Offshore power: Floating low-carbon energy solutions for remote areas

Chair:
Tim Yeo
Chairman
New Nuclear Watch Institute

Speakers:

Kirsty Gogan
Co-Founder, TerraPraxis

Elena Pashina
Marketing Director, Rusatom Overseas

Mikal Boe
Chief Executive Officer, Core Power

Peder Norborg,
Chief Technical Officer, Seaborg Technologies

Richard Jones
Head of Nuclear R&D, EDF Energy

17 November 2021

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INNOVATION FOR CLIMATE

ENERGY INNOVATION FOR A PROSPEROUS PLANET

November 2021

TERRA PRAXIS

ABOUT TERRAPRAXIS

- TerraPraxis specializes in assembling solutions: Innovative technology configurations, delivery and deployment models designed against well-defined market requirements
- TerraPraxis provides leadership across multiple disciplines to break the deadlock on decarbonisation
- TerraPraxis has a strong track record in leading successful engagements, identifying leaders and aligning stakeholders around a broader range of solutions
- TerraPraxis designs and executes complex, high leverage strategies that inspire and mobilise leaders to initiate activity in multiple spheres of influence that generate and sustain their own momentum

De-Risking the Terawatt Transition at COP26

Photo credit: Julie Broadfoot

H.E. Mohamed Al Hammadi, *Managing Director and Chief Executive Officer*, Emirates Nuclear Energy Corporation

Eng. Andrew N. Kamau, *Principal Secretary*, State Department of Petroleum, Kenya

H. E. Aminath Shauna, *Cabinet Minister of Environment and Climate Change,* Maldives Government

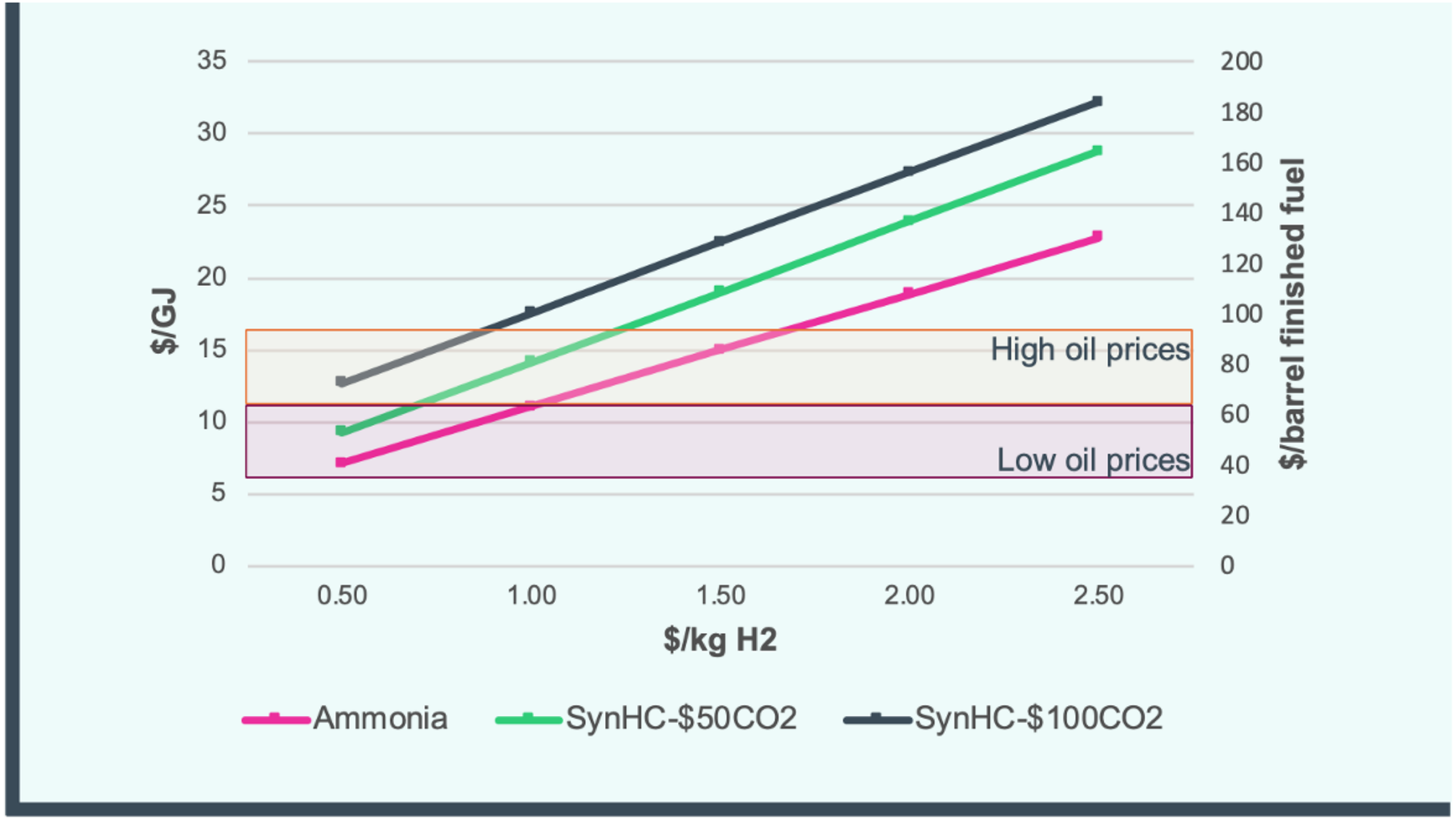
Dr Dirk Smit, *Chief Scientist*, Shell *(remotely)*

Dr Sama Bilbao y León, *Director General*, World Nuclear Association

Mr. Jens ÞÓRÐARSON, *Chief Operating Officer,* Icelandair *(remotely)*

Moderated by **Kirsty Gogan**, TerraPraxis

Cost: Oil price ‘guardrails’ of the hydrogen economy ($0.50–$1.50/kg)



Source:
***Missing Link to a Livable Climate*, LucidCatalyst (2020)**

Shipyard Construction of a Power, Fuels and Desalination Plant

Modular blocks are added to an FPSO under construction in a dry dock.

Ammonia Bunker Offloading from a Production Platform

Source:
***Missing Link to a Livable Climate*, LucidCatalyst (2020)**

See also: forthcoming report:
Electric Power Research Institute (EPRI) Report:
Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors. December 2021

Multi-Product Platform Making Hydrogen, Power, Ammonia and Fresh Water

Source:
***Missing Link to a Livable Climate*, LucidCatalyst (2020)**

See also: forthcoming report:
Electric Power Research Institute (EPRI) Report:
Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors. December 2021

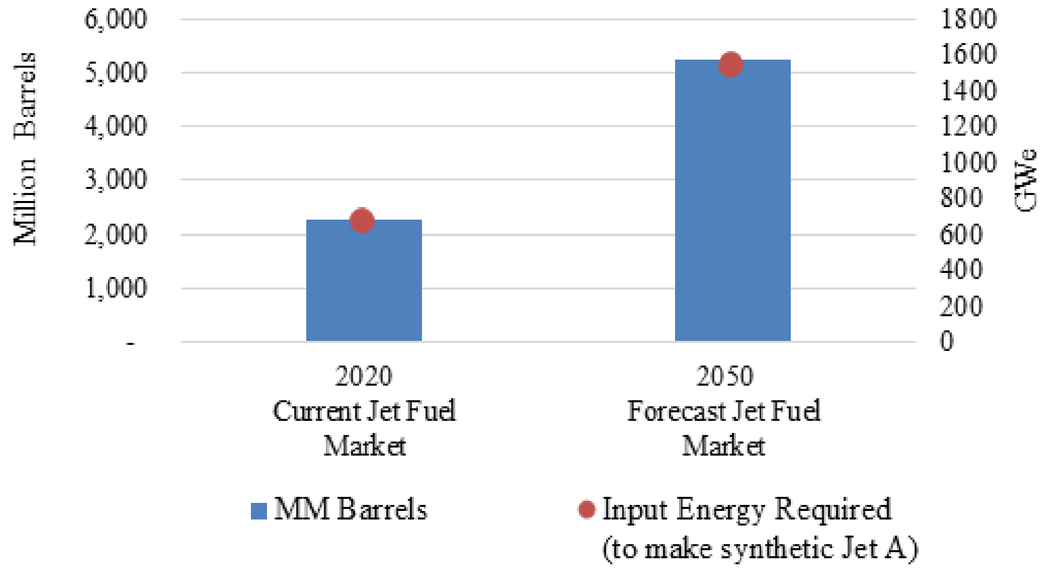
Zero-Carbon Commercial Aviation Fuel

Market Opportunity

Commercial air miles traveled are expected to nearly triple by 2050 from 2020.

