Environmental Life Cycle Assessment: A Tool to Guide Sustainable Economic Development

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Importance of LCA

Life cycle assessment (LCA) is becoming a standard tool for environmental management in the industry.

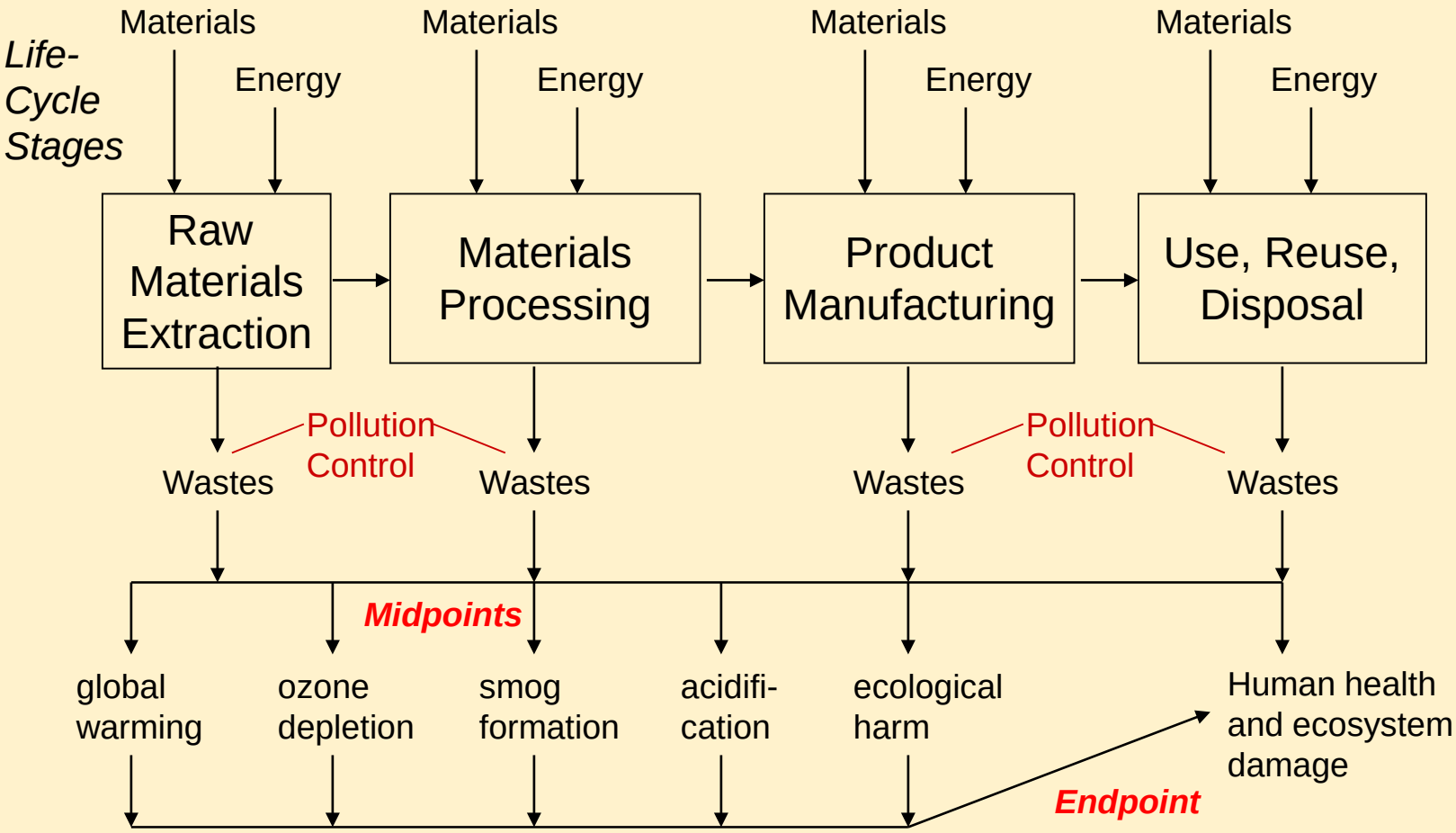
All major corporations have LCA experts on staff and conduct assessments of products, especially new products.

Government agencies also require LCAs in regulation of greenhouse gas emissions of biofuels.

Uses of Life Cycle Assessment

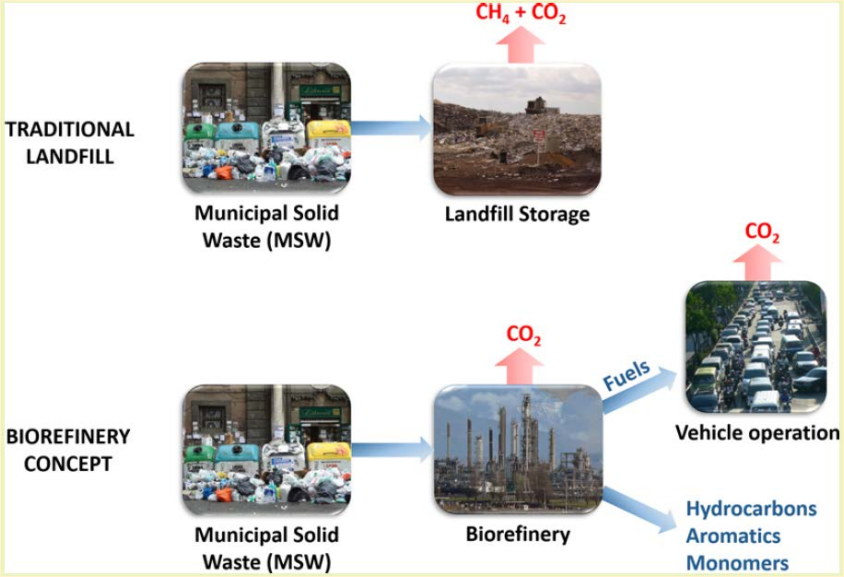
- Decision-making in industry and government
  - Strategic planning, investments, product/process design
- Communication with stakeholders
  - Shareholders, regulatory agencies, policy makers
- Research and Development
  - Early evaluations of projects, periodic re-evaluations
- Marketing
  - Environmental claim, ecolabeling

Scope of Environmental Impacts



Resource and Greenhouse Gas Assessments of the Thermo-chemical Conversion of Municipal Solid Waste in Mexico

Ulises R. Gracida-Alvarez; Ph.D. Candidate



- Landfills are reaching capacity
- GHG emissions to atmosphere

- A biorefinery producing fuels and chemicals
- GHG emissions to atmosphere

Could using MSW as a feedstock reduce the space required in landfills while providing an environmentally sustainable renewable fuel?

