Grid Modernization and the Discipline of Grid Architecture

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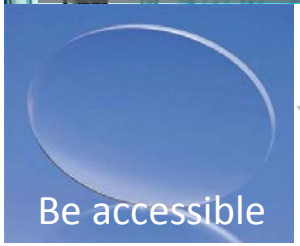
US Utility Industry in Complex Transition

20th Century Electric Utility Mission:

21st Century Electric Utility Mission:



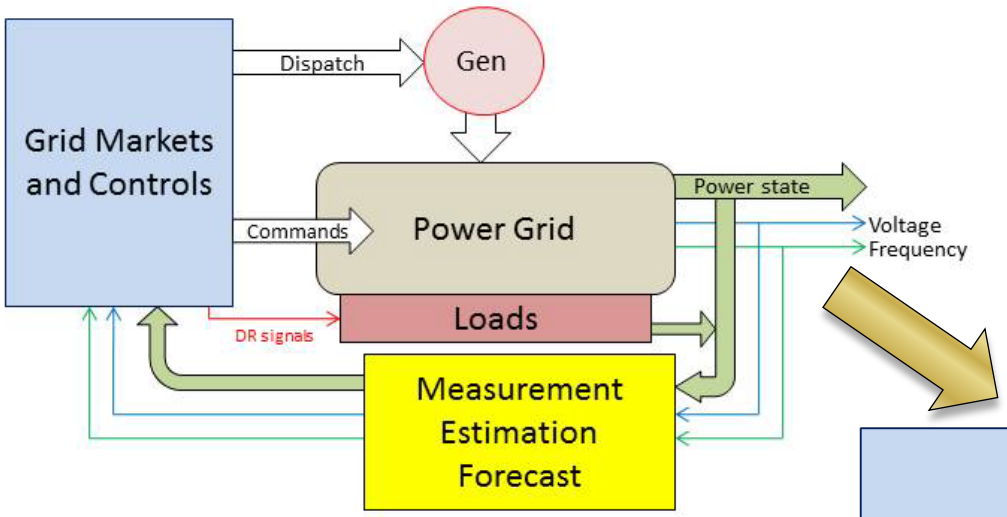
20th Century Grid Design Principles

- Generation is dispatchable
- No significant energy storage i e
- Power must be kept in
- Generation follo
- Distribution can be pending from Transmi
- Real power flows i distribution
- Voltage, reactive pow ystem frequency are regulated
- Designed for reliability, not economy

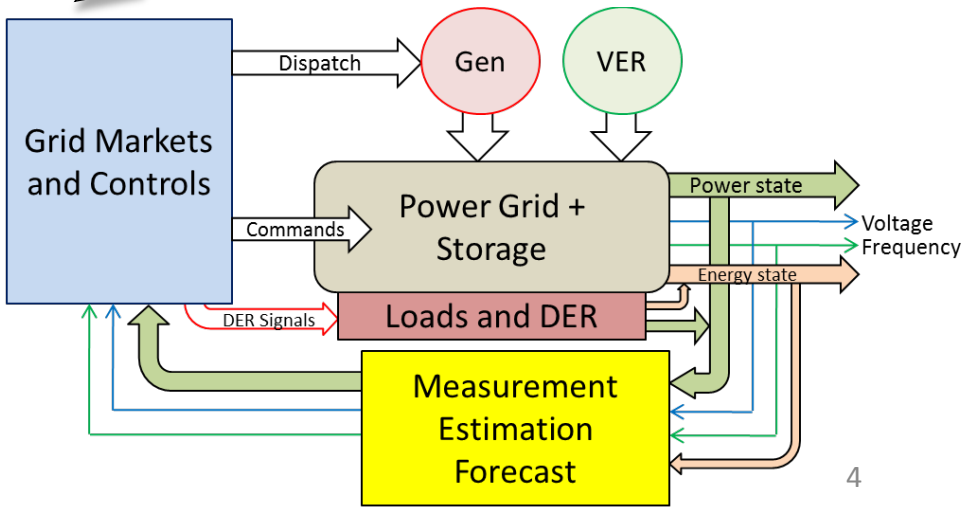
We are in the process of violating most of these principles!

The Grid Management Problem is Changing

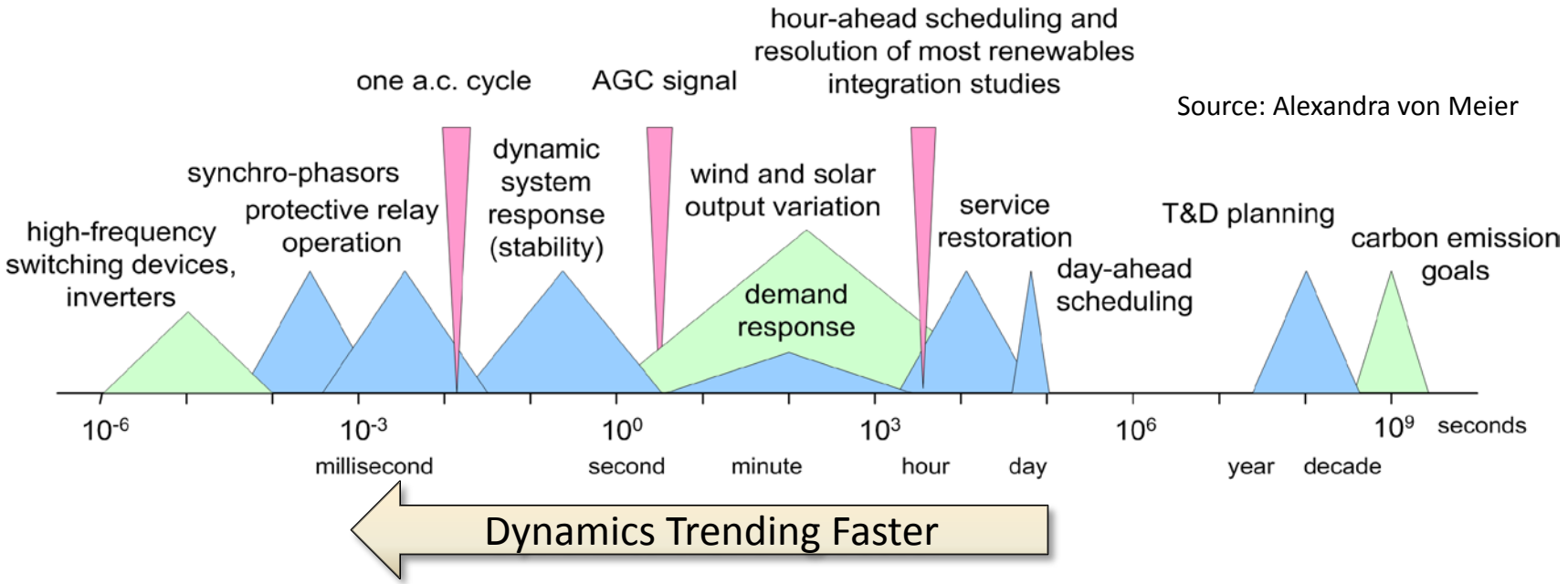
Old Model:
Power State Control
with
Constraints on Sys Frequency, Voltage



