Synchrophasor Technology: Benefits and Pitfalls

Mladen Kezunovic, Ph.D., P.E.
Director, Smart Grid Center

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Outline

History

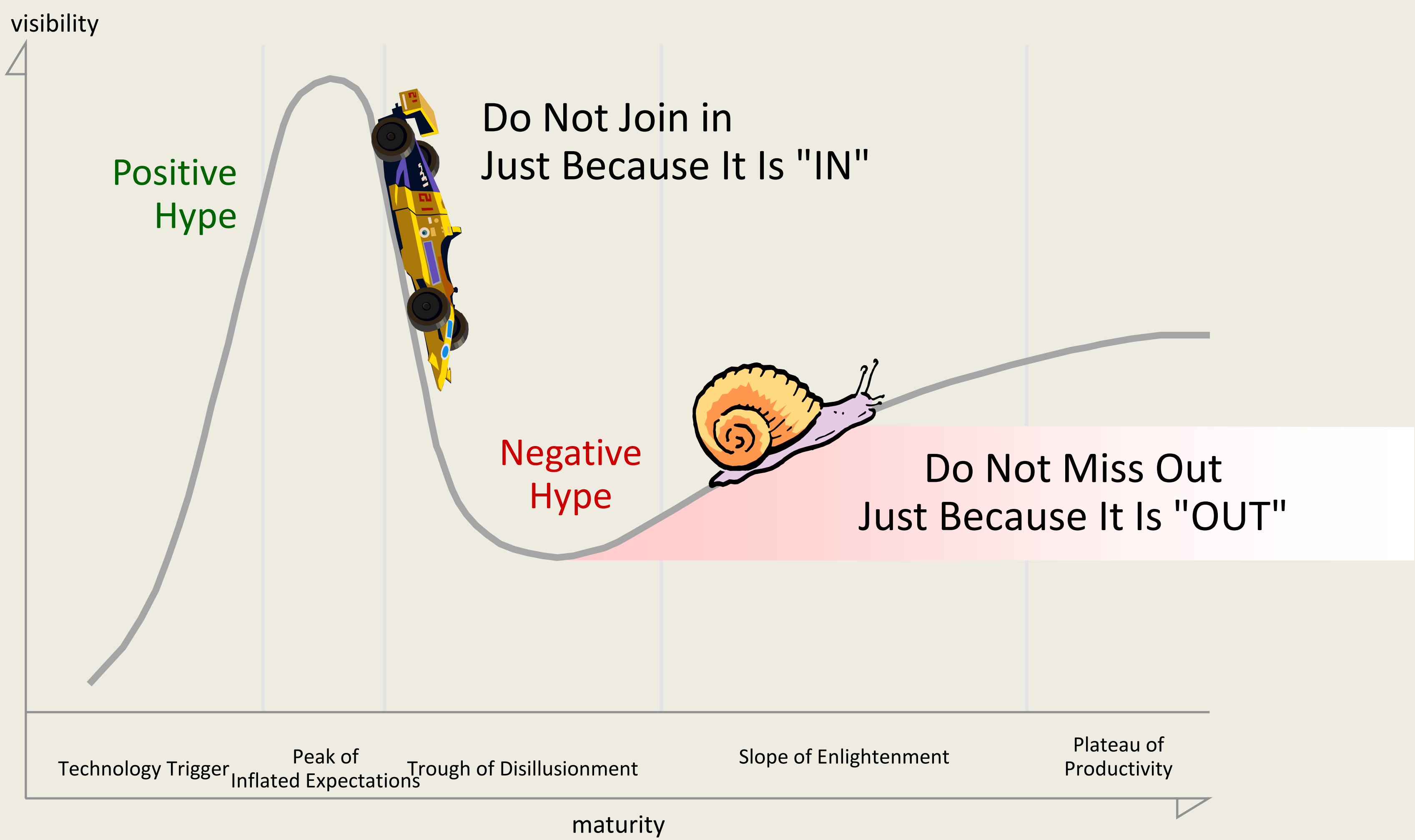
How it works

Benefits

Pitfalls

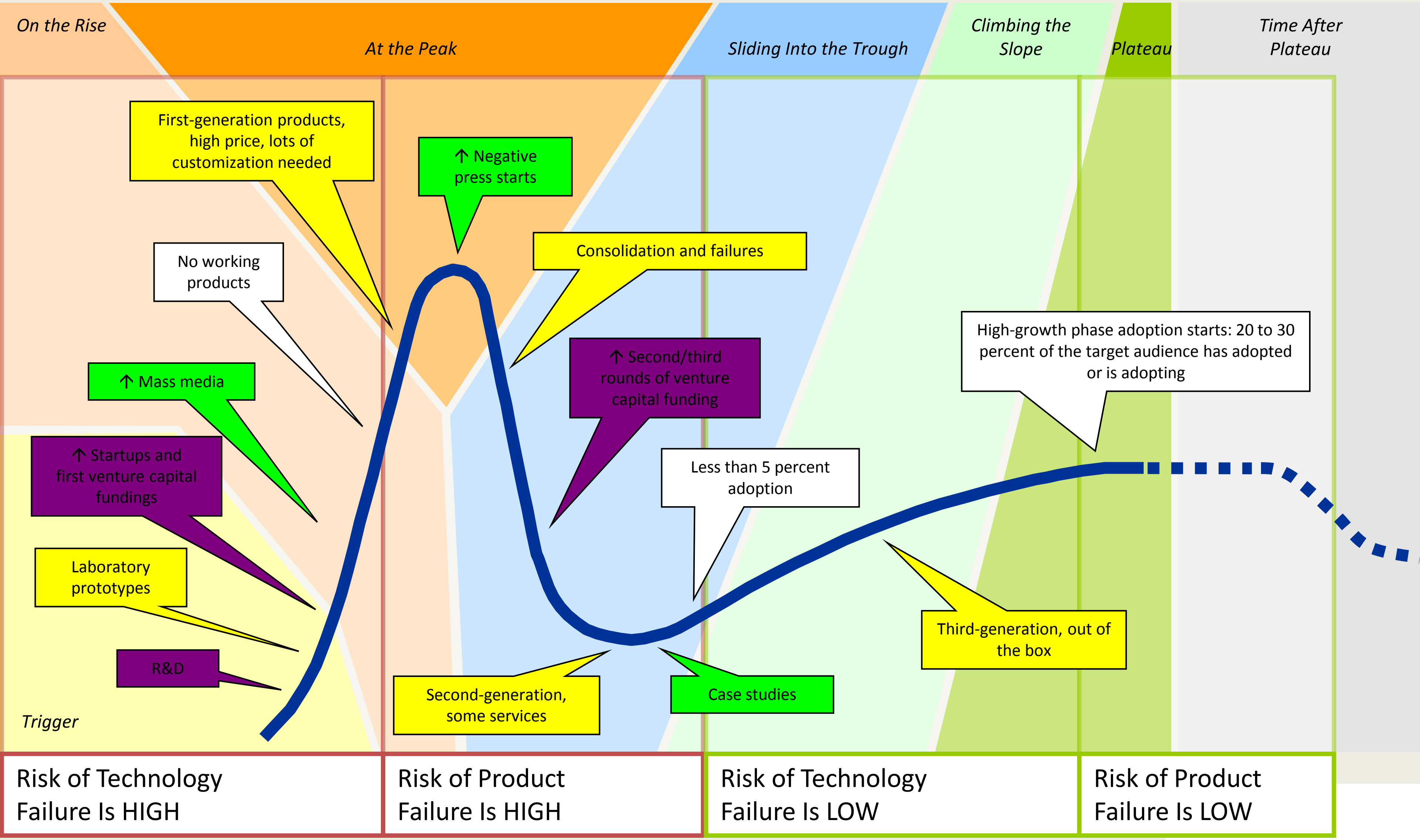
Q/A

Main Interpretation of the Hype Cycle



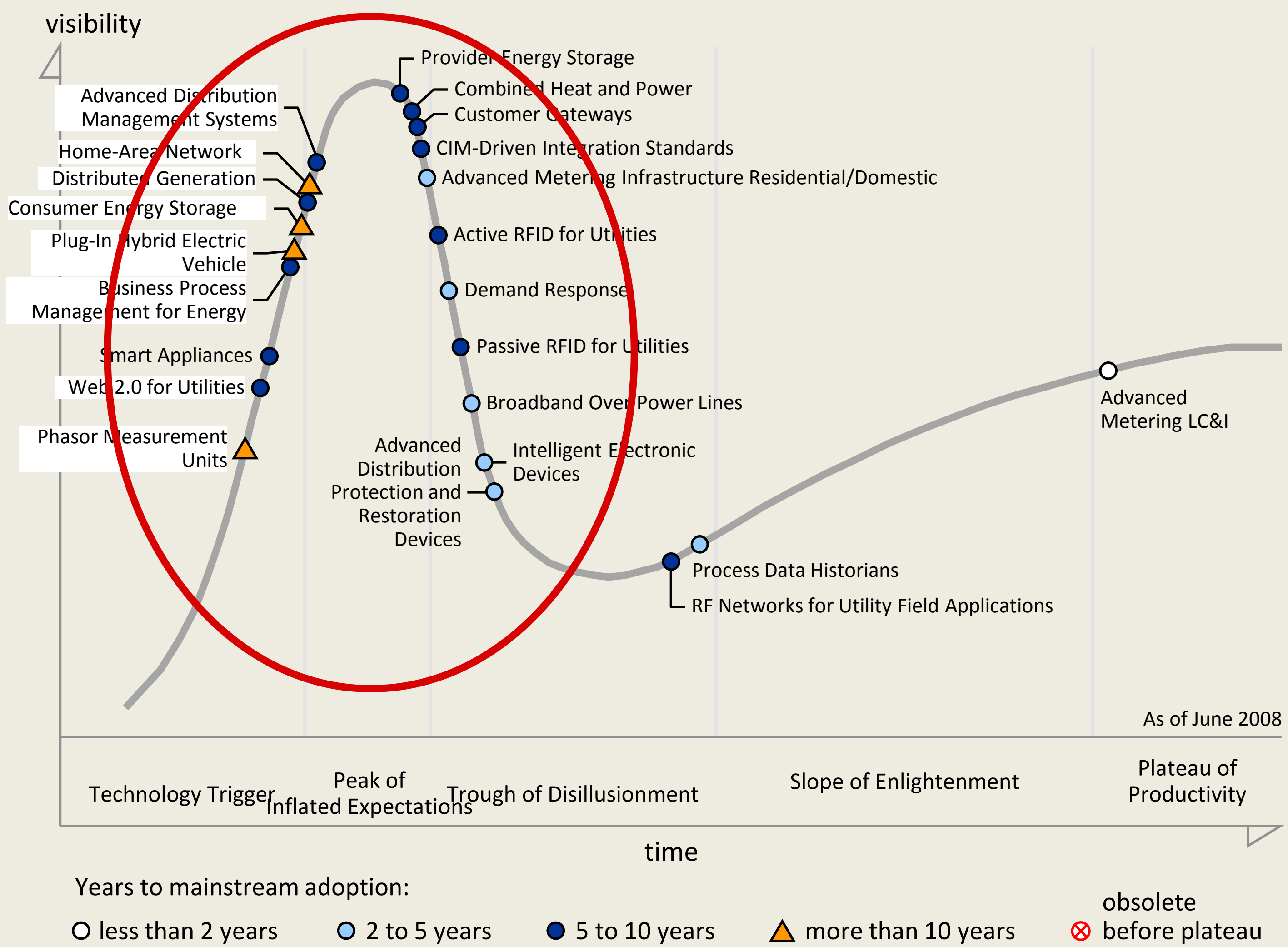
Source: Gartner, Inc.

