



Rolls-Royce SMR

New nuclear in the Netherlands beyond 2030

29 October 2021

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Covered topics

- 1. The need for competitively priced nuclear**
- 2. The Rolls-Royce SMR Design**
- 3. Approach to construction**
- 4. Use cases**
- 5. Programme**



Rolls-Royce's Nuclear Heritage

Rolls-Royce is **one of the world's leading industrial technology companies pioneering cutting-edge technologies that deliver clean, safe and competitive solutions**

- Rolls-Royce has a strong nuclear heritage with roots in defence and civil development
- Rolls-Royce has been designing, manufacturing and supporting Royal Navy submarines' small reactors for over 60 years
- Thanks to their 100+ years of experience and operations in 50+ countries, Rolls-Royce are a globally recognised and trusted partner

Civil Aerospace



Power Systems



Defence



Strong nuclear heritage with roots in defence and civil development

Nuclear Business Experience

Defence Nuclear

Submarines

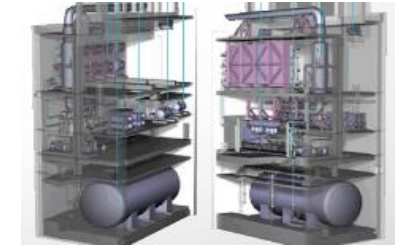


Civil Nuclear

Instrumentation and Control



Nuclear Services and Projects



- Sole technical authority for over 60 years
- Reactor plant design and supply
- Operation of licensed sites
- Fuel fabrication
- Through life services
- Provision of through-life 24 hour global operational support
- 6 generations of reactors

- Reactor protection system
- Rod control system
- Neutron instrumentation system
- Plant monitoring system
- In-core instrumentation systems

- Emergency diesel generator system
- Waste treatment systems
- Services: Inspection, predictive maintenance, inventory management
- Complex components supply



Rolls-Royce SMR is a revolutionary nuclear product; factory fabricated, road transported and site assembled.

The Rolls-Royce SMR approach is a holistic, integrated power station and not just a nuclear reactor design.

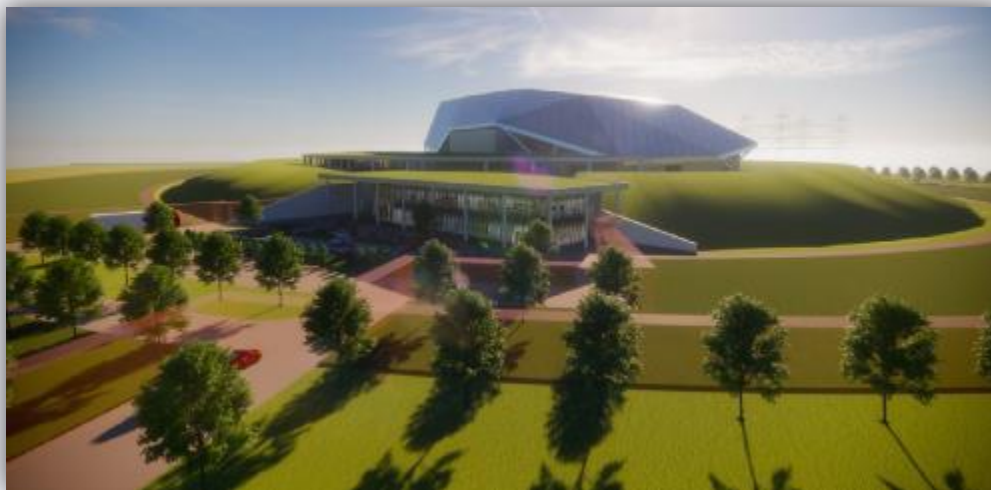
~470 MWe output

50 Hz design

Proven PWR Technology
& Standard Fuel

Power station delivery as
a turnkey project

4 yr Construction
(Nth unit)



Enhanced Gen III+ levels
of safety and security

1st unit on grid early 2030s

Capital cost under £1.8 Bn*

Adaptable, multi-use
power & heat output

LCOE £48 per MWh*
@95% availability

Rolls Royce SMR – Low cost, Deliverable, Investable Low Carbon Power



01

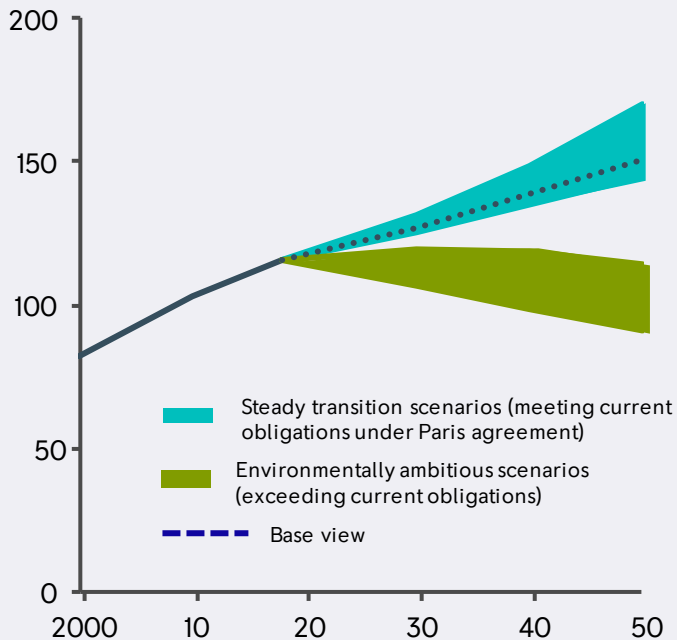
The need



Whilst energy forecasts vary, electricity growth is substantial in any future energy system scenario

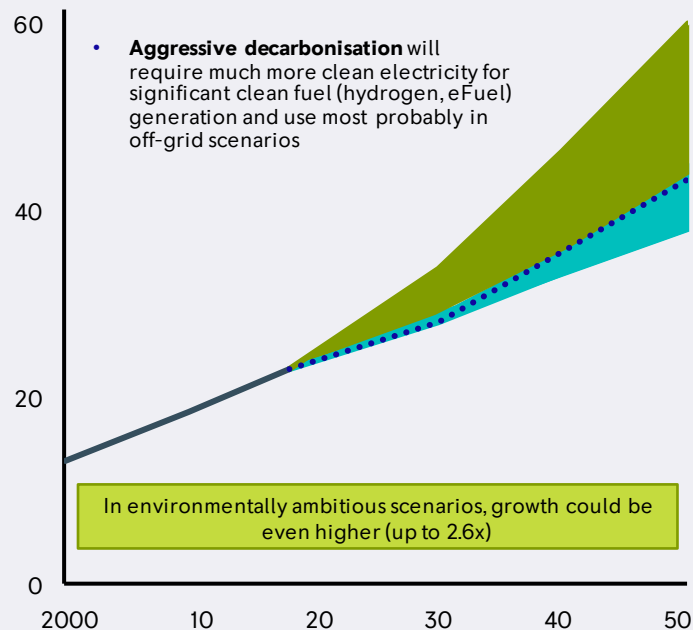
Consensus* outlook on final energy consumption (2000-2050F)

