Design and Planning Tools
Portfolio Overview

John Grosh – Design and Planning Tools Technical Area Lead

Lawrence Livermore National Laboratory

April 18, 2017
Arlington, VA

U.S. DEPARTMENT OF ENERGY

Design and Planning Tools
Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

What is the problem?

- Rapid changes in grid outpacing current modeling and analytic capabilities

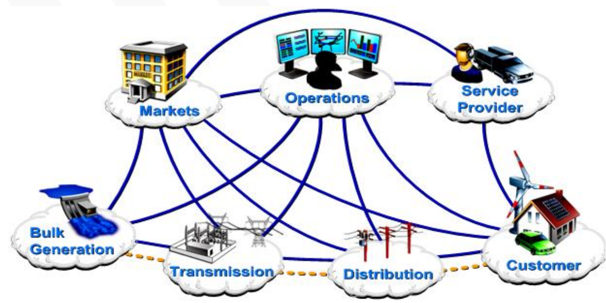
Expected Outcomes

- Drive development of next-generation tools that address evolving grid needs

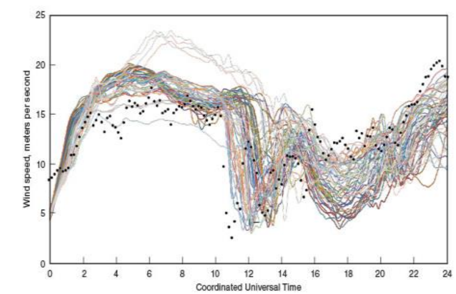
Federal Role

- Attack strategic technology gaps in tools capabilities
- Partner with industry for demonstrations and to focus R&D
- Work with vendors to transition R&D into practice

Technology Gaps



Simulating Interactions Across Domains



Modeling Uncertainty

Increase Resolution and Fidelity


Computational speed

Activities and Technical Achievements

MYPP Activity Description

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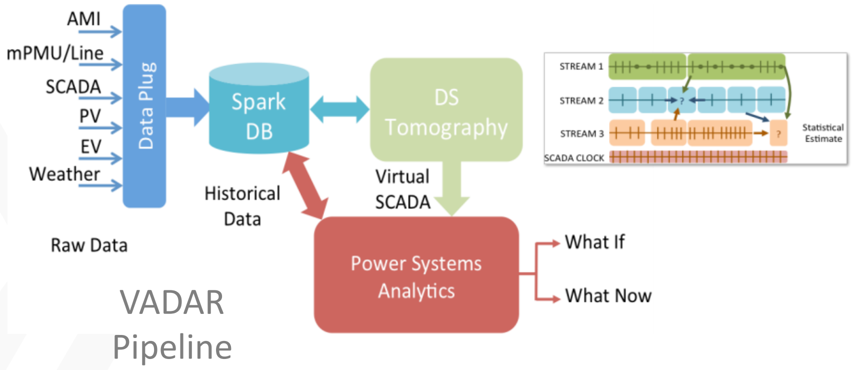
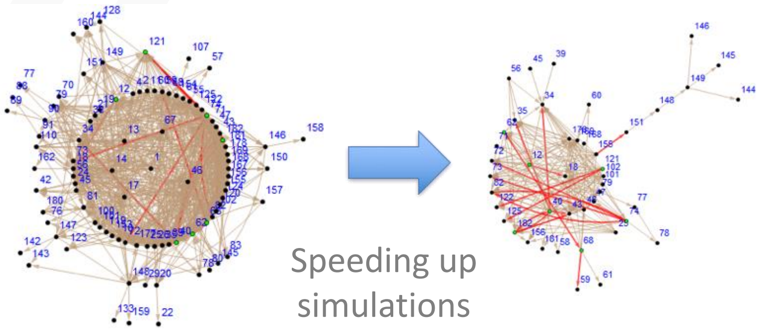
Activity	Technical Achievements by 2020
1. Scaling Tools for Comprehensive **Economic Assessment**	• Enhance performance of stochastic production cost modeling from 100 to 10,000 transmission nodes; expand to include distribution system.
2. Developing and Adapting Tools for Improving **Reliability and Resilience**	• Scalable simulation framework that couples transmission, distribution, and communications systems for integrated modeling at regional scale.
3. Building **Computational Technologies** and High Performance Computing (**HPC**) Capabilities to Speed up Analyses	• Scalable math libraries and tools for enhanced analysis; co-simulation frameworks to support coupling of tools and models, uncertainty quantification, and systems optimization.



New planning and design tool capabilities



Algorithms and libraries

Foundational Projects

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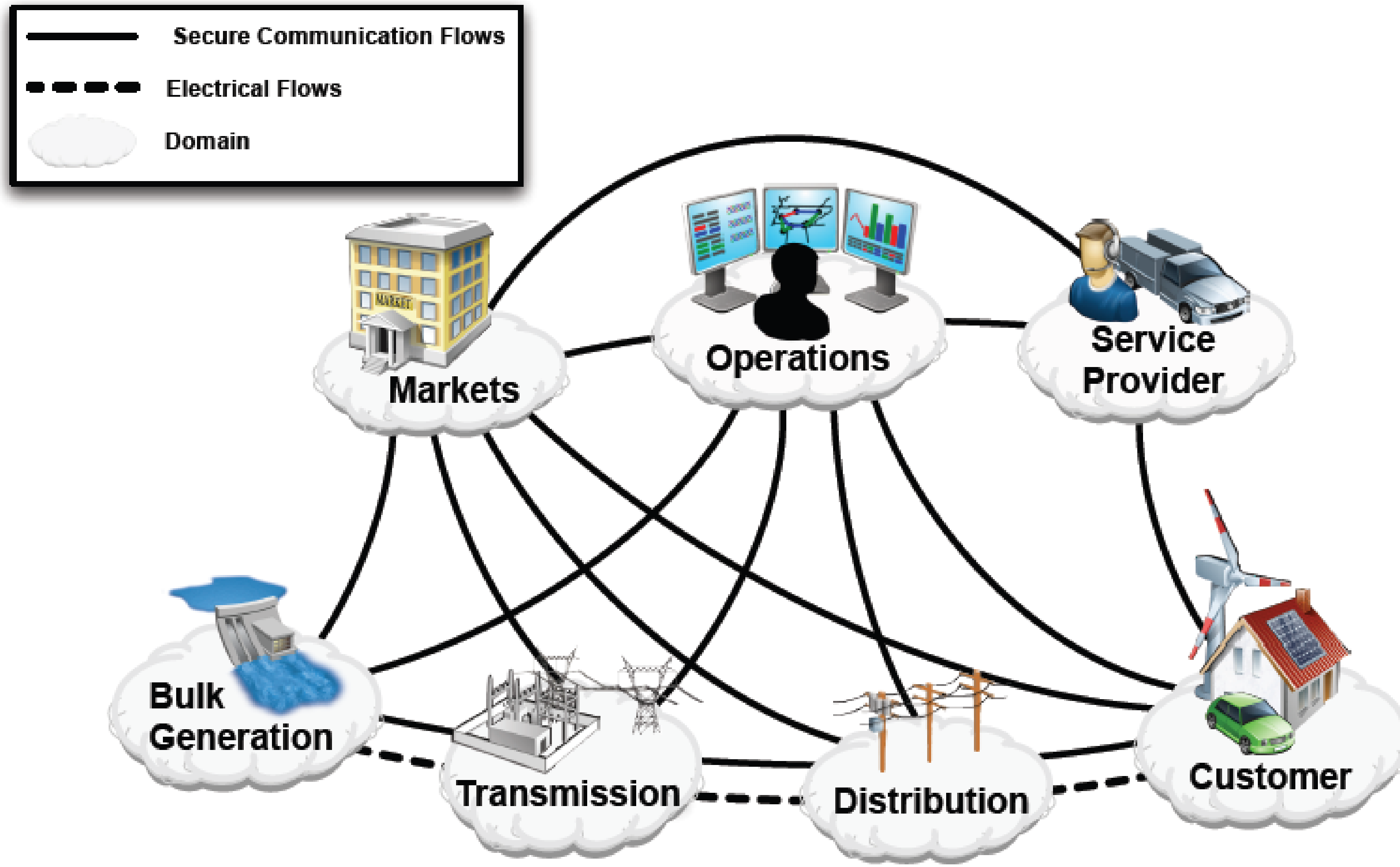
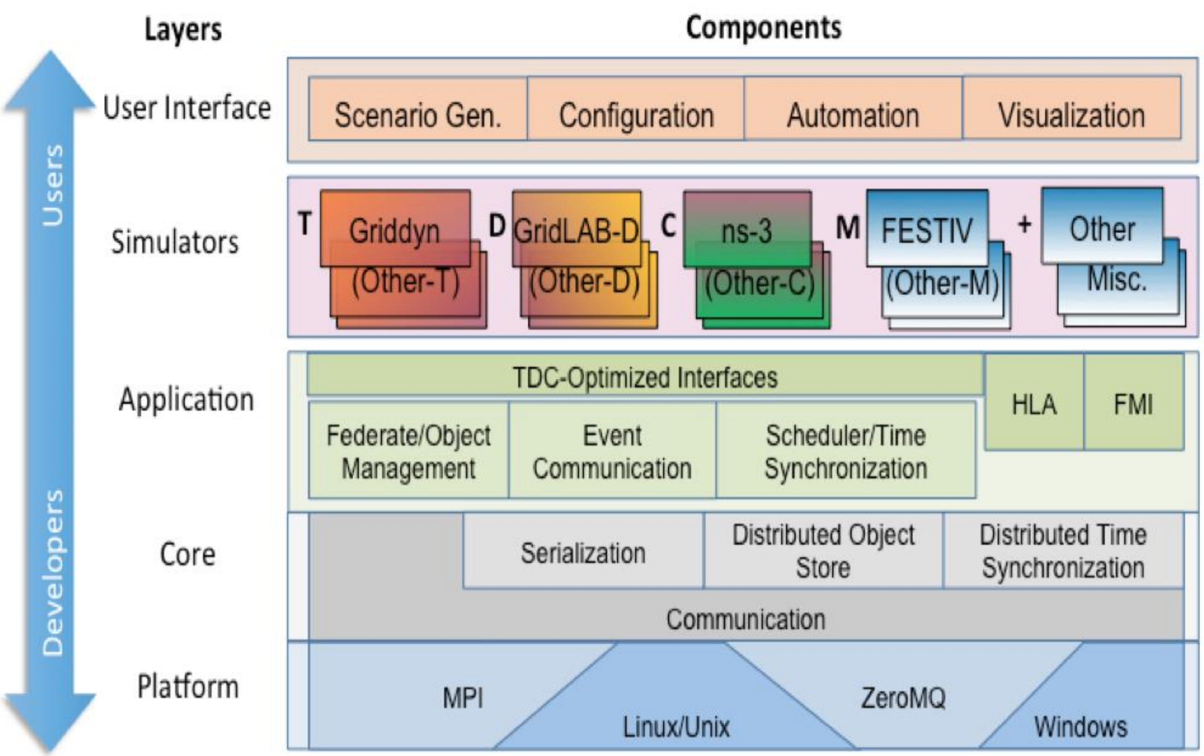


NIST Smart Grid Framework 1.0 January 2010

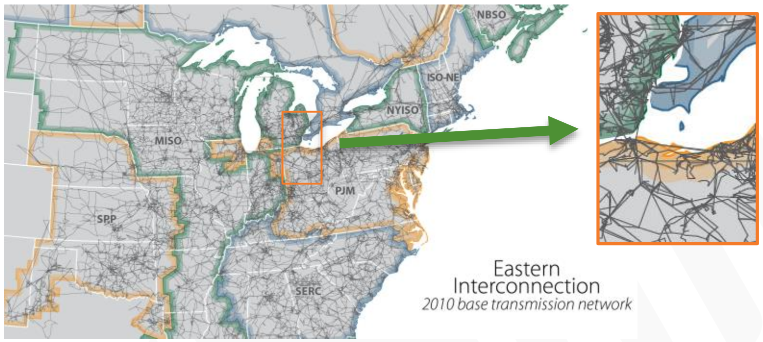
Foundational Projects

1.4.15 - Development of Integrated Transmission, Distribution and Communication Models (Lead: PNNL)



Create HELICS™, an **open-source co-simulation platform**, enabling interactions between leading commercial & lab developed simulators on a wide range of computing environments (HPC to laptop).

Foundational Projects

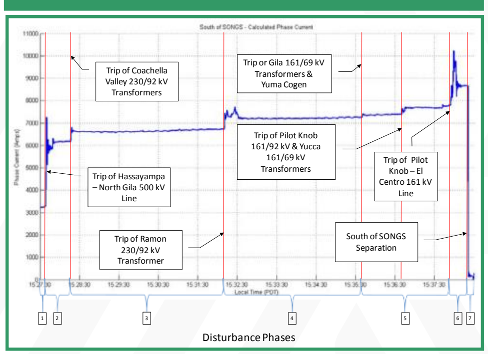


1.4.26 – Development of Multi-scale Production Cost Simulation (Lead: NREL)

- Develop scalable algorithms used for deterministic and stochastic PCM

Arizona / So Cal Outage FERC/NERC April 2012

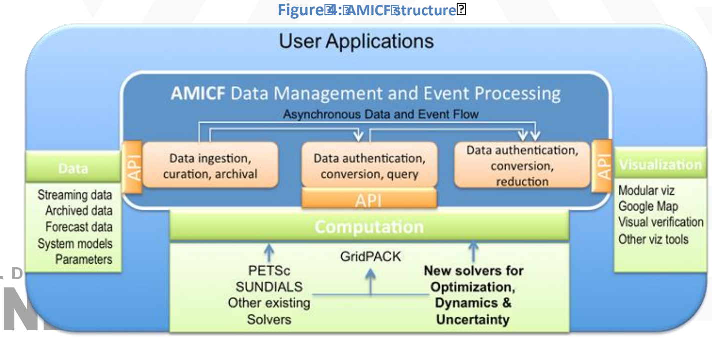
Figure 4: Seven Phases of the Disturbance



1.4.17 - Extreme Event Modeling (Lead: LANL)

- Improve performance of tools for modeling cascading outages and develop new approaches for contingency analysis

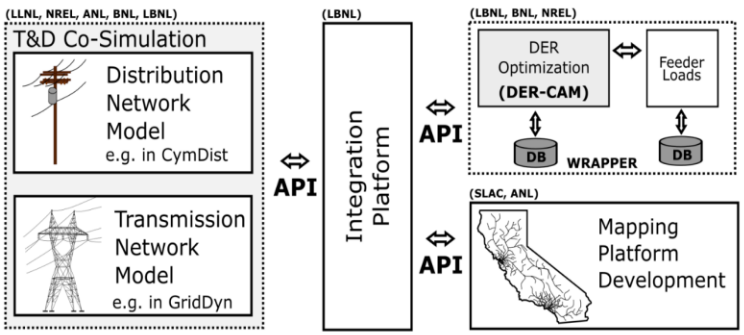
Figure 4: AMICF structure



1.4.18 - Computational Science for Grid Management (Lead: ANL)

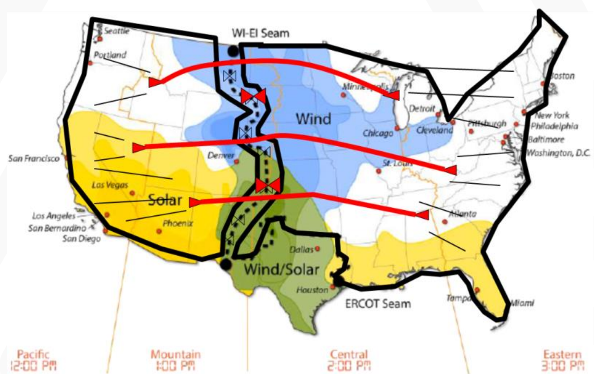
- Applying DOE innovations in computational science to develop unified grid math library optimization, dynamics, and uncertainty

Regional Partnership Projects



1.3.05 DER Siting and Optimization Tool for California (Co-Lead: LBNL and LLNL)

- DER tools integrating behind-the-meter adoption, distribution-transmission power flows, and visualization



1.3.33 Midwest Interconnect Study (Lead: NREL)

- Apply state-of-the-art tools to analyze economic efficiency and reliability benefits of 4 transmission futures for the U.S.


Riley Allen (RAP)

1.3.21 Alaska Microgrid Partnership (Lead: NREL)

- First-time consortia of DOE Labs and Alaska organizations developing best practices and tools for microgrid design and deployment

Program-Specific Projects

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Transmission

- GM0111 - Protection and Dynamic Modeling, Simulation, Analysis, and Visualization of **Cascading Failures** (Lead: ANL)
- GM0074 - Models and methods for assessing the value of **HVDC and MVDC technologies** in modern power grids (Lead: PNNL)
- WGRID-38: North American Renewable **Integration Study** (NARIS) (Lead: NREL)
- SI-1631: Assessing the Value and Impact of **Dispatchable Concentrating Solar** Power in a SunShot Future (Lead: NREL)

Distribution

- GM0057 - LPNORM: A LANL, PNNL, and NRECA Optimal **Resiliency Model** (Lead: LANL)
- SI-1545 - **Rapid QSTS** Simulations for High-Resolution Comprehensive Assessment of Distributed **PV Impacts** (Lead: SNL)
- SI-1756 - **Visualization and Analytics** of Distribution Systems with Deep Penetration of **Distributed Energy Resources** (VADER) (Lead: SLAC)
- SI-1639: System Advisor Model (Lead: NREL)

Multiple Domains

- SI-1625 - CyDER: A Cyber Physical **Co-simulation** Platform for **Distributed Energy Resources** in Smart Grids (Lead: LBNL)
- GM0229 - Integrated Systems Modeling of the Interactions between **Stationary Hydrogen, Vehicle and Grid Resources** (Lead: LBNL)

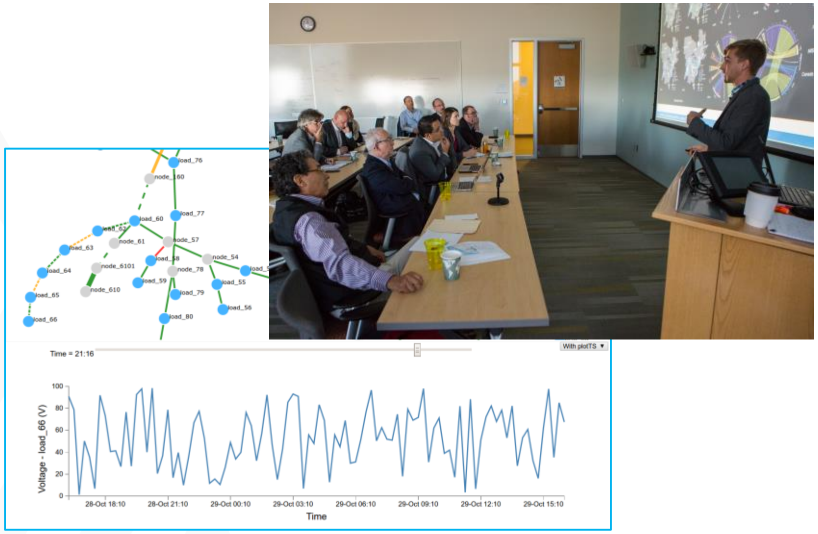
Load Modeling

- GM0094 - Measurement-Based Hierarchical Framework for Time-Varying **Stochastic Load Modeling** (Lead: ANL)
- GM0064 - Open-Source High-Fidelity Aggregate Composite Load Models of **Emerging Load Behaviors** for large-Sale Analysis (Lead: PNNL)

Accomplishments and Emerging Opportunities

Accomplishments

- Formed working group to coordinate release and sharing of software and data
- All GMLC-led projects hosted stakeholder meetings / technical review committees
- PCM, Seams Study, NARIS projects are coordinating R&D and review committees
- HELICS™ specification and use-case documents
- Extreme Event Strategy Roadmap
- Initial version of DER Optimal Siting Tool prototype completed
- Reduced runtime for important grid calculation (SCACOPF) from 10 hours to 10 min using DOE research (StructJuMP)



Next Year

- Significantly increased industry and vendor engagement
- Completion of addition software tool prototypes
- Tools demos on HPCs with 10X to 100X improvements

GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.3.5 – DER Siting and Optimization tool for California

JOHN GROSH & GONÇALO CARDOSO

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

DER Siting and Optimization tool for California
High Level Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

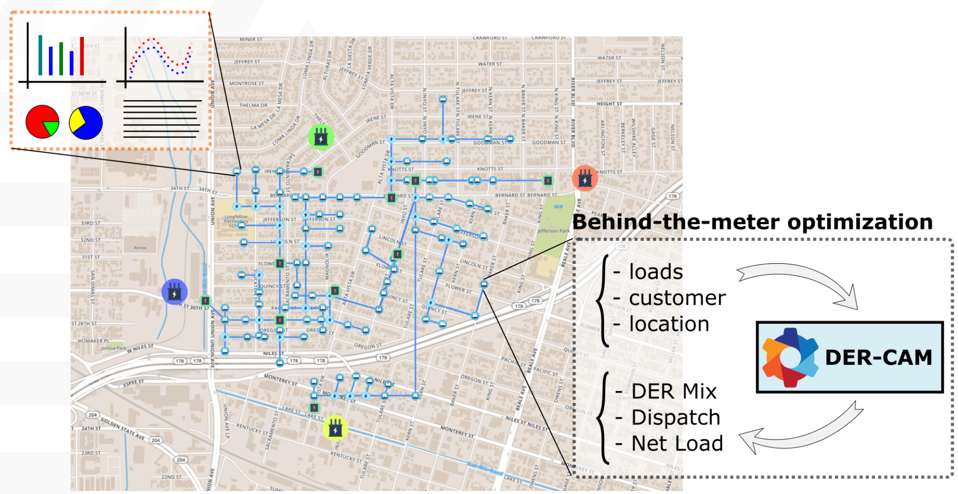
Prototype framework for integrated **distributed resource planning and optimization tool** able to identify **DER adoption** patterns, **microgrid sites**, and evaluate **DER impacts** on the distribution and transmission grid.

Project Objectives

- ✓ DER penetration patterns and operational strategies
- ✓ identify sites with economic potential for microgrid and DER
- ✓ address policy incentives and value of DER as grid assets
- ✓ consider network constraints in the DER location problem
- ✓ evaluate impacts of DER on the bulk electric grid system
- ✓ California as starting point for wider application (e.g NY)

Value Proposition

- ✓ Integrate private DER investment and dispatch decisions in grid planning
- ✓ Capture distribution and transmission gird interactions
- ✓ Unique methodology enables holistic view on grid impacts of DER



DER Siting and Optimization tool for California
Project Team

Project Participants and Roles

John Grosh, Liang Min - LLNL (*Current lead*) – T&D power flow co-simulation Lead, feeder data conversion, Demonstration, Dissemination

Michael Stadler*, Gonçalo Cardoso - LBNL *(Original lead, Plus One)* – Behind-the-meter DER modeling, Model Integration, Model Automation, Demonstration, Dissemination, Coordination

Sila Kiliccote - SLAC (*Plus One*) – Mapping and Results Visualization Lead, Demonstration, Dissemination

Anthony Florita - NREL – Load disaggregation Lead, feeder data conversion, Demonstration

Robert Lofaro - BNL – Support on T&D power flow, Data collection, Load disaggregation, Demonstration

Jianhui Wang - ANL – Support on T&D power flow, Mapping, Demonstration

CPUC, PGE, SCE + External Advisory Committee

PROJECT FUNDING			
Lab	**FY16 $**	**FY17$**	**FY18 $**
LBNL	114,107	315,893	-
SLAC	45,000	215,000	-
LLNL	65,000	170,000	-
NREL	73,333	56,667	-
BNL	53,333	76,667	-
ANL	24,333	90,667	-

Total funding: $1.3M
Duration: 18 (16) months
Due: End of Sep 2017

__MYPP Vision__: The future grid will solve the __challenges of seamlessly integrating conventional and renewable sources, storage, and central and distributed generation__ (…)

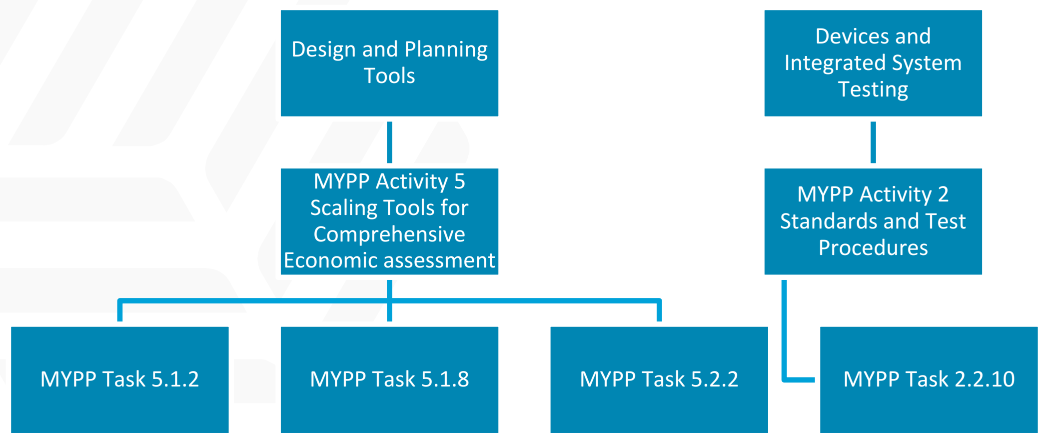
Direct relationship to MPYY vision by delivering a tool to ***estimate DER impacts on the electric grid***
(Behind-the-meter modeling + T&D co-simulation + Visualization)

5.1.2 – *Develop methods for **integrating distribution into system-wide planning**, (…) including distributed generation, demand response, electric vehicles, and energy storage*

5.1.8 – *Develop methodologies and **tools to produce simple-to-use desktop computer models from HPC-generated simulations and economic analysis***

5.2.2 – ***Scale modeling framework to the regional level**. Develop associated **models for load, distributed generation, energy storage, and controls to enable the design and evaluation of future EMS/DMS/BMS architectures** and novel wide-area sensor-control networks*

2.2.10 – *Establish and test methodologies for enabling **optimal dispatch of energy storage to serve multiple grid services***



DER Siting and Optimization tool for California

Approach

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Task	Task Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		-	-	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Milestones			MS			MS			GNG									
1	Integrated T&D Modeling																		
2	Mapping Platform																		
3	Model Automation for DER Adoption Paterns																		
4	Characterization of Feeder Loads																		
5	Demonstration and DER Market Concepts																		
6	Dissemination and Training																		
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
		FY 16						FY 17											

Task 1 – Integrated T&D Modeling
- Develop CA-representative integrated T&D power-flow model
- Collect, convert, test, and validate datasets required to enable T&D co-simulation

Task 2 – Mapping Platform
- Develop mapping and visualization capabilities
- Integrate all three main model components: behind-the-meter models, T&D model, visualization

Task 3 – Model Automation for DER Adoption Patterns
- Collect new DER-CAM datasets / update existing ones
- Enable automated DER-CAM model creation, parallel optimizations, automated data exchange

Task 4 – Characterization of Feeder Loads
- Identify and collect distribution datasets required to build representative CA T&D model
- Develop and apply load disaggregation methods

Task 5 – Demonstration and DER Market Concepts
- Select and conduct a demonstration case focusing on how this project complements and/or exceeds current DRP process
- Develop high-level DER market concepts focusing on revenue streams of DER-based solutions and DER potential as grid asset

Task 6 – Dissemination and Training
- Prepare project specific documentation and scientific publications
- Develop interactive training material, tutorial videos, and organize training sessions

Uniqueness: Integrated modeling tool brings together customer-oriented *behind-the-meter modeling* with *T&D co-simulation* and custom *visualization* capabilities.