Some Hype Cycle Forensics



Source: Gartner, Inc.

Intelligent Grid Technology Hype Cycle



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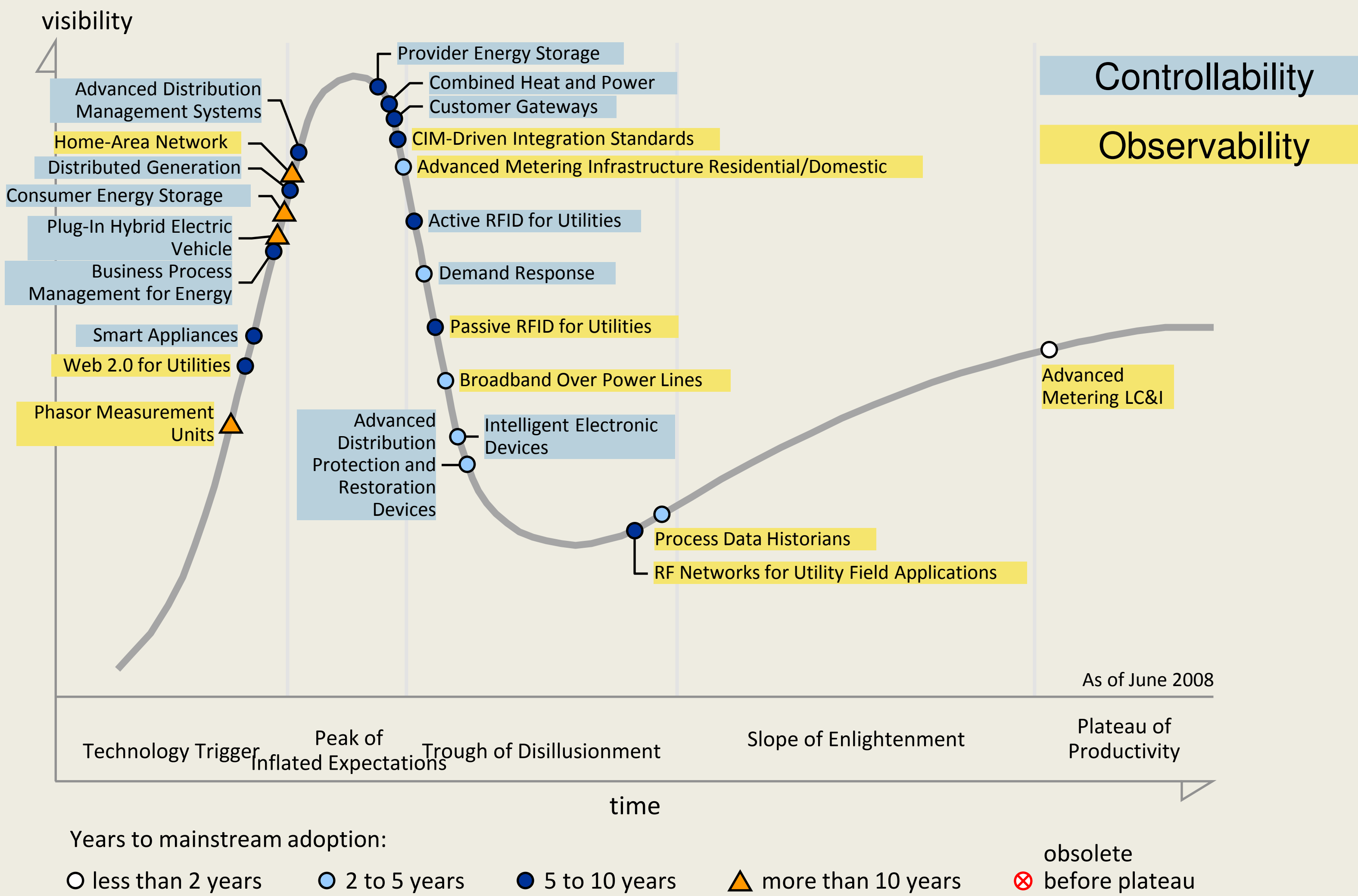
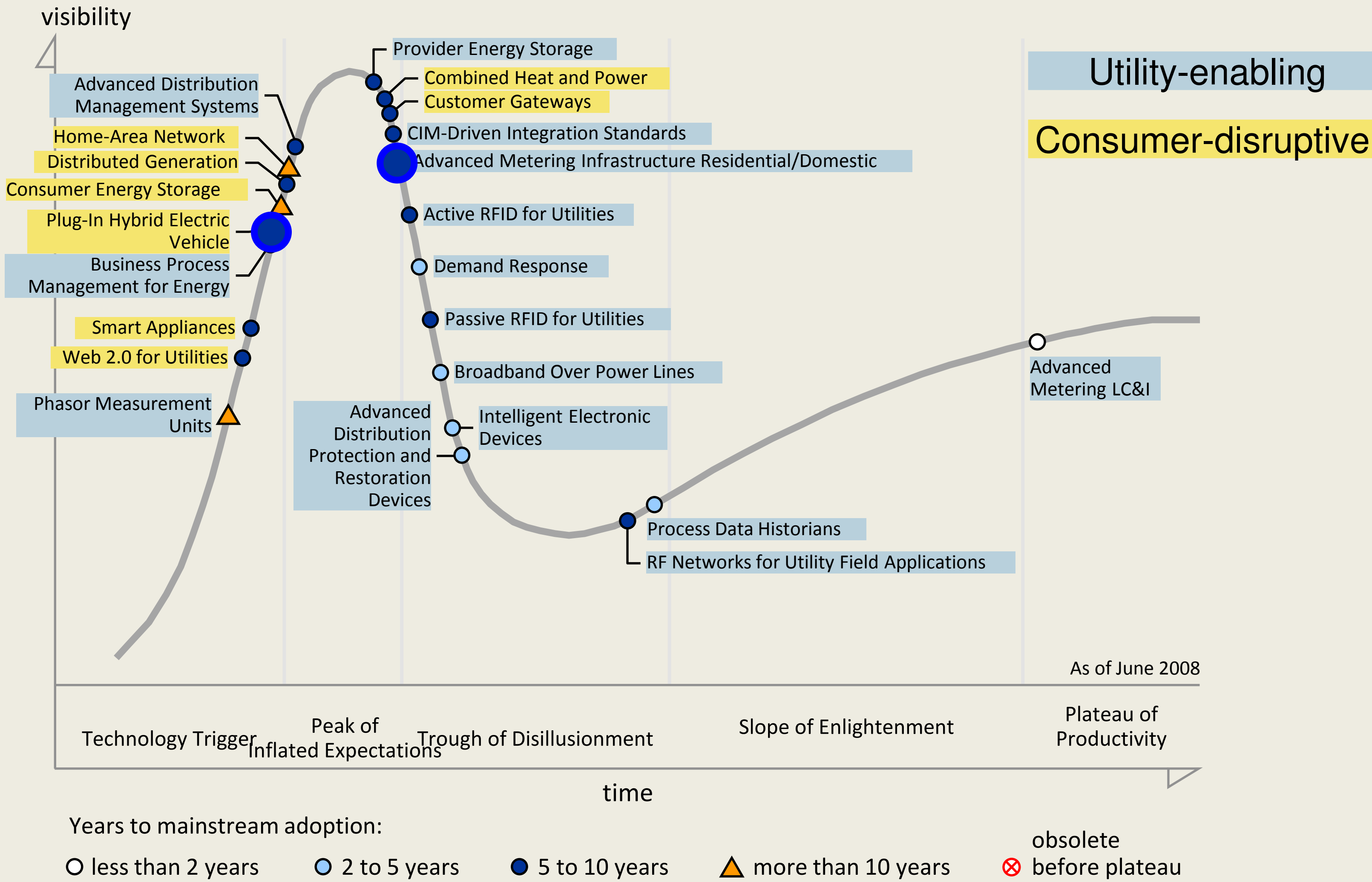
Intelligent Grid Technology Hype Cycle



Source: Gartner, Inc.

Intelligent Grid Technology Hype Cycle



Source: Gartner, Inc.

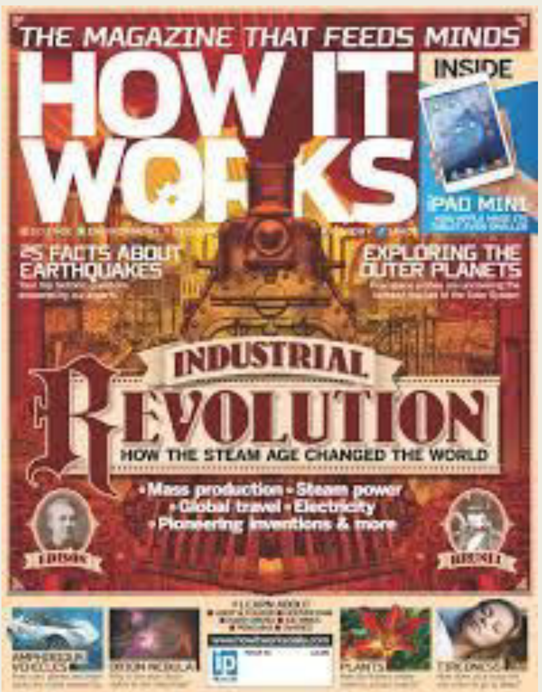
What's Coming; When and How Hard Will It Hit?

benefit	years to mainstream adoption: less than 2 years	2 to 5 years	5 to 10 years	more than 10 years
transformational		Advanced Metering Infrastructure Residential/Domestic Demand Response	Distributed Generation	
high	Advanced Metering LC&I		Business Process Management for Energy Combined Heat and Power Customer Gateways Web 2.0 for Utilities	Consumer Energy Storage Phasor Measurement Units Plug-In Hybrid Electric Vehicle
moderate		Advanced Distribution Protection and Restoration Devices Broadband Over Power Lines Intelligent Electronic Devices Process Data Historians	Active RFID for Utilities Advanced Distribution Management Systems CIM-Driven Integration Standards Passive RFID for Utilities Provider Energy Storage RF Networks for Utility Field Applications Smart Appliances	Home-Area Network
low				

As of June 2008

Source: Gartner, Inc.

