Innovation in Energy

Cotsen Hall, Athens

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Managing Director

LUCID CATALYST

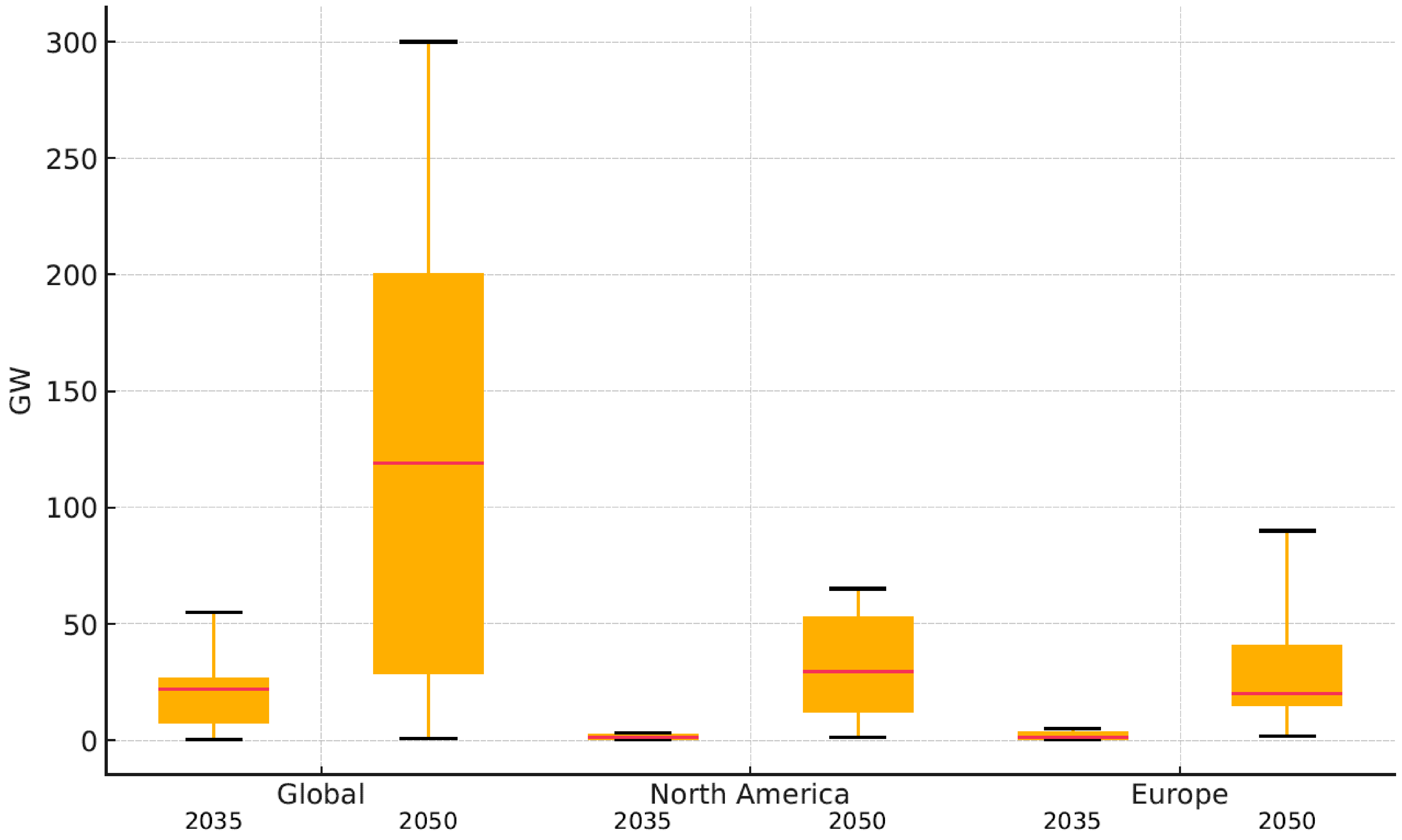
May 8, 2025

Market Growth Projection through 2050

Most studies indicate that the SMR market is set to grow, adding around 150-200 GW by 2050 globally

- The market takes off beyond 2035, with very limited additions before that date, and accelerates after 2040.
- After China, the US could drive most of this growth, fuelled by a higher appetite for SMR technology and a large internal market with a single regulator. However, competition in terms of energy prices will be tougher. The multiplicity of regulators could limit the overall internal market in Europe.
- The uncertainties of the global market towards 2050 are significant and are reflected by the width of the boxes.
    - Higher-end projections assume successful demonstration projects, significant learning, and cost reductions for SMRs.
    - Conversely, lower-end projections assume unsuccessful initial projects and unfavourable economics.
    - The overall market could exhibit a binary on/off behaviour, with a significant surge if economic and market conditions are favourable.

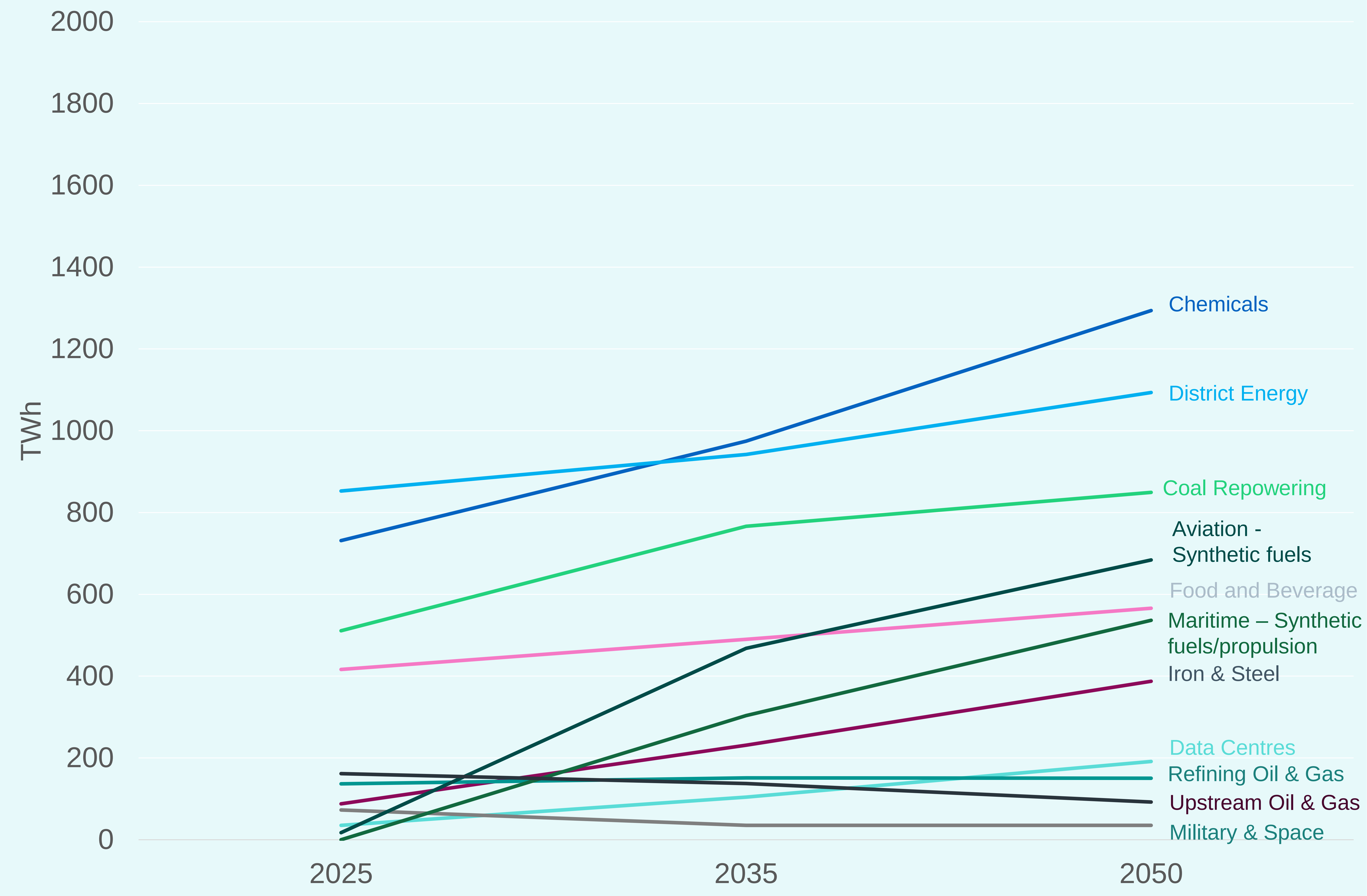
Projected SMR market projection in selected regions



Source: LucidCatalyst based on IEA 2025, IAEA 2024, Compass Lexecon 2024, DNV 2024, NEA 2022, INL 2021 and Vanatta et al 2024

Market potential from industry is growing

Market potential by industry, 2025-2050, Europe, APS

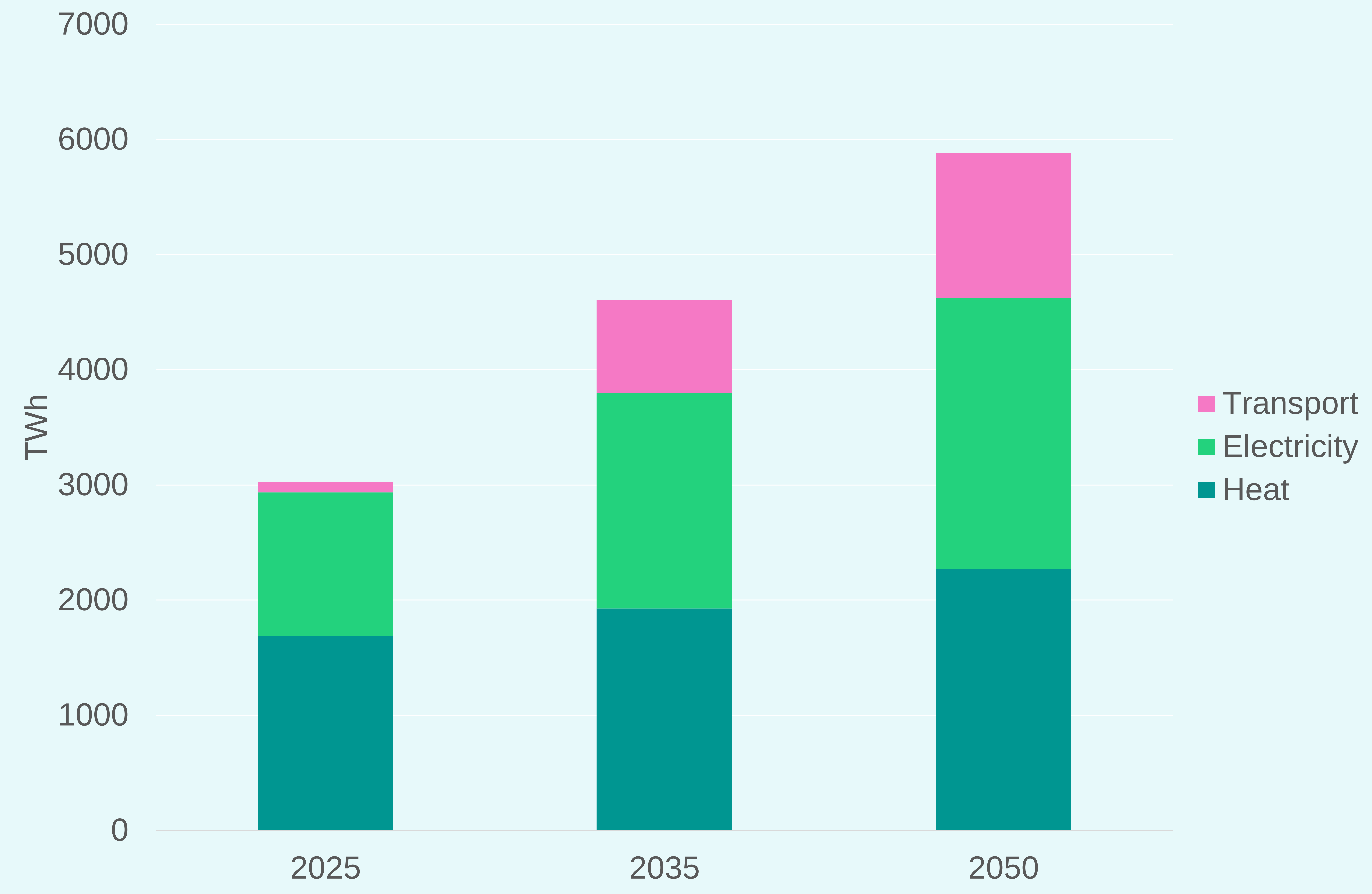


Source: LucidCatalyst
Note: The technical potential in TWh represents the final energy consumption in the industry across different energy carriers. For example, the technical potential for chemicals includes TWh of electricity, heat, and fuel used for industrial processes.

- Sectors that dominate in Europe include chemicals, district energy (heating and cooling), coal repowering and synthetic fuels for aviation, with district heating tripling in size compared to North America
- Oil and gas activities are significantly lower than in other regions such as North America and decline further under the APS scenario.
- While data centre demand increases over time, it remains below the top five sectors in terms of energy served by SMRs and AMR

SMR market potential by carrier

Technical potential by carrier, 2025-2050, Europe, APS

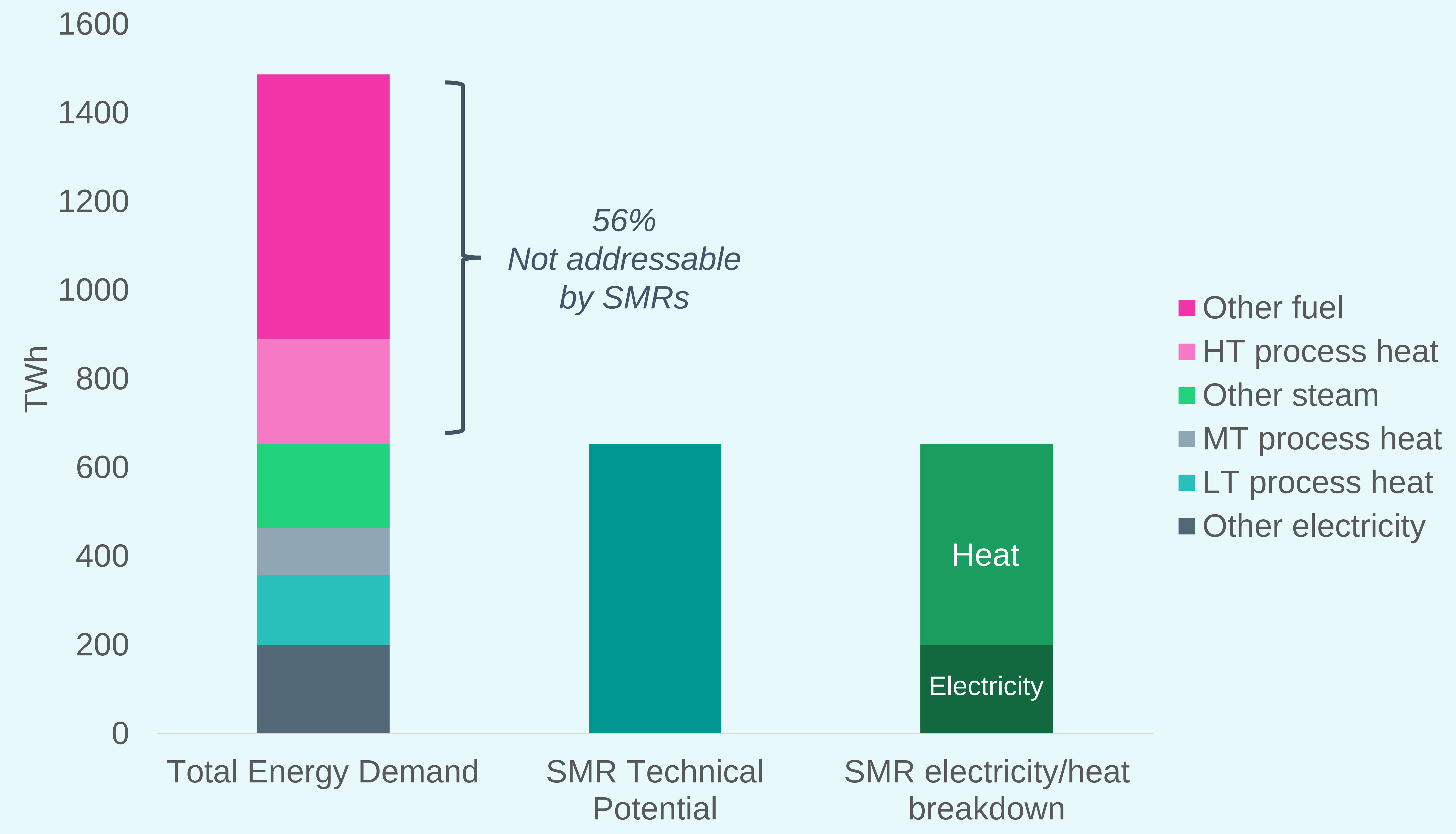


Source: LucidCatalyst

- SMR electricity generation dominates in Europe
- Heat gains some growth, driven by district energy and chemical sectors.