DER Siting and Optimization tool for California

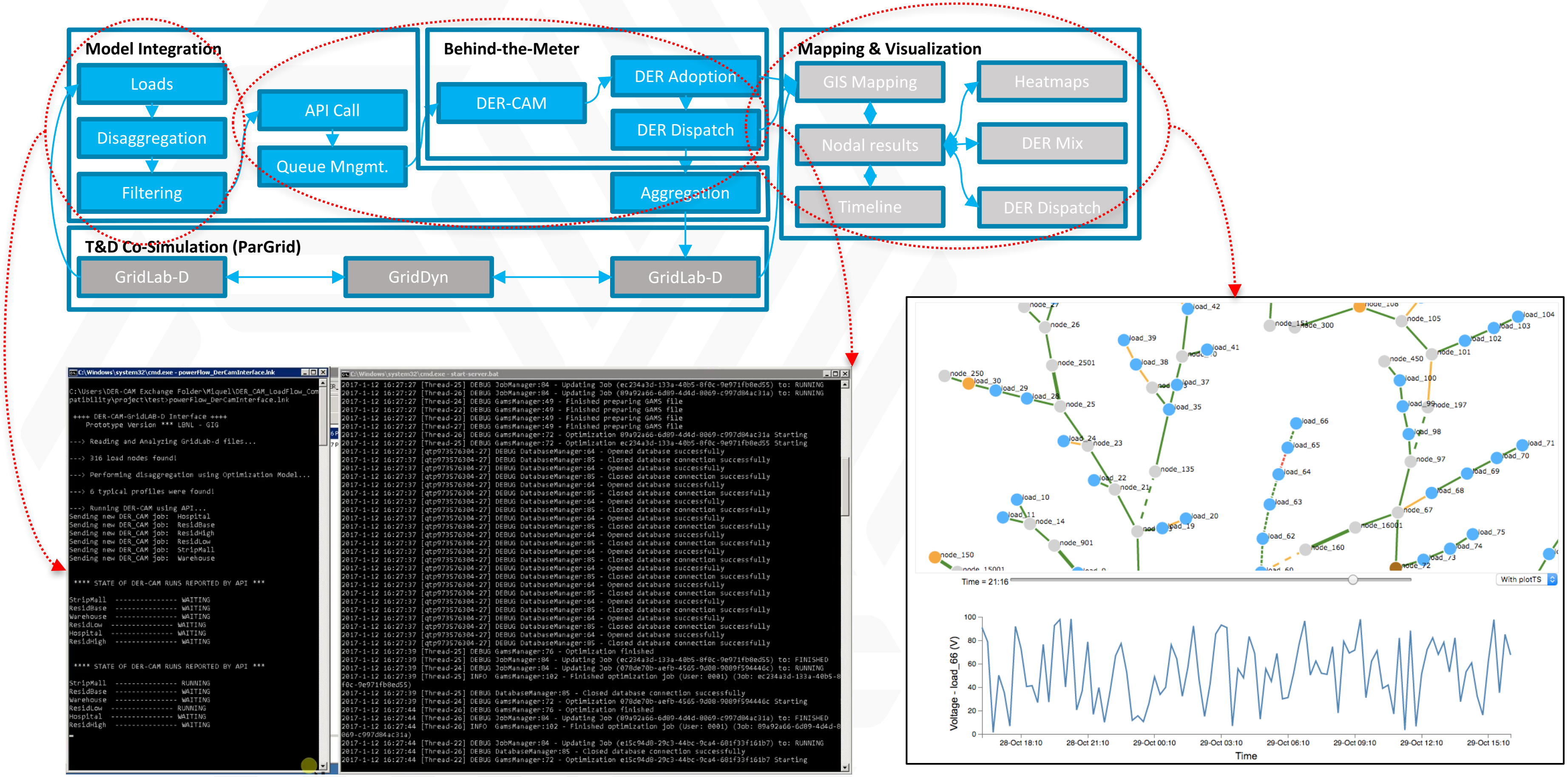
Key Project Milestones

Milestone (FY16-FY18)	Status	Due Date
Milestone #1 – Quarterly Progress Measure: Completed initial testing of PG&E distribution data (1.1); Initiated IOU GIS survey (2.1); Collected residential load data for DER-CAM and created residential load database (3.1 and 3.2); Engaged with IOUs to collect feeder data (4.1);	Completed	6/30/2016
Milestone #2 – Quarterly Progress Measure: Completed PG&E distribution data collection, conversion and validation (1.1); Completed initial testing of SCE distribution data (1.2); Completed IOU GIS survey and identified data exchange needs for the co-simulation platform (2.1); Completed data collection and database upgrades for DER-CAM (3.1 and 3.2); Completed feeder data collection and load data disaggregation (4.1 and 4.2) – End of Task 4.	Completed	9/30/2016
Annual Milestone #1 : Completed SCE distribution data collection, conversion and validation (1.2); Completed T&D modeling and co-simulation integration (1.3) – End Of Task 1; Completed mapping platform development and model integration (2.1 and 2.2); Completed DER-CAM modifications and model automation (3.3 and 3.4) – End of Task 3.	Completed	12/31/2016
Annual Milestone #2: By the end of September 2017 this project will be completed, delivering a platform to model system-wide impacts of DER penetration and to suggest optimal DER and microgrid locations, as well as a high level framework to establish DER markets.	On Time	9/30/2017

DER Siting and Optimization tool for California

Accomplishments to Date

Key achievement: Development of end-to-end software framework prototype



Model Integration DER-CAM Server

DER Siting and Optimization tool for California

Accomplishments to Date

End-to-end software prototype:

- T&D model for CA
- DER-CAM enhancements & data
- Model integration and APIs
- Visualization

Participation in workshops, meetings, and other stakeholder engagement:

- CPUC and involvement with DRP
  - Attended DRP WG meetings on both ICA & LNBA (8 + 6)
  - Led scoping of validation of ICA methods for long-term refinements, including one-on-one discussions with PG&E, CPUC Office of Ratepayer Advocates, SolarCity, and IREC
  - Presented validation approach to the DRP WG
  - Briefed DRP WG on the GMLC Project
- Technical advisory committee including CPUC and industry representatives

DER Siting and Optimization tool for California

Response to December 2016 Program Review

Recommendation	Response
Integrate of results with the Valuation work (1.2.4)	Engaged with the 1.2.4 project; Identified implementation strategy (Demonstration Case)
Determine connections with the Regional Partnership in Vermont	Engaged with the 1.3.10 project; Discussed complementarities and analysis methods for different use cases; strategy for coordination
Discuss implication of the new DRP	DRP focuses on short-term applications; Integration of 1.3.5 targets "long-term long-term" refinements (CPUC)
Let DOE when Annual Milestone #1 is complete	Annual milestone progress presented via webinar; Submitted supporting documentation
When will this tool be posted online?	July 2017 (aligned with Demonstration Case)

DER Siting and Optimization tool for California

Project Integration and Collaboration

(SUNSHOT) **CyDER – A Cyber Physical Co-Simulation Platform for Distributed Energy Resources in Smart Grids**

CyDER: interconnection and short-term operations using real-time data (PGE)

1.3.5: long-term planning for all of California, behind-the-meter DER dispatch, and policy applications

- ➢ Data sharing; Complementary in scale (space and time), and granularity

1.3.22 - Technical Support to NY REV

1.3.5 will provide access to DER-CAM and all other project developments

BNL is leading 1.3.22 and also participating in 1.3.5

- ➢ Demonstration Case; Technology Transfer

1.4.15 Development of Integrated Transmission, Distribution and Communication Models

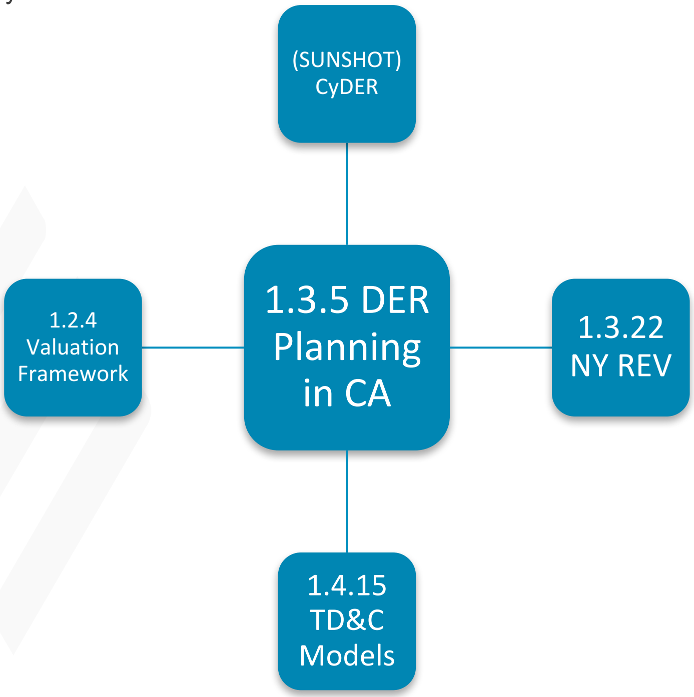
LLNL is participating in both 1.3.5 and 1.4.15

- ➢ Technology Transfer

1.2.4 Grid Services and Technologies Valuation Framework

LBNL, NREL, ANL are participating in both 1.3.5 and 1.2.4

- ➢ Integrate Valuation Framework in Demonstration Case



Communications:

Active participation in ICA and LNBA WG meetings (14 total)

Presentation to CPUC / DRP WG

Next steps:

Task 5 - Project demonstration DER Market Concepts [Apr – Sep]

- Demonstration Case (early start)
- Application in Policy scenarios
- Market Concept Development

Task 6 - Dissemination and Training [Jun – Aug]

- Documentation & Training

Possible additions or expansions:

- Integration of AMI data
- Integration with grid expansion models (LNBA)
- Application in different territories

DISCUSSION

GRID MODERNIZATION INITIATIVE PEER REVIEW

E. IAN BARING-GOULD

April 18-20

Sheraton Pentagon City – Arlington, VA

Alaska Microgrid Partnership

High Level Summary

Project Description
Develop and implement a pathway of technical and economic assessment leading to a 50% imported energy displacement in remote, islanded Alaskan community microgrids. First time a consortia of DOE Labs and Alaska organizations have undertaken this in a holistic way.


Photo Credit: Riley Allen

Value Proposition

- ✓ Alaskan and islanded communities have some of the most costly and least reliable energy in the U.S.
- ✓ Public sector funds decreasing but limited private investment models
- ✓ Potential huge worldwide market & learning potential

Project Objectives

- ✓ Develop pathways to reduce total imported fuel usage by 50% while lowering costs and improving reliability
- ✓ Using two pilot communities and existing analytical tools, articulate the use of this pathway to act as models, hopefully leading to actual projects.
- ✓ Develop data source and share information on the pathway that can be used by other stakeholders across Alaska and the Arctic.

Alaska Microgrid Partnership
Project Team

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
NREL	$352,255	$182,280	$0
LBNL	$77,400	$129,040	$0
PNNL	$70,900	$81,930	$0
SNL	$69,275	$36,920	$0

DOE National Labs:

NREL: Ian Baring-Gould (PI), Scott Haase, Tony Jimenez. Task 1,2, 3 leads. Project coordination, community assessment, design speck, and modeling.

LBNL: Peter Larsen (+1). Task 6 lead. Community assessment and web interface development.

PNNL: Trevor Hardy. Task 5 lead. Economic analysis.

SNL: David Rosewater, John Eddy. Task 4 lead. Project modeling, equipment testing oversight and design specifications.

Alaska-based Partners:

Renewable Energy Alaska Project: Alaska coordination, community readiness, community and corporate engagement

Alaska Center for Energy & Power: Diesel control and operational testing, design specifications, and web interface development

Intelligent Energy Systems: Design specification, pilot community engagement, and equipment testing.

Institute of Social & Economic Research: Data collection support; web interface development

External Technical Review Committee

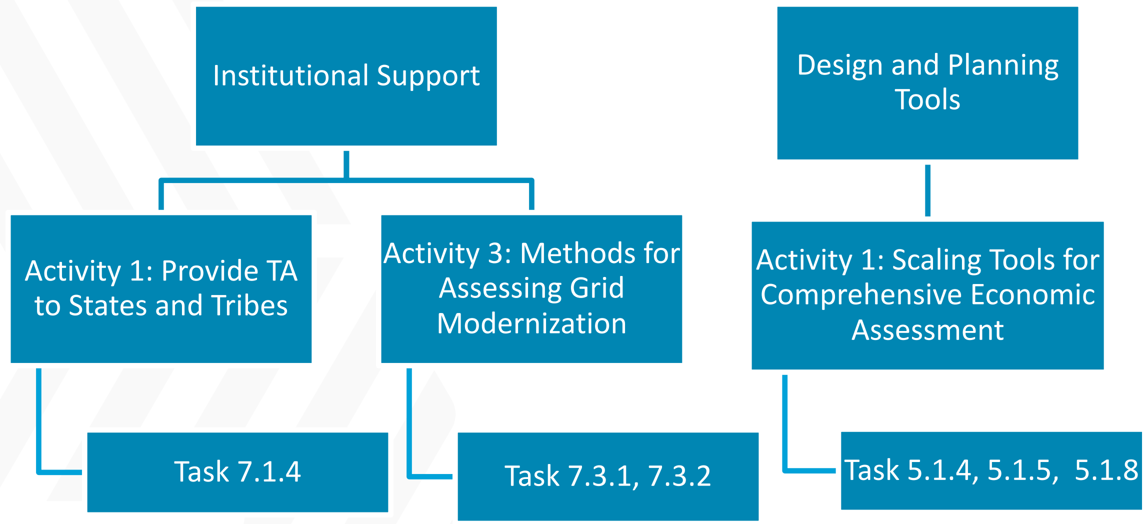
Alaska Microgrid Partnership

Relationship to Grid Modernization MYPP

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

MYPP Vision:

*The future grid will … **seamlessly integrating** conventional and renewable sources, storage …. deliver .. **Reliable … sustainable,** and **affordable** electricity to consumers.*



Topical Areas:

- *5.1.4:* Identify and classify data sources, define templates, and develop databases for new grid technologies
- *5.1.5:* Develop valuation methods and mathematical models for new energy technologies
- *5.1.8:* Develop methodologies and tools to produce simple-to-use desktop computer models *7.1.4:* As requested, DOE will provide technical support to analyze impacts of grid modernization on tribal entities
- *7.3.1:* Develop an analytical framework and tools for valuing potential benefits, costs, and impacts of distributed energy resources
- *7.3.2:* Develop and implement informational activity targeted at regulators, policy makers, consumers and utilities on valuation of DER technologies:

Alaska Microgrid Partnership

Approach

Key Tasks:

- ✓ Project management and coordination (Task 1)
- ✓ Develop and collect community capacity metrics and data (Task 2)
- ✓ Conduct and complete community system analyses (Task 3)
- ✓ Microgrid hardware assessment (Task 4)
- ✓ Business and financing case analyses (Task 5)
- ✓ Knowledge-sharing portal to attract interest from public/private sector developers (Task 6)

Key Issues:

- ✓ **High cost and low integration of sustainable energy solutions** for isolated communities
- ✓ **Lack of a streamlined, holistic approach** to conducting economic studies for microgrid projects
- ✓ Development of a pathway and supporting documentation to **allow additional communities or organizations to implement similar projects**
- ✓ Develop **case studies** based on **actual pilot projects**
- ✓ **Make the whole process available** on a web platform, so community-level data can be openly-shared

Pathway for Holistic Community Microgrid Development

Assess	• Determine community readiness (capacity)
Conduct	• Conduct needs assessments (EE, RE, buildings, transportation)
Analyze	• Analyze opportunities using existing analytical tools
Consider	• Determine what new technologies may be appropriate and which options should be considered
Design	• Design projects and systems to meet project objectives
Finance	• Determine the mix of private and public funds necessary to implement design
Share	• Share information to attract project developers and Financing (private and public)

Alaska Microgrid Partnership
Key Project Milestones

Milestone (FY16-FY17)	Status	Due Date
Identify pilot communities	COMPLETE (Chefornak & Shugnak)	8/1/2016
Early assessment of the identified pilot communities	COMPLETE, analysis complete with report development underway	10/1/2016
Design Framework for Standardized Systems (DRAFT)	IN PROGRESS, Initial draft under review by the project team	1/1/2017
Technical paper describing results of diesel testing (DRAFT)	IN PROGRESS, test plan under development, building off of current testing on a similar project (10% complete)	4/1/2017
Technical paper with assessment of storage options (DRAFT)	IN PROGRESS, several storage options in operation and Alaska focused storage assessment complete (50%)	4/1/2017
Review draft of generic business case analysis	IN PROGRESS, several existing pro-forma style assessments collected and being analyzed (10%)	7/1/2017
Final technical and business case studies for two pilot communities	IN PROGRESS, economic model developed, technical studies under analysis	10/1/2017

Alaska Microgrid Partnership
Accomplishments to Date

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

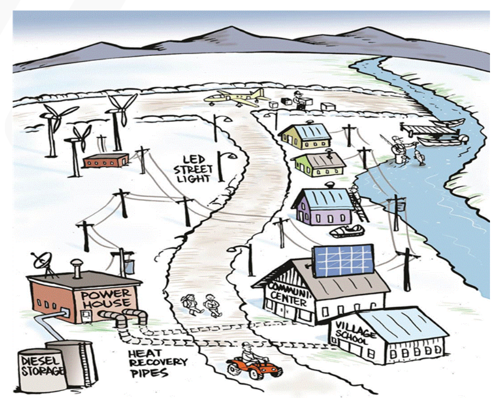
Early Insights:

- Critical to engage across the portfolio of energy consumption (electrical, thermal & transportation)
- Two pilot communities show that a 50% reduction in imported fuel use is possible if considering both electricity and heat
- Fuel reductions from transportation sector have been harder to tease out

Stakeholder Engagement:

- Formulation of the Technical Review Committee and Financiers' Roundtable
- Project has been discussed at several domestic and international conferences
- Project partner (Chris Rose) provided testimony to U.S. Senate E&NR Committee AMP project

Analysis must address total community loads, "Typical" remote Alaska homes provide opportunity Photo credit: Peter Larsen (LBNL)



A community energy system using high amounts of local energy sources is possible. Photo Credit: LBNL/RAP (2016)

Alaska Microgrid Partnership
Accomplishments to Date

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Near-term Accomplishments:

- Community readiness indicators developed to assess human, financial, and technical capacity to undertake energy infrastructure projects
  - Applied to Power Africa Beyond the Grid and ACEP teaching programs
- Screening of techno-economic modeling tools (DER-CAM, REopt, Microgrid Design Tool, HOMER, etc.)
- Design framework for system design

Two of three wind turbines over the bulk fuel tanks of the Kasigluk Power Station, a vision of what could be possible in the future. *Photo by Ian Baring-Gould, NREL 16097*

Long-term Accomplishments (planned):

- Develop and implement a technical and financial pathway for remote communities to develop reliable, inexpensive, and sustainable energy infrastructure
- Upgrade the Alaska Energy Gateway to communicate community-level financial, technical, and human capacity to undertake energy infrastructure projects

Alaska Microgrid Partnership

Response to December 2016 Program Review

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Recommendation	Response from AMP Team
Engage with other microgrid projects – specifically New Orleans, LA and Knoxville, KY.	*Initial discussions have taken place and information has been exchanged. The nature of the Alaska Microgrid Project (isolated systems and focused on the development of an implementation process) make direct linkages difficult.* *Results of the different projects are being shared.*

Rural Alaska "Power House"
Photo credit: Peter Larsen (LBNL)

Alaska Microgrid Partnership

Project Integration and Collaboration

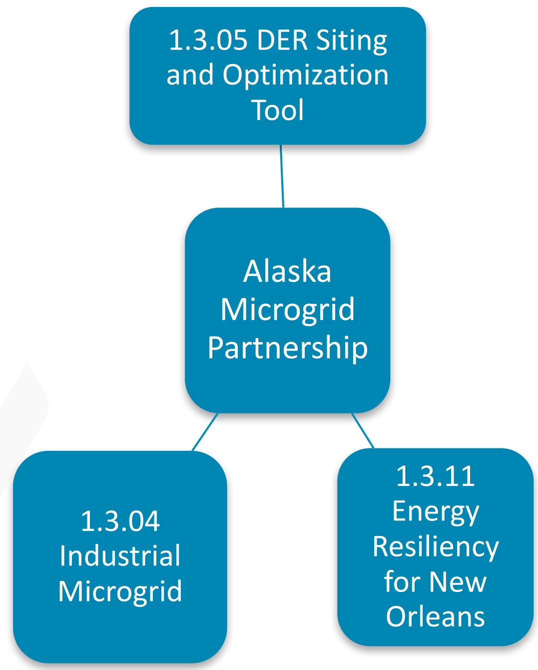
Project Collaboration:

- **1.3.04 Industrial Microgrid Analysis and Design for Energy Security and Resiliency** – microgrid analysis
- **1.3.05 DER Siting and Optimization Tool for California** – Der Cam included in screening assessment, improvements will support more detailed assessment
- **1.3.11 Grid Analysis and Design for Energy and Infrastructure Resiliency for New Orleans** – microgrid analysis

Communications:

Outputs from the AMP are influencing discussions across Alaska and beyond…

- Rural Alaska Energy Conference
- Alaska Power Association
- University of Alaska Fairbanks Arctic Remote Energy Networks Academy program
- International development programs: International Renewable Energy Agency, Power Africa



Alaska Microgrid Partnership
Next Steps and Future Plans

Near-Term Plans:
- Complete techno-economic modeling for two pilot communities (April 2017)
- Conduct business case analysis for the two pilot communities to identify viable financing models (July 2017)
- Develop template to allow application of the modeling and business-case approach to other communities (September 2017)
- Identify additional communities interested in implementing the pathway (September 2017)
- Establish the Alaska Energy Gateway 2.0 by expanding the existing Alaska Energy Data Gateway (September 2017)

Follow-on Work (pending additional support):
- Support two pilot communities in their pursuit of developing real energy infrastructure projects
- Collaborate with Harvard University students to integrate transportation sector assessments into the analysis process
- Implement the pathway produced from this project in additional communities
- Incentivize communities to upload additional financial, human, and technical capacity information into the Alaska Energy Gateway 2.0

Mid-term impact:
- Communities have been very conservative and piecemeal, only low imported energy saving systems have been applied in rural Alaska
- Approximately 20 (out of 200) communities could implement this process in the near-term

Questions?

Ian Baring-Gould
(303) 384-7021
Ian.baring-gould@nrel.gov

Backup Slides

Backup Slide #1: AMP
Typical Rural Alaska Community

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Significant Challenges in Rural Alaska:

- Approximately 200 remote Alaska communities rely on expensive, imported fuel for electricity, heat, and transportation.
- Electric power in these communities is some of the most expensive (up to 10x the national average cost) and least reliable in the United States.
- There is great potential for renewable energy, energy efficiency, and advanced technology solutions.
- The existing renewable energy retrofits (~40 communities) are mostly low- and medium-contribution systems. Although difficult, technical challenges related to high-contribution renewable energy systems can be solved.
- All projects to date have relied on federal and state grant funding, which is not viable going forward.
- After examining existing projects, no single model pathway has emerged to help other communities address dependence on imported fuels.
- The potential worldwide market and impact are huge:
    - 400 diesel microgrids in Canada, 70 in Greenland, more than 1,000 in Indonesia
    - IEA estimates that more than 700 million people currently without electricity access could be most cost-effectively served by mini-grids or microgrids.

Riley Allen (RAP)

Alaska "Power House"
Photo credit: Peter Larsen (LBN

Backup Slide #2: AMP
Project Partner - Details

Project Participants and Roles:

NREL: Project management, conduct techno-economic modeling for one community
LBNL: Community readiness assessment; Develop Alaska Energy Data Gateway 2.0
SNL: Conduct techno-economic modeling for one community
PNNL: Develop business case analysis for the financing of the opportunities identified in the techno-economic modeling
REAP (Renewable Energy Alaska Project): Coordinate Alaska-based partners, represent project at Alaska-based forums, support collection of community data
ACEP (Alaska Center for Energy & Power): Conduct hardware-in-the-loop laboratory testing of diesel generators operating with energy storage; Develop and host Alaska Energy Data Gateway 2.0
IES (Intelligent Energy Systems): Conduct cost and performance assessment of microgrid storage technology options
ISER (Institute of Social & Economic Research): Develop & host Alaska Energy Data Gateway 2.0

Technical Review Panel Members:

Rob Bensin	Bering Straits Development Corporation
Eric Hansen	Alaska Native Tribal Health Consortium
Dave Messier	Tanana Chiefs Conference
Sonny Adams	NANA
Brian Hirsch	Deerstone Consulting
Bill Stamm	Alaska Village Electric Cooperative (AVEC)
Tom Wolfe	Denali Commission
Givey Kochanowski	Office of Indian Energy, DOE
Michael Johnson	Department of Interior
Cady Lister	Alaska Energy Authority
Josh Craft	Alaska Energy Authority
Roderick Philip	Channinik Wind Group
Connie Fredenberg	Consultant
Steve Colt	Alaska Pacific University
Brent Petrie	AVEC (retired)
John Lyons	TDX Power
Robert Sheldon	Venture North Group

GRID MODERNIZATION INITIATIVE PEER REVIEW

Interconnections Seam Study 1.3.33

AARON BLOOM

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

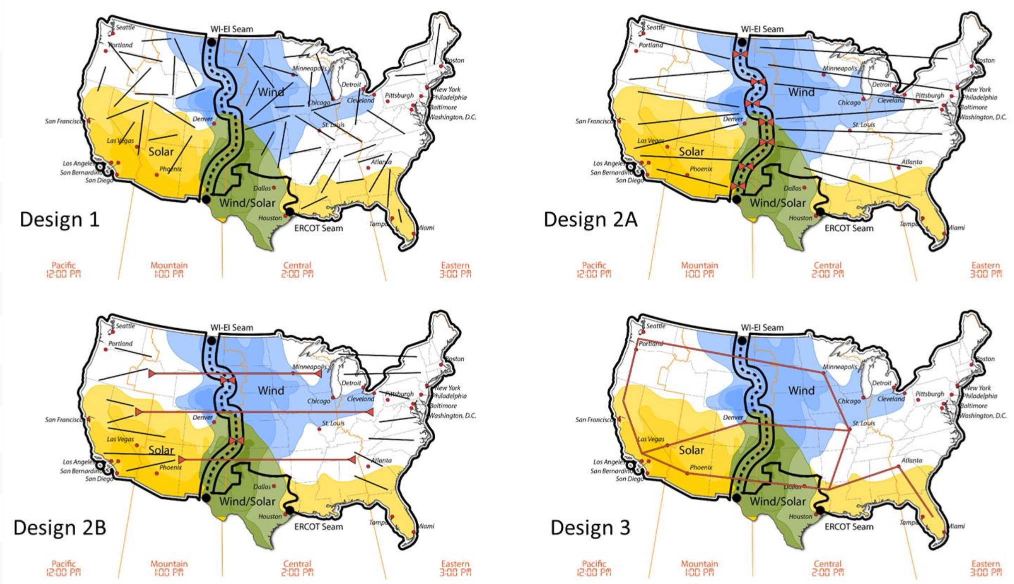
Interconnections Seam Study 1.3.33

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

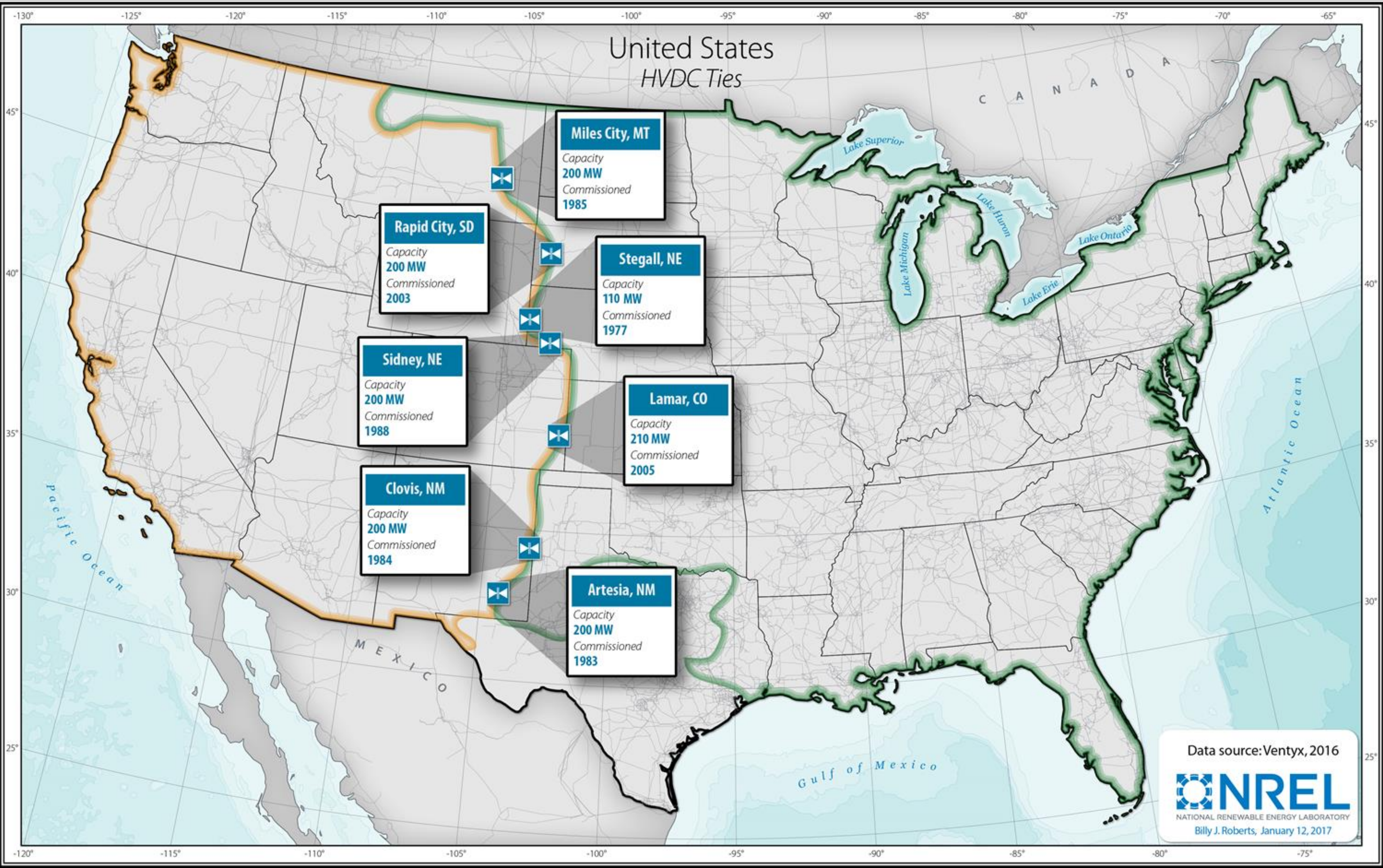
Project Description
What are the options for large scale transmission expansion between the interconnections?

Project Objectives
- ✓ Convene stakeholders
- ✓ Identify modern transmission options for connecting the interconnections

Value Proposition
- ✓ Increase electricity resilience
- ✓ Lower modernization costs through diversity
- ✓ Aging assets present an opportunity



What is the Seam?



Interconnections Seam Study
Project Team

Project Participants and Roles

- NREL
  - Project Lead
  - Production Cost Modeling
- PNNL
  - +1
  - AC Power Flow
- Iowa State University
  - Capacity Expansion Modeling
- ANL
- ORNL
- Management Team
  - Southwest Power Pool
  - Midcontinent Independent System Operator
  - Western Area Power Administration

- Technical Review Committee
  - 2 TRC Meetings, ~ **50 participants** at each event

NREL and SPP tour WAPA's Virginia Smith Converter Station

PROJECT FUNDING	
Lab	FY16 $
NREL	532
PNNL	422
ISU	160
ANL	43
ORNL	43

Interconnections Seam Study
Relationship to Grid Modernization MYPP

MYPP Vision: The future grid will solve the challenges of seamlessly integrating conventional and renewable sources, storage, and central and distributed generation (…)

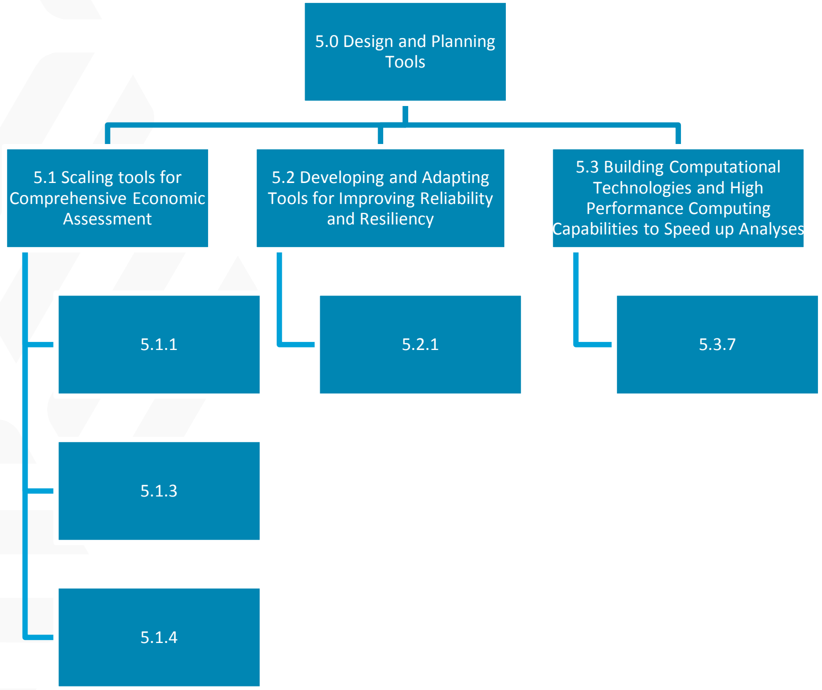
Direct relationship to MPYY vision by delivering a tool to ***estimate the value of national transmission planning***

5.1.1 – Task 5.1.1: Improve computational performance of production cost modeling for year-long sub-hour time resolution by decreasing run times from 2+ weeks to less than 1 day for (1) stochastic transmission and (2) deterministic combined transmission-distribution

5.1.3 – Develop advanced capacity expansion planning for generation, transmission, and distribution that captures operational flexibility, long and short term uncertainties, distributed energy technologies, market and policy impacts, and coupled network and generation optimization.

5.1.4 – Identify and classify data sources, define templates, and develop databases for new grid technologies, generation, load, and other components that compatible with modeling for high performance computers

5.2.1 –Develop scalable integration framework for dynamic modeling and simulation tools across transmission, distribution and communications for evaluation and design



Interconnections Seam Study

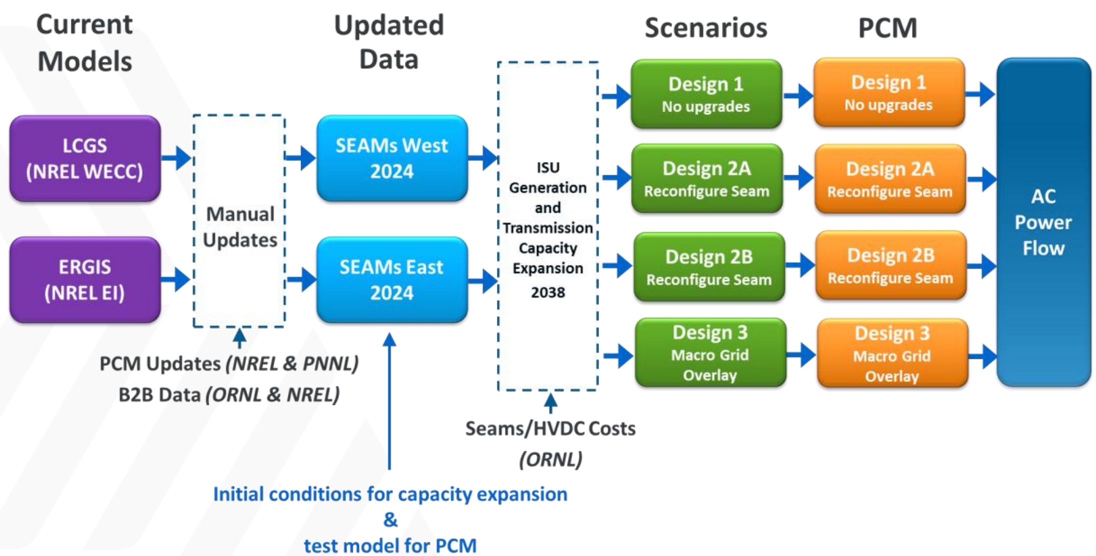
Approach

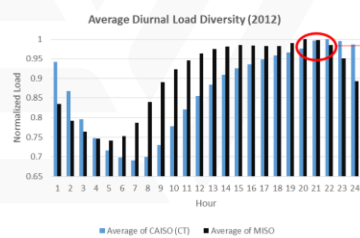
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

<u>Objective:</u> Comprehensive economic and reliability analysis for transmission.

