Energy as a Strategic Capability
The Case for Nuclear Derived Hydrogen

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Business Overview – ES&T

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Energy, Security & Technology

Design, Engineering, Scientific Research, Programme Management and Project Delivery

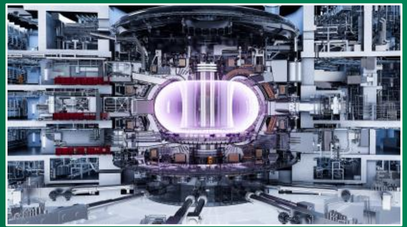

National Security & Defence


Aerospace


Independent Assurance & Regulatory Compliance


Civil Nuclear


Nuclear Decommissioning


Nuclear Fusion

Cyber Security


Space

Hydrogen & Energy Carriers


Environmental


Energy Transition


Critical Infrastructure

Working With:

Ministry of Defence

Defence Infrastructure Organisation

Submarine Delivery Agency

UK Atomic Energy Authority

Defence Nuclear Organisation

[dstl] The Science Inside

Royal Navy

Army

Royal Air Force

United Kingdom Space Command

Setting the Scene: MoD Challenges

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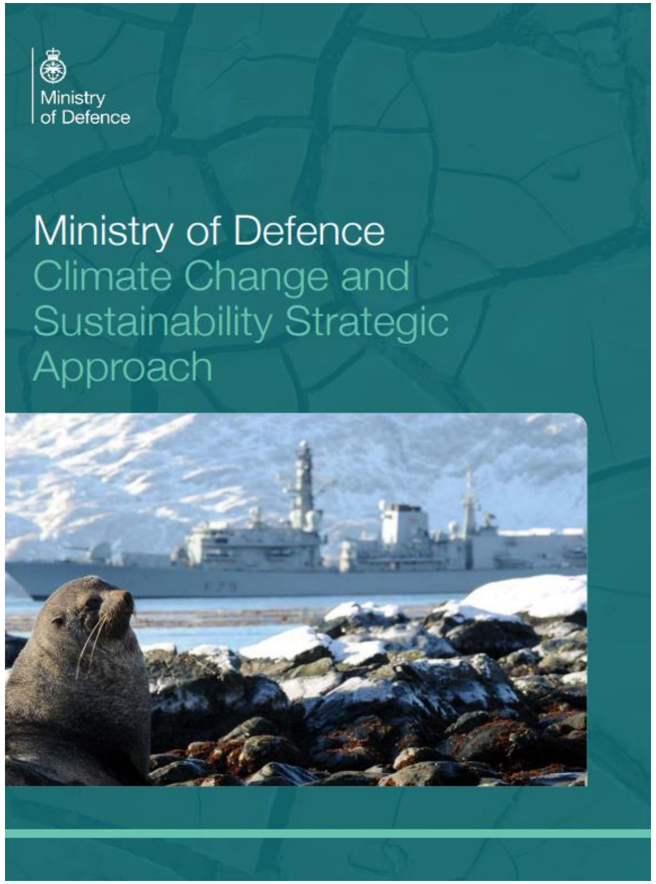
MOD faces a number of challenges related to ENERGY, ENERGY SECURITY, and achieving NET ZERO emissions

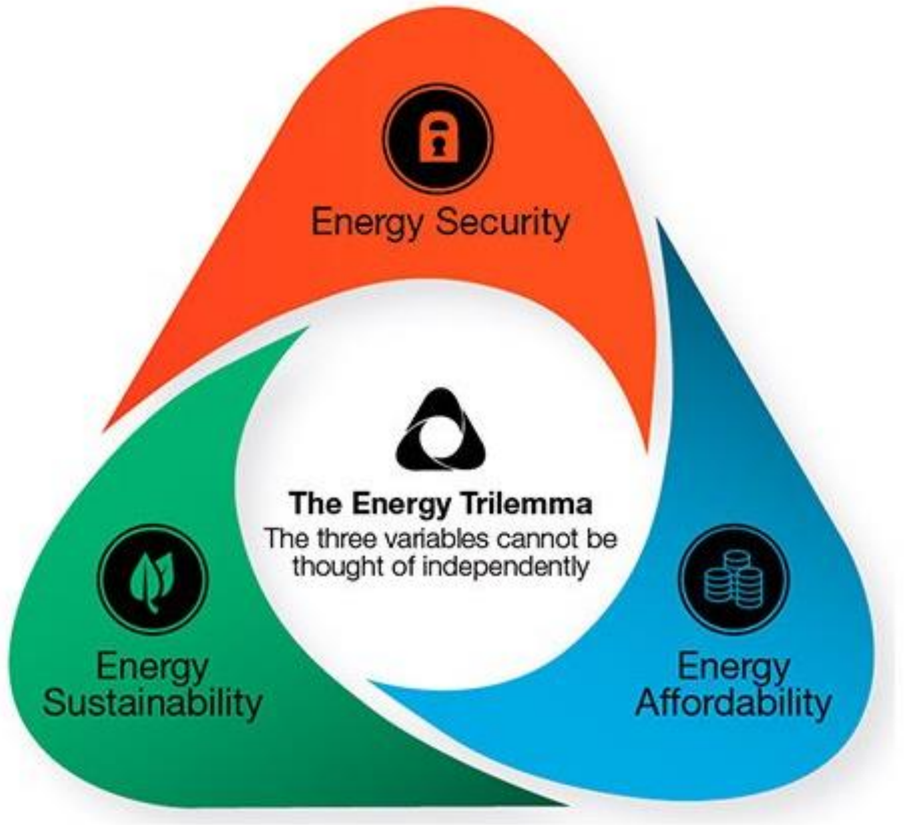
Challenges include:-

- Reducing the carbon footprint of military operations (2050 Target).
- Maintaining energy security.
- Ensuring energy resilience.
- Adapting to changing energy technologies and phasing out of hydro-carbon based solutions.
- Balancing energy and operational requirements (future demand / changing vectors / impact of new technologies.
- Reducing associated energy costs.



