INL/CON-23-72063-Revision-0

Designing Advanced Energy Infrastructure with MBSE Presentation

April 2023

Changing the World's Energy Future

Maria Eduarda Montezzo Coelho, Julia Catherine Morgan

Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

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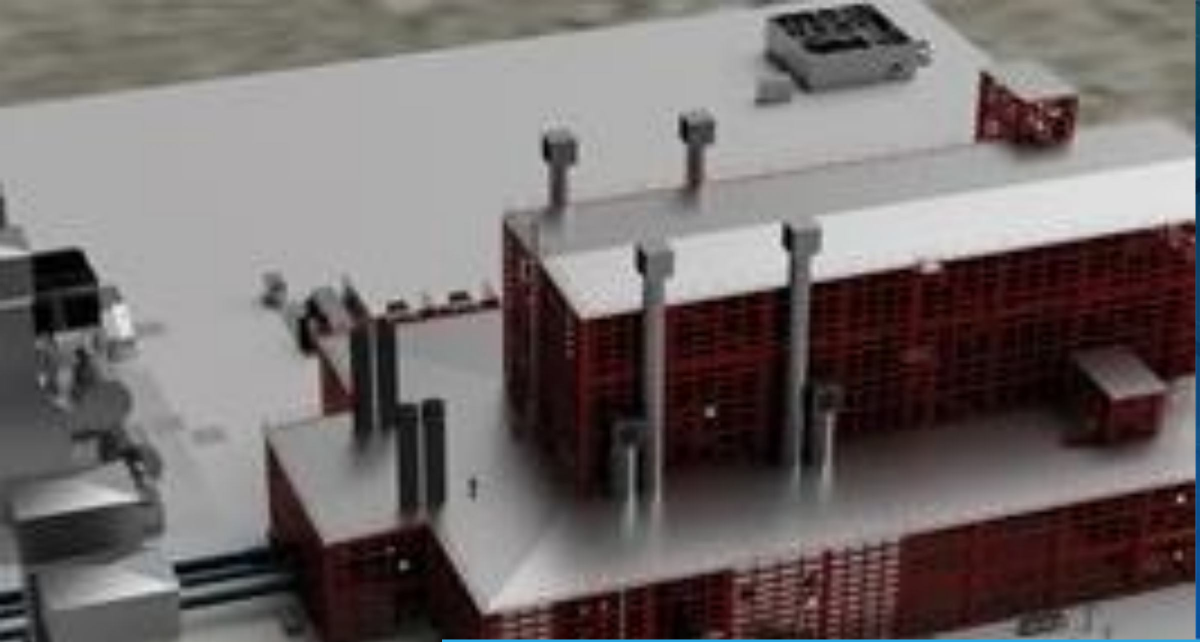

Julia Morgan
and
Maria Coelho

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Infrastructure Projects are Failing More Often

- **Project scope**
  - Defined objectives and scope clarity
- **Schedule Delay**
  - Correlated with cost overrun
  - Adjustments made due to uncontrollable circumstances
- **Cost Overrun**
  - Material expense increase over time
  - Delayed approval requests
  - Scope creep
  - Labor hires with necessary skill level

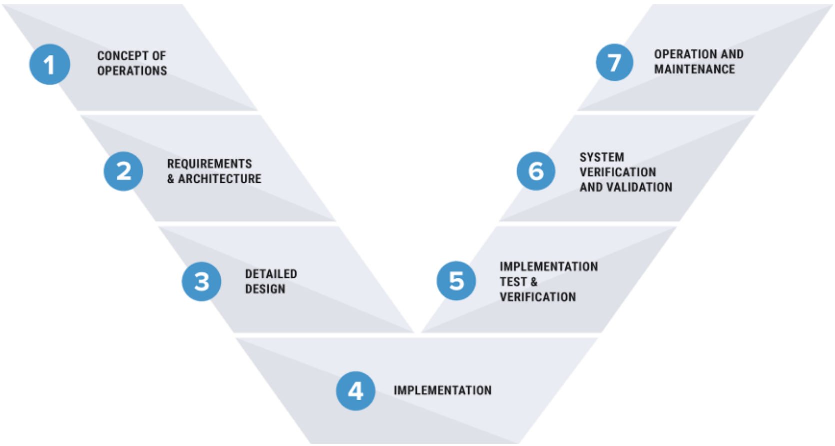
How Big Projects Performed
Source: Flyvbjerg Database

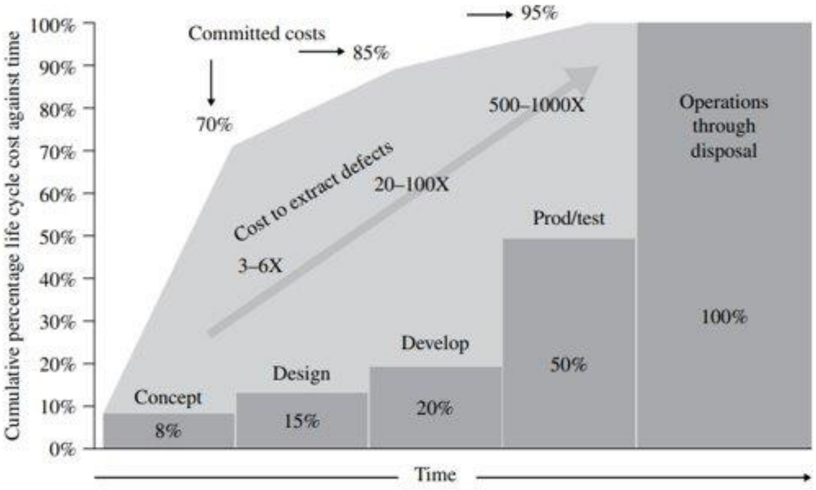
Project type	Mean cost overrun (%)	Projects (A) with ≥50% overruns (%)	Mean overruns of A projects (%)
Nuclear storage	238	48	427
Olympic Games	157	76	200
Nuclear power	120	55	204
Hydroelectric dams	75	37	186
IT	73	18	447
Nonhydroelectric dams	71	33	202
Buildings	62	39	206
Aerospace	60	42	119
Defence	53	21	253
Bus rapid transit	40	43	69
Rail	39	28	116
Airports	39	43	88
Tunnels	37	28	103
Oil and gas	34	19	121
Ports	32	17	183
Hospitals, health	29	13	167
Mining	27	17	129
Bridges	26	21	107
Water	20	13	124
Fossil thermal power	16	14	109
Roads	16	11	102

