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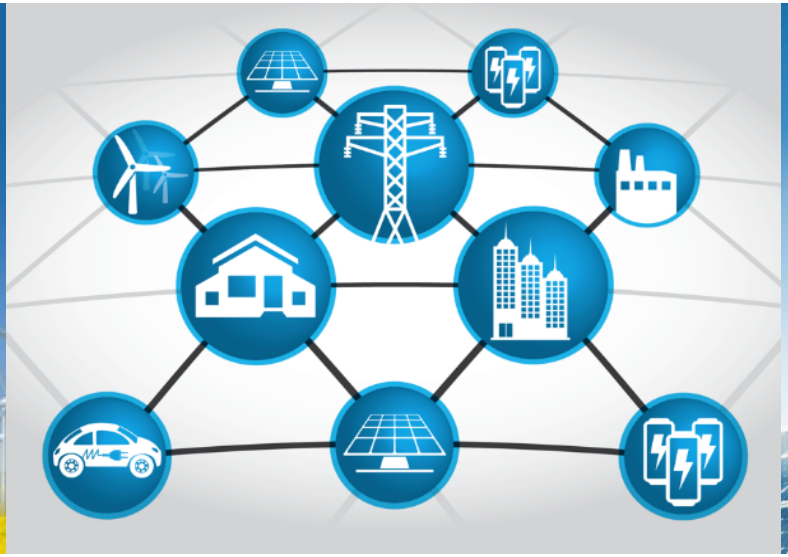
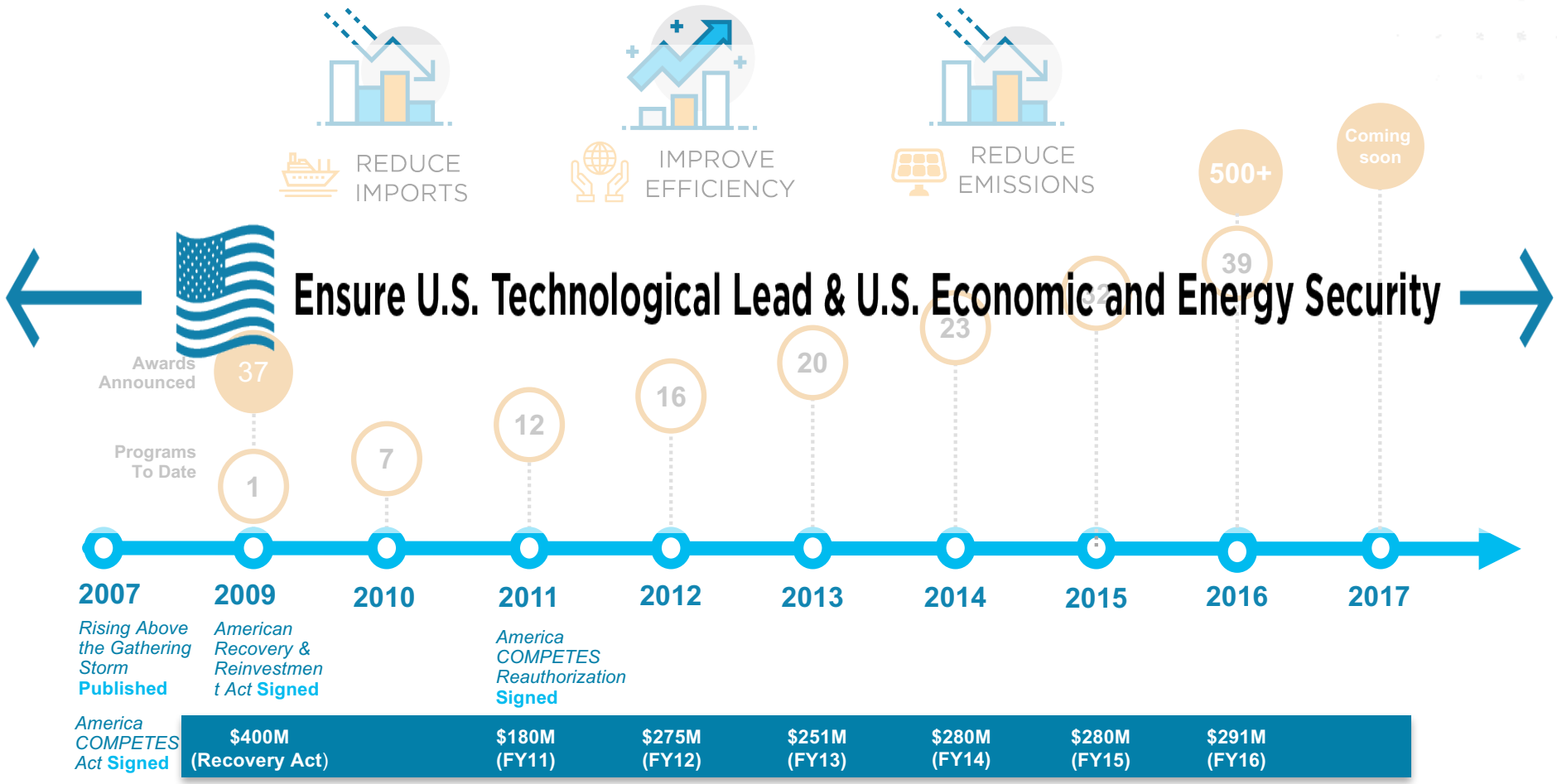
MAKING GRID SMART AND FLEXIBLE

Dr. Sonja Glavaski, Program Director


Mission & History of ARPA-E

Mission: To overcome long-term and high-risk technological barriers in the development of energy technologies



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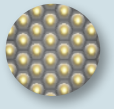
Focused Program Portfolio

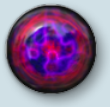
Active

Alumni

ELECTRICITY GENERATION


MOSAIC


GENSETS


ALPHA


REBELS


FOCUS

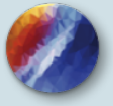

SOLAR ADEPT


IMPACCT

EFFICIENCY & EMISSIONS


ENLITENED


ROOTS


DELTA


SHIELD


MONITOR

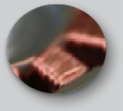

ARID


SWITCHES


METALS


REACT


BEETIT

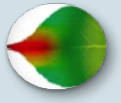

ADEPT

TRANSPORTATION & STORAGE


NEXTCAR


REFUEL

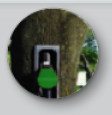

TRANSNET


TERRA


RANGE


REMOTE


MOVE


PETRO


ELECTROFUELS


AMPED


BEEST

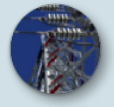
GRID & GRID STORAGE


IONICS


GRID DATA


NODES


CHARGES


GENI


HEATS


GRIDS

OPEN 2009, 2012, & 2015 Solicitations
Complement Focused Programs

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Measuring ARPA-E's Success

Since 2009 ARPA-E has provided $1.5 billion in R&D funding to more than 580 projects.

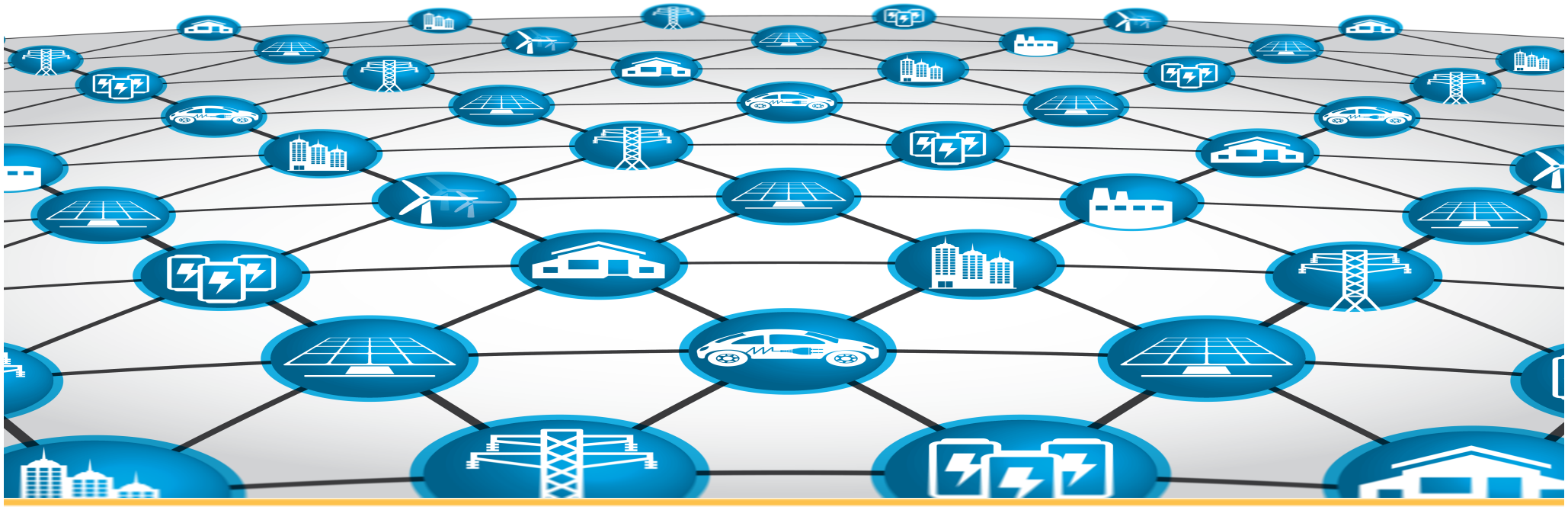
74 projects have attracted more than $1.8 billion in private-sector follow-on funding

