NIA New Build Group Meeting
More Than Just Electricity

Thursday 7th July 2022

Nuclear Industry Association

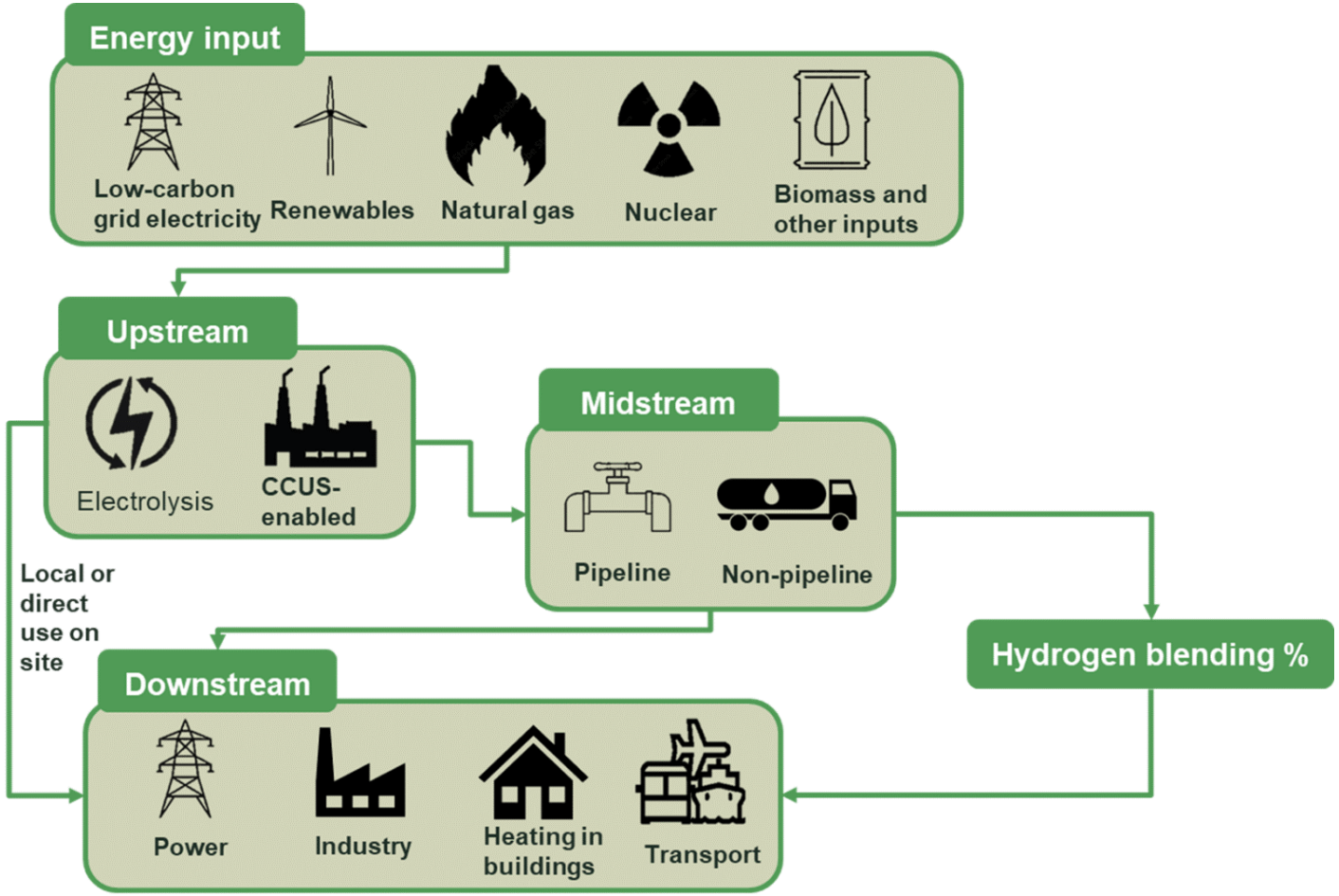
Nuclear Energy and Net Zero-Setting the Scene

NIA New Build Working Group Meeting
7th July 2022

Caroline Longman

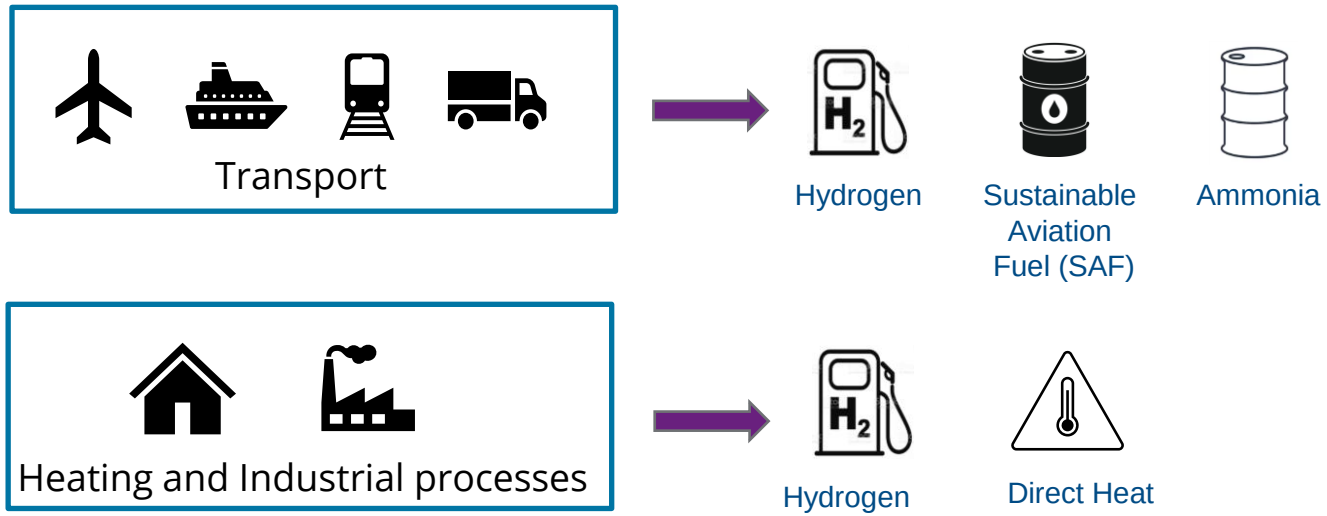
Introduction: Stepping Back-what is our Challenge

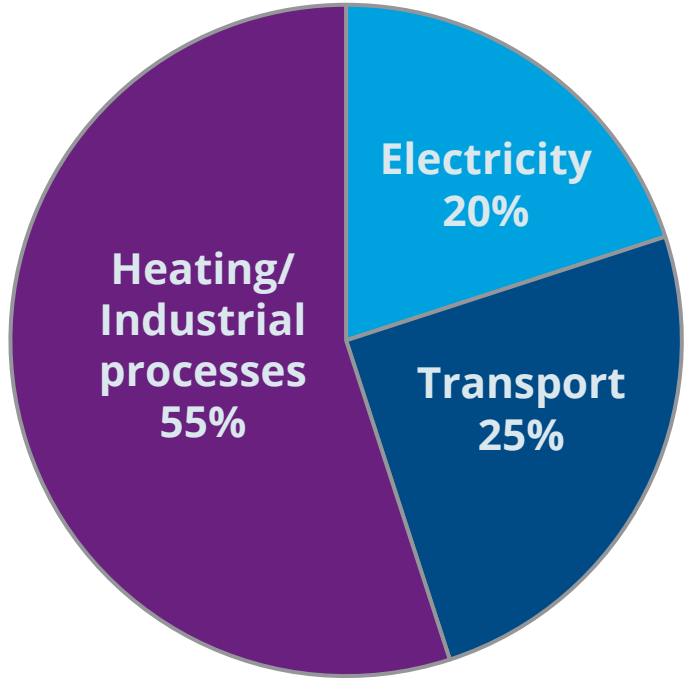
- Nuclear has delivered on clean baseload electricity production for decades
- Higher penetrations of renewables come onto the grid, traditional baseload energy will need to operate more flexibly
- Important for nuclear to join up with other sectors that make up the energy system



Emission Sources

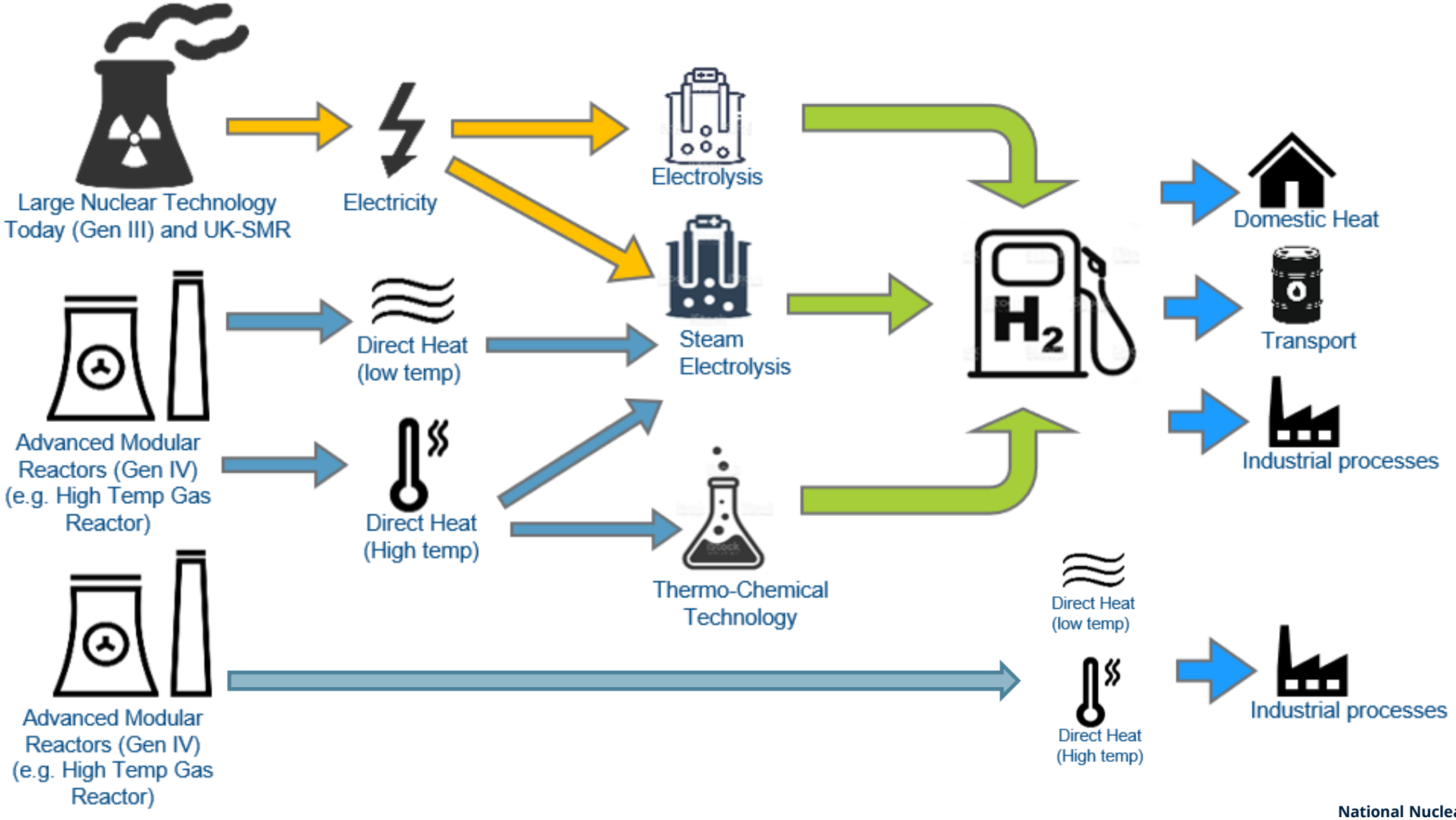
- Energy production 2/3 total global GHG Emissions
- Majority of this energy demand is non-electrical



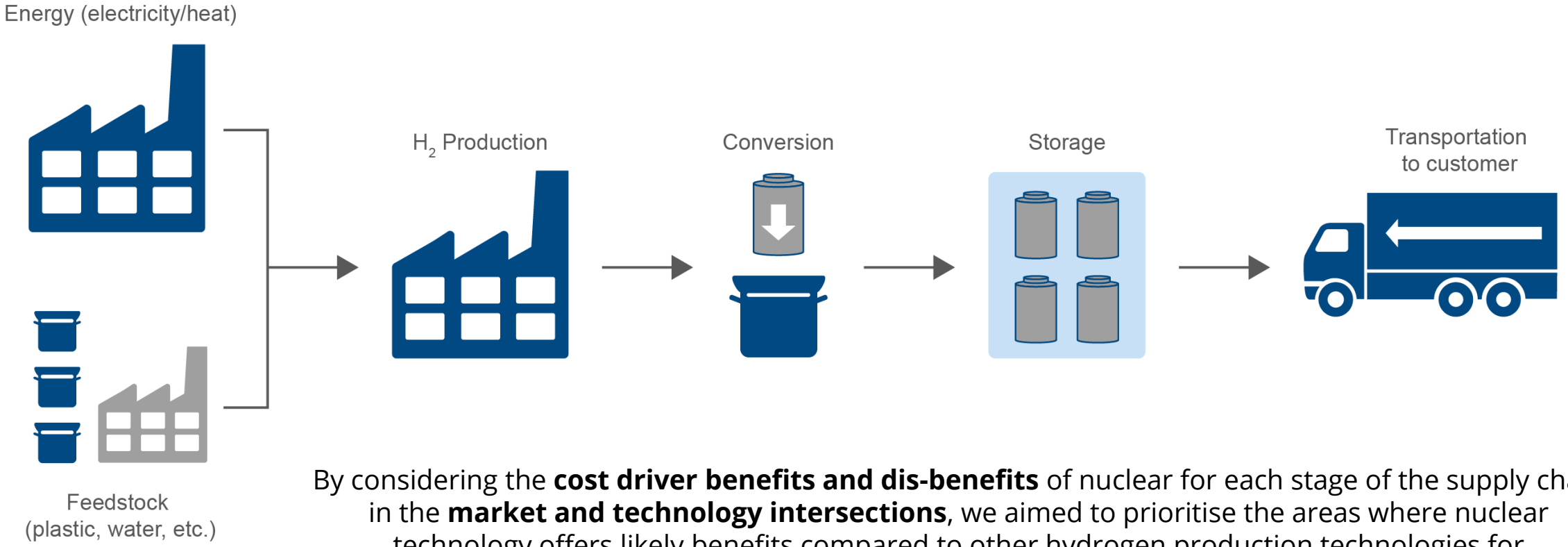


Share of end energy use (global)

Pathways to decarbonising Heat, Transport and Industry -Hydrogen & Heat

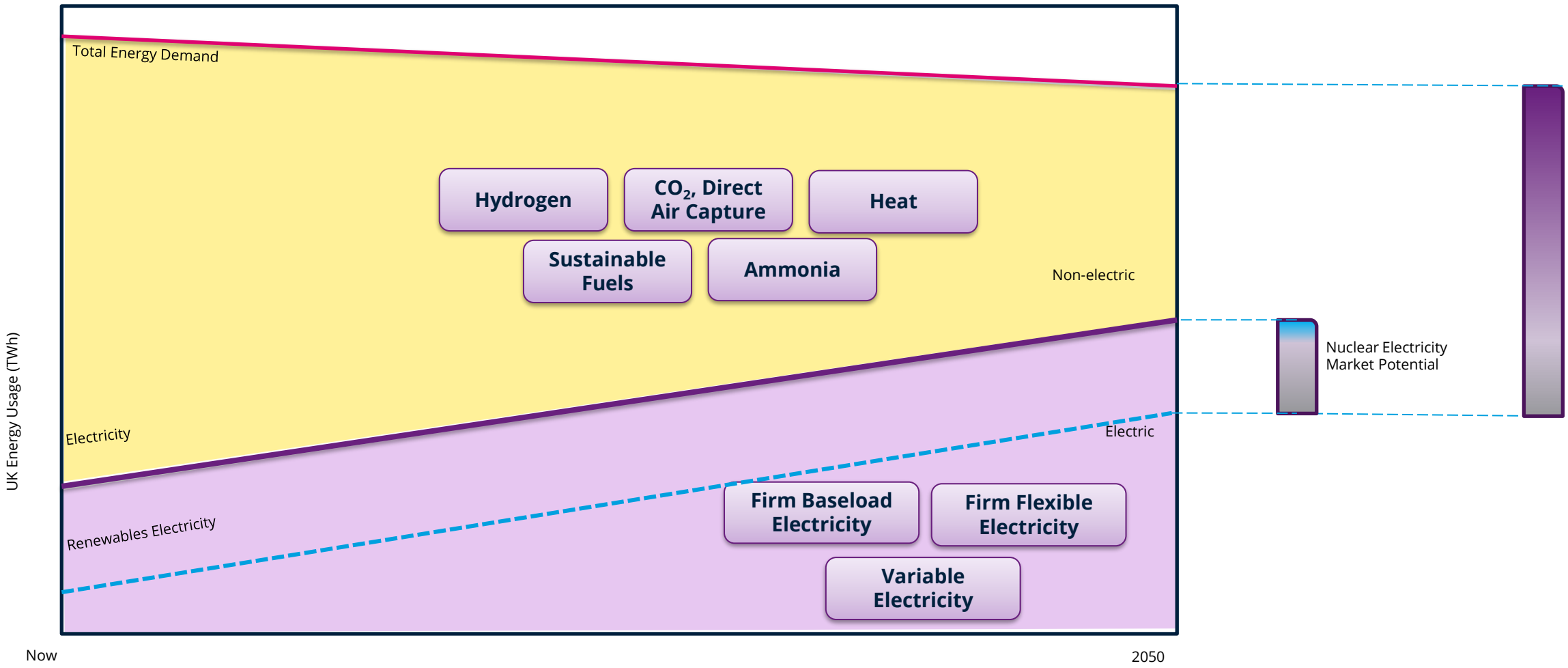


NNL Nuclear Hydrogen Programme



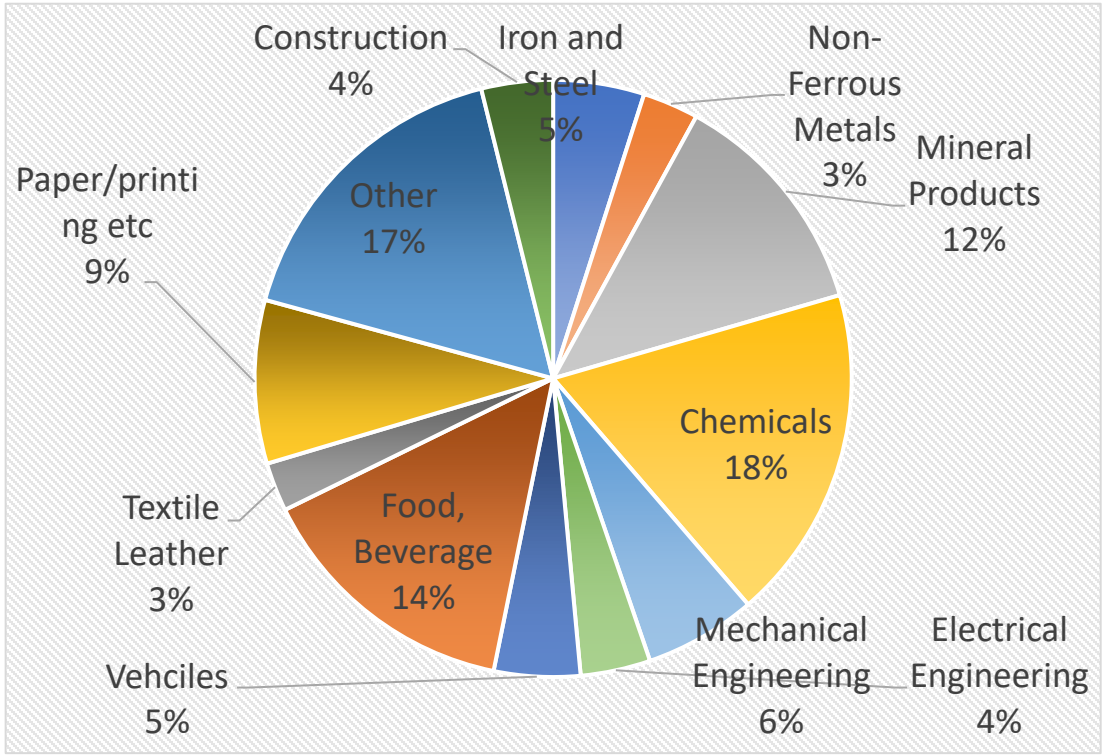
By considering the **cost driver benefits and dis-benefits** of nuclear for each stage of the supply chain in the **market and technology intersections**, we aimed to prioritise the areas where nuclear technology offers likely benefits compared to other hydrogen production technologies for technoeconomic assessment in phase two. This included questions around **market, geography, competitors, technology** and **supply chain** to produce a standardised **qualitative** assessment of the viability of the **intersection**.

Meeting future clean energy demand



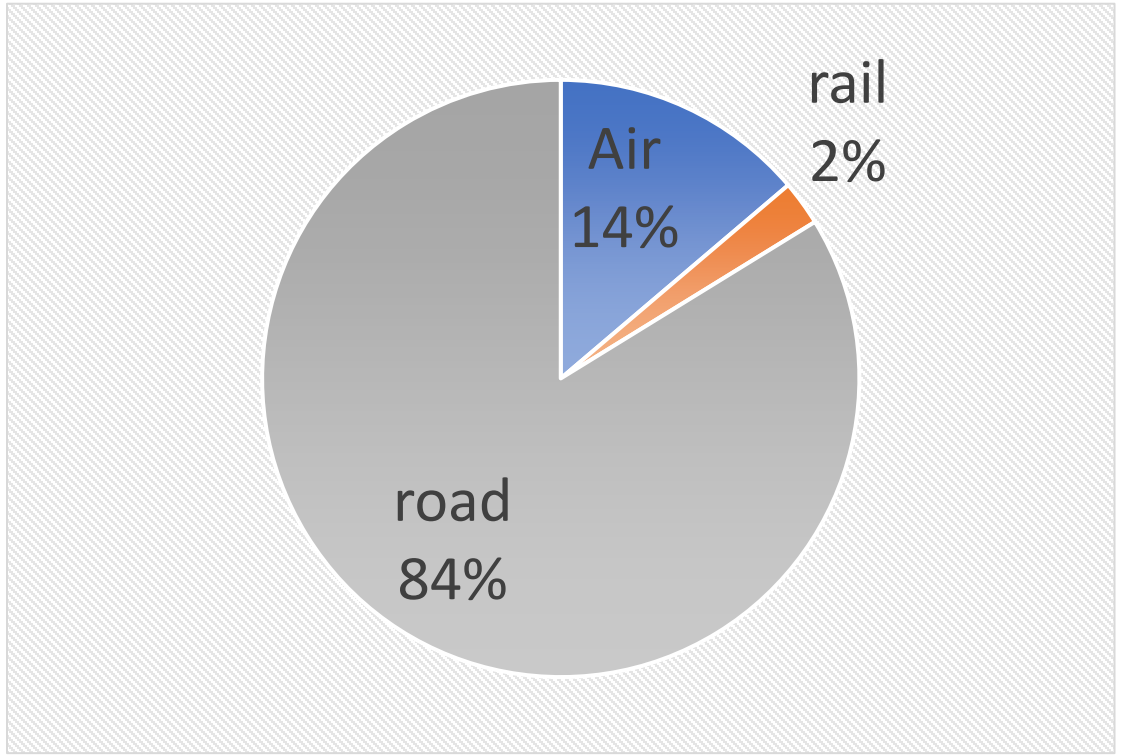
Future Energy Users

Industry



Aggregate Energy Balance

Transport



Meeting Heat Demand

NATIONAL NUCLEAR LABORATORY

Energy Users Covering Heat Demand Today and Tomorrow

Industrial Process Heat

Displacing
53 $MtCO_2e$
of emissions and
203 TWh
of energy consumption

Derivative Fuels

Displacing
63 $MtCO_2e$
of emissions and
187 TWh
of energy consumption

Hydrogen Production

Displacing
107 $MtCO_2e$
of emissions and
463 TWh
of energy consumption

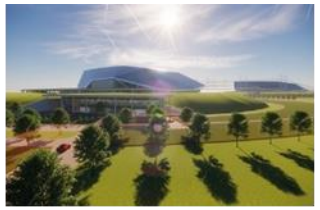
Scale of Opportunity

	GW scale LWR with direct electrolysis	UK SMR with direct electrolysis	UK SMR with low temperature steam electrolysis	HTGR with steam electrolysis	HTGR with thermochemical processes	LMFR with thermochemical processes	LMFR with steam electrolysis
Industrial – Chemicals	2	6	4	3	2	2	2
Industrial – Refineries	2	6	4	3	3	2	2
Mobility – Small scale land	41	154	101	62	61	37	51
Mobility – Large scale land	15	54	36	22	22	13	18
Mobility – Air	18	68	45	27	27	16	23
Mobility – Sea	4	13	9	5	5	3	5
Mobility - Space	1	2	1	1	1	1	1
Electricity & Storage							
Heating – Domestic	58	215	141	86	85	51	71
Heating - Industrial	19	71	47	29	28	17	24
Total	160	589	388	238	234	142	197

Where available, the values in the boxes indicate the number of reactors of that type that are estimated to be required to fulfil 100% of UK 2019 demand

Based on current available forecasts for overall plant efficiencies and data from DUKES 2020. Assumes constant consumption throughout year

Creating Momentum-Stakeholder Engagement



Decarbonise agriculture

Maintaining Manufacturing Competitiveness

Fuels for Export

Heating Homes

The Project

Complement Renewables

Powering Transport

Cooking on H2 Gas

Maintain user experience

Example of Nuclear Industry Cross Sector Working

Unlocking the UK's Nuclear Hydrogen Economy to Support Net Zero:

A Cross-Sector Action Plan for Consideration by the Nuclear Industry Council

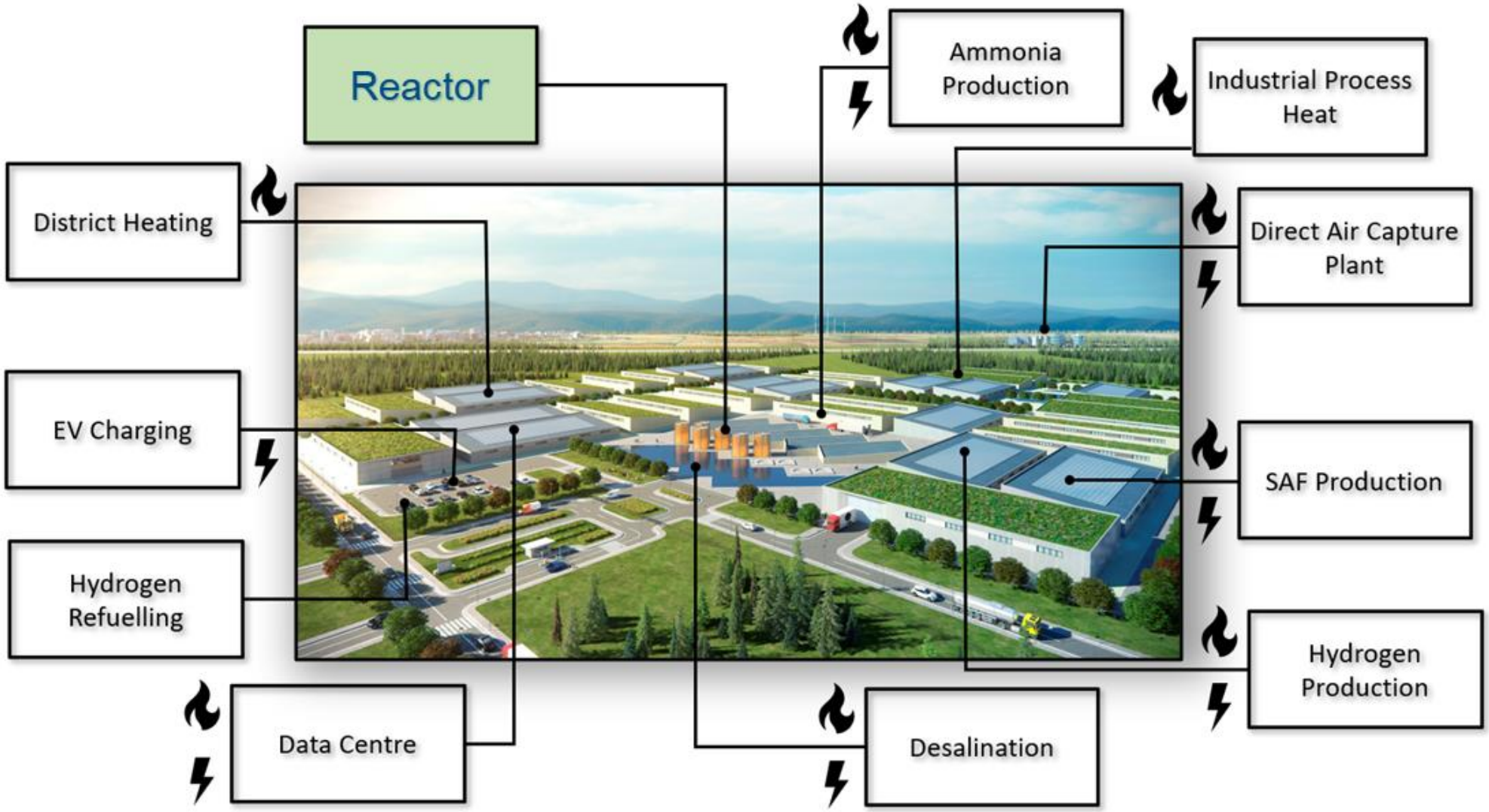
JULY 2021

SECTOR DEAL
NUCLEAR INNOVATION

NATIONAL NUCLEAR LABORATORY

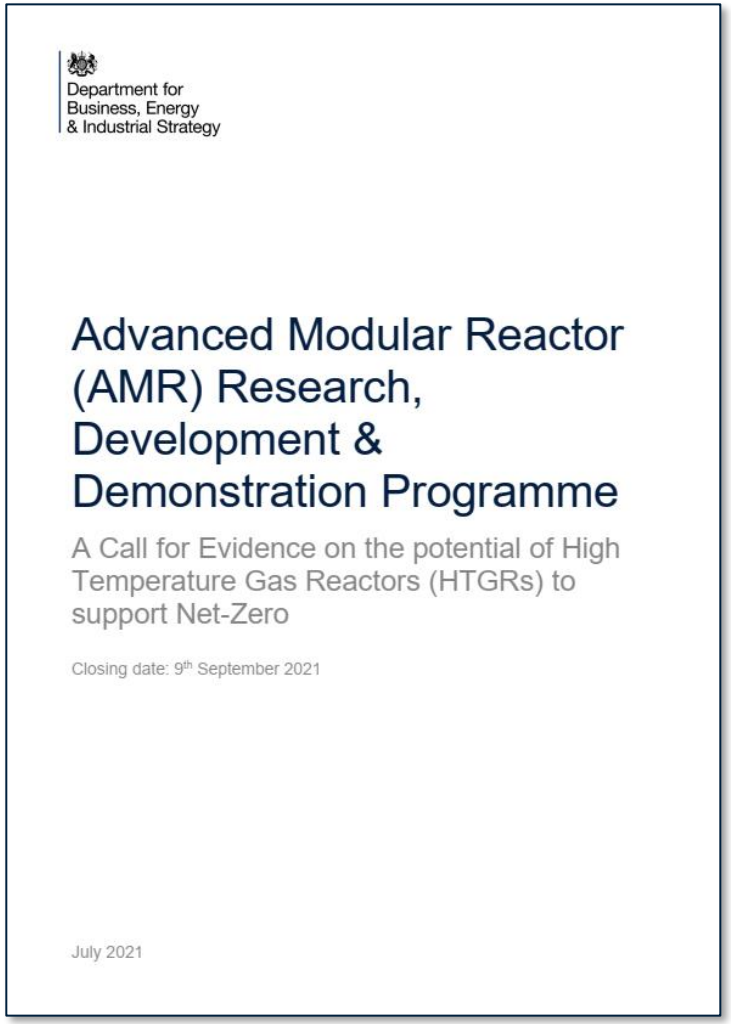
The Role of Nuclear

AMR infrastructure - The addressable market

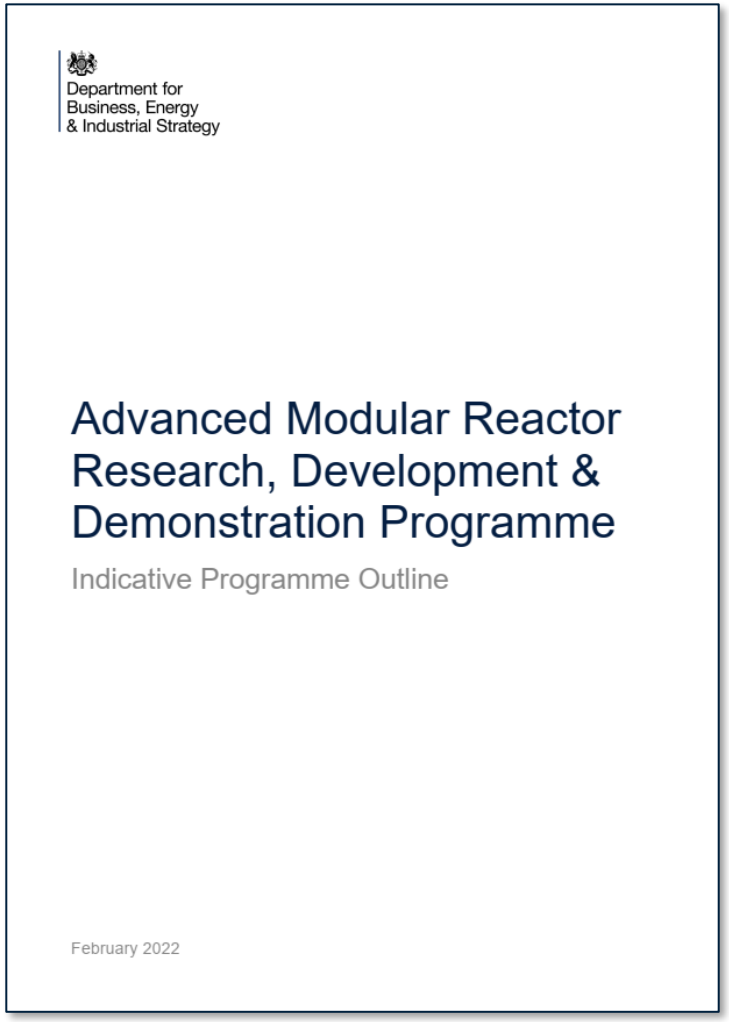


AMR Research, Development and Demonstration

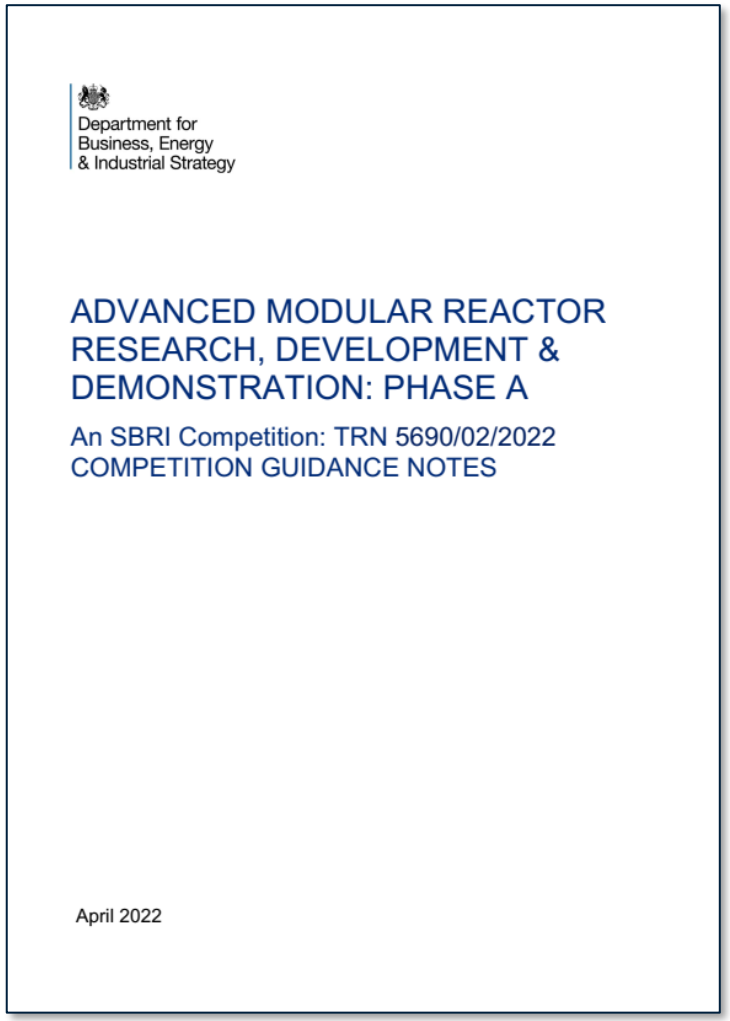
The UK prioritises HTGR for demonstration



July 2021



February 2022



April 2022

Thank you

National Nuclear Laboratory
5th Floor, Chadwick House
Warrington Road, Birchwood Park
Warrington WA3 6AE
T. +44 (0) 1925 933 744
E. customers@uknnl.com

www.nnl.co.uk

Nuclear Advanced Technologies

NIA New Build Group, July 2022

Matthew Billson

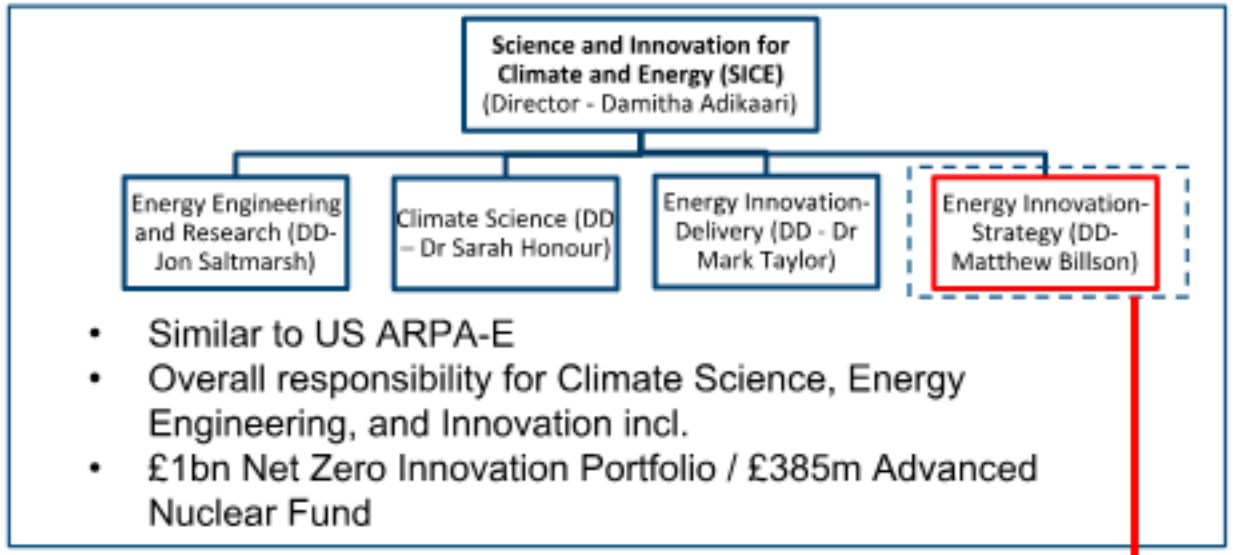
Matthew.billson@beis.gov.uk

Deputy Director, Energy Innovation Strategy & Portfolio, BEIS

Co-lead £1bn+ Net Zero Innovation Portfolio
(Nuclear, Renewables, Smart, Built)

Department for
Business, Energy
& Industrial Strategy

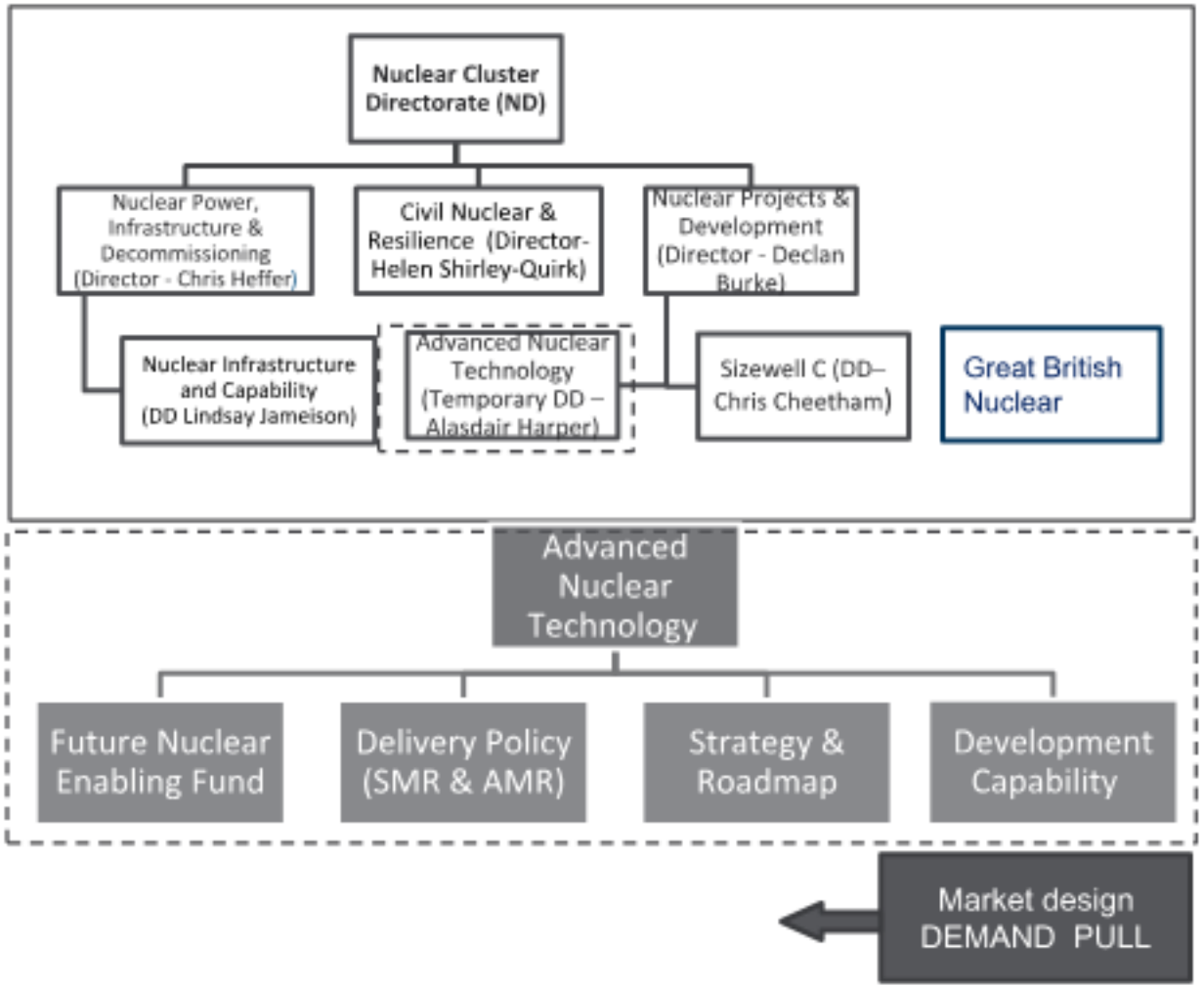
Context



- **£385m Advanced Nuclear Fund**, including:
  - RR-SMR "Low Cost Nuclear" R&D project (£210m grant)
  - AMR Research, Development & Demonstration Programme
- £56m Advanced Fuels with NNL ("AFCP"), funded from 2019 onwards

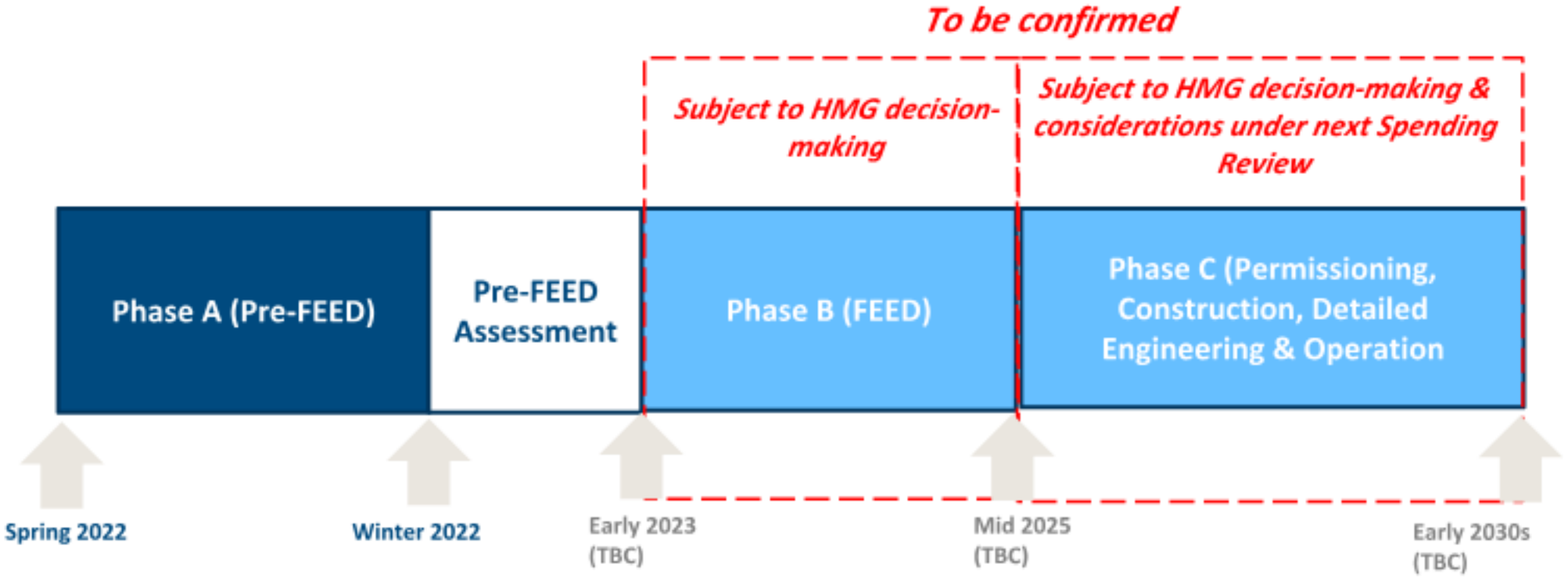
Technology PUSH

SICE led – technology focused. Provides the evidence, seed IP and direct technology investment (grants & procurement). *Opportunity for nuclear policy to shape where and what innovation funding is spent on and to what end.*



ND led - sets the aims and policy to influence both industry and innovation. Provides the structures and support that enable technologies to commercialise. (Regulation, Enabling Fund, delivery model). *How does government policy enable confidence for investment to cross the valley of death and then to succeed commercially?*

AMR - Proposed conceptual approach



babcock™

New Build Frigate Digital Transformation
Integrated Design, Build and Support

7th July 2022

Digital Transformation & the Digital Thread

Digital Facility

- Detail Design - distributed digital design and approvals.
- Production – Seamless transfer of information from design to build and full digital vessel acceptance and configuration.

Digital Twins

At the heart of digital tech. applications and transforming how complex assets are built & supported.

iSupport360

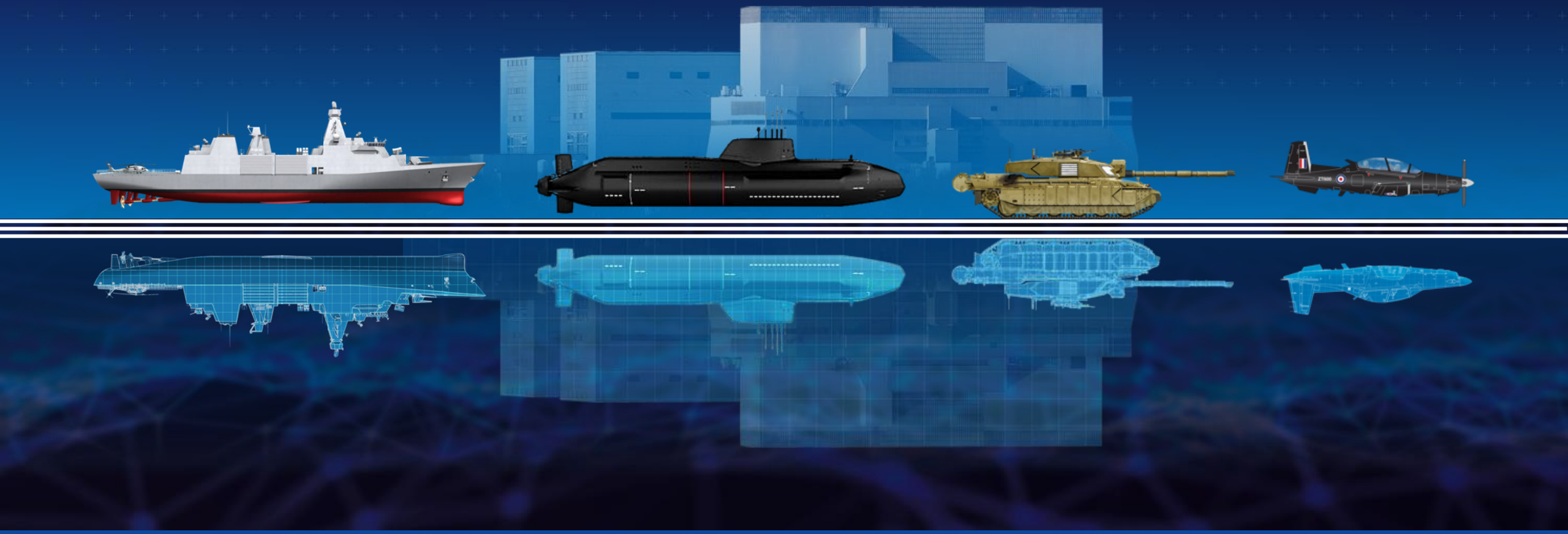
- Programmatic approach to solve complex challenges: through advanced analytics and digitisation.
- Deliver expertise: understand the data, understand the asset.
- Agility: Adapt as the journey changes. Responding more quickly to changing demands and conditions.

Secure Communications

babcock™

DIGITAL THREAD

Innovation through collaboration. Empowered by technology.



babcock™

DIGITAL DESIGN

TRAINING

SYSTEMS SUPPORT

EQUIPMENT MANAGEMENT

DIGITAL TWIN

CAD | CAM | DMS | PDM | BOM

babcock™

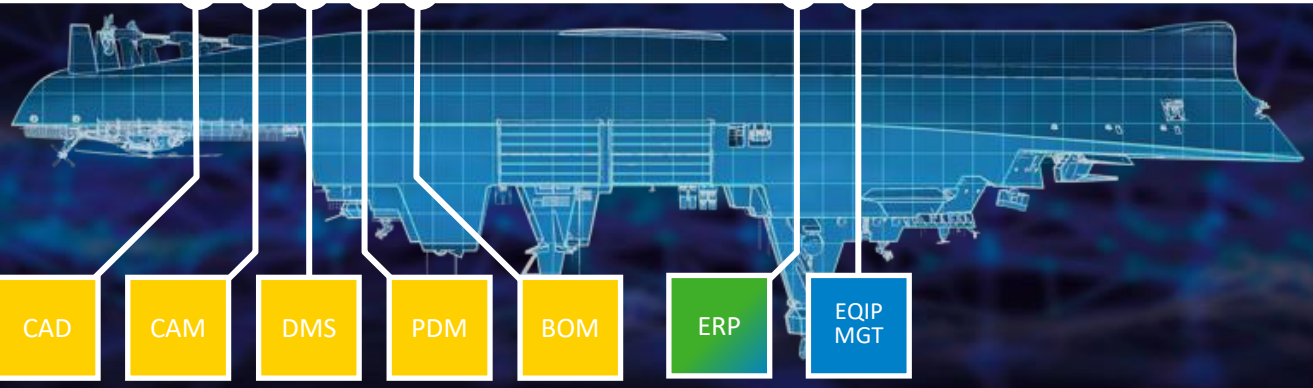
PRODUCTION

TRAINING

SYSTEMS SUPPORT

EQUIPMENT MANAGEMENT

DIGITAL TWIN



CAD | CAM | DMS | PDM | BOM | ERP | EQIP MGT

babcock™

OPERATION

TRAINING

SYSTEMS SUPPORT

EQUIPMENT MANAGEMENT

CAD | CAM | DMS | PDM | BOM | ERP | EQIP MGT | DASH BRD | ANALYTICS

babcock™

MAINTENANCE

TRAINING

SYSTEMS SUPPORT

EQUIPMENT MANAGEMENT

CAD | CAM | DMS | PDM | BOM | ERP | EQIP MGT | DASH BRD | ANALYTICS

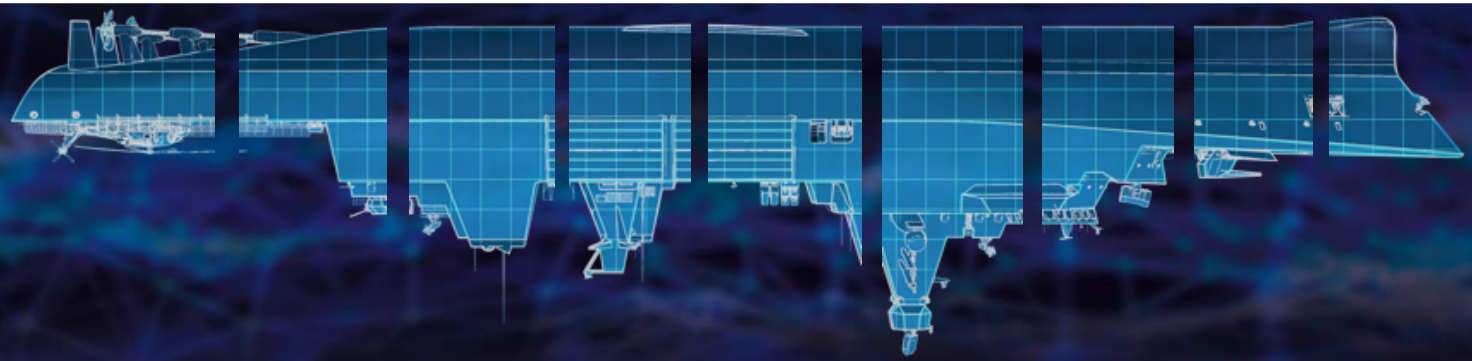
babcock™

DISMANTLING & DISPOSAL

TRAINING

SYSTEMS SUPPORT

EQUIPMENT MANAGEMENT



babcock™

Digital Facility

babcock™

Digital Facility

It's about integrating technology so everything works together, coupled with a shift in mindset to be more dynamic and responsive.