SMR Market opportunity

From total energy demand to SMR technical potential, chemicals, 2025, US



Source: LucidCatalyst

- The technical potential for SMRs in manufacturing industries includes:
  - All electricity and steam use categorized under “Other,”
  - Low-temperature (LT) and medium-temperature (MT) heat in process heating.
- High-temperature (HT) process heating and the fuel used in “Other” are not technically accessible with SMRs (temperatures too high or fuel is used for industrial process not energy carrier). These energy demands could instead be met by other solutions such as fuel switching to biofuels, hydrogen, and electrification

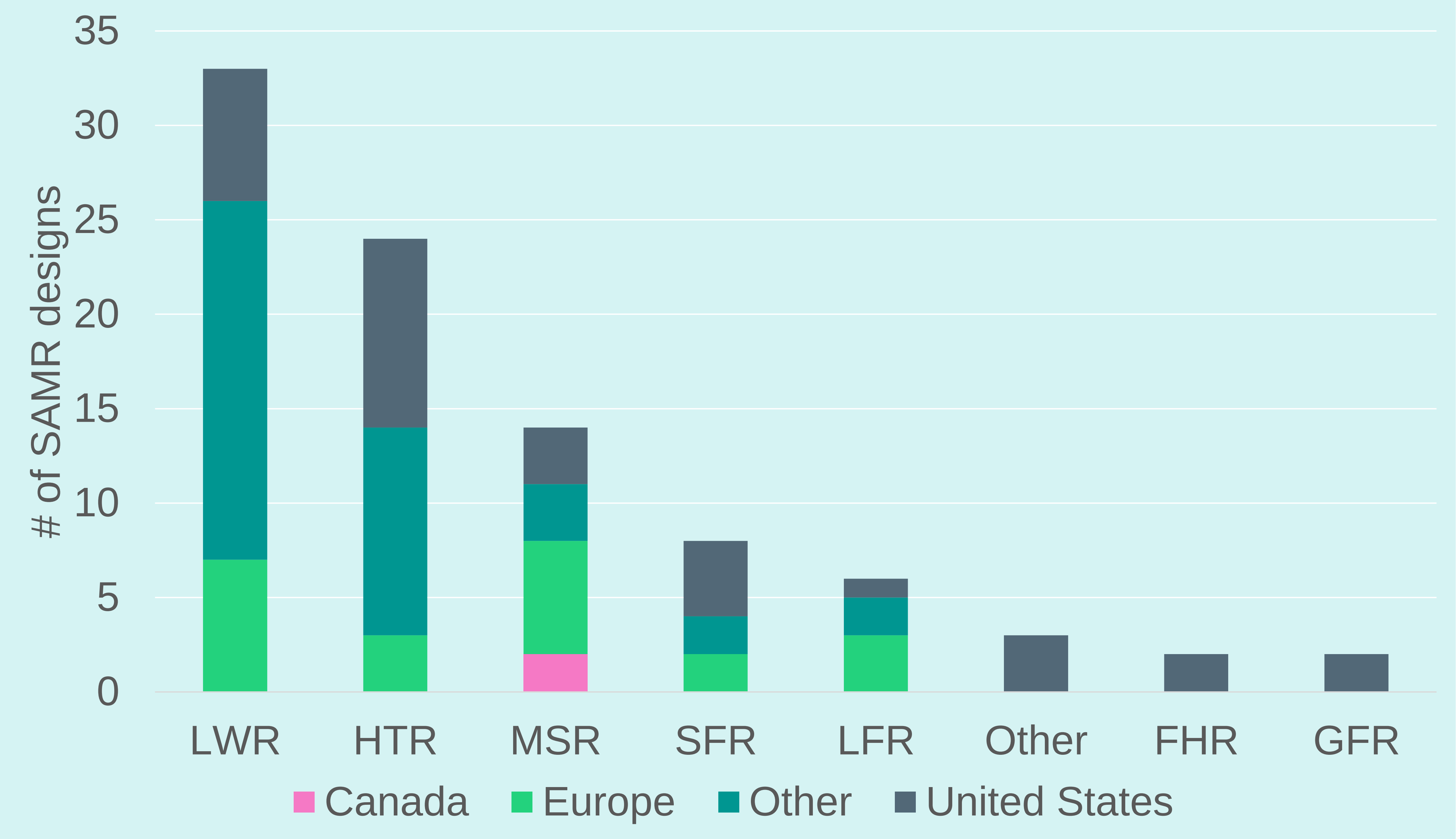
Competitive Landscape Overview

The SMR development ecosystem is highly dynamic, with more than 90 concepts proposed. While these developments are positive and provide optionality, end-users may find it difficult to identify the best solution for their needs, which can be a hurdle to commercialization

- From the 90 concepts being proposed
- 65% are advanced modular designs different from LWRs. While their technical and regulatory maturity and operational record are more limited compared to LWRs, they have the potential to bring drastic cost reductions and introduce new delivery models
- Only 60% can be considered under active development.[1]
- For some end-users, the variety of designs and deployment readiness levels complicates the assessment of the best solution for their needs, which can potentially hinder market adoption

Concepts reaching commercialization faster will have a first-mover advantage

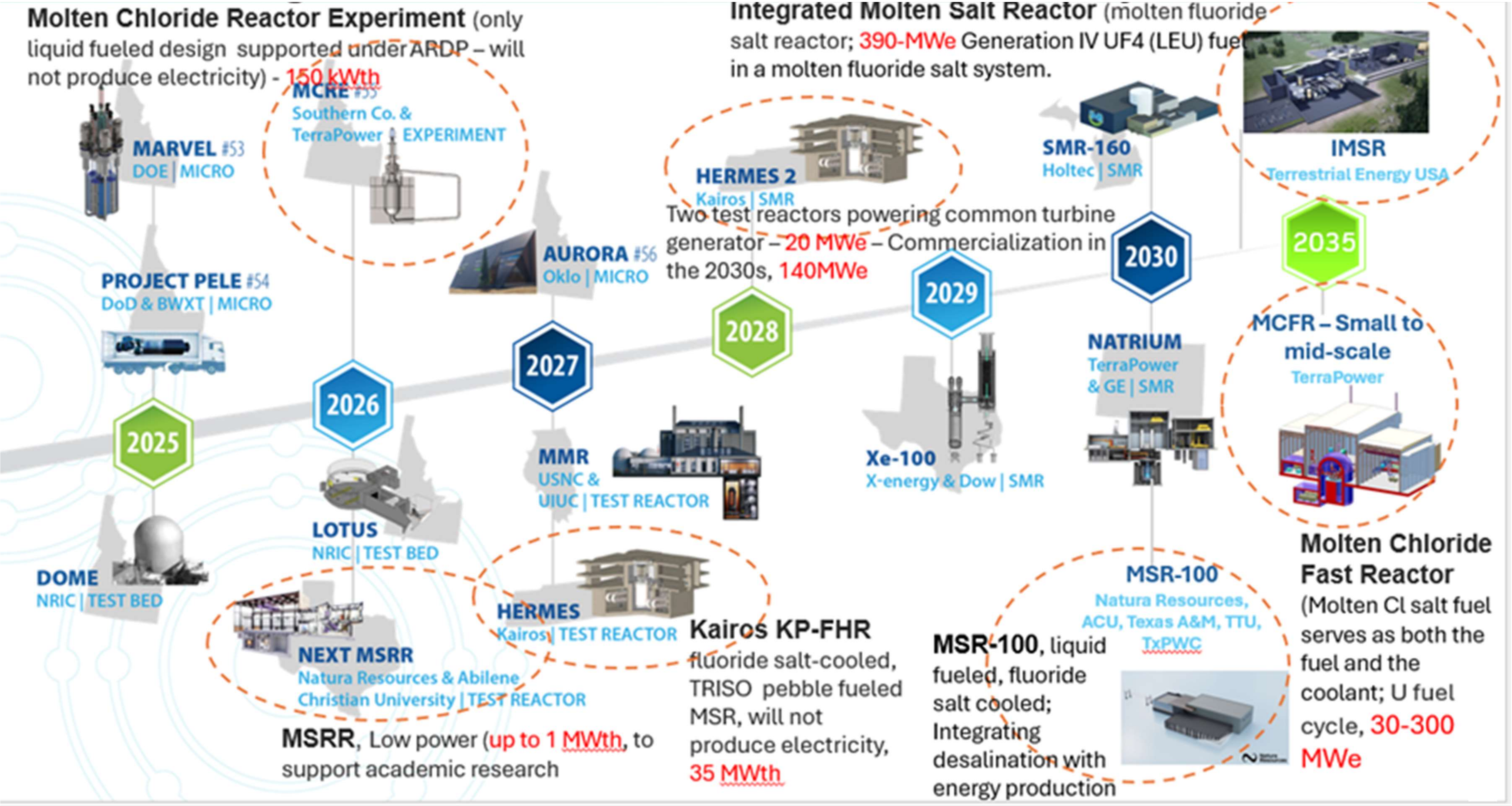
SAMR designs by technology type



Notes: This chart considers around 90 SAMR designs under development around the globe LWR = Light Water Reactor, HTR = High Temperature Gas-Cooled Reactor, MSR = Molten Salt Reactor, SFR = Sodium Fast Reactor, LFR = Lead Cooled Reactor, FHR = Fluoride Salt-Cooled High-Temperature Reactor, GFR = Gas Fast Reactor
Source: LucidCatalyst

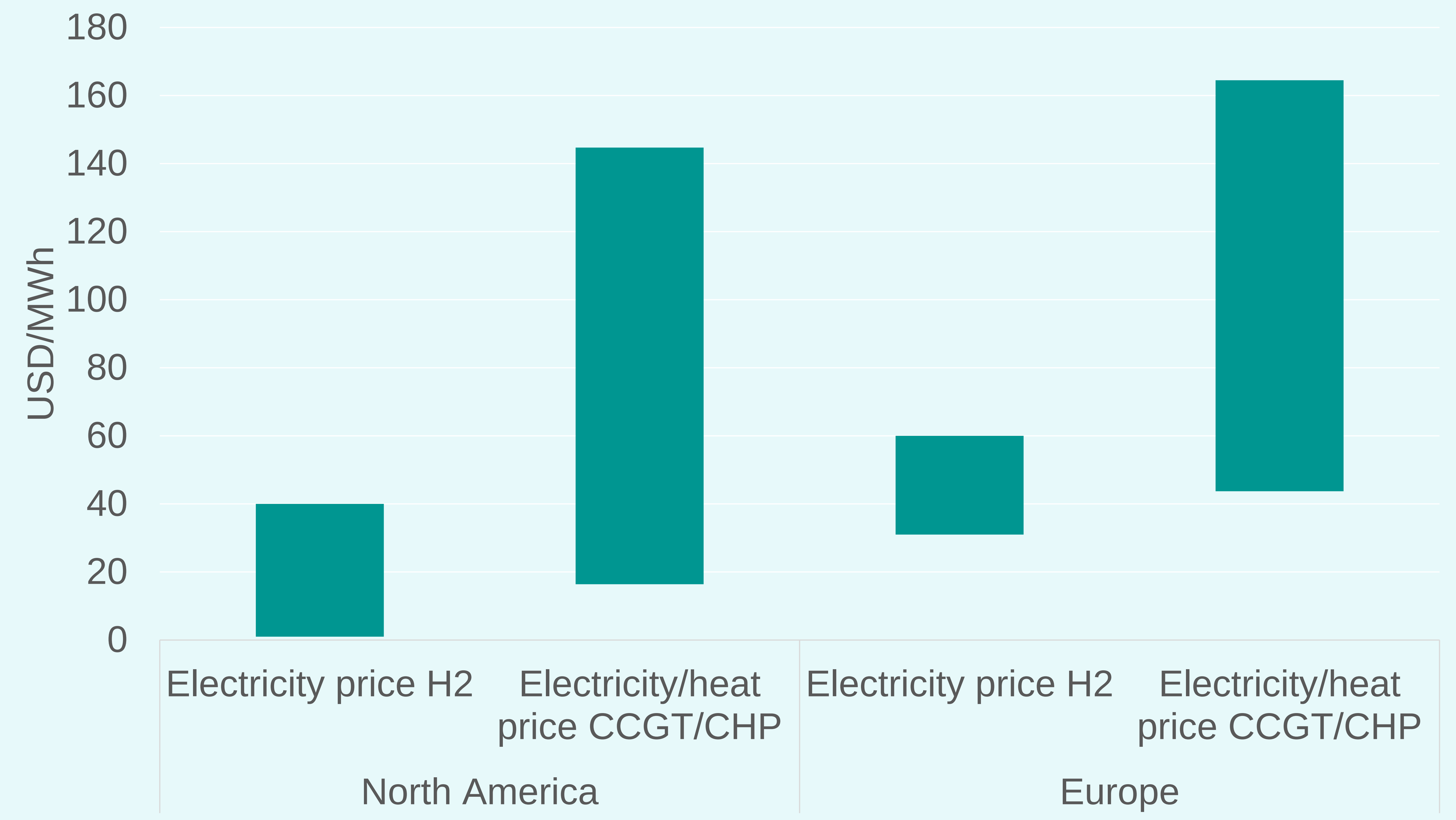
1. NEA (2024), The NEA Small Modular Reactor Dashboard: Second Edition

Multiple vendors in multiple technologies



Cost/Price Sensititvity

SMR Cost vs. Price threshold comparison across delivery and price scenarios and regions



Source: LucidCatalyst
Note: Electricity/heat price CCGT/CHP corresponds to the electricity and/or heat price of a combined cycle gas turbine or a combined heat and power unit powered with gas. H2 corresponds to the electricity price needed to produce H2 at a similar price as a gas-based H2 production. The H2, CCGT/CHP electricity/heat price ranges covers all price scenarios.

- Structurally, gas prices are higher in Europe than in North America.
- This increases the relative cost competitiveness of SMRs across all scenarios in Europe, systematically unlocking a larger addressable market.
- As a result, it is possible that in Europe, most of the addressable market is unlocked under lower-price scenarios (e.g. energy cost and energy security).
- Carbon pricing could impact addressable market (e.g. APS and Net Zero).

Data centres is changing

Integrated Data centre and power design solutions

Scale of data centres are getting bigger (scale and density)

Data centre capacity requiring programmatic build out over time with power growth (e.g. 1GW every year)

Individual campuses with very large capacity (5GW)

No longer some folk talking, its now very real discussions

Data Centre companies as utility providers?

Open RFI launched March 2024

Working together across the electricity ecosystem to develop new business models and aggregate demand for advanced clean electricity technologies including:

- Advanced nuclear
- Next-generation geothermal
- Clean hydrogen
- Long-duration energy storage (LDES) and others

Source: www.advancedcleanelectricity.com/

Data Centre companies as utility providers?

Artificial Intelligence

Google to buy power for AI needs from small modular nuclear reactor company Kairos

By **Timothy Gardner**

October 14, 2024 8:46 PM GMT+1 · Updated 20 hours ago

Aa

WASHINGTON, Oct 14 (Reuters) - Alphabet's (GOOGL.O) Google said on Monday it signed the world's first corporate agreement to buy power from multiple small modular reactors to meet electricity demand for artificial intelligence.

The technology company's agreement with Kairos Power aims to bring Kairos' first small modular reactor online by 2030, followed by additional deployments through 2035.

