Energy Reliability, Extreme Events & Sustainability

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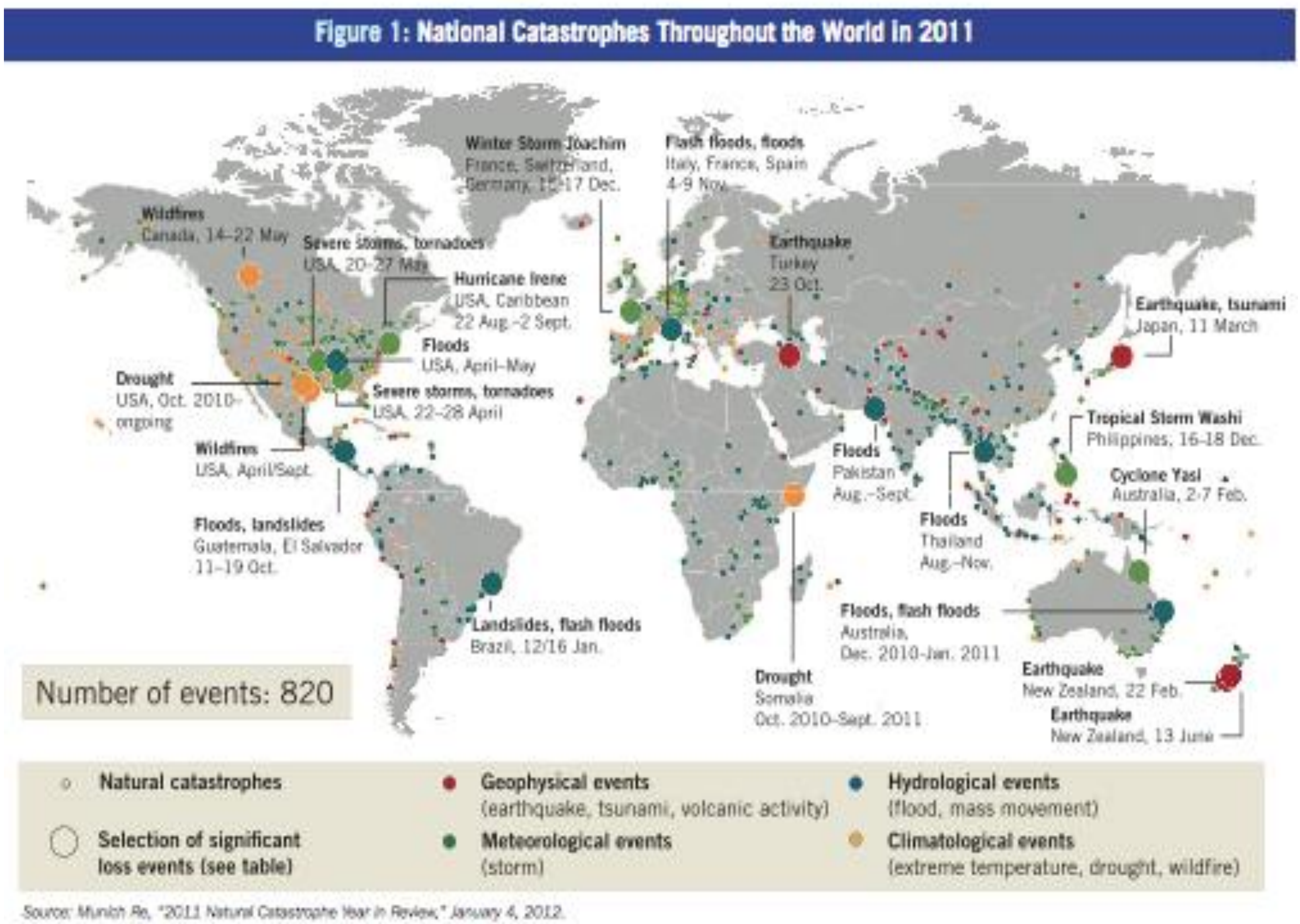
Overview

1) Extreme events
2) Extreme events compromise energy infrastructure and energy reliability
3) Energy systems can be modified to enhance energy reliability
4) Some energy changes that enhance reliability can enhance sustainability
5) Smart grid, reliability and sustainability
6) Barriers to moving toward more sustainable and resilient energy systems
7) Knowledge gaps for energy infrastructure needs

