Electricity Grid of the Future

Program Director: Dr. Sonja Glavaski

Outline

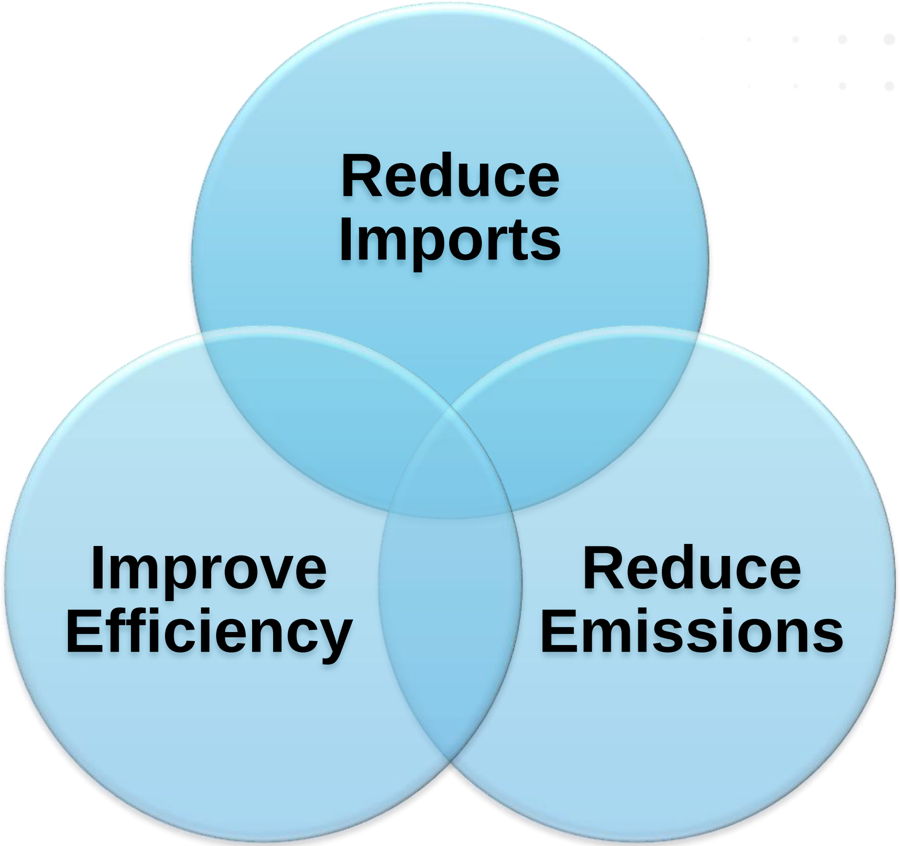
- **ARPA-e Overview**
- US Energy Landscape
- DERs and Grid Integration
- Grid of the Future (Vision & Long Term Goals)
- Enabling Technologies
- Going Forward

The ARPA-E Mission

Catalyze and support the development of transformational, high-impact energy technologies

Ensure America's

- National Security
- Economic Security
- Energy Security
- Technological Competiveness

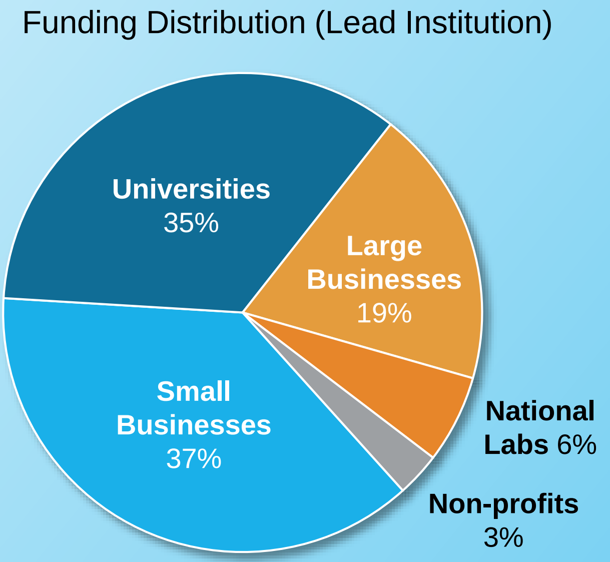


CHANGING WHAT'S POSSIBLE

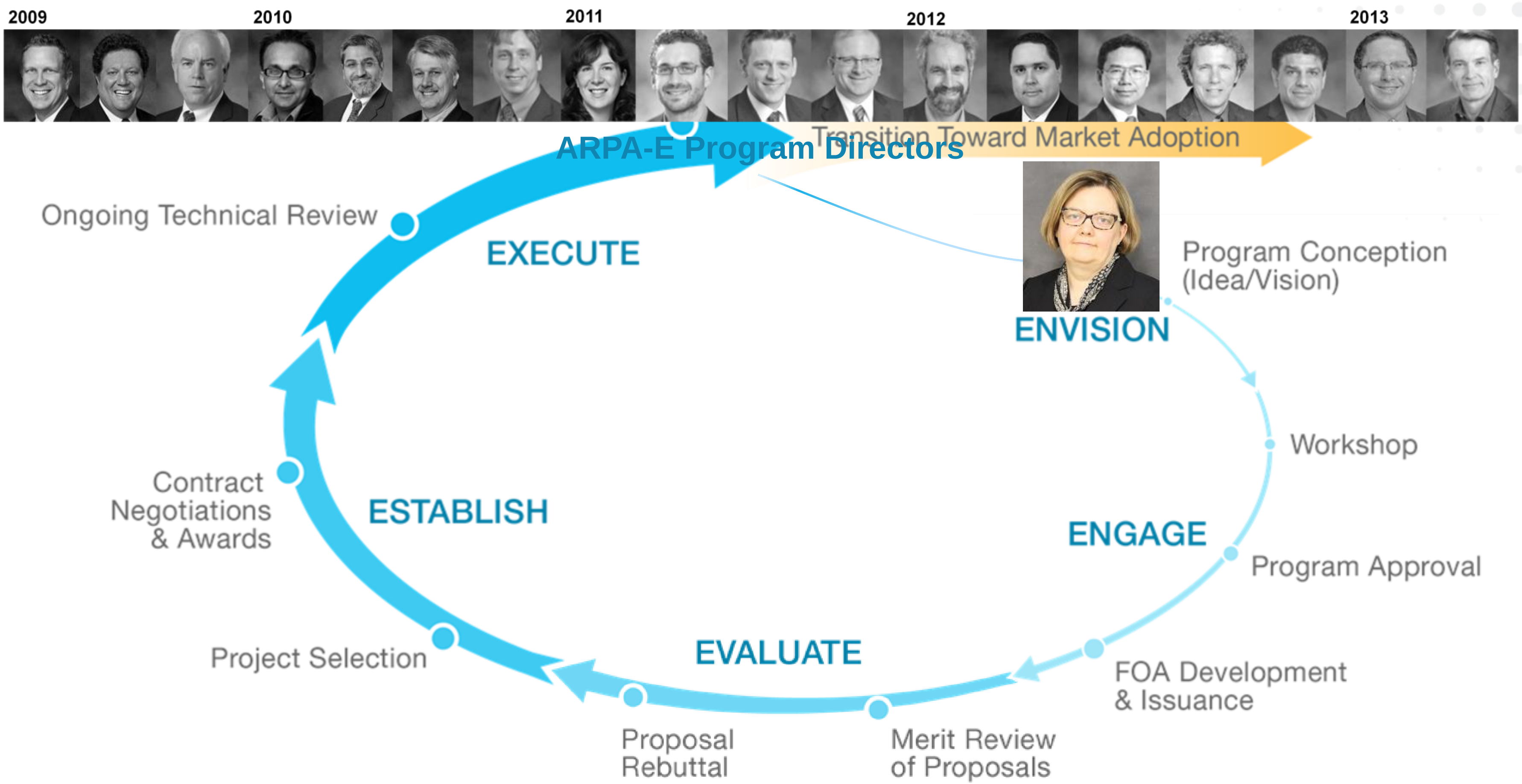
A Brief History of ARPA-E

- **2007**
  - *America COMPETES Act* signed, authorizing ARPA-E
- **2009**
  - *American Recovery & Reinvestment Act* signed, providing $400M to establish ARPA-E
- **2014**
  - *Over $900M invested in 362 projects funded*
  - *22 projects have attracted >$625M in private-sector funding*
  - *24 new companies formed*
  - *>16 projects partnered with other agencies for further development*

