Smart Electric Grids & Microgrids: Lessons Learned & Pathways Forward

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Midwest Reliability Organization - MRO (2013-2017); and Sigma Xi, MN (2011-2013)

September 14, 2023 -- https://www.climaterealitymsp.com/

The Climate Reality Project

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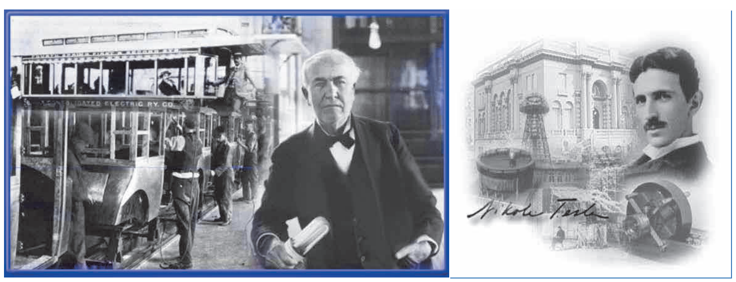
About You

- All of our members are advocates for clean energy / addressing climate change.
- About half of our members have attended former Vice President Al Gore's Climate Reality Leadership training.
- Our membership is truly a cross section of the public.
- Most are located in the metro, but we have members throughout the state, and few from neighboring states.
- Only a few are familiar with microgrids, but we recognize the importance of improving our power grids as we pursue increased electrification.

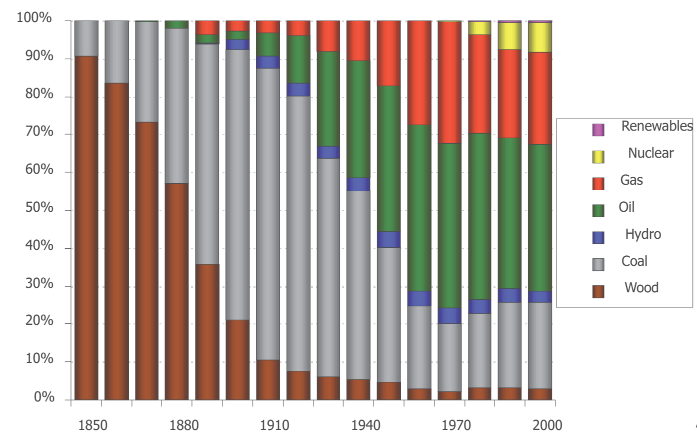
- A high level overview for the public to become informed of:
  1) what is the micro grid?
  2) what are the benefits
  3) what we can do (if anything) to support the cause.

Transforming Society



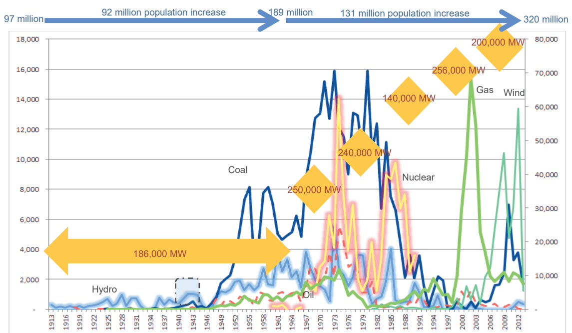
The vast networks of electrification are the greatest engineering achievement of the 20th century
– U.S. National Academy of Engineering

Context: US Energy Supply Since 1850



Author: Koonin
Source: EIA

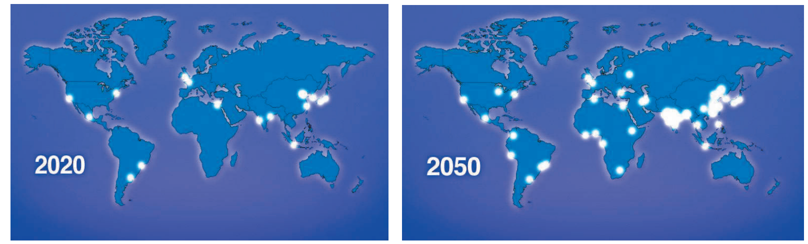
100 Years of Power Generation Development



Source: Adopted from Siemens

Context: Cities with 10 Million People

- By 2020, more than 30 mega-cities in the now less-developed world. By 2050, nearly 60 such cities.



- Increased population creates need for more resources. World's electricity supply will need to triple by 2050 to keep up with demand, necessitating nearly 10,000 GW of new generating capacity.

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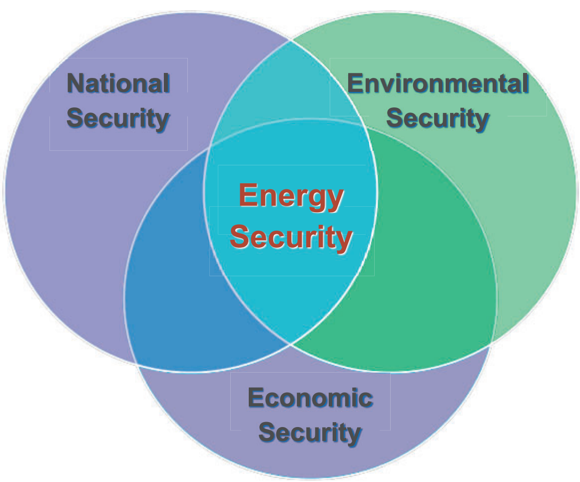

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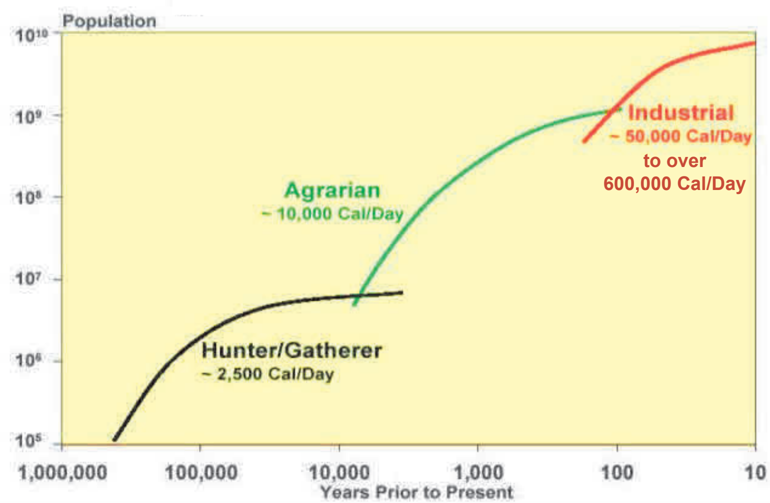

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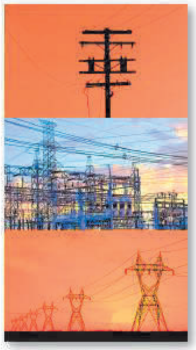
End-to-End Electric Power System

Generation



Delivery

Customer

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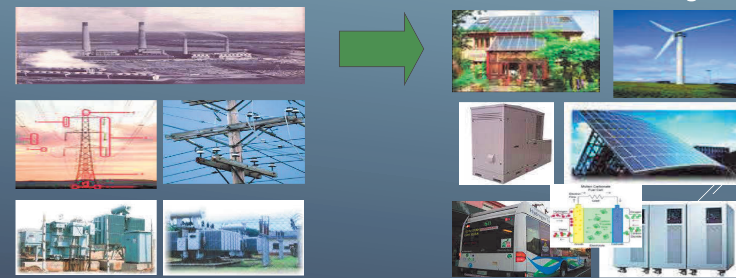
BACKGROUND: ENERGY TRANSITION – SLOW BUT STEADY INTERFACE OF SMART GRID AND MICROGRIDS

Smart Grid: Options, Costs and Benefits

- Fossil Fuel
- Long Distance Central Station
- An Aging Infrastructure
- Out of Capacity

- Renewable Power
- On-site
- Zero Energy Building
- Smart Grids & Microgrids



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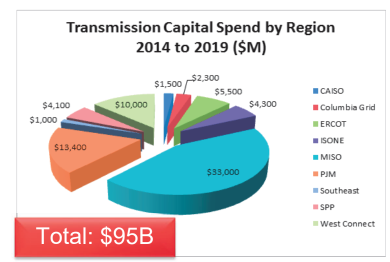
U.S. Industry Trends

Electric System Resiliency – Dept. of Homeland Security lists 17 critical infrastructures with Energy on the top as others require it

- Aging Infrastructure ***Investment*** - Electric utility industry will require up to $2 trillion by 2030, including generation (EEI)
- Reliability ***Investment*** – DOE estimates outage cost of $125B
  - White House estimates weather-related outages cost $18B to $33B annually
- Renewables and EV Integration and Microgrids ***Investment***
- Demand Side Management
- Natural Gas Interdependency
- FERC 1000 ROFR elimination



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Context: Many opportunities/challenges:

- Aging assets … ROI …. Reliability … Security … Resilience
- Confluence of multiple disruptive forces
- Severe weather events
- Physical and cyber attacks
- Dependencies and inter-relationships (say electricity/power, with energy, water, telecommunications, environment, markets etc.)
- Market and policy including recovery of investments

Source: IEEE report to the U.S. DOE for the White House's Quadrennial Energy Review (QER) to guide U.S. energy policy. See Chapter 4, on implications and importance of aging infrastructure and the options for addressing them: http://www.ieee-pes.org/final-ieee-report-to-doe-qer-on-priority-issues

Drivers

Let's frame the issues. As I see it, here are the top 10 drivers for change in the electric power sector, in no particular order:

1. Acceleration of efficiency (energy intensity dropping 2%/yr.);
2. Distributed generation and energy resources (DG & DERs), including energy storage & microgrids;
3. More cities interested in charting their energy future;
4. District energy systems;
5. Smart Grid;

Source: M. Amin, "The Case for the Smart Grid: Funding a new infrastructure in an age of uncertainty." Public Utilities Fortnightly, March 2015, pp. 24-32 and IEEE Smart Grid, January 2014 http://smartgrid.ieee.org/january-2014/1024-the-ieee-smart-grid-initiative-what-s-ahead-in-2014

Drivers (cont.)

6. Electrification of transportation;
7. New EPA regulations, such as for greenhouse gases under Section 111(d) of Clean Air Act;
8. Demand response (and 3rd-party aggregation of same);
9. Combined heat & power (CHP), plus waste heat recovery; and
10. The increasingly interstate and even trans-national nature of utilities (and contractors too, which leads to security concerns).

Source: M. Amin, "The Case for the Smart Grid: Funding a new infrastructure in an age of uncertainty." Public Utilities Fortnightly, March 2015, pp. 24-32 and IEEE Smart Grid, January 2014 http://smartgrid.ieee.org/january-2014/1024-the-ieee-smart-grid-initiative-what-s-ahead-in-2014

Key Questions

These drivers in turn lead to some important questions, both for the utility, as a business, and for regulators, as makers of policy:

1. What business models may develop, and how will they successfully serve both upstream electricity market actors and
2. What effects could these new business models have on incumbent utilities, and what opportunities may exist for other industry sectors to capitalize on these changes?
3. How will regulation need to evolve to create a level playing field for both distributed and traditional energy resources? →

Source: M. Amin, "The Case for the Smart Grid: Funding a new infrastructure in an age of uncertainty." Public Utilities Fortnightly, March 2015, pp. 24-32 and IEEE Smart Grid, January 2014 http://smartgrid.ieee.org/january-2014/1024-the-ieee-smart-grid-initiative-what-s-ahead-in-2014

Key Questions (cont.)

