

THE OKLAHOMA PIPELINE ENERGY STORAGE SYSTEM (OPESS) Functional ANALYSIS REPORT

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|  |  |  |
| --- | --- | --- |
| Document Name | Date | Reason for Change |
| Grinnell FAR | 9/2/22 | Initial Document |
| Grinnell FAR\_A | 9/5/22 | Revisions made per professor feedback |

Contents

[1 Functional Analysis Report Description 5](#_Toc113469822)

[2 OPESS ConOps 7](#_Toc113469823)

[2.1 System Need 7](#_Toc113469824)

[2.2 System Block Diagram 7](#_Toc113469825)

[2.2.1 OPESS Block Diagram 8](#_Toc113469826)

[2.2.2 ESS Block Diagram 8](#_Toc113469827)

[2.2.3 CaCS Block Diagram 9](#_Toc113469828)

[3 Functional Analysis 11](#_Toc113469829)

[3.1 Research 11](#_Toc113469830)

[3.2 Functional Decomposition 11](#_Toc113469831)

[3.3 Functional Linking 11](#_Toc113469832)

[4 Requirement Analysis 13](#_Toc113469833)

[4.1 Motivation for Requirement Update 13](#_Toc113469834)

[4.2 System Requirements 13](#_Toc113469835)

[4.3 Requirement Verification 13](#_Toc113469836)

[4.4 Key Performance Parameters 14](#_Toc113469837)

[4.5 Requirements Metric 16](#_Toc113469838)

[5 Earned Value Management 17](#_Toc113469839)

[5.1 Schedule 17](#_Toc113469840)

[5.2 Milestones 17](#_Toc113469841)

[5.3 EVM 18](#_Toc113469842)

[5.4 CPI and SPI Index 19](#_Toc113469843)

[6 Risk 19](#_Toc113469844)

[6.1 Risk 1: Weather 20](#_Toc113469845)

[6.2 Risk 2: Earthquake 20](#_Toc113469846)

[6.3 Risk 3: Residual Natural Gas 21](#_Toc113469847)

[6.4 Risk 4: Cyber Security 21](#_Toc113469848)

[7 References 22](#_Toc113469849)

[8 Appendix A: Requirements 23](#_Toc113469850)

[8.1 Originating Requirements 23](#_Toc113469851)

[8.2 Design Constraints 27](#_Toc113469852)

[8.3 Performance Requirements 32](#_Toc113469853)

[8.4 Functional Requirements 41](#_Toc113469854)

[9 Appendix B: Functional Behavioral Model 57](#_Toc113469855)

[9.1 Function List 57](#_Toc113469856)

[9.2 Behavior Model 59](#_Toc113469857)

[10 Appendix C: Verification Cross Reference Matrix 129](#_Toc113469858)

[12 Appendix D: Functional Traceability Matrix 148](#_Toc113469859)

Table of Figures

[Figure 1: OPESS Block Diagram End of FAR Version 8](#_Toc113294854)

[Figure 2:ESS Block Diagram End of FAR Version 9](#_Toc113294855)

[Figure 3: CaCS Block Diagram End of FAR Version 10](#_Toc113294856)

[Figure 4: OPESS Functional Hierarchy Diagram 11](#_Toc113294857)

[Figure 5: Functional Analysis Report Schedule 17](#_Toc113294858)

[Figure 6: CPI/SPI 19](#_Toc113294859)

[Figure 7: Rick 1 Weather 20](#_Toc113294860)

[Figure 8: Risk 2 Earthquake 20](#_Toc113294861)

[Figure 9: Residual Natural Gas 21](#_Toc113294862)

[Figure 10: Risk 4 Cyber Security 21](#_Toc113294863)

Table of Tables

[Table 1: MOE Summary 6](#_Toc113294864)

[Table 2: Scenario Summary 6](#_Toc113294865)

[Table 3 List of Solution Needs 7](#_Toc113294866)

[Table 4: Requirement Type 13](#_Toc113294867)

[Table 5: Verification Method 14](#_Toc113294868)

[Table 6: Key Performance Parameters 14](#_Toc113294869)

[Table 7: KPP Description 14](#_Toc113294870)

[Table 8: Requirements Metric 16](#_Toc113294871)

[Table 9:Milestones 17](#_Toc113294872)

[Table 10: EVM 18](#_Toc113294873)

# 1 Functional Analysis Report Description

The **Functional Analysis Report (FAR)** will be delivered as the third delivery of the **Oklahoma Pipeline Energy Storage System (OPESS)**. This report will be composed of a Concept of Operations as well as an analysis of the developed function. Additionally, a requirement analysis will be present in this document as additional requirements were developed during the creation of functions. Schedule, EVM and CPI/SPI will also be discussed during this project. The risks first detailed in the OPESS proposal will be updated with any risk reduction efforts that were performed in the functional development phase of the OPESS Project.

The concept of operations will provide a description of the functional need that the OPESS aims to fill. It will focus on spelling out the current makeup of the Oklahoma power grid, its increasing reliance on renewable sources of energy and why a new energy solution will be needed to meet future demand. After that, the ConOps will dive further into the design of the OPESS system through the use of block diagrams in an attempt to flesh out the two subsystems that compose the OPESS.

The functional analysis section with not in and of itself list out the requirements. A full list of functions and requirements can be found in the Appendixes below. Functions were developed during this phase and the requirements developed during both this report as well as the Requirement Analysis Report (RAR) will be linked to these functions to confirm full traceability. The requirement analysis section will consist of tables discussing the types of requirements that were written and how they plan to be tested initially. A further analysis of the test plan with possible updates will be provided in the Test Procedure delivery at a future date.

During the Requirement Analysis phase of the OPESS, a block diagram was developed for use in creating both requirements as well as functions. These requirements and function were both added into CORE and linked together to assure full traceability. This traceability can be found in Appendix 8.

The functions developed from the block diagram are broken down to their logical end points. In some cases, that end point might be just 4 levels down though in most cases it’s typically 5. Beyond this level it was found that the functions became to hardware or software specific for something that’s supposed to be functionally descriptive.

This document will also provide an update of the EVM as it stands as of this writing. Schedule updates, deliveries, the WBS and SPI/CPI will be discussed in this section

Risks will be the last real section of the FAR. In this section, the risks outlines in the initial proposal will be updated and new risk reduction techniques developed during the requirement development stage will be taken into account.

Lastly, several appendixes will be attached to this document. These appendixes will be a listing of requirements, functions and a cross reference matrix. Since this is fairly long winded and not written in a form conducive to a report, it was thought best to keep it in a separate format for reference purposes.

These appendixes consist of reports generated from CORE. Requirements, function and traceability are all present and verifiable there. The information listed includes requirements, functions, EFFBD interface diagrams and N2 charts. Finally, in Appendix D, all functions are listed out with the requirements they represent as well as the input and output of that particular function.

All KPP’s listed in section 3.5 trace to MOE 2 through MOE 4. These MOEs can be found in the table below. These remain unchanged from the RAR.

Table : MOE Summary

|  |  |
| --- | --- |
| MOE Number | Summary |
| MOE 1 | The energy efficiency of the OPESS must be high enough to be of worth to the market. |
| MOE 2 | The ESS must be able to store energy on the time span of months to years. |
| MOE 3 | The OPESS much adhere to proper cyber security standards. |
| MOE 4 | The ESS should be able to stand up to the elements. |
| MOE 5 | The OPESS must not produce carbon emissions. |

MOE 1 was left was not referenced by the KPPs since that particular MOE is really more of a market and financial requirement. This MOE is still an important one to have listed and reference as this requirement will ultimately be what decides the viability of the OPESS system.

The scenarios listed in the proposal, which can also be found below, were important to the creation of the OPESS FAR, however, they were a bit generic. The OPESS works in much the same way as a big, mechanical battery and in theory, should be able to do all the things a battery can do. As such, scenario 1 through 3 may be a bit generic. They are however, interesting discussion points and would be extremely important when discussing MOE 1.

Table : Scenario Summary

| Scenario Number | Summary |
| --- | --- |
| Scenario 1 | An overgeneration of power has led to a surplus of electricity on the grid. The OPESS store that power to keep the grid from being overloaded. |
| Scenario 2 | An under generation of power has led to a potential brownout situation. The OPESS will generate power using it’s stored reserves. |
| Scenario 3 | The OPESS system both generates and stores power on the grid at the same time. This smooths out the variates in the demand curve allowing for a better maintained grid. |

# 2 OPESS ConOps

## 2.1 System Need

In 2010 Oklahoma mandated that 15% of the state’s energy needs be provided by some form of renewable energy source. As early as 2012 the state surpassed that goal (Popovich & Plumer, 2020). In 2021, the amount of energy produced by renewable sources accounted for 45% of the state’s energy needs. That number continues to increase as new wind projects are stood up and roof top solar becomes more popular. Unfortunately, wind and solar are not a source of consistent power. When the sun goes down homeowners are forced to either pull power from a grid that still produces energy primarily from dirty sources or from an expensive battery pack. High pressure systems can also move in, causing time periods of low wind energy production or worse yet, strong winds can come in during storm season and produce an excess of wind energy, forcing wind turbines offline.

The solution is to install large amounts of grid level energy storage. This will help even out the peaks and valleys of energy production, allowing energy produces on high energy days to be used on low energy days. Batteries are expensive and will compete with electric cars as their demands rises and pumped hydro can’t really be used in Oklahoma as the state neither gets the required amount of rain or has enough in the way of mountains to make it practical.

What the state does have in abundance are natural gas wells. It is through the use of this resource common to the state that a form of green energy storage can be developed. A list of solution needs can be found is table 3.

Table List of Solution Needs

|  |  |  |
| --- | --- | --- |
| Number | Name | Description |
| 1 | Extra Storage | The OPESS needs to be able to store extra energy from renewable sources during times of over production. |
| 2 | Low-Cost Storage | The OPESS needs to be able to store energy produced on the grid during low rates for use during times of high rates |
| 3 | Long Term Storage | The OPESS needs to be able to store energy for a significant amount of time with minimal loss. This will be measured on the timeframe of months to years. |
| 4 | Grid Scale Storage | The OPESS needs to be able to provide an energy storage solution that can be maintained on a grid level. |

## 2.2 System Block Diagram

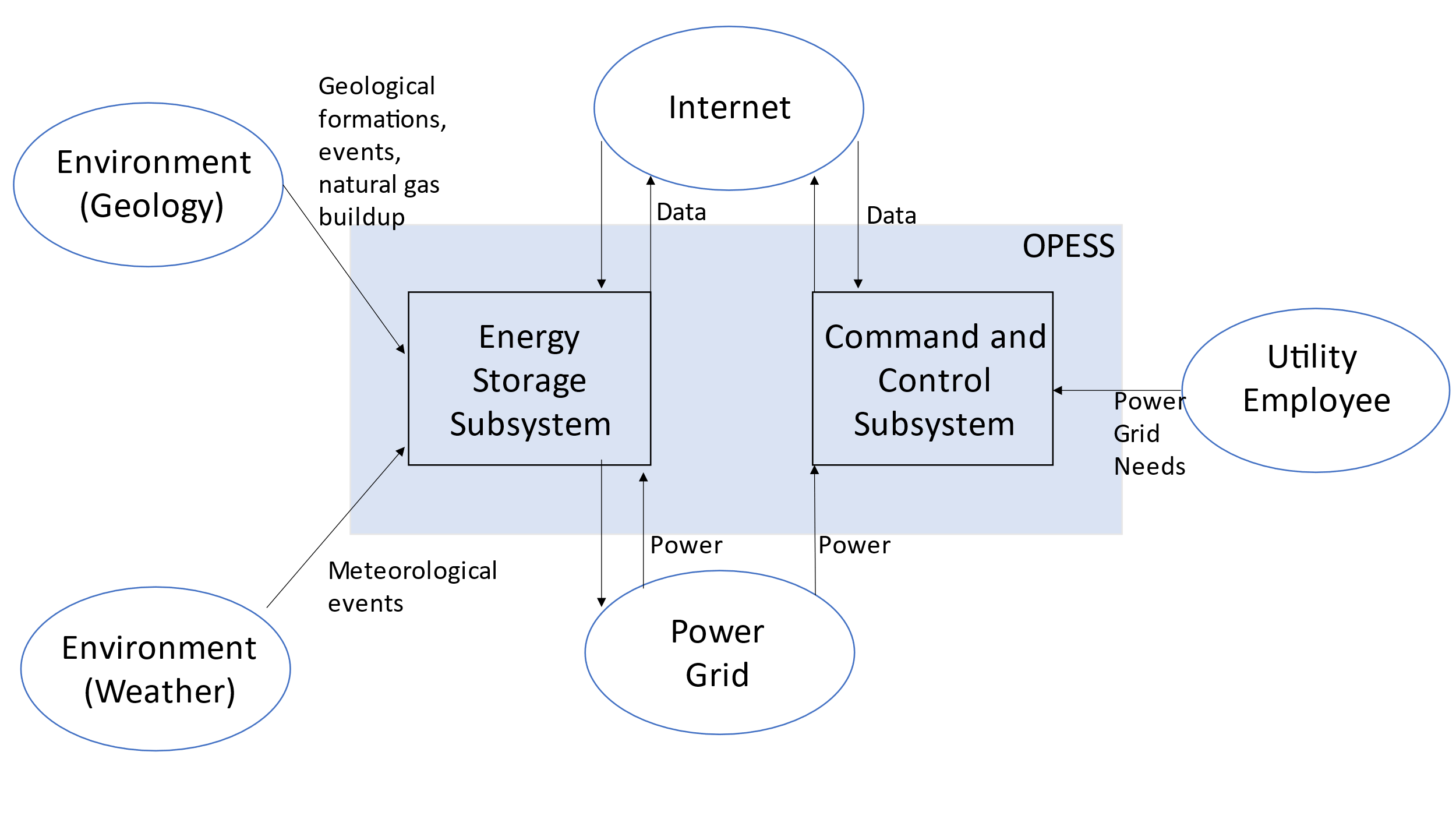
The block diagrams did not change though there were some modifications that were done building function in CORE that represented the behavior of the block diagrams. This is specifically in reference to the EFFBD diagrams present in CORE. When developing those diagrams is was discovered that they don’t radially allow for the two way flow of information through their diagram. As such, when developing the functions, on occasion a single block diagram might represent two almost identical EDDBD’s so that one function could represent data flowing into a device and one might represent data flowing out of that device. In the block diagram, this is easier to represent. As such, while the block diagram did not change between the RAR and the FAR, a further level of detail was still identified during the creation of functions and can be found represented in the functions below.

### 2.2.1 OPESS Block Diagram

The OPESS is composed of two major subsystems. The first is the Energy Storage Subsystem (ESS). The ESS is the actual storage system of the OPESS system. Functionally, it pulls power off the grid, compressed air for storage in spend natural gas wells, and then used that gas to spin a turbine for use on the grid. Since this device is outside, it is exposed to the elements and will thus need to be protected.

The second major subsystem is the Command-and-Control Subsystem (CaCS). As its name suggests, it performs the command-and-control functionality of the OPESS system. The CaCS allows communication between the OPESS and other utility companies and plants that might be powering the grid at the time. The CaCS communicated with the ESS over a secured internet connection.

Figure : OPESS Block Diagram End of FAR Version

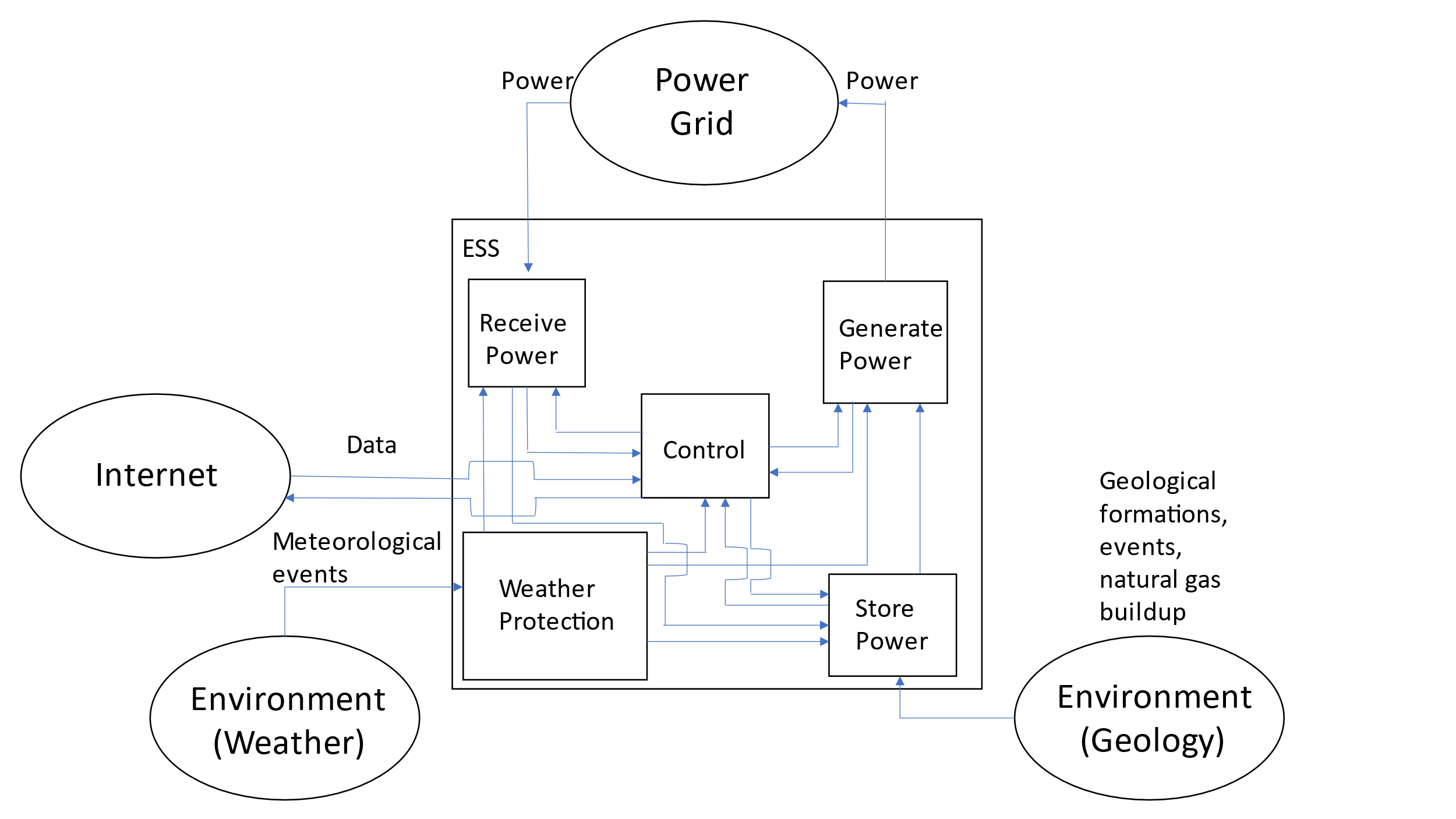


### 2.2.2 ESS Block Diagram

The ESS is the heart of the OPESS. It is composed of 5 functions, receive power, store power, generate power, a control node and weather protection. The primary function of the ESS is to act as a battery, hence the first three functions, however, unlike a batter, this is a complicated piece of equipment with lots of moving parts. A localized control note will have to be included in order to tell the individual components of the ESS how to behave. Additionally, this node will communicate with the CaCS and report and health and status issues the ESS might be experiencing.

Additionally, per risk 1, the ESS will be exposed to the elements on a regular bases and Oklahoma is famous for its bad weather. The final function, weather protection, is a risk reduction function meant to protect the ESS.

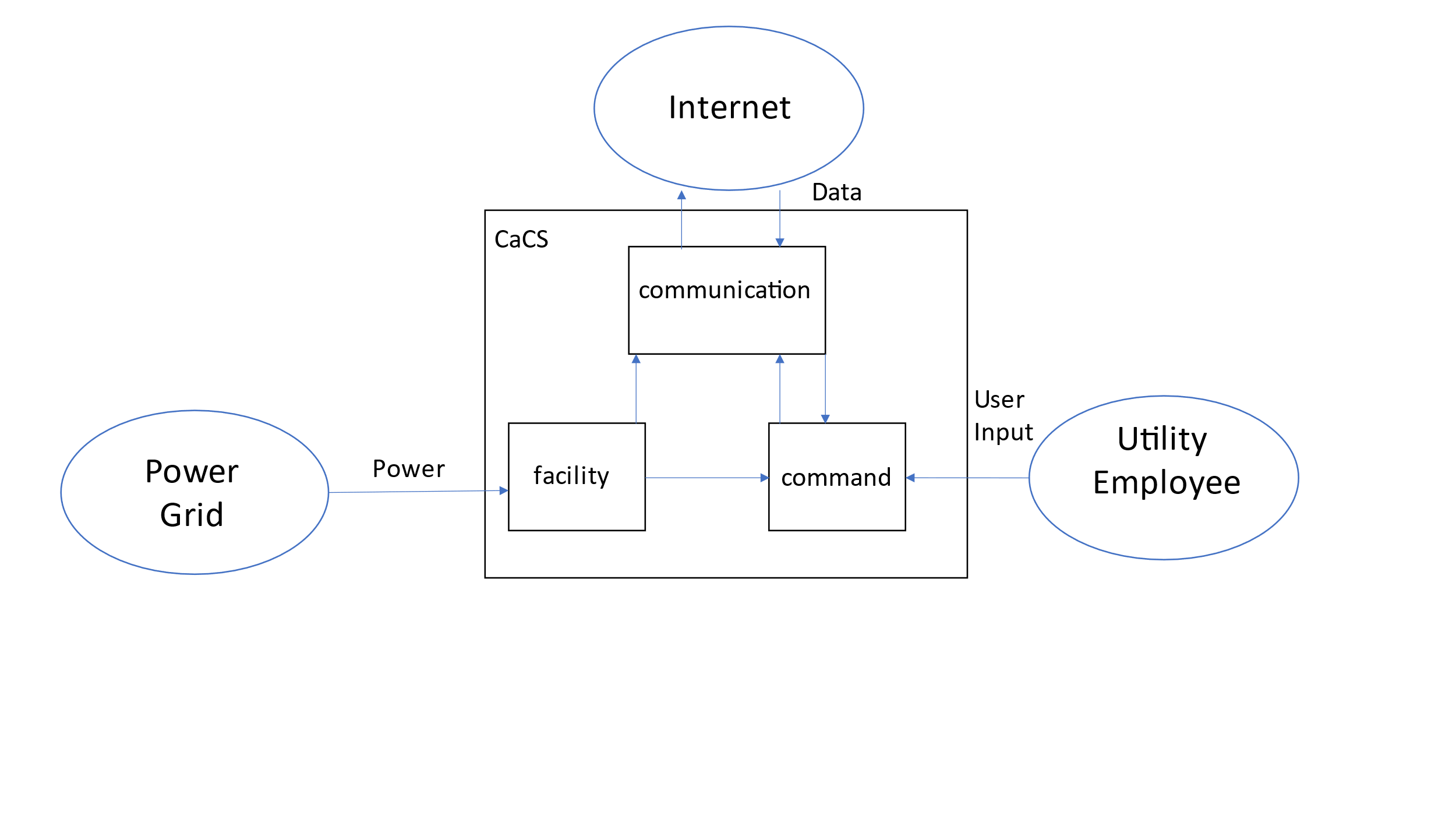
Figure :ESS Block Diagram End of FAR Version



### 2.2.3 CaCS Block Diagram

The CaCS is the brains of the OPESS system. It exists primarily as a an office space that allows utility workers, economists and engineers to communicate with other facilities both locally and across state lines in an effort to figure out what the future and current electrical needs will be. The CaCS will be able to allow employees access to modeling software in an effort of predict the future needs of the OPESS system on the grid. The CaCS will also allow employees to log into the ESS from their desk, monitor health and status and even control the ESS without having to go into the field. This will be helpful as issues can be diagnosed and handled without sending out technicians into the field.

