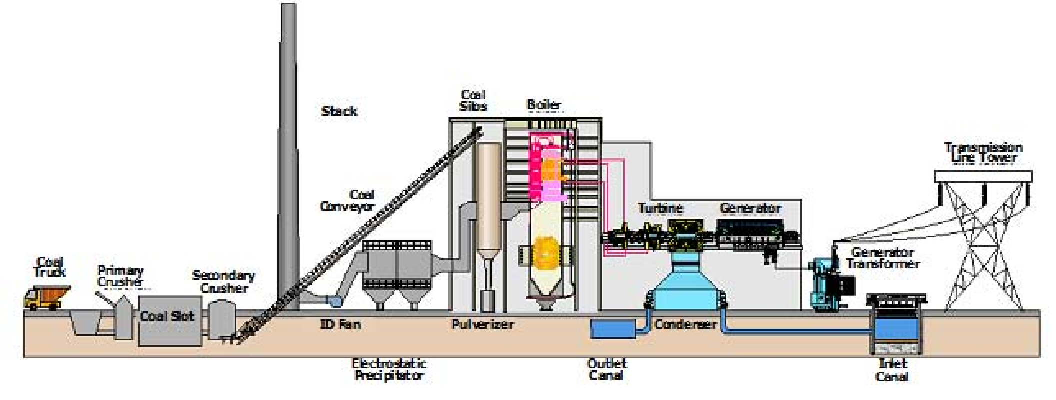


2 - Technical Accomplishments: Levelized Cost Of Electricity Model Assumptions

Economic Parameters	Overnight Cost	Capacity	Variable O&M	Fixed O&M	
Capital & Operating Costs	(2009 $/kW)	Factor	$/kW-hr	$/kW	Source/ Comments
Coal Fired Plants	-	85.6%	0.0048	29.31	All coal plants have had capital fully recovered
Biomass Cofire	213	85.6%	0.0060	32.24	EIA Energy Outlook 2010 erroneously raised from 203 to 213 in report
Wind (onshore)	2,251	29.9%	0	27.73	
Solar Photovoltaic	4,474	18.8%	0	25.73	
Natural Gas Conv	250	87.0%	0.0004	25.00	Raised from $203 as allowance for gas pipeline connection and metering
New Gas Combined Cycle	750	87.0%	0.000385	14.22	EIA updated capital discounted from $978 for existing cooling and electrical distribution systems

Fuel Costs $/MMBtu

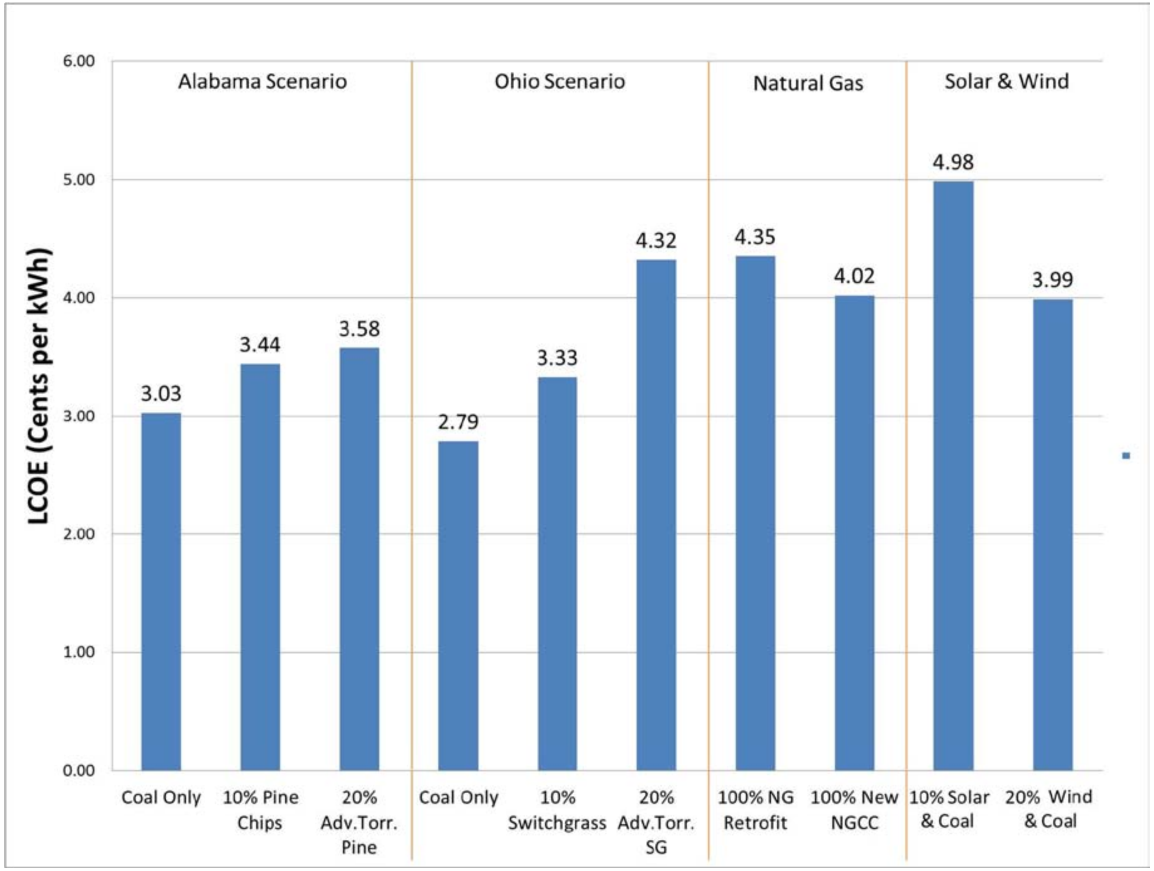
Alabama Coal	$2.24	EIA 2010 forms 923 and 860 for specific Alabama & Ohio plants US avg wind & solar
Alabama Pine Biomass	$7.17	Biomass only 10% of fuel
Alabama Adv. Torr. Biomass	$5.77	Biomass is 20% of fuel
Ohio Coal	$1.91	EIA 2010 forms 923 and 860 for specific Alabama & Ohio plants US avg wind & solar
Ohio Biomass	$7.19	Biomass only 10% of fuel
Ohio Adv. Torr. Biomass	$9.57	Biomass is 20% of fuel
Natural Gas	$4.00	EIA 2010 Energy Outlook projections



400 MW Representative Coal Plant – Sketch

Source: http://www.canadiancleanpowercoalition.com/index.php?cID=62

2 - Technical Accomplishments: Levelized Cost Of Electricity



NETL Study Results (cents/kWh):

