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Life Cycle Assessment of Pelletized Loblolly Pine (*Pinus taeda*) Residues for Coal Co-Firing in Virginia

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ABSTRACT

The goal of this study is to develop a real-world scenario life cycle with efficient, realistic, geologistics and minimum input demands. Woody biomass is projected to become a growing percentage of domestic electricity generation as a renewable fuel source. However, concerns persist regarding energy content, waste, emissions, ability to provide adequate biomass supply, and policies. Loblolly pine (Pinus taeda) is a short rotation woody crop grown in a substantial portion of the Southeastern United States for lumber and paper pulpwood. Once harvested, the fast-growing softwood can be delimbed and debarked leaving 20% of the biomass as underutilized residues. Pelletization and pulverized fuel combustion, direct coal cofiring, offer an energy pathway to decrease fossil fuel reliance and reduce carbon emissions. As a commercially scaled, cost-effective, and technologically feasible option to supplement coal power plants. Biomass coal cofiring must be evaluated by including residue acquisition and pelletization product stages to avoid emissions trade-offs. Evaluating the life cycle of loblolly pine wood residues for coal cofiring is necessary to target processes for improving environmental performance, understanding limitations of the feedstock for energy, and assessing sensitivity of varying loblolly pine-coal fuel blends. Using input parameters as a Virginia base case, this attributional life cycle assessment is designed in Simapro v8.5 software, supported by the EcoInvent v3.5 database, with eighteen midpoint indicators calculated using the ReCiPe (H) 2016 impact assessment method. The results of this study indicate 10% biomass-coal co-firing has less environmental impact in all categories except ozone depletion potential and terrestrial ecotoxicity.