Setting the Scene: The UK Energy Trilemma

- The UK currently faces an energy trilemma of Security, Decarbonisation and Affordability.
- The UK ambition is to boost the UK's energy generating capacity from **107GW** today to between **150 GW** and **363 GW** by 2050.
- The Energy Trilemma…. Cannot be acted upon in independent silos. Addressing all three of these aspects is a significant challenge.
- Nuclear offers a strong case: -
  - **Non-intermittent, secure energy supply.**
  - **Proven to offer low cost power/heat.**
  - **Net zero technology solution.**
- New Modular Nuclear Reactors offers a pathway to developing projects far quicker than traditional large GW scale power plants.
- **Alternative to grid concepts, provides a new use case for nuclear.**



UK Energy Mix - Now

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40%

Heat / Industrial Processes

20%

Electrical

40%

Transport

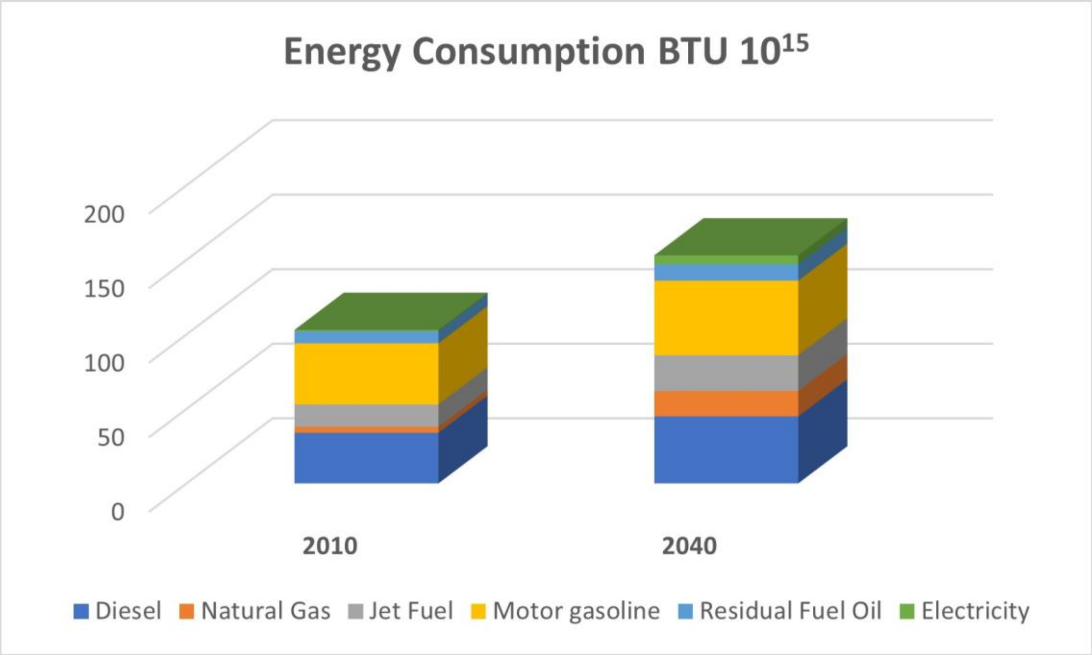
UK Energy in Breif 2022

Transportation Fuel Consumption

40%

Transport

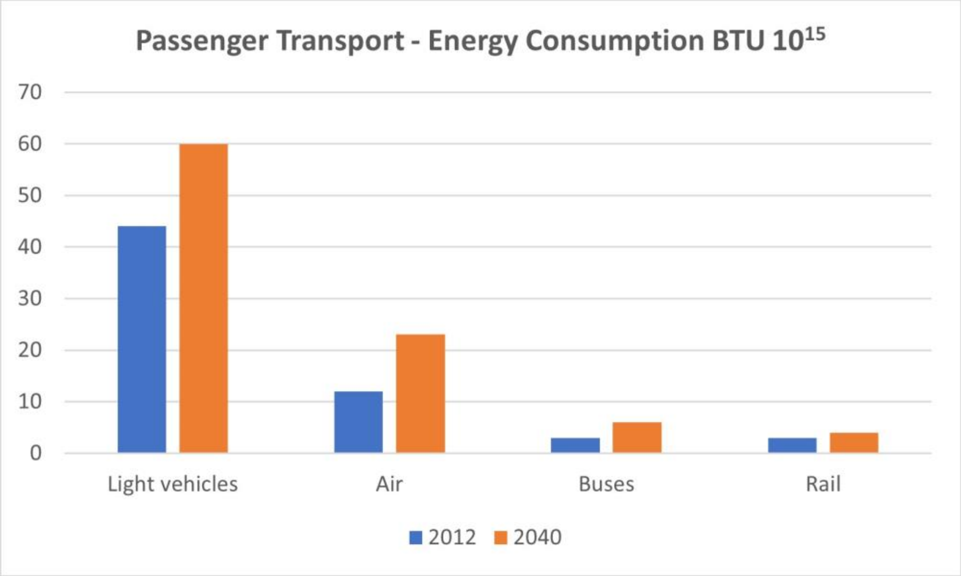
- Current predictions limit uptake of electric power in overall transportation mix (HGVs, passenger, trains, shipping, aviation).
- Battery technology is a factor – currently the power to weight ratio is a barrier outside of small cars.
- Diesel and Petrol still feature heavily until replacements become available.
- Use of hydrogen / synthetic fuels is at testing stage for both light and heavy transport, aviation and maritime.

