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STEP towards Model-based: Case Study covering Conceptual Design of a Fusion Power Plant

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Presentation Overview

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- Project Introduction
- MBSE Methodology Overview
- Capella Model Overview
- Capella in Systems Engineering Processes
- Model Status
- Modelling Challenges
- Next Steps

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STEP (Spherical Tokamak for Energy Production) Why? What? When?

Changing climate
What does it mean for the world's energy use?

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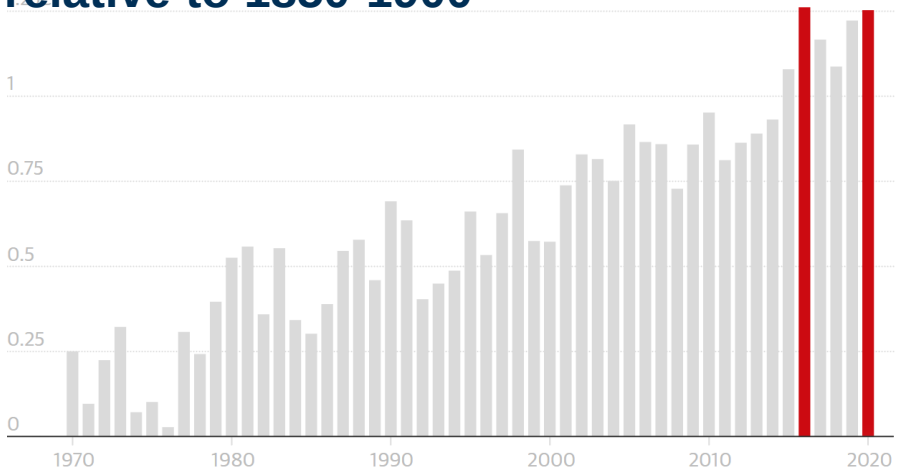
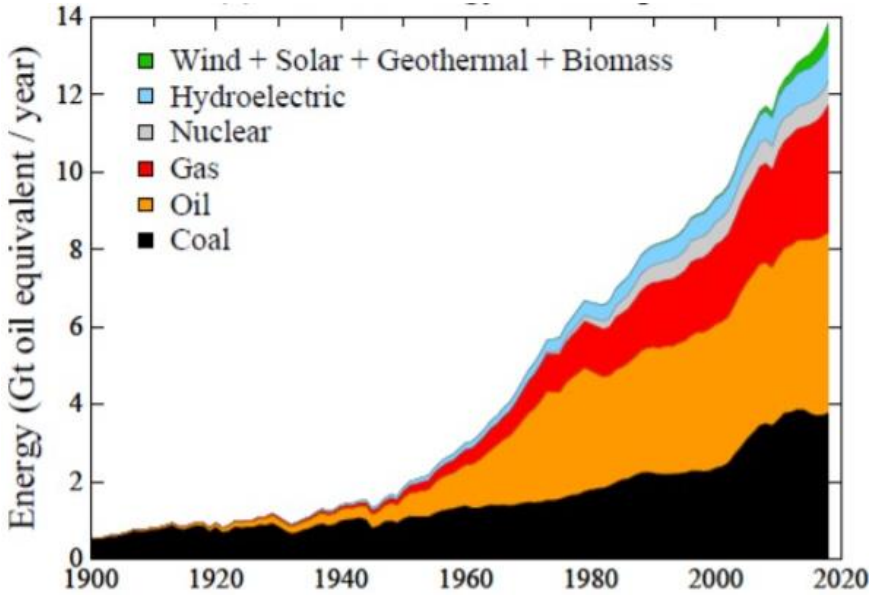
Average global temperature (Celsius) relative to 1850-1900



