Carbon (and Environmental) Footprint of Wind and Solar Resources

Michael H. Young, Gürcan Gülen, Atta Rehman, Jani Das
Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin

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Motivation for Studying Energy Systems

- *We are motivated to understand tradeoffs between society's goals of mitigating climate change, preserving biodiversity and ecosystems, and providing reliable and affordable energy to a global community of 8 billion people.*

Approach:

- Data-driven, science-based, interdisciplinary research into:
  - Life-cycle environmental and cost assessments of the energy transition
  - Global supply chain of critical materials
  - Future expansion of capacity and what supports it

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Current Generation Options Being Compared

1) Combined Cycle Gas Turbine (CCGT)

2) Wind Generation
3) Wind + Battery

4) PV Solar Generation
5) Solar + Battery

Base Case Functional Unit:
500 MW capacity CCGT, generating 3 TWh/yr of electricity

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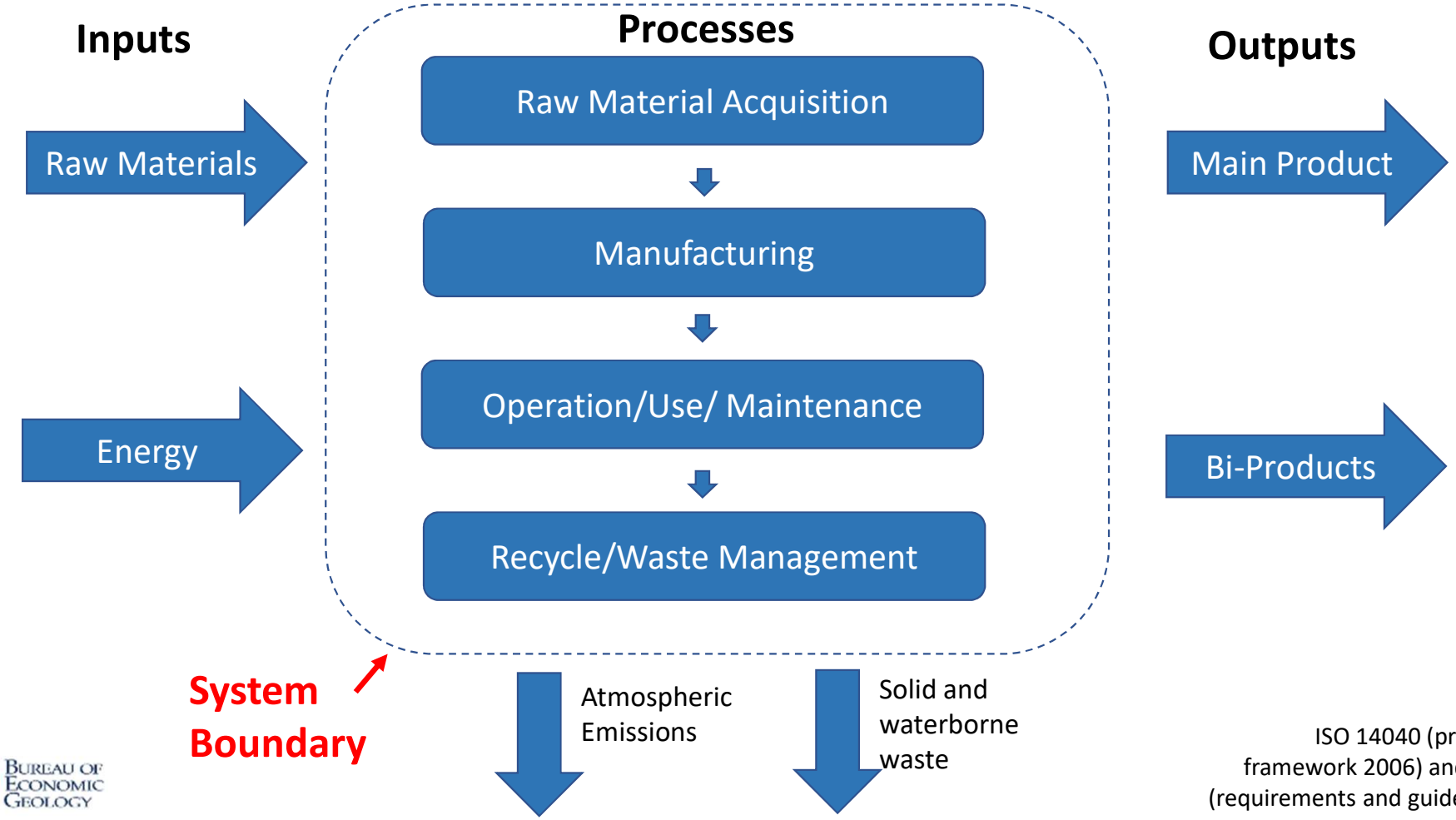
Assumptions Underlying Analyses

	Combined Cycle Gas Turbine	Wind	Solar	Wind + Battery Storage	Solar + Battery Storage
Characteristics of generation/storage units	500 MW capacity 68% capacity factor	912 MW capacity, 304 turbines, each 3 MW in size, 38% capacity factor	1350 MW capacity, 3 million panels, 450kW each, 34% capacity factor	Wind generation + 500 MW capacity battery, LFP chemistry (to increase capacity factor)	Solar generation + 500 MW capacity battery, LFP chemistry (to increase capacity factor)
Characteristics of fuel cycle and replenishment	Gas (or non-associated gas) wells replaced annually per decline curve	Routine maintenance	0.5% degradation rate, facility oversized at construction	Full battery replacement every 10 years	Full battery replacement every 10 years
Characteristics of supply chain	Fuel and facility domestically sourced	28% components sourced outside US, with mix of land and sea transport routes	70% components sourced outside US (mix from SE Asia, China, and Europe)	Wind turbines + global mix of material sourcing and processing, manufactured in US	Solar panels + global mix of material sourcing and processing, manufactured in US