56 projects have formed new companies

68 projects have partnered with other government agencies to further development

As of February 2017

U.S. Power Grid



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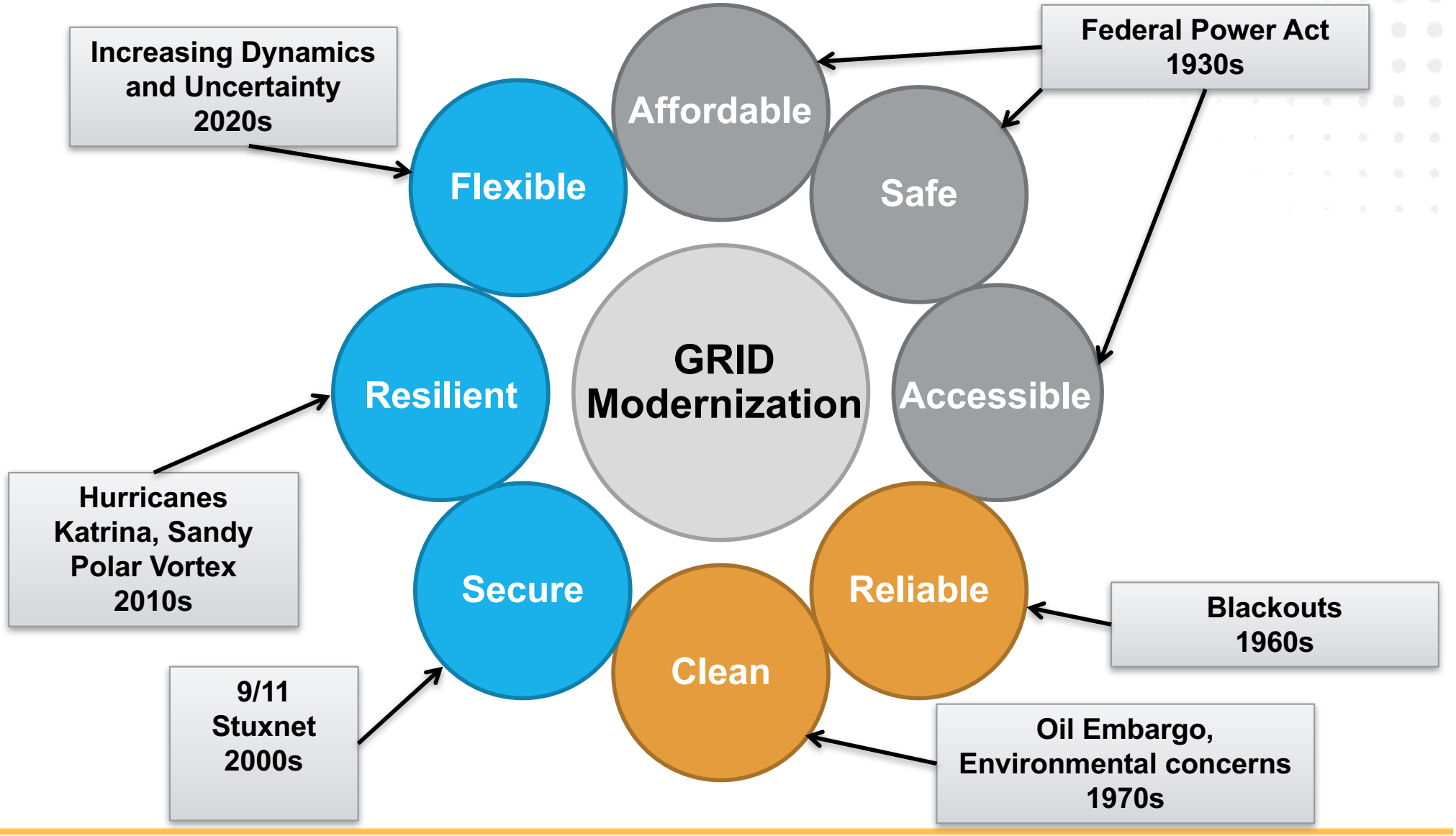
Evolution of Grid Requirements



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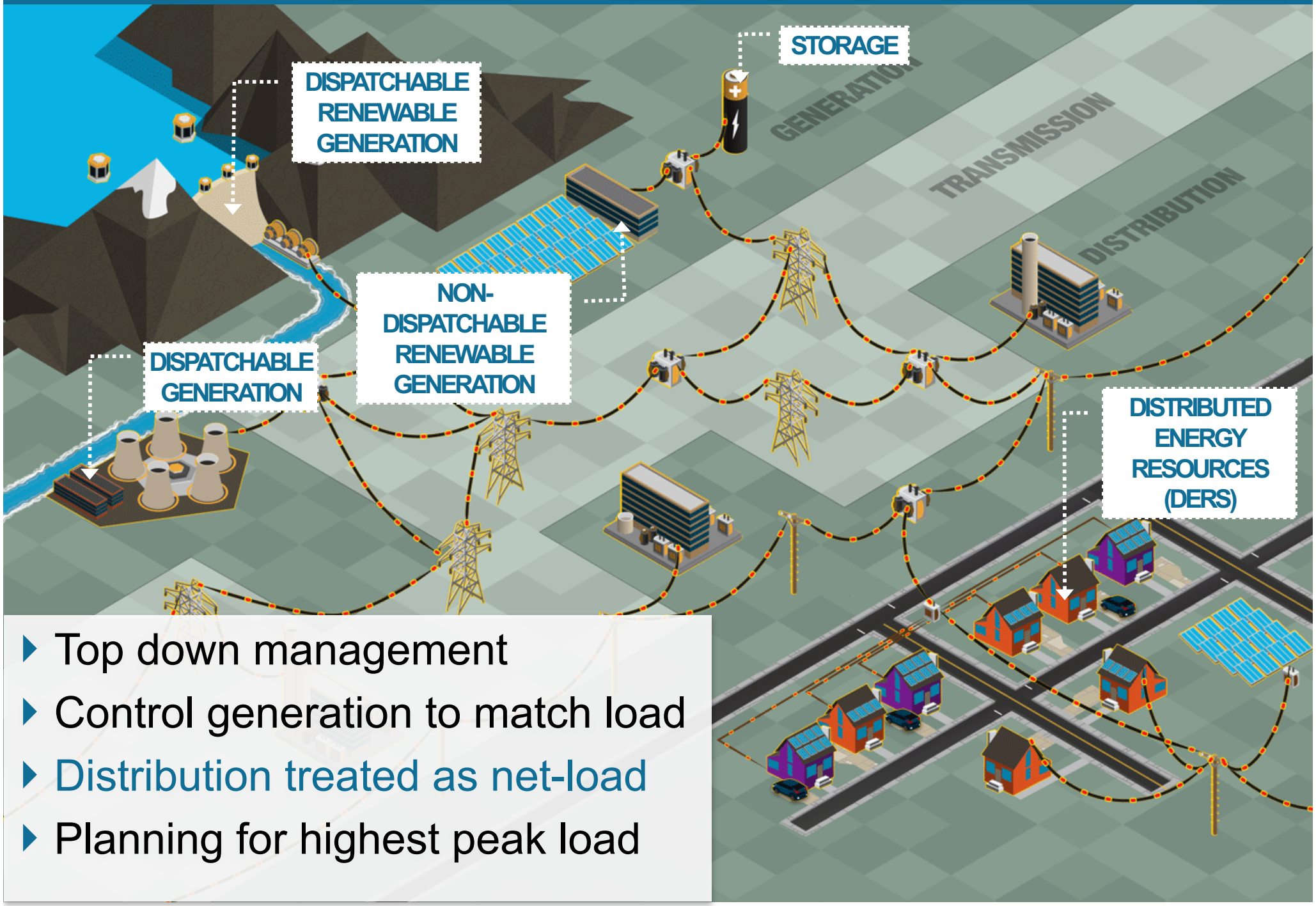
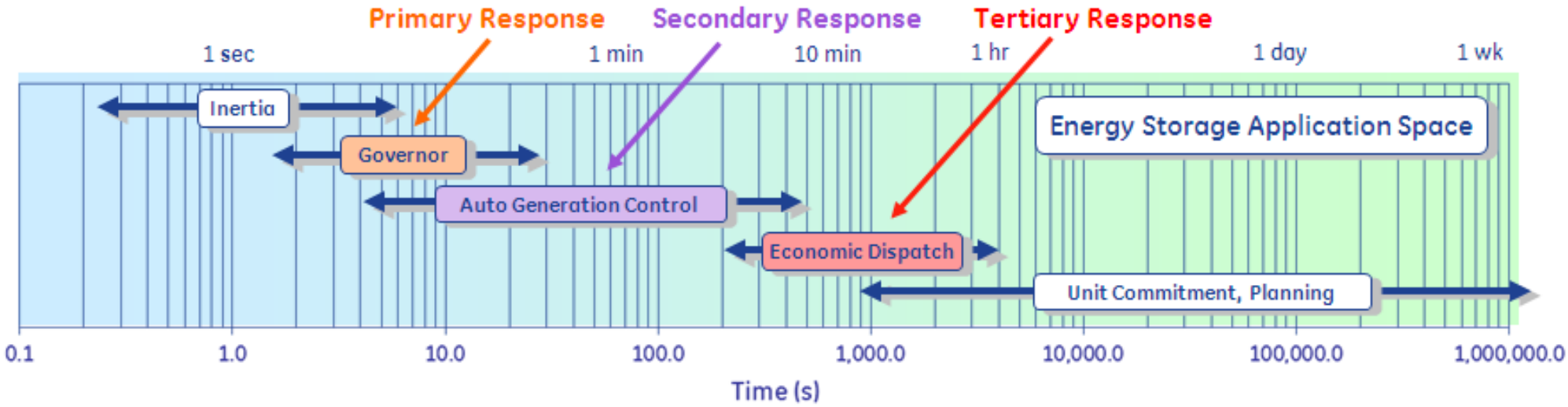
Source: DOE Grid Tech Team

