Grid Modernization Initiative
Crosscut Discussion

Kevin Lynn, Office of Energy Efficiency and Renewable Energy

July 8, 2015
U.S. Adaptive and Resilient Electric Grid Program

Core Science and Technology Program
Focuses on: the development, testing and validation of key elements required to create an adaptive and resilient U.S. electric grid.

- Create a system view
- Develop tools to see the T&D infrastructure
- Develop tools to collect and analyze data from T&D infrastructure
- Develop new architectural frameworks
- Develop new tools for control

Stakeholder Advisory Committee

Regional Grid Deployment Consortium 1
Challenges: wind, solar, and energy storage

Regional Grid Deployment Consortium 2
Challenges: severe weather events and changing fuel mix

Regional Grid Deployment Consortium 3
Challenges: renewable integration and severe weather events

March, 2014 Big idea Summit
15 labs – 19 contributors
An aggressive and urgent five-year grid modernization strategy for the Department of Energy that includes:

- Alignment of the existing base activities among the Offices
- An integrated Multi-Year Program Plan (MYPP)
- New activities to fill major gaps in existing base
- Development of a laboratory consortium with core scientific abilities and regional outreach
Lab Grid Consortium Vision

Move from a collection of DOE and Lab projects to a DOE-Lab Consortium Model that integrates and coordinates Laboratory expertise and facilities to best advance DOE Grid Modernization goals.
The future grid will solve the challenges of seamlessly integrating conventional and renewable sources, storage, and central and distributed generation. It will provide a critical platform for U.S. prosperity, competitiveness, and innovation in a global clean energy economy. It will deliver **reliable, affordable, secure, resilient**, and **clean** electricity to consumers where they want it, when they want it, how they want it.

**Security and Reliability for the Nation**
- Extreme weather
- Cyber threats
- Physical attacks
- Natural disasters
- Fuel and supply diversity
- Aging infrastructure

**Economic Growth and Innovation**
- New energy products and services
- Efficient markets
- Reduce barriers for innovation
- Clean energy jobs
- Access to reliable, affordable electricity

**Environmental Sustainability**
- 80% clean electricity by 2035
- State RPS and EEPS mandates
- Climate adaptation and resilience
DOE’s Grid Modernization Initiative Goal

Accelerate the modernization of the North American Grid through 2025, by

- Core R&D and proof of concept activities that integrate technology innovation
- Technical assistance and institutional support
- Regional demonstrations at multiple scales to demonstrate marketability
- Partnerships and FOAs with industry and the research community
- Technology transfer to industry
Trends and Needs

• Grid of the 20th Century isn’t sufficient for the 21st Century due to these TRENDS
  – Increasing incorporation of cleaner generation sources
  – Greater decentralization of energy sources
  – Greater consumer choice
  – Increasing challenges of grid security and resiliency
  – Emergence of interconnected electricity information and control systems

• NEEDs for a 21st Century grid
  – Seamlessly integrate generation from conventional and renewable sources, advanced storage technologies, and flexible end uses with cost-effective systems
  – Accommodate both central station and distributed generation, energy storage and customer-responsive loads
  – Fundamental development of advanced devices
  – Provide a secure architecture of information and control technologies at every level to improve asset management, real-time protection, improved planning and emergency response
  – Supply electricity services with minimal disruption, in light of all potential hazards
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<td></td>
<td>• Provide tools and data that enable more informed decisions and reduce risks on key issues that influence the future of the electric grid/power sector</td>
<td>• Create grid planning tools that integrate transmission and distribution and system dynamics over a variety of time and spatial scales</td>
<td>• Design and implement a new grid architecture that coordinates and controls millions of devices and integrates with energy management systems</td>
<td>• Advance low-cost sensors, analytics, and visualizations that enable 100% observability</td>
<td>• Develop new devices to increase grid services and utilization and validate high levels of variable generation integrated systems at multiple scales</td>
<td>• Develop advanced security (cyber and physical) solutions and real-time incident response capabilities for emerging technologies and systems</td>
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Institutional Support