The vast amount of arable land required to produce biofuel alternatives for aviation makes such a solution challenging

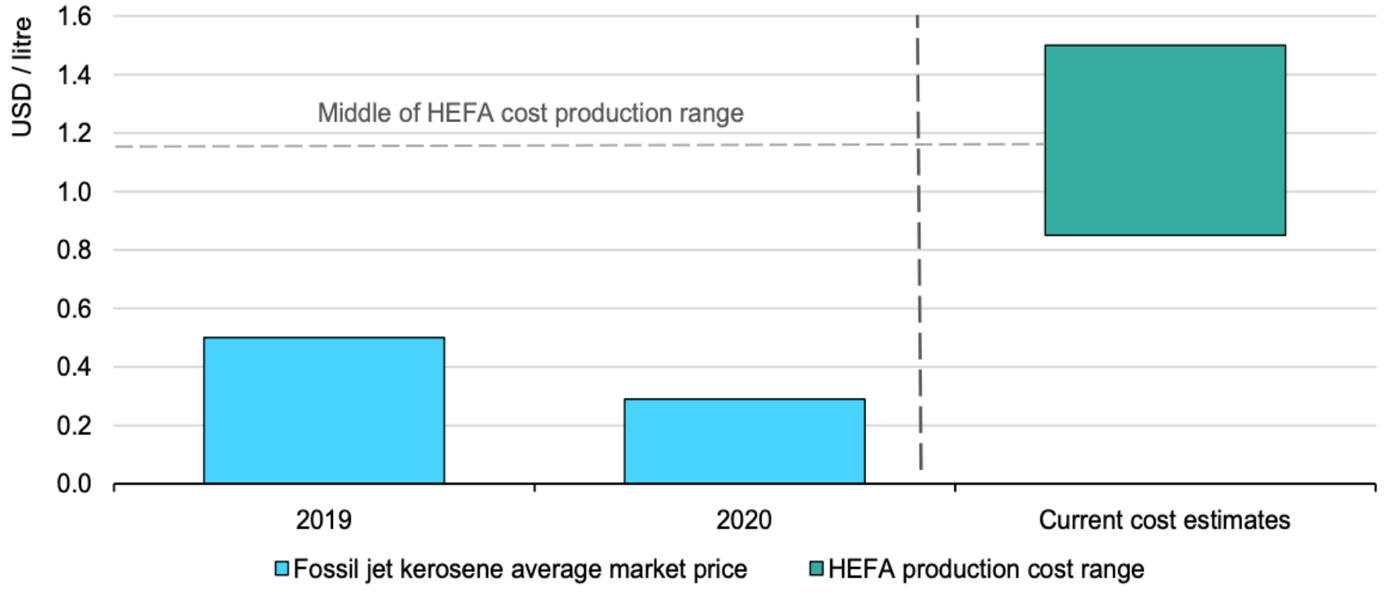
In the future, demand for greener air travel experiences could represent a major opportunity for producers of cost-competitive, carbon-neutral synfuels.

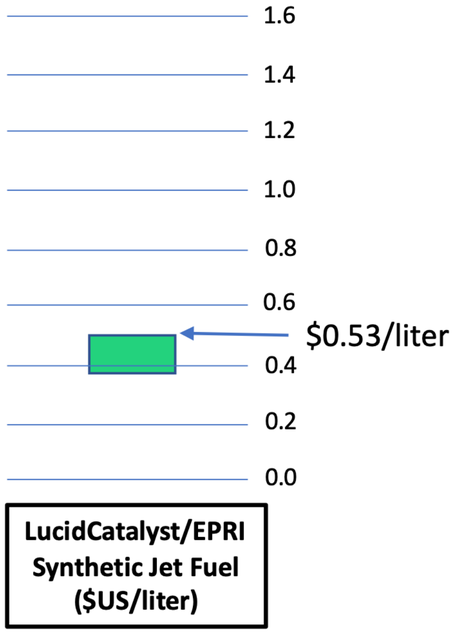


Current and Forecast Jet Fuel Market Potential and Energy Requirements (Gwe)

IEA: Sustainable Aviation Fuel Projected Costs Compared to Off-Shore Platform Synthetic Jet A Fuel

Figure 8.11 Fossil jet kerosene market price compared with HEFA aviation biofuel production cost





Source

Electric Power Research Institute (EPRI) Report: *Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors.* December 2021

Zero-Carbon Commercial Aviation Fuel

FPSO platform for production of synthetic Jet A with bulk carrier arriving alongside for delivery of limestone feedstock.

The bulk carrier (smaller vessel on right) drops off the limestone ($CaCO_3$) reagent and picks up lime (CaO) byproduct. Reagents and byproducts are stored in the hull of the FPSO close to the calcination equipment in the stern.

Bulker carrier moored alongside a Synfuel FPSO

Source
Electric Power Research Institute (EPRI) Report: *Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors.* December 2021

Carbon Negative Jet Fuel

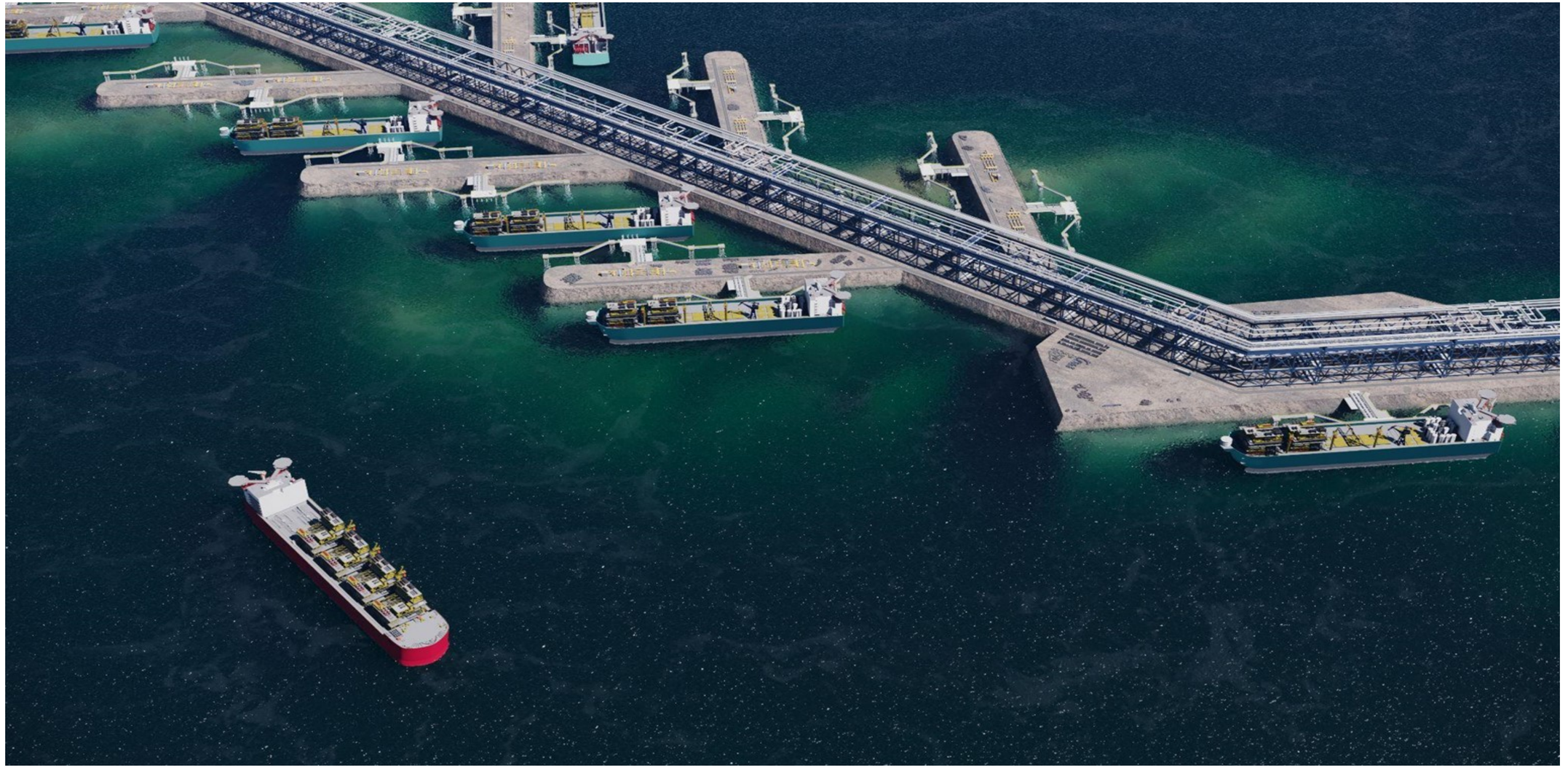
For a net carbon-negative fuel option, the byproduct lime can be dissolved in seawater to result in the net removal of 1.7 moles of CO_2 for each molecule of CO2 removed from the limestone.

Bulker carrier moored alongside a Synfuel FPSO

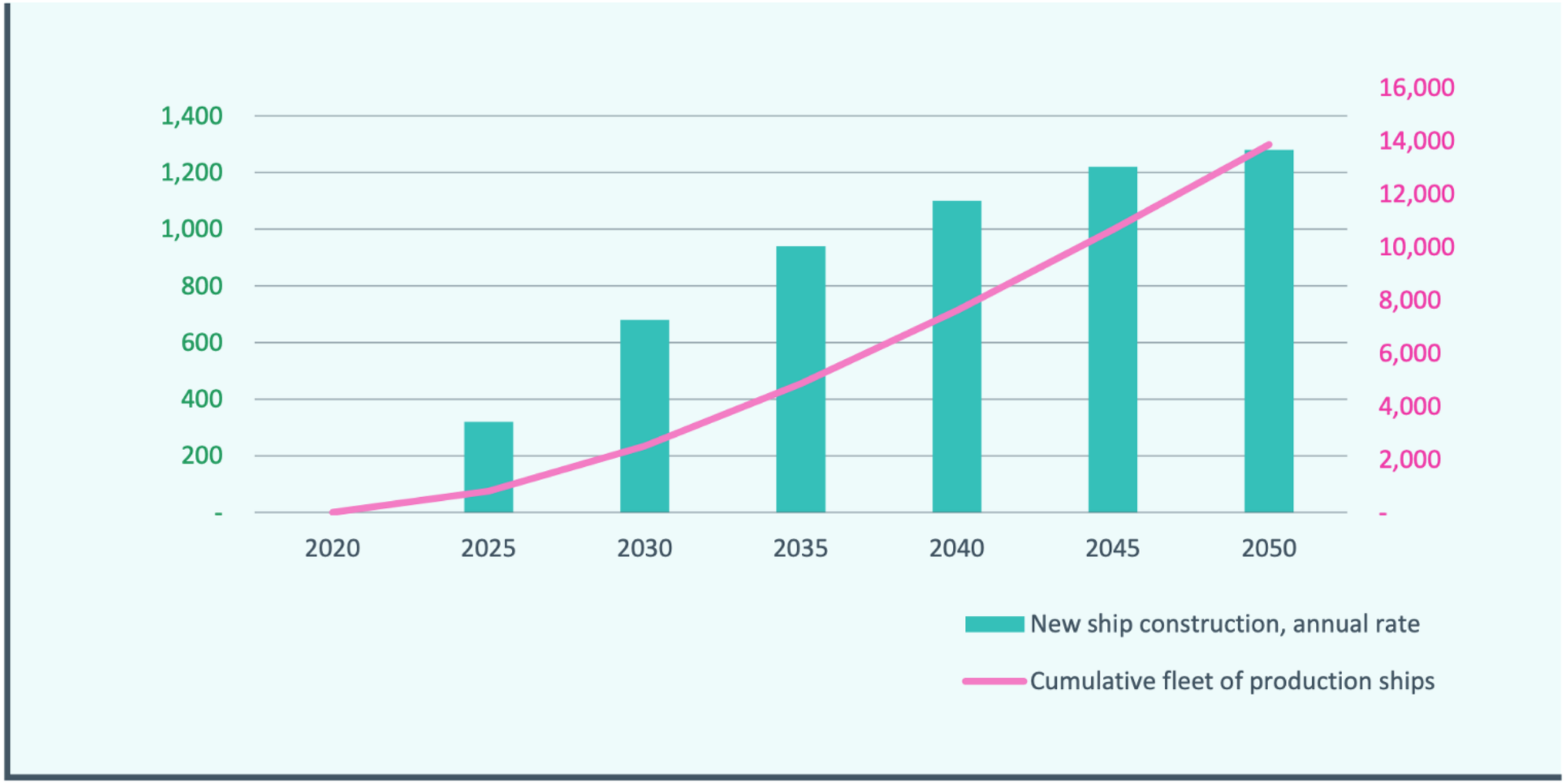
Source
Electric Power Research Institute (EPRI) Report: *Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors.* December 2021

