NREL Transforming ENERGY

HOPP – An Overview

11.02.2023

NREL HOPP Workshop after NAWEA/WindTech 2023

Omni Interlocken Hotel, Broomfield, CO

Photo by Dennis Schroeder, NREL 55200

Acknowledgements

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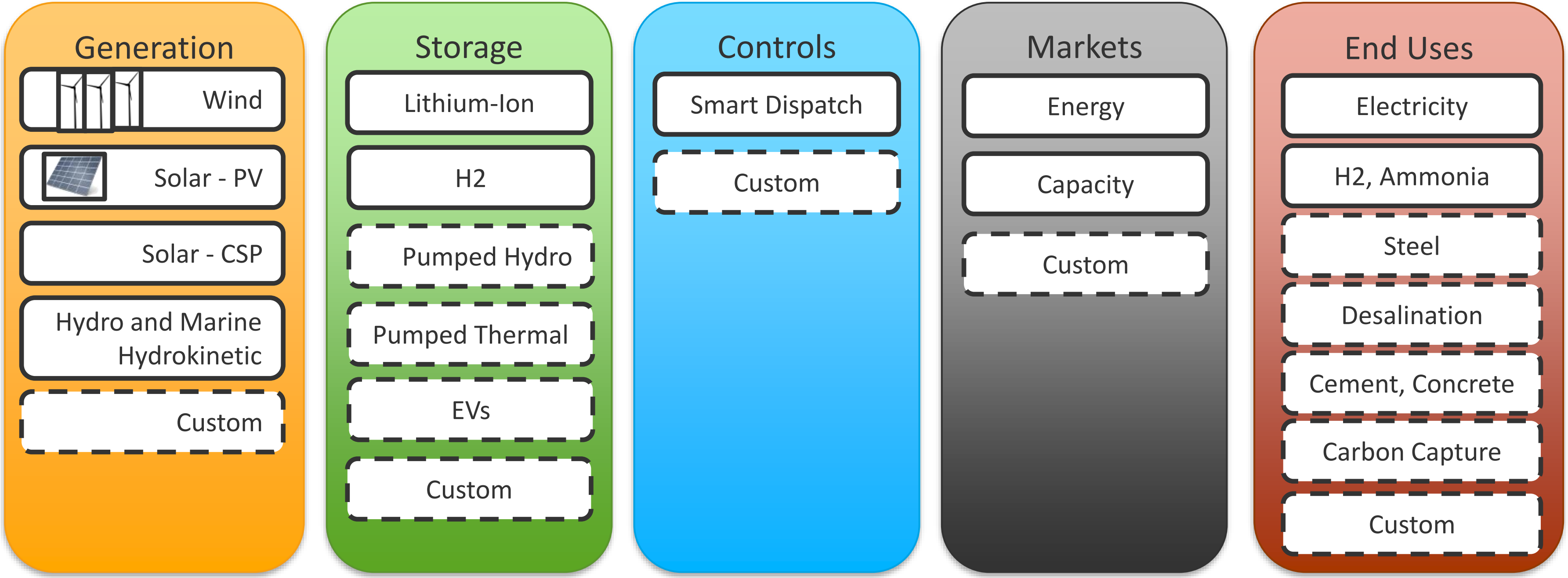
Overview of HOPP

- A brief history:
  - Original model developed by Charles Tripp, Darice Guittet, Aaron Barker, Jennifer King and Bill Hamilton in 2019 (software record)
  - Expanded into software with many technology modules:
    - Wind, solar, battery storage, concentrated solar power, hydrogen, wave
- HOPP combines different technology models together to form a hybrid plant. Used for
  - Hybrid power plant design studies under different objectives
  - Location studies
  - Plant operations studies

Hybrid Optimization and Performance Platform (HOPP)

- Open-source software developed by NREL
- Optimize co-located, utility-scale hybrid plants down to the component level for different markets
- Leverages expertise and tools across the lab for end-to-end analysis

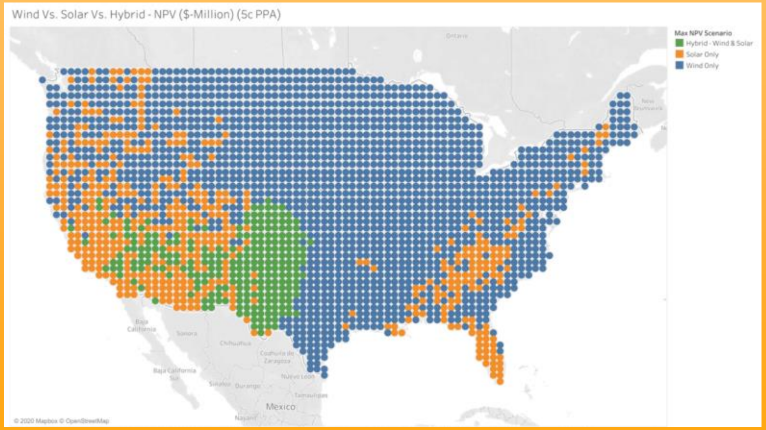


HOPP Capabilities

Analysis

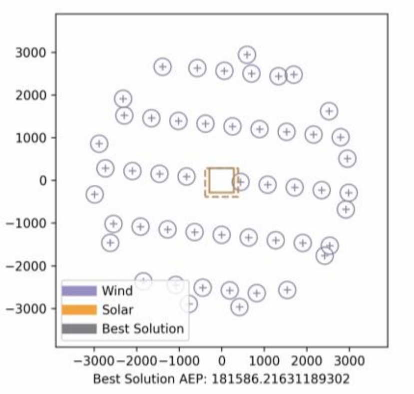
Where to build co-located hybrid plants?

- Resources are complementary
- Overbuild (Ex: 200MW plant at 100MW interconnect)
- Include storage



Optimization

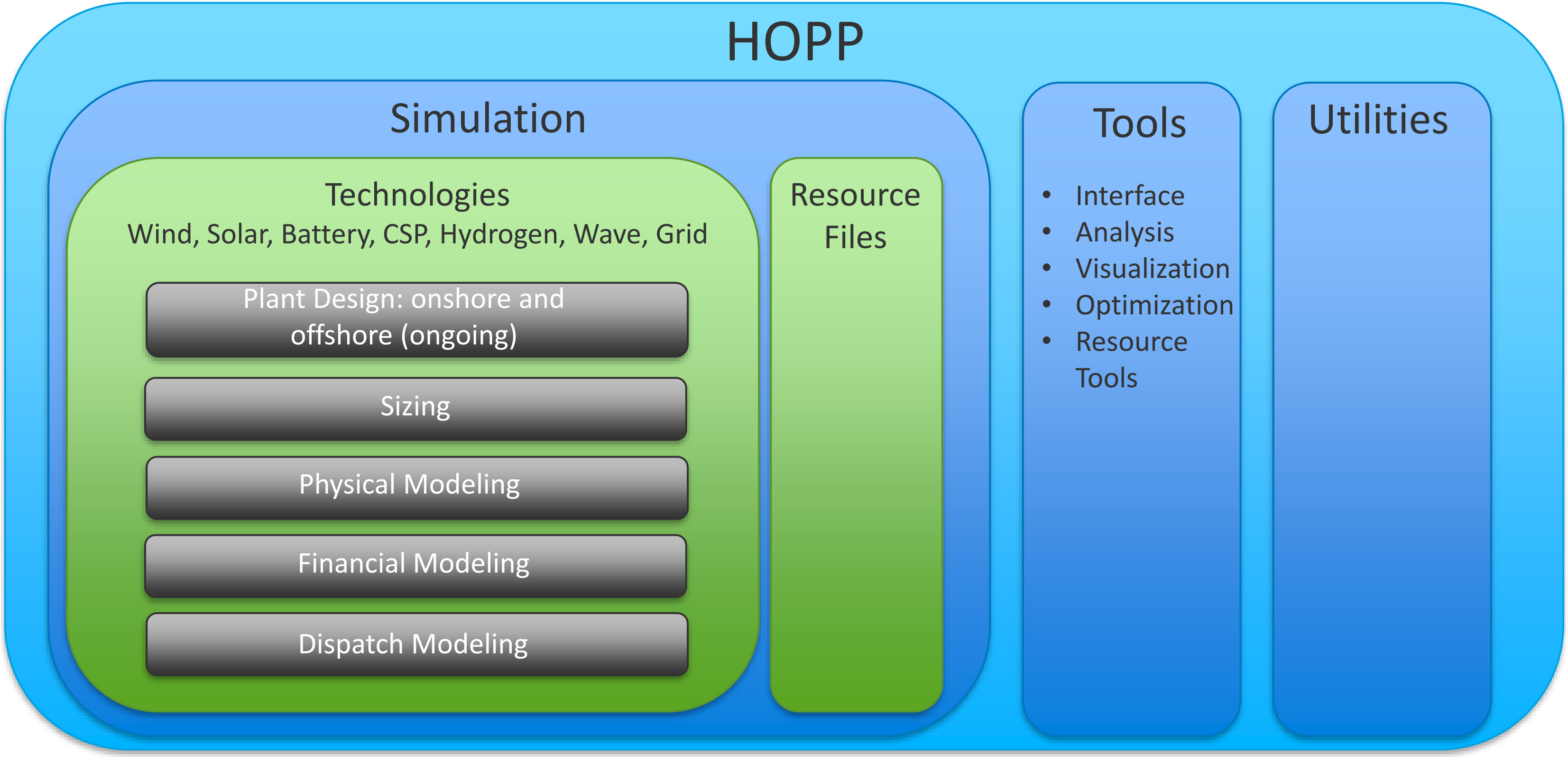
Optimize hybrid plants down to the *component* levels