Critical Tasks

- Develop new co-optimized transmission and generation expansion model with Iowa State University
- Develop and verify new wind, solar and load data
- Develop a new production cost model
- Develop dynamic models of the eastern and western interconnections

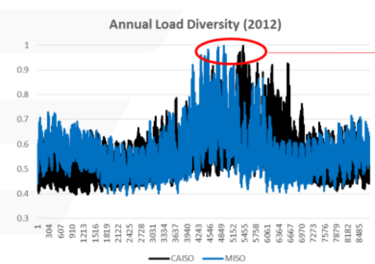




Average diurnal load diversity

From CAISO to MISO → (46,675*.025) = 1,167 MW

From MISO to CAISO → (96,769*.020) = 1,935 MW



Annual load diversity

From CAISO to MISO → (46,675*.2) = 9,335 MW

From MISO to CAISO → (96,769*.2) = 19,354 MW

U.S. DEPARTMENT OF ENERGY

Interconnections Seam Study

Key Project Milestones

Milestone (FY16-FY18)	Status	Due Date
Finalize the development of the capacity expansion, production cost model and AC power flow models for the Base case. Perform preliminary simulations for the base case to test the proposed approaches	100%	4/1/17
Submit draft journal paper on the results of the capacity expansion, production cost, and AC power flow analysis to major industry or academic journal such as IEEE, Science, etc.	25%	10/1/17

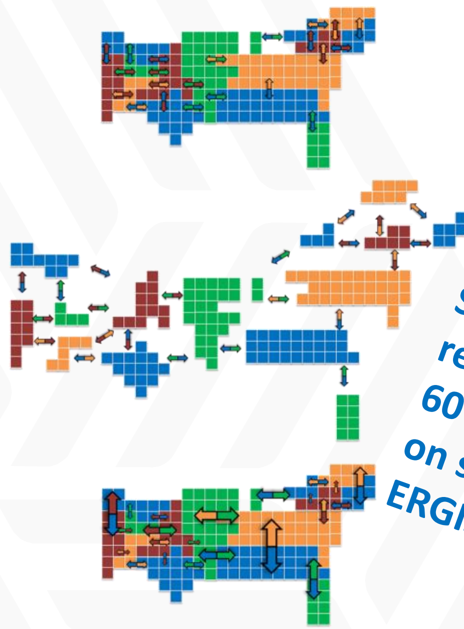
Interconnections Seam Study
Accomplishments to Date

Industry

- ▶ Technical Review Committee
  - ~50 participants
  - 2 in-person meetings
- ▶ Data Development
  - 2012 weather year
  - Unit specific heat rates
  - Topology and fleet
- ▶ Data sharing
  - Heat rates
  - Wind and solar

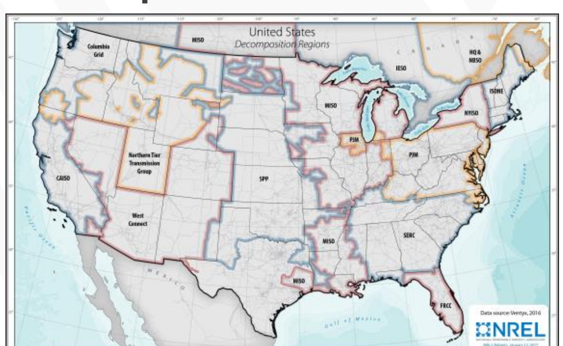
New Method:

Geographic Decomposition



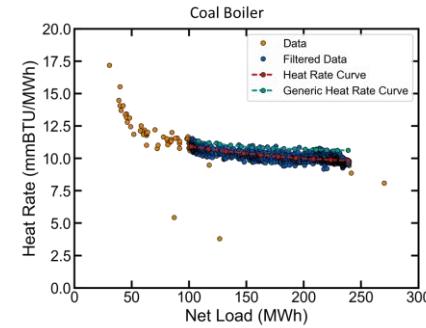
Solve time reduced from 60 to 25 hours on simplified ERGIS model!

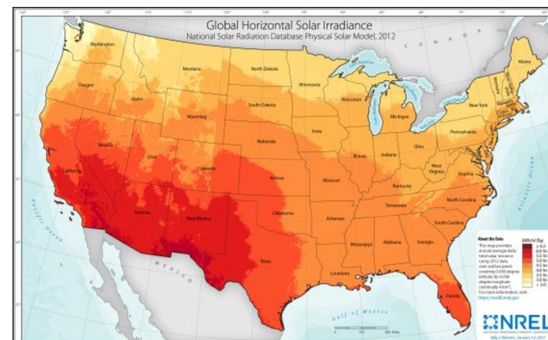
Improved representation of real markets

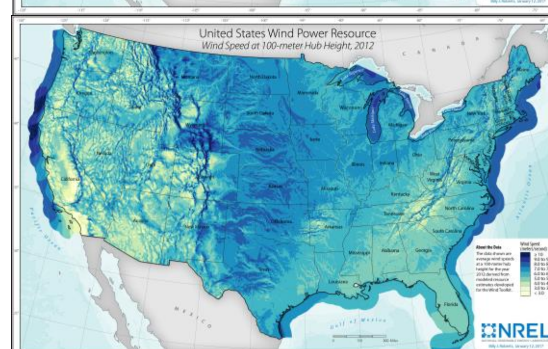


Data:

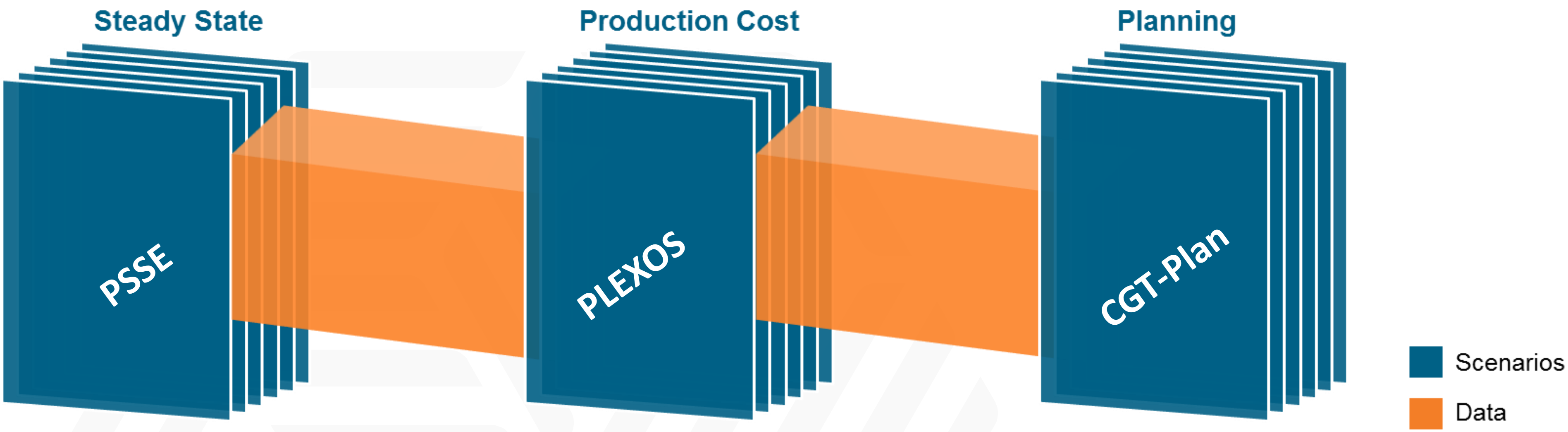
Deeper Insights







Interconnections Seam Study Comprehensive least cost reliability analysis



- Analyzes the full breath of economic and reliability impacts of the four transmission scenarios
- High Performance Computing and Big Data using commercial tools
- Common data across tools
  - WECC TEPPC 2026 and MMWG 2026 power flow and transmission
  - Consistent thermal assumptions
  - Consistent VG assumptions

Recommendation	Response
Please be ready to develop communication materials for state governments. They will be very interested in the results of this work.	A state level communications package has been drafted. Budget is likely insufficient for this activity.
The visualization was very effective in demonstrating the results of this project.	As part of NARIS, a new visualization capability is being developed. The timeline should enable use in the Seams study.

Draft State Level Fact Sheet

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Overview

At the western edge of the American prairie, just east of the Rocky Mountains, lies a collection of electrical resources that string together the workhorse of the American economy: the United States power system. Seven back-to-back high voltage direct current facilities enable 1,400 megawatts of electricity to flow between the Eastern and Western Interconnections. The 1,400 MW of transfer capability between the interconnections isn't much more than a rounding error compared to the size of the networks they connect—the larger Eastern Interconnection is home to 700,000 MW of generating capacity. But these facilities, located strategically where the East meets the West, are aging rapidly and they present a timely and impactful opportunity to modernize the U.S. electric grid. In the Interconnections Seam Study, the GMLC is investigating options for reconfiguring the electrical connections between the Eastern and Western Interconnection.

Why Nebraska Cares

Nebraska is home to two back to back HVDC facilities

Nebraska by the Numbers

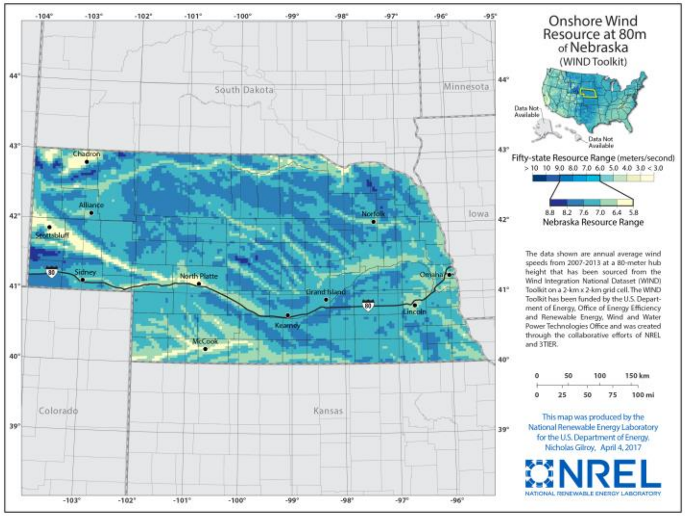
Seams Facilities

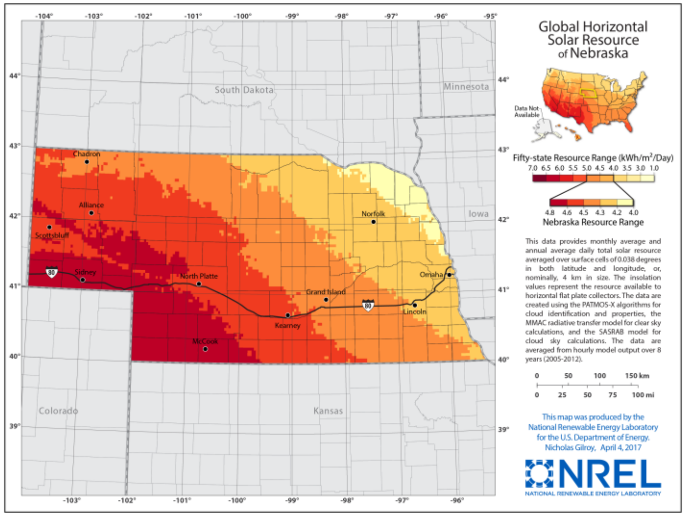
Installed generation

Miles of transmission

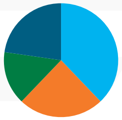
Generation today

Generation in Seams Scenarios

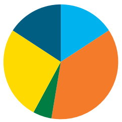




Today's Generation

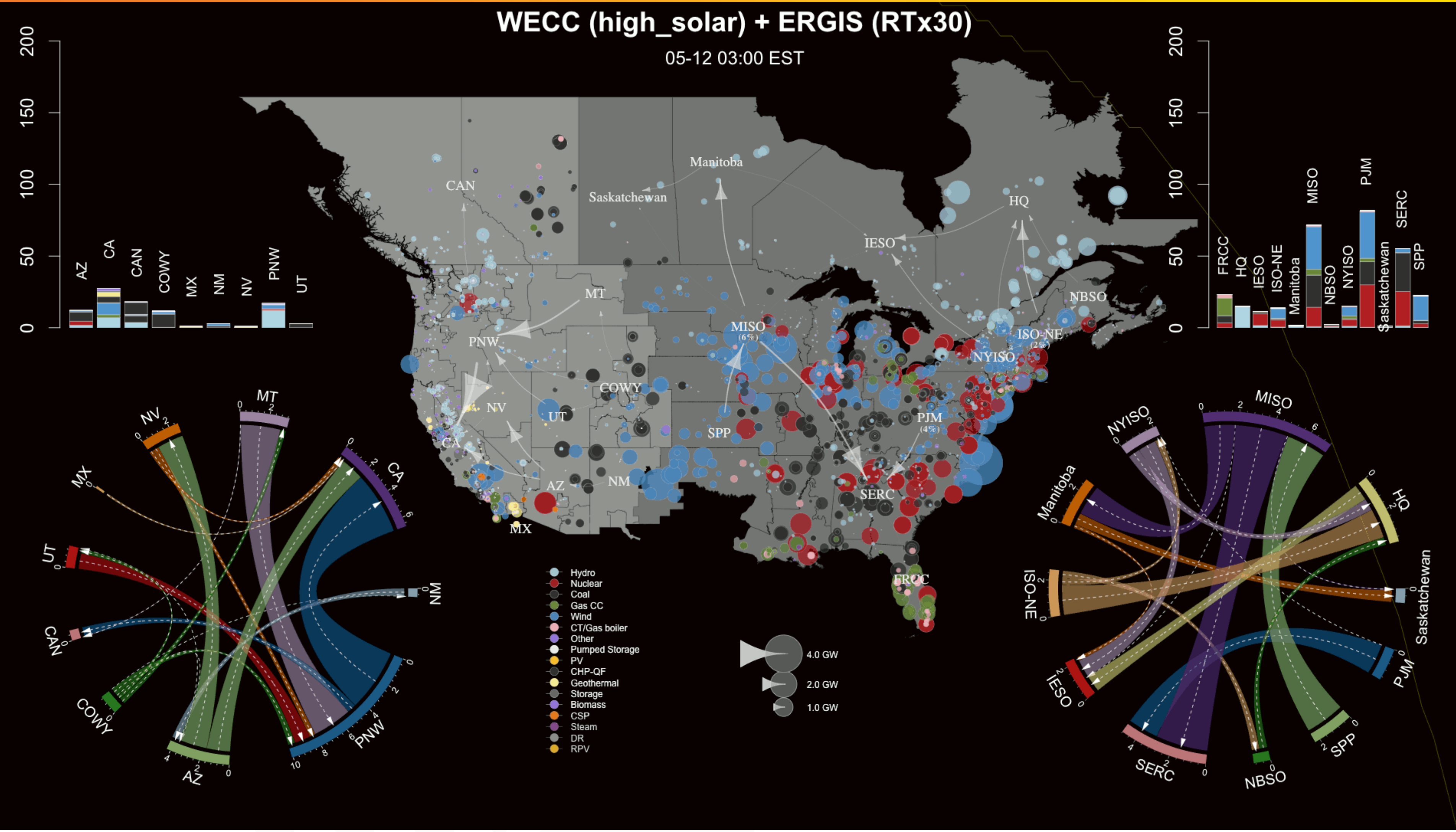


Seams Generation



U.S. DEPARTMENT OF ENERGY

Kaleidoscope 1.0
(What you saw last time)



Kaleidoscope—Alpha Update (What we've been up to)

PLEXOS Shiny Prototype

Generators

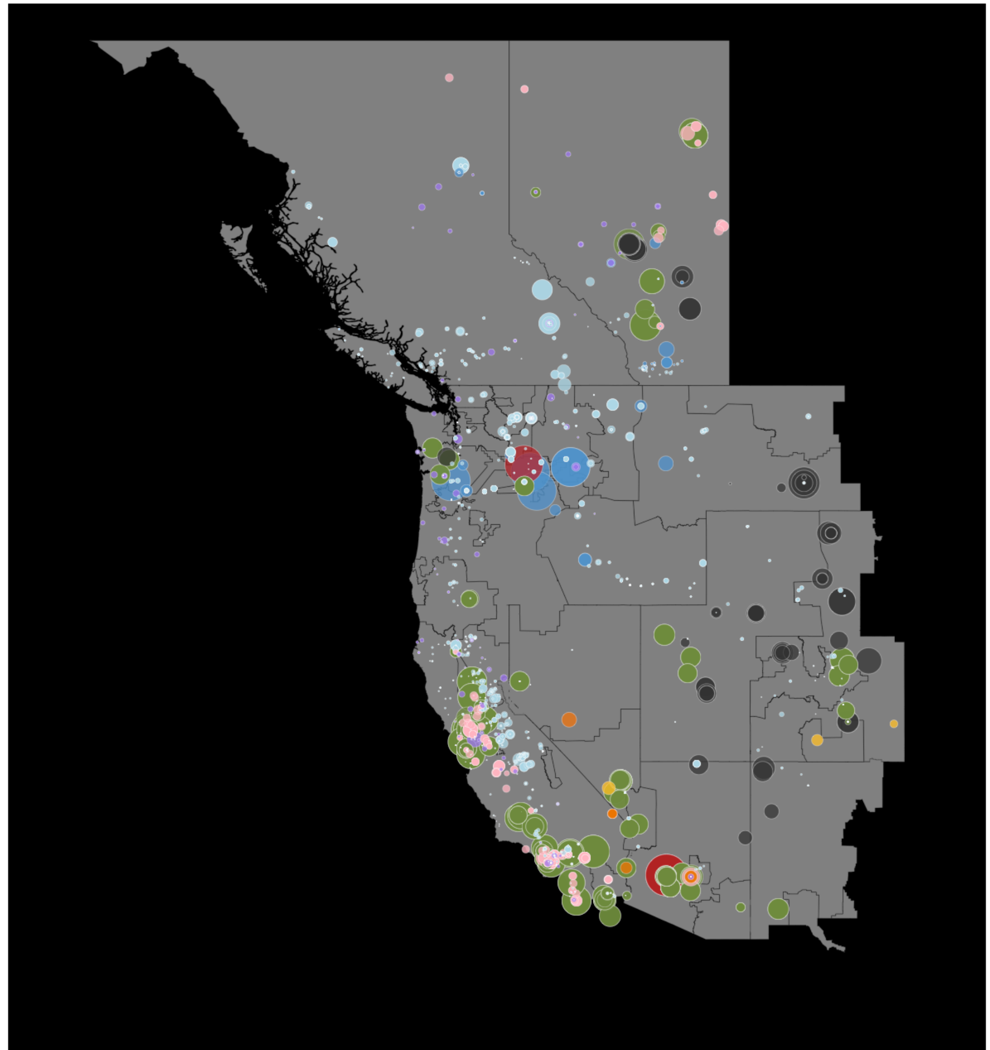
- [x] Wind
- [x] PV
- [x] Hydro
- [x] Coal
- [x] Gas CC
- [x] Gas CT
- [x] Nuclear
- [ ] CHP-QF
- [ ] Geothermal
- [x] Biomass
- [x] CSP
- [ ] Steam
- [ ] DR
- [ ] RPV
- [ ] Other

Time:

1 48

1 6 11 16 21 26 31 36 41 4648

Initialized 177504 rows in 3 s



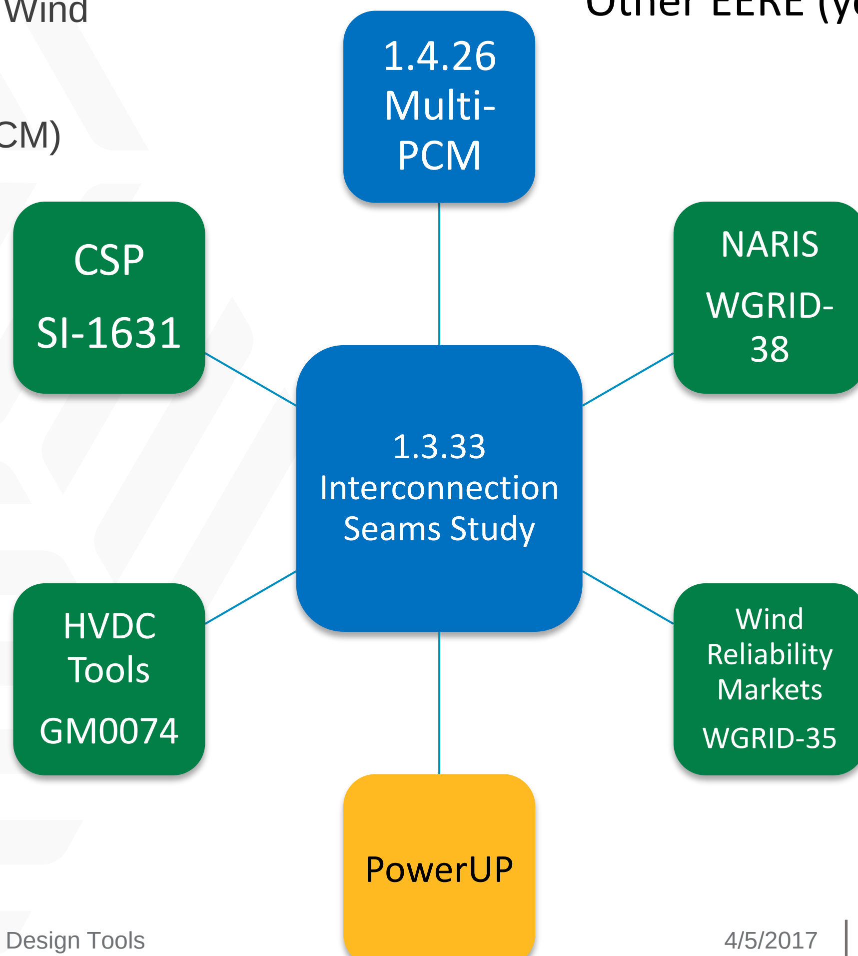
Interconnections Seam Study

Project Integration and Collaboration

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

- Data
  - Concentrating Solar Power (CSP)
  - North American Renewable Integration Study (NARIS)
  - Markets for Essential Reliability Services from Wind (Wind Reliability Markets)
  - PowerUP
  - Multi-scale Production Cost Modeling (Multi-PCM)
- TRC Coordination
  - NARIS
  - Multi-PCM
  - PowerUP
- Methods
  - Multi-PCM
  - NARIS
  - Wind Reliability Markets
  - HVDC for frequency response and congestion management (HVDC Tools)
- Tools
  - CGT-Plan
  - PLEXOS
  - MAGMA
  - Kaleidoscope
  - PSS/E

Category 1 (blue)
Category 2 (green)
Other EERE (yellow)



Interconnections Seam Study

Project Integration and Collaboration

1. Eagle's Nest Transmission Summit
    a. Aaron Bloom, NREL
    b. September 2016
    c. Location: New York

2. Utility Variable Generation Integration Group (UVIG) Forecasting Workshop
    a. Aaron Bloom, NREL
    b. October 2016
    c. Location: Denver, CO

3. Wind Energy Seminar.
    a. James McCalley, "Renewable-motivated co-optimized expansion planning of generation, transmission, distribution, and natural gas systems."
    b. http://home.eng.iastate.edu/~jdm/wesep594/Fall2016.htm.
    c. September 6, 2016
    d. Iowa State University, Ames Iowa.

4. 2016 International Conference on Probabilistic Methods Applied to Power Systems, keynote talk.
    a. James McCalley, "Co-optimized Expansion Planning Applications and Uncertainty."
    b. http://www.pmaps2016.org/index.php?m=content&c=index&a=lists&catid=12
    c. October 17, 2016.
    d. Tsinghua University, Beijing, China.

5. Transmission Summit West Executive Forum Case Study: Exploring Connecting WECC and the Eastern Interconnect
    a. Jay Caspary, SPP
    b. September 2016
    c. San Diego, CA

6. Transmission Summit West Panel Discussion: Perspectives on Regional Planning, Interregional Coordination and Competitive Projects
    a. Jay Caspary, SPP
    b. September 2016
    c. San Diego, CA

7. Midwestern Governors Association--Grid Modernization: Understanding Technology Advancements Conference Panel Discussion: Transmission and Interconnection in the Era of Modernization
    a. Jay Caspary, SPP
    b. October, 2016
    c. Columbus, OH

8. EPRI Power Delivery and Utilization 2016 Fall Advisory Council Meeting
    a. Doug Bowman, SPP
    b. September, 2016
    c. Hollywood Beach, FL

9. SPP Overview and the Future Grid Kansas Field Conference
    a. Jay Caspary, SPP
    b. August 18th, 2016
    c. Garden City, KS

10. Bulk Power System Overview and It's Evolution to the Future Grid, Harding University IEEE Student Meeting
    a. Jay Caspary, SPP
    b. September 22nd, 2016
    c. Searcy, AR

11. DOE Electricity Advisory Committee meeting, EI-WECC Seams Study Update
    a. Jay Caspary, SPP
    b. Dale Osborn, MISO
    c. September 28, 2016
    d. Arlington VA

12. ARPA-e, A Unified Grid
    a. Dale Osborn, MISO
    b. September 29, 2016
    c. Washington, DC

13. EPRI Power Delivery and Utilization 2016 Fall Advisory Council Meeting
    a. Dale Osborn, MISO
    b. September, 2016
    c. Hollywood Beach, FL

14. EUCI 2017 Transmission Summit
    a. Rebecca Johnson, WAPA
    b. February 27 and 28, 2017
    c. Orange County, CA

15. Transmission Summit 2017
    a. Jay Caspary, SPP
    b. March 6, 2017
    c. Washington DC

16. SPP Seams Steering Committee
    a. Jay Caspary, SPP
    b. March 8, 2017

17. Utility Variable Generation Integration Group
    a. Jim McCalley, ISU
    b. March 13-16
    c. Tucson, AZ

Next Steps and Future Plans

Next Steps

- May 17
  - TRC Meeting
- Finalize CEP scenarios and sensitivities
- Present 2026 PCM results
- Sync PCM and Steady State models
- Conduct 2038 PCM runs
- Conduct 2038 Stead State runs

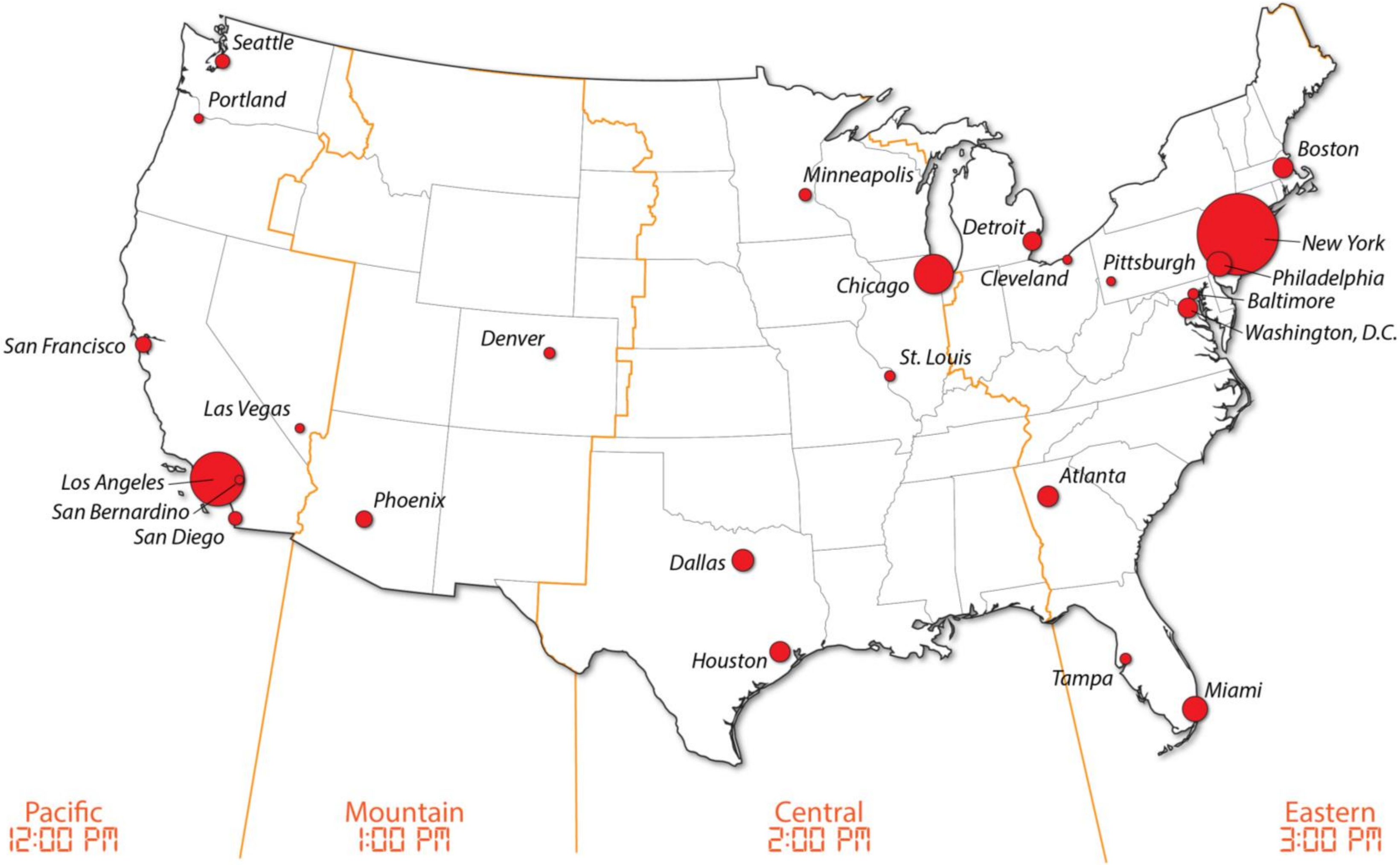
- Final Report October 1, 2017

Wish list

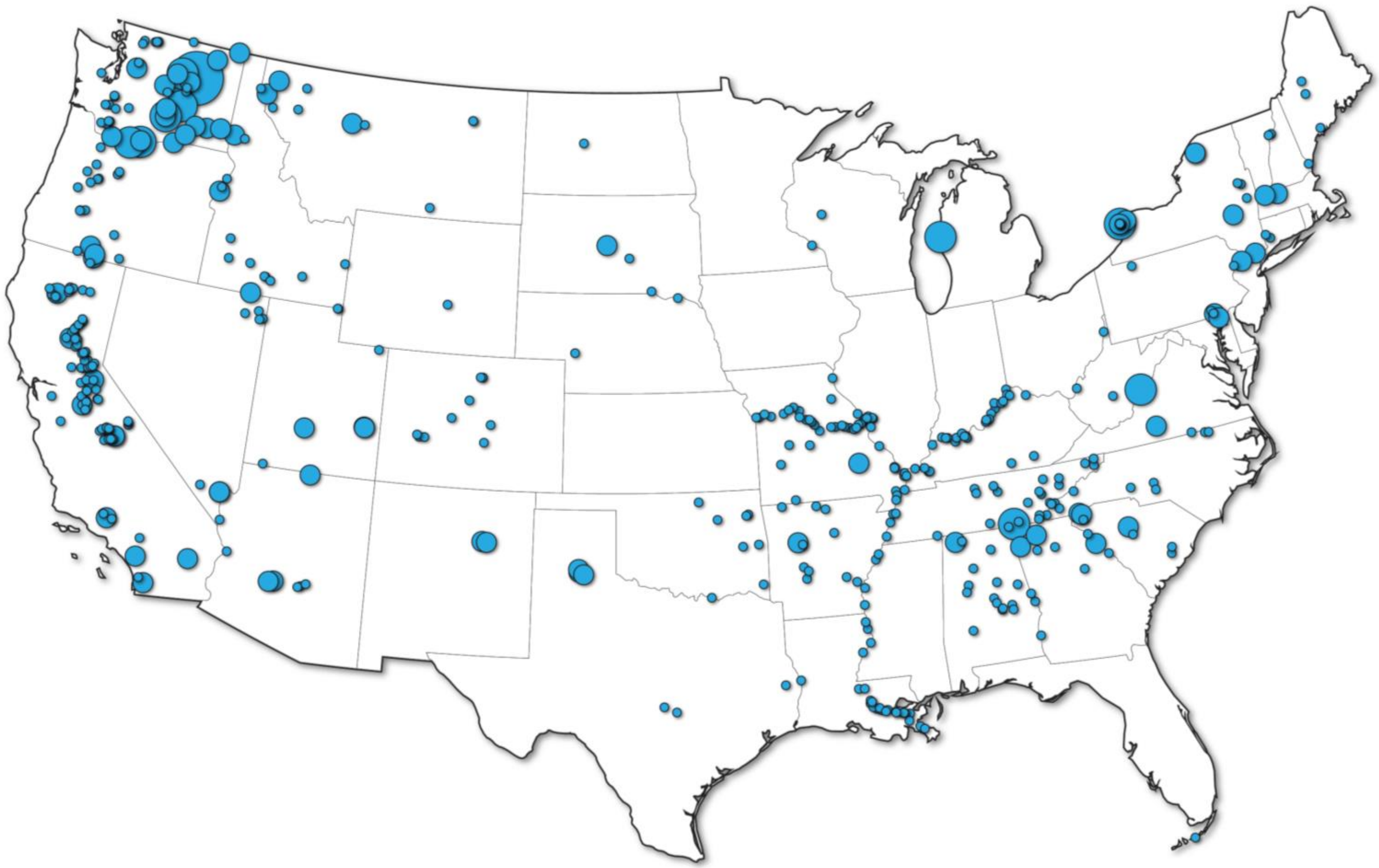
- HVDC Operational Practices
- Weather Sensitivity
- State level communications products
- Natural Gas Sensitivity
- Add ERCOT!

