The WETO Software Portfolio

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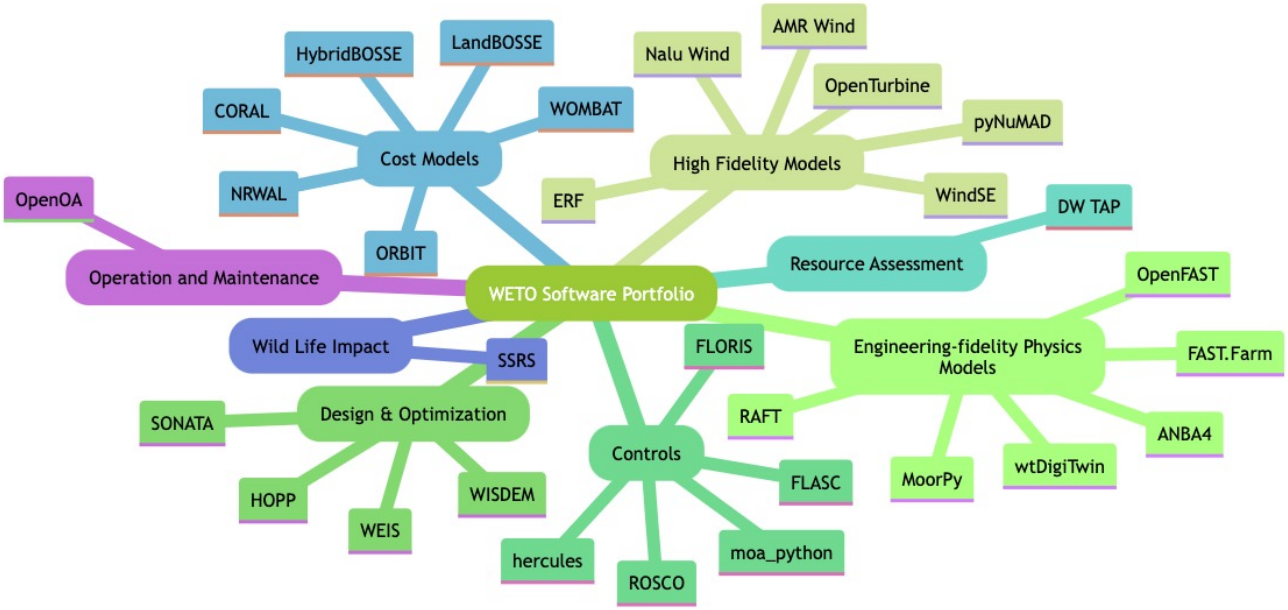
November 2, 2023

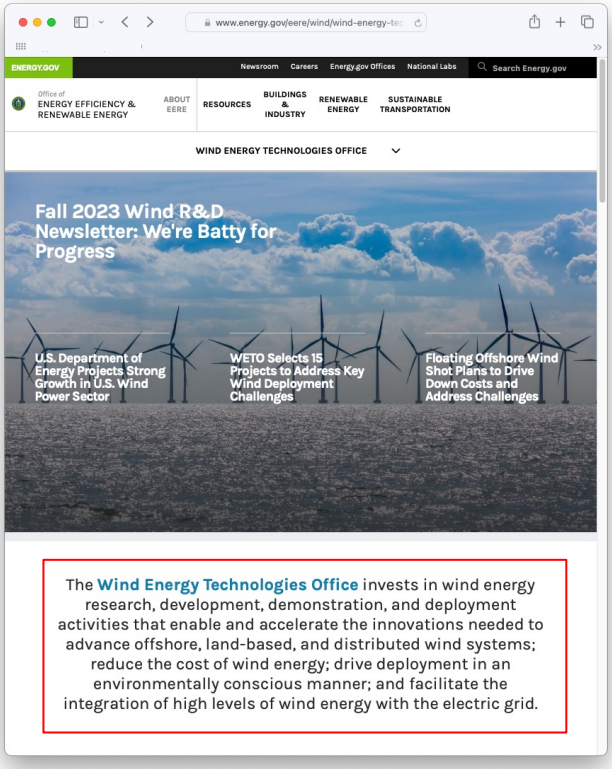
Wind Energy Research Software



Agenda

1. Holistic Modeling Project overview
2. WETO Software Portfolio introduction
3. Upcoming: Coordinated roadmap + development
4. Open ended discussion

Holistic Modeling Project
WETO Software Portfolio Coordination



WETO invests in wind energy research, development, demonstration, and deployment activities that enable and accelerate the innovations needed to advance offshore, land-based, and distributed wind systems; reduce the cost of wind energy; drive deployment in an environmentally conscious manner; and facilitate the integration of high levels of wind energy with the electric grid.

Pacific Northwest NATIONAL LABORATORY

Argonne NATIONAL LABORATORY

BERKELEY LAB
Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

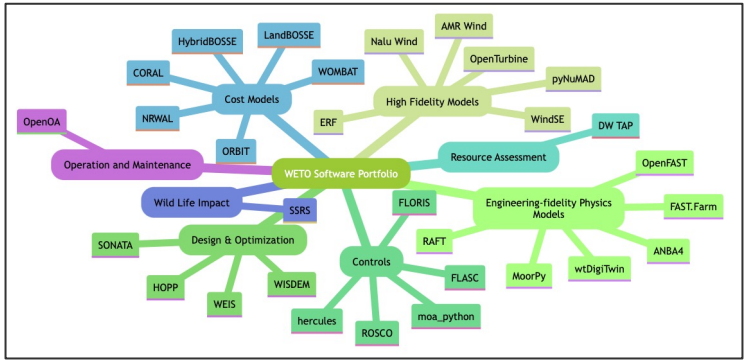
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

Holistic Modeling Project
WETO Software Portfolio Coordination

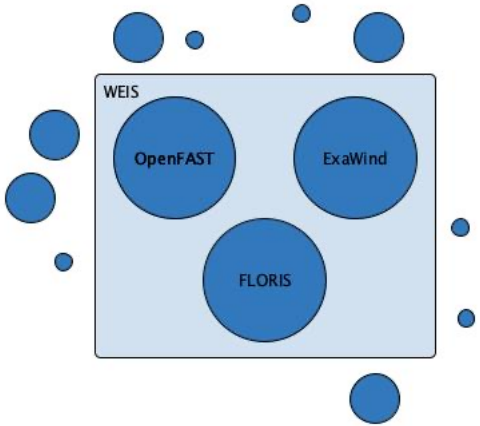
WETO Mission

The **Wind Energy Technologies Office** invests in wind energy research, development, demonstration, and deployment activities that enable and accelerate the innovations needed to advance offshore, land-based, and distributed wind systems; reduce the cost of wind energy; drive deployment in an environmentally conscious manner; and facilitate the integration of high levels of wind energy with the electric grid.

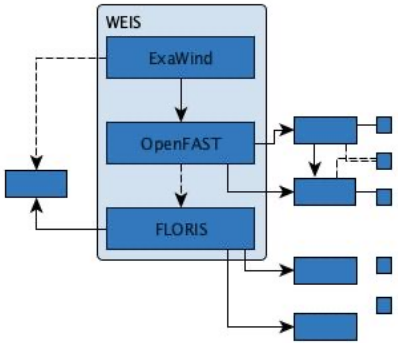


Holistic Modeling Project Overview

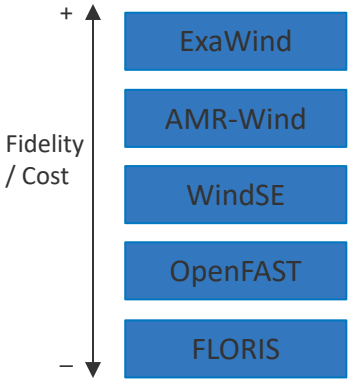
Current: Collection of tools covering a variety of topics; loosely organized and somewhat coupled



Target: Tech stack covering defined topics across established fidelities; coupled where relationships allow; capabilities exploration and tool selection



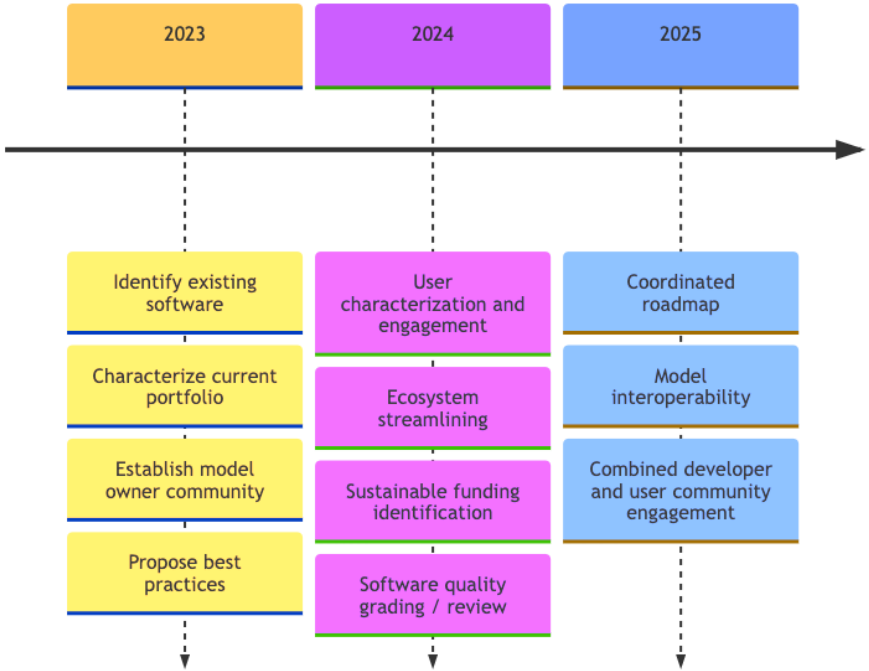
Capability - Aerodynamics Tools Selection:



Compare and relate based on attributes:

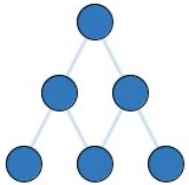
- Current funding level
- Release activity
- Documentation maturity
- Fidelity of physics
- Primary use

Holistic Modeling Project Overview



Holistic Modeling Project Year 1

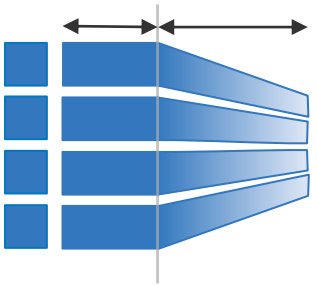
Model Listing & Capabilities Dashboard



Software Development Best Practices

- Quality
- Maintenance
- Usability
- Extendibility
- Robustness

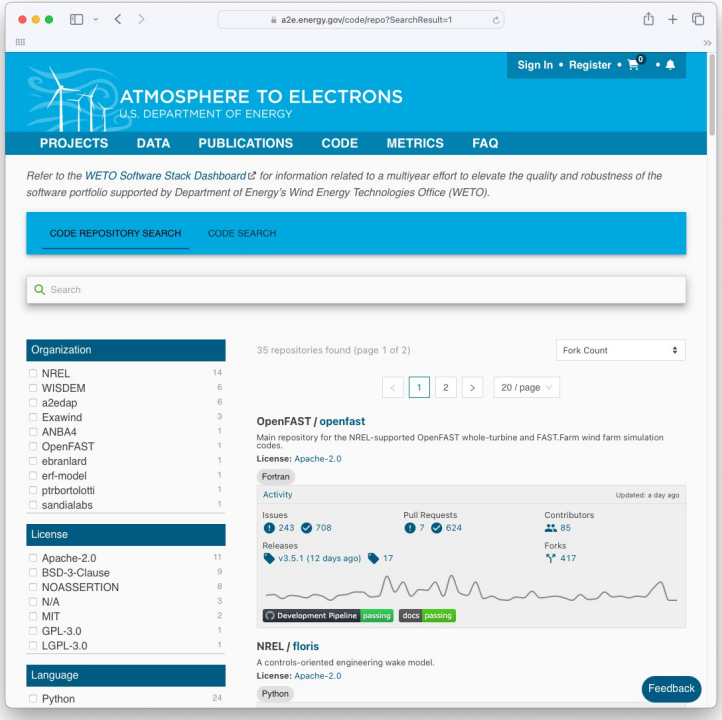
Portfolio Coordination



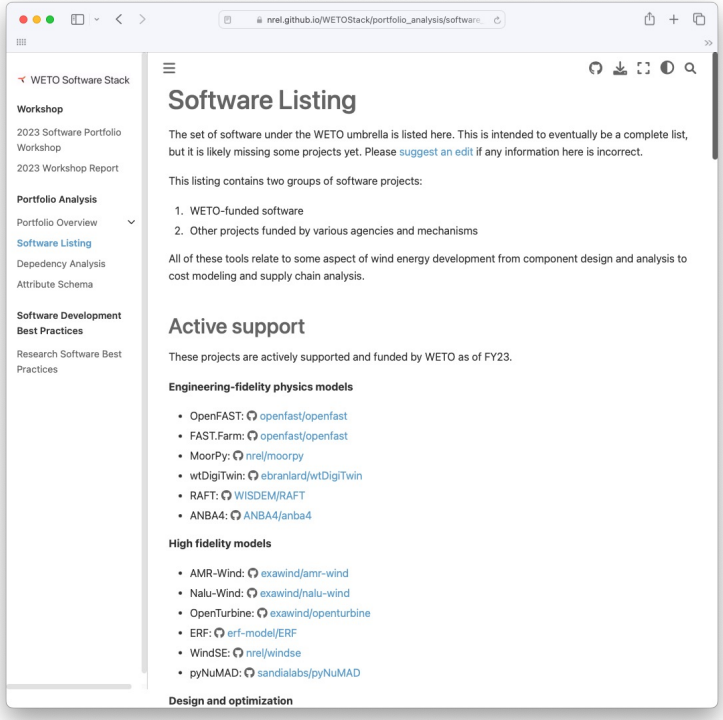
* Frameworks established in FY23 within ongoing updates in FY24 and FY25

