Plausible Futures for Electric Grid Architecture

-A Scenario Planning Exercise-

Presented to

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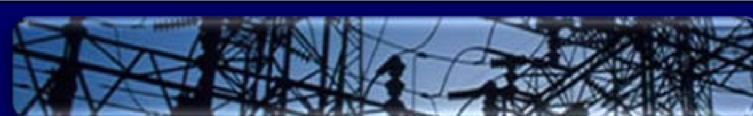

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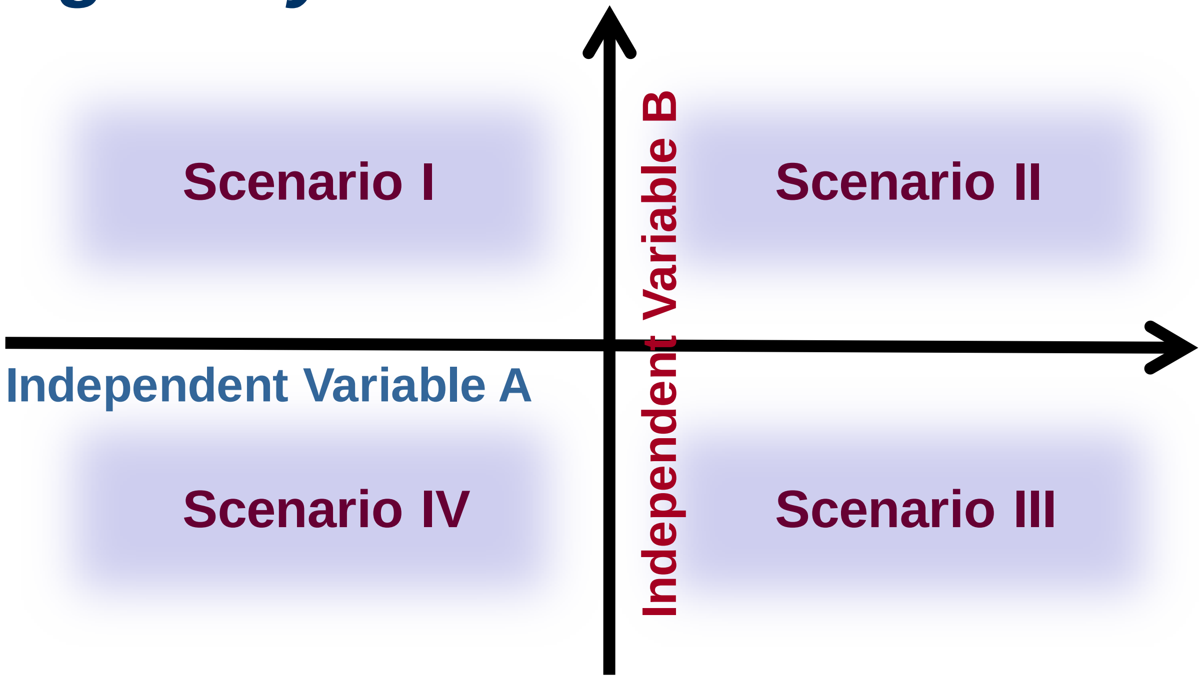
We explore the future of electric transmission and distribution systems through scenario planning analysis.



Different plausible futures are the logical implications of cause & effect interactions of the variables in each quadrant.

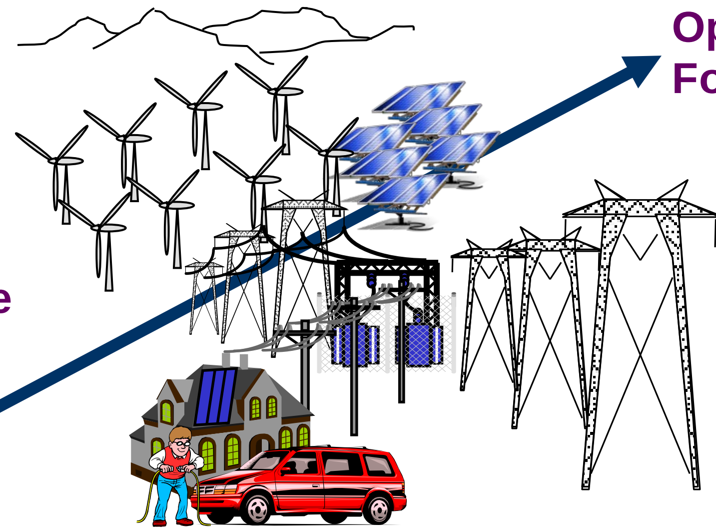
We begin by observing past changes of key properties of T&D community.

"~2050?"

Role: ?
Operation: ?
Form: ?

"Yesterday" – 1890s to 1960s

Role: Physical Link: Generator to the Meter under a Regulatory Compact
Operation: Deterministic & Planned
Form: Mostly Radial, Grew in Bulk more than Intelligence

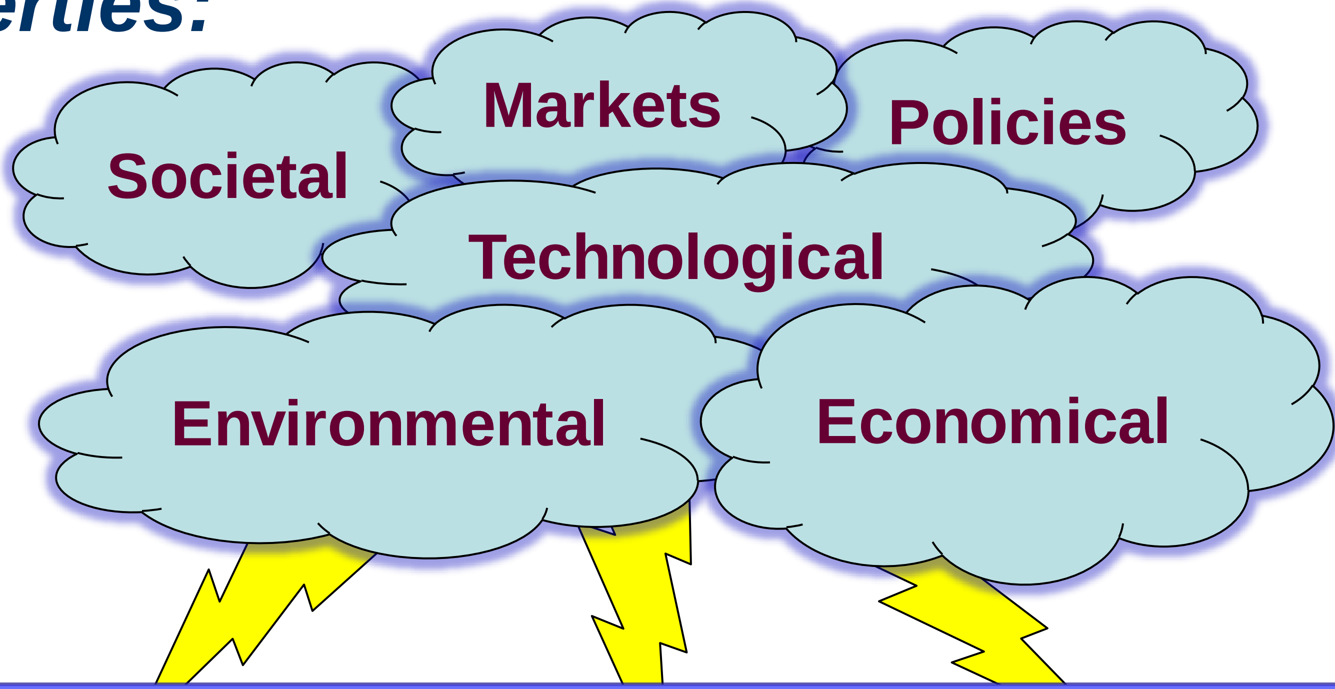


"Today" – 1970s to 2020s

Role: Market Facilitator & Power Delivery
Operation: Increasingly Real-Time & Probabilistic
Form: Increasingly Networked and Intelligent

Momentum will define much of look of 2020 T&D, but events of this decade will help shape much of the look of 2050. What are they?

Several interactive "exogenous" factors contain drivers that will force change in T&D properties:



It is most instructive to pick the pair of factors containing the highest degree of uncertainty in how key drivers will play out. But which two?