Life Cycle Assessment (LCA) Methodology



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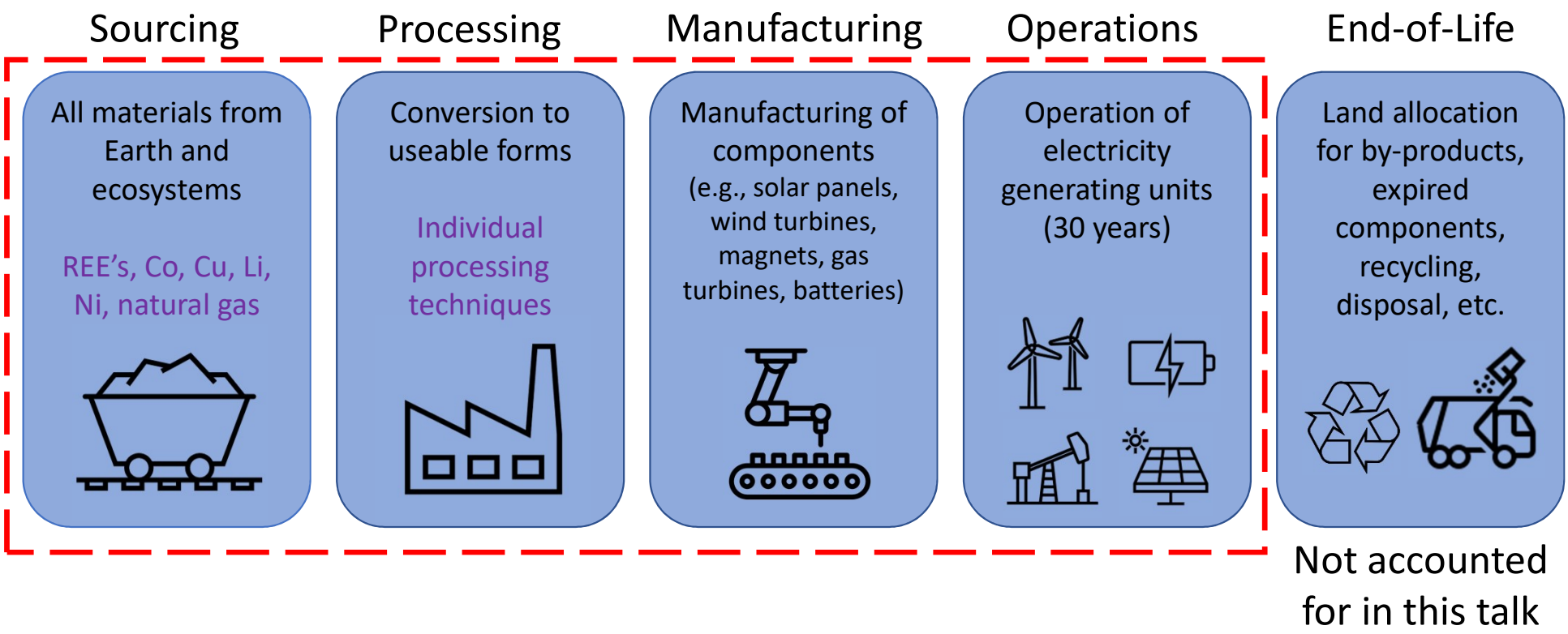
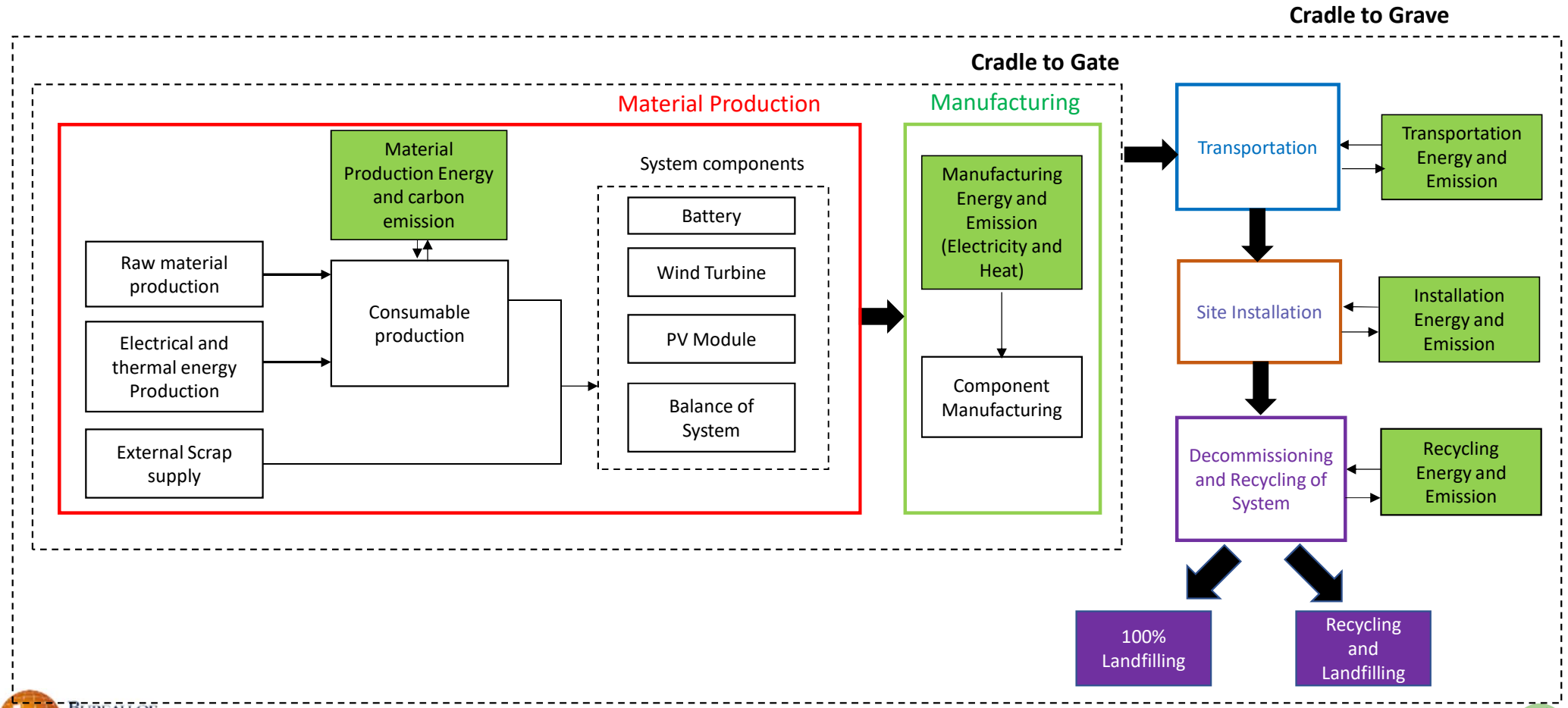
ISO 14040 (principles and framework 2006) and ISO 14044 (requirements and guidelines 2006)