Source: Copernicus Climate Change Service

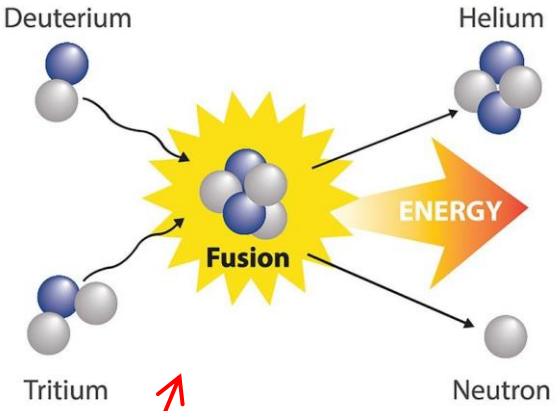


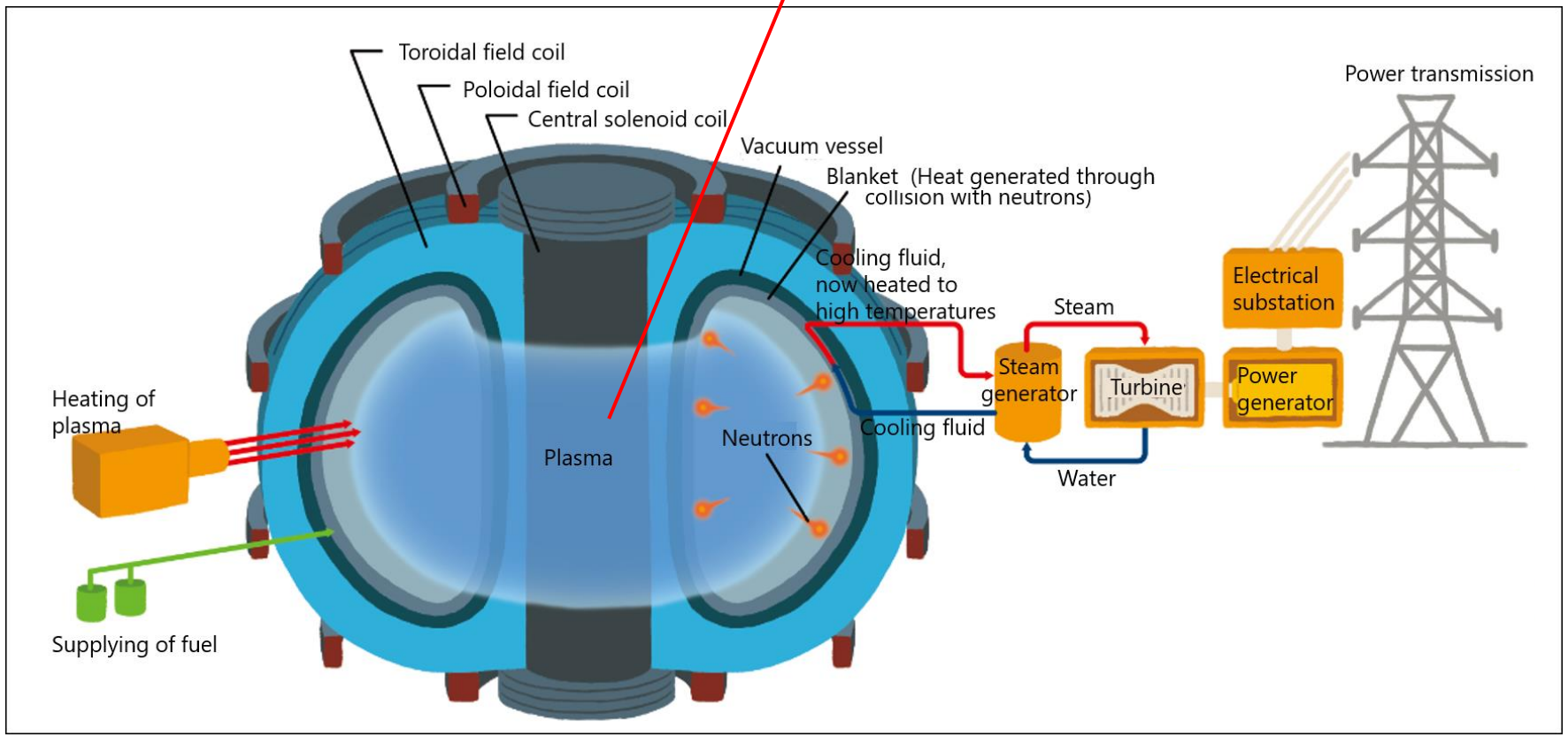
~11,000 days to 2050; ~11,000 Mtoe to displace*

This is equivalent to one nuclear power station per day, or the largest offshore wind farm in the world per day, every day, for 30 years

Needs ~£10Bn per day, which is ~4% global GDP

What is fusion?





Government is backing fusion development

“The UK is a world leader in the most promising fusion technologies with research capabilities across the technical challenges of fusion. The government has already committed over £400 million towards new UK fusion programmes. The aims are to develop a concept design for the Spherical Tokamak for Energy Production (STEP) – expected to be the world’s first compact fusion power plant, to be built in the UK by 2040 – and to invest in facilities and infrastructure to make the UK a global fusion industry hub.”

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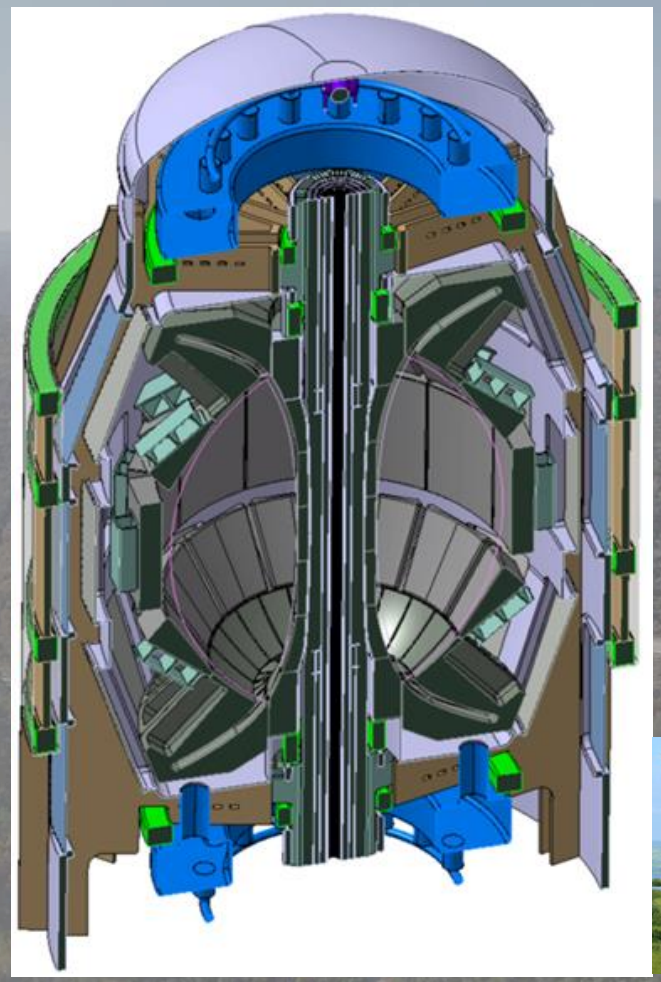
Deliver a UK prototype fusion energy plant, targeting 2040, and a path to commercial viability of fusion.

STEP mission

Deliverables



A physical STEP Prototype Plant (SPP), on a large scale industrial site

A Digital Twin

A “design recipe”, fully documented

Justification for fusion energy

An approved safety case

New codes and standards

IP portfolio

A developed supply chain, able to deliver commercial plant and, for the UK, compete internationally

Value from the investment delivered consistently through the programme

The capability to deliver commercial plant

STEP high-level schedule

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Concept (till 3/24)

- Concept / Reference Plant Design
- Programme Development
- Site selection
- Transition to Target Operating Model

Detailed Design and Mobilisation

- Engineering Design
- Long lead procurement
- Early Manufacture
- Site development

Main Construction

- Full plant manufacture and assembly
- Full site development
- Equipment and system testing

