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System Architecture as a Tool for Managing Complex Systems: Application to Electric Grids

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System Architecture Definition/Purpose

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- A *system architecture* is a model of a (complex) system whose purpose is to help think about the overall shape of the system, its attributes, and how the parts interact
- Some Uses of System Architecture
  - 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
  - Enable prediction of system qualities

The discipline arises from work at various organizations

California Institute of Technology 1891

MIT

University of Waterloo

Model-Based Systems Engineering SysML

Software Engineering Institute
Carnegie Mellon

HOME DSMweb.org

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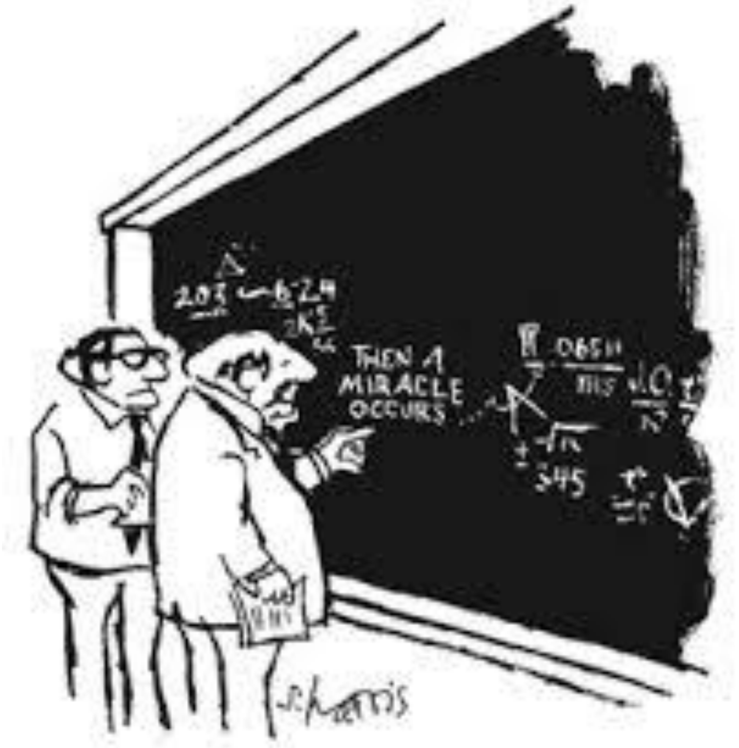
Elements of System Architecture (1)

- Abstract components
  - The individual parts, viewed as “black boxes”
  - Example: storage battery
    - At this level we do not specify how the battery works
    - Care about externally visible characteristics like storage capacity, max power rating
  - But thoroughly grounded in reality
    - no “magic” boxes or anti-gravity

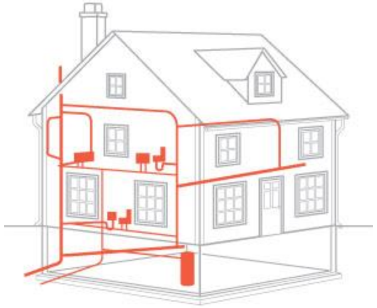


"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

Source: Sidney Harris

Elements of System Architecture (2)

- Abstract components
  - The individual parts, viewed as "black boxes"
  - But thoroughly grounded in reality (no "magic" boxes)
- Structures
  - The overall shape of the system and how components interact
  - Any complex system has multiple structures, requiring multiple views
  - No real architecture can be represented in a single diagram



Elements of System Architecture (3)

- Abstract components
  - The individual parts, viewed as "black boxes"
  - But thoroughly grounded in reality (no "magic" boxes)
- Structures
  - The overall shape of the system and how components interact
  - Any complex system has multiple structures, requiring multiple views
  - No real architecture can be represented in a single diagram
- Externally visible properties
  - Of components
  - Of structures
  - Of the whole system

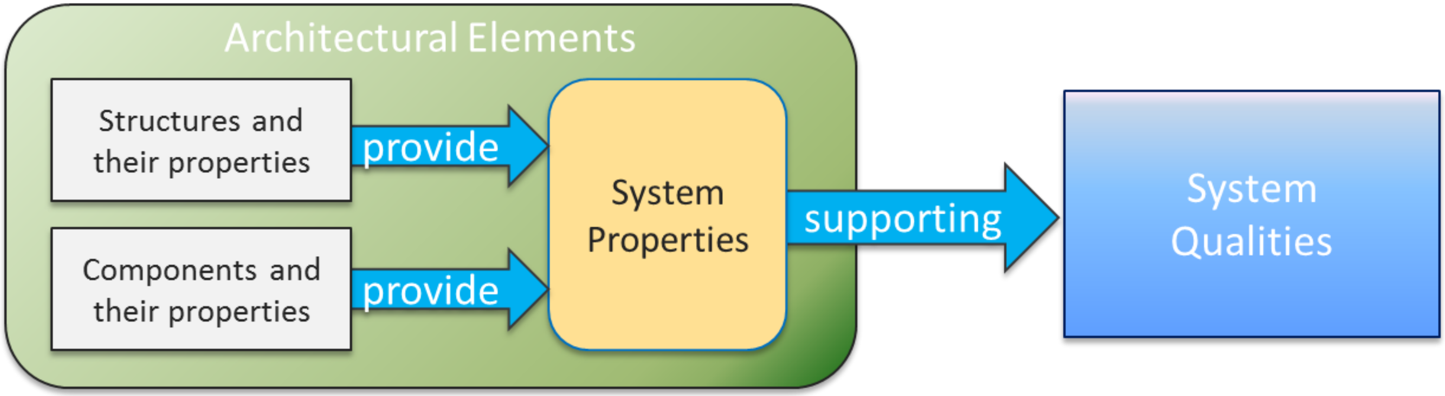
System Qualities & Architectural Properties

System Qualities

- Desired characteristics of the final or end state system (not just the architecture)
- Think of as high level requirements expressed qualitatively or quantitatively

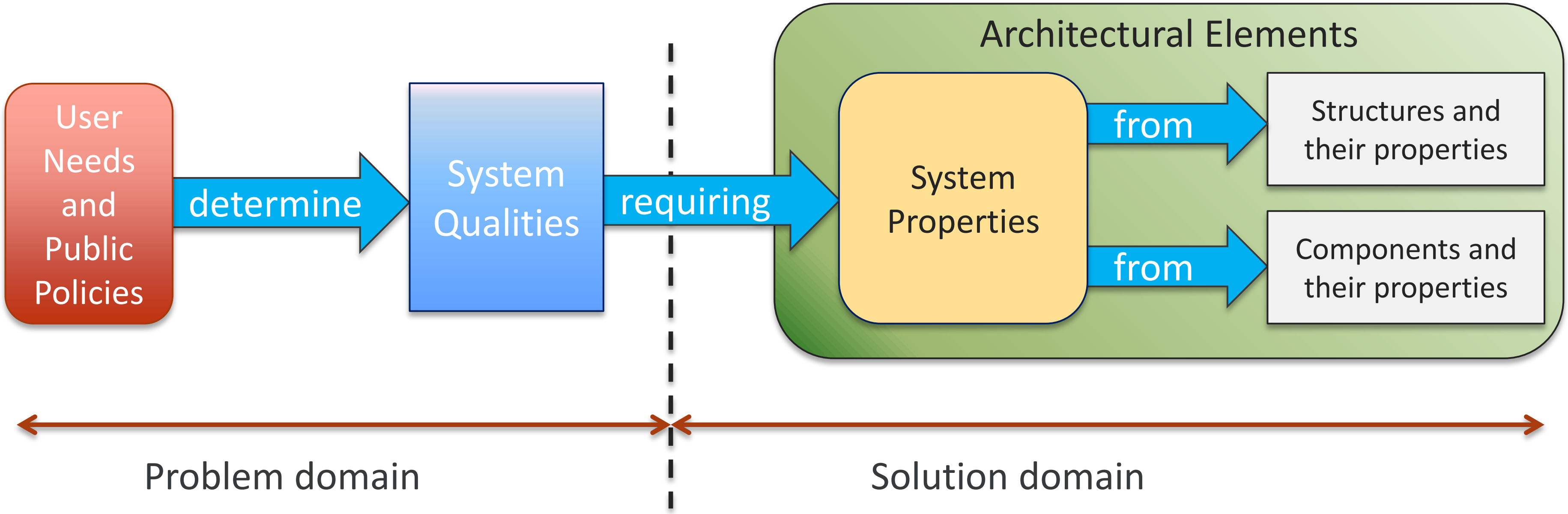
Architectural Properties (externally visible)

