

Energy Efficient Alternatives to Reduce the Carbon Emissions in the Production of Linerboard

**Rodrigo Buitrago-Tello, Richard A. Venditti*, Hasan Jameel,
Peter W. Hart¹, Ashok Ghosh¹**

**Department of Forest Biomaterials
North Carolina State University**

¹Westrock



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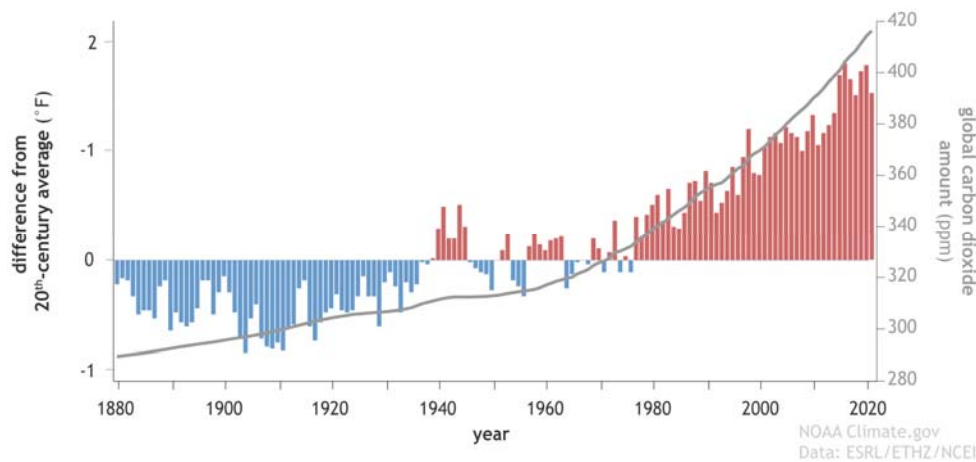


1. Introduction



Human Activities and Global Warming

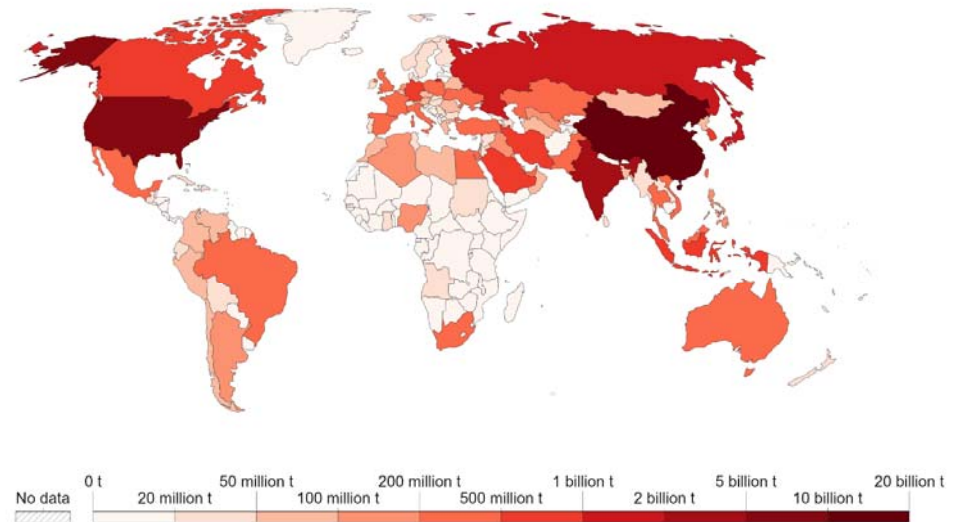
Change in global surface temperature and carbon dioxide emissions



Annual CO₂ emissions, 2021

Carbon dioxide (CO₂) emissions from fossil fuels and industry¹. Land use change is not included.

Our World
in Data



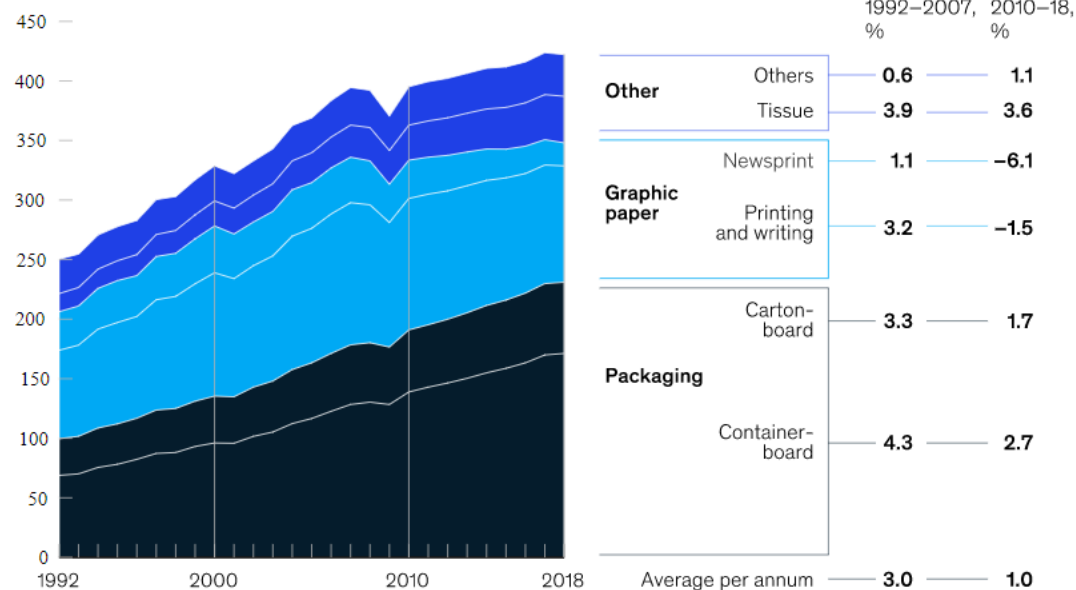
1. **Fossil emissions:** Fossil emissions measure the quantity of carbon dioxide (CO₂) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO₂ includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Human activities have significantly accelerated global warming in the last years



Pulp and Paper Industry - Contribution and Challenges

Global paper and paperboard market, million metric tons



CAGR: Compound annual growth rate

- The Industry continues to grow despite the decline in the graphic paper segment
- The Industry needs to break the dependency on fossil sources and improve the generation and use of energy

(1) IEA. Pulp & paper - Fuels & Technologies. <https://www.iea.org/fuels-and-technologies/pulp-paper>
 (2) IEA (2021), Tracking Industry 2021, IEA, Paris <https://www.iea.org/reports/tracking-industry-2021>
 (3) Zhao, Q.; Ding, S.; Wen, Z.; Toppinen, A. Energy Flows and Carbon Footprint in the Forestry-Pulp and Paper Industry. *Forests* **2019**, *10* (9), <https://doi.org/10.3390/f10090725>.
 (4) McKinsey & Company. <https://www.mckinsey.com/industries/paper-forest-products-and-packaging/our-insights/pulp-paper-and-packaging-in-the-next-decade-transformational-change>

World's fourth-largest energy-consuming industry

6% of the world's total industrial energy consumption

2% of global industrial direct carbon emissions

production is expected to expand 1.5 % annually to 2030

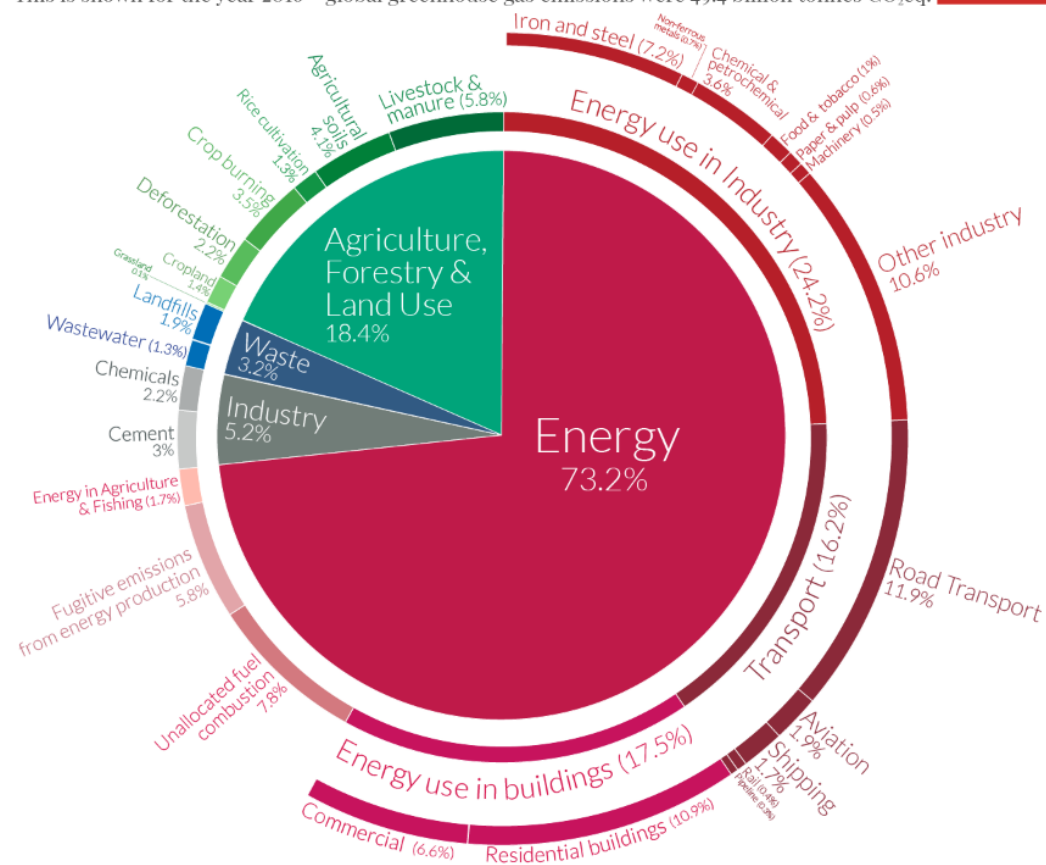
Increases in energy use need to be limited to 0.5% per year



Global greenhouse gas emissions by sector

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO₂eq.

