Developing an SMR for the Digital Century

JAIF 2018

Tokyo

10/04/18

Trusted to deliver excellence

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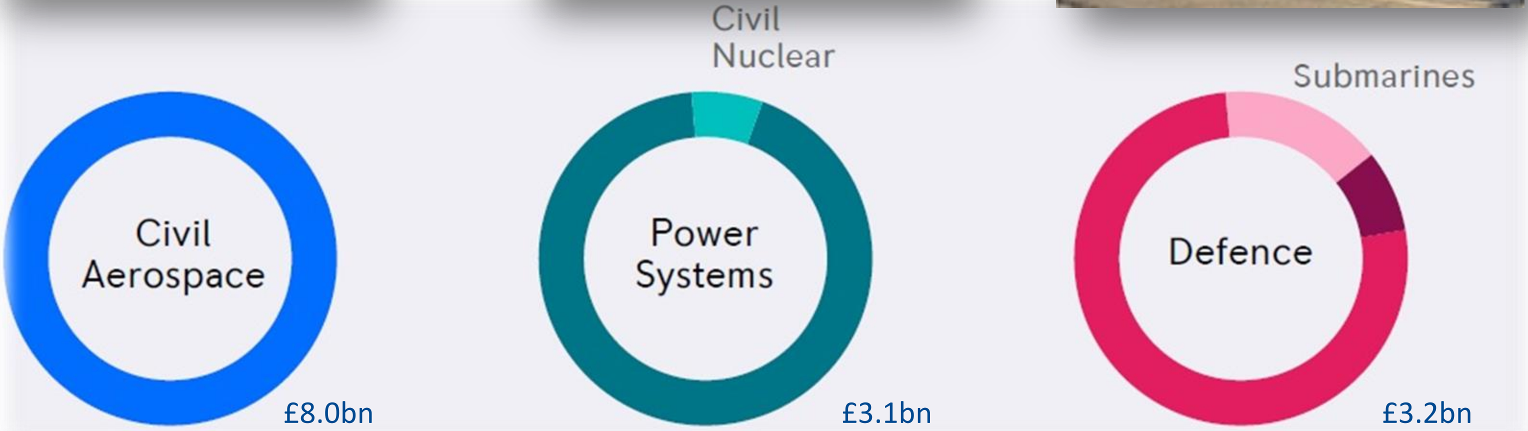
Our businesses



Nuclear Overview

Nuclear
(4100 highly skilled employees)

Defence Nuclear

Submarines

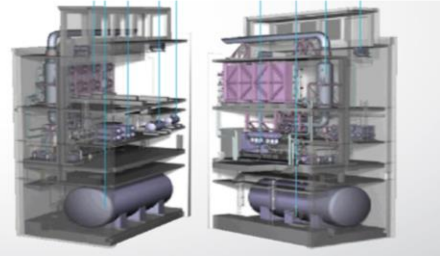
- Reactor plant design and supply
- Operation of licensed sites
- Fuel fabrication
- Through life services

Civil Nuclear

Instrumentation & Control

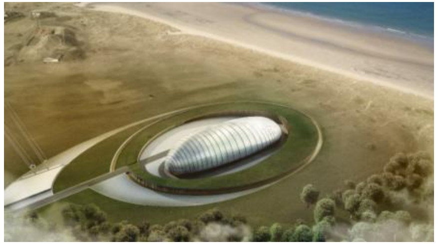
- Reactor Protection System
- Rod Control System
- Neutron Instrumentation System
- Plant Monitoring System
- In core Instrumentation Systems

Nuclear Services & Projects



- Emergency Diesel Generator System
- Waste Treatment Systems
- Services: inspection, Predictive Maintenance, Inventory management

SMR



- Design and development of SMR power station

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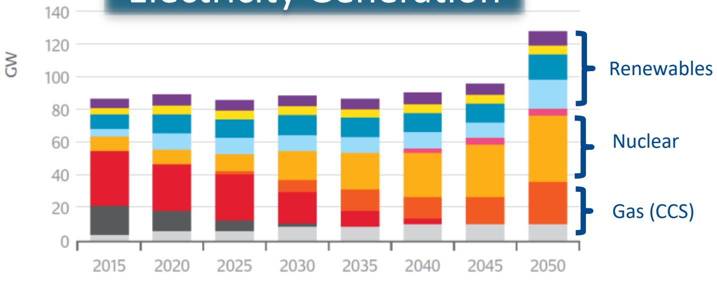
There is a clear demand for new low carbon electricity generation

