NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Grid Modernization and Energy Storage
Economics and Business Models

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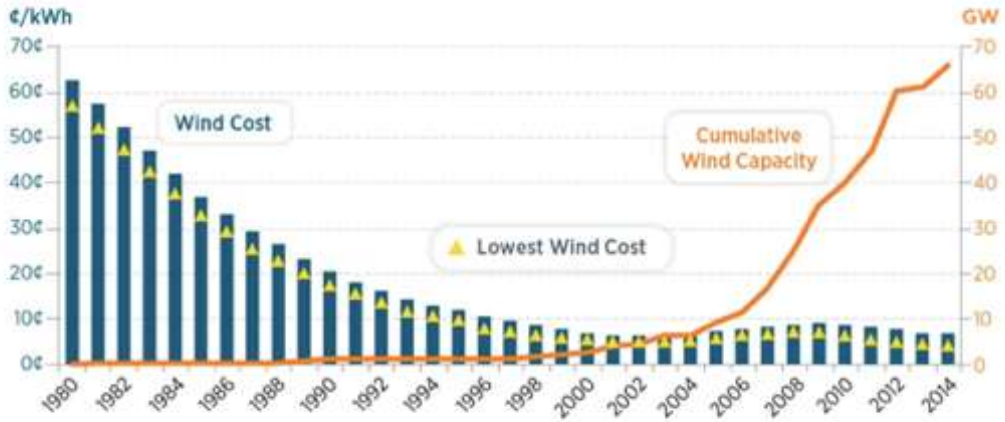
WHY GRID MODERNIZATION?

The existing U.S. power system has served us well…

but our 21st Century economy needs a 21st Century grid.

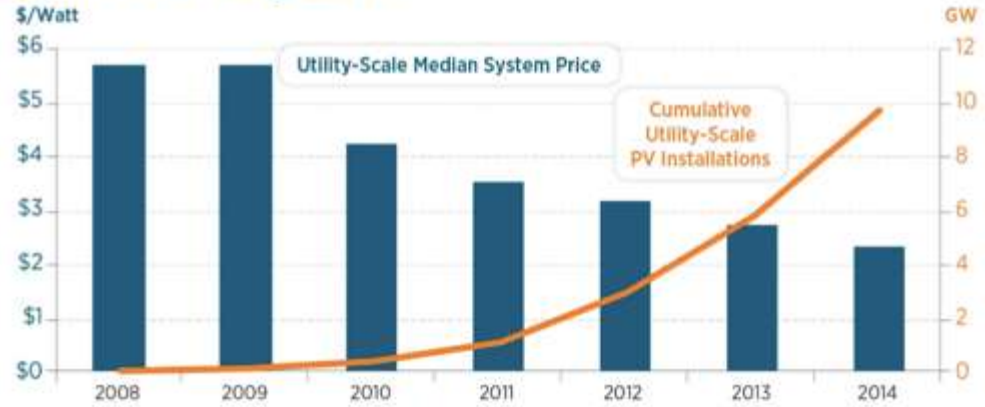
GROWTH IN VARIABLE RENEWABLES

Land-Based Wind Power



Notes: 1 gigawatt (GW) = 1,000 megawatts (MW). All costs shown are inflation adjusted to dollar year 2014 and exclude the production tax credit (PTC). Wind capacity as reported by market reports.[2] "Wind Cost" represents estimated levelized cost of energy from a representative wind site, and "Lowest Wind Cost" represents costs derived from power purchase agreements from good to excellent wind resource sites in the interior of the country.[3]

Solar PV: Utility-Scale



Notes: All prices are in $/W$_{DC}$ and inflation adjusted to dollar year 2014. 1 gigawatt (GW) = 1,000 megawatts (MW). Prices as reported in market report.[17] "Utility-scale" cumulative installations as reported in source in GW$_{DC}$.[18]

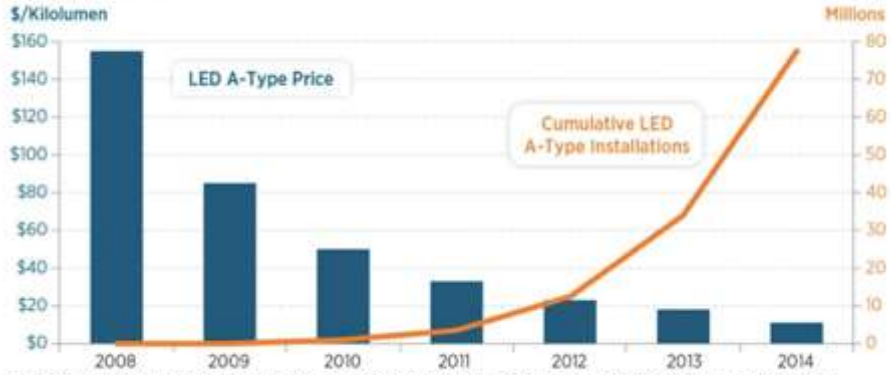
Source: DOE "Revolution Now", 2015

NEW CUSTOMER DEMANDS

Solar PV: Distributed Generation

Notes: All prices are in $/W$_{DC}$ and inflation adjusted to dollar year 2014. 1 gigawatt (GW) = 1,000 megawatts (MW). Capacity weighted average as reported by market report for residential systems only.[32] Non-residential systems are typically larger and have lower reported prices. Capacity is cumulative distributed residential and non-residential capacity, in GW$_{DC}$.[33]

LED Lighting



Notes: Kilolumen is a measure of visible light output by a source. Price data is in nominal dollars as reported in internal tracking report.[42] Cumulative LED A-type bulb installations as reported in market report.[43]

Electric Vehicles

Notes: Costs are modeled costs for high-volume battery systems, derived from DOE/UIS Advanced Battery Consortium PHEV Battery development projects and are representative of nominal dollars. Sales as reported by market tracker, here "EVs" include all plug-in hybrid and battery plug-in vehicles.[32]