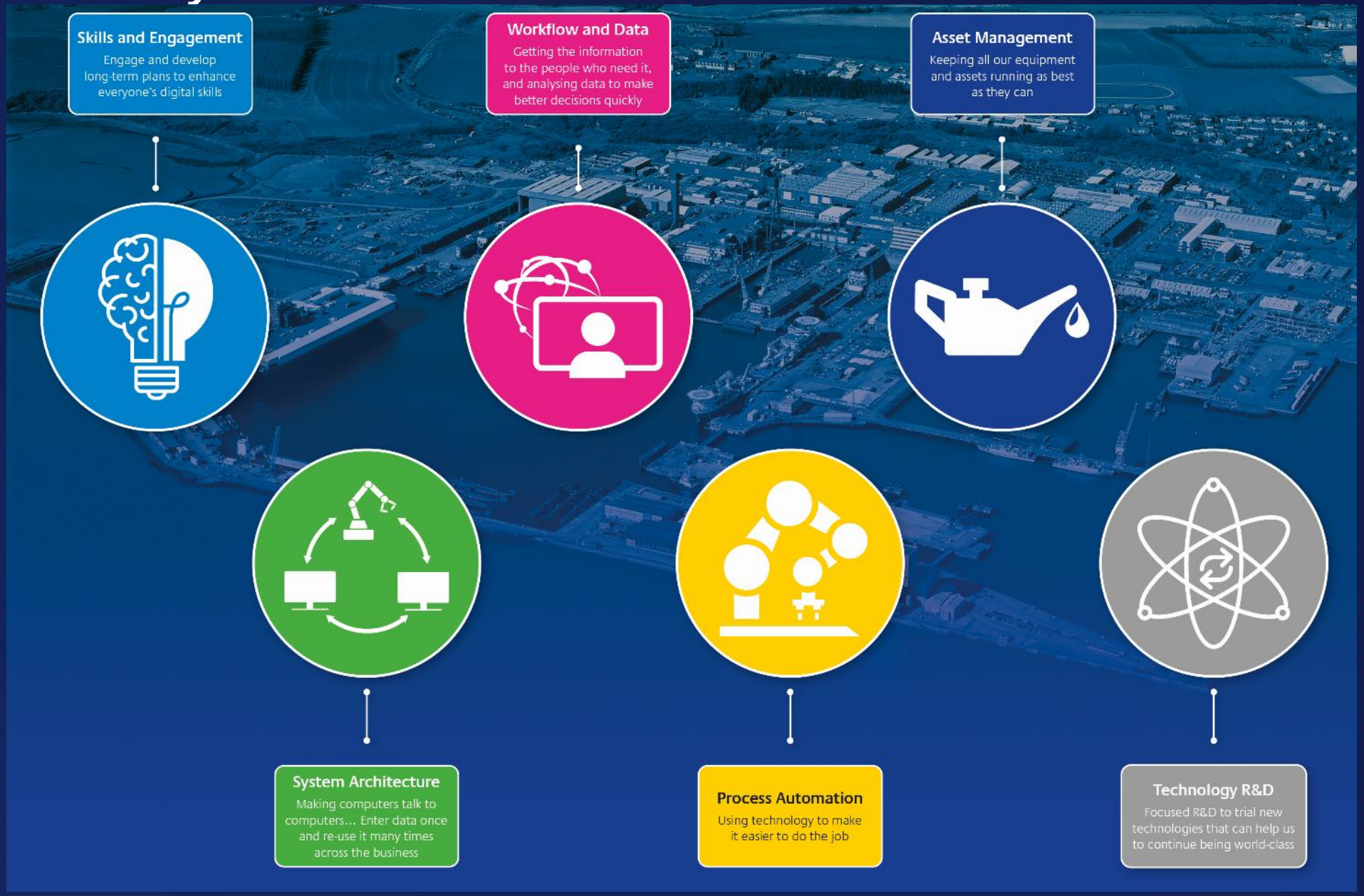
Our Digital Facility transformation will touch many areas of our shipyard, including:

- Having data flowing from design to delivery seamlessly
- Greater automation and repeatability
- Minimal paper on the shop-floor.

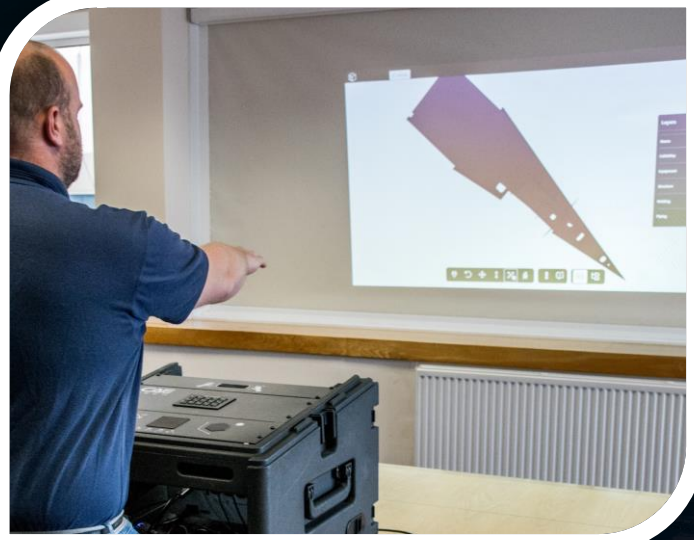
The Digital Facility will help us realise the full potential of our people and assets to deliver successful projects, be more competitive and secure future work.

Employee driven improvement and innovation

Digital Facility in Practice

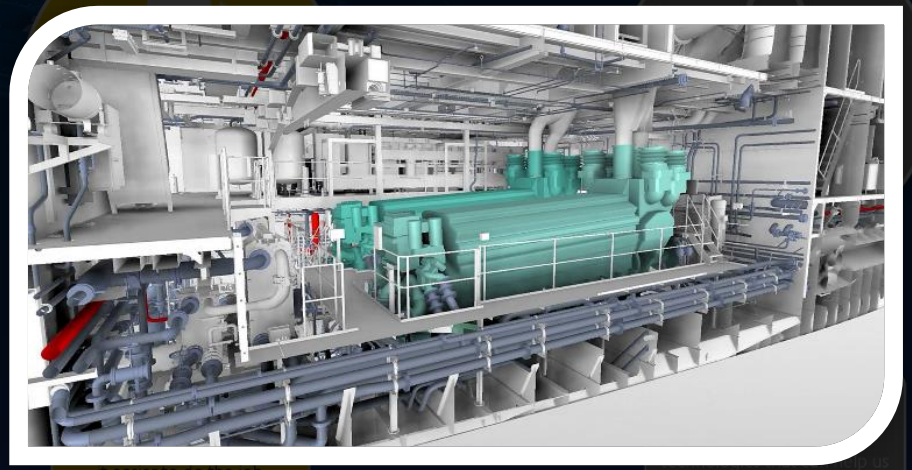


Digital Facility in Practice

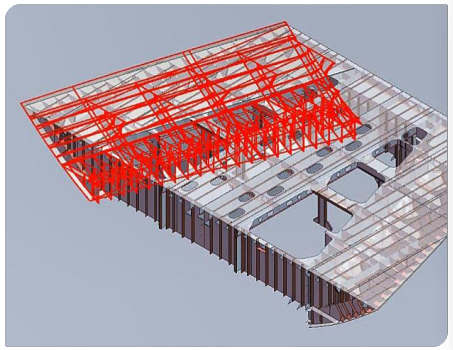


Digital skills training for shop floor personnel empowering them to use technology to access information they require such as 3D models

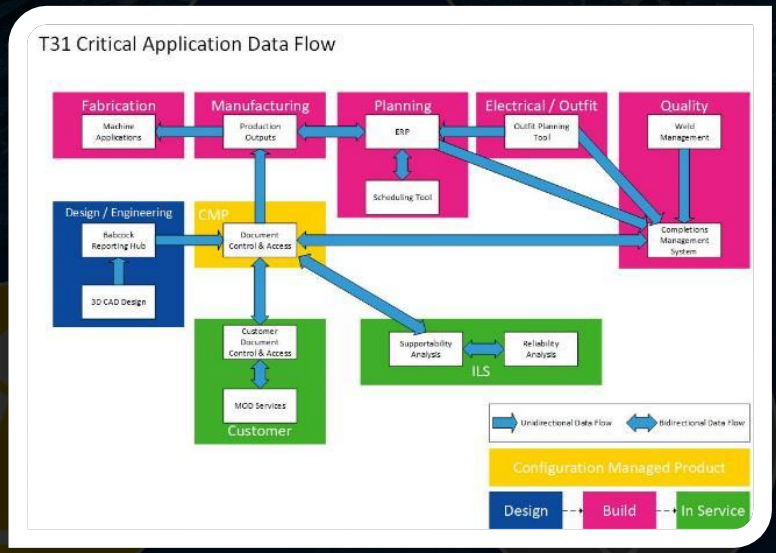
Training of "Super Users" for critical software packages embedded within front-line teams to maximise utilisation & capability of tool-set at the point of use

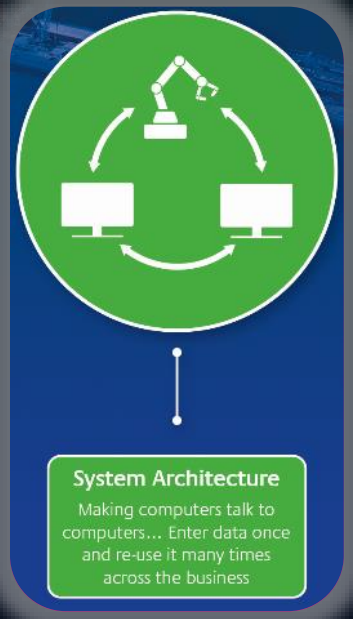


Digital Facility in Practice



Managed exports of 3D models straight into the production management tool for nesting and digital control instructions for our state of the art machines: significantly reducing the need for 2D drawing, saving time and resource





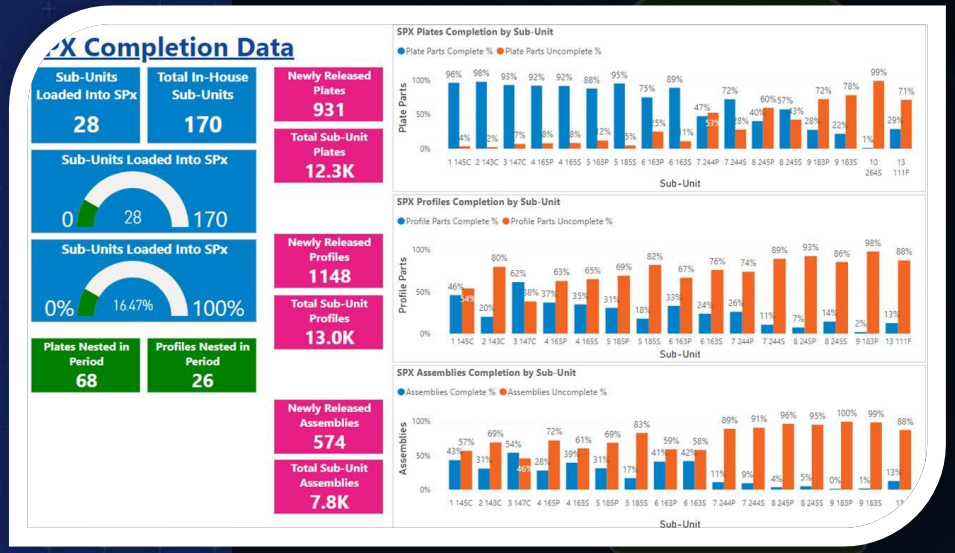
Development of a fully integrated Information Knowledge Management System which integrates core applications allowing for automated data transfers for better data quality & continuous flow of re-used data

Digital Facility in Practice

Skills and Engagement
Engage and develop long-term plans to enhance everyone's digital skills

Workflow and Data
Getting the information to the people who need it, and analysing data to make better decisions quickly

Introduction of mobile devices and shop floor kiosks allow operation teams to have information accessible at the point of work

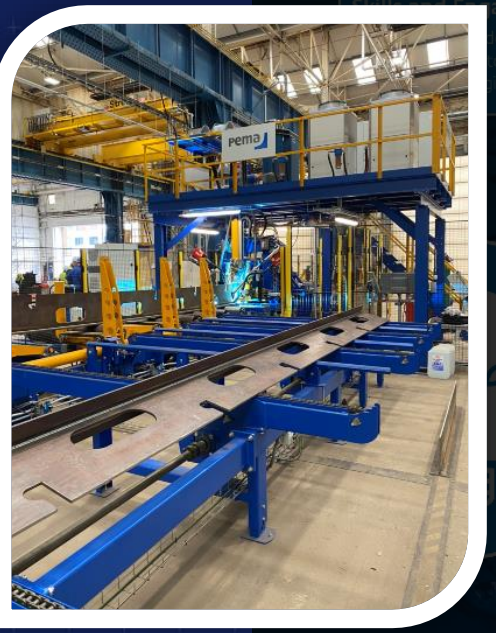


With shop floor digitisation implemented, data is updated as work is completed, allowing for real time reporting analytics

Process Automation
Using technology to make it easier to do the job

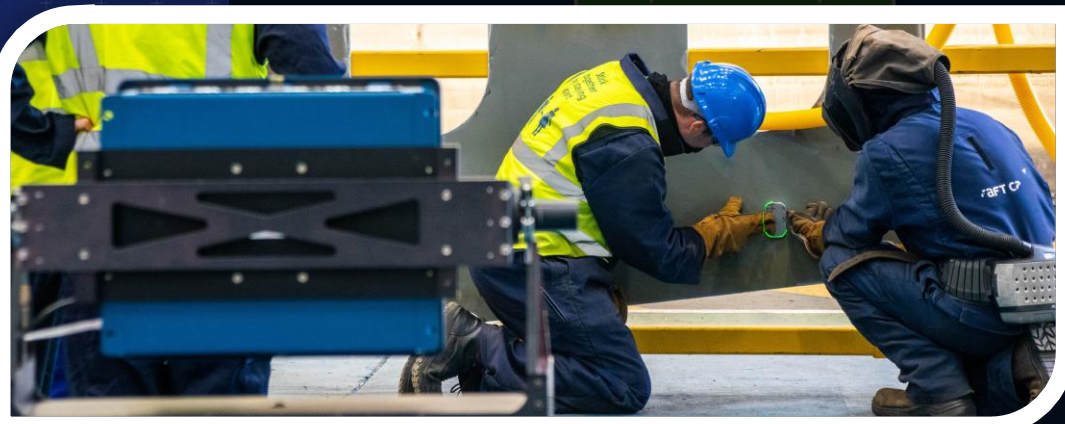
Technology R&D
Focused R&D to trial new technologies that can help us to continue being world-class

Digital Facility in Practice



T-Beam Machine increasing productivity and quality

The FARO Laser projector allows the fitting of outfit items to the ship to be done without the need of additional 2D drawings and traditional manual measuring and fitting



Process Automation
Using technology to make it easier to do the job

Panel Line with automated marking & cutting and robotic welding capable of producing complete ship deck & bulk heads

Digital Facility in Practice

Fully networked machining centres allowing for remote access for troubleshooting & maintenance support

Workflow and Data

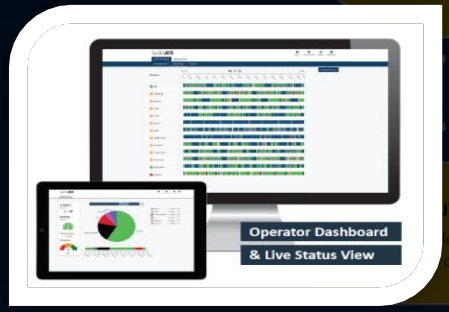
Getting the information to the people who need it, and analysing data to make better decisions quickly

Asset Management

Keeping all our equipment and assets running as best as they can

Resource	Status	Utilisation Current Day	Utilisation Week
Fx1	Running	38%	
Fx2	Unknown Stoppage	69%	

Data capture of asset utilisation allowing for improved capacity planning

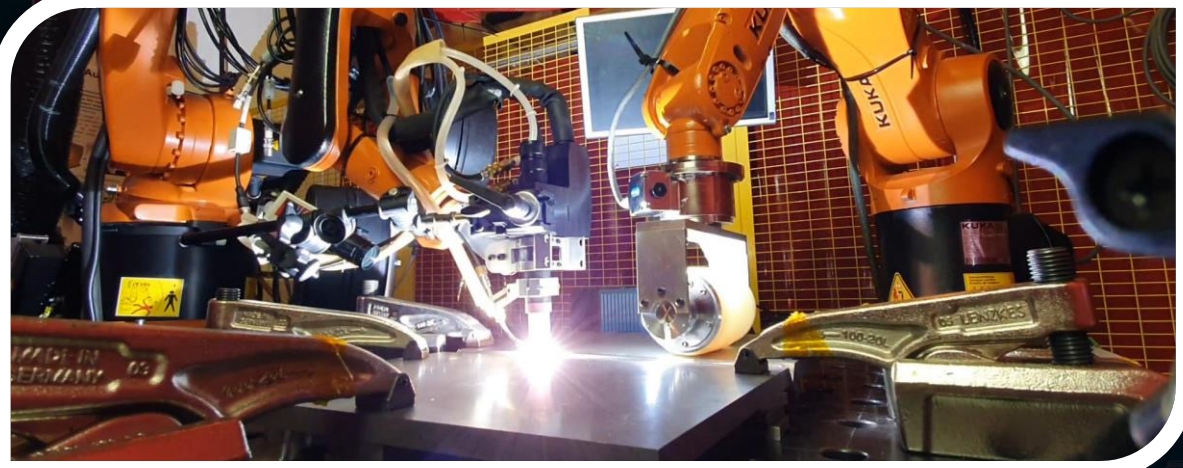


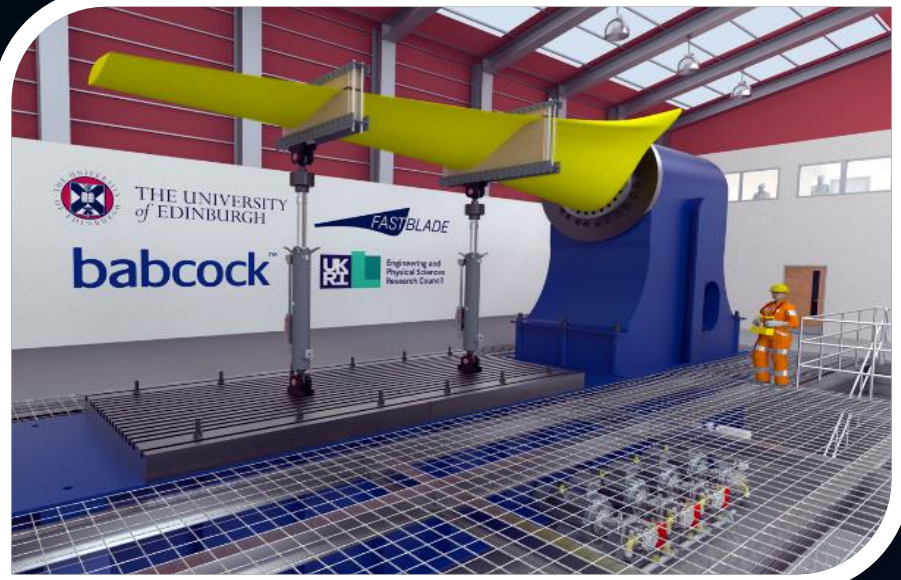
Technology R&D

Focused R&D to trial new technologies that can help us to continue being world-class

Digital Facility in Practice

Research into using machine learning to deliver high-integrity welding, weld inspection and potentially weld certification in near real time as part of the AWESIM Project





Fastblade facility developing tidal turbine technology along with digital twin knowledge and application

babcock™

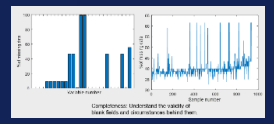
Digital Twins

Enabling innovation

Innovation through collaboration. Empowered by technology.

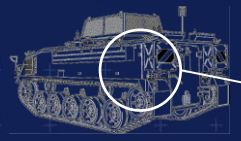
babcock™

Application of Digital Twins



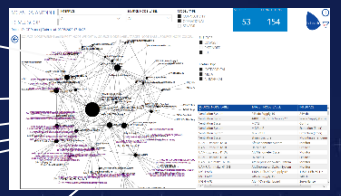
Data Quality Assurance application of AI

Phase 1: Identification and quantification of data problems
Phase 2: Data restoration
Phase 3: Data restructuring and reconciliation



DIGITAL TWIN

Digital Twin Models



System of Systems Platform Model

- Composite & Federated Digital Twin
- Standards Based approach
- Open Architecture Frameworks

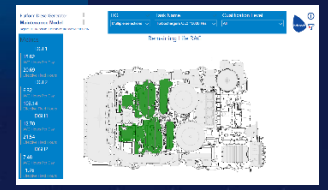
iSupport360

Lifing Models

DATA ANALYTICS, MODELLING, SIMULATION & PREDICTION

DECISION MAKING, PLANNING & IMPLEMENTATION

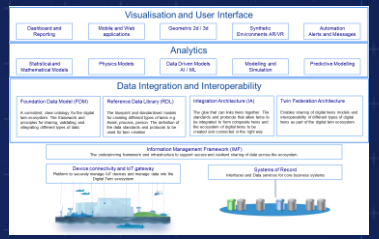
System Modelling



Operating Models

CYCLICAL CONTINUOUS IMPROVEMENT

Common Reference Architecture & Digital Backbone



DATA CAPTURE

Asset Digitisation

- Engineering Analysis
- Sensor application
- Edge – Data capture and processing
- Edge – Digital Twin model deployment

iSupport360 - Improving Availability

- Improving availability, while reducing cost & risk;
  - Data analytics
  - Predictive maintenance
  - Digital twin
- Exploiting & integrating our breadth of capabilities;
  - Engineering & ILS
  - Support Delivery
  - Equipment Management
  - Technology
  - Training

Digitally Enabled Performance & Support Solution

Data Driven Understanding of Availability and Reliability

Optimised System Performance

Transformed Support Solution

DIGITAL TWIN

Running Hours & Failure Data

USE OF DATA

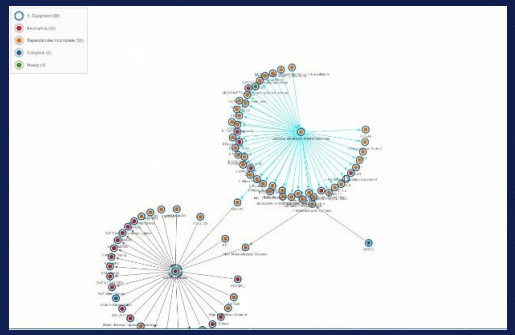
DATA BARRIER

METRICS

Operating Load & Profile Analysis

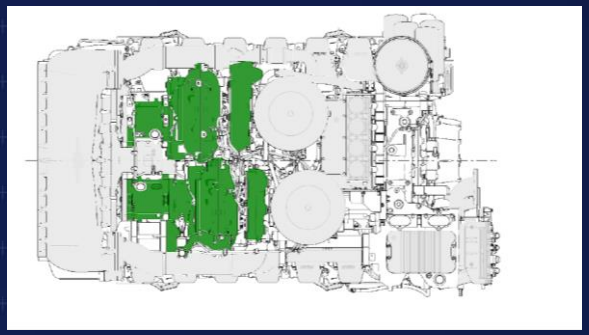
LIFE MODEL

System of Systems Analysis



SYSTEM INTERDEPENDENCIES

Detailed Equipment Forecasts

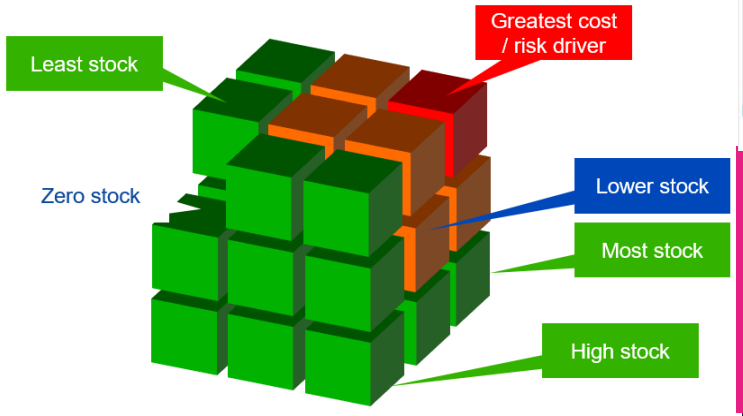


PLANNING FORESIGHT

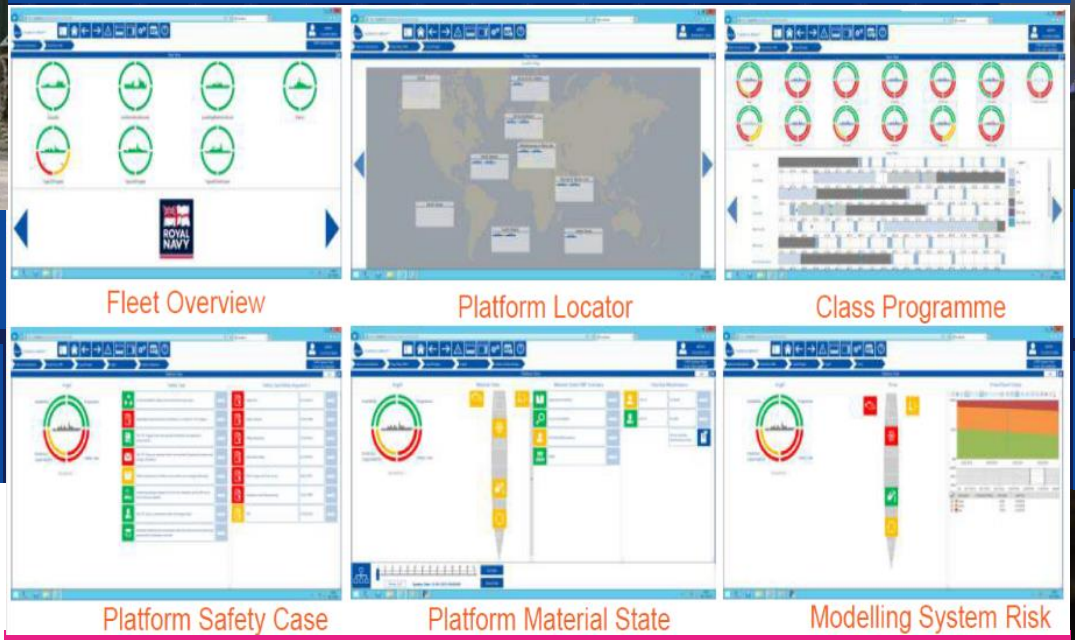
Operations Centre – Intelligent Support Planning

Data Capture

Red Cube – Supply Chain Optimisation



Optimised Support Fleet View Dashboards



Intelligent Decision Support

Data Analytics

Technology Exploitation

What makes our approach different?

Adopting an incremental approach

We break development down into discrete stages that provides benefits earlier, creating insight and removing future risk.

Analysing at the edge

We reduce transmission overhead by taking the processing to the asset, delivering immediate intelligence to the maintainers.

Adding the missing data

Many existing systems lack the engineering data to create a Digital Twin or provide effective support. We use sensor data and analysis to create modern data packs.

Applying Digital Twins to existing equipment

We believe that the biggest and most immediate gains are derived by improving the reliability of existing in-service equipment.

Accessing the broader support model

We integrate Digital Twins with our other support capabilities, including spares optimisation, logistics support and training.

Advanced Welding Equipment System for Inspection and Monitoring (AWESIM)

In-Process Weld Inspection

C. N MacLeod[1], D. Lines[1], R. Vithanage[1], M. Vasilev[1], C. Loukas[1], N. Sweeney[1], E. Foster[1], E. Mohseni[1], Y. Javadi[1], G. Dobie[1], S.G. Pierce[1], A. Gahagan[1], N.King[1], P. Applequist[1], A. Burnett[2], C. Murray[2], R. Whitmore[2], P. Robinson[2], B. Holt[3], M. Symington[3], J. Allan[3], G. Little[3], M. Smart[4], D.L Ayres[4], J. Leatherland[4],

1: Centre of Ultrasonic Engineering (CUE), Department of Electronic & Electrical Engineering, University of Strathclyde, Glasgow
2: Cavendish Nuclear, Babcock Technology Centre, Unit 100A, Bristol Business Park, Stoke Gifford
3: Doosan Babcock, Porterfield Rd, Renfrew 4: Nuclear Advanced Manufacturing Research Centre (NAMRC), University of Sheffield, Rotherham

Before AWESIM – Separate Distinct Disciplines

Fusion Arc Welding

Non-destructive testing (NDT) inspection

- Sequential activities
- Different disciplines
- Feedback loop slow (hours to days)

AWESIM Introduction

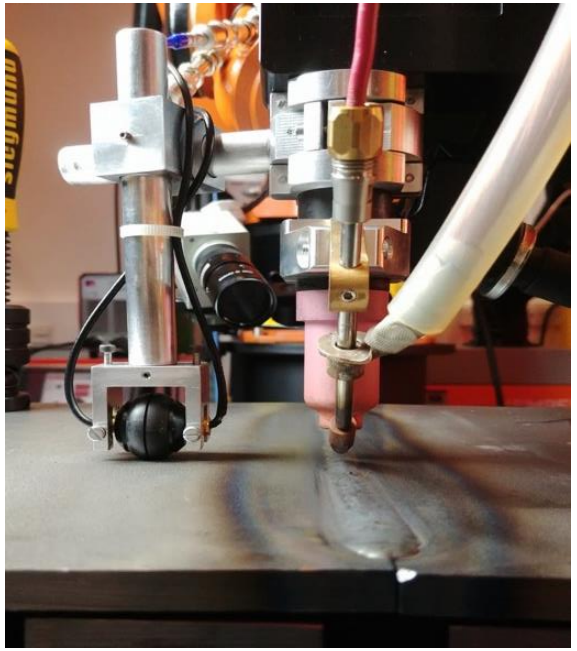
- **AWESIM (Advanced Welding Equipment System for Inspection and Monitoring)**

- AWESIM Stage 1 builds upon the in-process inspection activities of the EPSRC Prosperity Partnership and builds on the collaboration on the SIMPLE project with the Nuclear AMRC at University of Sheffield.