Fig. 1: Loblolly Pine for Lumber Production

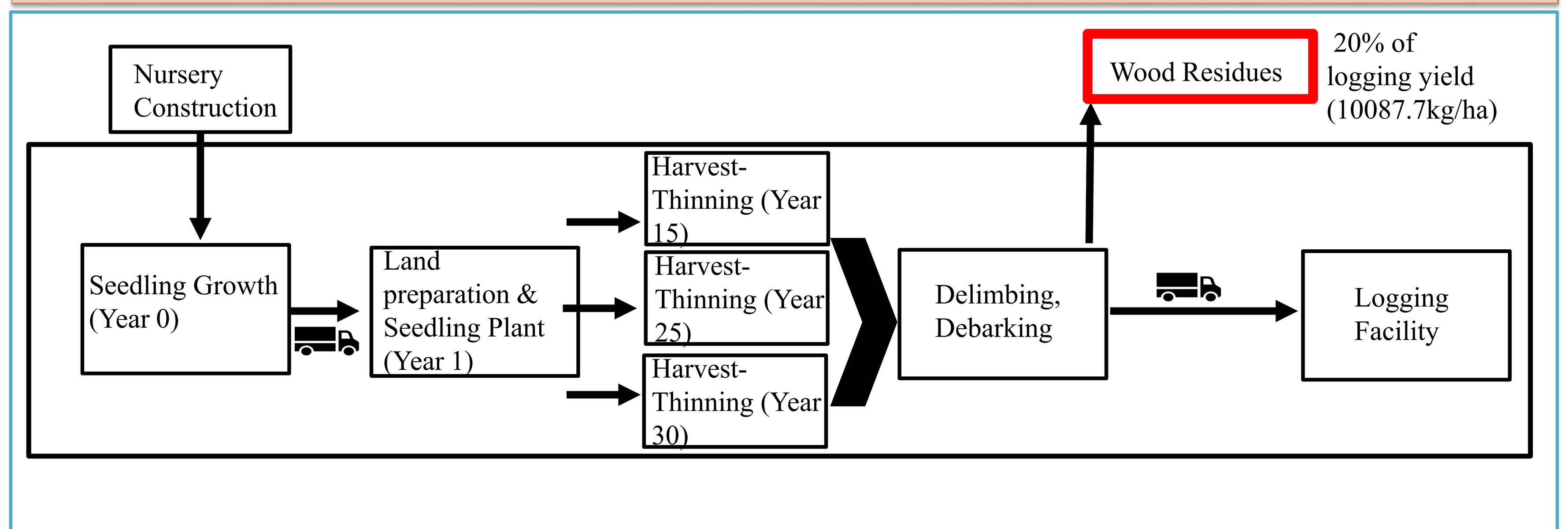


Fig. 2 System Boundary: Loblolly