

US ENERGY INFRASTRUCTURE



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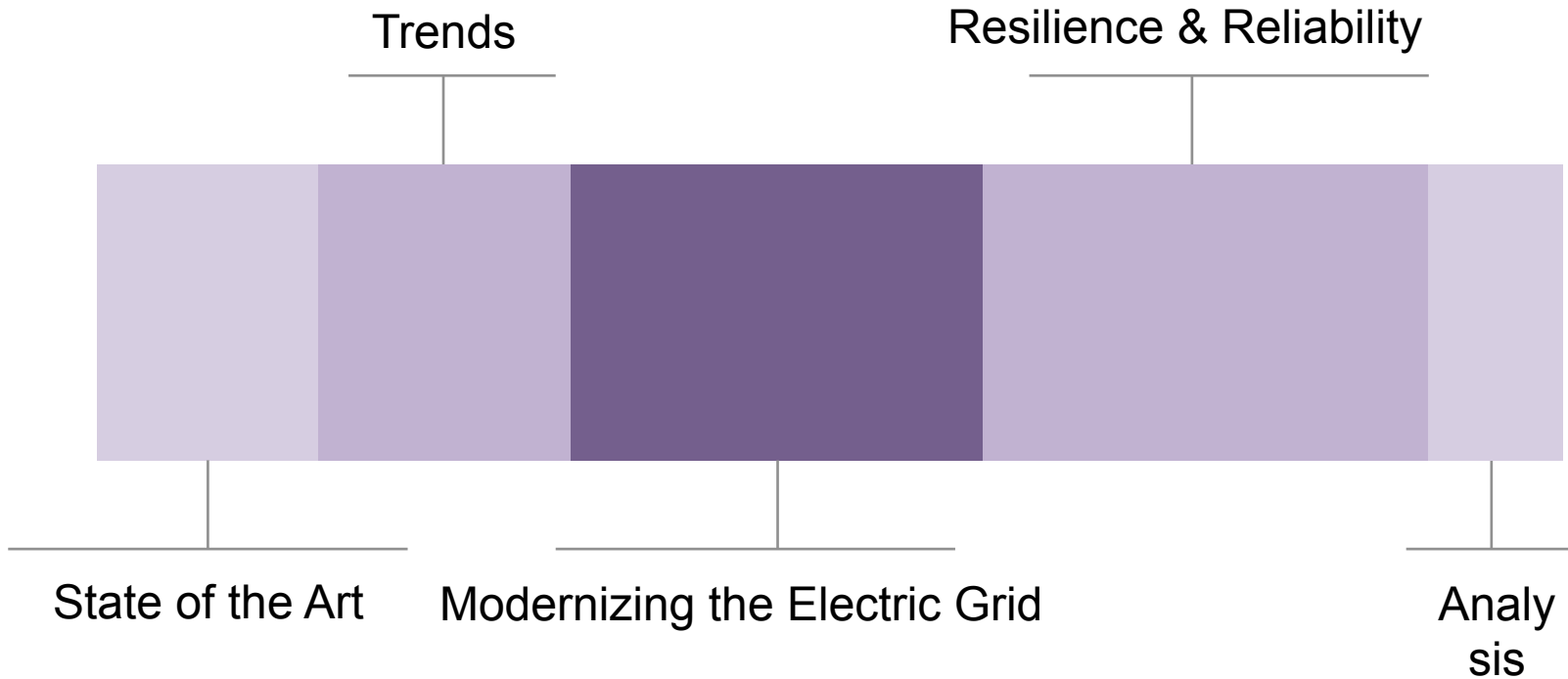
**G2 in
Chemistry**

**MSc in
Sustainable
Energy
Futures**

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2015**

PRESENTATION STRUCTURE

Talk roadmap.



Part 1: State of the Art

What do we have?



Transmission, Storage & Distribution

The infrastructure that links energy supplies, energy carriers, or energy by-products to immediate and end-users.

What do we have?

Electric Grid

19k

Generators

Making us
SIXTH
In the world
(Per capita)

6.3 million

Miles of distribution lines

(compare to 4 million mi. of roads¹)

Natural Gas & Oil Pipelines

2.6 million

Miles of pipelines

(0.3 million are dedicated to natural gas²)

