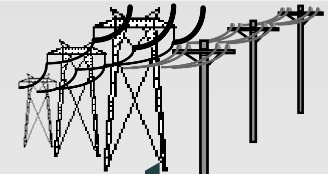

The Real Reasons We ~~Want~~ Must Have a Smarter Grid for the 21st Century

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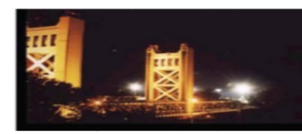

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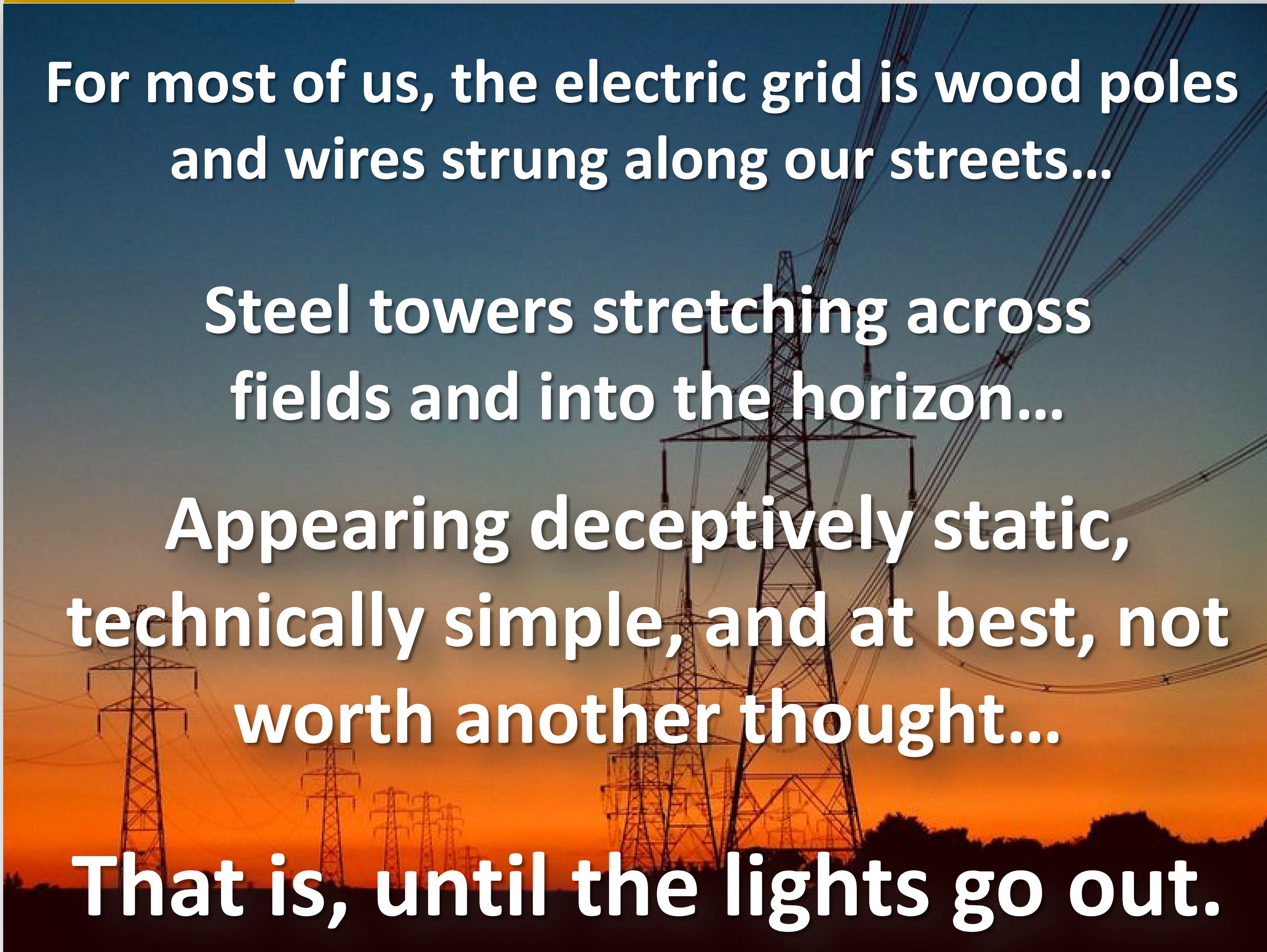

For most of us, the electric grid is wood poles and wires strung along our streets…
Steel towers stretching across fields and into the horizon…
Appearing deceptively static, technically simple, and at best, not worth another thought…
That is, until the lights go out.

Power outages are expensive, a threat to human health, safety and welfare, and national security, and just plain inconvenient.

The 21st Century grid faces new, unprecedented challenges that threaten to increase the risk of power outages or higher costs, unless it is *modernized*.

But it is important to understand that the grid also has its hands full with legacy issues from the 20th Century.

Hopefully this presentation will help you by providing:

A historical context for the complex origins of these issues that are creating the growing necessity for new technologies in the electric grid,

And the real reasons why the grid must become smarter for the 21st Century.

There's an ancient metaphor for how we can get incomplete understanding of complex systems, e.g., a smarter grid.

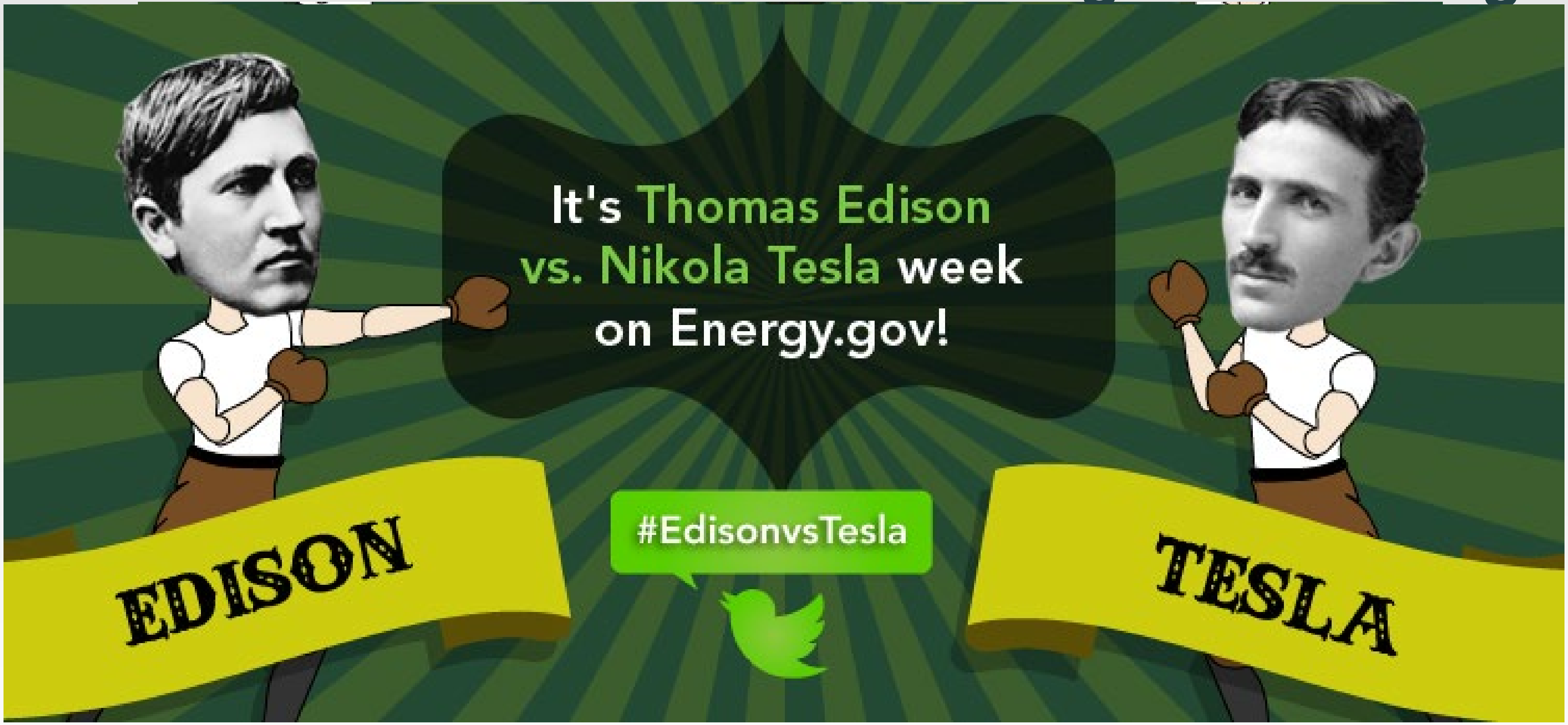
Blind Men and the Elephant by
John Godfrey Saxe (1816-1887)

"And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right
And all were in the wrong!"

Differing descriptions of a smarter grid and the reasons for it, led me to investigate the origins of what shaped the grid of today, …and will shape tomorrow.

Sources: https://en.wikipedia.org/wiki/Blind_men_and_an_elephant, and http://www.houd.info/elephant.pdf

My story begins by examining past events and trends that forced electric grid to change.



Edison "invented" the electric business, but Tesla "sealed" its future.

"Tesla's" electric grid became the standard as the electric provider of the 20th Century.

