U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability

Advanced Grid Modeling 2014 Peer Review

Next Generation Grid Data Architecture & Analytics Required for the Future Grid

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CURENT

Center for Ultra-wide-area Resilient Electric Energy Transmission Networks

an **Engineering Research Center** devoted to **improving** the nation's power grid

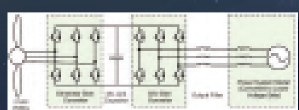
Wide-area Situational Awareness

Fully Integrated Grid with High Penetration of Renewables

Wide-area Closed Loop Control

Control

- closed loop control using wide-area monitoring across multiple time scales
- coordinated renewable energy source controls



Modeling & Estimation

- robust phasor-only static and dynamic estimator development
- real-time large scale data security

Actuation

- multi-terminal HVDC system control
- renewable energy converters as compensator
- hybrid AC/DC transmission architecture

Monitoring

- FNET/GridEye system allows for event detection, size, and location estimate
- automated oscillation alert and analysis
- improved visualization tools
- real-time situational awareness & visualization tools
- off-line pattern discovery

Testbeds

- a large-scale testbed provides simulation platforms to evaluate & demonstrate solutions for the future grid & advanced concepts
- the Hardware Universal Grid Emulator allows testing of various power system architecture and integration of key technologies

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Next Generation Grid Data Architecture

PURPOSE

- To foster open collaboration on issues, establish requirements and propose a specific next generation data architecture

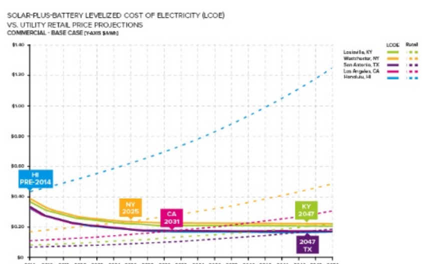
- To enable the production use of new computation methods for management and control of the grid

The scope of "Data Architecture" includes all the data-layer elements needed to support the production implementation of grid modeling and analytics systems – including messages/APIs for consuming data and communicating control actions.

Grid Information Requirements Are in High Flux

Decentralization of Control

Increased Scope of Control



RMI Grid Defection

The Future Electric Grid

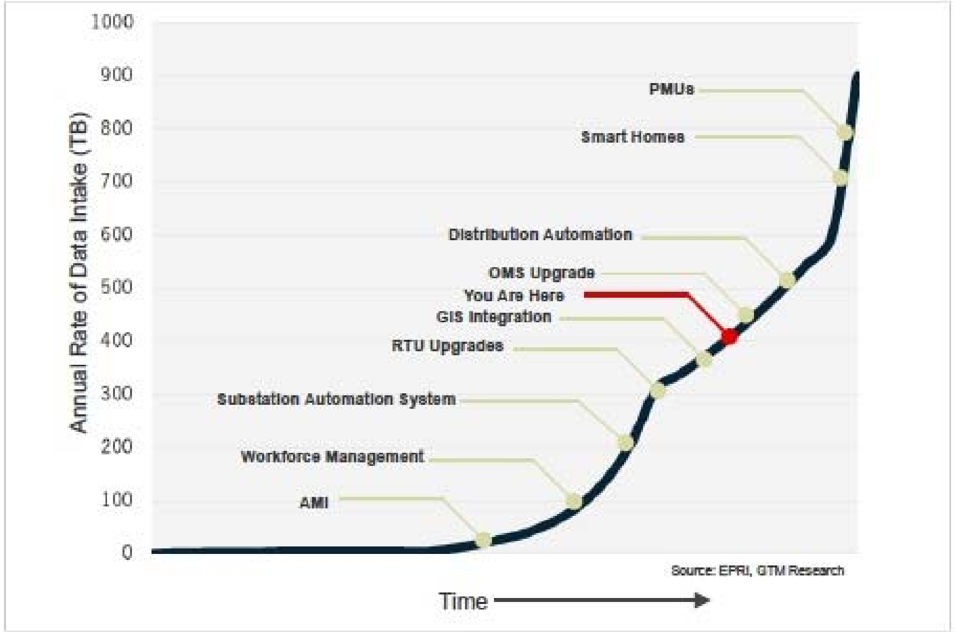
SmartGrid.gov

- More distributed and reconfigurable electric grid
- Many more measurements; more frequently
- Shorter analytics cycle times; advanced analytics
- Growing use of automated controls
- More third party information and energy service providers

Data-Perspective Motivation

- In the near-term, this project will propose solutions to utility issues associated with increased use of large volume data sources such as synchrophasors and metering systems
- A data architecture template, allows research to focus on innovative solutions rather than creation / re-invention of the data layer to support these solutions
- Reliable, high-performance information flows are not scalably supportable by current APIs and protocols

FIGURE 1-9: DATA GENERATION AND UTILIZATION



SOURCE: GTM RESEARCH

Roadmap Components

Architectures for Grid Sensors Information Flow

- Loose Coupling
- Flexible Coupling
- New Inflows at Control Centers

Analytics

- Offline/Batch and Online
- Control: stability and response signals determination

Architectures for Control

- Distributed Control Framework
- Signal Location Focus

Advanced Grid Modeling & Data Architecture

Phase 1

- Form University-Industry Consortium
- Defining common needs for data arch
- Kick-off initial meetings

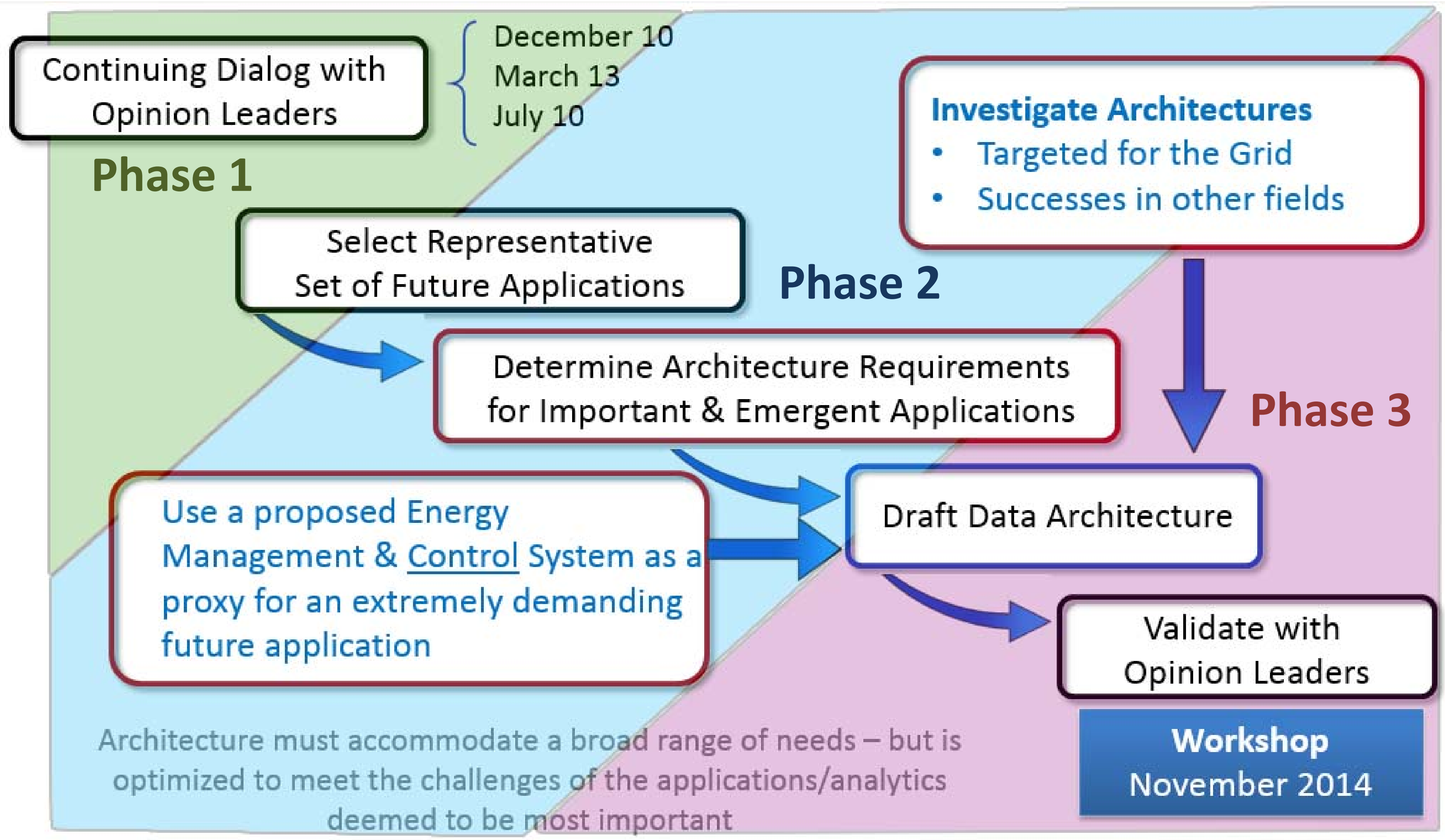
Phase 2

- Benchmark other sectors
- Statement of need document

Phase 3

- Draft Data architecture
- Data analytics R&D in parallel with developing data framework