Outline



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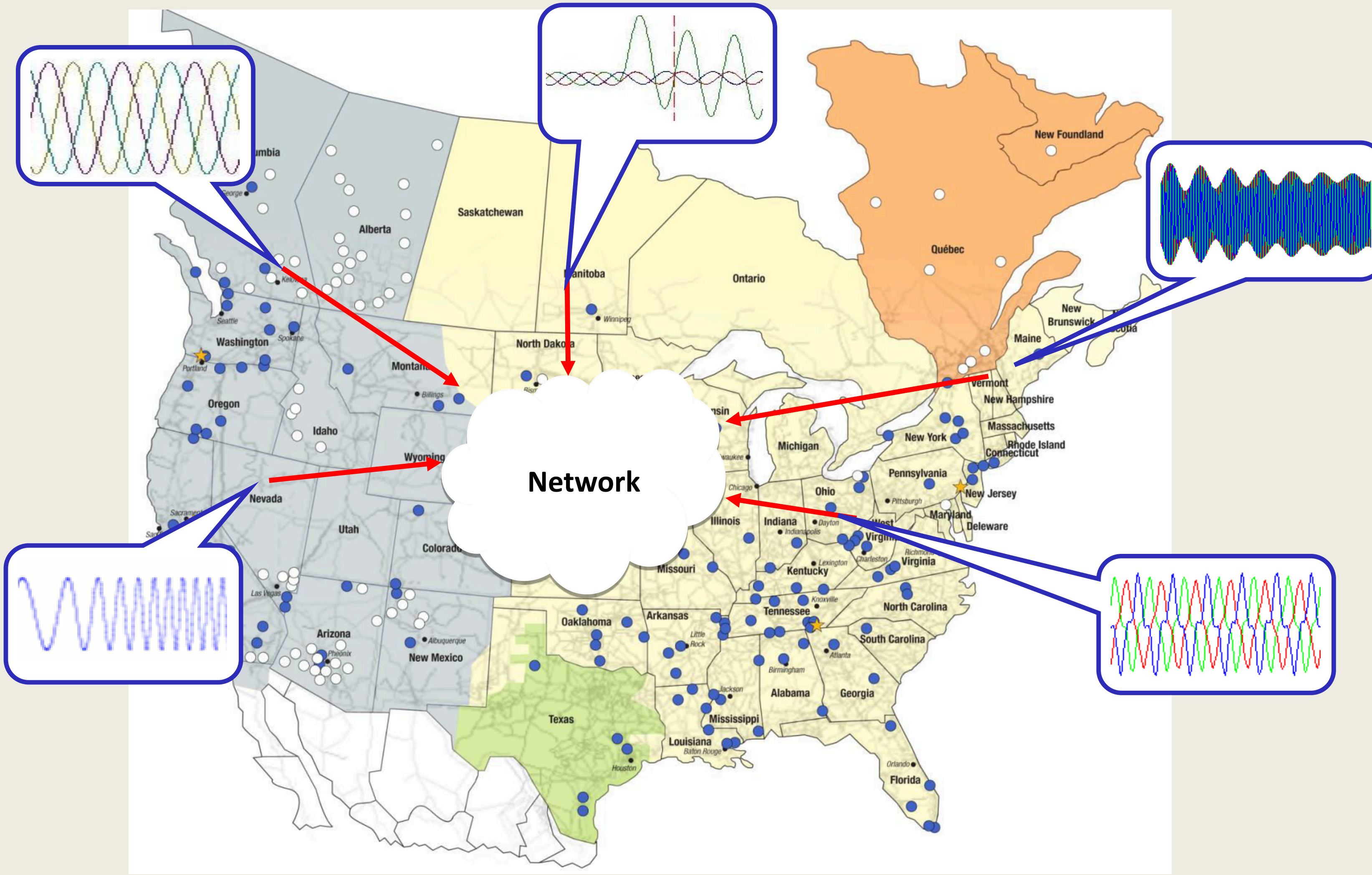
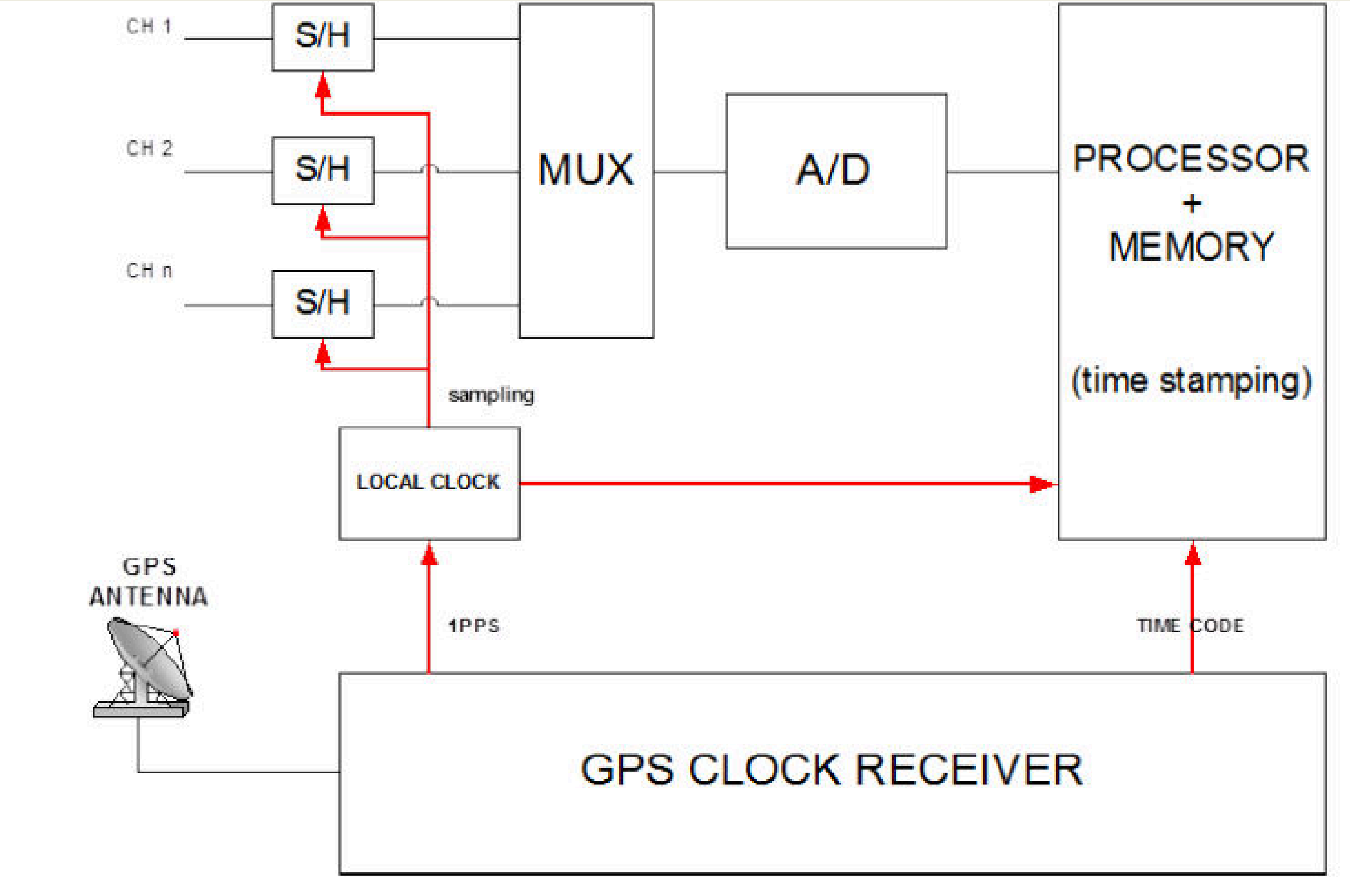
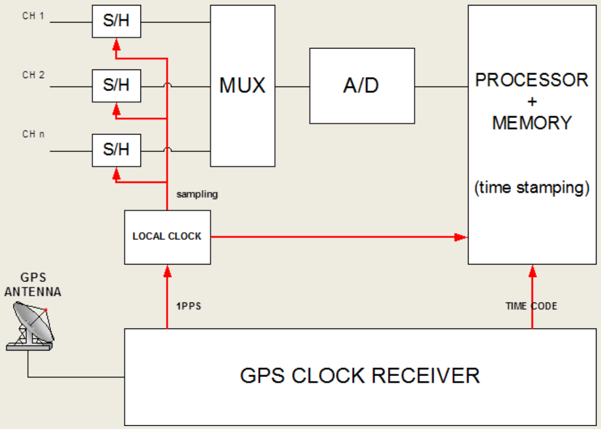
Introduction