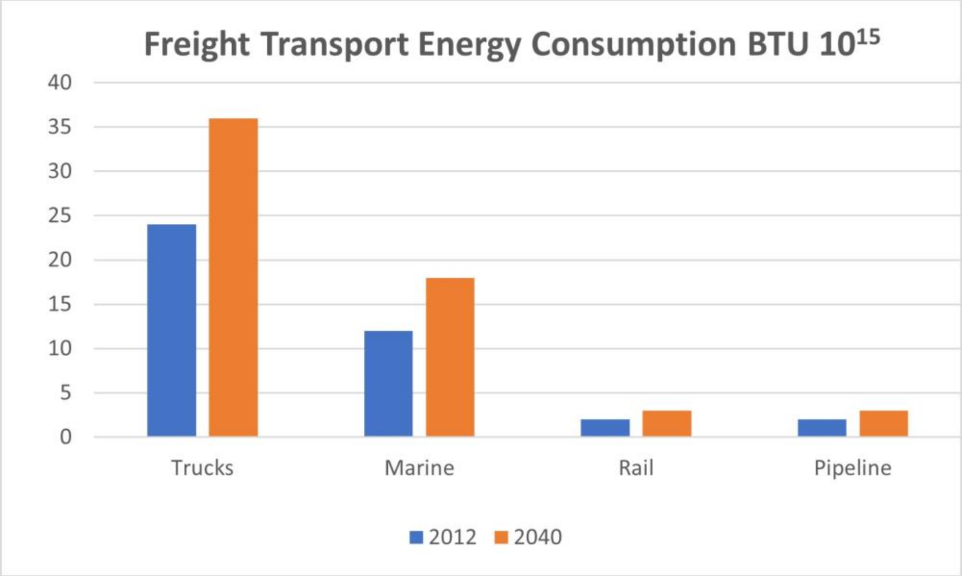


Source : International Energy Outlook 2016

Example: Road Transportation

Predictions ***show 50% increase*** in fuel requirement by 2050

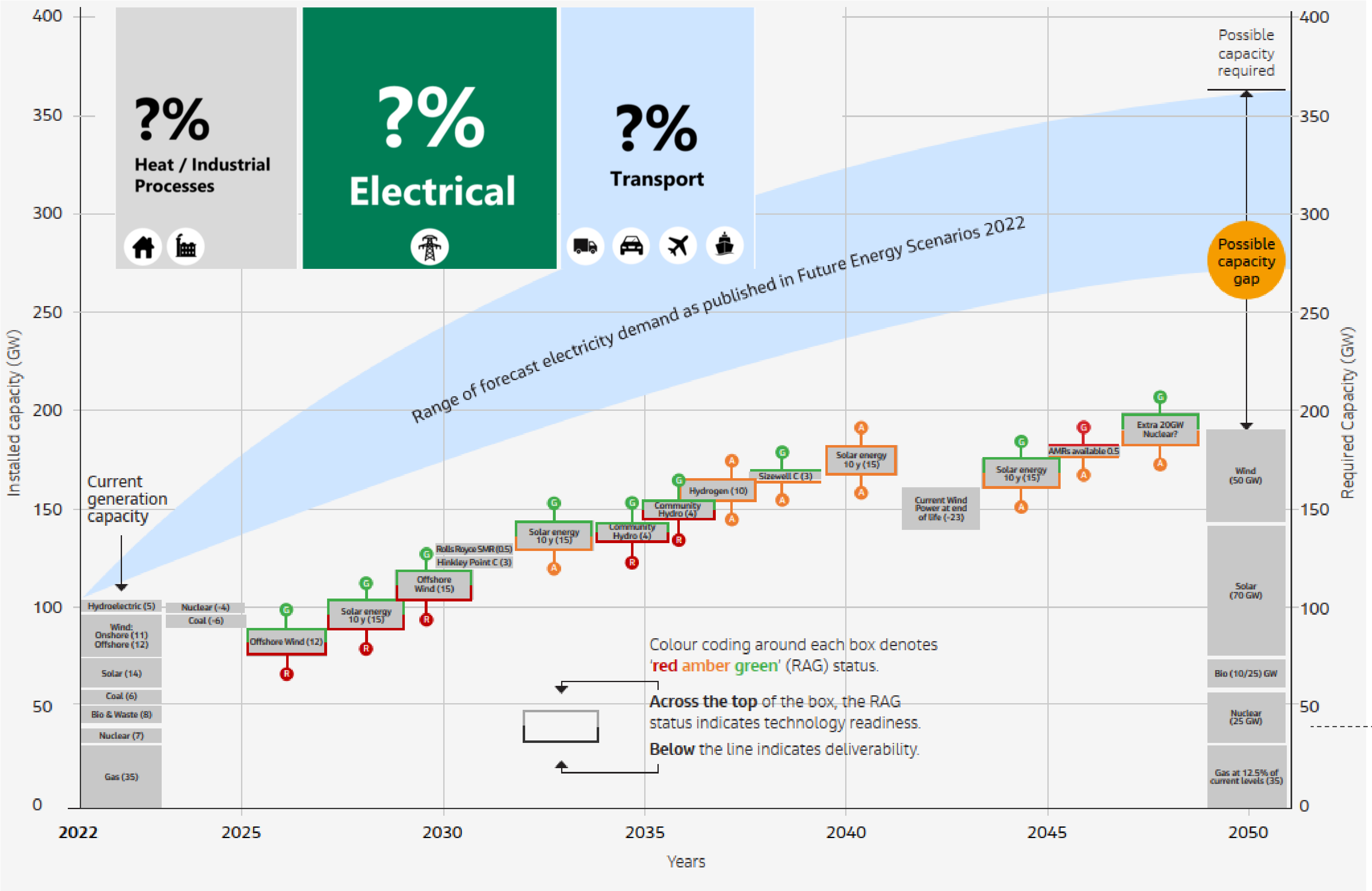




Current legislation e.g. U.K. ban on conventional petrol and diesel cars and vans from sale in the from 2030, the challenge to replace hydrocarbon fuels with an alternative (Hydrogen / Liquid Organic Hydrogen Carriers) is significant.

Source : International Energy Outlook 2016

The UK Energy Mix – Additional Demands



Additional Grid Demand

- Electrification of Homes
- Electrified Transportation
- Hydrogen Based Aviation
- Hydrogen Based Shipping
- Hydrogen Trucks / Cars
- Hydrogen Domestic Heat
- Hydrogen Industrial Heat

20-35% of the UK's energy consumption by 2050 could be hydrogen-based
(UK Hydrogen Strategy)

24GW Nuclear reflects mainly 'base load' electrical generation

UK Hydrogen Challenge

Growth in Demand by Fuel Switching - Examples

Example Hydrogen End Users - Hard to Abate Transportation

Hydrogen (Fuel Switching) Application	Electrical Power Required for H2 / Synthetic Fuel Production
Aviation (50% SAF fuel blend by 2050)	55 GW
Shipping (H2, Ammonia, Methanol)	30.5 GW
Total	85.5 GW

Based on 100% of 2019 UK Demand (Dukes 2020)

UK Hydrogen Strategy and UK's Independent Climate Change Committee.

UK Hydrogen Challenge

Requires 10 GW production capacity by 2030.

Production: 50% CCUS Enabled / 50% Electrolytic.

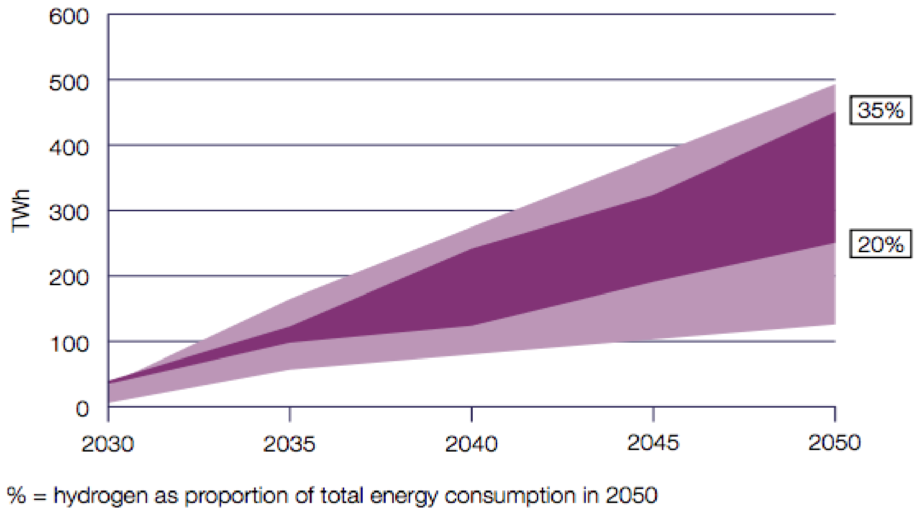
35% of the UK's energy consumption by 2050 could be hydrogen-based (circa 500 TWh).

