SAND2010-0286C

Smart Grid: Information Challenges

Shannon Spires
Sandia National Laboratories

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Part 1: Today's Grid

Part 2: Tomorrow's Grid

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Today's Grid

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Grid 101

"The North American Electric Grid is the most complicated machine ever devised by man"

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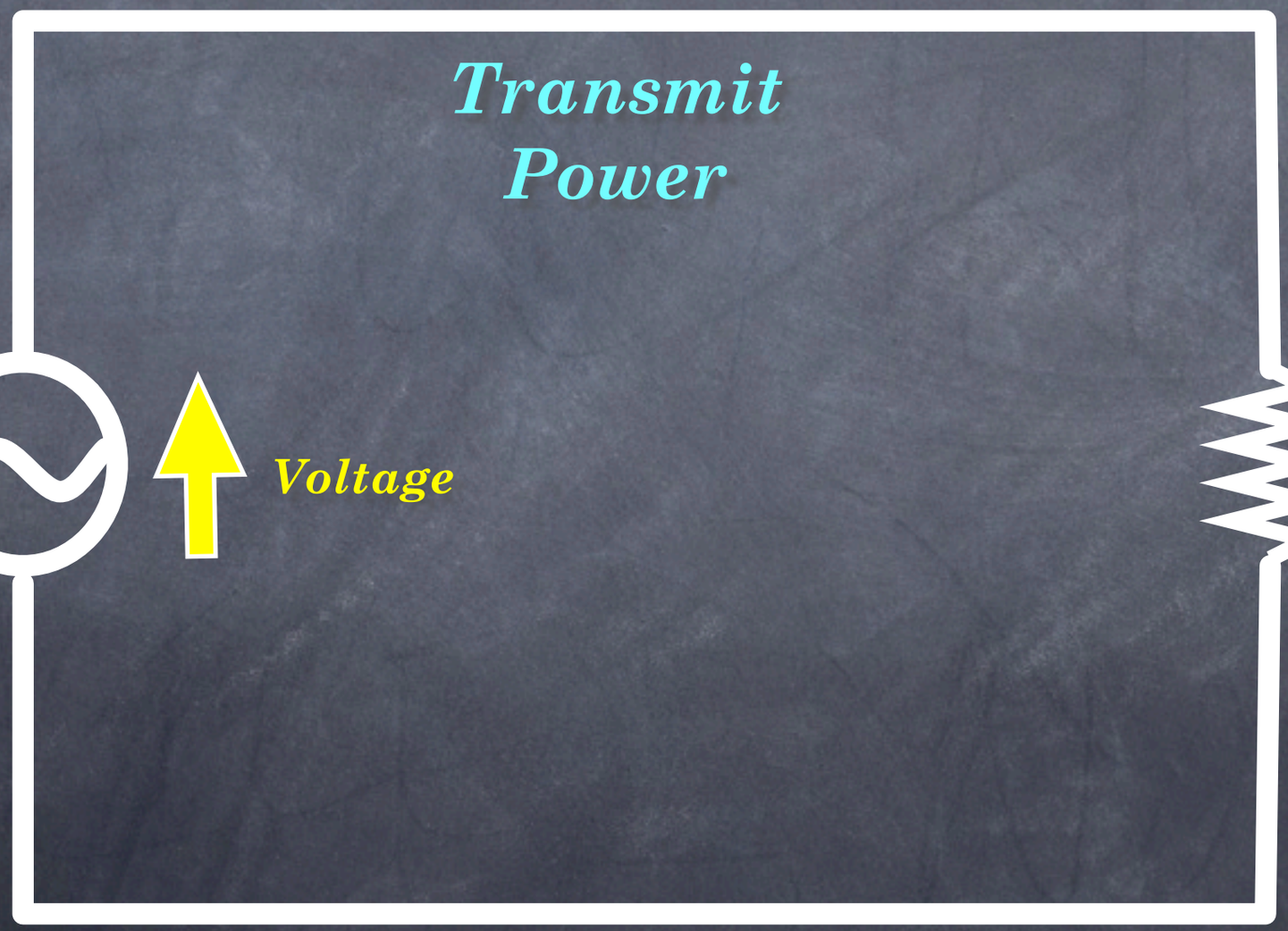
Grid 101



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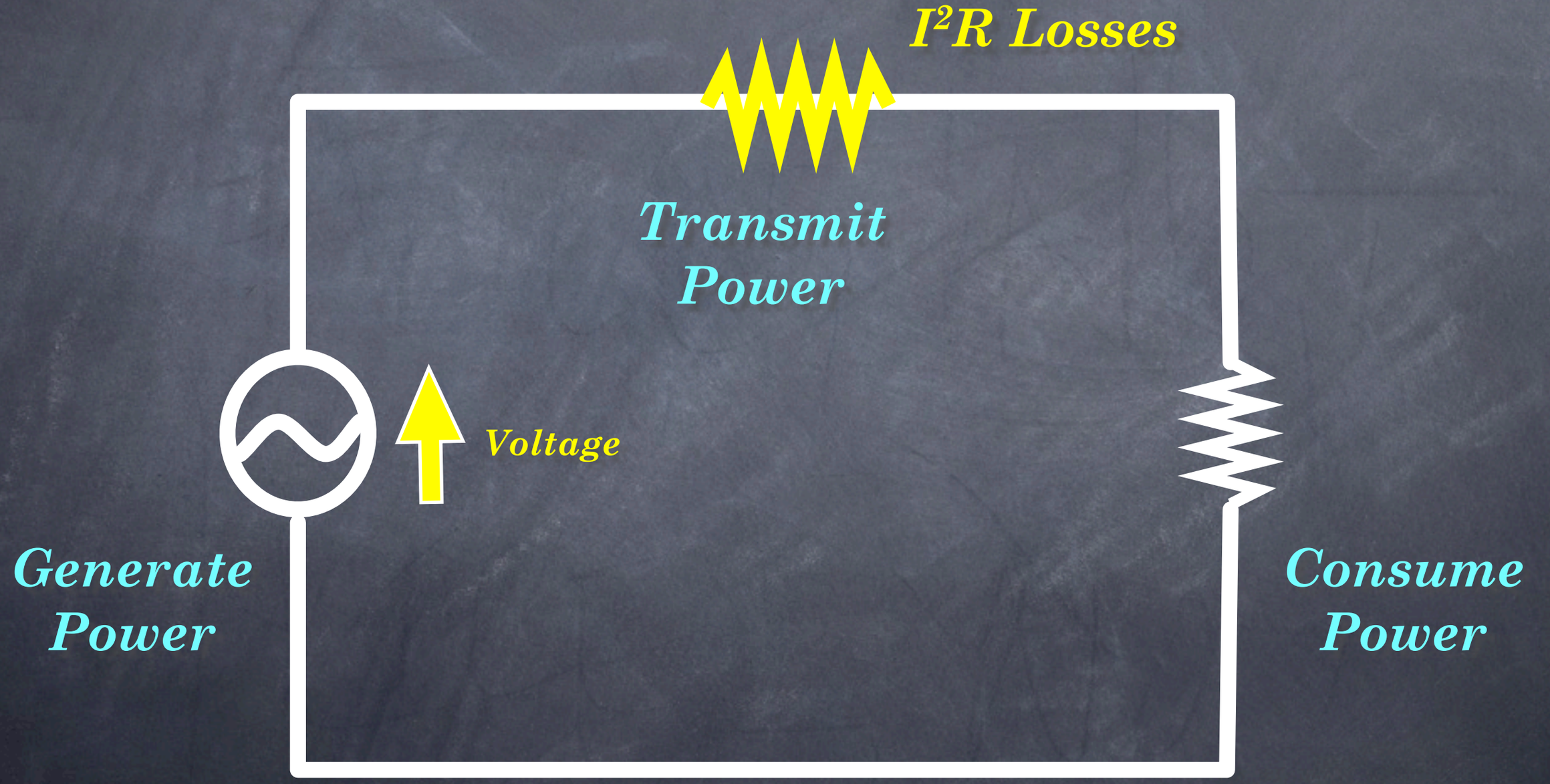
Grid 101



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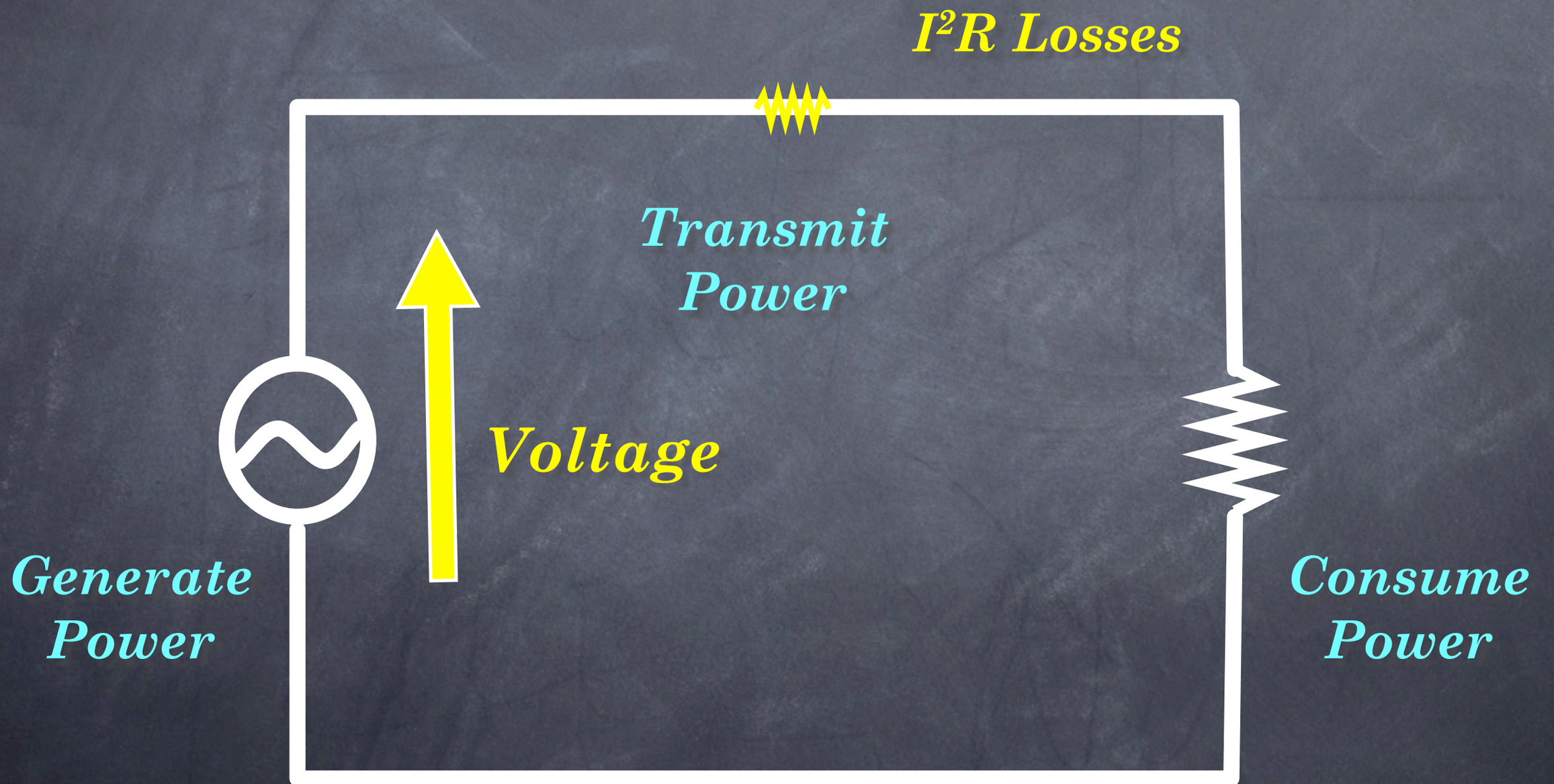

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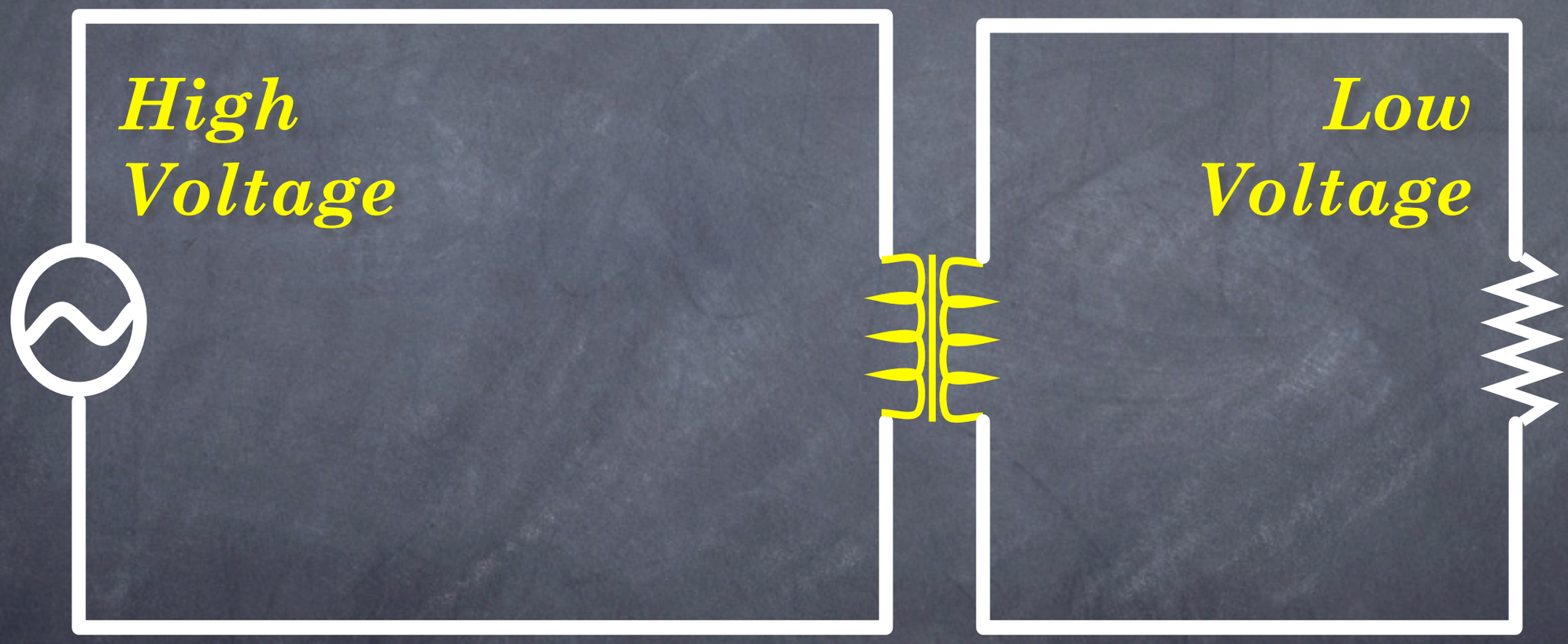

This is why our power is AC

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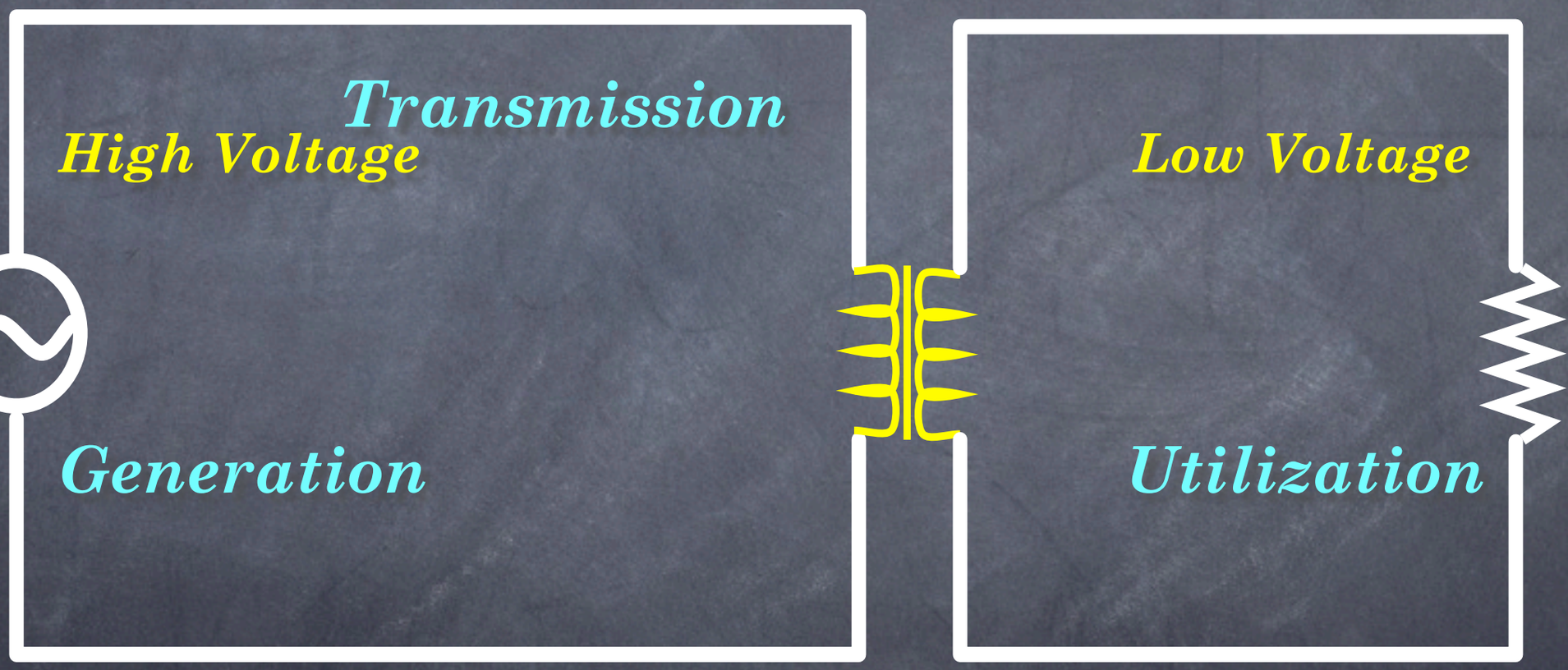
Grid 101