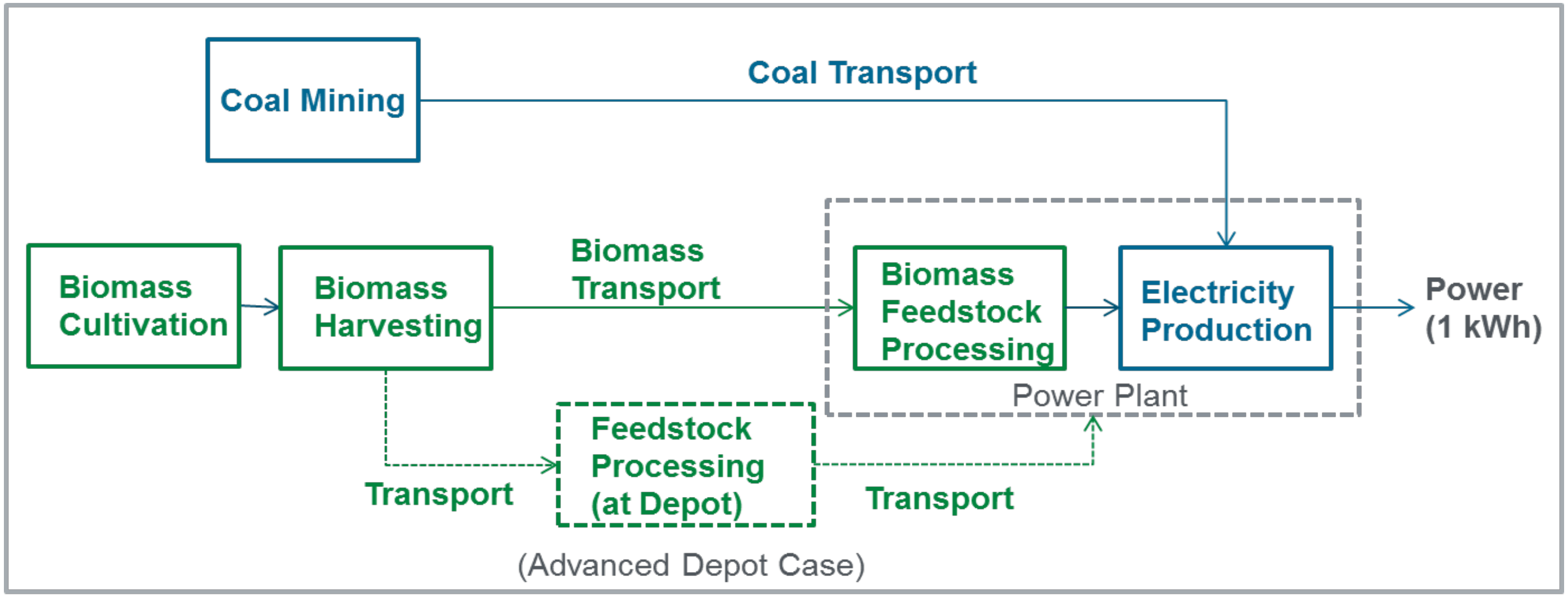
10% Hybrid Poplar 4.1

10% Forest Residue 3.5

DOE/NETL-2012/1537, Role of Alternative Energy Sources: Pulverized Coal and Biomass Co-firing Technology Assessment, August 30, 2012.

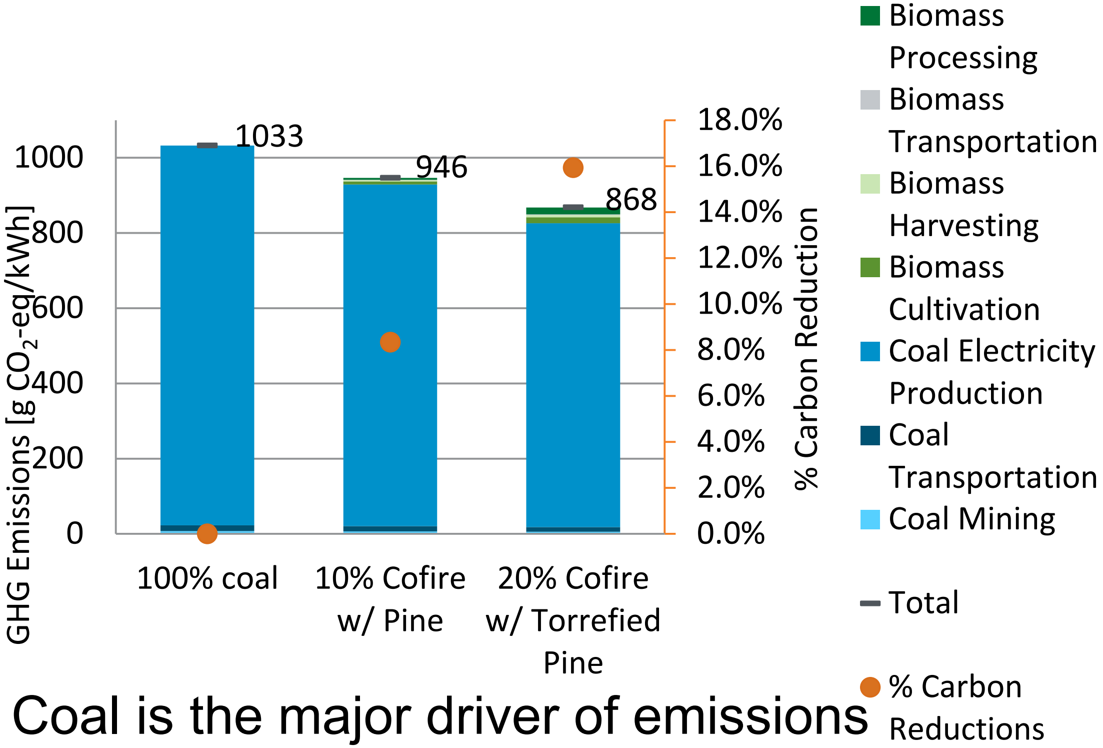
- 10% co-firing with biomass costs < 10% solar
- 20% co-firing with depot torrefied pine and depot switchgrass torrefied costs < 10% solar
- 20% co-firing with depot torrefied pine costs < 20% wind, 10% solar
- 100% NG is ≥ 20% co-firing with depot torrefied biomass

2 - Technical Accomplishments: GHG Modeling Scope and Assumptions



- Coal mining and biomass cultivation inventories derived from literature (Spath and Mann 1999, Ortiz *et al* 2011, ICF International 2008, Woods *et al.* 2006, Keoleian and Volk 2005, Searcy and Hess 2010, Hess *et al* 2009, and Qin *et al* 2006)
- Not included: direct and indirect land use change impacts, transmission losses, biogenic emissions (assumed CO_2 uptake = CO_2 emissions at plant)
- Assume plant heat rate is same for co-firing as 100% coal (no boiler efficiency hit)