Pine Residues for Coal Co-firing

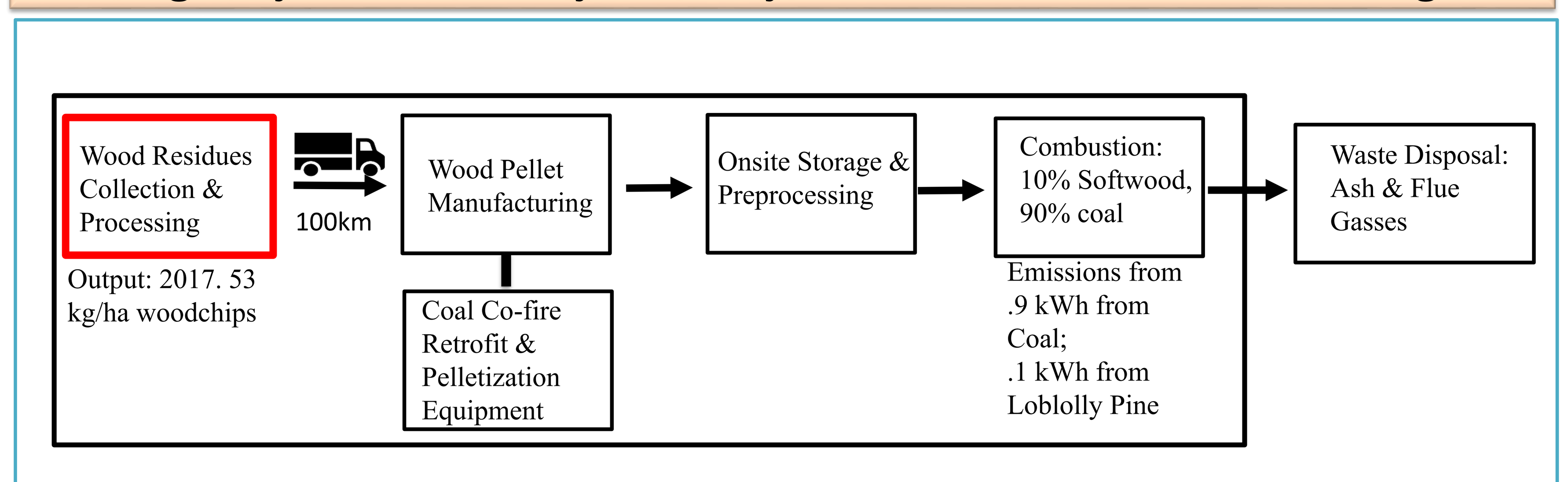
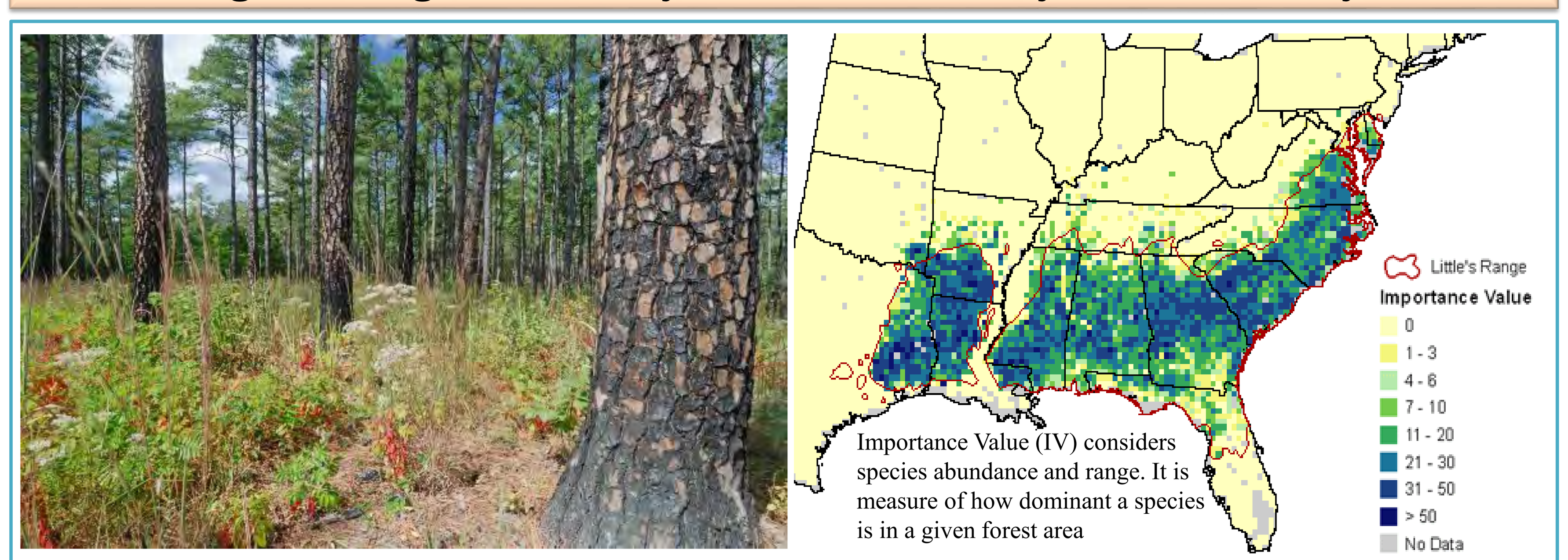