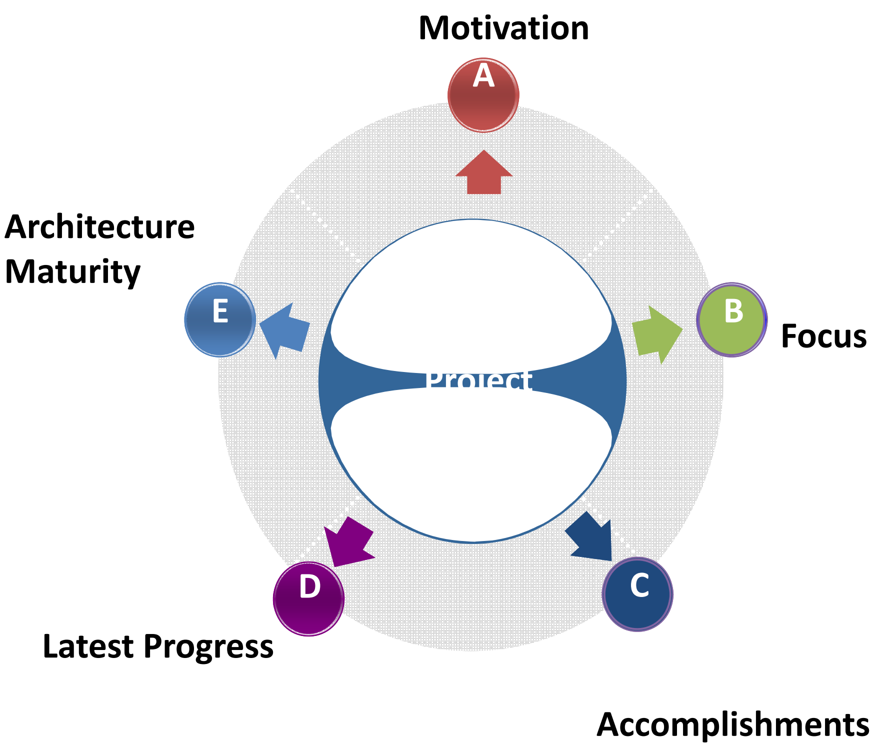
Project Work Process



Accomplishments

1. Investigate
   A. Recent Grid Architectures
   B. Benchmark other industry
2. Determine Requirements for Important & Emergent Applications
3. Use EMCS as a proxy for a demanding future application

1A - Investigate Current Grid Architectures



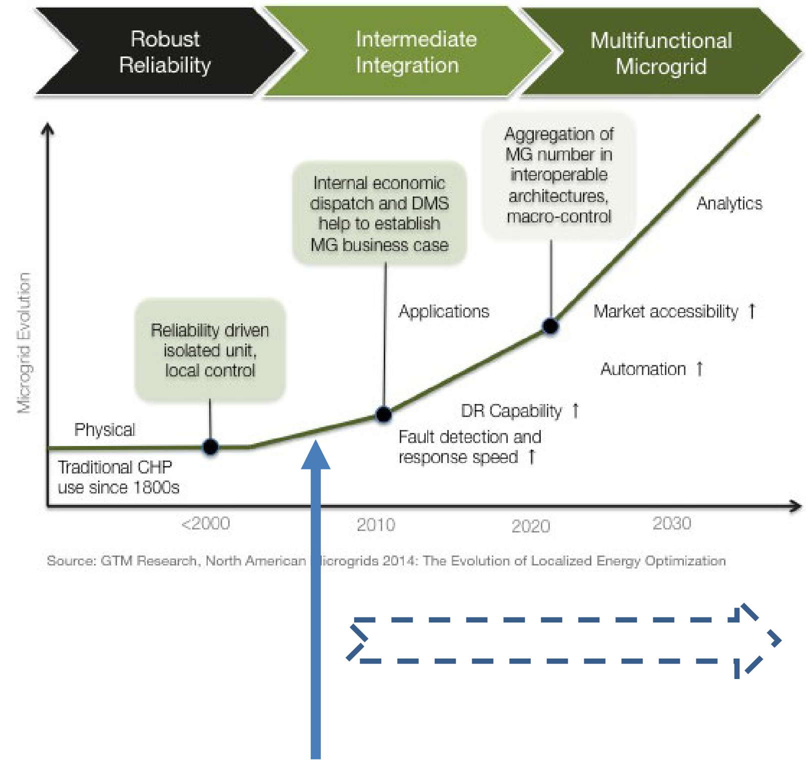
- Purpose is to identify architecture gaps.
- R&D projects for grid data architecture have so far emphasized particular facets of the problem:
  - Interoperability (Gridwise, Intelligrid)
  - Data transportation (Gridstat)
  - Data services bus (FPGI)
  - Conceptual modeling frameworks (European SGCG)
- Better understand new requirements for the data architecture based on renewable energy management and responsive load integration
  - e.g., iTESLA architecture has efforts in data mining technology for modeling stochastic system variables

Investigation Outcome Snapshot

Project Name	Sponsor/ Date	Objective/Content	Focus on data architecture
IntelliGrid	EPRI, 2001	• Integrate energy delivery system and information system	• Interoperability • Communication networks
Gridwise	DOE, PNNL, 2004	• Establish interoperability principles	• Interoperability for end-use
GridStat	NSF, WSU 2001	• Delivery of power grid operational status information	• Middleware technology
FPGI	PNNL, 2011	• Next-generation concepts and tools for grid operation and planning	• Data management • Software framework
SGCG	CEN/CENELEC/ET, 2011	• A framework to perform standard enhancement and development	• Modeling • Interoperability
iTESLA	European Commission, 2012	• Dynamic security assessment considering uncertainty	• Data mining • Data management
TCIPG	UIUC, UCD, WSU, etc, 2011	• Secure low-level devices, communications, and data systems	• Cyber security
SGIP	NIST, 2009	• To accelerate the implementation of interoperable Smart Grid devices/systems	• Interoperability
SG-framework	NIST, 2010	• To develop interoperable standards	• Interoperability • Standardization

