Tilting at Windmills: Drivers, Risk, Opportunity, Resilience and the 2021 Texas Electricity Grid Failure

Matthew Hause
Principal Systems Engineer
System Strategy, Inc
MHause@systemxi.com
Lars-Olof Kihlstrom
Syntell
Stockholm, Sweden
Lars-Olof.Kihlstrom@syntell.se

Agenda

- What did happen
- What didn't happen
- Incentives
- Systems of Systems
- UAF Overview
- Mapping a strategy
- What should happen next time
- Future research
- Conclusion

What Are the Facts?

- Winter storm Uri hit Texas causing freezing temperatures.
- Generators, and generator power sources (Coal, Gas, Nuclear, Water) failed
- Loss of generation put the grid stability at risk
- Load shedding to protect the grid cut off power from millions
- Almost 300 people died, many homes and businesses destroyed.
- The emergency lasted 4 days
- Texas was not prepared.

What Are the Myths?

- Overreliance on renewables was the major cause of the Texas Grid problems.
- Renewable energy makes up only a fraction of the generating capacity.
- Connecting the Texas Grid to the East or West Grid would have prevented the problem.
- The Texas Grid is inherently unstable.
- The grid failure was not foreseen.
- Deregulation was a major cause of the failure.

What Really Caused the Failure?

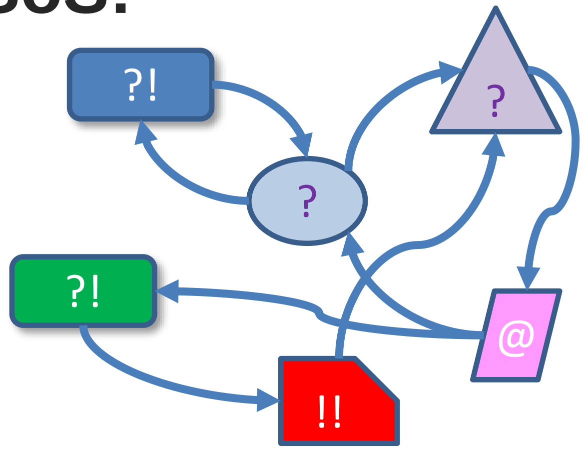
- **Texas infrastructure not prepared for an extended and unusual cold snap.**
  - Fossil Fuel Generation: gas generators, coal generators
  - Clean Generation: nuclear generators, wind turbines, solar
  - Supporting Infrastructure: gas drilling, gas distribution, water supplies
  - Buildings: houses, apartments, stores, hotels, office buildings, etc.
  - Transportation: roads, trains, buses, cars, trucking, etc.
- **Everything froze.**
  - Gas supplies froze limiting gas generation
  - Houses needed gas, further limiting supplies
  - Prices rose causing gas generators to shut down
  - Water supplies froze limiting nuclear, coal & gas
  - Demand exceeded supply
  - ERCOT mandated load-shedding to maintain critical services, hospitals, fire, etc.
  - Power was cut off to millions of homes & businesses

Why Weren't the Systems Winterized?

- **There was insufficient incentive and ROI to do so**
  - Winterization of infrastructure was not mandated by the government.
  - Similar cold snaps happen roughly every 40 years
  - The initial investment and maintenance for winterization is expensive
  - There was no effective business case to winterize unless required
- **The same reasoning was universally applied**
  - Homes, businesses, infrastructure, apartments, condominiums, etc.
- **Preparation for the next storm needs to be driven by both business and engineering.**
  - So, how to express these concepts?

Systems of Systems

- **Definition: A system of systems (SoS) is "a collection of systems, each capable of independent operation, that interoperate together to achieve additional desired capabilities.“ (Mitre)**
- **Maier (1998) postulated five key characteristics of SoS:**
  - operational independence of component systems
  - managerial independence of component systems
  - geographical distribution
  - emergent behavior, and
  - evolutionary development processes



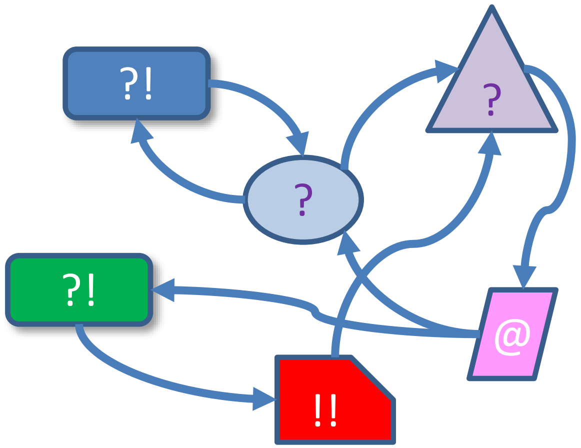
- **Other aspects**
  - Have multiple levels of stakeholders with mixed and possibly competing interests
  - Have multiple, and possibly contradictory, objectives and purpose
  - Have multiple, different, operational priorities with no clear escalation routes
  - Have multiple lifecycles with elements being implemented asynchronously
  - Have multiple owners making independent resourcing decisions

The Electric Grid as an SoS

- **Operational independence**
  - The Texas Energy SoS is operated by entities. They are a collection of independent operators, government institutions, municipal companies, and not for profit agencies. They operate independently to support their individual customers. Support of the overall is of secondary importance.
- **Managerial independence**
  - Each of the grid entities must comply with a variety of different standards, rules, laws and regulations. The Electric Reliability Council of Texas (ERCOT) oversees energy companies. However, they maintain their operational independence separate from that of the grid.
- **Evolutionary development**
  - New systems, technologies or ConOps may be introduced by any of the companies as required to evolve and adapt to the changing environment, latest technology needs or stakeholder requirements. This will affect both the individual system as well as the SoS.
- **Geographical distribution**
  - The Texas power grid is geographically distributed by its very definition.
- **Lifecycle independence**
  - Even within the individual companies there will be multiple system lifecycles across asynchronous acquisition and development efforts, involving legacy systems, developmental systems, and technology insertion to meet their customer needs.

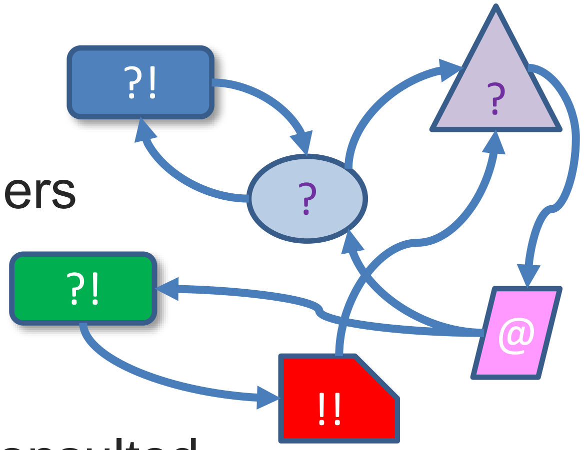
Types of SoS

- **Directed**
  - SoS is created and managed to fulfill specific purposes.
  - Constituent systems are subordinate
  - Airports, Air Traffic Management, etc.
- **Acknowledged**
  - Recognized objectives, a designated manager, and resources.
  - Systems retain their independence.
  - Changes are based on cooperative agreements
  - Defense systems, governments, etc.
- **Collaborative**
  - Component systems interact voluntarily to fulfill central purposes.
  - Public utilities, Cell phone network, Cable TV, Texas Energy Grid and supporting systems
- **Virtual (Basically, the internet)**
  - No central management authority or centrally agreed upon purpose.
  - Invisible mechanisms maintain it.
- **(Maier, 1998; Dahmann and Baldwin, 2008, ISO 21839, 2019):**



Importance of the SoS to the Texas Grid

- **Multiple levels of stakeholders**
  - Changes cannot simply be mandated but must be negotiated.
  - Changes will take time to negotiate and implement
- **Multiple, and contradictory, objectives and purpose**
  - There is no “Common Good”. Benefits for one will adversely affect others
  - Proposed changes will cause infighting delaying implementation
- **Multiple, different, operational priorities**
  - Systems must be taken offline for winterization, affecting income
  - Owners, stakeholders, shareholders, customers, regulators must be consulted
- **Multiple System lifecycles**
  - Peak electric is in the summer, gas in the winter, water in the summer
  - ROI to replace newly installed systems is difficult
- **Multiple owners making independent resourcing decisions**
  - Deregulation has cut operating margins limiting discretionary funds
  - Government will need to supplement, not traditionally a major government priority in Texas



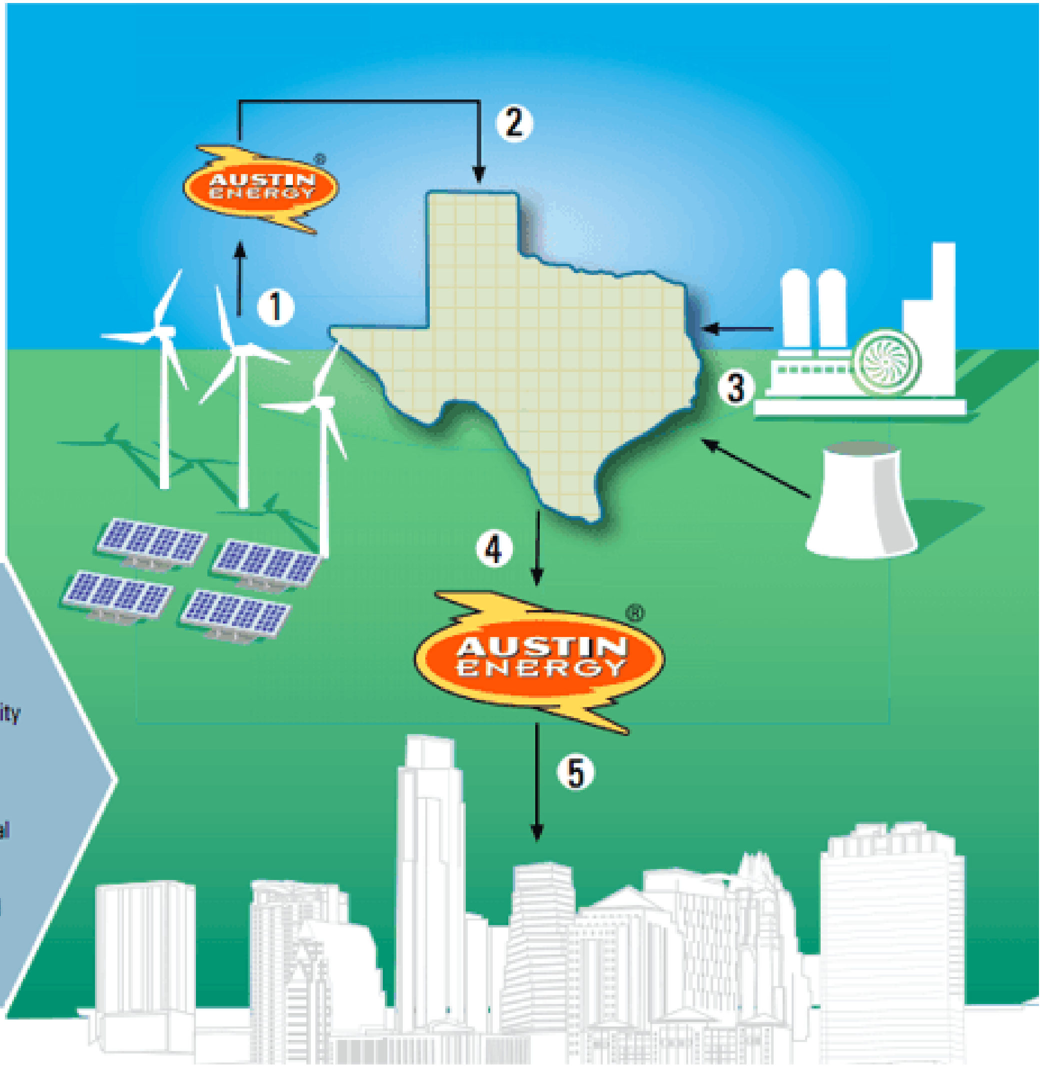
Example Problem: Austin Energy

- **Austin Energy is a vertically integrated utility**
  - AE Generates power
  - Sells to the wholesale market
  - Wholesaler sets the price
  - AE buys back needed power
  - AE distributes to its customers

Another significant change occurred in Texas in 2010 with the shift to the nodal market. The nodal market further centralized the wholesale buying and selling of electricity. As a consequence, Austin Energy no longer generates electricity to directly serve customers. Instead, Austin Energy sells power to the wholesale market and purchases power from the market to serve customers. The market sets the price for buying and selling electricity at the wholesale level, which ultimately affects the price customers pay for their electricity. The wholesale market redesign altered Austin Energy's risk profile. The utility must re-examine and respond to market changes in its strategic planning.

