February 10, 2025

Introducing Electricity and Electric Infrastructure in R&D GREET®

2:00-3:00 p.m. CT

Instructors

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Argonne National Laboratory Subject Matter Experts

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What Does R&D GREET Encompass?

R&D GREET covers many groups of energy systems

Petroleum

Electric Systems

Natural Gas

Renewable Energy/Fuels

Hydrogen

Electro-fuels

And More

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R&D GREET and electric systems

Electricity generation at U.S. plant level
Aggregate to national, NERC, state, EPA eGRID, and DOE Needs Study regional levels
Various power generation technologies with CCS, if applicable

Natural Gas
Coal
Residual Oil
Biomass
Nuclear
Hydro
Wind
Solar

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LCA of Electricity and Electric Infrastructure in R&D GREET

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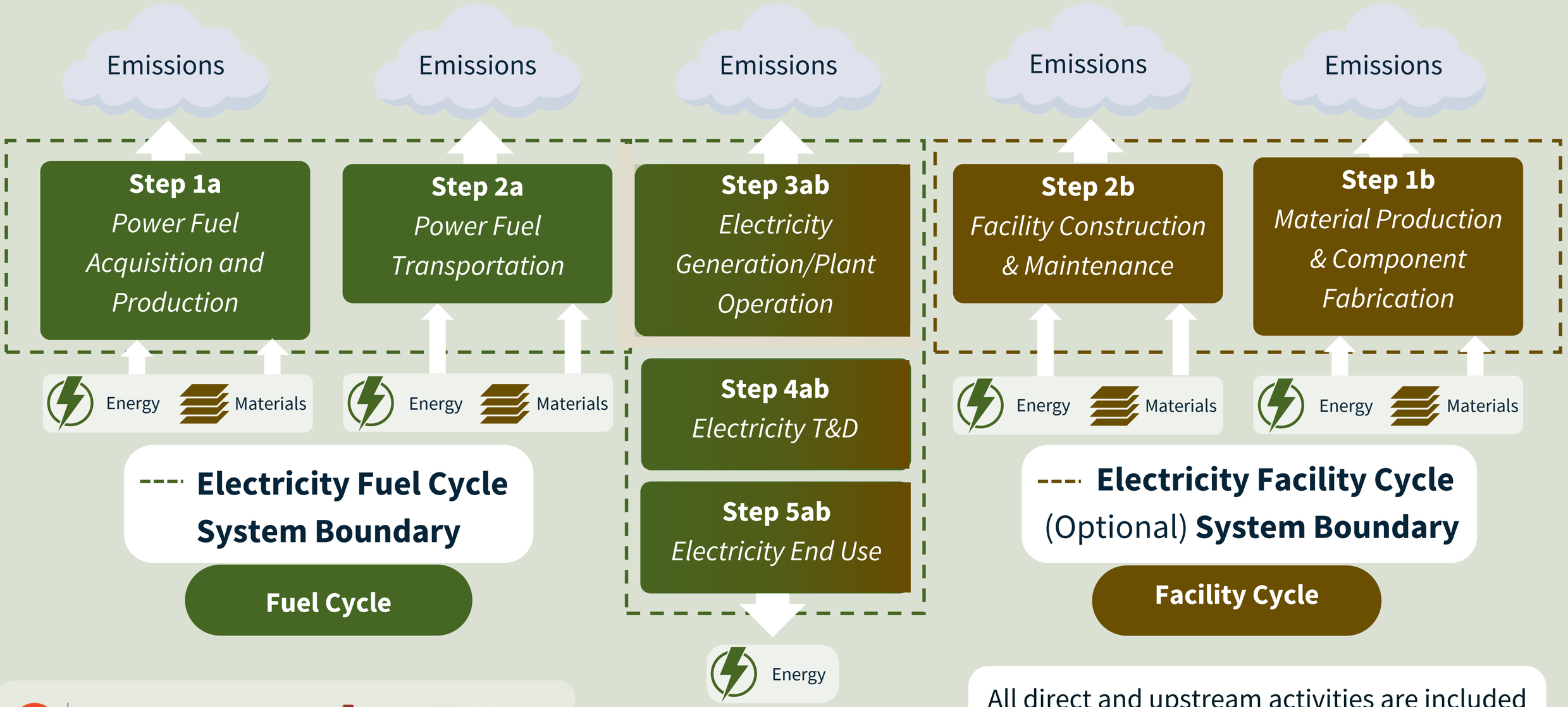
Life cycle of electricity in R&D GREET



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LCA of Electricity in R&D GREET

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Electricity fuel cycle

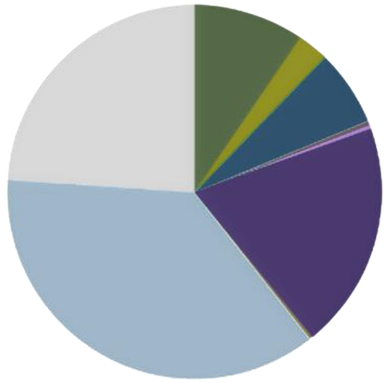
Step 1a: *Power Fuel Acquisition and Production*

