NIST Smart Grid Framework

And other cybersecurity resources

Avi Gopstein
Smart Grid Program Manager
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Outline

1. About NIST & the Smart Grid Framework
2. NIST Cybersecurity Framework & risk profiles
3. Understanding NERC CIP & NIST CSF
4. Advancing interoperability & securing interfaces

What is NIST?

National Bureau of Standards (NBS) was established by Congress in 1901

THE EVENING STAR, MONDAY, MARCH 11, 1901

CORRECT MEASURES

Function of the New Bureau of Standards.

LABORATORY TO BE ERECTED

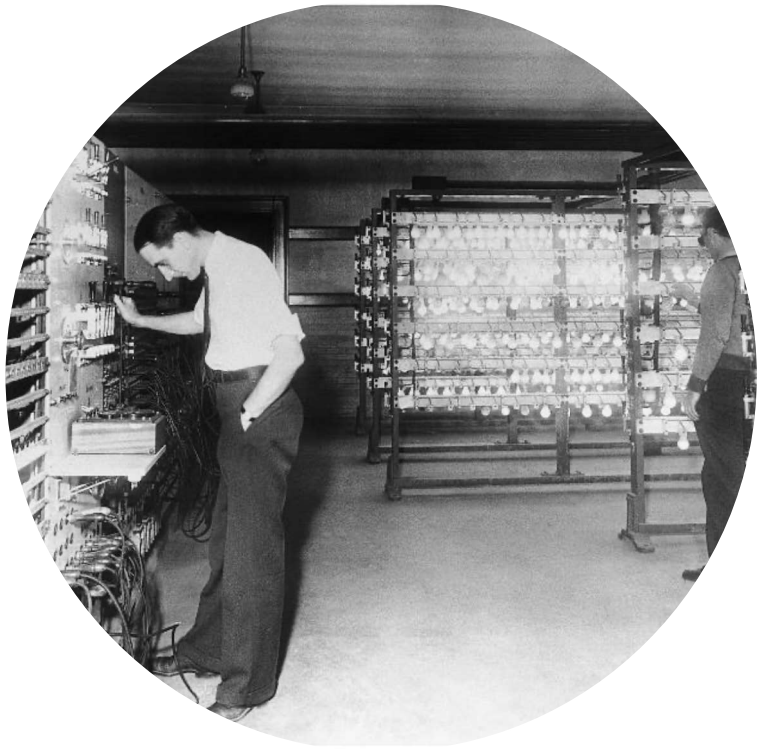
Prof. Stratton, the Director, Details Need of Establishment.

A HANDICAP REMOVED

A new bureau of the government, authorized by the last Congress, will be established in this city in the near future and will give employment to a number of persons. It is to be known as the national bureau of standards and is to be under the control of the Treasury Department. A separate building for a laboratory, to cost not to exceed $250,000, is to be erected on a site to be purchased at a cost of $25,000.

Mr. Samuel W. Stratton of Chicago has been appointed by the President to be chief of the bureau at an annual salary of $5,000. Prof. Stratton is to have the following assistants, to be appointed by the Secretary of the Treasury: One physicist, at an annual salary of $3,500; one chemist, at $3,500; two assistant physicists or chemists, each at an annual salary of $2,200; one laboratory assistant, at $1,800; one laboratory assistant, at $1,200; one secretary, at $2,000; one clerk, at $1,200; one messenger, at $720; one en-

Director Stratton.



Standards for electrical industry

Instruments calibrated overseas

Consumer products unreliable

Measurement infrastructure for commerce

NIST Mission

To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life

Measurement Science – Creating the experimental and theoretical tools – methods, metrics, instruments, and data – that enable innovation

Standards – Disseminating physical standards, providing technical expertise to documentary standards that enable interoperability and commerce

Technology – Driving innovation through knowledge dissemination and public-private partnerships to bridge gap between discovery /marketplace

Measurements are critical…

to commerce

"Uniformity in the currency, weights, and measures of the United States is an object of great importance, and will, I am persuaded, be duly attended to."

George Washington, State of the Union Address, 1790

to innovation

If you know how to measure something, you can design it, compare it, understand it, and improve it

NIST Illustrated,
https://youtu.be/2j9BGVKbzS4

and to international trade

- Up to 92% of U.S. exports affected by standards/technical regulations

NIST measurement science provides the foundation for innovation in every industry and economic sector, from manufacturing to health care to defense

Why NIST?

It is the policy of the United States to support the modernization of the Nation's electricity transmission and distribution system.

The National Institute of Standards and Technology shall have the primary responsibility to coordinate the development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems.

These [interoperability] *protocols and standards shall further align policy, business, and technology approaches in a manner that would enable all electric resources, including demand-side resources, to contribute to an efficient, reliable electricity network.*

[The Framework shall be] *designed to accommodate traditional, centralized generation and transmission resources and consumer distributed resources, including distributed generation, renewable generation, energy storage, energy efficiency, and demand response and enabling devices and systems.*

Energy Independence and Security Act (2007)

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Energy Independence and Security Act (2007)

What is Interoperability?

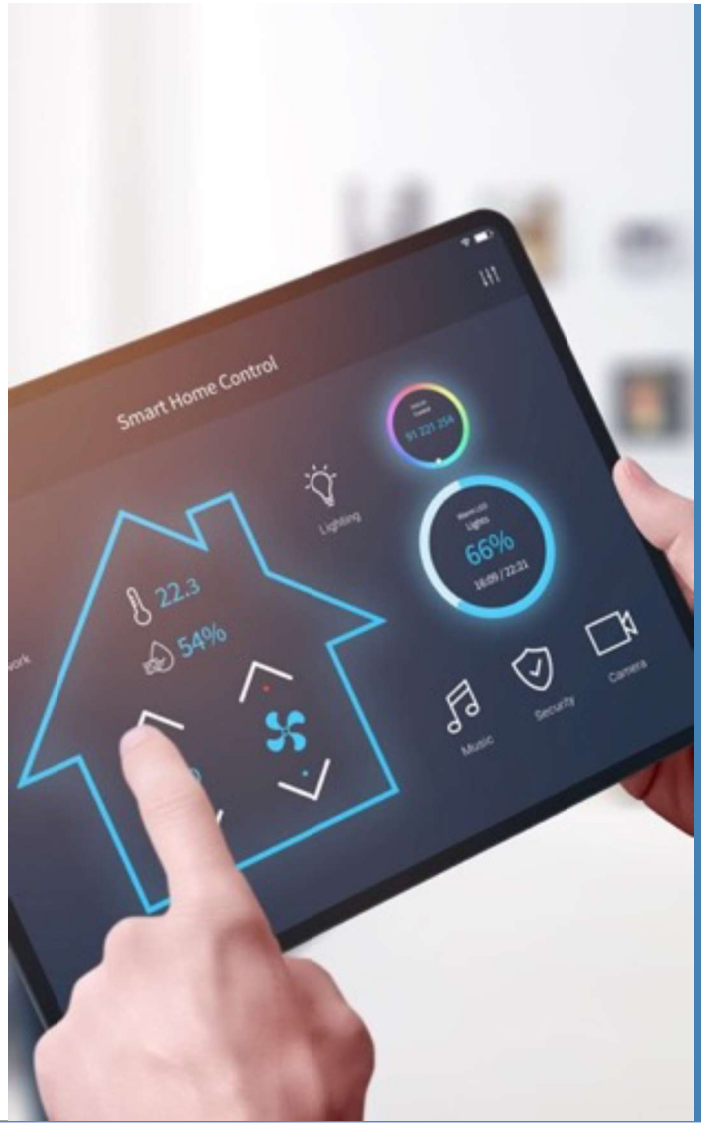
The ability of two or more systems or applications to securely and effectively exchange and readily use information with little or no user inconvenience.