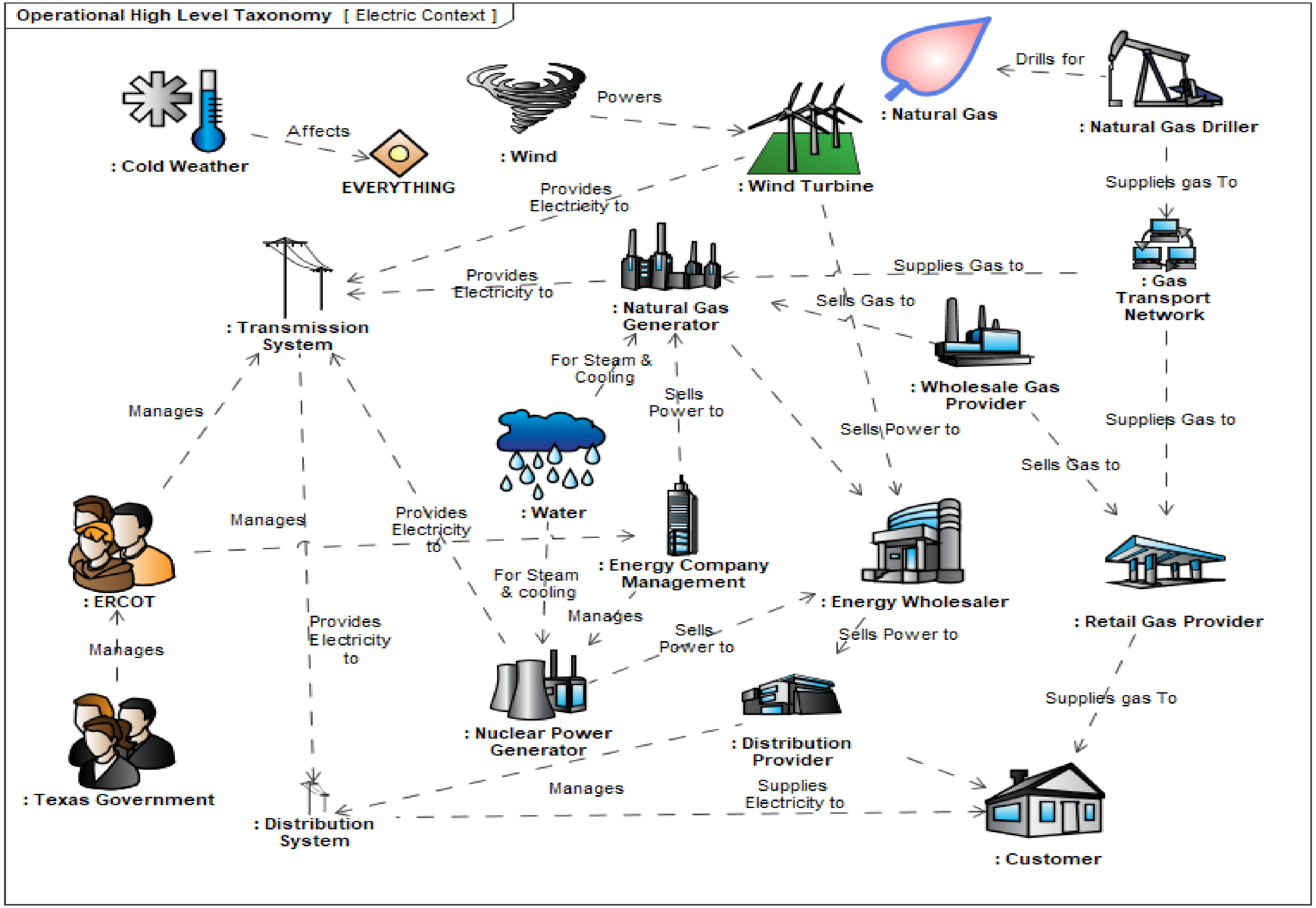
How Austin Energy works in the market

As a vertically integrated utility, Austin Energy generates electricity, transports electricity and provides electricity to the customers it serves. With purchase power agreements, the utility buys the produced electricity at the contracted price (1), and Austin Energy then sells that electricity into the wholesale market (2). For the power produced from Austin Energy's traditional generation, it is sold directly into the wholesale market (3). Austin Energy then buys all the power it needs to serve its load from the market (4), and delivers that power to its customers throughout the service area (5).



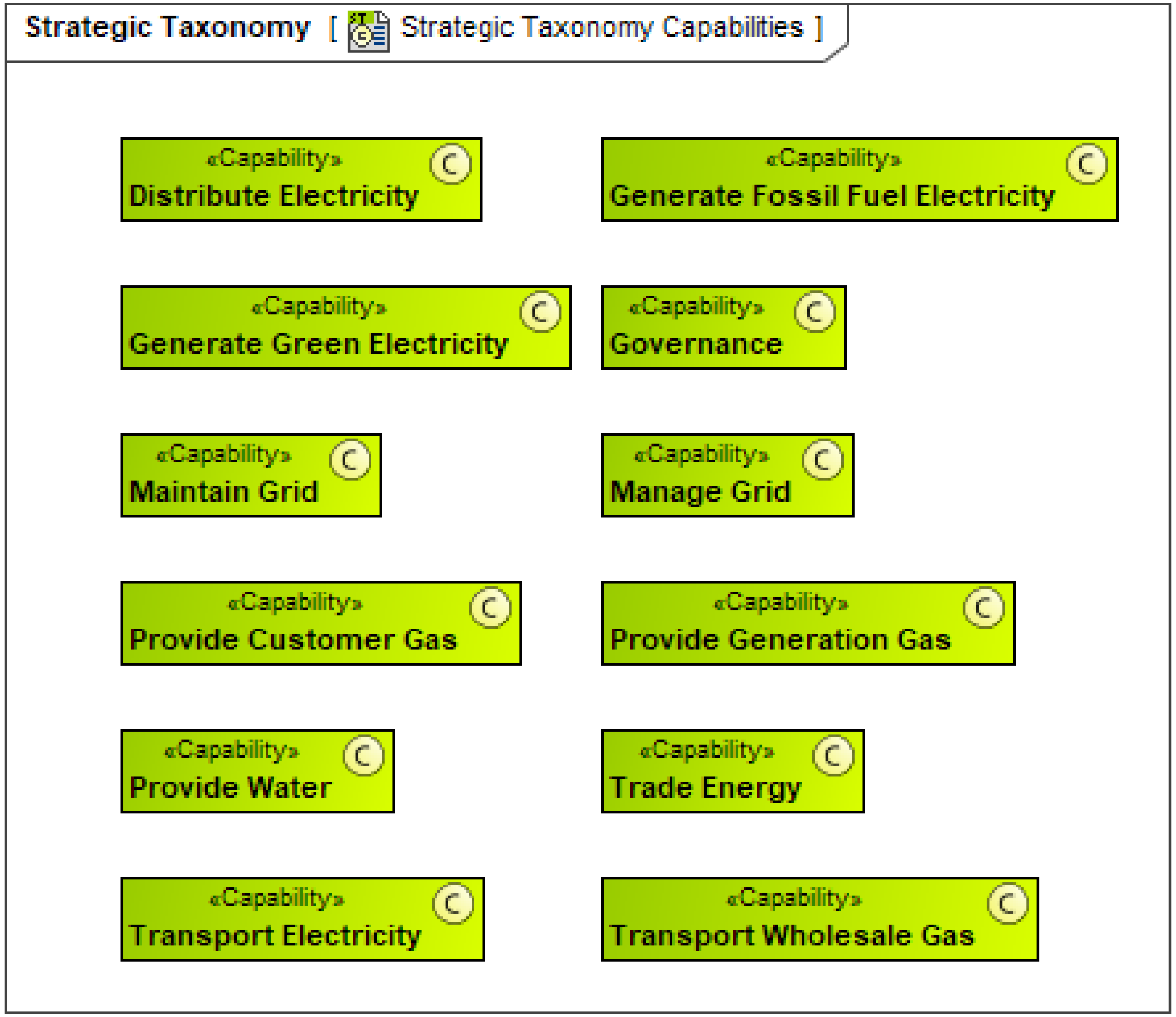
High Level Concept Diagram

- Generic diagram communicating concepts
- Shows conceptual relationships between entities
- Used to communicate with stakeholders



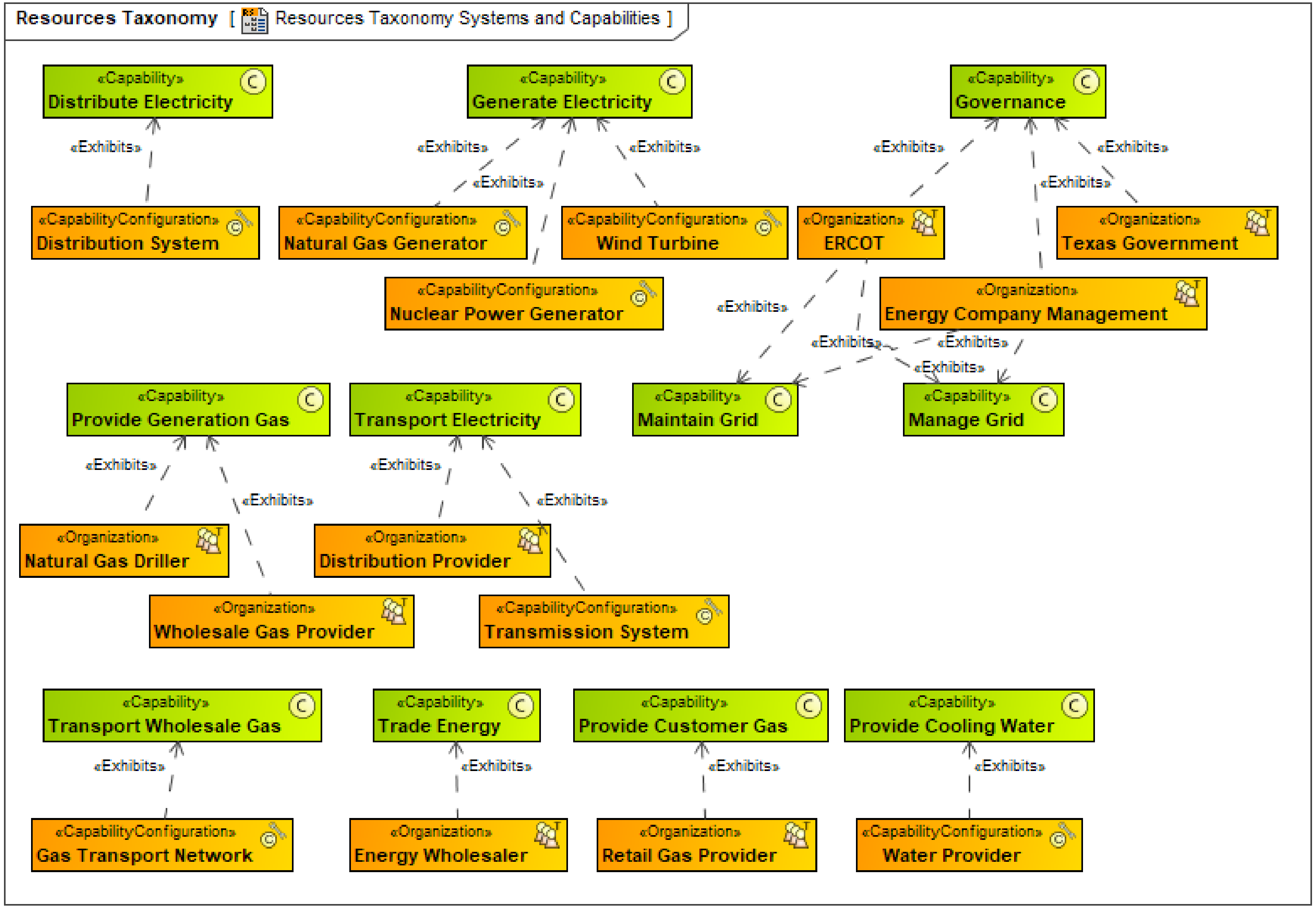
Energy Grid System of Systems Capabilities