Our World
in Data



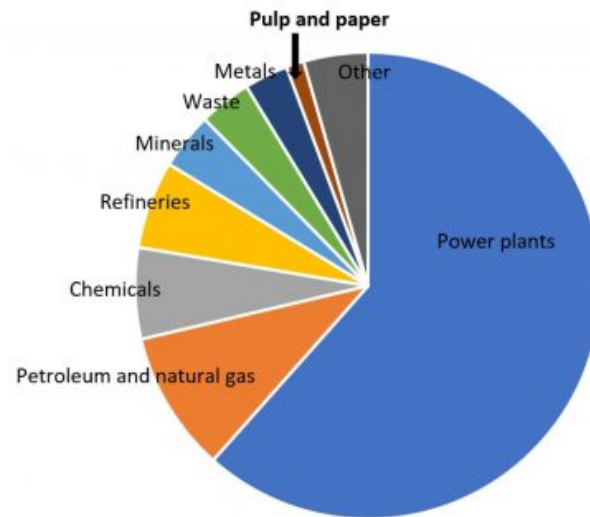
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Source: Climate Watch, the World Resources Institute (2020).

Licensed under CC-BY by the author Hannah Ritchie (2020).



U.S. industrial greenhouse gas emissions in 2017 (million metric tons of CO₂e)



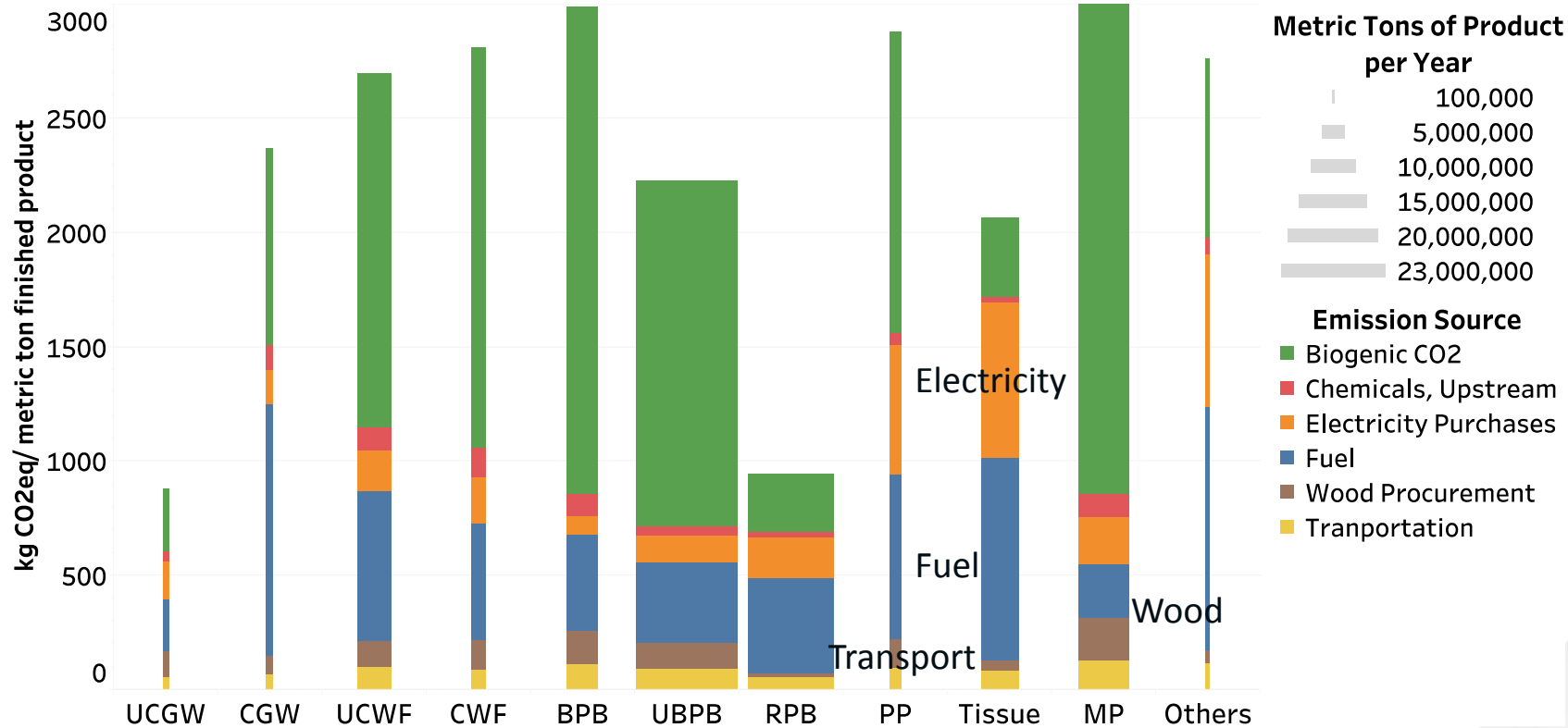
U.S. Environmental Protection Agency, 2018. Greenhouse gas reporting program.

<https://www.epa.gov/ghgreporting>

TwoSides: <https://twosidesna.org/US/greenhouse-gas-emissions-and-climate-change-key-facts-about-papers-impact/>



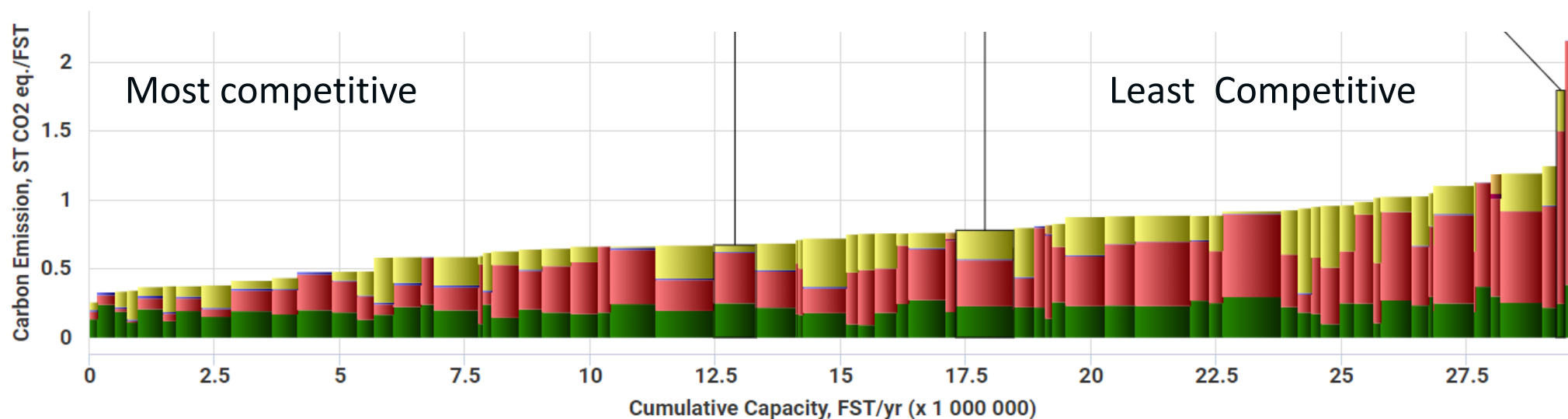
US Emissions P&P (84.4 Mt/y) Average Emissions: 942 kg CO2e/t average, 1232 kg CO2 biogenic/t



Tomberlin, K. E., Venditti, R., & Yao, Y. (2020). *BioResources*, 15(2), 3899-3914.