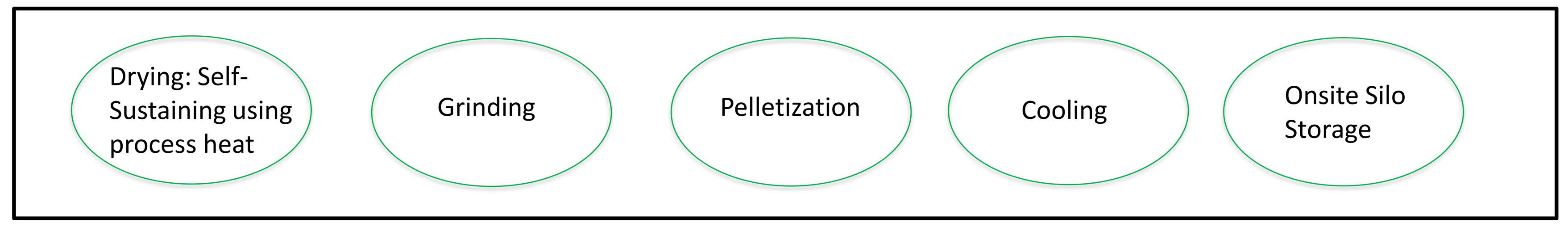
Fig. 3a: Virginia Loblolly Pine[1]; 3b: Loblolly Pine Inventory[2]



1:"Loblolly Pine (Pinus Taeda) Model Reliability: High." Current Distribution Maps for Loblolly Pine, United States Department of Agriculture - National Agricultural Statistics Service, www.fs.fed.us/nrs/atlas/tree/131.

2: Flemming, Gary. "The Natural Communities of Virginia Classification of Ecological Groups and Community Types." *Loblolly Pine Savannas*, Virginia Department of Conservation and Recreation, www.dcr.virginia.gov/natural-heritage/natural-communities/nctf2.