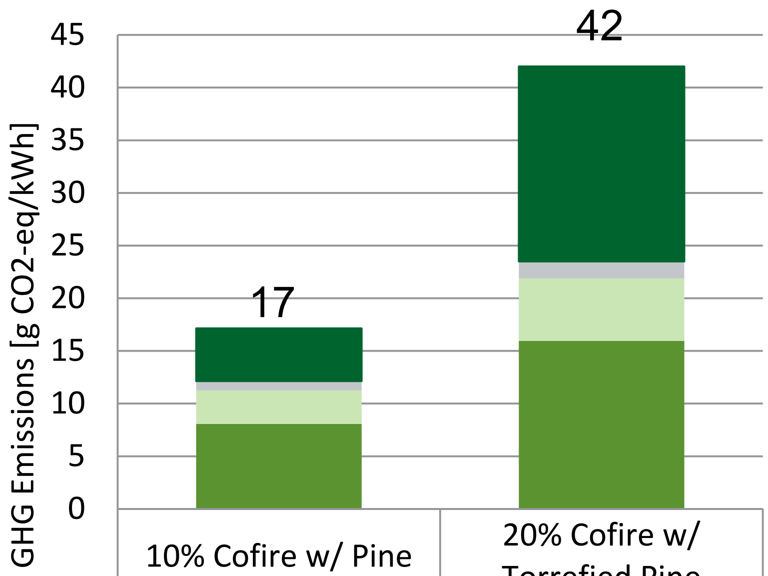
2 - Technical Accomplishments: GHGs for Co-firing Pine at Alabama Plant



Coal is the major driver of emissions

10% co-fire yields 8% GHG reduction

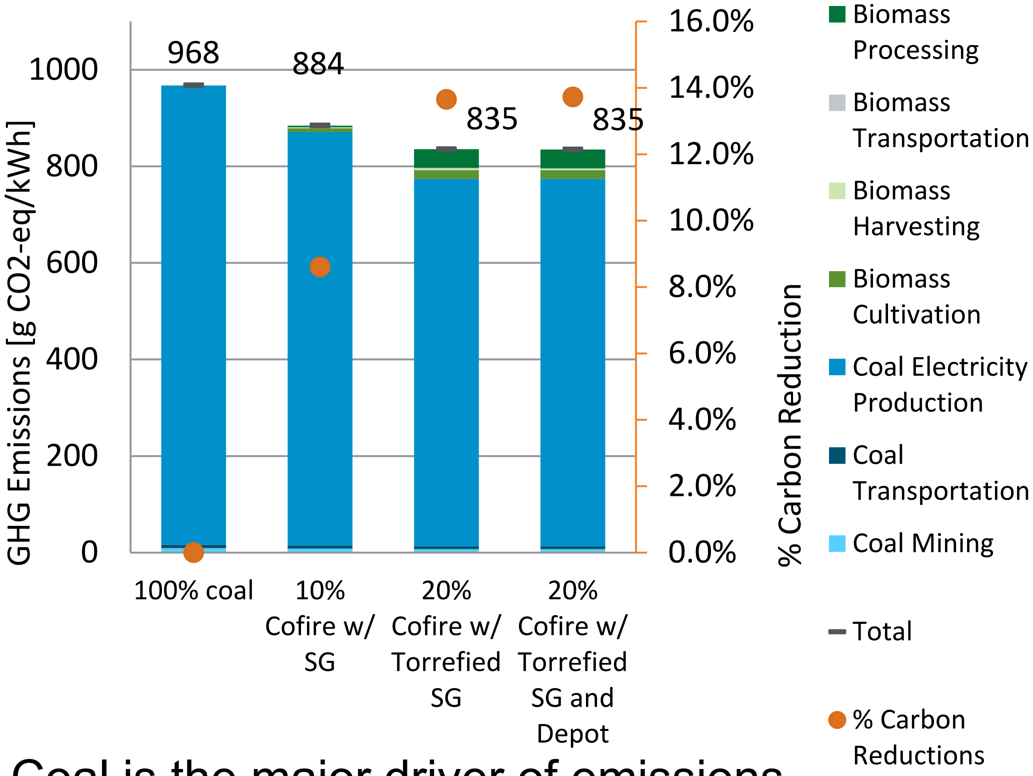
20% co-fire yields 16% GHG reduction



	10% Cofire w/ Pine	20% Cofire w/ Torrefied Pine
🟩 Biomass Processing	5.0	18.5
■ Biomass Transportation	0.9	1.6
🟩 Biomass Harvesting	3.2	5.9
🟩 Biomass Cultivation	8.1	16.0

At 20% biomass cultivation, harvesting, and transportation are roughly doubled while processing is nearly quadrupled due to torrefaction