4. What plausible visions do we see for the future of the power sector, including changes for incumbent utilities, new electricity service providers, regulators, policymakers, and consumers?

5. What measures are practical and useful for critical infrastructure protection (CIP) and the security of cyber physical infrastructure? energy consumers?

"Today's regulatory framework is keeping us locked into the 20th century."
- Anne Pramaggiore, Former CEO, ComEd

Source: M. Amin, "The Case for the Smart Grid: Funding a new infrastructure in an age of uncertainty." Public Utilities Fortnightly, March 2015, pp. 24-32 and IEEE Smart Grid, January 2014 http://smartgrid.ieee.org/january-2014/1024-the-ieee-smart-grid-initiative-what-s-ahead-in-2014

Energy Independence and Security Act

- Passed by U.S. Congress in 2007.
- "It is the policy of the United States to support the modernization of the Nation's electricity transmission and distribution system … that can meet future demand growth and to achieve each of the following, which together characterize a Smart Grid:
  1. **Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.**
  2. **Dynamic optimization of grid operations and resources, with full cyber-security…"**

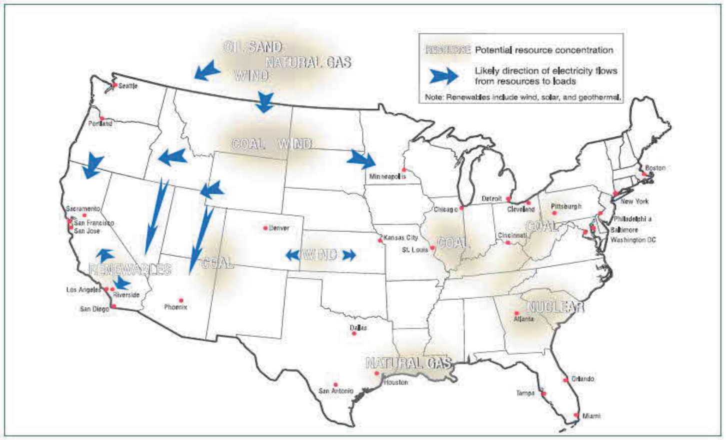
Integrate Dispersed Energy Sources into a Modern Grid to Provide Energy to Centers of Demand

Recommendations for moving to energy systems to meet demand of tomorrow

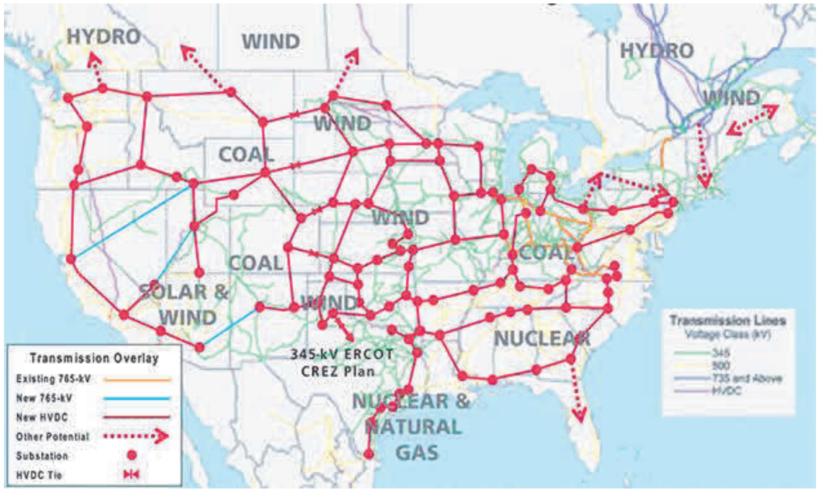
- **Build a stronger and smarter electrical energy infrastructure**
  - Transform the Network into a Smart Grid
  - Develop an Expanded Transmission System
  - Develop Massive Electricity Storage Systems
- **Break our addiction to oil by transforming transportation**
  - Electrify Transportation: Plug-In Hybrid Electric Vehicles
  - Develop and Use Alternative Transportation Fuels
- **Green the electric power supply**
  - Expand the Use of Renewable Electric Generation
  - Expand Nuclear Power Generation
  - Capture Carbon Emissions from Fossil Power Plants
- **Increase energy efficiency**

Source: Massoud Amin's Congressional briefings in September 2003, 2005, 2006, and March 2009 , Oct. 2009, May 2015, May and June 2017

Emerging Supply and Demand Patterns



Source: Massoud Amin's Congressional briefings in September 2003, 2005, 2006, and March 2009 , Oct. 2009, May 2015, May and June 2017



Map adapted from the U.S. DOE National Electric Transmission Congestion Study

Source: Massoud Amin's Congressional briefings in September 2003, 2005, 2006, and March 2009 , Oct. 2009, May 2015, May and June 2017

Smart Grids: What are we working on at the University of Minnesota?

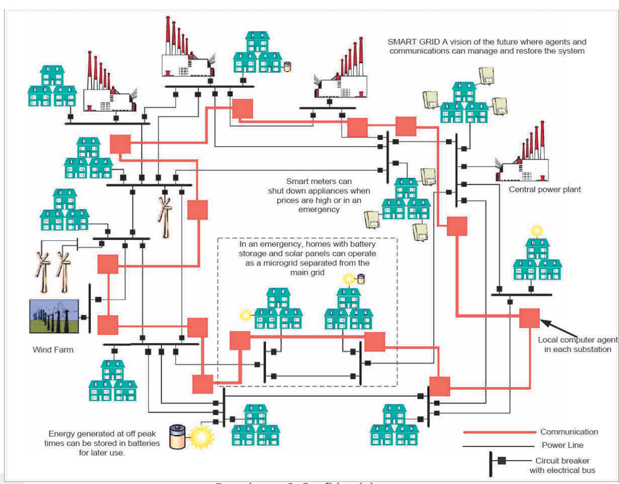
- Integration and optimization of storage devices and PHEVs with the electric power grid
- Grid agents as distributed computer
- Fast power grid simulation and risk assessment
- Security of cyber-physical infrastructure: A Resilient Real-Time System for a Secure & Reconfigurable Grid
- Security Analyses of Autonomous Microgrids: Modeling and Simulation of Failure Scenarios, and Development of Attack-Resistant Architectures

– Security
– Controller architecture
– Resiliency
– Dollars and watts -- Prices to devices
– Storage and Renewables integration
– Autonomous Microgrids
– IOT/Big Data

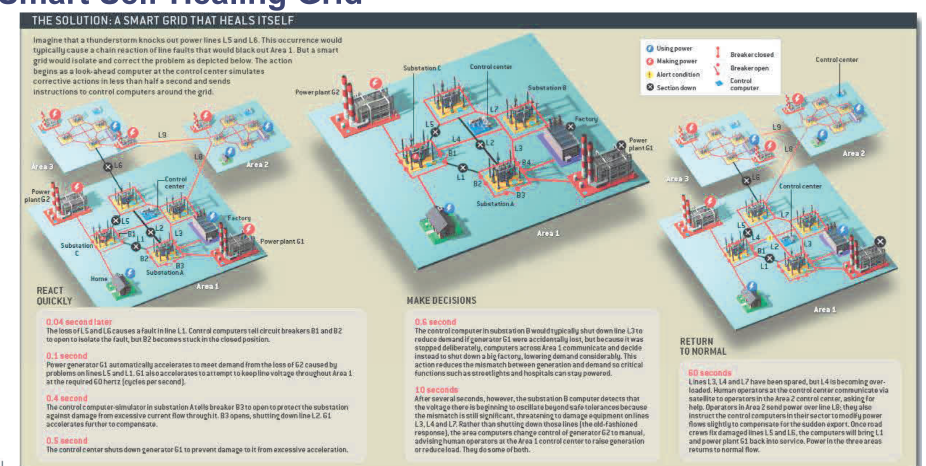
Examples:
– U of M - Morris campus project
– UMore Park Project
– Smart Grid U™
– Camp Ripley …

University of Minnesota Center for Smart Grid Technologies (2003-2023)
Faculty: Professors Massoud Amin and Bruce Wollenberg (NAE, retired)
Recent PhD Candidates/RA and Postdocs: Anthony Giacomoni (PJM), Jesse Gantz (GE), Laurie Miller (PNNL), Sara Mullen (EPRI), Vamsi Paruchuri (Siemens, PhD expected 2024), Trung Ha (Virgin Orbit, previously Cummins, PhD expected 2024)
PI: Massoud Amin, Support from EPRI, NSF, ORNL, Honeywell and SNL

A few examples: Our Smart Grid Research



Smart Self-Healing Grid

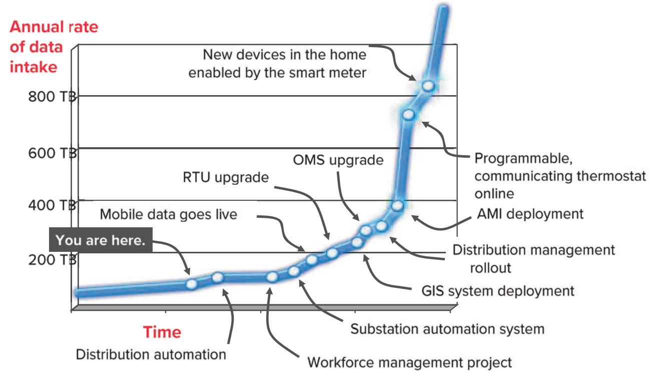


M. Amin and P. Schewe, "Preventing Blackouts," Scientific American, May 2007

Tsunami of Data Developing

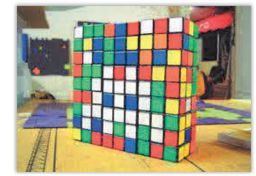
Tremendous amount of data coming from the field in the near future

Paradigm shift for how utilities operate and maintain the grid.