21st Century

20th Century

19th Century

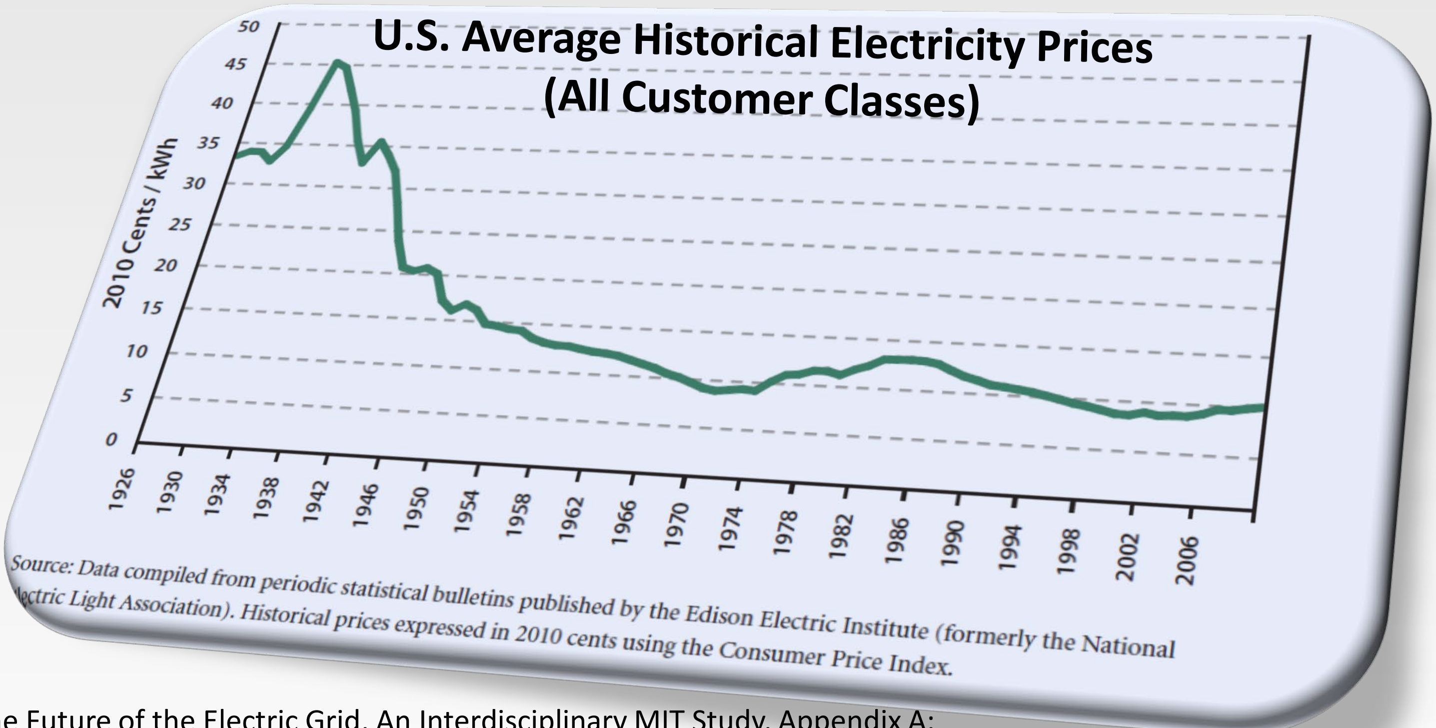
Grid's Role was the Physical Link for the Generator to the Meter under a Regulatory Compact

Grid's Operation was Deterministic & Planned

Grid's Form was mostly Radial, & Grew in Size more than Intelligence

Grid's Key Success Factor was Reliability

Despite demand growing at ~ 8% per year, the avg. real price of electricity fell until the 1970s.



Source: "The Future of the Electric Grid, An Interdisciplinary MIT Study, Appendix A: A Brief History of the U.S. Grid," 2011 Massachusetts Institute of Technology, p 237

Declining prices were due largely to economies of scale in unit size as larger new plants were built to meet demand.

The items involved in management decisions were few; the "equation" was simple:

$$f(\text{reliability}) \sim G(\text{utility-scale}) + [T(\text{utility}) + D(\text{utility})]_{\text{minor}}$$

Where:

f = investment decision

G = electric generation

T+D = transmission and distribution capacity

Success = Reliability. The big decision - largely the utility's - was choosing the next power plant.

Starting about the 1960's, an evolution of events and trends set the stage for major change.

2000s

1990s

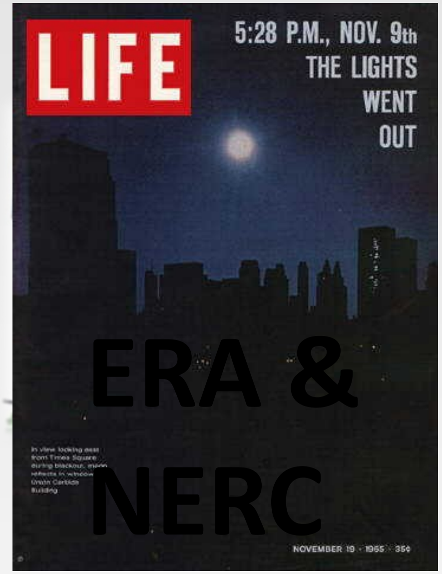
1980s

1970s

1960s

By the end of the 20th Century, the ways electric systems were planned, owned, built, operated, regulated, used, and bought and paid for would never be the same.

The "Interconnection" Trend:

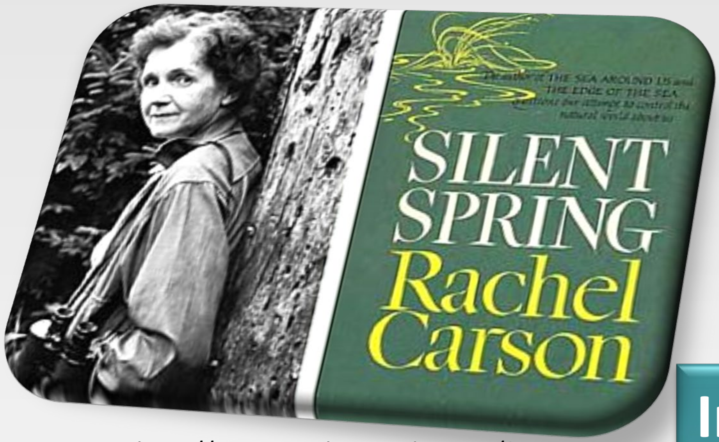


Growing like "mold on bread," small regional electric utilities began to interconnect.
In '62, the Eastern Interconnection was formed, followed by the Northeast Blackout of '65, followed by the Electric Reliability Act of '67, and by the creation of North American Electric Reliability Council (NERC) in '68.

Implications:

- An "unseen" outage in a neighboring utility could cause a wide-spread blackout, putting <u>your</u> utility customers in the dark.
- The stage was set for increasing attention to formal operating standards for the grid.
- Regardless of the blackout threats, this trend persisted.

The "Environmental" Trend



Source: http://www.pophistorydig.com/?p=11132

Rachel Carson popularized ecology.
In '62-'63, she wrote "The Silent Spring," and testified in US Senate, attacking DDT and its industry.
Although criticized, she prevailed.

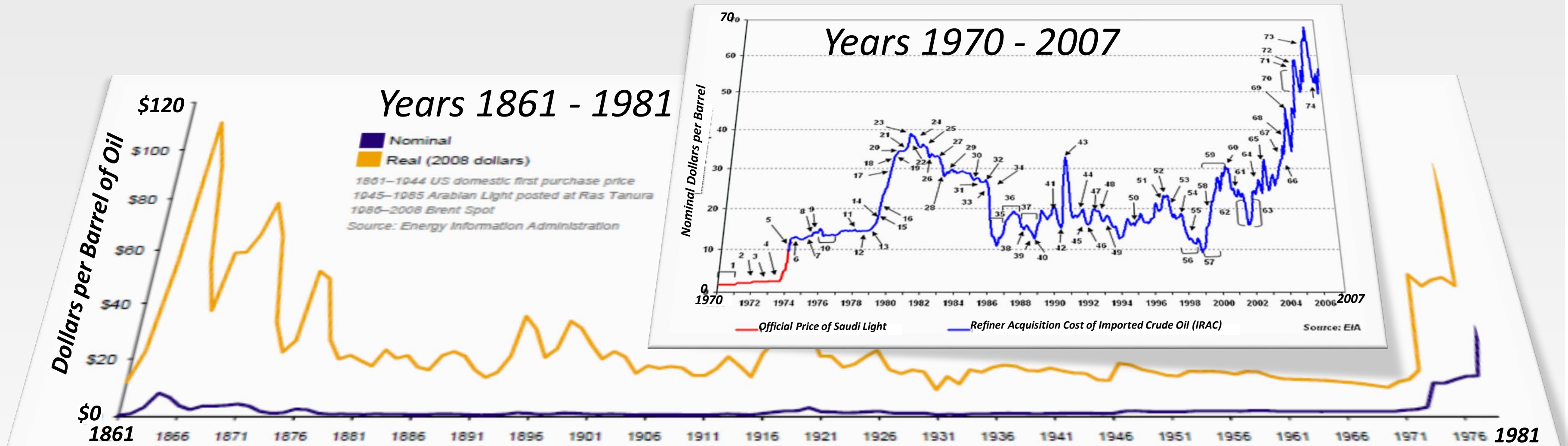
Implications:

- Environmental impact became a factor in selecting, siting & permitting new infrastructure, generally extending construction schedules.
- External costs of environmental protection began to be "internalized" in electricity costs - 1970 Clean Air Act.

The "Fuel-Price Volatility" Trend

For almost 40 yrs fuel prices were essentially flat and smooth.

In '73, the first oil embargo introduced the U.S. to its first energy crisis, fuel prices and price volatility rapidly increased.