Motivation – lots of extreme weather events

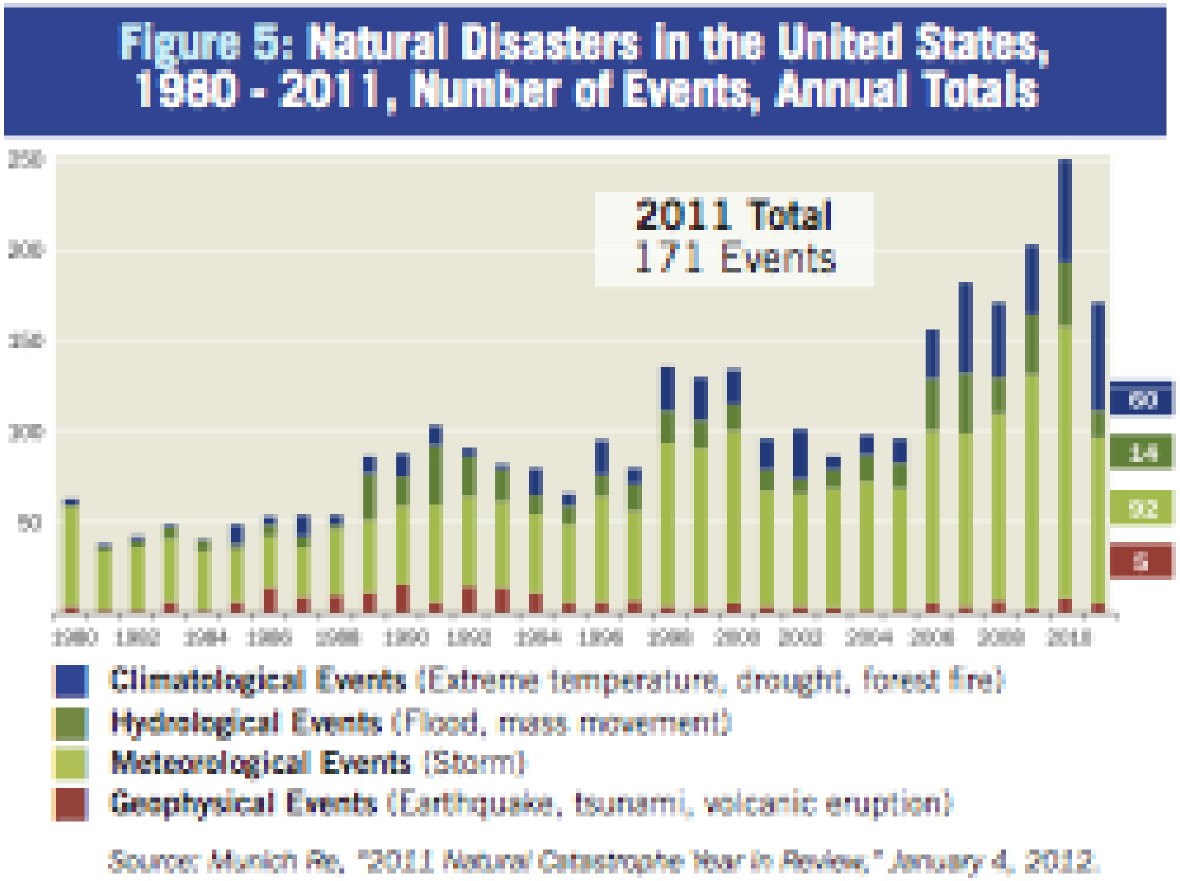
Worldwide



CERES, "Stormy Future for U.S. Property/Casualty Insurers: The Growing Costs and Risks of Extreme Weather Events, September 2012