US Grid Today in Few Words



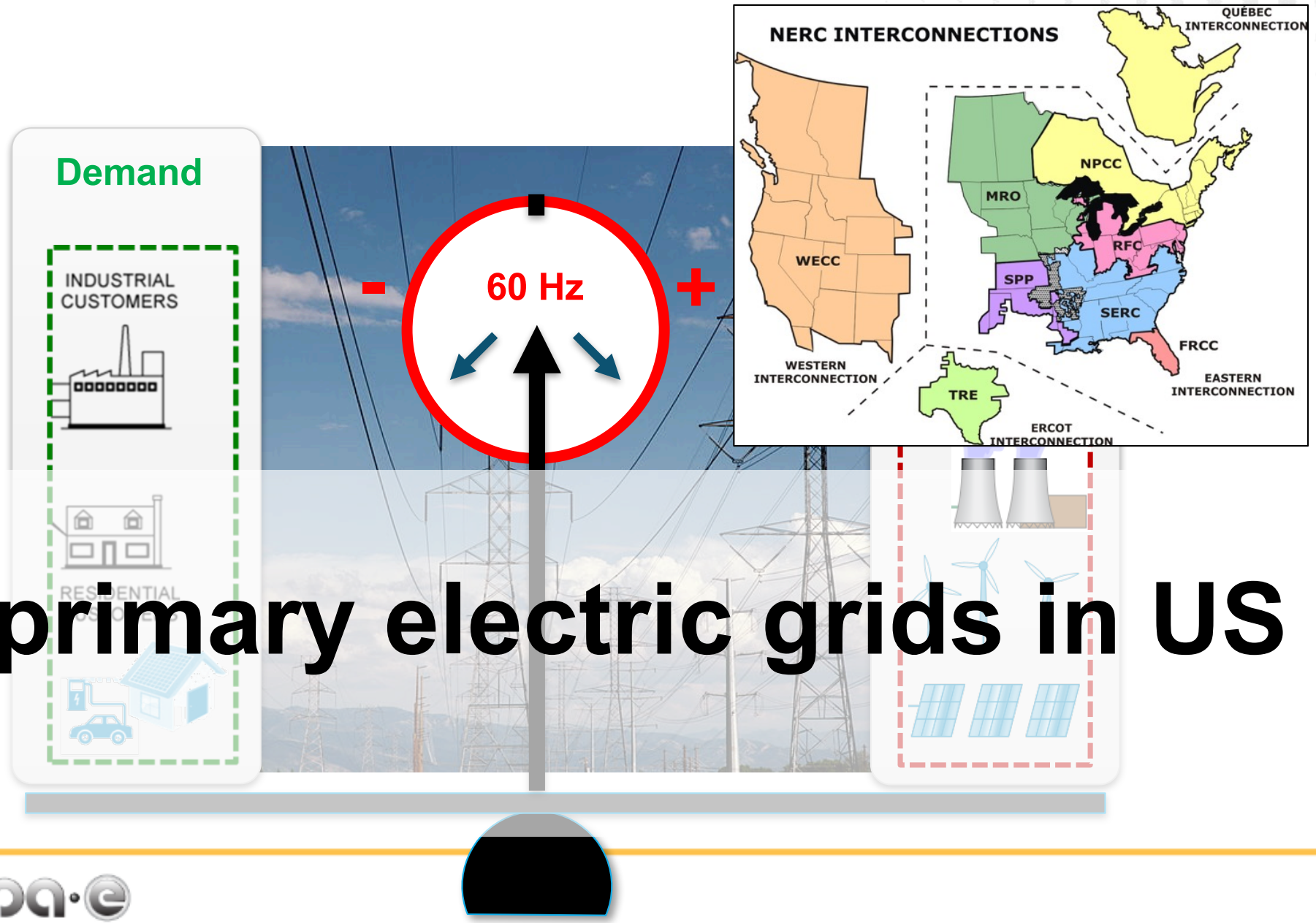
- Top down management
- Control generation to match load
- Distribution treated as net-load
- Planning for highest peak load

Grid Operation … timescales



- **Unit Commitment** - deciding which units will be operational at a given time (hours to days)
- **Economic Dispatch** - distributing loads among already-operating units (minutes to hours)
- **Frequency regulation and ancillary services** - only on certain participating generators (sub-seconds to seconds)

Who Manages U.S. Grid Reliability?

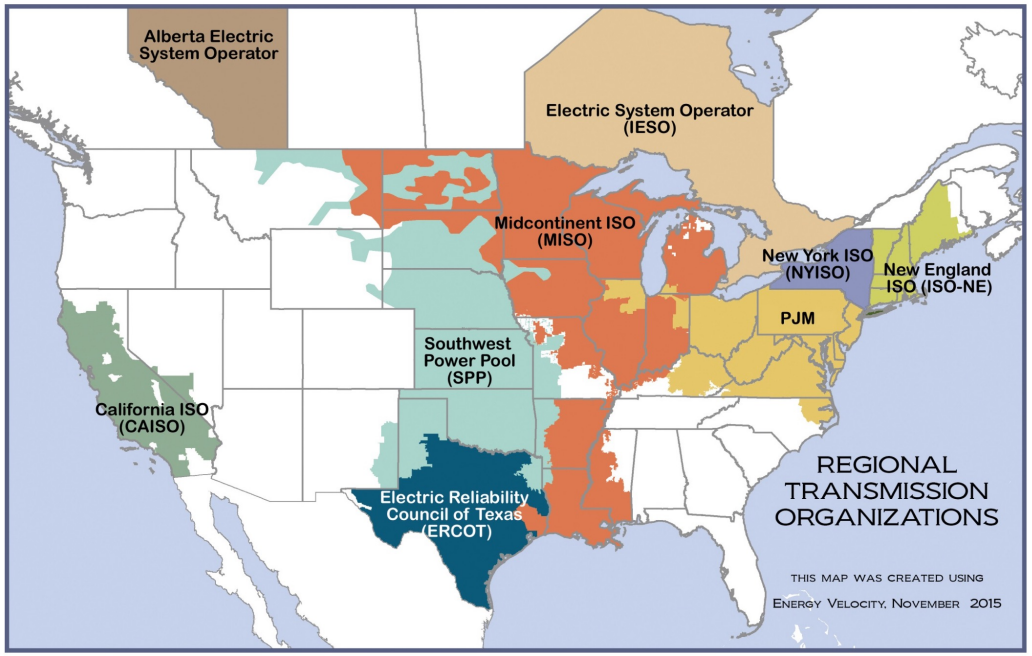


3 primary electric grids in US

Who Oversees U.S. Whole Sale Markets?

RTO/ISOs

- Operate the transmission grid
- Dispatch electricity based on marginal cost bids



RENEWABLES WATCH | California ISO

For Operating Day: **Tuesday, May 16, 2017**

The Renewables Watch provides important information about actual renewable production within the ISO grid as California moves toward a 33 percent renewable generation portfolio. The information provided is as accurate as can be delivered in a daily format. It is unverified raw data and is not intended to be used as the basis for operational or financial decisions.