Unbleached Paperboard US (22.5 Mt/y) Average Emissions:
710 kg CO₂e/t, 1510 kg CO₂ biogenic/t



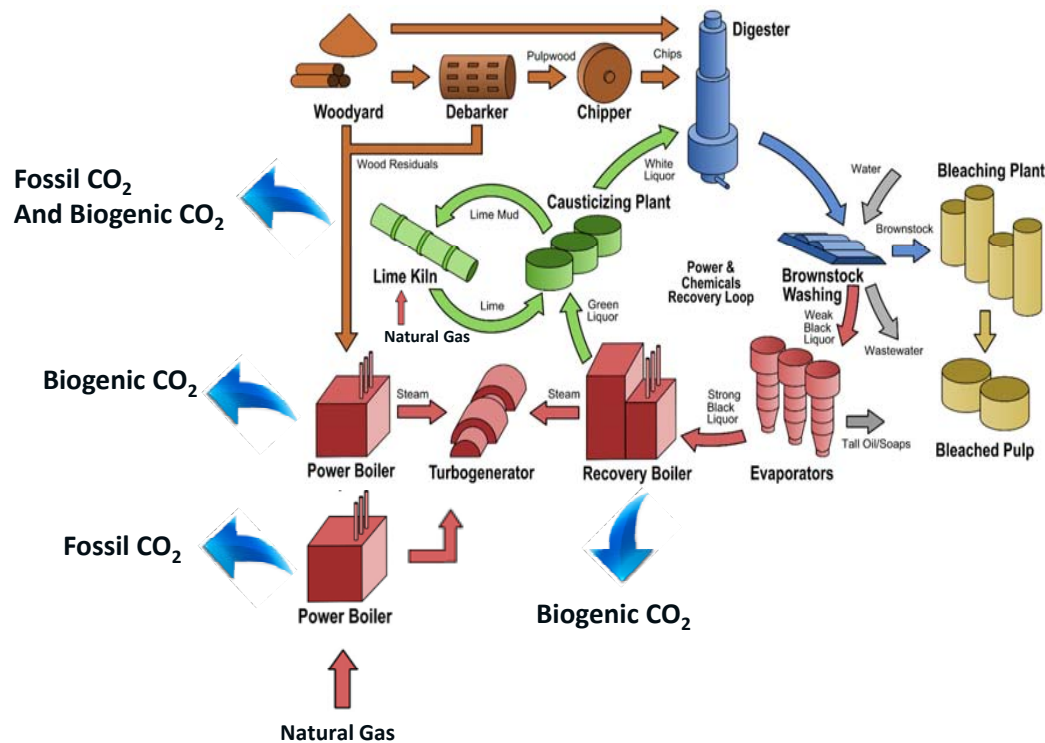
Yellow = electricity

Red = fuels

Green = wood/chem.

FisherSolve, 2023

How to reduce carbon emissions? The analysis is complex



- Multiple carbon emissions : Fossil, and biogenic, direct and indirect, from heat/power generation or chemical recovery
- Complex mass and energy balance given the relationships between areas
- How to reduce the dependency on fossil sources and reduce carbon emissions?
 - Increasing the use of bioenergy?
 - Implementing more energy efficient technologies?
- How the coproduction of bio-based products affect the environmental performance?

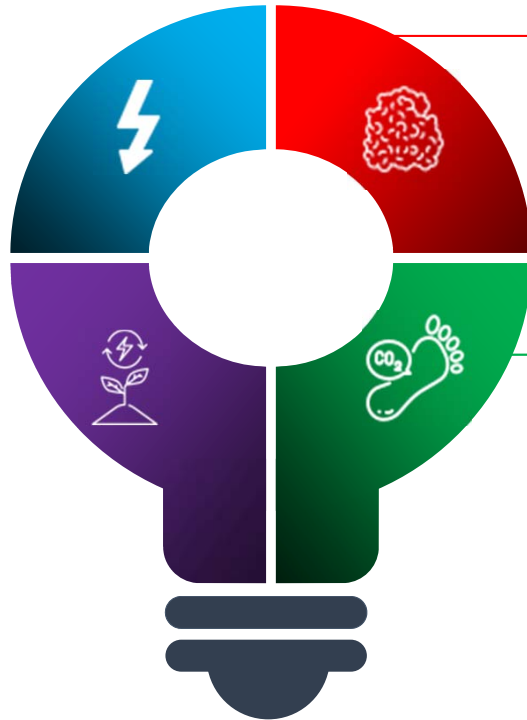
Source: Fuel Processing Technology 201 (2020) 106338



Research questions and motivation



Research Questions:

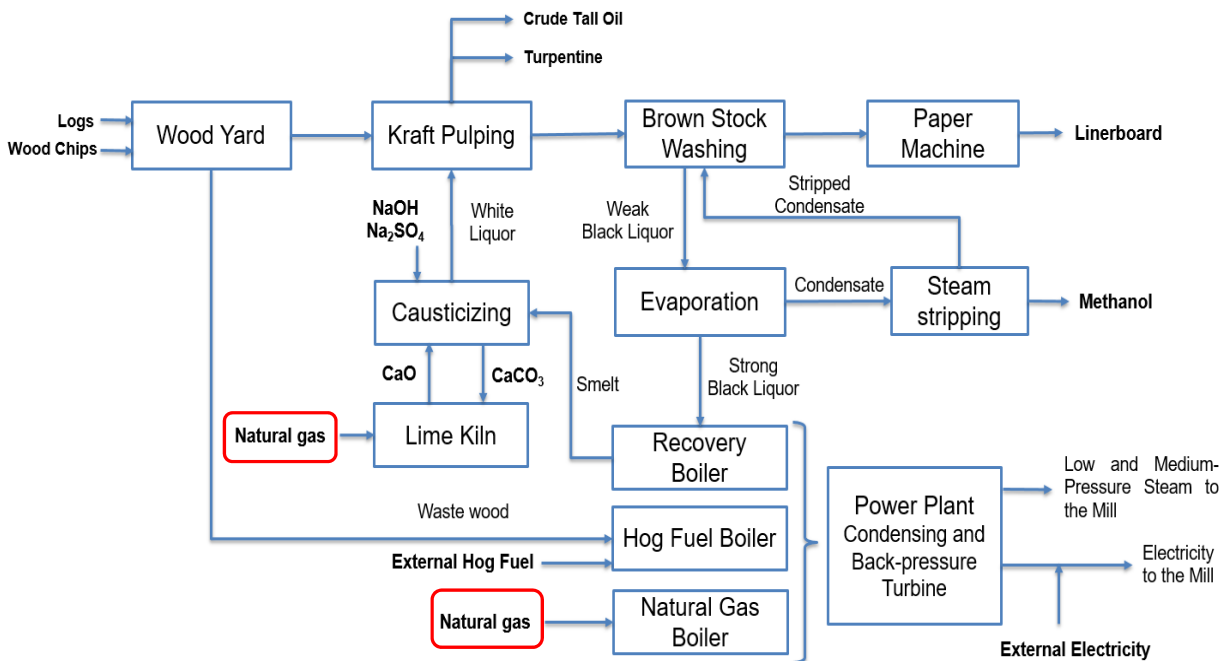


Can both emerging and existing technologies aimed at improving energy efficiency effectively **lower the carbon footprint** in the pulp and paper industry?

What is the cost to achieve potential carbon reductions? Are these technologies **techno-economically viable**?



Linerboard production - Motivation



- Linerboard is a key component in corrugated board packaging
- One of the largest and growing sectors in US P&P industry
- Dependency on fossil fuels
 - Heat demand
 - Chemical recovery
- Opportunities to improve energy demand
- Cost vs. environmental benefit?