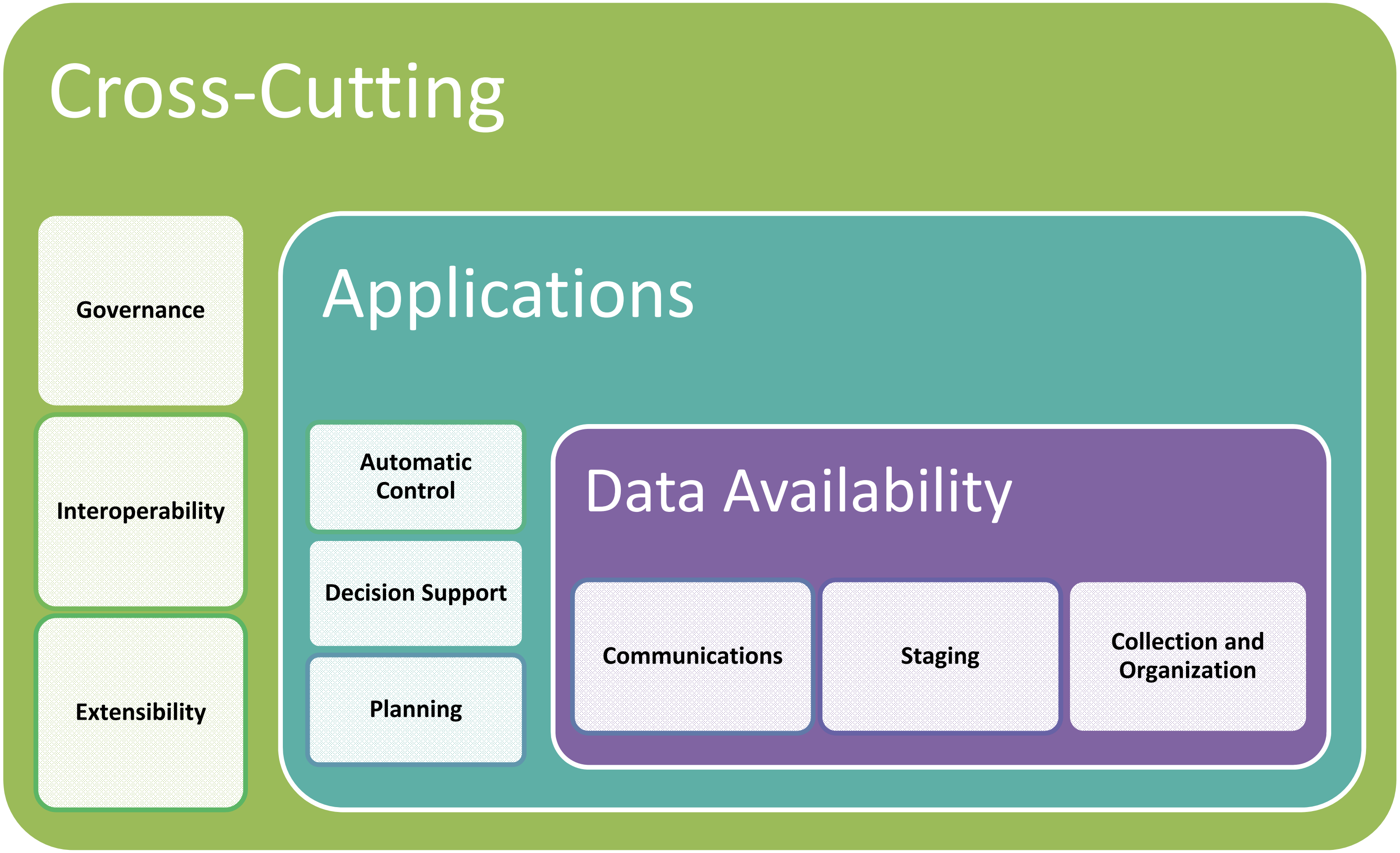
Grid Architecture Gap

- Structural: most current architectures discuss necessary functional abstractions of the information layer: e.g., Intelligrid, GWAC Stack, NIST Smart Grid, etc. However:
  Emerging DISTRIBUTED CONTROL structural requirements remain to be addressed.
- Functional: New data sources (e.g., smart inverters, PMUs, imagery), higher data volumes (e.g., 60 Hz+ sampling), and new applications (e.g., comfort signals, transactions)
  Emerging NEW APPLICATIONS and DATA ANALYTICS demands rely on the new data layer and data architecture definition.



New Requirements (Post 2008/ ARRA)

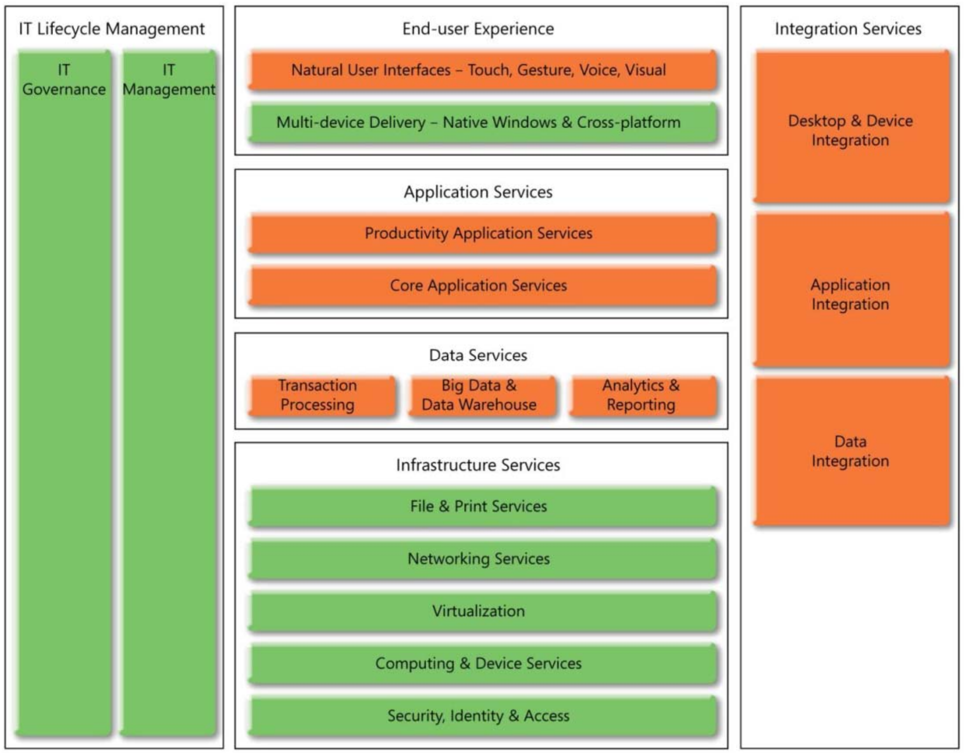
1B – Investigate Successes in Other Sectors



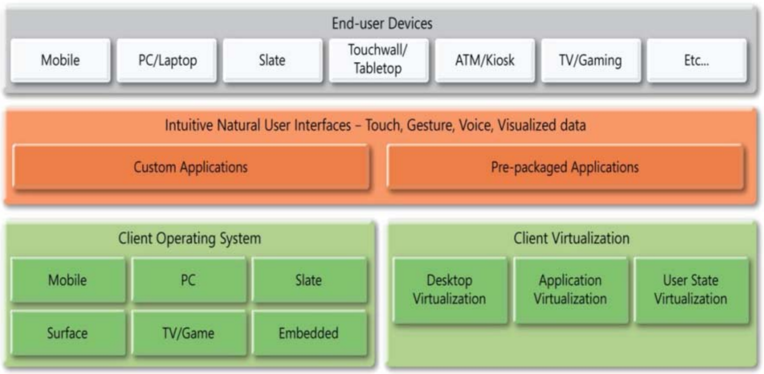
Parametric Views: Volumes, Resolution, Variability, Quality, Uncertainty, Latency

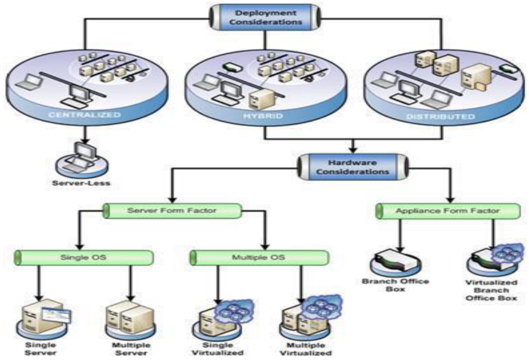
Finance Functional Architecture Stack

Technology Capabilities View – Microsoft Platform



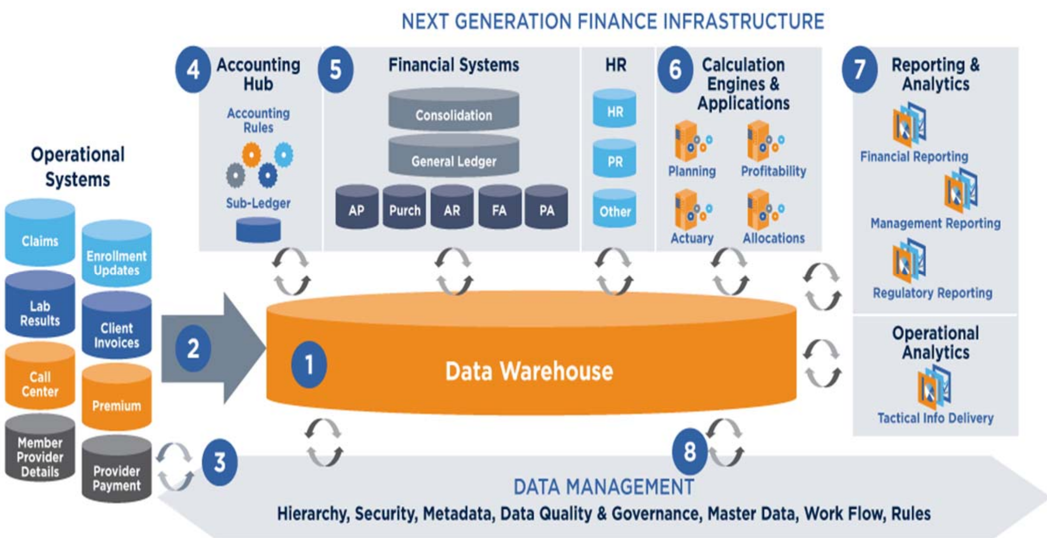
Technology Capabilities View – End-user Experience



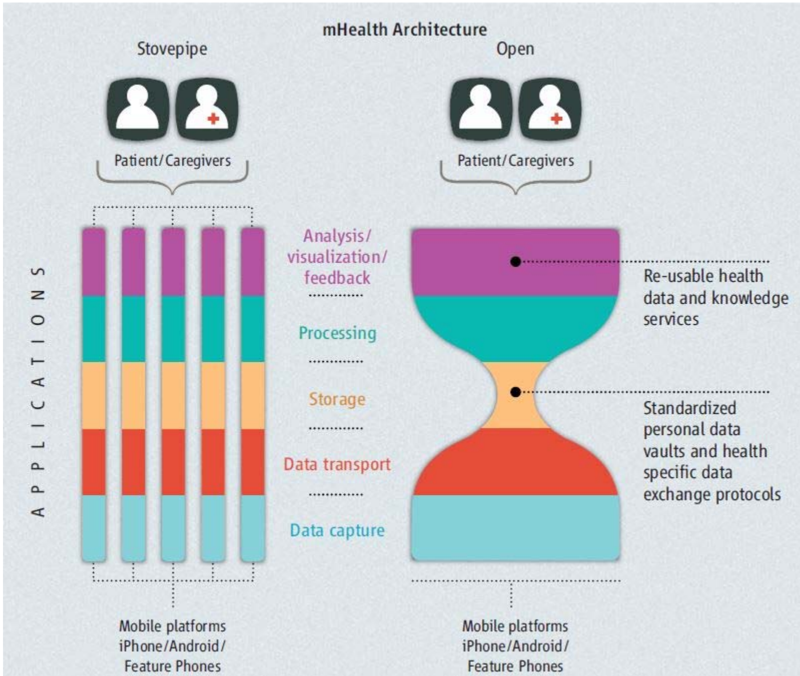


Source: Microsoft's Banking Reference Architecture Document 2012

Healthcare Reference Architecture Examples



Credit: Teradata.com



Credit: D. Estrin and I. Sim

Teradata Finance and Healthcare Centralized Large-Scale Processing

Distributed mHealth Goals

Benchmarking Lessons Learned

Grid systems can effectively leverage work in other sectors

- Scalable data-alignment (Extract-Transform-Load) at ingest is solved.
- Storage management is not a pain point.
- Stream handling of data is improved.
- Analytics on scalable and streaming data is available.
- Linking disparate data is possible.

