THE NEW NUCLEAR WATCH INSTITUTE

The synergy of the hydrogen economy and nuclear energy

17 December 14:00 – 15:30 GMT

Chaired by

Tim Yeo, Chairman, The New Nuclear Watch Institute

Speakers

Charles Hart	Senior Researcher, The New Nuclear Watch Institute
Elina Teplinsky	Advisor, Global Nuclear, Clean Air Task Force Partner, Pillsbury Winthrop Shaw Pittman LLP
Dr Tariq Dawood	Lead Engineer Asset Management, Nuclear & Renewables, EDF R&D UK Centre
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Kirsty Gogan	Co-founder, TerraPraxis

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THE NEW NUCLEAR WATCH INSTITUTE

The Synergy of the Hydrogen Economy and Nuclear Energy

Charles Hart
Senior Researcher, The New Nuclear Watch Institute

How can Nuclear-Produced Hydrogen Stimulate the Near-Term Development of a European Hydrogen Economy and what Policy Environment will Facilitate its Contribution?

Why Hydrogen?

Decarbonisation Potential for Integrated Energy Systems:

1. Industry:
   a) Existing Use: Oil Refineries, Ammonia Production, Methanol Production, Steel Production
   b) Future Use: High-Temperature Heat
2. Transport: HGVs, Rail, Aviation, Shipping
3. Heating: Blending, Hydrogen Conversion (Unit, Region, Grid), Fuel Cell Cogeneration
4. Power Generation: Storage and Flexibility, Co-Fired Ammonia

Obstacles to the Development of a Clean Hydrogen Economy:

1. Current Production is Carbon-Intensive
2. Production of Clean Hydrogen is Small-Scale and Expensive
3. Hydrogen Infrastructure is Limited

The European Hydrogen Strategy

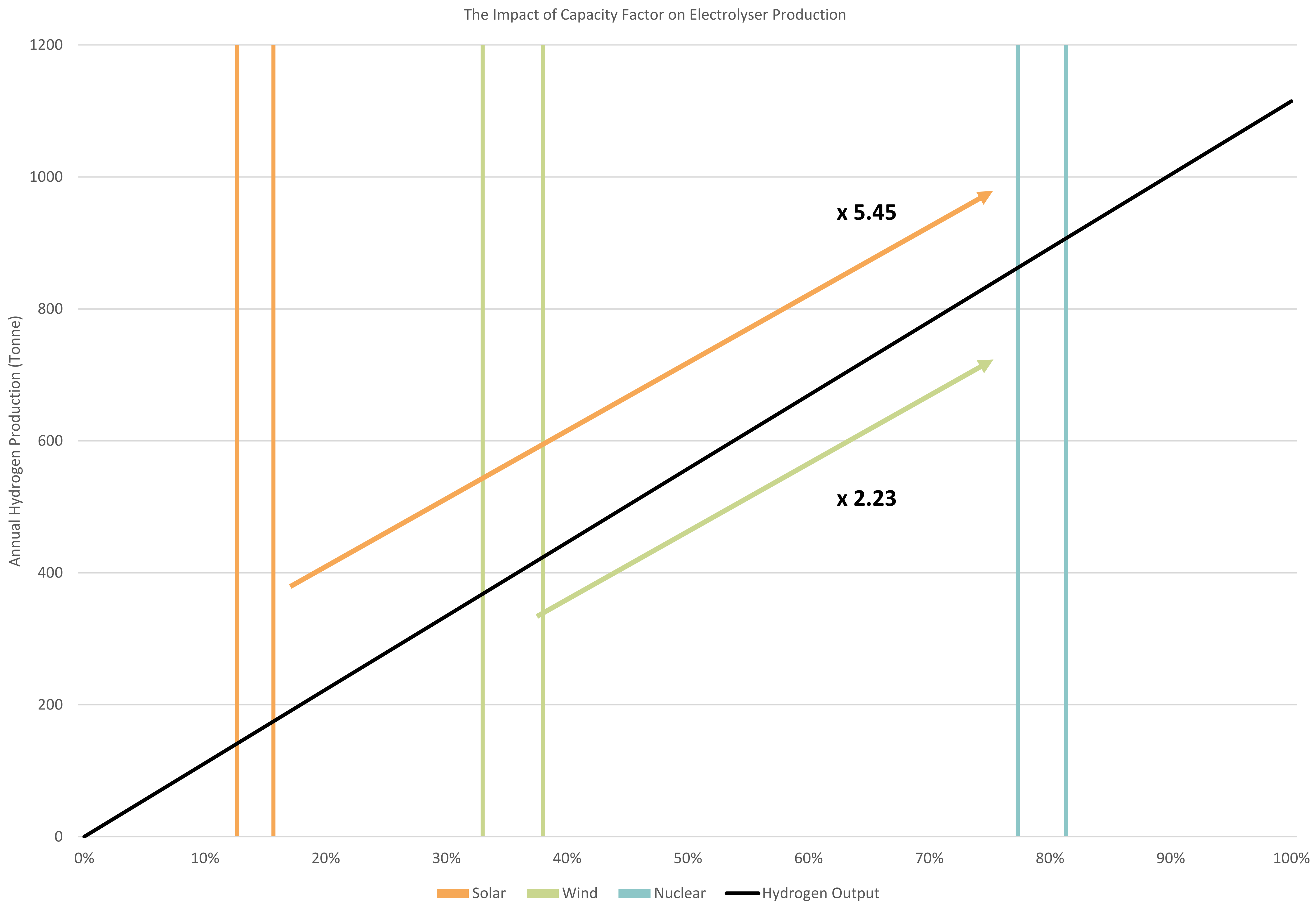
1. **Definitions:**
   - ‘Renewable Hydrogen’ refers to hydrogen produced via the electrolysis of water using electricity produced using renewable energy sources;
   - ‘Low-Carbon Hydrogen’ refers to hydrogen produced either using fossil fuels equipped with CCUS or electricity-based hydrogen (regardless of electricity source).
2. **Targets:**
   - ‘The Priority for the EU is to Develop Renewable Hydrogen’ (p.5)