Investing in America's Best and Brightest



Developing ARPA-E Programs



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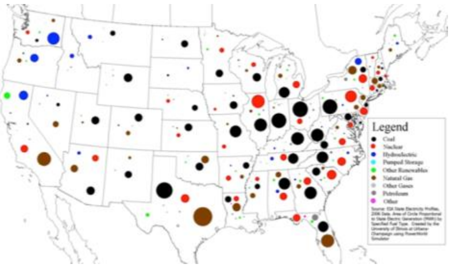
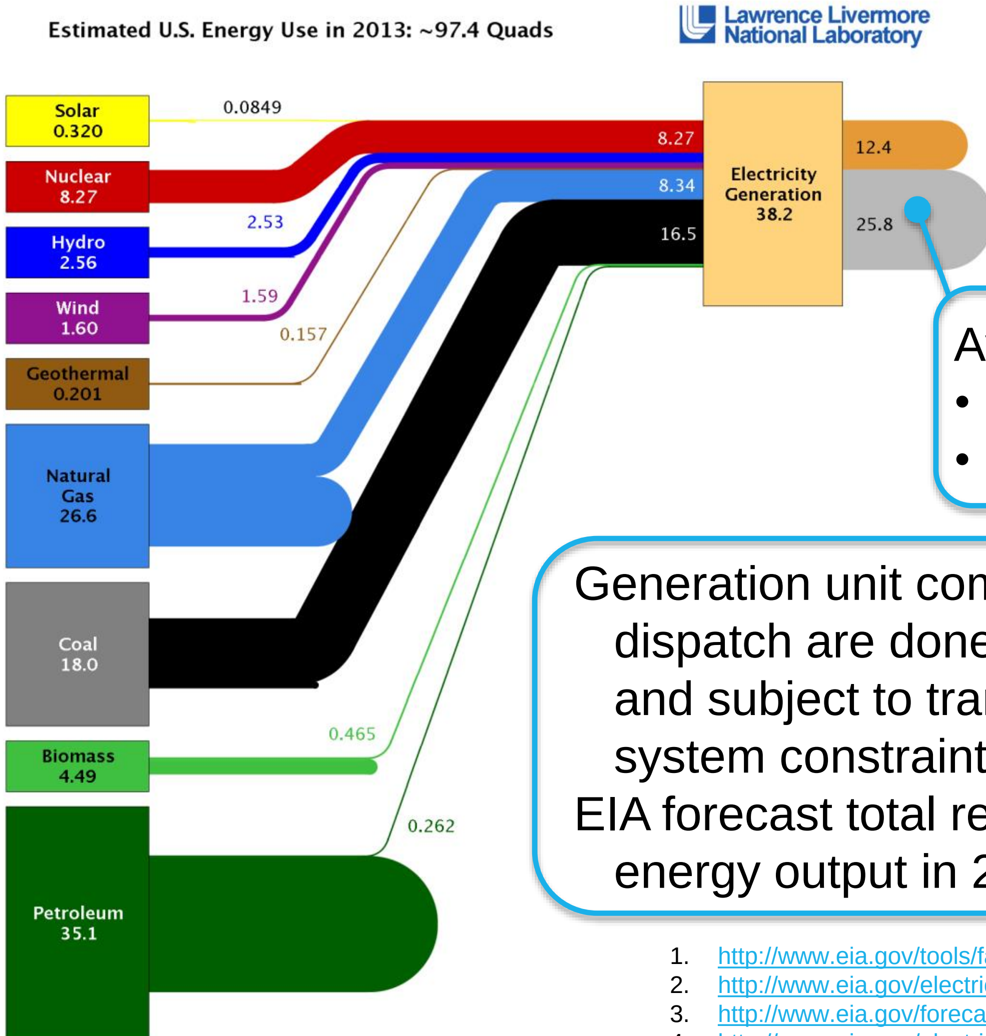
US Grid of Today: Generation





Average efficiency[2]:

- Coal: 32.5%
- Nuclear: 42.4%

87% of electric energy comes from central-station thermal generation[1]

25% of distributed generation is renewable[4]

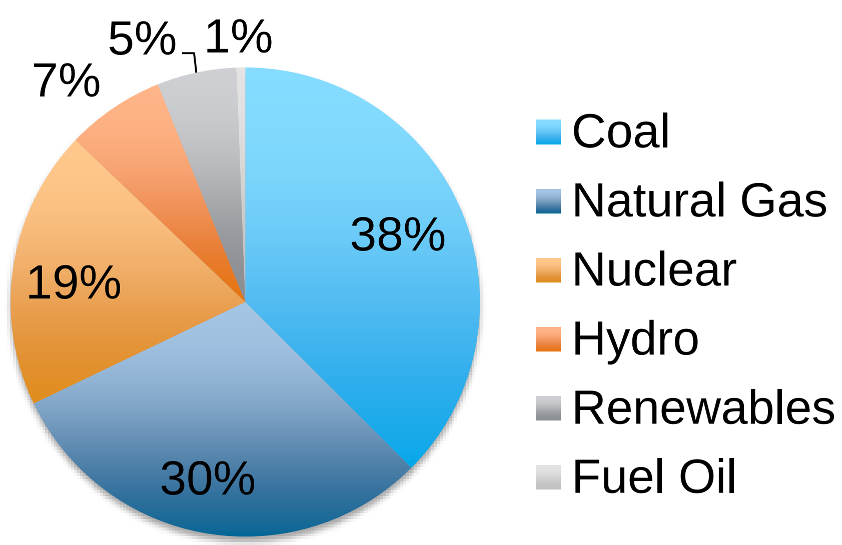
Generation unit commitment and dispatch are done in merit order and subject to transmission system constraints.

EIA forecast total renewable energy output in 2040 to be 16%.[3]

1. http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3
2. http://www.eia.gov/electricity/annual/html/epa_08_01.html
3. http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf
4. http://www.eia.gov/electricity/annual/html/epa_04_09.html

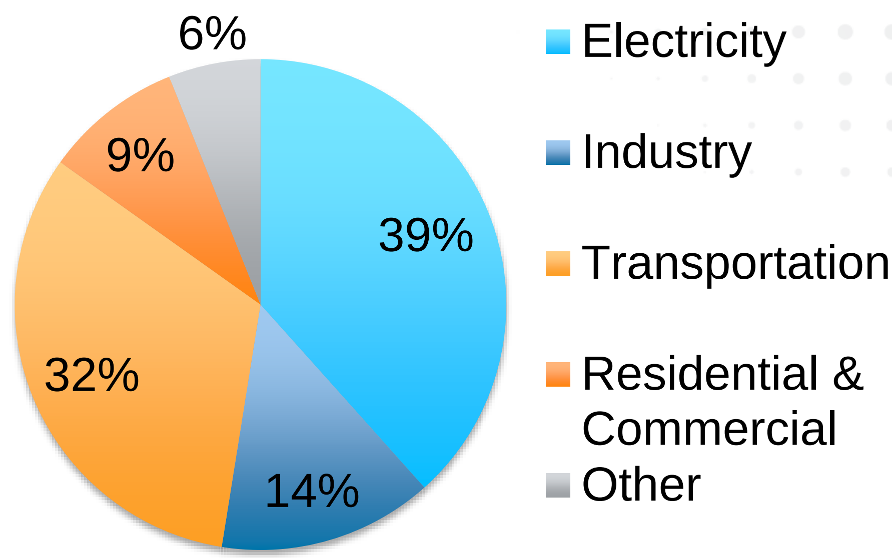
US Grid of Today – Fuel Sources & Emissions