Source: DOE "Revolution Now", 2015


OKAY...
NOW WHAT?!
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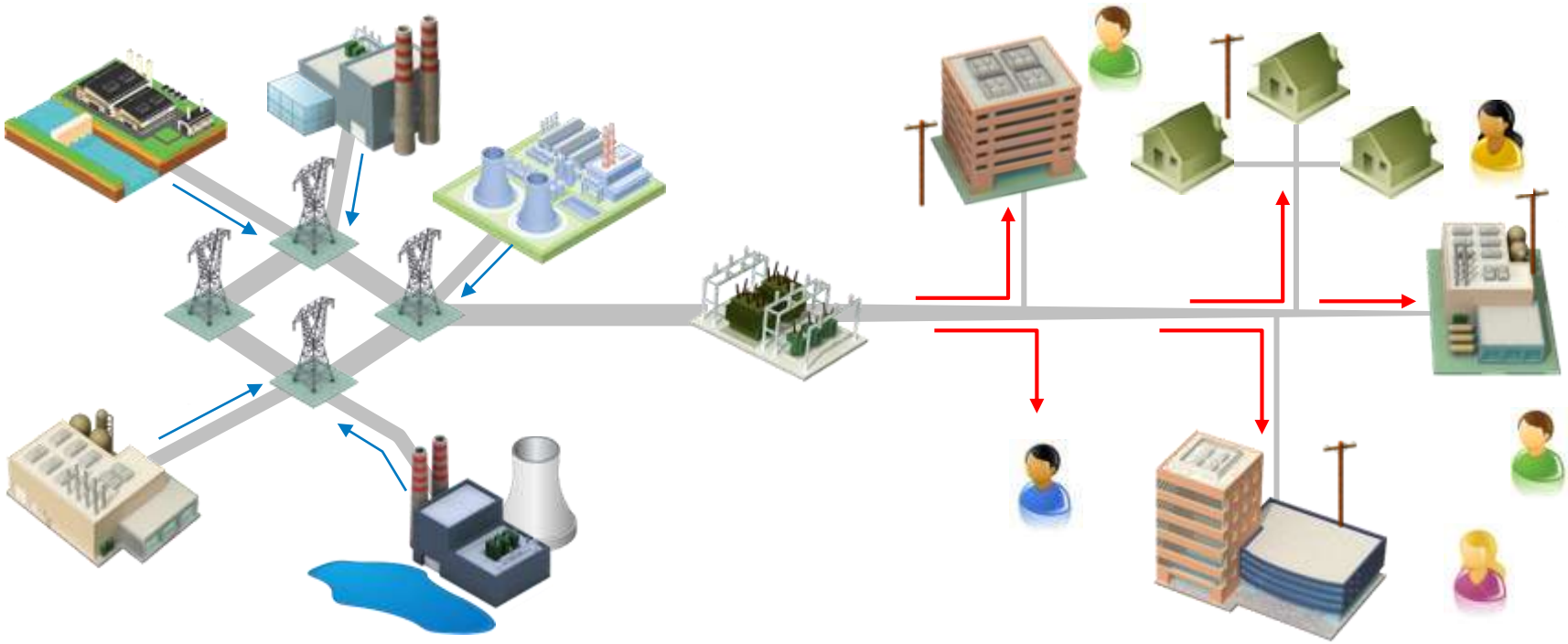
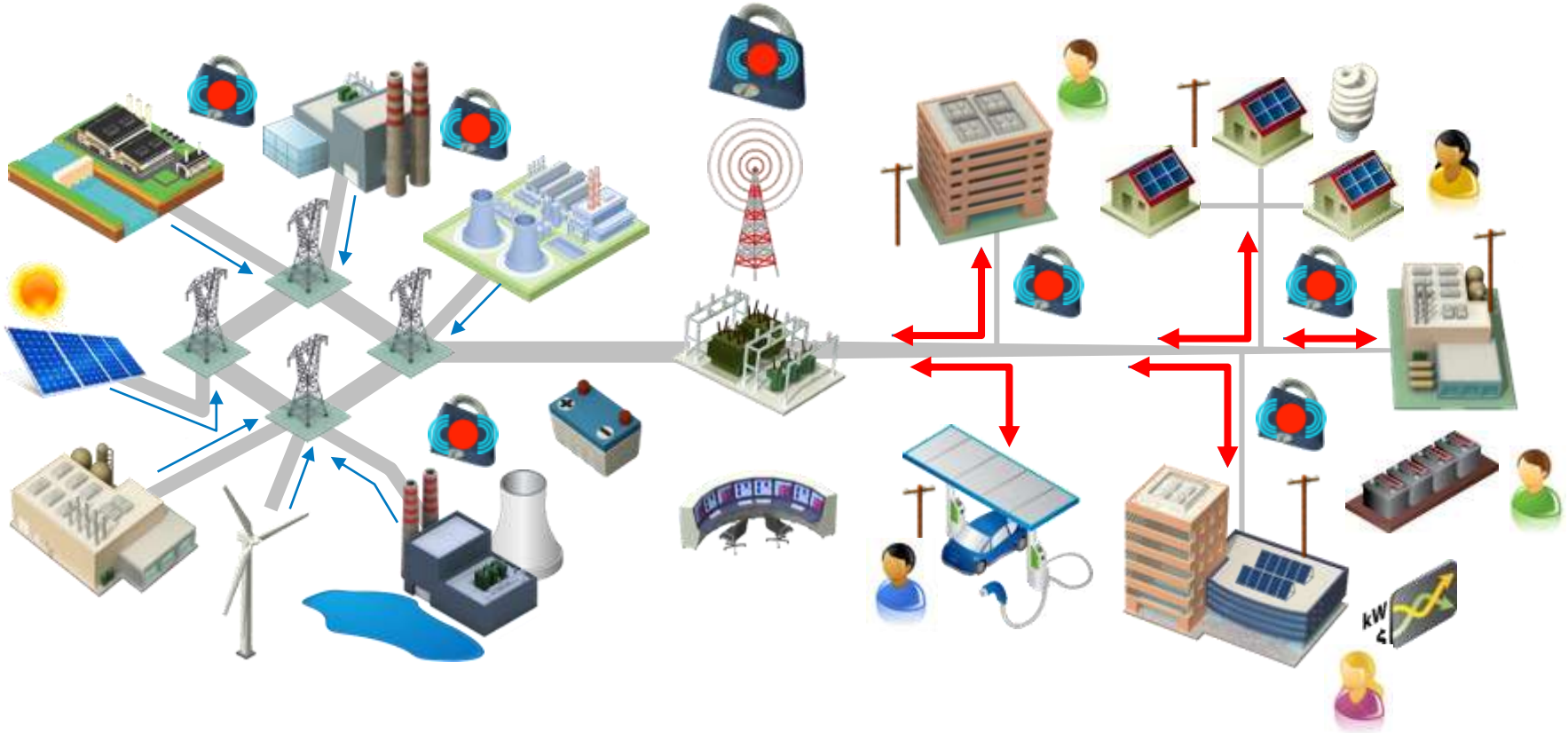
THE GRID OF THE PAST