- Capabilities define what the enterprise can accomplish without specifying how
- Enable desired effects and outcomes (Later)
- Define purpose of the enterprise
- Capabilities are realized by systems (Next)



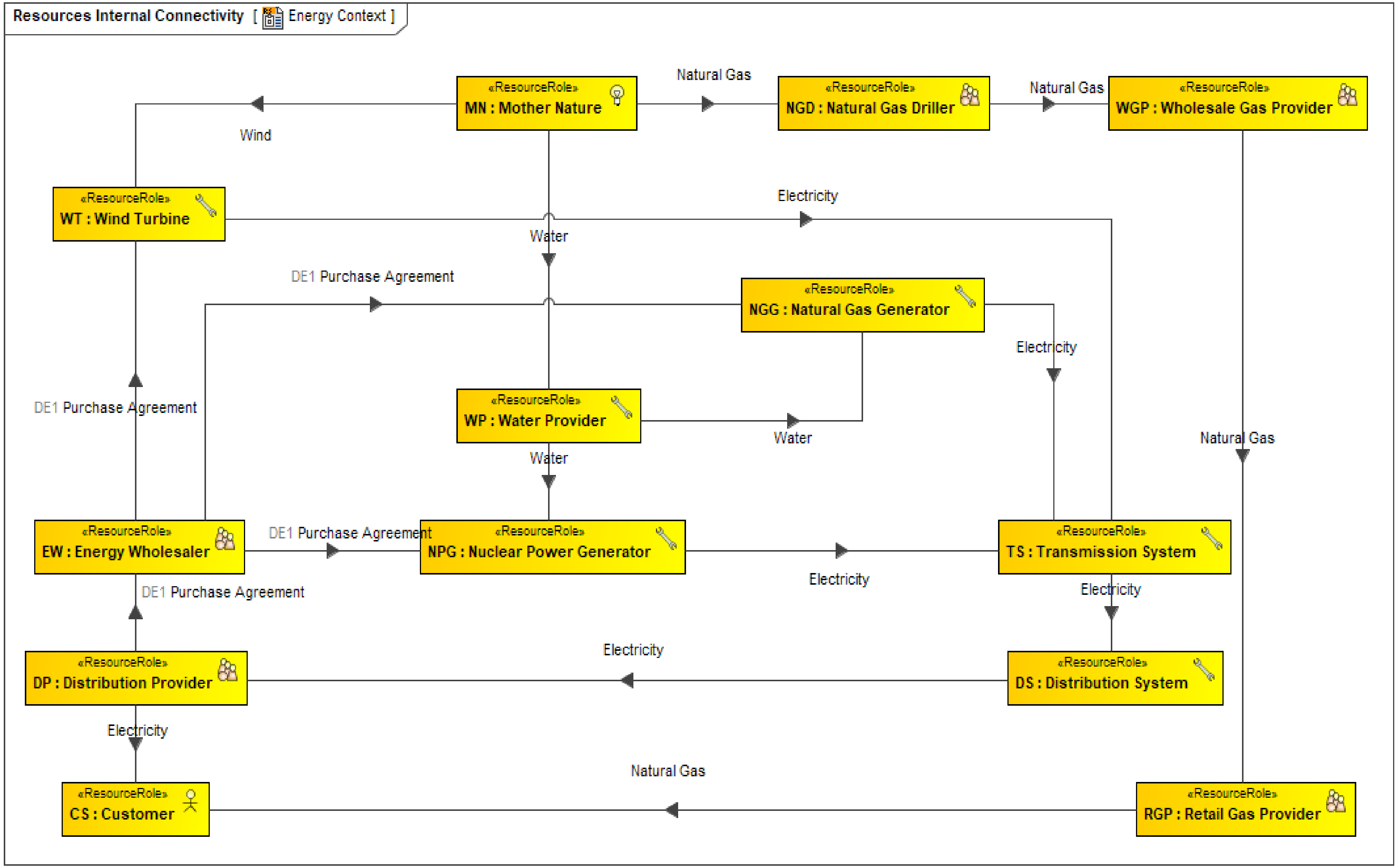
Capabilities and Implementing Resources

- Systems implement the capability by creating the desired effects
- Multiple systems implement a capability
- Capabilities and systems depend on one another



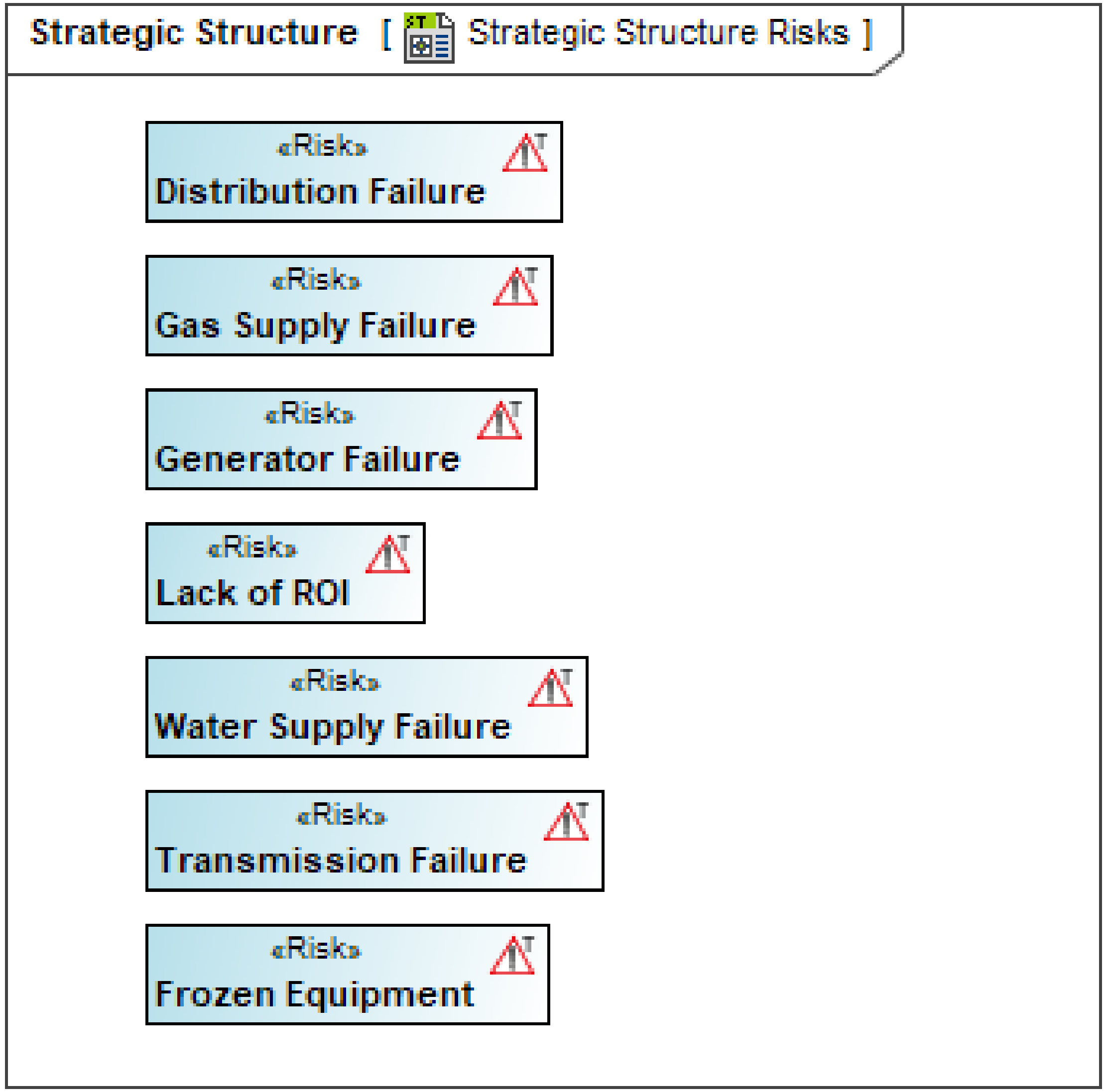
Energy System Architecture

- System connections and flows
- Demonstrates the interconnected-ness of the systems
- Failure of any connection will affect everything



