NNWI

FUELING THE ENERGY TRANSITION WITH NUCLEAR

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Panel 1: Harnessing Advanced Nuclear Technologies to Accelerate the Energy Transition

Chaired by Aliki van Heek

- Chirayu Batra, Chief Technology Officer, TerraPraxis
- Henri Paillere, Head, Planning and Economic Studies Section, IAEA
- Aliki van Heek, Sustainable Energy Business Research, Nuclear-21
- Alexis Honner, Business Development Manager, Rolls Royce SMR

Panel 1: Harnessing Advanced Nuclear Technologies to Accelerate the Energy Transition

ADVANCING NUCLEAR THROUGH PRODUCT BASED DEPLOYMENT STRATEGY

Chirayu Batra

Chief Technology Officer

Terra Praxis

https://www.terrapraxis.org/

June 2023

TERRA PRAXIS

Outline

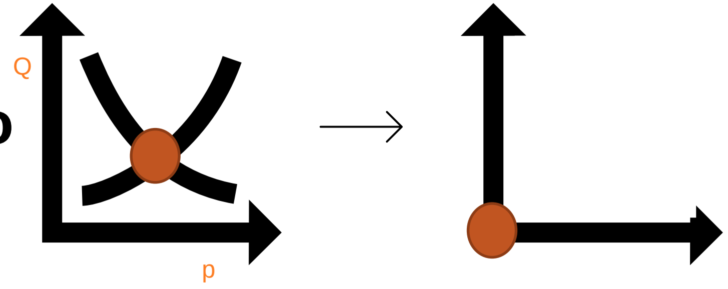
- Setting the context
  - The Problem
  - The Potential market
  - And why do we need a product based deployment strategy
- Example: Repowering Coal

SETTING THE CONTEXT

The Problem
The Potential market
And why do we need a product based deployment strategy

How many SMRs do we need?

- How much is the current demand? ~ **Zero**
- How much is the current supply? ~ **Zero**



- Two reasons why a product is not in demand
  1. Customer doesn't understand the product and is not talking about the product
  2. It is not value for money – too risky, or not useful

Create Demand with right customer and right cost

Find the right product-market fit

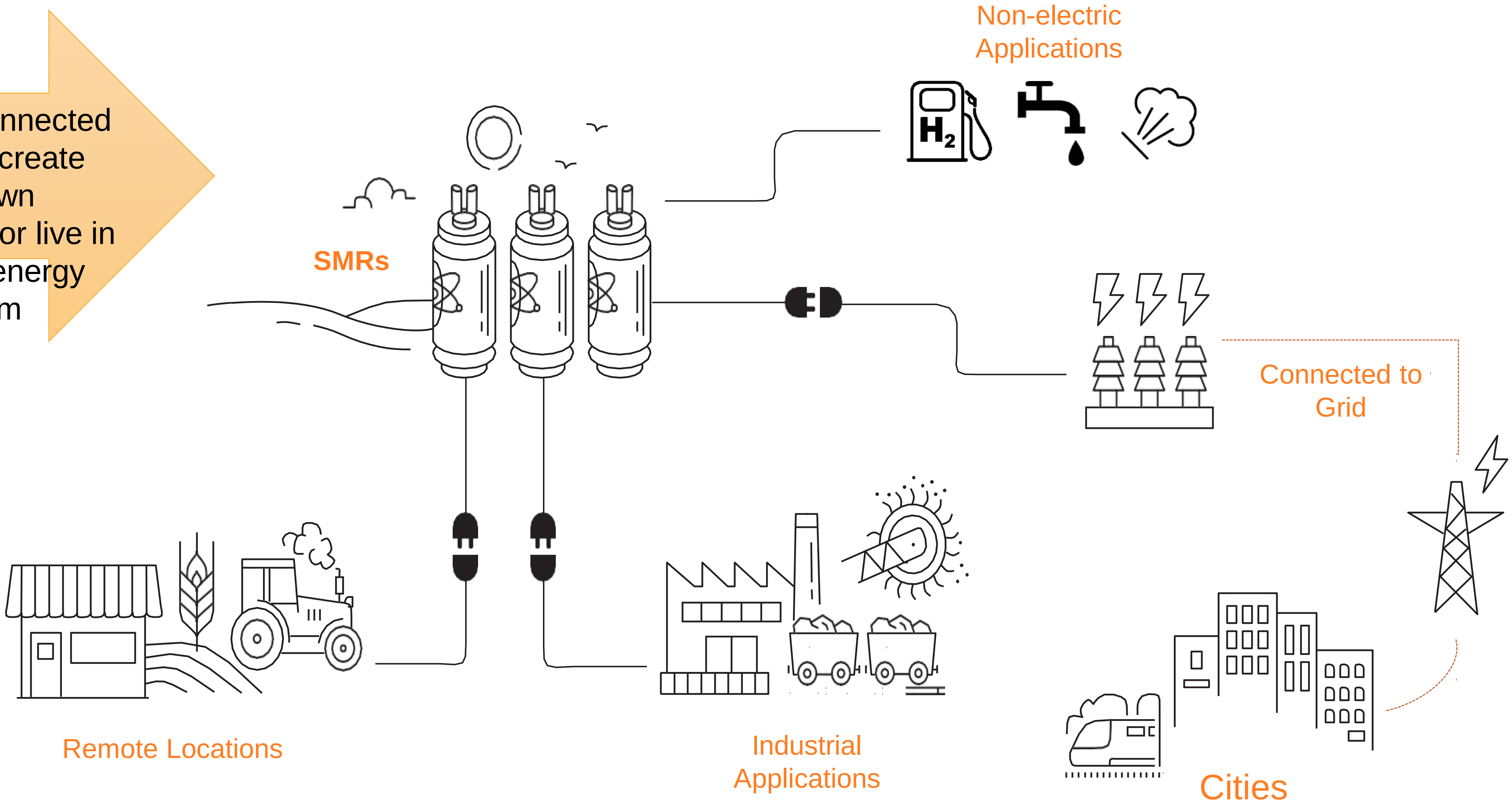
So, if there is no demand and no supply, why do we need them?

We DON'T need SMRs till we we find the right market and right application and then deliver them at cost, speed and scale

Product-Market Fit means putting yourself in the right market with a product that the market is satisfied with

Potential market and customer

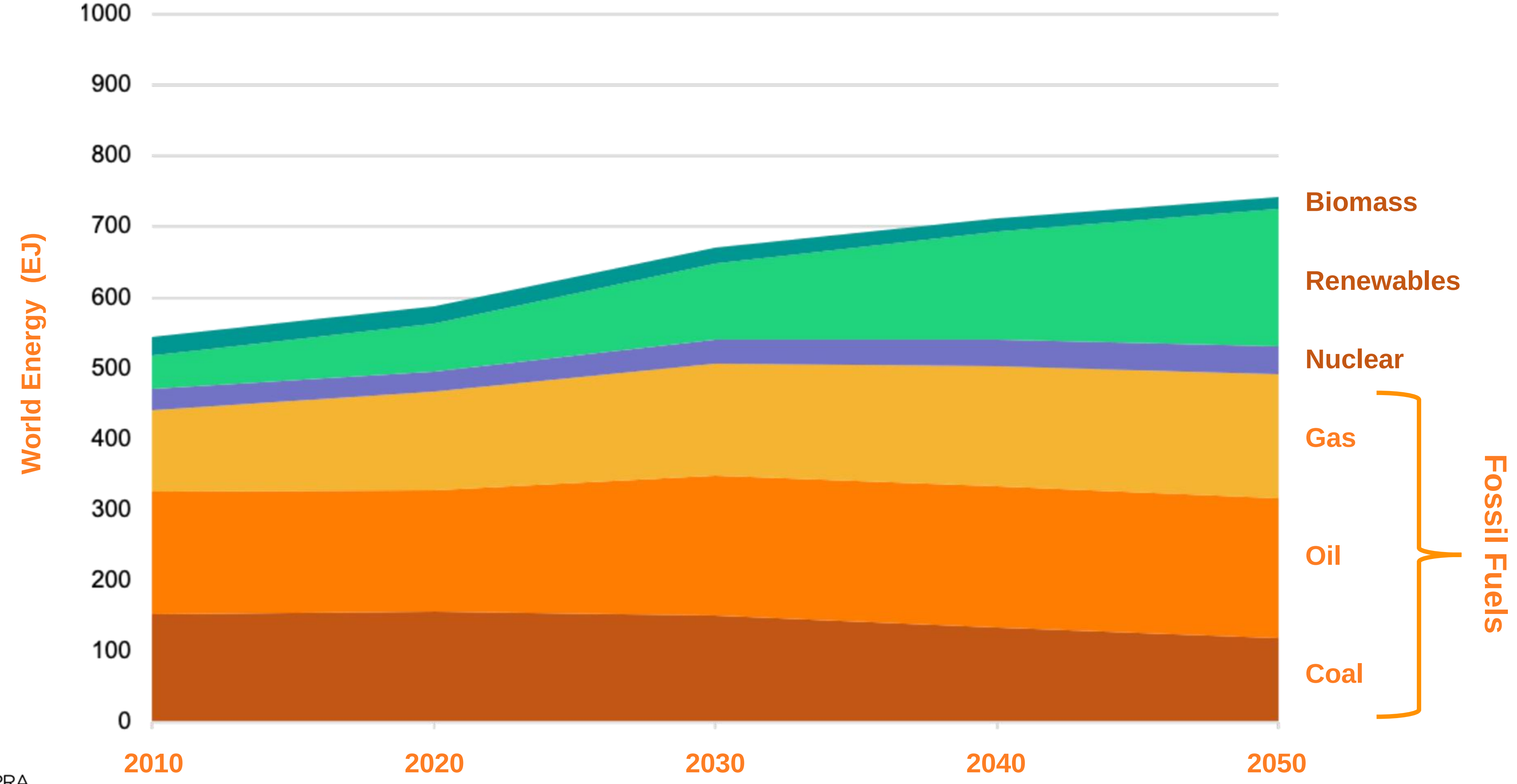
Either be connected to **grid** or create their own **ecosystem** or live in a **hybrid** energy system



A complete Nuclear Energy System

How much clean energy do we need?

Now, this question is different from the previous one



Are SMRs ready to deliver this amount of energy?

If yes, then how?

IEA's Stated Policies Scenario: World Energy by Source (IEA, 2021)

How to create a deployment strategy for such large scale deployment

- Think about the potential market and the customers – the global energy demand is much more than just electricity demand. There are sectors like steel, cement, refineries etc. which are highly energy and carbon intensive

- With customer centric approach define the product that can be useful for that customer – a valued product

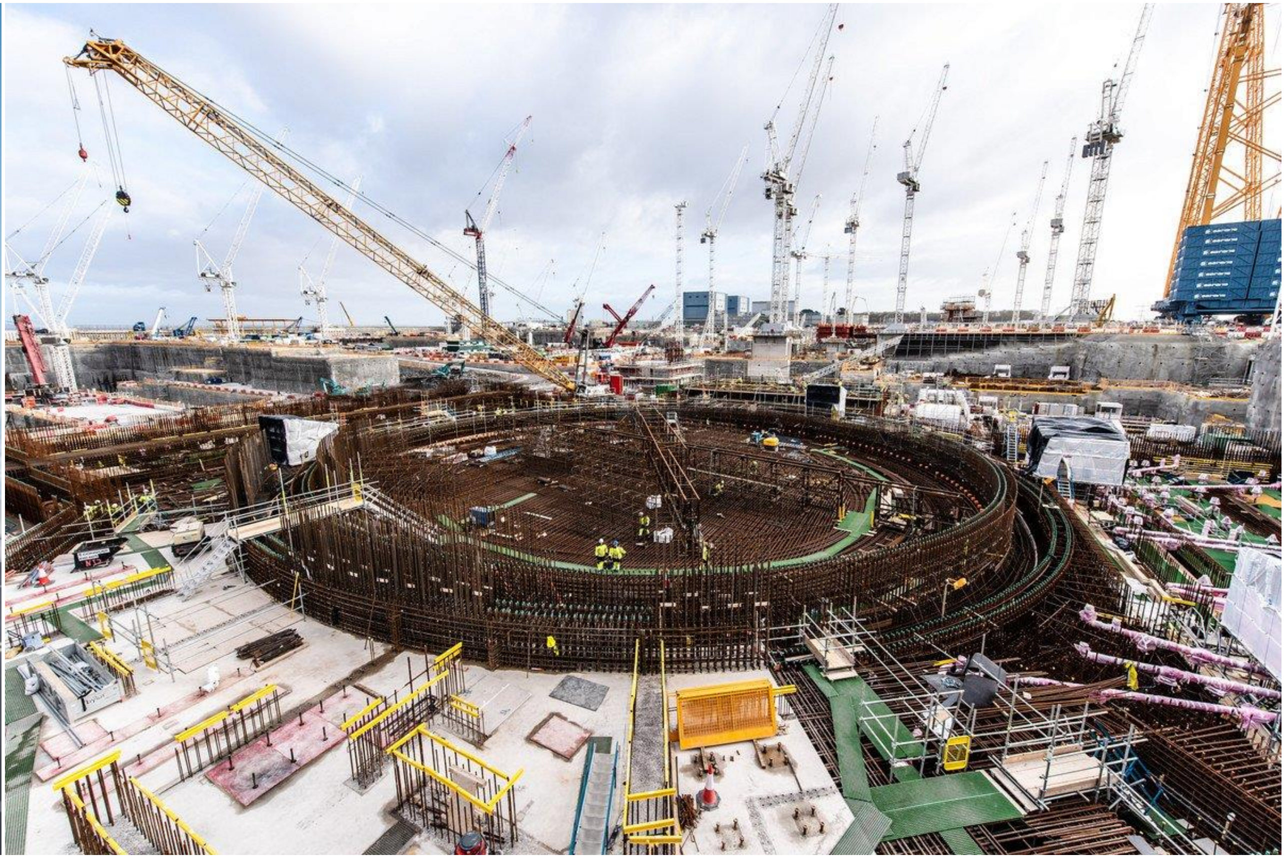
- De-risk the product development and deployment

Based on this approach – how can we deliver nuclear as a product?

How to deliver SMRs?

