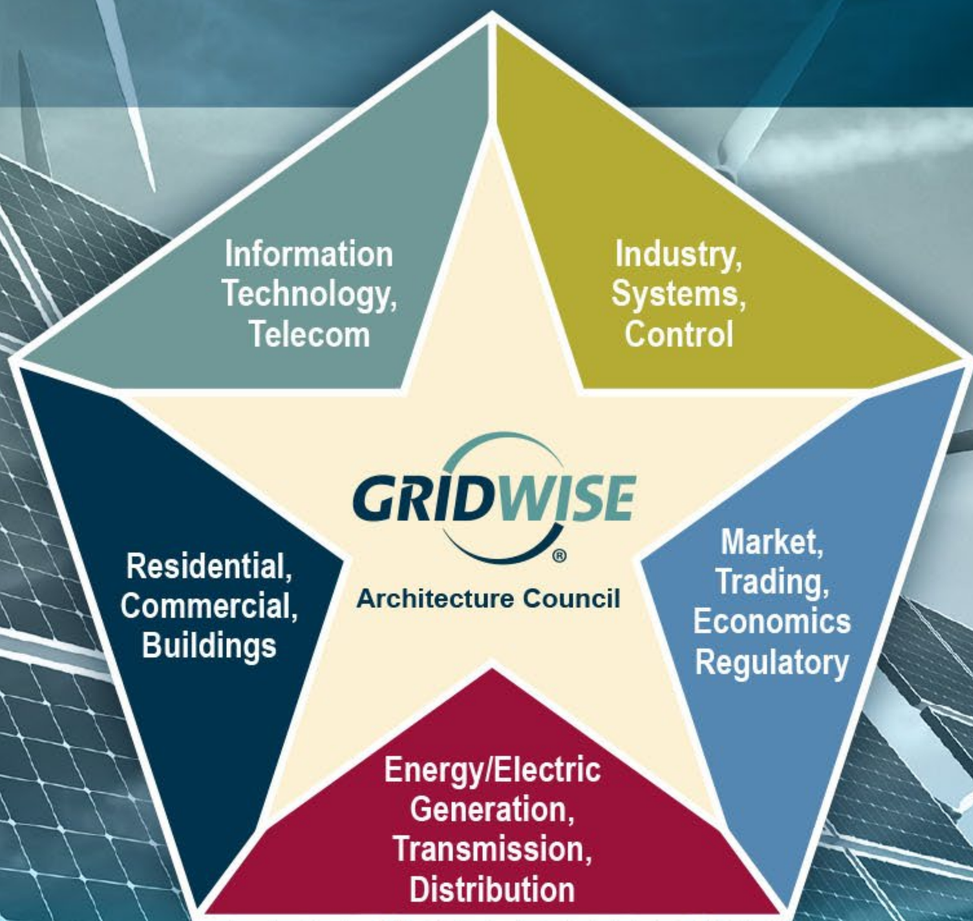
Future Electric Power Industry and Grids—Now What Again is Our Destination?

September 2024



PREPARED BY THE

GRIDWISE® Architecture Council

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About This Document

The GridWise Architecture Council (GWAC) was formed by the U.S. Department of Energy to promote and enable interoperability among the many entities that interact power system, provide industry guidance, and tools that make it an available resource for smart grid implementations. In the spirit of providing guidance to electric power system industry, an assessment and characterization of a sampling of visions and future statements of electric power industry and grids stakeholder organization reports is discussed in this paper assessment. GWAC insights including architectural challenges, Grid Architecture, and continued relevance of the interoperability framework are discussed in the document. The Executive Summary describes the main findings and insights that are further discussed in the main body of the document. Please see the www.gridwiseac.org website for more products of the GWAC that may be of interest to you.

Abstract

Having a vision that others agree to support and work toward is highly desirable but hard to achieve. We seem to lack a common and shared understanding of the vision—or worse, multiple visions (vivid mental images or documented statements) with varying areas of focus and details:

- some appear to be similar but have differing underlying goals and characteristics, or
- some reflect differing viewpoints as to effects on various stakeholders.

These desirable and undesirable situations apply to realizing visions for enterprise and industry, including the electricity sector.

Multiple industry stakeholder groups have developed goals, industry vision statements, and characterizations of the future. The viewpoints are promoted, discussed, refined by their stakeholder group, and often published to promote broad understanding and to inform or influence others.

The GridWise Architecture Council asked itself how well-aligned these characterizations of the future are.

If these publications collectively set the overall direction for the industry, it is useful to identify their answers to questions such as, where is the electric industry headed, guided by what objectives, and with what role(s) for the customers, electric utilities, and other stakeholders?

Are these goals, visions, and future states moving toward a common vision, do they provide value for the stakeholders, and are they likely to meet the objective stated?

This paper addresses these questions via an assessment and characterization of a sampling of stakeholder groups' publicly available vision and future state reports for the electricity industry. Identified electric power grid architectural topic areas needing further work are described, along with GridWise Architecture Council analysis and observation, potential collaborative work efforts, and suggested next steps.

About GridWise® and the GridWise Architecture Council

The GridWise vision rests on the premise that information technology will revolutionize the planning and operation of the electric power grid, just as it has transformed business, education, and entertainment. Information technology will form the "nervous system" that integrates new distributed technologies—demand response and distributed generation and storage—with traditional grid generation, transmission, and distribution assets. Responsibility for managing the grid will be shared by a "society" of devices and system entities.

Currently there are two electric industry organizations that were created to help move the electric power industry and grid towards the GridWise® vision: GridWise Architecture Council and GridWise Alliance. Each organization is independent of but complementary to the other in their missions and objectives.

The mission of the GWAC is to enable all elements of the electricity system to interact. We are an independent body that believes tomorrow's electricity infrastructure can be made more efficient and secure by integrating information technology and e-commerce with distributed, intelligent networks and devices. To achieve this vision of a transformed electricity system, GWAC is defining the principles for interaction among the information systems that will effectively and dynamically operate the grid. GWAC, with administrative support by the U.S. Department of Energy, includes 13 representatives from electric energy generation and delivery, industrial systems control, building automation, information technology, telecommunications, and economic and regulatory policy.

GWAC is shaping the guiding principles of a highly intelligent and interactive electricity system—one ripe with decision-making information exchange and market-based opportunities. This high-level perspective provides guidelines for interaction among participants and interoperability among technologies and automation systems. We seek to do the following:

- Develop and promote the policies and practices that will allow electric devices, enterprise systems, and their owners to interact and adapt as full participants in system operations.
- Shape the principles of connectivity for intelligent interactions and interoperability across all automation components of the electricity system, from end-use systems, such as buildings or heating, ventilation, and air conditioning systems, to distribution, transmission, and bulk power generation.
- Address issues of open information exchange, universal grid access, distributed grid communications and control, and the use of modular and extensible technologies that are compatible with the existing infrastructure.

GWAC is neither a design team nor a standards-making body. Our role is to bring together knowledgeable parties to identify actions, agreements, and standards that enable significant levels of interoperation among automation components. We act as a catalyst to outline a philosophy of inter-system operation that preserves the freedom to innovate, design, implement, and maintain each organization's role and responsibility in the electricity system.

Executive Summary

Do the electric power industry stakeholders have complementary visions for the electric power industry and the grid—its characteristics, their role(s) in it, and anticipated timelines?

In the past decade, multiple stakeholder organizations have published documents forecasting and making recommendations for the electric power industry's future. The GridWise® Architecture Council (GWAC) chartered a project to assess the electric power industry vision and future-state assessment documents and determine how well-aligned these views of the future are.

Project Summary

The project objectives were to identify

- stakeholders' visions and future states for the electric power industry and grid,
- their similarities, differences, divergences, and effects on stakeholders, and
- architectural gaps and challenges -gaps categories for organizing potential coordination and collaboration opportunities among multiple stakeholders.

The project approach steps included

- identifying, gathering, and assessing a sample of publicly available electric power grid stakeholder organizations' visions and future-state descriptions for similarities, differences, potential divergence, and effects on stakeholders,
- characterizing vision and future-state reports by decomposing the vision and future-state prose into discrete future statements, and then refactoring to allow a clearer view into similarities and differences across those statements,
- identifying and categorizing architectural challenges or gaps,
- developing this white paper with the added perspectives of the GWAC, and
- socializing the results with the industry stakeholder organizations.

Results and Conclusions

The GWAC Electric Industry Vision and Future States Assessment project team identified documents from 16 electric power industry organizations and 10 reports from nine organizations for assessment and characterization by the GWAC team. These stakeholder organization reports publication dates varied from December 2013 to April 2021; the report's vision and future states' target epochs varied across the years 2020–2050, depending on report topics.

The reports and documents had varied approaches, so a systematic assessment approach was developed, which is summarized below.

Report Characterization: The reports were assessed across 11 dimensions (bolded text), which indicated that

- **Scope**, **Completeness**, **Active Community Collaboration and Consensus, Architectural Needs,** and **Effects on Stakeholders** are reasonably well addressed.

- **Structural Models**, **Process Models**, **Metrics**, and **Ecosystem**s were moderately addressed, while
- **Workforce** had very light coverage.

Vision Statements Characterization: Four stakeholders' reports had readily identifiable vision statements.

- Commonalities included significant changes to the electricity grid, and efficiency, affordability, and economy as essential qualities.
- Differences were grouped by degree of stakeholder involvement, cleaner energy, and environmental protection.

Future Statements Characterization: The final report decomposition, refactoring, and tabulation identified the following:

- whether or not each report covered all topic areas,
- whether the topic areas address all the architectural types, and
- how grid and grid coordination were addressed because these topics included the most future statements.

Review Insights

Overall Assessment: The compilation of the 137 refactored future statements indicates

- most differences appear to be details about the future state from different stakeholder groups' points of view
- distinct statement differences appear where reports describe a spectrum of grid coordination options across three roles: entirely transmission system operator, hybrid transmission–distribution system operator, and primarily distribution system operator; these include what roles and responsibilities the grid, utilities, and aggregators would have in that spectrum.

This variability in approaches to deploying grid coordination is governed by national, regional, state, and local jurisdictions, including the timing and degree of addressing decarbonization, decentralization, and democratization.

Architectural Challenge-Gaps Categorizations – During the assessment and characterization of identified architectural challenges/gaps, structures were mentioned most frequently in the stakeholder reports, as articulated by the following:

- developing new industry structures
- developing effective data communications that enable control and coordination in distributed structures
- developing new structures that accommodate large quantities of distributed energy resources.

Depending on when the stakeholder organization reports were prepared, the architectural gaps generally arise from the increasing deployment of distributed energy resources in distribution systems. As a result, the identified architectural gaps are well aligned with elements of the Grid Architecture core project of the Department of Energy's Grid Modernization Laboratory Consortium (GMLC).

Drivers and Emerging Trends in the Electric Power Industry and Grid – GWAC assessed a draft report on GMLC topic 1.2.1, Grid Architecture: *Emerging Trends and Systemic Issues Influencing Today's U.S. Electric Grid - Context for Grid Architecture Development* (Xue et al. 2022). One of 10 trends discussed in the draft GMLC report focused on decentralization and flexible resource deployments; GWAC further discussed trends that influence decentralization and their relationships to grid architecture considerations. Additional trends from The National Academies of Sciences, Engineering, and Medicine 2021 assessment report (NASEM 2021) were also discussed.

Supply Chain Factors and Issues – Remediating supply chain vulnerabilities is critical to enable the transition to the envisioned future state. GWAC identified and discussed potential architectural techniques that address some supply chain issues.

Relevance of the GWAC Interoperability Framework to grid architecture – An overview of the GWAC Interoperability Framework (GWAC 2008) and tenets of its fundamental system-integration philosophy are described. The GWAC Interoperability Framework is discussed as an aid to industry stakeholders when addressing system architecting and integration tasks, including

- analyzing system qualities
- coupling with the National Institute of Standards and Technology Conceptual Model (NIST 2018) to provide a high-level stakeholder model of the grid
- assuring all relevant sources of requirements are considered via a consistent approach to validation of grid architecture designs.

Recommended Next Steps

Two significant steps are recommended to assist the transition to the future electric power industry and grid future state:

- Create a work plan that addresses the architectural gaps summarized above and identifies collaboration and coordination across electric power industry stakeholder organizations to maximize the effective use of stakeholder organization capabilities and resources.
- Develop a set of future-backward and present-forward roadmaps as qualified by anticipated present-vision–future-state pairs that reflect different starting points and a flexible range of the jurisdictional vision–future-state "how-to" expectations.

Acronyms and Abbreviations

CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	distributed energy resource
DOE	Department of Energy
DSO	distribution system operator
DSPx	Next Generation of Distribution System Platform
EPRI	Electric Power Research Institute
GMLC	Grid Modernization Laboratory Consortium
GWAC	GridWise Architecture Council
IEEE	Institute of Electrical and Electronics Engineers
IEN	Integrated Energy Network (EPRI)
IESO	Independent Electricity System Operator, Ontario, Canada
NIST	National Institute of Standards and Technology
NWA	non-wires alternatives
PEI	Pacific Energy Institute
TSO	transmission system operator
UTC	Utility Technology Council

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1.0 Introduction

In first half of 2020, the GridWise Architecture Council (GWAC) had discussions about the multiple vision and future-state documents that had been published forecasting the future state of the electric power industry.

During these discussions, a recurring question emerged: How similar and different are these visions? To answer that question, GWAC initiated a project with contributors, including GWAC members, associates, and other interested people.

The project objectives were to identify the following:

- stakeholders' visions and future states for the electric power industry and grid,
- their similarities, differences, divergences, and effects on stakeholders, and
- architectural challenge/gaps categories for organizing potential multi-stakeholder coordination and collaboration opportunities.

The project approach included five steps:

- Identify, gather, and assess a sample of publicly available electricity grid stakeholder organizations' visions and future-state descriptions for similarities, differences, divergences, and stakeholder effects,
- Characterize vision and future-state reports by decomposing the vision and future-state prose into discrete future statements, then refactor them to allow a clearer view into what was similar and different across those statements,
- Identify and categorize architectural challenges or gaps,
- Develop this white paper with the added perspectives of the GWAC, and
- Socialize the results with the industry stakeholder organizations.