- System properties
  - characteristics of the architecture as a whole that enable key capabilities
  - system properties are what enable the system qualities to be manifest
  - system properties emerge from structure, components, and their properties
- Structural properties – characteristics inherent in the architecture's structures
- Component properties – characteristics of individual components



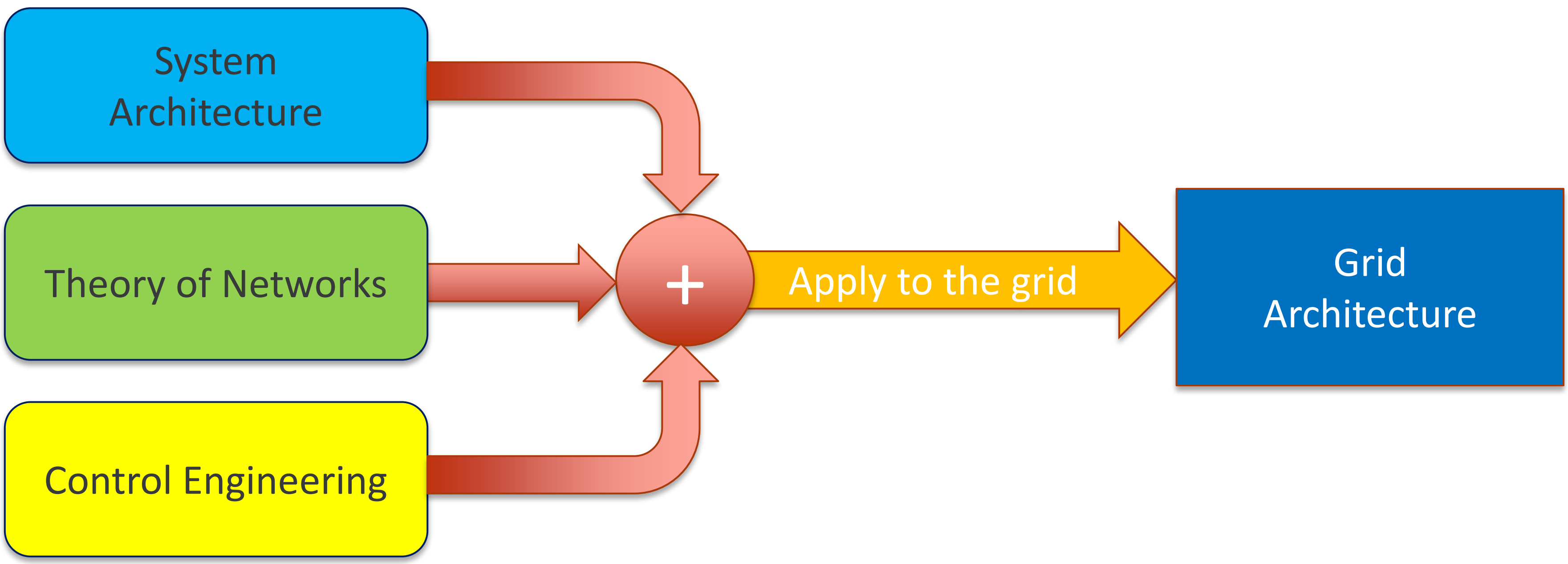
System Architecture Synthesis

- System Qualities come from the consumer viewpoint
- System Properties come from the provider viewpoint



What is Grid Architecture?

- Grid architecture is system architecture for power delivery chains
- Focus primarily on structure
- It is not enterprise IT architecture, nor is it "smart grid architecture"



Grid Architecture Methods and Paradigms

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- Network of (interacting) Structures
- Ultra-Large Scale Systems paradigm
- Coordination Framework
- Network Convergence and Platform Identification
- Advanced characteristics:
  - Control federation and disaggregation
    - Objective and constraint fusion
  - Local selfish optimization inside global coordination
  - Multi-scale views and layered decomposition
- Some of the key methods we use include:
  - Mappings: qualities/properties/elements; actors/roles
  - Architecture quantification: graph theory, matrix methods, optimization
  - Architecture Validation
    - Multi-Structure Simulations
    - DSM
    - Optimization

Some System Architecture Principles

- A good architecture is one that meets the needs of the stakeholders (especially the users) to their satisfaction, does not violate established principles of system architecture, and takes into account the relevant "ilities" by allowing for maintenance, evolution, further development, embedding, etc. as the customer requires.

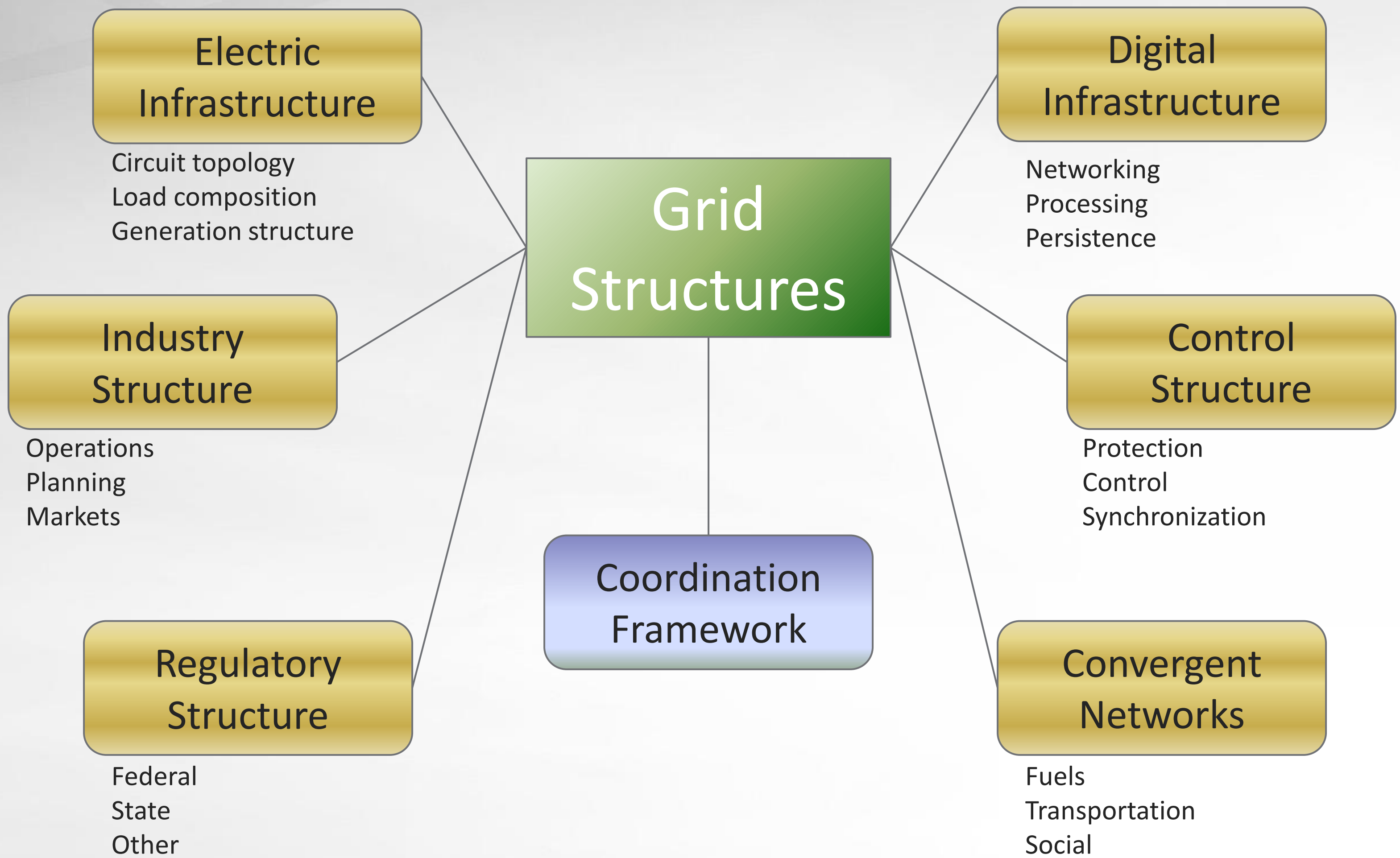
- Essential functionality drives complexity, not architectural "elegance."