2012 Generation Fuel



EIA

2012 Emissions



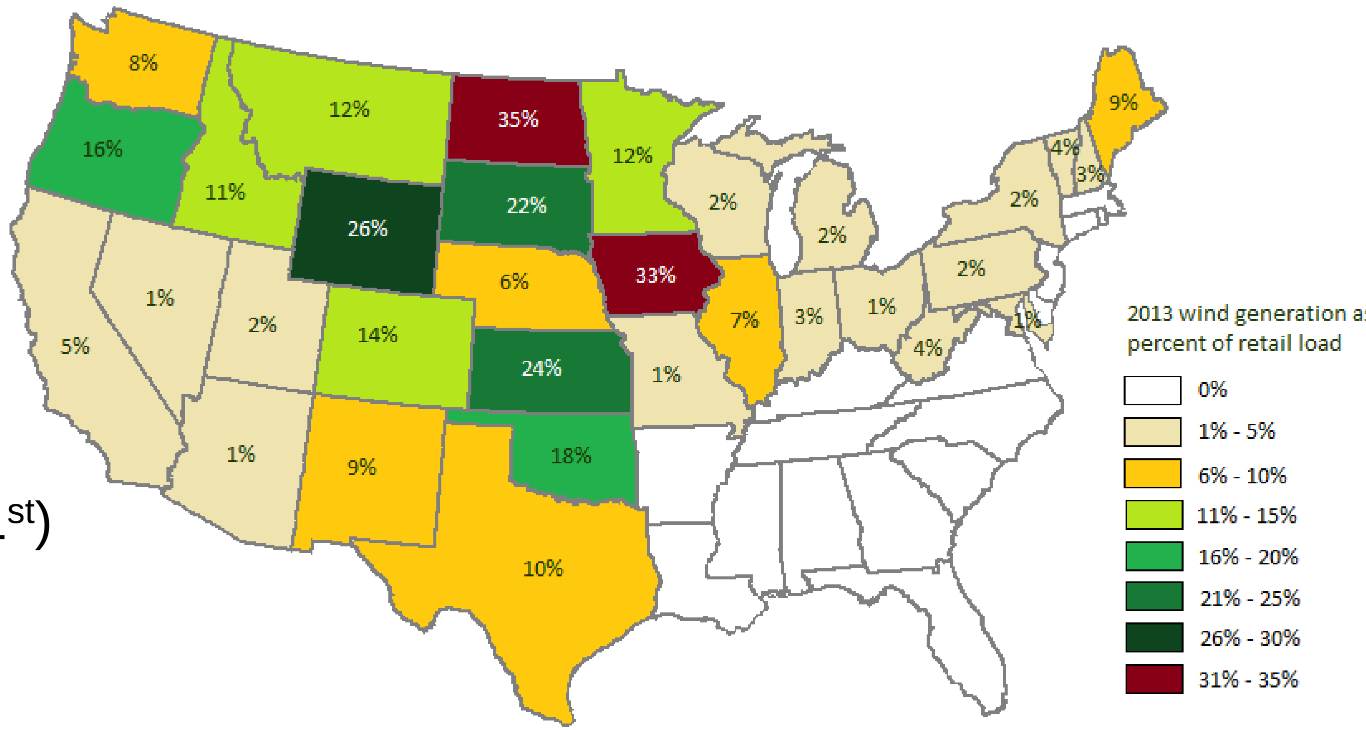
Emission estimates from the Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2012 - EPA

Improved energy efficiency in the electricity sector could significantly reduce CO_2 emissions

CHANGING WHAT'S POSSIBLE

U.S. Wind Power

- Total U.S. wind capacity reached 60 GW in 2012 (expected energy production of roughly a quarter of installed nuclear power)
- Expansion of wind surpassed gas in capacity, not in expected energy production



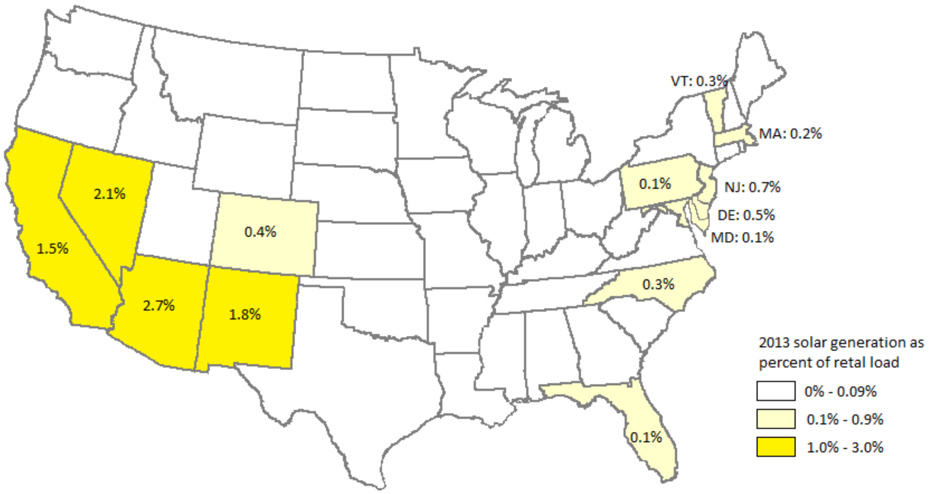
- 30% Denmark (1st)
- 4.4% U.S. (12th)

LBNL
2012 Wind Technologies
Market Report

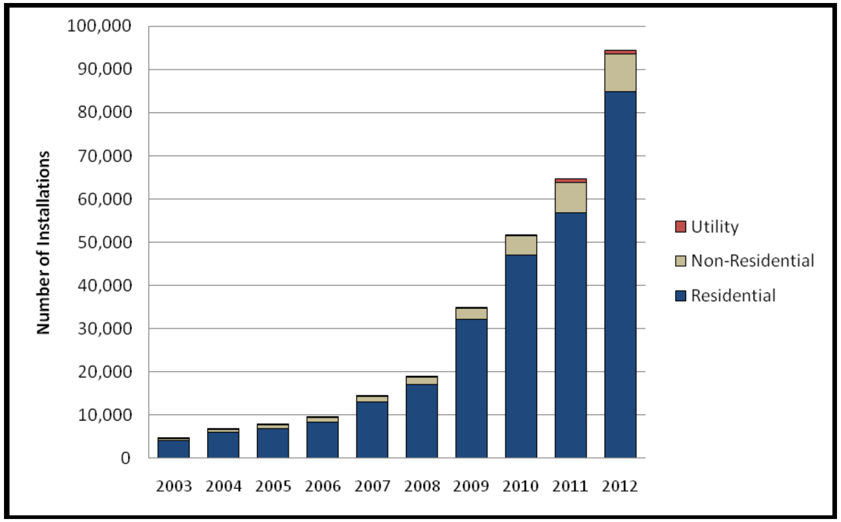
CHANGING WHAT'S POSSIBLE

U.S Solar Energy

- The capacity of PV systems installed in 2012, 3.3 GW_{DC}, was more than 10-times the capacity of PV installed in 2008
- Continued growth is anticipated owing to state renewable portfolio standards (RPS) and decreasing system costs
- Photovoltaic arrays are being installed at costs similar to wind's $3/W or less per panel



Cumulative U.S. Grid-Connected PV Installations



Technical Report NREL/TP-6A20-56290 June 2013

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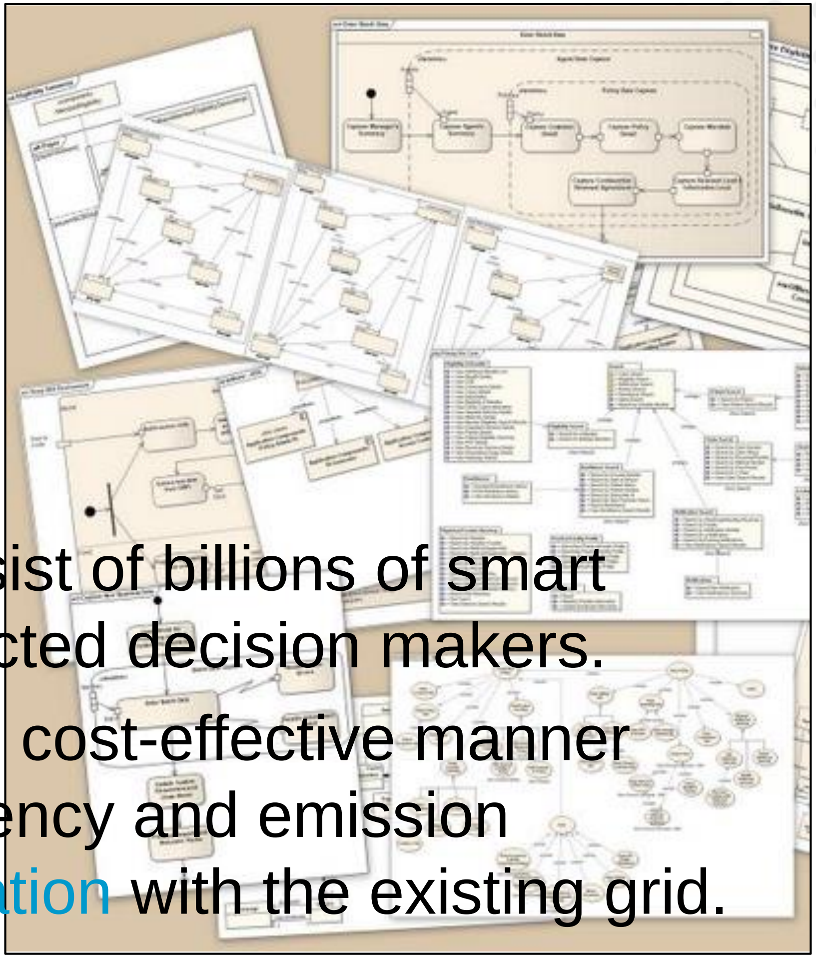
Distributed Energy Resources (DERs)

