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Introducing WISDEM™: An Integrated System Model of Wind Turbines and Plants

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Outline

- Wind energy systems engineering program and software by the National Renewable Energy Laboratory (NREL)
  - Integrated wind turbine and plant modeling
  - Software platform
  - Summary and future work.

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Integrated Wind Turbine and Plant Modeling

Wind Energy System Cost of Energy

Often use simplified cost of energy (COE) representation as a global system objective:

$$COE = \frac{F * (CAPEX) + OPEX}{AEP}$$

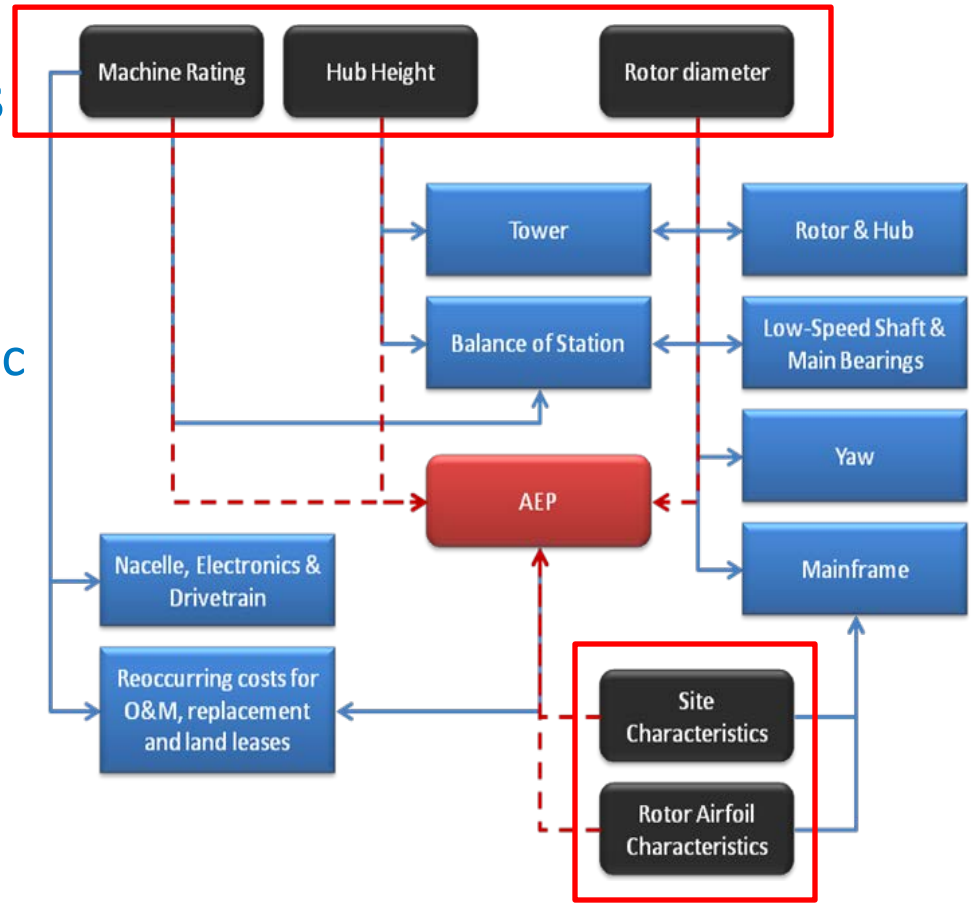
Where *COE* is the cost of energy, *F* is the financing rate to annualize investment costs, *CAPEX* is the sum of all capital expenditures, *OPEX* are the annual operating expenses, and *AEP* is the net annual energy production.

Graphic by Al Hicks, NREL

Determining Wind Cost of Energy

- **The NREL cost and scaling model uses parameterized functional relationships calibrated to historical trends**
  - Originated with detailed design studies in early 2000s (WindPACT)
  - Abstraction to simple parametric relationships
  - Useful for two primary types of analyses on system costs:
    - Changing input factor prices over time
    - Scaling of conventional technology within a limited range.
  - Publicly available model.