Commissioning and Operations

- Non-active and active commissioning
- Prototype ops

A STEP up the mountain

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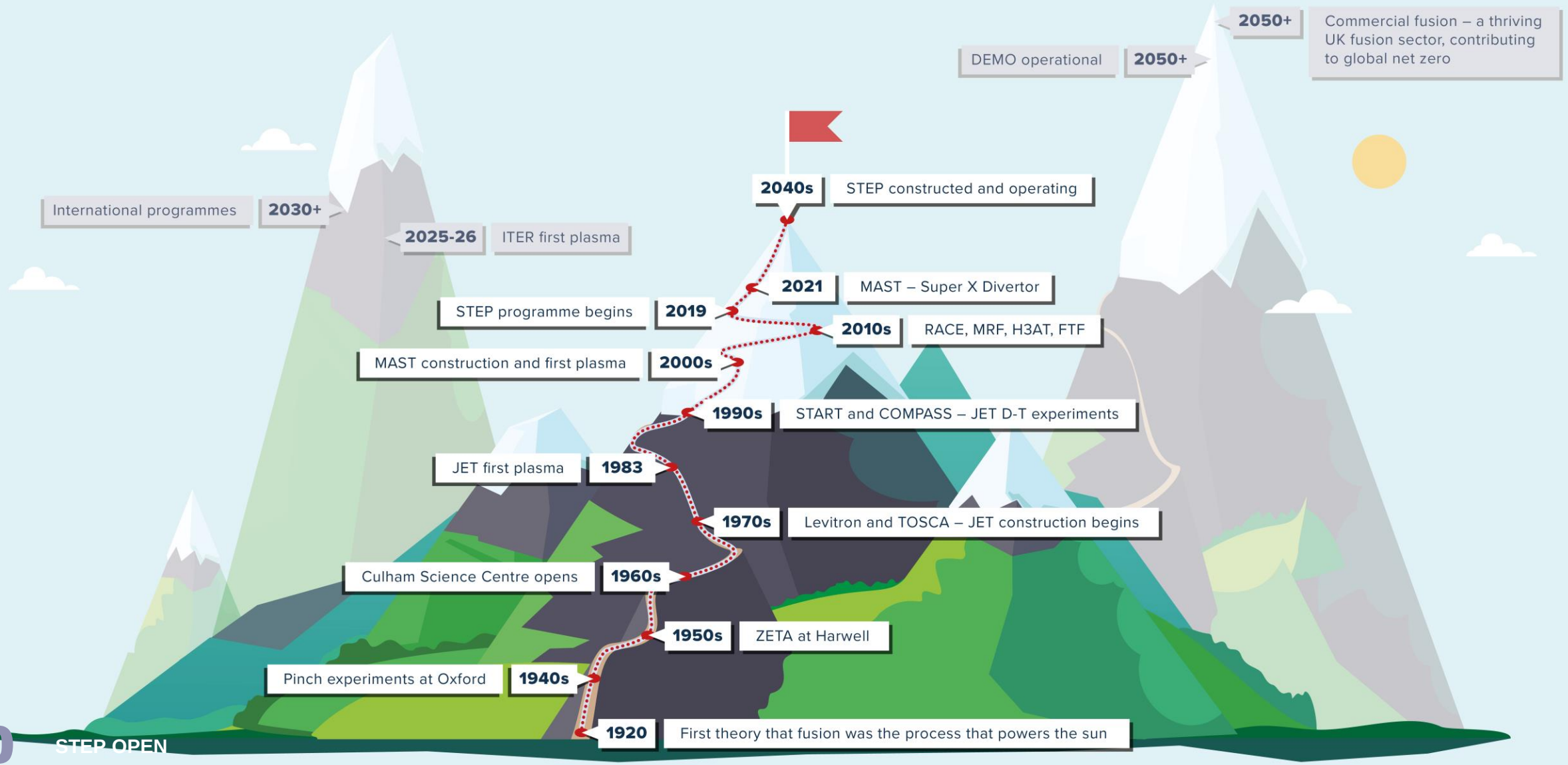

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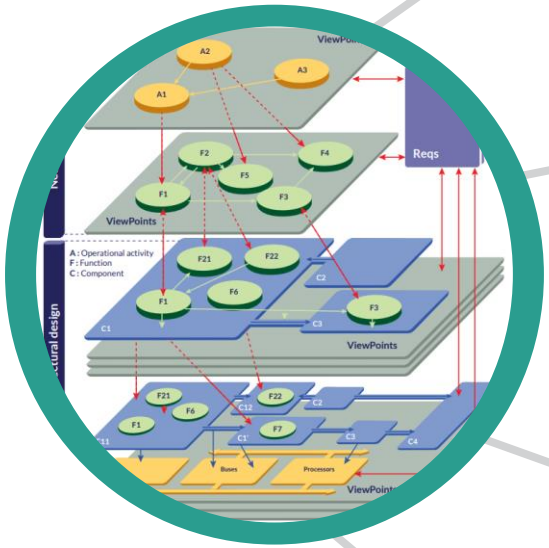
MBSE Methodology Overview

How does MBSE / Capella support STEP?



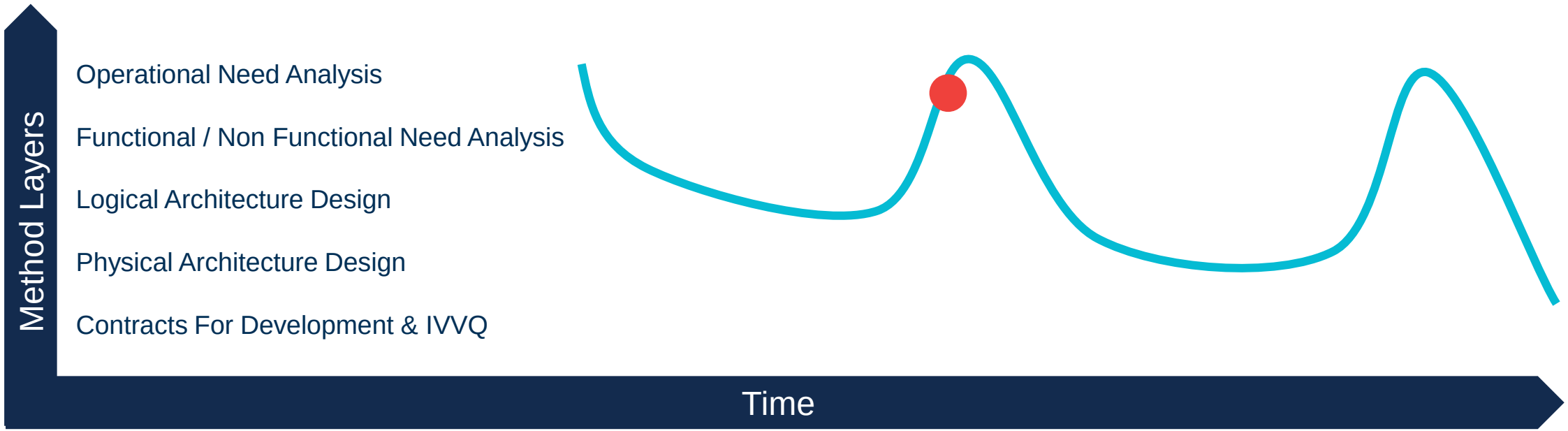
Communication
- Helping to onboard new starters
- Bringing development partners/suppliers up to speed quickly