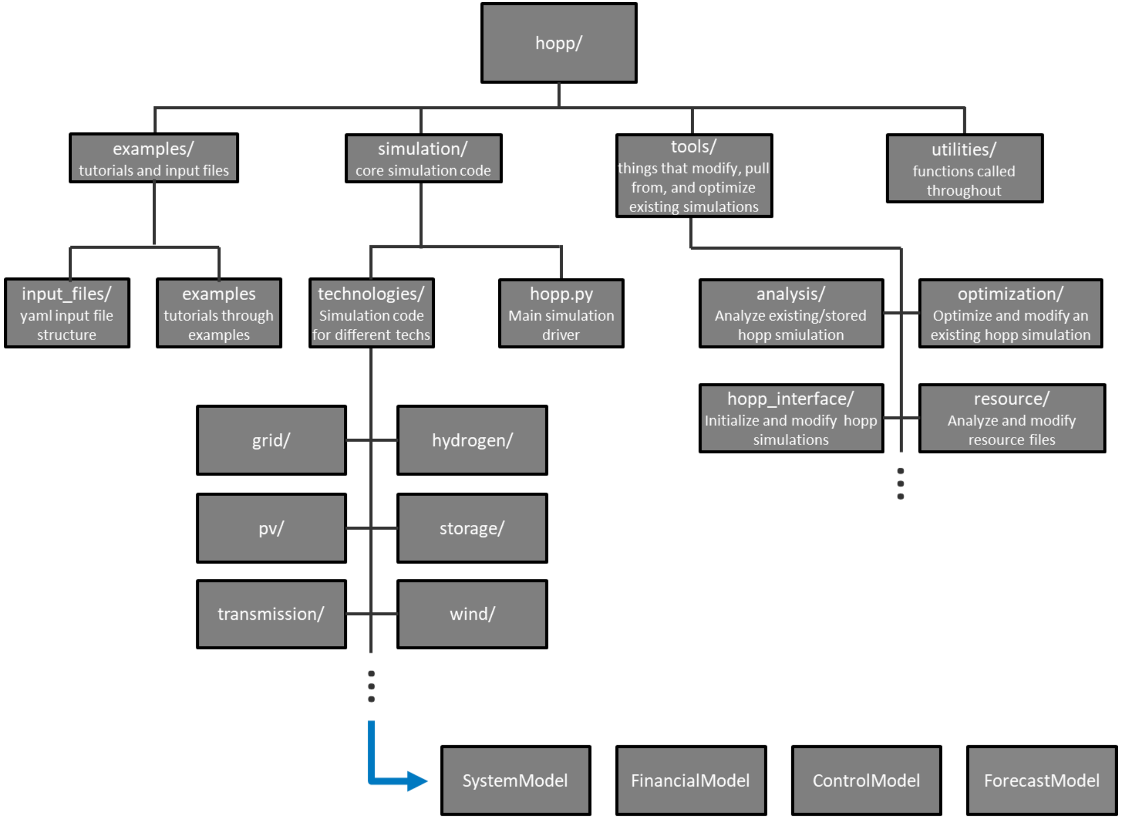
Control/Dispatch Algorithms

- **Wind-solar-storage** dispatch algorithms developed in HOPP
- Operation of plants down to the **10-minute timescale**
- Improve hybrid plant performance by > 5%

Overview of HOPP



HOPP Code Structure



Base classes defined for each technology;
enables API development for other codes

HOPP-Supported Modeling Tools

- Wind
  - PySAM: https://github.com/NREL/pysam
  - FLORIS: https://github.com/NREL/floris
- Solar
  - PySAM: PVsam v1 and PVwatts v8
- Battery
  - PySAM
- CSP
  - PySAM + Python model
- Hydrogen
  - Python model, internal to HOPP
- Wave
  - PySAM MHK model
- Grid
  - PySAM

Pulls wind input data (wind speeds, directions, etc.) from WIND Toolkit https://www.nrel.gov/grid/wind-toolkit.html

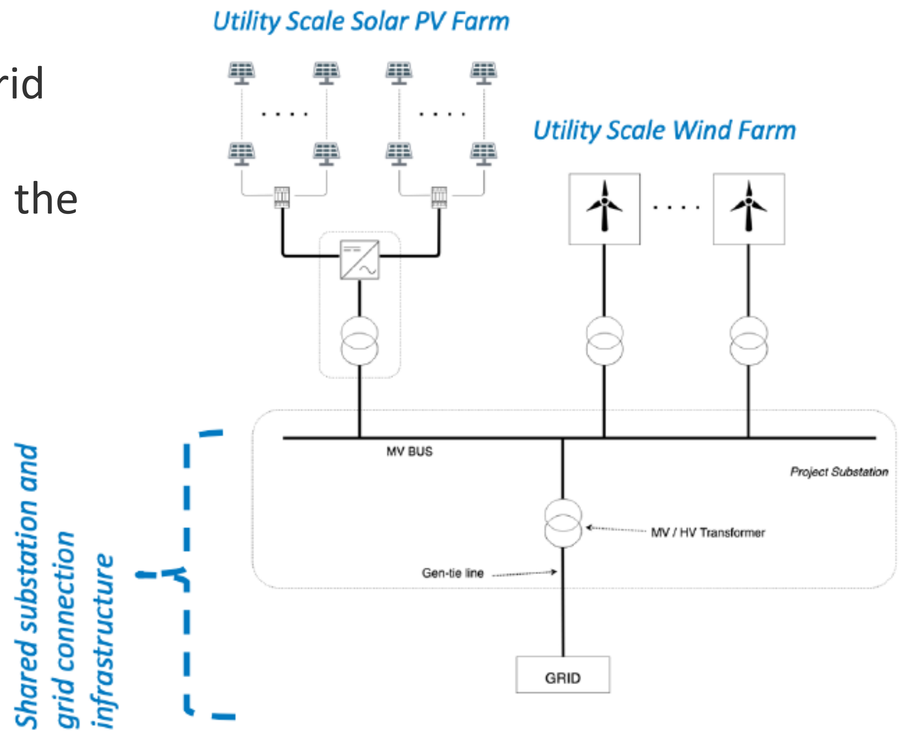
Pulls solar input data (irradiance, temperature, etc.) from the National Solar Radiation Database https://nsrdb.nrel.gov/

Supports user-provided price signals for financial analysis

HOPP Example

Example of a co-located hybrid plant setup

- Solar plus wind co-located hybrid plant layout
- Technologies are connected on the MV bus.