Phase	Renewable Electrolyser Capacity (GW)	Production of Renewable Hydrogen (Tonnes)
One: 2020-2024	6	1,000,000
Two: 2025-2029	40	10,000,000
Three: 2030-2050	500	Large-Scale Deployment

3. **Mechanisms:**
   - Low-Carbon Standard, GOs, Sustainability Certificates, CCfDs

Using Nuclear Power to Produce Hydrogen via Electrolysis (I)

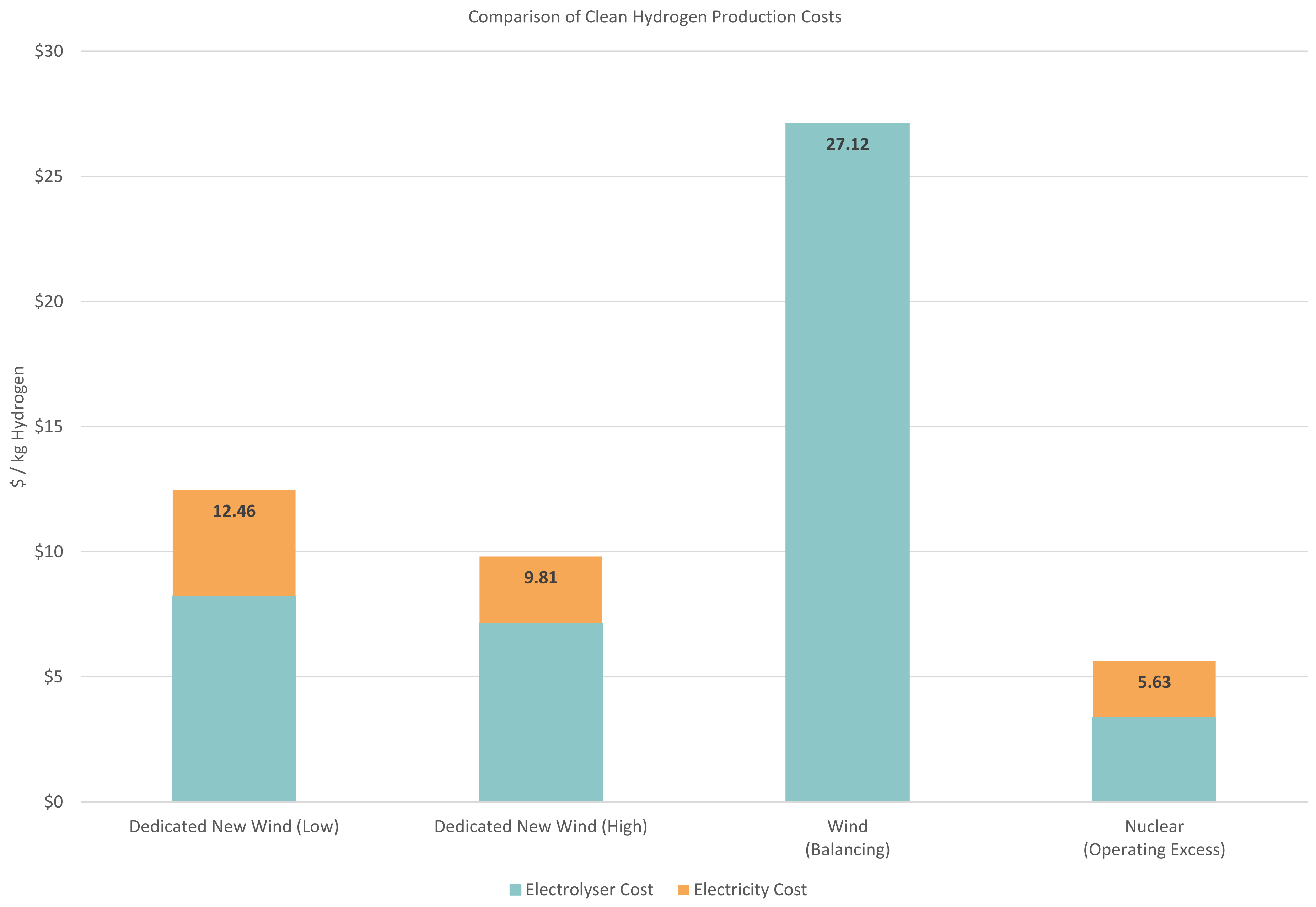
- **Volume**



- **Implications for Surface Area Requirements**

Using Nuclear Power to Produce Hydrogen via Electrolysis (II)

- **Cost**



Capacity Factor (%)	33	38	10	80
Power Cost ($/MWh)	54	34	0	28.50

Realising the Advantages of Nuclear-Produce Hydrogen in the Near-Term

Using Excess Nuclear Capacity to Produce Hydrogen:

- the global decline in nuclear power generation during 2019-2020 indicates that up to c.3-3.5 GW of nuclear capacity in the European Union is currently idle;