The results of this project are presented below in two major sections of work. The first section is a summary of the architectural implications of each paper. The second section provides the analysis and insights about the proposed future states from the perspectives of the project team.

2.0 Summary of the Assessed Future-State Documents

2.1 Challenges to Developing Vision and Future-State Documents

A business (enterprise) that has a well-formed vision, future state, continually acts upon them, and works toward them possesses

- a documented vision and future state for shared understanding and buy-in,
- a framework the organization can use for strategic planning,
- common focus and change-engagement opportunities for stakeholders, and
- documentation of aspirational and long-term outcomes of the organization's change efforts.

A well-formed future state inspires, creates excitement, supports eagerness and willingness to be a part of the vision, and provides clarity and a purpose for work.

Figure 1 provides a visual context of an electricity grid's future state, illustrating most stakeholders' representations including a high degree of distributed energy resource (DER) penetration.

Figure 1: Potential future state for a 9500 node test feeder. (Courtesy Pacific Northwest National Laboratory)

Statements that are poorly formed and/or not implemented engender several undesirable outcomes:

- multiple, siloed organizations or specific offerings of enterprise business units,
- lack of common or shared understanding of vision or future states across the enterprise,

- a wide spectrum of options created by the organization, business units, or even the groups that make up those business units to reach their perceptions of the future states that lack enterprise coherence and/or cohesion, and
- siloed offerings that do not consider all stakeholders' needs, concerns, or effects outside of the silo.

Poorly formed visions result in confusion, turf wars, failing projects, lower organizational performance, and less customer satisfaction.

One vision development approach that works well is extrapolating the creation of enterprise vision and future state by inviting participation from electric power industry groups with broad representation from all the industry stakeholders. Within a single business, individual employees and the enterprise business unit leadership directly influence the enterprise's ability to internally collaborate effectively to realize the enterprise's vision and future state and meet the needs of the organization's stakeholders. The members of the electricity industry stakeholder groups must collaborate with all the other stakeholders (organizations, individual companies, subject matter experts, and others) in crafting and aligning electric industry visions and future state(s).

Failures to realize stated visions and future state(s) in an industry are characterized by any of the following:

- having overly optimistic estimates of
  - how quickly the vision will be realized for most of the industry,
  - the value, benefits, and costs to achieve realization with equity for all affected stakeholder groups
- neglecting to prepare for and anticipate ways the visions and future states will be constrained or be forced to adopt significantly different visions, business models, technologies, and views of the future
- failing to acknowledge that the future states may need to be more heterogeneous and flexible than offering only a single option; i.e., there is more than one way to achieve the desired future state(s)
- seeing collaboration across stakeholder groups as optional or unnecessary
- underestimating the amount of cultural, technical, regulatory, or company requirements, societal change resistance, or resources needed to make the transition possible and sustainable.

2.2 Reports Identified on Electric Power Industry Visions and Future States

The GWAC Electric Industry Vision and Future States Assessment Project Team identified industry future reports from 19 electric power industry stakeholder organizations that were publicly available and web accessible. Sixteen reports from nine organizations were reviewed resulting in 11 vision and future states assessments and characterizations by the GWAC team as constrained by resource availability and deliverable due dates. Those assessed vision and future states' stakeholder organizations include

- Commonwealth Scientific and Industrial Research Organisation (CSIRO) Future Grid Forum
- Department of Energy Office of Electricity (DOE)
- Electric Power Research Institute (EPRI)
- GridWise Alliance
- Institute of Electrical and Electronics Engineers USA (IEEE)

- Independent Electricity System Operator (IESO)
- National Institute of Standards and Technology (NIST)
- Pacific Energy Institute (PEI)
- Utilities Technology Council (UTC).

Appendix A, "Assessed Electric Power Industry Stakeholder Source Matrix," provides information on the 16 source documents that were reviewed, with 11 being assessed and characterized, including the source organization name, document title, publication date, functioning URL, a short description, and the time-frame window for the vision and future states.

Three of the stakeholder organization reports were identified too late for this GWAC assessment effort. A potential addendum to this report may assess and characterize these and other recently released reports or papers related to industry vision and transition strategies, including:

- Energy Systems Integration Group (ESIG) *DER Integration into Wholesale Markets & Operations* (ESIG 2022)
- *California's Electricity System of the Future* (Newsom 2021)
- New England States Committee on Electricity (NESCOE) *New England States' Vision for a Clean, Affordable, and Reliable 21st Century Regional Electric Grid* (NESCOE 2021).

2.3 Similarities and Differences in Visions and Future States

The assessment approach for this project included identifying from the assessed reports and specific statements describing the future conditions (future statements), characterizing them using a set of 11 dimensions, and rating those characterizations on a 0–5 scale for each of the various dimensions, where 5 was the most complete and thorough coverage of that dimension. A few visuals will illustrate similarities and differences across the assessed stakeholder visions and future-state documents. The 11 characteristic dimensions are the following:

- **Domain(s) Scope** – How many of the NIST smart grid interoperability roadmap domains[1] were addressed in the vision and future states?
- **Completeness of Vision and Future Statements** – How detailed are descriptions of details, substantiations, and barriers?
- **Active Community** – What level of sustained activity and involvement of stakeholders to further champion, detail, and work to transition to the vision and future states is identified?
- **Effects on Stakeholder(s)** – What discussion is provided of how stakeholders are positively or negatively affected?
- **Architectural Need(s)** – What architectural work is needed to address capabilities necessary to help achieve the vision and future states?
- **Collaboration / Consensus Environments** – What types of stakeholder engagements are called for and recommended?

[1] The NIST Smart Grid Conceptual Model Domains are Customer, Markets, Service Provider, Operations, Generation Including DER, Transmission, and Distribution. (NIST 2018)

- **Ecosystems** – What ecosystems are discussed regarding steps of ideate, architect, design, build, deploy, operate, and support?
- **Metrics** – What measurements were discussed to help assess the transition from the current state to the future state, and eventually to assess whether the vision and future state had been realized?
- **Process Models** – What regulatory and business models were addressed?
- **Structural Models** – Which structural models were discussed—e.g., reference architectures, designs, context diagrams, interface, or interoperability?
- **Workforce** – What skills are needed to enable the transition to and sustainability of the vision and future states?

Note: the dimension titles in underlined text are a refactoring of the Grid 3.0 Future States categories in Appendix B.

Figure 2 is one of two visuals that help illustrate the similarities and differences between the assessed visions and future states across nine of the 11 characteristic dimensions. Effects on Stakeholders and Architectural Needs characteristics were not included.[2]

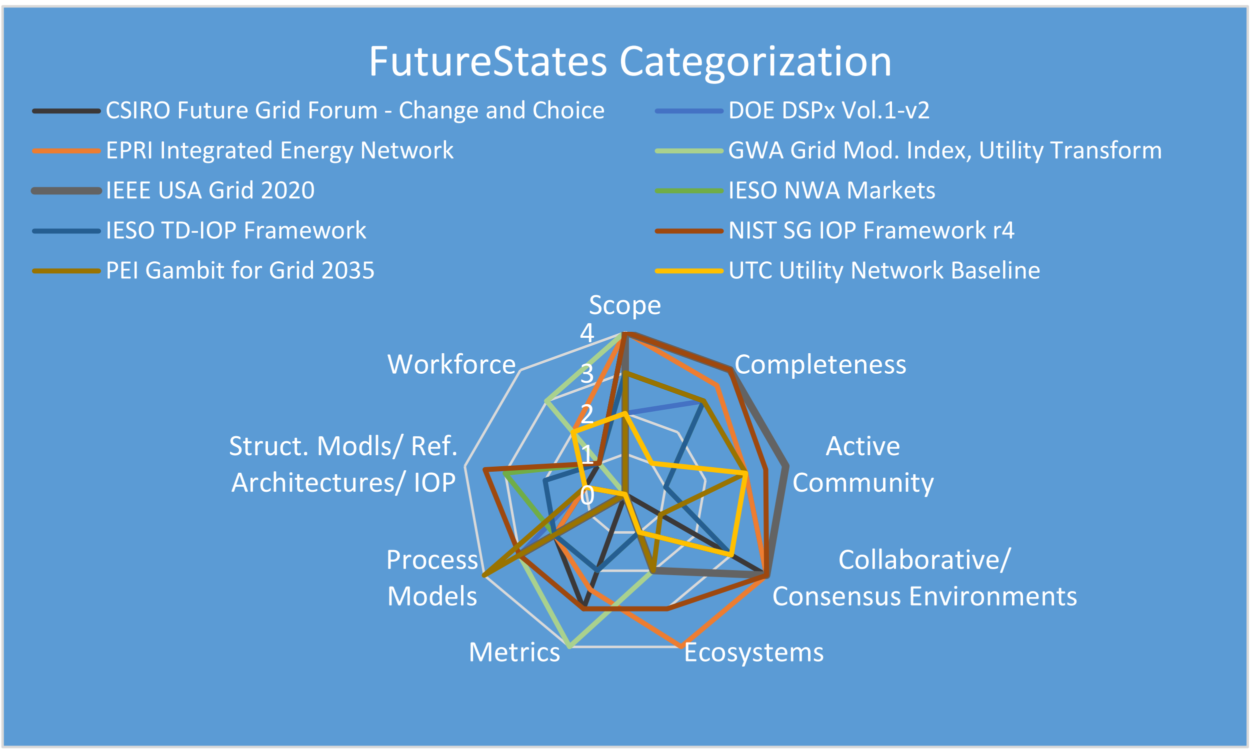

Figure 2: Future states characterization web/radar chart.

The desired position on the web/radar chart is for higher ratings, on the chart's perimeter.

[2] Effects on Stakeholders and Architectural Needs characteristics are a stakeholder organizations inclusion or not of statements on these topics. Assessment team decision was not to include those in these two visuals as they could not be scored against a 0 – 5 scale. Applying any that made any sense might be 0 – no statements made or 1 – some quantity of statements were made.

Appendix C, "Characterizations of Individual Source Future States" shows the web/radar charts for each vision and future-state document's characterization.

A few takeaways:

- The vision and future states documents reviewed do not sufficiently address the workforce dimension.
- Only moderate coverage is given to structural models, process models, metrics, and ecosystems.
- Scope, completeness, and active community collaboration/consensus were reasonably well addressed.

The same data and information can be shown in a "Harvey Balls" matrix, which pulls out the assessment characterizations with more visual clarity; this is shown in Table 1.

Table 1: Future States Characterization Harvey Balls Matrix

Characteristics → Source ↓	Scope	Completeness	Active Community Collaboration/Consensus	Ecosystems	Metrics	Process Models	Structural Models	Workforce
CSIRO Future Grid Forum - Change and Choice	●	●	●	●	○	◕	◑	◔	◔
DOE - DSPx vol. 1, v2	◑	◕	◕	●	◑	○	◕	◔	○
EPRI - Integrated Energy Network	●	●	◕	●	●	◕	◑	◔	◑
GWA - Grid Modernization Index, Utility Fast-Track Transformation	●	●	●	●	◑	●	◕	○	◕
IEEE - USA Grid 2020	●	●	●	●	◑	○	◕	○	○
IESO - NWA Markets	◕	◕	◔	◕	◔	◑	◑	◕	◔
IESO - T-D IOP Framework	◕	◕	◔	◕	◔	◑	◑	◑	◔
NIST - SG IOP Framework r4	●	●	●	●	◕	◕	◕	●	◔
PEI - A Gambit for Grid 2035	◕	◕	◕	◔	◑	○	●	◔	○
UTC - Utility Network Baseline	◑	◔	◕	◕	◔	○	○	◔	◑
Median Rating	3.5	3.25	3	4	2	2	2.5	1	1
Average Rating	3.3	3.3	3.0	3.4	1.8	1.7	2.4	1.4	1.1

Other similarities and differences observed when reviewing each of the visions and sets of future statements were their release dates and windows into the future.

2.3.1 Vision Statements' Characteristics

Four stakeholders' reports had readily identifiable vision statements and all four had two conclusions in common:

- Significant changes in the electric power grid are expected from their specific point-in-time perspectives.
- Efficiency, affordability, and economics are important qualities.

The reports differed from two main aspects:

- Degree of stakeholder involvement:
  - all parties/stakeholders would be engaged, or
  - the customer/prosumer was the primary focus of the reports.
- Degree of emphasis on cleaner energy and environmental protection:
  - half of the reports specifically called out environmental impacts in the future state.

2.3.2 Variability in Future Statements

Observations from the first, high-level decomposition/refactoring of the statements indicated the following:

- None of the stakeholders' future statements covered all 11 characteristics.
- A few of the reports provided a spectrum of future scenarios with descriptions.
- Several stakeholders' reports focused on a subset of industry stakeholders and domains specific to the scope of their focus.

The first decomposition and refactoring of the future statements prose resulted in 91 discrete future statements. These future statements were summarized and categorized as indicated in the following three tables, which illustrate the variability in stakeholder views.

Table 2 indicates the number of future statements extracted from each stakeholder organization's report(s). Table 3 indicates that Grid Modernization and Markets Transactive Energy Non-Wires Alternatives topic areas were a major focus of the future statements. Table 4 demonstrates that decarbonizing was a major focus of the future statements.

Table 2: Future statements by stakeholder organization.

Stakeholder	Document	No. of Future Statements	Reference
CSIRO	Change and Choice	6	CSIRO 2013
DOE	Modern Distribution Grid (DSPx)[a]	4	DOE 2019a
EPRI	Integrated Energy Network	7	EPRI 2017
GWA (2)	Grid Modernization Index, Utility Transformation	19	GridWise 2018, 2019
IEEE-USA	USA Grid 2020	4	IEEE-USA 2019, 2020
IESO (2)	NWA Markets, T-D Interoperability Framework	24	IESO 2020a, 2020b
NIST	Smart Grid Interoperability Framework	15	NIST 2021
PEI	A Gambit for Grid 2035	4	PEI 2021
UTC	Utility Network Baseline	8	UTC 2017
	Total	91	

a. DSPx stands for Next Generation of Distribution System Platform

Table 3: Future statements categorized by architecture and topic area.