Structure of NREL cost and scaling model



Fingersh, L.; Hand, M.; Laxson, A. (2006). *Wind Turbine Design Cost and Scaling Model*. 43 pp.; NREL Report No. TP-500-40566.

NREL Wind Energy Systems Engineering

- **The key focus of a wind energy systems engineering effort includes:**
  - Integrating wind plant engineering performance and cost software modeling to enable full system analysis
  - Applying a variety of advanced analysis methods in multidisciplinary design analysis and optimization (MDAO) and related fields
  - Developing a common platform and toolset to promote collaborative research and analysis among national laboratories, industry, and academia.

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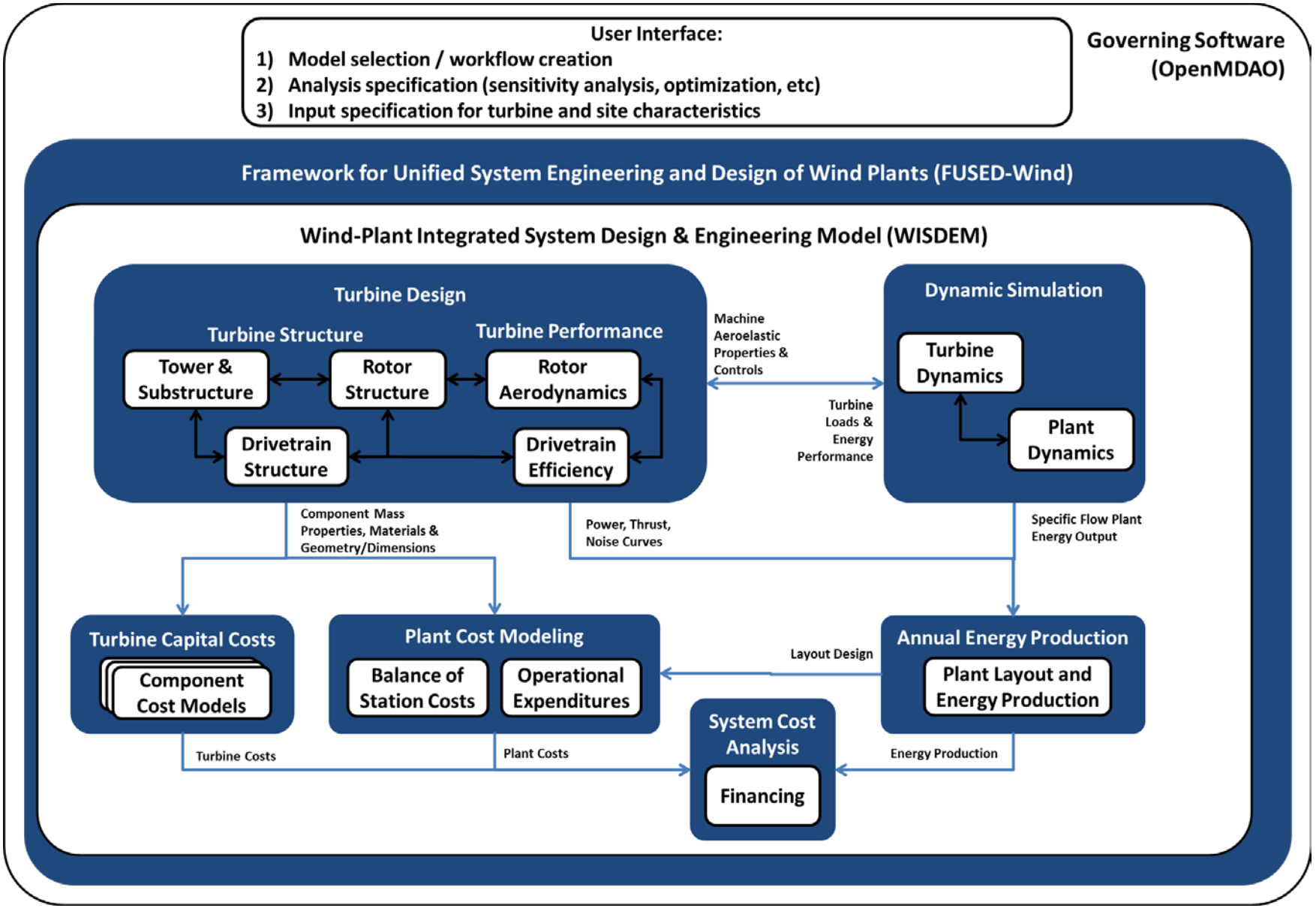
Software Platform