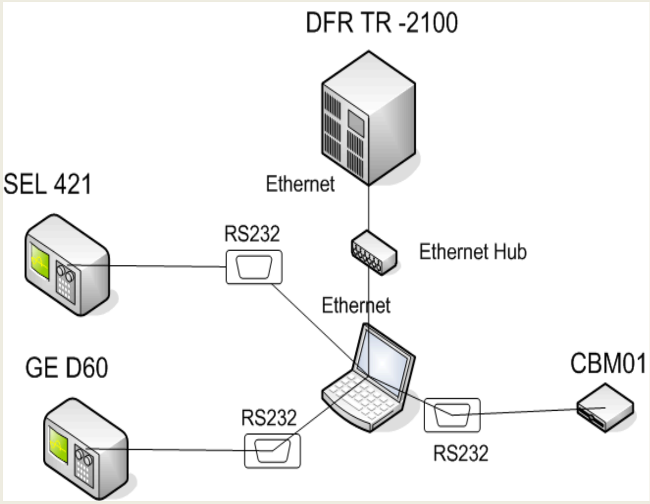


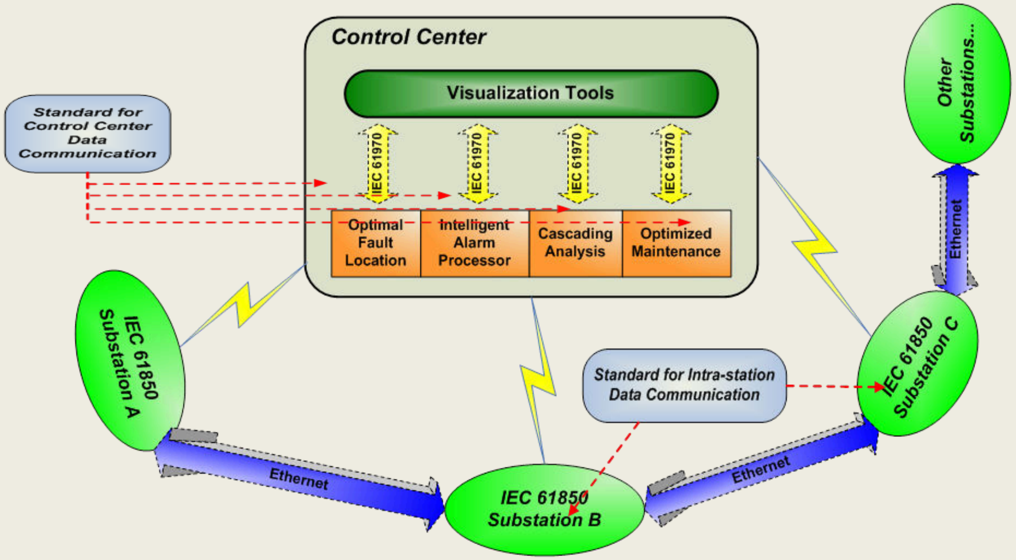
Key features



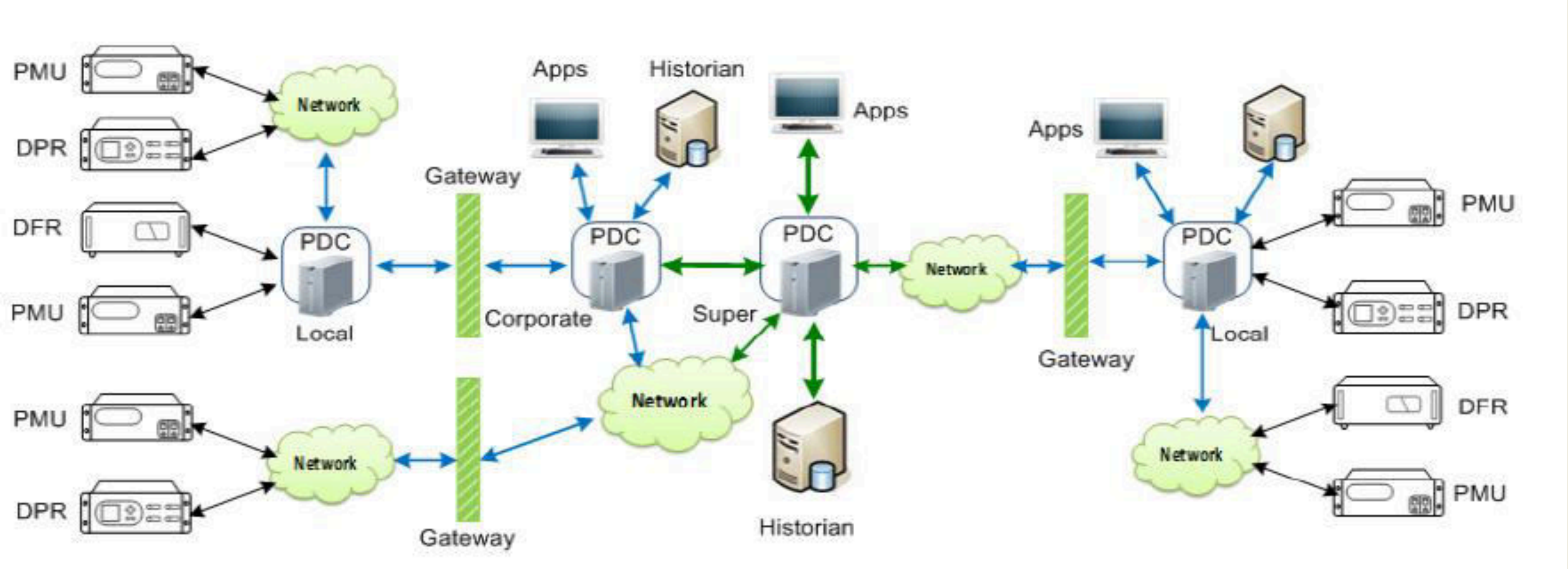
Solution layers



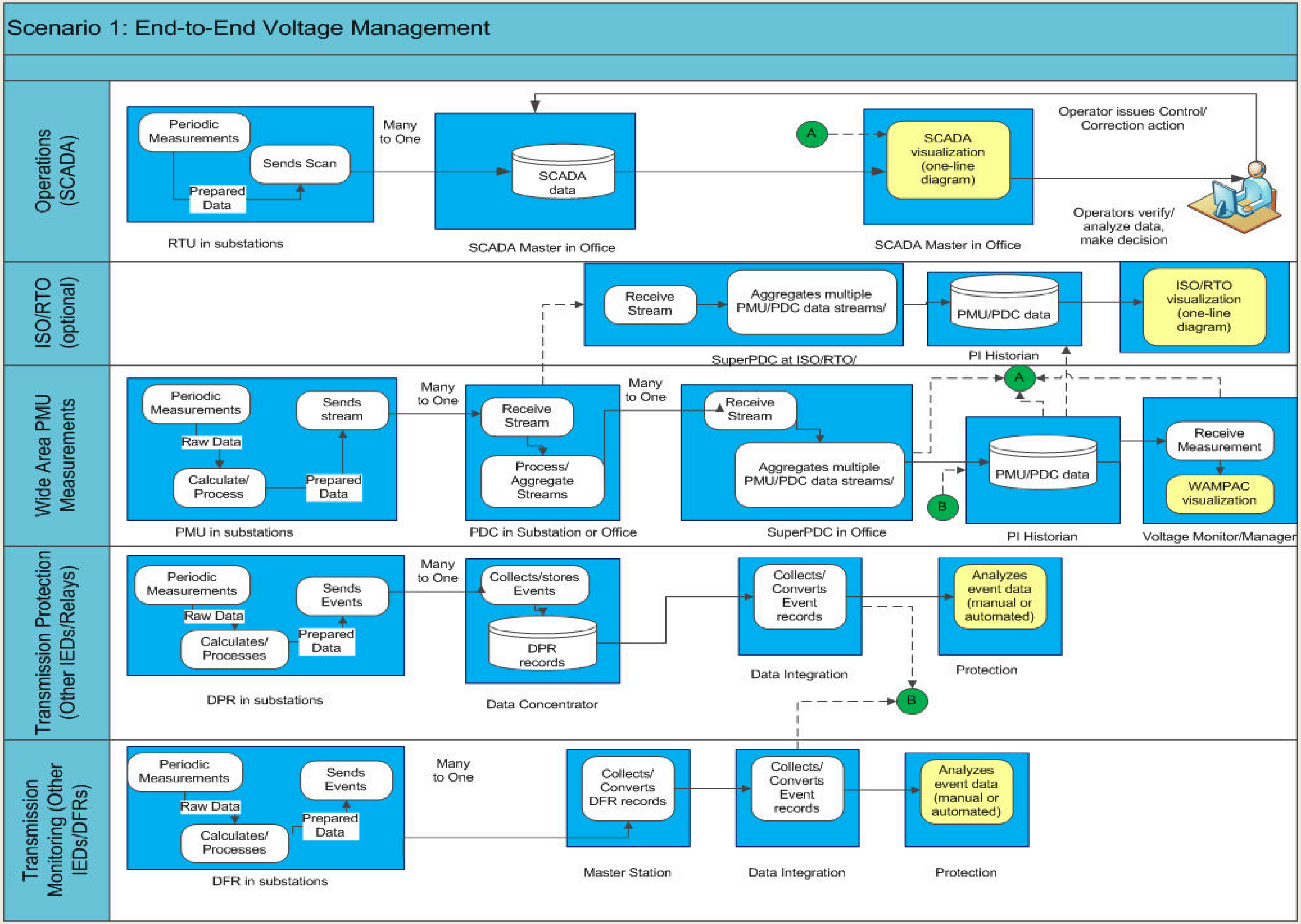




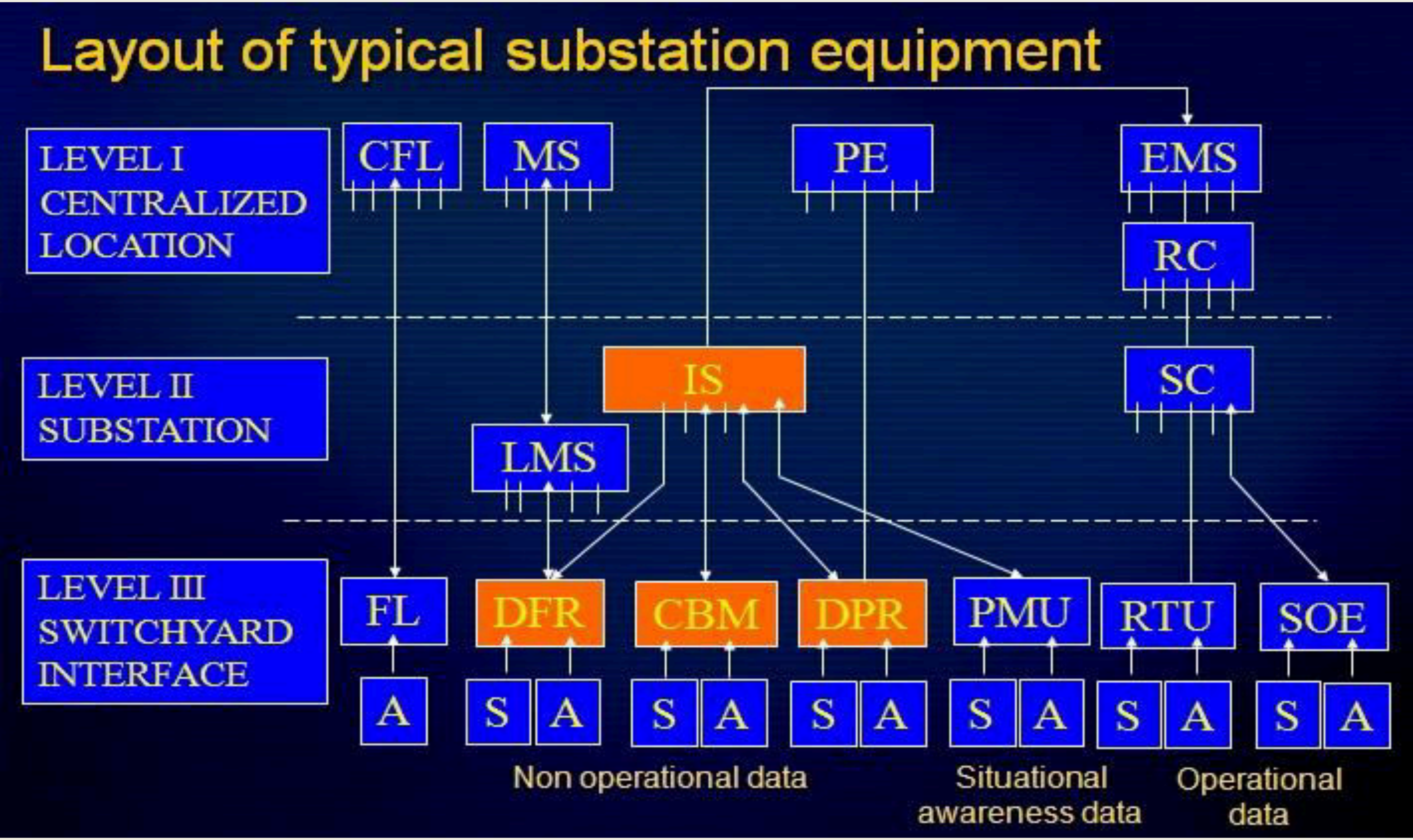
End-to-end solution



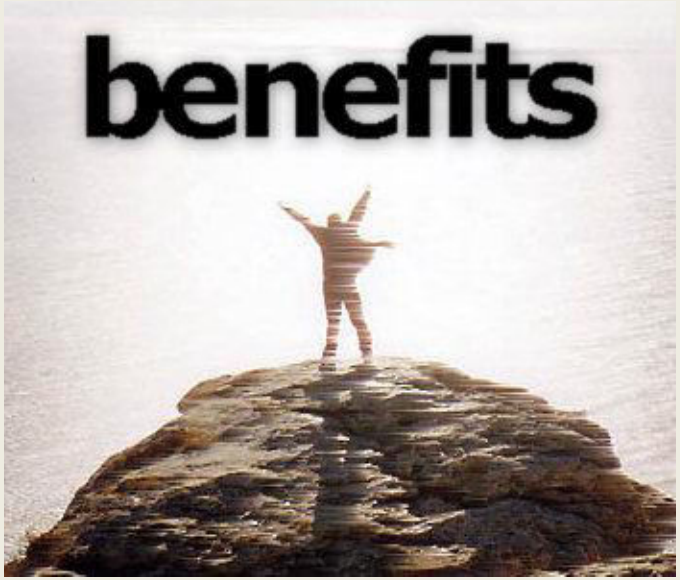
End-to-end Voltage Management



Integrated solution



Outline



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Research Goals

Figure 1: Summary of Research Goals and Milestones

Research Areas

- Visualization
- Monitoring
- Planning
- Phasor Infrastructure Management
- Control
- Protection
- Switching

