SAND2019-6815C

Validation and Verification: Beyond Planning
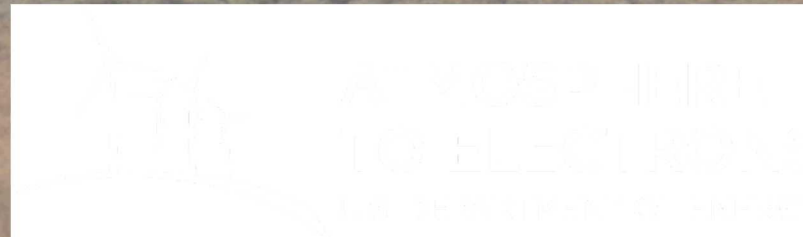
Jonathan Naughton

University of Wyoming Wind Energy Research Center

Wyoming Instrumentation Development

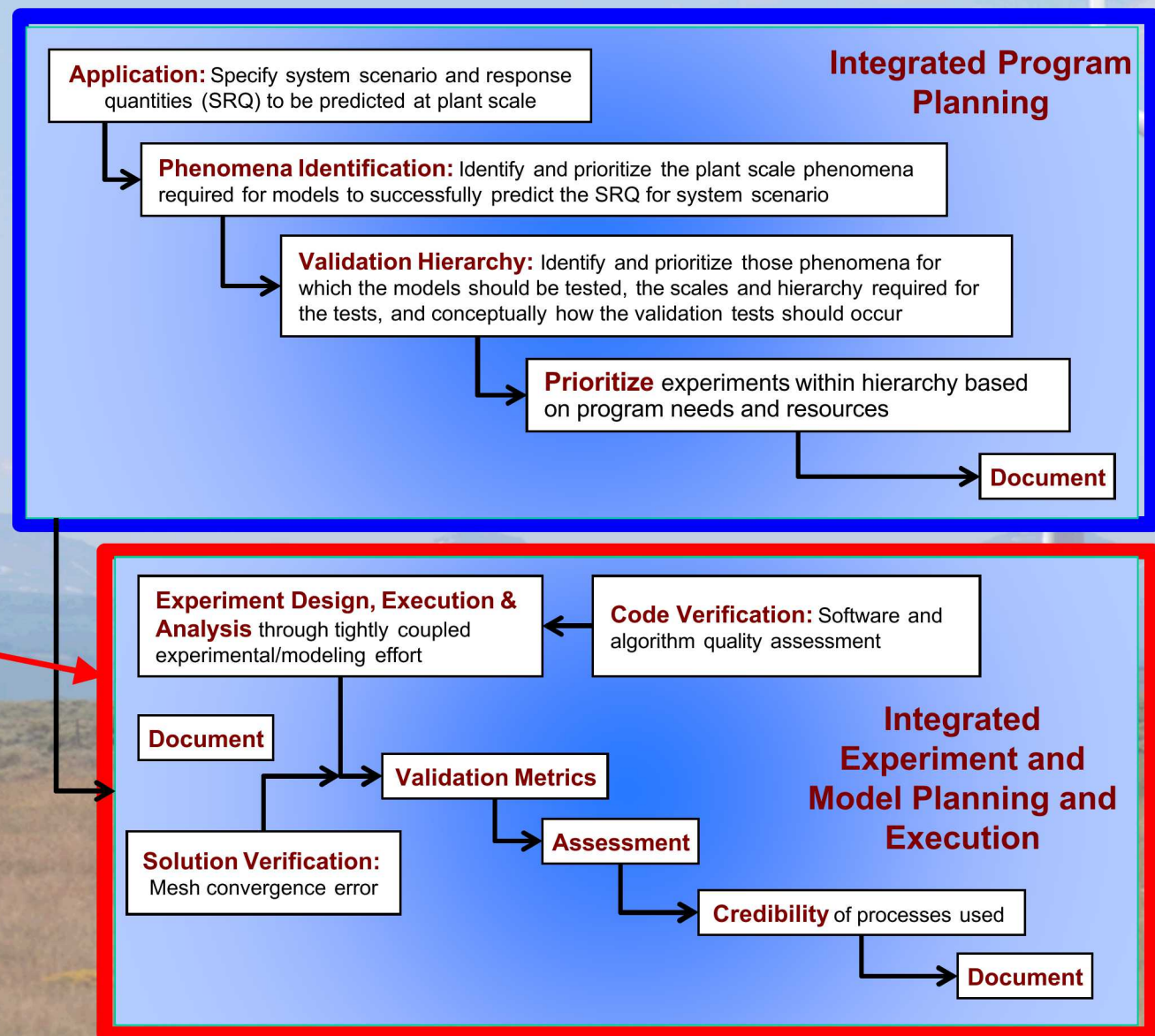## David Maniaci

Sandia National Laboratories

Overview

- **Summary of Integrated Project Planning (IPP)**

- **Transition from IPP to Integrated Experiment and Model Planning and Execution**

- **Overview of Integrated Experiment and Model Planning and Execution**
  - The Process
  - Integration of Efforts
  - Some Examples
  - Next Steps

Integrated Program Planning

Application: Specify system scenario and response quantities (SRQ) to be predicted at plant scale

Phenomena Identification: Identify and prioritize the plant scale phenomena required for models to successfully predict the SRQ for system scenario