		Severity of Harm (Impact)		
		Low (L)	Medium (M)	High (H)
Likelihood	High (H)	3	4	5
	Medium (M)	2	3	4
	Low (L)	1	2	3

Systems Engineering

- Application of systems thinking to **complex** engineering projects
- **Holistic**, encompassing approach to analyzing a problem and how the constituent parts interrelate
- **Interdisciplinary**, structured process



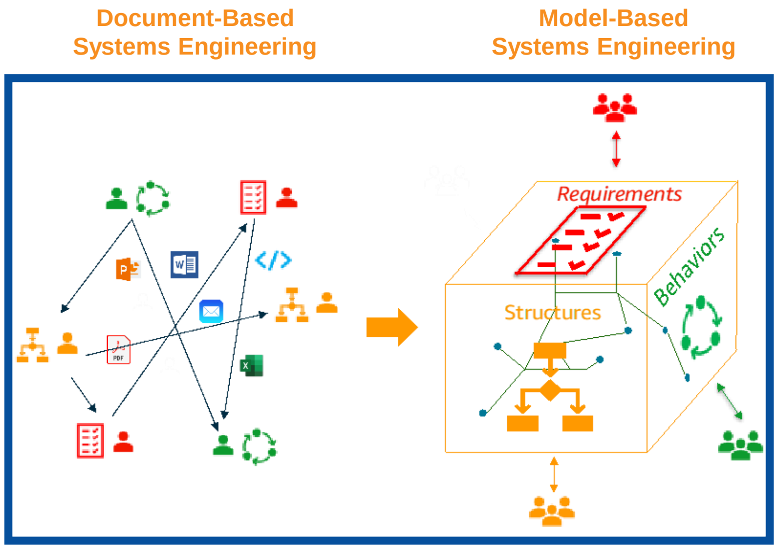


The Need for Digital Engineering Transformation in Systems Engineering

- Microsoft Word, PDFs, Spreadsheets, Paper Documents, Visio Diagrams, Legacy Systems, etc. dominate the design process
- Software tools and teams are **disparate** and **siloed**
- Changes are manually intensive, difficult to assess impacts
- None of this is "wrong", but it is tedious, costly, and induces significant delay

Model-Based Systems Engineering (MBSE)

- **MBSE:** shift from document-based, static approaches to use of LML/SysML models and databases as means of information exchange
- Transforms typical systems artifact documents to **data objects**
- Models and data form an integral part of the technical baseline, not just visual depictions
- Ensures the **right** thing is built the **first** time



Source: Amazon Web Services

MBSE at INL – Requirements & Functional Analysis

Relationship Type: traced to

	F.CFAHS.2.1 Perform CFA Solid O...	F.CFAHS.2.2 Compress CFA Hydro...	F.CFAHS.2.3 Start-Up CFA SOEC	F.CFAHS.2.4 Compress CFA Hydro...	F.CFAHS.2.5 Dry Hydrogen Produ...	F.CFAHS.2.6 Store CFA Hydrogen ...	F.CFAHS.2.7 Recycle Extracted DI ...	F.CFAHS.3.3 Store hydrogen at hi...
R.3.2.1.1 CFA Hydrogen System (CFAHS) ...								
R.3.2.1.1.1 CFA Hydrogen Production (CF...								
R.3.2.1.1.1.1 CFA Hydrogen Production Me...	X							
R.3.2.1.1.1.2 CFA External Hydrogen			X					
R.3.2.1.1.1.3 CFA SOEC Nitrogen Purging								
R.3.2.1.1.1.4 CFA Hydrogen Drying					X			
R.3.2.1.1.1.5 CFA Hydrogen Low-Pressure ...		X						
R.3.2.1.1.1.6 CFA Hydrogen Low-Pressure ...						X		
R.3.2.1.1.1.7 CFA Hydrogen High-Pressure...				X				
R.3.2.1.1.1.8 CFA Hydrogen High-Pressure...								X

R.3.2.1 CFA Functional and Operational Requirements

R.3.2.1.1 CFA Hydrogen System (CFAHS) Demonstration
The CFA location of the IES Complex shall demonstrate a commercial scale hydrogen system.

R.3.2.1.1.1 CFA Hydrogen Production (CFAHS-P)
The CFAHS system shall produce hydrogen.

R.3.2.1.1.1.1 CFA Hydrogen Production Method
The CFAHS shall produce hydrogen using solid oxide electrolyzer cells (SOEC).

R.3.2.1.1.1.1.1 CFA Hydrogen Production Configuration
The CFAHS shall produce hydrogen using 3 SOEC stamps.

R.3.2.1.1.1.1.2 CFA Hydrogen Production Quantity
The CFAHS shall produce 43 kg/h of hydrogen per stamp.

R.3.2.1.1.1.2 CFA External Hydrogen
The CFAHS shall have access to fresh hydrogen besides the one produced in site to be used during SOEC startup, shutdown, and idle modes.

R.3.2.1.1.1.2.1 CFA External Hydrogen Quantity
The CFAHS shall have access to 1.1 kg/h of external fresh hydrogen.

R.3.2.1.1.1.2.2 CFA External Hydrogen Type
The CFAHS external hydrogen shall be dry.