Railways

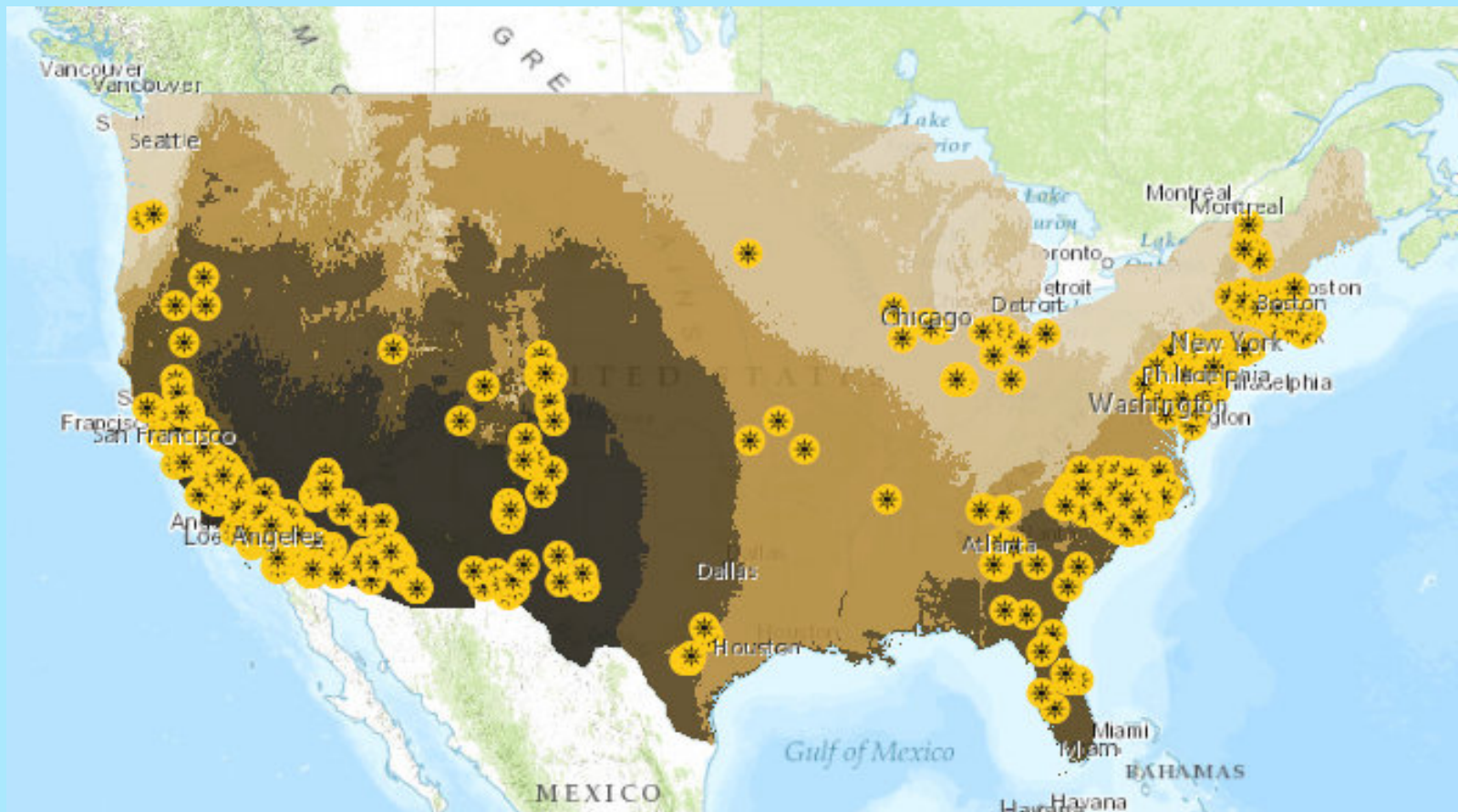
140

thousand miles Handling:
crude &
refined
petroleum,
LNG, coal

-- This all employs 1 million people --

U.S. Energy Mapping System

A superior way to procrastinate



Solar Power Plant

2.19 to 4.34

Photovoltaic Solar Potential



5.93 to 7.03 kWh/m²/Day PV Solar Potential



5.21 to 5.92



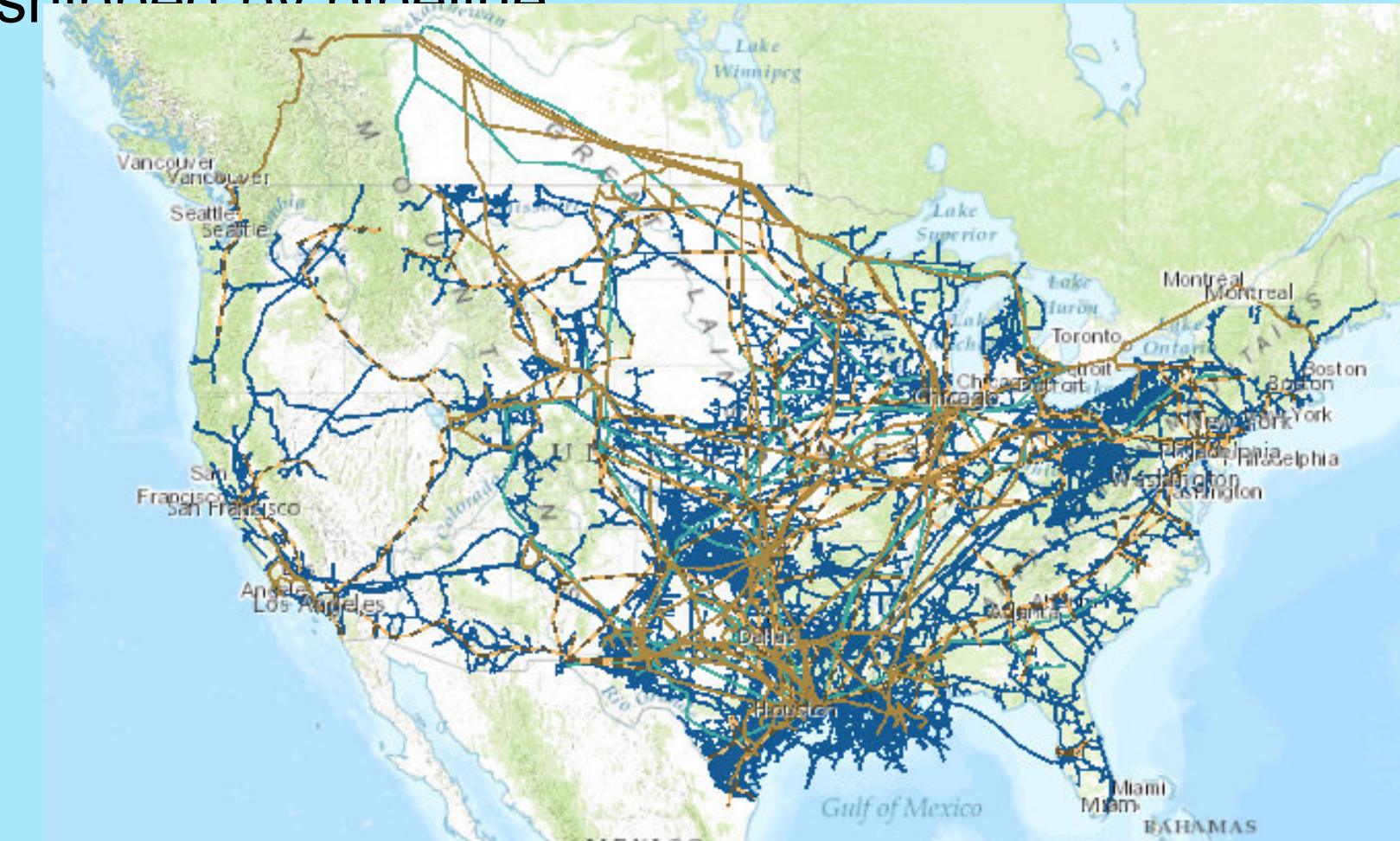
4.78 to 5.2



4.35 to 4.77

Us OIL infrastructure

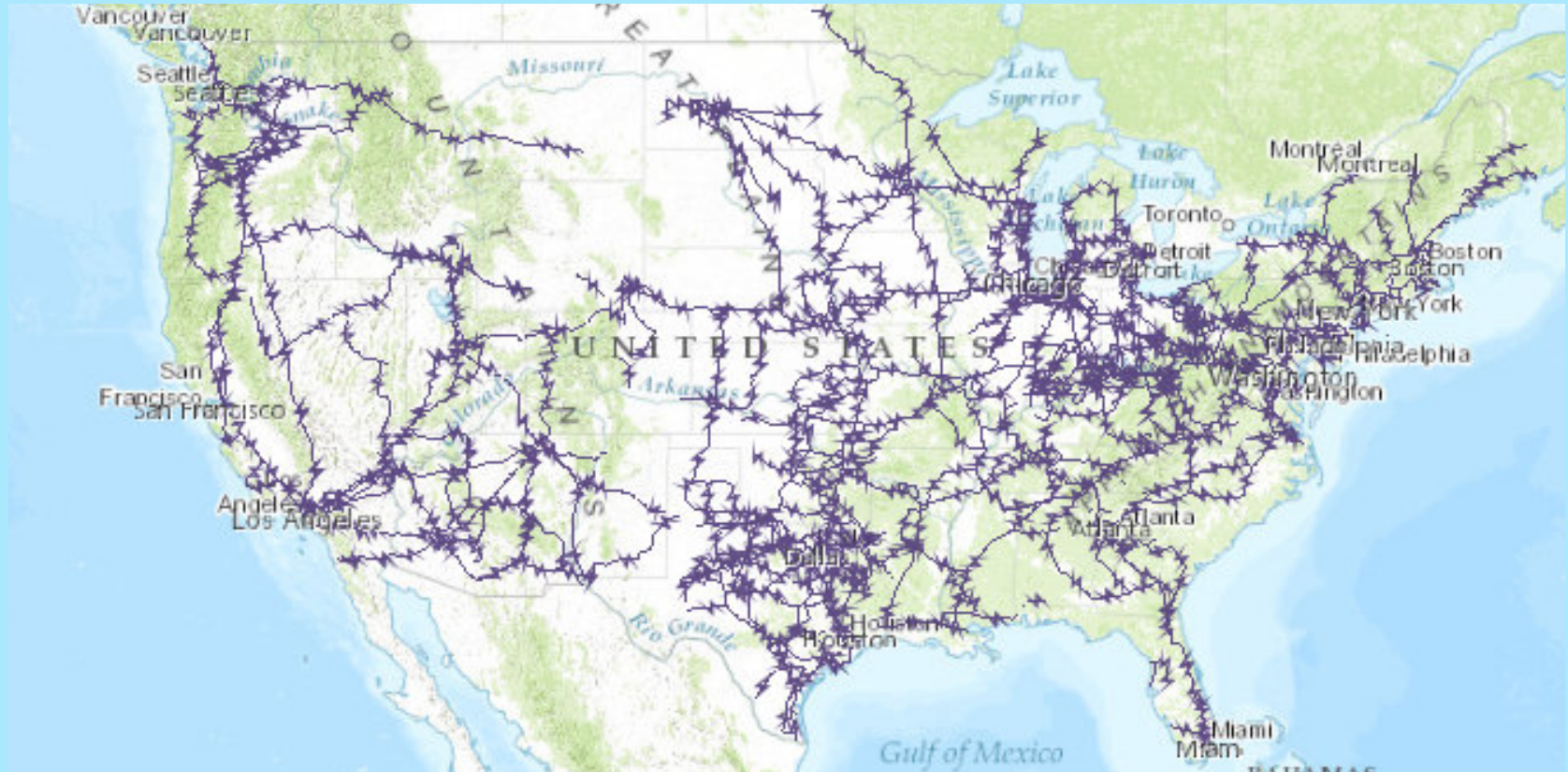
70% of crude oil and petroleum products are shipped by pipeline