Software Listings

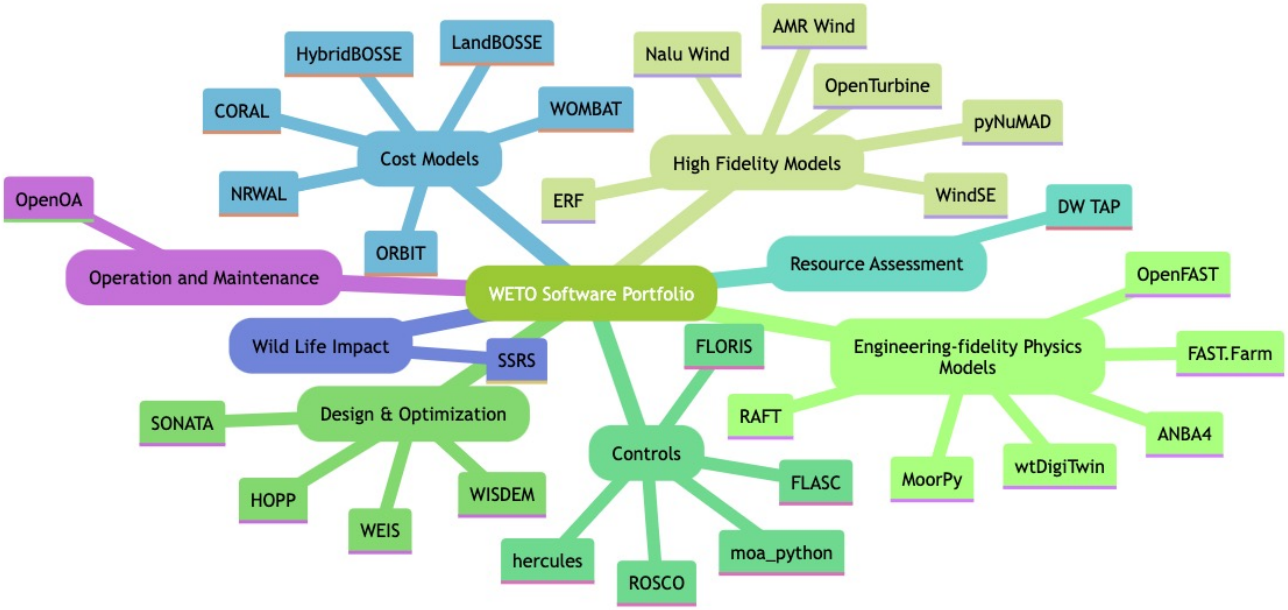
https://a2e.energy.gov/code/repo



https://nrel.github.io/WETOStack



WETO Software Portfolio

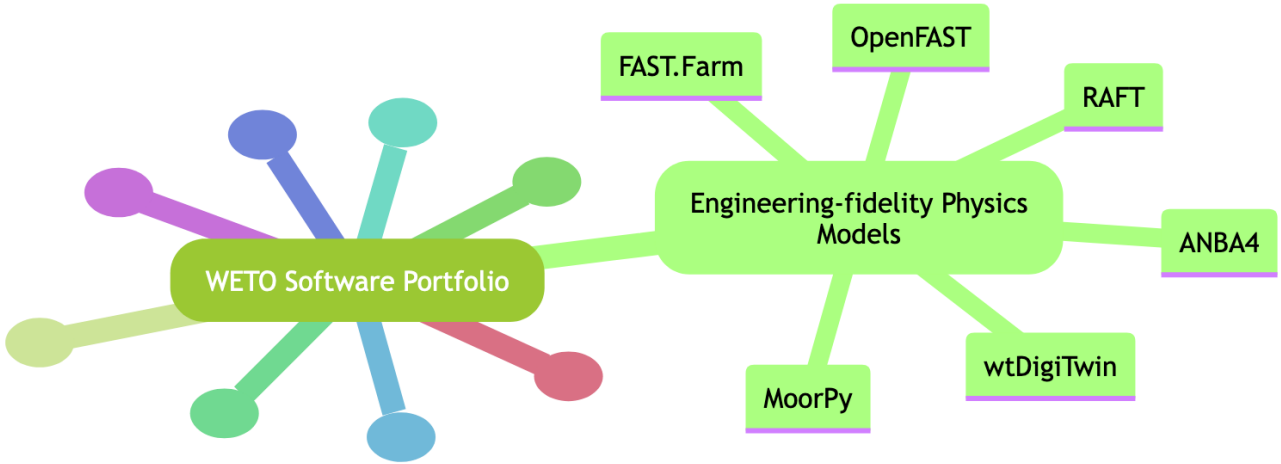


Active funding, active development: **30 projects + 20%?**

Technical Areas

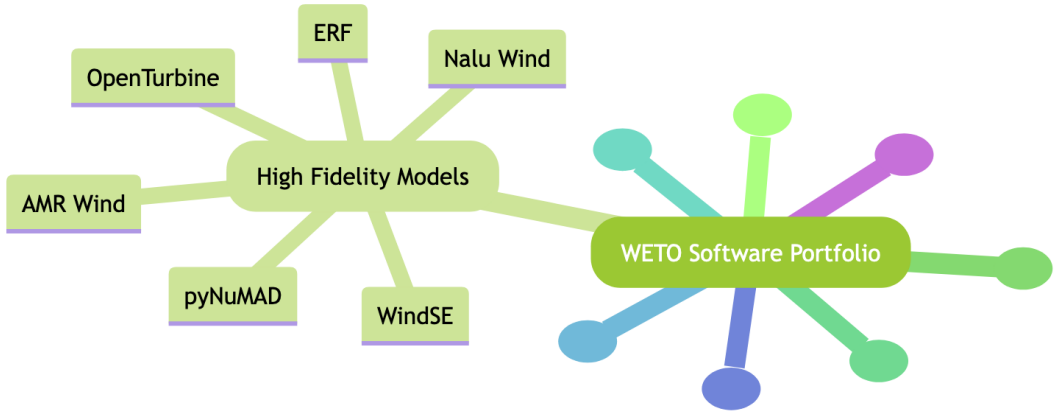
- Engineering-fidelity Physics Models
- High Fidelity Models
- Design & Optimization
- Controls
- Resource Assessment
- Cost Models
- Wildlife Impact
- Operation and Maintenance

Engineering-fidelity Physics Models



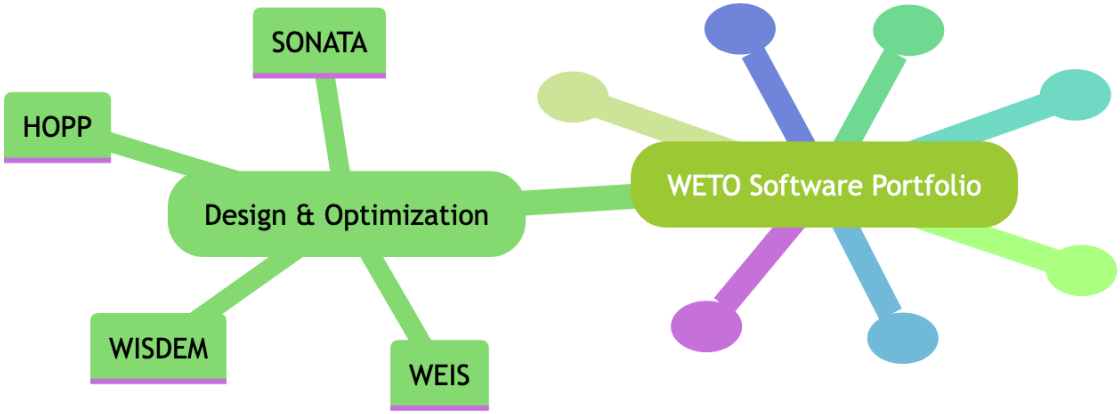
- OpenFAST openfast/openfast - Multi-physics tool for simulating the coupled dynamic response of wind turbines.
- FAST.Farm openfast/openfast - Mid-fidelity wind farm simulator that uses OpenFAST as a turbine model.
- MoorPy nrel/moorpy - Quasi-static mooring model and a suite of associated functions for mooring system analysis.
- wtDigiTwin ebranlard/wtDigiTwin - Digital twin model for wind turbine
- RAFT WISDEM/RAFT - Library for frequency-domain analysis of floating wind turbines.
- ANBA4 ANBA4/anba4 - Computes the 6x6 stiffness/mass matrices of arbitrarily complex composite beam cross sections

High Fidelity Models



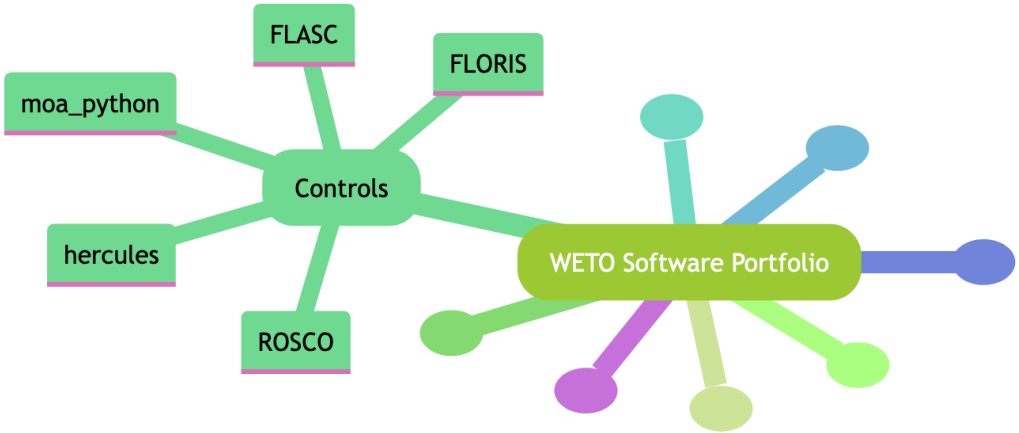
- AMR-Wind exawind/amr-wind - Massively parallel, block-structured adaptive-mesh, incompressible flow solver for wind turbine and wind farm simulations.
- Nalu-Wind exawind/nalu-wind - Generalized, unstructured, massively parallel, incompressible flow solver for wind turbine and wind farm.
- OpenTurbine exawind/openturbine - Wind turbine structural dynamics simulation code for land-based and offshore wind turbines specifically designed to couple with low-fidelity aerodynamic/hydrodynamic models (OpenFAST) and high-fidelity computational fluid dynamics (CFD) models (ExaWind).
- ERF erf-model/ERF - Compressible Navier-Stokes solver on an Arakawa C-grid for large-scale weather modeling.
- WindSE nrel/windse - Python package that uses a FEniCS backend to perform wind farm simulations and optimization.
- pyNuMAD sandialabs/pyNuMAD - Simplifies the process of creating a three-dimensional model of a wind turbine blade by providing an intermediary between raw blade data and analytical platforms (ANSYS, Cubit, OpenFAST, etc).