- The architect must be cognizant of the global system when optimizing subsystems.

- Stakeholders should be involved in the process as much as possible, giving frequent and honest feedback on all aspects of the system architecture.

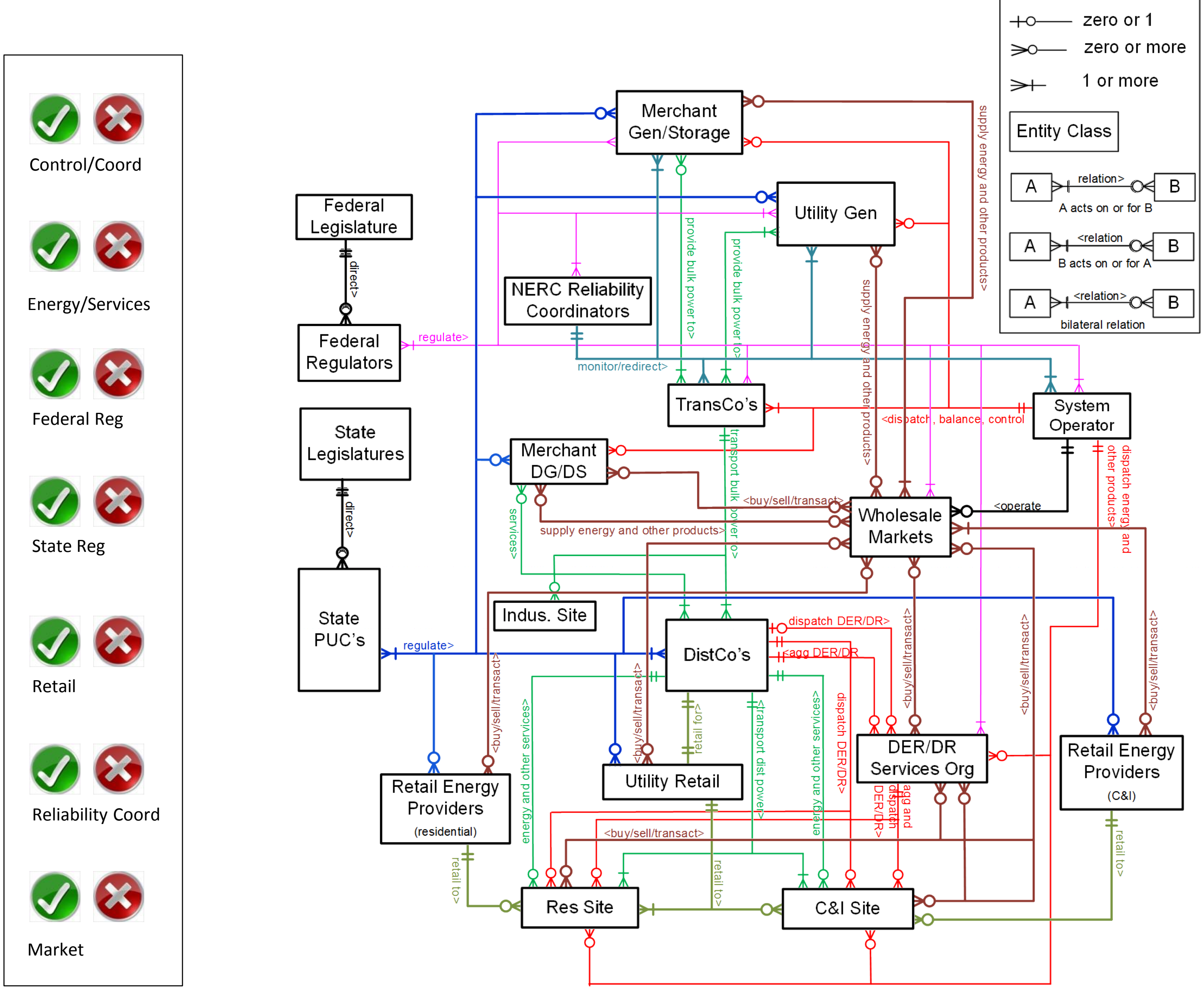
- Architecture must be consumable (i.e. understandable) by the users.

The Grid is a Complex Network of Structures



a few illustrations

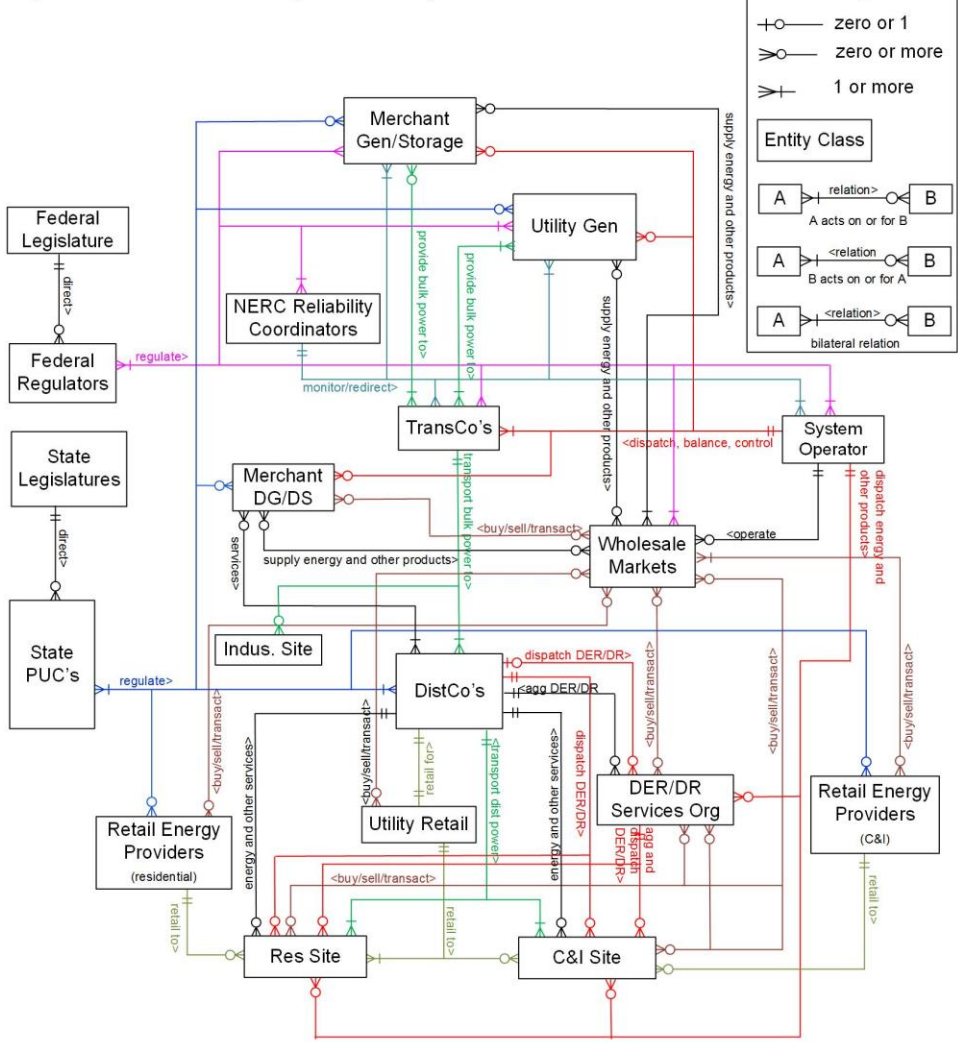
Disaggregated U.S. Utility Industry Operational Structure (Post 2000)



Notes: 1) Markets incl. bilateral and structured markets.
2) Other relationships exist for utility planning.