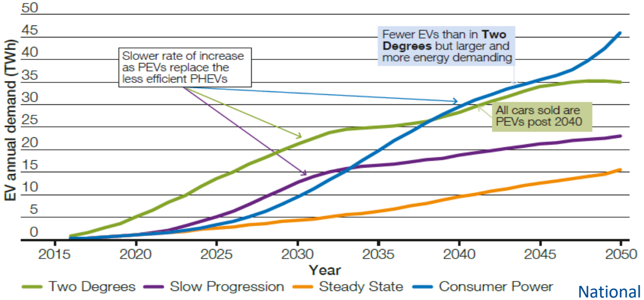
Greenhouse Gas Emissions

Electricity Generation



UK Energy Mix Clockwork Scenario (Installed Capacity) ETI, 2015

Figure 3.14
Annual demand from EVs



National Grid, 2017

Charging EVs

Heat Generation

Figure Two: Half-hourly GB electricity & low grade heat demand variation, 2010[1]

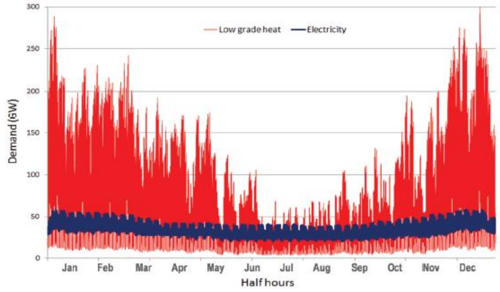
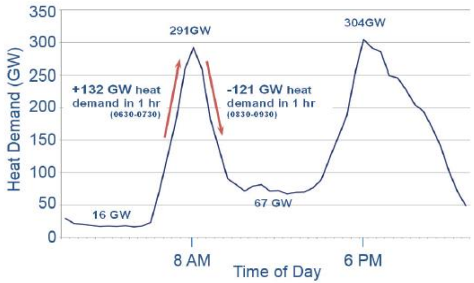


Figure Three: Winter Peak Heat Demand - 18th December 2010[2]



1 Half Hourly Electricity and Low Grade Heat Demand Variation 2010 - Robert Sansom, Imperial College.
2 Winter Peak Heat Demand - Data provided by Robert Sansom, Imperial College.

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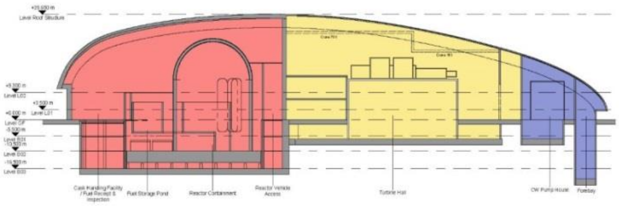
Principle considerations for Rolls-Royce SMR development

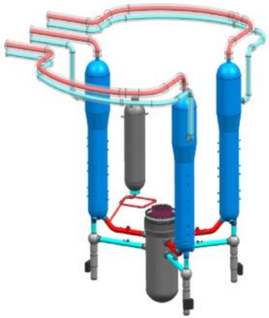
Must be commercially investible for utility operators (non-state backed):

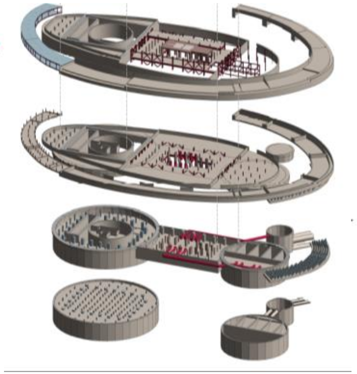
- SMRs must be capable of delivering affordable electricity
- Design for licensing, manufacture, construction, operation and decommissioning
- Construction methods (e.g. modularity) must address the high risk & cost areas (e.g. site activity)
- Must provide certainty of operation – i.e. Not be a constant FOAK
- Avoidance of large and expensive manufacturing facilities (need production line approach)
- Modularity is a solution not a driver and must be optimised

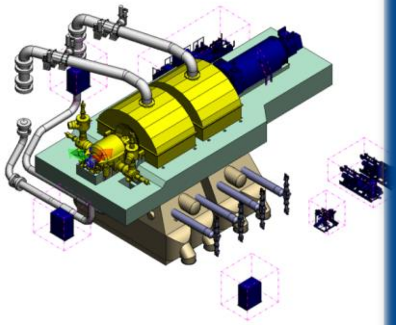
$$\text{Cost of Electricity (£/MWhr)} = \frac{\text{(capital + total O\&M + fuel costs + financing cost)}}{\text{Power Generating potential x Capacity factor}}$$

Requirements driven design promotes cost effective, safe solution









Design for Licensing

- Proven technologies where possible / low regulatory risk

Design for manufacture

- Simplification of manufacturing processes
- Optimise for production in controlled factory environments
- Account for facility and supply chain investments