- New DERs technology
  - Smaller power generation (CHP, fuel cells, residential PV)
  - Demand Response
  - Storage
  - PEVs
- Future electricity systems will consist of billions of smart devices and millions of interconnected decision makers.
- Deploying DERs in a reliable, and cost-effective manner while achieving system level efficiency and emission reduction requires complex integration with the existing grid.

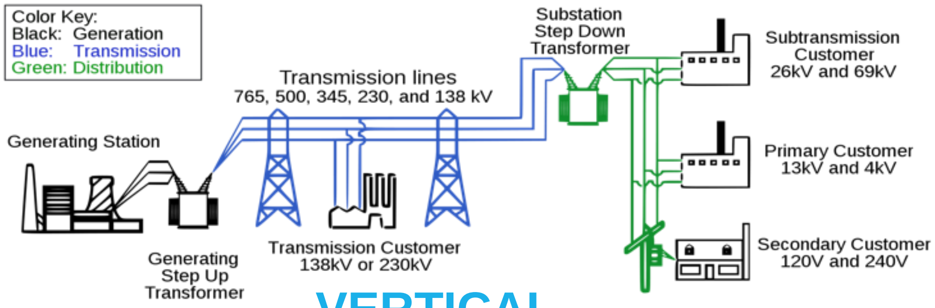


DERs may reach 33% of US installed capacity by 2020; EIA, DOE, FERC

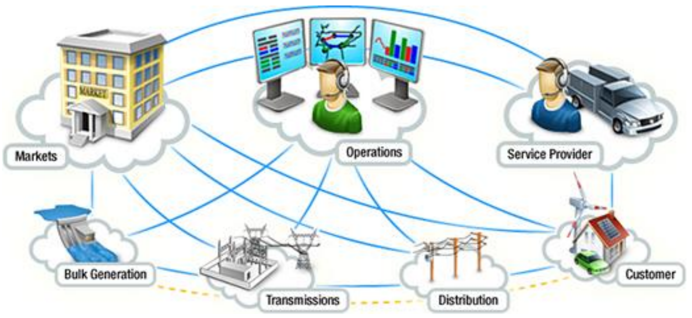
DERs Grid Integration

- **Homogeneous bulk power grid is rapidly evolving** into a composition of the old power grid and many loosely coupled local distribution grids and stand-alone micro-grids
- Traditional top-down **(VERTICAL)** planning and dispatching of electric power from central station generators to end-use customers does not leverage DERs and is thus sub-optimal
- Make Distributed Energy Resources (**DERs**) including power generation at distribution level part of the optimal system performance equation **(FLAT)**

NIST Special Publication 1108R2



VERTICAL



FLAT

DERs Driving Energy Landscape Change

- **Colorado's RPS requires min 30% renewable generation**
  - Colorado's RPS requires investor-owned electric utilities to provide 30% of generation from renewable energy resources by 2020, with 3% coming from distributed generation.

- **NY State PSC docket to increase distributed generation and demand response**
  - NY State Public Service Commission approved NYPSC Docket 14-M-0101 in April 2014, that is intended to change consumer behavior by
    - Installation of more distributed generation (e.g. solar)
    - Increased energy efficiency,
    - Increased usage of demand response.

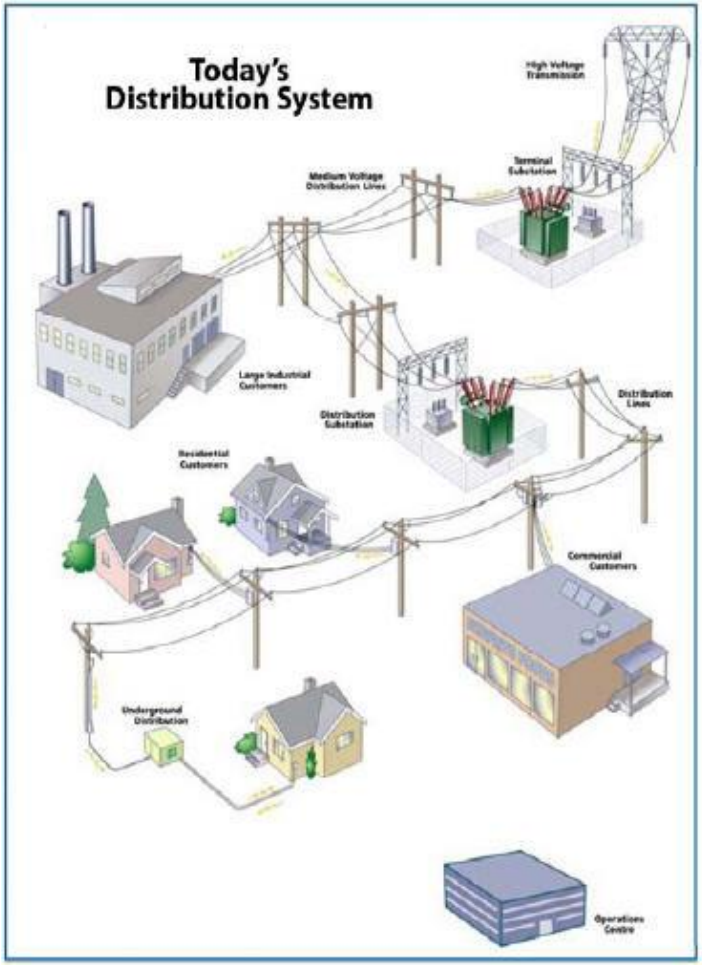
- **New Jersey BPU focusing on development of DERs to increase resiliency**
  - New Jersey Board of Public Utilities (BPU) approved in July 2014 an agreement with the New Jersey Economic Development Authority (EDA) to establish and operate an Energy Resilience Bank in the state that will focus on development of DERs at critical facilities throughout the state to impact resiliency.