Generation **Delivery** **Customer**

Source: EPRI, 2009

THE GRID OF THE FUTURE

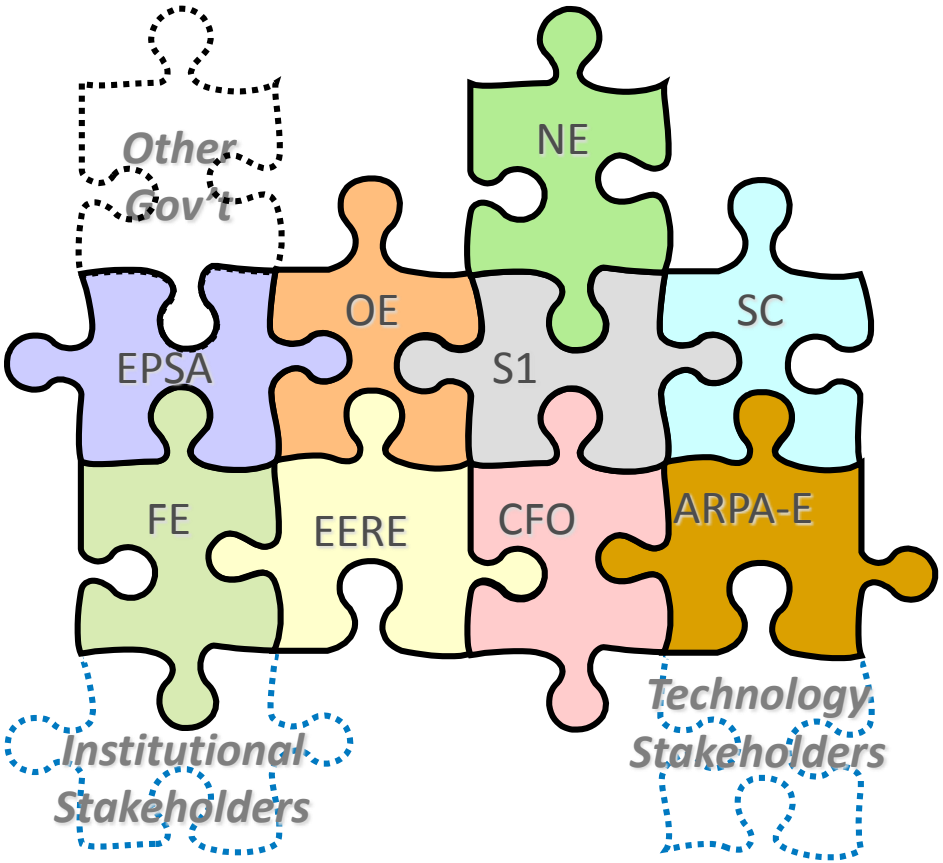


Source: EPRI, 2009

DOE GRID MODERNIZATION INITIATIVE

An aggressive five-year grid modernization strategy for the Department of Energy that includes

- **Alignment of the existing base activities among DOE 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**



GRID MODERNIZATION MULTI-YEAR PROGRAM PLAN

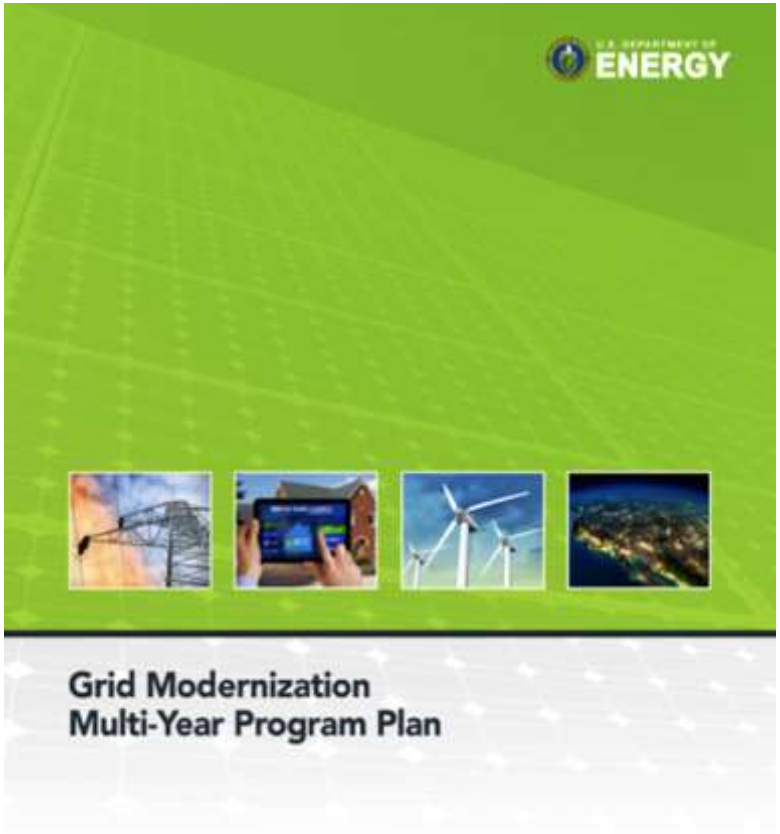
http://energy.gov/downloads/grid-modernization-multi-year-program-plan-mypp