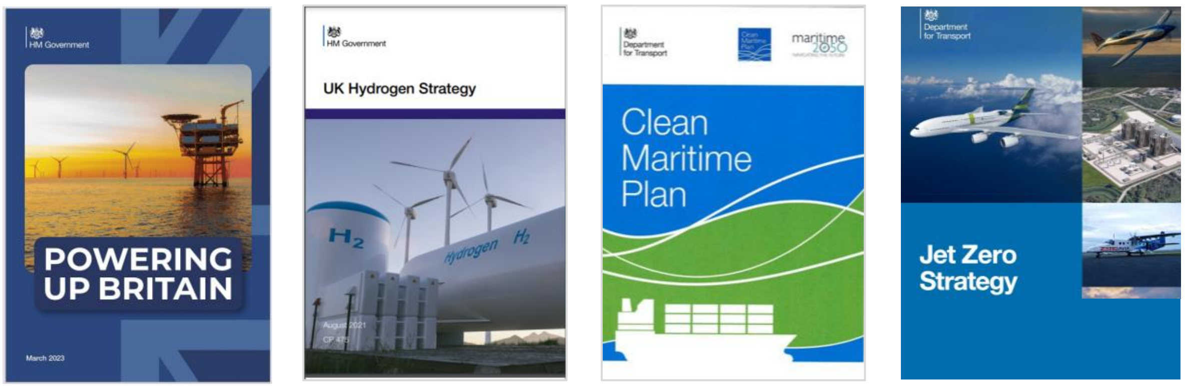
Switching to low carbon / net zero hydrogen is forecast to **cut emissions by 78%** by 2035.

Significant Challenge - <1.0GW of current production capacity, and 99% is "Grey Hydrogen" (94M tones per annum) - fossil fuel derived and carbon intensive.

Summary: Going to need vast quantities of hydrogen, production keep up with demand will be challenging.

UK Hydrogen Strategy and UK's Independent Climate Change Committee.





Hydrogen & Vectors (LOHC)

Current Methods of H2 Production

Steam Methane Reformer (SMR)

Water Electrolysis

Storage

Hydrogen (H2)

Direct Hydrogen Use

- Heat
- Grid Power (H2 Peaker Plants)
- Transportation (road)
- Aviation Fuel (liquid H2)

Synthetic Fuels (LOHC)

- Aviation (SAF / FHTP)
- Shipping (NH3 / Methanol)
- Transportation (NH3 / Methanol / FHTP)

(LOHC - Liquid Organic Hydrogen Carriers)

Hydrogen Production Methods

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	Low Carbon Hydrogen			Net Zero Hydrogen				
				Reactor Operational Efficiency Significantly Increases →				
	Carbon Intensive	CCS Enabled	Pyrolysis Enabled	Electrolytic (Cold Electrolysis)		Thermally Enhanced (Hot Electrolysis)		Thermochemical
Process	Steam Methane Reforming (0% CO2 Capture)	Steam Methane Reforming (50% - 90% CO2 Capture)	CO2 is captured in a solid state (98%+ CO2 Capture)	Electrolysis (PEM, Alkaline, AEM, Cryogenic)	Electrolysis (PEM, Alkaline, Cryogenic)	*Hot Electrolysis (SOEC Type Electrolysis	*Hot Electrolysis (SOEC Type Electrolysis)	*Thermo-Chemical Water Splitting (Catalytic)
				*H2 Production Efficiency Improves as Temperature Increases →				
Source	Methane or Coal	Methane or Coal	Methane or Waste Plastic	Renewables PV / Wind / Hydro, Tidal	**Nuclear Power Grid Connection	Nuclear Power 350 °C (Gen 3 / 3+)	Nuclear Power 650 °C (Gen 4)	Nuclear Power 500-2000 °C (Gen 4 VHT)
						Nuclear Derived Hydrogen		

