NREL
Transforming ENERGY

Department of Energy Special Session – Life cycle assessment research at National Renewable Energy Laboratory

Tapajyoti (TJ) Ghosh
Research Engineer
Strategic Energy Analysis Center
NREL

ACLCA
2022 Conference
NOVEMBER
7-11
VIRTUAL

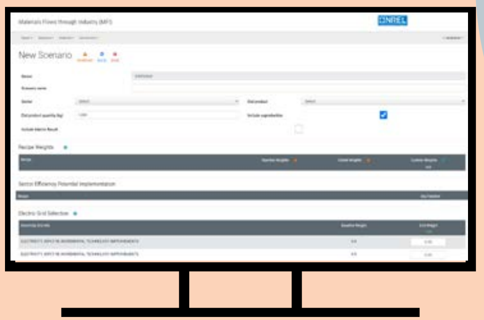
Material **F**lows Through Industry (**MFI**)

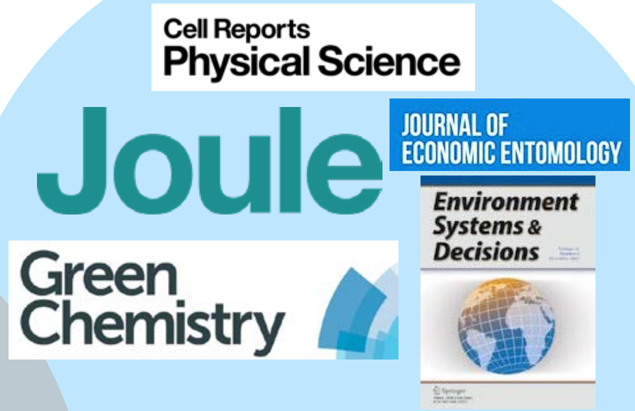
Team Members: Taylor Uekert, Swaroop Atnoorkar, Shubhankar Upasani, Greg Avery, Alberta Carpenter, Jason S. DesVeaux

Materials Flows through Industry (MFI) Tool

What are the **material**, **energy**, and **greenhouse gas emissions** impacts associated with the supply chains of industrially-significant **commodity materials**?

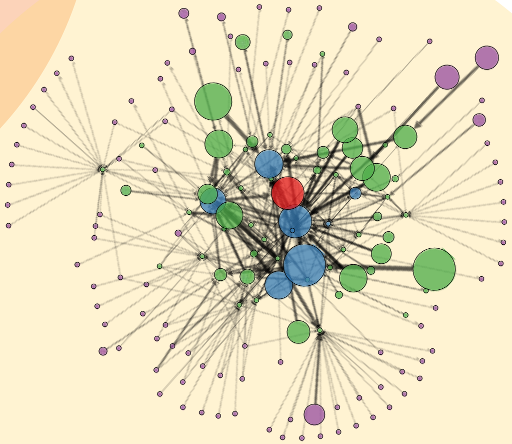
Approach: cradle-to-gate supply chain modelling tool containing detailed United States-specific inventory data





Seven published journal articles using MFI analysis, with several more under development

mfitool.nrel.gov
External-Facing Web Application
[175 new accounts added in FY22 Q1]



MFI is a key part of the BOTTLE Consortium analysis portfolio

bottle
changing the way we recycle™
U.S. DEPARTMENT OF ENERGY

Supply Chain Network Model Visualization
[In-house R model provides greater customization]

MFI Case Study: Wind Energy Technology

Research Question: What are the amounts of supply chain energy use, GHG emissions, and critical materials associated with the production pathways of wind turbine components in the US?

AMO MYPP: Sustainable Manufacturing Technology Area
Advance technologies and tools to improve resource efficiency in the manufacturing industries, including recycling and reuse, and lower the lifecycle cost and cross-sectoral energy impacts of manufactured products.

Project Goals:

#1 Renewable Energy and Energy Efficiency
Supply chain analysis of industrial production of wind turbine components can aid in the sustainable production of wind generated electricity

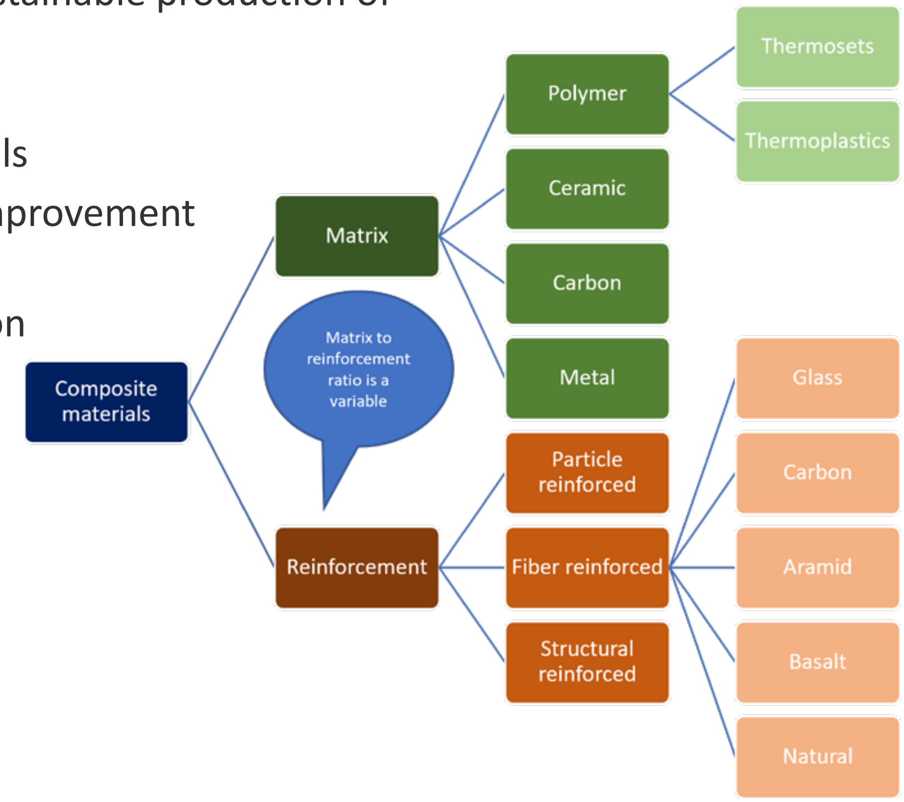
#7 Low-carbon Fuels, Chemicals, and Materials
MFI analysis can quantify the GHG emissions, fuel, and energy use as well as critical materials used in the production of wind turbine components as well as highlight opportunities for improvement

#8 Sustainability through Circularity
Recyclable composite materials used in wind turbine blades can advance the implementation of the circular economy and provide embedded energy savings

Project highlights:

- Blades made from CFRP composites and thermoplastic Elium resin compared with traditional fiberglass reinforced epoxy blades.
- Study evaluates supply chain impacts at component level, single turbine level, and at the level of the entire wind sector
- Future electricity production scenarios according to NREL's ReEDS model applied

Project PI: Alberta Carpenter ***Project Researcher:*** Shubhankar Upasani



Supply Chain Energy and Greenhouse Gas Analysis Using the Materials Flows through Industry (MFI) Tool:

Decarbonization Technology Scenarios for the U.S. Iron and Steel Manufacturing Sector

Iron and Steel: Sector Profile

- Essential for building critical infrastructure
- Will play vital role in the energy transition

5.4% of Total Energy Use

31.7% of Coal Use

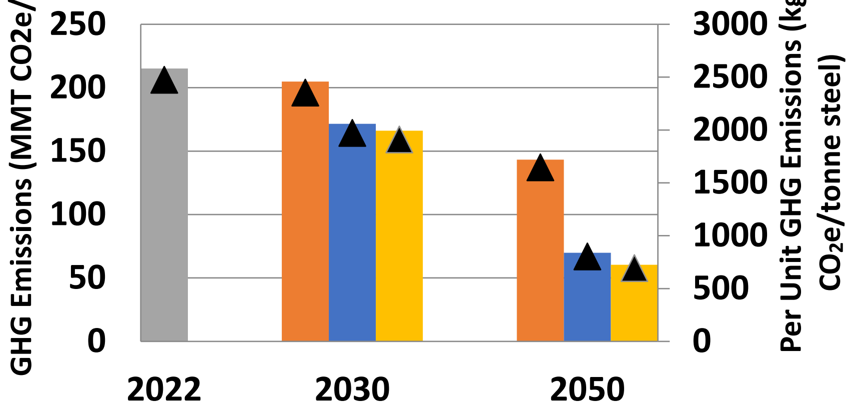
73.7 MMT GHG emissions

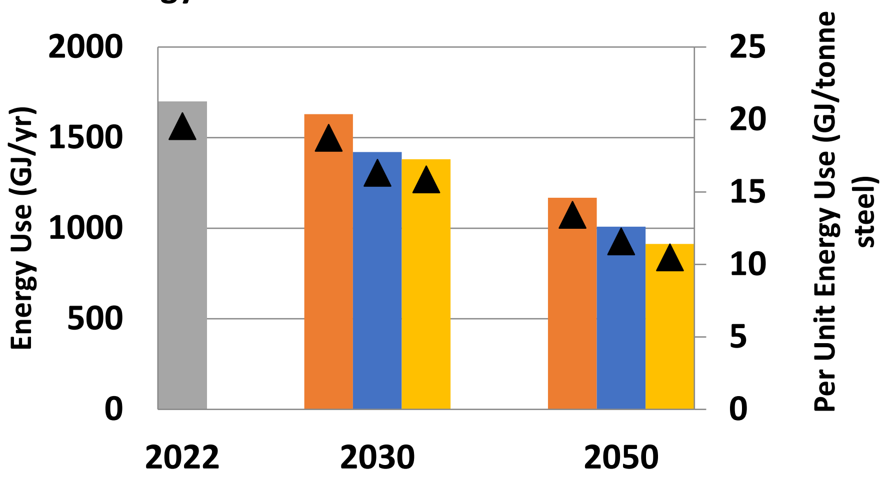
Methods

- Modeled technology and electricity grid scenarios in the Materials Flow Through Industry (MFI) Tool
- Analyzed the cradle-to-gate energy use and GHG emissions of individual steel production pathways and economy-wide industrial production

- Steel Production Technology mix
- Energy Efficiency
- Hydrogen Production Technology Mix
- Fuel Switching

Results





- Fuel switching and energy efficiency can reduce emissions of the sector by 75% by 2050.
- Phasing out BF-BOF steel production, switching to low emission fuels (H2) in DRI production, and decarbonizing the electricity grid are the multi-step changes required to achieve decarbonization

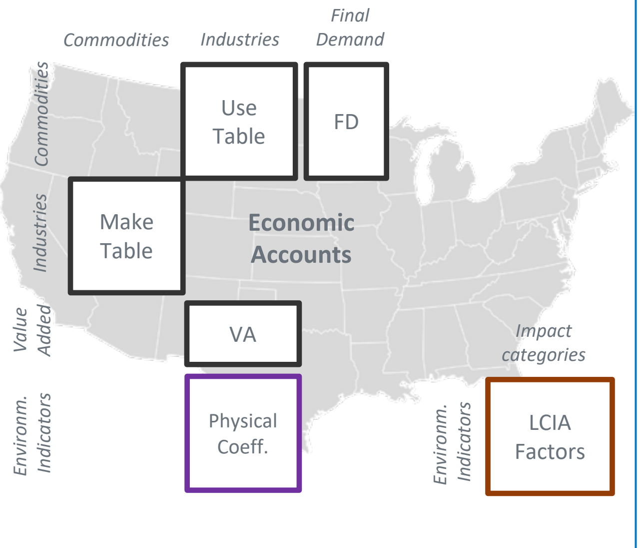
Bio-based circular carbon economy **E**nvironmentally-extended **I**nput-**O**utput **M**odel (BEIOM)

Team Members: **Andre F. T. Avelino**

BEIOM: Bio-based circular carbon economy Environmentally-extended Input-Output Model

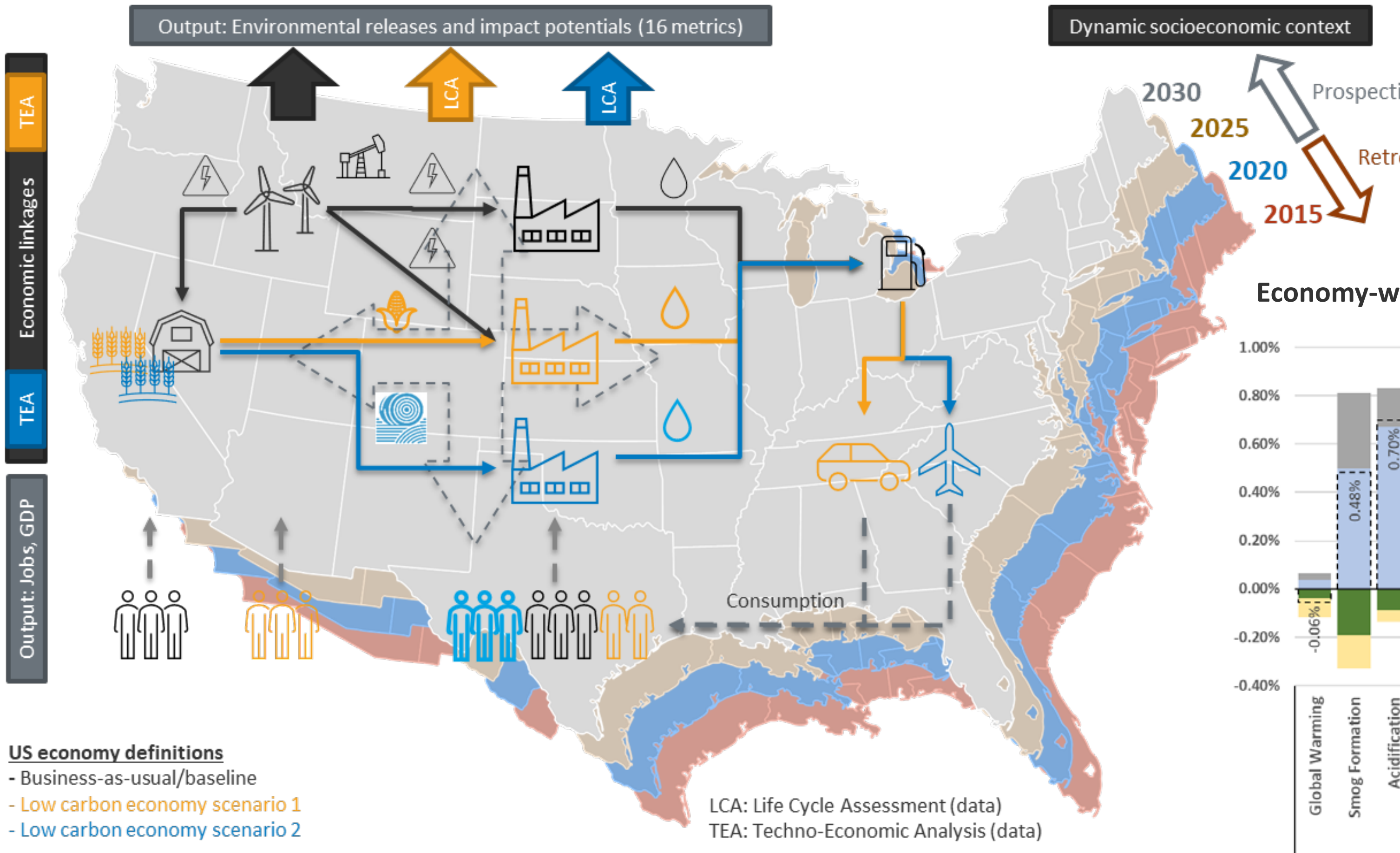
PI: Andre F. T. Avelino, NREL | Sponsors: DOE BETO