- Coal Mining
- Natural Gas Recovery & Processing
- Crude Recovery, Transport, & Refining
- Uranium Ore Mining & Uranium Enrichment
- Biomass Collection
- Geothermal Recovery
- Hydro Power
- Solar
- Wind

Step 2a: *Power Fuel Transportation*

- Coal Transportation
- Natural Gas Transportation
- Fuel Oil Transportation
- Enriched Uranium Transportation
- Biomass Transportation
- Geothermal Transportation

Step 3ab: *Electricity Generation*



U.S. Generation Grid Mix

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Electricity generation technologies: *fossil*

R&D GREET covers electricity generation from various sources and more than 30 generation technologies

Coal

Steam boiler (with or without carbon capture and sequestration (CCS)), *combined heat and power (CHP)*; integrated gasification combined cycle (IGCC)

Natural Gas

Combined cycle turbine (with or without CCS), *CHP*; simple cycle turbine, *CHP*; steam boiler, *CHP*; reciprocating combustion engine

Oil

Steam boiler; gas turbine; reciprocating combustion engine

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Electricity generation technologies: *nuclear*

R&D GREET covers electricity generation from various sources and more than 30 generation technologies

Nuclear

- Light water reactor (LWR)
  - Pressurized water reactor (PWR)
  - Boiling water reactor (BWR)
- High-temperature gas reactor (HTGR)

Other Generation III and Generation IV Reactors

Generation IV reactors contain technological advancements for enhanced sustainability

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- Generation IV Goals, Technologies and GIF R&D Roadmap | GIF Portal

Electricity generation technologies: *renewables*

Biomass

Steam boiler; IGCC; feedstock of forest residue, switchgrass, poplar, willow, miscanthus and more

Wind Turbine

On-shore and off-shore

Solar

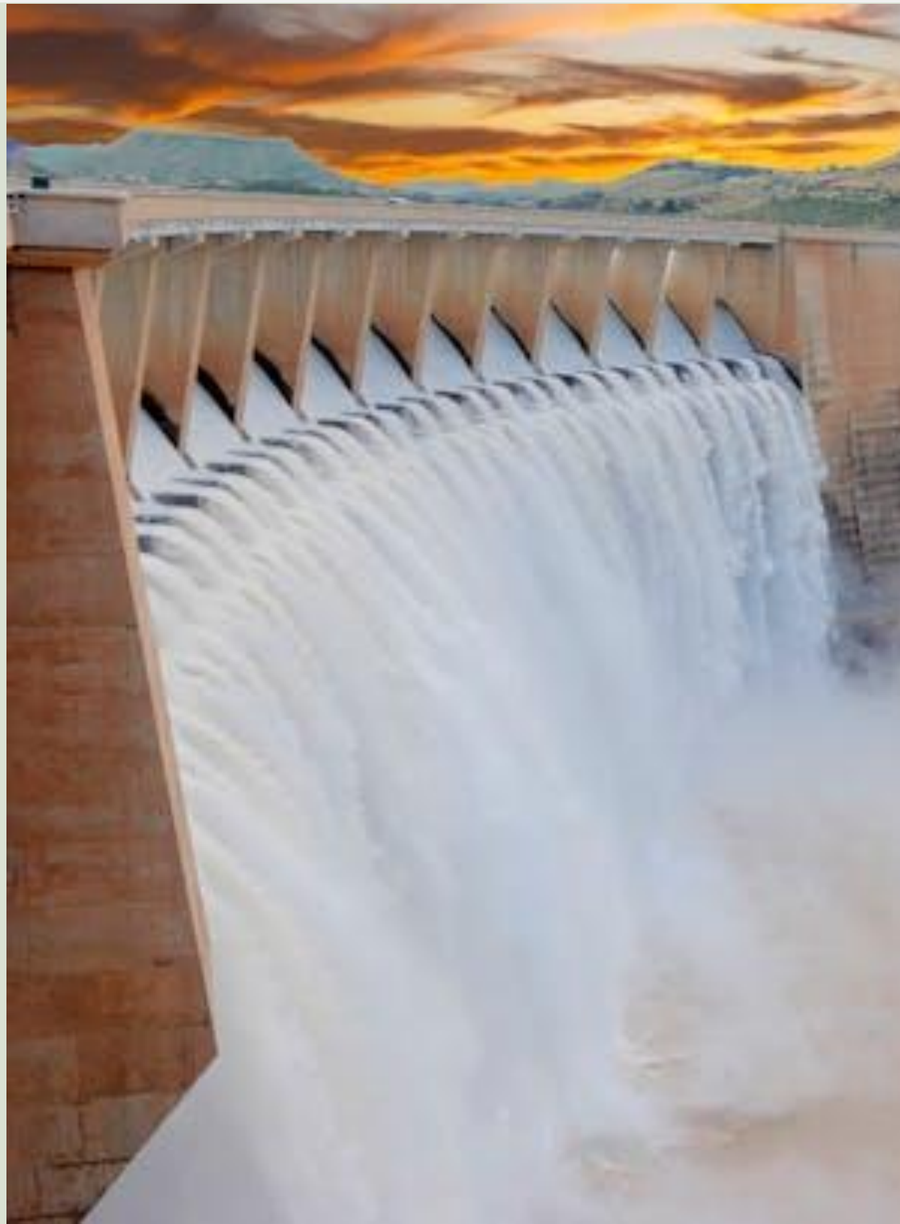
Single-cSiPV and multi-cSiPV

Geothermal

Hydrothermal flash; hydrothermal binary; enhanced geothermal systems

Hydropower

Concrete gravity dam and embankment dam



R&D GREET capabilities for LCA of electricity

Related LCA Inputs

- Source types
  - Coal, gas, oil, nuclear, biomass, wind, solar, hydro, geothermal, and more
- Generation technologies
  - Boiler, turbine, with CCS, CHP, and more
- Power grid decarbonization scenarios