Interface Management
- Capturing, controlling and communicating information at interfaces
- At each level of system decomposition e.g. external stakeholders to system boundary, subsystem-to-subsystem
- Help to provide a context for decision making

Requirements Development
- Assist in developing a complete and consistent set of requirements
- Helping to provide traceability from stakeholder objectives through to components in physical architecture

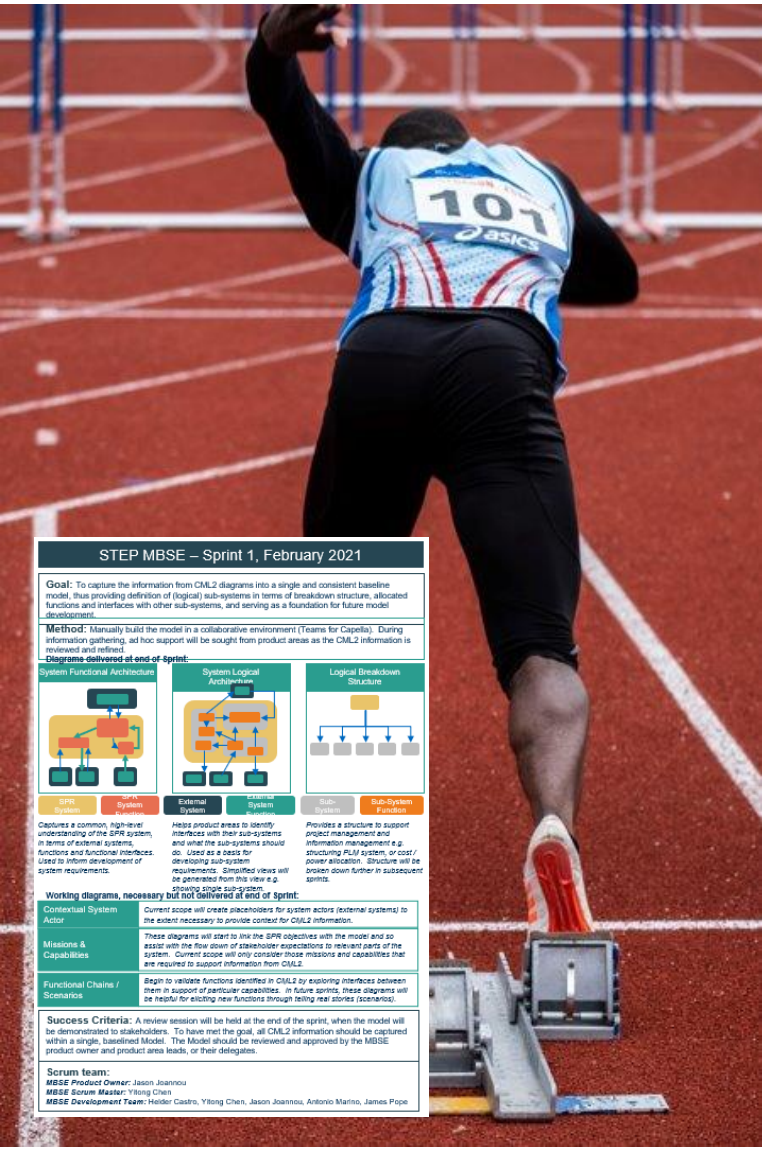
Provide an Information Framework
- Tracing system structure (e.g. PBS) from model to PLM system
- Informing and being informed by analytical models
- Digital twin, fully documented

Our Approach



- Adopting an iterative top-down approach
- Majority of time to date has been spent on the Logical Architecture Layer. This has allowed engagement with the Product Areas.
- Currently starting to go back down through the layers again, knitting together the new functions between layers, and then defining the Physical Architecture as design decisions are made.

Our Approach



Adopting an agile approach, building the model incrementally in series of sprints

Need to work with people who have the domain knowledge so that the model becomes an authoritative source of truth