Design & Optimization



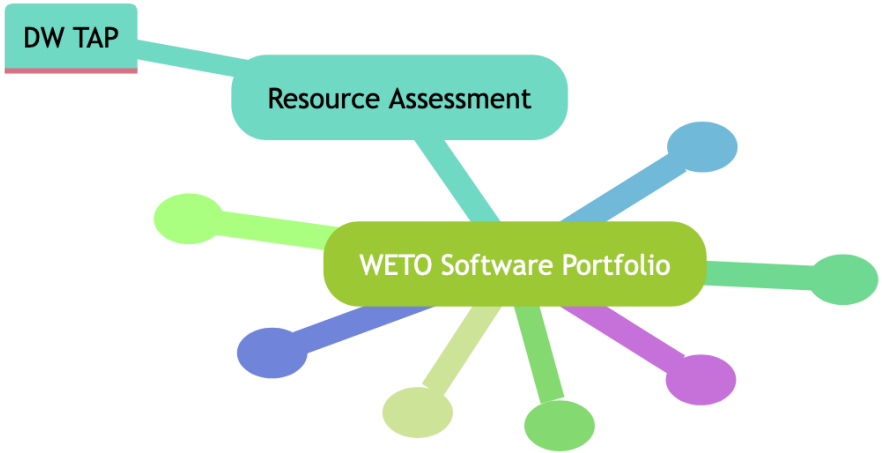
- WEIS [wisdem/weis] - Wind Energy with Integrated Servo-control performs multi-fidelity co-design of wind turbines to enable design optimization of floating offshore wind turbines.
- WISDEM [wisdem/wisdem] - Set of wind turbine and plant cost and energy production models along with financial models for assessing overall wind plant cost of energy.
- HOPP [NREL/HOPP] - Assesses optimal designs for the deployment of utility-scale hybrid energy plants, particularly considering wind, solar and storage.
- SONATA [ptrbortolotti/SONATA] - Toolbox for Multidisciplinary Rotor Blade Design Environment for Structural Optimization and Aeroelastic Analysis.

Controls



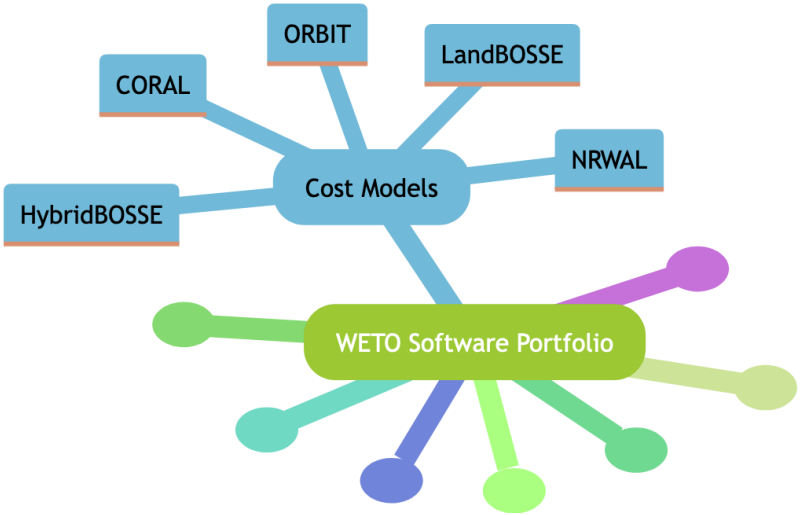
- ROSCO NREL/ROSCO - Reference controller with industry-standard functionality and generic tuning
- FLORIS nrel/floris - Controls-focused wind farm simulation software incorporating steady-state engineering wake models into a performance-focused Python framework.
- FLASC nrel/flasc - Suite of analysis tools for SCADA data filtering, analysis, wind farm model validation, field experiment design, and field experiment monitoring.
- hercules nrel/hercules - Wind farm emulator for controls testing with LES models.
- moa_python nrel/moa_python - Wind farm performance post processing and analysis tool.

Resource Assesment



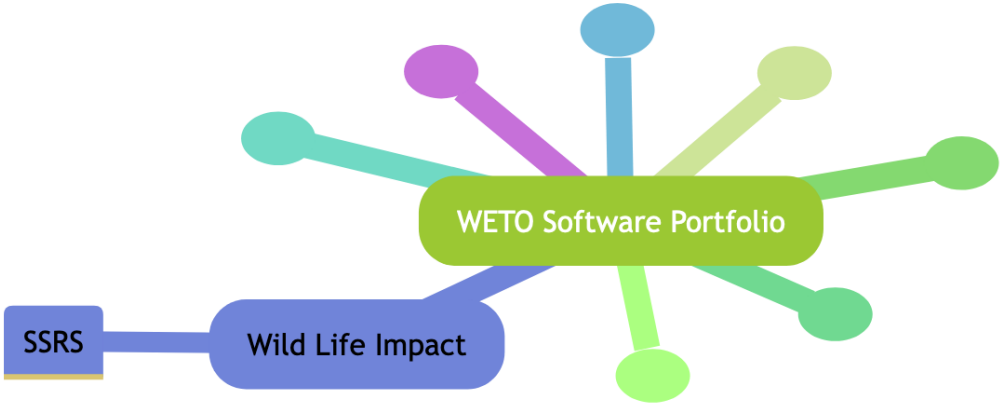
- DW TAP NREL/dw-tap-app - A simple tool for cost-effectively and accurately assessing wind resources without having to physically take direct measurements in the field.

Cost Models



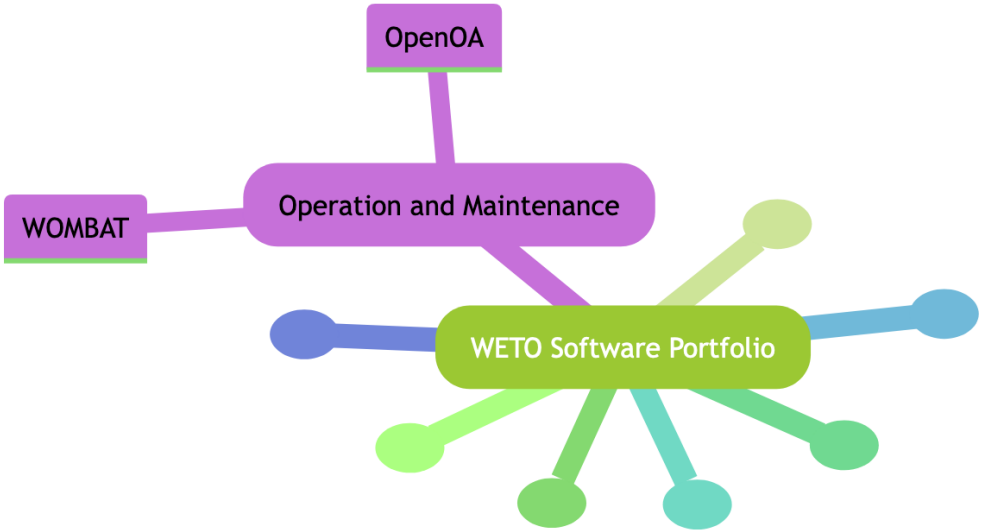
- LandBOSSE WISDEM/LandBOSSE - A systems engineering tool that estimates the balance-of-system (BOS) costs associated with installing utility scale wind plants.
- HybridBOSSE NREL/HybridBOSSE - A tool for estimating BOS costs for hybrid power plants ORBIT WISDEM/ORBIT - A model to study the cost and times associated with Offshore Wind Balance of System (BOS) processes.
- CORAL NREL/CORAL - Concurrent ORBIT for shared Resource Analysis Library
- NRWAL NREL/NRWAL - A library of offshore wind cost equations

Wildlife Impact



- SSRS NREL/SSRS - A stochastic agent-based model for predicting raptor movements through an orographic updraft field estimated using the spatially varying wind conditions and ground features (altitude, slope, aspect).