Design for construction

- Remove site activity where possible (reduce risk)
- Reduce construction time and risk
- Road transportable modules to reduce time and risk
- Whole plant modular approach

Design for operation and decommissioning

- Maximum power for lowest cost
- Digitally enabled product

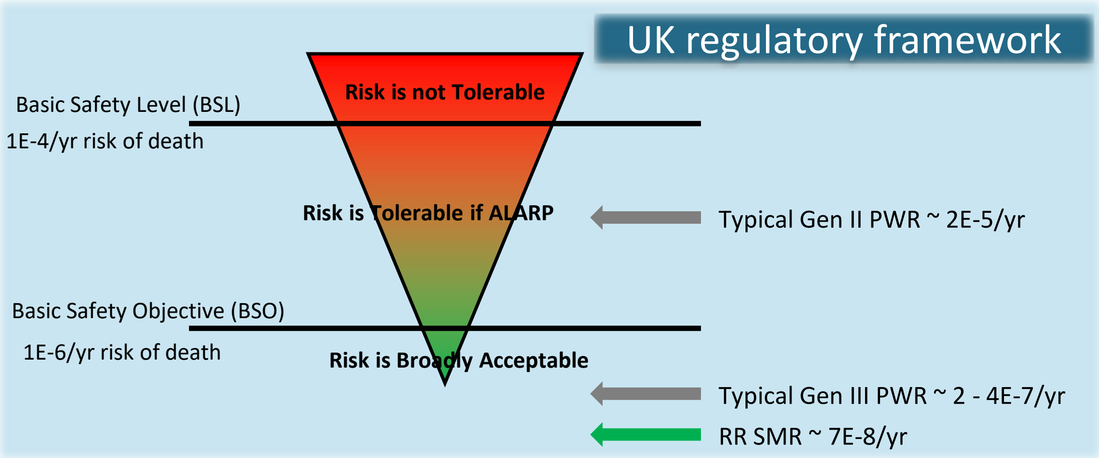
Safety through life is key to societal acceptance

Nuclear Safety

Conventional Health & Safety

Security

Environmental



ONR Office for Nuclear Regulation

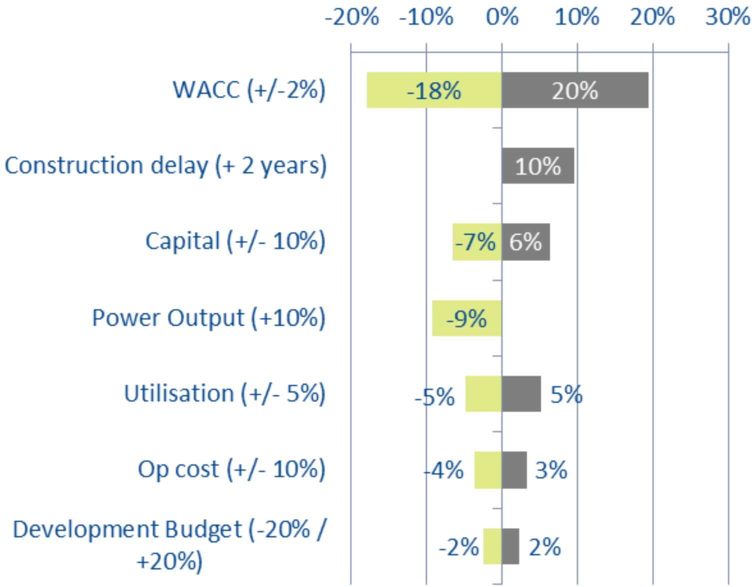
Environment Agency

HSE Health and Safety Executive

The business case is dominated by certainty of delivery

- Historically, nuclear reactors have pursued larger power output to gain economic benefits of scale based on:
  - Increased power per unit capital is a significant sensitivity to LCOE
  - Some operational costs are fixed and do not scale with power – greater power drives better economics
- However, this has been achieved at the expense of the major LCOE sensitivities:
  - Complexity of the build driving higher capital
  - Longer construction times driving higher total financed capital
  - Much higher risk profiles driving higher borrowing rate premiums
- This has subsequently driven an increased requirement for government intervention where financing is unavailable
- <u>Simplicity, short construction and programme certainty are therefore critical features of our SMR design</u>

LCOE sensitivity



Baseline £60/MWh based on 50:50 debt : equity ratio

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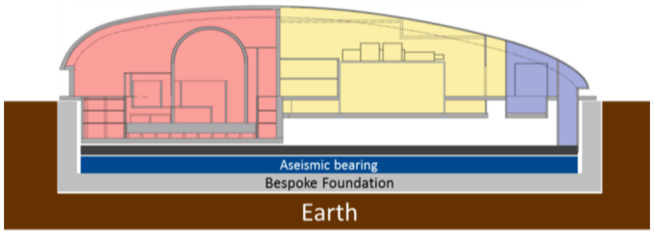
Build Certainty