ISO-Based Industry Structure

Disaggregated U.S. Utility Industry
Operational Structure (Post 2000)



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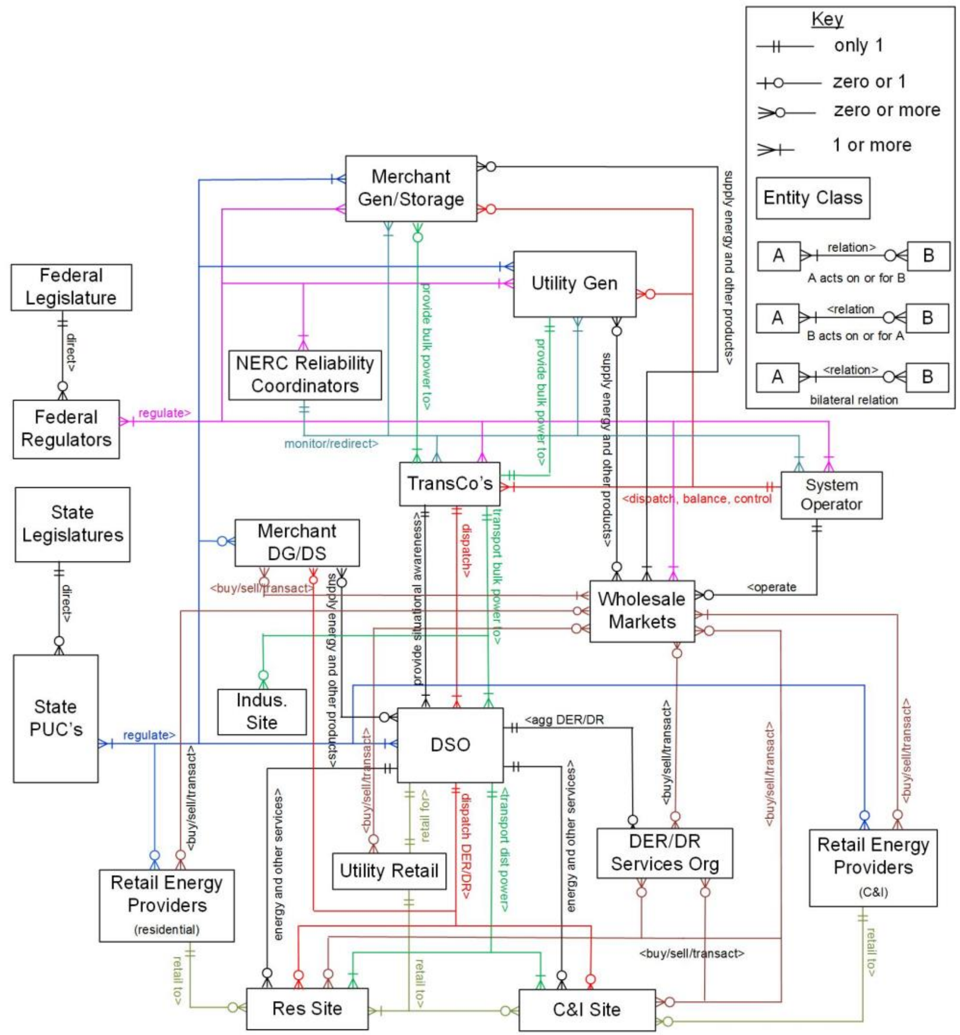
A DSO Model



Notes: 1) Markets incl. bilateral and structured markets.
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Present Coordination Structure

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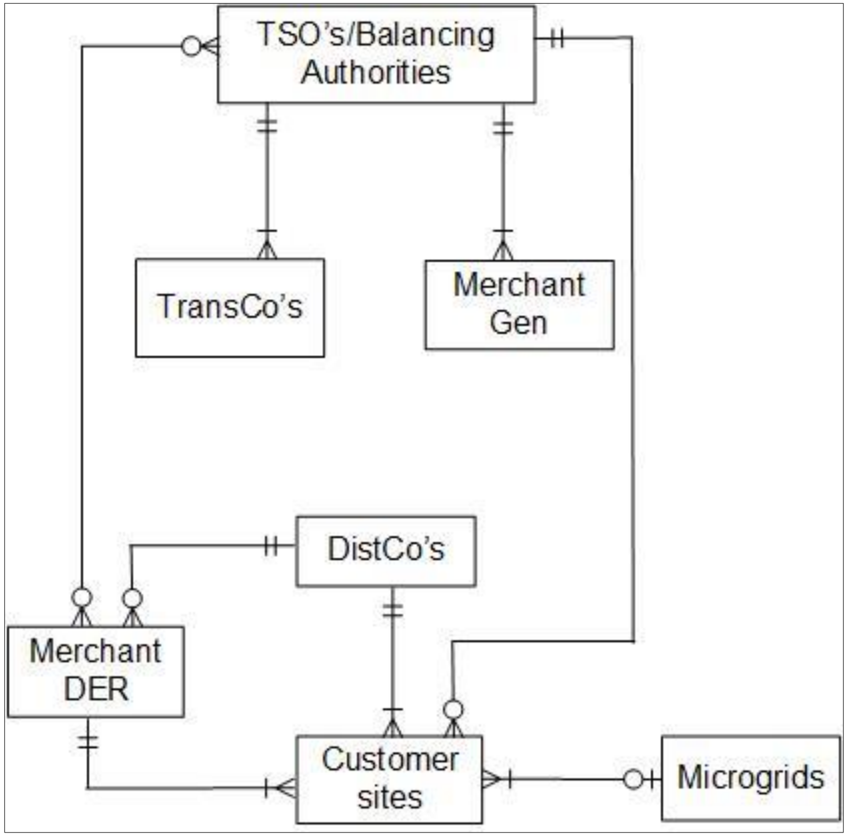

- Structurally problematic
  - no formal basis
- Tier bypassing leads to destabilization
- Ad hoc form limits understanding of properties
  - emergent (read unintended) behavior
- Scalability problems
- Unnecessary connectivity raises extra cyber-security issues

DSO-Based Coordination Structure

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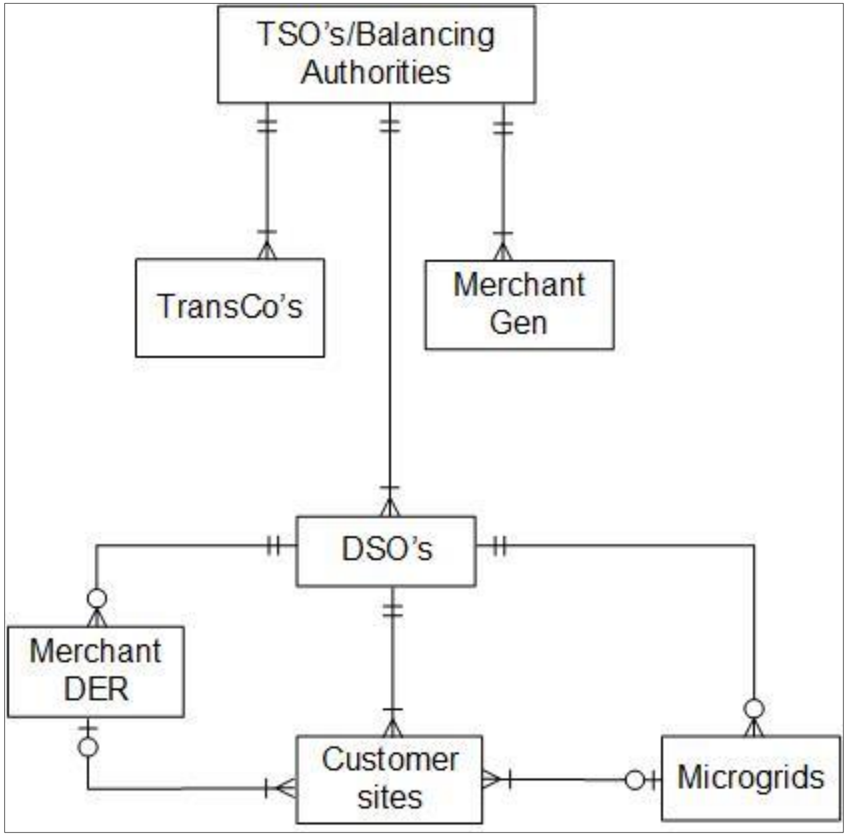