More motivation – it's getting scarier

United States



Extreme events

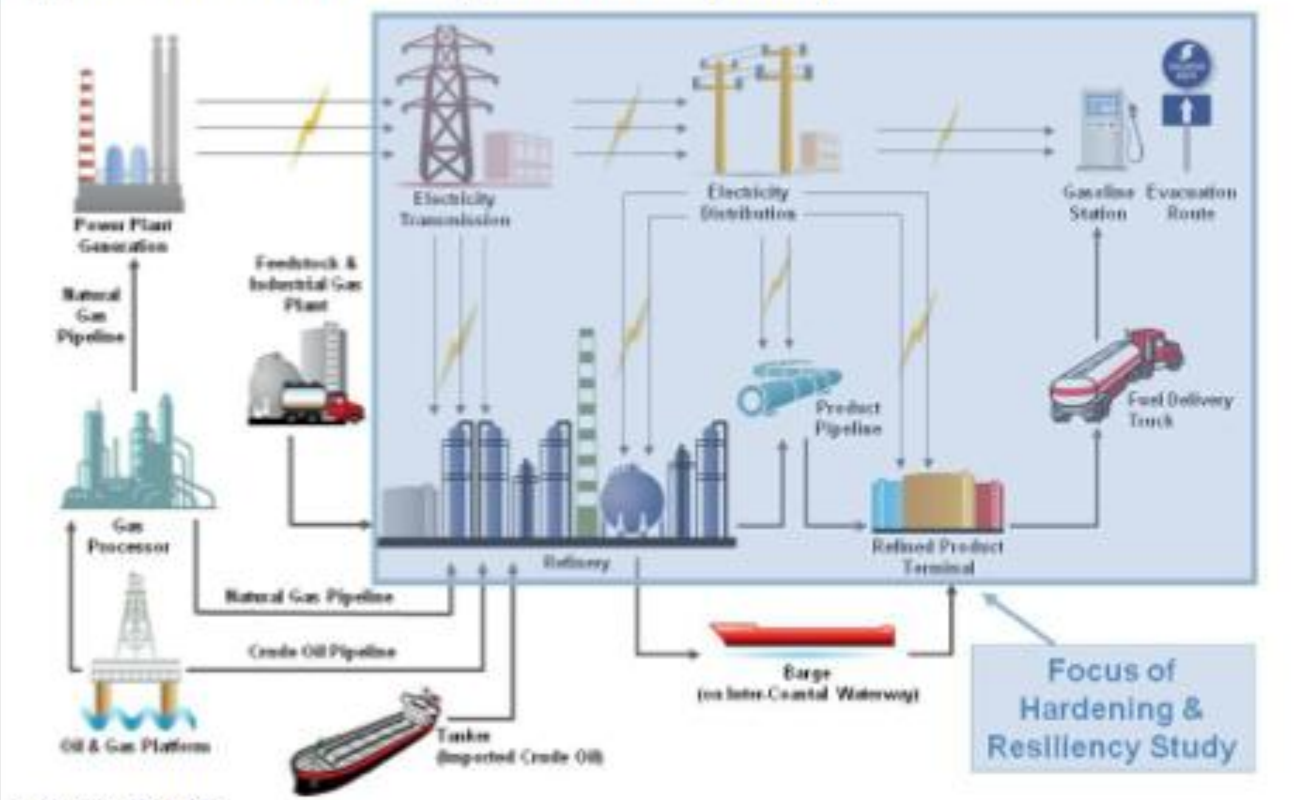
Most extreme events can harm energy infrastructure – particularly large and/or linear facilities (refineries, electric T&D, coal trains, oil & gas pipelines).

- Tornadoes and hurricanes break electric transmission and distribution poles & lines.
- Flooding harms power plants, T&D, transformers, refineries, pipelines.
- Earthquakes can break everything.
- Snow and ice storms can break T&D facilities and shut down ill-prepared power plants and pipelines.
- Geomagnetic storms can shut down electric and communications systems, pipelines, and more.
- Extended drought can compromise power plant operation and could damage buried infrastructure (ground shifting).

Energy system interdependencies

the neat version

Figure 2. Focus of Hardening and Resiliency Study



Source: SAIC, 2010.

DOE-OE, "Hardening and Resiliency – U.S. Energy Industry Response to Recent Hurricane Seasons", August 2010

Energy infrastructure interdependencies

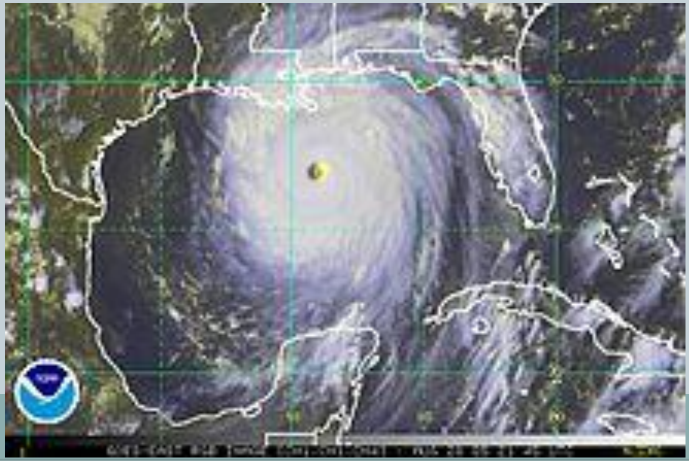
the messy version

James Peerenboom, "Infrastructure Interdependencies: Overview of Concepts & Terminology"; also Rinaldi, Peerenboom & Kelly, IEEE Control Systems Magazine, December 2001.