Why is it important?

Modern grid operations with diverse resources and economic structures will benefit from — and eventually rely upon — enhanced interoperability.

Who does it benefit?

Everybody. Interoperability is a hedge against technology obsolescence, maximizes the value of equipment, facilitates innovation, and empowers customers.



$10 Billion

Potential annual interoperability-derived savings available in the U.S. electric power industry.
(source: GWAC)

$140M - $1B

Range of annual per-company equipment integration costs reported to NIST by utilities and equipment manufacturers.

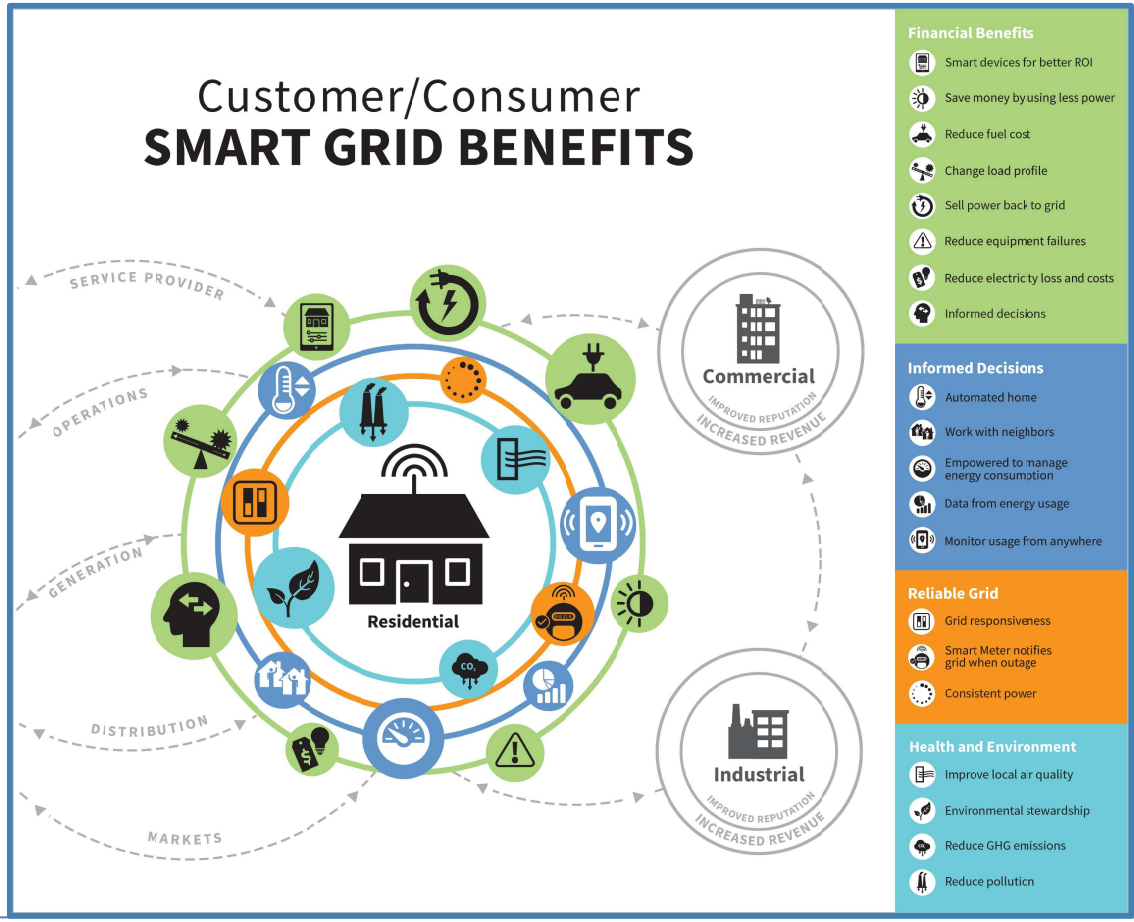
Empowered Customers

Traditional utility economics views interoperability as a mechanism to lower system integration costs

- EPRI (2017). Point-To-Point Standards Integration Cost Framework. Palo Alto, CA
- Limited usefulness due to utility revenue model

Modern interoperability provides many benefits

- Benefits can fit many value propositions
- Customers can choose which benefits to pursue
- Benefits derive from the interactions between different customers/actors