However, other sectors offer essentially no parallels to the cyber-physical scale of wide-area electric grid control. The electric grid infrastructure still needs new distributed data and control handling architectures.

2 – Understand Requirements

- Applications determine data-layer requirements
- Opinion leaders helped create list of representative future-state applications
- These applications were ranked based on their importance to operating the grid of the future
- Requirement issue areas for these applications were identified

Data Architecture & Data Analytics

- Collaborating with Stakeholders to define the Future Grid Data Architecture

Utility & RTOS

Vendors

Research & Consulting

Academia

Representative Application List

Adaptive Topology Control	Next-Generation SCADA/EMS
Adaptive Topology Planning	Optimized Power Flow
Advanced/Predictive Restoration Systems	Oscillation Detection
Alarm Integration and Management	Post-Trip Fault Analysis
Electrical Network Model Validation	Power Market Analysis
Fault Induced Delayed Voltage Recovery	Predictive Control
Forward Analysis (granular 60 minute look ahead)	Producer / Consumer (Prosumer) Systems
GIC, Solar, EM Disturbance Response	Remedial Action Schemes
Islanding Management	Renewables Integration
Look-Ahead Simulation and Control (10 Seconds)	Stability Monitoring and Frequency/Voltage Control
Modeling System Dynamics and Transients	State Calculation (vs. Estimation)
Multi-Resolution Frequency Analysis	Transmission Pathway and Congestion Management
N-1-1 Contingency Analysis	Wide-Area Profiling and System Management

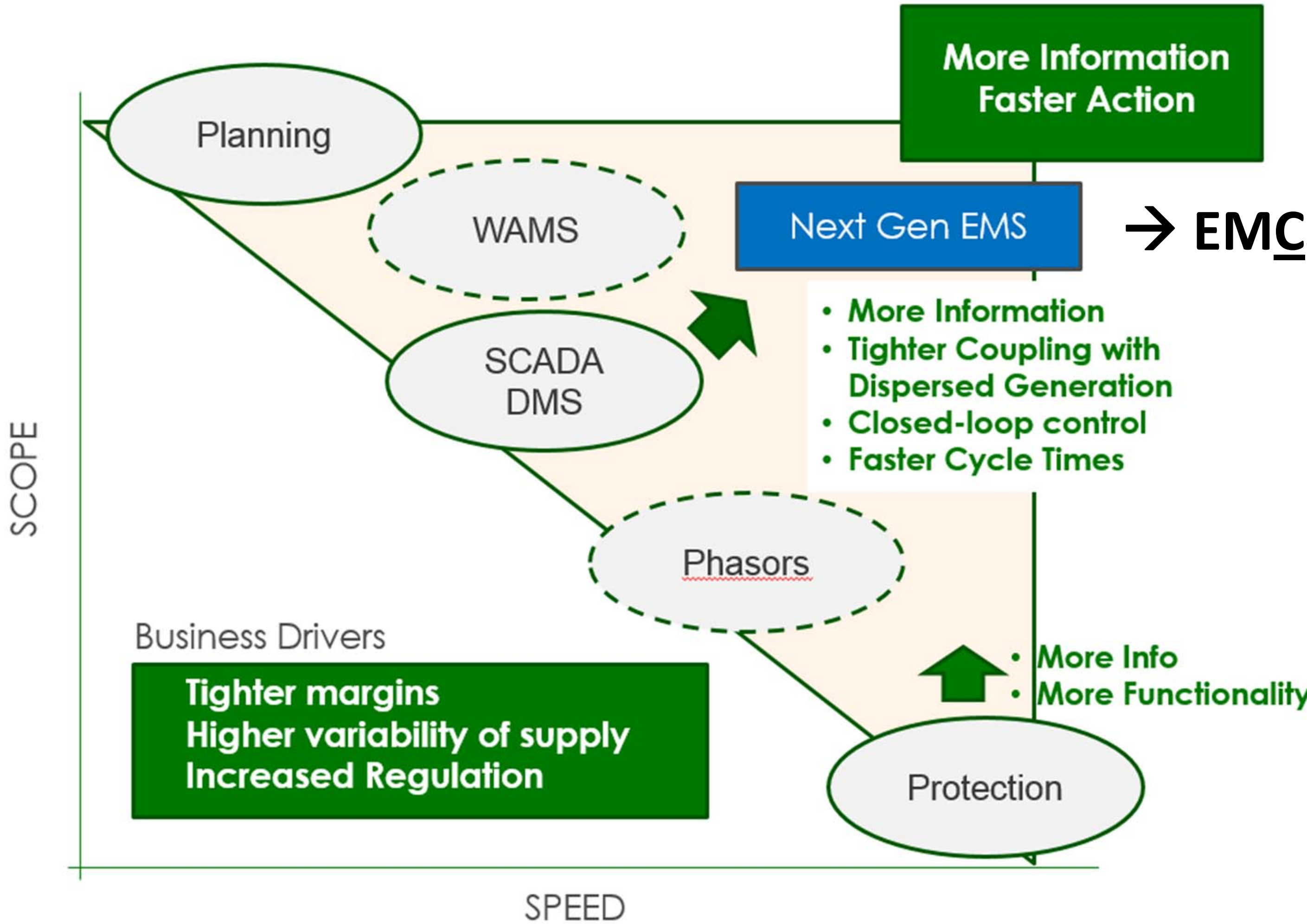
Next Generation Challenges

		Application	Priority Score	Application Challenge Dimensions				
				Computational	Configuration	Data		
						Volume	Velocity	Veracity
1	3	Advanced/Predictive Restoration Systems	25		Yes	Yes		
2	8	GIC, Solar, EM Disturbance Response	25				Yes	Yes
3	4	Alarm Integration and Management	19		Yes			
4	5	Electrical Network Model Validation	19		Yes			Yes
5	13	N-1-1 Contingency Analysis	19	Yes	Yes	Yes		
6	23	Stability Monitoring and Frequency/Voltage Control	19				Yes	
7	2	Adaptive Topology Planning	17	Yes	Yes			
8	7	Forward Analysis (granular 60 minute look ahead)	17	Yes	Yes	Yes	Yes	
9	9	Islanding Management	17				Yes	
10	22	Renewables Integration	17		Yes			
11	17	Post-Trip Fault Analysis	16					Yes
12	10	Look-Ahead Simulation and Control (10 Seconds)	15	Yes			Yes	Yes
13	11	Modeling System Dynamics and Transients	15	Yes	Yes			
14	26	Wide-Area Profiling and System Management	15	Yes	Yes	Yes		
15	1	Adaptive Topology Control	13		Yes			Yes
16	14	Next-Generation SCADA/EMS	13	Yes	Yes	Yes	Yes	Yes
17	16	Oscillation Detection	13			Yes	Yes	Yes
18	24	State Calculation (vs. Estimation)	13			Yes		Yes
19	6	Fault Induced Delayed Voltage Recovery	12	Yes			Yes	
20	12	Multi-Resolution Frequency Analysis	11	Yes		Yes		Yes
21	19	Predictive Control	11	Yes			Yes	
22	21	Remedial Action Schemes	11				Yes	
23	25	Transmission Pathway and Congestion Management	11		Yes			
24	15	Optimized Power Flow	9	Yes				
25	18	Power Market Analysis	9	Yes				
26	20	Producer / Consumer (Prosumer) Systems	8			Yes		

