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A better world through a systems approach

Early-Stage Digital Engineering for Complex Energy Decarbonization Projects

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Overview

- Context for Complex Energy Decarbonization (CED) Systems
- Research & Development Approach
- Opportunity for SE-Based Analysis of CED Systems
- CED System Modelling & Analysis
- Case Studies
- Overall insights

Context

- Challenge of Climate Change
- Australia has mandated for Net-Zero greenhouse gas emissions by 2050
- This will require a major investment
  - Estimated at ~ $7 Trillion [1]
- Large and growing number of CED projects
- Projects often undertaken
  - With limited whole-of-system understanding
  - Using overly optimistic assumptions
  - With a focus on subsidies
- High potential for wasted time, effort and resources

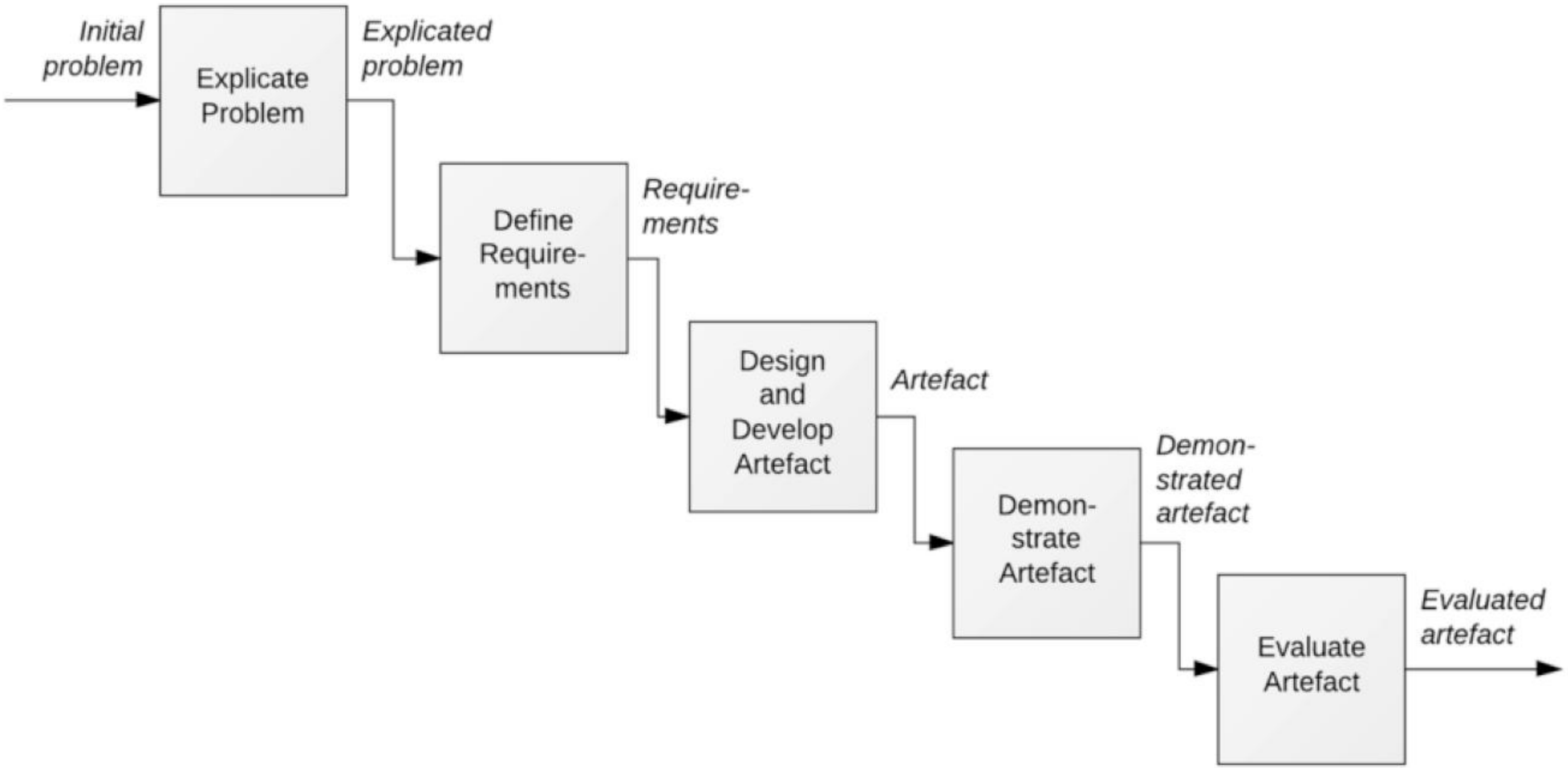
[1] Net-Zero Australia, 2023

Opportunity for SE

- CED systems and projects need SE to support
  - Advice to government departments
  - Advice to investors
  - Through-life support
- Government agencies and large corporation undertake internal modelling and analysis
- SE support by Small to Medium Enterprises (SMEs) is currently emergent
- **Business opportunity for SMEs – if cost effective**

Research Approach

Design Science Research Approach



[Johannsson, 2021]

Digital Engineering

- Tao (2024) states that engineering "has progressively adopted digital technologies to enhance the efficiency, accuracy, and innovation of activities within the engineering domain"

"The crux of digital engineering is the creation of computer readable models to represent all aspects of the system and to support all the activities for the design, development, manufacture, and operation of the system throughout its lifecycle." (SEBoK, 2024)

- DAU (2023) states that digital engineering is:

"An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal."

Digital Engineering Maturity

- DE is increasingly well established in the civil sector
- Digital Engineering classes:
  - DE 1.0: Digital Documentation
  - DE 2.0: Expansion into Modelling and Simulation
  - DE 3.0+: Advanced DE

Mission Engineering (ME)

- Origin in US DoD (Navy)
- The enterprise solution is driven by the ME approach
- Bring together the users and engineers
- Missions can be enduring and/or dynamic
- Increasingly ME is being applied to civil capabilities