R.3.2.1.1.1.2.3 CFA External Hydrogen Pressure
The CFAHS external hydrogen shall have a minimum of 10 bar(g) or 150 psig and a maximum of 35 bar(g) or 500 psig pressure.

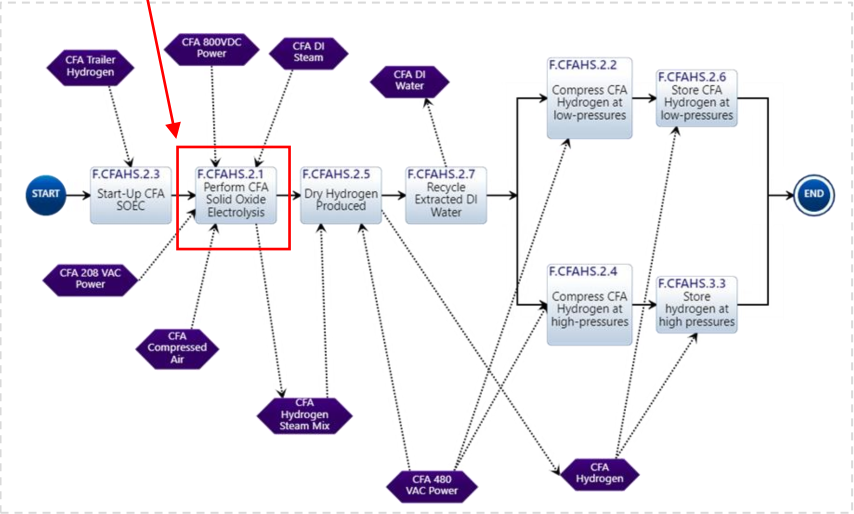
R.3.2.1.1.1.2.4 CFA External Hydrogen Temperature
The CFAHS external hydrogen shall be at ambient temperature.

R.3.2.1.1.1.2.5 CFA External Hydrogen Purity
The CFAHS external hydrogen shall have a 99.9% purity.

R.3.2.1.1.1.2.6 CFA External Hydrogen Connection
The CFAHS shall supply the external hydrogen through a connection to a ½" ASME 150lb flange inlet pipe made of SS 316L, Sch40 material.

R.3.2.1.1.1.3 CFA SOEC Nitrogen Purging
The CFAHS shall have access to nitrogen for SOEC purge.

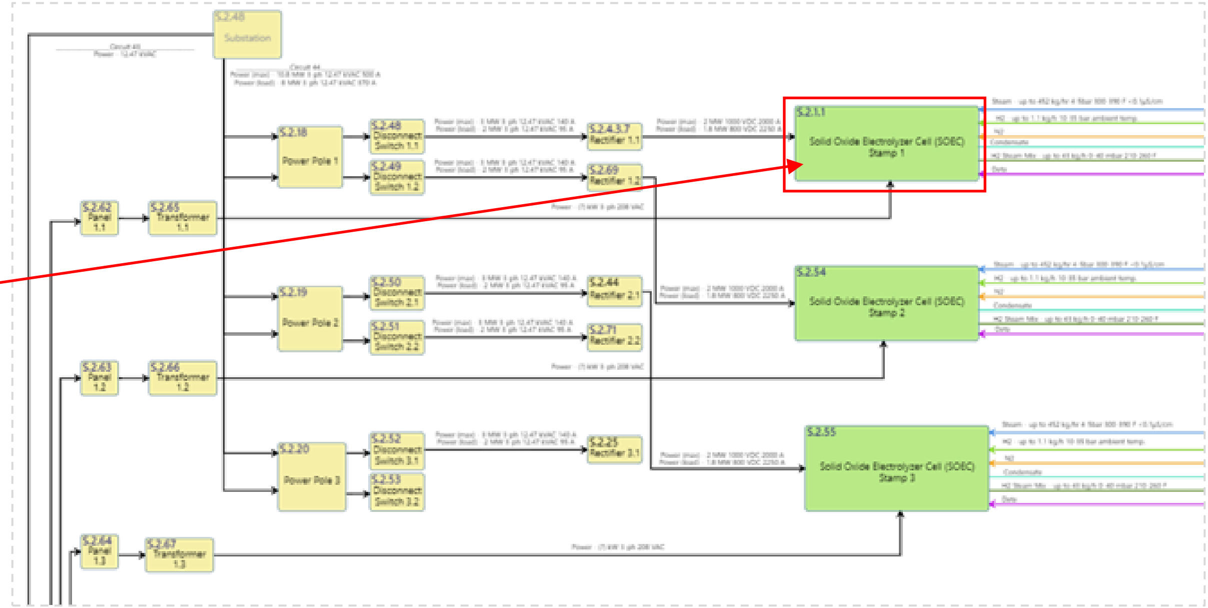
R.3.2.1.1.1.4 CFA Hydrogen Drying
The CFAHS shall dry the hydrogen produced.