Decarbonising Aviation

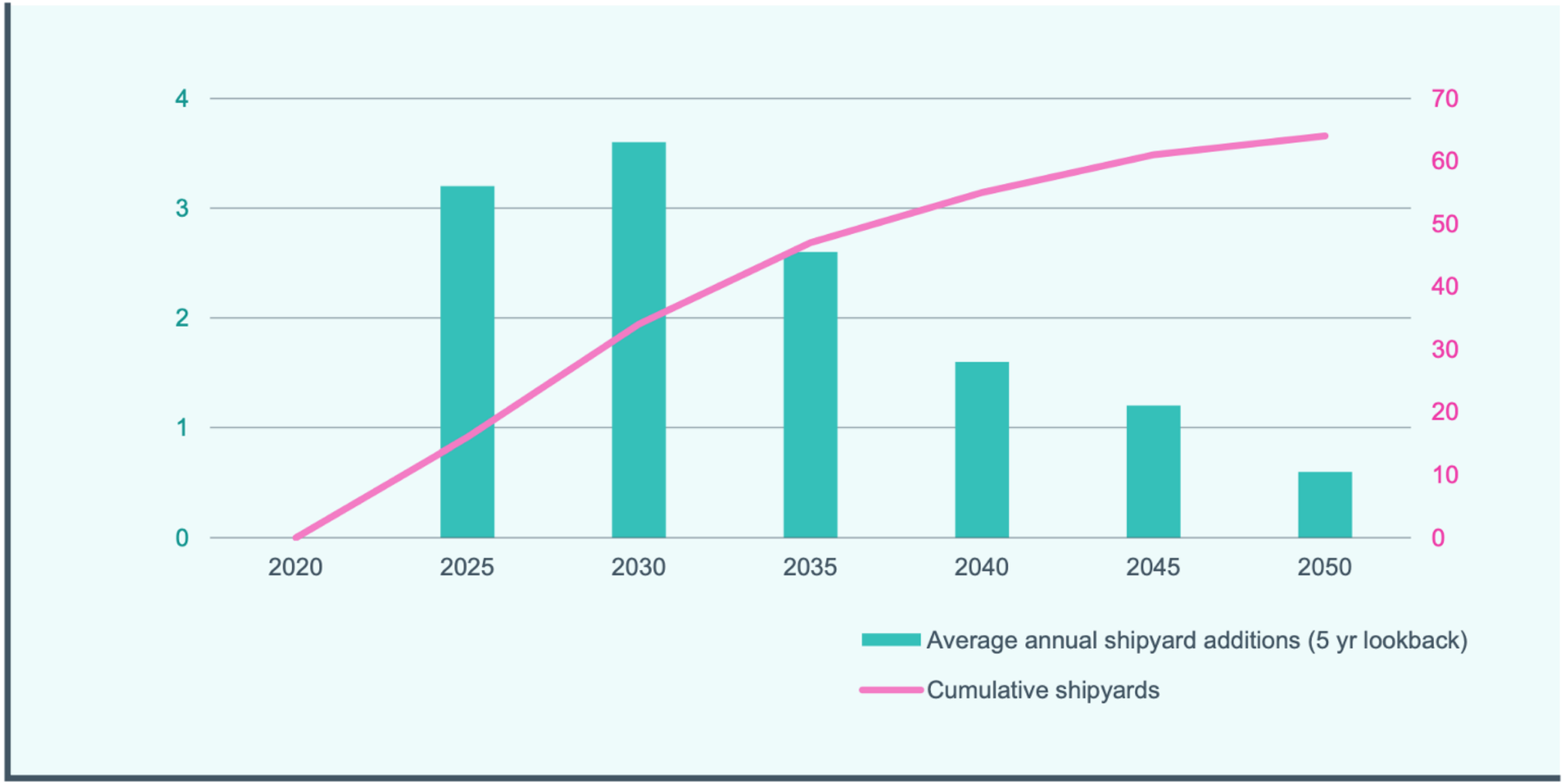
Large Scale Fuels Production for Global Markets



Additions and Cumulative Fuel Production Facilities



Shipyard Starts and Cumulative Operating Shipyards



ENERGY INNOVATION FOR A PROSPEROUS PLANET

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TERRA PRAXIS

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Elena Pashina
Marketing Director, Rusatom Overseas

17 November 2021

Rosatom SMR solutions for the market

Elena Pashina
Marketing Director

Rusatom Overseas
2021

ROSATOM global SMR strategy

FROM SUFFICIENT MARKET SIZE FOR SERIAL CONSTRUCTION AT HOME TO EXPORT OF A TRIED AND TESTED TECHNOLOGY:

- SMRs are a part of country's Energy strategy 2035
- SMRs are a key track of Comprehensive R&D program of Russian nuclear industry
- Special purpose office within ROSATOM was established with participants from Rosatom major subsidiaries
- Government support for FOAK projects implemented in Russia

Why is ROSATOM investing into small modular reactors?

EXISTING EXPERIENCE

The leader on nuclear power plant construction market

Vast experience in **small reactors** development for marine applications – more than **400 reactor-years**

NEW MARKET OPPORTUNITIES

Smart grids are developing

Energy systems **decentralization** is required where small capacity energy units prevail

Global trend for **decarbonization**

ROSATOM and development of small reactors

- **1945** – “birth” of Russian nuclear industry
- **Since 1954**, OKBM Afrikantov (ROSATOM) has been designing marine reactors (<60 MWe)
- **Over twenty small reactors** for civil marine applications have been manufactured and operated so far
- **Total experience** of operation of small reactors for icebreaker fleet – about **400 reactor-years**

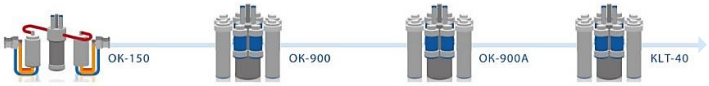
World’s only floating nuclear power plant “Akademik Lomonosov” commissioned in May 2020

TODAY THE FNPP PROVIDES **RELIABLE** AND **CLEAN** HEAT AND POWER SUPPLY TO LIVING AREAS AND **ENSURES POTENTIAL** FOR INDUSTRIAL DEVELOPMENT IN CHUKOTKA REGION

World’s first floating nuclear power plant Akademik Lomonosov commissioned

Displacement	**21 000 t**
Length	**140 m**
Beam	**30 m**
Draught	**5.6 m**
Fuel cycle	**3 years**
Design life	**40 years**
Time to maintenance	**12 years**

*including operational and support staff



2 x KLT-40S

Thermal capacity	**300 MW**
Electrical capacity	**Up to 77 MW**

COGENERATION MODE

Thermal power considering the electric power reduced to 45 MW	**146 Gcal/h**

FNPP construction

Floating nuclear power plant: layout

ROSATOM SMR evolution: from KLT-40S to RITM-200

- **Time proven PWR** technology
- **Integral** configuration
- **3+** generation
- **45% less** in the dimensions, **35% less** in mass*

more 400

Reactor-years of successful operation of small reactors on icebreakers

** Compated to KLT-40S*

RITM series reactors incorporate all the best features from its predecessors

ROSATOM small reactors evolution

- ✓ Based on **400 reactor-years** experience of ROSATOM in operation of small reactors for marine applications
- ✓ **Time proven PWR** technology
- ✓ **Integral** configuration
- ✓ **3+** generation
- ✓ **190** MWth
- ✓ Proven **efficiency** and **ultimate safety at all stages** of the life cycle
- ✓ **45% less** in the dimensions, **35% less** in mass compared to KLT-40S
- ✓ **Floating** or **land-based** NPP design is available

New Arktika icebreaker

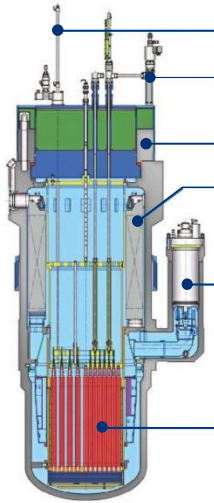
21 OCTOBER 2020 ARKTIKA ICEBREAKER OFFICIALLY ENTERED SERVICE WITH THE RUSSIAN NUCLEAR ICEBREAKER FLEET

- Equipped with **two RITM-200 reactors**
- Able to break through ice up to **3** meters
- **Sibir**, **Ural, Yakutia** icebreakers to enter operation in **2021**, **2022, 2025**

Source of the picture: United shipbuilding corporation

RITM series SMR: key components

RITM SERIES SMR ENVISAGES SIMPLIFIED INTEGRAL DESIGN WITH THE STEAM GENERATORS INCORPORATED INTO THE REACTOR PRESSURE VESSEL