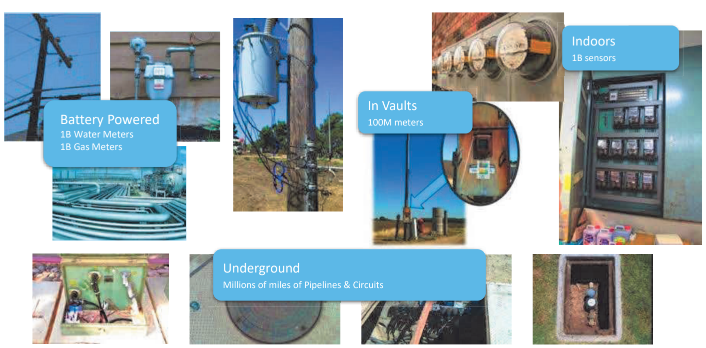
Paradigm Shift – Data at MN Valley Coop

- Before smart meters
  - Monthly read
  - 480,000 data points per year
- After smart meters
  - 15-60 minute kWh
  - Peak demand
  - Voltage
  - Power interruptions
  - 480,000,000 data points per year



Industry Needs to Connect 50 Billion Devices +

An unsolved problem costing billions per year in wasted resources requires radically improved wireless performance and lower cost



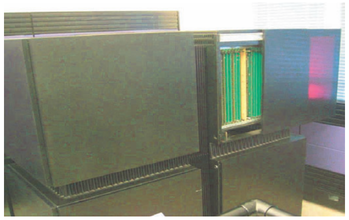
Pivotal and Emerging Technologies

1. Energy storage
2. Microgrids
3. Cyber-Physical Security
4. Advanced Controls with Secure Communications
   - Operating Platform – Advanced EMS/DMS
   - Sensors, Monitoring, and Diagnostics
   - Smart Breakers
5. From Smart Cities to Smart Buildings…. And In-home Technologies
   - Smart homes and Demand Response

The next phase of power grid evolution is managing demand through consumers as part of a well-managed, secure, and smarter grid

Fast Power Systems Risk Assessment

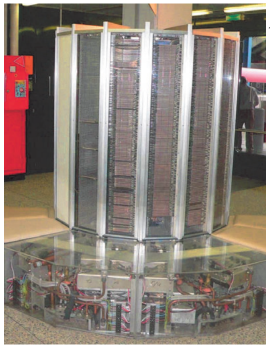
Doctoral Dissertation: Laurie Miller (June 2005-present)
ORNL contract, the U of MN start-up fund (2005-2008), and NSF grant (2008-2009), PI: Massoud Amin



Connection Machine 2: $5 million in 1987, only a few dozen made

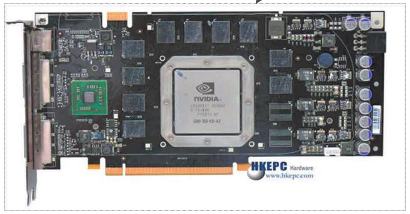
NVIDIA Tesla C870: $1300 in 2009, over 5 million sold

Fast Power Grid Simulation



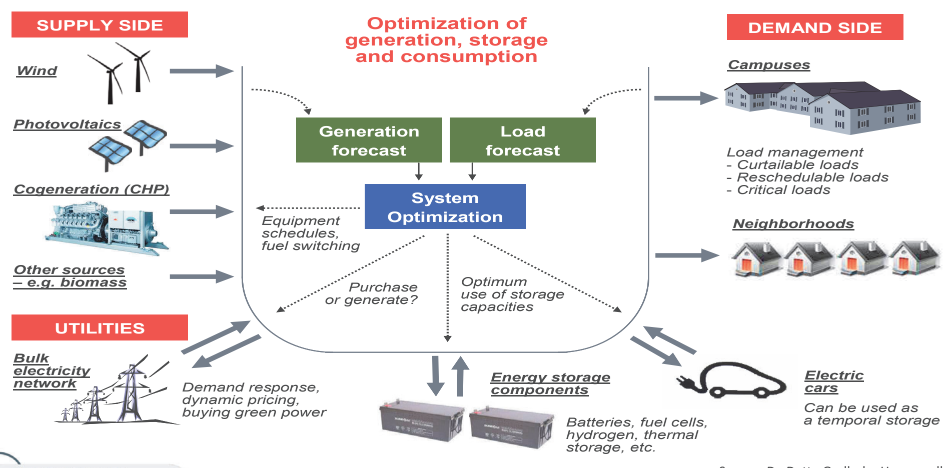
CRAY Supercomputer

Nvidia GeForce GPU card for PC



Use Nvidia GeForce GPU card to gain 15 times faster power flow calculation on PC

Integrated Microgrid Energy Optimization



Source: Dr. Datta Godbole, Honeywell

Context

- Microgrids are small power systems of several MW or less
- Primary Characteristics:
  - Distributed generation (controllable and uncontrollable)
  - Optional storage capacity
  - Autonomous load centers
  - Can interconnect or operate islanded from larger grid
- Microgrid assemblies are groups of interconnected microgrids “near” one another

Source: Dr. Anthony Giacomoni, PJM

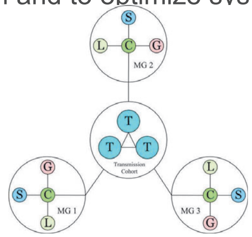
Autonomous Microgrids

- Operated and coordinated by intelligent and secure automatic controls without significant reliance on human intervention
- Maximum independence from other microgrids
- Interconnection policies should produce minimal links between microgrids in order to minimize:
  - Line losses and infrastructure costs
  - Propagation of cascading faults
  - Propagation of worms through the information network
  - Computations required to stabilize and optimize the microgrid assembly

Source: Dr. Anthony Giacomoni, PJM

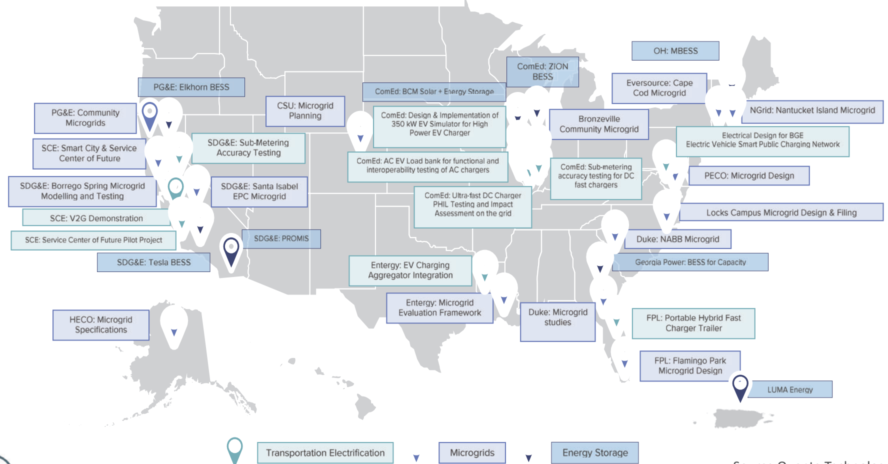
Multi-Agent Architecture

- Each microgrid and assembly is composed of numerous intelligent agents
- Agents gather and exchange information in real-time or near real-time to provide coordinated protection and to optimize system performance
- Types:
  - Generation-G
  - Load-L
  - Storage-S
  - Connection-C
  - Transmission-T



Source: Dr. Anthony Giacomoni, PJM

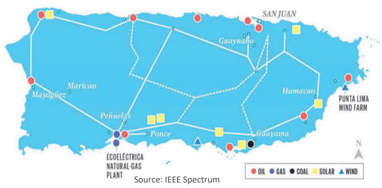
Microgrid, BESS and Transportation Electrification Projects:



Source Quanta Technology

Example: Puerto Rico

- Hurricane Maria destroyed 80% of Puerto Ricco's power grid resulting in an island wide outage on 20 September 2017
- Traditional grid system with generation focused in the south with majority population in the north (renewables account for just 2.4% of generation)
- After 8 months, estimated that 95% of power is restored but questions remain about resiliency to next storm
- Researchers determined that Puerto Rico has sufficient Solar, Wind, Water and Biomass to energize twice its annual consumption
- Resistance to DER due to initial upfront costs



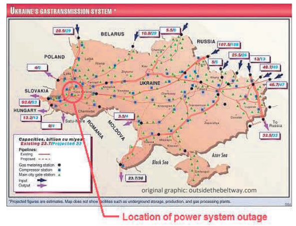
Source: IEEE Spectrum

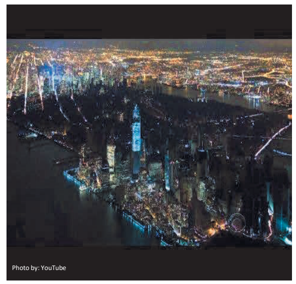

Photo: Erika P. Rodriguez
Broken solar panels in Humacao.

Source: Quanta Technology

Ukraine

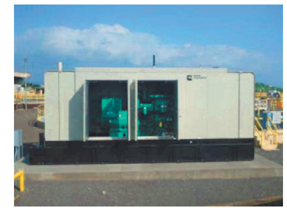
- December 2015: Hackers access Ukrainian power grid using malware known as BLACKENERGY 3
- Access to corporate networks facilitated a pivot to SCADA (Supervisory Control and Data Acquisition)
- Once in, hackers where able to manipulate switches causing out of phase events to disable transmission systems, resulting in more than 225,000 customers without power
- Second attack in December of 2016 took down the Ukrainian grid again, this time with a malware called Crash Override
- Purpose built malware to specifically target electric grid components





Example: Military - Camp Ripley, MN Microgrid

- Partnership with Minnesota Power to build a (size/KwH) solar field
- Shared with community but priority to CRTC in emergency
- Multi-tiered approach, renewables, generators and proposed storage
- Energy saving measures across post infrastructure
- Provides reliable, sustainable energy in the event of large-scale power outage event



Source: Col. Matt Vatter, MN Nat'l Guard

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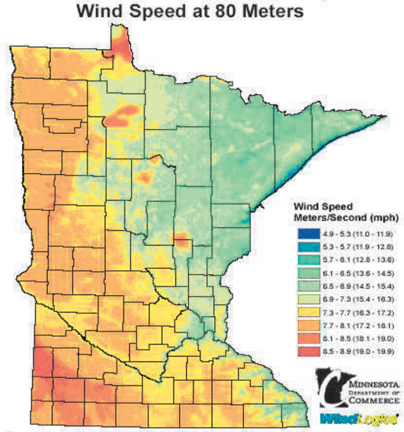
Minnesota's Wind Resource by Wind Speed at 80 Meters



January 2006

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Example: UM-Morris Smart Grid projects

- Location: Morris, MN
- Size: 1,800 student residential campus
- Energy Sources:
  - Biomass gasification plant
  - Solar thermal panels
  - Solar photovoltaic system
  - Two 1.65MW wind turbines (provides ~70% of campus's electricity needs)
- Load 300,000-750,000 kWh/month

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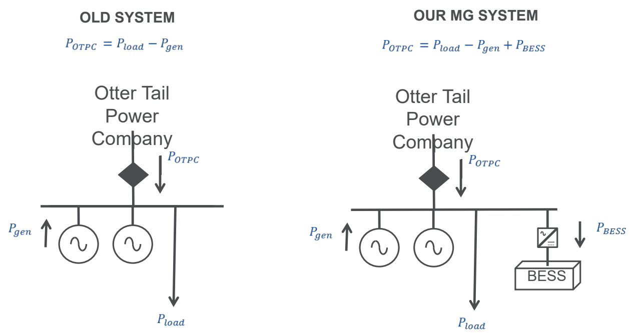
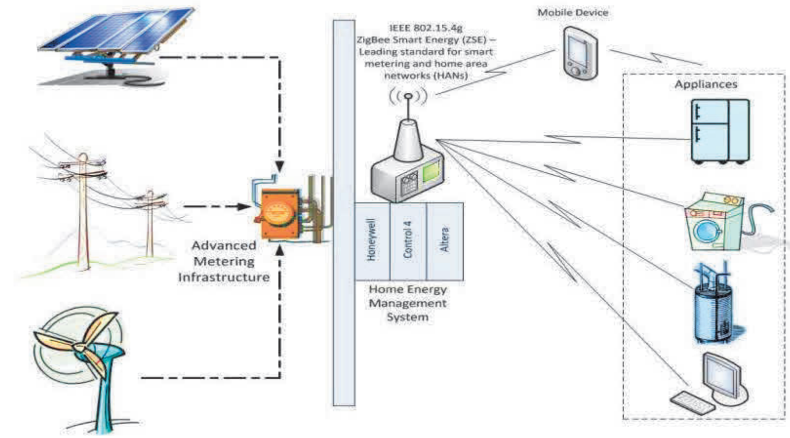
Example: University of Minnesota - Morris