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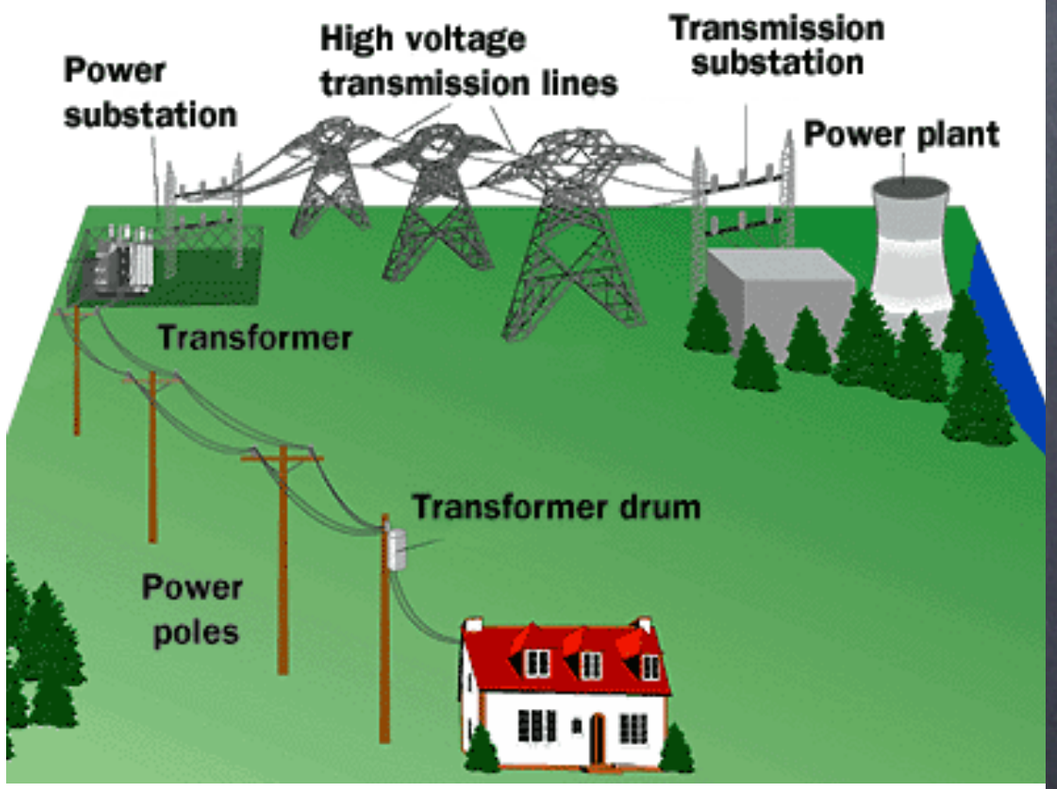
- Three major components
  - Generation (mostly centralized)
  - Transmission/distribution network
    - Lines, transformers, regulators, switches, …
  - Utilization (loads)
  - Storage (very little)
- Other physical components
  - Controls systems
  - Protection systems
  - Measurement
  - Communications



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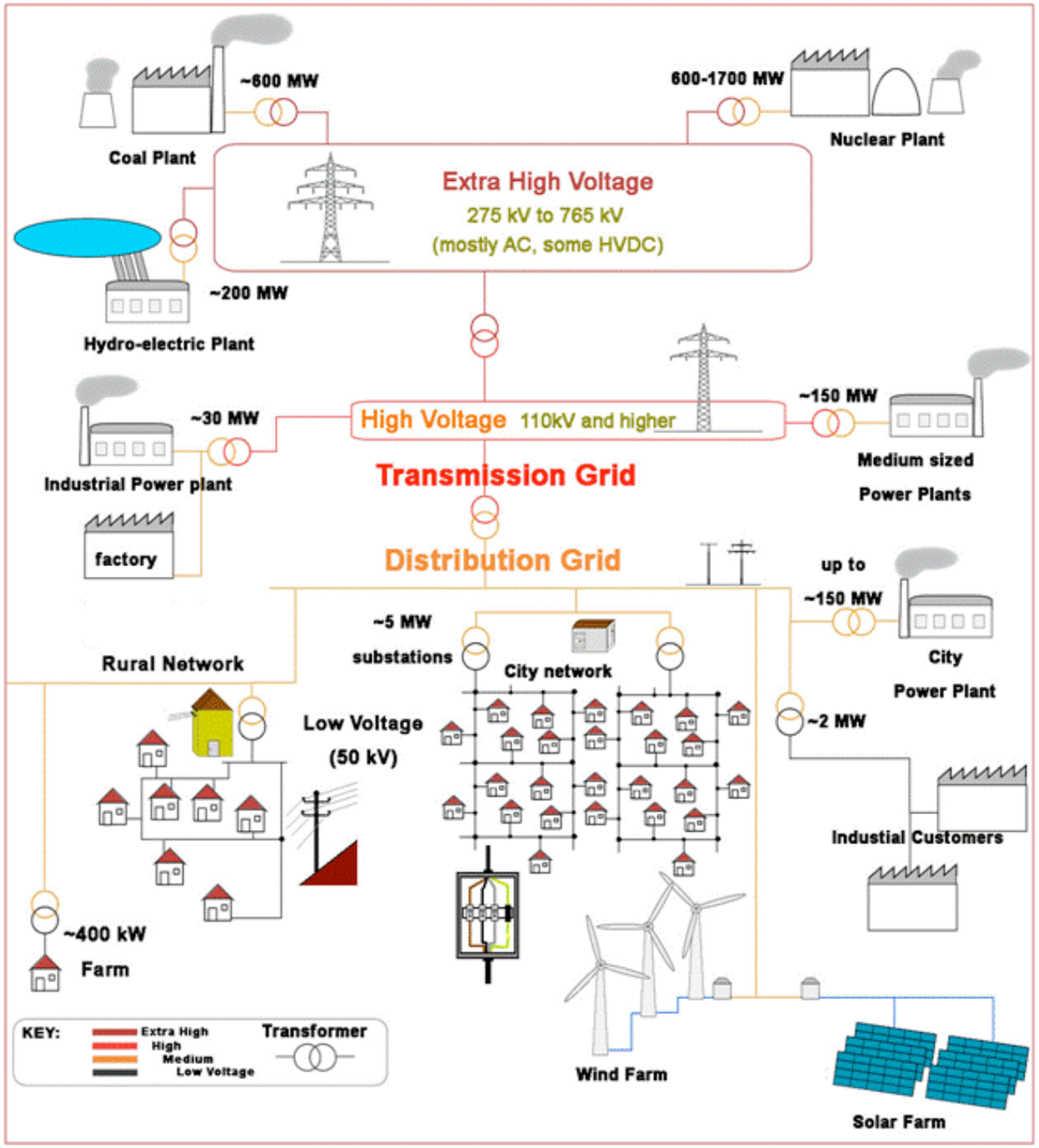
More Ramified



- Transmission System
  - Long-distance, Bulk power
  - Network
- Sub-Transmission System
  - Lower voltage
  - In/around cities
  - Network
- Distribution System
  - Down city streets
  - Radial
  - 3, 2 or 1 phase
- Residential/building
  - 120/240 V single phase or 480V three phase

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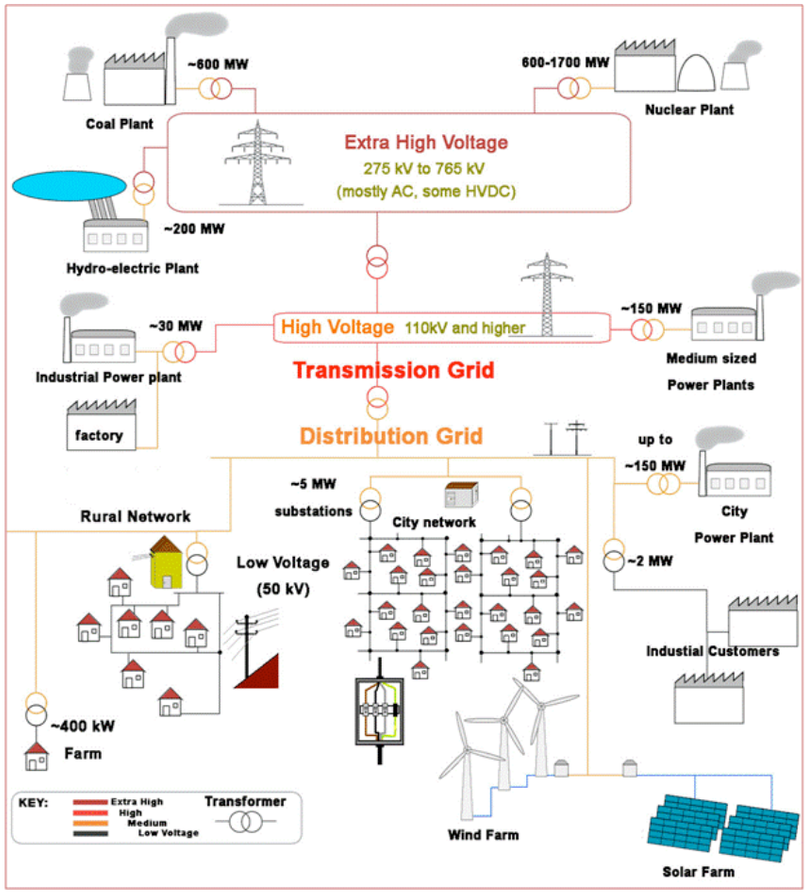
Control Regimes

More Control/Visibility



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Less Control/Visibility

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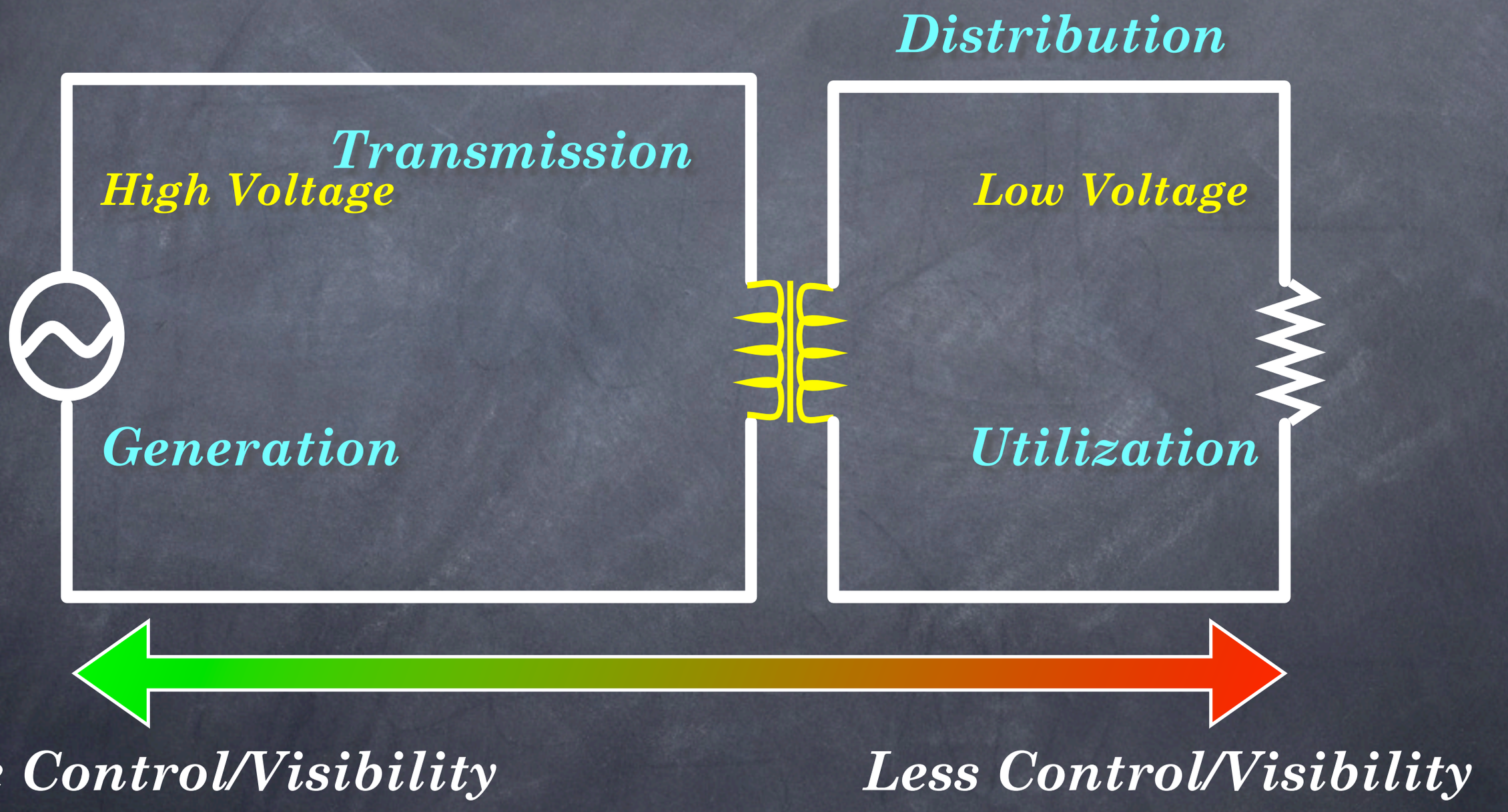
Control Regimes



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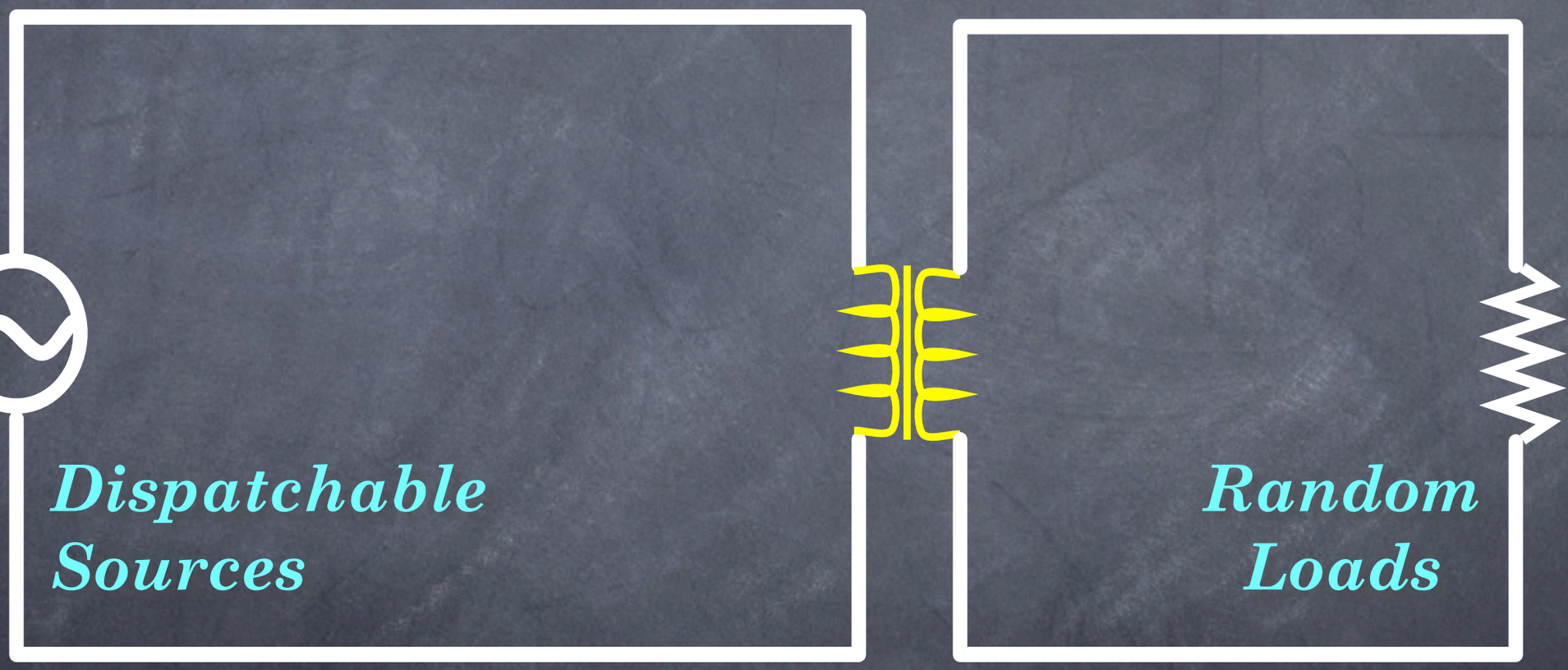
Grid 101