New Model:
Power State and Energy State Control
with
Constraints on Sys Frequency, Voltage



Less Time, More Data, More Endpoints

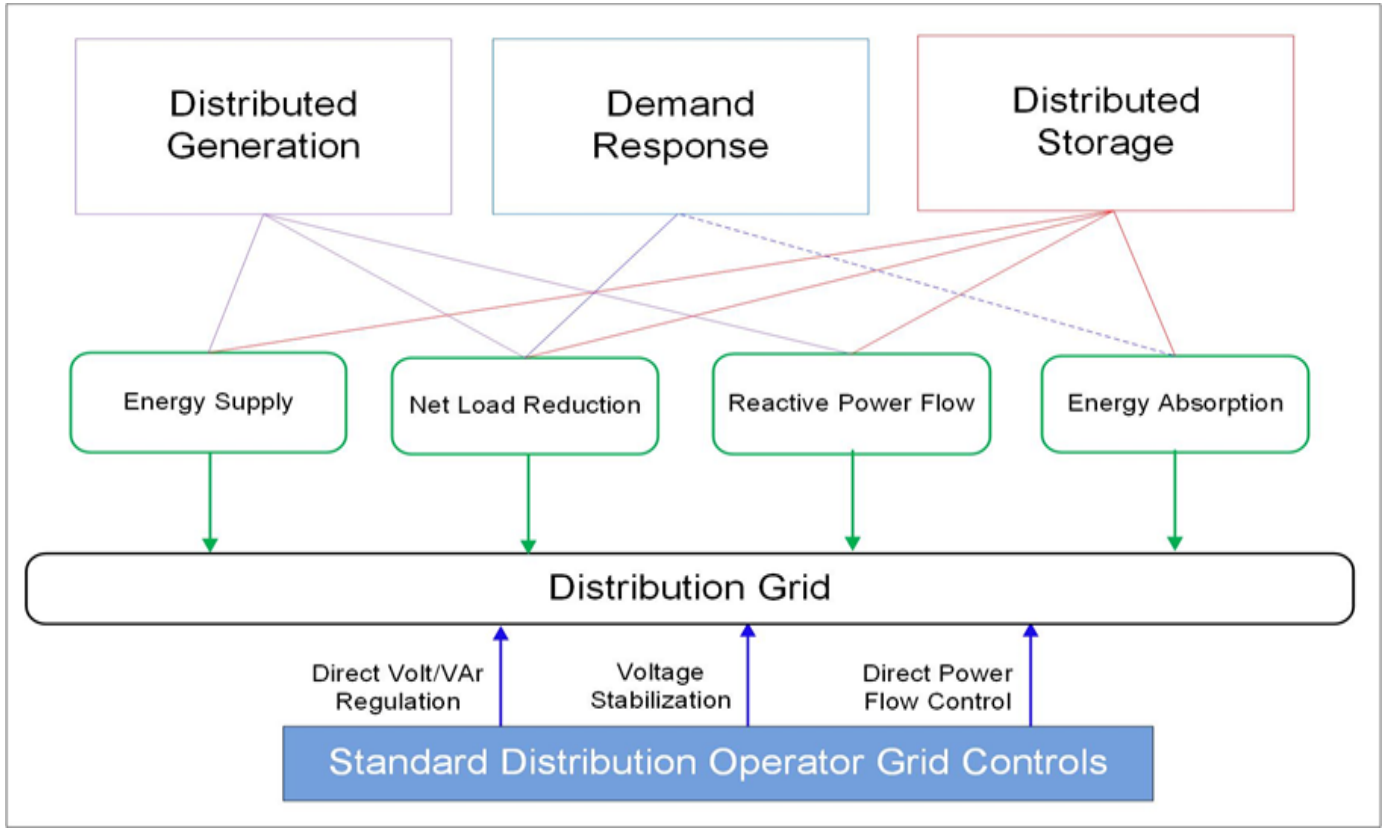


- Increasingly faster device/system dynamics
- Moving from slow data sampling to fast streaming data
- Massive numbers of sensing and control endpoints

Thousands of endpoints → WAMS/AMI/DER/DR/networking… → Tens of millions of endpoints

The Mixed DER Coordination Problem

- Functional capabilities overlap for some DER
- Not all DER perform the same way
- How should mixed DER be allocated/dispatched?