Renewables Production

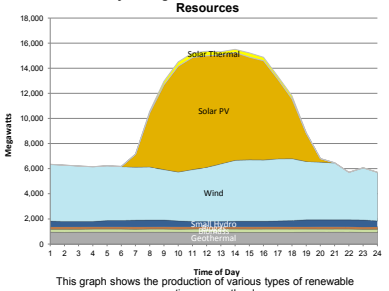
24-Hour Renewables Production

Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	11:36	365	3,093
Solar	10:36	9,012	85,031
Wind	17:25	4,989	104,612
Small Hydro	19:29	623	13,068
Biogas	10:04	157	3,652
Biomass	16:16	242	5,671
Geothermal	19:16	978	23,361
Total Renewables			**238,489**

Total 24-Hour System Demand (MWh): *589,105*

This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day.

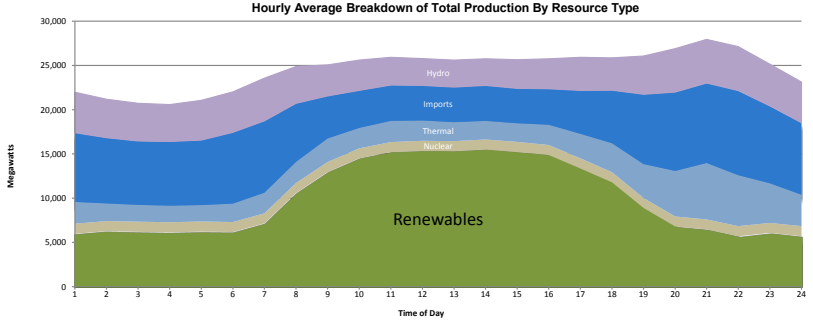
Hourly Average Breakdown of Renewable Resources



This graph shows the production of various types of renewable generation across the day.

System Peak Demand (MW) **28,074**
*one minute average
Time: **20:37**

Hourly Average Breakdown of Total Production By Resource Type



This graph depicts the production of various generating resources across the day.

Previous Renewables Watch reports and data are available at http://www.caiso.com/green/renewableswatch.html

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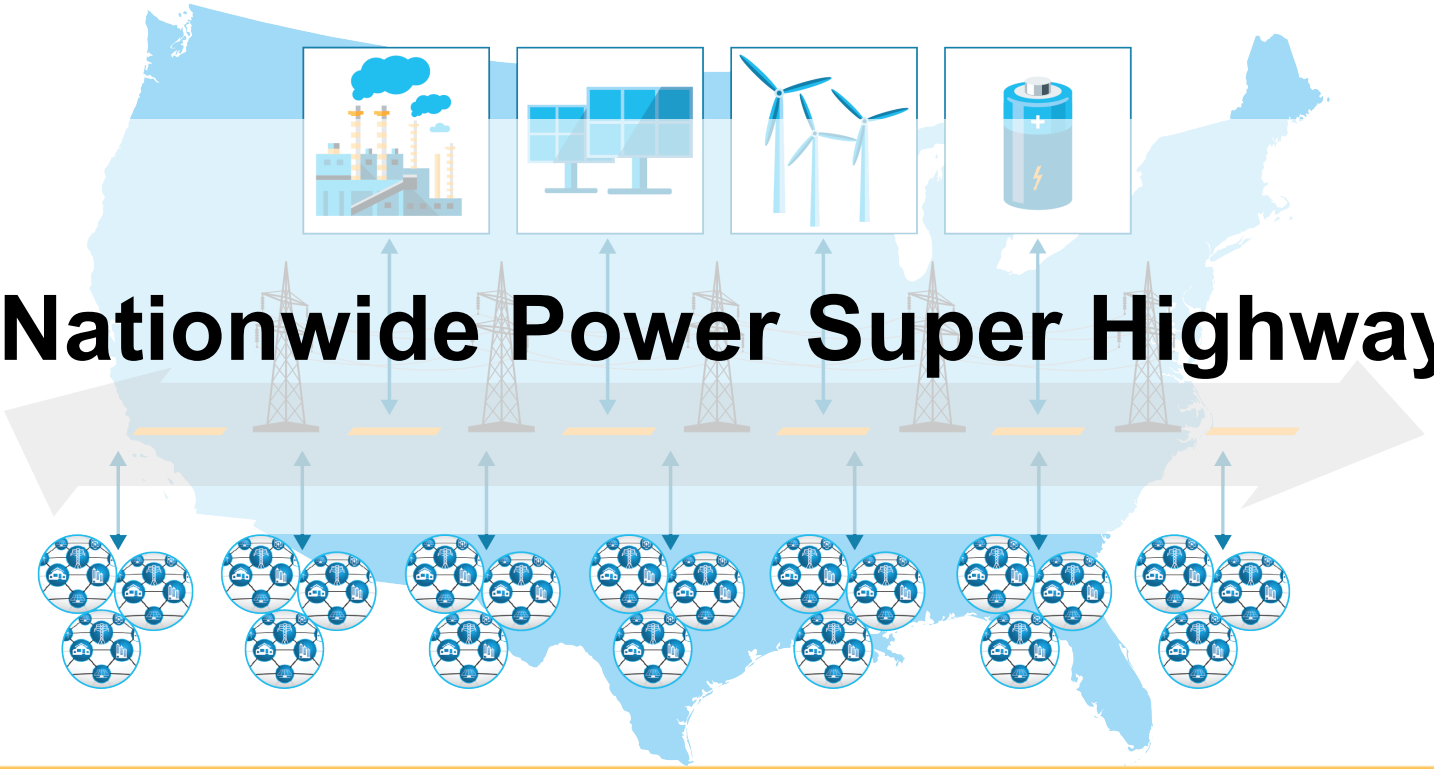
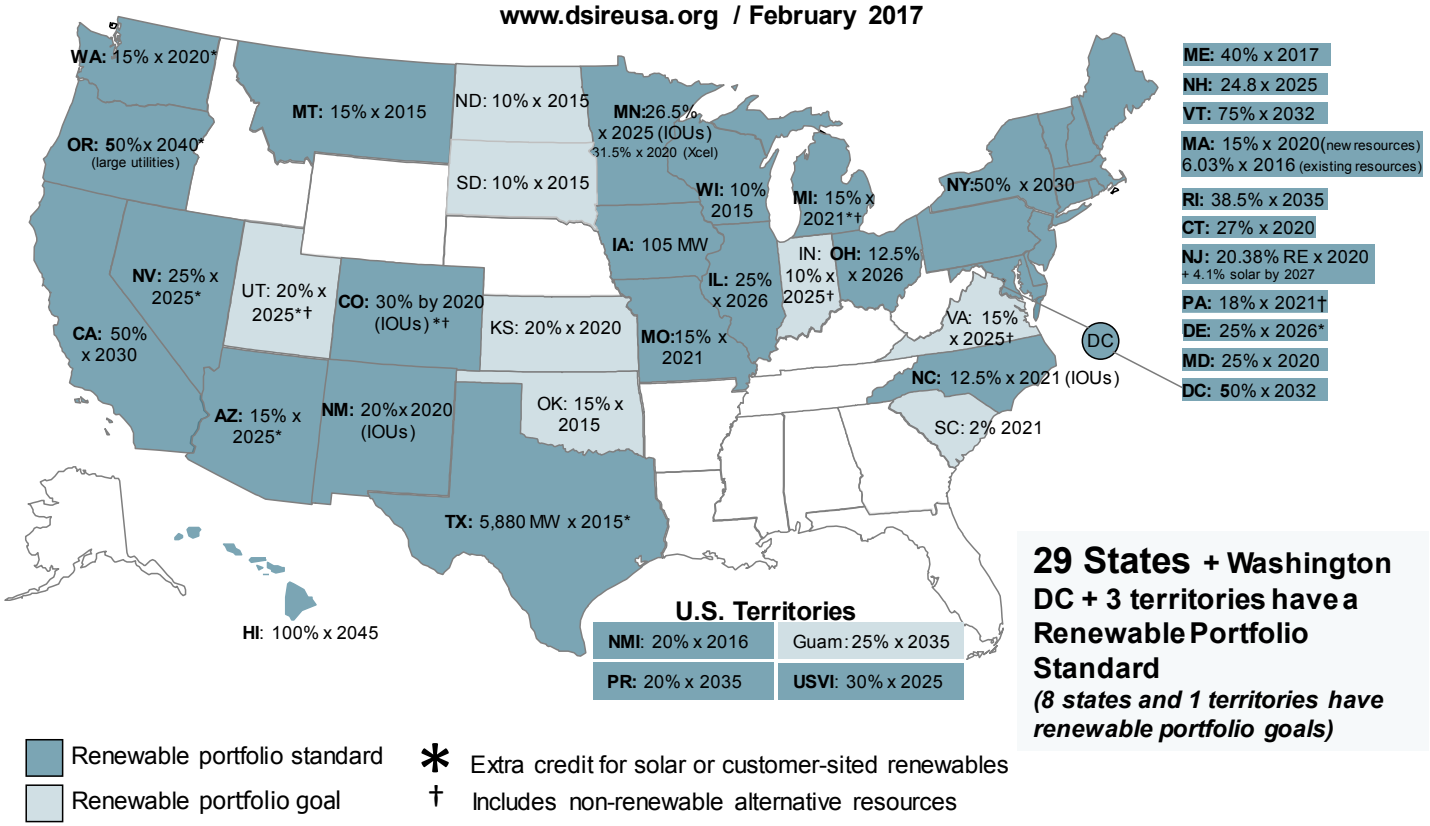
Technologies Making Power Grid "Smarter"

- Ubiquitous sensing and data collection
- Plug-and-play architecture
- Active Customer Engagement
- Enhanced Resiliency & Security



U.S. Power Grid is Changing!