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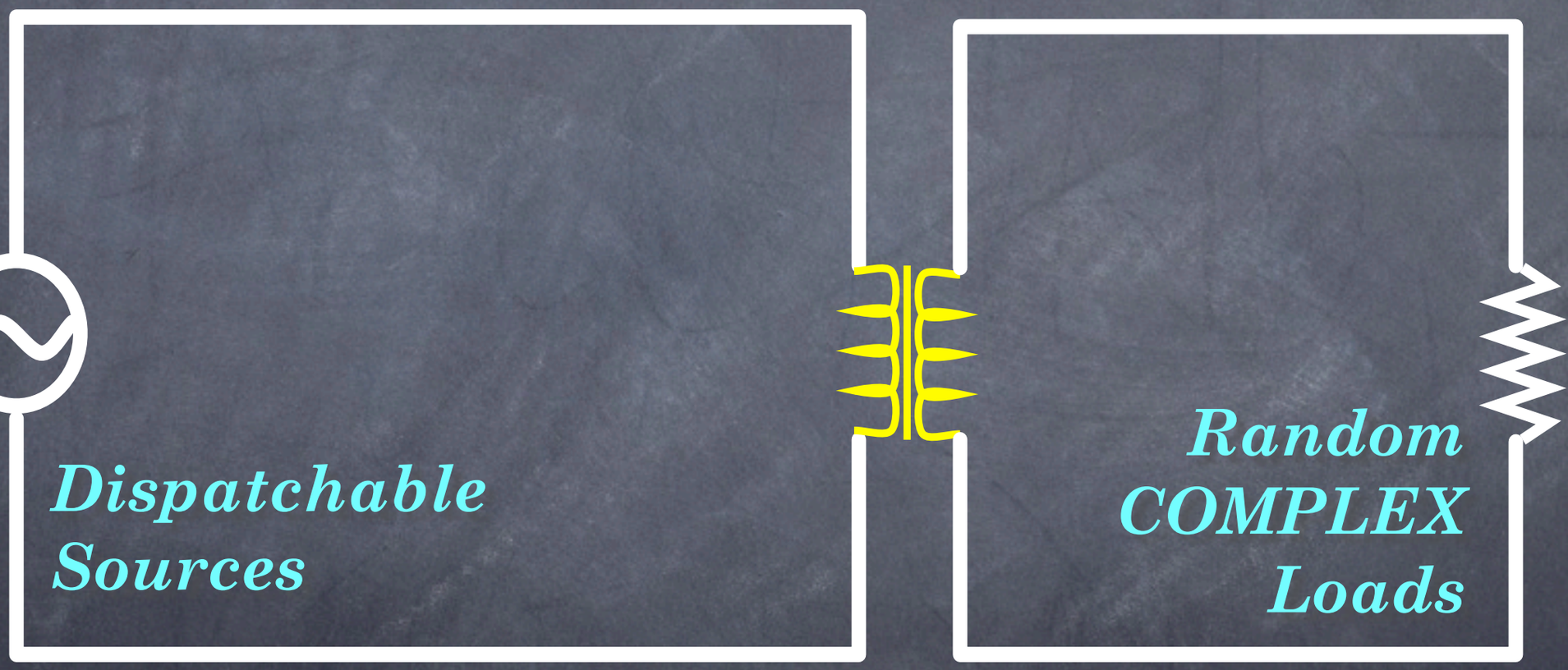
Grid 101



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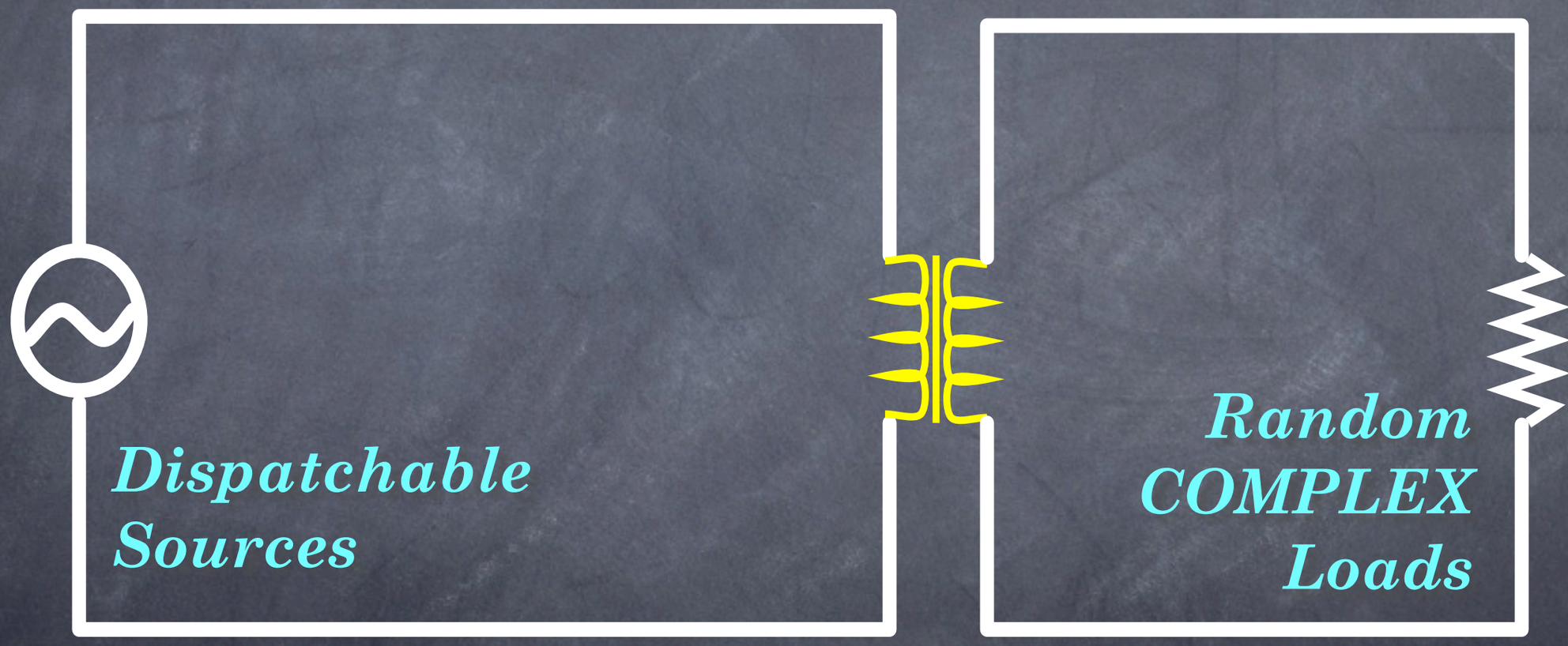

But our sources spew carbon, so we can't build new ones as load increases

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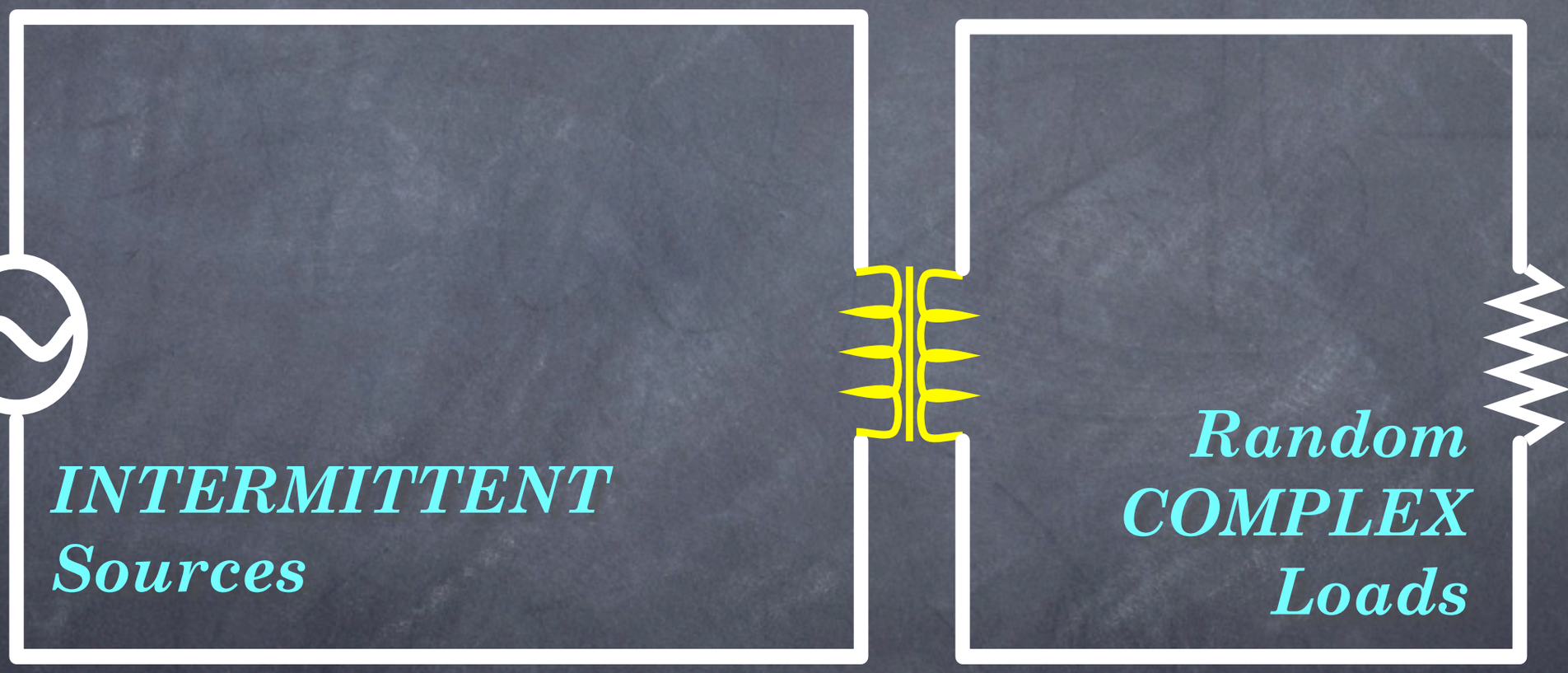
Grid 101



So we'll use renewable sources that are clean — but they're no longer dispatchable

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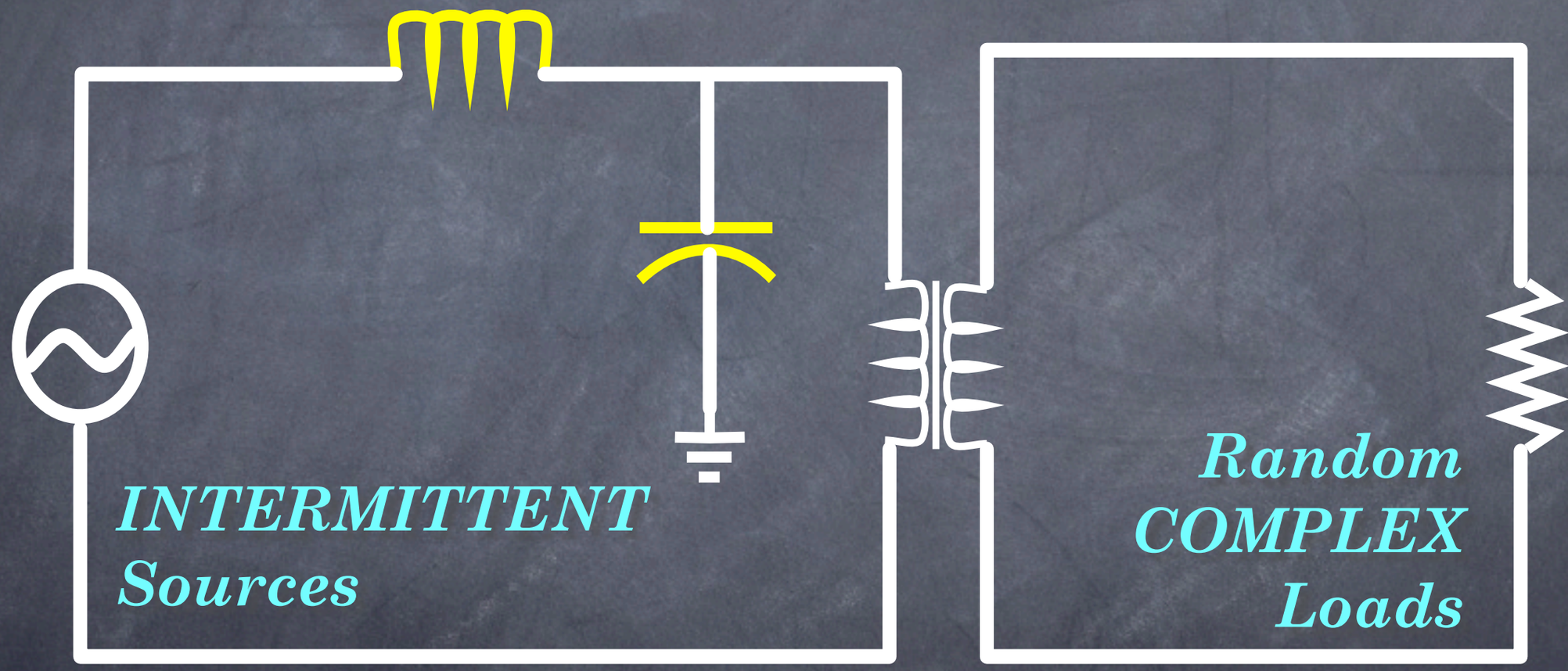
Lowpass Filter



Unfortunately, big energy storage elements necessary for the above are rare and expensive

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Visualizing The U.S. Electric Grid

The U.S. electric grid is a complex network of independently owned and operated power plants and transmission lines. Aging infrastructure, combined with a rise in domestic electricity consumption, has forced experts to critically examine the status and health of the nation's electrical systems.

About This Map »

Roll over the dots for detailed information about each power plant. Use the dropdown below to filter power plants by type.

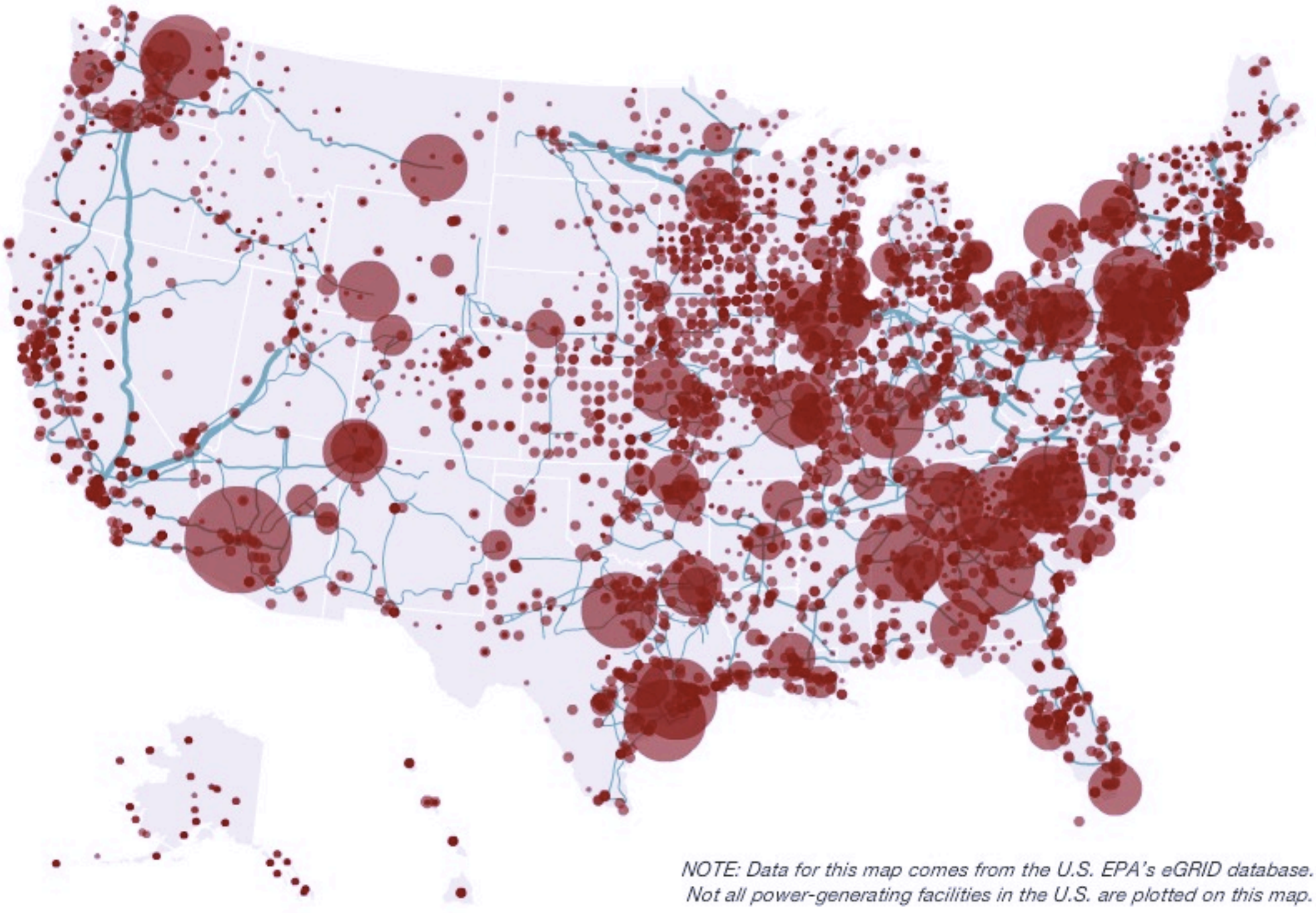
POWER PLANTS

All plants

Dots are sized with respect to each plant's annual net generation of power.