Source: http://en.wikipedia.org/wiki/1973_oil_crisis

Implications:

- Electric industry saw fuel price & resource uncertainties
- Door opened to non-utility and alternative generation

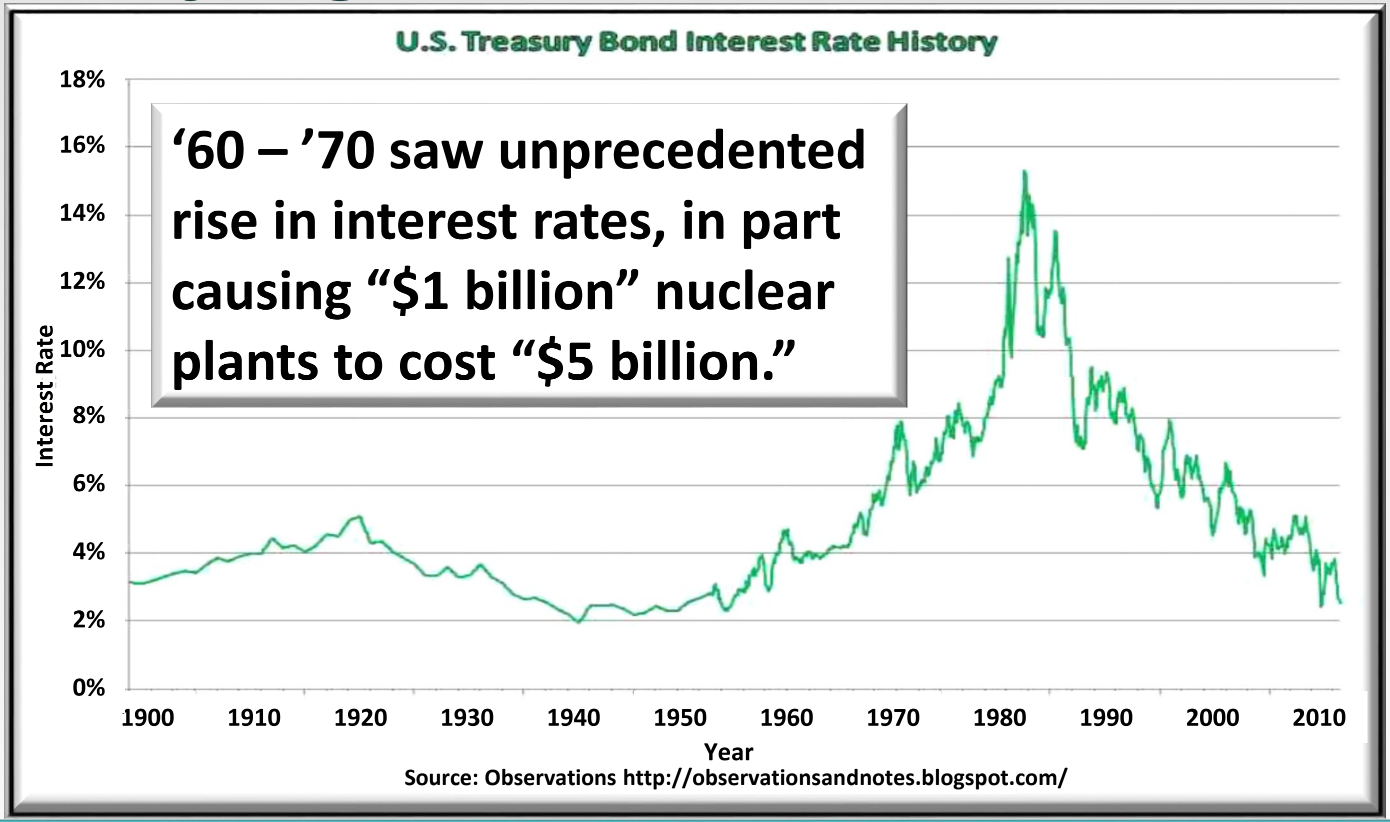
The "Alternative Generation" Trend

In '78, the Public Utility Regulatory Policies Act (PURPA) passed. It forced utilities to contract with non-utility generators (NUGs), to buy electricity at "avoided costs".

Implications:

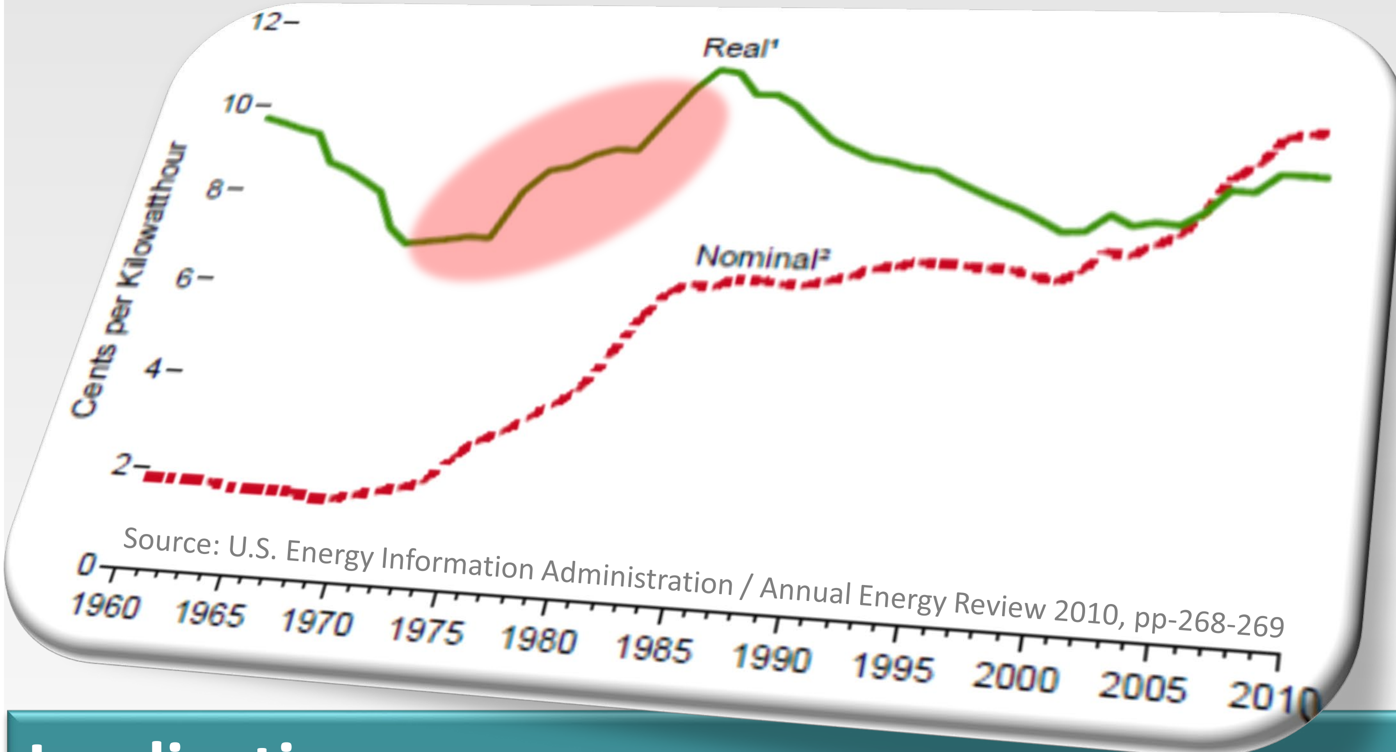
- PURPA opened the electric grid for 3rd party-owned generation, bringing into question the "natural monopoly" paradigm.
- Encouraged grid-integrated renewable generation, e.g., wind farms, and distributed generation, e.g., CHP & microturbines.

The “Very High Interest Rates” Event



Implication: Big power plant projects with long schedules cost more, economy of scale lost its punch, thus improving the competitiveness of smaller generation.

The "Reliability vs. Cost" Event

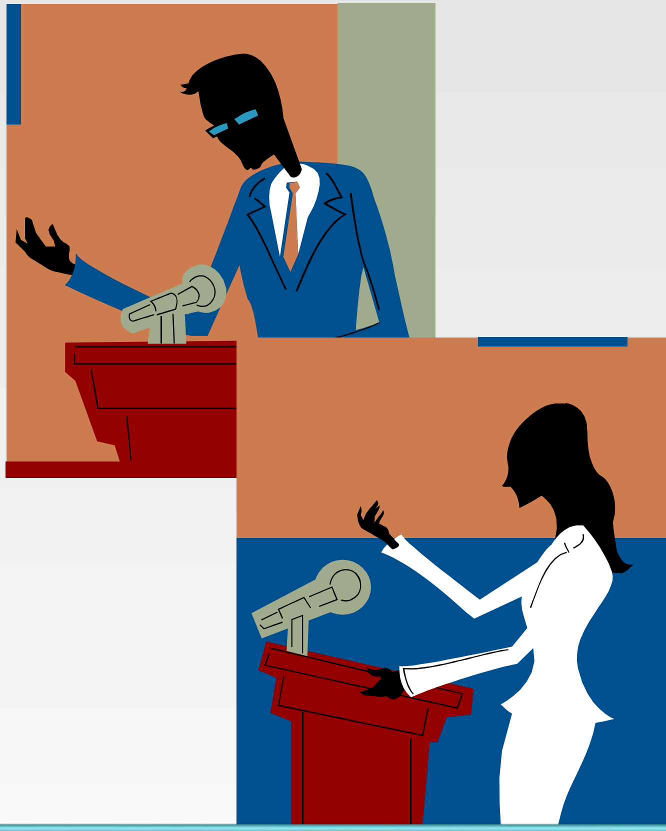


After two decades of falling prices, in the early '70s the real price of electricity sharply increased.