- CAISO opening markets to DERs (50% by 2030)
- NY Reforming the Energy Vision to increase renewables & DERs (50% by 2030)
- Hawaii to use only renewable power within the next 30 years (100% by 2045)
- Vermont to use mainly energy from green sources (90% by 2050)



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Grid Change Brings Challenges

Dispatched generation → Intermittent DG

Predictable load → Variable Net-Load

Capacity available → Capacity constrained

Renewables penetration is limited (< 30%) because of lack of capability to reliably and affordably manage its variability

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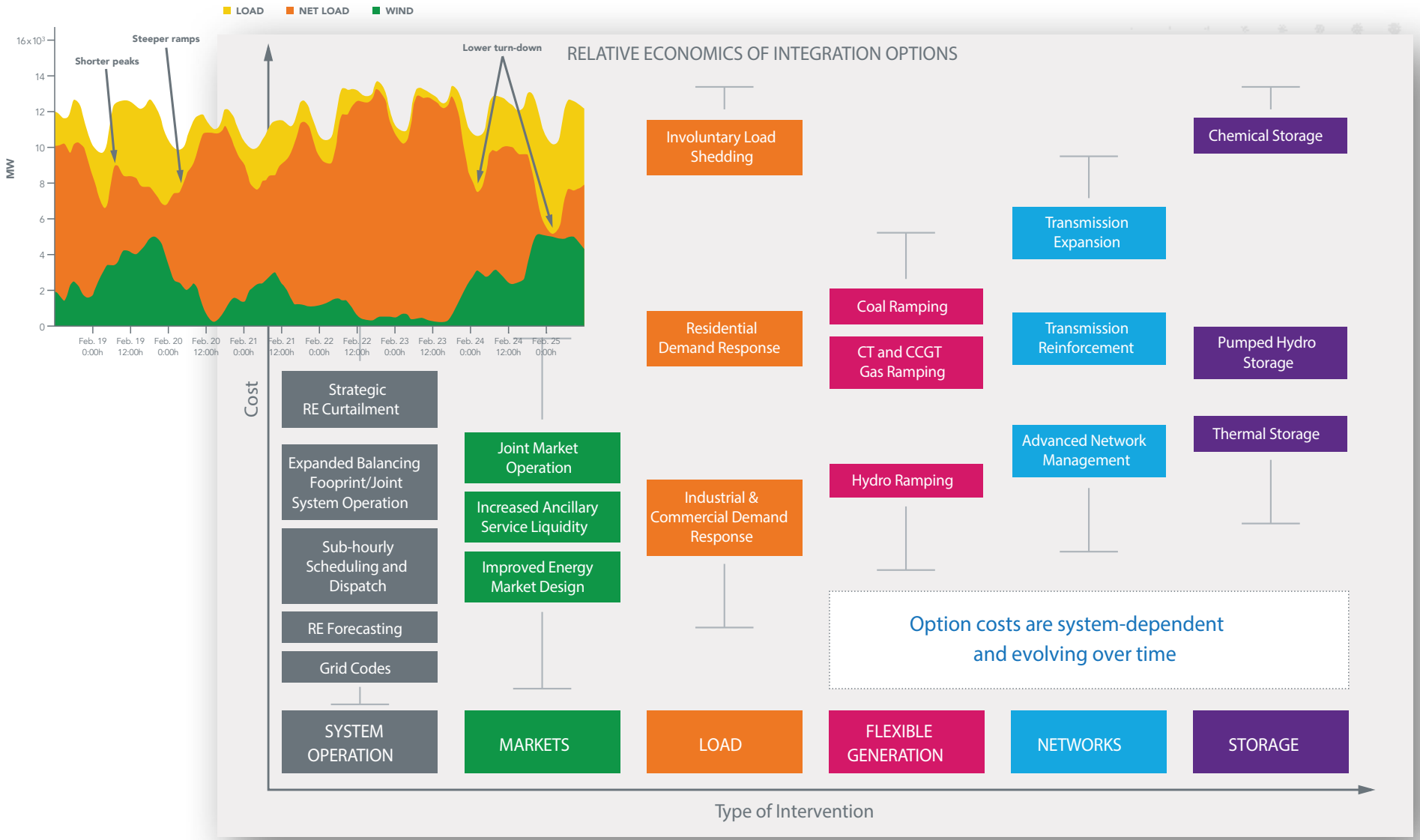
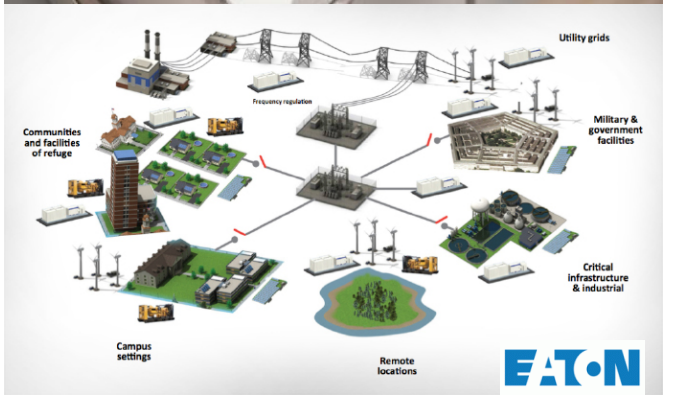
Sources of Grid Flexibility



http://greeningthegrid.org/resources/factsheets/sources-of-operational-flexibility

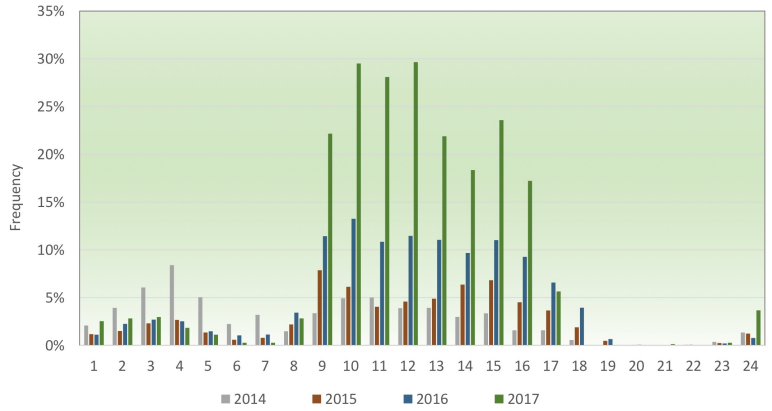
Emerging Grid Operation Paradigms

- **ISO & DER aggregators**
  - ISO manages transmission & wholesale
  - Aggregated DERs bid into bulk market
- **ISO & DSO**
  - ISO manages transmission & wholesale
  - DSO manages distribution & retail
- **Network of micro-grids**
  - Power supplied locally
  - Grid supplies backup power

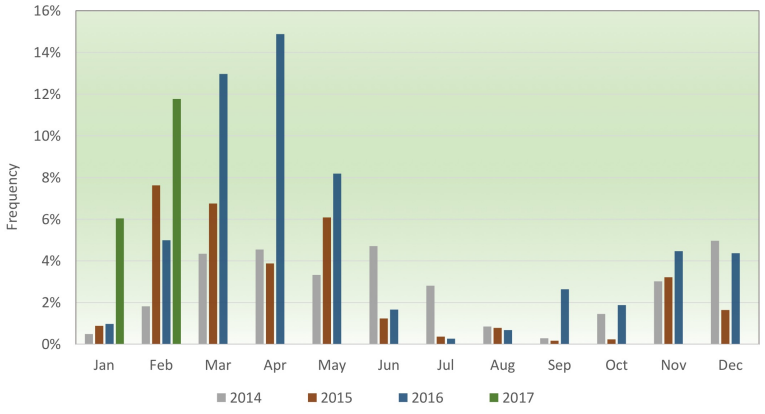


Are Markets Working?