Number of Future Statements		Mapping to Topic Areas				
Category	Architecture	Customer	Utility	Grid Modernization	Markets-TE-Non-Wires Alternatives[(a)]	Energy
Trend/Driver	18	5	2	6	–	5
Business Model	27	4	3	2	18	–
Strategy	13	1	1	5	4	2
Services-Functions/ Requirements	33	2	–	23	8	–
Total	91	12	6	36	30	7

(a) TE is transactive energy

Table 4: Future-statement categories and architecture mapping to 3-Ds. ([(a)]TESC 2022)

Number of Future Statements		Mapping to TESC 2022 3Ds[(b)]				
Category	Architecture	Decarbonize[(c)]	Decentralize	Decentralize / Decarbonize[(c)]	Democratize	Democratize / Decarbonize[(c)]
Trend/Driver	18	5	2	–	2	1
Business Model	27	7	–	1	2	6
Strategy	13	3	2	2	1	–
Services-Functions/ Requirements	33	5	3	3	1	–
Total	91	20	7	6	6	7

(a) The 3-Ds are decentralize, decarbonize, and democratize.
(b) Not all Architecture future statements map to 3-Ds.
(c) Including mentioning DER.

The initial future-statement assessment and characterization indicated that approximately half of the future statements were mentioned by only one source organization in the initial future statements refactoring.

Table 5 organizes a second decomposition and refactors it into hierarchical topic groups.

Table 5: Numbers of future statements by topic category, source, and architectural type.

	Number of Future Statements																
	Source											Architect					
Decomposed/ Second-Refactor Topic Categories ↓	CSIRO	DSPx	EPRI IEN	GWA	IEEE USA	IESO NWA-Markets	IESO TD-IOP Frmwrk	NIST IOP Frmwrk rel4	PEI	UTC	Item Total	Architecture-Business Model	Architecture Service Functions and Requirements	Architectural Strategy	Architectural Trend/ Driver	Energy Trend/ Driver	Item Total
Comm Network										10	10	3	2		5		10
Customer	4	1	1	3					2		11	1	5	1	4		11
Energy	3		2		3						8			4	2	2	8
Environmental			2		1						3			1		2	3
Grid		3	3	5		1		18		1	31	4	16	5	6		31
Grid Assets/Tech			1	8		2	3	2	1	1	18	1	8	4	5		18
Grid Coordn.				6		7	21				34	27	5	1	1		34
Value - Benefit - Optimize		1	4	6		2	2	7			22	1	9	7	2	3	22
Total	7	5	13	28	4	12	26	27	3	12	137	37	45	23	25	7	137

The second decomposition and refactoring future statements prose resulted in 137 hierarchically grouped discrete future statements with eight major topic categories and 35 subcategories, and 56 sub-subcategories. Table D-1 tallies the refactored future statements for level 1 and level 2 topic categories in more detail. Fewer of those future statements are sourced by only one organization than in the initial decomposition and refactoring, especially at the second level of the second refactoring hierarchy. Most future statements address different aspects of a future state's more significant concepts rather than being materially different from the other clustered or single-sourced future statements.

The exceptions are reports that propose a spectrum of solutions for coordinating markets, transmission system operators (TSOs), and distribution system operators (DSOs). Having jurisdictions experiment with differing coordination schemes and grid modernization strategies would help stakeholders determine which coordination, regulatory, and utility stakeholder business models would work best for specific local, state, and/or regional electric power grid needs. Abstracted coordination models must be vetted via field trials and/or pilots to help improve the models and provide guidance to stakeholders, integrators, and solution providers to satisfy the intended goals and objectives while still meeting associated requirements of grid physics.

Figure 3 charts an assessment of when the visions and future statements were documented in the source reports and the anticipated time frame for their realization. The goal of this assessment was to observe whether artifacts of the sampled industry vision and future statements progressed linearly or morphed between a report's creation, release, and realization of stated time horizons. The two efforts to decompose and refactor future statements identified no direct shifts in vision beyond the perception that the sampling of reports' future statements supplied information from varying stakeholder perspectives. The validity of what the future states and/or statements indicate for specific periods will be strongly influenced by all stakeholders' and or member companies' capabilities to

- respond to the calls for action, and
- address challenges in transition steps to reach the vision and future states as regulated by the jurisdictions where the stakeholder will participate.

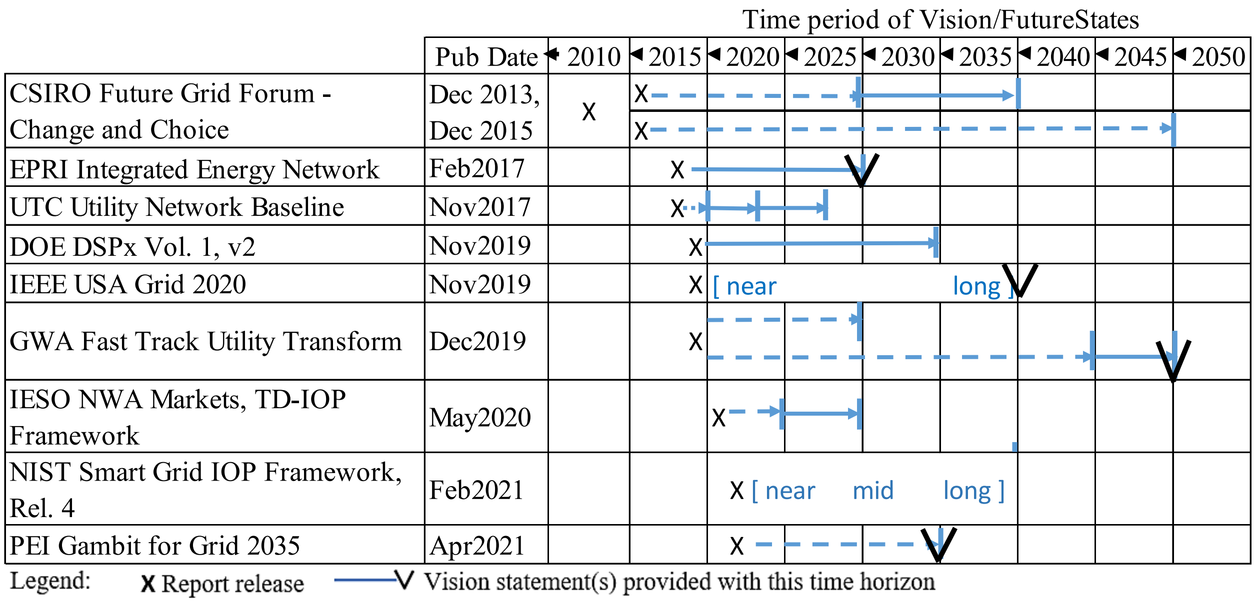

Figure 3: Time periods associated with visions and future states.

The question, “Is there one common electric industry vision and future state?” has a qualified response.

The answer is “Yes,” if the vision and future state are viewed at a high enough generalization of “decarbonize, democratize, and decentralize” the electric power grid along with the envisioned qualities, e.g., affordability, flexibility, sustainability, resilience, scalability, and security.

The answer is “No,” when considering how-to-deliver details on the vision and future-state statements including regulatory-business coordination processes, need for more regional grid connectivity and transmission line additions, utility scale renewal generation, and pesky laws of physics. This response is especially for new markets, including TSO–DSO, aggregator, customer, and utility coordination needs for specific nations, states, local jurisdictions.

Jurisdictional variability in the implementation and timing of moderate-to-high DER penetration levels will significantly affect the solution ecosystem when key functionality is needed. The speed to deploy and transition to the vision and future state is throttled by gaps in business capability across all stakeholder groups, the immaturity of the solution ecosystems to resolve the gaps, and implementation approaches to resolve the gaps reliably and economically. Building grid architectures, business, and technology solutions that have agreed-to minimum core functionality that is extendable via modular blocks of solution-specific functionality is a way to address the variability of the methods by jurisdiction, by time epoch driven by the level of DER penetration, or by regulatory requirement.

3.0 GWAC Insights

3.1 Challenges and Barriers to Visions and Future States

Achieving the desired future state will involve overcoming several challenges and barriers across the electric power industry stakeholders, which are listed in Table 6. From a consumer's perspective, the desired future state must be achieved without significantly increasing costs in the interim. Furthermore, the future state should ultimately reduce consumer costs as technology, increased competition, resource flexibility, and related efficiencies take effect.

Table 6: Electric Power Grid Ecosystem Stakeholder Categories

- Customers
- Manufacturers-developers (electricity grid, facility, system, telecom, security)
- Solution providers
- Jurisdictions (nation, Federal Energy Regulatory Commission, North American Electric Reliability Corporation, state, local)
- Operators (ISO-RTO[3], TSO, DSO)
- Service providers (utilities, aggregators, facility managers)

Regulatory oversight of changing markets and market designs will be critical to cost containment, effective performance, and resilience. Regulators may need to adopt policies encouraging distributed energy, including investments to provide new services. It will be challenging for regulators to adequately protect load serving entity and DSO business models without negatively affecting consumers in the absence of a firm understanding and commitment to a clear vision. Regulators and markets may need to transition away from centralized control to provide the responses and flexibility required to facilitate the necessary changes promptly. However, some stakeholders will argue for and implement even more-centralized control and market structures. Such diverse regulatory and market regimes will create barriers, especially for stakeholders participating in multiple markets. However, such diversity should help identify which regulatory and market designs best promote both the future state and the interests of consumers and other stakeholders.

Both the scope and pace of change will make improving and even maintaining system reliability a challenge. This challenge is compounded by increasing consumer expectations and demands. Satisfying the changing needs of customers and other stakeholders will drive more spending on equipment, operational systems, and cybersecurity. Demands on system operators will increase when customers have more control and more choices. Additionally, there is need for coordination and communication among system operators and market participants. There will be more market participants as some customers become producers who can better control their consumption.

Further incentivizing and enabling behind-the-meter storage will help shave demand peaks and allow customers to store and use power at the lowest available cost. Customers, or their grid-interactive devices, will not only find their roles changing but also become more aware of their options, system performance, needs, and costs, creating additional demands on regulators and other market participants. Coordination of and among markets will become more complicated if the DSO's roles do not similarly change. Roles and responsibilities will be redefined to satisfy the interaction of technology, policy, and economic influences as they grow more complex at the outset of a grid architecture transition; however, with software automation and digitalization of market functions, this complexity decreases and is normalized over time. Blending DSO and ISO models facilitates the growth in distributed resources and customer controls. Nevertheless, such complexity will also enable the desired change, and as such barriers are overcome, consumers should increasingly benefit from greener, cheaper, and more reliable energy—but only if regulators embrace a grid architecture that reduces total system costs. This approach may mean higher

[3] ISO-RTO is an independent system operator-regional transmission operator

per-unit energy costs but it will enable a higher degree of demand flexibility, customer autonomy, and greater roles for behind-the-meter assets in a supply-side resource portfolio.

Utilities, especially investor-owned utilities, face a variety of challenges in modernizing grids, systems, and processes to support the transition, including the following changes:

- from low to moderate and then to high DER penetration
- from regulated to deregulated models for their service territories
- from an integrated utility model to a style of new markets and a potentially wide range of coordination among operating models for entirely TSO, hybrid-TSO/DSO, and primarily DSO service providers
- from the current understanding of utility roles and responsibilities to new options for maintaining and operating grids (primarily the distribution grids) to satisfy the grids' roles across a utility's jurisdictions
- from incongruent retail and wholesale prices to new markets and flexible customer-service price structures that are consonant with each other
- from vulnerable business models that depend on customers being passive consumers of energy to active customer participation in the grid and customers' expectation of flexible services available from utilities
- from regulatory constructs that incentivize capitalization of infrastructure as a stopgap action to meet revenue requirements to newer utility revenue options, e.g., performance-formula based rates and flexible, innovative service offerings
- facing realities that modernizing antiquated grid architecture may require capital that cannot reasonably be captured through customer charges.

A utility's business models, roles, and responsibilities in the future electricity industry will change, but their forms across their jurisdictions and at specific levels of DER penetration and coordination frameworks have not been determined.

3.2 Architectural Challenges/Gaps

While assessing and characterizing the vision and future-state reports, the GWAC identified six major architectural challenges or gap areas:

- **Developing new industry structures** – Industry structure refers broadly to the relationships between the elements of electric power systems, both cyber-physical and organizational. New industry structures are needed to support, e.g., highly decarbonized energy systems, including new market structures (for example, markets in distribution systems), system operations (for example, the models being considered for the DSO), and transmission and distribution interactions.
- **Transitioning from centralized to distributed** – A key feature of future grid systems with large quantities of DER in distribution systems (both before and behind the meter) is a transition from centralized to distributed systems. This transition involves a fundamental architectural change, from large capacity generating plants, or wind/solar farms to dispersed smaller capacity generating resources, grid control, and/or operation (from centralized to decentralized at the grid edge), as well as grid optimization across the regional, state, local, distribution substation, and customer-facility levels.

- **Transitioning from silos to platforms** – Historically, many systems used by utilities have been single-purpose systems with an associated set of sensing, measurement, and sometimes communications dedicated to the purpose and function of each system individually. These are “siloed” systems. Siloed systems inherently limit the ability to access data for other purposes because they lack interfaces or because the interfaces are proprietary and integration costs become prohibitive. To help transition siloed systems, more modern platform architectures are being deployed. For example, most commercial advanced distribution management system products now incorporate a platform architecture. Current practices typically still have proprietary interfaces and data models. Still, the move to platform architectures is a move to integrate more cost-effectively, support growth in sources and quantities of data, and accommodate new technologies.
- **Developing effective data communications that enable control and coordination in distributed structures** – New communications structures and capabilities will be needed to support the transition from centralized to distributed delivery.
- **Standardizing interfaces and structures** – With growing system complexity, expanding deployment of DERs in distribution systems, new load growth such as electric vehicle charging, and increasing distribution automation, new and renovated systems will require electrical and informational integration. To cost-effectively achieve the needed integration for significant decarbonization, standardization of interfaces and structures will be needed to move the industry to plug-and-play integration wherever possible.
- **Accommodating large quantities of DER with new structures** – New grid architecture structural concepts that support control and coordination of large quantities of DERs will be needed for the optimal operation of highly decarbonized electric power systems.