Foundational R&D

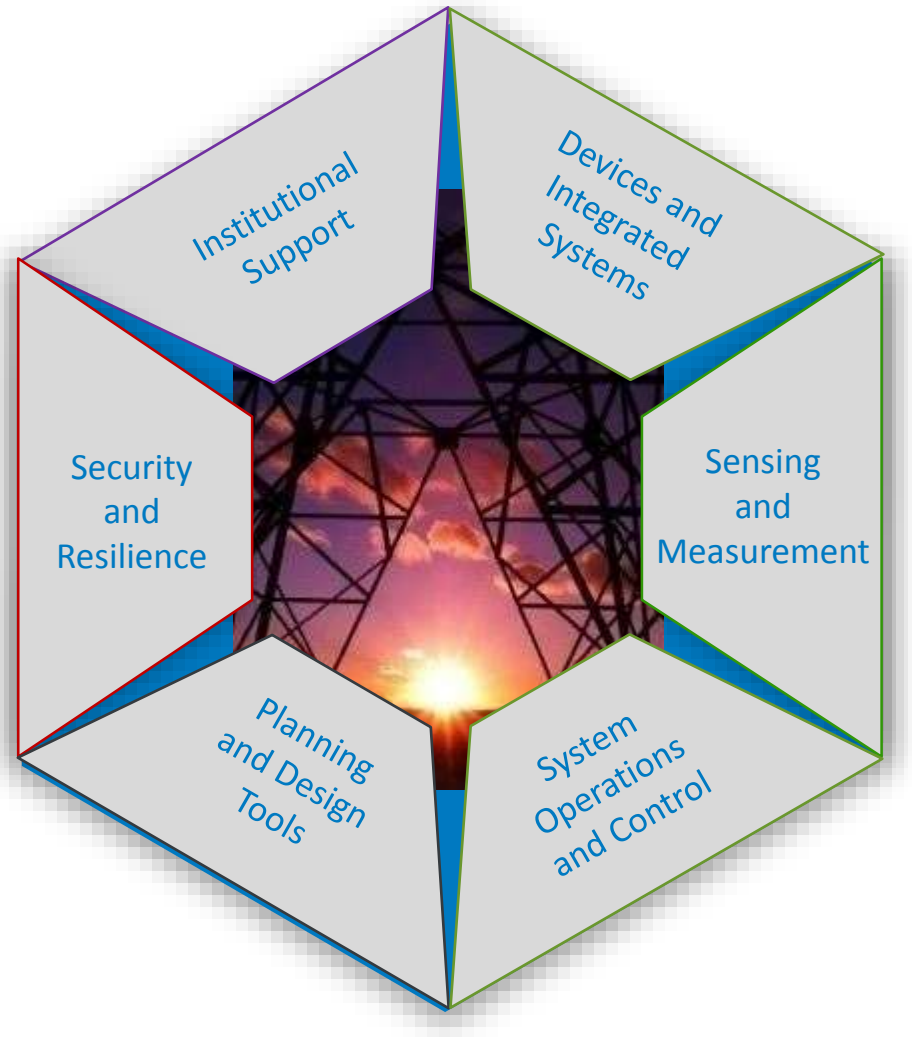
- Devices and Integrated Systems
- Sensing and Measurement
- System Operations and Control
- Design and Planning Tools
- Security and Resilience
- Institutional Support

Regional Demonstrations

- Low Reserve Margin Demo
- Clean Distribution Feeder
- Grid Analytics Platform



GRID MODERNIZATION LABORATORY CONSORTIUM



87 projects, $220M over 3 years

REGIONAL DEMONSTRATIONS

Three types of public-private partnerships that will accelerate transition of Foundational R&D outcomes to widespread deployment at scale

Lean Reserve Bulk Power Systems

Goals:

- Reliable operations with <=10% reserve margin; >33% variable wind, solar
- New capability for grid operators to leverage and manage distribution-level grid services
- Data-driven tools for precise, predictive real time grid operations

Target Partners:

- Transmission Utilities
- System Operators

Clean Distribution Systems

Goals:

- Demonstrate reliable and affordable feeder operations with >50% DER penetration
- Coordinated microgrid(s) control for resilience (20% fewer outages, 50% shorter recovery time)
- Distributed, hierarchical control for clean energy and new customer-level services

Target Partners:

- Distribution utilities
- Cities and municipalities with ambitious clean energy goals

Grid Planning and Analytics

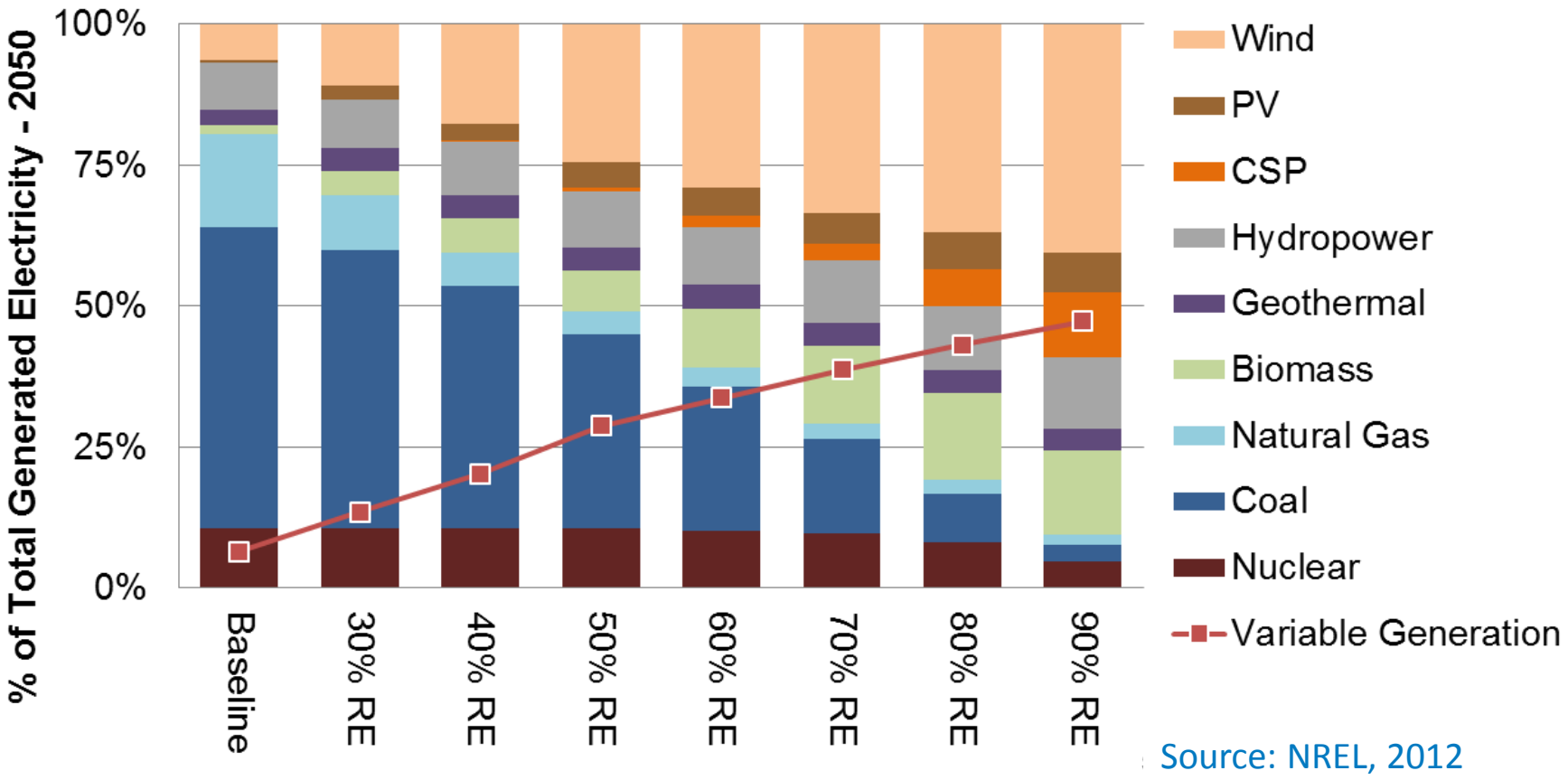
Goals:

- Use coupled T&D grid planning models with 1000x speed-up to address specific grid-related issues
- Work with States to evaluate new business models, impacts of policy decisions

Target Partners:

- States and local regulators
- Distribution utilities
- New market participants

WHAT A FUTURE GRID MIGHT LOOK LIKE



Source: NREL, 2012

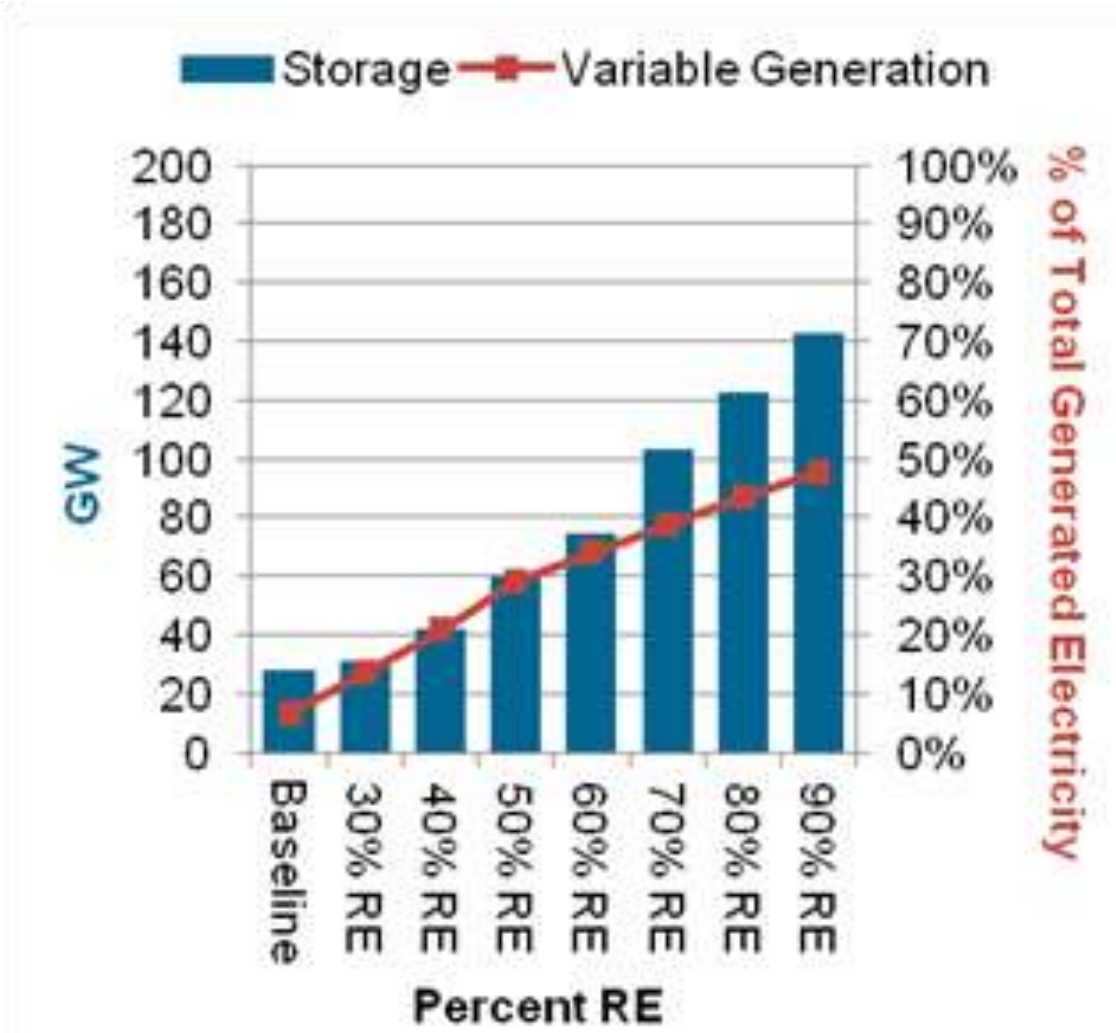
The need for grid flexibility will increase in proportion to the amount of variable generation

HOW MUCH ENERGY STORAGE?

Today in the U.S.

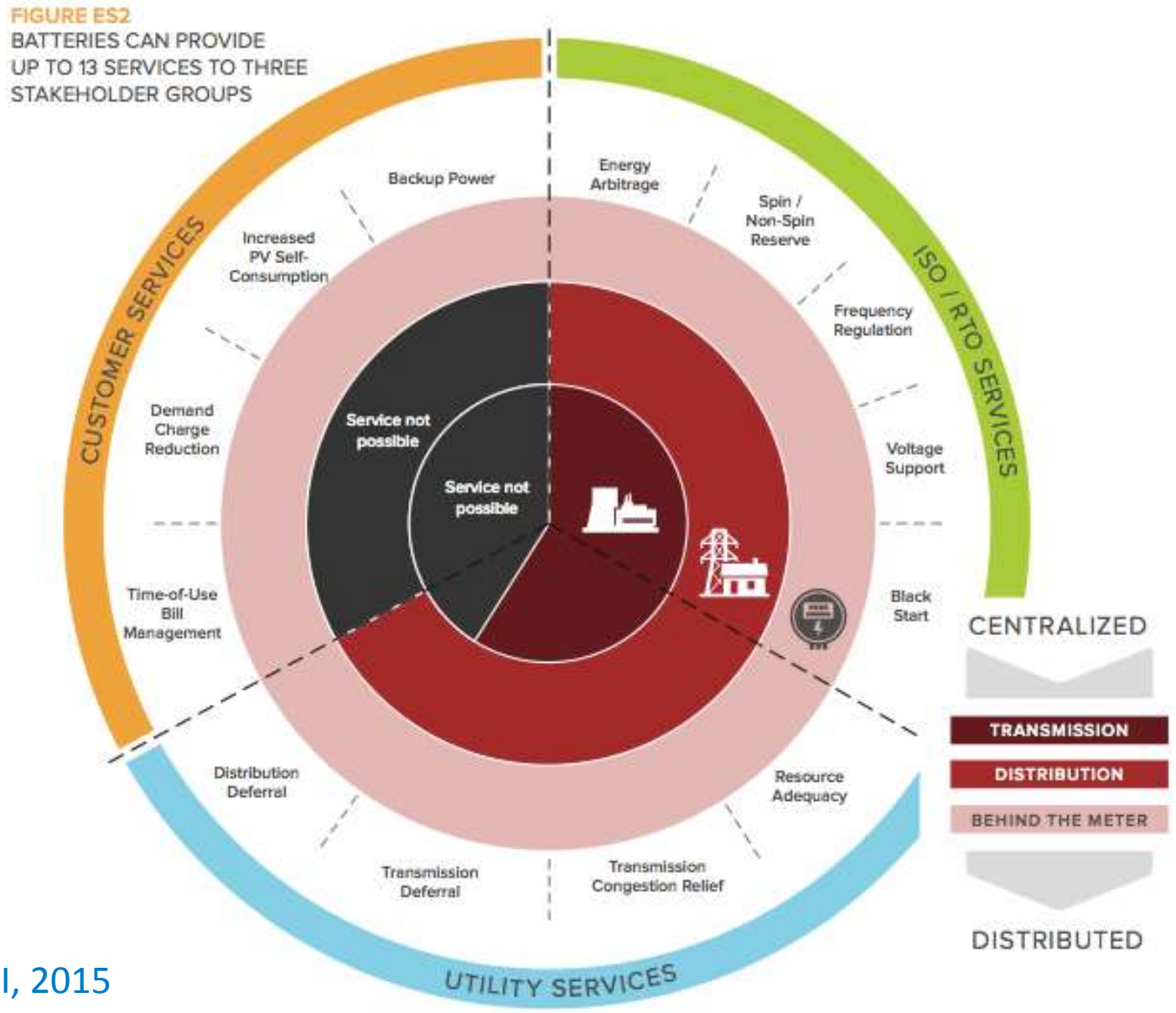
- 22.5 GW Pumped Hydro
- 0.6 GW Batteries
- 0.2 GW Flywheels
- 0.8 GW Thermal