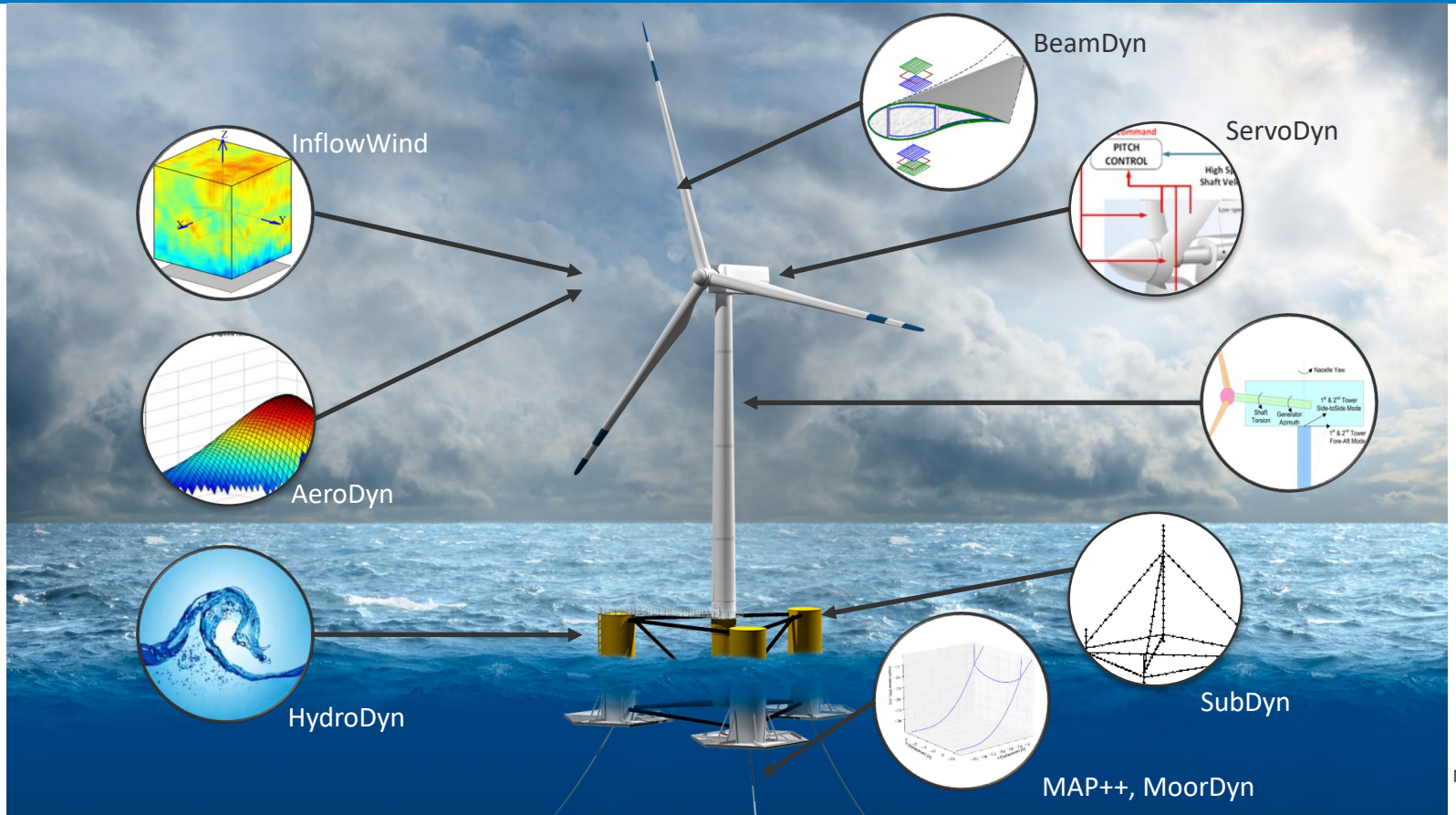
Operation and Maintenance



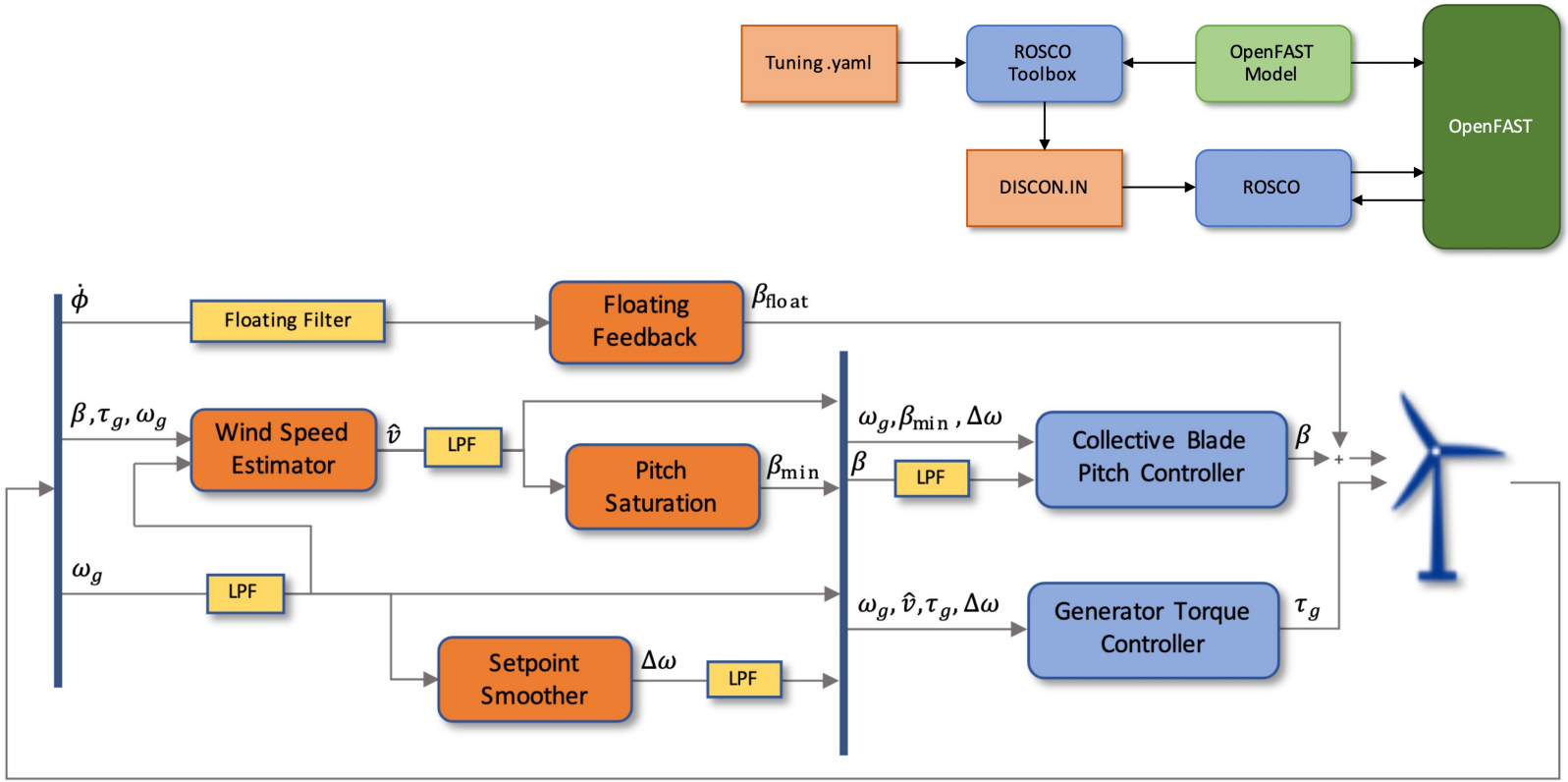
- WOMBAT WISDEM/WOMBAT - A library to simulate the operation and maintenance phase (O&M) of distributed, land-based, and offshore windfarms using a discrete event simulation framework.
- OpenOA nrel/openoa - A framework for working with large time-series data from wind plants, such as SCADA.

Capability Areas

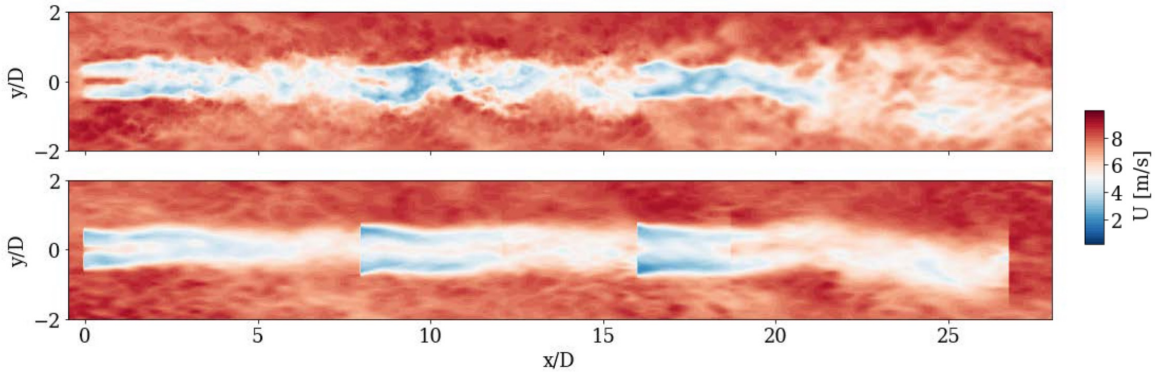
OpenFAST – Multi-physics Wind Turbine Simulation

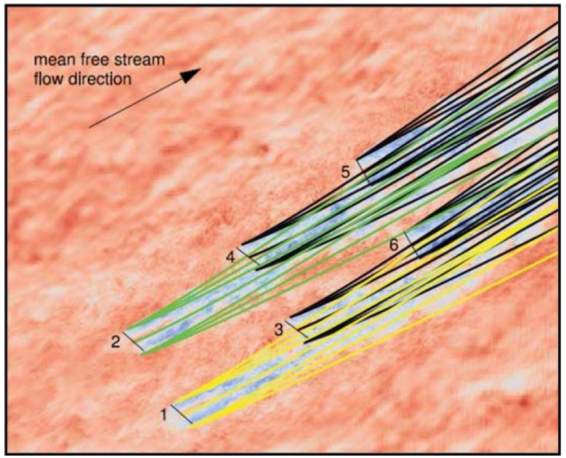


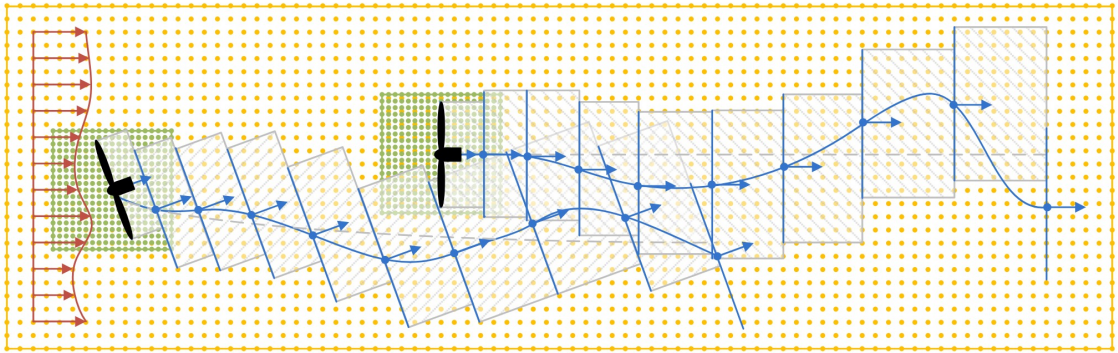
ROSCO - Open-Source Controller for OpenFAST



FAST.Farm – Wind Farm Simulation



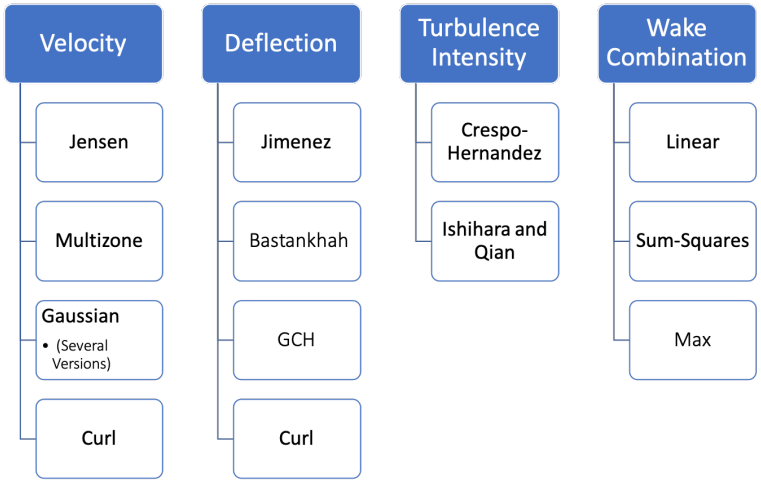




FLORIS – Wind Farm Control and Design Tool

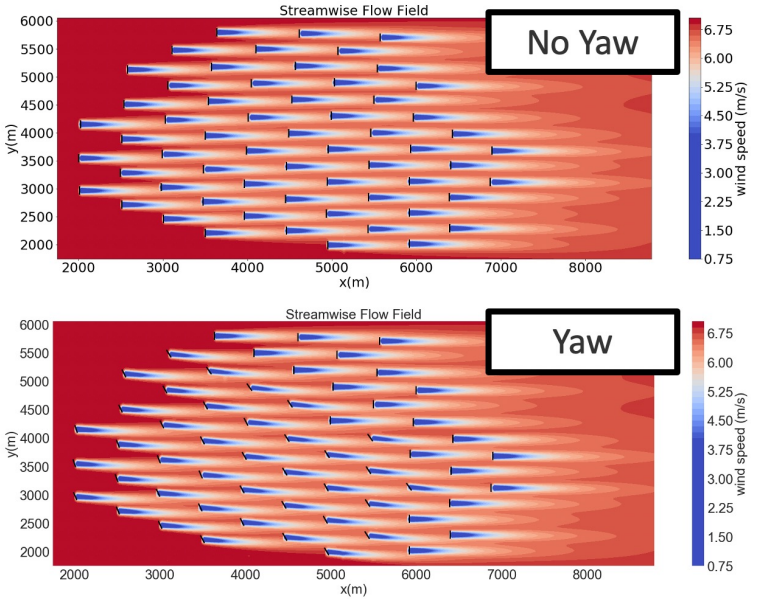
Design and analysis tools

- Controls design and analysis
- Site layout optimization and codesign
- Analysis of energy production



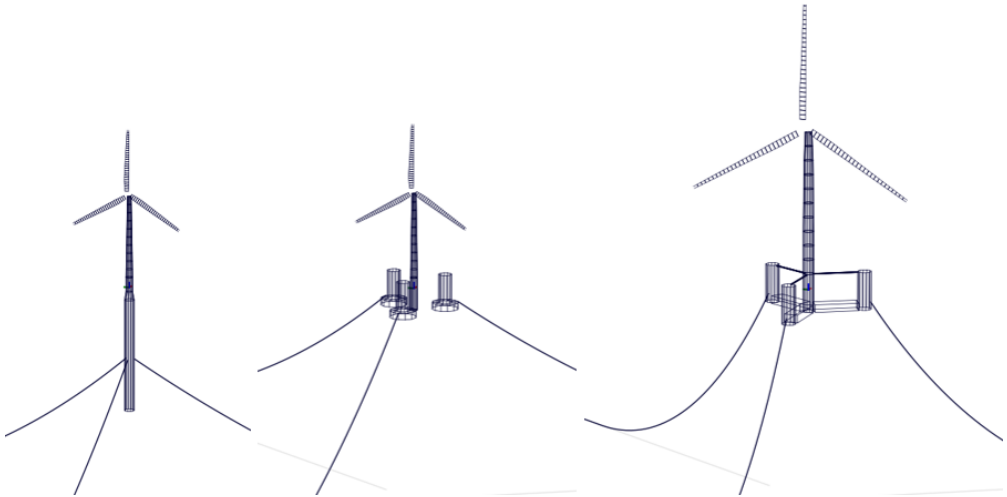
Wake Modeling

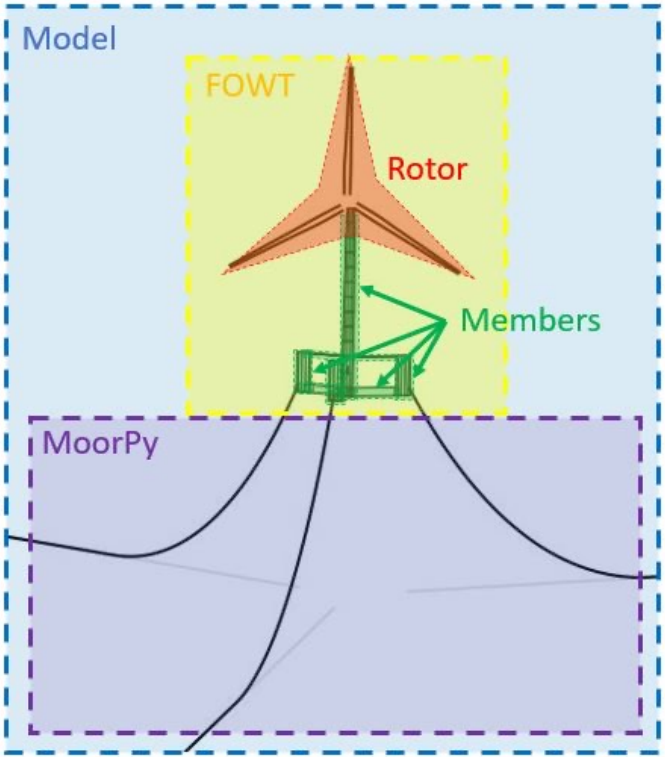
- Wake velocity, deflection, combination
- Turbulence propagation