• High Level Outcomes
  • Technical Assistance - Enhanced ability for regional, state, and tribal policymakers to make decisions on existing and emerging policy, technology, regulatory, and market issues in the electricity sector and for PUCs to assess proposals for changes to existing regulation and new business models
  • State Energy Plans - Reduced risks and better investment decisions regarding integration of emerging technologies, valuation of technologies, and opportunities for consumers to participate in the energy market

• Selected Major Technical Outputs
  • Valuation of DER - New methods for valuation of DER technologies and services that are clearly understood by stakeholders and enable informed decisions on grid investments
  • Distribution Planning - Technical assistance to at least 10 states improving their ability to review utility distribution system plans, including DER, and advanced grid components and systems

Design and Planning Tools

• High Level Outcomes
  • Stochastic - Tools that identify cost-effective approaches for capital and technology investments, operational approaches, and market designs to meet new operational and economic performance objectives
  • Reliability and Resilience - Engineering modeling tools that improve grid reliability and resilience
  • Algorithms and Modeling - Tools that reduce the time for solving complex grid modeling problems and substantially extend the complexity and volume of scenarios analyzed

• Selected Major Technical Outputs
  • Production Cost Model - Improve scaling to model electric and gas system inter-dependencies from 1,000 to 60,000 electric and 100 to 1,000 gas nodes
  • Security Tool - Improve performance of contingency analysis tools by 500x to capture extreme events; enable automated analysis of cascading events
GMI’s Technical Thrusts (continued)

System Operations, Power Flow, and Control

- **High Level Outcomes**
  - **Grid Architecture** - Architecture that defines grid structures for improving grid flexibility and resilience, and control theory to accommodate large numbers of interconnected distributed and semi-autonomous systems
  - **Grid Control Technologies** - Blended central-decentralized control systems allowing grid system to be operated with less reserve margin and integrating distributed/consumer load and generation, dramatically enhancing the economic efficiency of the overall system
  - **High Voltage Power Electronics and Grid Devices** - Performance and cost improvements enabling improved controllability and greater flexibility of the electrical grid

- **Selected Major Technical Outputs**
  - **Prototype Solid State Transformer** - Next generation transformer design and demonstration
  - **Distribution Management System** - New control system utilizing high levels of DER penetration and building inputs

Sensing and Measurements

- **High Level Outcomes**
  - **Low-Cost Sensors** - Reductions in the unit and implementation costs of sensors across transmission, distribution, and end-user building systems
  - **Accurate Sensors** - Enhanced accuracy of sensor and measurement devices to minimize uncertainty
  - **Unified Grid Communications Network** - Improved models, frameworks, and software to enhance interoperability, reliability, and security of communications

- **Selected Major Technical Outputs**
  - **Real-time Data Management Tool** - Tool to manage ultra-high velocities and volumes of grid data from T&D systems and the ability to identify and compensate for inaccuracies and errors
  - **Low-Cost, Multi-Purpose Sensor** - Development of (under $100 per sensor or two year payback) that operate in normal and off-normal operations for resiliency and reliability
GMI’s Technical Thrusts (continued)

Devices and Integrated Systems Testing

- **High Level Outcomes**
  - *Microgrids and Energy Storage* - Cost effective applications to improve customer reliability
  - *Interconnection & Interoperability* - Standards that streamline processes & reduce distributed energy integration costs
  - *Smart Interfaces* - Provide reserves to bulk power systems and reduce interconnection costs

- **Selected Major Technical Outputs**
  - *Energy Storage Devices* - Decrease the system costs of deployed in grid-scale, energy storage system to under $150/kWh
  - *Transactive Energy Operating System* - Enable buildings, large building loads, and EV charging systems to: 1) diagnose if they are functioning properly, 2) forecast their energy needs, 3) characterize their available flexibility, and 4) have embedded control and decision-making tools to provide capacity, energy and ancillary services