CONTROL AND SAFETY RODS

- Based on the drives used in KLT-40S reactor
- 12 control rods
- 6 safety rods

4 STEAM GENERATORS

- Steam of 295°C at 3.82 MPa
- 305 t/h – capacity

CORE

- 199 fuel assemblies
- Low-enriched cermet fuel
- 1650 mm – height of the core
- 8 TWh – assigned service life
- Power changes with a design rate of 0.1%/s

REACTOR PRESSURE VESSEL

- Integral reactor configuration almost eliminates the classic large LOCA

4 MAIN CIRCULATION PUMPS

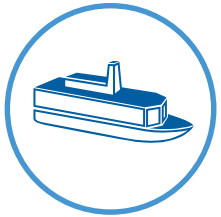
- Provide stable forced circulation of coolant
- Similar to those used on KLT-40S

Versatile applications of RITM series SMRs

RITM-200	RITM-200N	RITM-200M	RITM-400
			
Thermal capacity, MW **175**	Thermal capacity, MW **190**	Thermal capacity, MW **190**	Thermal capacity, MW **315**
Steam generating capacity, t/h **248**	Steam generating capacity, t/h **305**	Steam generating capacity, t/h **305**	Steam generating capacity, t/h **450**
Design lifetime, years **40**	Design lifetime, years **60**	Design lifetime, years **60**	Design lifetime, years **40**
Fuel cycle, years **4-7**	Fuel cycle, years **5-6**	Fuel cycle, years **10**	Fuel cycle, years **5**
Reactor containment dimensions, m **6 x 6 x 15.5**	Reactor containment dimensions, m **Ø8,8 x 22**	Reactor containment dimensions, m **6.4 x 6.6 x 16,2**	Reactor containment dimensions, m **9 x 8.2 x 17.5**
Status of the development **In operation**	Status of the development **Land-based NPP under development**	Status of the development **Technical design in progress**	Status of the development **Start of construction works**
Year of commissioning **2020**	Year of commissioning **2028**	Year of commissioning **2027/2028**	Year of commissioning **2027**

Two options of ROSATOM small NPPs based on RITM series SMRs

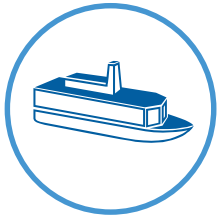
FLOATING NPP (FNPP) EQUIPPED WITH RITM SERIES SMR



LAND-BASED NPP EQUIPPED WITH RITM

Two options of ROSATOM small NPPs based on RITM series SMRs

FLOATING NPP (FNPP) EQUIPPED WITH RITM SERIES SMR



LAND-BASED NPP EQUIPPED WITH RITM

FNPP is capable of supplying energy to both onshore and offshore consumers

- OFFSHORE TERRITORIES
- OFFSHORE AGGLOMERATIONS
- PORTS

- ISLANDS
- ARCHIPELAGOS
- OFF-SHORE FACILITIES

- MINING FACILITIES
- LARGE FACILITIES UNDER CONSTRUCTION
- MINERAL PROCESSING FACILITIES

FNPP: optimized solution for coastal areas power supply

TECHNICAL PARAMETERS

Reactor	2 x RITM-200M
Electrical capacity	100 MW
Fuel cycle	up to 10 years
Design life	60 years
Displacement	18 670 tons
Length	112 m
Beam	30 m
Draught	5,84 m

CURRENT STATUS OF OPTIMIZED FNPP

- ✓ **August 2020** – conceptual design completed
- ✓ **IV quarter 2020** – start of technical design stage

OPTIMIZATION RESULTS COMPARED WITH FNPP AKADEMIK LOMONOSOV

by **28 m** – length reduction

by **4 320 t** – displacement reduction

30% – electrical capacity increase

Optimized FNPP benefits

ALL BENEFITS OF NUCLEAR POWER:

- **A continuous base-load power supply** within a 60-year life
- **Synergy with the renewable energy sources**
- **Effective cost management** due to fixed total electricity cost throughout a 60-year life
- **Multipurpose application** including water desalination, district heating

ADDITIONAL SPECIFIC ADVANTAGES OF FNPP

- **Short period of construction** works at the site
- **No decommissioning** at the site
- **Long fuel campaign** (up to 10 years)
- **Flexible life-time period**

Key principles of the FNPP safety

ENSURED nuclear and radiation safety

NO RADIATION EXPOSURE

RESISTANT TO EXTERNAL IMPACTS

GUARANTEED resistance against external events

NATURAL

MAN-CAUSED

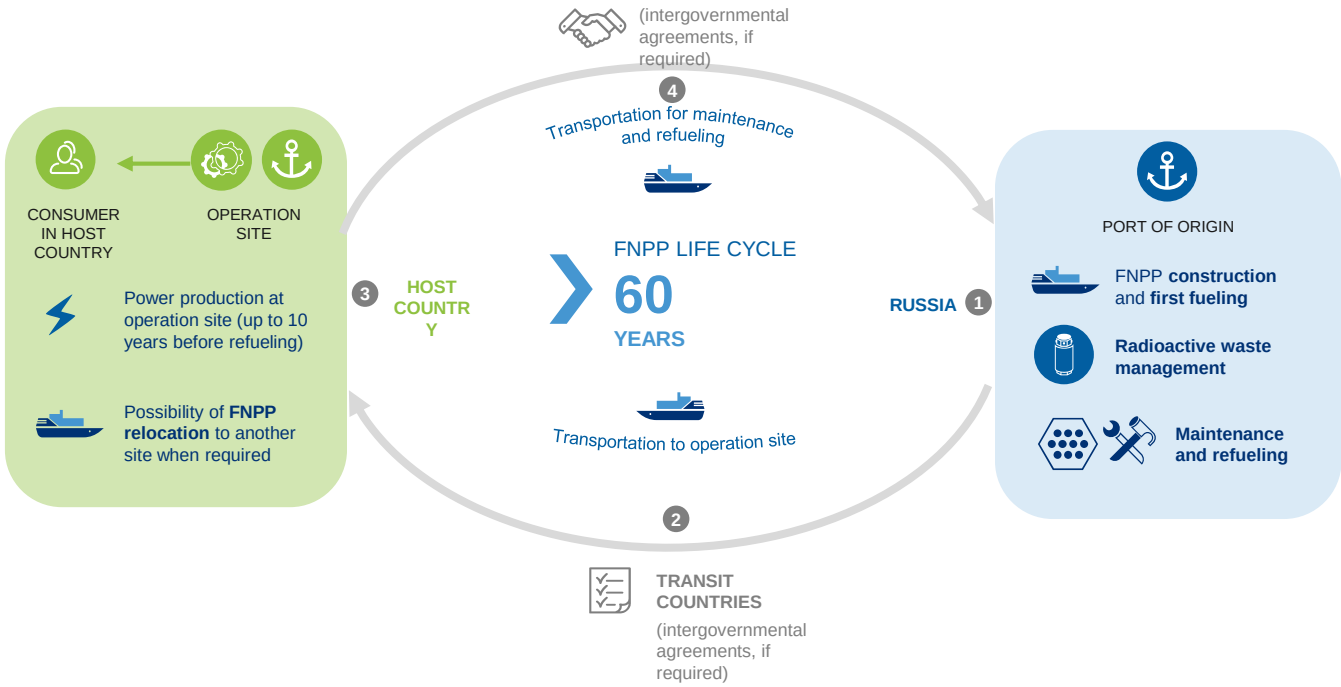
PITCHING & ROLLING

Radiation exposure on population during normal operation and design accident **has no impact on natural radiation background level**

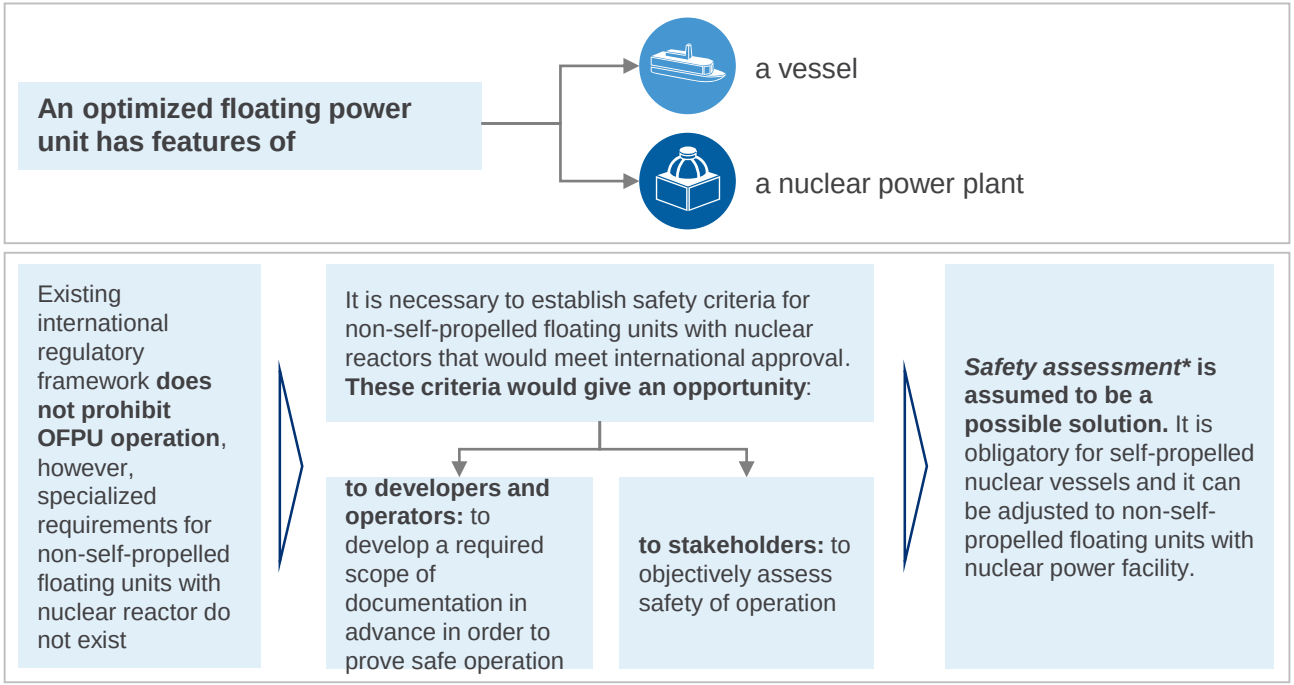
Application of the nuclear safety technical and organizational measures **excludes nuclear and radiation accidents**

