



American  
Forest & Paper  
Association



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# Teleconference of EPA Science Advisory Board Biogenic Carbon Emissions Panel

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BETTER PRACTICES  
BETTER PLANET **2020**  
Continuing AF&PA's Commitment to Sustainability

# Overview

- Use of biomass residues for energy is integral and incidental to manufacturing forest products (pulp, paper and solid wood products), results in fewer greenhouse gas emissions than alternatives, and should be exempt from regulation.
- These residues should be considered inherently carbon neutral and have a BAF of 0
- Emissions from logging residues should not be discounted and also have a BAF of 0.
- The forest products industry's efficient use of wood biomass should be included in the baseline.

# Use of Mill Residues and Byproducts For Energy

- E.g., spent pulping liquor, bark, sawdust, wood slabs, shavings
- Integral and incidental to manufacturing forest products
- Displaces use of fossil fuels
- Unsustainable not to beneficially use mill residues for energy
- Otherwise, immediate increase in CO2 emissions
  - E.g., incinerate spent pulping liquor without recovery of energy and chemicals??
- Environmentally and economically infeasible

# Use of Logging Residues for Energy

- E.g., tree branches, tops, pre-commercial thinnings
- Displaces use of fossil fuel
- Discounting logging residues by decay function unnecessary
  - Decay rate of logging residues typically used by forest products industry is rapid (26-31%/yr. in South) compared to relevant time horizon for EPA's carbon accounting (e.g., 100 yrs.)
  - Impractical to account for the many factors affecting residue decay rates

# Baseline

- Bioenergy associated with traditional forest products manufacturing has been generated for well over a century and should be included in the baseline.
- Demand for forest products provides an incentive for more land in sustainable forests.
- FIA data show growth exceeds drain in every region.
- EPA should use a reference point baseline, with a marginal approach, which provides the only objective way to identify incremental impacts of new stand-alone biomass energy facilities (e.g., coal utilities co-firing biomass, stand-alone biomass utilities, or pellet mills).

# Conclusion

- Framework must be both scientifically sound and workable.
- Emissions from forest products mill residues and byproducts are integral and incidental to the manufacturing process and should be exempt from regulation.
- Emissions from mill residues and byproducts should have a BAF of 0.
- Emissions from logging residues should not be discounted by decay function and also have a BAF of 0.
- Bioenergy associated with traditional forest products manufacturing should be included in the baseline.
- Thank you



March 16, 2012

EPA Scientific Advisory Board (SAB), Biogenic Carbon Emissions Panel  
Dr. Holly Stallworth  
Designated Federal Officer (DFO)  
SAB Staff Office

**Re: Comments on EPA's Draft Accounting Framework and the SAB's March 9<sup>th</sup> Draft Report**

Dear Science Advisory Board, Biogenic Carbon Emissions Panel Members:

The American Forest & Paper Association (AF&PA) appreciates the opportunity to comment on EPA's Draft Accounting Framework and the SAB's March 9, 2012 Draft Report. Thank you for your consideration of the important issues included in these comments.

**Executive Summary**

AF&PA wishes to highlight how forest products manufacturing mills use mill residues and byproducts and harvested forest residues to generate onsite energy. The use of these residues and byproducts should be assigned a Biogenic Accounting Factor (BAF) of 0 in EPA's Accounting Framework.

- The forest products industry uses forest biomass to manufacture products valued by its customers and society. The manufacture of those products creates biomass residues and bio-byproducts that are integral and incidental to the pulp and paper and wood products manufacturing processes.
- There are no economic or environmental alternatives for these biomass residues and byproducts that would prevent CO<sub>2</sub> from entering the atmosphere.
- The use of these biomass residues and byproducts for energy avoids the use of coal and other fossil fuels, and avoids the need to purchase large quantities of additional pulping chemicals.

The forest products industry should be included in the baseline.

- The forest products industry has been operating in the U.S. for more than a century and in doing so has helped maintain the carbon balance in forests nationwide.

- Data from the U.S. Forest Service's Forest Inventory Analysis shows that every region in the U.S. has a growth-to-drain ratio greater than 1.0. This has been true for as long as the Forest Service has collected and published this data. In contrast to fossil fuels, carbon is stored in biomass and after release upon combustion can be recaptured in biomass re-growth. The Forest Service data show that the forest products industry has taken great care to maintain the carbon stocks in U.S. forests. Various sustainable forestry management programs, best practices and educational programs promote responsible uses of U.S. forests. The Framework should incorporate a reference point baseline, which would provide the most objective mechanism to identify any marginal impact to forests from new stand-alone facilities constructed primarily to generate energy from biomass (e.g. utilities co-firing wood with coal, pellet mills, and stand-alone biomass facilities). The forest products industry should be included in whatever baseline ultimately is selected.

In sum, a BAF of zero should be assigned to emissions from:

- Mill residues and byproducts integral and incidental to forest products manufacturing
- Logging residues incidental to forest products manufacturing
- Other biomass where the growth-drain ratio is greater than 1.

## I. Introduction

The American Forest & Paper Association is the national trade association of the forest products industry, representing pulp, paper, packaging and wood products manufacturers, and forest landowners. Our companies make products essential for everyday life from renewable and recyclable resources that sustain the environment. The forest products industry accounts for approximately 5 percent of the total U.S. manufacturing GDP. Industry companies produce about \$190 billion in products annually and employ nearly 900,000 men and women, exceeding employment levels in the automotive, chemicals and plastics industries. The industry meets a payroll of approximately \$50 billion and is among the top 10 manufacturing sector employers in 47 states. Our industry also generates additional jobs throughout the supply chain and in local businesses, which further sustains communities and families.

AF&PA members manufacture valuable products that support society needs. Studies have shown the high value of the forests products industry to the economy and job creation. One study by RISI, a consulting firm focused on the forest products industry, found that, for a given volume of wood consumption, the forest products industry sustains five times as many core jobs (i.e., mill jobs) and nine times as many total jobs as the stand-alone biomass energy sector.<sup>1</sup>

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<sup>1</sup> RISI, "Job Creation in PPI and Energy Alternative in the United States", a report prepared for the American Forest & Paper Association (June 25, 2010).

We rely upon sustainably managed forests—a renewable and recyclable raw material -- to manufacture our products, and we are committed to ensuring a sustainable forest supply chain. Our products play an important role in creating a market for trees that are grown and harvested according to the highest standards of sustainability. Through continued strong economic performance and by supporting the needs of the communities in which we live and work, we contribute to their short- and long-term environmental, social, and economic well-being and to the well-being of the customers and consumers we serve.

Our production is accomplished while adhering to market-based sustainable forest management practices like the Sustainable Forest Initiative (SFI) or other credible forest certification programs that ensure that the wood fiber we use is grown in a responsible manner that ensures a reliable supply of raw material for the future. All AF&PA members that own forestland must conform to a credible sustainable forest management program and all members that source wood fiber from the forest must comply with sustainable procurement principles. Our demand for forest products provides the incentive for landowners to keep millions of acres of land sustainably forested for future use while providing habitat for wildlife and recreational opportunities for the community and sustaining the economy of the region. We have helped to combat illegal logging around the world and support the responsible use of forest resources.

AF&PA recently established a new initiative, Better Practices, Better Planet 2020, the next phase in the forest products industry's efforts to build on our legacy as a leader in sustainability. The initiative includes one of the most extensive set of quantifiable sustainability goals for a major U.S. manufacturing industry, with a commitment to transparently report progress towards achieving those goals.

#### A. Biomass Carbon Cycle

The carbon cycle is an intrinsic part of the forest products industry's operations. The forest products industry is the leading producer and user of renewable biomass energy and produces more energy from biomass than all the energy produced from U.S. solar, wind, and geothermal sources combined. The industry meets over 65% of its energy needs through the use of renewable biomass, largely through the use of the highly efficient combined heat and power processes.

The overwhelming majority of the biomass used for energy production is intrinsic and incidental to the forest products industry's manufacturing processes and to the harvesting of wood for raw materials for forest products. Not only do the forests that provide our primary feedstock sequester carbon dioxide (CO<sub>2</sub>), but also, significant quantities of CO<sub>2</sub> are kept out of the atmosphere through storage in forest-based products. The industry is a leader in the practice of sustainable forest management, which contributes to the renewability of the forest resource and the continued balance of the carbon cycle. EPA's comprehensive annual accounting of biogenic emissions and sinks from land use change reports that carbon storage in U.S. forests continues to increase, sequestering more than 800 million metric tons of carbon dioxide equivalents annually.

Given the continuous cycle of biogenic emissions (through combustion or decay) and sequestration (via photosynthesis), policymakers must assess whether the carbon cycle is in balance, rather than assessing individual sources and sinks or timeframes, which at any given moment could be serving as a source or sink for CO<sub>2</sub> emissions within the overall carbon cycle. Assessing biogenic emissions in a short term or small scale manner only measures a portion of the carbon cycle and will result in misleading conclusions regarding the benefits of biomass for greenhouse gas mitigation over the long term. In the U.S., the balance of the carbon cycle is assessed continually via Forest Inventory Analysis (FIA) data collected and managed by the Forest Service. This data is used to support the U.S. National Inventory of U.S. Greenhouse Gas Emissions and Sinks prepared by EPA and submitted to the United Nations Framework Convention on Climate Change annually. FIA data may also be used to assess the balance of the carbon cycle via ratios of forest growth to drain.

#### B. Biomass Energy Production and Forest Products

The forest products industry uses virgin wood and reclaimed paper fiber as feedstocks to produce pulp and paper products and uses mostly virgin wood and wood residues for solid wood products. The use of biomass for energy generation in forest products mills is integral and incidental to manufacturing these products. The generation of biomass residues and byproducts is part of the timber harvesting and manufacturing process. Utilizing biomass residues to produce thermal and electric energy, usually with highly energy efficient combined heat and power systems, is the most sustainable use of these materials. Using biomass residues on site for energy avoids the use of fossil fuels, the energy that it would take to produce and transport that fossil fuel and the landfills that would be needed to dispose of the residual biomass. Moreover, for pulping, the energy recovery from spent pulping liquors is simultaneous with the recovery of the pulping chemicals, which avoids the need for additional chemicals and the fossil fuels that otherwise would be needed for their manufacture and transportation.

Many forest products facilities convert biomass to heat and power as well as bio-based products. The industry also is a leader in highly efficient co-generation of energy, much of it from biomass, both for internal use and for electricity sold to the power grid. Co-generation is widely recognized as the most efficient method for producing energy, and our mills often can produce twice as many usable BTUs of energy than utilities from the same amount of biomass. Nearly all pulp, paper, and wood products mills that generate electricity produce electricity using co-generation technology. Utilizing such biomass residues to efficiently produce thermal energy and combined heat and power is the most sustainable use of these materials

The predominant biomass residues and byproducts used to generate energy include: spent pulping liquors, bark, shavings, sawdust, slabs and hogged fuel. Residues do not include merchantable roundwood, pulpwood, logs, longwood, wood chips or pellets.

i. Forest Residues

This category includes tops, limbs, branches, and other unmerchantable portions of trees harvested primarily to make wood pulp or lumber and other wood products. It also includes fuel treatment thinnings<sup>2</sup> and pre-commercial thinnings.<sup>3</sup> In some cases, this category also includes trees damaged by natural disasters such as wildfires, hurricanes, insects, and disease.

ii. Mill Residues

This category includes bark removed from logs used to produce pulp and wood products such as lumber, sub-standard logs that would otherwise be discarded and sawdust, slabs and shavings from wood product facilities.

iii. Spent Pulping Liquor

At Kraft, sulfite, and neutral sulfite semi-chemical pulp facilities, the pulping process generates spent pulping liquor, a byproduct of the process. Wood fiber is decomposed into cellulose fibers (from which paper is made), lignin fragments, and hemicellulose. Spent pulping liquor is an aqueous solution of lignin residues, hemicellulose, and the inorganic chemicals used in the pulping process. Spent pulping liquor contains more than half of the energy content of the wood fed into the digester. Spent pulping liquor is used in fuel recovery boilers and is extremely important to the energy profile of the pulp and paper industry. Spent pulping liquor produces between 50,000 and 65,000 BTUs per gallon, generating approximately 68% of the biomass energy generated by pulp and paper facilities. The energy generated by burning spent pulping liquor in recovery boilers is used to generate steam for paper dryers, evaporators and other steam-consuming processes in the mill as well as electricity.

iv. Pulping and Recycled Residuals

Some paper mills also generate energy from recovered fibers that have been rejected from the recycling process due to quality issues and paper mill sludge, which contains “fines” – tiny wood particles lost in the papermaking process.

v. Biomass Residuals and Debris

This category includes wood-based construction and demolition debris, urban tree trimmings along power lines and roads, and railroad ties.

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<sup>2</sup> Small trees that are harvested from dense growth to limit the risk of fire.

<sup>3</sup> Small trees that are harvested so that others have adequate access to sunlight, water and nutrients to grow to the desired size.

At solid wood facilities, sawdust, slab wood, and logs unsuitable for lumber production are fed into a “bark burner,” which is used to generate heat (primarily for operation of dry kilns) and power. Solid wood facilities also sell this material as hogged fuel to other facilities, primarily pulp mills. (Rejected logs may also be adequate for sale as pulp logs.)

On the pulp and paper side, facilities fall into three general categories: chip mills, pulp mills, and paper mills. They may exist separately or in combination, although a pulp mill will almost always have the capability to manufacture chips. The chipping process creates considerable residue in the form of bark and other trimmings. These are used or sold as hogged fuel. Finally, a paper mill will benefit from the energy produced at a pulp mill on the same site.

## II. ANY FRAMEWORK MUST BE CAREFULLY TAILORED TO ADDRESS THE REGULATORY SCOPE

Given the December 2009 Endangerment Finding and the May 2010 Tailoring Rule, the Clean Air Act’s Title V/PSD program requires that all new “major sources,” and all major sources undertaking modifications that result in a “significant” increase in emissions, obtain preconstruction permits and install “best available control technology” (BACT) for greenhouse gas emissions. In addition, sources emitting over 100 tons per year (tpy) of a GHG are generally required to obtain an operating permit under Title V of the Clean Air Act.

In July 2011, subsequent to the Endangerment Finding and the Tailoring Rule, EPA issued a final rule deferring for three years application of the Clean Air Act’s PSD and Title V permitting requirements to “CO<sub>2</sub>” emissions from biogenic stationary sources. In that Final Rule, EPA indicated that it would establish a Science Advisory Board and use the three-year deferral period to conduct an analysis of the impacts of emissions from bioenergy and other biogenic stationary sources prior to a final determination of how such emissions should be regulated.

Given that EPA’s Draft Framework for Biogenic CO<sub>2</sub> Emissions from Stationary Sources is intended to account for GHG emissions for purposes of Title V and PSD, the Framework must be carefully tailored. The Framework must only account for CO<sub>2</sub> from biogenic sources to the extent that EPA finds that it contributes to climate change and endangers public health and welfare.<sup>4</sup>

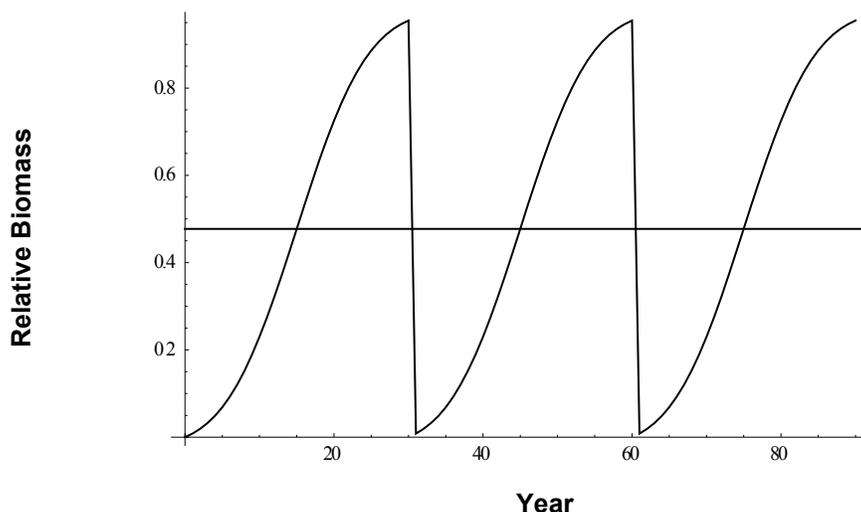
In EPA’s Proposed Rule for Deferral for CO<sub>2</sub> Emissions from Bioenergy and Other Biogenic Sources Under the PSD and Title V programs, the Agency found that biogenic emissions were inherently different than fossil fuels based on the role they play in the natural carbon cycle. AF&PA was pleased with this finding and supports EPA’s conclusion that it is appropriate to consider the carbon cycle when assessing GHG impacts of stationary source biomass combustion.

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<sup>4</sup> 74 FR 66496 (December 15, 2009).

AF&PA maintains that given the continuous cycle of biogenic emissions<sup>5</sup> (through combustion or decay) and sequestration (via photosynthesis), that the carbon cycle is in balance. At any given moment, a particular forest could be serving as a source or sink for CO<sub>2</sub> emissions within the overall carbon cycle. Figure 1 below represents the carbon cycle on a large number of plots over the course of a century from initial planting to harvest. The annual growth on all these plots taken together equals the rate of harvest so the relative biomass present at any point in time is constant.

**Figure 1.** A large plot where annual growth is equal to harvest.



Given the evidence that forest carbon stocks in the U.S. are stable or increasing<sup>6</sup>, there is every reason to conclude that the forest carbon cycle in the U.S., involving uptake of atmospheric CO<sub>2</sub> in the forest and return of biomass carbon to the atmosphere is, in fact, accomplishing net removals of CO<sub>2</sub> from the atmosphere. Consequently, it is AF&PA's position that biogenic CO<sub>2</sub> from biomass combustion is at least carbon neutral and should be counted as zero. Alternatively, any biogenic CO<sub>2</sub> accounting should only apply to the extent that EPA finds that it contributes to climate change and endangers public health and welfare.<sup>7</sup>

Any Accounting Framework should also be cost-effective. EPA's final PSD/Title V Permitting Guidance for Greenhouse Gases includes a methodology for cost effectiveness.<sup>8</sup> Further, § 169(3) of the Clean Air Act defines BACT as:

“an emissions limitation (including a visible emission standard) based on the maximum degree of reduction for each pollutant subject to regulation

<sup>5</sup> Biogenic emissions refers to carbon dioxide emissions throughout the document unless otherwise noted.

<sup>6</sup> Forest Resources of the United States,” U.S. Forest Service, Table 36.

<sup>7</sup> 74 FR 66496 (December 15, 2009).

<sup>8</sup> PSD and Title V Permitting Guidance for Greenhouse Gases. Appendix F.

under the Clean Air Act which would be emitted from any proposed major stationary source or major modification which the Administrator, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs...”

**III. BIOMASS RESIDUES AND BYPRODUCTS SHOULD BE CLASSIFIED AS INCIDENTAL OR “ANYWAY” EMISSIONS.**

In the case of manufacturing residues and byproducts used to generate onsite energy, there is very little uncertainty about alternative scenarios and their impacts. If these materials are not used to generate energy (and in the case of spent pulping liquor solids, to provide chemicals for pulping via the chemical recovery system) the carbon in these materials would return to the atmosphere anyway, but without providing any benefit. They would either be burned without energy recovery, returning the carbon to the atmosphere immediately, or in some cases, placed in landfills where the carbon would be returned to the atmosphere over time, some of it in the form of methane, a greenhouse gas that is 25 times as potent as CO<sub>2</sub> over a 100-year time frame. Even considering the relative efficiencies of using fossil fuels versus biomass to generate usable energy, the GHG benefits of using these materials for energy (and chemicals in the case of spent pulping liquor solids) are clear.<sup>9</sup>

**A. Emissions from Combustion of Forest Products Manufacturing Residues and Byproducts are Carbon Neutral Incidental Emissions.**

In the preamble to the Proposed Rule for Deferral for CO<sub>2</sub> emissions from Bio-energy and Other Biogenic Sources under the PSD and Title V programs proposed rule, EPA cites examples of feedstocks that have a “negligible impact on the net carbon cycle” when utilized to produce energy or that “would clearly reduce net atmospheric CO<sub>2</sub> levels.” These include:

- Residue material that would have decomposed under natural circumstances in a relatively short period of time (e.g., sawdust from milling operations);
- Dead trees, for example, killed by pine beetles; by removing and utilizing biomass materials that would otherwise be susceptible to fire or decompose in the forest, leading to CO<sub>2</sub> and CH<sub>4</sub> emissions from decomposition.
- Methane laden biogas, for example, from landfills, where “energy production reduces overall CO<sub>2</sub>-e emissions because of the higher global warming potential for methane.”

EPA’s draft Accounting Framework also treats emissions from combustion of forest product mill residues and byproducts and forest harvest residues as carbon neutral “anyway” emissions because those materials would have decayed and released CO<sub>2</sub> if they were not used for energy. We believe that emissions from the combustion of the biomass residues

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<sup>9</sup> NCASI Comments on 3-19-12 Deliberative Draft of the SAB’s Biogenic Carbon Emissions Panel.

and byproducts that are integral and incidental to forest products manufacturing and their emissions qualify as “anyway” emissions under the terminology of EPA’s Framework.

For example, EPA’s draft Framework report states, “mill residues are secondary forest-derived biomass procured from a wood processing facility such as a saw- or pulp mill. Sources from sawmills typically include peeler shavings, sawdust, and bark, while product streams from pulp mills also include lignin and other wood components, black liquor, or liquid fuels such as cellulosic ethanol. Most of this material is currently burned for energy or heat at the facilities . . . ; some may be sold for mulch or for processing into pulp.”<sup>10</sup> (p. 30). Later, in the Case Study for the pulp and paper mill, the report states:

“For residues from mills:

\* \* \* \* \*

“Because residues are a secondary forest-derived biomass from other wood processing mills, the assumption is that if not burned for energy at this plant, the feedstock would have been burned or decayed elsewhere, with or without energy productions, resulting in the same level of emissions. Thus, burning it for energy is avoiding the same emissions elsewhere . . . ”<sup>11</sup>

Regarding forest residues, EPA’s report states, “if harvest residue is not removed for bioenergy, it would have decayed or been burned in the forest. Under current biomass market prices in most regions, the procurement of residue does not trigger the harvest operation. . . ”<sup>12</sup>

Both mill residuals and by-products such as spent pulping liquor and harvested forest residuals should be included in this list of residuals and byproducts because they are integral and incidental to the forest products manufacturing processes and cannot be sustainably separated. These residuals and byproducts should require no further analysis under the draft Accounting Framework.

i. Harvested Forest Residues

For harvested residues, another way to demonstrate that the carbon cycle is in balance for existing users is by a plot-by-plot analysis. For illustrative purposes, Appendix A contains a set of graphs that have been designed to reflect a hypothetical landscape, managed on a 30-year rotation with 1/30th of the area harvested per year. Each of these 30 areas is considered to be a “plot”. Each year, one of the thirty plots is harvested and harvest residue is generated consisting of one unit of carbon.

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<sup>10</sup> Johnson, T.G., ed. 2001. *United States timber industry—an assessment of timber product output and use*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 1996. p. 30.

<sup>11</sup> Id at 99.

<sup>12</sup> EPA’s Accounting Framework for Biogenic CO<sub>2</sub> Emissions from Stationary Sources (September 2011). p. 33

There are two scenarios represented by Figures A1 and A2. Under the first scenario (Figure A1), the harvest residues remain on site to decay over a 30-year-period. Under the second (Figure A2), the harvest residues on one of the plots are removed and burned for energy, displacing fossil fuels. The result is that under both scenarios, the same amount of biogenic carbon is emitted to the atmosphere in a given year (Figure A3). This is because the residue decay on thirty plots generates the same amount of carbon as burning the harvest residues on a single plot. Given that paper and wood products mills have been using forest residues to generate energy for many years, the use of harvest residues to generate energy is an established practice that displaces fossil fuel, generates no new net emissions, and belongs in the baseline.

Table 1 summarizes a comparative analysis conducted by NCASI<sup>13</sup>. The analysis shows the number of years required for a biomass system to show lower annual emissions than the fossil fuel alternative system for existing facilities using harvested forest residues to generate energy instead of using a fossil fuel and either leaving the residues to decay in the forest or to burn them at harvest time. For all of the scenarios, there is no period of time required to attain lower emissions. The alternative is using a fossil fuel such as coal and incinerating the residue, which would result in emissions from both the coal and the residue.

#### ii. Mill Residues

Similar to harvested forest residues, Table 1 contains a comparative analysis for mill residues (also referred to as manufacturing residues). The second and third column show the number of years required to show lower emissions for using mill residues to generate energy instead of using fossil fuel and incinerating the mill residues. When the mill residues are incinerated and a fossil fuel is used instead, again there is no period of time required to attain lower emissions.

#### iii. Spent Pulping Liquor

Spent pulping liquor is a residual material from mill operations that would have decomposed under natural circumstances in the relatively short period of time. Spent liquor solids, account for over two-thirds of the biomass fuel used by the pulp and paper industry<sup>14</sup>. Spent pulping liquor is an unavoidable byproduct of chemical pulping of wood, and burning it for energy recovery does not increase the amount of wood harvested to make pulp and paper. Moreover, if spent pulping liquor is not burned for energy recovery, one scenario for comparison is that it would be discharged as part of a mill waste stream resulting in associated decomposition.<sup>15</sup> Thus, combustion of spent pulping liquor for heat

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<sup>13</sup> NCASI is the National Council for Air and Stream Improvement, an independent research organization of the forest products industry.