Implications:

- **Reliability now came with higher price for electricity.**
- **Tensions in rate cases grew among ratepayers, regulators & utilities**

The "Broken Regulatory Compact" Event

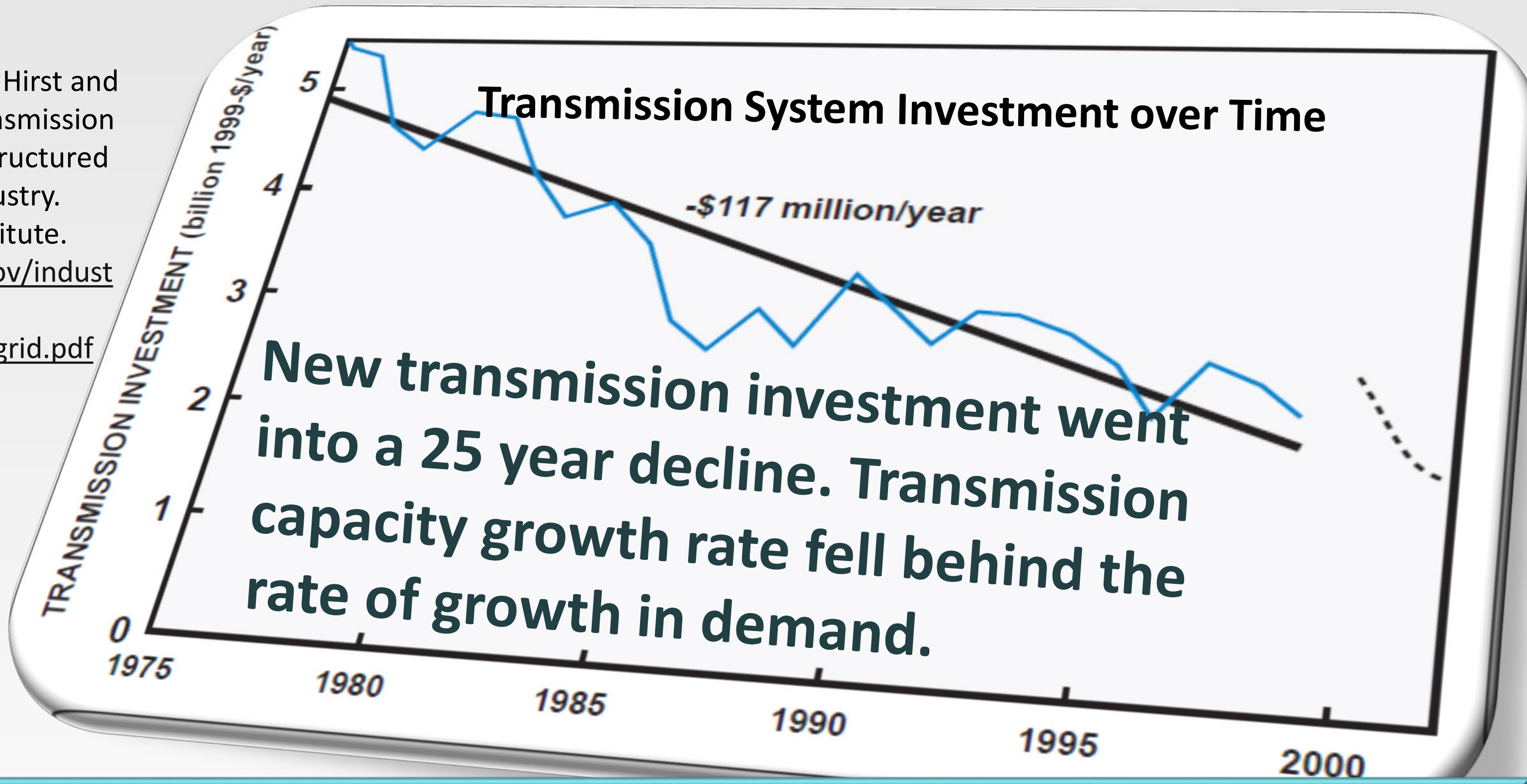


- **Customers complained** about higher rates.
- **Growth** in electricity demand began to **fall off**.
- Regulators threatened to, or did, **disallow rate recovery** for some large utility investments.
- Academics and policy makers began to talk about a new power system model based on **competition**.

Implications: Utilities (1) became averse to making new investments and asking for rate increases, and (2) began to see deregulation in the '90s.

The "Under-Investment" Trend - Transmission

Source: Source: E. Hirst and B. Kirby. 2001. Transmission Planning for a Restructured U.S. Electricity Industry. Edison Electric Institute. http://www.ferc.gov/industries/electric/gen-info/transmission-grid.pdf



Implications: Daily transmission constraints, i.e., "congestion," increased electricity costs, and the risk of blackouts.

The “Under-Investment” Trend - Distribution

Customer complaints about higher rates and threats of competition led to cost-cutting.

Implications:

- ***Assets, e.g., poles, etc., were used longer and longer.***
- ***O&M, e.g., tree-trimming, was done less and less.***
- ***“Aging infrastructure” and “more storm outages” were the result.***

The “Deregulation” Trend

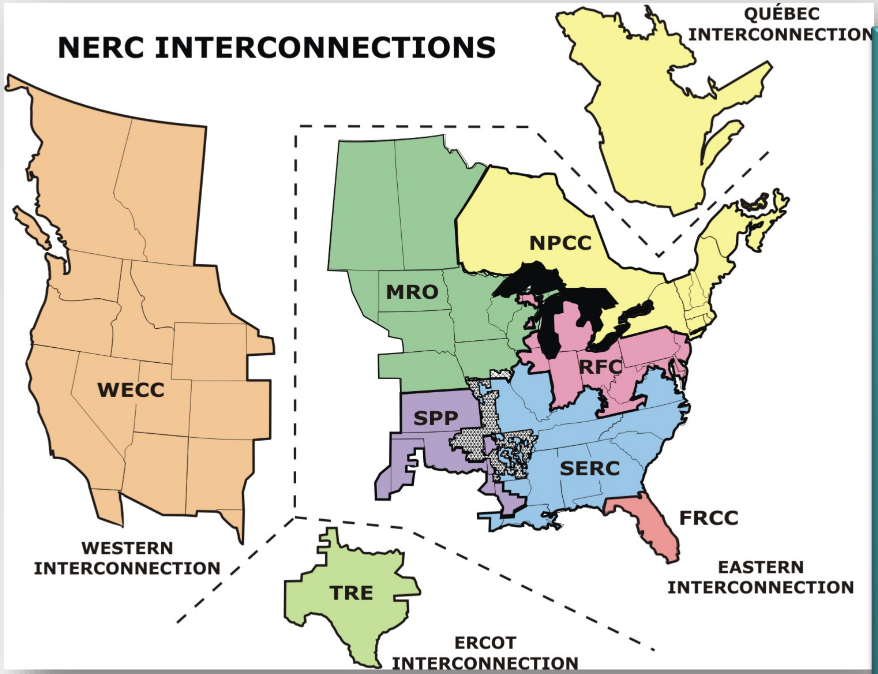
- In ’98, California established a wholesale power market.
- Dramatic price increases and blackouts in California in 2000/2001 rendered this deregulation attempt a flawed grand experiment.
- Despite this setback, a refined wholesale power market continued in California at the transmission level, and power markets eventually emerged in other parts of U.S.

Implications: Accommodating power markets has…

- ***…reduced grid’s ability to plan, and…***
- ***…added uncertainty in grid behavior, dramatically reducing operator time and control for responding to problems.***

Remember the "Interconnection" trend?

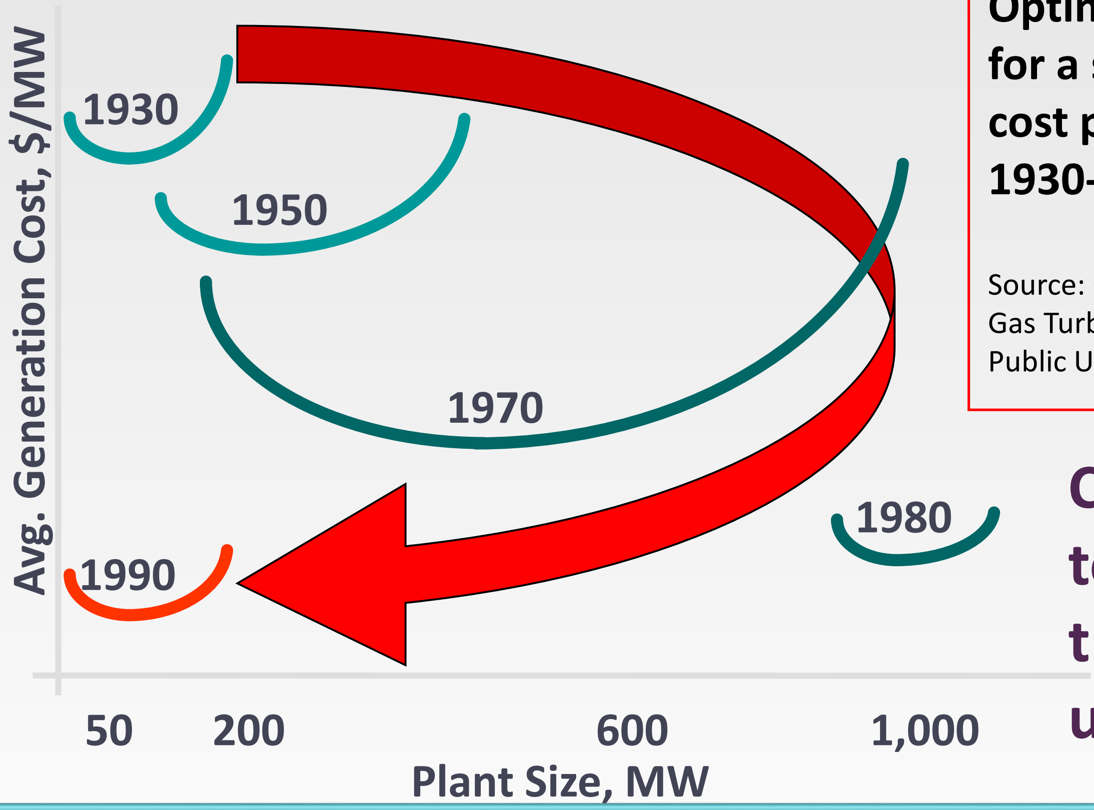
The grid continued to increasingly rely on large interconnections to improve reliability and lower costs, but at a price.



Implications:

- Underinvestment in T reduced the operating margins of safety.
- Operators didn't have adequate real-time wide-area situational information, controls and infrastructure to manage and plan with certainty.
- Local outages could, and did, cascade into massive wide-spread blackouts.

