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Stakeholders Harmonization of Hydrogen Supply Business: An UAF Approach to System Dynamics in Enterprise Architecture and Product Service Systems

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Overview and Motivation

🌍 Global Challenge

- **Paris Agreement:** Keep global temperature rise below 2°C
- **Japan's commitment:** Carbon neutrality by 2050
- Japan needs **1,000 hydrogen station by 2030.**

🏭 MHI's Mission NET ZERO

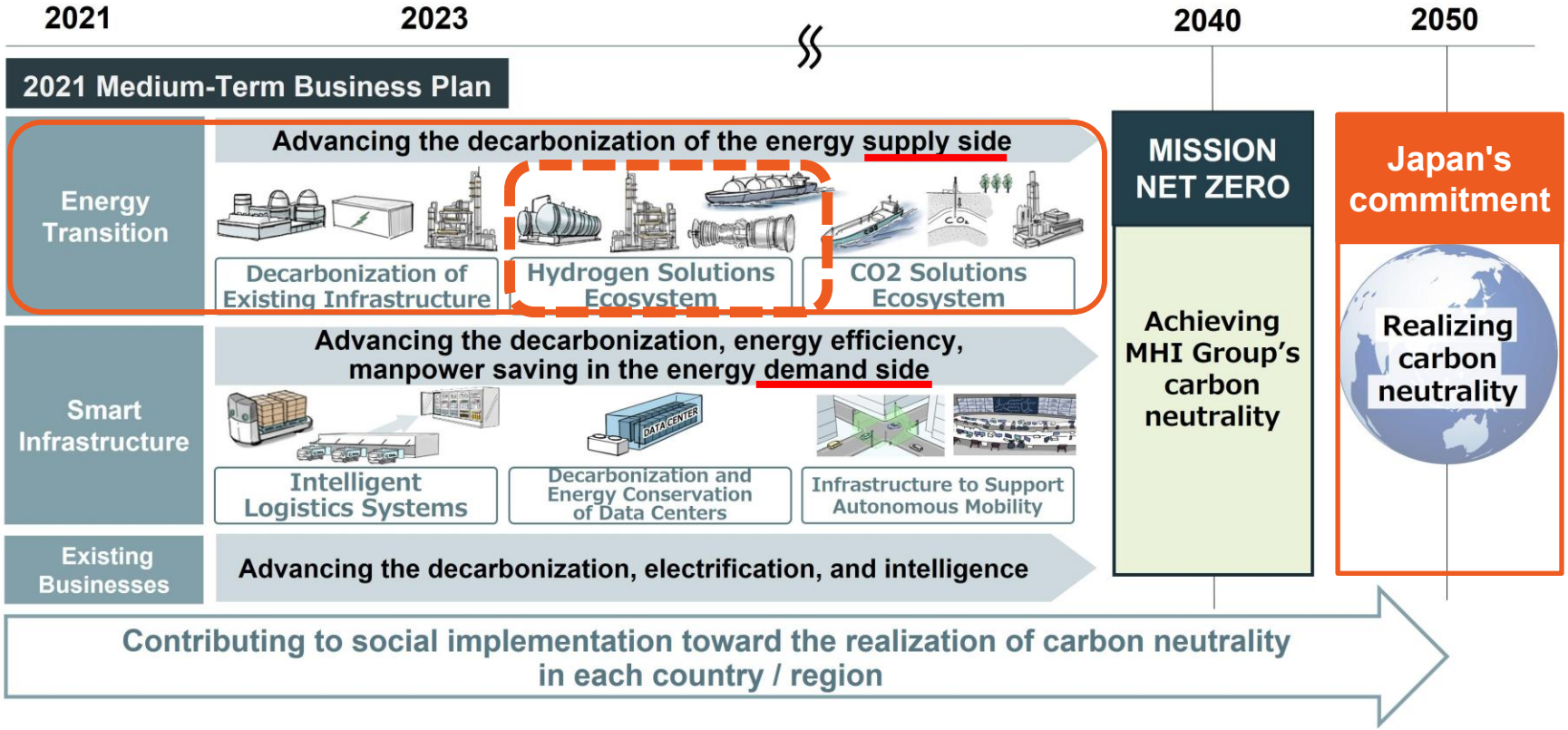
- Net zero CO_2 emissions **by 2040** across operations and value chain
- Focus on **Energy Transition** & Smart Infrastructure
- High-pressure liquid hydrogen pumps for hydrogen station as a part of solution.