- Structurally sound
  - formal basis available
- No tier bypassing
- Normalized form allows for property design and analysis
  - Boundary deference
  - Coordination/constraint fusion
- Scalable implementations available
- Connectivity and data flow patterns easier to secure

Whole System Control Model

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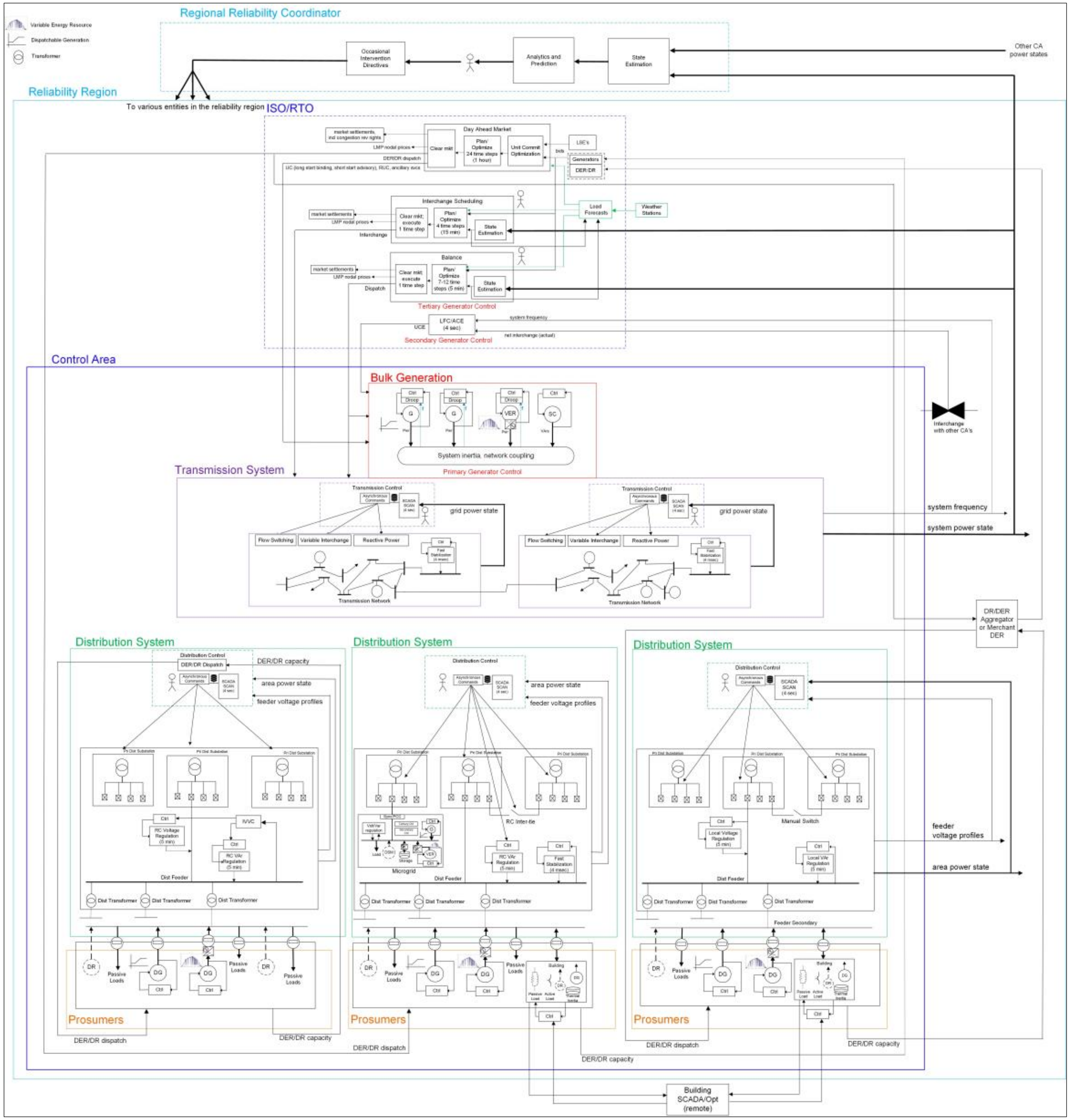

CA Bulk System Control and Wholesale Markets

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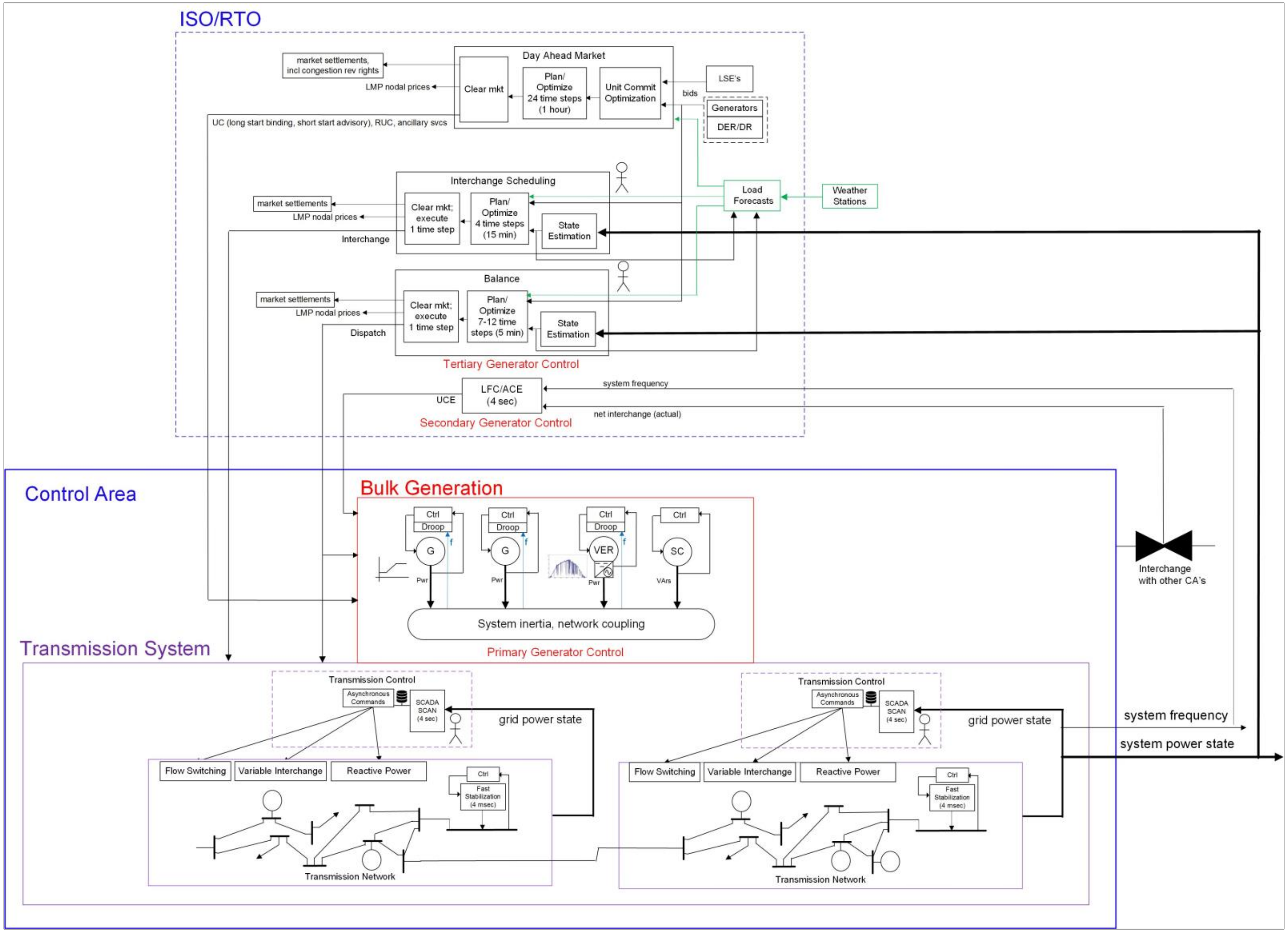