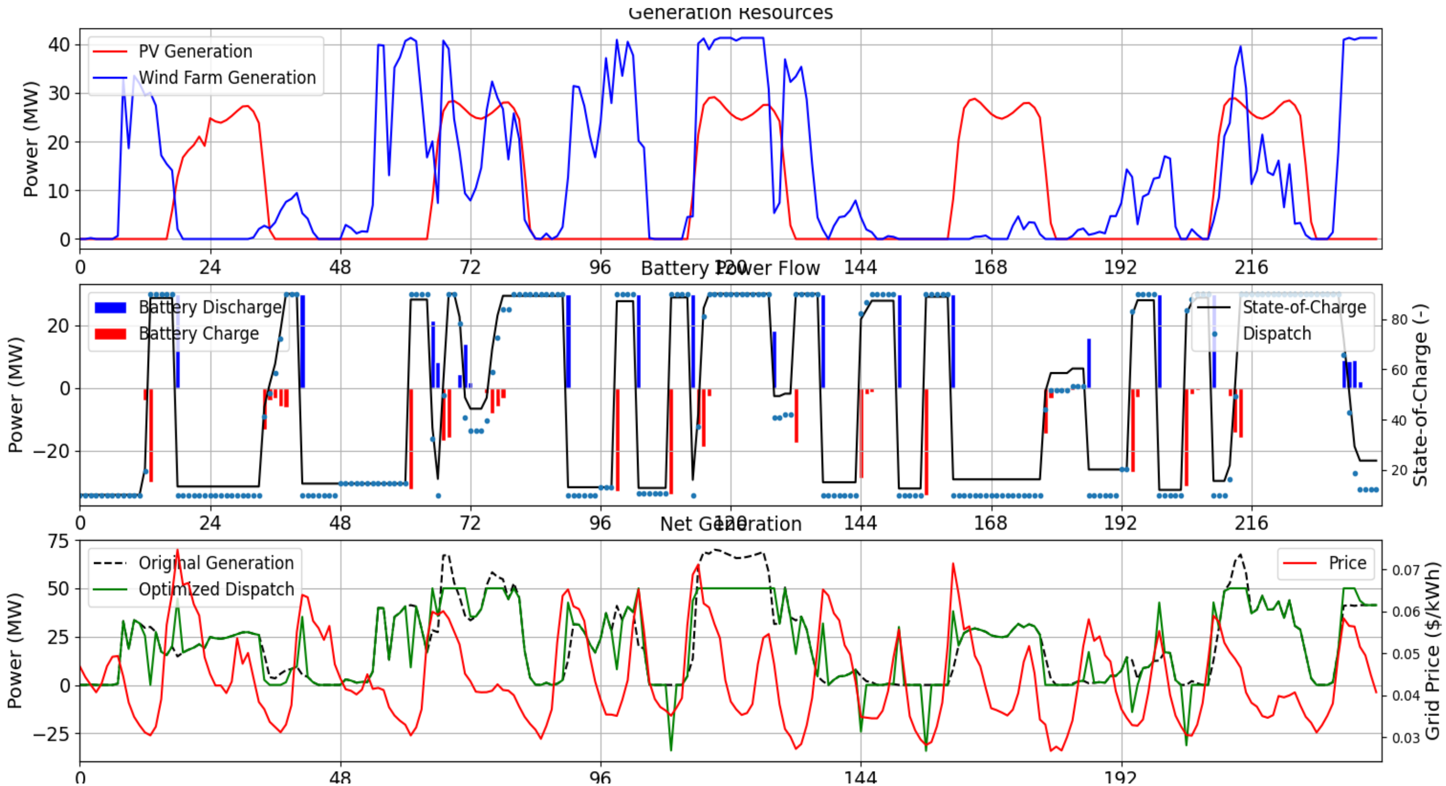


HOPP Example

Wind and solar power generation

Battery power and state of charge

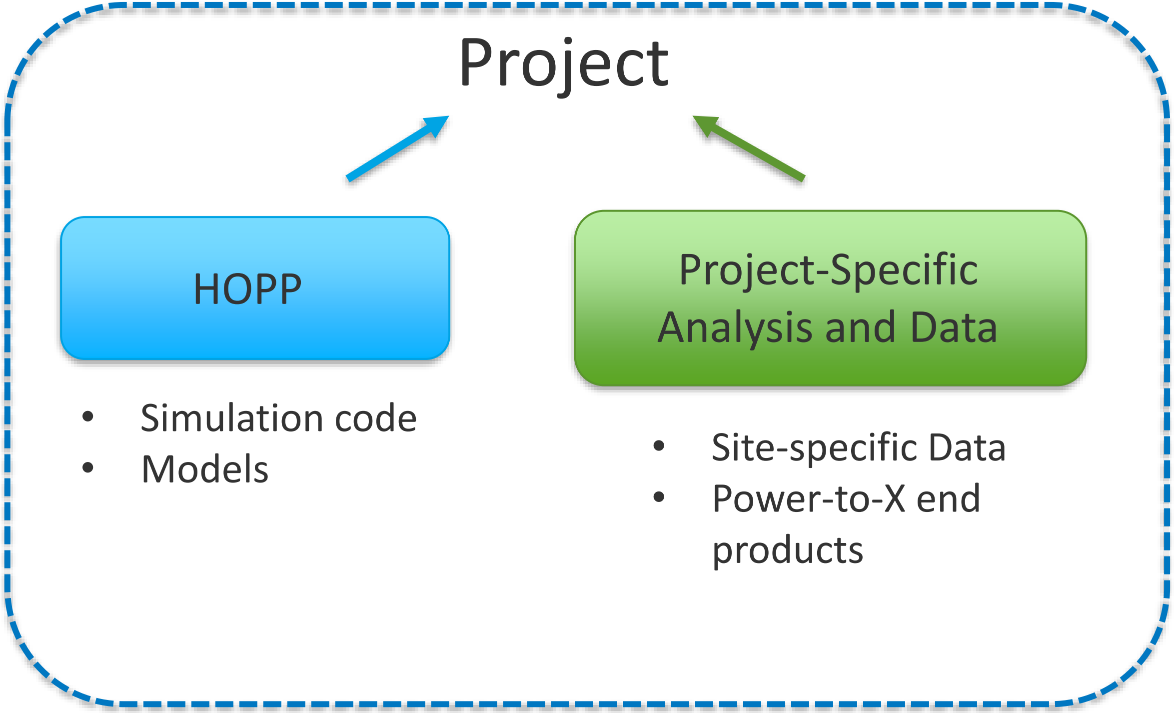
Original and optimized power dispatch compared to the energy price



HOPP Project Design

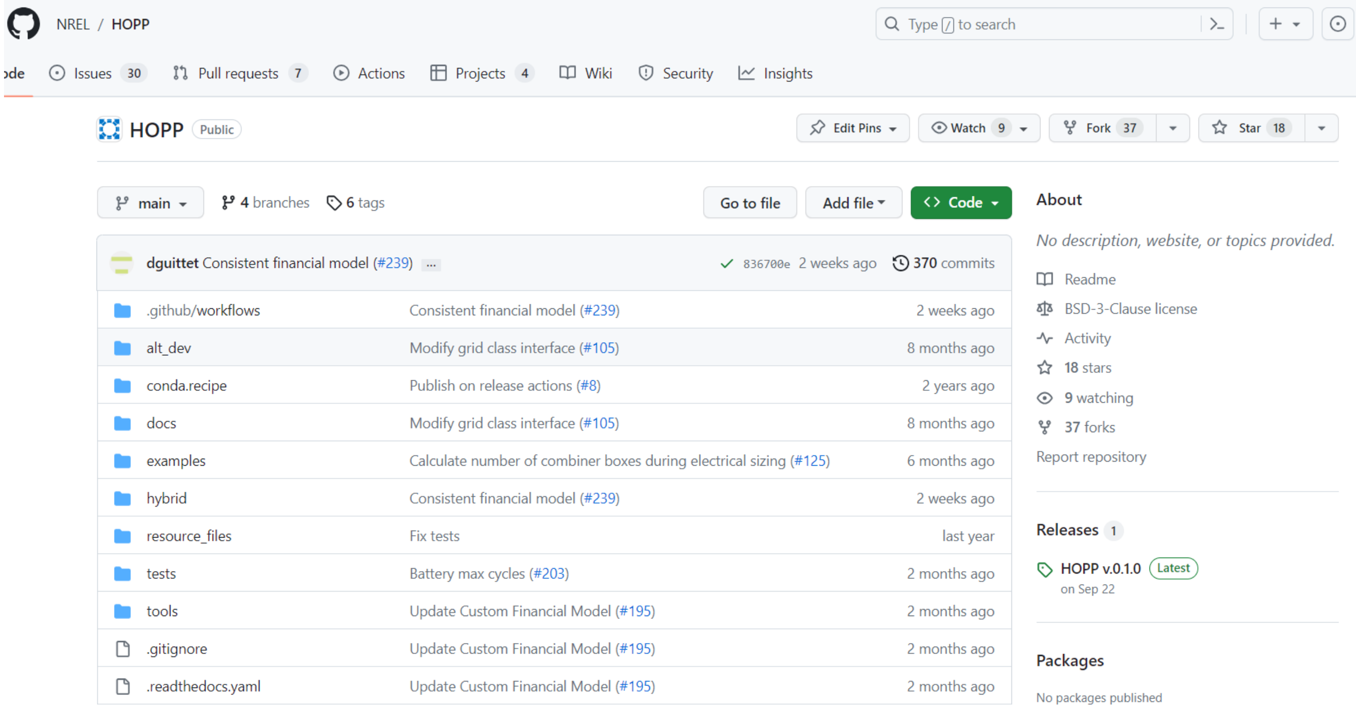
Two separate repositories for HOPP projects:

- The base simulation code in one
- The analysis and post-processing code in the other



HOPP Repository

- Open-source and available at: https://github.com/NREL/HOPP/tree/main

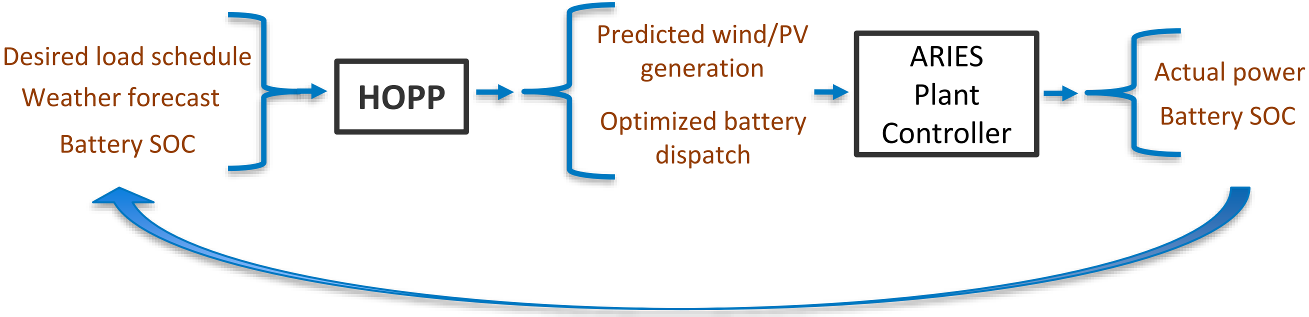


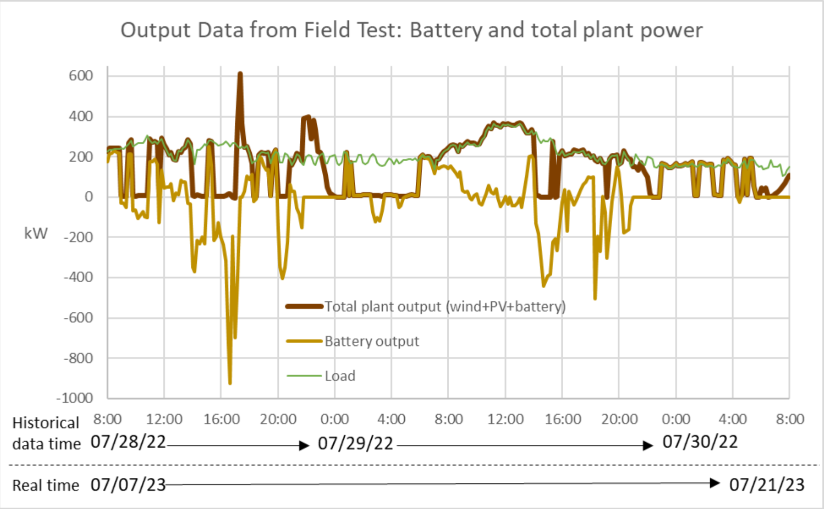
Recent Results

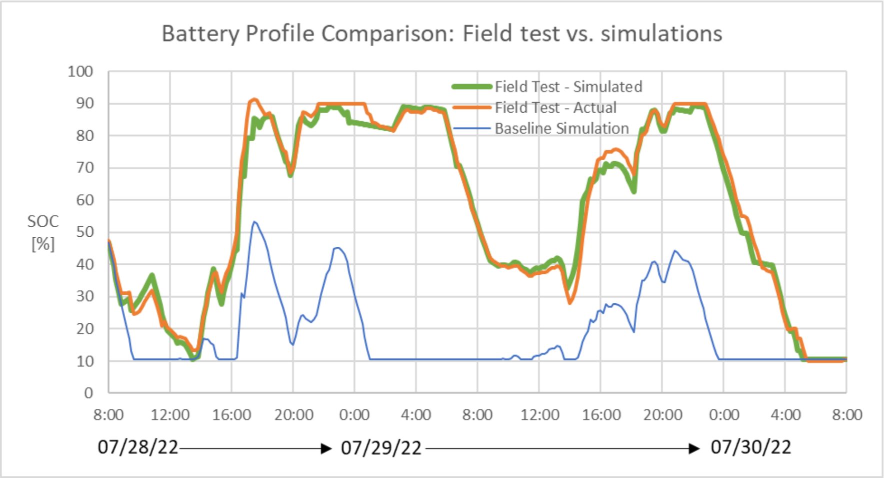
HOPP Field Testing

Tested the dispatch schedule optimized in HOPP on a physical 1 MW battery

- Validate battery power/SOC modeling
- Validate battery dispatch optimization to meet desired load schedules







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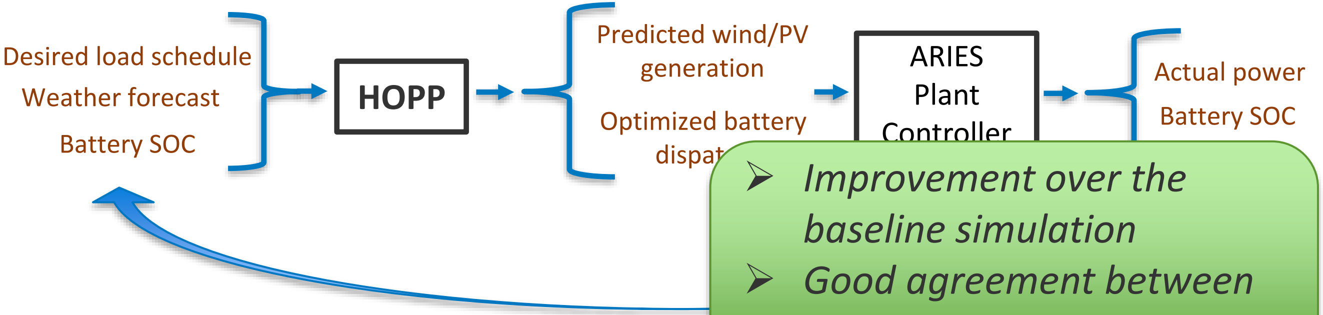
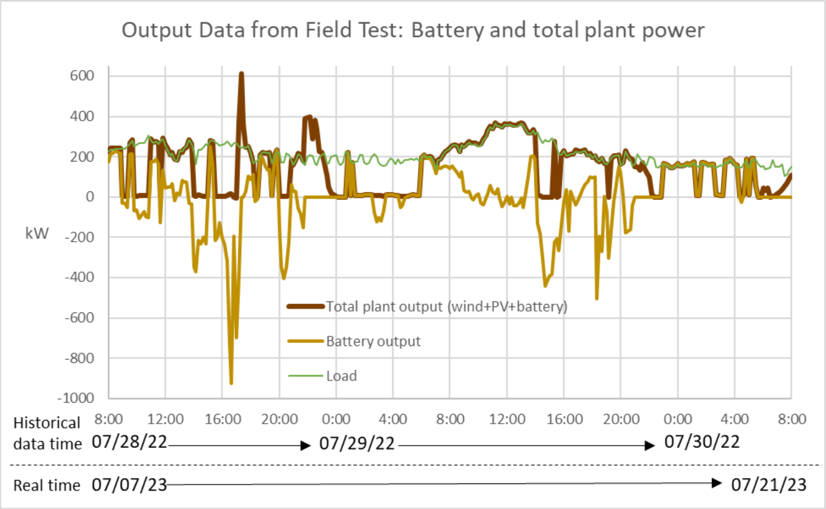
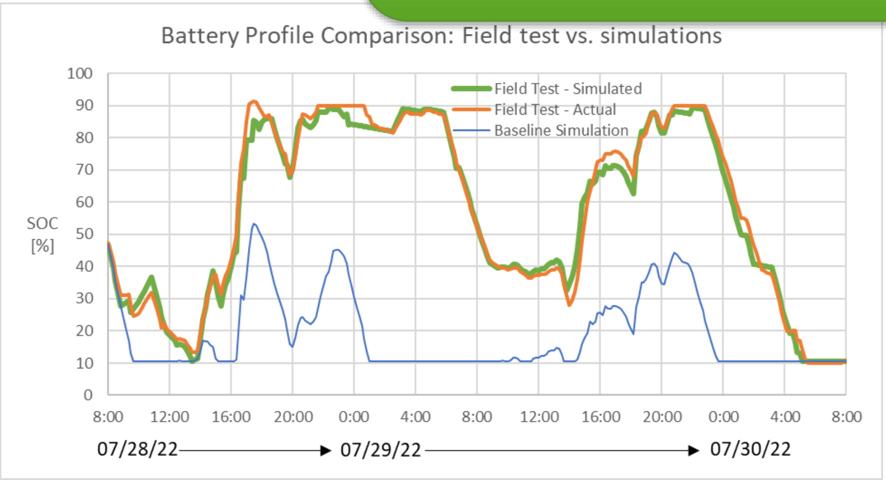
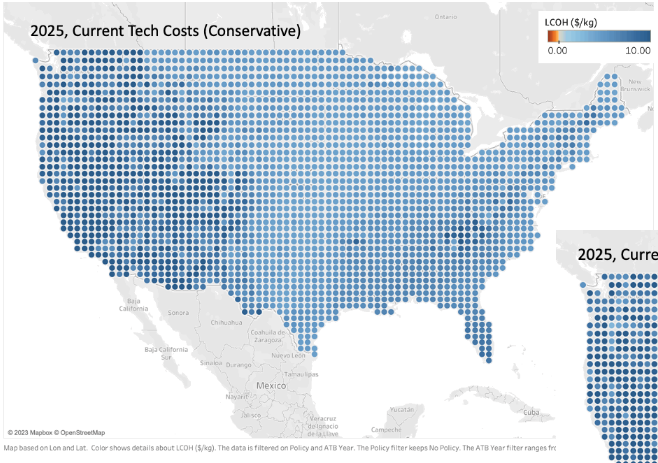


