Devices and Integrated Systems Portfolio Overview

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National Renewable Energy Laboratory

DOE GMI Peer Review,
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Devices and Integrated Systems

Focus Areas

- **Work across DOE Program offices to develop technologies that provide a range of grid services**
- **Develop and update interconnection and interoperability methods, protocols, standards & test procedures**
- **Conduct technology and integrated system testing and validation**

Expected Outcomes

- Develop new grid interfaces to **increase ability of new technology to provide grid services** for reliability, resilience and increase utilization of infrastructure
- Coordinate and support the development of interconnection and interoperability standards and test procedures for provision of grid services **across all element of the grid**
- Validate secure and reliability grid operation with **all forms of energy** at multiple scales (microgrids to transmission systems)

Federal Role

- Common approach across labs and industry test-beds for effective validation of emerging technologies
- Provide an unbiased method for develop common interoperability and interconnection standards and test procedures for industry / vendor community

MYPP Activities & Achievements

MYPP Activities	Technical Achievements by 2020
Develop Advanced Storage Systems, Power Electronics and other Grid Devices	• Develop inverter-based resources that can provide grid services, self-optimize around the market and energy environment and meet specific DOE applications' targets . • Decrease the system costs of deployed grid-scale, energy storage systems by establishing grid-scale storage systems' metrics for safety, reliability and performance, and through new energy storage technologies development. • Enable buildings, large building loads (e.g. HVAC systems, refrigerator systems) and EV charging systems to: characterize their available flexibility, and have embedded control and decision-making tools to provide services to the electrical grid and to system owners. • Develop innovative grid infrastructure technologies (e.g. advanced transformers, advanced grid materials) that reduce costs and improve device efficiency.
Develop Standards and Test Procedures	• Updated standards and test procedures that characterize the ability of devices to provide a full range of grid services and accelerate the uptake of these devices in the market. Codes and standards are also necessary to ensure deployed technologies are safe and effective. • Development of standards and test procedures for microgrids, storage and other energy management systems that reduce customer outages.
Build Capabilities and Conduct Device Testing and Validation	• Provide coordinated test facility integration and optimization, testing frameworks and component model libraries managed and operated by National Laboratories, universities and industry groups • Development of methods to couple hardware-in-the-loop (HIL) devices with advanced simulations including high performance computers (HPC) systems for evaluating systems at a variety of scales • Validate interconnection and interoperability requirements and test procedures • Characterization of a wide variety of technologies to validate individual devices can provide a full range of grid services using a variety of techniques including HIL
Conduct Multi-scale Systems Integration and Testing	• Validated multi-scale systems that enable integration of 100% renewable energy at the local level and 35% at the bulk system while reducing reserve margins and interconnection costs. • Validated transactive control constructs that coordinate distributed generation, storage, and controllable loads to reduce reserve margins. • Validated customer outage reductions by using advanced distribution system configurations (including microgrids) and advanced distribution management system applications. • Field demonstrations of energy storage providing multiple grid services cost effectively.

Devices and Integrated Systems Foundational Project

1.2.2 Interoperability

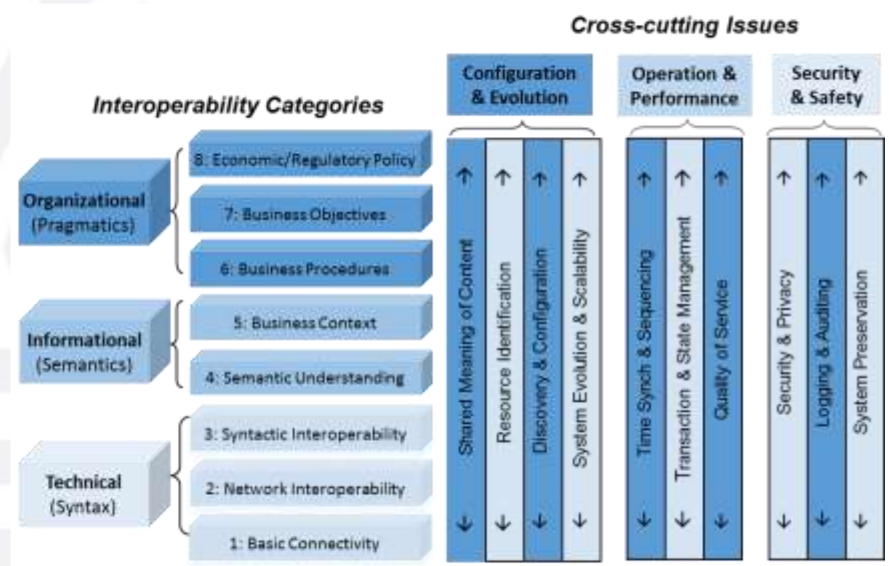
Project Description

Align stakeholders on a strategic vision for devices and systems integration and develop measures and tools to support interoperability

Interoperability is the ability of two or more systems or components to exchange information and to use the information that has been exchanged.
ISO/IEC/IEEE 24765

Value Proposition

- Reduction of cost and effort for system integration
- Improve grid performance, efficiency and security
- Increase in customer choice and participation
- Establishment of industry-wide best practices
- Catalyst of innovation



Partners

- Labs: PNNL, NREL, LBNL, ANL
- Partners: Industry, Industry Associations, Standards Development Organizations, Other Research Organizations

1.2.3 Testing Network and Open Library

Project Description

Accelerate grid modernization by improving access to National Lab testing infrastructure for grid devices and systems, and related models and tools. Enable national labs to drive innovation more effectively and synergistically.

Value Proposition

- Access to testing resources and validated models is vital to grid modernization
- Make optimal use of vast and growing set of grid-related testing and simulation resources at National Labs and beyond.
- Major opportunities to make an impact by improving information, accessibility, and collaboration

Partners

- Labs: Sandia, INL, NREL, ORNL, LBNL, ANL, PNNL, SRNL, BNL, LLNL
- Others: Utilities, Academia, Manufacturers

1.4.1 Standards & Test Procedures for Interconnection & Interoperability

Project Description

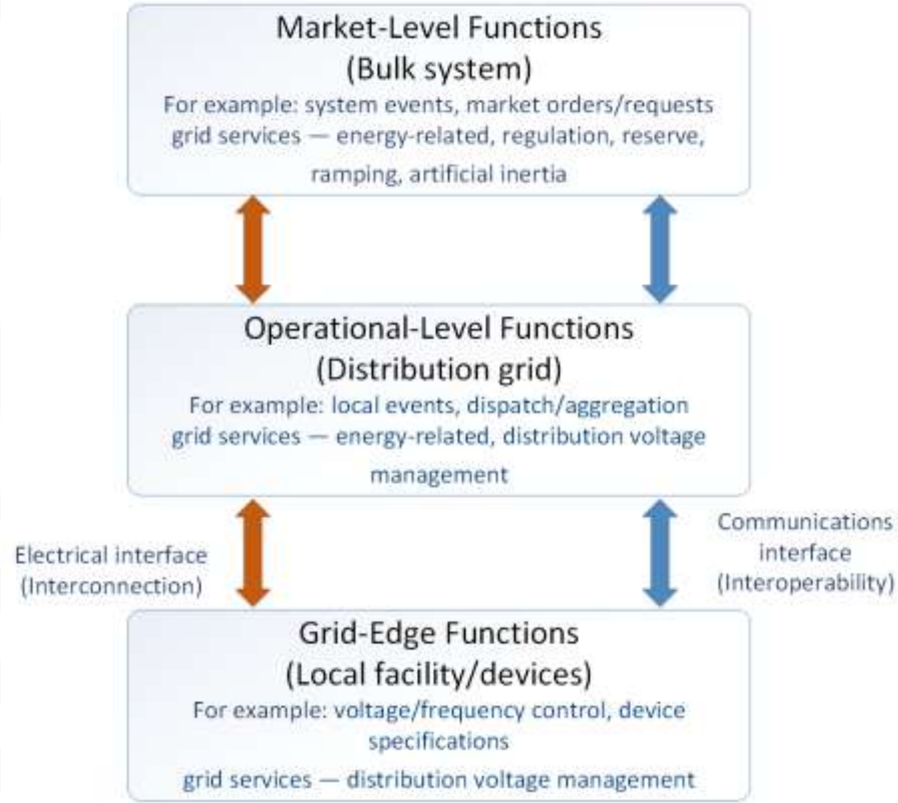
- Accelerate the development and validation of interconnection and interoperability standards
- Ensure cross-technology compatibility & harmonization of requirements for key grid services

Value Proposition

- Improve coordination of modern energy generation & storage devices with the grid
- Enable market expansion through improved interoperability
- Reduce barriers to deployment through improved standards

Partners

- Labs: NREL, PNNL, LBNL, ANL, Sandia, ORNL, INL
- Others: Vendors, utilities, system integrators, standards organizations



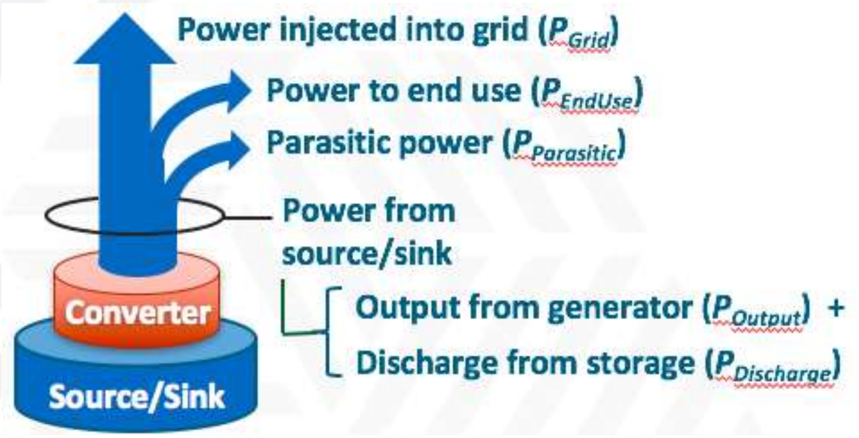
1.4.2 Grid Services

Project Description

- Develop and test high-resolution models of distributed energy resources (DERs) with a standardized interface in the form of a battery-equivalent (BEq) representation, for
- Ready access by planning and operational tools in assessing DERs' ability to provide operational flexibility in the form of valuable grid service at the bulk system and local distribution levels.

Value Proposition - Common BEq representation/interface allows:

- Grid operations & planning models to easily & accurately assess DER contributions
- Contribution of DER classes can be "summed"
- Grid control & optimization methods to be shared by across DER types
- Consideration of BEq as a grid flexibility metric
- Level-playing field for evaluating DERs



Partners

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- Others: Vendors, utilities, system integrators, standards organizations

Resilient Distribution System Projects

1.5.03 Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Project Description

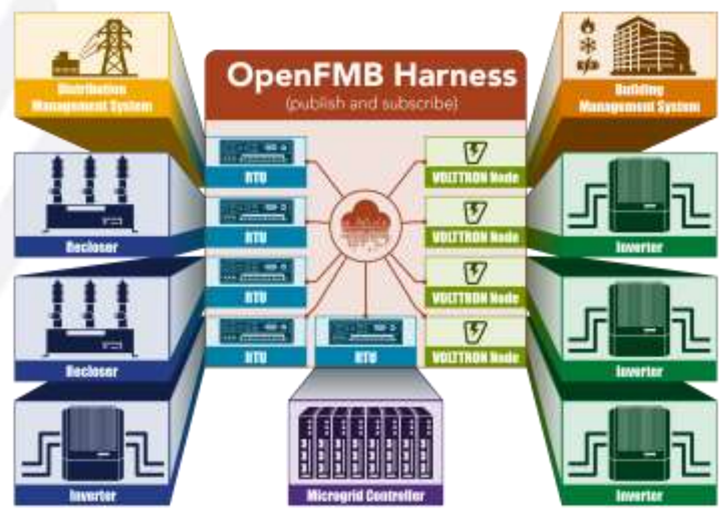
- Increase distribution resiliency through flexible operating strategies.
- Develop flexible operating strategies that integrate centralized and decentralized control systems
- Engage utility and non-utility assets to increase the resiliency of critical end-use loads to all hazards events

Value Proposition

- DER deployments at moderate to high penetration levels prevents a "business as usual" approach
- Duke Energy has halted some self-healing systems deployments due to high penetration PV concerns
- What is needed is a way to coordinate the operation of distributed PV, to make it a resource, and not an obstacle
- This is extensible to other centralized and decentralized system combinations

Partners

- Labs: PNNL, ORNL NREL
- Partners: Duke Energy, GE Grid Solutions, UNC-Charlotte, Univ. of Tennessee, SEPA



1.5.04 Integration of Responsive Residential Loads into Distribution Management Systems

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Project Description

Development of end-to-end, interoperable solutions leveraging open-standards to utilize responsive residential loads for improving grid resiliency