Requirement Gathering Highlights

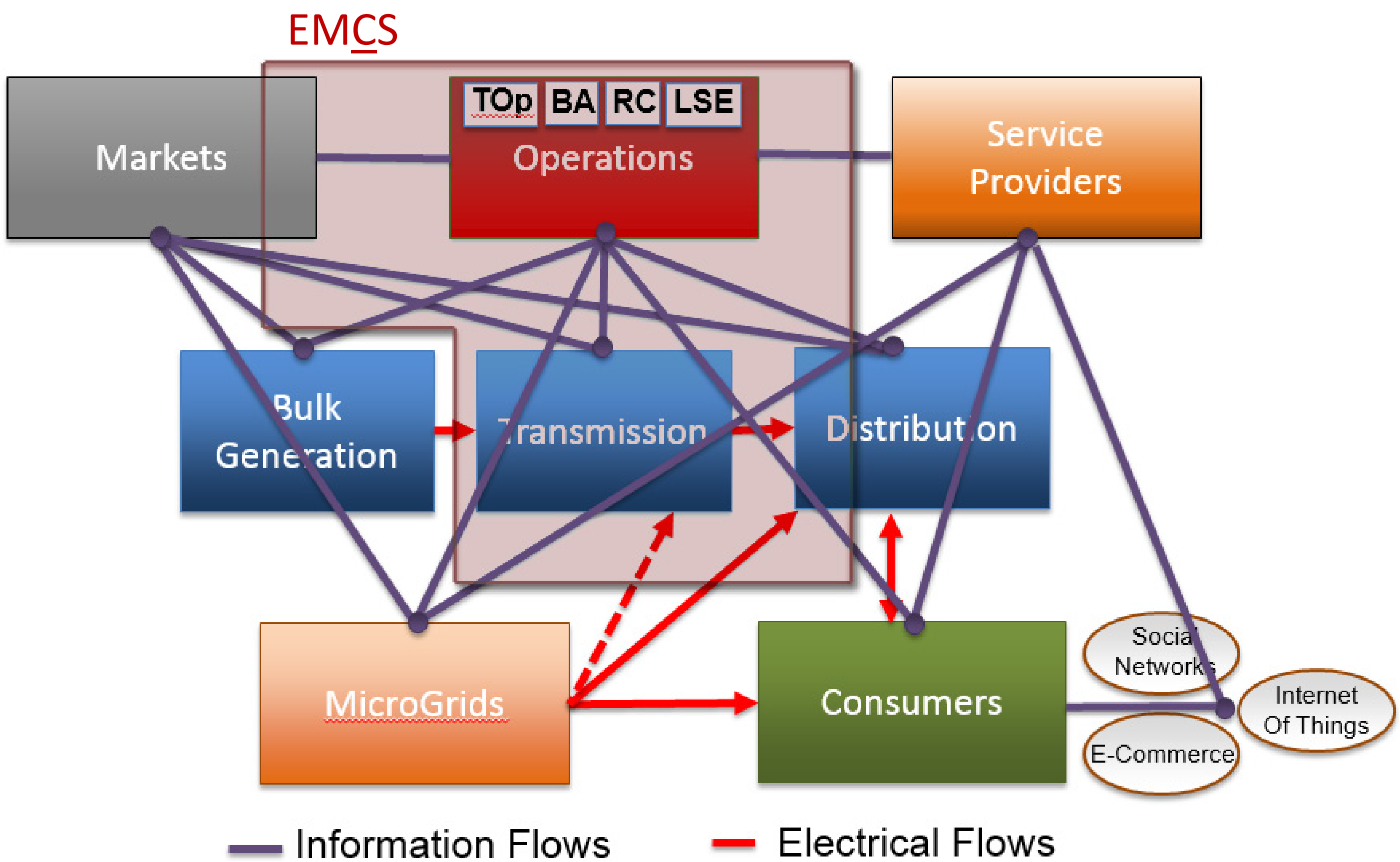
- Next-generation EMS/SCADA is one application that hits all the application challenge dimensions.
- Top five next generation challenges are applications that reside in current day EMS and their incorporation leads to next-generation EMS.
- Configuration management is a sleeper critical requirement.