Source: DOE Energy Storage Database



Source: NREL, 2012

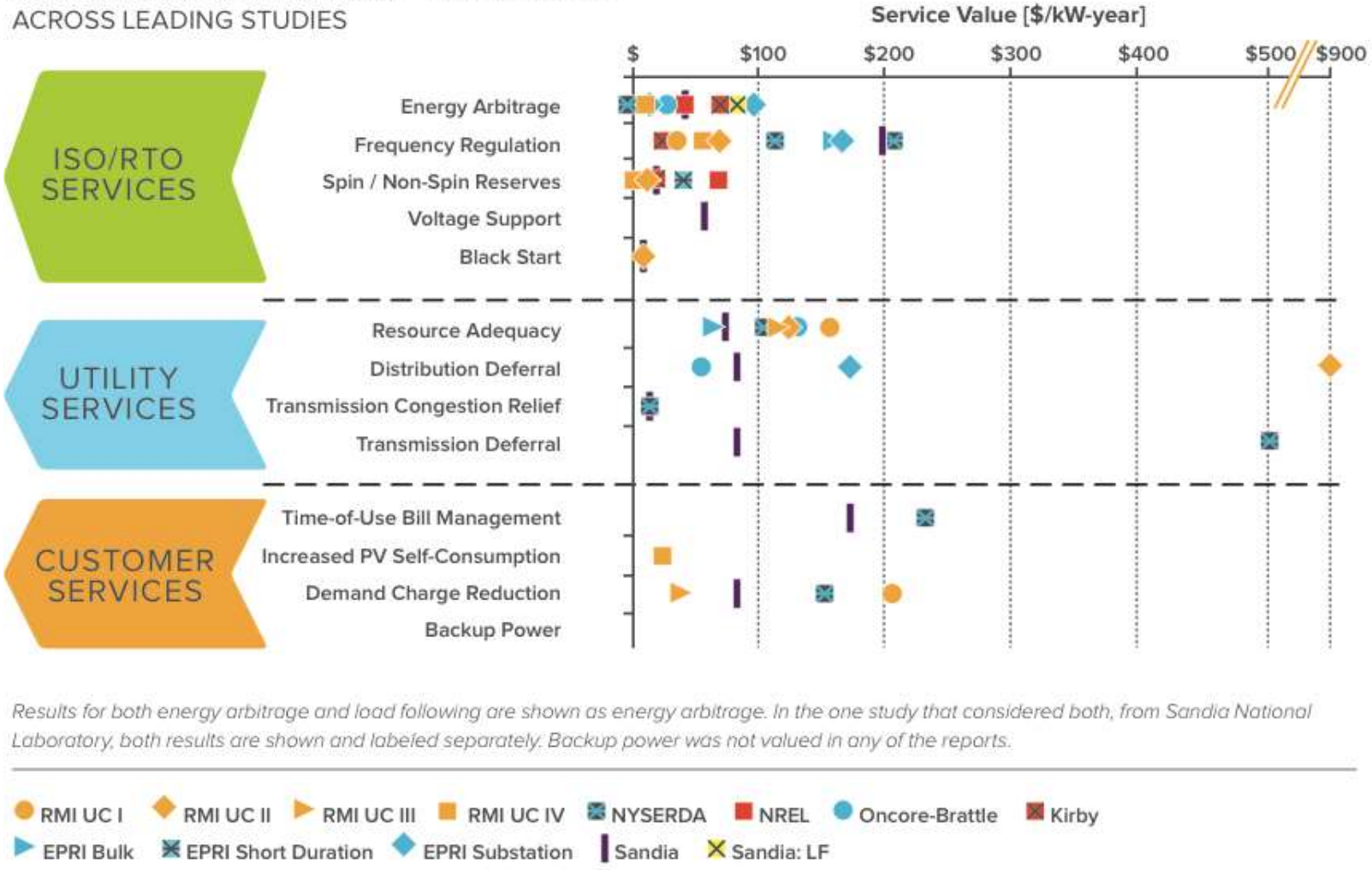
WHAT GRID SERVICES CAN STORAGE PROVIDE?