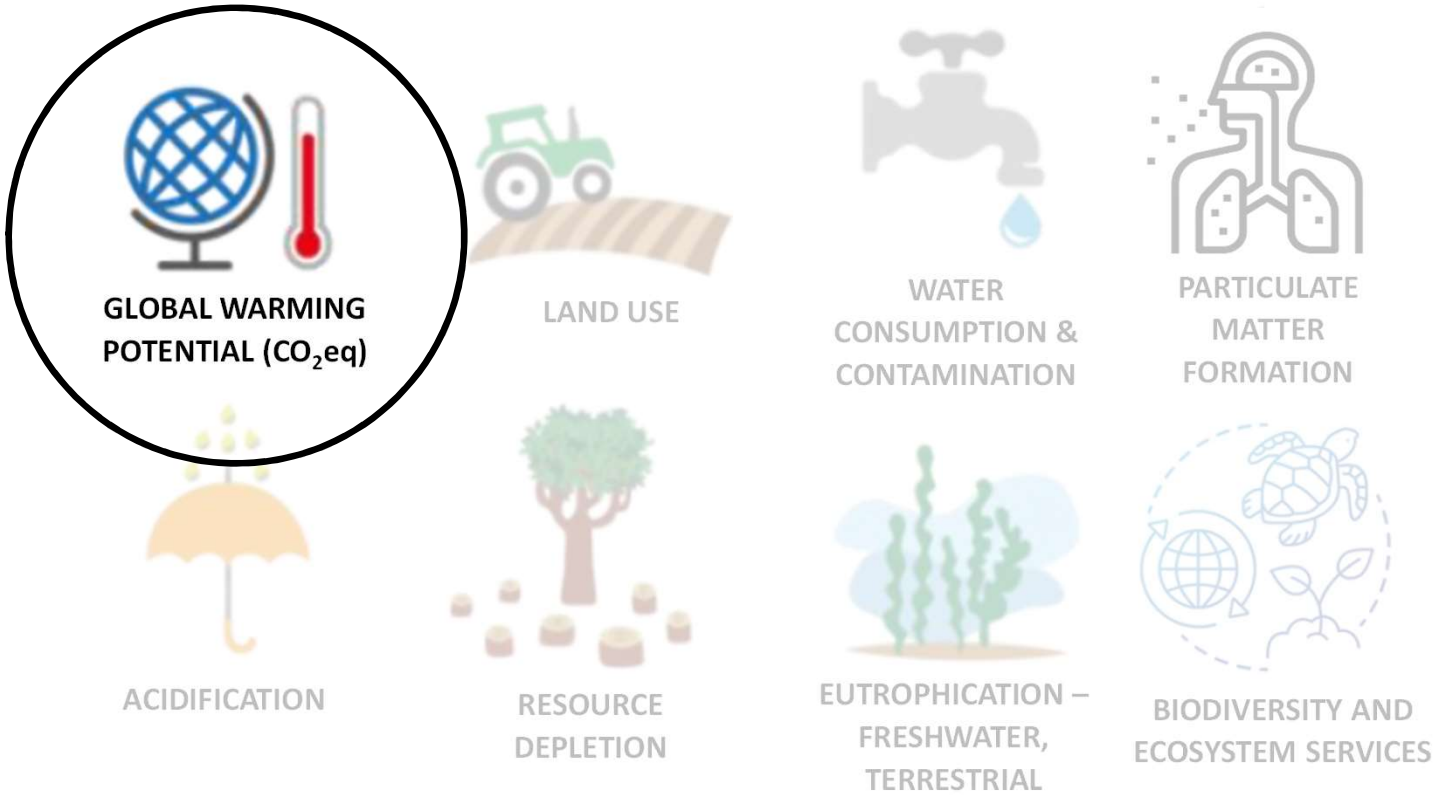
Generalized System Boundaries – Cradle-to-Gate/Grave



Life Cycle System Boundaries of PV-Wind-Battery System



We Consider Impact Categories that are Global …



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Images: Shutterstock, https://eplca.jrc.ec.europa.eu/

… And Other Impact Categories that are Local

GLOBAL WARMING POTENTIAL

LAND USE

WATER CONSUMPTION & CONTAMINATION

PARTICULATE MATTER FORMATION

ACIDIFICATION

RESOURCE DEPLETION

EUTROPHICATION – FRESHWATER, TERRESTRIAL

BIODIVERSITY AND ECOSYSTEM SERVICES

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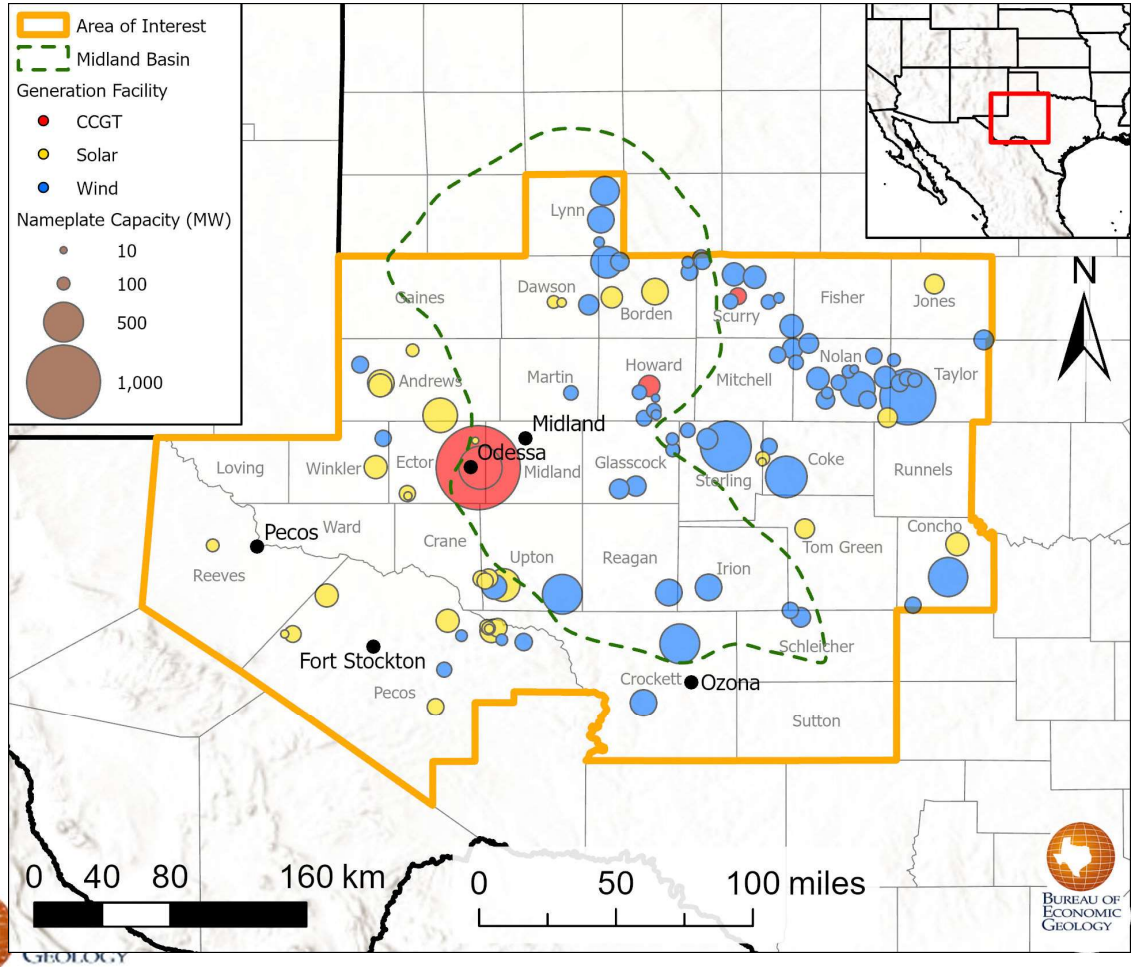
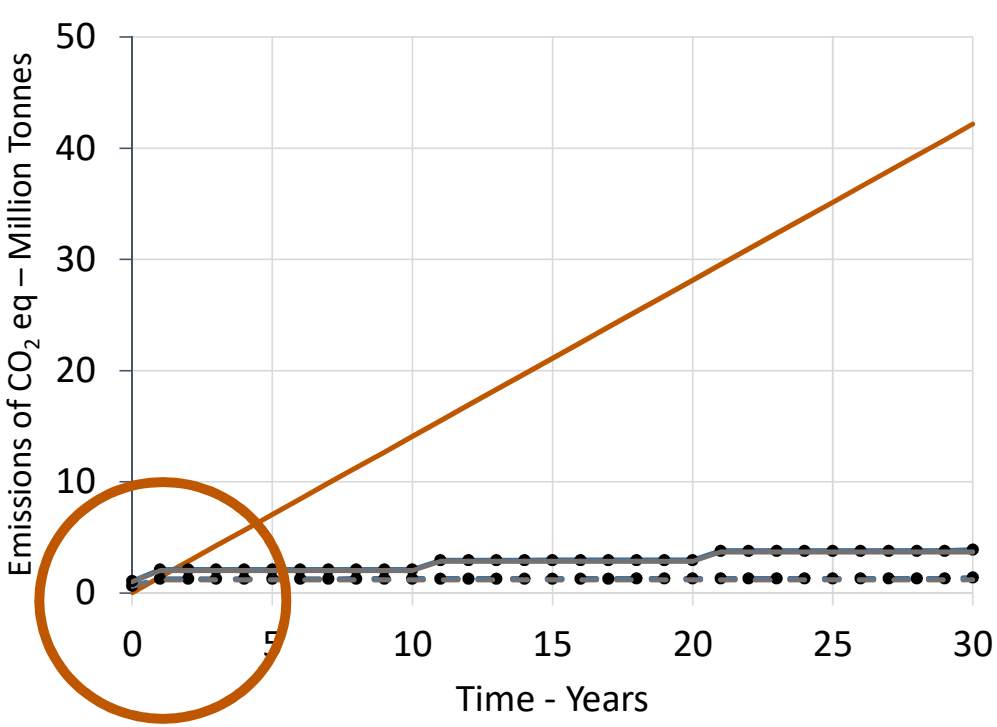
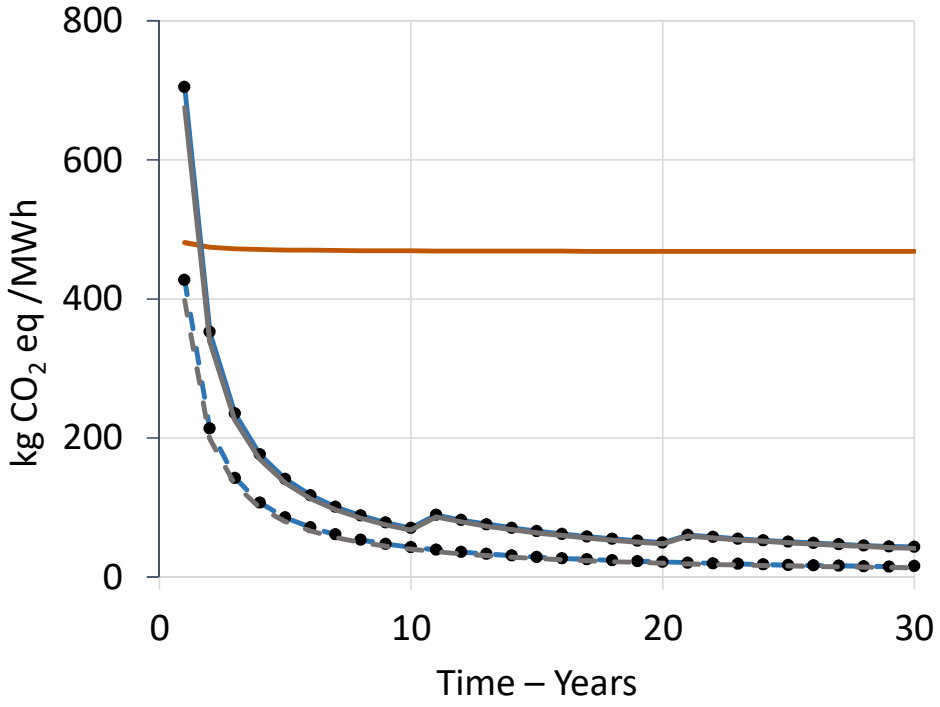
Area of Interest for Electricity Generation