Near-Term(1-2 Years)

- Wide-area visibility with common situational awareness screens
- Baseline normal operating conditions, limits and alarms for EI
- Demonstrate improved state estimation with phasor measurements
- Model validation for better system understanding
- Identify human factors & visualization needs for phasor based operations tools
- Define best practices for enhanced grid "forensics"
- Design next generation data and communications infrastructure
- Define research and demonstration approach for real-time control
- Identify research needs for federal investment

2006 - 2007

Mid-Term (2-5 Years)

- Wide-area visibility with full coverage
- Approaching real-time state measurement for operators
- Dynamic system security assessment tools
- Common operator tools deployed
- Congestion management
- Dynamic ratings
- Improved LMP
- Work with industry to initiate major demonstration of real-time control for dynamic security
- Work with industry to demonstrate adaptive islanding protection concepts to improve protection from wide-area blackouts
- Develop strategy for next-generation operational tool concepts

2007 - 2010

Long-Term (5-10 Years)

- Real-time protection
- Distributed closed loop control
- Automatic smart-switchable networks

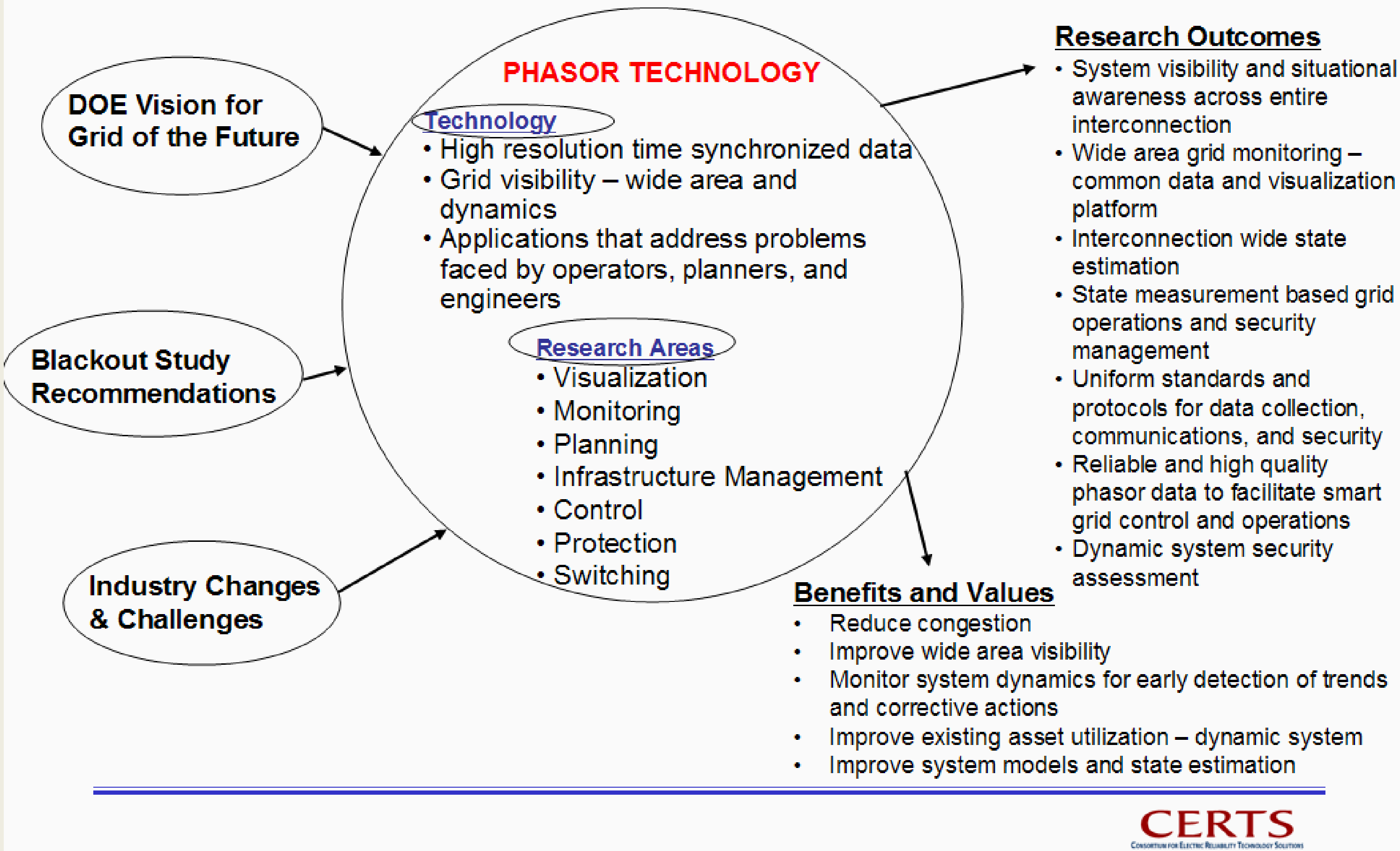
2010 - 2015

CERTS

Consortium for Electric Reliability Technology Solutions

Roadmap

Figure 5: *Phasor Technology Vision and Roadmap - Overview*



Roadmap

	Areas	Problems	Research Needs
Visualization	Wide Area Visibility	- Lack of knowledge beyond Control Area - Limited dynamics monitoring capability restricted to offline analysis	- Define real-time Interconnection-wide visualization system for operators and RCs - Research new performance metrics for dynamics and phasor information
	Display Management	- Lack of common displays across EI - Fast growing phasor network resulting in display clutter and overwhelming streaming data	- Define standardized situational awareness screens for communication across EI - Involve human factors experts to address visualization needs for phasor based tools - Define summary displays to present relevant information in an integrated fashion
Monitoring	Real-Time Alarming and Reporting	- Undefined alarming criteria on high resolution data and wide-area monitoring - Lack of automated reporting capabilities on system conditions, trends and analysis	- Identify alarming thresholds based on trends, simulations and operator experience - Define reporting requirements and procedures for early warning, threat analysis, etc.
	Interconnection Wide State Estimation	- Currently limited to utility jurisdiction - Convergence problems - Inaccurate system status/modeling - Data sources with inconsistent data rates	- Define optimal PMU placement - Validate traditional SE results with phasor data - Integrate phasor and SCADA data for SE (Hybrid SE) - Improve system topology info. with PMU data - Use of PMU data for boundary equivalents/model reduction - Resolving seams related issues for interconnection wide state estimation
	Measurement Based Sensitivities	Traditionally based on steady-state analysis using models	- Define monitoring points/parameters used in sensitivity computation (e.g. P-V, δ-P)
	Security Assessment	- Traditionally based on offline analysis and there fore conservative	- Dynamic line rating (thermal monitoring, volt. stability margins, damping monitoring) - Validate/improve nomograms using dynamic information - Develop new angle based nomograms
Planning	Post-Disturbance Analysis	Unsynchronized data from multiple sources	- Baseline normal operating conditions and limits - Set guidelines for cleaning/aligning data for offline analysis - Define procedures for enhanced grid "forensics" (e.g. Prony Analysis)
	Model Validation	Outdated dynamic models not representive of true field equipment characteristics	Fine-tune models based on simulations and real-time dynamics information Suggest active/passive ringdown signals appropriate for analysis
	Freq. Response	Require high resolution data	Assess system stiffness from frequency response observations
	Trending/Pattern Recognition	Dynamic/transient signatures require high resolution data	- Perform trending with time of day, season, peak load, major line outages, etc - Identify key signatures of events/system changes for event/topology change classification
Infrastructure Management	Phasor Devices	- Lack of common standards for different phasor devices (PMUs, DFRs, Relays)	- Benchmark existing devices with phasor measurement capabilities - Define performance standards for devices
	Data Quality	- Calibration errors - Transmission losses/corruption	- Determine errors sources and failure modes of PMU data - Suggest diagnostic techniques and recommend appropriate fixes - Define performance standards for different applications
	Communication Networking	- Communication latencies/Transmission losses	- Define communication/networking requirements for different types of applications - Plan for transition to production network
	Data Management	Inconsistent data rates/signal types	Define data requirements for different applications
Control	Regional Voltage Control	Voltage instability can be solved locally only to a limited extent	Recommend schemes for using wide-area measurements for load shedding or capacitor/reactor bank switching
	Small Signal Stability Control	Traditionally based on local measurements (Power System Stabilizers) which may be unsatisfactory against inter-area oscillations	- Determine mode shapes to define mode observability for control signals - Research modulation of HVDC lines, or use of FACTS devices to control oscillations - PSS tuning
	Transient Stability Control	- Limited ability to mitigate transient stability based on real-time information	- Research techniques for first swing instability classification - Recommend control actions such as load shedding or supervised islanding
Protection Switching	Remedial Action Schemes	Manual arming/disarming based on criteria determined by offline studies	Research and define phasor measurement based thresholds for arming/disarming points and RAS tripping requirements
	FACTS Transmission Control	Power transfers governed by engineering laws with limited control capability	Research the use of FACTS devices with coordinated wide-area control (TCSCs, static compensators, UPFCs) to increase the controllability of power transfers under steady-state operation.