Study case: Mexico's production of fuels and chemicals through thermochemical conversion

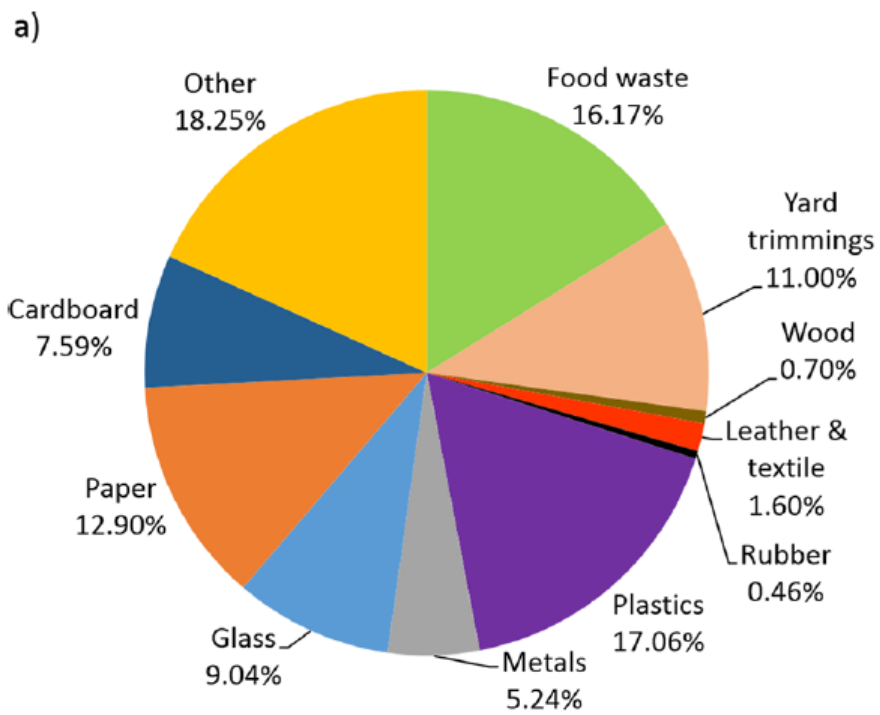
Resource assessment for MSW

- Six populated cities
  - Mexico city (5862 people/km^2)
  - Guadalajara (9876 people/km^2)
  - Monterrey (1270 people/km^2)
  - Puebla (2937 people/km^2)
  - Toluca (1959 people/km^2)
  - Merida (938 people/km^2)
- National average MSW statistics
- Methods
  - Literature review (Peer reviewed papers, national statistics)
  - Standardization of categories
  - Quantification

INEGI. (2012). Generación estimada de residuos sólidos por entidad federativa.
Durán-Moreno, A. et al (2013) Revista Internacional de Contaminación Ambiental, 29, 39-46.
Bernache-Pérez, G. et al (2001) Waste Management & Research, 19, 413-424.
Gobierno del Estado de Puebla. (2012). Programa de prevención y gestión de residuos para el estado de Puebla 2011-2017.
OPS. (2003). Evaluación general de los servicios de manejo de residuos sólidos municipales.
Iglesias-Piña, D. (2007) Equilibrio económico, 3, 131-148.
Echeverria Calero, R. (2009) Manejo integral de residuos sólidos en el municipio de Mérida, Yucatán, México. Quinto Encuentro Nacional de Playas Limpias.