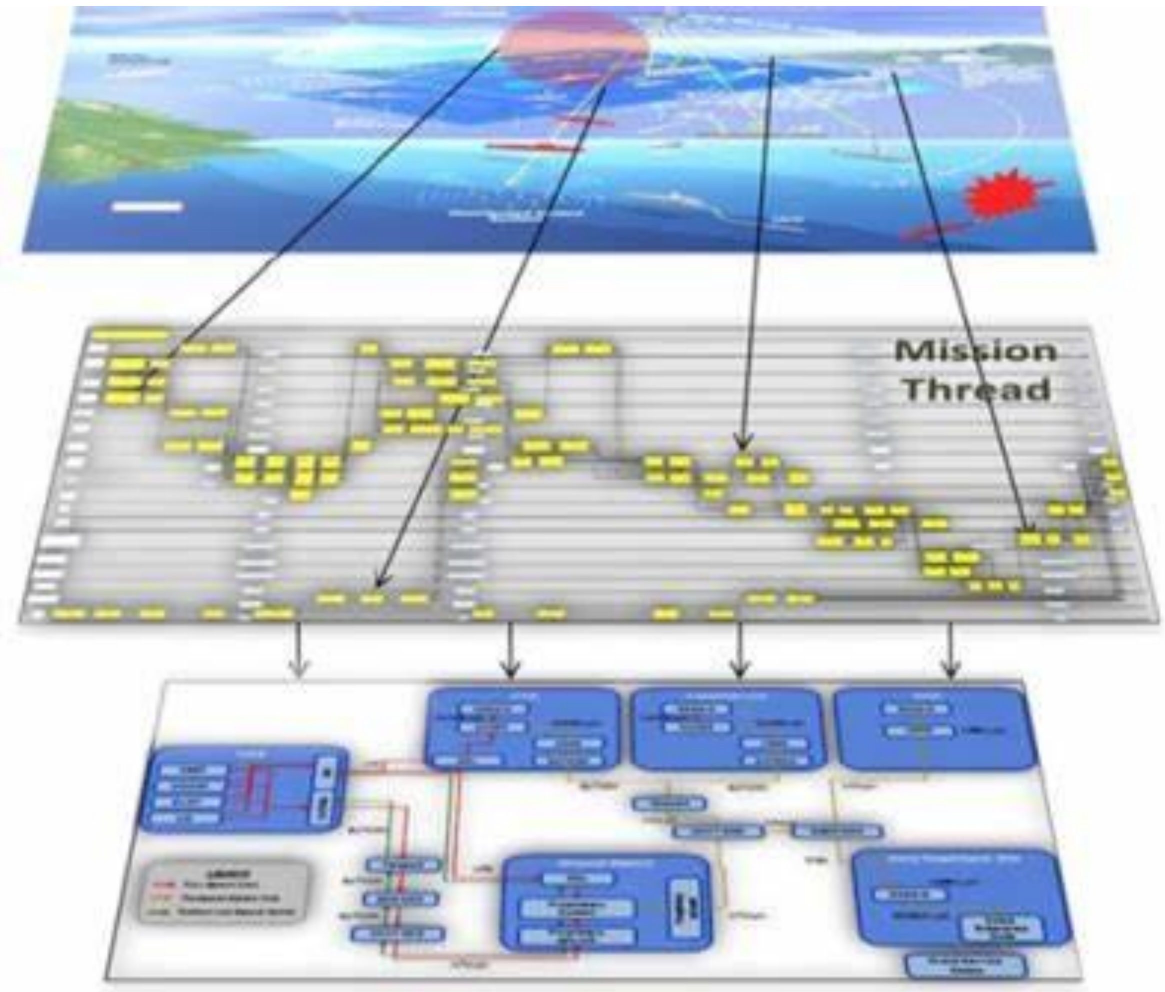
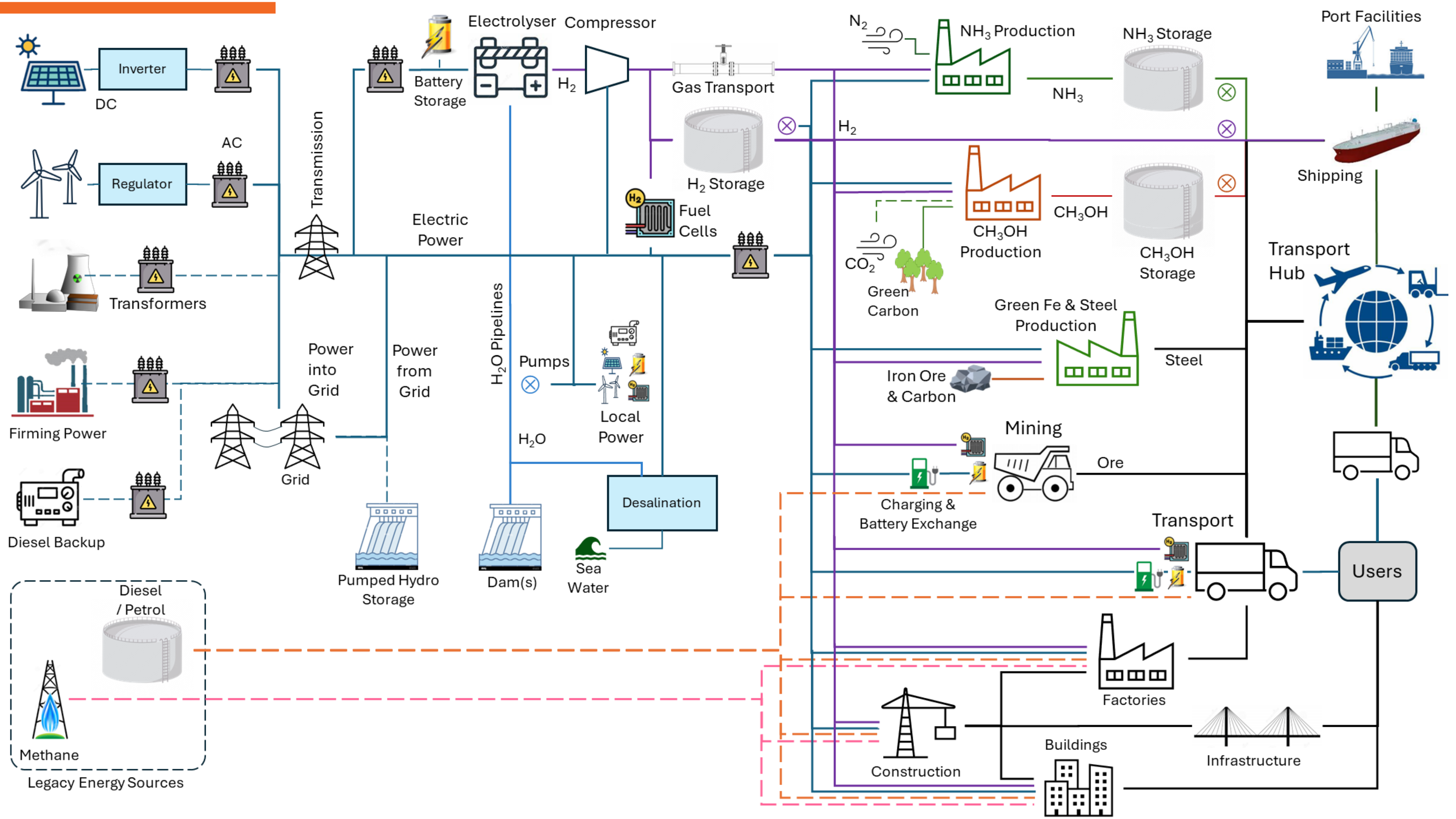


Image source: US DoD Mission Engineering Guide – 2023

Complex Energy Decarbonization Systems

Scope of Complex Energy Decarbonization Systems



CED Project Stages

- Key stages in CED Project
  1. **Feasibility Studies**
  2. **Conceptual Design**
  3. **Pre-FEED**
  4. **FEED**
     - Front End Engineering Design
  5. Detailed Design
  6. Procurement and Fabrication
  7. Construction and Installation
  8. Pre-Comm
  9. Handover
- Mapped on standard lifecycle models
- Focus of work is up to FEED stage