000' TWh (equivalent)



Consensus¹ outlook on final electricity consumption (2000-2050F)

000' TWh (equivalent)

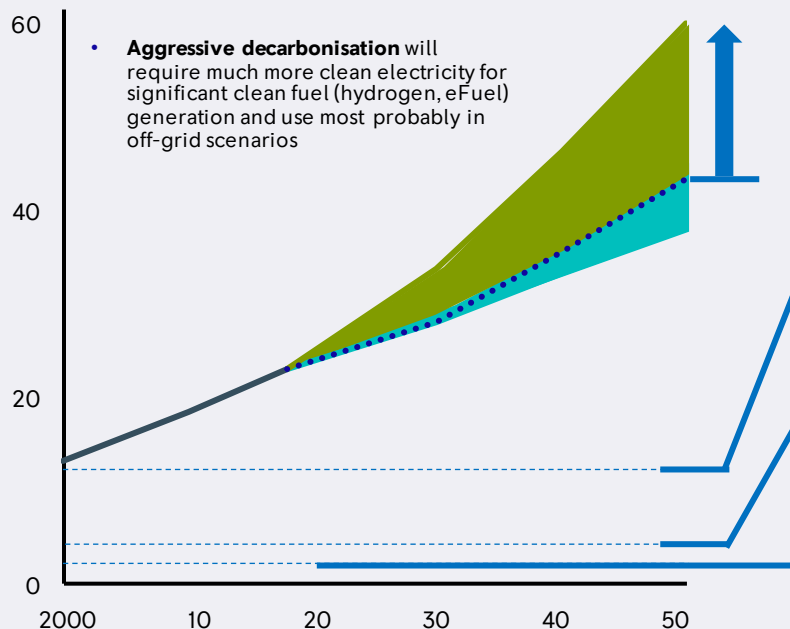




As a result, whilst energy forecasts vary, electricity growth is substantial in any future energy system scenario

Consensus¹ outlook on final electricity consumption (2000-2050F)

000' TWh (equivalent)



Base case delivers **200** units by 2050 (1.4% of global electricity mean case)

**More growth in Electrical demand?
More aggressive decarbonisation?
More nuclear penetration above 30%?**

Nuclear at 30% of global electricity in 2050

Equivalent to **4,200** Rolls-Royce SMR

Nuclear at 2020 proportion of global electricity in 2050 (11%)

4247 TWh nuclear generation

Equivalent to ~750 GWe installed capacity (Most new from now to 2050)

Equivalent to 1,600 Rolls-Royce SMR

Nuclear power in 2020

2553 TWh nuclear generation in 2020 (11% global electricity)

445 plants across 32 countries

~ 400GWe installed capacity

Equivalent to 850 Rolls-Royce SMR

Source: LEK

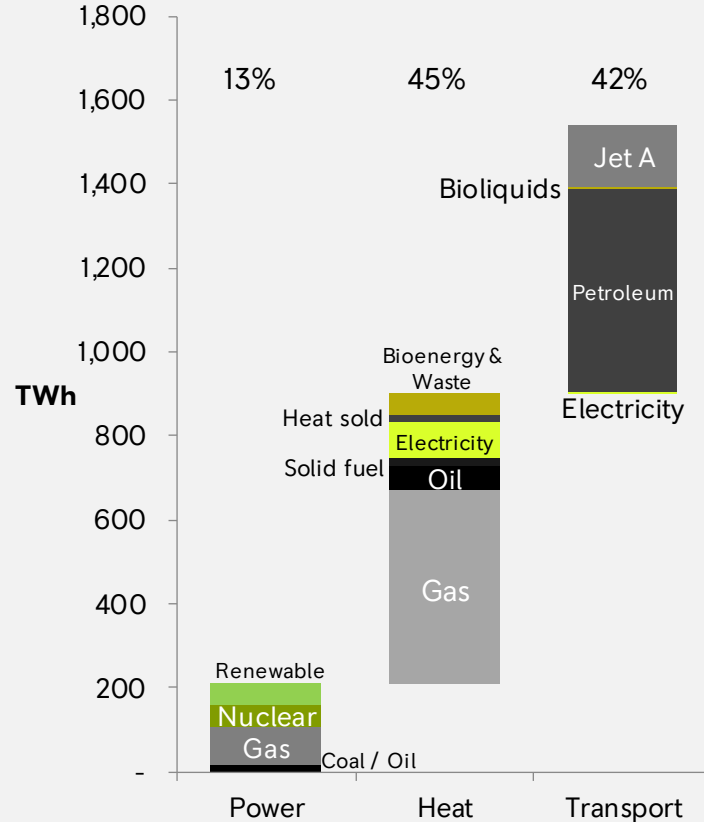
Note:

1. Consensus forecasters of energy and electricity growth include Bloomberg, BP, DNV-GL, EIA, Exxon Mobil, IEA and IRENA



Decarbonisation of the energy system is a huge challenge

UK total energy consumption by sector and fuel source



- The Power/electricity sector has been the historic focus
- But heat and Transport are a much greater challenge
 - Technically
 - Size
- Hydrogen can serve multiple markets of electricity balancing, heat and transport
- All forms of decarbonisation will require more clean electricity