In-Process Ultrasonic Weld Inspection

University of Strathclyde Engineering

- Quality of weld measured at point of deposition
- ***Defects detected when they occur***
- ***Reduced rework when compared to completed fully-filled welds***
- ***Increased Schedule Certainty***
- Increased Throughput
- Reduced Production Time
- Increased safety and lifetime benefits
- Opportunity for Process Control



In-Process Inspection Challenges

University of Strathclyde Engineering

Coupling – Traditional Liquid Coupling will invariably introduce defects

Electromagnetic Interference

Signal to Noise Challenges

Probe Deployment

High-Temperatures experienced in close proximity to weld

Speed of sound varying due to temperature change in material

Partially-Filled Groove Reflections

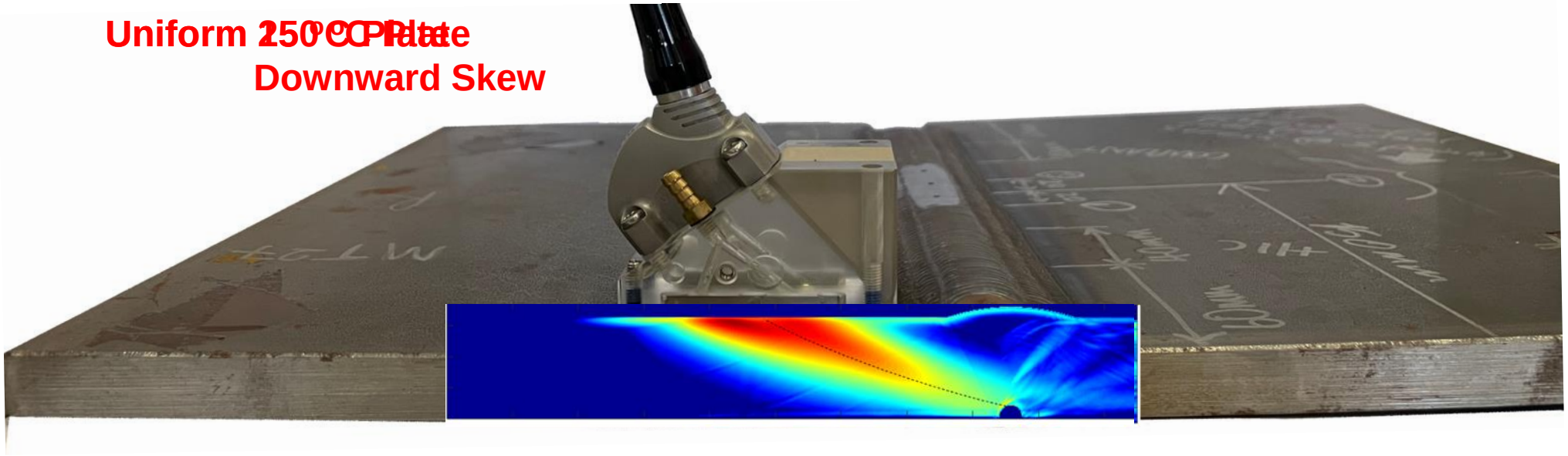
In-Process Wave Propagation - Temperature

Incorporating Weld Thermal Gradient

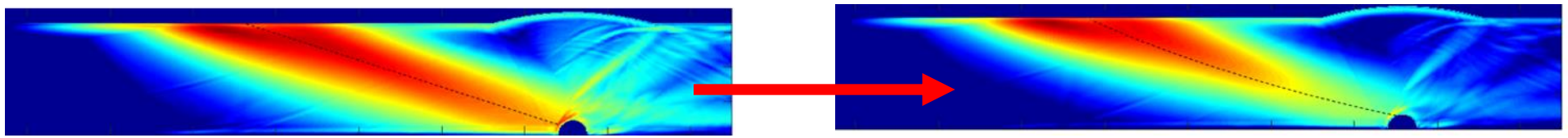
Continual Beam Bending

Uniform 250°C Plate

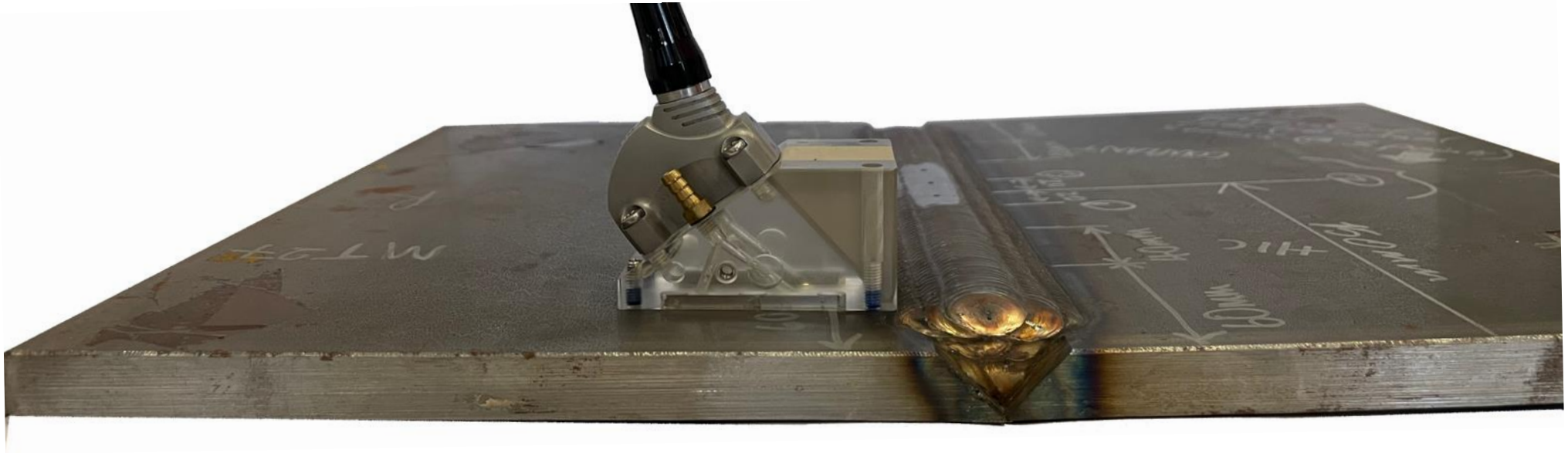
Downward Skew

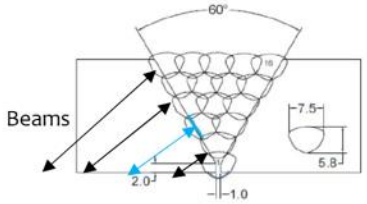


- Non-uniform thermal gradients present during in-process fusion weld inspection result in complex wave beam refraction, energy reduction and time shifts from weldment defects/reflectors present.

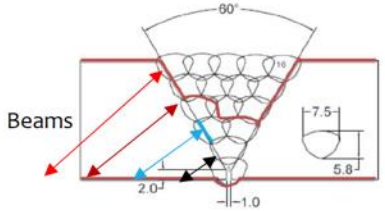


In-Process Inspection – Partially Filled Grooves





Standard Complete Weld and Correctly Reports LOF Defects (Blue)

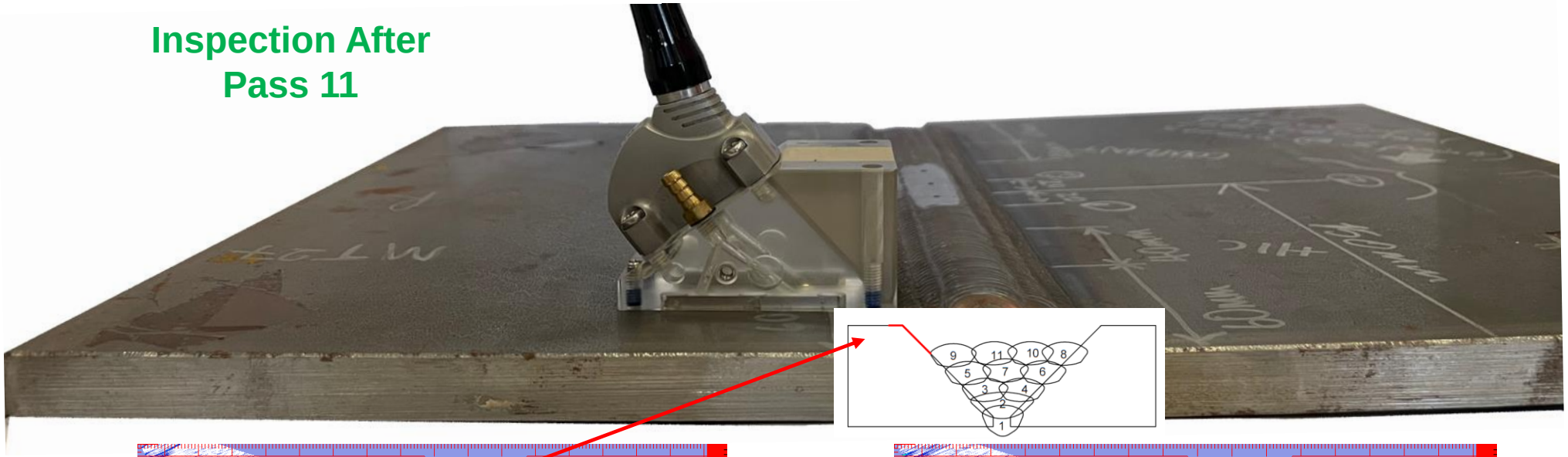


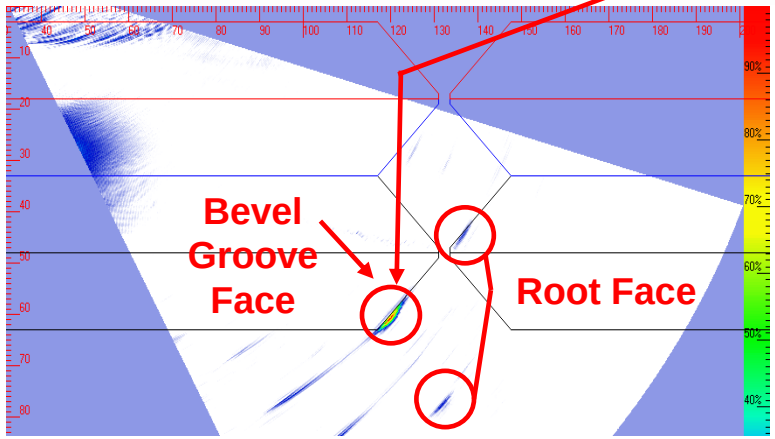
Defect During Welding: Need to detect LOF Defects (Blue), whilst rejecting False-Positive (Red)

In-Process Inspection – Partially Filled Grooves

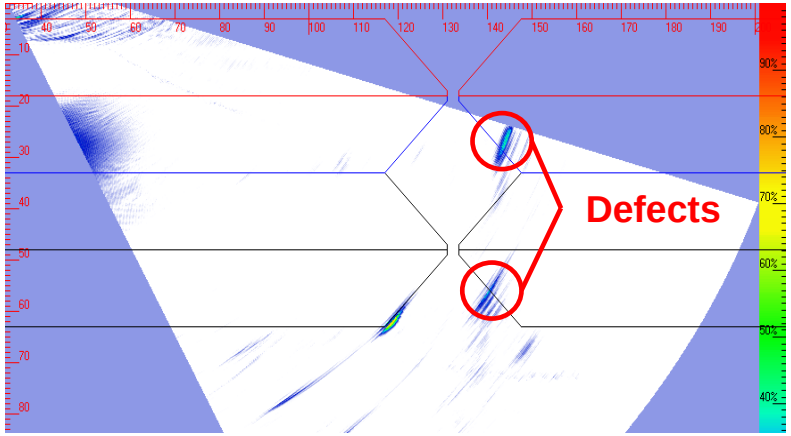
University of Strathclyde Engineering

Inspection After Pass 11





Position 1 - Un-Defected Zone

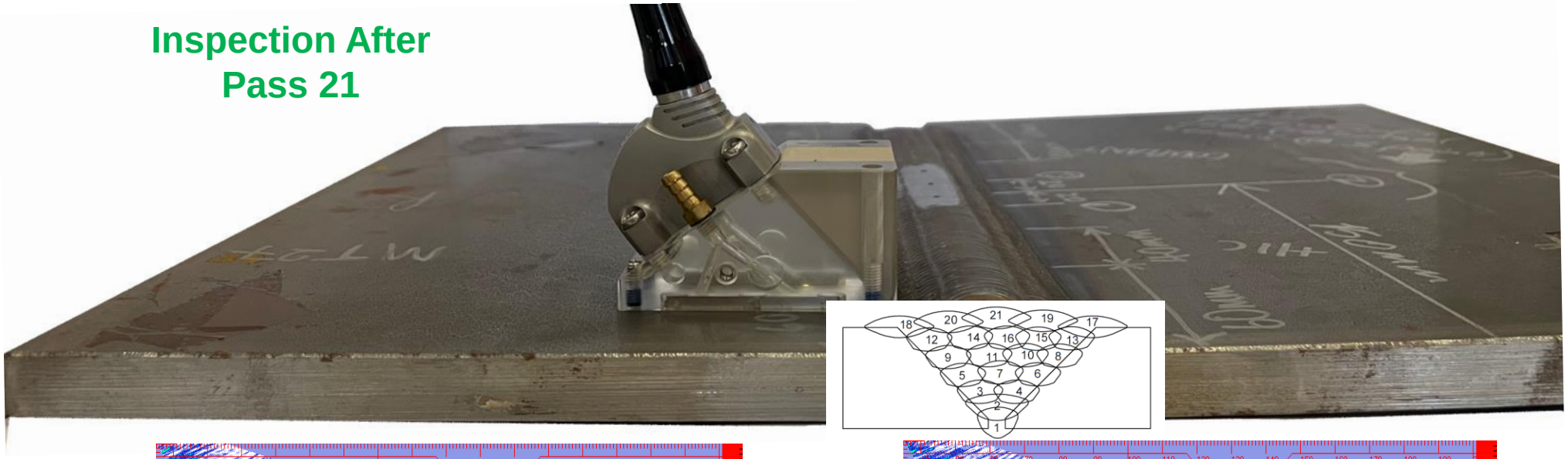


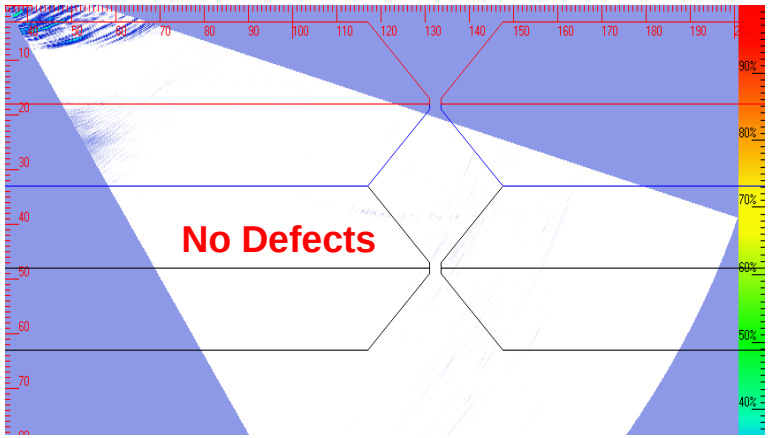
Position 2 - Defective Zone

In-Process Inspection – Partially Filled Grooves

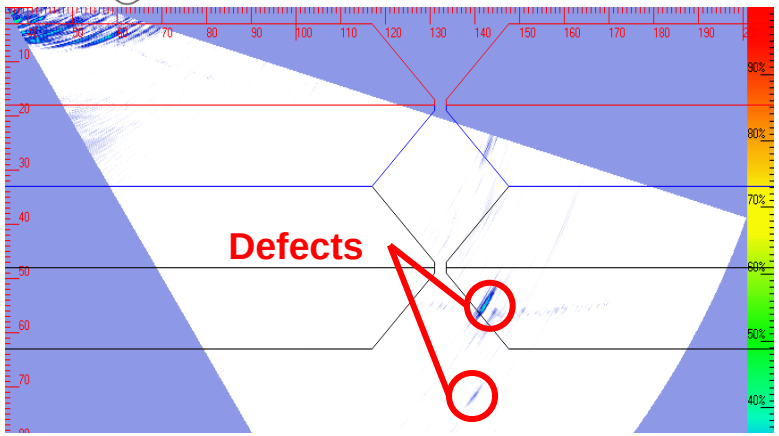
University of Strathclyde Engineering

Inspection After Pass 21



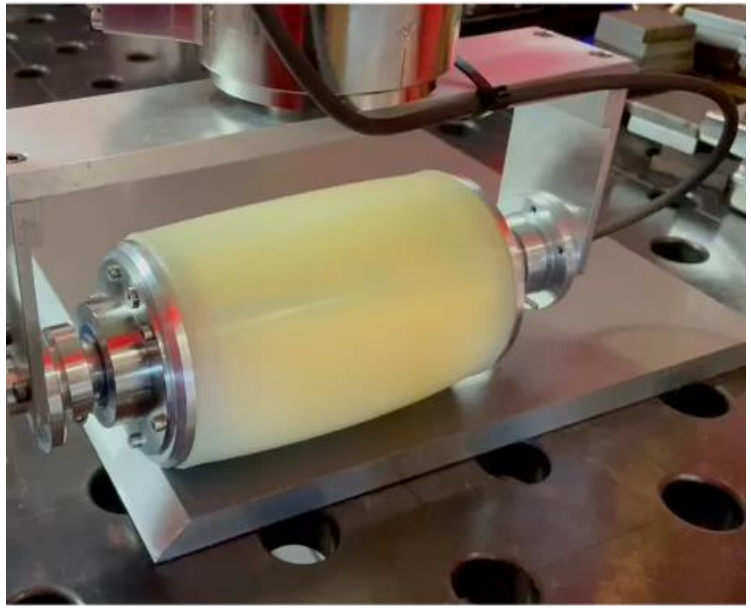


Position 1 - Un-Defected Zone

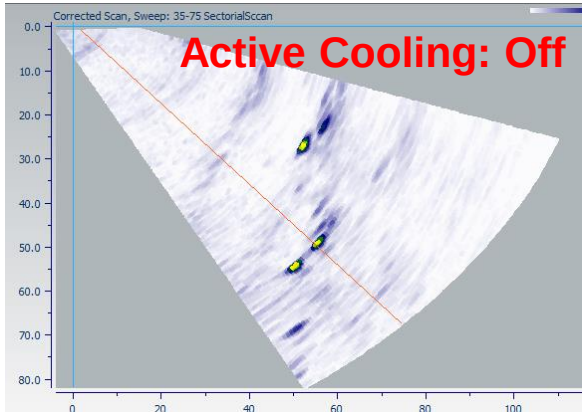


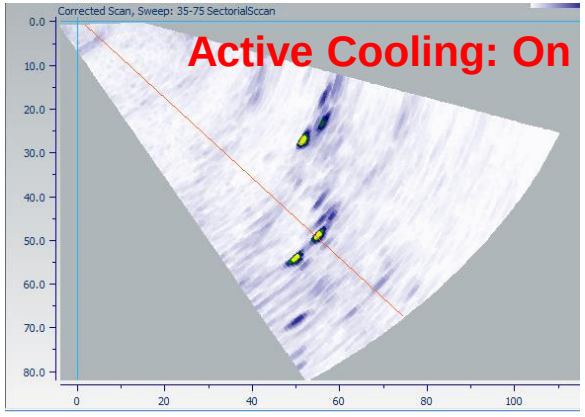
Position 2 - Defective Zone

Roller Probe – Dry-Coupled, High-Temperature Inspection



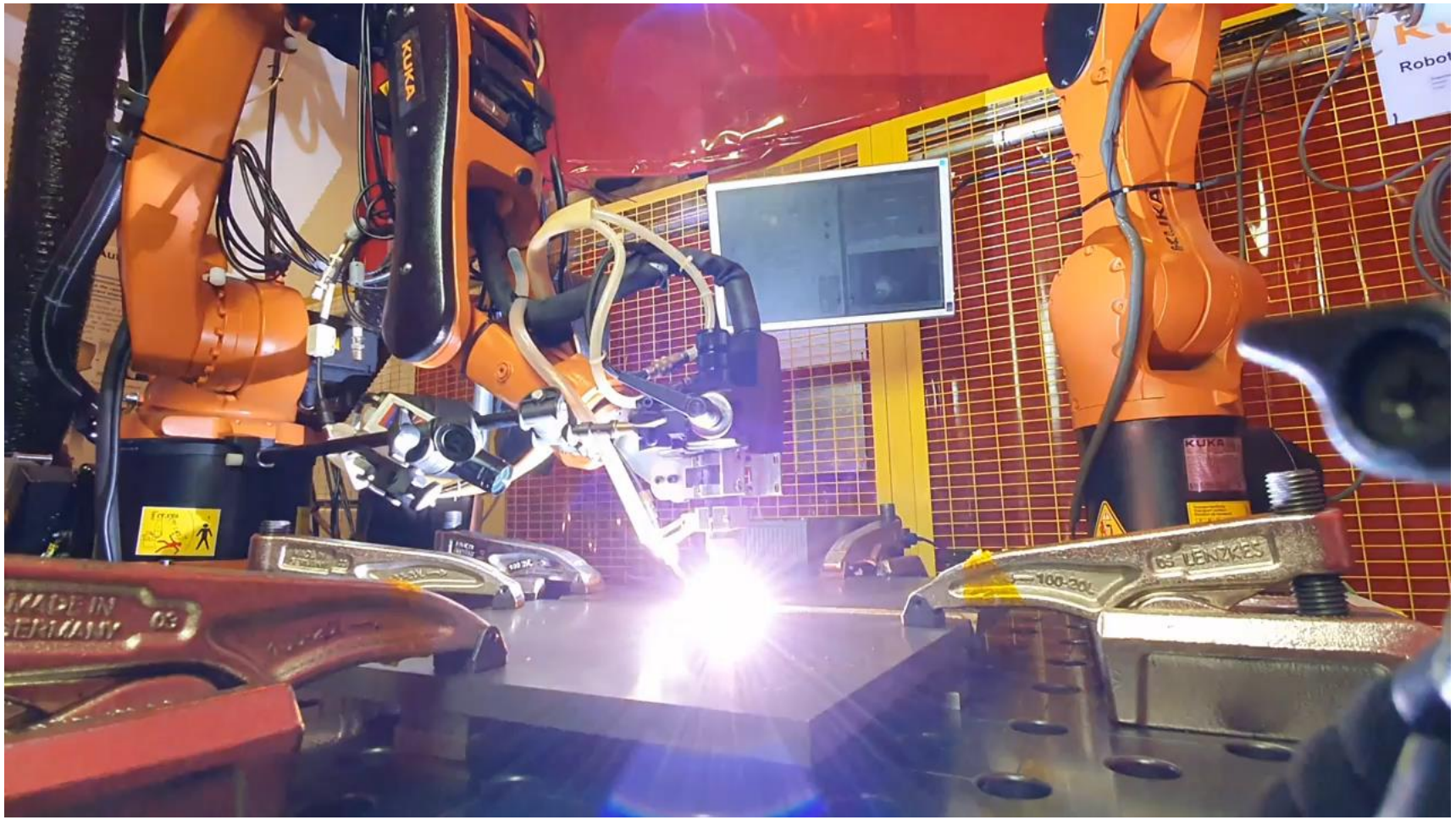
- High-Temperature (350 degC) inspection
- Reduced Liquid Couplant – *Dry Coupling*
- High-Temperature Tyre
- 55º Shear Wave Inspection
- 64 Elements, 5 MHz, 0.5 mm Probe
- Inter-pass multi-layer inspection
- Integrated Surface Temperature Measurement





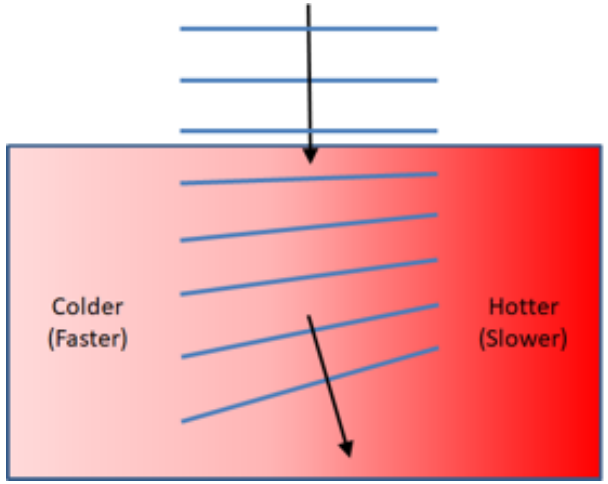
In-Process Inspection – Live Arc Trials

University of Strathclyde Engineering

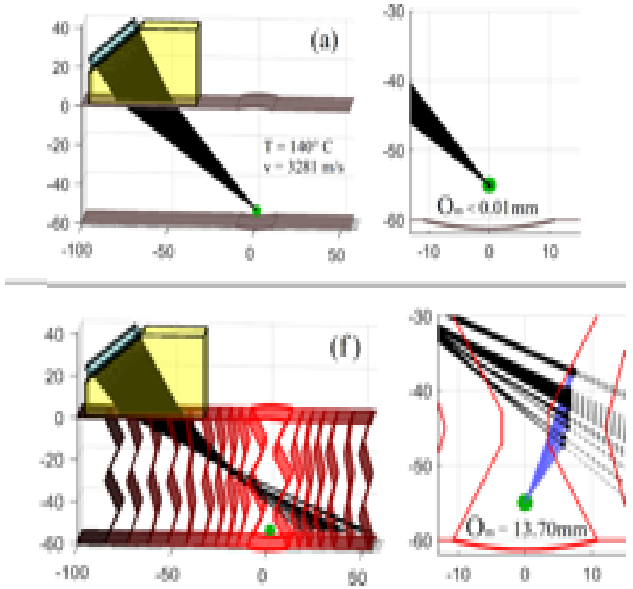


In-Process Inspection – Thermal Compensation

- Non-uniform thermal gradients present during in-process fusion weld inspection result in complex wave beam refraction, energy reduction and time shifts from weldment defects/reflectors present.
- *Ray Tracing Compensation – Enhanced Focusing*
- *Automated Compensation based on known geometry*



In the presence of a temperature gradient, the beam will tend to bend toward the heat



Cold Focused

Thermal Gradient Un-Focused

In-Process Inspection – Thermal Compensation

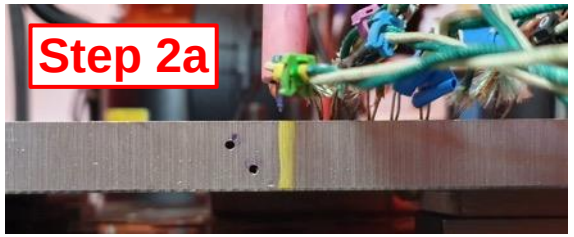
University of Strathclyde Engineering

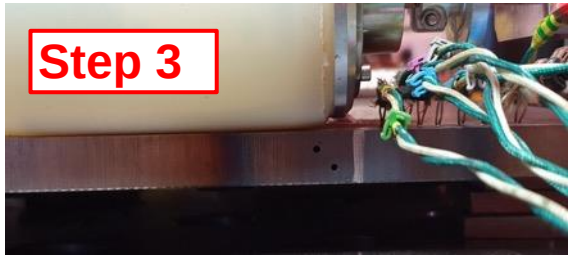
Thermal Compensation Verification Test

- 15 mm Pseudo Weld
- 2x 2.0 mm Diameter SDH
- 8 Thermocouples on mirror side of weld centre