Pgen = 2 x 1.65 MW Wind Turbines
Pload = 1.5 MW Peak

Example: Local MG System Communication Overlay



Single Customer Multi-Objective Optimization Model

Objective 1: Minimize Outage Costs

$$\underset{Y}{\text{minimize}} \sum_{n=1}^{N_{outage}} CDF\,(t_o - P_{load,n} \sum_{j=1}^{J_{types}} \frac{X_j}{S_{BESS,j}})$$

Objective 2: Minimize Energy Costs

$$\underset{SOC}{\text{minimize}} \sum_{t=1}^{T} (P_{load,t} - P_{gen,t} + P_{BESS,t}) C_{e,t} \Delta t$$

Objective 3: Minimize Demand Costs

$$\underset{SOC}{\text{minimize}} \sum_{p=1}^{P} \left(max(P_{load,t} - P_{gen,t} + P_{BESS,t})_p + PF_p \right) C_{d,p}$$

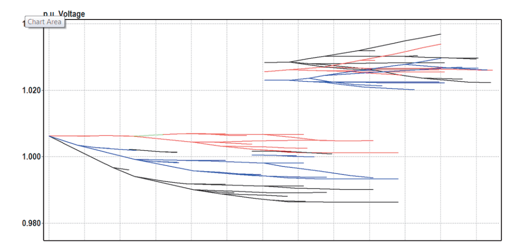
Objective 4: Minimize Capital Costs

$$\underset{X}{\text{minimize}} \sum_{j=1}^{t} C_j X_j$$

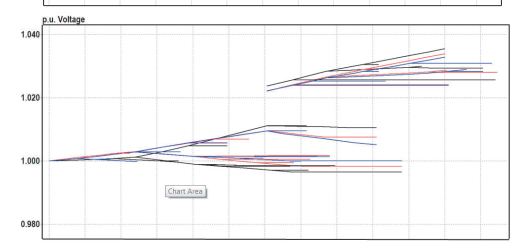
Where,
n: Outage index ϵ $\{1 \dots N_{outage}\}$
$CDF_i(*)$: Customer damage function
t_o: Duration of outage (min)
j: Storage type index ϵ $\{j \dots s\}$
X_j : Number of storage systems of type j selected
$P_{load,n}$: Ave. load during outage, n
$S_{BESS,j}$: kWh storage capacity
S_{cap}: kWh capacity of storage facility
Cj: Capital cost of storage unit type j

Benefits:
Voltage Profiles

Normal Operation:
1.04 – 0.98pu voltages



Priority Ride-Through:
1.04 – 0.99pu voltages

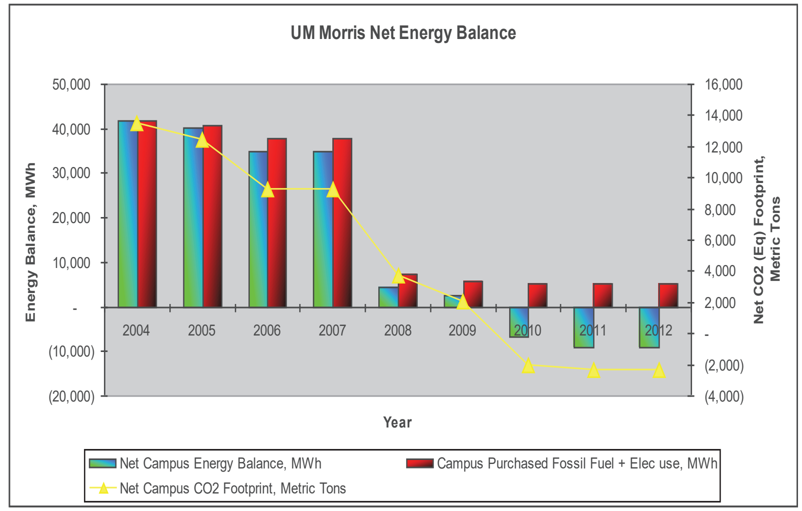


Optimal Mix and Placement

No. Units Selected	BESS Selected	Location	Capital Cost	Added Savings	Annual Outage Costs	Payback Period
0	None	--	$ 0	--	$ 1,435,814	---
1	Zinc Bromine 1	M4	$ 303,125	$ 285,776	$ 1,150,038	***1.06 years***
2	Zinc Bromine 1	M4	$ 606,250	$ 207,749	$ 942,289	***1.23 years***
3	Zinc Bromine 1	M4	$ 909,375	$ 224,758	$ 717,531	***1.27 years***
4	Zinc Bromine 1	M4	$ 1,212,500	$ 225,395	$ 492,136	***1.29 years***
5	Zinc Bromine 1	M3	$ 1,515,625	$103,449	$ 388,687	***1.45 years***

Index	M1	M2	M3	M4	M5
Total Cust.	200	85	44	72	112
Cust. Served	0	0	4	35	0

SAIDI: 3.93 (down 0.44) *SAIFI: 5.90 (down 0.66)* *CAIDI: 1.5 (same)*



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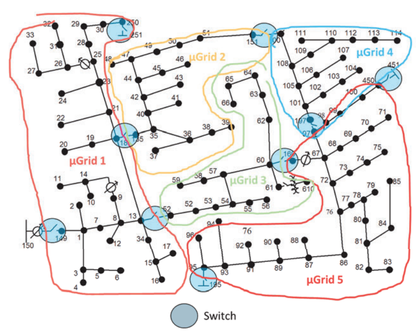
Feeder Reconfiguration/Intentional Islanding

Outline

- System divided into sub-networks joined by controllable switches
- The fault is isolated for a given outage situation
- Non-faulted sub-networks are intentionally islanded to supply back-up service to local loads

Simulation

- Perform Sequential Monte-Carlo simulation to simulate outages
- Determine optimal locations to place storage elements



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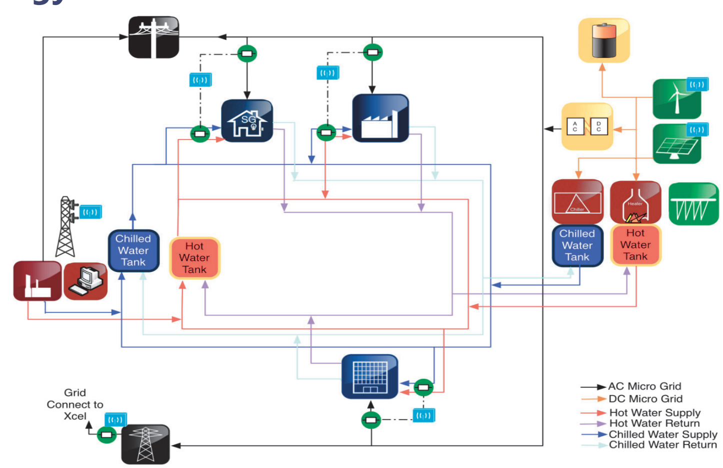
A District Energy Model



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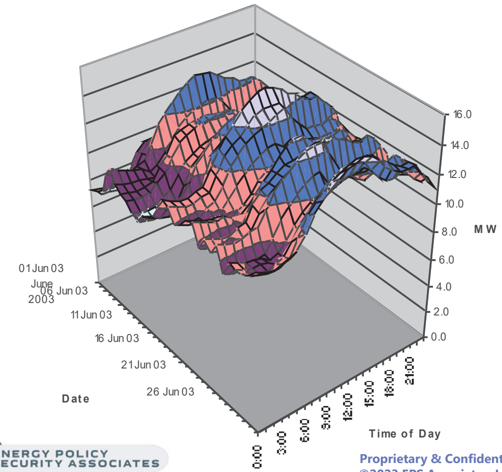
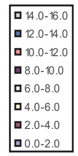
Example: Smart Grid U™





- Control algorithms and interfaces for turning individual energy components (storage, generation and loads) into an integrated, optimized energy system.
  - E.g., demand surface plots of raw data for demands, emissions, & efficiency

Next steps: demonstrate ability to integrate renewables/storage, cogeneration and achieve NZE status.

New Challenges for Smart Grids and Microgrids

- Need to integrate:
  - Large-scale stochastic (uncertain) renewable generation
  - Electric energy storage
  - Distributed generation
  - Plug-in hybrid electric vehicles
  - Demand response (smart meters)
- Need to deploy and integrate:
  - New Synchronized measurement technologies
  - New sensors
  - New System Integrity Protection Schemes (SIPS)
- Critical Security Controls

Microgrids: Lessons Learned

Electrical Engineering Challenges associated with the design and implementation of microgrids, including:

- **Integration of Distributed Energy Resources (DERs):** Microgrids often incorporate a variety of distributed energy resources such as solar panels, wind turbines, and energy storage systems, which can be challenging to integrate with the existing electrical infrastructure. DERs must be properly connected to the microgrid and the broader electrical grid for optimal performance and reliability.
- **Power Quality and Stability:** Microgrids must maintain a stable and high-quality power supply to the loads that they serve. Power produced by the DERs must be stable, with low voltage and frequency fluctuations, to prevent damage to sensitive electronic equipment.
- **Energy Storage System (ESS) Design**: Microgrids often rely on energy storage systems (ESS) to store excess energy produced by the distributed energy resources (DERs) and release it during times of high demand or low supply. The design of the ESS is critical for ensuring the reliability and performance of the microgrid. The ESS must be sized appropriately to meet the demand, and the battery chemistry, temperature control, and charge/discharge rates must be optimized to ensure a long lifespan and efficient operation.

Lessons Learned

Electrical Engineering Challenges, cont.:

- **Control and Protection Systems**: Advanced control and protection systems ensure that the microgrid operates safely and effectively.
  - **Control system:** regulates power flow to avoid overload or imbalance
  - **Protection system:** detects and isolates faults or abnormalities to prevent damage
    - Optimization: Sophisticated control and optimization algorithms are needed to ensure DERs are used in the most efficient and cost-effective way possible.
    - Requires managing energy inputs and outputs, maintaining stable voltage and frequency levels, responding to changes in demand and supply, factoring in changing weather conditions, energy prices, and load profiles to determine the most efficient use of the DERs and the ESS.

Lessons Learned

Engineering Challenges, cont.:

- **Cybersecurity**: Microgrids are targets for cyberattacks, which can compromise the safety and security of the microgrid and the broader electrical grid. Control and protection systems must be resistant to cyber threats.
- **Interconnection and Islanding**: Microgrids must be designed to safely and reliably interconnect with the larger electrical grid when necessary, and to operate in islanded mode when disconnected from the grid due to an outage or other event.
  - The engineering challenges associated with interconnection and islanding include designing the appropriate switchgear and protective relays, as well as ensuring that the microgrid can safely and seamlessly transition between grid-connected and islanded modes.
- **Grid Interconnection Standards**: Microgrids must meet certain grid interconnection standards to ensure that they can be safely and reliably connected to the existing electrical infrastructure. Standards vary depending on the location and regulations

Lessons Learned

Engineering Challenges, cont.:

- **Environmental Considerations**: Microgrids can have significant environmental impacts, including emissions from the DERs, noise pollution from wind turbines, and land-use impacts from the solar panels or wind turbines. The engineering challenges associated with environmental considerations include minimizing these impacts, as well as ensuring that the microgrid design complies with local environmental regulations.

