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Energy Efficiency and Renewable Energy  
Biomass Program

## Understanding the Science of Air Quality, Greenhouse Gases, and Woody Biomass

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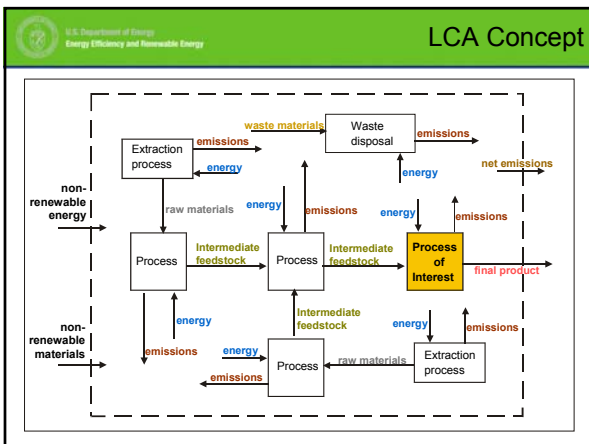
Forestry and Environmental Outreach Program  
Energy from Wood  
Exploring the Issues and Impacts for North Carolina

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## Life Cycle Assessment

**LCA is:**

- a systematic analytical method
- used to quantify the environmental benefits and drawbacks of a process
- performed on all processes, cradle-to-grave, resource extraction to final disposal
- ideal for comparing new technologies to the status quo
- helps to pinpoint areas that deserve special attention
- reveals unexpected environmental impacts (no show-stopping surprises)



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## LCA Framework

- (1) International Organization for Standards (ISO) 14000 series – Environmental Management
  - Specifically:** ISO 14040 thru 14049 discusses LCA
  - Provides principles and framework and some methodological requirements for conducting LCAs
- (2) Society for Environmental Toxicology and Chemistry (SETAC)
  - Specifically:** International LCA advisory group
  - Outlined a framework for LCA (follow ISO standards)
  - Mission is to advance the science, practice, and application of LCA (workshops and publications)

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## LCA Framework (cont'd)

**Some items:**

- Scope, boundaries, level of detail depend on subject and intended use
- LCA does not address the economic or social aspects
- Functional unit: reference to which inputs and outputs are related
- Data: collection, quality, and validation
- Critical review by others
- Reporting – fair, complete, and accurate

No one "right" way to perform an LCA. Detail, boundaries, data, etc. depend on purpose, time, and money.

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## Three Components of LCA

**INVENTORY**

- Mass and energy balances >> air, water, and solid waste emissions, energy and resource consumption

**IMPROVEMENT**

- Reduce environmental burden through process design changes, material substitution, recycle, etc.

**IMPACT ASSESSMENT**

Characterize environmental effects

- Less-is-better
- Stressor categories: climate change gases, carcinogens, resource depletion, ozone precursors
- Weighting factors: e.g., methane = 21 \* CO<sub>2</sub>
- Valuation: Assign values to each effect to achieve an overall environmental score or set of scores

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## Methodology & Peer Review

**First step:**

- Developed and disseminated methodology (BIGCC & coal)
  - Included review of general LCA literature and LCA studies
  - Peer reviewed by LCA experts and power generation experts

**Second step:**

- Held LCA workshop
  - Goal: experts provide comprehensive summary of how LCAs are done now, where the field is headed, and what resources (primarily software) are available

**Third step:**

- Performed LCAs
  - Peer reviewed by LCA experts and power generation experts (50-100 per study)
  - Sent out (including website address) over 250 copies of BIGCC LCA

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## Software & Data

**Use Tools for Environmental Analysis and Management (TEAM®)**

- Database: Data for Environmental Analysis and Management (DEAM®)
  - Missing information: models, literature, other sources
  - Checked DEAM database against other sources (consistent, reliable)


**Re-examined available LCA software in 2000:**

- # of software packages = 27
- Criteria: database, easy of use, cost, exportability, user input, modeling capabilities, acceptance of software by LCA community
- Conclusion: Compared to TEAM®, no other software packages with as many features at similar cost

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## Power Systems Examined

Biomass IGCC	Indirectly-heated gasification Dedicated hybrid poplar feedstock Zero carbon sequestration in base case
Average coal	Pulverized coal / steam cycle Illinois #6 coal - moderate sulfur, bituminous Surface mining
Biomass / coal cofiring	15% cofiring by heat input Biomass residue (urban, mostly) into PC boiler 0.9 percentage point efficiency derating Credit taken for avoided operations including decomposition (i.e., no biomass growth)
Direct-fired biomass	Biomass residue Avoided emissions credit as with cofiring
Natural gas	Combined cycle Upstream natural gas losses = 1.4% of gross



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## Purpose of Power Studies

**Biomass LCA was conducted to answer common questions:**

- What are the net CO<sub>2</sub> emissions?
- What is the net energy production?
- Which substances are emitted at the highest rate?
- What parts of the system are responsible for the greatest impacts?
- What should biomass R&D focus on?