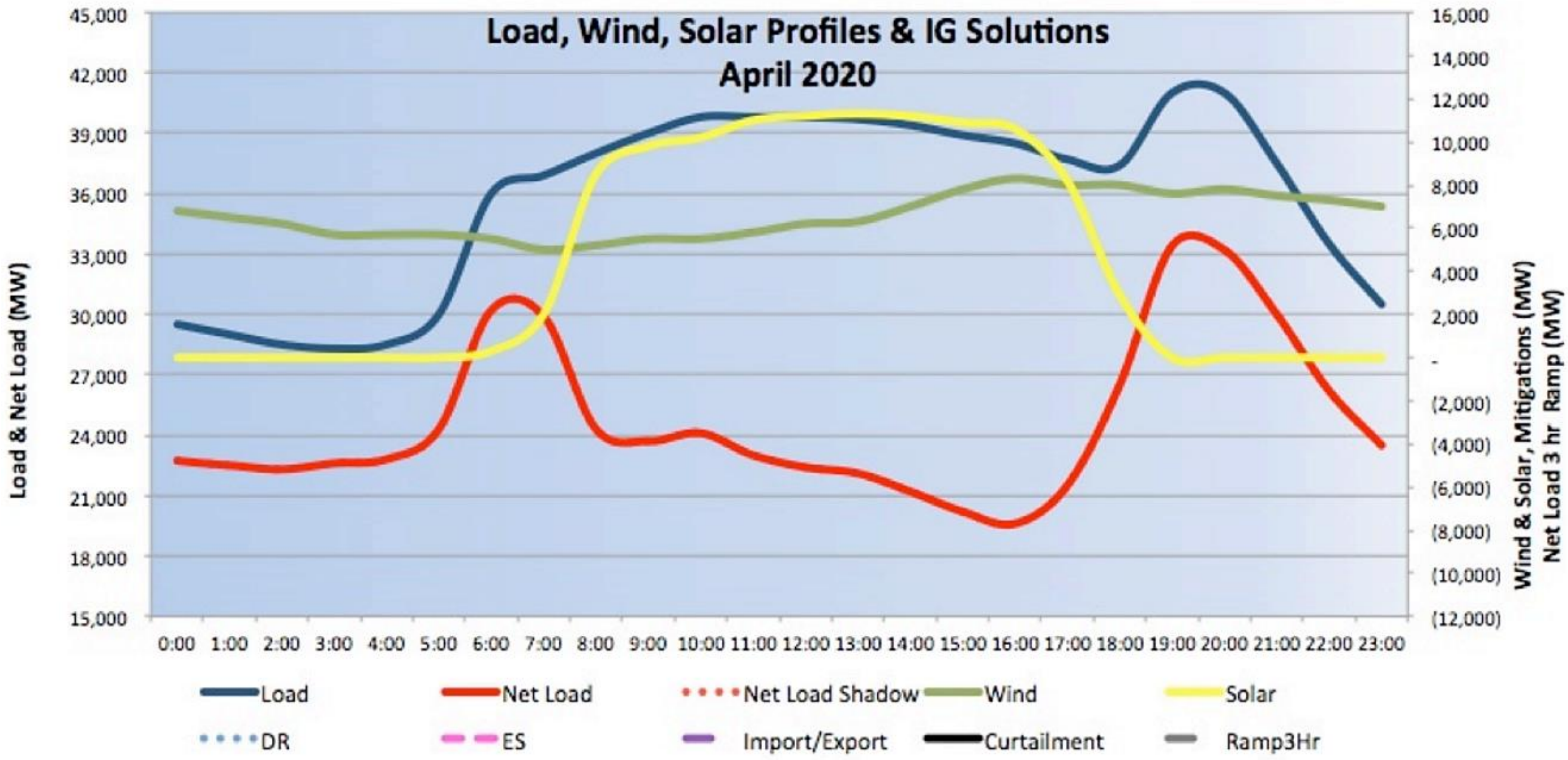
arpa·e
CHANGING WHAT'S POSSIBLE

Challenges for DERs Grid Integration

- Challenge for the transmission system operators arises from the need to consider increasingly dynamic net load
- Need to allow and dispatch power flows that could originate from any point on the system (transmission or distribution level) and from any one of dozens of different types of distributed energy resources (DER)
- Fundamental rethinking of operational and infrastructure-design aspects of power systems needed
  - One-off integration studies not scalable

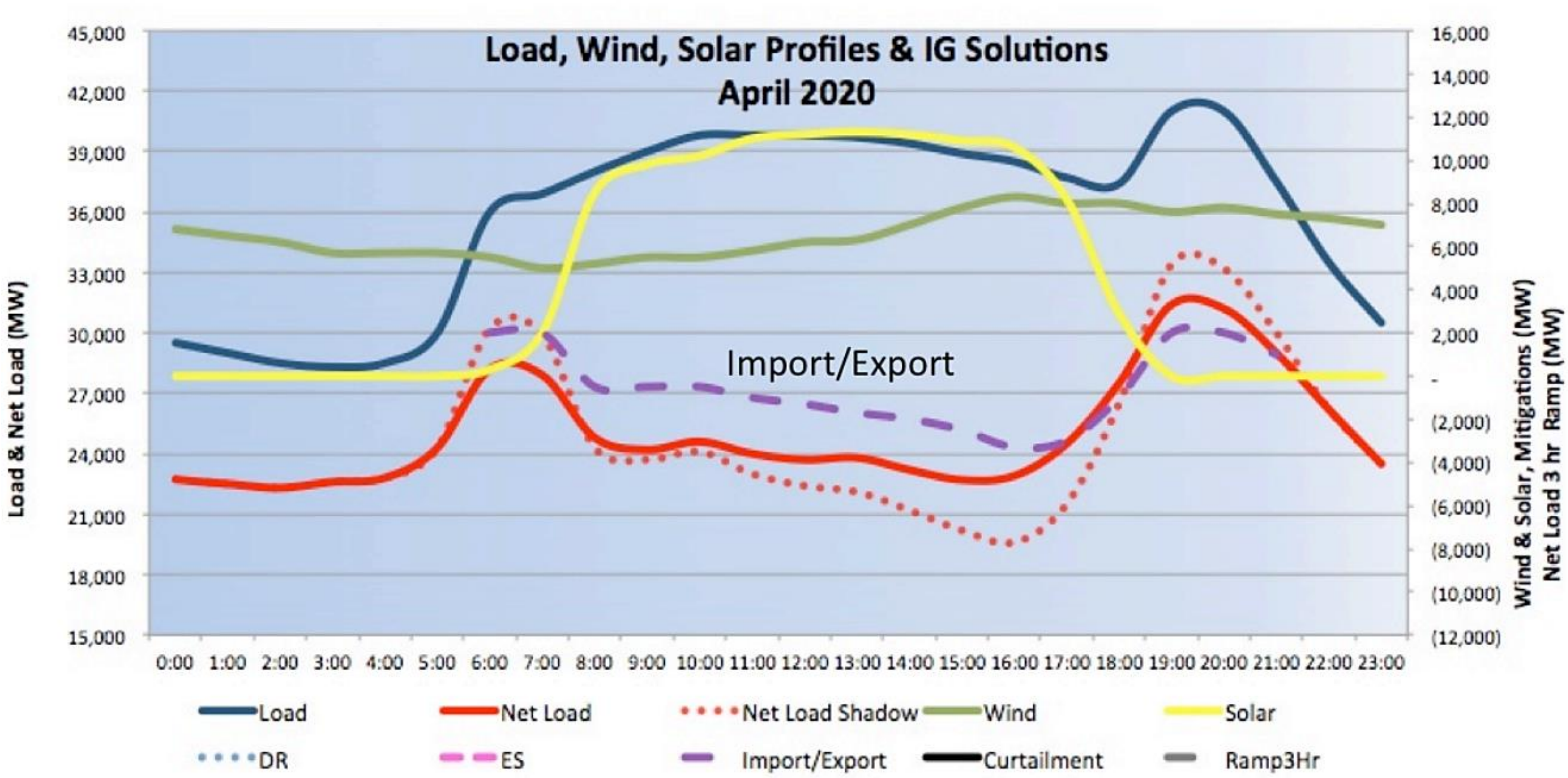


DERs Deployment Projected Impact



Clean Coalition projections for illustrative purposes, NOT actual CAISO projections