EXISTING LINES

Existing electric power grid



NOTE: Data for this map comes from the U.S. EPA's eGRID database. Not all power-generating facilities in the U.S. are plotted on this map.

Source: http://www.npr.org/templates/story/story.php?storyId=110997398

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THE GRID	SOURCES OF POWER	POWER PLANTS	SOLAR POWER	WIND POWER

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POWER PLANTS

Nuclear

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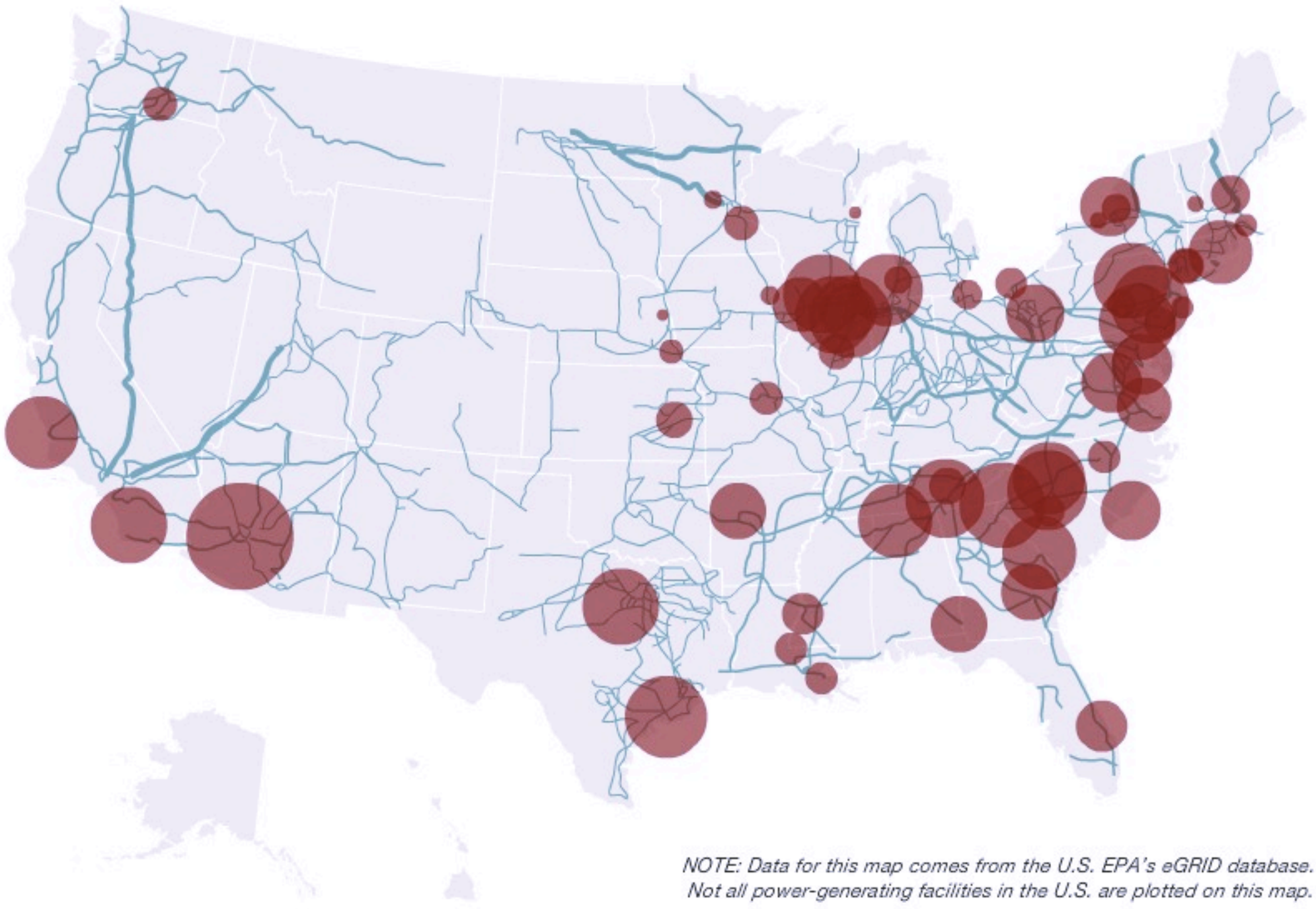
Existing electric power grid



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POWER PLANTS

Coal

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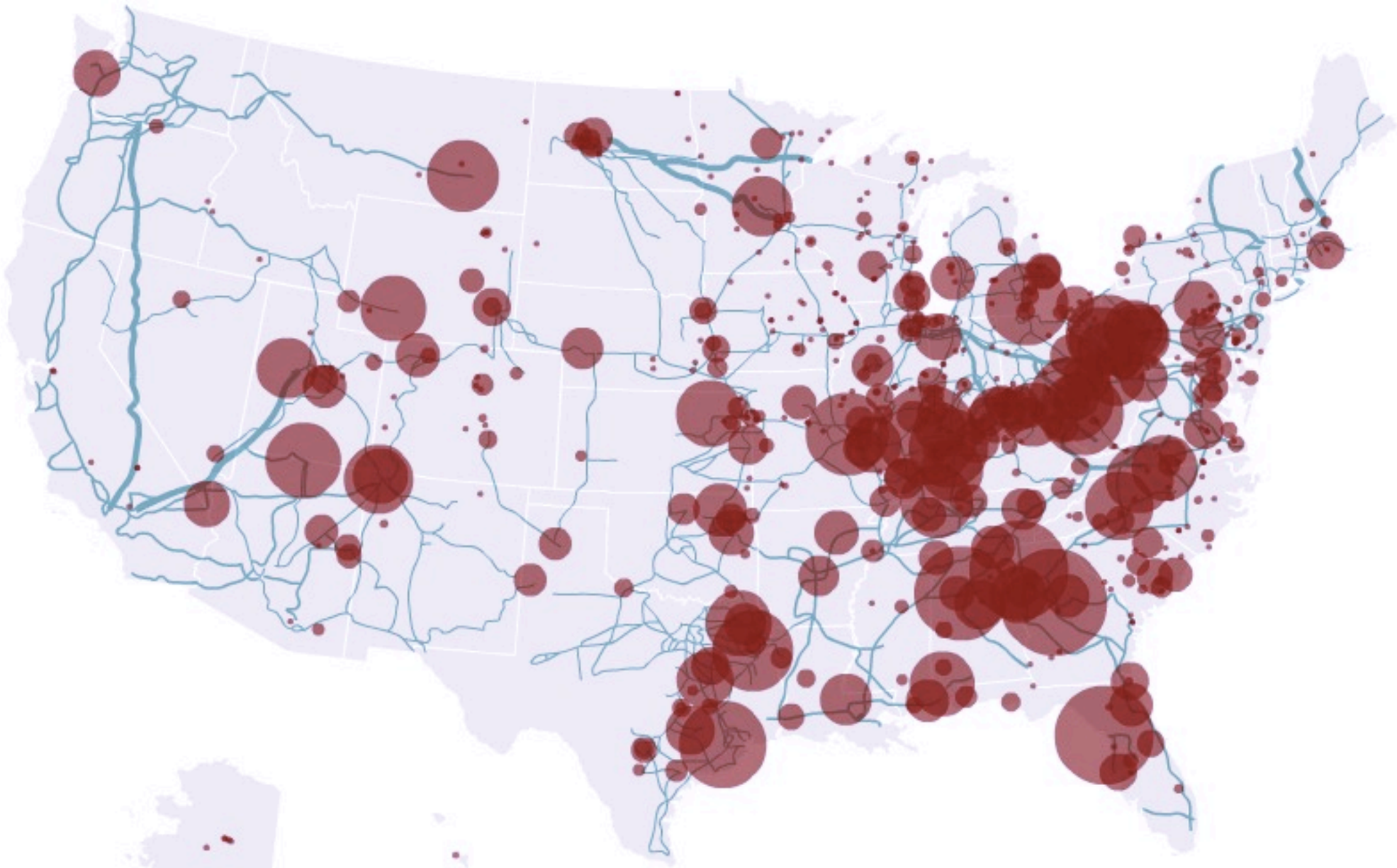
Existing electric power grid



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Hydro

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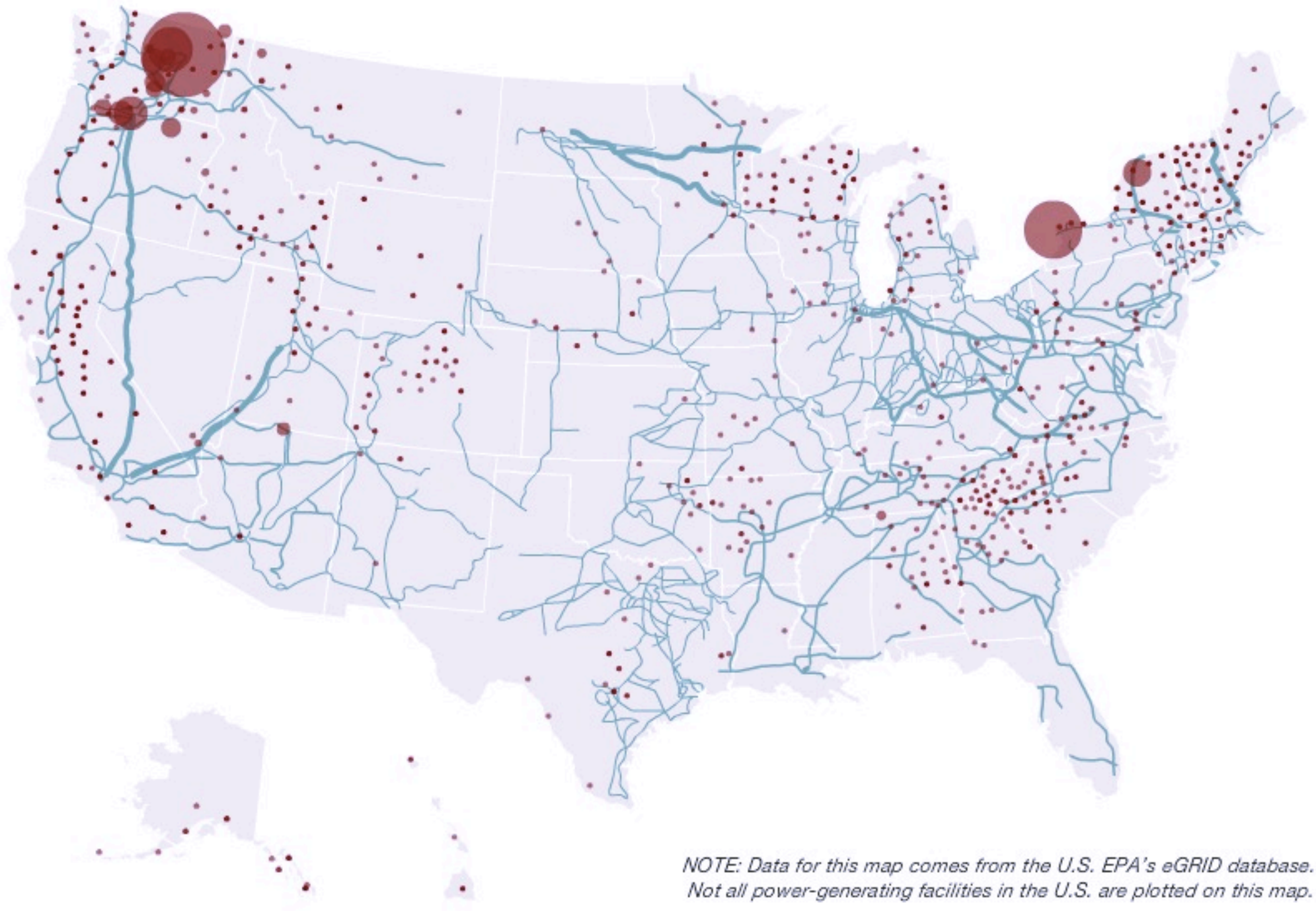
Existing electric power grid



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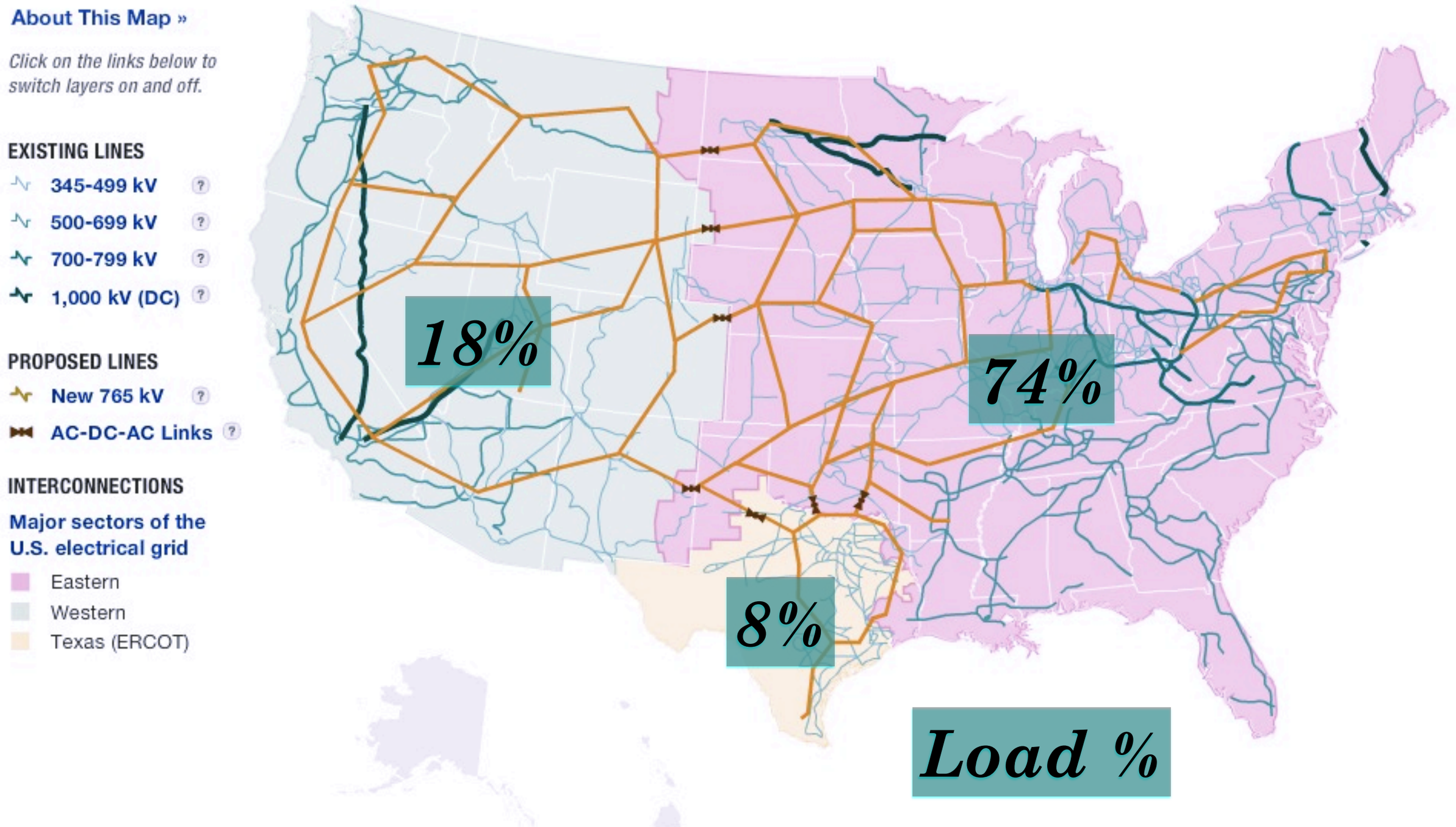