The "Smaller Generator" Trend



Optimal generation plant size for a single plant based on cost per megawatt [MW], 1930-1990

Source: Charles E. Bayless, "Less is More: Why Gas Turbines Will Transform Electric Utilities." Public Utilities Fortnightly 12/1/94

Changes in generation technologies improved the economics for small unit sizes.

Implications: Generator ownership became more feasible for non-utilities and electric customers. Distribution was not designed for this trend, especially the potential for two-way power flow.

The "Change in Customer" Trend

Electric customers changed too.

- **Customers became more "electrified."**
- **The behavior of the load became less "resistive/inductive" and more "electronic."**
- **Some customers are now beginning to buy electric vehicles.**
- **"Prosumers" have electric generators or storage connected to the grid.**

Implications:

- **Load behavior became more uncertain, modeling less accurate.**
- **Customers are becoming less passive, more participatory in grid.**
- **Grid, esp. distribution, was not designed for the new customer.**

The Second "Environmental" Trend: Climate Change

Climate change mitigation is:

- Restricting the release of CO_2 and other GHG
- Promoting electrification of transportation.

Implications:

- Dramatic rapid significant changes in electric generation resources.
- Potentially large changes in electric consumption patterns.

The Second "Environmental" Trend: Climate Change Threats to Electric System Security

Credit: Left - Mellimage/Shutterstock.com, center - Montree Hanlue/Shutterstock.com
Source: NASA, Global Climate Change, The consequences of climate change, http://climate.nasa.gov/effects/.

Implications:

- **Increased exposure of infrastructure to natural disasters**
- **Changes in energy resource mix and consumption patterns**

The "Electric Grid Resilience" Trend

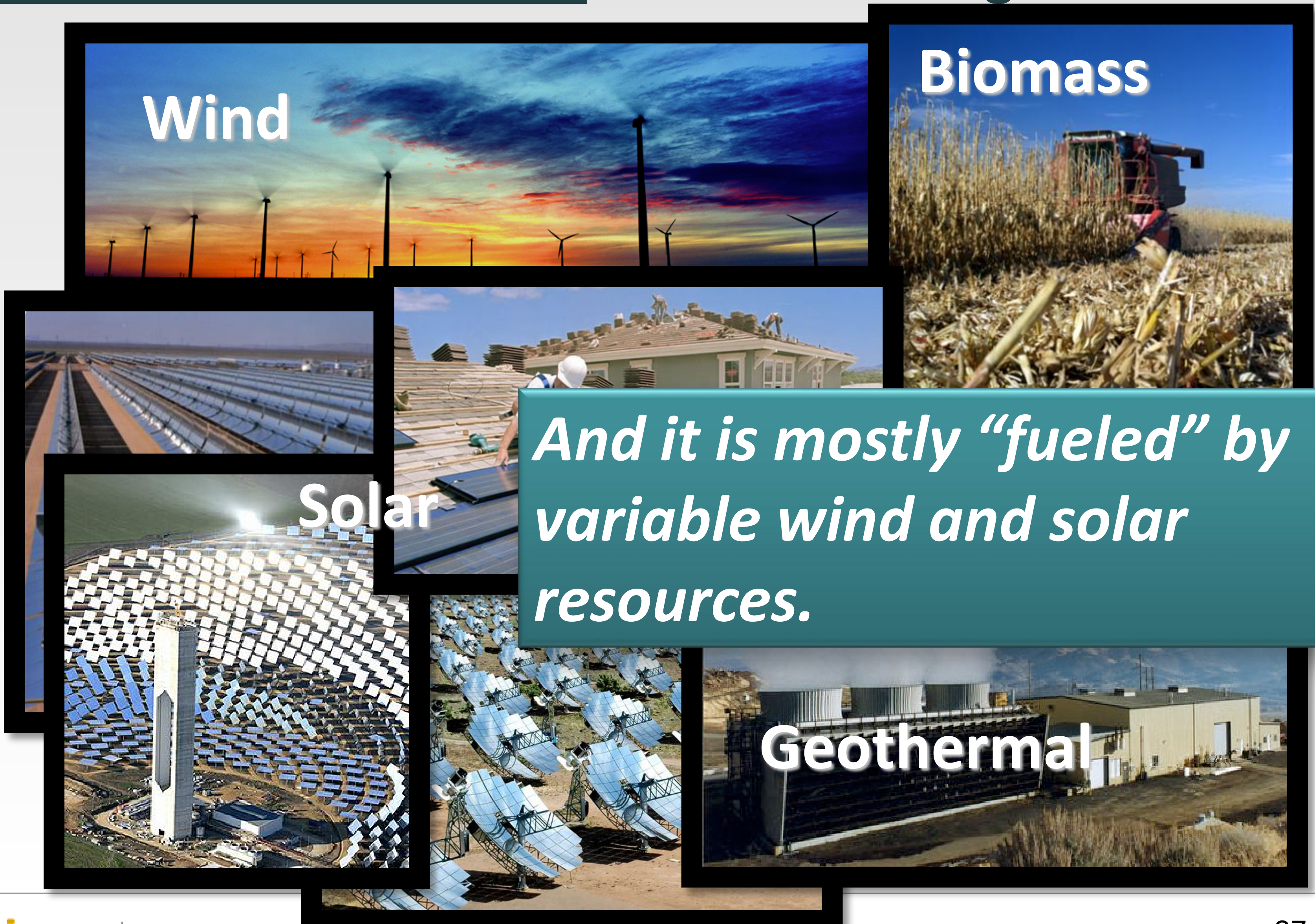
Recent extreme weather events, and other natural disasters, which threaten lives and cause great costs, are causing concern and attention to electric grid resiliency.

Implications: New utility practices and technologies are being developed to:

- ***Prevent*** **damage to electric distribution system**
- ***Recover*** **quickly from damage**
- ***Survive*** **at some basic level of electrical functionality to individual consumers or communities**

Source: "Grid Resiliency," Electric Power Research Institute, http://www.epri.com/Pages/Grid-Resiliency.aspx

The "Renewable" Trend: We are seeing more of this:

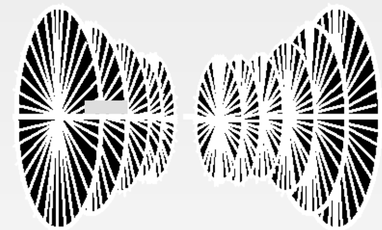


And it is mostly "fueled" by variable wind and solar resources.

Many variable renewable power plants have no inherent energy storage – a significant 1^{st} for the electric grid.

- **Traditional (thermal and hydro) power plants have built-in energy storage in the fuel or ponded water.**

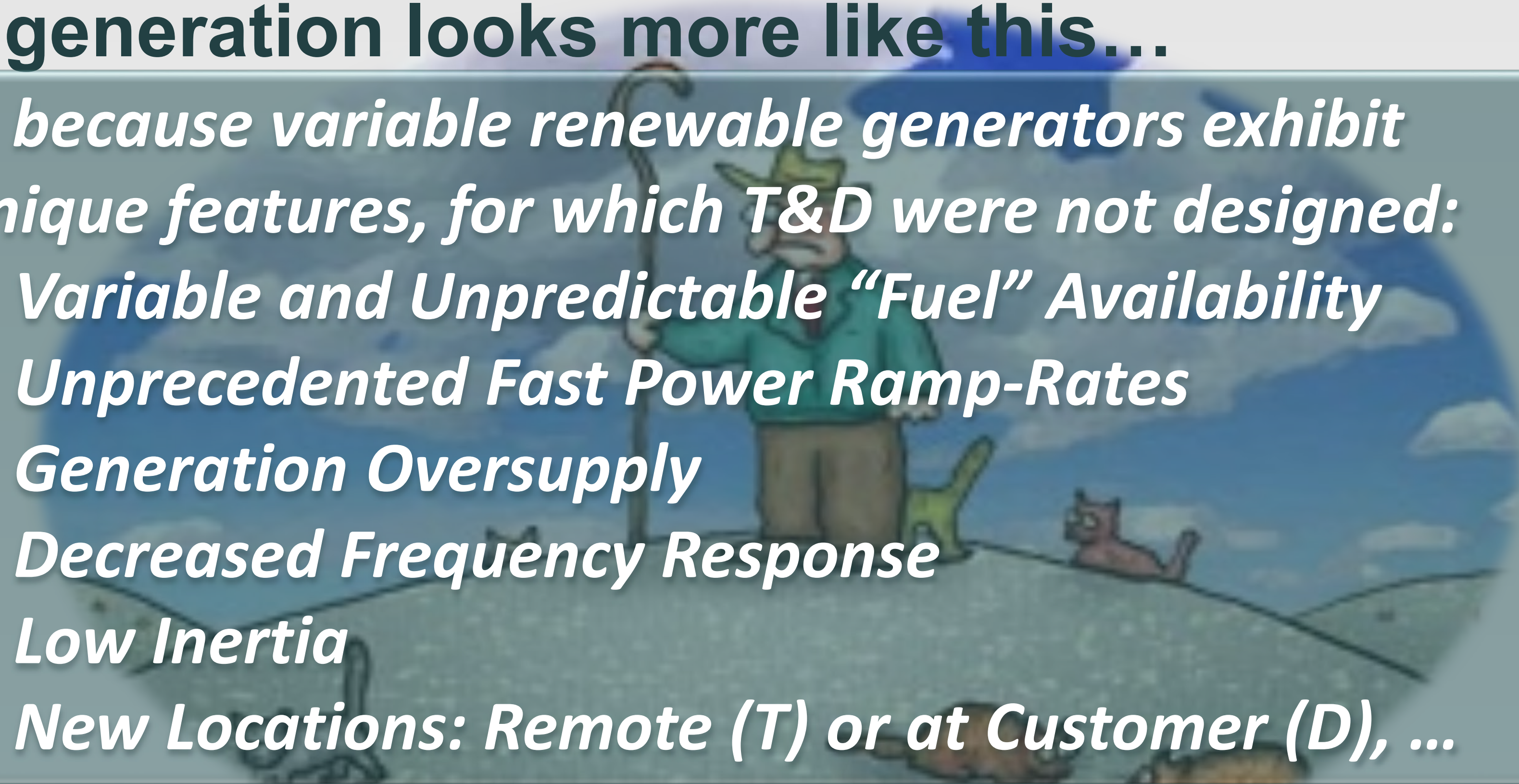
- **The power grid is designed and operated under the influence of inherent inertia in the rotational mass of the turbine-generators in traditional (thermal and hydro) power plants.**



- **But wind and some solar power plants using electronic power conversion have little or no fuel storage or inertia.**

This lack of these inherent energy storage features is unprecedented in the electric grid.