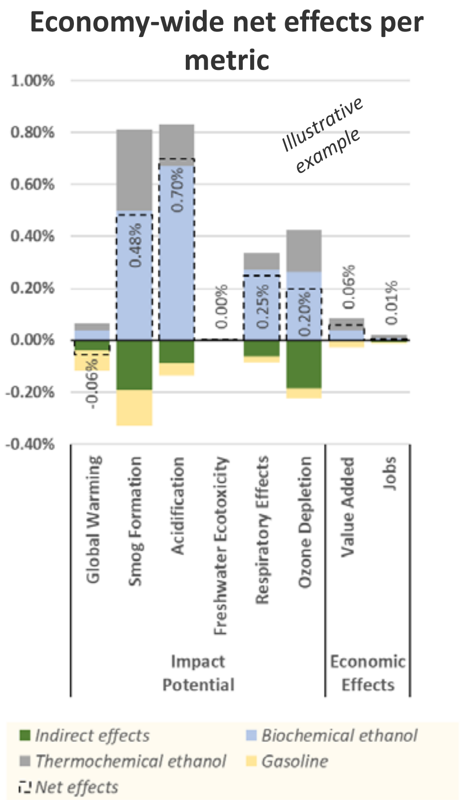
Method & Datasets



- *EEIO: established method to assess impacts of products or product portfolios (e.g., by Amazon)*
- *Uses national-level datasets from federal agencies (EPA, USDA, etc.)*
- *Traces structural changes in the US economy*
- *Analyzes sector interactions*
- *Includes feedback effects*
- *Does not apply system cut-offs within US geographical boundaries*

Defining new technologies/industries/paradigms





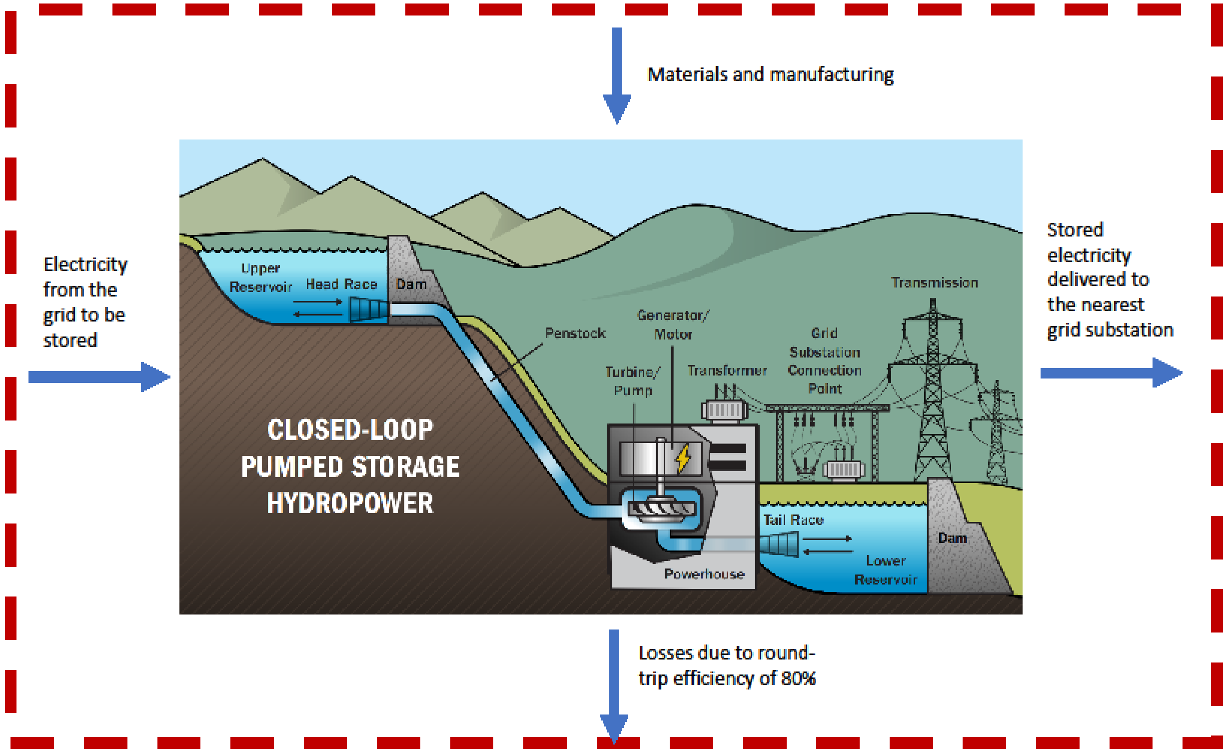
Using process-level techno-economic and life cycle inventory data, we can define any new technologies (or portfolios thereof) and assess their net socioeconomic and environmental effects at industrial scale in an economy-wide context.