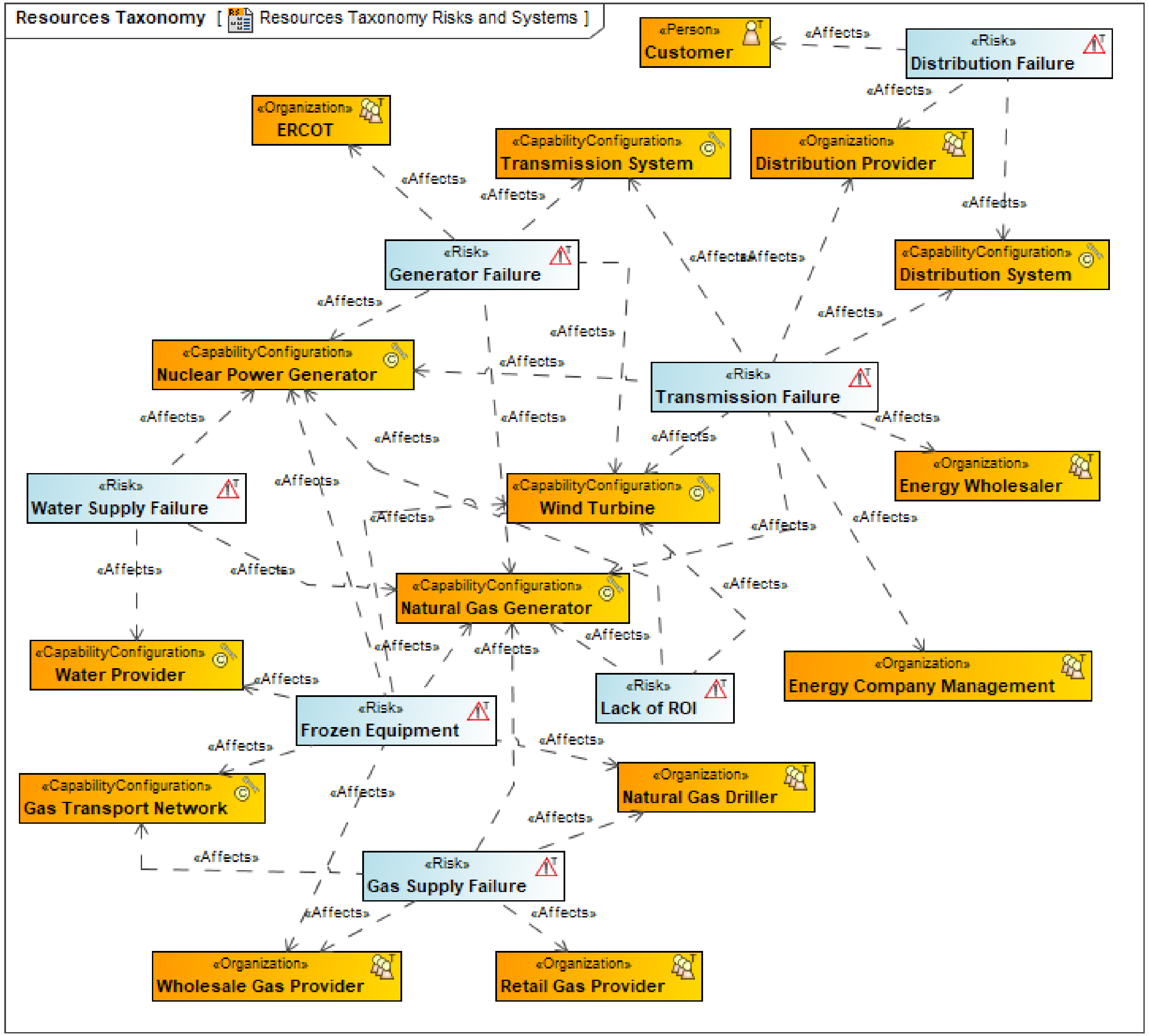
Energy System Risks

- **Risk: The chance or probability that an adverse event will occur. Risk analysis examines probability of risk as well as the adverse effect.**



Risks and Affected Resources

- **System Risks and elements they affect**
  - Gas supply failure affects Generation, Transportation, Wholesales, Retail, Driller and Customer.
  - Frozen Equipment affects almost everything
  - Lack of ROI affects generation infrastructure
- **So, can we mitigate these risks?**



Winterization is Now Mandated

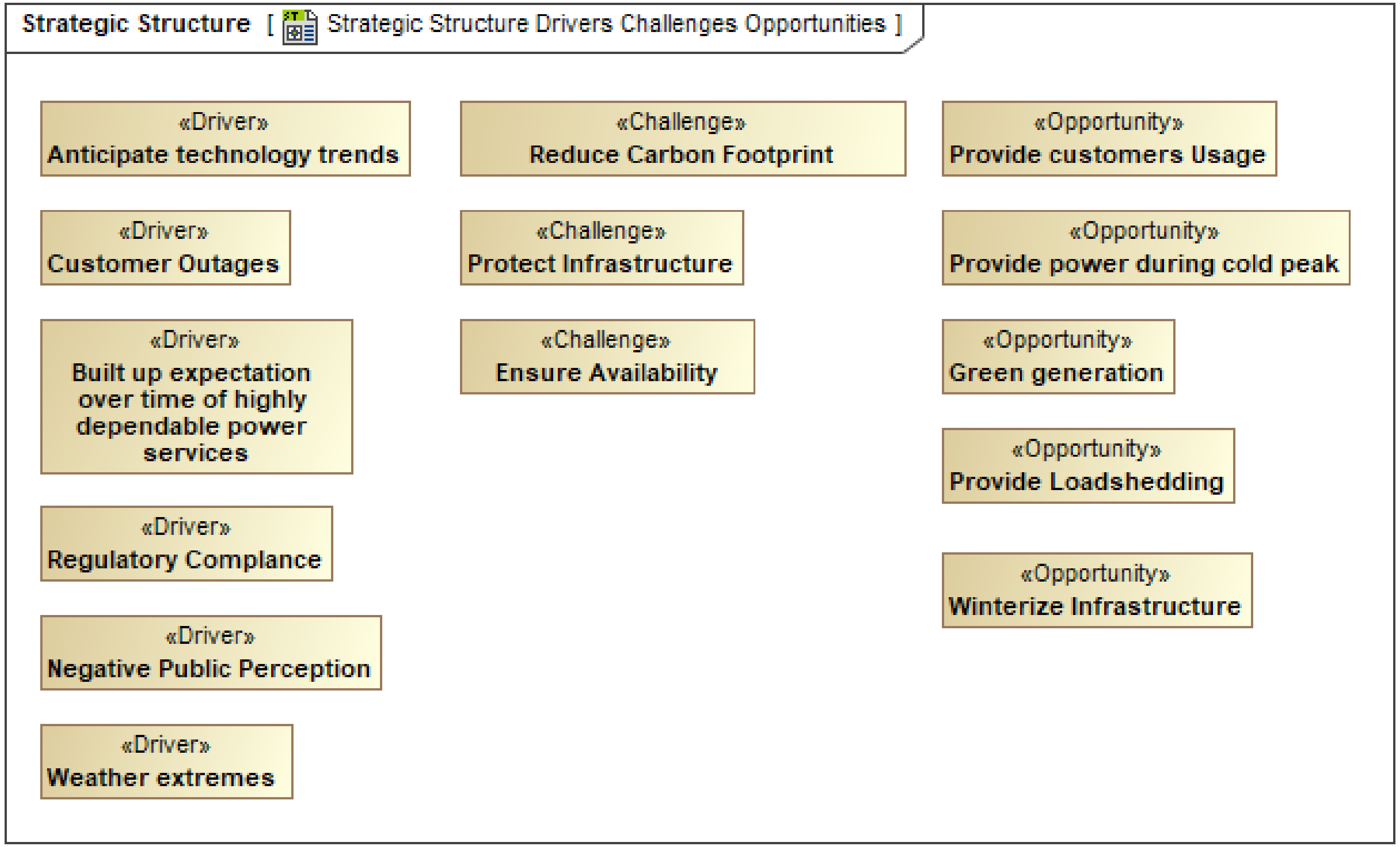
- On June 8, 2021, Texas Governor Greg Abbott signed Senate Bill 2 and Senate Bill 3 to reform the Electric Reliability Council of Texas (ERCOT). "A top priority that we had this legislative session was to fix the power to prevent any other power grid failure in the future," "The legislature passed comprehensive reforms to fix all of the flaws that led to the power failure. "Senate Bill 3 (SB3) requires electricity providers operating on the ERCOT grid to weatherize their equipment and improve communication during outages by creating an alert system. Abbott said the new legislation targeted weather for all seasons. (Fung, 2021)
- So, how does this change the business case?
- What systems are affected?
- How does this change the architecture?
- How do we demonstrate ROI on winterization?
- How do we model this?

Definition of Concepts

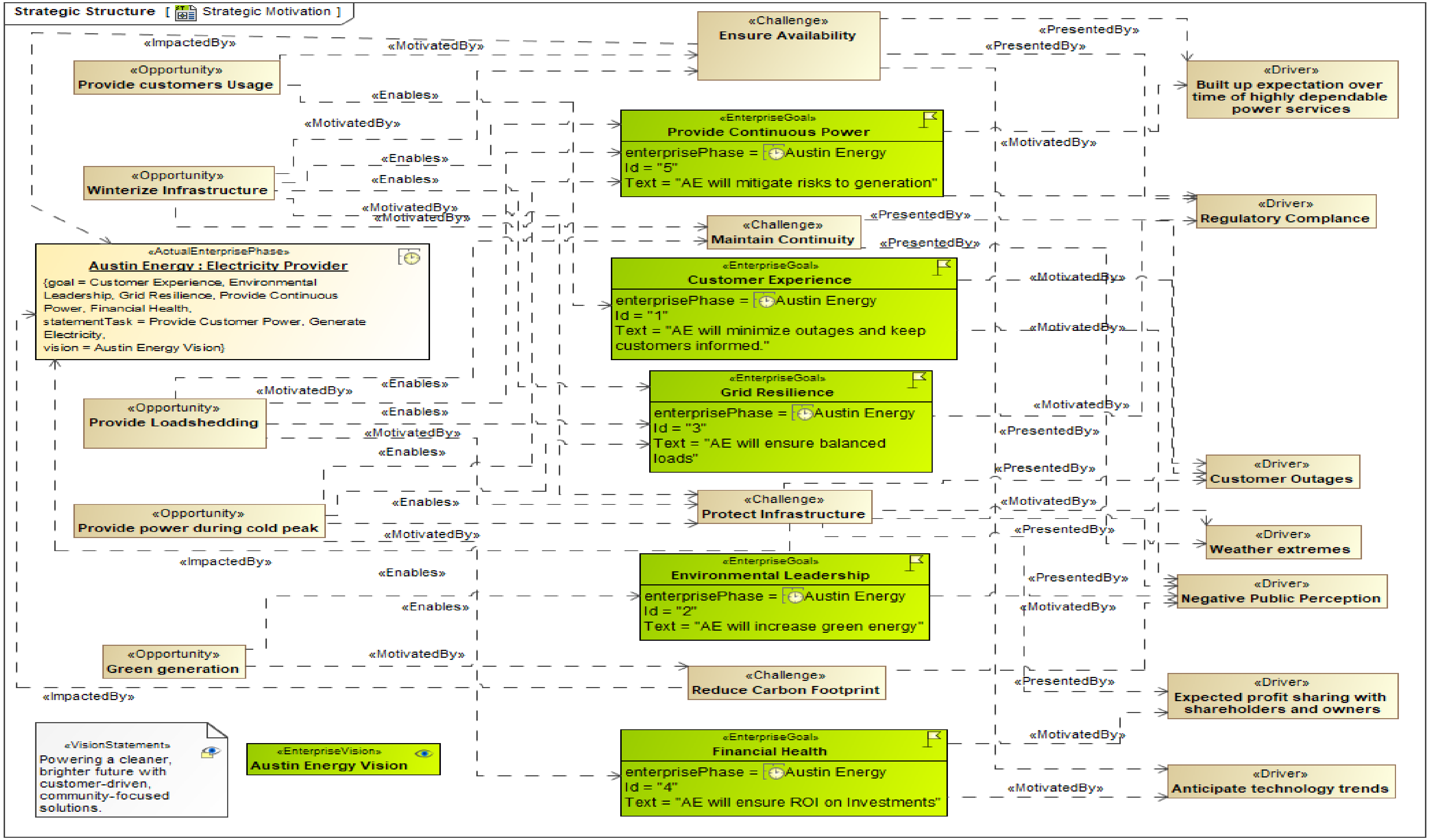
Concept	Definition
Driver*	Thing that forces us to work or act; that which urges you forward
Challenge*	A demanding or stimulating situation; a call to engage in a contest or fight
Enterprise State*	Condition with respect to circumstances or attributes
Capability	Ability to do something under particular conditions and environments, to achieve a desired effect.
Opportunity*	A possibility due to a favorable combination of circumstances
Risk*	A source of danger; a possibility of incurring loss or misfortune
Effect	A phenomenon that follows and is caused by some previous phenomenon
Outcome*	Something that happens or is produced as the final consequence or product