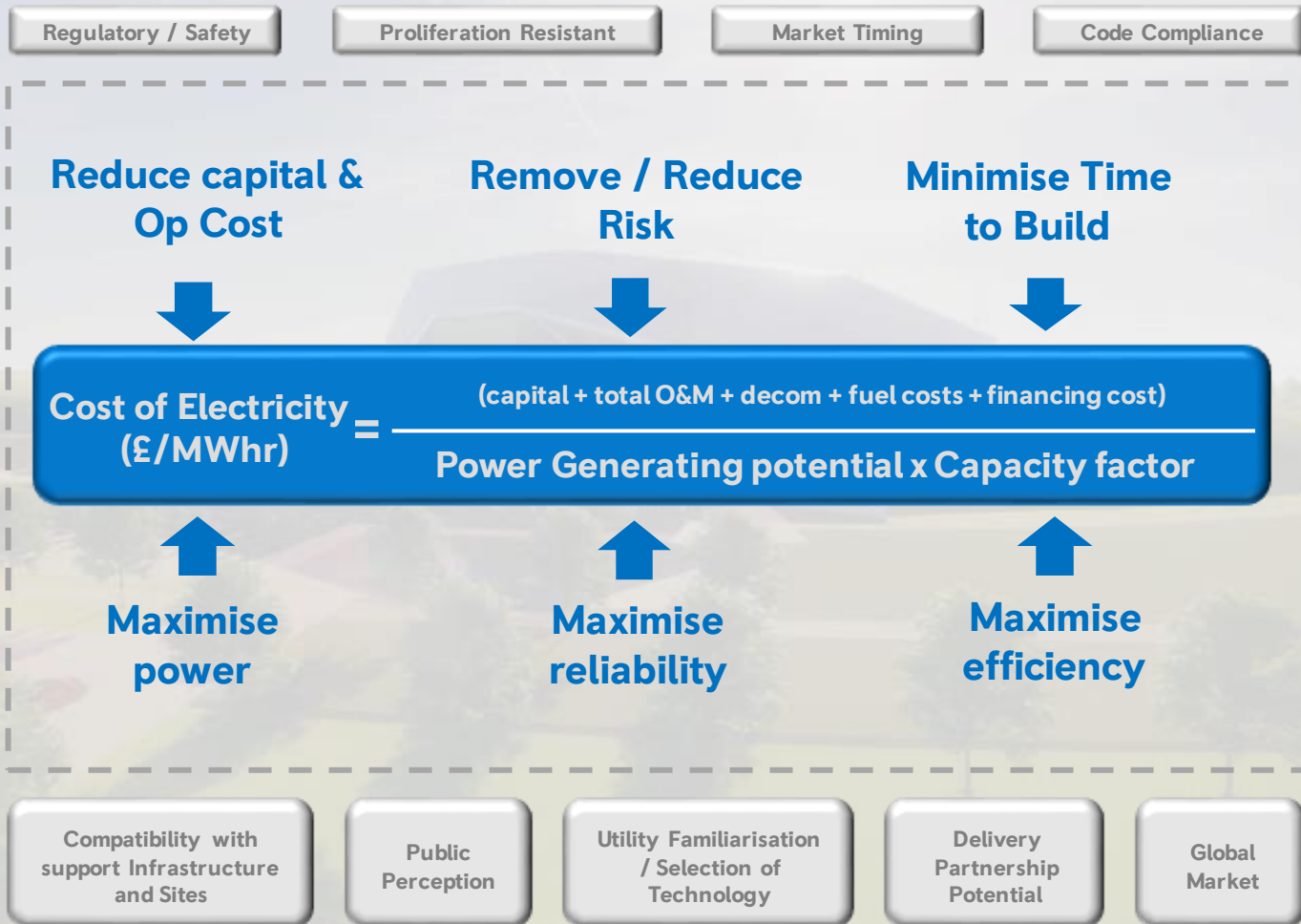
Source:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695626/Press_Noice_March_2018.pdf



SMRs can play a significant role, but not at any cost.

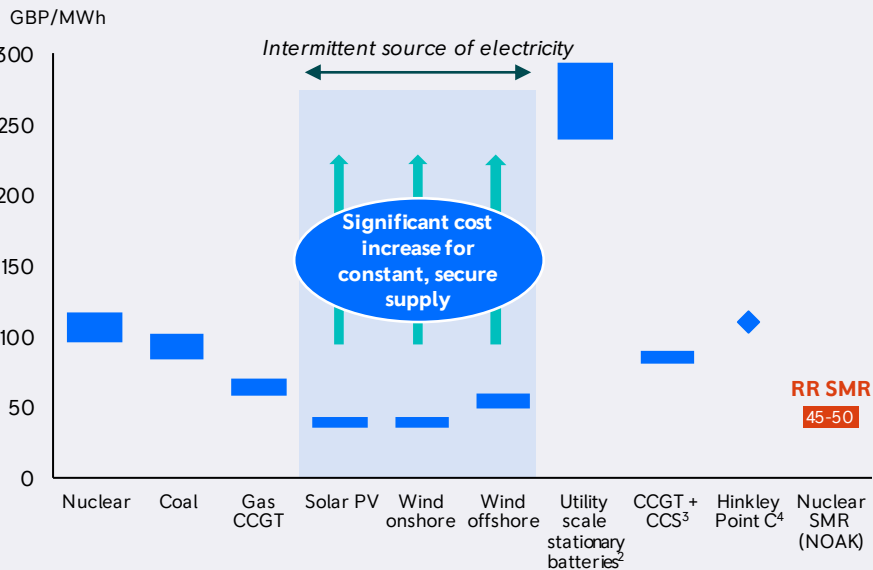
Market driven requirements must drive the design approach



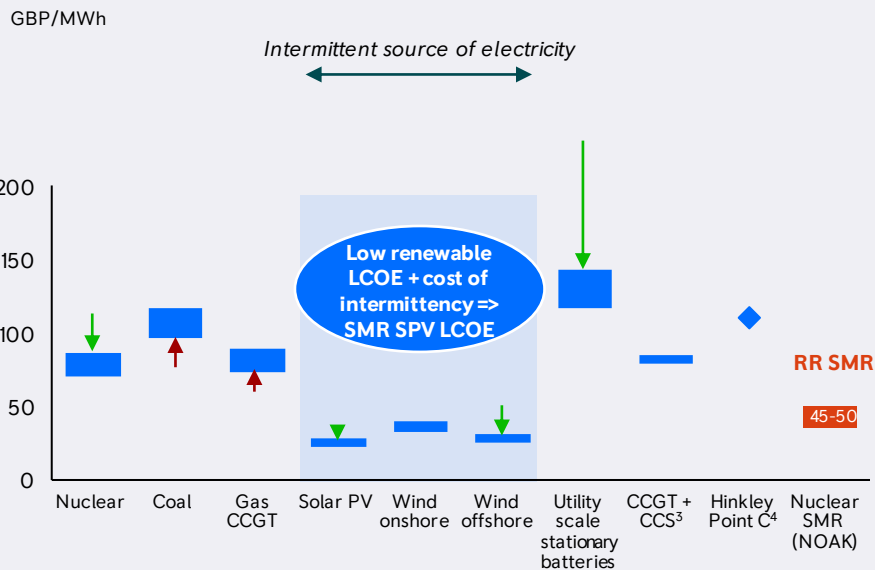


The LCOE for RR SMR is similar to renewable LCOEs and is significantly cheaper once storage costs for renewables are included

European LCOE / Levelised Cost of Storage (“LCOS”), by technology for indicative assets¹ commissioning in 2019



European LCOE / LCOS, by technology for indicative assets¹ commissioning in 2040



Sources: IEA WEO 2020, BEIS Electricity Generation Cost Report 2020

Notes: CCGT = Combined Cycle Gas Turbine; CCS = Carbon Capture and Storage; USD = United States Dollar