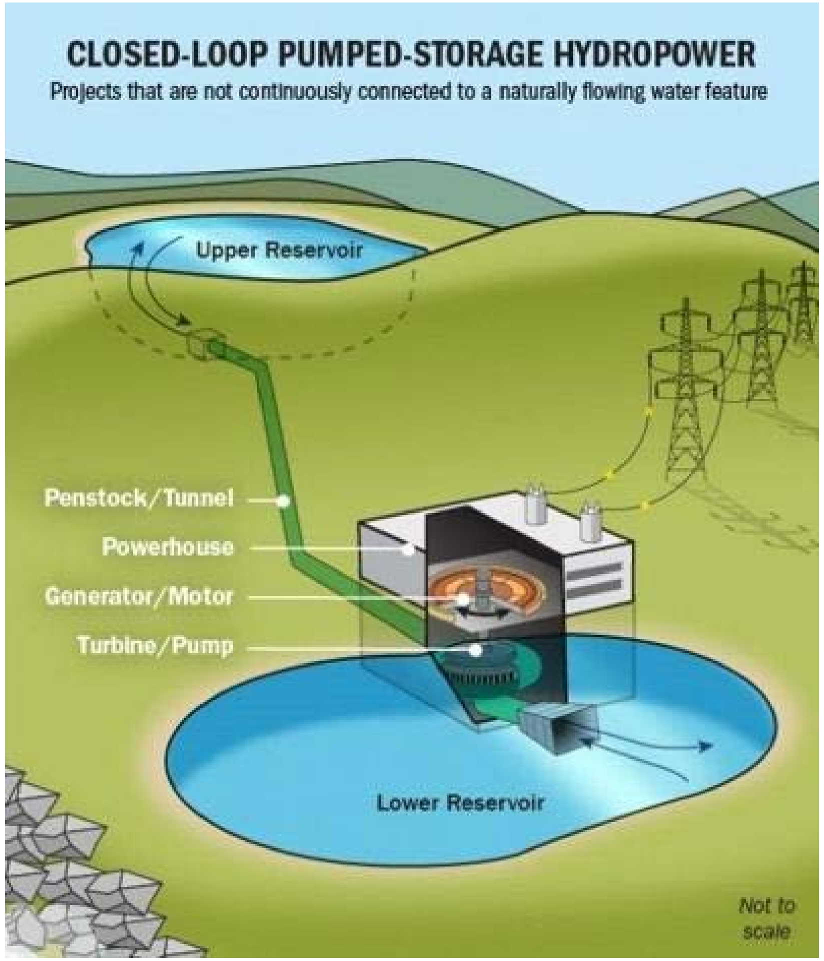
Pumped **S**torage **H**ydropower LCA **(PSH)**

Team Members: Daniel Inman

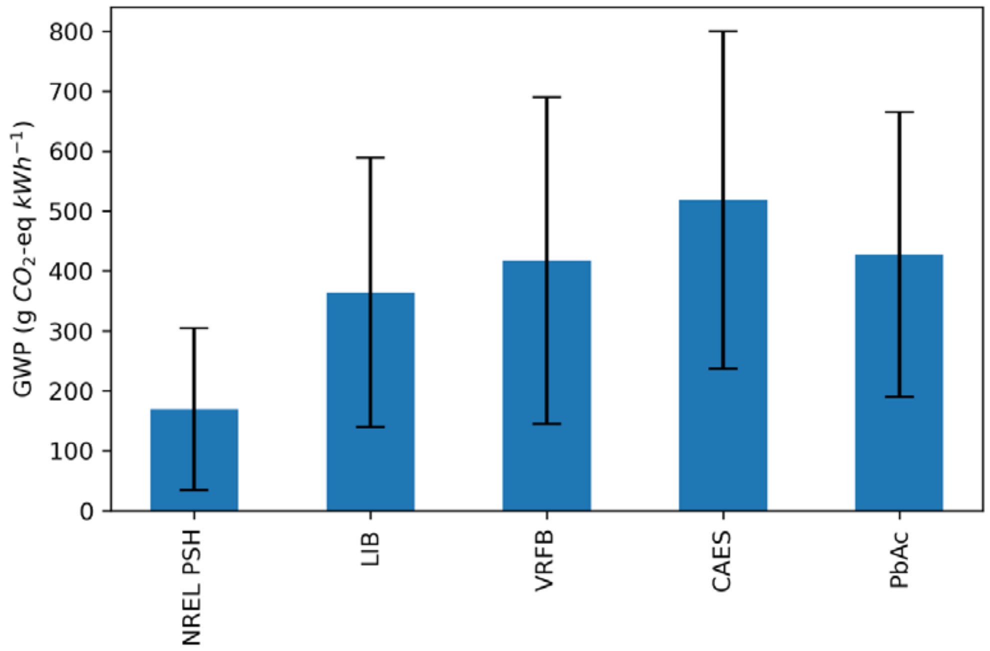
NREL Pumped Storage Hydropower LCA

- PI: Daniel Inman, PhD. NREL
- Funding: DOE-WPTO

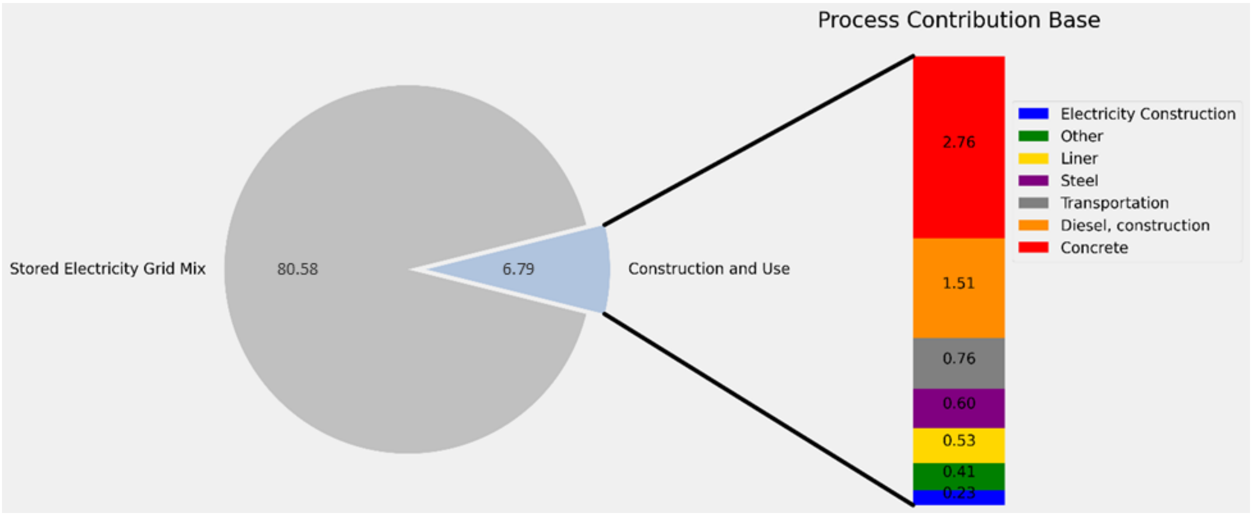




The Global Warming Potential of Closed-Loop PSH is Estimated to be 58 to 302 g CO_2e kWh^{-1}



Global warming potential (GWP) of closed-loop PSH compared to lithium-ion battery storage (LIB), vanadium redox flow batteries (VRFB), compressed-air energy storage (CAES), and lead-acid battery energy storage (PbAc).



Emissions from the source of stored electricity account for most of the Greenhouse Gas Emissions from closed-loop PSH.