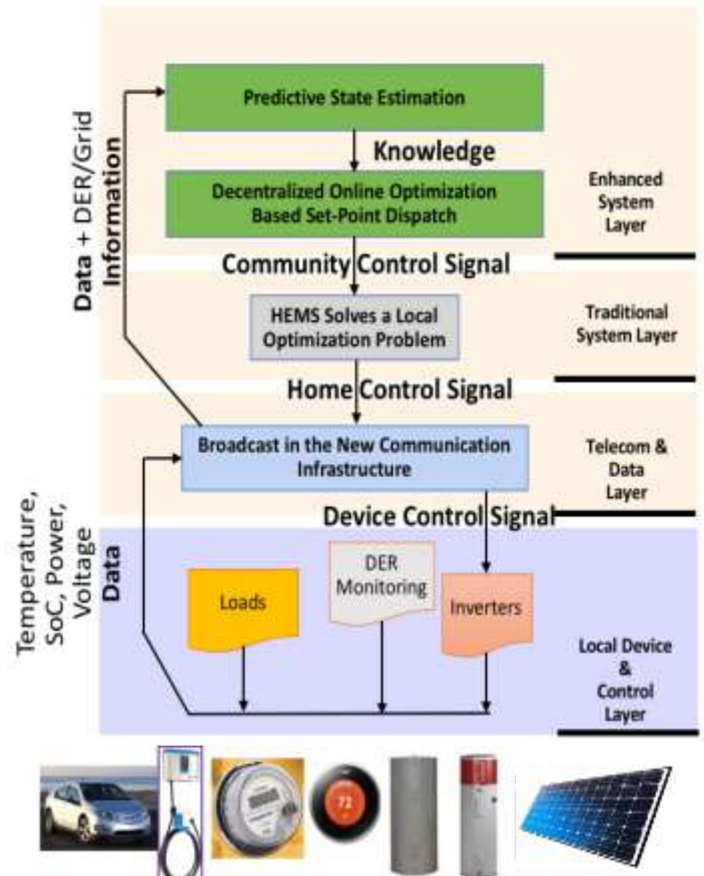
The hierarchical control and optimization technology will demonstrate coordinated response from large number of assets in time and magnitude to provide grid benefit while meeting customer and safety constraints

Value Proposition

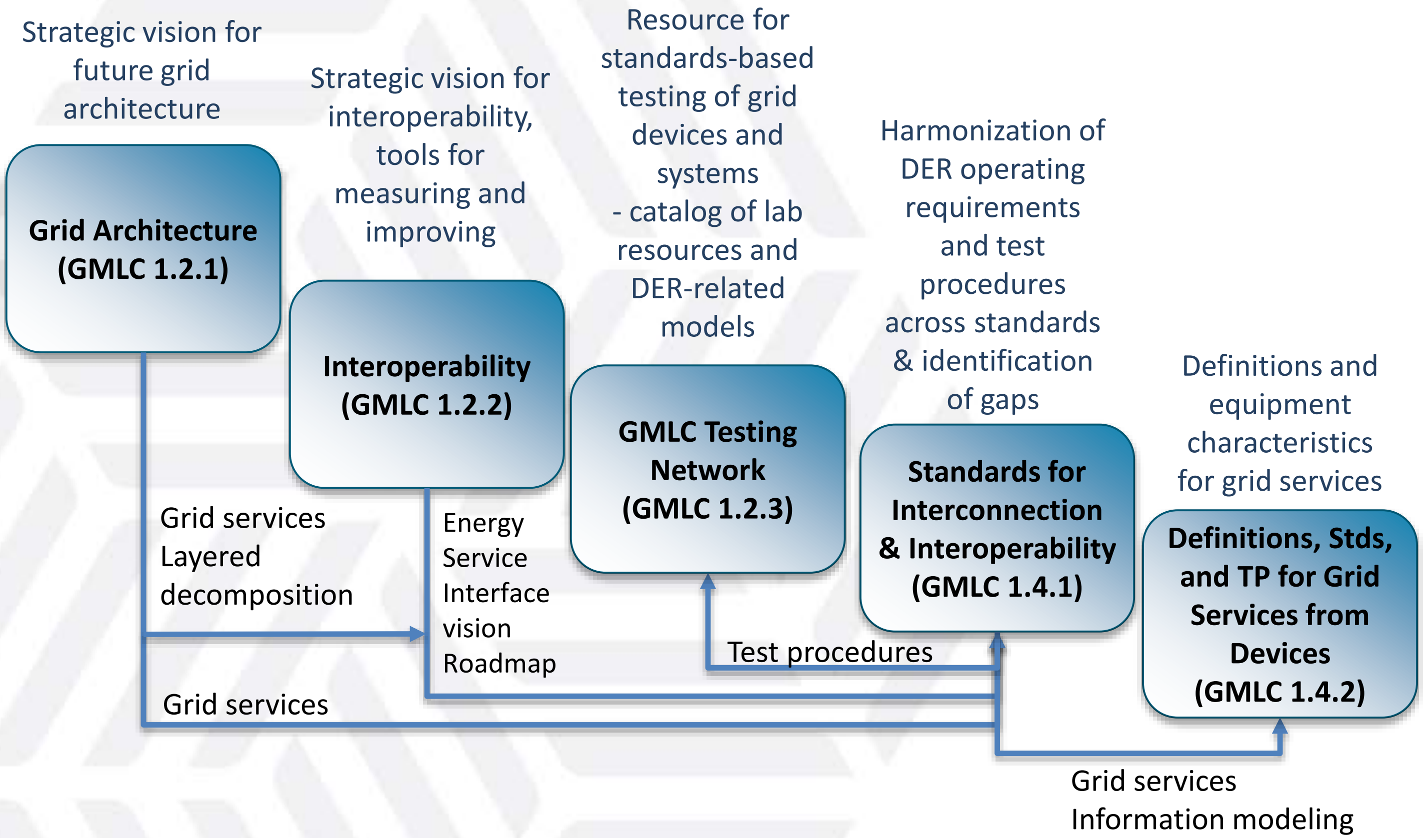
- Evaluate in field open-standard end-to-end solution for improving distribution-level resiliency using end-use loads
- Enable interoperability across the meter to engage residential loads for grid services
- Validating performance of residential loads to provide grid services

Partners

- Labs: ORNL, PNNL,
- Others: EPRI, Southern Co, TVA, Duke Energy, ConEd, EPB Jackson EMC



GMLC Project Coordination



Connections and Collaborations

Foundational and Program Projects

19 Partnership Projects between National Labs – Industry – Universities

GRID MODERNIZATION LABORATORY CONSORTIUM

MYPP Area	Foundational Projects	Program Specific Projects
Develop Advanced Storage Systems, Power Electronics, and other Grid Devices Goal: Increase electric grid flexibility, reliability, resiliency, and asset utilization by making step changes in the performance of grid-connected devices and technologies.		GM0060 - Improving Distribution Transformer Efficiency GM0204 - Inverter Driver Interface for VOLTTRON SI-1583 - Grid-Forming Distributed Inverter Controllers SI-1689 - Additively Manufactured PV Inverter SI-1699 - Combined PV/Battery with High Freq Magnetics Power Electronics
Develop Standards and Test Procedures Goal: Work with standards development organizations (SDOs) to accelerate the development and validation of standards and test procedures for device interoperability, performance, and safety.	1.2.2 Interoperability 1.4.1 Interconnection/Interoperability Standards 1.4.2 Grid Services from DER	SI-1695 - Accelerating Codes and Standards WGRID-05 - Support to Achieve Large Amounts of Wind Power
Build Capabilities and Conduct Device Testing and Validation Goal: Develop a testing infrastructure and validate device performance in both the laboratory and the field using the developed standards and test procedures.	1.2.3 GMLC-TN 1.4.1 Interconnection/Interoperability Standards 1.4.2 Grid Services from DER 1.3.29	GM0130 - Demo for Battery Secondary Use GM0222 - HV Testing and Modeling of Transformers WGRID-49 - Short-term Energy Storage and Large Motor Loads for Active Power Controls by Wind Power
Conduct Multi-Scale Systems Integration and Testing Goal: Ensure that integrated systems of devices and controls are able to connect, communicate, and operate in a coordinated fashion at multiple scales.	1.3.29 Grid Frequency Support from Distributed Inverters in Hawaii 1.5.03 Flexible DER and Microgrid Assets Enabled by OpenFMB 1.5.04 Responsive Residential Loads	GM0008 - Energy Storage Demonstrations GM0237- Advanced Distribution Management System (ADMS) Testbed

Accomplishments and Emerging Opportunities

Accomplishment

- 1.2.2 Developed strategic Vision document for Interoperability
- 1.2.3 Publish catalog of lab capabilities and started open library
- 1.4.1 Developed Interconnect/Interop Gap Analysis and reviewed with Industry
- 1.4.2 Battery-equivalent model of devices for defining ability to provide grid services

Path Forward

- 1.2.2 Complete roadmap trials Plug-n-Play Challenge results
- 1.2.3 Update Library and Publicize gridPULSE
- 1.4.1 Work with SDOs to implement interconnection and interoperability harmonization
- 1.4.2 Complete testing and analysis of battery-equivalent model for devices

Summary

- ► Working with DOE Programs and Industry, identified new technologies and methods to determine grid services
- ► Working with Standards Development Organizations and Industry, charted pathway for interoperability and interconnection standardization and harmonization
- ► Started validation of devices capability to provide grid services, created a catalog of National Laboratory capabilities, and started model library for providing standard device information

PNNL-SA-137393

Grid Modernization Initiative Peer Review

GMLC 1.2.2 Interoperability

STEVE WIDERGREN, PACIFIC NORTHWEST NATIONAL LABORATORY

September 4–7, 2018

Sheraton Pentagon City Hotel – Arlington, VA

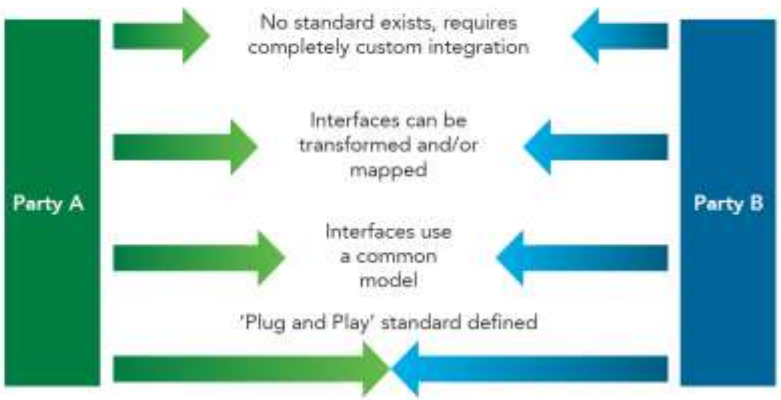
1.2.2 Interoperability
High-Level Project Summary

The ability of two or more systems or components to exchange information and to use the information that has been exchanged.
ISO/IEC/IEEE 24765

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Align stakeholders on a strategic vision for devices and systems integration and develop measures and tools to support interoperability

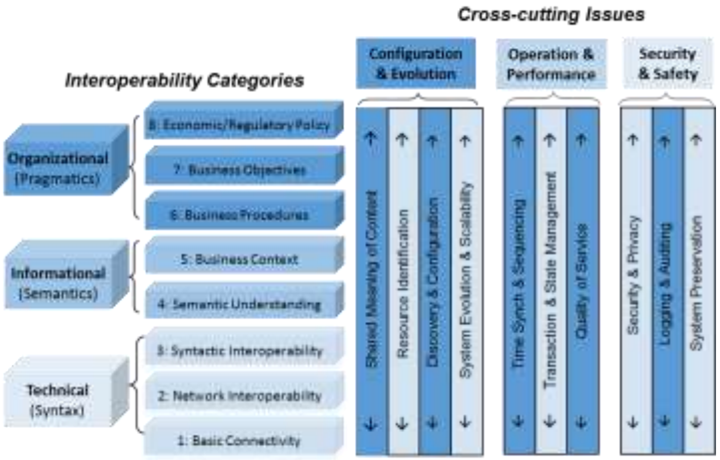


MYPP Goals/Vision

- Consolidation of standards used in practice for buildings, power distribution, and bulk power systems (MYPP Task 2.2.4).
- Coordination across grid modernization programs, laboratories, and external organizations to avoid duplication of effort and increase leverage, for the most impactful results (MYPP Sec 2.5).
- Increase industry involvement and uptake as private and public organizations adopt interoperability incentive mechanisms (necessary for adoption and advancing interoperability in deployments, a general MYPP desire).
- Demonstrations of approaches that address advanced interoperability capabilities (MYPP Introduction for RD&D Leveraged Capabilities).