The companies did not reveal financial details of the agreement or where in the U.S. the plants would be built. Google said it has agreed to buy a total of 500 megawatts of power from six to seven reactors, which is smaller than the output of today's nuclear reactors.

Source: Reuters

Data Centre companies as utility providers?

amazon

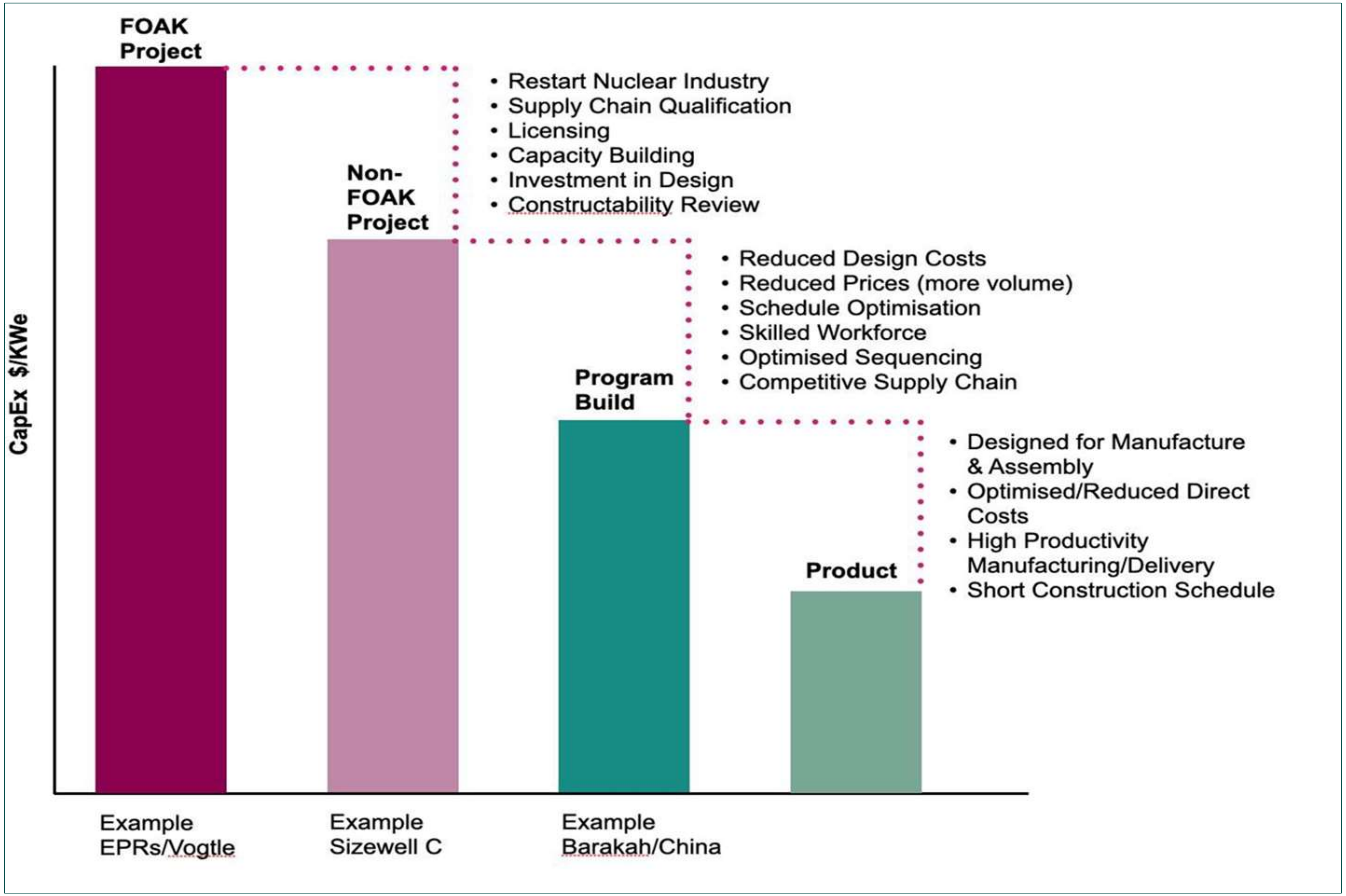
Amazon signs agreements for innovative nuclear energy projects to address growing energy demands

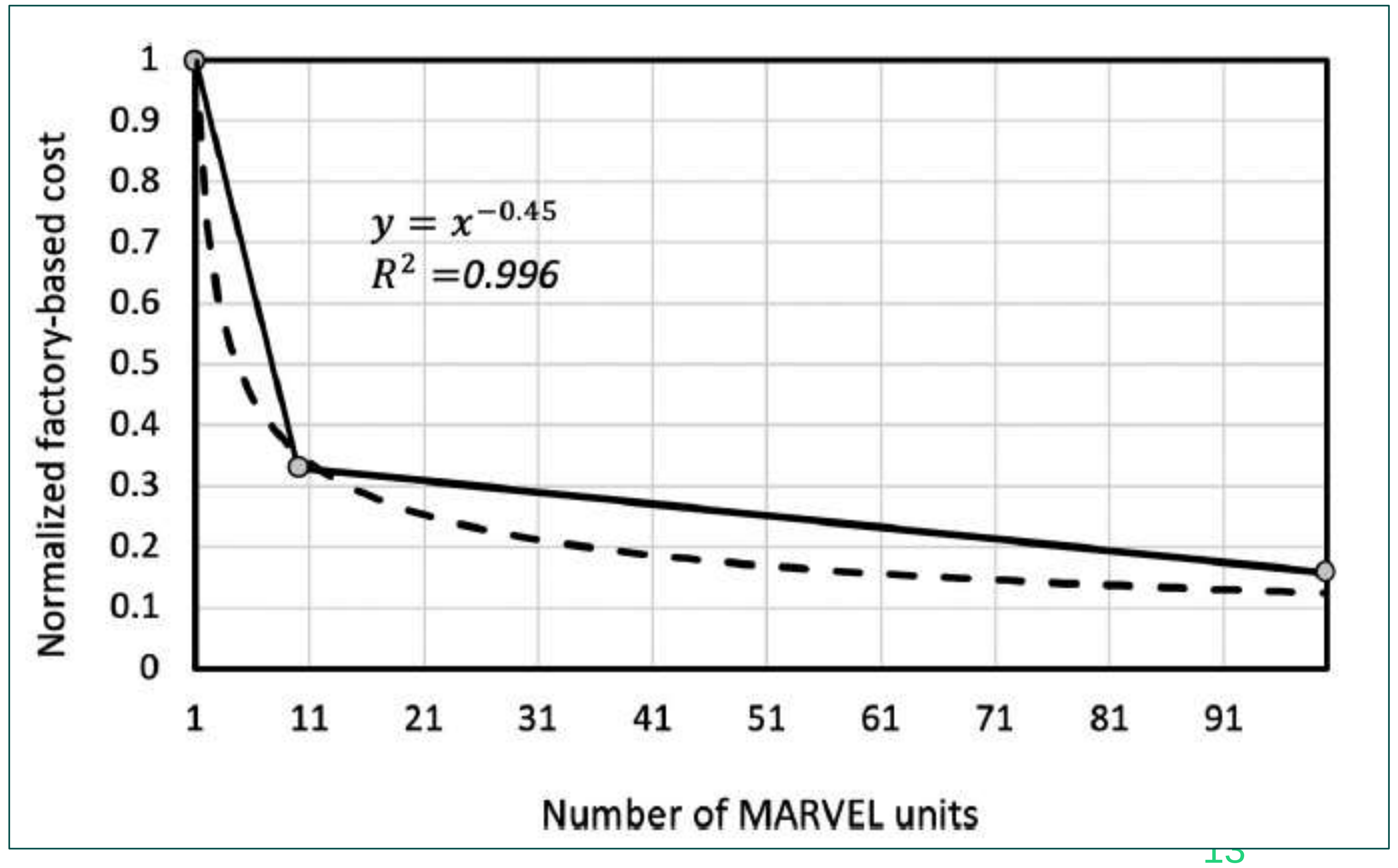
New Small Modular Reactor agreements are part of Amazon’s plan to transition to carbon-free energy.

Source: www.aboutamazon.com

Transforming the approach from site to product

Evolution of cost reduction from land-based LWR to mass production

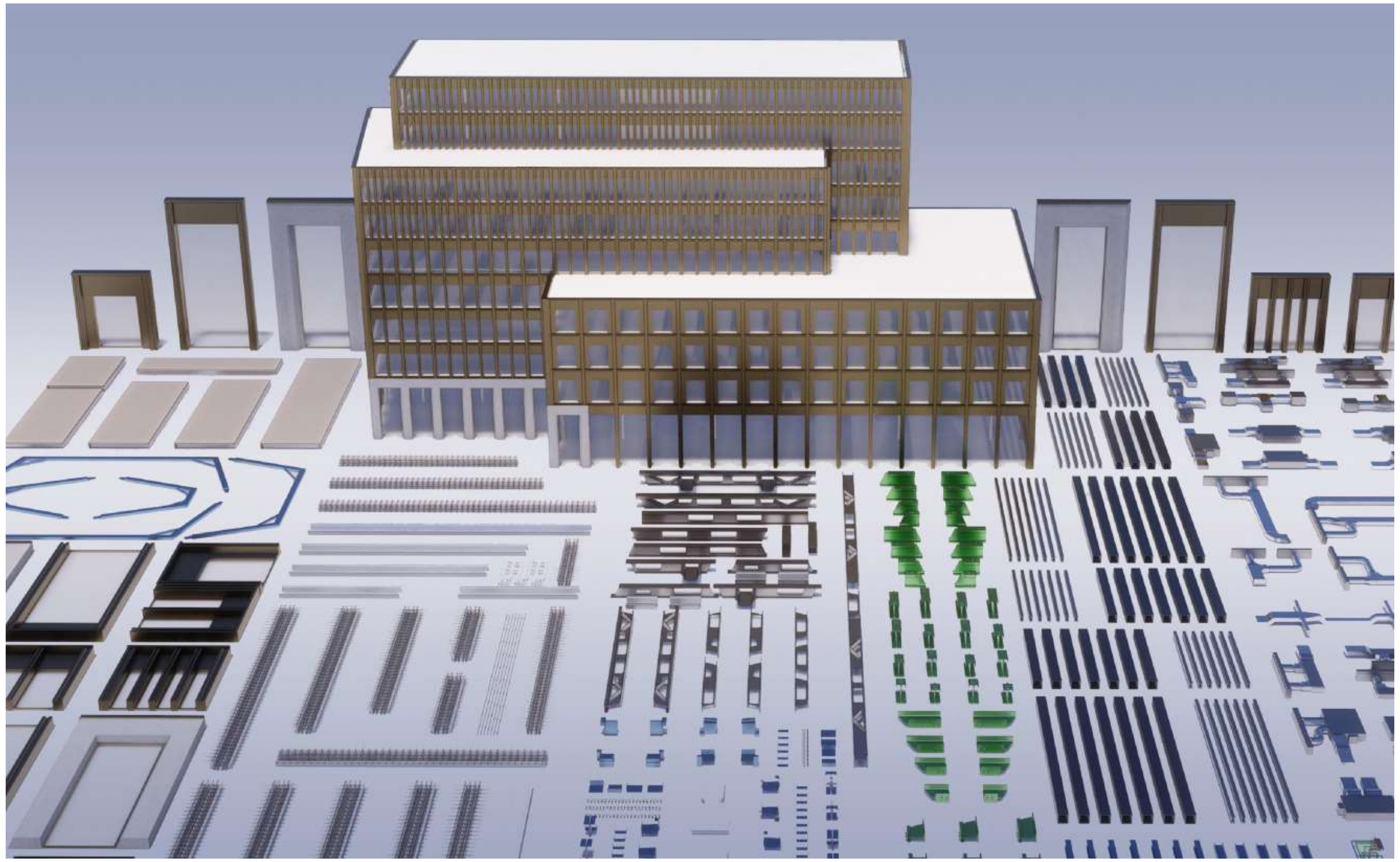




Source: LucidCatalyst (2020), The Missing Link to a Livable Planet, (2021) Beautiful Nuclear and INL(2023) Assessing the Impact of Mass Production on Microreactor Costs

Transforming delivery from slow complicated and financially risky projects…

…into a fast, low cost, and repeatable manufacturing and assembly process



DfMA - **D**esign **f**or **M**anufacture and **A**ssembly commodification – from project to product

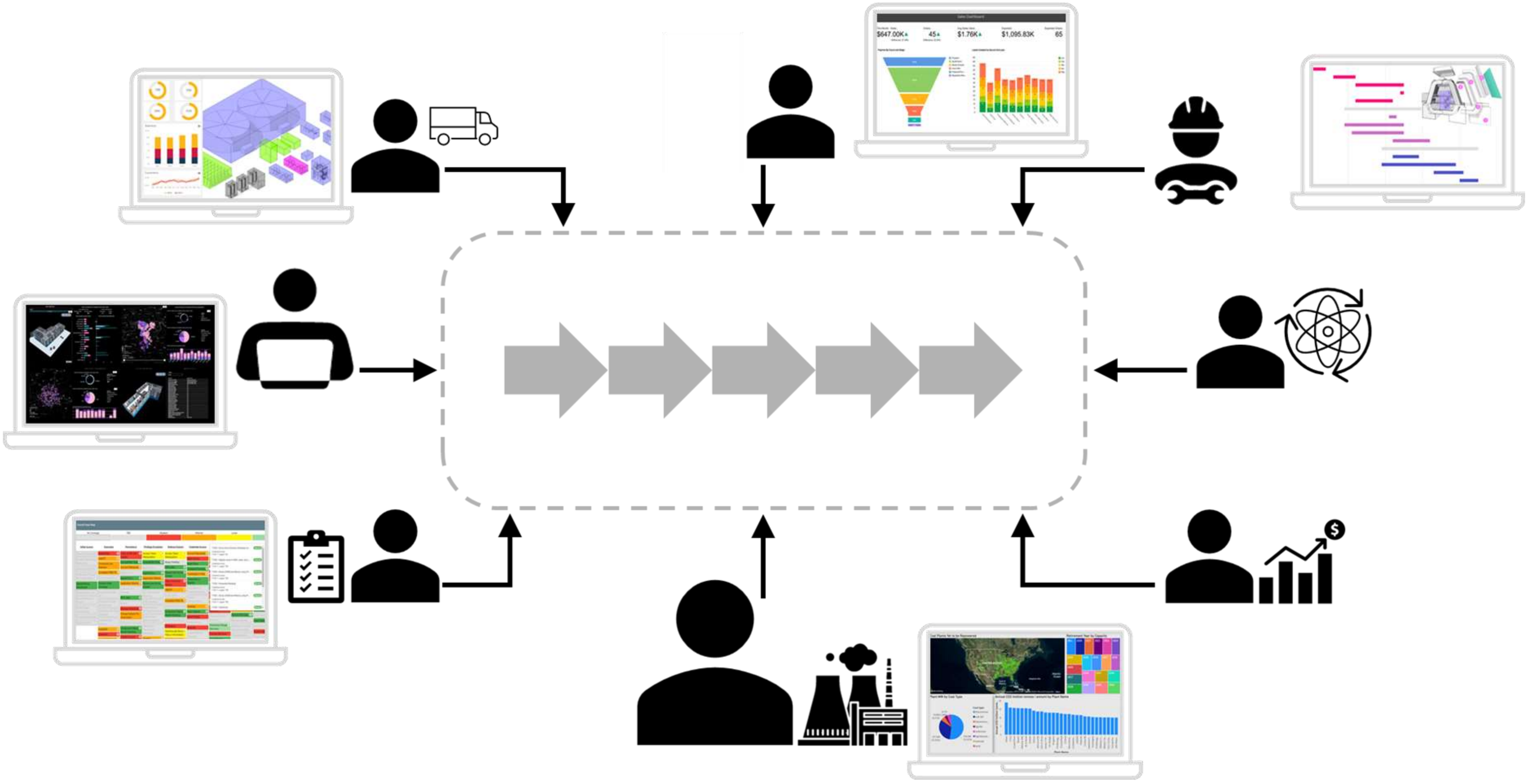
Applied to the Open Architecture approach to simplify, de-risk and accelerate deployment – Hyperscale Clean Power