Extreme events with extreme energy consequences

Hurricane Katrina & floods

- All Gulf oil platforms and drilling rigs shut, many harmed
- Gulf refineries shut down
- All pipelines shut down
- Millions of electric customer facilities harmed
- Gas stations and gas deliveries disabled across 4 states for weeks



Fukushima earthquake & tsunami

- Tsunami destruction of 3 units of Fukushima Daiichi nuclear plant
- Earthquake cut electricity to 220,000 households
- Fire & destruction of LNG tanks
- Tsunami destroyed much of coastal area

Some disaster and energy impact factoids

- Hurricane Gustav (Category 2) broke electrical poles and wires 50 miles inland; Superstorm Sandy had a 1,100 mile diameter (impact span).
- 90% of electrical outages due to storm from distribution system damage.
- Storm surges 50 to 100 miles wide sweep across the coastline near hurricane landfall; since 1900, flooding caused by storm surge has killed more people in the U.S. than all other hurricane-related threats combined (freshwater flooding, winds and tornadoes).
- Salt water destroys energy infrastructure by corroding metal, electric components and wiring.
- Refinery and pipelines damaged most by flooding and storm surges; but 2-3 week refinery shutdowns are caused primarily by lack of electric supply.
- The March 13, 1989 solar storm created geomagnetic currents that harmed several transformers, creating a collapse that took down the entire Hydro Quebec grid – 9 hours, 5 million people affected, cost exceeding $2 billion.
- The 2008 southern China ice storm (January 10-29), caused the collapse of about 4,100 transmission towers, damaged another 9,300 towers, 36,740 transmission lines (miles?) needed repair, affecting 200 million people, and killing 129 people.

Managing energy systems to reduce vulnerability

We can't do much to reduce the probability or severity of extreme event threats in the near term, so we have to find ways to reduce the exposure of energy assets and populations to extreme events, and to reduce their vulnerability to harm from those events.

- **Hardening** = physically changing the infrastructure to make it less susceptible to damage from extreme events, to improve durability and stability
- **Resiliency** = the ability of the facility or system to continue operating and/or recover quickly from damage to its components or the external systems on which it depends.
- **Reduce population exposure** – not my scope…

Energy system & facility hardening measures

- Build/strengthen berms, levees, floodwalls
- Elevate substations, pump stations, control rooms
- Relocate and/or strengthen lines and facilities
- Underground distribution lines (outside flood zones)
- Put back-up generators or batteries at key facilities
- Upgrade and secure poles, structures, cabling
- Asset databases and tools
- Cyber-security
- Electromagnetic Farraday cages for transformers

Energy system & facility resiliency measures

Physical asset measures

- Monitoring, communications and analytics for better situational awareness and system management (e.g., smart grid, T&D automation)
- Redundant communications & controls systems, including tracking and communications with key employees
- Distributed generation and energy storage (with different interconnection) support customers during outages
- Equipment inspection and maintenance
- Maintain spares of critical equipment (transformers, circuit breakers, poles)
- Energy efficiency make it easier for affected populations to get through disaster-based outages with less discomfort

More resiliency measures

Operational practices

- Proactive vegetation management
- Facilitate employee and partner equipment evacuation and movement
- Maintain minimum product volumes in product tanks and pipelines
- Disaster preparedness planning and training, drills and exercises, maps and protocols
- Acquire and pre-position key supplies, staff and staging areas (generators, fuel, command vehicles, communications, equipment)
- Participate in mutual assistance groups
- Proactive communications with citizens and government officials
- Take proactive equipment and system outages to protect equipment

Hardening v. resiliency

In many cases, measures to improve resiliency are often more effective and cost-effective than measures to harden assets.

- Many extreme events cause common damages (e.g., distribution lines can be broken by big winds, floods, and ice storms, solar flare and EMP and cyber-attack could all harm communications systems and controls).
- It's cheaper and easier to undertake resilience measures that mitigate multiple threats and can be delivered to disaster-affected points across the utility system (e.g., replacement poles and lines, mobile transformers, distributed generation) than to harden **all** of the facilities throughout the system against specific threats.
- ConEd example
  - It will spend about $450 million on post-Sandy grid repairs in and around New York, adding about 3% to average electric bills
  - It would cost $800 million to protect the 10 substations that flooded during Sandy
  - Fully storm-proofing its system might cost 100x that amount -- putting distribution lines underground would cost about $40 billion, with rates tripling for a decade to pay for it.