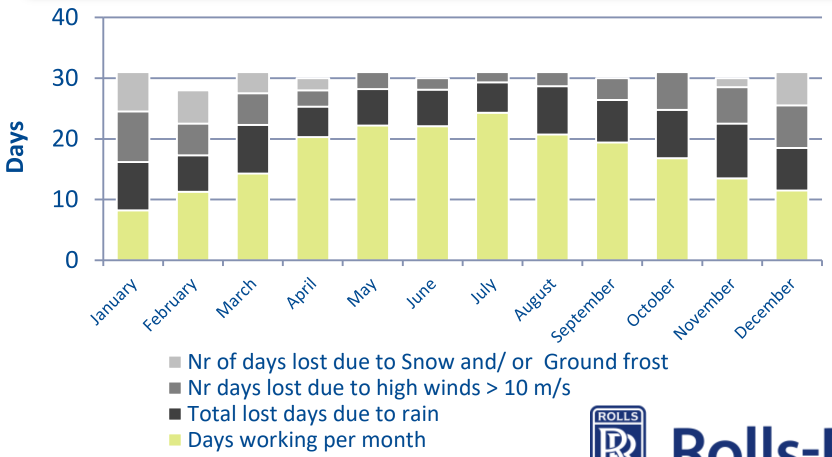
Rolls-Royce SMR site construction shelter

Rolls-Royce SMR two phase construction



- Every delay during construction is a significant additional cost
- Our SMR will be constructed in two phases;
  - Site groundworks and civil engineering to aseismic bearing
  - Standardised modular assembly of the power station – off-site manufacture of systems and components
- Both phases conducted under cover, isolation from weather conditions

Average weather assessment at Wylfa - September 2014



Build Certainty

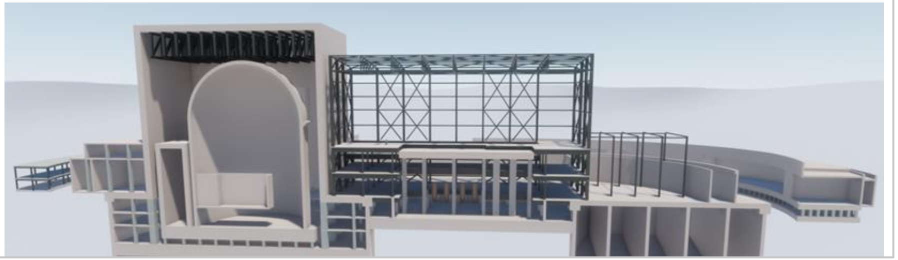
- Certainty around a short construction period is essential:
  - *We are allowing 7 years for the first unit to prove the construction sequence*
- Learner curves will provide NOAK timeframes of:
  - *2 years site preparation and seismic raft*
  - *2 years ‘factory project’ of module delivery, installation and test*
- Our design is aimed at introducing innovative financing options / construction models
- We have options such as splitting the project into 2 phases to prevent allocating higher costs of capital to lower risk, factory delivered product

Project 1: Ground works and laying the seismic mat:

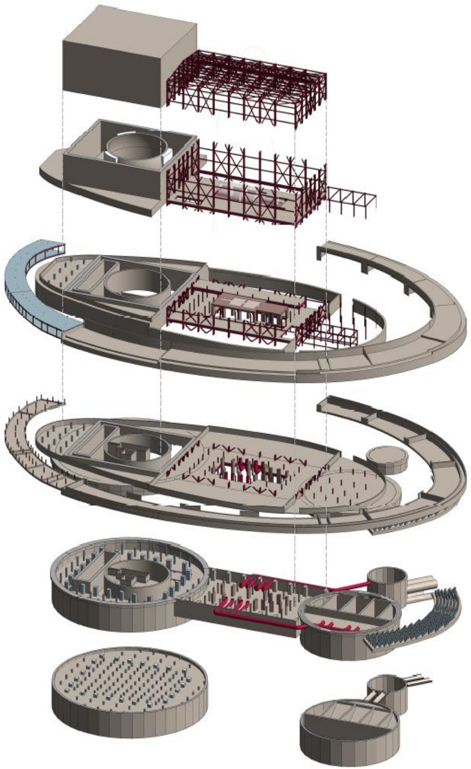
- ~£250M, 2 year duration
- higher risk project due to uncertainties with site and ground conditions