Fig. 4 Pelletization



METHODS & MATERIALS

Goal & Scope: To identify 'hot-spots' and conduct an attributional comparison of traditional SERC coal to loblolly pine residue-coal co-firing in Virginia.

Key Assumptions: The system boundary is outlined in Fig. 2. Residue collection is based on single Debarker-delimber-chipper (DDC) process accounting for operational inputs only (9.764kg lubricating oil;153.21kg diesel fuel oil). DDC allocation is 100% associated with loblolly pine chips as a worst case scenario liberal estimate. Transportation is limited to 100km proximity of chipped wood via 32 tonne truck. Pelletization energy inputs are accounted for and include required infrastructure for retrofitting the coal power plant. Pellet combustion is modeled using SO2, PM 2.5, CO, NOx, and CO2, emissions only then aggregated with .9kWh of hard coal combustion.

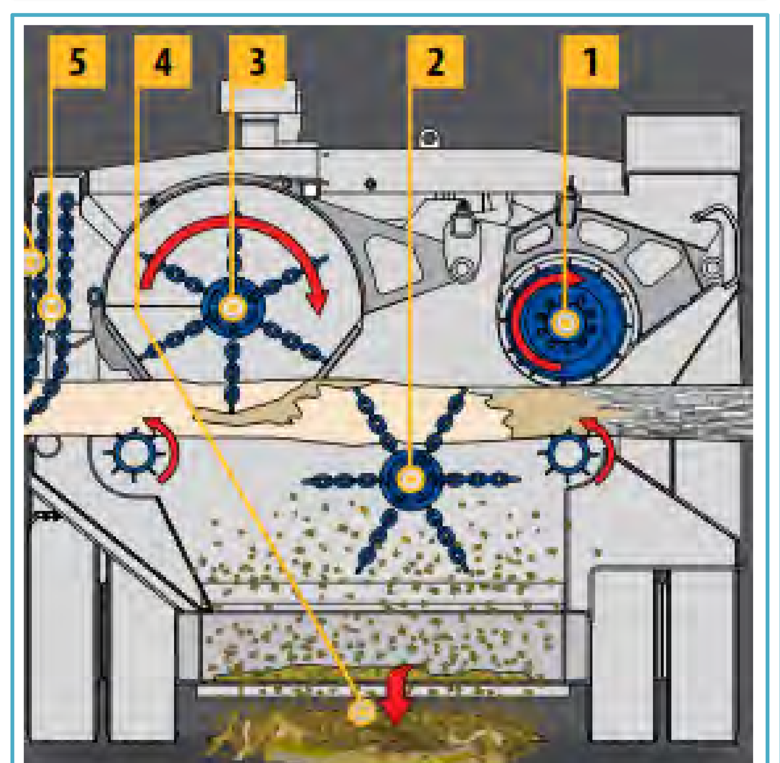
Functional Unit: 1-kWh electricity generated

Life Cycle Inventory (LCI): The inventory was developed using peer-reviewed literature and EcoInvent v. 3.4. Process modifications were made to represent realistic, technologically feasible, environmentally conservative operations, and to account for regional applicability.

Impact Assessment/LCA/LCIA is conducted in SimaPro v. 8 software using the ReCiPe (H) midpoint methodology. The Hierarchist model this is often considered to be the default model based on 100 year impact timeframes used as policy principals.

Selection & Definition of Impact Categories (yr/kg): Global Warming (CO2-eq.); Stratospheric ozone depletion (CFC-11-eq.); Ionizing radiation (Cobalt-60-eq.); Ozone formation, human health (NOx-eq.); Fine particulate matter formation (PM 2.5); Ozone formation, terrestrial ecosystems (NOx-eq.); Terrestrial acidification (SO2-eq.); Freshwater eutrophication (P-eq.); Marine eutrophication (N-eq.); Terrestrial /Freshwater/Marine ecotoxicity (1,4-dichlorobenzene); Human carcinogenic/non-Carcinogenic toxicity (1,4-dichlorobenzene); Land use (m2*yr); Mineral resource scarcity; Fossil resource scarcity (kg oil eq.); Water use (m3)