3. Use EMCS as an Application Proxy

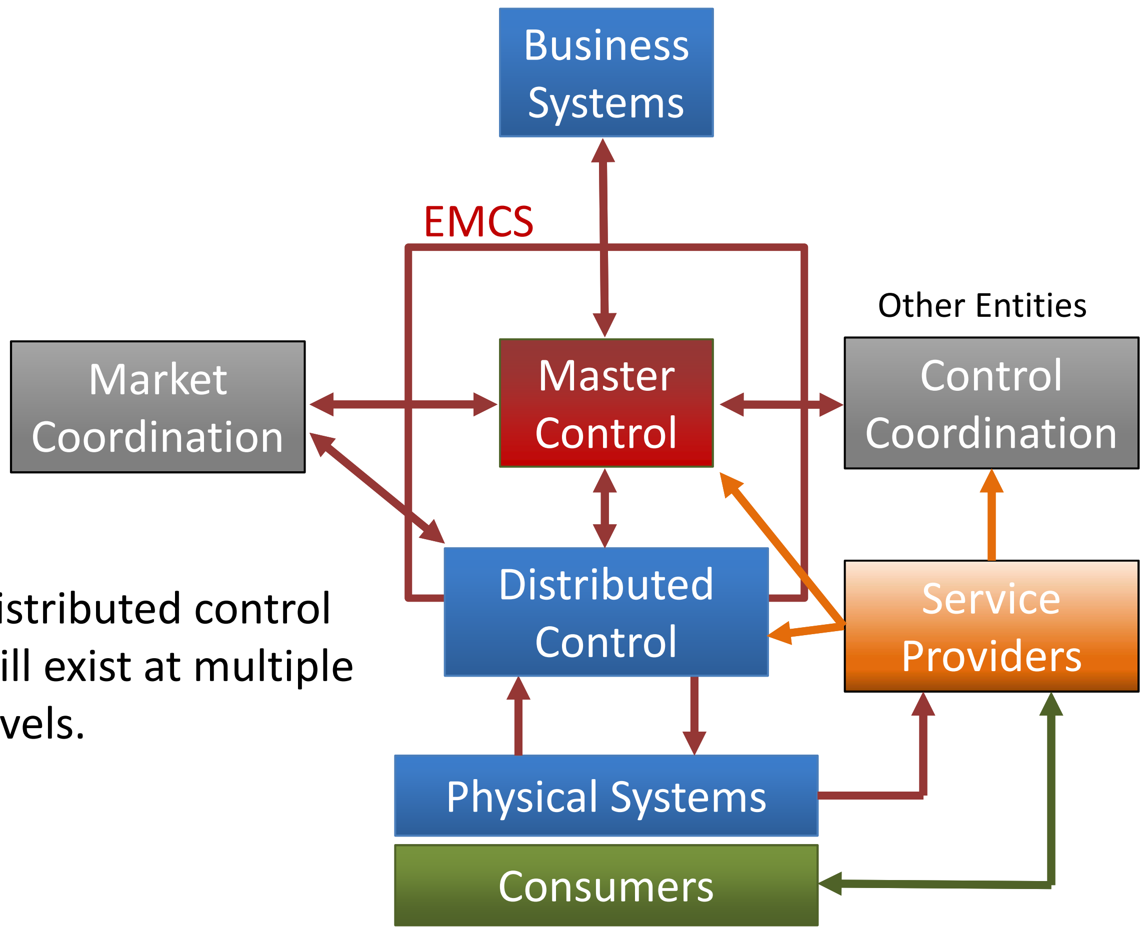


→ **EMCS**

EMCS – Grid Operations Ownership



EMCS Includes New Interfaces

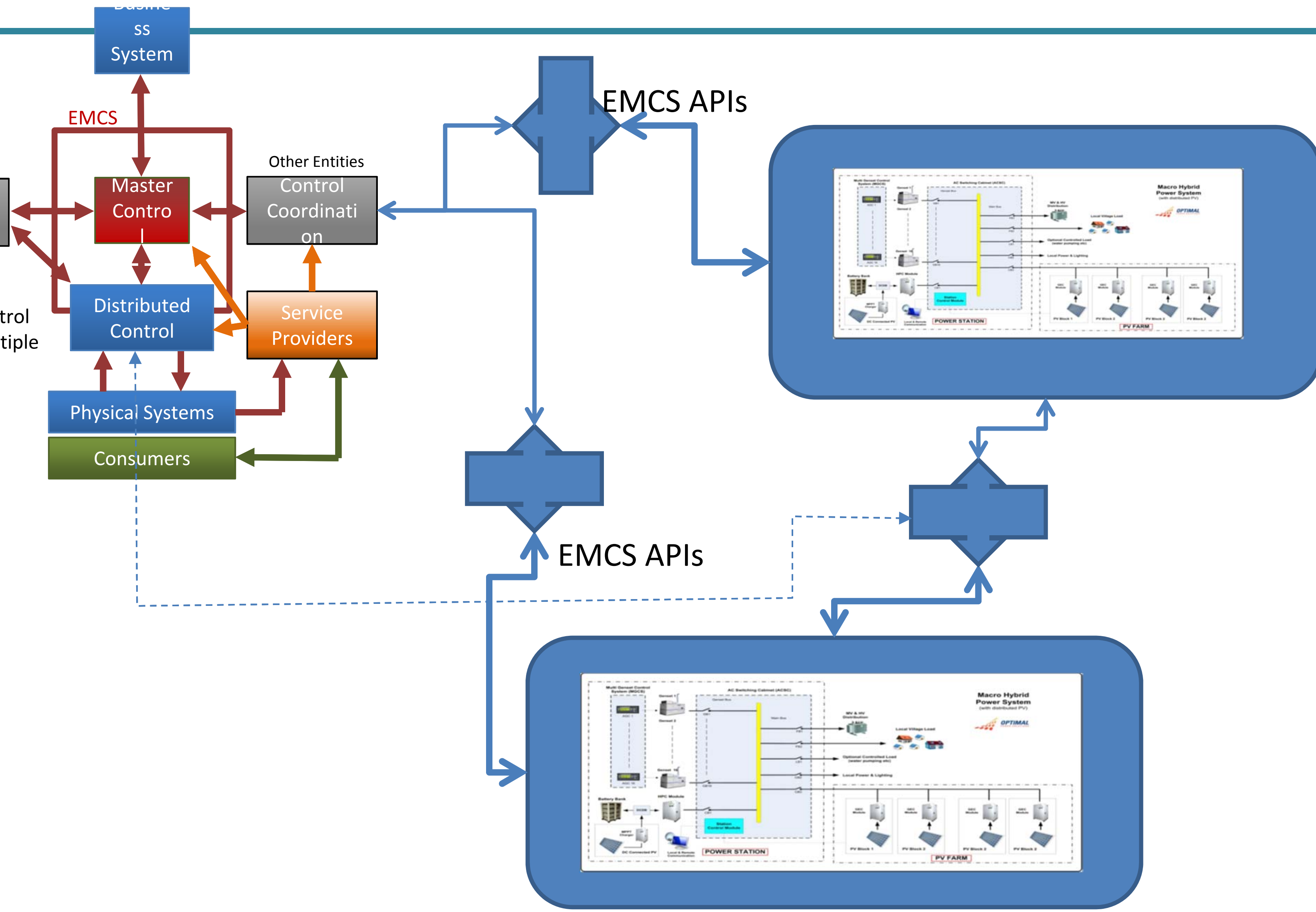


Distributed control will exist at multiple levels.

Necessary Data Architectural Elements

- Streaming and Transactional Data Acquisition
  - Conventional grid data
  - High volume data sources
- Data Conditioning / Organization
- Data Storage
- Data Systems Middleware / APIs
  - High performance real-time data services
  - Historical data services for off-line analytics and business systems
  - Services and support for legacy applications
- Control Middleware / APIs
- Grid Metadata

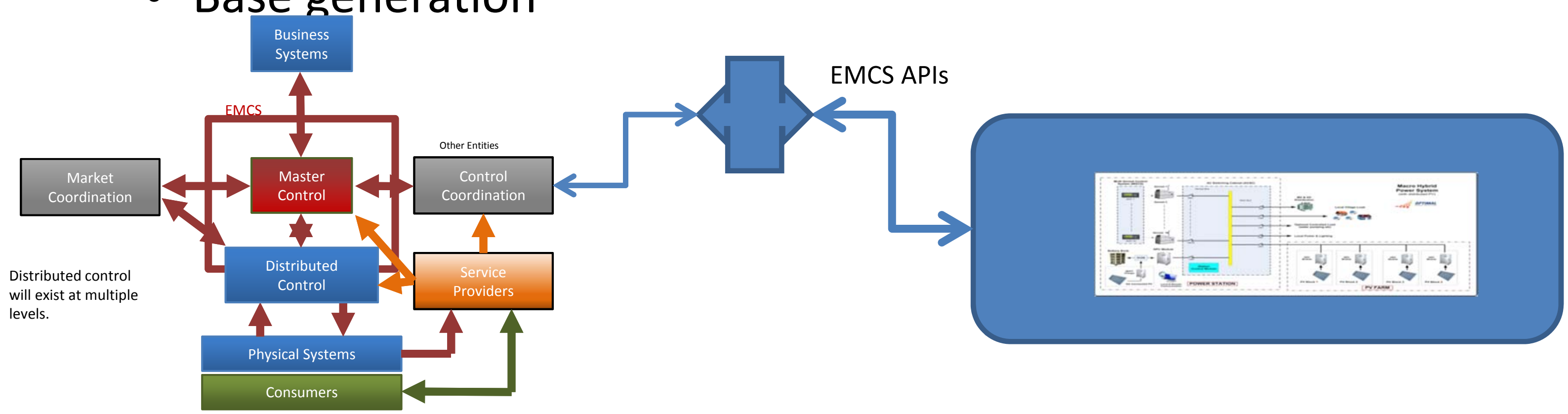
Addressing Structural Needs of Local and Regional Stability



Distributed control will exist at multiple levels.

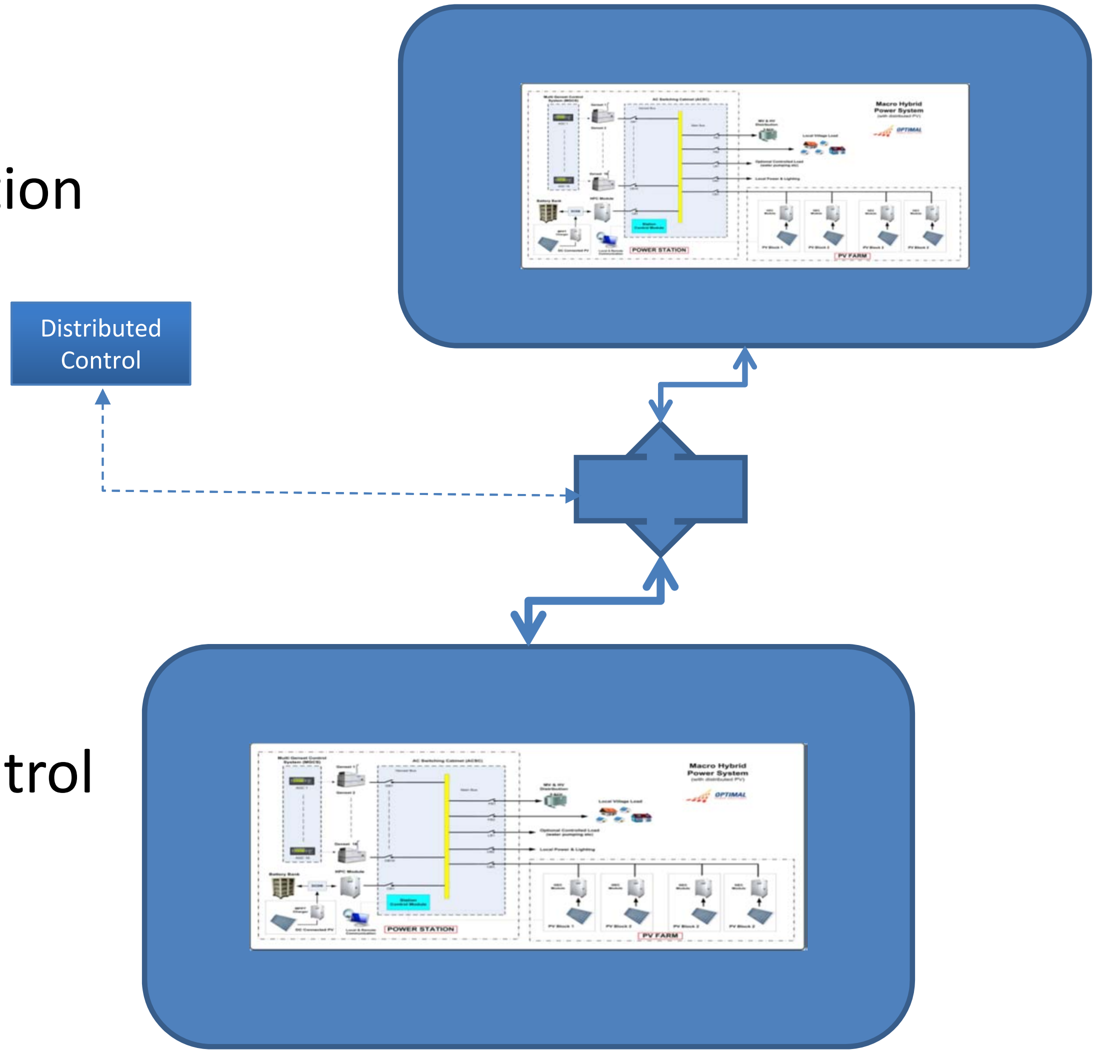
Control and Coordination Messages

- Control Signals
  - Near-Real-Time
    - +/- Load
    - +/- Gen for Regulation
    - Price signals
  - Scheduled
    - Base generation
- Status and Request APIs
  - Dynamic event status
    - Unscheduled mechanical, weather
    - Unscheduled load
  - "Comfort" services