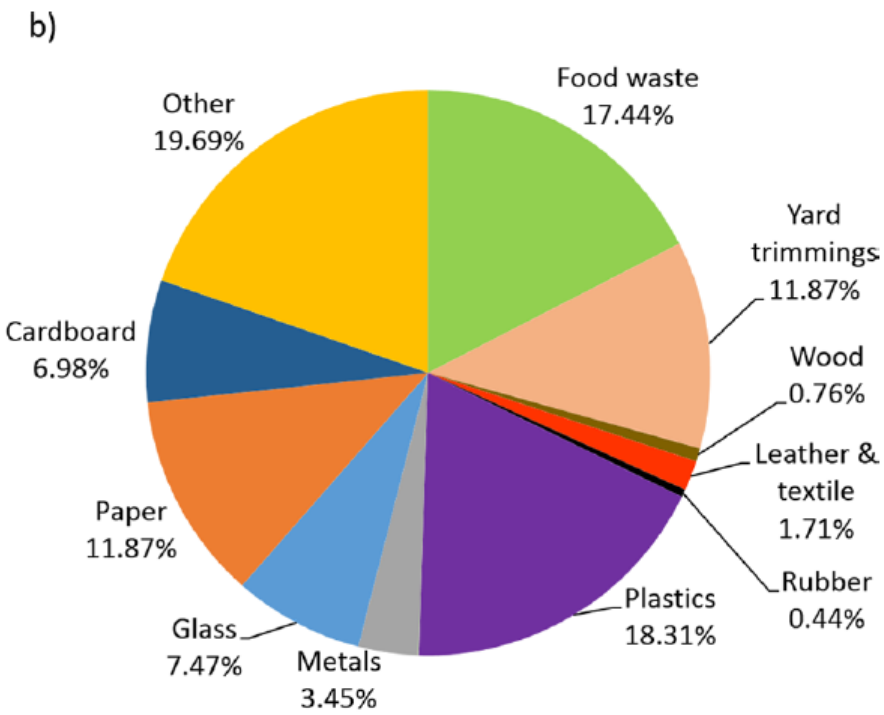
MSW in Mexico

Generated



Total: 26.16 million tonnes per year

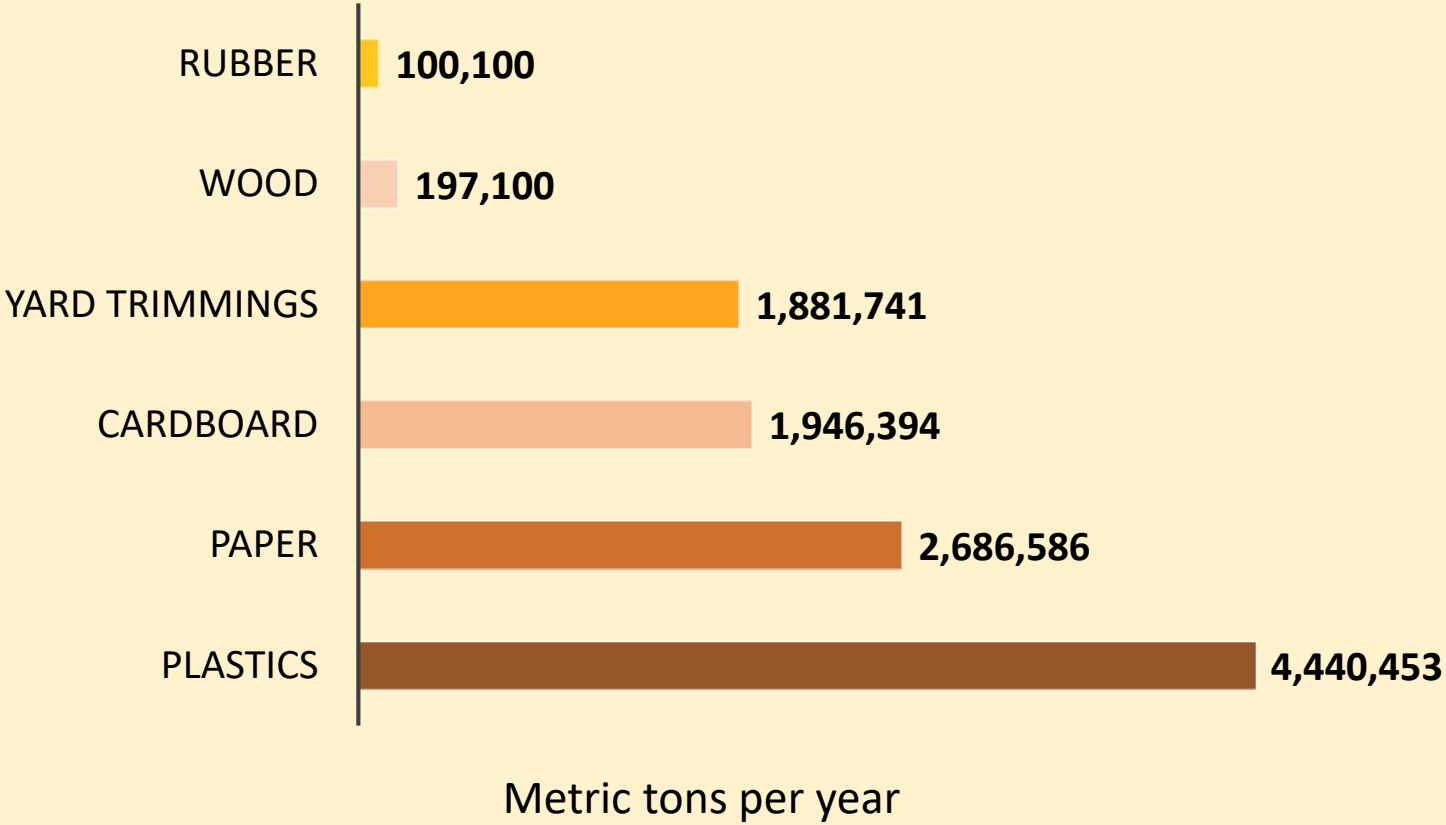
Landfilled



Total: 24.25 million tonnes per year

Resource assessment results

- Available (not recycled) feedstock for further processing (dry weight basis)