🎯 Research Objective

Develop an SE approach to evaluate and improve hydrogen supply business using **UAF**, **System Dynamics**, and **Product Service Systems** to support consensus building among multiple stakeholders

Overview and Motivation

MHI business growth will contribute to achieve Net Zero (MHI web-page, 2024)

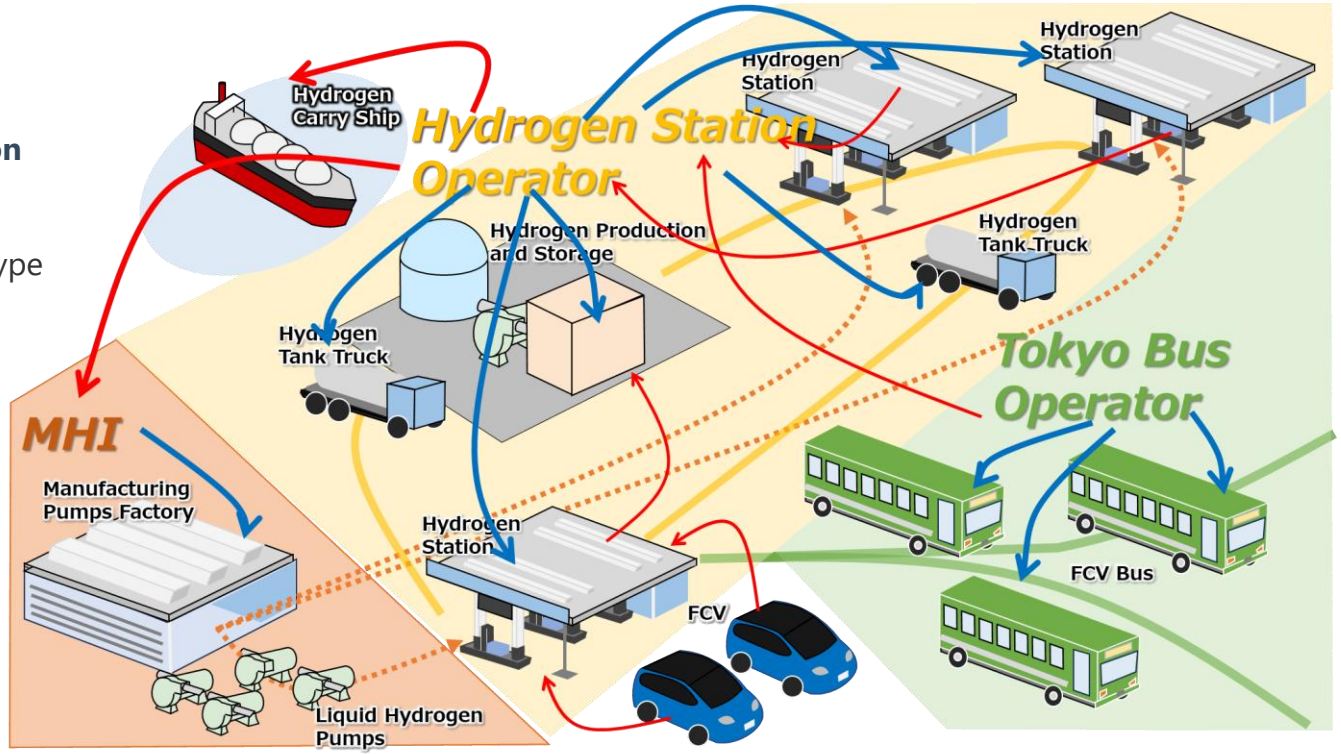


Hydrogen Supply Business Context

MHI contributes to hydrogen stations for Tokyo FCV Bus operator by supplying efficient liquid hydrogen solution and helps their operational improvement.

MHI's Liquid Hydrogen Solution

- **3x** hydrogen supply capacity
- **1/4** energy consumption vs gas-type
- Significant space & cost savings



Hydrogen Supply Business Context

Japanese government indicated targets for hydrogen station(ST) businesses.
The challenges are complex and it is difficult to make investment decisions.

	Today	2030	Future
Amount	2 mega ton	3 mega ton	12 mega ton (2040)
Cost	100 Yen/ Nm^3	30 Yen/ Nm^3	< 20 Yen/ Nm^3
Stations	168	1,000	-
FCV Bus	120	1,200	-

Business Expectation:

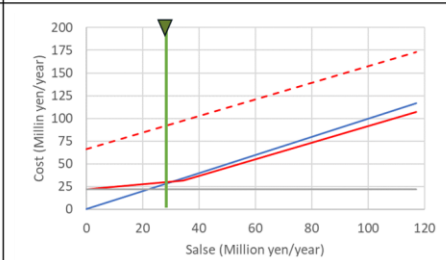
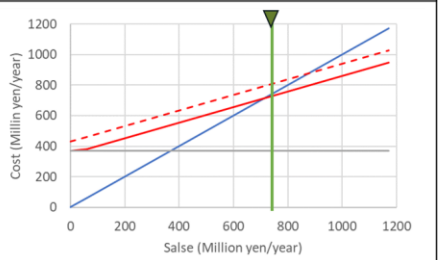
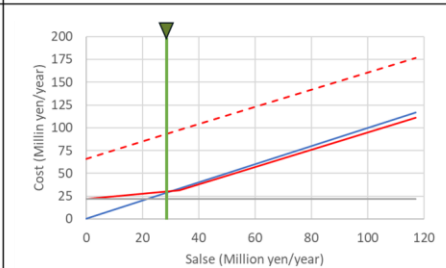
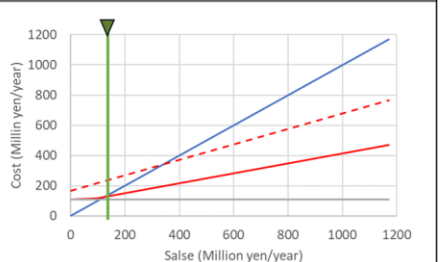
- Growing hydrogen market
- Increasing hydrogen stations.