- 33 country region centered on Midland basin, spanning over 10.5 million hectares
- West Texas used in this LCA study
- Location chosen given substantial knowledge of O&G, wind and solar resources, as well as T&D infrastructure
- Study approach ensures transportability of approach to any other location or region

Total Life-Cycle CO_2eq and How it Changes With Time





CCGT — Wind — Solar — Wind + BESS — Solar + BESS

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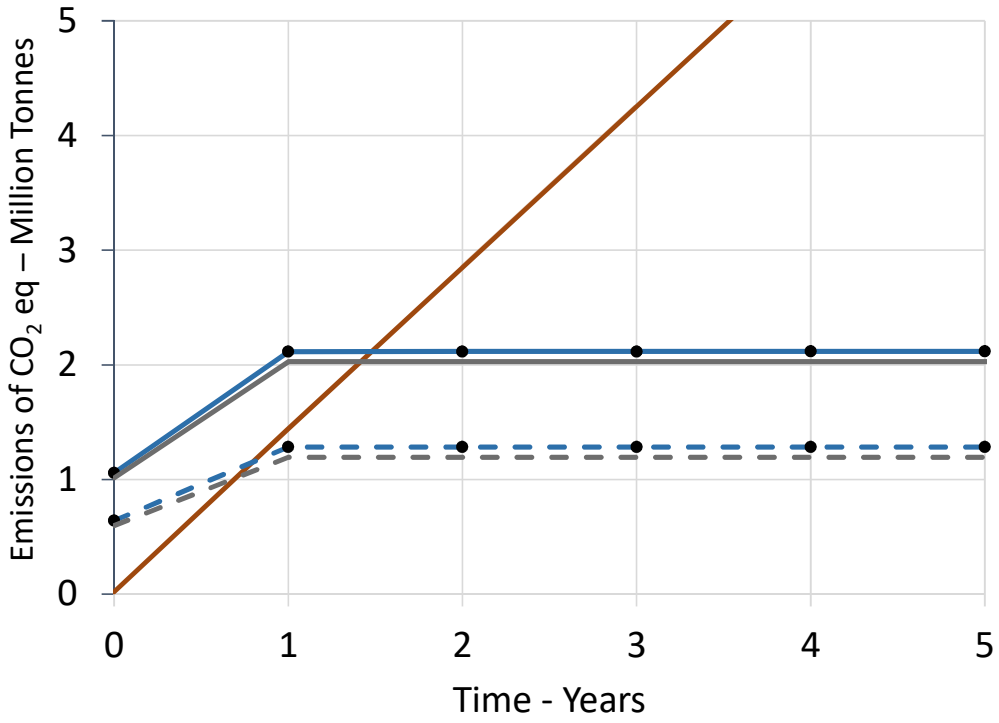
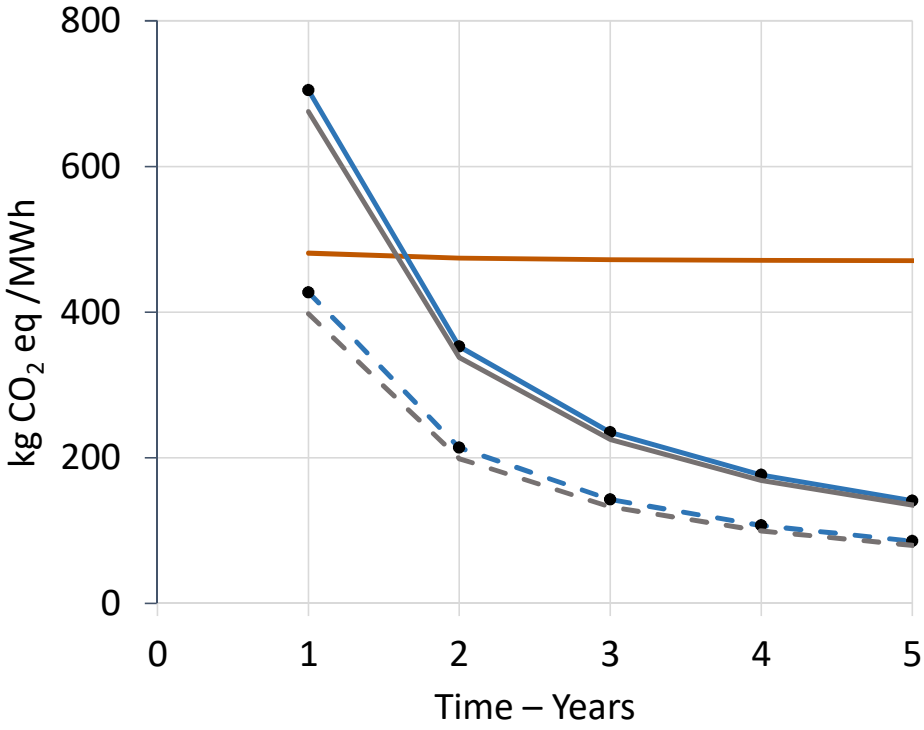
Zooming into First 5-year Life-Cycle of CO_2eq and How it Changes With Time