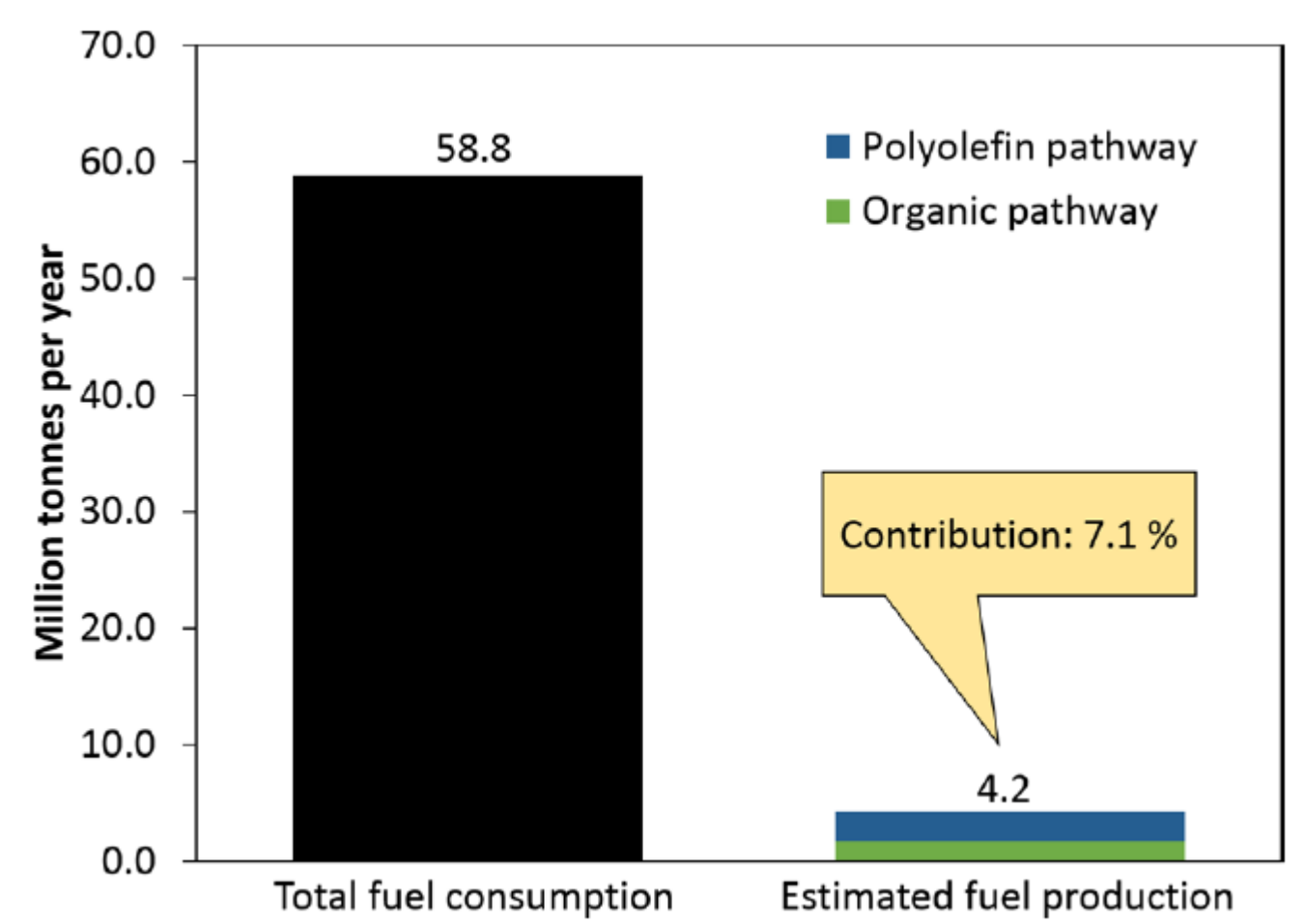


Total amount: 11.25 million Metric Tons per year

Estimation of yields: Fuels from MSW

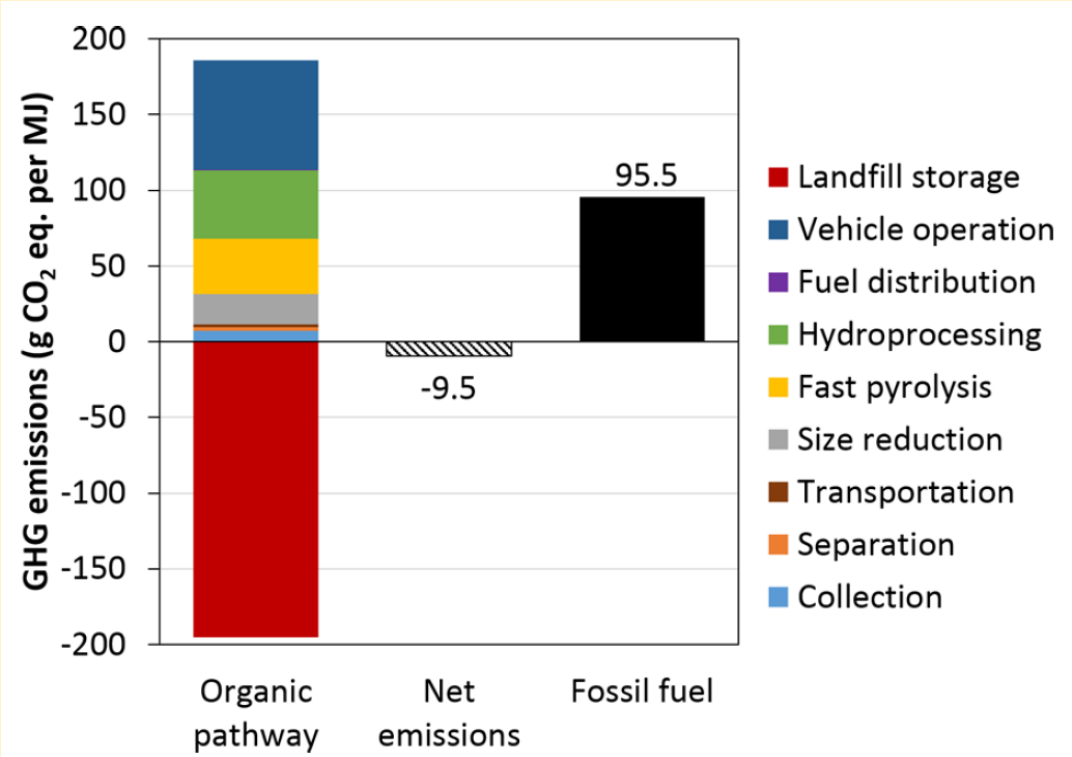
Yield: 0.237 kg fuel/kg organic waste

Yield: 0.86 kg fuel/kg polyolefin waste



Environmental assessment: Organic MSW

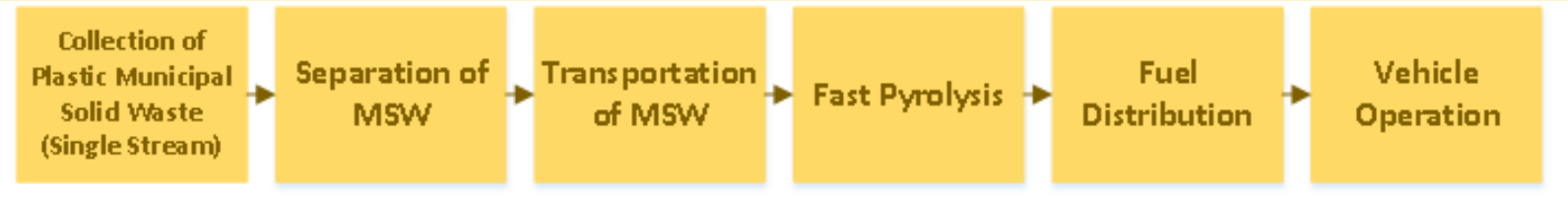
- Global warming potential for organic waste pyrolysis (g CO_2 eq/MJ)

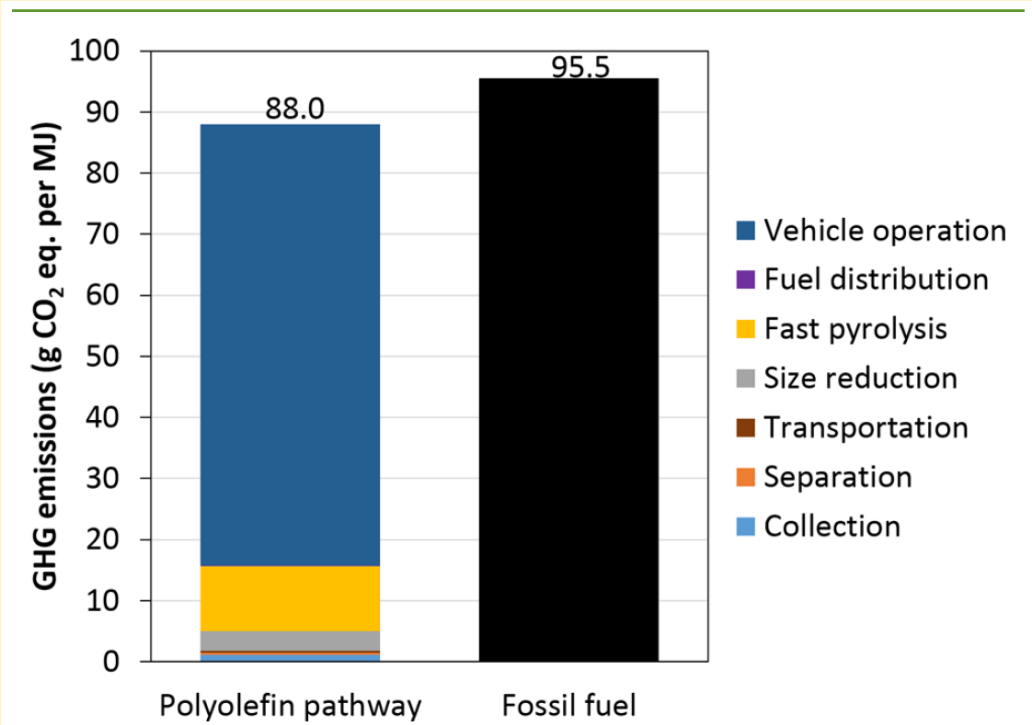


Gracida-Alvarez, U.R., Keenan, L.M., Sacramento-Rivero, J.C., Shonnard, D.R., (2016) Resource and Greenhouse Gas Assessments of the Thermochemical Conversion of Municipal Solid Waste in Mexico, *ACS Sustainable Chemistry & Engineering*, DOI: 10.1021/acssuschemeng.6b01143