No necessity for compulsory evacuation measures planning zone

FNPP lifecycle



Optimized floating power unit legal regulation



** Safety assessment is required by SOLAS-74 and by Code of safety for nuclear merchant ships Res. A..491 (XIII) passed by International Maritime Organization*

International cooperation in the field of SMR development

IAEA

- Technical Working Group on Small or Modular Reactors (**3** participants, **2** observers)
- INPRO TNPP-2 (**8** participants, **40** side experts)
- Regional TC Project RER2014 Facilitating Capacity Building for Small Modular Reactors: Technology Developments, Safety Assessment, Licensing and Utilization (**3** participants)
- Small Modular Reactor (SMR) Regulators' Forum (**5** participants)
- Working Group on Licensing Issues

WNA

Cooperation in Reactor Design Evaluation and Licensing (CORDEL)

- Licensing and Permitting Task Force
- Small Modular Reactors Task Force

NEA OECD

Nuclear Law Committee

- Working Party on the Legal Aspects of Nuclear Safety (Licensing of SMRs)

Committee on Nuclear Regulatory Activities

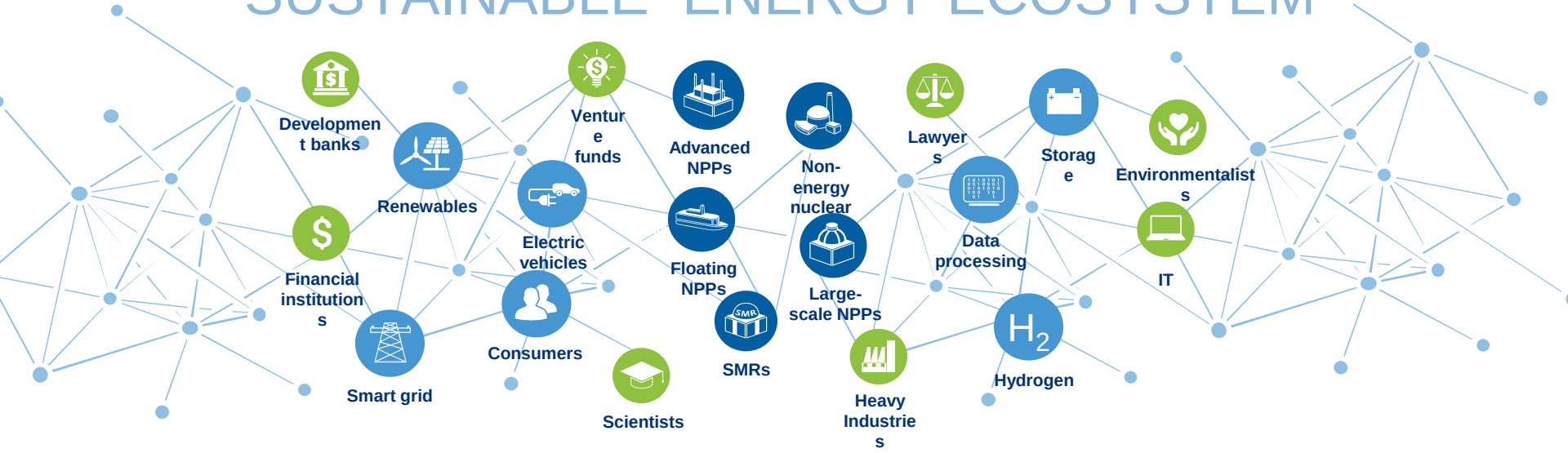
- Working Group on the Regulation of New Reactors (WGRNR)
- Codes and Standards Working Group

Multinational Design Evaluation Programme (MDEP)

Nuclear can become a stable and reliable element for the all-out support of the system

ROSATOM

SUSTAINABLE ENERGY ECOSYSTEM



NUCLEAR POWER IS A WIN-WIN LOW-CARBON SOLUTION FOR COUNTRIES TO STRIKE THE RIGHT BALANCE BETWEEN ALL THE ELEMENTS

Thank you
for your attention

2021

Offshore power: Floating low-carbon energy solutions for remote areas

Mikal Boe
Chief Executive Officer, Core Power

17 November 2021

Molten salt future.

Molten salt → **electric ships.**
Electric ships → **clean power in ports.**
Clean power in ports → **offshore processing.**
Offshore processing → **improved value chains.**
Improved value chains → **competitive industry.**

Clean energy you can rely on. Always there, always from CORE POWER – www.corepower.energy / mikal.boe@corepower.energy

Offshore power: Floating low-carbon energy solutions for remote areas

Peder Norborg
Chief Technical Officer, Seaborg Technologies

17 November 2021

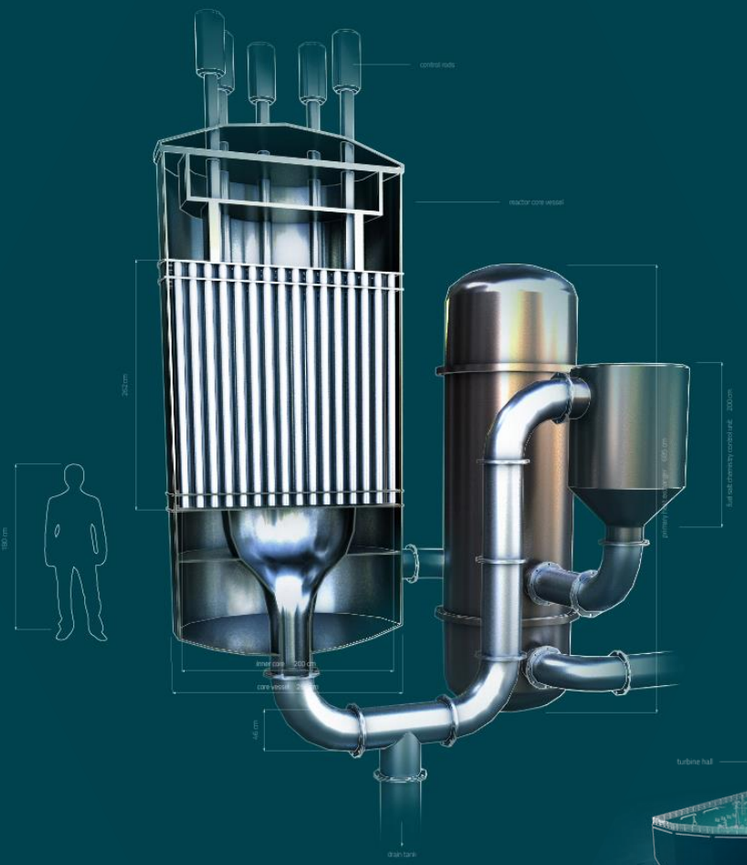
SEABORG

Rethinking nuclear

Enabling world wide deployment by design and regulatory approach

Peder Norborg
Chief Technical Officer

THE CMSR POWER BARGE



Developing

The Compact Molten Salt Reactor

- Small modular nuclear reactor
- Mass produced
- Deployed on barges
- 200-800 MWe power barges

SEABORG IN A NUTSHELL

Privately held and
privately funded company

Partnerships with shipyards,
nuclear and heavy industry

75+ employees

Scaling to **90 employees** in 2021

HQ in Copenhagen, Denmark

Business offices in South Korea & Singapore

We will only reach our goals for **decarbonisation** if the alternative is **cheap** enough and scales **fast**.

VISION

Transform energy markets and **out-compete fossil fuels** to create a bright future with abundant clean energy for everyone.

UNPRECEDENTED OPPORTUNITY

Executing a rapid **world-wide deployment** of the Compact Molten Salt Reactor via **shipyard serial production** of power barges.

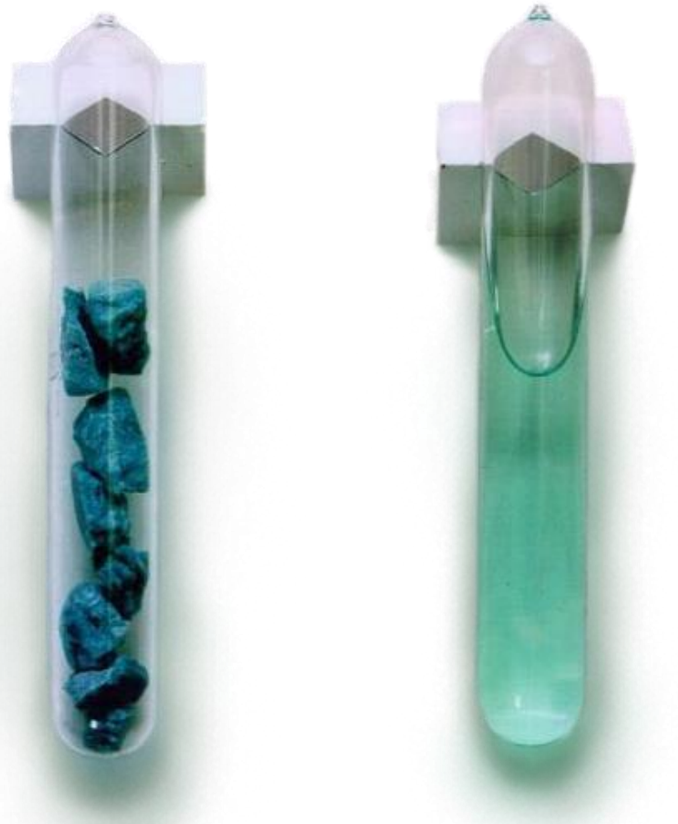
THE MAGIC IS IN THE SALT

Molten fluoride salt makes nuclear inherently safe

The fluoride salt contains the radioactive elements

- No release of gases
- Very low solubility in water
- Below 490°C, it is a rock
- Boils at 1500 °C