Some specific drivers of change in T&D are:

- Economic pressure for lower costs
- Electric loads will grow and continue to shift from resistive/inductive to electronic
- Less land available for T&D infrastructure
- Energy efficiency, demand response, distributed generation and renewables impacts
- Enabling T&D technology development for smart grid, new materials, and analysis & design
- How technology will be used
- Energy markets and tariffs
- Siting/permitting of power plants and grid infrastructure
- Environmental laws

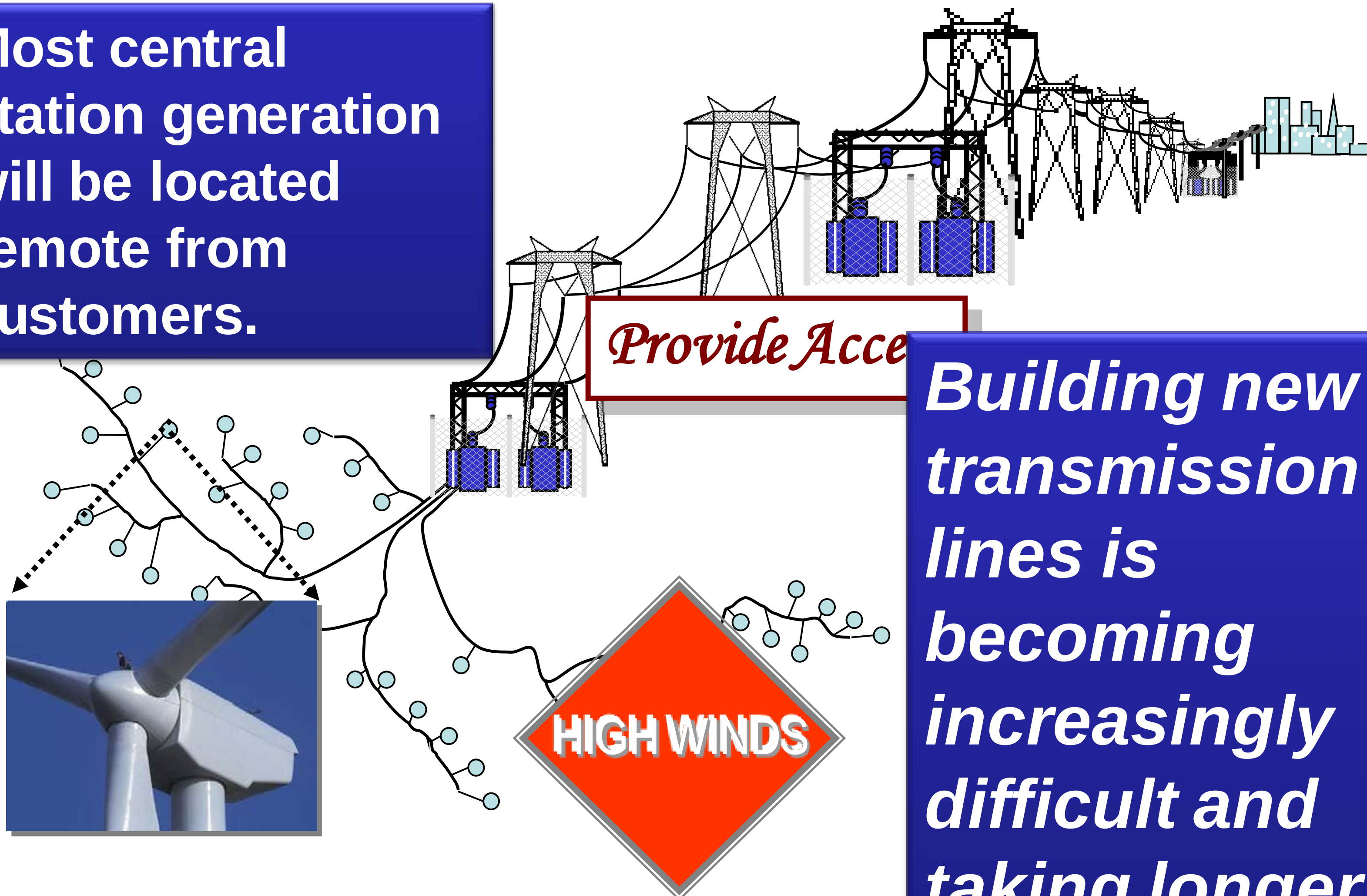
~Uncertainty

Which pair of drivers will interact to create the most uncertainty for the future grid?

A look at how these drivers affect grid expansion & operations today provides insights.

The Saga of Transmission Expansion and Operations

Most central station generation will be located remote from customers.



Building new transmission lines is becoming increasingly difficult and taking longer.

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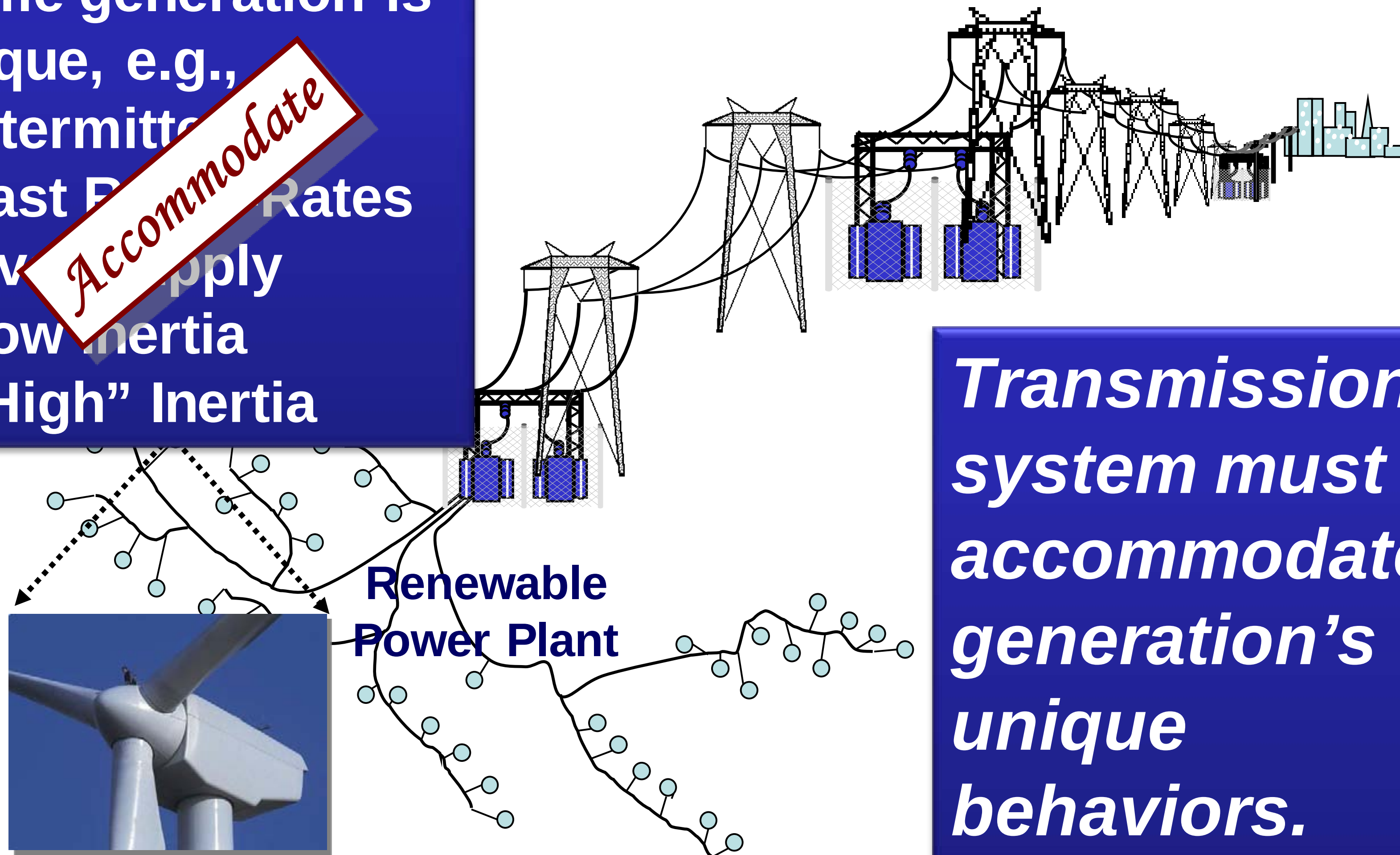
The Continuing Saga of Transmission Expansion and Operations