- **Maintenance and Monitoring**: Microgrids require regular maintenance and monitoring to ensure that the components are operating as intended and to detect and resolve any issues before they become major problems. The engineering challenges associated with maintenance and monitoring include designing a system that can be easily maintained and monitored, as well as implementing remote monitoring and diagnostic capabilities to reduce the need for on-site inspections.

- **Integration**: The microgrid must be carefully designed to meet the power demands of any existing data center infrastructure.

Overcoming these challenges requires specialized expertise in power systems engineering, control systems, and cybersecurity, among other areas.

Non-Engineering Challenges of Using Microgrids

- **Regulatory and Policy Environment**: Microgrids can operate in a complex regulatory environment. Implementation may require changes to existing policies and regulations. Regulatory framework varies depending on the location and type of microgrid, which can create additional challenges for project developers and investors.

- **Business Model**: The economic benefits of a microgrid may be difficult to quantify, and there may be challenges associated with financing, revenue streams, and cost recovery. This is particularly for projects that involve multiple stakeholders

- **Community Engagement & Public Perception** : Microgrids often require community engagement and support, particularly for projects that involve siting renewable energy sources or storage systems. Community engagement may involve public outreach, education, and participation in the decision-making process.
  - The public perception of microgrids can have a significant impact on their implementation and success. Some members of the public may have concerns about the safety, reliability, or environmental impact of the microgrid, which can create additional challenges for project developers and investors.

Non-Engineering Challenges of Using Microgrids

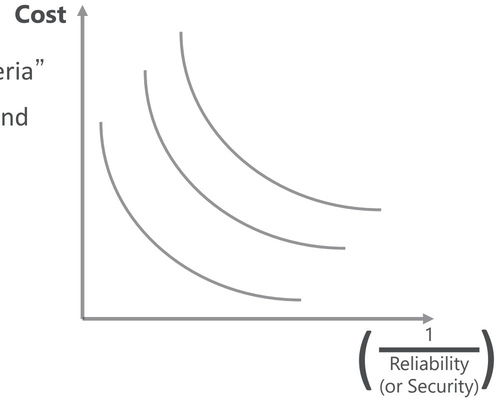
Requires a comprehensive understanding of the regulatory and policy environment, business models, community engagement, cybersecurity, and public perception.

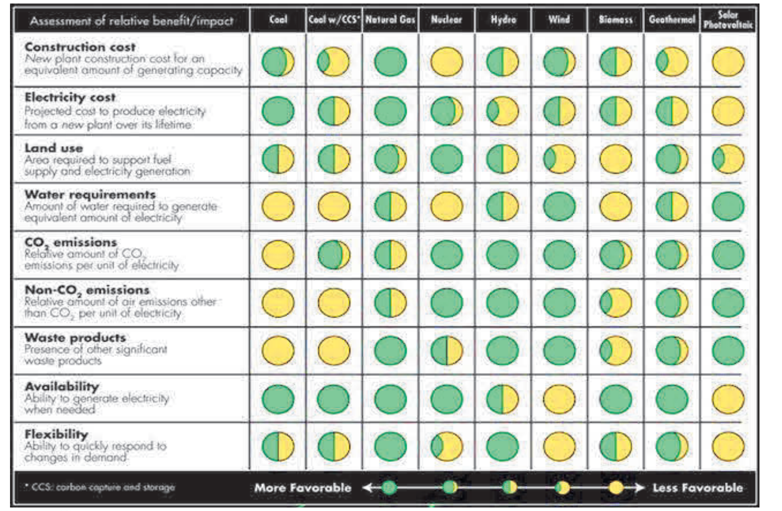
Successful microgrid projects often involve collaboration among multiple stakeholders, including project developers, utilities, regulators, and community members.

Multi-Criteria Optimization: Pareto Optimal

Cost/CapEX (acquire, upgrade, & maintain assets) vs. Reliability, Efficiency, Security, Sustainability/GHG Emissions, Resiliency, and Flexibility…

- Incorporate them early as "design criteria"
- Provide cost, reliability, sustainability and policy impact statement
- E.g. tradeoffs between the optimization criteria/objectives
- Plot the space
- There is no mathematical optimal point!





Source: EPRI http://sites.epri.com/refcard/comparison.html

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Smart Grid: Technological Innovations

Customer

- Smart Appliances
- Electric Vehicles
- Energy Efficiency
- Demand Response
- Distributed Energy Resources

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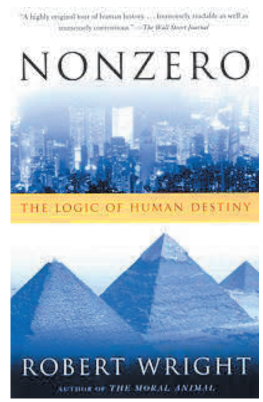
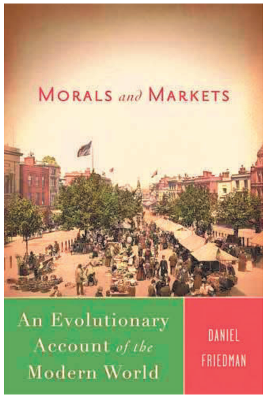
Technologies are diverse value creation mechanisms





Also see Paul Romer's Charter Cities Video: http://www.ted.com/talks/paul_romer.html

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Smarter about education, safety, energy, water, food, transp., e-gov… Innovative Cities:

- **Smarter transportation**
  Stockholm, Dublin, Singapore and Brisbane are working with IBM to develop smart systems ranging from predictive tools to smart cards to congestion charging in order to reduce traffic and pollution.
- **Smarter policing and emergency response**
  New York, Syracuse, Santa Barbara and St. Louis are using data analytics, wireless and video surveillance capabilities to strengthen crime fighting and the coordination of emergency response units.
- **Smarter power and water management**
  Local government agencies, farmers and ranchers in the Paraguay-Paraná River basin to understand the factors that can help to safeguard the quality and availability of the water system. Malta is building a smart grid that links the power and water systems, and will detect leakages, allow for variable pricing and provide more control to consumers. Ultimately, it will enable this island country to replace fossil fuels with sustainable energy sources.
- **Smarter governance**
  Albuquerque is using a business intelligence solution to automate data sharing among its 7,000 employees in more than 20 departments, so every employee gets a single version of the truth. It has realized cost savings of almost 2,000%.

'Cities are perfect for promoting change and renewable energies. Cities can serve as innovation platforms, creating clusters of business around green energy."

Top 10 cities

Rank	Country	City	Rating
1	Canada	**Vancouver**	98.0
2	Austria	**Vienna**	97.9
3	Australia	**Melbourne**	97.5
4	Canada	**Toronto**	97.2
5	Canada	**Calgary**	96.6
6	Finland	**Helsinki**	96.2
7	Australia	**Sydney**	96.1
8=	Australia	**Perth**	95.9
8=	Australia	**Adelaide**	95.9
10	New Zealand	**Auckland**	95.7

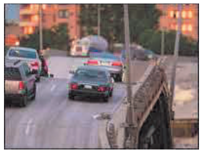
Example: I-35W bridge

Just after 6:00 p.m. on Aug. 1, Prof. Massoud Amin was at work in his office on the University of Minnesota's West Bank, where he heard and watched the unthinkable happen—the collapse of the I-35W bridge about 100 yards away.

"As an individual, it was shocking and very painful to witness it from our offices here in Minneapolis," says Amin, director of the Center for the Development of Technological Leadership (CDTL) and the H.W. Sweatt Chair in Technological Leadership. Amin also viewed the tragedy from a broader perspective as a result of his ongoing work to advance the security and health of the nation's infrastructure.

In the days and weeks that followed, he responded to media inquiries from the BBC, Reuthers, and the CBC, keeping his comments focused on the critical nature of the infrastructure. He referred reporters with questions about bridge design, conditions, and inspections to several professional colleagues, including Professors Roberto Ballarini, Ted Galambos, Vaughan Voller, and John Gulliver in the Department of Civil Engineering and the National Academy of Engineering Board on Infrastructure and Constructed Environment.

For Amin, Voller, and many others, the bridge collapse puts into focus the importance of two key issues—the tremendous value of infrastructure and infrastructure systems that help make possible indispensable activities such as transportation, waste disposal, water, telecommunications, and electricity and power, among many others, and the search for positive and innovative ways to strengthen the infrastructure.



To Improve the Future and Avoid a Repetition of the Past

Sensors built in to the I-35W bridge at less than 0.5% total cost by TLI alumni

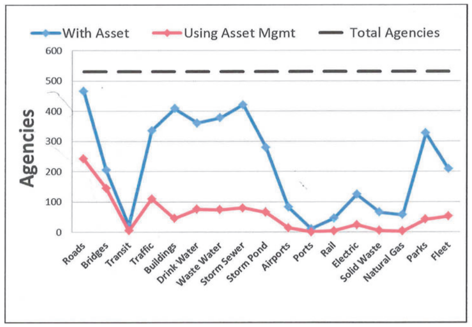
Terry Ward, Heidi Hamilton, Val Svensson, Joe Nietfeld

Not Just Utilities … Our Role in Minnesota: MN2050 Survey

MN 2050 — Infrastructure planning, long term success

	Small City	Large City	County	State	Total
Roads	$4,174,022,424	$10,517,476,430	$27,647,815,260	$29,338,312,840	$71,677,626,954
Bridges	$1,151,894,172	$807,350,570	$1,456,009,206	$6,592,940,562	$10,008,194,510
Transit	$0	$0	$0	$0	$0
Traffic	$14,168,440	$138,820,460	$59,985,398	$0	$212,974,298
Buildings	$7,583,657,510	$13,724,959,690	$4,869,723,674	$501,696,056	$26,680,036,930
Water	$1,499,020,952	$6,279,799,230	$0	$0	$7,778,820,182
Wastewater	$1,704,463,332	$4,244,983,540	$0	$6,494,782,638	$12,444,229,510
Storm sewer	$0	$2,085,960,070	$0	$0	$2,085,960,070
Storm ponds	$150,185,464	$65,757,060	$5,453,218	$0	$221,395,742
Airports	$1,240,446,922	$1,344,366,560	$0	$0	$2,584,813,482
Ports	$0	$0	$0	$0	$0
Rail	$0	$0	$3,173,772,876	$0	$3,173,772,876
Electrical	$0	$10,564,967,640	$0	$0	$10,564,967,640
Solid Waste	$0	$94,982,420	$796,169,828	$0	$891,152,248
Natural Gas	$2,056,549,066	$2,747,183,840	$0	$0	$4,803,732,906
Total	**$19.5B**	**$52.6B**	**$38.0B**	**$42.9B**	**$153B**

Not Just Utilities …
Our Role in Minnesota: 2015 MN2050 Survey



2015 Values

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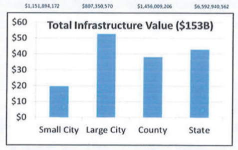