<sup>14</sup> American Forest & Paper Association (AF&PA). 2010. *2010 AF&PA Sustainability Report*.

Washington DC: American Forest & Paper Association. <http://www.afandpa.org/Sustainability/>

<sup>15</sup> This is a purely hypothetical scenario, as mills would never discharge this material due to economic and environmental reasons.

generation and its associated displacement of fossil fuel energy, definitely improves global CO<sub>2</sub> concentrations over the baseline of not using the spent liquor heat value. The energy recovery from spent pulping liquors is simultaneous with the recovery of inorganic pulping chemicals, which also avoids the need for additional chemicals in the manufacturing process.

Life Cycle Analysis results show the GHG and renewable energy benefits of combusting spent pulping liquors for energy. In December 2010, AF&PA submitted to EPA a life cycle analysis by the National Council for Air & Stream Improvement (NCASI) (see Appendix B) and requested that spent pulping liquors be listed and affirmed as having a negligible impact on the net carbon cycle. In the study, NCASI compared the GHGs emitted, and non-renewable energy required, to produce one gigajoule (GJ) of energy output and the same quantities of pulping chemicals in several systems (the amounts of wood used and pulp produced are equal in all systems): 1) the use of black liquor solids in the Kraft recovery process; and 2) various fossil fuel-based systems.

The results from the analysis are as follows:

- The GHG emissions and non-renewable energy consumption for a system using black liquor solids in the Kraft recovery system are approximately 90% lower than those of a comparable fossil fuel-based system.
- Use of black liquor solids in the Kraft recovery system avoids approximately 140kg CO<sub>2</sub> equivalent per GJ of energy output from the system.
- Applying these results to the production of Kraft pulp in the U.S., the avoided emissions are approximately 100 million tonnes CO<sub>2</sub> equivalents per year.
- These avoided emissions are essentially equal to the total Scope 1 (direct emissions) + Scope 2 (purchased electricity) emissions from the U.S. forest product industry (all mills).

These benefits occur without affecting the amount of wood harvested or the amount of chemical pulp produced. The results do not depend on the accounting method for biogenic carbon. The findings are valid across a range of assumptions about the displaced fossil fuel, the GHG-intensity of the grid, and the fossil fuels used in the lime kiln. Even without including highly-efficient Combined Heat and Power (CHP)<sup>16</sup>, 80% to 90% of the benefits are retained.

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<sup>16</sup> Virtually all pulp mills that produce electricity do so using CHP.

## Table 1. Residue Use for Energy By Forest Products Industry

Mill Residues Integral and Incidental to Forest Products Manufacturing				Harvest Residues Incidental to Forest Products Industry			
Variables	Facility continues to use black liquor solids in the kraft recovery cycle instead of purchasing energy and chemicals for pulping <sup>£</sup>	Facility continues to use mfg residue <sup>λ</sup> that would otherwise be incinerated <sup>§</sup> . Burn as a substitute for coal	Facility continues to use mfg residue <sup>λ</sup> that would otherwise be incinerated <sup>§</sup> . Burn as a substitute for natural gas	Facility continues to use harvest residuals to displace coal. Residuals would otherwise decay in the forest	Facility continues to use harvest residuals to displace coal. Residuals would otherwise be pile-burned	Facility continues to use harvest residuals to displace natural gas. Residuals would otherwise decay in the forest	Facility continues to use harvest residuals to displace natural gas. Residuals would otherwise be pile-burned
Decay half-life (years) =	£	NA <sup>Δ</sup>	NA <sup>Δ</sup>	5	NA <sup>Δ</sup>	5	NA <sup>Δ</sup>
Non-decomposable fraction =	£	NA <sup>Δ</sup>	NA <sup>Δ</sup>	0	NA <sup>Δ</sup>	0	NA <sup>Δ</sup>
Fraction of decomposed carbon that is released as methane =	£	NA <sup>Δ</sup>	NA <sup>Δ</sup>	0	NA <sup>Δ</sup>	0	NA <sup>Δ</sup>
GWP for methane =	NA <sup>Δ</sup>	NA <sup>Δ</sup>	NA <sup>Δ</sup>	NA <sup>Δ</sup>	NA <sup>Δ</sup>	NA <sup>Δ</sup>	NA <sup>Δ</sup>
Ratio of fossil fuel carbon to biomass carbon needed to generate the same amount of steam =	See NCASI (2011) <sup>Δ</sup>	0.77***	0.46***	0.77***	0.77***	0.46***	0.46***
Time from today for biomass system to show lower annual emissions than fossil fuel alternative =	< 0 years <sup>Δ</sup>	< 0 years	< 0 years	< 0 years	< 0 years	< 0 years	< 0 years

<sup>£</sup> It is important to note that it is neither economically nor technically rational to operate a kraft pulp mill without using kraft black liquor solids in the kraft recovery system to generate energy and regenerate pulping chemicals. The burning of kraft black liquor solids in the kraft recovery system is integral to the process of making kraft pulp.

<sup>λ</sup> “mfg residue” is manufacturing residue from wood products, pulp, paper and paperboard manufacturing.

<sup>§</sup> There are significant economic benefits to using as fuel many of the manufacturing residuals that are not suitable as raw material for other forest products manufacturing. In many cases, it is inconceivable that these materials would be landfilled or burned without energy recovery because their use as fuel is so integral to the economic viability of the manufacturing operations.

<sup>Δ</sup> NA means not applicable

<sup>Σ</sup> The details for these calculations are shown in Attachment 1.

\* Values from EPA National Inventory report for wood disposed in landfills

\*\* As generated, 50% of the carbon in landfill gas is methane, but some of it is oxidized as it migrates to the surface. NCASI knows of no wood waste landfills that are capped to capture and burn methane

\*\*\* Calculated based on differences in fuel carbon content and boiler efficiencies on the various fuels.

<sup>Δ</sup> National Council for Air and Stream Improvement, Inc. (NCASI). 2011. *Greenhouse gas and non-renewable energy benefits of black liquor recovery*. Technical Bulletin No. 984. Research Triangle Park, N.C.: National Council for Air and Stream Improvement, Inc.

Source: NCASI

#### **IV. ANY ACCOUNTING FRAMEWORK SHOULD NOT DISCOUNT BIOMASS RESIDUES OR BYPRODUCTS ACCORDING TO A DECAY FUNCTION**

One of the many areas of debate that is included in the SAB's Draft Report and was a topic of discussion during the January 27, 2012, conference call is the question of the time period that should be used in an Accounting Framework. Some participants have argued that a very short time frame is appropriate while others assert that 100 years is adequate. The reality however, is that the time period is largely irrelevant. The CO<sub>2</sub> emissions associated with residues and byproducts, such as residues left on the forest floor versus using them for energy production is de minimis. The alternative is using fossil based fuel for energy which results in a net increase in emissions.

##### **A. Forest Products Mills**

Table 1, based on NCASI's analysis, shows that no time period is required to attain lower emissions using residues and byproducts for energy generation as opposed to fossil fuel alternatives at existing forest products mills. In the case of black liquor (also referred to as spent pulping liquor), the time period is zero because there is no reasonable alternative to energy production for this incidental byproduct of the pulping process. For manufacturing residues such as bark, there is no time period required because the alternative is using a fossil fuel such as coal and incinerating the bark, which would result in emissions from both the coal and the bark.

##### **B. New Biomass Users**

Table 1 provides the payback periods for existing forest products facilities for energy production. All of the time periods required to attain lower emissions are "zero" because existing facilities in the forest products sector use biomass to produce electricity that is integral or incidental to the manufacturing process at these facilities. In addition, the facilities in the forest products industry have been in existence long enough that the carbon cycle for these facilities is well established and is in equilibrium.

Future demand growth in the short-term will largely be limited to coal utilities co-firing wood biomass, biomass electric utilities and pellet mills, and longer term growth will likely include bio-refineries. These industries are different because they use biomass solely for energy generation. For an electric utility that uses biomass in place of natural gas, for example, the time period required to attain lower emissions could be 21 years. Similarly, the time period required for substituting biomass for coal at a new energy facility could be 8 years.

##### **C. A GHG Comparison Between Biomass and Fossil Fuel Alternatives**

Recent years have seen both a rise in the interest in substituting biomass for fossil fuels and increasing skepticism about the greenhouse gas benefits of this substitution. While programs that promote the use of biomass as a substitute for fossil fuel have important connections to the issues of energy security and economic sustainability, it is the questions

about greenhouse gas mitigation benefits that have been at the center of the debate on whether and how to increase the reliance on the use of biomass for energy.

An important distinction between biomass carbon and the carbon in fossil fuels is that the carbon in biomass-derived fuels was only recently removed from the atmosphere. When biomass is burned, decays, or is otherwise oxidized, the resulting CO<sub>2</sub> is returned to the atmosphere. This is in contrast to carbon from fossil fuels, which is an irreversible flow that permanently adds to the total amount in the biosphere. This aspect of the biogenic carbon cycle forms the basis for using a zero emission factor at the point of combustion for biomass-derived fuels<sup>17,18</sup>, and it represents an accepted benefit of using biomass derived fuels rather than fossil fuels<sup>19</sup>.

There is a difference between the life cycle impacts of a biomass fuel and the emission factor (for an emissions inventory) of a biomass fuel. The emission factor of a biomass fuel pertains only to emissions that occur at the point of combustion. Life cycle impacts are based on these point of combustion emissions in combination with “upstream” (e.g., land use change, silvicultural/harvesting, transport, processing) and “downstream” (e.g., end-of-life) emissions. Because of these upstream, non-combustion emissions, the life cycle impacts assigned to biomass fuel use can be non-zero even where the release of biogenic CO<sub>2</sub> upon combustion is in balance with carbon uptake via regrowth.<sup>20</sup> Where the amounts of CO<sub>2</sub> that return to the atmosphere are less than the amounts removed, the difference represents increases in stocks of stored carbon (net removals from the atmosphere). Where net returns are greater than the amounts removed, the difference represents depleted stocks of stored carbon.

There are different types of biomass used for energy and different regimes of land use/carbon stock changes associated with them. Biomass fuels obtained from residuals (agricultural, manufacturing, forestry residuals, etc.) are typically not associated with land use/carbon stock changes.<sup>21,22</sup>

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<sup>17</sup> Abbasi, T., and Abbasi, S.A., “Biomass Energy and the Environmental Impacts Associated with its Production and Utilization.” *Renewable and Sustainable Energy Reviews*. 2010. 14:919-937; doi:10.1016/j.rser.2009.11.006 (2010)

<sup>18</sup> Cherubini, F., GHG balances of bioenergy systems – Overview of key steps in the production chain and methodological concerns, *Renewable Energy*. December 2009. 35:1565-1573; doi:10.1016/j.renene.2009.11.035 (2010).

<sup>19</sup> Abbasi and Abbasi 2010; Froese et al. 2010; Schlamadinger et al. 1997.

<sup>20</sup> Abbasi and Abbasi 2010.

<sup>21</sup> Schlamadinger, B., M. Apps, F. Bohlin, L. Gustavsson, G. Jungmeier, G. Marland, K. Pingoud, and I. Savolainen. “Towards a Standard Methodology for Greenhouse Gas Balances of Bioenergy Systems in Comparison with Fossil Energy Systems.” *Biomass and Bioenergy*. 1997. 13(6):359-375.

<sup>22</sup> Mann, M. and P. Spath. “A life cycle assessment of biomass cofiring in a coal-fired power plant. *Clean Technologies and Environmental Policy*. 2001. 3(2):81-91.

D. The Starting Point for Biomass Carbon Cycle Accounting Should Recognize that the Carbon Cycle is in Equilibrium.

During the last January 2012 SAB conference call, there was much debate about whether the starting point for biomass carbon accounting was at harvest or at seed planting. The starting point is indeed important because it determines whether the carbon cycle is viewed with a negative or a positive value of carbon sequestered. The forest products industry has been harvesting biomass in a sustainable manner and recovering spent pulping liquors for almost a century. Much private forestland is managed as timberland because of the wood demand from the forest products industry. Using initial harvest as the starting point for carbon accounting and thereby assigning a negative value is inappropriate. Sustainable forest management spans planting through harvesting, and the sequestration of CO<sub>2</sub> occurs throughout. The forest products industry has long term and sustainable operations that encourage landowners to keep land sustainably forested.

The growth of a forest is not constant. Although young trees grow rapidly and hence sequester substantial carbon, mature forests experience little net growth and therefore sequester little additional carbon. Mature forests are typically not harvested for biomass energy because of their more valuable use in wood products. Thus, most wood biomass used for energy is likely to come from wood residues from industrial forestry and from young, low-value pulpwood. Dead wood and debris, which typically decomposes in the forest, releasing carbon to the atmosphere, can also constructively be used for energy. Thus, a careful systems management approach can generate near-term offsets to carbon releases by using biomass debris to reduce fossil fuel emissions and by “promoting” low sequestration sites to higher levels of sequestration, thereby providing for a carbon-neutral utilization of biomass energy in the near term as well as over time.<sup>23</sup>

E. It Is Impractical to Account for the Many Factors Affecting Residue Decay Rates.

Decay rates are highly variable and it would be impractical and inaccurate to assign decay rates to categories of biomass feedstocks. AF&PA finds this approach impractical because of the many factors that affect the decay rates of residues. These factors include temperature, soil moisture, water saturation, soil texture, topography, salinity, acidity, and vegetation and biomass production.<sup>24</sup> Biomass decay occurs more rapidly in:

- tropical climates as opposed to more temperate climates;
- as annual precipitation increases but not during periods of soil saturation;
- soils with high clay contents;
- areas where the topography is at its lowest elevation;
- soil that has a neutral pH value;

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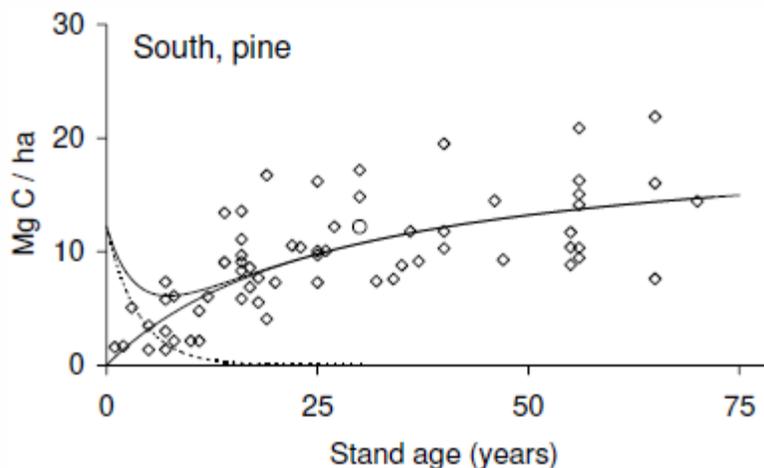
<sup>23</sup> Sedjo, Roger. Carbon Neutrality and Bioenergy: A Zero Sum Game. Resources for the Future. April 2011.

<sup>24</sup> Bot, Alexandra and Benites, Jose. Food and Agriculture Organization of the United Nations. Document Repository. The Importance of Soil Organic Matter. 2005. Chapter 3.  
<http://www.fao.org/docrep/009/a0100e/a0100e06.htm>

- areas that have higher biomass growth rates due to adequate sunlight, rain, and a long growing season.

Each of these factors is specific to a very small landscape and affects the decay rate of any given biomass residue, and therefore it is not practical to account for each of these factors. Figure 2<sup>25</sup> supports this assertion. The data points represent the carbon found in individual studies while the solid line represents the best estimate of the decay rate to be derived from the studies overall. This suggests that attempts to differentiate between different types of residue will be subject to great uncertainty. One must ask whether such differentiation is necessary when (1) it introduces such complexity and uncertainty and (2) under most commonly encountered situations, the carbon benefits of using biomass are so clear, especially in the intermediate- to long-term carbon. With collection costs already serving to discourage the use of many of these residuals, it would seem counterproductive to put in place a carbon accounting program that increases transaction costs and further discourages the use of these materials which show such clear atmospheric carbon benefits.

**Figure 2.** Pine tree decay rates (measured in forest floor carbon) in the southern U.S. estimated as a function of stand age.



F. Some Models that Show Long Periods of Time to Attain Lower Emissions for Biomass Residues include Assumptions not Applicable to the Forest Products Industry.

On the January 27, 2012 SAB conference call, a model was cited that used a methodology that included a single plot containing abandoned forest residues where, in 100 years, only 1% is left. The decay rate for the plot was calculated to be 4.63% per year. The model was then extrapolated to 100 plots. Under this scenario, if one plot is harvested each year for 100 years, the average level of non-decayed logging residues at any point in time would

<sup>25</sup> U.S. Department of Agriculture. A Model of Forest Floor Carbon Mass for United States Forest Types. Available at: [http://www.fs.fed.us/ne/durham/4104/papers/smith\\_heath\\_2002.pdf](http://www.fs.fed.us/ne/durham/4104/papers/smith_heath_2002.pdf)

be 22%. If harvest rotation periods were reduced to 50 or 25 years, the average level of non-decayed residues would increase significantly.

This model includes assumptions that are not applicable to the kind of harvest residues typically used by forest products mills for energy. For example, the model uses a decay rate of 4.6%, which is a valid decay rate for the U.S Pacific Northwest but is not representative of the South, the primary wood basket for forest products and where decay occurs much more rapidly. Moreover, while some studies focus on biomass with long decay cycles such as stumps and coarse roots,<sup>26</sup> the forest products industry primarily uses thin-diameter forest residues that are comprised of tops, limbs, branches, and the unmerchantable portions of trees harvested to make wood pulp or lumber and other wood products. Pre-commercial thinnings also are used for energy.

The decay rate of “logging residues” (i.e., small-diameter materials such as branches and tree tops) is typically very rapid relative to the longer time horizons that are most relevant to EPA’s carbon accounting objectives (e.g., 100 years). Information presented in Smith and Heath (2002) suggests that the half-lives of logging residues are less than three years in the South, which accounts for 60% of annual timber production in the United States. Half-lives of logging residues are somewhat longer in other regions (2 to 17 years) but nevertheless short enough to support a conclusion that adjustment of biogenic emissions for decay rates of logging residues is not necessary.

**V. ANY ACCOUNTING FRAMEWORK MUST INCORPORATE A BASELINE THAT ACCOUNTS FOR THE MARGINAL IMPACT OF NEW BIOMASS ENERGY FACILITIES**

**A. A Reference Point Baseline Would Account for New Biomass Demand.**

AF&PA agrees with EPA’s assessment that the chosen approach for a baseline is important and will affect how facilities or categories of biomass are treated under an Accounting Framework. In the Draft Accounting Framework, EPA states<sup>27</sup>:

A “baseline” against which to compare the impact of biogenic feedstock production and utilization is another critical component of an accounting framework for adjusting biogenic CO<sub>2</sub> emissions at stationary source. The determination of what baseline to use can make a significant difference in results and will likely depend on the specific context(s) in which the accounting framework is applied.

As EPA points out in its Draft Accounting Framework, a “reference point baseline approach seeks to answer the question, is there more or less carbon stored in the system at the end

<sup>26</sup> Sathre, Roger and Gustavsson, Leif. Time-dependent climate benefits of using forest residues to substitute fossil fuels. Mid Sweden University, Department of Engineering and Sustainable Development. Journal of Biomass and Bioenergy. 2011. Volume 35, Number 7. 2011. Table 1.

<sup>27</sup> Accounting Framework for Biogenic CO<sub>2</sub> Emissions from Stationary Sources. U.S. EPA. September 2011. page v.

of an assessment period than there was at the beginning?”<sup>28</sup> AF&PA suggests that EPA use a reference point baseline in the Accounting Framework. A reference point baseline would account for any new biomass demand that would result in a decrease in forest stocks and sequestered carbon. As previously discussed in these comments, many of the recent studies around biomass largely limit their analysis to future demand growth in the wood pellet and biomass electric power sector. Incorporating a reference point baseline into EPA’s Accounting Framework will provide a mechanism to hold these new users of biomass accountable if they negatively impact forest stocks and sequestered carbon.

We support EPA’s use of a reference point baseline with a marginal approach that would focus on new stand-alone biomass energy facilities, not the longstanding use of biomass materials that are integral and incidental to forest products industry manufacturers.

There is inherent complexity and uncertainty associated with “anticipated future baselines”. The most important limitation is the impossibility of knowing the future. This is not a small problem. The errors that can be introduced are enormous and are completely dependent on assumptions. Consider, for instance, the following real-world example.

**Figure 3.** Pine Pulpwood Plantation Productivity Improvements:  
1980 to 2000 (based on Fox et. al. 2004)

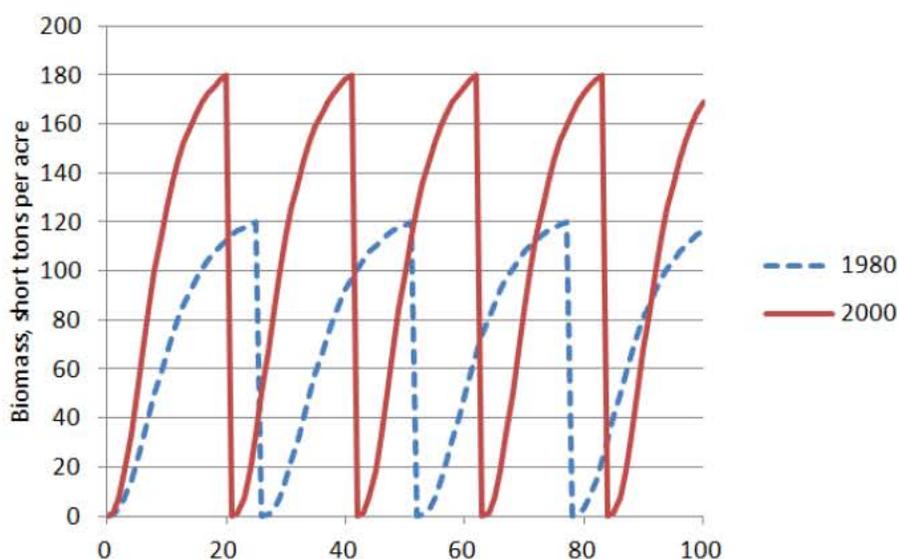


Figure 3 presents information indicating that rotation lengths on southern pine pulpwood plantations decreased from approximately 25 years to 20 years between 1980 and 2000.<sup>29</sup> The same source indicates that over the same period, the biomass yield at harvest on these plantations increased from approximately 120 to 180 short tons per acre. Anticipated future baselines developed in 1980 that failed to take these improvements into account

<sup>28</sup> Fargione, J., J. Hill, D. Tilman, S. Polasky, et al. Land clearing and the biofuel carbon debt. *Science*. 2008. 319 (5867):1235-1238.

<sup>29</sup> Fox, T.R. et al. Forest Fertilization in Southern Pine Plantations. 2004.

would have severely underestimated the benefits of continued use of the land for pulpwood production. If you assume that these improvements were implemented gradually over a landscape, you find that over just this twenty year period, an anticipated future baseline based on 1980 productivity would have understated the benefits of associated with continued pulpwood production on this land by over 40%.<sup>30</sup>

Anticipated future baselines, while predictable in theory, are more like long range weather predictions. There are too many unknown variables to credibly predict future carbon stocks. An anticipated future baseline will only reflect the biases of those making the prediction. While a reference baseline has its limitations, it is much more objective than an anticipated future baseline. Moreover, an anticipated future baseline likely will involve greater complexity and cost to the regulatory system, which could reduce incentives to keep lands forested, particularly for smaller entities.

**B. Future Biomass Users' Businesses Do Not Reflect the Steady State of the Forest Products Industry.**

Given that the overwhelming majority of the biomass consumed by the forest products industry for energy production comes from manufacturing residues and byproducts, it is important to consider projected future demand growth for biomass and the analysis that has been done in this area. For example, a recent study, Biomass Supply and Carbon Accounting for Southeastern Forests, examines future demand and the potential implications. While we do not agree with the analysis and the assumptions used in the study<sup>31</sup>, we note that it is primarily focused on industries that are likely to comprise future demand growth. These industries are not engaged in the same course of business that reflects the steady state of the forest products industry. They are largely driven by public policies that create significant incentives or mandates to use biomass for energy that give them a competitive advantage over industries that are not so favored by public policy. Projections prepared by Forisk Consulting for AF&PA in 2010 show the long-term demand outlook for pulpwood-sized logs used to make paper and oriented strand board to be about stable, with 2020 volume projected at 248 million green tons, versus 258 million green tons in 2008.<sup>32</sup>

**VI. FOR REGIONS WITH GROWTH TO DRAIN RATIOS GREATER THAN 1, ALL BIOMASS SHOULD BE EXEMPT FROM ANY ACCOUNTING FRAMEWORK.**

**A. The Framework Should Incorporate a National or Large Regional Scale.**

AF&PA considers the IPCC accounting approach to be the superior accounting approach for biogenic emissions as it results in the most comprehensive accounting method for

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<sup>30</sup> See NCASI Comments on 3-9-12 Deliberative Draft of the SAB's Biogenic Carbon Emissions Panel.

<sup>31</sup> Id.

<sup>32</sup> Forisk Consulting, Forecast 2010-2020.

biogenic emissions and is most representative of the natural carbon cycle. The terrestrial area over which it is applied is a secondary (but important) question. The origin of the carbon in the biogenic fuel is the same regardless of the spatial dimension. It is carbon resulting from the sequestration of atmospheric CO<sub>2</sub> and its storage in organic biomass.