Security and Resilience

- **High Level Outcomes**
  - *Increased Physical and Cyber Security* - Improved ability to identify, protect against, detect, respond to, and recover from threats, hazards, and incidents.
  - *Development of Standards and Guidelines* - Industry shares best practices, demonstration and validation of devices, advanced cyber-physical analytics, methodologies and architectural frameworks, advanced substation and transformer technologies, and hardened communications

- **Selected Major Technical Outputs**
  - *Hardened Transformers* - Design and construct solid-state distribution (10-kV and 50-kV) and transmission (100-kV and 345-kV) transformers and deploy with greater resiliency characteristics
  - *Resilient Architectures* - Adaptive and agile operating technologies framework that optimizes stability and efficiencies of operation while accommodating high penetration of distributed, renewables generation, smart loads, and energy storage
Stakeholder Engagement and Partnership

- Conduct regional dialogues to gather input on grid modernization needs and priorities
- Hold annual Grid Modernization Initiative progress summits
- Expand technical assistance to states, regions and tribes
- Develop partnerships to define and develop regional demonstrations
- Issue competitive research funding opportunities (e.g., FOAs and CRADAs)
- Engage in technology transfer from DOE programmatic advances
- Carry out ongoing peer review
The GMI specific focus areas align with several dimensions of DOE’s Federal role

| **RD&D** | Resources to promote new technology research at the basic science and applied level and to demonstrate effectiveness in full-scale applications |
| **Convening Power** | Ability to bring national and regional parties together to develop effective solutions that are regionally based and promote national goals |
| **Institutional Support** | Direct technical assistance to States, tribes, and others. Develop widely accepted, quantifiable methods to value the potential benefits and costs of DER for state regulators |
| **Techno-Economic Evaluation** | Reputation for unbiased technical and economic evaluations that will accelerate the market uptake of new technologies |
| **National Laboratories** | Deep and specialized technical expertise with strong regional connections that can assist with research, testing and technology transfer |
## GMI as a 10-Year Journey

**DOE delivers new capacity for modernization (analytical and valuation tools, architecture platforms, technical assistance, technologies, tech transfer)**

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<th>2015</th>
<th>2019</th>
<th>2020</th>
<th>2024</th>
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<tbody>
<tr>
<td>Regional outreach to hear needs and priorities</td>
<td>Funding Opportunity Announced for regional demos</td>
<td>Implement regional demos</td>
<td>Begin to deliver outcomes</td>
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<tr>
<td>Core R&amp;D and technical assistance in six research streams</td>
<td>Planning of regional demos</td>
<td>Scale up regional demos</td>
<td>Continue scale up regional demos</td>
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<tr>
<td>Request for Information to identify regional partners</td>
<td>Initiate regional demos</td>
<td>Continue tech transfer to industry</td>
<td>Additional outcomes delivered</td>
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<tr>
<td>Initial tech transfer to industry</td>
<td>Potential additional Funding Opportunity Announced</td>
<td>Continue select areas of core R&amp;D and technical assistance</td>
<td>Demos complete with proofs of concept</td>
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<td>Wrap up majority of core R&amp;D and technical assistance</td>
<td>Continue tech transfer to industry</td>
<td>Concepts taken by industry and applied elsewhere</td>
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<td></td>
<td></td>
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<td>Tech transfer complete</td>
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**Outputs from demos and technology transferred to utilities, vendors, states, and consumers to modernize the grid and deliver outcomes**
Measuring Successful Demonstrations

- How much are we increasing power quality and reliability?
- How much are we controlling costs to consumers?
- How much have we increased protection to our critical infrastructure?
- How far are we reducing our environmental impact?
- How quickly do we recover from any situation?