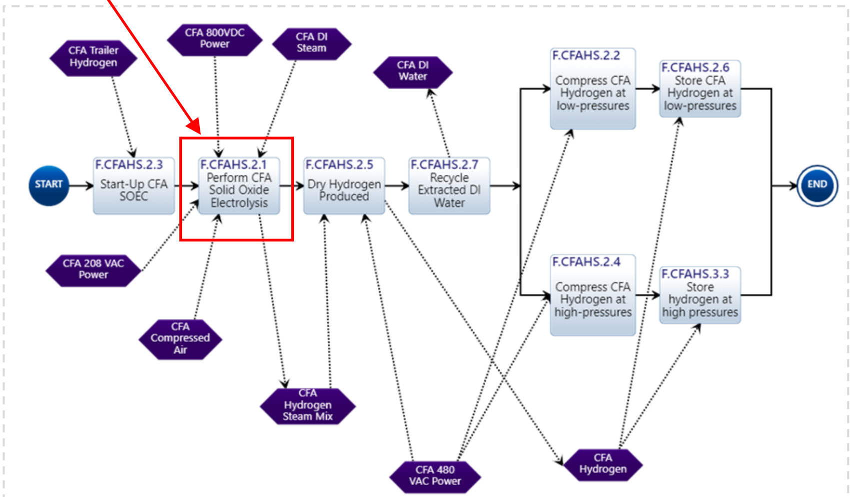


MBSE at INL – Systems Architecture & Analysis

Relationship Type: performed by

	S.2.1.1 Solid Oxide Electrolyzer C...	S.2.1.2 Low-Pressure Compressor	S.2.1.4 N2 Liquid Storage Tank	S.2.1.5 H2 Trailer	S.2.1.15.1 Solid Oxide Fuel Cell (S...	S.2.1.15.2 Flare Stack	S.2.4.3.7 Rectifier 1.1	S.2.4.3.8 Combined Heat	S.2.11.1 Water S	S.2.11.
F.CFAHS.1 CFA Hydrogen System (CFAHS...										
F.CFAHS.2 Produce Hydrogen at CFA										
F.CFAHS.2.1 Perform CFA Solid Oxide Ele...	X									
F.CFAHS.2.2 Compress CFA Hydrogen at l...		X								
F.CFAHS.2.3 Start-Up CFA SOEC				X						
F.CFAHS.2.4 Compress CFA Hydrogen at ...										
F.CFAHS.2.5 Dry Hydrogen Produced										
F.CFAHS.2.6 Store CFA Hydrogen at low-p...										
F.CFAHS.2.7 Recycle Extracted DI Water										
F.CFAHS.3 Use Hydrogen at CFA										
F.CFAHS.3.1 Produce Electricity					X					
F.CFAHS.3.2 Flare Hydrogen						X				