Energy and Environmental Metrics

Energy intensities of total, fossil (petroleum, gas, coal), renewable (biomass, hydro, wind, solar), nuclear, water use intensities, GHG emission intensities (total and CO_2, CH_4, and N_2O separately), air pollutants' emissions intensities of VOC, CO, NO_x, $PM_{2.5}$, PM_{10}, SO_x, BC, and OC

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Domestic coverage of electricity LCA in R&D GREET

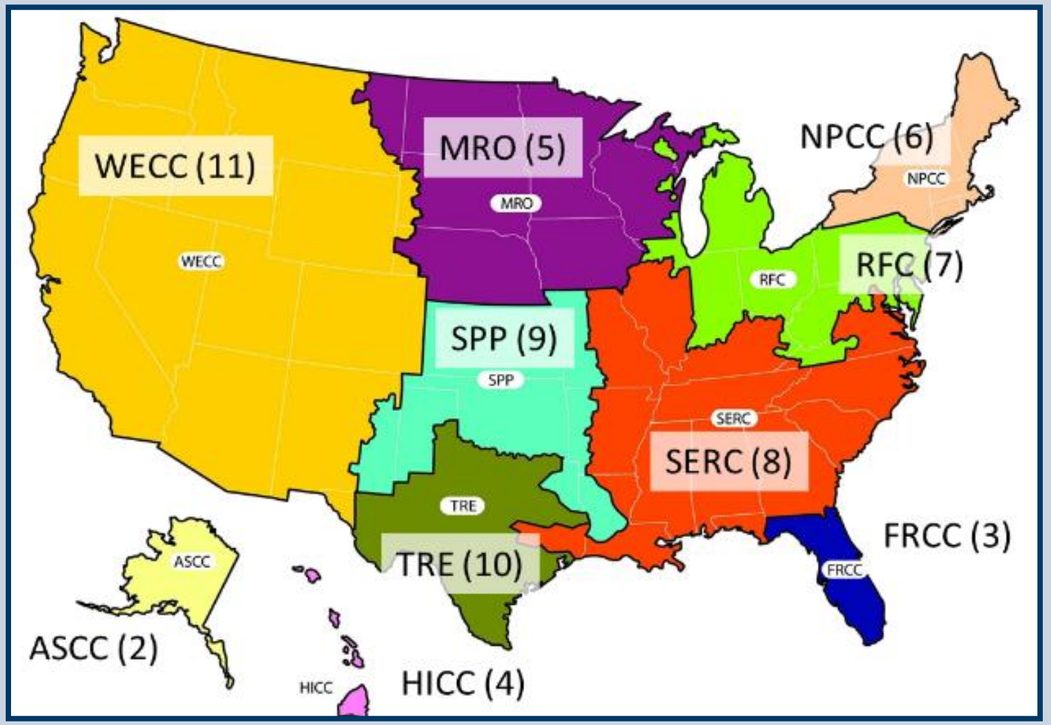
U.S. National Average

Emissions & Generation Resource Integrated Database (**EPA eGRID**) regions

DOE Needs Study regions

States in the United States

North American Electric Reliability Corporation (**NERC**) regions



- NERC 2022

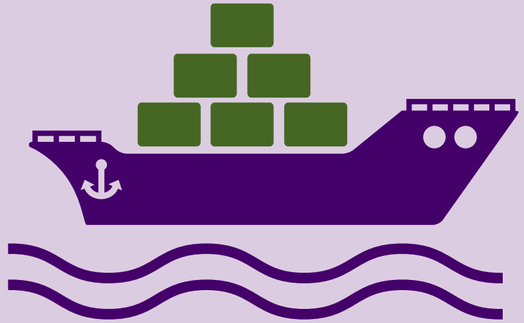
International and domestic coverage of electricity LCA in supply chains in R&D GREET

30+ Countries

- **North America**: Canada, Jamaica, Mexico
- **Asia**: China, Japan, Korea, Singapore, Indonesia, Bahrain, UAE, India, Kazakhstan, Papua New Guinea, Philipines
- **Europe**: Finland, Norway, Russia, France, Germany, Poland, Ukraine
- **South America**: Brazil, Chile, Argentina, Venezuela
- **Africa**: South Africa, Congo
- **Oceania**: Australia, New Caledonia

Supply Chain-specific Results

- Europe, China, Japan, and Korea mixes for **aluminum production**
- Congo mix for **cobalt production**
- Chile mix for **lithium production**
- Alberta mix for **Canadian oil sand recovery**
- and more



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Data Sources for R&D GREET Electricity LCA