Environmental assessment: Plastic MSW

- Global warming potential for polyolefin waste pyrolysis (g CO_2 eq/MJ)



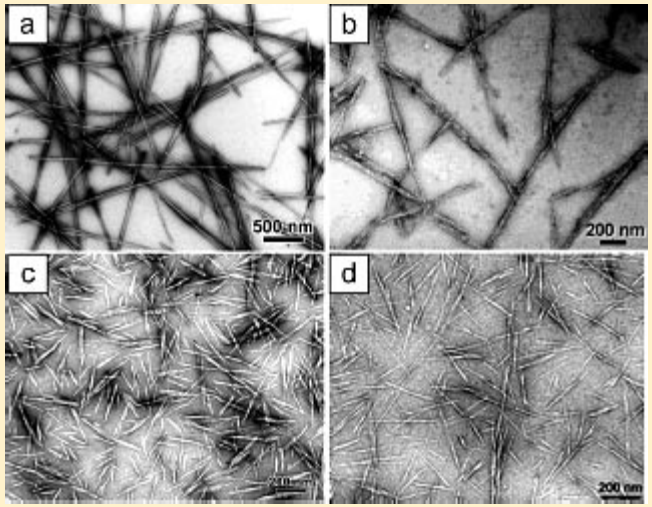


Gracida-Alvarez, U.R., Keenan, L.M., Sacramento-Rivero, J.C., Shonnard, D.R., (2016) Resource and Greenhouse Gas Assessments of the Thermochemical Conversion of Municipal Solid Waste in Mexico, *ACS Sustainable Chemistry & Engineering*, DOI: 10.1021/acssuschemeng.6b01143

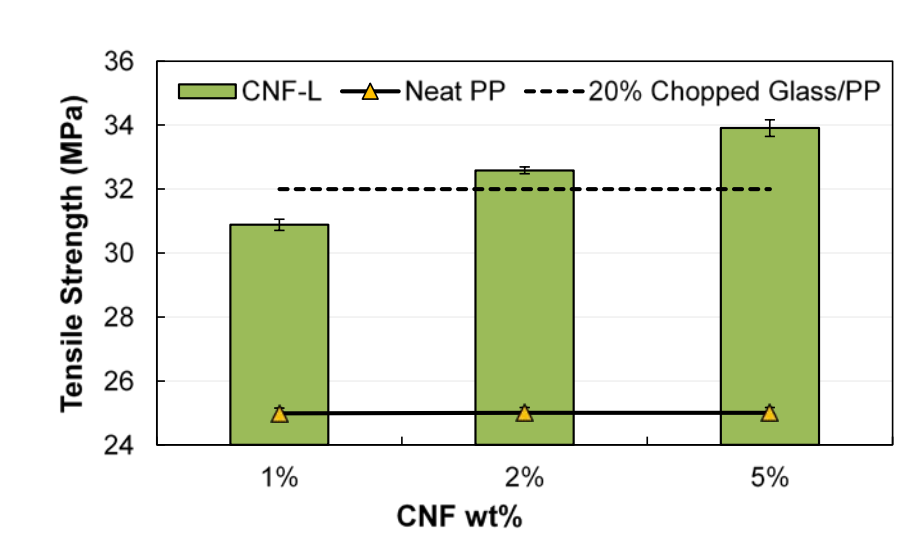
Conclusions

- There are 11.25 million metric tons/year of MSW available for thermochemical conversion.
- The amount of fuels that can be produced accounts for 4 million tons /year.
- This could satisfy 7.1% of Mexico's annual fuel consumption.
- The C footprint for the pyrolysis-based biofuels is -9.2 and 88.0 g CO_2 eq / MJ for organic and polyolefin plastics, respectively.
- The simplified LCA method demonstrated to be a useful tool to guide future research about conversion of MSW to biofuels.

Automotive Plastics Reinforced with Nanocellulose Save Greenhouse Gas Emissions through Vehicle Lightweighting