Given the continuous cycle of biogenic emissions (through combustion or decay), regrowth and sequestration (via photosynthesis) policymakers must assess whether the carbon cycle is in balance, rather than assessing individual sources and sinks in isolation. Roger Sedjo addresses this issue in his study, *Carbon Neutrality and Bioenergy*:

“A forest system also behaves differently from a site. In the United States, for example, large landscapes are managed as forest systems. Management activities in one place are related to activities elsewhere in the system, beyond the specific site. For example, a steady flow of wood may not be possible in sufficient volumes from an individual site but can be achieved from a system. The same could be true for carbon emissions, where sequestration on one site offsets emissions from another.”<sup>33</sup>

Assessing biogenic emissions in the short term or on a small scale only measures a portion of the carbon cycle and will result in misleading conclusions regarding the benefits of biomass for greenhouse gas mitigation over the long term. In addition, this comprehensive approach allows policymakers the ability to assess emissions and sinks from natural and manmade occurrences such as forest fires and land use changes or conversions.

#### B. Every FIA Region Has a Growth/Drain Ratio Greater than 1.0.

Current removals from U.S. forestlands are about 26.7 billion cubic feet annually and nearly 320 million dry tons.<sup>34</sup> This level of harvest is well below net annual forest growth and only a very small fraction of the total timberland inventory. In 2006, the ratio of forest-growing stock growth (wood volume increases) to growing stock removals (harvest, land clearing, etc.) in the United States was 1.72,<sup>35</sup> which indicates that net forest growth exceeded removals by 72%.<sup>36</sup> The data also suggests a national trend of increasing net growth relative to growing stock removals. However, this trend varies by geographic region, species, and ownership, such as public forests and private industrial forests. In the case of private ownership (excluding Alaska), the growth to removals ratio is 1.3 as compared to a ratio of 5.3 for public lands.

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<sup>33</sup> Sedjo, Roger. *Carbon Neutrality and Bioenergy: A Zero Sum Game*. Resources for the Future. April 2011.

<sup>34</sup> U.S. Billion Ton Update. United States Department of Energy. Oak Ridge National Laboratory. August 2011. p. 2.

<sup>35</sup> Forest Resources of the United States,” U.S. Forest Service, Table 36.

<sup>36</sup> Smith, WB; Miles PD; Perry CH; and Pugh SA. *Forest Resources of the United States, 2007*. Gen. Tech. Rep. WO-78. U.S. Department of Agriculture, Forest Service, Washington, DC. 2009. p. 336.

**Table 2.** Net annual growth and removals of timberland in the U.S. by region, 2006

Region	Net Growth	Removals	Growth/Removals Ratio
	In thousand cubic feet		
North	6,575,675	2,820,106	2.33
South	13,272,393	9,696,347	1.37
Rocky Mountain	1,760,930	542,757	1.74
Pacific Coast	5,135,361	2,474,272	2.08
Total	26,744,360	15,533,482	1.72

Slightly more than 70% of the volume of current U.S. wood removals is roundwood, with the remainder consisting of logging residues and other removals. Total logging residue and other removals in the United States currently amount to nearly 93 million dry tons annually: 68 million dry tons of logging residue and 25 million dry tons of other removal residue.<sup>37</sup> The logging residue material largely consists of tops, branches and limbs, salvageable dead trees, rough and rotten trees, non-commercial species, and small trees.

All FIA regions in the U.S. have a growth to drain ratio greater than 1.0. This demonstrates that every region enjoys the benefits of a sustainable forest where the rate of sequestered carbon exceeds CO<sub>2</sub> emissions. EPA's Accounting Framework should establish a reference point baseline that encourages future users of biomass to maintain the existing growth to drain ratios.

## VII. CONCLUSION

In summary, the use of biomass as a fuel for energy generation in the forest products industry is incidental and integral to the manufacture of forest products and cannot be separated from the manufacturing processes in a sustainable manner. The use of residues and byproducts for energy by forest products mills is carbon neutral and should be excluded from the Accounting Framework.

The Accounting Framework should use a reference point baseline that distinguishes between existing biomass users that have developed and foster market-based sustainable forest management practices and those new entrants driven by public policies promoting energy from renewable fuels that may disrupt the growth to drain equilibrium. Forest products mills should be included in the baseline. FIA data demonstrate that current

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<sup>37</sup> Id.

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biomass users are maintaining carbon stocks in U.S. forests. The Accounting Framework should incorporate a reference point baseline to recognize the current growth to drain ratios and focus its efforts on the impacts of new stand-alone biomass to energy facilities.

We appreciate your consideration of these comments. If you have any questions, please contact me at (202) 463-2700 or at [paul\\_noe@afandpa.org](mailto:paul_noe@afandpa.org).

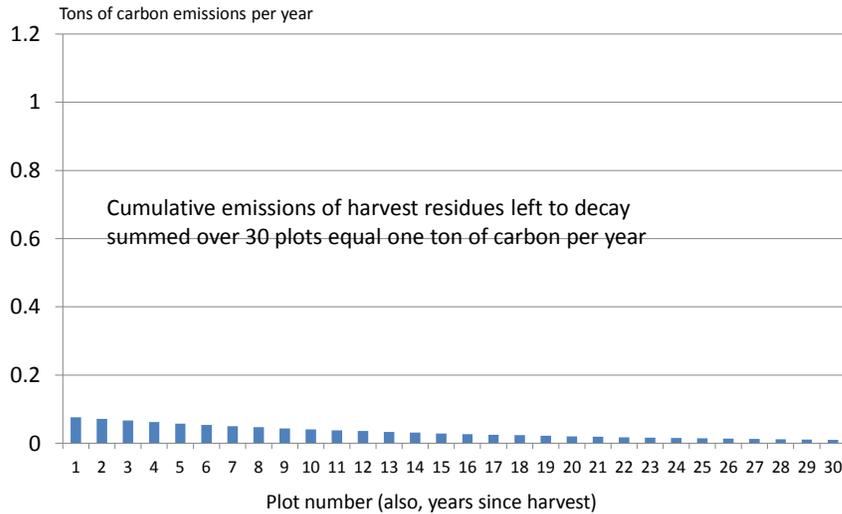
Sincerely,

Paul Noe  
Vice President, Public Policy  
American Forest & Paper Association

Appendix A

Graph A-1

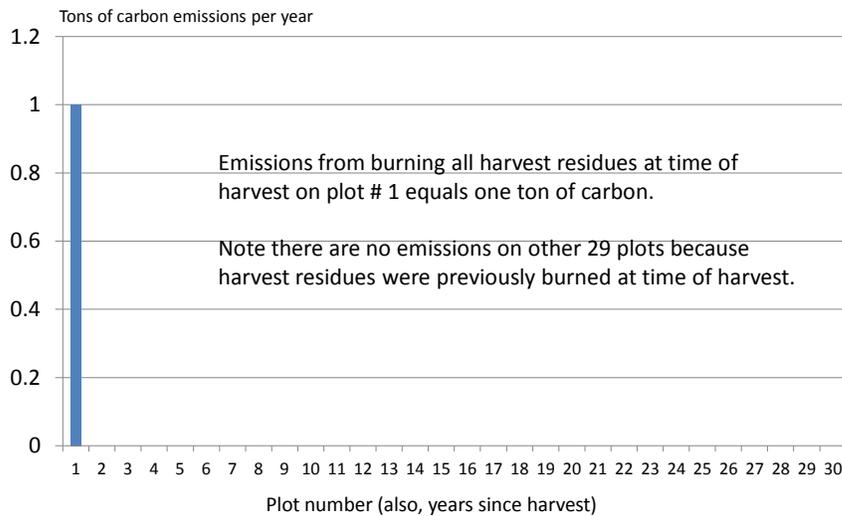
One-year's carbon emissions from decay of uncollected harvest residues from 30 plots on a 30-year rotation with a residue decay half life of 10 years



Source: NCASI

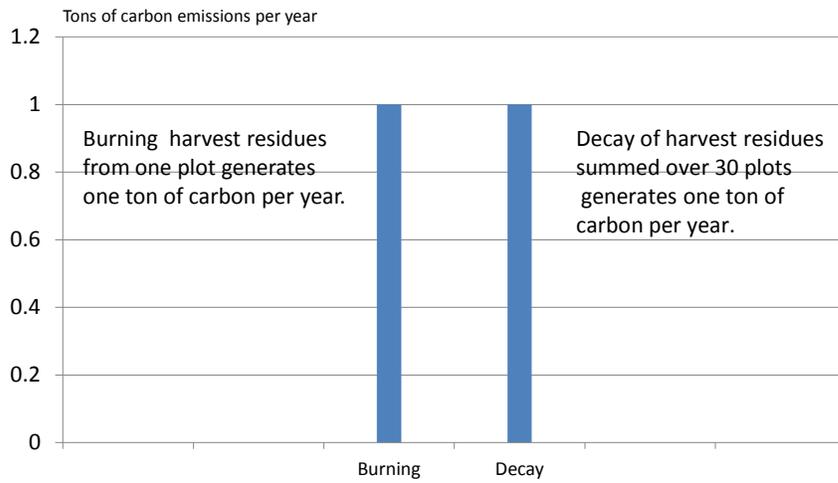
Graph A-2

One-year's carbon emissions from burning harvest residues from 30 plots on a 30-year rotation



Source: NCASI

Graph A-3  
One-year's carbon emissions from decay of uncollected harvest residues vs.  
burning of residues cumulative over 30 plots



Source: NCASI

Appendix B

Attachments

1. Greenhouse Gas and Non-Renewable Energy Benefits of Black Liquor Recovery, National Council for Air and Stream Improvement, Inc., April 2011
2. Greenhouse Gas and Resource Conservation Benefits of Using Black Liquor for Energy Production, National Council for Air and Stream Improvement, Inc. Presentation to U.S. EPA, December 2010



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NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

**GREENHOUSE GAS AND  
NON-RENEWABLE ENERGY BENEFITS  
OF BLACK LIQUOR RECOVERY**

**TECHNICAL BULLETIN NO. 984  
APRIL 2011**

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## **PRESIDENT'S NOTE**

In several recent announcements, the Environmental Protection Agency has made known its interest in understanding the life cycle greenhouse gas benefits associated with using biomass in order to support the development of various programs governing the use of biomass and releases of greenhouse gases. The decisions EPA makes on this topic have the potential to increase greatly the costs of doing business as well as to impair the perception of industry's products in the marketplace. The forest products industry, therefore, has a great deal at stake in ensuring that the agency's deliberations on this topic are well informed.

Black liquor solids comprise about half of the fuel used by the pulp and paper industry. Yet, among the various types of biomass used by the industry, the life cycle benefits of using black liquor solids are the least well understood, having been essentially ignored in the life cycle studies of biomass published to date. To remedy this lack of understanding of the life cycle greenhouse gas and non-renewable energy benefits of using black liquor solids in the kraft recovery system, NCASI undertook such a study, the results of which are contained in this report.

In this study, NCASI has compared a system using black liquor solids in the kraft recovery system to a fossil-fuel based system providing an equal amount of energy as well as chemicals for pulping. The results indicate that fossil fuel-related greenhouse gas emissions and non-renewable energy consumption are approximately 90% lower when black liquor solids are used in the kraft recovery system than in a comparable fossil fuel-based system. More than half of the benefits are attributable to the highly efficient production of pulping chemicals from black liquor solids in the kraft recovery system.

Based on 2004 data, approximately 100 million tonnes of fossil-fuel derived CO<sub>2</sub> emissions are avoided per year by using black liquor solids at US kraft mills. These avoided greenhouse gas emissions are approximately equal to the total of the forest products industry's emissions from fossil fuel combustion plus the emissions from electric power companies attributable to electricity purchased by the industry. These results do not depend on the accounting method for biogenic carbon (because biogenic CO<sub>2</sub> emissions are the same for the systems compared) and the results are valid across a range of assumptions.

This study is one of a series of ongoing NCASI projects having the objective of helping the forest products industry and its stakeholders better understand the greenhouse gas and energy impacts of using forest biomass as a raw material and fuel.

A handwritten signature in black ink, appearing to read "Ron Yeske".

Ronald A. Yeske

April 2011



## **MOT DU PRÉSIDENT**

Dans plusieurs annonces récentes, l'Agence de protection de l'environnement des États-Unis (EPA) a fait connaître son intérêt pour la compréhension des avantages liés à de l'utilisation de la biomasse en ce qui concerne les émissions de gaz à effet de serres et ce, en adoptant une approche cycle de vie. Ceci à pour but de soutenir le développement de divers programmes régissant l'utilisation de la biomasse et les émissions de gaz à effet de serre reliées. Les décisions potentielles de l'EPA sur ce sujet ont le potentiel d'accroître considérablement les coûts pour les entreprises ainsi que de nuire à la perception des produits de biomasse dans le marché. L'industrie des produits forestiers, par conséquent, a intérêt à ce que les délibérations de l'EPA sur ce sujet soient bien informées.

Les solides de la liqueur noire représentent environ la moitié du carburant utilisé par l'industrie des pâtes et papiers. Pourtant, parmi les différents types de biomasse utilisés par l'industrie, les avantages du cycle de vie de l'utilisation des matières solides de la liqueur noire sont les moins bien compris. En effet, à ce jour, essentiellement aucune étude n'a été publiée à ce sujet. Pour remédier à ce manque de compréhension des avantages cycle de vie (gaz à effet de serre et énergie non-renouvelable) de l'utilisation des solides de la liqueur noire dans le cycle de récupération des produits chimiques de la pâte kraft, NCASI a entrepris une telle étude, dont les résultats sont contenus dans le présent rapport.

Dans cette étude, NCASI a comparé un système utilisant les solides de la liqueur noire dans le système de récupération des produits chimiques de la pâte kraft à un système produisant la même quantité d'énergie et de produits chimiques, mais à partir de combustible fossiles. Les résultats indiquent que la récupération de la liqueur noire réduit les émissions gaz à effet de serre de source fossile et la consommation d'énergie non-renouvelable d'environ 90%. Plus de la moitié de cette réduction est généralement attribuable à la production efficace de produits chimiques de mise en pâte dans le cycle de récupération de la liqueur noire.

Sur la base de données de 2004, environ 100 millions de tonnes d'émissions de CO<sub>2</sub> de source fossile fossiles sont évitées par an en utilisant les solides de la liqueur noire dans les usines de pâte kraft aux États-Unis. Ces émissions évitées de gaz à effet de serre sont à peu près égales au total des émissions de l'industrie des produits forestiers provenant de la combustion de combustibles fossiles ainsi qu'aux émissions dues à la production de l'électricité qu'elle achète. Ces résultats ne dépendent pas de la méthode de comptabilisation du carbone biogénique (parce que les émissions de CO<sub>2</sub> biogénique sont les mêmes pour les deux systèmes comparés) et sont valides pour toute une gamme d'hypothèses.

Cette étude fait partie d'une série de projets de NCASI dont l'objectif est d'aider l'industrie des produits forestiers et ses intervenants à mieux comprendre les émissions de gaz à effet de serre et la consommation d'énergie attribuables à l'utilisation de la biomasse forestière en tant que matière première et source d'énergie.



Ronald A. Yeske

Avril 2011



# **GREENHOUSE GAS AND NON-RENEWABLE ENERGY BENEFITS OF BLACK LIQUOR RECOVERY**

TECHNICAL BULLETIN NO. 984  
APRIL 2011

## **ABSTRACT**

In this study, the life cycle greenhouse gas (GHG) and fossil fuel benefits of black liquor recovery are analyzed. These benefits are due to two effects: the production of energy that can be used in the pulping process or sold, and the recovery of the pulping chemicals that would otherwise need to be produced from other resources.

The fossil GHG emissions and non-renewable energy consumption for a system using black liquor solids in the kraft recovery system are approximately 90% lower than those for a comparable fossil fuel-based system. Across all scenarios, the systems relying on black liquor solids achieve a median reduction of approximately 140 kg CO<sub>2</sub> eq./GJ of energy produced, compared to the systems relying on fossil fuels to provide the same energy and pulping chemical production functions. The benefits attributable to the recovery of pulping chemicals vary from 44% to 75% of the total benefit. Applied to the total production of kraft pulp in the US, the avoided emissions are enough to offset all of the total Scope 1 and Scope 2 emissions from all mills in the US forest products industry. These results do not depend on the accounting method for biogenic carbon (because biogenic CO<sub>2</sub> emissions are the same for the systems compared) and the results are valid across a range of assumptions about the displaced fossil fuel, the GHG intensity of the grid, the fossil fuels used in the lime kiln, and the level of cogeneration at pulp and paper mills. The benefits occur without affecting the amount of wood harvested or the amount of chemical pulp produced.

## **KEYWORDS**

black liquor, energy, greenhouse gases, life cycle assessment

## **RELATED NCASI PUBLICATIONS**

None



# **AVANTAGES POUR LES ÉMISSIONS DE GAZ À EFFET DE SERRE ET LA CONSOMMATION D'ÉNERGIE NON RENOUVELABLE DE LA RÉCUPÉRATION DE LA LIQUEUR NOIRE**

BULLETIN TECHNIQUE NO. 984  
AVRIL 2011

## **RÉSUMÉ**

Dans cette étude, les avantages de la récupération de la liqueur noire pour les émissions de gaz à effet de serre (GES) et la consommation d'énergie non renouvelable sont analysés en utilisant une approche cycle de vie. Deux causes permettent d'expliquer ces avantages : la production d'énergie pouvant être utilisée dans la fabrication de la pâte et du papier ou vendue, ainsi que la récupération des produits chimiques de mise en pâte qui, autrement, devraient être produits à partir d'autres ressources.

Les émissions de GES et la consommation d'énergie fossile non renouvelable pour un système utilisant les solides de la liqueur noire dans le système de récupération des produits chimiques de la pâte kraft sont environ 90% inférieurs à ceux d'un système comparable à base de combustibles fossiles. Lorsque tous les scénarios analysés sont pris en compte, la récupération de la liqueur noire produit une réduction moyenne d'environ 140 kg de CO<sub>2</sub> équivalents par gigajoule d'énergie produite, par rapport à un système produisant la même quantité d'énergie et de produits chimiques de mise en pâte, mais à partir de combustibles fossiles. Les avantages attribuables spécifiquement à la production de produits chimiques de mise en pâte varient entre 44% et 75% du total. Lorsqu'appliquées à la production totale de pâte kraft aux États-Unis, les émissions évitées sont suffisantes pour compenser la totalité des émissions de Scope 1 et de Scope 2 de l'industrie américaine des produits forestiers. Ces résultats ne dépendent pas de la méthode de comptabilisation du carbone biogénique (parce que les émissions de CO<sub>2</sub> biogénique sont les mêmes pour les deux systèmes comparés) et sont valables pour toute une gamme d'hypothèses incluant le type de combustibles fossiles déplacé, les émissions de GES produites par le réseau électrique, les combustibles fossiles utilisés dans les fours à chaux et le niveau de cogénération dans les usines de pâtes et papiers. Les avantages observés se produisent sans affecter la quantité de bois récolté ou la quantité de pâte chimique produite.

## **MOTS CLÉS**

Liqueur noire, énergie, gaz à effet de serre, analyse du cycle de vie

## **PUBLICATIONS DE NCASI RELIÉES**

Aucune



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# GREENHOUSE GAS AND NON-RENEWABLE ENERGY BENEFITS OF BLACK LIQUOR RECOVERY

## 1.0 INTRODUCTION

Recent years have seen both a rise in the interest in substituting biomass for fossil fuels and increasing skepticism about the greenhouse gas (GHG) benefits of this substitution. While programs that promote the use of biomass as a substitute for fossil fuel have important connections to the issues of energy security and economic sustainability, it is the questions about greenhouse gas mitigation benefits that have been at the center of the debate on whether and how to increase the reliance on the use of biomass for energy.

An important distinction between biomass carbon and the carbon in fossil fuels is that the carbon in biomass-derived fuels was only recently removed from the atmosphere. When biomass is burned, decays, or is otherwise oxidized, the resulting CO<sub>2</sub> is returned to the atmosphere. This aspect of the biogenic carbon cycle forms the basis for using a zero emission factor at the point of combustion for biomass-derived fuels (Abbasi and Abbasi 2010; Cherubini 2010; Cherubini et al. 2009; Lattimore et al. 2009; Robinson, Rhodes, and Keith 2003), and it represents an accepted benefit of using biomass-derived fuels rather than fossil fuels (Abbasi and Abbasi 2010; Froese et al. 2010; Schlamadinger et al. 1997). This is recognized by the ISO series of standards on life cycle assessment (ISO 2003, 35):

*“The characterization model that describes the net-zero C emitted when burning biomass fuel is typically a recycling model, in which CO<sub>2</sub> from the atmosphere (and its C expression) are sequestered by the photosynthesis process [...]. [...] the CO<sub>2</sub> emissions from the combustion are considered equal to those already sequestered and those that will be subsequently sequestered. This is different from the CO<sub>2</sub> emissions of fossil fuel that result from the use of C from long-term carbon sinks rather than from the atmosphere. The characterization factor used is 0.”*

There is a difference between the life cycle impacts (i.e., “footprint”) of a biomass fuel and the emission factor (for an emissions inventory) of a biomass fuel. The emission factor of a biomass fuel pertains only to emissions that occur at the point of combustion. Life cycle impacts are based on these point of combustion emissions in combination with “upstream” (e.g., land use change, silvicultural/harvesting, transport, processing) and “downstream” (e.g., end-of-life) emissions. Because of these upstream, non-combustion emissions, the life cycle impacts assigned to biomass fuel use can be non-zero even where the release of biogenic CO<sub>2</sub> upon combustion is in balance with carbon uptake via regrowth (Abbasi and Abbasi 2010; Cherubini 2010). Where the amounts of CO<sub>2</sub> that return to the atmosphere are less than the amounts removed, the difference represents increases in stocks of stored carbon (net removals from the atmosphere). Where net returns are greater than the amounts removed, the difference represents depleted stocks of stored carbon.

There are different types of biomass used for energy and different regimes of land use/carbon stock changes associated with them. Biomass fuels obtained from residuals (agricultural, manufacturing, forestry residuals, etc.) are typically not associated with land use/carbon stock changes (Cherubini 2010; Mann and Spath 2001; Schlamadinger et al. 1997). Manufacturing residuals include many things such as wood manufacturing residues (e.g., bark, sawdust, planer shavings, sander dust from sawmills, panel plants, and pulp and paper mills, including material in on-site bark/hog piles).

Recent life cycle assessment (LCA) studies of wood residue-based energy systems, summarized in Table 1.1, typically demonstrate significant greenhouse gas mitigation benefits compared to energy derived from fossil fuels. Wood residues investigated in these studies included forest residuals (Cherubini et al. 2009; Froese et al. 2010; Mann and Spath 2001; Pehnt 2006; Robinson, Rhodes, and Keith 2003), mill residues (Mann and Spath 2001; Petersen Raymer 2006), urban “waste,” or demolition wood (Mann and Spath 2001; Pehnt 2006; Petersen Raymer 2006).

**Table 1.1** Life Cycle GHG Mitigation Benefits for Wood-Based Residues Energy Systems

Study	Biofuel Type	Fossil Fuel Offset	GHG Mitigation <sup>a</sup>
Froese et al. 2010	Forest residuals	Coal electricity (cofiring)	100%
Mann and Spath 2001	Various woody residuals	Coal electricity (cofiring)	123% <sup>b</sup>
Robinson et al. 2003	Forest and agriculture residues	Coal electricity (cofiring)	≈ 95%
Pehnt 2006	Forest wood, woody biomass energy crops, waste wood	Energy mix in Germany for electricity generation and home heating in 2010	85-95%
Cherubini et al. 2009	Forest residuals	Various fossil fuels used for heat and electricity production	70-98%
Petersen Raymer 2006	Fuel wood, sawdust, wood pellets, demolition wood, briquettes, bark	Coal electricity (cofiring) and heating oil	81-98%

<sup>a</sup> Percent for base case; for cofiring situations the mitigation pertains to the cofire rate (e.g., if 10% fossil fuel is replaced by biomass and emissions decrease by 9%, mitigation of 90% is assigned).

<sup>b</sup> Mitigation greater than 100% due to avoided end-of-life methane emissions.

Black liquor solids, a by-product of the kraft pulping process, account for approximately half of the fuel used by the pulp and paper industry (AF&PA 2010). Yet, even in a time when the industry and its stakeholders are anxious to understand the benefits of using biomass fuels, there has been no comprehensive life cycle-based assessment of the benefits of using black liquor solids. Having identified this information need, NCASI recently undertook a life cycle study of the greenhouse gas and non-renewable energy impacts of using black liquor solids in the kraft recovery system. This report contains the results of that study.