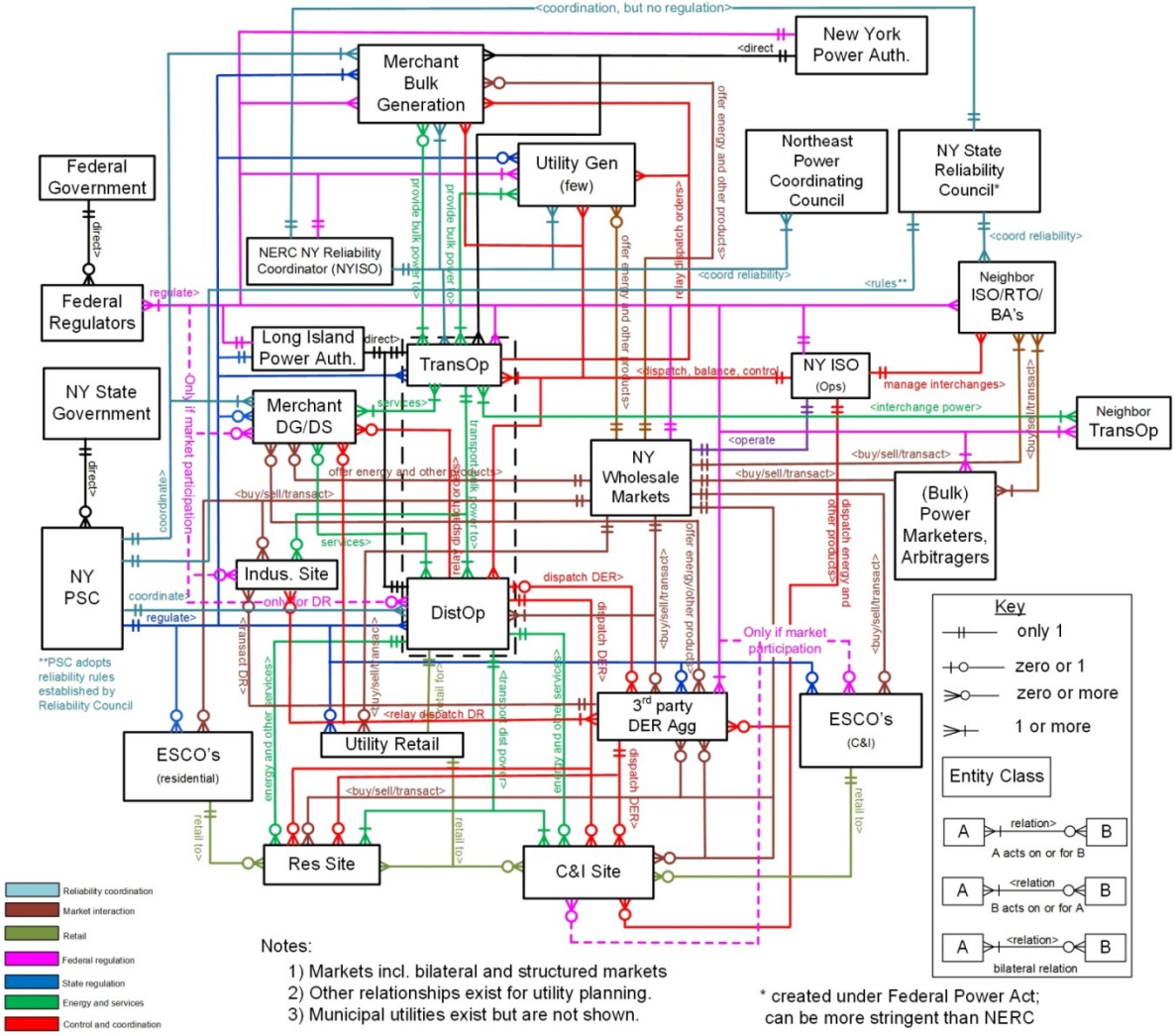
Any Grid Change Has A Context

Any change exists in the context of the Network of Structures:

- Electric
- Industry
- Regulatory
- ICT
- Control
- Coordination
- Other convergent networks

Grid architecture principle: The architect must be cognizant of the global system when optimizing subsystems.

Industry Structure Model, New York 2015 **



** Model created by PNNL

So What are the Big Obstacles?

- Old view:
  - Data tsunami
  - Interoperability
  - Cost-effective technology
- Present view:
  - Future roles for utility entities
  - Exogenous structure changes and legacy limitations
    - Generation bifurcation and inertia loss
  - Complexity management

Grid Complexity

Low Complexity → Medium Complexity → High Complexity → Ultra-Large Scale Complexity

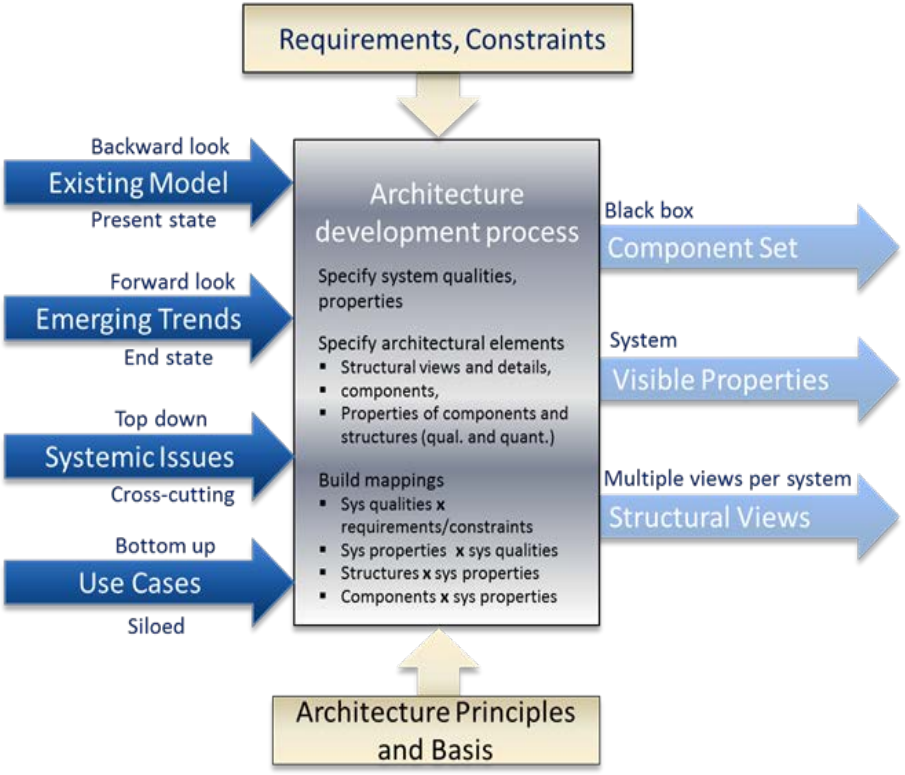
- Heterogeneous, inconsistent, and changing elements
- Geographic distribution
- Wide time scales
- “Normal” failures

- Decentralized data, development, and control
- Inherently conflicting diverse requirements
- Continuous (or at least long time scale) evolution and deployment