Architectural challenges and gaps that were identified in the assessed vision and futures reports are categorized into topic areas in Table 7.

Table 7: Specific architectural challenge/gap areas found in source reports.

Source ↓ Gap→	Industry Structure	Centralized to Distributed	Silos to Platforms	Effective Data Comm. (Sprinting) Control/Coord. of Distribution Structures	Standardization of Interfaces and Structure	Structures Accommodating Large Qty of DER
CSIRO Future Grid Forum - Change and Choice	×	×	×	×	×	×
DOE DSPx Vol. 1-v2	×		×			
EPRI Integrated Energy						×
GridWise Alliance Grid Mod. Index		×		×		
IEEE USA Grid 2020						
IESO NWA Markets						×
IESO TD-IOP Framework		×	×		×	×
NIST SG IOP Framework r4	×			×	×	×
PEI A Gambit Grid 2035	×					×
UTC Utility Network Baseline				×		

3.2.1 Summary of Identified Architectural Gaps

Depending on when the source material was prepared, the architectural gaps generally arose from the increasing deployment of DER in distribution systems. As a result, the identified architectural gaps are well aligned with elements of the U.S. Department of Energy's Grid Modernization Laboratory Consortium's (GMLC's) Grid Architecture core project (GMLC 2018). That project documented emerging trends and systemic issues that provide a consistent backdrop for these architectural gaps. The five reference architectures developed by the GMLC project include a statement of system qualities and properties directly related to these architectural gaps.

The architectural gaps are related and are ordered from left to right, from broad to more specific. For example, the gaps between "Industry Structure" and "Centralized to Distributed" are comprehensive. The gap on the far right that summarizes the recognition of new structures to accommodate the deployment of large quantities of DER is more focused on distribution systems. Examples of such structures are included in the GMLC Grid Architecture Project's reference architectures (GMLC 2022) for High Resilience and High DER/Distribution Automation/Storage.

One of the challenges in addressing the gaps is avoiding stranded assets. Distribution system transformation to accommodate decarbonization through the increasing deployment of distribution-level DER is incredibly challenging. The development of new architectures must consider how to evolve from today's grid to the future grid that supports the current assets while minimizing the number of stranded assets as the system progresses from legacy systems to intermediate steps to the envisioned future state. Supporting architecture that is applicable to different regional jurisdictional requirements requires architecture flexibility. Examples of approaches to this include standardization using existing or new standards, developing common core functional elements, and modular architectures.

3.3 Effects on the Electric Power Industry and Grid Drivers and Emerging Trends

GWAC assessed GMLC 1.2.1 project report draft, *Emerging Trends and Systemic Issues Influencing Today's U.S. Electric Grid - Context for Grid Architecture Development* (Xue et al. 2022). A few of the key trends include

- Reliability of aged equipment is declining.
- Decentralization and flexible resource deployments require network design changes.
- Resilience is as essential as reliability.
- Security at the physical and cyber layers is foundational.
- Scalability is required to accommodate changes in customer needs.

Figure 4 illustrates the decentralization trend and identifies some of the considerations for grid architecture.

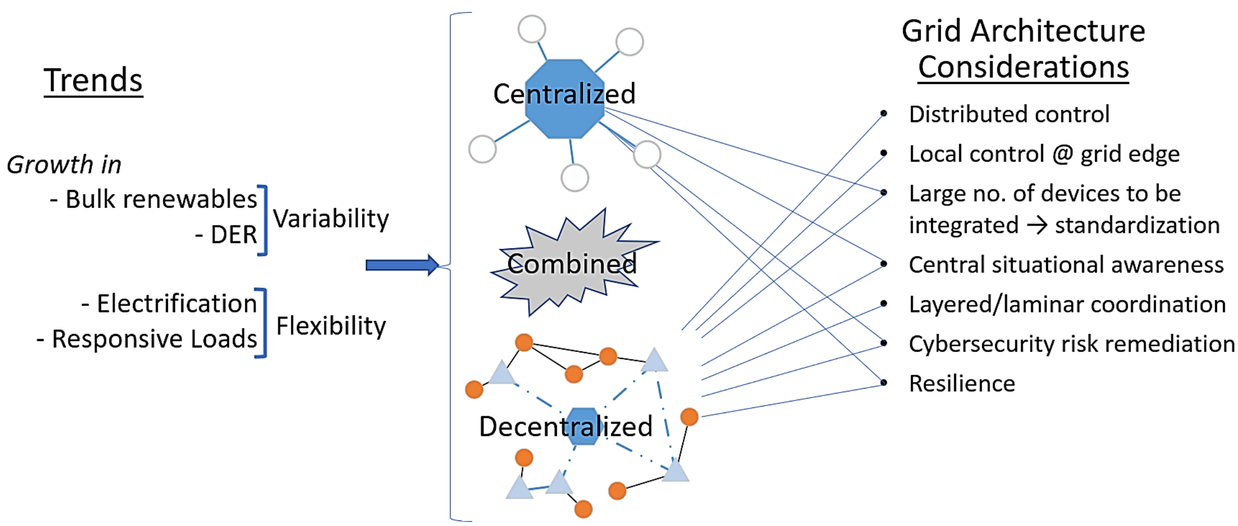

Figure 4: Trends Driving Architectural Considerations for Grid Centralization or Decentralization[4]

The National Academies of Sciences, Engineering, and Medicine, in a 2021 assessment report (NASEM 2021) looked to the future but chose not to predict what the future will look like; however, they

[4] Cunningham R. 2020. "Electric Industry Visions and FutureStates & Trends: GWAC Project Development and Grid Ops Trends," slide 9. IEEE Power and Energy Society Transactive Energy Systems Conference (TESC 2020), GWAC Foundations Session, "Grid: Visions of the Future," December 8, 2020.

documented several driving forces that likely will alter the U.S. power system landscape in coming decades. Six of the drivers identified are listed below:

- Possible large growth in future demand for electricity
- Efforts to decarbonize the U.S. economy and eliminate the emission of conventional pollutants. These may be accomplished both by transitioning power generation to low- or zero-emission sources and by making much greater use of decarbonized electricity as a substitute for fossil fuels in transportation, buildings, and industry
- Developments at the edge of the grid, such as distributed generation, storage, microgrids, energy-management resources, and energy-efficiency measures
- Grid stability challenges arising because of high penetrations of non-dispatchable sources of generation, such as wind and solar
- A desire to reduce social inequities
- Concerns about the effects of the energy transition on employment.

Other gathered drivers and trends include

- A changing international environment, including powerful market forces arising from globalization, shifts in the locus of electricity-relevant innovation, and growing concerns about state-sponsored competition and disruption
- A broad movement to the grid edge (SCE 2020)
  - growth rate of customer demand and renewable generation
  - utility infrastructure challenges
  - energy savings and demand flexibility
- Global supply chain issues – automotive industry, computer chip shortage, utility industry (e.g., transformers, battery storage, solar panels).

Figure 5 illustrates several areas within a typical supply chain where disruptions can have downstream effects, including

- constrained, disabled, or collapsed capability to deliver assets and services from one entity (node/circle in Figure 5) to another entity
- constraint, disablement, or collapse of an entity's capability to produce and/or consume an asset or service.

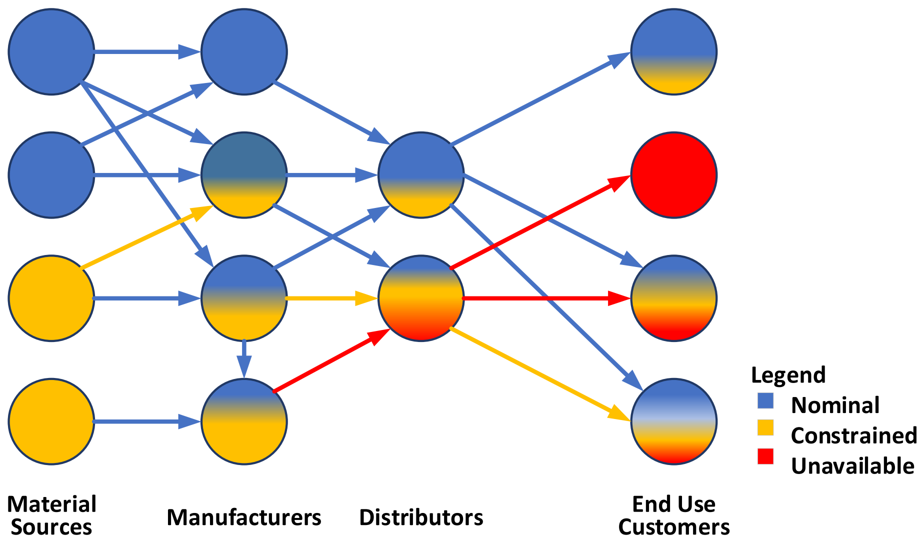

Figure 5: Supply chain interruptions. (Adapted from Anuat et al. 2022)

Typical best practices for avoiding problems from supply chain interruptions include using multiple sources of materials and delivery service providers, maintaining access to a ready source of key asset inventory, and researching alternative solutions for designs and key scarce material resources. Some architectural techniques to reduce the vulnerability of any supply chain are available:

- modularizing systems with standardized interfaces
- use of system-subsystem, hardware, software interoperability standards and profiles.

3.4 Relevance of the GWAC Interoperability Framework to Grid Architecture

The widely referenced GWAC Interoperability Framework (informally, the GWAC Stack) (GWAC 2008) continues to be an essential tool for designing and validating grid architecture. The GWAC Stack (shown in Figure 6) embodies the following four fundamental tenets of system-integration philosophy:

1. Agreement at the interface – a contract

In any business engagement, the associated parties establish and capture the ground rules in a contract or an agreement. Sometimes these rules are assumed (such as communicating using the English language), sometimes they are referenced (e.g., consistent with the commercial code of the State of Louisiana), and most of the time, the particulars are documented in a signed contract. Each party exchanges goods and services as an independent entity. The terms and conditions describe how goods and services flow between parties, the price, the scope, the schedule, and the quality of the deliverable. They also describe the consequences of failure to perform. They rarely state how the good or service is created or obtained.

Similarly, it can be presumed that agreements between automation components concentrate at the boundaries where each pair of components meets—their interface. By establishing an interface agreement, each automation component preserves its integrity. It can change internally and react to various pressures independent of other automation components if it meets its interface agreements.

2. **Boundary of authority**

   Though agreements can specify how automation goods and services are developed, competition and innovation are enhanced when the transacting parties concentrate on measurable aspects of the commodity exchanged, such as its scope, delivery schedule, quality, and price. In addition, respecting boundaries clarifies the system-integration activity and reduces the contract-management effort.

   The boundary of authority includes addressing rights of privacy and disclosure. Interface expectations must be met, or the consequences are suffered, e.g., stipulating audit trails or other internal controls for review, judgment, and immediate versus delayed settlement.

3. **Decision-making in very large networks**

   Forming hierarchies is the most common approach to "scale up" as organizations grow. Each branch performs its function, contributing to its higher-level branch's objectives until the entire organization's objectives are addressed at the top of the hierarchy. For example, hierarchical approaches can organize efforts by function, allowing for higher-level aggregations of functions into superfunctions. They can also organize activity by location and aggregate locations into higher-level regions. Decision-making in such an organization usually flows down through the structure, resulting in a chain-of-command style delegation of authority. Such organizations can be very effective in systems where objectives are clear and stable and where consistency can be controlled. These systems are internally homogeneous, and even communication across hierarchy branches can be standardized.

   The analogy in the design of systems of many interacting automated components is the distributed, multiple-agent environment. In these networked systems, software agents personify the intelligent decision-making aspects of an automation component. They act in response to the information at their disposal, with the resources under their control. They have a clear boundary of authority, and they honor contracts of behavior with the other agents with whom they collaborate.

   More importantly for interoperability, the characteristics of distributed (decentralized) decision-making in a multi-agent approach eases scalability issues and simplifies the automation component integration and upgrade process. These automation components, which are preferred to be self-contained, can be more easily connected with other automation components in the system and help mechanize the work of configuring and adapting themselves for a continually changing environment.

4. **The role of standards**

   The GWAC Interoperability Framework intends to assist communication and coordination across multiple electricity-related industry sectors. Because of this, it is agnostic concerning specific standards that apply at the architecture (model), design, and solution levels. Nevertheless, standards are essential to improve interoperability because they specify an agreement between interacting parties.

   For a standard specification to be effective, it must be available to its potential users. Proprietary standards may be available only to a community that purchases a specific product. Open standards are desirable because they are available to anyone who wants to use them. Beyond availability, openness implies that there is adequate information to support equal opportunities to produce compliant automation components from independent suppliers.

Open standards can encourage a competitive, multiple-supplier environment. Allowing multiple solution suppliers to compete encourages innovation in features and performance. It also reduces the likelihood that a system or subsystem will be stranded if a supplier stops supporting an automation component.

However, using a standard, even an open standard, is not a panacea. As technology changes over time, standards go through life-cycle phases in commercial adoption and technical maturity. Today's up-and-coming standard is tomorrow's legacy specification. Also, there is no shortage of standards as one looks across the complicated landscape of interface specifications in electric power, manufacturing, building automation, and information technology in general. The framework encourages the development and use of standards to enhance product interoperability capability offerings, but it avoids mandating or endorsing any standard. Hopefully, the context provided by the framework can help identify integration pressure points where standards from different organizations can come together to resolve issues.