- Crude Oil Pipeline (z)
- Petroleum Product Pipeline (z)
- HGL Pipeline (z)
- Natural Gas Inter/Intrastate Pipeline (z)

Us GRID infrastructure

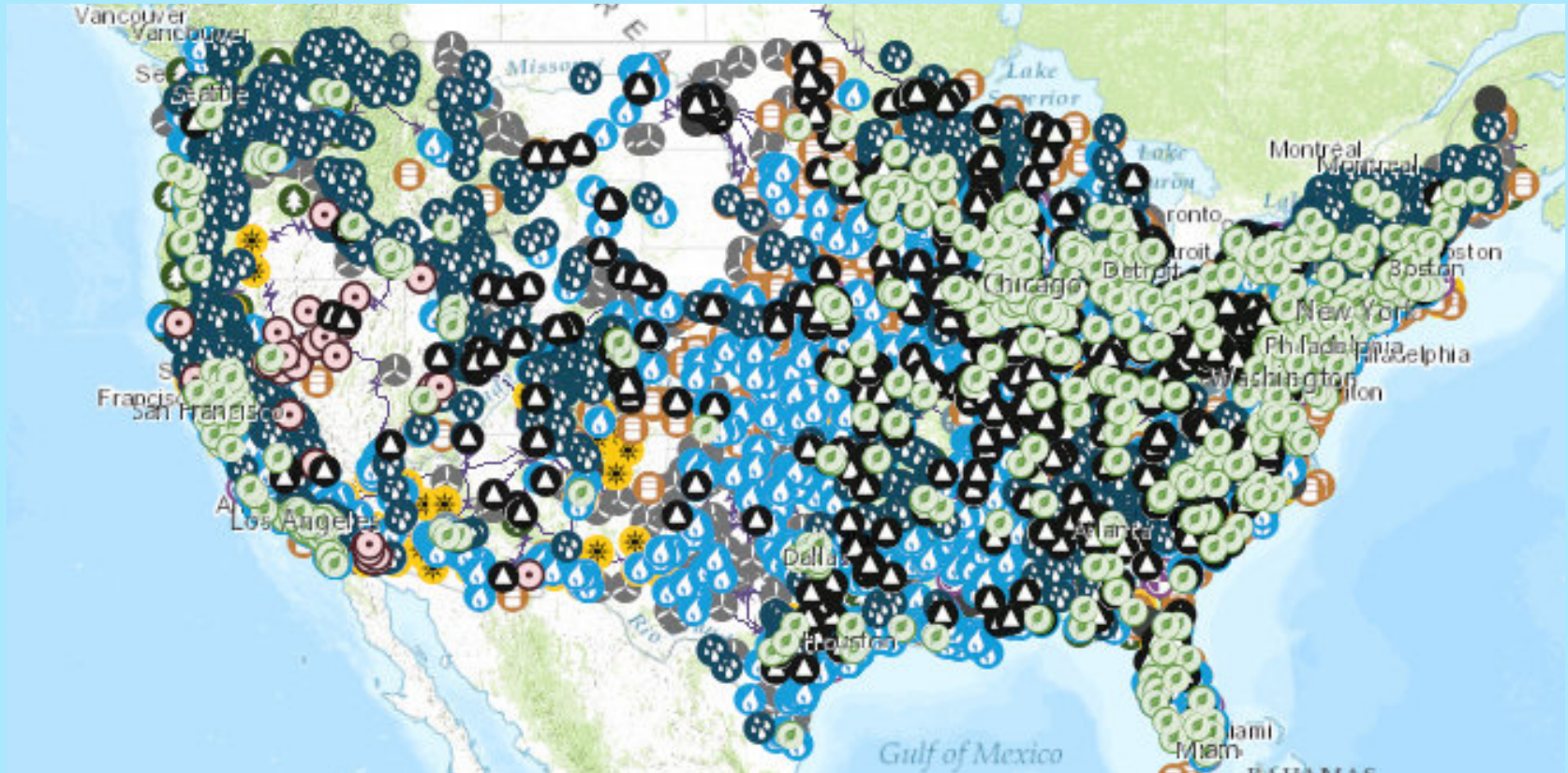
200,000 miles of transmission lines



— Electric Transmission Line ($\geq 345\text{kV}$) (z)

Us GRID infrastructure

200,000 miles of transmission lines



Biomass Power Plant	Other Power Plant	Wood Power Plant
Coal Power Plant	Other Fossil Gases Power Plant	Electric Transmission Line (≥345kV) (z)
Geothermal Power Plant	Petroleum Power Plant	
Hydroelectric Power Plant	Pumped Storage Power Plant	
Natural Gas Power Plant	Solar Power Plant	
Nuclear Power Plant	Wind Power Plant	

Trends affecting TS&D choices

PART 2

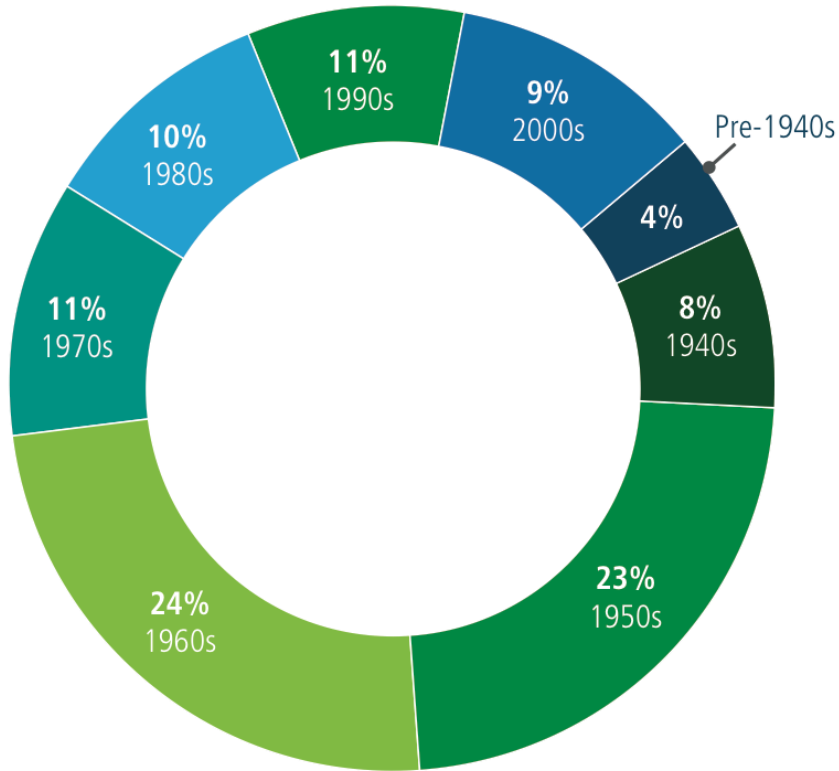
Trend #1: Aging infrastructure, changing requirements

“

*aging, inefficient, congested,
and incapable of meeting the
future energy needs of the
information economy without
significant operational changes
and substantial public-private
capital investment*

- US DOE, 2003

”