Strategic Motivation Diagram

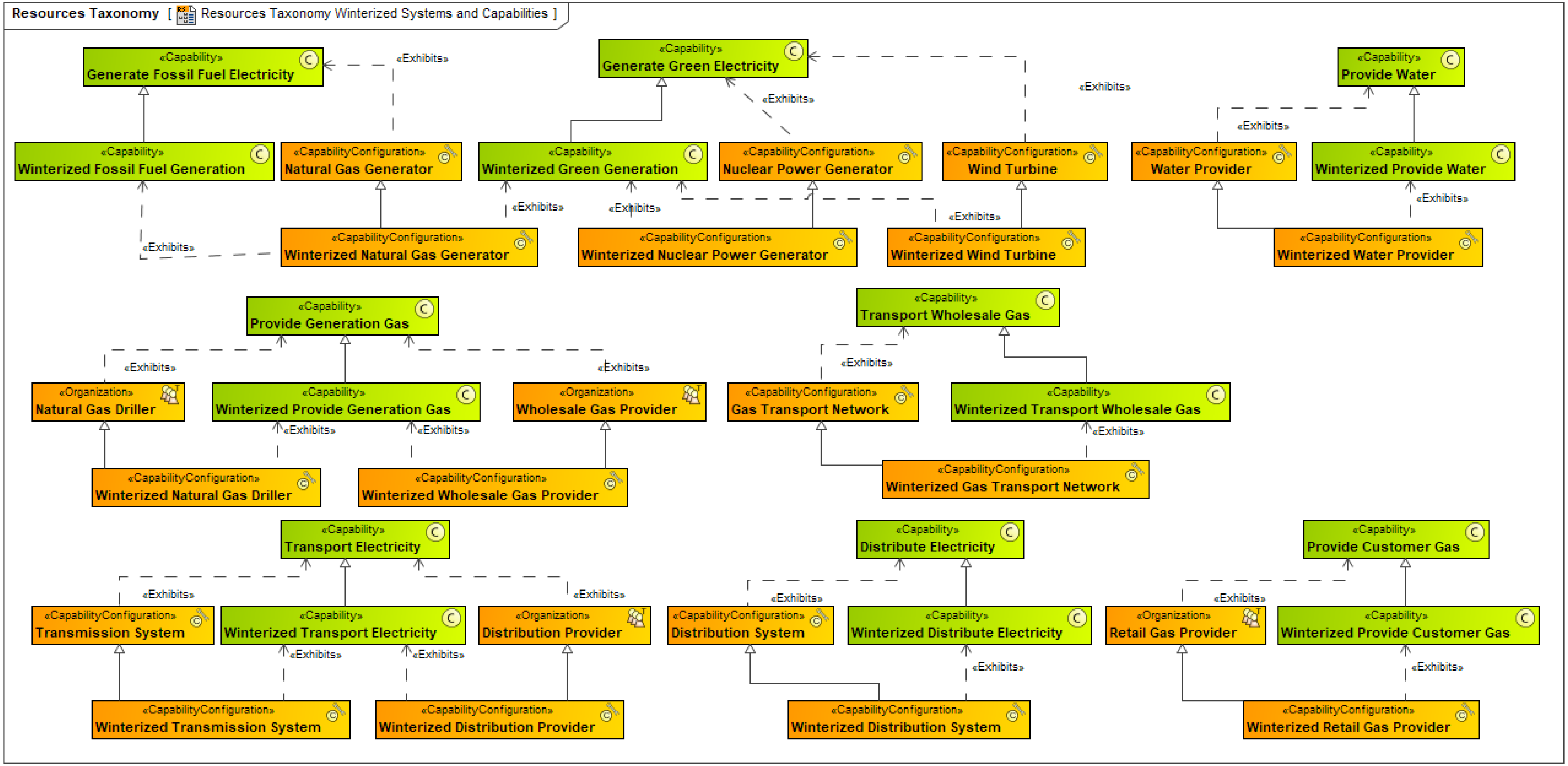
- **Drivers present Challenges to the enterprise**
- **Challenges are conditions that can be addressed by Opportunities**
- **Each Opportunity can present the circumstances for new Risks to the Enterprise**
- **Existing or new Capabilities can help the enterprise pursue these Opportunities**