Make a PRODUCT

Product



Construction Project
(Not a Product)

These business models have very different incentives

Design project each time

Incentives:
Design hours are revenue
Licensing hours are revenue
Construction oversight is revenue
Goal is to maximize revenue per project

Incentives:
Design to reduce marginal cost
Invest to reduce marginal cost
Eliminate non-scalable processes
Increase profit/unit * # of units

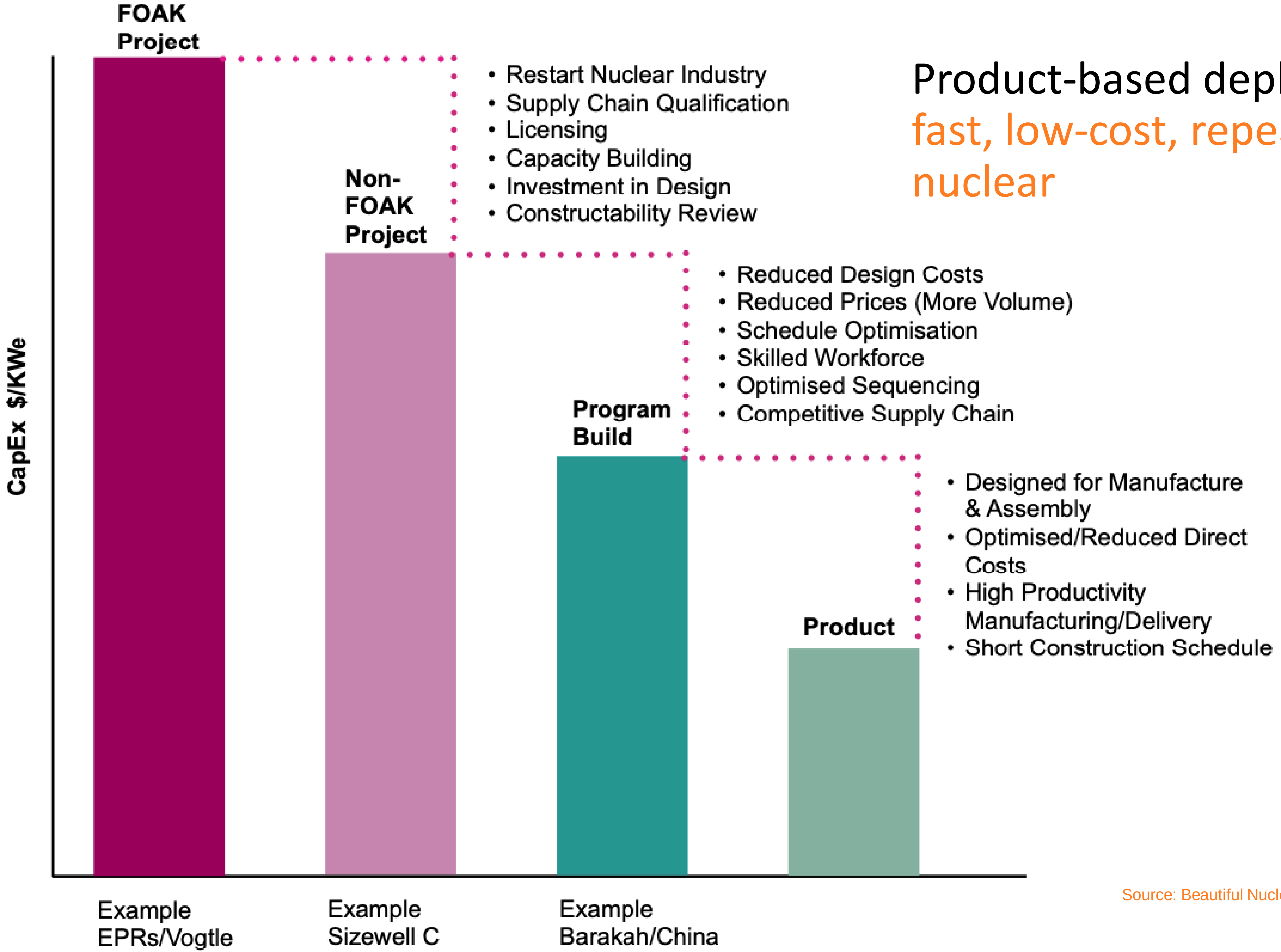
Product

- **More 'new engineering'**
- **Large engineering cost**
- **More chance for errors**
- **Longer licensing review**
- **Less certainty on cost**
- **More schedule risk**

- **No 'new engineering'**
- **Minimal engineering cost**
- **Errors previously eliminated**
- **Shorter licensing review**
- **Certainty on cost**
- **Minimal schedule risk**

Project Vs Product

Product-based deployment: Pathway to fast, low-cost, repeatable and scalable nuclear

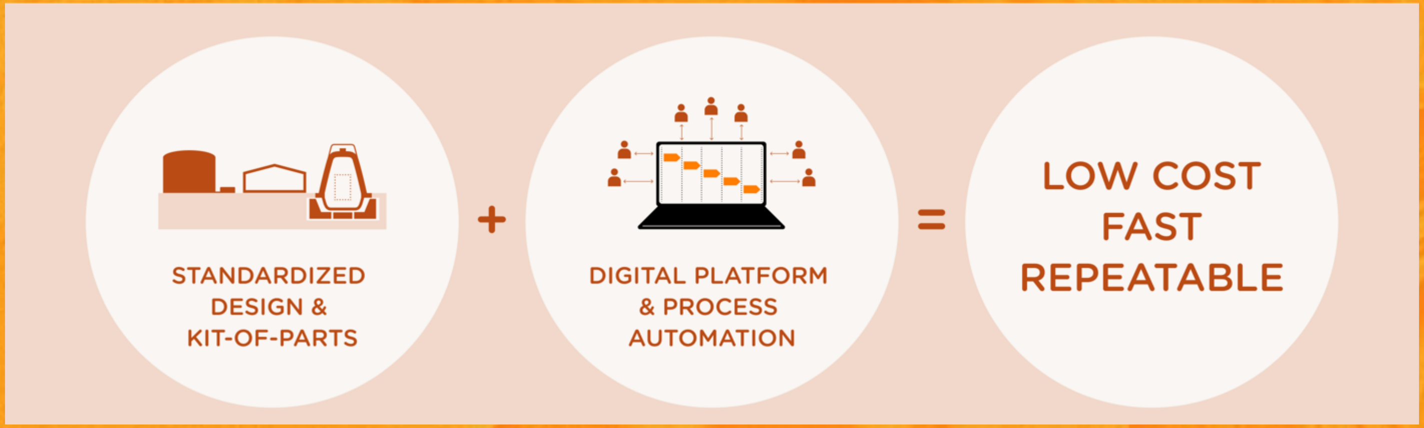


Source: Beautiful Nuclear, LucidCatalyst (2021)

FAST, LOW-COST, REPEATABLE

Example Product:

Designing the Global Coal Repowering System



TERRA PRAXIS

A Platform for Repurposing Coal

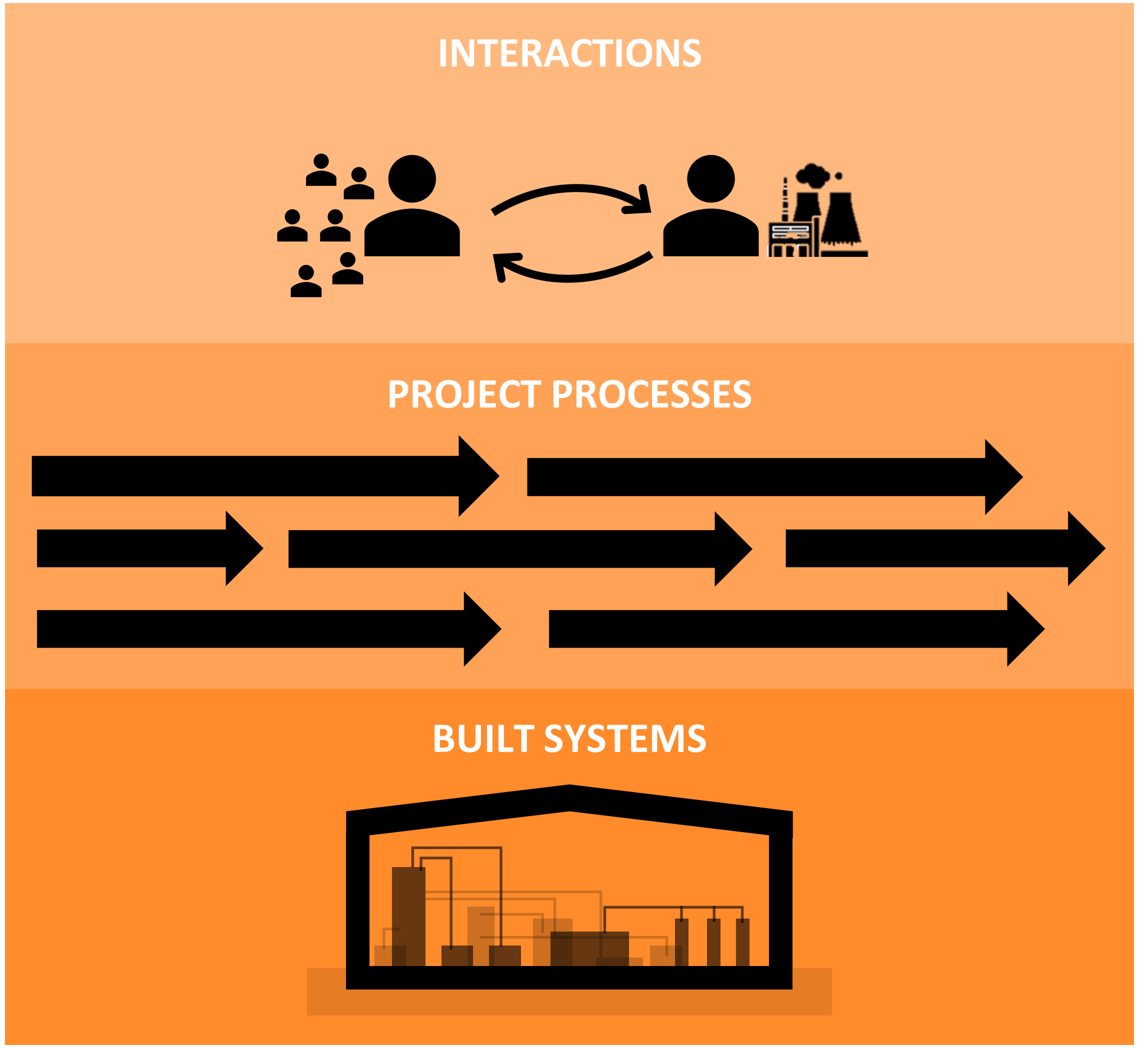
- Repurpose 2TWe coal fleet
- De-risk and accelerate clean energy transition
- Social, economic and environmental justice benefits

What if we brought state-of-the-art design and supply chain management to systematically address all these challenges?

The Need

2,000 GWe

100
sites/year



The Problems

Costly, slow, risky

Few customers want it

Few suppliers can provide it

Using the strategies for moving from projects to products

- Think in terms of cost↓, speed↑ and, scale↑
- Standardize most of the structure, system and components along with the supply chain to deliver them → Modular by design (DfMA)
- Design for a large enough set of sites but with sufficiently common characteristics to enable highly standardized design
- Design special features to isolate the plant from the variation in the set of chosen sites
- Design to be repeatable with no safety relevant variation

REPOWER COAL PLANT FOR $2,000/KWE IN JUST FIVE YEARS WITH LOWER RISK

The emissions-free repowered plants will be more profitable to operate than before and help to ensure continuity for communities reliant these plants for energy, jobs and continued economic development.

REPOWER COAL PLANT FOR $2,000/KWE IN JUST FIVE YEARS WITH LOWER RISK

Reuse of existing power island

Standardized design eliminates plant-specific design cost

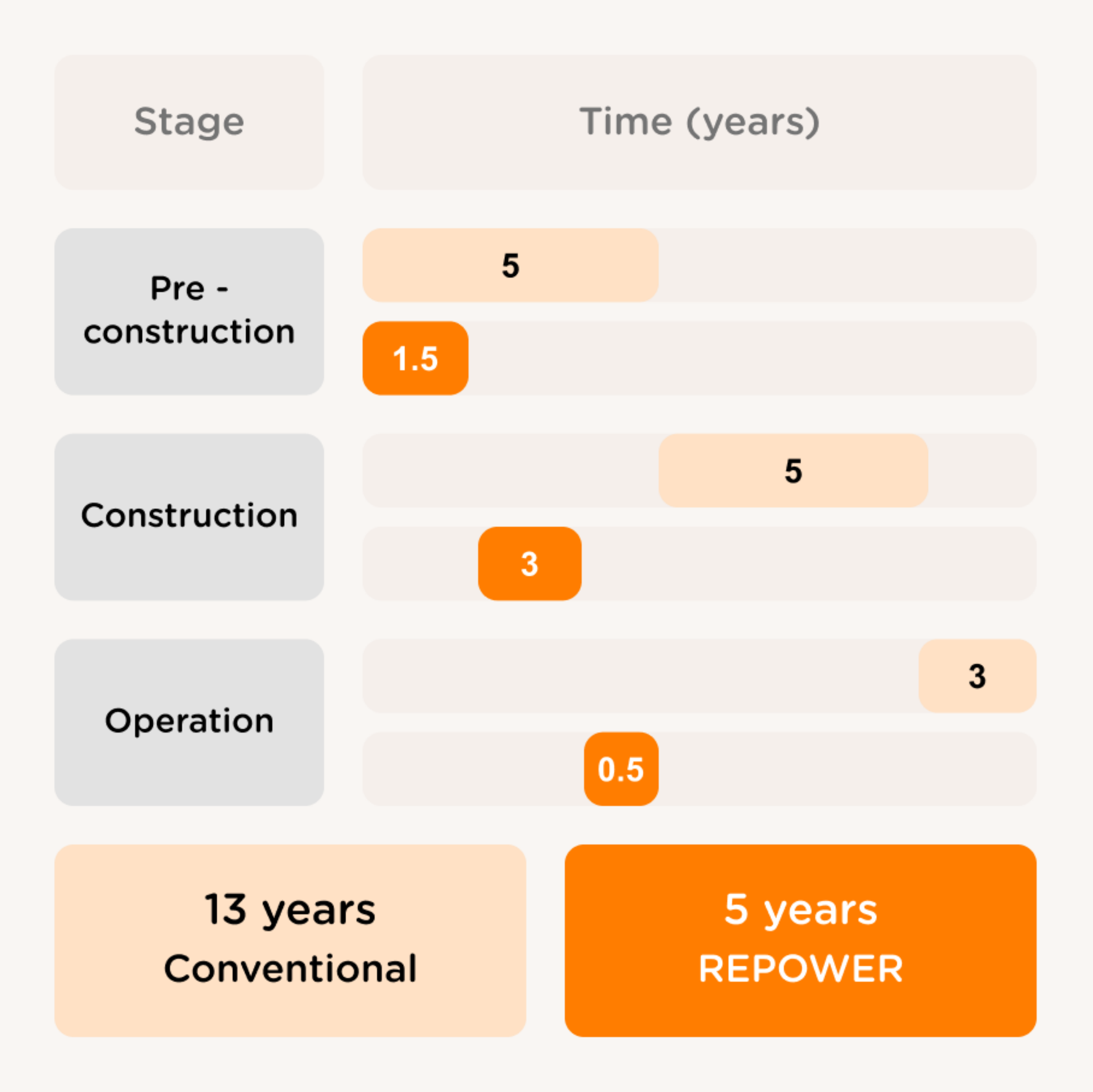
Reduced indirect DfMA

Standardized licensing (Repeat)