To grid owners and operators, renewable generation looks more like this…

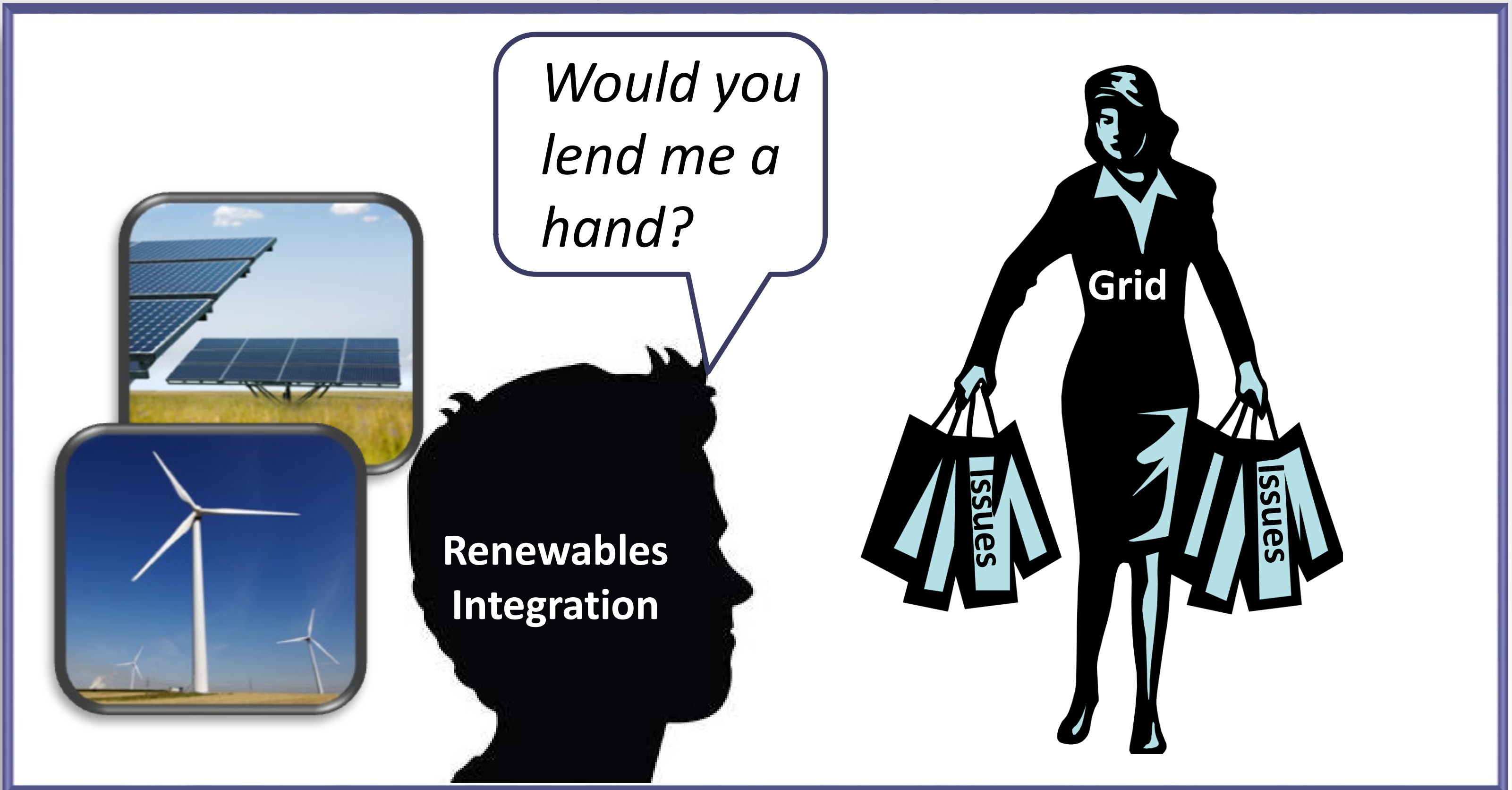


… because variable renewable generators exhibit unique features, for which T&D were not designed:

- ***Variable and Unpredictable "Fuel" Availability***
- ***Unprecedented Fast Power Ramp-Rates***
- ***Generation Oversupply***
- ***Decreased Frequency Response***
- ***Low Inertia***
- ***New Locations: Remote (T) or at Customer (D), …***

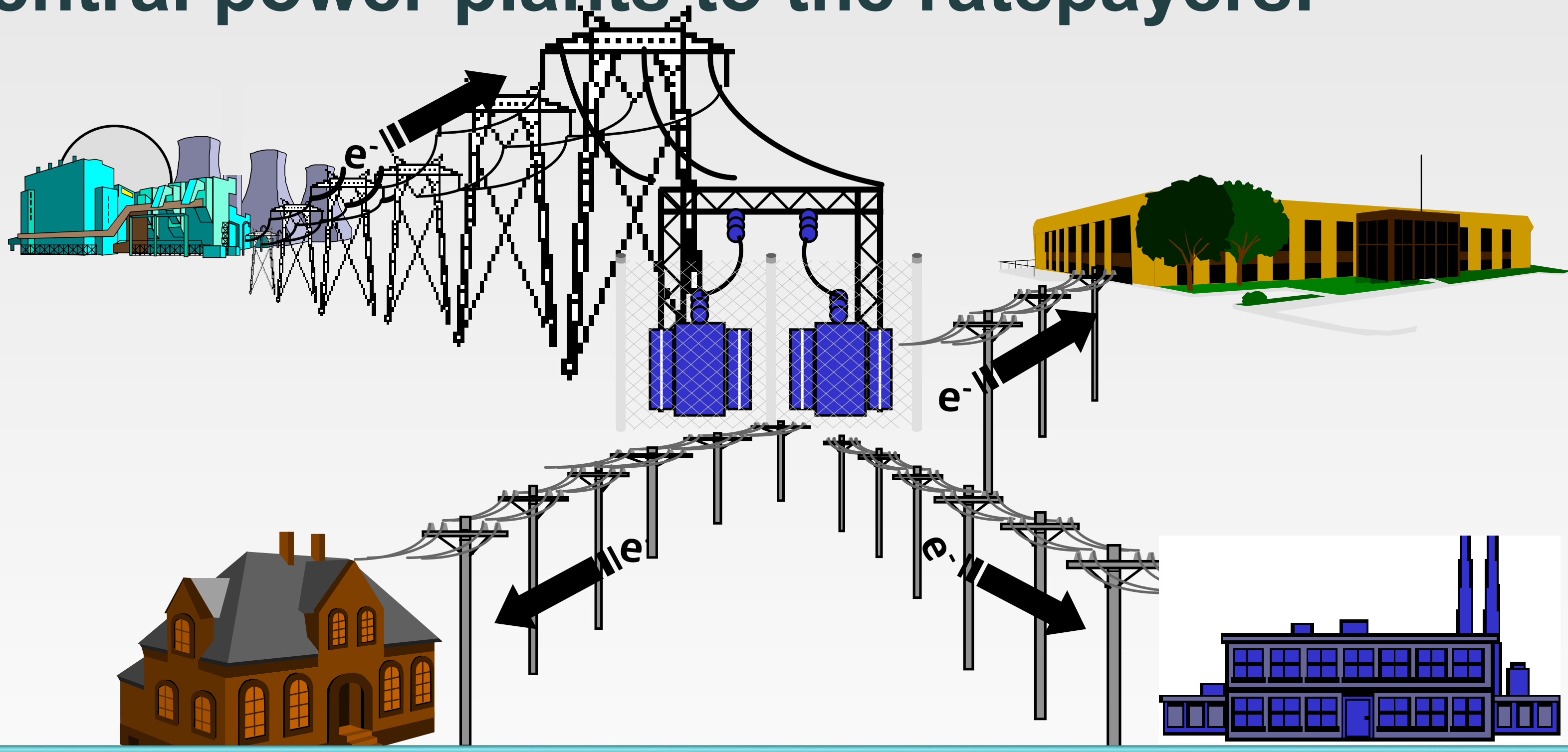
... causing great uncertainty for T&D owners and operators, and concerns about reduced reliability, safety and power quality, and higher costs.

Renewables integration is a major new challenge for the 21st Century electric grid.



But it is important to remember that the grid also has its hands full with legacy issues from the 20th Century.

For most of the 20th Century, the electric grid had a relatively simple role: moving electricity from central power plants to the ratepayers.



Its behavior was predictable, operation was largely deterministic, and an operator was in control.

But the 21st Century electric grid faces:

- A growing tension between reliability and cost
- Aged underbuilt infrastructure strained to the limits; new infrastructure increasing difficult to site and permit
- Inadequate situational visibility of grid for operators
- The threat of extremely costly and disruptive wide-area blackouts, and increased enforcement of grid standards.
- Accommodating the uncertainty of electric markets in planning and operation, and a growing and changing electric customer base
- Complying with public policy pressures, esp. concerning environmental impacts & regulations, high use of renewable generation
- Protecting grid security and customer privacy

The result is growing uncertainty, complexity, inadequacy, and conflict, and need for flexibility, robustness, real-time situational awareness, probabilistic forecasting, and rapid response.