Mentoring and guidance from Capella experts

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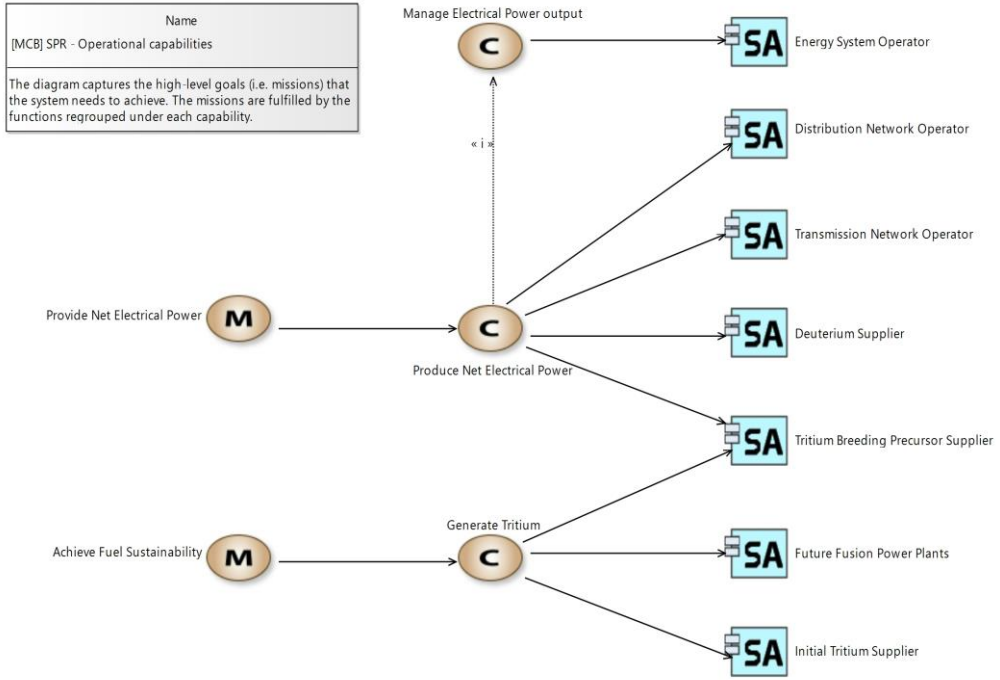
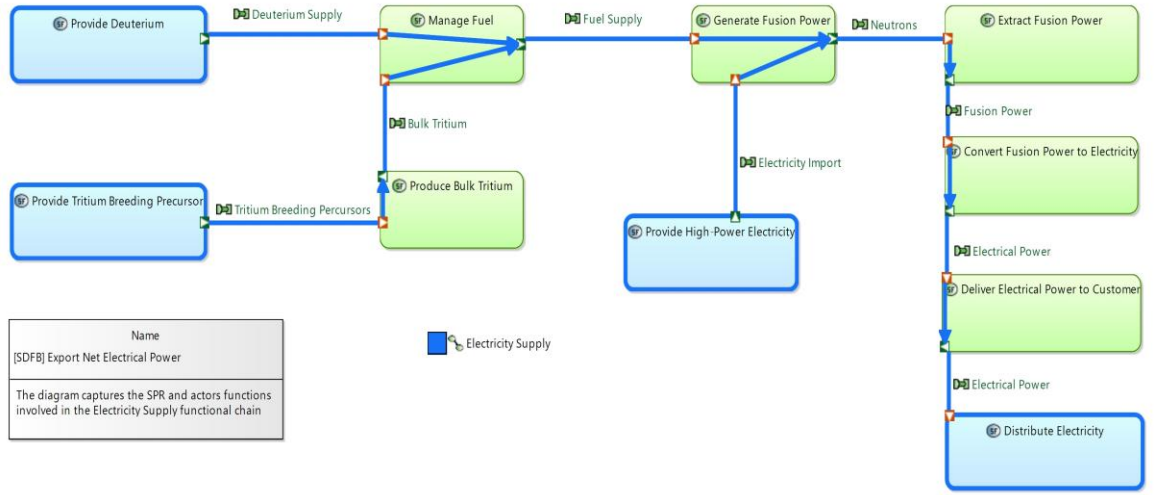
Model Overview

System Analysis

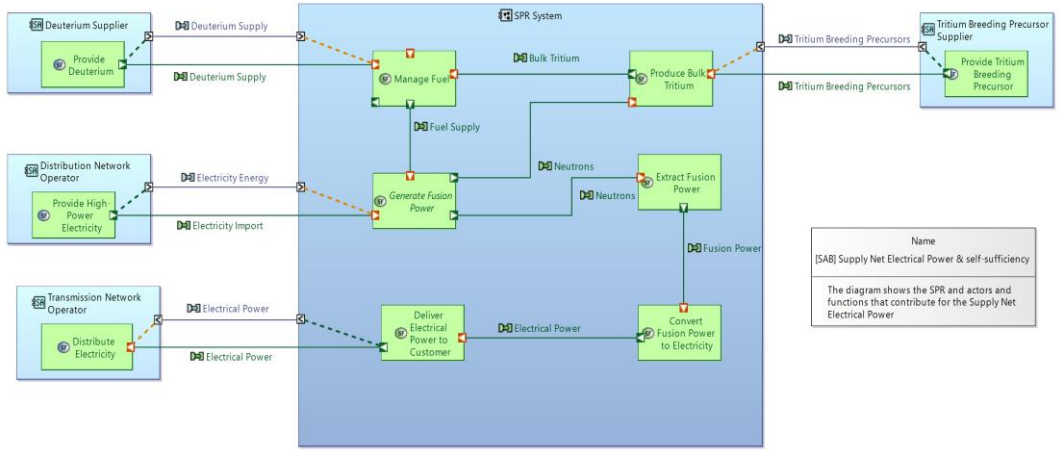
Views Used:
Function Scenario
Mode State Machine
Contextual System Actors
Missions Capabilities Blank
System Architecture Blank
System Data Flow Blank
System Function Breakdown



System missions and capabilities



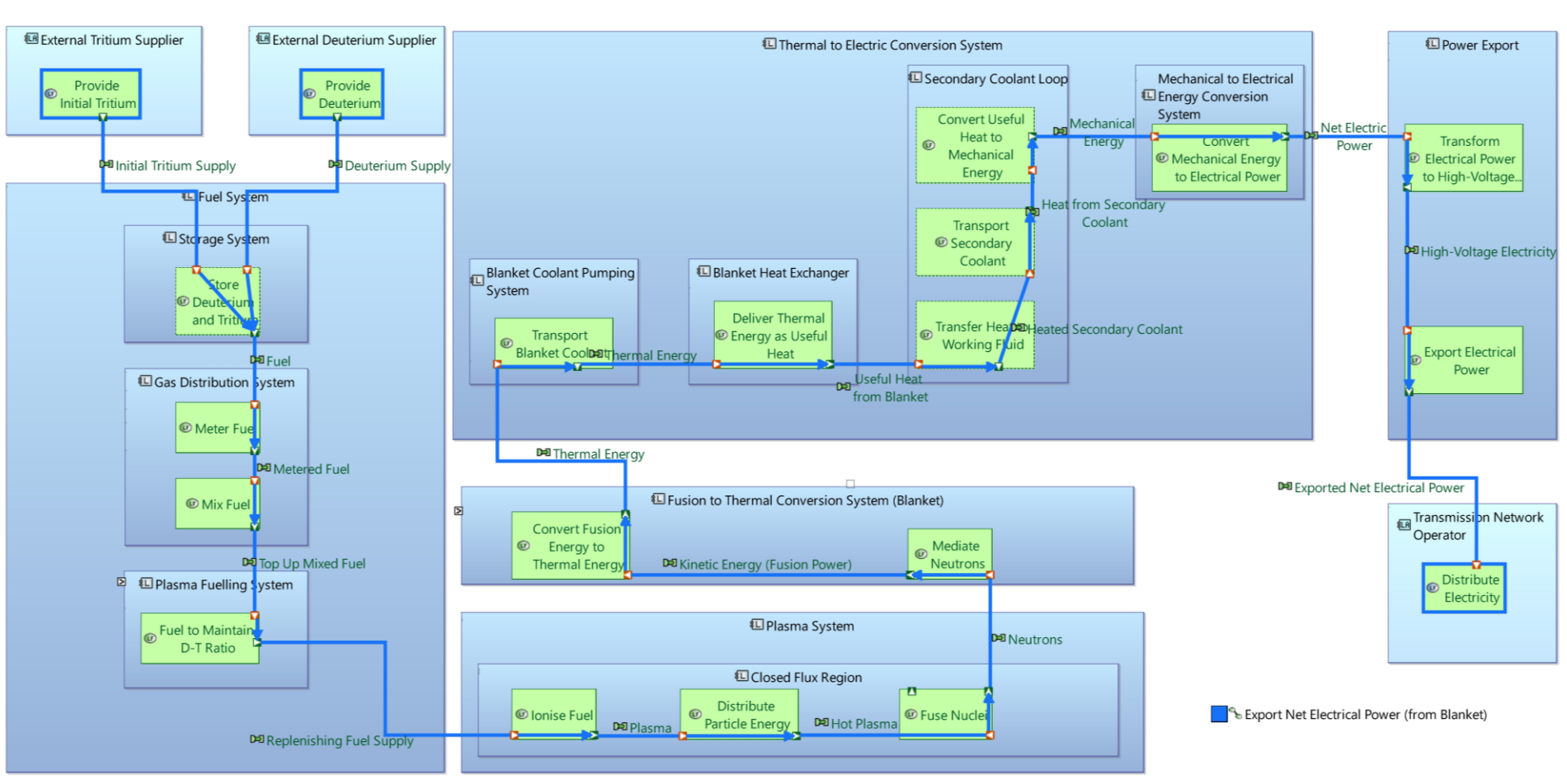
System data flow view on Electricity Supply functional chain