- this capacity, if fully used, could produce up to 280,000 tonnes of clean hydrogen, in turn eliminating up to 2.8 million tonnes of carbon dioxide compared to present production;
- the volume and relative competitiveness of the nuclear-produced hydrogen (compared to 'renewable hydrogen') would provide a greater stimulus to the adoption of clean hydrogen by end-users as well as the required investment in hydrogen infrastructure.

What is Required?

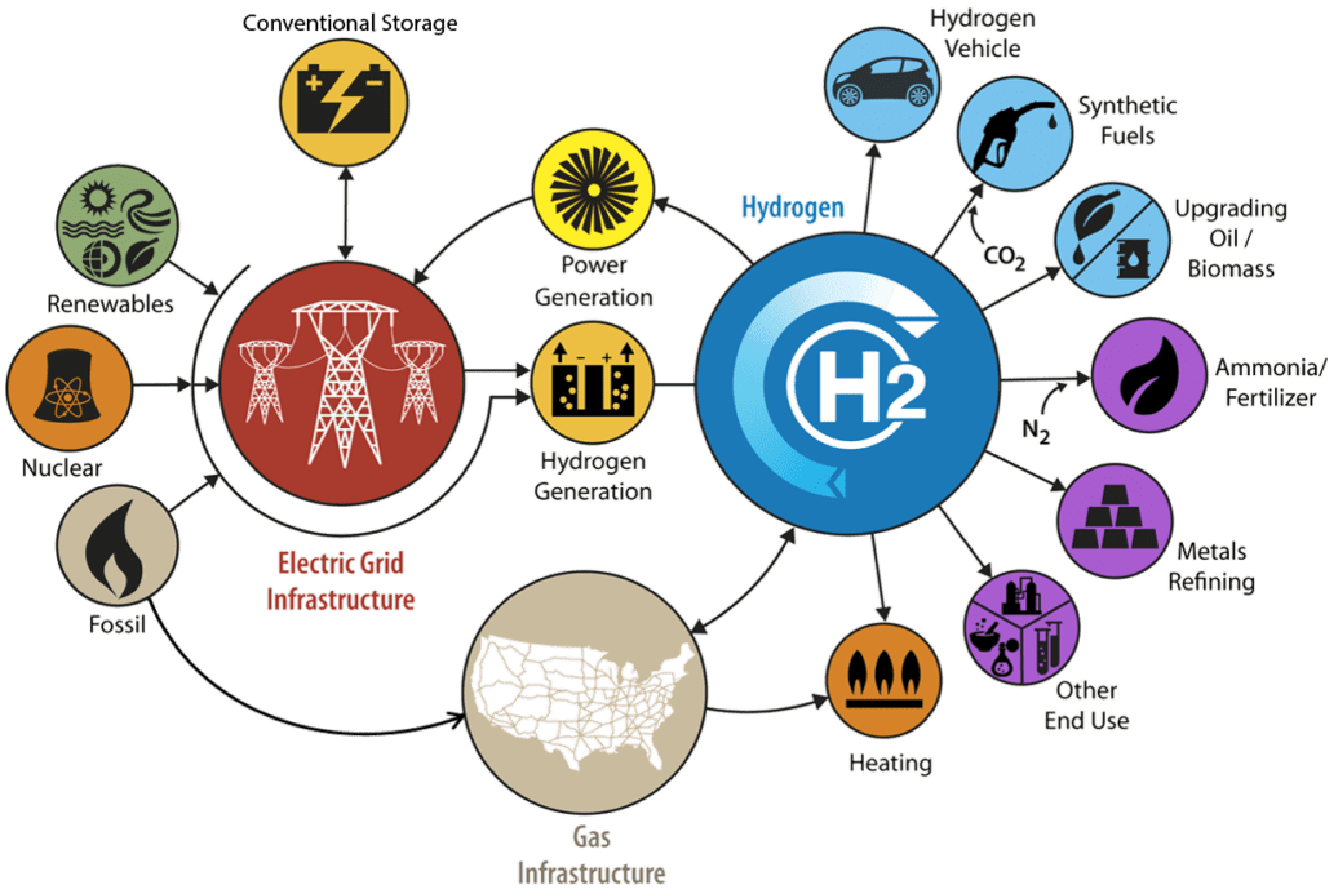
- a technologically neutral policy framework for the hydrogen economy that facilitates investment in production capacity by providing a long-term, sustained commitment to all low-emission hydrogen production methods.