Some generation is unique, e.g.,

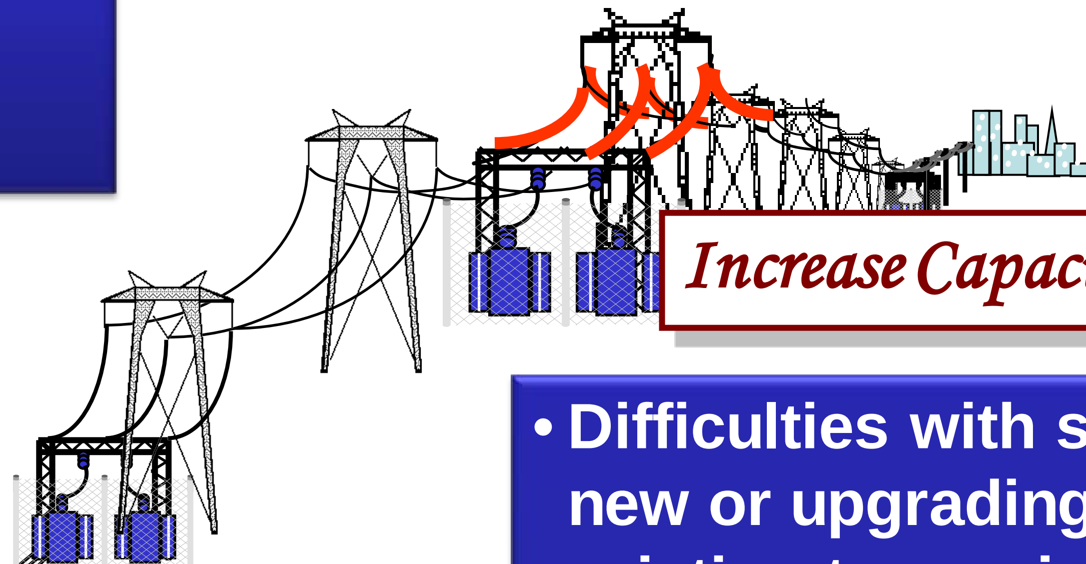
- Intermittency
- Fast Ramp Rates
- Oversupply
- Low Inertia
- "High" Inertia

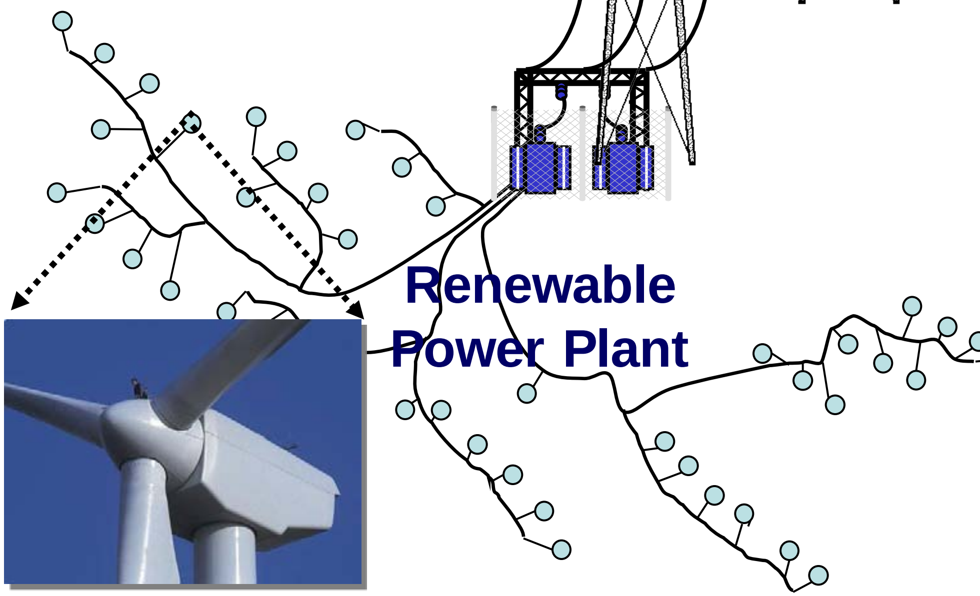


Transmission system must accommodate generation's unique behaviors.

The Continuing Saga of Transmission Expansion and Operations

Existing infrastructure is constrained.





- **Difficulties with siting new or upgrading existing transmission**
- **Thermal Limits**
- **Stability Constraints (Voltage, Transient, Dynamic)**
- **“N-1” Contingencies**

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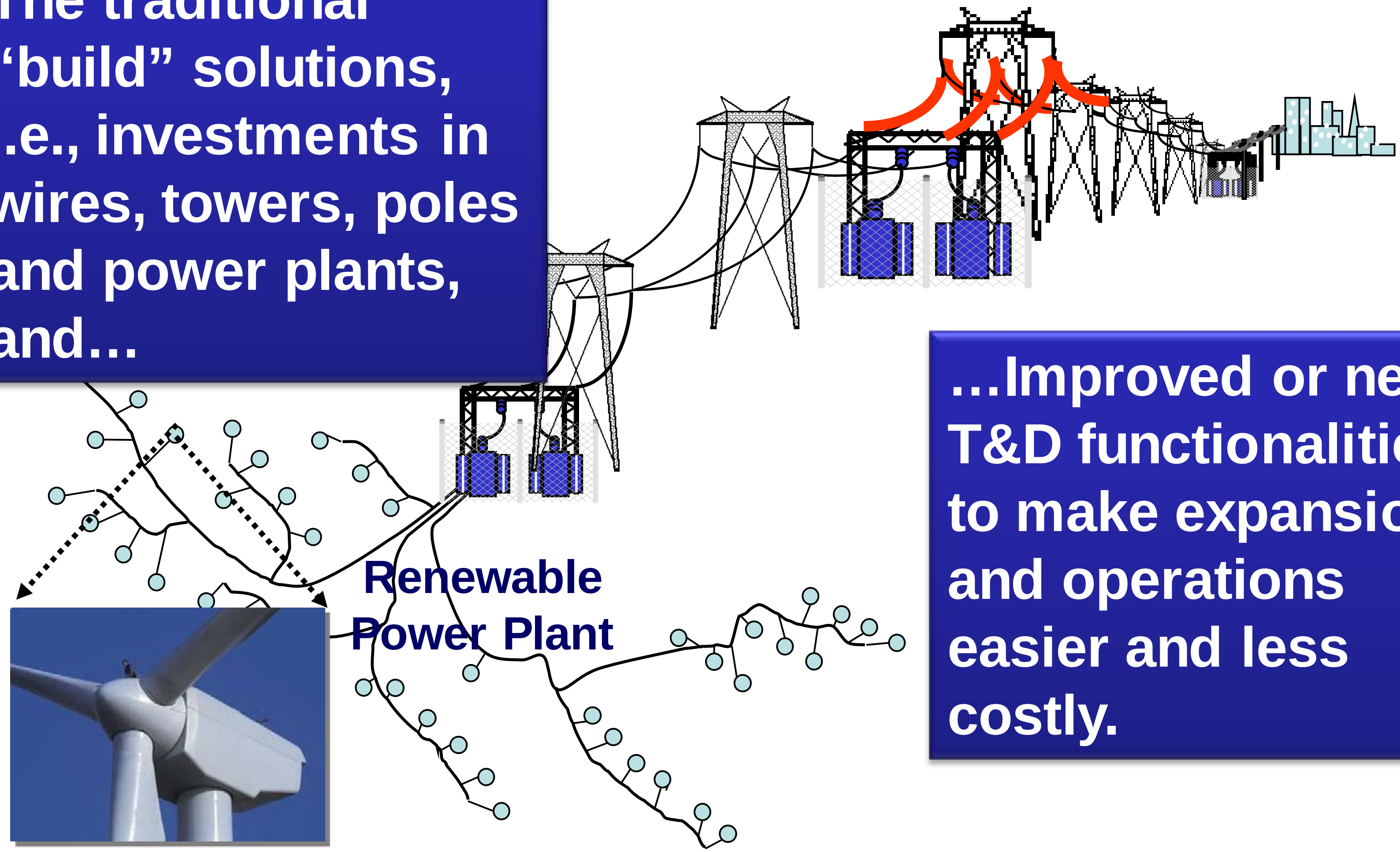
There are essentially two options for successful expansion and operations of T&D:

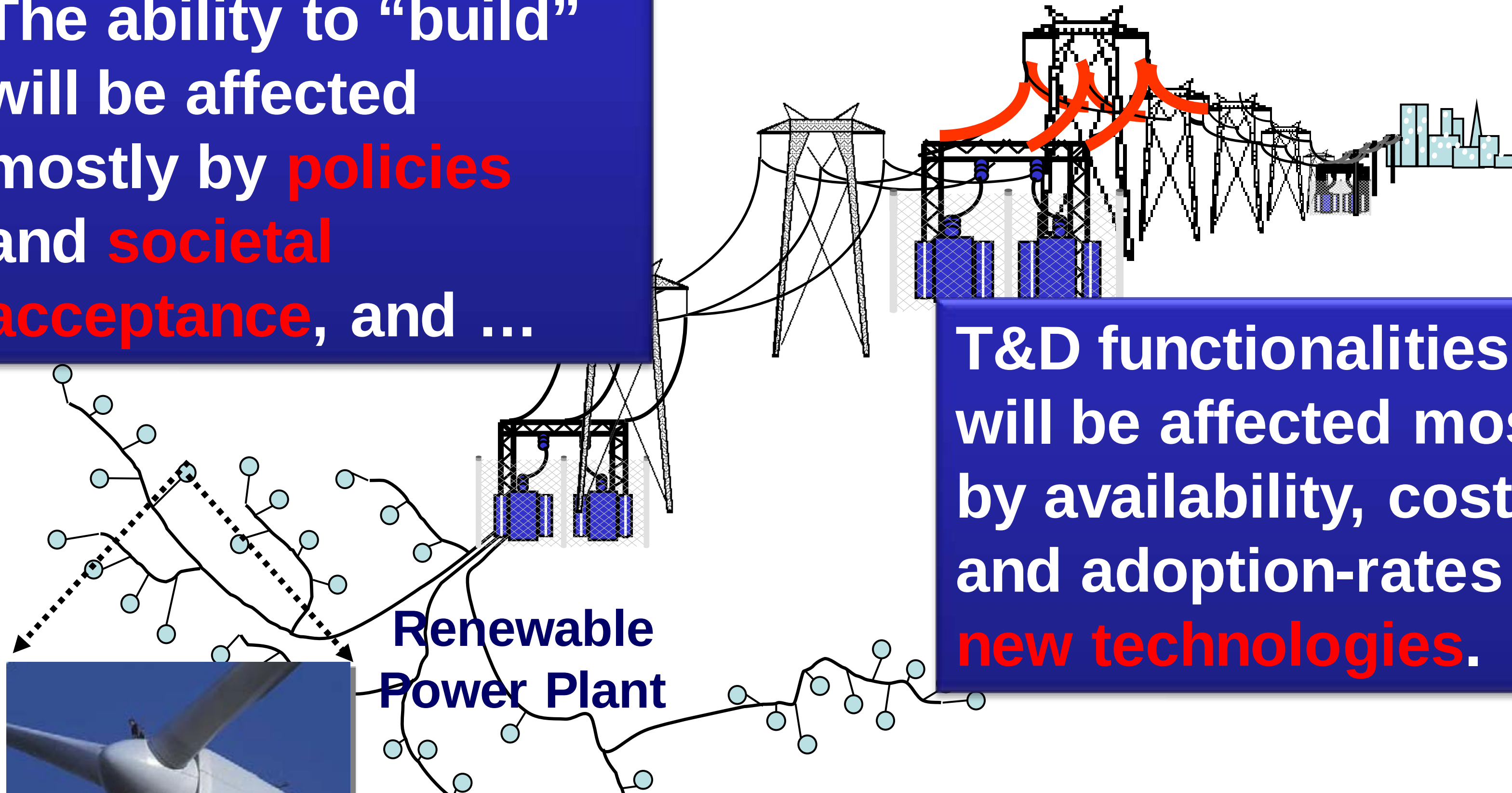
The traditional "build" solutions, i.e., investments in wires, towers, poles and power plants, and…



…Improved or new T&D functionalities to make expansion and operations easier and less costly.

From this study we make two assertions:

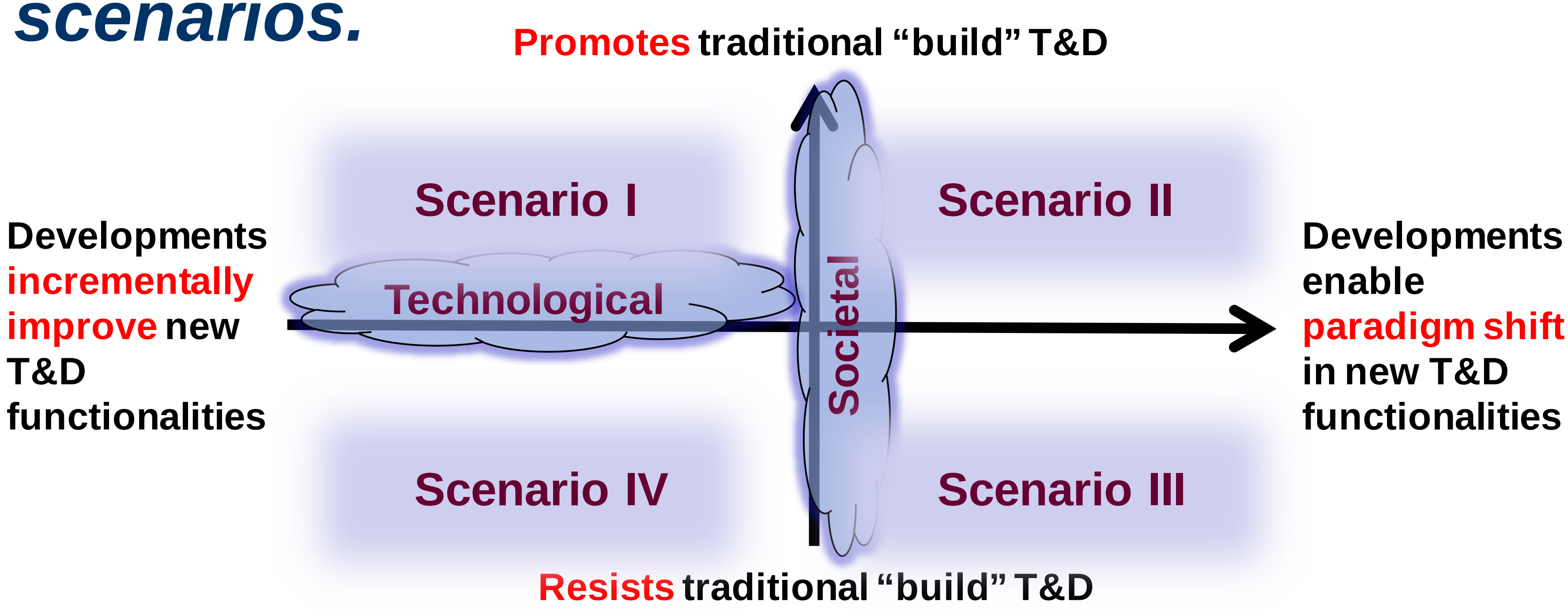
The ability to "build" will be affected mostly by policies and societal acceptance, and …



T&D functionalities will be affected mostly by availability, costs and adoption-rates of new technologies.

Note: These two sets of drivers – societal and technological – are among those we considered most uncertain.

Interactions between the 2 orthogonal axes of uncertainty – societal policies & norms and technological developments & use – form 4 scenarios.



It helps to define each uncertainty continuum in the terms of its extremes.