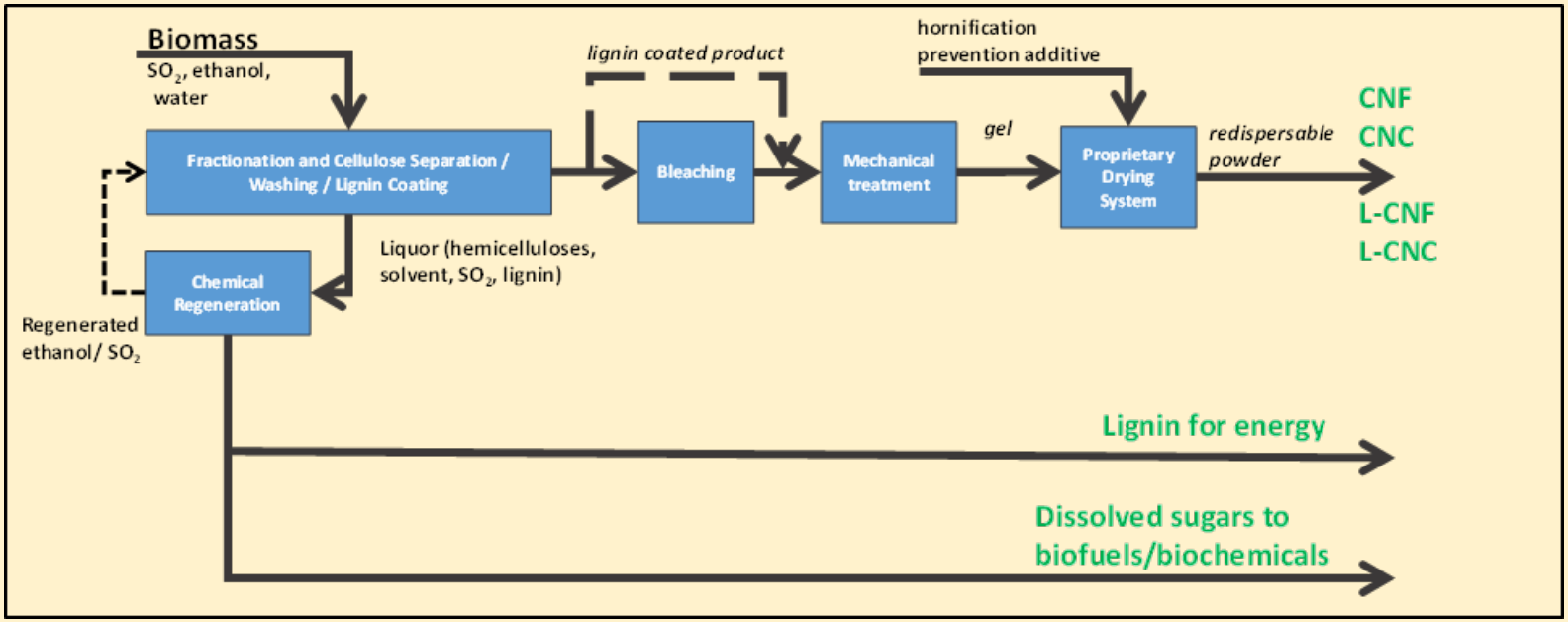


- Tensile strength similar to aluminum
- Stiffness comparable to Kevlar and better than glass fiber
- Strength to weight ratio 8 times stainless steel



- Automobile polymer composites containing cellulosic nanofibers (CNF) at 1-2% (wt.) is comparable to 20% (wt.) glass fiber composites
- CNF allows for vehicle lightweighting

BioPlus Process – American Process, Inc.



Kim Nelson, VP
knelson@americanprocess.com

Theodora Retsina, CEO
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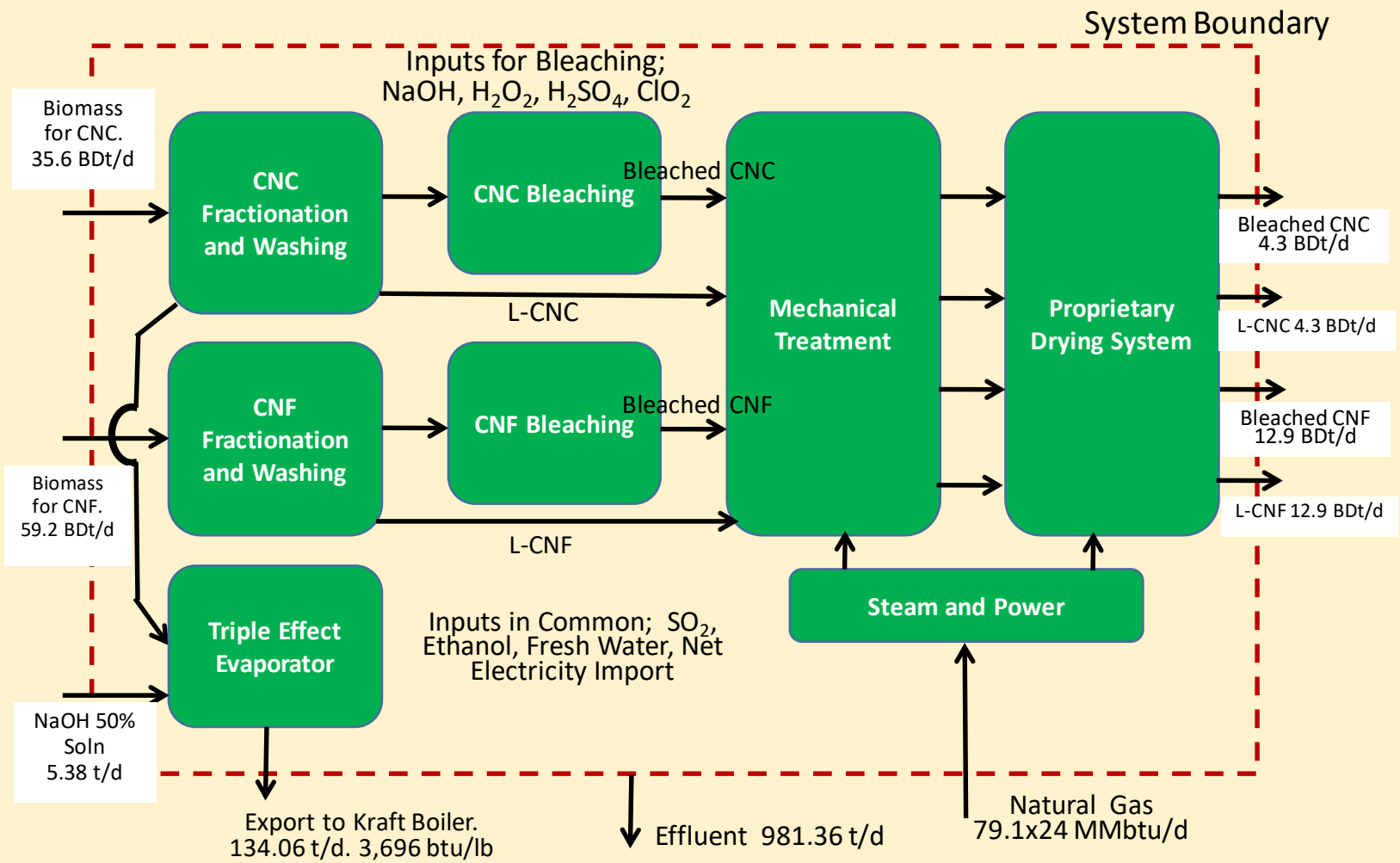
BioPlus Process – Inputs / Outputs



Vehicle Lightweighting

- 15% of vehicle weight is plastic composite whose weight can be reduced
- 1% (wt.) L-CNF in polypropylene (PP) composite parts in automobiles
- Replaces 20% (wt.) glass fiber PP composite parts
- 42.6 kg is the maximum total weight savings that may be expected
- Fuel reduction value (FRV) of 0.15 liters fuel saved / 100 kg wt. savings / 100 km
- 32.2 gallons gasoline saved from lightweighting over 120,000 mile life