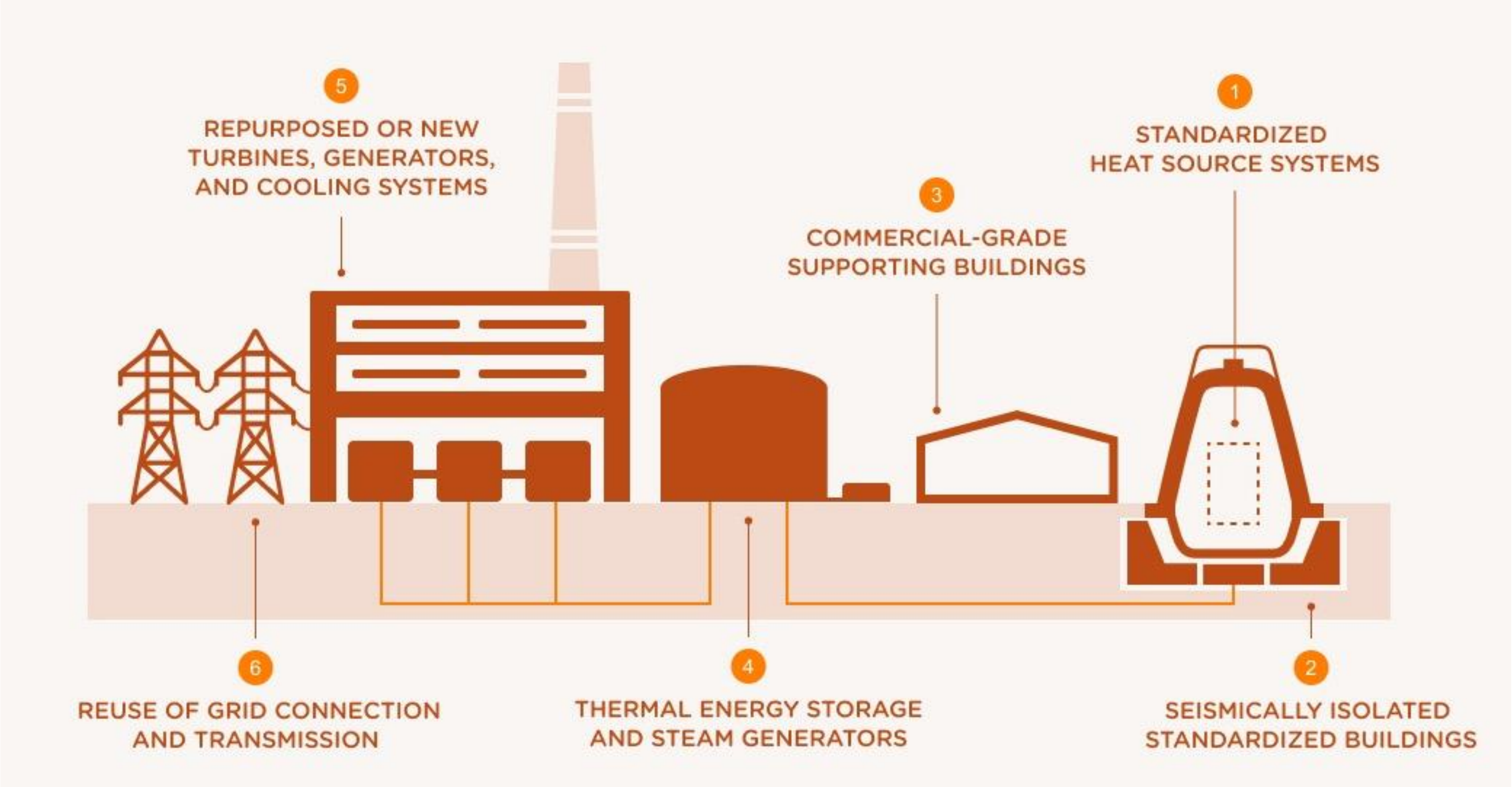
Manufactured system low cost sourcing

Reduced duration

COST TO REPOWER



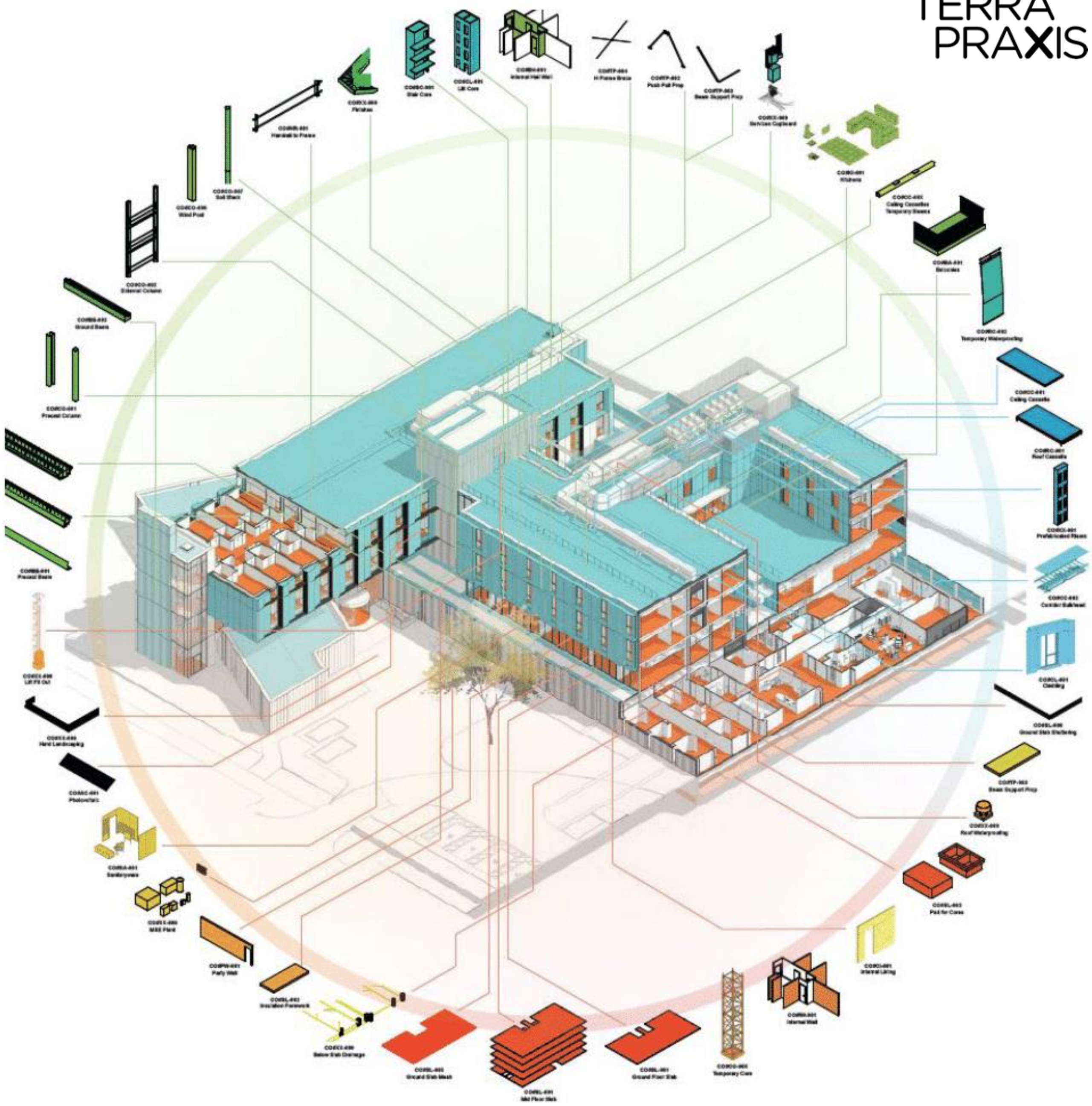
Built Systems Must Enable Scale and Speed



Proven Approach

TERRA PRAXIS

Bryden Wood



40%

Reduced cost

40%

Reduced programme

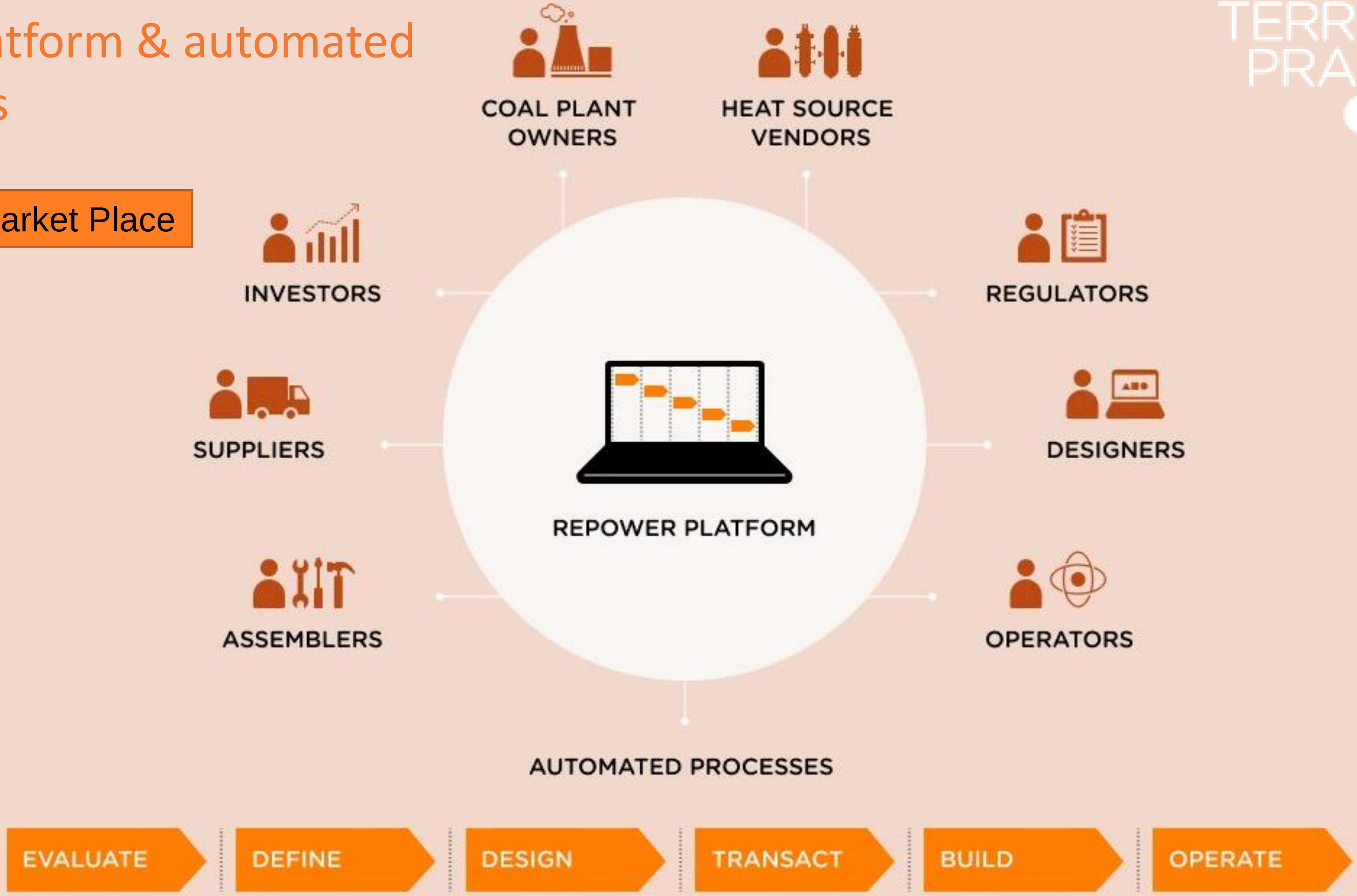
Design time:

~~Years~~

Weeks

Digital platform & automated processes

Creating a Market Place



TERRA PRAXIS REPOWER

University at Buffalo

TERRA PRAXIS

Microsoft

Schneider Electric

Bryden Wood

CLIMATE X PROSPERITY

THANK YOU 🙏

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TERRA PRAXIS

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Addressing climate and economic development objectives: role of advanced reactors

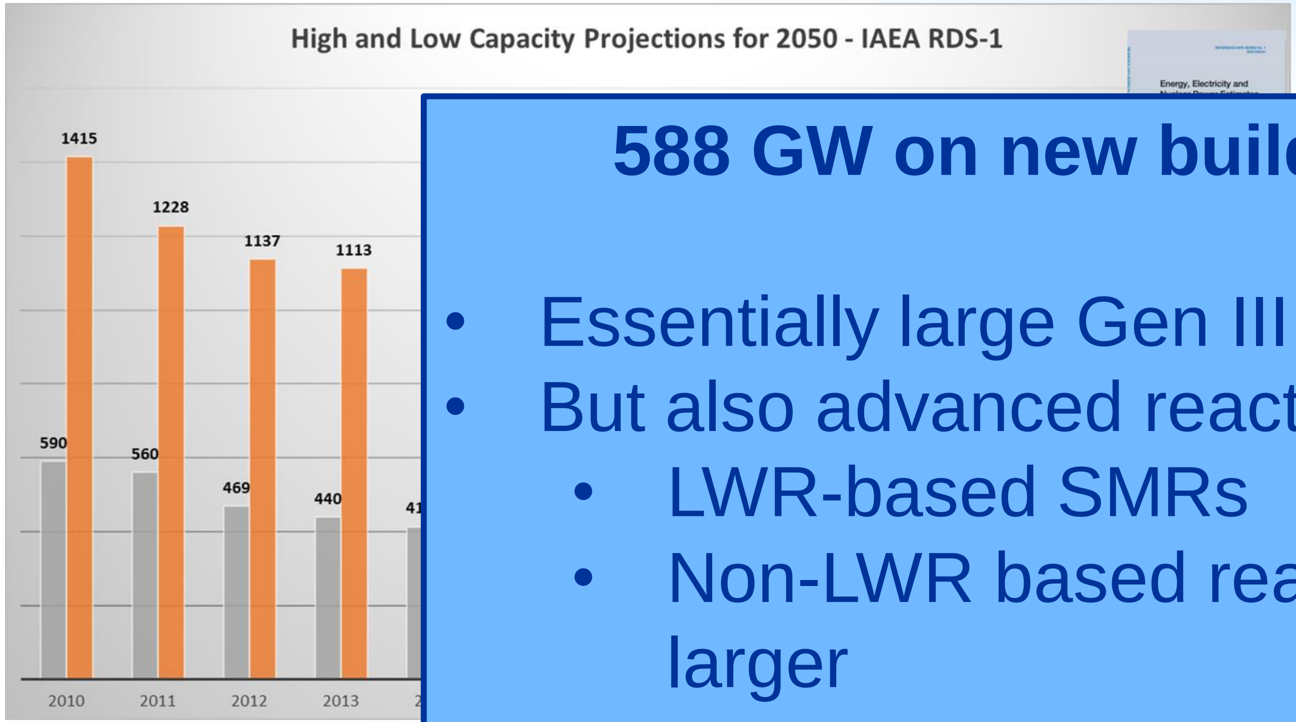
Henri PAILLERE
Head, Planning and Economics Studies Section
International Atomic Energy Agency