Validation Hierarchy: Identify and prioritize those phenomena for which the models should be tested, the scales and hierarchy required for the tests, and conceptually how the validation tests should occur

Prioritize experiments within hierarchy based on program needs and resources

Document

Integrated Experiment and Model Planning and Execution

Experiment Design, Execution & Analysis through tightly coupled experimental/modeling effort

Code Verification: Software and algorithm quality assessment

Document

Solution Verification: Mesh convergence error

Validation Metrics

Assessment

Credibility of processes used

Document

Summary of Integrated Program Planning
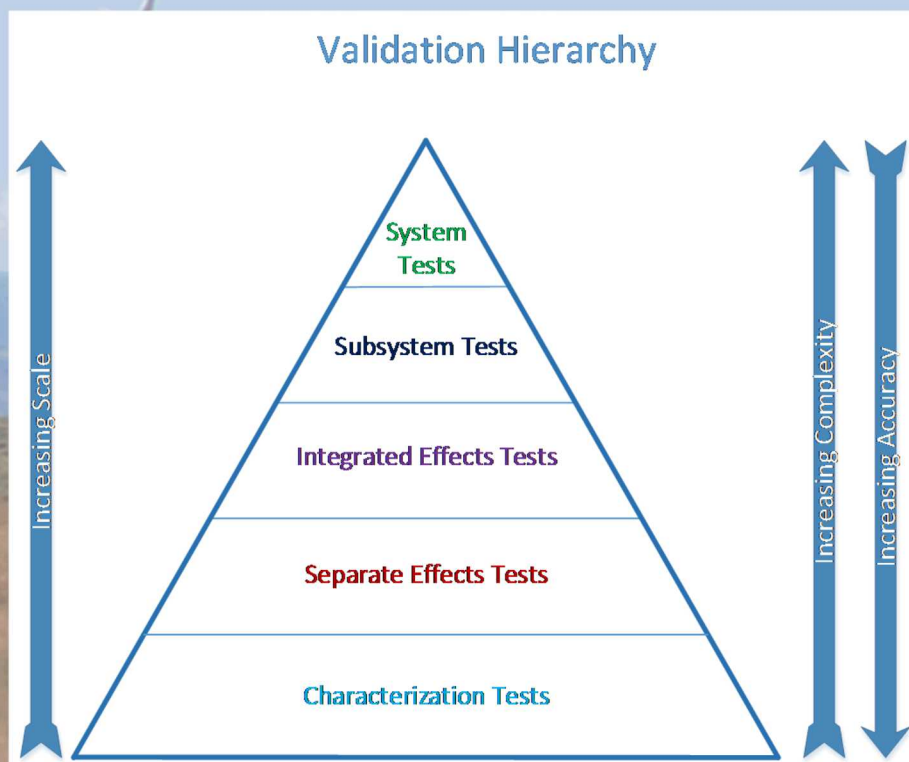
- **PIRTs have been developed from HFM perspective for wind applications**
- **Validation hierarchy developed from PIRTs**