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Solar

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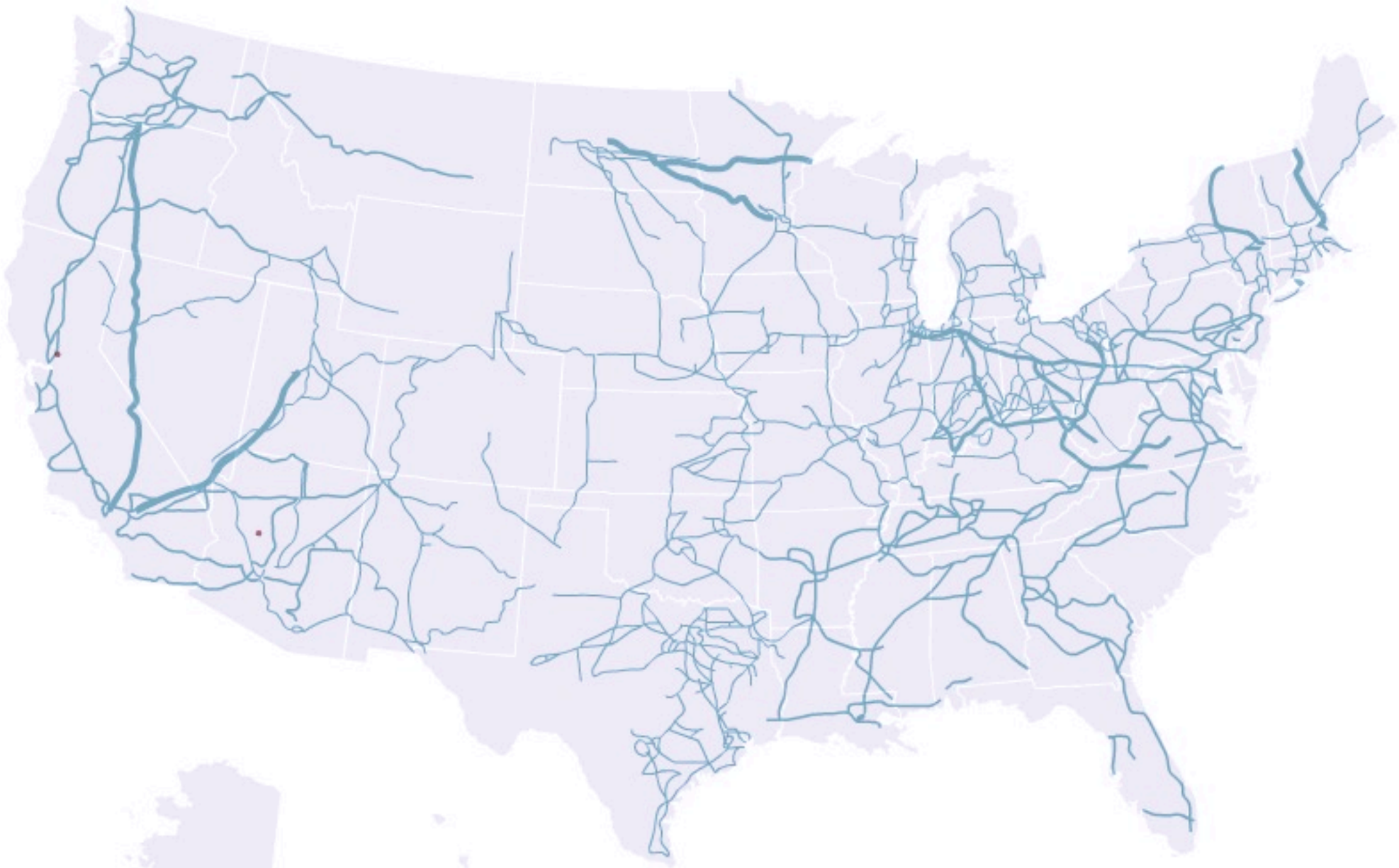

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Wind

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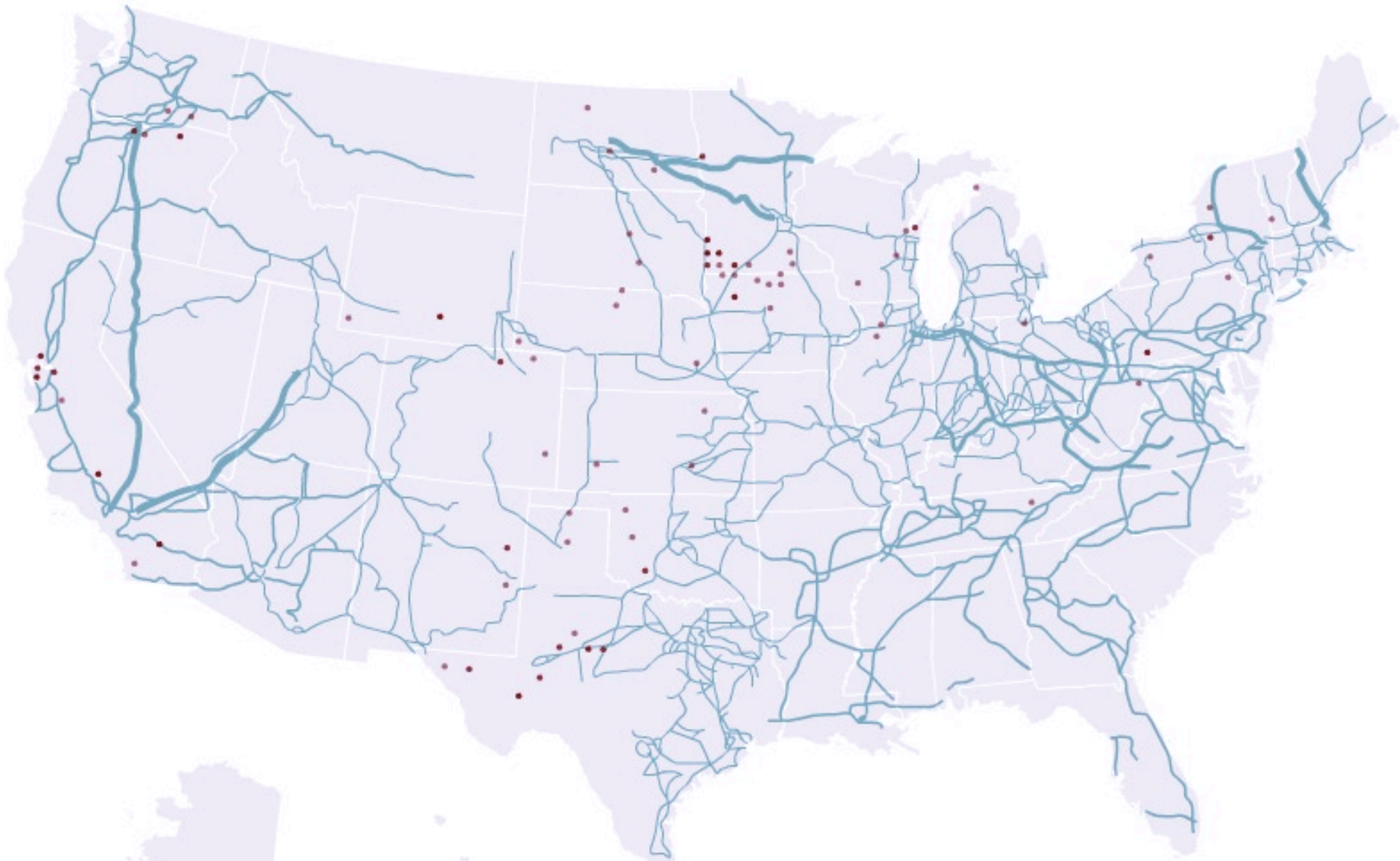

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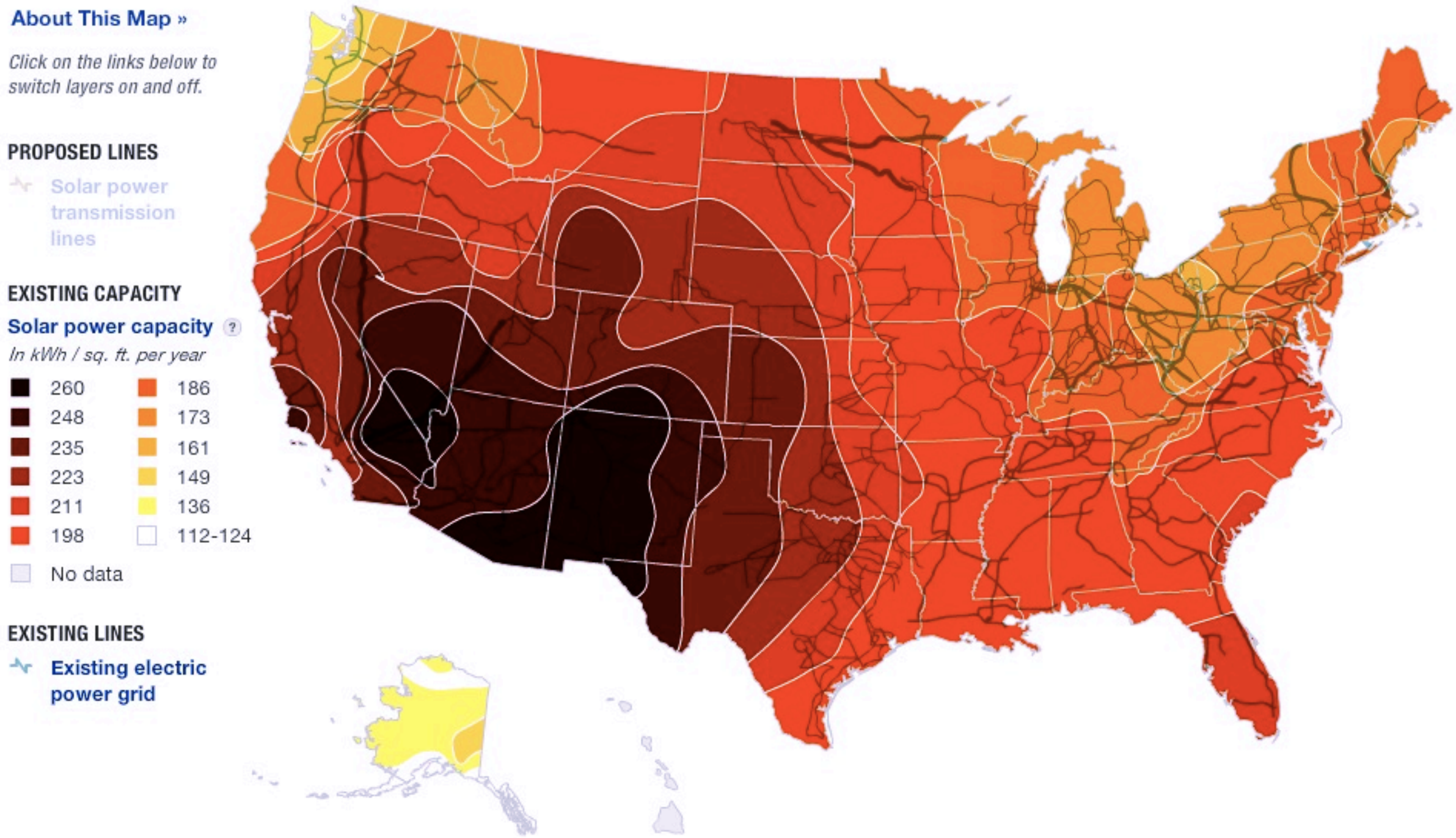

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About This Map »

Click on the links below to switch layers on and off.

EXISTING LINES

- Existing electric power grid

PROPOSED LINES

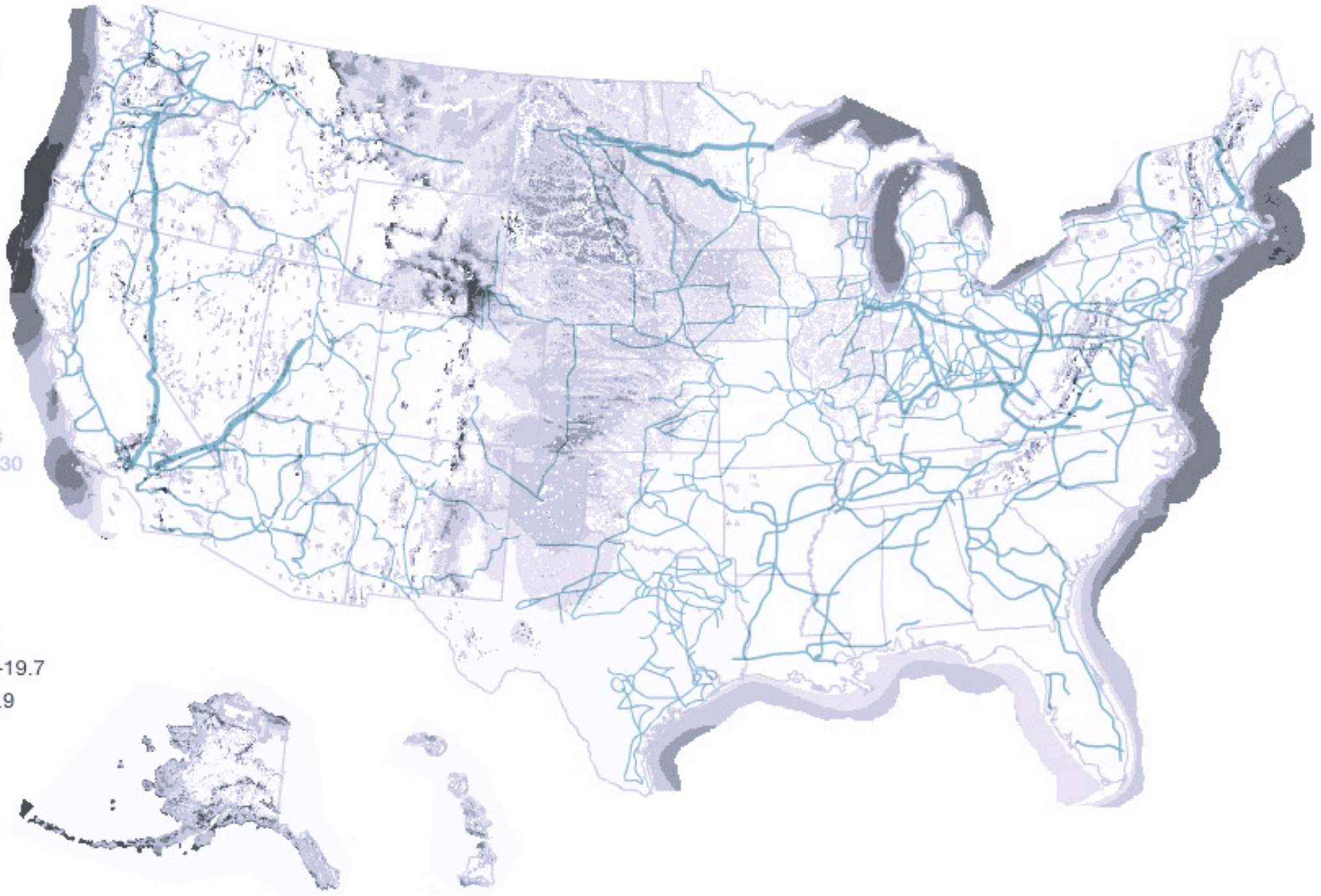
- Wind power transmission lines in 2030
- New wind power transmission lines projected after 2030

EXISTING CAPACITY

Wind speed

At 50m (164 ft), in mph

- Superb: 19.7-24.8
- Outstanding: 17.9-19.7
- Excellent: 16.8-17.9
- Good: 15.7-16.8
- Fair: 14.3-15.7



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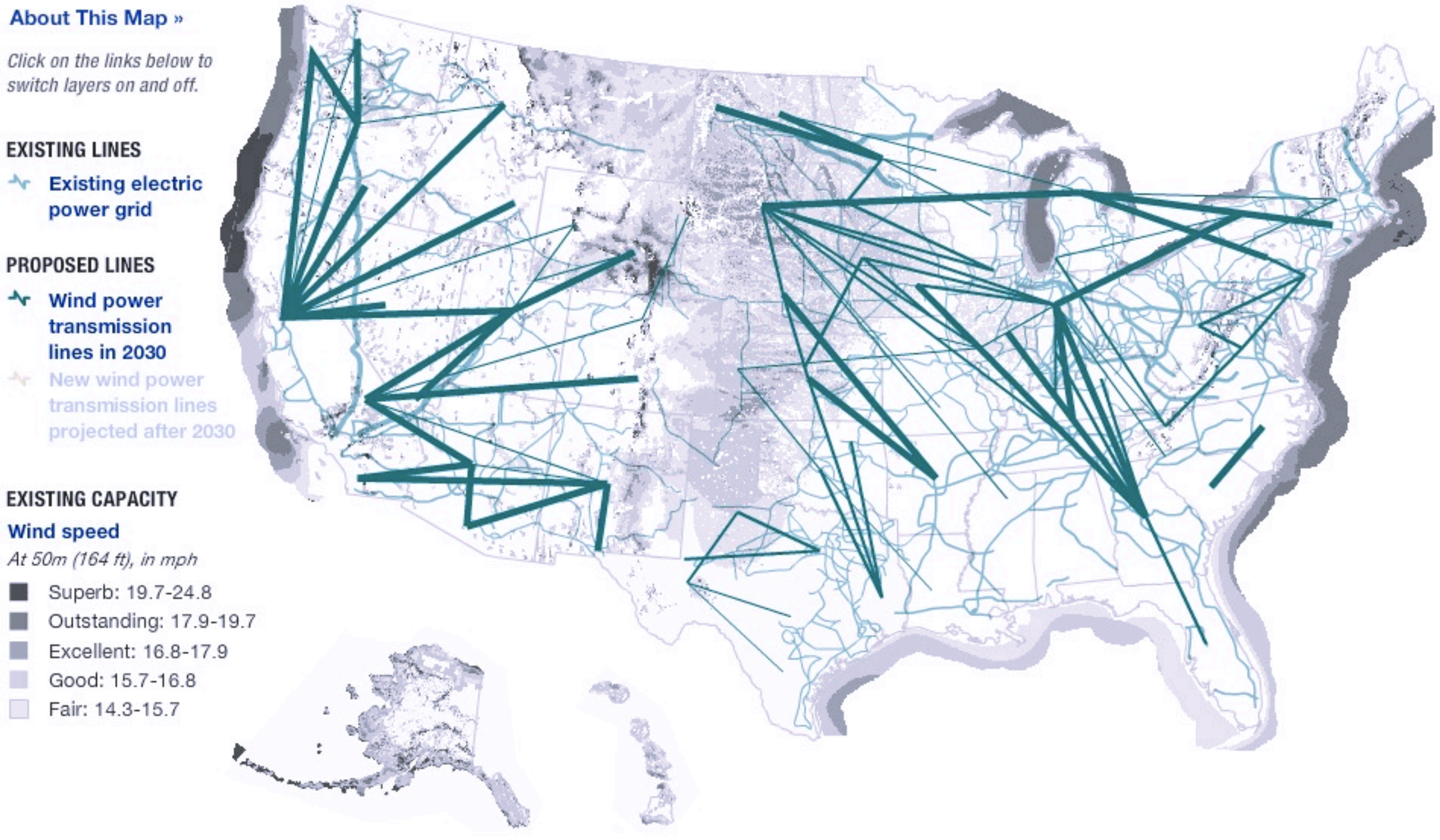