grid architecture

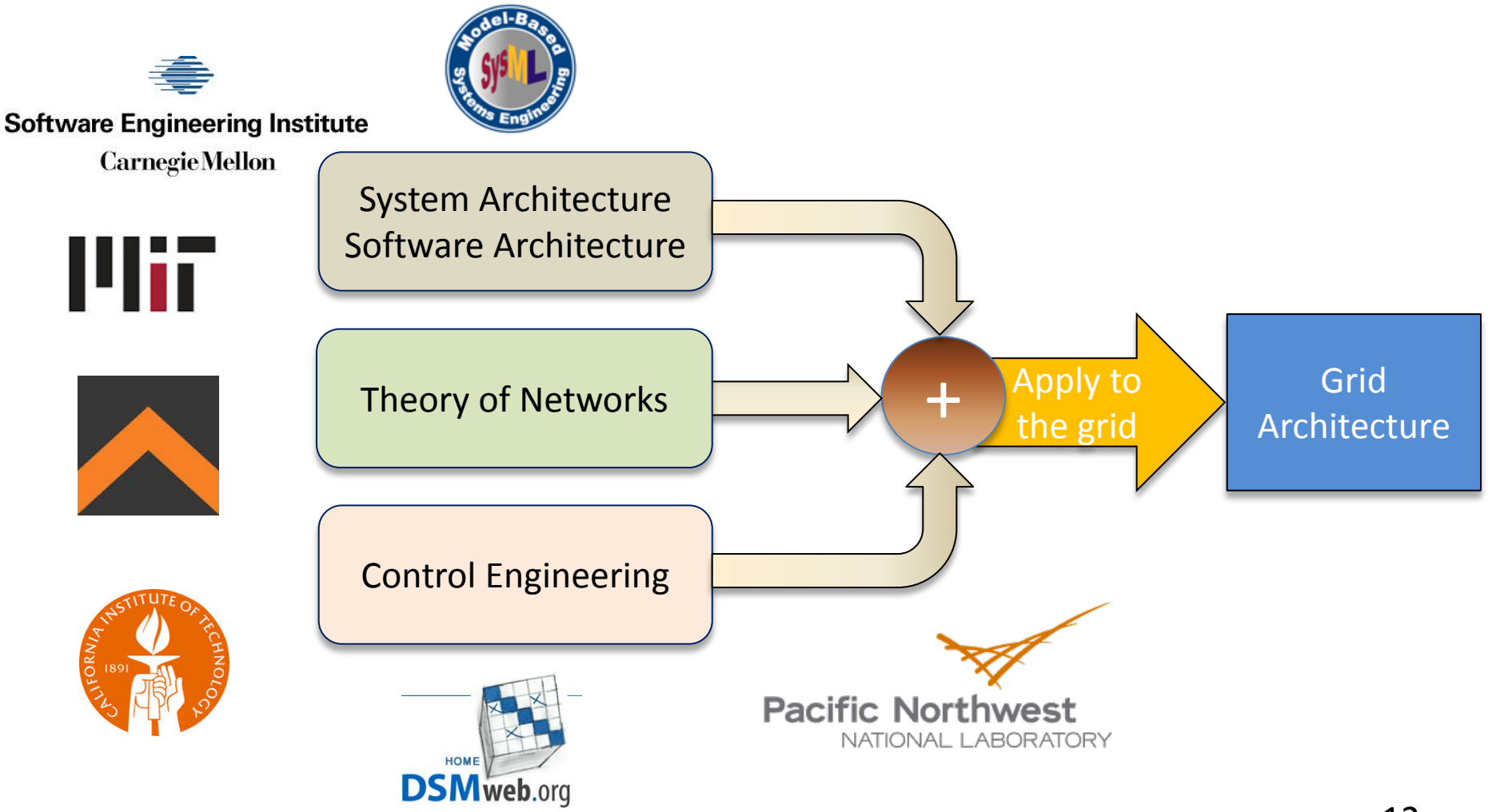
Grid Architecture Definition & Purposes

A grid architecture is the highest level depiction of the complete grid, and is a key tool to help understand and define the many complex interactions that exist in present and future grids.

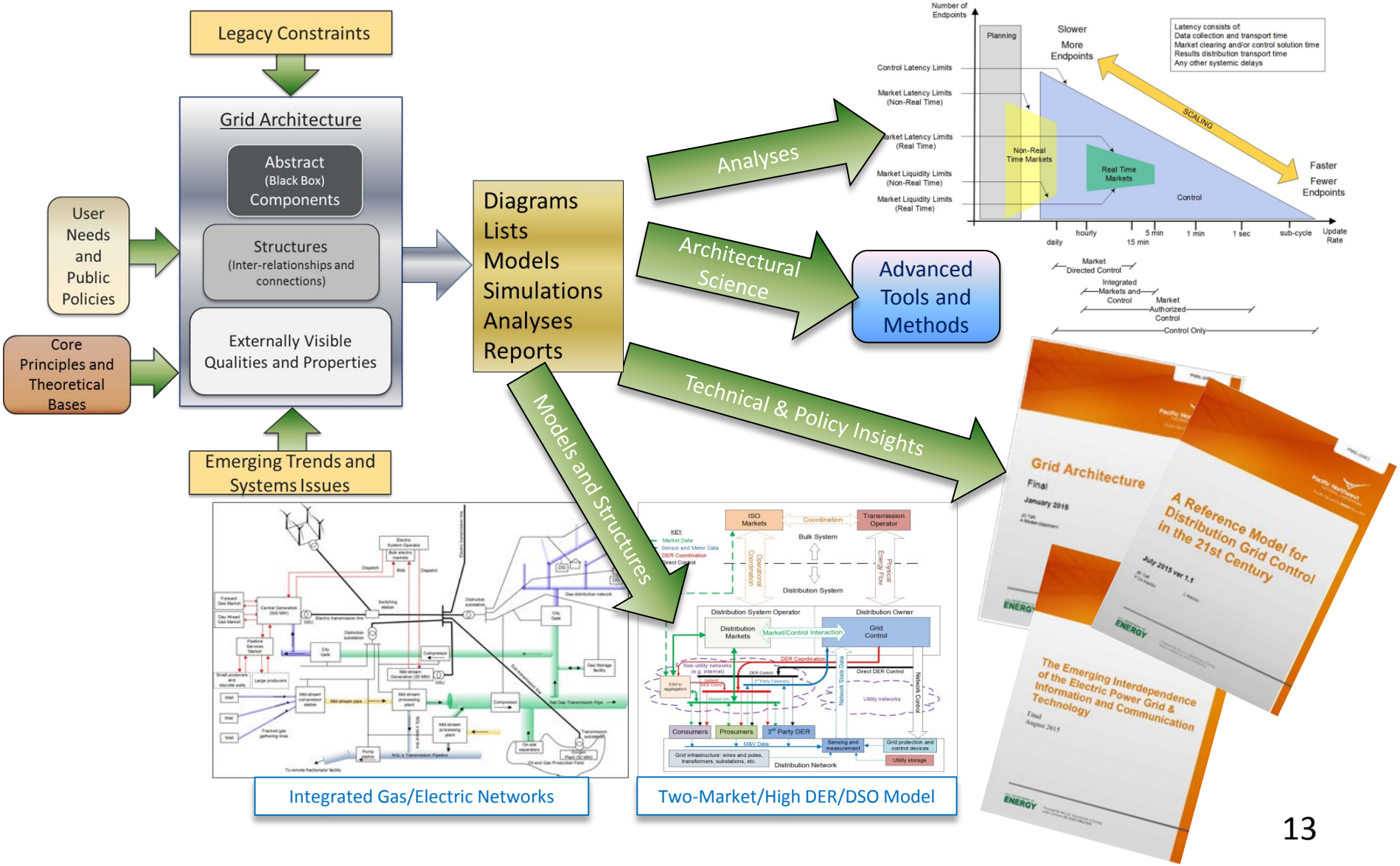


- Help manage complexity (and therefore risk)
- Assist communication among stakeholders
- Remove barriers and define essential limits
- Identify gaps in theory, technology, organization, regulation…
- Identify/define interfaces and platforms