Figure : CaCS Block Diagram End of FAR Version



# 3 Functional Analysis

## 3.1 Research

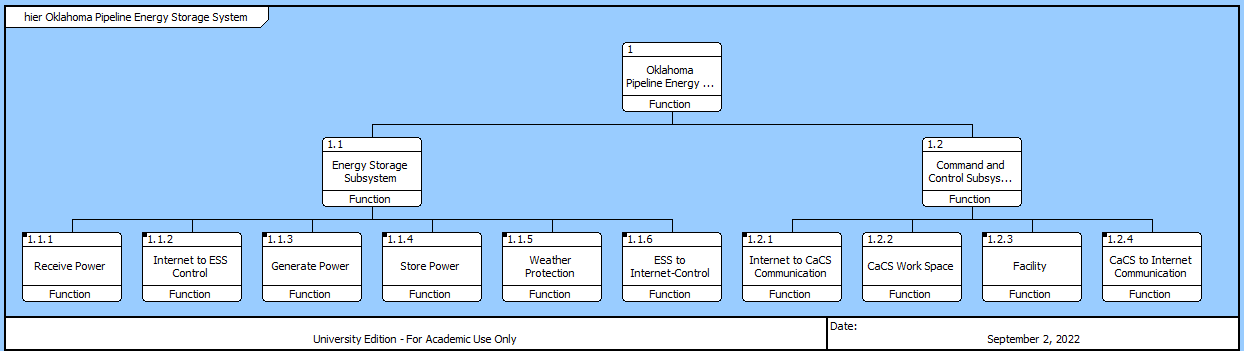
Research and interviews were conducted during the Requirement Analysis phase. During that phase, 104 requirements and 26 block diagrams were developed and saved in either CORE or power point. These requirements and block diagrams are what was used during the functional development portion of this project.

All in all, 75 functions were developed as a part of the Functional Development process. Of those 75 requirements, all were broken down to at least 4 levels of detail with most being broken down to 5. This was done to ensure that the functional detail of the system was specific enough to actually be useful during the future trade studies and physical breakdown reports.

## 3.2 Functional Decomposition

At a high level the OPESS system can be broken up into two functions, the ESS, which is the actual energy storage device, and the CaCS which acts as the command-and-control center for the whole OPESS. These functions can then themselves be further broken down several levels to further develop the necessary detail to describe the OPESS. The functional breakdown to three levels can be found in figure 4.

Figure : OPESS Functional Hierarchy Diagram



It is of importance to note that function 1.1.2 and 1.16 read to be almost identical. This is because they really are the same function but represent data flowing in two different directions. CORE, when building the EFFBD graphs, did not allow for two-way data transfer. Normally this might be a good thing, but when communication is established over the internet to a command site, maintaining that two-way conversation critical. As such, this function was broken down into two related functions. One receives information from the internet and one sends it.

Surprisingly, this actually comes with a little bonus. Cyber security has been a major factor during the development of the OPESS. So much so in fact that that risk 4 is entirely dedicated to it. By breaking the internet connection up into both incoming and outgoing functions, more detail can be discovered as to what kinds of information assurance needs to be implemented of this program.

## 3.3 Functional Linking

All functions developed under the FAR are linked together and model the function flow of the full OPESS. EFFBD charts and N2 diagrams can be found in Appendix B of the FAR and demonstrate this linking. Additionally, each function ties to at minimum, one requirement though several functions tie to many. Additionally, requirements can tie to multiple functions depending on if the execution of that requirement requires more then one function to perform it. Appendix D lists out all the functions, ordered by function ID, and lists what requirements they trace to as well as what input and output that function might require. The Appendix D table reads a lot like the EFFBD tables except written out instead of being a graphical representation of the information. Again, requirements are included in Appendix D for full tracability.

# 4 Requirement Analysis

## 4.1 Motivation for Requirement Update

While mapping requirements to functions, it was noted that a good portion of the functions defined did not have a corresponding requirement to justify it. This was because several requirements that were originally written to support these functions had been rewritten during the RAR development to be more physical requirements then functional. As such, an additional 25 requirements were written that were not a part of the original RAR. The analysis in the section represents another analysis of the requirements developed during both the RAR and FAR phases.

## 4.2 System Requirements

The requirements written for the OPESS system can be broken up into four different types:

Originating Requirements: The requirements stem from interviews from experts on various topics. They sometimes fill a performance or functional role in the OPESS system and can mostly be found labeled as both a originating and a performance/functional requirement.

Design Constraint: Design Constraints are choices that were made on the part of a requirement to achieve a goal. For example, “shall store energy” may be a functional phrase but “shall use a natural gas well” is a design choice on the part of the OPESS system.

Performance Requirements: Performance Requirements are any requirement that specifies some measure of performance of the OPESS system. These can be found as percentages, amounts or minimal standards as in the case of some software requirements.

Functional Requirements: Functional Requirements are requirements that provide or describe a function of the system. The phrase “shall store energy” describes a function of the OPESS system.

Table : Requirement Type

|  |  |
| --- | --- |
| Requirement Type | Number |
| Originating Requirements | 15 |
| Design Constraints | 21 |
| Performance Constraints | 43 |
| Functional Constraints | 64 |
| Total | 143 |

Additionally, since some of the Originating Requirements can double as both Functional or Performance most of them have actually been counted twice in the OPESS system with the exception of one. As such, that 144 number presented in Table 2 should actually read 129.

## 4.3 Requirement Verification

The requirements are verified through four verification methods.

Inspection: An inspection requirement is any requirement that can be verified via looking or some form of observation. Potential examples could be something like confirming a piece of software is coded per requirement or looking at a documented spec from a supplier.

Analysis: An analysis requirement is any requirement that requires multiple runs so that data can be built up. This data can then be analyzed to confirm that the behavior meets the requirement.

Demonstration: A demonstration requirement is any requirement that requires a demonstration of the functionality. An example might be like confirming that a pipe can hold up to 30 psi. Once the pipe is filled to that level, the requirement passes.

Test: A test requirement is any requirement that requires some form of formal test procedure. These can be related to demonstration requirements but typically require confirming consistent behavior of the system under multiple situations.

Table : Verification Method

|  |  |
| --- | --- |
| Verification Method | Number |
| Inspection | 37 |
| Analysis | 16 |
| Demonstration | 48 |
| Test | 28 |
| Total | 129 |

## 4.4 Key Performance Parameters

Key performance parameters (KPP’s) are requirements that were developed specifically to dictate key functions or standards important to the OPESS. These requirements form the backbone of the system.

Table : Key Performance Parameters

|  |  |
| --- | --- |
| Key Performance Parameters | Number |
| True | 12 |
| False | 117 |

Table : KPP Description

| KPP # | Req. # | Req. Name | Req. Description | Quantitative Vs. Qualitative | Verification Method |
| --- | --- | --- | --- | --- | --- |
| 1 | 1.1.1.5 | ESS Internet Interface | The ESS control node shall maintain a secure connection with the CaCS. | Qualitative | VerificationRequirement Test |
| 2 | 1.1.2.1.3 | ESS Generator Storage Interface | The ESS generator shall use compressed air coming from the natural gas well to spin a turbine and generate power. | Qualitative | VerificationRequirement Demonstration |
| 3 | 1.1.2.4.1 | ESS Carbon Capture Percent | The ESS carbon capture system shall remove no less than 50 percent of the hydrocarbons from the compressed air. | Quantitative | VerificationRequirement Test |
| 4 | 1.1.3.2.2 | ESS Storage Time | The ESS storage shall be able to keep compressed air for a period of up to 1 year. | Quantitative | VerificationRequirement Demonstration |
| 5 | 1.1.3.3.2 | ESS Storage Gas Safety Sensor | The ESS pressurized connection shall have an emergency release when the gas mixture reaches 4% according to the sensors. | Quantitative | VerificationRequirement Test |
| 6 | 1.1.3.3.4 | ESS Storage Leak | The ESS shall not allow the pressurized connection to leaked at a rate of more than 5% a year. | Quantitative | VerificationRequirement Test |
| 7 | 1.1.3.3.5 | ESS Storage Pressure | The ESS pressurized connection shall be able to handle up to 300 PSI. | Quantitative | VerificationRequirement Test |
| 8 | 1.1.4.1.1 | ESS Air Compressor | The ESS pump shall compress air and send it to the natural gas interface at pressure. | Qualitative | VerificationRequirement Demonstration |
| 9 | 1.1.5 | ESS Weather | The ESS shall be protected from the weather. | Qualitative | VerificationRequirement Test |
| 10 | 1.2.1.3 | CaCS Syber Security | The CaCS shall have a secure connection to the internet. | Qualitative | VerificationRequirement Test |
| 11 | 1.2.3 | CaCS Utility Interface | The CaCS shall receive data and commands from local utility employees. | Quantitative | VerificationRequirement Demonstration |
| 12 | 1.2.3.6 | CaCS Models | The CaCS shall provide software capable of creating and using utility models. | Qualitative | VerificationRequirement Demonstration |

## 4.5 Requirements Metric

The below table presents a list of all the metrics regarding the requirements derived for the FAR. This table will summarize the number of total requirements, KPP’s, qualitative vs quantitative and how each requirement will be verified.

Table : Requirements Metric

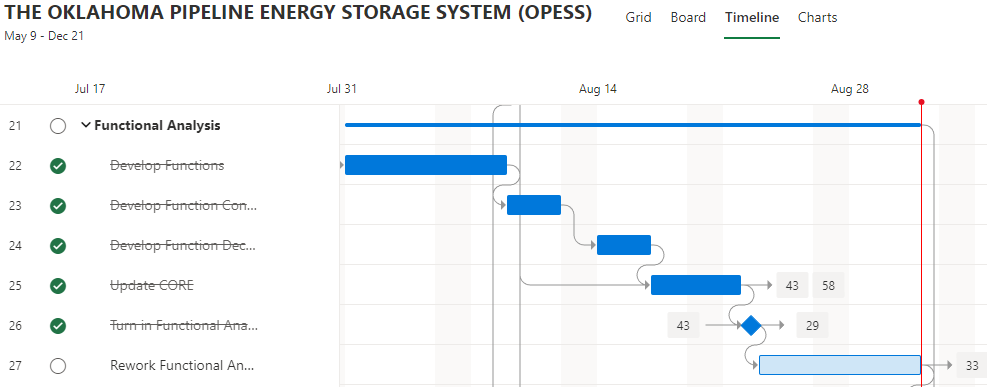
|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Report | Requirements | KPP’s | Qualitative | Quantitative | Inspection | Analysis | Demonstration | Test |
| RAR | 104 | 12 | 50 | 54 | 29 | 14 | 37 | 24 |
| FAR | 129 | 12 | 75 | 54 | 37 | 16 | 48 | 28 |
| TS |  |  |  |  |  |  |  |  |
| CDR |  |  |  |  |  |  |  |  |
| TP |  |  |  |  |  |  |  |  |
| A-Spec |  |  |  |  |  |  |  |  |
| Final |  |  |  |  |  |  |  |  |

# 5 Earned Value Management

## 5.1 Schedule

Since block diagrams were created during the RAR phase, it was thought that the FAR might serve as a little bit of a return to green plan. It did not. While this report is getting turned in late, it is thought that perhaps during the schedule can be compressed slowly over the next month or two. With luck, the schedule should return to green by mid-October.

Figure : Functional Analysis Report Schedule



## 5.2 Milestones

Items in red were turned in late per the original due date. All other deliveries are expected to be on time.

Table :Milestones

| **Milestone** | **Date** |
| --- | --- |
| Project Proposal | 7/8/2022 |
| Requirements Report | 8/12/2022 |
| Functional Analysis | 9/2/2022 |
| Concept of Operations | 9/21/2022 |
| Trade Study | 10/7/2022 |
| Risk Management Report | 10/21/2022 |
| Test Plan | 11/11/2022 |
| System Specifications | 11/30/2022 |
| Final Report | 12/12/2022 |
| Oral Presentation | 12/16/2022 |

## 

## 5.3 EVM

Table : EVM

| WBS number | Name | % Complete | Budget | BCWP | ACWP | SPI | CPI |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **3** | **Requirements Report** | **100.00%** |  |  |  |  |  |
| 3.1 | Research Technical information | 100.00% | 6 | 6.00 | 4 | 1 | 1.50 |
| 3.2 | Schedule Interviews | 100.00% | 3 | 3.00 | 1 | 1 | 3.00 |
| 3.3 | Perform Interviews | 100.00% | 3 | 3.00 | 2 | 1 | 1.50 |
| 3.4 | Create Appendix of Interviews and Site Sources | 100.00% | 3 | 3.00 | 0.5 | 1 | 6.00 |
| 3.5 | Develop ConOps | 100.00% | 5 | 5.00 | 6 | 1 | 0.83 |
| 3.6 | Develop Key Performance Parameters | 100.00% | 3 | 3.00 | 1 | 1 | 3.00 |
| 3.7 | Begin VCRM | 100.00% | 2 | 2.00 | 0.5 | 1 | 4.00 |
| 3.8 | Turn in Requirements Report | 100.00% | 0.5 | 0.50 | 3 | 1 | 0.17 |
| 3.9 | Rework Requirements Report | 100.00% | 10 | 10.00 | 3 | 1 | 3.33 |
| **4** | **Functional Analysis** | **83.33%** |  |  |  |  |  |
| 4.1 | Develop Functions | 100.00% | 10 | 10.00 | 6 | 1 | 1.67 |
| 4.2 | Develop Function Connectivity | 100.00% | 5 | 5.00 | 7 | 1 | 0.71 |
| 4.3 | Develop Function Decomposition | 100.00% | 5 | 5.00 | 6 | 1 | 0.83 |
| 4.4 | Update CORE | 100.00% | 3 | 3.00 | 10 | 1 | 0.30 |
| 4.5 | Turn in Functional Analysis | 100.00% | 0.5 | 0.50 | 3 | 1 | 0.17 |
| 4.6 | Rework Functional Analysis | 0.00% | 10 | 0.00 |  | 0 |  |

## 5.4 CPI and SPI Index

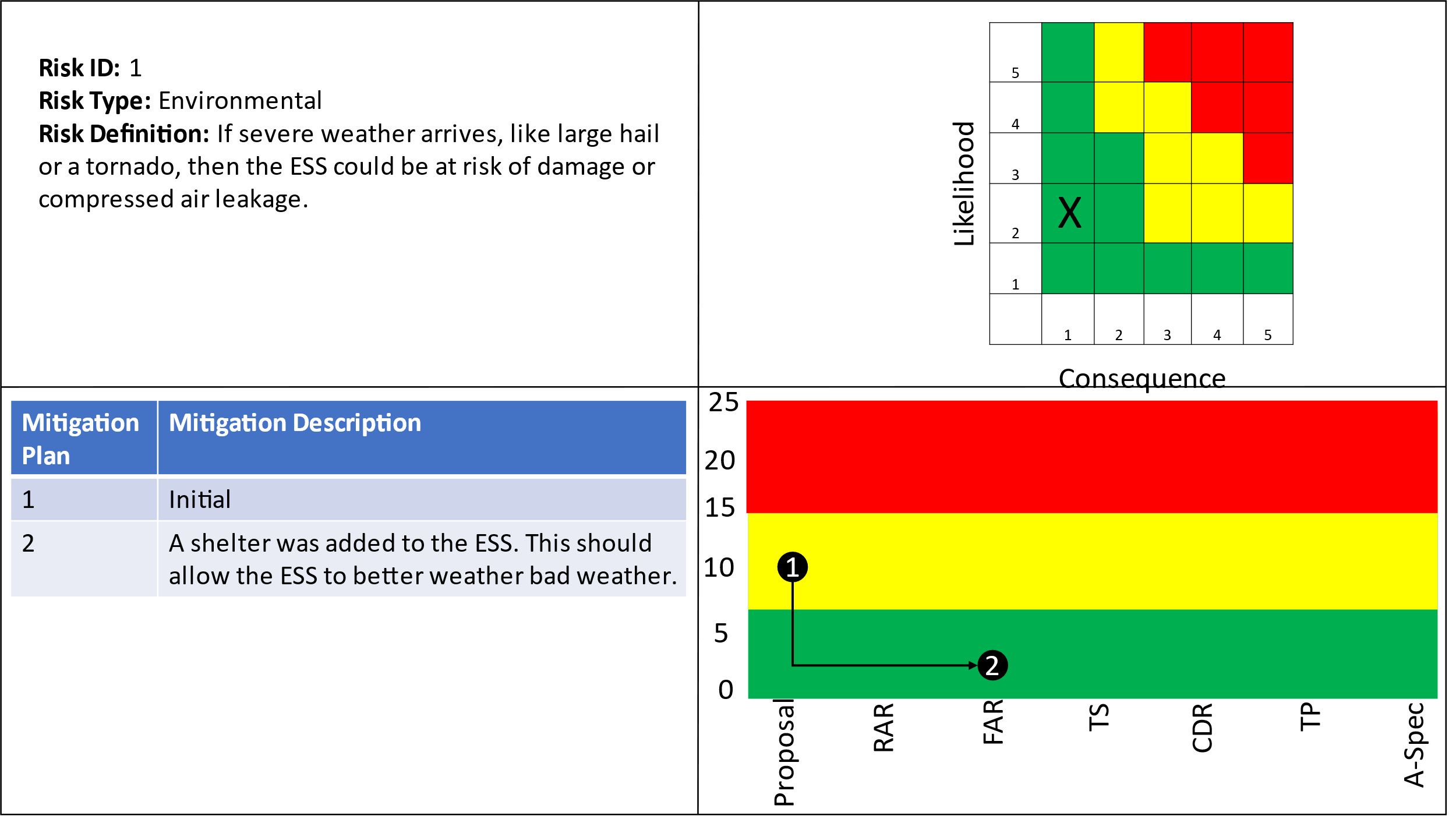
Figure : CPI/SPI

# 6 Risk

No new risks were discovered when writing the FAR. The OPESS risks were all developed through an interaction from the OPESS with the outside world in some way. Since both the functions and requirements were developed off of the same block diagrams, no risk was reduced during the functional development phase.