CCGT — Wind — Solar — Wind + BESS — Solar + BESS

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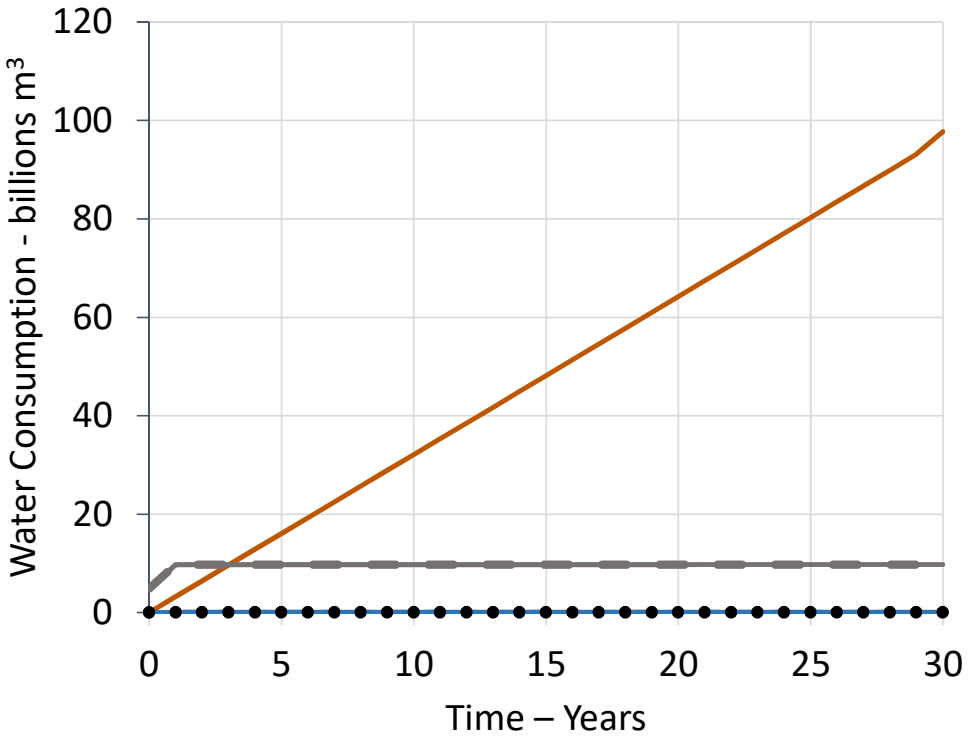
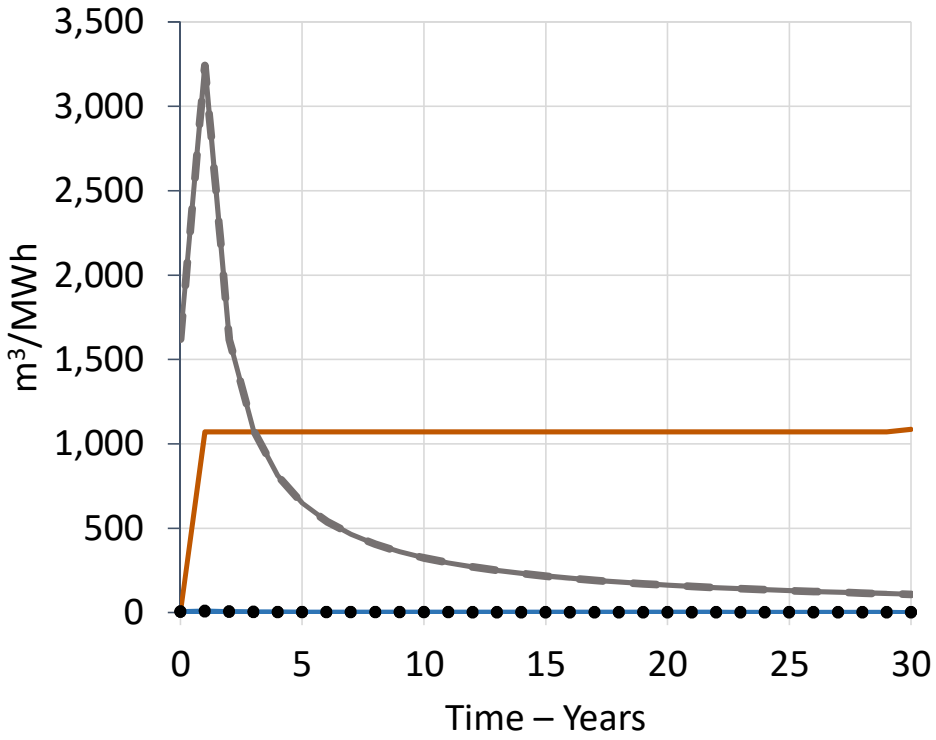
Total Water Consumption at Different Locations and Life Cycle Phases