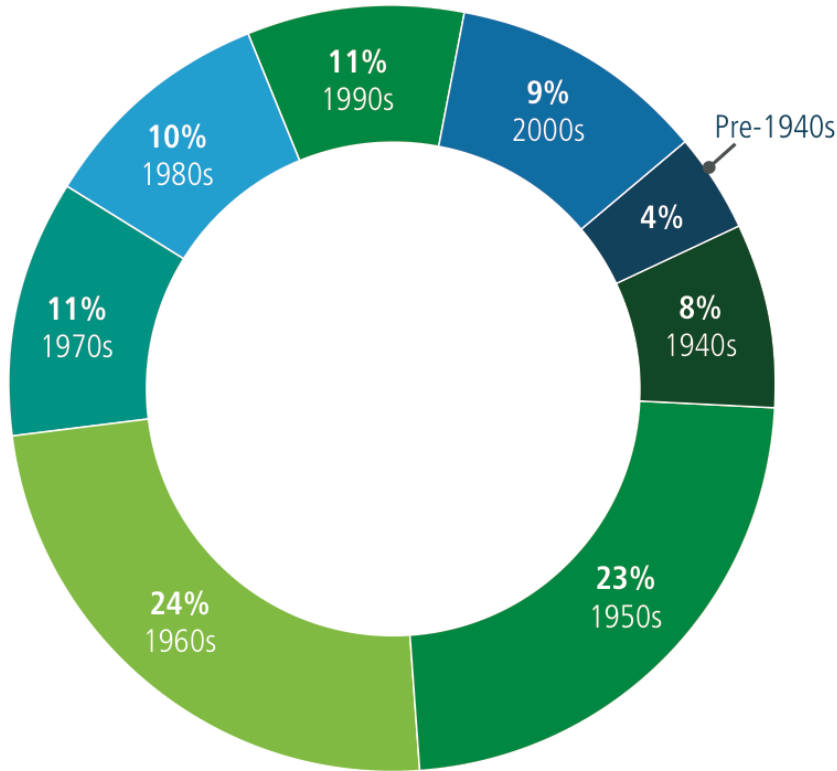
Age by decade of U.S. gas transmission and gathering pipelines⁴

SHINY

NEW

equipment

Trend #1: aging infrastructure, changing requirements



Age by decade of U.S. gas transmission and gathering pipelines⁴

- We need to replace the 50% of NG pipelines built in the 1950's and 1960's, to the tune of \$270 billion
- We haven't kept pace with changes in volume and geography of oil/gas production

-
- FFs compete w/ transport for food and fuel

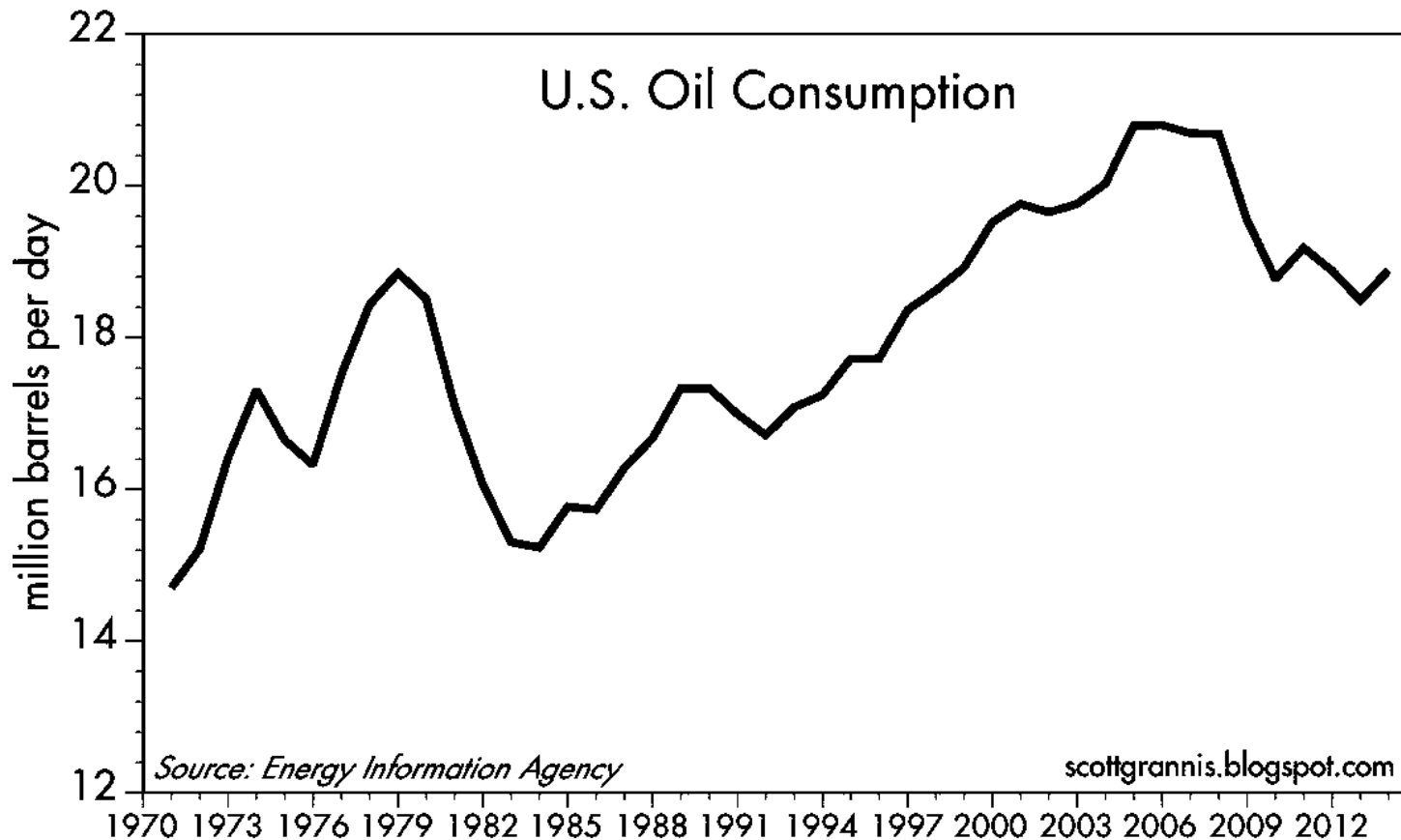
Trend #2: increased oil & natural gas

- Inc'd 35% between 2011-2013. US is now the largest combined producer of oil and natural gas⁴
- Oil not coincide w/ existing pipelines (e.g. North Dakota)
 - Reverse flows
 - Convert NG to oil lines
 - Move oil by truck, barge, rail
- Shale gas: same story⁴. 70% net increase in proved gas reserves in just PA & WV



Trend #3: decrease in oil consumption

Why? Better fuel economy, More HEV & EV, Biofuels:
Ethanol is ___ vol % of US gasoline, Economic recession^{4,5}