Assets Managed by Cities, Counties and State Agencies

	Assets Managed	Road	Bridge	Transit	Traffic	Buildings	Drink Water	Waste Water	Storm Sewer	Storm Pond	Airports	Ports	Railways	Electrical	Solid Waste	Natural Gas	Total
Small Cities	14	97	11	1	55	71	92	92	89	54	15	0	7	18	5	9	616
Large Cities	15	187	88	4	112	109	128	139	137	133	19	2	9	54	9	7	1137
Counties	14	132	99	4	64	45	7	5	36	18	8	0	4	4	18	3	447
State Agencies	7	9	3	0	3	7	0	4	2	2	0	0	0	0	0	0	30
Totals =		425	201	9	234	232	227	240	264	207	42	2	20	76	32	19	2230

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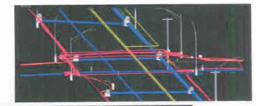
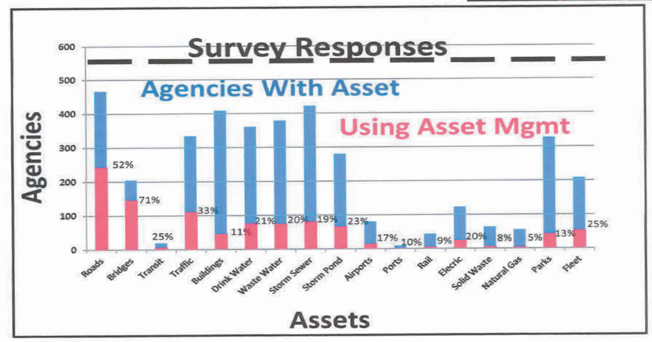
Minnesota
Asset Management Usage





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An Engine for Economic Growth

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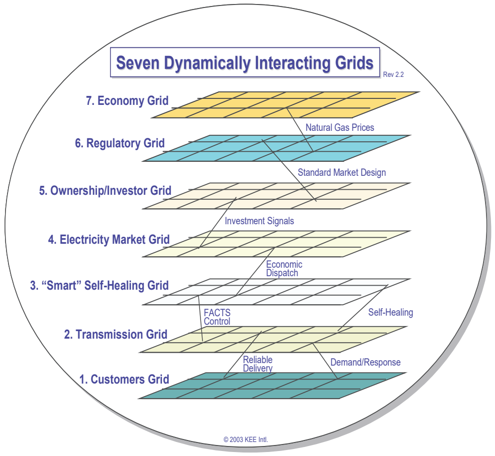
Globally Interlocked Dynamics:
Understanding the Full Impacts of Decision Pathways

"Global Transition Dynamics Unfolding the Full Social Implications of National Decision Pathways," Chauncey Starr and Massoud Amin, 2003

- To unfold the full potential of social progress requires an integrated understanding of the many dimensions of social development, their underpinnings, and the role of science and technology.
- Goal: To target our constrained development resources to maximize benefit and minimize unintended consequences

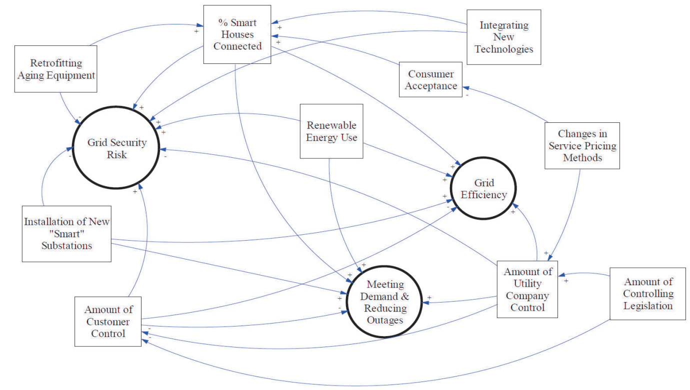
Technology Development, Transition and Implementation: … the really hard part

- Steps in STEM-based R&D to enable secure, efficient, resilient and adaptive infrastructure
- Markets and Policy framework, implementation, and evaluation
- Wind-tunnel testing of designs, markets and policy
- Making the business case for the opportunity
- Decision Support Dashboard: Have a plan …



Smart Grid Interdependencies

Security, Efficiency, and Resilience



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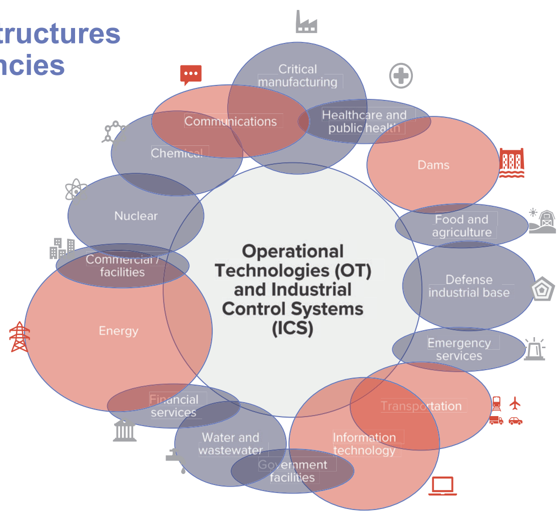
Critical Infrastructures Interdependencies



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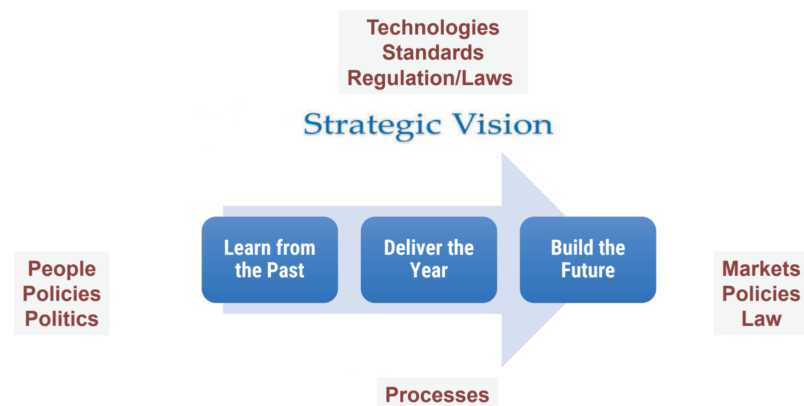
Holistic Assessments, Investments, and Execution: Strategic Innovation Imperative (https://eps-associates.com/)



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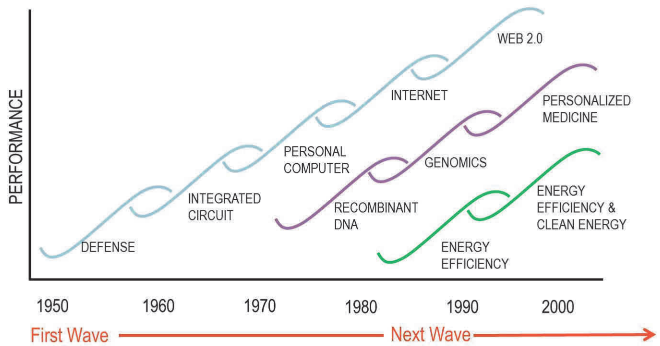
Technology Is BIG Business

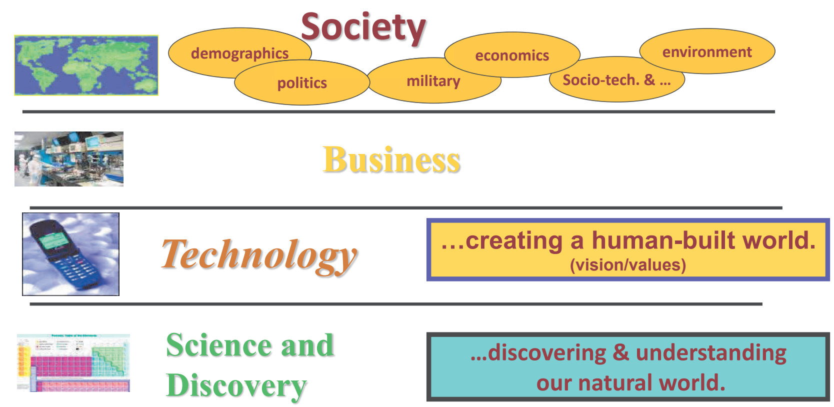
Technology drives over **60%** of the U.S. GDP.*



Metrics to measure impacts: "You Manage only What You Measure" is a prerequisite to "You Manage Even Better if You Value/Price it" and that "Even if you can't measure it, you still must manage it"

*Research findings of Dr. Robert Solow, MIT professor & Nobel Laureate in Economic Sciences

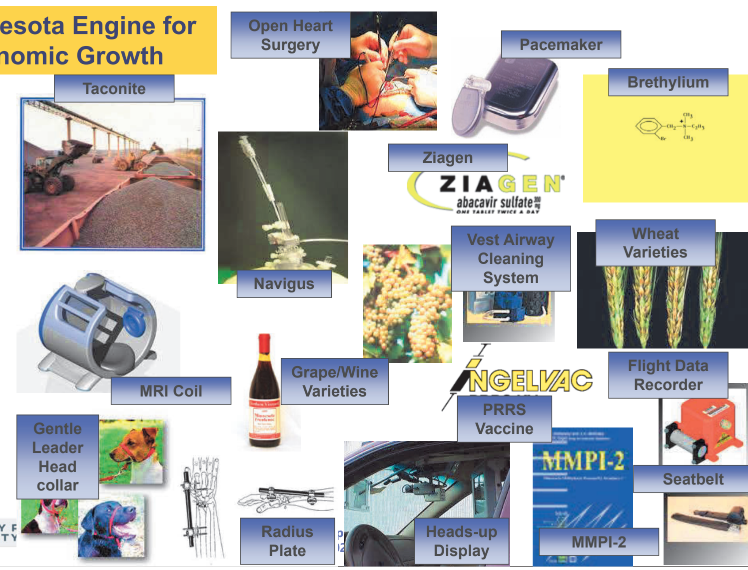
The "T" model – Leaders have both a wide range AND depth



Entrepreneurship:

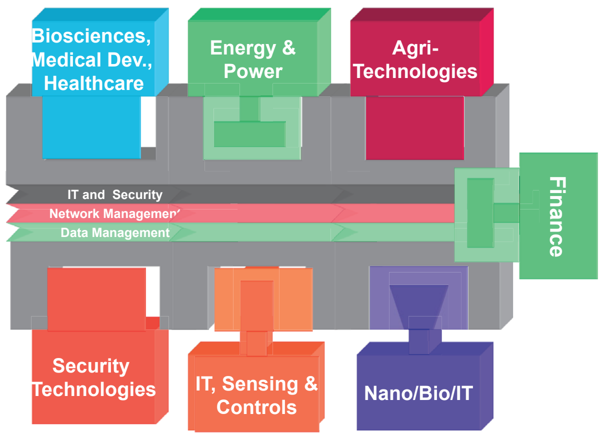
- College of Science and Engineering Founders2005 Survey of alumni who have started businesses:
  - 15,000 alumni responded
  - 3,024 have founded one or more companies
  - 2,600 active companies in Minnesota (employing 175,000 in Minnesota), with annual global revenue of $90B ($46B in Minnesota)
  - with Faculty also active in start-ups, often with former graduate students.