Lifecycle **A**nalysis **I**ntegration into **S**calable **O**pensource **N**umerical models

(LiAISON)

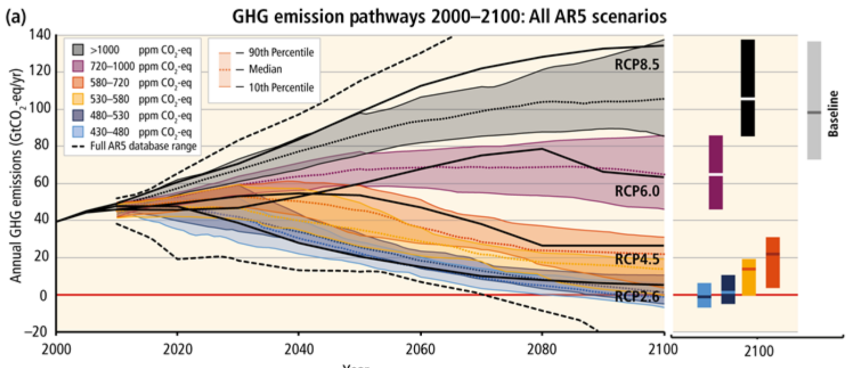
Team Members: Patrick Lamers (PI), TJ Ghosh, Shubh Upasani

LIAISON: LIfecycle Analysis Integration into Scalable Opensource Numerical models

PI: Patrick Lamers, NREL

Funding: DOE AMO

IPCC scenarios (background)

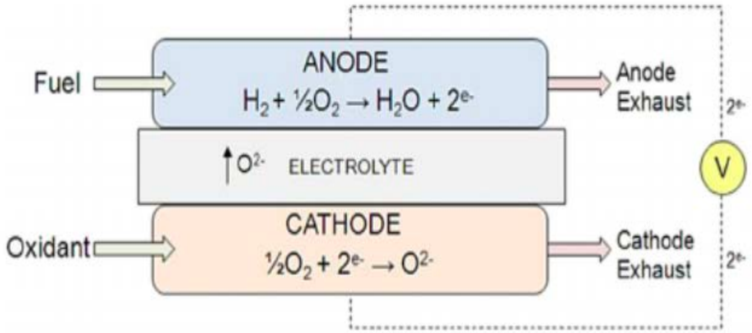


IPCC 2014, AR5 SPM

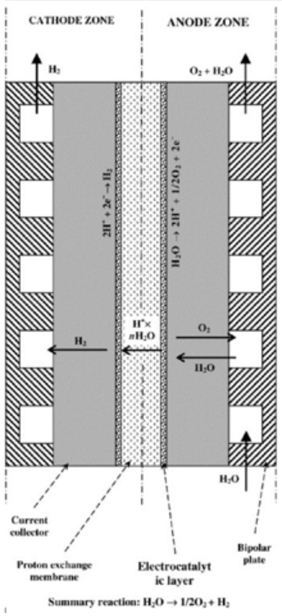
Standardized pathways

- Mitigation & adaptation (RCP)
- Socio-economic development (SSP)
- Global with regional detail
- All sectors

Emerging EERE technologies (foreground)

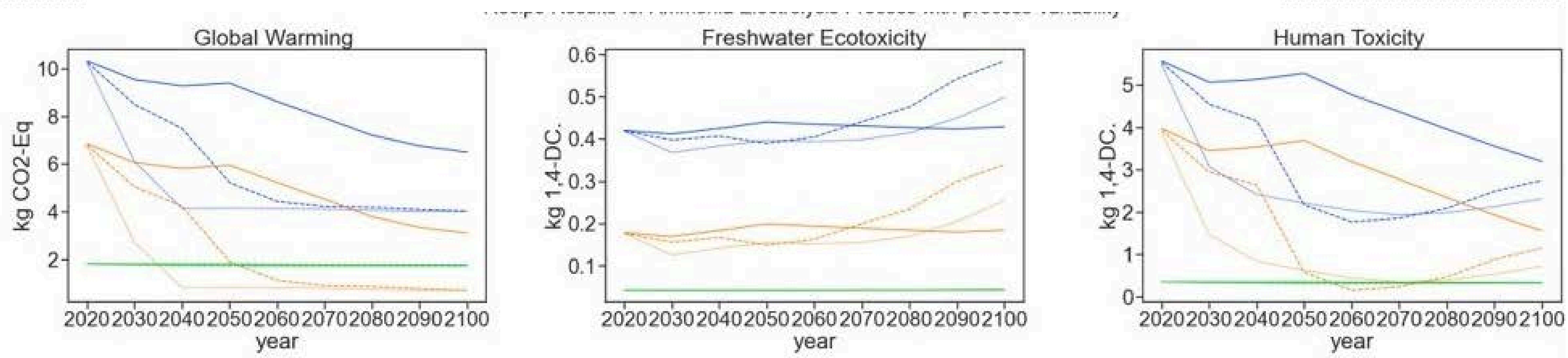


Solid Oxide Fuel Cell



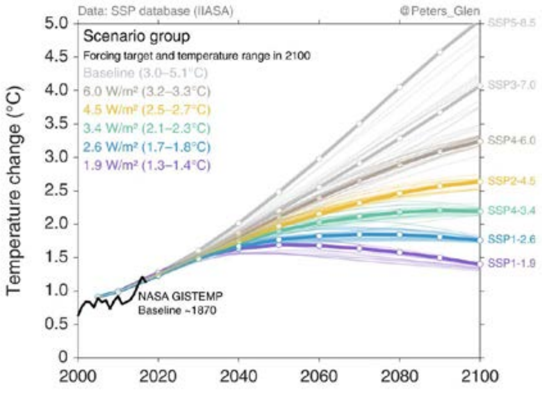
Electrolysis

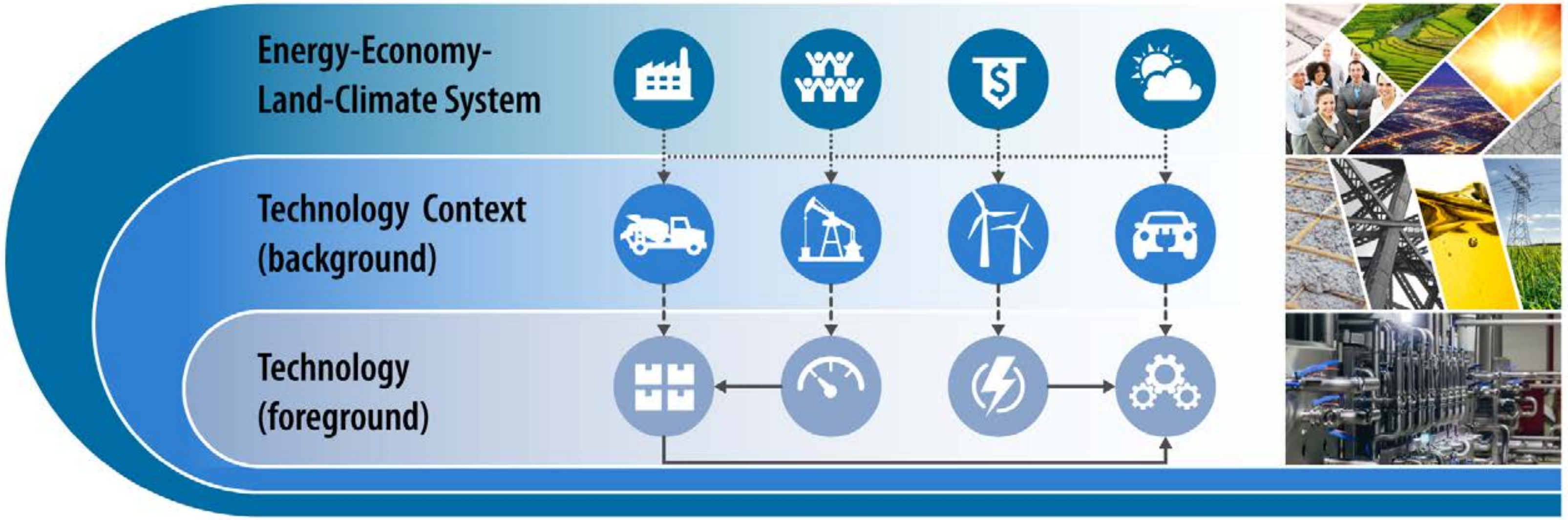
Regionally & temporally explicit, prospective life cycle impacts