Origins of Grid Architecture



Grid Architecture Produces *Insight*

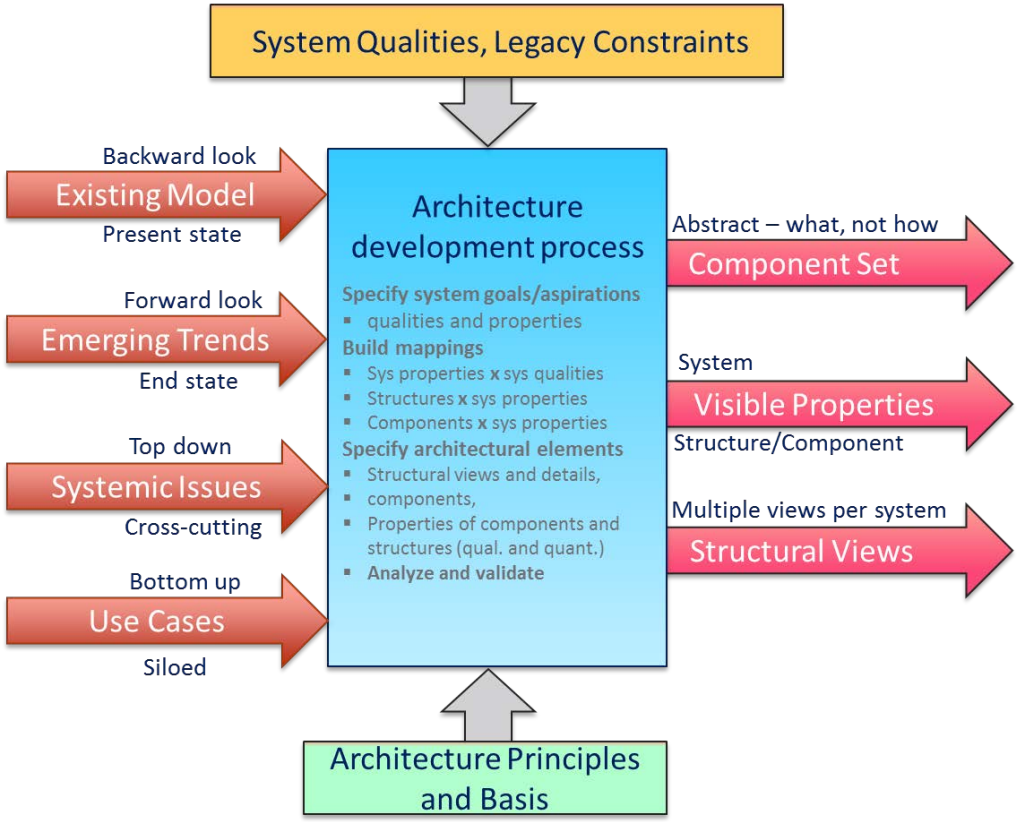


Integrated Gas/Electric Networks

Two-Market/High DER/DSO Model

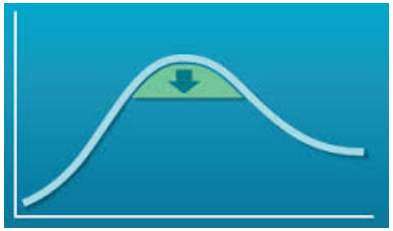
Elements of System Architecture

- Components
  - Abstract “black boxes”
  - Not concerned with internals
- Structures
  - The overall shape of the system and how components interact
  - Any complex system has multiple structures, requiring multiple views
  - Structures set essential limits
- Externally visible properties
  - of components
  - of structures
  - of the system



Components and Abstraction

- Components are black boxes but…
- No *relying* upon anti-gravity or magic boxes
  - but can aid gap analysis
- Beware of over-abstraction



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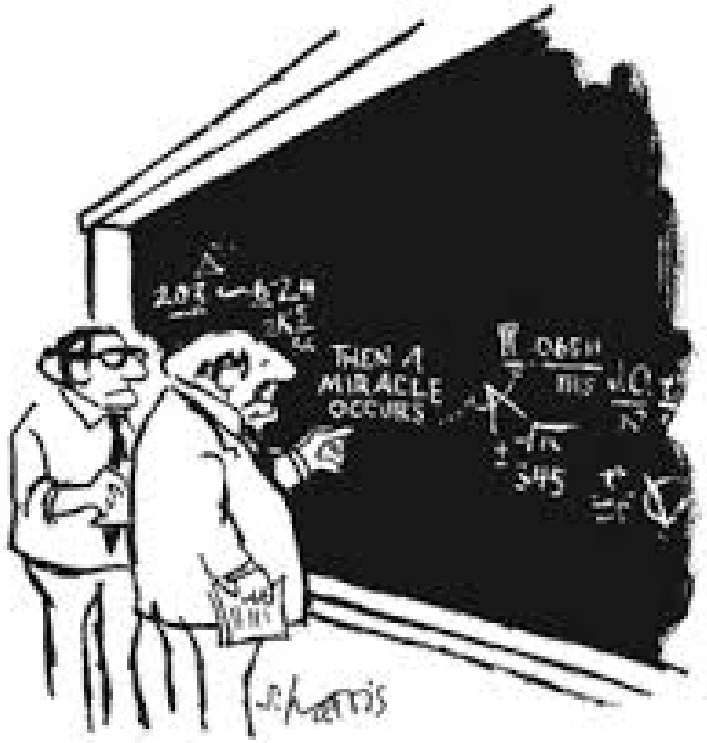