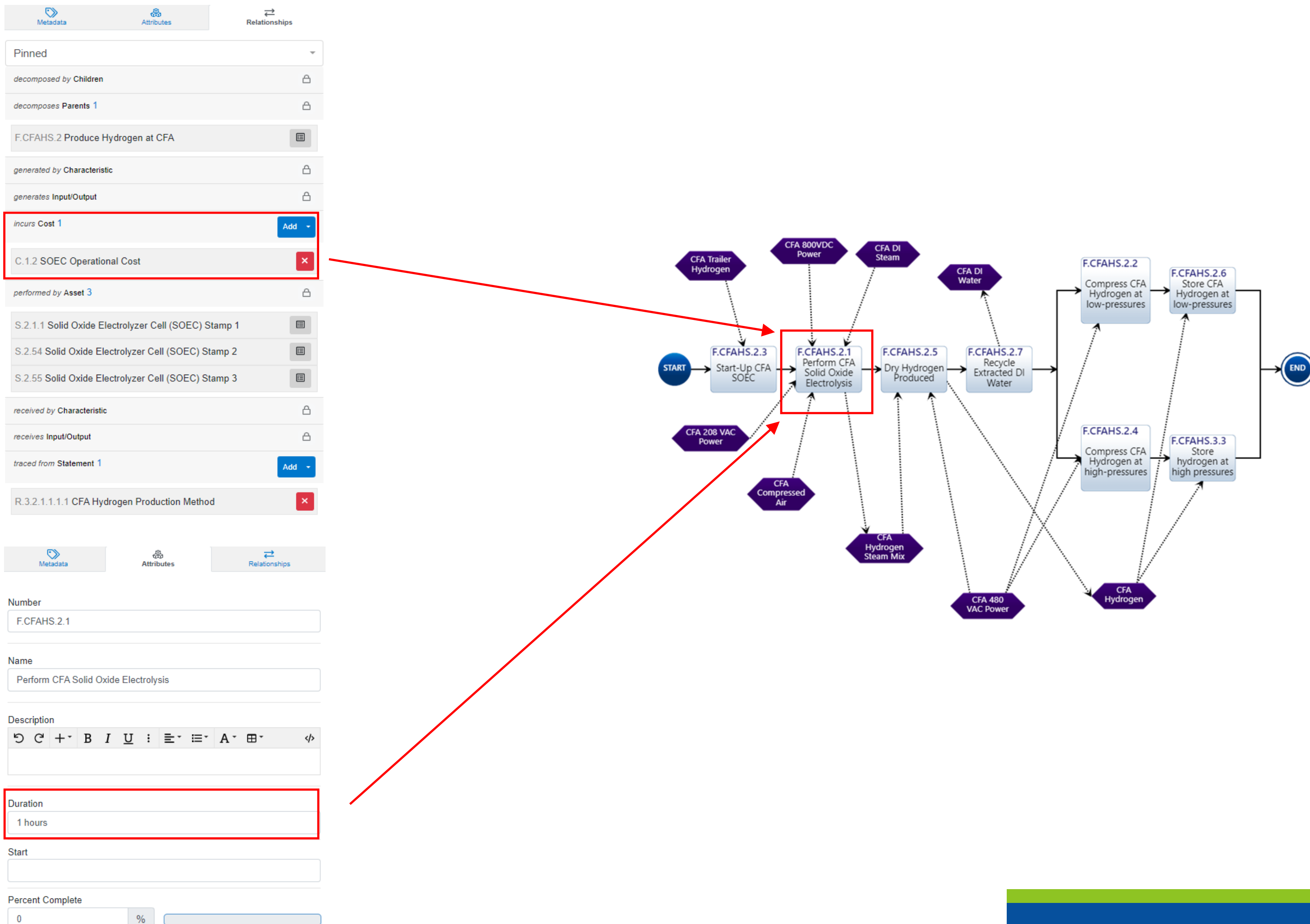




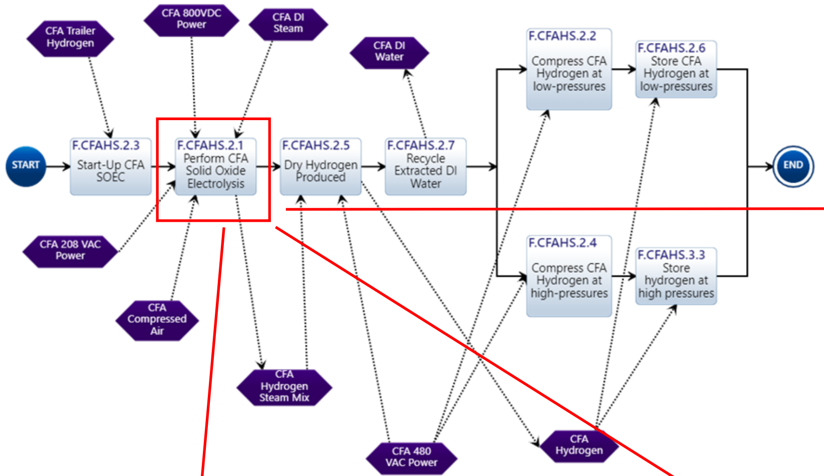
MBSE at INL – Traceability Analysis

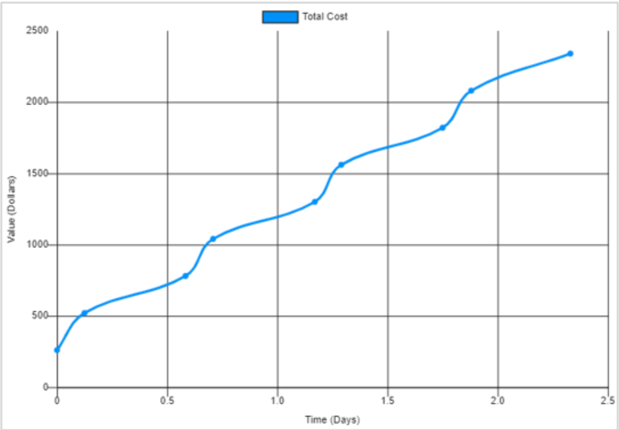
Requirements			Functions		Assets	
Number	**Name**	**Description**	**traced to Number**	**traced to Name**	**performed by Number**	**performed by Name**
R.3.2.1.1	CFA Hydrogen System (CFAHS) Demonstration	The CFA location of the IES Complex shall demonstrate a commercial scale hydrogen system.	F.CFAHS.1	CFA Hydrogen System (CFAHS) Operation	S.2.1	CFA Hydrogen System (CFAHS)
R.3.2.1.1.1	CFA Hydrogen Production (CFAHS-P)	The CFAHS system shall produce hydrogen.	F.CFAHS.2	Produce Hydrogen at CFA	S.2.1.14	CFA Hydrogen Production System (CFAHS-P)
R.3.2.1.1.1.1	CFA Hydrogen Production Method	The CFAHS shall produce hydrogen using solid oxide electrolyzer cells (SOEC).	F.CFAHS.2.1	Perform CFA Solid Oxide Electrolysis	S.2.1.1	Solid Oxide Electrolyzer Cell (SOEC) Stamp 1
					S.2.54	Solid Oxide Electrolyzer Cell (SOEC) Stamp 2
					S.2.55	Solid Oxide Electrolyzer Cell (SOEC) Stamp 3
R.3.2.1.1.1.2	CFA External Hydrogen	The CFAHS shall have access to fresh hydrogen besides the one produced in site to be used during SOEC startup, shutdown, and idle modes.	F.CFAHS.2.3	Start-Up CFA SOEC	S.2.1.5	H2 Trailer
R.3.2.1.1.1.3	CFA SOEC Nitrogen Purging	The CFAHS shall have access to nitrogen for SOEC purge.	F.CFAHS.6	Purge CFA SOEC	S.2.1.4	N2 Liquid Storage Tank
R.3.2.1.1.1.4	CFA Hydrogen Drying	The CFAHS shall dry the hydrogen produced.	F.CFAHS.2.5	Dry Hydrogen Produced	S.2.34	Chiller
R.3.2.1.1.1.5	CFA Hydrogen Low-Pressure Compression	The CFAHS shall compress the hydrogen produced at low-pressure.	F.CFAHS.2.2	Compress CFA Hydrogen at low-pressures	S.2.1.2	Low-Pressure Compressor
R.3.2.1.1.1.6	CFA Hydrogen Low-Pressure Storage	The CFAHS shall store the low-pressure post-processed hydrogen.	F.CFAHS.2.6	Store CFA Hydrogen at low-pressures	S.2.35	Low-Pressure Storage
R.3.2.1.1.1.7	CFA Hydrogen High-Pressure Compression	The CFAHS shall compress the hydrogen produced at high-pressure.	F.CFAHS.2.4	Compress CFA Hydrogen at high-pressures	S.2.16	High-Pressure Compressor
R.3.2.1.1.1.8	CFA Hydrogen High-Pressure Storage	The CFAHS shall store the high-pressure post-processed hydrogen.	F.CFAHS.3.3	Store hydrogen at high pressures	S.2.17	High-Pressure Storage
R.3.2.1.1.2	CFA Hydrogen Usage (CFAHS-U)	The CFAHS system shall use the produced hydrogen.	F.CFAHS.3	Use Hydrogen at CFA	S.2.1.15	CFA Hydrogen Usage System (CFAHS-U)
R.3.2.1.1.2.1	CFA Fuel Cell	The CFAHS shall use produced hydrogen to fuel a fuel cell.	F.CFAHS.3.1	Produce Electricity	S.2.1.15.1	Solid Oxide Fuel Cell (SOFC)