CCGT — Wind — Solar — Wind + BESS — Solar + BESS

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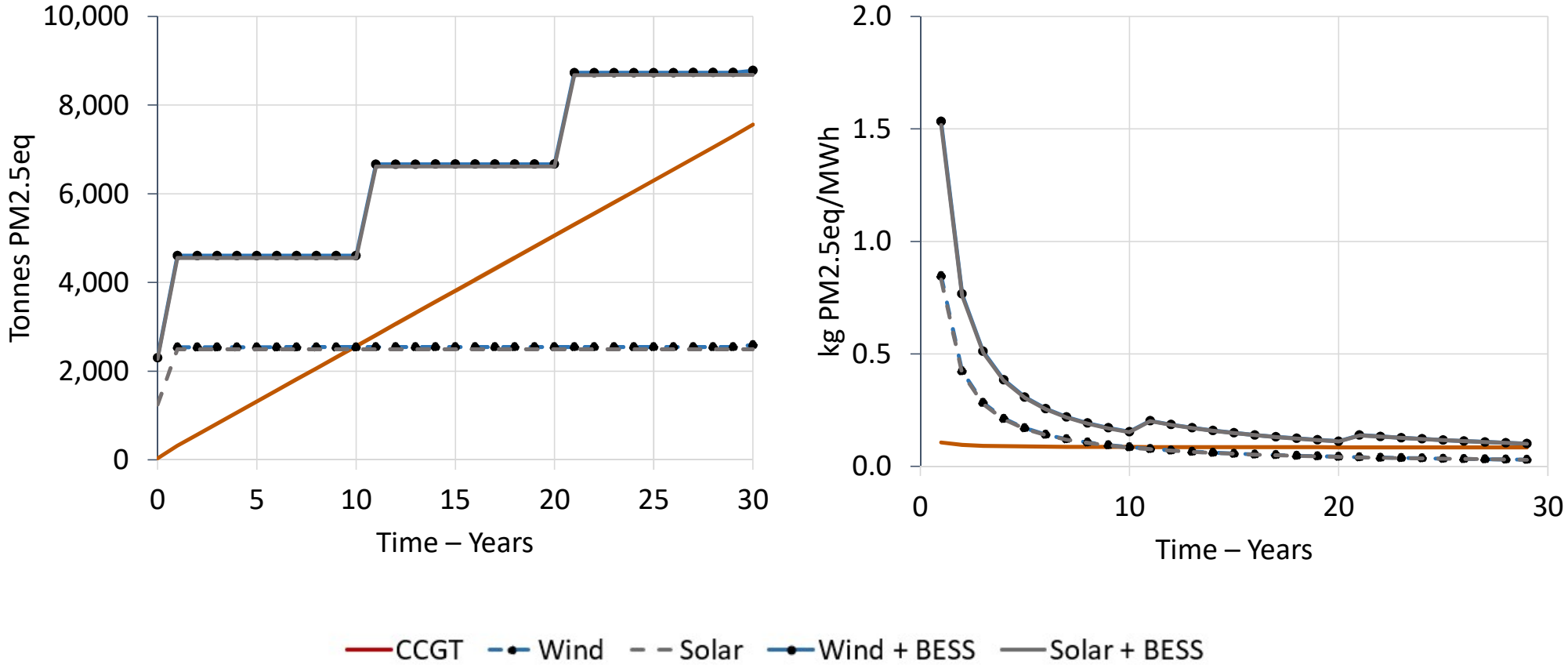
Total Particulate Matter Formation (PM2.5) at Different Locations and Life Cycle Phases and How it Changes With Time



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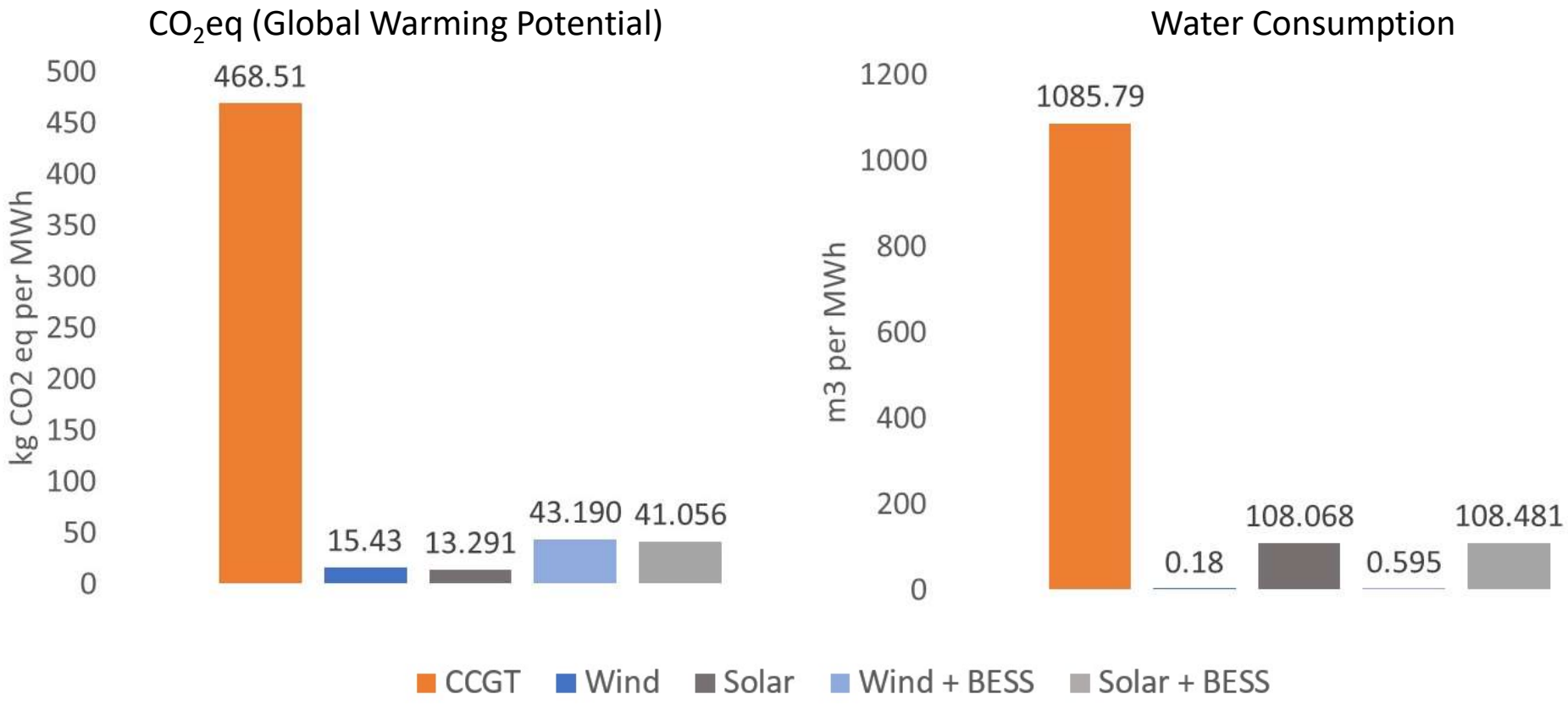
Total Life-Cycle CO_2eq and Water Consumption Potential