1. Data from IEA WEO 2020, converted from USD to GBP (0.7) with +/-10% range applied
2. IEA Data - 2020 base year
3. Data from BEIS Electricity Generation Cost Report 2020 - Refers to 2025 LCOE as this is the first estimated deployment date of this technology
4. GBP92.5 CFD agreed price, scaled by CPI to 2019, as per CFD agreement

RR SMR Range determined by financing mechanism



02

Rolls-Royce SMR Design

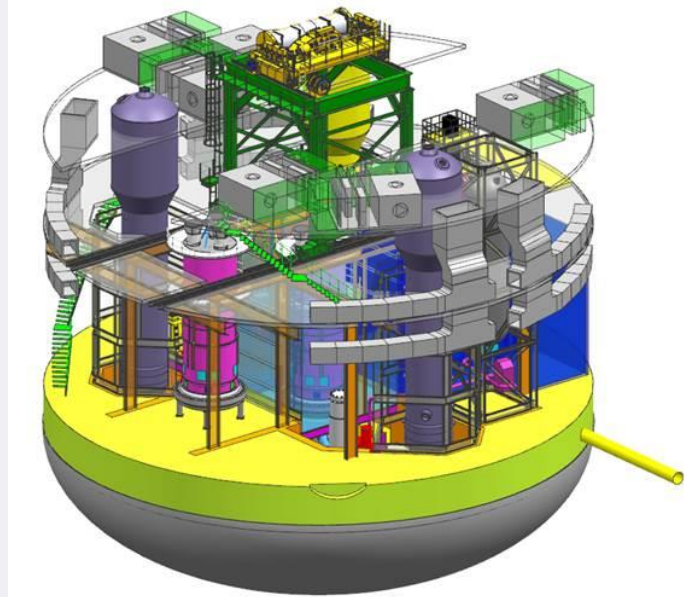


Rolls-Royce SMR Power Station Basic Design

The reactor plant is the heart of the power station and converts nuclear heat to steam that can be used for work

Reactor Systems

- A robust and licensable design incorporating:
 - A 3-loop PWR
 - 3 reactor coolant pumps (one in each loop)
 - 3 vertical **u-tube** steam generators
 - Steam pressurised using a **pressuriser**



Reactor Core and Reactivity Control

- Nuclear fuel is industry standard **UO₂** enriched up to **4.95%**, clad with a zirconium alloy and arranged in a 17x17 assembly
- **No concentration of soluble boron** is maintained in the primary coolant for duty reactivity control, which facilitates a **simplified plant design** and eliminates risks associated with handling hazardous boric acid as well as enabling a **low environmental impact** by minimising boron discharge
- Duty reactivity control is instead provided through movement of control rods and use of the negative moderator temperature coefficient inherent to PWRs. It is a **goal to achieve a zero liquid discharge plant**

Turbine Island

Turbine system configuration

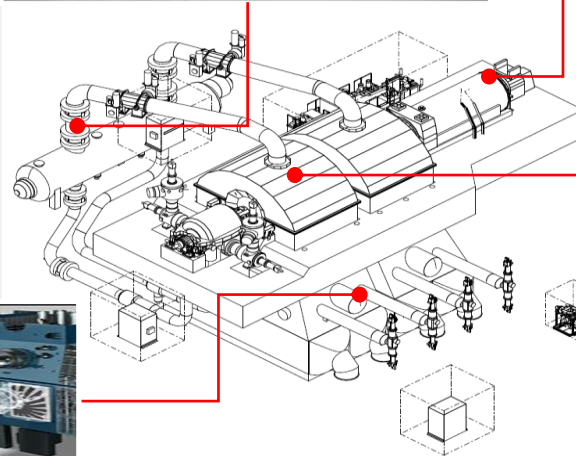
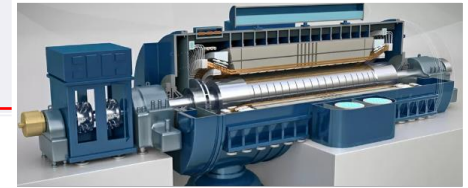
The turbine systems use the energy in steam to create electricity for the market

- The Turbine Island comprises a **commercially available** turbine and generator set delivering $\geq 470\text{MWe}$
- The use of a standard market product allows **supply chain resilience** and **low implementation risk**. The turbine solution consists of:
 - A **full-speed turbine** with a Single Bearing Configuration
 - A double shell multi-pressure condenser with series flows at Low Pressure (“LP”) turbines
 - A **horizontal Moisture Separator Reheater (“MSR”)** arrangement, with 1 MSR and 1 reheater configuration
 - A combined **hydrogen and water-cooled generator**, with brushed static excitation system with thyristors

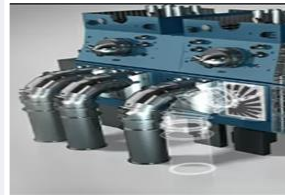
MSR



Generator



LP & High Pressure Turbines



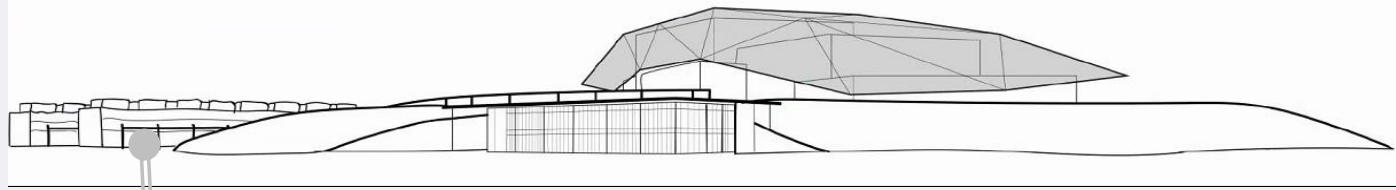
Main Condensers





Rolls-Royce SMR Power Station Basic Design

The Cooling Towers cool, treat and recycle cooling water back into the turbine so reducing environmental impact



- The Cooling Water Island uses **modular cooling towers** to remove heat from the turbine island
- Thus, it **supports the conversion of thermal energy from the reactor (steam) into electricity**. The broader system also provides **cooling to safety systems** within other areas of the power station
- Use of modular Cooling Towers:
 - Enables the **widest site application** and is scalable for global deployment
 - **Minimises water abstraction** to limit impact on the environment
 - **Removes significant sub-sea and sea-based infrastructure**, significantly reducing programme/schedule risk
 - Provides consistent build sequence by spreading the work face across a more accessible area thereby **reducing ‘clashes’ within the construction phase**
 - **Innovates proven technology** to provide long lasting operational flexibility and minimise cost in both the build and operational phases