UK Energy Mix – Current & Future

2022 - 30 GW

2050 - 50 GW

Offshore Wind
35% Capacity Factor

Onshore Wind
28% Capacity Factor

2022 - 30 GW

2050 - 70 GW

Solar (PV)
12% to 28% Capacity Factor

2022 - 35 GW

2050 - 5 GW

CCGT (Gas) Plants
N/A

GAS Peaker Plants
N/A

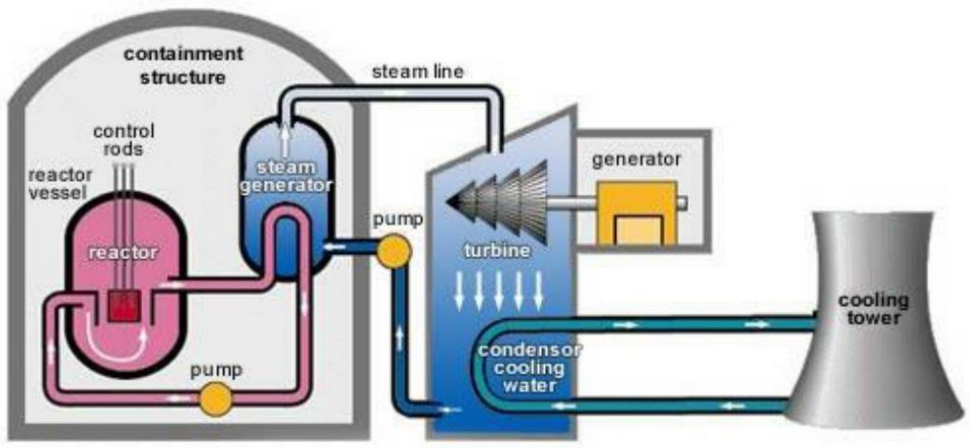
2022 - 6 GW

2050 - 24 GW

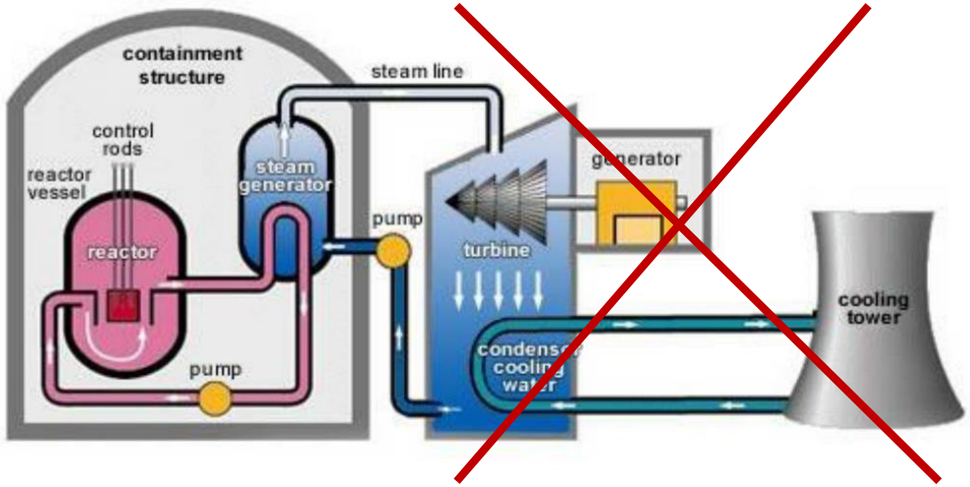
Nuclear
93% Capacity Factor

2050 – 150 GW Total

Nuclear Technology Overview



Nuclear Plant – Electrical Generation
Typically 35% Efficient



Nuclear Plant – Steam Generation
Typically +80% Efficient

Nuclear Technology Overview – Example Footprint

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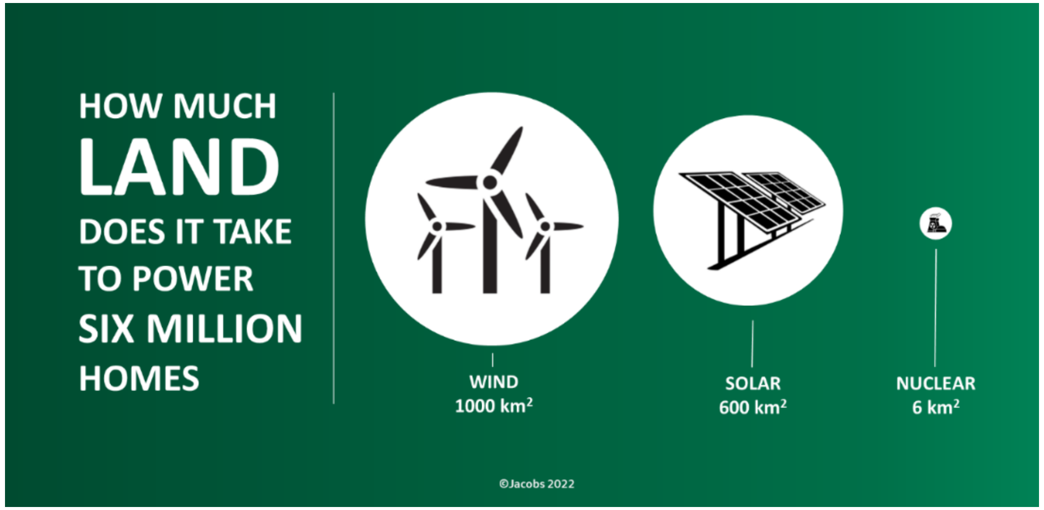
AMR Nuclear

Hydrogen Production

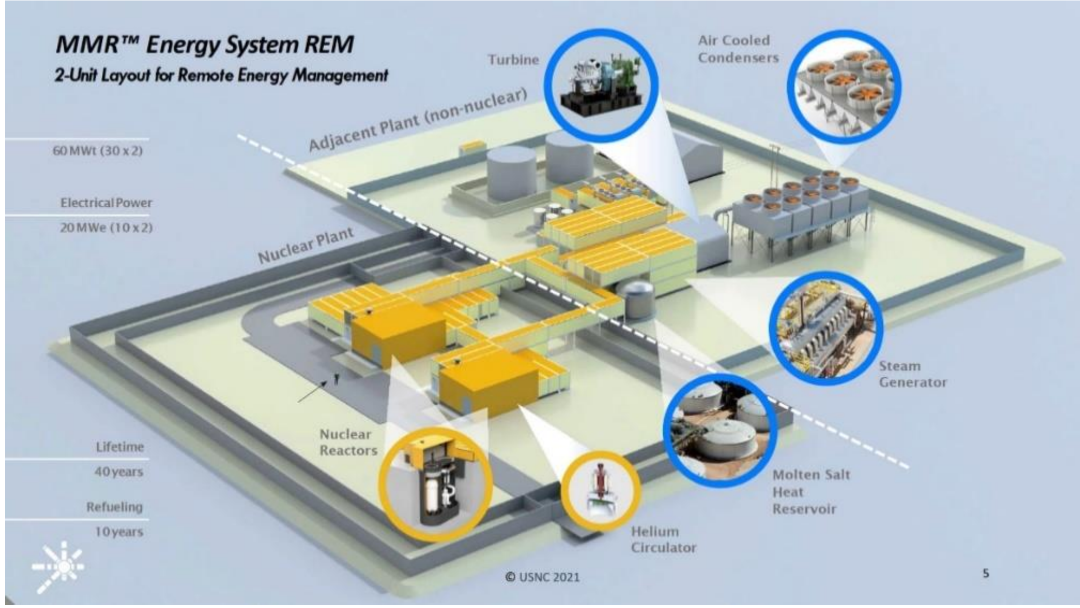
Ammonia Plant

Synthetic Fuel Plant (FT)

Nuclear Derived Hydrogen Scale and Footprint Examples: NNL (2022)



"Nuclear power offers the highest energy density, in the smallest footprint of any available technology, whilst maintaining net zero credentials"



USNC, 2 x 10 MWe / 40 MWth Micro Nuclear Reactors (MMR) Foot Print Example

Nuclear Technology Overview (Re-cap)