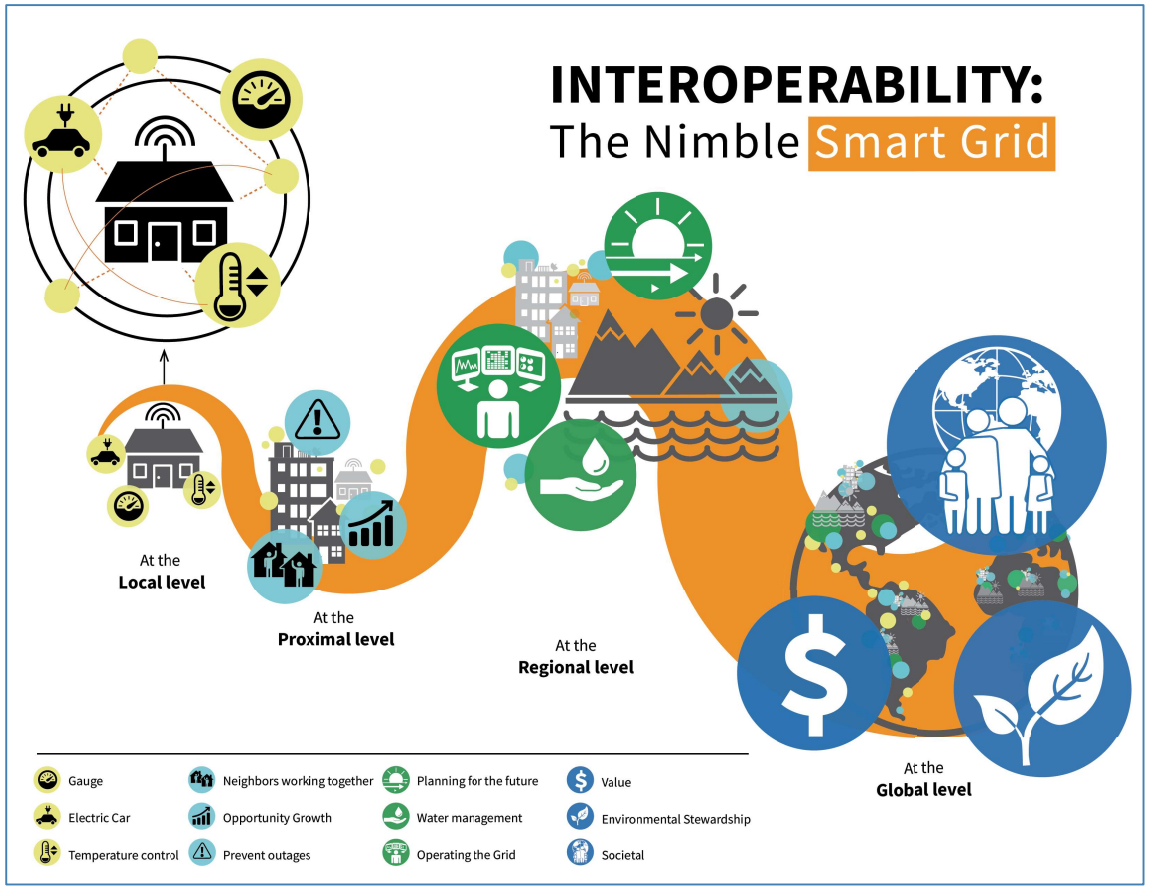
Technology Adoption

Breaking asset specificity

- Sharing information with a new set of actors allows systems purchased to perform one set of tasks the ability to contribute to an entirely different set of applications.
- Aggregation anyone?

Hedge against technology obsolescence

- Grid functional assets were often specified decades earlier for very specific tasks on a very different grid.
- Equipment that lasts beyond planned operational lifetime tends to be over-specified.
- The task of interfacing information technology systems from different eras is simplified when relying on open standards.



Context - Inverter function

Mandatory DER Functions
(Regulatory Requirements from IEEE 1547 and Rule 21)

#	DER Functions	Description and Key Parameters
	Mandatory DER Functions (Regulatory Requirements from IEEE 1547 and California's Rule 21)	
1.	**Disconnect/Connect Function** Disconnect or connect the DER from the grid at its ECP	The disconnect command initiates the galvanic separation (usually via switches or breakers) of the DER at its ECP or at the PCC. There may be a time delay between receiving the command and the actual disconnect The connect command initiates or allows the reconnection of the DER at its ECP or at the PCC. A permission to reconnect may also be issued.
2.	**Cease to Energize and Return to Service** The DER ceases all active power output Allow active power output at the PCC	"Cease to energize" is a different function from disconnect/connect. The (draft) definition is "the DER shall not export active power during steady-state or transient conditions. Reactive power exchange (absorb or supply) shall be less than x% (maybe 10%?) of nameplate DER rating and shall exclusively result from passive devices." There may be a time delay between receiving the command and the actual
3.	**High/Low Voltage** … **Mode** The DER rides throu … fluctuations in voltag …	
4.	**High/Low Frequen** … **Mode** The DER rides throu … fluctuations in freque …	
5.	**Dynamic Reactive** … **Mode** The DER reacts agai … changes (spikes and … dynamic system stab … dV/dt	

#	DER Functions	Description and Key Parameters
6.	**Frequency-Watt Mode** The DER responds to large frequency excursions during abnormal events at a Referenced ECP by changing its production or consumption rate	The DER is provided with frequency-watt curves that define the changes in its watt output based on frequencies around the nominal frequency during abnormal events. When the emergency frequency-watt mode is enabled, the DER monitors the frequency and adjusts its production or consumption rate to follow the specified emergency frequency-watt curve parameters.
7.	**Volt-Watt Mode** The DER responds to changes in the voltage at the Referenced ECP by changing its production or consumption rate	The DER is provided with voltage-watt curves that define the changes in its watt output based on voltage deviations from nominal, as a means for countering those voltage deviations. When the volt-watt mode is enabled, the DER receives the voltage measurement from a meter (or other source) at the Referenced ECP. The DER adjusts its production or consumption rate to follow the specified volt-watt curve parameters.
8.	**Fixed (Constant) Power Factor Mode** The DER power factor is set to a fixed value.	The DER power factor is set to the specified power factor. A leading power factor is positive and a lagging power factor is negative, as defined by the IEEE or IEC sign conventions.

#	DER Functions	Description and Key Parameters
14.	**Limit Active Power Production or Consumption Mode** Limits the production and/or consumption level of the DER based on the Referenced ECP	The production and/or consumption of the DER is limited at the Referenced ECP, indicated as absolute watts values. Separate parameters are provided for production or consumption limits to permit these to be different.
15.	**Low Frequency-Watt Emergency Mode** for demand side management (fast load shedding)	Enable automatic « low frequency » disconnection of a specified proportion of their demand (in stages) in a given time frame.
16.	**Low Voltage-Watt Emergency Mode** for demand side management	Provide capabilities to … enable automatic or manual load tap changer blocking and automatic « low voltage » disconnection.
17.	**Monitoring Function** The DER provides nameplate, configuration, status, measurements, and other requested data	The DER provides status, measurements, alarms, logs, and other data as authorized and requested by users. Examples include connect status, updated capacities, real and reactive power output/consumption, state of charge, voltage, and other measurements. Also of interest are forecast statuses and expected measurements.
	…r Settings and	The DER follows the schedule which consists of a time offset (specified as a number of seconds) from the start of the schedule and is associated with: • a power system setting • the enabling/disabling of a function • a price signal
	…ER Functions	
	…ng Mode …load at the …er it exceeds a …er level	The active power output of the DER limits the load at the Referenced ECP if it starts to exceed a target power level, thus limiting import power. The production output is a percentage of the excess load over the target power leve. The target power level is specified in absolute watts.
	…ode …s the load by a …ferenced ECP, …ed a threshold	The active power output of the DER follows and counteracts the load at the Referenced ECP if it starts to exceed a target power level, thus resulting in a flat power profile. The production output is a percentage of the excess load over the target power level. The target power level is specified in absolute watts.
	…ng Mode	The consumption and/or production of the DER follows and