Grid Modernization
Major Achievement #1 – Lean Bulk Power Systems

- **Reliable**: Maintain reliable operations with a 10% transmission reserve margin or lower
- **Affordable**: New operations capability for grid operators to safely run system closer to “edge” for increased asset utilization and to leverage distribution-level grid services will require less generation reserve
- **Secure**: Incorporate advance physical and cyber security measures for the integration of large numbers of devices. Deploy predictive operations tools to detect and mitigate risk in real-time.
- **Clean**: Real-time tools enhance wind resources with higher transmission asset utilization and management of system dynamics. Leverage of demand reduces emission from standby generation.
- **Resilient**: Reduce outages by order of magnitude with improved prediction, detection, and distributed controls
• Major Achievement #2 – Clean Distribution Systems

  – **Reliable & Resilient**: Coordinated microgrids control for resilience (e.g., 20% fewer outages, 50% shorter recovery time)
  – **Affordable**: Distributed, hierarchical control for clean energy and new customer-level innovation for asset utilization
  – **Secure**: Cyber resilient design of responsive loads and controls. Automation for outage detection and topology awareness for state estimation.
  – **Clean**: Demonstrate reliable and affordable feeder operations with greater than 50% DER penetration. Engage interactive efficiency concepts in buildings.
DOE Major Achievements (continued)

• Major Achievement #3 – Grid Planning and Analytics
  – **Reliable & Resilient**: Use coupled T&D grid planning models with 1000x speed-up to address specific grid issues
  – **Affordable**: Work with States to more rapidly evaluate new business models, impacts of policy decisions
  – **Secure**: Ensure high-level cybersecurity for all data-driven and operational models
  – **Clean**: Develop with stakeholders new data-driven approaches to DER valuation and market design
Selected Projects (under negotiation):

**Topic Area 1 (Connected Devices):**

**EPRI:** Project will test the ability of a set of connected devices to provide grid services. The primary focus is on standardizing device services for various clean energy technology types and developing communication interfaces to improve the ability of intelligent electronic devices to supply grid services.

**University of Delaware:** The project will evaluate the ability of V2G capable bidirectional electric vehicles to provide grid services, as well as to implement and test open protocols for coordination of those services.

**Topic Area 2 (Communication & Control Systems):**

**EPRI:** This project will provide and demonstrate an end-to-end framework of communication, information, and computation (CIC) technologies, integrating operation of different domains within distribution systems (DMS, demand response service, residential appliance scheduling) through open source software tools.

**Topic Area 3 (Integrated Systems):**

**Omnetric Group:** The project will demonstrate a Distributed Intelligence Platform Reference Architecture (DIP Architecture) that will enable the grid to effectively support large-scale complex operations, such as with distribution systems at electric utilities, which allow for an integration and wider penetration of renewable, clean energy resources.

**Smarter Grid Solutions:** The project will deploy and demonstrate an integrated distribution grid management solution, using Active Network Management (ANM), to enhance grid capacity and services for renewable energy by more fully utilizing existing network assets.
**EPRI Topic Area 1**

<table>
<thead>
<tr>
<th>Topic Area</th>
<th>Technology Area(s)</th>
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<tr>
<td>1 – Connected Devices</td>
<td>Thermostats, pool pumps, EV chargers, PV inverters, Community battery energy storage</td>
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**Proposed ESIF Demonstration**

**Project Title:** Cohesive Application of Standards-Based Connected Devices to Enable Clean Energy Technologies

**Project will provide and test a set of key connected devices in terms of their performance of needed grid-supportive services.** Connected devices include thermostats, pool pumps, EV chargers, PV inverters, and community battery energy storage. The individual grid-supportive functionalities provided by these products will be tested in the context of higher-level goals, in which the devices are capable of functioning in concert, working together to enable more clean energy technologies on the grid.

**Focus on standardization of device services and communication interfaces (CEA-2045 & DNP3) will improve the ability of intelligent electronic devices to supply grid services.**

**Project Partners**

- PowerHub Systems, Fronius, ClipperCreek, Emerson, Pentair
ERGIS-Eastern Renewable Grid Integration Study