Source: RMI, 2015

VALUE OF STORAGE CAN VARY DRAMATICALLY

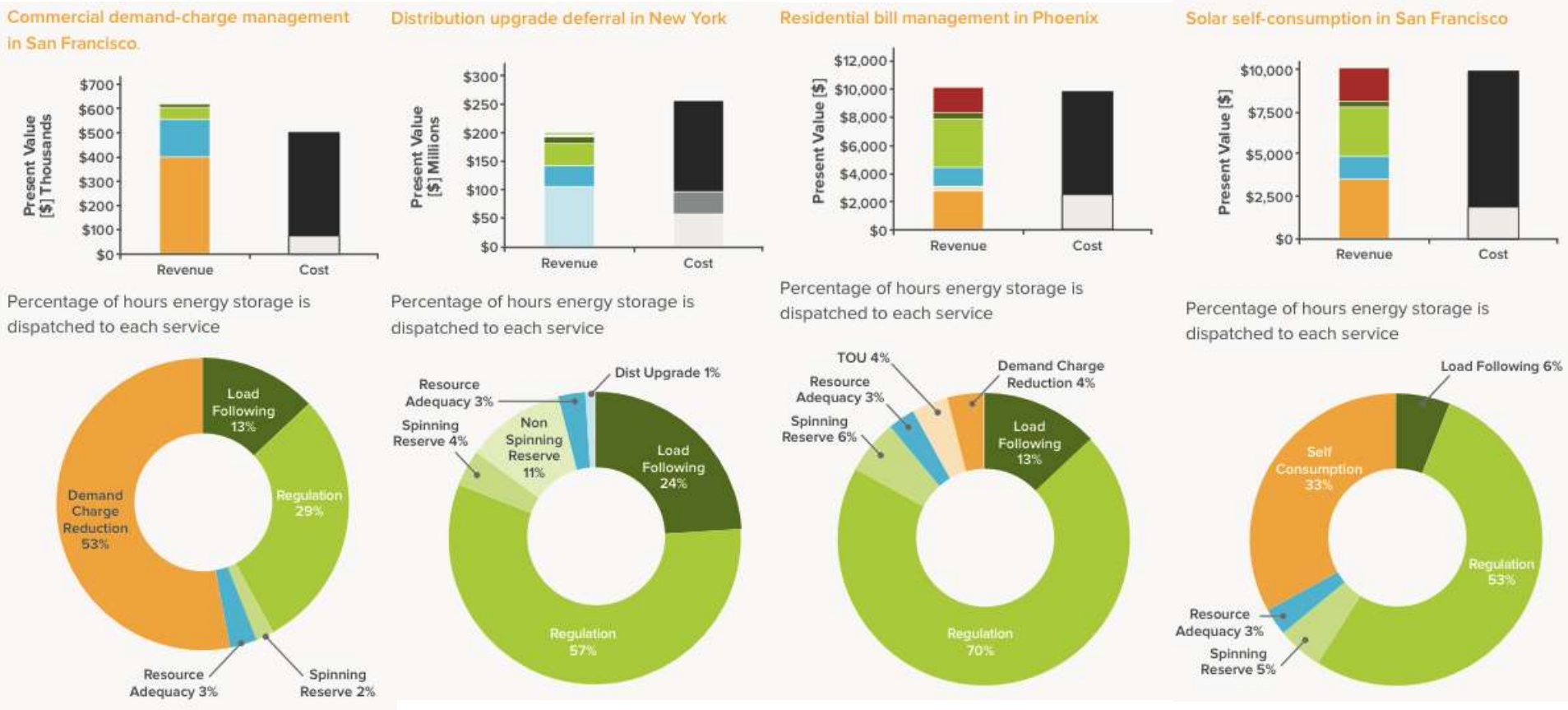
FIGURE 3
ENERGY STORAGE VALUES VARY DRAMATICALLY ACROSS LEADING STUDIES



Results for both energy arbitrage and load following are shown as energy arbitrage. In the one study that considered both, from Sandia National Laboratory, both results are shown and labeled separately. Backup power was not valued in any of the reports.

Source: RMI, 2015

VALUE IS USE CASE DEPENDENT



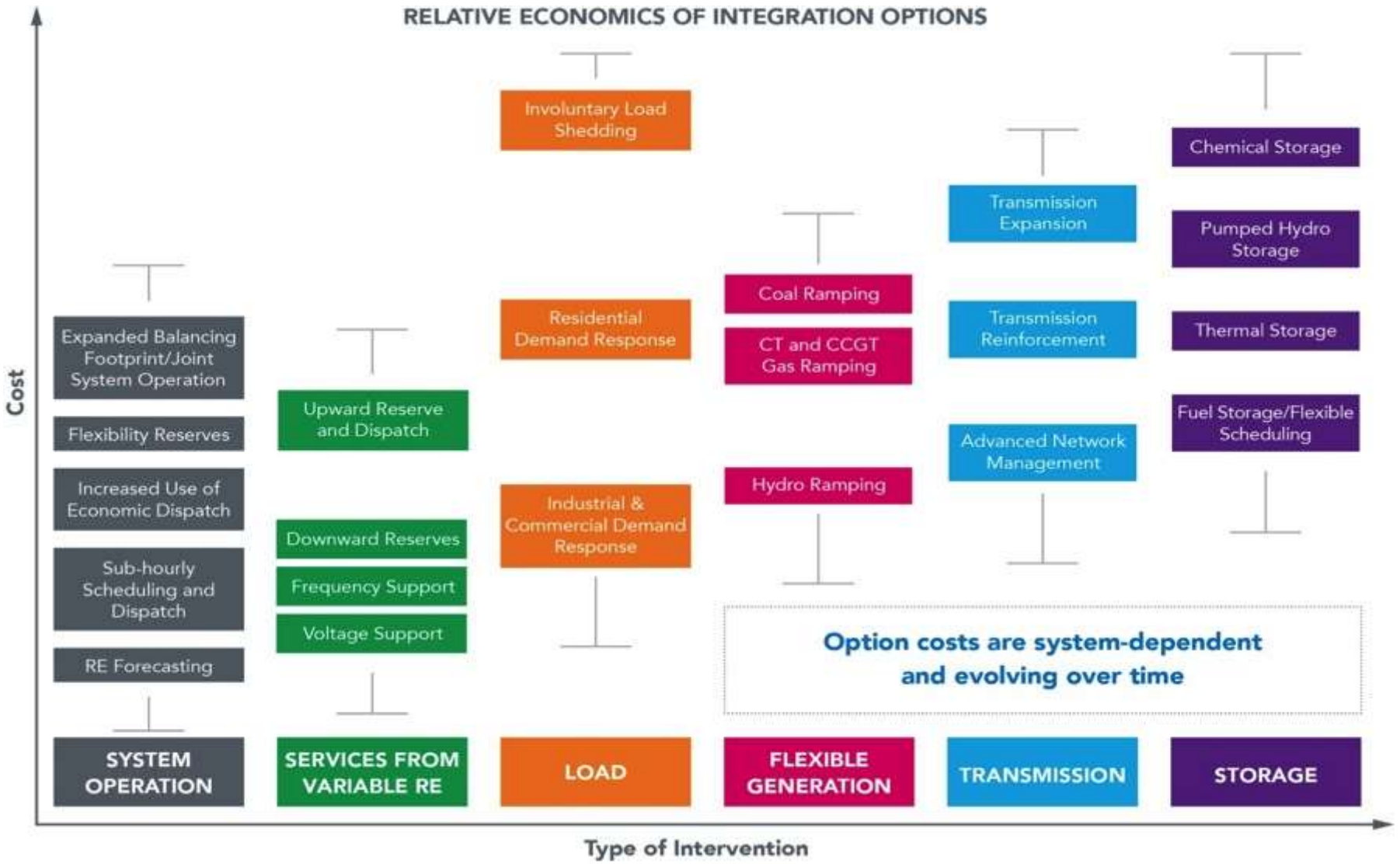
ISO/RTO SERVICES: Load Following, Frequency Regulation, Spin Reserve, Non-Spin Reserve, Black Start