- ➢ *Improvement over the baseline simulation*
- ➢ *Good agreement between simulation and field test results*



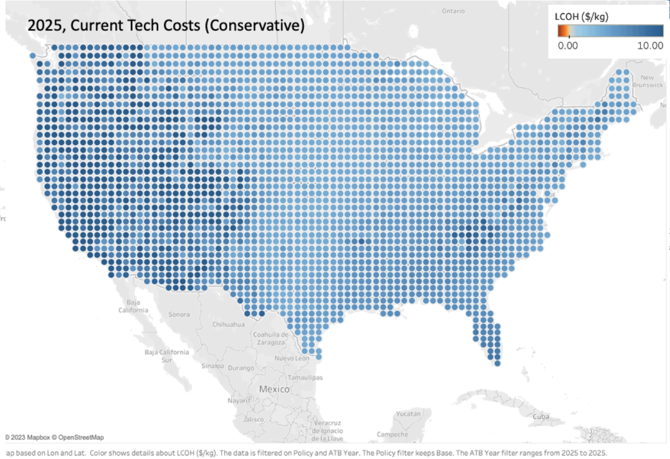


Green H2 with Land-Based Wind

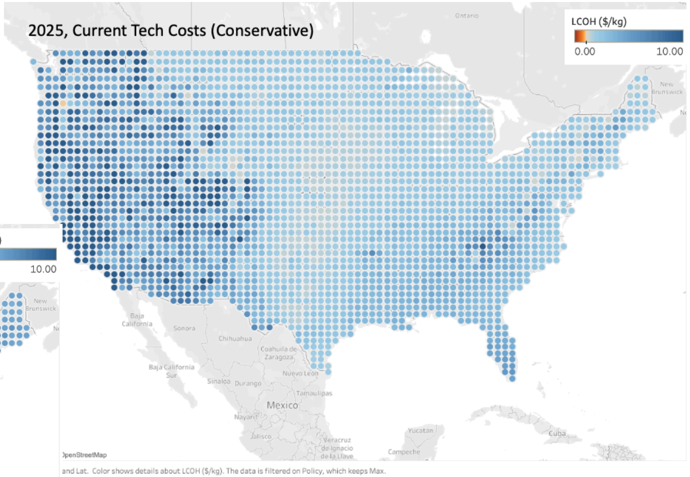


No Policy Scenario:
- No Wind PTC
- No H2 PTC

Year	Wind CAPEX ($/kW)	Electrolyzer CAPEX ($/kg)	Electrolyzer Efficiency (kWh/kg)
Current (Conservative)	1081	1500.00	55
Current (Moderate)	1081	1000.00	55
2025	1081	450.00	55
2030	704	337.65	51
2035	660	225.15	46



Base Policy Scenario:
- Wind PTC - $0.003/kWh USD1992
- H2 PTC - $0.60/kg H2 USD2022

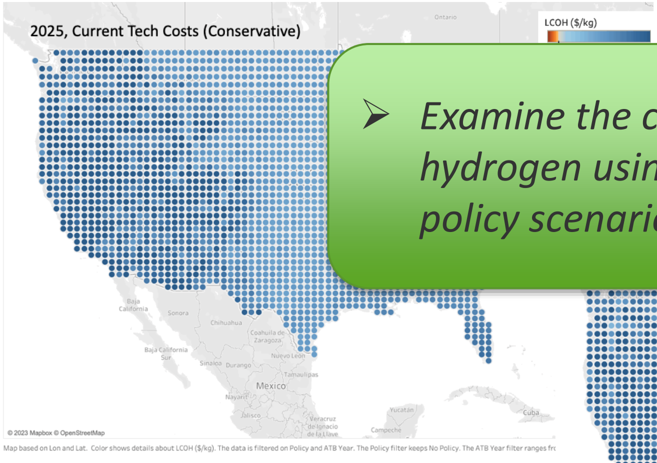


Max Policy Scenario:
- Wind PTC - $0.003/kWh USD1992
- H2 PTC - $0.60/kg H2 USD2022
- +5X credit value multiplier
- +10% domestic content bonus credit

Clark, C. E., Barker, A., Brunik, K., Kotarbinski, M., Grant, E., Roberts, O., ... & Bay, C. (2023). Opportunities for green hydrogen production with land-based wind in the United States. *Energy Conversion and Management*. https://doi.org/10.1016/j.enconman.2023.117595

Green H2 with Land-Based Wind

➢ *Examine the cost of hydrogen using different policy scenarios*



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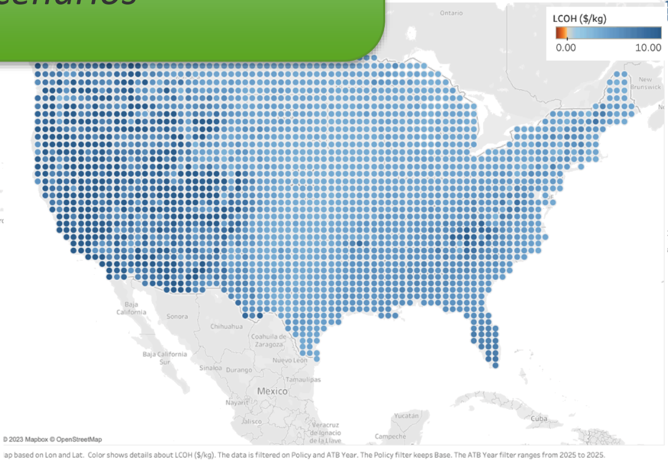