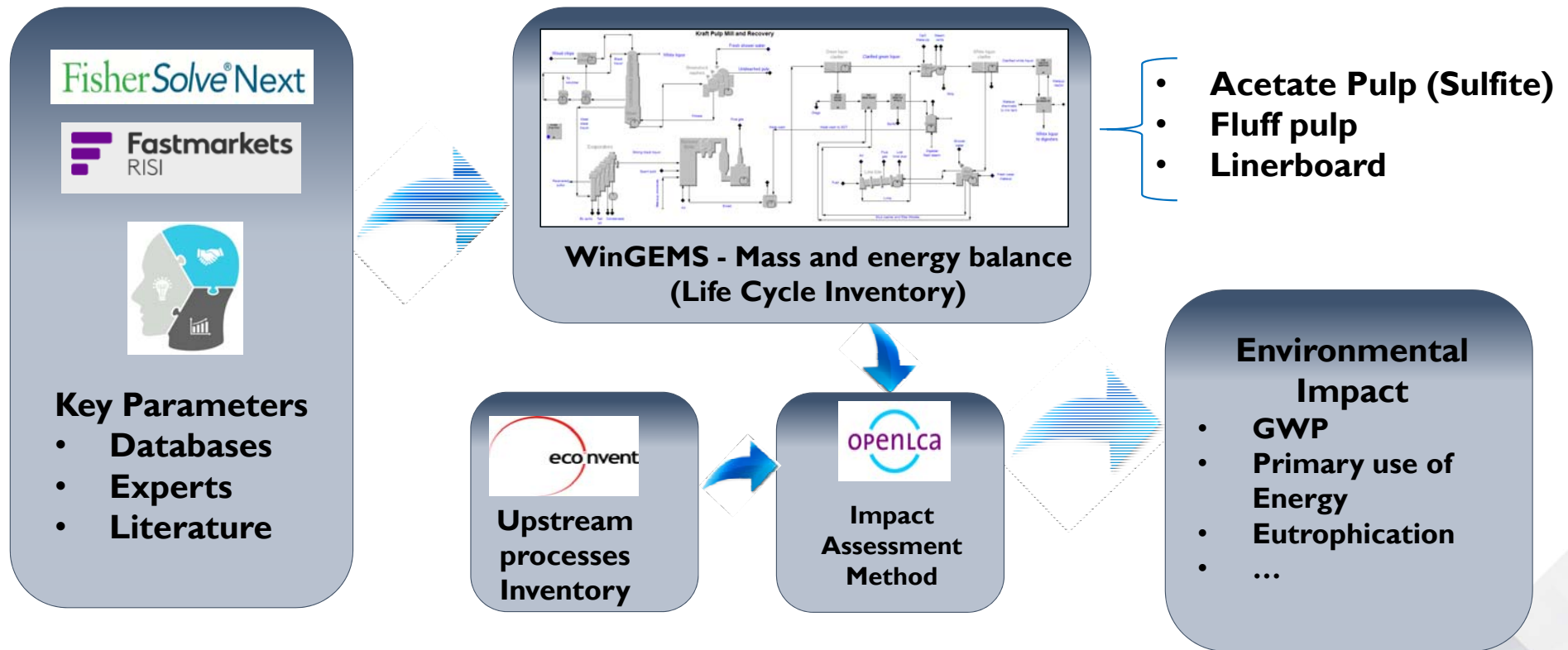


Methodology

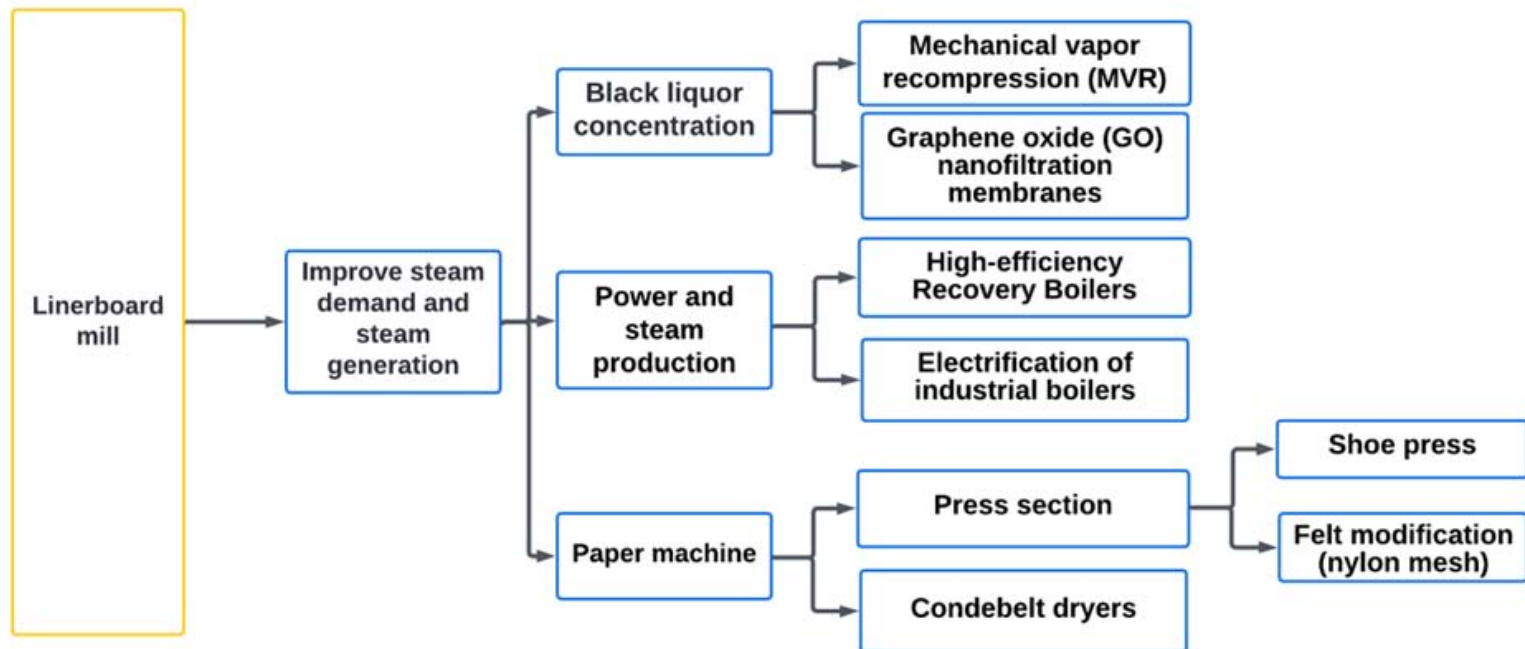


Methodology

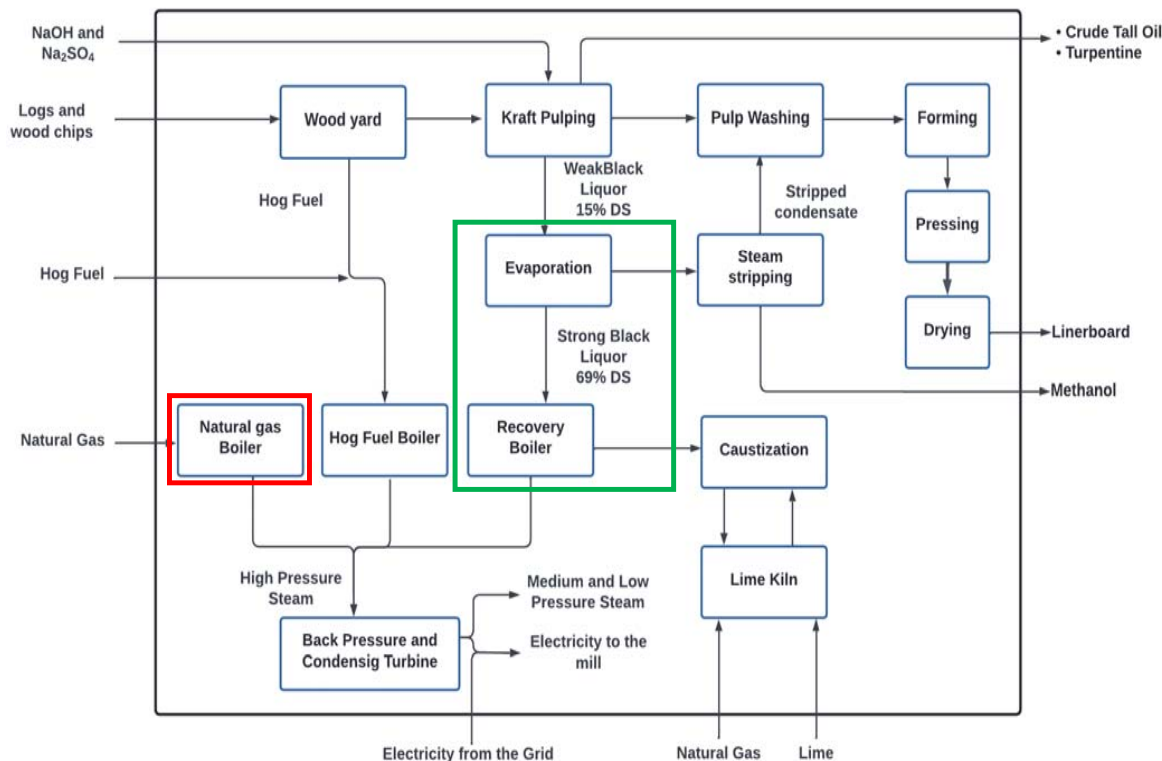
Process Simulation and Life Cycle Assessment



Alternatives to Decarbonize Linerboard Production



Alternatives to improve the steam demand and steam generation in the production of Linerboard



High-efficiency Recovery Boiler

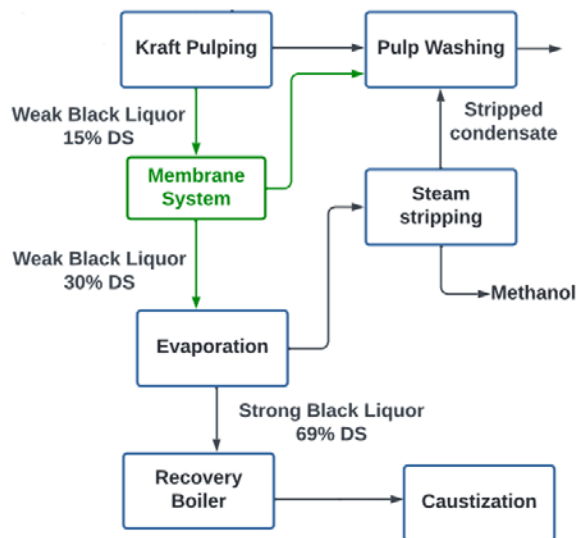
- Steam condition: from 850 F and 850 psi to 960 F and 1600 psi
- Flue gas temperature: From 482 F (250°C) to 356 F (180°C)
- Strong black liquor solids content: from 69% to 75%
- Condensing turbine and the ME evaporator are rebuilt to operate under new conditions

Electric Boilers

- Natural gas boiler replaced by two electric boilers that generate steam at 1015 psi, 662 F (350°C) with a 99% efficiency, requires clean electricity grid