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Data sources for R&D GREET electricity LCA:

U.S. plant operation

Thermal Efficiencies

Unit-level performance data (EIA 923 and 860)

Aggregated to technology, regional, and national levels

GHG Emission Factors

CH_4 and N_2O GHG reporting rule (EPA 2009)

CO_2 fuel's carbon content and carbon balance

Criteria Air Pollutants (CAP)

Plant-level emissions (EPA NEI 2017, EIA, and e-GRID)

Water Use

EIA and USGS's plant-level data

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Data sources for R&D GREET electricity LCA: *CAP EF*

Top-down approach is used for estimating CAP emission factors (EF)

$$EF = \frac{\sum_{fuel,technology} Emission}{\sum_{fuel,technology} Elec\_gen}$$

U.S. Energy Information Administration (EIA) 923

Facility-level net power generation, primary fuel, and primary combustion technology

EPA's Clean Air Market's Division (CAMD)

Facility-level CO_2 and NO_x and SO_x emission data for the power plants reporting to CAMD programs

National Emissions Inventory (NEI)

Facility-level pollutant emissions

Data sources for R&D GREET electricity LCA:

transmission losses

U.S. Transmission Losses

EIA electricity profiles

Other Country Transmission Losses

World Bank Database

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Data sources for R&D GREET electricity LCA:

electricity generation mixes

Unit-level Generation Data (EIA 923)

Aggregated to technology, regional, and national levels

U.S. Future Projections

NREL's Standard Scenarios & EIA's Annual Energy Outlook

Other Countries Future Projections

Informational Energy Agency's (IEA) electricity information

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Data sources for R&D GREET electricity LCA:

upstream

Plant fuels are linked to their upstream production pathways in R&D GREET

- **Coal**: coal mining, cleaning, and transportation
- **Gas**: natural gas recovery, processing, and transportation
- **Oil**: crude recovery, transportation, refining, and fuel oil transportation
- **Biomass**: farming, harvesting, and transportation
- **Nuclear**: uranium mining, yellowcake conversion, enrichment, and fuel rod fabrication

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Life Cycle Emissions of Electricity

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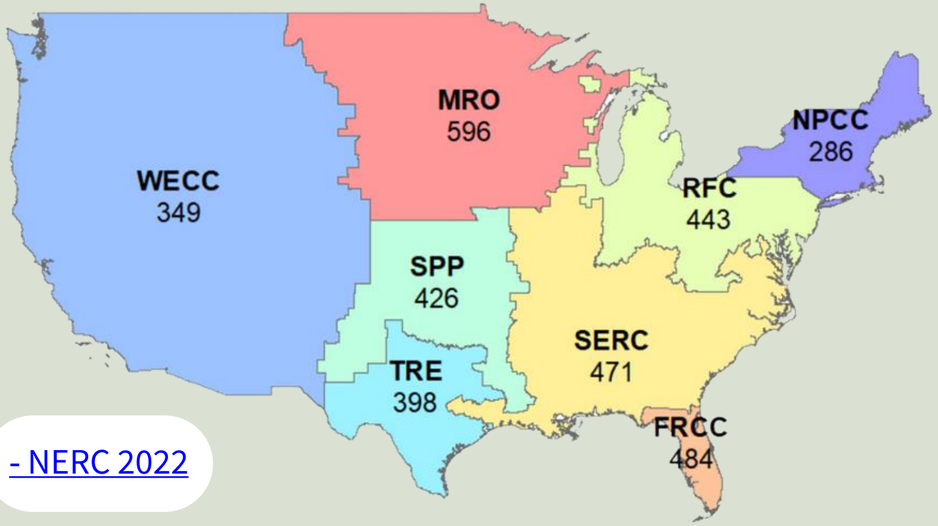
Well-to-wheels GHG emissions in R&D GREET

2022 U.S. Electricity GHG Intensity

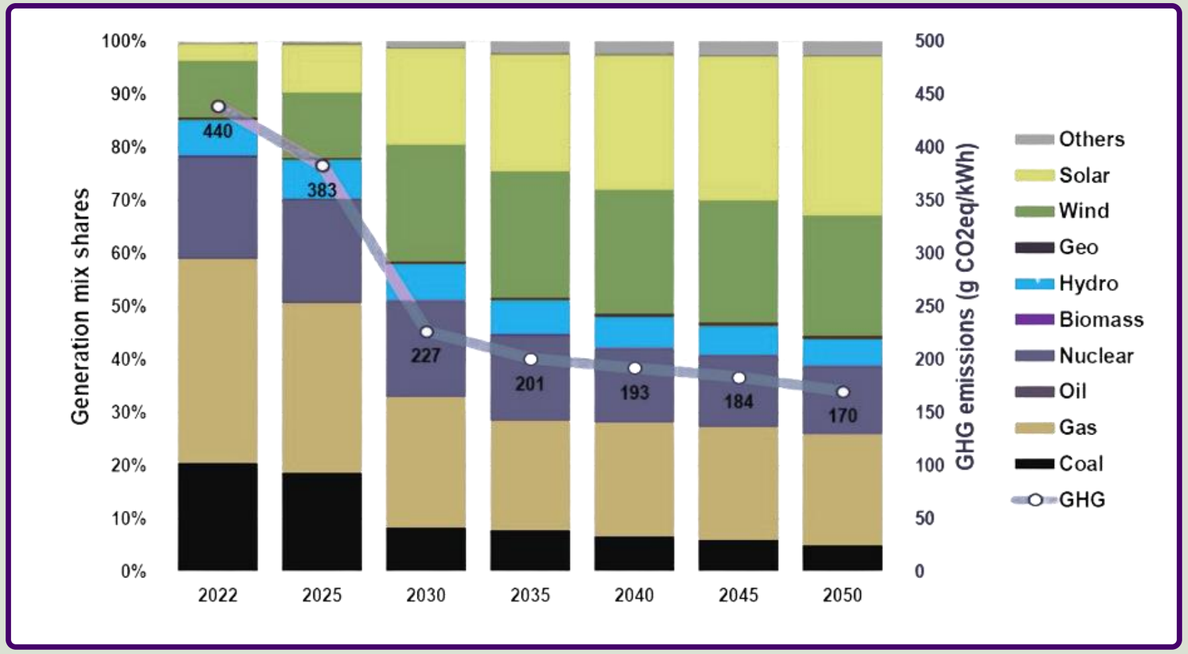
Mix: gas 39%, coal 21%, nuclear 19%, renewable 21%