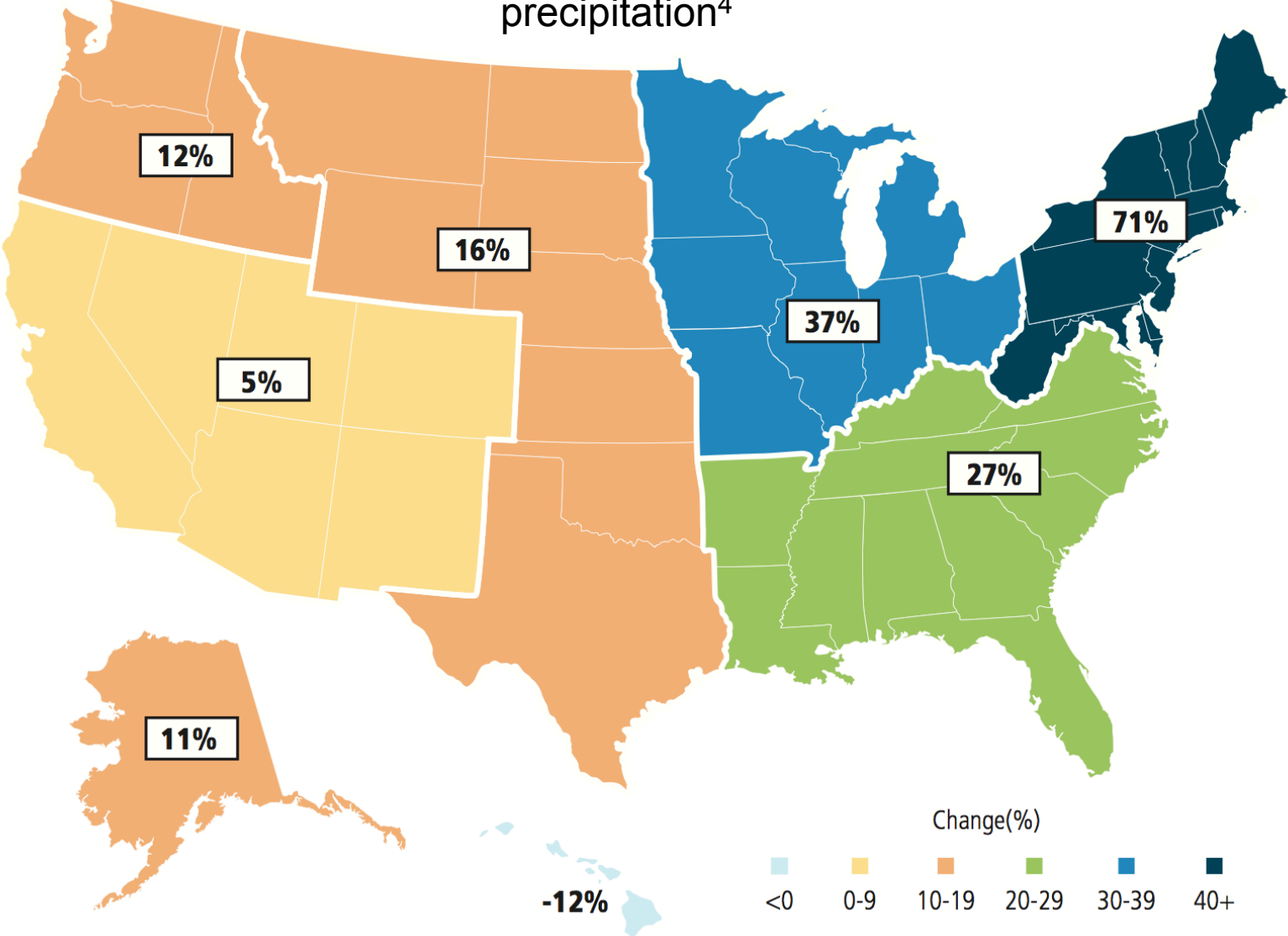
Trend #4: increase in petroleum products & natural gas exports

- **Petroleum** becomes: gasoline, distillate, jet fuel and hydrocarbon gas liquids, which ship from Gulf of Mexico
- **NG** can serve growing demand in Mexico



Trend #5: climate change

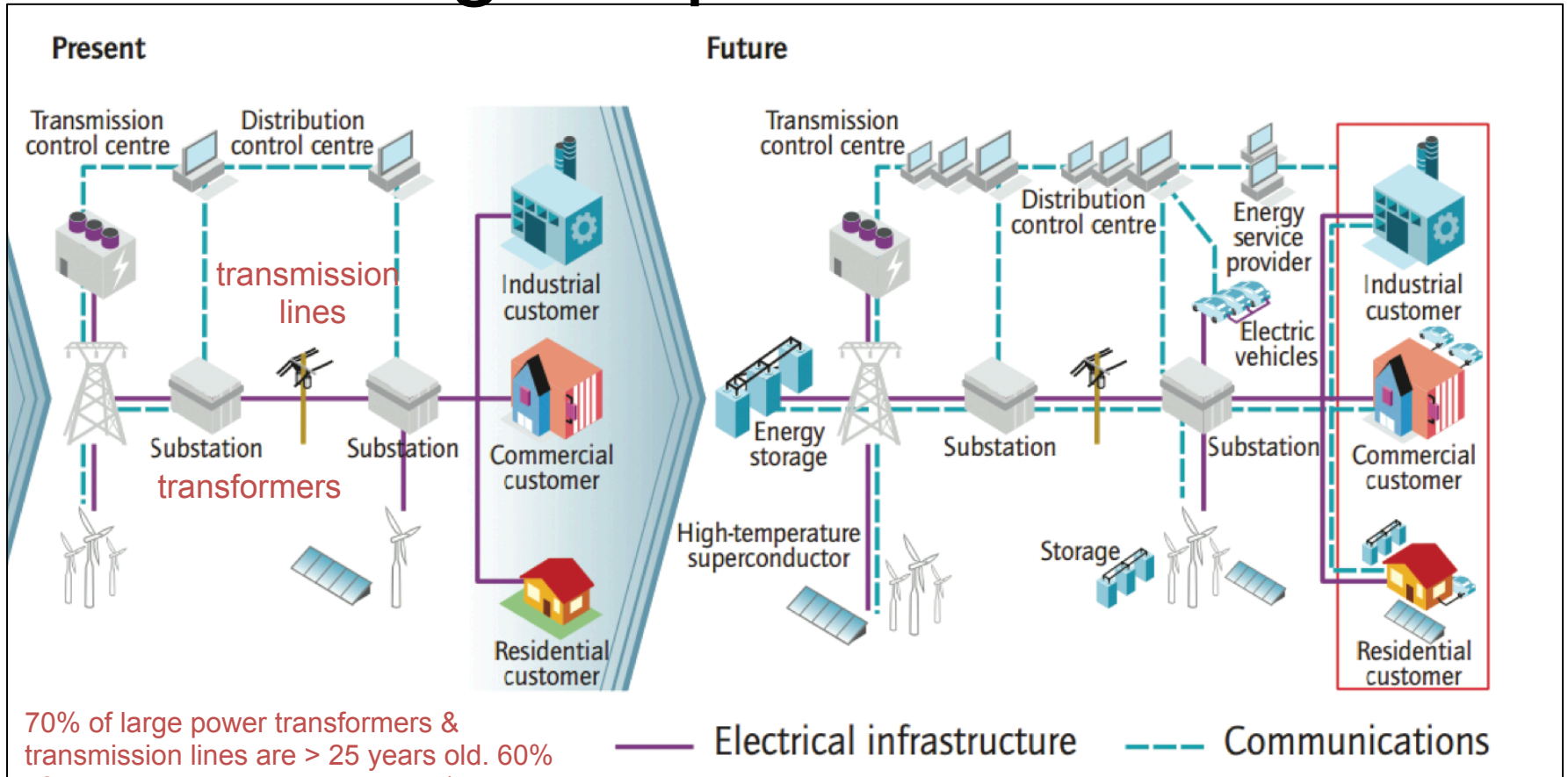
Observed change in very heavy precipitation⁴



Modernizing the electric grid

PART 3

Us Electric grid operation



Present:

- Hierarchical control structures
- Large scale generation remote from consumers
- Limited energy storage
- Passive loads
- Minimal feedback

Future:

- More distributed control
- Two-way flows of electricity & information
- More energy storage
- “Prosumers”
- Built-in cybersecurity protections

TRANSMISSION SYSTEM

TECHNICAL CHALLENGES

In Aug 2003, the Northeast Blackout took 4 days to restore, with 50 million people affected.

WHY?

**Different power flows
than system built for**

**Congestion can't be detected
b/c not enough sensors**



PHASOR MEASUREMENT UNIT (PMU)

Detects grid stress

1300

PMUs deployed in 2009

But we still need predictive capabilities b/c humans can't respond to all events.