Energy modifications that improve sustainability

- Distributed generation (CHP, PV, community wind, microgrids) enhance system resilience, increase resource efficiency, reduce fuel use, emissions and water use.
- Greater use of renewables will reduce fossil fuel use and could reduce dependence on disaster-vulnerable pipelines, refineries and off-shore platforms.
- Energy and water efficiency measures could potentially reduce U.S. energy use by 25% or more.
- Smart grid contributes to efficiency and renewables and DG integration.

Smart grid

- Smart grid is the web of sensors, monitors, analytics, communications and controls being installed to operate the grid in a more integrated and efficient fashion.
- Smart grid elements on the grid include:
  - Transmission automation
  - Synchrophasor monitoring system
  - Distribution automation
  - Field workforce management system
  - Advanced meters
  - Outage management system
  - High speed communications system
  - Extensive analytics integrated across the enterprise

Smart grid and extreme events

- Smart grid technology can't protect customers or the grid from destruction of energy assets (because the smart grid field assets get damaged along with the traditional assets they monitor or control)
- But it can reduce the consequences of an extreme event by preventing some outages and shortening service restoration:
  - Fast identification of potential damage and repositioning operations to avert or reduce the occurrence or scope of that damage (especially to prevent cascading failures)
  - Immediate identification of damaged facilities
  - Better managing unharmed assets and switching electricity flows around damaged assets to maintain reliable operations
  - With integration of smart meters to the outage management system, GIS, field workforce management and equipment logistics, the utility knows what customers are out of service and can manage repairs better

Smart grid and sustainability

Smart grid systems enhance sustainability

- Better integration of low-emissions renewables – distributed (PV) and utility-scale (wind, PV, geothermal, batteries, other)
- Facilitates customer-side energy efficiency and voluntary conservation, so reduces energy use, water use and emissions
- Facilitates customer load-shifting and use of demand-side assets instead of fossil generation for ancillary services
- More efficient use of the transmission & distribution grid lowers generation requirements and electricity- and fuel source-related emissions and water use
- Advanced metering lets utilities reduce truck rolls and transportation-associated fuel consumption and emissions

Barriers to improving energy infrastructure resiliency and sustainability

1) Capital – all these initiatives are sound over the long-term but have significant costs over the short-term in a time when the economy is weak and regulators don't want to raise rates further.
   - Resiliency measures tend to mitigate a variety of threats and are lower cost so easier to get cost recovery approval.
   - Customer benefit of redundant capital assets isn't obvious
   - For the electric system in particular, it is usually more cost-effective to let it break and fix it than to harden the system (e.g., undergrounding distribution lines costs from $500,000 to $5 million/mile).
   - Example -- PSE&G says it cost $250-300 million to restore its T&D system after Hurricane Sandy and now plans to invest $3.9 billion over the next 10 years to strengthen its electric and gas systems against future extreme weather events.

More barriers

2) Societal support – energy systems are already used as instruments to implement societal goals, and there is little political consensus about energy policy priorities.
3) Too many decision-makers – there are many players and influencers in the energy business (particularly electricity) with conflicting aims, overlapping jurisdictions, and slow processes.
4) Complex interdependencies are not always well-recognized and easy to anticipate and mitigate.
5) Asset inertia -- many existing energy assets are large and long-lived (40+ years), and executives and regulators want to extract the maximum value from them even as technologies and policies evolve.
6) Asset acquisition challenges – some critical assets (e.g., high voltage transformers) are very expensive, customized, slow to build, and hard to replace; others (transmission lines, substations, power plants and pipelines) can be hard to site.
7) Business model inertia – there are few opportunities for current actors to make money from improving energy resiliency and sustainability.

Knowledge gaps?

We know – at the big picture level – what needs to be done to improve energy system sustainability and resiliency. The problem is that these systems are so complex and costly and have so many stakeholders and moving parts that we don't have all the detailed information, analytics and leverage needed to identify and effect useful changes.

Examples:

- Use less energy to use less water (and vice versa) – more energy-water data and analysis needed
- Use more decentralized renewables – we still don't have cost-effective energy storage technology nor the analytics, flexible supply- and demand-side assets, and operational tools to maintain reliability consistently at reasonable cost in high-penetration grids
- Do more net-zero buildings and microgrids – these are feasible but hand-crafted and costly, and they lean on the grid at times and impose non-trivial costs on other energy actors and customers.

Selected sources

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- Institute for Policy Studies for NARUC, "Utility Interdependencies," April 2005
- NIAC, "A Framework for Establishing Critical Infrastructure Resilience Goals," October 2010
- NERC, "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," June 2010
- NERC, "Severe Impact Resilience: Considerations & Recommendations," May 2012
- Rinaldi, Peerenboom & Kelly, "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies," IEEE Control Systems Magazine, December 2001