Two Extremes of the T&D Technological Continuum Future

Incremental Improvements

T&D functionalities improved only incrementally because new technology:

- Development encounters intrinsic physical difficulties
- Is used to "patch" the old infrastructure because it cheaper & easier
- Is too risky for T&D owners, operators, investors and regulators

Paradigm Shifts

T&D functionalities substantially improved because new technologies cost-effectively enable:

- Improved access for new generation by putting new T&D lines in a "better light."
- Accommodating unique generator and demand behavior through a smarter and more flexible grid
- Increased T&D capacity by optimizing the grid for greater power flow.

How will technology use, or under use, affect role, operation & form of future T&D?

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Two Extremes of the Societal Continuum → Future

Society Resists T&D Build-out

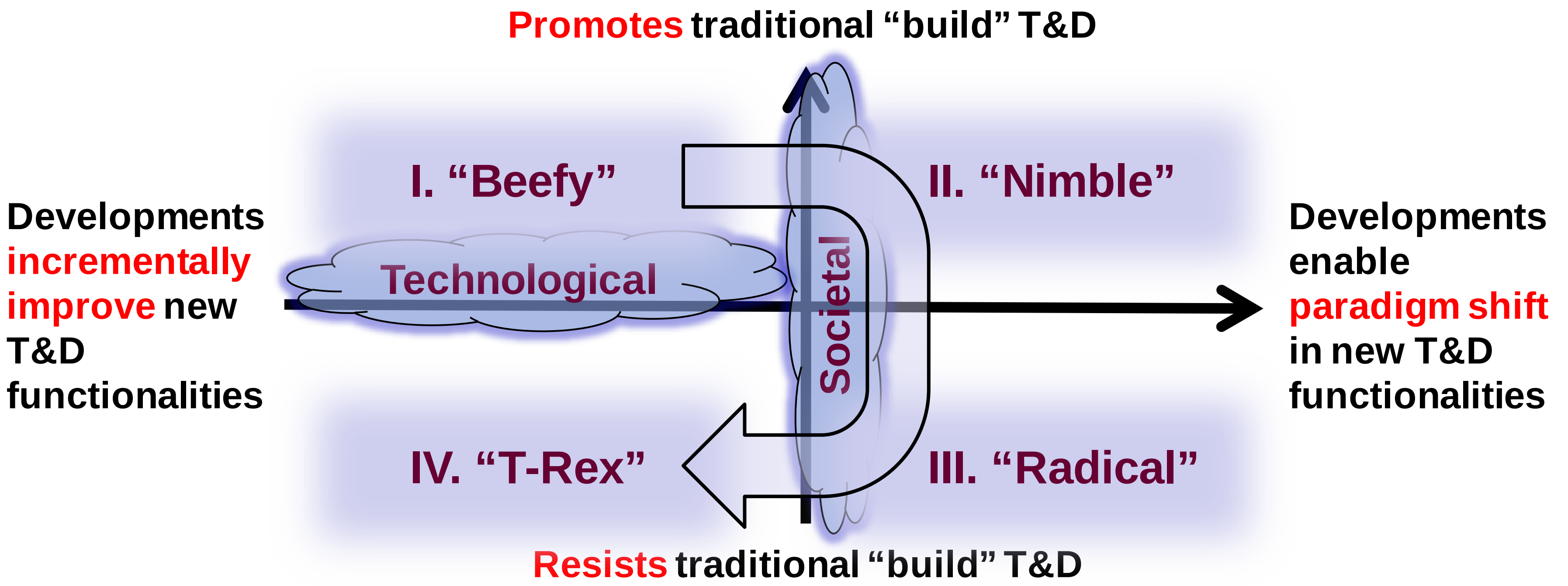
- Permitting of transmission projects takes longer or doesn't happen.
- Cost/benefit allocations contested/prolonged.
- Pressure to keep down infrastructure costs.
- Incentive tariffs and regulations for demand response, energy efficiency and/or distributed generation succeed.

Society Promotes T&D Build-out

- Concerns about power outages, congestion costs, national security and economic health lead to more use of eminent domain, pro-T&D legislation and/or tolerance for T&D projects .
- Incentive tariffs and regulations for demand response, energy efficiency and/or distributed generation fall short.

How will societal policies and norms affect the role, operation & form of future T&D?

Imagine how T&D might uniquely evolve under the conditions in each quadrant.



Let's look at the three properties of role, operation and form for each scenario.

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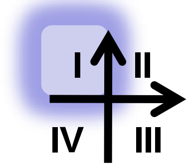
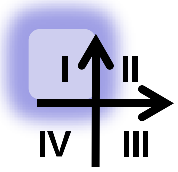
I. The “Beefy” T&D Infrastructure

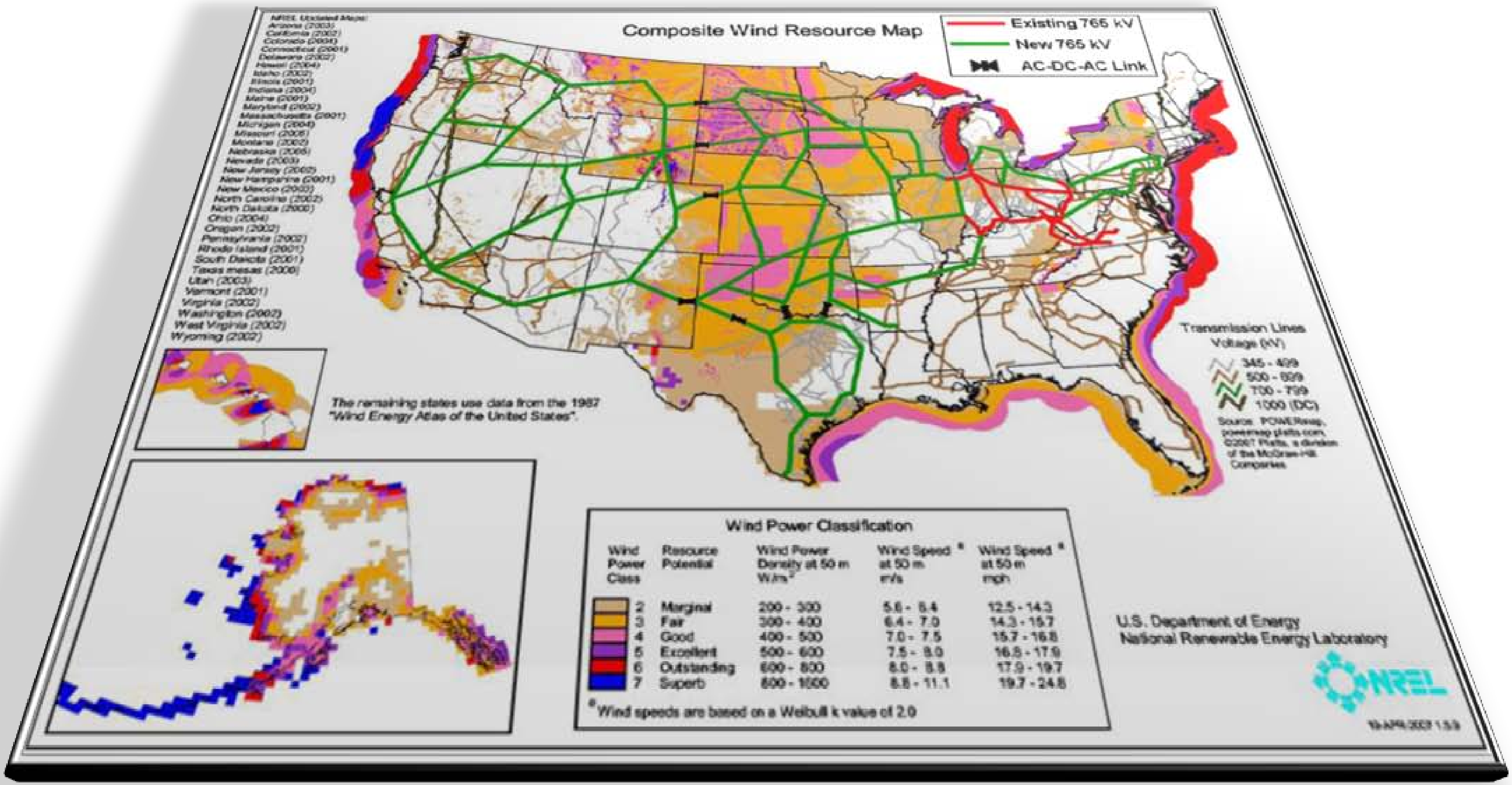


- **Role – Same as “Legacy Grid”**
  - To deliver and market significant amounts of electricity generated by central station power plants.
- **Operations – Same as “Legacy Grid”**
  - Smart grid largely limited to situational awareness for reliability, and business and market transactions among generators and consumers.
- **Form – Much more of the “Legacy Grid” → “Metallic Sky”**
  - Wires, towers and poles make a visible presence.
  - Wind in the central and solar in the southwest U.S. lead to “interstate highway” high voltage grid.
  - Demand response & distributed generation limited by inflexible grid

Caveat: A.C. instability resulting from large power transfers over long distances could cap growth of system.