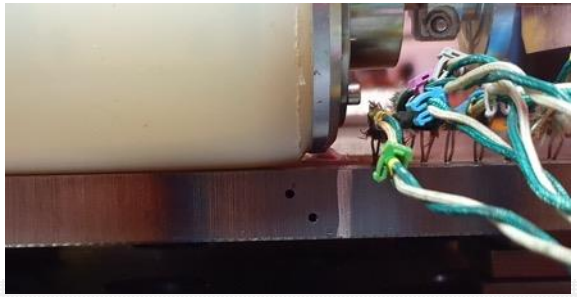
- Step 1: Cold Inspection with PAUT Roller Probe
- Step 2: Autogenous Weld for Thermal Input
- Step 3: Inspection with PAUT Roller Probe with Thermal Gradient

- Thermocouple Logging Throughout
- PAUT Images Analysed





In-Process Inspection – Thermal Compensation

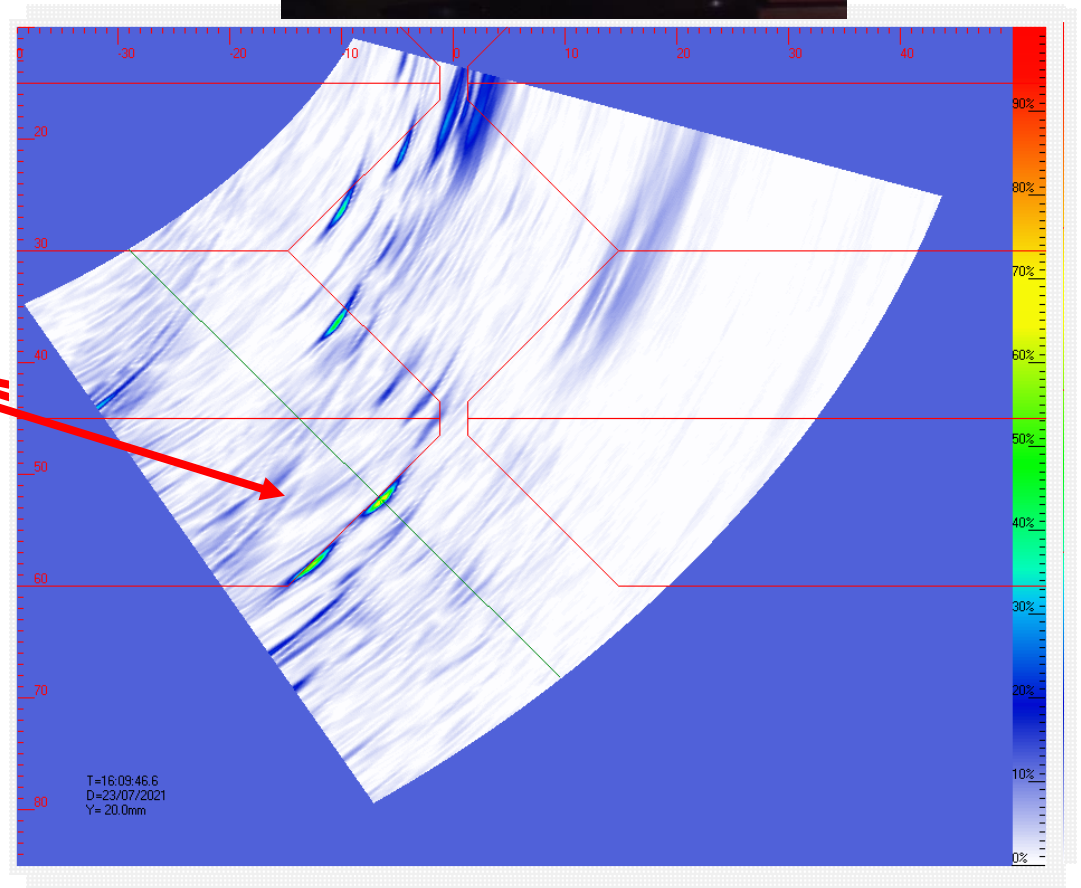


Side Drilled Holes

Note Shift in Weld Image

Correction aligned to Position

Overlay

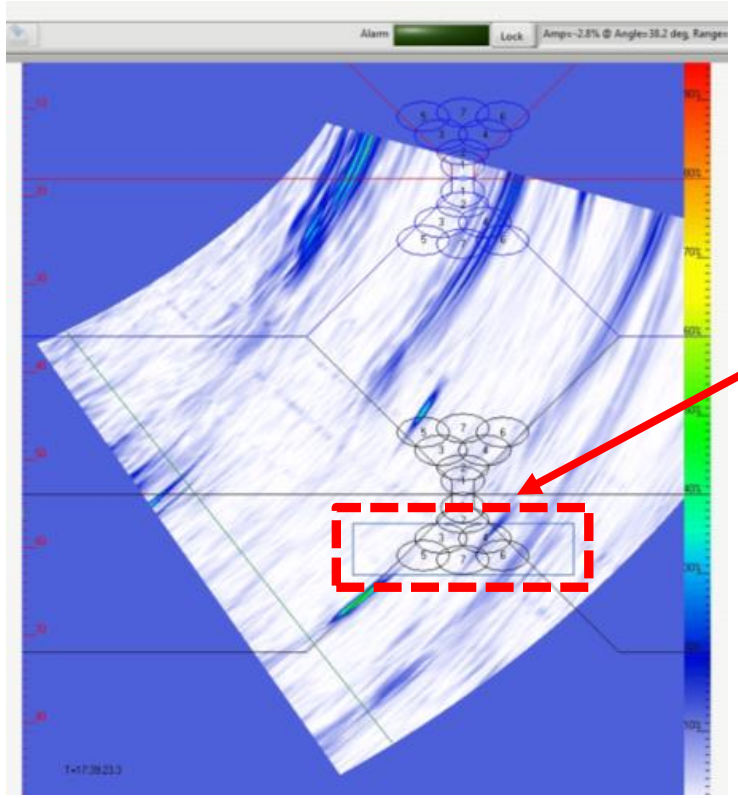


Autogenous Weld Thermal Gradient: Compensated Image

Uniform 240°C Reference Image

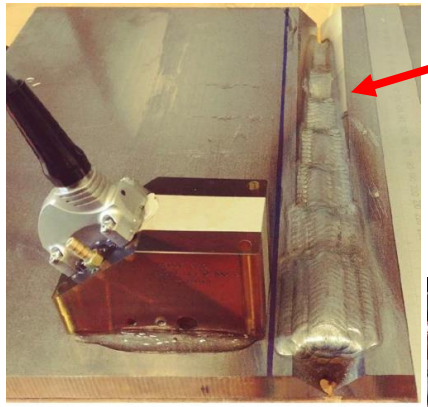
In-Process Inspection – Region of Interest

- Monitors echoes within adaptive Region of Interest (ROI) and sets Alarm if over a user-defined threshold
- Calibrated via Staircase Sample or real-time Laser Profiler data input



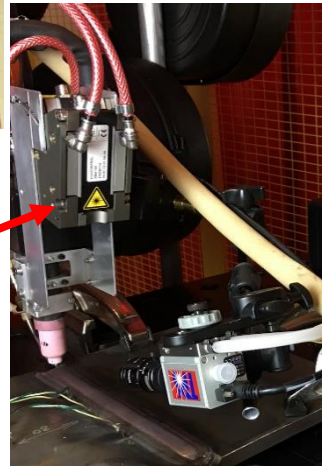
Region of Interest (ROI) Window

Dynamically adapts to varying filled groove



Staircase Sample

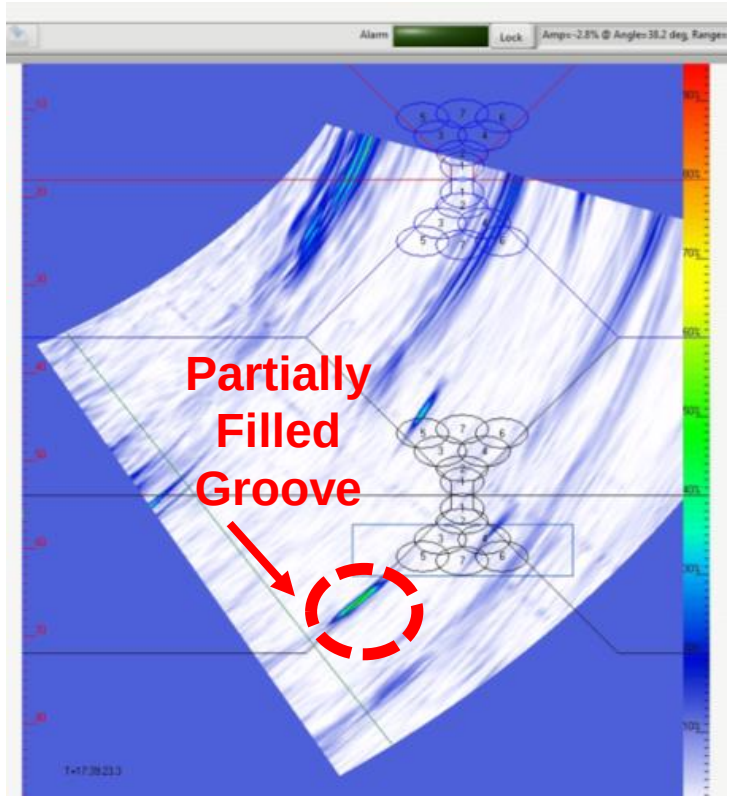
Laser Profiler



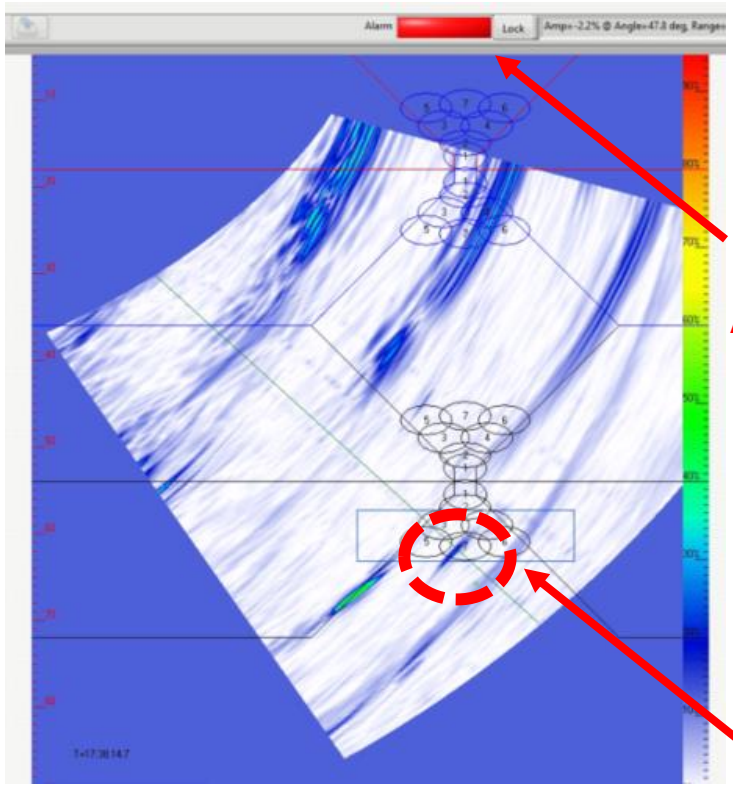
In-Process Inspection – Region of Interest

- Monitors echoes within adaptive Region of Interest (ROI) and sets Alarm if over a user-defined threshold

After Pass 7 - No defect 18mm thick 90° V-Groove



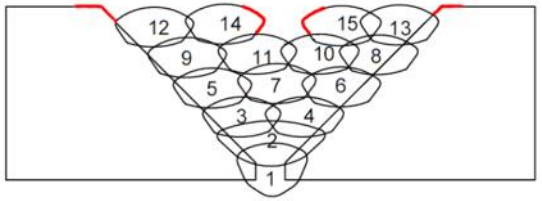
After Pass 7 - Tungsten Tube (1.0 mm ID 30 mm long) (Pass 7) 18mm thick 90° V-Groove



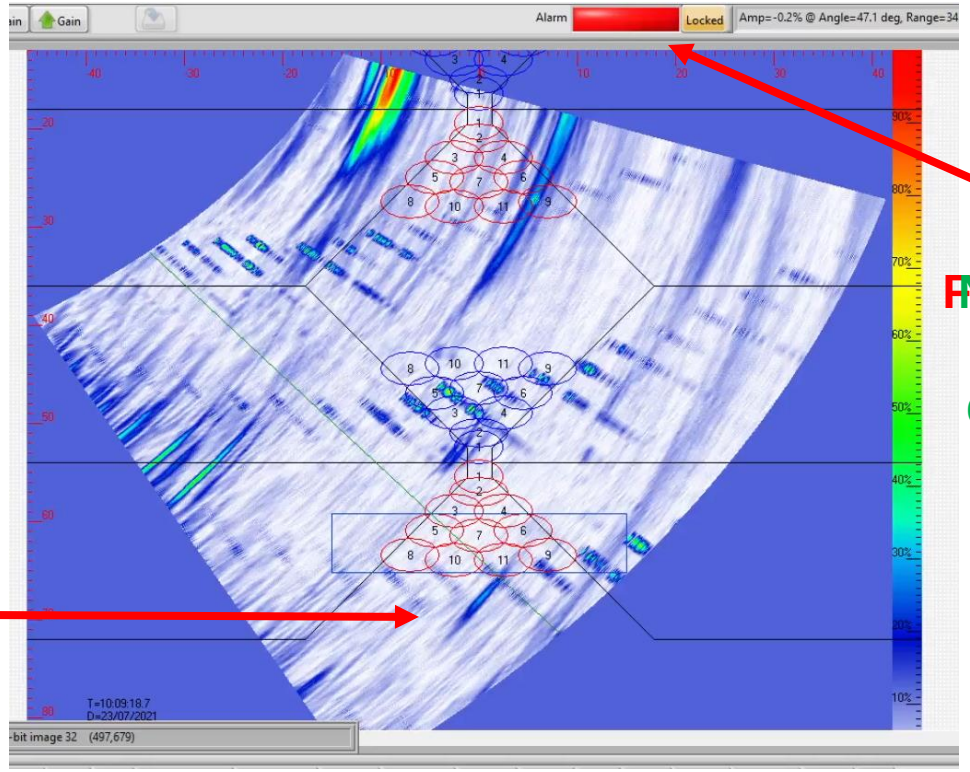
In-Process Inspection – Noise Suppression

- Electromagnetic Interference and Noise from Robot Servo Drives appears in filtered PAUT frequency window (*3.75 – 7. 5 MHz*)
- Non-Linear Noise Suppression Strategy developed

Inspection after Pass 15



Reflection From Bevel & Pass 15



No Triggered Alarm

No Triggered Alarm

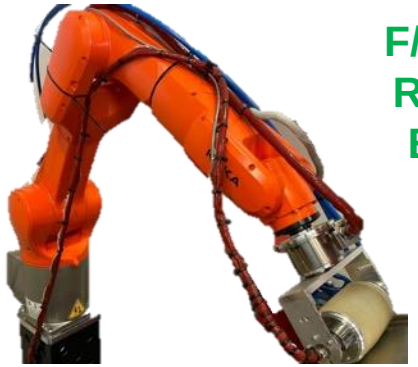
No defect in ROI

Adaptive Filtering

Adaptive Filtering

AWESIM System Configuration

University of Strathclyde Engineering



Inspection Robot:
250 Hz Ethernet

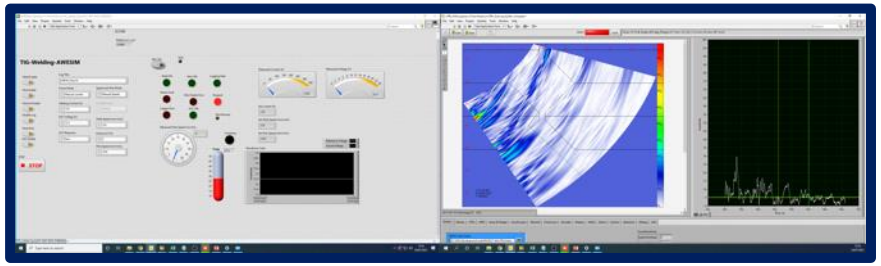
F/T Sensor
Real-Time
Ethernet

Welding Robot &
Head Stock:
250 Hz Ethernet

HDR Camera:
1 GbE
Ethernet

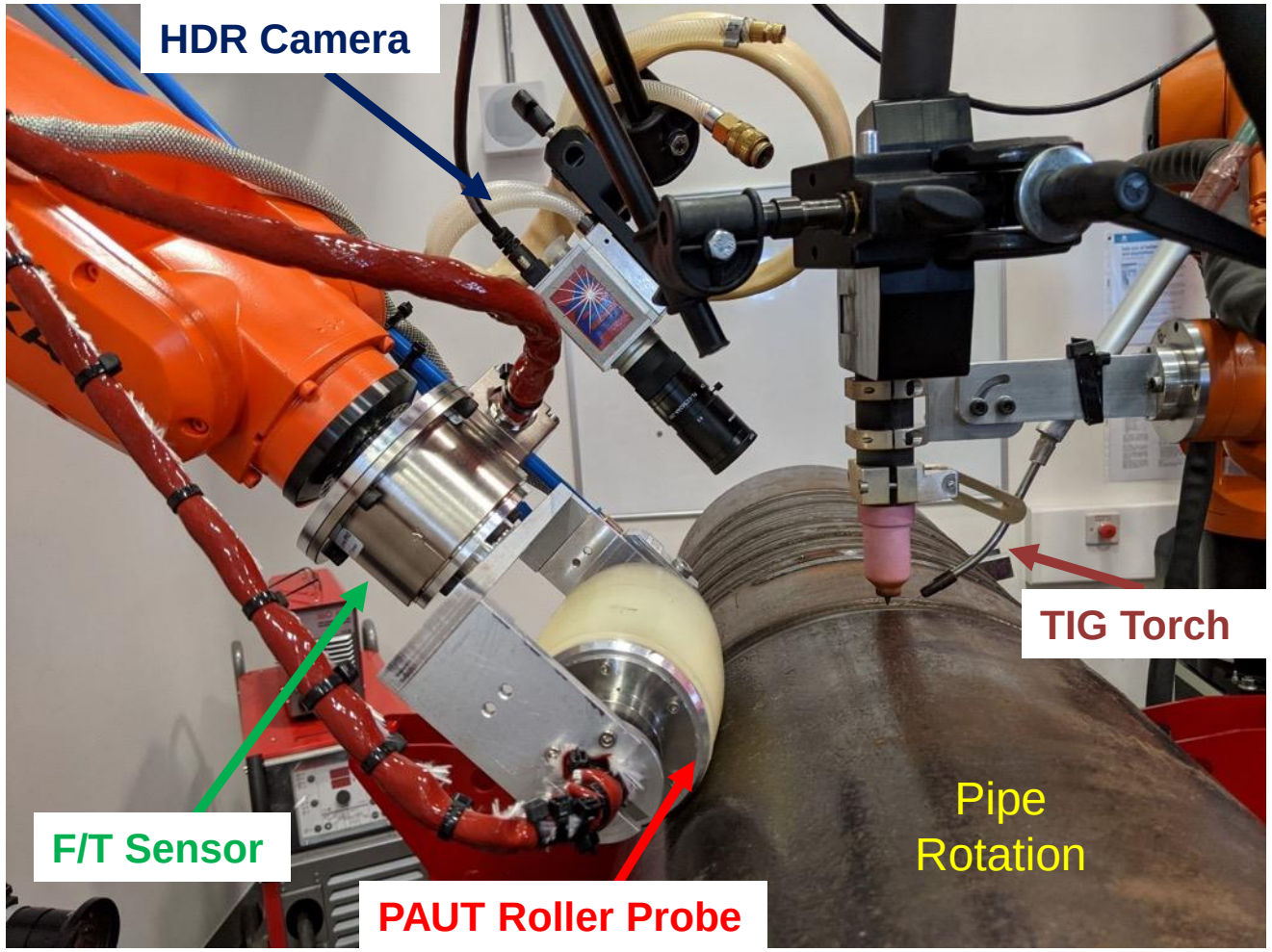
PEAK NDT
Custom PAUT
Array Controller
1 GbE Ethernet

Custom Real-Time
Welding & NDT Controller
& Graphical User Interface



Custom
TIG & Wire
Feeder
Real-Time
Connection

AWESIM System Configuration



- Welding torch at 12 o'clock (1G) position.
- Roller probe is approximately 100 mm behind weld torch

AWESIM System Configuration

- Artificial Defect Embedded
- Objective: Simulate point defects/porosity
- Tungsten Tube: ID = 1.0 mm, OD = 2.9mm and L=30mm
- Secured within a groove created on pass 7

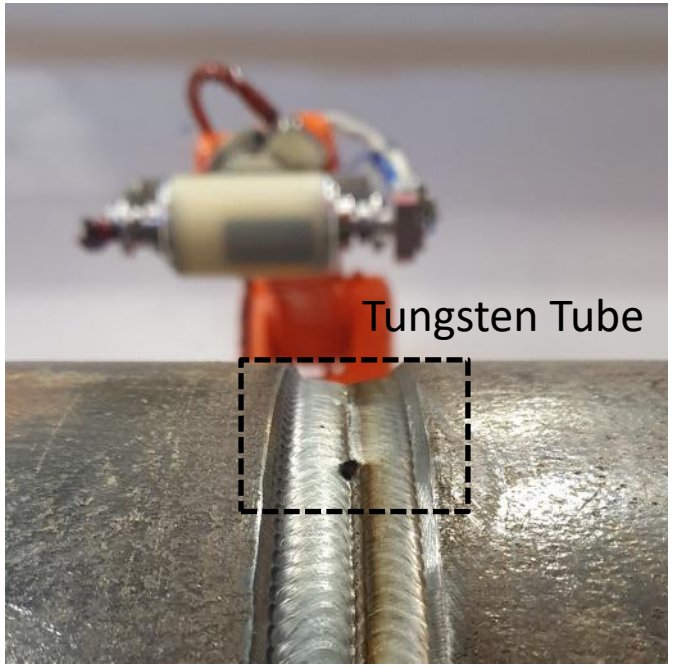
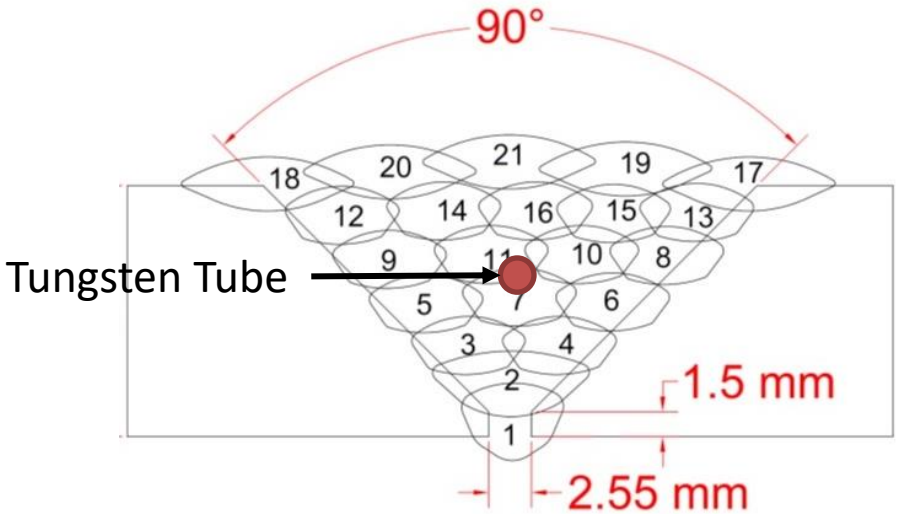
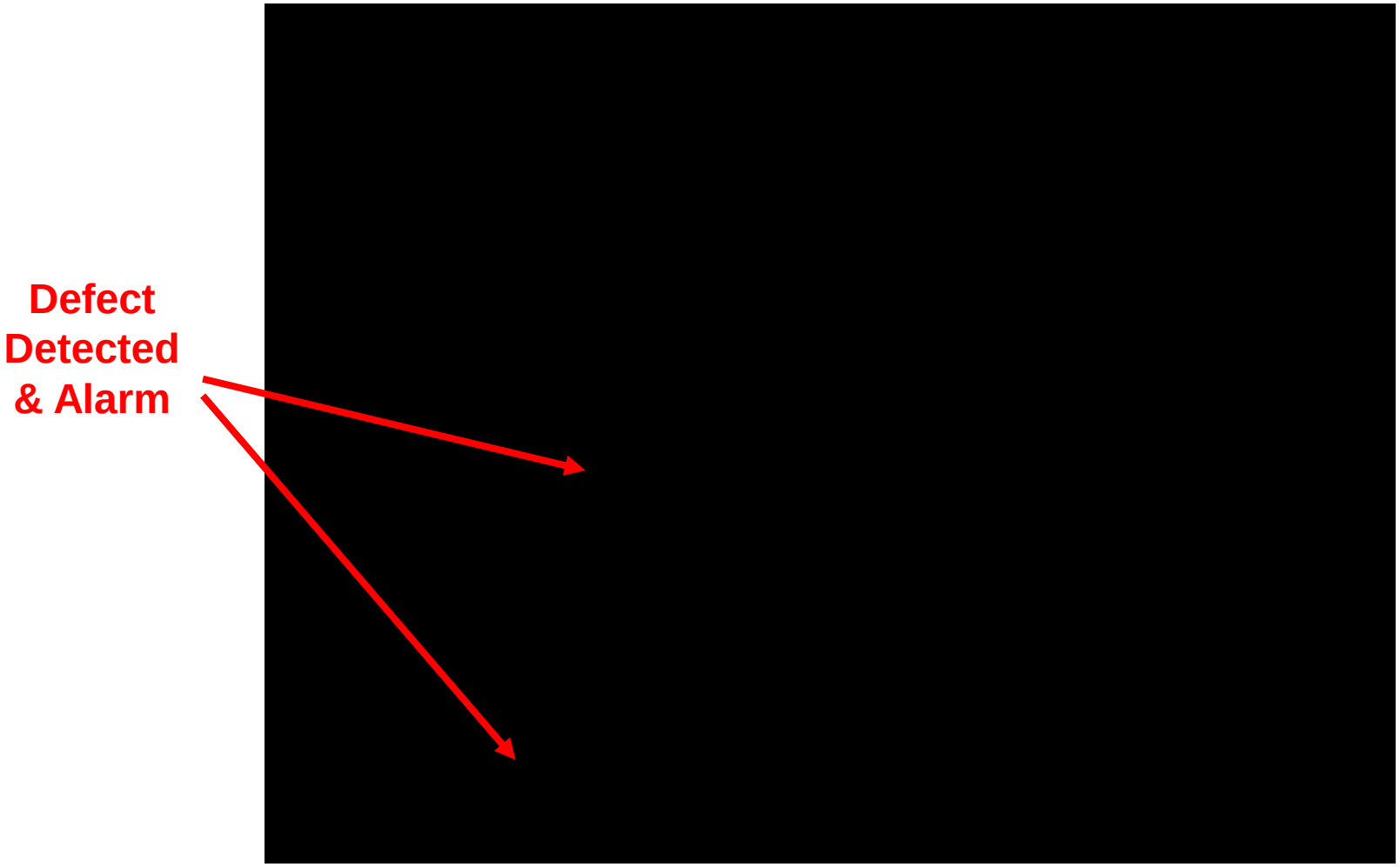