System architecture view of STEP power plant

Logical Architecture

Views Used:
Logical Architecture Blank
Logical Component Breakdown
Logical Data Flow Blank
Logical Function Breakdown



Logical architecture view of allocation of Export Net Electrical Power functions to logical components

Operational Analysis

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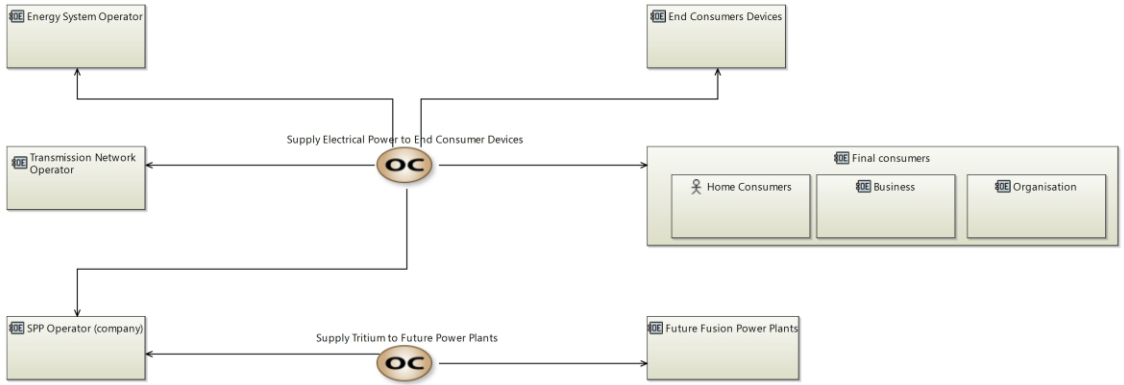
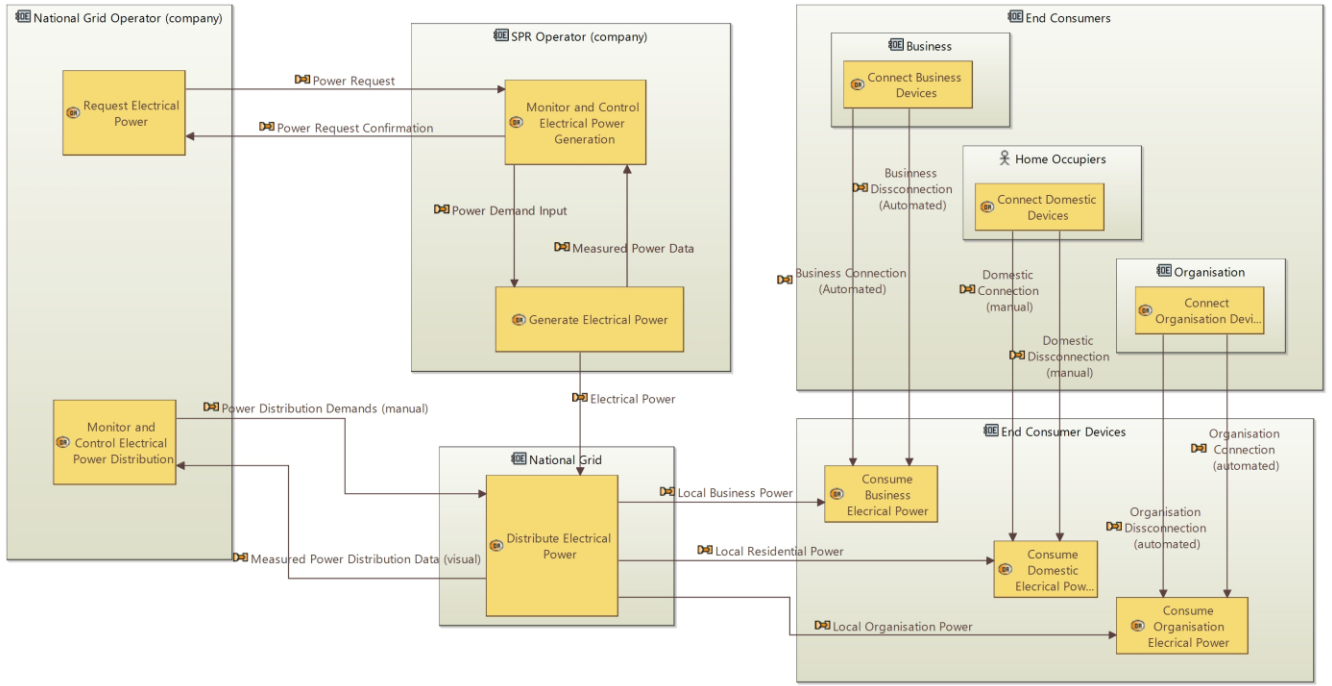
Views Used:
Operational Activity Interaction
Operational Capabilities
Operational Architecture
Operational Entities Breakdown