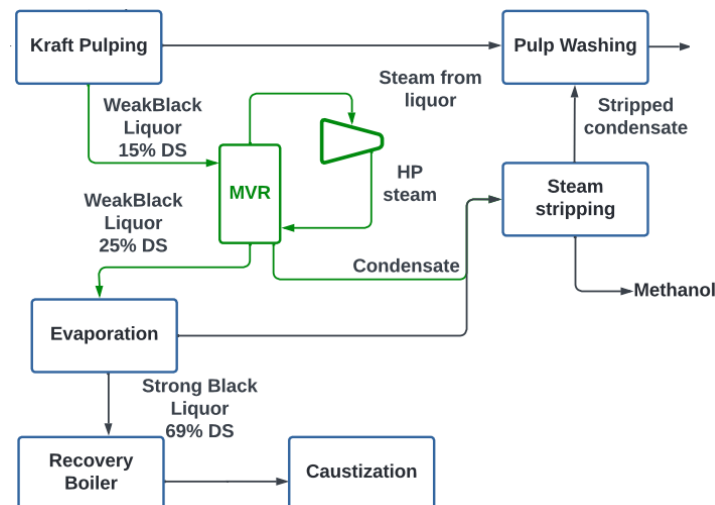


Alternatives to improve the steam demand and steam generation in the production of Linerboard



Graphene oxide (GO) nanofiltration membranes

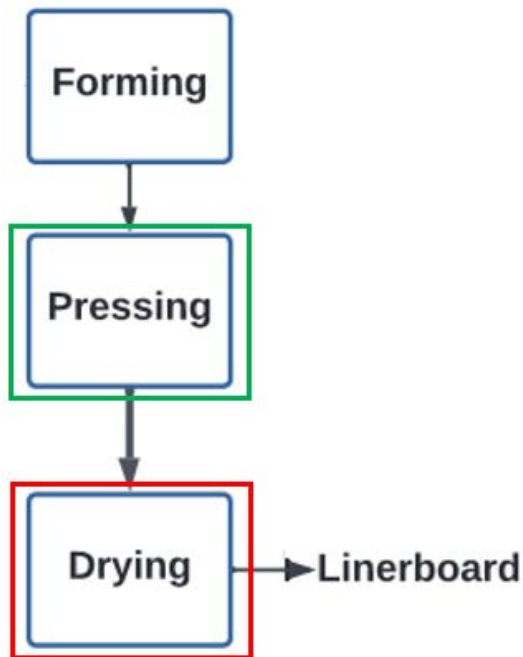
- Pre-concentrate WBL from 15% to 30%.
- The filtrate is used to wash the pulp.
- Reduction in evaporator steam
- Increased electricity to run membranes (60 Mpa)



Mechanical vapor recompression (MVR)

- Pre-concentrate WBL from 15% to 25%
- Pressured water vapor from the black liquor evaporation as the heat source
- The system partially replaces the steam demand with electricity from the grid

Alternatives to improve the steam demand and steam generation in the production of linerboard



Shoe press

- Web solids **from 50 to 54%**
- 3.4 % increase in the paper machine electricity demand

Felt modification (nylon mesh)

- Web solids **from 50 to 61%**, without affecting the electricity demand

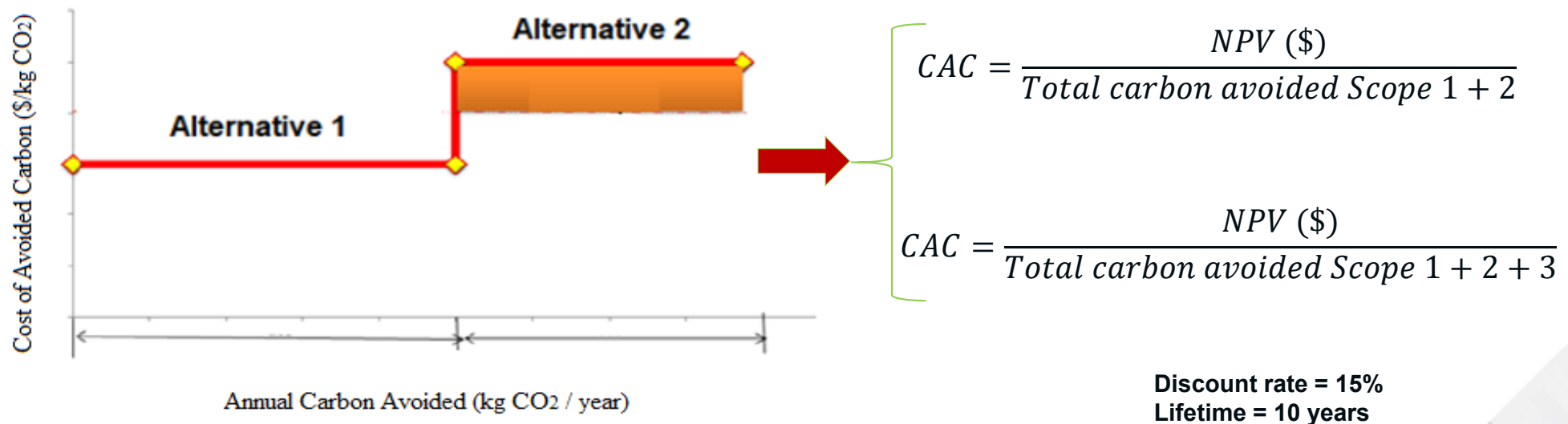
Condebelt

- 1.6 GJ/t paper savings in steam
- 20 kWh/t paper savings in electricity



Marginal abatement cost (MAC) curve

Marginal abatement cost (MAC) curve: Compares the cost and emissions impact of different technologies.