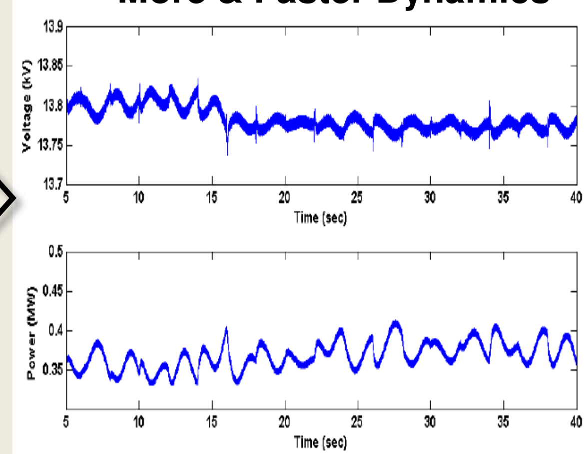
Roadmap

Areas		Current Situation	Near Term Priorities	Long Term Goals	Industry Role	DOE Role
Visualization	Wide Area Visibility	- Sparse PMU coverage - Potential for expansion using existing devices - Limited experience with PMU data in operations	- Identify monitoring holes - Deploy real-time tools in operations environment - Operator education & training	- Situational awareness - Improved reliability	- Installation and maintenance of devices - Serve as testers for new prototype - Provide feedback	- Support human factors research towards defining common situational awareness screens - Facilitate research towards defining and validating new performance metrics.
	Display Management	- Inconsistency in operator displays - Display clutter due to growing installations	- Define standardized operator displays - Define visualization interplay between local and wide-area monitoring screens	- Common operator tools deployed - Develop strategy for next generation operational tool concepts	- Work with vendors to implement standardized operator displays	
Monitoring	Real-Time Alarming and Reporting	- Lack of real-time alarming criteria on grid dynamics - Absence of automated reporting processes	- Define new alarming criteria based on wide-area dynamics visibility - Define automated reporting procedures	- Establish real-time alarming, reporting and emergency response practices	- Put in place real-time alarming and reporting systems	- Facilitate research for new compliance monitoring guidelines using dynamics visibility
	Interconnection Wide State Estimation	Early research suggests that 10% strategically placed PMU coverage is adequate to improve SE	- Identify and resolve data quality issues - Perform hybrid SE demo & quantify benefit	- Better security assessment - Improved asset utilization and LMP calculation	Incorporate phasor measurements into their state estimators	Coordinate and support utility demonstration efforts towards interconnection wide state estimation
	Measurement Based Sensitivities	- Promising concepts & initial results - Requires further evaluation for reliable assessment capability	Demonstrate feasibility of reliable sensitivity calc. from phasor measurements	Improved reliability	- Define key monitoring points - Undertake demonstration projects	Support research and validation activities towards advanced applications for better reliability and security assessment tools
	Security Assessment		Define stability indices for: - Voltage stability monitoring - Small signal monitoring	Dynamic Security Margins		
Planning	Post-Disturbance Analysis	- Limited wide-area understanding of EI system dynamics - Sync. data available from EIPP starter network will facilitate this process	Baseline normal EI system operation by: - selecting events/outages of interest for analysis - coordinate analysis efforts	Enhanced grid 'forensics"	- Provide data & expertise for collaborative effort	Coordinate EI research efforts towards improved system understanding & modeling
	Trending		Perform trending with time of day, season, peak load, major line outages, etc	Improved system modeling		
Infrastructure Management	Phasor Devices	- Initial starter system in it's infancy; requires assessment - Early standards definition activities in progress	- Benchmark existing devices - Define new performance standards	Establish industry standards for performance & protocols	Install, maintain, & upgrade phasor acquisition/management systems as needed to meet application needs, and evolving performance guidelines and industry standards.	Facilitate standards development & system design towards a fully reliable and redundant phasor system
	Data Quality		- Evaluate performance assessment of current EI phasor network & propose fixes	Performance standards for reliable, secure, redundant network		
	Data Management/ Communication Networking		Research & define communication/data management architectures to support current/future application needs	- Guidelines for phasor data acquisition, archiving & retrieval - Redundant data management		
Protection Control Switching	Voltage / Transient / Small Signal Stability Control	Limited experience in this area within EI	Work with individual utilities to identify demonstration pilot projects on the use of phasor measurements for protection & control	- Automated remedial action schemes - Improve reliability & asset utilization	Undertake demonstration projects to address utility specific problems	- Support utility sponsored research and demonstration projects - Facility information sharing and technology transfer
	Remedial Action Schemes					