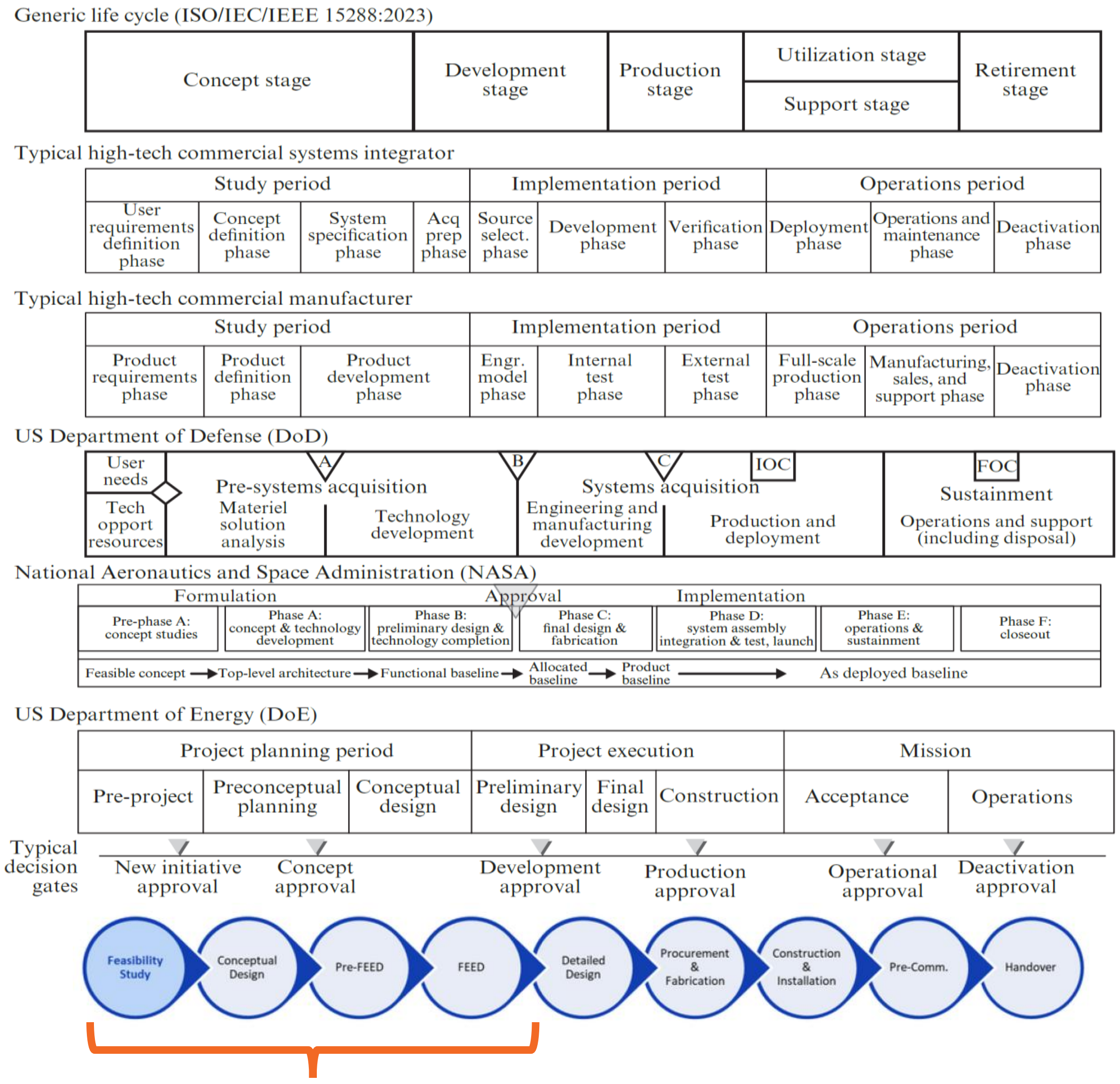
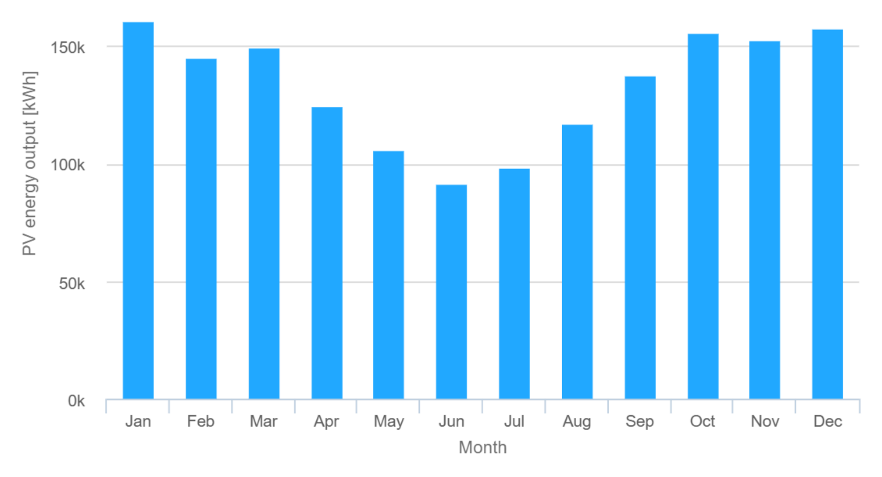


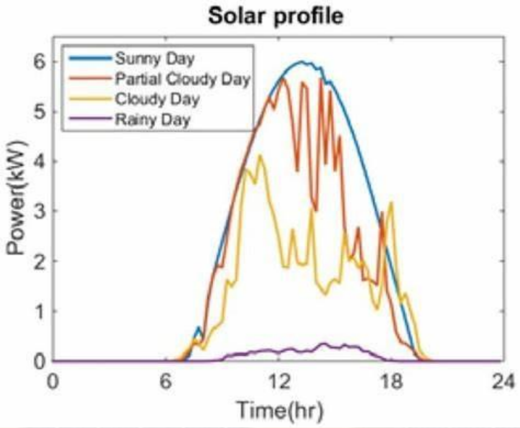
Image source: INCOSE SE Handbook 5th Edition

Complexity in CED Systems

- Complexity is driven by 'the non-trivial relationships between cause and effect" (Sillitto, 2019)
- CED systems have multiple sources of complexity
  - Socio-Political Complexity
  - Structural Complexity
  - Dynamic Complexity
- The sources of complexity can combine in non-linear and often unexpected ways



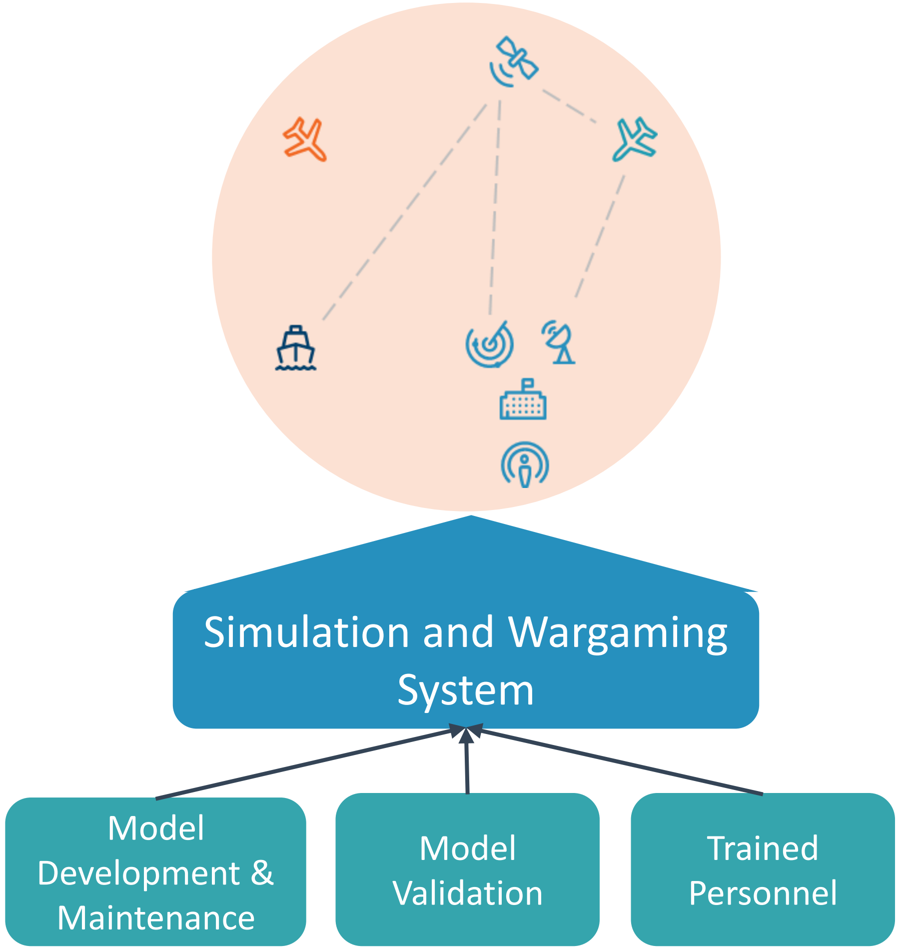
Yearly solar variation (PVGIS – Adelaide, Australia)



Daily solar variation (Zhu et. al, 2016)