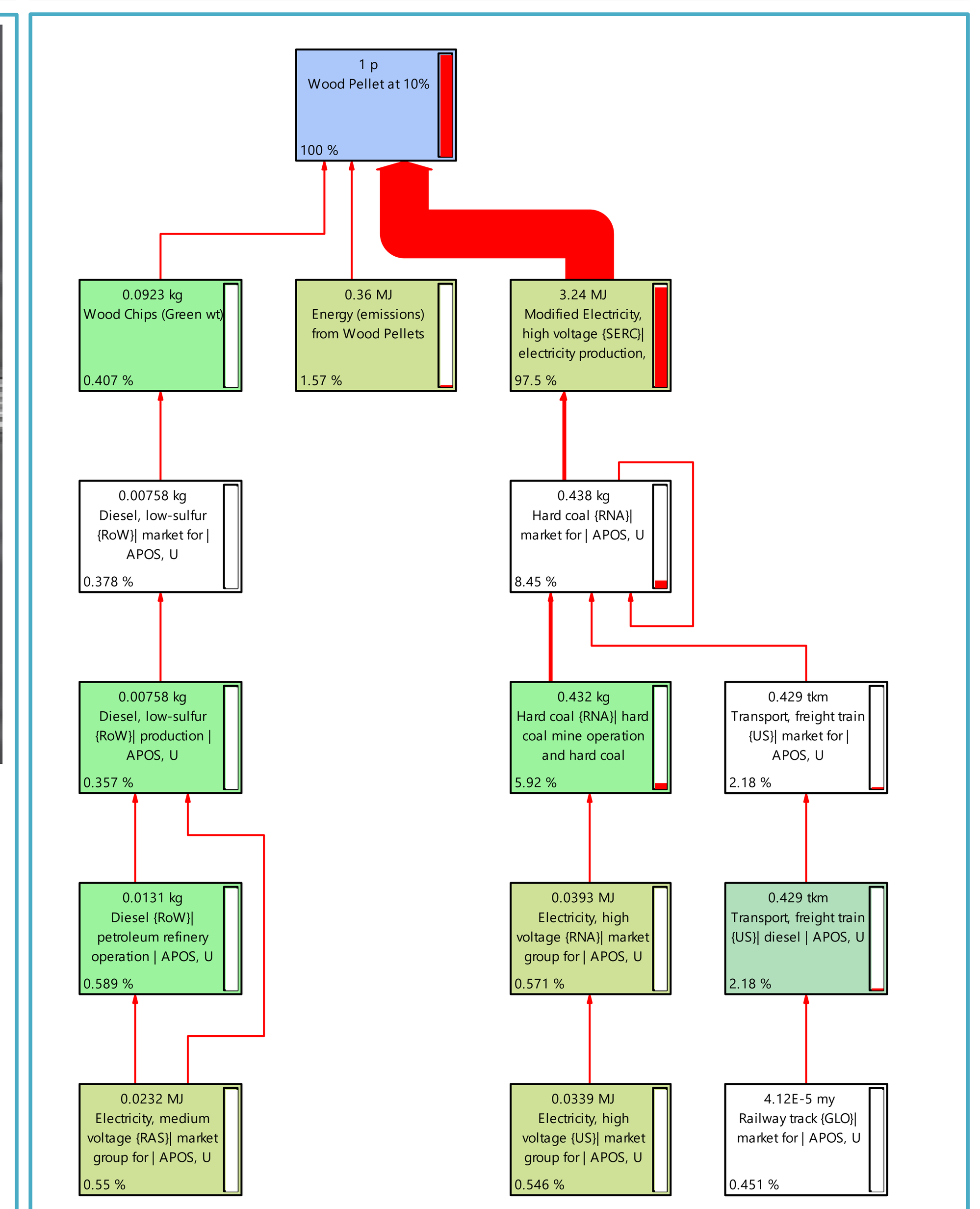
Fig. 5 Debarker-Delimber[3]



1. Direct drive upper feed feeds the machine 2. Fixed lower chain flail removes the bark from the underside of the stems 3. Floating upper chain flail removes the bark from tops & side of the stem 4. Bark & limbs as waste residues 5. Chain curtain sweep

3: Peterson Corporation. "Chipper and Flail Combinations." September, 2015.