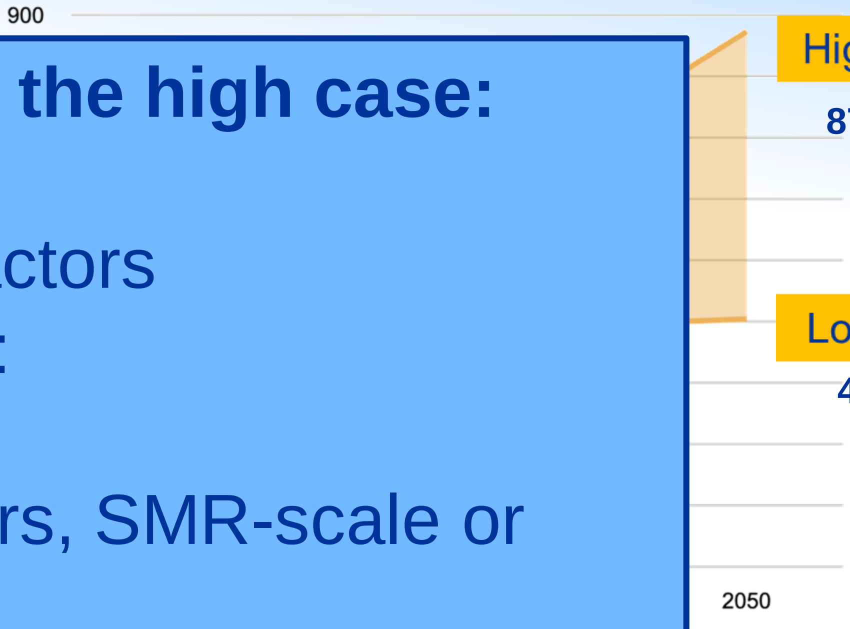
Fueling the Energy Transition with Nuclear
Panel 1: Harnessing Advanced Nuclear Technologies to Accelerate the Energy Transition
19-20 June 2023, Budapest

Outline

- IAEA nuclear projections for 2050
- General Considerations for nuclear's role in clean energy transitions
    - Low Carbon and Sustainability credentials
    - Enabling integration of large shares of renewables
    - Security of supply and climate resilience
    - Decarbonization beyond electricity
- Role of advanced reactors:
    - Example: Coal to Nuclear
    - Deployment challenges are being addressed
- IAEA's 2nd International Conference on Climate Change and the Role of Nuclear Power (9-13 Oct 2023)
- IAEA's Atoms4NetZero initiative

IAEA nuclear projections to 2050 (2022 edition)





High case

873 GW

Low case

403 GW

588 GW on new build in the high case:

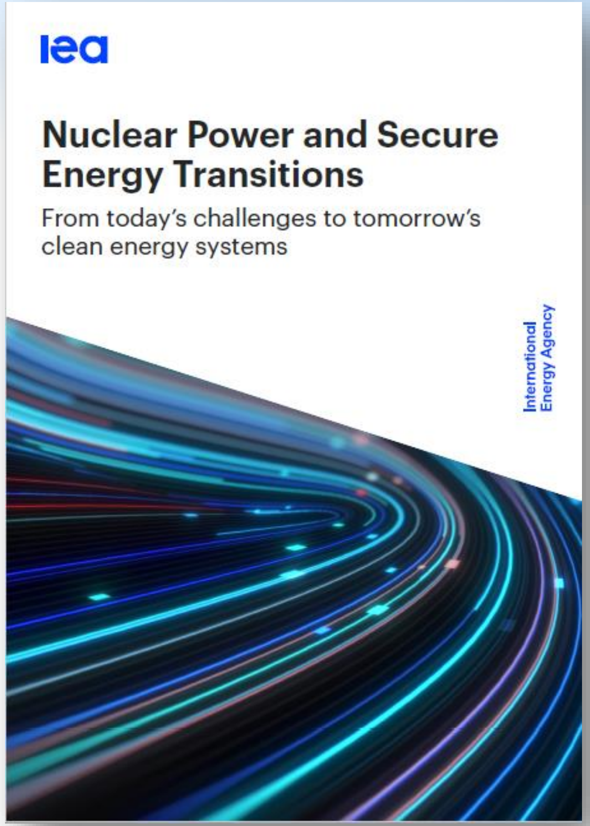
- Essentially large Gen III reactors
- But also advanced reactors:
  - LWR-based SMRs
  - Non-LWR based reactors, SMR-scale or larger

- Contribution of advanced reactors will depend on how fast they can reach commercial status and be licensed

High case (2022) by 2050, correspo ambitious LTO + a **GW** of new build i decades

Nuclear power, backbone of low C energy systems

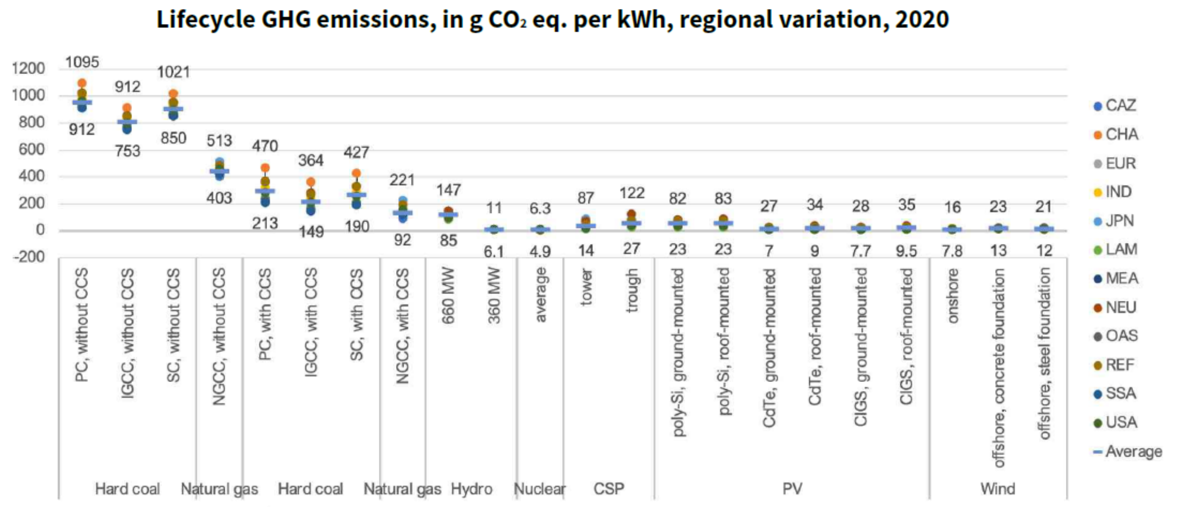
- Sustainable:
  - Low carbon:
    - Smallest low C footprint among low C technologies
    - 70Gt CO_2 avoided in past five decades, more 1Gt avoided each year
  - Management of back-end: → integration into EU taxonomy
- Flexible, dispatchable:
  - Supports cost-effective integration of large %share of renewables
- Security of supply:
  - Low dependency on cost fuel, widespread U resources, storage fuel on site
  - Among the low C technologies least intensive in critical minerals
- Can contribute to climate-resilient energy systems
- Can help decarbonize beyond the power sector



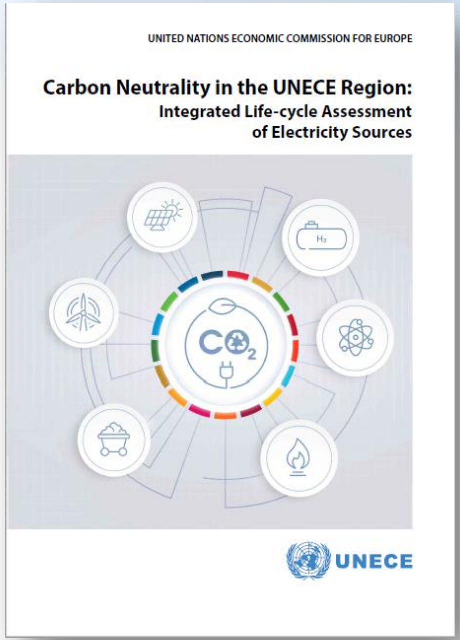
Without additional nuclear, the clean energy transition becomes ***more difficult and more expensive*** **(IEA)**

Low carbon and sustainability

Figure 37 Lifecycle greenhouse gas emissions' regional variations for year 2020. Variability is explained by several factors: electricity mix (all regions), methane leakage rates (fossil fuels), load factors (renewables). Nuclear power is modelled as a global average except for back-end.

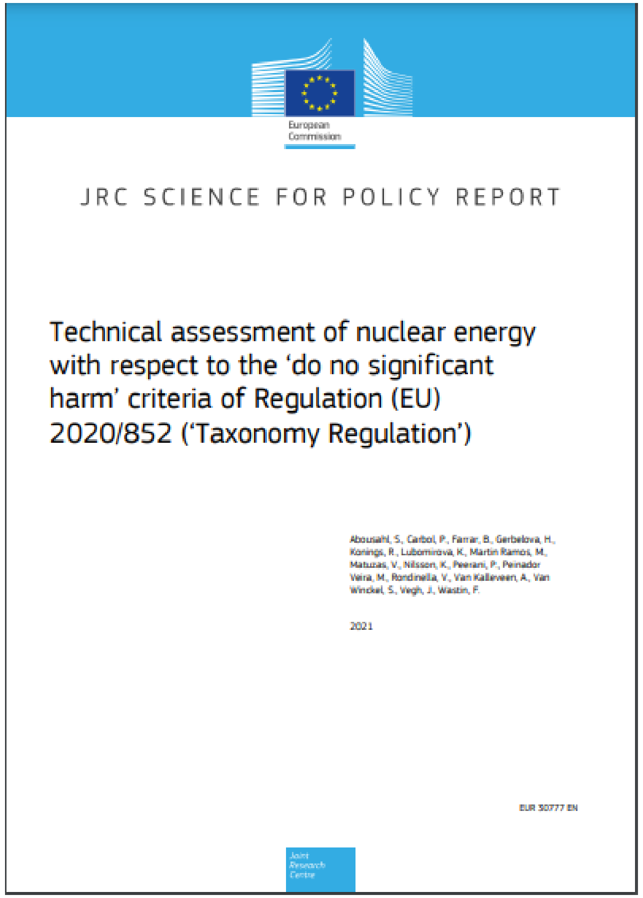


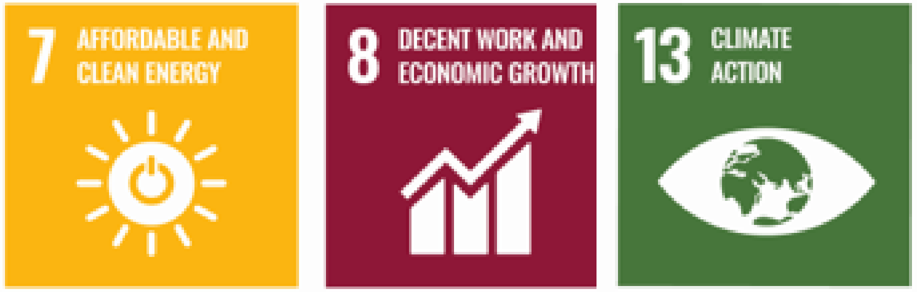
Smallest carbon footprint among low C technologies



(2022)

*IAEA estimates that over the last 5 decades, about **70Gt CO_2** have been avoided thanks to NP*



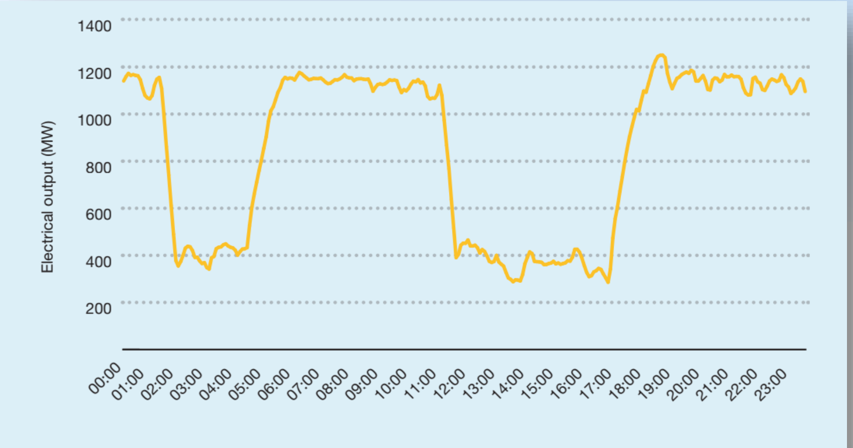


IAEA: Nuclear Energy for a Net Zero World (2021)

Enabling integration of large % renewables

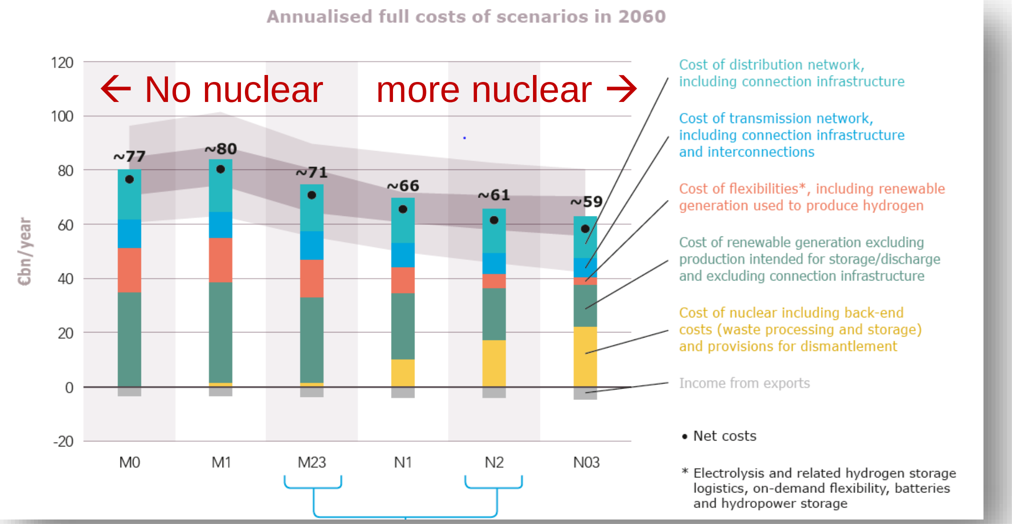
- Nuclear is a **dispatchable and flexible** source of low C power that can support the deployment of large shares of variable renewables such as solar PV and wind.
- Without nuclear, even more renewable capacities and energy storage technologies would need to be deployed.
- Analysis of overall (system) costs of energy transitions show that **transitions with nuclear are less costly** than transitions without nuclear, even if nuclear is more expensive than wind/solar (LCOE).
- It's also a question of **risk** for transitions

Flexibility of nuclear generation



Power output of a French nuclear power plant in one day (courtesy of EDF).