U.S. Demand for Electricity is Diverse

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

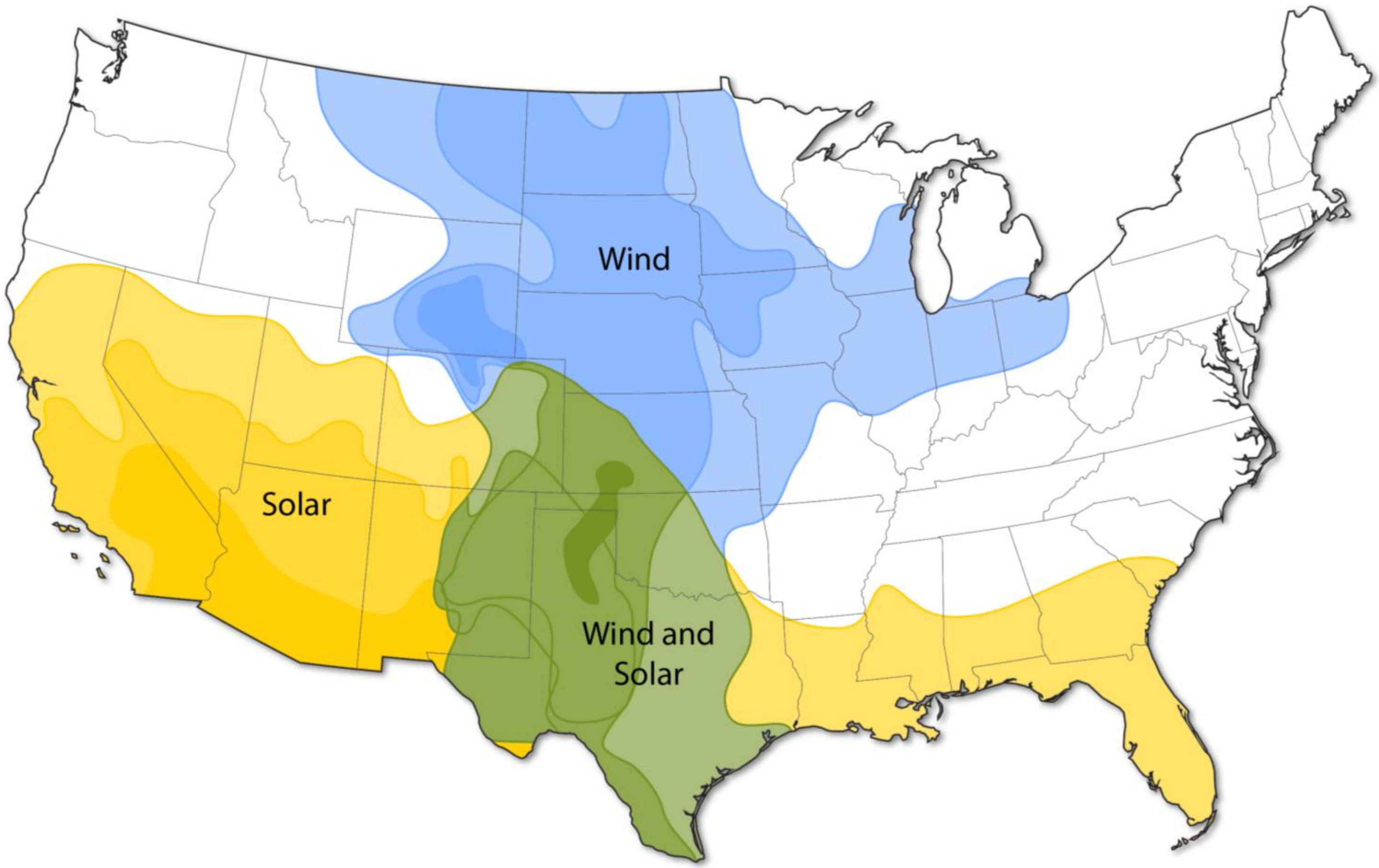


River Basins are Diverse

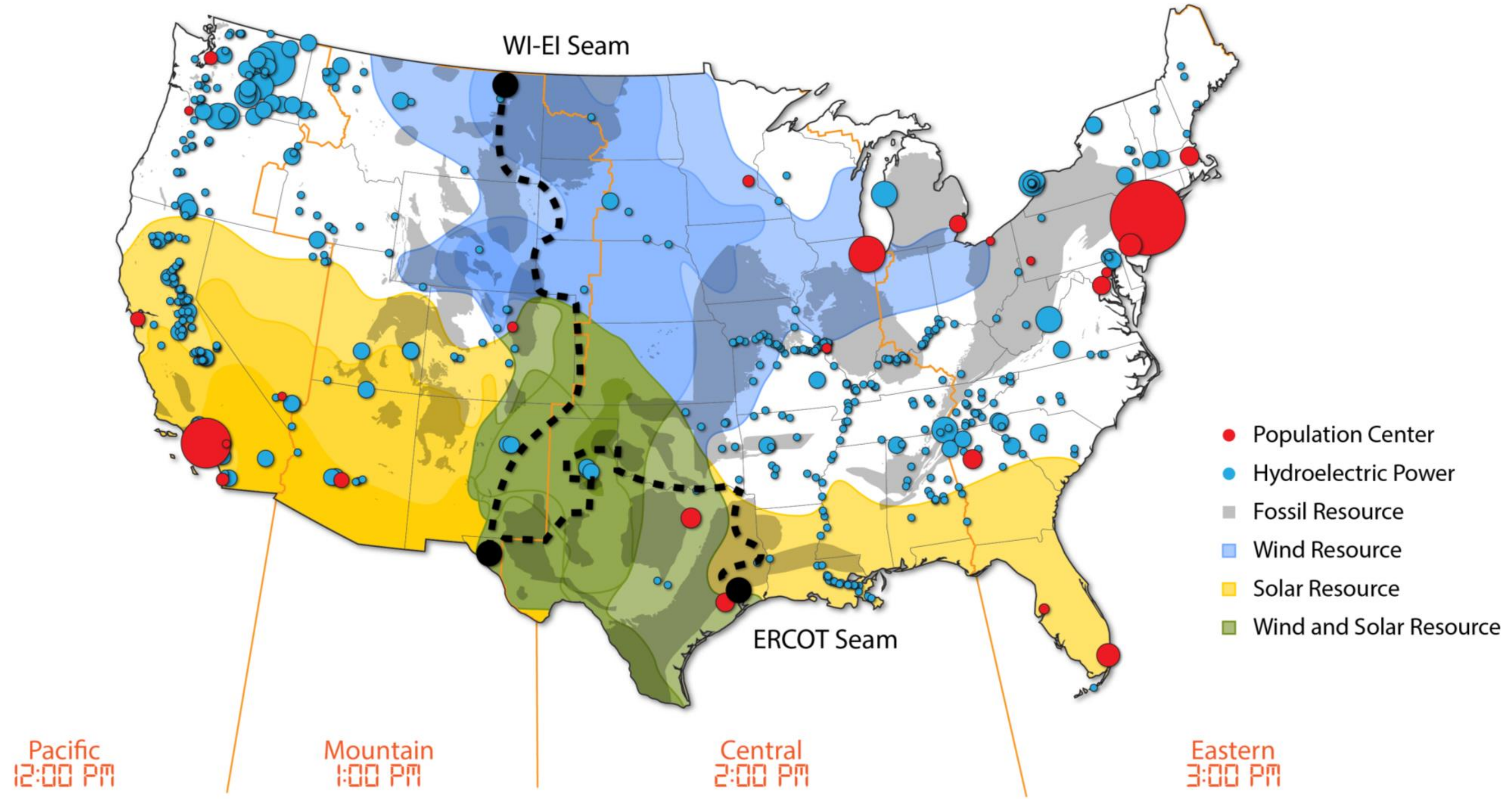


Fossil Fuel Reserves are Broadly Available

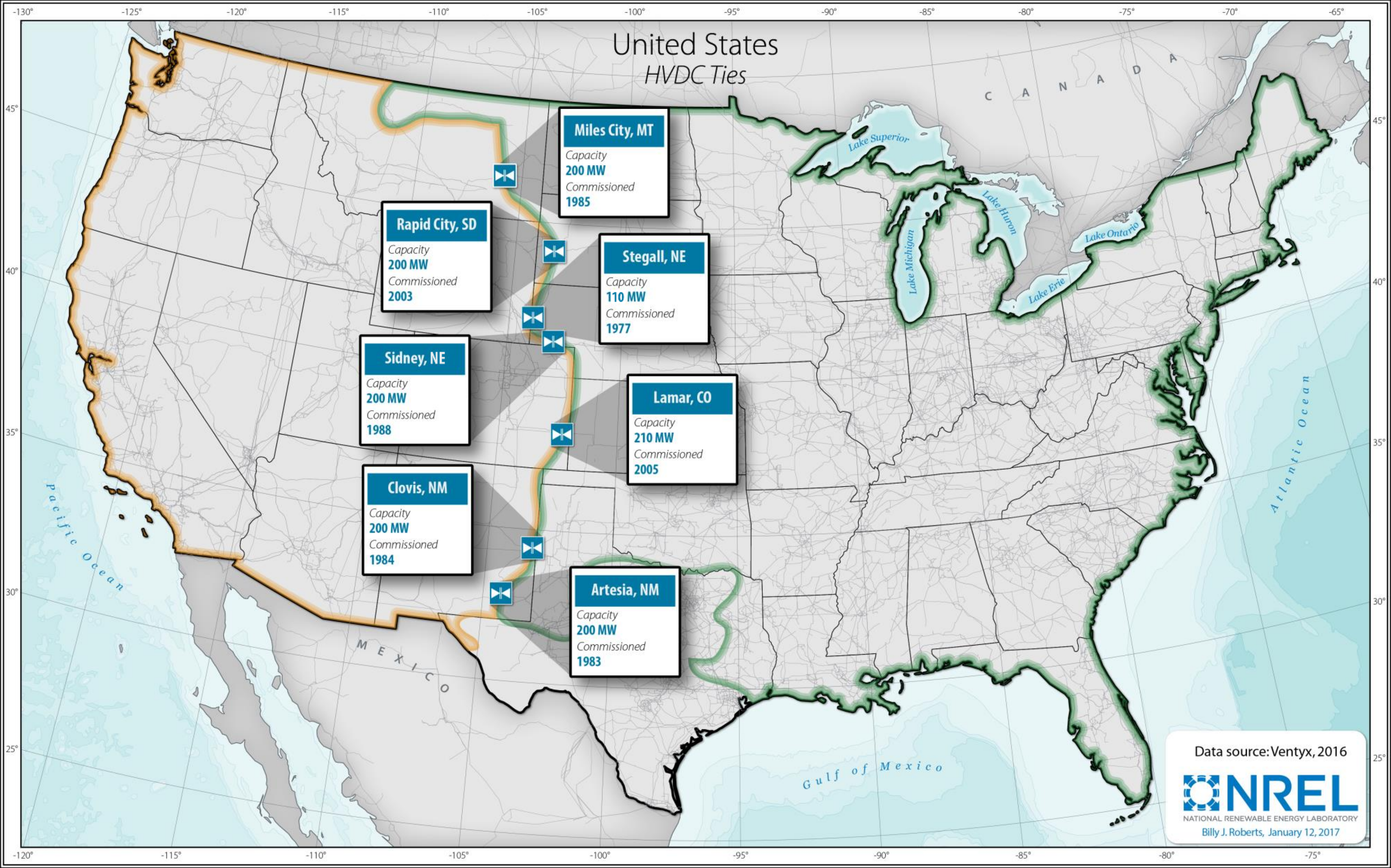
U.S. has Exceptional Wind and Solar



The Resources are Split Up



Interconnections Seam Study 1.3.33



GRID MODERNIZATION INITIATIVE PEER REVIEW

1.4.15 - Development of Integrated Transmission, Distribution and Communication (TDC) Models

HENRY HUANG

April 18-20

Sheraton Pentagon City – Arlington, VA

GMLC 1.4.15 TDC Models
High Level Summary

Project Description
This project aims to enable large-scale TDC interdependency studies through a flexible and scalable, open-source co-simulation platform for the following industry drivers

Project Objectives
- ✓ Provide foundational capabilities for grid planning, operation, and control
- ✓ Engage and educate grid developers on the value of multi-domain planning

Value Proposition
- ✓ There is currently a gap in simulation and modeling technology that inhibits integrated planning across multiple domains
- ✓ Left to it's own devices, the grid community is unlikely to develop capabilities to overcome planning stovepipes (in near term)
- ✓ The DOE plays a unique role in initiating this effort and creating foundational tools that support both research and industry

Image from smartgrid.ieee.org

GMLC 1.4.15 TDC Models

Project Team

Project Participants and Roles

+ 15-member Technical Review Committee (academia and industry experts)

PROJECT FUNDING			
Lab	FY16	FY17	FY18
PNNL	$430K	$430K	$430K
LLNL	$325K	$325K	$325K
NREL	$195K	$195K	$195K
ANL	$165K	$165K	$165K
ORNL	$95K	$95K	$95K
SNL	$60K	$60K	$60K
INL	$60K	$60K	$60K

Name	Organization
Jun Wen	SCE
Babak Enayati	National Grid
Jianzhong Tong	PJM
Slaven Kincic	Peak RC
Mike Zhou	InterPSS Systems
Ernie Page	The MITRE Corporation
Bernie Zeigler	U. Arizona
Calvin Zhang	Nexant
Anjan Bose	WSU
Aidan Tuohy	EPRI
Jens Boemer	EPRI
Craig Miller	NRECA
Cynthia Hsu	NRECA
David Pinney	NRECA
Devin Van Zandt	GE

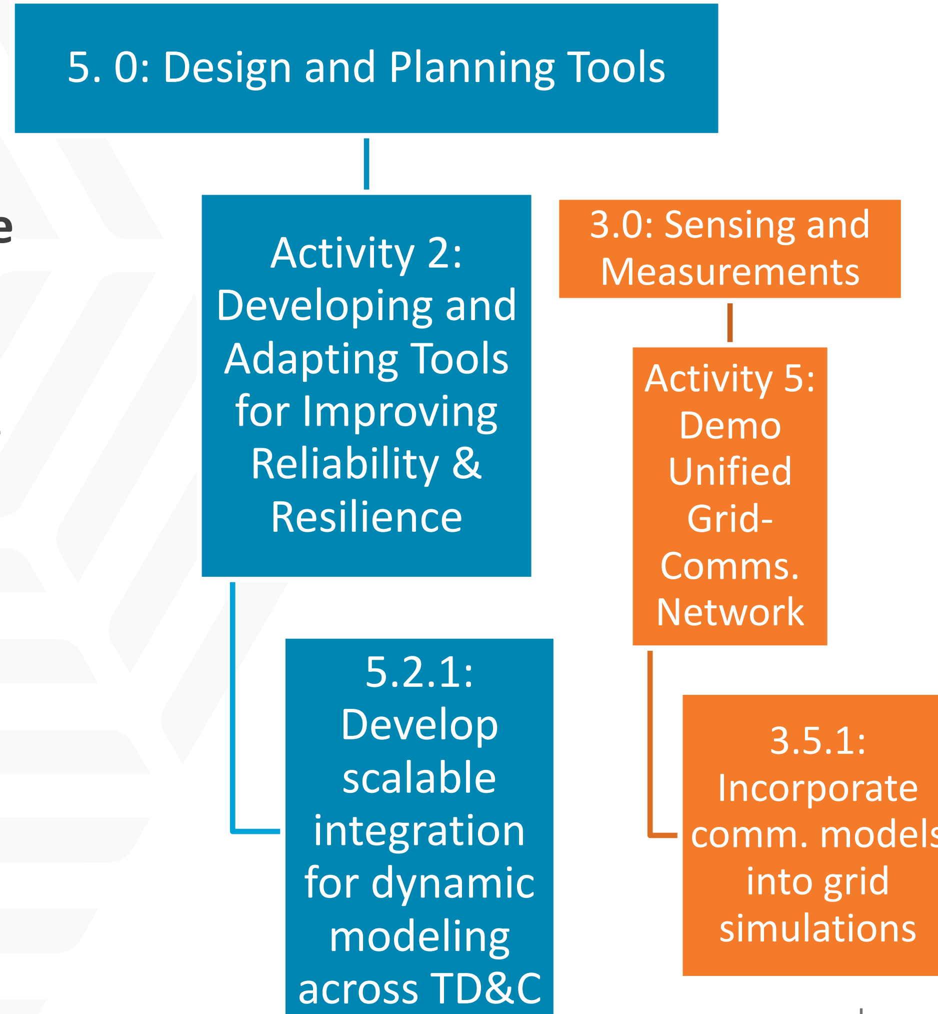
GMLC 1.4.15 TDC Models

Relationship to Grid Modernization MYPP

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

A high-fidelity TDC integrated simulation capability will help address MYPP national outcomes:

- to **design, with confidence, the future grid** to minimize outages and outage costs;
- operate the grid with a leaner reserve margin and still maintain reliability **through holistic analysis**; and
- increase penetration of DERs by **informing decision-makers with quantified impacts** on the system reliability and economics.

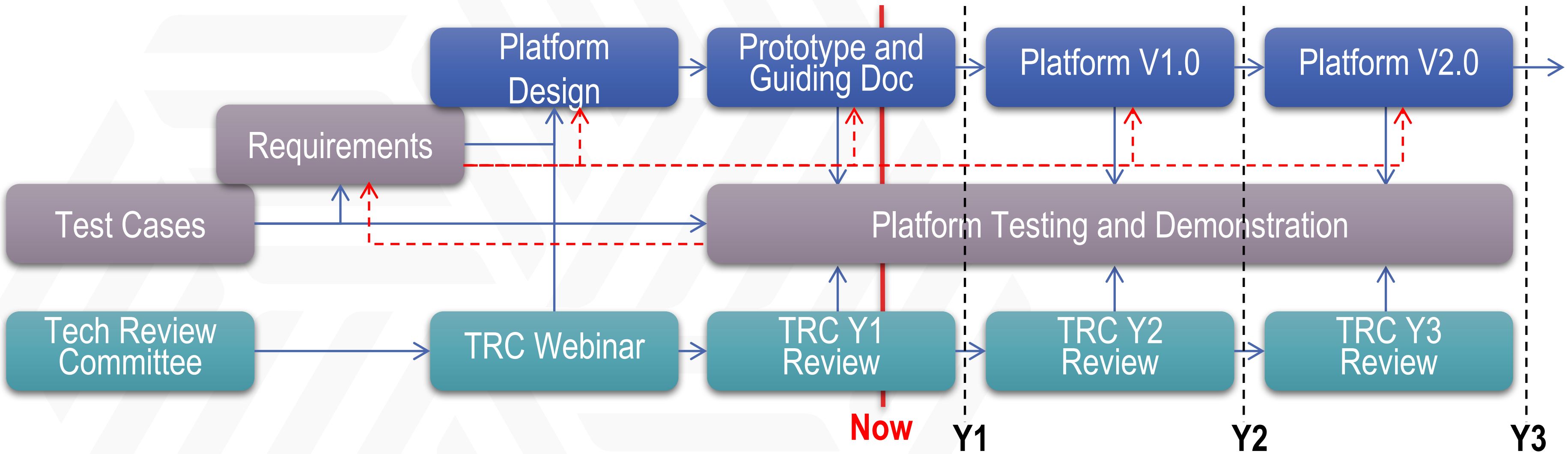


GMLC 1.4.15 TDC Models (HELICS)

Approach

Three tracks (test case driven):

TEST CASES, PLATFORM DESIGN AND DEVELOPMENT, OUTREACH



Development plan targets open-source release of the co-simulation platform

HELICS – Hierarchical Engine for Large-scale Infrastructure Co-Simulation

GMLC 1.4.15 TDC Models (HELICS)

Approach – Use Case Driven

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U.S. Department of Energy

Support a variety of simulation types:

- Discrete Event
- Time Series
- QSTS
- Dynamics
- Transients

Evaluate systems of unprecedented scale:

- 2-100,000+ Federates
- HPC, including cloud
- But also workstations and laptops

No	Title	Description
1	**Impacts of DER's on Bulk Systems Reliability**	The test case will analyze a combined T&D test system with and without advanced distributed systems with high penetrations of distributed solar PV. Studying the impact on reliability metrics such as the NERC Control Performance Standards 1 and 2 as well as other main metrics can quantify the impacts of advanced distribution systems.

	Domain				Simulation			Comm	
	Transmission	Distribution	Communication	Market	Steady State	Dynamic	Transient	Latency	Packets
DER's on Bulk Systems Reliability	X	X			X				
Load Modeling under high penetration of DERs	X	X				X			
Wide Area Voltage Stability Support Using DERs	X	X	X		X			X	
Voltage and Frequency Ride-Through Settings for Smart Inverters	X	X	X			X			
Real-time Co-simulation of Power Systems and Communication Networks for Transient Assessment	X	X	X				X	X	
Communications Architecture Evaluation for High-Pen Solar	X	X	X		X				X
New Control Paradigm – Centralized vs Distributed to Prevent Voltage Stability Collapse	X	X	X			X		X	
Wide Area Monitoring, Protection, and Control (WAMPAC)	X		X			X		X	X
Impacts of Distributed Energy Resources on Wholesale Prices	X	X		X	X				
Mitigating T/D Interface Congestion Through Demand Side Management	X	X		X	X			X	
Regional Coordinated Electric Vehicles Charging	X	X		X	X			X	
Real-time Coordination of Large Scale Solar PV and Energy Storage	X	X			X			X	

GMLC 1.4.15 TDC Models (HELICS)

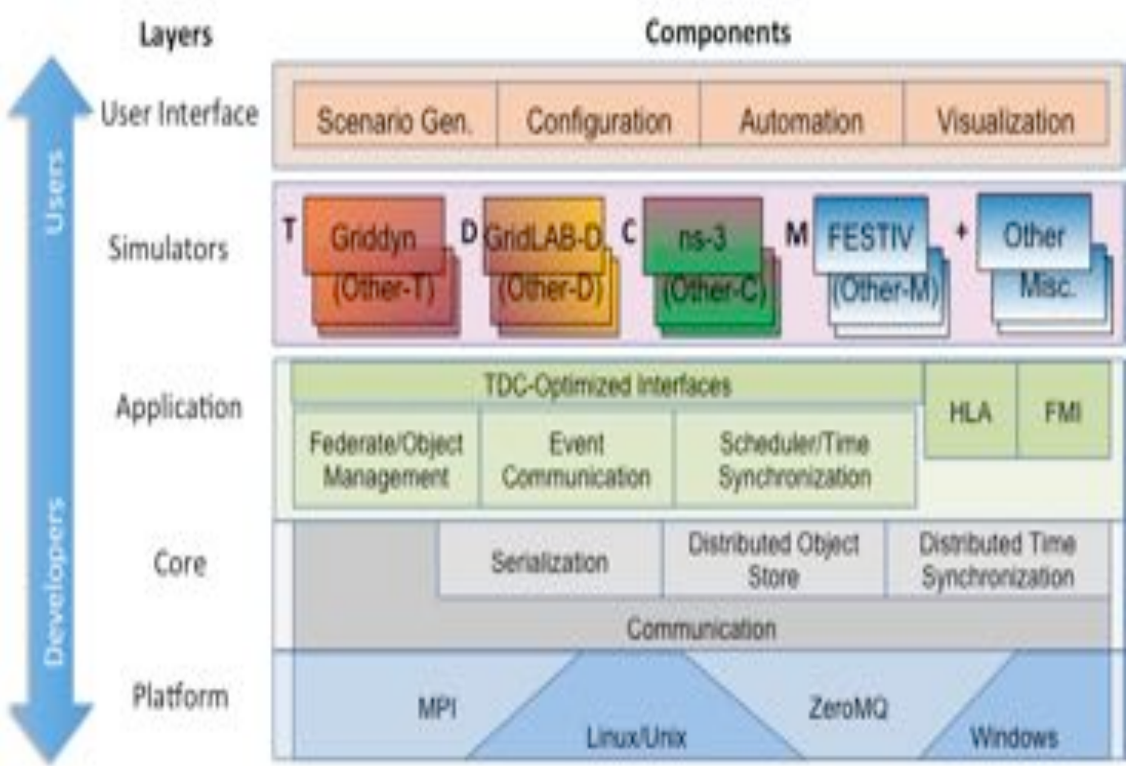
Approach – Use Case Driven

Layered and modular architecture to support:

- Laboratory, open-source, and commercial tools
- Interchangeable time synchronization algorithms (depending on use case)
- Reiteration, when necessary

Support standardized interfaces:

- HLA, FMI, etc.
- Tuned APIs for highly used tools (e.g., GridLAB-D, ns-3)



GMLC 1.4.15 TDC Models (HELICS)

Key Project Milestones

Milestone (FY16-FY18)	Status	Due Date
M1: Document initial test cases	100%. Delivered 19 test cases and reviewed at the TRC webinar.	9/1/2016
M2: Organize a TRC webinar to review test cases and initial TDC platform design	100%. Held the TRC webinar on 11/14/2016. Completed the draft of the summary report .	12/1/2016
M3: Report documenting test case studies	100%. Derived requirements and metrics from 12 test cases.	3/1/2017
M4: Deliver a guiding document for TDC simulation	90%. Draft document complete, under review.	6/1/2017
M5: Organize a industry stakeholder workshop to review the guiding document	90%. Scheduled, agenda developed. Preparation is ongoing.	6/1/2017
M6: Deliver an initial prototype platform to open source	90%. Platform developed, under testing with three example cases.	6/1/2017
M7: Deliver ver1.0 platform to open source	50%. Prototype operational.	12/1/2017
M8: Host an industry stakeholder meeting to review ver1.0	0%.	6/1/2018
M9: Deliver ver2.0 platform to open source	0%.	12/1/2018
M10: Demonstrate ver2.0 platform with selected use cases	0%.	12/1/2018

GMLC 1.4.15 TDC Models (HELICS)

Accomplishments to Date – Use Cases & Outreach

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- Developed "use case" document with 12 detailed use cases to drive software design.
  - Mapped the use cases to high-level MYPP outcomes.
  - Mapped the use cases to requirements for the software platform.
- Received feedback on use cases from TRC.
- Created a series of use cases to-be-tested on the HELICS platform when available.
- Completed TRC webinar in November 2016. TRC meeting scheduled for May 2017.

Reliability/Sustainability
Test Case 1: Impacts of DER's on Bulk Systems Reliability
Test Case 5: Evaluate modeling adequacy of composite load model under high penetration of DERs
Test Case 12: Wide Area Voltage Stability Support Using DERs
Test Case 11: Adaptive Voltage and Frequency Ride-Through Settings for Smart Inverters

Security/Sustainability
Test Case 9: Real-time Co-simulation of Power Systems and Communication Networks for Transient Assessment
Test Case 10: Communications Architecture Evaluation for High-Pen Solar

Resilience/Sustainability
Test Case 7: New Control Paradigm – Centralized vs Distributed to Prevent Voltage Stability Collapse
Test Case 8: Wide Area Monitoring, Protection, and Control (WAMPAC)

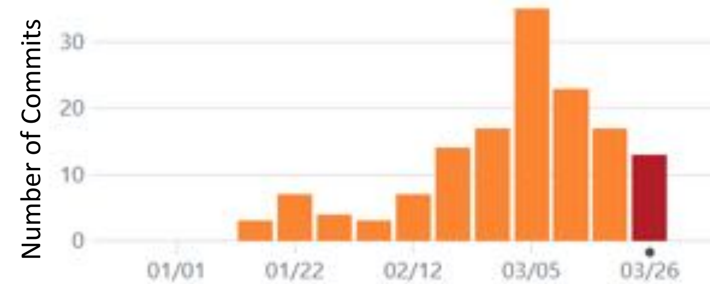
Affordability/Sustainability
Test Case 2: Impacts of Distributed Energy Resources on Wholesale Prices
Test Case 6: Mitigating T/D Interface Congestion Through Demand Side Management

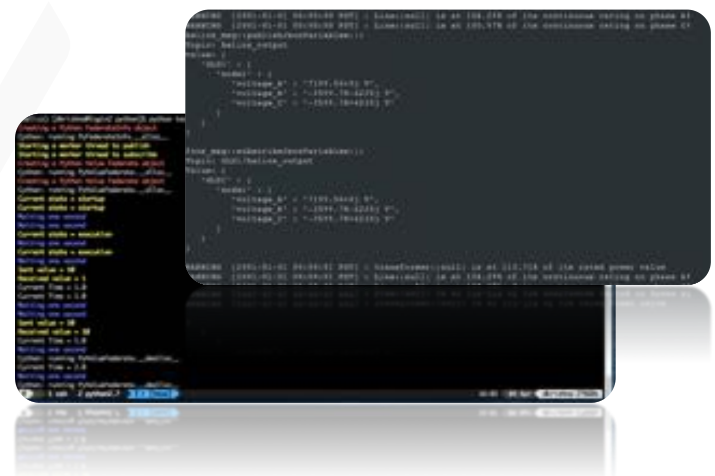
Flexibility/Sustainability
Test Case 3: Regional Coordinated Electric Vehicles Charging
Test Case 4: Real-time Coordination of Large Scale Solar PV and Energy Storage

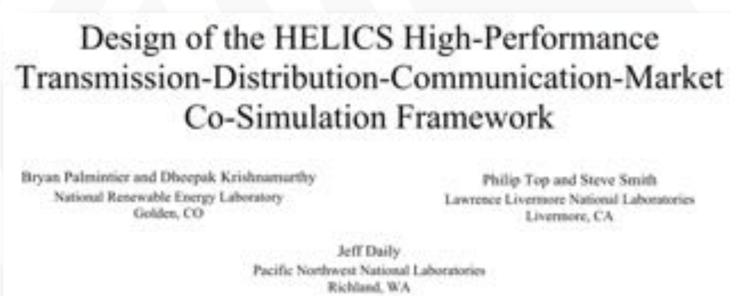
GMLC 1.4.15 TDC Models (HELICS)

Accomplishments to Date – Platform Design

- Held a team workshop to extract platform requirements from use cases.
- Developed a platform specification and design document to align software development across three laboratories.
- Received feedback on design elements from TRC.
- Created a GitHub project and repository to start collaborative software development.
  - >200 commits
- Completed the HELICS platform prototype with three test case examples.
- Publication on the HELICS platform design accepted to *2017 Workshop on Modeling and Simulation of Cyber-Physical Energy Systems.*






Design of the HELICS High-Performance Transmission-Distribution-Communication-Market Co-Simulation Framework

Bryan Palmintier and Dheepak Krishnamurthy
National Renewable Energy Laboratory
Golden, CO

Philip Top and Steve Smith
Lawrence Livermore National Laboratories
Livermore, CA

Jeff Daily
Pacific Northwest National Laboratories
Richland, WA

GMLC 1.4.15 TDC Models (HELICS)

Response to December 2016 Program Review

Recommendation	Response
Please share the 19 test cases with DOE program managers. Many other projects are using test cases, and it is important that others are aware of your approach.	Yes. We have 12 cases fully developed and are posted on an accessible SharePoint site. These will be made publically available when the GitHub project is made open source in May.
Getting relevant data to use is critical for the success of this project. While it was mentioned in the meeting that ARPA-E grid data could be used as a backstop, it is not clear that this is true for communications data. Please be ready to discuss your data sources moving forward at the Annual Peer Review in April 2017.	Communication data is hard to obtain due to strict adherence to CIP. Have gathered a shortlist of public resources, but they are insufficient. Working with P&DT WG on Data and Software, fellow researchers, program offices, TRC, etc. to fill gap.
While it was mentioned that applying this work to grid operations was "outside the scope of this project," please coordinate with the operations projects 1.4.10 and 1.4.11. We need to make sure there is synergy in the use cases being developed between the operations and planning and design tools technical areas.	Jason (PNNL PI) developed the Year 2 test plan for project 1.4.10; this will co-sim JuliaOpt, MATLAB, and GridLAB-D. Liang (LLNL PI) is lead for 1.4.11; use cases for operations include EMS-DMS-BMS and will use TDC platform to validate controls before deployment.