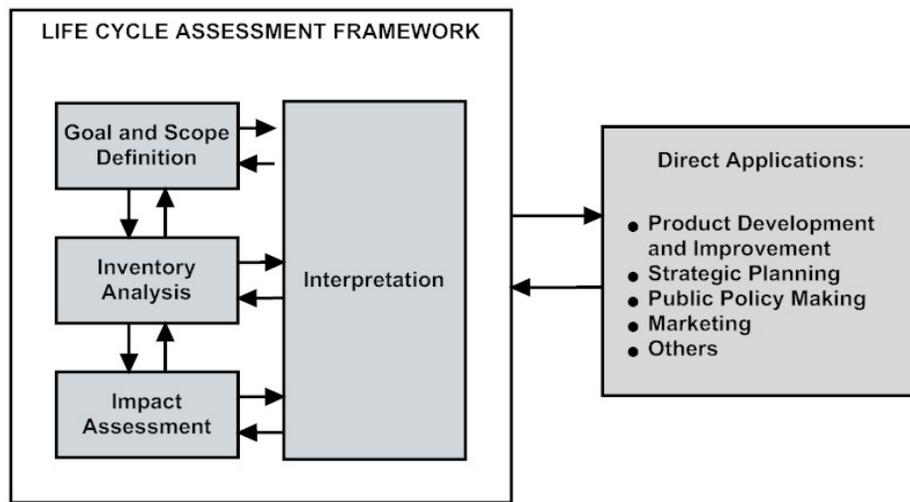
## 2.0 GOAL AND SCOPE OF THE LIFE CYCLE STUDY

Life Cycle Assessment (LCA) is a “*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle,*” the life cycle being “*consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal*” (ISO 2006a, 2).

LCA principles and methodology are framed by a set of standards (ISO 2006a, 2006b) and technical report specifications (ISO 2000, 2002, 2003) from the International Organization for Standardization (ISO). ISO describes LCA methodology in four phases (as illustrated in Figure 2.1):

- 1) **Goal and scope definition** in which the aim of the study, the product system under study, its function and functional unit, the intended audience, and the methodological details on how the study will be performed are defined;

- 2) **Life cycle inventory analysis (LCI)** which is the “*phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle*” (ISO 2006a, 2);
- 3) **Life cycle impact assessment (LCIA)** which is the “*phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product*” (ISO 2006a, 2); and
- 4) **Life cycle interpretation** which is the “*phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations*” (ISO 2006a, 2).



**Figure 2.1** Life Cycle Assessment Phases (ISO 2006a)

In this study, a simplified (streamlined) LCA methodology has been applied. Streamlining generally can be accomplished by limiting the scope of the study or simplifying the modeling procedures, thereby limiting the amount of data or information needed for the assessment (Todd and Curran 1999). Many different streamlining approaches can be applied. In this study, two main approaches were taken: limiting the impact assessment to two indicators (global warming, life cycle non-renewable energy demand), and using mainly site-generic information to model the fossil fuel system. Because of this, the study does not fully comply with ISO 14044 requirements for comparative assertions disclosed publically. However, the study aligns as much as possible with this standard.

## 2.1 Objective of the Study

The objective of this study is to characterize the GHG and non-renewable energy conservation benefits of using black liquor solids for energy production when compared to the GHGs from the fossil fuel it replaces.

## 2.2 Function and Functional Unit

The ISO 14044 standard requires that “*the scope of an LCA shall clearly specify the functions (performance characteristics) of the system being studied*” and that the “*functional unit shall be consistent with the goal and scope of the study*” (ISO 2006b, 8). The objective of this study is to

compare two alternative ways of producing energy (function) and the primary functional unit is defined as *the production of 1 GJ of energy (heat and power)*<sup>1</sup>.

The production of energy using black liquor solids results in secondary functions that need to be dealt with. This is discussed below.

## **2.3 Description of the Systems Compared, System Boundaries, and Allocation**

The methodology used in this study follows life cycle principles, by calculating emissions from “cradle to final energy” including end conversion efficiency. In other words, it is extended beyond the point of combustion to include transformation into electricity/steam (including transformation efficiency and distribution losses where applicable). Two different systems are compared and discussed hereinafter: a system in which 1 GJ of energy is produced from black liquor solids and an equivalent system in which the same amount of energy is produced from fossil fuels.

### **2.3.1 Black Liquor Product System**

#### **2.3.1.1 Description of the Product System**

A schematic of the kraft pulping process is presented in Figure 2.4. Kraft pulping involves cooking wood chips in an aqueous solution of pulping chemicals, resulting in the extraction of cellulose from the wood by dissolving the lignin that binds the cellulose fibers together. In the kraft process, white liquor containing sodium hydroxide (NaOH) and sodium sulfide (Na<sub>2</sub>S) is used to cook the chips in digesters at elevated temperature and pressure. The cooked chips are blown from the digester and washed to separate the spent cooking chemicals and dissolved organics, which together comprise “black liquor solids,” from the fibers. The black liquor solids are sent for further processing in the kraft recovery system. The recovery system is critical to the economic viability of kraft pulping. It has two main functions: the recovery and regeneration of the inorganic pulping chemicals, and the combustion of the dissolved organic material with recovery of the energy content as process steam and electrical power. In some cases, it is also used to recover valuable organic by-products such as turpentine and tall oil.

Weak black liquor from pulp washing is sent to multiple-effect evaporators to increase its solids content to around 50%. The evaporation process requires a significant amount of energy. The resulting strong (concentrated) black liquor is sent to concentrators to increase the solids content further to between 65 and 80% (some older mills use direct contact evaporators instead of concentrators to increase the solids content to about 65%). The black liquor solids are then burned in a furnace known as a recovery boiler. Energy is produced in the oxidative zone of the boiler from organic matter in the liquor. This energy drives the chemical reactions in the reduction zone of the furnace, converting spent pulping chemicals into a molten smelt. Kraft black liquor solids are typically generated at a rate of between 1,300 and 1,900 kg of dry solids per metric tonne of pulp (2,600 to 3,800 lb/short ton). They have a higher heating value, ranging from about 12.6 to 15.2 GJ/tonne of black liquor solids (5,400 to 6,600 Btu/lb), so they are a significant source of energy for the pulp mill. Generally, the high pressure steam produced from recovery boilers is used to generate electricity through a process called combined heat and power (CHP) or cogeneration. With CHP or cogeneration, the high pressure steam turns a turbine to make electricity. Useful thermal energy (low or medium pressure steam) is also extracted from the turbine and used in the manufacturing process.

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<sup>1</sup> The heat to power ratio depends on the mill scenario investigated and is equivalent in the two systems compared.

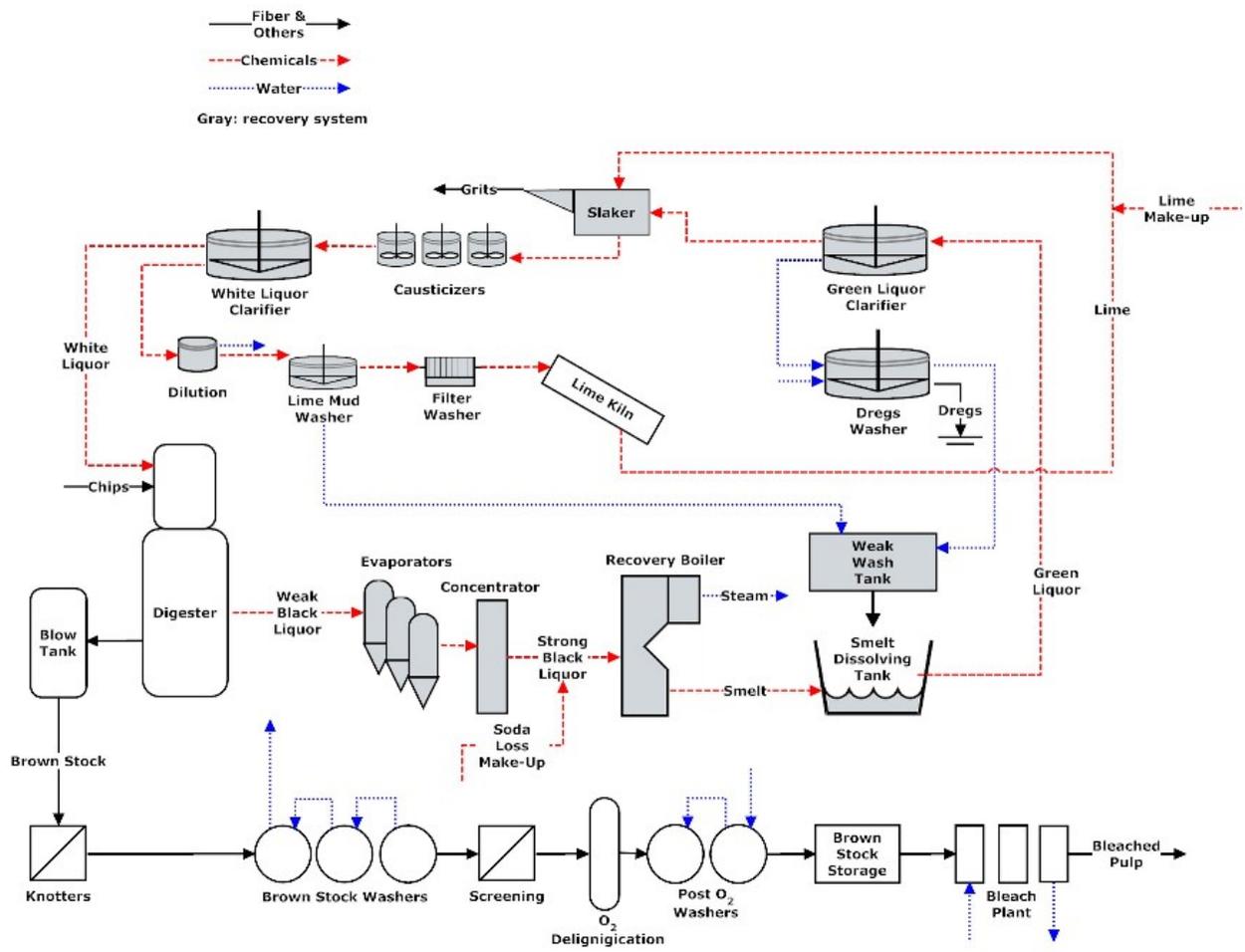


Figure 2.2 Flow Diagram of a Typical Kraft Pulping Process, Including Recovery and Bleaching

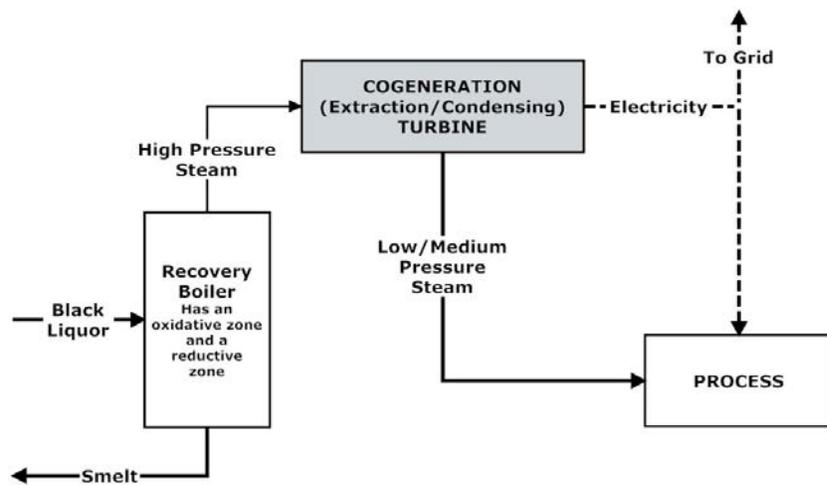
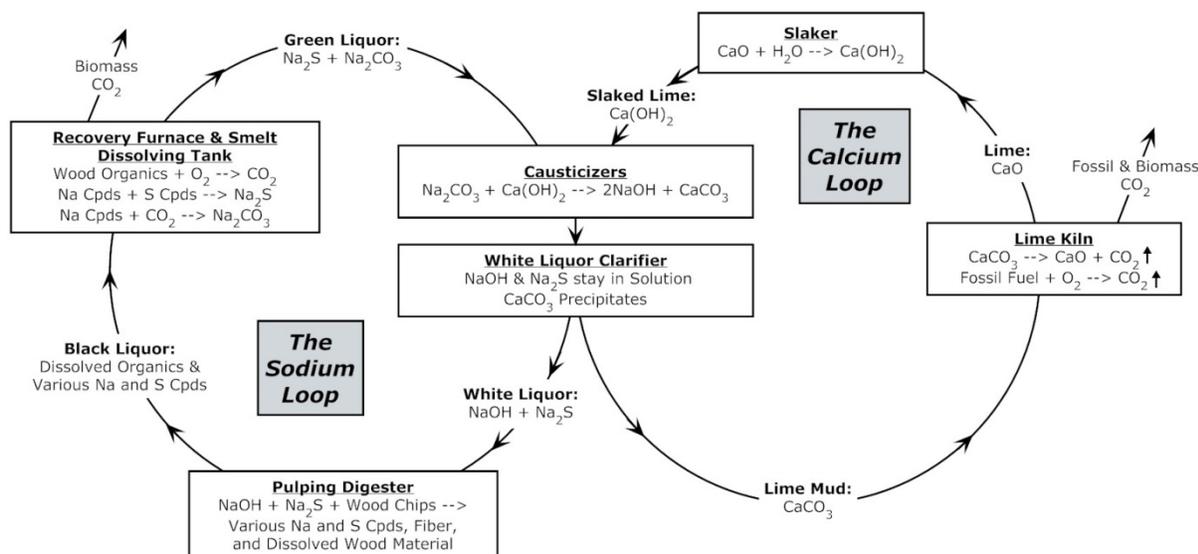


Figure 2.3 Cogeneration from Steam Produced in Recovery Boilers

The smelt, containing mainly sodium sulfide and sodium carbonate, is dissolved in weak wash (from the mud washing system) in the smelt dissolving tank to produce green liquor. The green liquor is clarified to remove solids (green liquor dregs) and sent to the slaker, which is then followed by a series of causticizers. Returned lime (CaO) from the lime kiln (see below) or fresh lime is added to the slaker where it is slaked to form calcium hydroxide. The calcium hydroxide reacts with sodium carbonate present in the green liquor within the causticizers to form sodium hydroxide and calcium carbonate, the latter precipitating due to its low solubility. The resulting white liquor is clarified to remove calcium carbonate (lime mud) and inerts (slaker grits) prior to being sent to the pulp mill for use in the digester. The lime mud from the clarifier is washed, filtered, and sent to the lime kiln to convert calcium carbonate back into calcium oxide for reuse in the slaker. In the lime kiln, lime mud (about 55% to 80% calcium carbonate, with the balance being water) is calcined to form lime (CaO) and CO<sub>2</sub>. The source of heat for this reaction is typically natural gas or fuel oil. Occasionally, petroleum coke is also used. A simplified representation of the chemistry in the kraft pulping and chemical recovery system is illustrated in Figure 2.4.



**Figure 2.4** Chemistry of the Kraft Pulping Process

### 2.3.1.2 System Boundary and Allocation

When performing an LCA, the product system needs to be defined and the system boundary established. When several products (or functions) from different product systems share the same unit process or group of unit processes, an allocation problem is encountered. The allocation problem consists of the need to attribute the environmental load among each of the products (or functions) delivered by the shared process, which are sometimes referred to as multifunctional processes. Two types of co-products can be differentiated: co-products that are used within the investigated system, and co-products that are used in other product systems.

Several strategies can be used when an allocation problem is encountered. The ISO 14044 standard (ISO 2006b) on LCA recommends the following hierarchy of approaches, in preferential order:

- 1) Avoid allocation through
  - a. System subdivision or
  - b. System expansion;
- 2) Perform allocation using an underlying physical relationship; or
- 3) Perform allocation using another relationship.

When applying the ISO 14044 standard, system subdivision and system expansion strategies should be selected over allocation wherever possible. System expansion is possible and advantageous in this context, so it is applied. The advantage of system expansion in this study is that it allows the consideration of existing benefits outside the studied system. This is required in order to fully account for the potential benefits of the chemicals produced in the kraft recovery system as co-products of the energy produced in that system.

Two allocation problems are encountered in life cycle of energy production using black liquor. First, the black liquor solids that are the primary raw material for producing the energy do not exist in isolation but rather are a co-product of kraft pulp production. In other words, the kraft pulping unit process is shared between the kraft pulp and the black liquor solids. Second, the kraft recovery system, in which the energy is produced, also generates chemicals that are reused within the kraft pulping process (i.e., the kraft recovery system is shared between the energy and the chemicals). The application of a system expansion approach to these allocation problems discussed below explains the final system boundary as will then be illustrated in Figure 2.7.

#### *System Expansion for the Kraft Pulping Process*

A simplified schematic of the kraft pulping allocation problem is illustrated in Figure 2.5. In order to apply system expansion to that allocation problem, it is necessary to determine which of the three following statements best describes the case of black liquor.

- 1) Black liquor solids and kraft pulp are produced independently.
- 2) The production of kraft pulp is dependent on the production of black liquor solids.
- 3) The production of black liquor solids is dependent on the production of kraft pulp.

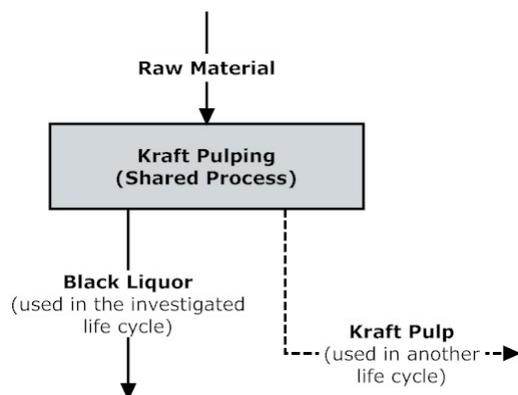
Statement #3 is the one which best describes the black liquor solids case. The production of both products (kraft pulp and black liquor solids) is determined by the demand for kraft pulp. Black liquor solids are produced because of that demand, and management actions chosen for black liquor solids will have little effect on the amount of pulp (and black liquor solids) produced. This is illustrated by the definition, for comparison purposes, of a parallel fossil fuel system in which kraft pulping remains constant (see Section 2.3.2 for more details). Using more black liquor solids for energy production will not affect the production of pulp. Instead, in theory<sup>2</sup>, increased use of black liquor solids for energy results in less black liquor solids going to alternative management processes. For those specific situations, system expansion best practices (Ekvall and Weidema 2004) present two options:

- 1) exclude the shared process from the system boundary of the product under investigation and subtract from it equivalent alternative management process; or
- 2) exclude the shared process from the system boundary of the product under investigation and add an equivalent alternative management process to the system being compared.

Option 2 is used in this study because it gives systems that are more easily understood (see Section 2.3.2 for more details).

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<sup>2</sup> In practice, black liquor is always almost fully utilized for energy production.



**Figure 2.5** Kraft Pulping Allocation Problem

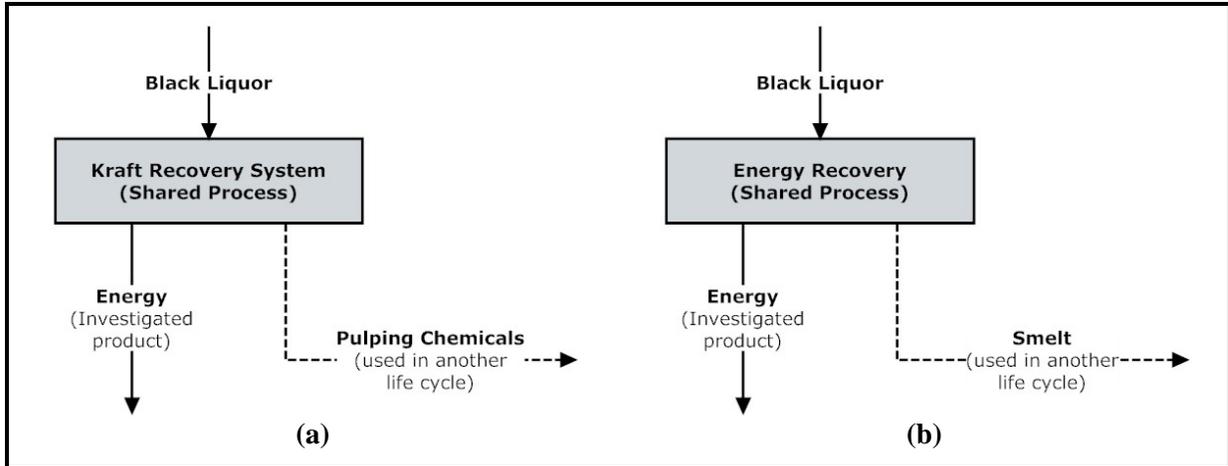
### *System Expansion for the Kraft Recovery System*

A simplified schematic of this second allocation problem is shown in Figure 2.6a. Once again, it is necessary to determine which of the following statements best applies to the case of the energy.

- 1) Energy and pulping chemicals are produced independently.
- 2) The production of chemicals is dependent on the production of energy.
- 3) The production of energy is dependent on the production of pulping chemicals.

Black liquor solids are burned in the recovery boiler to recover the inorganics in a suitable chemical form to regenerate the pulping chemicals and energy is produced at the same time. One could decide not to recover the energy and this would not have an effect on the regeneration of chemicals. At the same time, one could, in theory, decide to burn the black liquor solids for the energy and not to recover the chemicals. Therefore, Statement #1 is the one which best describes the kraft recovery system. In this case, best system expansion practices recommend subdividing the shared process into its individual components. In doing so, two subprocesses specific to each of the products (energy and pulping chemicals) are defined: the energy recovery subprocess (evaporation, concentration, burning in recovery boilers), and the chemical recovery subprocess (smelt dissolution, green liquor clarification, causticizing, lime reburning, white liquor clarification). The energy recovery process is now shared between the energy and the smelt that is used as a raw material for pulping chemical production. This is illustrated in Figure 2.6b. It is still necessary to determine which of the following statements best applies to the case of the energy.

- 1) Energy and smelt are produced independently.
- 2) The production of smelt is dependent on the production of energy.
- 3) The production of energy is dependent on the production of smelt.

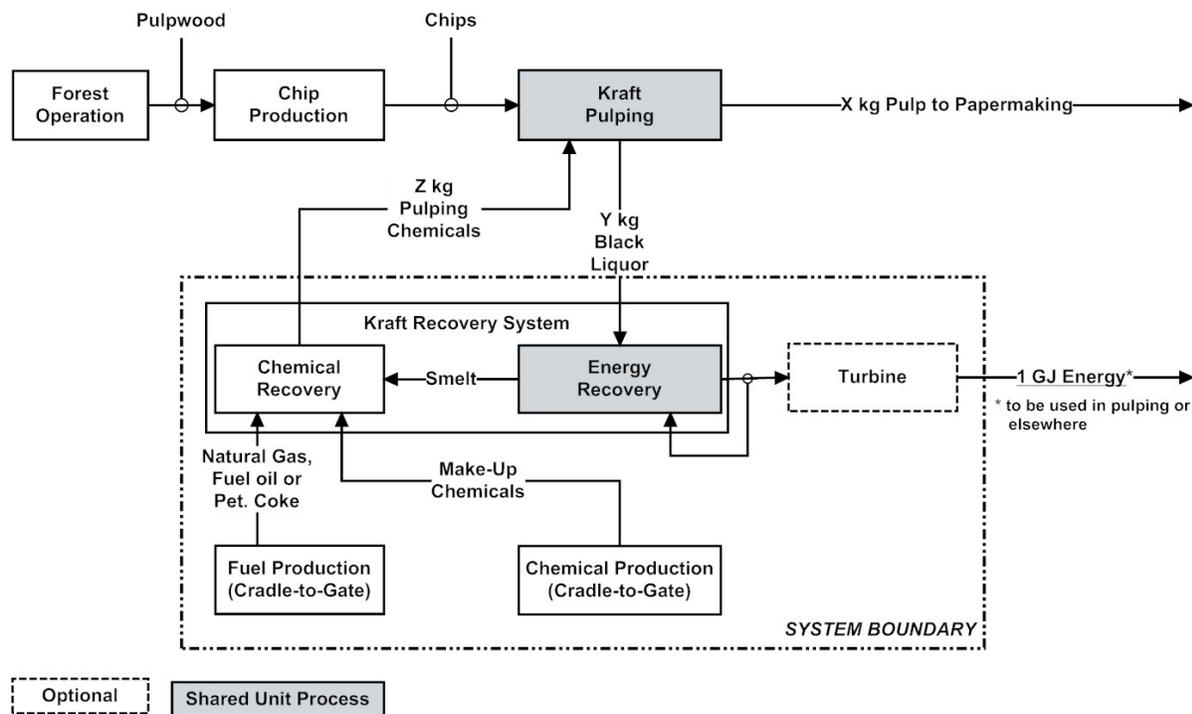


**Figure 2.6** Kraft Recovery System Allocation Problem as Portrayed at a) System Level, b) Energy Recovery Level

The production of smelt is now clearly dependent on the production of energy, which is the investigated product of this study. Reducing the combustion of black liquor solids that would otherwise be used to produce energy would reduce the production of smelt and pulping chemicals that would have to be produced otherwise. System expansion best practices for this situation are to include the shared process (energy recovery) in the system boundary and to include in the system boundary any other process that would be affected by a change in smelt production. This can be done by two different means:

- 1) expanding the system boundary to include the production of pulping chemicals using smelt and subtracting the alternative pulping production; or
- 2) expanding the system boundary to include the production of pulping chemicals using smelt and adding the alternative pulping chemical production to the compared system.

Option 2 is used in this study. The final system boundaries for the black liquor system are shown in Figure 2.7. The implications for the compared systems are discussed below.



**Figure 2.7** System Boundary for Energy Production Using Black Liquor Solids

### *Additional Functions*

The primary functional unit of the system depicted in Figure 2.7 is the production of 1 GJ of energy. However, using the system expansion approach the investigated system has been expanded to include two secondary functions:

- the production of a fixed amount of pulping chemicals; and
- the management of black liquor solids.