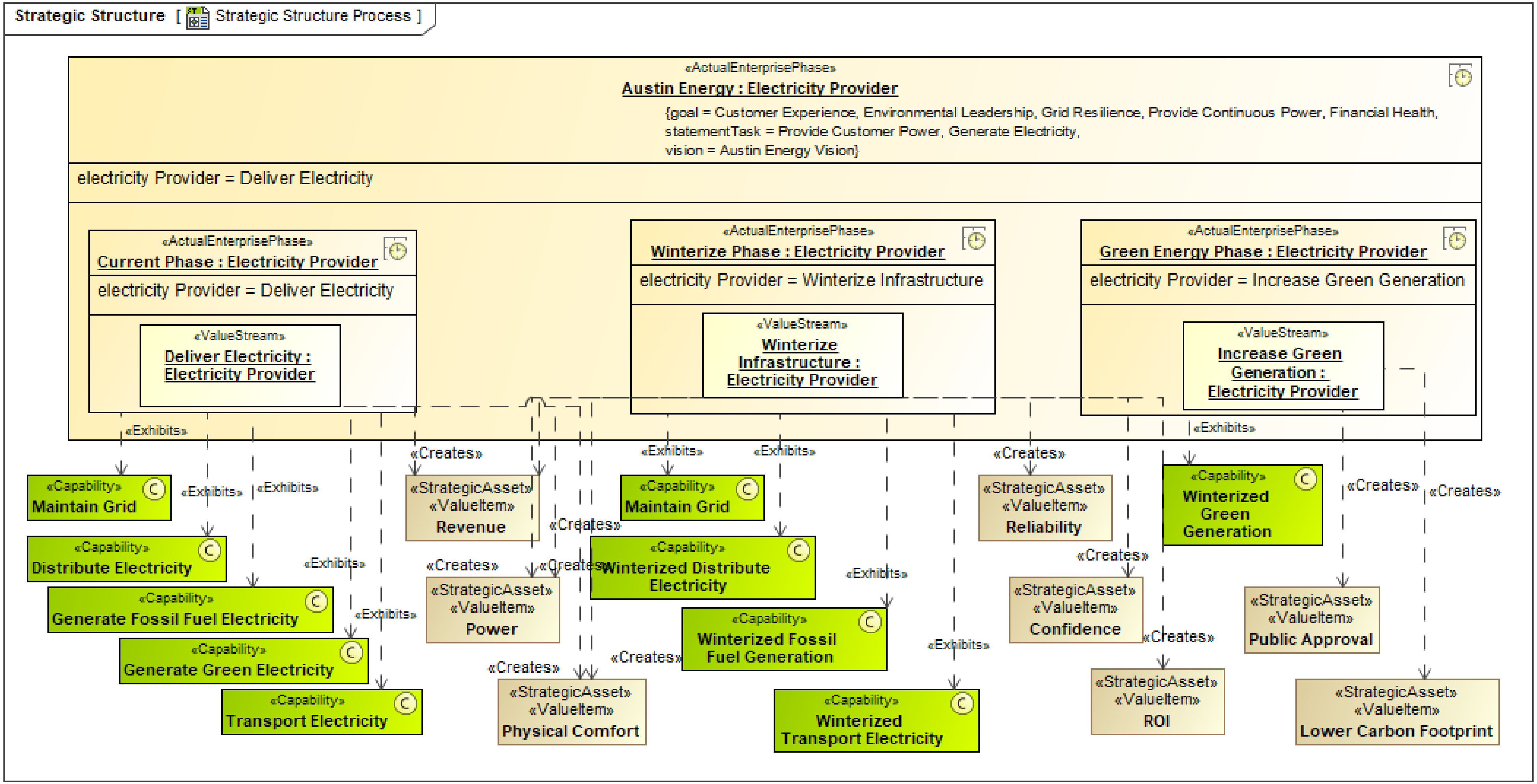
Strategic Motivation Diagram



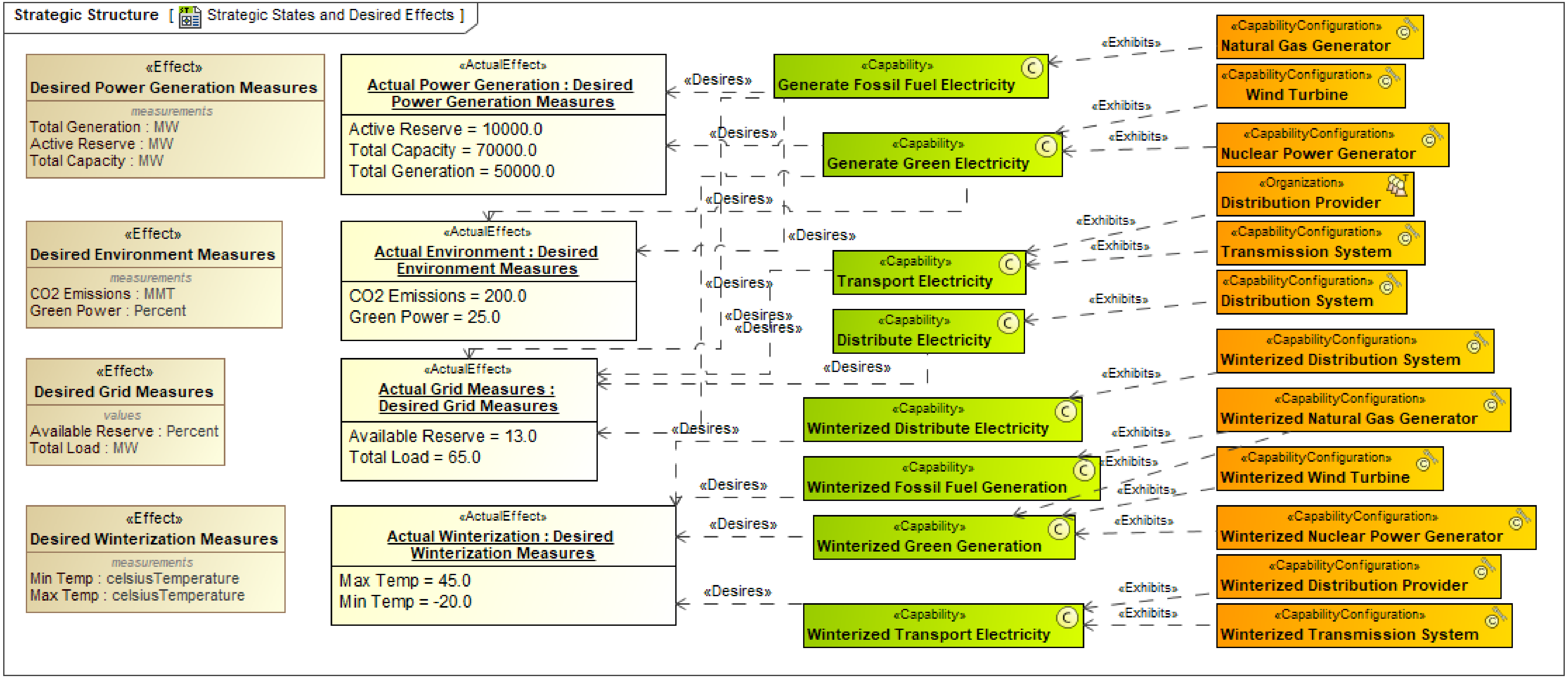
Winterized Capabilities & Resources



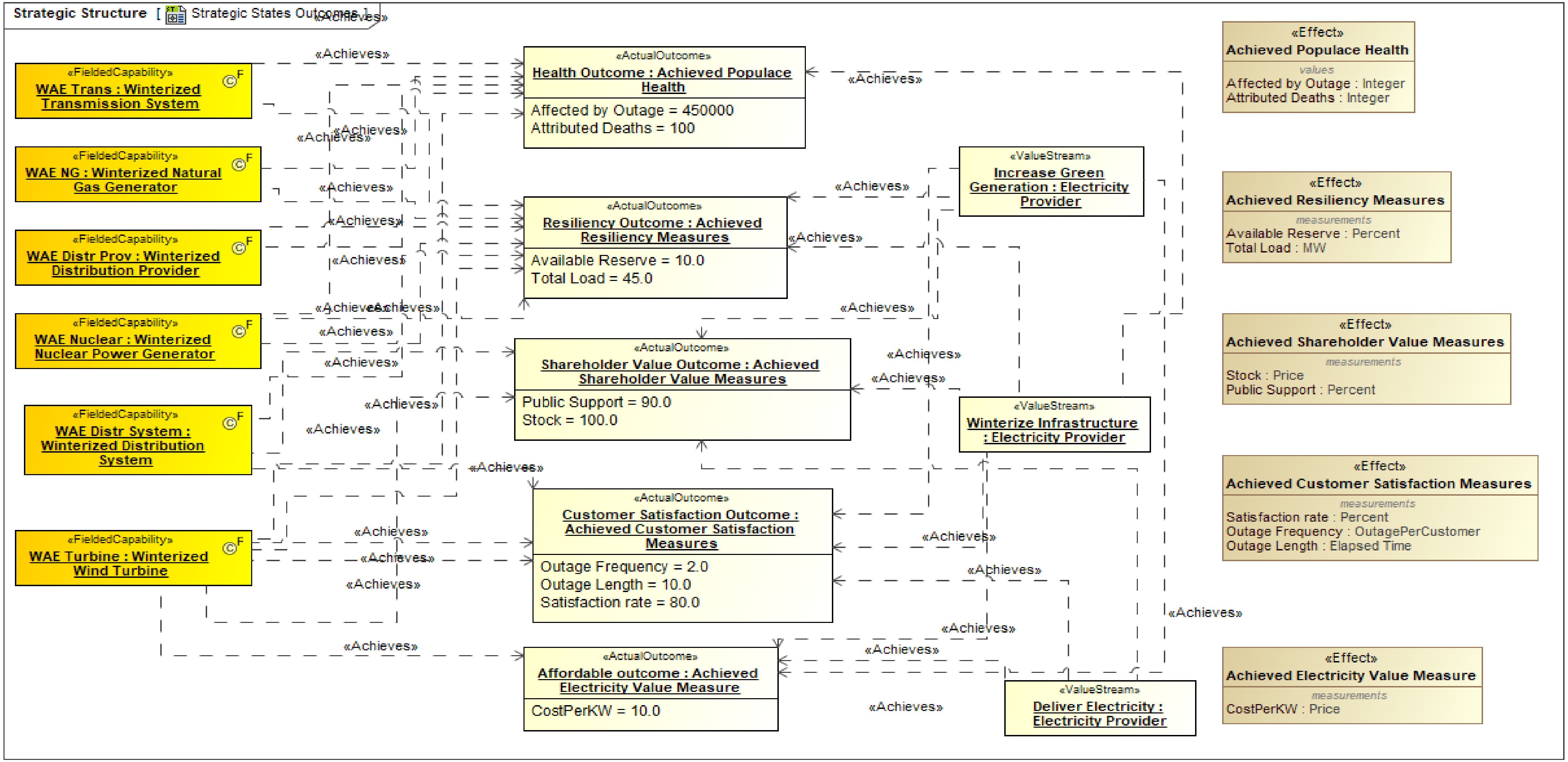
Strategic Structure Diagram

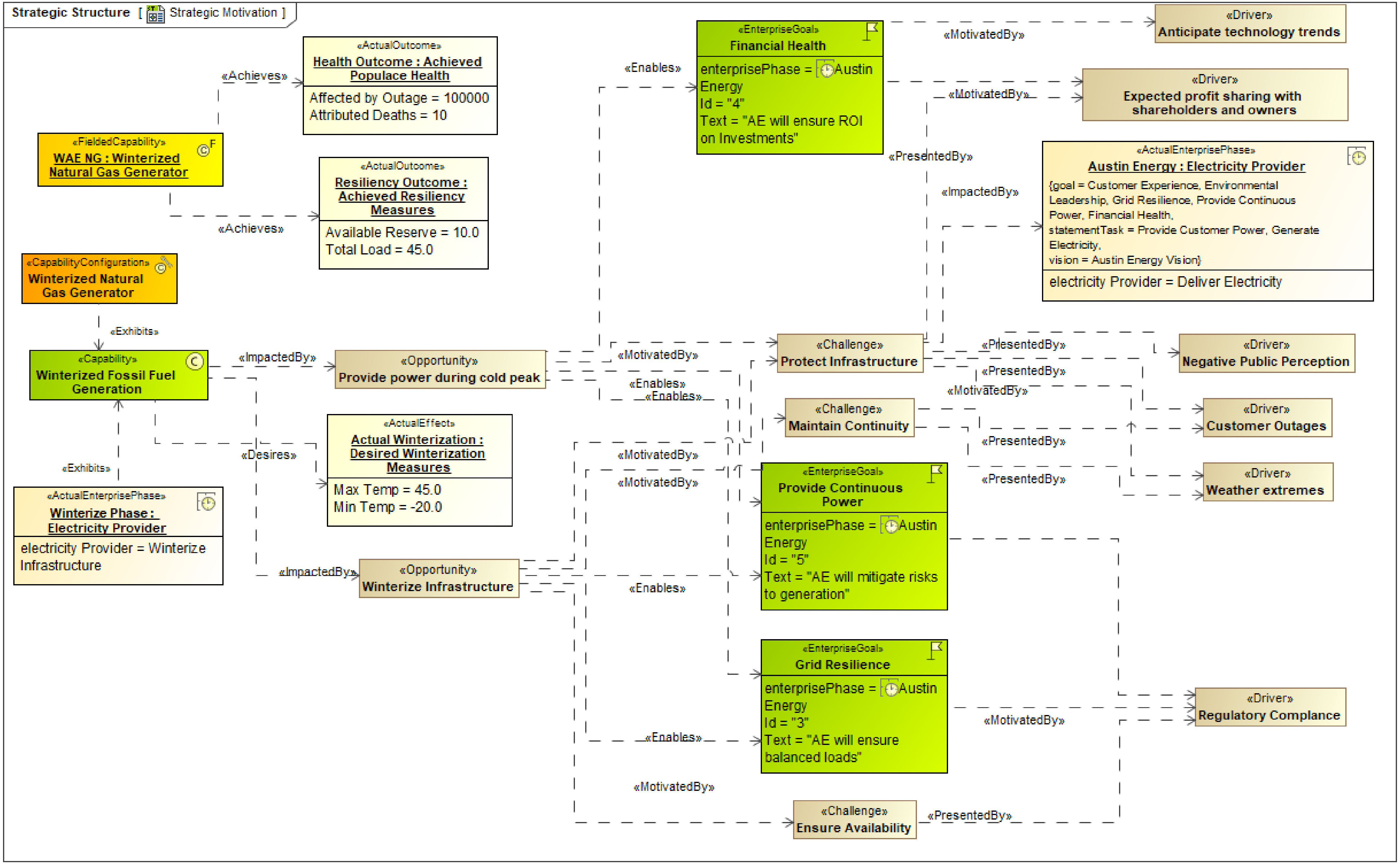


Strategic States Diagram (Effects)



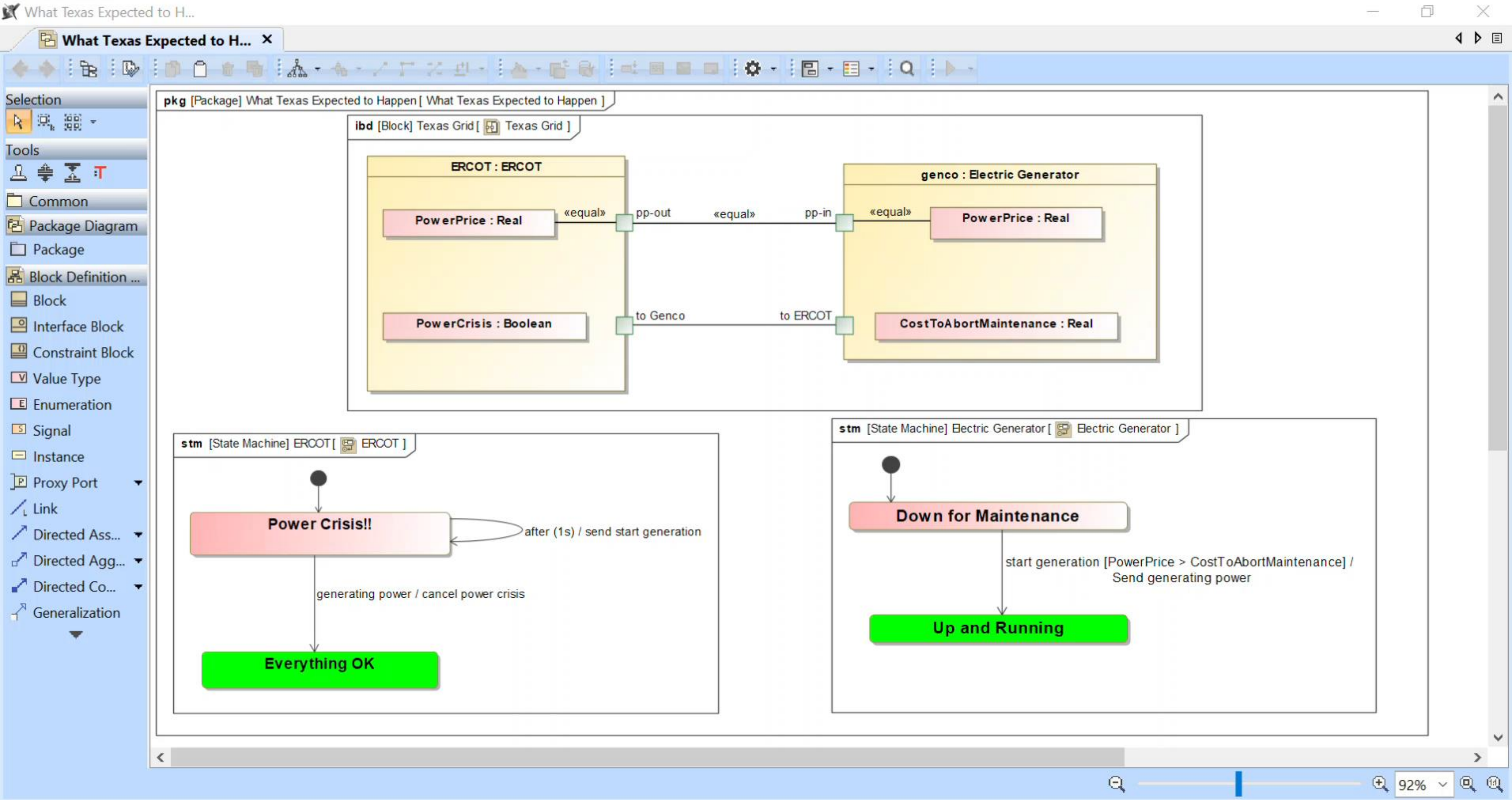
Strategic States Diagram (Outcomes)