Joint Gas/Electric Structure

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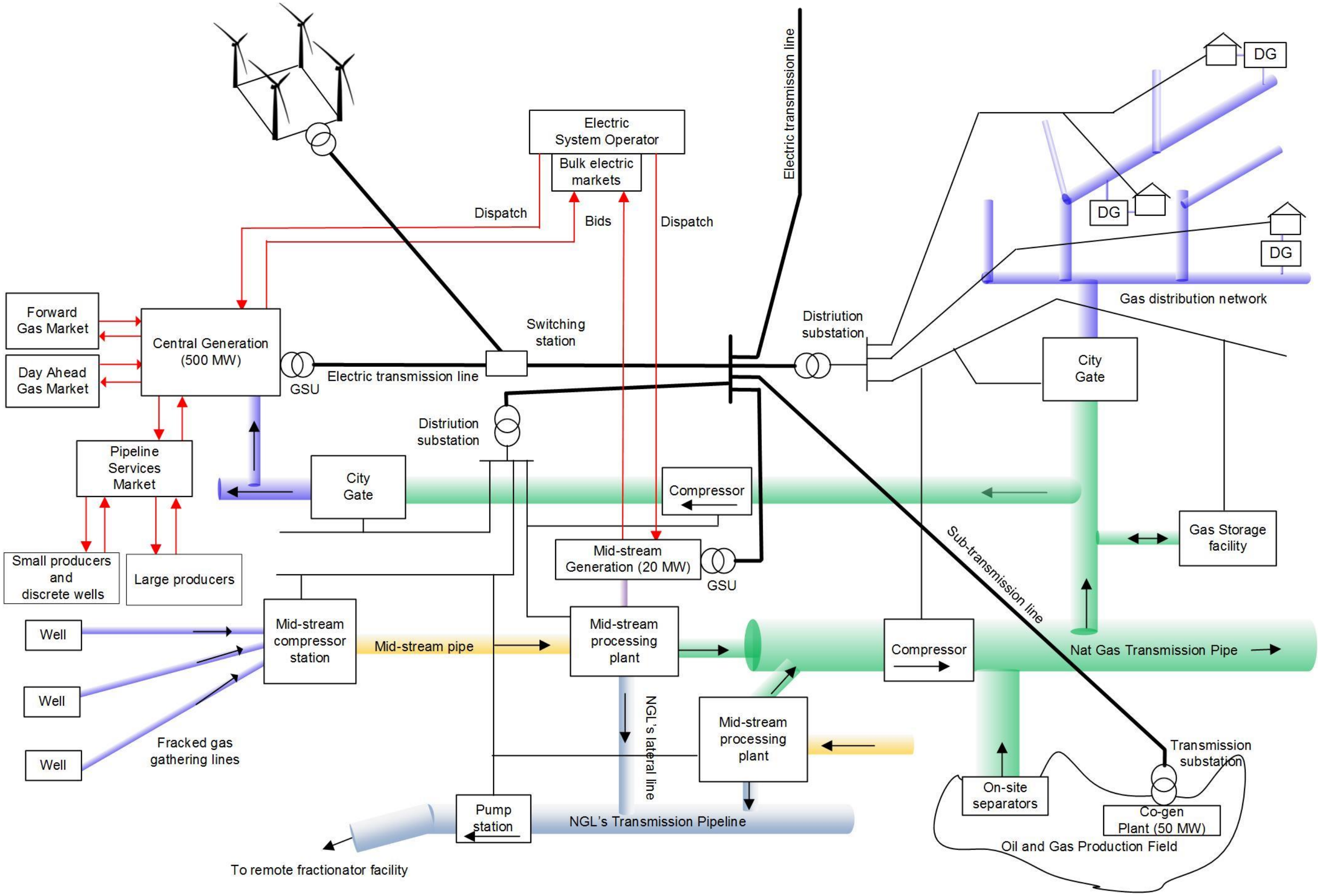
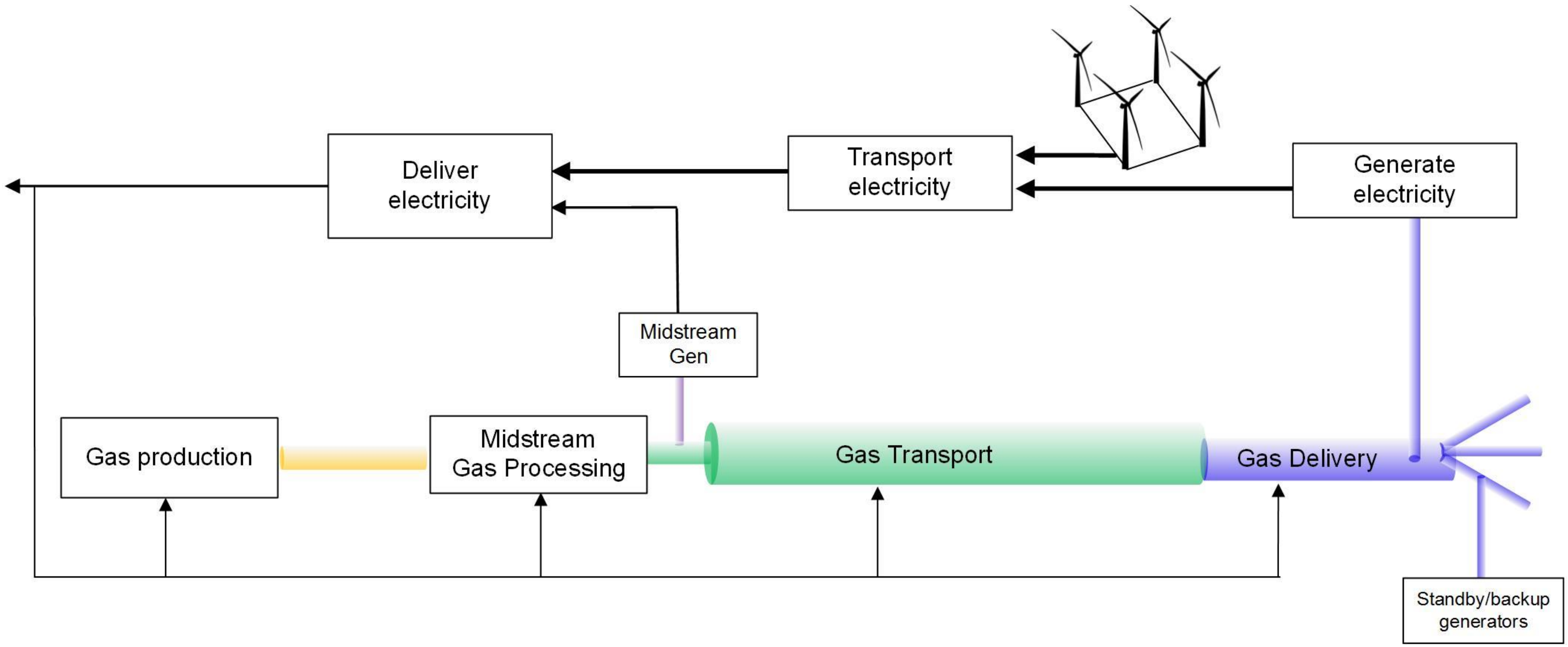