Nuclear Zero Carbon Fuels Production: Partnership Opportunities

Elina Teplinsky
Partner, Pillsbury Winthrop Shaw Pittman LLP
Advisor, Global Nuclear, CATF

DECEMBER 17, 2020

Hydrogen can play a critical role in the low-carbon technology portfolio - eliminating carbon from electricity, transport, industry and buildings



Some key obstacles to hydrogen market growth

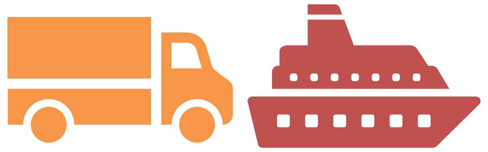
$

Production is currently expensive

€1.5/kg for current (grey, high-carbon) production

€2/kg for blue fossil-derived hydrogen with CCS

€2.5–€5.5/kg for renewable hydrogen



Transportation can be difficult

Gaseous H2 compressed and delivered by trucks
have limited range and are larger and heavier than gasoline trucks and thus more expensive.
Materials + components needed for compact, lightweight, H2 storage systems while enabling > 300 miles in all light-duty vehicle platforms.

Gaseous H2 delivered by pipeline
high initial capital costs of new pipeline construction
option: adapt part of the natural gas delivery infrastructure to accommodate hydrogen

Shipping of H2
has to be liquefied by chilling to temperatures below −253°C, using up 1/3 of its energy content
option: convert to ammonia, liquefies at −10°C and more infrastructure handling and transporting ammonia in place

Zero carbon hydrogen markets can achieve scaling by:

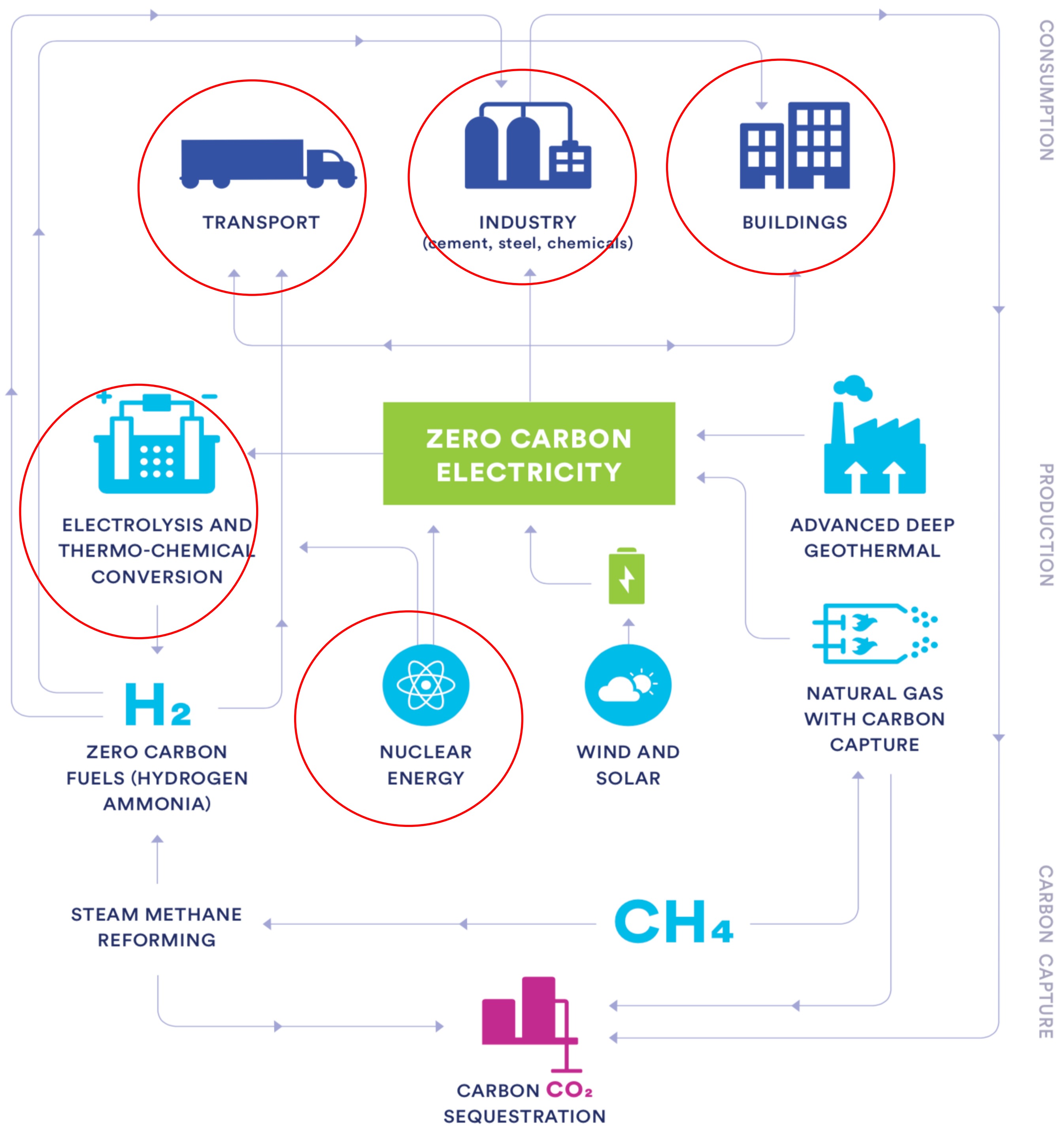
- **Reducing production costs**
- **Investing into RD&D and infrastructure**

Hydrogen Council:

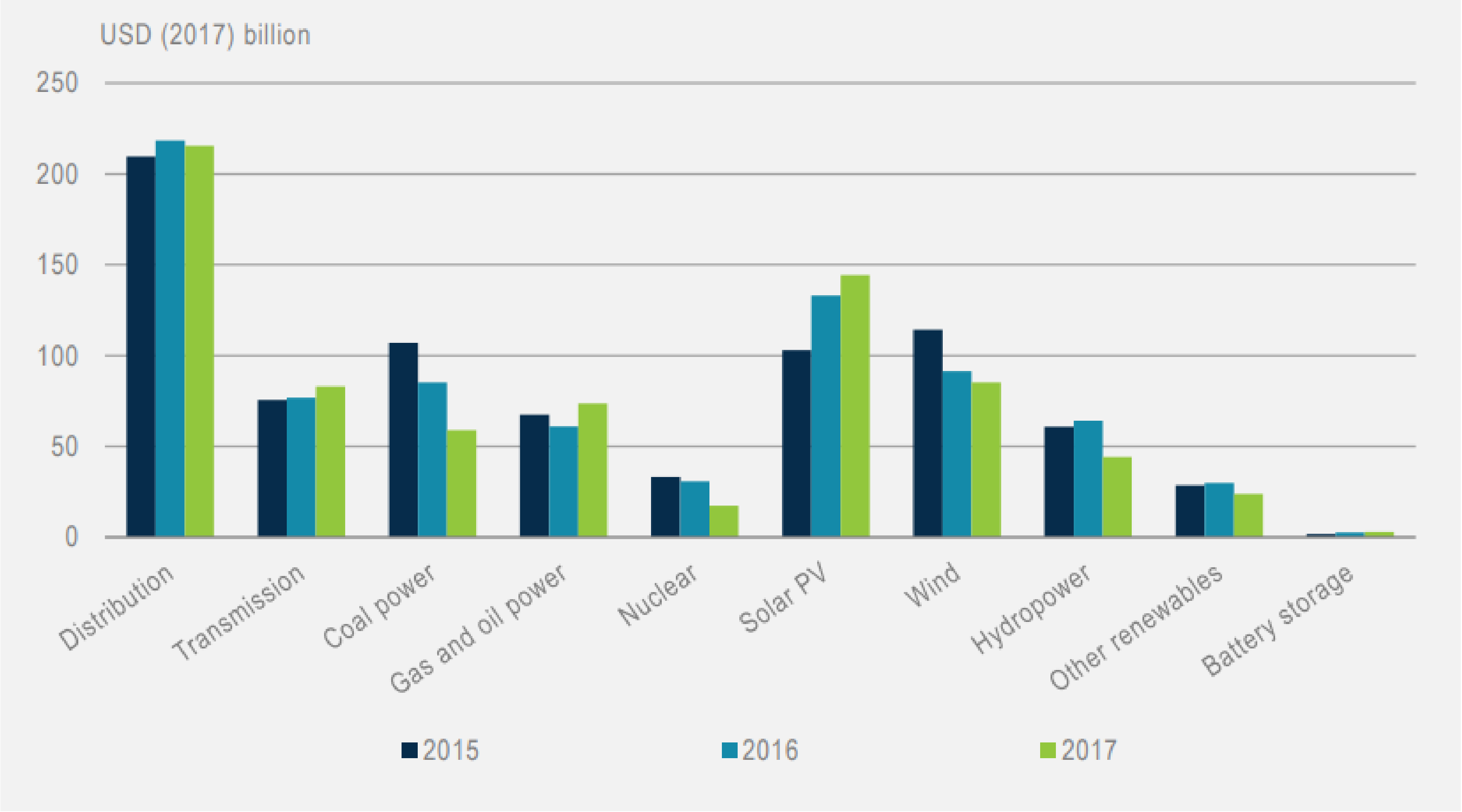
Scaling up the hydrogen economy will take investments of $20-$25B each year through 2030.

Nuclear energy can address non-electric energy and carbon via efficient and low cost zero carbon fuel production

A Zero Carbon Energy System



But nuclear has stagnated, with nuclear investment a small fraction of total energy investment



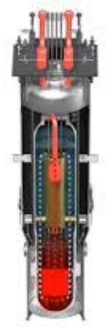
Some of the Challenges to Meaningful Nuclear Deployment

Markets

- Global power market limited for nuclear
  - Competition from natural gas & renewables
  - Emerging markets can represent high barrier to entry
- Procurement challenges
  - Most customers for nuclear power are state-owned
  - Requires significant government support
  - Burdensome government procurement process
  - Political risk

Cost & Financing

- Historically:
  - High capital cost and liquidity required
  - Long construction period: 5-6 years at best
  - Significant construction risk – in the West, cost overruns + schedule delays
  - Longer tenor for debt repayment
  - High weighted average cost of capital (WACC), further magnified by construction risk
- Few sources of equity and debt (governments and balance sheets of large utilities, some vendor financing)
- No nuclear project financing to date; limited financing model/precedent