440 g CO_2e/kWh at the wall outlet

Electricity GHG intensities are low in the east and west coast and high in the mountain and central U.S.



- NERC 2022



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- R&D GREET

U.S. electricity GHGs will continue to decrease overtime *(EIA AEO2023 reference)*

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Electricity Tabs in R&D GREET

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Electricity tabs in R&D GREET 1

Primary

Electric

Generation_mixes

Bioelectricity

Some Secondary

Inputs

Results

Petroleum

NG

RNG

BioOil

Fuel_Specs

Vehicles

T&D

T&D Flowcharts

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LCA of Electric Infrastructure in R&D GREET

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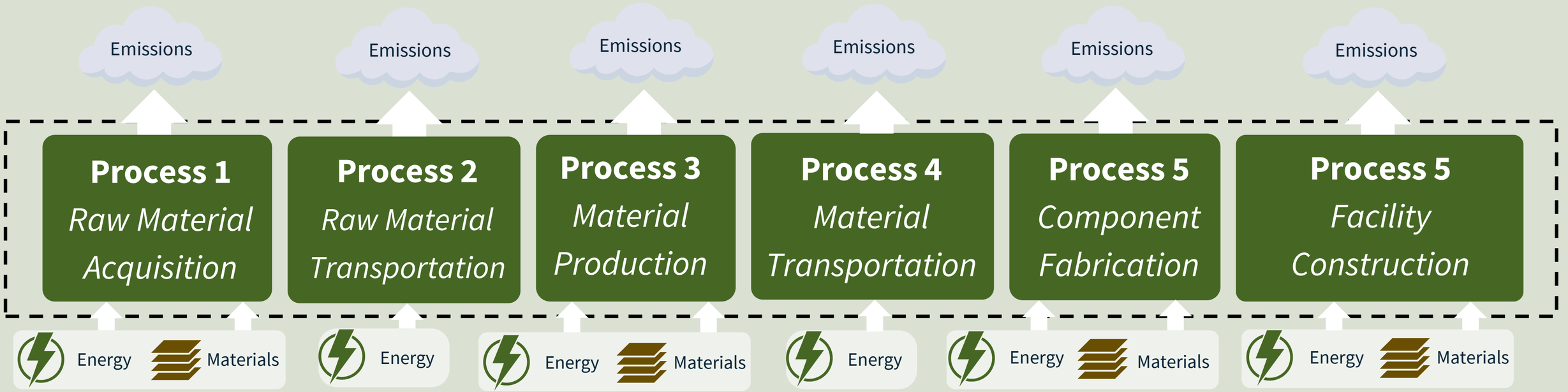
Electricity facility cycle



Facility Types

Coal-fired power facilities, gas-fired power facilities, oil-fired power facilities, nuclear power facilities, biomass-fired power facilities, geothermal stations, hydropower dams, solar photovoltaic (PV) systems, and wind turbines

-- Life Cycle System Boundary

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Electric infrastructure technologies

Fossil

Coal, natural gas, and oil

Nuclear

Renewables

Wind, solar, hydropower, geothermal, and biomass

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Facility cycle of solar in R&D GREET

Including plant embodied emissions has significant impact on the emission estimate for renewable power technologies