#	DER Functions	Description and Key Parameters
22.	**Dynamic Active Power Smoothing Mode** The DER produces or absorbs active power in order to smooth the changes in the power level at the Referenced ECP. Rate of change of power – dW/dt	The DER follows the specified smoothing gradient which is a signed quantity that establishes the ratio of smoothing active power to the real-time delta-watts of the load or generation at the Referenced ECP. When the power smoothing mode is enabled, the DER receives the watt measurements from a meter (or other source) at the Referenced ECP. New data points are provided multiple times per second.
23.	**Frequency-Watt Primary Control mode** The DER changes its watt output or input to maintain frequency within normal limits	The DER changes its watt output or input based on parameters or curves, to provide primary frequency control with the purpose of maintaining frequency within the normal frequency limits
24.	**Automatic Generation Control (AGC) Mode** The DER responds to raise and lower power level requests to provide frequency regulation support	When AGC mode is enabled, the DER responds to signals to increase or decrease the rate of consumption or production every 4 to 10 seconds, with the purpose of managing frequency.
25.	**Operating Reserve (Spinning Reserve) mode** The DER provides operating reserve	The DER can provide reserve power available within about 10 minutes
26.	**Dynamic Frequency-Watt Mode** The DER responds to the rate of change of frequency (ROCOF) by changing its watt output or input to minimize spikes and sags	The DER responds to the rate of change of frequency (ROCOF) by changing its watt output or input to minimize spikes and sags
27.	**Coordinated Charge/Discharge Management Mode** The DER determines when and how fast to charge or discharge so long as it meets its target state of charge level obligation by the specified time *(focus is on Electric Vehicle consumption)*	The DER is provided with a target state of charge and a time by which that SOC is to be reached. This allows the DER to determine when to charge or discharge based on price. The DER takes into account not only the duration at maximum consumption / production rate, but also other factors, such as that at high SOC the maximum consumption rate may not be able to be sustained, and vice versa, at low SOC, the maximum discharge rate may not be able to be sustained

#	DER Functions	Description and Key Parameters
28.	**Frequency-Watt Smoothing Mode** The DER responds to changes in frequency at the Referenced ECP by changing its consumption or production rate based on frequency deviations from nominal, as a means for countering those frequency deviations d²/dt	The DER is provided with frequency-watt curves that define the changes in its watt output based on frequency deviations from nominal, as a means for countering those frequency deviations and smoothing the frequency. When the frequency-watt mode is enabled, the DER monitors the frequency and adjusts its production or consumption rate to follow the specified frequency-watt curve parameters. New data points are provided multiple times per second.
29.	**Power Factor Limiting (Correcting) Mode** The DER supplies or absorbs VArs to hold the power factor at the Referenced ECP within the PF limit	When the PF limiting (correcting) mode is enabled, the DER is provided with the target PF. The DER supplies or absorbs VArs in order to maintain the PF at the Referenced ECP within the limits of the target PF.
30.	**Delta Power Control Function** Decrease active power output to ensure there remains spinning reserve amount that was bid into the market	Decrease active power output to ensure there remains spinning reserve amount that was bid into the market
31.	**Power Rate Control** The power is limited by the maximum ramp rate.	Manage active power ramp time, when the activ … the required power level by the end of the ramp … the required power level earlier, but not later.
32.	**Dynamic Volt-Watt Function** Dynamically absorb or produce additional watts in proportion to the instantaneous difference from a moving average of the measured voltage	Dynamically absorb or produce additional watts … instantaneous difference from a moving average … voltage. This function utilizes the same basic co … the Dynamic Reactive Current function but uses … output rather than reactive current.
	Non-Operational Requirements	
33.	**Collect and Provide Historical Information** Collect and provide detailed measurement and performance data which may be valuable to record in an operational historian	Collect and provide detailed measurement and … which may be used to assess the real-time respo … events, control commands, and autonomous fun … could also be used to determine actual capabilit … compliance, and other characteristics of DER sy …

#	DER Functions	Description and Key Parameters
	Capabilities Not Yet Defined by Regulations, EPRI, or IEC 61850	
34.	**Microgrid Separation Control (Intentional Islanding)** Process for normal separation, emergency separation, and reconnection of microgrids	Process for normal separation, emergency separation, and reconnection of microgrids. These microgrids could be individual facilities or could be multiple facilities using Area EPS grid equipment between these facilities.
35.	**Provide Black Start Capability** Support the reestablishment of power after an outage	Ability to start without grid power, and the ability to add significant load in segmented groups.
36.	**Provide Backup Power (Often implemented, but not standardized)** Ability to provide power to local loads when not connected to the grid	Ability to provide power to local loads behind a PCC when the facility is not connected to the grid, either during an outage or due to intentional or unintentional islanding.

The FRAMEWORK (v4)

01. Purpose and Scope
Background on the role of interoperability and the Framework

02. Models for the Smart Grid
Models and language to understand the modern grid

03. Operations
Interoperability for utilities, technologies, and customers

04. Economics
Changing system economics and benefits from interoperability

05. Cybersecurity
Understanding and managing risks, protecting new interfaces

06. Testing and Certification
Critical to unlocking capability and value across the system
Interoperability Profiles

MODELS for the SMART GRID

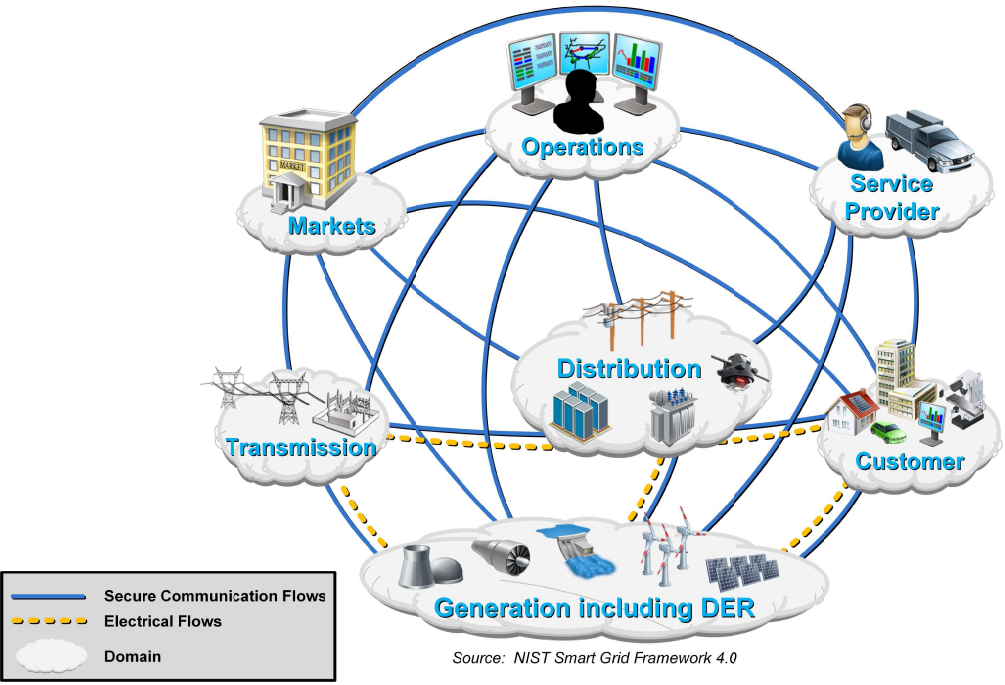
A. Conceptual Model
Lets customers see where they are in the system