These system-integration philosophy tenets are best framed by considering interacting automation components that different organizations manage. In such situations, the transacting parties clearly and formally establish the lines of authority and rules of engagement. They maintain their autonomy while collaborating to share their resources in a federated manner.

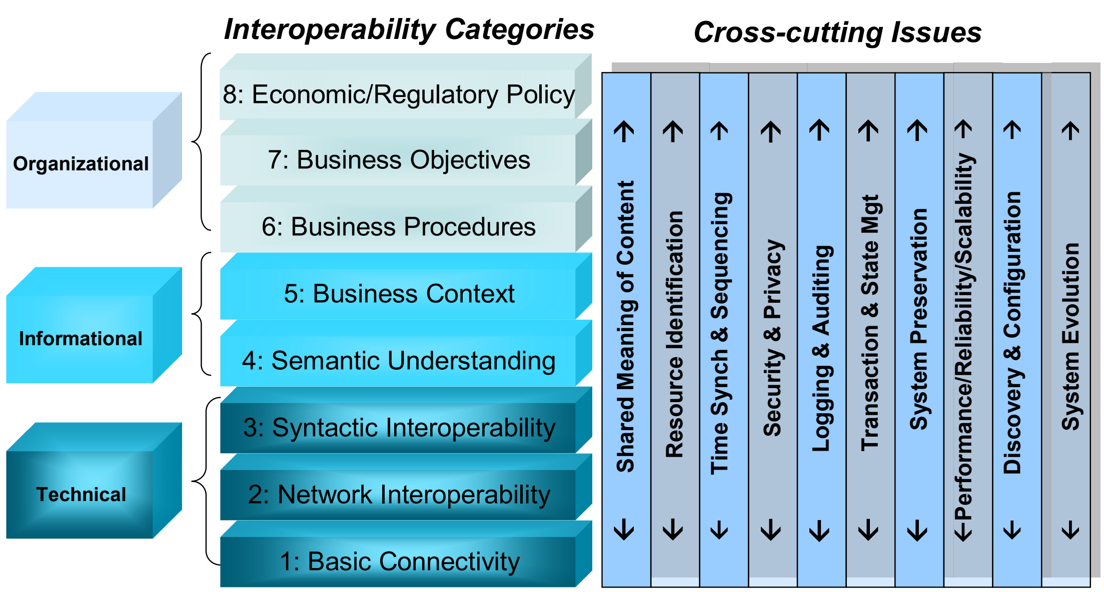

Figure 6. GWAC interoperability framework and crosscutting Issues—the "GWAC Stack." (GWAC 2008)

The interoperability categories or layers are described below. These categories are further grouped into three categories, as shown on the left in the figure. Finally, several crosscutting design issues are called out:

1. Economic/Regulatory Policy – political and economic objectives as embodied in policy and regulation
2. Business Objectives – strategic and tactical objectives shared between businesses
3. Business Procedures – alignment between operational business processes and procedures

4. Business Context – awareness of the business knowledge related to a specific interaction
5. Semantic Understanding – understanding of the concepts contained in the message data structures
6. Syntactic Interoperability – understanding of data structures in messages exchanged between systems
7. Network Interoperability – mechanism to exchange messages between multiple systems across a variety of networks
8. Basic Connectivity – mechanism to establish physical and logical connections between systems.

3.4.1 Putting the GWAC Stack into the Context of Grid Architecture

The System of Systems paradigm is primarily component-focused and extends the software engineering concepts of module strength and module coupling to whole information technology systems. While useful as a paradigm for design and implementation, it does not capture essential multi-structural properties needed for grid architecture work. A more helpful paradigm is to represent the grid as an ultra-large-scale network of structures, subject to hidden and overt interactions and cross-couplings, complex constraints, dependencies, and convergences, as depicted in the following figures.

Figure 7 introduces a complete set of grid architecture structures. These include everything from the physical grid through the regulatory ecosystem.

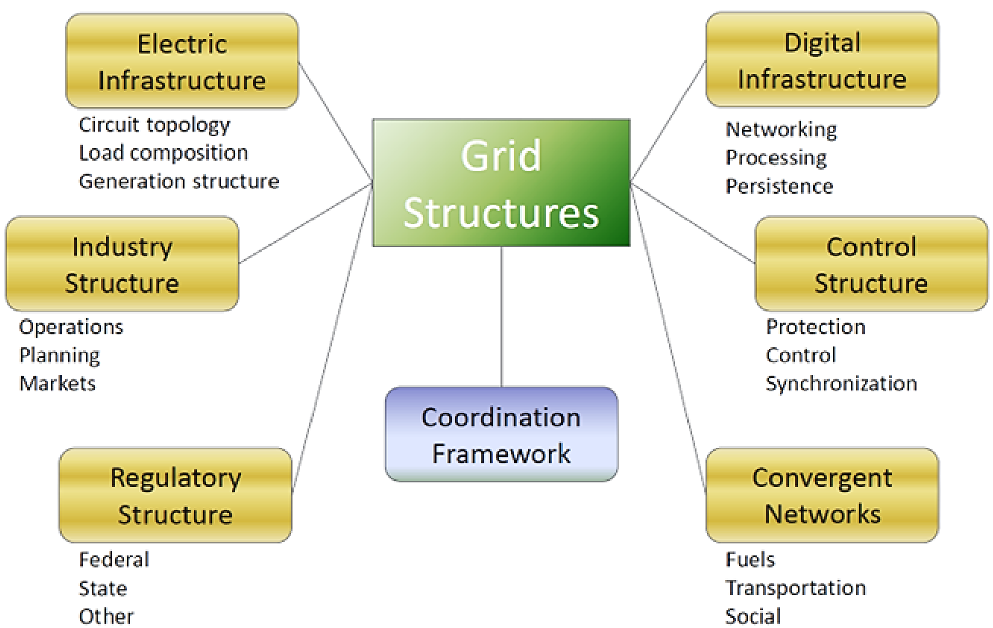

Figure 7: Grid Architecture Network of Structures (Taft 2015).

Figure 8 then puts those structures into a layered relationship diagram to help convey the dependences and complex relationships of the network of structures.

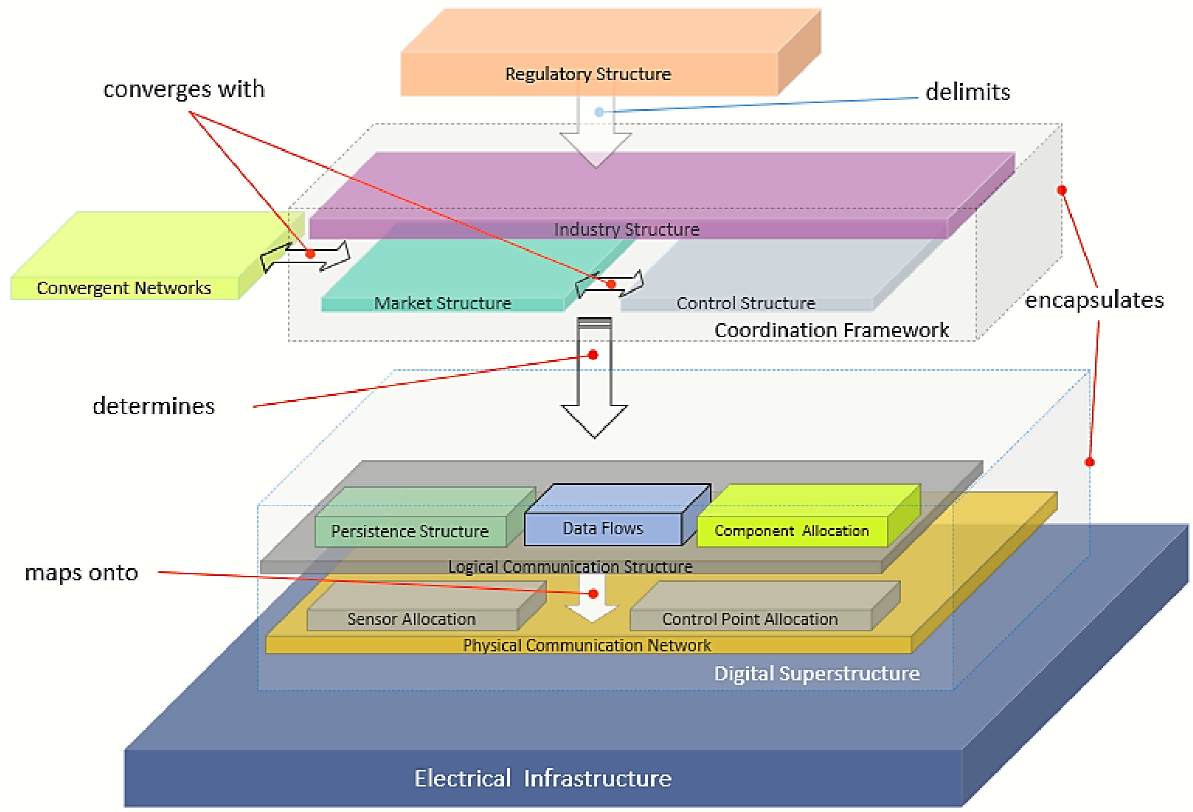

Figure 8: Structure-class relationships.

Comparing this layered structure diagram to the GWAC Stack, it is relatively easy to see the corresponding layers. For example, the Regulatory Structure at the top of Figure 8 maps directly to the economic/regulatory policy layer of the GWAC Stack in Figure 6.

Similarly, the structures from the Physical Communication Network up to the Logical Communication Structure in Figure 8 map into the Basic Connectivity and Network Interoperability layers from the technical category of the GWAC Stack.

3.4.2 The GWAC Interoperability Stack Continues to Be an Important Tool

Beyond retaining its relevance in the technical and information interoperability categories and increasing attention on the organizational category, the GWAC Stack can be leveraged for grid architecture by providing the following:

- a framework for assuring that all relevant sources of requirements are fully considered, and
- a consistent approach to grid architecture design validation when coupled with the NIST Conceptual Model (NIST 2018).

3.4.3 Analyzing System Qualities

Analyzing system qualities is an example of applying the GWAC Stack in practice. As represented in Figure 9, one can use the layers of the GWAC Stack from Basic Connectivity up through Policy (or some relevant sub-range of layers, depending on the system qualities being considered) to make sure that requirements are considered from all contexts. In particular, this can help avoid the pitfall of focusing only on the requirements of the technical and informational layers when designing and validating a grid architecture.

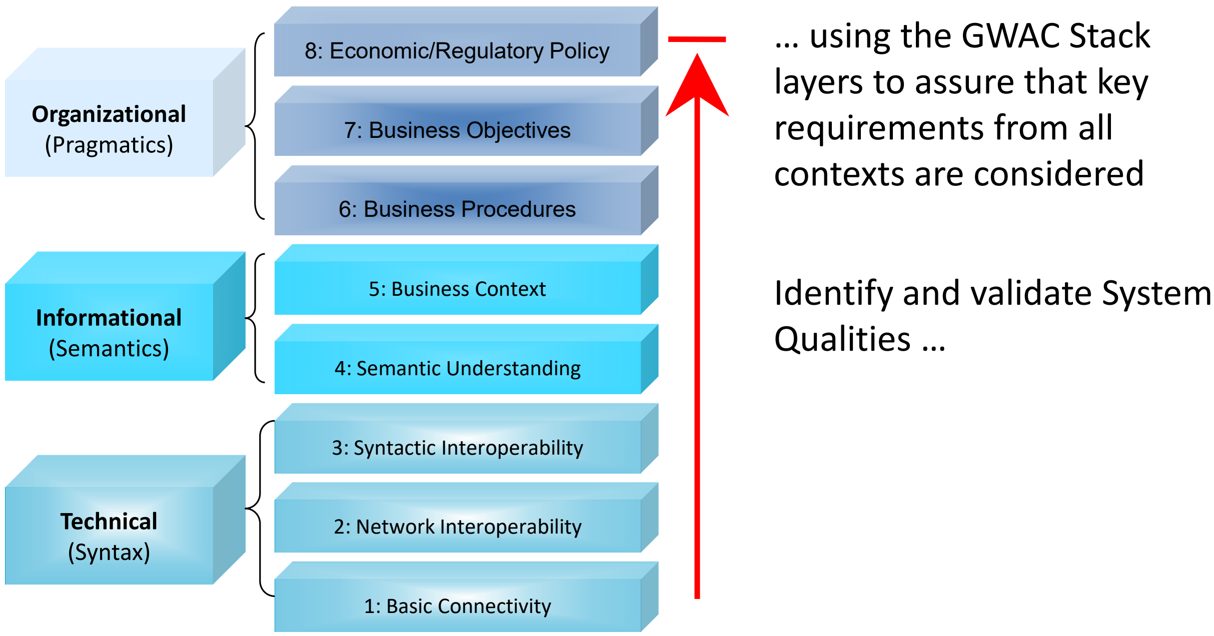

Figure 9: Applying the GWAC stack in practice.

3.4.4 The NIST Conceptual Model

The NIST Conceptual Model (NIST 2018) complements the GWAC Stack in practical use by providing a high-level stakeholder model of a modern grid. The stakeholder domains in the NIST Conceptual Model can each be decomposed into the layers of the GWAC Stack since they capture orthogonal views of the overall system. The following four figures (courtesy of NIST) provide a brief review of how the NIST model is structured, using the Customer Domain as an example.

Figure 10 shows the top-level stakeholder domains and captures the evolution of the generation domain into a domain that includes bulk generation, system-resident distributed generation and customer-premises distributed generation.