Business Issues:

- Hydrogen supply cost is expensive
- Hydrogen vehicles has not increased
- Highly depending on subsidies.

EA Evaluation will Accelerate Stakeholder Harmonization

MHI's liquid hydrogen solution shows superior break-even characteristics when the market scales.

Pattern	Today Heavily dependent on government subsidies	2030 10x demand increase + hydrogen price reduction to 1/3
1		
2		

EA Pattern 1 (Gas-Type) Results

- High CAPEX and OPEX
- Lower efficiency per station grid
- **Limited profitability**

EA Pattern 2 (MHI Liquid-Type) Results

- Fewer grids required
- Superior flow rate efficiency
- Significantly improved break-even point
- **Strong future profitability potential**

CAPEX: Capital Expenditure
OPEX: Operating Expenditure

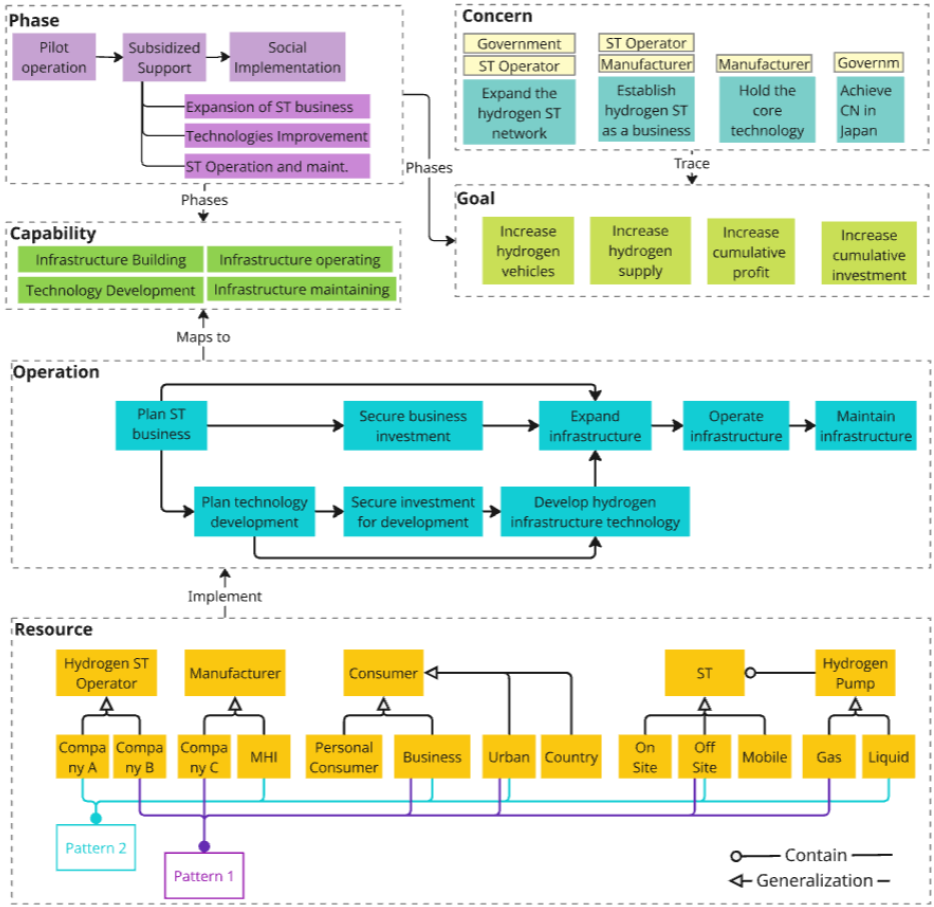
Concerns and EA Overview

Stakeholders have individual **concerns** but they need to agree on common goals

Government
- Achieve carbon neutrality in Japan
- Expand hydrogen network infrastructure

Hydrogen Station Operators
- Establish hydrogen ST as profitable business
- Expand hydrogen ST network efficiently
- Optimize operational performance