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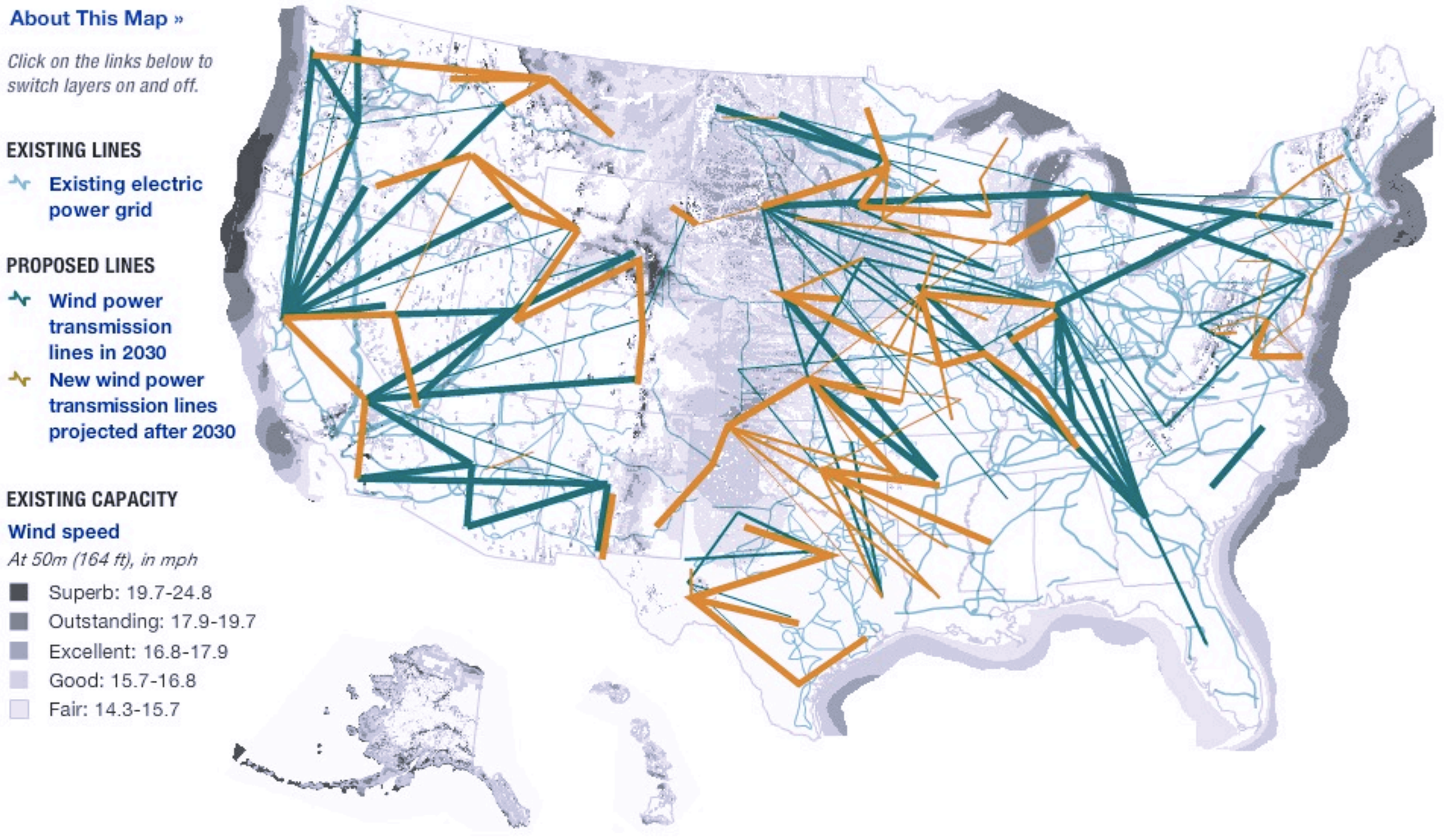

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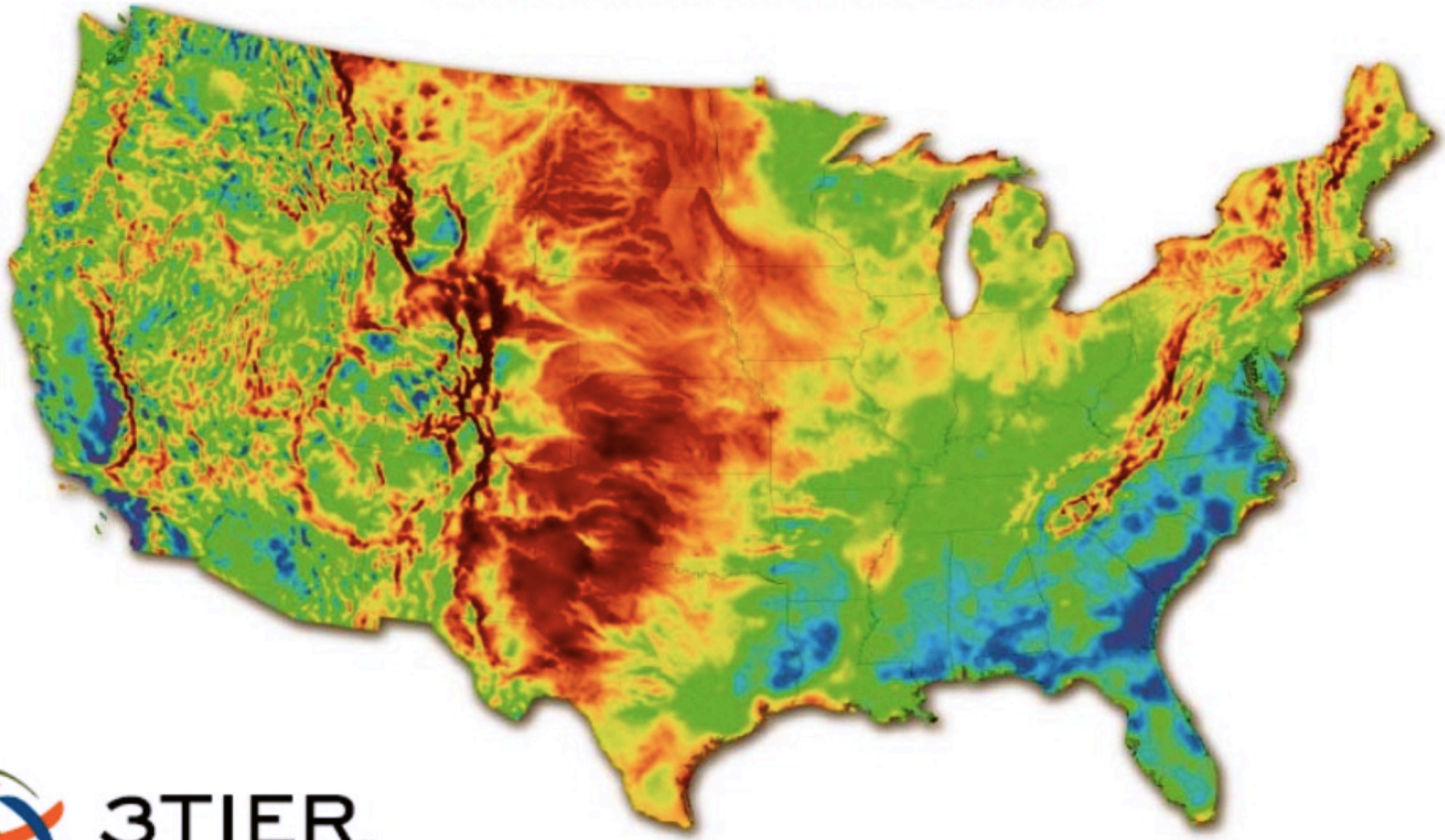
National Wind Resource



3TIER

Tomorrow's Grid

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Exogenous Forces

- Electricity demand rising (40% increase projected by 2030)
- Grid is NOT growing to match demand
- Must reduce carbon emissions
- Must reduce dependence on foreign energy sources
- Increased awareness of energy (in)security

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Outages: $150 billion/year and growing

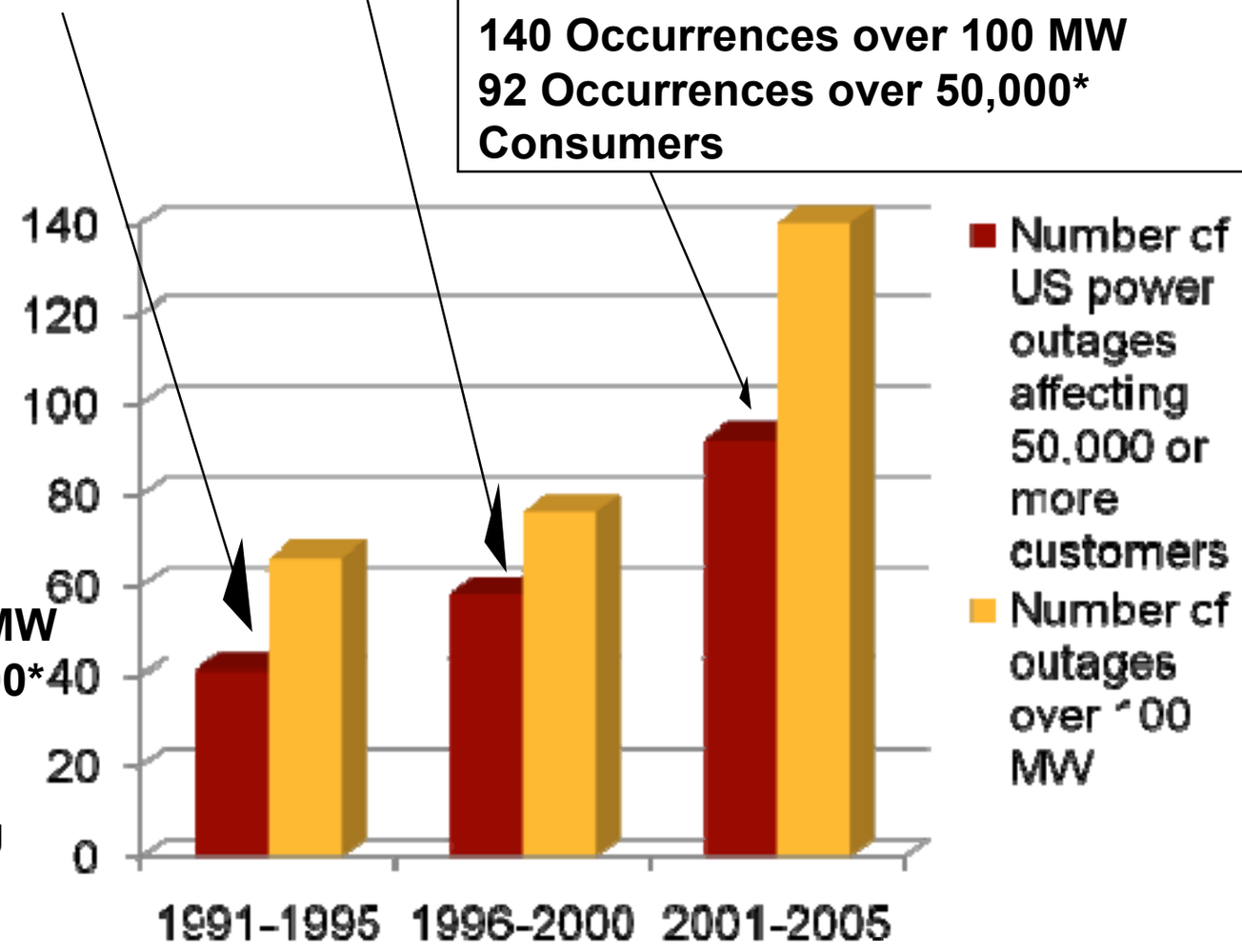
Historical Analysis of U.S. outages (1991-2005)

66 Occurrences over 100 MW
41 Occurrences over 50,000* Consumers

76 Occurrences over 100 MW
58 Occurrences over 50,000* Consumers

140 Occurrences over 100 MW
92 Occurrences over 50,000* Consumers

Result: Large blackouts are growing in number and severity.



*Analyzing 2006 outages:
24 Occurrences over 100 MW
34 Occurrences over 50,000* or more Consumers
Data courtesy of NERC's Disturbance Analysis Working Group database

*Note: Annual increase in load (about 2%/year) and corresponding increase in consumers should be taken into account.

Center for the Development of Technological Leadership | University of Minnesota Driven to Discover℠

source: Massoud Amin

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Trends

	Today's Grid	Tomorrow's Grid
# Sources	thousands	millions
Average Source Size	Large	Small
Architecture	Centralized	Decentralized
Predominant fuel	Fossil	Renewable
Source predictability	Predictable	Intermittent
Power flows	Unidirectional	Bidirectional
Information flows	Sparse	Dense

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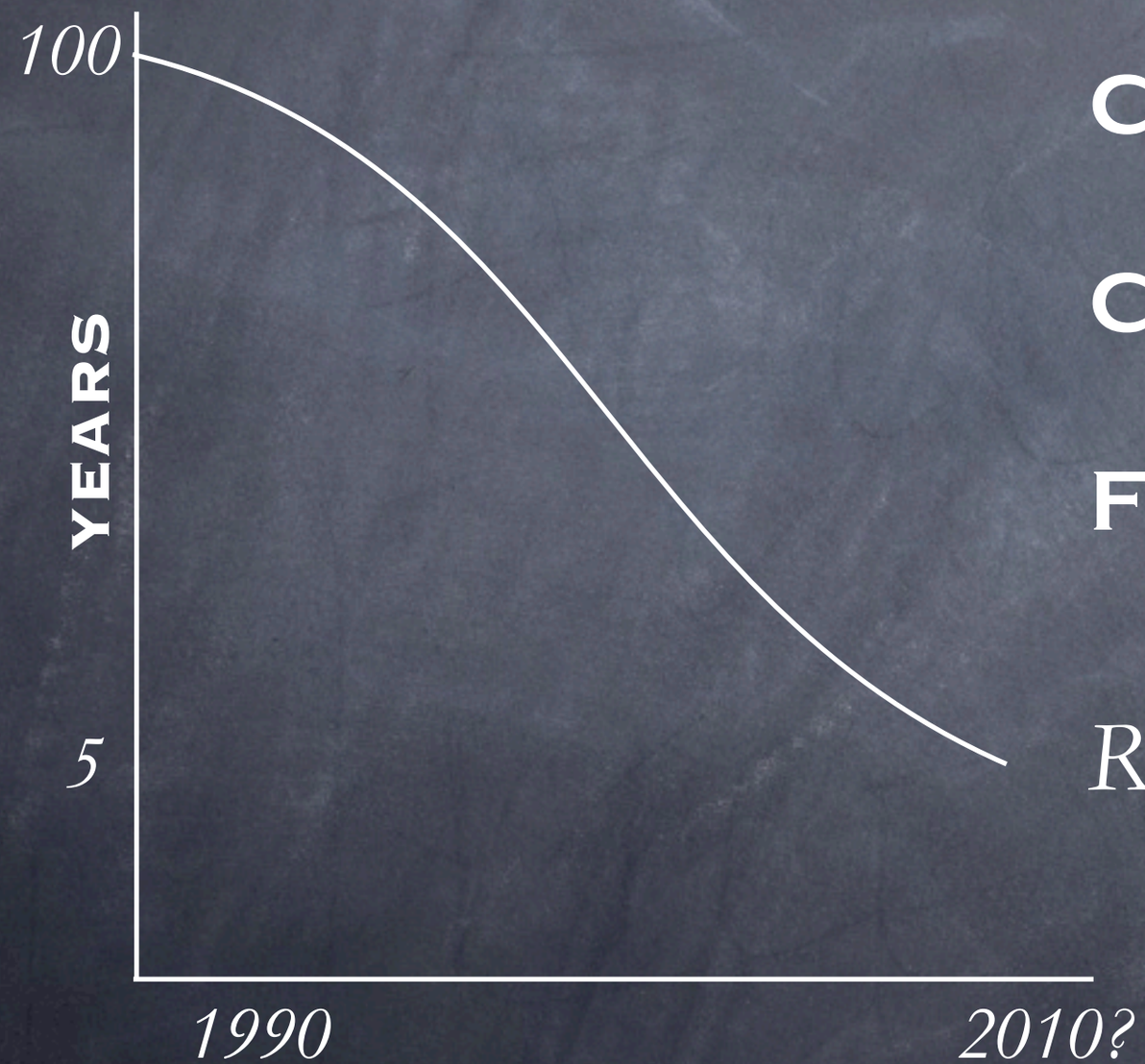
Payback on Home PV



(notional)

Cost of cells ↓

Cost of electricity ↑

Financial incentives ↑

Result: There will be more residential PV, and thus more small sources

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Trends (continued)

	Today's Grid	Tomorrow's Grid
Control	Top Down & Largely Manual	Distributed & Automatic
Consumer Choice	None	Much
Price Transparency	Opaque	Transparent
Sensors/ Instrumentation	Some	Ubiquitous
Energy Management Automation	Some	Ubiquitous
Storage	Rare	Ubiquitous

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Trends (continued)

	Today's Grid	Tomorrow's Grid
Waveform	Mostly AC	Both AC & DC
Domains	Transmission, Distribution, Generation	Transmission, Distribution, Generation, Storage*
Energy Flows	Passive	Transactive
"Shock Absorbing" Capacity	Low	Very High (Both Temporally and Spatially)
Utility Involvement	Mandatory for virtually all customers	Optional for many customers
Business Model	Vertically Integrated Monopolies	Competition

** Or maybe it's only one domain?*

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Trends (continued)

	Today's Grid	Tomorrow's Grid
Transportation Fuel	Fossil	Electric

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What we MUST Do

- Eliminate inefficiencies
- Reengineer for intermittent sources
- Reengineer for distributed energy
- Reengineer for real competition at all levels
- Reengineer for security

Requires Information Processing

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So we need to add a lot of computers and communication.