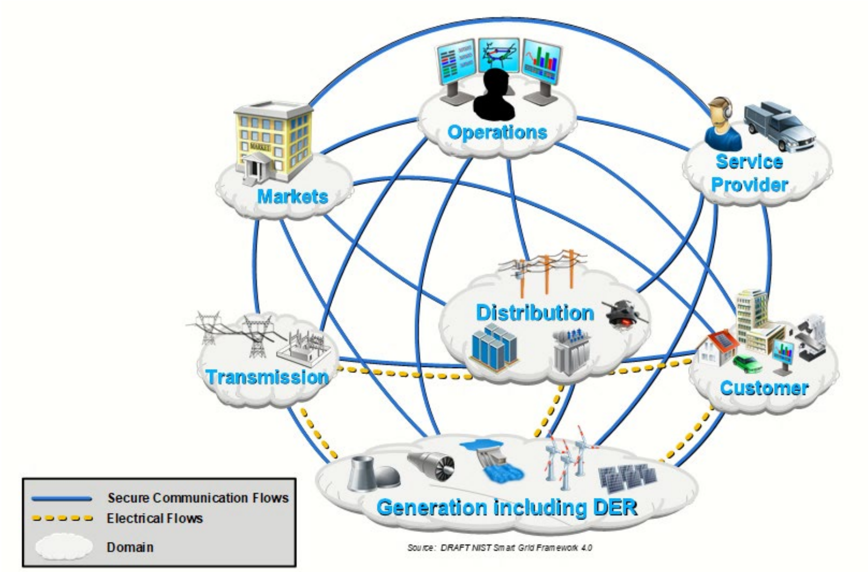

Figure 10: Updated NIST Smart Grid Conceptual Model. (NIST 2021)

Figure 11 and Figure 12 show how each top-level domain comprises complex collections of domain physical infrastructure and functions or services.

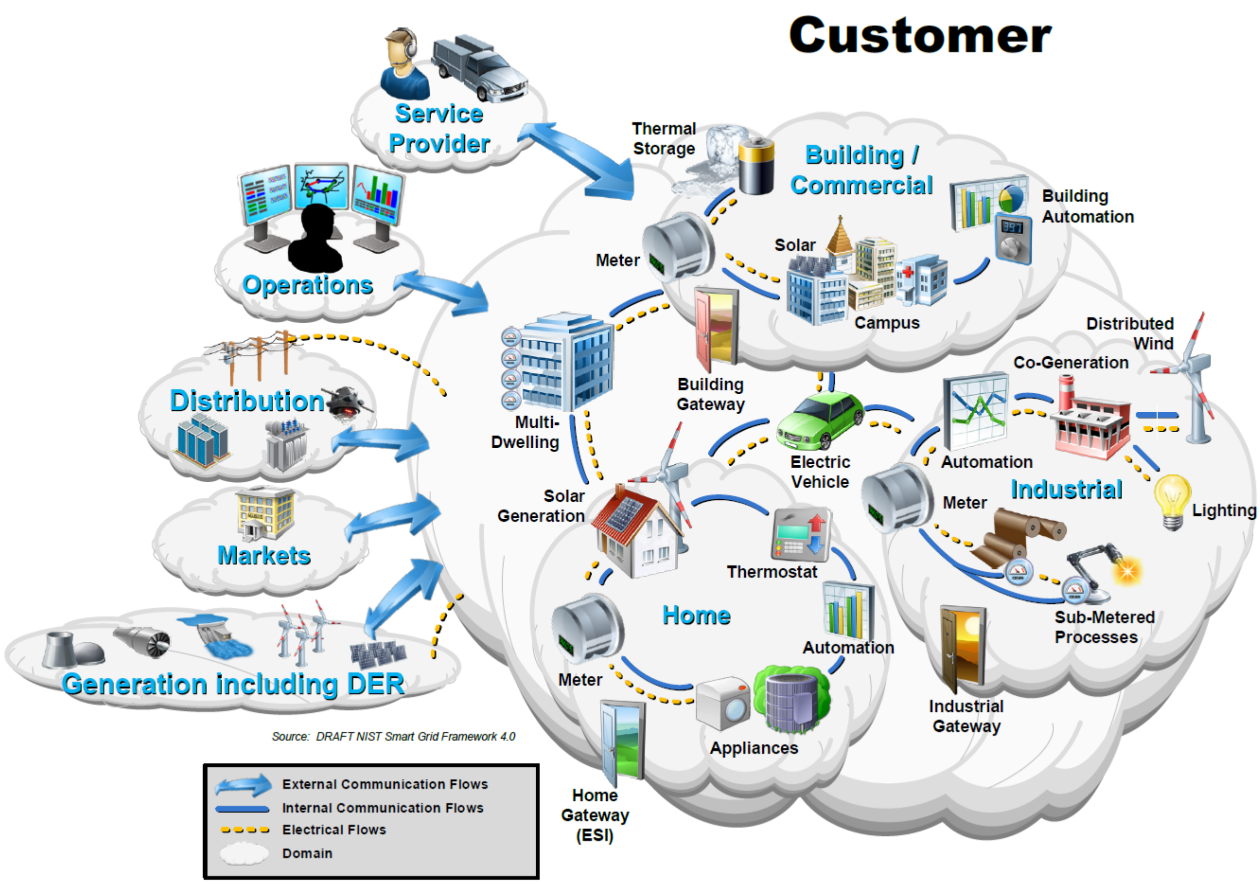

Figure 11: Overview of the customer domain. (NIST 2021)

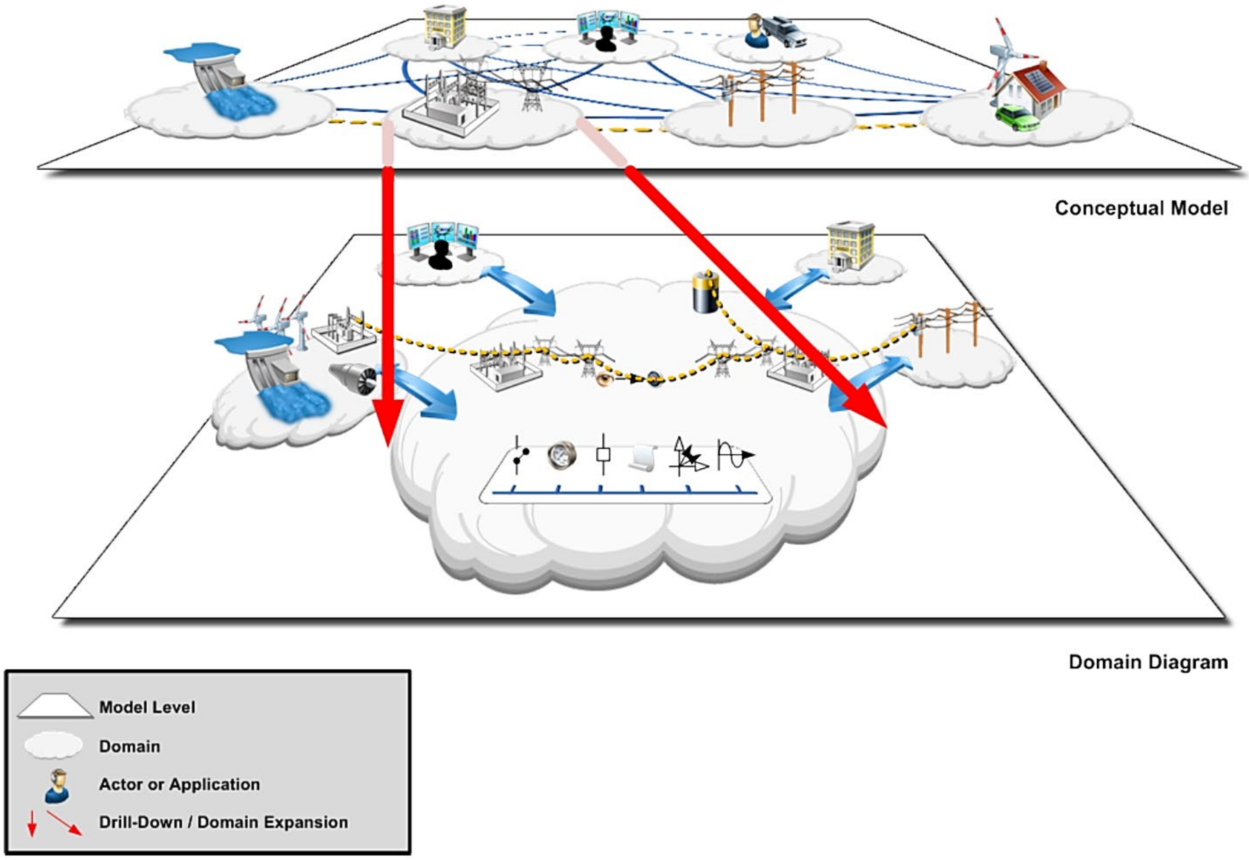

Figure 12: Levels of the conceptual model (adapted from NIST 2021)

Finally, Figure 13 shows how one can overlay a specific use case on one or more domains to determine how to assemble architectural elements of the system into an implementation of that use case.

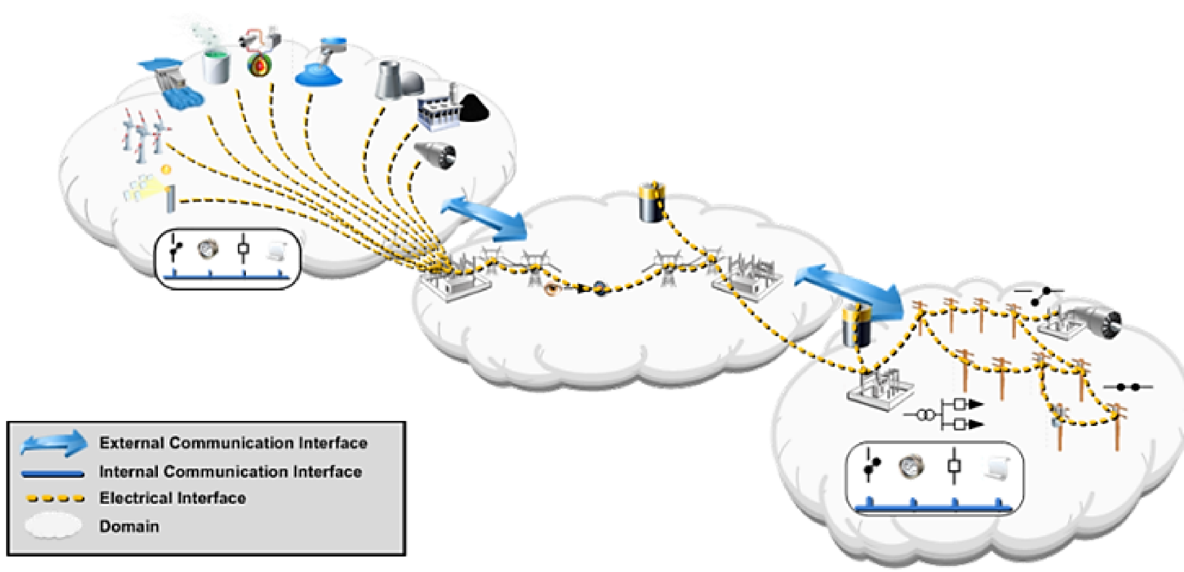

Figure 13: Use cases: Paths through the model.

4.0 Recommended Next Steps

The following are critical steps in carrying this work forward for the electric power industry:

- Create a work plan that
  - addresses the architectural gaps summarized in Section 3.2.1 and identifies collaboration and coordination opportunities across electric power industry stakeholder organizations to maximize the effective use of capabilities and resources of stakeholder organizations,
  - updates the stakeholder organizations' assessments when the vision and future-state reports are revised,
  - includes coordination and or collaboration with e.g., Smart Energy Power Alliance, National Association of Regulatory Utility Commissioners, Edison Electric Institute, state energy offices, other regulatory bodies, and standards development organizations.
- Create a separate paper that describes this paper's framework and techniques for
  - selection of additional stakeholder vision and future-state reports to add to this paper's sample-set of assessed reports
  - use of framework worksheets, assessment and characterization criteria, and future-statement decomposition and refactoring techniques.
- Develop a set of future-backward and present-forward roadmaps as qualified by present state and vision–future-statement mappings that reflect different starting points and a flexible range of the jurisdictional vision–future-state expectations,
- Create an addendum to this paper to include characterizations of other electric power industry stakeholder organization vision–future-state reports.
- Document or develop a case study of a jurisdiction successfully implementing a shared-systems architecture transition.
- Create a regulators' checklist for transition readiness.

5.0 Terms and Definitions

A knowledge graph visualizes the relationships among important terms used in this paper. Figure 14 is a knowledge graph that represents the vision-future state, enterprise and grid architecture terms used throughout this paper. The terms are the rounded rectangles (nodes), and relationships are the directed connectors (edges) between node pairs. This diagram can be read from any point of view by selecting any term and following its relationships with another term in a simple statement of fact. As an example, "Trend" influences the ideation of "Vision" (subject-predicate-object). The visual grouping (boundary outlines) of sets of terms indicates terms are members of a knowledge domain (area of study), where some terms have relationships across those areas of study.