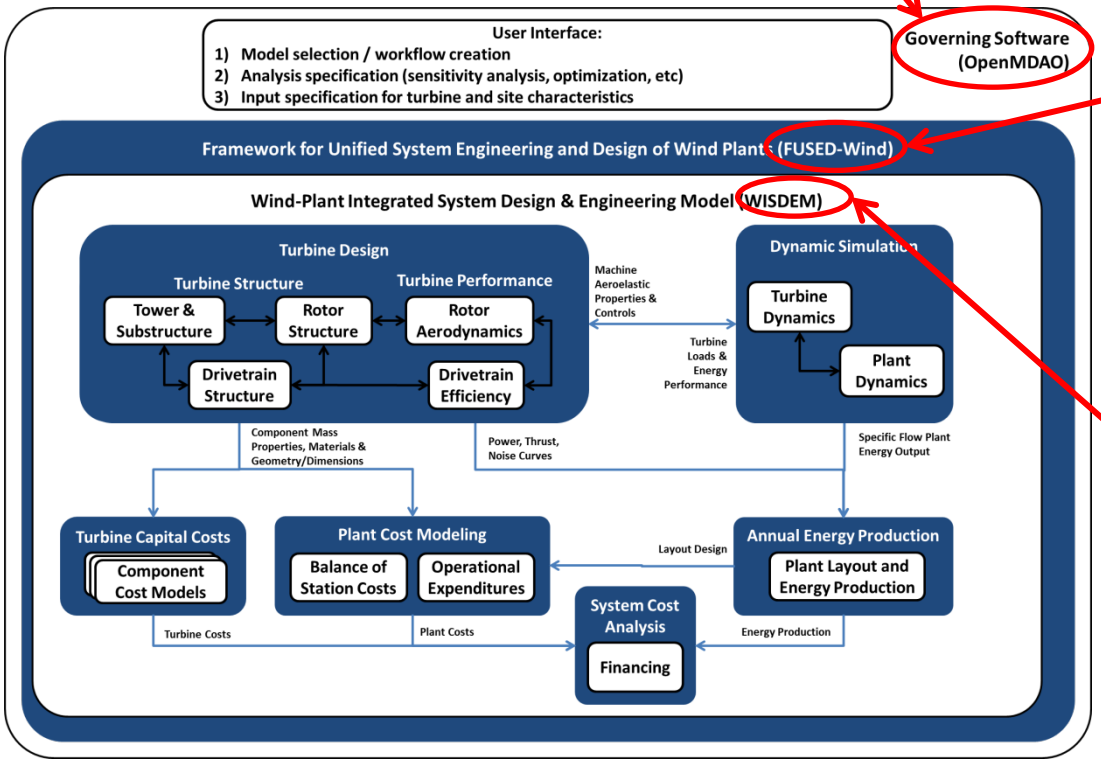
Systems Engineering Software Framework



Systems Engineering Software Framework

OpenMDAO:

- Work flows integrate models together in structured ways (use of National Aeronautics and Space Administration's [NASA]'s OpenMDAO software)
- Easily reconfigured (model selection and analysis structure).