L-CNF

Glass fiber

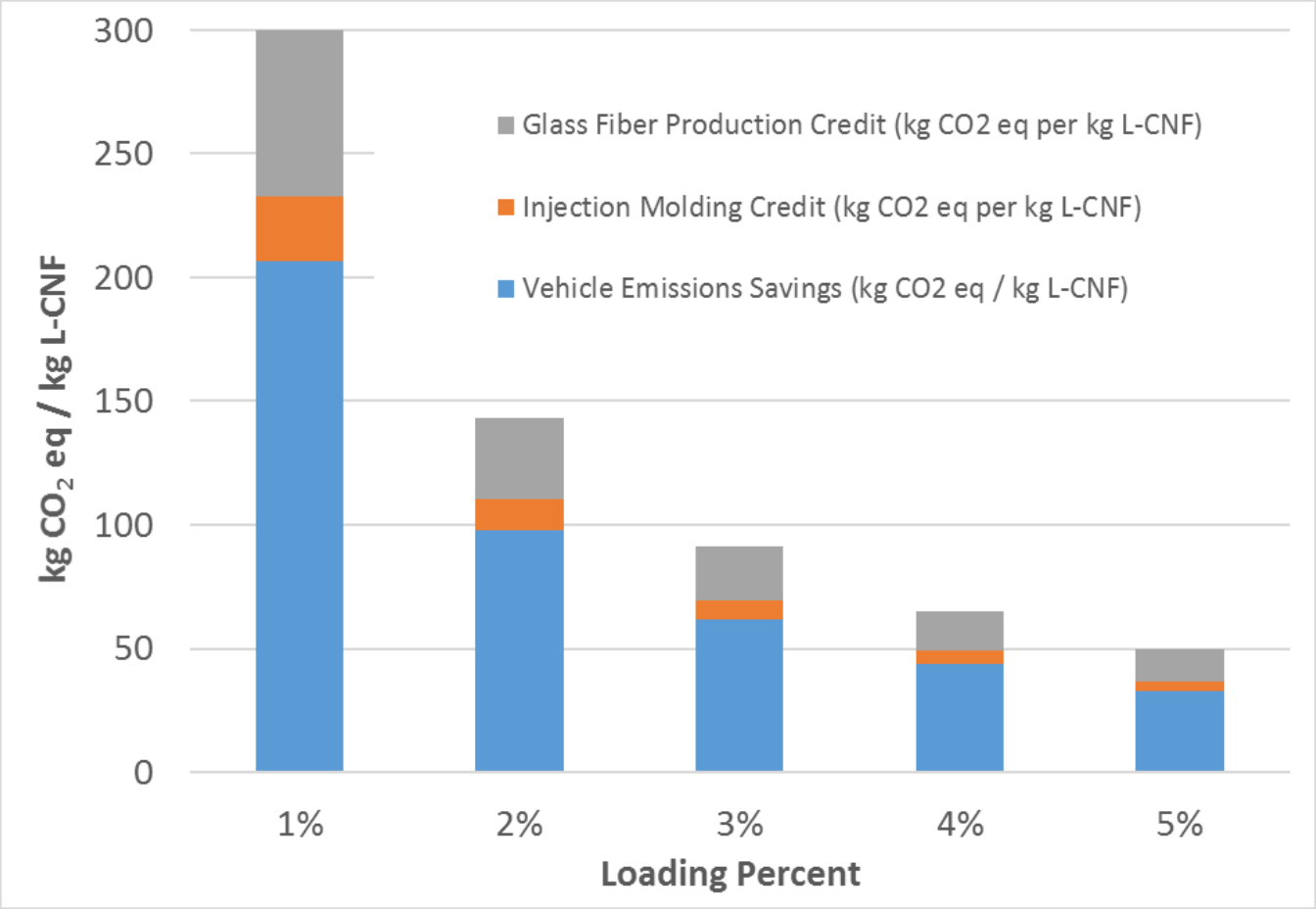
GHG Emissions: Lignin-Coated Cellulose Nanofibers (L-CNF)

Production Stages	**GHG Emissions (kg CO_2 equivalents / kg L-CNF)**
Wood Supply Chain	
Wood Harvesting	0.2233
Wood Chipping	0.0397
Fractionation and Washing	
Sulfur Dioxide	0.0467
Ethanol	0.138
Water	0.0587
Electricity (Southeast US Grid)	2.13
Sodium Hydroxide	0.1036
Steam and Power Production	3.89
Bleaching Operation	
Nanocellulose Product Transport (1,000 km by road)	0.171
Waste Disposal (wastewater and ash)	0.0325
Kraft Mill Credit (lignin displacing coal)	-4.2
Total for Nanocellulose Production (cradle-to-gate)	**2.63**
Glass Fiber and Composites Processing Credits	
Glass Fiber Production Credit	-66.8
Injection Molding Composites Process Credit	-26.2
Use Stage	
Vehicle Use Phase (200,000 km) after Lightweighting	-206.76
Total Emissions (All Stages, with Credits)	-299.8

GHG Emissions: L-CNF vs Other Materials

	kg CO_2 eq. / kg matl.	Source
BioPlus L-CNF (lignin displacing coal)	2.63	This study
BioPlus L-CNF (lignin displacing ng)	4.38	This study
BioPlus L-CNF (lignin displacing biomass)	6.19	This study
Glass fiber	2.55	[21]
Carbon fiber	29.5	[22]
Carbon nanotubes (ARC)	79,910	[23]
Carbon nanotubes (CVD)	199,300	[23]
Carbon nanotubes (HiPco)	32,700	[23]

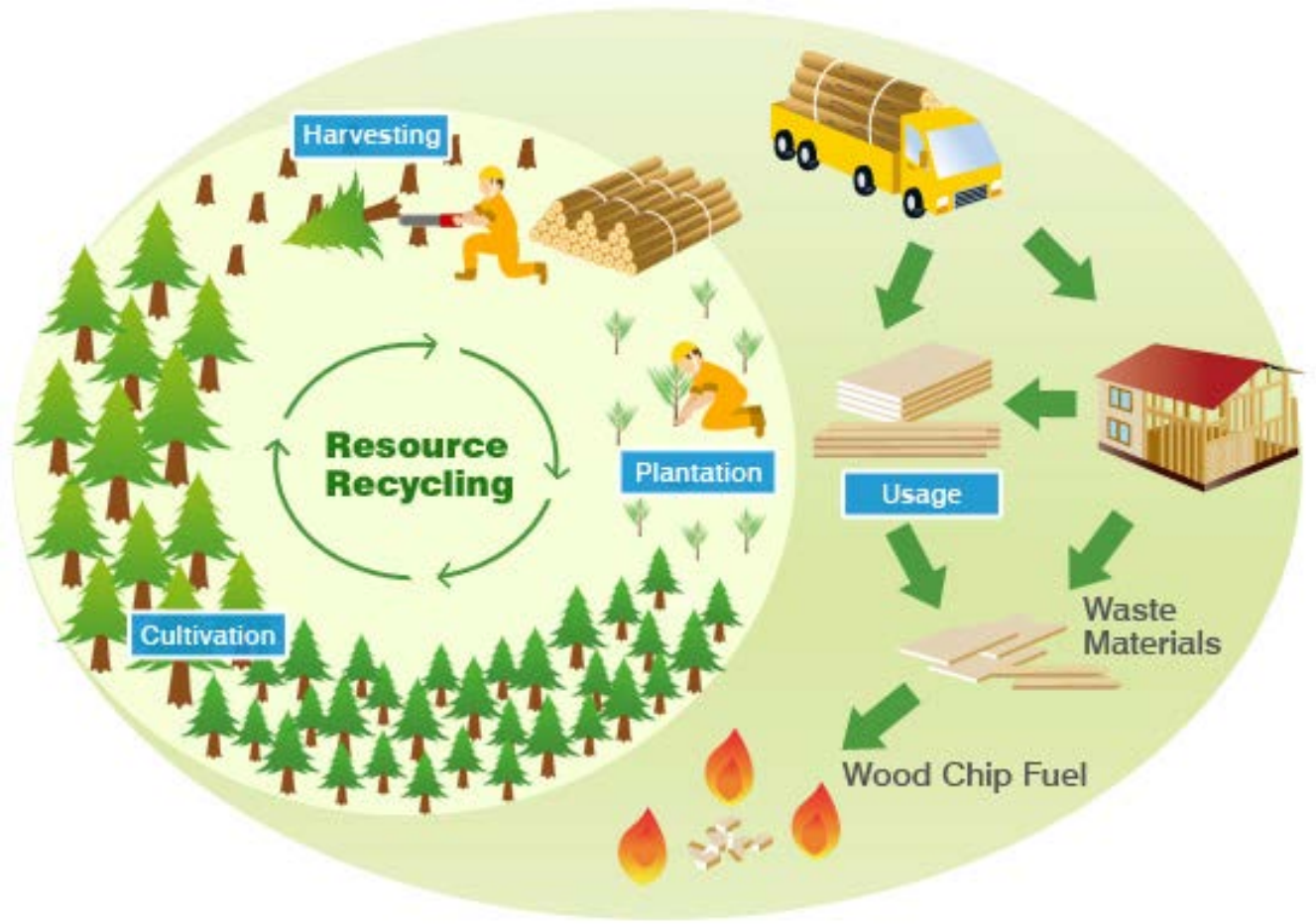
GHG Emission Savings: Effects of L-CNF Loading Percent