Configuration and Evaluation tools

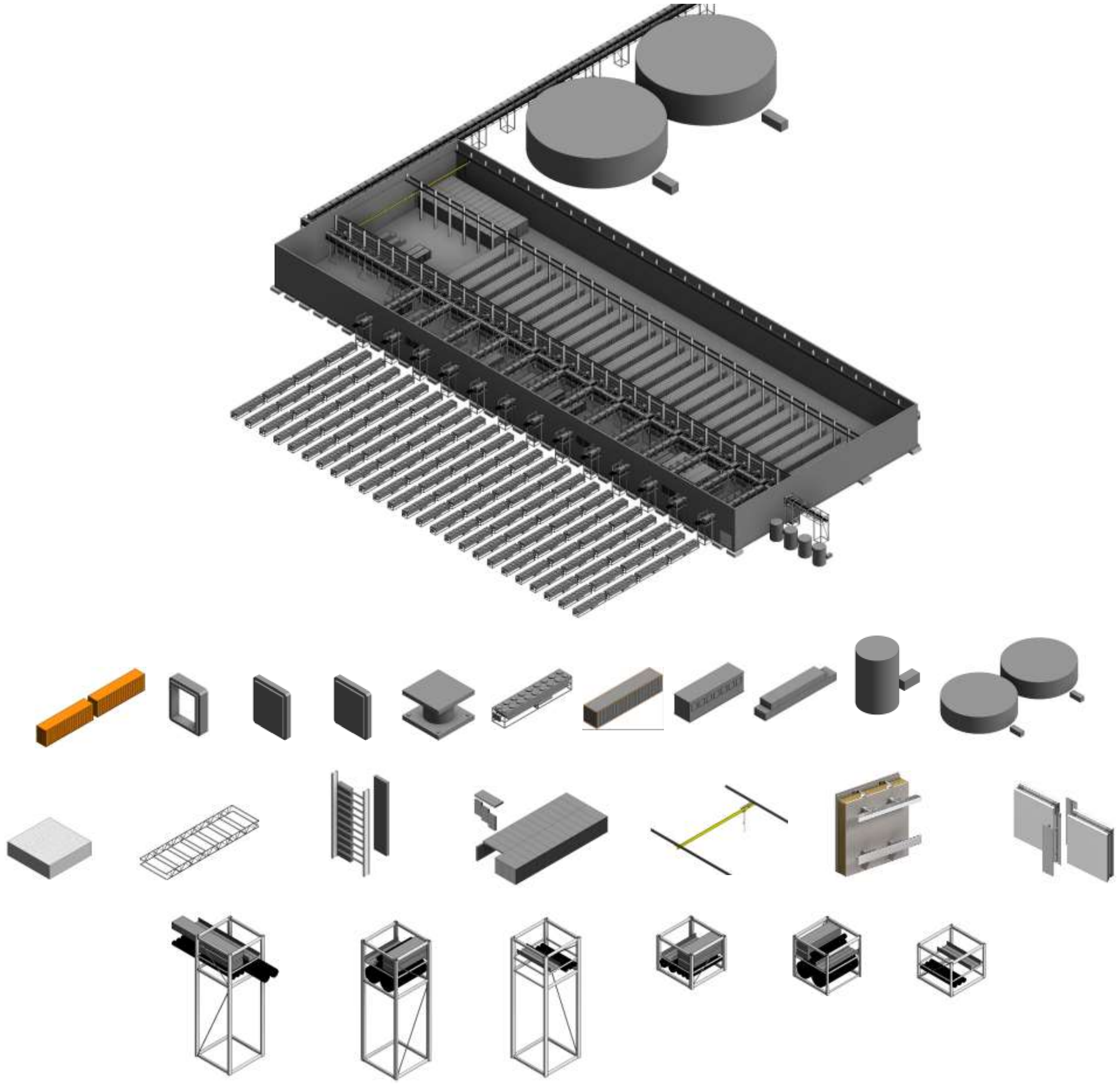
Rapid multi-site, multi-configuration evaluation

Open Architecture System

De-risking planning, procurement, construction, schedule and regulation



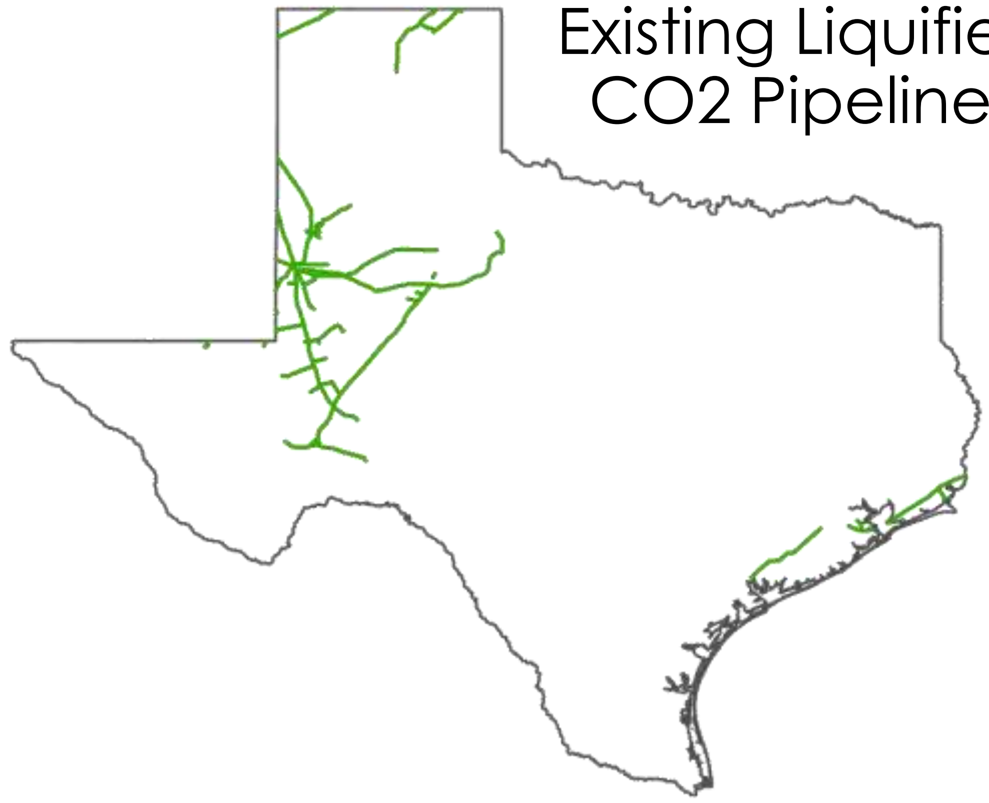
‘Open Architecture Development & Configuration tools’



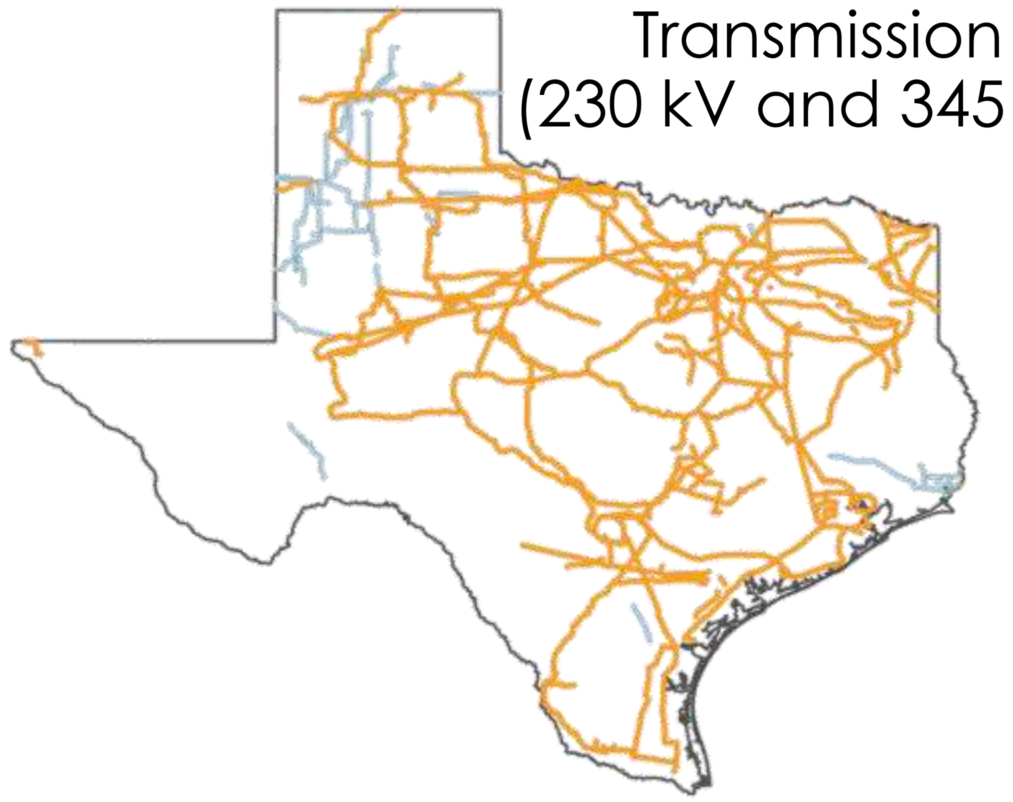
‘Standardised Common Platform Designs for Deployment using DfMA approach’

Siting Tools

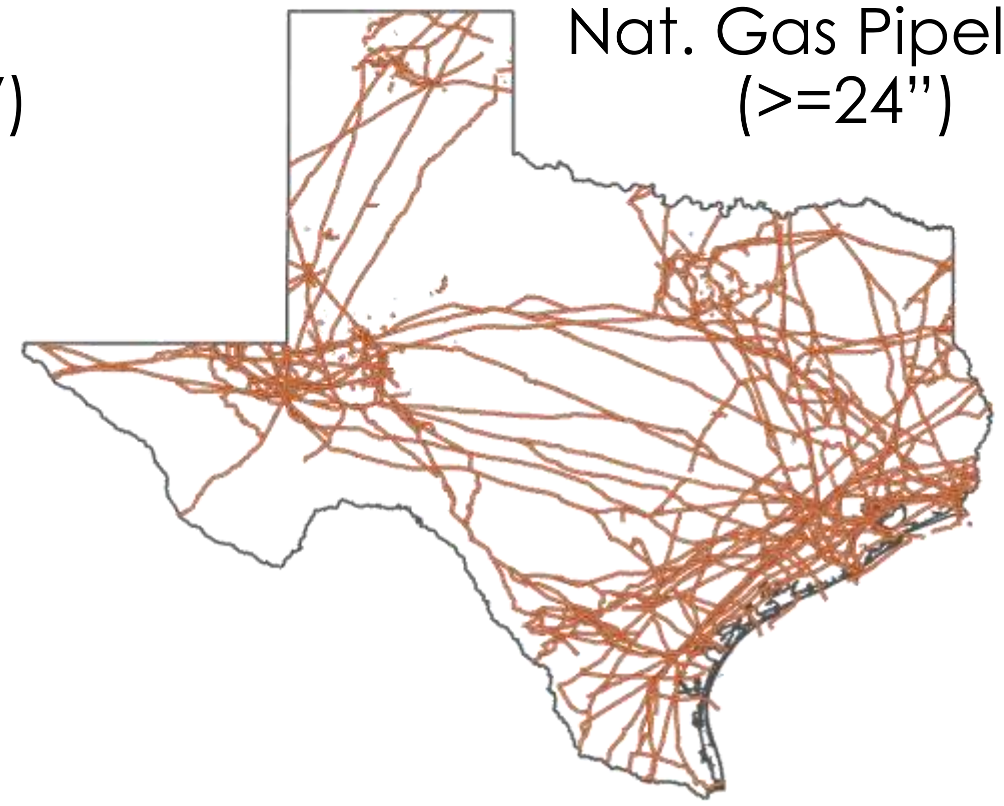
Accelerated site analysis



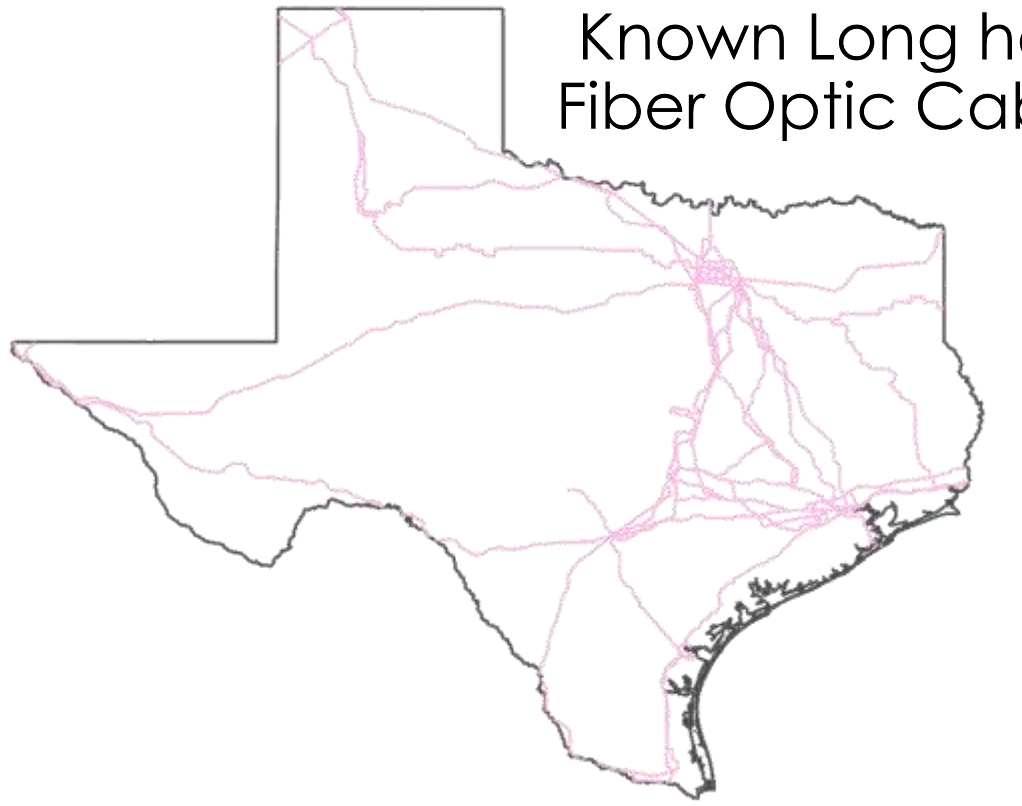
Existing Liquified CO_2 Pipelines



Transmission (230 kV and 345 kV)