- Jointly funded by WWPTO, SETO, and OE
- Draft Report being reviewed by the studies Technical Review Committee and DOE sponsors (Final Report to be completed by July 31, 2015)
- Use of NREL’s HPC reduced the computation time for scenario runs from 400 days to 20.
- Study Premise-
  - ERGIS simulated four power system scenarios for the U.S. EI to determine the sub-hourly impacts of very high levels of wind and PV. These simulations were conducted using industry leading tools and datasets and resulted in the most comprehensive operations study of the EI ever conducted. Operations for the entire EI and Quebec Interconnection were simulated for a single year and included detailed representation of nearly every generator on the system.
- Major findings-
  - Efficient utilization of available wind and PV depends upon transmission availability and characteristics of the generation fleet
  - Simulated levels of wind and PV generation can be balanced during normal operations even at high spatial and temporal resolution in the Eastern Interconnection
  - Annual wind and PV penetrations of 30% decrease production costs and emissions by approximately 30%
  - Wind and PV significantly impact the operation of traditional generation sources in the Eastern Interconnection
  - High instantaneous penetrations highlight questions about dynamic stability (not studied within the scope of this study)
Vision: PV as an Appliance

- Off-the-shelf consumer product
- Automatic permitting & inspection
- Simple installation
- Automatic grid interconnection
- Cost meeting SunShot target $1.5/W
- System design appeal to broad segments of homeowners

Two Awards:
- Fraunhofer USA
- North Carolina State University / FREEDM Center
PV output vs load consumption

Load triggers when PV output is > 900W

RTU stays on for 10 minute control period to avoid short cycling

• Load tracks PV with in safety constraints while reducing number of cycles
• Load is ~3X the maximum capacity of the PV generation capacity
• Resolution of load controllability is carefully chosen
• 4 Packaged RTUs controlled to provide renewable support

*Significant possibility exists for load to provide “renewability regulation” – load as a resource. Control response can be generated in a centralized or decentralized fashion*
PREVIOUS SLIDES
## Devices and Integrated System Testing

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<tr>
<th>Activity</th>
<th>Technical Achievements by 2020</th>
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</table>
| **1. Develop Advanced Storage Systems, Power Electronics, and other Grid Devices** | • Increased functionality of energy generation, storage, delivery technologies, and controllable loads to provide grid services needed to reduce the cost of integrating renewables by 50%, reduce reserve margins by 33%, and reduce outages by 10%.  
  • Energy storage will be widely deployed at all levels of the system and power conversion technology employing wide-bandwidth semiconductors, advanced magnetics and capacitors will see initial deployment. |
| **2. Develop Standards and Test Procedures** | • Updated standards and test procedures that characterize the ability of devices (50% of building loads and all new generation and storage) 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 systems that reduce customer outages by 10%. |
| **3. Build Capabilities and Conduct Device Testing and Validation** | • The Grid Modernization Laboratory Consortium – Testing Network (GMLC-TN) provides test facility integration and optimization, testing frameworks, and component model libraries managed and operated by National Laboratories, universities, and industry groups.  
  • Characterization of a wide variety of technologies to validate individual devices can provide a full range of grid services. |
| **4. 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 by 33%.  
  • Validated 10% outage reductions by using advanced distribution system configurations (including microgrids) and fault location, isolation, and service restoration (FLISR) systems.  
  • Field demonstrations of energy storage providing multiple grid services. |
## Sensing and Measurement

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<th>Activity</th>
<th>Technical Achievements by 2020</th>
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<tr>
<td>1. Improve Sensing for Buildings &amp; End-Users</td>
<td>• Development of low cost sensors (under $10 per sensor) for enhanced controls of smart building loads and distributed energy resources to be “grid friendly” in provision of ancillary services such as regulation and spinning reserve while helping consumers understand benefits of energy options.</td>
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<tr>
<td>2. Enhance Sensing for Distribution System</td>
<td>• Development of low cost sensors (under $100 per sensor) and ability to effectively deploy these technologies to operate in normal and off-normal operations.</td>
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<td>• Development of visualization techniques and tools for visibility strategy to help define sensor type, number, location, and data management. Optimize sensor allocation for up to 1,000 non-meter sensing points per feeder.</td>
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<tr>
<td>3. Enhance Sensing for the Transmission System</td>
<td>• Development of advanced synchrophasor technology that is reliable during transient events as well as steady state measurement.</td>
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<td>• Development of low cost sensors to monitor real-time condition of electric grid components.</td>
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<tr>
<td>4. Develop Data Analytic and Visualization Techniques</td>
<td>• Real-time data management for the ultra-high velocities and volumes of grid data from T&amp;D systems.</td>
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<td>• 100% visibility of generation, loads, and system dynamics enabled across the electric system through the development of visualization techniques and software tools</td>
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<td>• Development of measurement and modeling techniques for estimating and forecasting renewable generation both for centralized and distributed generation for optimizing buildings, transmission, storage, and distribution systems.</td>
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<td>5. Demonstrate unified grid-communications network</td>
<td>• Secure, scalable communication framework created with a coherent IT-friendly architecture that serves as a backbone for information and data exchange between stakeholders and decision makers.</td>
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## System Operation, Power Flow, and Control