Conclusions: Nanocellulose LCA

- The GHG impacts for production of L-CNF are comparable to production of glass fiber.
- Innovations in drying of the L-CNF materials led directly to GHG emission reduction for L-CNF
- Other types of automobile composite plastics fillers (carbon fiber, carbon nanotubes) are much higher in GHG emissions.
- The effects of vehicle lightweighting are dominant in the L-CNF life cycle, leading to large GHG emission savings compared to glass fiber.

Forest Products Sustainability



http://www.newsustainabilityinc.com/tag/the-future-we-want-2/

- Renewable resources
- Storage of atmospheric C in long-life products
- Reduction in production emissions compared to concrete and steel
- LCA captures systemic effects in product life cycles

Thank you for your attention!

Contact information

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Appendix: MJ of fuel produced

- Organic pathway

Organic MSW (Metric tons)	6,205,871.48
Estimated fuel production (Metric tons)	1,469,234.59
Lower Heating value (MJ/kg)	44
Estimated fuel production (million MJ)	64,646

- Plastic pathway

Fuel products BP process (Perugini et al, 2005)	Yield per kg of polyolefins (kg)	Fuel produced (kg)	LHV (MJ/kg)	Fuel produced (Million MJ)
Gas fraction	0.147	431,253,661.04	46.898	20,225
Heavy fraction (waxes)	0.448	1,314,296,871.73	41.5	54,543
Light fraction (liquid)	0.265	777,430,069.21	44	34,207

Total: 108,975

Environmental assessment

- A simplified LCA was used to estimate the Global Warming Potential (GWP) for different process stages in CO_2 equivalent emissions.

Stage	Source	Notes
Collection	Fitzgerald et al, 2012	Factors for computing upstream emissions from provided combustion emissions. Diesel: 9.0 %, Electricity: 10.0 %, Natural Gas: 17.0 %
Separation	Fitzgerald et al, 2012	
Transportation	Simapro 8.0 database	Transportation distance of 108 km
Pyrolysis	Organic waste: Hsu, 2011 Polyolefin waste: Perugini et al, 2005	Upstream and combustion emissions obtained from ecoinvent™ in SimaPro 8.0
Hydroprocessing	Hsu, 2011	Only considered for organic waste
Fuel distribution	Simapro 8.0 database	Transportation distance of 108 km
Vehicle Operation	Organic waste: Hsu, 2011 Polyolefin waste: CO_2 produced from combustion	Stoichiometric CO_2 formation from representative compounds of each fraction.
Landfill	Organic waste: LCFS HSAD, 2012 Polyolefin waste: No emissions considered	Landfill gas production ($CH4:CO_2$ - 50:50) Active organic MSW carbon in landfill: 63.3 %
Carbon Accounting		All MSW C is accounted for; biogenic + fossil C along the pathways

Appendix

- Computing of the GWP for the vehicle operation stage of polyolefin waste pyrolysis

Fraction from pyrolysis	HC species	HC species fraction	representative component	Combustion emissions (kg CO2/kg HC)
gas	paraffins	0.4304	C_2H_6	2.93
	olefins	0.5696	C_3H_6	3.14
liquid	paraffins	0.5612	C_6H_{14}	3.07
	olefins	0.4132	C_6H_{12}	3.14
	aromatics	0.0255	toluene	3.35
solid	paraffins	0.5215	$C_{20}H_{42}$	3.12
	olefins	0.3763	$C_{20}H_{40}$	3.14
	aromatics	0.1023	naphthalene	3.44

Fuel products BP process (Perugini et al, 2005)	Combustion emissions (kgCO2/kg HC)
Gas fraction	3.05
Heavy fraction (waxes)	3.11
Light fraction (liquid)	3.16

Appendix: Landfill emissions

Organic waste
(2.7 million tons of C)

Activated C (63.3%)
1.8 million tons

Released as CO_2 (50%)
0.9 million tons

Released CO_2
3.23 million tons

Released as CH_4 (50%)
0.9 million tons

Released CH_4
1.17 million tons

CH_4 collected in flares(75%)
0.88 million tons

Combusted CH_4 (99 %)
0.87 million tons

Released CO_2
2.4 million tons

CH_4 released in flares (1%)
0.01 million tons

Released CO_2
0.22 million tons

CH_4 escaped from flares (25%)
0.29 million tons

CH_4 oxidized to CO_2 (10 %)
0.03 million tons

Released CO_2
0.08 million tons

Released CH_4 (90 %)
0.26 million tons

Released CO_2
6.6 million tons

LCFS HSAD, 2012, Proposed Low Carbon Fuel Standard (LCFS) Pathway for Production of Biomethane from High Solids Anaerobic Digestion (AD) of Organic (Food and Green) Waste. California Environmental Protection Agency.