1. Life cycle sustainability of solid oxide fuel cells: From methodological aspects to system implications, Mehmeti et. al Journal of Power Sources 325:772–785
2. Pure hydrogen production by PEM electrolysis for hydrogen energy, Grigoriev et. al, https://doi.org/10.1016/j.ijhydene.2005.04.038

Lifecycle Analysis Integration into Scalable Opensource Numerical models (LiAISON)





NREL Team: Patrick Lamers (PI), TJ Ghosh, Shubh Upasani

EERE Pillar: Decarbonizing Energy Intensive Industries

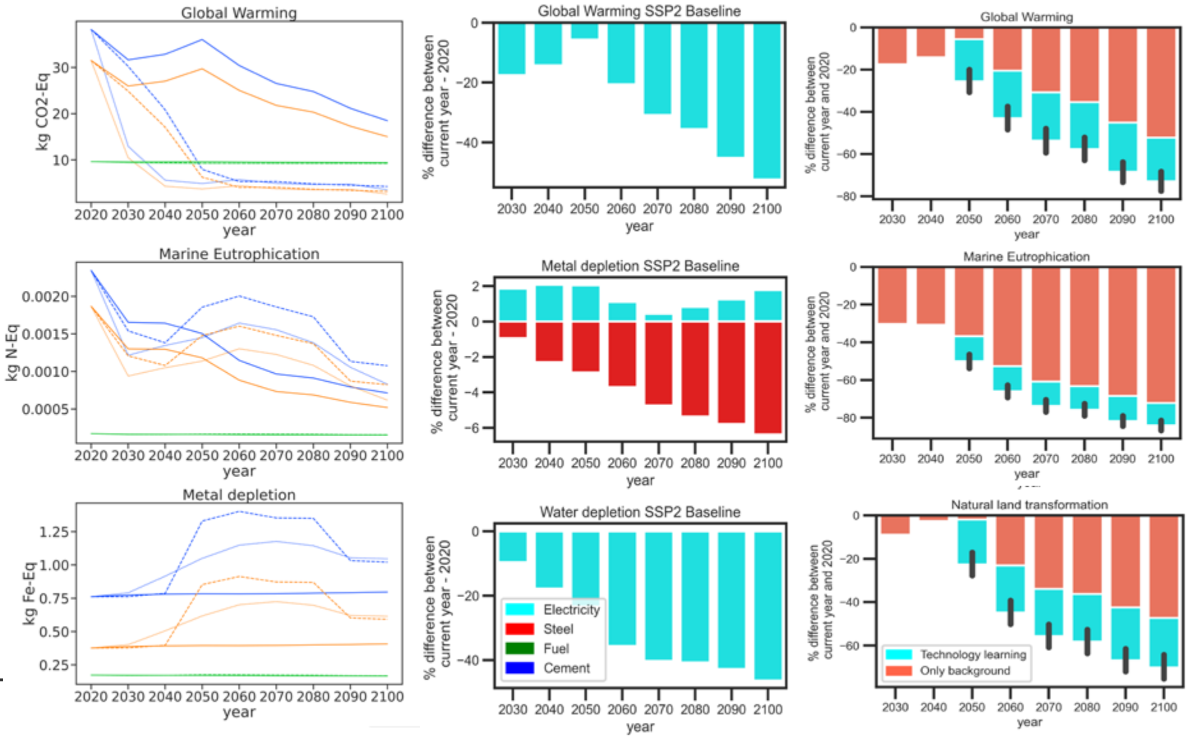
NREL Goal: Future Energy Systems

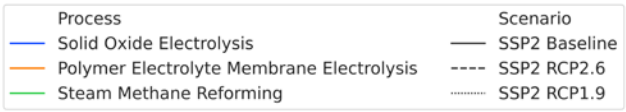
RQ: What are the future impacts and tradeoffs of present-day novel technologies accounting for transitions in the energy and manufacturing sectors as well as technology improvements?

Method: Coded, prospective life cycle assessment using long-term, coherent scenarios of the energy-economy-land-climate system to quantify the effects of background system changes and foreground technology improvements for various technologies.

Value-add: Inform R&D prioritization for novel technologies and preemptively address potential tradeoffs and unintended consequences of their large-scale deployment.

Example: Power-to-Hydrogen technologies (1 kg H_2)





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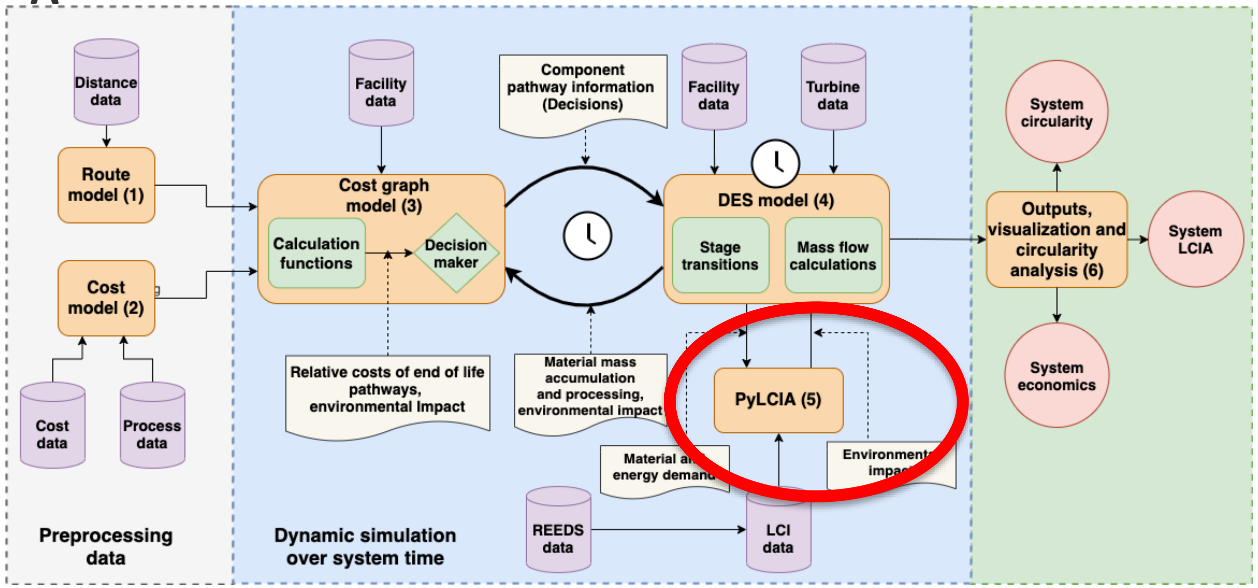
Circular **E**conomy **L**ife cycle **A**ssessment **vi**sualization (**CELAVI**)