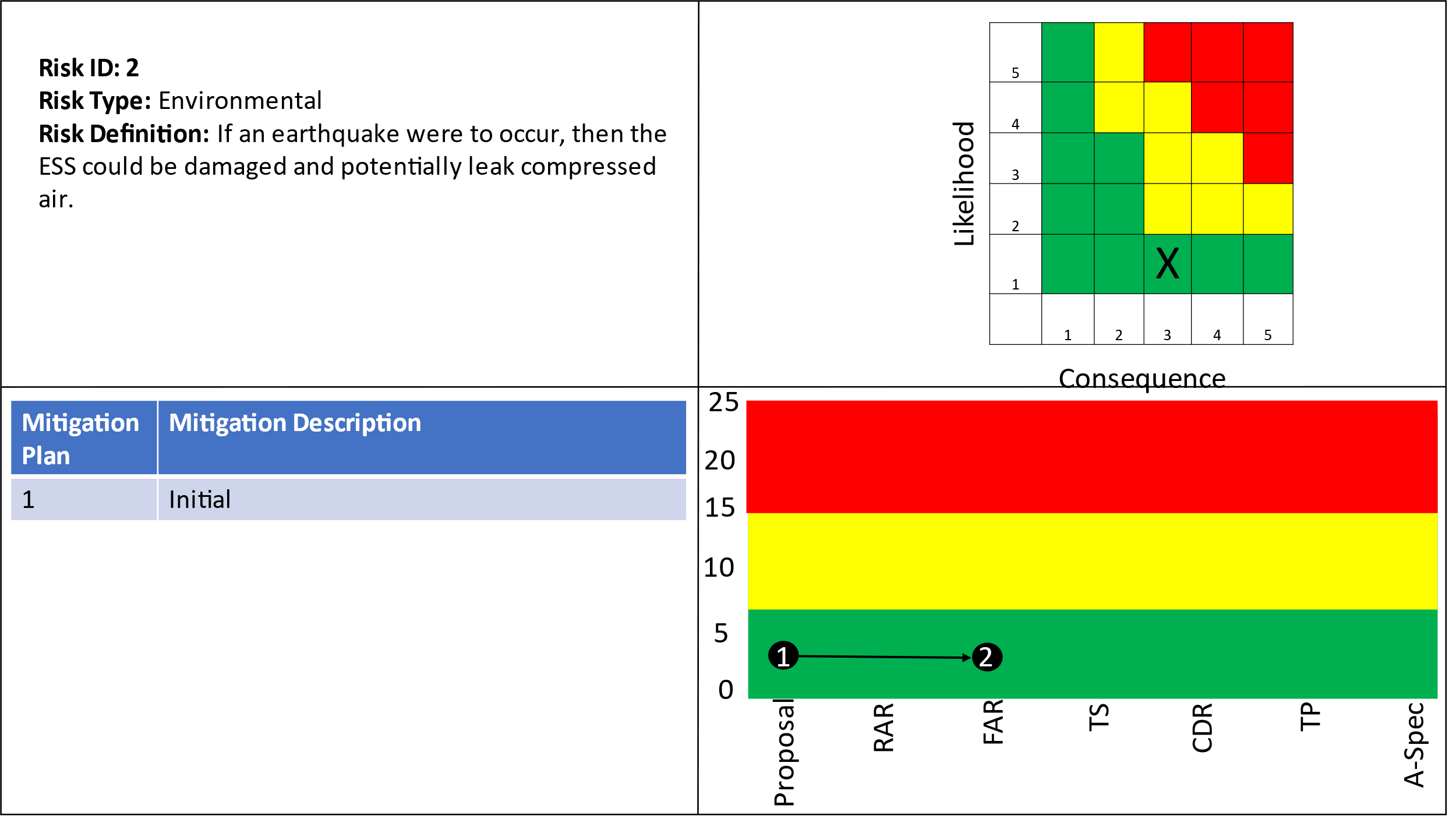
## 6.1 Risk 1: Weather

Figure : Rick 1 Weather



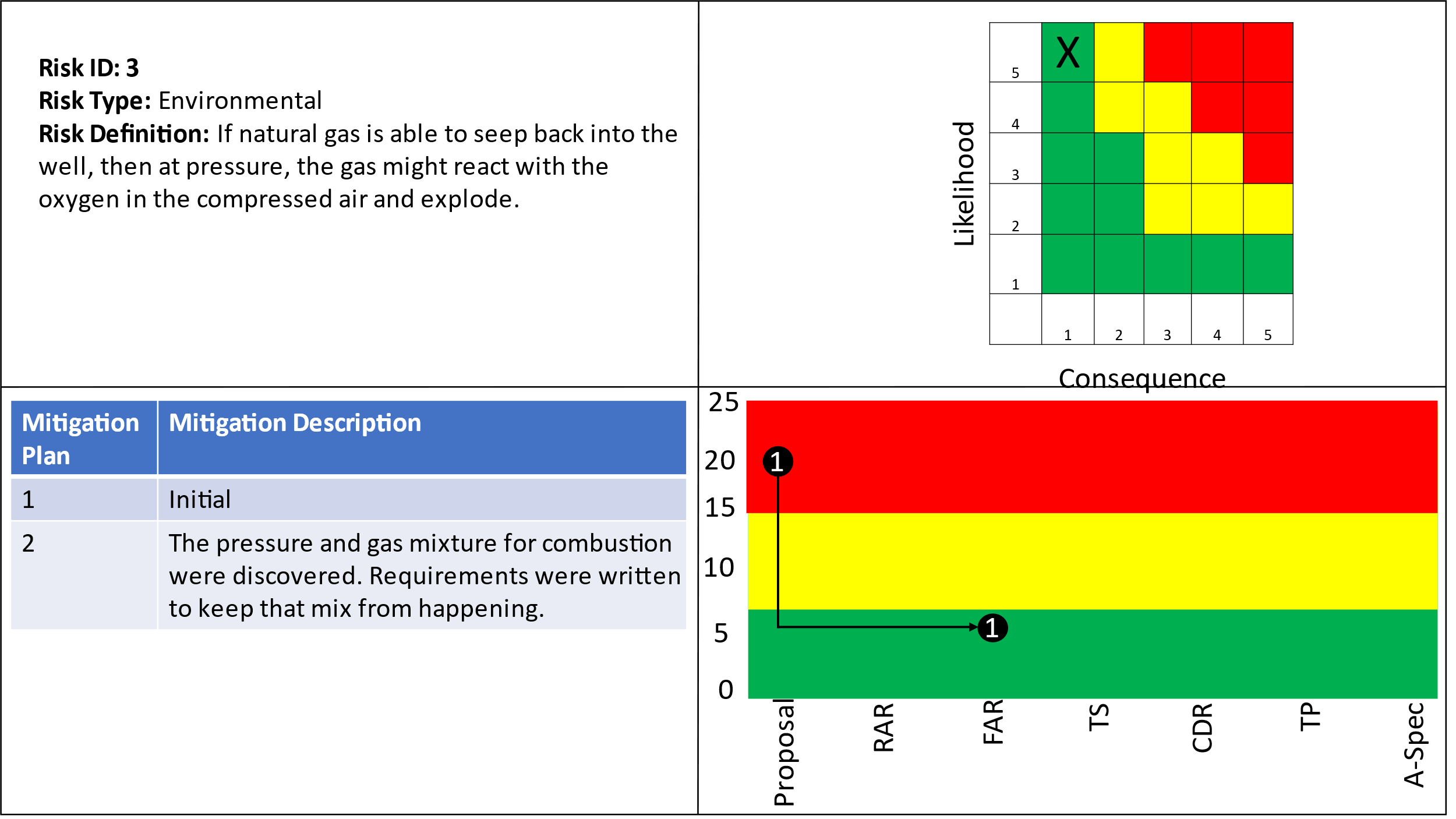
## 6.2 Risk 2: Earthquake

Figure : Risk 2 Earthquake



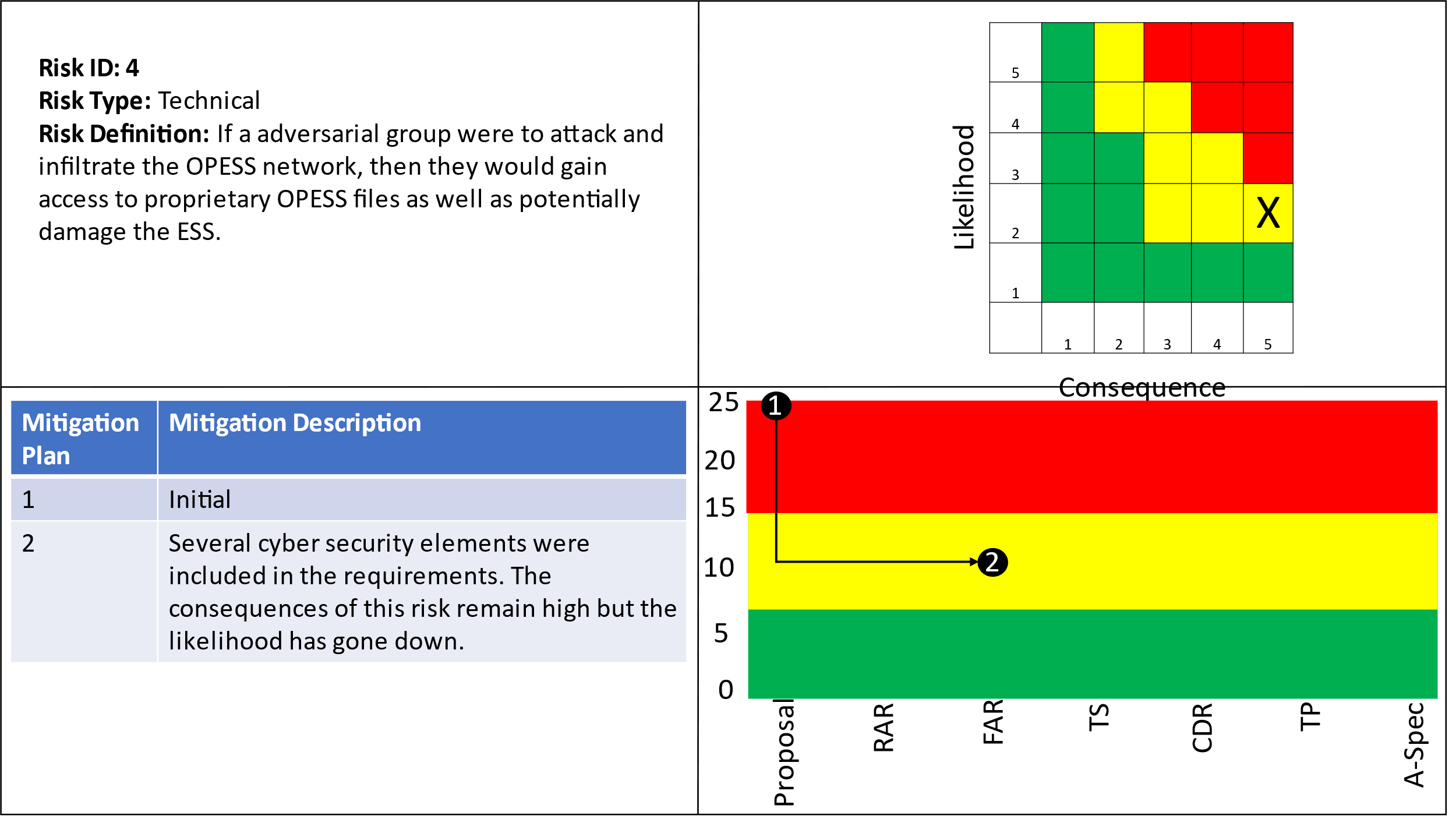
## 6.3 Risk 3: Residual Natural Gas

Figure : Residual Natural Gas



## 6.4 Risk 4: Cyber Security

Figure : Risk 4 Cyber Security



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# 8 Appendix A: Requirements

## 8.1 Originating Requirements

1 OPESS Requirements

Requirement Statement:

The Oklahoma Pipeline Energy Storage System (OPESS) shall operate as an energy storage system on the electrical grid.

Requirement Rationale:

Design decision

Refined By Subordinate Requirements:

1.1 ESS Requirement

1.2 CaCS Requirements

Basis Of:

Function: 1 Oklahoma Pipeline Energy Storage System

1.1.1.5.2 ESS Encryption

Requirement Statement:

The ESS connection to the CaCS shall be encrypted with a AES-256 connection or stronger

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.3 ESS Fiber Optics

Requirement Statement:

The ESS shall use either a IEEE802.3 Ethernet or Fiber Optic connection.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.4 ESS Firewall

Requirement Statement:

The ESS shall operate a firewall with IPS, TLS inspection and ERL filtering.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.6 ESS TCP/IP

Requirement Statement:

The ESS shall use a TCP/IP connection.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.2.1.3.1 CaCS Anti-Virus

Requirement Statement:

The CaCS shall provide an antivirus for all CaCS networked CaCS devices.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.1.3.2 CaCS Cyber Filtering

Requirement Statement:

The CaCS shall communicate with the internet through a firewall with IPS and TLS inspection and URL filtering.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.1.3.3 CaCS Firewall

Requirement Statement:

The CaCS shall communicate with the internet through a firewall that uses different IPS signatures then the ESS firewall.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.1.3.4 CaCS Intrusion Detection

Requirement Statement:

The CaCS shall have an intrusion detection system.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

Basis Of:

Function: 1.2.1.1.2 Internet Cyber Security

Function: 1.2.4.1.1 CaCS Cyber Security

1.2.1.3.5 CaCS TCP/IP

Requirement Statement:

The CaCS shall communicate across a TCP/IP connection to the internet

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

Basis Of:

Function: 1.2.1.3 Internet to Internal Network

Function: 1.2.4.3 Internal Network to Internet

1.2.3.1.3 CaCS Two Factor Authentication

Requirement Statement:

The CaCS shall use two factor authentication when a user logs onto the ESS software.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.1 CaCS Control

Basis Of:

Function: 1.2.2 CaCS Work Space

1.2.3.6.1 CaCS Federal Utility Company Interface

Requirement Statement:

The modeled power needs shall be calculated based on input provided from other utility companies across state lines.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

Basis Of:

Function: 1.2.2 CaCS Work Space

1.2.3.6.2 CaCS Local Utility Company Interface

Requirement Statement:

The modeled power needs shall be calculated based on input provided from other utility companies locally.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

Basis Of:

Function: 1.2.2 CaCS Work Space

1.2.3.6.3 CaCS Model Accuracy

Requirement Statement:

The CaCS models shall become more accurate as the modeled time period gets closer.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

1.2.3.6.4 CaCS One Month Model

Requirement Statement:

The CaCS models shall be able to model power usage out to a month out.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

## 8.2 Design Constraints

1.1.1.5.3 ESS Fiber Optics

Design Constraint Statement:

The ESS shall use either a IEEE802.3 Ethernet or Fiber Optic connection.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.6 ESS TCP/IP

Design Constraint Statement:

The ESS shall use a TCP/IP connection.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.2.1.4 ESS Generator Utility Interface

Design Constraint Statement:

The ESS shall send its power to the Utility Connection.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.1 ESS Generator

1.1.2.2 ESS Power Uptake

Design Constraint Statement:

The ESS shall send electrical power onto the utility grid via a utility interface

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2 ESS Generate Power

Refined By Lower-Level Requirements:

1.1.2.2.1 ESS Generator Grid interface

1.1.2.2.2 ESS Generator Transformer

1.1.2.2.1 ESS Generator Grid interface

Design Constraint Statement:

The ESS shall send power from the step-up generator to the electrical grid

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.2 ESS Power Uptake

1.1.2.2.2 ESS Generator Transformer

Design Constraint Statement:

The ESS shall send power from the generator to a step-up transformer.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.2.2 ESS Power Uptake

1.1.3.1.1 ESS Gas Monitoring

Design Constraint Statement:

The ESS sensors shall monitor the gas makeup throughout the well and send that information to the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.1 ESS Compressed air monitoring

1.1.3.1.2 ESS Storage pressure monitoring

Design Constraint Statement:

The ESS sensors shall monitor pressure throughout the well and send that information to the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.1 ESS Compressed air monitoring

1.1.3.1.3 ESS Storage Sensors

Design Constraint Statement:

The ESS shall imbed sensors in the natural gas well.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.1 ESS Compressed air monitoring

1.1.3.1.4 ESS SW Max Gas mix

Design Constraint Statement:

The ESS sensors shall send a fault to the CaCS when the natural gas makeup reaches 3%.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.3.1 ESS Compressed air monitoring

1.1.3.1.5 ESS SW Max PSI

Design Constraint Statement:

The ESS sensors shall send a fault to the CaCS telling them the well is full at 200 PSI.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.3.1 ESS Compressed air monitoring

1.1.3.2.1 ESS Gas Safety

Design Constraint Statement:

Upon initialization, the ESS natural gas well shall be filled with nitrogen gas such that residual natural gas makes up 2% or less.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.3.2 ESS Compressed air storage

1.1.3.2.3 ESS Well Initialization

Design Constraint Statement:

The ESS shall use only depleted natural gas wells.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.2 ESS Compressed air storage

1.1.3.2.4 ESS Well Initialization Gas Release

Design Constraint Statement:

Once the well is full of nitrogen, the ESS shall release the gas mixture and repeat the process until the residual natural gas makes up less than .5% of the gas mixture at atmospheric pressure.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.3.2 ESS Compressed air storage

1.1.3.3.1 ESS Emergency Pressure Release

Design Constraint Statement:

The ESS pressurized connection shall have an emergency pressure release that automatically trips at 250 PSI.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.1.3.3.2 ESS Storage Gas Safety Sensor

Design Constraint Statement:

The ESS pressurized connection shall have an emergency release when the gas mixture reaches 4% according to the sensors.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.2.3.2 CaCS Computer Network

Design Constraint Statement:

The CaCS shall connect all computers to the network.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

1.2.3.3 CaCS Computer Power

Design Constraint Statement:

The CaCS shall provide power for all computers.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

1.2.3.4 CaCS Computers

Design Constraint Statement:

The CaCS shall provide a computer for all employees.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

1.2.3.5 CaCS Email

Design Constraint Statement:

The CaCS shall provide an email client.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

1.2.3.7 CaCS Software

Design Constraint Statement:

The CaCS shall provide office software.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

## 8.3 Performance Requirements

1.1.1.1.1 ESS Health and Status Send

Performance Requirement Statement:

The ESS processor shall scan the health and status updates and send them to the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.1.2 ESS Processor Communication

Performance Requirement Statement:

The ESS processor shall receive commands from the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.1.3 ESS Processor Health and Status Receive

Performance Requirement Statement:

The ESS processor shall receive health and Status from the components.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.1.4 ESS Processor Response

Performance Requirement Statement:

The ESS processor shall automatically respond to any health or safety issue its receives.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.2 ESS Control Node Process Commands

Performance Requirement Statement:

The ESS control node shall process input from the generator, storage and compressor apparatus.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1 ESS Communications

1.1.1.3 ESS Control Node Receive Commands

Performance Requirement Statement:

The ESS control node shall receive information from the generator, storage and compressor apparatus.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1 ESS Communications

1.1.1.4 ESS Control Node Send Commands

Performance Requirement Statement:

The ESS control node shall send CaCS commands to the generator, storage apparatus and the compressor.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1 ESS Communications

1.1.1.5.1 ESS Cyber Scans

Performance Requirement Statement:

The ESS shall undergo security scans at least once a quarter.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.2 ESS Encryption

Performance Requirement Statement:

The ESS connection to the CaCS shall be encrypted with a AES-256 connection or stronger

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.5 ESS High Speed Internet

Performance Requirement Statement:

The ESS shall maintain a high-speed connection to the internet.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.6 ESS Send Health and Status

Performance Requirement Statement:

The ESS control node shall send the input from the generator, storage and compressor apparatus to the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1 ESS Communications

1.1.2.1 ESS Generator

Performance Requirement Statement:

The ESS shall use compressed air to run a generator.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2 ESS Generate Power

Refined By Lower-Level Requirements:

1.1.2.1.1 ESS Generator Commands

1.1.2.1.2 ESS Generator Health and Status

1.1.2.1.3 ESS Generator Storage Interface

1.1.2.1.4 ESS Generator Utility Interface

1.1.2.1.1 ESS Generator Commands

Performance Requirement Statement:

The ESS generator shall receive commands from the CaCS telling it to turn on, off and how hard to run.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.1 ESS Generator

1.1.2.1.2 ESS Generator Health and Status

Performance Requirement Statement:

The ESS generator shall send health and safety information to the processor as well as receive any emergency commands.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.1 ESS Generator

1.1.2.1.3 ESS Generator Storage Interface

Performance Requirement Statement:

The ESS generator shall use compressed air coming from the natural gas well to spin a turbine and generate power.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.1 ESS Generator

1.1.2.4.1 ESS Carbon Capture Percent

Performance Requirement Statement:

The ESS carbon capture system shall remove no less than 50 percent of the hydrocarbons from the compressed air.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.4 ESS Carbon Capture

1.1.2.4.2 ESS Carbon Capture Release

Performance Requirement Statement:

Once passed through the carbon capture system, the ESS shall release all the compressed air used by the generator into the environment.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.4 ESS Carbon Capture

1.1.3.2.2 ESS Storage Time

Performance Requirement Statement:

The ESS storage shall be able to keep compressed air for a period of up to 1 year.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.2 ESS Compressed air storage

1.1.3.3.3 ESS Storage Generator Requirement

Performance Requirement Statement:

The ESS shall be able to send air to the generator at pressure.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.1.3.3.4 ESS Storage Leak

Performance Requirement Statement:

The ESS shall not allow the pressurized connection to leaked at a rate of more than 5% a year.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.1.3.3.5 ESS Storage Pressure

Performance Requirement Statement:

The ESS pressurized connection shall be able to handle up to 300 PSI.

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.1.3.3.6 ESS Storage Pump Interface

Performance Requirement Statement:

The ESS shall be able to receive air from the compressor at pressure.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.1.4.1.1 ESS Air Compressor

Performance Requirement Statement:

The ESS pump shall compress air and send it to the natural gas interface at pressure.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.1 ESS Air Pump

1.1.4.1.4 ESS Health and Status communication

Performance Requirement Statement:

The ESS shall send the ESS control it's health and status.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.1 ESS Air Pump

1.1.4.2.2 ESS Transformer

Performance Requirement Statement:

The ESS shall have a step-down transformer to lower the voltage to US Standard 120V 60Hz.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.2 ESS Power Intake

1.1.4.3 ESS Pump Storage Interface

Performance Requirement Statement:

The ESS shall send the compressed air from the pump to the storage device through a pressurized interface.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4 ESS Receive Power

1.1.5.1 ESS Cooling

Performance Requirement Statement:

The ESS shall be able to maintain a working temperature of 100 degrees Fahrenheit or below

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.5 ESS Weather

1.1.5.2 ESS Hail

Performance Requirement Statement:

The ESS shall be able to withstand up to baseball size hail.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.5 ESS Weather

1.1.5.3 ESS Heating

Performance Requirement Statement:

The ESS shall be able to maintain a working temperature of 40 degrees Fahrenheit or above.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.5 ESS Weather

1.1.5.4 ESS Tornado

Performance Requirement Statement:

The ESS shall be able to withstand a EF4 tornado.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.5 ESS Weather

1.1.5.5 ESS Wind

Performance Requirement Statement:

The ESS shall be able to withstand up to 60 mph strait line winds.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.5 ESS Weather

1.2.1.1.2 CaCS Log In

Performance Requirement Statement:

The CaCS VM shall provide a secure log in for every employee.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.1 CaCS Internal Network

1.2.1.1.4 CaCS Security Scan

Performance Requirement Statement:

The CaCS shall run information assurance scans of all networked devices monthly.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.1 CaCS Internal Network

1.2.1.1.5 CaCS VM

Performance Requirement Statement:

The CaCS shall maintain a VM for every employee.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.1 CaCS Internal Network

1.2.1.2.1 CaCS Server Backup

Performance Requirement Statement:

The CaCS shall make a backup of the servers every night.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.2 CaCS Servers

1.2.1.2.2 CaCS Server Backup Schedule

Performance Requirement Statement:

The CaCS shall keep the backups for one week.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.2 CaCS Servers

1.2.1.2.3 CaCS Server Infrastructure

Performance Requirement Statement:

The CaCS shall maintain a series of servers.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.2 CaCS Servers

1.2.1.3.2 CaCS Cyber Filtering

Performance Requirement Statement:

The CaCS shall communicate with the internet through a firewall with IPS and TLS inspection and URL filtering.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.1.3.3 CaCS Firewall

Performance Requirement Statement:

The CaCS shall communicate with the internet through a firewall that uses different IPS signatures then the ESS firewall.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.2.2 CaCS Standard Power

Performance Requirement Statement:

The CaCS shall receive standard US 120V, 60Hz from the electrical grid.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.2 CaCS Receive Power

1.2.3.1.2 CaCS ESS Interface

Performance Requirement Statement:

The CaCS shall be able to control any connected ESS once logged on.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3.1 CaCS Control

1.2.3.6.3 CaCS Model Accuracy

Performance Requirement Statement:

The CaCS models shall become more accurate as the modeled time period gets closer.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

1.2.3.6.4 CaCS One Month Model

Performance Requirement Statement:

The CaCS models shall be able to model power usage out to a month out.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

## 8.4 Functional Requirements

1.1 ESS Requirement

Performance Requirement Statement:

The Energy Storage Subsystem (ESS) shall actively store and generate energy for use on the electrical grid.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1 OPESS Requirements

Refined By Lower-Level Requirements:

1.1.1 ESS Communications

1.1.2 ESS Generate Power

1.1.3 ESS Power Storage

1.1.4 ESS Receive Power

1.1.5 ESS Weather

1.1.1 ESS Communications

Performance Requirement Statement:

The ESS shall send and receive information and commands from the CaCS via the internet.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1 ESS Requirement

Refined By Lower-Level Requirements:

1.1.1.1 ESS Control

1.1.1.2 ESS Control Node Process Commands

1.1.1.3 ESS Control Node Receive Commands

1.1.1.4 ESS Control Node Send Commands

1.1.1.5 ESS Internet Interface

1.1.1.6 ESS Send Health and Status

1.1.1.1 ESS Control

Performance Requirement Statement:

The ESS control node shall process commands from the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1 ESS Communications

Refined By Lower-Level Requirements:

1.1.1.1.1 ESS Health and Status Send

1.1.1.1.2 ESS Processor Communication

1.1.1.1.3 ESS Processor Health and Status Receive

1.1.1.1.4 ESS Processor Response

1.1.1.1.5 ESS Command Process

1.1.1.1.6 ESS to Component Connection

1.1.1.1.7 ESS Component Processor Communication

1.1.1.1.8 ESS Component Communication

1.1.1.1.5 ESS Command Process

Performance Requirement Statement:

The ESS shall process commands and responses coming from the ESS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.1.6 ESS to Component Connection

Performance Requirement Statement:

The ESS shall connect the ESS components to the internet through a processor

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.1.7 ESS Component Processor Communication

Performance Requirement Statement:

The ESS shall monitor health and status and report that information to the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.1.8 ESS Component Communication

Performance Requirement Statement:

The ESS shall allow the ESS components to communicate with the ESS processor.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.1 ESS Control

1.1.1.5 ESS Internet Interface

Performance Requirement Statement:

The ESS control node shall maintain a secure connection with the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1 ESS Communications

Refined By Lower-Level Requirements:

1.1.1.5.1 ESS Cyber Scans

1.1.1.5.2 ESS Encryption

1.1.1.5.3 ESS Fiber Optics

1.1.1.5.4 ESS Firewall

1.1.1.5.5 ESS High Speed Internet

1.1.1.5.6 ESS TCP/IP

1.1.1.5.7 ESS Internet Connection

1.1.1.5.8 ESS Cyber Security Suite

1.1.1.5.9 ESS Secure Connection

1.1.1.5.4 ESS Firewall

Performance Requirement Statement:

The ESS shall operate a firewall with IPS, TLS inspection and ERL filtering.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.7 ESS Internet Connection

Performance Requirement Statement:

The ESS network shall connect to the Internet.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.8 ESS Cyber Security Suite

Performance Requirement Statement:

The ESS internet connection shall function with a cyber security suite.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.1.5.9 ESS Secure Connection

Performance Requirement Statement:

The ESS shall connect to the Internet through a secure connection.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.1.5 ESS Internet Interface

1.1.2 ESS Generate Power

Performance Requirement Statement:

The ESS shall generate power from storage for use on the power grid.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1 ESS Requirement

Refined By Lower-Level Requirements:

1.1.2.1 ESS Generator

1.1.2.2 ESS Power Uptake

1.1.2.3 ESS Storage Generator Interface

1.1.2.4 ESS Carbon Capture

1.1.2.3 ESS Storage Generator Interface

Performance Requirement Statement:

The ESS shall pull compressed air from the storage device through a pressurized interface.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2 ESS Generate Power

Refined By Lower-Level Requirements:

1.1.2.3.1 ESS Power Generation

1.1.2.3.2 Generator Health and Status

1.1.2.3.3 Power Generation Gauge

1.1.2.3.4 Compressed Air Power Generation

1.1.2.3.5 Generation to Grid Connection

1.1.2.3.6 ESS Generator to Grid

1.1.2.3.7 Generator Step Up

1.1.2.3.1 ESS Power Generation

Performance Requirement Statement:

The ESS shall generate power.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.3 ESS Storage Generator Interface

1.1.2.3.2 Generator Health and Status

Performance Requirement Statement:

The ESS shall monitor the ESS generator health and status.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.3 ESS Storage Generator Interface

1.1.2.3.3 Power Generation Gauge

Performance Requirement Statement:

The ESS shall control the amount of power generated by the generator.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.3 ESS Storage Generator Interface

1.1.2.3.4 Compressed Air Power Generation

Performance Requirement Statement:

The ESS shall generate power from compressed air as needed.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.3 ESS Storage Generator Interface

1.1.2.3.5 Generation to Grid Connection

Performance Requirement Statement:

The ESS generator shall connect to the electrical grid.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.3 ESS Storage Generator Interface

1.1.2.3.6 ESS Generator to Grid

Performance Requirement Statement:

The ESS shall connect the power grid to the generator.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.3 ESS Storage Generator Interface

1.1.2.3.7 Generator Step Up

Performance Requirement Statement:

The ESS shall step up the power generated for use on the electric grid.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2.3 ESS Storage Generator Interface

1.1.2.4 ESS Carbon Capture

Performance Requirement Statement:

The ESS shall send all the compressed air used by the generator through a carbon capture system.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.2 ESS Generate Power

Refined By Lower-Level Requirements:

1.1.2.4.1 ESS Carbon Capture Percent

1.1.2.4.2 ESS Carbon Capture Release

1.1.3 ESS Power Storage

Performance Requirement Statement:

The ESS shall store power in natural gas wells.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1 ESS Requirement

Refined By Lower-Level Requirements:

1.1.3.1 ESS Compressed air monitoring

1.1.3.2 ESS Compressed air storage

1.1.3.3 ESS Pressure

1.1.3.1 ESS Compressed air monitoring

Performance Requirement Statement:

The ESS storage shall monitor gas in the natural gas well.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3 ESS Power Storage

Refined By Lower-Level Requirements:

1.1.3.1.1 ESS Gas Monitoring

1.1.3.1.2 ESS Storage pressure monitoring

1.1.3.1.3 ESS Storage Sensors

1.1.3.1.4 ESS SW Max Gas mix

1.1.3.1.5 ESS SW Max PSI

1.1.3.1.6 Chemical Monitoring

1.1.3.1.7 Pressure Monitoring

1.1.3.1.6 Chemical Monitoring

Performance Requirement Statement:

The ESS shall monitor the gas makeup in the natural gas wells.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.1 ESS Compressed air monitoring

1.1.3.1.7 Pressure Monitoring

Performance Requirement Statement:

The ESS shall monitor the pressure in the natural gas wells.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.1 ESS Compressed air monitoring

1.1.3.2 ESS Compressed air storage

Performance Requirement Statement:

The ESS storage shall keep compressed air in natural gas wells.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3 ESS Power Storage

Refined By Lower-Level Requirements:

1.1.3.2.1 ESS Gas Safety

1.1.3.2.2 ESS Storage Time

1.1.3.2.3 ESS Well Initialization

1.1.3.2.4 ESS Well Initialization Gas Release

1.1.3.3 ESS Pressure

Performance Requirement Statement:

The ESS storage shall be able to handle compressed air at pressure.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3 ESS Power Storage

Refined By Lower-Level Requirements:

1.1.3.3.1 ESS Emergency Pressure Release

1.1.3.3.2 ESS Storage Gas Safety Sensor

1.1.3.3.3 ESS Storage Generator Requirement

1.1.3.3.4 ESS Storage Leak

1.1.3.3.5 ESS Storage Pressure

1.1.3.3.6 ESS Storage Pump Interface

1.1.3.3.7 Constant Pressure

1.1.3.3.8 ESS Emergency Release

1.1.3.3.7 Constant Pressure

Performance Requirement Statement:

The ESS shall maintain and hold a constant pressure when either the generator or pump are not in use

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.1.3.3.8 ESS Emergency Release

Performance Requirement Statement:

The ESS shall have an emergency pressure release.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.3.3 ESS Pressure

1.1.4 ESS Receive Power

Performance Requirement Statement:

The ESS shall receive power off the power grid and send it to storage.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1 ESS Requirement

Refined By Lower-Level Requirements:

1.1.4.1 ESS Air Pump

1.1.4.2 ESS Power Intake

1.1.4.3 ESS Pump Storage Interface

1.1.4.1 ESS Air Pump

Performance Requirement Statement:

The ESS shall use a pump to compress air.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4 ESS Receive Power

Refined By Lower-Level Requirements:

1.1.4.1.1 ESS Air Compressor

1.1.4.1.2 ESS Command

1.1.4.1.3 ESS Health and Status

1.1.4.1.4 ESS Health and Status communication

1.1.4.1.5 ESS Transformer Connection

1.1.4.1.6 ESS Compressed Air

1.1.4.1.7 Compressed Air Transport

1.1.4.1.2 ESS Command

Performance Requirement Statement:

The ESS pump shall receive its commands from the from the ESS control.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.1 ESS Air Pump

1.1.4.1.3 ESS Health and Status

Performance Requirement Statement:

The ESS shall report Its health and status to the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.1 ESS Air Pump

1.1.4.1.5 ESS Transformer Connection

Performance Requirement Statement:

The ESS shall connect to the step-down transformer for power

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.4.1 ESS Air Pump

1.1.4.1.6 ESS Compressed Air

Performance Requirement Statement:

The ESS shall compress air.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.1 ESS Air Pump

1.1.4.1.7 Compressed Air Transport

Performance Requirement Statement:

The ESS shall send compressed air to a natural gas well.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.1 ESS Air Pump

1.1.4.2 ESS Power Intake

Performance Requirement Statement:

The ESS shall receive power off the grid by way of a utility interface.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4 ESS Receive Power

Refined By Lower-Level Requirements:

1.1.4.2.1 ESS Power Connection

1.1.4.2.2 ESS Transformer

1.1.4.2.3 ESS Voltage Adjust

1.1.4.2.1 ESS Power Connection

Performance Requirement Statement:

The ESS shall have a hardwired connection to the high voltage lines of the power grid

Requirement Rationale:

Derived from Research

Refines Higher-Level Requirement:

1.1.4.2 ESS Power Intake

1.1.4.2.3 ESS Voltage Adjust

Performance Requirement Statement:

The ESS shall adjust the voltage coming from the utility lines to a lower voltage.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.4.2 ESS Power Intake

1.1.5 ESS Weather

Performance Requirement Statement:

The ESS shall be protected from the weather.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1 ESS Requirement

Refined By Lower-Level Requirements:

1.1.5.1 ESS Cooling

1.1.5.2 ESS Hail

1.1.5.3 ESS Heating

1.1.5.4 ESS Tornado

1.1.5.5 ESS Wind

1.1.5.6 Weather Protect

1.1.5.7 Climate Control

1.1.5.6 Weather Protect

Performance Requirement Statement:

The ESS shall be protected from outside weather.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.5 ESS Weather

1.1.5.7 Climate Control

Performance Requirement Statement:

The ESS shall implement climate control.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.1.5 ESS Weather

1.2 CaCS Requirements

Performance Requirement Statement:

The Command-and-Control Subsystem (CaCS) shall act as the operational command center of the OPESS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1 OPESS Requirements

Refined By Lower-Level Requirements:

1.2.1 CaCS Communications

1.2.2 CaCS Receive Power

1.2.3 CaCS Utility Interface

1.2.1 CaCS Communications

Performance Requirement Statement:

The CaCS shall communicate with the ESS and other utilities via the internet.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2 CaCS Requirements

Refined By Lower-Level Requirements:

1.2.1.1 CaCS Internal Network

1.2.1.2 CaCS Servers

1.2.1.3 CaCS Syber Security

1.2.1.1 CaCS Internal Network

Performance Requirement Statement:

The CaCS shall maintain an active internal network.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1 CaCS Communications

Refined By Lower-Level Requirements:

1.2.1.1.1 CaCS High Speed Network

1.2.1.1.2 CaCS Log In

1.2.1.1.3 CaCS Ring Network

1.2.1.1.4 CaCS Security Scan

1.2.1.1.5 CaCS VM

1.2.1.1.1 CaCS High Speed Network

Performance Requirement Statement:

The CaCS shall use a high-speed network.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.1 CaCS Internal Network

1.2.1.1.3 CaCS Ring Network

Performance Requirement Statement:

The CaCS shall use a ring network.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.1 CaCS Internal Network

1.2.1.2 CaCS Servers

Performance Requirement Statement:

The CaCS shall maintain shared servers across its network.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1 CaCS Communications

Refined By Lower-Level Requirements:

1.2.1.2.1 CaCS Server Backup

1.2.1.2.2 CaCS Server Backup Schedule

1.2.1.2.3 CaCS Server Infrastructure

1.2.1.2.4 CaCS Backup Server

1.2.1.2.4 CaCS Backup Server

Performance Requirement Statement:

The CaCS shall back up the servers.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1.2 CaCS Servers

1.2.1.3 CaCS Syber Security

Performance Requirement Statement:

The CaCS shall have a secure connection to the internet.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.1 CaCS Communications

Refined By Lower-Level Requirements:

1.2.1.3.1 CaCS Anti-Virus

1.2.1.3.2 CaCS Cyber Filtering

1.2.1.3.3 CaCS Firewall

1.2.1.3.4 CaCS Intrusion Detection

1.2.1.3.5 CaCS TCP/IP

1.2.1.3.1 CaCS Anti-Virus

Performance Requirement Statement:

The CaCS shall provide an antivirus for all CaCS networked CaCS devices.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.1.3.4 CaCS Intrusion Detection

Performance Requirement Statement:

The CaCS shall have an intrusion detection system.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.1.3.5 CaCS TCP/IP

Performance Requirement Statement:

The CaCS shall communicate across a TCP/IP connection to the internet

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.1.3 CaCS Syber Security

1.2.2 CaCS Receive Power

Performance Requirement Statement:

The CaCS shall receive power from the electric grid.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2 CaCS Requirements

Refined By Lower-Level Requirements:

1.2.2.1 CaCS Distribute Power

1.2.2.2 CaCS Standard Power

1.2.2.1 CaCS Distribute Power

Performance Requirement Statement:

The CaCS shall distribute power though out the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.2 CaCS Receive Power

1.2.3 CaCS Utility Interface

Performance Requirement Statement:

The CaCS shall receive data and commands from local utility employees.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2 CaCS Requirements

Refined By Lower-Level Requirements:

1.2.3.1 CaCS Control

1.2.3.2 CaCS Computer Network

1.2.3.3 CaCS Computer Power

1.2.3.4 CaCS Computers

1.2.3.5 CaCS Email

1.2.3.6 CaCS Models

1.2.3.7 CaCS Software

1.2.3.8 Office Space

1.2.3.1 CaCS Control

Performance Requirement Statement:

The CaCS shall provide an interface capable of interacting with the ESS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

Refined By Lower-Level Requirements:

1.2.3.1.1 CaCS ESS Health and Status

1.2.3.1.2 CaCS ESS Interface

1.2.3.1.3 CaCS Two Factor Authentication

1.2.3.1.1 CaCS ESS Health and Status

Performance Requirement Statement:

All ESS heath safety and status information shall be saved and viewable from the CaCS.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3.1 CaCS Control

1.2.3.1.3 CaCS Two Factor Authentication

Performance Requirement Statement:

The CaCS shall use two factor authentication when a user logs onto the ESS software.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.1 CaCS Control

1.2.3.6 CaCS Models

Performance Requirement Statement:

The CaCS shall provide software capable of creating and using utility models.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

Refined By Lower-Level Requirements:

1.2.3.6.1 CaCS Federal Utility Company Interface

1.2.3.6.2 CaCS Local Utility Company Interface

1.2.3.6.3 CaCS Model Accuracy

1.2.3.6.4 CaCS One Month Model

1.2.3.6.1 CaCS Federal Utility Company Interface

Performance Requirement Statement:

The modeled power needs shall be calculated based on input provided from other utility companies across state lines.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

1.2.3.6.2 CaCS Local Utility Company Interface

Performance Requirement Statement:

The modeled power needs shall be calculated based on input provided from other utility companies locally.

Requirement Rationale:

Derived from Interviews

Refines Higher-Level Requirement:

1.2.3.6 CaCS Models

1.2.3.8 Office Space

Performance Requirement Statement:

The CaCS shall provide office space.

Requirement Rationale:

Design decision

Refines Higher-Level Requirement:

1.2.3 CaCS Utility Interface

# 9 Appendix B: Functional Behavioral Model

## 9.1 Function List

1 Oklahoma Pipeline Energy Storage System

1.1 Energy Storage Subsystem

1.1.1 Receive Power

1.1.1.1 Utility Interface

1.1.1.1.1 Power Grid Interface

1.1.1.1.2 Grid to ESS power Adjustment

1.1.1.2 Pump

1.1.1.2.1 Pump Power Input

1.1.1.2.2 Pump Health and Status

1.1.1.2.3 Pump Control

1.1.1.2.4 Compressed Air Pump

1.1.1.3 Natural Gas Interface

1.1.2 Internet to ESS Control

1.1.2.1 Internet to ESS-ESS Communications

1.1.2.1.1 ESS Internet Connection

1.1.2.1.2 ESS Cyber Security

1.1.2.1.3 ESS Network Interface

1.1.2.2 Internet to ESS-Processor

1.1.2.2.1 ESS Commands

1.1.2.2.2 Processor Data Link

1.1.2.2.3 ESS Health and Status

1.1.2.3 Internet to ESS - Component Communications

1.1.3 Generate Power

1.1.3.1 Generate Power Natural Gas Interface

1.1.3.2 Generator

1.1.3.2.1 Generator Control

1.1.3.2.2 Generator Health and Status

1.1.3.2.3 Electrical Generator

1.1.3.2.4 Generator Power Output

1.1.3.3 Carbon Capture

1.1.3.4 Generator to Utility Interface

1.1.3.4.1 Generator to Grid Power Adjustment

1.1.3.4.2 Generator to Grid Connection

1.1.4 Store Power

1.1.4.1 Pressure Release

1.1.4.1.1 Maintain Pressure

1.1.4.1.2 Pressure Safety Release

1.1.4.2 Natural Gas Well Storage

1.1.4.3 Well Safety

1.1.4.3.1 Gas Sensors

1.1.4.3.2 Pressure Sensors

1.1.5 Weather Protection

1.1.5.1 Exterior Protection

1.1.5.2 Climate Control

1.1.6 ESS to Internet-Control

1.1.6.1 ESS to Internet-ESS Communications

1.1.6.1.1 ESS Connection

1.1.6.1.2 Device Cyber Security

1.1.6.1.3 ESS Device Connection

1.1.6.2 ESS to Internet-Component Communication

1.1.6.3 ESS to Internet-Processor

1.1.6.3.1 Component Commands

1.1.6.3.2 Component Processor Data Link

1.1.6.3.3 Component Health and Status

1.2 Command and Control Subsystem

1.2.1 Internet to CaCS Communication

1.2.1.1 Internet Communication

1.2.1.1.1 Inbound Internet Connection

1.2.1.1.2 Internet Cyber Security

1.2.1.2 Internet Server Connection

1.2.1.2.1 Inbound Sharable Drive

1.2.1.2.2 Inbound Server Backup

1.2.1.3 Internet to Internal Network

1.2.2 CaCS Work Space

1.2.3 Facility

1.2.3.1 Facility Power

1.2.3.2 Office Network

1.2.4 CaCS to Internet Communication

1.2.4.1 CaCS Communication

1.2.4.1.1 CaCS Cyber Security

1.2.4.1.2 Outbound Internet Connection

1.2.4.2 CaCS Server Connection

1.2.4.2.1 Outbound Sharable Drive

1.2.4.2.2 Outbound Server Backup

1.2.4.3 Internal Network to Internet

## 9.2 Behavior Model

1 Oklahoma Pipeline Energy Storage System

Based On:

1 OPESS Requirements



Figure 1 Oklahoma Pipeline Energy Storage System (Enhanced FFBD)



Figure 2 Oklahoma Pipeline Energy Storage System (N2 Diagram)

1.1 Energy Storage Subsystem

Based On:

1.1 ESS Requirement

| Table 1 1.1 Energy Storage Subsystem Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| CaCS to ESS (data over Internet) | Input To:  1.1 Energy Storage Subsystem  1.1.2 Internet to ESS Control  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.1 ESS Internet Connection  Output From:  1.2 Command and Control Subsystem  1.2.4 CaCS to Internet Communication  1.2.4.3 Internal Network to Internet |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Geology | Input To:  1.1 Energy Storage Subsystem  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |
| Weather | Input To:  1.1 Energy Storage Subsystem  1.1.1.2.4 Compressed Air Pump  1.1.5 Weather Protection  1.1.5.1 Exterior Protection  1.1.5.2 Climate Control |



Figure 3 Energy Storage Subsystem (Enhanced FFBD)



Figure 4 Energy Storage Subsystem (N2 Diagram)

1.1.1 Receive Power

Based On:

1.1.4 ESS Receive Power

| Table 2 1.1.1 Receive Power Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Compressed Air (To NG) | Input To:  1.1.4 Store Power  1.1.4.1 Pressure Release  1.1.4.1.1 Maintain Pressure  Output From:  1.1.1 Receive Power |
| ESS Commands | Input To:  1.1.1 Receive Power  1.1.3 Generate Power  1.1.3.2.1 Generator Control  Output From:  1.1.2 Internet to ESS Control  1.1.2.3 Internet to ESS - Component Communications |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |
| Receive Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.1 Receive Power  1.1.1.2 Pump  1.1.1.2.3 Pump Control |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 5 Receive Power (Enhanced FFBD)



Figure 6 Receive Power (N2 Diagram)

1.1.1.1 Utility Interface

Based On:

1.1.4.2 ESS Power Intake

| Table 3 1.1.1.1 Utility Interface Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Process Electricity | Input To:  1.1.1.2 Pump  1.1.1.2.1 Pump Power Input  Output From:  1.1.1.1 Utility Interface  1.1.1.1.2 Grid to ESS power Adjustment |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 7 Utility Interface (Enhanced FFBD)



Figure 8 Utility Interface (N2 Diagram)

1.1.1.1.1 Power Grid Interface

Based On:

1.1.4.2.1 ESS Power Connection

| Table 4 1.1.1.1.1 Power Grid Interface Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| High Voltage | Input To:  1.1.1.1.2 Grid to ESS power Adjustment  Output From:  1.1.1.1.1 Power Grid Interface |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |

1.1.1.1.2 Grid to ESS power Adjustment

Based On:

1.1.4.2.3 ESS Voltage Adjust

| Table 5 1.1.1.1.2 Grid to ESS power Adjustment Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Process Electricity | Input To:  1.1.1.2 Pump  1.1.1.2.1 Pump Power Input  Output From:  1.1.1.1 Utility Interface  1.1.1.1.2 Grid to ESS power Adjustment |
| High Voltage | Input To:  1.1.1.1.2 Grid to ESS power Adjustment  Output From:  1.1.1.1.1 Power Grid Interface |

1.1.1.2 Pump

Based On:

1.1.4.1 ESS Air Pump

| Table 6 1.1.1.2 Pump Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Air (from Pump) | Input To:  1.1.1.3 Natural Gas Interface  Output From:  1.1.1.2 Pump  1.1.1.2.4 Compressed Air Pump |
| Controller Pump Command | Input To:  1.1.1.2 Pump  1.1.1.2.3 Pump Control |
| ESS Process Electricity | Input To:  1.1.1.2 Pump  1.1.1.2.1 Pump Power Input  Output From:  1.1.1.1 Utility Interface  1.1.1.1.2 Grid to ESS power Adjustment |
| Receive Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.1 Receive Power  1.1.1.2 Pump  1.1.1.2.3 Pump Control |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 9 Pump (Enhanced FFBD)



Figure 10 Pump (N2 Diagram)

1.1.1.2.1 Pump Power Input

Based On:

1.1.4.1.5 ESS Transformer Connection

| Table 7 1.1.1.2.1 Pump Power Input Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Process Electricity | Input To:  1.1.1.2 Pump  1.1.1.2.1 Pump Power Input  Output From:  1.1.1.1 Utility Interface  1.1.1.1.2 Grid to ESS power Adjustment |
| Pump Communication | Input To:  1.1.1.2.2 Pump Health and Status  Output From:  1.1.1.2.1 Pump Power Input |

1.1.1.2.2 Pump Health and Status

Based On:

1.1.4.1.3 ESS Health and Status

| Table 8 1.1.1.2.2 Pump Health and Status Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Pump Communication | Input To:  1.1.1.2.2 Pump Health and Status  Output From:  1.1.1.2.1 Pump Power Input |
| Pump HaS | Input To:  1.1.1.2.3 Pump Control  Output From:  1.1.1.2.2 Pump Health and Status |

1.1.1.2.3 Pump Control

Based On:

1.1.4.1.2 ESS Command

| Table 9 1.1.1.2.3 Pump Control Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Controller Pump Command | Input To:  1.1.1.2 Pump  1.1.1.2.3 Pump Control |
| Pump Control Command | Input To:  1.1.1.2.4 Compressed Air Pump  Output From:  1.1.1.2.3 Pump Control |
| Pump HaS | Input To:  1.1.1.2.3 Pump Control  Output From:  1.1.1.2.2 Pump Health and Status |
| Receive Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.1 Receive Power  1.1.1.2 Pump  1.1.1.2.3 Pump Control |

1.1.1.2.4 Compressed Air Pump

Based On:

1.1.4.1.6 ESS Compressed Air

| Table 10 1.1.1.2.4 Compressed Air Pump Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Air (from Pump) | Input To:  1.1.1.3 Natural Gas Interface  Output From:  1.1.1.2 Pump  1.1.1.2.4 Compressed Air Pump |
| Pump Control Command | Input To:  1.1.1.2.4 Compressed Air Pump  Output From:  1.1.1.2.3 Pump Control |
| Weather | Input To:  1.1 Energy Storage Subsystem  1.1.1.2.4 Compressed Air Pump  1.1.5 Weather Protection  1.1.5.1 Exterior Protection  1.1.5.2 Climate Control |

1.1.1.3 Natural Gas Interface

Based On:

1.1.4.1.7 Compressed Air Transport

| Table 11 1.1.1.3 Natural Gas Interface Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Air (from Pump) | Input To:  1.1.1.3 Natural Gas Interface  Output From:  1.1.1.2 Pump  1.1.1.2.4 Compressed Air Pump |
| Air (to Natural Gas) | Output From:  1.1.1.3 Natural Gas Interface |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |

1.1.2 Internet to ESS Control

Based On:

1.1.1 ESS Communications

| Table 12 1.1.2 Internet to ESS Control Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| CaCS to ESS (data over Internet) | Input To:  1.1 Energy Storage Subsystem  1.1.2 Internet to ESS Control  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.1 ESS Internet Connection  Output From:  1.2 Command and Control Subsystem  1.2.4 CaCS to Internet Communication  1.2.4.3 Internal Network to Internet |
| ESS Commands | Input To:  1.1.1 Receive Power  1.1.3 Generate Power  1.1.3.2.1 Generator Control  Output From:  1.1.2 Internet to ESS Control  1.1.2.3 Internet to ESS - Component Communications |



Figure 11 Internet to ESS Control (Enhanced FFBD)



Figure 12 Internet to ESS Control (N2 Diagram)

1.1.2.1 Internet to ESS-ESS Communications

Based On:

1.1.1.5 ESS Internet Interface

| Table 13 1.1.2.1 Internet to ESS-ESS Communications Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| CaCS to ESS (data over Internet) | Input To:  1.1 Energy Storage Subsystem  1.1.2 Internet to ESS Control  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.1 ESS Internet Connection  Output From:  1.2 Command and Control Subsystem  1.2.4 CaCS to Internet Communication  1.2.4.3 Internal Network to Internet |
| Secure Network Output | Input To:  1.1.2.2 Internet to ESS-Processor  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.3 ESS Network Interface |



Figure 13 Internet to ESS-ESS Communications (Enhanced FFBD)



Figure 14 Internet to ESS-ESS Communications (N2 Diagram)

1.1.2.1.1 ESS Internet Connection

Based On:

1.1.1.5.7 ESS Internet Connection

| Table 14 1.1.2.1.1 ESS Internet Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| CaCS to ESS (data over Internet) | Input To:  1.1 Energy Storage Subsystem  1.1.2 Internet to ESS Control  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.1 ESS Internet Connection  Output From:  1.2 Command and Control Subsystem  1.2.4 CaCS to Internet Communication  1.2.4.3 Internal Network to Internet |
| Raw Inbound TCP/IP | Input To:  1.1.2.1.2 ESS Cyber Security  Output From:  1.1.2.1.1 ESS Internet Connection |

1.1.2.1.2 ESS Cyber Security

Based On:

1.1.1.5.8 ESS Cyber Security Suite

| Table 15 1.1.2.1.2 ESS Cyber Security Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Inbound Internal Network | Input To:  1.1.2.1.3 ESS Network Interface  Output From:  1.1.2.1.2 ESS Cyber Security  1.2.1.2.2 Inbound Server Backup  1.2.1.3 Internet to Internal Network |
| Raw Inbound TCP/IP | Input To:  1.1.2.1.2 ESS Cyber Security  Output From:  1.1.2.1.1 ESS Internet Connection |

1.1.2.1.3 ESS Network Interface

Based On:

1.1.1.5.9 ESS Secure Connection

| Table 16 1.1.2.1.3 ESS Network Interface Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Inbound Internal Network | Input To:  1.1.2.1.3 ESS Network Interface  Output From:  1.1.2.1.2 ESS Cyber Security  1.2.1.2.2 Inbound Server Backup  1.2.1.3 Internet to Internal Network |
| Secure Network Output | Input To:  1.1.2.2 Internet to ESS-Processor  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.3 ESS Network Interface |

1.1.2.2 Internet to ESS-Processor

Based On:

1.1.1.1 ESS Control

| Table 17 1.1.2.2 Internet to ESS-Processor Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Processor Commands | Input To:  1.1.2.3 Internet to ESS - Component Communications  Output From:  1.1.2.2 Internet to ESS-Processor  1.1.2.2.2 Processor Data Link |
| Secure Network Output | Input To:  1.1.2.2 Internet to ESS-Processor  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.3 ESS Network Interface |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 15 Internet to ESS-Processor (Enhanced FFBD)



Figure 16 Internet to ESS-Processor (N2 Diagram)

1.1.2.2.1 ESS Commands

Based On:

1.1.1.1.5 ESS Command Process

| Table 18 1.1.2.2.1 ESS Commands Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Commands to Processor | Input To:  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.2.1 ESS Commands |
| Processor Commands ACK | Input To:  1.1.2.2.1 ESS Commands  Output From:  1.1.2.2.2 Processor Data Link |

1.1.2.2.2 Processor Data Link

Based On:

1.1.1.1.6 ESS to Component Connection

| Table 19 1.1.2.2.2 Processor Data Link Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Commands to Processor | Input To:  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.2.1 ESS Commands |
| ESS Processor Commands | Input To:  1.1.2.3 Internet to ESS - Component Communications  Output From:  1.1.2.2 Internet to ESS-Processor  1.1.2.2.2 Processor Data Link |
| Processor Commands ACK | Input To:  1.1.2.2.1 ESS Commands  Output From:  1.1.2.2.2 Processor Data Link |
| Processor HaS | Input To:  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.2.3 ESS Health and Status |
| Processor HaS ACK | Input To:  1.1.2.2.3 ESS Health and Status  Output From:  1.1.2.2.2 Processor Data Link |
| Secure Network Output | Input To:  1.1.2.2 Internet to ESS-Processor  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.3 ESS Network Interface |

1.1.2.2.3 ESS Health and Status

Based On:

1.1.1.1.7 ESS Component Processor Communication

| Table 20 1.1.2.2.3 ESS Health and Status Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Processor HaS | Input To:  1.1.2.2.2 Processor Data Link  Output From:  1.1.2.2.3 ESS Health and Status |
| Processor HaS ACK | Input To:  1.1.2.2.3 ESS Health and Status  Output From:  1.1.2.2.2 Processor Data Link |

1.1.2.3 Internet to ESS - Component Communications

Based On:

1.1.1.1.8 ESS Component Communication

| Table 21 1.1.2.3 Internet to ESS - Component Communications Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Commands | Input To:  1.1.1 Receive Power  1.1.3 Generate Power  1.1.3.2.1 Generator Control  Output From:  1.1.2 Internet to ESS Control  1.1.2.3 Internet to ESS - Component Communications |
| ESS Processor Commands | Input To:  1.1.2.3 Internet to ESS - Component Communications  Output From:  1.1.2.2 Internet to ESS-Processor  1.1.2.2.2 Processor Data Link |

1.1.3 Generate Power

Based On:

1.1.2 ESS Generate Power

| Table 22 1.1.3 Generate Power Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Carbon Credits | Output From:  1.1.3 Generate Power  1.1.3.3 Carbon Capture |
| Compressed Air (From NG) | Input To:  1.1.3 Generate Power  1.1.3.1 Generate Power Natural Gas Interface  Output From:  1.1.4 Store Power  1.1.4.1 Pressure Release |
| ESS Commands | Input To:  1.1.1 Receive Power  1.1.3 Generate Power  1.1.3.2.1 Generator Control  Output From:  1.1.2 Internet to ESS Control  1.1.2.3 Internet to ESS - Component Communications |
| Generate Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.3 Generate Power  1.1.3.2 Generator  1.1.3.2.1 Generator Control |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 17 Generate Power (Enhanced FFBD)



Figure 18 Generate Power (N2 Diagram)

1.1.3.1 Generate Power Natural Gas Interface

Based On:

1.1.2.3 ESS Storage Generator Interface

| Table 23 1.1.3.1 Generate Power Natural Gas Interface Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Compressed Air (From NG) | Input To:  1.1.3 Generate Power  1.1.3.1 Generate Power Natural Gas Interface  Output From:  1.1.4 Store Power  1.1.4.1 Pressure Release |
| Controlled Compressed Air | Input To:  1.1.3.2 Generator  Output From:  1.1.3.1 Generate Power Natural Gas Interface |

1.1.3.2 Generator

Based On:

1.1.2.3.1 ESS Power Generation

| Table 24 1.1.3.2 Generator Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Controlled Compressed Air | Input To:  1.1.3.2 Generator  Output From:  1.1.3.1 Generate Power Natural Gas Interface |
| Generate Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.3 Generate Power  1.1.3.2 Generator  1.1.3.2.1 Generator Control |
| Power to need | Input To:  1.1.3.4 Generator to Utility Interface  1.1.3.4.1 Generator to Grid Power Adjustment  Output From:  1.1.3.2 Generator  1.1.3.2.4 Generator Power Output |
| Used Compressed Air | Input To:  1.1.3.3 Carbon Capture  Output From:  1.1.3.2 Generator  1.1.3.2.3 Electrical Generator |



Figure 19 Generator (Enhanced FFBD)



Figure 20 Generator (N2 Diagram)

1.1.3.2.1 Generator Control

Based On:

1.1.2.3.3 Power Generation Gauge

| Table 25 1.1.3.2.1 Generator Control Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Commands | Input To:  1.1.1 Receive Power  1.1.3 Generate Power  1.1.3.2.1 Generator Control  Output From:  1.1.2 Internet to ESS Control  1.1.2.3 Internet to ESS - Component Communications |
| Generate Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.3 Generate Power  1.1.3.2 Generator  1.1.3.2.1 Generator Control |
| Generator Commands | Input To:  1.1.3.2.2 Generator Health and Status  1.1.3.2.3 Electrical Generator  Output From:  1.1.3.2.1 Generator Control |
| Generator Status Update | Input To:  1.1.3.2.1 Generator Control  Output From:  1.1.3.2.2 Generator Health and Status |

1.1.3.2.2 Generator Health and Status

Based On:

1.1.2.3.2 Generator Health and Status

| Table 26 1.1.3.2.2 Generator Health and Status Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Generator Commands | Input To:  1.1.3.2.2 Generator Health and Status  1.1.3.2.3 Electrical Generator  Output From:  1.1.3.2.1 Generator Control |
| Generator Status Update | Input To:  1.1.3.2.1 Generator Control  Output From:  1.1.3.2.2 Generator Health and Status |

1.1.3.2.3 Electrical Generator

Based On:

1.1.2.3.4 Compressed Air Power Generation

| Table 27 1.1.3.2.3 Electrical Generator Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Generator Commands | Input To:  1.1.3.2.2 Generator Health and Status  1.1.3.2.3 Electrical Generator  Output From:  1.1.3.2.1 Generator Control |
| Generator Power | Input To:  1.1.3.2.4 Generator Power Output  Output From:  1.1.3.2.3 Electrical Generator |
| Used Compressed Air | Input To:  1.1.3.3 Carbon Capture  Output From:  1.1.3.2 Generator  1.1.3.2.3 Electrical Generator |

1.1.3.2.4 Generator Power Output

Based On:

1.1.2.3.5 Generation to Grid Connection

| Table 28 1.1.3.2.4 Generator Power Output Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Generator Power | Input To:  1.1.3.2.4 Generator Power Output  Output From:  1.1.3.2.3 Electrical Generator |
| Power to need | Input To:  1.1.3.4 Generator to Utility Interface  1.1.3.4.1 Generator to Grid Power Adjustment  Output From:  1.1.3.2 Generator  1.1.3.2.4 Generator Power Output |

1.1.3.3 Carbon Capture

Based On:

1.1.2.4 ESS Carbon Capture

| Table 29 1.1.3.3 Carbon Capture Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Carbon Credits | Output From:  1.1.3 Generate Power  1.1.3.3 Carbon Capture |
| Used Compressed Air | Input To:  1.1.3.3 Carbon Capture  Output From:  1.1.3.2 Generator  1.1.3.2.3 Electrical Generator |

1.1.3.4 Generator to Utility Interface

Based On:

1.1.2.3.6 ESS Generator to Grid

| Table 30 1.1.3.4 Generator to Utility Interface Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |
| Power to need | Input To:  1.1.3.4 Generator to Utility Interface  1.1.3.4.1 Generator to Grid Power Adjustment  Output From:  1.1.3.2 Generator  1.1.3.2.4 Generator Power Output |



Figure 21 Generator to Utility Interface (Enhanced FFBD)



Figure 22 Generator to Utility Interface (N2 Diagram)

1.1.3.4.1 Generator to Grid Power Adjustment

Based On:

1.1.2.3.7 Generator Step Up

| Table 31 1.1.3.4.1 Generator to Grid Power Adjustment Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Adjusted Power Output | Input To:  1.1.3.4.2 Generator to Grid Connection  Output From:  1.1.3.4.1 Generator to Grid Power Adjustment |
| Power to need | Input To:  1.1.3.4 Generator to Utility Interface  1.1.3.4.1 Generator to Grid Power Adjustment  Output From:  1.1.3.2 Generator  1.1.3.2.4 Generator Power Output |

1.1.3.4.2 Generator to Grid Connection

Based On:

1.1.2.3.6 ESS Generator to Grid

| Table 32 1.1.3.4.2 Generator to Grid Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Adjusted Power Output | Input To:  1.1.3.4.2 Generator to Grid Connection  Output From:  1.1.3.4.1 Generator to Grid Power Adjustment |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |

1.1.4 Store Power

Based On:

1.1.3 ESS Power Storage

| Table 33 1.1.4 Store Power Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Compressed Air (From NG) | Input To:  1.1.3 Generate Power  1.1.3.1 Generate Power Natural Gas Interface  Output From:  1.1.4 Store Power  1.1.4.1 Pressure Release |
| Compressed Air (To NG) | Input To:  1.1.4 Store Power  1.1.4.1 Pressure Release  1.1.4.1.1 Maintain Pressure  Output From:  1.1.1 Receive Power |
| Geology | Input To:  1.1 Energy Storage Subsystem  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |
| Store Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 23 Store Power (Enhanced FFBD)



Figure 24 Store Power (N2 Diagram)

1.1.4.1 Pressure Release

Based On:

1.1.3.3 ESS Pressure

| Table 34 1.1.4.1 Pressure Release Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Compressed Air (From NG) | Input To:  1.1.3 Generate Power  1.1.3.1 Generate Power Natural Gas Interface  Output From:  1.1.4 Store Power  1.1.4.1 Pressure Release |
| Compressed Air (To NG) | Input To:  1.1.4 Store Power  1.1.4.1 Pressure Release  1.1.4.1.1 Maintain Pressure  Output From:  1.1.1 Receive Power |
| Compressed Air In | Input To:  1.1.4.2 Natural Gas Well Storage  Output From:  1.1.4.1 Pressure Release  1.1.4.1.2 Pressure Safety Release |
| Compressed Air Out | Input To:  1.1.4.1 Pressure Release  1.1.4.1.2 Pressure Safety Release  Output From:  1.1.4.2 Natural Gas Well Storage |



Figure 25 Pressure Release (Enhanced FFBD)



Figure 26 Pressure Release (N2 Diagram)

1.1.4.1.1 Maintain Pressure

Based On:

1.1.3.3.7 Constant Pressure

| Table 35 1.1.4.1.1 Maintain Pressure Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Compressed Air (To NG) | Input To:  1.1.4 Store Power  1.1.4.1 Pressure Release  1.1.4.1.1 Maintain Pressure  Output From:  1.1.1 Receive Power |
| Constant pressure | Input To:  1.1.4.1.2 Pressure Safety Release  Output From:  1.1.4.1.1 Maintain Pressure |
| Pressure Outlet | Input To:  1.1.4.1.1 Maintain Pressure  Output From:  1.1.4.1.2 Pressure Safety Release |

1.1.4.1.2 Pressure Safety Release

Based On:

1.1.3.3.8 ESS Emergency Release

| Table 36 1.1.4.1.2 Pressure Safety Release Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Compressed Air In | Input To:  1.1.4.2 Natural Gas Well Storage  Output From:  1.1.4.1 Pressure Release  1.1.4.1.2 Pressure Safety Release |
| Compressed Air Out | Input To:  1.1.4.1 Pressure Release  1.1.4.1.2 Pressure Safety Release  Output From:  1.1.4.2 Natural Gas Well Storage |
| Constant pressure | Input To:  1.1.4.1.2 Pressure Safety Release  Output From:  1.1.4.1.1 Maintain Pressure |
| Pressure Outlet | Input To:  1.1.4.1.1 Maintain Pressure  Output From:  1.1.4.1.2 Pressure Safety Release |

1.1.4.2 Natural Gas Well Storage

Based On:

1.1.3.2 ESS Compressed air storage

| Table 37 1.1.4.2 Natural Gas Well Storage Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Compressed Air In | Input To:  1.1.4.2 Natural Gas Well Storage  Output From:  1.1.4.1 Pressure Release  1.1.4.1.2 Pressure Safety Release |
| Compressed Air Out | Input To:  1.1.4.1 Pressure Release  1.1.4.1.2 Pressure Safety Release  Output From:  1.1.4.2 Natural Gas Well Storage |
| Natural Gas Well Environment | Input To:  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors  Output From:  1.1.4.2 Natural Gas Well Storage |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |

1.1.4.3 Well Safety

Based On:

1.1.3.1 ESS Compressed air monitoring

| Table 38 1.1.4.3 Well Safety Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Geology | Input To:  1.1 Energy Storage Subsystem  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |
| Natural Gas Well Environment | Input To:  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors  Output From:  1.1.4.2 Natural Gas Well Storage |
| Store Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |



Figure 27 Well Safety (Enhanced FFBD)



Figure 28 Well Safety (N2 Diagram)

1.1.4.3.1 Gas Sensors

Based On:

1.1.3.1.6 Chemical Monitoring

| Table 39 1.1.4.3.1 Gas Sensors Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Geology | Input To:  1.1 Energy Storage Subsystem  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |
| Natural Gas Well Environment | Input To:  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors  Output From:  1.1.4.2 Natural Gas Well Storage |
| Store Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |

1.1.4.3.2 Pressure Sensors

Based On:

1.1.3.1.7 Pressure Monitoring

| Table 40 1.1.4.3.2 Pressure Sensors Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Geology | Input To:  1.1 Energy Storage Subsystem  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |
| Natural Gas Well Environment | Input To:  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors  Output From:  1.1.4.2 Natural Gas Well Storage |
| Store Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |

1.1.5 Weather Protection

Based On:

1.1.5 ESS Weather

| Table 41 1.1.5 Weather Protection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Weather | Input To:  1.1 Energy Storage Subsystem  1.1.1.2.4 Compressed Air Pump  1.1.5 Weather Protection  1.1.5.1 Exterior Protection  1.1.5.2 Climate Control |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 29 Weather Protection (Enhanced FFBD)



Figure 30 Weather Protection (N2 Diagram)

1.1.5.1 Exterior Protection

Based On:

1.1.5.6 Weather Protect

| Table 42 1.1.5.1 Exterior Protection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Internal Environment | Input To:  1.1.5.2 Climate Control  Output From:  1.1.5.1 Exterior Protection |
| Weather | Input To:  1.1 Energy Storage Subsystem  1.1.1.2.4 Compressed Air Pump  1.1.5 Weather Protection  1.1.5.1 Exterior Protection  1.1.5.2 Climate Control |

1.1.5.2 Climate Control

Based On:

1.1.5.7 Climate Control

| Table 43 1.1.5.2 Climate Control Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Internal Environment | Input To:  1.1.5.2 Climate Control  Output From:  1.1.5.1 Exterior Protection |
| Weather | Input To:  1.1 Energy Storage Subsystem  1.1.1.2.4 Compressed Air Pump  1.1.5 Weather Protection  1.1.5.1 Exterior Protection  1.1.5.2 Climate Control |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |

1.1.6 ESS to Internet-Control

Based On:

1.1.1 ESS Communications

| Table 44 1.1.6 ESS to Internet-Control Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Generate Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.3 Generate Power  1.1.3.2 Generator  1.1.3.2.1 Generator Control |
| Receive Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.1 Receive Power  1.1.1.2 Pump  1.1.1.2.3 Pump Control |
| Store Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |



Figure 31 ESS to Internet-Control (Enhanced FFBD)



Figure 32 ESS to Internet-Control (N2 Diagram)

1.1.6.1 ESS to Internet-ESS Communications

Based On:

1.1.1.5 ESS Internet Interface

| Table 45 1.1.6.1 ESS to Internet-ESS Communications Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Outbound Processor Commands | Input To:  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.1 ESS Connection  Output From:  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link |



Figure 33 ESS to Internet-ESS Communications (Enhanced FFBD)



Figure 34 ESS to Internet-ESS Communications (N2 Diagram)

1.1.6.1.1 ESS Connection

Based On:

1.1.1.5.7 ESS Internet Connection

| Table 46 1.1.6.1.1 ESS Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Device Status | Input To:  1.1.6.1.2 Device Cyber Security  Output From:  1.1.6.1.1 ESS Connection |
| Outbound Processor Commands | Input To:  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.1 ESS Connection  Output From:  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link |