B. Communications Pathways Scenarios
Allow us to examine connectedness and interoperability interfaces

C. Ontology for the Grid
Gives us a more precise language to describe what we want and need

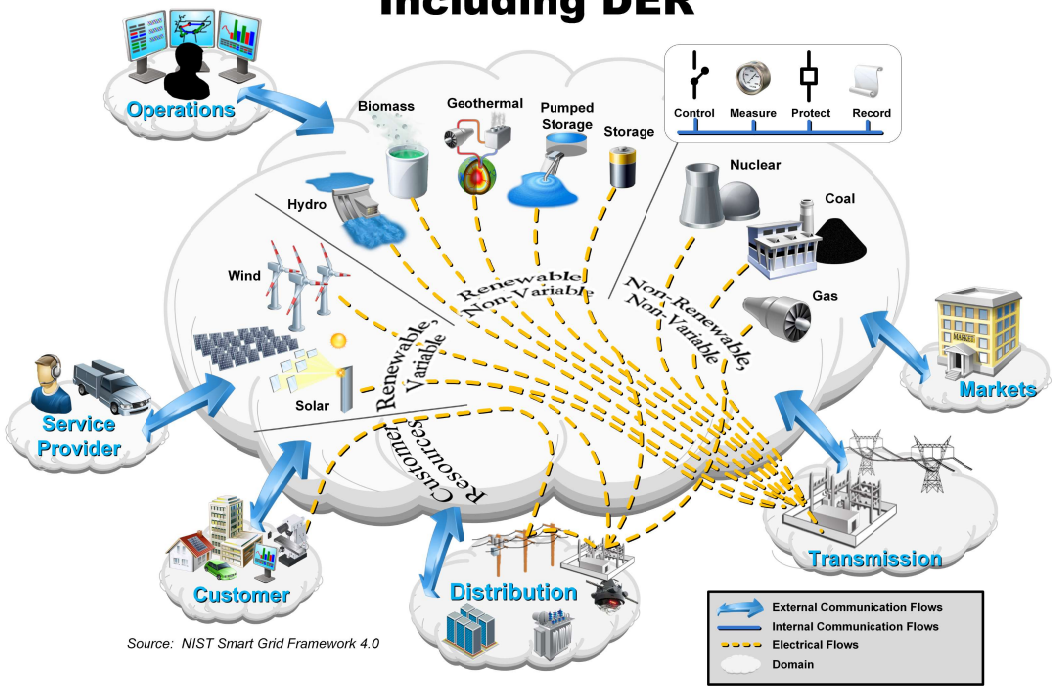
Conceptual Model

Smart Grid Conceptual Model



Source: NIST Smart Grid Framework 4.0

Generation Including DER



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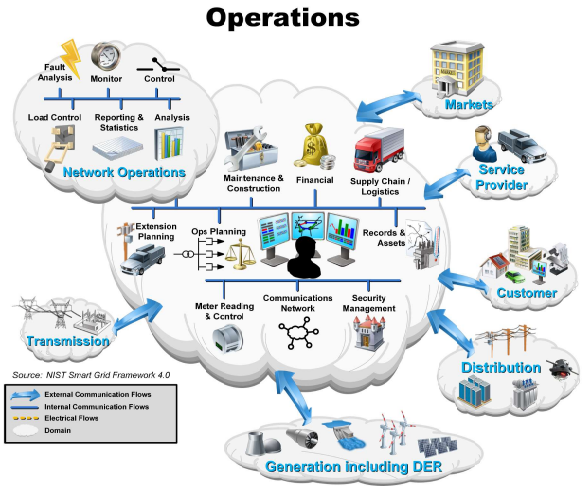
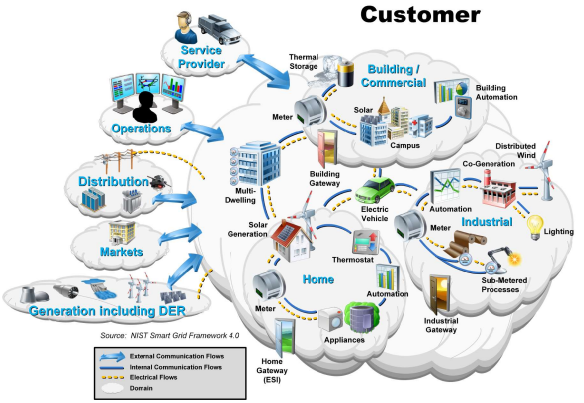
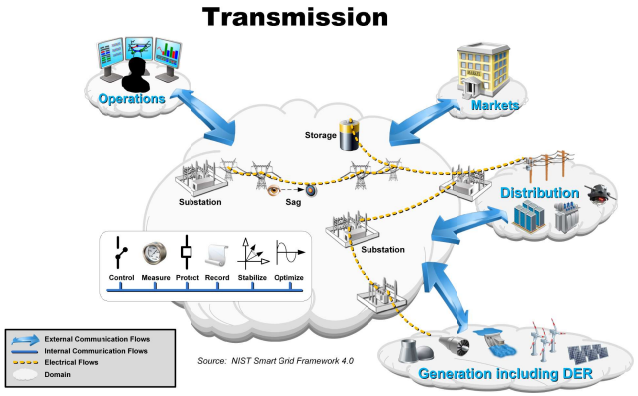
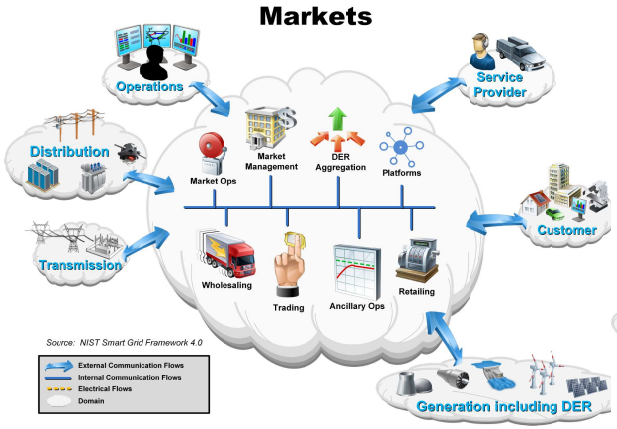
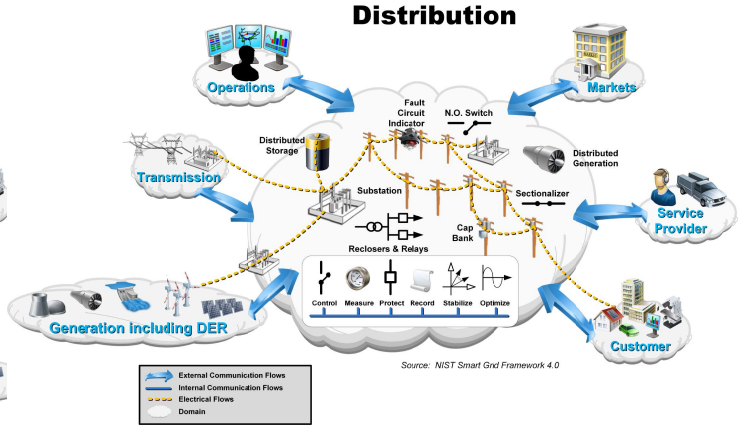