Safety is ensured by the laws of nature



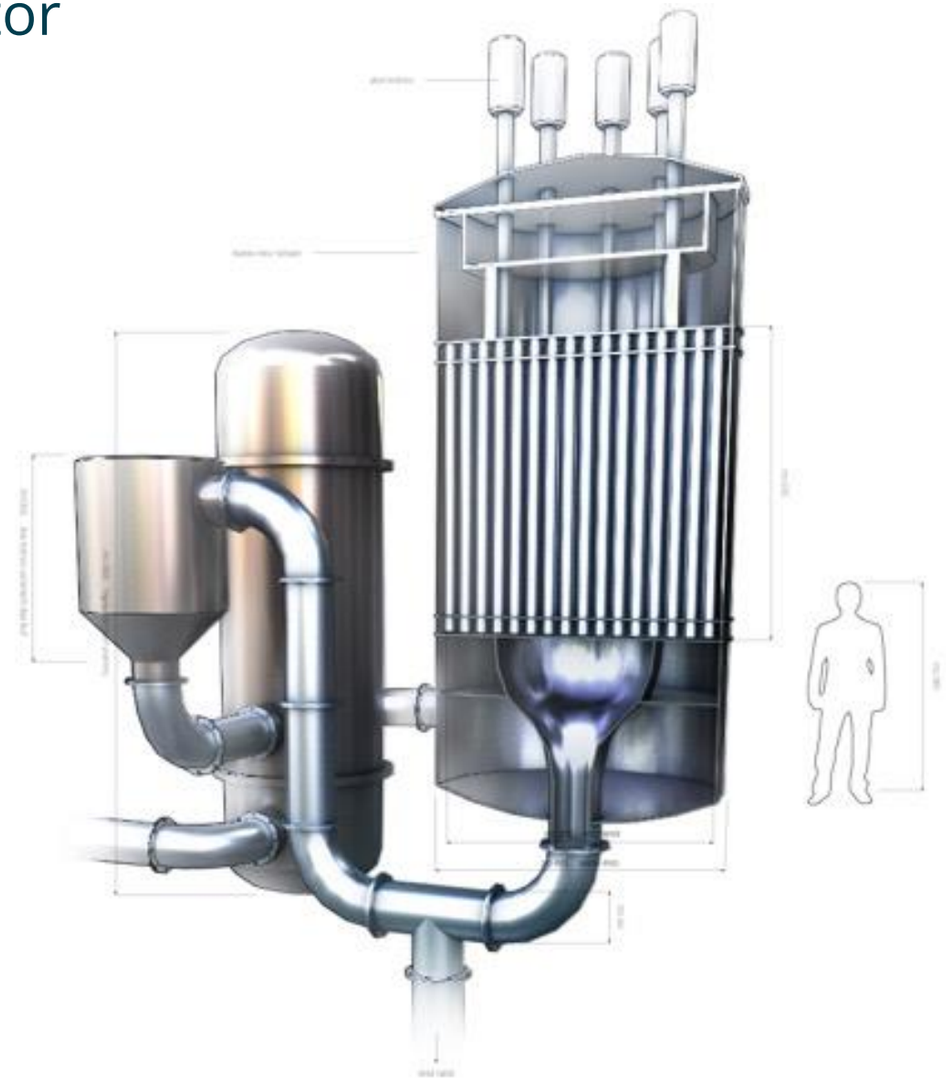
FUNaK Fuel Salt

SAFE, CHEAP AND CLEAN NUCLEAR

Seaborg's modular Compact Molten Salt Reactor

The Seaborg CMSR is inherently safe. It:

- **Cannot** melt down or explode
- **Cannot** release radioactive isotopes to air or water
- **Cannot** be used for nuclear weapons
- Operates for **12 years without refuelling**



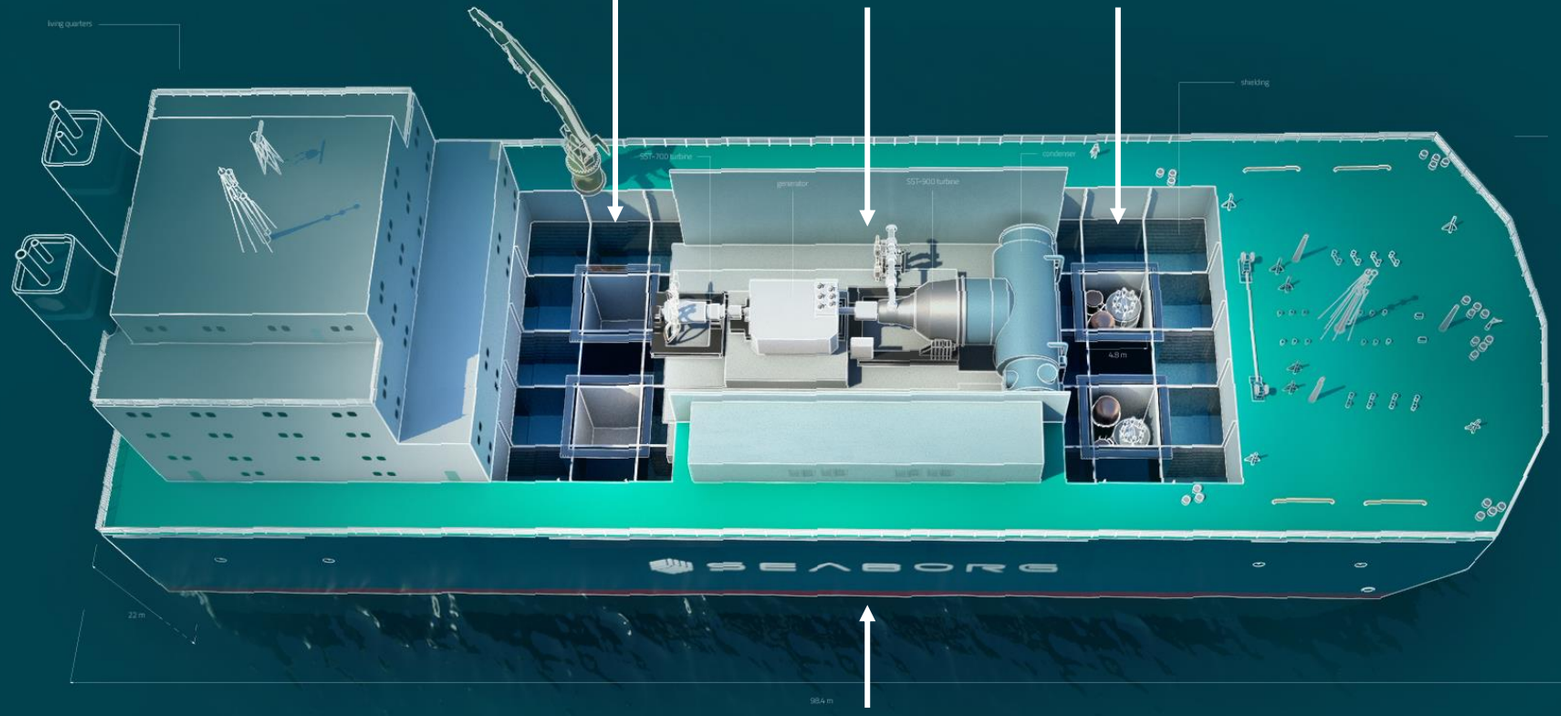
MODULAR CMSR POWER BARGE

24 years operational life time

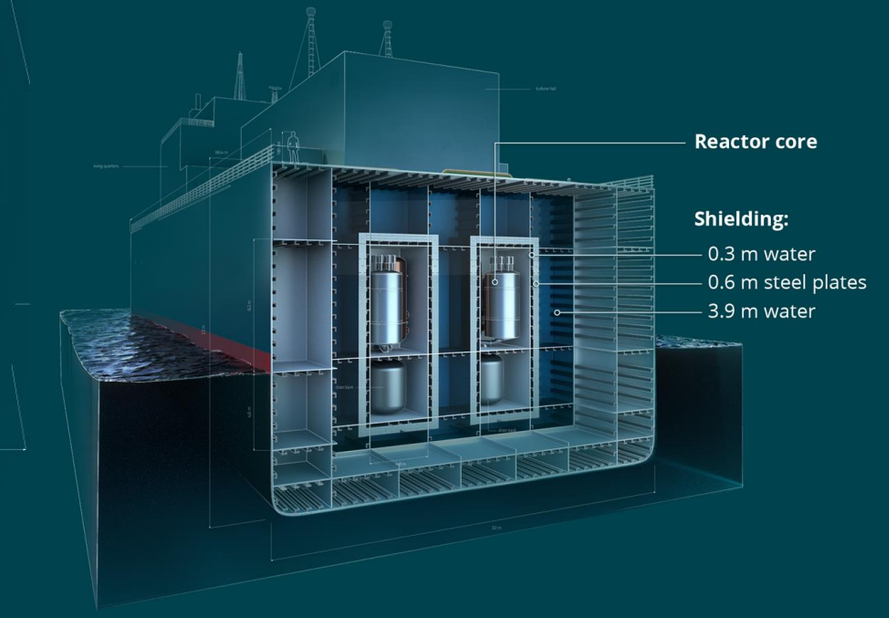
2 empty CMSR compartments for the second 12-year fuel cycle

Steam turbine with generator and condenser

2 CMSRs for the first 12-year fuel cycle



Compartments below turbine with auxiliaries for steam generation, power transmission and the CMSR



TURNKEY FLOATING POWER PLANT

The CMSR Power Barge

Flexible, convenient and fast:

- **Standard designs** with 200/400/600/800 MWe
- **3 years** from order to grid
- Fully commissioned **at shipyard**
- **First power barge delivered in 2026**

	Length [m]	Thermal output [MWt]	Electrical output [MWe]
2x CMSR	98.4	500	200
4x CMSR	160.8	1000	400
6x CMSR	223.2	1500	600
8x CMSR	285.6	2000	800

UN REGULATORY FRAMEWORK

Complying with IAEA through IMO regulations

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

IMO
INTERNATIONAL MARITIME ORGANIZATION

The International Atomic Energy Agency - is the world's central **intergovernmental forum** for scientific and technical **co-operation** in the nuclear field.