Making decisions for the *21st Century grid* uses an increasingly complex "equation."

f(reliability vs. price) ~ G(utility, non-utility, imported, renewable, distributed, customer,) + T(utility, merchant, interconnection, dynamic control) + D(utility, dynamic control, microgrid) + E(customer, grid, generation) + S(utility-scale, distributed, customer) + DR (utility, customer)

Where: f = policy, planning or investment decision; G = electric generation capacity or energy; T+D = transmission and distribution capacity; E = energy efficiency; S = energy storage; DR = demand response

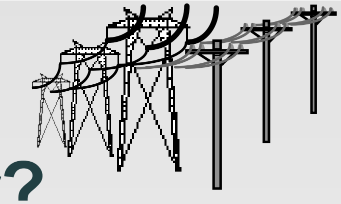
There will be many players, including customers, making many decisions, requiring unprecedented smarts.

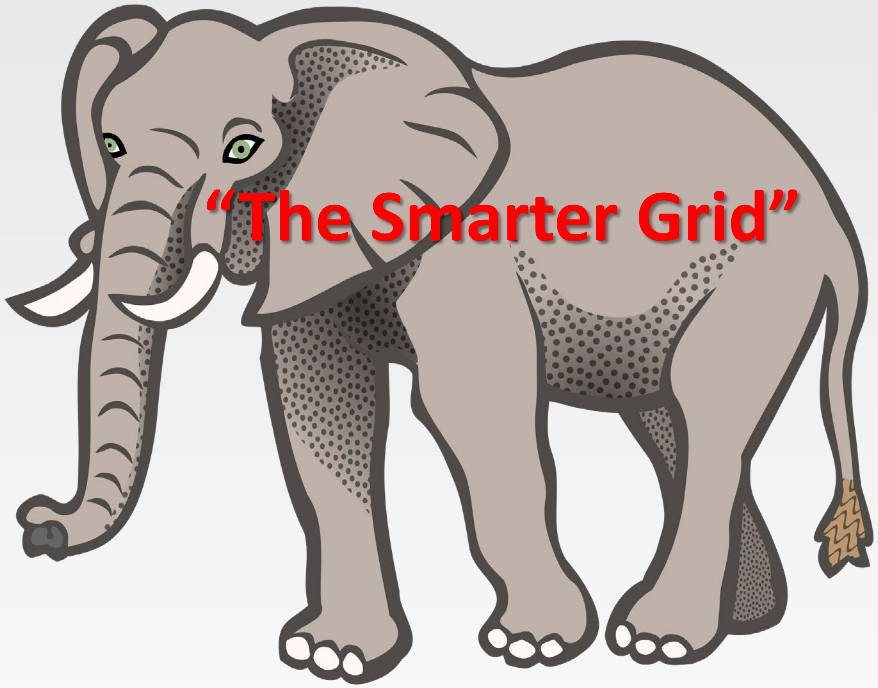
Assertions: Perhaps for now we can "build" our way out of these problems, but soon…

- …traditional "build" solutions, i.e., investments in wires, towers and power plants, can't do it alone.
- New technologies will be needed to make planning, siting, building, and operating easier and less costly…

…especially technologies that make the grid smarter.

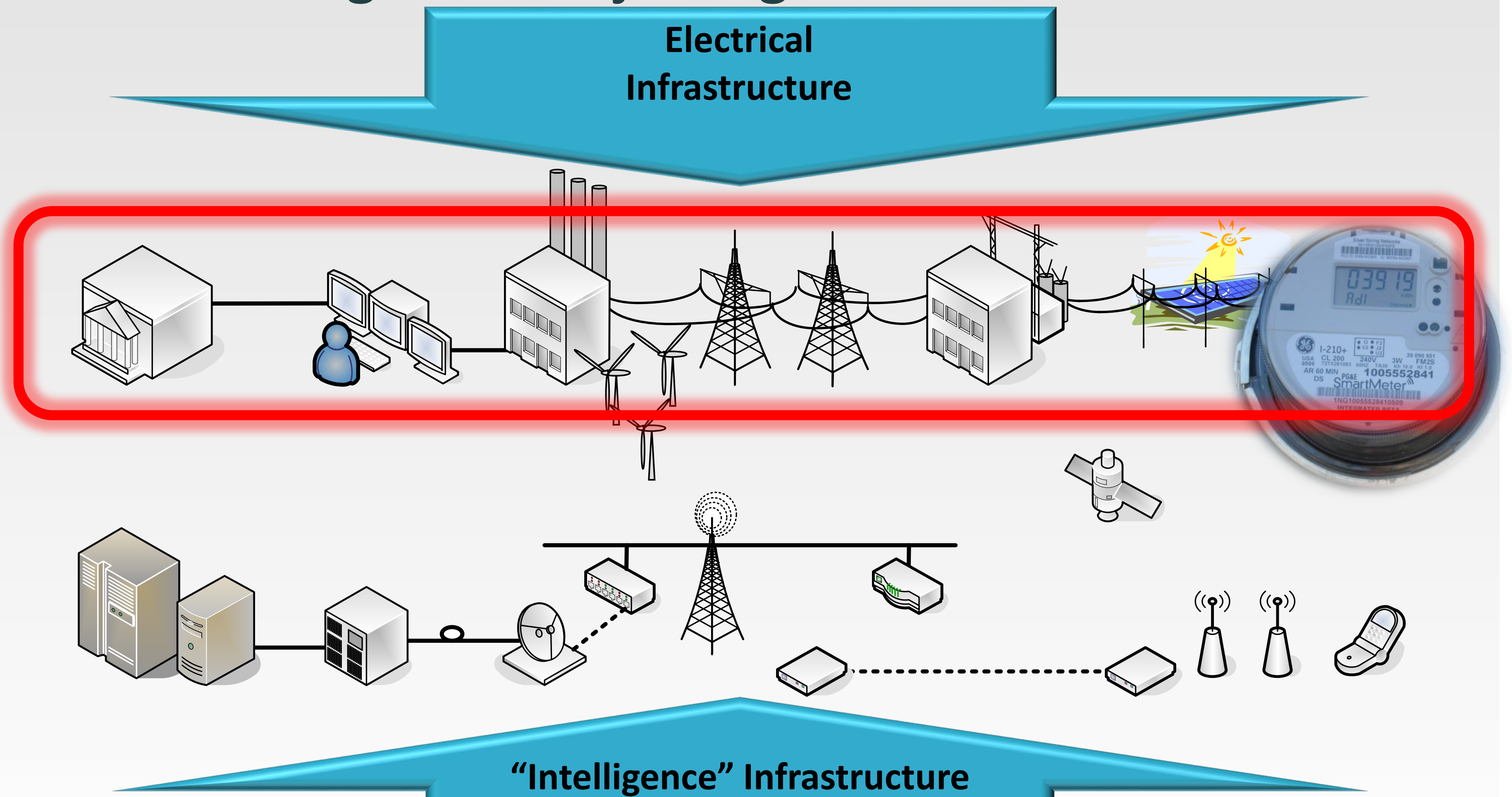
Now that we perhaps see the “elephant” more clearly, does it matter?





If “form” is to correctly follow “function,” I think it does matter that we see the smarter grid in it historical complexity. A few cautions follow in the next few slides.

A smarter grid is the joining of two infrastructures:



While the focus has been on the smart meter, "smarts" must be applied throughout the grid value chain.

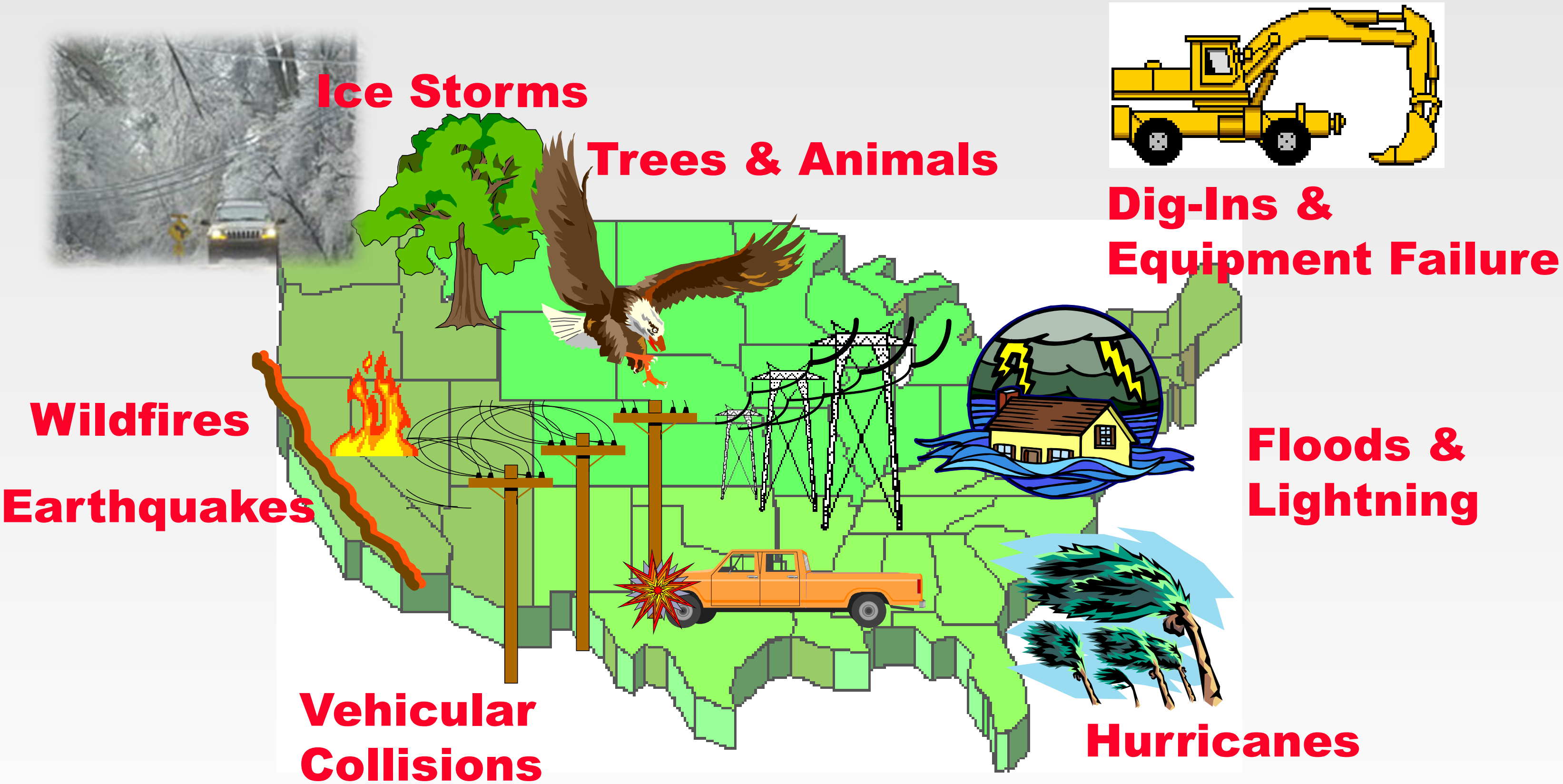
Automation is a “natural” for the smarter grid.