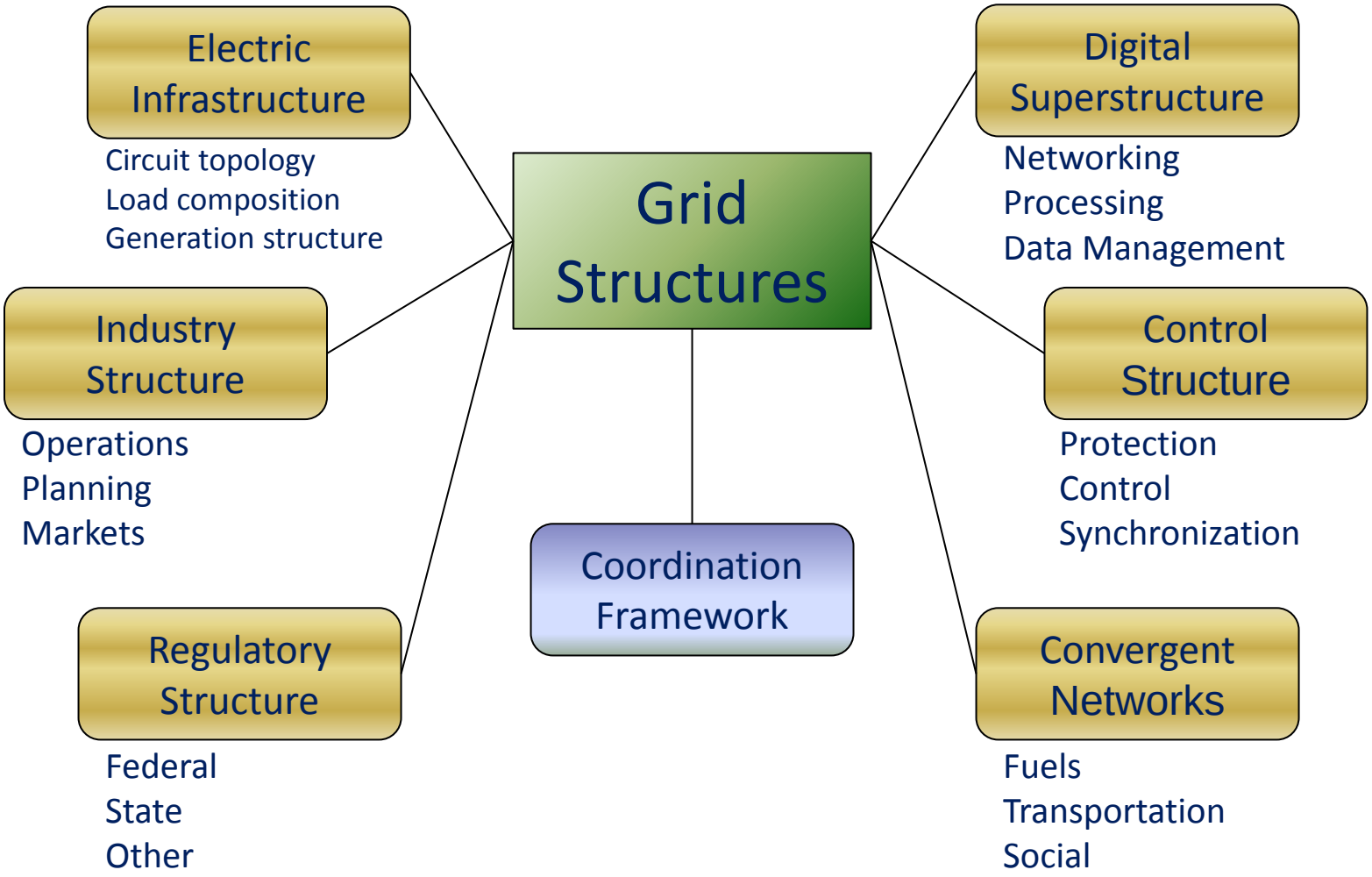
"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

Source: Sidney Harris

Old and New Architecture Paradigms

Traditional "smart grid"		Advanced "grid modernization"
Focus on components	→	Focus on structures
Structure is improvised	→	Structure is formalized
Grid is a big circuit; control is an app	→	Grid/market/control interactions
System of Systems	→	Network of Structures
Data tsunami	→	Ultra-Large Scale complexity
System integration	→	Convergence and platforms
Architectural "elegance"	→	Architectural quantification

The Grid as a Network of Structures



Network Convergence

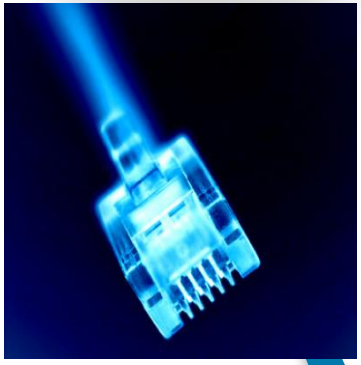
- System integration is the connection of various components and subsystems so that the resulting overall system can deliver some specified set of capabilities
- Convergence is the transformation of two or more networks or systems to share resources and interact synergistically via a common and seamless architecture to enable creation of new value streams
- Convergence often results in new platforms that enable the new value streams

Where Does Convergence Occur?

Power Grids

Financial Networks (Markets)