The International Maritime Organization – is the United Nations **global standard-setting authority** for the **safety, security and environmental** performance of international shipping.

BUILDING THE SAFETY CASE

- 1. Introduction and General Description of the Plant and Supporting Facilities
- 2. Site Requirements
- 3. General Design Safety
- 4. Ship and its general safety
- 5. Description and conformance to the design of plant systems
- 6. Safety Analyses
- 7. Commissioning
- 8. Operational Aspects
- 9. Transport Arrangements
- 10. Radiological Protection
- 11. Emergency Preparedness & Response
- 12. Radioactive waste management
- 13. Safeguards and Security
- 14. Decommissioning
- 15. Control of Non-Radiological Hazards
- 16. Environmental Protection

16 Chapters

1. Introduction and General Description of the Plant and Supporting Facilities
- 1.1 General Ship Description
- 1.2 General Plant Description
- 1.3 Overview of the designer organization and supply chain capability
- 1.4 Applicable legislation, regulations, guidance, codes, and standards
- 1.5 Scope of the report: facilities on-site and facilities off-site which the plant relies upon for operation
- 1.6 Overview of the plant layout
- 1.7 Operating modes of the nuclear power unit
- 1.8 Comparison Tables
- 1.9 Description of the overall quality management philosophy
- 1.10 Management of safety
- 1.11 Requirements for Further Technical Information
- 1.12 Material incorporated by reference

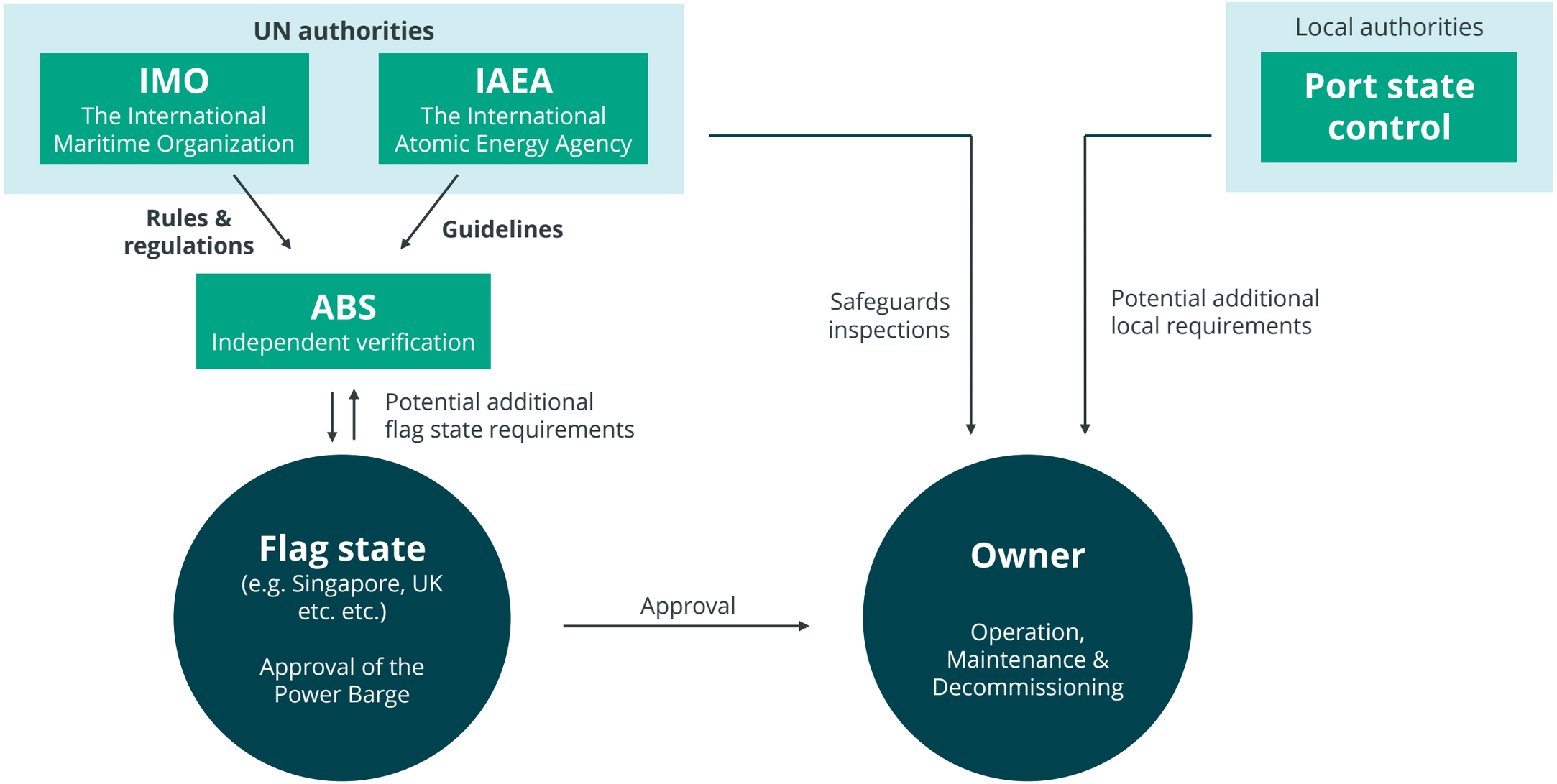
149 Sub-Chapters

ABS – CLASSIFICATION SOCIETY

American Bureau of Shipping (ABS) is a member of the **International Association of Classification Societies (IACS)**

- Founded in 1862 with HQ in Texas. Operates 200 offices with **5,500 employees.**
- Rules established by IACS also adopt and include the rules from the **International Maritime Organization** on behalf of the **flag states.**
- Assessments for the United States Department of Homeland Security and US Coast Guard.
- American Bureau of Shipping (ABS) Group has performed **advanced compliance assessments** for several **nuclear facilities.**

REGULATORY ROLES



ABUNDANT, CHEAP AND CLEAN ENERGY

200 Power Barges per year by 2035

Develop in Denmark

Build in South Korea

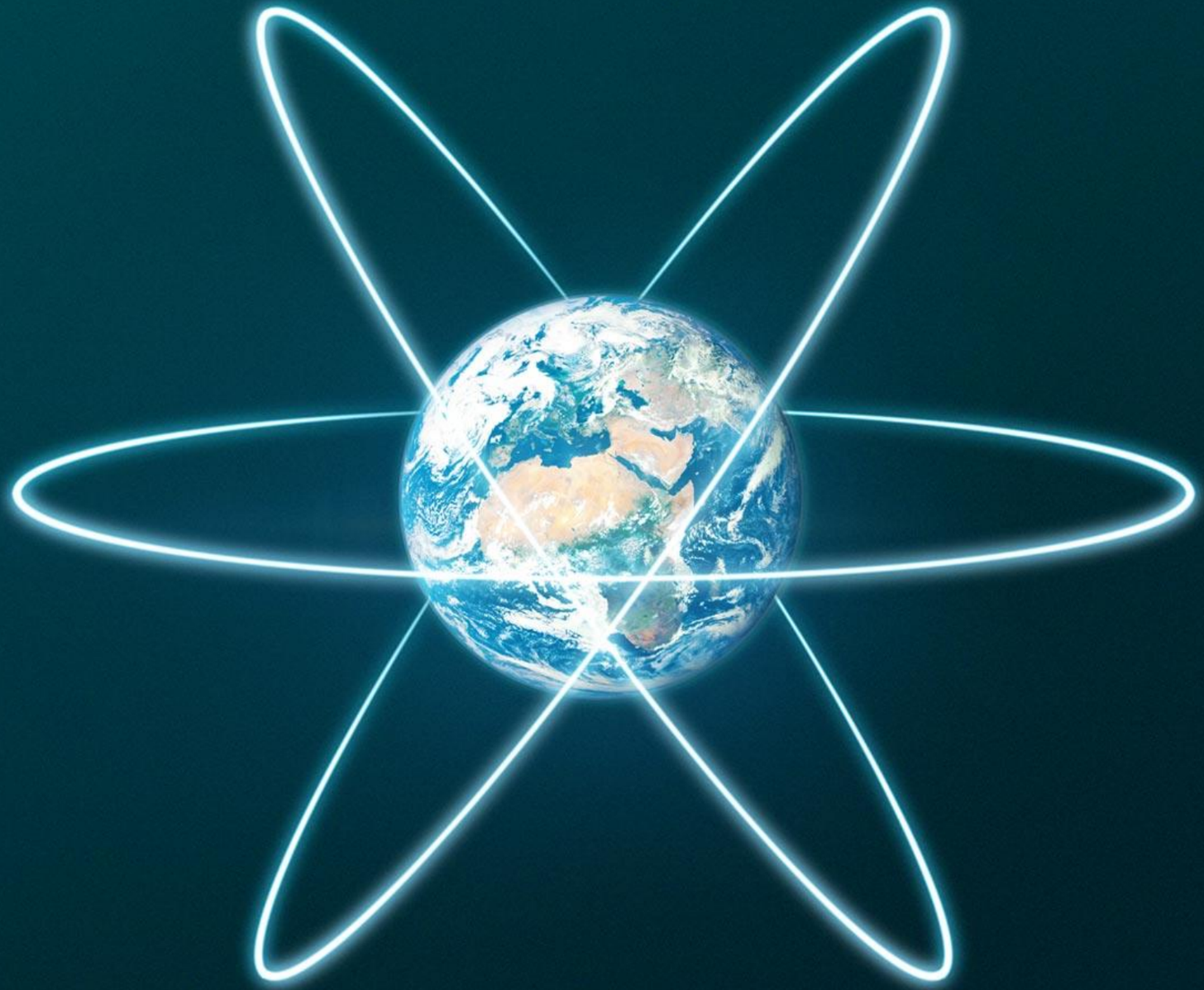
Power the World

Electricity

- Replacing coal and gas power
- Solving grid stability
- **Powering hydrogen production**

Heat

- **Process heat for industry**
- Production of ammonia
- Production of fresh water



Thank you!