FUSED-Wind:

- Developed in collaboration with the Danish Technical University Wind Energy Department
- Support software for structured interface of wind turbine and plant modeling tools into OpenMDAO
- Allows interchange of models, and sharing of common turbine and plant input descriptions.

NREL WISDEM™:

- Collection of NREL engineering and cost turbine and plant analysis tools integrated into FUSED-Wind and OpenMDAO
- Full wind turbine and plant model set planned for release.

RotorSE (with CCBlade, PreComp, and pBEAM)

- Rotor model includes submodels for aerodynamics and structure
- Either aero or structural models can be tied to optimizer (or both together).

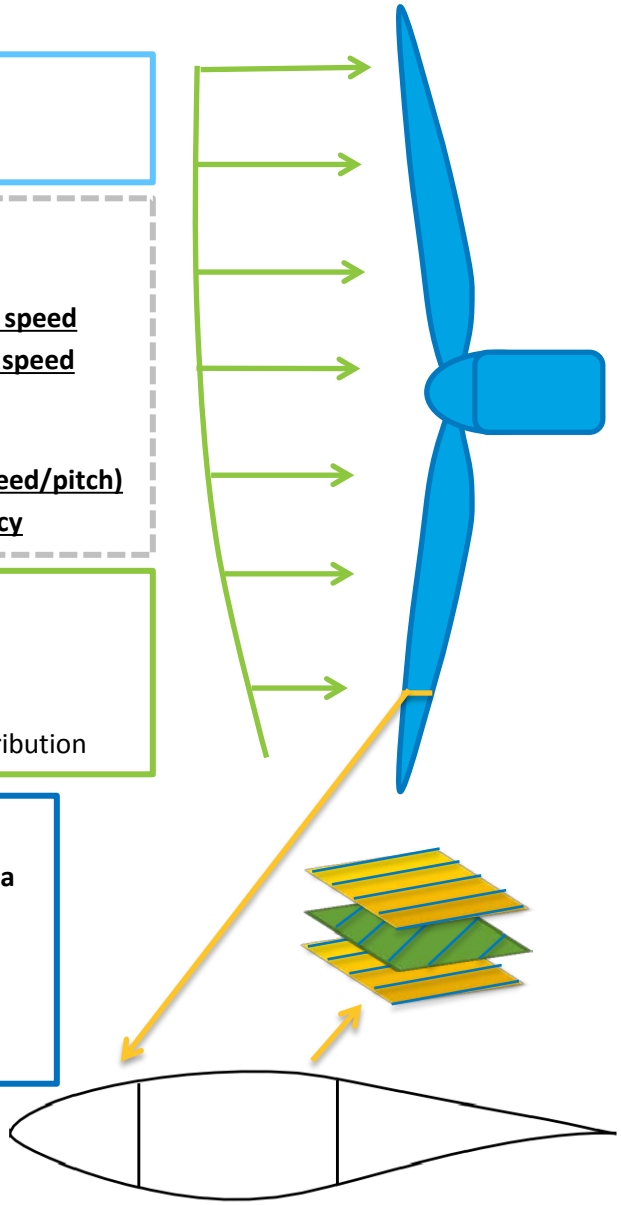
<<< INPUTS

ROTOR INPUTS
- Number of blades
- Precone, tilt

TURBINE INPUTS
- Hub height
- Cut-in and cut-out speed
- Min/max rotation speed
- Rated power
- Machine type (Fixed/variable speed/pitch)
- Drivetrain efficiency

ATMOSPHERE
- Density
- Viscosity
- Shear exponent
- Wind speed distribution

LAMINATE STACK
- Sequence of lamina
- Number of plies
- Ply thickness
- Ply orientation
- Ply material



OUTPUTS >>>

ROTOR STRUCTURE AND PERFORMANCE
- Blade mass and moments of inertia
- Cost
- Power curve
- Turbine AEP
- Hub loads
- Sound power level
- Natural frequencies
- Blade displacements
- Panel buckling loads
- Axial and shear stress

AIRFOIL
- Radial location, chord, twist
- Profile shape
- Lift curves and drag polars (parameterized by Re and t/c)
- Web locations

Turbine Assembly and Turbine_CostsSE

- Model integrates components and passes loads from the rotor to the drivetrain to the tower
- System-level optimization of turbine possible for a number of different configurations
- Costs calculated based on component mass-to-cost relationships.