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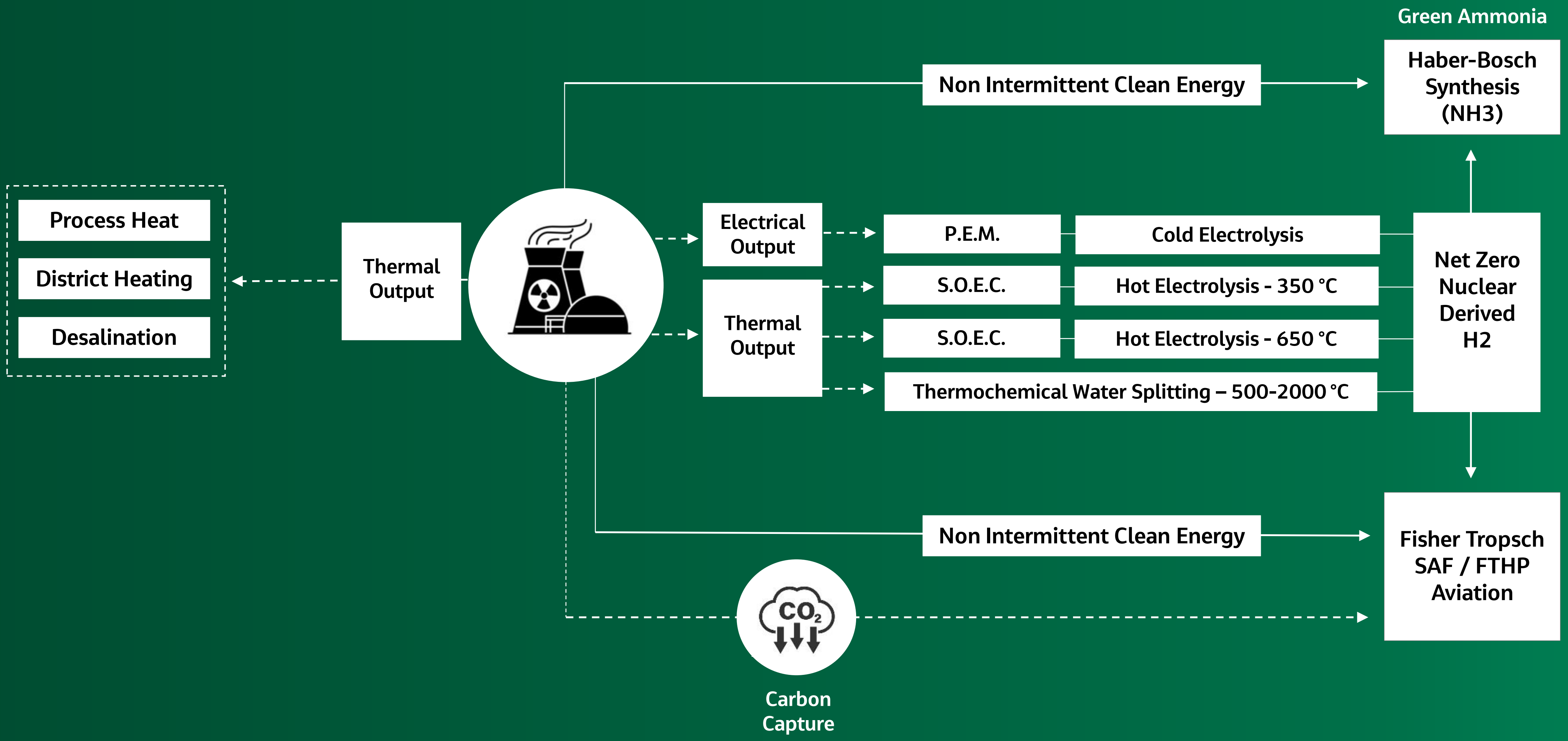

Nuclear Technology – Reactor Classes

Designation	Power Range	Heat Output	Technology	Maturity	Deployment Strategy
GW Scale Large, Traditional Nuclear (e.g. Sizewell C)	>1.0GW	300-400 Deg C	• Water Based • Advanced Gas Reactors (AGRs)	Current UK NPP Fleet	Coastal
MMR Micro Modular Reactors Generation 3&4 Technology	1 – 20 MWe	550 – 950 Deg C	• High Temperature Gas Reactor • Molten Salt Reactor • Liquid Lead Fast Reactor • Sodium Cooled Fast Reactors		Flexible e.g. close to industry
SMR Small Modular Reactors Generation 3 Technology	50 – 470 MWe	350 Deg C	• Water Based	End of 2020s	Flexible e.g. close to industry
AMR Advanced Modular Reactors Generation 4 Technology	30 – 300 MWe	550 – 900 Deg C	• High Temperature Gas Reactor • Molten Salt Reactor • Liquid Lead Fast Reactor • Sodium Cooled Fast Reactors • MOX Reactors	Mid 2030s	Flexible e.g. close to industry

Nuclear Technology – Reactor Options

There are over 50+ vendors of Modular Nuclear Reactors, with designs of MMR/AMR/SMR, ranging from TRL level 1 (concept design) to TRL8/9 (approaching commercialisation after successful first real-world installation).

Vendor	Reactor	Capacity	Type	Technology
Westinghouse	eVinci	5 MWe	AMR	Heatpipe FNR
USNC	USNC-MMR	5 MWe	AMR	HTGR
USNC	USNC-MMR+	10 MWe	AMR	HTGR
NuScale	NuScale Micro	10 MWe	AMR	Heatpipe
HolosGen	Holos Quad	13 MWe	AMR	Lead Fast Reactor
Last Energy	PWR-20	20 MWe	SMR	PWR
Starcore	Starcore	20 MWe	AMR	HTGR
Newcleo	LCFR-30	30 MWe	AMR	Lead Fast Reactor (MOX)*
NuScale	NuScale-PM	77 MWe	SMR	PWR
X-Energy	Xe-100	80 MWe	AMR	HTGR
KAERI	SMART	100 MWe	SMR	PWR
GE-Hitachi	ARC-100	100 MWe	AMR	Sodium FNR
Terrestrial Energy	Integral MSR	192 MWe	AMR	Molten Salt Reactor
Newcleo	LCFR-200	200 MWe	MMR	Lead Fast Reactor
GE-Hitachi	BWRX-300	300 MWe	SMR	BWR
Moltex	SSR-W	300 MWe	AMR	Molten Salt Reactor
TerraPower	Natrium	345 MWe	AMR	Sodium FNR
Roll Royce	UK SMR	470 MWe	SMR	PWR

IAEA Advanced Reactors Information System - Advances in Small Modular Reactor Technology Developments (2020 Edition).