DERs Deployment Projected Impact



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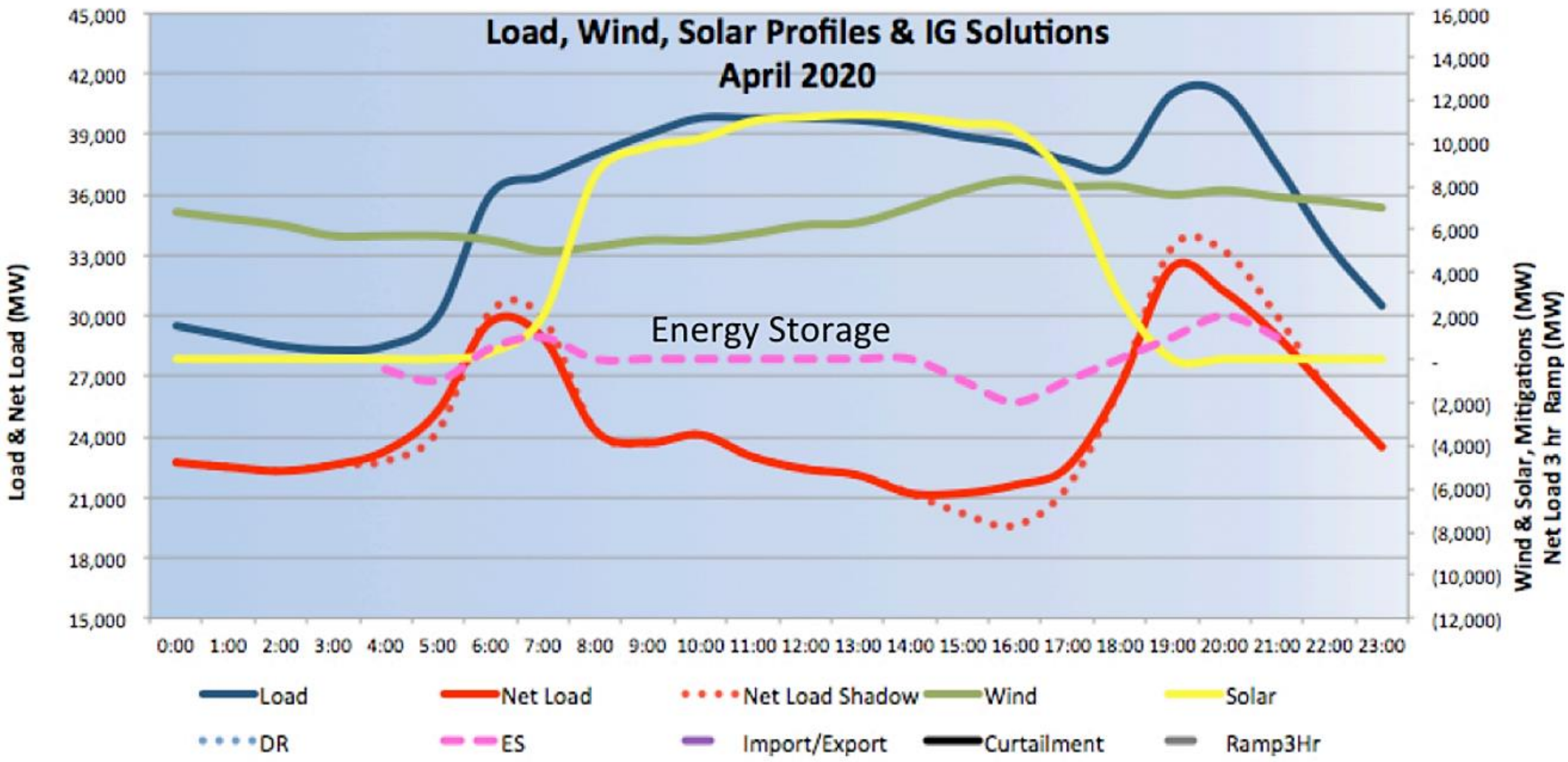

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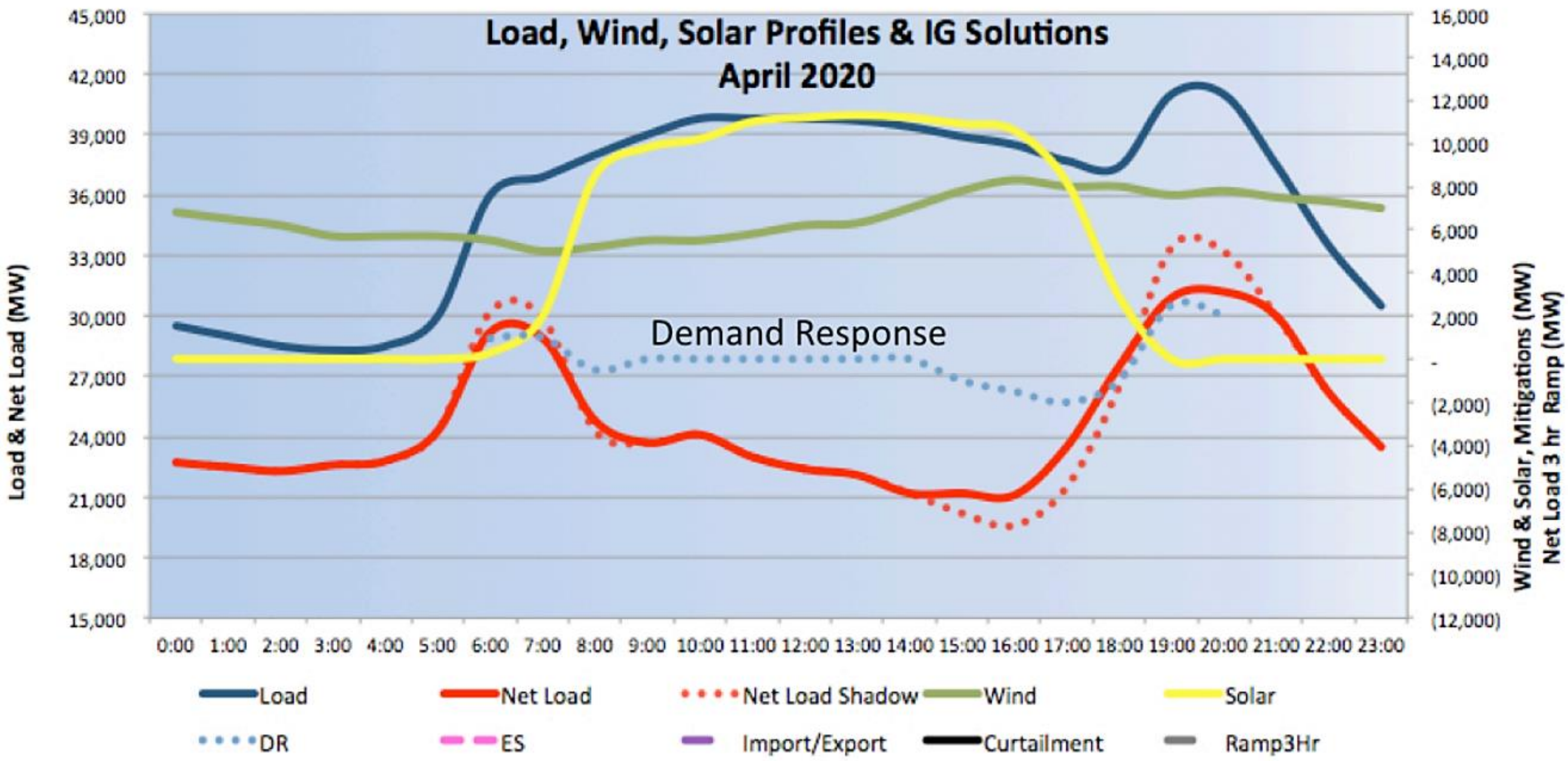