Wind Plant Validation Hierarchy
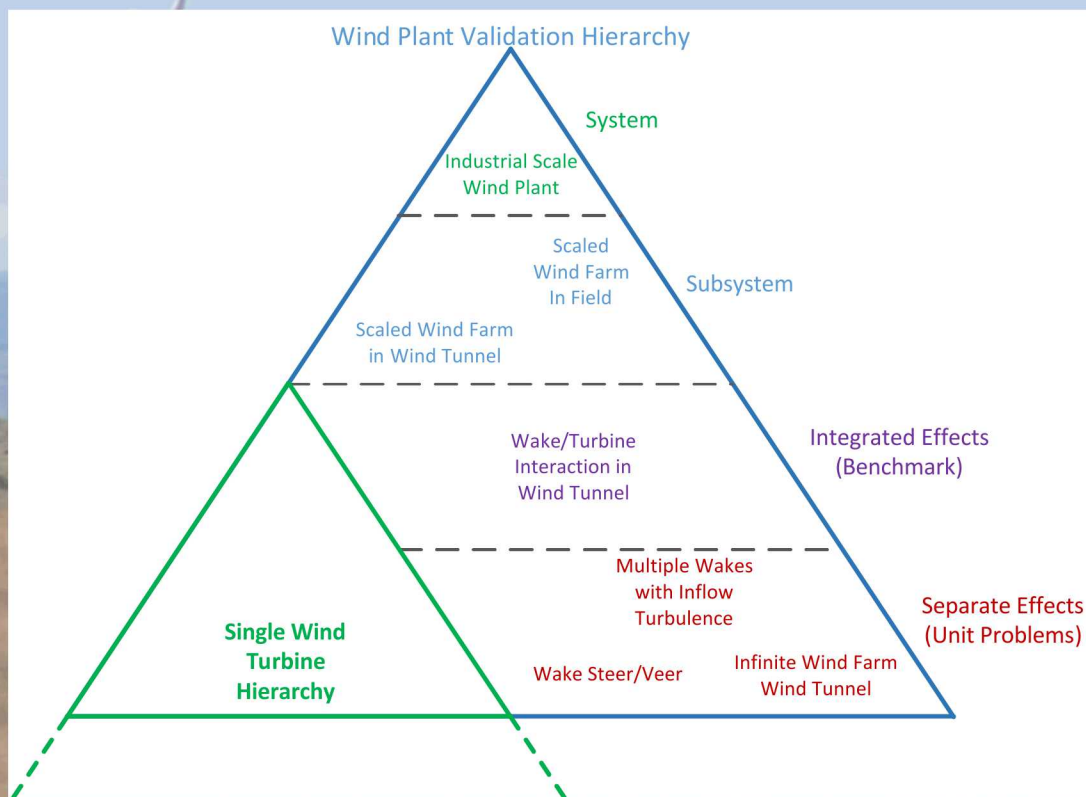
Phenomenon	Importance at Application Level	Model Adequacy		
		Physics	Code	Val
Inflow Turbulence/Wake Interaction				
Wind direction (shear/veer/assymetry)	H	L	M	M
Turbulence characteristics (intensity, spectra, coherence, stability)	H	L	M	M
Coherent turblence structure	H	L	M	L
Surface conditions (roughness, canopy, waves, surface heat flux, topography)	H	L	M	M
Momentum transport (horizontal and vertical fluxes)	H	L	L	L
Multi-Turbine Wake Effects				
Wake interaction, merging, meander	H	L	L	L
Plant flow control for optimum performance	H	M	M	L
Wake steering (yaw & tilt effects)	H	L	L	L
Wake dissipation	H	L	L	L
Wake Impingement (full, half, etc.)	H	L	L	L
Deep array effects (change in turbulence, etc.)	H	L	L	L
Other Effects				
Wind plant blockage effects and plant wake	M	M	M	L
Acoustic Propagation	H	L	L	L