Value Proposition

- Reduction of cost and effort for system integration
- Improve grid performance, efficiency and security
- Increase in customer choice and participation
- Establishment of industry-wide best practices
- Catalyst of innovation



Expected Outcomes

- Establish an interoperability strategic vision
- Describe the state, challenges, and path forward to advance interoperability
- Offer tools to facilitate gap analysis, develop roadmaps, and demonstrate vision concepts

1.2.2 Interoperability
Project Team

Project Participants and Roles

National Lab	FY16 Funding	FY17 Funding	FY18 Funding	Total Funding
PNNL	$500,000	$450,000	$500,000	$1,450,000
NREL	$200,000	$200,000	$200,000	$600,000
LBNL	$150,000	$200,000	$150,000	$500,000
ANL	$150,000	$150,000	$150,000	$450,000
Total	$1,000,000	$1,000,000	$1,000,000	$3,000,000

PNNL – lead, strategic vision, measurement tool
NREL – gaps and roadmap methodology
LBNL – demonstrate visionary interoperability capability
ANL – support interoperability assessment and roadmap (electric vehicles)

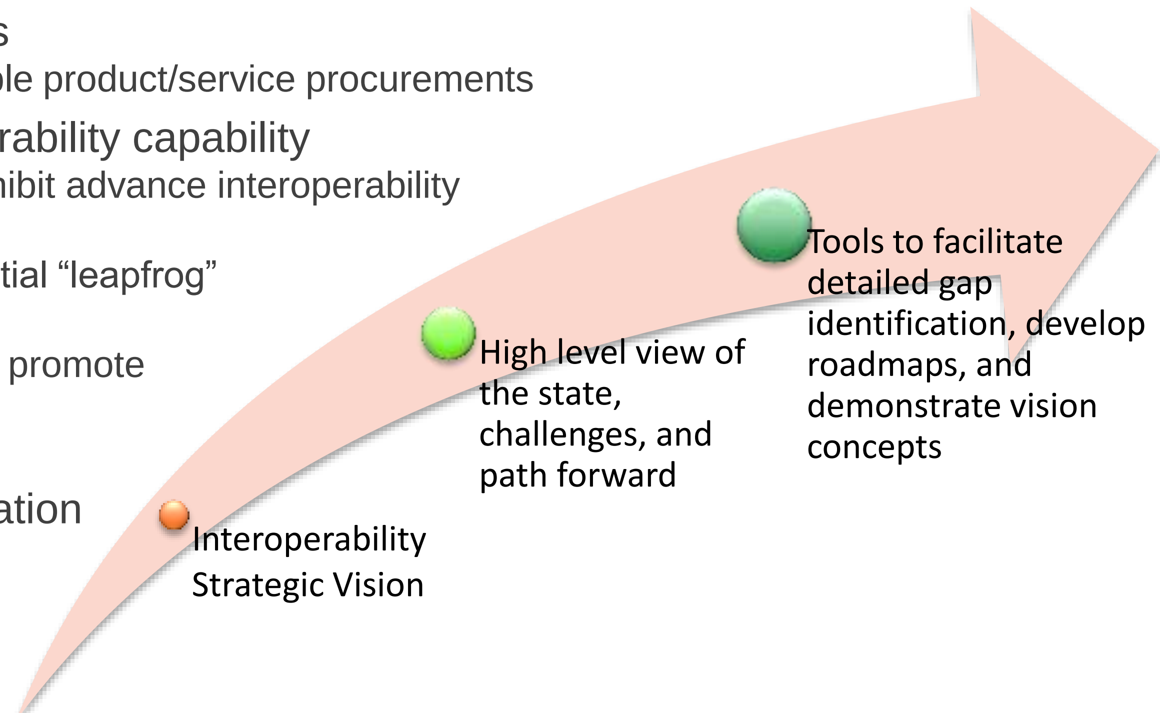
Partners: Smart Energy Power Alliance (SEPA), National Institute of Standards and Technology (NIST), GridWise Architecture Council (GWAC), Electric Power Research Institute (EPRI), Institute of Electrical and Electronics Engineers (IEEE), International Electrotechnical Commission (IEC), Industrial Internet Consortium (IIC), (General Services Administration (GSA), ENERGY STAR, United States Army Corpse of Engineers (USACE), Software Engineering Institute Carnegie-Mellon (SEI-CM), Society of Automotive Engineers (SAE), LonMark, National Electrical Manufacturing Association (NEMA), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Consumer Technology Association (CTA), European Commission Joint Research Center (EC-JRC)

Meetings with partners every 2-3 months: review work products, status, and plans

1.2.2 Interoperability
Approach

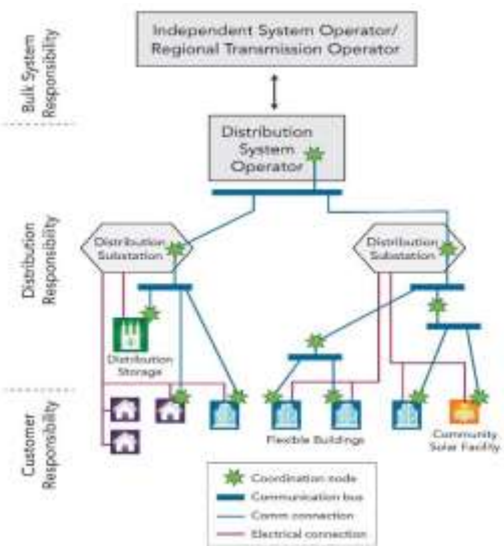
- Strategic vision
  - State of interoperability and desired integration experience
  - Document with stakeholder buy-in, socialization
- Gaps & roadmaps
  - Tools to measure interoperability/ease of integration
  - A roadmap methodology for technology communities to set goals and a path to achieve them
- Industry engagement incentives
  - Tools to encourage interoperable product/service procurements
- Demonstrate visionary interoperability capability
  - Industry directed contest to exhibit advance interoperability concepts
  - Identify priority gaps and potential “leapfrog” capabilities
  - Conduct project/contest(s) and promote results for follow-on efforts

- Y2 focused on industry participation in work activities

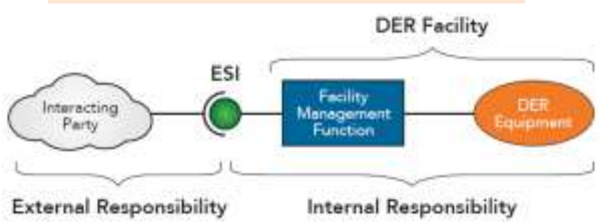


Accomplishments
Interoperability Strategic Vision

Layered decomposition



Energy Services Interface

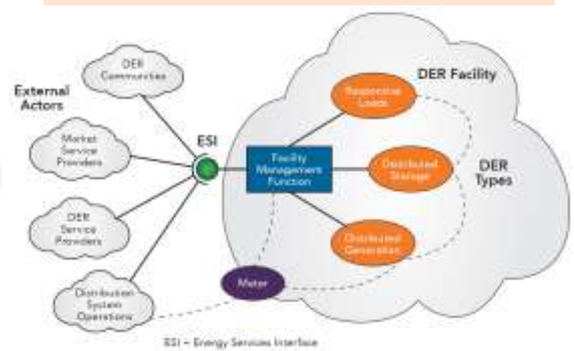


Interop Strategic Vision 20 page whitepaper (Mar 2018)

- Defines interoperability and the mission to ease integration of grid components
- Provides an example for DER integration, state of interoperability, gaps, and a path forward
- Targets integration ecosystems for advancing interoperability
- Introduces interoperability measurement, roadmap tools, and incentives for engagement
- Input from two industry workshops (Sep 2016, May 2017) and reviews by partners and experts

https://gridmod.labworks.org/resources/interoperability-strategic-vision

Performance-oriented, technology neutral



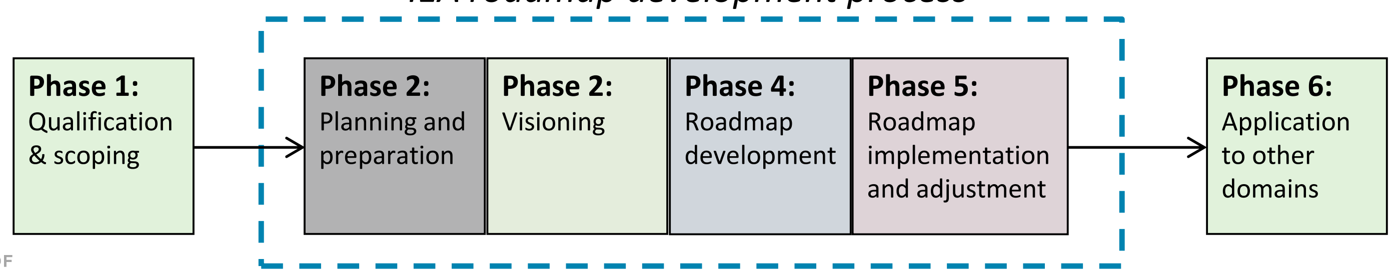
Standards convergence

Accomplishments

Trial Interoperability Roadmaps

- Year 1 developed tools refined in Year 2
  - Interoperability Maturity Model (IMM): tool to measure interoperability maturity (Apr 2017)
    - https://gridmod.labworks.org/sites/default/files/resources/InteropIMMTool2017-04-22.pdf
  - Roadmap Methodology: process for an integration ecosystem to develop a plan improve interoperability (Dec 2017)
    - https://gridmod.labworks.org/project-highlights/interoperability-roadmap-methodology-published
- Trial interoperability roadmap ecosystem engagements
  - **IEEE 2030.5 ecosystem**: driven by PV smart inverter integration in CA, HI
    - IEEE-SA hosted introductory meeting with ~25 diverse stakeholders (held Jun 2018)
    - Formed an Industry Connections Activity (ICA) in IEEE-SA to host the work
    - Outlined ~9 month effort to produce interoperability roadmap
  - **EV charging ecosystem**: driven by EV charging systems integration in US and EU
    - Arranged DOE coordination with European Commission Joint Research Center (JRC) (Aug 2018)
    - Planning underway with JRC leadership to host the work with diverse stakeholder members

IEA roadmap development process



Accomplishments

Reference Interop Procurement Language

Objective: incentive mechanisms for industry attention to interoperability – develop model procurement language for interoperability requirements

- **Approach**: work with technology buyers to advance interoperability performance in product acquisition
  - Use IMM to draft performance-based statements for products and systems suppliers to provide evidence
  - Develop a guide for applying reference language in procurement specifications
- **Industry Engagement**: formed SEPA Reference Interoperability Procurement Language (RIPL) TF (Mar 2018)
  - Interested parties from utilities, technology suppliers, government agencies
  - Draft IMM-based interoperability procurement language statements found to provide a good start

Accomplishments

Demonstrate Visionary Interop Capability

Plug & Play DER Challenge

- Theme: use the Energy Services Interface (ESI) to provide a visionary direction for proposals
- Phase 1: Conceptualization of an ESI interface specification
- Phase 2: Demonstrate selected concepts

Status

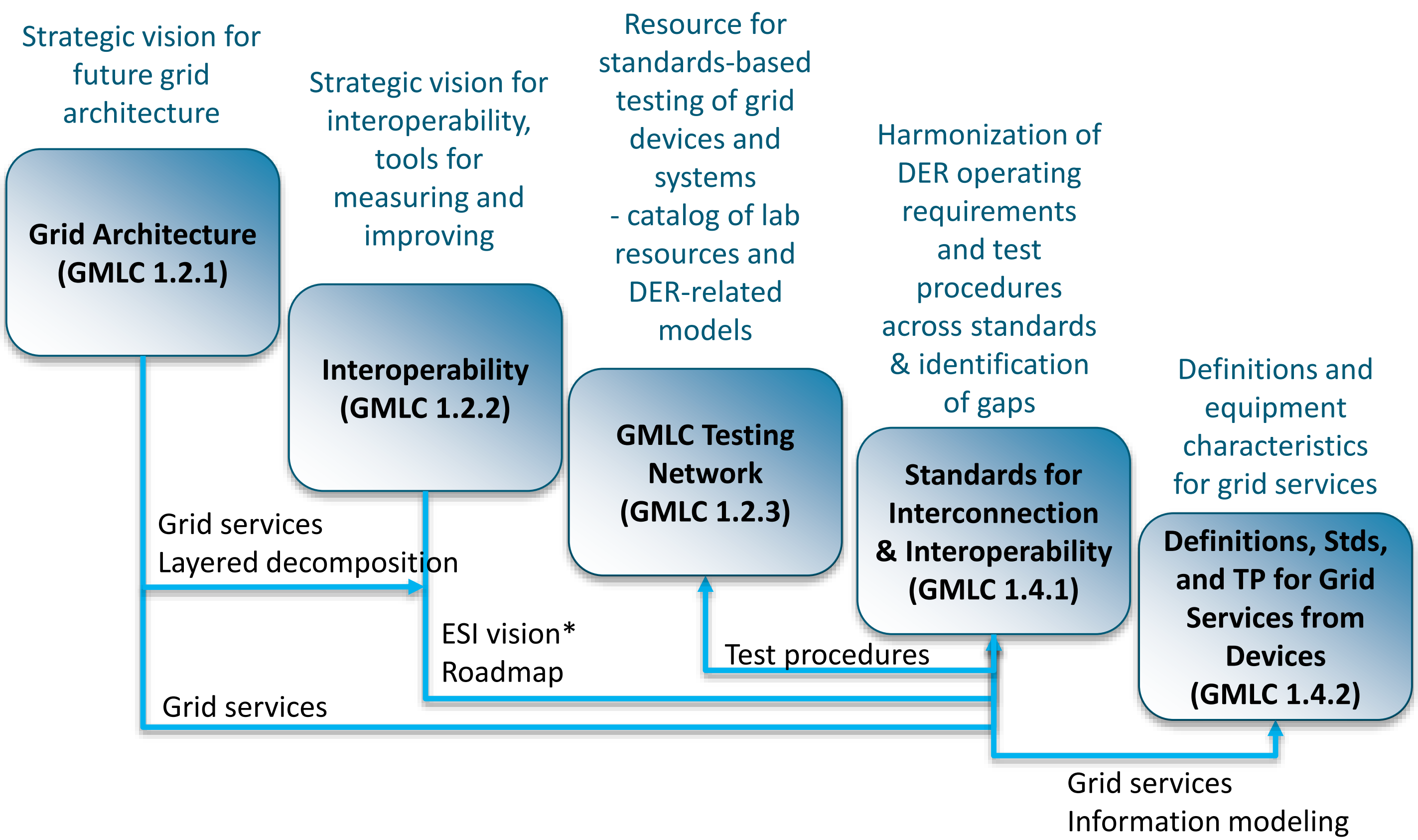
- Phase 1 launched Jul 2018
  - Website: http://plugandplayder.org/
  - Presentations at Solar Power International 26 Sep 2018
- Phase 2 planning underway, investigating approaches for funding potential submitters
  - Phase 1 submitters have opportunity to form teams and update proposals for moving into Phase 2