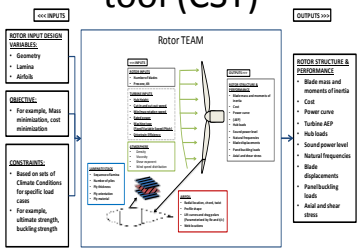
<<< INPUTS

TURBINE MODEL INPUT DESIGN PARAMETERS:

- Wind, water, and soil statistics
- Rotor diameter
- Rotor airfoil class
- Rotor geometry
- Drivetrain gearbox/generator configuration
- Machine rating
- Hub height
- Tower geometry

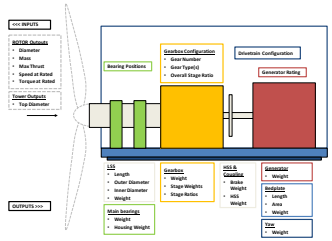
Turbine model

Rotor cost and sizing tool (CST)



- Rotor speed
- Max thrust
- Torque
- Moment
- Mass/modal properties

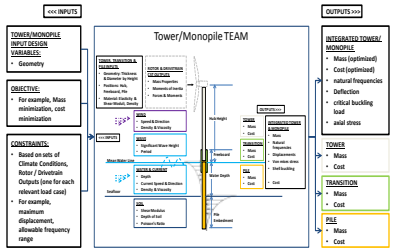
Drivetrain CST



Rotor nacelle assembly (RNA)

- RNA forces and moments
- RNA mass/modal properties

Tower/monopile CST



OUTPUTS >>>

TURBINE CAPITAL COSTS AND PROPERTIES:

- Mass
- Cost

COMPONENT COSTS AND PROPERTIES:

- Mass
- Cost
- Natural frequencies
- Deflection
- Critical buckling load
- Axial stress

Plant_EnergySE (With openWind)

- **Basic energy production model based on wind resource statistics and loss inputs**
- **Wrapper for AWS Truepower openWind allows for flow model with wake effects**
  - Updated wrapper for current openWind Enterprise version to be released in 2014.

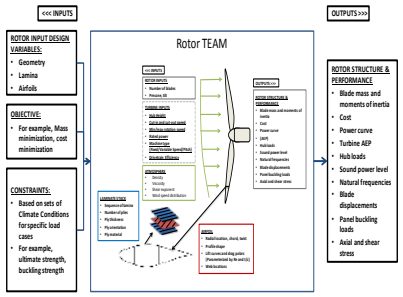
<<< INPUTS

ROTOR MODEL INPUT DESIGN PARAMETERS

- **Wind statistics**
- **Rotor diameter**
- **Rotor airfoil class**
- **Rotor geometry**
- **Drivetrain gearbox /generator configuration**
- **Machine rating**
- **Hub height**
- **Drivetrain efficiency**

Annual energy production model

Rotor CST

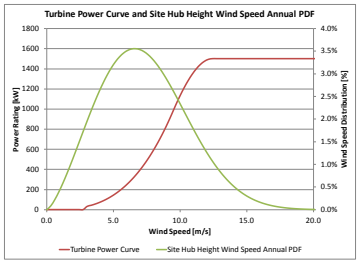


•Power curve

O&M model

•Availability

Energy production model



x Availability

x Plant losses

OUTPUTS >>>

ENERGY PRODUCTION:

- **AEP**
- **Plant capacity factor**

Systems Engineering Software Framework

- Integration of models into FUSED-Wind-based WISDEM (http://nwtc.nrel.gov/WISDEM) includes several areas:
    1. Turbine component structure and cost models
    2. Plant energy production and cost models
- For each area, multiple levels of fidelity are possible.