Image: Tungsten tube covered by pass 8 and 9



AWESIM In-Process Weld Inspection

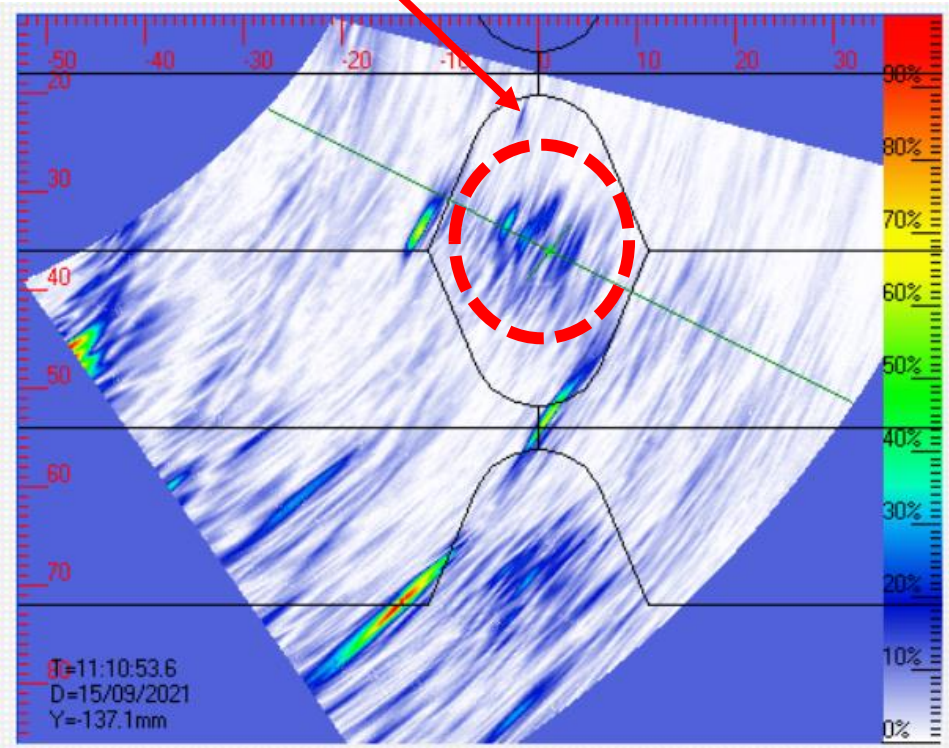
University of Strathclyde Engineering



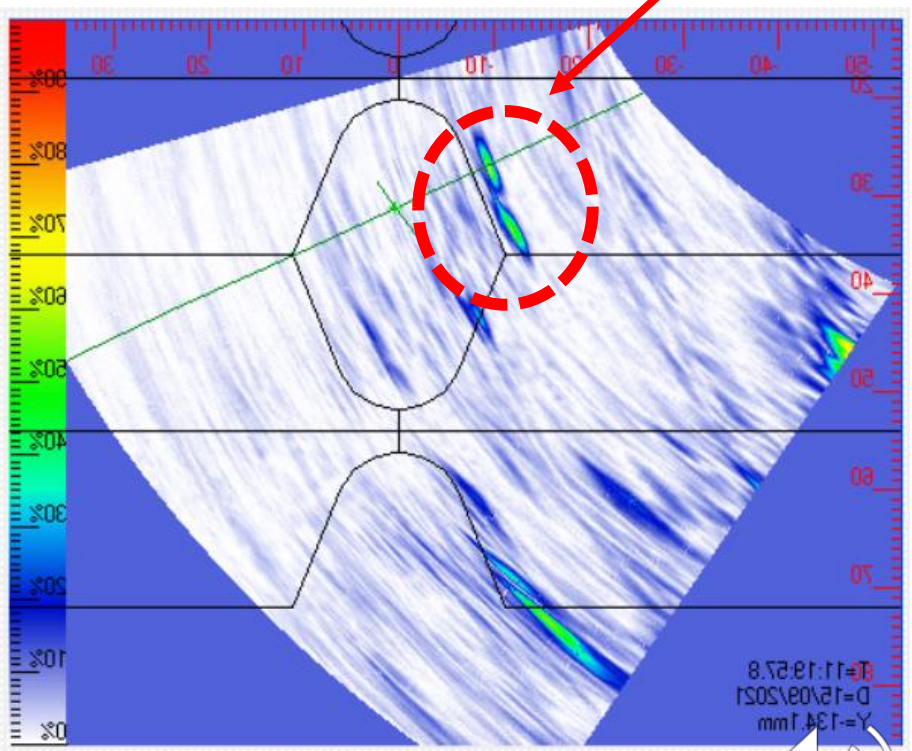
- ***World First: In-Process PAUT Inspection ≈ 100 mm behind Arc***

AWESIM In-Process Images

- **Position 3: Porosity**



- ***Position 7: Lack of Sidewall Fusion***



AWESIM Summary

AWESIM
Automated Welding Equipment System Inspection Monitoring

University of Strathclyde Engineering

1. Dry-coupled high-temperature in-process ultrasonic weld inspection directly at the point of manufacture
2. Novel compensation for geometric distortion and beam de-focusing due to the elevated temperatures and thermal gradients of the welding process.
3. Compensation for the false-positive echoes from the bevelled edges of the partially-filled weld groove present during in-process inspection
4. In-process inspection demonstrated on flat and circumferential welds
5. In-Process Weld Inspection offers ***significant commercial*** benefits:
   - Confidence in final build
   - Reduced re-work
   - Improved schedule certainty
6. In-Process Weld Inspection offers ***significant technical*** benefits:
   - Inspection at temperature with no liquid coupling
   - Reduced heating and cooling cycles on components (*Sustainability Benefits*)
7. **Suitable for all high-value manufacturing featuring high-integrity welding**

University of Strathclyde Engineering

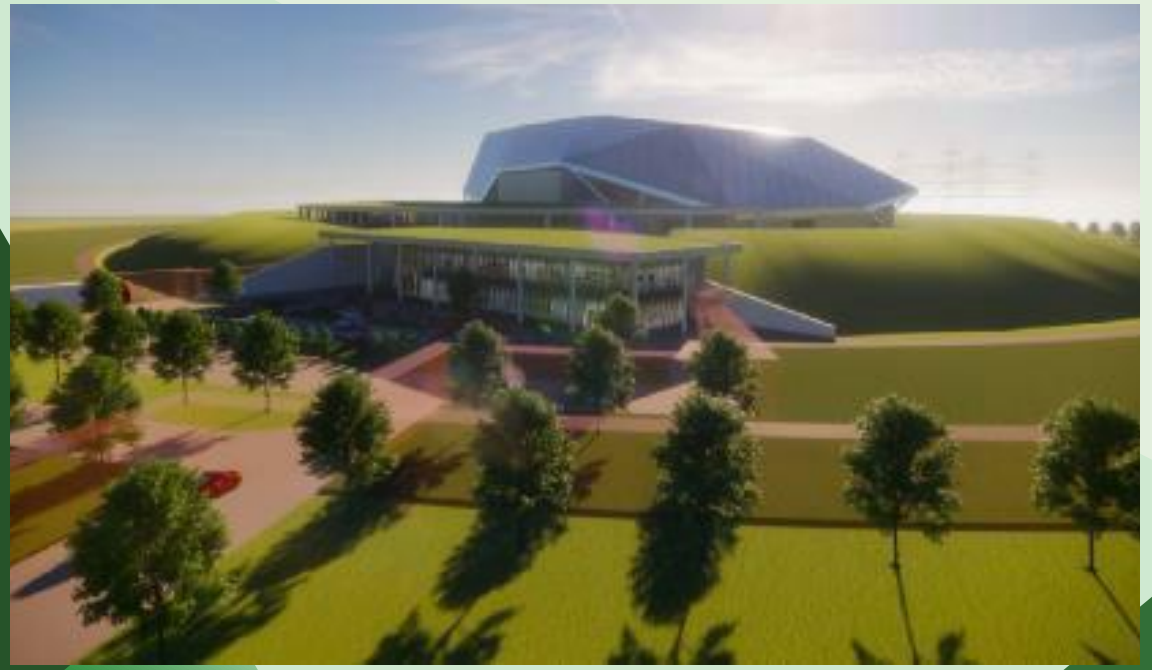
Thank You

charles.macleod@strath.ac.uk

New Build Group
More Than Electricity

Small Modular Reactor (SMR)

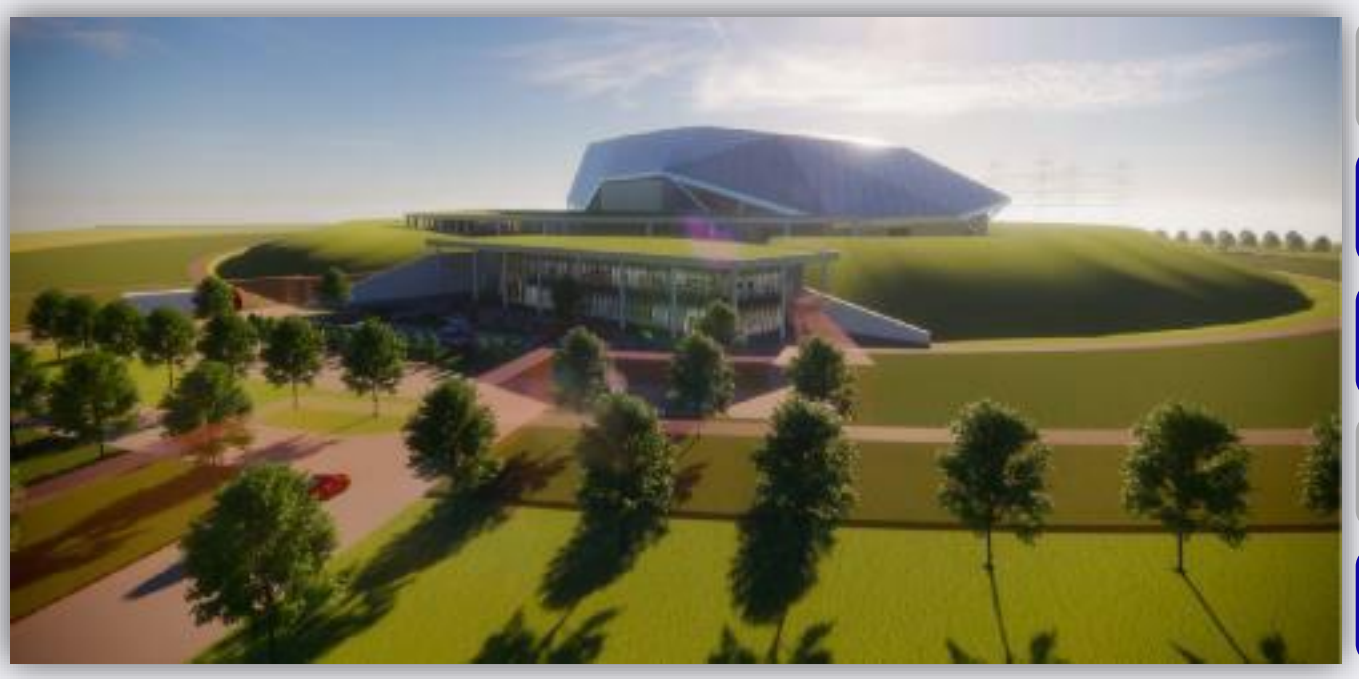
BAM Innovation – Site Factory



Rolls-Royce SMR is a completely different way of building nuclear; factory fabricated, road transported and site assembled.

The RR 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 £35-£50 per MWh*

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

The SMR Phase 1 (complete)

Consortium Partners

- Rolls Royce
- Assystem
- Atkins
- BAM
- Jacobs
- LOR
- Nuclear AMRC
- NNL
- TWI

Consortium formed to secure UKIR funding to develop SMR Proof Of Concept

Key objectives: improving productivity & predictability

The Rolls Royce Challenge

How do we do better?

3 Years (2009)

Height - 310m

1.5 Years (1930)

Height -381m

Our concept represents a completely different way of building new nuclear power plants

Whole plant factory fabrication

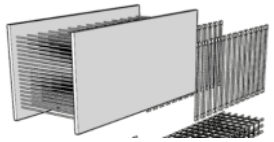
90% power plant factory fabricated across three main factories:

Road transportable factory products taken to site

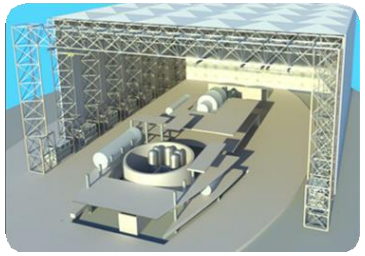
Primary plant

Civil modules

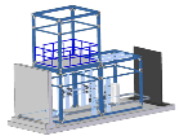
Systems modules

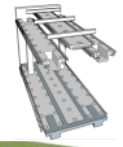


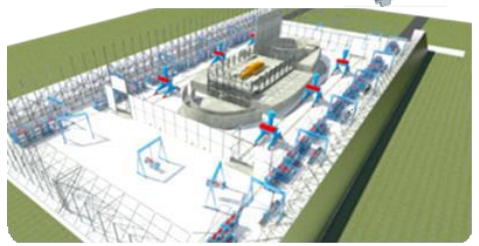
Site factory for build certainty



In a controlled environment under our site canopy / 4th factory to remove risk



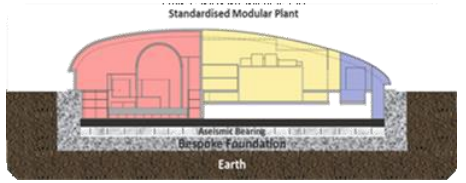




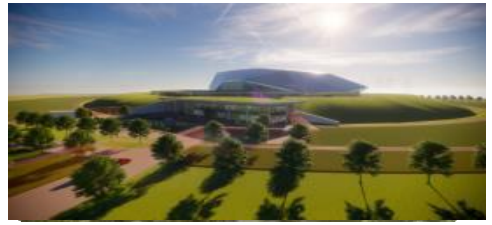
Modules designed to expedite site assembly

Designed for a compact footprint

Assembly on an aseismic bearing to enable repeatability without cause for site specific redesign



Coming together to deliver a complete low cost, investible, power plant across a number of sites



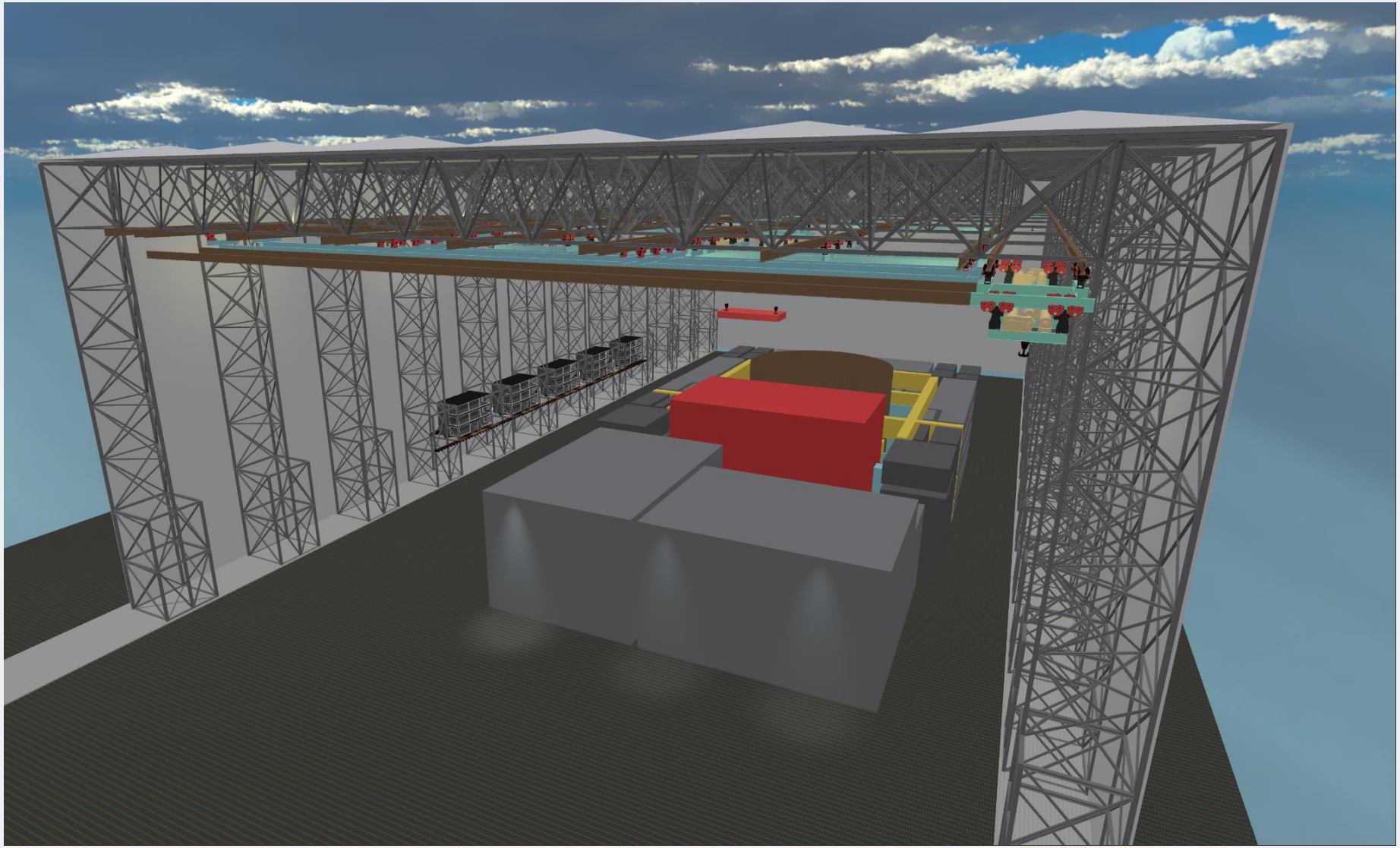
Low cost power for a net zero world

To provide low carbon power in a flexible manner for electrical grid, hydrogen production, or synthetic fuels

“The Site Factory”

BAM have developed the Site Factory (Patent No. GB 2591785).

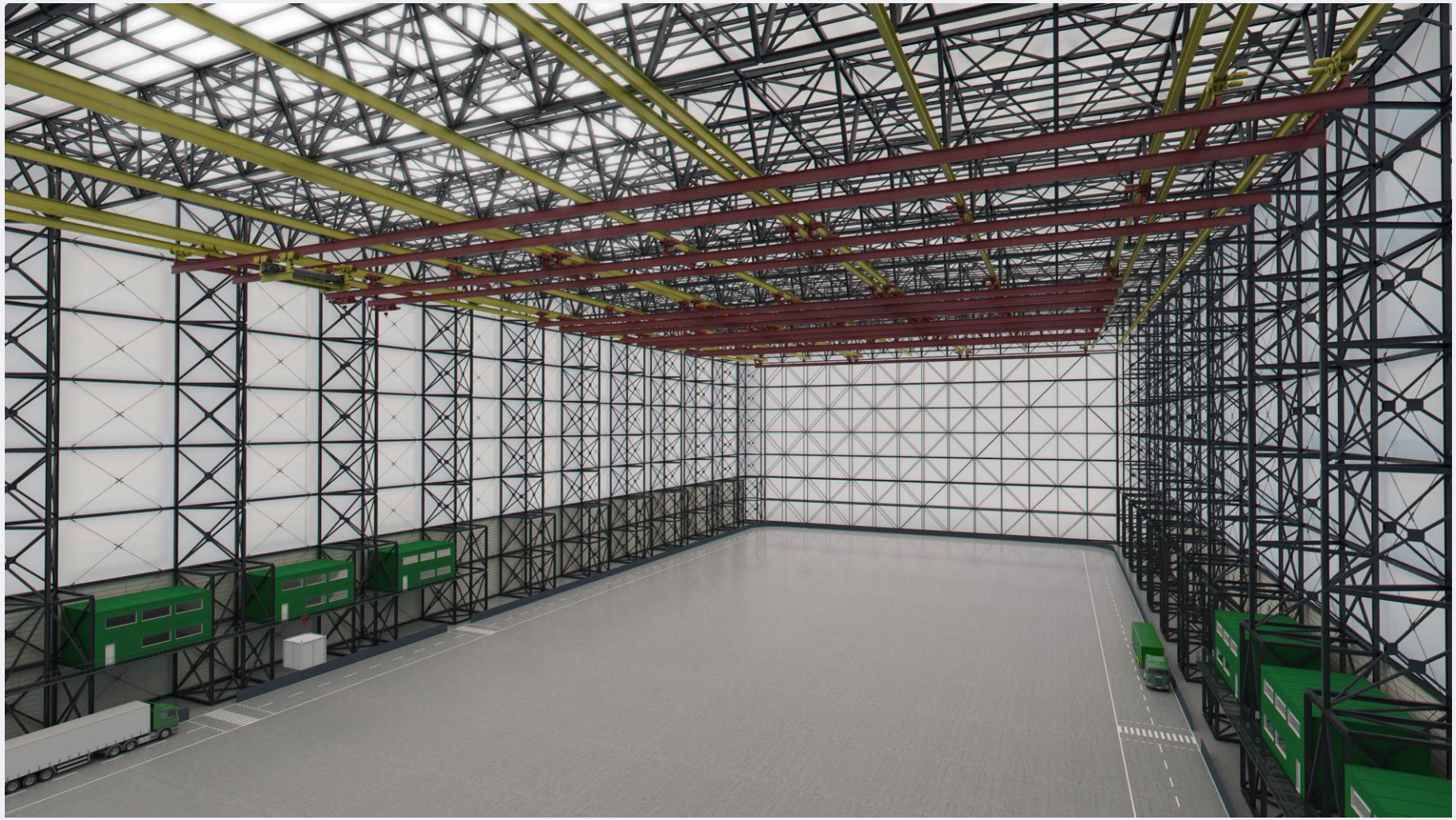
The objective of the Site Factory is to enable the delivery of the SMR complex infrastructure & systems within a manufacturing environment.



“The Site Factory”

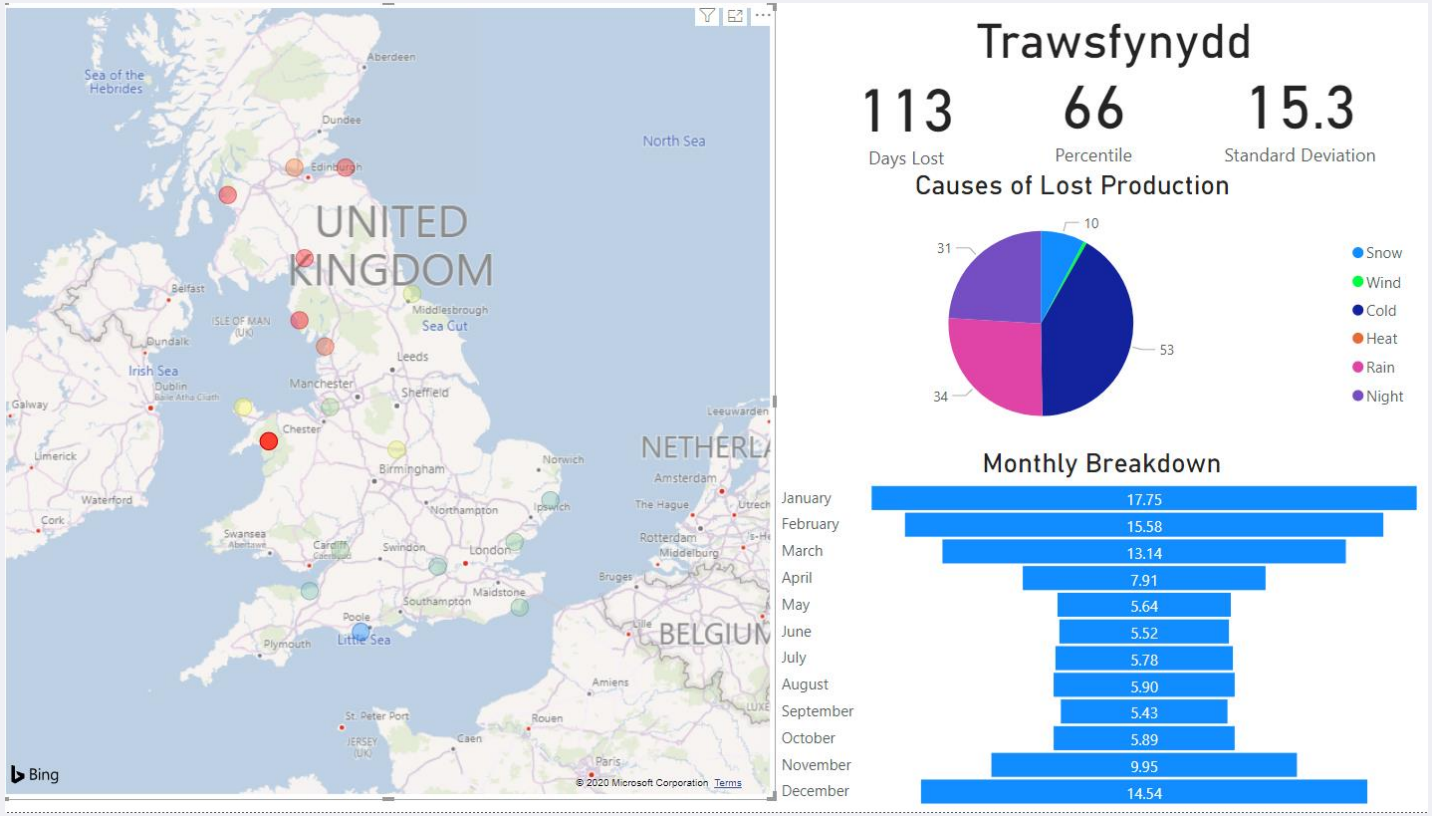
BAM have developed the Site Factory (Pending Patent No. GB 2001631.7).

The objective of the Site Factory is to enable the delivery of the SMR complex infrastructure & systems within a manufacturing environment.



UK Nuclear Sites

- Approved Nuclear sites of interest compared.
- Winfrith least impacted by weather with 75 days lost.
- Trawsfynydd one of the most impacted with 113 days lost.
- Wylfa’s leading cause of disruption is Wind.



“The Site Factory”

Protects the environment from the project

Protects the project from the environment

Key objectives: improving productivity & predictability

- Healthier & Safer environment with a more diverse workforce
- DCO Mitigation for the EIA
- Replicable environment for global delivery
- An environment that provides certainty for quality delivery
- Perfect environment for innovation
- Perfect weather
- Perfect temperature
- Perfect lighting
- Perfect controlled environments for specialist activities
- Enables 24hr working, 365 days a year

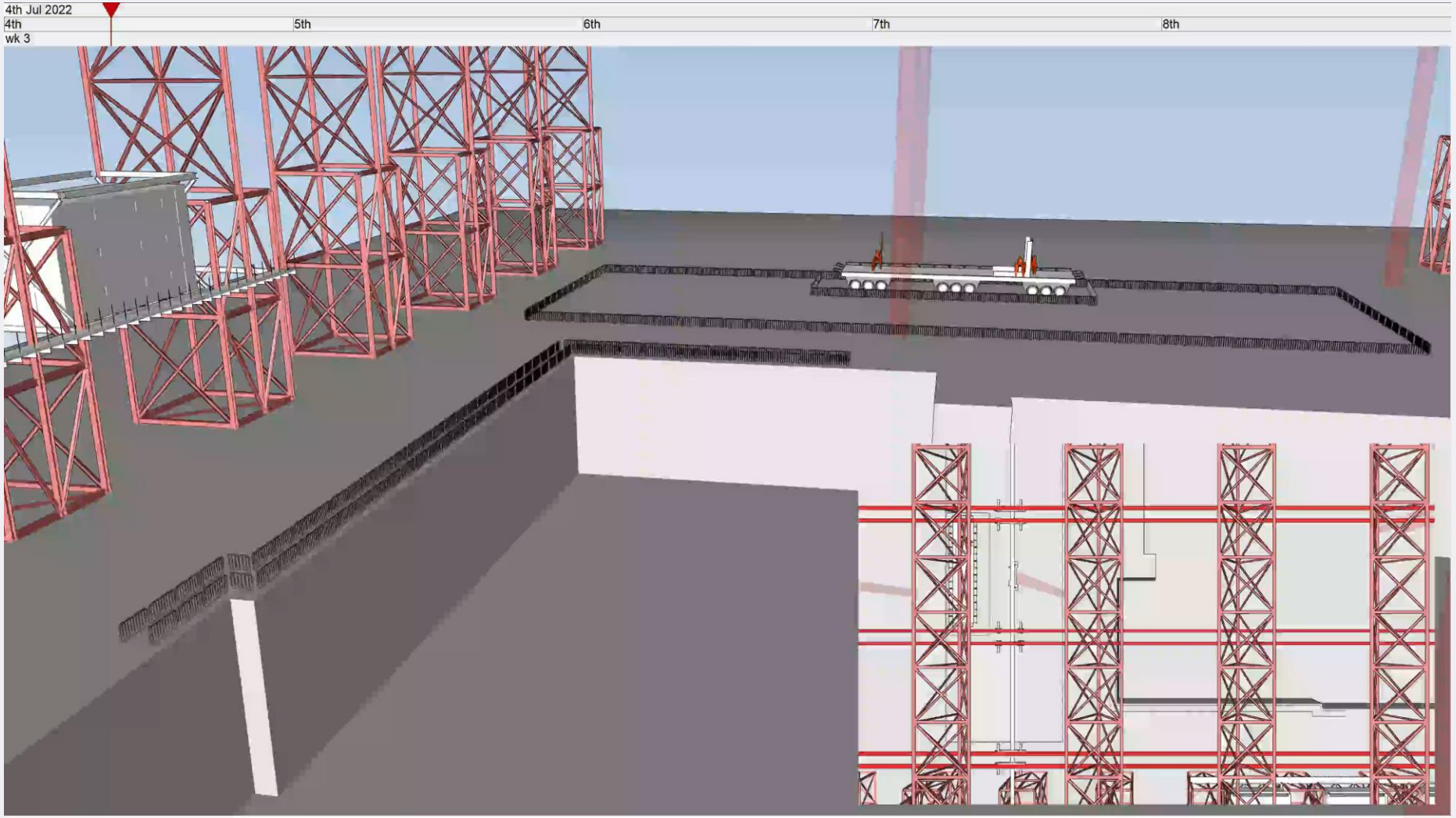
An enabler for productivity, innovation & certainty which in turn creates an investible solution for zero carbon, guaranteed baseload power generation.