Partners: SEPA, EPRI, NIST

1.2.2 Interoperability
Engagements & Publications

- ✓ Documents: www.gridmod.labworks.org/projects/1.2.2
  - ➢ Declaration of Interoperability
  - ➢ Interoperability Strategic Vision whitepaper & report
  - ➢ Interoperability Maturity Model (IMM)
  - ➢ Interoperability Roadmap Methodology
- ➢ Articles and Presentations
  - ➢ Public Utilities Fortnightly article, Apr 2017
  - ➢ IEEE Smart Grid Newsletter article, Jun 2018
  - ➢ Interactions at SEPA Grid Evolution Summit, IEEE Power & Energy Society ISGT, T&D, and General Meetings, Transactive Energy Systems Conference, AHR Expo, GWAC
- ✓ Demonstrable public stakeholder involvement
  - ➢ Established partnership with 16 organizations and held 14 web coordination meetings
  - ➢ Sep 2016 and May 2017 stakeholder technical meetings with ~50 participants from various industry segments
  - ➢ Jun 2018 IEEE 2030.5 ecosystem interoperability roadmap meeting with ~25 members
  - ➢ Aug 2018 Plug & Play DER Challenge webinar, ~90 registered

GMLC Project Coordination



*Energy Services Interface

1.2.2 Interoperability
Year 3 Upcoming Objectives and Plan

- **Interoperability strategic vision** continue communications and socialization, Mar 2019
  Impact – align stakeholder community on vision for integration
- Complete **roadmap trials** with using methodology and interoperability maturity model
  Impact – test interoperability measurement and path forward tools
  - 2030.5 ecosystem roadmap, Mar 2019
  - JRC EV charging ecosystem, Jun 2019
  - Revise roadmap methodology and IMM with lessons learned, Jun 2019
- Complete **reference interoperability procurement language** with industry stakeholders participation, Mar 2019
  Impact – incentives for industry participation to advance interoperability
- Announce Phase 1 concepts finalists, form Phase 2 teams, and **demonstrate visionary interoperability capability**, Jun 2019
  Impact – encourage interoperability advancement

Grid Modernization Initiative
Peer Review
GMLC Project 1.2.3: Testing Network and Open Library

MATTHEW LAVE,
SANDIA NATIONAL LABORATORIES

ROB HOVSAPIAN,
IDAHO NATIONAL LABORATORY

September 4–7, 2018

Sheraton Pentagon City Hotel – Arlington, VA

1.2.3 Testing Network and Open Library
High-Level Project Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

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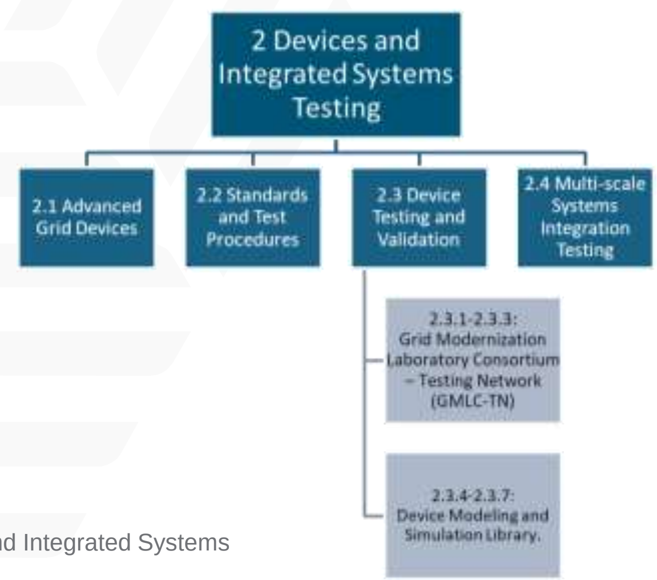
Value Proposition

- ✓ Access to testing resources and validated models is vital to grid modernization
- ✓ Make optimal use of vast and growing set of grid-related testing and simulation resources at National Labs and beyond.
- ✓ Major opportunities to make an impact by improving information, accessibility, and collaboration

Project Objectives

- ✓ Establish a Testing Network (GMLC-TN) as a federated, lab-based resource for testing and performance validation of grid devices and systems
- ✓ Establish an Open Library (GMLC-OL) as a public repository for validated models, simulation tools and testing resources

MYPP



Aligns with other activities:

- Devices developed in 2.1 can be tested in the TN
- Test procedures developed in 2.2 can be collected in the OL
- Multi-scale testing in 2.4 can utilize the TN

1.2.3 Testing Network and Open Library

Project Team

Project Participants and Roles	
Sandia	Project lead, lead for TN task
INL	Lead for OL task
NREL, ORNL, LBNL	Support TN and OL tasks, including partnerships & outreach; supply models, simulation tools and testing resources
ANL, PNNL, SRNL, BNL, LLNL	Former team members who contributed (and continue to contribute) to testing information and model collection
Utilities, Natl. Labs, Academia, Manufacturers	Stakeholders: users of TN and OL; contributors to OL; future members of TN

PROJECT FUNDING

Lab	**PY1** (Apr 16-Apr 17) **[$k]**	**PY2** (Apr 17-Apr 18) **[$k]**	**PY3** (Apr 18-Apr 19) **[$k]**
Sandia	350	300	200
Idaho	150	250	250
NREL	75	150	50
Oak Ridge	75	150	50
Berkeley	75	150	50
Argonne	75		
Pacific Northwest	75		
Savannah River	75		
Brookhaven	25		
Lawrence Livermore	25		
TOTAL	**$1M**	**$1M**	**$600k**

1.2.3 Testing Network and Open Library

Approach

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Stakeholder outreach and coordination

	End of Year Results
PY1 – Establish Foundations 1. Host TN stakeholder workshop 2. Catalog and publish testing capabilities at DOE Natl. Labs 3. Design common framework for testing capability and OL 4. Engage existing consortia, conduct pilot to inform TN/OL	Framework for TN established; TN and OL coordination on specifications for grid-related devices; initial catalog of National Lab testing capabilities. Value of TN/OL confirmed through stakeholder workshop.
PY2 – Deploy GMLC TN/OL 1. Launch TN via Membership Agreement & website 2. Publish expanded testing capability assessment. 3. Populate the OL with models from Natl Labs/GMLC	TN formally established and launched through a fully functional public website, including an interactive catalog of testing resources and an initial implementation of the OL.
PY3 – Ensure Future Sustainability 1. Develop sustainability plan including operations costs 2. Outreach including technical sessions at conferences 3. Expand OL to increase tools/models and improve usability	By the end of PY3, a mechanism to sustain the TN and OL without dedicated federal investment will be put in place.

>PY3 – Transition

1.2.3 Testing Network and Open Library
Accomplishments to Date

Testing Capabilities Catalog (March 2018)

http://gridmodtools.org/testing-catalog/

- Extensive self-assessment of grid test capabilities and facilities
  - 12 DOE National Labs
  - 49 distinct facilities
  - 100s of test facility/test capability pairs
- Formatted as report:
  - Introduction on motivation and how to use information
  - Appendix on partnerships
  - Test facility/capability information presented as both overview tables and detailed paragraphs

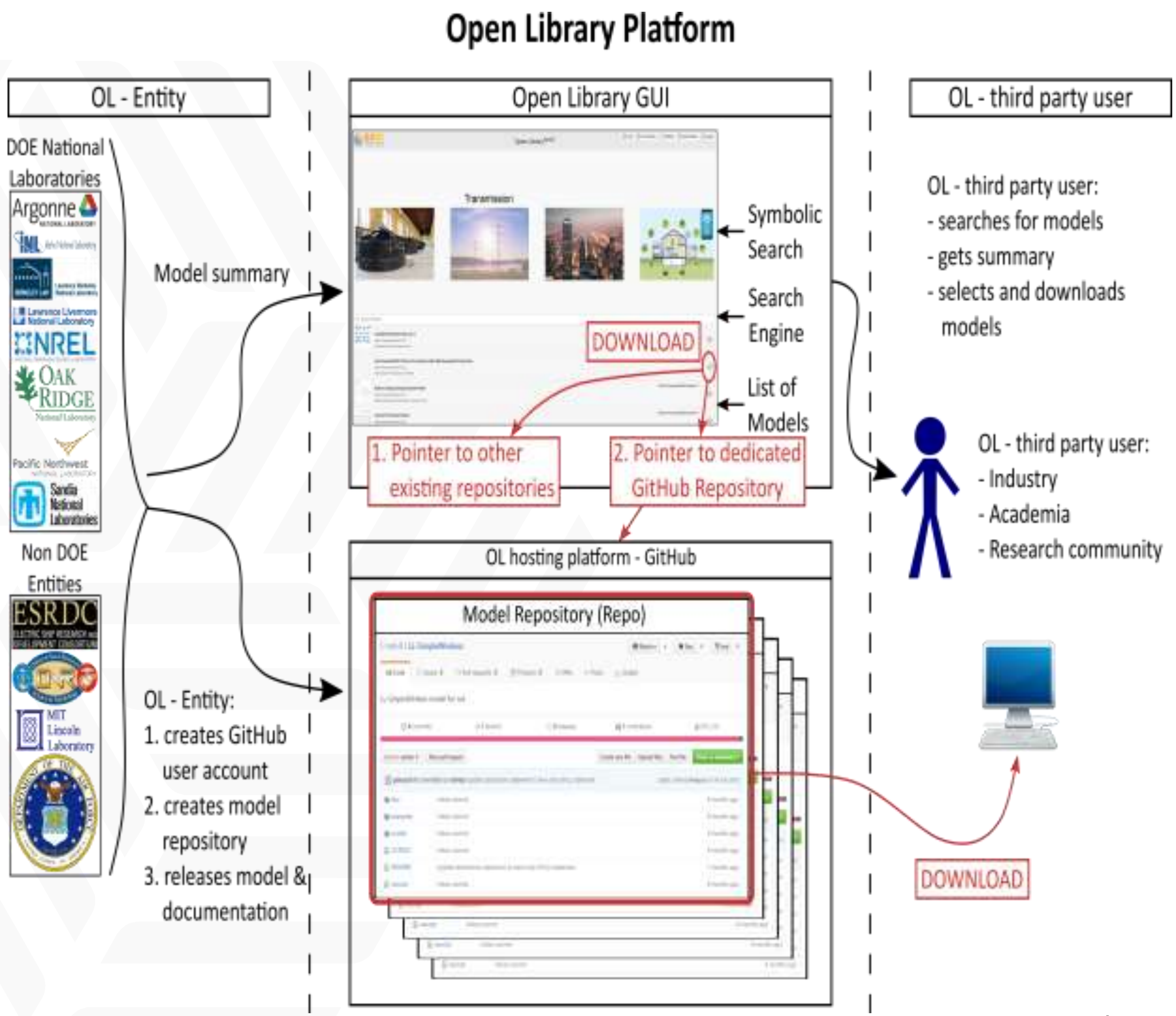
Test Facility
- Energy Systems Integration Facility (NREL)
- Distributed Energy Technologies Laboratory (Sandia)
- …

Test Capability
- Communications Interoperability
- Cybersecurity
- Hardware in the Loop
- Grid Compatibility and Interconnection
- Reliability / Safety / Failure Analysis
- Systems Integration and Control

Application Tech.
- Building Technologies
- Dist. Sys. Components
- Electric Vehicles
- Energy Storage
- Fuel Cells
- ICT and AMI
- Integrated Energy Systems
- Microturbines and Gensets
- PV
- Trans. Sys. Components
- Wind

Open Library

- Store and access:
  - Models
  - Data
  - Test plans
  - Procedures
- Configuration management
  - Highlight proprietary models
  - Link to models on github repository
  - Link to models on other existing repository
  - Validation of results