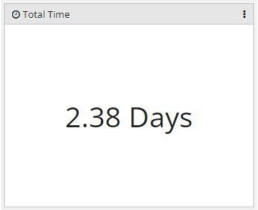
MBSE at INL – Functional Analysis

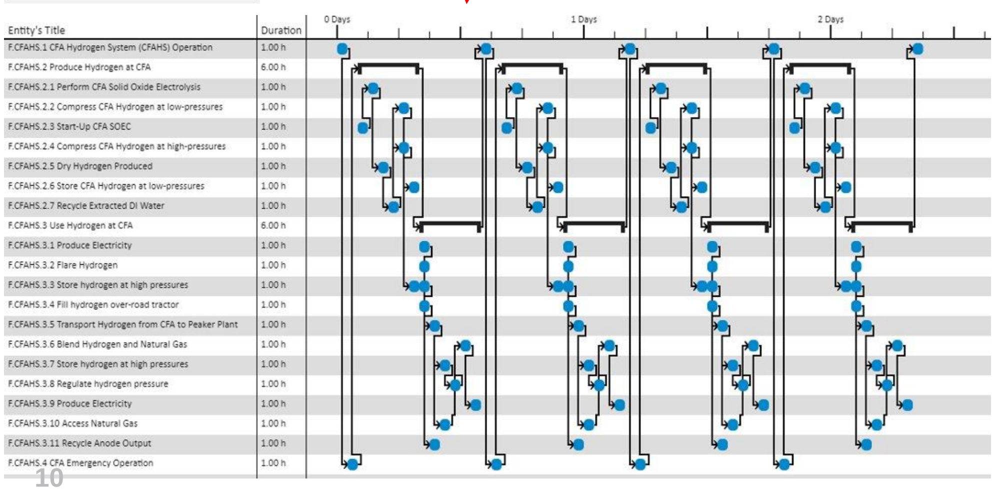


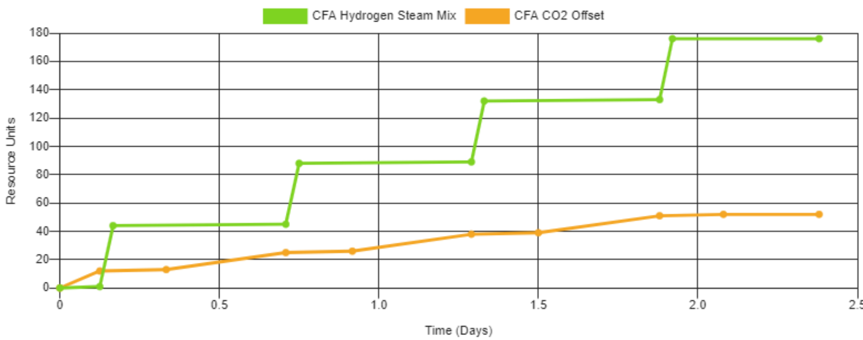
MBSE at INL – Functional Analysis









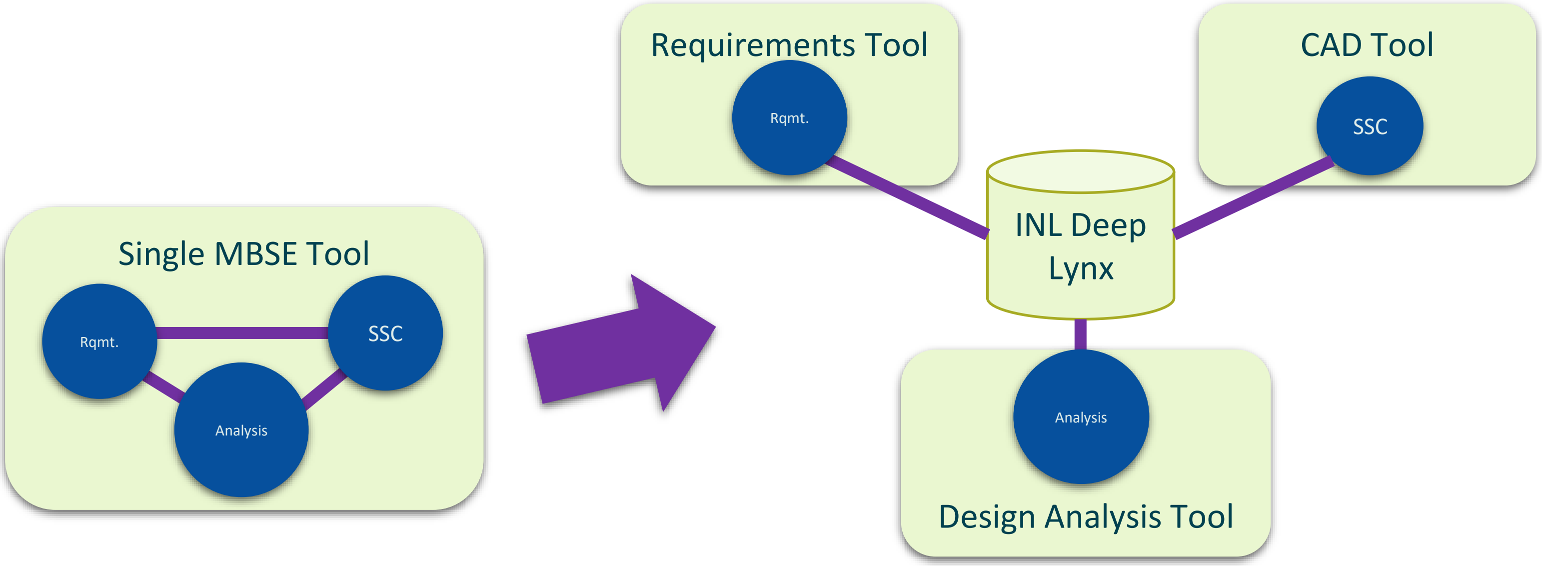


Further Digital Transformation

- MBSE tools have some **shortcomings** in the infrastructure domain / use case, especially in nuclear energy
  - New, never been used before tools and processes
  - Insufficient configuration management
  - No physics/multi-physics simulation & analysis or 3D geometric design
  - Nuclear is beholden to documentation being the “source of truth”
  - Manual linking & relationships
- We need to augment MBSE with **Data-Driven Systems Engineering**