Summary of Integrated Program Planning

- **Hierarchy and PIRTs lead to Prioritized Phenomena Experimental Mapping (PPEM)**

Validation Hierarchy

Increasing Scale

System Tests

Subsystem Tests

Integrated Effects Tests

Separate Effects Tests

Characterization Tests

Increasing Complexity

Increasing Accuracy

Physics Present/Physics Measured

- ⬤ Entirely
- ◒ Mostly
- ◯ Somewhat
- ⊖ Limited
- ⚫ Missing

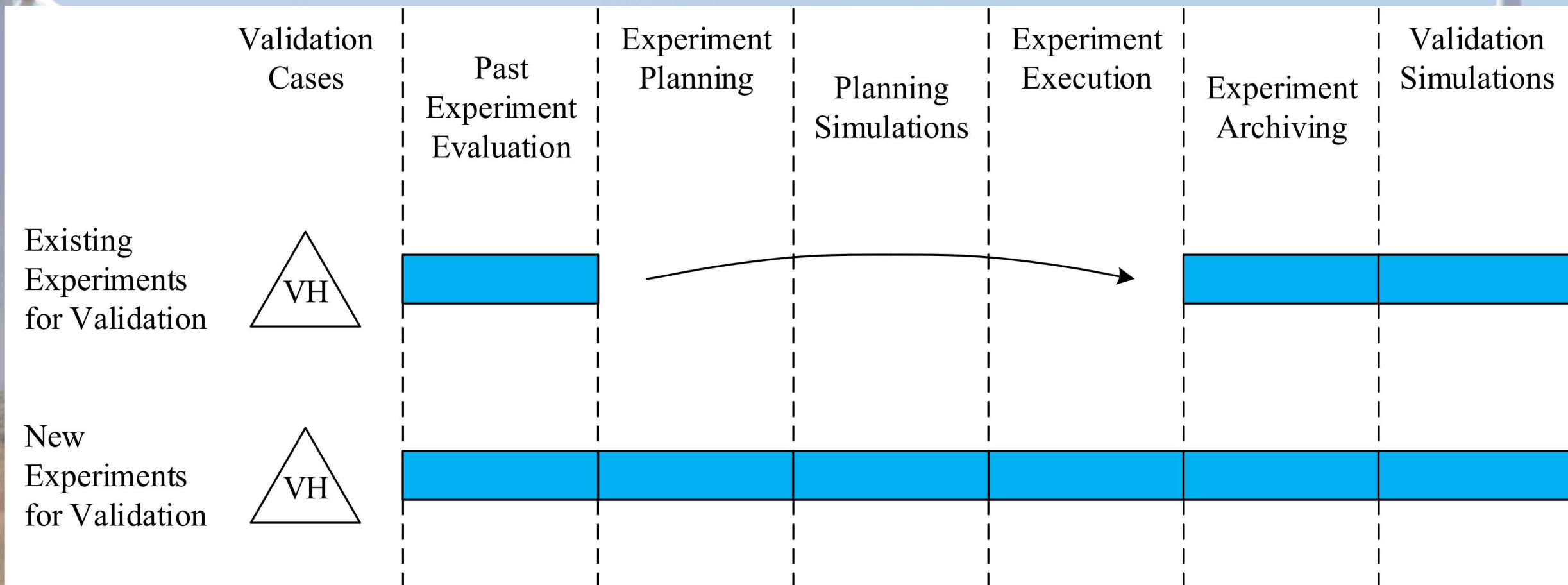|	Blade Aero/Wake Generation	Blade Load Distribution Effects	Tip & Root Vortex Evolution	Vortex Sheet Evolution	Blade Generated Turbulence	Root Flow Acceleration	Boundary Layer Development	Surface Roughness Effects	Boundary Layer Near LE and TE	Rotational Augmentation	Dynamic Stall	Unsteady Inflow Effects *	Blade Flow Control	Icing	Testing Issues — Boundary Conditions	Testing Issues — Scale Effects
Boundary Layer																
Physics Present																
Physics Captured by Measurements																
Axisymmetric Wake (with Swirl)																
Physics Present																
Physics Captured by Measurements																
Pitching Airfoil																
Physics Present																
Physics Captured by Measurements																
Airfoil with Icing																
Physics Present																
Physics Captured by Measurements																
Scaled Turbine in Field (~30m rotor)																
Physics Present																
Physics Captured by Measurements																
Industrial Scale Turbine in Field (~120m rotor)																
Physics Present																
Physics Captured by Measurements																