Fig. 6 Contribution, GWP, %



RESULTS

Fig. 7 SERC 100% Hard Coal v. 90% Coal-10% Biomass Co-Firing, 1 kWh

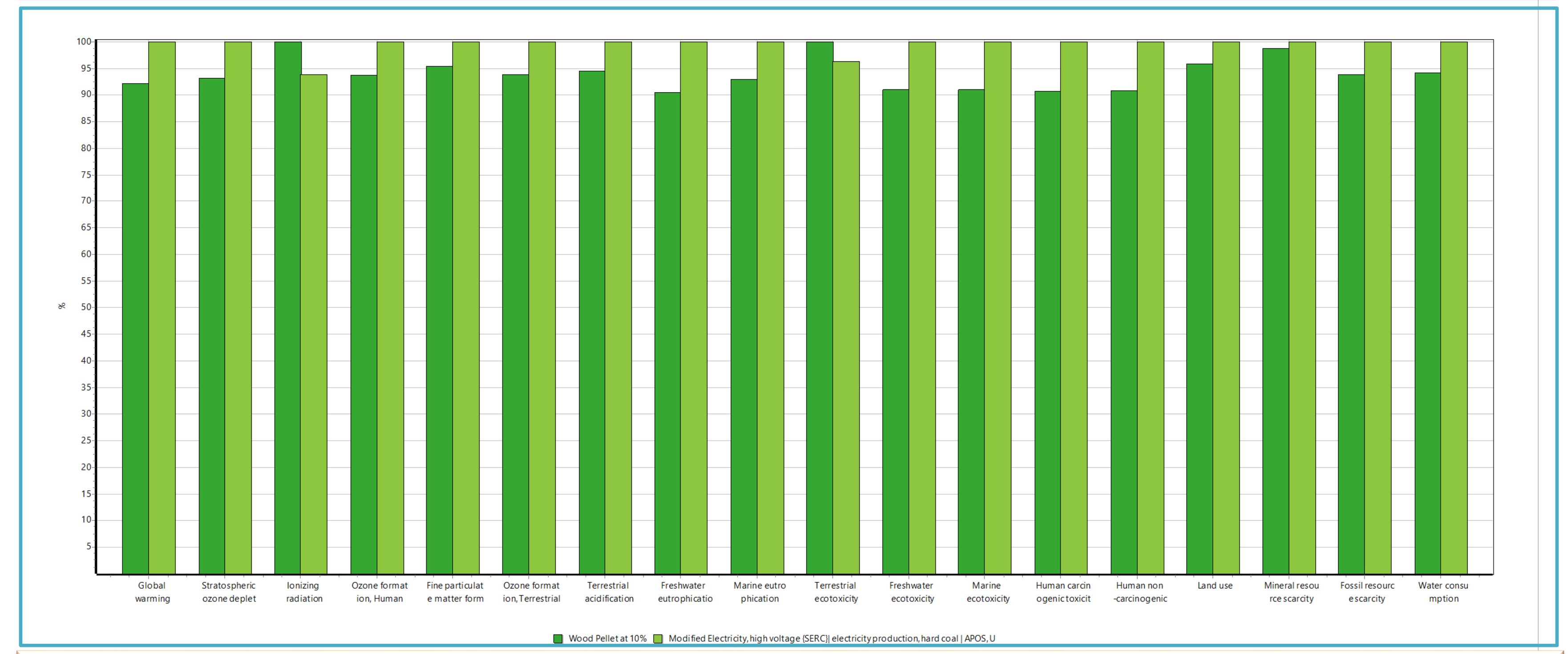


Fig. 8a: SERC Hard Coal v. Biomass Processes; 8b: Impact Assessment 90% Coal-10% Biomass Co-Firing, 1 kWh