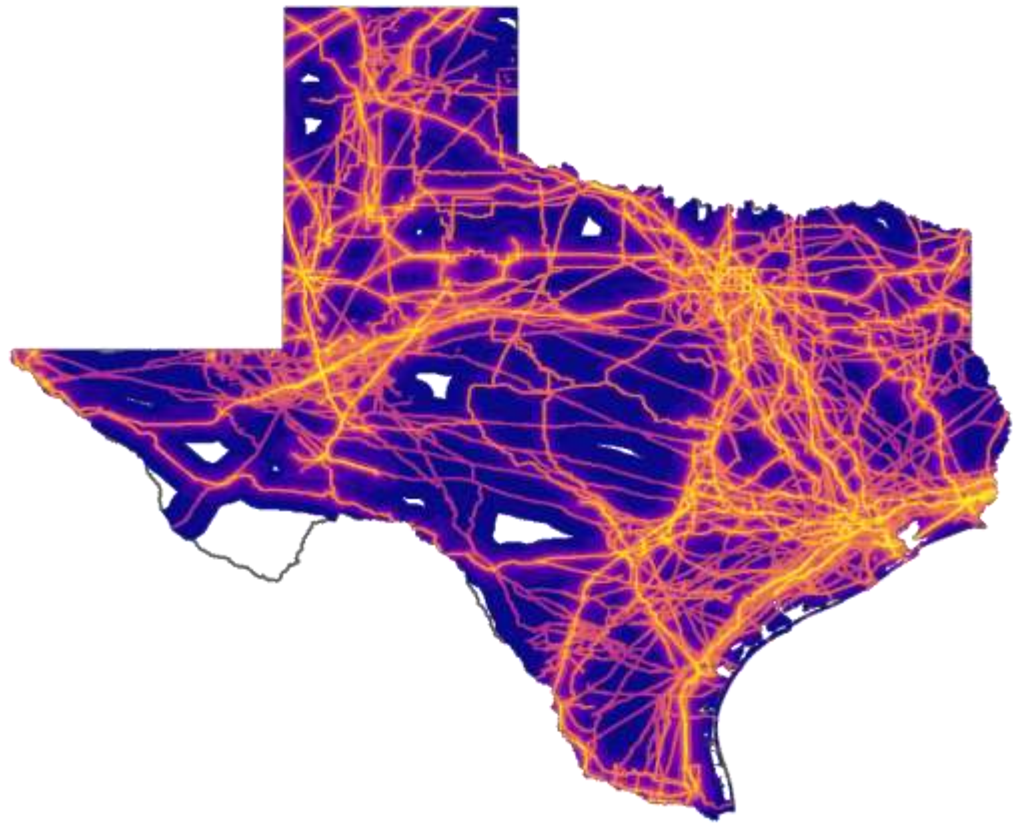


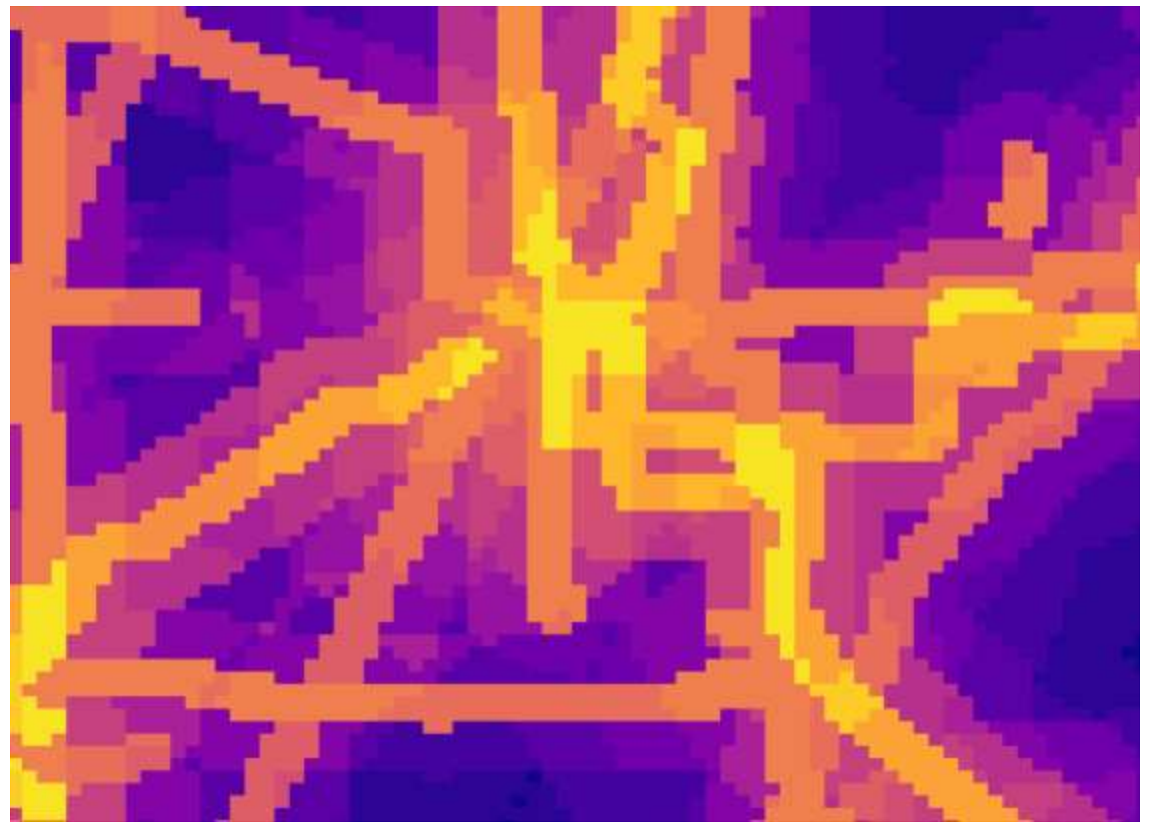
Nat. Gas Pipelines (>=24")



Known Long haul Fiber Optic Cables

GIS Analysis: Assigned relative weights to siting criteria to yield "heat map" of optimal sites.





Siting Tools

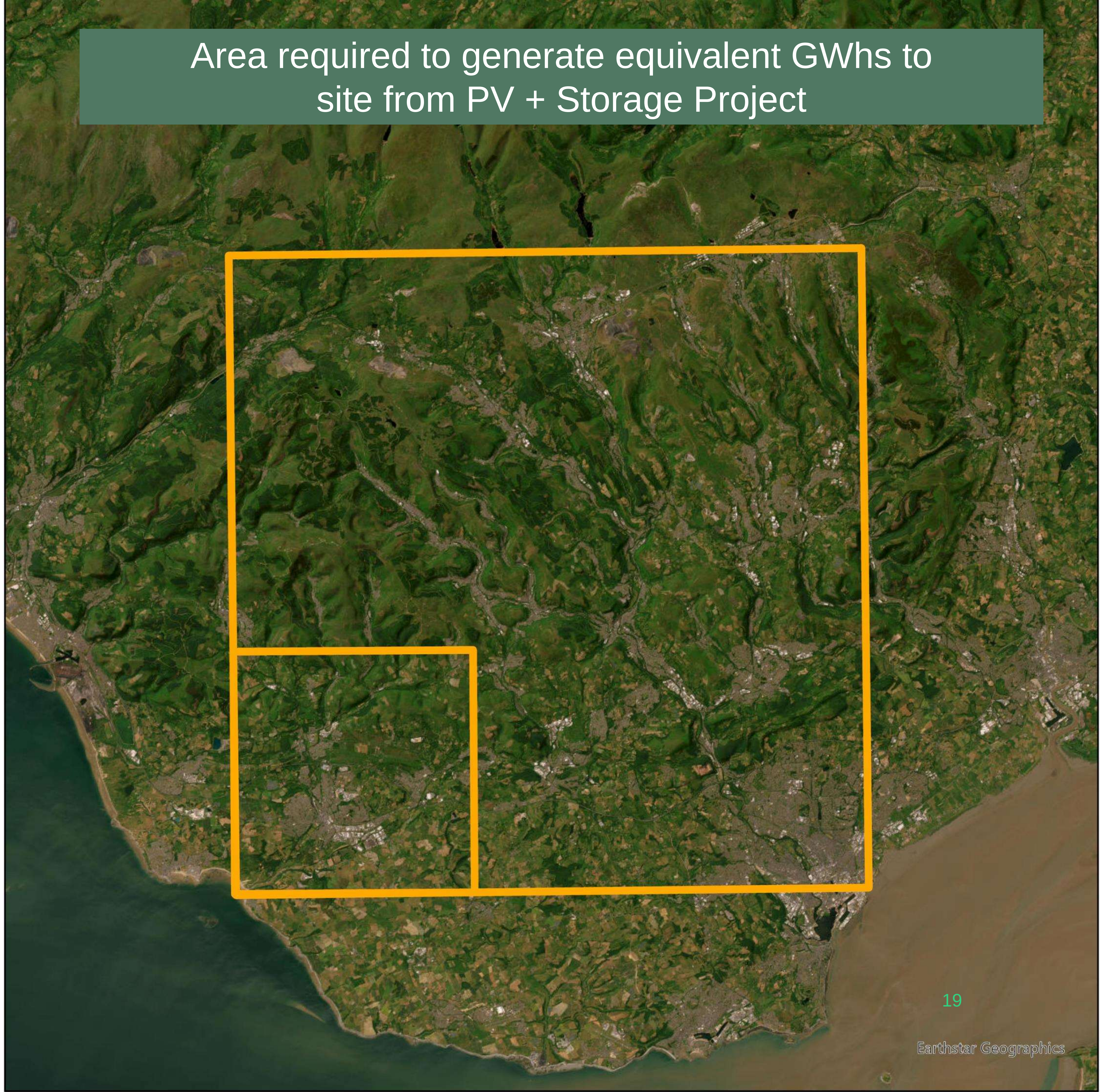
Site evaluation assessment

Plant Capacity: 1,560 Mwe
Capacity Factor: 90%

PV Assumptions
Cost: $1/W
Summer CF: 18.7%
Winter CF: 2.7%
WACC: 6%

Storage Assumptions
Cost: $150/kWh
Roundtrip Efficiency: 90%
WACC: 6%

Model Outputs	Sized based on Summer Months	Sized based on Winter Months
PV Project Size	9,114 Mwe	63,474 Mwe
PV Project Cost	$9.12B	$63.4B
Storage Size	30,452 MWhs	36,420 MWhs
Storage Cost	$6.2B	$7.2B
Cost per MWh	**$77.29**	**$145**
Total System Cost	**$15.6B**	**$29.3B**

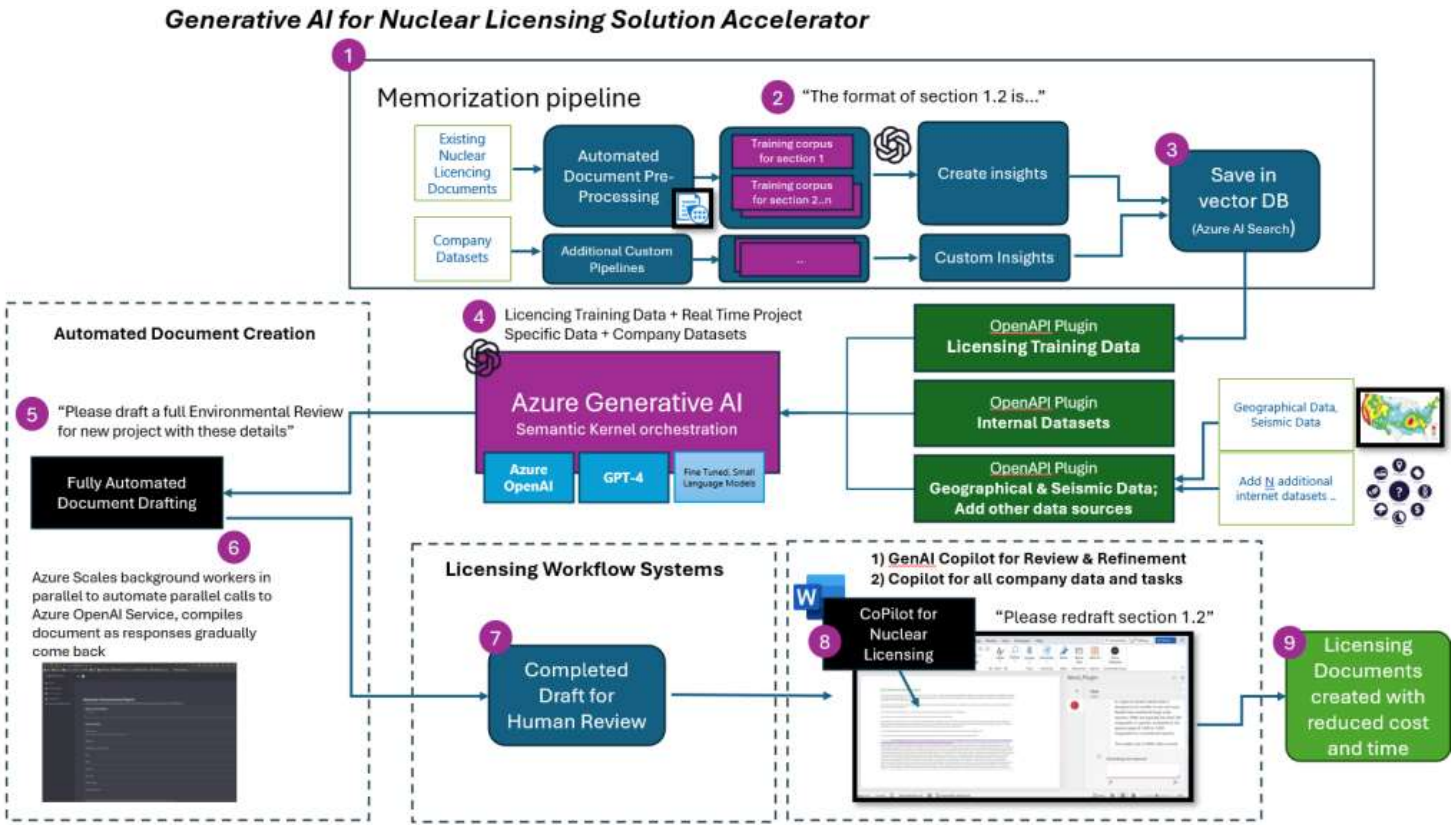


AI and Digital Licensing Tools

Technical and process innovation to accelerate regulatory licensing and permitting

Terra Praxis is working with tech-sector partners like Microsoft to build and deploy a suite of tools to automate the evaluation, design, and regulatory approval processes

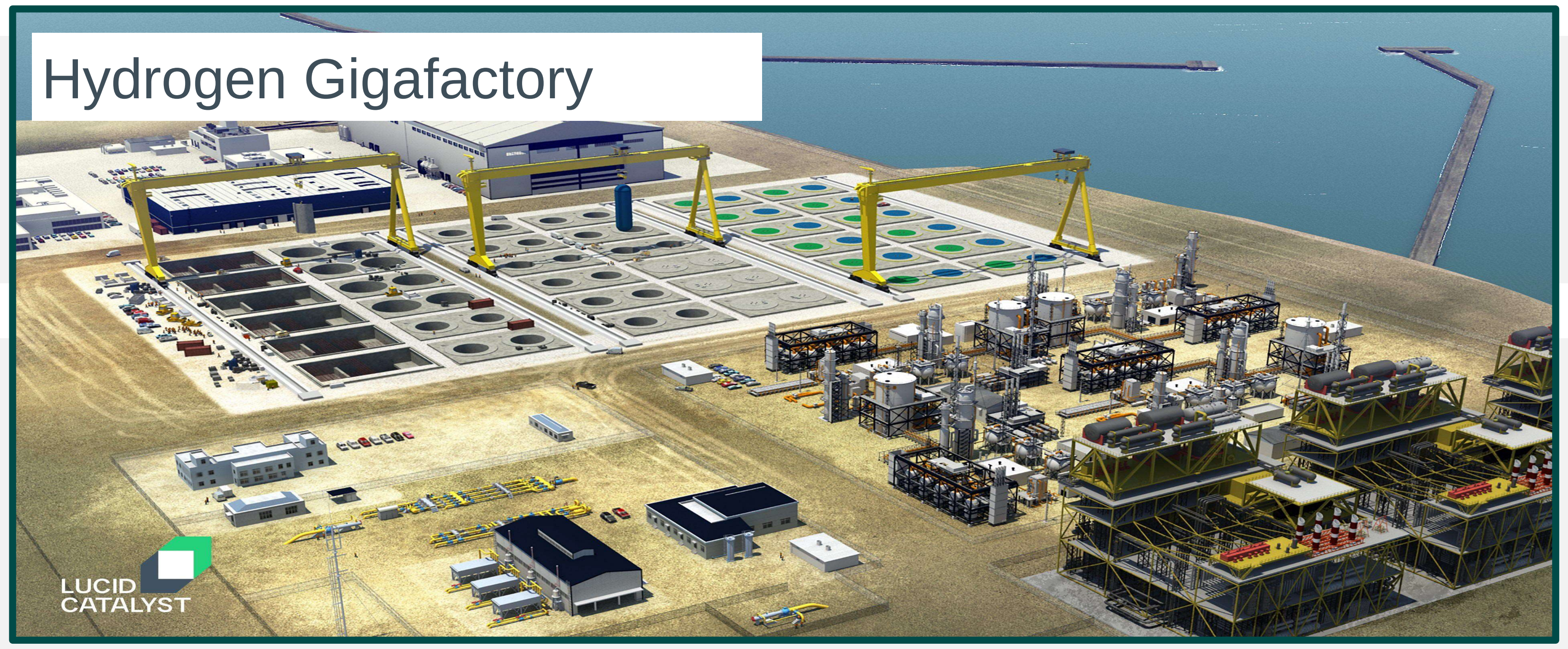
- First digital application to decarbonize coal plants at COP27
- Demonstrated a prototyped Generative AI Solution Accelerator for vendors to achieve this increased licensing efficiency.
- Open access EVALUATE application enables stakeholders to quickly evaluate the business case for repowering a coal plant or fleet.