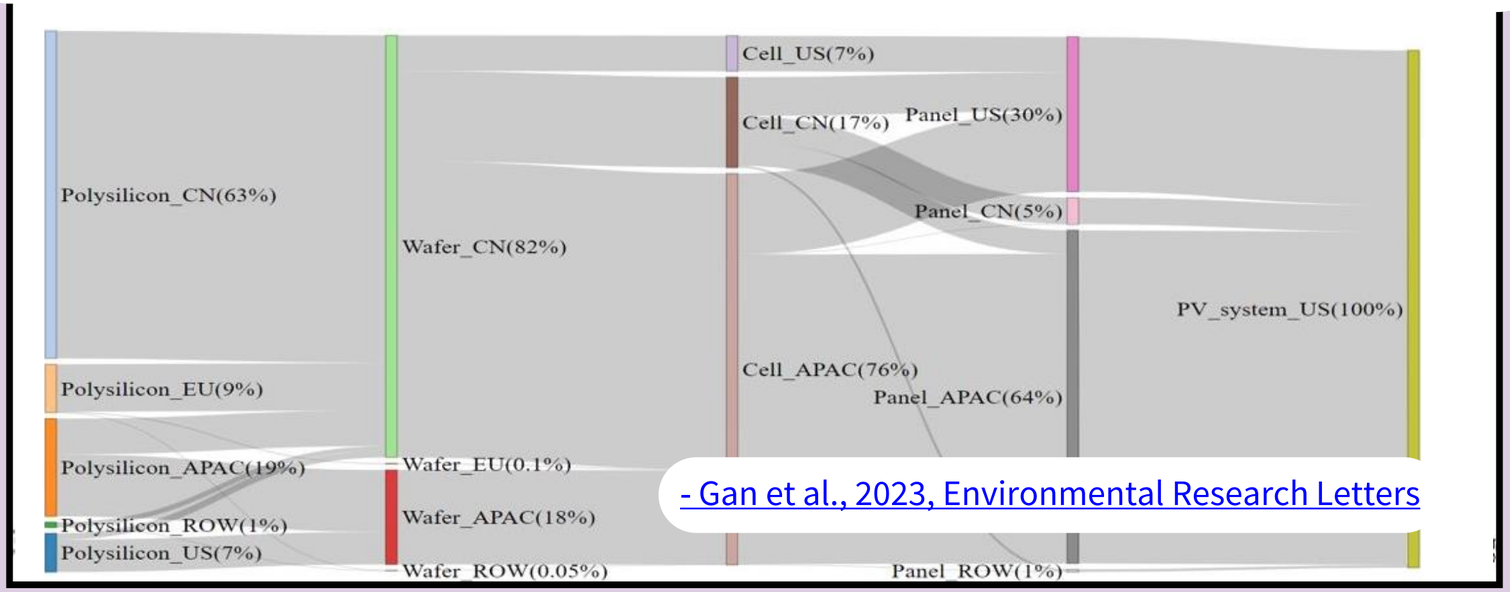
From production of polysilicon, silicon wafer, PV cells, PV panels, to installed PV systems

- China dominates the global silicon supply chain, followed by other Asia-Pacific and European countries
- U.S. plays a limited role in the upstream and midstream supply chain of solar PV

Consider **regionalized electricity mixes** and material production

Consider regionalized solar irradiance, mounting/installation type, PV system lifespan, system performance ratio (PR) and its degradation over time, PV conversion efficiency, and more

Polysilicon - Silicon Wafers – PV Cells – PV Panels - PV System



- Gan et al., 2023, Environmental Research Letters

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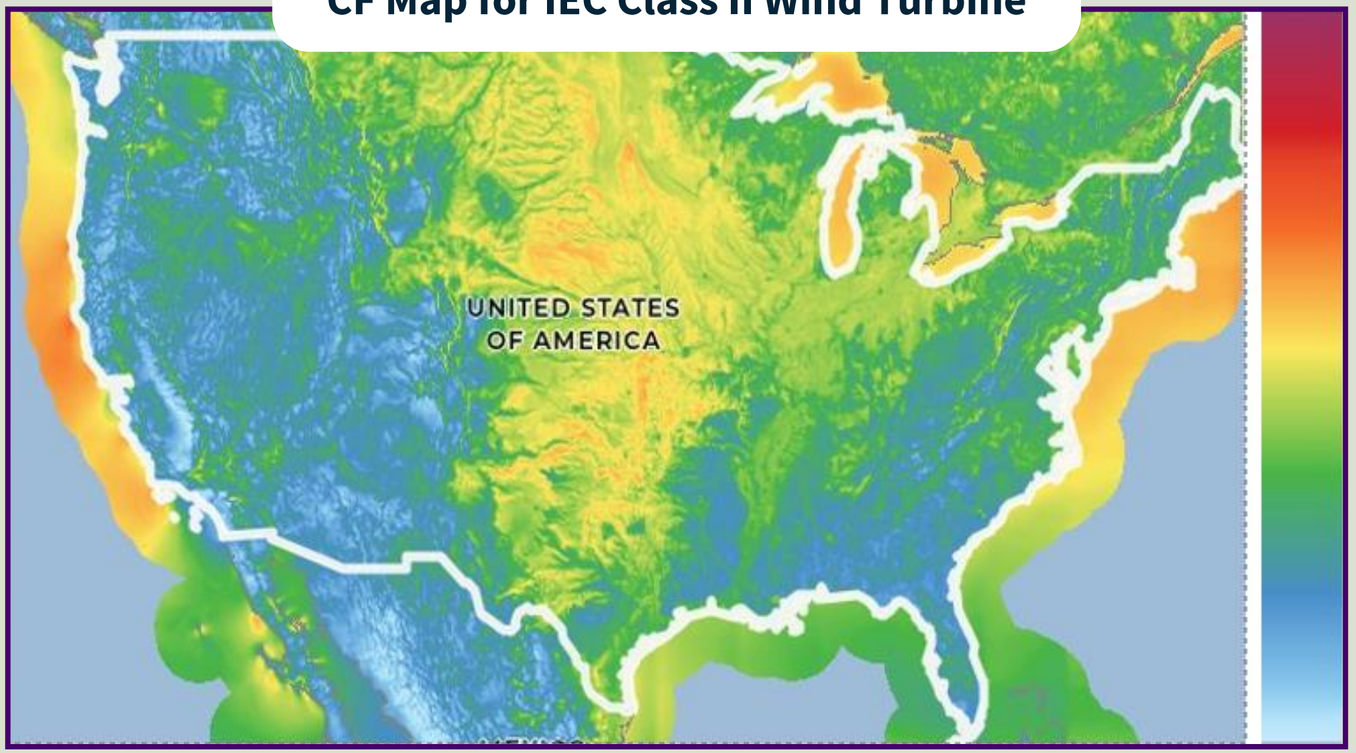
Facility cycle of wind turbines in R&D GREET