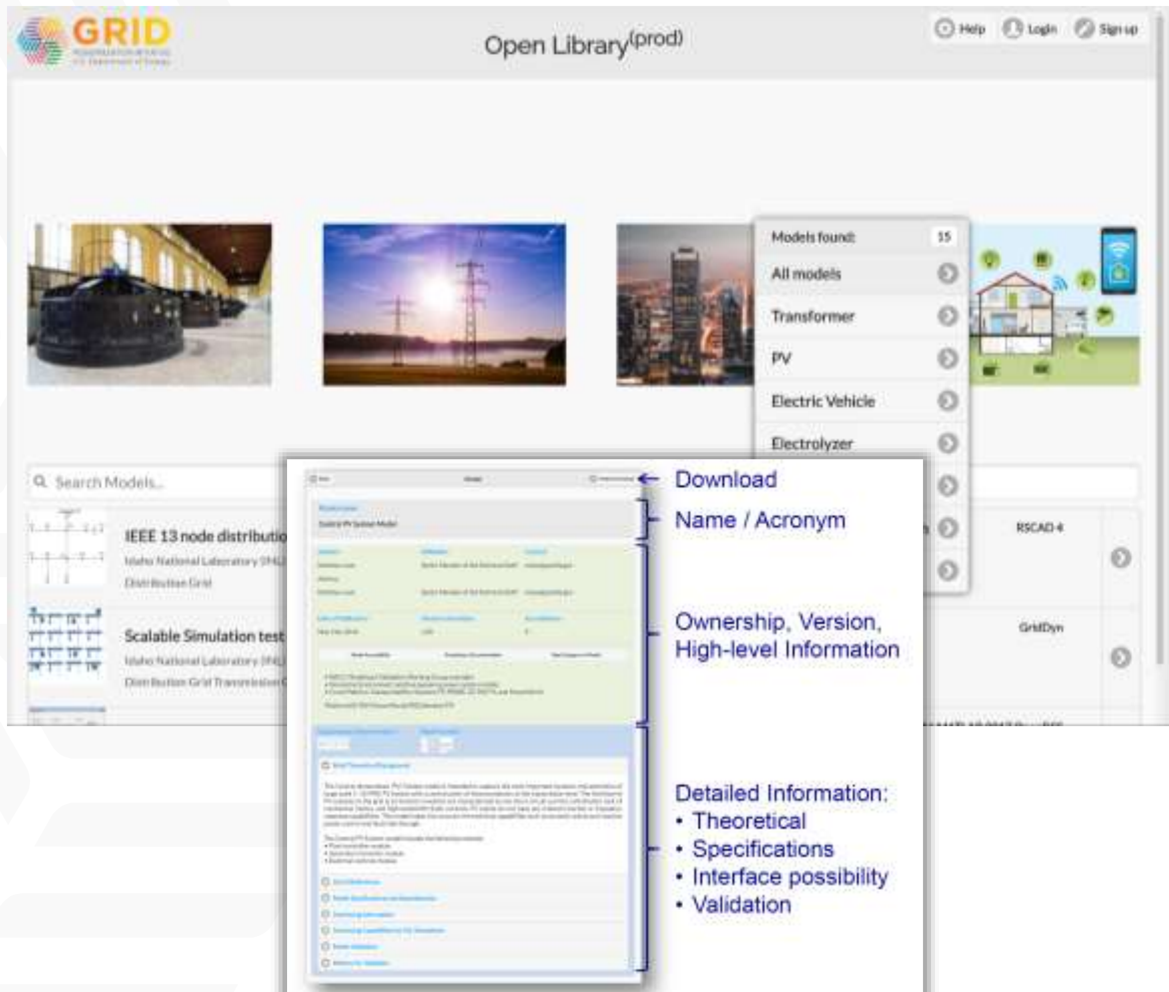
1.2.3 Testing Network and Open Library

Accomplishments to Date

Open Library Implementation (March 2018)

http://gridmodtools.org/open-library/

- Searchable, sortable database of open models related to grid modernization
  - 4 main categories: Generation, Transmission, Distribution, Smart Home
  - Sub-categories (e.g., PV)
- Models collected from National Labs/GMLC projects
  - >30 models across 10 National Labs
  - Will be the repository for models and tools resulting from GMLC projects
- Model upload by non-National Lab members will be implemented shortly



1.2.3 Testing Network and Open Library
Accomplishments to Date

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Team
Sandia National Laboratories
INL Idaho National Laboratory
BERKELEY LAB
NREL
OAK RIDGE National Laboratory

GMLC 1.2.3

Testing Network (TN)

Federated, lab-based resource for testing and performance validation of grid devices and systems.

Open Library (OL)

Public repository for validated models, simulation tools, and testing resources.

gridPULSE

Public User Library for Systems Evaluation

Consortium formed in October 2017 to address the project's goals of accelerating grid modernization by enabling access to a comprehensive testing infrastructure and model library

project organization | project outcome

1.2.3 Testing Network and Open Library

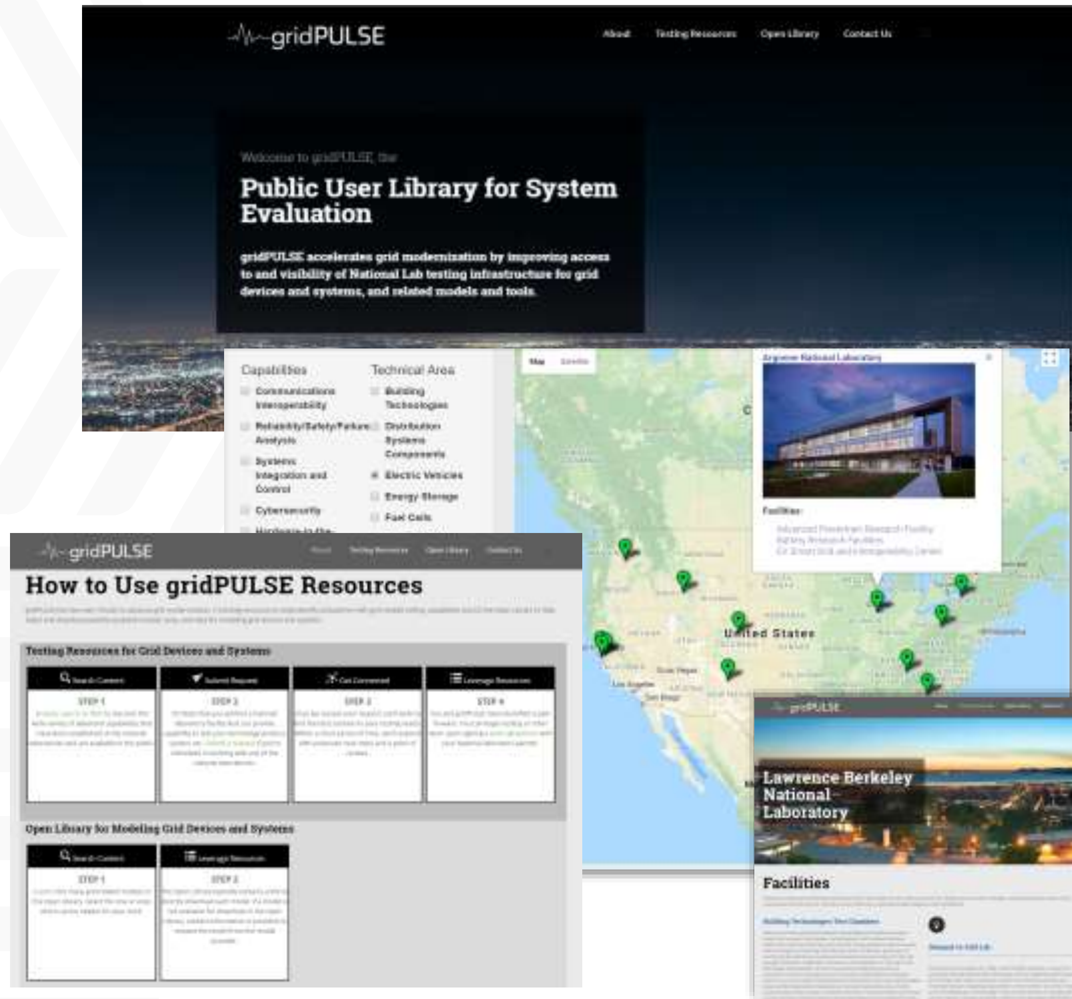
Accomplishments to Date

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

gridPULSE website (April 2018)

http://gridmodtools.org/

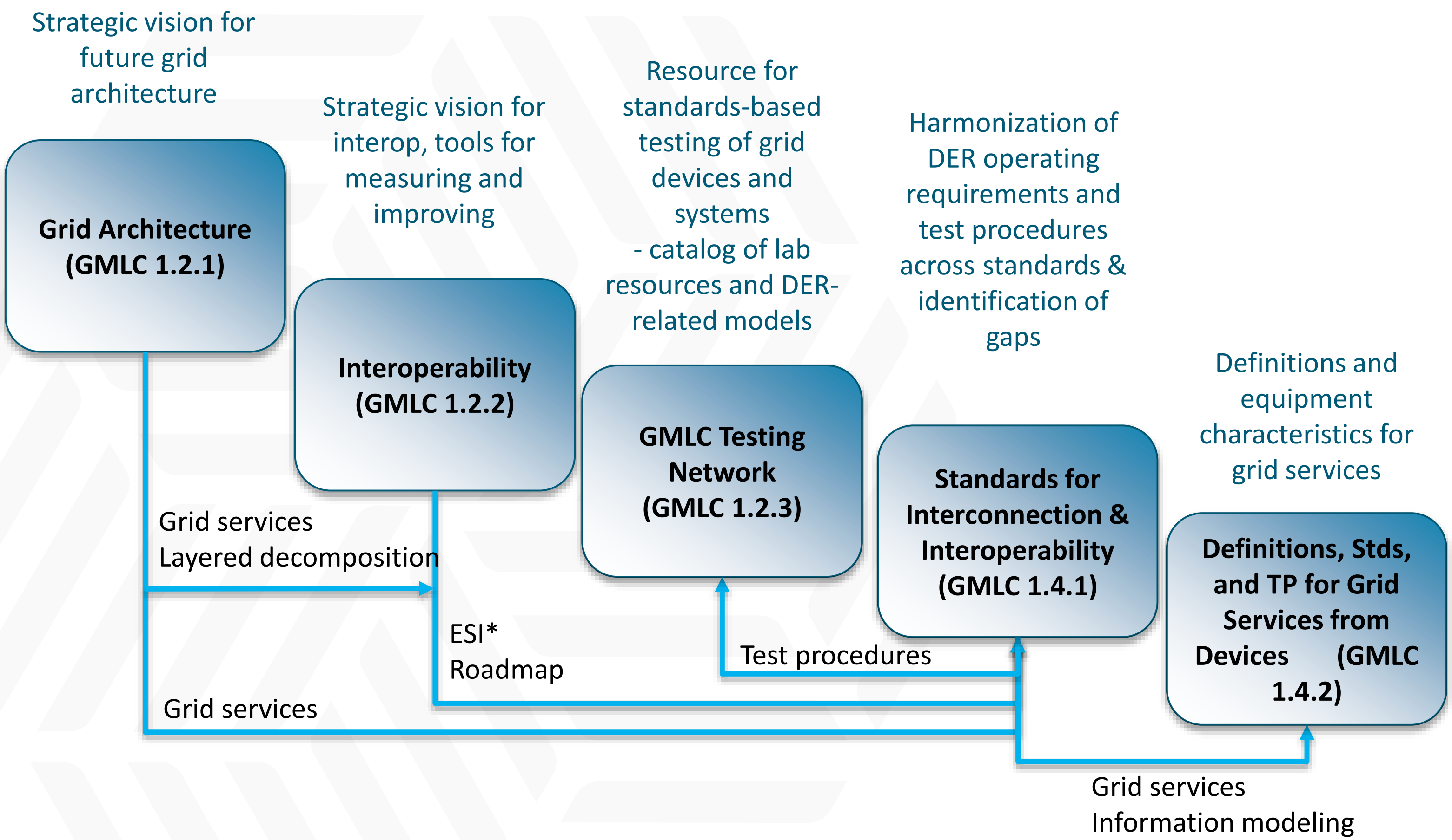
- About
  - How to Use gridPULSE Resources
  - Partnering with DOE National Labs
- Testing Resources
  - Sortable Matrix
  - Interactive Map
  - By Lab
- Open Library
- Contact Us



- Interactive presentation of information
- Facilitates quick updates to testing capabilities and to open library
- Hyperlinks to partnerships contacts, additional information on Lab facilities, model download, contact

1.2.3 Testing Network and Open Library

Accomplishments to Date



*Energy Services Interface

1.2.3 Testing Network and Open Library

Next Steps and Future Plans

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

gridPULSE is a public resource for testing capabilities and models

- Enduring resource that supports grid modernization by enhancing access to and collaboration among test facilities and models

Project Goals (by end of PY3 – Apr 2019)

- Update capabilities catalog and open library
  - Facilities/capabilities updates quickly added to website
  - Adapt information organization to highlight additional user interests (e.g., “resilience” capabilities)
  - Expand open library, including opening model submission to non-National Lab members
- Develop sustainability plan
  - Value proposition
  - Cost funding plan
  - Success metrics
- Outreach to spread word about gridPULSE
  - Webinar (Oct. 23, 2018),
  - Conferences (2 in June 2018, more upcoming),
  - Networking e.g. Linkedin
  - Education among existing Laboratory programs (e.g., research alliances, small business programs)

1.2.3 Testing Network and Open Library

Next Steps and Future Plans

beyond PY3…

Sustainability

- Developing business cases – quantify how industry uses gridPULSE and the benefit they receive
- Modeling after other DOE consortia (e.g., LightMAT) and other groups (e.g., DERLAB)
- Exploring funding options – gridPULSE utilized as repository for and funded by upcoming projects linking lab capabilities; include gridPULSE services in DOE funding calls to industry; support through lab discretionary money; etc.