“The Site Factory”

An environment for

- Innovation
- Productivity
- Certainty

Key objectives: improving productivity & predictability

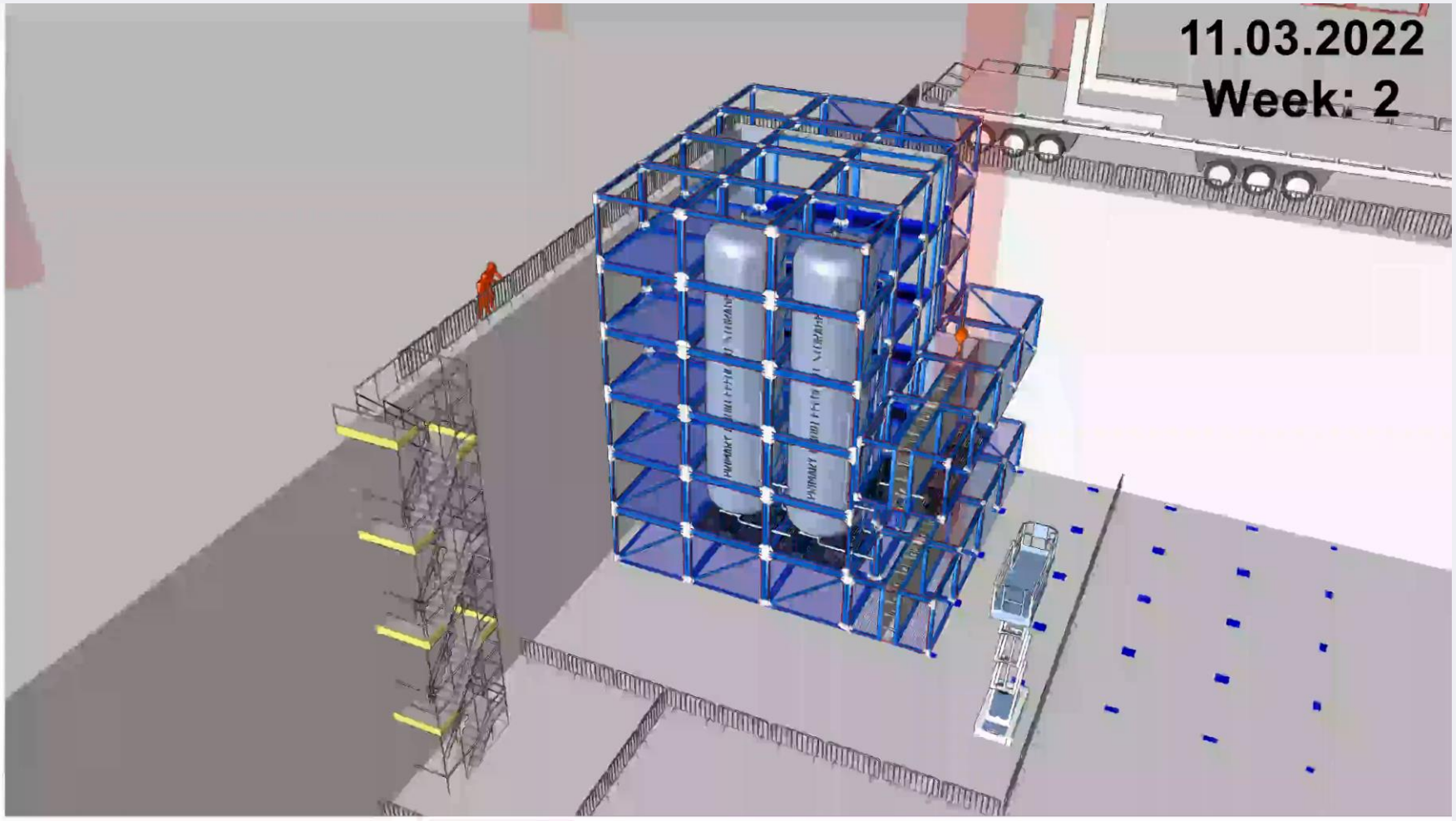


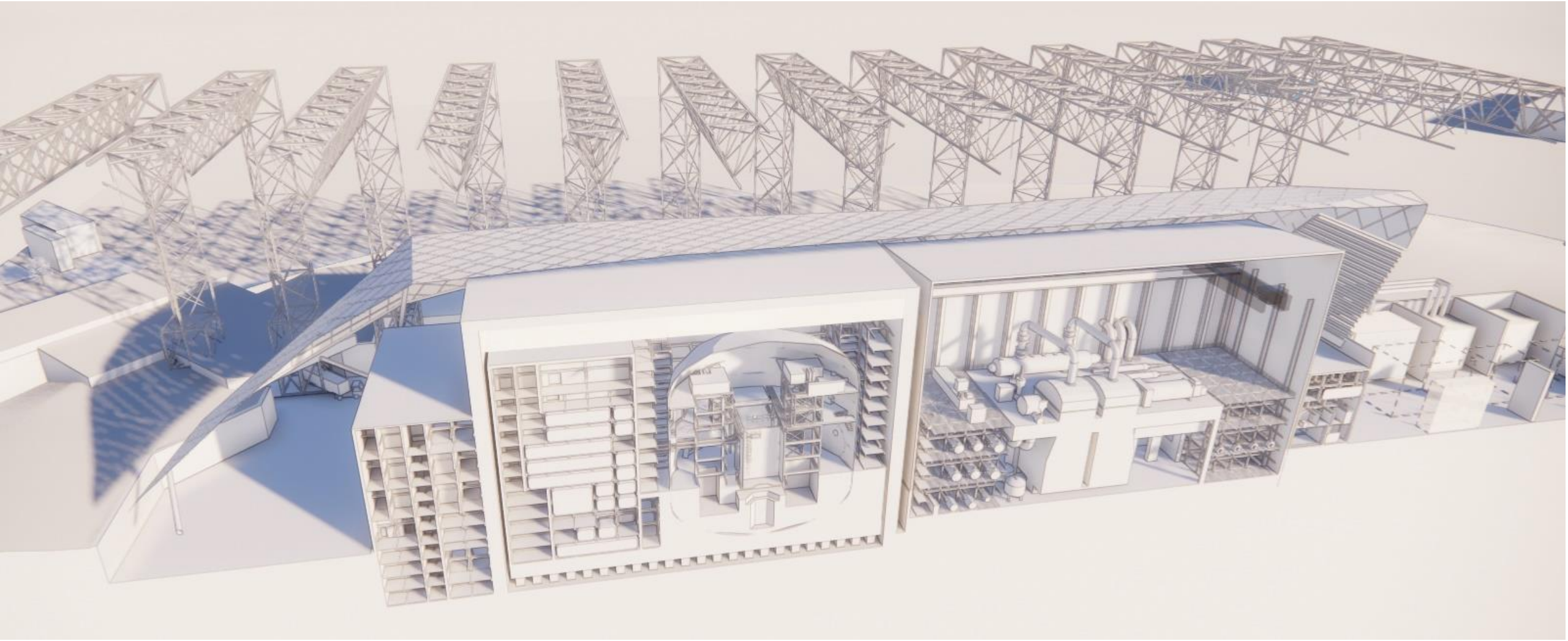
“The Site Factory”

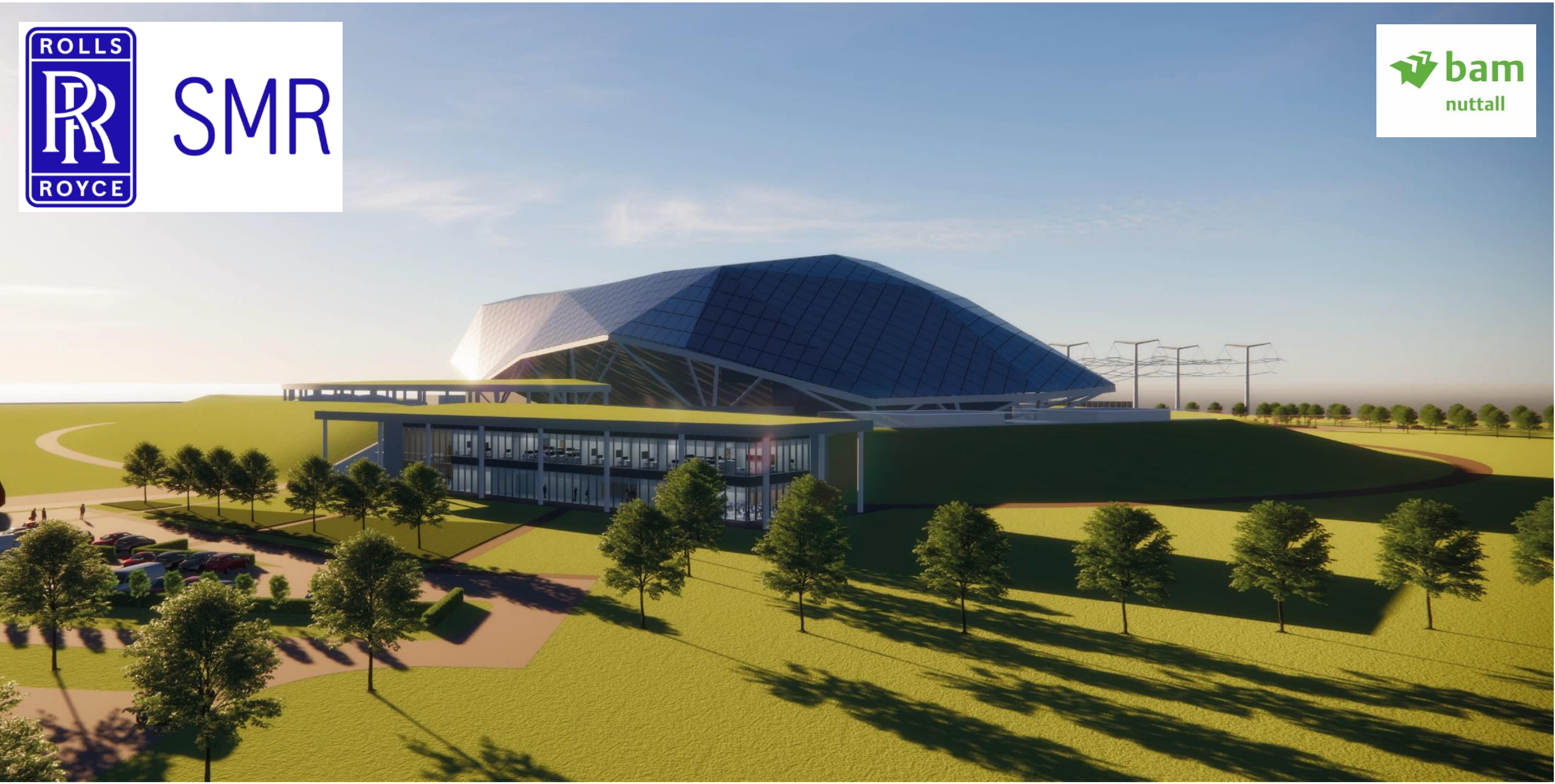
An environment for

- Innovation
- Productivity
- Certainty

Key objectives: improving productivity & predictability







Innovation Panel Session

John Prothero - BAM
Blair Jamieson - Babcock
David Bradbury - Tuv-UK
Matthew Bilson - BEIS
Caroline Longman – NNL

Nuclear Industry Association

NIA New Build Group
More Than Just Electricity

Lunch

Nuclear Industry Association

We advise on all aspects of nuclear energy

"Cradle to Grave" across conventional NPP and SMR projects

Early works

- Planning & consenting
- Project structuring
- Technology selection

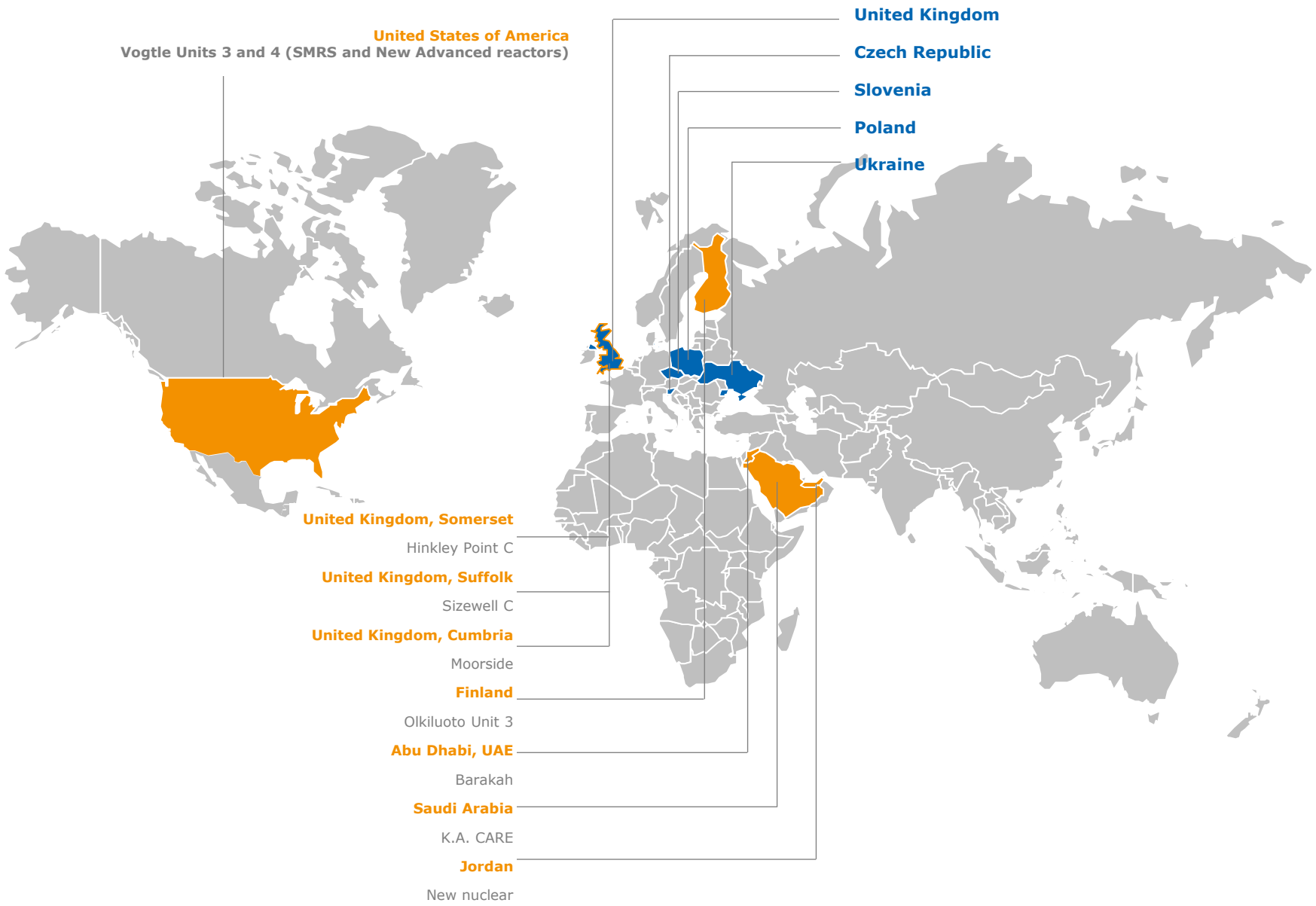
Project Development

- Construction
- O&M
- Financing (debt & equity)
- Fuel supply

Regulatory

- Nuclear liability
- Licensing & grid connection
- Waste management & decommissioning

Our breadth of experience in nuclear new build projects



Eversheds Sutherland is one of the leading global nuclear energy practices

Eversheds Sutherland have an outstanding reputation. Their lawyers are accessible and understand the nature of the relationship – they're a valued partner, not just a trusted advisor. They know how to put themselves in my seat and think about all of the things that I may not be thinking about. They are my preferred trusted legal partner. Eversheds Sutherland are more responsive and have deeper thinkers than most of the other firms in the market.

Chambers USA 2020

Get in touch

Matthew Honeyben

Partner | Global Energy

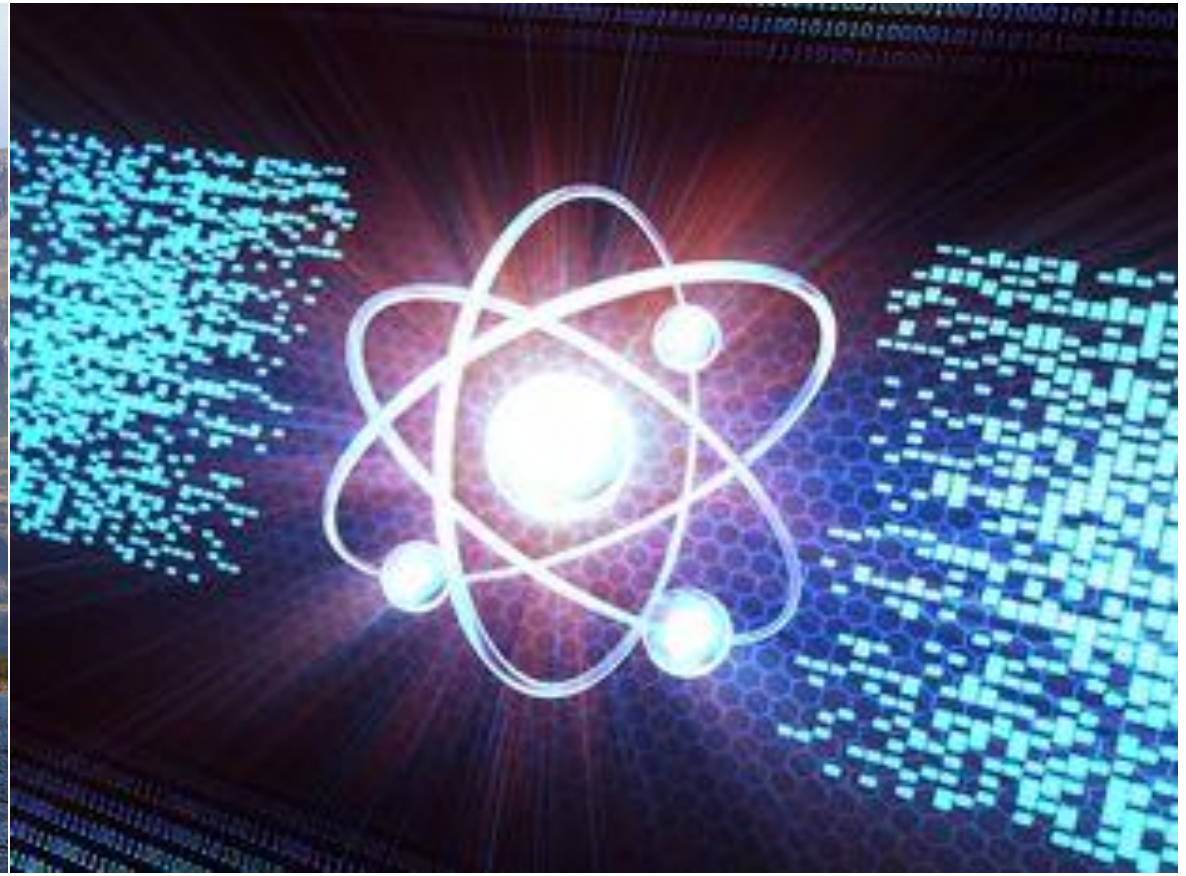
+44 20 7919 4929

matthewhoneyben@eversheds-sutherland.com

Connect on LinkedIn https://www.linkedin.com/in/matthew-honeyben-a3304a39

Follow our energy team https://www.linkedin.com/showcase/eversheds-energy/


cwmni
Egino



NIA NEW BUILD GROUP MEETING, JULY 7TH 2022: “MORE THAN JUST ELECTRICITY”

HOW TO GET THE BEST OUT OF NUCLEAR HEAT

Dr David Bradbury & Professor Joe Howe
Associates, TÜV UK

TÜV UK – Specialist Nuclear & Energy Consultancy Service Areas

Over 500 years collective experience from an elite team of 20 expert Associate consultants, some of whom have held the most senior positions in the:
UK Regulatory system, Government, Academia & Nuclear industry

Our services are cross cutting over three key areas:

Business & Assurance

Nuclear Operations & Decommissioning

Nuclear New Build & Advanced Technologies

The three developments needed for nuclear fission

- Three technical papers by TÜV UK Associates
- Better waste management and rigorous application of the waste hierarchy
  - "Blueprint for Future Nuclear Power"
  - An abbreviated version was published in Industry Link Winter 2020
- Nuclear **heat** is needed, not just for electricity production
- Improved public understanding of nuclear hazards – nuclear power is (by objective standards) one of the safest forms of energy generation
- Second and third papers in preparation
- Second paper is relevant to today's meeting and is the topic of this presentation

Nuclear energy and renewable energy need to work together

- Renewable Energy (Wind power and solar power) are
  - Diffuse (generated over a large area and not necessarily where the energy is needed)
  - Intermittent (Provided only when the sun shines or the wind blows)
- Nuclear Energy is:
  - Intense (generated in a small area and potentially where it is needed)
  - Firm power (Provided when required)
- The two sources need to work together in harmony – because that will be the best strategy for combatting climate change

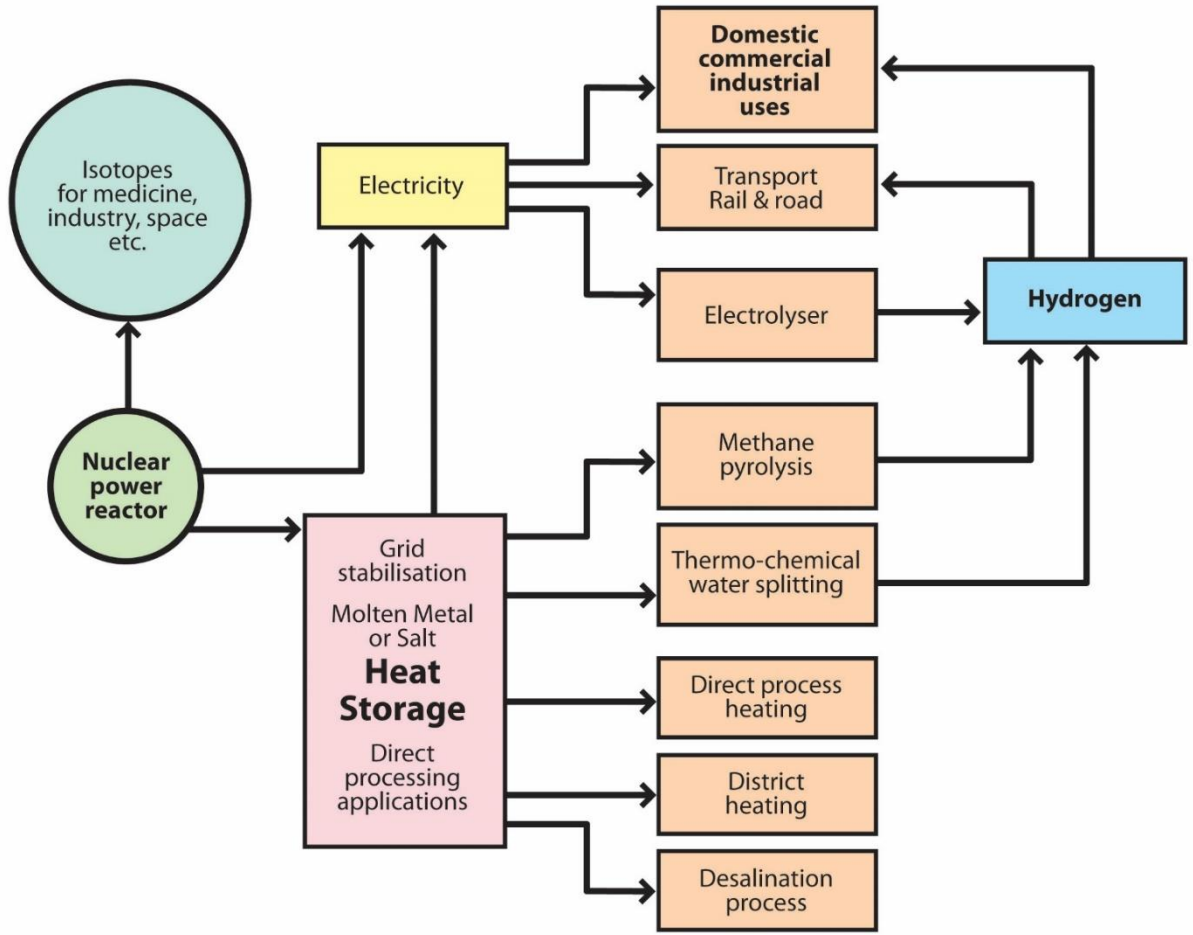
Source: World Nuclear News

Bill Gates' Terrapower "Natrium" Reactor supplies heat to a store during daytime when the sun is shining and the stored heat is used to make electricity at night

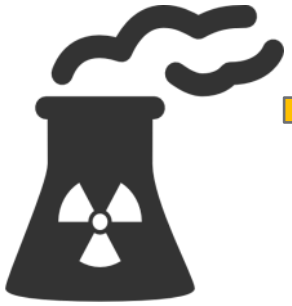
Nuclear power is needed for more than just electricity

Nuclear **heat** is needed for

- Hydrogen production
- Water desalination
- Industrial process heat
- District heating
- Direct air capture of CO_2
- Marine propulsion



How does Nuclear Energy make Hydrogen



Large Nuclear Technology Today (Gen III) and UK-SMR

Electricity

Direct Heat (low temp)

Advanced Modular Reactors (Gen IV) (e.g. High Temp Gas Reactor)

Direct Heat (High temp)

Electrolysis

2021 Deployable now. Existing Technology.

Steam Electrolysis

2025 Deployable soon. UK demonstration now

Thermo-Chemical Technology

2028 Deployable in the future

Electrolysis is well established green hydrogen technology, but when pair with nuclear can be deployed in much greater capacities and be economically attractive for large scale plant.