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CHANGING WHAT'S POSSIBLE

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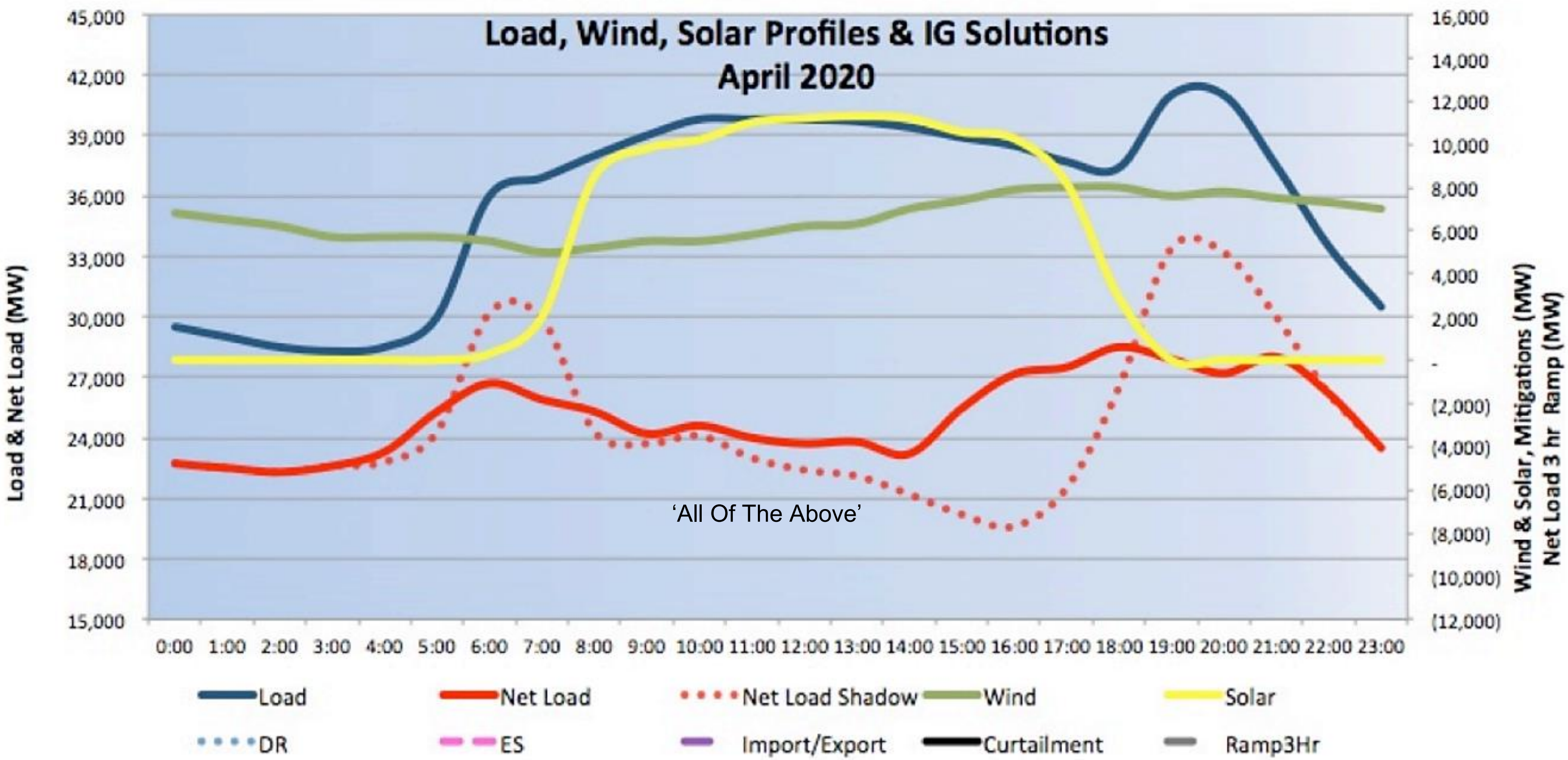

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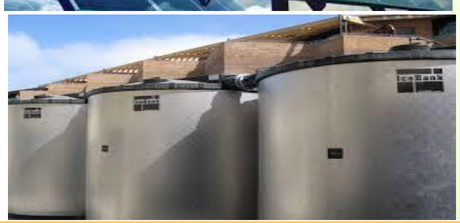
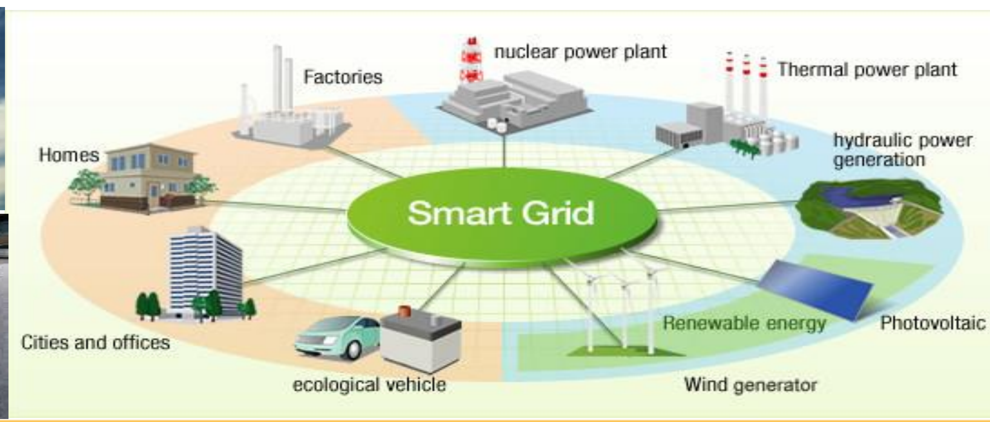
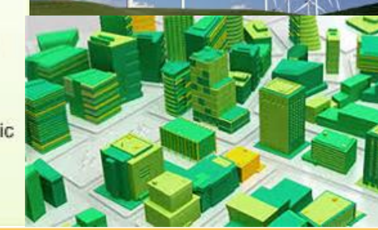
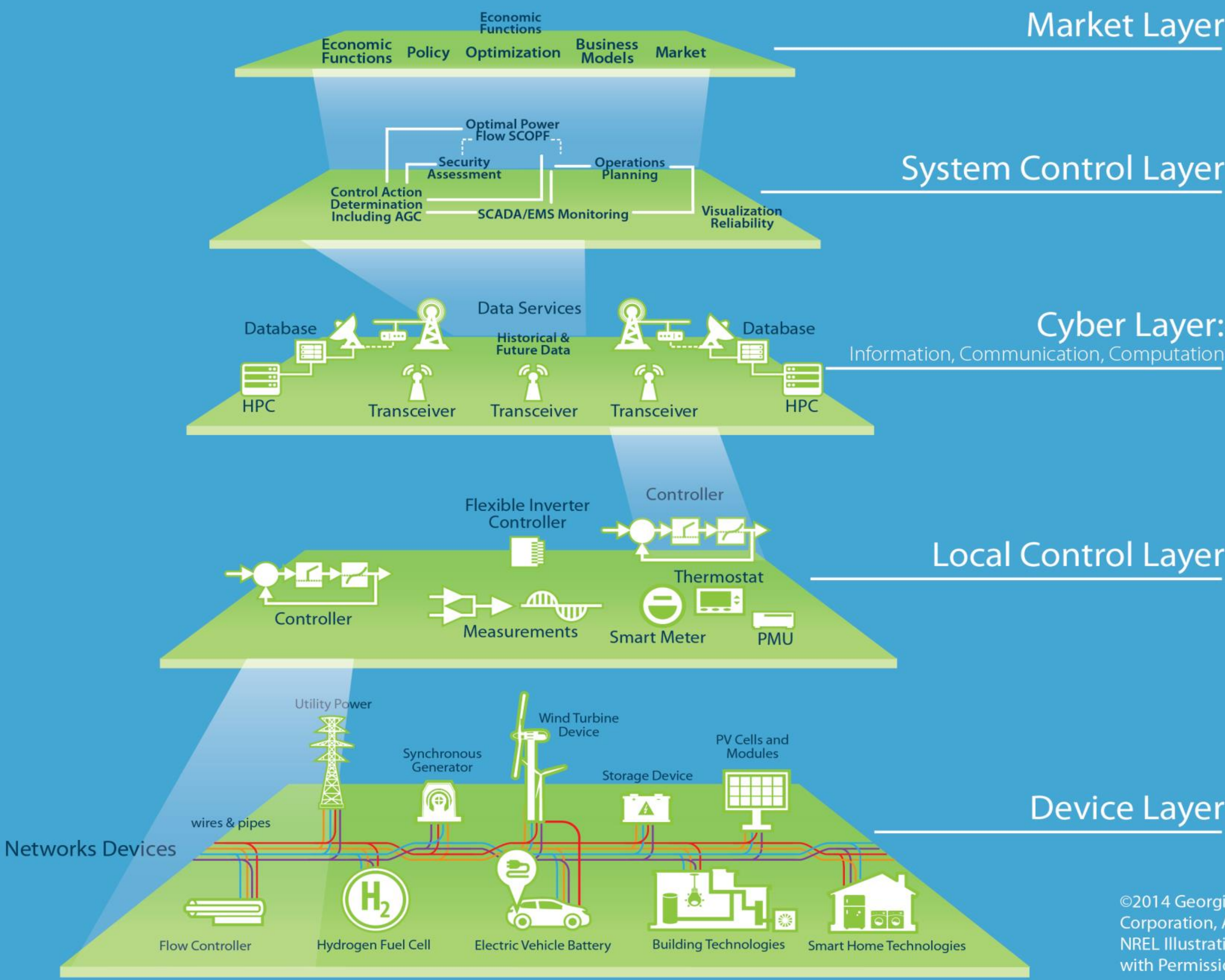
The Grid of the Future: From Vertical to Flat