Source: https://www.theguardian.com/technology/2016/oct/11/crash-how-computers-are-setting-us-up-disaster

1. Should human operators “babysit” the automation, or
2. Should automation “babysit” the human operators?

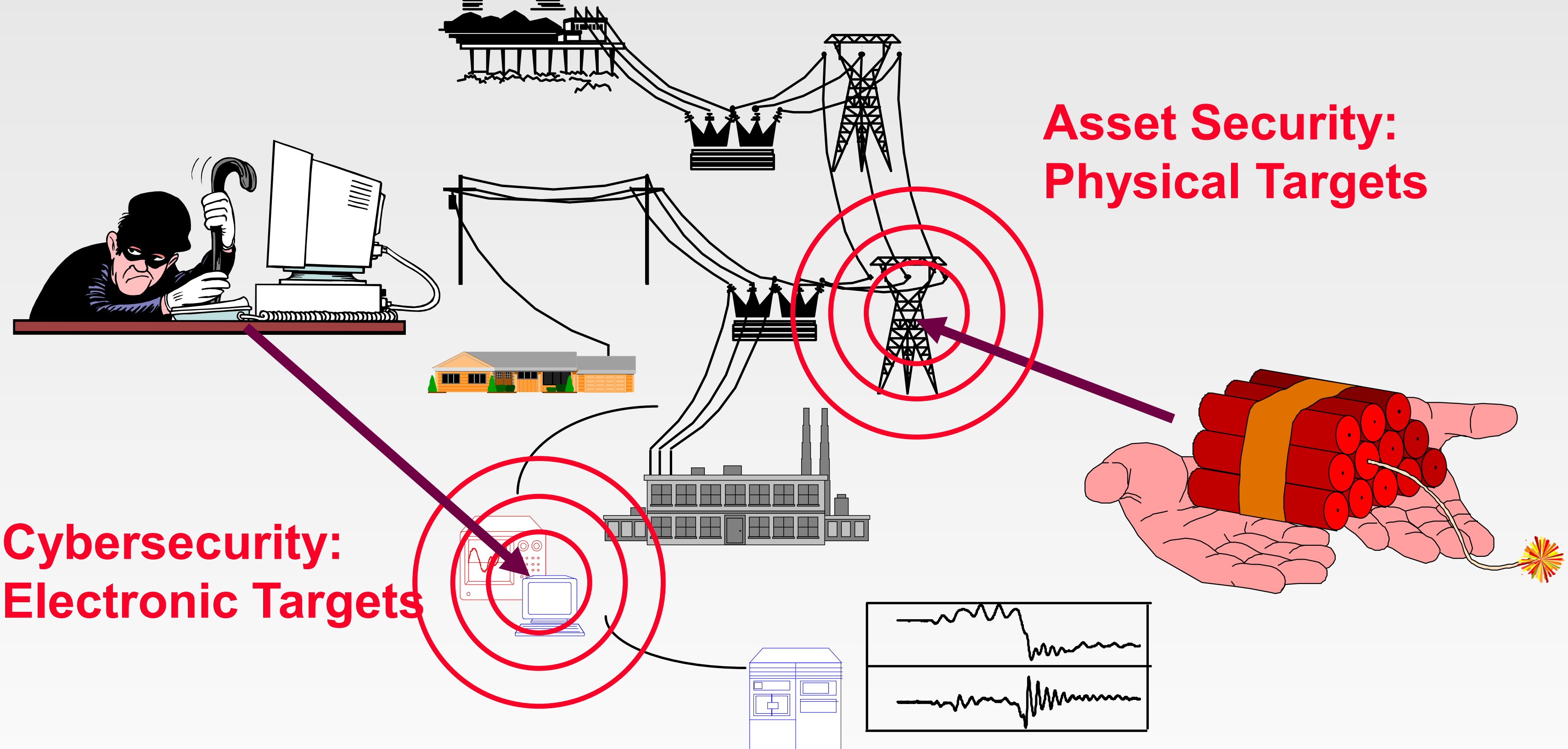
There’s argument for #2, but would that significantly reduce the role of automation?

Disruptions from acts of nature and accidents are random.



Many events are frequent, with low impacts; others, while rare (for now), can become major disasters. The vast majority of outages are at the distribution level.

Terrorism and Vandalism are a growing organized threat to energy security.



Cybersecurity is uniquely a factor of the smarter grid; and the "internet of things" is especially worrisome.

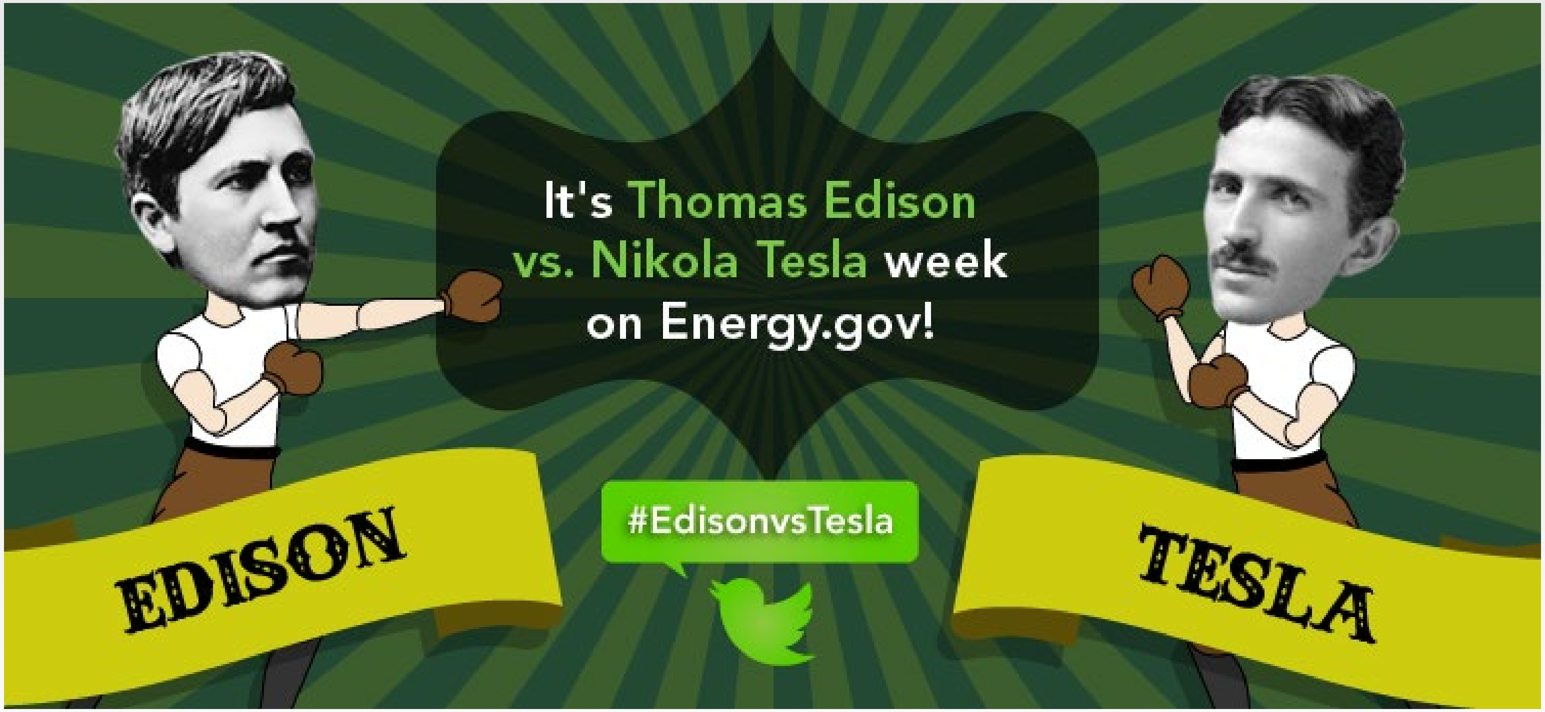
Must avoid creating an "inverse Frankenstein monster" from a Smart Grid.

- To be useful, even superb knowledge must be actionable.
- To be superbly actionable requires a superb physique.

The physical "electrical" infrastructure for the 21st Century grid also needs new technology and assets.

A smarter grid is not an option; it is a necessary, if not sufficient, investment for keeping the lights on and electricity prices in check for the 21st century.

Has a century of changes brought us full circle?



Edison's DC grid might be being revived for a new technology era in the 21st Century electric grid.

"People tend to overestimate what can be accomplished in the short run but to underestimate what can be accomplished in the long run."

Arthur C. Clarke

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