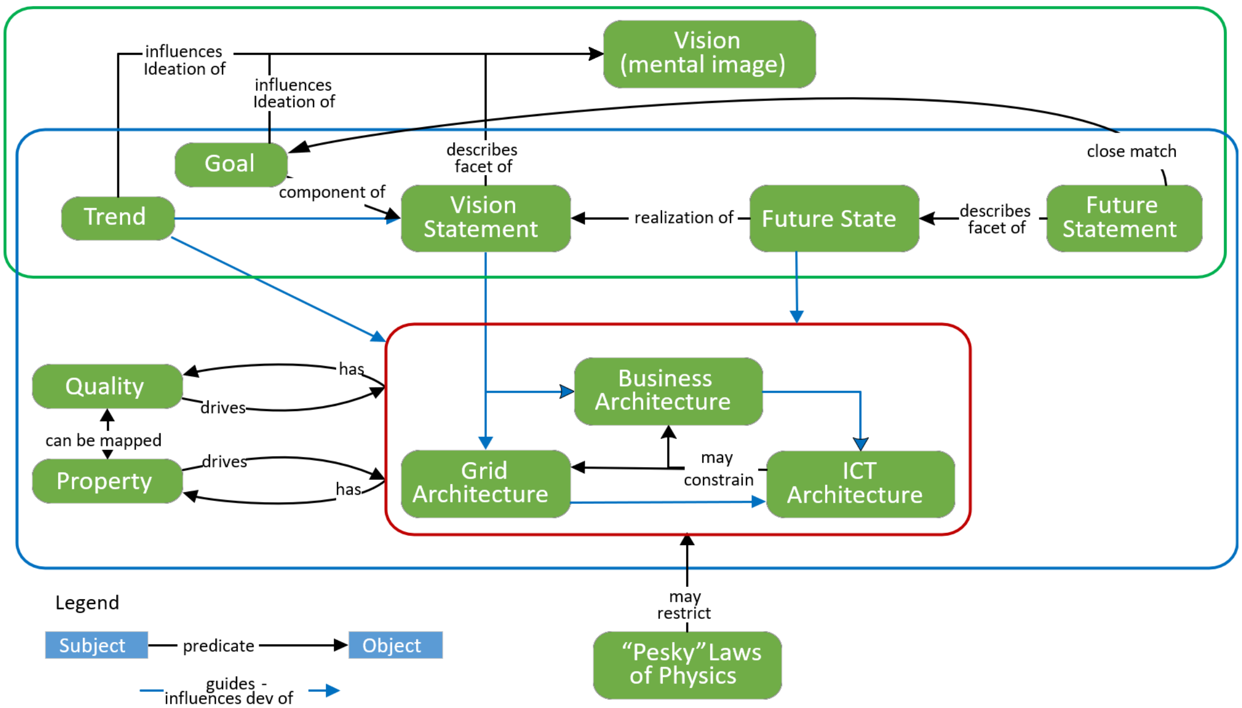

Figure 14: How terms are related. [5]ICT is information and communication technology.

Terms used in Figure 14 are defined below.

Architecture – A formal description of a system or a detailed plan of the system at the component level to guide its implementation

Future State – Description of a realization of the vision via a collective "*set of conditions [future statements] necessary to meet the business needs. . . to successfully implement the solution the future state has to be well defined, achievable with the available resources and acceptable to all the stakeholders.*" (Functional BA n.d.) Each condition/future statement is for a particular facet of the vision statement, and when all conditions have been satisfied, that vision can considered realized.

Future Statement – business description/conditions of a specific facet of a vision statement.

[5] Cunningham R. 2020. *Electric Industry Visions and FutureStates & Trends: GWAC Project Development and Grid Ops Trends*, slide 3. IEEE Power and Energy Society Transactive Energy Systems Conference (TESC 2020), GWAC Foundations Session, "Grid: Visions of the Future," December 8, 2020.

Goal:

- "an idea of the future or desired result that a person or a group of people envision, plan and commit to achieve." (Locke and Latham 1990)
- "an endpoint, accomplishment or target an organization wants to achieve in the short term or long term. Business goals can take many different forms and be aspirational or motivational, such as driving an organization toward a certain objective like improved customer service. They can also have very specific objectives, such as reaching a particular revenue target, net income, profit margin, profit goal or other financial milestone." (Kerner 2022)
- "Goal" has similarity with "Future Statement," especially Specific, Measurable, Achievable, Relevant, Time-Bound **(S.M.A.R.T.) goals** (Doran et al. 1981). The nuanced difference is that future statements generally do not include a time-bound qualifier. They are conditions that, if met, satisfy that facet of a future state.

Relation:

- "is a connection between two things" or " simply notes the existence of a connection" Grammarhow.com https://grammarhow.com/relation-vs-relationship/
- **From Engram https://www.engram.us/vs/12/relation-vs-relationship:**
  - **refers to a connection or association between two or more things or people.**
  - can be used in different contexts such as math, physics, chemistry, and social sciences.
  - can be positive or negative, direct or indirect, and can be measured based on different criteria.

Relationship:

- **"describes how or why two things are connected"** Grammarhow.com https://grammarhow.com/relation-vs-relationship/
- **From Engram https://www.engram.us/vs/12/relation-vs-relationship:**
  - refers to the **way two or more people or things are connected** or the emotional or personal connection between people.
  - often used to describe romantic, familial, or friendship connections but can also be used in math and science.
  - can be positive or negative, healthy or toxic, and easy or difficult to maintain.

System Property – Such properties emerge from structure, components, and their properties; they enable system qualities to be manifested, and they are composed of intrinsic characteristics and functional capabilities:

- System intrinsic characteristics are mostly associated with structures.
- System functional capabilities are mostly associated with components. (In a "white-box" model, the developers and operators of the system have knowledge of the details of what is inside the box and how inputs are transformed into outputs).

System Quality – a desired characteristic of the system, thought of as a high-level requirement expressed qualitatively or quantitatively. (In a "black box" model, the users of the system see it as a box that is opaque; they see the inputs into the box and what comes out, but do not see the details inside the box).

Trend:

– "a general direction in which something is developing or changing" (Oxford 2023)

– "a general development or change in a situation or in the way that people are behaving" (Cambridge 2023)

– "a prevailing or general movement or inclination" (Merriam-Webster 2023)

Observers might not know what people's, organizations', or industries' goals are, but they note a change, shift, or movement (trend) from their previous nominal operating state.

Vision – *"[a vivid mental image] of what you [leadership] want[s] your business to be at some point in the future, based on business goals and aspirations."* (Queensland Government 2022)

Vision Statement:

"describes what a company desires to achieve in the long-run, generally in a time frame of five to ten years, or sometimes even longer. It depicts a vision of what the company will look like in the future and sets a defined direction for the planning and execution of corporate-level strategies." (CFI 2023)

"Vision answers the question "What will the future look like as we fulfill our mission? What will be different?" … The vision needs to be more than a statement. It should be a description. This description may be a paragraph or a whole page. It should paint a picture of the future that will come to be as we carry out our mission." (CIO 2023)

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Appendix A

Assessed Electric Power Industry Stakeholder Source Matrix

Table A-1 provides information on the source documents that were assessed and characterized, including the source organization name, document title, publication date, a functioning URL (as of 24 May, 2023), a short description of the document, and the time frame window for the vision and future states.

Table A-1: Assessed documents.

Organization	Vision and Future State Document(s)	Description
Commonwealth Scientific and Industrial Research Organisation (CSIRO) – Future Grid Forum	• *Change and Choice* – Dec 2013. https://publications.csiro.au/rpr/download?pid=csiro:EP1312486&dsid=DS13 • Scenarios summary; *1312 CSIRO Future Grid Forum - Summary of 2050 Scenarios*. https://www.slideshare.net/slideshow/1312-csiro-future-grid-forum-summary-of-2050-scenarios/58639933 • *Modelling the Future Grid Forum scenarios*. December 2013. https://publications.csiro.au/rpr/download?pid=csiro:EP1311347&dsid=DS3. • *Electricity Network Transformation Roadmap: Future Grid Forum 2015 Refresh.* https://www.energynetworks.com.au/resources/reports/future-grid-forum-2015-refresh-technical-report/	CSIRO (the Australian Government's national science agency) published an analysis of four business scenarios/pathways of a visioned Australian electric industry for 2050. The report was refreshed in 2015.

Organization	Vision and Future State Document(s)	Description
Department of Energy (DOE) –Office of Electricity	• *Modern Distribution Grid (DSPx) Volume I: Objective Driven Functionality.* Version 2, November 2019. https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid_Volume_I_v2_0.pdf.	DOE prepared this version and benefited from Version 1 being used in 20+ states and from associated regulatory and industry insights. The time horizon for the content of this document is the next 15 years from the published date to support customers' needs and state objectives.
Electric Power Research Institute (EPRI)	• *Integrated Energy Network*, – (website http://integratedenergynetwork.com/); Feb2017. *The Integrated Energy Network: Connecting Customers to Reliable, Safe, Affordable, and Cleaner Energy*. Publication 3002009917. https://www.epri.com/research/products/000000003002009917.	The IEN frames a future where customers have increased flexibility in grid interaction. IEN provides a community to further detail the pathway to reach this vision. Associated deliverables characterize that future to the 2030 time frame.

Organization	Vision and Future State Document(s)	Description
GridWise Alliance	(a) *Grid Modernization Index* - 2018, Dec2018, GridWise Alliance and E9 Insights. https://gridwise.org/grid-modernization-index-2018/. (b) *In an accelerated energy transition, can U.S. utilities fast-track transformation?*. Dec2019, GridWise Alliance and EY. https://gridwise.org/wp-content/uploads/2019/12/Perspectives-on-a-Future-Distribution-System.pdf.	(a) This is the fifth issue of the index (first one in 2013), which assesses and ranks all 50 USA states and Washington DC on progress in modernizing the state's electricity grid via 75 metrics grouped under three criteria. (b) Builds on a January 2019 EY (EY Global Services Limited) work on the future electricity grid in Europe and addresses the report's title/question. The future horizon is 2030 and 2045–50.
Institute of Electrical and Electronics Engineers (IEEE)-USA	(a) *National Energy Policy Recommendations*, 22 November 2019. https://ieeeusa.org/assets/public-policy/positions/energy/NEPR1119.pdf. (b) *Building an Intelligent Electric Grid for the 21st Century*, December 2, 2020. https://ieeeusa.org/assets/public-policy/white-paper/IEEEUSAWP-BuildinganIntelligentGrid2020.pdf.	(a) IEEE-USA states vision and goals in the near and long terms but does not specify the years. The report does cite other forecasts for various energy measures in the 2020, 2023, and 2030 time frames. (b) White paper discussing challenges and considerations for the title topic. The topic time periods are short/near term, long term, and next 10–20 years; alternatively, the projection period 2020–50 with some cited forecasts.
Independent Electricity System Operator (IESO)	(a) *Innovation and Sector Evolution White Paper Series: Non-Wires Alternatives Using Energy and Capacity Markets*, May 2020. https://www.ieso.ca/-/media/Files/IESO/Document-Library/White-papers/IESO-NWAs-Using-Energy-and-Capacity-Markets.ashx?sc_lang=en&hash=62F4A6F5BBA1002315DAE1FD4E2C7A28. (b) *Innovation and Sector Evolution White Paper Series: Development of a Transmission-Distribution Interoperability Framework*, May 2020. https://www.ieso.ca/-/media/Files/IESO/Document-Library/White-papers/IESO-T-D-Coordination-Framework.ashx.	(a) IESO white paper that discusses non-wires alternatives (NWAs) and investigates potential energy and capacity market processes that coordinate DERs with associated grid actors. The time frame for realizing this topic is not specified in years, but as whenever DER penetration gets to the point that existing markets and techniques cannot handle high DER penetration and NWAs and different markets/processes are needed. (b) Intelligent Community Forum Canada prepared this white paper for IESO that describes how interoperability between transmission and distribution systems might evolve to support higher DER penetration and provides a framework for those domains and the associated operators. The topic time frame is the next 5–10 years.

Organization	Vision and Future State Document(s)	Description
National Institute of Standards and Technology (NIST)	*NIST Framework and Roadmap for Smart Grid Interoperability Standards*, Release 4.0, February 2021, Special Publication 11008r4. https://doi.org/10.6028/NIST.SP.1108r4.	This is the fourth release of the smart grid interoperability standards framework and roadmap. The first release appeared in January 2010. This release discusses the effects on interoperability of changing grid technologies via four areas: grid operations, cybersecurity, grid economics, and standards testing & certification. The grid architectural models were updated via communication pathway diagrams, a smart grid ontology was shifted to a cyber-physical systems framework with architectural challenges called out, and additional appendices were added. The topics are addressed in the near, mid, and long terms without specifying the number of years.
Pacific Energy Institute (PEI)	*A Gambit for Grid 2035: A Systemic Look into the Disruptive Dynamics Underway*, April 2021. https://pacificenergyinstitute.org/wp-content/uploads/2021/08/A-Gambit-for-Grid-2035-final-version.pdf.	PEI's initial white paper describes "the "why" and "whats" of these systemic changes and related considerations" for the electricity systems worldwide. The paper's title indicates the topic time frame, i.e., out to 2035.
Utilities Technology Council (UTC)	*Utility Network Baseline*, November 2017. https://www.energy.senate.gov/services/files/2AC00DB6-EAB7-43A5-AB87-9EC6A6F837D7.	UTC surveyed its members concerning their current and anticipated telecommunication networks' capabilities. A 2019 update of the survey was performed. The report's future time frames were 3–5 and 5–10 years.

Appendix B

Grid 3.0 Future States and Issues

Grid 3.0 Future States

Background: *The formative work on the Grid 3.0 Future States was a deliverable from the initial Grid 3.0 Workshop 26-27Mar2015 hosted by NIST at Gaithersburg, MD. The definition for the term Grid 3.0 at that time (and still used): "Grid 1.0" can be thought of as the legacy grid of the 20th century, "Grid 2.0" is the emergence of the smart grid with automation and information technology improvements, and "Grid 3.0" is what comes next: for example, a future grid with advanced grid operations and greater interactions with consumers and other infrastructures".*

Subsequently, the Workshop Organizing Committee refined the workshop key themes and developed aspirational Grid 3.0 future statements "Future States" with the later addition (in concept) of Communications [not written up].