Embodied emissions in wind turbines depend on the type of turbine, model of turbine, and installation location

Installation Location

- On-shore
- Off-shore
  - Shallow water (bottom fixed foundation)
  - Deep water (floating foundation)

CF Map for IEC Class II Wind Turbine



- Global Wind Atlas | Technical University of Denmark

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Life Cycle Emissions of Electricity and Electric Infrastructure

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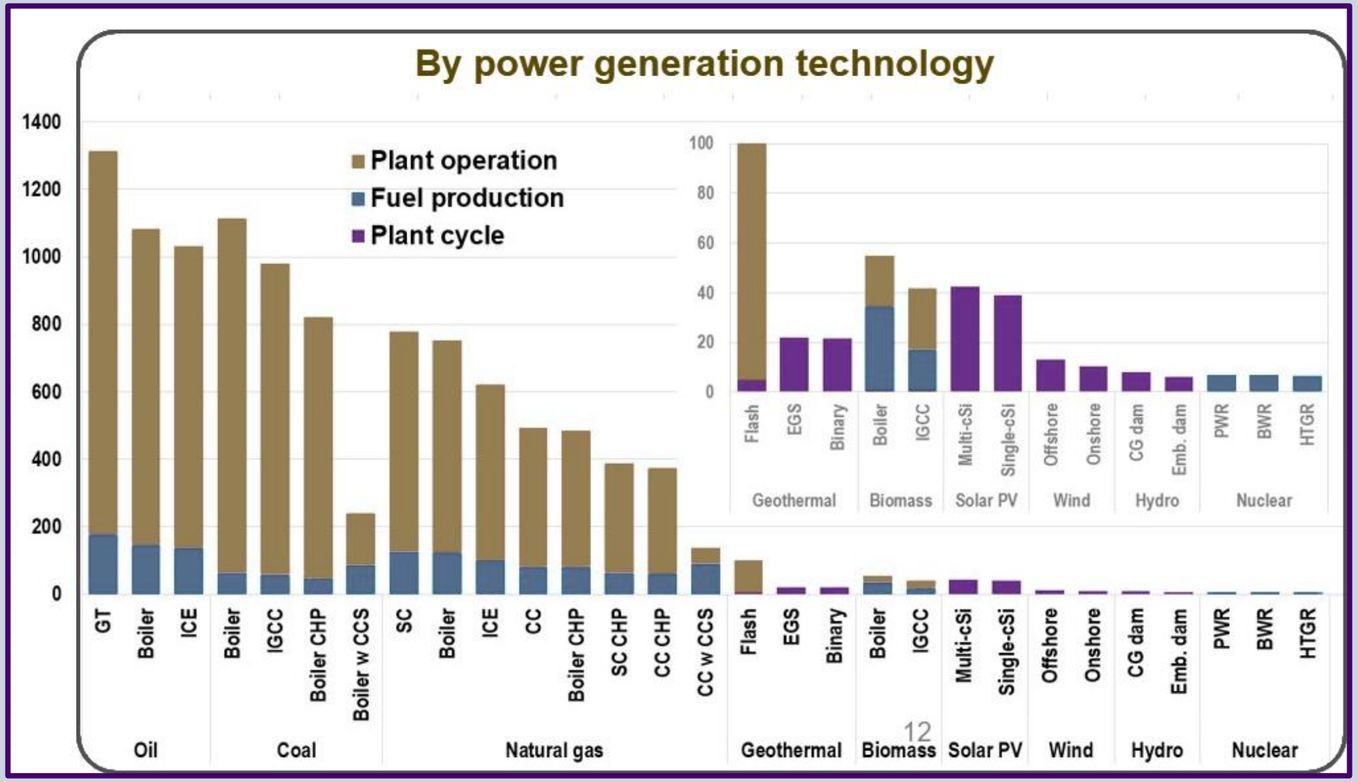
Full life cycle GHG emissions with facility cycle

Including plant embodied emissions has significant impact on the emission estimate for renewable power technologies

Thermal power plants (coal, gas, oil, and biomass) results are dominated by GHG emissions from **plant operation** and **plant fuel production** stages

Renewable power facilities have higher **facility cycle** GHG emissions than fossil-fired and nuclear plants