Integrated Program Planning Transitions to Integrated Experiment and Model Planning and Execution

- **A2e Planning Stage Essentially Complete**
  - □ Some work related to specific modeling efforts still needed
- **Integrated Experiment and Model Planning and Execution Now Underway**
  - □ Prioritized efforts underway
  - □ Better coordination and interaction among participants needed
    - **Streamline process**
    - **Identification of roles**
    - **Ensure best outcomes**

Integrated Program Planning

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Integrated Experiment and Model Planning and Execution
The Process

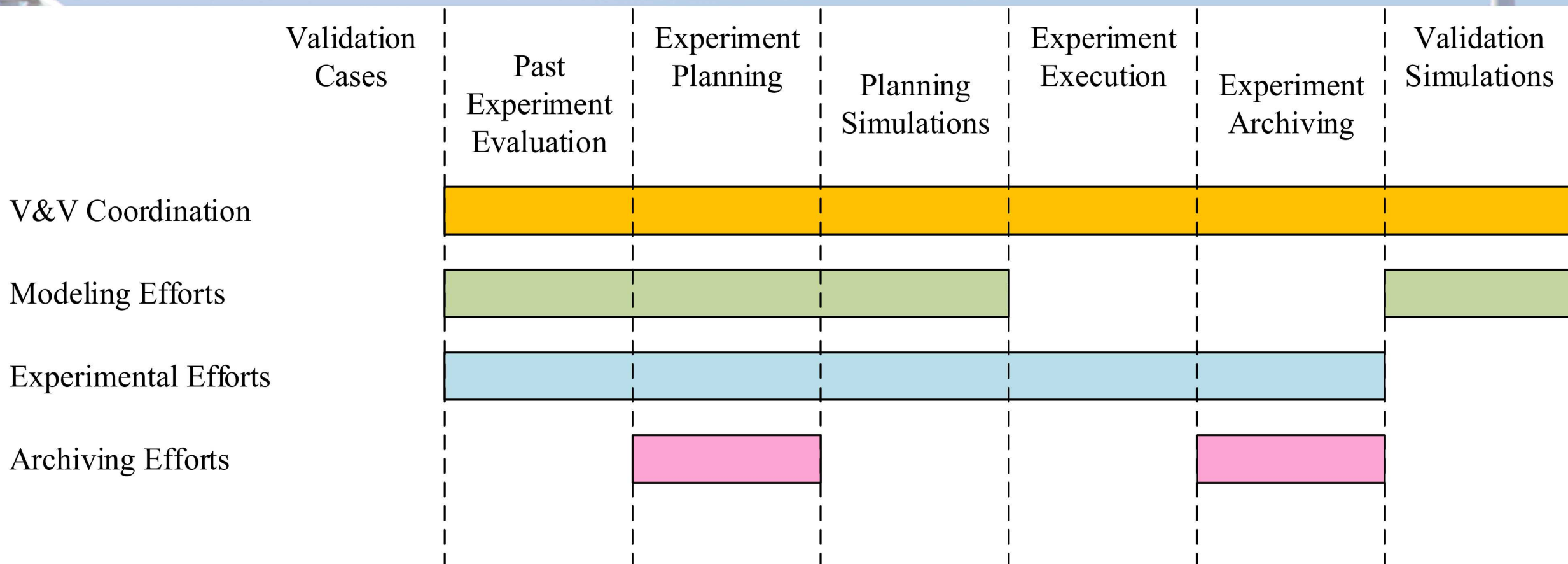# Integrated Experiment and Model Planning and Execution
The Process