Mechanical Draft Cooling Tower (cellular)



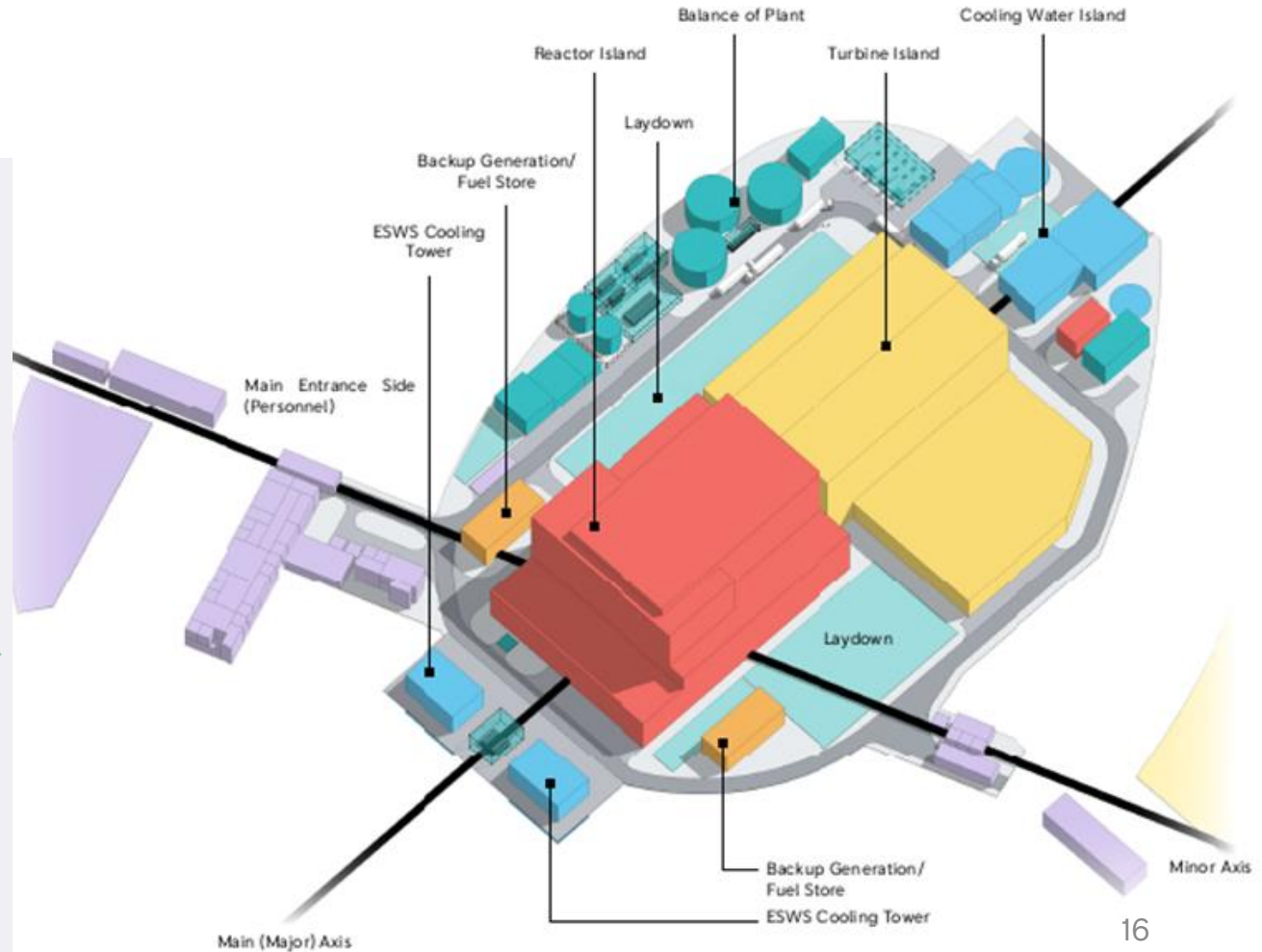
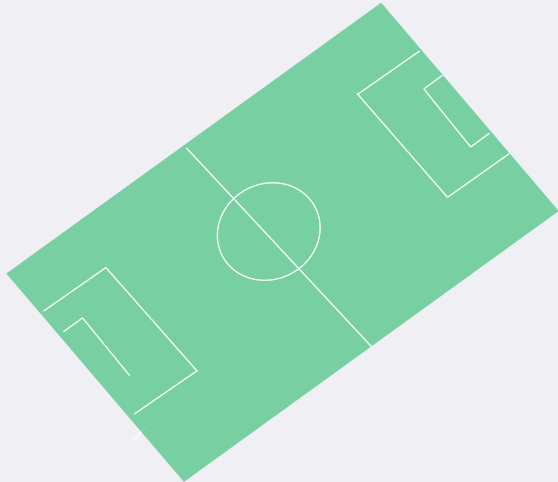
03

Rolls-Royce SMR Construction



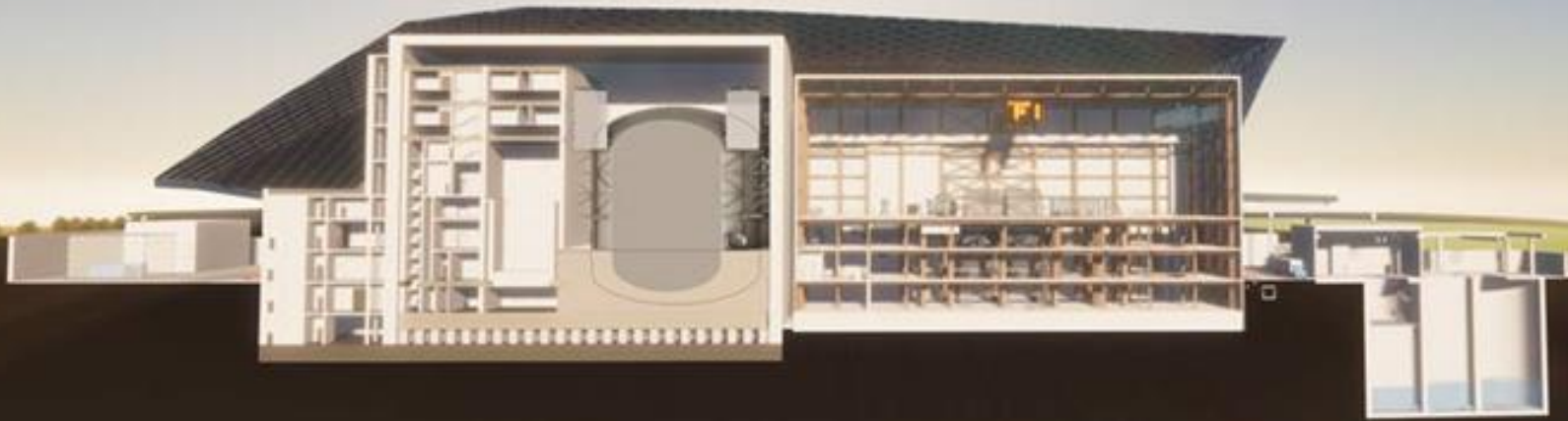
Small site footprint

- Reduces complexity of site activity
- Removes need for expensive infrastructure (ports, roads)
- Reduces cost of groundworks (no earth offsite)