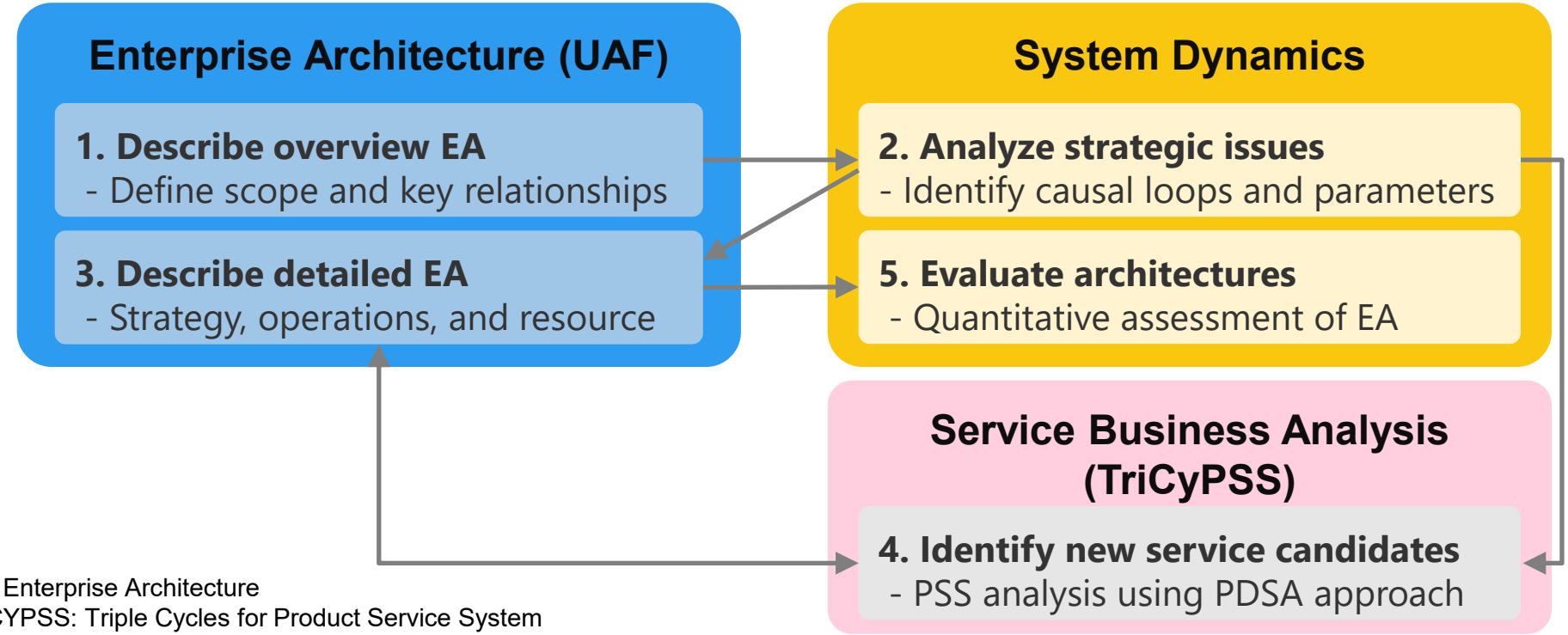
Equipment Manufacturers
- Advance core hydrogen technologies
- Expand equipment market presence
- Contribute to carbon neutrality



Overview of Hydrogen Supply Business Architecture by UAF

Proposed Methodology

Integrated method of UAF, System Dynamics, and Service Business Analysis to harmonize stakeholder concerns and support consensus building is proposed.