Distribution of negative prices have shifted from early morning hours to midday hours*

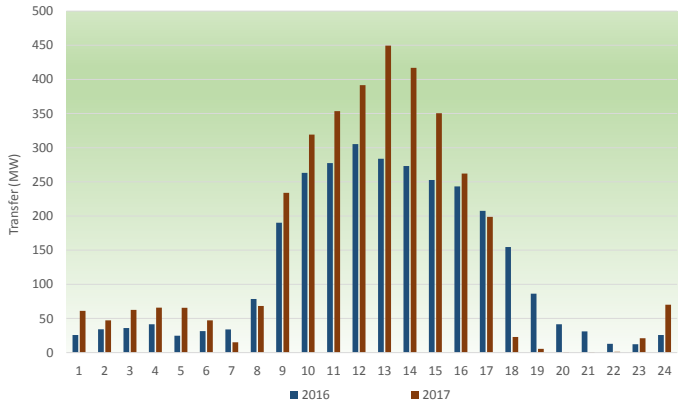


Frequency of negative system prices has steadily increased year over year

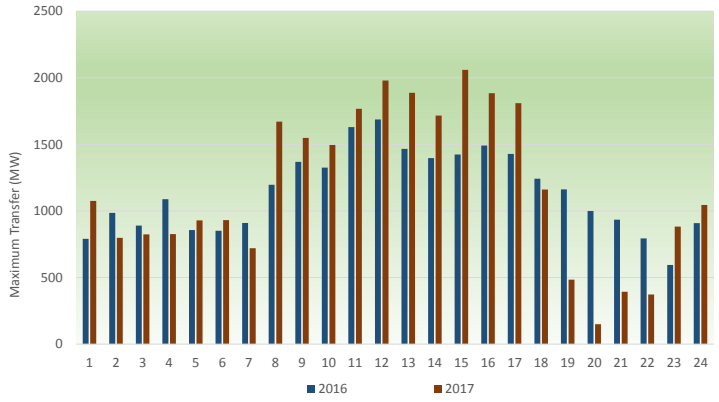


California ISO

The gross volume of transfers out of the ISO BAA occurs during midday hours



The maximum transfer from the ISO to other BAAs in in 2017 have been the highest



California ISO

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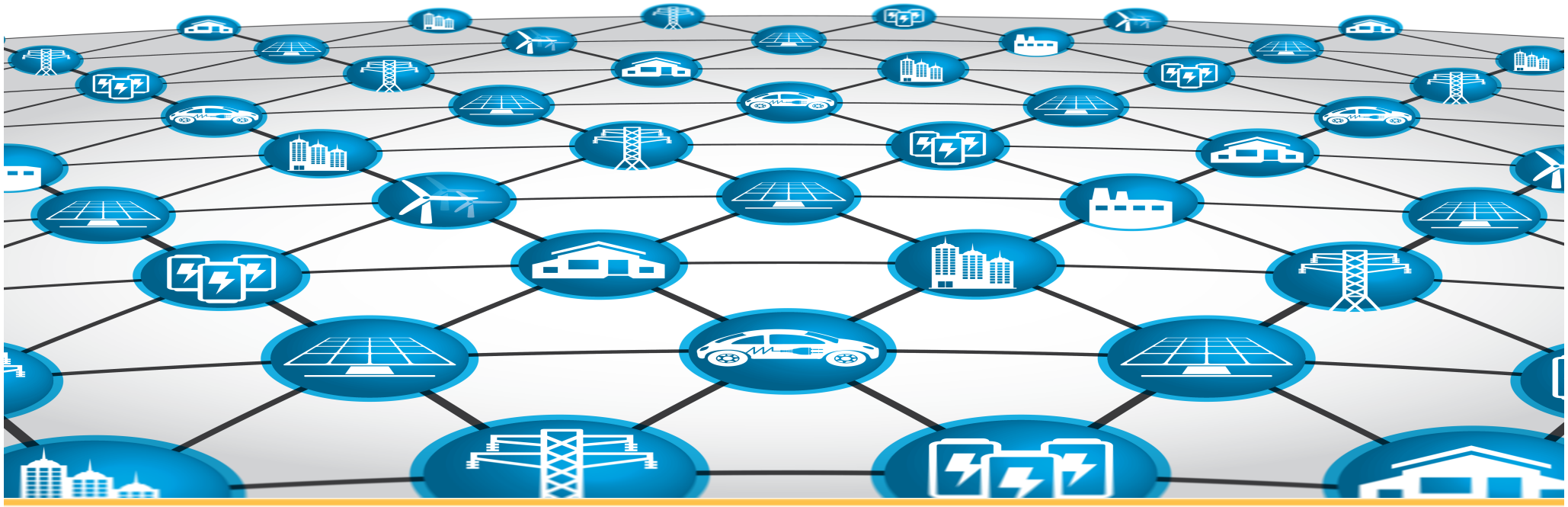
Network Optimized Distributed Energy Resources (NODES) Program



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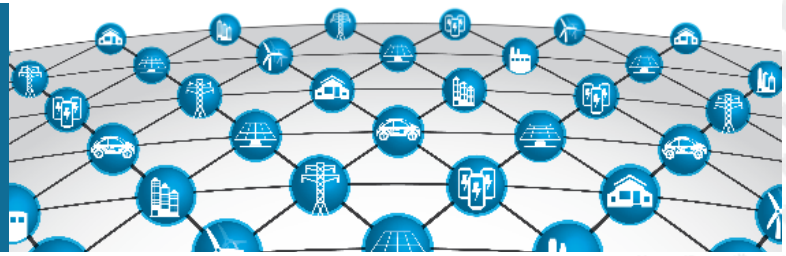
If we can actively control Net-Load,
50% renewable integration is possible

NODES

Network Optimized Distributed Energy Systems



Mission

Reliably manage dynamic changes in the grid by leveraging flexible load and Distributed Energy Resources' (DERs) capability to provide ancillary services to the electric grid at different time scales.

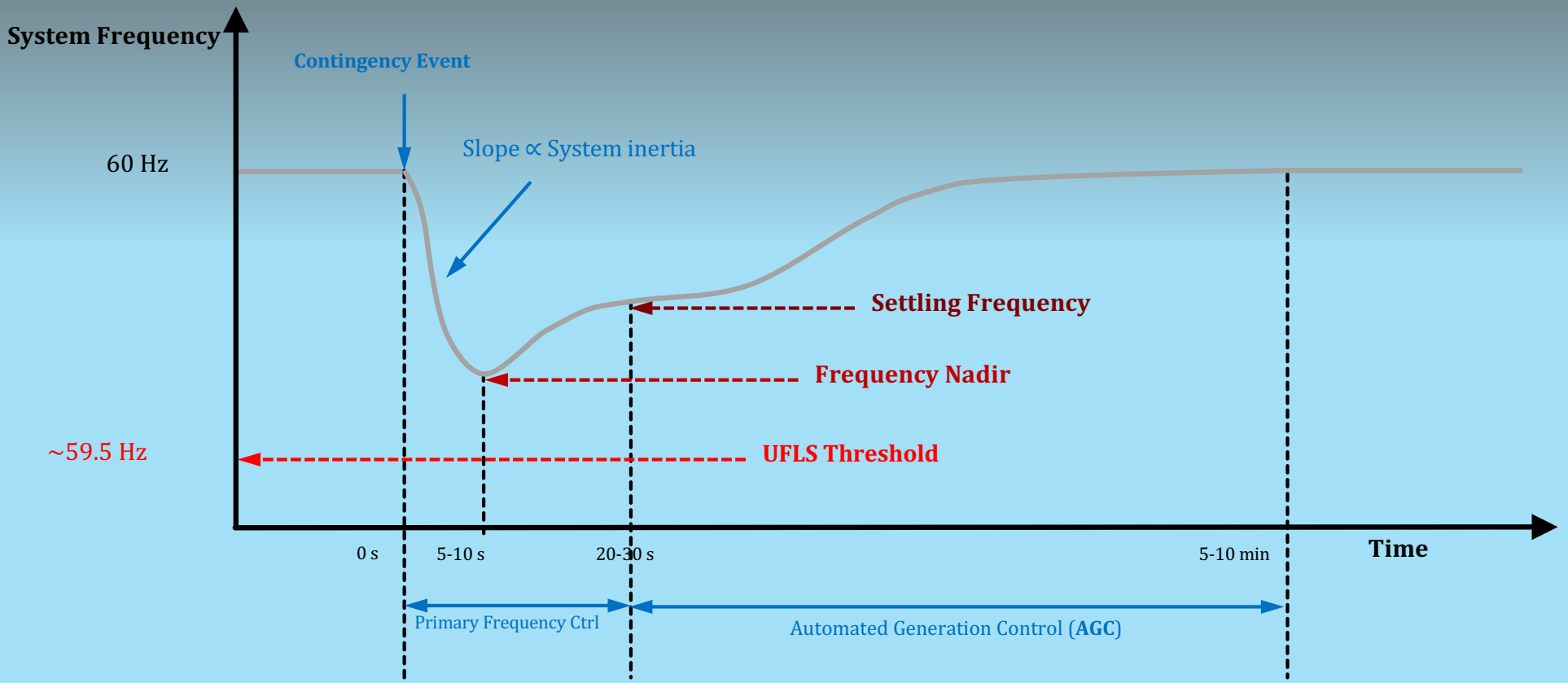
Goals

- **Enable renewables penetration at > 50%**
- **Improve overall grid efficiency & reliability**
- **Reduce CO_2 emissions**
- **Guarantee Level-of-Service to the Grid**
- **Guarantee customers' QoS**