A whole power plant approach focused on standardisation, repeatability, commoditisation where allowable



Reactor Island

Turbine Island

Cooling Water Island



A factory fabricated product - Road transportability of modules is a pre-requisite ..reduced Capex per MW and improves delivery time & certainty

Factory dominated workforce with long term sustainable load



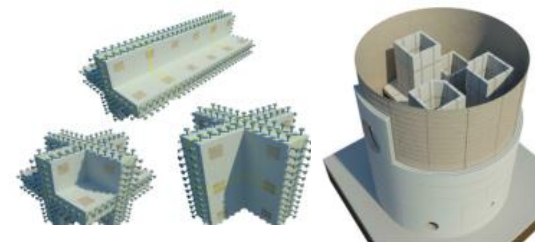
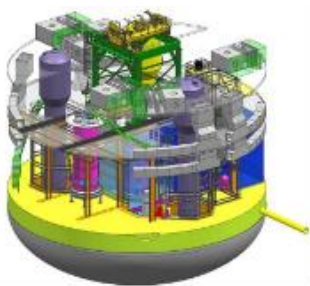
Primary modules



MEP modules



Civil modules





Factory design is a critical part of the cost and schedule reduction

- Turnkey delivery of the entire power station changes the business model
- Factories must be designed to manufacture the product
- The product must be designed to be manufactured in the factory
- A production line approach – not a “jobbing shop”
- Avoidance of high and heavy modules
 - Factory costs increase exponentially with weight and size
- Factory acceptance testing to reduce site works
 - Modules must be transported as a single unit



Primary modules



Civil modules



MEP modules



Modularisation is a solution to reduce capital cost, schedule and programme risk

- **Must be done across the whole plant** not just the reactor
- **Road transportable** without disassembly
- **Standardisation** of product, module sizes and interfaces – improve learner effect
- **Production line** approach to module manufacture – 10s of parts a year, forever
- **Use of Commercial / commodity** products
- **Use of digital twin** – design for maintenance

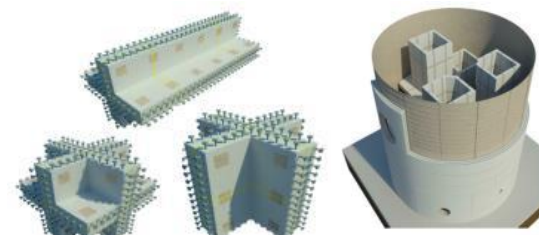
Nuclear Island



BOP & systems



Civil construction



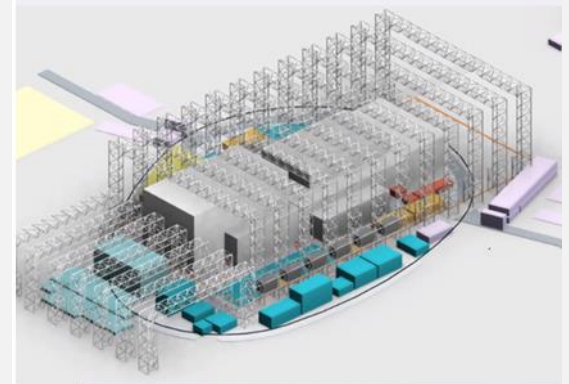
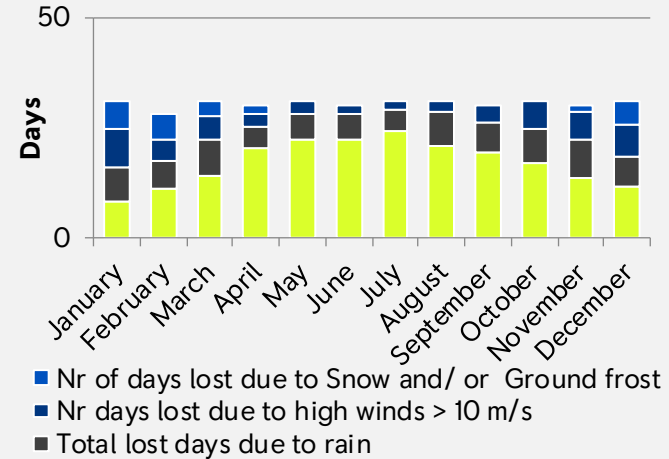
Benefits or learner of amplified through a shift from site construction to factory module construction

Schedule certainty

The Site Assembly Facility (4th factory) can provide major benefits in certainty of delivery schedule

- The potential impact of weather:
 - Potential lost days over 4 year construction period ~641 days
 - Avoids potential extension of programme of ~18 to 24 months
 - Avoids overspend from non-re-deployable costs
- The removal of this risk will enable:
 - **Certainty on a baseline plan with shorter schedule and lower cost**
 - **Lower premiums on financing costs**
 - **Lower LCOE**

Average weather assessment at Wylfa, UK





Big nuclear vs Rolls-Royce SMR Build risk

Turning nuclear into a product not a one-off mega infrastructure project



× EPC (mega project)



EMA (factory product)

Engineering
Manufacturing
Assembly



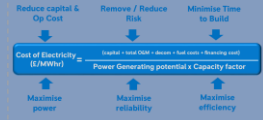
Conventional EPC
(e.g. Large nuclear)

- Mega project GBP10bn+
- High probability of interface failure
- High impact across multiple parties with cross-dependency
- Long build duration

Designed for the market

- LCOE drivers set design requirements
- Avoidance of technology for technology's sake

Regulatory Uncertainty Proliferation Potential Market Timing Cost Compliance



Factory Product

- Lower Capex
- Repeatable product



SMR – Risk Reduction (probability and impact)