Project 2: Module delivery, installation, and test

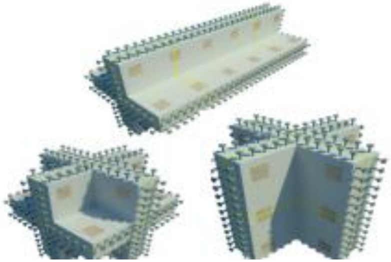
- ~£1,250M, 2 year duration
- Commons modules independent of site (insulated from site conditions)
- Factory produced assembly line plant and machinery
- Civil modules included from civil module facility

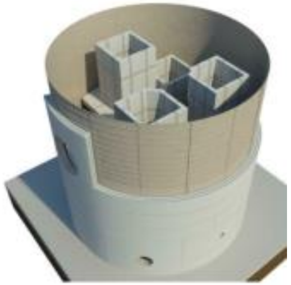


Digital Construction



- Modular approach to construction reduces , capital cost, construction period and risk profile (site to factory for civil structures)
- Therefore cost of financing is reduced
- Modular installation of steel containment
  - *internal structures (Primary circuit supports) using prefabricated reinforced concrete panels*
  - *Reactor island basement floor and wall slabs (seismically qualified structures), again using prefabricated reinforced concrete panels.*
  - *MEP modules in reactor island basement*
- All modelled in 4D digital environment during design and programme development to ensure smooth and harmonious programme for manufacture, construction and installation





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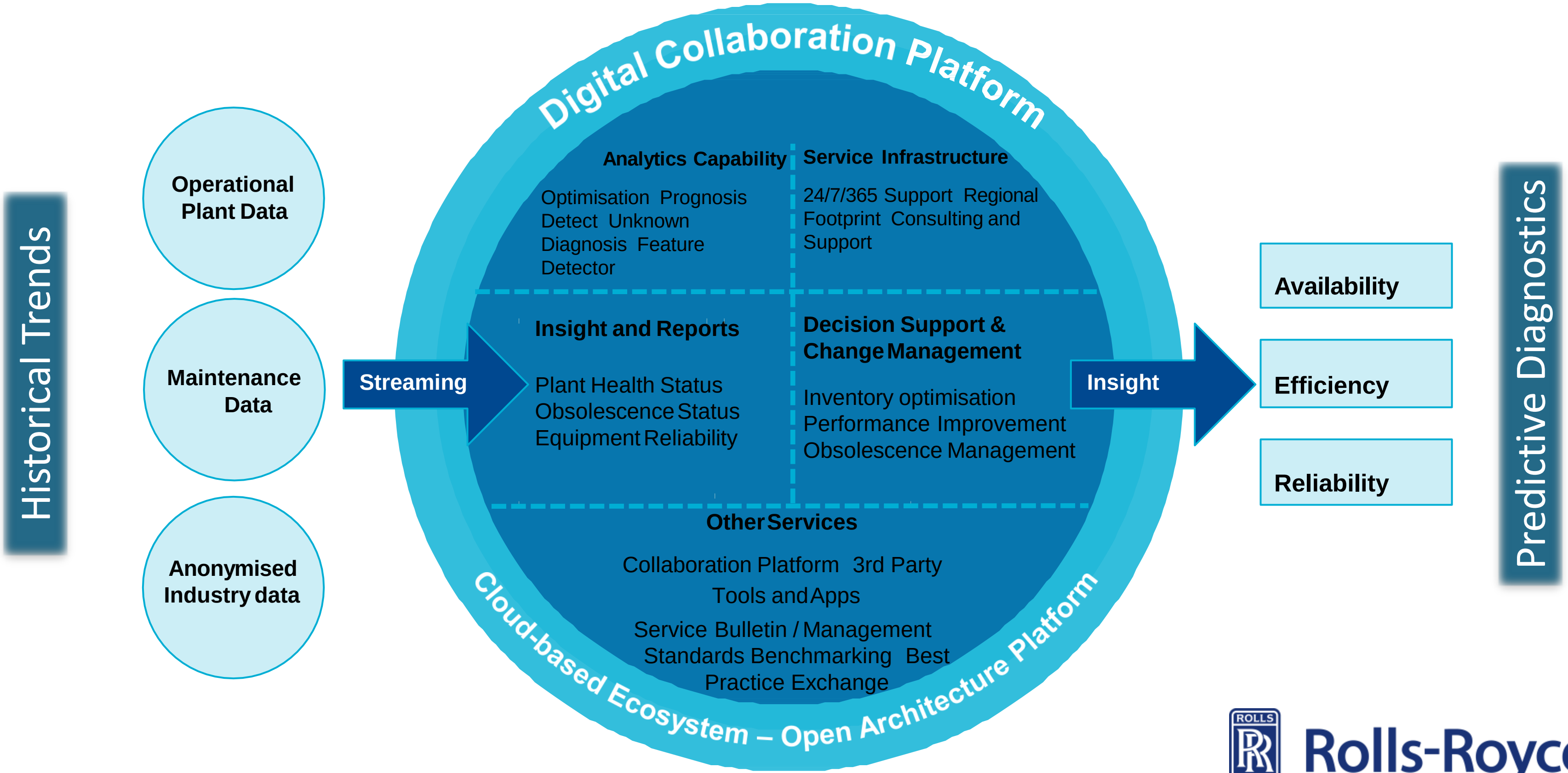
Existing Digital Operations – First Steps…