GMLC 1.4.15 TDC Models (HELICS)

Project Integration and Collaboration

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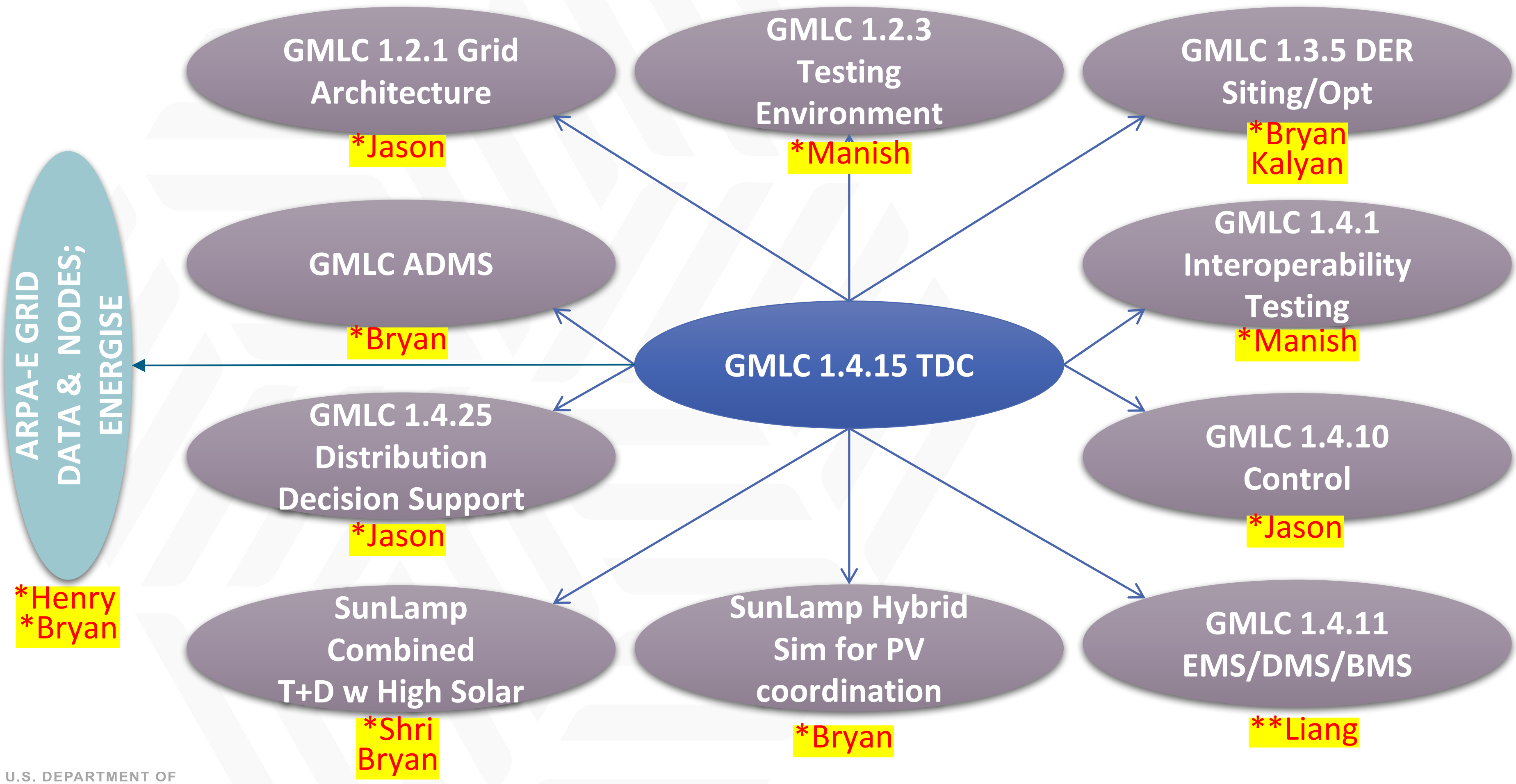
TDC Modeling and Simulation is Foundational



GMLC 1.4.15 TDC Models (HELICS)

Next Steps and Future Plans

- Release v0.1 of HELICS to the open source in May 2017, including Guiding Document and example use cases
  - Currently securing licensing and copyright agreements
- TRC Meeting in May 2017 in Richland, WA
- Add additional simulators as identified by working with other GMLC projects and TRC members
- Implement HPC Platform Layer (MPI-based) to address large numbers of federates
- Develop use cases to explore limits of tool (and address) and increase value
- Develop (and release) tools to increase usability of tool
- Release subsequent versions to open source

GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.4.17 – Extreme Event Modeling

RUSSELL BENT

April 18-20

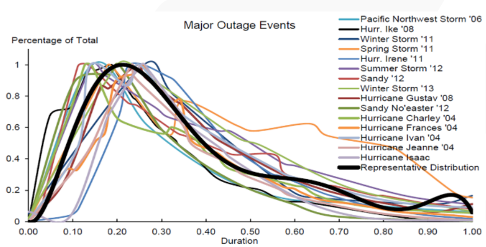
Sheraton Pentagon City – Arlington, VA

Extreme Event Modeling

High Level Summary

Project Description

- Natural and man-made extreme events pose enormous threats



Source: Department of Energy, Office of Electrcity Delivery and Energy Reliability

- Cascading and N-k modeling have large gaps
  - Inadequate modeling
    - Reliability standards (NERC Standard TPL-001-4) challenged
  - Computational efficiency
    - Considerable speed up required for faster than real time planning
  - N-k contingency analysis
    - Existing k=3 analysis misses large-scale adversary attacks
    - Neglects high likelihood failures

Project Objectives

- ✓ A prototype set of tools for efficient cascade modeling and probabilistic N-k identification.
- ✓ Tools that are 500x faster than existing industry cascade simulation packages
- ✓ Identify the worst (probabilistic) k contingencies where k is twice as big as existing practices
- ✓ Demonstration on a large-scale system (WECC)

Value Proposition

- ✓ Identify extreme event risk prior to event occurrence
- ✓ Plan proactively

Extreme Event Modeling
Project Team

Project Participants and Roles

- **Russell Bent** (LANL): PI, Task Lead for *3.4: Most probable N-k identification*
- **Yuri Makarov** (PNNL): +1, Task Lead for *1.1: Integrating multiple temporal scales, 1.2: Inadequate Modeling—Integrating Protection System models*
- **Liang Min** (LLNL): Task Lead for *1.3: Integrating renewables, 2.3: Parallel computing for massive dynamic contingency*
- **Junjian Qi** (ANL): Task Lead for *2.1: Predicting critical cascading path*
- **Yilu Liu** (ORNL): Task Lead for *2.2: Model Reduction Techniques*
- **Meng Yue** (BNL): Task Lead for *3.1: Component Failure Probabilities*
- **Kara Clark** (NREL): Task Lead for *3.2: Mitigation Plan Modeling*
- **Jean-Paul Watson** (SNL): Task Lead for *3.3: Worst Case N-k identification*

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
LANL	155K	130K	145K
PNNL	210K	235K	180K
LLNL	160K	260K	210K
ANL	125K	95K	125K
ORNL	125K	95K	125K
BNL	50K	45K	45K
NREL	50K	45K	45K
SNL	125K	95K	125K

Industry and Academic Partners: GMLC, NERC, FERC, IEEE Cascading Failure Working Group, Dominion Virginia Power, PJM, ERCOT, UTK

- Webinar participation
- Power system data

Extreme Event Modeling
Relationship to Grid Modernization MYPP

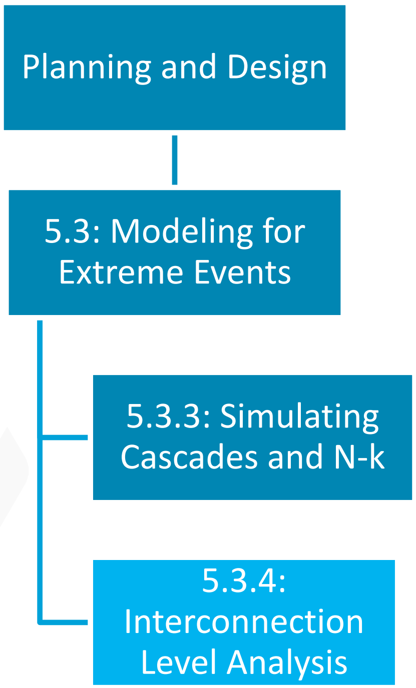
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Primary MYPP Goal: A 10% reduction in the economic costs of power outages by 2025

Executive Summary: *greater resilience to hazards of all type*

MYPP Activities

- Planning and Design Activity 2: Developing and Adapting Tools for Improving **Reliability** and **Resilience**
- Sub Activity 5.3: Modeling for Extreme Events
  - *Task 5.2.3:* Develop methodologies to simulate cascading events and protection systems and improve solution times by 500x via scalable computational math algorithms and automation techniques. Include probabilistic approaches in N-k contingency analysis
    - Project Deliverable: Tools that are 500x faster than existing industry cascade simulation packages (2019)
    - Project Deliverable: Tools that identify the worst (probabilistic) k contingencies where k is twice as big as existing practices
  - *Task 5.2.4:* Develop tools needed to perform interconnection level analysis of extreme events such as weather, EMP, GMD, and cyber and physical attacks.
    - Project developments are a necessary foundation for future tools and capabilities for mitigating the consequences of such events and modeling of sources of extreme events



* As of https://energy.gov/sites/prod/files/2016/01/f28/Grid%20Modernization%20Multi-Year%20Program%20Plan.pdf

Extreme Event Modeling

Approach

- Cascade Modeling: Inadequate Modeling
  - Integrating multiple temporal scales
    - Description: Develop new methods for modeling phenomena at different time multiple time scales
    - Key Issues: Fundamentally different methods used at different time scales, difficult to integrate
    - Novelty: Unique hybrid approach for combining phenomena and mathematics at different time scales
  - Integrating protection system models
    - Description: Develop models of Zone 3 protection
    - Key Issues: The extent and ordering of protection execution is often unknown
    - Novelty: New methods for estimating the behavior of protection during cascades.
  - Integrating Renewables
    - Description: Develop mathematical models and implementations of long-term wind dynamics
    - Key Issues: No stability simulation platform that combines computational capabilities with models needed for assessing the implications of wind energy resources dynamics
    - Novelty: new mathematical models of wind dynamics suitable for cascades
- Cascade Modeling: Computational Efficiency
  - Predicting critical cascading paths
    - Description: Develop statistical methods for identifying cascading paths
    - Key Issues: The number of possible cascade evolutions can be to large to enumerate
    - Novelty: Models and software tools that statistically characterize component interactions that significantly limit the number cascade evolutions that need to be simulation
  - Model Reduction techniques
    - Description: Methods and software for reducing the size of networks
    - Key Issues: Network models can be too large for exhaustive cascade modeling
    - Novelty: New approaches for model reduction based on measurement data
  - Parallel computing for massive dynamic contingency analysis
    - Description: Leverage HPC to improve efficiency of cascade modeling
    - Key Issues: The number of cascades are too many to enumerate serially
    - Novelty: Extensive leveraging of DOE and lab investments in HPC to improve computation by 500x
- Probabilistic N-k
  - Component failure probabilities
    - Description: Develop probabilistic models of component failure based on data
    - Key Issues: Utilities currently do not have rigorous approaches for build probabilistic models of failure
    - Novelty: Formal probabilities for N-k
  - System failure probabilities
    - Description: Develop probabilistic models of system failures based during extreme events
    - Key Issues: Data is sparse for examples of extreme event system failures
    - Novelty: Formal probabilistic of extreme event system failures
  - Worst-Case N-k Identification
    - Description: Tools for identifying sets of k component failures with the biggest impact
    - Key Issues: It is computationally intractable to find k > 3 worst failures
    - Novelty: New approaches for doubling the size of k
  - Most probable N-k Identification
    - Description: Tools for identifying sets of k component failures whose probabilistic outcome is worst.
    - Key Issues: Computationally very difficult to find sets of large k
    - Novelty: Tools that combine probabilistic models with N-k optimization

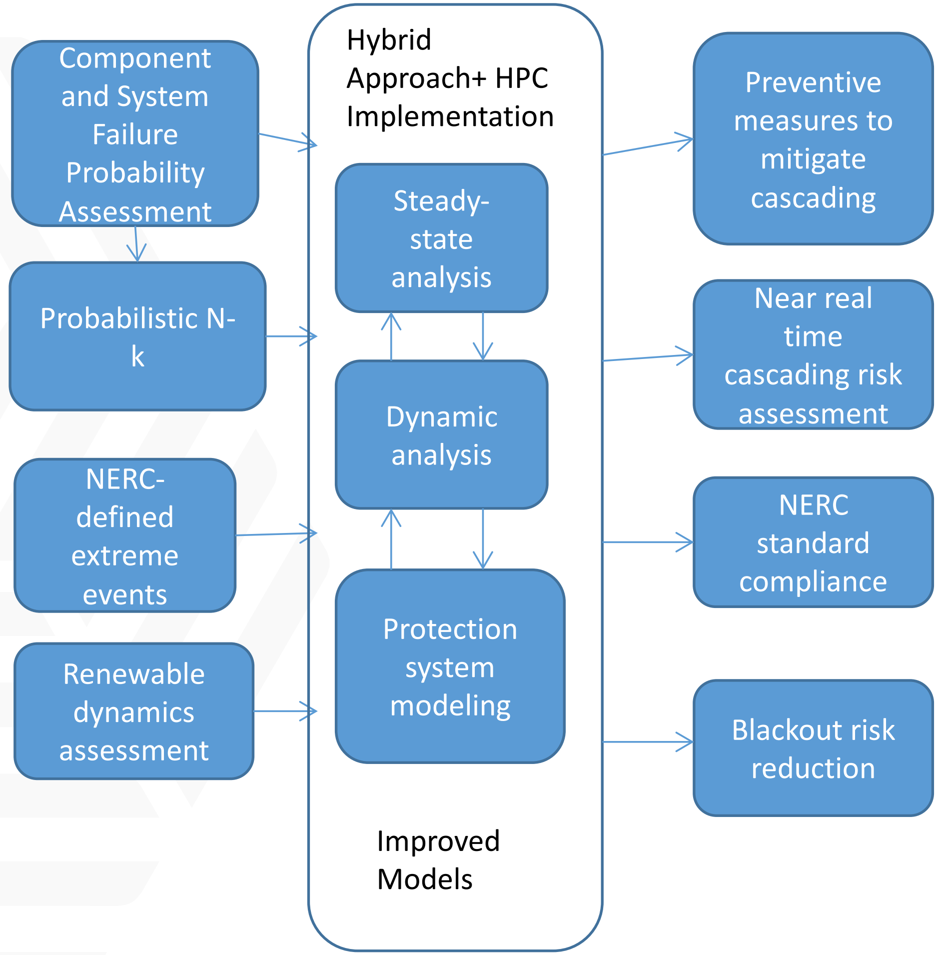
Extreme Event Modeling
Key Project Milestones

Milestone (FY16-FY18)	Status	Due Date
Protective measures approach identified and a strategy for implementation in DCAT completed	Complete	10/1/16
Implementation of protective measures in DCAT	Complete	1/1/17
Report detailing survey of past outages and extreme events	Complete – Delivered on GMLC share site	1/1/17
Cascade modeling demonstrates 10x of cascade simulations as compared to existing tools	Started: Work focused on developing underlying HPC architecture	10/1/17
Scale N-k approaches to networks that are 10x larger than existing tools can handle	Started: Initial N-k software framework developed in Pyomo	10/1/17
Cascade modeling demonstrates 100x of cascade simulations as compared to existing tools	Not started	10/1/18
Open source prototype release that 1) Integrates multiple temporal scales, protection system modeling, and renewables into cascade models, 2) demonstrates 500x speedup of cascade simulations as compared to existing tools, and 3) improves computation of N-k by increasing k by twice as much over existing practices.	Not started	4/1/19

Extreme Event Modeling

Accomplishments to Date

- Technical Insights and Accomplishments
  - Extreme event strategy document
    - Gaps in extreme modeling, directions for addressing gaps
  - Dynamic Contingency Analysis Tool (DCAT)
    - Hybrid models, zone 3 protection, ACOPF
  - Survey of Past Outages and Extreme Events
    - Lack of statistical data and rigorous analysis of the data can lead to misleading or even erroneous information for making decisions
  - Predicting Cascading Paths
    - Cascading path reduction can lead to 100X speed up
  - N-k Contingency Analysis
    - Developed methods for computing exact deterministic N-k solutions, to realistic N-k power flow models from American Electric Power
    - Demonstrated that probabilistic N-k is complimentary to deterministic N-k

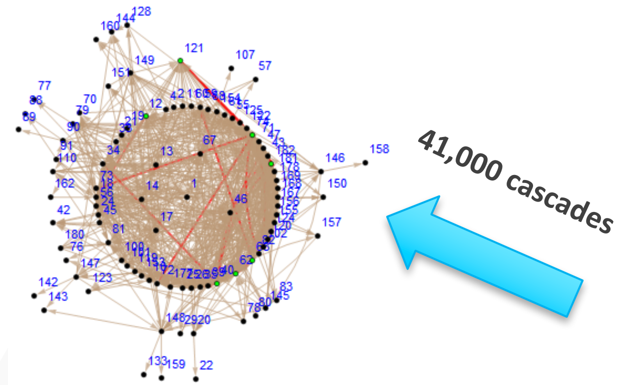


Extreme Event Modeling

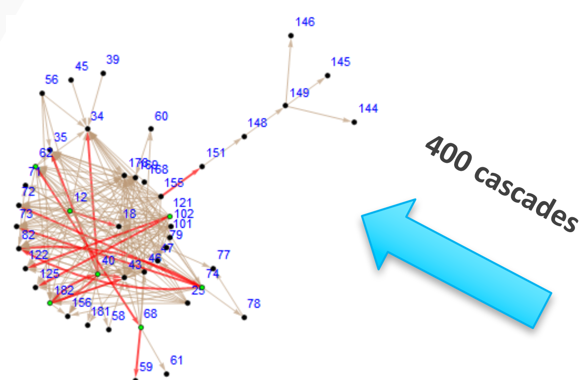
Accomplishments to Date

- Stakeholder engagement
  - Industry webinars
    - June 16, 2016, Jan. 25, 2017
    - FERC, Caiso, Idaho Power, MISO, PLM, DOM, SPP, NERC, DVP
  - DCAT shared with Idaho Power, NERC, and ERCOT
  - Model Reduction
    - The ARX transfer function approach has been applied to a measurement based oscillation damping control tool for the NYPA system.
    - Research stage for the TERNA (Italy) Grid.
- Publications
  - X. Zhang, Y. Xue, Y. Liu, J. Chai, L. Zhu, and Y. Liu, *Measurement-based System Dynamic Reduction Using Transfer Function Models*, submitted to 2017 North American Power Symposium (NAPS), Morgantown, WV, Sept. 17-19, 2017.
  - Q. Huang, B. Vyakaranam, R. Diao, Y. Makarov, N. Samaan, M. Vallem, and E. Pajuelo, *Modeling Zone-3 Protection with Generic Relay Models for Dynamic Contingency Analysis*, PES General Meeting, 2017
  - Wenyun Ju, Kai Sun, and Junjian Qi, *Multi-Layer Interaction Graph for Analysis and Mitigation of Cascading Outages*, IEEE Journal on Emerging and Selected Topics in Circuits and Systems, under review
  - J. Qi. *Efficient Estimation of Component Interactions for Cascading Failure Analysis by EM Algorithm*, IEEE Transactions on Power Systems, under review.
  - A. Florita, M. Folgueras, E. Wenger, V. Gevorgian, and K. Clark. *Grid Frequency Extreme Event Analysis and Modeling in the Western Interconnections. Solar and Wind Integration Workshop*, under review.

Example Accomplishment: Statistical modeling of component interactions can reduce the number of cascade simulations by a factor of 100



Identified **top 7 key components** and **top 13 key links** using 400 cascades are the same as those using 41,000 cascades



Extreme Event Modeling

Response to December 2016 Program Review

Recommendation	Response
Please provide the "Strategy Document" due in April to the DOE program managers before the peer review in April 2017.	Strategy Document will be provided to DOE program managers no later than April 7, 2016
Before the April 2017 peer review, please identify at least one strong utility partner that you can work with to evaluate your new models	The team has selected WECC as the utility partner for new models • 2025 planning model with dynamics • Ease of NDA process • Data acquisition process documented • LANL, PNNL, LLNL, ANL have access, other labs are following process.
Please make sure to collaborate with the Metrics Analysis team (project 1.1). Of particular interest will be the report detailing survey of past outages and extreme events. Continue collaborations with New Orleans (1.3.11).	Will reach out to Metrics Analysis Team in FY17 Q2-Q3 with *Survey of Past Outages and Extreme Events* that was completed in Dec. 2016.

Extreme Event Modeling

Project Integration and Collaboration

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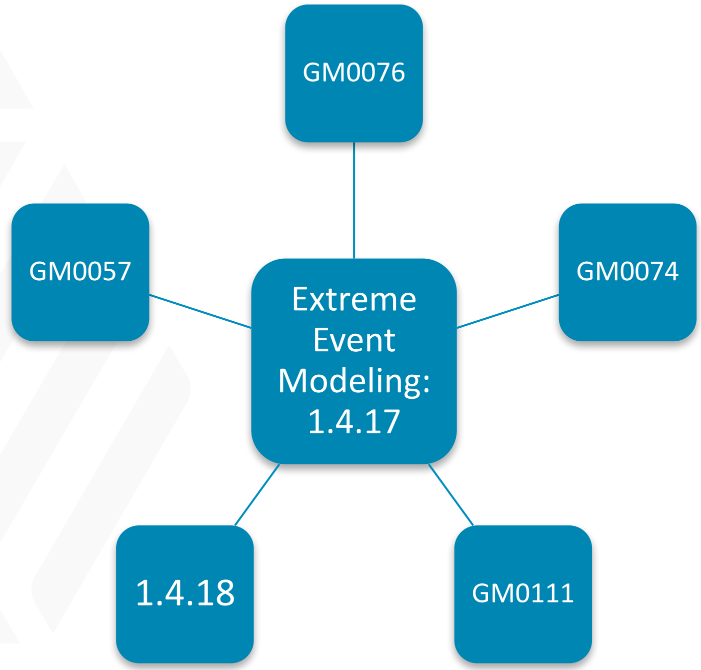
- GM0076: Emergency monitoring and controls through new technologies and analytics
  - This project addresses a new generation of protection systems based on advanced analytics, frequent measurements, HPC and fast controls.
  - Project collaborations focus on mitigation of extreme events.
- GM0074: Models and methods for assessing the value of HVDC and MVDC technologies in modern power grids
  - This project addresses the use of HVDC for AC grid services.
  - Collaborations focus on the potential of DC modulation to stabilize extreme events and restore the system after disturbances.
- GM0057: LPNORM A LANL PNNL and NRECA Optimal Resiliency Model
  - This project focuses on resilient distribution system design.
  - Collaborations are focused on integrating probabilistic N-k fundamentals into resilient design.
- GM0111: Protection and Dynamic Modeling Simulation Analysis and Visualization of Cascading Failures
  - This project focuses on advancing the state-of-art in dynamic and protection system modeling.
  - Collaborations are focused on connecting the modeling to cascading failure analysis
- 1.4.18 Computational Science for Grid Management
  - This project is focused on foundational computational frameworks.
  - Collaborations are focused on generating use cases for the computational framework and possible future activities that could leverage the framework (cascade mitigation)
- GMLC Planning and Design
  - Data and Software Working Group

Communications

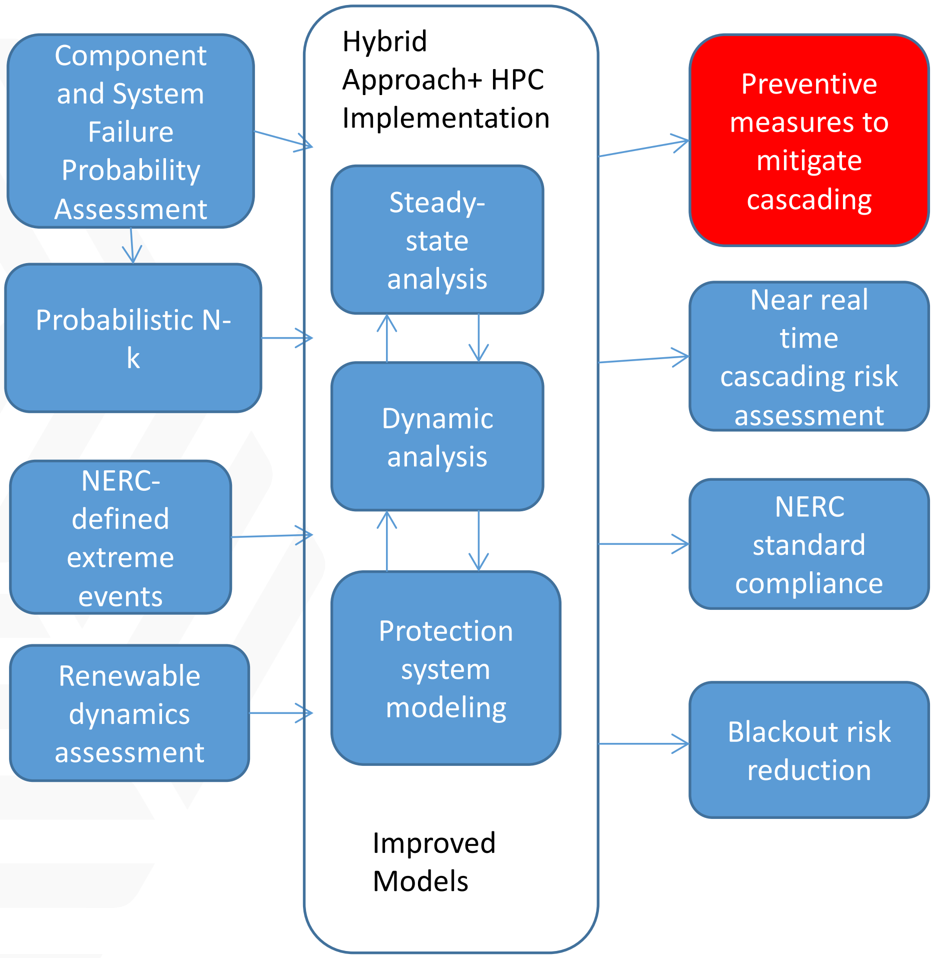
- Regular industry webinars
  - June 16, 2016, Jan. 25, 2017
- IEEE Cascading Failure Working Group
- Feb 2017 Presentation of DCAT at ERCOT Dynamic Working Group
- June 2017: Invited Presentation at NERC Power System Modeling Workshop



Extreme Event Modeling

Next Steps and Future Plans

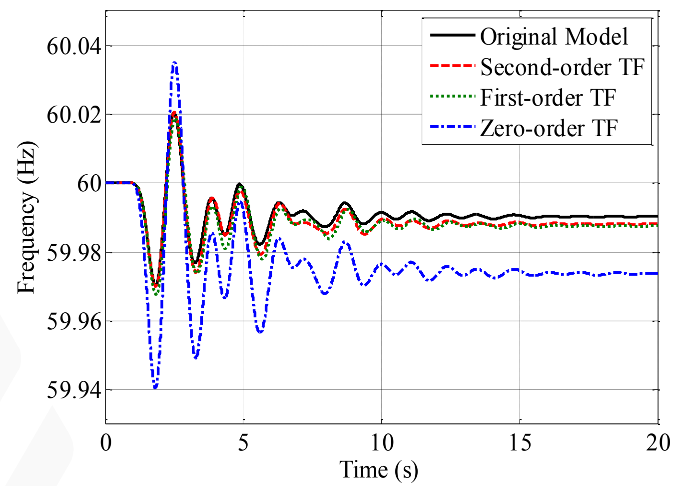
- April 2017 – April 2018 highlights
  - Comprehensive implementation of corrective actions through optimization
  - Develop a combined dynamic simulation/protection model for WECC coordinated with BPA and GE
  - Demonstrate 10x time speedup of dynamic contingency analysis (HPC)
    - Major milestone for meeting near real time analysis capabilities
  - 10x scalability of N-k approaches
    - Significantly larger k failures than state-of-the-art
- Extreme Event Modeling Follow ons
  - Strategy document outlines possible future activities
  - Mitigation capability development is significant
    - Required to meet MYPP goal: *10% reduction in the economic costs of power outages by 2025*
  - Resilience
  - Integrating ancillary services into cascading models of renewables
    - SOW sent to DOE PMs

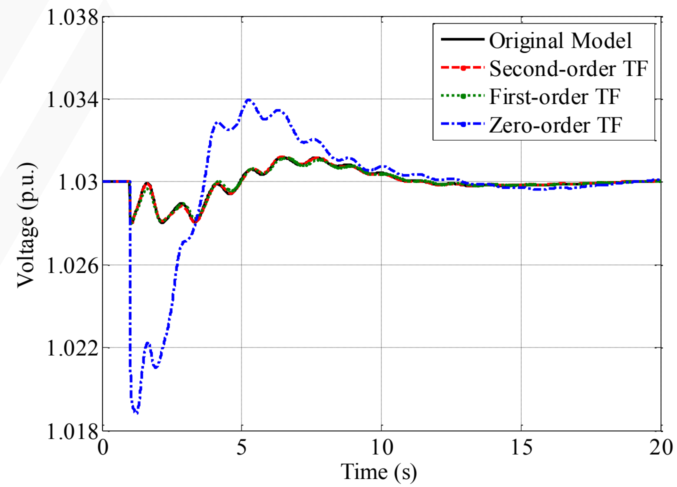


Extreme Event Modeling

Technical Details – Model Reduction

- Dynamic model reduction is required to meet both time-critical and accuracy requirements. Conventional methods in commercial software can only be used for offline system analysis and cannot cope with the fast-changing nature of dynamic grids.
- We develop measurement based model reduction approaches, which offer the advantages of highly accurate system dynamics of external behaviors in real time, and significantly increased simulation speed.
- Specifically, frequency-domain transfer function models with much reduced orders are derived and identified based on real-time phasor measurements. Performances have been tested on a 23-bus system, the NPCC system and the EI system.