MoorPy - Quasi-Static Mooring Toolset

- Used by RAFT for mooring simulation





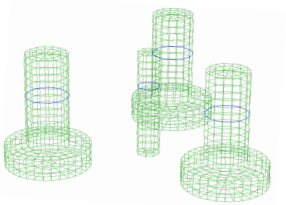
RAFT - Response Amplitudes of Floating Turbines

- Frequency-domain dynamics model for support structure optimization
- Level 1 model within WEIS, providing dynamics to complement WISDEM

Inputs:

- Design description (WEIS/WISDEM/custom)
- Load case settings

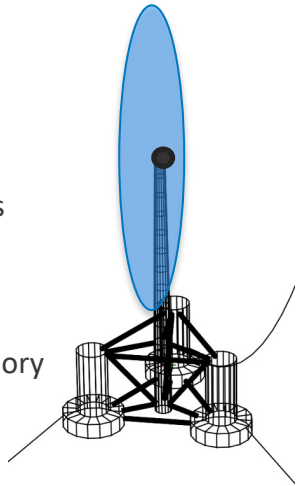
Substructure meshing



Hydrodynamics solver pyHAMS in-the-loop

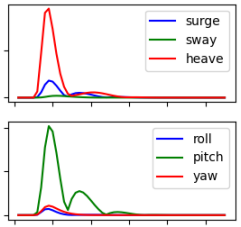
RAFT Model

- Linearized BEM aerodynamics from CCblade
- Turbine controls
- Tower flexibility
- Hydrodynamics
  - linear strip theory
  - potential flow
- Linear mooring reactions (MoorPy)



Outputs:

- Response spectra



- Motion/load metrics:
  - means & variances
  - extreme statistics
  - fatigue estimates

Impact:

- Efficient (~1 minute) dynamics evaluation for rapid floating wind design optimization

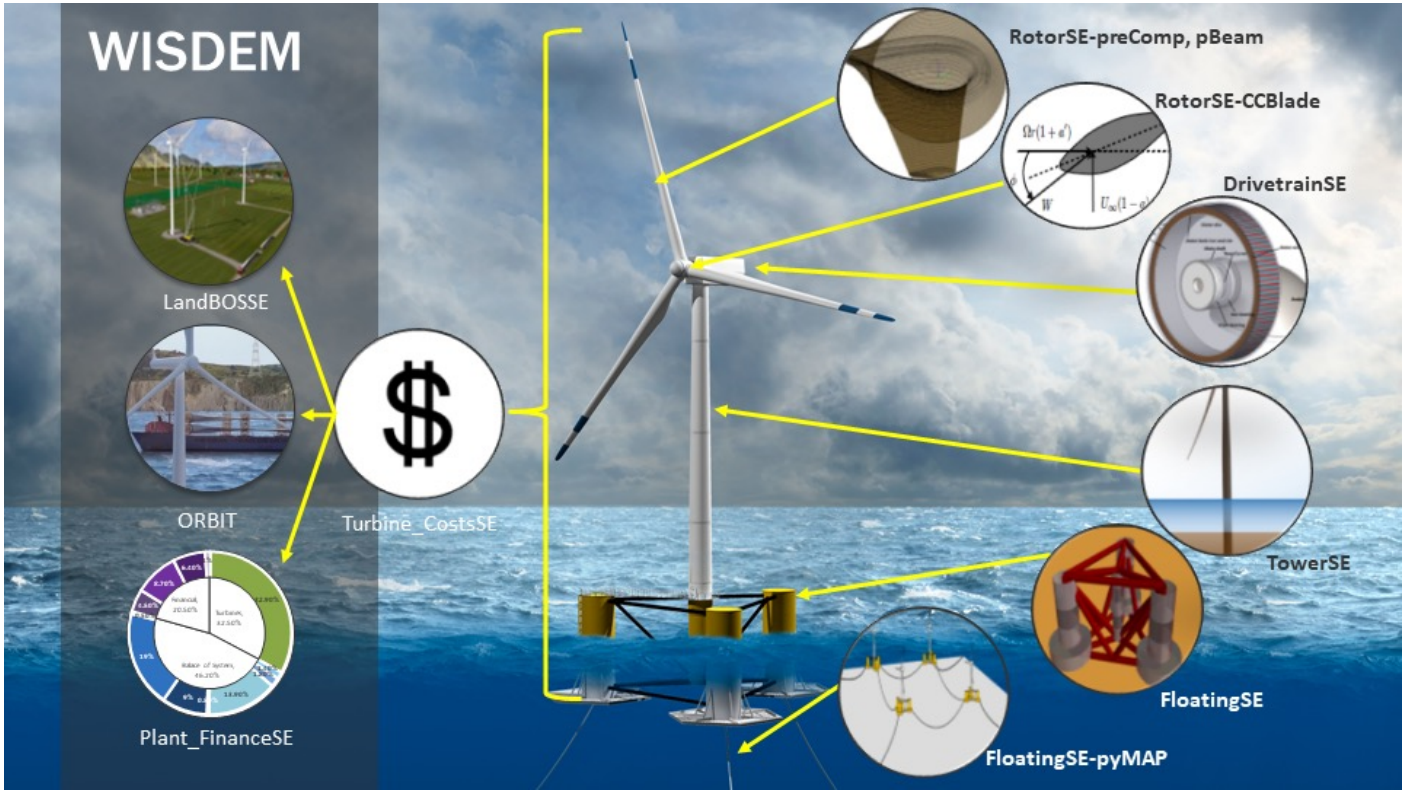
Current Funding:

- ATLANTIS – WEIS

Roadmap:

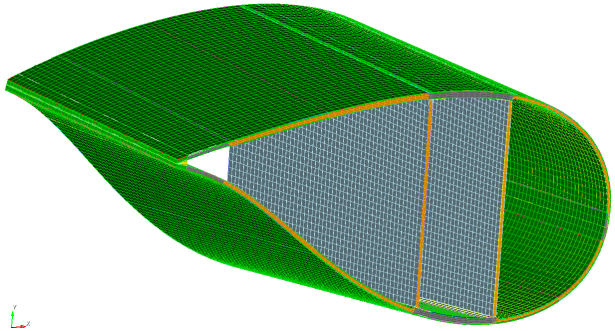
- Complete aerodynamics and control for WEIS
- Expanded aerodynamic, control, and structural modeling
- Multi-fidelity coupling

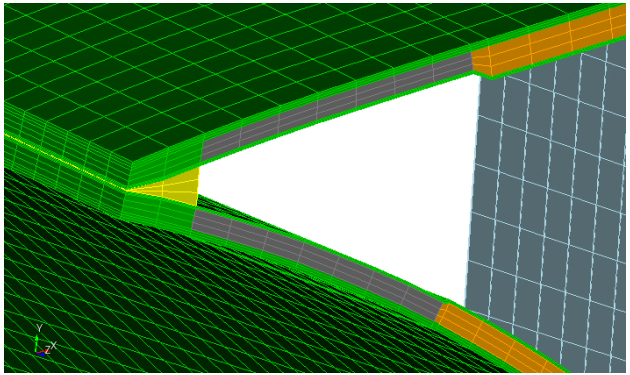
WISDEM – Wind Plant COE Assessment



pyNuMAD – Blade Design

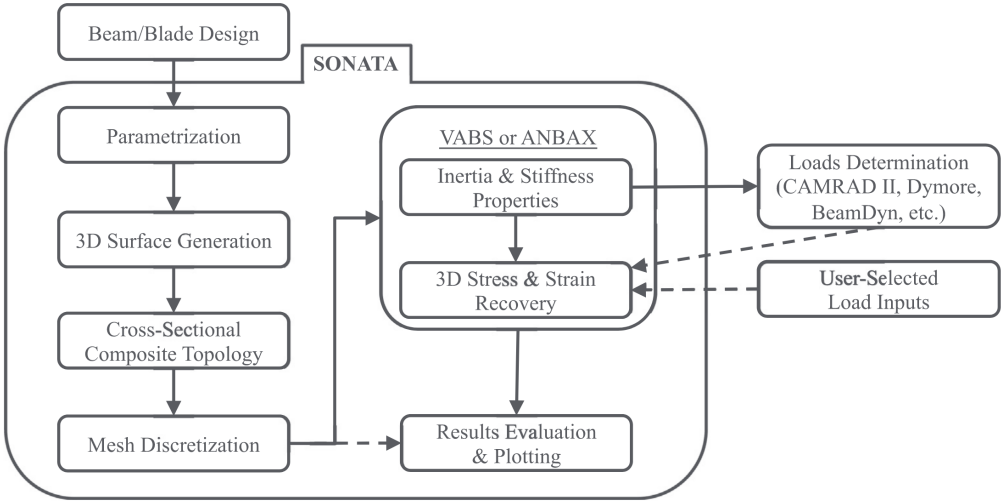
- Creates blades for beam, shell, and solid models
- Branched from NuMAD but with increased fidelity, robustness, and usability
- Currently interfaces with