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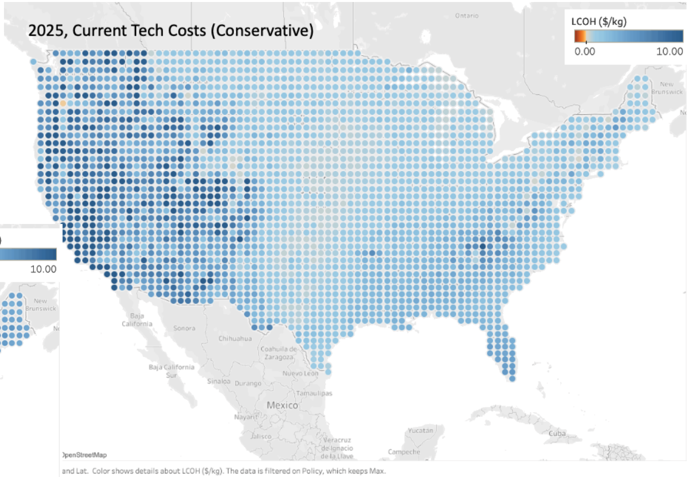

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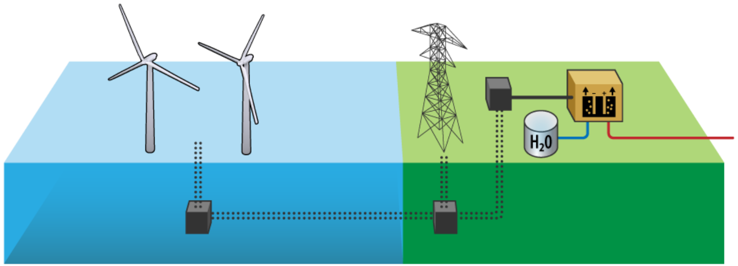
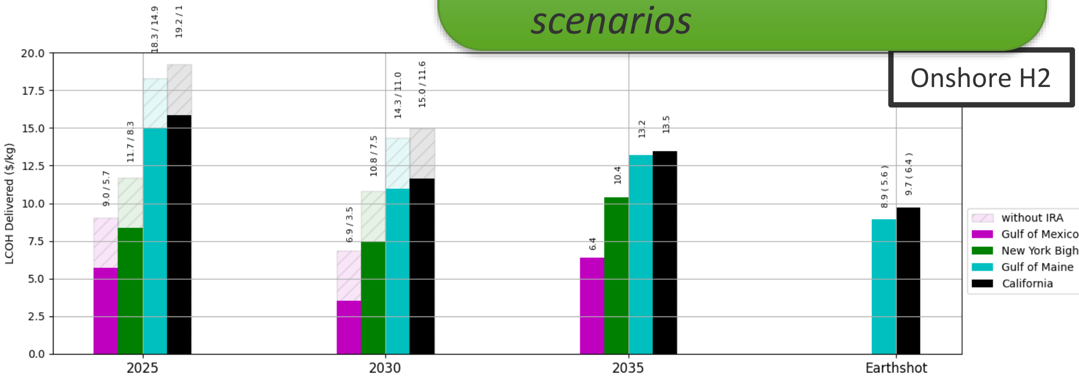
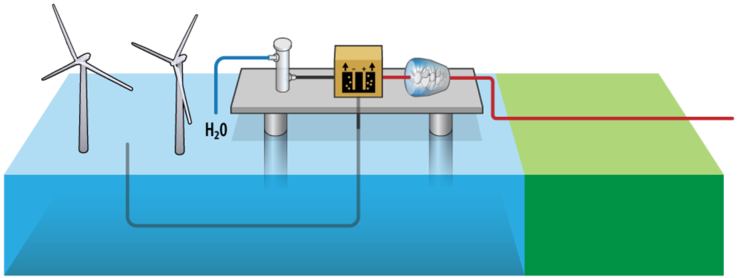
Offshore Wind to H2 Project

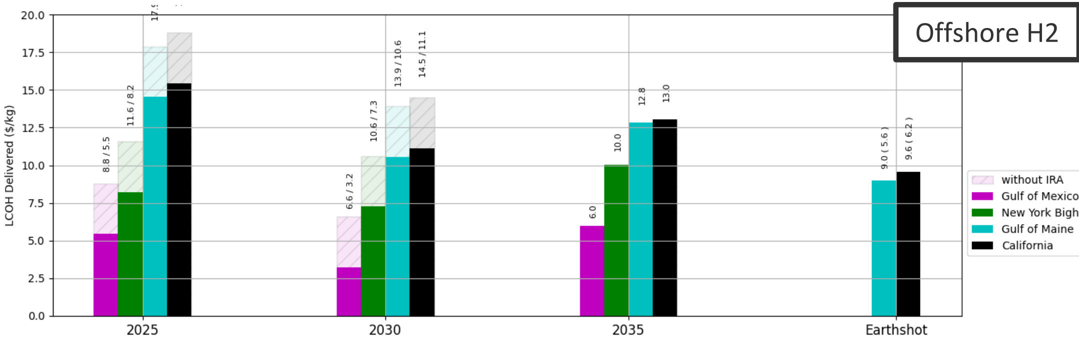
- ➢ *Compare onshore vs. offshore H2 placement*
- ➢ *Compare across different years, locations and policy scenarios*

Goal: reference designs for purpose-built hybrids for end uses that can accelerate the path to decarbonization for hard to abate industries.

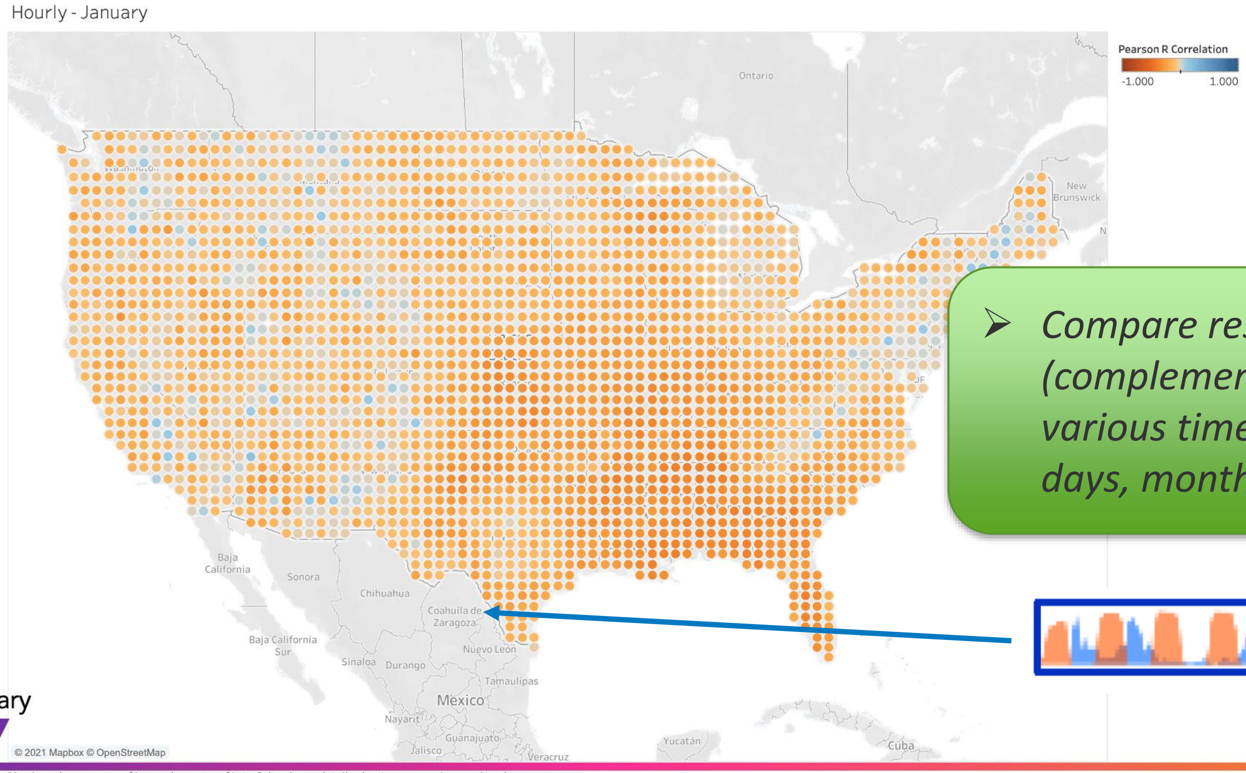








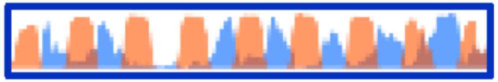
National Solar and Wind Complementarity



Map based on average of Lon and average of Lat. Color shows details about pearson r January hourly.