2 - Technical Accomplishments: GHGs for Co-firing Switchgrass at Ohio Plant

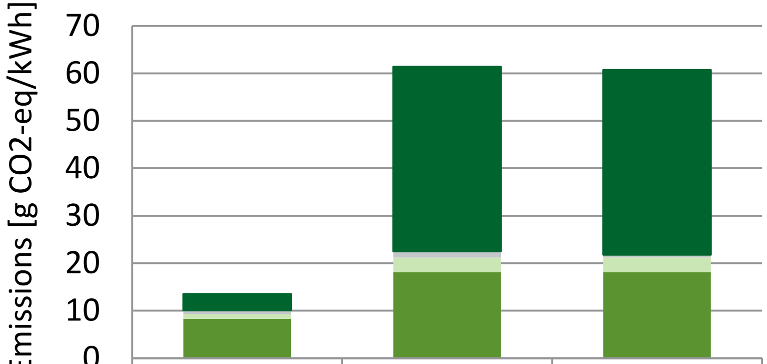


Coal is the major driver of emissions

10% co-fire yields 8% GHG reduction

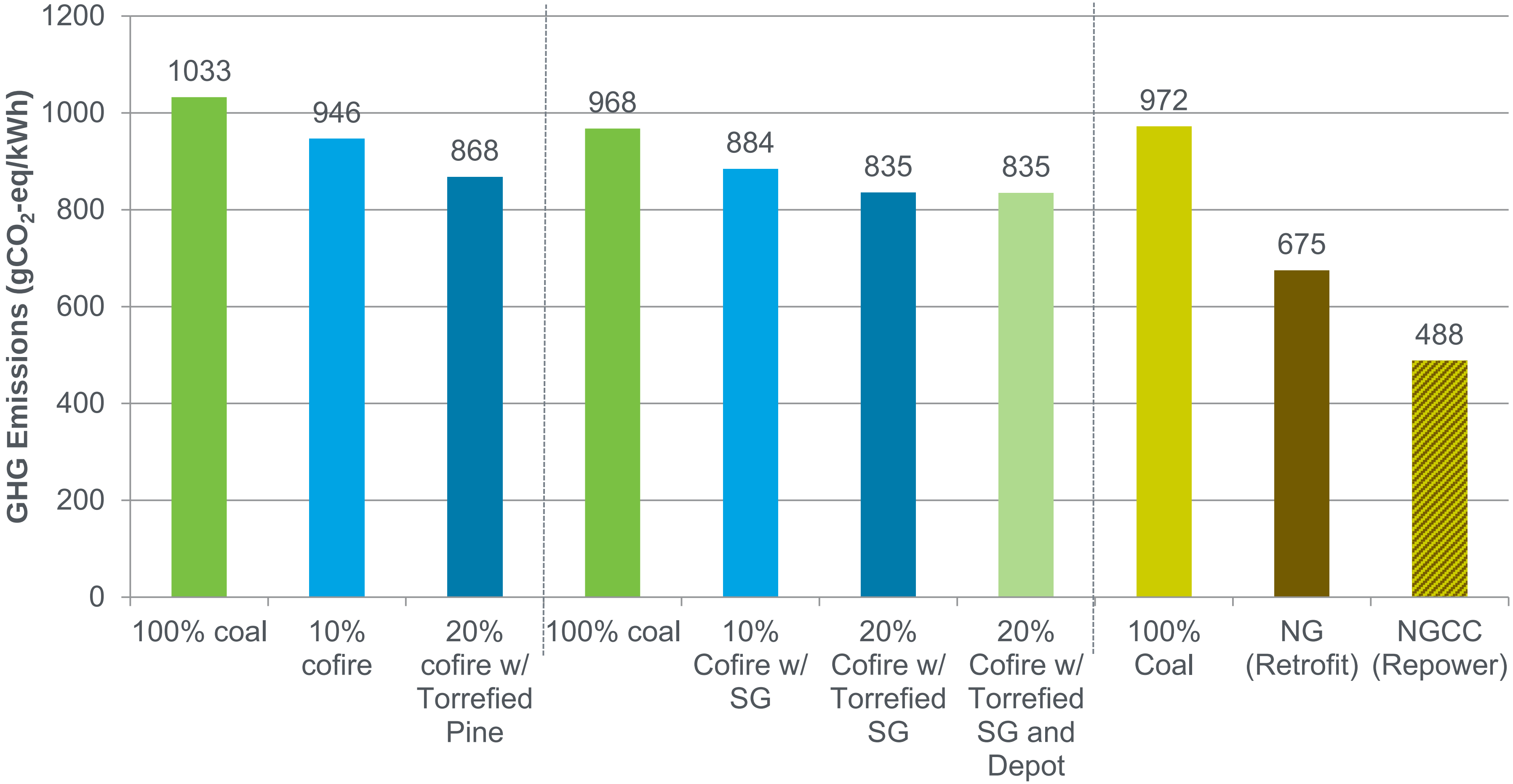
20% co-fire yields 14% GHG reduction

At 20% biomass cultivation is roughly doubled while processing is > 10x due to torrefaction, densification, and leaching



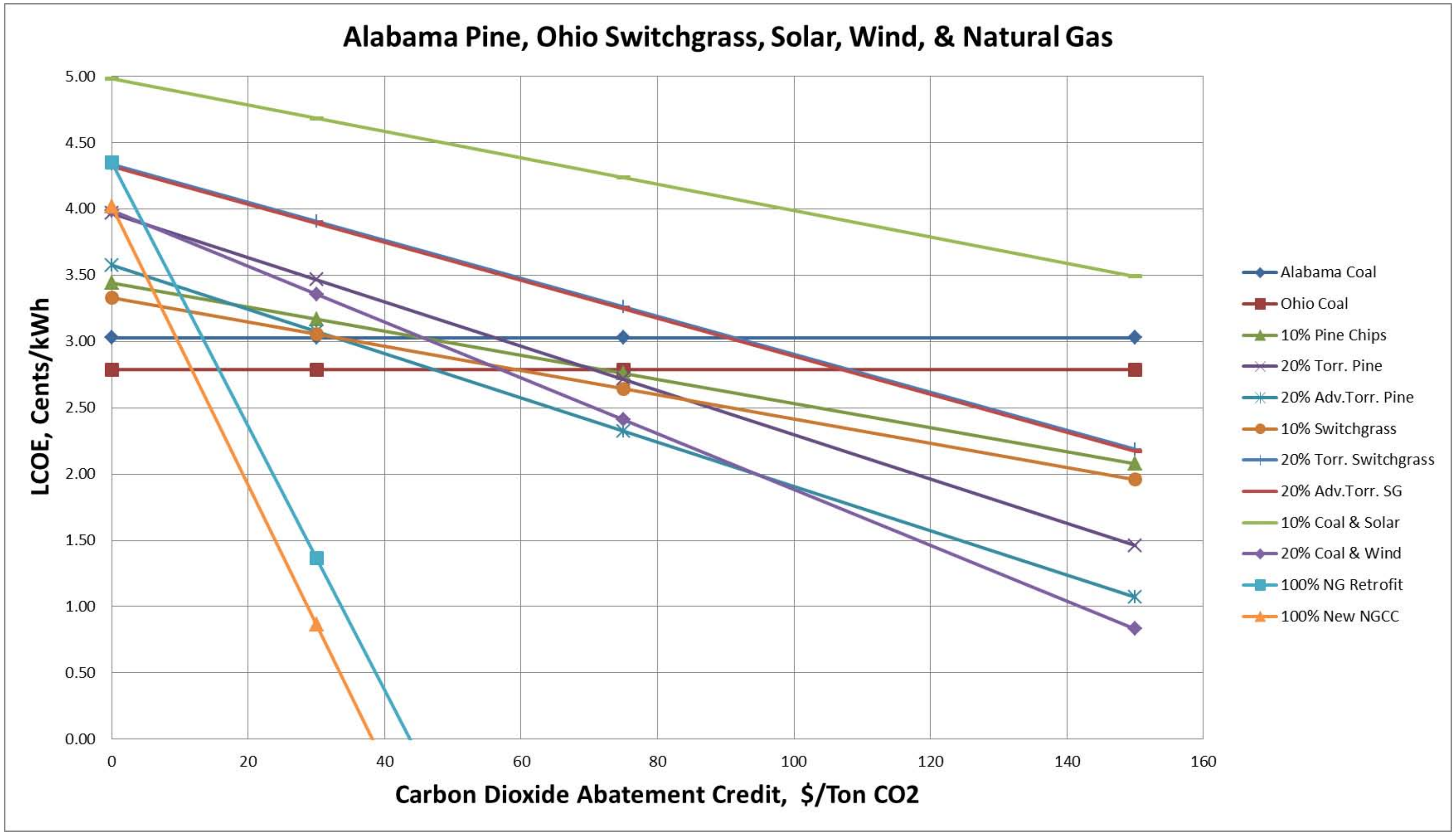
	10% Cofire w/ SG	20% Cofire w/ Torrefied SG	20% Cofire w/ Torrefied SG and Depot
🟩 Biomass In-Plant Processing	3.4	38.9	38.9
▨ Biomass Transportation	0.8	1.3	0.6
🟩 Biomass Harvesting	1.0	3.0	3.1
🟩 Biomass Cultivation	8.3	18.2	18.2

2 - Technical Accomplishments: GHG Emissions – Summary of Scenarios



- 10% co-firing results in 8% GHGs reduction for pine and 9% GHGs reduction for SG
- 20% co-firing with torrefied biomass results in 16% lower GHGs for pine and 14% lower GHGs for SG
- NG cases are for 100% replacement of coal

2 - Technical Accomplishments: LCOE with Carbon Credit Sensitivity



- NG impact is markedly different due to 100% composition
- At $75/ton CO_2 10% switchgrass, 10% pine, and 20% torriefied pine is competitive with coal
- 20% depot torrefied pine is competitive with 20% wind at $90/ton CO_2
- 20% depot torrefied pine and 20% wind is competitive with100% coal at $50-60/ton CO_2