DISTRIBUTION SYSTEM

TECHNICAL CHALLENGES



90% of outage minutes originate on distribution system

why?

- Large # of connections (145 mil. customers, 6.3 mil. miles distribution lines)
- Most expensive part of system
- Most difficult to upgrade

Causes of disruption

What is the leading cause of electric grid disturbances in the US?

Extreme temperatures

Hurricanes

Earthquakes

Drought

Wildfires

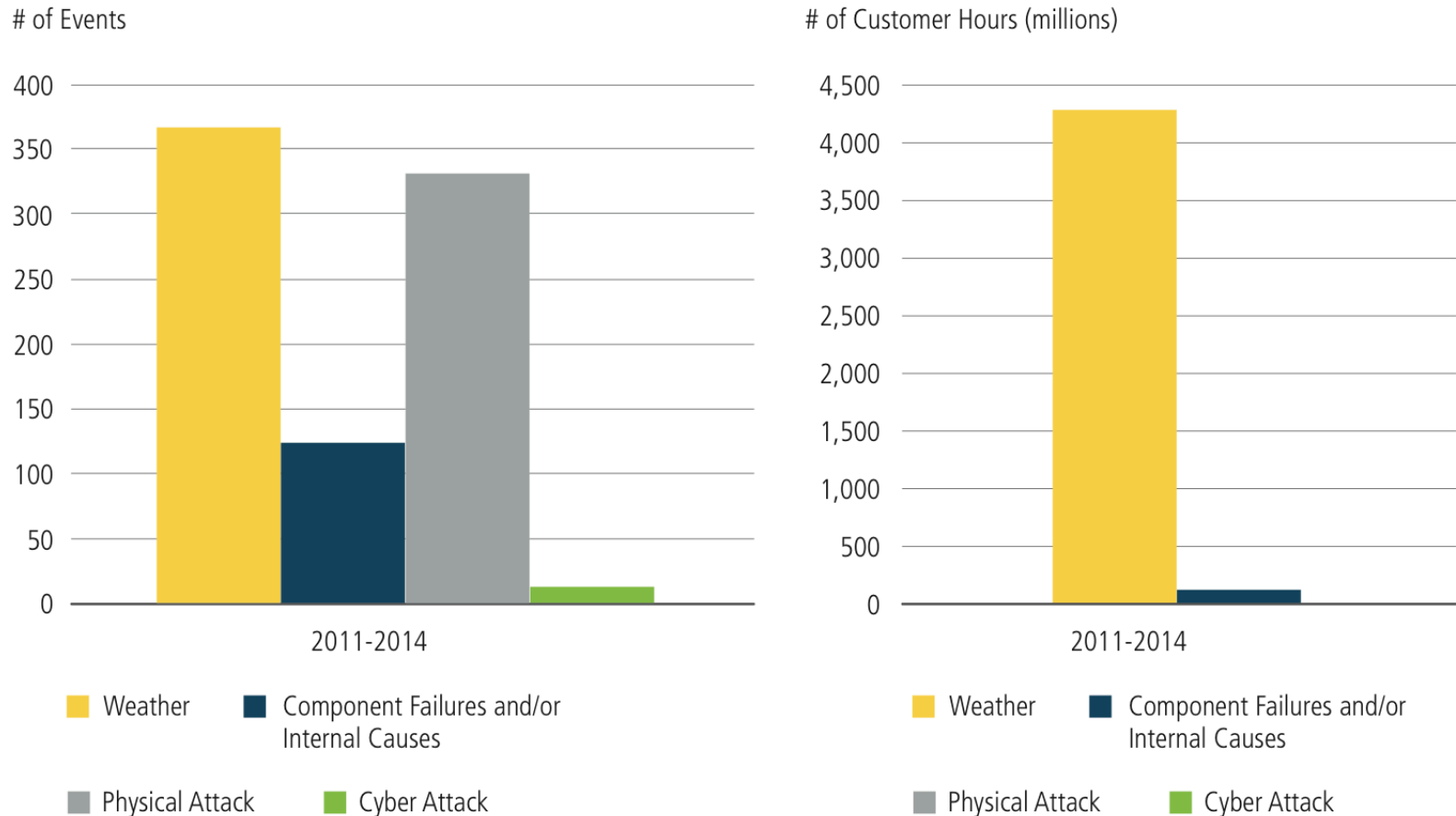
Flooding

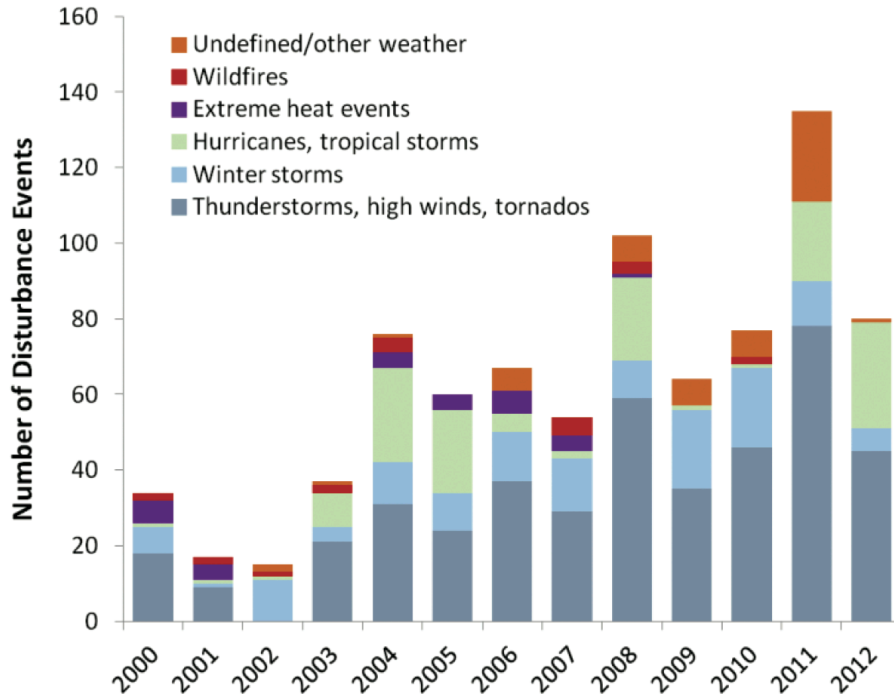
Bears, oh my!

Causes of disruption

What is the leading cause of electric grid disturbances in the

Figure 2-3. Left Figure: Electric Disturbance Events, January 2011–August 2014; Right Figure: Customer Hours Affected by Electric Disturbance Events, 2011–August 2014¹⁸