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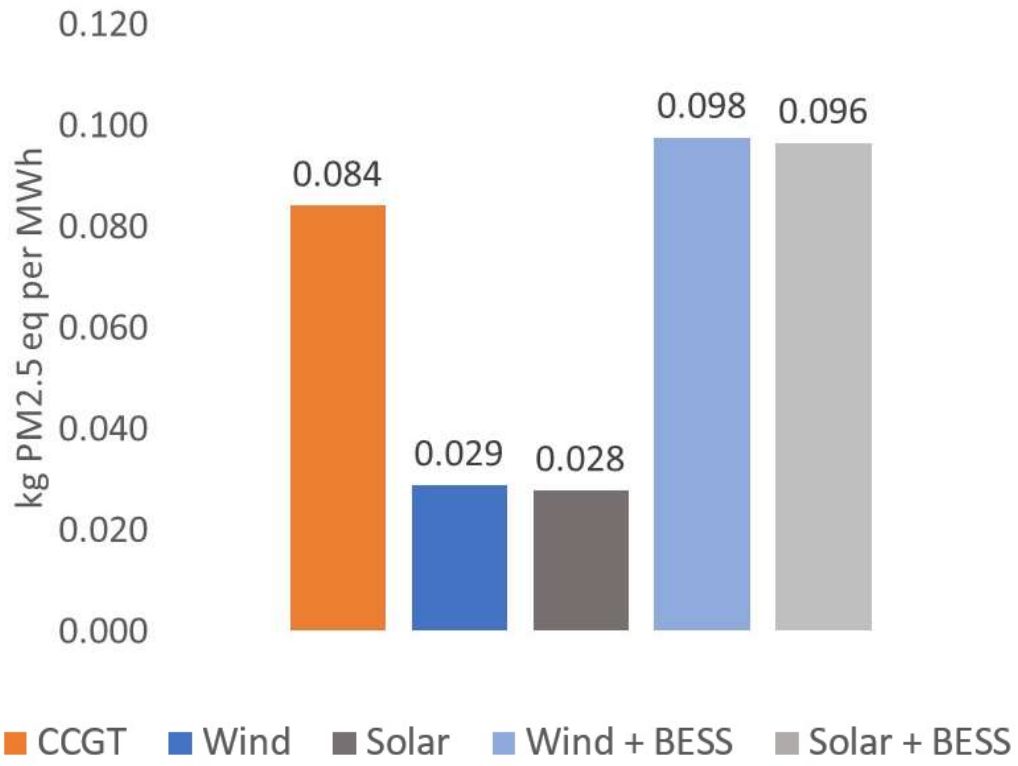
Total Life-Cycle Particulate Matter (PM2.5eq) Formation



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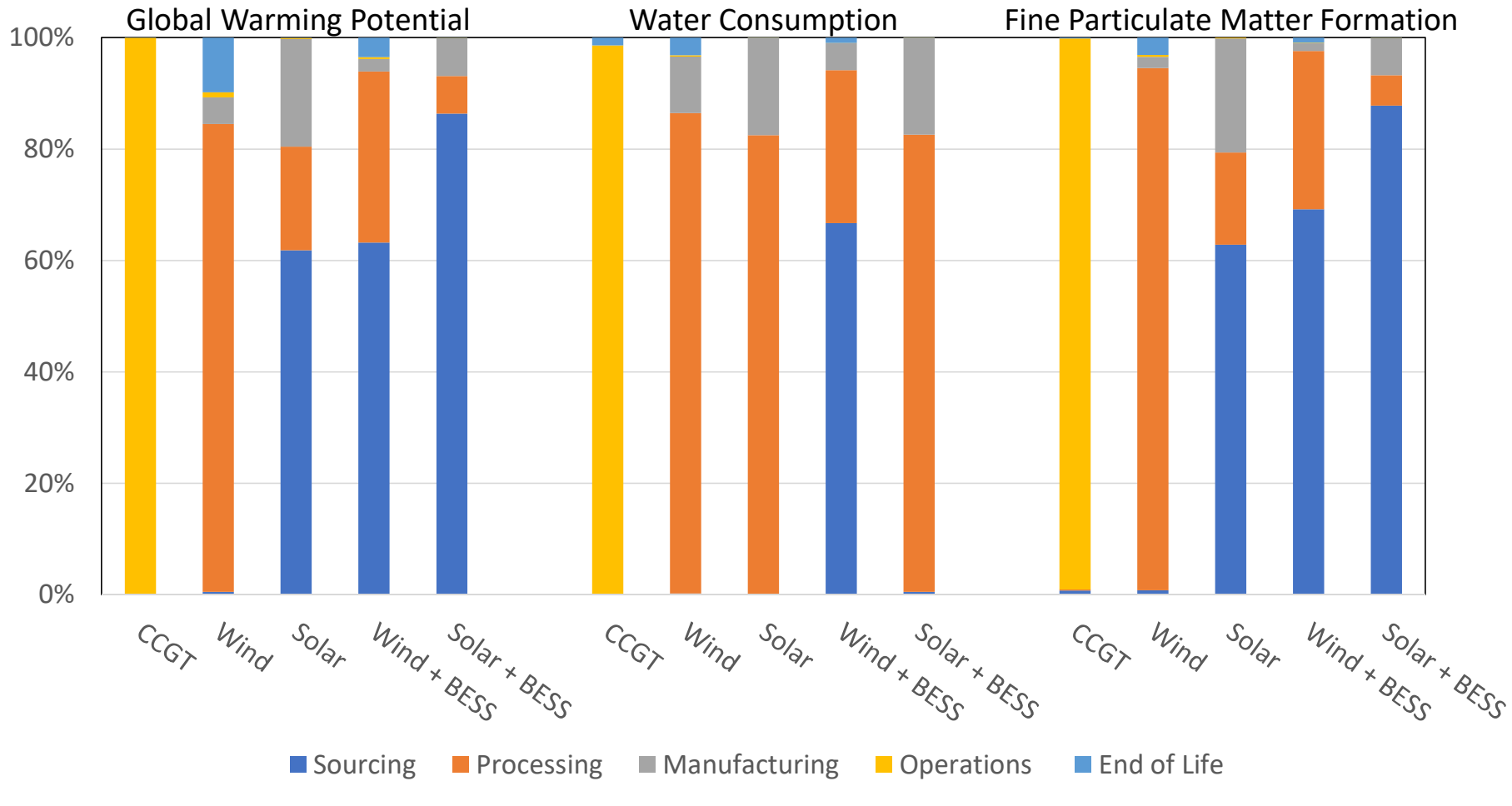
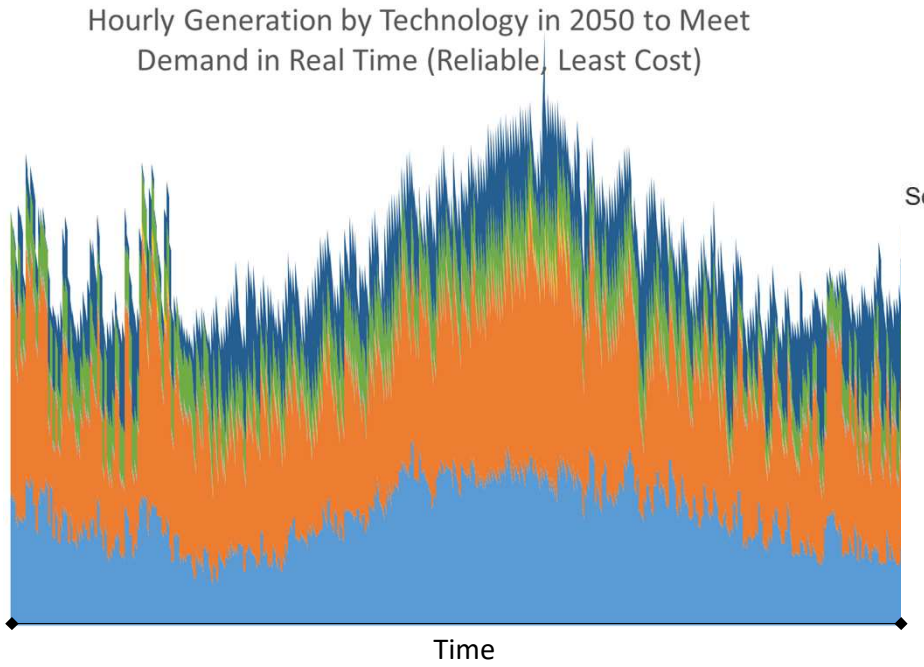
How Do Technologies Compare Along Life Cycle Stages?