IAEA: Nuclear Energy for a Net Zero World (2021)

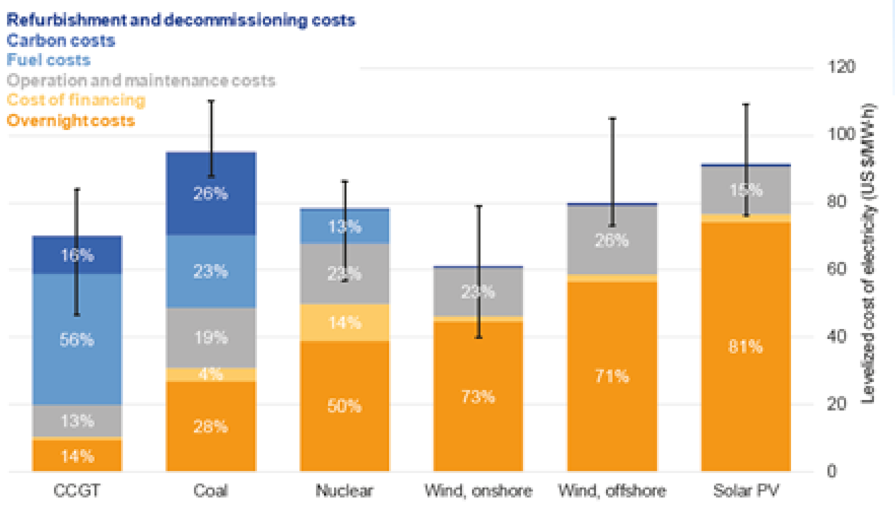


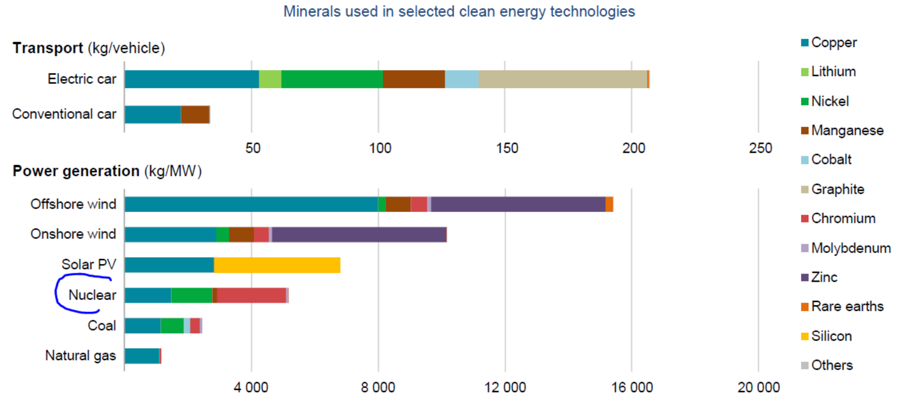
French grid operator RTE report "Energy Pathways to 2050" (2021)

Security of energy supply

- Cost of nuclear generation is **not very sensitive to the cost of fuel** (contrary to coal and gas generation)
- **Uranium resources are widely available** globally.
- Nuclear fuel can easily be **stored on site**
- Nuclear generation is among the low C technologies **least dependent on critical minerals** – *IEA report on Critical Minerals (2021)*
- Climate Change / Extreme weather can impact all technologies – and energy systems. IAEA operational data suggests that nuclear power is resilient – and adaption measures can be deployed to reduce vulnerabilities.

Adapted from IEA/NEA Projected Costs of Electricity Generation (2020)





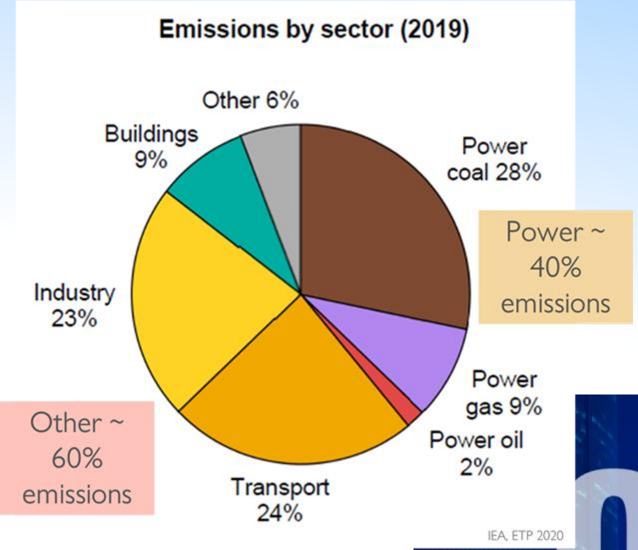
IEA, The Role of Critical Minerals in Clean Energy Transitions (2021)

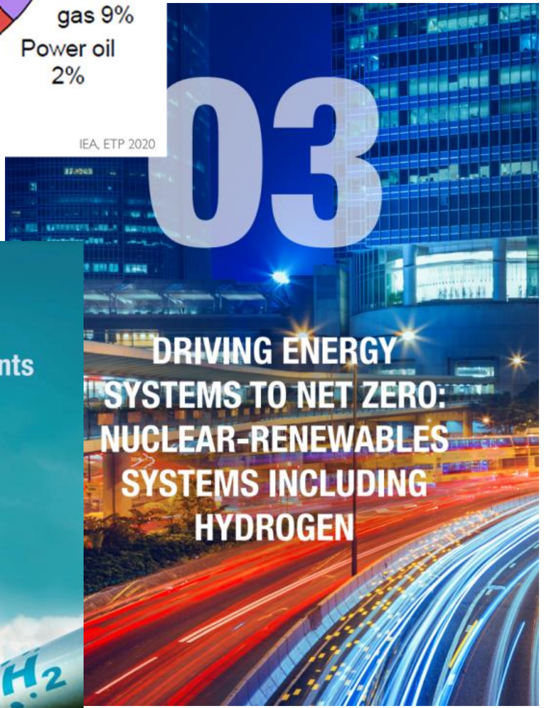
Decarbonization beyond electricity

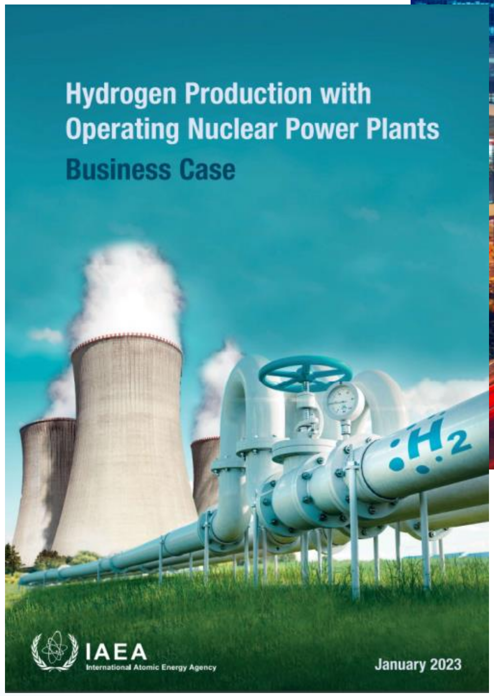
- Nuclear energy = **source of low carbon heat, electricity and hydrogen**

- Nuclear heat supply:
    - Long experience of District Heating
    - Advanced reactors can also deliver high temperature steam for industrial applications

- Growing interest in hydrogen as an enabler of the transition to NZ (storage, flexibility, heat, etc). Nuclear can produce low C H2
    - Through electrolysis like other low C technologies
    - Through thermal splitting processes (more efficient)







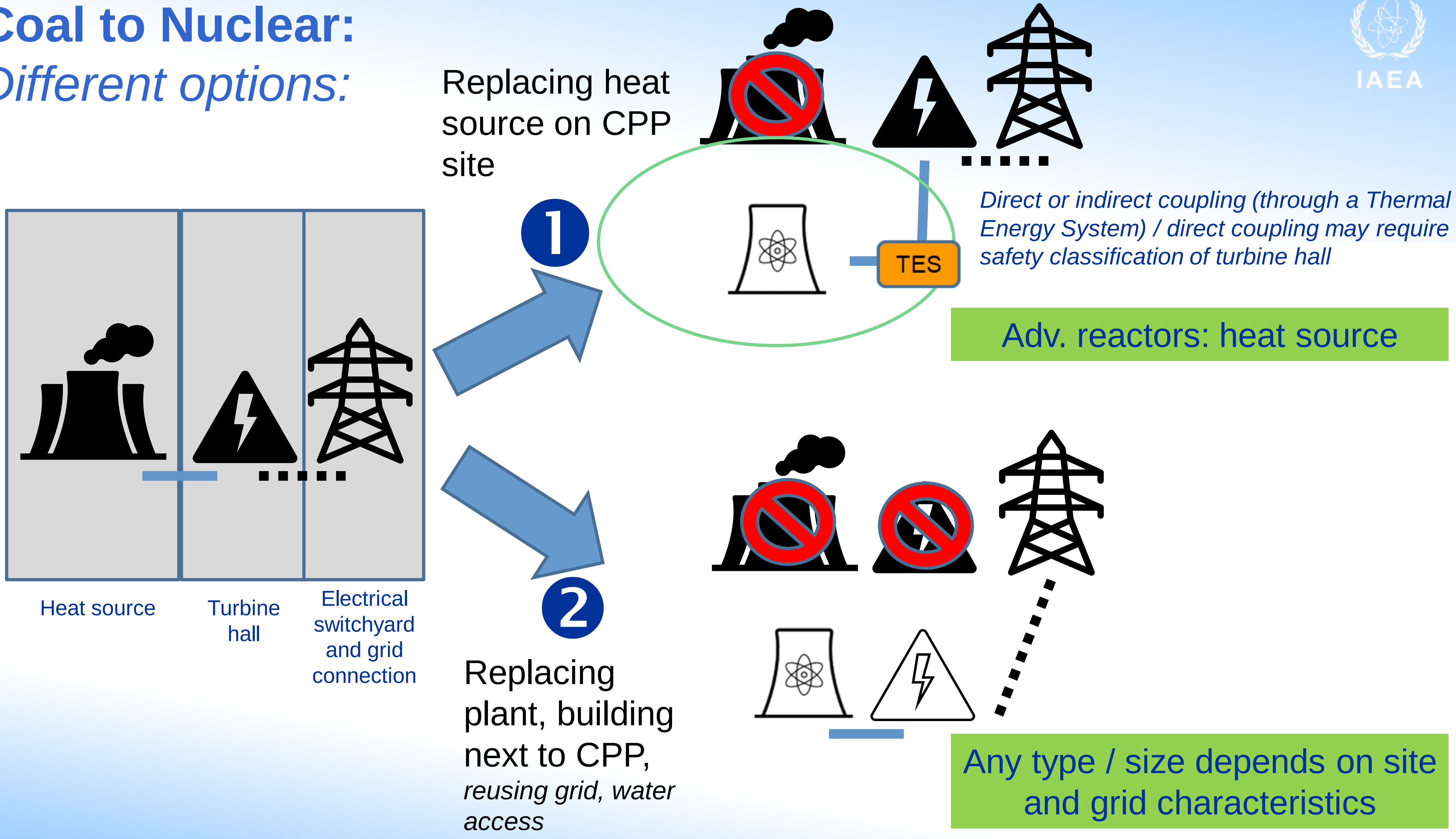
Coal to Nuclear – the technical options

Nuclear reactor design	Plant output: Electricity	Plant output: Low temperature heat (300°C) (district heat, industry, H_2)	Plant output: High temperature heat (600-700°C) (industry, H_2)	Coal replacement applications	Technological and commercial maturity
Large water cooled	✓	✓		Multi-unit power plant	Mature; more than 300 units in operation
SMR, water cooled	✓	✓		Single unit, power or CHP	Demonstration; pre-commercial; conventional nuclear licensing process widely applicable
SMR, advanced (gas/sodium cooled)	✓	✓	✓	Single unit, power, CHP, industrial boiler, H_2	Design phase; demonstrated technology; pre-commercial
SMR, advanced (salt or lead cooling; micro-reactors)	✓	✓	✓	Single unit, power, CHP, industrial boiler, H_2	Research, development and demonstration

Table 1. Categorizing selected nuclear technologies suitable for replacing coal.