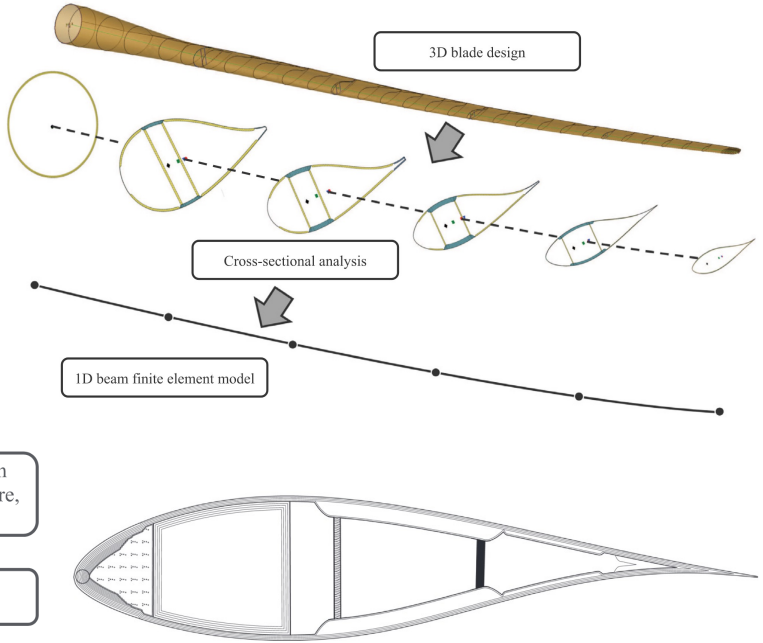




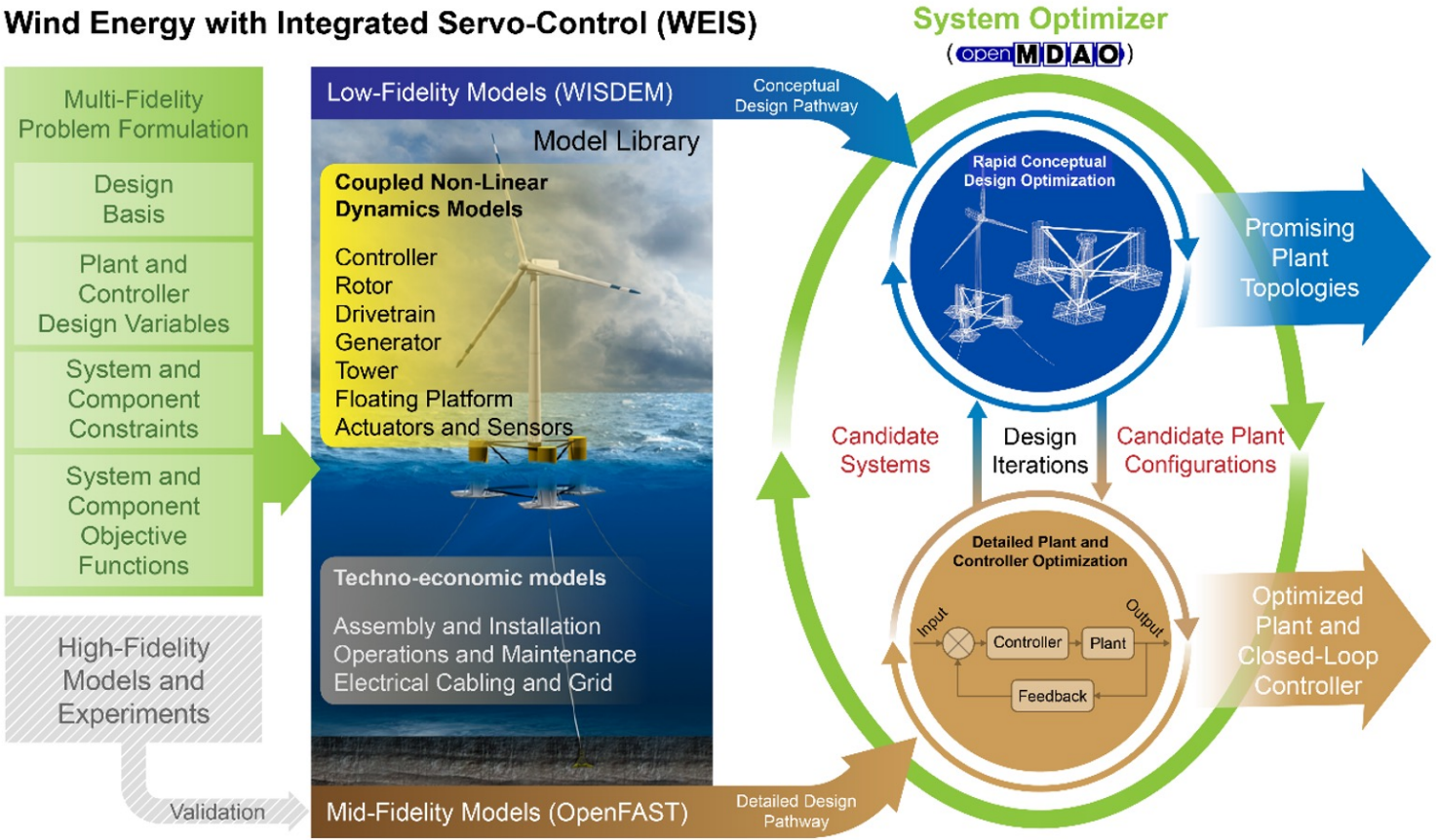
SONATA – Blade Cross-Section Design

- Uses structural solvers
  - VABS and ANBA4

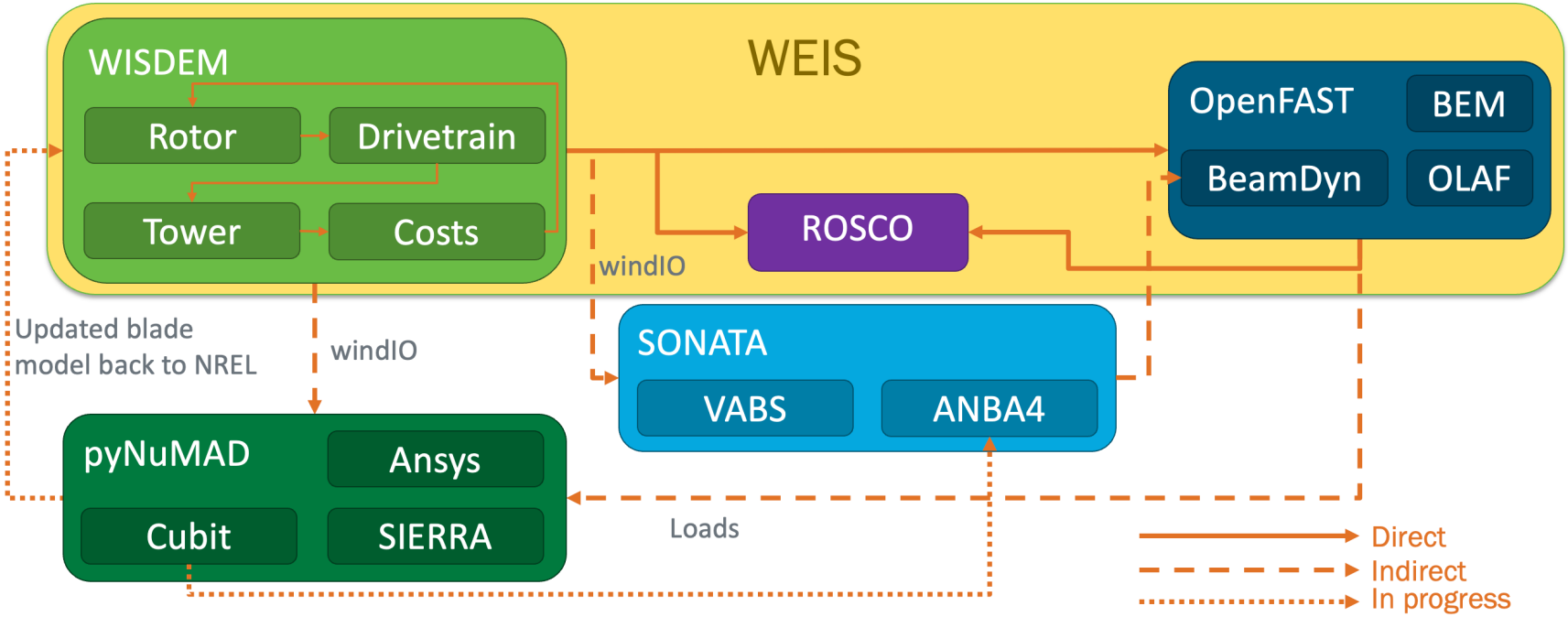




WEIS – Wind Turbine Multi-fidelity Co-Design

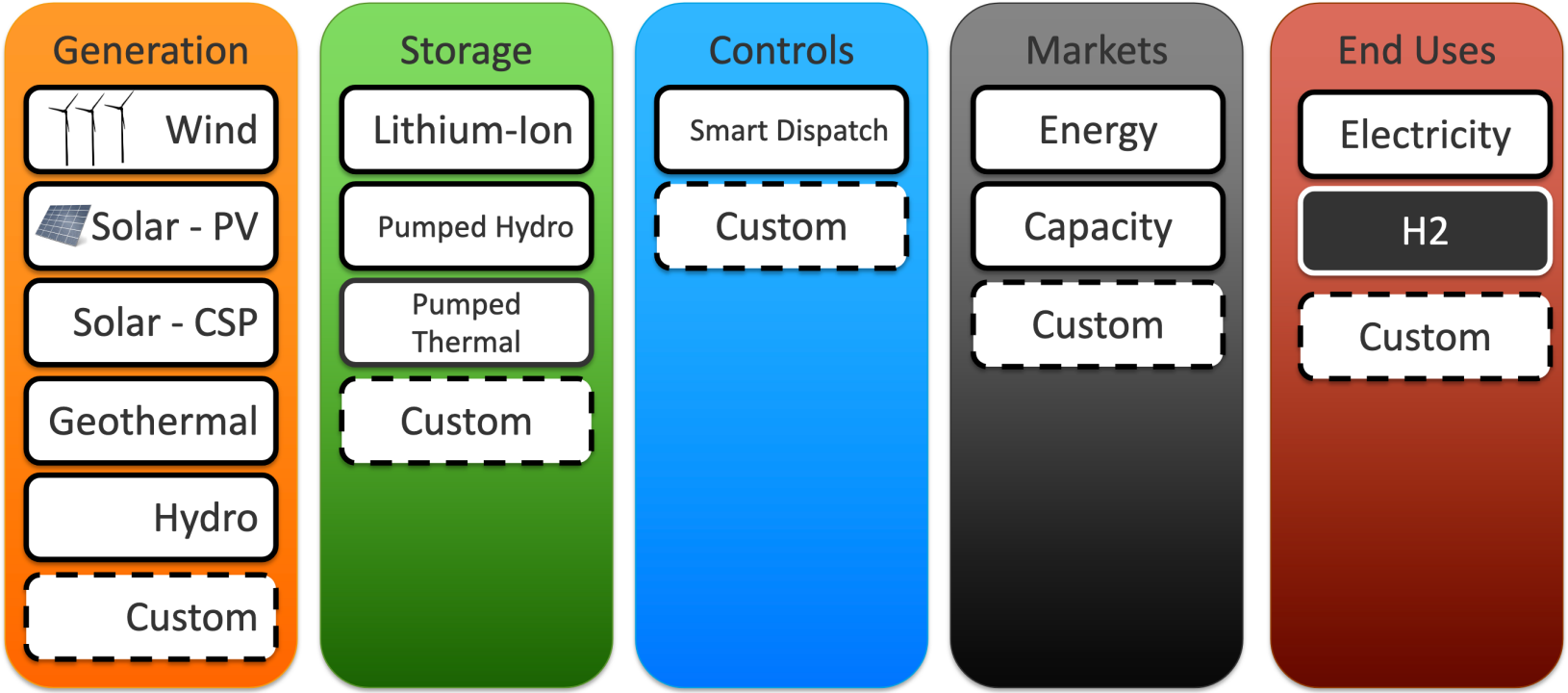


WEIS Interdependencies



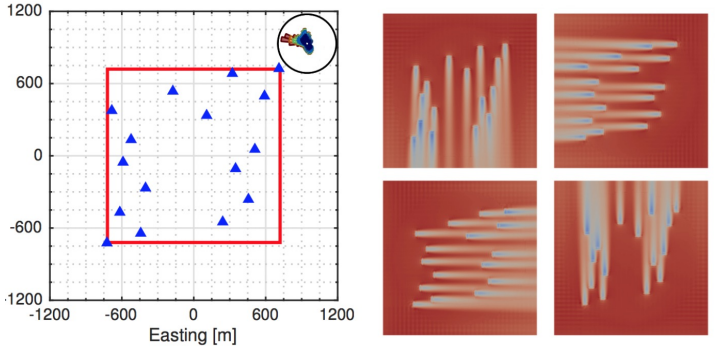
HOPP – Hybrid Optimization & Performance Platform

Optimize co-located, utility-scale hybrid plants down to the component level for different markets

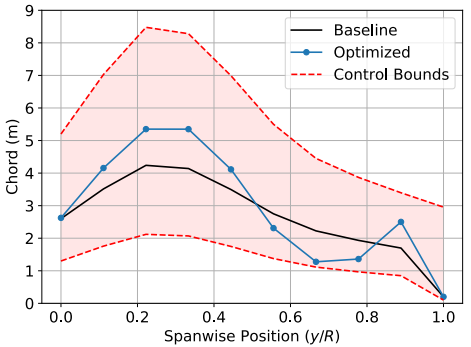


WindSE – Wind Farm Simulation & Optimzation

- `WindSE` is an open-source, Python package for wind plant simulation and optimization
- Supports both **steady and unsteady simulations** modeling turbines using **actuator disks and actuator lines**
- Adjoint gradient calculation enables performing optimizations with many controls
- **Current bottleneck:** how to perform optimizations of unsteady problems simulated with many timesteps and high spatial resolution
- Missed opportunities: unable to perform layout optimizations using higher-fidelity actuator lines with controls at the level of individual turbines



Layout optimization using steady-state solver to maximize power



Chord profile optimization using unsteady solver to maximize lateral wake deflection during yawed operation