**Coal and natural gas LCAs the foundation for quantifying the benefits of biomass power.** (Coal accounts for 50% of U.S. electricity and natural gas accounts for 15%)

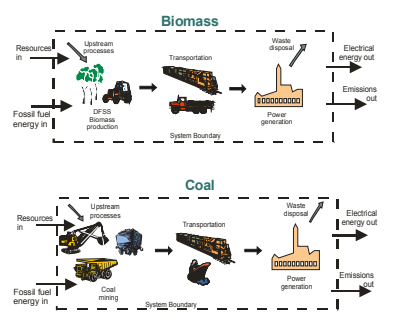
**Direct-fired biomass system describes current biomass power industry.**

**Cofiring LCA examined near-term option for biomass utilization.** (biomass properties compared to coal: less sulfur, less ash, more volatiles, less nitrogen)

**Each assessment conducted separately - common systems not excluded.**

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## Scope of Systems Studied



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## Carbon Cycle & GHG Emissions

**Example flows:**

- Biomass energy crop - photosynthesis, carbon sequestration in soil
- Biomass residue - avoided decomposition emissions
- Coal - coal mine methane, coal mine waste
- Natural gas - fugitive emissions, leaks
- General - incomplete combustion, upstream fossil fuel consumption

**Key question: On a life cycle basis, what are the net greenhouse gas emissions of these systems?**

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## BIGCC: Hybrid Poplar & Soil Carbon

- Literature values (from -4.5 to 40.3 Mg/ha over 7 years):
- Hanson (1993): loss of C in stands < 6 yrs, gain in older stands, particularly those > 12 yrs.
  - Perlak, et al (1992): gain of 13.4-17.9 Mg/ha over 7 yrs
  - Marland & Schlamadinger (1996): 40.3 Mg/ha over 7 yrs
  - Ranney & Mann (1994): 30-40 Mg/ha over 20-50 yrs, then equilibrium
  - Recent info from field trials indicates a loss of soil carbon

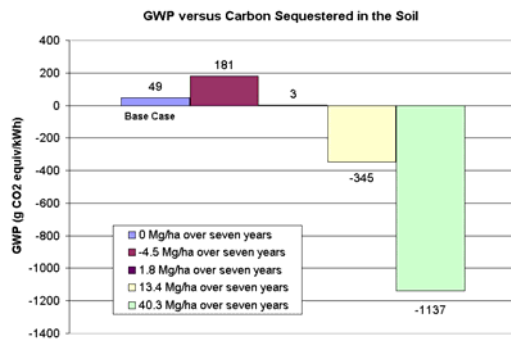
Actual amount sequestered will be site-specific

Base case assumption: Zero carbon sequestration

Sensitivity analysis determined 1.8 Mg/ha over seven year rotation is results in a zero net CO<sub>2</sub> process

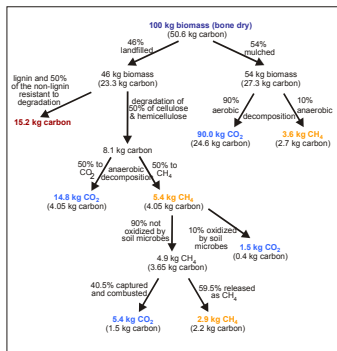
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## BIGCC: Soil Carbon Results



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## Biomass Residue: Soil Carbon Results

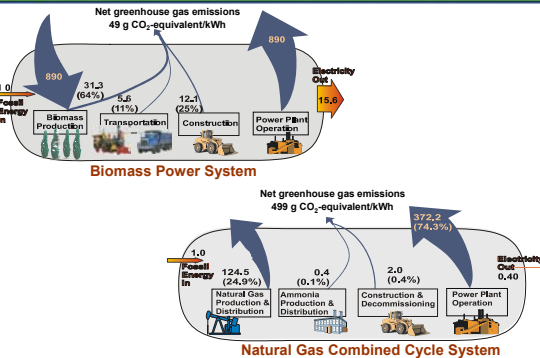


Avoided emissions per 100 kg of biomass:  
111.7 kg CO<sub>2</sub> + 6.5 kg CH<sub>4</sub>  
= 248 kg CO<sub>2</sub>-equiv

If 100 kg biomass were to completely decompose aerobically: 185 kg CO<sub>2</sub>

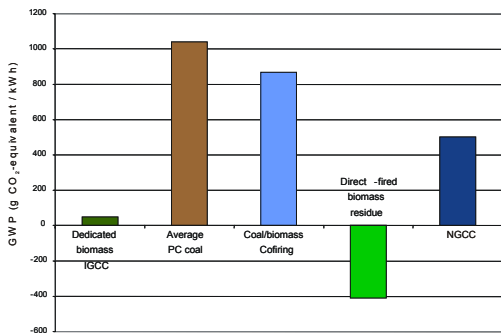
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## GWP: BIGCC vs NGCC