There's a lot of low-hanging fruit; the grid is pretty primitive by modern IT standards.

We know how to do IT; just look at the Internet.

Oh wait...

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But…

- When the Internet fails, people usually don't die.
- What elements of the grid must become "smarter"?

  What information processing do they do?

  What information do they exchange?

- On whose behalf will all these computers work?
- How do we keep all these computers from becoming a new attack vector?

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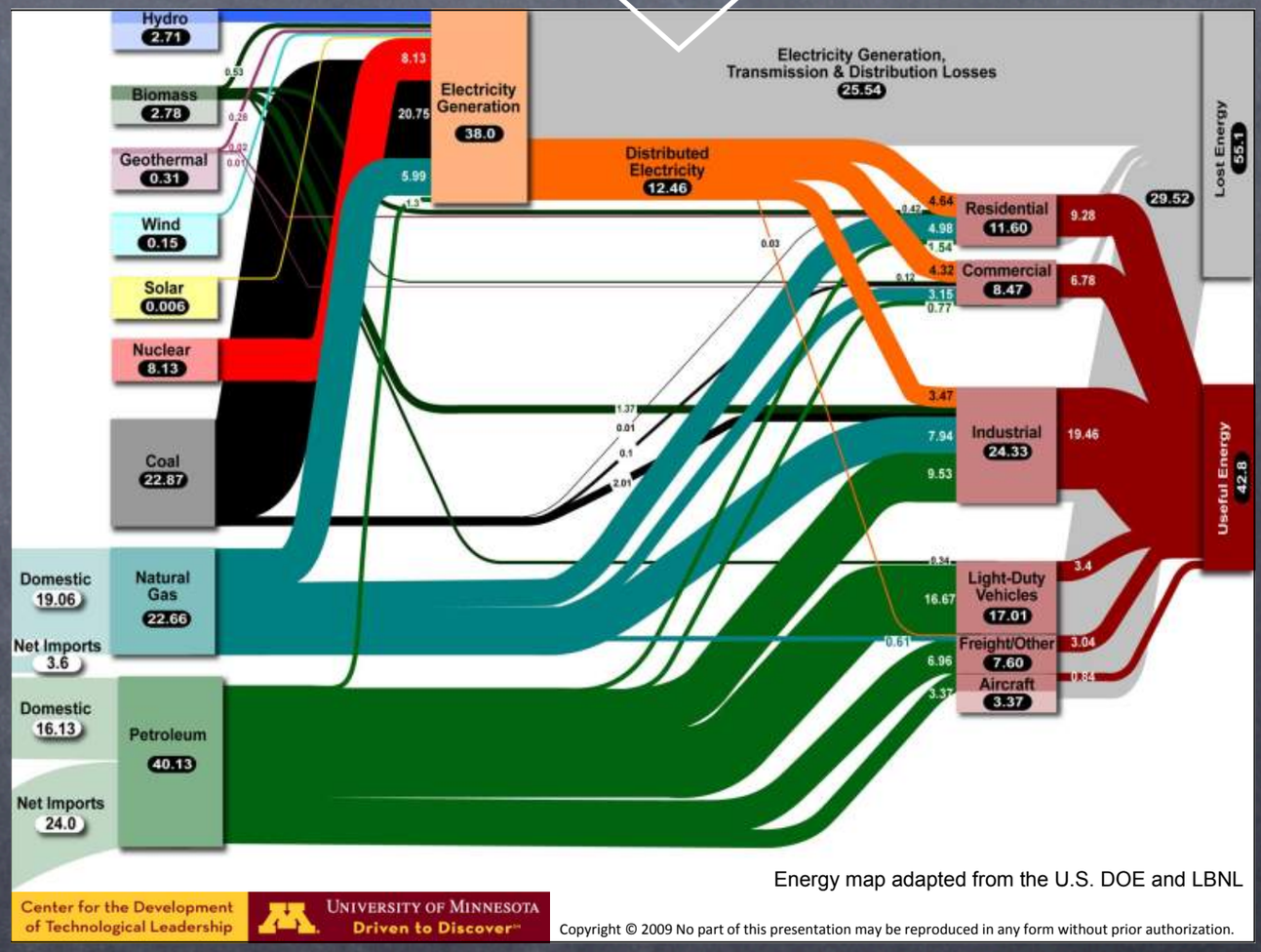
Eliminate inefficiencies

Higher voltages for transmission

Use more DC

Move sources closer to loads

Smarter, more ubiquitous control



Energy map adapted from the U.S. DOE and LBNL

Reengineer for intermittent sources

Renewable sources are "Green"

- Low carbon emissions
- Less dependence on other countries for energy
- Sustainable (Fuel-efficient or zero fuel)

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But...

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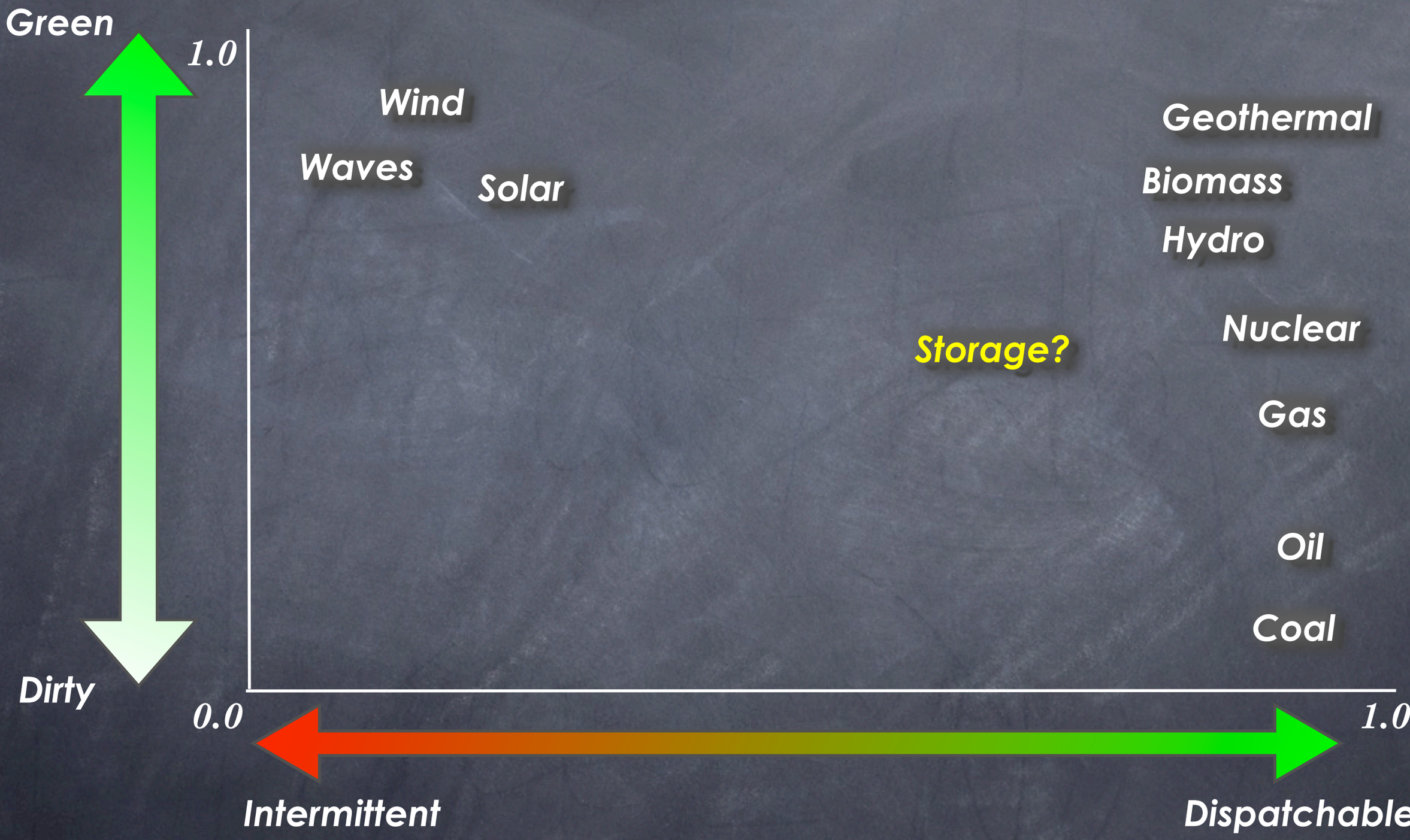
Green vs. Dispatchable



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How much Intermittency is Too Much?

- 10% ?
- 15%
- 20?
- 30?
- 100?

Everybody has an opinion, but nobody knows!
Maybe somebody should do the science.
Better yet, maybe we should rethink the problem.

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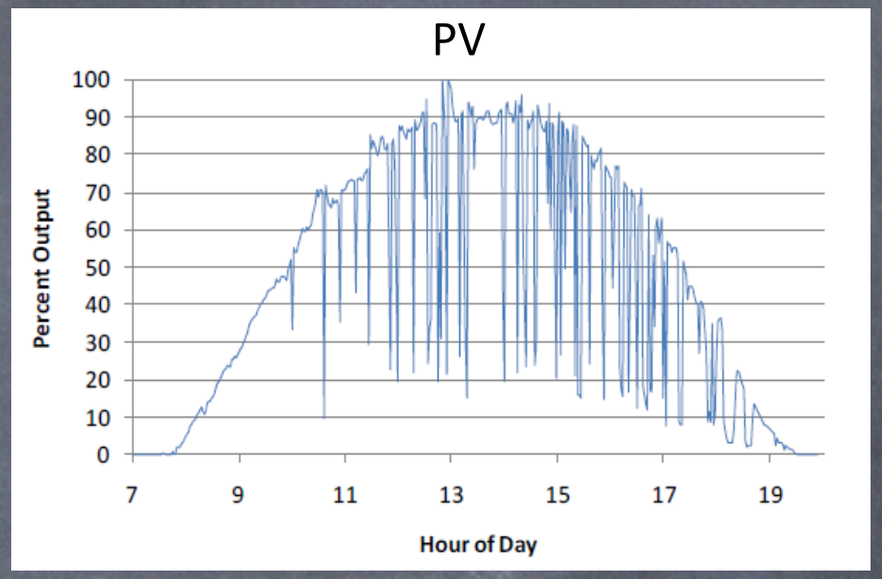
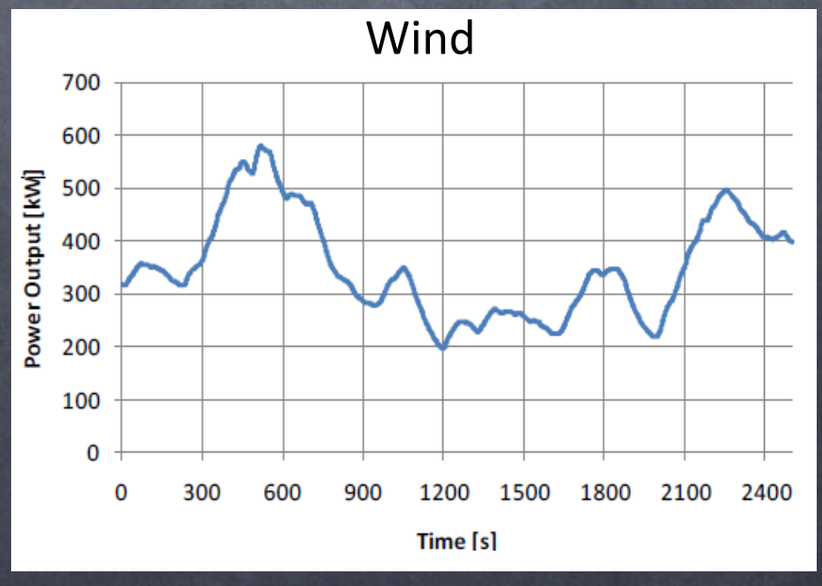
Reengineer for intermittent sources

Incorporate SOTA weather forecasting

Take advantage of geographic diversity where possible

Couple load statistics to source statistics using market signals

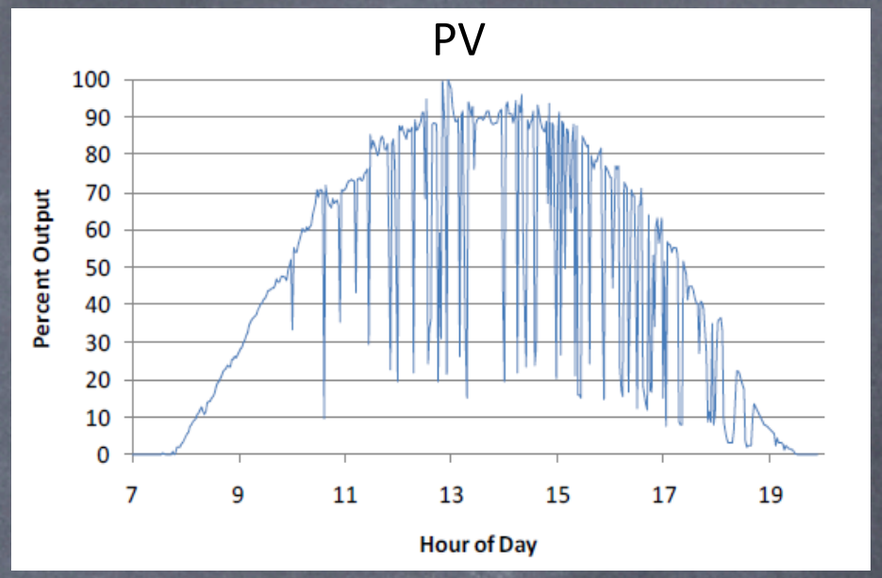


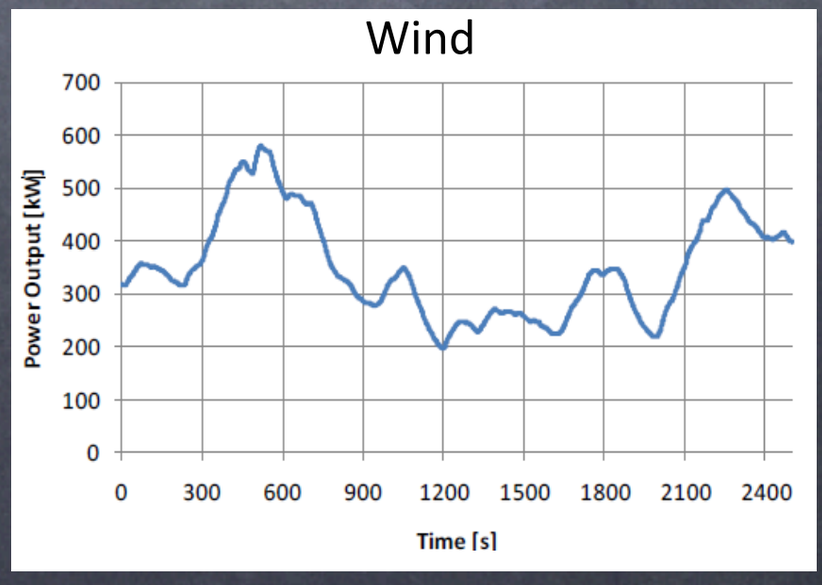


Reengineer for intermittent sources

Invent new storage technologies that are 10x less expensive with 10x the energy density of today's.

Use SOTA information science to mitigate the problem.





"Without a radically expanded and smarter electrical grid, wind and solar will remain niche energy sources."

Talbot, David "Lifeline for Renewable Power", MIT Technology Review, January/February 2009.