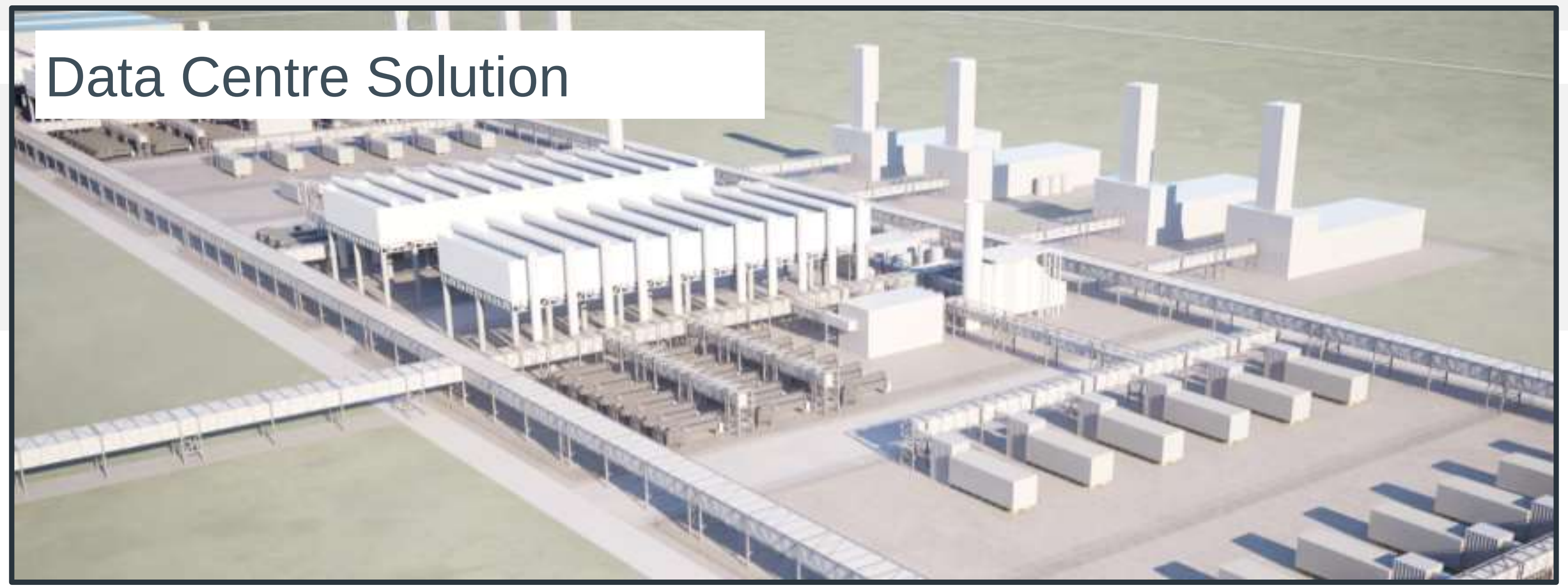


Applying to multiple applications

REMOVING CHALLENGES

- Schedule
- Uncompetitive, expensive, and shallow supply chains
- Expensive bespoke construction
- Long, expensive, and unpredictable licensing process
- Unpredictable and high costs





KEY OUTCOMES

- Schedule Compression
- Reduction in nuclear scope
- Reduction in nuclear construction
- Reduction in licensing complexity and duration
- Commercially-attractive economics

Repowering Coal Case Study

Terra Praxis Repower Vision

Repowering Coal Case Study

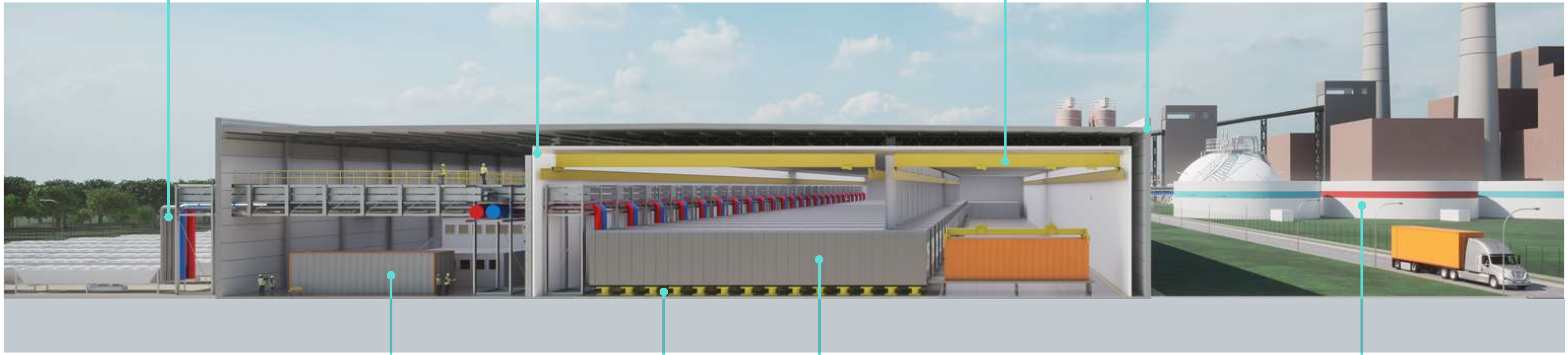
Terra Praxis Repower Vision

Modular distribution systems for heat and services.

Modular shielding and airtight panels protect operators and environment.

Remote crane and robots help construct and operate facility.

Modular building systems provide overall enclosure.



Modular plant and accommodation support and cool advanced heating system.

Seismic isolation system makes building design independent of local condition.

Modular advanced heat source enclosure protects and shields mass-manufactured containerized reactor (shown in orange) it isolates, reduces, and controls complexity.

Heat transfer storage system isolates heat island from existing coal plant.

Source: Repower (2024)

Shipyard-manufactured fuel production platform

Ammonia bunker offloading ammonia from a production platform

Source: LucidCatalyst 2020, The Missing Link to a Livable Planet

Key features[1]

Annual production capacity	0.2 MtH_2 / 1.2 $MtNH_3$
H_2 production costs	<2 USD/kgH_2
Process	High Temperature Electrolysis

- Capital costs reductions enabled by the high productivity levels of shipyard manufacturing
- Multiple products (e.g. power, fuels, and fresh water) can be supplied to large coastal cities without requiring major additional investments in terrestrial infrastructure projects
- Offshore siting eliminates land use challenges and siting issues associated with proximity to population centers
- Safety concerns can be alleviated as the reactors are surrounded by coolant (i.e., ocean water) or remove the loss of coolant accident scenario

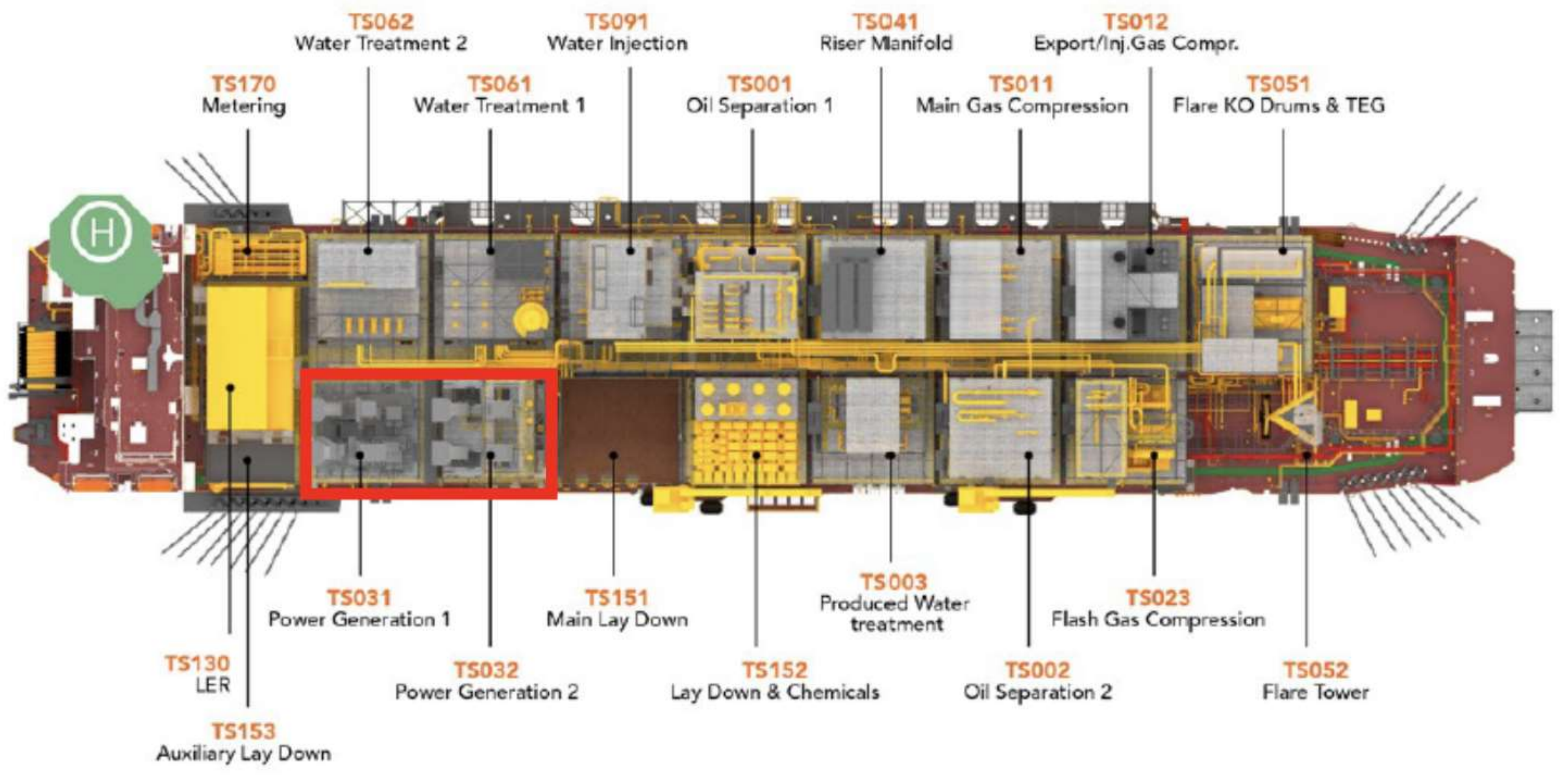
1. Data from EPRI (2021) Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors

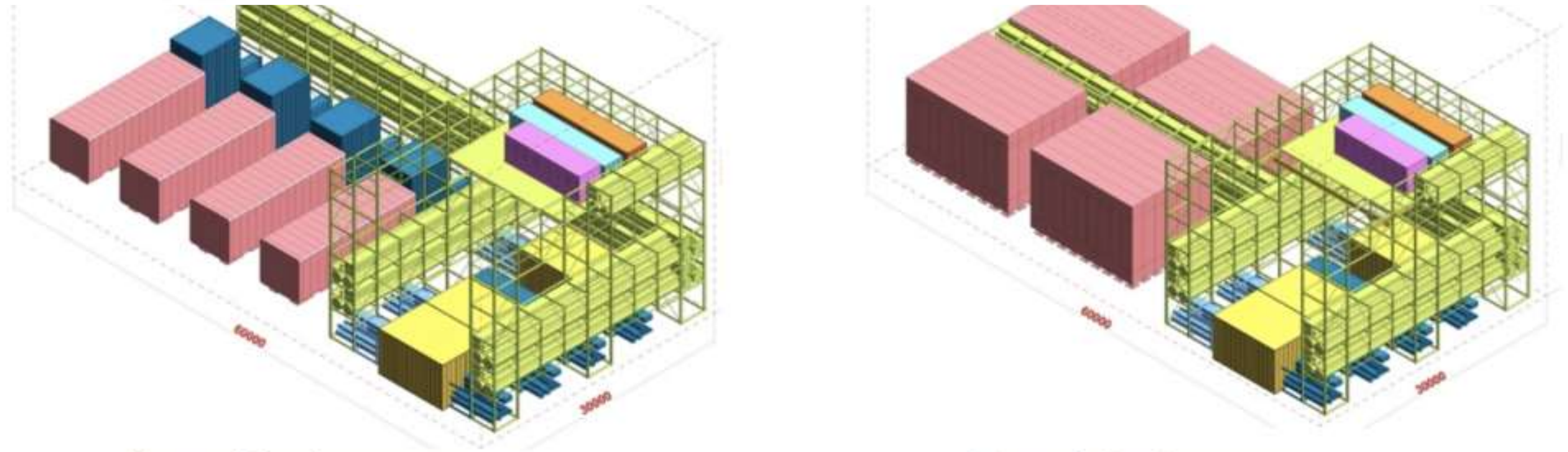
Floating Productions Storage and Offloading

Application of nuclear reactors to FPSO

Key Findings for adopting nuclear with Open Architecture system:

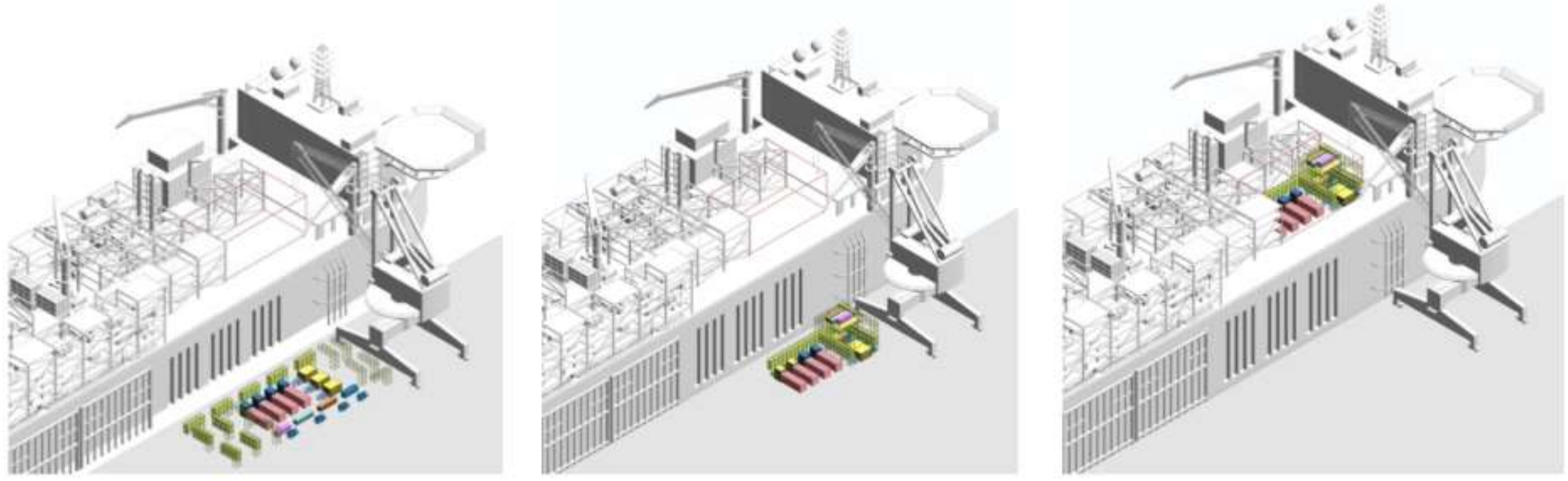
- Could provide cost-effective and reliable technology to minimize the carbon intensity
- Nuclear power modules are feasible and investment to accelerate deployment is justified
- Zero-emissions nuclear energy will secure future access to resources without compromising on cost and performance
- Open architecture enables a competitive nuclear supply chain with de-risked non-nuclear modules
- [Oil Major’s] highly disciplined project execution systems can deliver nuclear power modules by end of the decade
- Open architecture, standardization, and serialization have improved FPSO outcomes and can be applied to the new modules, minimizing/avoiding, impacts on FPSO design
- Expert review has concluded that a wide range of advanced reactor technologies are suitable for FPSOs and can comply with [Oil Major’s] HSE requirements





Type 1 Architecture

Type 2 Architecture



Ready for assembly

Assembled

Installed

10GWe REFINERY-SCALE HYDROGEN GIGAFACTORY

LUCID CATALYST

10GWe Refinery-scale hydrogen gigafactory

Hydrogen Gigafactory

Source: LucidCatalyst 2020, The Missing Link to a Livable Planet

Key features[1]