UTILITY SERVICES: Resource Adequacy, Dist Deferral CUSTOMER SERVICES: TOU, Self-Consumption, Demand Charge Reduction

COSTS/TAX: Capital Cost, O&M & Charging, Tax Cost, Tax Benefits

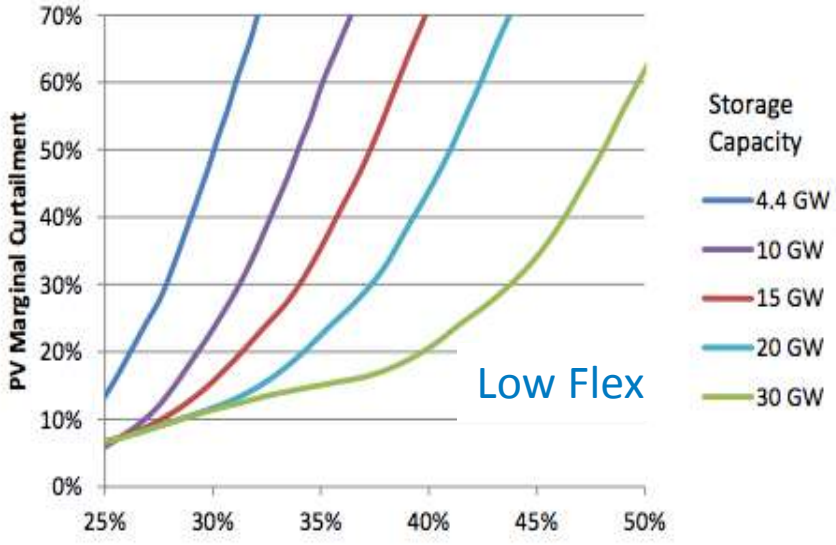
Source: RMI, 2015

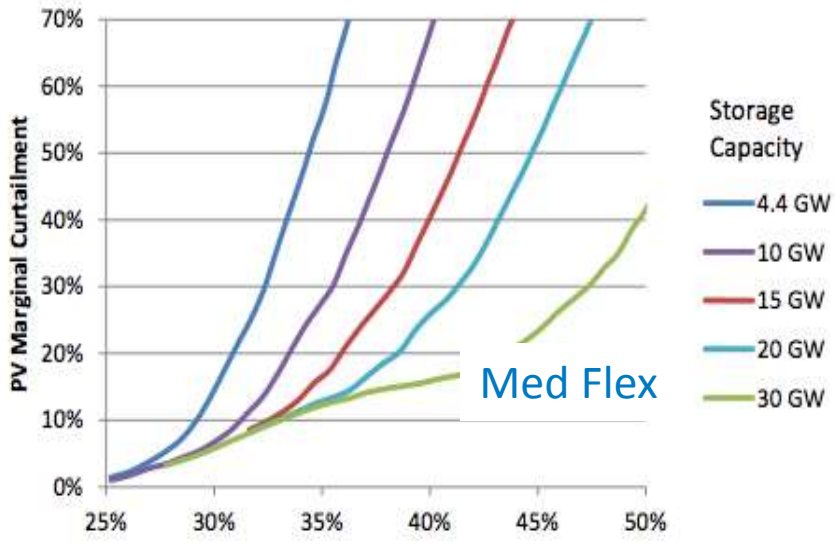
STORAGE ISN'T THE ONLY FLEXIBILITY OPTION



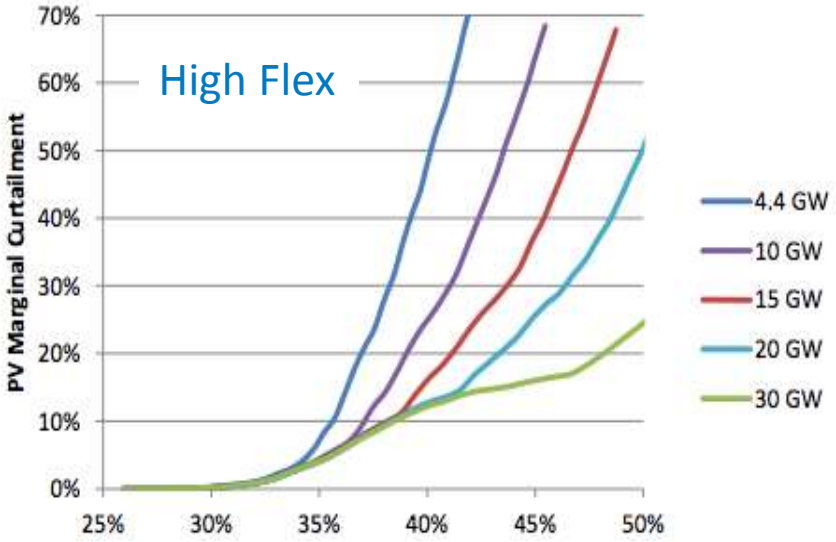
Source: Cochran et al., NREL, 2015

STORAGE REQUIREMENTS FOR CALIFORNIA





- Other flexibility options can complement energy storage to enable high PV penetration
  - Flexible generation
  - Transmission capacity
  - Demand response
  - Electric vehicle charging



Source: Denholm and Margolis, NREL, 2016

KEY TAKEAWAYS

- Flexibility will be important for the modernized grid
- Storage is a key option for providing flexibility, BUT
  - Must realize multiple values to be economic today
  - VERY use case specific
- Continued innovation needed for storage to co-exist with other flexibility options
  - At very high RE levels, all options will be needed

FOR MORE INFORMATION

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http://energy.gov/under-secretary-science-and-energy/grid-modernization-initiative