Rotor aero	Rotor structure	Nacelle structure	Tower and support structure	Turbine costs	Plant balance of station (BOS)	Plant OPEX	Plant energy production	Plant finance
NREL cost and sizing models (CSM)				NREL CSM	NREL CSM	NREL CSM	NREL CSM	NREL CSM
RotorSE	RotorSE	NacelleSE (with DriveSE option)	TowerSE/ JacketSE	Turbine_ CostsSE	NREL onshore/ offshore BOS	NREL OPEX/ ECN Offshore O&M model	AWS Truepower openWind	NREL System Advisor Model (SAM)

Ongoing/Future WISDEM Model Development

- **Planned model fidelity build-out over time with coordinated efforts through FUSED-Wind activities**
- **Current model development**
  - Updated turbine cost models
  - Support structure design
    - Floating platform design
  - Plant energy production
    - FLORIS_SE
    - WindSE
  - Plant costs
    - NREL BOS models
    - NREL OPEX models
  - Plant finance
    - SAM wrapper.

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Summary and Future Work

Summary

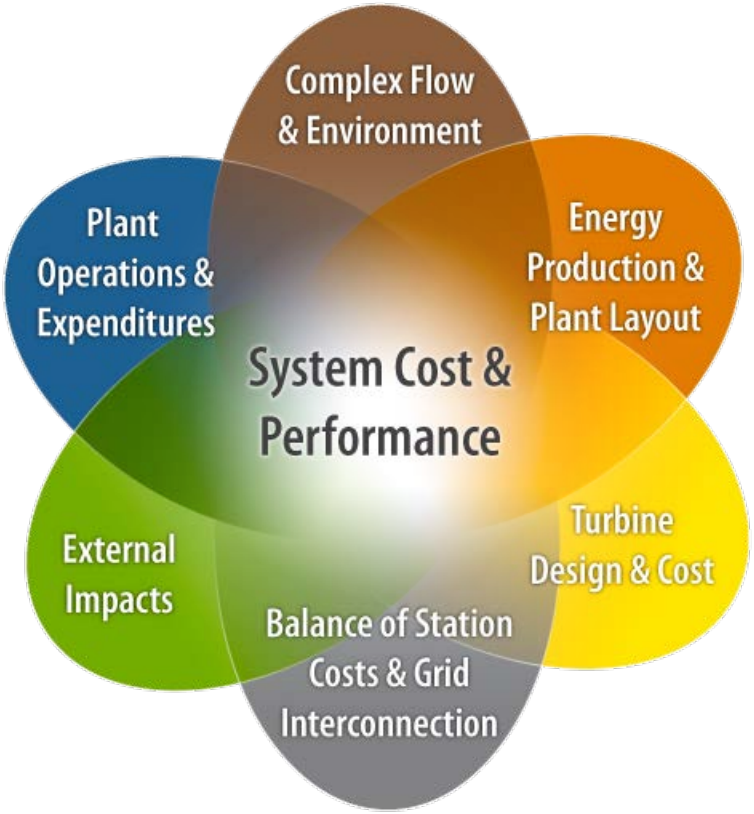
- **WISDEM is a toolset for modeling integrated wind plant systems for performance and cost that has the ability to select different model fidelities for different parts of a system**

- **WISDEM provides a collaborative platform via FUSED-Wind so that models can be mixed and matched among users for many different applications**

- **The first version includes a relatively simple model set to span the full system. Additional models of higher levels of fidelity will be included over time (or can be contributed from the larger wind model development community).**

Discussion/Q&A

http://www.nrel.gov/wind/systems_engineering



http://nwtc.nrel.gov/WISDEM
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