January

- *Compare resource viability (complementarity) over various timescales (hours, days, months)*



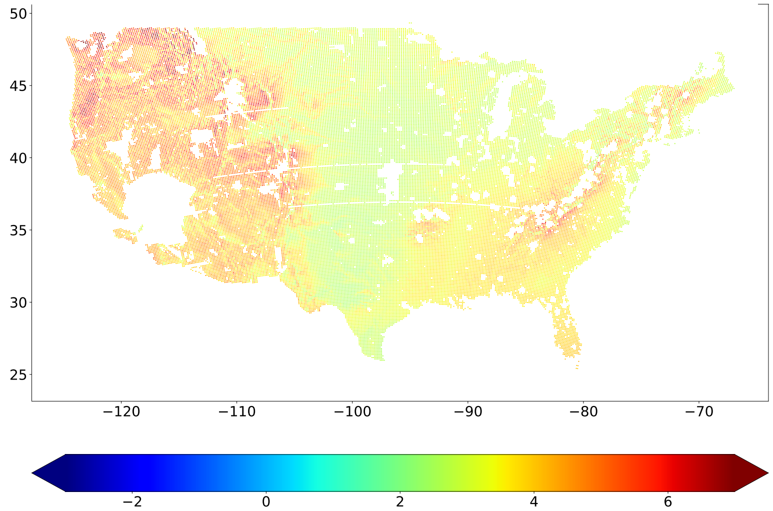
Clark, Caitlyn E., Barker, Aaron, King, Jennifer, and Reilly, James. *Wind and Solar Hybrid Power Plants for Energy Resilience*. United States: N. p., 2022. Web. doi:10.2172/1842446. https://www.osti.gov/biblio/1842446.

Green Steel Project

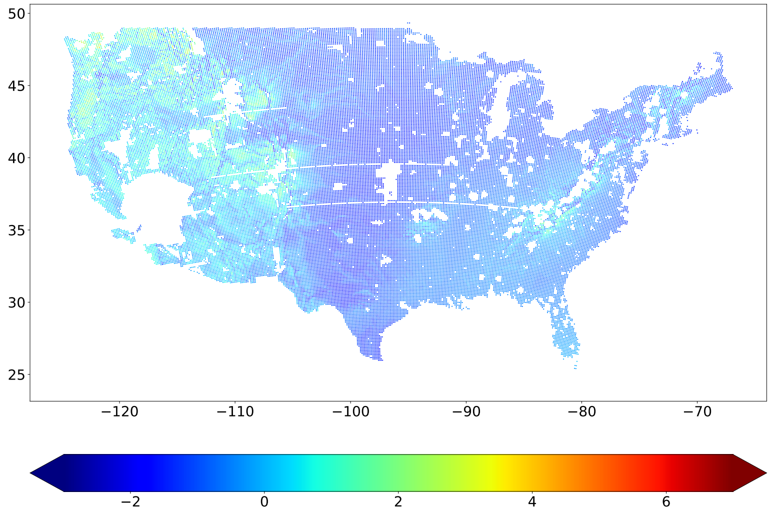
Goal: design an optimal hybrid renewable energy plant to minimize the cost of green hydrogen production for 50k sites in the U.S.

- *Compare many locations across US in different policy scenarios*

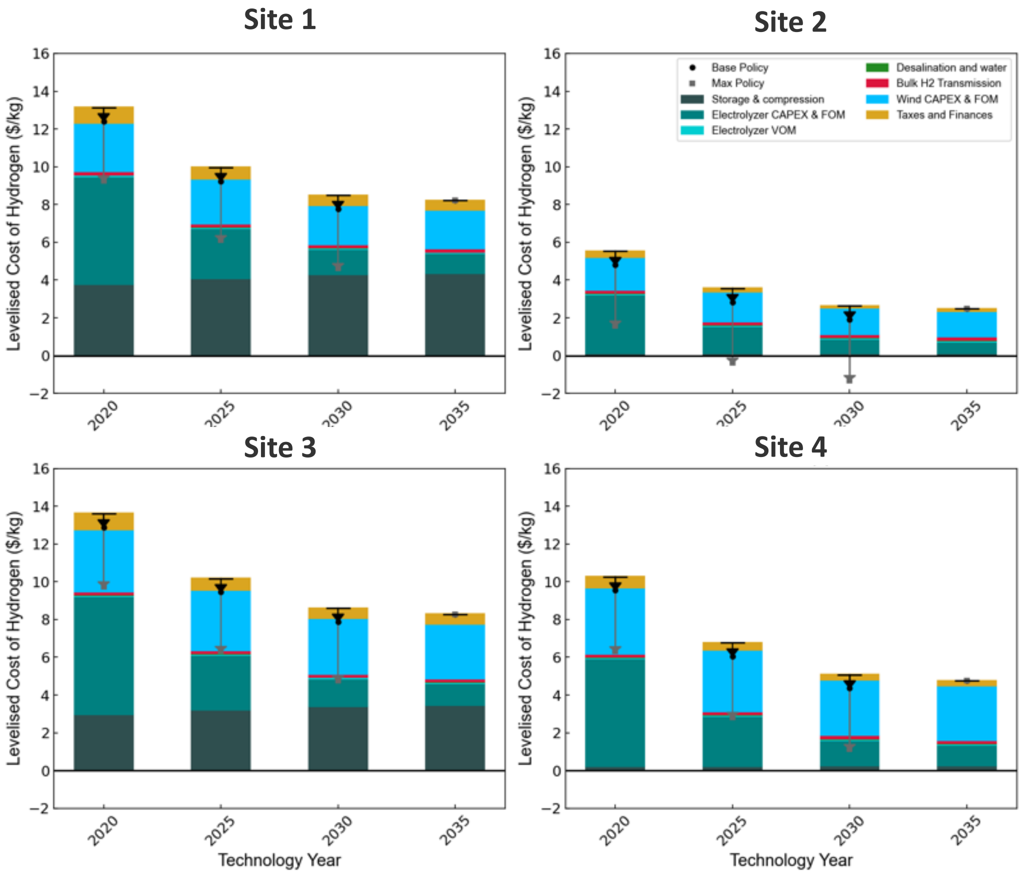
LCOH with no policy



LCOH with max policy



Green Steel Project



Goal: determine component cost impact on LCOH for wind-hydrogen off-grid systems for different cost years.

- *Detailed analysis across four sites, including CAPEX, storage, desalination and transport*

Hybrid Renewable Energy → H_2 → Green Steel / Ammonia

Vision: New integrated analysis capability, GreenHEART, to analyze optimized GW-scale off-grid, purpose-built systems composed of wind/PV/storage tightly coupled electrolyzers, optimized for LCOH, co-located with steel/ammonia production facilities.

National Roadmap, locally optimized for green H2 production and industry end use.

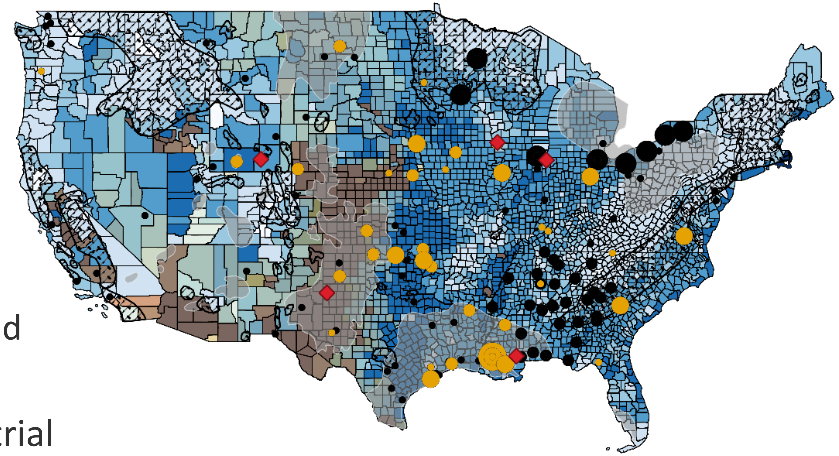
Novelty and Advantages:

- Optimized LCOH for the specific end use,
- Holistic approach, increased efficiency, & reduced capital costs,
- Independence from natural gas price volatility, grid connection permits and new large-scale transmission build outs.