Convergence occurs at the grid market/control systems



Information and Communication Networks

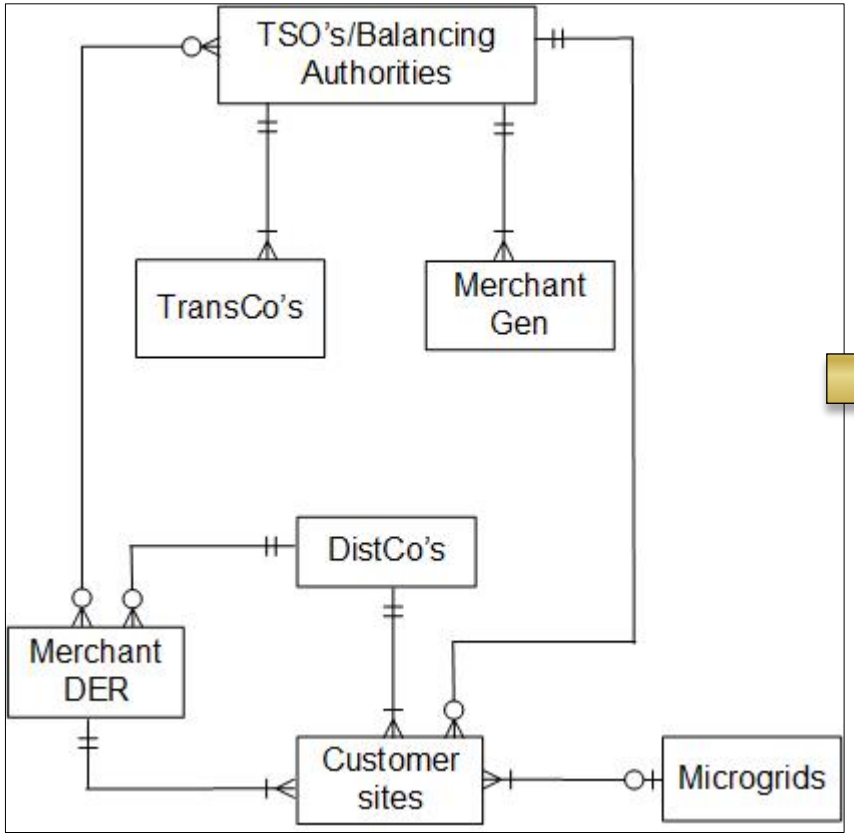
Social Networks

This is why we find ourselves focusing on grid/market/control issues so much

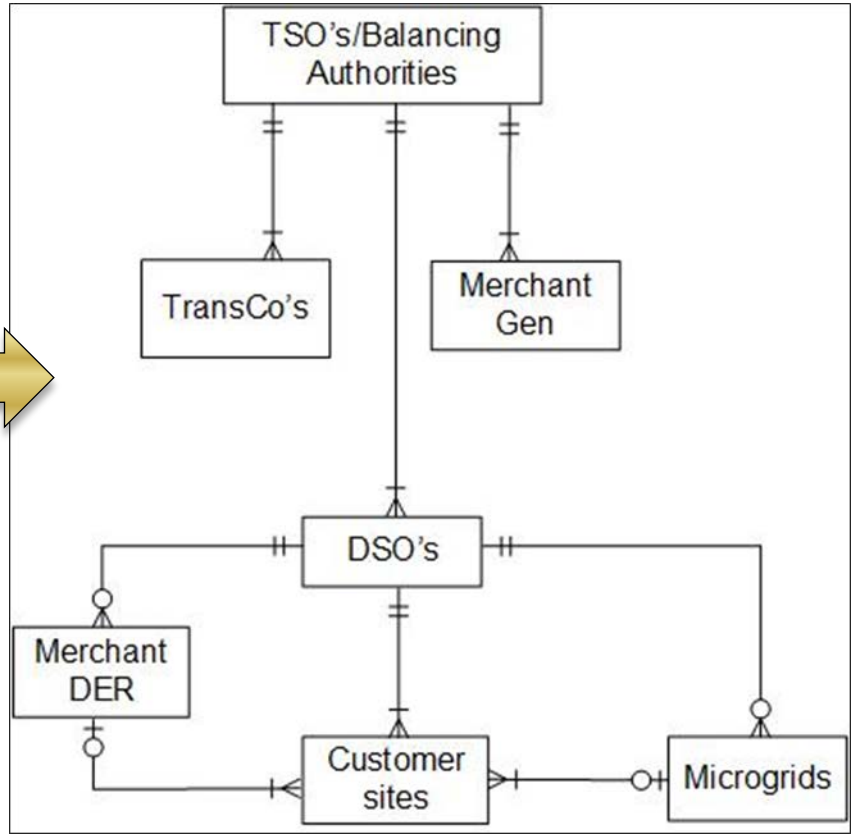
recent work

Distribution Structure Change

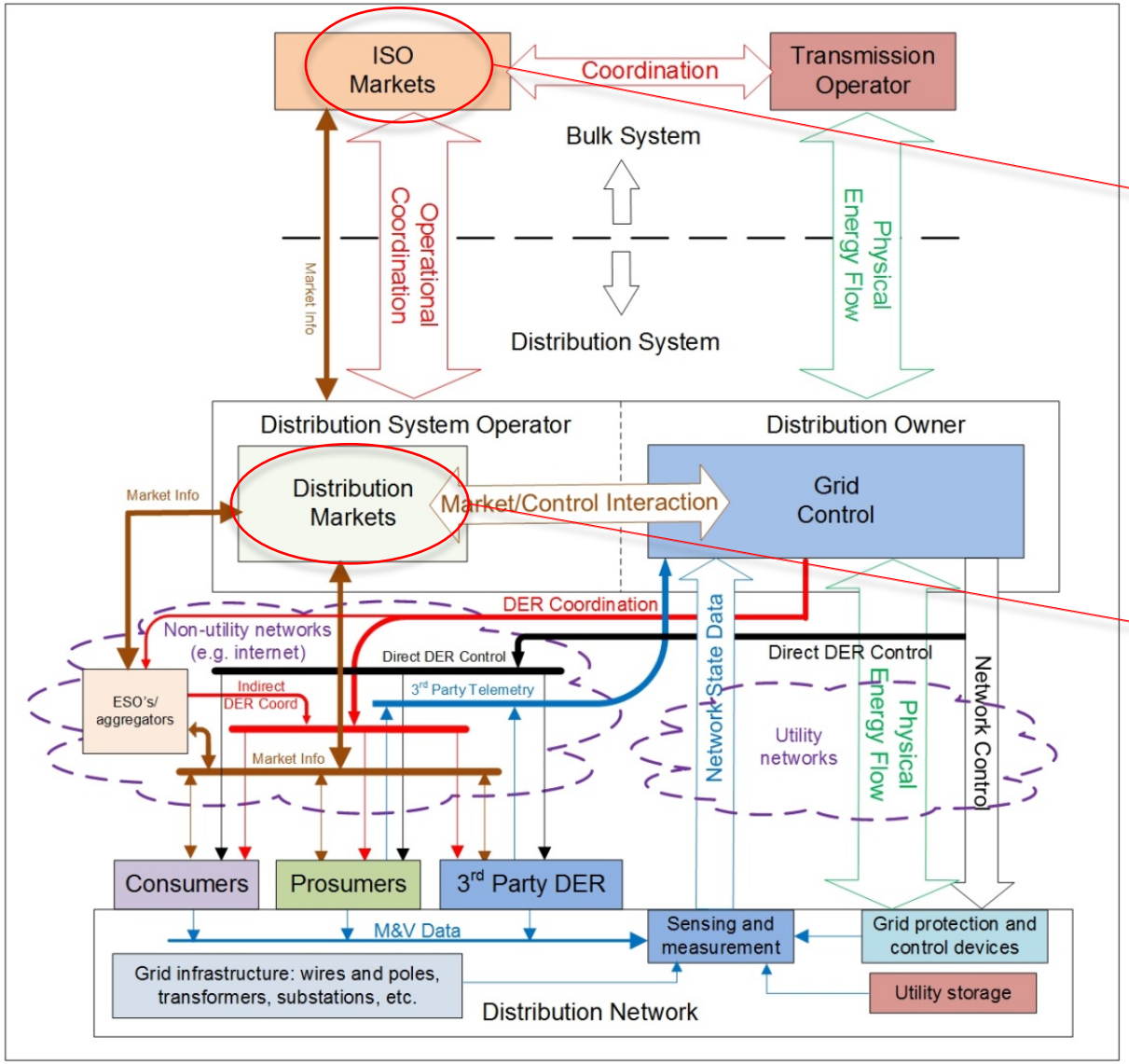
Traditional



Emerging



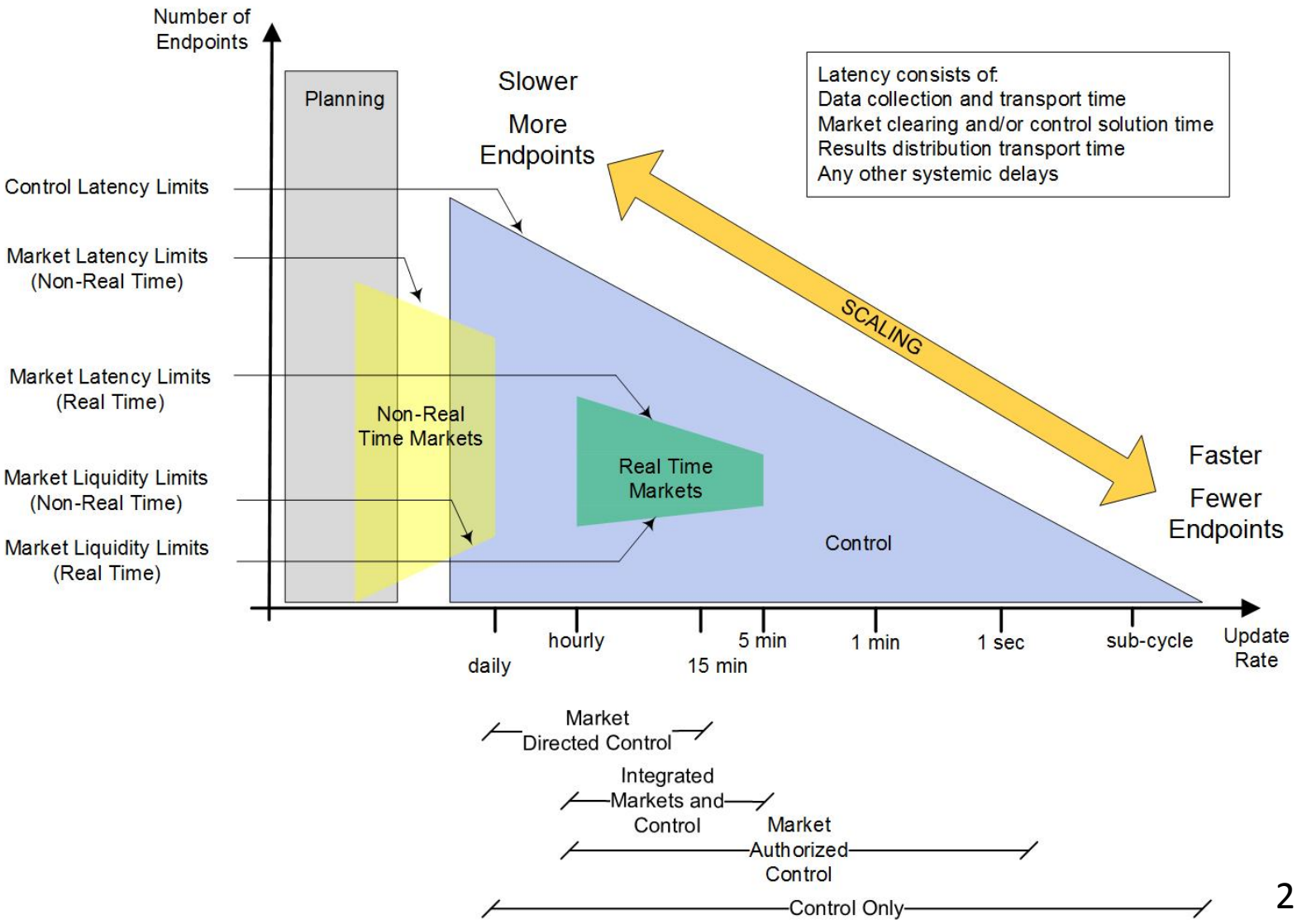
Evolution of Two-Market Systems



Existing Bulk Organized Markets

Emerging Distribution DER Markets

Market and Control Interaction Regimes

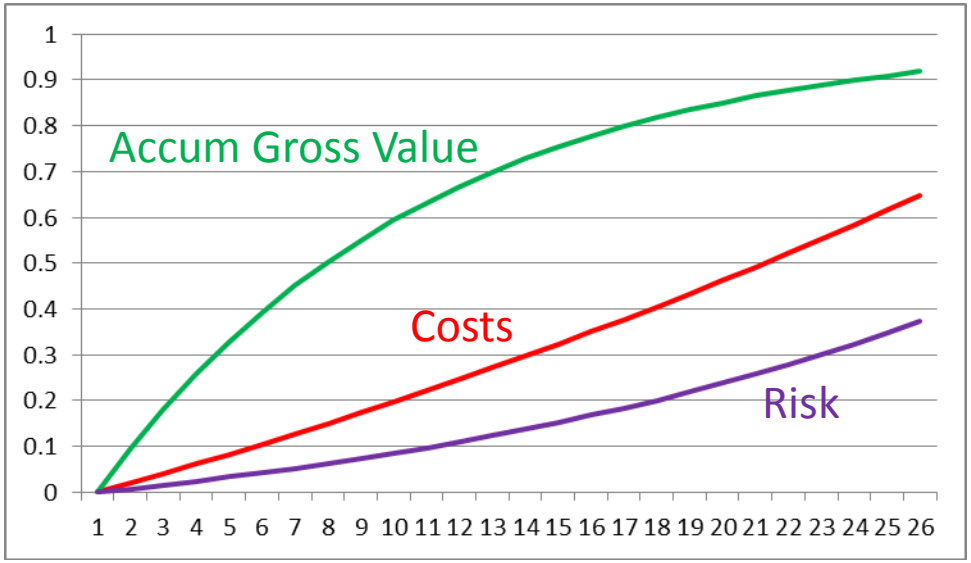


Effect of Granularity on Net DER Value*

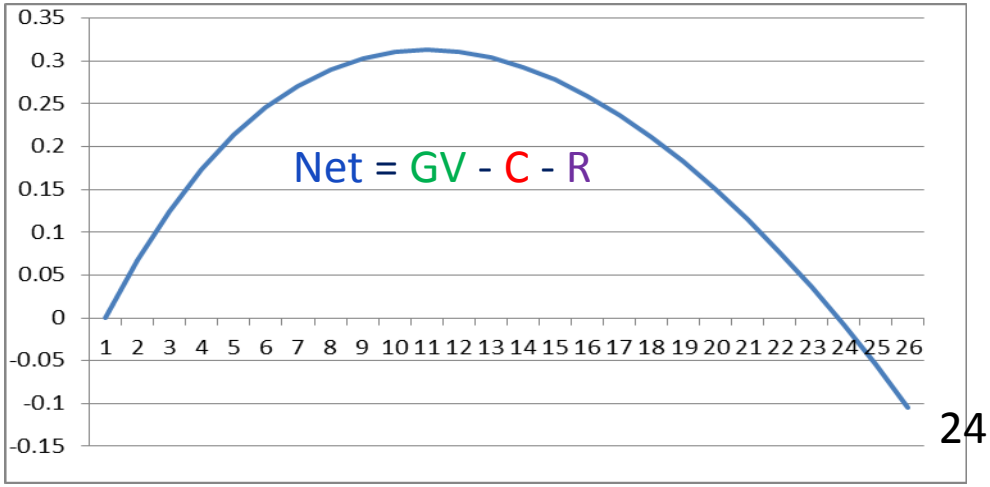
- Bulk System
  - DER location is only weakly coupled to value as seen at the bulk system level
  - Granularity is barely visible
- Distribution System
  - All DER's have strong locational value components
  - Granularity can be completely visible if system is so designed

* Concept source: P De Martini, Resnick Sustainability Institute

Distribution Component Curves vs. Granularity



Net Distribution DER Value vs. Granularity



Final Comments

- Much of the change in the US electric industry is happening at the distribution level but also drives change at the bulk system level.

- Grid complexity is extensive and growing; management of the complexity of grid modernization is one of the industry's greatest challenges.

- The industry has developed an appreciation for architectural approaches that did not exist five years ago.

Thank You

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