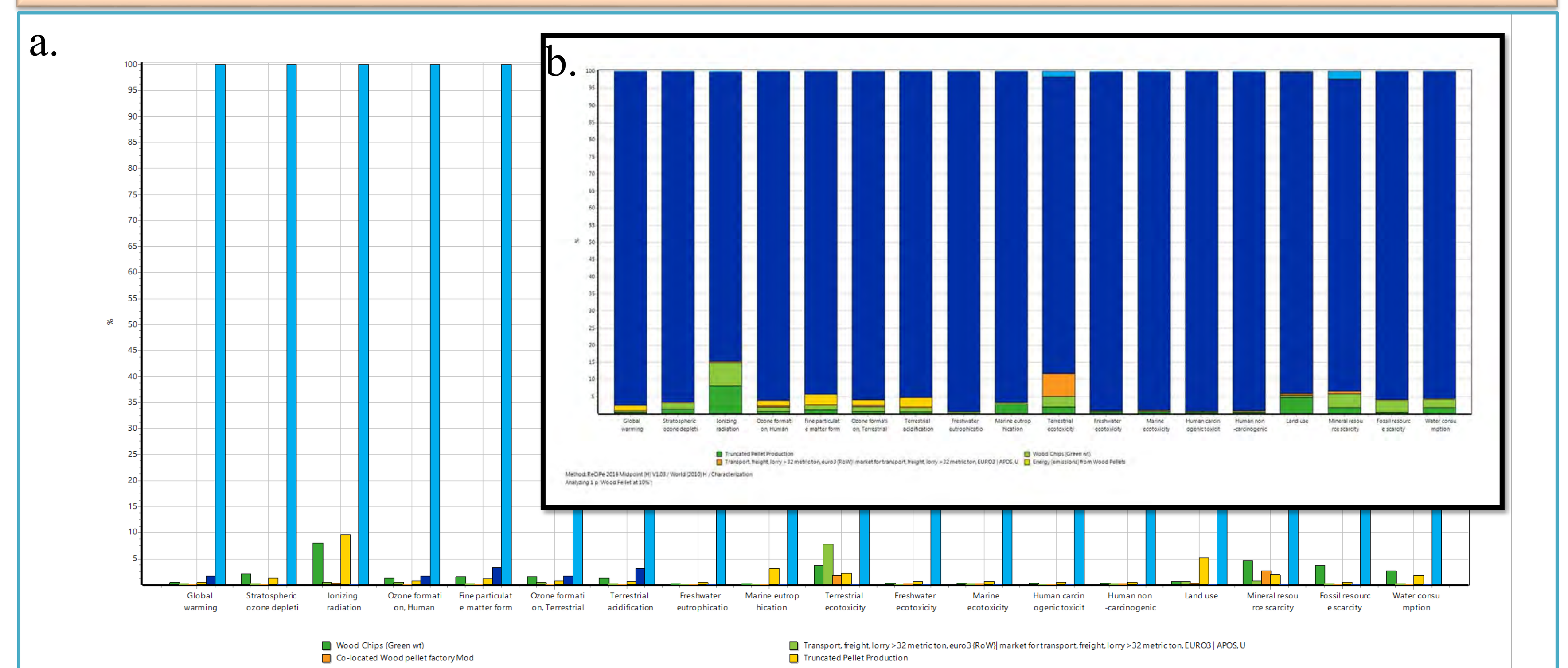
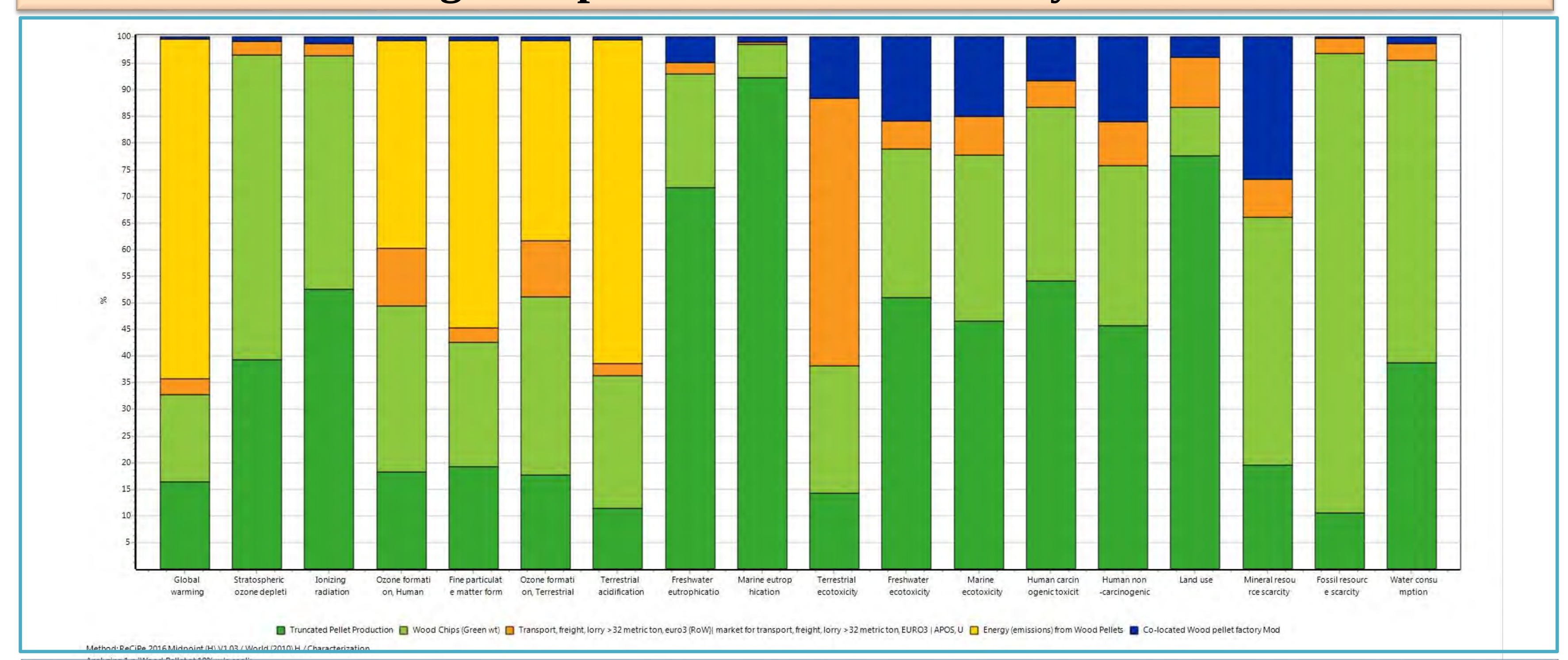


Fig. 9 Impact Assessment Loblolly Pine



DISCUSSION & CONCLUSION

- Coal cofiring **decreases** environmental impact in 16 of 18 impact categories.
- Ionizing radiation & terrestrial ecotoxicity **increase** 6% and 4% respectively when compared to 100% SERC coal power production.
- ~11% terrestrial ecotoxicity emissions are from transportation and pellet production
- 15% ionizing radiation is result of pelleting production and woodchip processing
- Hotspots include **transportation** for GWP, ozone formation, fine PPM, ozone formation, and terrestrial acidification; **Residue collection** for stratospheric ozone, water consumption, and fossil resource scarcity; **pelletization** for ionizing radiation, FW & marine eutrophication/ecotoxicity, HH canc/non-canc, and land use.
- Future research should asses energy balancing, economic feasibility, and capacity of loblolly pine waste reserves to fulfill co-firing demands.