Reduce risks and accelerate H2-based pathways to industrial decarbonization.

5 DOE Lab Collaboration NREL (lead) + ANL, LBNL, ORNL, & SNL

Co-funded by DOE Hydrogen and Wind Offices.



TEA/LCA Assessment of CO2/H2-to-Methanol Processes

- Methanol – key decarbonization target
  - Mainly produced from fossil fuels (coal, NG)
  - Potential replacement for fossil fuels in hard-to-electrify marine transport
- Highest *low-carbon* production currently in **captured CO_2** and **green H_2** to methanol routes
  - H_2 from water electrolysis
    - Electricity from wind/solar hybrids
- Need to investigate relative economic feasibility & environmental impact of 2 different routes:
  1. Baseline commercialized process
  2. Novel NREL process under development – Reactive Capture and Conversion (RCC)

...ty analyses:

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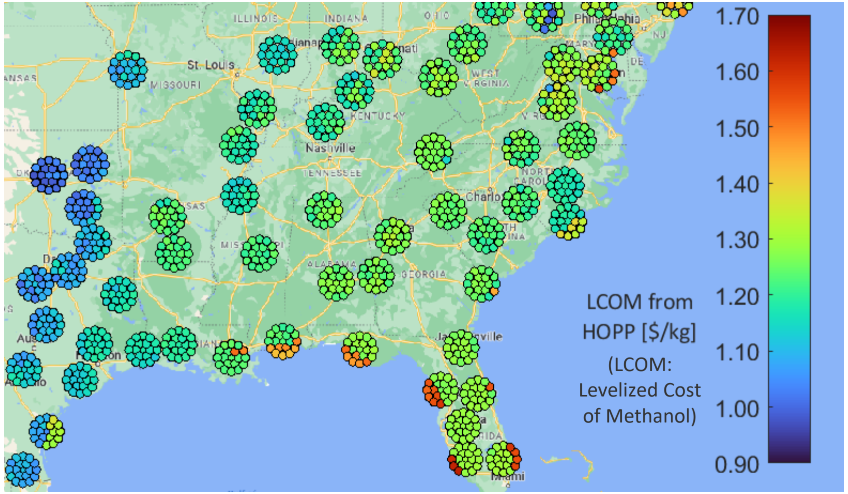
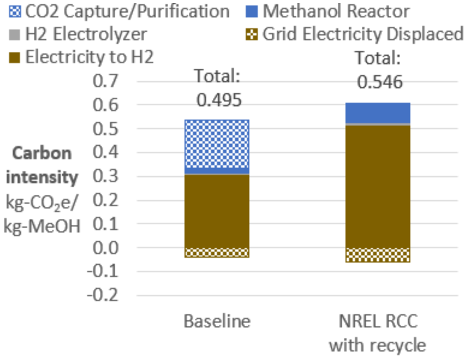
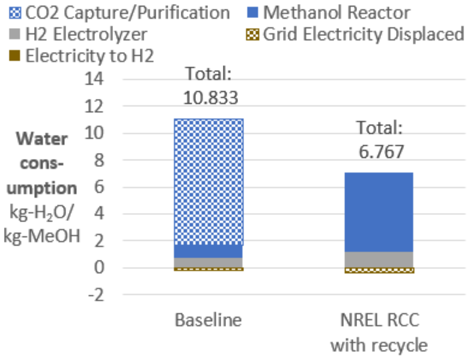
> ➢ *Used for resource portion of Methanol TEA study*
>
> ➢ *Power-to-X capabilities under development*

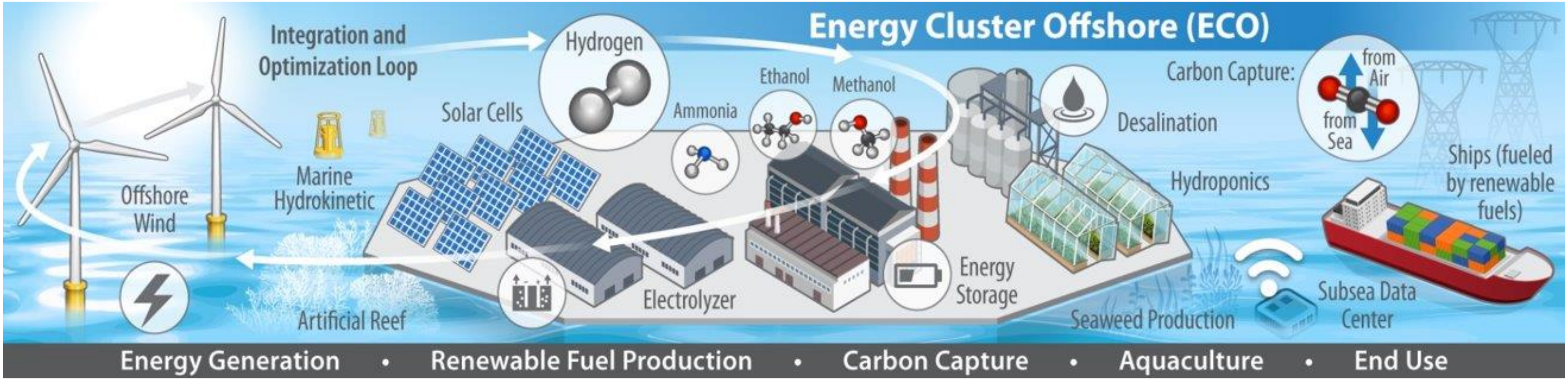






Future Directions

ECO Project

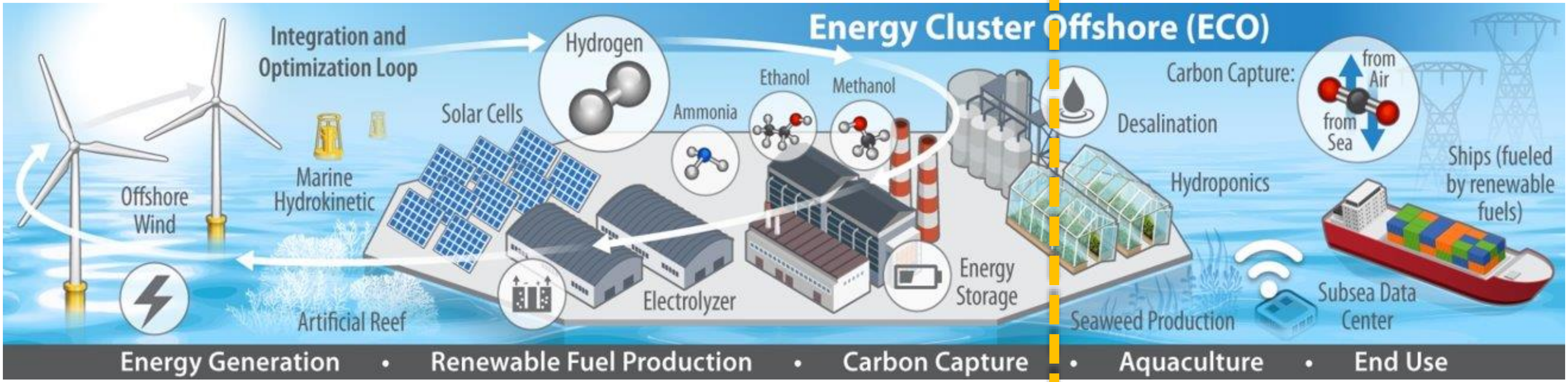


Currently includes the following technologies:

- Wind
- Wave
- Solar
- Battery
- Hydrogen

Image from NREL Laboratory Directed Research and Development funded project "Energy Clusters Offshore (ECO)" (see funding statement slide)

ECO Project



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Mostly integrated in HOPP

Future development of HOPP

Image from NREL Laboratory Directed Research and Development funded project "Energy Clusters Offshore (ECO)" (see funding statement slide)

HOPP Code Future

- Continue to merge in ongoing capability development
  - ➢Power-to-X end uses
  - ➢Hydrogen infrastructure
  - ➢Offshore infrastructure
- Development of analysis tools
- Formalization of code development workflow
- Incorporation of control strategies from field test
- Continued dispatch developments
- Continued development of component-level design and site considerations

→ New Releases of HOPP

HOPP Installation and Examples