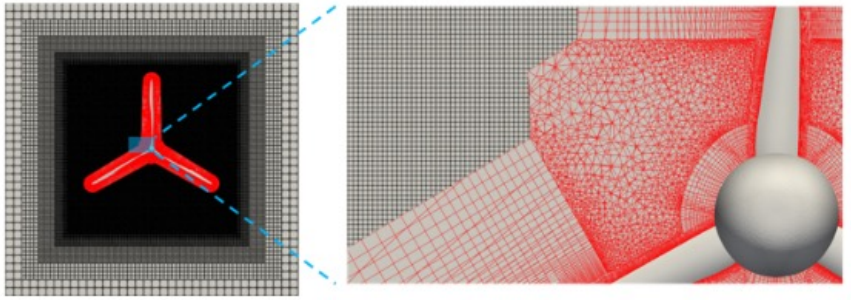
AMR-Wind / Nalu-Wind / ERF / OpenTurbine

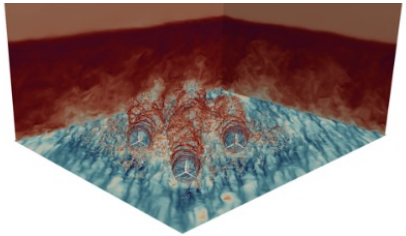
AMR-Wind
- Incompressible / anelastic fluid equations
- Structured-grid finite volume with MR
- Built on AMReX, a framework for block-structured adaptive mesh refinement

Nalu-Wind
- Fluid-solid interaction
- Unstructured-grid finite volume
- Built on Trilinos

OpenTurbine
- Whole-turbine structural simulation code

ERF
- Compressible fluid equations
- Structured-grid finite volume with MR
- Built on AMReX

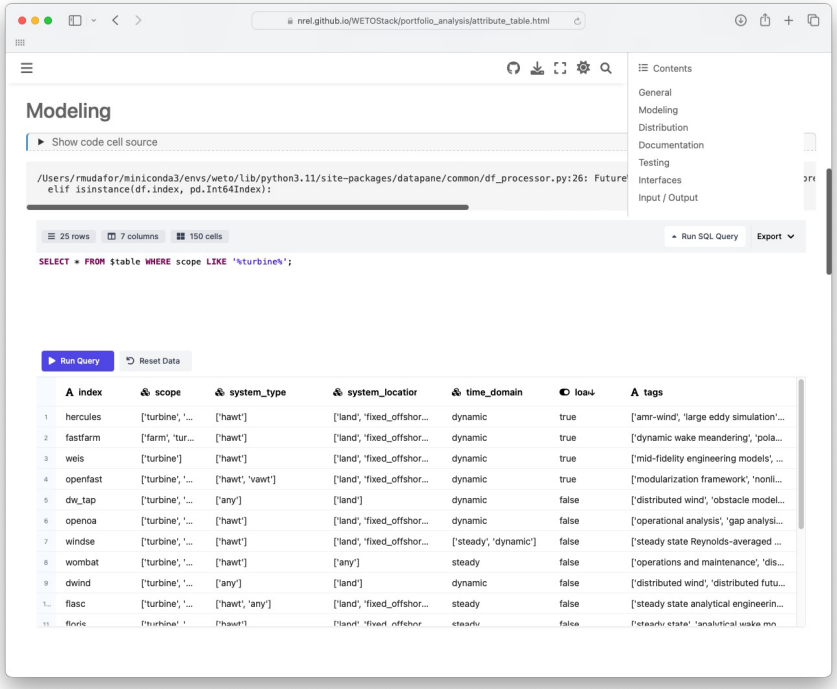


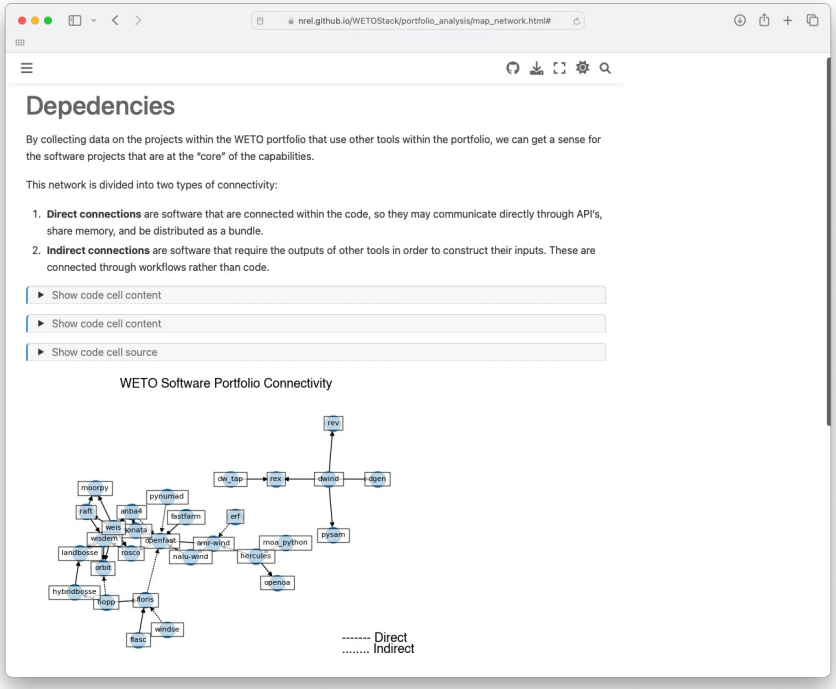


Questions?

Portfolio Analysis Tools

https://nrel.github.io/WETOStack

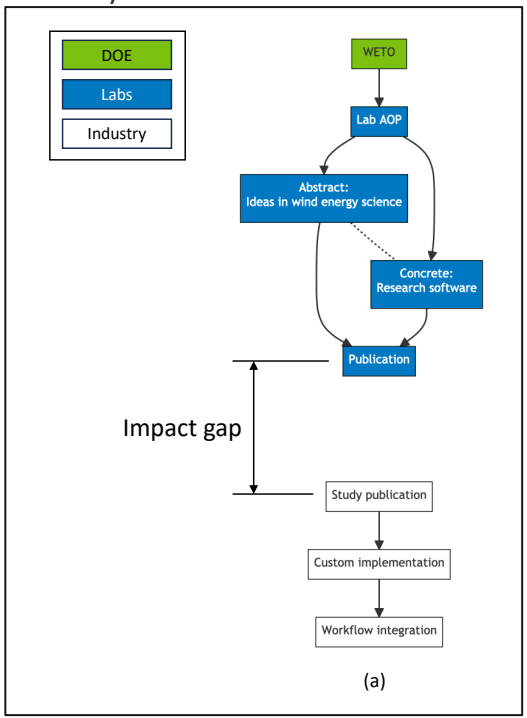




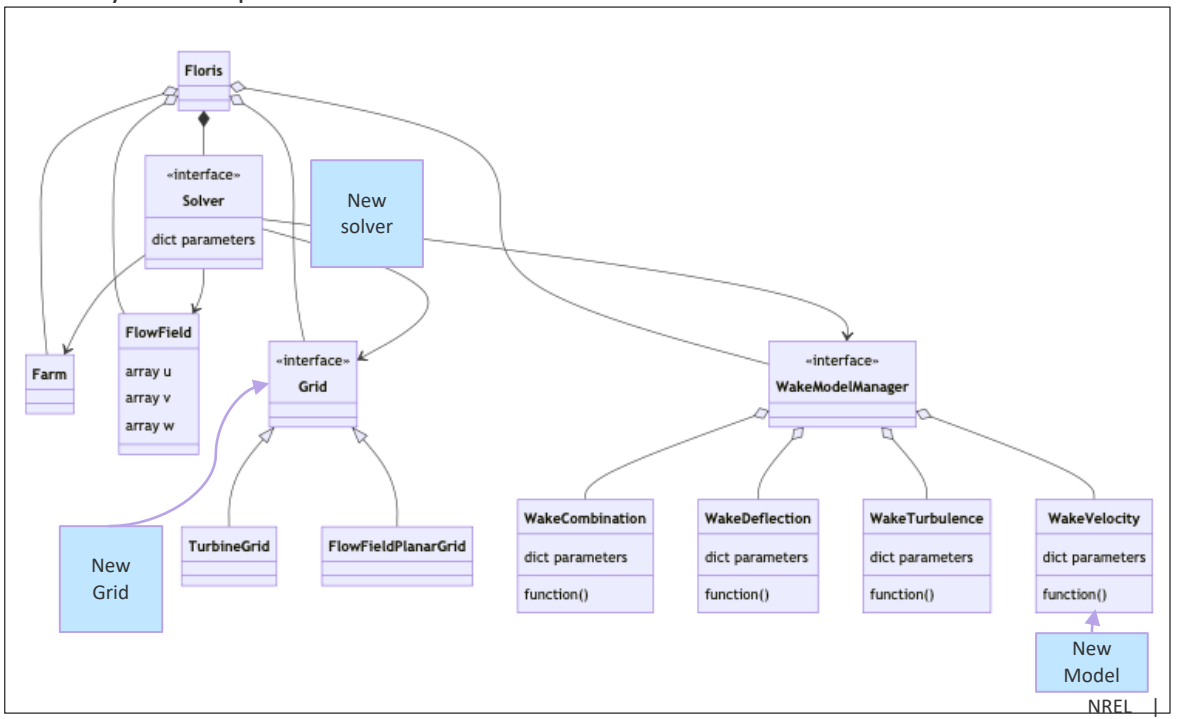
WETO Software Best Practices

https://nrel.github.io/WETOStack/best_practices.html

Usability - Practitioner



Usability - Developer



Holistic Modeling Upcoming

- User survey in early 2024
- **User-focused workshop in May/June 2024** ← Rafael.Mudafort@nrel.gov
- Ecosystem streamlining
  - Improved dependency management
  - Consolidate or decouple, as needed
- Software quality grading and review system
- Refine and expand portfolio analyses

- All activities will be documented on the WETOStack repository!
  https://nrel.github.io/WETOStack

Q&A / Open Discussion

Rafael.Mudafort@nrel.gov
github.com/NREL/WETOStack

- Where do you see the strengths and gaps in the WETO Software Portfolio?
- Regarding WETO software, what is appealing and what is currently lacking?