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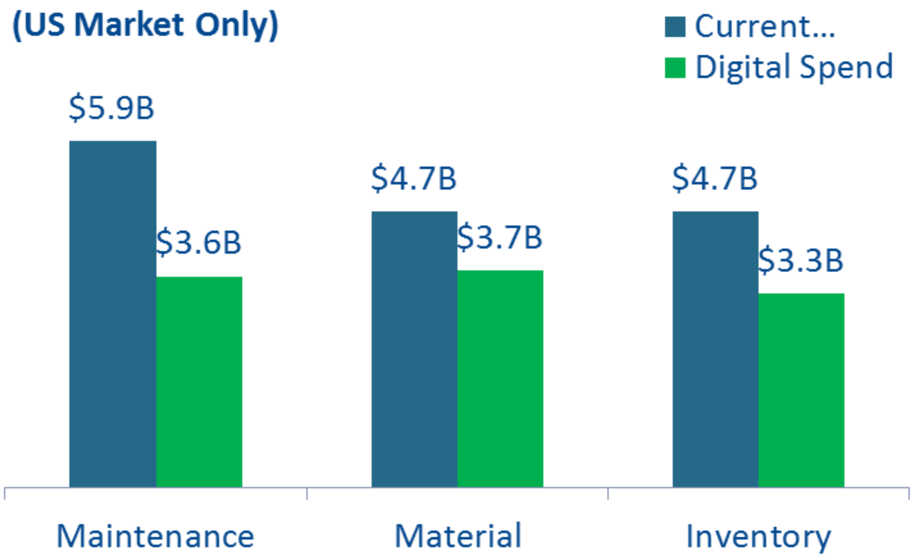
Digital Operations - Potential



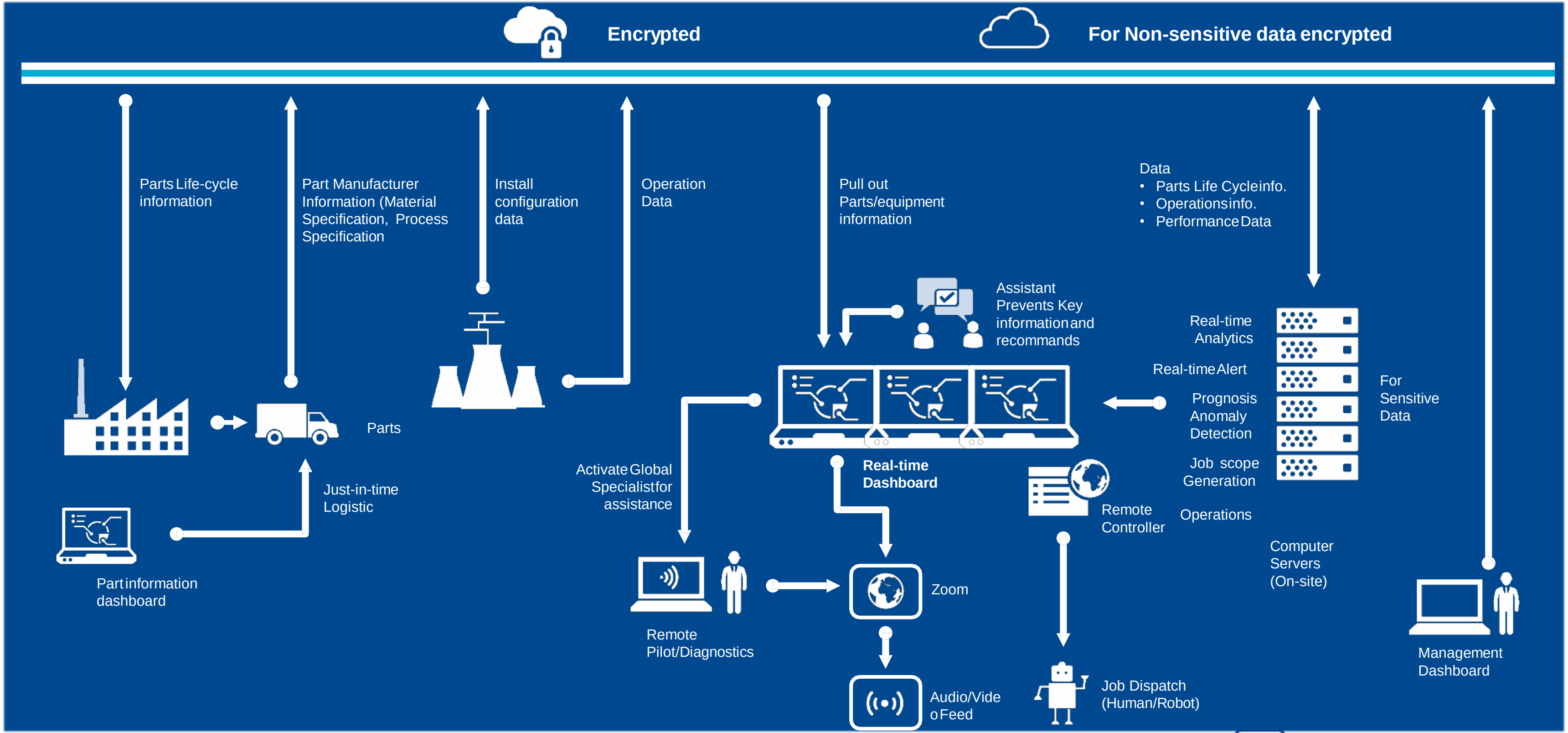
Industry Impact (Over 3 Years)