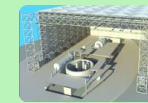
Site standardization

- Much smaller footprint
- Seismic Isolation



Schedule certainty

- Site assembly factory



Commercial simplification

- RR SMR turnkey supply

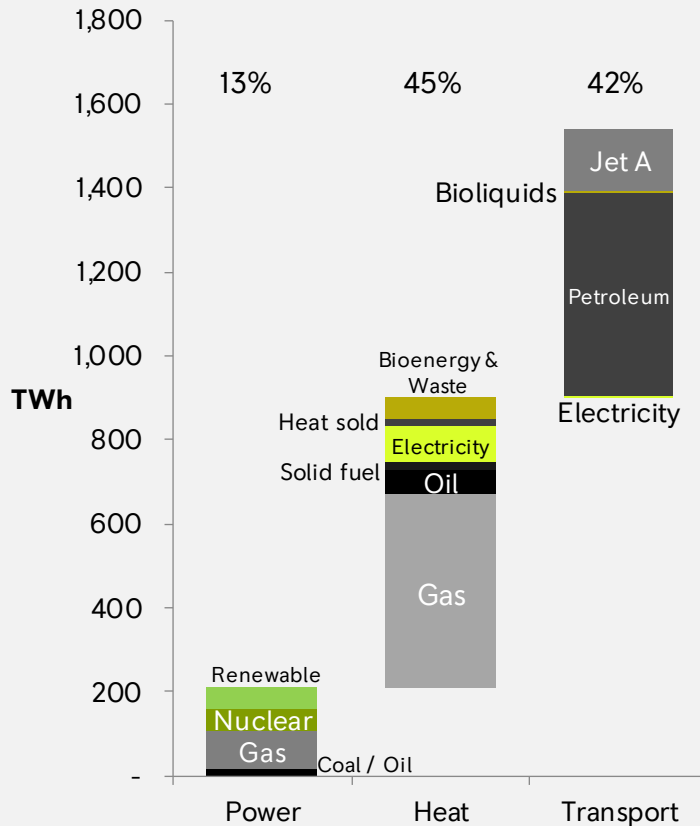


04

Rolls-Royce SMR Use Cases

Decarbonisation of the energy system is a huge challenge

UK total energy consumption by sector and fuel source



- The Power/electricity sector has been the historic focus
- But heat and Transport are a much greater challenge
 - Technically
 - Size
- Hydrogen can serve multiple markets of electricity balancing, heat and transport
- All forms of decarbonisation will require more clean electricity

New industries are already emerging to deliver low carbon solutions and the scale of clean power requirement is increasing



Cummins forecast 2,500GW of electrolyser capacity
(equiv. 5,300 SMRs)



ITM building a 1GW p.a. electrolyser factory
(equiv. 2 SMRs)



0.5-1.0GW for a single data centre
(equiv. 2 SMRs)



c.23GW p.a. current combined data centre demand



Bitcoin requires **c.13GW p.a.**



Netherlands necessitates **c.13GW p.a.**

Source: Company information
Note:

One SMR and associated plant can...

1 **Hydrogen & Synthetic Fuel Production**



Produce 170 tonnes of H₂ / 280 tonnes of net-zero synthetic fuel per day (~50 short haul flights per day)