Future Growth Opportunities

- Extend the testing network beyond DOE National Labs (DoD, NIST, universities, industry)
- Facilitate linking National Laboratory testing capabilities to produce “integrated capabilities”
- Expand open library to present systems-level solutions – combinations of component models to simulate complex grid systems

GRID MODERNIZATION INITIATIVE
PEER REVIEW

Standards & Test Procedures for Interconnection & Interoperability

Updating Standards for the Modern Grid (GMLC 1.4.01)

DAVID NARANG

September 4–7, 2018

Sheraton Pentagon City Hotel – Arlington, VA

Standards & Test Procedures for Interconnection & Interoperability

Project Summary

GRID
MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

- **Accelerate** the development and validation of interconnection and interoperability standards
- Ensure **cross-technology compatibility** & harmonization of requirements for key grid services

Project Objectives

✓ **Harmonize requirements** among standards development organizations

✓ **Minimize conflicting requirements** across technology domains

✓ **Streamline** conformance test procedures to the fullest extent possible

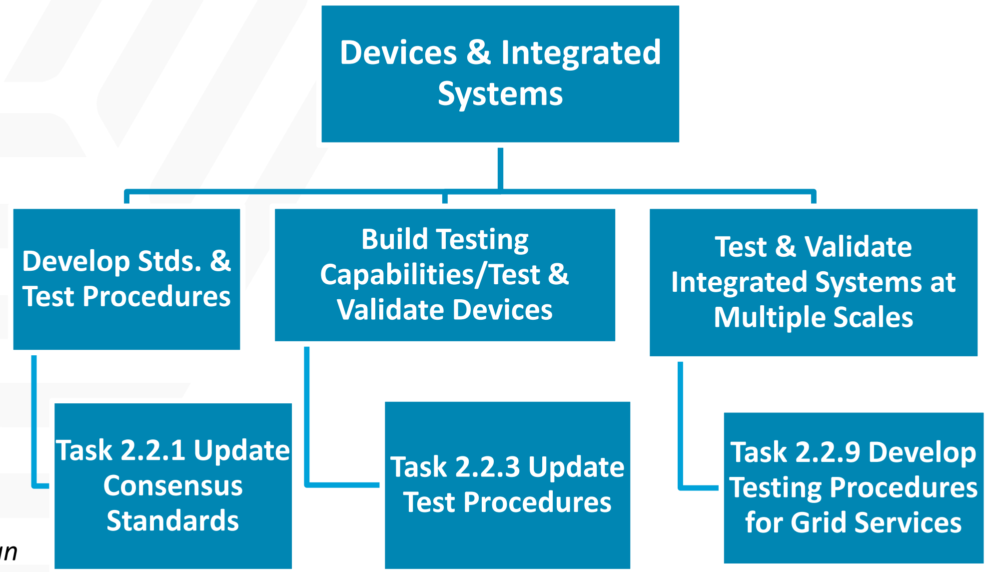
Value Proposition

✓ **Improve coordination** of modern energy generation & storage devices with the grid

✓ **Enable market expansion** through improved interoperability

✓ **Reduce barriers** to deployment through improved standards

Alignment with DOE MYPP* Goals & Vision



**Multi-Year Project Plan*

Standards & Test Procedures for Interconnection & Interoperability

Approach

Key Issues

- Standards are typically developed within each domain area and often lack a complete vision for end-to-end interoperability to deliver grid services cost-effectively, securely and reliably.
- Standards for distributed energy resources need to be updated to effectively deploy and utilize modern grid-interactive generation and storage devices/systems.
- Updated standards will enable important technologies to securely interact with each other and the grid to optimize solutions among multiple objectives, stakeholders and markets.

Distinctive Characteristics

- This team is unique in having such a wide breadth of lab capabilities and team member expertise under the same project. This greatly improves the ability to harmonize across multiple standards and technology domains.

Approach

- The 1.4.1 team is providing leadership and direct technical contribution to key standards development activities at multiple standards organizations.

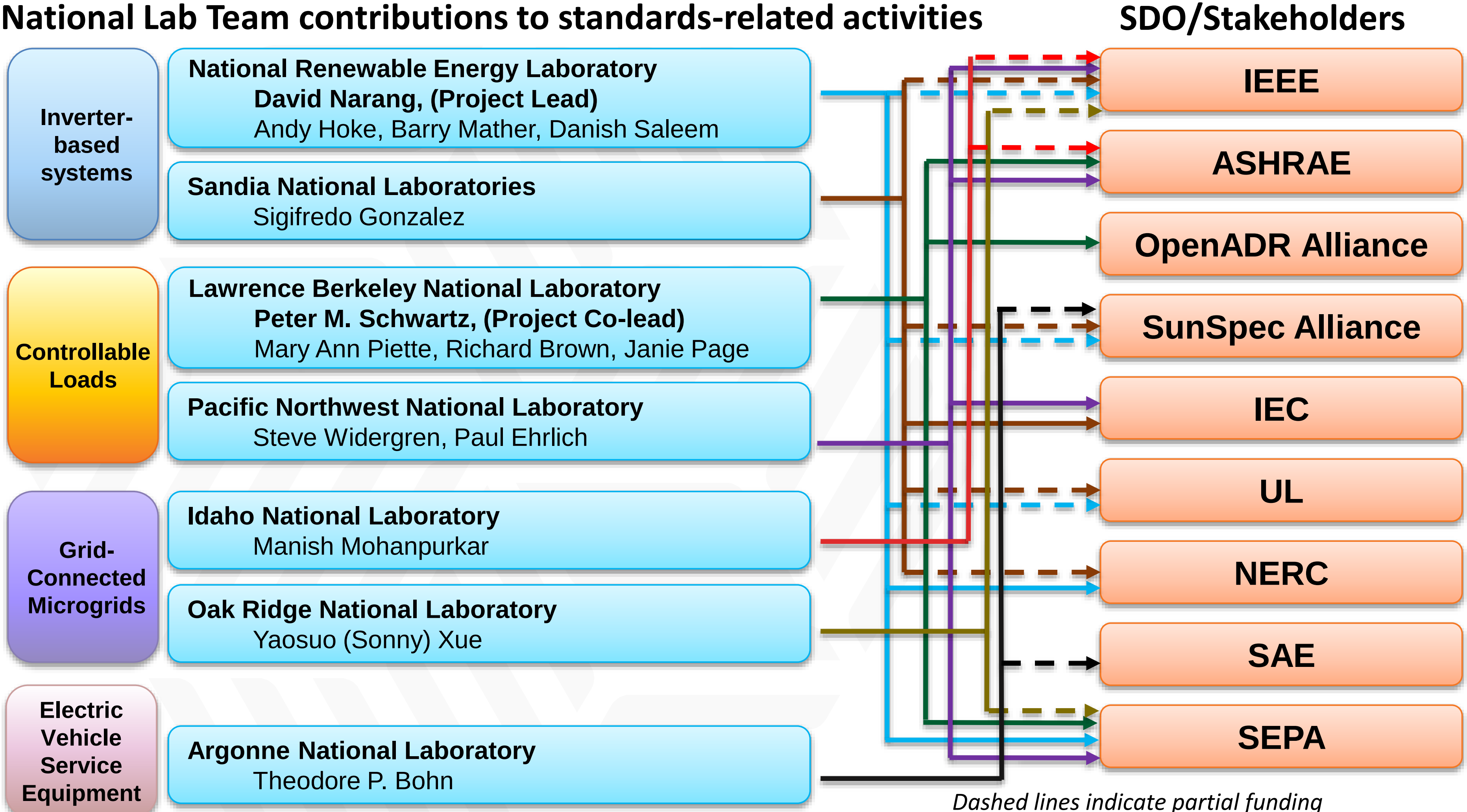
PROJECT FUNDING

Lab	FY16 $	FY17$	FY18 $
NREL	$240,000	$230,000	$230,000
LBNL	$240,000	$230,000	$230,000
PNNL	$240,000	$230,000	$230,000
SNL	$160,000	$153,333	$153,333
ANL	$160,000	$153,333	$153,333
ORNL	$80,000	$76,667	$76,667
INL	$80,000	$76,667	$76,667
Total	**$1,200,000**	**$1,150,000**	**$1,150,000**

Standards & Test Procedures for Interconnection & Interoperability

Project Team and Focus/Roles

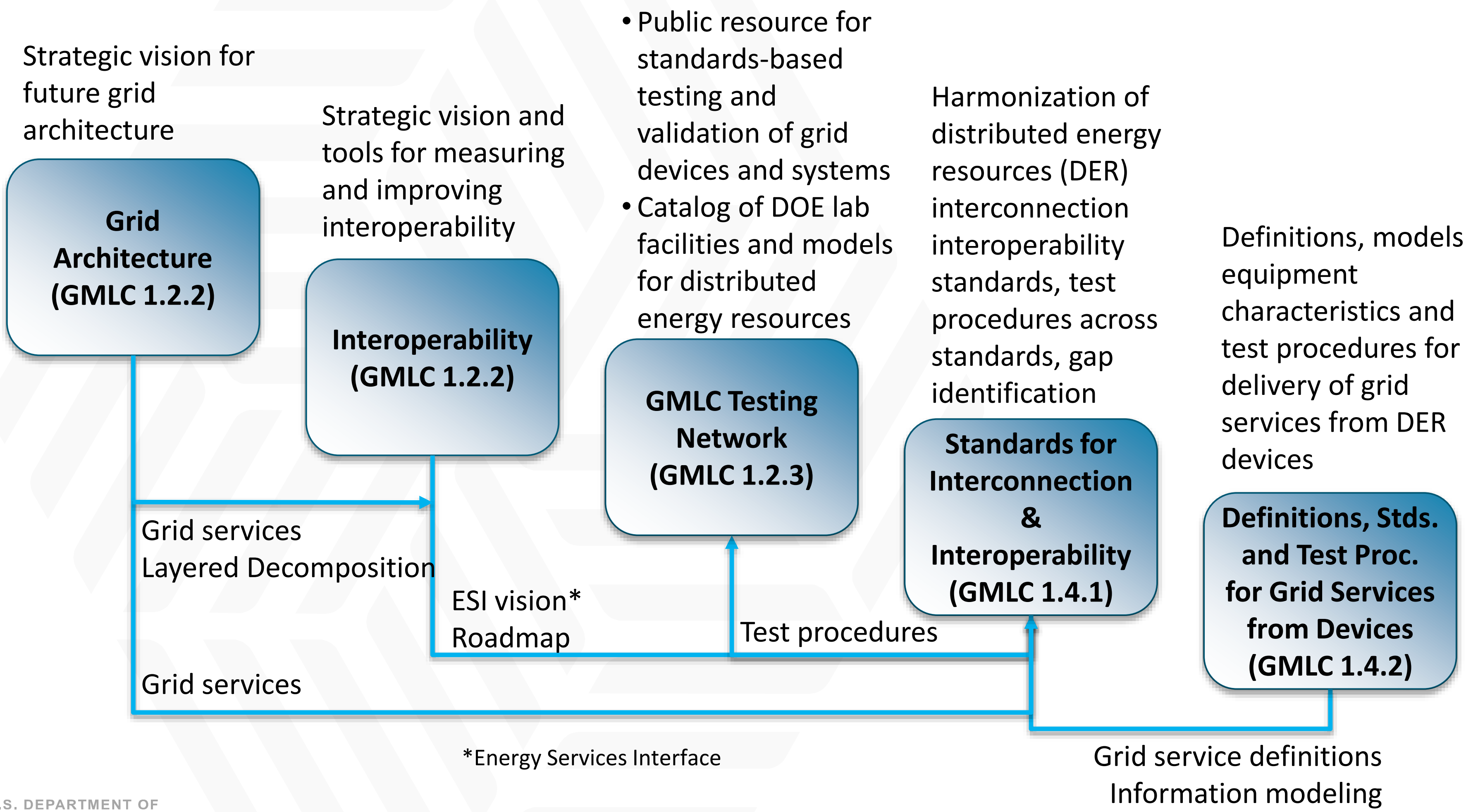
National Lab Team contributions to standards-related activities



Dashed lines indicate partial funding

Devices and Integrated Systems

Project Coordination

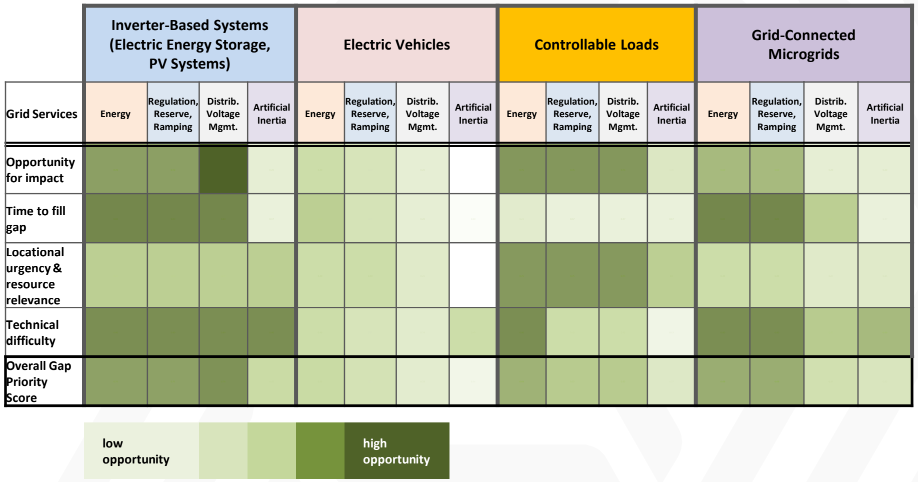


*Energy Services Interface

Standards & Test Procedures for Interconnection & Interoperability

Accomplishments to Date – Gap Prioritization Highlights

Gap Analysis and Prioritization - Revised in Year 2 (May 2018)



Observations/Recommendations: Inverter-based systems

- Photovoltaics and electric energy storage are already capable of providing most or all of the grid services highlighted
- Interconnection and interoperability standards already do support or are near to supporting the highlighted grid services
- More work is needed on cybersecurity

Observations/Recommendations: Controllable Loads

- There is a high opportunity for these types of assets to provide grid services.
- To date, demand response has been the most widely implemented.
- Common standards for using loads/local generation to provide other grid services don’t exist or are in the very early stages.
- Many conceptual frameworks require an energy services interface but there are no standardized specifications

Observations/Recommendations: Grid-connected microgrids

- Microgrids can be considered flexible assets that may assist distribution system operators during both normal and emergency situations.
- Common standards for using these assets to provide grid services don’t exist or are in the very early stages.