Annual production capacity	1.6 MtH_2 / 9.1 $MtNH_3$
H_2 production costs	<2 USD/kgH_2
Process	Thermochemical

- Simplified heat source designs and factory setting minimize installation labor costs and enable the application of fast, high-quality manufacturing techniques
- Streamlined licensing is enabled by reusable designs and repeatable processes in a standardized factory, managed by fixed teams, operating continuously
- Low-cost hydrogen can be fed directly into existing gas pipeline infrastructure or used for other applications, such as synthetic fuels production
- Hydrogen Gigafactories can be sited on former coastal refinery and industrial sites

1. Data from EPRI (2021) Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors

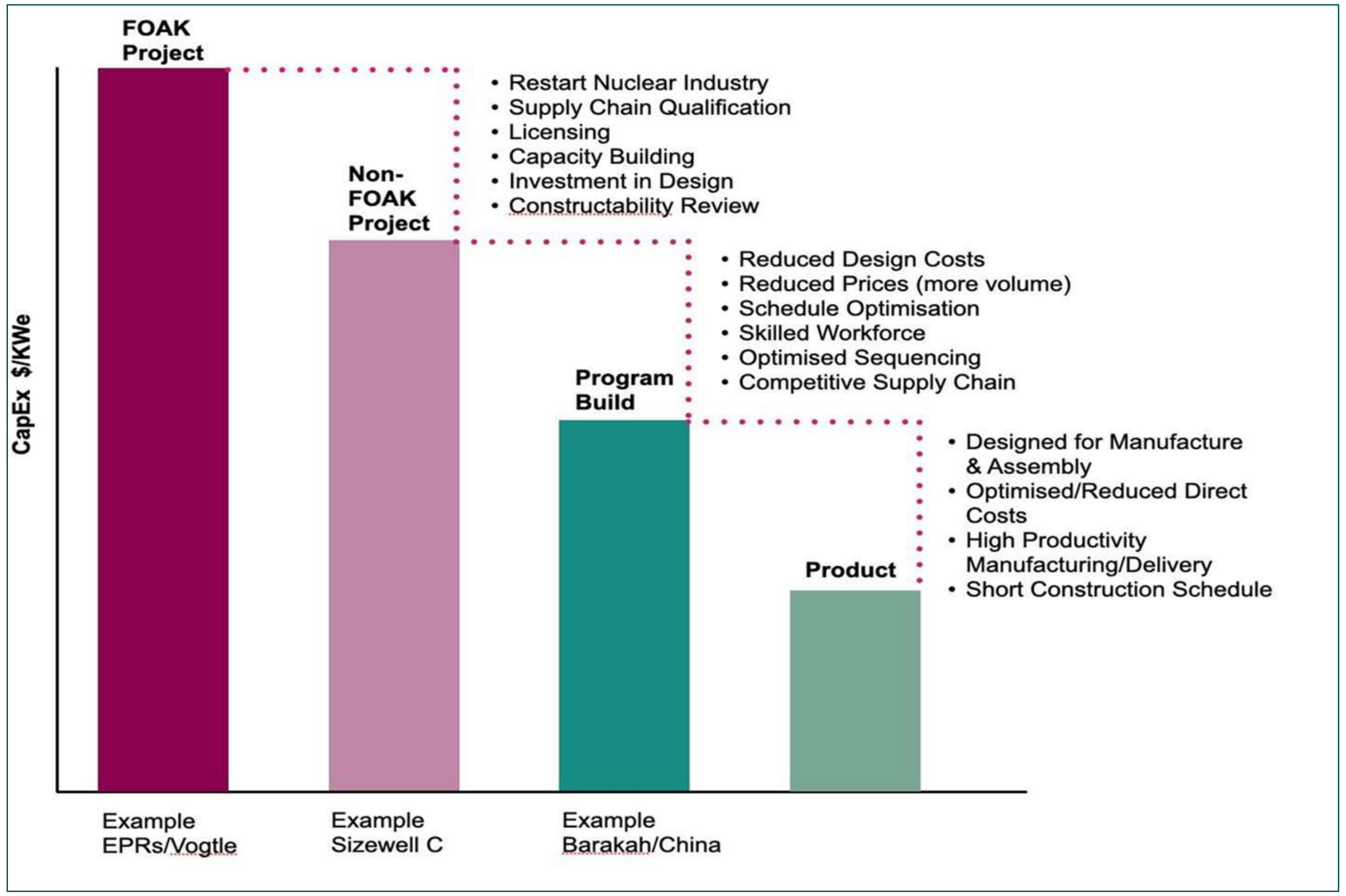
Large-scale production for global markets

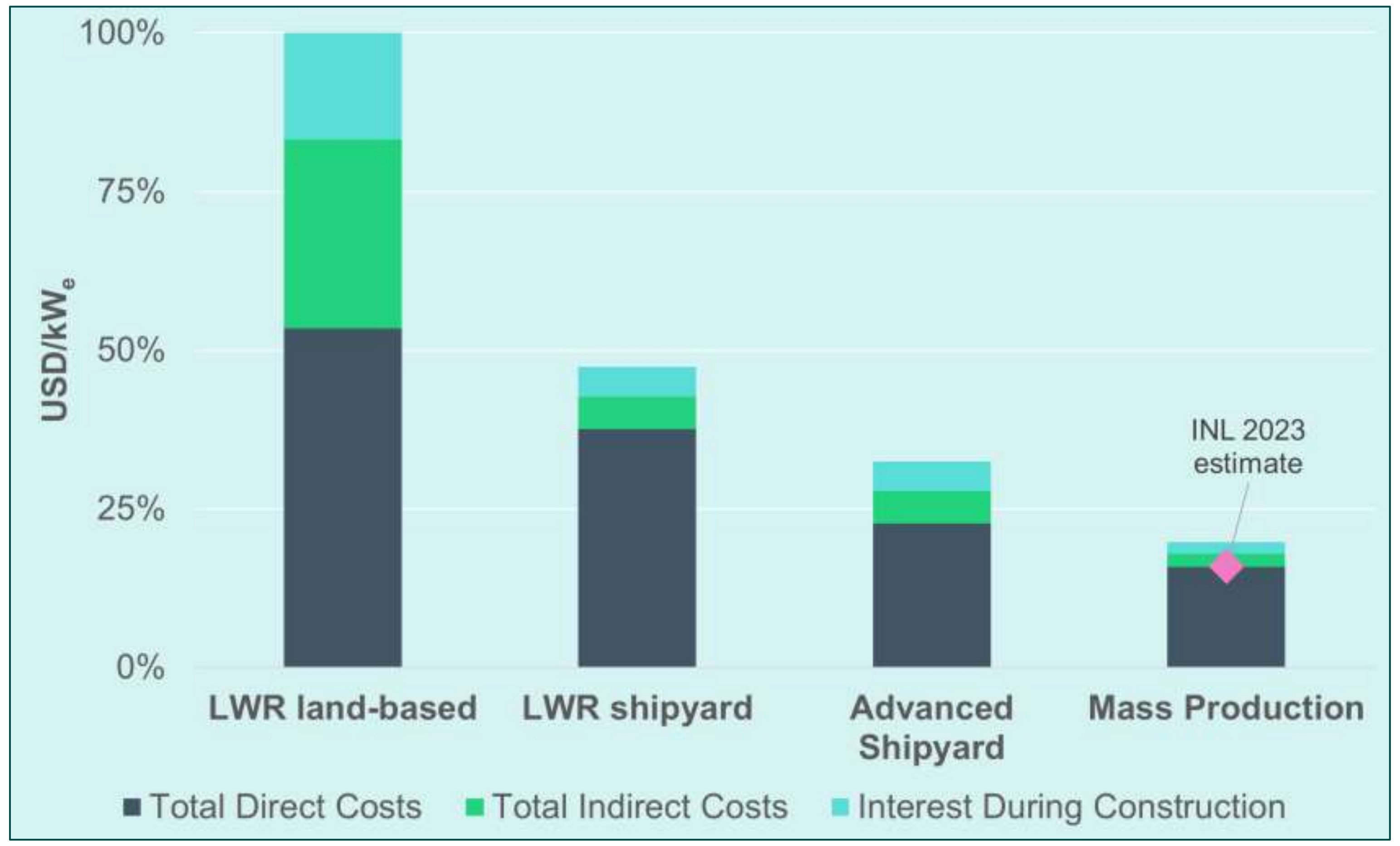
- 2 Mt of H_2 per year
- Cost <2 USD/kgH_2
- Land footprint <4km^2
- Access to existing infrastructure

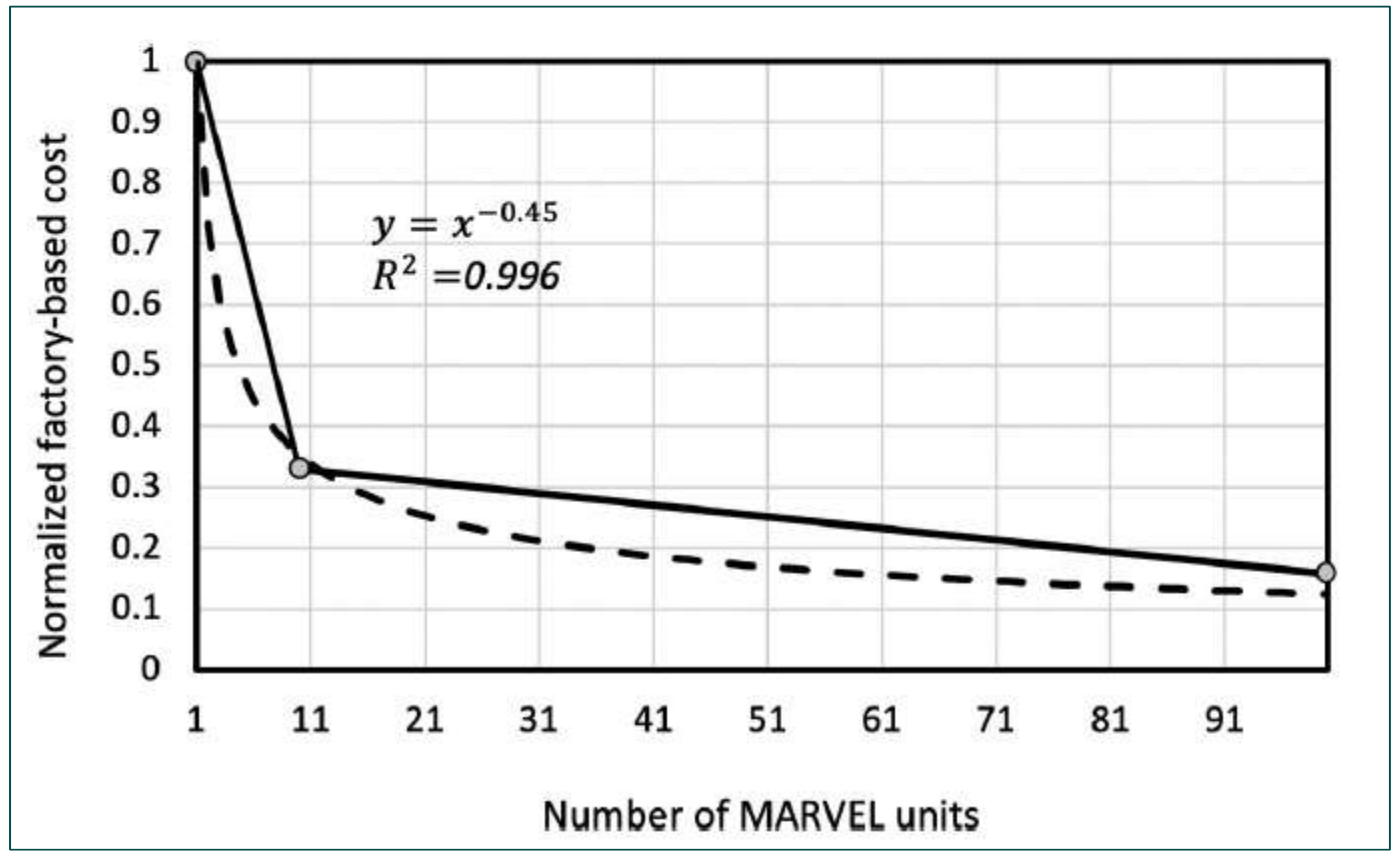
Underpinning analysis validates the strategy

Evolution of cost reduction from land-based LWR to mass production

- A significant share of the capital costs of land-based nuclear power plants is associated with the indirect costs of civil works engineering and oversight. The low productivity of civil works leads to longer deployment lead times, increasing interest during construction.
- Shipyard manufacturing is a highly productive environment where indirect costs associated with civil works are largely eliminated.
- Optimizing nuclear design for shipyard and mass manufacturing lines further reduces costs.
- 84% cost reduction from FOAK to NOAK
- New study looking at 1000+ mass production volumes







Source: LucidCatalyst (2020), The Missing Link to a Livable Planet, (2021) Beautiful Nuclear and INL(2023) Assessing the Impact of Mass Production on Microreactor Costs

Underpinning analysis validates the strategy

Low cost nuclear at 20% capacity factor is competitive with conventional fuel prices today

Analysis is driving questions from new nuclear end users:

- How to get low CapEx cost of \$2,000/kW instead of \$6,000/kW?
- No one is really making a reactor for ships, how do I get one?
- What are the implications of bigger, faster ships? How big, how fast?
- What do I have to do to get a boat in the water?
- How do I get it sooner so I can capture more competitive advantage?