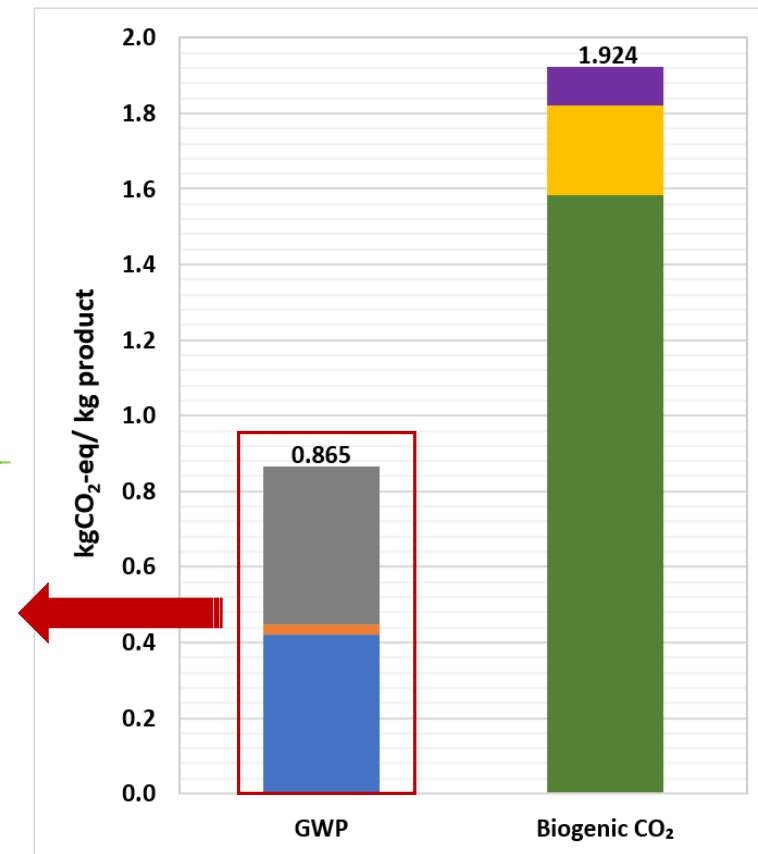


Results

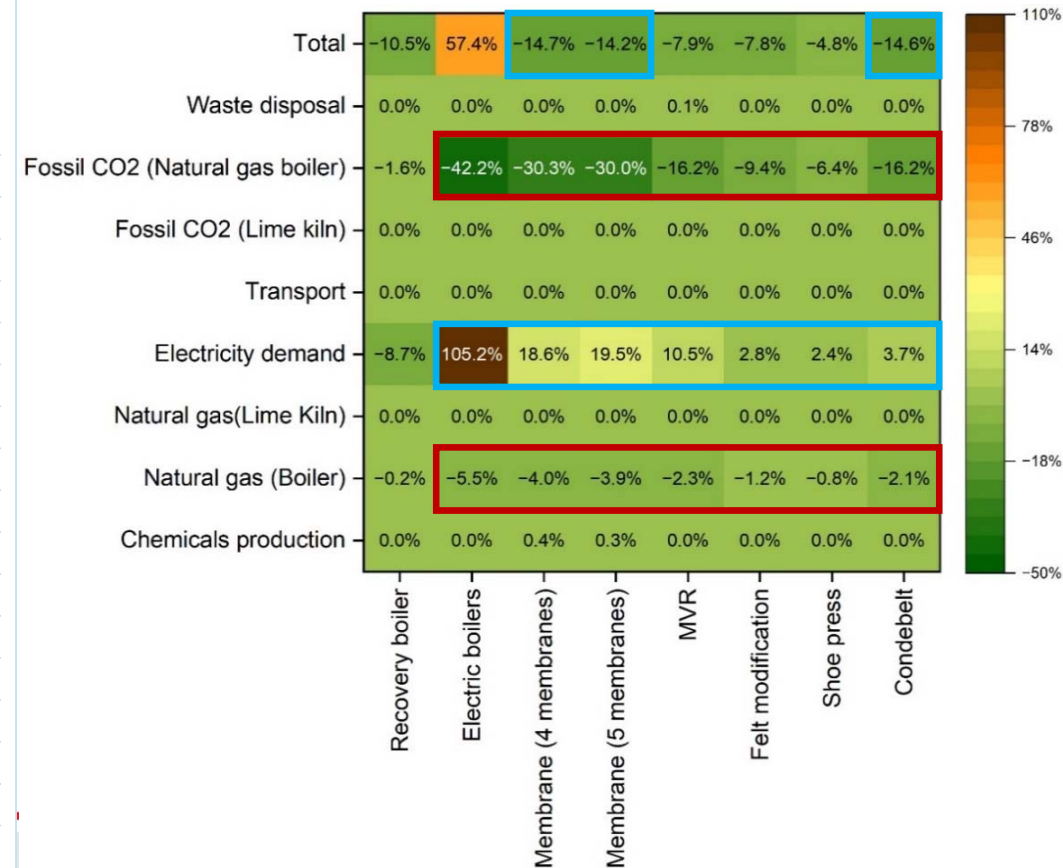
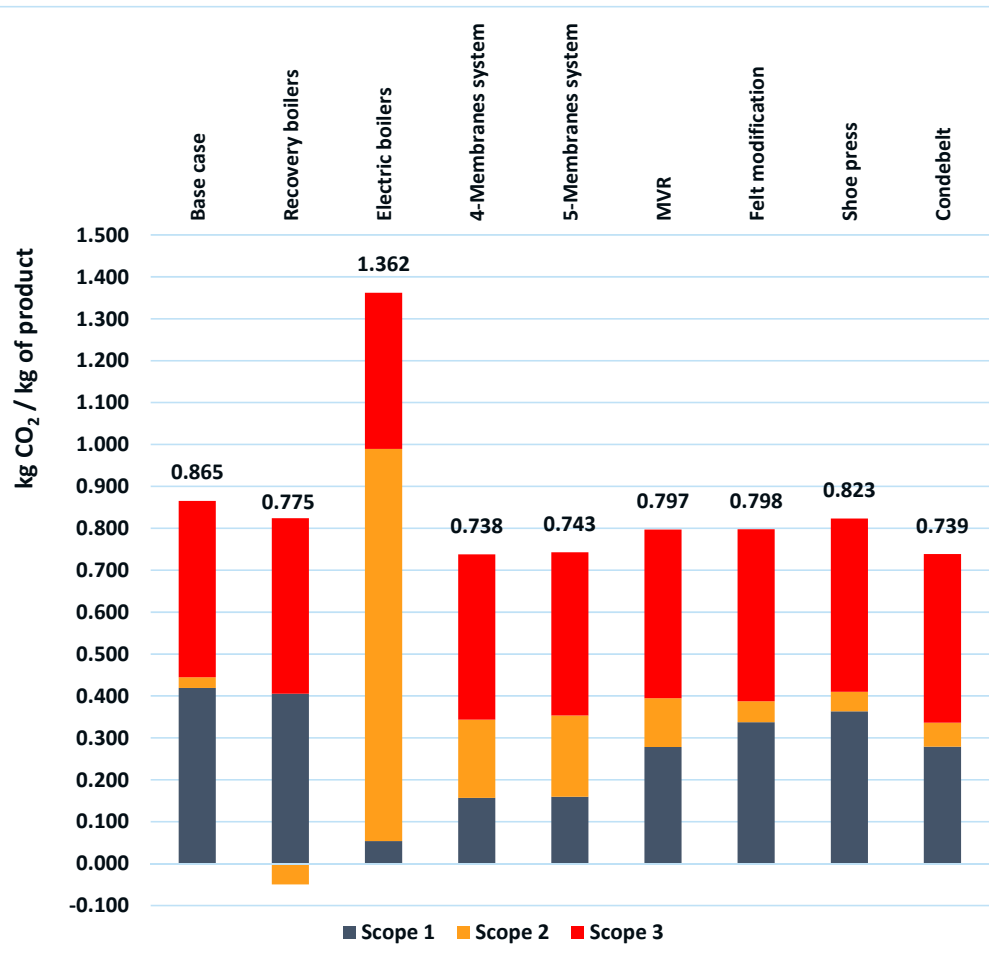


Base Case: GWP- Hotspot Analysis

SCOPE	Process	Subprocess	GWP (kg CO ₂ -eq/kg product)	Contribution (%)
Scope 1	On-site emissions	Fossil CO ₂ Lime kiln	5.34x10 ⁻²	6.17%
		Fossil CO ₂ Natural gas boiler	3.63x10 ⁻¹	41.92%
Scope 2	Electricity from the grid	Electricity demand	2.85x10 ⁻²	3.30%
Scope 3	Production of external fuels	External hog (Power plant)	3.48x10 ⁻³	0.40%
		Natural gas - Boiler	4.75x10 ⁻²	5.48%
		Natural Gas - Lime kiln	6.99x10 ⁻³	0.81%
	Pulp biomass	Forestry activities (Logs)	7.28x10 ⁻²	8.41%
		Wood chips	8.29x10 ⁻²	9.58%
	Makeup chemicals	NaOH makeup	9.73x10 ⁻³	1.12%
		Na ₂ SO ₄ makeup	9.39x10 ⁻⁴	0.11%
		CaO	2.33x10 ⁻²	2.69%
	Tall Oil Production	H ₂ SO ₄	3.76x10 ⁻⁴	0.04%
	Transport	Transport biomass	1.53x10 ⁻¹	17.66%
		Transport materials	6.16x10 ⁻⁴	0.07%
	Waste disposal	Dregs	3.39x10 ⁻³	0.39%
		Grits	4.46x10 ⁻³	0.51%
		Ashes	2.00x10 ⁻⁵	0.002%
		Sludge	1.14x10 ⁻²	1.3%
TOTAL			8.65x10 ⁻¹	100%