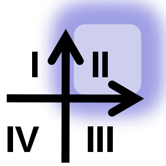
The "interstate highway" high voltage grid might be a sign of the "Beefy" grid.





But is there a stability limit to capacity?

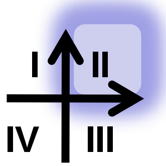
II. The "Nimble" T&D Infrastructure

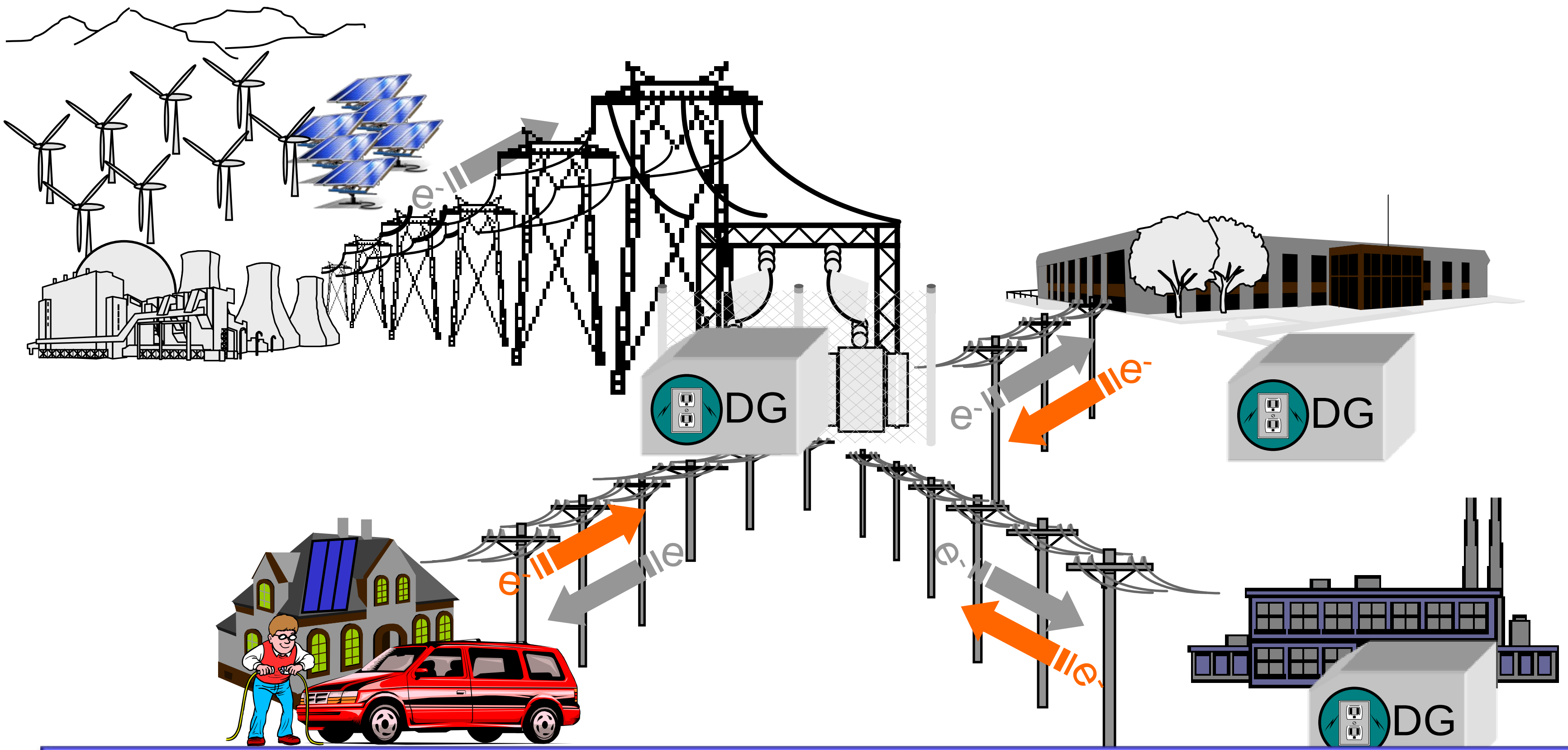


- **Role – Same as "Legacy Grid" but w/ "Finesse"**
  - **To deliver and market electricity generated by a broad spectrum of central station and distributed resources.**
- **Operations – The "Optimized Legacy Grid"**
  - **Smart grid used for "command and control," increasing roles of demand response, EVs, power flow control, etc.**
  - **Optimized to reduce costs and improve services**
- **Form - more of the "Legacy Grid" but no "Metallic Sky"**
  - **Wind in the central and solar in the southwest U.S. lead to "*smart* interstate highway" high voltage grid.**
  - **Temporal (storage) and power flow controls used for grid support/stability**
  - **Distributed generation accommodated by flexible and resilient distribution system.**

Motto: "Deliver a kWhr from anywhere to anyone at anytime."

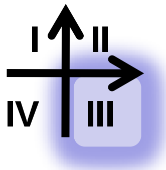
In the “Nimble” scenario, distributed generation emerges and sends power upstream.





Optimized operations via technology means fewer wires & towers.

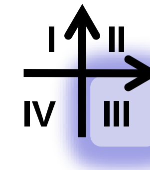
III. The "Radical" T&D Infrastructure

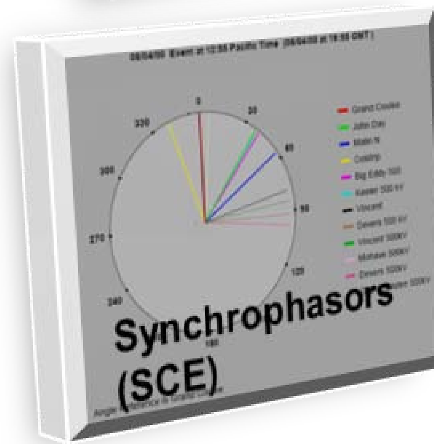


- **Role – Full-Spectrum Service**
  - To deliver and market electricity generated by some central station and significant numbers of distributed power plants.
  - Generators and consumers are clients of T&D services.
- **Operations – "Tricky"**
  - Smart grid used for "command and control," heavy roles for demand response, EVs, time (storage) & power flow controls, etc., and optimization of supply, demand and grid assets.
- **Form – Local and Regional Networks**
  - Underground transmission, compact design, dynamic ratings, etc., are in a "horse race" with distributed generation, demand response and microgrids.
  - Time (storage) and power flow controls used for grid support and optimized utilization

The grid "body" has a "legacy look" on the outside with a "radical mind & sole" inside.

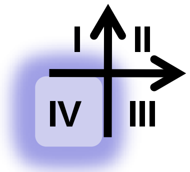
The "Radical" scenario is all about technology and complicated operations and services.





Scenario III might be the scene of a contest between the "invisible T" and the "microgrid."

IV. The “T-Rex” “T&D” Infrastructure



- **Role – Support a Local Electric Market**
  - o **To market and deliver electricity at the “distribution” level**
- **Operations – Two-Way Power Flow**
  - o **Low-voltage distribution network, with two-way flow, operated much liked mini-transmissions with smart grid used for situational awareness, supervision and control**
- **Form – T-Rex and Microgrids**
  - o **Transmission becomes the “pay phone booth,” a dinosaur**
  - o **Microgrids, with distributed generation, especially fuel cells, connected by distribution network**
  - o **Electric transmission largely replaced by pipelines for fuel, e.g., hydrogen, produced by wind in the central U.S., and solar in the southwest U.S., nuclear, etc.**

While “T” struggles to survive, electricity production and consumption shift to “D.”