### **2.3.1.3 Summary of Processes Included and Excluded**

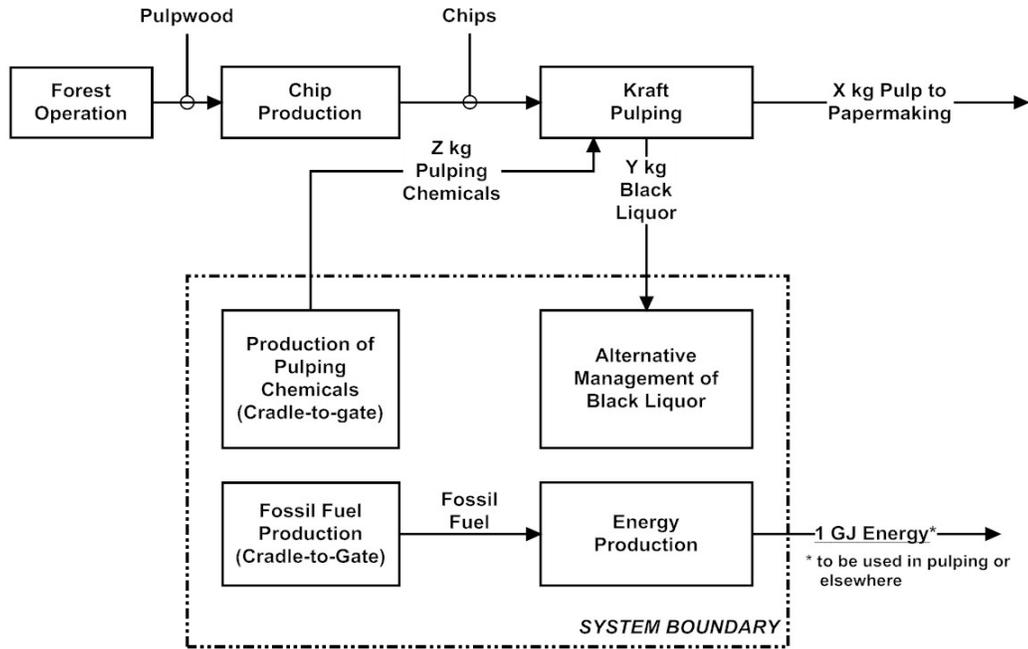
The system boundary includes the production and transportation of material (mainly make-up chemicals) and energy used in the kraft recovery process (mainly fuels for the lime kiln operations), as well as all other related upstream processes, the kraft recovery process itself and the turbine where applicable. It is assumed that the heat requirement for the kraft recovery system is satisfied internally. Capital equipment is not included.

### **2.3.2 Fossil Fuel Product System**

To assess the potential benefits of the kraft recovery system, a parallel fossil fuel system has been defined. The ISO standard requires that in comparative studies “systems shall be compared using the same functional unit and equivalent methodological considerations [...]” For this reason, the fossil fuel system needs to encompass the same primary functional unit and the same two secondary functional units as the black liquor system:

- the production of 1 GJ of energy (in the same form as for the black liquor system);
- the production of a fixed amount of pulping chemicals; and
- the management of black liquor solids.

This is illustrated in Figure 2.8. The system boundary includes the extraction, processing, and transportation of fossil fuels prior to their conversion to energy, as well as the conversion processes themselves. The system boundary is expanded to include the alternative production of pulping chemicals and management of black liquor solids.



**Figure 2.8** System Boundary for Energy Production Using Fossil Fuels

## 2.4 Impact Assessment and Other Indicators

Two indicators are characterized in this study: global warming, and life cycle non-renewable energy demand. More detail concerning these indicators is given in Table 2.1.

**Table 2.1** Indicators Characterized

Indicator	Method	Unit	Description
Global warming	Intergovernmental Panel on Climate Change – 100 years (IPCC 2006)	kg CO <sub>2</sub> eq.	This indicator refers to the potential change in the earth’s climate caused by the buildup of GHGs that trap heat radiated from the earth that would have otherwise passed out of the earth’s atmosphere.
Life cycle non-renewable energy demand (NRE)	ecoinvent cumulative energy demand (Frischknecht et al. 2007; Goedkoop et al. 2008)	MJ	The objective of this indicator is to investigate the energy use throughout the life cycle of a good or service. This includes the direct uses as well as the indirect consumption of energy due to the use of, for example, construction materials or raw materials. The method includes renewable energy demand and non-renewable energy demand. Only the latter component is included in this study.

Net benefits are calculated as follows:

$$\text{Net GHG benefits (\%)} = \frac{\text{GHG}_{\text{Black liquor system}} - \text{GHG}_{\text{Fossil fuel system}}}{\text{GHG}_{\text{Fossil fuel system}}} \times 100$$

$$\text{Net resource benefits (\%)} = \frac{\text{NRE}_{\text{Black liquor system}} - \text{NRE}_{\text{Fossil fuel system}}}{\text{NRE}_{\text{Fossil fuel system}}} \times 100$$

## 2.5 Scenarios

Multiple scenarios are defined concerning 1) level of cogeneration from black liquor steam, 2) the fuel burned in lime kilns, 3) the heat energy displaced, and 4) the electricity displaced (see Table 2.2). The base case scenario (1.1, AI) assumes that all the steam produced from recovery boilers is sent to cogeneration turbines to produce electricity, that residual fuel oil is burned in lime kilns, that heat energy displaces energy from coal, and that cogenerated electricity displaces average electricity in the US (average grid). All scenarios are listed in Table 2.2. All possible combinations were analyzed, for a total of 36 scenarios.

**Table 2.2** Scenarios Analyzed

Level of Cogeneration		Fuel Burned in Lime Kilns		Electricity		Heat Displaced	
1	Full	1	Residual fuel oil	A	Average US grid	I	Coal
2	None	2	Natural gas	B	Coal mix	II	Natural gas
		3	Petroleum coke	C	Natural gas combined cycle		

## 3.0 MODELING AND ASSUMPTIONS

### 3.1 Black Liquor System

#### 3.1.1 General Process Modeling

A modular process simulation model using WinGEMS<sup>3</sup> was created to represent the material and energy flows in the digester, brown stock washing, recovery area, and steam and power system. The model simulates a bleached kraft pulp mill producing 1500 air-dried metric tonnes (admt) of bleached kraft pulp per day. A schematic of the full mill simulation is included in Appendix A. The sodium, potassium, sulfur, and chloride balance for the kraft pulping, oxygen delignification, and recovery areas is provided in Appendix B. The uncoated freesheet (UFS) results from the North American life cycle assessment report for printing and writing paper products served as the basis for tuning the base case simulation model for energy use and self-generated electricity amounts (NCASI 2010). There are 31 North American mills included in the UFS category in the North American life cycle assessment report. Of these 31 mills, energy inputs to 19 integrated<sup>4</sup> U.S. mills were used to tune the base case simulation model. The summary energy source information for the 19 US integrated mills producing primarily UFS product and the corresponding base case simulation fuel inputs and on-site electricity

<sup>3</sup> WinGEMS is a process simulation program designed to model pulp and paper processes.  
[http://www.metso.com/automation/pp\\_prod.nsf/WebWID/WTB-050701-2256F-46EA1](http://www.metso.com/automation/pp_prod.nsf/WebWID/WTB-050701-2256F-46EA1)

<sup>4</sup> Integrated mills produce kraft pulp on site that is used to manufacture uncoated freesheet on site.

production amounts are given in Table 3.1. The major non-steam generating use of fuels is the energy requirements for lime kilns.

Based upon typical equipment operating conditions within the industry, the base case simulation model was used to quantify the material flows of cooking chemicals (NaOH and Na<sub>2</sub>S), the steam and electricity generated by the black liquor recovery boiler and turbine system, and the energy consumed within the recovery area. Six simulation cases were constructed to provide cooking chemical material flow values and recovery area steam and electricity generation and consumption values for the life cycle modeling. The six simulation cases were divided into two subsets; one subset of the simulation model included cogeneration of electricity (i.e., a steam turbine generator system was integrated into the simulations), and one subset did not include cogeneration. The cases with and without cogenerated electricity were constructed to quantify the effects of cogenerated electricity on the life cycle results. Three simulation cases were constructed within the subsets by selecting different primary fuels in the lime kiln: residual fuel oil, natural gas, and petroleum coke. The three different lime kiln fuel simulations were constructed to provide complete coverage of the most common fuels used in lime kilns within the US pulp and paper industry.

Details of the key input parameters and output results for the simulation cases are provided in Appendix C.

**Table 3.1** Production-Weighted Mean (PWM) Fuel Input and Electricity Production Values of 19 US Integrated Mills Producing Primarily Uncoated Freesheet Compared to Base Case Simulation Values

	PWM of UFS Mills		Base Case Simulation Values	
Black liquor solids fuel energy	18.55	GJ/admt	20.9	GJ/admt
Hogged fuel energy	6.39	GJ/admt	6.39	GJ/admt
Coal fuel energy	3.64	GJ/admt	3.64	GJ/admt
Natural gas fuel energy	4.02	GJ/admt	0.00	GJ/admt
Residual fuel oil	0.63	GJ/admt	1.78	GJ/admt
<b>Total</b>	33.2	GJ/admt	32.7	GJ/admt
Onsite electricity production	700	kWh/admt	703	kWh/admt

### 3.1.2 Lime Kiln Fuel Energy

The fuel mix for lime kilns operating at pulp and paper mills within the US, based on the NCASI combustion source database (NCASI 2005), is presented in Table 3.2.

**Table 3.2** Fuel Mix for US Lime Kilns (NCASI 2005)

Fuel	Proportion in Mix <sup>a</sup> (%)
Natural gas	40.3
Residual fuel oil	56.4
Petroleum coke	3.3

<sup>a</sup> On an energy content basis.

The elemental composition, moisture content, and higher heating value (HHV) are required fuel specifications for the WinGEMS lime kiln model. Built-in fuel information for residual fuel oil and natural gas were adopted for the simulation and are presented in Table 3.3. Petroleum coke fuel

specifications were not available within the WinGEMS lime kiln model, and therefore literature value were used (Lee et al. 1997, 1999).

**Table 3.3** Lime Kiln Fuel Specifications

Specification	Residual Fuel Oil	Natural Gas	Petroleum Coke
Carbon (wt. %)	85.8	74.8	86.3
Hydrogen (wt. %)	11	25.2	3.5
Nitrogen (wt. %)	-	-	1.6
Sulfur (wt. %)	3	-	5.5
Oxygen (wt. %)	0.45	-	0.5
Ash (wt. %)	0.05	-	0.3
Moisture (wt. %)	-	-	2.3
HHV (MJ/kg)	40.6	55.6	34.9

### 3.1.3 Kraft Mill Steam Requirements

Table 3.4 shows the department-level medium and low pressure steam requirements in the base case simulation model (residual fuel oil, with cogeneration). The small amount of high pressure steam used for recovery and power boiler sootblowing is not included in Table 3.4. Existing benchmarking results (Bruce 2000) indicate typical mill steam consumption values of between 17 GJ/admt for a 1990s vintage North American softwood bleached kraft mill to 22 GJ/admt for a 1980s vintage North American softwood bleached kraft mill.

**Table 3.4** Department Medium and Low Pressure Steam Requirements—Base Case Simulation

Department	Steam Requirement (GJ/admt)
<i>Medium pressure steam</i>	
Digester	2.9
Oxygen delignification	1.7
<i>Low pressure steam</i>	
Pulp dryer	4.2
Evaporators	5.3
Steam stripper	1.5
Other <sup>a</sup>	2.4
Bleach plant	1.2
Digester	1.5
ClO <sub>2</sub> plant	0.2
<i>Total medium and low pressure steam</i>	20.9

<sup>a</sup> Other includes steam to deaerator, chiller, and other miscellaneous steam uses.

### 3.1.4 Kraft Mill Electricity Requirements

Steam and material flows were characterized within the simulation model. Kraft mill electricity requirements have been reviewed in a number of energy benchmarking studies involving hypothetical

model mills and data compiled from operating mills. The departmental electricity requirements from four studies are presented in Table 3.5. The “typical” 1990s North American mill in Bruce (2000) is based upon results from 1990s vintage operating mills. Other study results (Francis, Tower, and Browne 2002; Nygaard 1992) are based upon hypothetical model mills and would represent electricity consumption given best available technology.

**Table 3.5** Departmental Electricity Requirements for Bleached Kraft Mills

Department <sup>a</sup>	Model Bleached Market Kraft Pulp Mill (Francis et al. 2002)	“Typical” 1990s North American Mill (Bruce 2000)	1980s US Mill (Nilsson et al. 1995)	1990 Model Mill (Nygaard 1992)
	(kWh/admt)			
Chip conveying	20	24	25	55
Digester	40	168	43	85
Washing and screening	30	-	103	-
Oxygen delignification	75	-	47	40
Bleaching <sup>b</sup>	100	124	42*	55
Screening and storage	-	-	74	45
Pulp machine	141	155	153	120
Black liquor evaporators	30	125	66	35
Steam stripping	-	-	-	-
Power plant	60	191	125	70
Kiln and recausticizing	50	30	42	60
Hot water supply	32	68	-	10
Wastewater treatment	30	-	-	30
Miscellaneous	30	-	61	20
Chemical preparation and oxygen	-	59	-	5
<b>Total</b>	638	944	781	630
<b>Total – Kraft recovery only<sup>c</sup></b>	180	514	276	250

<sup>a</sup> Electricity consumption, mostly by pumping and air handling systems (Larson and Nilsson 1991), was not explicitly considered in the simulation model. Bleached kraft mill benchmarking studies from the literature were used to characterize the electricity requirements associated with the kraft recovery system, so these electricity requirements could be considered in the life cycle modeling.

<sup>b</sup> Three-stage bleaching.

<sup>c</sup> An average value was used in this study.

### 3.1.5 Process Simulation Results

The simulation results on a per air-dried metric tonne (admt) of bleached pulp and a per gigajoule (GJ) of energy output are summarized in Table 3.6 and Table 3.7, respectively.

**Table 3.6** Process Simulation Results (unit/admt of Bleached Pulp)

Material	Unit	Scenario					
		1.1	1.2	1.3	2.1	2.2	2.3
<b>Inputs</b>							
Black liquor solids	bdmt <sup>a</sup>	1.52	1.54	1.54	1.54	1.52	1.54
NaOH, 100%	kg	11.7	13.4	13.4	13.4	11.7	13.4
Na <sub>3</sub> H(SO <sub>4</sub> ) <sub>2</sub> addition from R8/R10 plant	kg	18.6	16.3	16.2	16.3	18.6	16.2
Make-up lime (CaO)	kg	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162
Steam	GJ	6.80	6.80	5.50	5.40	5.70	5.90
Natural gas	GJ	1.90	0.00	0.00	1.78	0.00	0.00
Fuel oil	GJ	0.00	1.78	0.00	0.00	1.90	0.00
Petroleum coke	GJ	0.00	0.00	1.70	0.00	0.00	1.70
Electricity	GJ	0.834	0.834	0.834	0.834	0.834	0.834
<b>Outputs</b>							
Steam	GJ	14.5	14.4	14.4	16.1	16.1	16.1
Electricity	GJ	1.60	1.60	1.60	0.00	0.00	0.00
NaOH, 100%, to pulping	kg	328	332	333	333	328	333
Na <sub>2</sub> S, to pulping	kg	114	124	124	124	114	124

<sup>a</sup> Bone dry metric tonne.

**Table 3.7** Process Simulation Results (unit/GJ of Net Energy Output)

Material	Unit	Scenario					
		1.1	1.2	1.3	2.1	2.2	2.3
<b>Inputs</b>							
Black liquor solids	bdm <sup>a</sup>	0.178	0.182	0.158	0.143	0.148	0.151
NaOH, 100%	kg	0.00	0.00	0.00	0.00	0.00	0.00
Na <sub>3</sub> H(SO <sub>4</sub> ) <sub>2</sub> addition from R8/R10 plant	kg	2.19	1.92	1.67	1.51	1.78	1.59
Make-up lime (CaO)	kg	0.00191	0.00191	0.00166	0.00150	0.00156	0.00162
Steam	GJ	0.00	0.00	0.00	0.00	0.00	0.00
Natural gas	GJ	0.223	0.00	0.00	0.650	0.00	0.00
Fuel oil	GJ	0.00	0.211	0.00	0.00	0.182	0.00
Petroleum coke	GJ	0.00	0.00	0.174	0.00	0.00	0.167
Electricity	kWh	0.00	0.00	0.00	0.00	0.00	0.00
<b>Outputs</b>							
Net energy output <sup>b</sup>	GJ	1.00	1.00	1.00	1.00	1.00	1.00
Steam	%	90.5	90.6	91.8	100	100	100
Electricity	%	9.50	9.40	8.20	0.00	0.00	0.00
NaOH, 100%, to pulping	kg	37.2	37.8	32.8	29.8	30.3	31.3
Na <sub>2</sub> S, to pulping	kg	13.5	14.7	12.7	11.5	11.0	12.1

<sup>a</sup> Bone dry metric tonne.

<sup>b</sup> Energy output from which energy inputs have been subtracted.

### 3.1.6 Chemicals and Fuels Used in Black Liquor System

Chemicals and fuel consumed in the black liquor system were modeled based on data from a commercial life cycle inventory database (U.S. LCI). The datasets used are presented in Table 3.8.

**Table 3.8** Data Sources for Chemicals and Fuels Used in Black Liquor System

Material	Database	Dataset
Natural gas	U.S. LCI	Natural gas, combusted in industrial equipment/RNA
Fuel oil	U.S. LCI	Residual fuel oil, combusted in industrial boiler/US
Petroleum coke	U.S. LCI	Petroleum coke, at refinery/kg/US, CO <sub>2</sub> combustion emissions from NCASI
Make-up lime	U.S. LCI	Quicklime, at plant/US

NOTE: RNA=North America.

## 3.2 Fossil Fuel System

### 3.2.1 General Modeling Assumptions

The fossil fuel system has been modeled using data from commercially available databases (U.S. LCI, ecoinvent). These databases include energy production efficiencies. For electricity, it was assumed that transmission losses were 7% of the produced power (U.S. Energy Information Agency 2010). Datasets used are presented in Table 3.9.

**Table 3.9** Data Sets Used for the Fossil Fuel System

Energy type	Database	Dataset
Heat from coal	U.S. LCI	Bituminous coal, combusted in industrial boiler/US
Heat from natural gas	U.S. LCI	Natural gas, combusted in industrial boiler/US
Average U.S. electricity	U.S. LCI/ecoinvent	Based on 2006 fuel mix: Electricity, coal mix, at power plant/US (U.S. LCI); Electricity, residual fuel oil, at power plant/US (U.S. LCI); Electricity, natural gas, at power plant/US (U.S. LCI); Electricity, nuclear, at power plant/US (U.S. LCI); Electricity, hydropower, at power plant/SE (ecoinvent); Electricity, at wind power plant 800kW/RER (ecoinvent); Electricity, production mix photovoltaic, at plant/US (ecoinvent); Electricity, biomass, at power plant/US (U.S. LCI); No data for geothermal
Coal-based electricity	U.S. LCI	Electricity, coal mix, at power plant/US
Electricity from natural gas combined cycle	ecoinvent	Natural gas, burned in gas turbine/DE

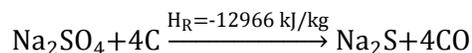
NOTES: SE=Sweden, DE=Germany.

### 3.2.2 Alternative Chemical Production

The recovery of black liquor solids results in the production of two essential chemicals for the pulping process: sodium hydroxide (NaOH) (“caustic”) and sodium sulfide (Na<sub>2</sub>S). To make the fossil fuel system equivalent to the black liquor system, it is necessary to include an equivalent alternative chemical production in the fossil fuel system.

Life cycle data for caustic production are from the U.S. LCI database (see Table 3.10).

No life cycle data are available for sodium sulfide production. For this reason, a data set was constructed. Industrially, sodium sulfide can be produced through several different process pathways. In this study, it was assumed that sodium sulfide is produced by the reduction of sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>) with carbon (charcoal). This process pathway was selected because it already takes place in pulp and paper mills given that sodium sulfate is often used as a make-up chemical. Resource and energy requirements were estimated from stoichiometry and heat of reaction:



Also, since this reaction occurs at high temperatures (900°C-1000°C), an additional energy requirement (2215 kJ/kg Na<sub>2</sub>S) for bringing the reactants to the appropriate temperature was included. The energy was assumed to be provided by natural gas. Natural gas life cycle information was obtained from the U.S. LCI database while sodium sulfate and charcoal life cycle information was obtained from the ecoinvent database (see Table 3.10).

There are several process pathways to produce sodium sulfide, but it is unlikely that the choice of pathway has a significant impact on energy requirements. For instance, in contrast to the pathway selected above, a different pathway involves the saturation of a caustic soda solution with hydrogen sulfide (H<sub>2</sub>S) and further reaction with caustic. This pathway has an enthalpy of reaction very similar to the previous one. It does not require as high a temperature but the solution produced with caustic and sodium sulfide needs to be concentrated before further reaction. Furthermore, the life cycle GHG emissions associated with the chemicals used in this latter pathway are similar to those in the previous pathway.

**Table 3.10** Data Sources for Alternative Chemical Production

Material	Database	Dataset
Caustic	U.S. LCI	Sodium hydroxide, production mix, at plant/kg/RNA
Sodium sulfate	ecoinvent	Sodium sulphate, powder, production mix, at plant/RER
Carbon	ecoinvent	Charcoal, at plant/GLO, assuming charcoal is 95% carbon
Natural gas	U.S. LCI	Natural gas, combusted in industrial equipment/RNA

NOTES: RNA= North America, RER=average Europe, GLO=global.

### 3.2.3 *Alternative Management of Black Liquor Solids*

The recovery of black liquor not only provides energy and chemicals for the pulp and paper process, it also allows disposing of the organic matter. For this reason, to make the fossil fuel- and black liquor-based kraft recovery systems equivalent, it is necessary to include an equivalent management of black liquor solids in the fossil fuel-based system.

A detailed model of alternative management of black liquor solids would have required too much speculation, but the management would almost certainly ultimately involve returning the biogenic carbon in the liquor to the atmosphere. In the best case, it would return as CO<sub>2</sub>, so this is what has been modeled. The alternative management may involve greater emissions of GHGs if, for instance, some the biogenic carbon is returned to the atmosphere as methane or if fossil fuels were required. For this reason, the approach taken is conservative.

## 3.3 Other Supporting Information

### 3.3.1 *Transportation*

Data to estimate emissions related to transportation of materials are based on the U.S. LCI database where available or estimated from the 2002 U.S. Commodity Flow Survey (U.S. Department of Transportation and U.S. Department of Commerce 2004, Table 6), (<http://www.census.gov/svsd/www/cfsdat/2002cfs-us.html>)<sup>5</sup>. One-way trips were assumed. More information can be found in Table 3.11 and Table 3.12. Transportation processes were modeled using the U.S. LCI and ecoinvent databases (see Table 3.13).

<sup>5</sup> Neglecting multimodal transportation.

**Table 3.11** Transportation Distances and Modes Based on US LCI Database

Material	Unit	Truck	Rail	Water, Inland	Pipeline
		tkm/unit	tkm/unit	tkm/unit	tkm/unit
Natural gas	m <sup>3</sup>	0.199	0.0119	-	1.19
Fuel oil	L	0.00525	0.00336	0.0284	-
Petroleum coke	kg	0.0290	0.676	0.0470	-
Bituminous coal	kg	0.00676	1.04	-	0.00502

**Table 3.12** Transportation Distances and Modes Based on Commodity Flow

SCGT 3-Digit Category	Used for	Truck		Rail		Water, Inland	
		%	Distance (km)	%	Distance (km)	%	Distance (km)
Sodium hydroxide (caustic soda) and potassium hydroxide (caustic potash)	NaOH	41.3	230	39.7%	927	19.0%	776
Inorganic chemicals	CaO, Na <sub>2</sub> S, sodium sulfate	73.7%	183	21.9%	1088	4.3%	489
Other wood product	Charcoal	100%	303	-	-	-	-

**Table 3.13** Data Sets for Transportation Processes

Transportation Process	Database	Dataset
Truck	U.S. LCI	Transport, combination truck, average fuel mix/US
Rail	U.S. LCI	Transport, train, diesel powered/US
Water, inland	U.S. LCI	Transport, barge, average fuel mix/US
Pipeline	ecoinvent	Transport, natural gas, pipeline, long distance/RER Transport, crude oil pipeline, onshore/RER

### 3.3.2 Heat Contents

The process simulation produced energy balances in energy units while some U.S. LCI database combustion data are in mass units. Hence, heating values presented in Table 3.14 were used.

**Table 3.14** Fuel Heating Values

Fuel	Unit	Heating Value (GJ LHV <sup>a</sup> /unit)
Natural gas	m <sup>3</sup>	0.0351
Fuel oil	L	0.0420
Coal	kg	0.0295

<sup>a</sup> 1 GJ HHV ≈ 0.95 GJ LHV.

## 4.0 RESULTS

The main GHG mitigation benefits results are presented in Table 4.1. The results for the individual scenarios can be found in Appendix B.

These results show that for the base case scenario (full cogeneration, natural gas burned in the kilns, average US grid displaced, and heat from coal displaced), the recovery of black liquor produced a reduction of approximately 182 kg CO<sub>2</sub> eq./GJ, or 91% of fossil fuel CO<sub>2</sub>.