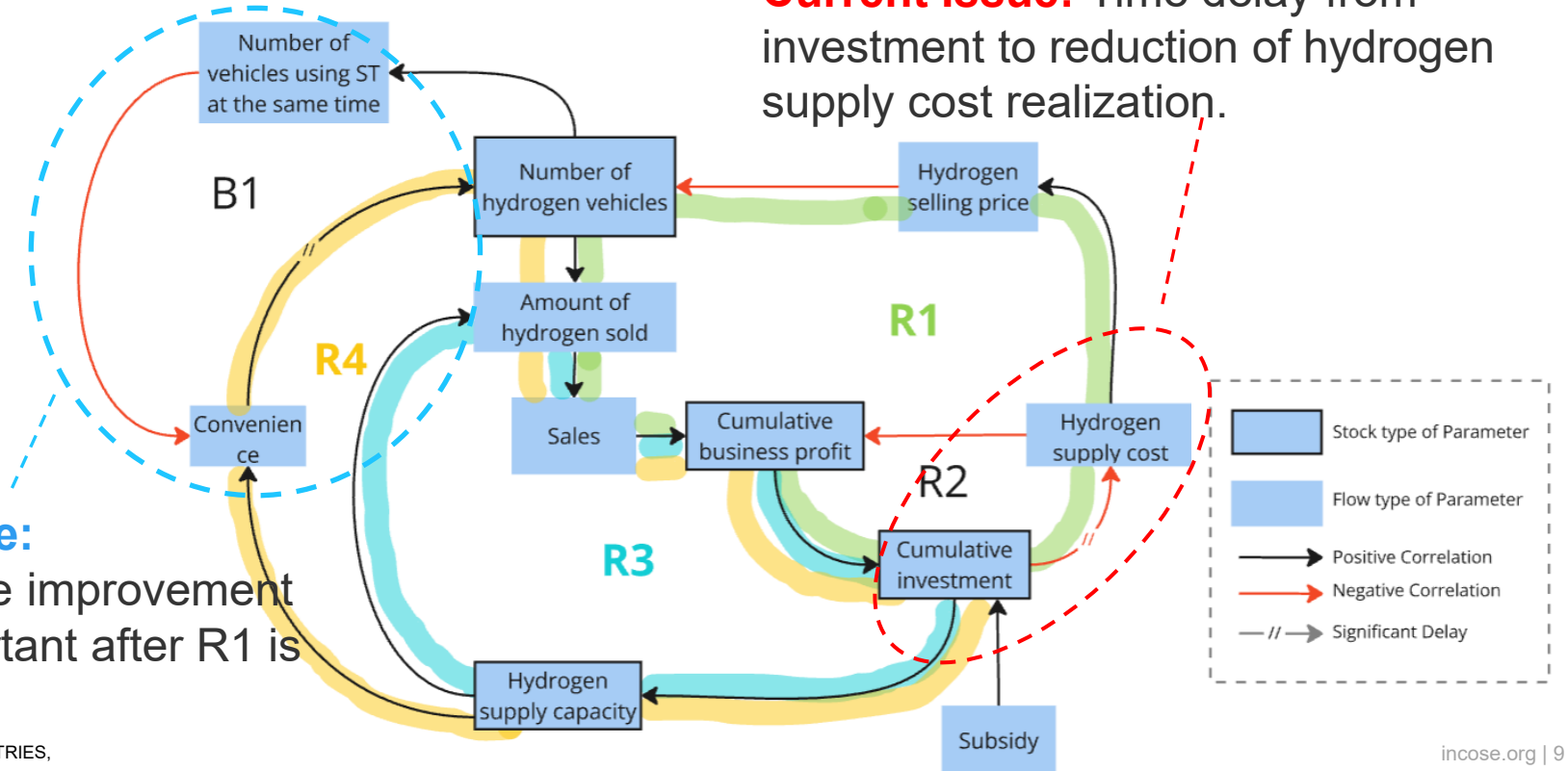


EA: Enterprise Architecture
TriCYPSS: Triple Cycles for Product Service System
PDSA: Plan Do Study and Action

Strategic Business Issues

- Causal loops are made based on the overview EA.
- Identify current and future business issues on causal loops.

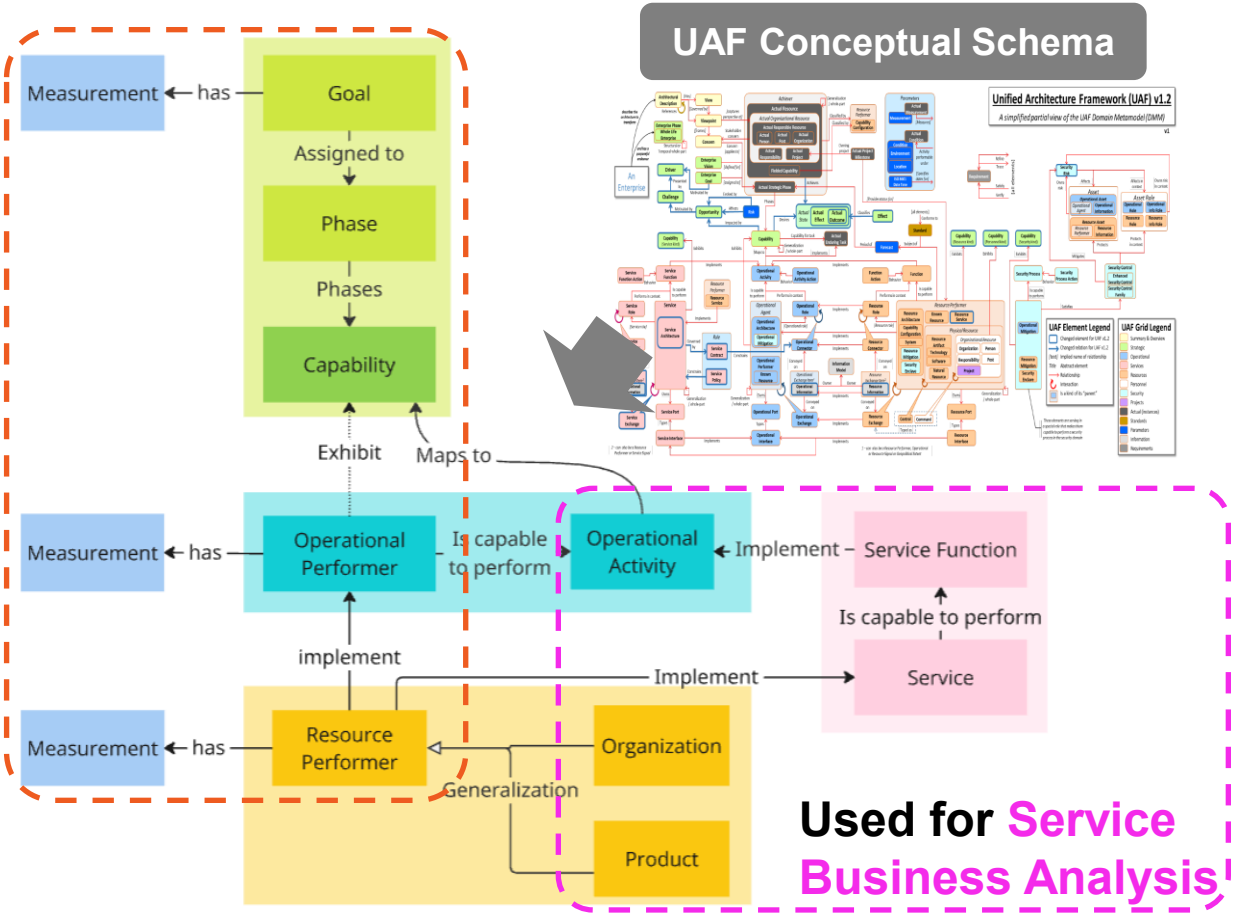
Current Issue: Time delay from investment to reduction of hydrogen supply cost realization.