Distribution Applications

Distribution System

More & Faster Dynamics



Stability Analysis & Dynamic Monitoring

Protection

State Estimation

Voltage/Var/Watt Control

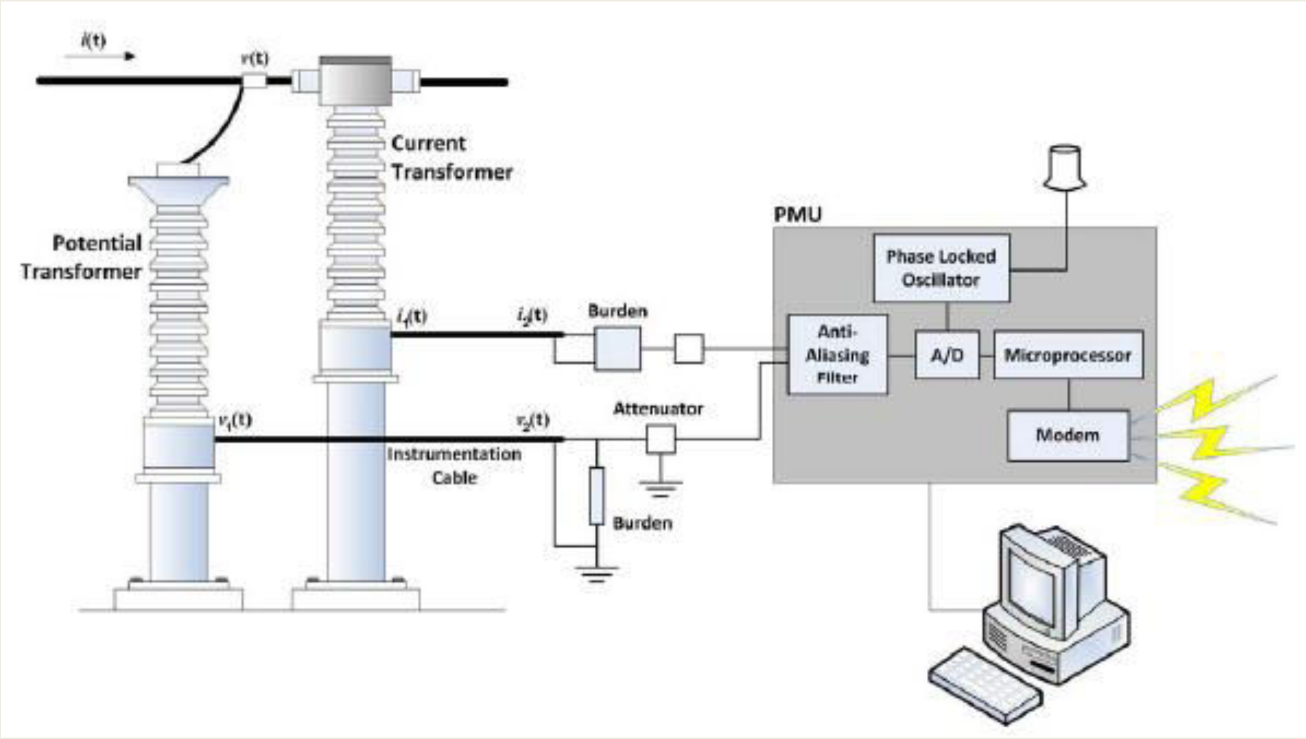
Fault Location

Load Monitoring

…

Affected functions

Micro PMU



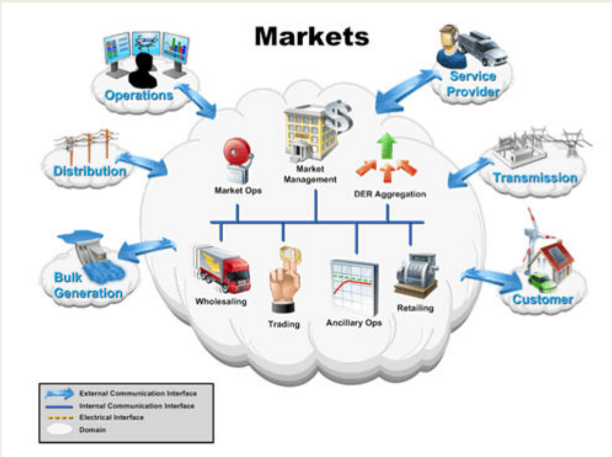
Investment

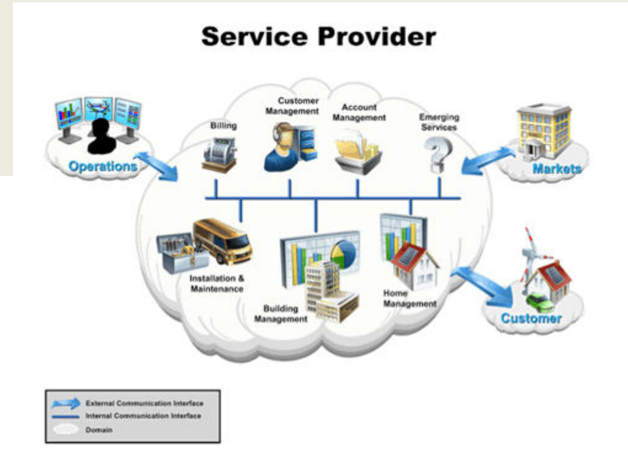
Reporting Rate

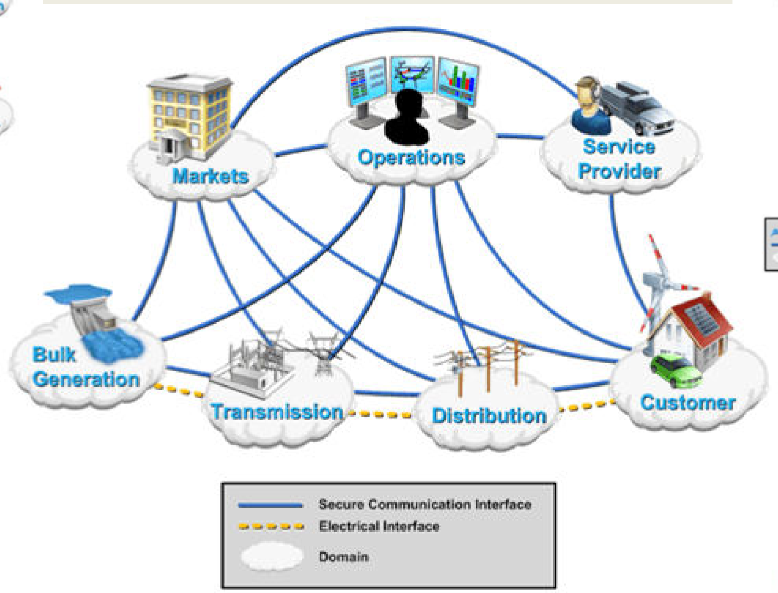
Phasor Estimation Method & TVE

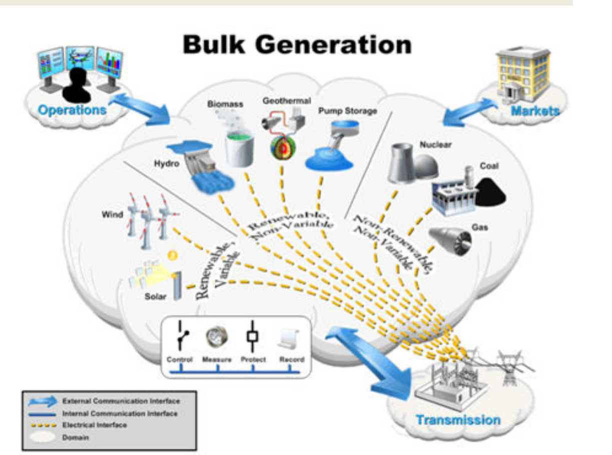
Communication Infrastructure

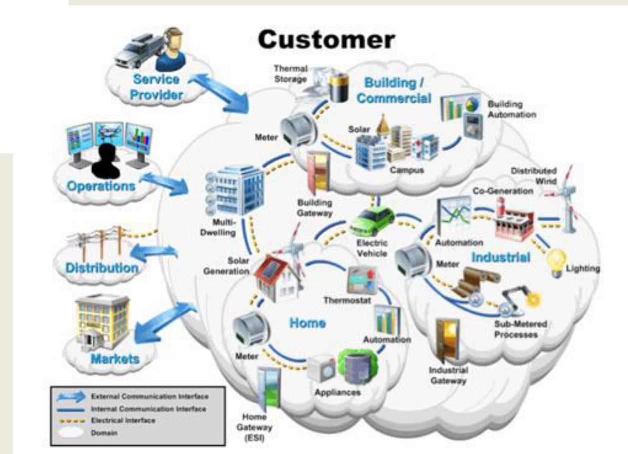
Future Electricity Grid











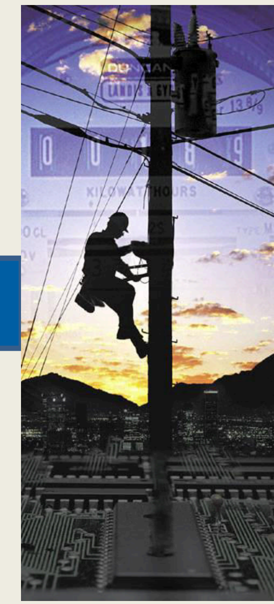
Ultimate Goals

Technology Inventions

Business Cases

Integrating smart, wise, intelligent, future, modern, perfect, empowered

Application Solutions



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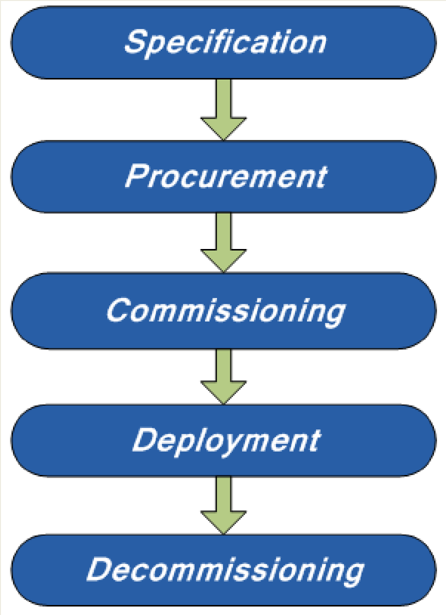
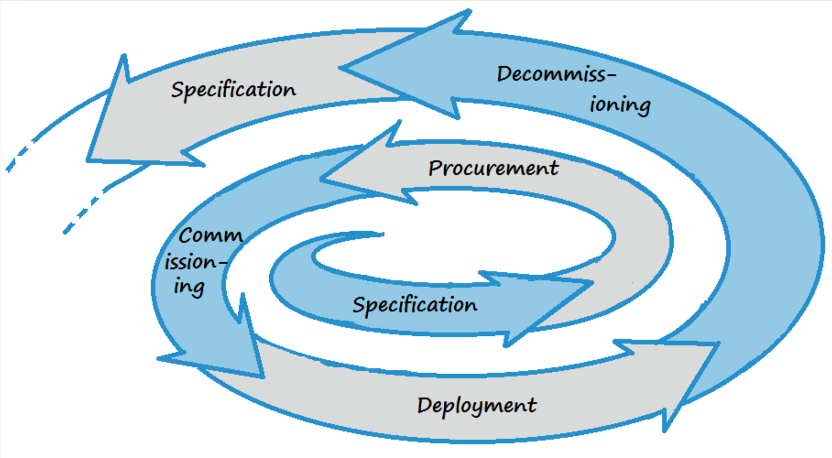
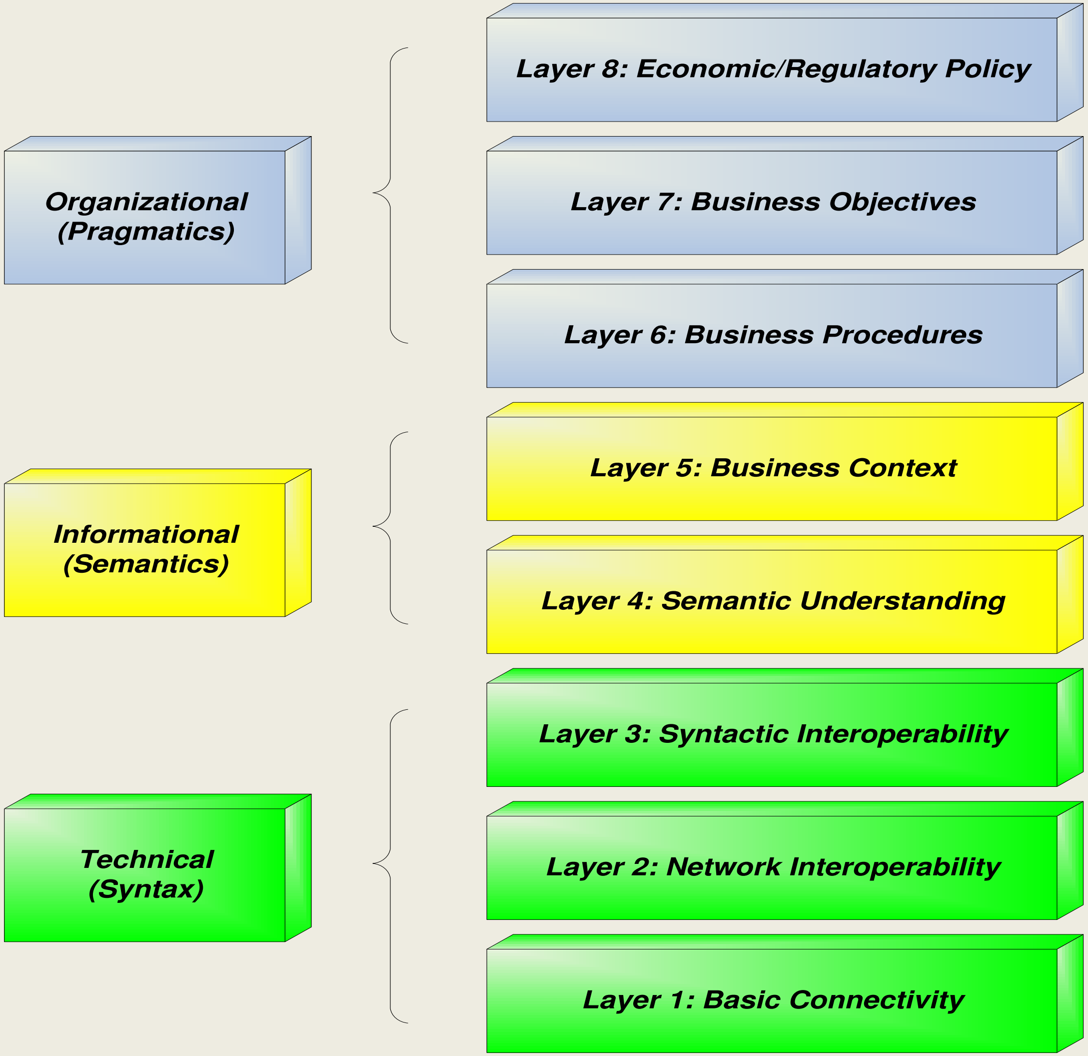
System evolution