Project Categories	Response Time	Ramp Time	Duration
C1: Synthetic Frequency Reserves	< 2 sec	< 8 sec	> 30 sec
C2: Synthetic Regulating Reserves	< 5 sec	< 5 min	> 30 min
C3: Synthetic Ramping Reserves	< 10 min	< 30 min	> 3 hr

Grid Reliability - Frequency Stability

Directly affected by generation-demand balance



Category 1: Synthetic Frequency Reserves

Objective

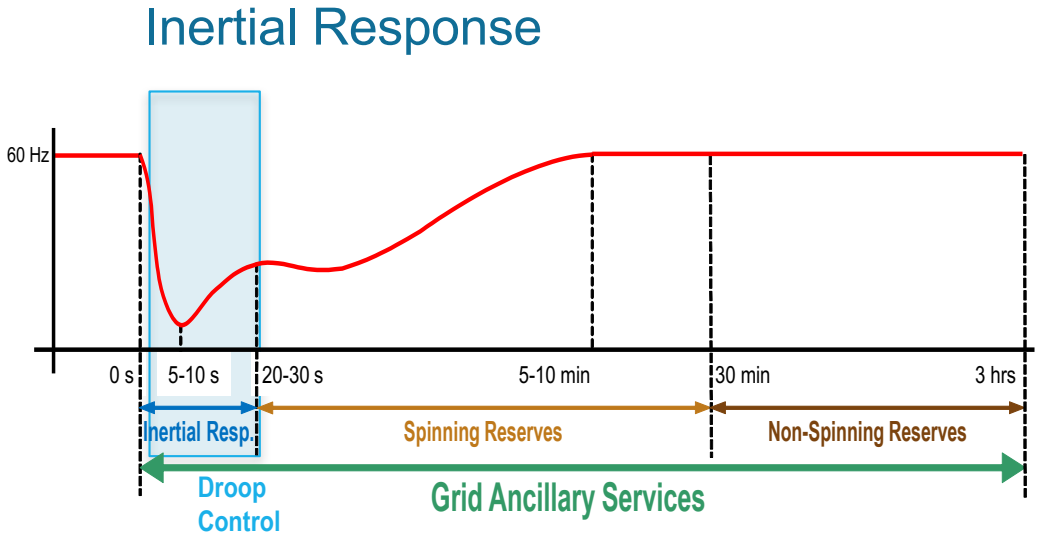
- Increase “inertia” in the system

Approach

- Load providing inertial response while using local measurements

Challenges

- Guarantee stability of the system
- Guarantee improvements of frequency compared to the traditional generation control only
- Response speed



Validation

- HIL validation with a minimum of 100 actual devices at power
- Large-scale simulation (optional) to demonstrate the robustness and scalability

Category 2: Synthetic Regulating Reserves

Objective

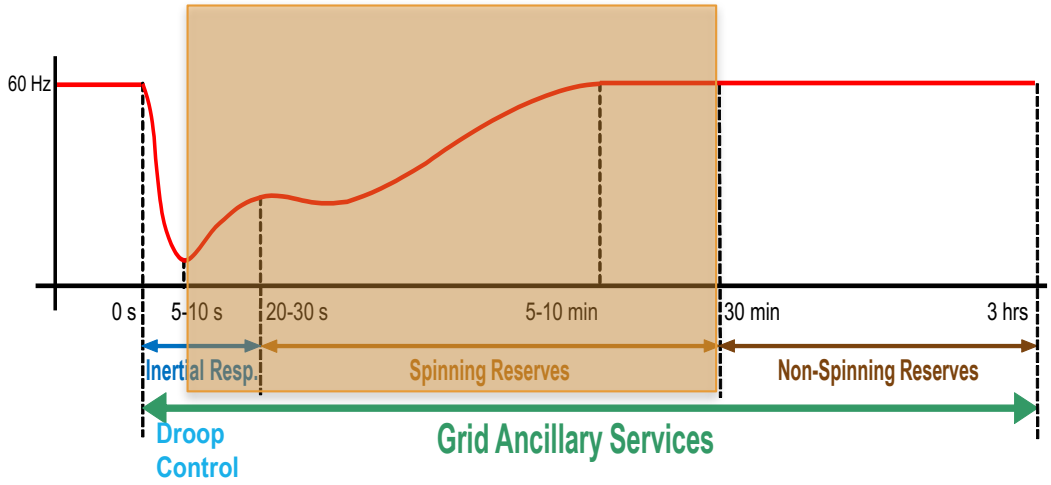
- Support frequency recovery/stability of the system

Approach

- Use coordinated net-load control to adjust magnitude and shift in time

Challenges

- Coordination of large number of heterogeneous energy resources
- Understanding trade-off between peer-to-peer communication and optimal performance



If successful, load adjustment + shift could help enable 50% renewables at 92% utilization

Validation

- HIL validation with a min of 100 actual devices at power
- Large-scale simulation (optional) to demonstrate the robustness and scalability

Category 3: Synthetic Ramping Reserves

Objective

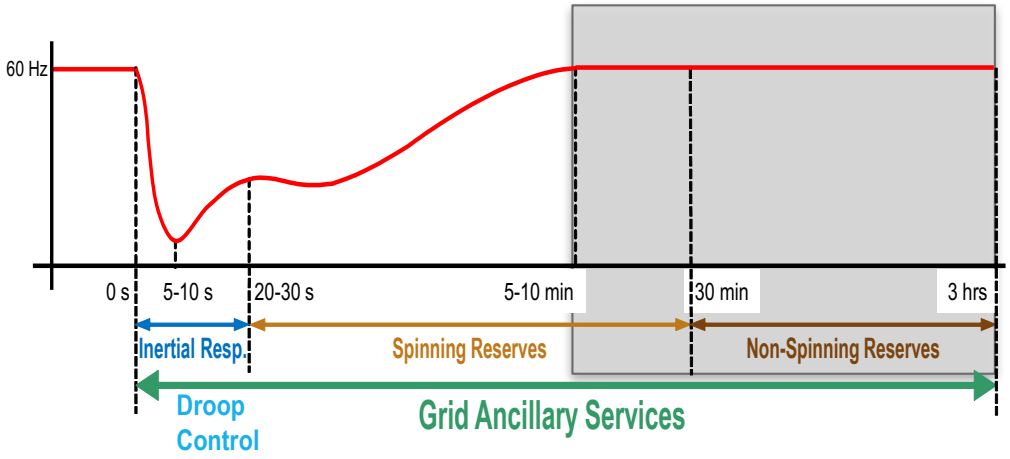
- Coordinated long term shifting of load with thermal/electric storage (buildings, warehouses), and non-critical load (pool pumps, PEVs) to reduce curtailment of renewables

Approach

- Forecasting aggregated loads capacity
- Supervisory control enabling load balancing signal tracking

Challenges

- Modeling and control of a populations of controlled loads
- Determining control requirements for guaranteed aggregate load performance