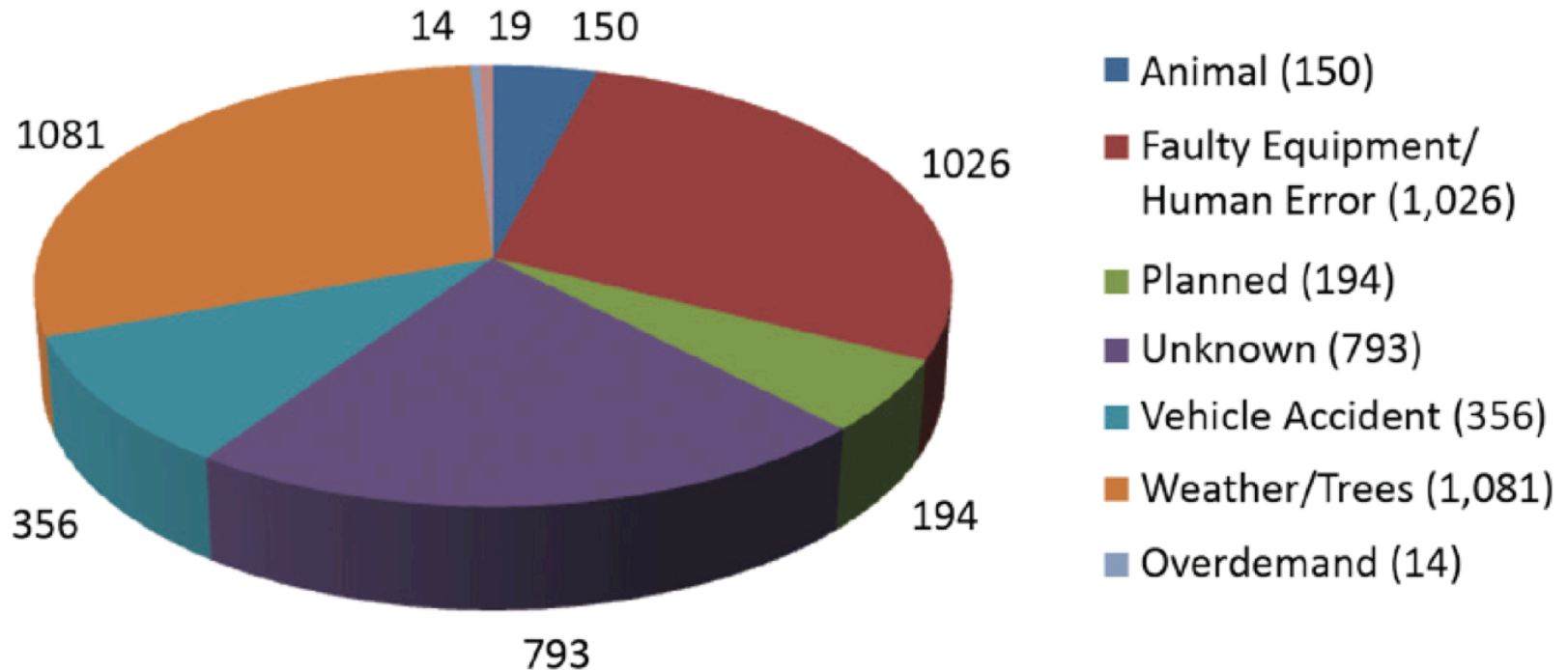




Disruptions
are
Increasing

Trends show steadily increasing weather-related grid disruptions, with major disruptions every few years.⁴

But why?



2014 Power Outages. The highest number of unplanned outages are caused by weather, faulty equipment, and unknown circumstances.⁶

Grid of The future



- Develop/analyze new grid architecture⁴
- Develop advanced software, models, tools using data from PMU's to provide robust “
- Material innovations for high-power, high-frequency, and high-reliability grid applicatio
- Advanced “smart” technologies
- Control systems that can survive a physical incident or cyberattack

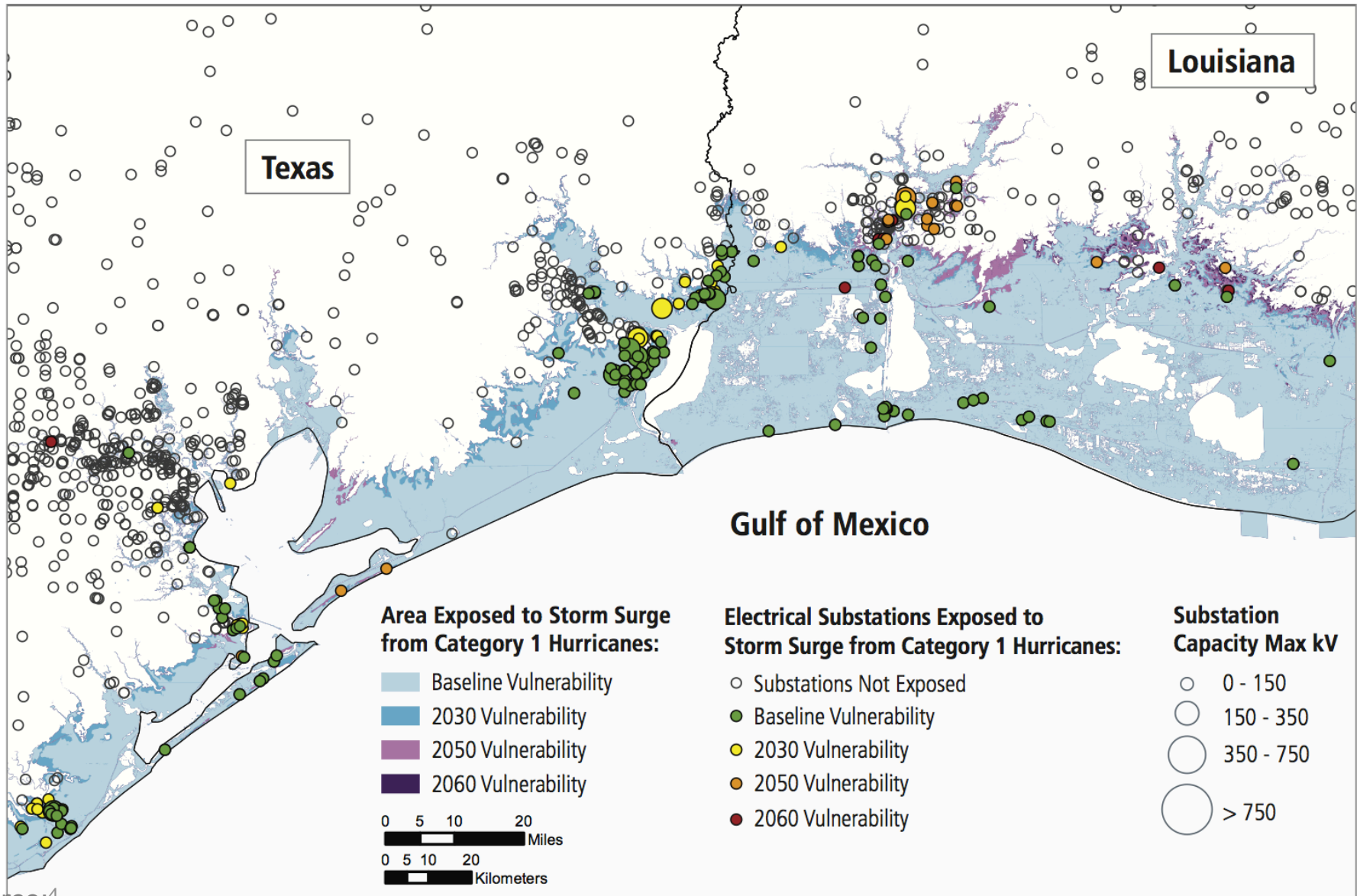
Resilience & reliability

PART 4

Table 2-1. Probability and Severity of Hurricane Damage to Liquid Fuels and Natural Gas Infrastructure^{13, d}

Infrastructure	Tropical Storm (39-73 MPH)		Hurricane Cat 1-2 (74-95 MPH, 96-110 MPH)		Hurricane ≥ Cat 3-5 (111-129 MPH, 130-156 MPH, >157 MPH)	
	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage
Loss of Electrical Power	Med	Significant	Med-High	Major	High	Catastrophic
Gulf of Mexico Platforms	Low	Insignificant	Med-High	Major	Med-High	Major
Pumping/Compressor Station	Low	Insignificant	Med	Significant	Med-High	Major
Pipelines	Low	Insignificant	Low-Med	Interrupting	Med-High	Major
Rail	Low	Insignificant	Low-Med	Interrupting	Med-High	Major
Ports	Low	Insignificant	Med-High	Major	High	Catastrophic
Crude Tank Farm	Low	Insignificant	Low-Med	Interrupting	Med	Significant
Refineries	Low	Insignificant	Med	Significant	Med-High	Major
Natural Gas Plants	Low	Insignificant	Med	Significant	Med-High	Major
Product Storage Terminals	Low	Insignificant	Low-Med	Interrupting	Med-High	Major
Propane Tanks	Low	Insignificant	Low	Insignificant	Low	Insignificant
Underground Storage	Low	Insignificant	Low	Insignificant	Low	Insignificant
LNG Terminals	Low	Insignificant	Med	Significant	Med-High	Major
Local Gas Distribution	Low	Insignificant	Med	Significant	Med-High	Major
Filling Stations	Low	Insignificant	Med	Significant	Med-High	Major
SPR/NEHHOR	Low	Insignificant	Low-Med	Interrupting	Med	Significant