Extreme Event Modeling

Technical Details-Predicting critical cascading path

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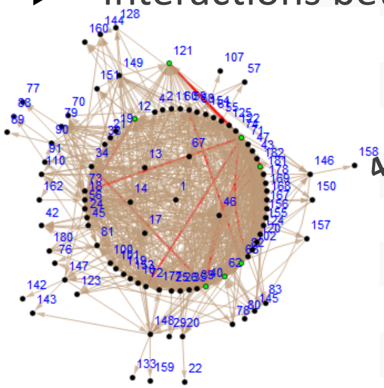
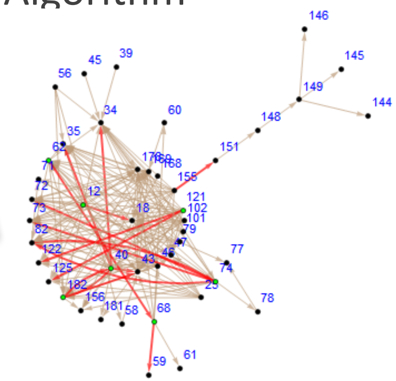
- Interactions between components estimated by Expectation Maximization Algorithm



41,000 cascades

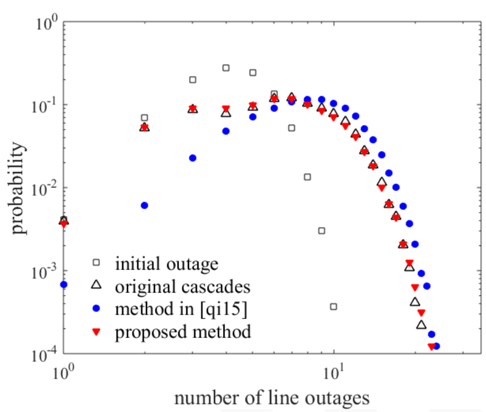
	generation 0	generation 1	generation 2	$\cdots$
cascade 1	$F_0^{(1)}$	$F_1^{(1)}$	$F_2^{(1)}$	$\cdots$
cascade 2	$F_0^{(2)}$	$F_1^{(2)}$	$F_2^{(2)}$	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
cascade M	$F_0^{(M)}$	$F_1^{(M)}$	$F_2^{(M)}$	$\cdots$

400 cascades

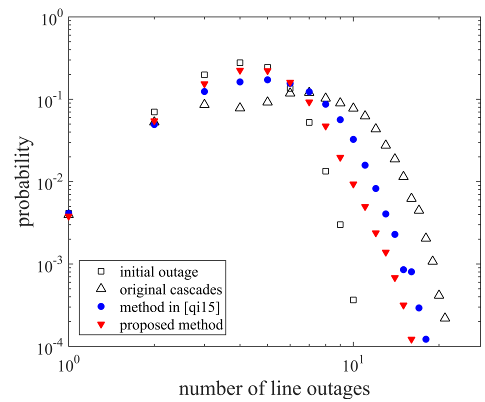


Identified **top 7 key components** and **top 13 key links** using 400 cascades are the same as those using 41,000 cascades

- Probabilistic interaction model simulation based on estimated interactions



Probability distribution of line outages from the interaction model simulation matches well with that from detailed cascading failure model simulation



Good mitigation effect (greatly reduced probability for large-scale cascading failures) by removing the top 10 key links

- Efficiency improvement: a speedup of **100.61x** by interaction model

[qi15] J. Qi, K. Sun, and S. Mei, "An interaction model for simulation and mitigation of cascading failures," *IEEE Trans. Power Syst.*, vol. 30, no. 2, pp. 804-819, Mar. 2015.

Extreme Event Modeling

Technical Details-Data collection and probabilistic modeling of component and system failures

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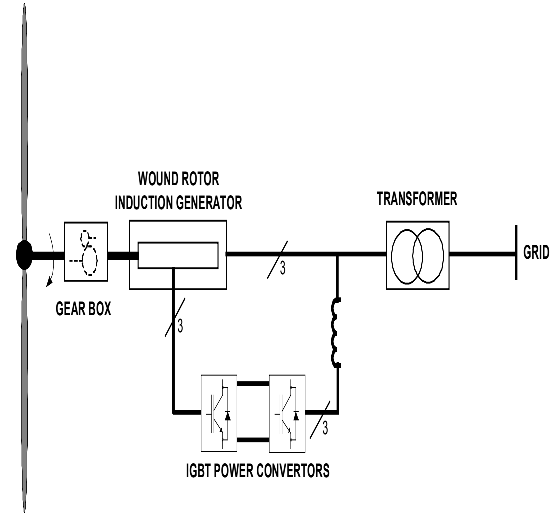
- **System Failures**
  - **Overview:** Analyzing historical extreme event data and developing tools and methods to identify predictors leading to extreme events.
  - **Significance:** Tool developed will aid utilities in their efforts to predict and plan for extreme events in an operational context.
  - **Existing Efforts:** Probabilistic N-k event analysis and cascade modeling, with two sub-foci:
    - *Causal Impact Simulation*: Wind ramping extreme events simulated for the Western Interconnection to produce test dataset.
    - *Response Analysis*: Probability modeling of frequency events obtained at NREL for the Western Interconnection; validated (or not) with NERC records of extreme (frequency) events.
  - **Success:** A priori probability models leading to accurate predictions of extreme events relative to a posteriori realizations.
  - **Suggested R&D:** Energy policy / investment model for the appropriate level of grid robustness in the face of extreme events.
- **Component Failures**
  - Development of a compendious and expandable repository for outage data for transmission circuits, transformers, generators, and common mode outages from many disparate sources
  - Investigation of data poolability issues
  - Development of statistical distributions and a tool for outages of different grid components.

Extreme Event Modeling

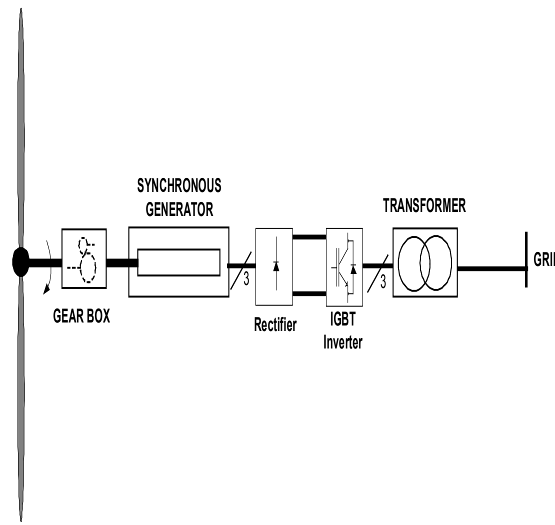
Technical Details-Renewable Energy Modeling

- Survey of studies and models that are linked to slowly varying dynamics of renewables
- Extended-term dynamic simulations to be used in cascading analysis using LLNL's open-source power transmission system simulator *GridDyn*
- Simulation of representative renewable variability and ramp events
- Implementation of WECC Type-3 and Type-4 generic wind turbine generator (WTG) models on GridDyn, along their with generator/converter, converter control, and pitch control models
- Analysis of the impact of the two WTG models on dynamic performance of power systems

Type-3 Wind Turbine Generator: Double-Fed Asynchronous Generator



Type-4 Wind Turbine Generator: Full Power Conversion



Extreme Event Modeling
Technical Details—Deterministic N-k

Key assumption: Intentional adversary, with full knowledge of the system structure/parameters

Deterministic model: Adversary can disable k components (generators or lines) in the system

Severity measure: *Worst-case* load shed given k concurrent disablements of components

Power flow physics: Linearized (aka "DC") power flow, due to presence of binary decision variables

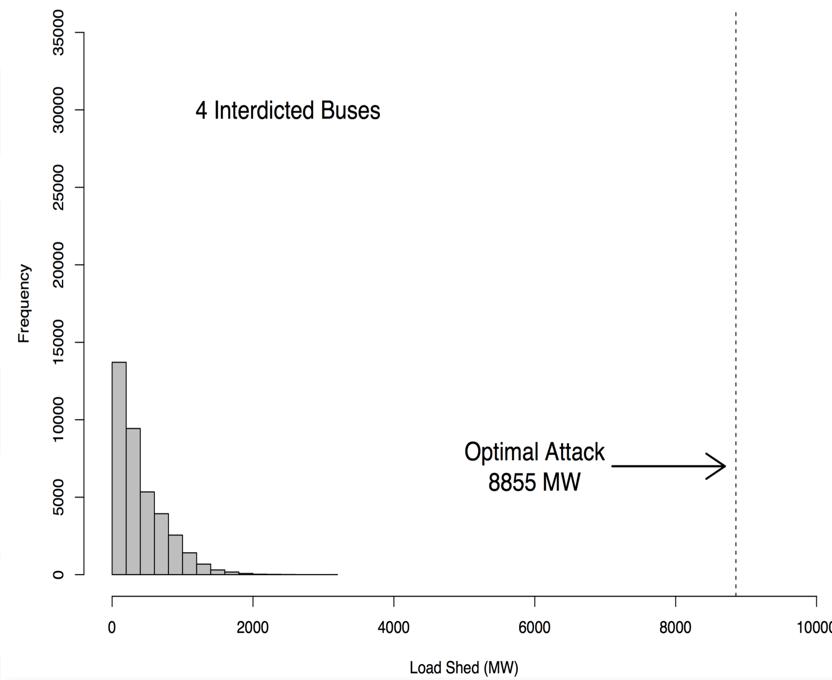
Key findings:

- (Exact) Worst-case algorithms enable quantification of relative costs of protecting against intentional vs. natural / probabilistic adversaries
- Heuristic algorithms fail to identify optimal solutions, often by large margins

Test cases

Small / Medium: IEEE 30 / IEEE 300

Large: American Electric Power (proprietary)



Loss of load when randomly disabling 4 buses in the IEEE 300-bus system, versus the optimal (worst-case) attack

Extreme Event Modeling

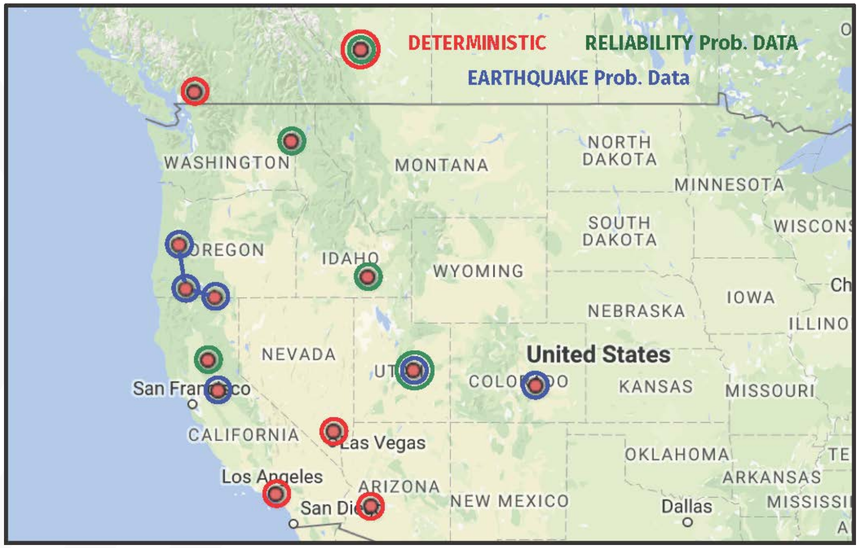
Technical Details—Probabilistic N-k

Probabilistic model: each component has a line failure probability
Severity measure: Probability of N-k scenario x Load shed
Power flow physics: Convex relaxation—second order cone (SOC), DC approximation and Network flow approximation

Key findings:

- SOC and DC approximation produce similar results
- AC feasibility test for all models indicate same level of severity
- Better power-flow physics (SOC) yields better computation time
- Probabilistic N-k will deliver analysis that compliments deterministic N-k

Impact regions produced by the N-k for different scenarios when k=5



WECC 240

The worst k failures in a power system change depending on the probabilistic model of failure

GRID MODERNIZATION INITIATIVE PEER REVIEW
Project 1.4.18: Computational Science for Grid Management

MIHAI ANITESCU, ARGONNE NATIONAL LABORATORY

April 18-20

Sheraton Pentagon City – Arlington, VA

Computational Science for Grid Management

High Level Summary

Project Description

Future driven by DER, Renewable, …
(a) rapidly increasing complexity, (b) vastly increased dynamics ranges, and (c) greater uncertainty in supply and demand results in >100 times "real" time for computational analyses.
In this project, we aim to reduce this by >100x by using parallelism and new algorithms of optimization, uncertainty and dynamics.

Project Objectives

- ✓ Prototype integration of solvers for OUD for increased performance for *entire problem classes.*
- ✓ Design and Instantiate an advanced framework (AMICF) that allows 10x faster prototyping of computationally intense analyses.
- ✓ Adjust and tune open source OUD solvers to compute 100x faster by harnessing parallelism.
- ✓ Identify high value use cases for demonstrating benefits framework and solvers at scale.

Value Proposition

- ✓ Improve time-to solution for optimization + uncertainty + dynamics (OUD) by 100x, 10x.
- ✓ All margins and reliability computations are OUD driven, would help GMI in its margin reduction and reliability increase objectives.

Example OUD Outcome

- ✓ SCACOPF – security constrained AC OPF is a required technique for computation of LMPs.
- ✓ Currently solved with sequential linearization and contingency filtering -- 4-20 active contingencies.
- ✓ Uncertainty may need hundreds – thousands active contingencies – we aim to solve them with *full nonlinearity, at scale, in real time*

Computational Science for Grid Management

Project Team

Project Participants and Roles

- Mihai Anitescu (ANL): PI. Task Lead 1.1 (O) Optimization and Integration.
- Cosmin Petra(LLNL): Task 1.1 Parallel optimization, automatic differentiation.
- Slaven Peles (LLNL). Task Lead 1.2 (D) Dynamics Interfaces and Solvers.
- Jean-Paul Watson (SNL). Task Lead 1.3 (U) Interfaces and support for stochastic and chance-constrained optimization paradigm.
- Russel Bent (LANL). Task 1.3 (U) Robust Formulations.
- Zhenyu (Henry) Huang (PNNL): +1. Task Lead 2.1 (A) Computation and Visualization Functions.
- Wesley Jones (NREL), Task Lead 2.2 (W): Workflow and data generation and access.

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
ANL	290K	50K	50K
PNNL	263K	50K	50K
NREL	157K	30K	30K
LLNL	220K	70K	70K
SNL	85K		
LANL	85K		

Industry Partners:

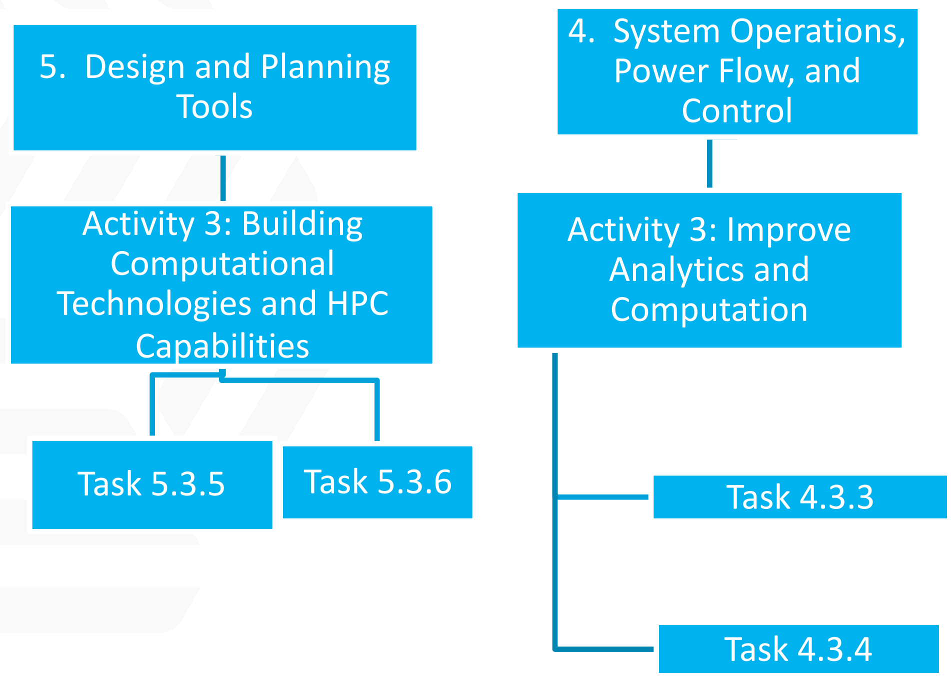
- PJM -- Jianzhong Tong
- NEISO -- Eugene Litvinov

Computational Science for Grid Management
Relationship to Grid Modernization MYPP

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

MYPP Vision: … develops the next generation of modeling and simulation tools needed for power system planning …. handle emerging needs driven by changing technologies and operational capabilities, larger and more complex models, more challenging forecasting (…)

- *Task 4.3.4:* Demonstrate the application of parallel and distributed computing algorithms on existing and emerging computational platforms.
- *Task 4.3.3:* Develop efficient linear, mixed-integer, and nonlinear mixed-integer optimization solution techniques customized for stochastic power system models, novel bounding schemes to use in branch and bound, and structure exploiting algorithms.
- *Task 5.3.5:* Develop and distribute advanced libraries of algorithms, solvers, uncertainty quantification, and stochastic optimization modules.
- *Task 5.3.6:* Develop computing frameworks that enable the coupling of advanced computation tools, data, and visualization technologies with easy workflow management.



Computational Science for Grid Management

Approach

- **State of art and practice:**
  - Dynamic Simulation WECC (30s) – 2minutes. Dynamics Security Assessment needed by new dynamical content >x1000.
  - Optimization and Dynamics are done by different tools and interact by files. Factors of 100s are lost in efficiency for transient constrained analyses without derivative information.
  - SCACOPF (~ISO, estimated) 20mins-3hours: Under Uncertainty (estimated) > 100 hours. Need to get it to minutes, or < 1 hr.
- **Task 1 – *Computational Core*** Creation of an advanced computational infrastructure for OUD. (ANL, with LANL, LLNL, and SNL). *Achieve a factor of 100 speed up in key computational patterns by enabling and tuning massive parallelism*. Subtasks:
  - 1.1 Optimization and integration. Open, fast, scalable environments and solvers for scenario-based optimization. Fast, automatic differentiation for nonlinear optimization.
  - 1.2 Dynamics. Novel dynamics algorithms and interfaces, improve performance and accuracy of design outcomes by online use of transient simulations in optimization with adjoint-based derivatives.
  - 1.3 Interfaces and Support for Optimization under Uncertainty: Novel scenario generation and robust formulations. Chance-constrained stochastic multi-period optimal power flow.
- **Task 2 – *Advanced Modeling and Integration Framework (AMICF)*** Definition and reference implementation of a framework for scalable integration of data, computation, and visualization functions. (PNNL, with NREL). *Achieve a factor of 10 increase in productivity of problem formulation/instantiation.* Subtasks:
  - 2.1 Computation and Visualization Functions. Design and implement a novel, compact, flexible, open framework for maximum performance. Engage stakeholders design and adoption.
  - 2.2 Data Functions. Create renewable energy forecasts and scenarios.
- *Task 1 and 2 interact through 3 use cases defined and refined at stakeholder workshop (below).*

Computational Science for Grid Management

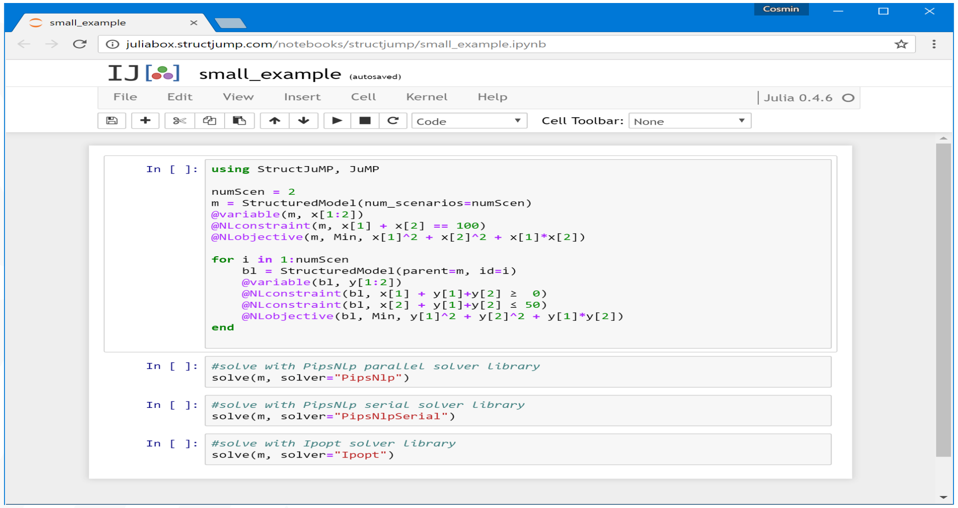
Key Project Milestones

Milestone (FY16-FY18)	Status	Due Date
Middle of the road parallel runs for SCOPF with the PIPS-NLP suite using StructJuMP annotations.	100%	09/30/16
Conduct a stakeholder workshop and produce framework design document.	100%	11/23/16
Demonstrate AMICF prototype on Industry inspired use case using NREL data.	100%	3/31/17
AMICF parallel nonlinear optimization under uncertainty capability run.	100%	03/31/17
Estimation of margins reduction due to transient expression in optimization problem.	100%	03/31/17
AMICF Reference Implementation.	100%	03/31/17
AMICF Documentation.	Not Started	09/30/17
Technical Publications.	Not Started	09/30/18

Computational Science for Grid Management

Technical Details: AMICF-StructJuMP; FY 16 Q2

- In FY16, Q4, released StructJuMP, a scalable, open, free, Julia-based Environment for massively parallel nonlinear optimization.
  - high-level, high-performance, open-source dynamic language for technical computing
  - keeps productivity of dynamic languages without giving up speed (2x of C/C++/Fortran)
  - Very efficient to extend by use of macros (@)
- StructJuMP: Algebraic modeling framework; faster derivative support for scenario-driven optimization.*
- *C -like performance with Matlab-like syntax, and full parallel support* by means of the other 1.4.18 tasks.
- It accelerates the development time by a factor of 10.
- Deployed on Amazon Cloud and clusters.



#procs	Model initiation (seconds)	Structure building (seconds)	Function & derivative evaluation (seconds)	Total time (seconds)
1	6.42	2.09	20.56	390.34
2	4.70	1.59	10.19	279.15
4	4.21	1.58	5.96	230.16
8	4.10	1.49	3.5	208.48
16	4.14	1.46	1.86	192.85
24	4.09	1.42	1.47	179.96
48	3.96	1.31	0.72	191.75

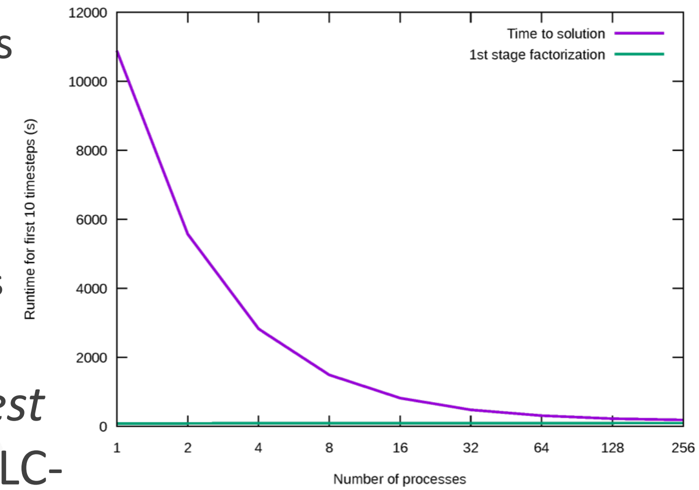
C. G. Petra, F. Qiang, M. Lubin, J. Huchette, ”On efficient Hessian computation using the edge pushing algorithm in Julia”,

Computational Science for Grid Management

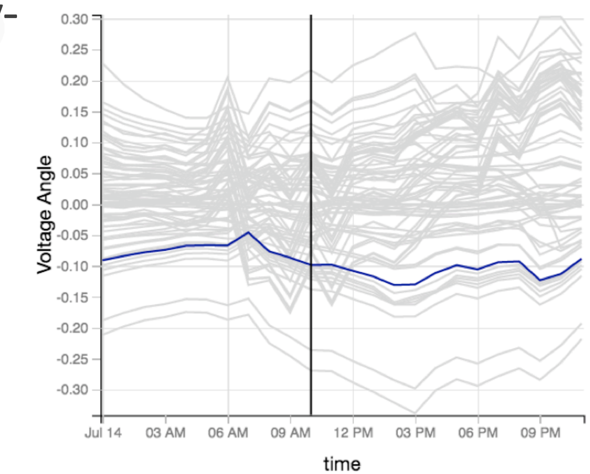
Accomplishments highlight: Integrated NLP-Uncertainty

- Highest Performance Nonlinear Optimization under Uncertainty integrated with Planning Models, in the user's language (integration level ~ 80%), around *StructJuMP.*
  - Gridpack-AMICF module converts PSS/E to *StructJuMP*.
  - PIPS-NLP solver takes *StructJuMP* input and runs in parallel.
  - AMICF-Data/Viz interacts w. Planning (PLEXOS, 1.4.26); runs *StructJuMP*; and returns/displays system metrics.
- Demo capability: (a) SCACOPF Pegase, *possibly largest bus x scenario ever in under 10 minutes*; and (b) GMLC-RTS uncertainty ACOPF for computation of uncertainty-induced voltage swings, integrated w. planning.
- Pleasant surprise: Algebraic-centric StructJuMP allowed much faster integration of data/uncertainty and planning function than even we expected!
- *Can solve ANY scenario-driven nonlinear optimization at scale*.

Time to Solution



PEGASE 2869 buses 512 scenarios



GMLC-RTS model with planning integration (PLEXOS) (100 scenarios)

Computational Science for Grid Management

Accomplishments highlight: Stakeholder Workshop

In November 2016, conducted a stakeholder workshop and produce framework design document in Richland.

- Three use cases defined to derive solver adjustment and framework design: (UC1) SC(AC) OPF under uncertainty, (UC2) transient security assessment under uncertainty, (UC3) transient security constrained optimal power flow under uncertainty.
- Framework design document produced.
- Stakeholder workshop refined the framework requirements based on industry input
- Use cases were tweaked and "value proposition" demos recommended.
  - An increased focus on planning (see integration of StructJuMP w PLEXOS, planned multiperiod work).
  - An increased focus on representation of uncertainty from reduced distribution models.
- Participants included Lab Scientists, and 10 Industry Participants from utilities and software vendors.

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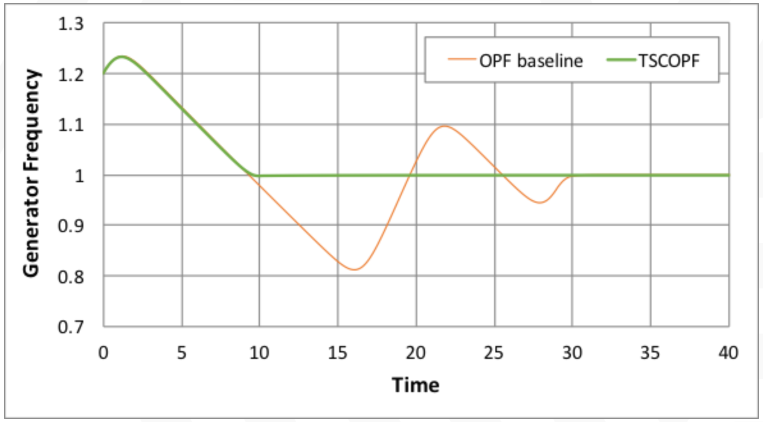
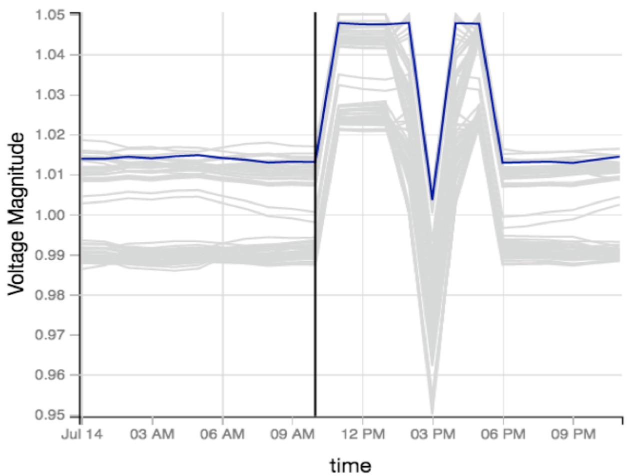
U.S. Department of Energy

Recommendation	Response
While DOE appreciates the scientific merit of the effort, the principal investigators need to do a better job to communicate the benefit of this work to the grid.	Demos were designed that quantify the benefits for physical quantities-of-interest, and viz tools to display relevant metrics were created.



Improvement in Generator Response from Transient-constraint optimization (v. static)



Effects of wind-power uncertainty on voltage swings; GMLC-RTS model with planning integration (PLEXOS) (100 scenarios)

Computational Science for Grid Management

Project Integration and Collaboration

Collaborations with GMLC projects and activities

Framework Openness and flexibility has allowed us to prototype new functions in 6-8 weeks what would take ~ 10 months in C++. Coupled with the 100X speed increase and generality, it can impact several other GMLC projects.

Activities carried out:

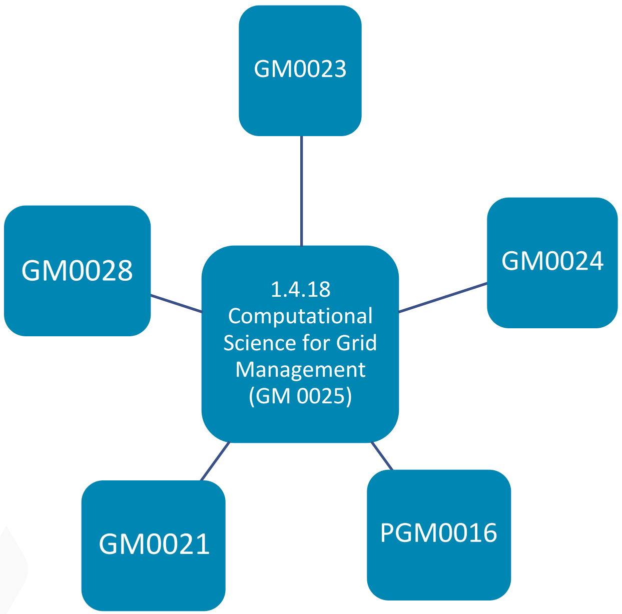
- GM0021: Control Theory: For this project we collaborate in providing new tools for optimal control accounting for transient response (Peles)
- GM0028: Development and Deployment of Multi-Scale Production Cost Models. We provide data workflow and scenario reduction tools (Watson, Jones)
- GMLC Planning and Design Team - Data and Software Working Group (Jones)

Planned/In Discussion.

- PGM0016: Midwest Interconnection Seams Study: (Jones)
- GM0023: Development of Integrated Transmission, Distribution, and Communication (TDC) Models. (Huang)
- GM0024 Extreme Event Modeling. (Bent).

Collaborations with ASCR projects and activities

- The Multifaceted Mathematics for Complex Energy Systems (MACS); GMLC focused on use case development and tuning, M2ACS on mathematical framework design and algorithms.
- The Exascale Project for Grid Optimization (ExaGrid) – massive parallel architecture solver and framework tuning.



Communications

- Stakeholder workshop (Richland, November 2016).
- The Exascale all-hands project meeting.
- The IEEE HPC working group.
- Publication: C. G. Petra, F. Qiang, M. Lubin, J. Huchette, "On efficient Hessian computation using the edge pushing algorithm in Julia".

Computational Science for Grid Management

Next Steps and Future Plans

Value Demonstrations:

- Determine the optimal and safe selection of margins under realistic uncertainty while accounting for voltage effects – GMI: Reduce Margins.
- Quantify voltage swing mitigation/feasibility benefits of advanced forecasts with uncertainty – GMI: Increase Reliability.