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## GWP: 5 Power Systems

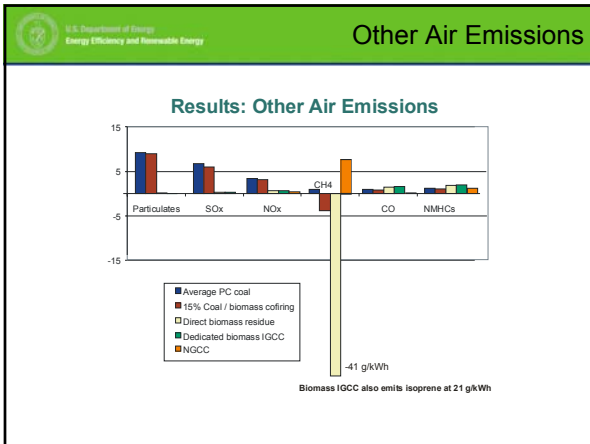


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## Additional Findings

Compared to the fossil systems:

- Biomass systems consume smaller quantities of natural resources
- Generally, biomass systems produce lower levels of particulates, NO<sub>x</sub> and SO<sub>x</sub>
- Net energy consumption of biomass systems is lower even if natural gas and coal feedstock energy is excluded from fossil systems (due to energy consumption in natural gas extraction, coal mining, transportation, and flue gas clean-up)



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## Definitions - Energy Balance

### Definition of Life Cycle Energy Ratios

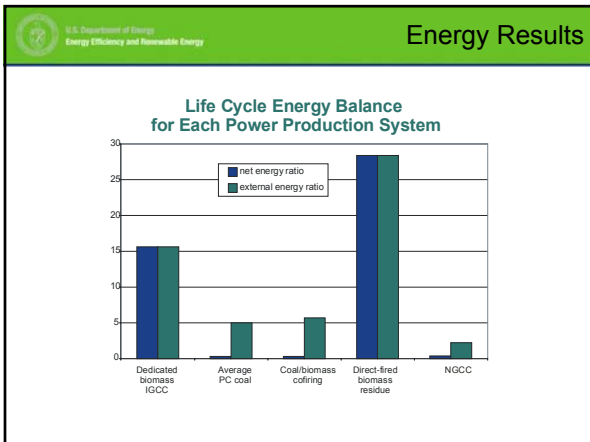
Net energy ratio: (includes all fossil inputs)

$$\frac{E_g}{E_{ff}}$$

External energy ratio: (shows upstream energy consumption)

$$\frac{E_g}{E_{ff} - E_c - E_n}$$

where:  
 Eg = electric energy delivered to the utility grid  
 Ec = LHV of coal to power plant  
 En = LHV of natural gas to power plant  
 Eff = fossil fuel energy consumed within the system



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## Summary

**Greenhouse gases:**

- Biomass IGCC nearly zero net GHGs
- Coal system: ~1,000 g CO<sub>2</sub>-equiv/kWh
- NGCC system: ~600 g CO<sub>2</sub>-equiv/kWh

**Energy:**

- Coal: negative system energy balance.
- Natural gas production is a large energy consumer.
- Biomass: even neglecting the energy content of the fossil feedstock, biomass systems are more energy efficient.

**Air Emissions:**

- Biomass: few particulates, Sox, NOx, and methane.
- Coal: upstream CO and NMHC emissions are lower.
- NGCC: system methane emissions are high.

**Resource Consumption:** Biomass systems consume extremely small quantities of natural resources compared to fossil systems.

**Cofiring:**

- 15% cofiring reduces GWP of coal system by 18%
- Reduces emissions, resource consumption, and energy use

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- ## LCA Resources/Documents
- Biomass-fired integrated gasification combined cycle (IGCC) system using a biomass energy crop (<http://www.nrel.gov/docs/legosti/fy98/23076.pdf>)
  - Pulverized coal (PC) boiler representing an average U.S. coal-fired power plant, NSPS, and LEBS (<http://www.nrel.gov/docs/fy99osti/25119.pdf>)
  - Cofiring biomass residue with coal (journal article in Clean Products & Processes ([http://link.springer.de/link/service/journals/10098/contents/01/00109/paper/s10098\\_0100109.pdf](http://link.springer.de/link/service/journals/10098/contents/01/00109/paper/s10098_0100109.pdf)))
  - Natural gas combined cycle power plant (<http://www.nrel.gov/docs/fy00osti/27715.pdf>)
  - Power Production comparison paper: Mann, M.; Spath, P. (2002). "Life Cycle Assessment Comparisons of Electricity From Biomass, Coal, and Natural Gas." *AICHE 2002 Annual Meeting*, Indianapolis, IN, November 3-8.