Future Issue:
Convenience improvement will be important after R1 is reinforced.

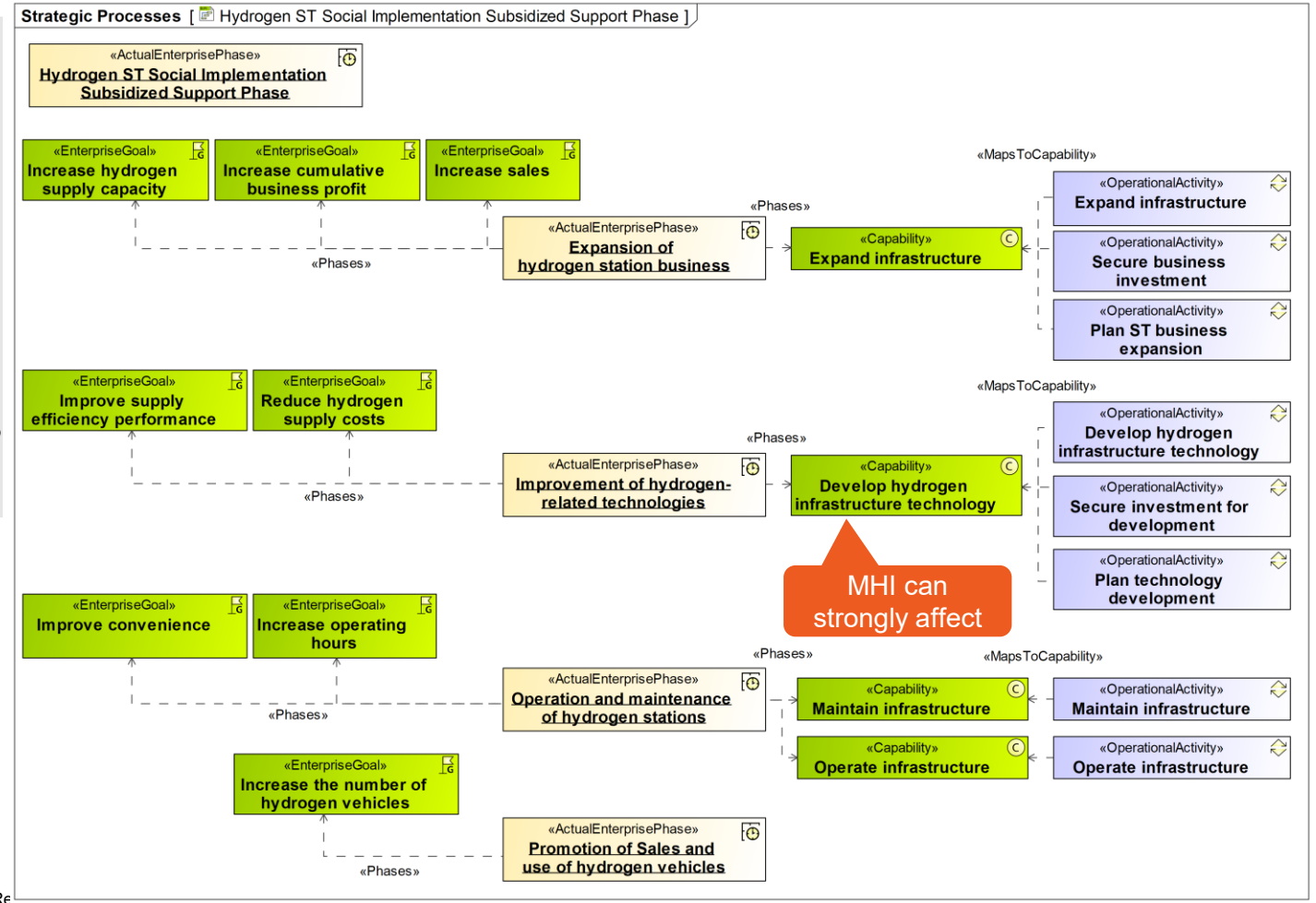
Ontology (conceptual schema) of EA Description

- A part of UAF conceptual schema is used.
- The EA is for revenue evaluation and service business analysis.