Answer = Open architecture + shipyard or mass manufactured reactors

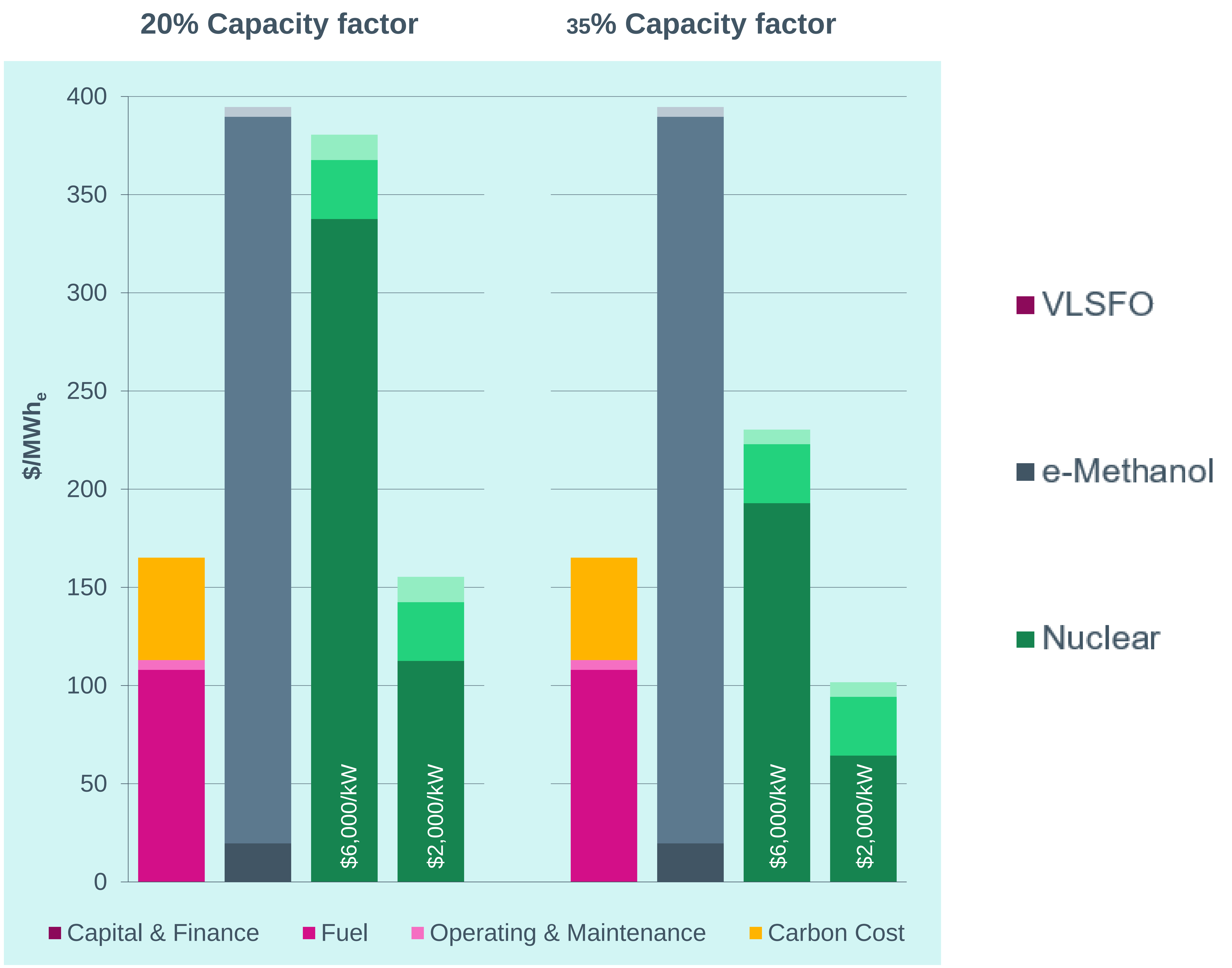


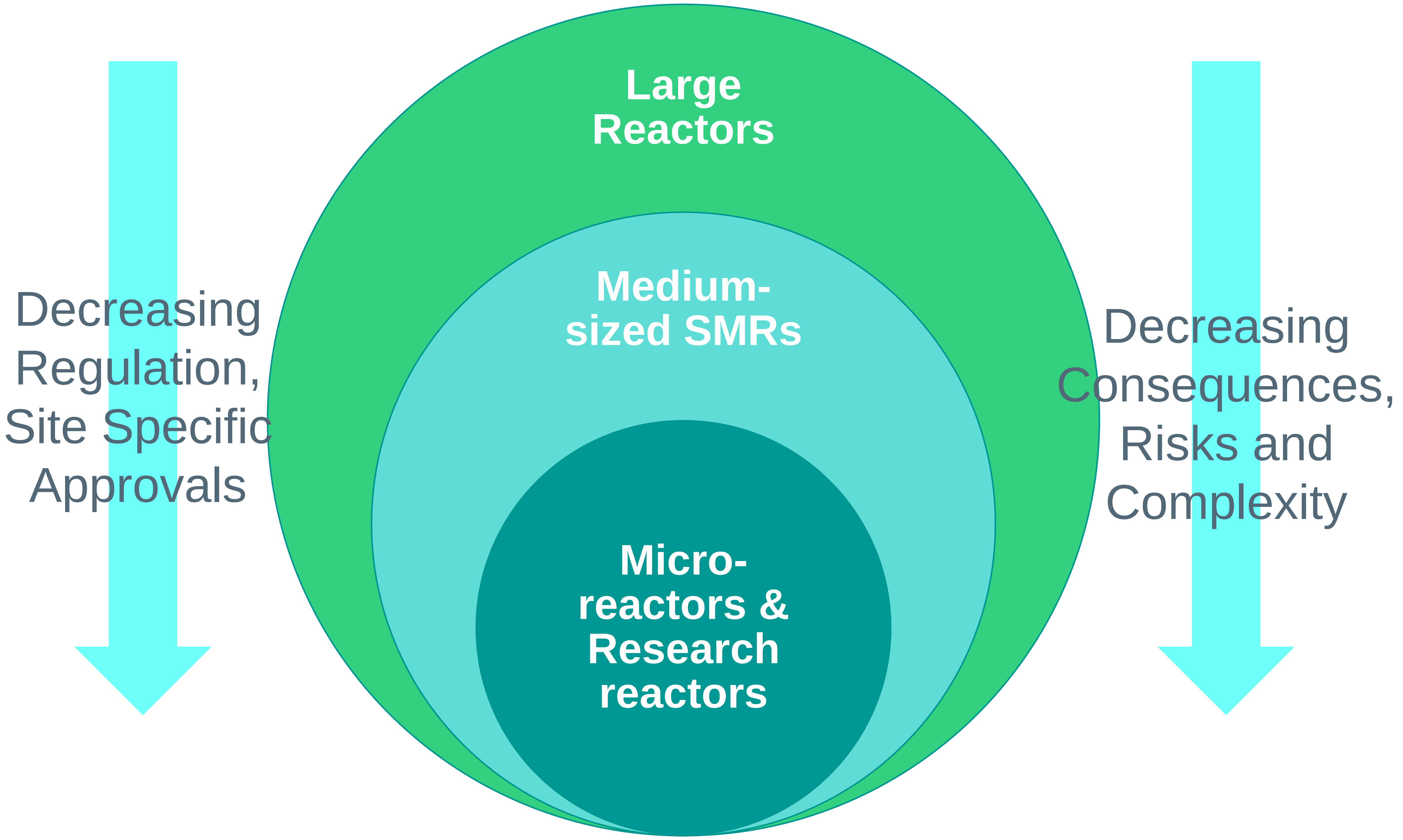
Figure: Indicative unit cost comparison of nuclear vs. alternate technology choices under various load factors

A new mission for regulatory drivers is being developed

Commercially-viable and proportionate licensing pathway

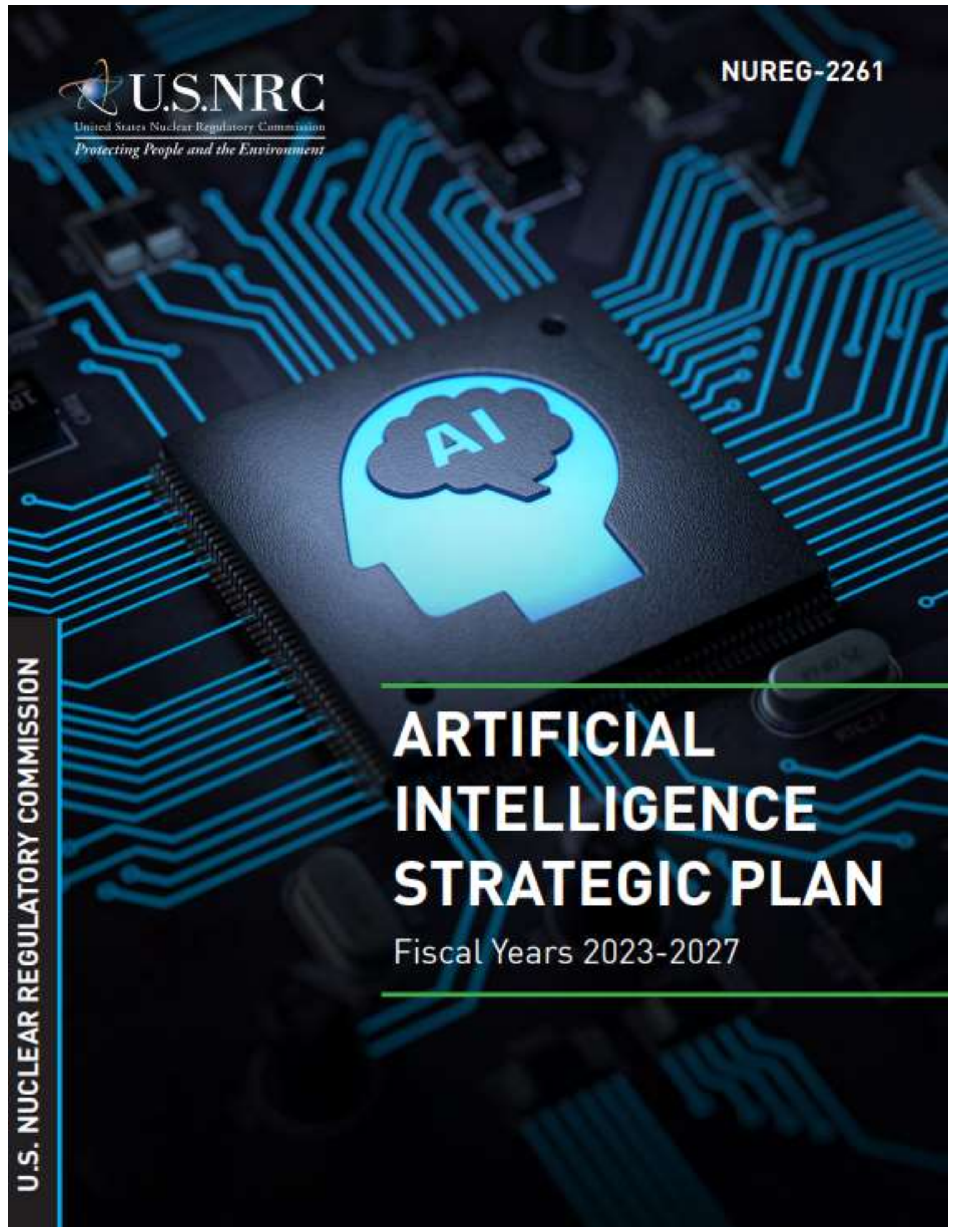
- Current mismatch between the decarbonization timelines of industrial end-users willing to adopt nuclear power and the regulatory timeframe
- Regulators are addressing the emergence of business models where reactors could be licensed in less than one year after the site has been identified and at a lower licensing costs.
- Micro-reactors are, in terms of size and source term, can be very similar to non-power research reactors and could follow a tailored, streamlined licensing process aligned with the reduced risks (proportionate regulation).
- Processes should be flexible and leverage consequence-based, risk-informed approaches already in place in some regulatory regimes.

Figure 8: Relative comparison of potential consequences for selected nuclear technologies



Source: Adapted from LucidCatalyst and NEI (2024)

Ecosystem is changing faster than you think



NRC adoption of **AI for licence** assessment


THE WALL STREET JOURNAL.

EXCLUSIVE

Microsoft Targets Nuclear to Power AI Operations

The tech company aims to expedite the nuclear regulatory process using AI

"**AI could cut by as much as 90%** the amount of human hours spent getting a new nuclear-power plant approved.“

Eric Ingersoll to WSJ

Manufactured reactors taskforce

The Advance Act

- Directs the NRC to develop guidance to license and regulate microreactor designs within **18 months**
- **Eliminates costs** associated with pre-application activities and early site permits

Rapid progress on Maritime Regulation

- Marine, oil and gas, and off-shore energy users are actively pursuing maritime nuclear applications
- The regulatory framework is rapidly evolving, with international initiatives like ATLAS being established to accelerate adoption
- New developments could quickly alter market dynamics
- First movers gain supply chain advantage
- Design and supply chain strategies can enable faster realisation of the benefits

Kick-off meeting of the Technology Licensed for Applications at Sea (ATLAS) Initiative led by the International Atomic Energy Agency (August 2024)

Underpinning analysis validates the strategy

Transformed economics and risk

"This work highlights how innovative technology configurations…for hydrogen and synthetic fuels production facilities can transform global prospects for an achievable clean energy transition within a reasonable timeframe."

Global clients, partners and leading energy users

(Top) DG Grossi, IAEA, Vienna, 2020

(Below) Brad Smith, President of Microsoft, Microsoft-Terra Praxis strategic collaboration agreement signing, Seattle, 2022

Microsoft
IAEA
Department of State United States of America
Department of Energy United States of America
ExxonMobil
Shell
NOV
Manchester 1824 The University of Manchester
Vattenfall
iea International Energy Agency
NEA Nuclear Energy Agency
OXY
HM Government
arpa-e Advanced Research Projects Agency • ENERGY
World Economic Forum
EPRI
NREL National Renewable Energy Laboratory
MIT Massachusetts Institute of Technology
Chesapeake Energy
ConocoPhillips
urenco The Energy to Succeed
Allseas
EDF Energy
National Nuclear Laboratory
Catapult Energy Systems
Mitsubishi Heavy Industries
Fortum
Bryden Wood
nirab
CMA CGM
TerraPower
tvo
INL Idaho National Laboratory
CATF
energy technologies institute
LR
مؤسسة الإمارات للطاقة النووية
Emirates Nuclear Energy Corporation
NEI Nuclear Energy Institute
ClearPath
GE
Hitachi
Tenaga Nasional
Terra Praxis
uniper

Terra Praxis' global REPOWER consortium

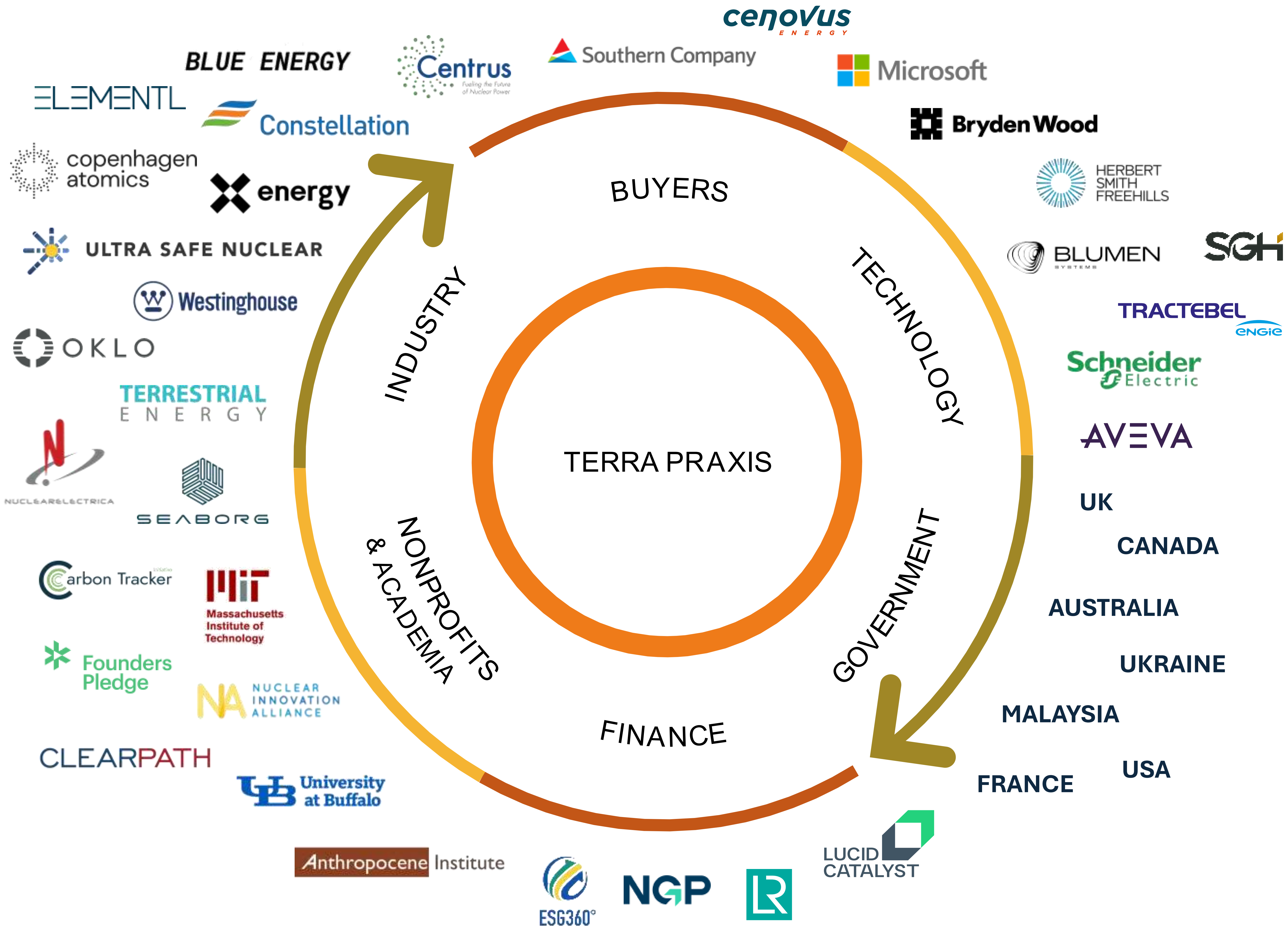
TERRA PRAXIS

Coalition of market demand and market pull

U.S. Special Presidential Envoy for Climate John Kerry at COP27.
(Photo: Embassy of Ukraine in the United States of America)

Project Phoenix

Out of the Ashes - Conversion of Coal to Clean SMR Energy Supply



LucidCatalyst delivers strategic thought leadership to enable rapid decarbonization and prosperity for all.

LUCID CATALYST