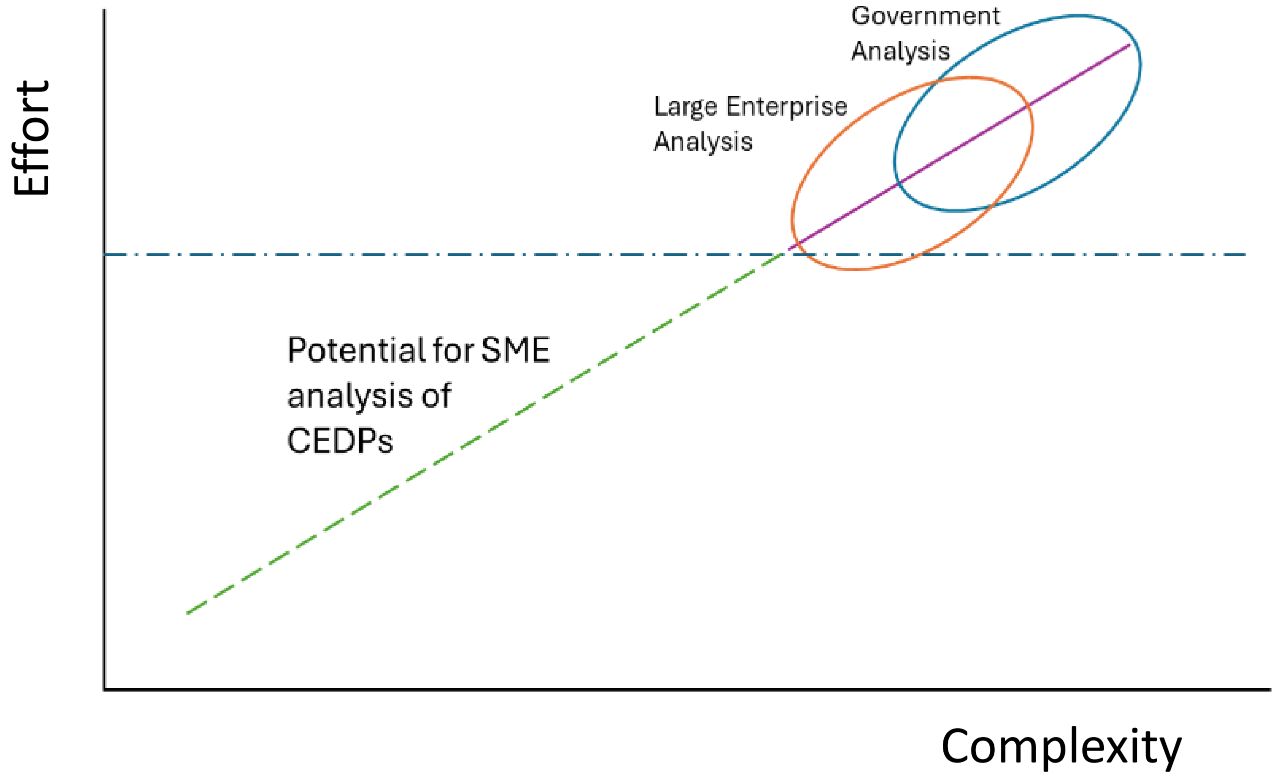
Large Scale Modelling, Simulation and OR

- Defence has long used modelling and simulation (M&S) + operations research to analyse military operations
- Modern tools are effective but require numerous highly-capable personnel and significant resources
- Similar modelling is undertaken by large corporations
- Such M&S is beyond most SMEs



Opportunities for SMEs: SE Analysis of CED Systems

- SE-based analysis scales with complexity
- Very complex systems (e.g. warfighting) undertaken by governments & large corporations
- There are a range of moderately complex CED systems that will need support
- Opportunity for SMEs
  - If it can be undertaken at SME scale

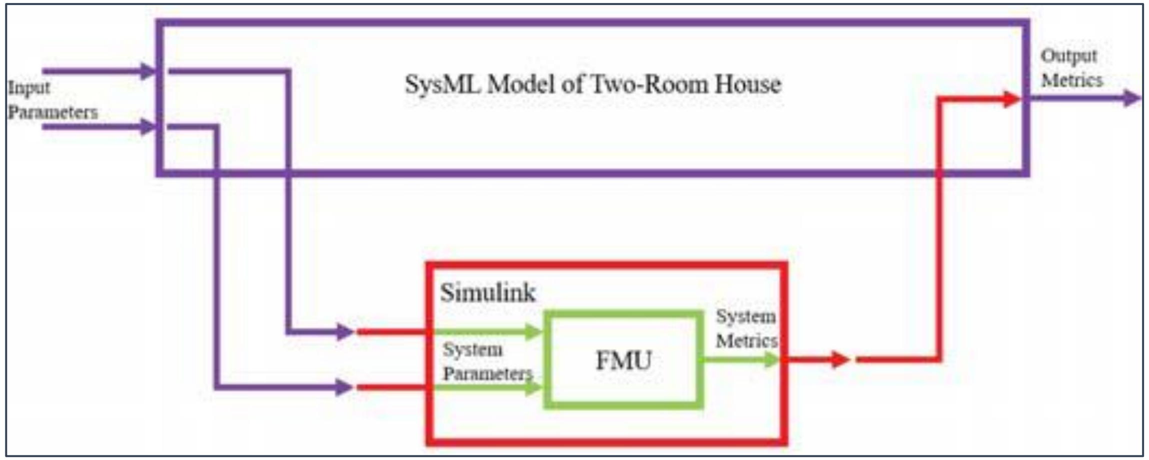


CED System Modelling & Analysis

Approach
Skilled personnel
Development Environment

Approach – Modular DE

- Leverage similarities between many CED systems
- Build tailorable modules
  - MBSE modules (SysML / UAF)
  - Analytical models
- **Keep the analytical models as simple as possible**
- Construct CED system model from module library
- Experimented with loose and tight MBSE to analysis coupling
  - Loose MBSE – analytical coupling in early stages
  - Tighter MBSE – analytical coupling in later stages
- Use Operations Research to examine larger scale dynamic behaviours



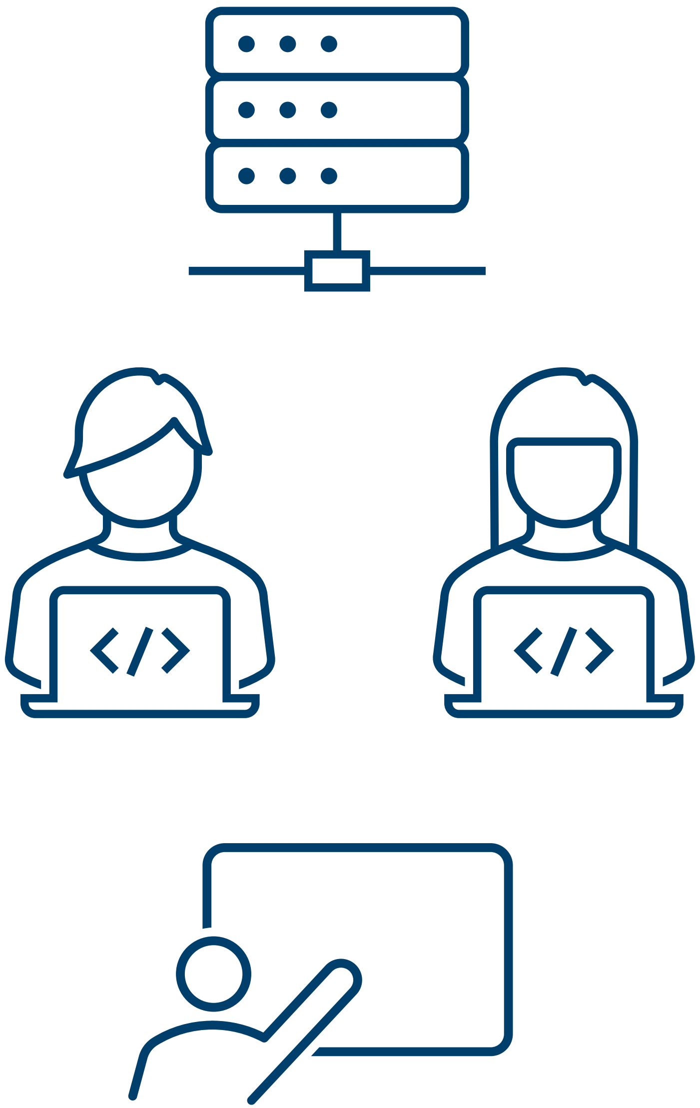
Cawasji and Baras (2018)