Nuclear Technology Overview – Reactor Options

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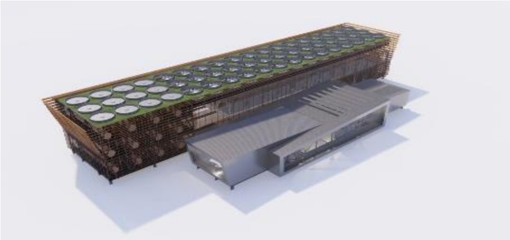
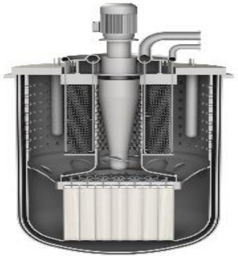
USNC - 10 MWe MMR

Westinghouse - 5 MWe - MMR

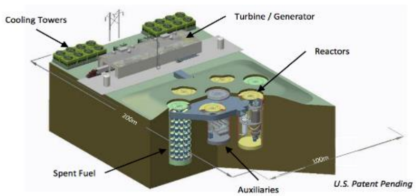


Last Energy - 20 MWe - MMR

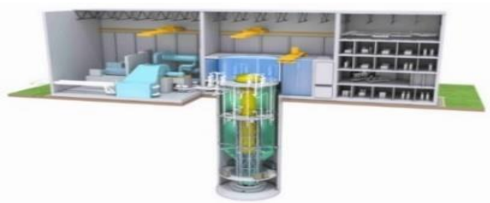


Newcleo - 30 MWe – MMR

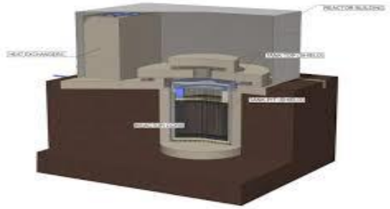
NuScale - 77 MWe - SMR



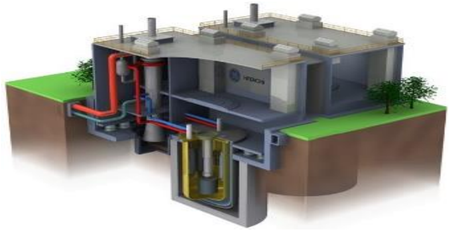
X-Energy - 80 MWe - AMR



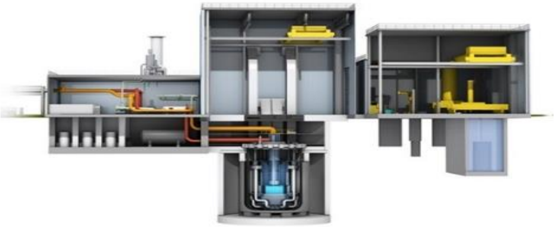
GE Hitachi - 100 MWe - AMR



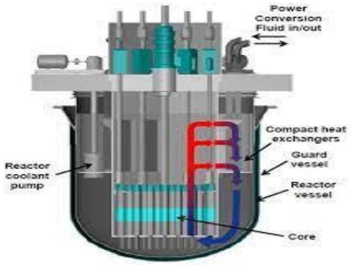
Moltex - 300 MWe - AMR



GE Hitachi - 300 MWe - SMR



TerraPower - 345 MWe - AMR



Westinghouse - LFR 450 MWe - AMR

Rolls Royce - 470 MWe - SMR

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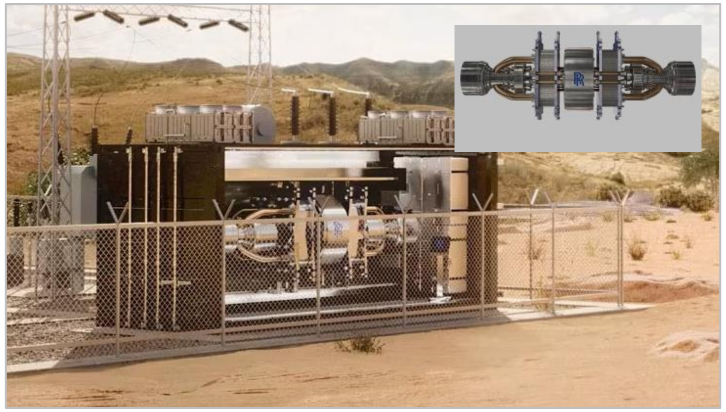
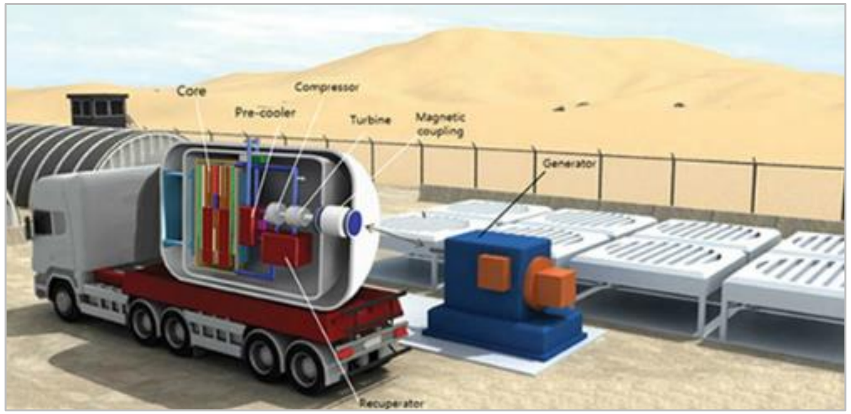
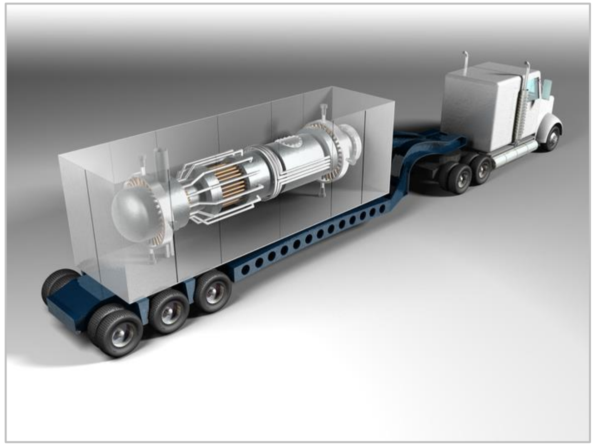
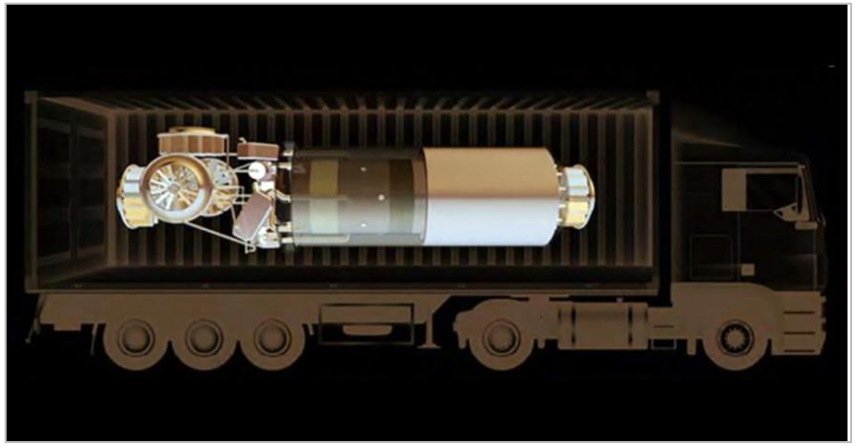
Nuclear Technology Overview – Reactor Options