- **$3.3B in reduced operating cost**
- **$1.4B in improved cash flow performance**
- **Improved equipment reliability**

Market Assessment

- Industry slow to change existing culture
- Savings based on time based data – Step change in industry O&M costs by using predictive intelligence
- Opportunity for the industry to rationalize resources and assets to drive O&M costs down to competitive level

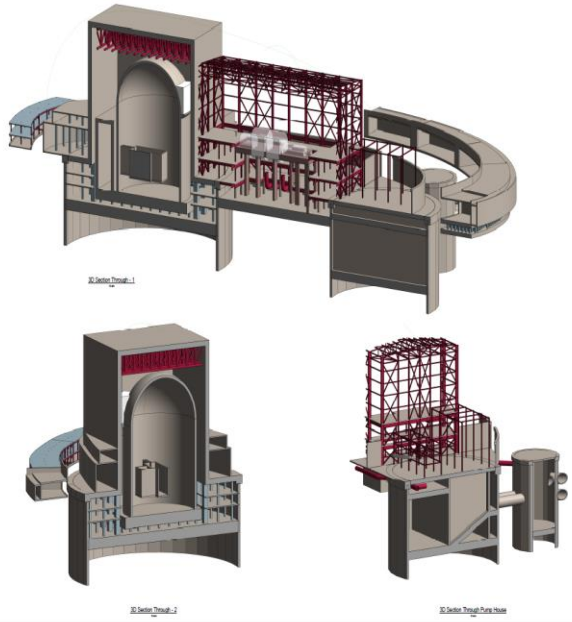
Advanced Digital Operations (including SMR)



Decommissioning

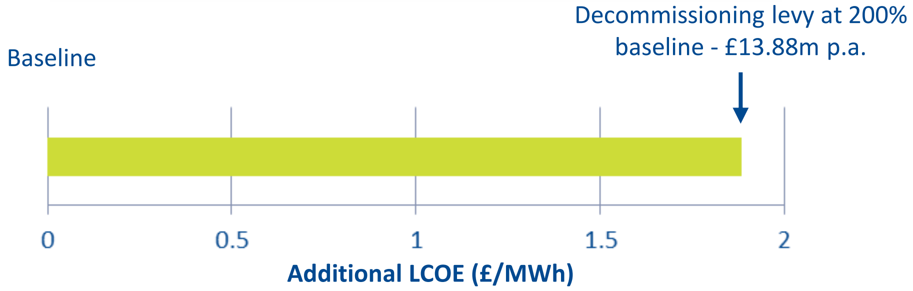
Key Benefits:

- Targeting zero discharges through operations
- Modular disassembly
- Minimised overall components and systems
- Emphasis placed on material selection benefits, e.g. steel containment
- Conventional PWR Fuel
- All waste streams consistent with existing UK treatment infrastructure