Skilled Personnel

- The effort of skilled personnel is the dominant cost
- Build on existing skills of personnel
- Choose tools that suit the personnel
- Align with skills of university graduates
- Shoal's skills build on:
  - MBSE – SysML / UAF
  - Modelling and simulation using a range of tools
  - Operations research experience
- Extensive experience across:
  - Defence, Space, Transport, Infrastructure

Development Environment

- An effective development environment is essential to deliver cost effective analysis of CED systems
- Information management
- Knowledge management
- Appropriate tools
  - Modelling
  - Visualization



Modular DE Modelling & Analysis Examples

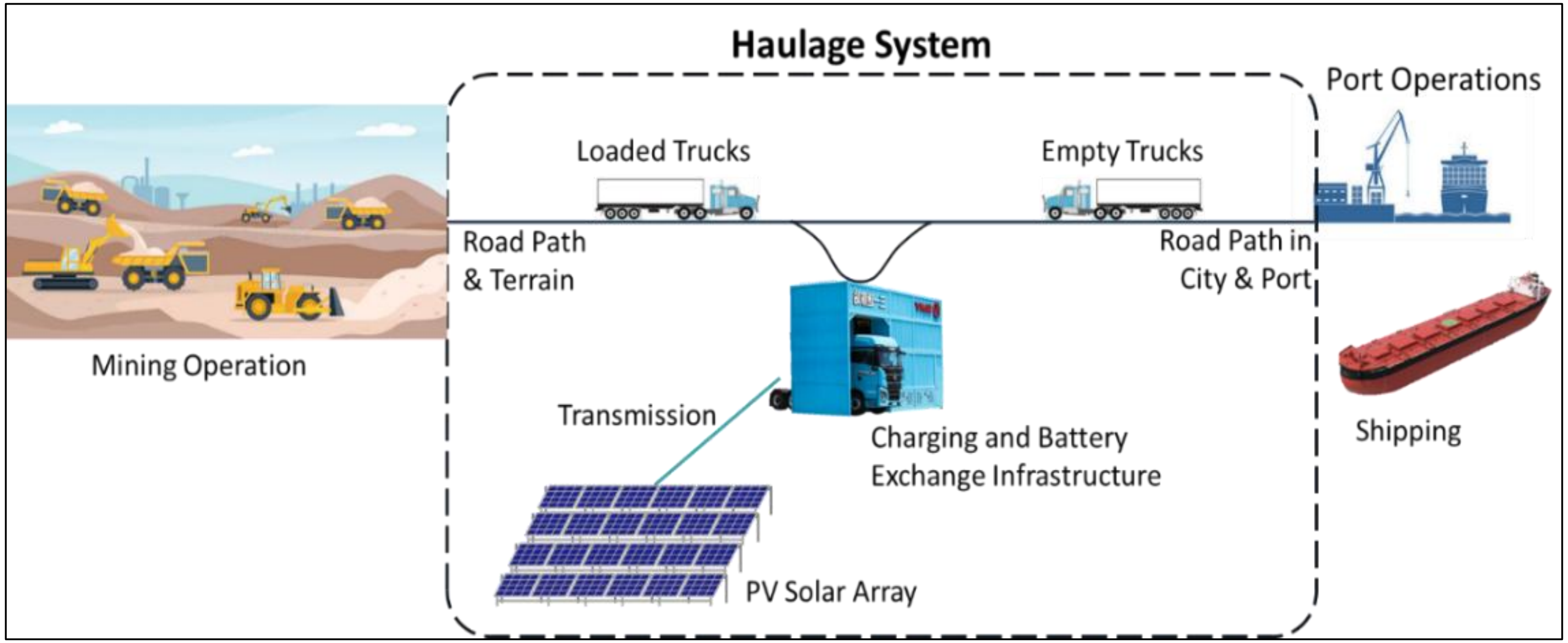
Decarbonized Haulage Operations

- Diesel ➔ Green haulage operations
- Support heavy haulage decarbonization
- Mines – Mine operations and optimization

Diesel

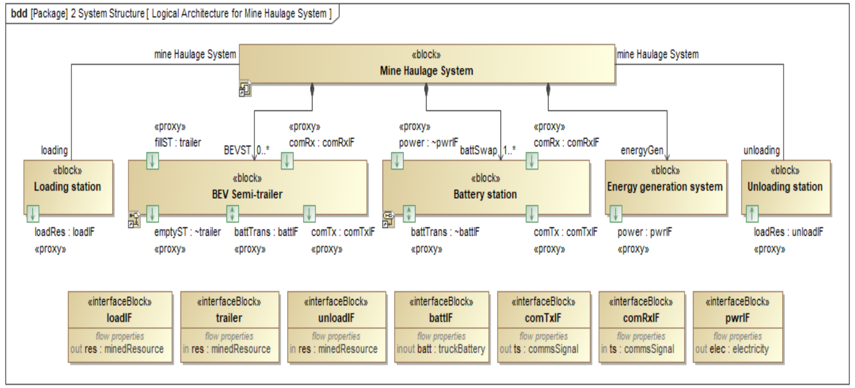
Electric

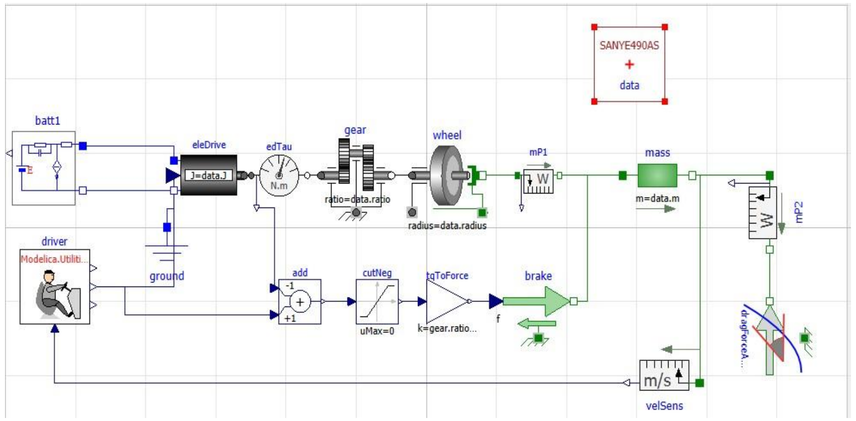
Initial Testcase: Mine to Port Haulage

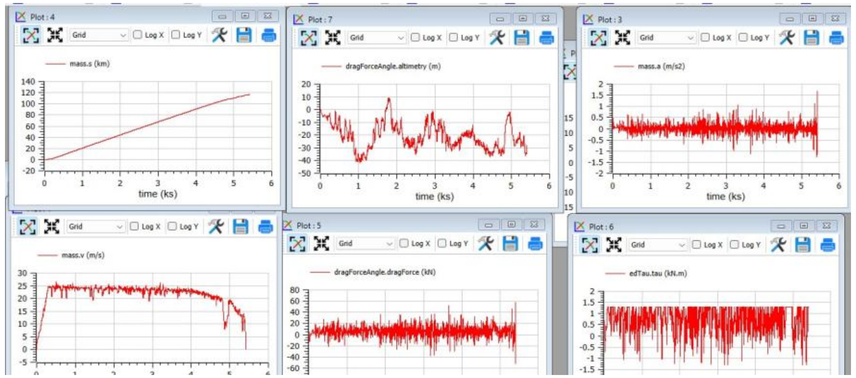


Modelling & Simulation

- Systems Engineering
  - Whole-of-capability consideration
  - Identify and manage the risks and opportunities
- Digital Engineering based Modelling & Simulation
- Analyse many ideas at low cost