Details of EA Description

- 4 detailed phases.
- Each phase has individual goals and capabilities.
- High level operational activities are mapped



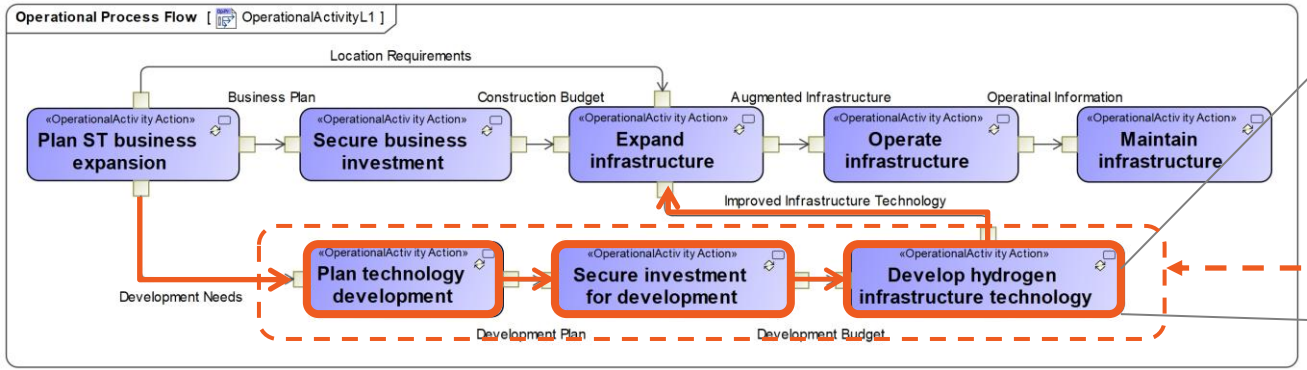
Details of EA Description

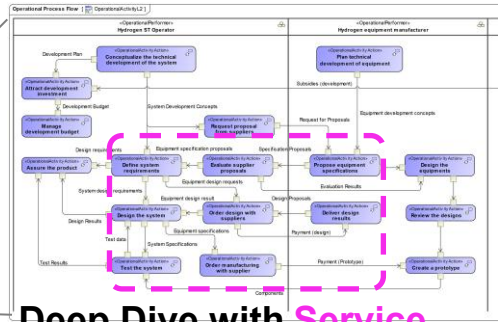
- Critical operational activities are identified from the captured current issue.
- Operational activities, that MHI relates strongly, are detailed.
- Critical path is analyzed.

Capture the Current Issue:
Time delay from **investment** to hydrogen supply **cost reduction** realization.

Extracted operational activities from the measurement defined in the causal loops.

Measurement	Value Item	Enterprise Goal	Actual Enterprise Phase	Capability	Operational Activity
Hydrogen supply cost	Hydrogen supply cost	EG15 Reduce hydrogen supply costs	Improve hydrogen-related technologies : Strategy::Strategic Processes::Improve hydrogen-related technologies	Develop hydrogen infrastructure technology	Plan technology development Secure investment for development Develop hydrogen infrastructure technology
Increase cumulative business profit of hydrogen equipment manufacturers	Cumulative business profit	EG2 Increase cumulative business profit	Expansion of hydrogen station business : Strategy::Strategic Processes::Expansion of hydrogen station business	Expand infrastructure	Plan ST business expansion Secure business investment Expand infrastructure