- **Validation Cases**
  - Identified as part of the IPP
  - Prioritize specific cases
- **Past Experiment Evaluation**
  - Perform an evaluation of previous experiments that address the validation case of interest
  - Results in two outcomes
    - **Past experiment fully meets validation requirements**
    - **Past experiment partially meets validation requirements**
- **Experiment Planning**
  - Establish the validation metrics
  - Design experiment accordingly

- **Planning Simulations**
  - Part of experiment planning
  - Simulations support experiment design
  - Simulations identify issues early on in validation process
- **Experiment Execution**
  - Experiment is performed
  - Data is analyzed
  - Validation metrics determined
- **Experiment Archiving**
  - Data documented and efficiently stored for use in validation efforts
- **Validation Simulations**
  - Assessment of simulations performed

Integrated Experiment and Model Planning and Execution
Integration of Efforts

	Validation Cases	Past Experiment Evaluation	Experiment Planning	Planning Simulations	Experiment Execution	Experiment Archiving	Validation Simulations
V&V Coordination		██					
Modeling Efforts		██████████████████████████████					███████
Experimental Efforts		██					
Archiving Efforts			███████			███████	

Integrated Experiment and Model Planning and Execution Integration of Efforts

- **Validation and Verification Coordination**
  - Overall coordination and guidance for validation activities
  - Most often will not do experiments or simulations themselves
- **Modeling Campaign Efforts**
  - Aid in identifying needs for validation experiments
  - Support development of validation experiments
  - Perform validation exercises
- **Experiment Campaign Efforts**
  - Aid in identifying needs for validation experiments
  - Develop validation experiments with support from other groups
  - Perform experiments and analyze data
  - Support data archiving effort
- **Data Archive Efforts**
  - Support development of validation experiments
  - Lead data archiving effort

Integrated Experiment and Model Planning and Execution
Some Examples

- **Wake Dynamics: AWAKEN and SWiFT**
  - SWiFT wake measurement benchmark in IEA Task 31 (https://a2e.energy.gov/projects/wake)
  - AWAKEN: American Wake Experiments (https://openei.org/wiki/AWAKEN)
    - Collaborative international wake observation and validation campaign planned for 2021/2022
- **OC6: Offshore Code Comparison Collaboration, Continued, with Correlation and uncertainty**
  - Focus is on validating offshore wind modeling tools, including uncertainty quantification
  - Development and application of a three-way validation procedure between engineering-level tools, higher-fidelity tools and measurements
  - https://a2e.energy.gov/projects/oc6
- **WFIP2: Wind Forecasting Improvement Project 2**
  - Complex terrain field measurement campaign to assess how physical processes over a broad range of spatial scales alter wind speeds across the rotor diameter.
  - https://a2e.energy.gov/projects/wfip2

Integrated Experiment and Model Planning and Execution Next Steps

- **Identify high priority flow phenomena from the validation hierarchy**
  - Select some that will be relevant to one or more modeling effort
  - Some should be short term experiments while others should be longer term efforts
- **Apply the IEMPE process**
  - Shorter term efforts can serve as model cases for future efforts
  - Existing efforts should employ approach as well as new efforts
- **Make the validation data available**
  - Data should be easy to find and extract
  - Use of data should be tracked
- **Engage the community to use the validation data**
  - Develop validation suites
  - Publicize/encourage validation efforts (workshops, special conference sessions, etc.)

QUESTIONS?