Policy, Regulation & Business Model

A) Develop and publicly document a well-articulated, industry-shaped consensus on future states of the electric power grid through a collaborative process

ISSUES: ○ Wide range opinions/entrenched positions
- Gridlock in the Federal Government; spending caps
- Lack of staff education in the Federal Government
- Lack of "burning platform" moving policy forward
- Need means to provide policy makers, including Congress staffers and members (Federal, state, and local levels), with both process and understanding

B) A clearly defined set of regulatory models with a clear understanding of state and federal jurisdictions

ISSUES: ○ Lack of a coordinating organization to drive a spectrum of future regulatory models
- Few states are working on a comprehensive future state regulatory model
- Statutes limit innovation in state regulatory models
- Lack of policy framework as context for models
- Focus at the state level of "bite sizing" the changes in the regulatory model; lack of funding

C) Clear, sustainable business models and value propositions that allow the industry stakeholders to profitably support the needs of the economy

ISSUES: ○ Lack clear policy and regulatory framework
- Business models to reward stakeholders for real innovation; for understand/meet customer needs
- Business models that clearly support the economic proactive deployment of solutions to support customer and societal needs
- Clear roles and responsibilities for third party service providers, that allow innovation and expansion of solution options for customers
- Real cost models that remove artificial cost penalties from innovation and implementation

D) Provide an environment and web-based info outreach tools where all stakeholders have an equal place at table and ability to explore a broad range of solutions to their needs and desires without artificial economic penalties

ISSUES: ○ Regulatory framework limits the roles of many stakeholders to an adversarial process
- Informal frameworks for discussion tend to be dominated by special interest groups
- Regulatory framework can limit the options and solutions available to customers
- Real costs not be reflected in tariffs, and incentives
- Customers have no ed./ incentives to be pro-active

E) Forums and processes exist to facilitate regional cooperation and collaboration across multiple stakeholder categories

ISSUES: ○ Regional cooperation must bridge multiple state (plus fed) jurisdictions, need +(pos.) examples
- For collaboration across stakeholders, need more consumer outreach, who benefit from ed./incent.
- Informal frameworks for discussion can be dominated by special interest groups and do not necessarily provide for interests of the consumer

Technical Development

F) Provide a set of conceptual architecture models which can be made available to any electric sector stakeholder as a starting point for sustainable businesses and processes

ISSUES: ○ Lack of a policy and regulatory framework to develop workable architectures within
- Lack of broad stakeholder understanding of architecture discipline, why needed, and how used
- Lack of business case framework for develop arch
- No clear repository for architectural artifacts, templates, data object, and supporting documents
- Limited collaborative development of broadly available architectural models and documentation
- Existing industry archs focus on automation and data aspects rather than broader industry needs

G) Well defined points of interoperability with agreed-on standards exist/utilized by all electric sector stakeholders

ISSUES: ○ Some needed standards are moving too slowly (e.g. CIM); existing standards not being specified in procurements or applied broadly
- Limited guidance on where well-defined points of interoperability should be; lack of capability of utilities to adopt new interoperability stds
- Limited external support for initial cost of moving to stds-based interop. products/solutions (bus value)

- Some vendors choose to avoid standards to maintain lock-in as strategic business objective
- Limited T&C processes for existing standards
- Limited ref. implementations for select stds; lack of test cases libraries freely available and maintained for verifying specific implementations
- Limited ability to quickly develop new information models and standards for new device classes, business models and applications

H) Provide a well-defined decision support environment that uses the best principles of the industry architecture and interoperability to allow efficient use of both data and stakeholders knowledge and ability

ISSUES:
- Outdated data retention regulations
- Lack of shared analytic algorithms and supporting test data; fear of a data tsunami; tension between customer privacy and innovation with data
- Legacy design of operational tech systems and inability support high vol data for decision support
- Lack of publicly available data repository for data mining use by startups and other third parties

I) Provide range of coordinated reference designs and documentation that supports choices stakeholders can make in their making/moving/using of electricity

ISSUES:
- Outdated planning manuals and planning systems; complexity of planning for distributed generation aspects (max hosting capacity, banking reqs. and phase balancing)
- Lack of clear regulatory compliance requirement and standards for many emerging areas
- Blending legacy equipment with new innovative technology in reference designs that provide guidance in majority situations/ not special case
- Lack of topologically/electrically correct system models for plan/design/operational support
- Lack of a clear repository where reference designs are housed; lack of mechanism for updating/maintaining reference models
- Lack of a verification process and "certifying organization" for new reference designs prior to wide-spread release

J) Well defined and clearly understood privacy ecosystem that both allows use of data to sustain the industry and provides for individual needs

ISSUES:
- Competing privacy standards and entrenched interests for each standard
- Lack clear statutory & regulatory requirements
- Lack of privacy management systems that allow individual customers to make changes to their privacy settings in economically prudent fashion
- Fear of privacy violations by people and sensational media stories about the impacts of utility data on individual privacy and lifestyles

K) Well defined and clearly understood proactive security ecosystem that sustains the operational and business needs of all stakeholders

ISSUES:
- Completing standards and regulatory organizations do not provide clear & consistent guidance for security architecture/implement
- Costs of security are not well understood
- The evolution of "black hat" techniques make security frameworks much harder to design, implement and maintain
- Lack of a clear training pipeline for security specialists and their supervisors/managers
- Security mostly "bolted-on" rather than built in
- Security devices with limited update & expansion capability and thus limited useful life increases investment in "as-is" vs. "to-be" environment
- Current compliance regulations and standards tend to focus stakeholders on small (but high value) portions of the ecosystem

L) Security information sharing is hard to do, and gaining access to the current sharing mechanisms typically requires a long wait period for clearance

Workforce and Metrics

M) Provide an environment that retains and attracts motivated individuals who thrive with continuous incremental education and skills improvement in an evolving industry

ISSUES:
- Limited number of education and education delivery options available; lack of clearinghouse for info (ed. & reqs. and job opportunity stats)
- Lag between identification of new educational requirements to available training; limited statutory/regulatory support for training
- Limited career paths available for many individuals and roles, with slow progression

N) Clearly defined and utilized metrics exist for electric system infrastructure (e.g. reliability, resiliency, quality, security, economics, customer-related and efficiency)

ISSUES:
- Lack of architectural and business models that can be used to define key metrics
- Lack of an organization who is empowered to define industry metrics and definitions for same
- Lack of a clear business case to adopt/use metrics beyond currently accepted set of metrics
- Lack of supporting decision support systems and data to automate metric collection/calculation
- Lack of regulatory support for costs associated with collecting metrics
- "Penalties only" regulatory mind set on metrics

Appendix C

Characterizations of Individual Source Future States

These web-radar charts characterize individual stakeholder organizations' vision and future-states reports.

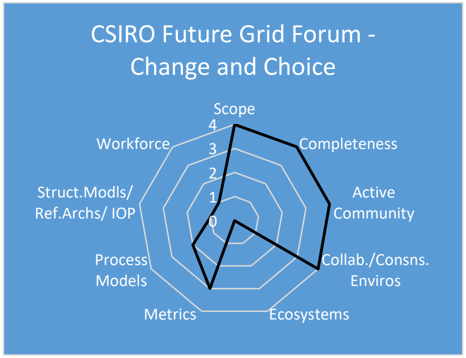

Figure C-1: CSIRO Future Grid Forum

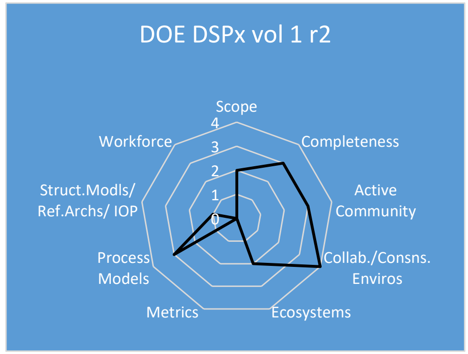

Figure C-2: DOE DSPx vol. 1, r2

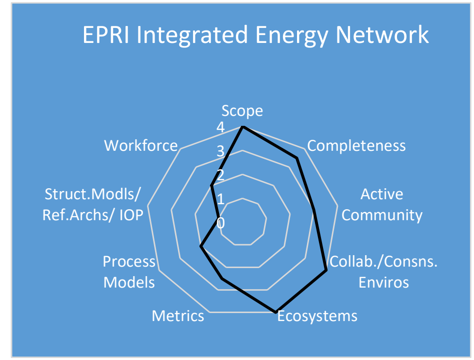

Figure C-3: EPRI Integrated Energy Network

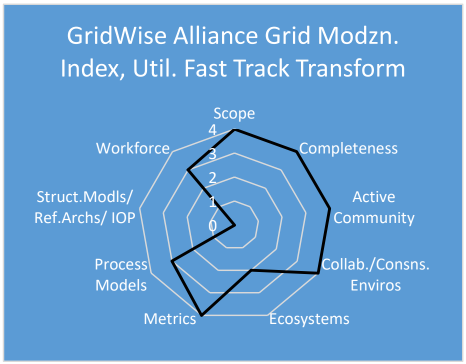

Figure C-4: GridWise Alliance Grid Modzn, Index, Util. Fast-Track Transform

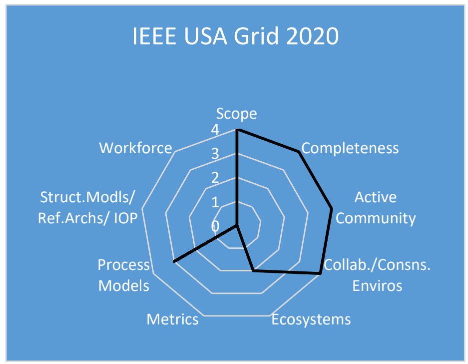

Figure C-5: IEEE-USA Grid 2020

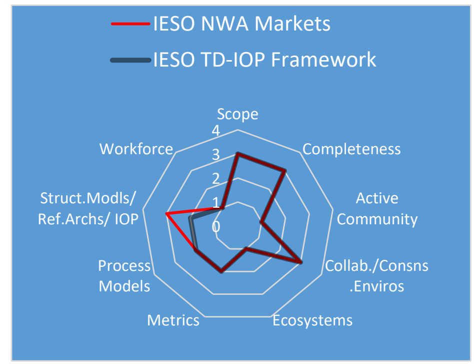

Figure C-6: IESO NWA Markets & TP-IOP Framework

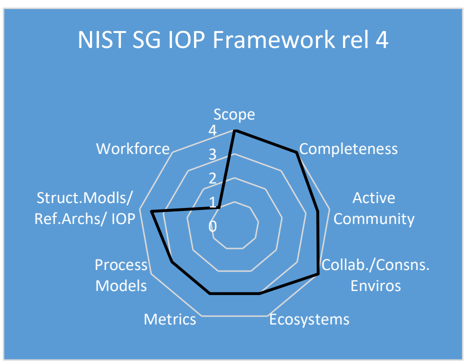

Figure C-7: NIST SG IOP Framework Release 4

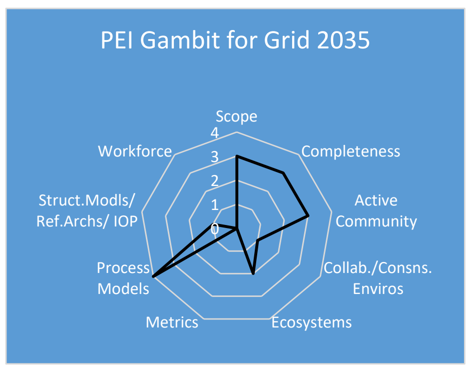

Figure C-8: PEI A Gambit for Grid 2035

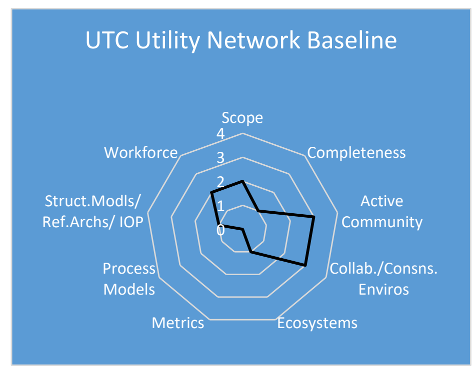

Figure C-9: UTC Utility Network Baseline

Appendix D

Future Statements Refactored by Topic Category, Sources, and Architectural Types

Table D-1: Refactored Future-Statement Assessments by Topic Category, Source, and Architectural Type for Level 1 and Level 2 Categories.

	Count of Future Statements																
	Source											Architectural Type					
Decomposed / Second Refactor – Topic Categories ↓	CSIRO	DSPx	EPRI IEN	GWA	IEEE USA	IESO NWA-Markets	IESO TD-IOP Frmwrk	NIST IOP Frmwrk rel4	PEI	UTC	Item Total	Arch-Bus Model	Arch-Srvc-Funct/Rqmts	Arch-Strategy	Arch-Trend/Driver	Energy-Trend/Driver	Item Total
Comm network										10	10	3	2		5		10
5G										5	5	3	1		1		5
Bandwidth										2	2		1		1		2
Cybersecurity										1	1				1		1
Utility										2	2				2		2
Customer	4	1	1	3					2		11	1	5	1	4		11
Choice	2	1							2		5	1	1		3		5
Electrification			1								1				1		1
Services				1							1		1				1
Tech	2			2							4		3	1			4
Energy	3		2		3						8			4	2	2	8
Consumption			1								1					1	1
Electric $	3										3			1	2		3
National needs met					3						3			3			3
Natural gas			1								1					1	1
Environmental			2		1						3			1		2	3
Electricity generation			1								1					1	1
Emissions			1								1					1	1
Stewardship					1						1			1			1
Grid		3	3	5		1		18		1	31	4	16	5	6		31
Asset owners				1				4			5	2	2		1		5
Cybersecurity								2			2		2				2
Interoperability								6			6		3	3			6
Modernization		2	3	1				3			9	1	2	2	4		9
Ops/planning		1		3		1		3		1	9	1	7		1		9
Grid assets/tech			1	8		2	3	2	1	1	18	1	8	4	5		18
Ecosystem									1		1			1			1
Innovation			1							1	1				2		1
Non-wires alt.				7		2	3	2			14	1	7	3	3		14
Sensors				1							1		1				1
Grid coord				6		7	21				34	27	5	1	1		34
Increased							1				1		1				1
Markets				4		1	1				6	3	2		1		6
Models				2		5	19				26	24	1	1			26
Multi-srvc framework						1					1		1				1
Value-benefit-optimize		1	4	6		2	2	7			22	1	9	7	2	3	22
Customer				1							1		1				1
Energy			1								1					1	1
Environmental			2								2					2	2
Grid		1		2				7			10		5	4	1		10
Grid assets/tech			1	3		2					6		2	3	1		6
Grid coord							2				2	1	1				2
Total	7	5	13	28	4	12	26	27	3	12	137	37	45	23	25	7	137