Team Members: Rebecca Hanes, TJ Ghosh, Julien Walzberg, Alicia Key, Annika Eberle (PI)

Circularity assessments: regional impacts & uncertainty

A



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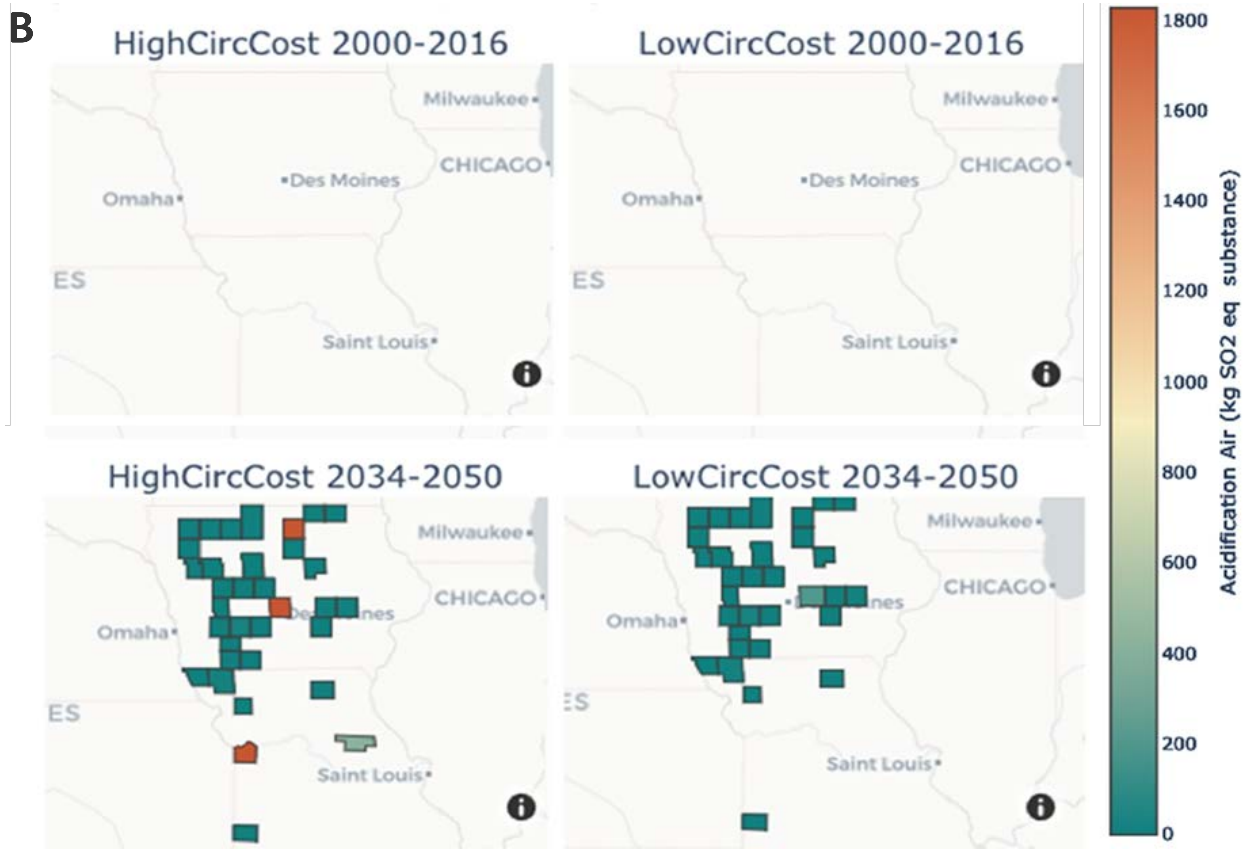

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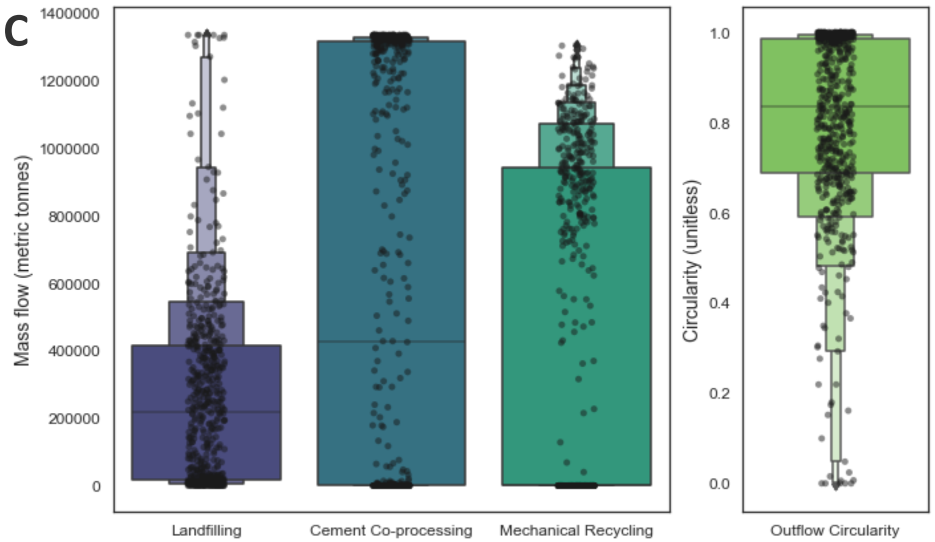


A. The Circular Economy Life Cycle Assessment and Visualization (CELAVI) Framework models impacts of supply chain circularity transition (SCCT)
B. CELAVI provides regionalized life cycle inventories of the wind blade SCCT
C. The techno-economic parameters that condition SCCT are uncertain creating uncertainty on future circularity and impacts of wind blade end-of-life management