Gas/Electric Double Loop Structure



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recent progress

DOE Grid Architecture Work to Date

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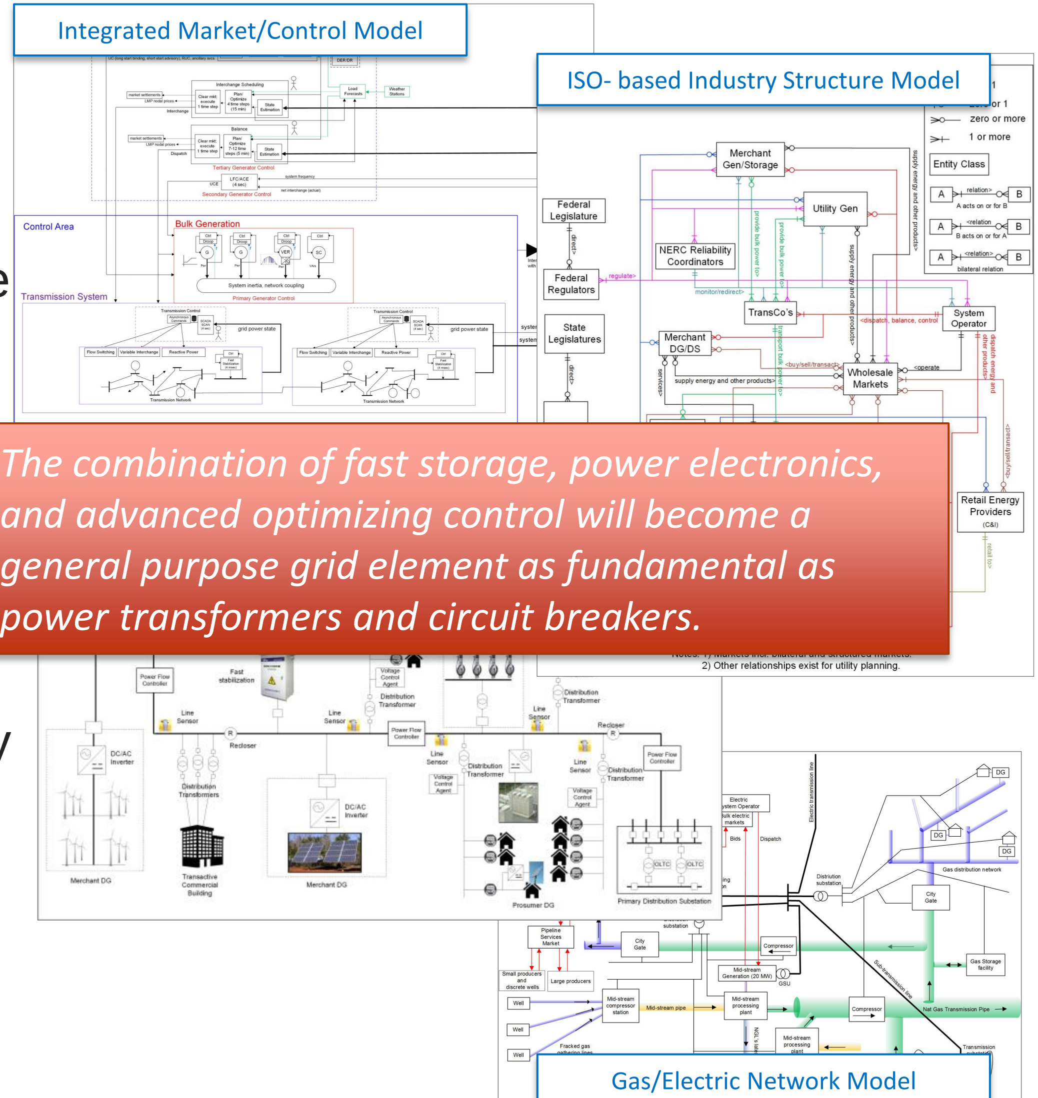
- Done as part of QER
- Limited scope – not full architecture
- 115 page main document plus support documents
- 47 diagrams, 7 tables, 20 alternate architectures reviewed, 18 emerging trends and 39 systemic issues analyzed
- Many new grid architectural insights produced

Example

The combination of fast storage, power electronics, and advanced optimizing control will become a general purpose grid element as fundamental as power transformers and circuit breakers.



- Work has started to go viral – has been referenced in conferences by industry people and is even already being used in an energy law class at GWU
- Presented to NY REV working group, resulting in request for PNNL to engage with NY REV on architecture