Strategic Structure [Strategic Motivation]
«ActualOutcome»
Health Outcome : Achieved Populace Health
Affected by Outage = 100000
Attributed Deaths = 10
«Achieves»
«FieldedCapability»
WAE NG : Winterized Natural Gas Generator
«ActualOutcome»
Resiliency Outcome : Achieved Resiliency Measures
Available Reserve = 10.0
Total Load = 45.0
«Achieves»
«CapabilityConfiguration»
Winterized Natural Gas Generator
«Exhibits»
«Capability»
Winterized Fossil Fuel Generation
«ImpactedBy»
«Opportunity»
Provide power during cold peak
«ActualEffect»
Actual Winterization : Desired Winterization Measures
Max Temp = 45.0
Min Temp = -20.0
«Desires»
«Exhibits»
«ActualEnterprisePhase»
Winterize Phase : Electricity Provider
electricity Provider = Winterize Infrastructure
«ImpactedBy»
«Opportunity»
Winterize Infrastructure
«EnterpriseGoal»
Financial Health
enterprisePhase = Austin Energy
Id = "4"
Text = "AE will ensure ROI on Investments"
«Enables»
«MotivatedBy»
«Driver»
Anticipate technology trends
«MotivatedBy»
«Driver»
Expected profit sharing with shareholders and owners
«PresentedBy»
«ImpactedBy»
«ActualEnterprisePhase»
Austin Energy : Electricity Provider
{goal = Customer Experience, Environmental Leadership, Grid Resilience, Provide Continuous Power, Financial Health,
statementTask = Provide Customer Power, Generate Electricity,
vision = Austin Energy Vision}
electricity Provider = Deliver Electricity
«MotivatedBy»
«Challenge»
Protect Infrastructure
«PresentedBy»
«Driver»
Negative Public Perception
«Enables»
«Enables»
«PresentedBy»
«MotivatedBy»
«Challenge»
Maintain Continuity
«Driver»
Customer Outages
«PresentedBy»
«MotivatedBy»
«MotivatedBy»
«EnterpriseGoal»
Provide Continuous Power
enterprisePhase = Austin Energy
Id = "5"
Text = "AE will mitigate risks to generation"
«PresentedBy»
«Driver»
Weather extremes
«Enables»
«EnterpriseGoal»
Grid Resilience
enterprisePhase = Austin Energy
Id = "3"
Text = "AE will ensure balanced loads"
«Enables»
«MotivatedBy»
«Driver»
Regulatory Compliance
«MotivatedBy»
«Challenge»
Ensure Availability
«PresentedBy»

Model Simulation – Sunny Day

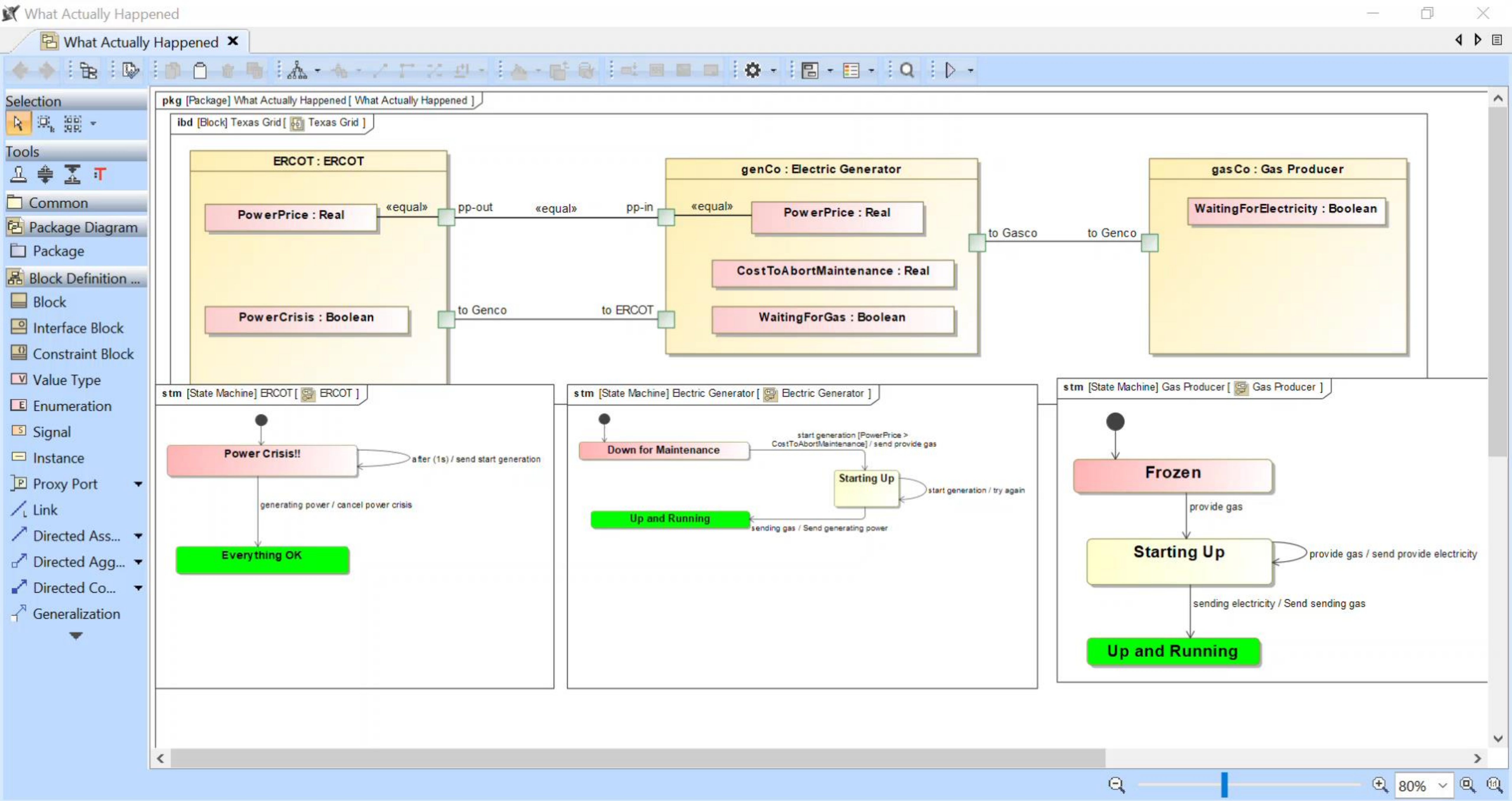
- **What Texas Expected to Happen**
  - Electric generator is down for maintenance
  - Crisis happens
  - ERCOT starts raising power price
  - Eventually the price gets high enough to make it worth it for the electric generator to abort the maintenance cycle and start generating
  - Crisis averted
- **Happy, happy, happy**



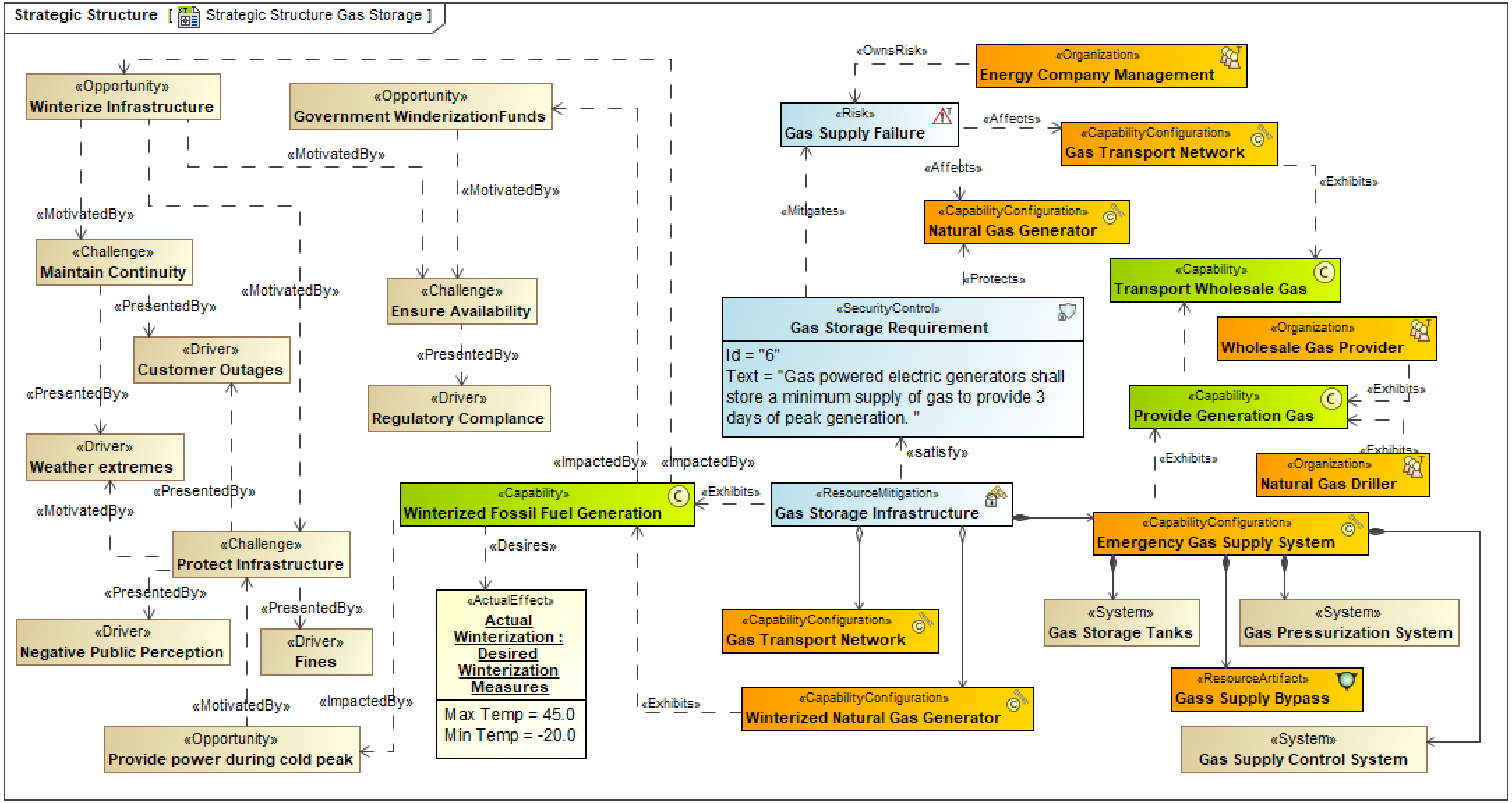
What Texas Expected to H...
pkg [Package] What Texas Expected to Happen [What Texas Expected to Happen]
ibd [Block] Texas Grid [Texas Grid]
ERCOT : ERCOT
PowerPrice : Real
«equal»
pp-out
«equal»
pp-in
«equal»
genco : Electric Generator
PowerPrice : Real
PowerCrisis : Boolean
to Genco
to ERCOT
CostToAbortMaintenance : Real
stm [State Machine] ERCOT [ERCOT]
Power Crisis!!
after (1s) / send start generation
generating power / cancel power crisis
Everything OK
stm [State Machine] Electric Generator [Electric Generator]
Down for Maintenance
start generation [PowerPrice > CostToAbortMaintenance] /
Send generating power
Up and Running
Selection
Tools
Common
Package Diagram
Package
Block Definition ...
Block
Interface Block
Constraint Block
Value Type
Enumeration
Signal
Instance
Proxy Port
Link
Directed Ass...
Directed Agg...
Directed Co...
Generalization
92%