2 **District Heating/Cooling**



Heat or cool a city the size of Sheffield

3 **Desalination**



500m cubic meters of potable water per year

4 **Clean Electricity**



Can power a city the size of Leeds



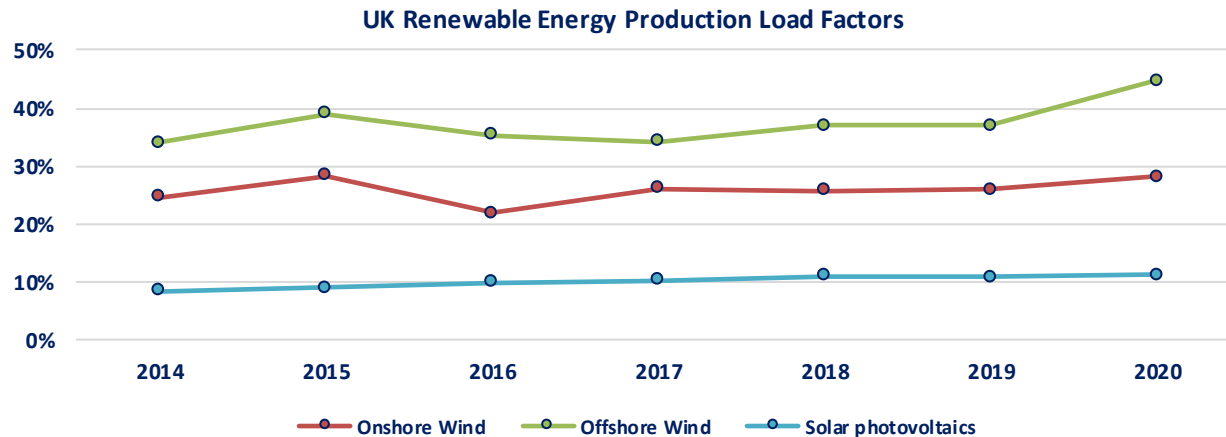
Power for Industry

UK is well placed for wind power

Even so load factors currently in the 20% – 50% range

Off-shore wind may increase to 45 – 55% by 2035

Industry needs consistent competitively priced power at high load factors



Option 1: Grid power only

- Industry accepts inherent CO2 emissions
- Network transmissions costs incurred

Option 2: Renewables & Grid back-up connection

- Industry accepts inherent CO2 emissions
- Network transmissions costs incurred

Option 3: Renewables at low load factors

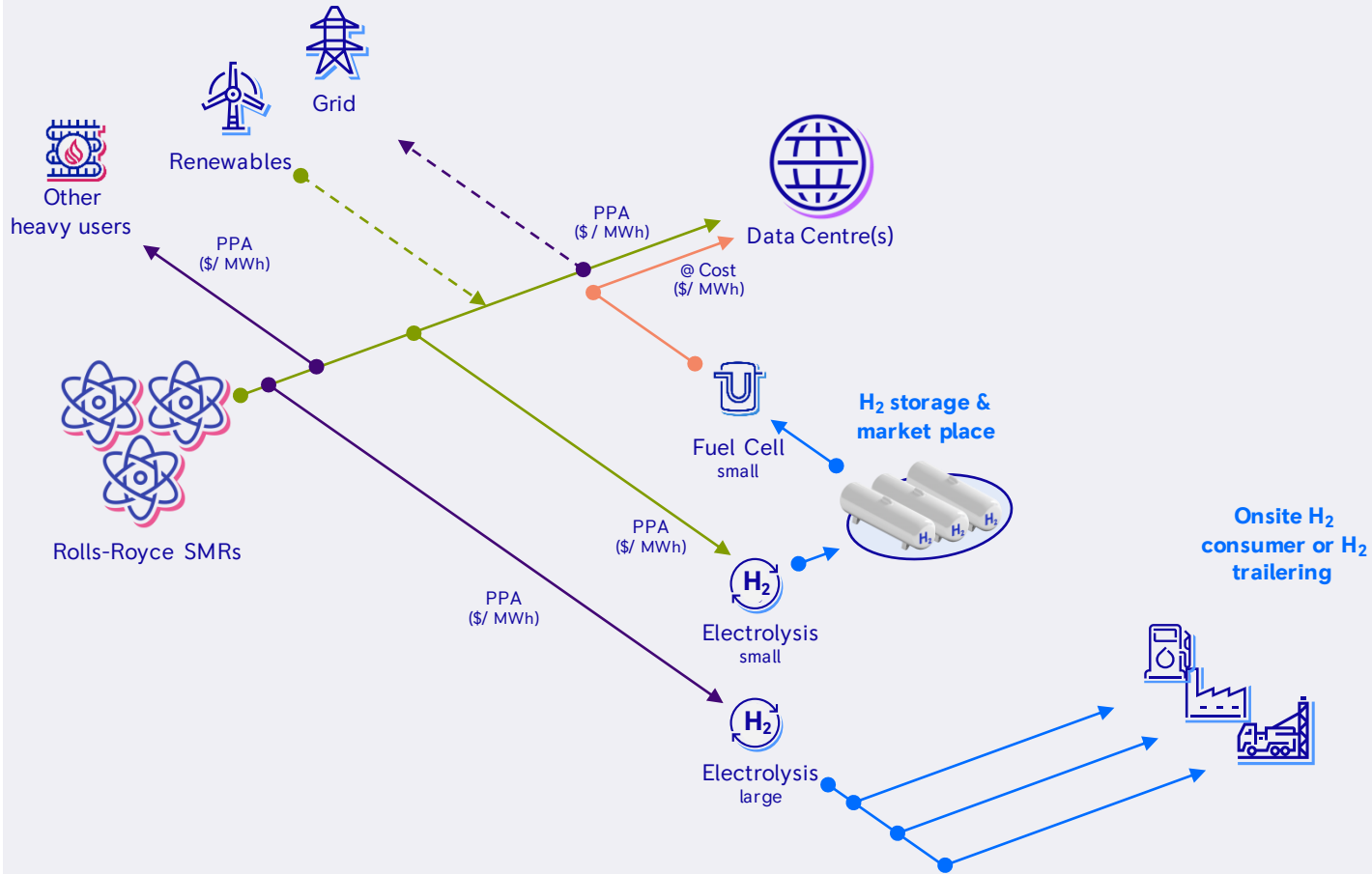
- Industry accepts low utilisation and therefore low output

Option 4: Renewables only, 100% utilisation

- Capacity 2-3 times required generation, and storage (hydrogen or battery)
- CAPEX & OPEX costs greatly increased



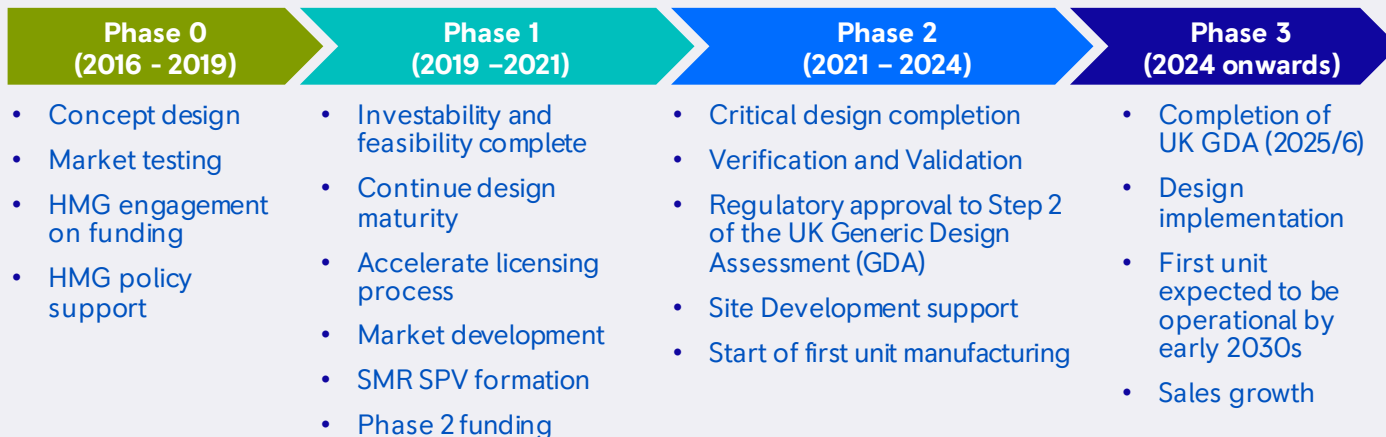
Energy Park





Rolls-Royce SMR Programme

From design, development and construction to the operation of first plant by early 2030s (10yrs after contract award)





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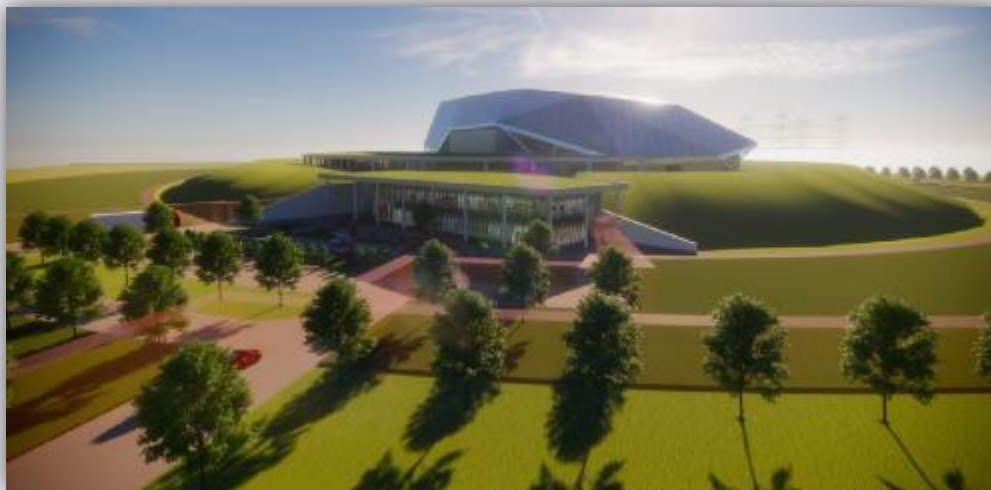
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Rolls-Royce SMR

Website: <https://www.rolls-royce.com/innovation/small-modular-reactors.aspx>

YouTube video: https://www.youtube.com/watch?v=cFFS_P3EnMk

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