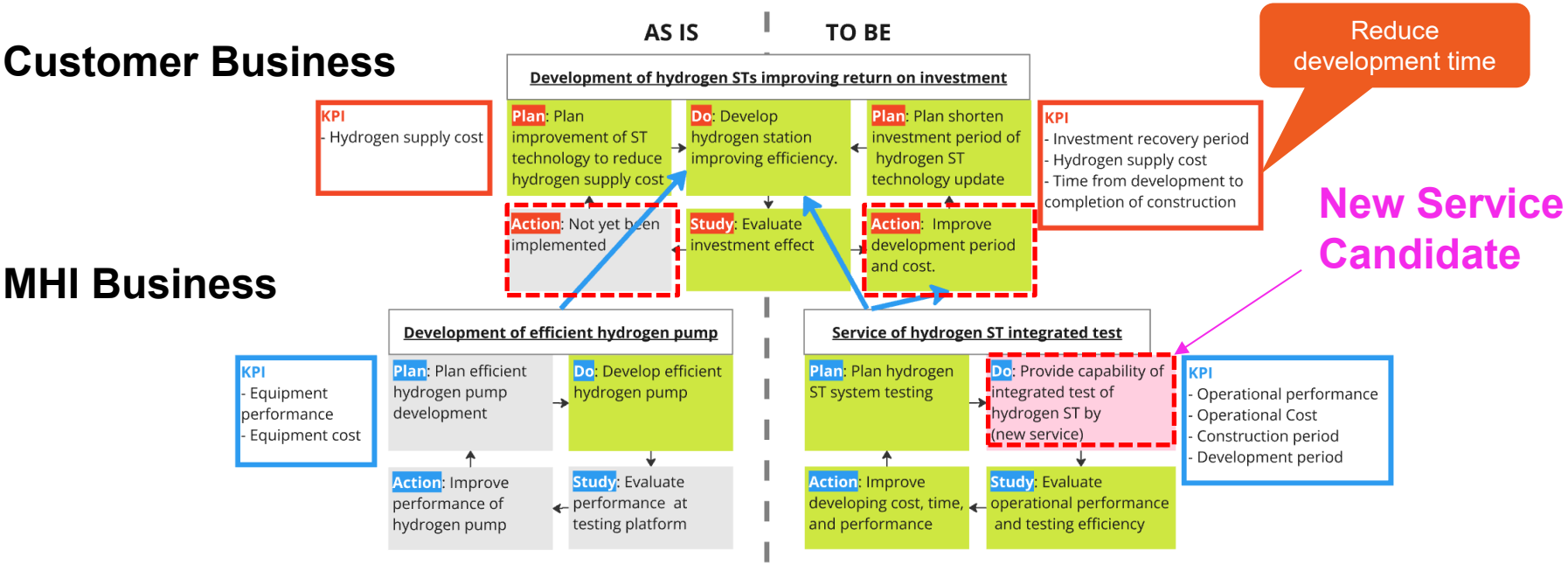




Deep Dive with Service Business Analysis

Service Business Analysis (TriCYPSS)

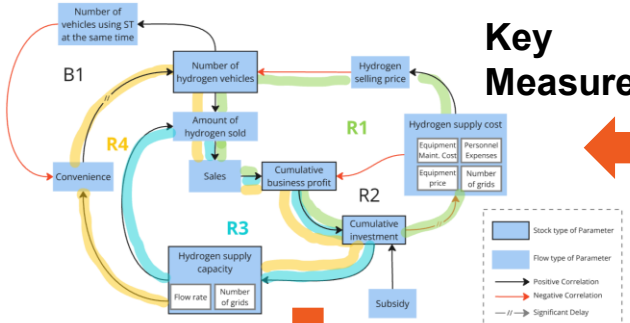
New MHI service candidate has been identified by analyzing PDSA cycles:
Enhancing existing MHI test platform to verify the entire hydrogen ST operation to reduce development period.



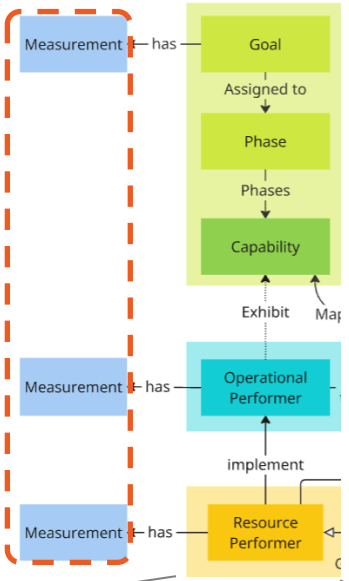
TriCYPSS: Triple Cycles for Product Service System
PDSA: Plan Do Study and Action

Quantitative Evaluation of Resource Patterns

- Measurements relationships are shown as causal loops.
- Causal loops are translated into formulation.
- Actual values of resources are used for evaluation



Key Measurements



Formulation of Revenue Eval.

$$CBP = SA - HSC$$

$$SA = HSP \times FR \times NG \times OT$$

$$HSC = OPEX - SUB_O + \frac{CAPEX}{DP}$$

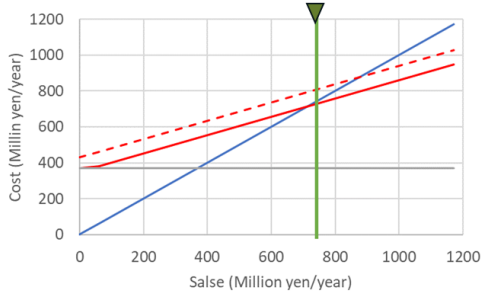
$$OPEX = OC + PC$$

$$OC = EMC + PE + EC$$

$$PC = HP \times HCV$$

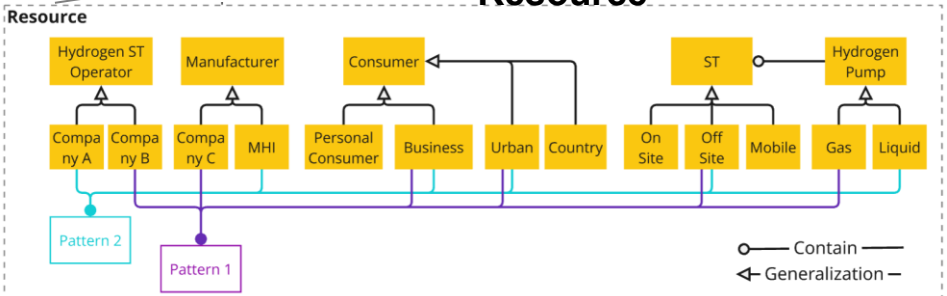
$$CAPEX = DC + CC + LC - SUB_C$$

EA Evaluation Result (Break Even Point)



Actual Values

Patterns of Resource



Conclusion

1. Methodology

✔UAF is applied to hydrogen energy sector and EAs are quantitatively evaluated.

2. Business Value

✔ MHI liquid hydrogen solution shows superior scaling characteristics.

3. Future Impact

✔ Proposed method can be used for more complex energy infrastructure architecture.

💡 Why MHI Uses UAF:

- Common language and Integrated decision across hundreds of projects.
- Find optimized combination of MHI' Solutions

MOVE THE WORLD FORWARD

MITSUBISHI
HEAVY
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Role to Execute the Proposed Approach