Iterative approach between layers

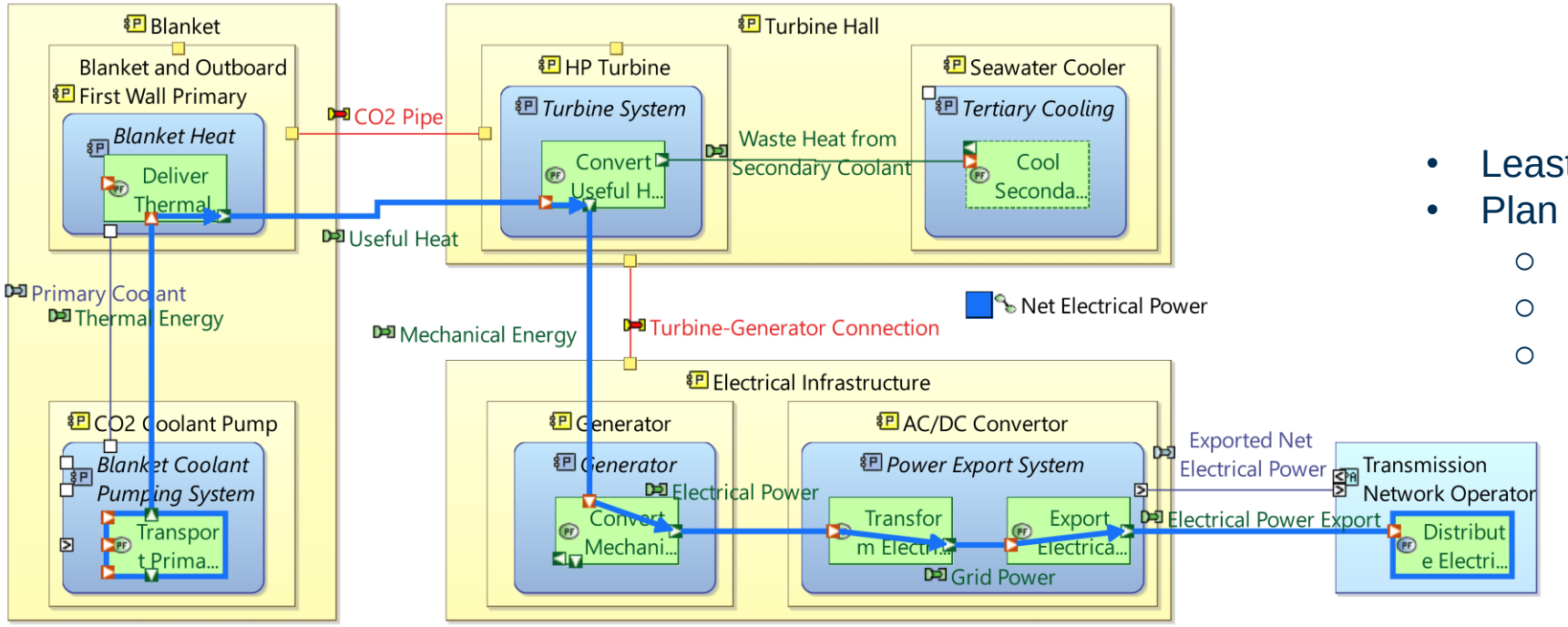


Operational capabilities view



Operational architecture view on energy production

Physical Architecture



Physical architecture view of thermal to electric conversion subsystem

- Least mature layer
- Plan to populate:
  - Physical Architecture Blank
  - Physical Path Description
  - Physical Component Breakdown

Model Metrics

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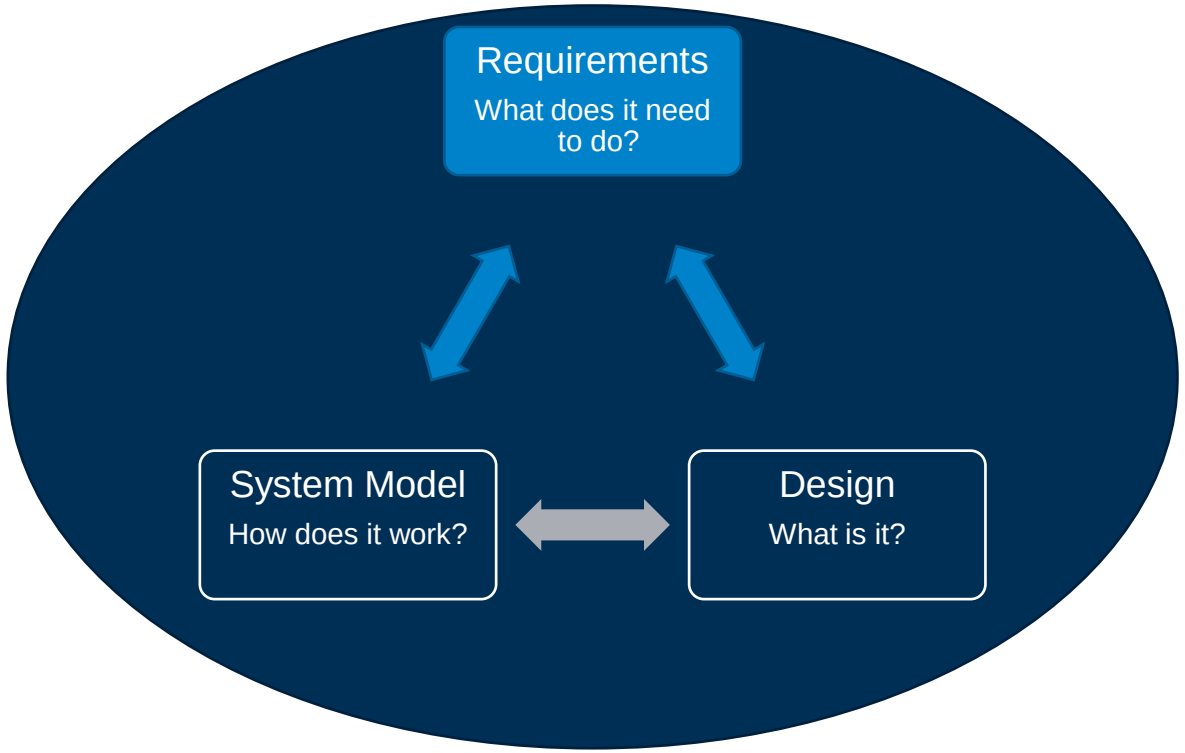
System Analysis Metrics