2 - Technical Accomplishments: Observations

- Co-firing is technically feasible
- Feedstock pre-processing is necessary to minimize capital expenditure
- Co-firing in existing power plants to displace coal can produce immediate GHG reduction benefits (in 2010, if 20% of coal was replaced with biomass, CO_2 emissions would have been reduced by 350 million metric tonnes or 6% of net annual GHG emissions requiring 225 million tons of dry biomass)
- Co-firing LCOE is comparable with other renewables, and higher than baseline coal
- Co-firing could accelerate the development of a biomass feedstock commodity market
  - Biopower market should not compete with other uses, such as paper, biofuels, etc. (i.e. incremental implementation in retiring coal plants)
  - Biopower could serve as short-term bridge to enable GHG reduction during transition from coal to other energy production such as NGCC, or other renewables

3 - Relevance

- **Advancement of Renewable Energy:** From the Impact Analysis in the MYPP “Assess impacts of changes and development of various elements of the biomass-to-bioenergy supply chain and identify impacts of supply chain modifications on deployment…”
  - This project examined the impact of pretreatment to increase biomass co-firing and yielded new knowledge on the advantages of torrefied pine at a depot
- **Expected outcome:** From Strategic Analysis Support of Program Performance Goals in the MYPP “Developing analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts”
- **Supports MYPP Vision:** “A viable, sustainable domestic biomass industry that: Produces renewable biofuels, bioproducts, and biopower… Provides environmental benefits, including reduced GHG emissions…”
- This project offers a distinct perspective of the use of co-firing at existing, large scale power generation plants and benefits from EPRI’s insights

MYPP Barriers addressed: - Ft-M. Overall Integration and Scale-Up
- St-F. Systems Approach to Bioenergy Sustainability
- At-C. Inaccessibility and Unavailability of Data

4 - Critical Success Factors

- Technical: ensuring consistent and appropriate assumptions across Biopower supply chain:
  - Frequent telephone conferences between INL and PNNL engineers
  - Quarterly reporting to Bioenergy Technologies Office (BETO)
  - Frequent updates of project status with BETO to capture any desired changes in scope
- Technical: how to best incorporate scientific data for better model predictions (empirical vs. predictive, scale-up assumptions, sustainability)
  - Actively engaging researchers in analysis
  - Leveraging research from other areas with the BETO portfolio
- Market:
  - Listening to EPRI and others – reaching out for external industrial review
  - Leveraging researchers with both fossil and renewable energy experience
- Co-firing in existing large scale power plants to displace coal can produce immediate GHG reduction benefits, and co-firing LCOE can be comparable with other renewables, and higher than baseline coal – this analysis is distinct from other agencies
- BETO is now equipped with its own biopower models and able to examine the specifics of changing assumptions and direct impact on high level outcomes in order to analyze market transformations

5 - Future Work

- This project is complete upon publication of the final report in FY2013 Q3
- Additional aspects of co-firing feasibility remain:
  - Near term Opportunities for Co-firing:
    - Regulatory constraints impacting coal power plants
    - Retiring coal plants
    - Transition from coal to other power generation (i.e. NGCC) and the timeline for Capital Expenses versus Operational Expenses
- Future Opportunities:
  - GHG abatement credits and the trajectory for Carbon Capture and Sequestration (CCS) costs
  - Natural gas market volatility

Summary

Approach: Determine if co-firing biomass in utility-scale boilers can be cost and GHG emissions competitive with other sources of fossil and renewable energy (e.g., natural gas, wind, and solar)

Technical Accomplishments: Integrated cost, and GHG analysis has shown that co-firing LCOE is higher than baseline coal, but comparable with other renewables, and that co-firing can produce immediate GHG reduction benefits

Relevance: "A viable, sustainable domestic biomass industry that: Produces renewable biofuels, bioproducts, and biopower… Provides environmental benefits, including reduced GHG emissions…"

Critical Success Factors/Challenges: Market – the importance of listening to EPRI and others

Future Work: This project is complete upon publication of the final report in FY2013 Q3

Tech Transfer: This work suggests biomass co-firing provides benefits as a means to transition older coal boilers to a lower emission fuel (NG), on the way to greener energy options (CCS)

Overall Impressions: Biomass co-firing provides a means to develop a commodity market for biomass feedstock to benefit other bioenergy R&D areas

Additional Slides

Acknowledgements

- Bioenergy Technologies Office
  - Elliott Levine, Neil Rossmeissl, Zia Haq, Paul Grabowski, Brian Duff, Valerie Sarisky Reed
- BCS, Inc.
  - George Kervitsky
- Electric Power Research Institute
  - Luis Cerezo
- Idaho National Laboratory
  - Corrie Nichol, Tyler Westover, Kara Cafferty, Erin Searcy, Rick Wood
- Pacific Northwest National Laboratory
  - Sue Jones, Mark Bearden, Yunhua Zhu, Lesley Snowden-Swan, Sarah Widder, Corinne Valkenburg, James Cabe, George Muntean

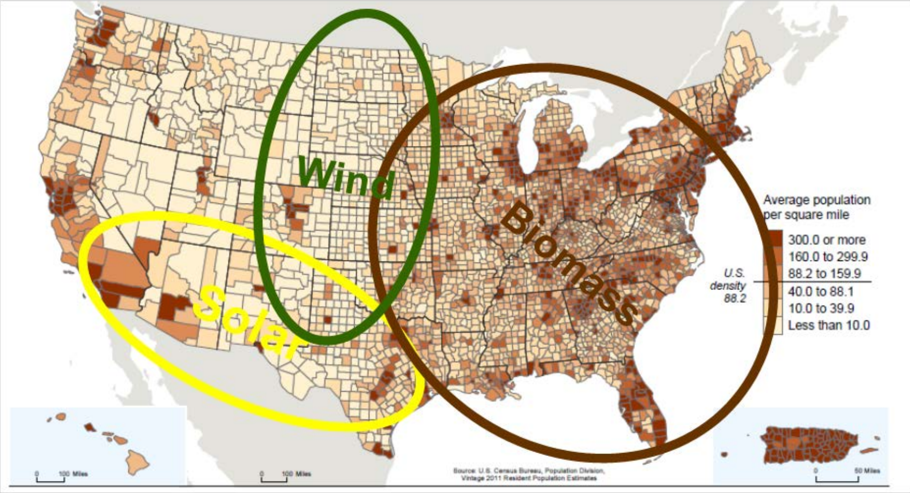
Responses to Previous Reviewers' Comments