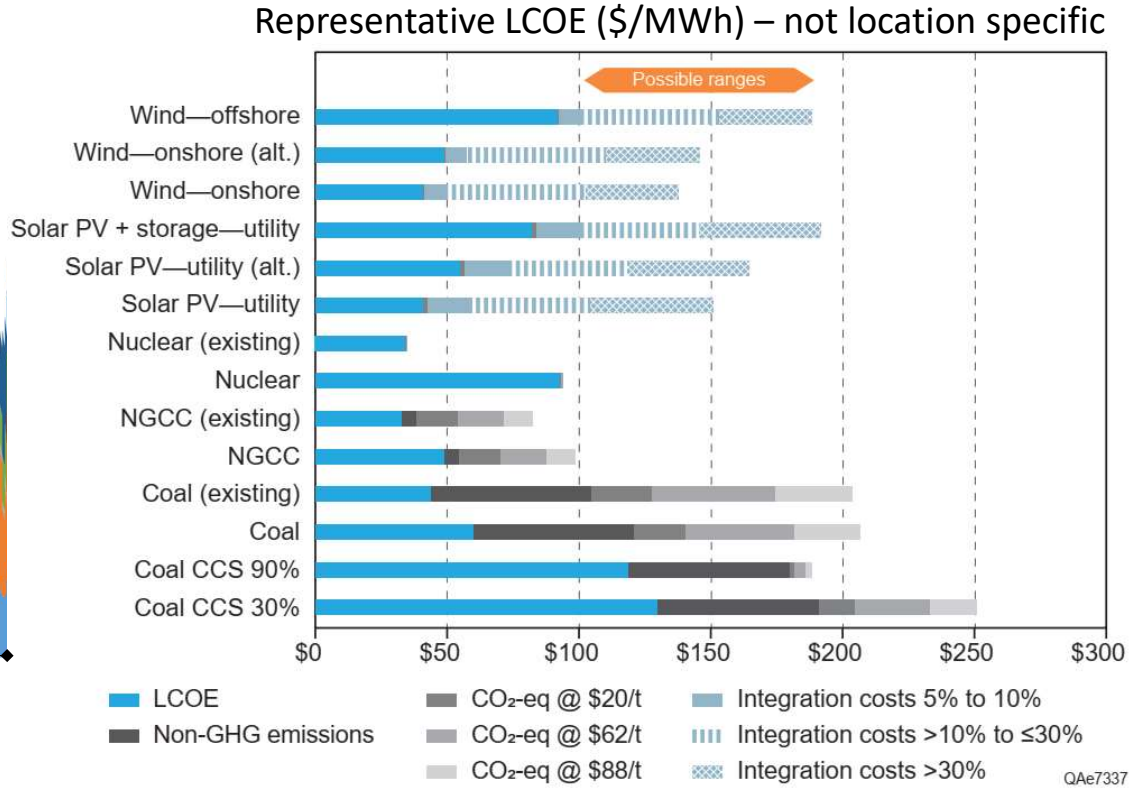
What Did We Find?

- Environmental impacts across full life cycle of different generation options vary by over time and location:
  - CO_2 emissions are global in nature, many others are local in nature
- CO_2 and other impacts from build-out of wind, solar and batteries are front-loaded
- Faster adoption to low-carbon energy leads to higher near-term CO_2 emissions, when manufacturing of infrastructure is fossil-fueled
- In many cases, emissions from material processing for wind, solar and batteries exceed those from CCGT generation throughout facility life

How the Results Will Be Incorporated into Future Studies



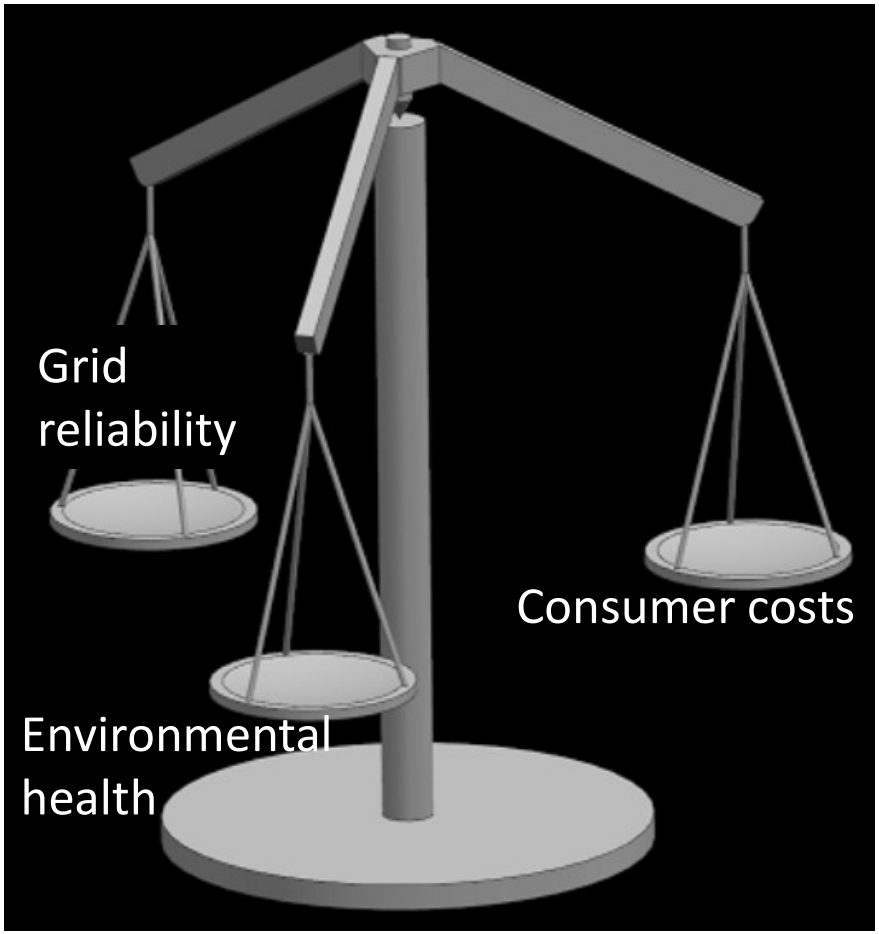
Combine individual systems into a grid model



Develop estimates of electricity costs to consumers

Final Take-Aways

- Grid mix in industry-heavy locations matters … a lot
- Important to broaden consideration to account for local impacts and to local communities
- CO_2 emissions is only part of the story
- Consider actual costs to consumers, including externalities



https://puzzling.stackexchange.com/

Thank you for your interest!!

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Contact: michael.young@beg.utexas.edu

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