Model Element	Number
System Function	70
System Component	20
Mission	8
Capability	22

Logical Architecture Metrics

Model Element	Number
Logical Function	257
Logical Component	196
Functional Exchange	203
Component Exchange	156
Functional Chain	8

Requirements Approach

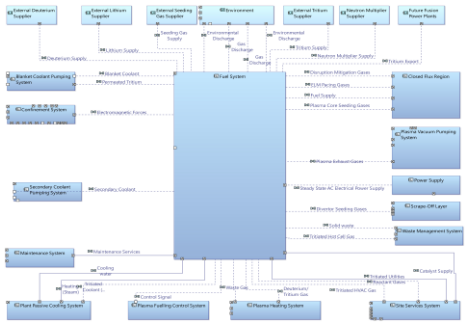


- Model has been useful in eliciting requirements.
- **Requirements Viewpoint** add-on used to link to textual requirements.
- Exploring option to use the model to express requirements

Interface Management

- Clear understanding of interfaces is needed, where interface documents are exported from the model (at logical architecture)
- So far, interface document generated for 9 subsystems.
- PVMT used to describe interfaces.

STEP ICD template



Capella Architecture
(LAB – Context Diagram)

M2Doc

2.2 Interface Summary

2.2.1 Interfaces with Blanket Coolant Pumping System

Name	Type	Interfacing Component	Linked Child Logical Component	Direction	Property Values
Blanket Coolant	Fluid	Blanket Coolant Pumping System	Blanket Coolant Detritiation	INOUT	Mass Flowrate: kg/h Composition_T: mol% Temperature: deg C Pressure: Pa
Permeated Tritium	Fluid	Blanket Coolant Pumping System	Tritium Breeding System	OUT	Permeation Rate: g/h

Model-based ICD

Support to CML Process

Concept Maturity Level (CML) process from NASA is adopted and tailored on STEP to guide the expectations of the concept phase.

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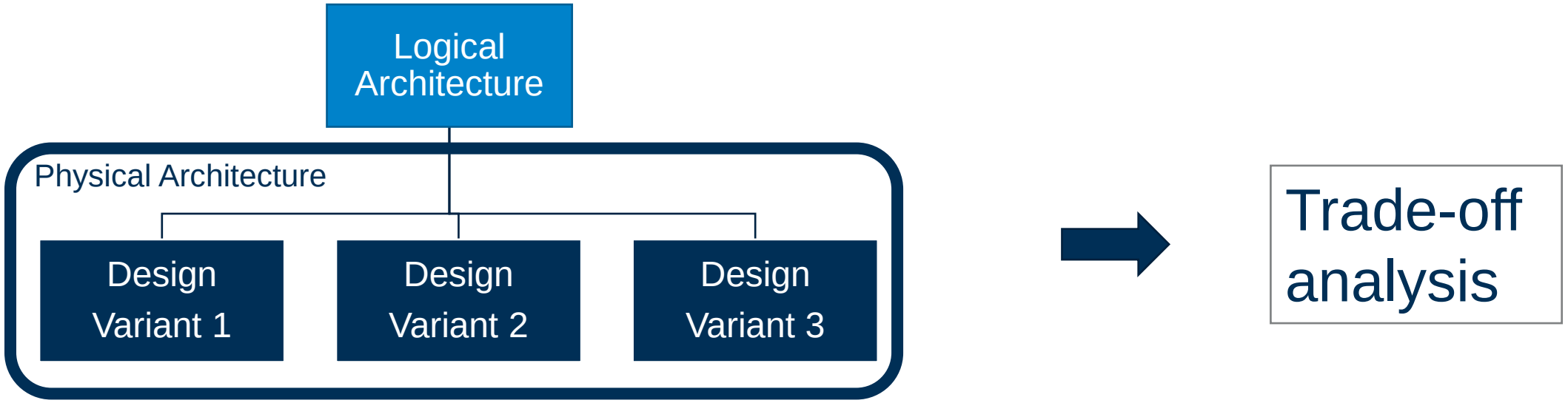
Challenges & Feedback

Challenges: Variant Modelling & Trade Studies

- At concept phase we are evaluating many architecture options
- Currently there's no standardised way to generate variant physical architecture candidates whilst maintaining traceability with high-level logical architecture
- Lack of tools to link to simulation
- Options explored so far are: Pure Variants, Fragmentation, System to Subsystem Transition



Specifying the trade-off analysis problem in MBSE model

Other Modelling Challenges/ Learnings

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- Engagement with non-modellers: articulate benefits of MBSE, help people understand the problem space (too much focus on physical)
- Arcadia method accommodates top-down approach, whereas STEP currently adopts middle-out approach. Transition from bottom to top layers is a manual process.
- Differentiation between different Arcadia layers: what level of abstraction is captured in the Logical Architecture VS Physical Architecture
- Change propagates to all other diagrams – Reformatting takes a significant amount of modelling time

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Next Steps

Next Steps

- Spent a lot of time in logical model. Want to iterate through top down process again. Knitting together more developed top levels with logical architecture
- Begin development of the physical architecture
- Building in maintenance and control concepts
- Linking with safety
- Move from ‘capturing’ to ‘driving’
- Start to integrate the model with the information framework that will be implemented in a PLM system
- Explore simulation

Q: What world-changing idea, small or big, would you like to see implemented by humanity?
A: **This is easy. I would like to see the development of fusion power** to give an unlimited supply of clean energy

Stephen Hawking, ‘Brief Answers to the Big Questions’, 2018

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Q&A

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