By using both heat and electricity from nuclear reactors, Steam electrolysis can offer a step change in efficiency of green hydrogen production

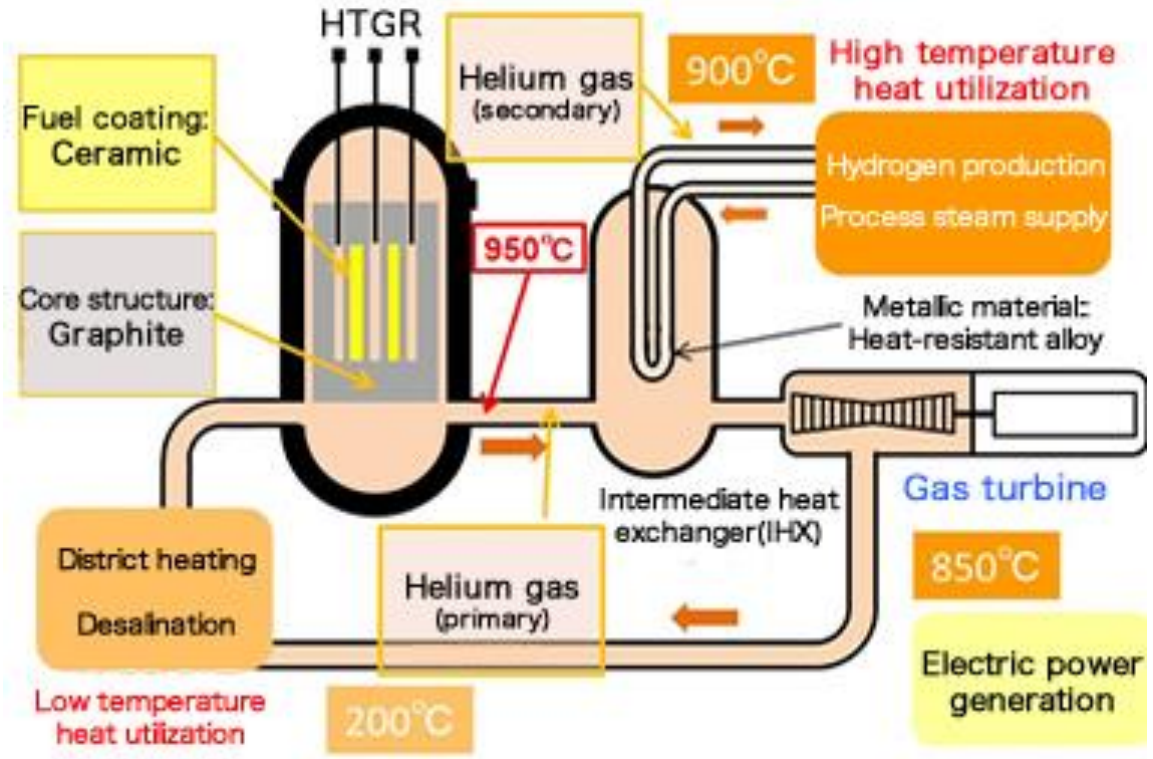
High Grade heat from advanced nuclear reactors could unlock highly efficient hydrogen production-step change for cost competitive hydrogen at scale

Sustainable Aviation Fuel (SAF)

Source: NNL

Deploying nuclear heat

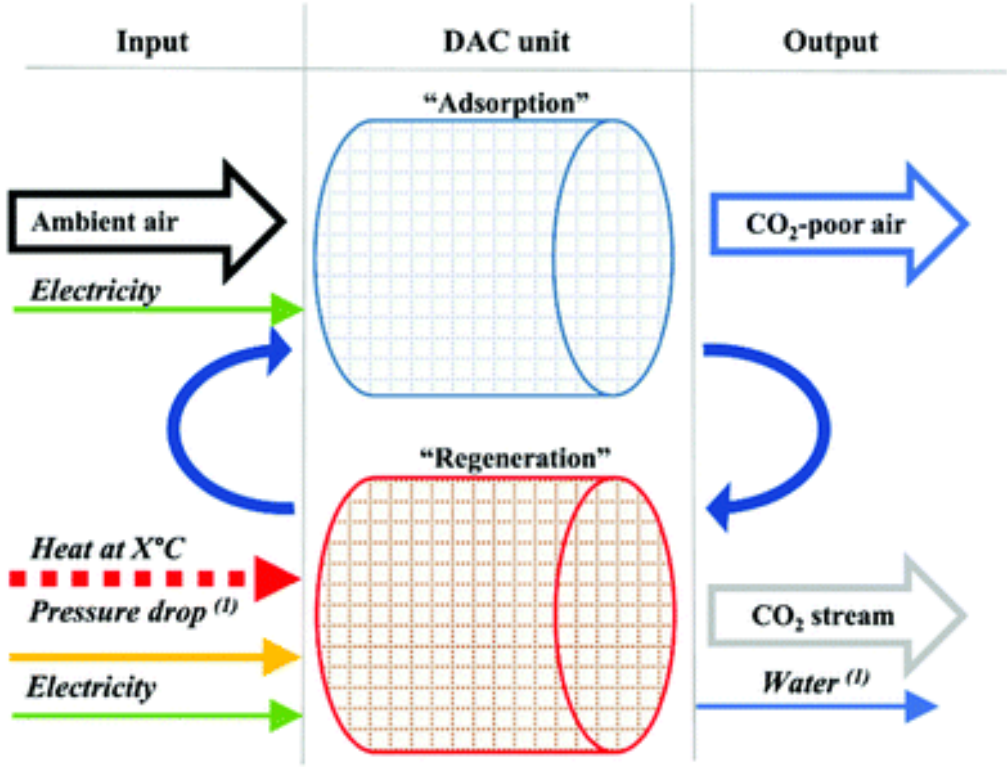
- The nuclear plant ideally needs to be close by
- A “nuclear park” concept e.g.
  - Premises heated by district heating
  - Industrial processes driven by nuclear heat
  - Direct carbon capture
  - Water desalination



Source :JAEA

Direct air capture of CO_2 with nuclear heat

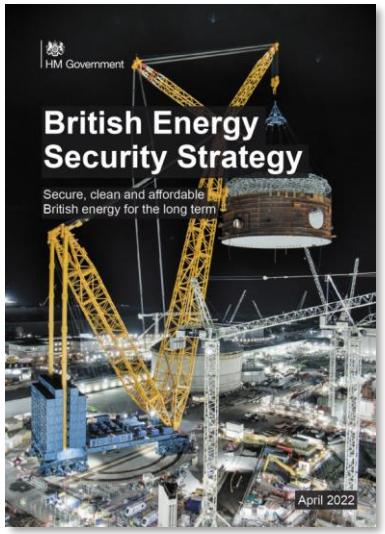
- Solid sorbent used to capture carbon dioxide from air
- Regenerated with waste heat from nuclear plant to release pure carbon dioxide
- Successful experiments recently reported
- Planned implementation at Sizewell C
- “Megatonnes” of carbon dioxide capture foreseen by this mechanism



Source: Royal Society of Chemistry

Addressing the British Energy Security Strategy

Launched 7 April 2022



British energy security strategy - GOV.UK (www.gov.uk)

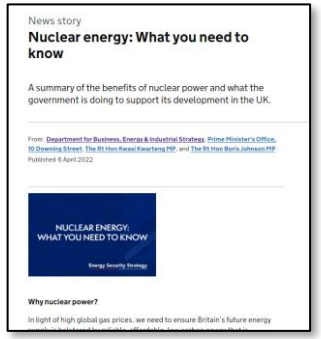
British Energy Security Strategy sets out HMG plans to reduce reliance on energy from overseas, specifically:

Nuclear – major increase in support, target of up to 24 GW by 2050 stated. HTGR supported as the AMR of choice.

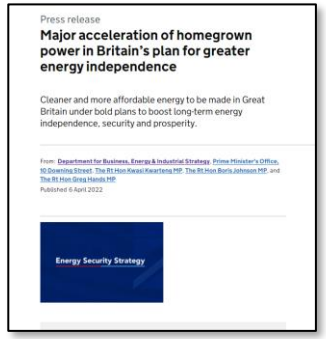
Hydrogen - 10GW by 2030, with at least half of this from electrolytic hydrogen. No reference yet to high heat processes.

We believe there is an opportunity to make local propositions in response to this national ambition

Alongside the strategy was a press release and an article on **Nuclear energy: What you need to know**



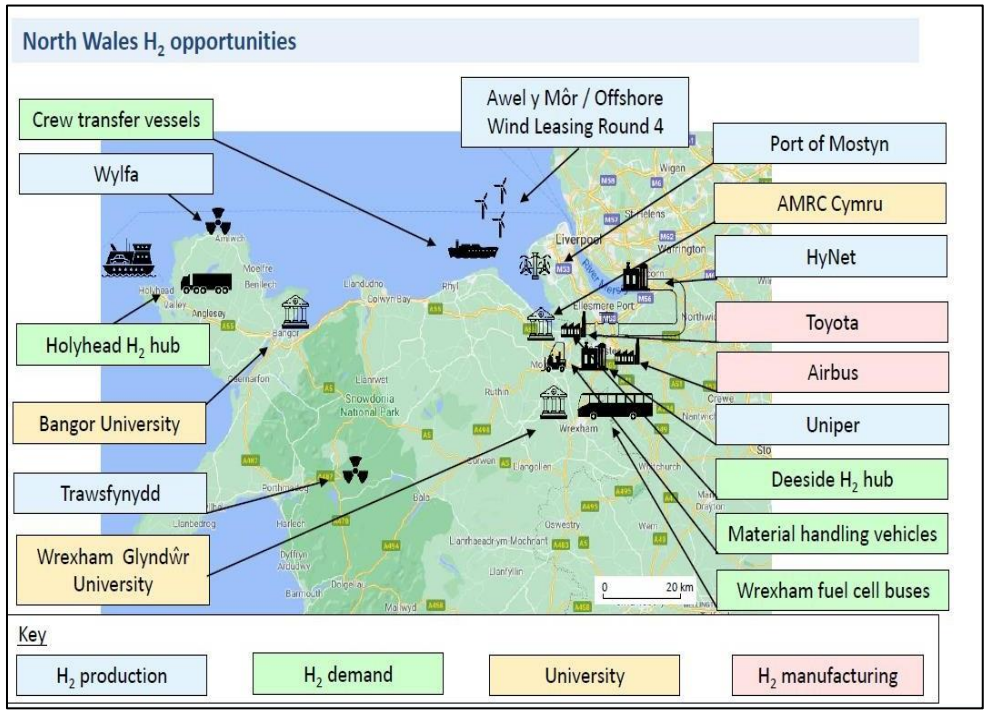
Major acceleration of homegrown power in Britain's plan for greater energy independence - GOV.UK (www.gov.uk)



Nuclear energy: What you need to know - GOV.UK (www.gov.uk)

Working collaboratively between Northern Nuclear Alliance and NW Hydrogen Alliance

- Northwest of the UK consumes about 5% UK's total energy in a small area around Chester/Manchester)
  - Perfect opportunity to address UK government's ambition for an "AMR (HTGR) – led" industrial complex
  - Potential for hydrogen storage in an off-shore gas-field
  - Plan for 2,000 homes in the area to be heated with hydrogen – a "hydrogen village"
  - The "Welsh connection" Wylfa and Trawsfynydd nuclear sites
  - NNA (Northern Nuclear Alliance) and NWHA (Northwest Hydrogen Alliance) coming together to define this opportunity



Source: Welsh Government

NORTHERN NUCLEAR ALLIANCE

North West Hydrogen Alliance

TÜV NORD

Public understanding of nuclear safety

- This is probably the biggest challenge
- Nuclear energy is objectively one of the safest forms of energy generation
- That is not how the public generally views it
- Addressing these concerns will be a real challenge for the “nuclear park” concept
- We must face this challenge head-on, or risk nuclear energy failing to play its essential role in combatting climate change
- Nuclear parks are also an opportunity – more familiarity will generate more public understanding
- NIA can help!

“The anti-nuclear movement to which I belonged has misled the world about the impacts of radiation on human health”

George Monbiot, Environmentalist, April 2011

Summary

- Nuclear energy is essential for combatting climate change effectively
- Renewable and nuclear energy working together is the most effective strategy
- Nuclear heat is needed for purposes additional to electricity generation
- “Nuclear parks” will be necessary to gain the full benefit of these concepts
- The biggest challenge is to improve the public understanding of nuclear hazards

TÜV UK
NUCLEAR DIVISION

WE WOULD LIKE TO THANK YOU FOR YOUR KIND ATTENTION.

Dr David Bradbury
Associate, TÜV UK Ltd
dbradbury@tuv-nord.com

Professor Joe Howe
Associate, TÜV UK Ltd
j.howe@chester.ac.uk

Ammonia Industry

What is ammonia used for?

- Household cleaners such as glass cleaner, stainless steel and porcelain surfaces
- Industrial Refrigerant. Ammonia is a very efficient cooling fluid

- Intermediaries for chemical industry e.g. UREA
- Fertilizers as an essential nutrient for plants and our crops. Currently 80% of ammonia produced today is used for fertilizers

Source: https://techiescientist.com/uses-of-ammonia/

- Clean Fuel as ammonia does not contain carbon, nor would its combustion generate greenhouse gases or other contaminants
- Why?
  - *Its carbon free*
  - *It could replace gasoline, diesel and kerosene*
  - *Leaks can be easily detected*
  - *Its already produced today so experience in production and transportation*
  - *It has three hydrogen atoms so is a hydrogen carrier*
  - *Distribution channels already established*

Source: https://techiescientist.com/uses-of-ammonia/

- Ammonia could be a potential fuel solution and hydrogen carrier. The challenge is the heat source for hydrogen cracking stage
- Engines, gas turbines and other combustion systems could be adapted to work with ammonia. Engines are targeting readiness for maritime by 2024
- Producing ammonia with clean energy is needed to ensure it is truly a low carbon fuel solution. This is where nuclear can be the solution. The selection of the right Fission technology and design drives the economics of heat and power generation that produces cost effective ammonia

Advantage & Disadvantages of Ammonia as a hydrogen carrier

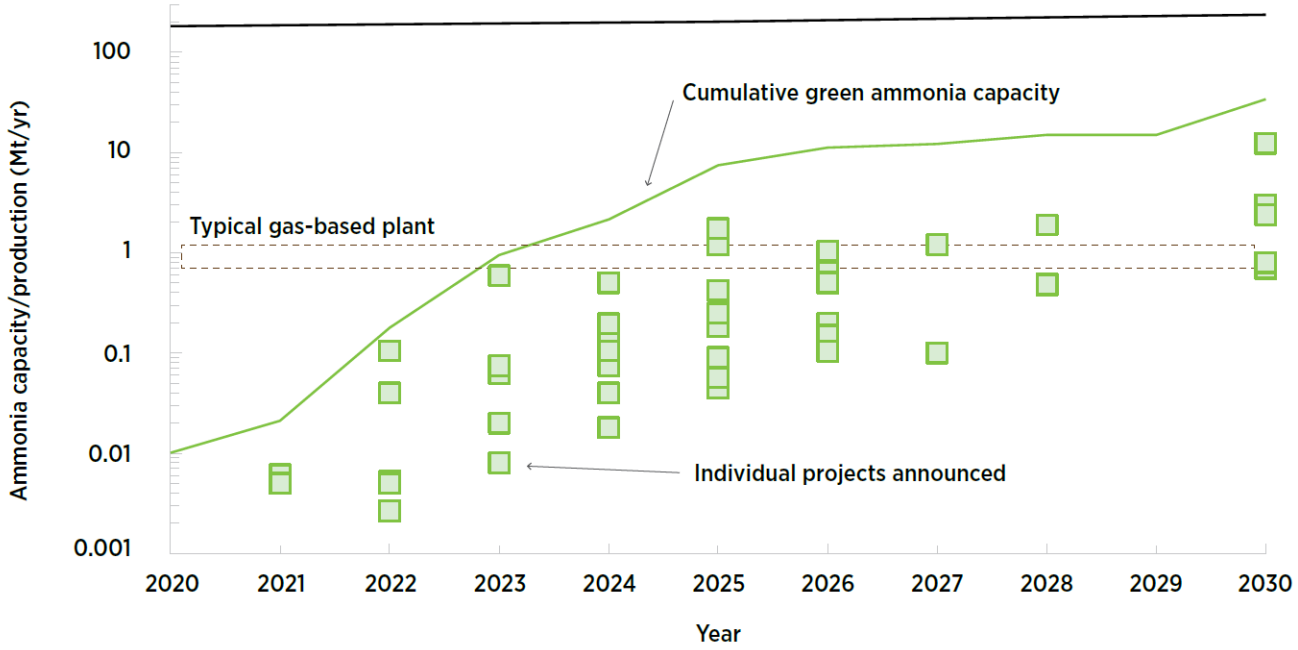
Advantages	Disadvantages
• Already produced on a large scale • Already globally traded • Low transport losses • High energy density and hydrogen content • Carbon-free carrier • Can be used directly in some applications (e.g. fertilisers, power generation, maritime fuel) • Can be easily liquefied (20°C at 7.5 bar or -33°C at 1 bar)	• High (12-26%) energy consumption for ammonia synthesis • High (13-34%) energy consumption for reconversion (importing region) with high temperature requirement (up to 900°C but more commonly in the 500-550°C range) • Ship engines using ammonia as fuel need to be demonstrated • Might require further purification of the hydrogen produced • Hydrogen compression needed for most applications • Higher NOx (nitrogen oxides) production during shipping would require flue gas treatment • Toxic and corrosive • Flexibility of the ammonia synthesis and cracking still to be proven

Ammonia Market Scale

Rising Market Trends

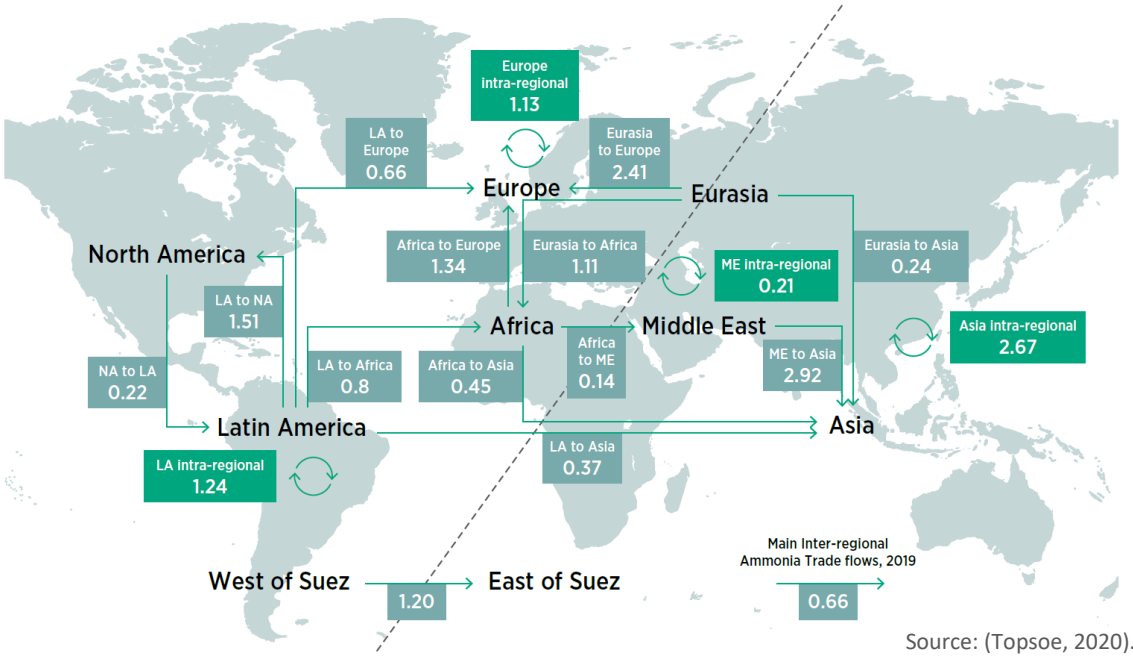
- 320MtCO2 from fossil fuels for energy. 50GW to produce 20Mt/yr ammonia
- Expanding market looking at ammonia as fuel for shipping
- 34Mt/yr within next decade
- Most forecast does not include reconversion to H2 yet

FIGURE 2.3. Projected green ammonia capacity according to project announcements



Citation: IRENA (2022), Global hydrogen trade to meet the 1.5°C climate goal: Part II – Technology review of hydrogen carriers, International Renewable Energy Agency, Abu Dhabi

FIGURE 2.1. Global trade flows of ammonia in 2019 (Mt)



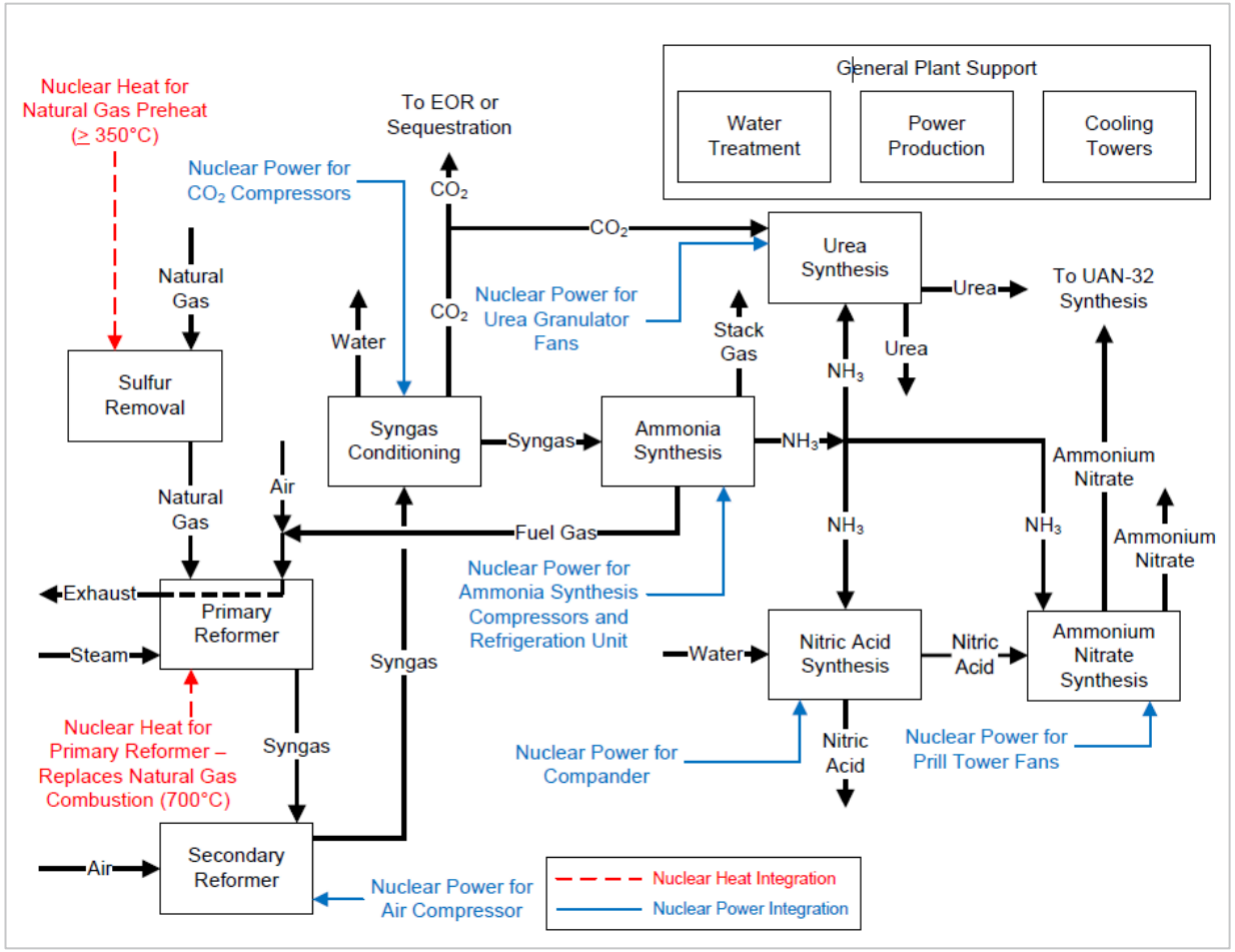
Source: (Topsoe, 2020).

Global Market

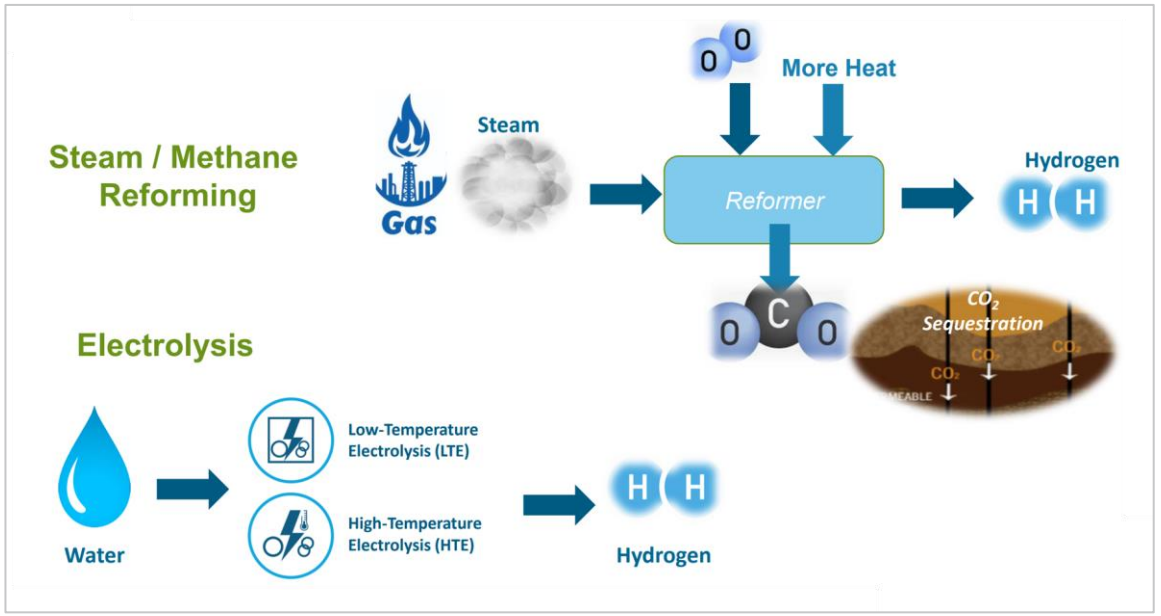
- Ammonia facilities are located inland
- Multiple storage facilities e.g. US has over 10,000
- 183Mt/yr in 2020 requiring 32.4MtH_2
- 72% is made from natural gas

What's the role of nuclear?

What's Nuclear role



Source: Idaho National Laboratory



Source: Idaho National Laboratory

Nuclear Role

- Decarbonise the energy used
- Provide competitive electricity, and high quality industrial heat
- Take advantage of the exothermic release of heat (8%)

IMSR is a fission technology delivering "high-quality" heat and electricity at a low cost to enable an essential pathway to Net Zero

Our technology supports decarbonisation of ammonia

Michael Drury

D5 Culham Science Centre

Abingdon

Oxfordshire , OX14 3DB

+44 7775 616 995

info@TerrestrialEnergy.com

www.TerrestrialEnergy.com

twitter.com/TerrestrialMSR

Disclaimer

Confidentiality
This document is confidential. It is being provided to you on the condition that it not be forwarded, copied or otherwise distributed without the prior written consent of Terrestrial Energy Inc.

No Offer or Solicitation
The information in this document is for informational purposes only and is not an offer to sell or the solicitation of any offer to buy securities. The only purpose of this document is to provide information regarding Terrestrial Energy Inc. Any such offer will be made only through the offering materials, which will be available only to accredited investors.

Forward Looking Statements
This document may contain forward-looking statements based on Terrestrial Energy Inc.'s expectations and projections. Those statements are sometimes indicated by words such as "expects," "believes," "will" and similar expressions. In addition, any statements that refer to expectations, projections or characterizations of future events or circumstances, including any underlying assumptions, are forward-looking statements. Such statements are subject to certain risks, uncertainties and assumptions that are difficult to predict.

NIA New Build Group
More Than Just Electricity

Wrap up

Thank you and safe travels…

Nuclear Industry Association

Nuclear Industry Association

Tower House, 10 Southampton Street
London WC2E 7HA

NIAUK.ORG

020 7766 6640

INFO@NIAUK.ORG

Follow us: @NIAUK