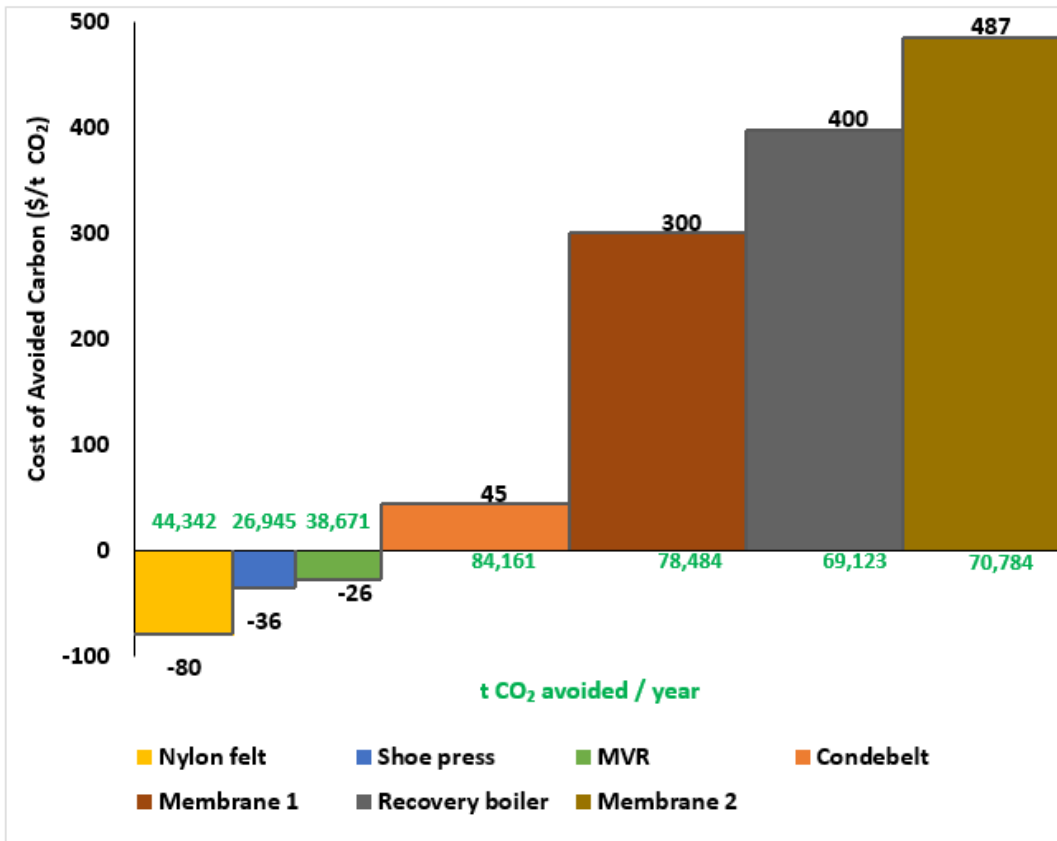


Alternatives to improve the steam demand and steam generation - CO₂ reductions

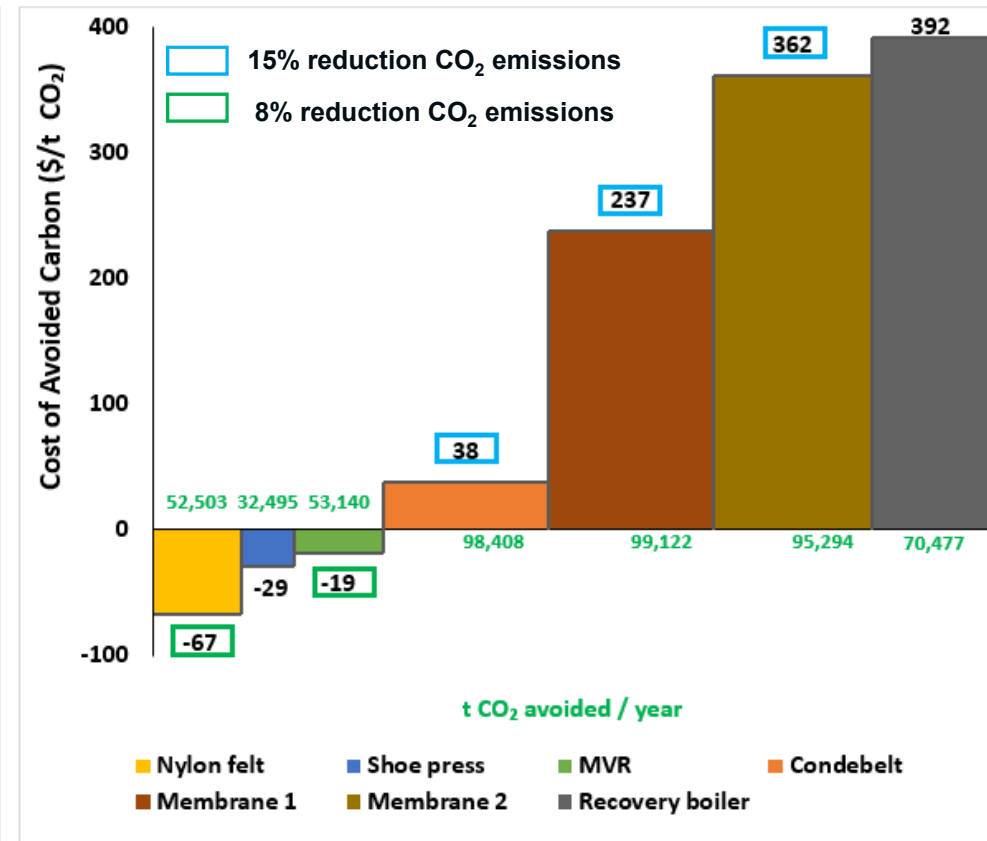


Marginal Abatement Cost Curve

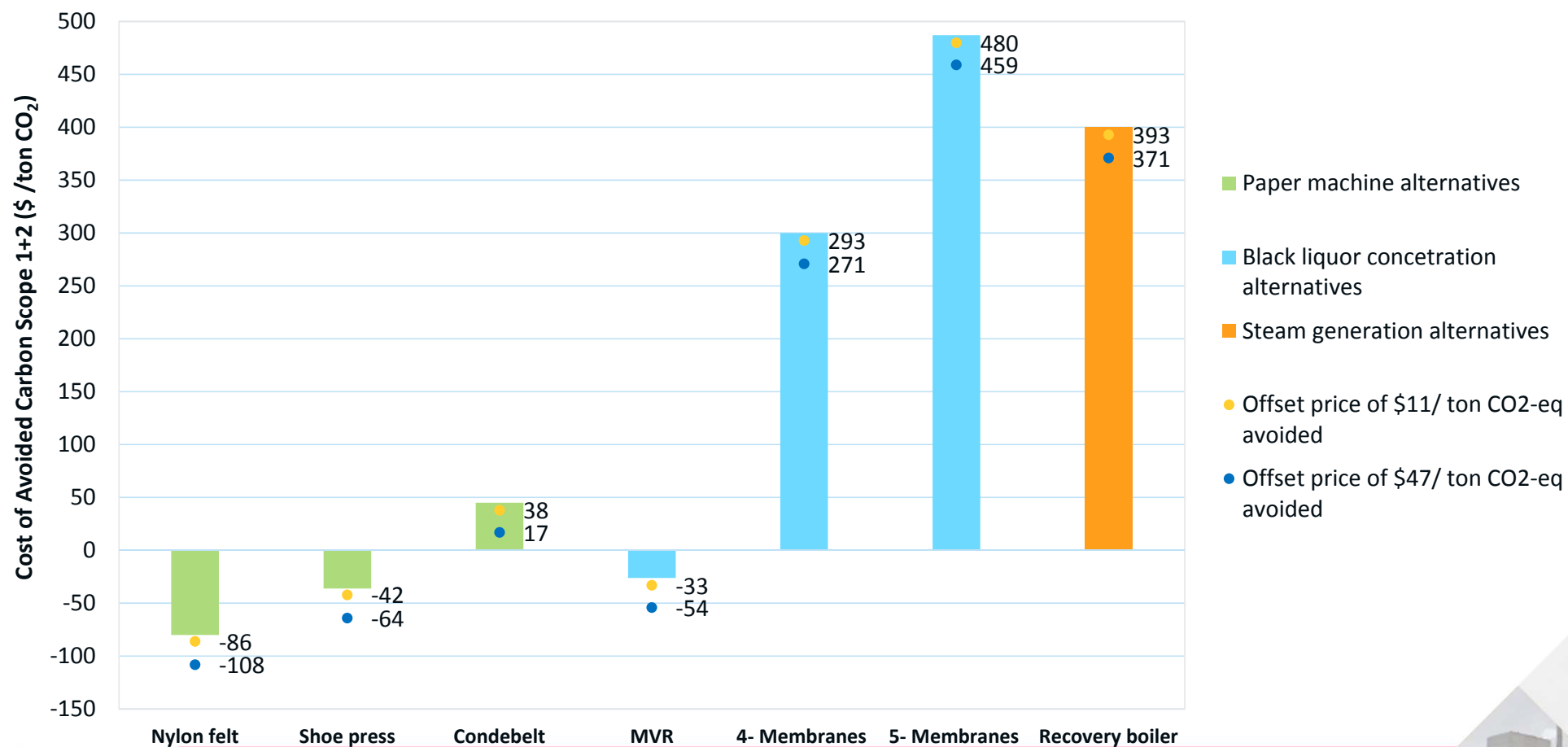
CAC Scope 1 and 2



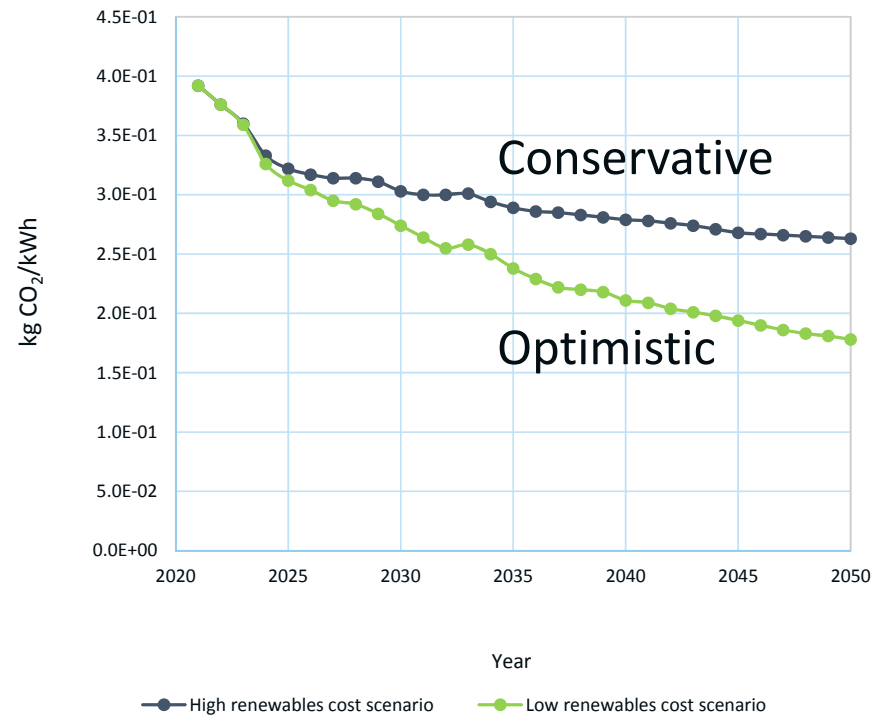
CAC Scope 1, 2 & 3



Effect of Carbon Offset Price on CAC (Scope 1 & 2)