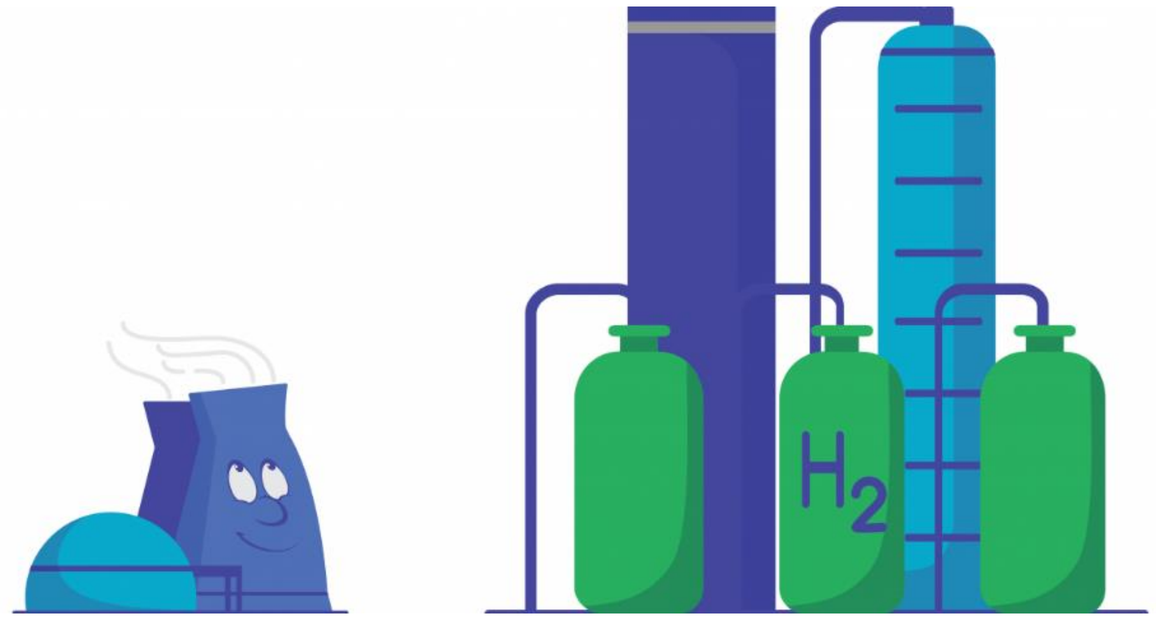


FOAK New Tech

- SMRs can address construction risks and some financing challenges
  - Lower capital costs
  - Shorter lead times
  - Lower completion risk
  - Lower interest rate exposure and WACC
- **However, technology needs to be demonstrated**
  - Significant investment in higher-risk FOAKs is required
  - Licensing timelines / costs
  - Supply chain expansion / qualification

Nuclear + Hydrogen

- The nuclear industry, hydrogen producers and the hydrogen supply chain should collaborate to advance common goals and a broader decarbonization initiative
  - **Collaboration goals:**
    - Policy support for hydrogen production through nuclear
    - Government funding for commercial demonstration of nuclear H2 production (e.g., through HTE and TC)
    - Joint development
    - Offtake contracts
    - Co-financing
    - Supply chain cross-pollination



Policy Development: Examples

- **United States:** Integrated Energy Systems Act of 2019
  - directs the U.S. Department of Energy (DOE) to establish an integrated energy systems program to, in part expand the use of emissions-reducing energy technologies (including nuclear) into nonelectric sectors
  - *However:* appropriations for demonstrations and other incentives (e.g., tax) are required to be meaningful
- **United Kingdom:** UK Energy White Paper
  - aiming for 5GW of low-carbon hydrogen production capacity by 2030 and supportive of both new large nuclear and SMRs
  - *However:* no clear recognition of the opportunity for nuclear zero carbon fuels production

Significant work in the policy area is required!

Co-Financing Example: H2 Mankala

- **Industrial consumers of nuclear power – underexplored source of equity**
  - Prime example: Finland. Also used in Belgium and France, but for operating reactors.
- Consumer funders **need not be limited to power**. Hydrogen users can be funders.

How would an H2 Mankala work?

- Hydrogen users invest into the NPP in exchange for hydrogen offtake
- Limited liability company is run like a zero-profit-making co-operative for the benefit of its shareholders
- Shareholders absorb price and volume risk

Hydrogen Market Players

Customers and Others

3M
AIRBUS
Air Liquide
AIR PRODUCTS
ALSTOM
AngloAmerican
aramco
BMW GROUP
BOSCH Invented for life
bp
国家能源集团 CHN ENERGY
CNH INDUSTRIAL
Cummins
DAIMLER
eDF
ENGIE
equinor
faurecia
GM
Great Wall
HONDA
HYUNDAI
Iwatani
JM Johnson Matthey Inspiring science, enhancing life
JXTG Nippon Oil & Energy
Kawasaki
KOGAS
Linde
MICHELIN
PLASTIC OMNIUM
SCHAEFFLER
SIEMENS Ingenuity for life
SINOPEC
thyssenkrupp
TOTAL
TOYOTA

Electrolyzer Producers

McPhy Driving clean energy forward
AGC Your Dreams, Our Challenge
PROTON® ON SITE
ALCHEMR™
DOW®
sunfire
Nouryon

As a follow-up from our Dec 2-3 webinar, CATF is forming working nuclear H2 groups in four areas. Interested in joining? Please contact us.

- ☐ **Policy**

  Note: this group may set up sub-groups focused on regional, country-specific and local policies. Topics such as carbon policies as well as government incentives for nuclear hydrogen and ammonia production to be discussed.