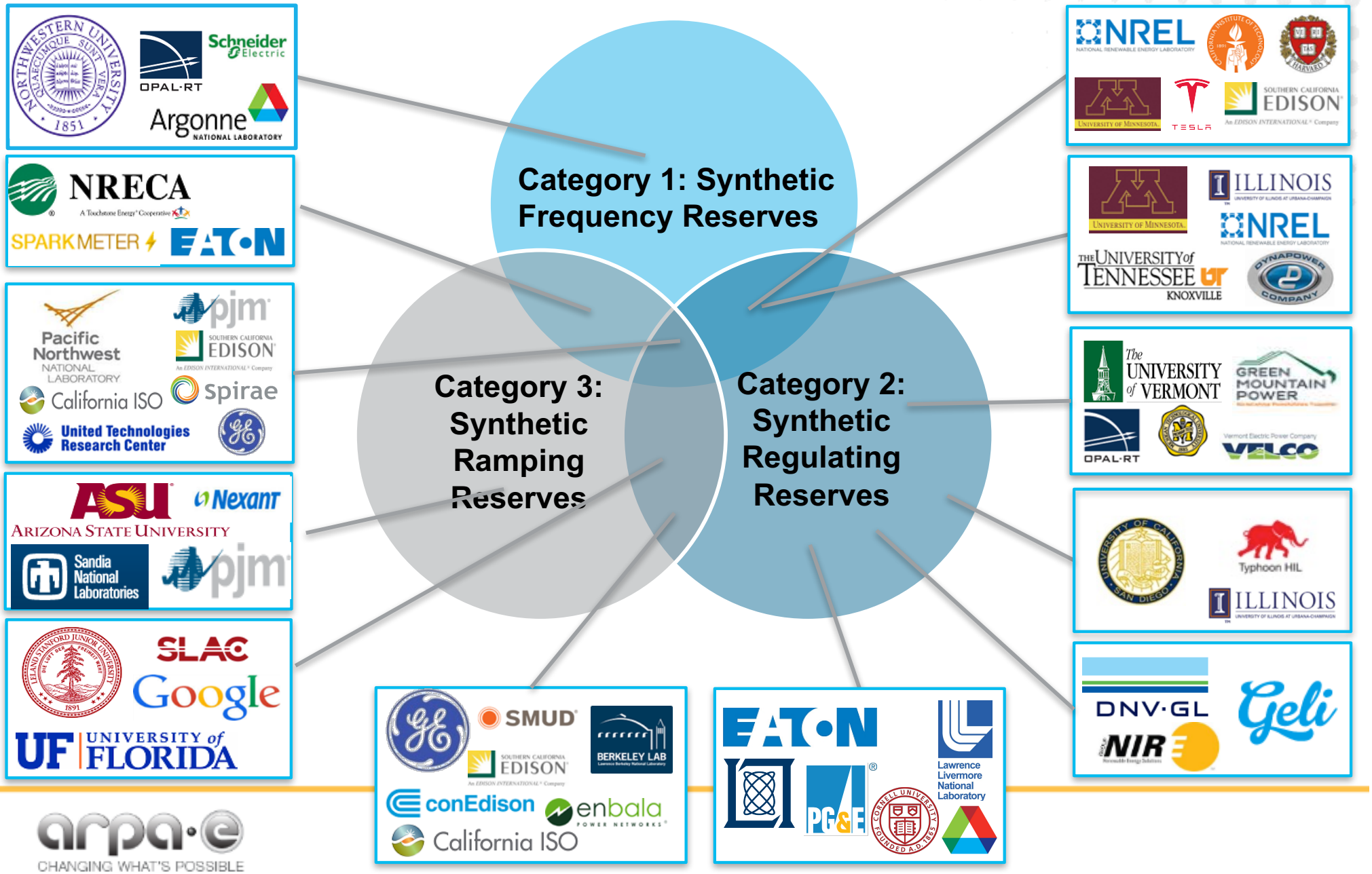


If successful, load adjustment + shift (>10%) could enable 50% renewables at 95% utilization

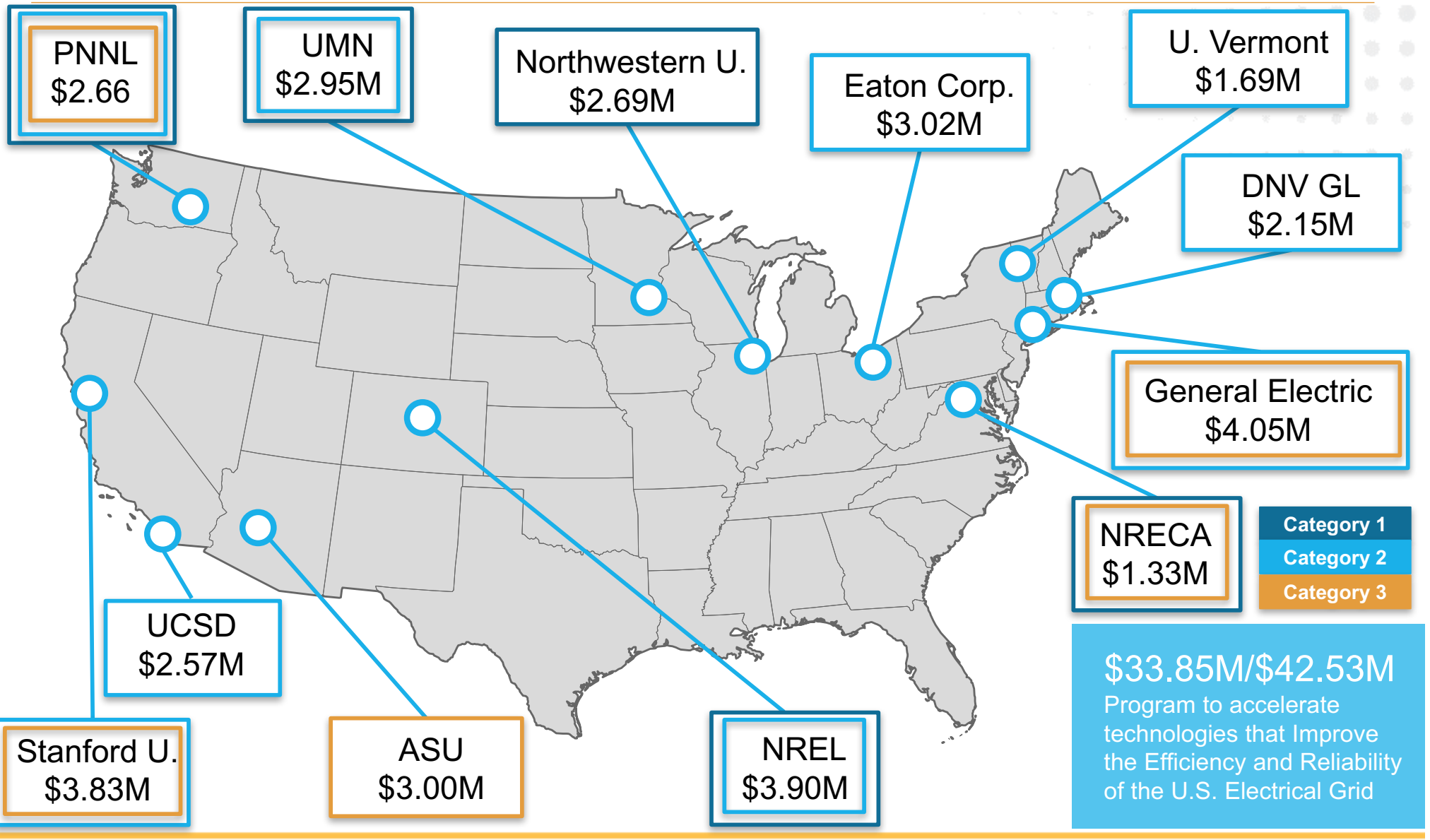
Validation

- Large-scale simulation to demonstrate the robustness and scalability

NODES Project Portfolio



NODES Projects by Team Lead Geography



$33.85M/$42.53M

Program to accelerate technologies that Improve the Efficiency and Reliability of the U.S. Electrical Grid

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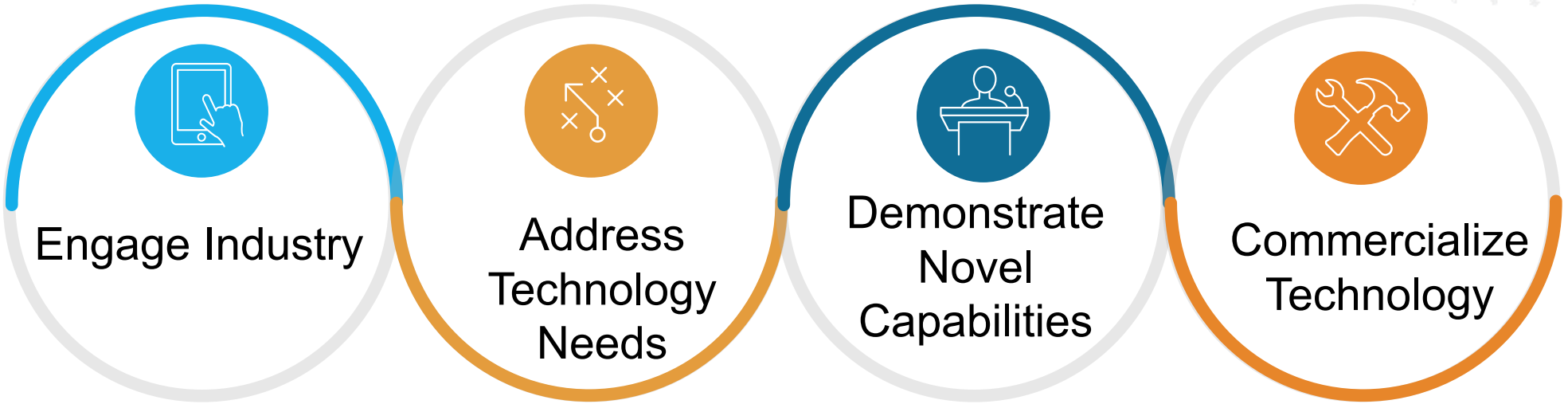
Next Steps

01 Recruit Industrial Advisory Board (IAB) Members for teams

03 Validate solutions in HIL & Large Scale Simulation



02 Develop grid management & control technology enabling large scale flexible loads & DERs integration

04 Work with teams & IABs on technology to market plans and strategies

Members of Industrial Advisory Boards

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