When combining all scenarios, a median reduction of approximately 140 kg CO<sub>2</sub> eq./GJ, or 90% of fossil fuel CO<sub>2</sub>, is estimated. When no cogeneration is considered about 90% of the benefit is reached. Finally, the benefits from the recovery of the chemicals vary from 44% to 75% of the total benefit.

**Table 4.1** Summary of GHG Mitigation Benefits Results

Scenario/Case	Absolute Reduction (kg CO <sub>2</sub> eq./GJ)	Relative Reduction (%)	Contribution of Chemical Recovery (%)
Base case (1.1, AI)	182	90.5%	49.8%
Min	97.9	69.0%	74.9%
Median	142	88.0% (89.9%, 79.9%) <sup>a</sup>	54.3%
Max	192	92.4%	44.2%

<sup>a</sup> (with cogeneration, without cogeneration).

Table 4.2 frames the GHG emission reduction due to black liquor recovery in the context of the emissions of the entire US forest products industry. It shows that the reduction is essentially enough to fully offset Scope 1 (direct) and Scope 2 (purchased electricity) emissions.

**Table 4.2** US Total GHG Emissions Reduction Due to Use of Black Liquor Solids

Energy from black liquor solids in US in 2004	1.05e09 GJ (Heath et al. 2010)
Total potential GHG reduction due to black liquor recovery	149 Tg CO <sub>2</sub> eq. <sup>a</sup>
Scope 1 & 2 GHG emissions (fossil) by the whole US forest products manufacturing facilities in 2004	108 Tg CO <sub>2</sub> (Heath et al. 2010)

<sup>a</sup> Calculated: 142 kg CO<sub>2</sub> eq./GJ x 1.05E09 GJ = 1.49E11 kg CO<sub>2</sub> eq. = 149 Tg CO<sub>2</sub> eq.

The main non-renewable energy consumption benefits results are presented in Table 4.3. The results for the individual scenarios can be found in Appendix E.

**Table 4.3** Summary of Non-Renewable Energy Conservation Benefits Results

Scenario/Case	Absolute Reduction (GJ <sub>NR</sub> /GJ) <sup>a</sup>	Relative Reduction (%)	Contribution of Chemical Recovery (%)
Base case (1.1, AI)	2.51	89.8%	55.2%
Min	1.49	71.1%	68.4%
Median	1.91	87.1% (89.2%, 77.0%) <sup>b</sup>	55.4%
Max	2.51	90.7%	47.0%

<sup>a</sup> GJ<sub>NR</sub>: Life cycle non-renewable energy required to produce 1 GJ of energy.

<sup>b</sup> (with cogeneration, without cogeneration).

These results show that for the base case scenario (full cogeneration, natural gas burned at the kilns, average US grid displaced, and heat from coal displaced), the recovery of black liquor solids produced a reduction of approximately 2.51 GJ non-renewable energy for each GJ of energy output (90% reduction). When considering all scenarios, a median reduction of approximately 1.91 GJ/GJ is achieved. When no cogeneration is considered, about 90% of the benefit is reached. The benefits from recovery of the pulping chemicals vary from 47% to 68% of the total benefit.

## 5.0 LIMITATIONS

The intent of this study was to improve the understanding of the GHG mitigation and fossil fuel conservation benefits of black liquor solids recovery. It is important to understand the limitations of the study before drawing conclusions. The main limitations of the study are the following:

- the use of assumptions regarding the types of energy displaced, and particularly the nature of the alternative chemical production processes, introduces uncertainty;
- the completeness and applicability of some of the inventory data used are open to question especially regarding:
  - the modeling of the production of sodium sulfide; and
  - the use of some secondary data from European LCI database (ecoinvent);
- the limited scope of the life cycle impact assessment precludes a comprehensive view of the life cycle impacts; and
- because LCIA indicator results are relative expressions they cannot be used to predict impacts on category endpoints, exceedances of thresholds, safety margins, or risk.

## 6.0 CONCLUSIONS

In this study, the life cycle GHG and fossil fuel-related benefits of black liquor solids recovery were analyzed. These benefits are due to two effects: the production of energy that can be used in the pulping process or sold, and the recovery of the pulping chemicals that would otherwise need to be produced from other resources.

The fossil GHG emissions and non-renewable energy consumption for a system using black liquor solids in the kraft recovery system are approximately 90% lower than those for a comparable fossil fuel-based system. When applying this reduction to the production of kraft pulp in the US, the avoided emissions are enough to offset all of the total Scope 1 and Scope 2 emissions from the entire US pulp and paper industry (all mills). This result does not depend on the accounting method for biogenic carbon because biogenic CO<sub>2</sub> emissions are the same for the systems compared and the result is valid across a range of assumptions about the displaced fossil fuel, the GHG intensity of the electricity grid, the fossil fuels used in the lime kiln, and the level of cogeneration at pulp and paper mills. The benefits occur without affecting the amount of wood harvested or the amount of chemical pulp produced.

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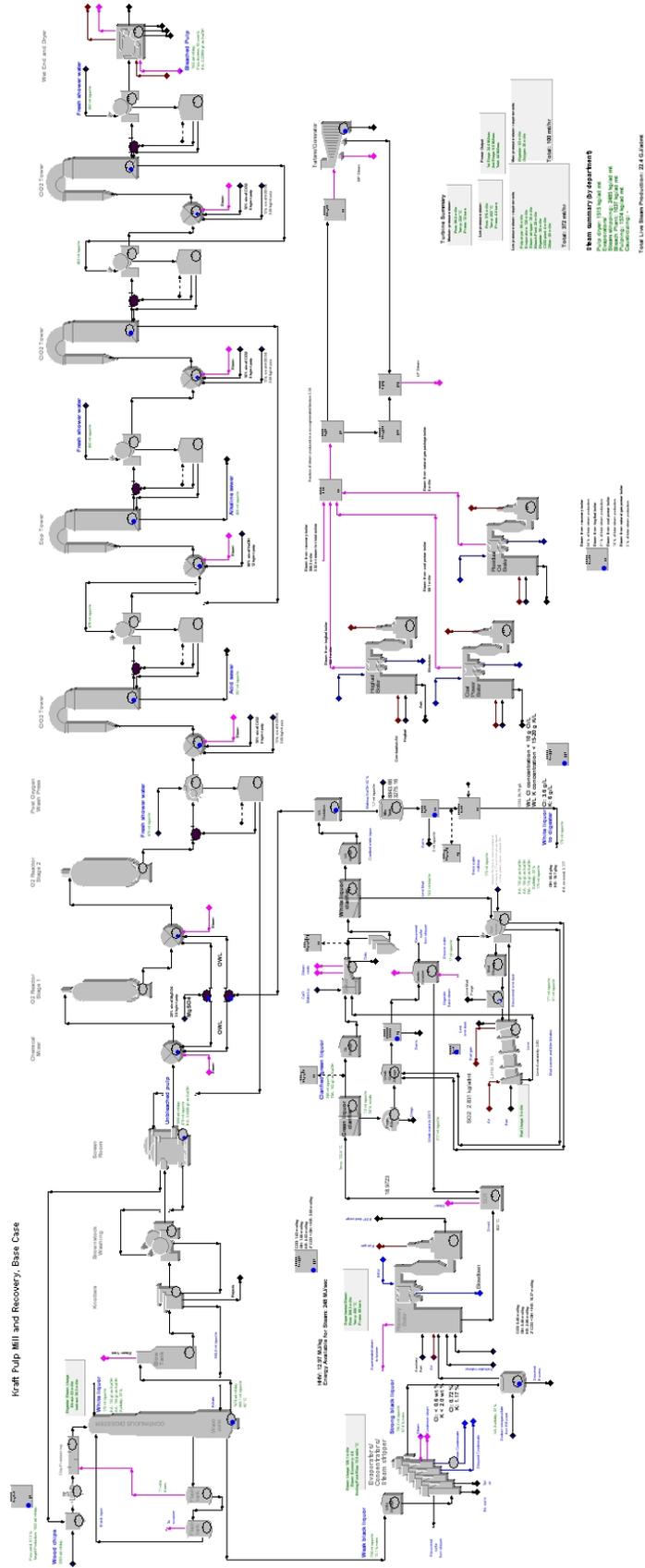
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# APPENDIX A

## SCHEMATIC OF THE FULL MILL SIMULATION





## APPENDIX B

**SODIUM, POTASSIUM, SULFUR, AND CHLORIDE BALANCE FOR THE KRAFT  
PULPING, OXYGEN DELIGNIFICATION AND RECOVERY AREA**

Material	Production (1500 admt/day)			
	Na	K	S	Cl
	kg/admt	kg/admt	kg/admt	kg/admt
<b>Input</b>				
Raw material	0.11	1.17	0.19	0.69
Caustic make-up	7.73	-	-	-
Na <sub>3</sub> H(SO <sub>4</sub> ) <sub>2</sub> from R8/R10	4.89	-	4.55	-
Kiln Oil	-	-	2.68	-
O <sub>2</sub> MgSO <sub>4</sub>	-	-	0.95	-
<b>Total</b>	<b>12.73</b>	<b>1.174</b>	<b>8.38</b>	<b>0.69</b>
<b>Output</b>				
Wash losses to bleach plant	2.10	0.41	0.68	0.00
Accidental black liquor losses	2.79	0.18	0.62	0.11
Accidental white liquor losses	2.14	0.13	0.52	0.08
Dregs and grits	0.51	0.03	0.12	0.02
Purged ESP dust	3.60	0.36	2.22	0.42
Recovery boiler flue gas	0.43	0.04	0.26	0.05
Purged lime dust	0.35	0.00	0.24	0.00
Knotter rejects	0.21	0.02	0.06	0.01
Sewered neutralized spent acid	0.62	0.00	0.58	0.00
Evaporator foul condensates	-	-	0.43	-
Evaporator NCG	-	-	0.38	-
Digester flash steam scrubber	-	-	0.87	-
Kiln flue gas	-	-	1.42	-
<b>Total</b>	<b>12.73</b>	<b>1.175</b>	<b>8.40</b>	<b>0.69</b>



**APPENDIX C**

**KEY INPUT PARAMETERS AND OUTPUT RESULTS FOR THE SIMULATION CASES**

Key Output Values	Co-generation cases				Non co-generation cases				Units
	Kiln fired with...				Kiln fired with...				
	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>		Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>		
<b><i>Bleached Pulp</i></b>									
Production rate	1500	1500	1500		1500	1500	1500		admt/day (10% moisture)
Production rate	1425	1425	1425		1425	1425	1425		machine dried mt/day (5% water)
<b><i>Unbleached Pulp</i></b>									
Production rate	1562	1562	1562		1562	1562	1562		admt/day
Fresh shower water to O <sub>2</sub> wash press	475	475	475		475	475	475		mt/hr
O <sub>2</sub> wash press dilution factor	5.8	5.8	5.8		5.8	5.8	5.8		-
O <sub>2</sub> wash press wash liquor ratio	3.5	3.5	3.5		3.5	3.5	3.5		-
Sodium losses from brown stock	2.2	2.2	2.2		2.2	2.2	2.2		kg Na/admt pulp
<b><i>White Liquor</i></b>									
Flow rate	175	171	175		175	171	175		mt/hr
Temperature	101	101	101		101	101	101		°C
EA	130	131	130		130	131	130		g/L as NaOH
Sulfidity	32.0	30.3	32.0		32.0	30.3	32.0		%
Carbonate (as Na <sub>2</sub> CO <sub>3</sub> )	26	27	26		26	27	26		g/L
Caustic make-up (50% NaOH solution)	1.7	1.5	1.7		1.7	1.5	1.7		mt/hr
Mass flow of hydroxide in white liquor	20.8	20.5	20.8		20.8	20.5	20.8		mt/hr as (100% NaOH)
Mass flow of hydrosulfide in white liquor	7.7	7.1	7.7		7.7	7.1	7.7		mt/hr as (100% Na <sub>2</sub> S)



Key Output Values	Co-generation cases			Non co-generation cases			Units
	Kiln fired with...			Kiln fired with...			
	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	
Energy content of superheated steam leaving boiler	16.1	16.1	16.1	16.1	16.1	16.1	GJ/admt
High pressure steam used for sootblowing	7.9	7.9	7.9	7.9	7.9	7.9	mt/hr
High pressure steam used for sootblowing	2.50	2.50	2.50	2.50	2.50	2.50	% of total recovery boiler steam
Calculated black liquor HHV	12.97	13.07	12.97	12.97	13.07	12.97	MI/kg solids
As-fired black liquor flow rate	100.6	99.1	100.7	100.6	99.1	100.7	mt solids/hr
As-fired liquor dry solids	1.61	1.59	1.61	1.61	1.59	1.61	kg dry solids/admt pulp
Black liquor fuel energy	20.9	20.7	20.9	20.9	20.7	20.9	GJ/admt
<i>Black liquor elemental composition</i>							
C	34.8	35.3	34.8	34.8	35.3	34.8	wt % solids
H	4.0	4.0	4.0	4.0	4.0	4.0	wt % solids
S	5.5	5.2	5.6	5.5	5.2	5.6	wt % solids
Na	19.8	19.5	19.8	19.8	19.5	19.8	wt % solids
O	33.6	33.7	33.6	33.6	33.7	33.6	wt % solids
K	1.3	1.3	1.3	1.3	1.3	1.3	wt % solids
Cl	0.9	1.0	0.9	0.9	1.0	0.9	wt % solids
Na <sub>3</sub> H(SO <sub>4</sub> ) <sub>2</sub> addition from R8/R10 plant	1.02	1.16	1.02	1.02	1.16	1.01	mt/hr
Auxiliary Fuel <sup>1</sup>	0.00	0.00	0.00	0.00	0.00	0.00	mt/hr
<b>Power Boiler</b>							
Hogged fuel flow (including hogged fuel water content) <sup>3</sup>	38.96	38.96	38.96	36.95	36.36	36.96	mt/hr
Moisture content of hogged fuel	0.50	0.50	0.50	0.50	0.50	0.50	mass fraction
Hogged fuel energy	6.39	6.39	6.39	6.06	5.96	6.06	GJ/admt
Steam production from hogged fuel boiler	102.1	102.1	102.1	96.8	95.3	96.8	mt/hr

Key Output Values	Co-generation cases				Non co-generation cases				Units
	Kiln fired with...				Kiln fired with...				
	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>		Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>		
Steam production from hogged fuel boiler	21.3	21.3	21.3		23.9	23.6	23.9		% of total steam production
Coal flow to power boiler <sup>4</sup>	7.4	7.4	7.4		0.0	0.0	0.0		mt/hr
Coal fuel energy	3.64	3.64	3.64		0.00	0.00	0.00		GJ/admt
Steam production from coal power boiler	68.1	68.1	68.1		0.0	0.0	0.0		mt/hr
Steam production from coal power boiler	14.2	14.2	14.2		0.0	0.0	0.0		% of total steam production
Natural gas flow to power boiler <sup>5</sup>	0.0	0.0	0.0		0.0	0.0	0.0		mt/hr
Natural gas fuel energy	0.0	0.0	0.0		0.0	0.0	0.0		GJ/admt
Steam production from natural gas power boiler	0.0	0.0	0.0		0.0	0.0	0.0		mt/hr
Steam production from natural gas power boiler	0.0	0.0	0.0		0.0	0.0	0.0		% of total steam production
<b>Smelt Dissolving Tank</b>									
Smelt flow rate	39	38	39		39	38	39		mt/hr
Steam flow rate	4.9	4.8	4.9		4.9	4.8	4.9		mt/hr
(2*EA - AA)/(TTA + 2EA - 2AA)*100	18.9	19.3	19.0		18.9	19.3	19.0		%
<b>Clarified Green Liquor</b>									
Flow rate	249	245	249		249	245	249		mt/hr
Temperature	100	100	100		100	100	100		°C
Green liquor CO <sub>3</sub> <sup>=</sup> concentration	66.1	67.3	66.0		66.1	67.3	66.0		g/L
Green liquor OH <sup>-</sup> concentration	19.1	18.9	19.1		19.1	18.9	19.1		g/L
<b>Slaking/Causticizing</b>									
Steam flow rate	8.8	8.8	8.8		8.8	8.8	8.8		mt/hr
(2*EA - AA)/(TTA + 2EA - 2AA)*100	82.4	82.5	82.4		82.4	82.5	82.4		%
Fresh water to liquor preparation	190	187	190		190	187	190		mt/hr

Key Output Values	Co-generation cases			Non co-generation cases			Units
	Kiln fired with...			Kiln fired with...			
	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	
Lime make-up	0.001	0.001	0.001	0.001	0.001	0.001	mt/hr
<b>Lime Mud</b>							
Flow rate	74	75	75	74	75	75	mt/hr
<b>Lime Kiln</b>							
Fuel usage	2.70	2.11	3.00	2.70	2.11	3.00	mt/hr
Energy consumption per weight of product	6.80	7.24	6.42	6.80	7.24	6.42	GJ/mt
Energy consumption per weight of lime	8.09	8.62	7.72	8.09	8.62	7.72	GJ/mt
Energy consumption per admt of bleached pulp	1.78	1.90	1.70	1.78	1.90	1.70	GJ/admt
<b>Energy Summary</b>							
<i>Medium pressure steam flow from turbines</i>							
Temperature	100	99	100	0	0	0	mt/hr
Pressure	223.6	223.6	223.6	0.0	0.0	0.0	°C
Enthalpy	12.0	12.0	12.0	0.0	0.0	0.0	bar
<i>Low pressure steam flow from turbines</i>	2871.9	2871.9	2871.9	2872.6	2872.6	2872.6	kJ/kg
Temperature	213	214	213	0	0	0	mt/hr
Pressure	147.9	147.9	147.9	0.0	0.0	0.0	°C
Enthalpy	4.5	4.5	4.5	0.0	0.0	0.0	bar
<i>Medium pressure steam requirements</i>							
Digester	2741.0	2741.0	2741.0	2786.7	2786.7	2786.7	kJ/kg
<i>Low pressure steam requirements</i>							
Oxygen delignification	63	63	63	63	63	63	mt/hr
<i>Low pressure steam requirements</i>	36	36	36	37	37	37	mt/hr
<i>Low pressure steam requirements</i>							
Pulp dryer	95	95	95	95	95	95	mt/hr
Evaporators	120	119	120	120	120	120	mt/hr

Key Output Values	Co-generation cases			Non co-generation cases			Units
	Kiln fired with...			Kiln fired with...			
	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	
Steam stripper	35	35	35	35	35	35	mt/hr
Other <sup>6</sup>	55	55	55	55	55	55	mt/hr
Bleach plant	28	28	28	28	28	28	mt/hr
Digester	35	35	35	35	35	35	mt/hr
ClO <sub>2</sub> plant	3.9	3.9	3.9	3.9	3.9	3.9	mt/hr
Total steam consumption	20.9	20.9	20.9	21.2	21.2	21.2	GJ/admt
Turbine condensate	2.9	2.9	2.9	0.0	0.0	0.0	mt/hr
<b>Power Production</b>							
1 <sup>st</sup> turbine stage	34.4	34.4	34.4	0.0	0.0	0.0	MW
MP steam extraction	99.5	99.2	99.5	0.0	0.0	0.0	mt/hr
2 <sup>nd</sup> turbine stage	9.6	9.6	9.6	0.0	0.0	0.0	MW
MP steam extraction	213.4	214.0	213.4	0.0	0.0	0.0	mt/hr
Total	44.0	44.0	44.0	0.0	0.0	0.0	MW
Fraction of high pressure steam not passing through turbine	0.34	0.34	0.34	1.00	1.00	1.00	
High pressure turbine steam from recovery boiler	203.5	203.8	203.5	0.0	0.0	0.0	mt/hr
High pressure turbine steam from hogged fuel boiler	67.4	67.4	67.4	0.0	0.0	0.0	mt/hr
High pressure turbine steam from coal power boiler	45.0	45.0	45.0	0.0	0.0	0.0	mt/hr
High pressure turbine steam from natural gas power boiler	0.0	0.0	0.0	0.0	0.0	0.0	mt/hr
Produced electricity-to-heat ratio	33.6	33.8	33.6	0.0	0.0	0.0	KWh of power produced/GJ steam produced

Key Output Values	Co-generation cases			Non co-generation cases			Units
	Kiln fired with...						
	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	Fuel oil <sup>2</sup>	Natural Gas <sup>5</sup>	Petcoke <sup>7</sup>	
Turbine electricity-to-heat ratio	51.0	51.2	51.0	0.0	0.0	0.0	kWh of power produced/GJ HP steam to turbine
Electricity production	703	704	703	0.0	0.0	0.0	kWh of power produced/admt

<sup>1</sup> No. 2 Fuel Oil: C - 87.3%, H - 12.6%, S - 0.22%, O - 0.04 %, Ash - < 0.01%, HHV - 44.7 MJ/kg; <sup>2</sup> No. 6 High Sulfur Fuel Oil: C - 85.5%, H - 11%, S - 3%, O - 0.45 %, Ash - 0.05%, HHV - 40.6 MJ/kg; <sup>3</sup> Dry Hopped fuel: C - 51.5%, H - 6.1%, S - 0.1%, O - 41.1 %, Ash - 1.1%, N - 0.1 %, HHV - 20.5 MJ/kg; <sup>4</sup> Coal: C - 76.2%, H - 5.1%, S - 1.5%, O - 6.7%, Ash - 8.9%, N - 1.6 %, HHV - 32.2 MJ/kg; <sup>5</sup> Natural gas: C - 74.8%, H - 25.2%, HHV - 55.6 MJ/kg; <sup>6</sup> Other includes steam to deaerator, chiller, and other misc. steam uses; <sup>7</sup> Petcoke: C: 86.3%, H 3.5%, S 5.5%, O 0.5%, Ash 0.3%, HHV 34.9 MJ/kg



## APPENDIX D

## GHG MITIGATION BENEFITS—FULL RESULTS

Scenario	Black Liquor System	Fossil Fuel System	Difference		Chemical Contribution	
	(kg CO <sub>2</sub> eq./GJ, %)					
1.1, AI	19.1	201	-182	-90.5%	-90.4	49.8%
1.1, AII	15.7	169	-154	-90.7%	-86.1	56.1%
1.1, BI	15.7	207	-191	-92.4%	-86.1	45.0%
1.1, BII	15.7	180	-164	-91.3%	-86.1	52.4%
1.1, CI	15.7	183	-167	-91.4%	-86.1	51.6%
1.1, CII	15.7	156	-140	-89.9%	-86.1	61.6%
1.2, AI	15.7	196	-181	-92.0%	-86.1	47.7%
1.2, AII	19.1	174	-155	-89.0%	-90.4	58.5%
1.2, BI	19.1	211	-192	-91.0%	-90.4	47.0%
1.2, BII	19.1	184	-165	-89.7%	-90.4	54.7%
1.2, CI	19.1	187	-168	-89.8%	-90.4	53.9%
1.2, CII	19.1	160	-141	-88.1%	-90.4	64.2%
1.3, AI	19.3	187	-168	-89.7%	-78.2	46.6%
1.3, AII	19.3	160	-140	-87.9%	-78.2	55.7%
1.3, BI	19.3	196	-177	-90.2%	-78.2	44.2%
1.3, BII	19.3	169	-150	-88.6%	-78.2	52.3%
1.3, CI	19.3	175	-156	-89.0%	-78.2	50.2%
1.3, CII	19.3	148	-128	-86.9%	-78.2	60.9%
2.1, AI	33.2	170	-137	-80.5%	-70.2	51.3%
2.1, AII	27.9	141	-113	-80.2%	-71.0	62.8%
2.1, BI	36.8	171	-134	-78.5%	-71.0	53.0%
2.1, BII	36.8	141	-104	-73.9%	-71.0	68.1%
2.1, CI	16.6	171	-154	-90.3%	-71.0	46.0%
2.1, CII	16.6	141	-124	-88.3%	-71.0	57.1%
2.2, AI	27.9	171	-143	-83.7%	-71.0	49.7%
2.2, AII	33.2	140	-107	-76.3%	-70.2	65.6%
2.2, BI	42.3	170	-128	-75.1%	-70.2	55.0%
2.2, BII	42.3	140	-98	-69.8%	-70.2	71.7%
2.2, CI	21.5	170	-149	-87.3%	-70.2	47.3%
2.2, CII	21.5	140	-119	-84.7%	-70.2	59.2%
2.3, AI	35.6	175	-139	-79.6%	-74.8	53.8%
2.3, AII	35.6	145	-109	-75.4%	-74.8	68.5%
2.3, BI	44.9	175	-130	-74.3%	-74.8	57.7%
2.3, BII	44.9	145	-100	-69.0%	-74.8	74.9%
2.3, CI	23.7	175	-151	-86.5%	-74.8	49.5%
2.3, CII	23.7	145	-121	-83.7%	-74.8	61.7%