Predictions of Renewable Energies in the US Electric Grid

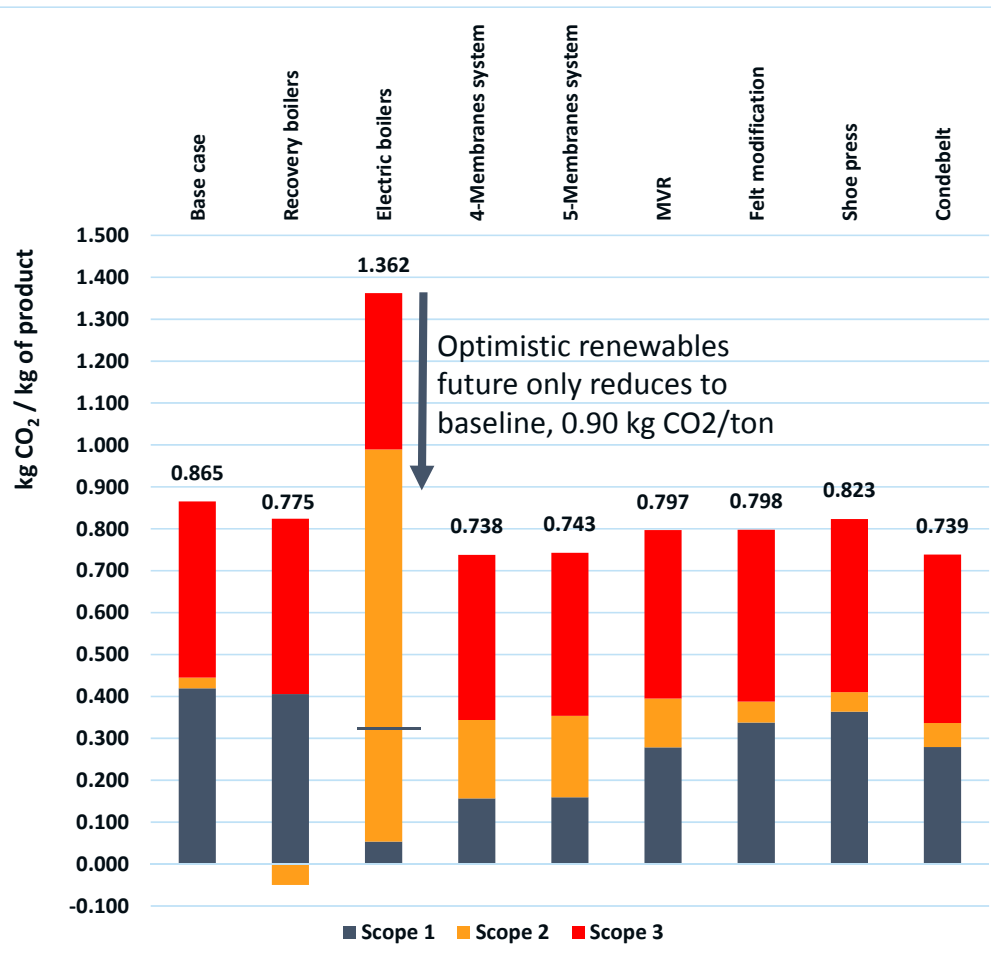


- i) High cost for renewable energies: no cost reductions in renewable technologies
- ii) Low cost for renewable energies: renewables achieve 40% lower overnight capital costs by 2050

U.S. Energy Information Administration. Annual Energy Outlook 2022. Table: Table 18. Energy-Related Carbon Dioxide Emissions by Sector and Source. <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=17-AEO2022&cases=hirencst~lorenrst&sourcekey=0>. Published 2022.

U.S. Energy Information Administration. Annual Energy Outlook 2022 Table: Table 1. Total Energy Supply, Disposition, and Price Summary. <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=1-AEO2022&cases=hirencst~lorenrst&sourcekey=0>. Published 2022



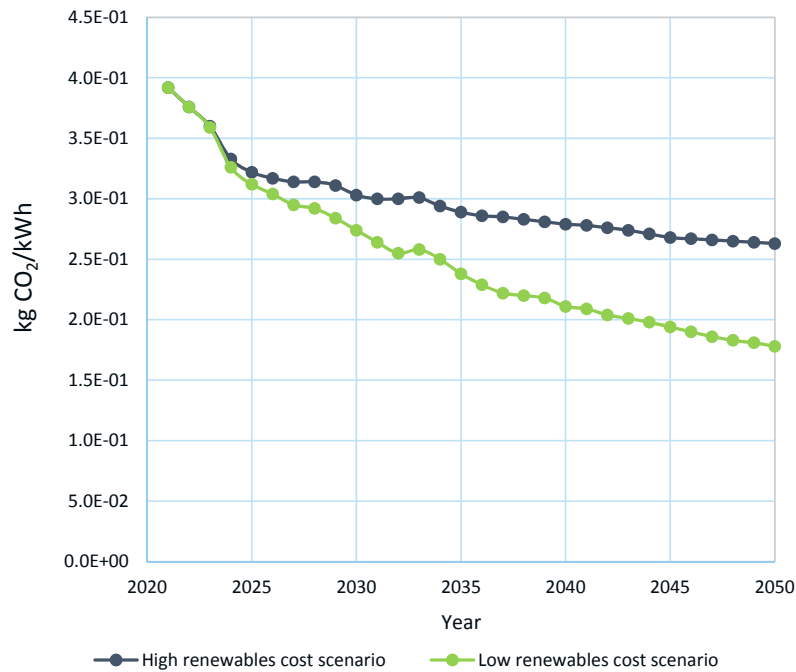


Electric Boilers:

Optimistic renewables future only reduces to baseline



Introduction of Renewable Energies in the US Electric Grid System



- i) High cost for renewable energies: no cost reductions in renewable technologies
- ii) Low cost for renewable energies: renewables achieve 40% lower overnight capital costs by 2050

Alternative	Total carbon saved 2023-2033 (ton CO ₂)			CAC emissions scope 1,2 and 3 (\$ /ton CO ₂)		
	Ecoinvent	High renewables cost	Low renewables cost	Ecoinvent	High renewables cost	Low renewable cost
Recovery Boiler	7.05x10 ²	3.39x10 ²	3.25x10 ²	\$392	\$814	\$851
Electric boilers	-3.86x10 ³	1.03x10 ³	1.21x10 ³	-	\$383	\$327
4-Membranes	9.91x10 ²	2.03x10 ³	2.06x10 ³	\$237	\$116	\$114
5-Membrane	9.53x10 ²	2.03x10 ³	2.06x10 ³	\$362	\$170	\$167
MVR	5.31x10 ²	1.11x10 ³	1.13x10 ³	(\$19)	(\$9)	(\$9)
Nylon felt	5.25x10 ²	7.20x10 ²	7.25x10 ²	(\$67)	(\$49)	(\$49)
Shoe press	3.25x10 ²	4.79x10 ²	4.83x10 ²	(\$29)	(\$20)	(\$20)
Condebelt	9.84x10 ²	1.27x10 ³	1.27x10 ³	\$38	\$30	\$30

U.S. Energy Information Administration. Annual Energy Outlook 2022. Table: Table 18. Energy-Related Carbon Dioxide Emissions by Sector and Source. <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=17-AEO2022&cases=hirencst~lorenct&sourcekey=0>. Published 2022.

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Conclusions

- Marginal abatement cost curve: Methodology to identify technologies with potential carbon and cost savings
 - Condebelt and Black liquor membranes: 15% carbon reductions, but at a CAC of 40 and 240 US \$/ton CO₂ avoided
 - Black liquor MVR and Nylon felt: 8% carbon reduction, at CAC of -20 and -70 US \$ / ton CO₂ avoided
- Potential to improve CAC by having a price in the market for the carbon offsets
 - MVR-CAC goes from -26 to -54 while Nylon felt goes from -80 to -108 to US \$ / ton CO₂ avoided
- Electric boilers are not advantageous for carbon savings currently, only with future cleaner electricity grids might this be viable
- Carbon reductions are improved by introducing renewable energies in the electric system, except for High efficiency recovery boiler



Acknowledgements

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 **WestRock**

 **Fisher**
INTERNATIONAL

 **FULBRIGHT**
Colombia

 **ICETEX**
Invertimos en el talento de los colombianos



Q & A



Thank you

Richard Venditti
richardv@ncsu.edu



Increase the use of bioenergy - CO₂ reductions

Emission	Scope 1+2	Total Scope 1+2+3	Total Biogenic
Base case (kg CO₂ /kg machine dry linerboard)	0.445	0.865	1.924
Change in the emissions (%)			
Biomass Boiler	-81.5%	-41.3%	34.4%
Pulverized biomass (25%)	-3.0%	-1.4%	1.3%
Pulverized biomass (50%)	-5.8%	-2.9%	2.5%
Pulverized biomass (100%)	-11.6%	-5.6%	5.0%
Biomass Gasification	-11.2%	-2.6%	6.3%
Tall oil pitch (25%)	-2.8%	-1.2%	1.0%
Tall oil pitch (50%)	-5.6%	-2.5%	1.9%
Tall oil pitch (100%)	-11.7%	-5.3%	3.9%
Crude tall oil (25%)	-2.0%	-0.8%	1.9%
Crude tall oil (50%)	-4.6%	-2.1%	3.3%
Crude tall oil (100%)	-10.8%	-5.7%	7.1%
Lignin (25%)	-5.0%	-0.2%	3.7%
Lignin (50%)	-7.3%	-0.7%	4.2%
Methanol (10%)	-0.9%	-0.4%	0.7%
Turpentine (10%)	-0.8%	-0.4%	0.6%



Marginal Abatement Cost Curve (scopes 1, 2 & 3)