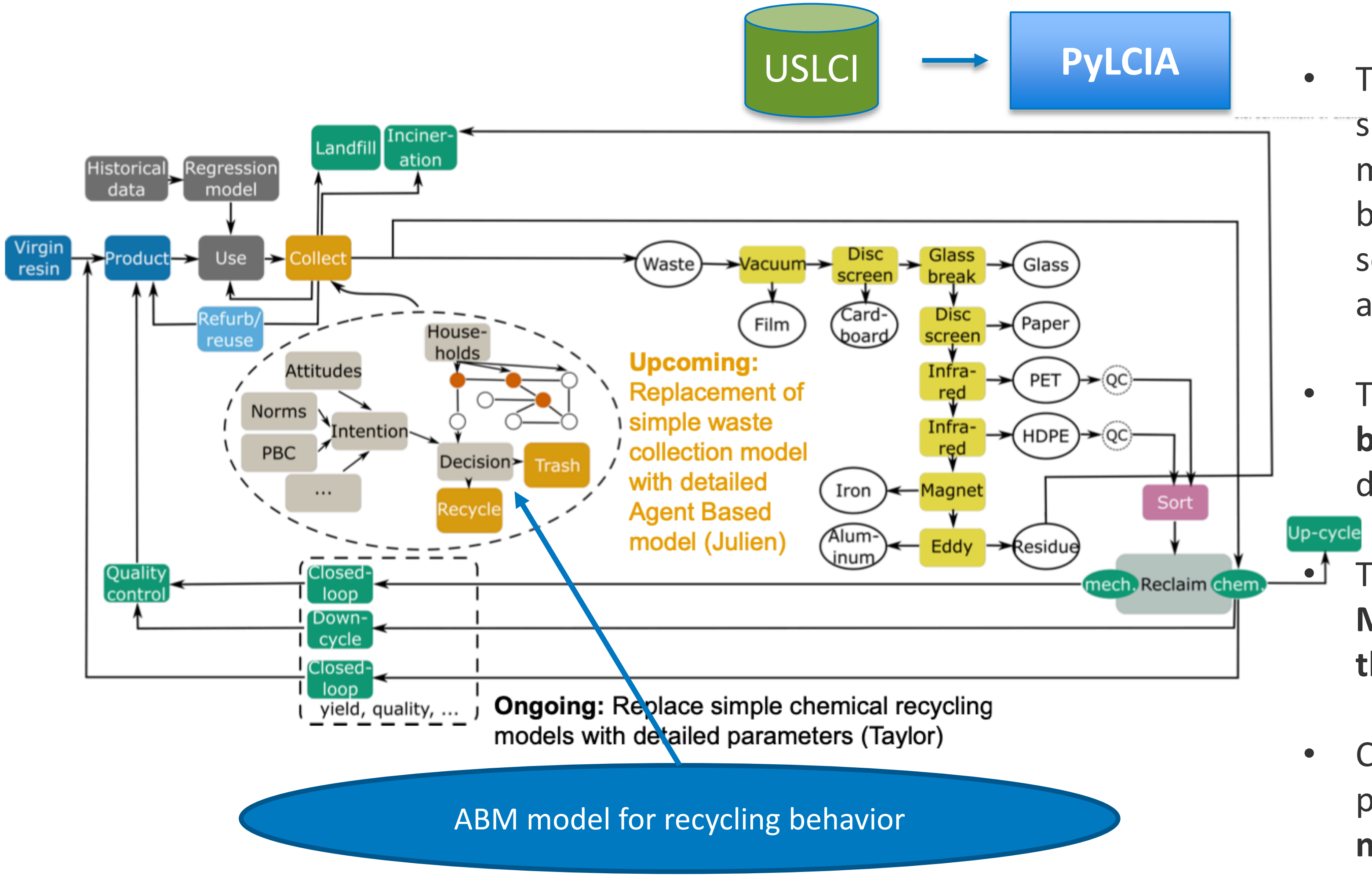
Ghosh, T., et al. (2022). Resources, Conservation and Recycling, 185, 106531. doi:https://doi.org/10.1016/j.resconrec.2022.106531

Plastic **P**arallel **P**athways **P**latform (4P)

Team Members: Taylor Uekert (PI), TJ Ghosh, Julien Walzberg

Plastic Parallel Pathways Platform (4P)

Research question: Develop a framework capable of quantitatively comparing the plastic end-of-life strategies that generate different products.



- Tracking the flow of plastics in the economy within single and multiple life cycles. Implementing metrics for measuring circularity for complex systems. Process-based life cycle assessment to compare circular solutions' environmental impacts. Techno-economic analysis of end-of-life pathways.
- The **ABM simulates households' waste disposal behavior** and forms an integral part of a system dynamics model for plastic recycling
- This study links with **NREL's Circular Economy for Energy Materials critical objective and goal 8: Sustainability through Circularity**
- Closing the linear flow of plastics ensure reduction of plastic waste in the environment as well as **carbon mitigation** by displacement of virgin material production.

Additional NREL presentations at ACLCA 2021

- ***Title:*** "A comparative analysis of closed-loop recycling technologies for most common plastics" – will be on Nov 8th during the 2:30-4pm ET session. **Authors:** Taylor Uekert.

- ***Title:*** "Plastic Parallel Pathways Platform" will be on Nov 10th during the 4:30 – 6 pm ET sessions. **Authors** – Tapajyoti Ghosh, Taylor Uekert, Julien Walzberg, Alberta Carpenter.

- ***Title***: "Supply chain energy and greenhouse gas tradeoffs associated with United States wind turbine technology improvement opportunities in the context of net-zero emissions target by 2050." will be on Nov 9th during the 2:30-4pm ET **Authors – Shubh Upasani**

Publications / Submissions

- Ghosh, T., Hanes, R., Key, A., Walzberg, J., & Eberle, A. (2022). The Circular Economy Life Cycle Assessment and Visualization Framework: A Multistate Case Study of Wind Blade Circularity in United States. *Resources, Conservation and Recycling*, *185*, 106531.
- The inclusion of uncertainty in circularity transition modeling: a case study on wind turbine blade end-of-life management. Full author list: Julien Walzberg; Rebecca Hanes; Tapajyoti Ghosh; Alicia Key; Kristi Potter; Annika Eberle (Submitted)
- Towards a circular economy for PET bottle resin using a system dynamics inspired material flow model. (Submitted and Accepted) Tapajyoti Ghosh, Greg Avery, Arpit Bhatt, Taylor Uekert, Julien Walzberg, Alberta Carpenter.
- Linking life cycle and integrated assessment modeling to evaluate technologies in an evolving system context: a Power-to-Hydrogen case study for the United States. Patrick Lamers, Tapajyoti Ghosh, Shubhankar Upasani, Romain Sacchi, Vassilis Daioglou. (Submitted)
- Technical, economic, and environmental comparison of closed-loop recycling technologies for most common plastics Taylor Uekert, Avantika Singh, Jason S. DesVeaux, Tapajyoti Ghosh,Arpit Bhatt Geetanjali Yadav, Shaik Afzal, Julien Walzberg, Katrina M. Knauer, Scott R. Nicholson, Gregg T. Beckham, and Alberta C. Carpenter (Submitted)
- Uekert, Taylor, Jason S. DesVeaux, Avantika Singh, Scott R. Nicholson, Patrick Lamers, Tapajyoti Ghosh, John E. McGeehan, Alberta C. Carpenter, and Gregg T. Beckham. "Life cycle assessment of enzymatic poly (ethylene terephthalate) recycling." *Green Chemistry* 24, no. 17 (2022): 6531-6543
- Arpit H. Bhatt, Yimin Zhang, Anelia Milbrandt, Emily Newes, Kristi Moriarty, Bruno Klein, Ling Tao. 2022. Evaluation of performance variables to accelerate the deployment of sustainable aviation fuels at a regional scale. *Energy Conversion & Management*.

Thank you

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tghosh@nrel.gov

acarpenter@nrel.gov

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