1.1.6.1.2 Device Cyber Security

Based On:

1.1.1.5.8 ESS Cyber Security Suite

| Table 47 1.1.6.1.2 Device Cyber Security Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS Device Status | Input To:  1.1.6.1.2 Device Cyber Security  Output From:  1.1.6.1.1 ESS Connection |
| Raw Outbound TCP/IP | Input To:  1.1.6.1.3 ESS Device Connection  Output From:  1.1.6.1.2 Device Cyber Security |

1.1.6.1.3 ESS Device Connection

Based On:

1.1.1.5.9 ESS Secure Connection

| Table 48 1.1.6.1.3 ESS Device Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Raw Outbound TCP/IP | Input To:  1.1.6.1.3 ESS Device Connection  Output From:  1.1.6.1.2 Device Cyber Security |

1.1.6.2 ESS to Internet-Component Communication

Based On:

1.1.1.5 ESS Internet Interface

| Table 49 1.1.6.2 ESS to Internet-Component Communication Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Component Health and Status | Input To:  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.6.2 ESS to Internet-Component Communication |
| Generate Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.3 Generate Power  1.1.3.2 Generator  1.1.3.2.1 Generator Control |
| Receive Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.1 Receive Power  1.1.1.2 Pump  1.1.1.2.3 Pump Control |
| Store Power Health and Status | Input To:  1.1.6 ESS to Internet-Control  1.1.6.2 ESS to Internet-Component Communication  Output From:  1.1.4 Store Power  1.1.4.3 Well Safety  1.1.4.3.1 Gas Sensors  1.1.4.3.2 Pressure Sensors |

1.1.6.3 ESS to Internet-Processor

Based On:

1.1.1.1 ESS Control

| Table 50 1.1.6.3 ESS to Internet-Processor Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Component Health and Status | Input To:  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.6.2 ESS to Internet-Component Communication |
| Outbound Processor Commands | Input To:  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.1 ESS Connection  Output From:  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |



Figure 35 ESS to Internet-Processor (Enhanced FFBD)



Figure 36 ESS to Internet-Processor (N2 Diagram)

1.1.6.3.1 Component Commands

Based On:

1.1.1.1.5 ESS Command Process

| Table 51 1.1.6.3.1 Component Commands Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Component Processor ACK | Input To:  1.1.6.3.1 Component Commands  Output From:  1.1.6.3.2 Component Processor Data Link |
| Processor Commands | Input To:  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.6.3.1 Component Commands |

1.1.6.3.2 Component Processor Data Link

Based On:

1.1.1.1.6 ESS to Component Connection

| Table 52 1.1.6.3.2 Component Processor Data Link Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Component Health and Status | Input To:  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.6.2 ESS to Internet-Component Communication |
| Component Processor ACK | Input To:  1.1.6.3.1 Component Commands  Output From:  1.1.6.3.2 Component Processor Data Link |
| Outbound Processor Commands | Input To:  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.1 ESS Connection  Output From:  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link |
| Outbound Processor H&S | Input To:  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.6.3.3 Component Health and Status |
| Outbound Processor H&S ACK | Input To:  1.1.6.3.3 Component Health and Status  Output From:  1.1.6.3.2 Component Processor Data Link |
| Processor Commands | Input To:  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.6.3.1 Component Commands |
| Weather Protection | Input To:  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.2 Pump  1.1.1.3 Natural Gas Interface  1.1.2.2 Internet to ESS-Processor  1.1.3 Generate Power  1.1.4 Store Power  1.1.4.2 Natural Gas Well Storage  1.1.6.3 ESS to Internet-Processor  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.5 Weather Protection  1.1.5.2 Climate Control |

1.1.6.3.3 Component Health and Status

Based On:

1.1.1.1.7 ESS Component Processor Communication

| Table 53 1.1.6.3.3 Component Health and Status Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Outbound Processor H&S | Input To:  1.1.6.3.2 Component Processor Data Link  Output From:  1.1.6.3.3 Component Health and Status |
| Outbound Processor H&S ACK | Input To:  1.1.6.3.3 Component Health and Status  Output From:  1.1.6.3.2 Component Processor Data Link |

1.2 Command and Control Subsystem

Based On:

1.2 CaCS Requirements

| Table 54 1.2 Command and Control Subsystem Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| CaCS to ESS (data over Internet) | Input To:  1.1 Energy Storage Subsystem  1.1.2 Internet to ESS Control  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.1 ESS Internet Connection  Output From:  1.2 Command and Control Subsystem  1.2.4 CaCS to Internet Communication  1.2.4.3 Internal Network to Internet |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |
| Utility Employee | Input To:  1.2 Command and Control Subsystem  1.2.2 CaCS Work Space |



Figure 37 Command and Control Subsystem (Enhanced FFBD)



Figure 38 Command and Control Subsystem (N2 Diagram)

1.2.1 Internet to CaCS Communication

Based On:

1.2.1 CaCS Communications

| Table 55 1.2.1 Internet to CaCS Communication Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Inbound Internet | Input To:  1.2.3 Facility  1.2.3.2 Office Network  Output From:  1.2.1 Internet to CaCS Communication |



Figure 39 Internet to CaCS Communication (Enhanced FFBD)



Figure 40 Internet to CaCS Communication (N2 Diagram)

1.2.1.1 Internet Communication

Based On:

1.2.1.1 CaCS Internal Network

1.2.1.3 CaCS Syber Security

| Table 56 1.2.1.1 Internet Communication Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Secure Inbound Connection | Input To:  1.2.1.2 Internet Server Connection  Output From:  1.2.1.1 Internet Communication  1.2.1.1.2 Internet Cyber Security |



Figure 41 Internet Communication (Enhanced FFBD)



Figure 42 Internet Communication (N2 Diagram)

1.2.1.1.1 Inbound Internet Connection

Based On:

1.2.1.1.1 CaCS High Speed Network

1.2.1.1.3 CaCS Ring Network

| Table 57 1.2.1.1.1 Inbound Internet Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| ESS to CaCS (Data over Internet) | Input To:  1.2 Command and Control Subsystem  1.2.1 Internet to CaCS Communication  1.2.1.1 Internet Communication  1.2.1.1.1 Inbound Internet Connection  Output From:  1.1 Energy Storage Subsystem  1.1.6 ESS to Internet-Control  1.1.6.1 ESS to Internet-ESS Communications  1.1.6.1.3 ESS Device Connection |
| Raw Inbound Internet | Input To:  1.2.1.1.2 Internet Cyber Security  Output From:  1.2.1.1.1 Inbound Internet Connection |

1.2.1.1.2 Internet Cyber Security

Based On:

1.2.1.3.4 CaCS Intrusion Detection

| Table 58 1.2.1.1.2 Internet Cyber Security Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Raw Inbound Internet | Input To:  1.2.1.1.2 Internet Cyber Security  Output From:  1.2.1.1.1 Inbound Internet Connection |
| Secure Inbound Connection | Input To:  1.2.1.2 Internet Server Connection  Output From:  1.2.1.1 Internet Communication  1.2.1.1.2 Internet Cyber Security |

1.2.1.2 Internet Server Connection

Based On:

1.2.1.2 CaCS Servers

| Table 59 1.2.1.2 Internet Server Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Inbound Server Connection | Input To:  1.2.1.2.1 Inbound Sharable Drive  1.2.1.3 Internet to Internal Network  Output From:  1.2.1.2 Internet Server Connection |
| Secure Inbound Connection | Input To:  1.2.1.2 Internet Server Connection  Output From:  1.2.1.1 Internet Communication  1.2.1.1.2 Internet Cyber Security |



Figure 43 Internet Server Connection (Enhanced FFBD)



Figure 44 Internet Server Connection (N2 Diagram)

1.2.1.2.1 Inbound Sharable Drive

Based On:

1.2.1.2.3 CaCS Server Infrastructure

| Table 60 1.2.1.2.1 Inbound Sharable Drive Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Inbound Server Connection | Input To:  1.2.1.2.1 Inbound Sharable Drive  1.2.1.3 Internet to Internal Network  Output From:  1.2.1.2 Internet Server Connection |
| Server Backup Data | Input To:  1.2.1.2.1 Inbound Sharable Drive  Output From:  1.2.1.2.2 Inbound Server Backup |
| Server Data Refresh | Input To:  1.2.1.2.2 Inbound Server Backup  Output From:  1.2.1.2.1 Inbound Sharable Drive |

1.2.1.2.2 Inbound Server Backup

Based On:

1.2.1.2.4 CaCS Backup Server

| Table 61 1.2.1.2.2 Inbound Server Backup Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Inbound Internal Network | Input To:  1.1.2.1.3 ESS Network Interface  Output From:  1.1.2.1.2 ESS Cyber Security  1.2.1.2.2 Inbound Server Backup  1.2.1.3 Internet to Internal Network |
| Server Backup Data | Input To:  1.2.1.2.1 Inbound Sharable Drive  Output From:  1.2.1.2.2 Inbound Server Backup |
| Server Data Refresh | Input To:  1.2.1.2.2 Inbound Server Backup  Output From:  1.2.1.2.1 Inbound Sharable Drive |

1.2.1.3 Internet to Internal Network

Based On:

1.2.1.3.5 CaCS TCP/IP

| Table 62 1.2.1.3 Internet to Internal Network Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Inbound Internal Network | Input To:  1.1.2.1.3 ESS Network Interface  Output From:  1.1.2.1.2 ESS Cyber Security  1.2.1.2.2 Inbound Server Backup  1.2.1.3 Internet to Internal Network |
| Inbound Server Connection | Input To:  1.2.1.2.1 Inbound Sharable Drive  1.2.1.3 Internet to Internal Network  Output From:  1.2.1.2 Internet Server Connection |

1.2.2 CaCS Work Space

Based On:

1.2.3 CaCS Utility Interface

1.2.3.1 CaCS Control

1.2.3.1.1 CaCS ESS Health and Status

1.2.3.1.3 CaCS Two Factor Authentication

1.2.3.6 CaCS Models

1.2.3.6.1 CaCS Federal Utility Company Interface

1.2.3.6.2 CaCS Local Utility Company Interface

| Table 63 1.2.2 CaCS Work Space Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Network Bandwidth | Input To:  1.2.2 CaCS Work Space  Output From:  1.2.3 Facility  1.2.3.2 Office Network |
| Network Communications | Input To:  1.2.3 Facility  1.2.3.2 Office Network  Output From:  1.2.2 CaCS Work Space |
| Utility Employee | Input To:  1.2 Command and Control Subsystem  1.2.2 CaCS Work Space |

1.2.3 Facility

Based On:

1.2.2 CaCS Receive Power

| Table 64 1.2.3 Facility Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Inbound Internet | Input To:  1.2.3 Facility  1.2.3.2 Office Network  Output From:  1.2.1 Internet to CaCS Communication |
| Network Bandwidth | Input To:  1.2.2 CaCS Work Space  Output From:  1.2.3 Facility  1.2.3.2 Office Network |
| Network Communications | Input To:  1.2.3 Facility  1.2.3.2 Office Network  Output From:  1.2.2 CaCS Work Space |
| Outbound Internet | Input To:  1.2.4 CaCS to Internet Communication  1.2.4.1 CaCS Communication  1.2.4.1.1 CaCS Cyber Security  Output From:  1.2.3 Facility |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |



Figure 45 Facility (Enhanced FFBD)



Figure 46 Facility (N2 Diagram)

1.2.3.1 Facility Power

Based On:

1.2.2.1 CaCS Distribute Power

| Table 65 1.2.3.1 Facility Power Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Facility Power Output | Input To:  1.2.3.2 Office Network  Output From:  1.2.3.1 Facility Power |
| Power Grid (Electricity) | Input To:  1.1 Energy Storage Subsystem  1.1.1 Receive Power  1.1.1.1 Utility Interface  1.1.1.1.1 Power Grid Interface  1.2 Command and Control Subsystem  1.2.3 Facility  1.2.3.1 Facility Power  Output From:  1.1 Energy Storage Subsystem  1.1.3 Generate Power  1.1.3.4 Generator to Utility Interface  1.1.3.4.2 Generator to Grid Connection |

1.2.3.2 Office Network

Based On:

1.2.3.8 Office Space

| Table 66 1.2.3.2 Office Network Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Facility Power Output | Input To:  1.2.3.2 Office Network  Output From:  1.2.3.1 Facility Power |
| Inbound Internet | Input To:  1.2.3 Facility  1.2.3.2 Office Network  Output From:  1.2.1 Internet to CaCS Communication |
| Network Bandwidth | Input To:  1.2.2 CaCS Work Space  Output From:  1.2.3 Facility  1.2.3.2 Office Network |
| Network Communications | Input To:  1.2.3 Facility  1.2.3.2 Office Network  Output From:  1.2.2 CaCS Work Space |

1.2.4 CaCS to Internet Communication

Based On:

1.2.1 CaCS Communications

| Table 67 1.2.4 CaCS to Internet Communication Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| CaCS to ESS (data over Internet) | Input To:  1.1 Energy Storage Subsystem  1.1.2 Internet to ESS Control  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.1 ESS Internet Connection  Output From:  1.2 Command and Control Subsystem  1.2.4 CaCS to Internet Communication  1.2.4.3 Internal Network to Internet |
| Outbound Internet | Input To:  1.2.4 CaCS to Internet Communication  1.2.4.1 CaCS Communication  1.2.4.1.1 CaCS Cyber Security  Output From:  1.2.3 Facility |



Figure 47 CaCS to Internet Communication (Enhanced FFBD)



Figure 48 CaCS to Internet Communication (N2 Diagram)

1.2.4.1 CaCS Communication

Based On:

1.2.1.1 CaCS Internal Network

1.2.1.3 CaCS Syber Security

| Table 68 1.2.4.1 CaCS Communication Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Outbound Internet | Input To:  1.2.4 CaCS to Internet Communication  1.2.4.1 CaCS Communication  1.2.4.1.1 CaCS Cyber Security  Output From:  1.2.3 Facility |
| Secure Outbound Connection | Input To:  1.2.4.2 CaCS Server Connection  1.2.4.2.1 Outbound Sharable Drive  Output From:  1.2.4.1 CaCS Communication  1.2.4.1.2 Outbound Internet Connection |



Figure 49 CaCS Communication (Enhanced FFBD)



Figure 50 CaCS Communication (N2 Diagram)

1.2.4.1.1 CaCS Cyber Security

Based On:

1.2.1.3.4 CaCS Intrusion Detection

| Table 69 1.2.4.1.1 CaCS Cyber Security Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Outbound Internet | Input To:  1.2.4 CaCS to Internet Communication  1.2.4.1 CaCS Communication  1.2.4.1.1 CaCS Cyber Security  Output From:  1.2.3 Facility |
| Secure Data Package | Input To:  1.2.4.1.2 Outbound Internet Connection  Output From:  1.2.4.1.1 CaCS Cyber Security |

1.2.4.1.2 Outbound Internet Connection

Based On:

1.2.1.1.1 CaCS High Speed Network

1.2.1.1.3 CaCS Ring Network

| Table 70 1.2.4.1.2 Outbound Internet Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Secure Data Package | Input To:  1.2.4.1.2 Outbound Internet Connection  Output From:  1.2.4.1.1 CaCS Cyber Security |
| Secure Outbound Connection | Input To:  1.2.4.2 CaCS Server Connection  1.2.4.2.1 Outbound Sharable Drive  Output From:  1.2.4.1 CaCS Communication  1.2.4.1.2 Outbound Internet Connection |

1.2.4.2 CaCS Server Connection

Based On:

1.2.1.2 CaCS Servers

| Table 71 1.2.4.2 CaCS Server Connection Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Outbound Server Connection | Input To:  1.2.4.3 Internal Network to Internet  Output From:  1.2.4.2 CaCS Server Connection  1.2.4.2.2 Outbound Server Backup |
| Secure Outbound Connection | Input To:  1.2.4.2 CaCS Server Connection  1.2.4.2.1 Outbound Sharable Drive  Output From:  1.2.4.1 CaCS Communication  1.2.4.1.2 Outbound Internet Connection |



Figure 51 CaCS Server Connection (Enhanced FFBD)



Figure 52 CaCS Server Connection (N2 Diagram)

1.2.4.2.1 Outbound Sharable Drive

Based On:

1.2.1.2.3 CaCS Server Infrastructure

| Table 72 1.2.4.2.1 Outbound Sharable Drive Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Outbound Server Data | Input To:  1.2.4.2.2 Outbound Server Backup  Output From:  1.2.4.2.1 Outbound Sharable Drive |
| Outbound Server Refresh Data | Input To:  1.2.4.2.1 Outbound Sharable Drive  Output From:  1.2.4.2.2 Outbound Server Backup |
| Secure Outbound Connection | Input To:  1.2.4.2 CaCS Server Connection  1.2.4.2.1 Outbound Sharable Drive  Output From:  1.2.4.1 CaCS Communication  1.2.4.1.2 Outbound Internet Connection |

1.2.4.2.2 Outbound Server Backup

Based On:

1.2.1.2.4 CaCS Backup Server

| Table 73 1.2.4.2.2 Outbound Server Backup Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| Outbound Server Connection | Input To:  1.2.4.3 Internal Network to Internet  Output From:  1.2.4.2 CaCS Server Connection  1.2.4.2.2 Outbound Server Backup |
| Outbound Server Data | Input To:  1.2.4.2.2 Outbound Server Backup  Output From:  1.2.4.2.1 Outbound Sharable Drive |
| Outbound Server Refresh Data | Input To:  1.2.4.2.1 Outbound Sharable Drive  Output From:  1.2.4.2.2 Outbound Server Backup |

1.2.4.3 Internal Network to Internet

Based On:

1.2.1.3.5 CaCS TCP/IP

| Table 74 1.2.4.3 Internal Network to Internet Interfacing Items | |
| --- | --- |
| Interfacing Items | Source / Destination |
| CaCS to ESS (data over Internet) | Input To:  1.1 Energy Storage Subsystem  1.1.2 Internet to ESS Control  1.1.2.1 Internet to ESS-ESS Communications  1.1.2.1.1 ESS Internet Connection  Output From:  1.2 Command and Control Subsystem  1.2.4 CaCS to Internet Communication  1.2.4.3 Internal Network to Internet |
| Outbound Server Connection | Input To:  1.2.4.3 Internal Network to Internet  Output From:  1.2.4.2 CaCS Server Connection  1.2.4.2.2 Outbound Server Backup |