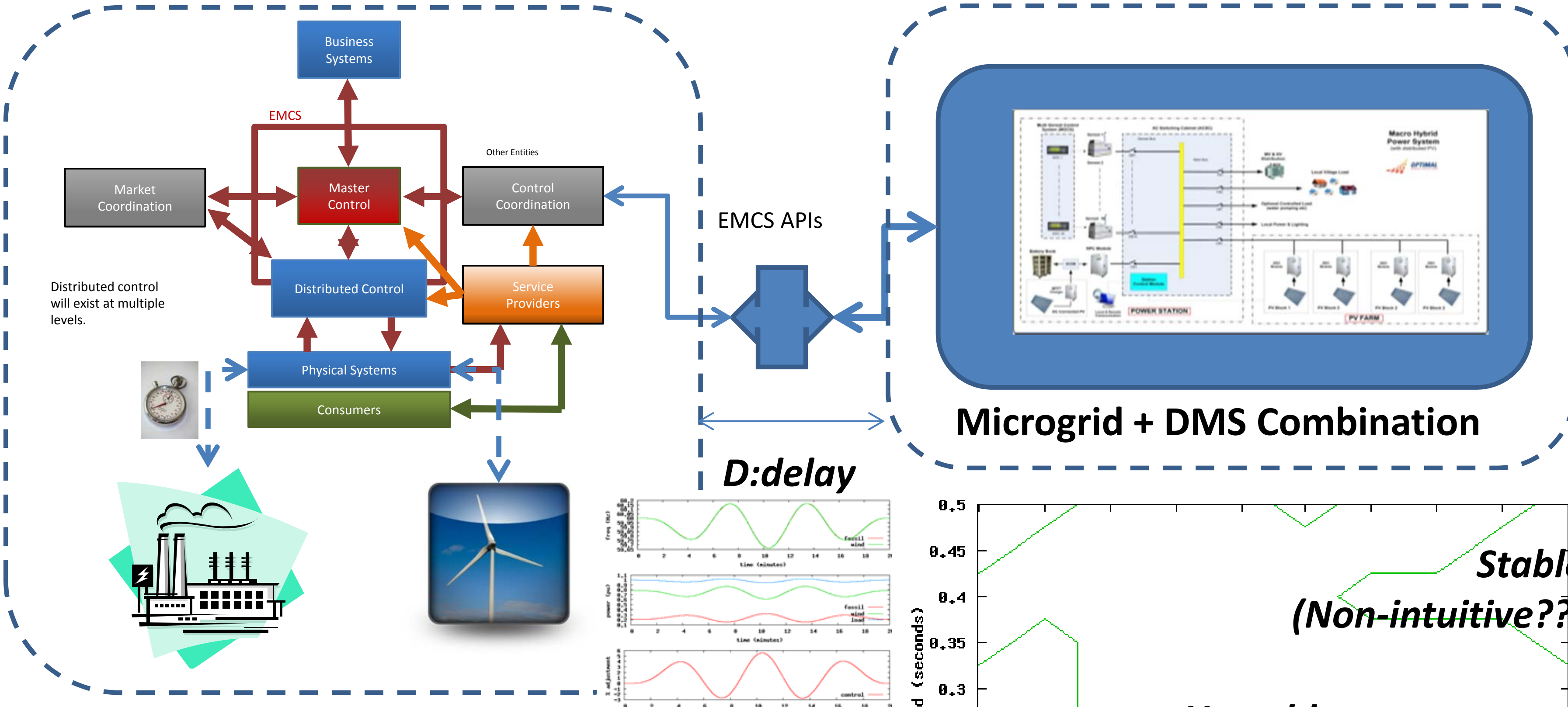


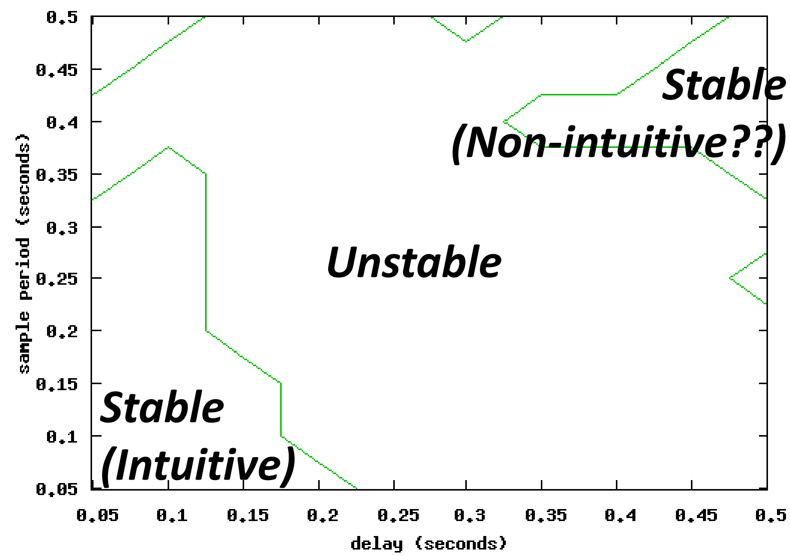
Distributed Control Messages

- Events
  - Stability and Regulation
  - Islanded operations
- Peering messages
  - Price signals
  - Event status
- Peered agreements
  - Status to master control
  - Schedules



Preliminary Analysis of Data-Transport Impact on Future Control Scenarios





- Sample(rate *s*) arrives at the control after a delay *d.*
- Control causes a step change in load that is proportional to the measured frequency.

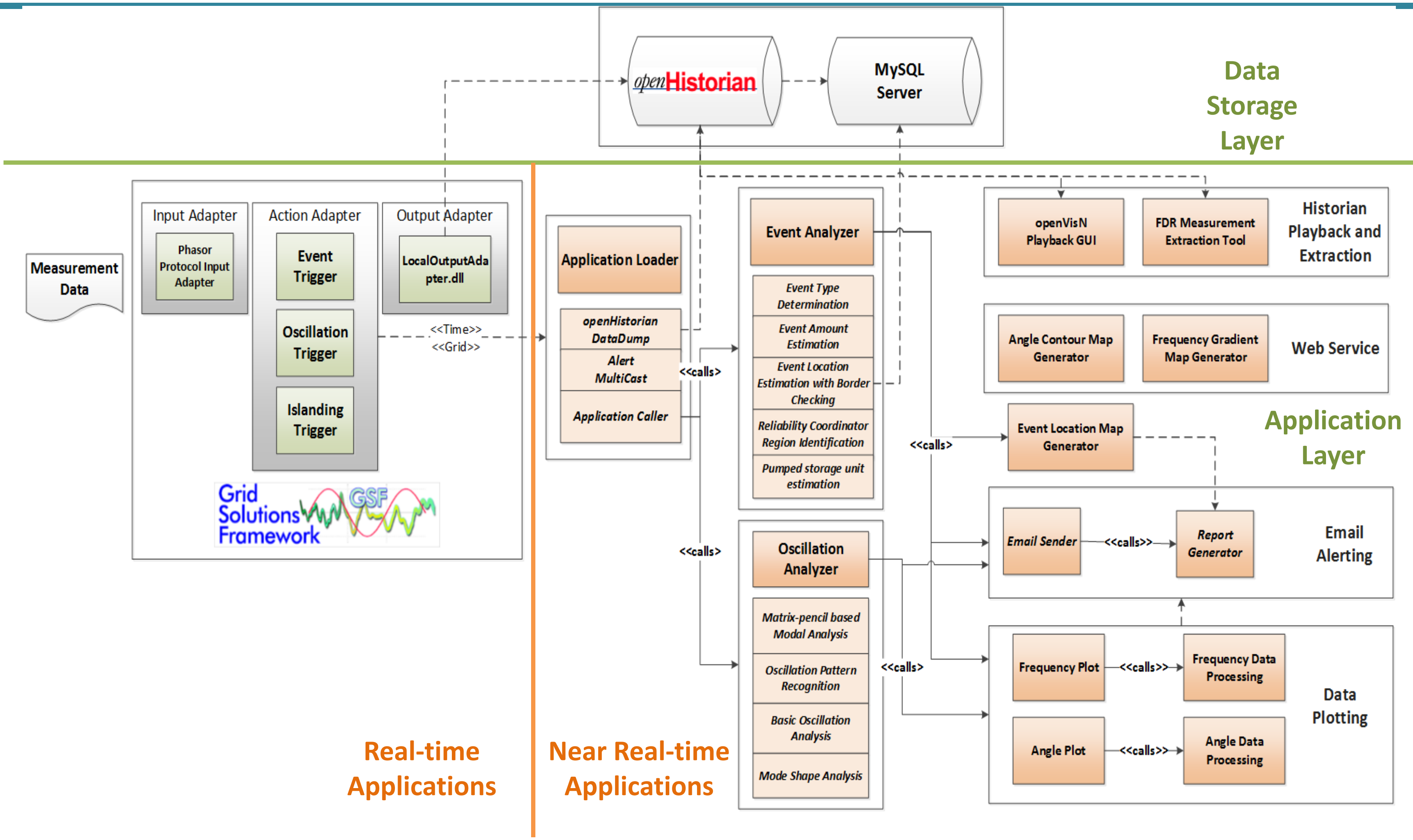
Accomplishment Summary

- Conducted 2 working group meetings
- Identified top quartile applications and their respective requirements
- Conducted an architecture survey of 9 recent grid architectures
- Looked at two architecture successes from other industry
- Developed a candidate list of data and control layer components for the future EMCS