**APPENDIX E**  
**NON-RENEWABLE ENERGY BENEFITS—FULL RESULTS**

Scenario	Black Liquor System	Fossil Fuel System	Difference		Chemical Contribution	
	(GJ <sub>NR</sub> /GJ, %)					
1.1, AI	0.257	2.51	-2.25	-89.8%	-1.24	55.2%
1.1, AII	0.275	2.58	-2.31	-89.3%	-1.19	51.5%
1.1, BI	0.275	2.58	-2.30	-89.3%	-1.19	51.5%
1.1, BII	0.275	2.71	-2.43	-89.8%	-1.19	48.8%
1.1, CI	0.275	2.28	-2.01	-88.0%	-1.19	59.1%
1.1, CII	0.275	2.41	-2.14	-88.6%	-1.19	55.5%
1.2, AI	0.275	2.45	-2.18	-88.8%	-1.19	54.5%
1.2, AII	0.257	2.64	-2.38	-90.3%	-1.24	52.2%
1.2, BI	0.257	2.63	-2.38	-90.3%	-1.24	52.2%
1.2, BII	0.257	2.76	-2.51	-90.7%	-1.24	49.5%
1.2, CI	0.257	2.34	-2.08	-89.0%	-1.24	59.7%
1.2, CII	0.257	2.47	-2.21	-89.6%	-1.24	56.2%
1.3, AI	0.271	2.31	-2.04	-88.3%	-1.07	52.5%
1.3, AII	0.271	2.45	-2.18	-88.9%	-1.07	49.4%
1.3, BI	0.271	2.42	-2.15	-88.8%	-1.07	49.9%
1.3, BII	0.271	2.56	-2.29	-89.4%	-1.07	47.0%
1.3, CI	0.271	2.17	-1.90	-87.5%	-1.07	56.6%
1.3, CII	0.271	2.30	-2.03	-88.2%	-1.07	52.9%
2.1, AI	0.435	2.05	-1.62	-78.8%	-0.97	59.7%
2.1, AII	0.435	2.21	-1.77	-80.3%	-0.98	55.1%
2.1, BI	0.539	2.06	-1.52	-73.9%	-0.98	64.0%
2.1, BII	0.539	2.21	-1.67	-75.6%	-0.98	58.5%
2.1, CI	0.296	2.06	-1.77	-85.7%	-0.98	55.2%
2.1, CII	0.296	2.21	-1.91	-86.6%	-0.98	51.0%
2.2, AI	0.435	2.06	-1.63	-78.9%	-0.98	59.9%
2.2, AII	0.435	2.20	-1.76	-80.2%	-0.97	54.8%
2.2, BI	0.566	2.05	-1.49	-72.4%	-0.97	65.0%
2.2, BII	0.566	2.20	-1.63	-74.2%	-0.97	59.3%
2.2, CI	0.566	2.05	-1.49	-72.4%	-0.97	65.0%
2.2, CII	0.566	2.20	-1.63	-74.2%	-0.97	59.3%
2.3, AI	0.502	2.11	-1.61	-76.3%	-1.03	63.7%
2.3, AII	0.502	2.26	-1.76	-77.8%	-1.03	58.5%
2.3, BI	0.612	2.11	-1.50	-71.1%	-1.03	68.4%
2.3, BII	0.612	2.26	-1.65	-72.9%	-1.03	62.4%
2.3, CI	0.356	2.11	-1.76	-83.2%	-1.03	58.4%
2.3, CII	0.356	2.26	-1.90	-84.3%	-1.03	54.0%

# **GREENHOUSE GAS AND RESOURCE CONSERVATION BENEFITS OF USING BLACK LIQUOR FOR ENERGY PRODUCTION**

Prepared by  
National Council for Air and Stream Improvement, Inc.  
(NCASI)  
Research Triangle Park, NC

Presentation to USEPA, December 20, 2010

# Background

- In paper making, strong fiber bonding and brightness require
  - the separation of wood fibers
  - the removal of lignin from wood fiber
- This provided the impetus for the development of chemical pulping technologies
- Late 1800s and early 1900s pulping technologies
  - Sulfite pulping: Easily bleached pulp. Inexpensive pulping chemicals did not need to be recovered. Liquor discharged, often without treatment
  - Soda pulping: Worked only on hardwood. Modest pulp strength properties . Expensive make up chemicals

# The Kraft process

- Soda process required additions of expensive  $\text{NaOH}/\text{Na}_2\text{CO}_3$  to make up for lost chemicals
- In the late 1800s, German chemist C.F. Dahl discovered that when he used a less expensive chemical ( $\text{Na}_2\text{SO}_4$ ) to supply the sodium, the introduction of sulfur was very beneficial
  - produced increased yield
  - gave a process that worked on a range of wood species
  - increased pulp strength (“kraft” is German for “strong”)
- 1930s – Tomlinson Recovery furnace was developed/deployed for recovering pulping chemicals and recovering energy from the organic matter in the spent Kraft pulping liquor (black liquor)
- By the 1950s, Kraft pulping was dominant
- Currently, about 99% of U.S. chemical pulp production is from Kraft mills (based on AF&PA statistics for 2006)
  - Even considering all wood pulp (chemical, semi-chemical and mechanical), Kraft pulp represents about 85% of the U.S. total

# A bit more about Spent Pulping Liquor

- When pulp is produced from wood chips using a chemical process, such as the Kraft process, the fibers are separated from the remainder of the chip
- The residual liquid is called spent pulping liquor. It contains the dissolved portions of the wood not needed for pulp and paper making as well as the spent cooking chemicals
- Spent pulping liquor can be concentrated to produce a combustible material used as fuel in a recovery furnace (also called a recovery boiler)
  - The “recovery” consists of recovering pulping chemicals and energy from the spent pulping liquor
- The most common form of spent pulping liquor is black liquor produced by the Kraft pulping process

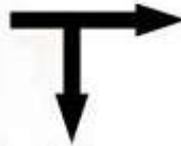
# Black Liquor

Black liquor is separated from pulp in washing



**Unwashed  
Pulp**

Washing

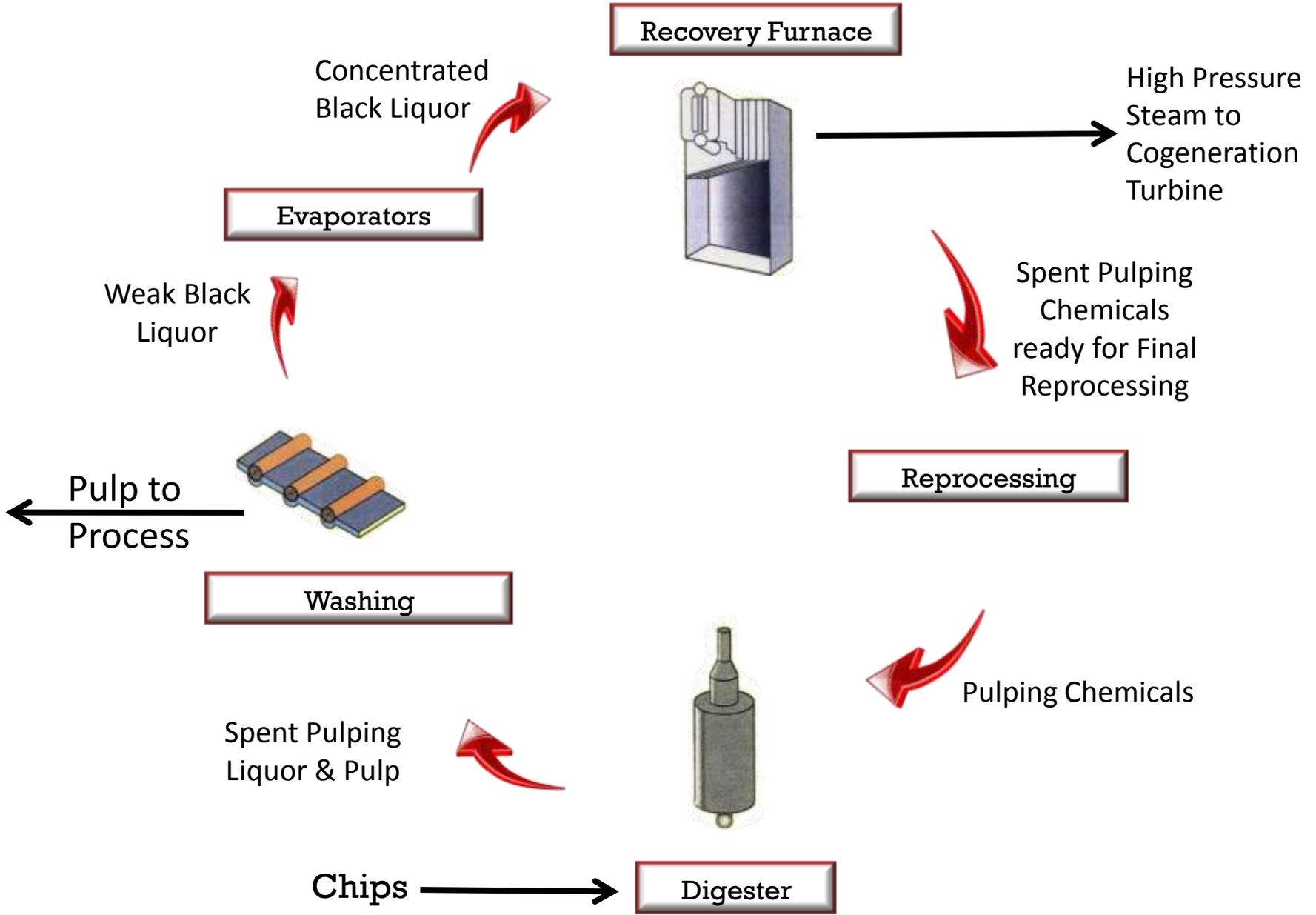


**Black  
Liquor**



**Washed Pulp**





Recovery Furnace

Concentrated Black Liquor

Evaporators

High Pressure Steam to Cogeneration Turbine

Weak Black Liquor

Spent Pulping Chemicals ready for Final Reprocessing

Reprocessing

Pulp to Process

Washing

Pulping Chemicals

Spent Pulping Liquor & Pulp

Chips

Digester

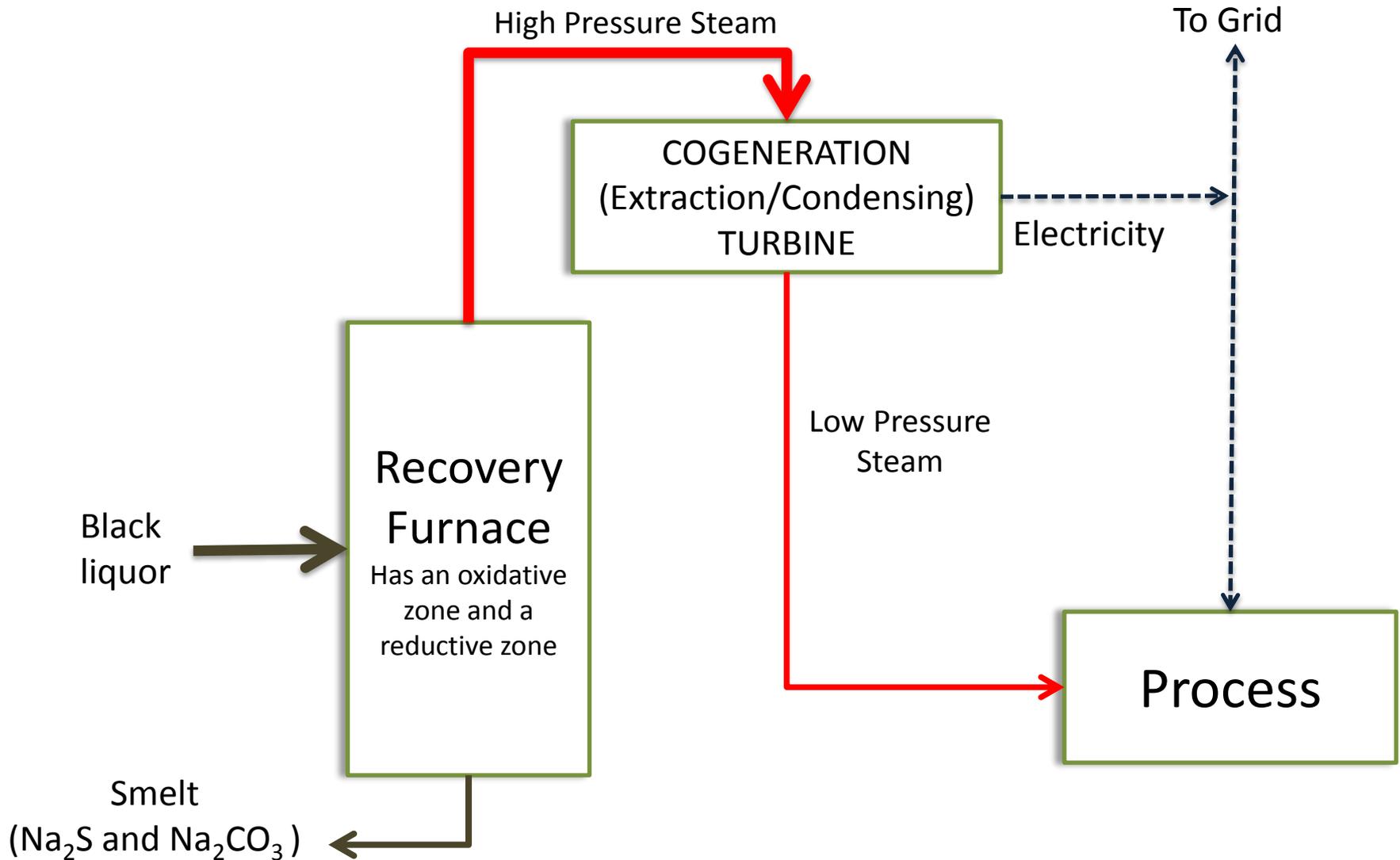
# Recovery Furnace



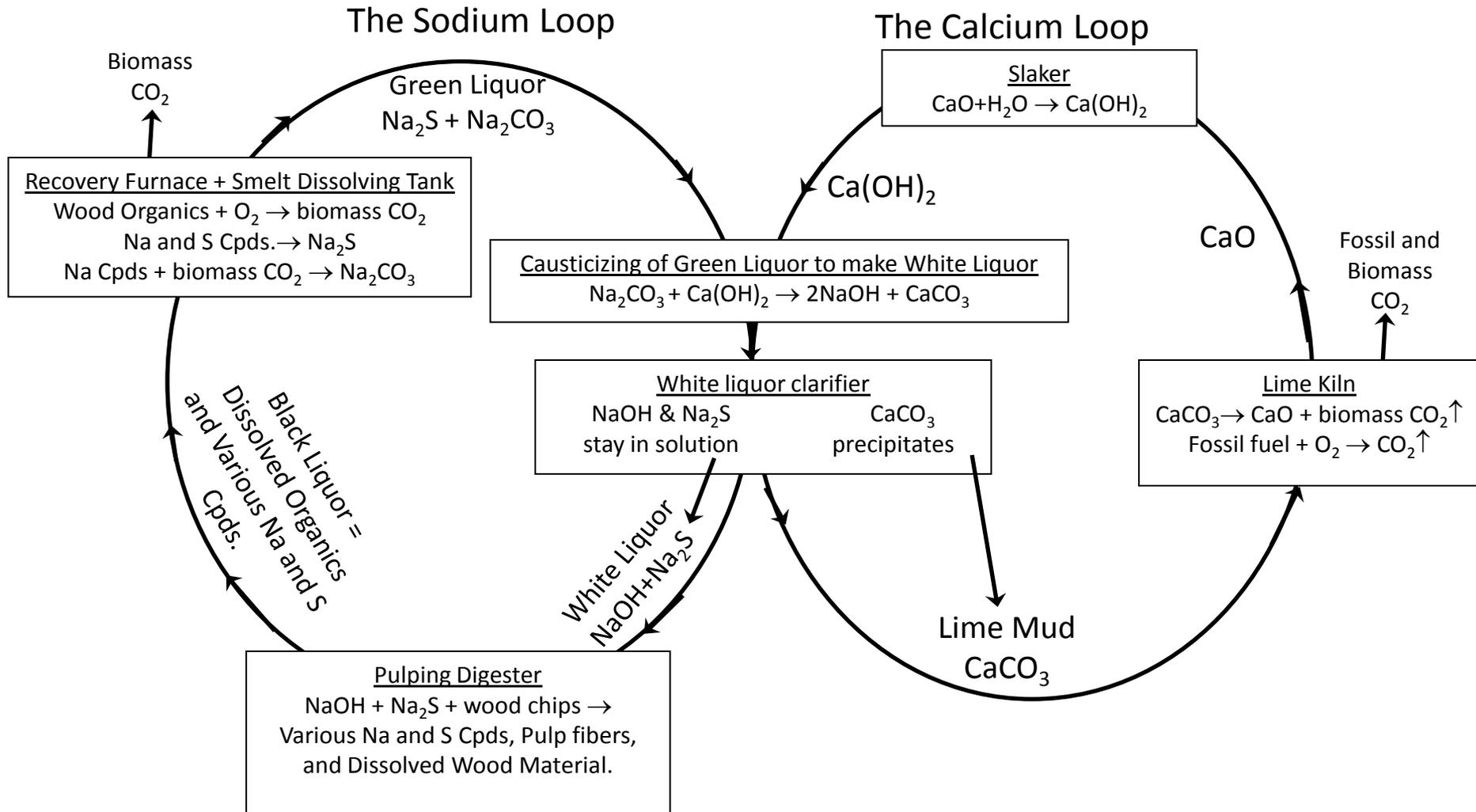
# Energy Products – Steam & Electricity Through CHP or Cogeneration

- Virtually all forest products facilities that produce high pressure steam and use it to generate electricity do so through a process called Combined Heat and Power (CHP) also known as Cogeneration
- With CHP or Cogeneration the high pressure steam turns a turbine to make electricity
- Useful thermal energy (low pressure steam) is also extracted from the turbine and used in the manufacturing process

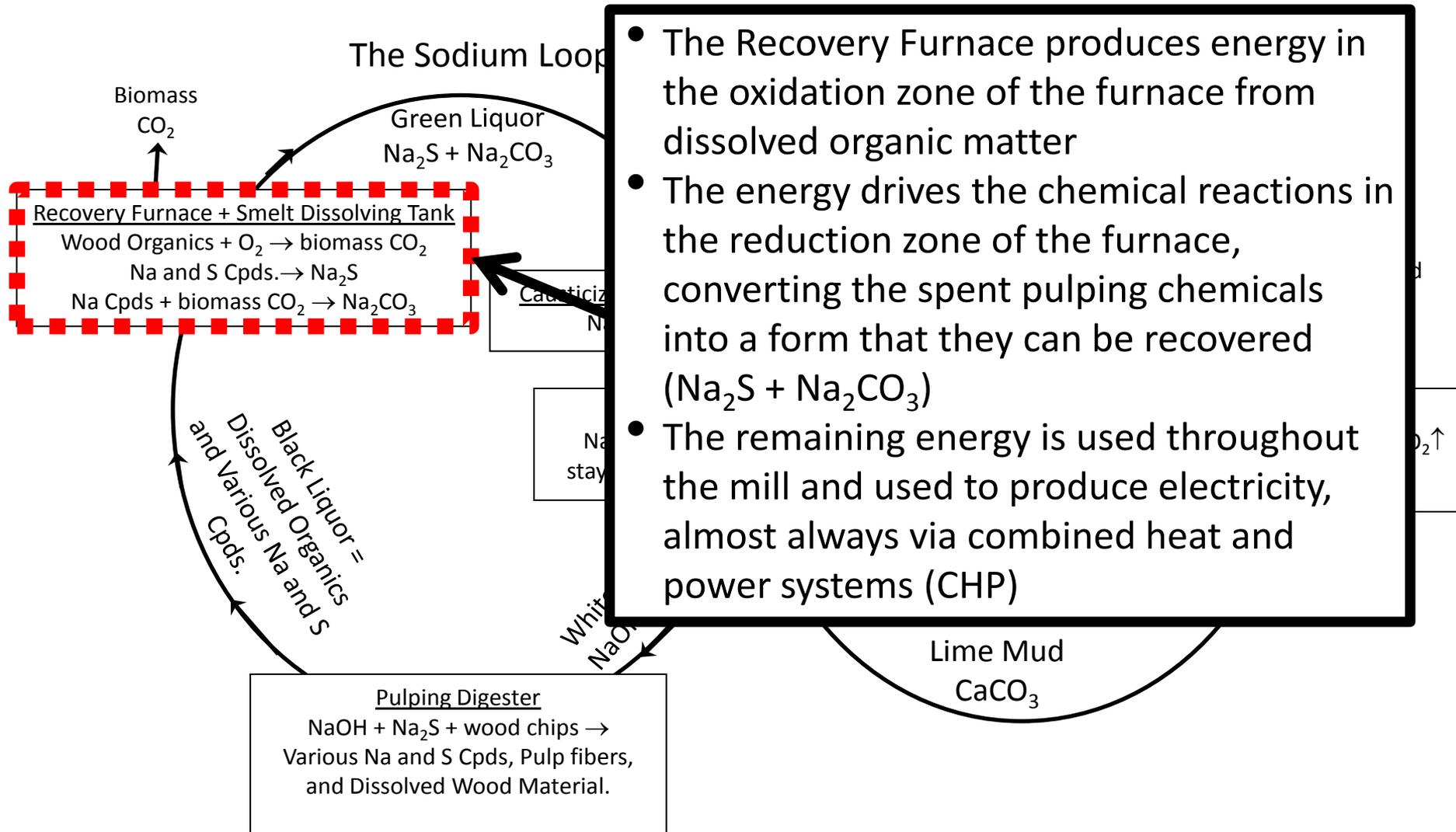
# Electricity in Typical Cogeneration System in Forest Products Industry



# A Simplified Representation of the Chemistry in the Kraft Pulping and Chemical Recovery System



# A Simplified Representation of the Chemistry in the Kraft Pulping and Chemical Recovery System

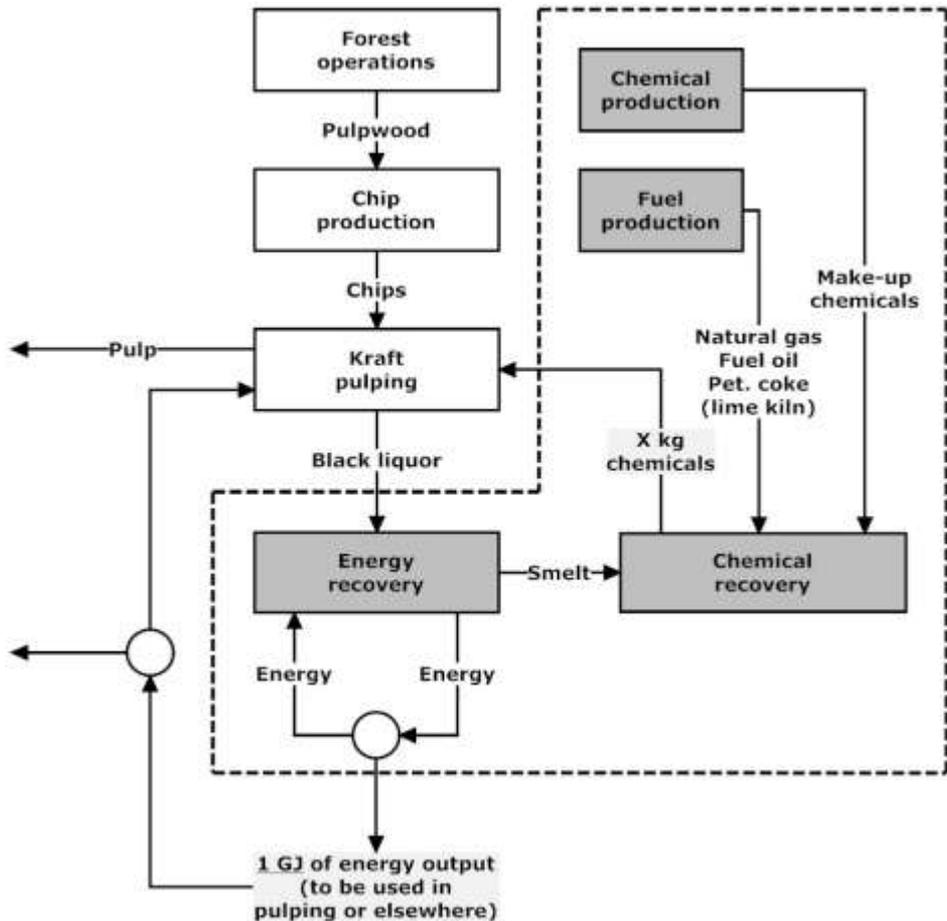


# This study

- The question: What are the greenhouse gas and resource conservation benefits of using black liquor solids in the Kraft recovery system?
  - Relative to a comparable system relying on fossil fuels
- Use life cycle thinking to compare the GHGs emitted, and non-renewable energy required to produce one gigajoule of energy output and the chemicals required for pulping via;
  - the use of black liquor solids in the Kraft recovery process
  - various fossil fuel-based systems to produce the same quantities of energy output and pulping chemicals
  - where the amounts of wood used and pulp produced are equal in both systems