# 10 Appendix C: Verification Cross Reference Matrix

| Number | Name | Description | Refined By | Refines | KPP | Verification Method | Rationale | Title |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | OPESS Requirements | The Oklahoma Pipeline Energy Storage System (OPESS) shall operate as an energy storage system on the electrical grid. | Requirement 1.1 ESS Requirement Requirement 1.2 CaCS Requirements |  | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.1 | ESS Requirement | The Energy Storage Subsystem (ESS) shall actively store and generate energy for use on the electrical grid. | Requirement 1.1.1 ESS Communications Requirement 1.1.2 ESS Generate Power Requirement 1.1.3 ESS Power Storage Requirement 1.1.4 ESS Receive Power Requirement 1.1.5 ESS Weather | Requirement 1 OPESS Requirements | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.1 | ESS Communications | The ESS shall send and receive information and commands from the CaCS via the internet. | Requirement 1.1.1.1 ESS Control Requirement 1.1.1.2 ESS Control Node Process Commands Requirement 1.1.1.3 ESS Control Node Receive Commands Requirement 1.1.1.4 ESS Control Node Send Commands Requirement 1.1.1.5 ESS Internet Interface Requirement 1.1.1.6 ESS Send Health and Status | Requirement 1.1 ESS Requirement | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.1.1 | ESS Control | The ESS control node shall process commands from the CaCS. | Requirement 1.1.1.1.1 ESS Health and Status Send Requirement 1.1.1.1.2 ESS Processor Communication Requirement 1.1.1.1.3 ESS Processor Health and Status Receive Requirement 1.1.1.1.4 ESS Processor Response Requirement 1.1.1.1.5 ESS Command Process Requirement 1.1.1.1.6 ESS to Component Connection Requirement 1.1.1.1.7 ESS Component Processor Communication Requirement 1.1.1.1.8 ESS Component Communication | Requirement 1.1.1 ESS Communications | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.1.1.1 | ESS Health and Status Send | The ESS processor shall scan the health and status updates and send them to the CaCS. |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.1.1.2 | ESS Processor Communication | The ESS processor shall receive commands from the CaCS. |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.1.1.3 | ESS Processor Health and Status Receive | The ESS processor shall receive health and Status from the components. |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.1.1.4 | ESS Processor Response | The ESS processor shall automatically respond to any health or safety issue its receives. |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.1.1.5 | ESS Command Process | The ESS shall process commands and responses coming from the ESS. |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.1.1.6 | ESS to Component Connection | The ESS shall connect the ESS components to the internet through a processor |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.1.1.7 | ESS Component Processor Communication | The ESS shall monitor health and status and report that information to the CaCS. |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.1.1.8 | ESS Component Communication | The ESS shall allow the ESS components to communicate with the ESS processor. |  | Requirement 1.1.1.1 ESS Control | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.1.2 | ESS Control Node Process Commands | The ESS control node shall process input from the generator, storage and compressor apparatus. |  | Requirement 1.1.1 ESS Communications | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.1.1.3 | ESS Control Node Receive Commands | The ESS control node shall receive information from the generator, storage and compressor apparatus. |  | Requirement 1.1.1 ESS Communications | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.1.4 | ESS Control Node Send Commands | The ESS control node shall send CaCS commands to the generator, storage apparatus and the compressor. |  | Requirement 1.1.1 ESS Communications | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.1.5 | ESS Internet Interface | The ESS control node shall maintain a secure connection with the CaCS. | Requirement 1.1.1.5.1 ESS Cyber Scans Requirement 1.1.1.5.2 ESS Encryption Requirement 1.1.1.5.3 ESS Fiber Optics Requirement 1.1.1.5.4 ESS Firewall Requirement 1.1.1.5.5 ESS High Speed Internet Requirement 1.1.1.5.6 ESS TCP/IP Requirement 1.1.1.5.7 ESS Internet Connection Requirement 1.1.1.5.8 ESS Cyber Security Suite Requirement 1.1.1.5.9 ESS Secure Connection | Requirement 1.1.1 ESS Communications | TRUE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.1.5.1 | ESS Cyber Scans | The ESS shall undergo security scans at least once a quarter. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Inspection | Derived from Interviews | Quantitative |
| 1.1.1.5.2 | ESS Encryption | The ESS connection to the CaCS shall be encrypted with a AES-256 connection or stronger |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Inspection | Derived from Interviews | Qualitative |
| 1.1.1.5.3 | ESS Fiber Optics | The ESS shall use either a IEEE802.3 Ethernet or Fiber Optic connection. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Inspection | Derived from Interviews | Qualitative |
| 1.1.1.5.4 | ESS Firewall | The ESS shall operate a firewall with IPS, TLS inspection and ERL filtering. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Inspection | Derived from Interviews | Qualitative |
| 1.1.1.5.5 | ESS High Speed Internet | The ESS shall maintain a high-speed connection to the internet. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Analysis | Design decision | Quantitative |
| 1.1.1.5.6 | ESS TCP/IP | The ESS shall use a TCP/IP connection. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Inspection | Derived from Interviews | Qualitative |
| 1.1.1.5.7 | ESS Internet Connection | The ESS network shall connect to the Internet. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.1.5.8 | ESS Cyber Security Suite | The ESS internet connection shall function with a cyber security suite. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.1.5.9 | ESS Secure Connection | The ESS shall connect to the Internet through a secure connection. |  | Requirement 1.1.1.5 ESS Internet Interface | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.1.1.6 | ESS Send Health and Status | The ESS control node shall send the input from the generator, storage and compressor apparatus to the CaCS. |  | Requirement 1.1.1 ESS Communications | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.2 | ESS Generate Power | The ESS shall generate power from storage for use on the power grid. | Requirement 1.1.2.1 ESS Generator Requirement 1.1.2.2 ESS Power Uptake Requirement 1.1.2.3 ESS Storage Generator Interface Requirement 1.1.2.4 ESS Carbon Capture | Requirement 1.1 ESS Requirement | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.2.1 | ESS Generator | The ESS shall use compressed air to run a generator. | Requirement 1.1.2.1.1 ESS Generator Commands Requirement 1.1.2.1.2 ESS Generator Health and Status Requirement 1.1.2.1.3 ESS Generator Storage Interface Requirement 1.1.2.1.4 ESS Generator Utility Interface | Requirement 1.1.2 ESS Generate Power | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.2.1.1 | ESS Generator Commands | The ESS generator shall receive commands from the CaCS telling it to turn on, off and how hard to run. |  | Requirement 1.1.2.1 ESS Generator | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.2.1.2 | ESS Generator Health and Status | The ESS generator shall send health and safety information to the processor as well as receive any emergency commands. |  | Requirement 1.1.2.1 ESS Generator | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.2.1.3 | ESS Generator Storage Interface | The ESS generator shall use compressed air coming from the natural gas well to spin a turbine and generate power. |  | Requirement 1.1.2.1 ESS Generator | TRUE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.2.1.4 | ESS Generator Utility Interface | The ESS shall send its power to the Utility Connection. |  | Requirement 1.1.2.1 ESS Generator | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.2.2 | ESS Power Uptake | The ESS shall send electrical power onto the utility grid via a utility interface | Requirement 1.1.2.2.1 ESS Generator Grid interface Requirement 1.1.2.2.2 ESS Generator Transformer | Requirement 1.1.2 ESS Generate Power | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.2.2.1 | ESS Generator Grid interface | The ESS shall send power from the step-up generator to the electrical grid |  | Requirement 1.1.2.2 ESS Power Uptake | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.2.2.2 | ESS Generator Transformer | The ESS shall send power from the generator to a step-up transformer. |  | Requirement 1.1.2.2 ESS Power Uptake | FALSE | VerificationRequirement Inspection | Derived from Research | Qualitative |
| 1.1.2.3 | ESS Storage Generator Interface | The ESS shall pull compressed air from the storage device through a pressurized interface. | Requirement 1.1.2.3.1 ESS Power Generation Requirement 1.1.2.3.2 Generator Health and Status Requirement 1.1.2.3.3 Power Generation Gauge Requirement 1.1.2.3.4 Compressed Air Power Generation Requirement 1.1.2.3.5 Generation to Grid Connection Requirement 1.1.2.3.6 ESS Generator to Grid Requirement 1.1.2.3.7 Generator Step Up | Requirement 1.1.2 ESS Generate Power | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.2.3.1 | ESS Power Generation | The ESS shall generate power. |  | Requirement 1.1.2.3 ESS Storage Generator Interface | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.2.3.2 | Generator Health and Status | The ESS shall monitor the ESS generator health and status. |  | Requirement 1.1.2.3 ESS Storage Generator Interface | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.2.3.3 | Power Generation Gauge | The ESS shall control the amount of power generated by the generator. |  | Requirement 1.1.2.3 ESS Storage Generator Interface | FALSE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.2.3.4 | Compressed Air Power Generation | The ESS shall generate power from compressed air as needed. |  | Requirement 1.1.2.3 ESS Storage Generator Interface | FALSE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.2.3.5 | Generation to Grid Connection | The ESS generator shall connect to the electrical grid. |  | Requirement 1.1.2.3 ESS Storage Generator Interface | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.2.3.6 | ESS Generator to Grid | The ESS shall connect the power grid to the generator. |  | Requirement 1.1.2.3 ESS Storage Generator Interface | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.2.3.7 | Generator Step Up | The ESS shall step up the power generated for use on the electric grid. |  | Requirement 1.1.2.3 ESS Storage Generator Interface | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.1.2.4 | ESS Carbon Capture | The ESS shall send all the compressed air used by the generator through a carbon capture system. | Requirement 1.1.2.4.1 ESS Carbon Capture Percent Requirement 1.1.2.4.2 ESS Carbon Capture Release | Requirement 1.1.2 ESS Generate Power | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.2.4.1 | ESS Carbon Capture Percent | The ESS carbon capture system shall remove no less than 50 percent of the hydrocarbons from the compressed air. |  | Requirement 1.1.2.4 ESS Carbon Capture | TRUE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.2.4.2 | ESS Carbon Capture Release | Once passed through the carbon capture system, the ESS shall release all the compressed air used by the generator into the environment. |  | Requirement 1.1.2.4 ESS Carbon Capture | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.1.3 | ESS Power Storage | The ESS shall store power in natural gas wells. | Requirement 1.1.3.1 ESS Compressed air monitoring Requirement 1.1.3.2 ESS Compressed air storage Requirement 1.1.3.3 ESS Pressure | Requirement 1.1 ESS Requirement | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.3.1 | ESS Compressed air monitoring | The ESS storage shall monitor gas in the natural gas well. | Requirement 1.1.3.1.1 ESS Gas Monitoring Requirement 1.1.3.1.2 ESS Storage pressure monitoring Requirement 1.1.3.1.3 ESS Storage Sensors Requirement 1.1.3.1.4 ESS SW Max Gas mix Requirement 1.1.3.1.5 ESS SW Max PSI Requirement 1.1.3.1.6 Chemical Monitoring Requirement 1.1.3.1.7 Pressure Monitoring | Requirement 1.1.3 ESS Power Storage | FALSE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.3.1.1 | ESS Gas Monitoring | The ESS sensors shall monitor the gas makeup throughout the well and send that information to the CaCS. |  | Requirement 1.1.3.1 ESS Compressed air monitoring | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.3.1.2 | ESS Storage pressure monitoring | The ESS sensors shall monitor pressure throughout the well and send that information to the CaCS. |  | Requirement 1.1.3.1 ESS Compressed air monitoring | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.3.1.3 | ESS Storage Sensors | The ESS shall imbed sensors in the natural gas well. |  | Requirement 1.1.3.1 ESS Compressed air monitoring | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.1.3.1.4 | ESS SW Max Gas mix | The ESS sensors shall send a fault to the CaCS when the natural gas makeup reaches 3%. |  | Requirement 1.1.3.1 ESS Compressed air monitoring | FALSE | VerificationRequirement Test | Derived from Research | Quantitative |
| 1.1.3.1.5 | ESS SW Max PSI | The ESS sensors shall send a fault to the CaCS telling them the well is full at 200 PSI. |  | Requirement 1.1.3.1 ESS Compressed air monitoring | FALSE | VerificationRequirement Test | Derived from Research | Quantitative |
| 1.1.3.1.6 | Chemical Monitoring | The ESS shall monitor the gas makeup in the natural gas wells. |  | Requirement 1.1.3.1 ESS Compressed air monitoring | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.3.1.7 | Pressure Monitoring | The ESS shall monitor the pressure in the natural gas wells. |  | Requirement 1.1.3.1 ESS Compressed air monitoring | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.3.2 | ESS Compressed air storage | The ESS storage shall keep compressed air in natural gas wells. | Requirement 1.1.3.2.1 ESS Gas Safety Requirement 1.1.3.2.2 ESS Storage Time Requirement 1.1.3.2.3 ESS Well Initialization Requirement 1.1.3.2.4 ESS Well Initialization Gas Release | Requirement 1.1.3 ESS Power Storage | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.1.3.2.1 | ESS Gas Safety | Upon initialization, the ESS natural gas well shall be filled with nitrogen gas such that residual natural gas makes up 2% or less. |  | Requirement 1.1.3.2 ESS Compressed air storage | FALSE | VerificationRequirement Analysis | Derived from Research | Quantitative |
| 1.1.3.2.2 | ESS Storage Time | The ESS storage shall be able to keep compressed air for a period of up to 1 year. |  | Requirement 1.1.3.2 ESS Compressed air storage | TRUE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.3.2.3 | ESS Well Initialization | The ESS shall use only depleted natural gas wells. |  | Requirement 1.1.3.2 ESS Compressed air storage | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.1.3.2.4 | ESS Well Initialization Gas Release | Once the well is full of nitrogen, the ESS shall release the gas mixture and repeat the process until the residual natural gas makes up less than .5% of the gas mixture at atmospheric pressure. |  | Requirement 1.1.3.2 ESS Compressed air storage | FALSE | VerificationRequirement Test | Derived from Research | Quantitative |
| 1.1.3.3 | ESS Pressure | The ESS storage shall be able to handle compressed air at pressure. | Requirement 1.1.3.3.1 ESS Emergency Pressure Release Requirement 1.1.3.3.2 ESS Storage Gas Safety Sensor Requirement 1.1.3.3.3 ESS Storage Generator Requirement Requirement 1.1.3.3.4 ESS Storage Leak Requirement 1.1.3.3.5 ESS Storage Pressure Requirement 1.1.3.3.6 ESS Storage Pump Interface Requirement 1.1.3.3.7 Constant Pressure Requirement 1.1.3.3.8 ESS Emergency Release | Requirement 1.1.3 ESS Power Storage | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.3.3.1 | ESS Emergency Pressure Release | The ESS pressurized connection shall have an emergency pressure release that automatically trips at 250 PSI. |  | Requirement 1.1.3.3 ESS Pressure | FALSE | VerificationRequirement Test | Derived from Research | Quantitative |
| 1.1.3.3.2 | ESS Storage Gas Safety Sensor | The ESS pressurized connection shall have an emergency release when the gas mixture reaches 4% according to the sensors. |  | Requirement 1.1.3.3 ESS Pressure | TRUE | VerificationRequirement Test | Derived from Research | Quantitative |
| 1.1.3.3.3 | ESS Storage Generator Requirement | The ESS shall be able to send air to the generator at pressure. |  | Requirement 1.1.3.3 ESS Pressure | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.3.3.4 | ESS Storage Leak | The ESS shall not allow the pressurized connection to leaked at a rate of more than 5% a year. |  | Requirement 1.1.3.3 ESS Pressure | TRUE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.3.3.5 | ESS Storage Pressure | The ESS pressurized connection shall be able to handle up to 300 PSI. |  | Requirement 1.1.3.3 ESS Pressure | TRUE | VerificationRequirement Test | Derived from Research | Quantitative |
| 1.1.3.3.6 | ESS Storage Pump Interface | The ESS shall be able to receive air from the compressor at pressure. |  | Requirement 1.1.3.3 ESS Pressure | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.3.3.7 | Constant Pressure | The ESS shall maintain and hold a constant pressure when either the generator or pump are not in use |  | Requirement 1.1.3.3 ESS Pressure | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.3.3.8 | ESS Emergency Release | The ESS shall have an emergency pressure release. |  | Requirement 1.1.3.3 ESS Pressure | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.4 | ESS Receive Power | The ESS shall receive power off the power grid and send it to storage. | Requirement 1.1.4.1 ESS Air Pump Requirement 1.1.4.2 ESS Power Intake Requirement 1.1.4.3 ESS Pump Storage Interface | Requirement 1.1 ESS Requirement | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.4.1 | ESS Air Pump | The ESS shall use a pump to compress air. | Requirement 1.1.4.1.1 ESS Air Compressor Requirement 1.1.4.1.2 ESS Command Requirement 1.1.4.1.3 ESS Health and Status Requirement 1.1.4.1.4 ESS Health and Status communication Requirement 1.1.4.1.5 ESS Transformer Connection Requirement 1.1.4.1.6 ESS Compressed Air Requirement 1.1.4.1.7 Compressed Air Transport | Requirement 1.1.4 ESS Receive Power | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.4.1.1 | ESS Air Compressor | The ESS pump shall compress air and send it to the natural gas interface at pressure. |  | Requirement 1.1.4.1 ESS Air Pump | TRUE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.4.1.2 | ESS Command | The ESS pump shall receive its commands from the from the ESS control. |  | Requirement 1.1.4.1 ESS Air Pump | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.4.1.3 | ESS Health and Status | The ESS shall report Its health and status to the CaCS. |  | Requirement 1.1.4.1 ESS Air Pump | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.1.4.1.4 | ESS Health and Status communication | The ESS shall send the ESS control it's health and status. |  | Requirement 1.1.4.1 ESS Air Pump | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.1.4.1.5 | ESS Transformer Connection | The ESS shall connect to the step-down transformer for power |  | Requirement 1.1.4.1 ESS Air Pump | FALSE | VerificationRequirement Inspection | Derived from Research | Qualitative |
| 1.1.4.1.6 | ESS Compressed Air | The ESS shall compress compressed air. |  | Requirement 1.1.4.1 ESS Air Pump | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.4.1.7 | Compressed Air Transport | The ESS shall send compressed air to a natural gas well. |  | Requirement 1.1.4.1 ESS Air Pump | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.4.2 | ESS Power Intake | The ESS shall receive power off the grid by way of a utility interface. | Requirement 1.1.4.2.1 ESS Power Connection Requirement 1.1.4.2.2 ESS Transformer Requirement 1.1.4.2.3 ESS Voltage Adjust | Requirement 1.1.4 ESS Receive Power | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.1.4.2.1 | ESS Power Connection | The ESS shall have a hardwired connection to the high voltage lines of the power grid |  | Requirement 1.1.4.2 ESS Power Intake | FALSE | VerificationRequirement Inspection | Derived from Research | Qualitative |
| 1.1.4.2.2 | ESS Transformer | The ESS shall have a step-down transformer to lower the voltage to US Standard 120V 60Hz. |  | Requirement 1.1.4.2 ESS Power Intake | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.1.4.2.3 | ESS Voltage Adjust | The ESS shall adjust the voltage coming from the utility lines to a lower voltage. |  | Requirement 1.1.4.2 ESS Power Intake | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.4.3 | ESS Pump Storage Interface | The ESS shall send the compressed air from the pump to the storage device through a pressurized interface. |  | Requirement 1.1.4 ESS Receive Power | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.1.5 | ESS Weather | The ESS shall be protected from the weather. | Requirement 1.1.5.1 ESS Cooling Requirement 1.1.5.2 ESS Hail Requirement 1.1.5.3 ESS Heating Requirement 1.1.5.4 ESS Tornado Requirement 1.1.5.5 ESS Wind Requirement 1.1.5.6 Weather Protect Requirement 1.1.5.7 Climate Control | Requirement 1.1 ESS Requirement | TRUE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.5.1 | ESS Cooling | The ESS shall be able to maintain a working temperature of 100 degrees Fahrenheit or below |  | Requirement 1.1.5 ESS Weather | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.5.2 | ESS Hail | The ESS shall be able to withstand up to baseball size hail. |  | Requirement 1.1.5 ESS Weather | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.5.3 | ESS Heating | The ESS shall be able to maintain a working temperature of 40 degrees Fahrenheit or above. |  | Requirement 1.1.5 ESS Weather | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.5.4 | ESS Tornado | The ESS shall be able to withstand a EF4 tornado. |  | Requirement 1.1.5 ESS Weather | FALSE | VerificationRequirement Analysis | Design decision | Quantitative |
| 1.1.5.5 | ESS Wind | The ESS shall be able to withstand up to 60 mph strait line winds. |  | Requirement 1.1.5 ESS Weather | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.1.5.6 | Weather Protect | The ESS shall be protected from outside weather. |  | Requirement 1.1.5 ESS Weather | FALSE | VerificationRequirement Test | Design decision | Qualitative |
| 1.1.5.7 | Climate Control | The ESS shall implement climate control. |  | Requirement 1.1.5 ESS Weather | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2 | CaCS Requirements | The Command-and-Control Subsystem (CaCS) shall act as the operational command center of the OPESS. | Requirement 1.2.1 CaCS Communications Requirement 1.2.2 CaCS Receive Power Requirement 1.2.3 CaCS Utility Interface | Requirement 1 OPESS Requirements | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.2.1 | CaCS Communications | The CaCS shall communicate with the ESS and other utilities via the internet. | Requirement 1.2.1.1 CaCS Internal Network Requirement 1.2.1.2 CaCS Servers Requirement 1.2.1.3 CaCS Syber Security | Requirement 1.2 CaCS Requirements | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2.1.1 | CaCS Internal Network | The CaCS shall maintain an active internal network. | Requirement 1.2.1.1.1 CaCS High Speed Network Requirement 1.2.1.1.2 CaCS Log In Requirement 1.2.1.1.3 CaCS Ring Network Requirement 1.2.1.1.4 CaCS Security Scan Requirement 1.2.1.1.5 CaCS VM | Requirement 1.2.1 CaCS Communications | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2.1.1.1 | CaCS High Speed Network | The CaCS shall use a high-speed network. |  | Requirement 1.2.1.1 CaCS Internal Network | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.2.1.1.2 | CaCS Log In | The CaCS VM shall provide a secure log in for every employee. |  | Requirement 1.2.1.1 CaCS Internal Network | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.2.1.1.3 | CaCS Ring Network | The CaCS shall use a ring network. |  | Requirement 1.2.1.1 CaCS Internal Network | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.2.1.1.4 | CaCS Security Scan | The CaCS shall run information assurance scans of all networked devices monthly. |  | Requirement 1.2.1.1 CaCS Internal Network | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.2.1.1.5 | CaCS VM | The CaCS shall maintain a VM for every employee. |  | Requirement 1.2.1.1 CaCS Internal Network | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.2.1.2 | CaCS Servers | The CaCS shall maintain shared servers across its network. | Requirement 1.2.1.2.1 CaCS Server Backup Requirement 1.2.1.2.2 CaCS Server Backup Schedule Requirement 1.2.1.2.3 CaCS Server Infrastructure Requirement 1.2.1.2.4 CaCS Backup Server | Requirement 1.2.1 CaCS Communications | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.2.1.2.1 | CaCS Server Backup | The CaCS shall make a backup of the servers every night. |  | Requirement 1.2.1.2 CaCS Servers | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.2.1.2.2 | CaCS Server Backup Schedule | The CaCS shall keep the backups for one week. |  | Requirement 1.2.1.2 CaCS Servers | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.2.1.2.3 | CaCS Server Infrastructure | The CaCS shall maintain a series of servers. |  | Requirement 1.2.1.2 CaCS Servers | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2.1.2.4 | CaCS Backup Server | The CaCS shall back up the servers. |  | Requirement 1.2.1.2 CaCS Servers | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2.1.3 | CaCS Syber Security | The CaCS shall have a secure connection to the internet. | Requirement 1.2.1.3.1 CaCS Anti-Virus Requirement 1.2.1.3.2 CaCS Cyber Filtering Requirement 1.2.1.3.3 CaCS Firewall Requirement 1.2.1.3.4 CaCS Intrusion Detection Requirement 1.2.1.3.5 CaCS TCP/IP | Requirement 1.2.1 CaCS Communications | TRUE | VerificationRequirement Test | Design decision | Qualitative |
| 1.2.1.3.1 | CaCS Anti-Virus | The CaCS shall provide an antivirus for all CaCS networked CaCS devices. |  | Requirement 1.2.1.3 CaCS Syber Security | FALSE | VerificationRequirement Inspection | Derived from Interviews | Quantitative |
| 1.2.1.3.2 | CaCS Cyber Filtering | The CaCS shall communicate with the internet through a firewall with IPS and TLS inspection and URL filtering. |  | Requirement 1.2.1.3 CaCS Syber Security | FALSE | VerificationRequirement Inspection | Derived from Interviews | Quantitative |
| 1.2.1.3.3 | CaCS Firewall | The CaCS shall communicate with the internet through a firewall that uses different IPS signatures then the ESS firewall. |  | Requirement 1.2.1.3 CaCS Syber Security | FALSE | VerificationRequirement Inspection | Derived from Interviews | Quantitative |
| 1.2.1.3.4 | CaCS Intrusion Detection | The CaCS shall have an intrusion detection system. |  | Requirement 1.2.1.3 CaCS Syber Security | FALSE | VerificationRequirement Inspection | Derived from Interviews | Quantitative |
| 1.2.1.3.5 | CaCS TCP/IP | The CaCS shall communicate across a TCP/IP connection to the internet |  | Requirement 1.2.1.3 CaCS Syber Security | FALSE | VerificationRequirement Inspection | Derived from Interviews | Quantitative |
| 1.2.2 | CaCS Receive Power | The CaCS shall receive power from the electric grid. | Requirement 1.2.2.1 CaCS Distribute Power Requirement 1.2.2.2 CaCS Standard Power | Requirement 1.2 CaCS Requirements | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.2.2.1 | CaCS Distribute Power | The CaCS shall distribute power though out the CaCS. |  | Requirement 1.2.2 CaCS Receive Power | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2.2.2 | CaCS Standard Power | The CaCS shall receive standard US 120V, 60Hz from the electrical grid. |  | Requirement 1.2.2 CaCS Receive Power | FALSE | VerificationRequirement Test | Design decision | Quantitative |
| 1.2.3 | CaCS Utility Interface | The CaCS shall receive data and commands from local utility employees. | Requirement 1.2.3.1 CaCS Control Requirement 1.2.3.2 CaCS Computer Network Requirement 1.2.3.3 CaCS Computer Power Requirement 1.2.3.4 CaCS Computers Requirement 1.2.3.5 CaCS Email Requirement 1.2.3.6 CaCS Models Requirement 1.2.3.7 CaCS Software Requirement 1.2.3.8 Office Space | Requirement 1.2 CaCS Requirements | TRUE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.2.3.1 | CaCS Control | The CaCS shall provide an interface capable of interacting with the ESS. | Requirement 1.2.3.1.1 CaCS ESS Health and Status Requirement 1.2.3.1.2 CaCS ESS Interface Requirement 1.2.3.1.3 CaCS Two Factor Authentication | Requirement 1.2.3 CaCS Utility Interface | FALSE | VerificationRequirement Analysis | Design decision | Qualitative |
| 1.2.3.1.1 | CaCS ESS Health and Status | All ESS heath safety and status information shall be saved and viewable from the CaCS. |  | Requirement 1.2.3.1 CaCS Control | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2.3.1.2 | CaCS ESS Interface | The CaCS shall be able to control any connected ESS once logged on. |  | Requirement 1.2.3.1 CaCS Control | FALSE | VerificationRequirement Demonstration | Design decision | Qualitative |
| 1.2.3.1.3 | CaCS Two Factor Authentication | The CaCS shall use two factor authentication when a user logs onto the ESS software. |  | Requirement 1.2.3.1 CaCS Control | FALSE | VerificationRequirement Analysis | Derived from Interviews | Quantitative |
| 1.2.3.2 | CaCS Computer Network | The CaCS shall connect all computers to the network. |  | Requirement 1.2.3 CaCS Utility Interface | FALSE | VerificationRequirement Analysis | Design decision | Quantitative |
| 1.2.3.3 | CaCS Computer Power | The CaCS shall provide power for all computers. |  | Requirement 1.2.3 CaCS Utility Interface | FALSE | VerificationRequirement Demonstration | Design decision | Quantitative |
| 1.2.3.4 | CaCS Computers | The CaCS shall provide a computer for all employees. |  | Requirement 1.2.3 CaCS Utility Interface | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.2.3.5 | CaCS Email | The CaCS shall provide an email client. |  | Requirement 1.2.3 CaCS Utility Interface | FALSE | VerificationRequirement Inspection | Design decision | Quantitative |
| 1.2.3.6 | CaCS Models | The CaCS shall provide software capable of creating and using utility models. | Requirement 1.2.3.6.1 CaCS Federal Utility Company Interface Requirement 1.2.3.6.2 CaCS Local Utility Company Interface Requirement 1.2.3.6.3 CaCS Model Accuracy Requirement 1.2.3.6.4 CaCS One Month Model | Requirement 1.2.3 CaCS Utility Interface | TRUE | VerificationRequirement Demonstration | Derived from Interviews | Qualitative |
| 1.2.3.6.1 | CaCS Federal Utility Company Interface | The modeled power needs shall be calculated based on input provided from other utility companies across state lines. |  | Requirement 1.2.3.6 CaCS Models | FALSE | VerificationRequirement Demonstration | Derived from Interviews | Qualitative |
| 1.2.3.6.2 | CaCS Local Utility Company Interface | The modeled power needs shall be calculated based on input provided from other utility companies locally. |  | Requirement 1.2.3.6 CaCS Models | FALSE | VerificationRequirement Demonstration | Derived from Interviews | Qualitative |
| 1.2.3.6.3 | CaCS Model Accuracy | The CaCS models shall become more accurate as the modeled time period gets closer. |  | Requirement 1.2.3.6 CaCS Models | FALSE | VerificationRequirement Analysis | Derived from Interviews | Quantitative |
| 1.2.3.6.4 | CaCS One Month Model | The CaCS models shall be able to model power usage out to a month out. |  | Requirement 1.2.3.6 CaCS Models | FALSE | VerificationRequirement Analysis | Derived from Interviews | Quantitative |
| 1.2.3.7 | CaCS Software | The CaCS shall provide office software. |  | Requirement 1.2.3 CaCS Utility Interface | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |
| 1.2.3.8 | Office Space | The CaCS shall provide office space. |  | Requirement 1.2.3 CaCS Utility Interface | FALSE | VerificationRequirement Inspection | Design decision | Qualitative |