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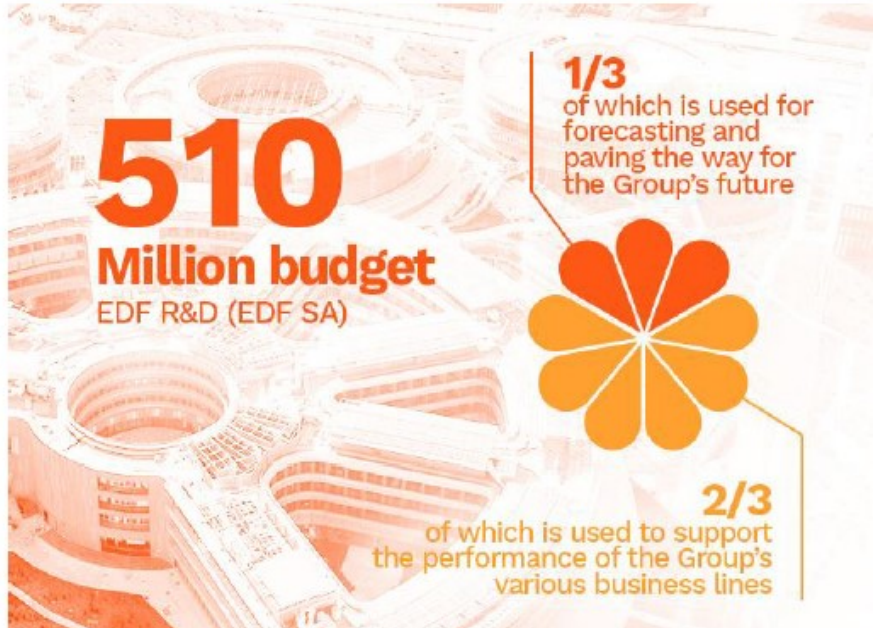
Offshore power: Floating low-carbon energy solutions for remote areas

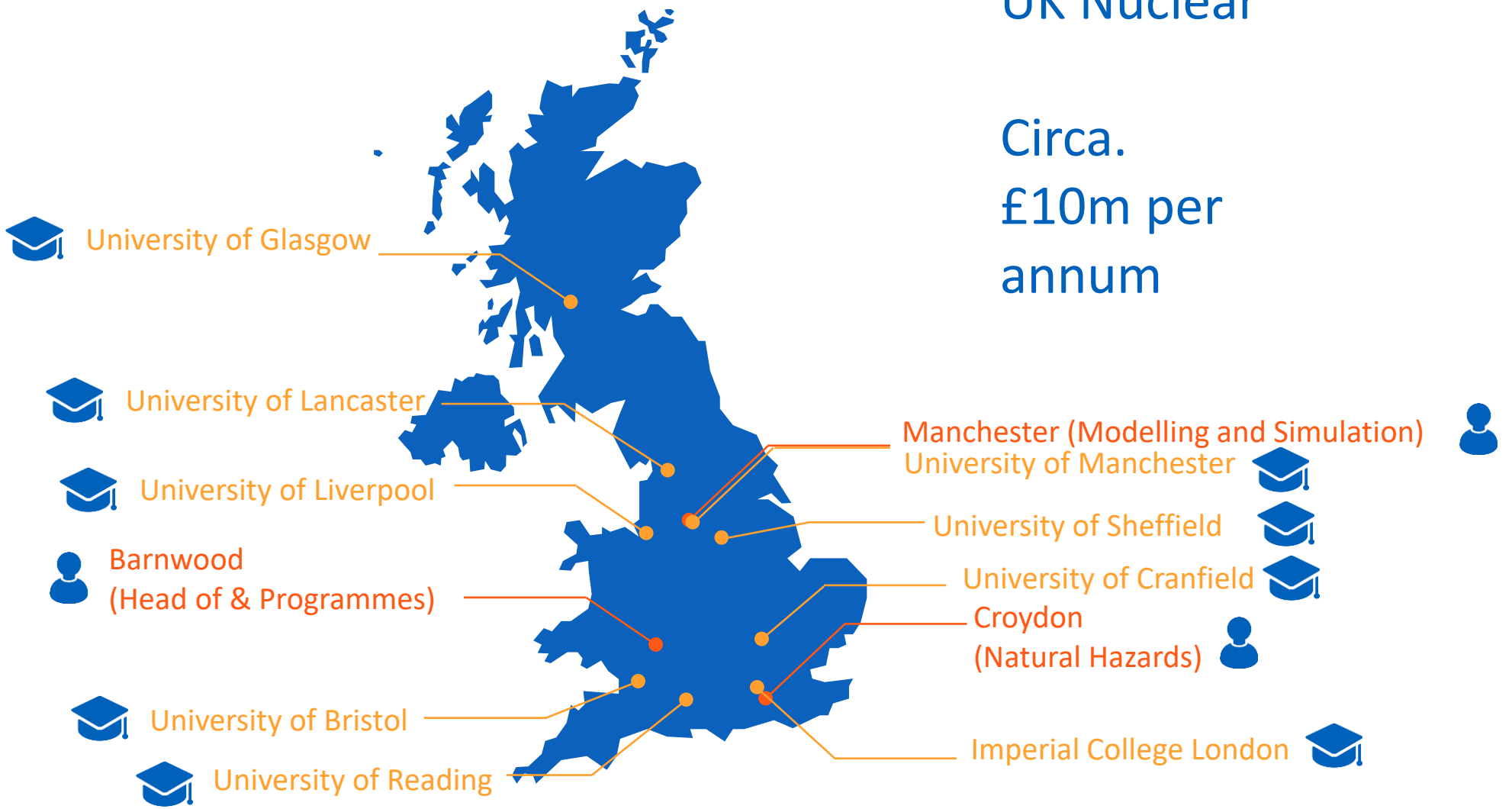
Richard Jones
Head of Nuclear R&D, EDF Energy

17 November 2021

EDF R&D in Figures



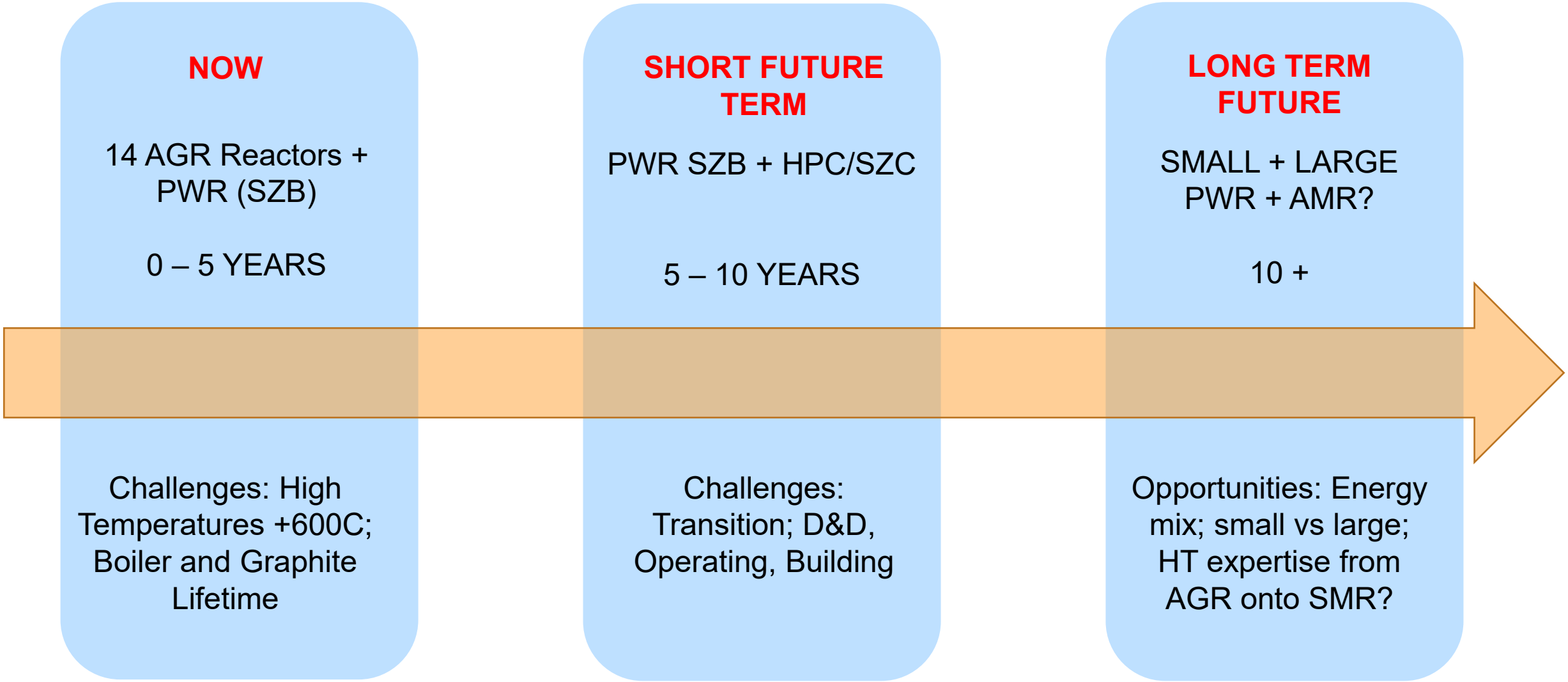
UK R&D Nuclear - Who are we?



UK Nuclear

Circa.
£10m per
annum

UK R&D Nuclear – Where are we and where are we going?



UK R&D Nuclear – Floating Off-Shore Nuclear?

- UK an Island – lots of water! Reactors next to coast…
- Large projects (HPC) are complicated and costly… but provide large efficiencies
- Land is at a premium for new nuclear – “not in my back yard”
- Opportunity to combine small/with HT UK expertise… why not offshore?

- No special site for construction
- Low impact on local communities and environment
- Ease of transport – no roads?
- Earthquake safety?
- Movable

- How do staff “get to work”?
- How do emergency services get to site?
- Security – submarine attack for example
- Major sea pollution risk?