This project started in September 2011 and was not reviewed previously

Publications, Presentations, and Commercialization

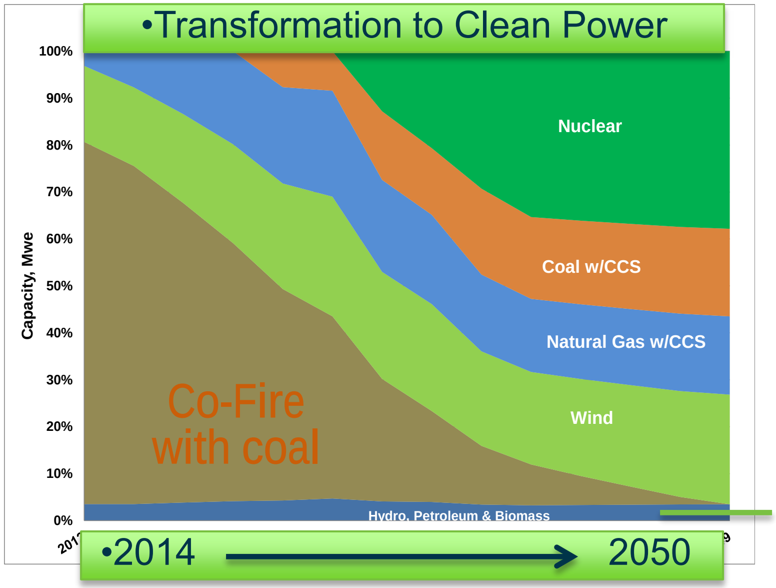
- Logistics, Costs, and GHG Impacts of Utility-Scale Co-firing with 20% Biomass, *in review.*
- Characterization of Dried and Torriefied *Arundo Donax* Biomass for Inorganic Species Prior to Combustion, Matyáš, J.; Johnson, B.R.; Cabe, J.E. August 2012, PNNL-21690.
- Formulation, Pretreatment, and Densification Options to Improve Biomass Specifications for Co-Firing High Percentages with Coal, Tumuluru, J. S.; Hess, J. R.; Boardman, R. D. *et al*. Industrial Biotechnology 2012, 8 (3), 113-132.

When Does Biopower Make Sense?



Source: U.S. Census Bureau, Population Division, Vintage 2011 Resident Population Estimates

- Renewable energy versus the population
- Large-scale Biopower is dispatchable
- Co-firing transitions to biofuels with conversion of coal to clean power options
- **This study examines biomass feedstock logistics necessary for large-scale commercial supply**



Niche biopower – not typically dispatchable

Small-scale, distributed/community power

Technical and Economical Assessment Approach

Select feedstock collection distance and use KDF tool to establish county level feedstock supply amount/price

Use Biomass Logistics Model (BLM) to compute feedstock price at Power Plant in-feed (“drop-in” to reactor throat/combustor)

Calculate co-firing combustion efficiency, Levelized Cost of Electricity (LCOE), and LCA for CO_2 equivalent emissions

Compare LCOE and LCA with wind, natural gas re-fueling, and natural gas combined cycle

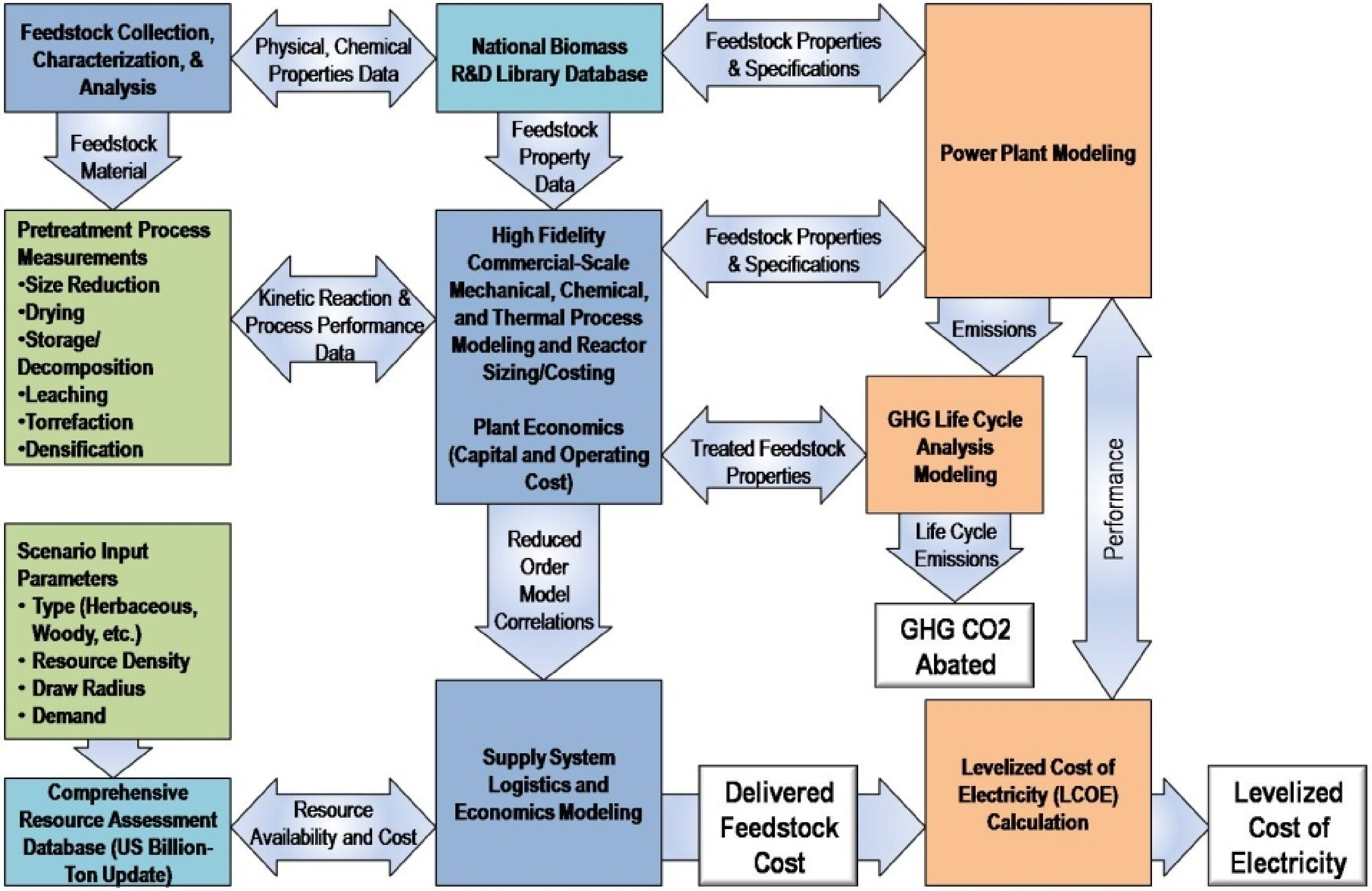
Complete torrefaction, leaching, and milling tests to evaluate assumptions and to calibrate BLM sub-models for unit operations