A Minnesota Engine for Economic Growth



Minnesota's Technological Leadership Role:

Enabling Economic Growth→ First Build the Right Foundation



Build The Right Foundation

Security

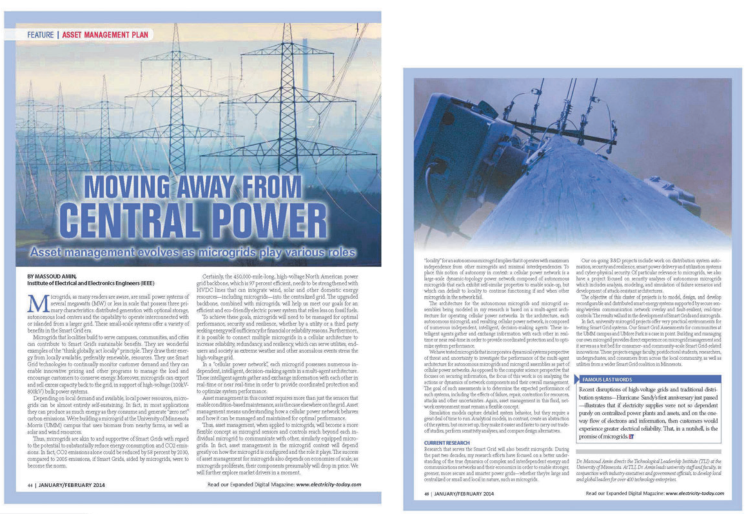
Network Management

Data Management

Interoperability

Key Technologies for Minnesota

1. Energy and Power
2. AI, ML, Bog Data, Information Technologies (IT), Operational Technologies (OT)
3. Security Technologies
4. Medicine and Medical Devices
5. Agricultural Technologies
6. Nano/Bio/IT

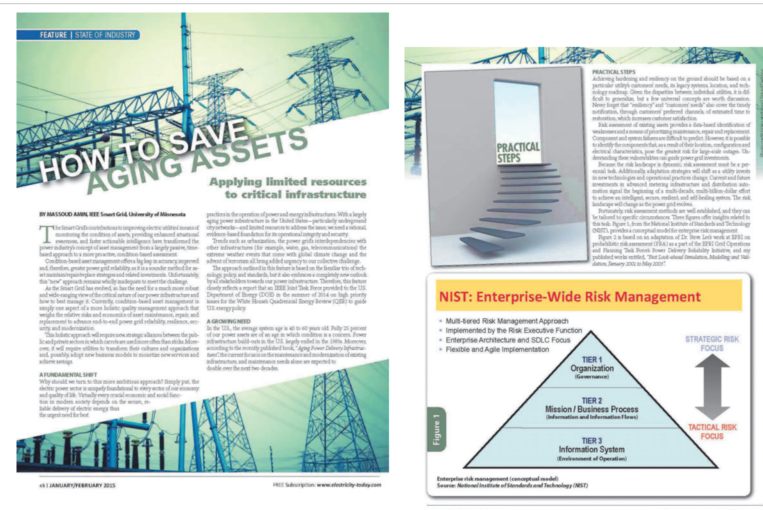


FEATURE | ASSET MANAGEMENT PLAN

MOVING AWAY FROM CENTRAL POWER

Asset management evolves as microgrids play various roles

BY MASSOUD AMIN, Institute of Electrical and Electronics Engineers (IEEE)



FEATURE | STATE OF INDUSTRY

HOW TO SAVE AGING ASSETS

Applying limited resources to critical infrastructure

BY MASSOUD AMIN, IEEE Smart Grid, University of Minnesota

PRACTICAL STEPS

NIST: Enterprise-Wide Risk Management

- Multi-tiered Risk Management Approach
- Implemented by the Risk Executive Function
- Enterprise Architecture and SDLC Focus
- Flexible and Agile Implementation

TIER 1 Organization (Governance)

TIER 2 Mission / Business Process (Information and Information Flows)

TIER 3 Information System (Environment of Operation)

STRATEGIC RISK FOCUS

TACTICAL RISK FOCUS

Figure 1

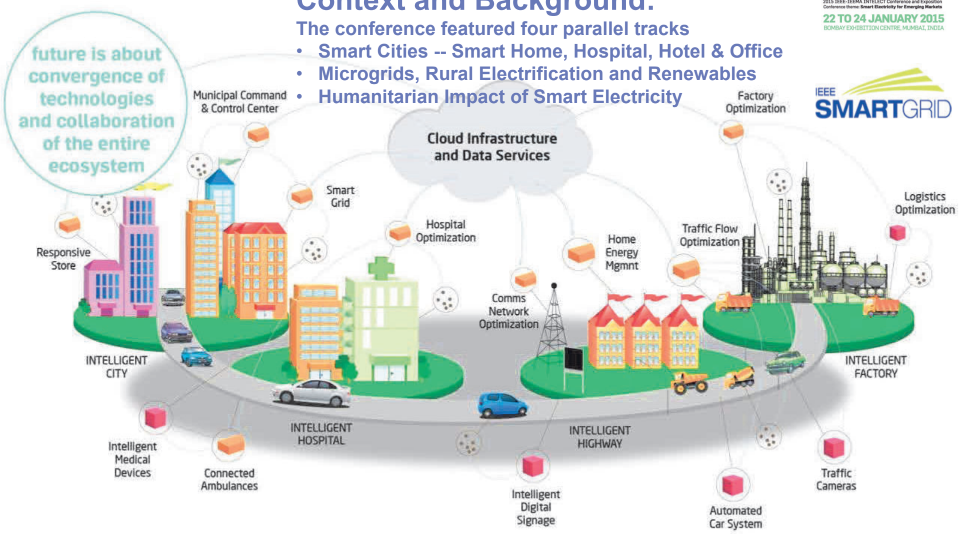
Context and Background:

The conference featured four parallel tracks

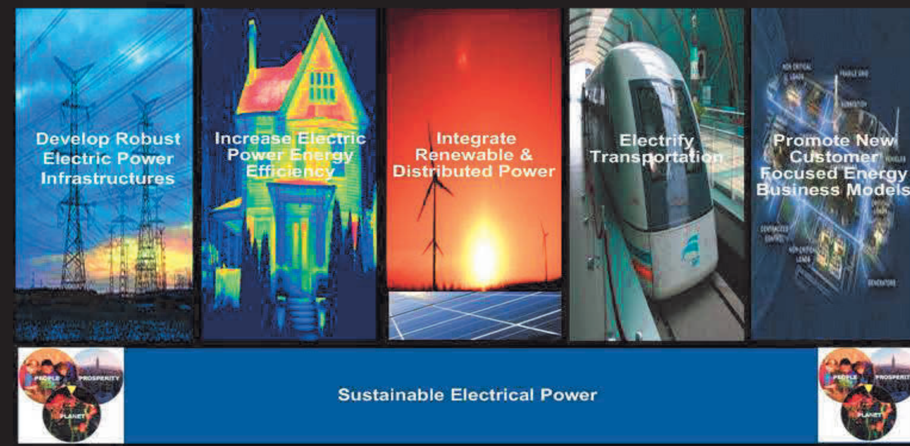
- Smart Cities -- Smart Home, Hospital, Hotel & Office
- Microgrids, Rural Electrification and Renewables
- Humanitarian Impact of Smart Electricity

INTELECT 22 TO 24 JANUARY 2015

IEEE SMARTGRID

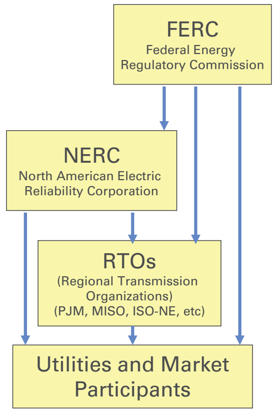


Smart Grid Goals



Source: M. Amin, Chairman, IEEE Smart Grid

Bulk Electric System (BES) Reliability Oversight Is a Shared Responsibility

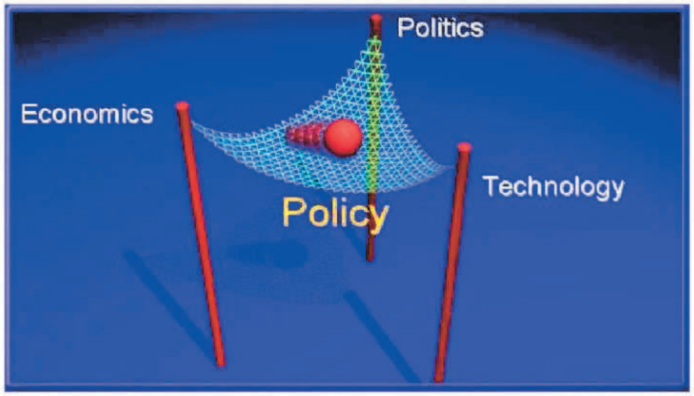


- FERC has regulatory jurisdiction over transmission tariffs, wholesale market rules and BES reliability standards
  - State regulators are engaged and very influential but do not have direct authority over the Bulk Electric System
  - Interstate Commerce per US Supreme Court
  - States have authority for siting of transmission lines
- NERC develops and enforces FERC approved mandatory reliability standards
- RTOs and all "users, owners and operators of the bulk power system" are bound by FERC/NERC standards and regulations

SMART GRID POLICY IMPLICATIONS

- Focus on Consumer-Societal Benefits
  - Seamless Supply/Demand Interconnect
  - Consumer Empowerment
  - Reliability Transformation
- Help Utilities Deal with the Inevitable
  - Universal Real Time Pricing
  - Distributed Generation Microgrids
  - Security (IT/OT and physical)
  - Climate Resilience
  - Retail Service Competition

Unresolved Issues Cloud Planning for the Future



Recommendations

- Support **holistic, integrated approach** in simultaneously managing fleet of assets to best achieve optimal cost-effective solutions addressing the following:
  - **Aging infrastructure,**
  - **Supply Chain Security, Resiliency, and Interdependencies,**
  - **Grid and Micro-Grid hardening (including weather-related events, physical vulnerability, and cyber-physical security) for Smarter Cities,**
  - **System reliability.**
- **Urgently address managing new Smart Grid assets** such as advanced metering infrastructure (AMI) and intelligent electronic devices, and systemic issues extended to Smarter Cities

Discussion, Options, and the Road Ahead:

- What are the sustainability, security, resilience, power & energy innovation, investment, and policy opportunities?
  - **What is your vision for the future– what will it look like or how will it perform in 2024-2030?**
  - **Pinch points:** What are the difficult challenges to overcome to achieve your vision?
  - **Pathways:** What enabling **technologies, policies, and investments** are needed to address these?
  - **Foresight:** What critical issues should we consider in beginning plans for 2024 and beyond?

Observations and the Road Ahead:

- What are the key energy, environmental and economic issues facing our cities, our nations, and the world?
- "What are the range of new services enabled by smart grids and Microgrids?"
- Smart grids (enabling Smart Cities, Smart Homes and Buildings) included in all energy legislation
- Smart grid's potential as an "enabler in state and federal regulatory policies" to drive economic growth

Bottom Line:

"Only three things happen naturally in organizations:
friction, confusion and underperformance.
Everything else requires leadership."