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<tr>
<th>Activity</th>
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| 1. Develop Architecture and Control Theory   | • Comprehensive architectural model, associated control theory, and control algorithms to support a variety of applications to improve grid flexibility, future adaptability, and resilience while not compromising operational reliability or security.  
• Wide-area control strategies to improve reliability, resilience, and asset utilization. |
| 2. Develop Coordinated System Controls       | • New control grid operating system designs reflecting emerging system control methodologies.  
• Framework(s) for integrating the next generation energy management system (EMS), distribution management system (DMS), and building management system (BMS) platforms. |
| 3. Improve Analytics and Computation for Grid Operations and Control | • Future and real-time operating conditions with short decision time frames and a high degree of uncertainty in system inputs can be evaluated.  
• Automation with predictive capabilities, advanced computational solvers, and parallel computing. This includes non-linear optimization of highly stochastic processes.  
• Decision support to operators in control rooms through pinpoint visualization and cognitive technologies. |
| 4. Develop Enhanced Power Flow Control Device Hardware | • Low-cost, efficient and reliable power flow control devices that enable improved controllability and flexibility of the grid. |
GTT coordinates budget formulation, planning and execution; however, this entity does have budget authority.
# Design and Planning Tools

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| **1. Scaling Tools for Comprehensive Economic Assessment**              | • Enhance performance of stochastic production cost modeling from 100 to 10,000 transmission nodes; expand modeling to include distribution system.  
• Easy-to-use decision support tools based upon complex HPC results that enable cost-benefit analysis for regulators and institutional analysis.  
• Improve scaling of stochastic tools to model electric and gas system interdependencies from 1,000 to 60,000 electric and 100 to 1,000 gas nodes. |
| **2. Developing and Adapting Tools for Improving Reliability and Resilience** | • Scalable framework to couple transmission, distribution, and communications models for integrated analysis at regional scale  
• Data-driven tools to automate construction and validation of models of devices, loads, generation, and customer behavior.  
• Improve performance of contingency analysis tools by 500x to capture extreme events; enable automated analysis of cascading events.  
• Develop standards and libraries to couple hardware-in-the-loop (HIL) devices with HIL devices and with HPC systems at a national 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.  
• Federation of five computational centers established to host grid software, manage access controls, provide data sets for model development and validation, and support analysis for Institutional Support.  
• Six “prototype-to-practice” projects conducted every year to drive adoption of research results into industry. |
## Security and Resilience

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<thead>
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<th>Activity</th>
<th>Technical Achievements by 2020</th>
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<tbody>
<tr>
<td>Improve Ability to Identify Threats and Hazards</td>
<td>• An all hazards approach for threat identification and emergency response, which is accepted and implemented by the energy sector.</td>
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</table>
| Increase Ability to Protect Against Threats and Hazards | • Standards, methods, testing and evaluation procedures for physical and cyber security enabled designs.  
• Development, demonstration, and field validation of novel energy, communications, and control system models and logistical optimization techniques.  
• Grid components which are inherently protective of grid services to all-hazards. |
| Increase Ability to Detect Potential Threats and Hazards | • Advanced cyber-physical data analytics and cognitive learning, spanning time scales and data sources across the system lifecycle, to enable proactive and real-time information flow by the end of FY20. |
| Improve Ability to Respond to Incidents       | • Methodologies and architectures frameworks which assess system degradation to all hazards, provide diverse attack recognition, and mixed-initiative response on multiple timescales, and optimize operational efficiencies/priorities for the power grid. |
| Improve Recovery Capacity/Time                | • Advanced substation and transformer designs and standards that facilitate improved transformer portability and rapid substation recovery.  
• Hardened fail-safe and wireless communications capabilities and devices for grid control systems that resist impacts from cyber, geomagnetic disturbance, and electromagnetic pulse events. |
## Institutional Support