Technical Capabilities

- Scalable **multi-period nonlinear optimization** problems under uncertainty to improve analytics for longer horizons decisions (planning) and reduced decision time scales.
- **Bi-directional functional integration** of optimization under uncertainty and dynamics with planning models.

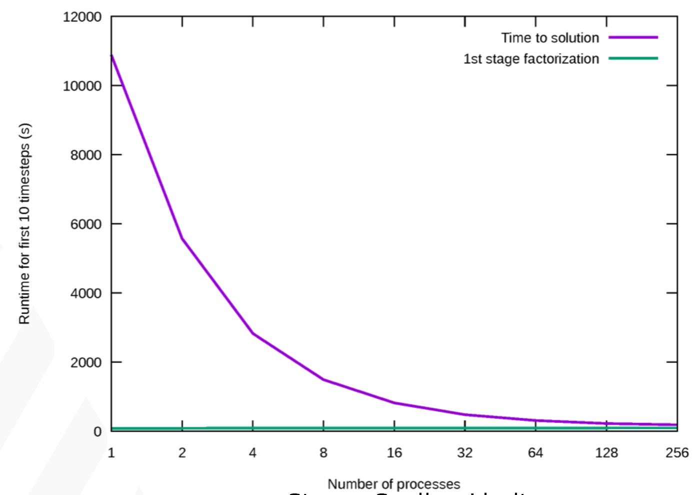
- Tune optimization solvers for emerging massively multi-core architectures, e.g KNL.
- Extend the framework for seamless dynamic simulation and integration of dynamics and optimization, efficient adjoint computations. Tune and adjust dynamical solvers at scale.
- Formulate a cascade mitigation/response optimization problem using 1.4.17 tools and models.

Computational Science for Grid Management

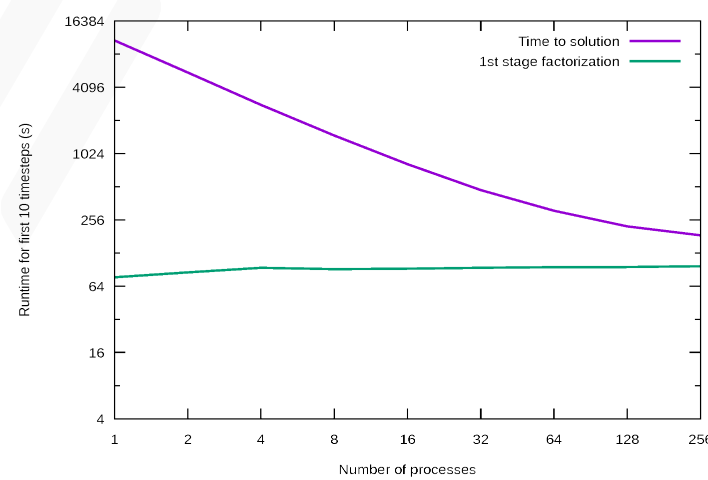
Technical Details: Optimization; FY 17 Q1

- OUU: Scenario-Based Nonlinear Optimization is a prevalent computational pattern (SCACOPF, Stochastic OPF), our Use Case 1.
- In FY17 Q1, accelerated the PIPS-NLP solver and deployed on massively parallel architecture.
- Created OUU SCOPF instantiation from PEGASE 2869 buses (MATPOWER); created 512 contingency data, in StructJuMP
- **Speedup: 63=11000/173** (s, 10 iter) on 256 cores.
- Takes about 10 minutes (35 iters) to solve at industry standard (1e-3).
- Possibly largest number of SCACOPF contingencies ever solved simultaneously (512; seen 75 on 16 cores,30).

Time to Solution



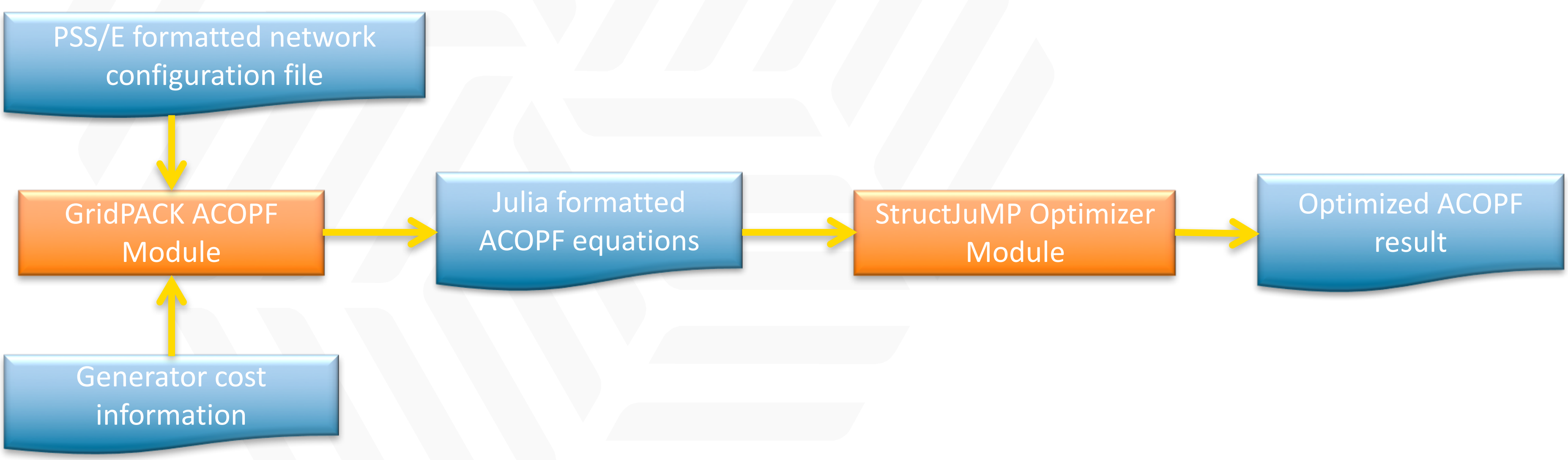
Strong Scaling Limit



Computational Science for Grid Management

Technical Details: AMICF Computation Support; FY 17 Q1

- In Q2 FY 17, we created the novel AMICF OU framework.
- By extending GridPACK while using the Q4 FY16 Julia-based deliverable StructJuMP, users can create scalable OU instances from PSS/E input.
- The AMICF/PIPS-NLP allow (in principle) maximum performance access at scale (thousands of buses, thousands of scenarios, parallel computing), for **~0 additional development cost, and entirely open source** for OU such as SCOPF.



Computational Science for Grid Management

Technical Details: AMICF Data Services; FY 17 Q1

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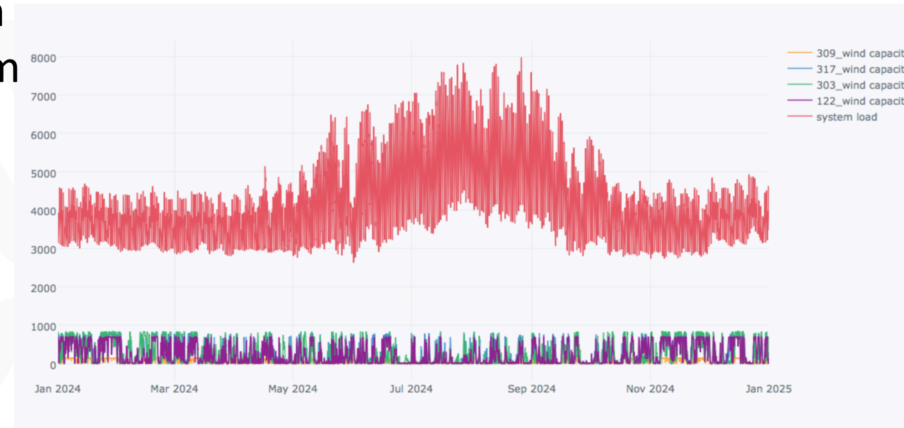
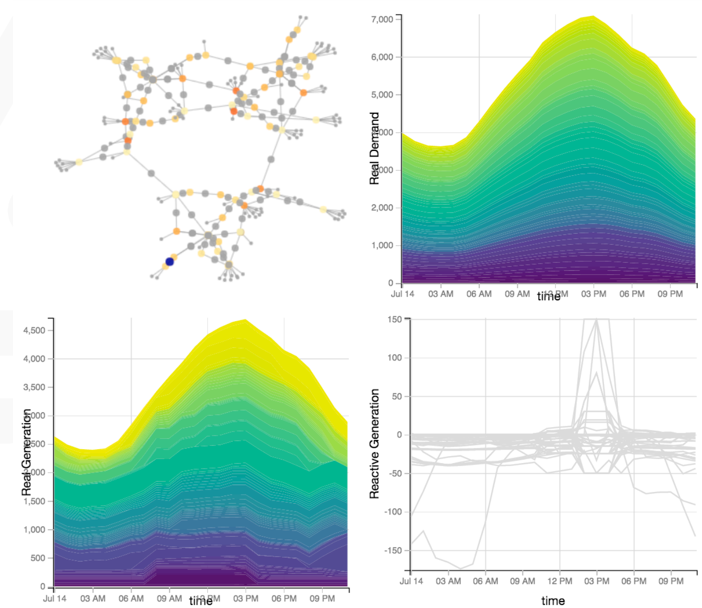
U.S. Department of Energy

- Delivered Modules to process uncertainty in wind generators by site and time of day from NREL data, and display output.
- Integration with OU through StructJuMP Stochastic ACOPF modeling/solver.
- Integration of Production Cost Modeling (PCM: PLEXOS) with Day-Ahead unit commitment to inform 5-minute economic dispatch.
- An HPC and Cloud ready interface for execution of workflow
- Demo: updated **GMLC-RTS system** with 73 buses, 96 thermal generators, and 4 wind plants.
- Ready to answer optimal margin selection under wind uncertainty, and voltage swing/limit questions, in an operations/planning context.





U S DEPARTMENT OF
ENERGY

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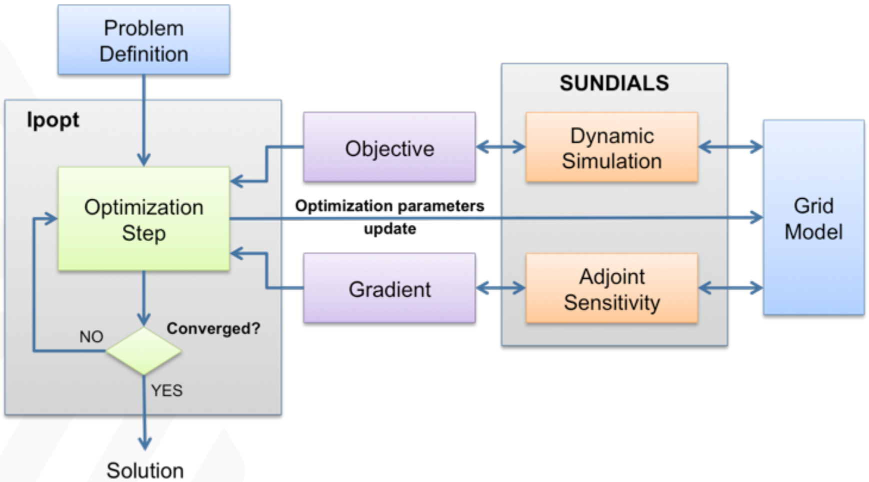
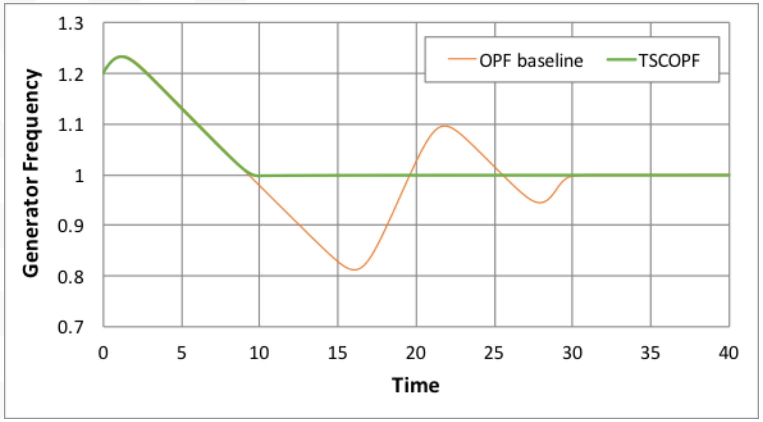
Technical Details: Dynamics; FY 17 Q1

- In current practice, optimal design in power grid does not directly account for transient performance.
- This results in higher margins and/or decreased reliability.
- Use Case 3: Optimization under Dynamics and Uncertainty, aims to cover this gap.
- In FY17 Q2, we have developed an integrated Transient Constrained Optimization approach (top figure).
- It results in far improved governor control parameter selection (bottom figure).



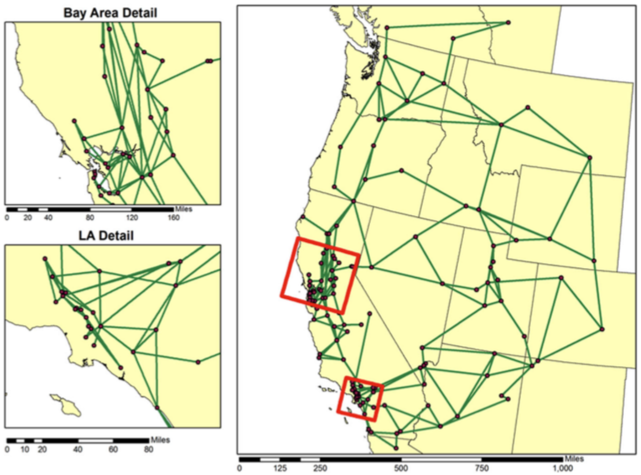


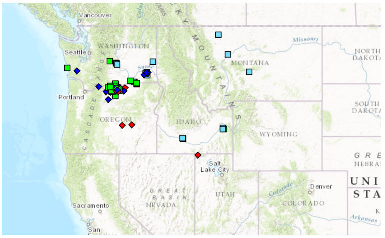
Computational Science for Grid Management

Technical Details: Optimization/UQ; FY 17 Q1

Multi-period OPF with wind: Chance-constraints and stochastic programming approaches

- Developed data needs and software API for modeling multi-period OPF with uncertain wind production that supports
  - Chance constrained OPF
  - Two-stage stochastic programming OPF
- Computational Framework
  - OPF models implemented in JuMP (Julia) and Pyomo (Python)
  - Open source
  - Ready for integration with Computational Framework under development by PNNL.
- Case Study Demonstration
  - WECC 240 System
  - Wind data from BPA: actuals and forecast
  - Compare the results and computational performance of Chance constraint modeling and stochastic programming modeling.





Appendix: Industry Technical Contacts

Participated with the 1.4.18 team at the two-day Frameworks Workshop Nov 9-10

Name	Organization
Ting Chan	Global Energy Interconnection Research Institute North America
Kwok Cheung	General Electric
Eugene Litvinov	ISO New England
Guangyi Liu	Global Energy Interconnection Research Institute North America
Teems Lovett	United Technologies Research Center
David Sun	Glarus Group
Fengyu Wang	Midcontinent Independent System Operator
Zhiwei Wang	Global Energy Interconnection Research Institute North America
Lei Wang	PowerTech Labs
Jun Wen	Southern California Edison

GRID MODERNIZATION INITIATIVE PEER REVIEW

Multi-scale Production Cost Modeling 1.4.26

AARON BLOOM

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

Multi-scale Production Cost Modeling

High Level Summary

Project Description

The goal of this project is to dramatically reduce the time required by industry to analyze future power system scenarios through production cost modeling (PCM), while considering higher-fidelity representations of the underlying systems.

Project Objectives

- ✓ Develop new modeling algorithms
- ✓ Expand research domain by using high performance computing
- ✓ Deploy capabilities and data to industry

Value Proposition

- ✓ Improve commercial tools through advanced use
- ✓ Provide deeper insights into how systems should be modernized
- ✓ Enable broader economic competitiveness

Multi-scale Production Cost Modeling
Project Team

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Participants and Roles

Project Management: NREL, SNL
- Stakeholder engagement
- Implements project plan

Deterministic PCM: NREL, ANL
- Geographic Decomposition
- MIP Warm-Start

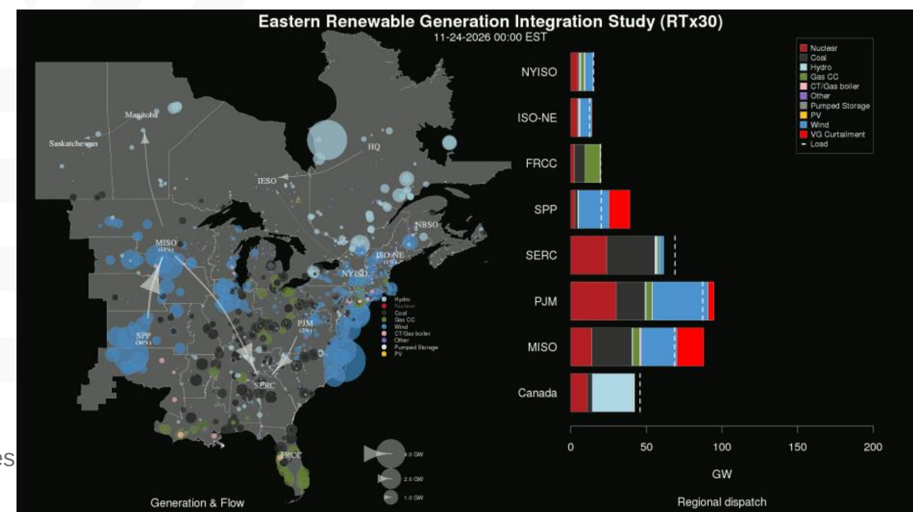
Stochastic PCM: LLNL, SNL
- Stochastic Data
- Stochastic Tools

Advisory: PNNL

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
NREL	300K	360K	360K
SNL	269K	235K	235K
ANL	270K	235K	235K
LLNL	130K	139K	139K
PNNL	31K	31K	31K

Technical Review Committee:
SPP, MISO, PJM, ERCOT, Energy Exemplar, PSO, ABB, GE, NextEra, Xcel, Great River Energy, OSU, UC Berkley, UChicago, EPRI, National Grid, PNM, FERC

Technical Review Committee members participate in a workshop to learn how to use visualization tools.



Multi-scale Production Cost Modeling

Relationship to Grid Modernization MYPP

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

MYPP Vision: The future grid will solve the challenges of seamlessly integrating conventional and renewable sources, storage, and central and distributed generation (…)

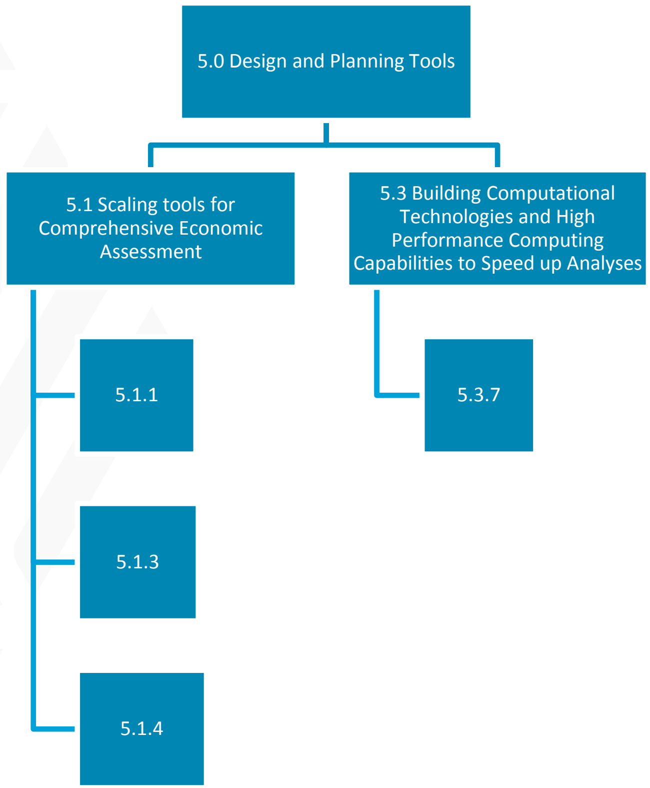
Direct relationship to MYPP vision by delivering a tool to ***estimate the value of national transmission planning***

5.1.1 – Task 5.1.1: Improve computational performance of production cost modeling for year-long sub-hour time resolution by decreasing run times from 2+ weeks to less than 1 day for (1) stochastic transmission and (2) deterministic combined transmission-distribution

5.1.3 – Develop advanced capacity expansion planning for generation, transmission, and distribution that captures operational flexibility, long and short term uncertainties, distributed energy technologies, market and policy impacts, and coupled network and generation optimization.

5.1.4 – Identify and classify data sources, define templates, and develop databases for new grid technologies, generation, load, and other components that compatible with modeling for high performance computers

5.3.7 – Implement "prototype to practice" program. Competitive process will be used to solicit important challenge problems, form teams comprised of GMLC members and problems owner



Multi-scale Production Cost Modeling
Approach

Accelerating deterministic production cost modeling

- Geographic decomposition (NREL)
  - Decompose large (e.g., eastern interconnect) planning models into geographically distinct regions (e.g., by ISO)
  - Iteratively solve smaller planning models in a coordinated manner, to accelerate mixed-integer solve times
- Sequential warm-starting (ANL)
  - Leverages similarity between unit commitment inputs and solutions for sequential days and/or historically similar days
  - Exploit similarity to accelerate mixed-integer solve times, e.g., by providing a near-optimal starting solution
- Temporal decomposition (ANL)
  - Decompose 48-hour or 72-hour unit commitment models into a sequence of linked, smaller unit commitment models
  - Iteratively solve smaller models in an coordinated manner, to accelerate mixed-integer solve times

Accelerating and evaluating stochastic production cost modeling

- Decomposition via Progressive Hedging (SNL and LLNL)
  - Objective is to tune decomposition algorithms to solve stochastic commitment models within a reasonable factor (e.g., 5 or 10) of the time required to solve deterministic commitment models
  - Advanced scenario-based decomposition using modest-scale parallelism for tractable run times
- Evaluation of stochastic on ERGIS sub-regions (SNL and LLNL)
  - Using realistic (ERGIS) planning models with high renewables penetration, rigorously evaluation the performance of stochastic versus deterministic commitment models for production cost modeling

Multi-scale Production Cost Modeling

Key Project Milestones

Milestone (FY16-FY18)	Status	Due Date
Deliver the ERGIS database to Energy Exemplar for public hosting and sharing across project team.	100%	8/30/16
Coordinate and host at least 1 TRC meetings with other GMLC projects, i.e. Midwest Regional Partnership, and North American Renewable Generation Integration Study. Meetings should have at least 10 non-lab participants.	100%	10/31/16
Improve functionality of existing NREL temporal decomposition methods through improved software tools for running PLEXOS in Linux	100%	10/31/16
Submit a document for DOE review that quantifies differences in production cost model results under zonal vs. nodal transmission assumptions.	100%	10/31/16
Complete literature review on general MIP warm-starting techniques and field knowledge on expediting deterministic sequential UCs.	100%	8/30/16
Identify warm-starting techniques that are ready to implement in sequential deterministic UCs; implement and test the performance of the preliminary warm-starting techniques on small-scale test system. 2) Develop and implement a temporal decomposition method based on well-known techniques (e.g., Lagrangian relaxation); collect and analyze the performance of the preliminary results from the method on small-scale test systems.	100%	10/31/16
Identify ERGIS sub-region for stochastic analysis, and convert database into use with PRESCIENT stochastic production cost model.	100%	8/30/16
Integrate relevant WIND and SIND data from NREL into PRESCIENT, and demonstrate ability to generate stochastic renewables production scenarios.	100%	10/31/16
Identify stochastic decomposition scheme to develop/extend, and coordinate with SNL to utilize same stochastic production cost model for LLNL algorithms	100%	8/30/16
1) Participate in technical review committee meeting, and coordinate stochastic renewable generation scenarios with SNL. 2) Test stochastic decomposition schemes for real-world but smaller scale instances than the ERGIS scenarios.	100%	10/31/16
Enable external access to Peregrine HPC to enable workshop participants to execute test runs using NREL temporal decomposition and data management tools developed by research team by hosting at least 1 deployment workshop.	100%	2/28/17
Document the findings from the initial development and testing of warm-start and temporal decomposition methods in two conference/journal papers.	100%	2/28/17
1) Participate in advanced PCM workshop, and document initial work in technical reports. 2) Create stochastic PCM models derived from SNL models for LLNL decomposition schemes.	100%	2/28/2017

Multi-scale Production Cost Modeling
Accomplishments to Date

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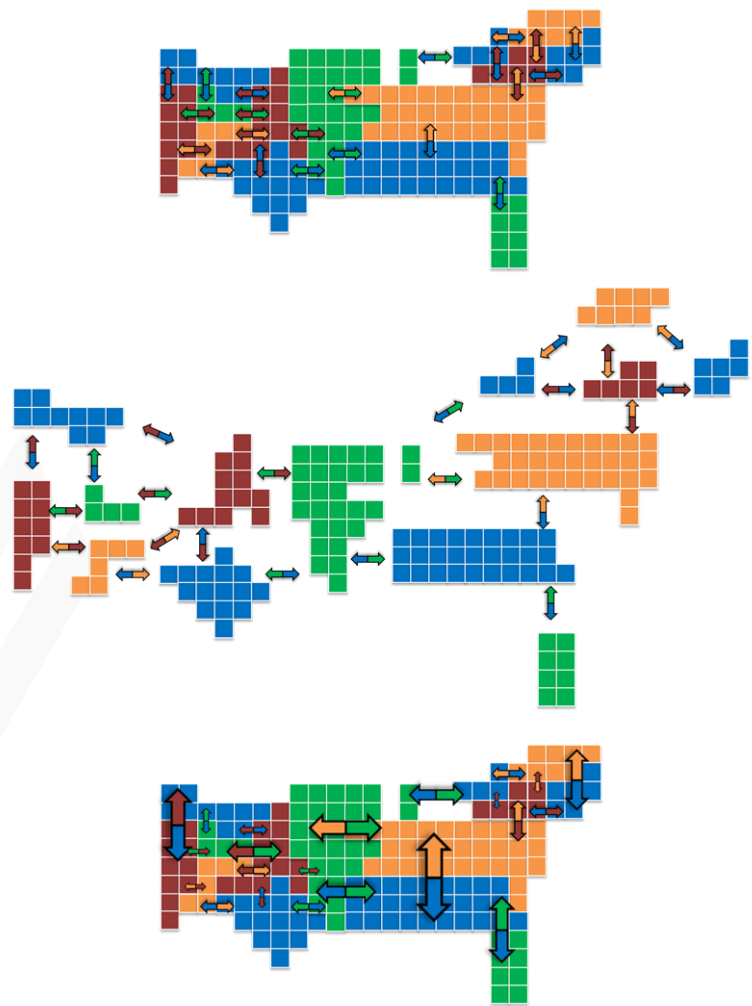
Geographic Decomposition

- Increasing accuracy reducing solve time
- Three steps
  - Interchange Forecast
  - Regional Day Ahead
  - Joint Redispatch
- Preliminary testing = 50% reduction in solve time

Model Phase	Centralized UC	Geographic Decomposition UC
Simplified Day-Ahead	10 hours	10 hours
Day-Ahead	50 hours	1-5 hours/region run in parallel
Real-Time	10 hours	10 hours
Total	60 hours	25 hours



Multi-scale Production Cost Modeling
Accomplishments to Date

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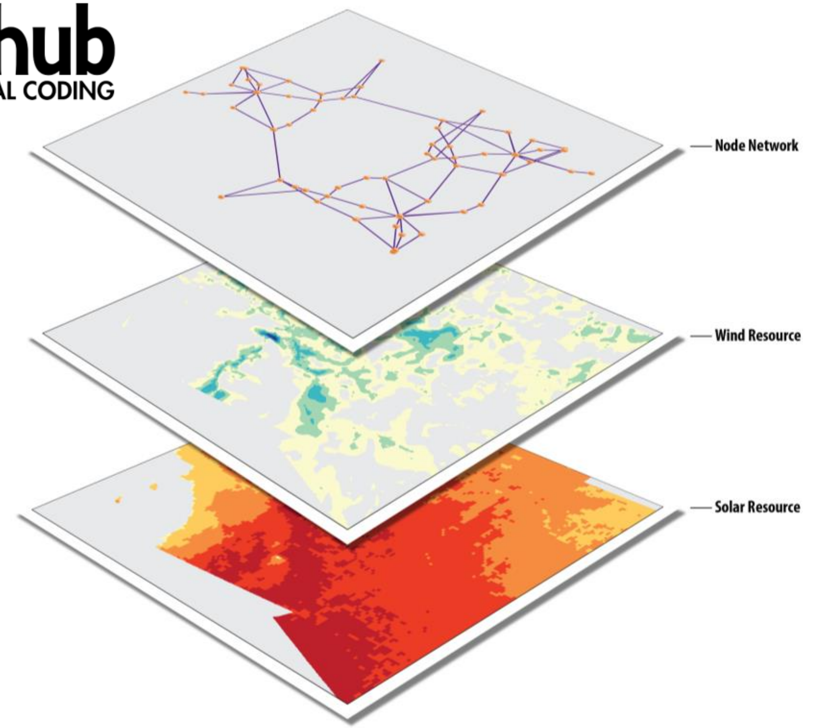
Technical Review Committee

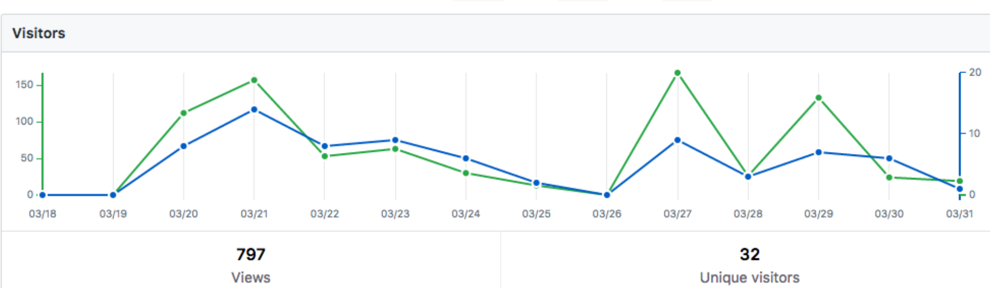
- In-person TRC meeting, October 2016
  - 30 participants
- Advanced PCM Workshop May 16, 2017
  - Deployed tools to industry and software developers

Reliability Test System (RTS-GMLC)

- IEEE asked for help to update RTS-96
- Critical updates
  - Addition of modern natural gas generation
  - Spatial and temporal diversity for load, wind and solar
- Online collaborators from industry, software, and academia: GE, UT, ISU, IEEE, NAU, PSO, Energy Exemplar

github SOCIAL CODING





Multi-scale Production Cost Modeling
Accomplishments to Date

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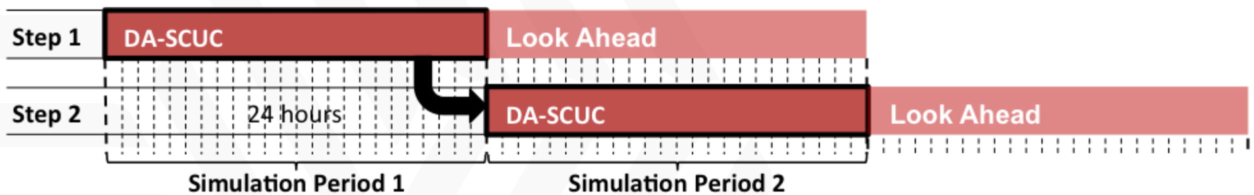
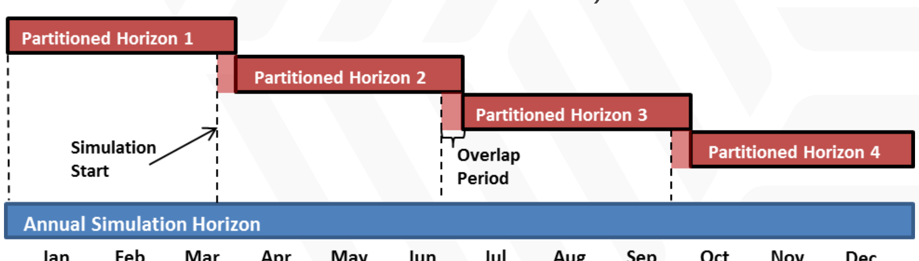
Problem: PCMs repetitively solve **similar** MIPs on **sequential** time steps

- Yesterday's schedule constrains today's operations
- Yesterday isn't that different from today



▶ Temporal Decomposition

- Parallelizing solution by decomposing MIP step sequence
- Implemented using open source software packages (Julia w/ DSP and Coin-Alps)
  - Easy to try different formulations (with different constraints and variables)



▶ MIP Warm-Starting

- *Warm-start*: accumulates useful information (branch-and-bound tree, cuts, feasible solutions, etc.); used to expedite next solves

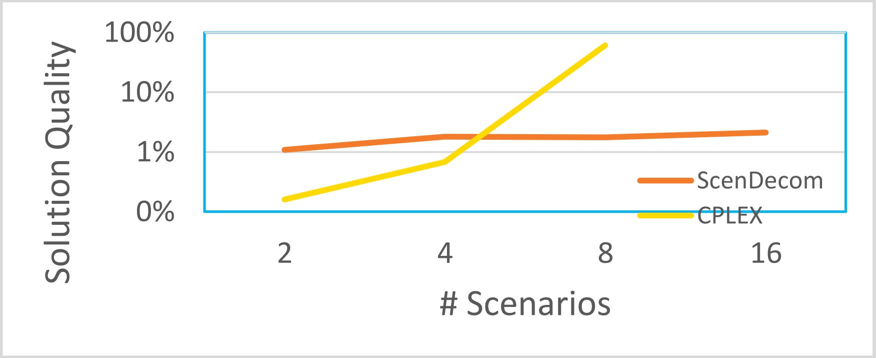
Case	Instance	% Improvement with Warm-starting
Diff. loads (pure Branch & Bound)	30-bus	~38%*
Diff. objective coeff. (Branch & Cut)	30-bus	~59%

- Directions for future work:
  - Enhancements: cut modifications, improved branching strategies, etc.
  - Transferability: facilitate performance improvements to commercial solvers

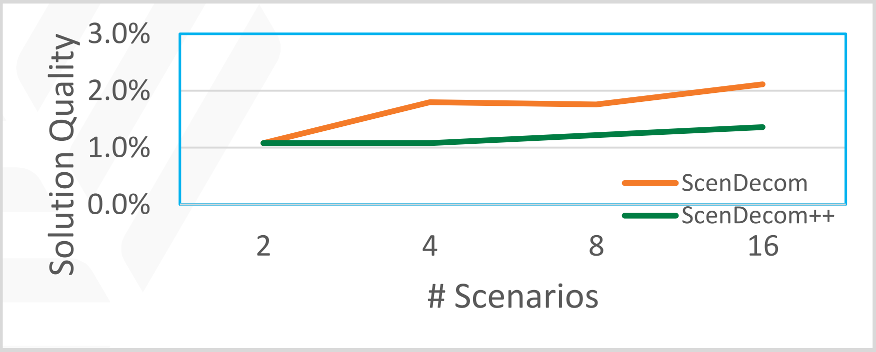
Multi-scale Production Cost Modeling
Accomplishments to Date

Accelerating Stochastic PCM and Enabling Stochastic vs. Deterministic PCM Evaluation

- **Scenario Decomposition and Grouping for Stochastic Unit Commitment**
  - Parallelizing solution by decomposition
  - CWE (Central-Western Europe) instances
    - 679 nodes and 1037 lines, 637 thermal units
  - Goal: Provide guarantee on solution quality
  - MIP solvers scale exponentially!
  - ScenDecom scales almost linearly!