Coastal grid is vulnerable to climate change



managing disruption

Not.
Sophisticated

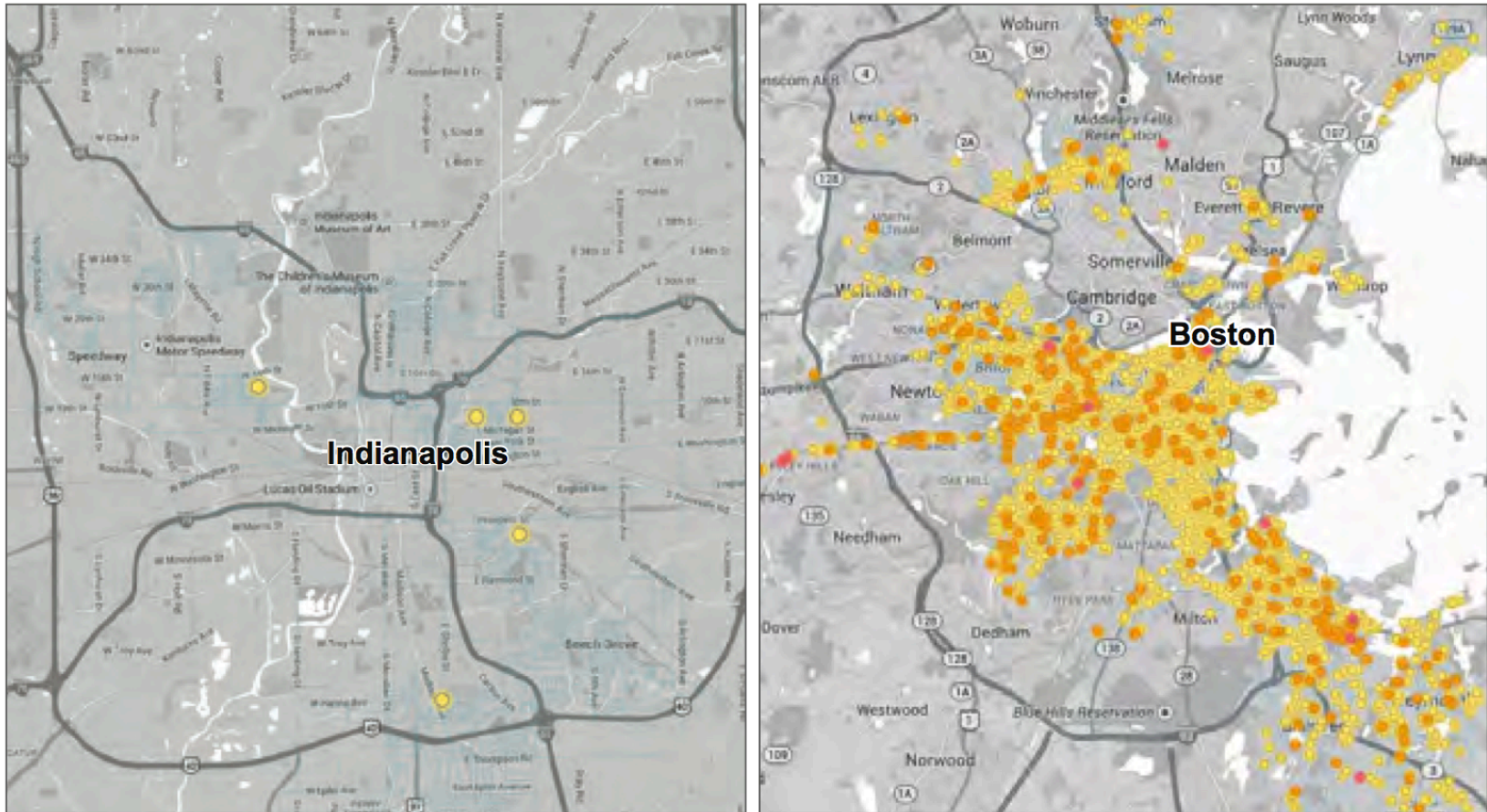


- **Building physical barriers**
 - **Building moving equipment**
 - **Building backup systems**
 - **Building reinforced poles**
 - **Burying lines underground**
 - **Vegetation management (tree trimming)**
- **Smart meters**
 - **Automated switching devices for recovery from disruption**

Ex: 90% of Hurricane Sandy resilience project funds were spent on bulk infrastructure changes & add'l maintenance rather than upgrading infrastructure components

Takeaway: Incorporation of new technology is happening slow

Figure 2-6. Methane Emissions from Natural Gas Distribution Systems in Indianapolis and Boston, 2013^{72, p. 9}



Emissions Rate

- **Low** (The same near-term climate impacts as driving a car between 100 and 1,000 miles everyday. Rate: 700 to 9,000 liters/day.)
- **Medium** (The same near-term climate impacts as driving a car between 1,000 and 9,000 miles everyday. Rate: 9,000 to 60,000 liters/day.)
- **High** (The same near-term climate impacts as driving a car more than 9,000 miles everyday. Rate: More than 60,000 liters/day.)

Resilience: what happens now?

- Develop data, metrics, and framework for energy infrastructure resilience/reliability/security
- Pipeline replacement and maintenance programs for natural gas distribution

*The estimated cost⁴ for this program is \$2.5 billion to \$3.5 billion over 10 years.
(\$250 million/year)*



150 trillion Ritz crackers



How big is the DOE's budget for TS&D?

270 \$million

For grid & resilience.

Out of:

10.7 \$billion

DOE annual budget

Compare
with...

30 \$billion

NIH annual budget

500 \$billion

DOD annual budget

Budgeting for resilience & the grid

	FY'16\$
<i>Supporting DOE Programs</i>	10.7B
✓ Electricity Delivery and Energy Reliability	270M
✓ Energy Efficiency and Renewable Energy	2.72B
<i>Sustainable Transportation</i>	793M
<i>Renewable Energy</i>	645M
<i>Energy Efficiency</i>	1.03B
<i>Crosscutting Programs</i>	255M
✓ Fossil Energy	842M
✓ Indian Energy Policy and Programs	20M
✓ Nuclear Energy	908M
<i>Subtotal, Applied Energy</i>	<i>4.8B</i>
✓ Science	5.34B
✓ Advanced Research Projects Agency—Energy	325M
✓ Energy Information Administration	131M
✓ Energy Policy and Systems Analysis	35M
✓ International Affairs	24M
✓ Loan Programs	17M
✓ Power Marketing Administrations	82M

Bottom line:

- Money and politics cause improvements to be slow.
- Other things are important too. E.g. NIH, DOD

Summary



- New supply and demand trends (geographic, economic, social), new threats (climate, cyber), and approaching replacement horizons are causing the US energy infrastructure to change
- It's adapting only slowly, leading to disruptions, safety issues, and vulnerabilities
- Aside from political capital, new technology/devices and engineering tools (models, software) are needed to bring the grid up to speed.

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SOURCES

1. <http://www.fhwa.dot.gov/>
2. http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/index.html
3. <http://www.eia.gov/state/maps.cfm>
4. US Quadrennial Energy Review (2015).
5. EIA via Scott Grannis
6. US Quadrennial Technology Review (2015).
7. <http://energy.gov/budget-performance>