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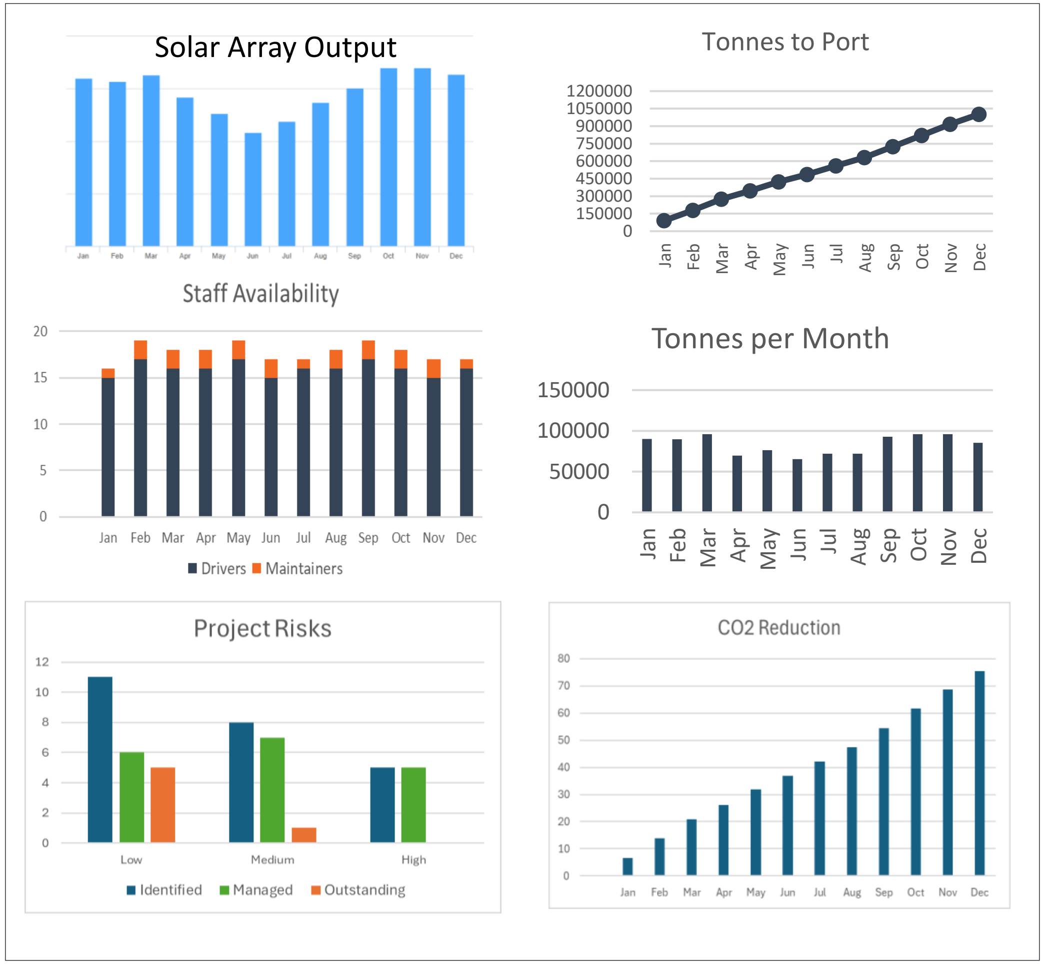
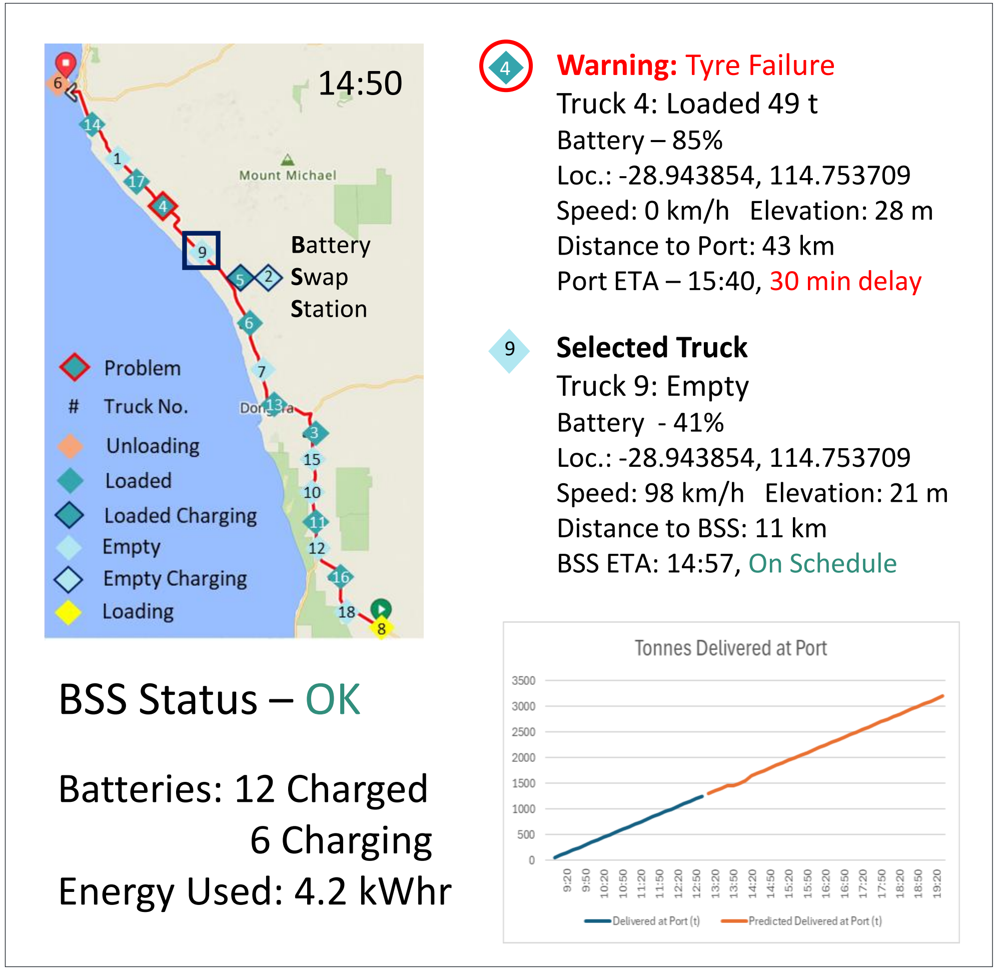
Tailored Visualization of Results