Observations/Recommendations: Electric Vehicles

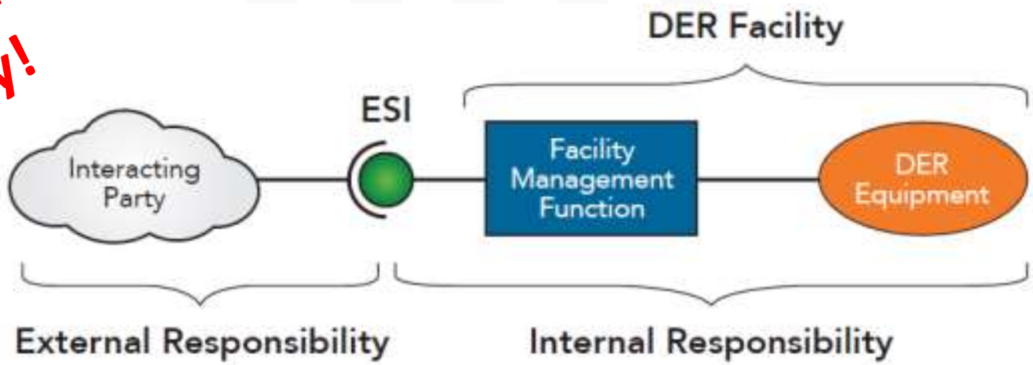
- Use of electric vehicles to provide grid services is still in the development stages.
- There are significant gaps in developing the business case and market for this application
- Common standards for using these assets to provide grid services don’t exist or are in the very early stages.

Standards & Test Procedures for Interconnection & Interoperability

Accomplishments to Date – Addressing Gaps

Lack of a common definition and requirements for an Energy Services Interface (ESI) was noted as a key gap for controllable loads in Year 1

Collaboration opportunity!



High level diagram of ESI and related functions (courtesy S. Widergren)

This team is contributing to development of requirements for the energy services interface

- ESI requirements kickoff webinar on May, 2018, hosted by LBNL, with over 100 participants
- ESI test plan in development for responsive load use case at LBNL
- Coordination with interoperability team on ESI concepts in the “Plug & Play DER Challenge”
- The 1.4.1 team is collaborating with SEPA & broader stakeholder group on ESI definition, standardization, and interaction with existing interconnection and interoperability standard

Standards & Test Procedures for Interconnection & Interoperability

Accomplishments to Date – Project Outreach

Stakeholder Engagement

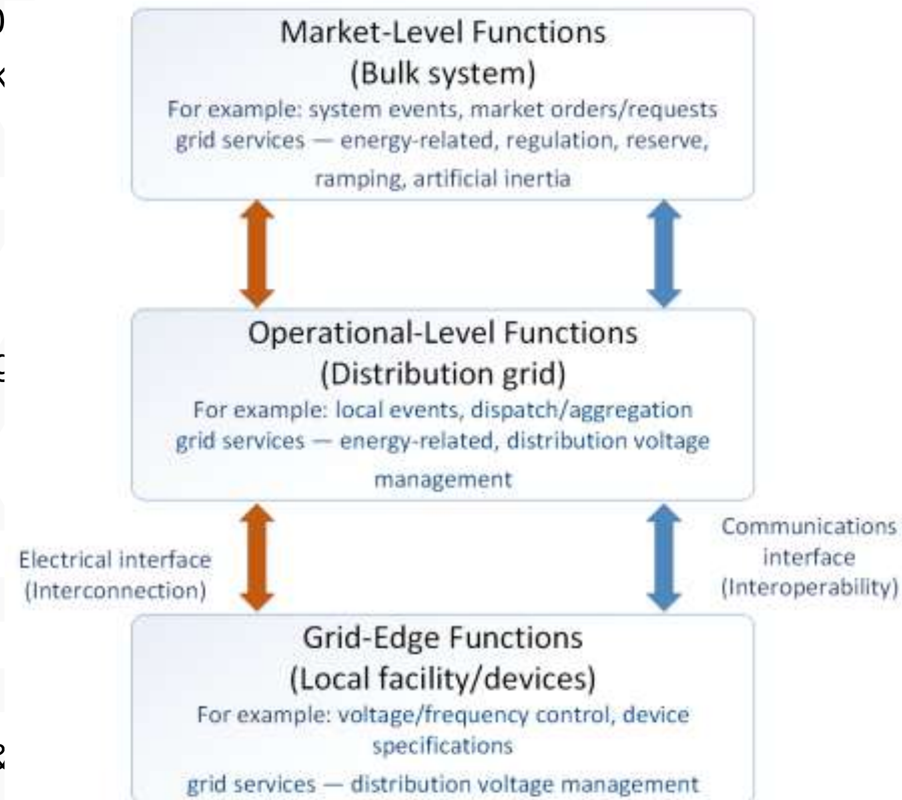
- Webinar – Energy Services Interface (ESI) (May, 20
- Discussions with ASHRAE BACnet Smart Grid work group for collaborations on ESI (Jan, 2018)
- Discussions with SEPA technical committees for collaboration on ESI use case development (July, 2018)
- Team web conferences with individuals representing SunSpec Modbus, IEEE 2030.5, and OpenADR (throughout year)

Publications

- Gap Analysis & Prioritization (Revised May, 2018)

Closing Gaps in Standards

- Collaboration with SEPA on ESI concept definition & standardization



High-level view of coordinated grid operations

Standards & Test Procedures for Interconnection & Interoperability

Next Steps and Future Plans

Planned future project activities & impacts

- Q1 FY 2019 … Contribute to ESI definition in collaboration with SEPA/NIST (possibly leveraging interoperability roadmap method developed in 1.2.2, create a roadmap for standardization of the ESI)
- Q2 2019….Collaboration with GMLC 1.2.2. team to review “Plug and Play DER Challenge” proposals for future standards-related material
- Q2/Q3 2019….Collaboration with SunSpec Alliance to create electric vehicle supply equipment (EVSE) test environment for IEEE 2030.5 test and certification
- Q4 FY 2019….Revised gap analysis under review by DOE for publication

GRID MODERNIZATION PEER REVIEW

GMLC 1.4.02: DEFINITIONS, STANDARDS AND TEST PROCEDURES FOR GRID SERVICES FROM DEVICES

ROB PRATT, PRINCIPAL INVESTIGATOR

September 4–7, 2018

Sheraton Pentagon City Hotel – Arlington, VA

Definitions, Standards and Test Procedures for Grid Services from Devices

High-Level Project Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

- **Develop and test high-resolution models of distributed energy resources** (DERs) with a **standardized interface** in the form of a **battery-equivalent (BEq) representation**, for
- Ready access by planning and operational tools in assessing DERs' ability to provide operational flexibility in the form of valuable grid services
- At the bulk system and local distribution levels.

Project Objectives

✓ **High-resolution models explicitly model** engineering, operational, & human constraints

✓ **Standard battery-equivalent model interface** applicable to all device classes

✓ **Prototypical "drive cycles" for** devices providing a **wide variety of grid services**

✓ **Trial analysis** using models & drive cycles **to exemplify device potentials**

Value Proposition

Common BEq representation/interface allows:

✓ Grid operations & planning models easily & accurately assess DERs

✓ Contributions of DER classes to be "summed"

✓ Grid control & optimization methods to be shared across DER types

✓ Consideration of BEq as a grid flexibility metric

✓ Level-playing field for evaluating DERs

Activities of this project

GMMYPP Goal 1:
lean reserve margin

GMMYPP Goal 2:
resilient distribution w/ renewables

GMMYPP GOAL 3:
advanced planning & analytics

Definitions, Standards and Test Procedures for Grid Services from Devices

Project Team

Project Participants and Roles			Project Funding			
Lab	**Device Class**	**Grid Services**	**FY16**	**FY17**	**FY18**	**Total**
PNNL		A. Peak load management B. Artificial inertia/primary frequency response	$351K	$406K	$196K	$953K
NREL	1. Water heaters 2. PV/inverters	C. Distribution voltage management / PV impact mitigation	$226K	$351K	$508K	$1,085K
SNL	3. Batteries/ inverters		$106K	$153K		$259K
ANL	4. Electric vehicles (V1G)		$141K	$276K	$508K	$925K
ORNL	5. Com. HVAC 6. Com. refrigeration		$146K	$308K	$508K	$962K
LBNL		D. ISO capacity market (e.g., PJM's) E. Fast Regulation F. Slow regulation G. Spinning reserve	$211K	$225K		$436K
INL	7. Fuel cells 8. Electrolyzers		$146K	$158K		$304K
LLNL		H. Wholesale energy market price response	$94K	$154K	$38K	$286K
Totals			**$1,421K**	**$2,031K**	**$1,758K**	**$5,210K**

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Approach:

- Represent wide variety of grid services (n=8) as prototypical time-series events ("drive cycles")
  - Time-series injection/withdrawal of real or reactive power
  - Metrics summarizing engineering & economic performance of device fleets
- Develop high-fidelity quasi-steady time-series device simulation models (n=8) in Python
  - Physics & operational constraints (e.g., control, human behavior)
  - Represent diversity in DER fleets using population of individual devices with distributions of characteristics
- Conduct informative trial analysis of 8 devices x 8 grid services
- Develop common representation of all device classes as "battery-equivalents" (BEqs)
  - Simple, common standard interface allows ready use by high-level planning & operations tools
- Identify possible extensions of DOE efficiency standard's testing to provide device parameters
- Obtain parameters & validate models (water heaters, com. refrigeration, EVs) via characterization test

Key Issues:

- Scope changed after year 1, dropping testing/rating protocols
  - Re-cycled device models, grid service drive cycles, BEq concept from Year 1
  - Added needs: diverse device fleets; ease of use requires more software architecture & integration

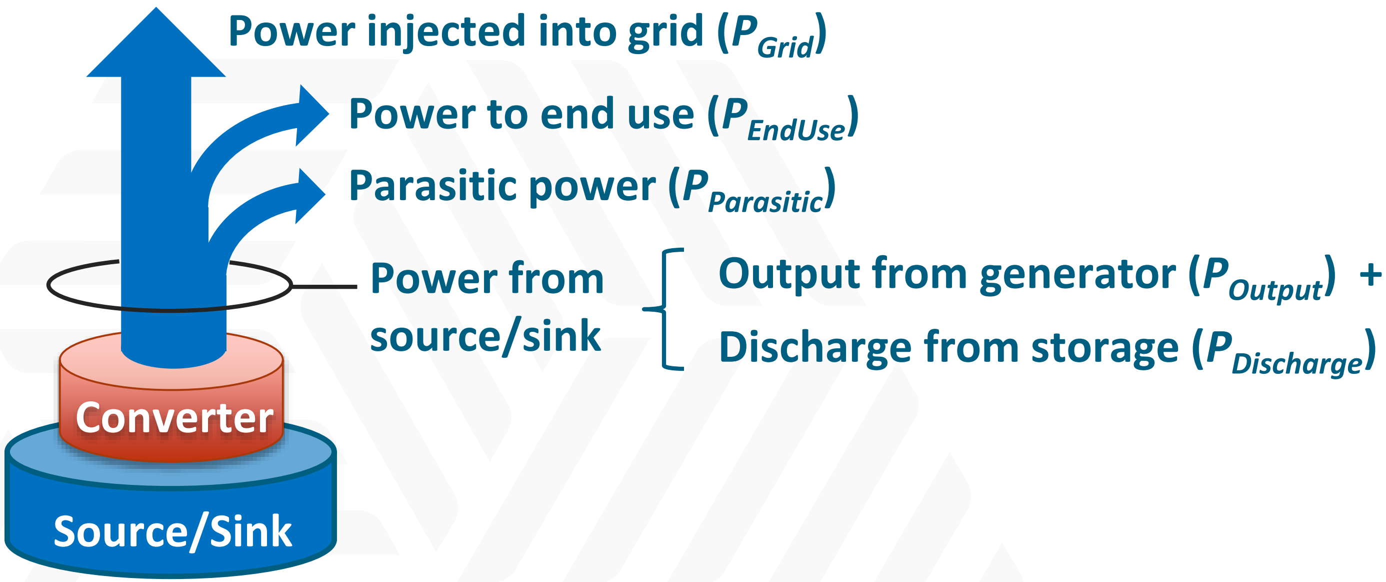
What is a *Battery-Equivalent Model*?