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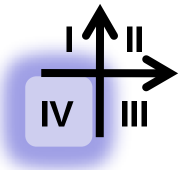
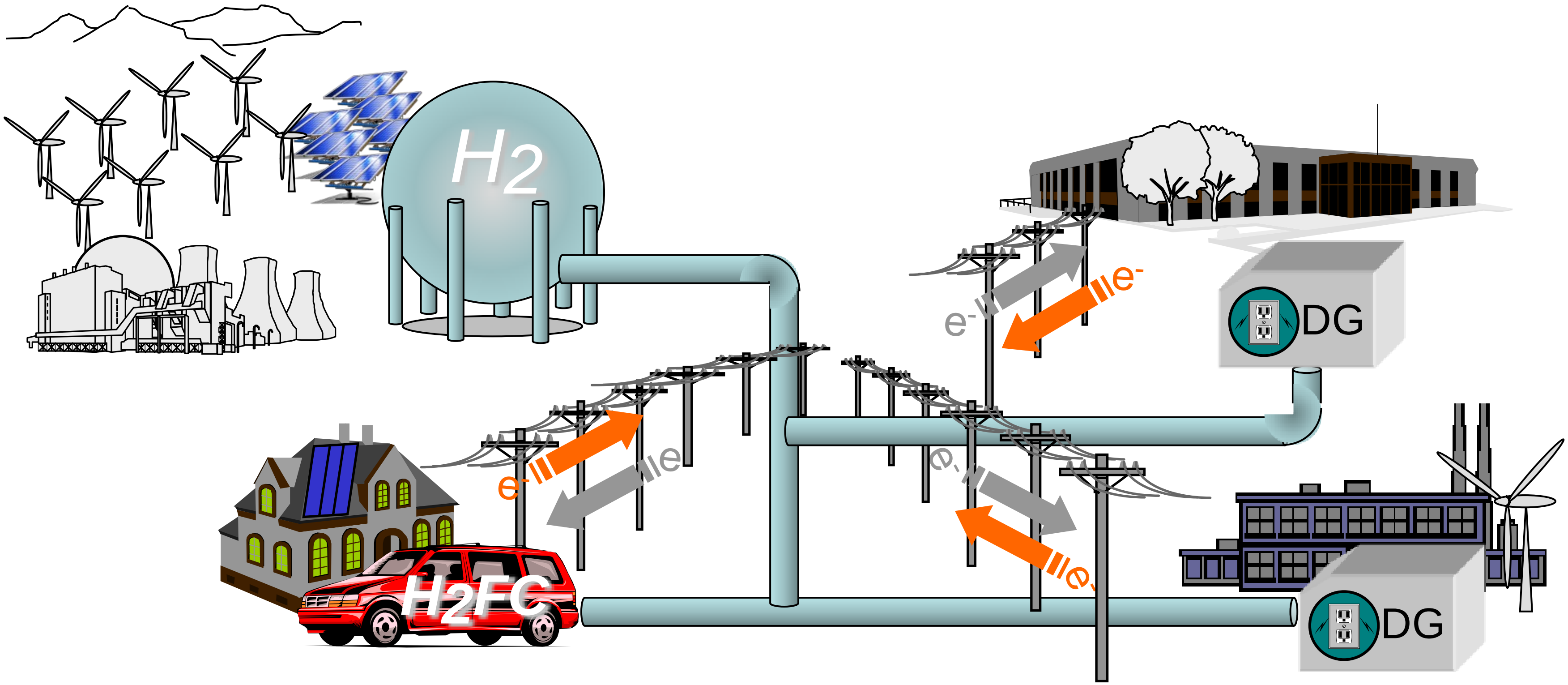
In the "T-Rex" scenario, transmission's energy delivery role gets picked up by a sustainable hydrogen energy infrastructure.





The electricity business is transacted in "smart" distributed generation networks, i.e., microgrids.

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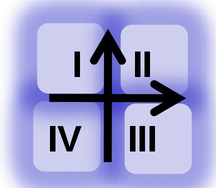
Concluding Observations



- In Beefy and T-Rex scenarios, transmission is limited, or severely limited, respectively, unless new grid technologies are used,…
  - And the Beefy scenario has a definite limit on the amount of central station power that can be served.
- In order for T&D to continue to serve there must be:
  - Some event(s) that causes policies/society to let/promote new T&D to be built, and/or
  - Improved T&D functionalities through new T&D technologies:
    - To provide same level of service with a smaller amount of visible metal, and/or
    - To compensate for inability to build.
- Note: Distribution plays a major role in all scenarios.

Traditional "build" solutions can't do it alone; new T&D functionalities are needed, and that means new T&D technologies.

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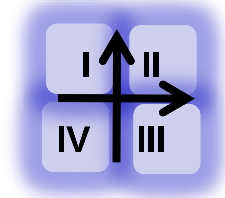
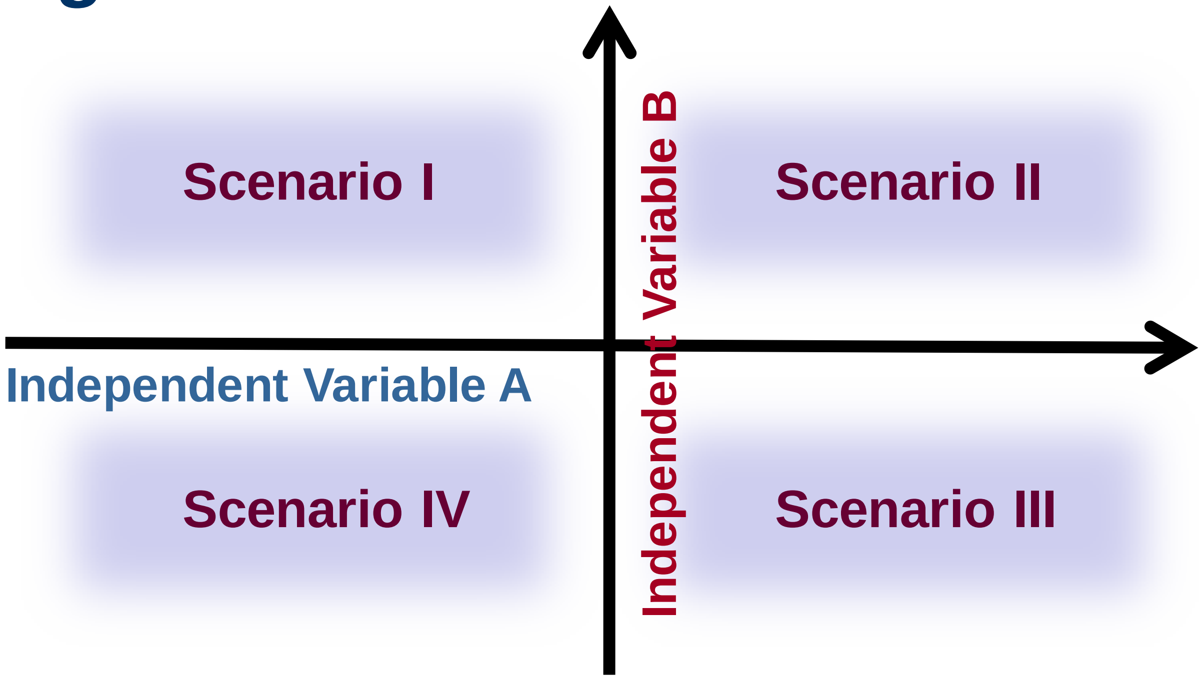
Next Steps: Using scenarios, discuss these questions:



- **According to whom, what scenario seems to be most desirable, and what might be done to achieve it? And which one is least desirable, and can it be avoided?**
- **Which scenario are we in, or seems to be unfolding, today?**
    - **Hint: Identify “signposts” that indicate which scenario is unfolding.**
- **What is the best strategy to use in each scenario?**
    - **What technologies would be most desirable?**
    - **Which policies would be most desirable??**
- **What would each of these scenarios mean to society? To your company?**

Next Steps: Using the scenario "kit," pick your own two variables and do your own planning.