# 12 Appendix D: Functional Traceability Matrix

| Number | Name | Based On | Inputs | Outputs |
| --- | --- | --- | --- | --- |
| 1 | Oklahoma Pipeline Energy Storage System | Requirement 1 OPESS Requirements |  |  |
| 1.1 | Energy Storage Subsystem | Requirement 1.1 ESS Requirement | Item CaCS to ESS (data over Internet) Item Geology Item Power Grid (Electricity) Item Weather | Item ESS to CaCS (Data over Internet) Item Power Grid (Electricity) |
| 1.1.1 | Receive Power | Requirement 1.1.4 ESS Receive Power | Item ESS Commands Item Power Grid (Electricity) Item Weather Protection | Item Compressed Air (To NG) Item Receive Power Health and Status |
| 1.1.1.1 | Utility Interface | Requirement 1.1.4.2 ESS Power Intake | Item Power Grid (Electricity) Item Weather Protection | Item ESS Process Electricity |
| 1.1.1.1.1 | Power Grid Interface | Requirement 1.1.4.2.1 ESS Power Connection | Item Power Grid (Electricity) | Item High Voltage |
| 1.1.1.1.2 | Grid to ESS power Adjustment | Requirement 1.1.4.2.2 ESS Transformer Requirement 1.1.4.2.3 ESS Voltage Adjust | Item High Voltage | Item ESS Process Electricity |
| 1.1.1.2 | Pump | Requirement 1.1.4.1 ESS Air Pump | Item Controller Pump Command Item ESS Process Electricity Item Weather Protection | Item Air (from Pump) Item Receive Power Health and Status |
| 1.1.1.2.1 | Pump Power Input | Requirement 1.1.4.1.5 ESS Transformer Connection | Item ESS Process Electricity | Item Pump Communication |
| 1.1.1.2.2 | Pump Health and Status | Requirement 1.1.1.1.1 ESS Health and Status Send Requirement 1.1.4.1.3 ESS Health and Status | Item Pump Communication | Item Pump HaS |
| 1.1.1.2.3 | Pump Control | Requirement 1.1.4.1.2 ESS Command | Item Controller Pump Command Item Pump HaS | Item Pump Control Command Item Receive Power Health and Status |
| 1.1.1.2.4 | Compressed Air Pump | Requirement 1.1.4.1.6 ESS Compressed Air | Item Pump Control Command Item Weather | Item Air (from Pump) |
| 1.1.1.3 | Natural Gas Interface | Requirement 1.1.4.1.1 ESS Air Compressor Requirement 1.1.4.1.7 Compressed Air Transport Requirement 1.1.4.3 ESS Pump Storage Interface | Item Air (from Pump) Item Weather Protection | Item Air (to Natural Gas) |
| 1.1.2 | Internet to ESS Control | Requirement 1.1.1 ESS Communications | Item CaCS to ESS (data over Internet) | Item ESS Commands |
| 1.1.2.1 | Internet to ESS-ESS Communications | Requirement 1.1.1.5 ESS Internet Interface | Item CaCS to ESS (data over Internet) | Item Secure Network Output |
| 1.1.2.1.1 | ESS Internet Connection | Requirement 1.1.1.5.5 ESS High Speed Internet Requirement 1.1.1.5.6 ESS TCP/IP Requirement 1.1.1.5.7 ESS Internet Connection | Item CaCS to ESS (data over Internet) | Item Raw Inbound TCP/IP |
| 1.1.2.1.2 | ESS Cyber Security | Requirement 1.1.1.5.1 ESS Cyber Scans Requirement 1.1.1.5.2 ESS Encryption Requirement 1.1.1.5.4 ESS Firewall Requirement 1.1.1.5.8 ESS Cyber Security Suite | Item Raw Inbound TCP/IP | Item Inbound Internal Network |
| 1.1.2.1.3 | ESS Network Interface | Requirement 1.1.1.5.3 ESS Fiber Optics Requirement 1.1.1.5.9 ESS Secure Connection | Item Inbound Internal Network | Item Secure Network Output |
| 1.1.2.2 | Internet to ESS-Processor | Requirement 1.1.1.1 ESS Control | Item Secure Network Output Item Weather Protection | Item ESS Processor Commands |
| 1.1.2.2.1 | ESS Commands | Requirement 1.1.1.1.2 ESS Processor Communication Requirement 1.1.1.1.5 ESS Command Process Requirement 1.1.1.4 ESS Control Node Send Commands | Item Processor Commands ACK | Item Commands to Processor |
| 1.1.2.2.2 | Processor Data Link | Requirement 1.1.1.1.6 ESS to Component Connection | Item Commands to Processor Item Processor HaS Item Secure Network Output | Item ESS Processor Commands Item Processor Commands ACK Item Processor HaS ACK |
| 1.1.2.2.3 | ESS Health and Status | Requirement 1.1.1.1.1 ESS Health and Status Send Requirement 1.1.1.1.3 ESS Processor Health and Status Receive Requirement 1.1.1.1.4 ESS Processor Response Requirement 1.1.1.1.7 ESS Component Processor Communication Requirement 1.1.4.1.4 ESS Health and Status communication | Item Processor HaS ACK | Item Processor HaS |
| 1.1.2.3 | Internet to ESS - Component Communications | Requirement 1.1.1.1.8 ESS Component Communication | Item ESS Processor Commands | Item ESS Commands |
| 1.1.3 | Generate Power | Requirement 1.1.2 ESS Generate Power | Item Compressed Air (From NG) Item ESS Commands Item Weather Protection | Item Carbon Credits Item Generate Power Health and Ststus Item Power Grid (Electricity) |
| 1.1.3.1 | Generate Power Natural Gas Interface | Requirement 1.1.2.1.3 ESS Generator Storage Interface Requirement 1.1.2.3 ESS Storage Generator Interface | Item Compressed Air (From NG) | Item Controlled Compressed Air |
| 1.1.3.2 | Generator | Requirement 1.1.2.1 ESS Generator Requirement 1.1.2.2 ESS Power Uptake Requirement 1.1.2.3.1 ESS Power Generation | Item Controlled Compressed Air | Item Generate Power Health and Ststus Item Power to need Item Used Compressed Air |
| 1.1.3.2.1 | Generator Control | Requirement 1.1.2.1.1 ESS Generator Commands Requirement 1.1.2.3.3 Power Generation Gauge | Item ESS Commands Item Generator Status Update | Item Generate Power Health and Status Item Generator Commands |
| 1.1.3.2.2 | Generator Health and Status | Requirement 1.1.1.1.1 ESS Health and Status Send Requirement 1.1.2.1.2 ESS Generator Health and Status Requirement 1.1.2.3.2 Generator Health and Status | Item Generator Commands | Item Generator Status Update |
| 1.1.3.2.3 | Electrical Generator | Requirement 1.1.2.3.4 Compressed Air Power Generation | Item Generator Commands | Item Generator Power Item Used Compressed Air |
| 1.1.3.2.4 | Generator Power Output | Requirement 1.1.2.1.4 ESS Generator Utility Interface Requirement 1.1.2.2.1 ESS Generator Grid interface Requirement 1.1.2.3.5 Generation to Grid Connection | Item Generator Power | Item Power to need |
| 1.1.3.3 | Carbon Capture | Requirement 1.1.2.4 ESS Carbon Capture Requirement 1.1.2.4.1 ESS Carbon Capture Percent Requirement 1.1.2.4.2 ESS Carbon Capture Release | Item Used Compressed Air | Item Carbon Credits |
| 1.1.3.4 | Generator to Utility Interface | Requirement 1.1.2.3.6 ESS Generator to Grid | Item Power to need | Item Power Grid (Electricity) |
| 1.1.3.4.1 | Generator to Grid Power Adjustment | Requirement 1.1.2.2.2 ESS Generator Transformer Requirement 1.1.2.3.7 Generator Step Up | Item Power to need | Item Adjusted Power Output |
| 1.1.3.4.2 | Generator to Grid Connection | Requirement 1.1.2.3.6 ESS Generator to Grid | Item Adjusted Power Output | Item Power Grid (Electricity) |
| 1.1.4 | Store Power | Requirement 1.1.3 ESS Power Storage Requirement 1.1.3.2.3 ESS Well Initialization Requirement 1.1.3.2.4 ESS Well Initialization Gas Release | Item Compressed Air (To NG) Item Geology Item Weather Protection | Item Compressed Air (From NG) Item Store Power Health and Status |
| 1.1.4.1 | Pressure Release | Requirement 1.1.3.3 ESS Pressure | Item Compressed Air (To NG) Item Compressed Air Out | Item Compressed Air (From NG) Item Compressed Air In |
| 1.1.4.1.1 | Maintain Pressure | Requirement 1.1.3.2.2 ESS Storage Time Requirement 1.1.3.3.7 Constant Pressure | Item Compressed Air (To NG) Item Pressure Outlet | Item Constant pressure |
| 1.1.4.1.2 | Pressure Safety Release | Requirement 1.1.3.3.1 ESS Emergency Pressure Release Requirement 1.1.3.3.5 ESS Storage Pressure Requirement 1.1.3.3.8 ESS Emergency Release | Item Compressed Air Out Item Constant pressure | Item Compressed Air In Item Pressure Outlet |
| 1.1.4.2 | Natural Gas Well Storage | Requirement 1.1.3.2 ESS Compressed air storage Requirement 1.1.3.3.3 ESS Storage Generator Requirement Requirement 1.1.3.3.4 ESS Storage Leak Requirement 1.1.3.3.6 ESS Storage Pump Interface | Item Compressed Air In Item Weather Protection | Item Compressed Air Out Item Natural Gas Well Environment |
| 1.1.4.3 | Well Safety | Requirement 1.1.1.1.1 ESS Health and Status Send Requirement 1.1.3.1 ESS Compressed air monitoring Requirement 1.1.3.1.4 ESS SW Max Gas mix Requirement 1.1.3.2.1 ESS Gas Safety | Item Geology Item Natural Gas Well Environment | Item Store Power Health and Status |
| 1.1.4.3.1 | Gas Sensors | Requirement 1.1.3.1.1 ESS Gas Monitoring Requirement 1.1.3.1.3 ESS Storage Sensors Requirement 1.1.3.1.6 Chemical Monitoring Requirement 1.1.3.3.2 ESS Storage Gas Safety Sensor | Item Geology Item Natural Gas Well Environment | Item Store Power Health and Status |
| 1.1.4.3.2 | Pressure Sensors | Requirement 1.1.3.1.2 ESS Storage pressure monitoring Requirement 1.1.3.1.3 ESS Storage Sensors Requirement 1.1.3.1.5 ESS SW Max PSI Requirement 1.1.3.1.7 Pressure Monitoring | Item Geology Item Natural Gas Well Environment | Item Store Power Health and Status |
| 1.1.5 | Weather Protection | Requirement 1.1.5 ESS Weather | Item Weather | Item Weather Protection |
| 1.1.5.1 | Exterior Protection | Requirement 1.1.5.2 ESS Hail Requirement 1.1.5.4 ESS Tornado Requirement 1.1.5.5 ESS Wind Requirement 1.1.5.6 Weather Protect | Item Weather | Item Internal Environment |
| 1.1.5.2 | Climate Control | Requirement 1.1.5.1 ESS Cooling Requirement 1.1.5.3 ESS Heating Requirement 1.1.5.7 Climate Control | Item Internal Environment Item Weather | Item Weather Protection |
| 1.1.6 | ESS to Internet-Control | Requirement 1.1.1 ESS Communications | Item Generate Power Health and Status Item Receive Power Health and Status Item Store Power Health and Status | Item ESS to CaCS (Data over Internet) |
| 1.1.6.1 | ESS to Internet-ESS Communications | Requirement 1.1.1.5 ESS Internet Interface | Item Outbound Processor Commands | Item ESS to CaCS (Data over Internet) |
| 1.1.6.1.1 | ESS Connection | Requirement 1.1.1.5.5 ESS High Speed Internet Requirement 1.1.1.5.6 ESS TCP/IP Requirement 1.1.1.5.7 ESS Internet Connection | Item Outbound Processor Commands | Item ESS Device Status |
| 1.1.6.1.2 | Device Cyber Security | Requirement 1.1.1.5.1 ESS Cyber Scans Requirement 1.1.1.5.2 ESS Encryption Requirement 1.1.1.5.3 ESS Fiber Optics Requirement 1.1.1.5.4 ESS Firewall Requirement 1.1.1.5.8 ESS Cyber Security Suite | Item ESS Device Status | Item Raw Outbound TCP/IP |
| 1.1.6.1.3 | ESS Device Connection | Requirement 1.1.1.5.9 ESS Secure Connection | Item Raw Outbound TCP/IP | Item ESS to CaCS (Data over Internet) |
| 1.1.6.2 | ESS to Internet-Component Communication | Requirement 1.1.1.5 ESS Internet Interface | Item Generate Power Health and Status Item Receive Power Health and Status Item Store Power Health and Status | Item Component Health and Status |
| 1.1.6.3 | ESS to Internet-Processor | Requirement 1.1.1.1 ESS Control | Item Component Health and Status Item Weather Protection | Item Outbound Processor Commands |
| 1.1.6.3.1 | Component Commands | Requirement 1.1.1.1.5 ESS Command Process Requirement 1.1.1.6 ESS Send Health and Status | Item Component Processor ACK | Item Processor Commands |
| 1.1.6.3.2 | Component Processor Data Link | Requirement 1.1.1.1.6 ESS to Component Connection Requirement 1.1.1.2 ESS Control Node Process Commands | Item Component Health and Status Item Outbound Processor H&S Item Processor Commands Item Weather Protection | Item Component Processor ACK Item Outbound Processor Commands Item Outbound Processor H&S ACK |
| 1.1.6.3.3 | Component Health and Status | Requirement 1.1.1.1.7 ESS Component Processor Communication Requirement 1.1.1.3 ESS Control Node Receive Commands | Item Outbound Processor H&S ACK | Item Outbound Processor H&S |
| 1.2 | Command and Control Subsystem | Requirement 1.2 CaCS Requirements | Item ESS to CaCS (Data over Internet) Item Power Grid (Electricity) Item Utility Employee | Item CaCS to ESS (data over Internet) |
| 1.2.1 | Internet to CaCS Communication | Requirement 1.2.1 CaCS Communications | Item ESS to CaCS (Data over Internet) | Item Inbound Internet |
| 1.2.1.1 | Internet Communication | Requirement 1.2.1.1 CaCS Internal Network Requirement 1.2.1.3 CaCS Syber Security | Item ESS to CaCS (Data over Internet) | Item Secure Inbound Connection |
| 1.2.1.1.1 | Inbound Internet Connection | Requirement 1.2.1.1.1 CaCS High Speed Network Requirement 1.2.1.1.3 CaCS Ring Network | Item ESS to CaCS (Data over Internet) | Item Raw Inbound Internet |
| 1.2.1.1.2 | Internet Cyber Security | Requirement 1.2.1.3.1 CaCS Anti-Virus Requirement 1.2.1.3.2 CaCS Cyber Filtering Requirement 1.2.1.3.3 CaCS Firewall Requirement 1.2.1.3.4 CaCS Intrusion Detection | Item Raw Inbound Internet | Item Secure Inbound Connection |
| 1.2.1.2 | Internet Server Connection | Requirement 1.2.1.2 CaCS Servers Requirement 1.2.1.3.5 CaCS TCP/IP | Item Secure Inbound Connection | Item Inbound Server Connection |
| 1.2.1.2.1 | Inbound Sharable Drive | Requirement 1.2.1.2.3 CaCS Server Infrastructure | Item Inbound Server Connection Item Server Backup Data | Item Server Data Refresh |
| 1.2.1.2.2 | Inbound Server Backup | Requirement 1.2.1.2.1 CaCS Server Backup Requirement 1.2.1.2.2 CaCS Server Backup Schedule Requirement 1.2.1.2.4 CaCS Backup Server | Item Server Data Refresh | Item Inbound Internal Network Item Server Backup Data |
| 1.2.1.3 | Internet to Internal Network | Requirement 1.2.1.3.5 CaCS TCP/IP | Item Inbound Server Connection | Item Inbound Internal Network |
| 1.2.2 | CaCS Work Space | Requirement 1.2.3 CaCS Utility Interface Requirement 1.2.3.1 CaCS Control Requirement 1.2.3.1.1 CaCS ESS Health and Status Requirement 1.2.3.1.2 CaCS ESS Interface Requirement 1.2.3.1.3 CaCS Two Factor Authentication Requirement 1.2.3.5 CaCS Email Requirement 1.2.3.6 CaCS Models Requirement 1.2.3.6.1 CaCS Federal Utility Company Interface Requirement 1.2.3.6.2 CaCS Local Utility Company Interface Requirement 1.2.3.6.3 Cacs Model Accuracy Requirement 1.2.3.6.4 CaCS One Month Model Requirement 1.2.3.7 CaCS Software | Item Network Bandwidth Item Utility Employee | Item Network Communications |
| 1.2.3 | Facility | Requirement 1.2.2 CaCS Receive Power | Item Inbound Internet Item Network Communications Item Power Grid (Electricity) | Item Network Bandwidth Item Outbound Internet |
| 1.2.3.1 | Facility Power | Requirement 1.2.2.1 CaCS Distribute Power Requirement 1.2.2.2 CaCS Standard Power Requirement 1.2.3.3 CaCS Computer Power | Item Power Grid (Electricity) | Item Facility Power Output |
| 1.2.3.2 | Office Network | Requirement 1.2.1.1.2 CaCS Log In Requirement 1.2.1.1.5 CaCS VM Requirement 1.2.3.2 CaCS Computer Network Requirement 1.2.3.4 CaCS Computers Requirement 1.2.3.8 Office Space | Item Facility Power Output Item Inbound Internet Item Network Communications | Item Network Bandwidth |
| 1.2.4 | CaCS to Internet Communication | Requirement 1.2.1 CaCS Communications | Item Outbound Internet | Item CaCS to ESS (data over Internet) |
| 1.2.4.1 | CaCS Communication | Requirement 1.2.1.1 CaCS Internal Network Requirement 1.2.1.3 CaCS Syber Security | Item Outbound Internet | Item Secure Outbound Connection |
| 1.2.4.1.1 | CaCS Cyber Security | Requirement 1.2.1.1.4 CaCS Security Scan Requirement 1.2.1.3.1 CaCS Anti-Virus Requirement 1.2.1.3.2 CaCS Cyber Filtering Requirement 1.2.1.3.3 CaCS Firewall Requirement 1.2.1.3.4 CaCS Intrusion Detection | Item Outbound Internet | Item Secure Data Package |
| 1.2.4.1.2 | Outbound Internet Connection | Requirement 1.2.1.1.1 CaCS High Speed Network Requirement 1.2.1.1.3 CaCS Ring Network | Item Secure Data Package | Item Secure Outbound Connection |
| 1.2.4.2 | CaCS Server Connection | Requirement 1.2.1.2 CaCS Servers | Item Secure Outbound Connection | Item Outbound Server Connection |
| 1.2.4.2.1 | Outbound Sharable Drive | Requirement 1.2.1.2.3 CaCS Server Infrastructure | Item Outbound Server Refresh Data Item Secure Outbound Connection | Item Outbound Server Data |
| 1.2.4.2.2 | Outbound Server Backup | Requirement 1.2.1.2.1 CaCS Server Backup Requirement 1.2.1.2.2 CaCS Server Backup Schedule Requirement 1.2.1.2.4 CaCS Backup Server | Item Outbound Server Data | Item Outbound Server Connection Item Outbound Server Refresh Data |
| 1.2.4.3 | Internal Network to Internet | Requirement 1.2.1.3.5 CaCS TCP/IP | Item Outbound Server Connection | Item CaCS to ESS (data over Internet) |