- **Optimal Scenario Grouping Techniques Improve Scenario Decomposition schemes by 40%**
  - Provides higher-quality solutions



- **Probabilistic renewables production forecasts from NREL WIND and SIND toolkits**
  - Integrated in Prescient PCM simulator
- **Improved stochastic PCM solvers in Prescient by 25%**
  - Achieved by leveraging advanced Python bindings available in commercial MIP solvers

Multi-scale Production Cost Modeling

Response to December 2016 Program Review

Recommendation	Response
Please move forward in developing a GitHub site for the GMLC.	The GitHub site for the RTS-GMLC is live and already has several users from academia, industry, and software developers.
Please decide on a framework for sharing the results of this project with industry.	We will use a direct industry engagement framework that depends on presentations at leading industry events such as IEEE, UVIG, CIGRE, SC
Should there be a focus on U.S. industry only?	This area of the scope could be expanded but may be difficult to prioritize with current funding

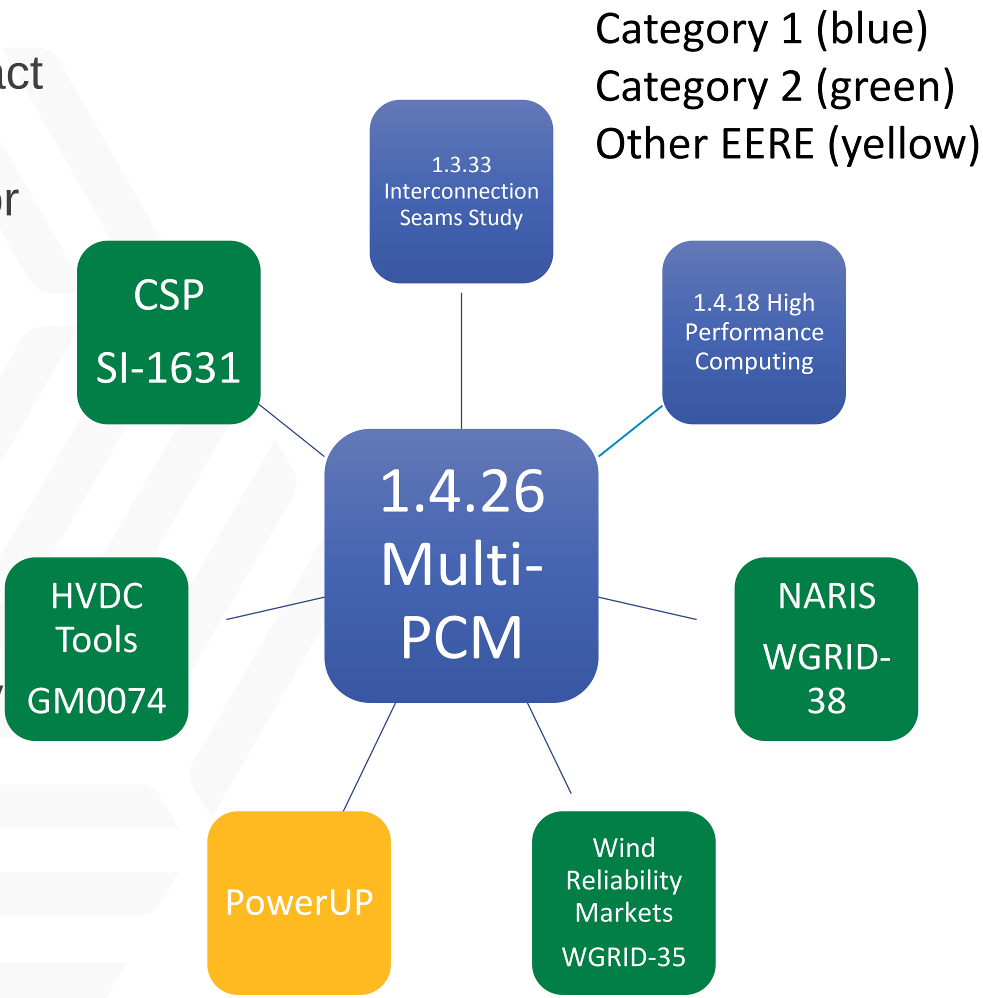
Multi-scale Production Cost Modeling

Project Integration and Collaboration

Advanced PCM capabilities directly impact other GMLC and related ”study” projects

- Reduced simulation times required for at-scale deterministic PCM studies
- Facilitates more extensive sensitivity analyses

Improvements in the fidelity of PCM simulations (e.g., directly accounting for uncertainty) translate into improved confidence that long-term planning study outcomes reflect future power system realities



Multi-scale Production Cost Modeling

Past and Planned Presentations

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Past

- Utility Variable Generation Integration Group
  - NREL
  - March, 2017
- INFORMS Annual Meeting
  - LLNL, SNL, ANL
  - November, 2016
- INFORMS Computing Society
  - LLNL, ANL
  - January, 2017

Planned

- Joint TRC Meeting
  - Entire team
  - May 16-18
- IEEE PES
  - NREL, SNL, LLNL, ANL
  - July 2017
- SIAM Optimization
  - ANL, SNL, LLNL
  - May 2017
- FERC Software Conference
  - SNL, ANL, NREL
  - July 2017
- INFORMS
  - SNL, ANL
  - October 2017

Multi-scale Production Cost Modeling

Next Steps and Future Plans

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Next Steps

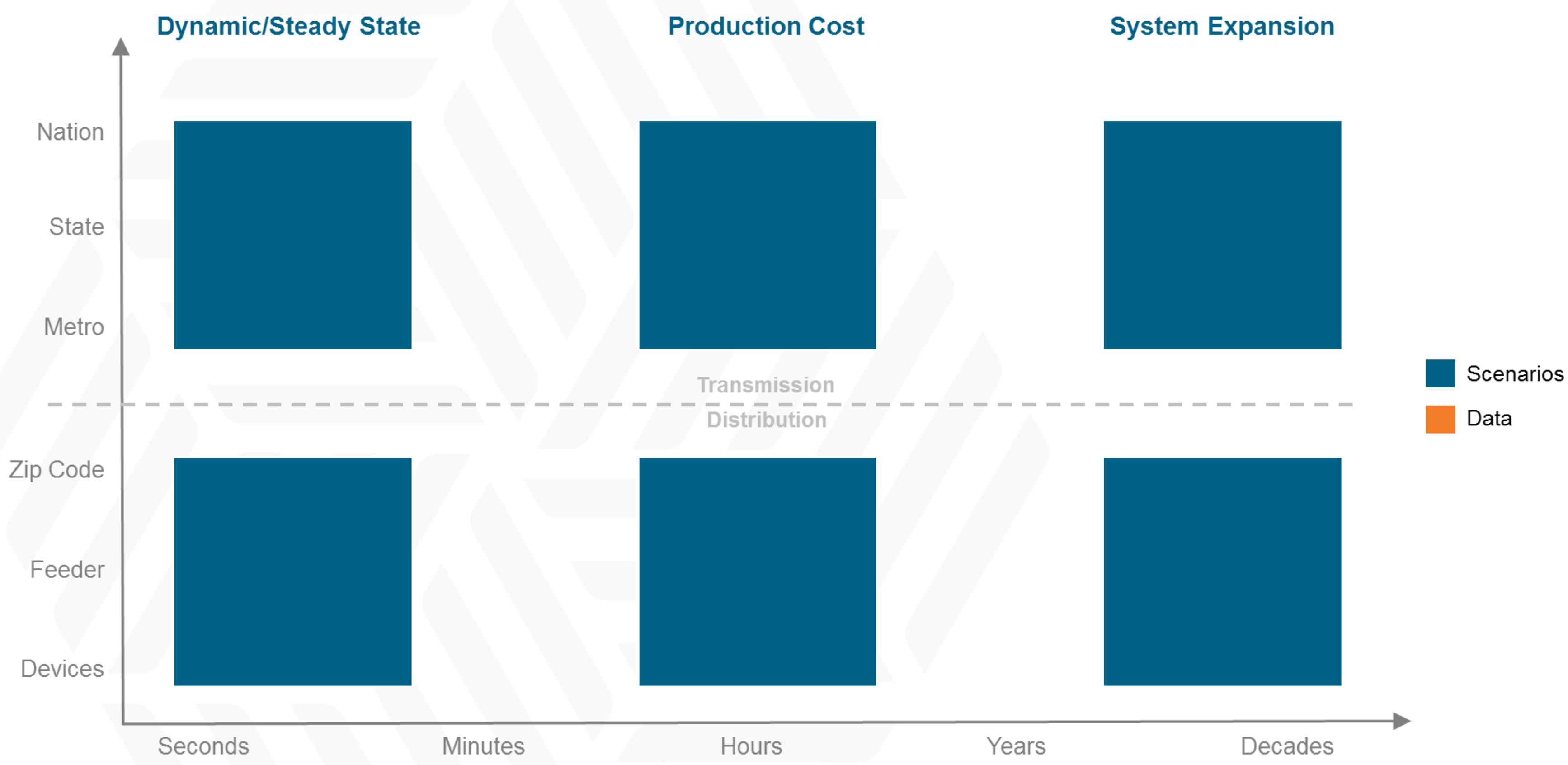
- Combine temporal and geographic decomposition
- Deploy combined decomposition methods to the Interconnections Seams Study
- In-person TRC meeting
- Submit paper to IEEE for RTS-GMLC
- Submit papers on temporal decomposition and MIP warm-starting/improved UC formulations
- Complete initial comprehensive stochastic “versus” deterministic PCM study
- Complete stochastic version of RTS-GMLC
- Submit paper on scenario grouping and decomposition techniques

Wish List

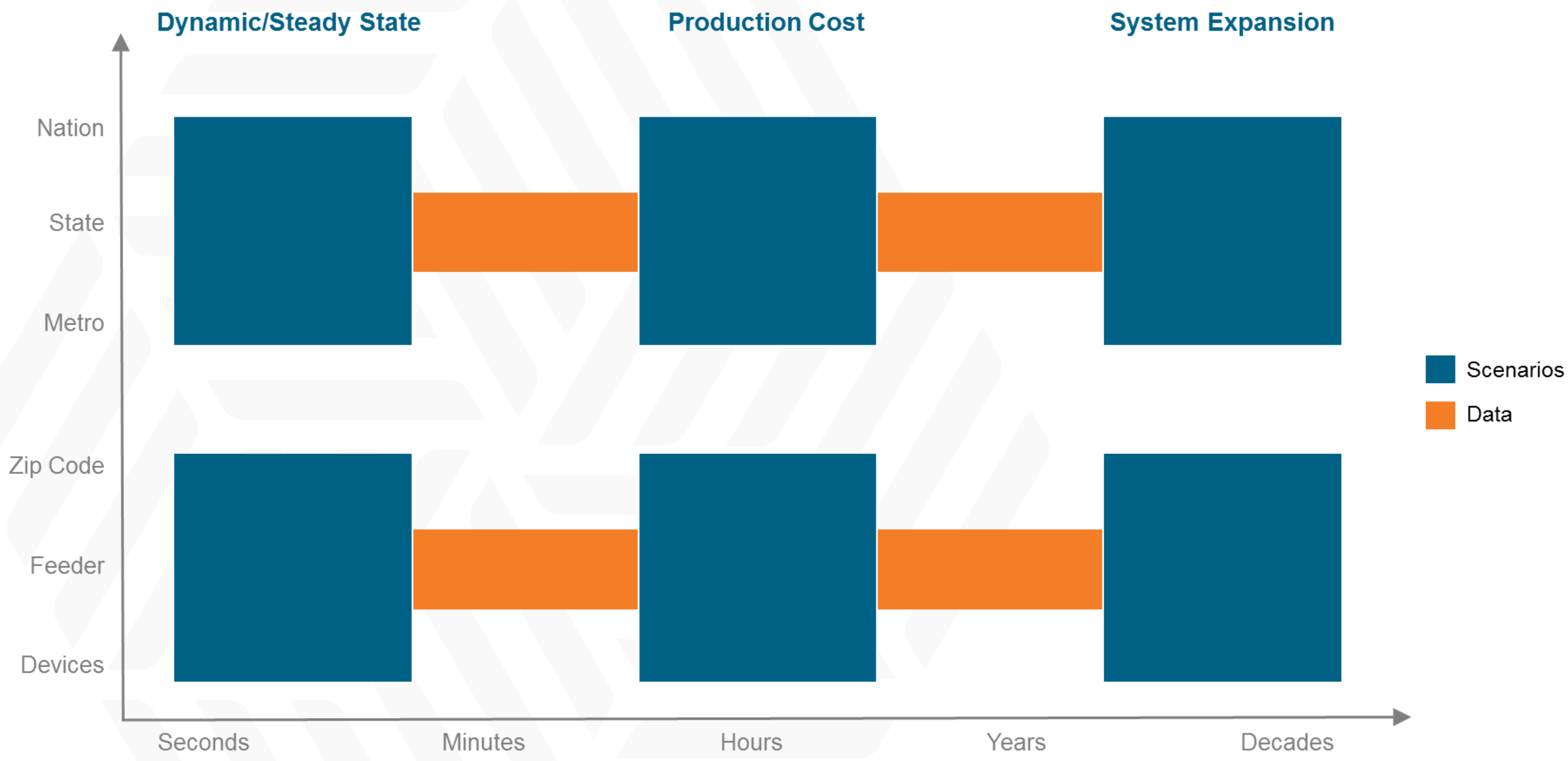
- Get inside the black boxes
  - Create open source production cost model (Prescient?, PSST?)
- Journal of Supercomputing
- Bigger computers!!!

Scales of Reliability and Efficiency

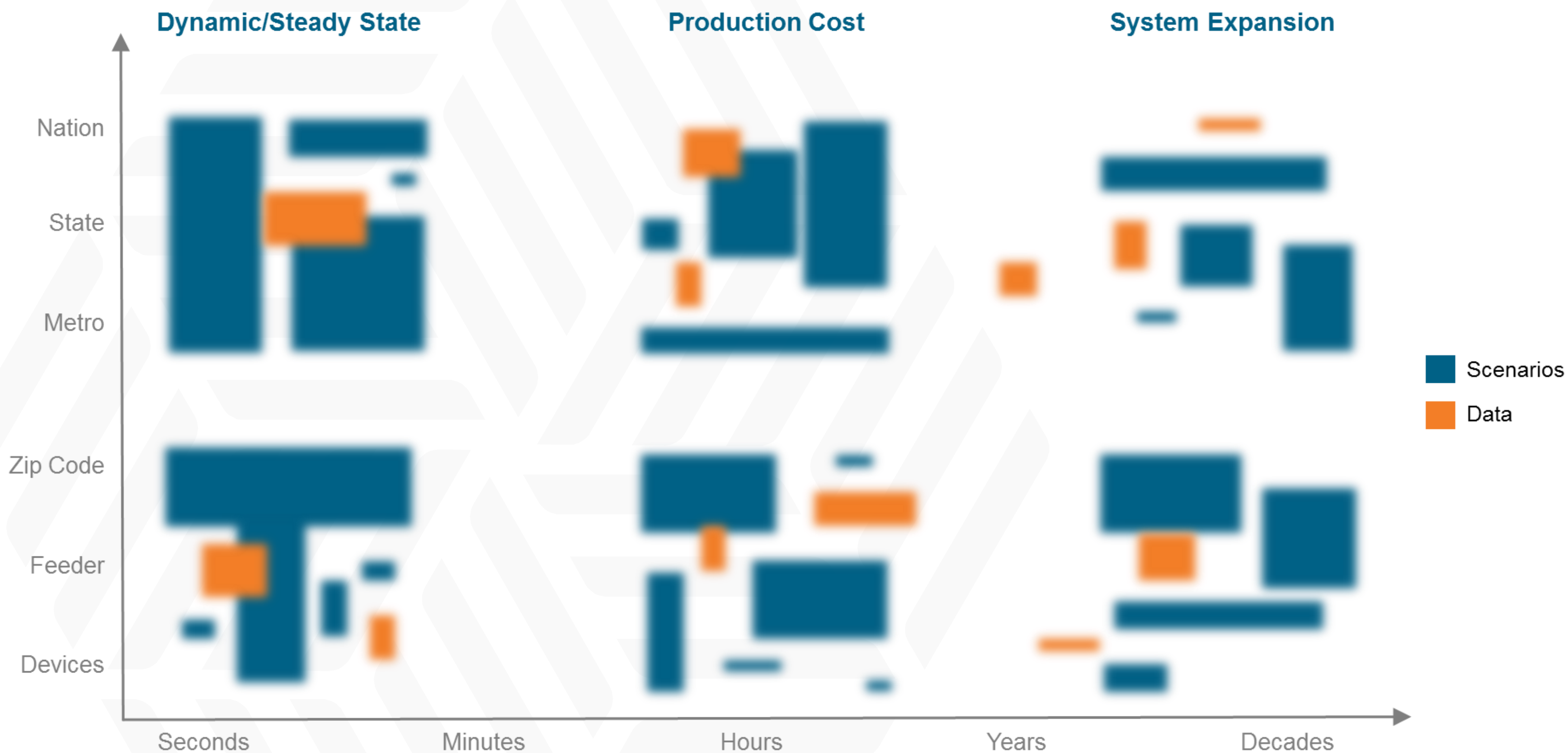
Power System Planning Models



Current Practice, hopeful



Current Modeling, more accurate



Near Term Modeling Goal

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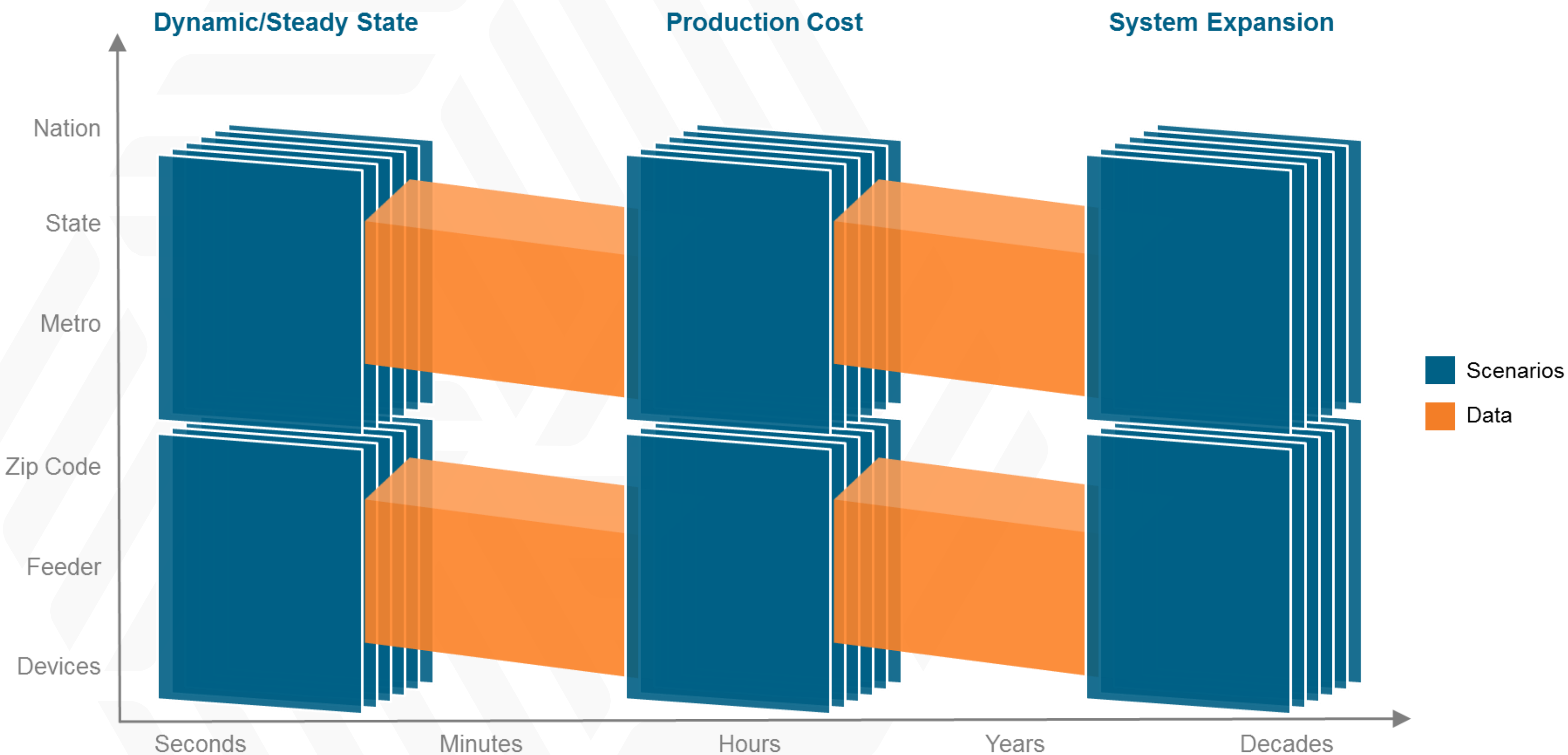
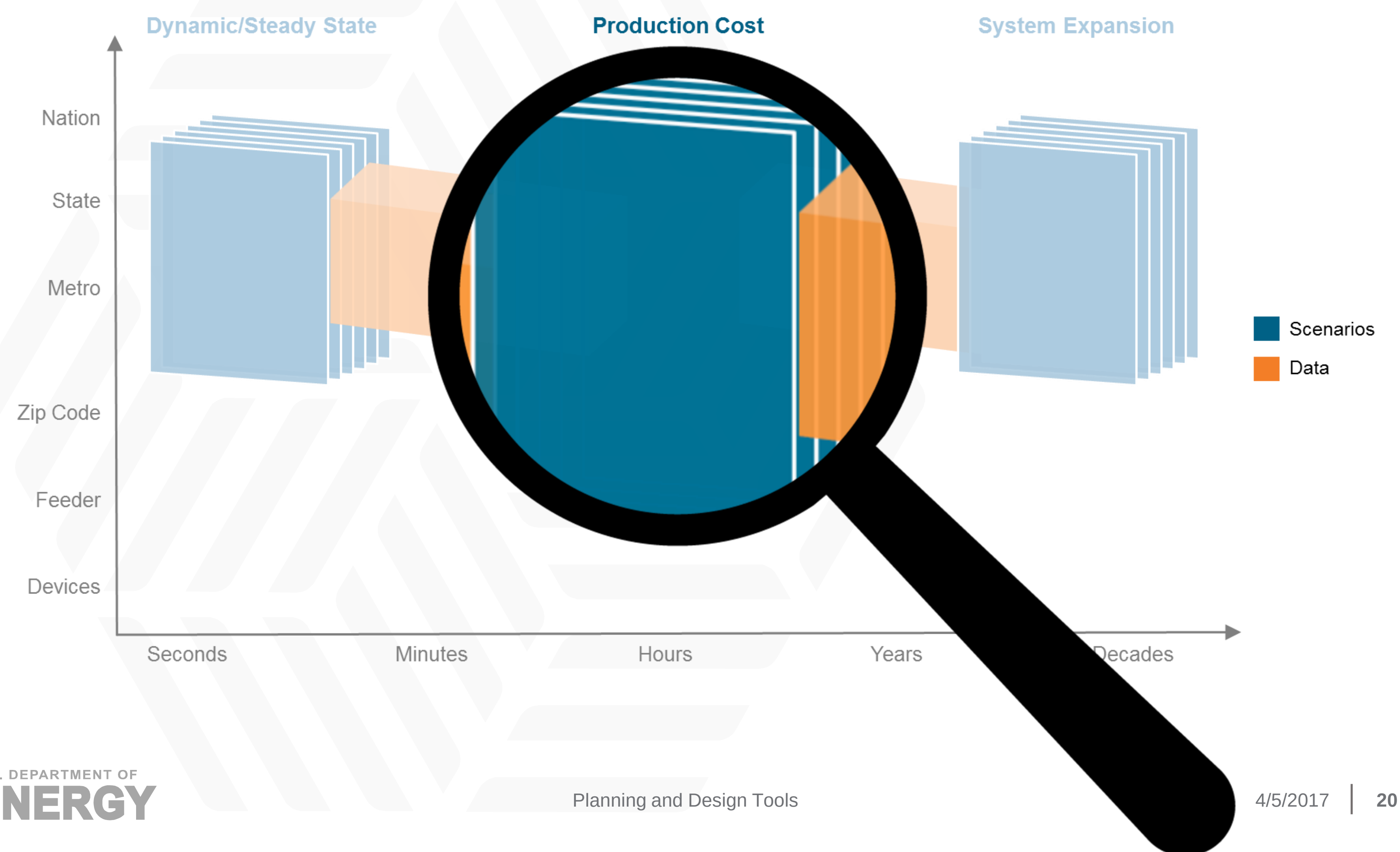
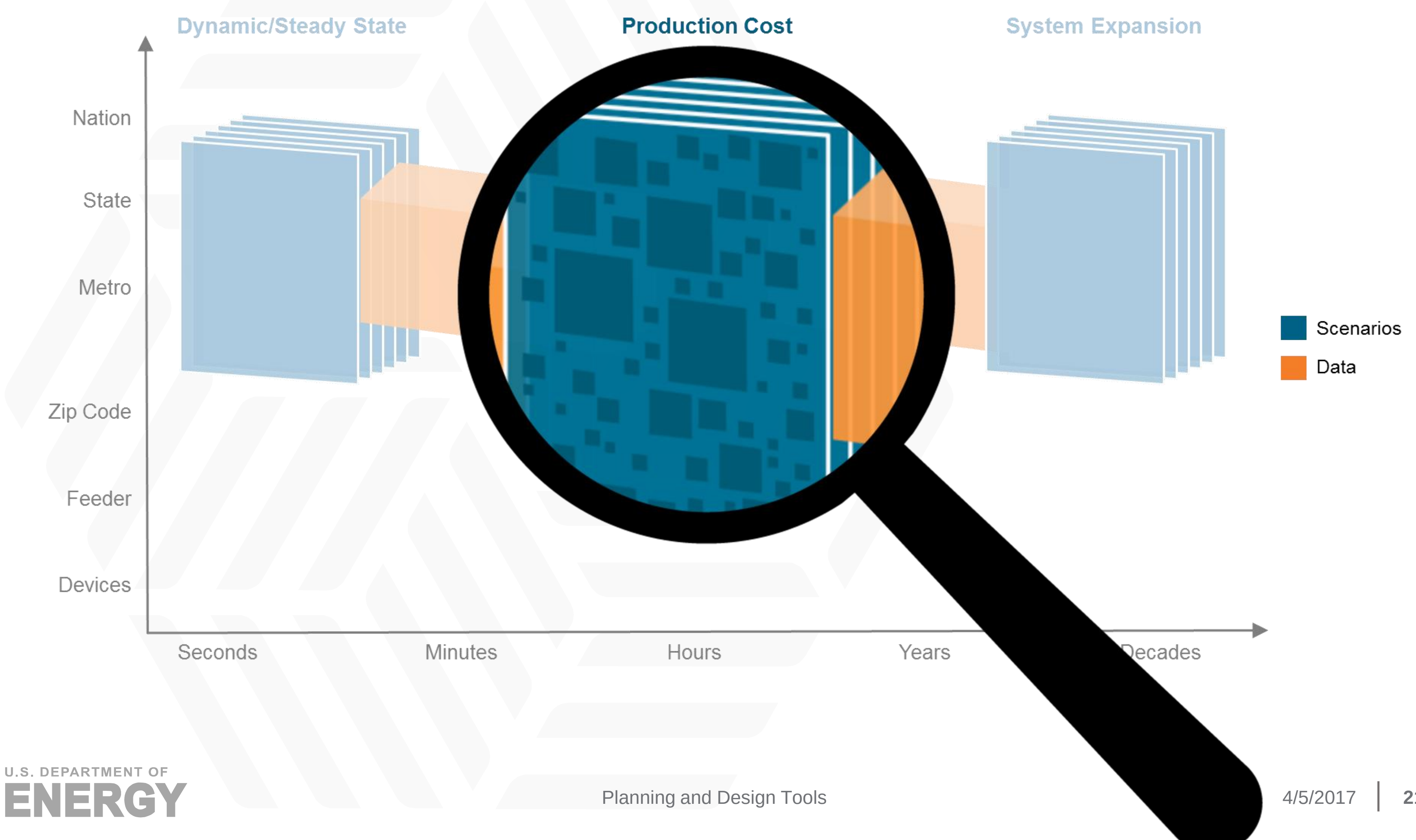


Multi-scale Production Cost Modeling 1.4.26



Adding Resolution



Increasing robustness