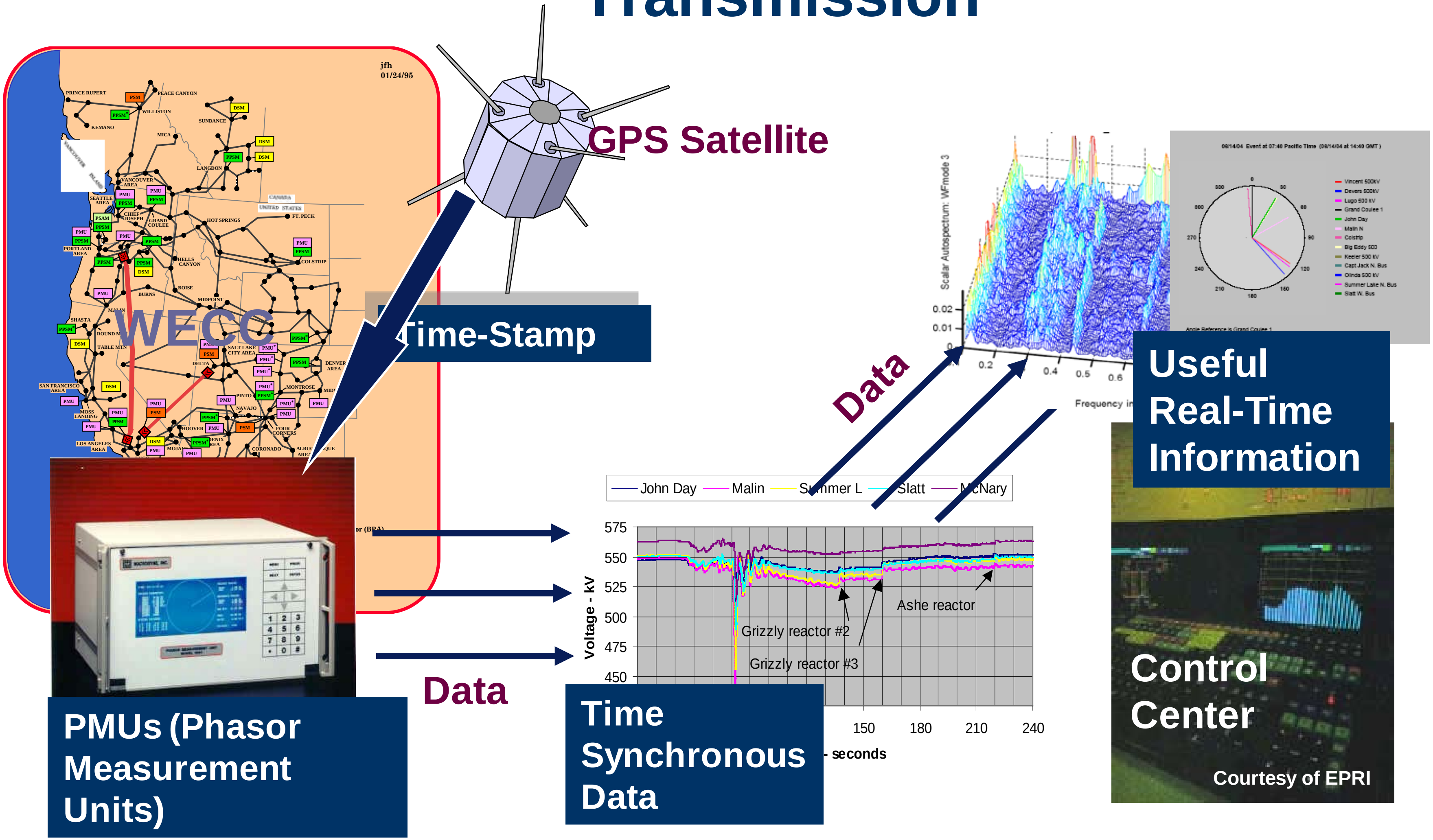
Who knows, it might better prepare you for the future.

Intro to Next Week's i4energy Seminar Spring 2011 Series Presentation*: "Synchrophasors: How They Are Making the Grid Smarter,"* by Lloyd Cibulka, CIEE

Traditional "build" solutions can't do it alone; new T&D functionalities are needed, and that means new T&D technologies.

…especially technologies that make the grid smarter.

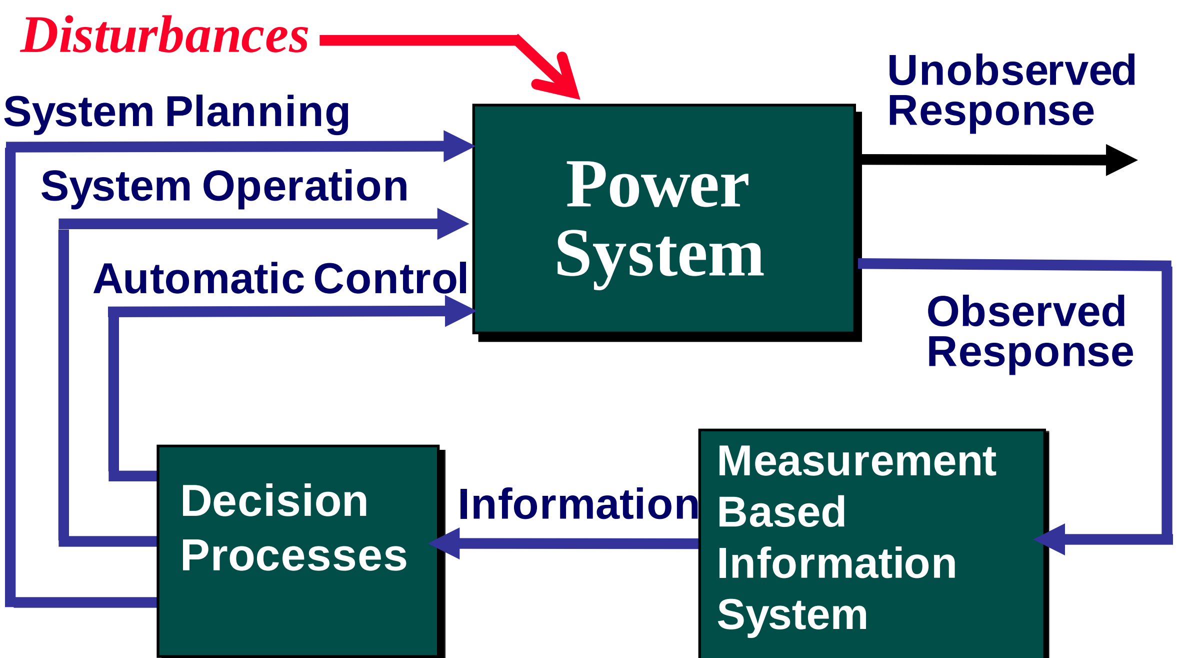
Synchrophasor Measurements – The Basis of the “Smart Grid” Transmission

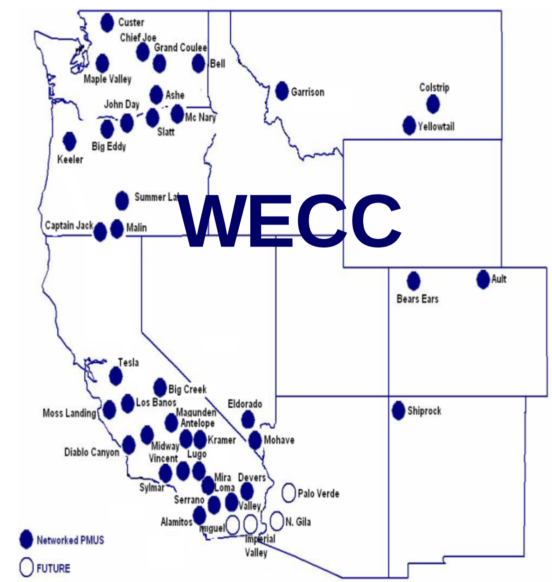


Are like “X-ray” to “MRI” improvements in diagnostics capability.

The Before and After of Synchrophasor Measurements

Synchrophasors 30/second
^ ^
~~Traditional~~ Real-Time Data Rate = Every ~~4-5 seconds~~





An unprecedented ability to see, know, plan and control.

For additional information or discussion, contact :

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And he'll find someone to help you.

> ***"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**