Nuclear Energy for a Net Zero World (IAEA, 2021)

Coal to Nuclear: *Different options:*



Just transition: example of EU countries

- A large proportion of coal power plants and mines are located in **lower income regions**, i.e. regions with a GDP per capita below the national average.
- → importance of maintaining jobs, economic activity

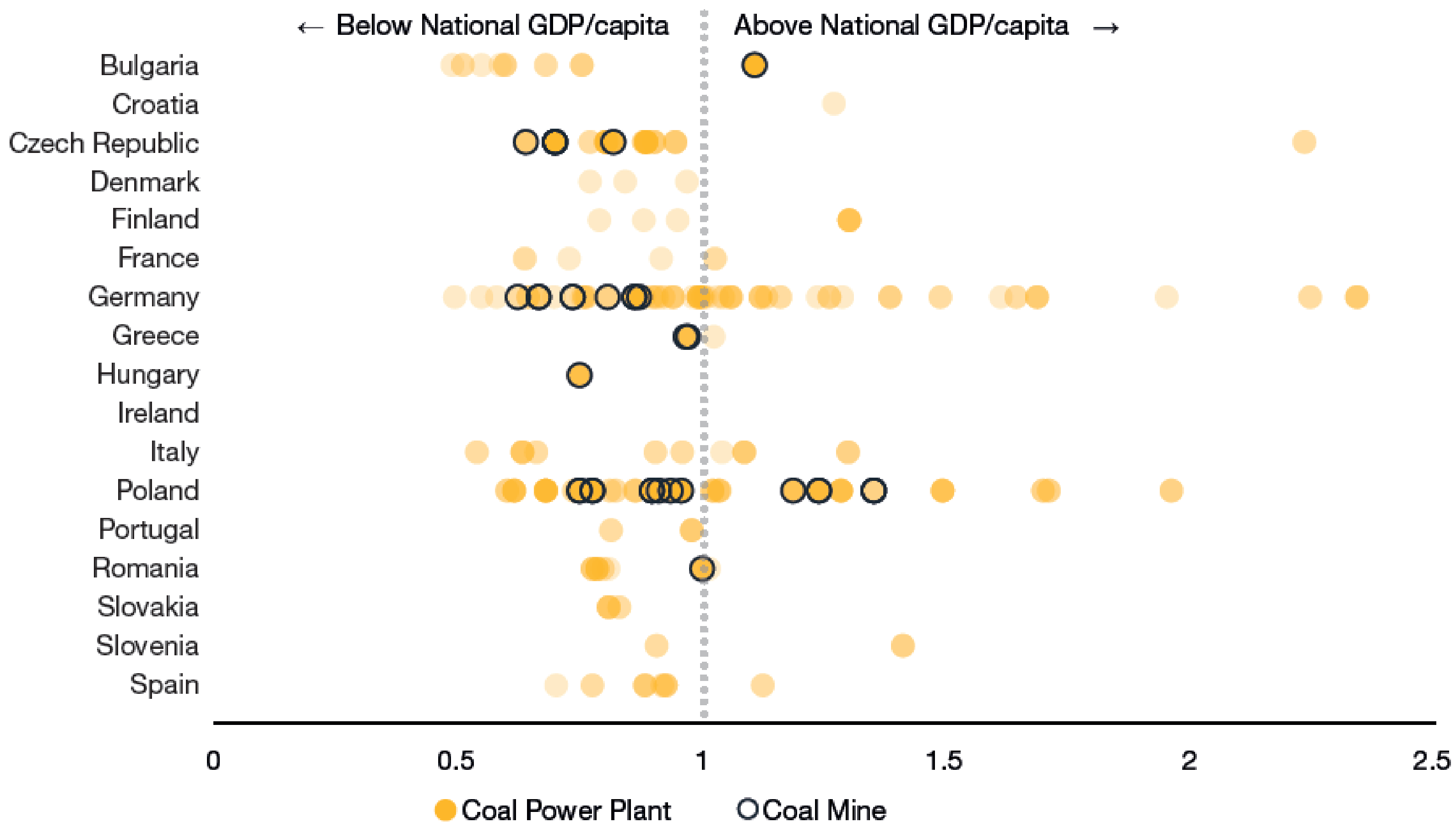
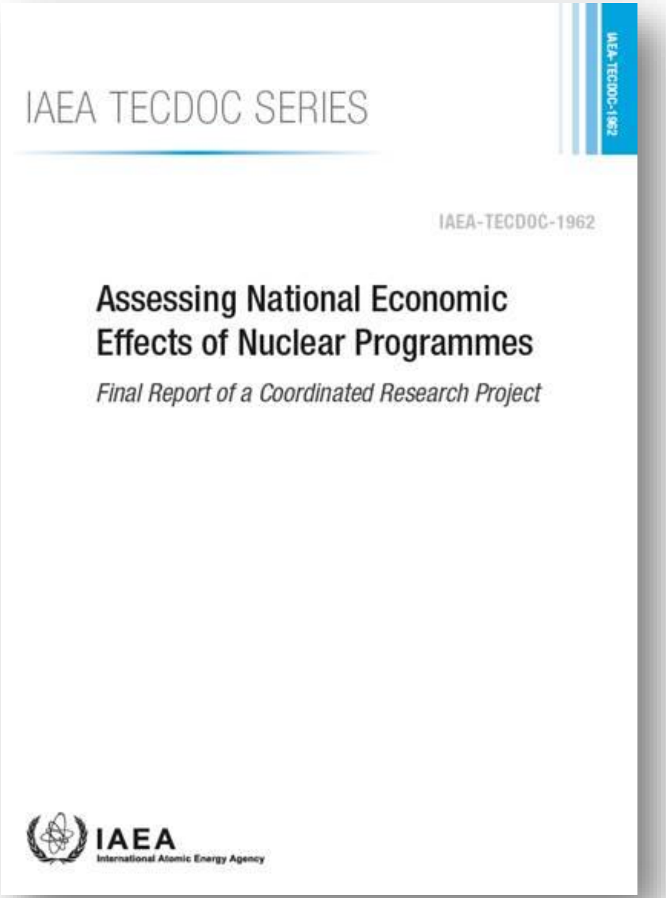


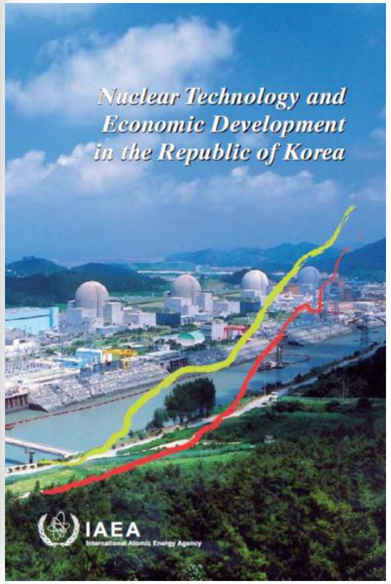
Figure 6. Relative GDP/capita in regions with coal fired generating plants and coal mines, compared to the average national GDP/capita for selected countries in 2018. Refs [34–36]. Note: Dark shades of yellow indicate a larger number of units at coal plants.

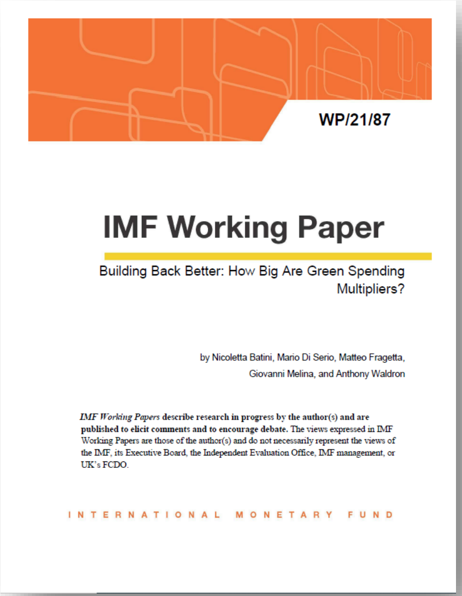
Nuclear Energy for a Net Zero World (IAEA, 2021)

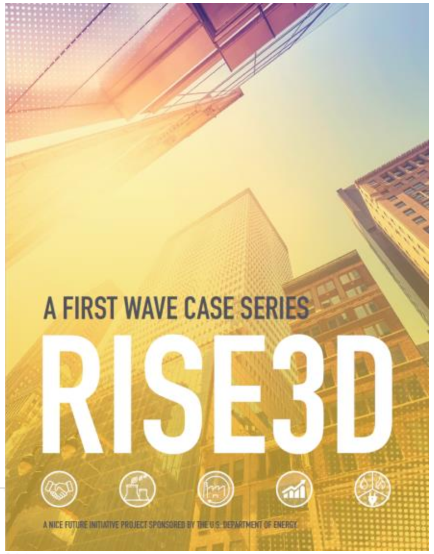
Macroeconomic impacts of nuclear investments / Just Transition

- Can clean energy investments compensate for the economic losses associated with the transition away from fossil fuel activities?
- Analyses (including from IMF) suggests that **“green investments” can have positive impacts – and nuclear investments can have the highest GDP multipliers**
- Level of supply chain localization is an important consideration.









Research teams from 10 IAEA MSs (Croatia, Indonesia, Korea, Malaysia, Poland, RF, South Africa, Tunisia, Uruguay, Viet Nam) applied the new macroeconomic model (EMPOWER) to estimate economy-wide effects from construction and operation of a nuclear plant

Takeaways: deployment challenges are being addressed

- **Policies:**
  - Energy and climate crises → renewed interest in nuclear
- **Public acceptance:**
  - More open discussion of nuclear option in different fora (including COP, G20, CEM)
  - On safety, waste management, costs
- **Costs and access to finance:**
  - Cost reductions from FOAK Gen III to NOAK
  - Supply Chain improvements
  - New financing models are being developed, inclusion of nuclear in sustainable finance being discussed
- **New technologies and initiatives:**
  - SMRs
  - Standardization of designs and harmonization of regulatory requirements – the IAEA **Nuclear Harmonization and Standardization Initiative** (NHSI)
  - **Atoms4NetZero** initiative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IAEA Initiative Sets Ambitious Goals to Support the Safe and Secure Deployment of SMRs

Joanne Liou, IAEA Office of Public Information and Communication

JUL 4 2022

IAEA Director General Rafael Mariano Grossi delivers his opening remarks at the Nuclear Harmonization Standardization Initiative (NHSI) kick-off meeting on 23 June at the IAEA headquarters in Vienna. (Photo: D. Calma/IAEA)

Enhanced harmonization of regulatory activities and the standardization of industrial approaches are expected as the outcome of a new IAEA initiative, which kicked off in June. Senior nuclear regulators and industry leaders met for the first time under the IAEA's Nuclear Harmonization and Standardization Initiative (NHSI) on 23-24 June to discuss roadmaps to accelerate the safe and secure deployment of advanced nuclear reactors, with a particular focus on small modular reactors (SMRs).

The NHSI aims to facilitate the safe and secure deployment of SMRs to maximize their contribution to reach net zero carbon emissions by 2050. At last week's kick-off meeting, 125 participants from 33 countries worked in two separate but complementary tracks – one for regulators and the other for

Related stories
- What are Small Modular Reactors (SMRs)?
- Accelerating SMR Deployment: New IAEA Initiative on Regulatory and Industrial Harmonization
- Nuclear Power for the Future: New IAEA Publication Highlights Status of SMR Development
- IAEA Presents New Platform on Small Modular Reactors and Their Applications
- Safety of SMRs Highlighted at General Conference

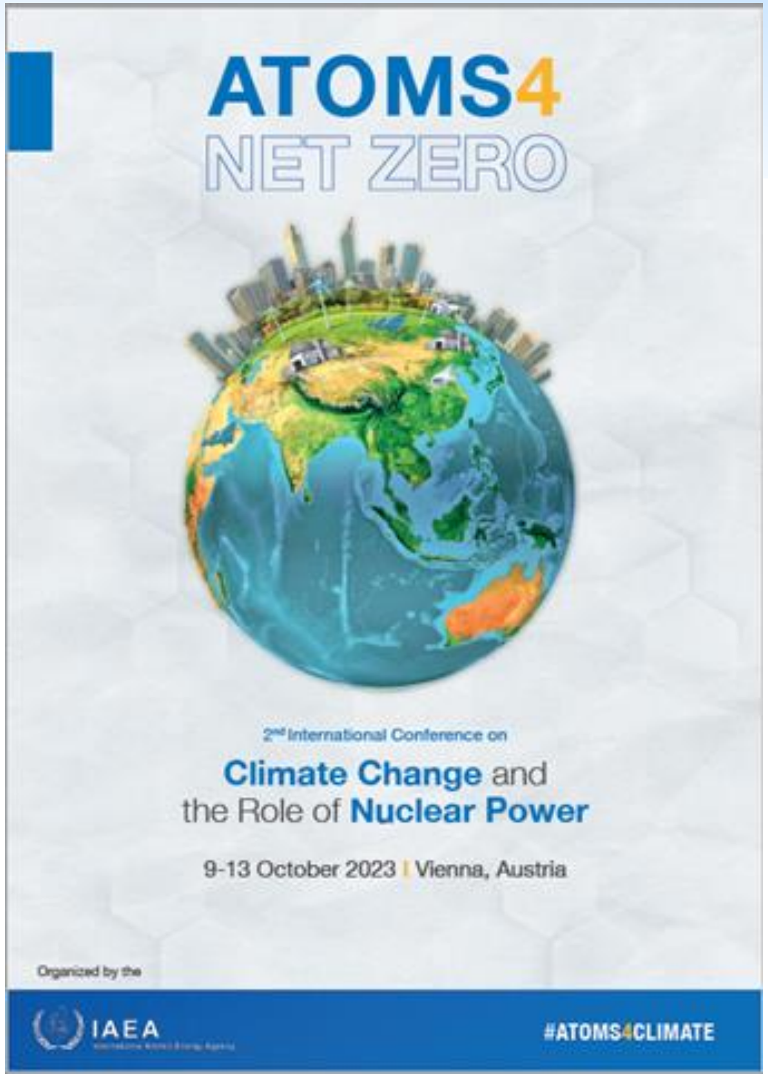
Related resources
- Small modular reactors
- Small Modular Reactor (SMR) Regulators' Forum
- Technology Roadmap for Small Modular Reactor Deployment
- Nuclear Power: The Road to a Carbon Free Future

2nd International Conference on Climate Change and the Role of Nuclear Power: Atoms4NetZero

Includes Topic "Releasing the full potential of nuclear energy":

- What are the latest innovation breakthroughs and advancements in nuclear energy
- What are the keys to fast development of advanced reactors including SMRs
- How to enable safe and economical Long-Term Operation of Nuclear Power Plants
- How to accelerate the demonstration and commercialization of non-electric applications of nuclear energy (heating, hydrogen, desalination.)
- Several side events, including one on Coal to Nuclear

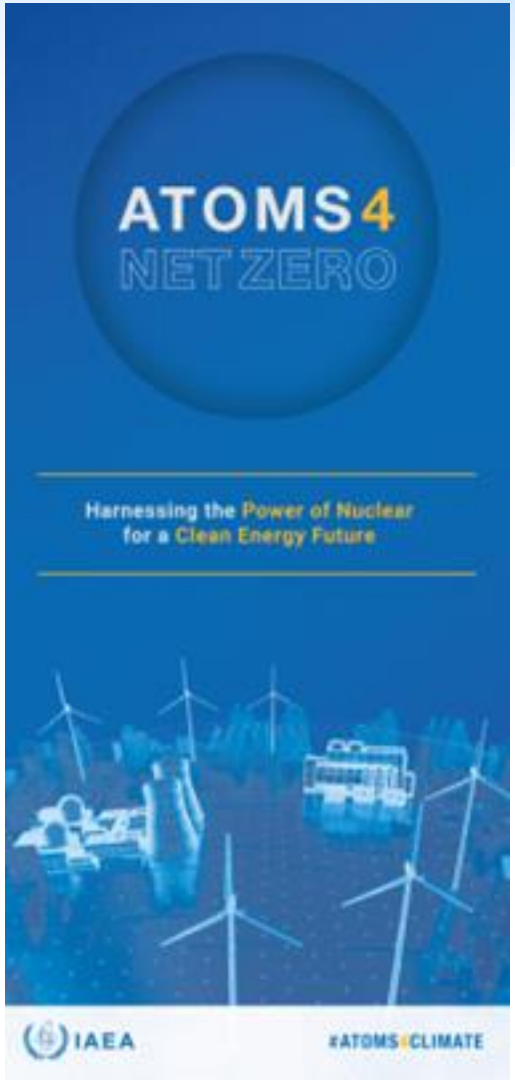
Register (no fees) through the Conference website



Atoms4NetZero: designing net zero climate-resilient energy infrastructures, harnessing the full power of nuclear

- Planning for energy systems that can supply significant electricity demand and reliable / affordable power
- critical to jointly address mitigation and adaptation to climate change, designing more climate resilient habitats and infrastructures, including clean energy systems, with nuclear options for countries choosing that option, and to support **net zero objectives**
- Address the role of nuclear power in net zero scenario models – for both electric and non-electric applications

- IAEA welcomes Member States and industrial/financial partners and institutions willing to support initiative.



IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thank you!

Contact: h.paillere@iaea.org

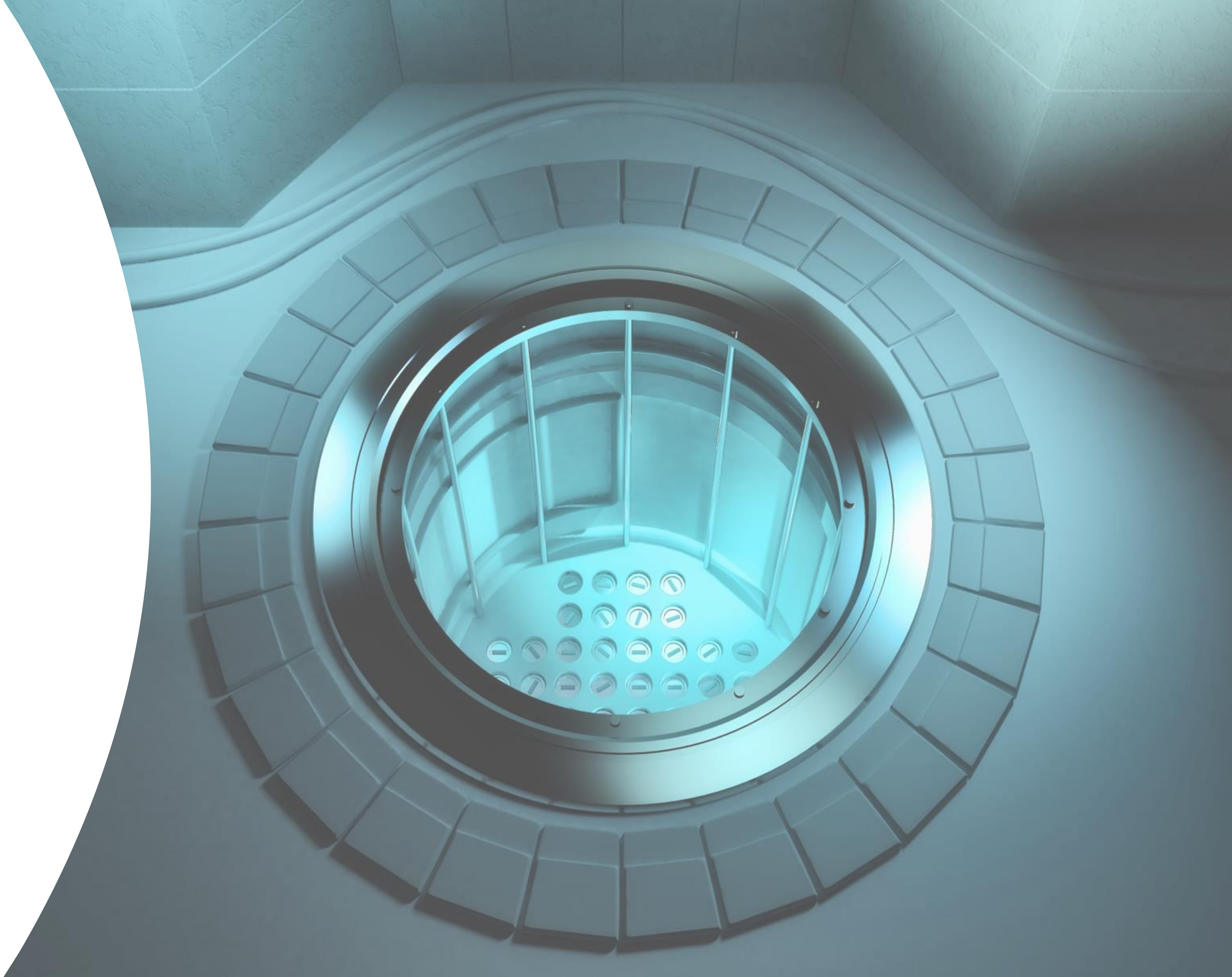
SMALL MODULAR REACTORS

FROM PROMISING CONCEPTUAL DESIGN TO SOUND BUSINESS MODEL

Dr.ir. Aliki van Heek
Nuclear-21
www.nuclear-21.net

Budapest Conference
“Fueling the Energy Transition with Nuclear”
New Nuclear Watch Institute
June 20, 2023

Content



SMRs

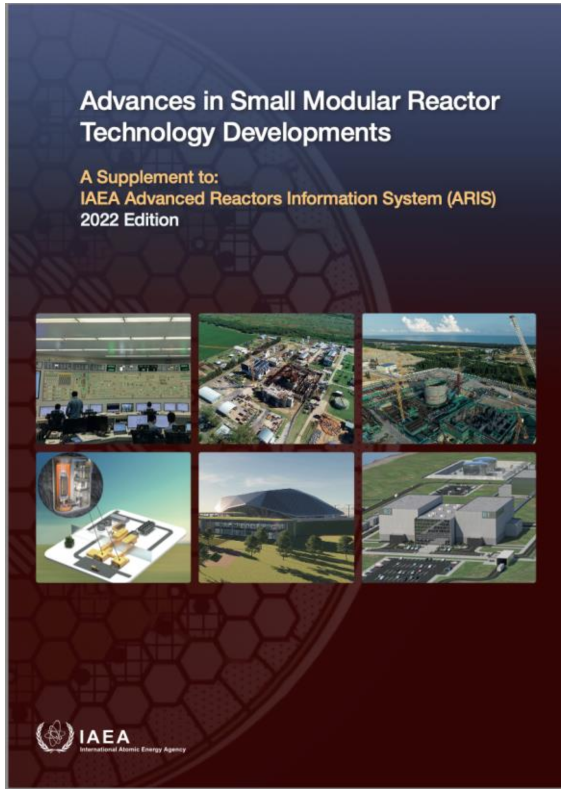
A variety of designs using different technologies for different markets

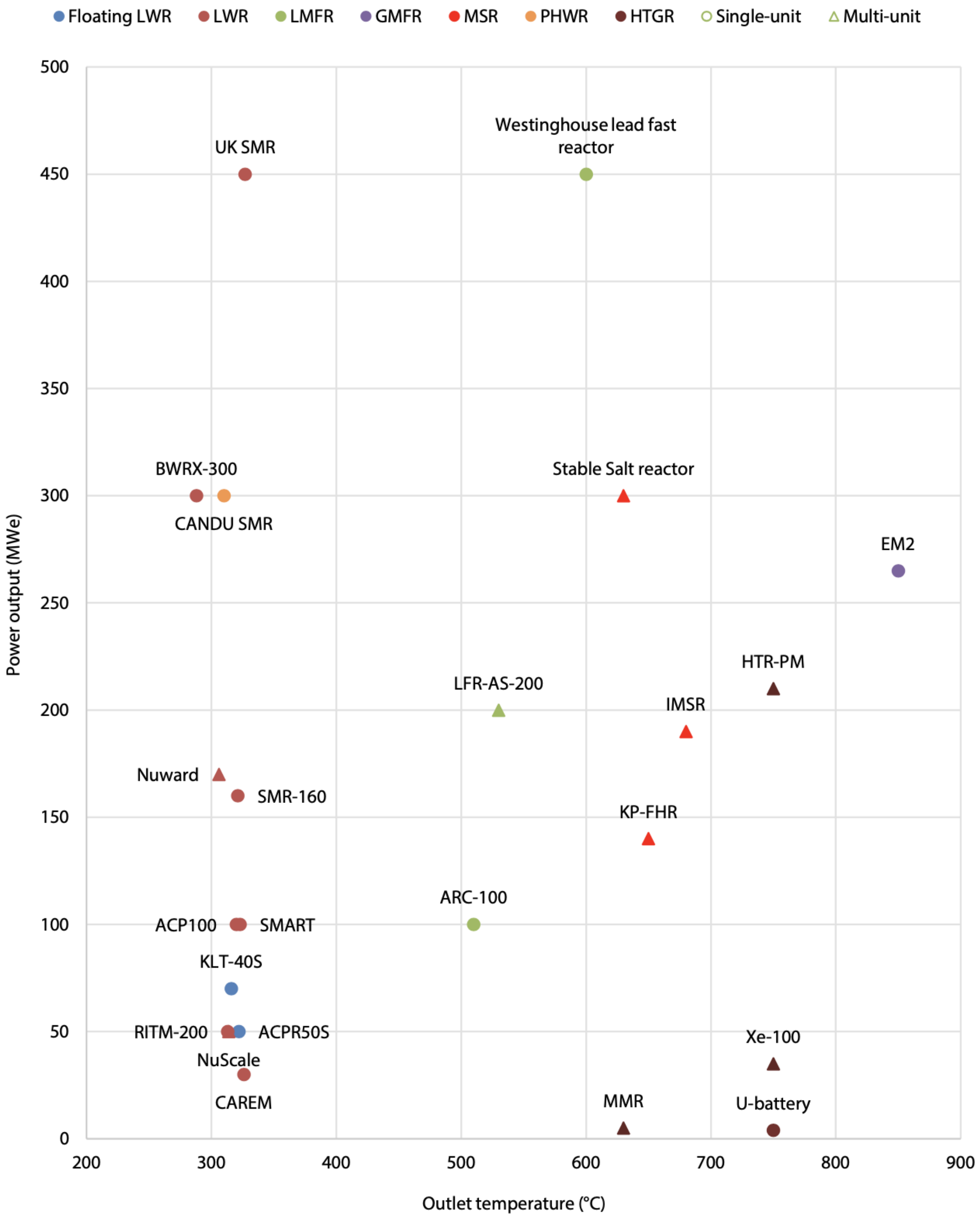
IAEA publication 2022:

84 SMR designs

4 built

3 under construction





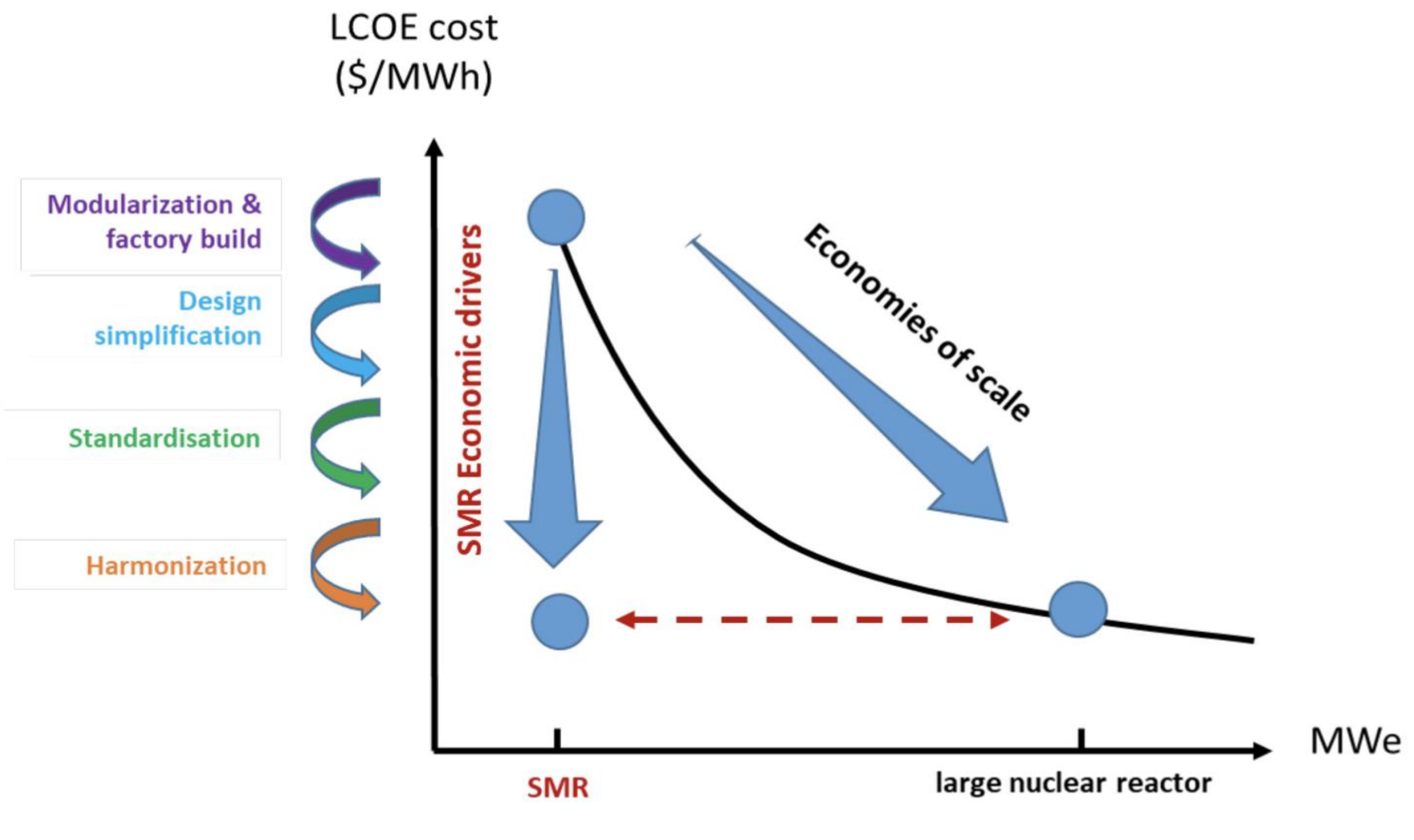
Source: OECD NEA, Small Modular Reactors: Challenges and Opportunities, 2021

SMR: economy of numbers

Essential cost reduction measure: compensate lack of economy of scale by economy of numbers

→ factory production as a series product

However..



Source: NEA (2020).