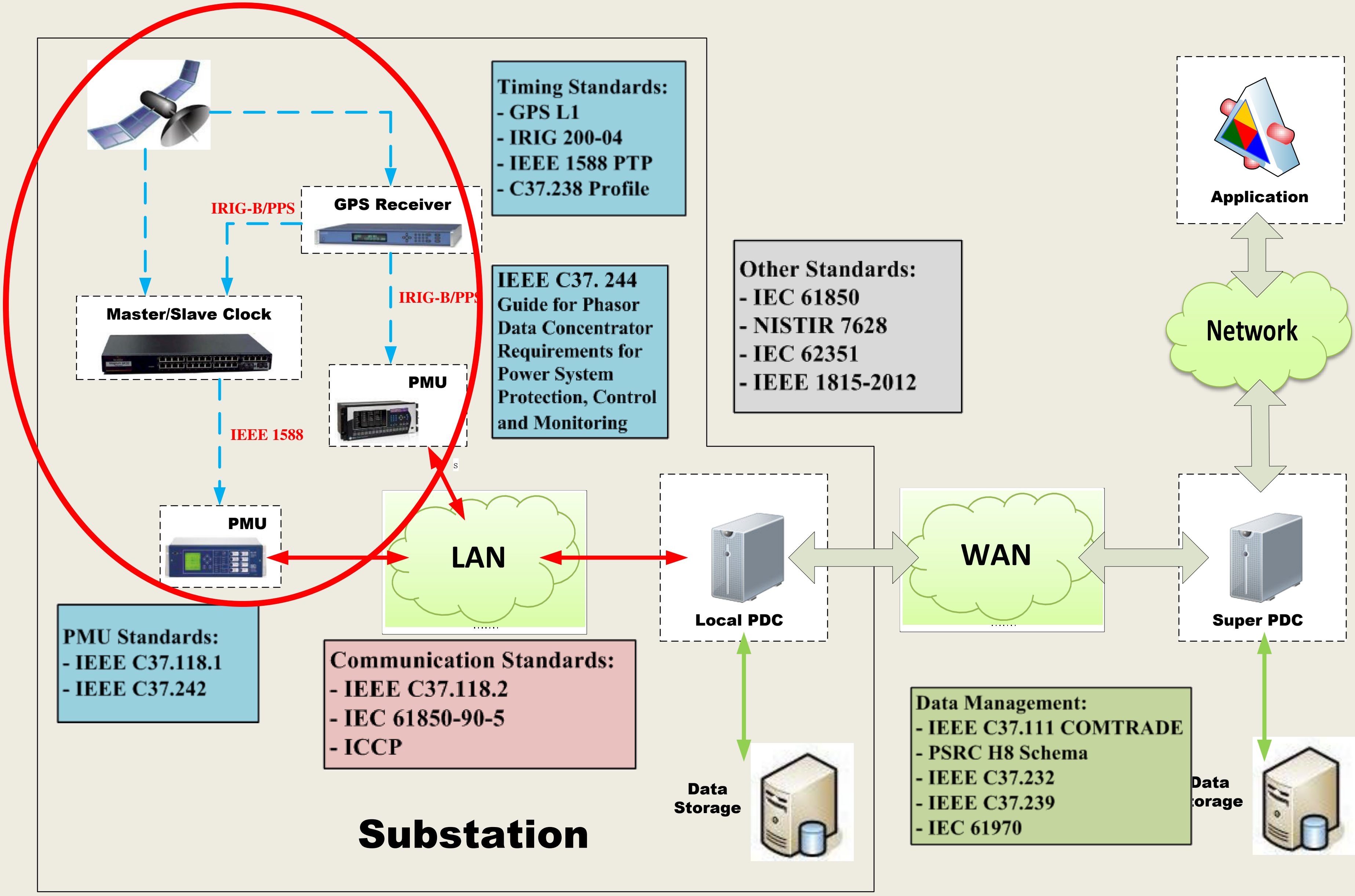




Interoperability



Standards Landscape



Testing and Certification

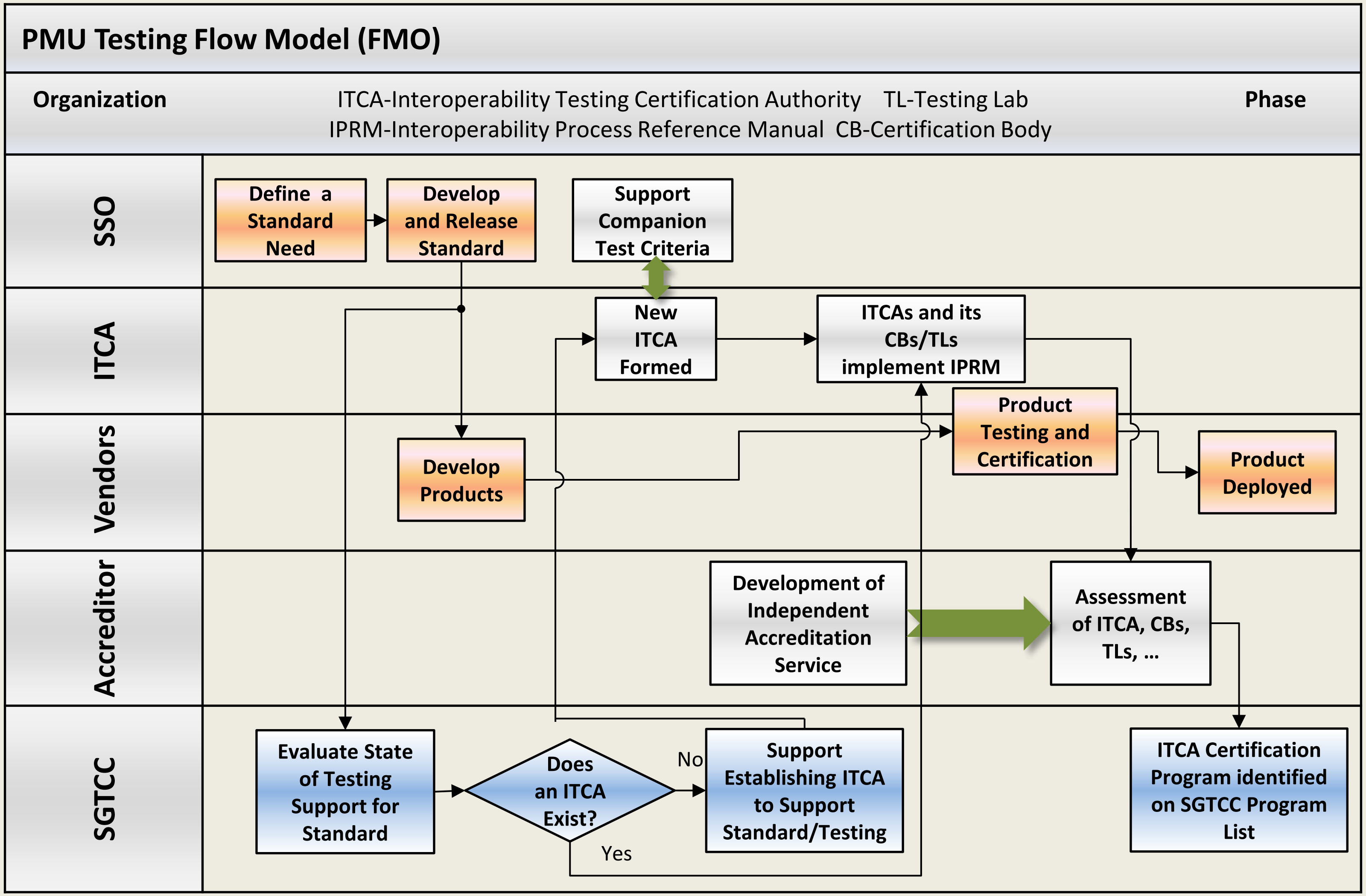
Testing is a Procedure

- The object of testing:
  - device, standard
- Test objective:
  - Conformance
  - Interoperability
- Test Lab:
  - Equipment
  - Test plan
- Test results:
  - yes/no
  - % deviation

Certification is a Process

- Identify Interoperability Testing & Certification Authority (ITCA), ISO 17065
- Accredit labs (equipment) and test plan, ISO 17025
- Define process and certification body for issuance of certificate
- Propose business model: how the process works and who pays?

What is T&C Focus



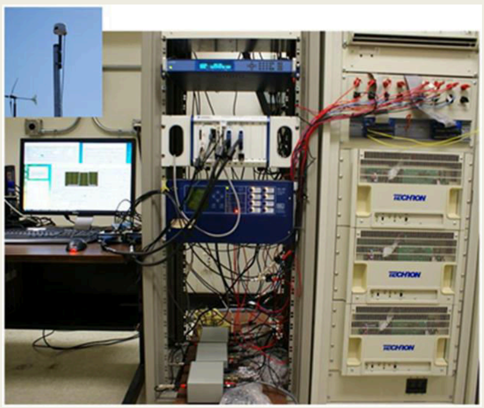
Credit: SGIP TCC IPRM

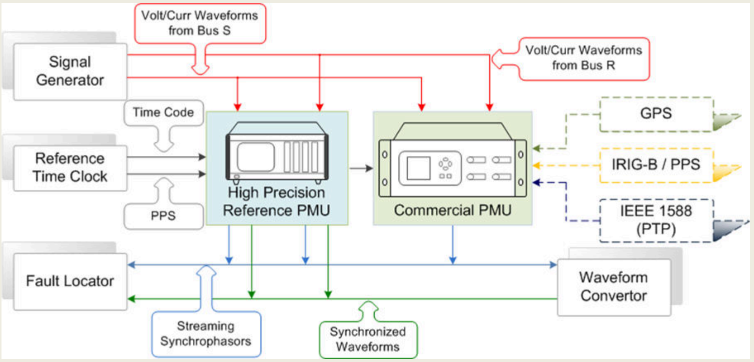
Why T&C Matters

- It assures solution/product under tests conforms to relevant standards:
  - Synchrophasor measurement standards
  - Timing synchronization standards
  - Communication and data management standards
  - Cybersecurity standards
- It assesses whether the solution/product is interoperable
  - PMUs and PMU-enabled IEDs with time-synchronization devices
  - PMUs with PDCs, and PDCs with PDCs
  - PDCs with data analytics and visualization analytics
- It provides confidence that an application is not adversely impacted by the solution/product used to supply data
  - State estimation by measurements of states and contacts
  - Voltage instability detection by measurement of voltage
  - Frequency tracking by measurement of frequency

Why T&C Matters

Procedure: how to test?

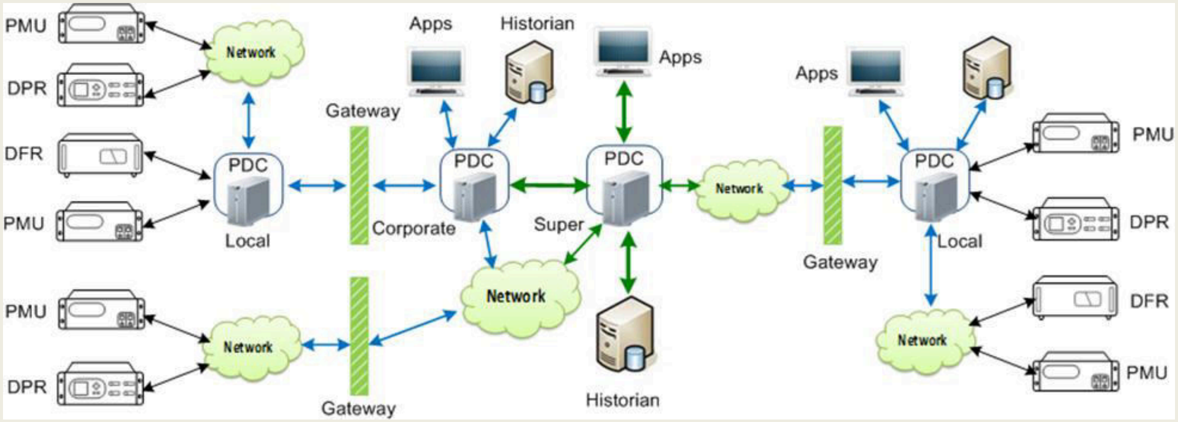


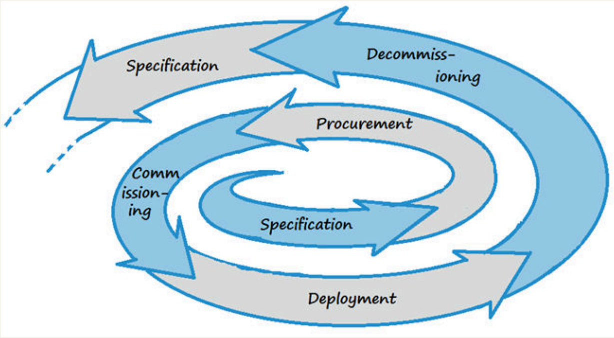


PMU	Class		Dynamic State Test								
			Measurement Bandwidth			Frequency Ramp			Step Change		
			TV E	FE	RF E	TV E	FE	RF E	R T	D T	M O
A	P		S	F	S	S	F	F	F	F	F
	M		S	F	S	F	F	F	S	F	F
A-1*	P		S	F	S	S	F	F	F	S	F
	M		S	F	S	S	F	F	S	S	F
B	P		S	F	S	S	F	F	S	F	S
	M		F	F	S	F	F	F	S	F	S
C	P		S	F	S	S	F	F	S	S	S
	M		S	S	S	F	F	F	S	S	S
D	P		S	F	S	S	F	F	F	F	F
	M		F	F	S	F	F	F	S	F	F
E	P		S	F	S	S	F	F	F	S	F
	M		F	F	S	S	F	F	S	S	F
F	P		S	F	S	F	F	F	S	S	S
	M		F	F	S	F	F	F	S	S	S
G	P		S	F	S	S	F	F	F	S	F
	M		S	F	S	S	F	F	S	S	F
H	P		S	S	S	S	F	F	S	S	S
	M		S	S	S	S	F	F	S	S	S

Why T&C Matters

Process: how to certify?





	PMU A	PMU A*	PMU B	PMU C	PMU D	PMU E	PMU F	PMU G	PMU H
PDC A	S	S	S	S	S	S	S	S	S
PDC B**	F	F	F	S	S	S	N	S	S
PDC C***	S	S	S	F	F	F	F	F	F

How to proceed going forward?

- Establish facts: existing testing practice does NOT meet T&C requirements and T&C process does NOT exists as defined by ISO 17065 and 17025
- Recognize that standards and products are CHANGING and hence T&C procedures and processes are needed to consistently verify outcomes
- Assess the role of NIST, IEEE, Test labs, SGIP TCC and broader stakeholder community in establishing T&C process and procedures

Recommended Reading

- **ISO 17065**-Conformity Assessment-Requirements for bodies certifying products, processes and services
- **ISO 17025**-General requirements for the competence of testing and calibration laboratories
- **SGIP TCC**- Interoperability Process Reference manual, 2012
- **SGIP TCC**- Interoperability Testing and Certification Authorities (ITCA) Development Guide, 2012

FYI

Smart grid center:

http://smartgridcenter.tamu.edu/sgc/

EV-TEC:

http://ev-tec.org

PSerc:

http://www.pserc.org

ARPA-E:

http://smartgridcenter.tamu.edu/ratc/

Smart Energy Campus Initiative:

http://smartgridcenter.tamu.edu/seci/

Q/A

Together - building a prosperous future

where energy is
clean, abundant, reliable, safe, secure and affordable