-- Peter Drucker

Thank you

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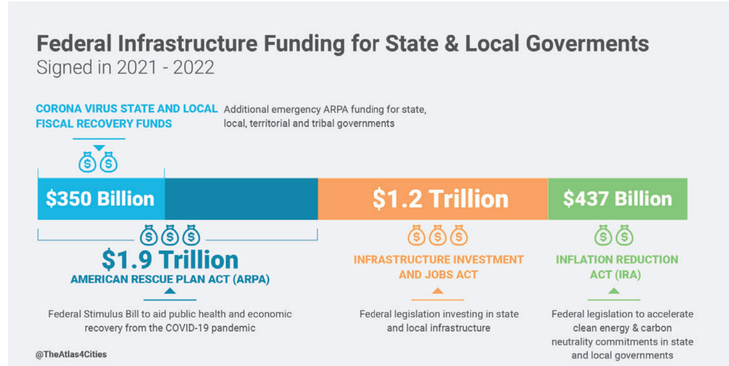
Appendix

Summary of Recent Federal Infrastructure Funding



Infrastructure Investment and Jobs Act (IIJA) – Overview

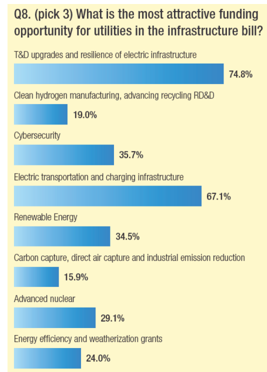
Of the $1.2 trillion package, the IIJA if11990 (congress.gov) and guidebook Building a Better America - The White House) offer:

- **>$62 B** for electric and grid infrastructure.
- **>$47 B** for resilience, including cybersecurity and resilience.
- **Significant funding** for broadband and electric-vehicle (EV) charging infrastructure.

The bill includes funding for electric transmission improvements, including:

- Creation of a Grid Deployment Authority to oversee electricity grid upgrades: BUILDING-A-BETTER-AMERICA-V2.pdf (whitehouse.gov).
- Additional siting authority for the Federal Energy Regulatory Commission.
- More on nuclear power and carbon capture technology.
- Preparation for Utilities: 5 Steps for Utilities Preparing for IIJA Funding (power-grid.com).
- NGA: IIJA Implementation Resources - National Governors Association (nga.org).

Infrastructure Investment and Jobs Act (IIJA) – Overview



Source: Public Utilities Fortnightly, 2021 survey

Key provisions of Infrastructure bill:

- $ Directing the Department of Energy (DOE) to establish a **$5 B grant program for grid hardening and weatherization** to help reduce the impacts of extreme weather events on the grid.
- $ Authorizing **$6 B toward grid reliability and resilience research, development and demonstration,** including **$1 B for rural areas** specifically.
- $ This new program includes **innovative approaches to transmission, distribution and storage infrastructure** that are implemented at the state level by publicly regulated entities on a cost-share basis.
- $ Authorizing **$3 B to deploy technologies that enhance grid flexibility** in the Smart Grid Investment Matching Grant Program**.**
- $ Establishing a **$2.5 B Transmission Facilitation Fund and a Transmission Facilitation Program,** positioning DOE to leverage federal funding to reduce the overall risks of transmission projects.
- $ Authorizing **$500 M to support state transmission and distribution planning** among other activities in the State Energy Program.
- $ Authorizing **$350 M to develop advanced cybersecurity technologies** for energy sector

Key Provisions for the Electric Grid Sector

Grid hardening and weatherization
Directing the Department of Energy (DOE) to establish a $5 B grant program for grid hardening and weatherization to help reduce the impacts of extreme weather events on the grid.

Grid reliability and resilience
Authorizing $6 B toward grid reliability and resilience research, development and demonstration, including $1 B specifically for rural areas.

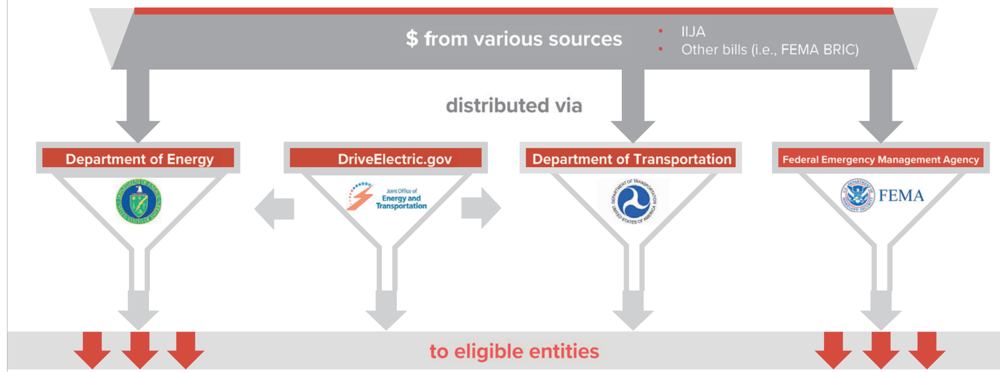
Smart grid
Authorizing $3 B in the Smart Grid Investment Matching Grant Program to deploy technologies that enhance grid flexibility.

Transmission facilitation
Establishing a $2.5 B Transmission Facilitation Fund and a Transmission Facilitation Program, positioning DOE to leverage federal funding to reduce the overall risks of transmission projects.

T&D planning
Authorizing $500 M to the State Energy Program to support state transmission and distribution planning, among other activities.

Electrification
- $7.5 B for transportation electrification infrastructure.
- $250 M for reduction of truck emissions at ports.

Where Are We Today?



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IIJA and IRA Programs: Example: Cyber Security, Physical Security, and Resilience - A $750 Billion Opportunity

Transportation Electrification

IIJA: $156B	IRA:
National Highway Performance Program	$148B
Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT)	$8.7B

Grid Resilience and Innovation Partnerships *(FOA DE-0002740 expected Q1 2023)*

GRID DEPLOYMENT OFFICE

OCED

Grid Resiliency and Access

IIJA: $625B	IRA: $232M
Low Income Home Energy Assistance	$500B
Energy Improvement in Rural or Remote Areas	$100B
Natural Estuary Grant Program	$132M
Pollution Prevention Grant	$100M
Program Upgrading our Electric Grid and Ensuring Reliability and Resilience	$1B
Preventing Outages and Enhancing the Resilience of the Electric Grid	$5B
Cost-Effective Codes Implementation for Efficiency and Resilience	$225M

Cyber Resilience

IIJA: $585m	IRA: $14.7b
Sector Risk Management Agencies	$35M
Rural and Municipal Utility Advanced Cybersecurity Grant	$250M
Cybersecurity for the Energy Sector Research, Development, and Demonstration Program	$250M
Energy Sector Operational Support for Cyber Resilience	$50M
Investments in Clean Energy Manufacturing and Energy Security	$14.7B

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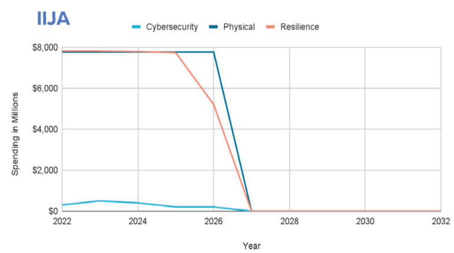
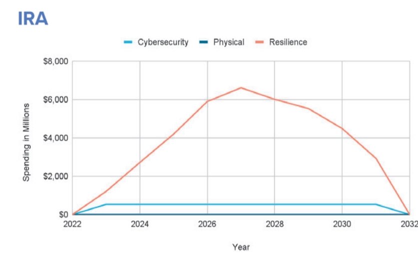
Example: Cybersecurity, Physical Security, and Resilience





- **IIJA has a baseline of $6.2B over 10 years** in cybersecurity, physical security, and resilience (other foci to be assessed/offered).
- **Just this one area has $620M available per year in this area in IIJA.** A lot of funds are for capital equipment.
- **Our opportunity is in the frontend:** a unique, broad offering that is deep, comprehensive, and integrated. ***Assessments → Execution***

Business + Regulatory + Engineering + Technology + Environmental + Societal + Workforce

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Other funding from the IIJA DOE for say Rural Cooperatives Includes:

Funding available under each program can vary – often subject to annual appropriations by Congress.

- **Rural Energy Savings Program** – Funding to rural electric cooperatives to help their members finance energy efficiency upgrades. **$1B over five years.**
- **Rural Energy for America Program** – Funding to rural businesses and agricultural producers for renewable energy and energy efficiency projects. **$1.5B over five years.**
- **Energy Efficiency and Conservation Loan Program** – Providing low-interest loans to rural electric cooperatives to finance energy efficiency projects. **$1B over five years.**
- **Rural Utility Service Programs** – Funding for rural electric infrastructure, including transmission and distribution systems, as well as renewable energy and energy efficiency projects. **$2.5B over five years.**

Funding from the IIJA DOE for Cities and Municipalities Includes:

Funding available under each program can vary – often subject to annual appropriations by Congress.

- **Energy Efficiency and Conservation Block Grant Program** – Grants to state, local, and tribal governments for energy efficiency and conservation projects. **$3.5B over five years.**
- **Weatherization Assistance Program** – Funding to improve the energy efficiency of low-income homes. **$3B over five years.**
- **Clean Cities Program** – Funding to help cities and municipalities reduce their petroleum use through the use of alternative fuels and vehicles. **$500M over five years.**
- **State Energy Program** – Funding to states and territories to support energy efficiency and renewable energy projects. **$1.5B over five years.**
- **Building Energy Codes Program** – This program provides technical assistance and funding to support adoption and implementation of building energy codes. **$200M over five years.**

Funding from the IIJA DOE for a Range of Clean Energy, Energy Efficiency, and Climate Resilience Initiative, Includes (1/2):

Funding available under each program can vary – often subject to annual appropriations by Congress.

- **Advanced Research Projects Agency-Energy (ARPA-E)** – Funding high-risk, high-reward research on breakthrough energy technologies. **$3B over five years.**
- **Energy Efficiency and Conservation Block Grant Program** – Grants to state, local, and tribal governments for energy efficiency and conservation projects. **$3.5B over 5 years.**
- **Weatherization Assistance Program** – Funding to improve the energy efficiency of low-income homes. **$3B over 5 years.**
- **Clean Cities Program** – Funding to help cities and municipalities reduce their petroleum use through the use of alternative fuels and vehicles. **$500M over 5 years.**
- **State Energy Program** – Funding to states and territories to support energy efficiency and renewable energy projects. **$1.5B over 5 years.**

Funding from the IIJA DOE for a Range of Clean Energy, Energy Efficiency, and Climate Resilience Initiative, Includes (2/2):

Funding available under each program can vary – often subject to annual appropriations by Congress.

- **Rural Energy Savings Program** – Funding to rural electric cooperatives to help their members finance energy efficiency upgrades. **$1B over five years.**
- **Rural Energy for America Program** – Funding to rural businesses and agricultural producers for renewable energy and energy efficiency projects. **$1.5B over five years.**
- **Energy Efficiency and Conservation Loan Program** – Providing low-interest loans to rural electric cooperatives to finance energy efficiency projects. **$1B over five years.**
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