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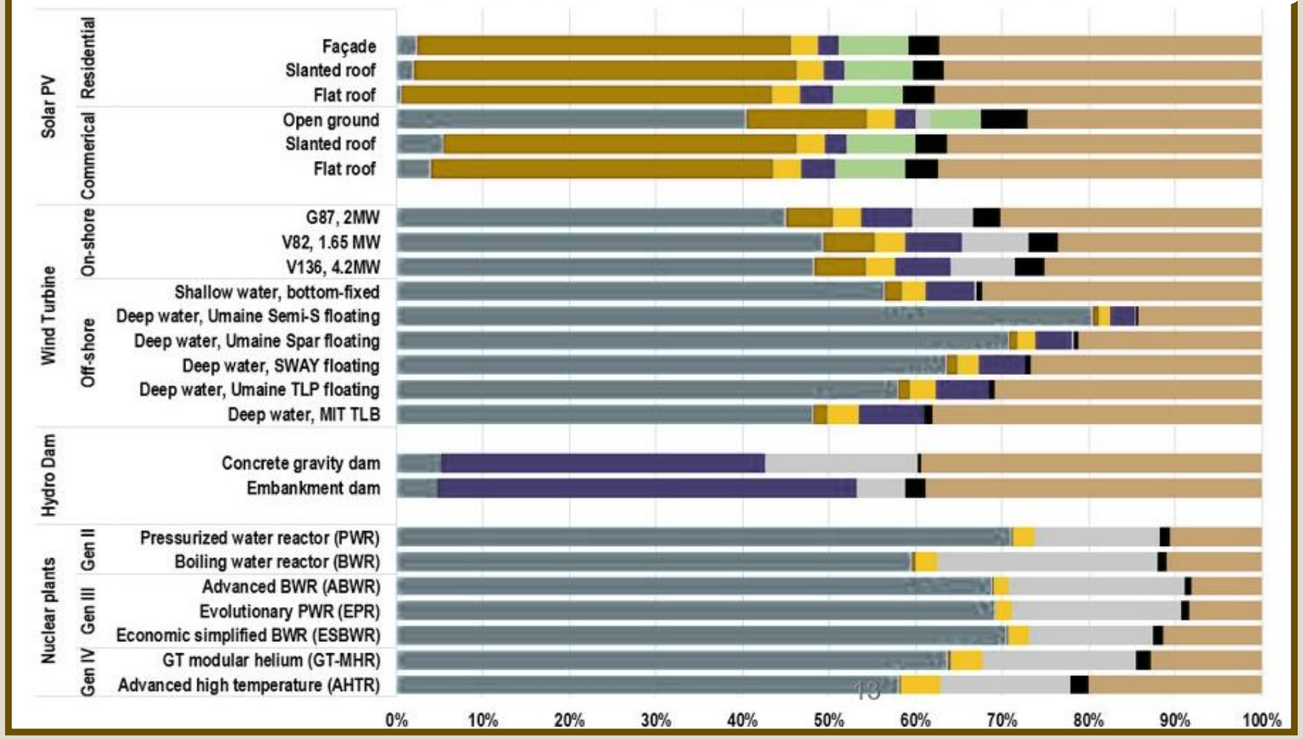
Full life cycle GHG emissions with facility cycle

Facility cycle emissions depend on facility types, designs, models, and locations

Source Breakdowns of Embodied GHG Emissions in Plant Cycles



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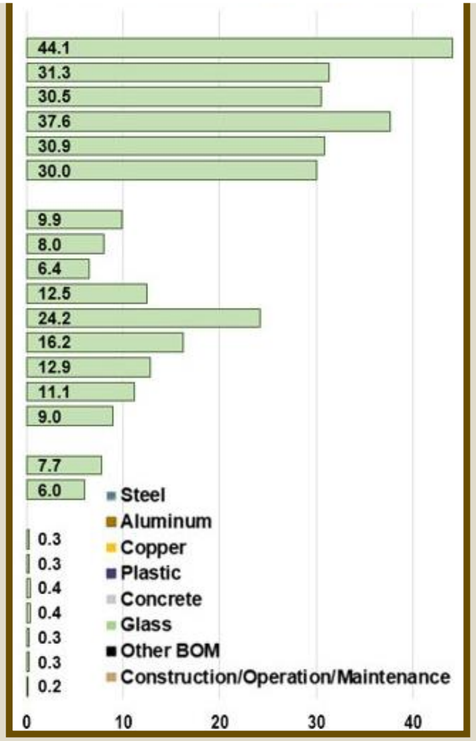
Embodied GHG (g CO_2e/kWh)



Per kWh GHG Emissions

Solar PV > wind turbine > hydro dam > nuclear plants

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Electric Infrastructure Tabs in R&D GREET

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Electric infrastructure tabs in R&D GREET 1

Primary

Electric

ElecInfra

OilGasCoalInfra

Some Secondary

Inputs

Results

Fuel_Specs

EF

T&D

T&D Flowcharts

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Electric infrastructure tabs in R&D GREET 2

Primary

Wind_Turbine

Solar_PV

Hydropower

Nuclear_Power

Some Secondary

TEC_Results

MHDV_TEC_Results

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