Predictive Mine Operations Dashboard to Underpin Investor Decision-Making



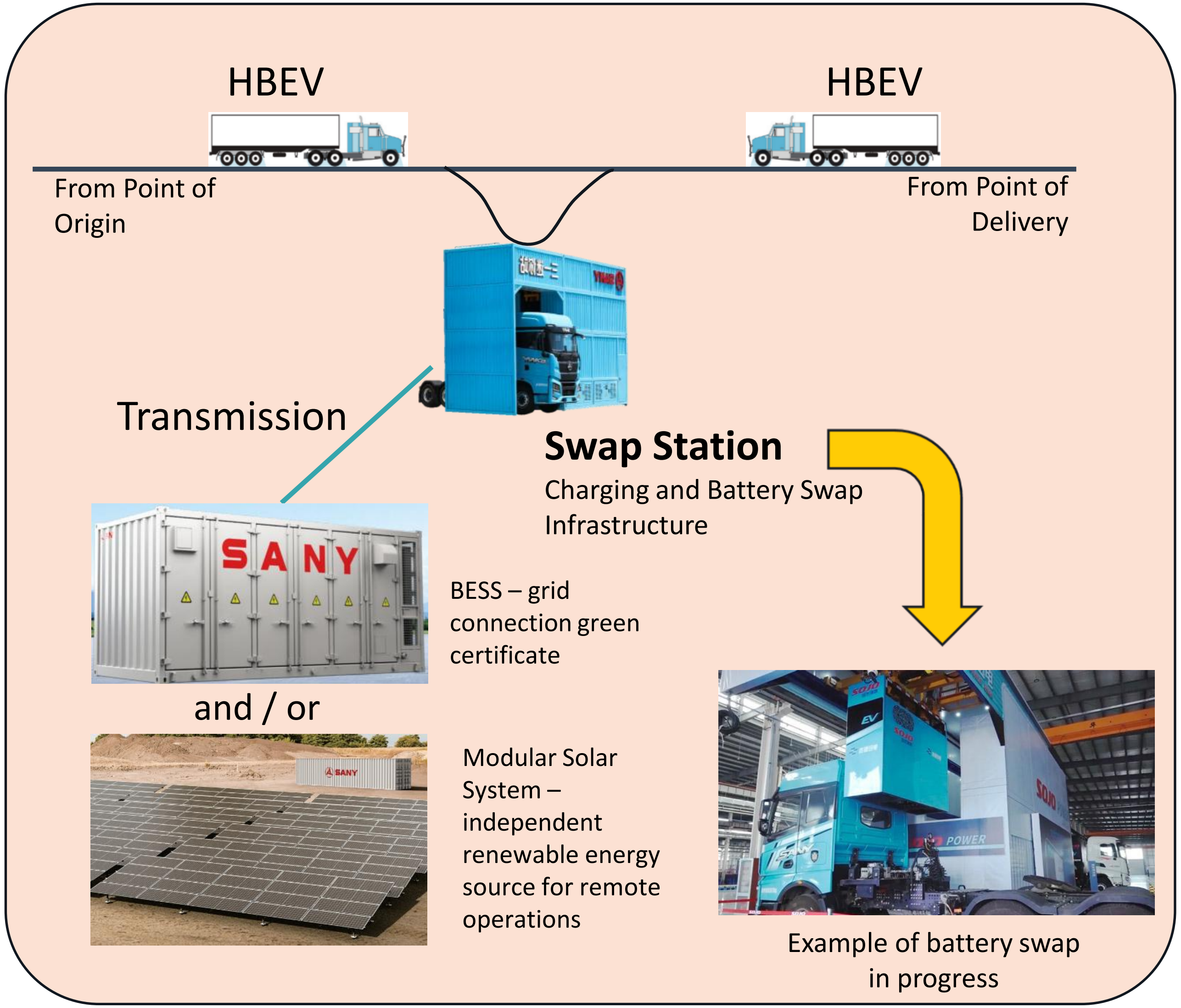
Simulation to Shape Mine Haulage Real- Time Operations Dashboard (concept)

Findings - Mine to Port Haulage Testcase

Application of Mission Engineering	✓ Useful in focusing efforts on key operational outcomes, then solution options
Application of Enterprise Architecture Modeling	× Limited due to time constraints. Basic architecture developed primarily to support pilot M&S.
Application of executable MBSE + physics-based modeling	✓ Developed a set of MBSE and Modellica modules for BEV haulage simulation. ✓ Demonstrated concept feasibility × Development time much greater than anticipated – no existing DE library modules

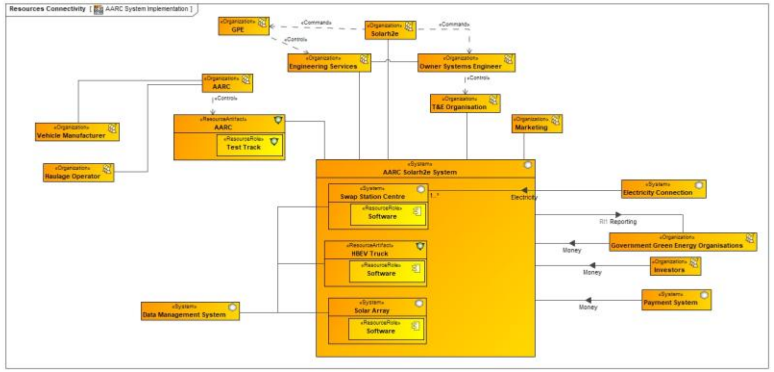
Decarbonized Intra-City Haulage: Solarh2e

- BEV haulage with fast battery exchange – SANY
- Australia's first electric freight corridor between Melbourne and Sydney
  - 900 km or 560 miles
- To be expanded to other cities and regions over time

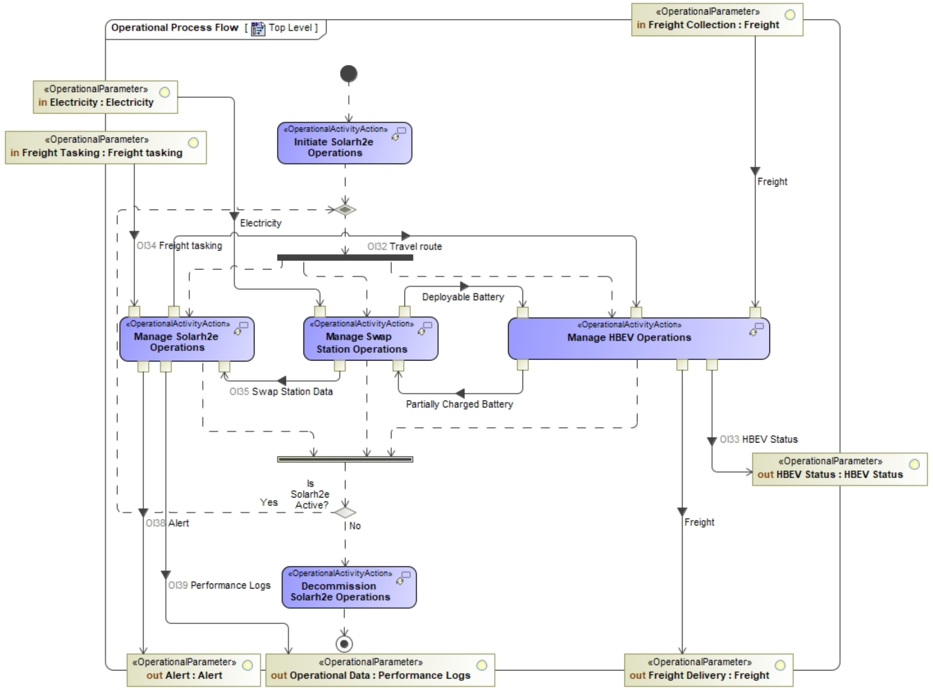


Analysis of Solarh2e

- Feasibility & Concept analysis
  - Many options considered
  - Shaped project way forward
- High-level modelling
  - MS Excel based
- Deeper modelling
  - UAF based
  - Modular design