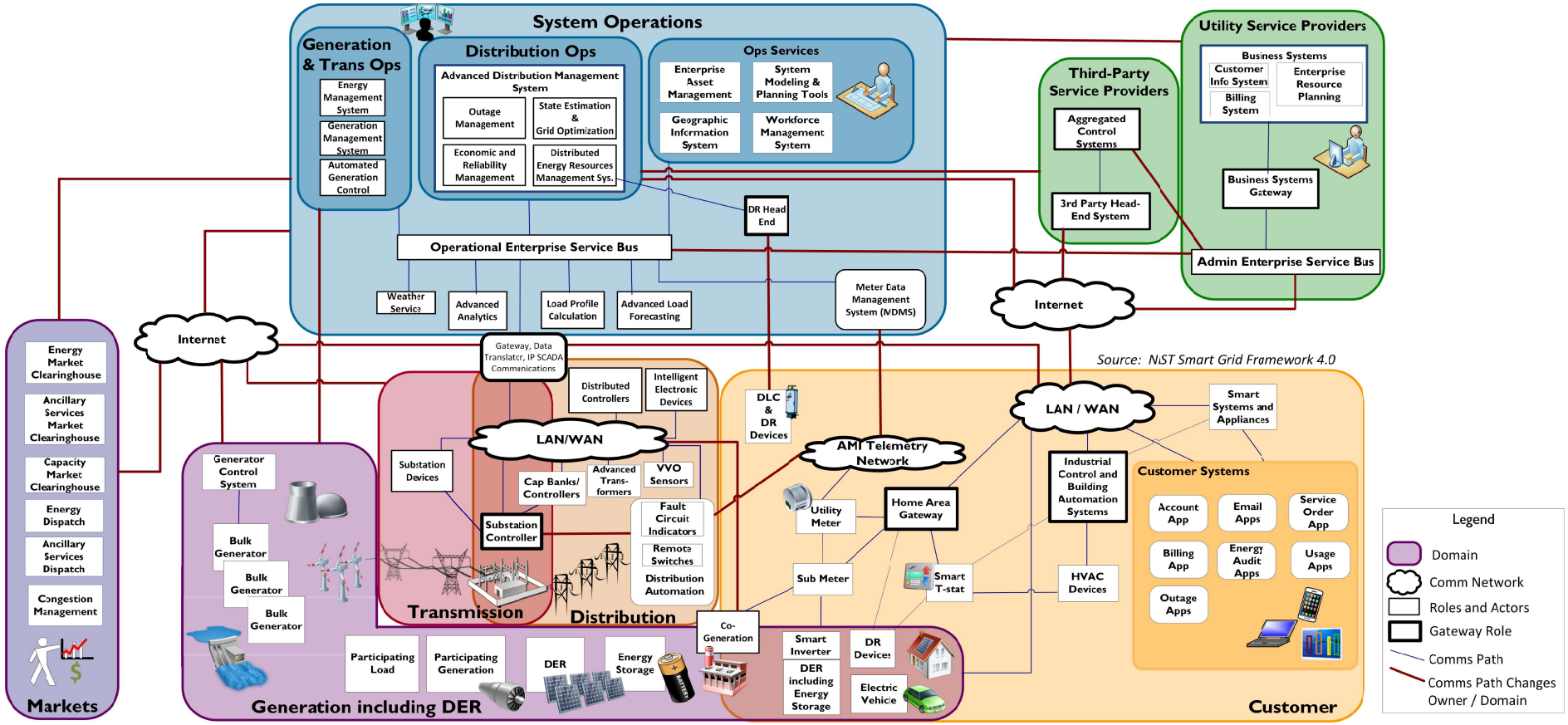








Communication Pathways Scenarios



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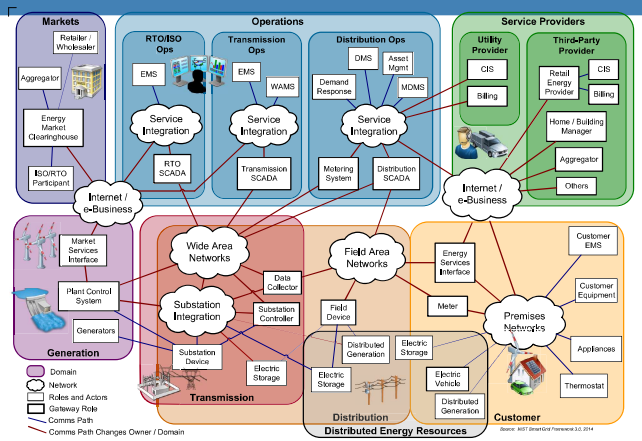
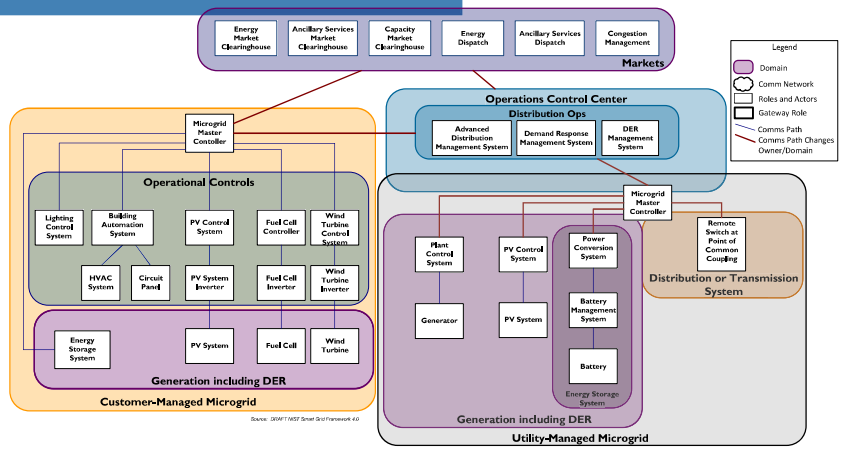
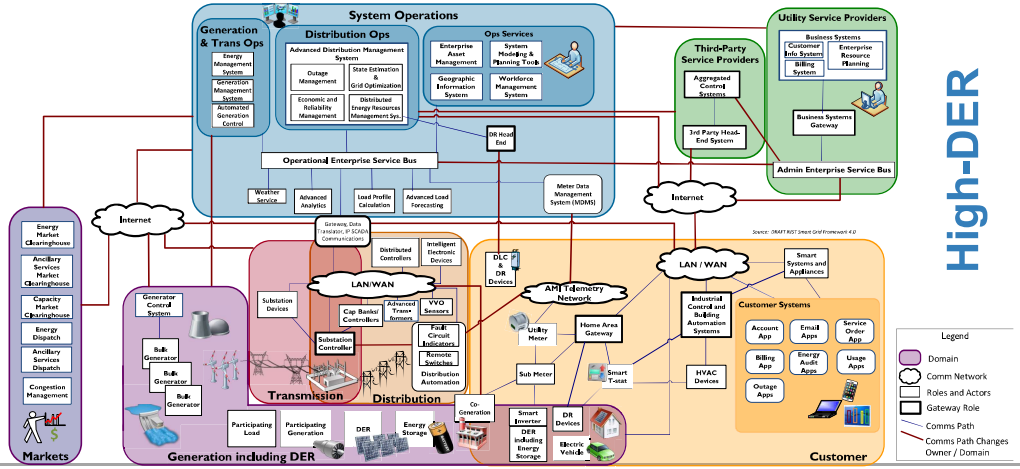