Cases Overview

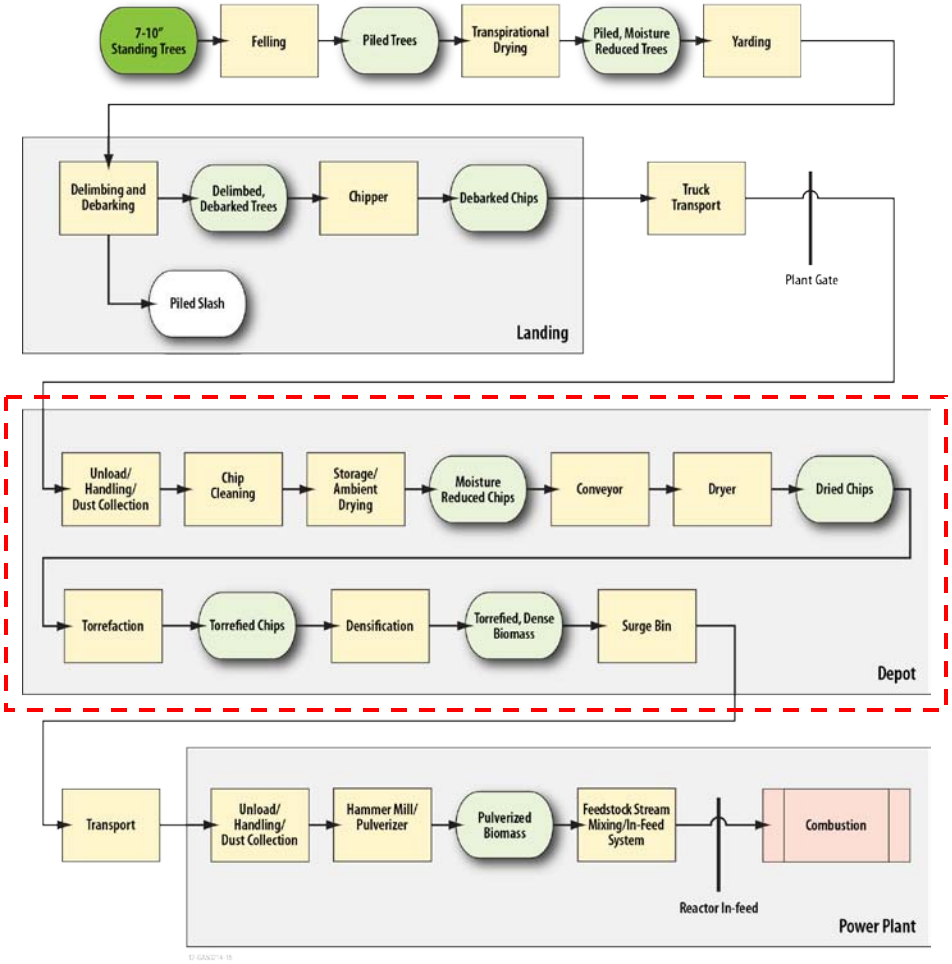
- Cases For Woody Scenario:
  - Conventional: 10% Cofire with Raw Wood Chips Trucked Locally to Power Plant
  - Advanced: 20% Cofire with Wood Chips Torrefied at the Power Plant
  - Advanced Depot: 20% Cofire with Wood Chips Torrefied and Densified at a Depot and Transported to the Power Plant
- Cases For Herbaceous Scenario:
  - Conventional: 10% Cofire with Raw Switchgrass – Trucked Locally to Power Plant
  - Advanced: 20% Cofire with Switchgrass Leached and Torrefied at the Power Plant
  - Advanced Depot: 20% Cofire with Switchgrass Leached, Torrefied and Densified at a Depot and Transported to the Power Plant

Methodology

- Include logistics and pre-processing operation models
- Model life cycle GHG emissions



Advanced Depot (20% Cofire Torrefied & Densified Woodchips)



Energy Needs for Preprocessing

Feedstock	Pre-Processing Energy, btu/DM ton
Pine	944,300
Pine – torrefied	2,029,300
Switchgrass	268,970
Switchgrass – torrefied	2,323,820

Summary of Feedstock Feedrates, Costs, & Optimum Collection Distance

Summary of biomass feedstock costs based on Case-Specific Feedrate Requirements

Scenario		Case		Total Power	Biomass Feed Rates and Cost				Coal Feed Rates and Cost†					
					Total Harvested	Optimal Draw Dist.	Processed Biomass Feedrate	Cost*	Bituminous$^{\psi}$		Sub Bituminous		Total	Total Cost
				MW_e	DM Ton/Day	Miles	DM Ton/Day	$/DM Ton	Ton/ Day	$/Ton	Ton/ Day	$/Ton	Ton/ Day	$/Ton
1	Alabama	1	Baseline Coal	3000	--	**--**	--	**--**	24981	$48.81	4740	$27.27	29721	**$42.98**
1	Alabama	2	Raw Southern Pine	3000	4707	**100**	4613	**$68.71**	22483	$48.81	4266	$27.27	26748	**$42.98**
1	Alabama	3	Torrefied Southern Pine	3000	9415	**250**	8134	**$113.33**	20234	$48.81	3839	$27.27	24074	**$42.98**
1	Alabama	4	Depot Torrefied So. Pine	3000	9415	**250**	8134	**$77.17**	18211	$48.81	3455	$27.27	21666	**$42.98**
2	Ohio	5	Baseline Coal	4169	--	**--**	--	**--**	10827	$73.37	33205	$33.07	44033	**$45.38**
2	Ohio	6	Raw Switchgrass	4169	10394	**250**	9770	**$112.96**	9745	$73.37	29885	$33.07	39630	**$45.38**
2	Ohio	7	Torrefied Switchgrass	4169	20548	**100**	10664	**$185.82**	8770	$73.37	26896	$33.07	35667	**$45.38**
2	Ohio	8	Depot Torrefied Sg.	4169	20548	**250**	10664	**$184.32**	7893	$73.37	24207	$33.07	32100	**$45.38**

* Cost of biomass delivered to the point of insertion into the coal boiler feed stream. Cost taken as minimum cost collection distance.

† Weighted average cost of coal (bit. and sub.) consumed, as reported for 2010 (EIA Form 923 for 2010).

Ψ Alabama scenario is based on Appalachian bituminous; Ohio scenario is based on Pittsburg #8 bituminous.

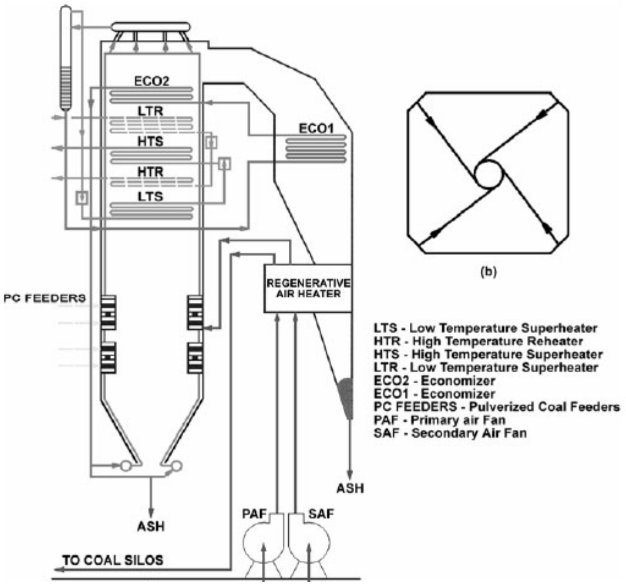
Feedstock costs and conclusions corroborate RAND Study

Rand Corporation: http://www.rand.org/pubs/technical_reports/TR984.html:

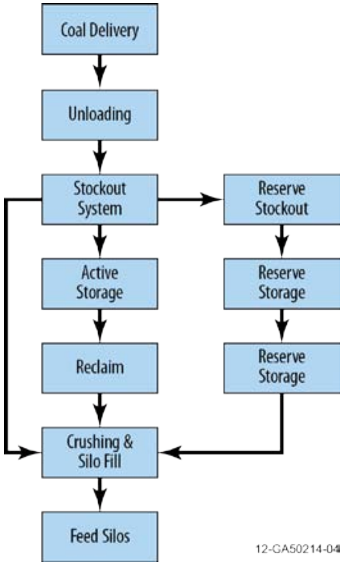
(2011) *Near-Term Opportunities for Integrating Biomass into the U.S. Electricity Supply*

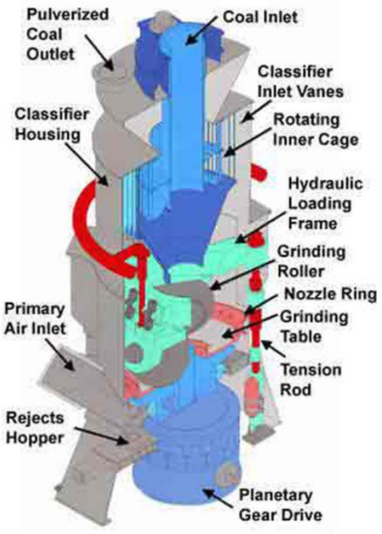
Baseline Coal Scenario

- Aspen Process Simulator Model
- EIA Data for Generic U.S. Pulverized Coal-Fired Power Plant
- Sub-bituminous Coal
- Low NO_X Burners
- Electrostatic Precipitators

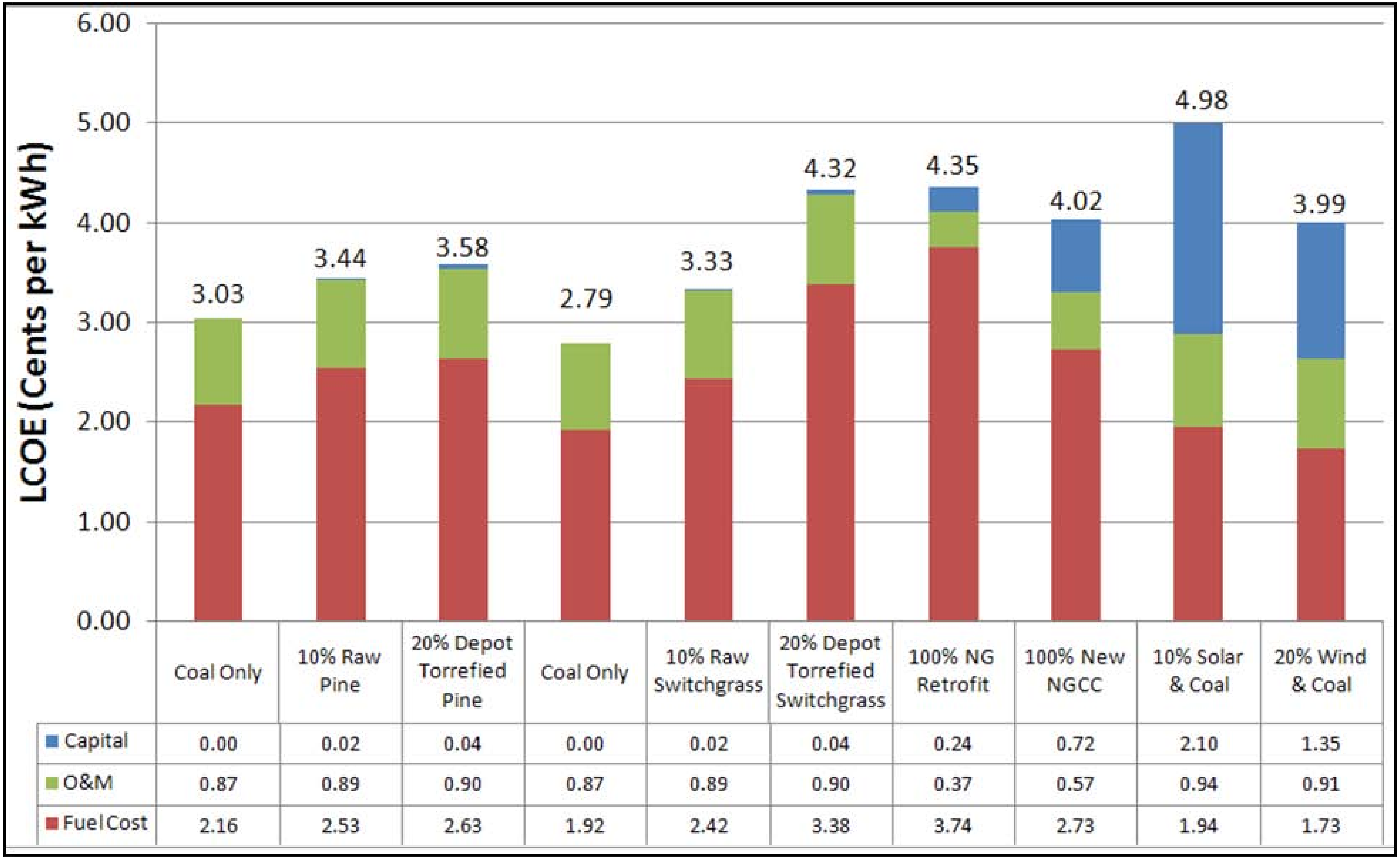


LTS - Low Temperature Superheater
HTR - High Temperature Reheater
HTS - High Temperature Superheater
LTR - Low Temperature Superheater
ECO2 - Economizer
ECO1 - Economizer
PC FEEDERS - Pulverized Coal Feeders
PAF - Primary air Fan
SAF - Secondary Air Fan





Summary of Case-Specific Breakdown of LCOE Costs



	Coal Only	10% Raw Pine	20% Depot Torrefied Pine	Coal Only	10% Raw Switchgrass	20% Depot Torrefied Switchgrass	100% NG Retrofit	100% New NGCC	10% Solar & Coal	20% Wind & Coal
🟦 Capital	0.00	0.02	0.04	0.00	0.02	0.04	0.24	0.72	2.10	1.35
🟩 O&M	0.87	0.89	0.90	0.87	0.89	0.90	0.37	0.57	0.94	0.91
🟥 Fuel Cost	2.16	2.53	2.63	1.92	2.42	3.38	3.74	2.73	1.94	1.73

Basis Set For LCA

Coal Assumptions	**Reference**
Coal mining emissions	Spath and Mann (1999); Ortiz et al (2011); ICF International (2008)
Coal transport - Diesel emissions, energy density; fuel efficiency of rail and barge	NETL (2008); Kruse et al (2009)
Biomass Assumptions	
Pine cultivation emissions (modeled after willow)	Kaoleian and Volk (2005)
Switchgrass cultivation emissions	Qin et al (2006)
Biomass harvest, collection and pre-processing	INL
Other	
NG Production and Transport	Spath and Mann, 2000
Plant emissions	Aspen models