OT&E implementation



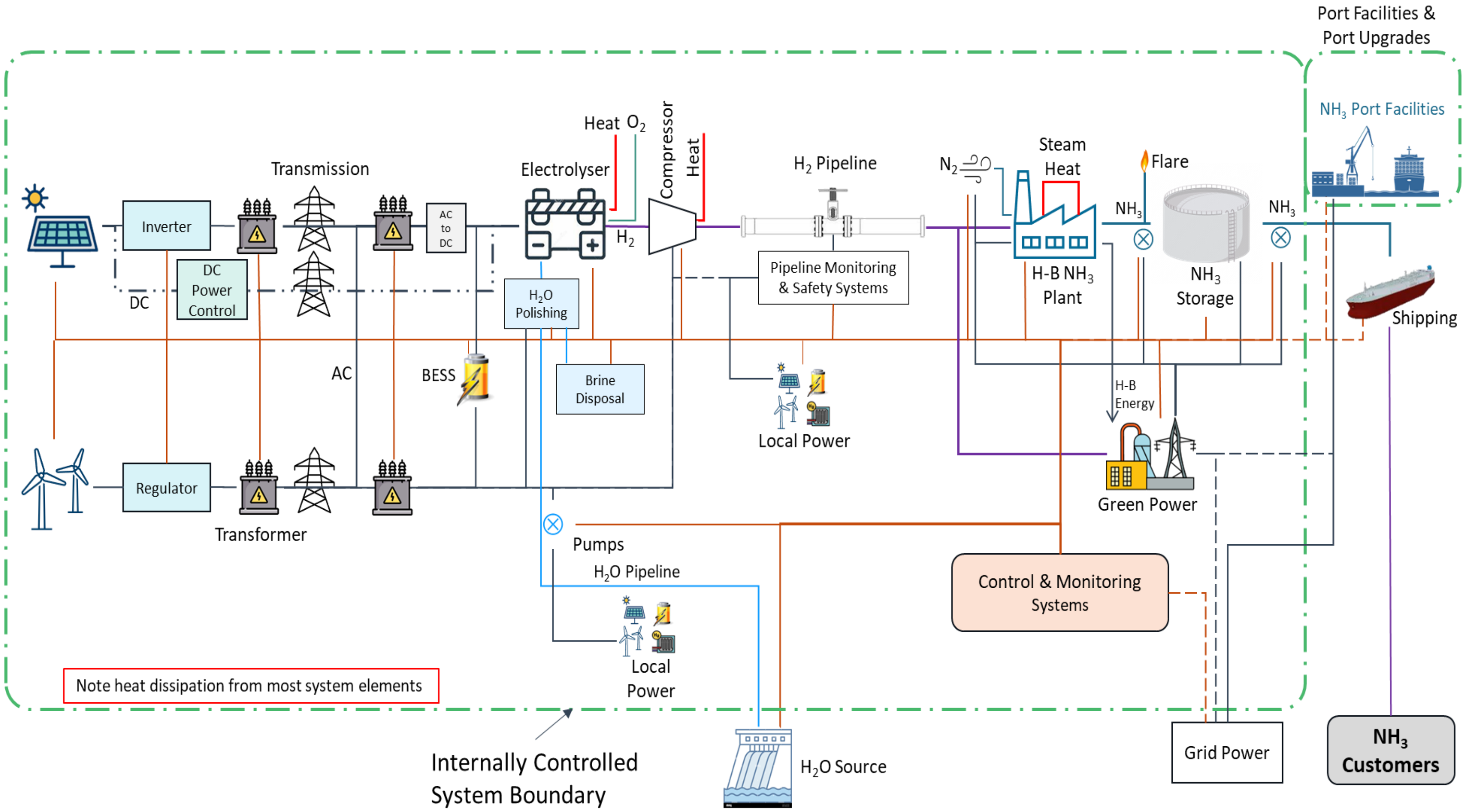
Battery swap model

Findings to date - Intra-City Haulage

Application of Mission Engineering	✓ Leveraged internally developed UAF EA+ME frameworks ✓ Useful in focusing efforts on key operational outcomes, then solution options
Application of Enterprise Architecture Modeling	✓ Useful (to date) in identifying broader requirements, interfaces and dependencies (e.g. energy network, legal/regulatory, finance, organisations, personnel, social licence) ✓ Developed internal proficiency in UAF
Application of executable MBSE + physics-based modeling	✓ Early days, however tracking for successful re-use of BEV haulage simulation modules.

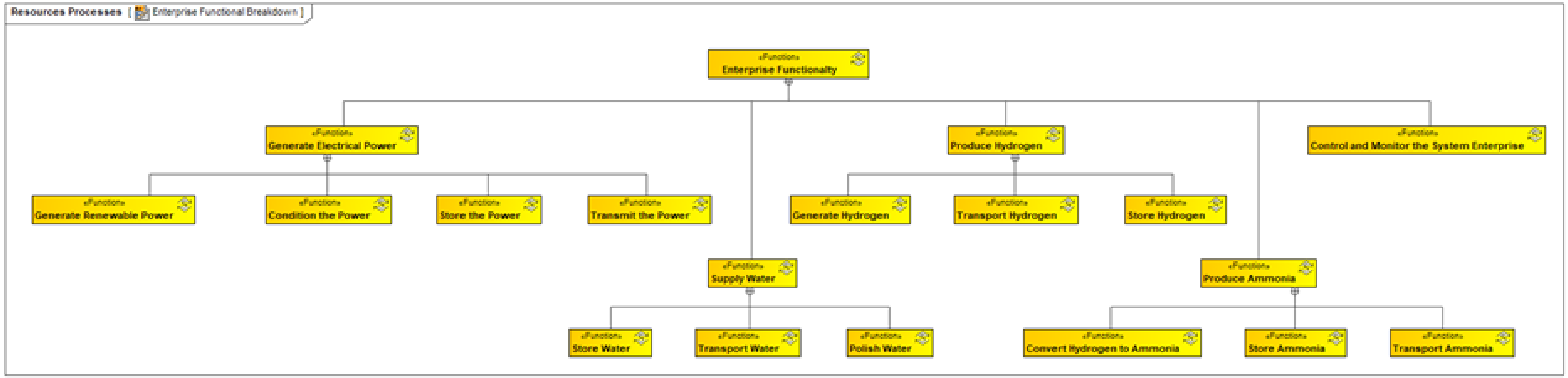
Analysis of Large-Scale Hydrogen & Ammonia

- Large scale green energy project
- Solar and Wind energy
  → Hydrogen
  → Ammonia
- Ammonia for export



Analysis of Large-Scale Hydrogen & Ammonia

- ‘Owner’s SE’ role – quality assurance
- Engaged in concept stage to support technical risk management
- Underpinned by DE-based analysis
- UAF enterprise model and suitably detailed analytical models
- Risk and opportunity analysis
- Sensitivity and trade-off analysis
- **Provided a range of key insights**



Top level functional hierarchy

Findings - Large-Scale Hydrogen & Ammonia

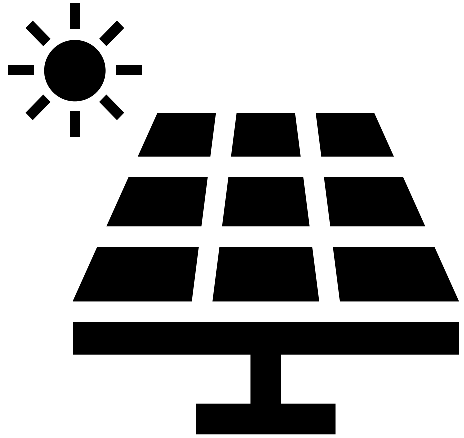
Application of Mission Engineering	• Limited, focused on high-level process modelling
Application of Enterprise Architecture Modeling	✓ High-level architecture developed to support assurance. ✓ Appropriate level for pre-FEED stage
Application of executable MBSE + physics-based modeling	✓ Some prototype process modules developed • Simpler analysis approaches employed

Insights and Conclusion

Lessons from initial application of modular DE approach

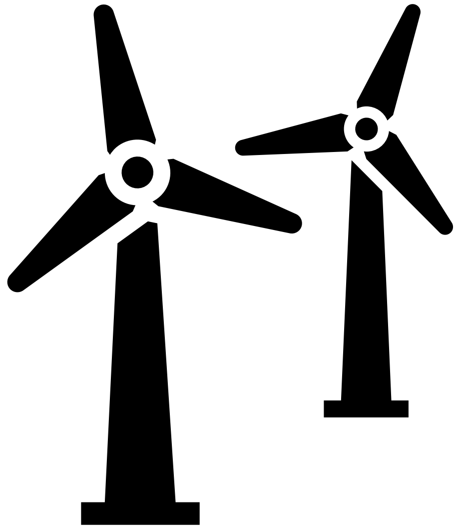
Overall Insights

- SE based modelling and analysis enhances investor confidence
- Lessons from modular DE modelling and analysis
  - Effort aligned with the project stage
    - Early stages – design held in MBSE loosely coupled with analysis & modelling
    - Later stages – stronger coupling between more stable architecture and analysis
  - Simplest approach possible
- Initial work has shown the potential of a modular approach to enable an SME to deliver cost effective support to complex energy projects



Conclusion

- Multitude of CED systems and projects
  - ~ $100s billions to trillions over next 25 years
- Critical to understand the risks and opportunities
- **SMEs have an opportunity to support and de-risk these projects**
- **Shoal has developed an austere DE approach for CED systems**
  - Combines MBSE, analytical modelling, plus OR
  - Modular design
  - Keep modelling as simple as possible
  - Development environment
- **Enables cost effective DE support to CED projects at SME scale**



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Questions and comments

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