SMR: economy of numbers – but not from the start

Time gap between first plant(s) and the series production

Analogy with other machine development

- *Not produced in series from the beginning*
- *Niche markets*
- *Not the cheapest solution*
- *Business case closed by other advantages*

SMR: business opportunity examples

Canada: mining in remote areas

- *Off-grid, remote or northern areas*
- *Also to serve local communities*
- *20 to 60% cost advantage in LCOE over diesel*

Puerto Rico, USA: island

THE NUCLEAR ALTERNATIVE PROJECT

- *Rebuild from 2017 hurricane damage*
- *High energy prices – no imports*
- *Complement for intermittent solar needed*

Indonesia: alternative product – ammonia

- *Fertiliser production on island*
- *Cooperation with 4 Danish companies*
- *30% more efficient than competition*
- *25-unit MSR*

Limburg, The Netherlands: energy intensi industry

- *Increasing climate and import constraints*
- *Electricity + heat*
- *Complementary to off-shore wind power expansion*

SMR for Limburg, Netherlands

Double challenge for the energy-intensive industry in Europe:

- *securing energy supply*
- *decarbonizing energy supply*

Nuclear power only if value creation

Nuclear-21 analysed this challenge for the provincial government of Limburg in The Netherlands for the 2030-2035 time frame.

- projected energy needs, both electricity and heat
- possible role options and challenges for nuclear energy
- *Limburg has a large chemical industry cluster*
- Three energy system development scenarios
- *taking into account the expansion of off-shore wind power and the high voltage grid in the as part of the Dutch national energy policy*

1. renewables and imports without nuclear
2. larger (200-300 MWe) SMR
3. both larger and smaller (20-50 MWe) SMR

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SMR for Limburg, Netherlands – nuclear energy products

2030-2035 time frame for the integration of nuclear energy in the energy mix only realistic for NPP based on LWR technology.

Large NPP almost impossible - too limited cooling water capacit

SMR essential options

Nuclear energy option should be embedded in an integrated energy system with objectives to both

- strengthen the robustness of the electrical network in Limburg,
- offer an appropriate and sustainable heat mix to both industry ar the built environment,
- enable new energy vectors such as hydrogen and synthetic fuels.

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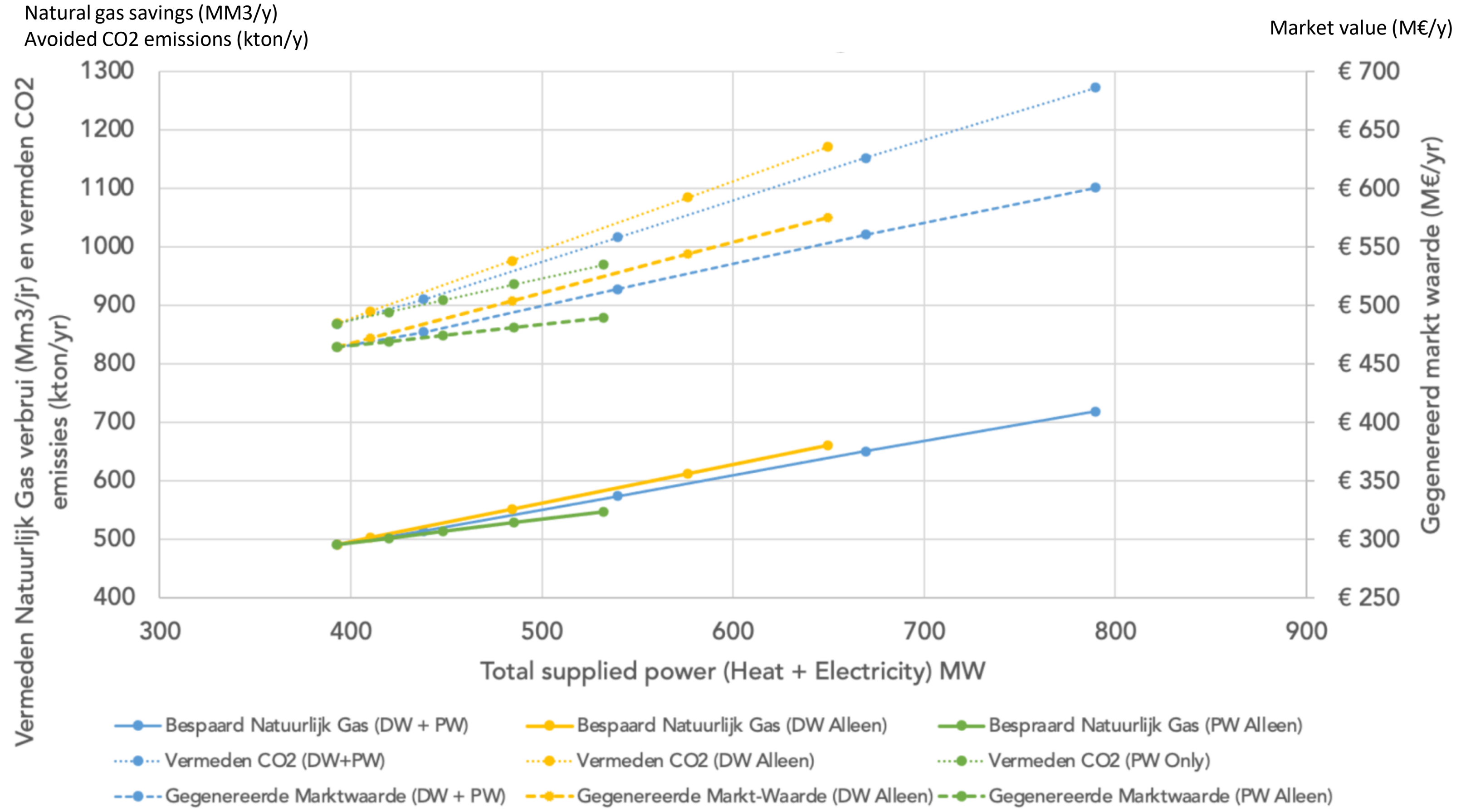
| SMR for Limburg, Netherlands – market value and natural gas savings as a function of heat supply by SMR

Basis: 1000 MWth/393 MWe SMR

Process Heat (PW)

District Heat (DW)

Both PW and DW



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SMR for Limburg, Netherlands – government role and industrial opportunity

Dutch government has a role

- in strengthening the nuclear ecosystem already present in the Netherlands and
- drawing up a strong programme for enhanced capacity building in all areas required for the realisation of multiple nuclear plants.

From 2030: demand for SMR may increase significantly

→ may be hampered by limited critical component supply chain capacity

→ opportunity for Dutch industry strategic positioning.

Approach and methodology are applicable to other regions as well, both in the Netherlands, Europe and beyond.

Take away messages

SMR is a container term, it is not one particular reactor design, but a group of small-scale designs.

Economy of numbers – factory production

Time gap between first plant(s) and the series production

Find the business case for specific regions and constraints

- *Remote areas, islands, alternative products or climate constraints*

Example of Limburg, Netherlands applicable to many regions

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Thank You

www.nuclear-21.net

Accelerating the Energy Transition

Rolls-Royce SMR

Alexis Honner, Business Development Manager, Rolls-Royce SMR

Accelerating a Clean Energy Future

ROLLS ROYCE SMR

The SMR design has been driven by market requirements from conception

Those that we can control within the design

Those that we must recognise as key influencing factors on design and technology choices

Low cost

Deliverable

Investable

Global and scalable

Regulatory / Safety

Proliferation Resistant

Market Timing

Code Compliance

Reduce Capex & Opex

Remove / Reduce Risk

Minimise Time to Build

$$\text{LCOE (Levelized Cost of Electricity, USD/MWh)} = \frac{\text{Capex + total O\&M + Decom + Fuel + Financing}}{\text{Power Generation x Capacity factor}}$$

Maximise Power

Maximise Reliability

Maximise Efficiency

Compatibility with support Infrastructure and Sites

Public Perception

Utility Familiarisation / Selection of Technology

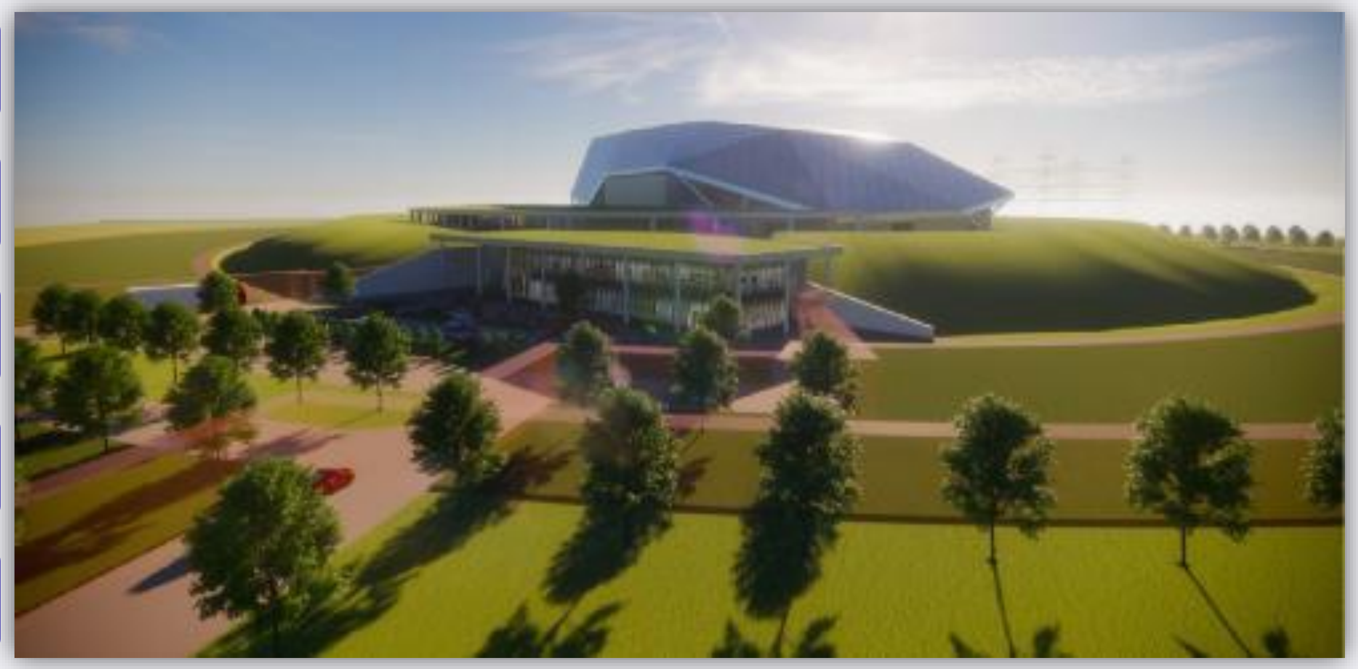
Delivery Partnership Potential

Global Market

ROLLS-ROYCE SMR

Rolls-Royce SMR is a new way of building nuclear to meet the dual needs of Energy Security & Net Zero

- ~470 MWe net output
- 50 Hz design
- Proven PWR Technology & Standard Fuel
- Power station turnkey delivery
- 4 yr on-site Construction (Fleet unit)

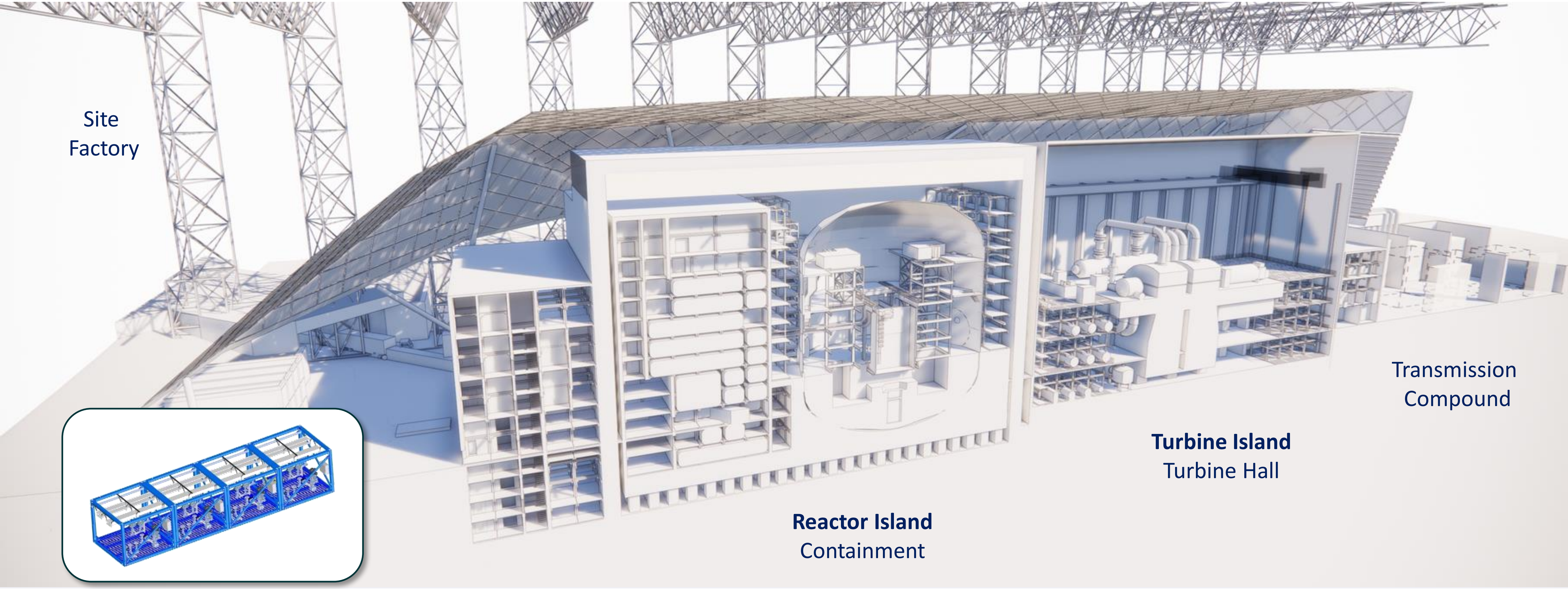


- Enhanced safety and security
- 1st unit on grid early 2030s
- Capital cost under €2.3bn*
- Adaptable, multi-use power & heat output
- LCOE range €57-€80 per MWh**

Low cost | Deliverable | Global and scalable | Investable

* 2021 economics, fleet unit; £1:€1.1406 (5yr average), costs based on UK labour rates
** 2021 economics, 2 unit plant, range dependent on financing mechanism

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

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Panel 1: Harnessing Advanced Nuclear Technologies to Accelerate the Energy Transition

Chaired by Aliki van Heek

- Chirayu Batra, Chief Technology Officer, TerraPraxis
- Henri Paillere, Head, Planning and Economic Studies Section, IAEA
- Aliki van Heek, Sustainable Energy Business Research, Nuclear-21
- Alexis Honner, Business Development Manager, Rolls Royce SMR

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