New Breed of Mobile-MMR (Micro Modular Reactors) in Early Development









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Nuclear Technology Overview

Case Study: U.S.A.F. - Eielson Airforce Base

The concept of modular reactor use in a defence setting, is already a reality in other areas of the world. Eielson Air Force Base has been selected by the U.S. Air Force to receive its first nuclear microreactor, a nuclear 5MWe / 15MWt power plant, which could be operational as soon as 2027.

Eielson Air Force Base (AFB) is the Department of Air Force's (DAF) preferred location to pilot its first micro-reactor. The next-generation energy technology has the potential to provide the installation with a clean, reliable, and resilient energy supply for critical national security infrastructure.

Mark Correll, the Deputy Assistant Secretary of the Air Force for Environment, Safety and Infrastructure, said "*Energy is a critical asset to ensure mission continuity at our installations. Microreactors are a promising technology for ensuring energy resilience and reliability and are particularly well-suited for powering and heating remote domestic military bases like Eielson AFB and other critical national security infrastructure*."

Nuclear Derived Hydrogen: Potential Scale

Example Industry Deployment: Decarbonisation of Aviation

Aviation (H2 / FTHP / SAF by 2050)

300 MW Design (2 x Football Pitches)	SMR Direct Cold Electrolysis	SMR *350 °C Hot Electrolysis	AMR **650 °C Enhanced Hot Electrolysis	AMR Thermochemical Water Splitting
Reactor Number by Type	180	118	74	42

→ **Levelised Cost of Hydrogen Production Reduces** →

***300 °C Hot Electrolysis could deliver net zero hydrogen <$2/kg**

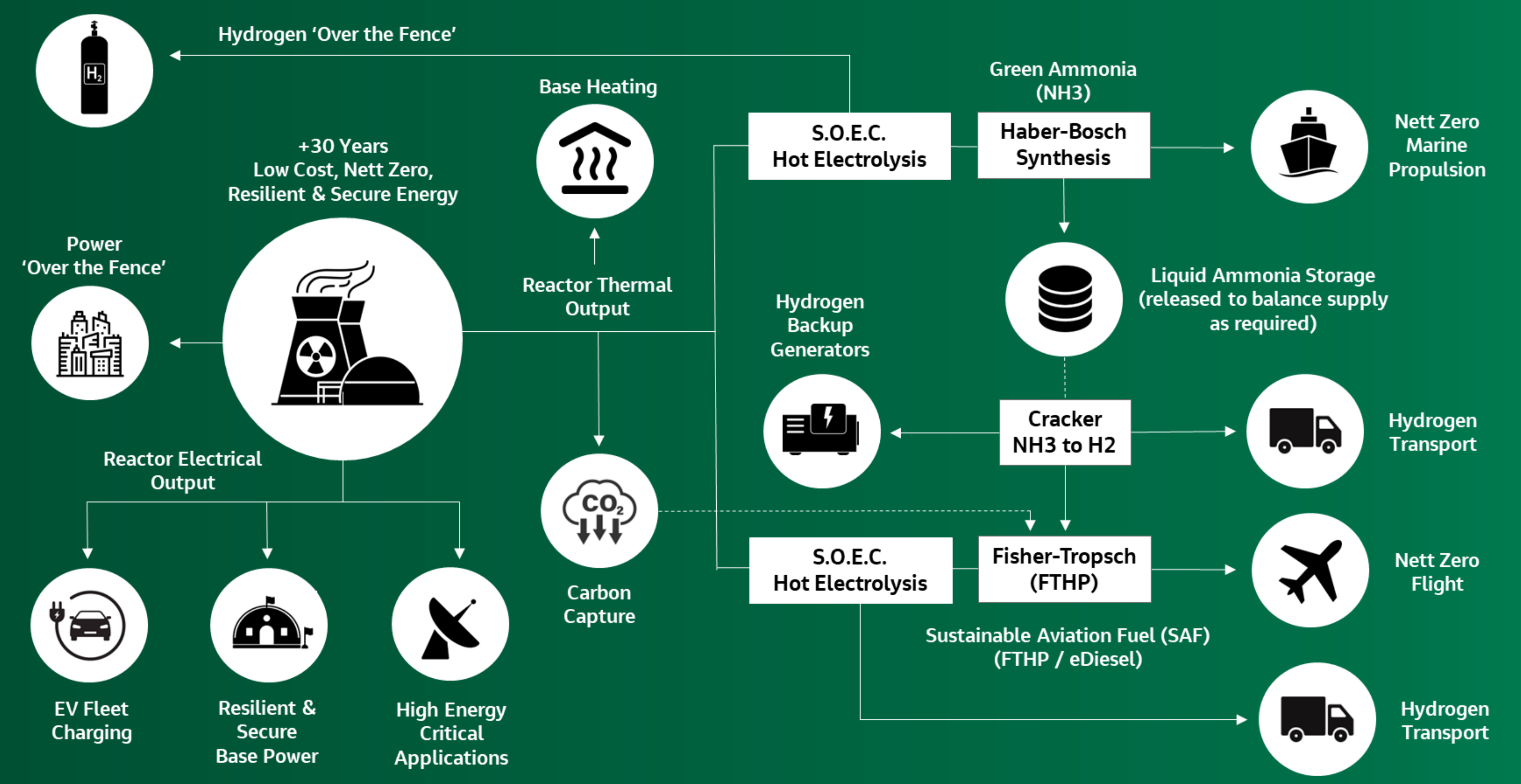
****650°C Next Generation - Advanced Modular Reactors could achieve <$0.90/kg**

(Hydrogen Council 2020; IEA, NREL, M. Ruth et al. Yan)
(Prof Juan Matthews, Dalton Institute 2023) (Idaho National Labs)

Based on 100% of 2019 UK Demand (Dukes 2020)

Reactor Estimates: NNL, Extract from New Build Working Group Report, Scale of Opportunity

Building a UK Approach to MoD use of Modular Reactors



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