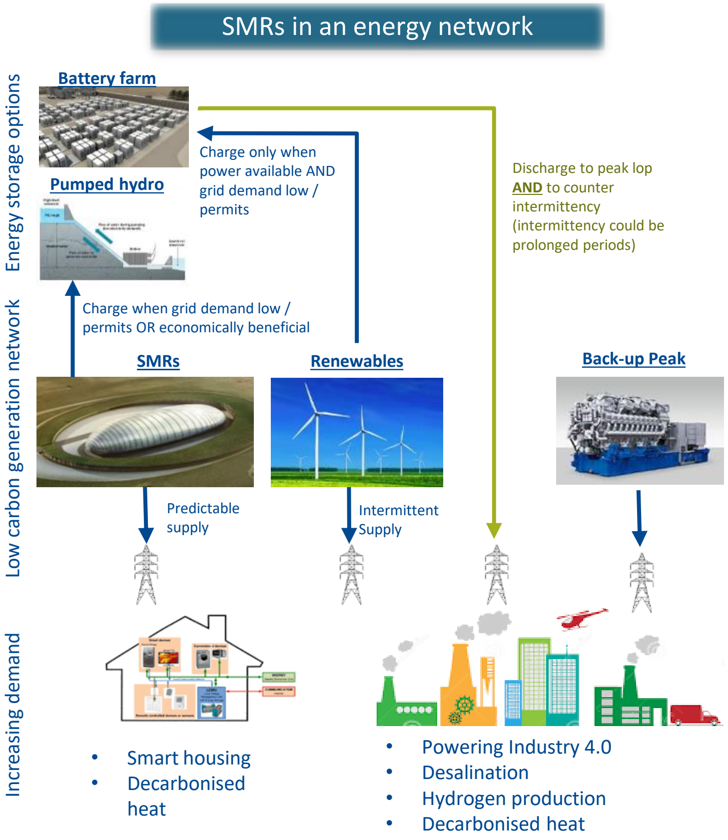
- Decommissioning is funded through a decommissioning levy charged within the operating costs
- Design for decommissioning is built in to our modular construction (i.e. modular deconstruction)

LCOE sensitivity to decommissioning certainty



Integrated System Approach

- Energy storage can be beneficial to any form of energy generation
- Unlike intermittent sources, SMRs can select when to ‘charge’ and when to power the grid
- This removes the need for additional capital to install additional capacity to accommodate both power and ‘charge’ capacity when conditions are favourable
- SMRs can therefore flex grid output providing load following capability to ‘peak lop’ when coupled with batteries / energy storage
- Battery storage, pumped hydro, and hydrogen production are all appropriate for SMRs and improve the economics
- In certain geographies, ‘free’ process heat from an SMR can significantly improve economics
- Equally, SMRs can provide efficient power for desalination in certain international markets



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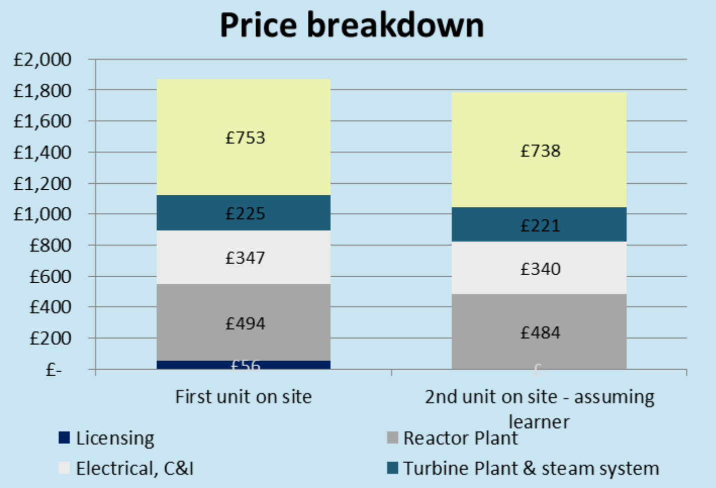
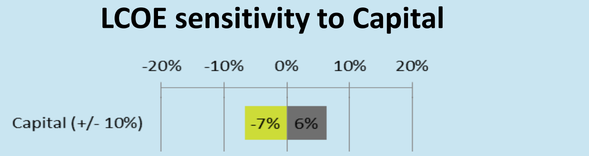
Product price

- Target of capital cost <£2Bn is achieved
- LCOE <£60 MWhr is achieved
- Twin unit sites are economically advantageous
- Combination of reduced financing costs and application of innovative design ensures cost per MWe of installed capacity is competitive

	Overnight capital cost	
SMR first unit on a site	£1,874m	£4.23/MW
SMR second unit on a site	£1,784m	£4.03/MW





Note 1: https://workspace.imperial.ac.uk/icept/Public/Cost%20estimates%20for%20nuclear%20power%20in%20the%20UK.pdf
Note 2: http://textlab.io/doc/5703003/hpc-and-uk-nuclear-new-build

Summary of our SMR design

440MWe Close Coupled PWR SMR

- Operator requirements lead the design
- A Power station design NOT only a nuclear reactor
- Highest power for lowest cost (lowest LCOE)
- Time to market:
    - Low regulatory risk
    - Proven technologies
    - Design for manufacture / construction
- Enhanced passive safety
- Compact Modular design
- Utilisation of volume economies
- Design for lifecycle operation