Battery-equivalent model of devices:

- Common, uniform means of representing properties of any DER device as a "virtual battery"
  - In terms used to characterize battery/inverter systems
  - Extended with additional generalized properties & constraints needed to describe other types of DERs
  - Like a "virtual power plant" concept except more general: consumes, stores, discharges ("produces") energy

- Individual discretely variable ("on/off") devices can't act in continuously variable way a battery does – fleets of such devices can do so

Power/Energy Balance & Grid Services for a DER



Power Balance:

$$P_{Grid}(t) = P_{Discharge}(t) + P_{Output}(t) - P_{Enduse}(t) - P_{Parastic}(t)$$

Power for Grid Service:

$$P_{Service}(t) = P_{Grid}(t) - P_{GridBase}(t)$$

; where Base indicates base case

$$P_{Service}(t) = \Delta P_{Discharge}(t) + \Delta P_{Output}(t) - \Delta P_{Enduse}(t) - \Delta P_{Parasitic}$$

; where Δ is the difference between the service case & base case

Definitions, Standards and Test Procedures for Grid Services from Devices

Battery-Equivalent Representations of DERs

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Attribute	Batteries	PV Systems	Air Conditioning	Electric Vehicles (charging only)
Source/Sink	electrochemical battery	PV array	thermal mass of building	electrochemical battery
State-of-Charge	$\frac{\text{energy stored}}{\text{energy capacity}}$	N/A	$\frac{T_{room\_max} - T_{mass}}{T_{room\_max} - Troom_{\_min}}$	$1 - \frac{\text{deferred charging energy}}{\text{max. deferrable charging}}$
Converter	AC/DC inverter		refrigerant cycle	DC power supply
Power Generated	N/A	AC output from inverter (real and/or reactive)	N/A	
Power to End-Use	N/A		power to maintain current mass temp.	N/A
Parasitic Power	inverter standby power + self-discharge losses + any thermal conditioning	inverter standby power	fans + pumps	charger standby losses + any pre-heating/cooling
Power Conserved	N/A		reduced demand due to increased room temp.	N/A
Charging Efficiency	inverter/battery charging efficiency	N/A	system efficiency under current conditions	current charging efficiency
Discharging Efficiency	inverter/battery discharging efficiency	N/A	100% (already in thermal form)	100% (simple energy deferral)

Definitions, Standards and Test Procedures for Grid Services from Devices

Battery-Equivalent Representations of DERs

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

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Converter				
Power Generated				
Power to End-Use				
Parasitic Power				
Power Conserved				
Charging Efficiency				
Discharging Efficiency				

Developed rigorous basis for describing diverse DERs as equivalent batteries (July 31 2018)

- Not shown: water heaters, commercial refrigeration, electrolyzers, fuel cells

Other attributes not shown:

- Real & reactive power for services, max. & min
- Max. ramp rate, up & down
- Time limit for holding zero state-of-charge (SoC)
- Time of day SoC must be restored to desired condition (e.g., 100%)
- Incentive threshold ($) – covers impact on equipment & users

Grid needs simplified, unified view of DERs

- Shields planners & operators from complexity inherent in each device class

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Grid Services: Diverse, Complex, Regional, & Dynamically Variable

Service	Operational Objective	Time Scale	Event Duration	Recurrence	Power for Service
Peak capacity management	reduce net load to meet an infrastructure constraint	15-min to 1-hour	4-8 hours	10-15 days/yr	supply: up load: down
Capacity market value	supply reserve "generation" on demand	15-min to 1-hour	4-6 hours	~5 days/yr	supply: up load: down
Energy price response	reduce price spikes by shifting net load to low price periods	5-min	Real-time or day-ahead	continuously	supply: up & down load: down & up
Frequency Regulation	supplement power plants in continually balancing supply & demand	4-sec	continuously	continuously	supply: up & down load: down & up
Spinning reserve	rebalance supply & demand after sudden loss of generation (or transm.)	~1-min	<2-hour	~15 times/yr	supply: up load: down
Artificial inertia / primary freq. response	arrest rapid frequency change & re-stabilize it during grid contingencies (usually loss of generation)	~1/60 sec	~1 or 10 - min	continually	supply: up* & down load: down* & up
Distribution voltage management	minimize voltage fluctuations from rapidly changing PV output by injecting or consuming reactive power	~1-min	~1-hour/day	continually; especially on cloudy days	supply: up & down load: down & up

Grid Services: Diverse, Complex, Regional, & Dynamically Variable

Service	Operational Objective	Time Scale	Event Duration	Recurrence	Power for Service
Peak capacity management	reduce net load to meet an infrastructure constraint	15-min to 1-hour	4-8 hours	10-15 days/yr	supply: up load: down
Capacity market value	sup dem	-			
Energy price response	red load		-		
Frequency Regulation	sup con dem				
Spinning reserve	reb sud	-	-		
Artificial inertia / primary freq. response	arr stab (usually				n p
Distribution voltage management	minim rap inje	-	-		

Many types of services, distinguished by

- Operational objective
- Time granularity of controls/operations
- Time duration of events
- Occurrence patterns of events
- Requires power up, down, or both

Grid operational objectives are <u>universal</u>; service are <u>designed</u> to meet one or more (July 31, 2018)

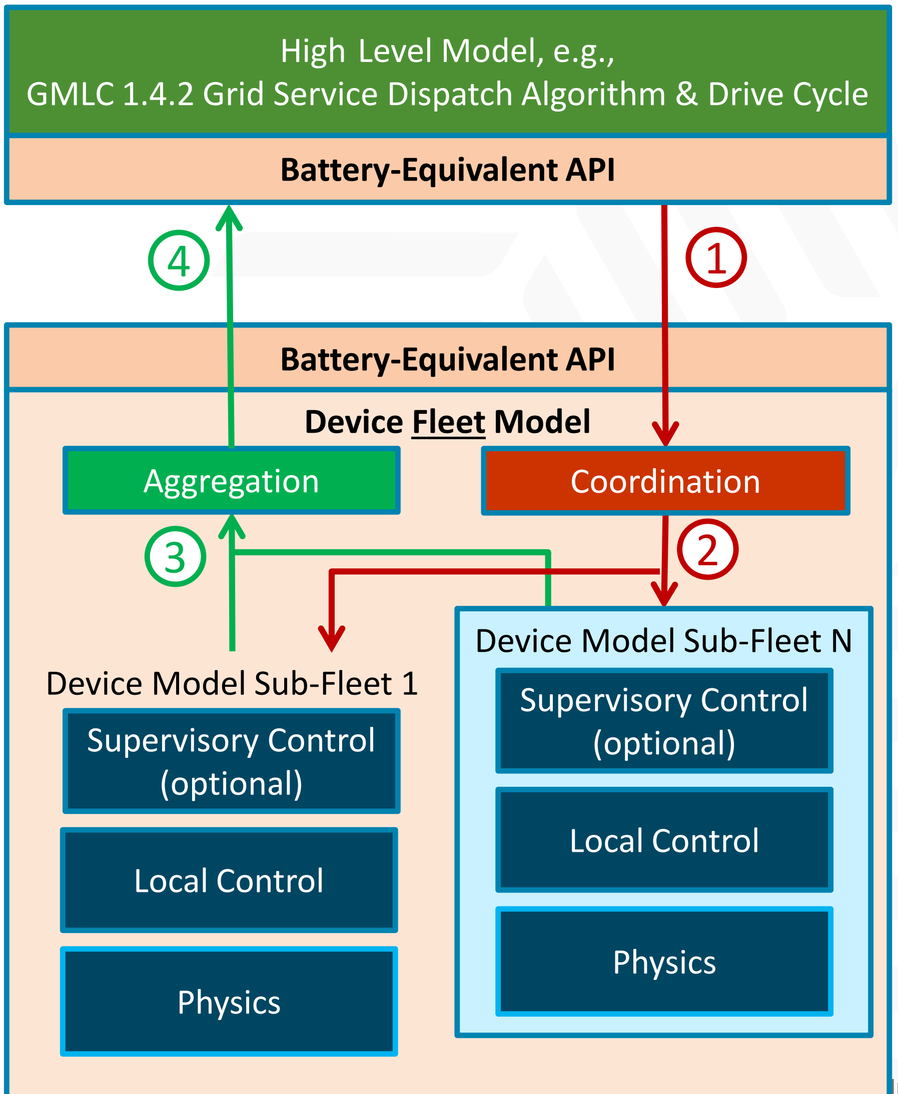
- Services are regionally-specific, named differently, etc.

DERs need much simpler translation:

- How much power? Up or down? How long? How often? How many $?

Definitions, Standards and Test Procedures for Grid Services from Devices

Software Architecture: Device & Fleet Models



High Level Model of Grid Planning or Operations

1. Requests power for service from fleet via battery-equivalent API

Device Fleet Model
(N sub-fleets representing diverse population, each with uniform parameters, usage patterns, etc.)

2. Coordination: Allocates request to sub-fleets
4. Aggregates & returns fleet's current state:
   - Power delivered for service
   - Power injected into grid
   - Base case power injected into grid

   Aggregates & returns constraints for next time step:
   - Energy stored & total capacity
   - Charge/discharge efficiencies
   - Power, price, time constraints

Device Model (1 device · sub-fleet weighting factor)

3. Returns sub-fleet's current state (see step 4)
   Returns sub-fleet constraints for next time step (4)

Accomplishments – Devices (July 31, 2018)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

<table>
<tr><th>Device</th><th>Status</th></tr>
<tr><td>Water Heaters</td><td rowspan="9">

Device Model Implementation in Code (Compelte)
Device Model Functions in Stand-Alone Test (Complete)
Battery Equivalent Interface Implemented, Ready for Integration Test (Complete)
Fleet Model Implementation in Code (Complete)
Integration with a Service (PV and Battery Inverters Complete, rest in progress)
Device Model Producing Validated Results (In Progress)
Fleet Model Producing Validated Results (In Progress)
Autonomous Response to Frequency and Voltage (In progress)
Final Testing Results Documentation

</td></tr>
<tr><td>PV/Inverters</td></tr>
<tr><td>Battery/Inverters</td></tr>
<tr><td>Electric Vehicles</td></tr>
<tr><td>Fuel Cells</td></tr>
<tr><td>Electrolyzers</td></tr>
<tr><td>Air Conditioners</td></tr>
<tr><td>Commercial Refrigeration</td></tr>
</table>

Accomplishments – Services (July 31, 2018)

Service	Status
Peak Load Management	• Implemen-tation of Drive Cycle in Code (five services completed, other near completion) • Grid Service Functions in Stand-Alone Test of Code (four services completed, others in progress)) • Battery Equivalent Interface Implemented, Ready for Integration Test (three services completed, others in progress) • Successfully Integrated with a Device (In progress) • Grid Service Scaling Complete & Validated (ADVR service complete, others in progress) • Scoring Method for Device Fleet Performance Complete & Validated ((ADVR service complete, others in progress) • Final Testing Results Documentation
Autonomous Frequency Response	
Capacity Market Dispatch	
Traditional Frequency Regulation	
Spinning Reserve	
Dynamic Frequency Regulation	
Autonomous Distributed Voltage Response (ADVR)	
Wholesale Market Price Response	

Definitions, Standards and Test Procedures for Grid Services from Devices

Next Steps and Future Plans

Year 3 focus:

- Testing 3 devices & models
- Continue & expand interactions with (among others)
  - Device testing workshops (3 device classes)
  - Industry meeting on modeling & devices
  - On models: GMLC 1.4.15 (co-simulation), 1.4.26 (production cost models)
  - On services: GMLC 1.2.1 (grid architecture), 1.2.3 (testing network), 1.2.4 grid services & valuation, 1.4.25 (distribution decision support) 1.4.27 (valuation for emerging tech.)
- Completing/publishing trial analysis from Year 2

Next Steps and Future Plans

Year 3 focus:

- Testing 3 devices & models (April 1, 2019)
- Continue & expand interactions with (among others)
  - Device testing workshops (3 device classes)
  - Industry meeting on modeling & devices
  - On models: GMLC 1.4.15 (co-simulation), 1.4.26 (production cost models)
  - On services: GMLC 1.2.1 (grid architecture), 1.2.3 (testing network), 1.2.4 grid services & valuation, 1.4.25 (distribution decision support) 1.4.27 (valuation for emerging tech.)
- Completing/publishing trial analysis from Year 2

Potential future work:

- Develop models for additional device types
  - E.g., V2G-EVs, thermal (ice) storage
  - Extend to bulk generation: hydro, solar thermal + molten salt
- Test/characterize additional device types & validate models
- Integrate device models with DOE's HELICS co-simulation
- More rigorous, nationally representative analysis of technical potential of various device classes
- Develop drive cycles for additional grid services