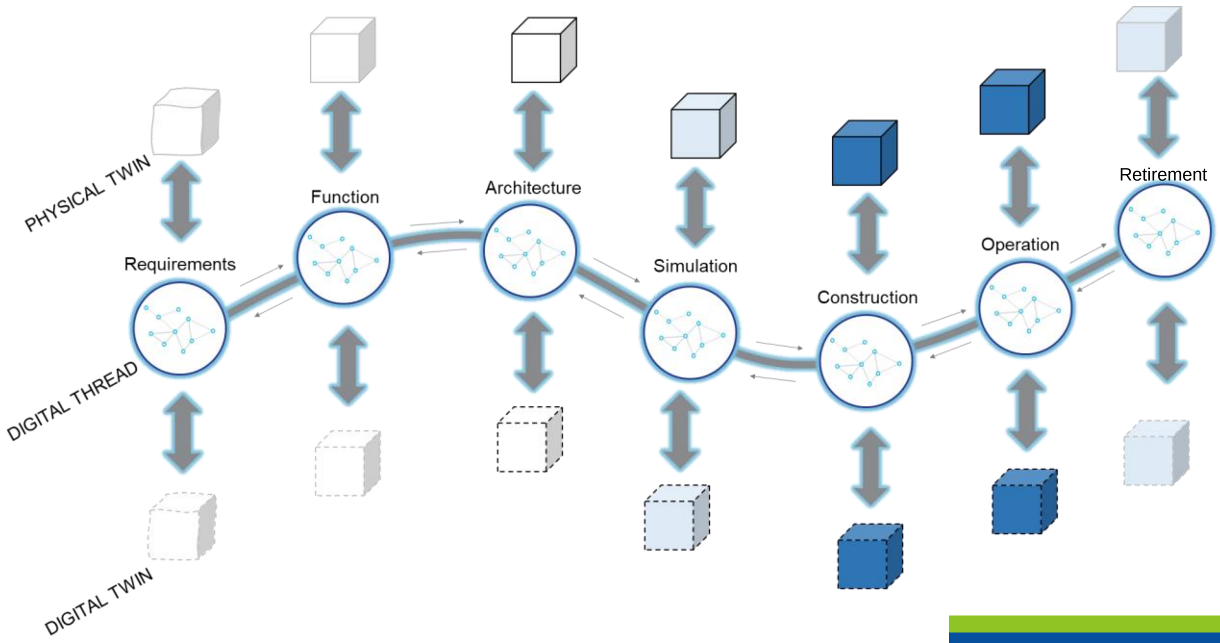
Data-Driven Systems Engineering

- Basic Premise: Use purpose-built, data-driven tools to generate the **right design data** with the least interference with legacy practices
- **Automate data connection** on the backend using custom software adapters and database APIs to accomplish the function of model-based systems engineering
- **Store data** in single repository under a common ontology