- **Plug-and-play architecture** for seamless integration of DERs
- **Real-time adaptation** to power events and environmental changes enabling increased DERs penetration resulting in
  - Substantial decrease in CO_2 emissions
  - Increased thermal efficiency of central power fleet
- **Relaxing transmission limits** unlocking ability of DG and DERs to positively contribute to dynamic system recovery

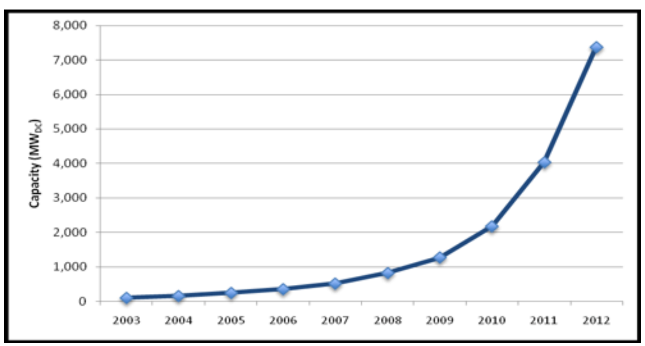
Layered Energy Cyber-Physical System



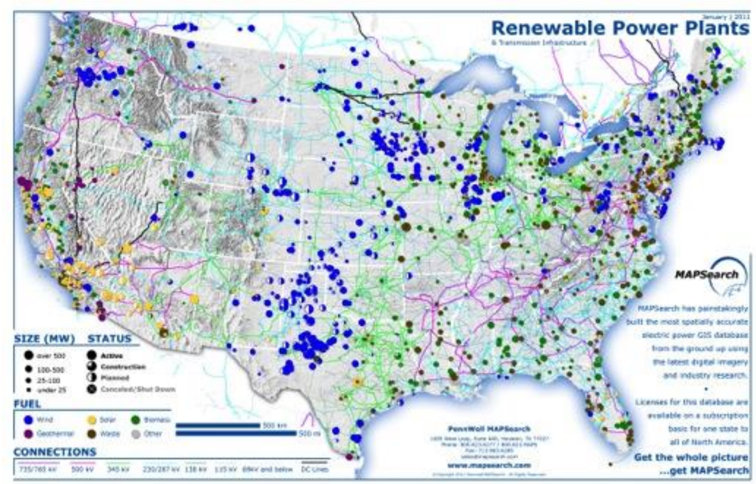
The Grid of the Future: Long Term Goals

- Provide at least 50% of generation from renewable energy resources by 2030, with 30% coming from distributed generation
- Decrease total emissions of the central-station fleet by 30% by 2030.
- Enhance system asset utilization and deliver better services to customers with lower total operational costs from current

Cumulative U.S. Grid-Connected PV Installations



Source: IREC: 2013 Annual Updates and Trends, October 2013



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Grid of the Future Enabling Technologies

Novel Capabilities

- Dispatching both central plant and distributed generation
- Proactive shaping of load over all relevant time horizons
- Consumers and central stations (both with advanced coordination control systems deployed) adapt their operation to achieve system-wide energy efficiency and emissions targets

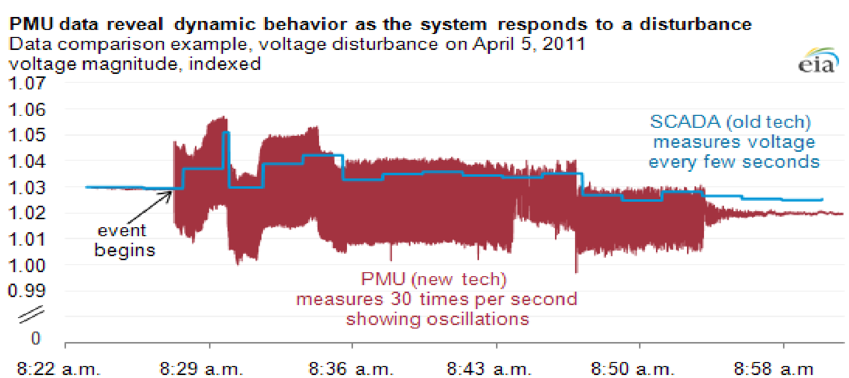
Enabling Technologies

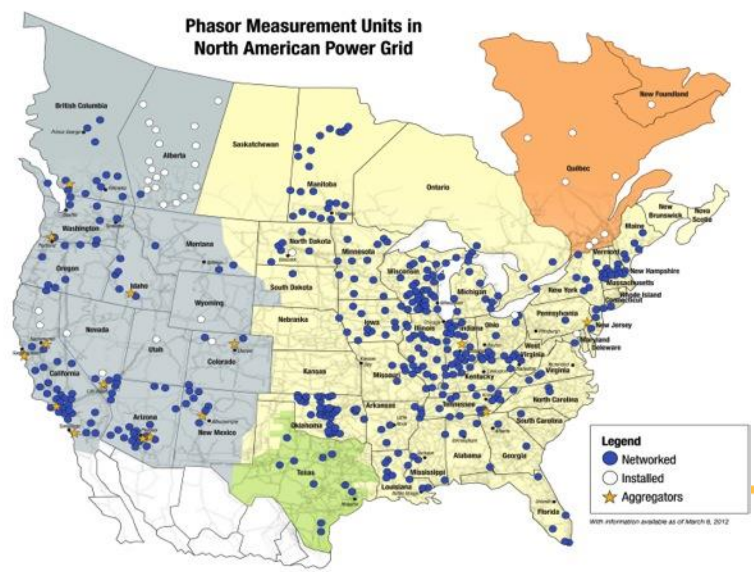
- Distributed Sensing – new data streams
- Data Analytics – uncertainty management
- Decentralized Control – scalability, flexibility, and resiliency

Sensing, Monitoring and Telemetry

- The monitoring grid components which collect the data include dedicated sensors, embedded sensing capabilities within distribution equipment, and operating data from AMI.
- These devices need to be integrated with communication and control infrastructure, typically using fiber and wireless communications equipment.
- Interoperability standards necessary.

"They simply can't see the grid!" Clark Gelling, EPRI.





CHANGING WHAT'S POSSIBLE

Analytics for Monitoring & Operation

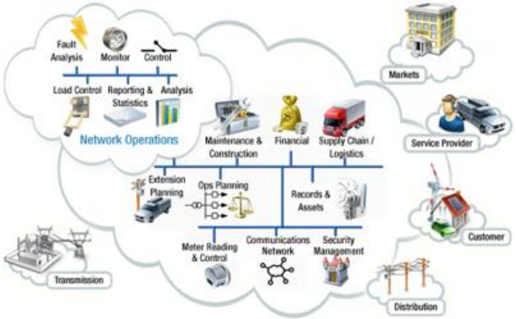
Develop monitoring, advisory, and control tools to **enhance human operation**

- Start from current best practices from human system operators
- Gradually introduce automation to assist operators in decision making
- Develop fully automated data driven control systems that minimize the need for human intervention as required response times decrease
- Develop tools for accurate weather, generation, demand, and consumer behavior prediction

Transition human factor knowledge from aerospace

Decentralized Control

- Goal is to maximize energy savings potential by incorporating anticipatory and adaptive measures
- Need control methodology for real-time optimized system operation through management of DERs.
- Decompose problem by time-scale separation and decentralization: Reduced communication; Simpler computation; Greater resiliency.
- Need localized, automated systems to balance generation and load in real time while integrating a variety of DERs (e.g. intermittent generation and energy storage)



Current power grid is operating in open loop

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Going Forward

- **Define architectures**: How will the future grid enable large scale Distributed Energy Resources (DERs) integration?
- **Identify technologies**: What developments in grid control and monitoring will increase grid reliability and efficiency?
- **Quantify adoption** penetration of new monitoring and control technology required to achieve long term goals.
- **Identify paths** to technology adoption and other initial markets.
- **Define benchmarking** platforms and processes for the technology developments.

Thank You!