Model Simulation – Frozen Day

- **What Actually Happened**
  - Same as before, but…
  - When the electric generator tried to start, there was no gas…. So they asked for gas.
  - But the gas producer was down because of no electricity …. So they asked for electricity
  - What systems engineers call a “Deadlock”
  - Both players end up stuck in start up
  - Price of electricity climbs endlessly
- **Unhappy, unhappy, unhappy**


What Actually Happened
Selection
Tools
Common
Package Diagram
Package
Block Definition ...
Block
Interface Block
Constraint Block
Value Type
Enumeration
Signal
Instance
Proxy Port
Link
Directed Ass...
Directed Agg...
Directed Co...
Generalization
pkg [Package] What Actually Happened [What Actually Happened]
ibd [Block] Texas Grid [Texas Grid]
ERCOT : ERCOT
PowerPrice : Real
PowerCrisis : Boolean
«equal»
pp-out
«equal»
pp-in
«equal»
to Genco
to ERCOT
genCo : Electric Generator
PowerPrice : Real
CostToAbortMaintenance : Real
WaitingForGas : Boolean
to Gasco
to Genco
gasCo : Gas Producer
WaitingForElectricity : Boolean
stm [State Machine] ERCOT [ERCOT]
Power Crisis!!
after (1s) / send start generation
generating power / cancel power crisis
Everything OK
stm [State Machine] Electric Generator [Electric Generator]
Down for Maintenance
start generation [PowerPrice > CostToAbortMaintenance] / send provide gas
Starting Up
start generation / try again
Up and Running
sending gas / Send generating power
stm [State Machine] Gas Producer [Gas Producer]
Frozen
provide gas
Starting Up
provide gas / send provide electricity
sending electricity / Send sending gas
Up and Running
80%

Updated Incentives and Mitigations



Can these models solve the problem?

- No, they can’t. However, they can help identify the problem. They can also go beyond the technical aspects and identify other problems and solutions.
- Multiple tools are available in the electrical industry for designing, managing, controlling, running, evaluating and forecasting the electric grid and its needs.
- These are specialty tools developed over a number of years that are well suited to the energy industry of the 20th century.
- The electric grid of the 21st century and beyond will need to cope with the smart grid, cyber-attacks, space weather, Electro-Magnetic Pulse (EMP) weapons, proliferation of clean energy sources, phase-out of fossil fuels, increased home generation, grid instability, etc.
- Systems, SoS, and enterprise engineering examine the entire problem and derive creative ways to cope with the problems of the 21st century and beyond.
- As Einstein said, “We can't solve problems by using the same kind of thinking we used when we created them.”
- Systems engineering will provide that new way of thinking, and MBSE for SoS with UAF in the form of a grid model integrated with specialty tools will provide the means to realize the solutions.

Future Research

- **Quantitative analysis**
  - Linking desired effects, actual effects, outcomes and system capabilities
- **Conflicting goal analysis**
  - This enterprise model lists the goals of Austin Electric. We should include the goals of ERCOT, the gas industry (all parts), water industry, business, industrial and residential customers, government, environmental, etc.
  - These can be compared, and conflicts identified
- **Value stream simulation**
  - Functional and state simulation to define high level functionality
- **Detailed risk and failure analysis**
  - Not at the component level, but at the enterprise level – several companies went bankrupt as a result of the grid failure.
- **Create stakeholder consumable views**
  - Translate the data into reports and graphics that enable decision making

Conclusion

- **Unlike Don Quixote, we should not see the windmills as evil monsters to be battled.**
  - Wind turbine generators were not the villains in this story, all the systems and actors contributed to the failure.
  - Wind turbine generators provide green energy and investing in them is the responsible thing to do.
  - However, we need a diverse, reliable and winterized array of generation sources.
- **Virtually all the entities involved (including homeowners) failed to invest in winterization due to lack of motivation and incentives.**
- **This resulted in frozen systems, degraded electric provision, & eventually frozen pipes and houses and several deaths.**
- **The Texas Grid failure of 2021 was a system of systems failure**
- **The Texas Legislature has mandated winterization of the generation systems.**
- **However, a wholistic winterization approach to the supply chain is required (including the windmills)**
  - This will ensure that we stay warm on those cold Texas winter nights, no matter how infrequent they are.

Thanks!

Any questions?

Matthew Hause
Principal Systems Engineer
System Strategy, Inc
MHause@systemxi.com

Lars-Olof Kihlstrom
Syntell
Stockholm, Sweden
Lars-Olof.Kihlstrom@syntell.se

References

- Attorney General, 2018, Attorney General Shapiro Announces $575 Million 50-State Settlement With Wells Fargo Bank, Available online from https://www.attorneygeneral.gov/taking-action/attorney-general-shapiro-announces-575-million-50-state-settlement-with-wells-fargo-bank-for-opening-unauthorized-accounts-and-charging-consumers-for-unnecessary-auto-insurance-mortgage-fees/
- Austin Energy Strategic Plan 2020-2025, 2020, Available from https://austinenergy.com/wcm/connect/fda4d3be-4615-4ca3-b131-b7527af2f7e9/AECorp172907ExternStrategPlan101117FinFin.pdf?MOD=AJPERES&CVID=lZ-uMW2
- BBC News, 2021, Reality Check team, Texas weather: Are frozen wind turbines to blame for power cuts? Available from https://www.bbc.com/news/world-56085733
- Brown, Ed, Newsweek, 2021, Available from https://www.newsweek.com/how-much-power-texas-renewable-coal-gas-wind-turbines-1570238
- Borberly, A. and Kreider, J. F. (2001). Distributed Generation: The Power Paradigm for the New Millennium. CRC Press, Boca Raton, FL. 400 pgs.
- Causalis, 2008, European Electricity Blackout, November 2006, http://www.causalis.com/EuropeanElectricityBlackout.pdf
- Con Edison, 2011, A Brief History of Con Edison, Available online at http://www.coned.com/history/electricity.asp
- Dillingham, D, Program Director, HARC, 2021, The Great Texas Blackout of 2021: How does this not happen again? Available from https://harcresearch.org/news/the-great-texas-blackout-of-2021-how-does-this-not-happen-again/?gclid=EAIaIQobChMI3PLA6c-e9AIVIG1vBB0vHQfzEAAYASAAEgI3W_D_BwE
- Epact, 1992, US Government. Available online at http://www1.eere.energy.gov/vehiclesandfuels/epact/pdfs/epact_titles_3-4-5-6-19.pdf
- El-Hawary, (1995), M., Electrical Power Systems: Design and Analysis, Wiley-IEEE Press, 808 pages
- Fairley, P, 02 Aug 2004, The Unruly Power Grid - Advanced mathematical modeling suggests that big blackouts are inevitable, Published in IEEE Spectrum
- Friedenthal, S., Moore, A., Steiner, R. Practical Guide to SysML: The Systems Modeling Language, Morgan Kaufman September 2008
- Fung, K, 2021, Newsweek Article, Greg Abbott Signs Sweeping Legislation to Prevent Another Weather Disaster from Crippling State, Available from https://www.newsweek.com/texas-gov-greg-abbott-signs-sweeping-legislation-prevent-another-weather-disaster-crippling-state-1598691
- Gilder, G, 2021, Life After Capitalism, the Information Theory of Economic, published in National Review.
- **Hartley, Dale, 2016, The Cobra Effect: Good Intentions, Perverse Outcomes - No loophole goes unexploited, Available from https://www.psychologytoday.com/us/blog/machiavellians-gulling-the-rubes/201610/the-cobra-effect-good-intentions-perverse-outcomes**
- **Hause, M. 2014. "SOS for SoS: A New Paradigm for System of Systems Modeling." Paper presented at the IEEE, AIAA Aerospace Conference, Big Sky, US-MT, 1-8 March.**
- **Hause, M., F. Dandashi, 2015. "UAF for System of Systems Modeling , Systems Conference (SysCon)." Paper Presented at the 9th Annual IEEE Systems Conference, Vancouver, CA-BC, 13-16 April.**
- Hause, M, 2017, "**Using MBSE to Evaluate and Protect the Electrical Grid as a System of Systems, presented at the 27th Annual INCOSE International Symposium, Adelaide, Australia.**
- Jackson, T, 2021, Big Takeaways From 7 Electric Utility Strategic Plans, Available from https://www.clearpointstrategy.com/electric-utility-strategic-plans/
- Lambermont, September 1, 2020, California Will Continue to Reap the Blackouts It Sows On grid reliability, Available from https://catalyst.independent.org/2020/09/01/california-blackouts-grid-reliability/?gclid=EAIaIQobChMI8eCy97ms9AIVsxXUAR2DhQBhEAAYASAAEgIvXvD_BwE
- Mazer, A. (2007). Electric Power Planning for Regulated and Deregulated Markets. John, Wiley, and Sons, Inc., Hoboken, NJ. 313pgs.
- Martin, J 2020, "Enterprise Architecture Guide for the Unified Architecture Framework (UAF)," presented at the INCOSE International Symposium.
- Martin, J 2022, Model-Based Capability Planning and Enterprise Portfolio Management, Submitted to the 32nd INCOSE International Symposium, Detroit, Michigan.
- NERC, 2004, North American Electric Reliability Council, Technical Analysis of the August 14, 2003, Blackout: What Happened, Why, and What Did We Learn? http://www.nerc.com/docs/docs/blackout/NERC_Final_Blackout_Report_07_13_04.pdf
- **Object Management Group (OMG). 2013. OMG2013-08-04:2013. Unified Profile for DoDAF/MODAF (UPDM) V2.1, http://www.omg.org/spec/UPDM/2.1/PDF**
- **Object Management Group (OMG), 2019. OMG2012-06-01.OMG Systems Modeling Language (OMG SysML™), V1.6, http://www.omg.org/spec/SysML/1.6/PDF/.**
- **Object Management Group (OMG), 2019a, The Unified Architecture Framework, (UAF) Version 1.1, Available from https://www.omg.org/spec/UAF**
- Object Management Group (OMG), 2022, The Unified Architecture Framework, (UAF) version 1.2, expected date of publication, March 2022.
- Patel, S., 2022, Powermag, Winter Freeze Testing Texas Power Grid Reforms, Available from https://www.powermag.com/winter-freeze-testing-texas-power-grid-reforms/
- Penney, V, Feb. 19, 2021, How Texas' Power Generation Failed During the Storm, in Charts, Available from https://www.nytimes.com/interactive/2021/02/19/climate/texas-storm-power-generation-charts.html
- Quick Electricity, 2021, Texas Electricity: Facts and Figures, Available from: https://quickelectricity.com/texas-electricity-facts/
- Segal, Troy, 2021, Enron Scandal: The Fall of a Wall Street Darling, Available online from https://www.investopedia.com/updates/enron-scandal-summary/
- Smith, A, 1776, The Wealth of Nations, published by W. Strahan and T. Cadell, London
- **US Department of Defense 2003, *Department of Defense Directive 5000.1. The Defense Acquisition System*, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Washington, DC (US).**
- US News, 2019, Energy Rankings, Measuring States' Energy Infrastructure, Available from https://www.usnews.com/news/best-states/rankings/infrastructure/energy
- Wikipedia, 2011, Available online, http://en.wikipedia.org/wiki/Northeast_Blackout_of_2003