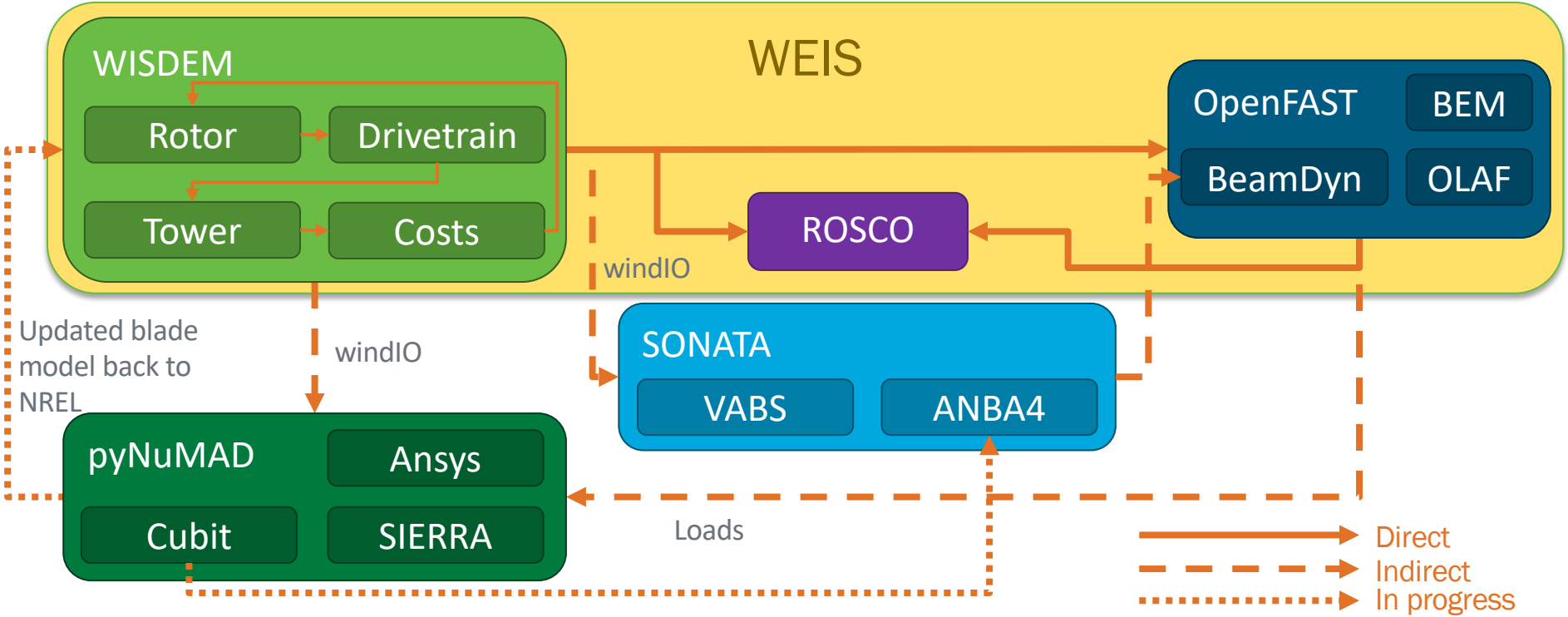
Photo from iStock-627281636

NREL
Transforming ENERGY

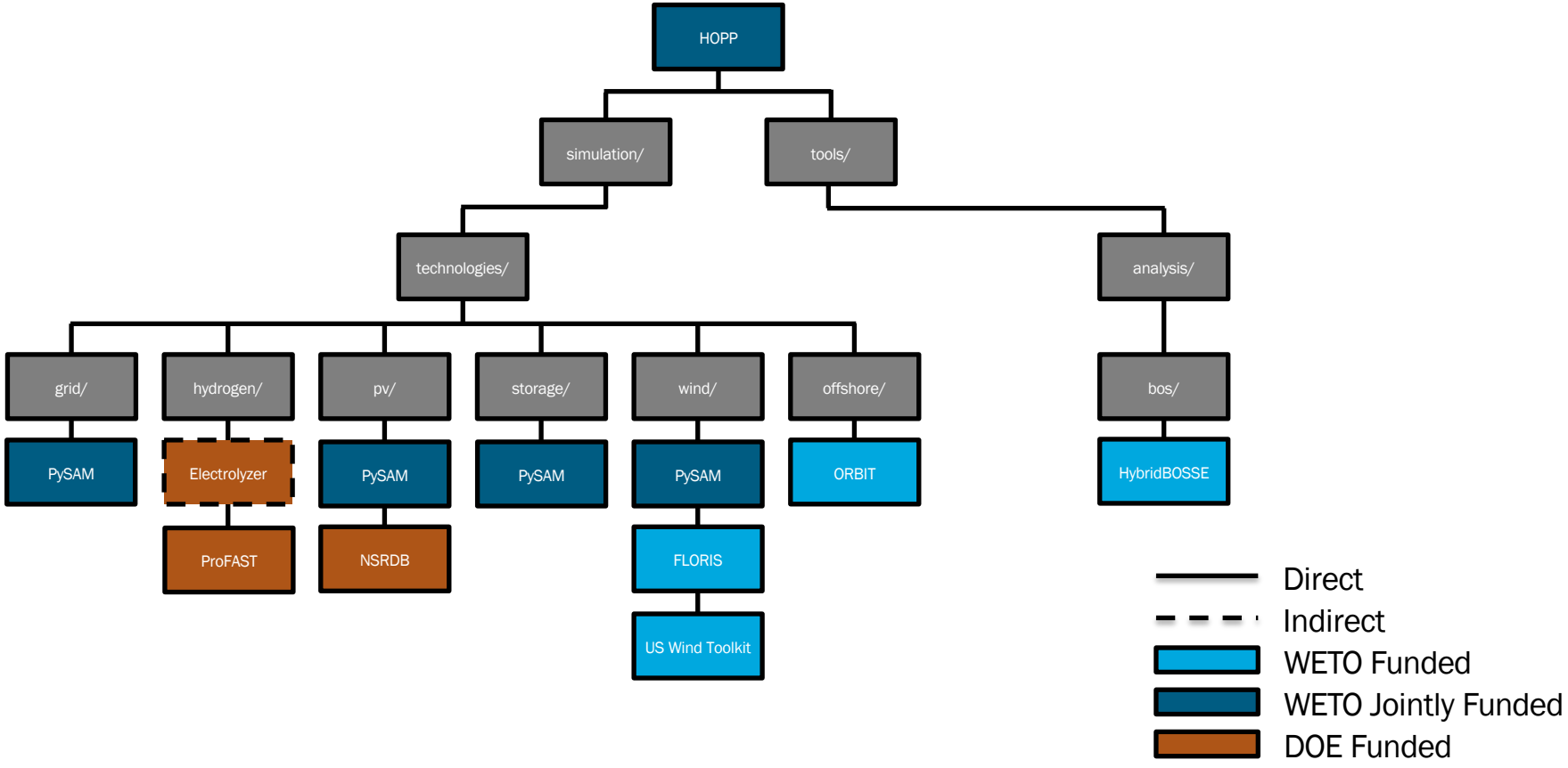
Design and Optimization: Big Adaptive Rotor

The Toolchain used in the Design Studies of the BAR Project

Sequential design process at increasing fidelity, using open-source tools

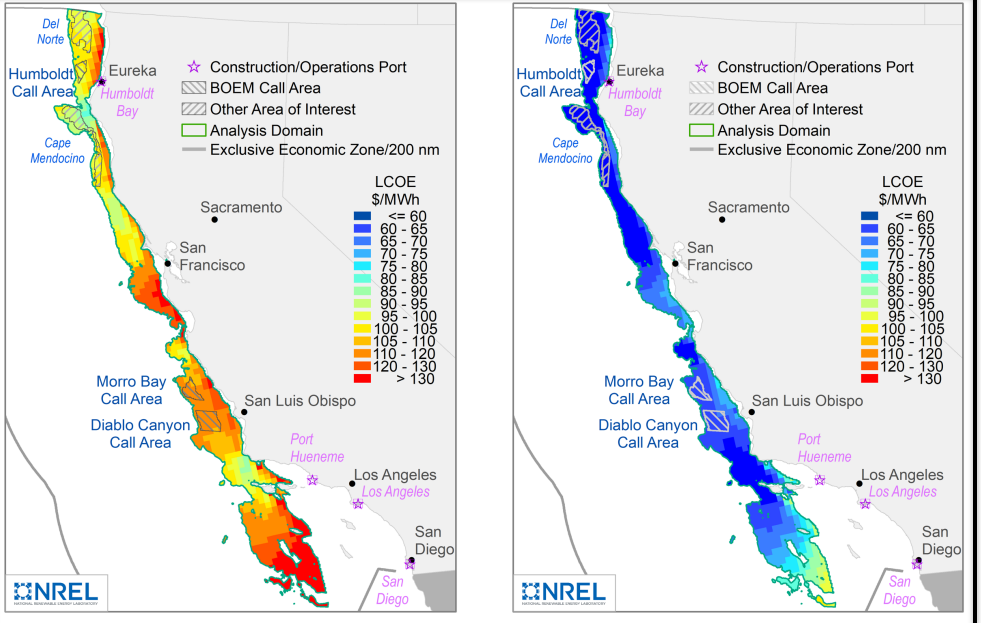


HOPP – Hybrid Optimization Performance Platform

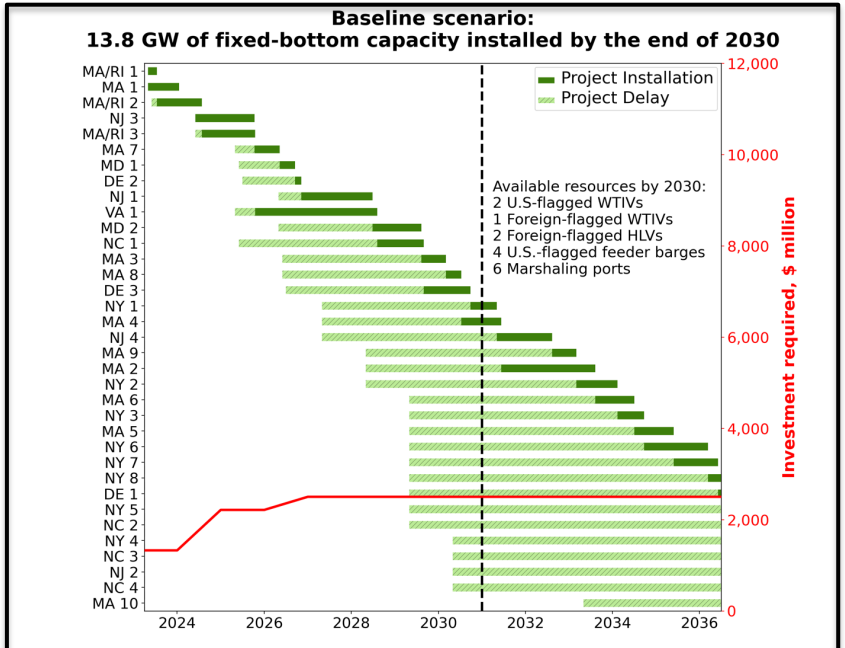


Techno-Economic Analysis

NREL develops open-source techno-economic modeling tools to evaluate high-impact cost, technology, logistics, and supply chain questions for offshore wind energy



Levelized cost of energy for offshore wind in California for a commercial operation date in 2019 (left) and 2032 (right). From Beiter, et al, 2020



Evaluation of deployment bottlenecks due to port and vessel supply limitations. From Shields et al. (2023)

Primary research questions and relevant tools

- How do technology and process innovations impact the costs, logistics, risks, and performance of individual projects?

Project scale cost and logistics	Future cost projections	Regional/national scale
• LandBOSSE • ORBIT • WOMBAT • HybridBOSSE	• FORCE	• NRWAL • CORAL

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Primary research questions and relevant tools

- How do technology and process innovations impact the costs, logistics, risks, and performance of individual projects?
- How could costs evolve over time given technology choices and broader industry development?
- What drives costs and deployment bottlenecks throughout the broader industry?

Project scale cost and logistics	Future cost projections	Regional/national scale
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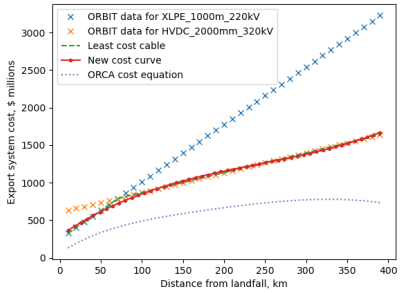
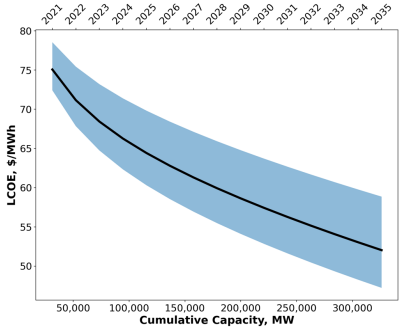
Model integration with broader NREL tool sets

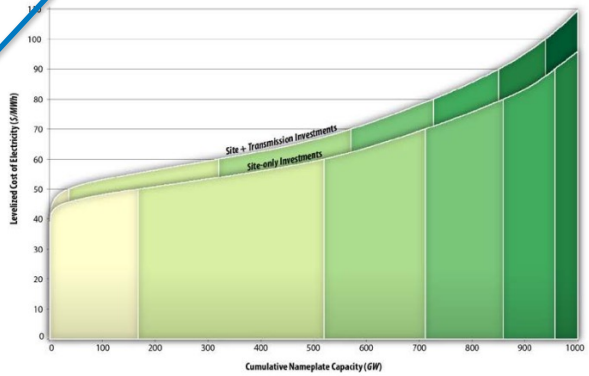
Design space of project costs



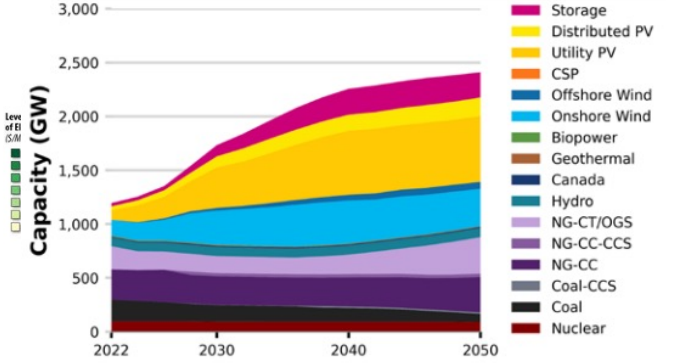
Cost projections



Supply curves (reV)



Capacity expansion (ReEDS)



WETO models

All technology