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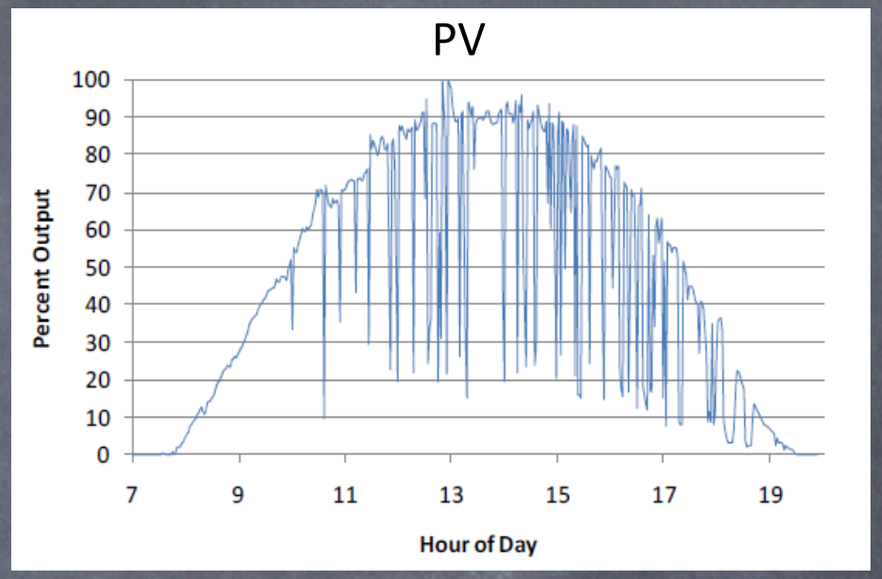
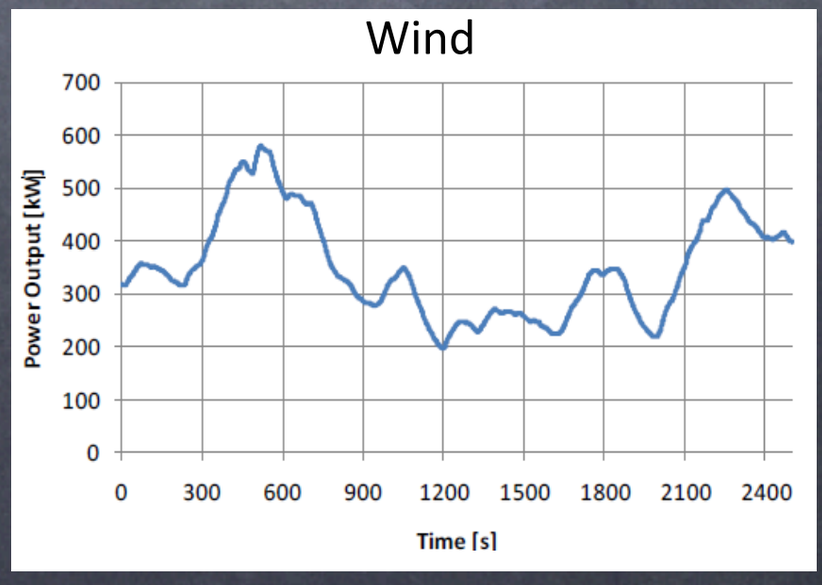
Reengineer for intermittent sources

Incorporate SOTA weather forecasting

Take advantage of geographic diversity where possible

Couple load statistics to source statistics using market signals



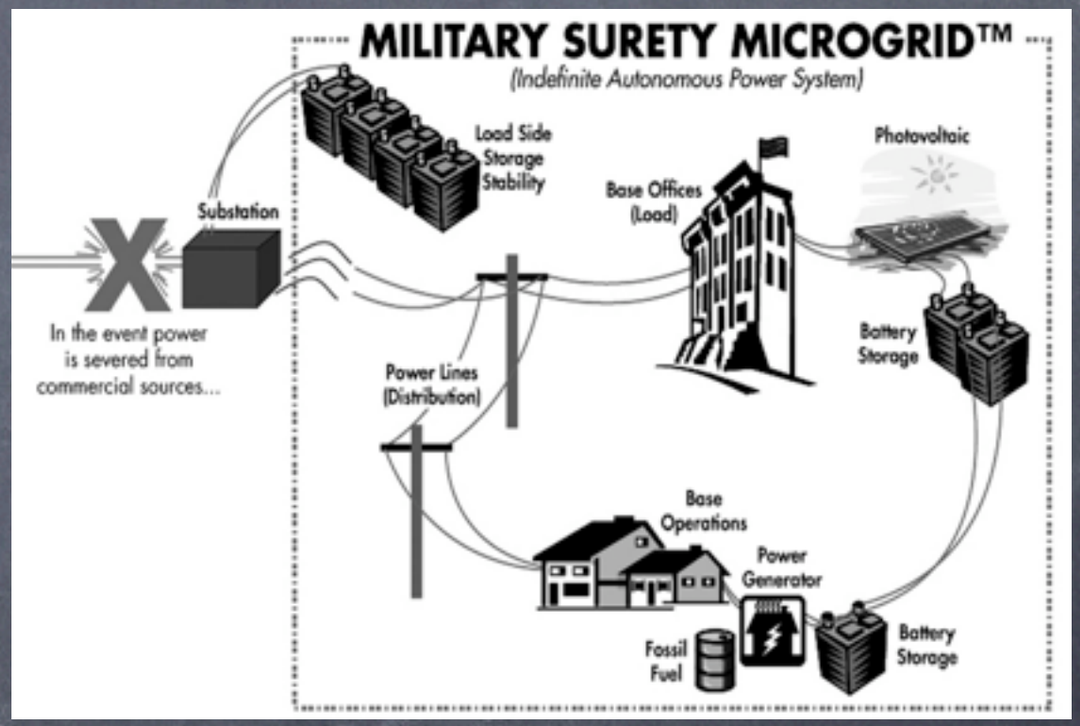


Reengineer for distributed energy

Ubiquitous sensing and control

Peer-based self-organization, self-healing, self-* systems

Agent-based microgrid systems



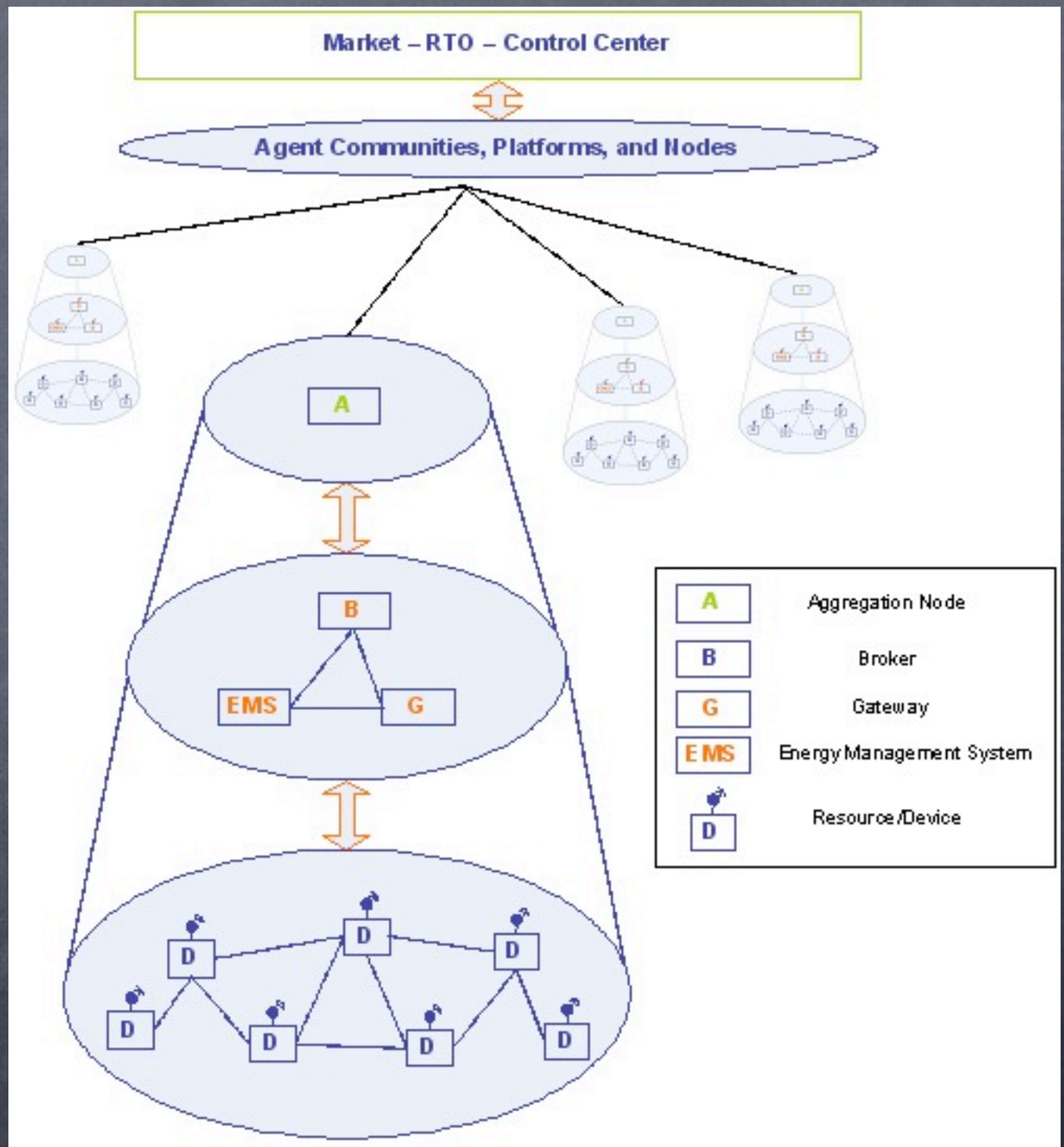
"The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming - and interconnected with everything else."

http://www.wired.com/wired/archive/9.07/juice.html

Reengineer for distributed energy

We need adaptive, model-based reasoning agents with models of:

- *Themselves*
- *Electric networks*
- *Stability*
- *Load behavior*
- *Weather*
- *Emissions*
- *Economics*
- *Security*



Reengineer for real competition at all levels

"Virtual" utilities enabled by common interoperability standards

Federated microgrids that can connect/ disconnect as needed

New Business Models

- What new business models will Tomorrow's Grid engender?
- How can existing businesses adopt the new models?
- How much money will they spend preserving legacy business models rather than innovating?

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"Clear leadership is needed, or else nations will keep trying technologies promoted by industries rather than vetted by scientists."

Scientific American *November 2009, Page 65*

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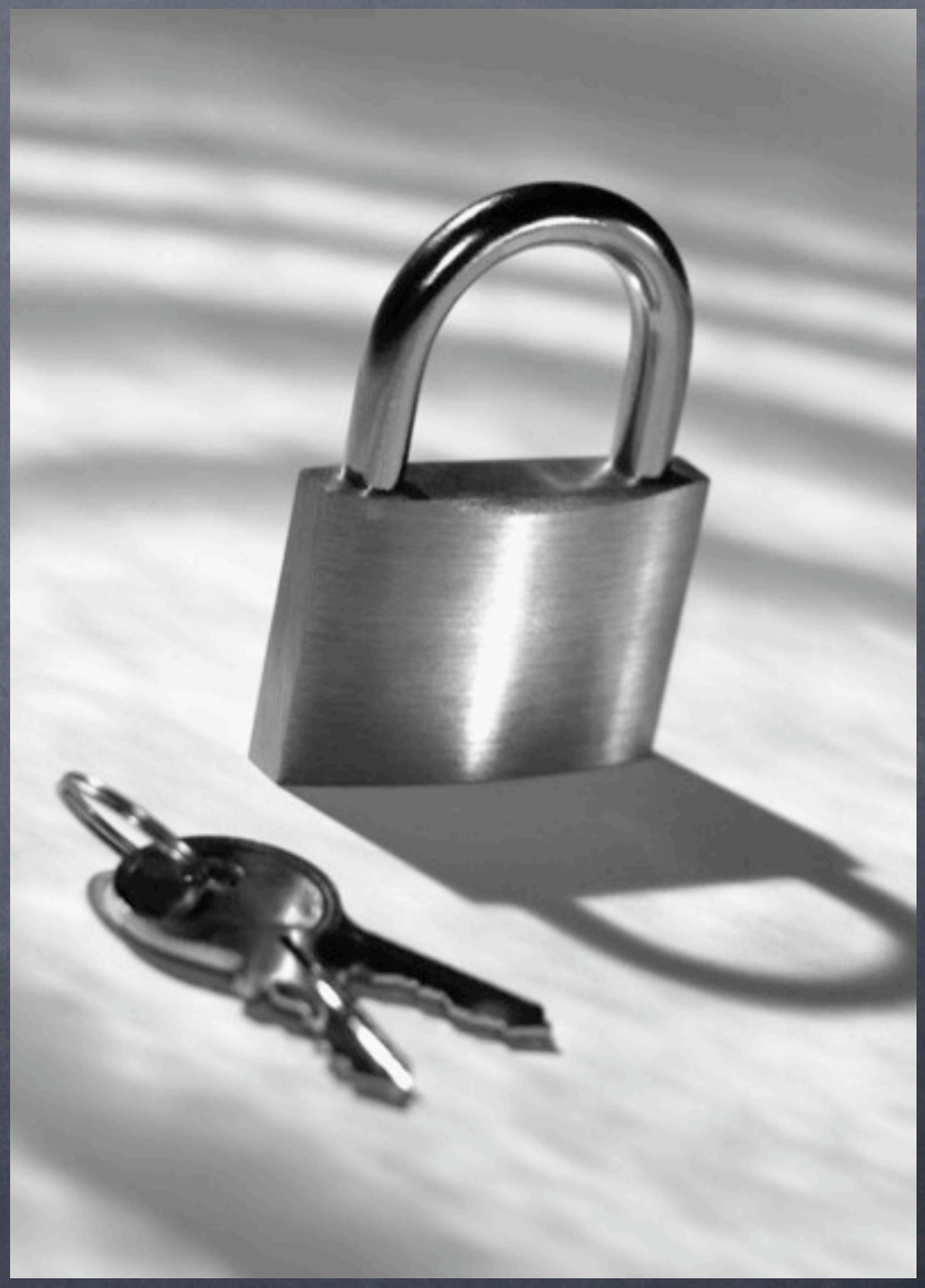
Reengineer for security

Security must be designed in as a fundamental engineering requirement



Obstacles

- Regulation: too much and too little
- Legacy Mindset
- Incentives are wrong
- Can't build new coal plants
- Can't build new transmission lines

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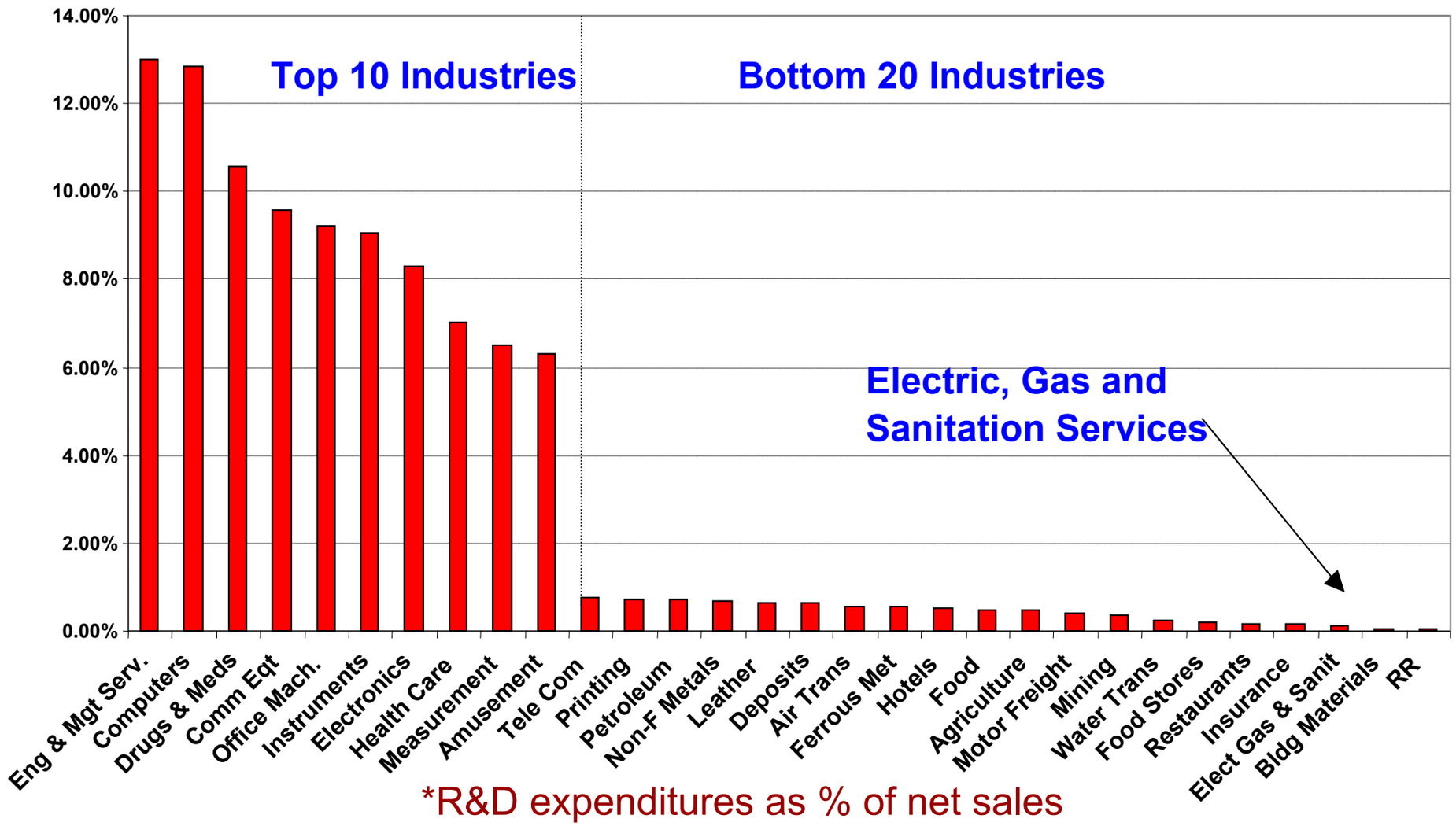
"Electric utilties spend less on R&D than the pet food industry"

Context: R&D Expenditures*



*R&D expenditures as % of net sales

source: Massoud Amin

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Two options

1. More of the same

2. Innovate

Which one do people mean when they talk about "Smart Grid"?

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1. More of the Same

Bolt lots of COTS information technology onto the existing grid and hope for the best.

e.g. AMI, Crypto, Windows, etc.

If we do this, what will be the consequences?

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2. Innovate

If we designed the power grid today from scratch, what would it look like?

If we did this, how could we transition from here to there?

What's the cost? What's the cost of NOT doing it?

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Meta-Process

- What *processes* led to today's grid, and how will (or should) the process that gets us to the next-generation grid be different?
- Can we make a new grid that incorporates a mechanism that sustains its own evolving morphology?

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Questions?

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