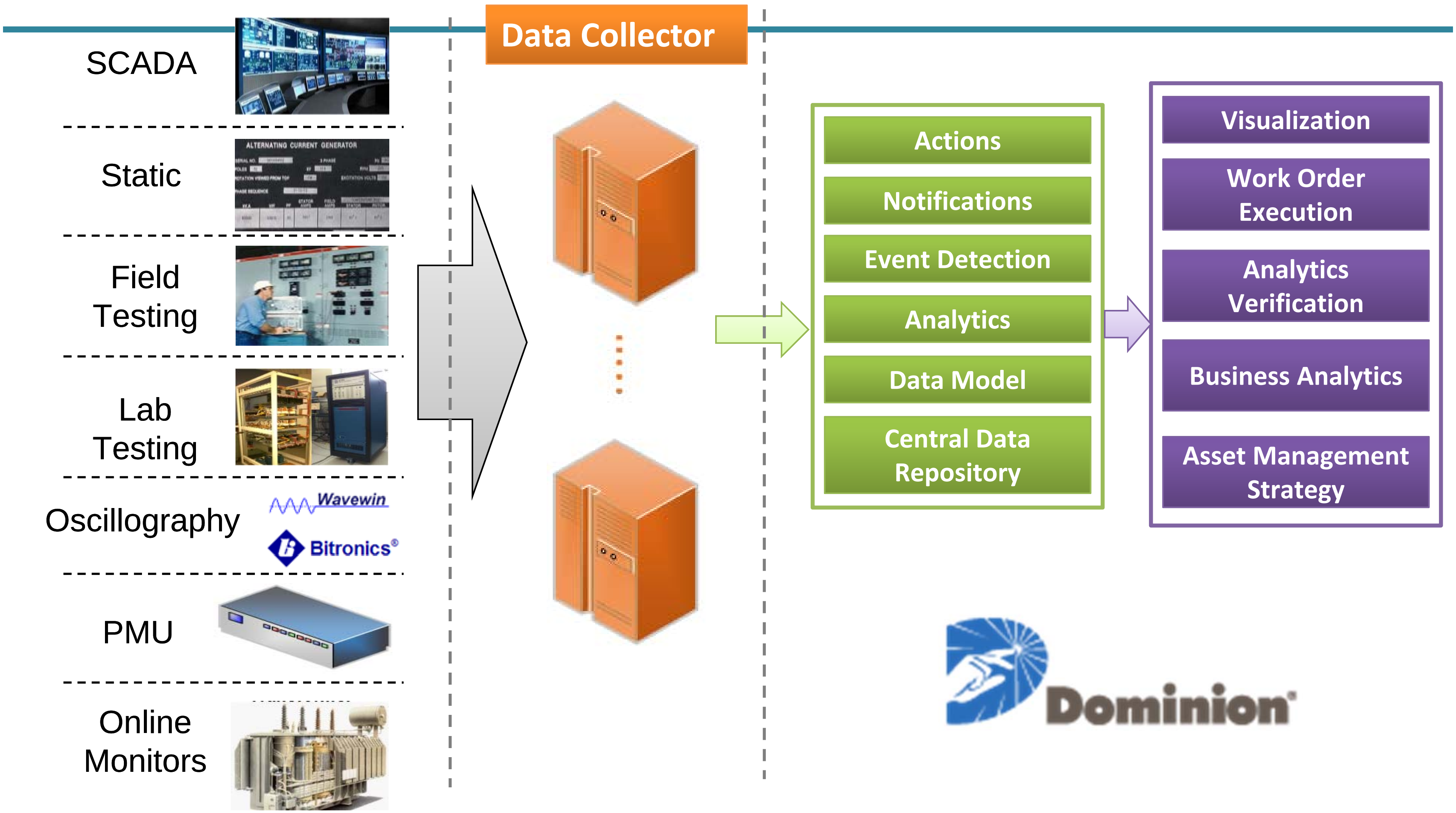
Upcoming Work

- Implement the distributed coordination use-case in a model
- Develop the message types for the distributed and centralized close-loop control API
- Analytics
  - Develop and evaluate algorithms for EMCS distributed coordination operations
  - Use phasor data to perform dynamic assessment
  - Compare SCADA-based and phasor-based analytics for flexible control algorithms

Example #1: FNET/GridEye Data flow



Example #2: Dominion Comprehensive Data Repository



Addressing Emerging Functional Needs through Analytics

- Traditional
  - Static and dynamic analysis (power-flow): state-estimation
  - (Scalable) contingency analysis
  - Protection schemes
  - Optimization routines for markets

Central control

- New analytics requirements
  - Optimization of distributed schedules (bin-packing) and dispatch
  - Distributed peering coordination
  - New regulation possibilities

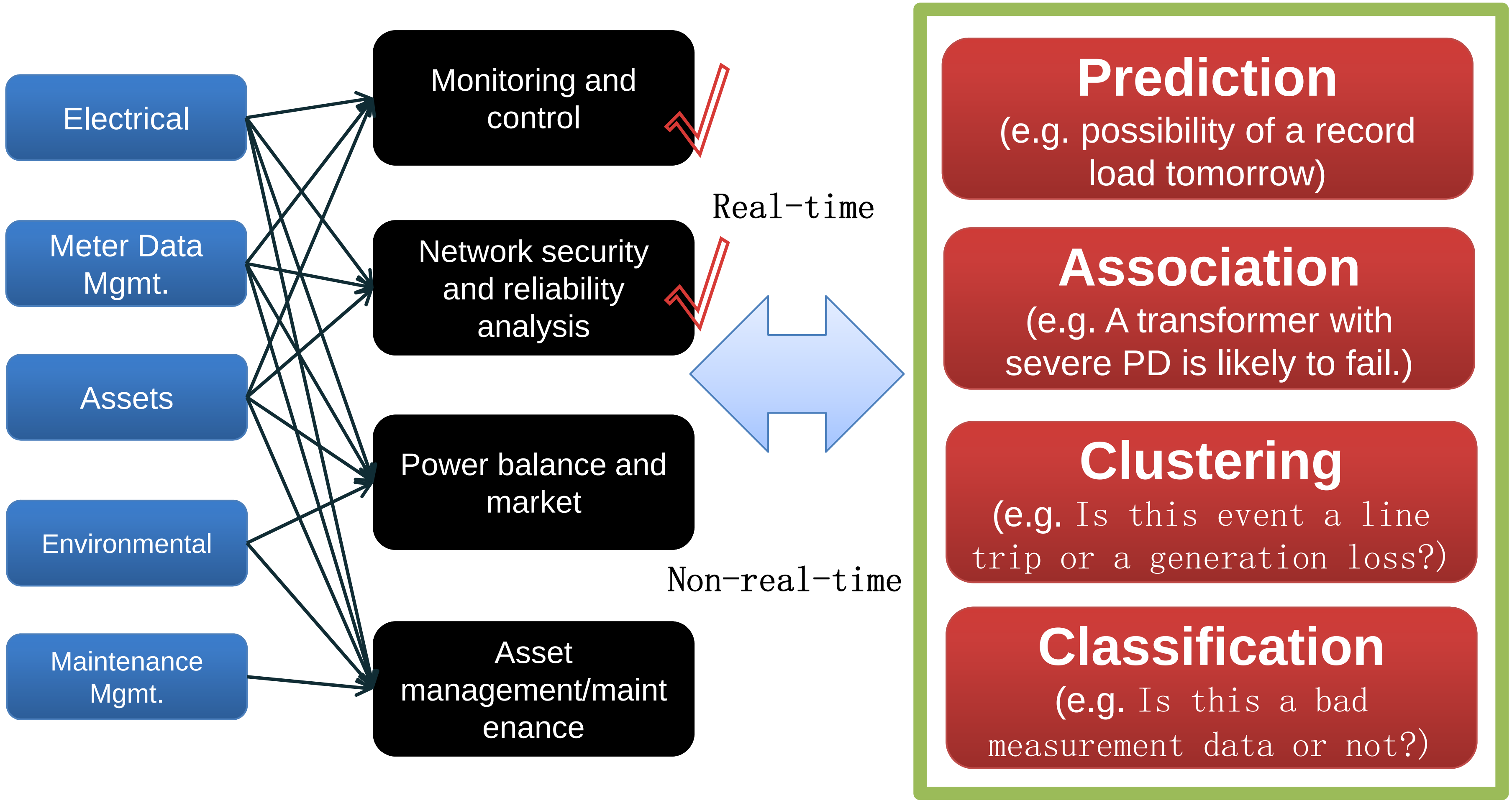
Central oversight of Increasing autonomy

Multi-University Data Analytics Projects

- Measurement-Based Estimation of Power Flow Jacobian: Algorithms and Computational Architectures (UIUC)
- Data Compression and Reconstruction for Large-scale Synchrophasor Measurements (RPI)
- Use of Big Data For Outage Management in Distribution Systems (TAM)
- Cyber-Physical System Security Assessment Involving Multiple Substations (WSU)
- Frequency Distribution and Event Discovery from Synchrophasor Data (UTK)

Data Analytics Overview

Data sources **Applications** **What does data analytics do?**



Next Generation Grid Data Architecture

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Analytics Required for the Future Grid

Questions ?