Legacy

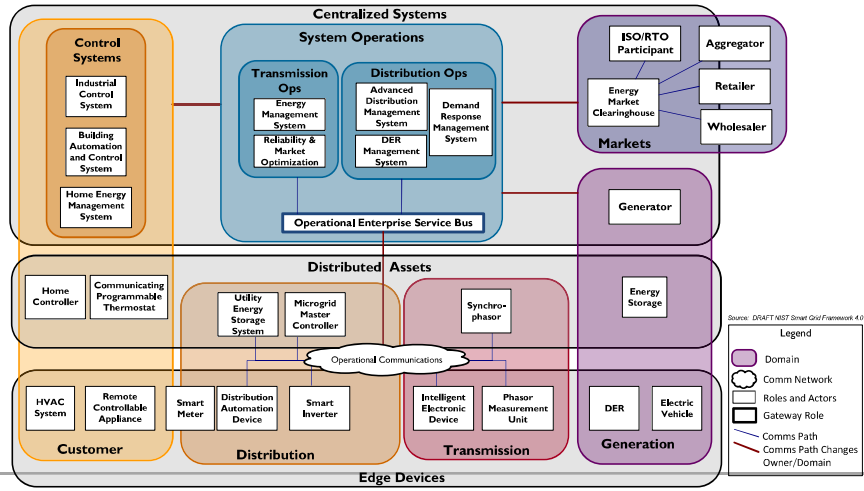
Microgrid



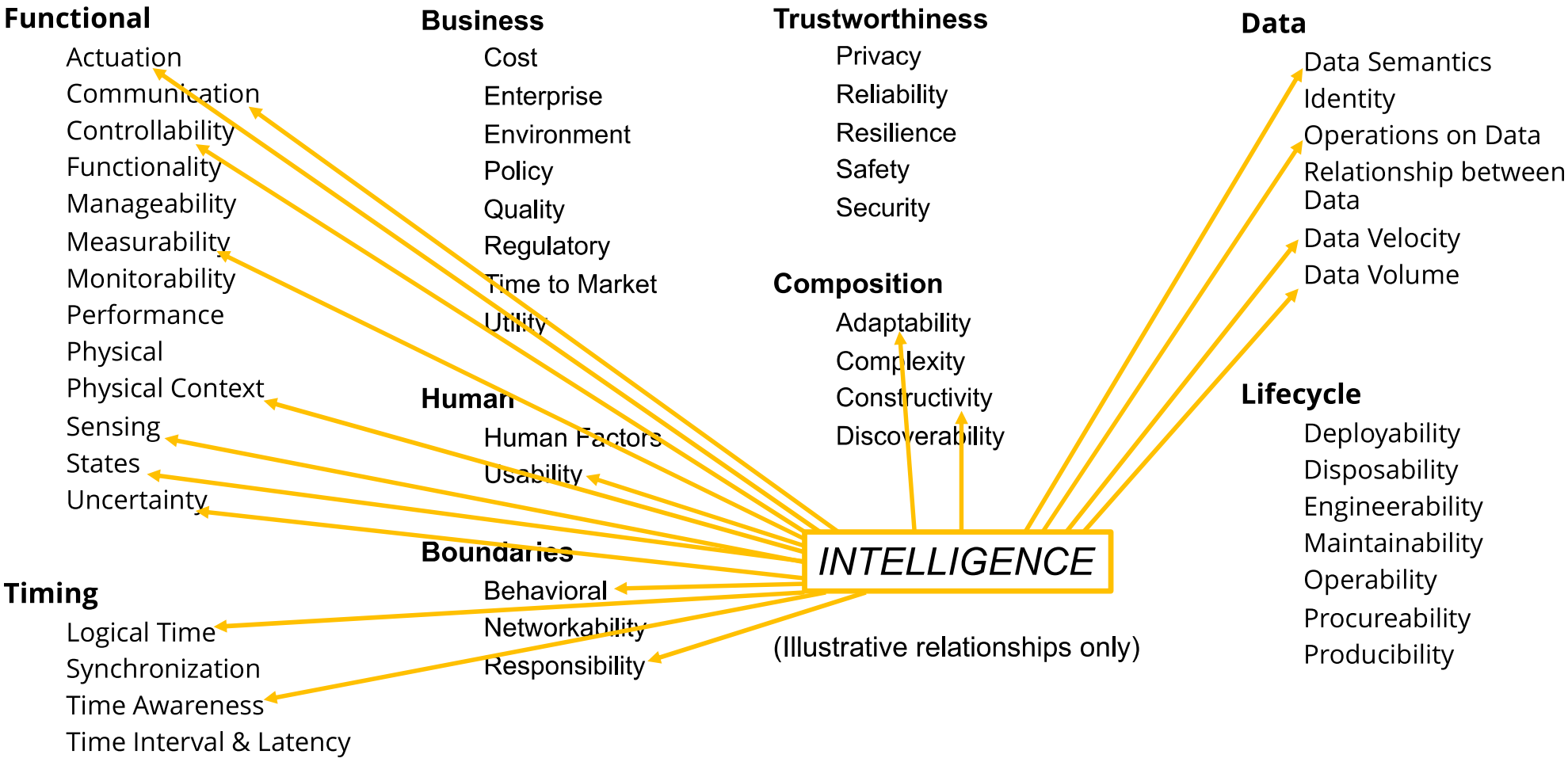
High-DER



Hybrid



Ontology for the Grid



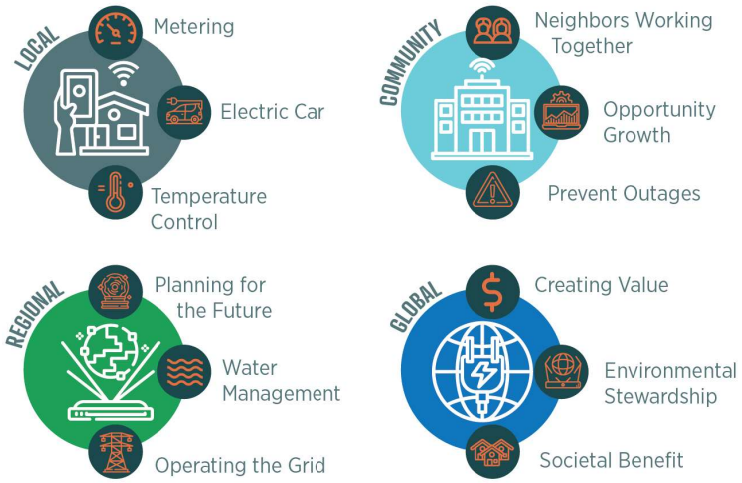
Ontology for the Grid

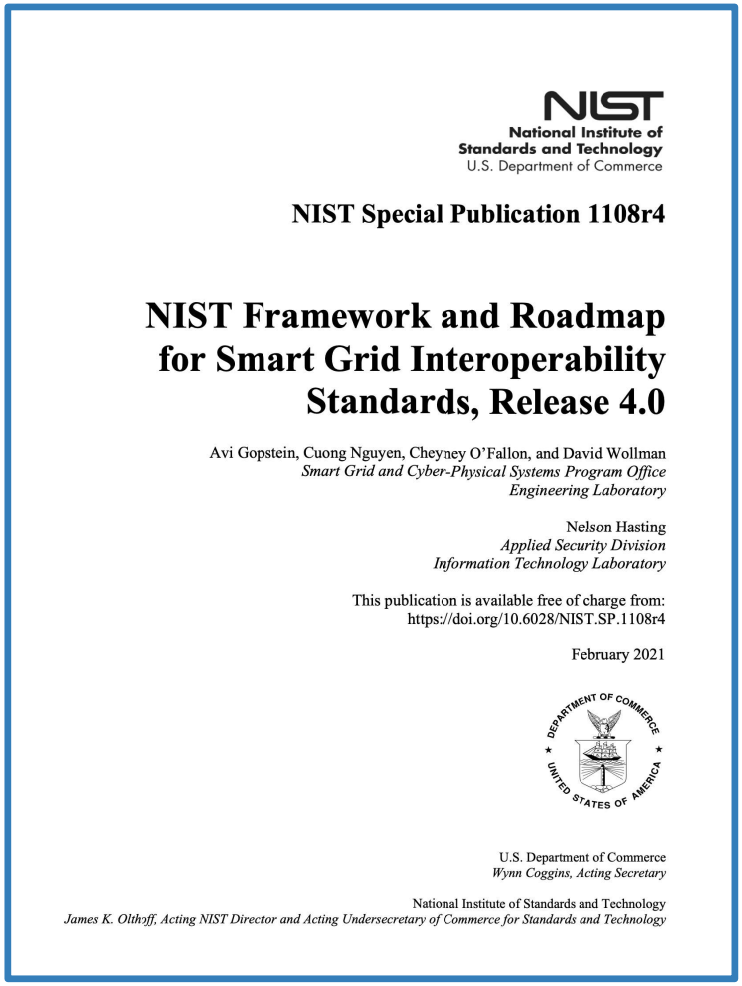
Aspect	Concern	Description	Grid Context for CPS Concern	Grid CPS Concern Description	Architecture Significance
Functional	**Controllability**	Ability of a CPS to control a property of a physical thing. There are many challenges to implementing control systems with CPS including the non-determinism of cyber systems, the uncertainty of location, time and observations or actions, their reliability and security, and complexity. Concerns related to the ability to modify a CPS or its function, if necessary.	• Controllability requires the condonation of sensing, processing and acting • Multiple inputs are needed to make control decisions • Most grid control systems and hardware were not designed to accommodate large numbers of DERs. • More dynamic monitoring and control to respond to the dynamic network	• Ability to control grid properties (sense, process and change); e.g., intentionally change a phenomenon / property	• Coordination of sensing and processing functions to produce accurate control signals. • Architectures needs to support control applications that input and evaluate multiple optimization factors including carbon usage and market prices • Architecture needs to support use of group commands (e.g. DNP3 settings groups) and third-party aggregator control of DERs • Architecture support of faster input of sensor data from traditional SCADA devices and newer devices including phasor measurement units (PMUs)
Functional	**Functionality**	Concerns related to the function that a CPS provides	• The constant evolution of the power system creates new grid functions. • Grid control functionality has expanded to include management of generation assets which require different functionality e.g. diverse generation assets require additional control functionality including distributed assets.	• Ability to provide grid functions e.g. control functions, sensing functions, service-related functions.	• Innovative grid technology needed to facilitate Power Markets, DERs, Microgrids, Electric Vehicles, etc. • Architecture needs to support management of DERs constraints that differ from older types of generation.
Functional	**Manageability**	Concerns related to the management of CPS function.	• Need the ability to manage change across multiple devices at different grid levels.	• Ability to manage change internally and externally to the grid at the cyber-physical boundary e.g. digital equipment and actuators affected by EMC	• Communication topology views and key externally visible properties for multi-tier distribution communications needed for system control, substations, field operations, and Transmission/Distribution integration[74]

Questions?

INTEROPERABILITY: THE NIMBLE SMART GRID

The ability of systems to securely exchange and readily use information, known as interoperability, is key to unlocking value across the power grid in homes, communities, regions and society as a whole.





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U.S. Department of Commerce

NIST Special Publication 1108r4

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 4.0

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