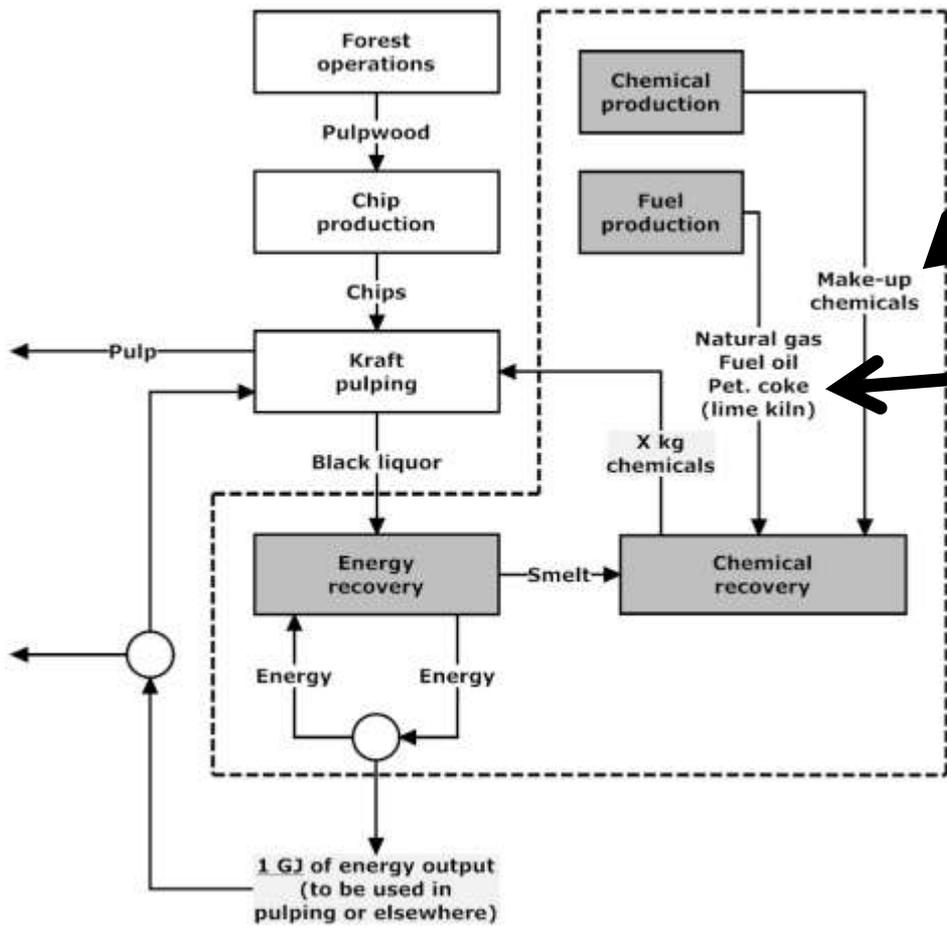
# The system based on using black liquor solids in the Kraft recovery system

OPTION 1: BLACK LIQUOR-BASED SYSTEM



# The system based on using black liquor solids in the Kraft recovery system

OPTION 1: BLACK LIQUOR-BASED SYSTEM



Small additions to make up for losses from the recovery system

Some fossil fuel required in lime kiln (not suited to burning black liquor)

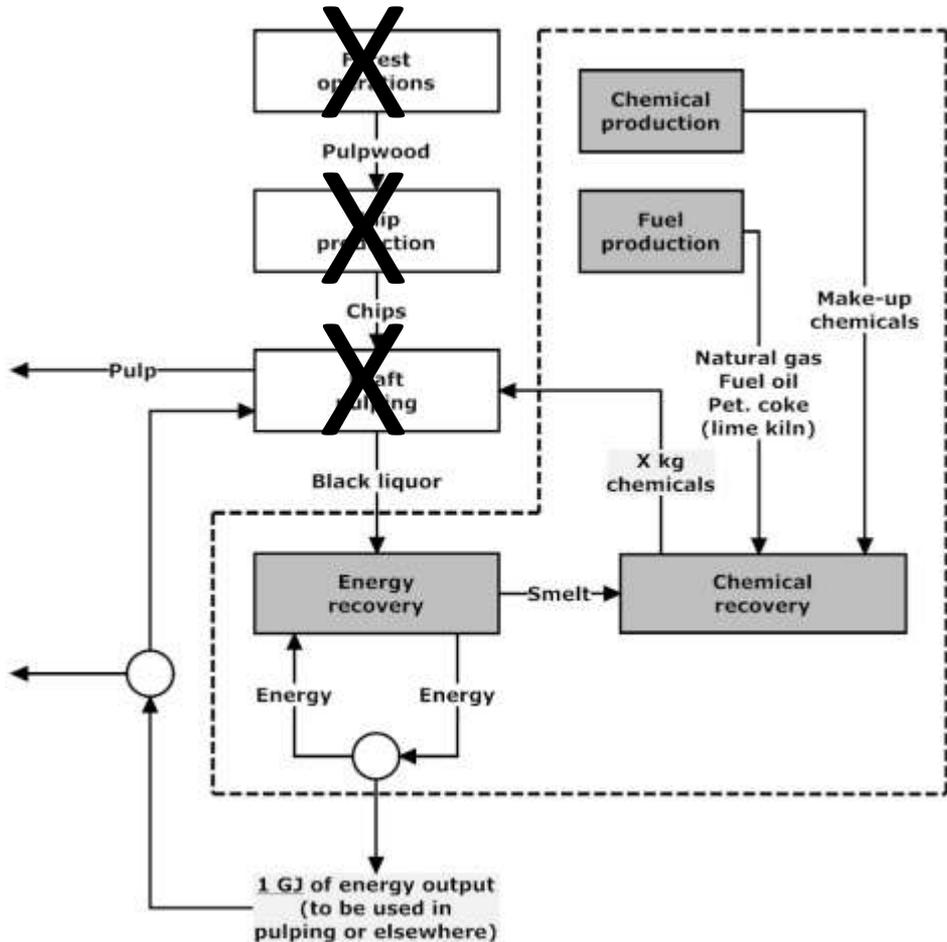
# The Kraft recovery process

- Has 2 functions
  - chemical production
  - energy production (almost always via combined heat and power, CHP)
- For comparison purposes, we need to consider an alternative fossil fuel-based system that provides the same functions

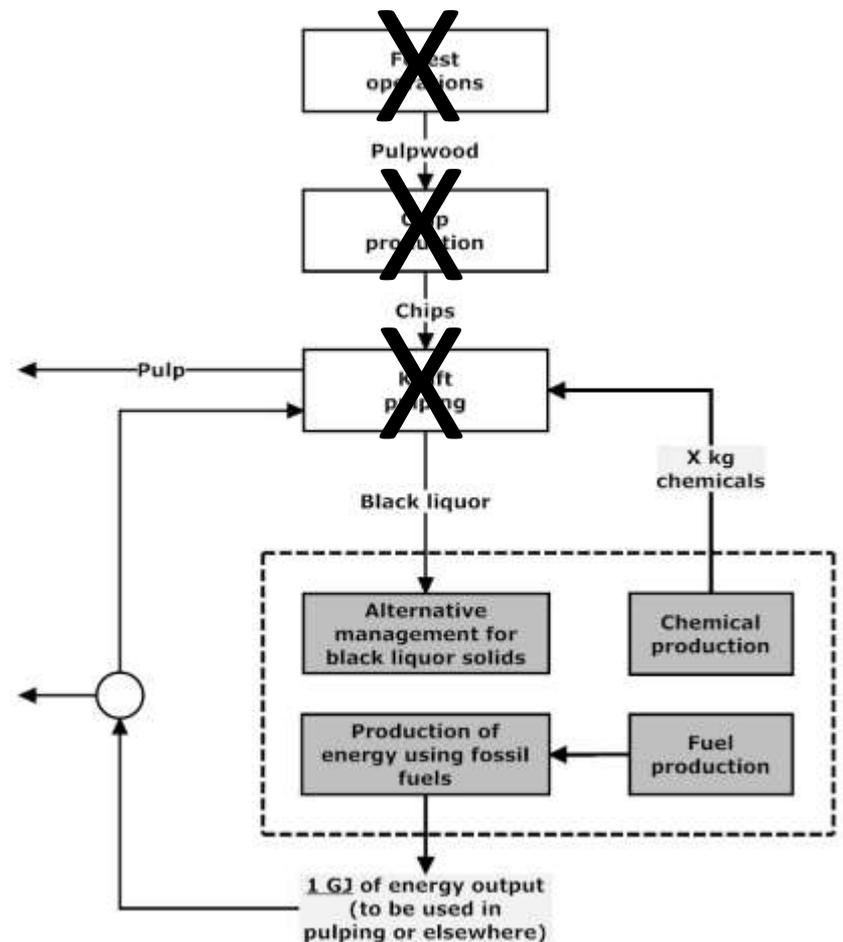


Since we are interested in the difference, we only need to model those aspects that are different

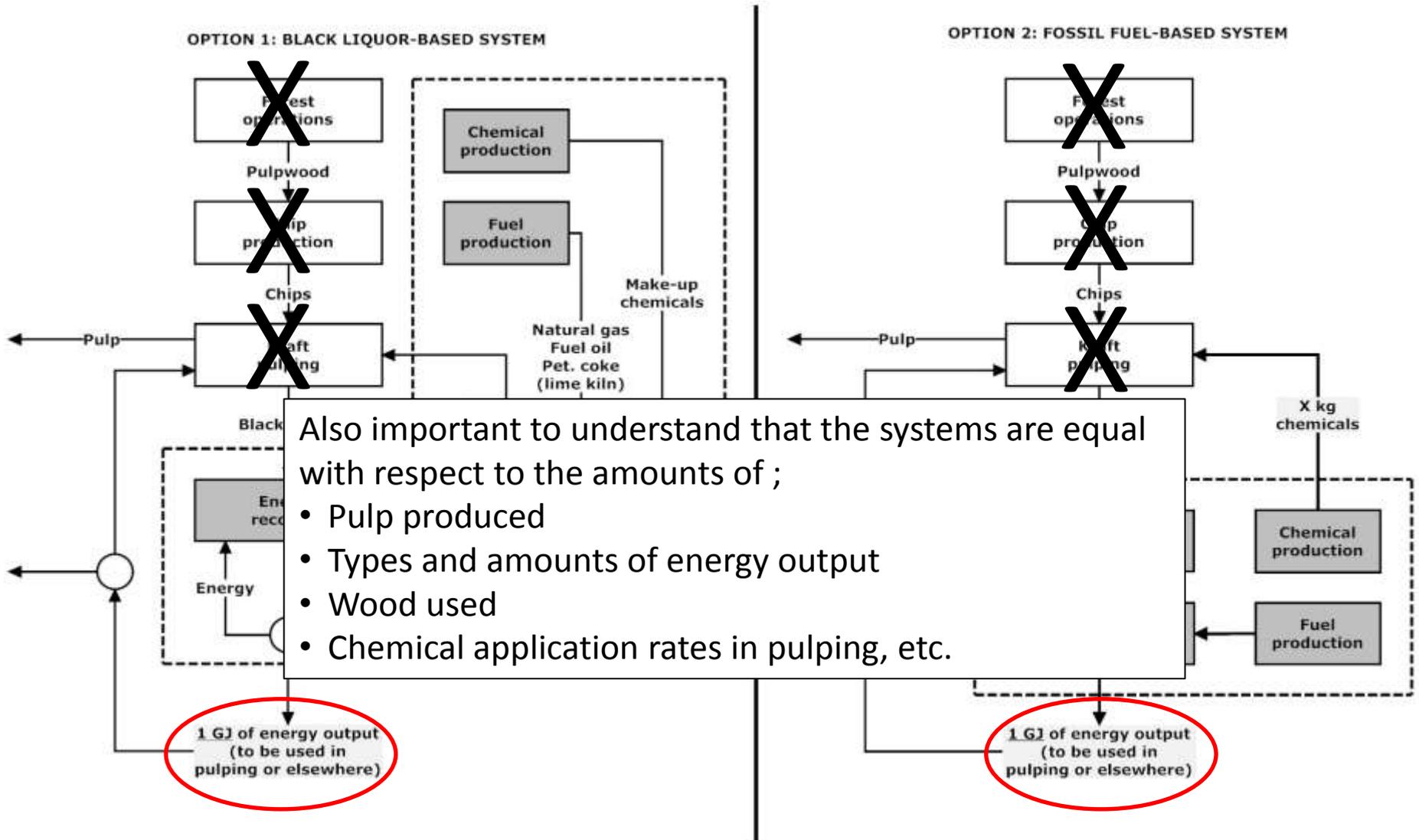
OPTION 1: BLACK LIQUOR-BASED SYSTEM



OPTION 2: FOSSIL FUEL-BASED SYSTEM



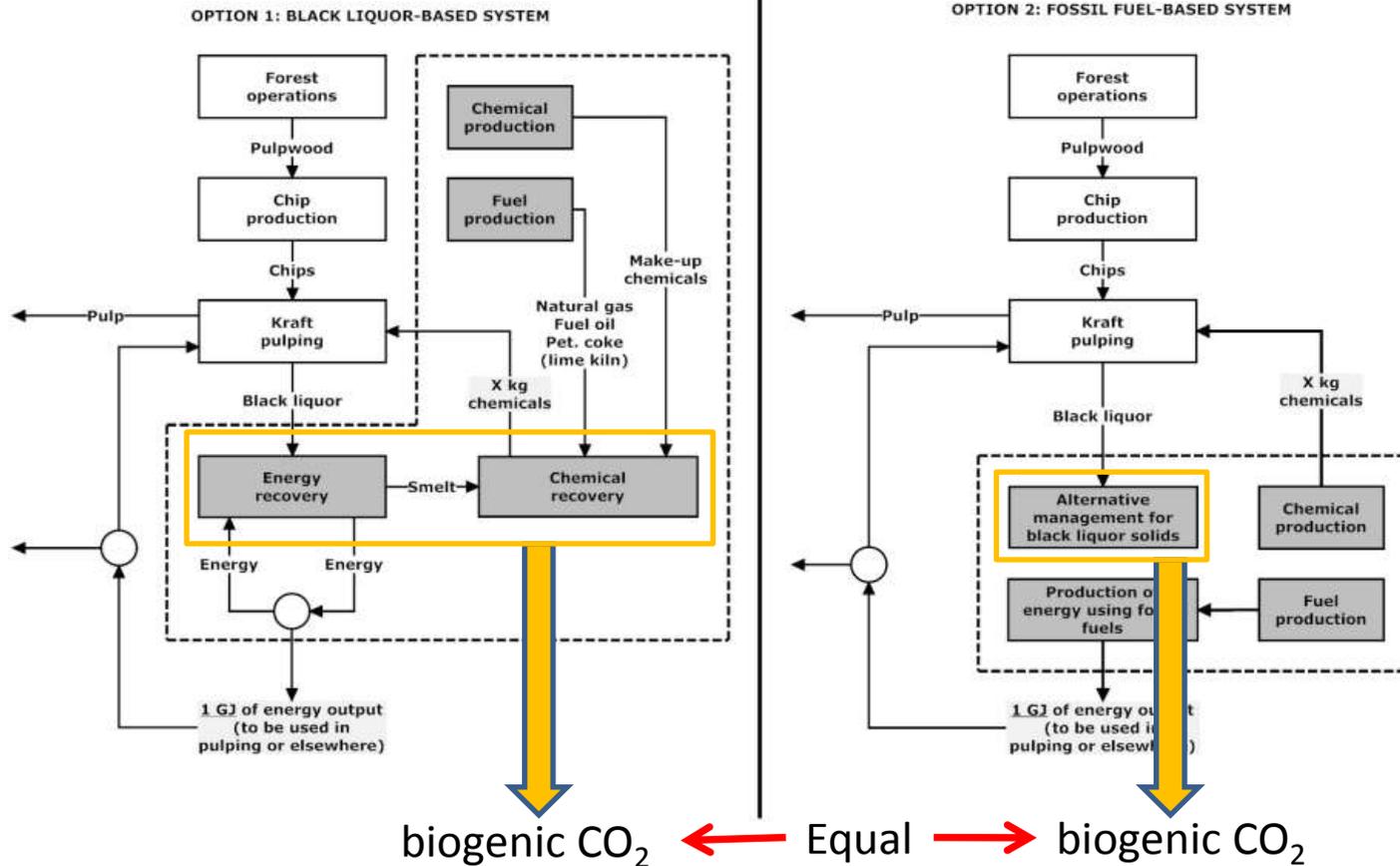
Since we are interested in the difference, we only need to model those aspects that are different



# Modeling of processes within the system boundaries

- No modeling needed for processes that are the same in both systems
- Model for Kraft recovery system
  - Modeled using representative industry conditions
  - Based on a recent industry LCA study and WinGEMS, a widely-used mass and energy balance model for pulp and paper mills
- Model for chemical production to supply chemicals if not produced from Kraft BLS
  - public LCI databases
- Model for fossil fuel production
  - public LCI databases
- Model black liquor solids management if not recovered
  - Too much uncertainty to model
  - Instead, the analysis ignores the emissions and non-renewable energy associated with any hypothetical alternative management, resulting in an understatement of the benefits of managing the material in the Kraft recovery system

# Regarding biogenic CO<sub>2</sub> emissions...



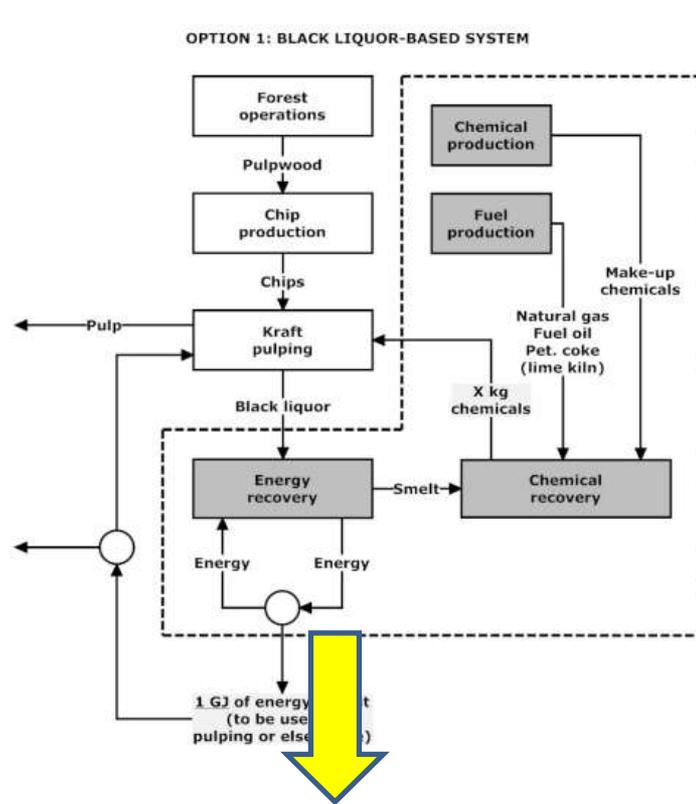
- Alternative management methods for black liquor solids would result in the biogenic carbon in black liquor solids being returned to the atmosphere
- So the flows of biogenic carbon to the atmosphere are the same for both systems, and can be ignored

# Scenarios analyzed

- All possible combinations of the following scenarios
  - Lime kiln fueled with natural gas, fuel oil, or petroleum coke
  - Kraft system equipped/not equipped with cogeneration (CHP)
  - Fossil fuel-based electricity produced by U.S. average grid, coal, combined cycle natural gas
  - Fossil fuel-based steam produced from coal or natural gas

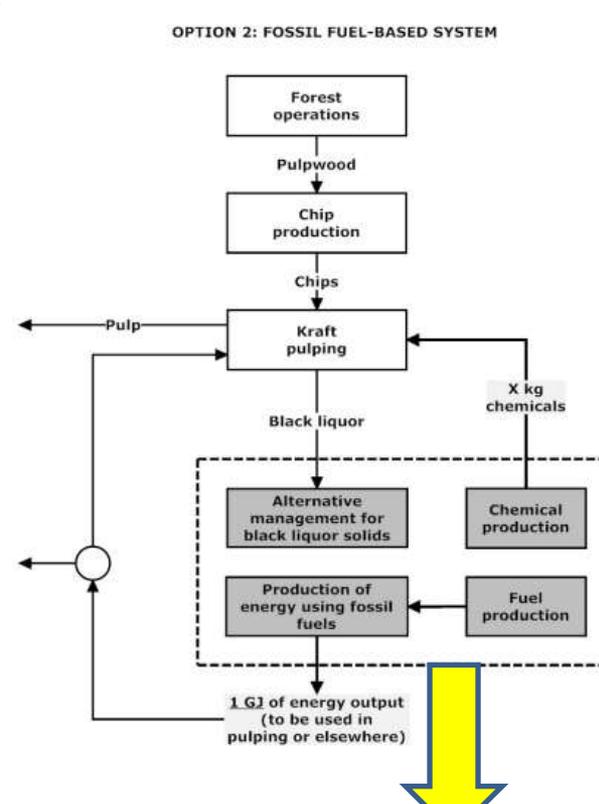
# Results – GHG emissions

(with CHP in the Kraft system: almost universally applied)



Emissions

≈ 16 to 19 kg CO<sub>2</sub> eq./GJ energy output



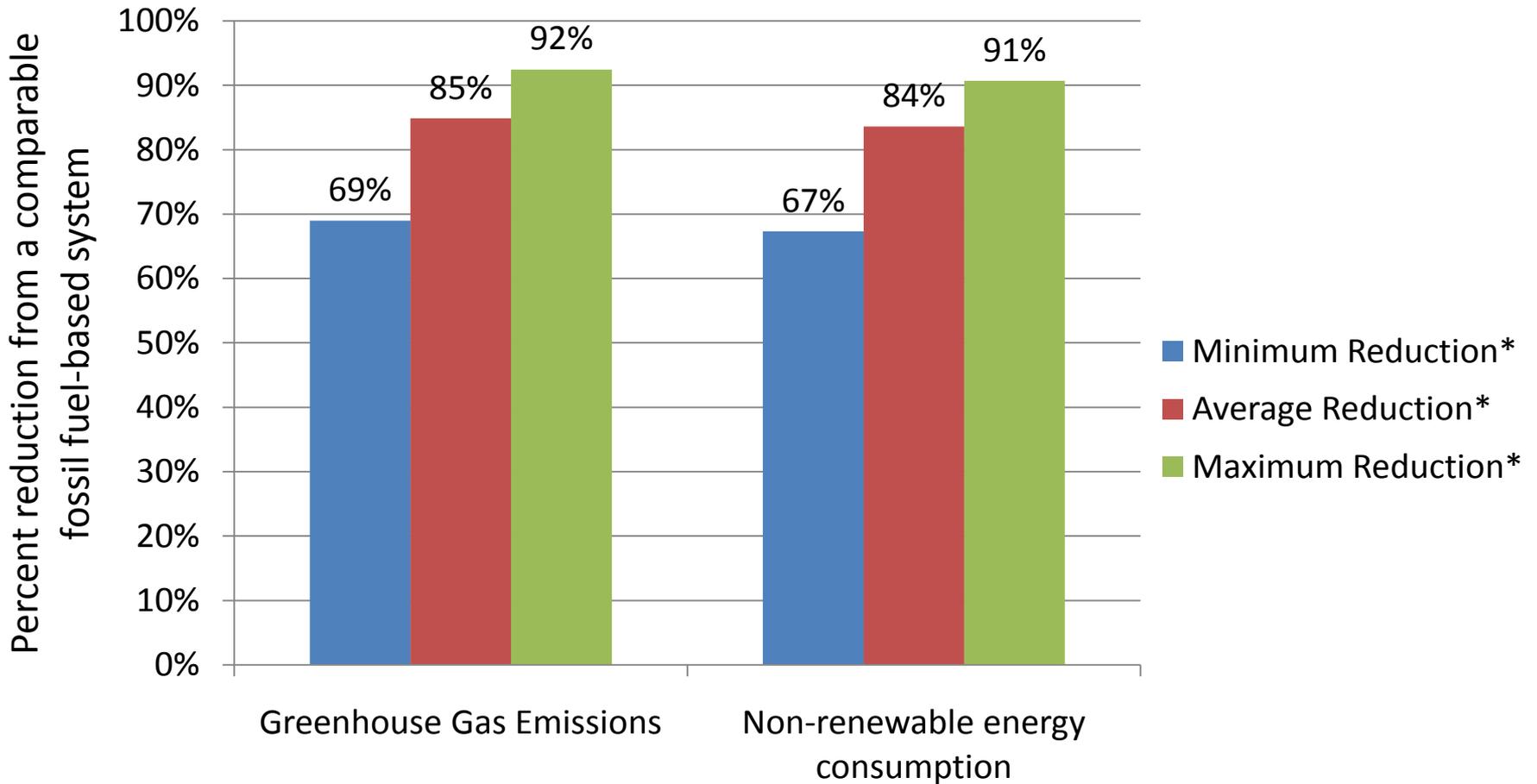
Emissions

≈ 150 to 210 kg CO<sub>2</sub> eq./GJ energy output

Average advantage for the black liquor solids-based system with CHP  
≈ 160 kg CO<sub>2</sub> eq./GJ energy output

# GHG and Non-renewable energy results

Reductions accomplished relative to a comparable fossil fuel-based system\*



\* The ranges reflect the variation in the results of the different scenarios examined in the study. Scenarios include systems with CHP and systems without CHP

# Results: page 1 of 2

- The GHG emissions and non-renewable energy consumption for a system using black liquor solids in the Kraft recovery system are approximately 85% lower than those for a comparable fossil fuel-based system
- Use of black liquor solids in the Kraft recovery system avoids approximately 160 kg CO<sub>2</sub> eq. per GJ of energy output from the system
- Applying these results to the production of Kraft pulp in the U.S., the avoided emissions are approximately 80 million tonnes CO<sub>2</sub> equivalents per year
  - These avoided emissions are essentially equal to the total Scope 1 + Scope 2 emissions from the U.S. pulp and paper industry (all mills)

# Results: page 2 of 2

- The results are robust
  - The benefits occur without affecting the amount of wood harvested or the amount of chemical pulp produced
  - The results do not depend on the accounting method for biogenic carbon
  - The findings are valid across a range of assumptions about the displaced fossil fuel, the GHG-intensity of the grid and the fossil fuels used in the lime kiln
  - Even without CHP, 80 to 90% of the benefits are retained

Thank you

Questions?