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thank you

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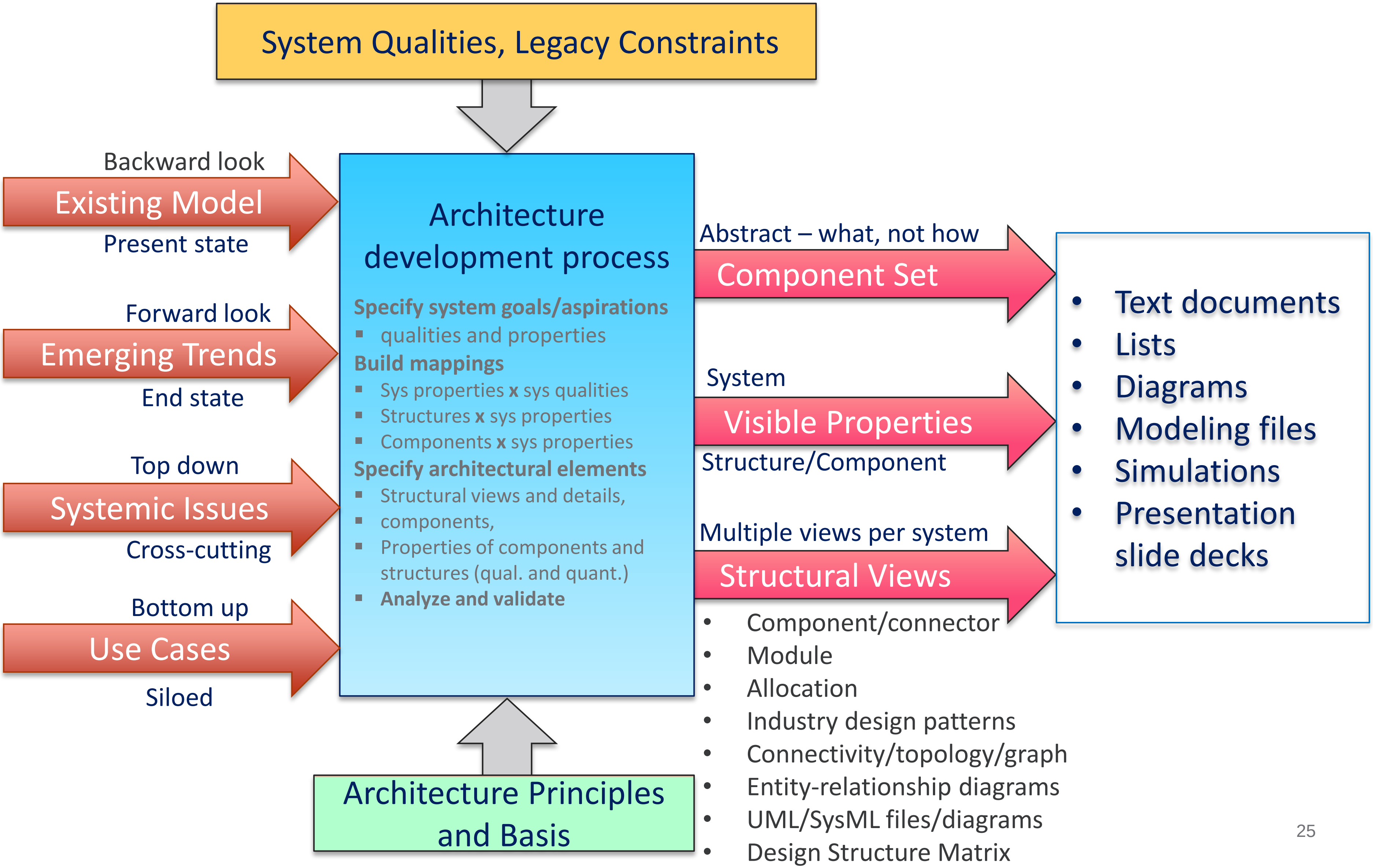
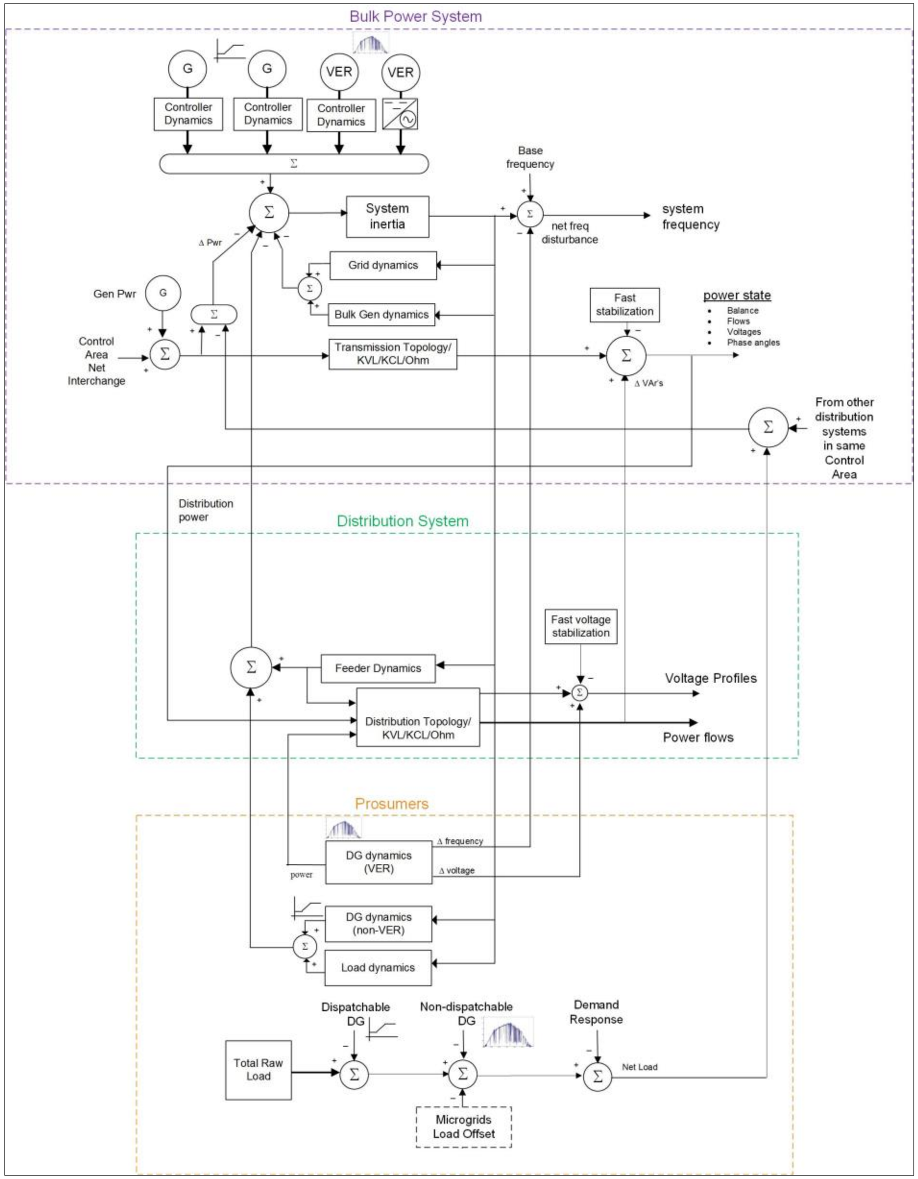
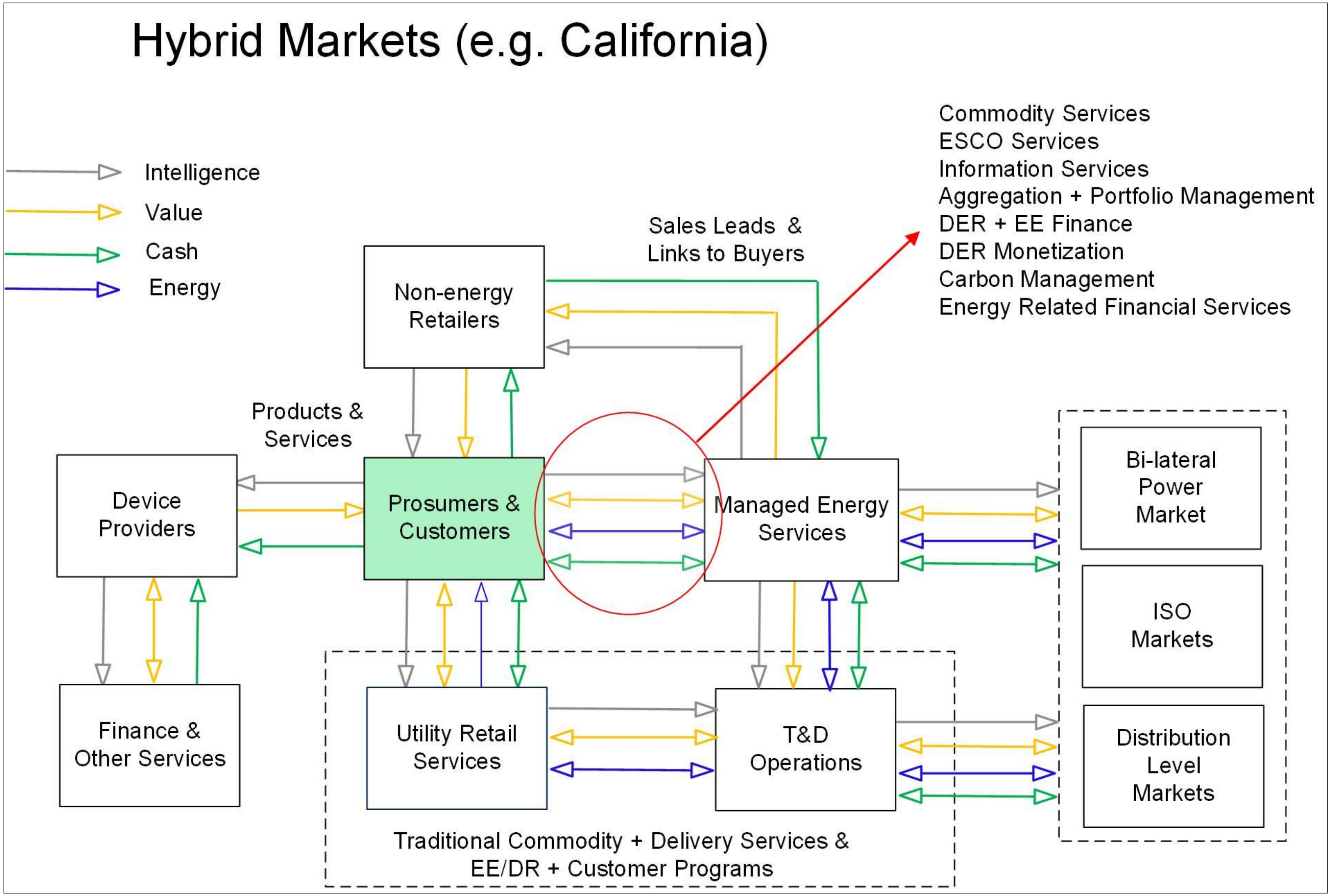
What Goes Into A System Architecture?



Electric Coupling and Interactions



Value Stream Allocation and Analysis



Source: Paul De Martini