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<th>Activity</th>
<th>Technical Achievements by 2020</th>
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</table>
| **Provide Technical Assistance to States and Tribal Governments** | • Technical assistance to all states and tribes to inform their electricity policy decision making and accelerate state policy innovation.  
• Technical support to at least 10 states that allows them to establish formal processes to review utility distribution system plans, including guidance on how to consider non-wires alternatives, distributed energy resources, and advanced grid components and systems.  
• At least 10 other states have developed comprehensive energy system plans. |
| **Support Regional Planning and Reliability Organizations** | • Assisted regional planning & reliability organizations in developing institutional frameworks, standards, and protocols for integrating new technologies.  
• Facilitated long-term regional planning in each U.S. interconnection.  
• Coordinated regional long-term planning process in states that uses standardized, publicly available databases of transmission and regional resource data and planning assumptions. |
| **Develop Methods and Resources for Assessing Grid Modernization: Emerging Technologies, Valuation, and Markets** | • New methods for valuation of DER technologies and services that are defined and clearly understood by stakeholders and enable informed decisions on grid investments and operations.  
• Analysis tools and methods that facilitate States’ and tribes’ integration of emerging grid technologies into decision-making, planning, and technology deployment.  
• New Grid Modernization performance and impact metrics and data collection methods, which are used by States and tribes to track Grid Modernization progress. |
| **Conduct Research on Future Electric Utility Regulations** | • 3-5 states have adopted fundamental changes and 8-10 states have adopted incremental changes to their regulatory structure that better aligns utility interests with grid modernization and clean energy goals. |
Reliability

• Definition

The ability of the grid system or its components to operate within limits so that instability, uncontrolled events, or cascading failures do not result if there is a disturbance, whether the disturbance is a disruption from outside the system or an unanticipated failure of system elements. Reliability also means that a system’s components are not unexpectedly failing under normal conditions.

• Metrics

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<th>Baseline</th>
<th>Goal</th>
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<td>SAIFI</td>
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<td>MAIFI</td>
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<td>Average annual customer minutes out (CMO)</td>
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Affordability

• Definition

Ensures that at both the grid system and component levels, costs and defined needs (or requirements) of users are balanced with their ability to pay and consider the value created by the energy goods or services for the users or the system.

• Metrics

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<th>Metric</th>
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<tr>
<td>Capital, marginal and/or operating costs of transmission - $/mile and $/MWh</td>
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<td>Average real retail electricity rates</td>
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<td>Levelized cost of electricity (LCOE)</td>
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<tr>
<td>Percent of consumer disposable income spent on electricity</td>
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Security

- **Definition**
  Minimization of disruptions to grid infrastructure caused by natural or human-induced disturbances, including cyber attacks, and mitigation of the impacts of disruptions, including economic impacts.

- **Metrics**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Baseline</th>
<th>Goal</th>
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<tr>
<td>Number of intrusions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of disruptive intrusions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost per event</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost of events</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Clean

• Definition
  Maximizes efficiency and clean energy resources, and minimizes air pollution including carbon.

• Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Baseline</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of clean energy in the system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy productivity – GDP/unit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Resilience

• Definition

The ability of the electric system and its components to withstand small to moderate disturbances without loss of service, to maintain minimum service during severe disturbances, and to quickly return to normal service after a disturbance.

• Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Baseline</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of customers affected per event</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average recovery time following events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent of critical loads able to withstand events</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>