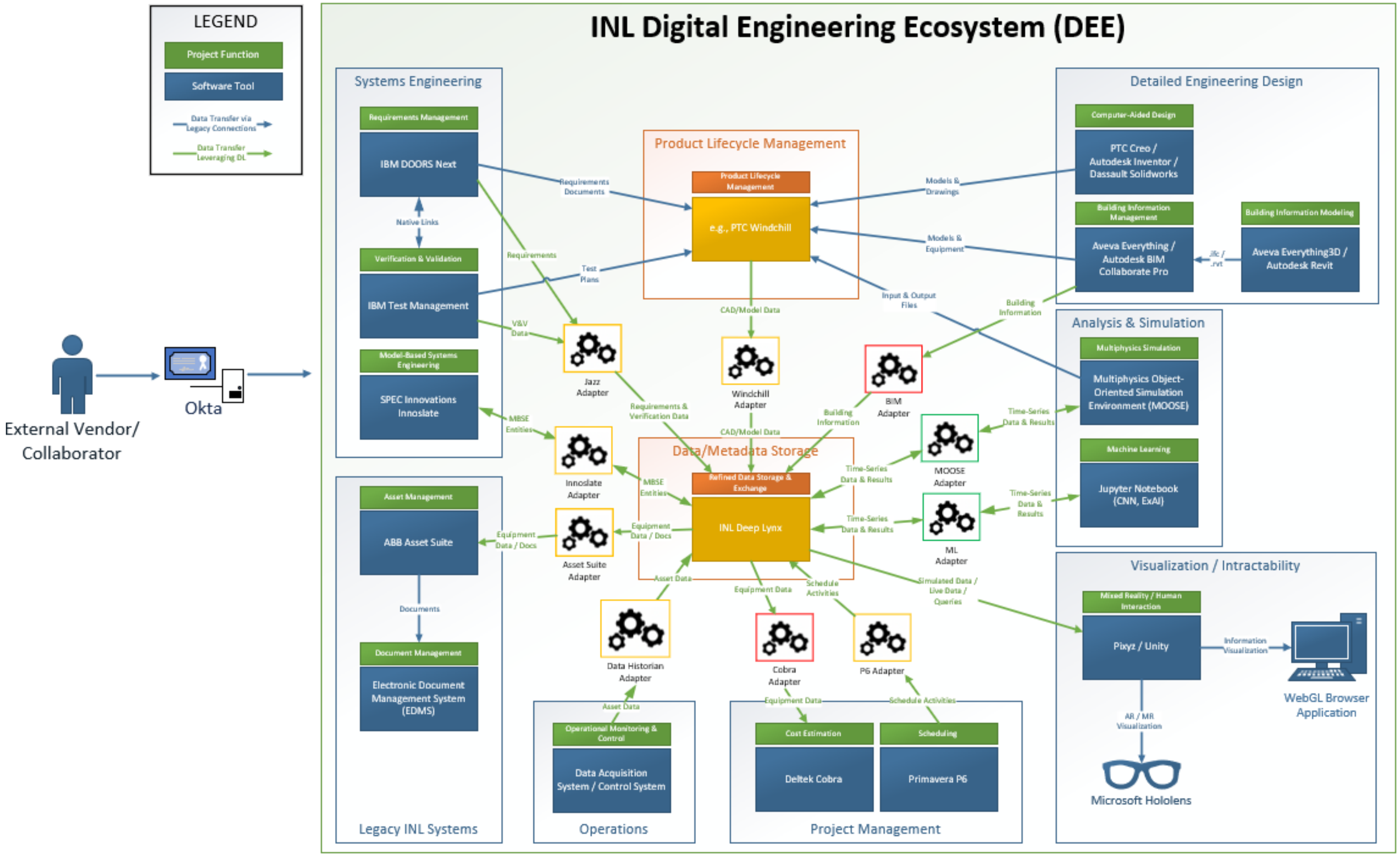


Digital Threads

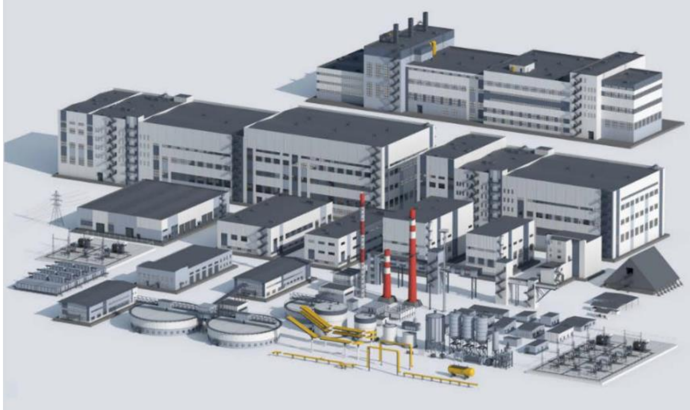
- **Interconnected** software data exchange used to enable digital engineering and digital twinning systems.
- **Connects** MBSE model to digital definitions created later in the development process
- Maintains system **integrity** across lifecycle.



Developing the Digital Thread

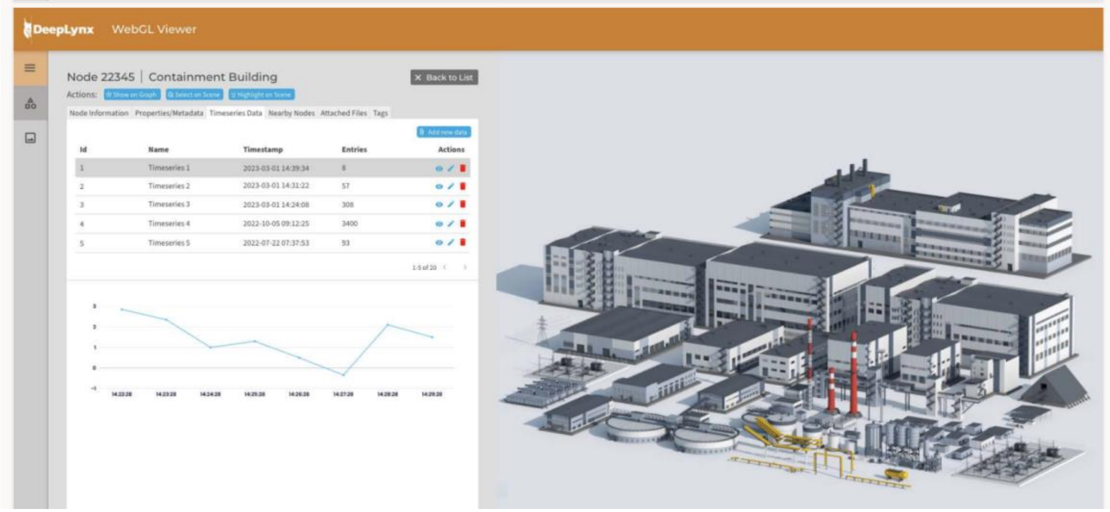


Democratization and Visualization



Pixyz / Unity 3D Model

MR Visualization



Information Visualization

Future Roadmap

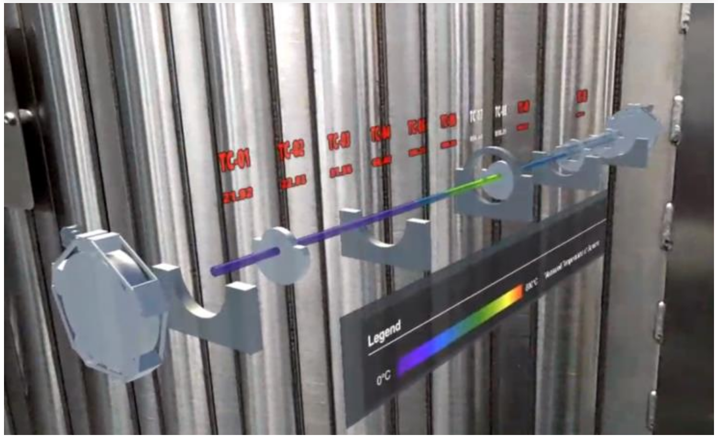
Next

Informative Digital Twins

Displaying real temperature values recorded by operating sensors on a 3D model using mixed reality

Then

Predictive Digital Twins



Overlaying predicted temperature values from a machine learning algorithm on a digital representation of an operating asset using mixed reality

Digital Engineering Conference

April 25 & 26 | Idaho Falls

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