- ☐ **R&D, Technology and Regulation**

  Issues identified during the event: regulation of co-location; potential cost-reduction through provision of grid services (e.g. capacity, ancillary services) while producing hydrogen at >90% capacity.

- ☐ **Commercial Partnerships**

  Goal: facilitating discussion between producers, supply chain and potential customers.

- ☐ **Project Structuring and Financing**

  Goals: identifying project structures for bankable nuclear H2 projects; facilitating discussions with financial community.

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Hydrogen from Nuclear
The EDF Experience

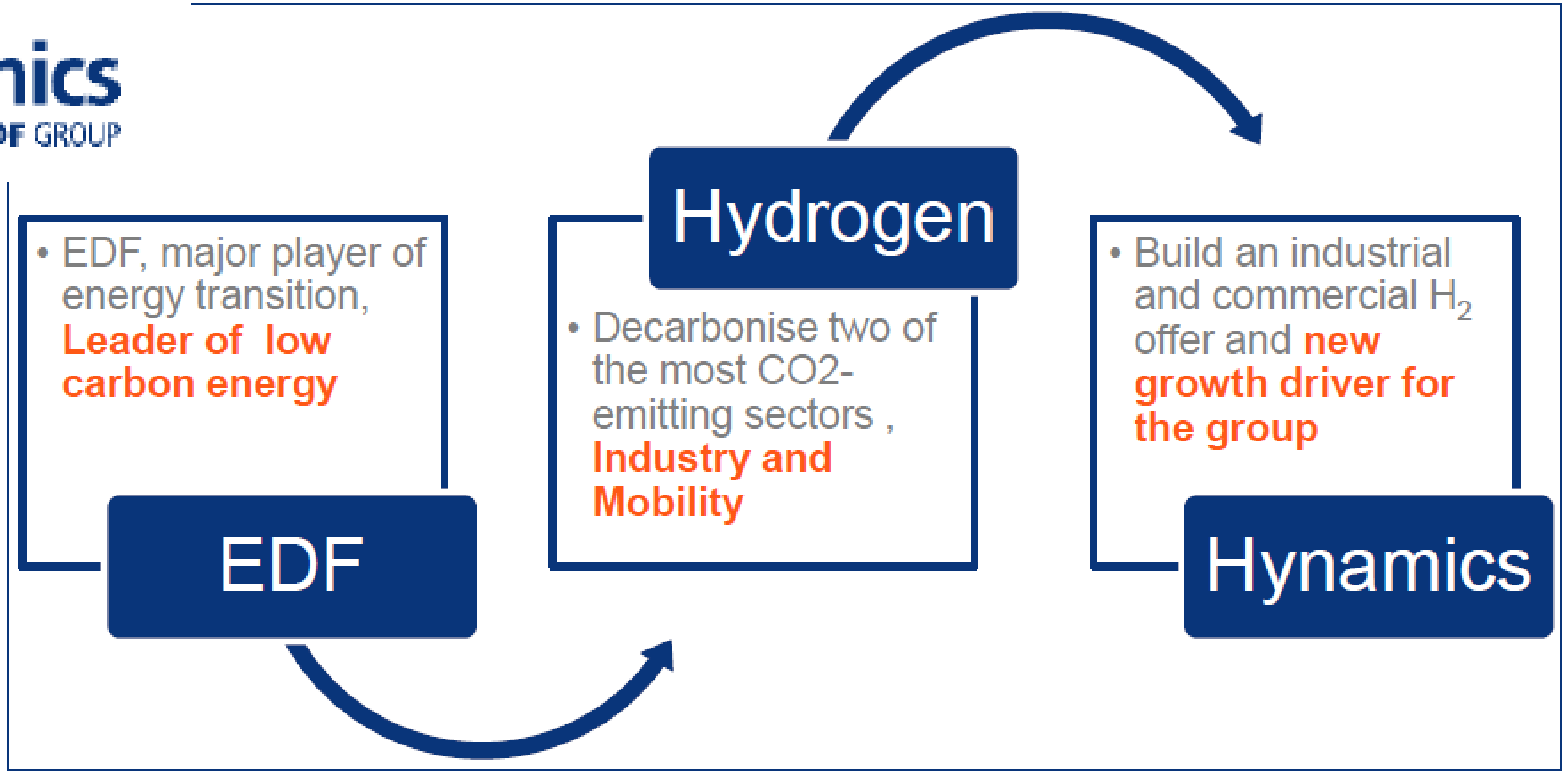
Dr Tariq Dawood
Lead Engineer Asset Management – Nuclear & Renewables

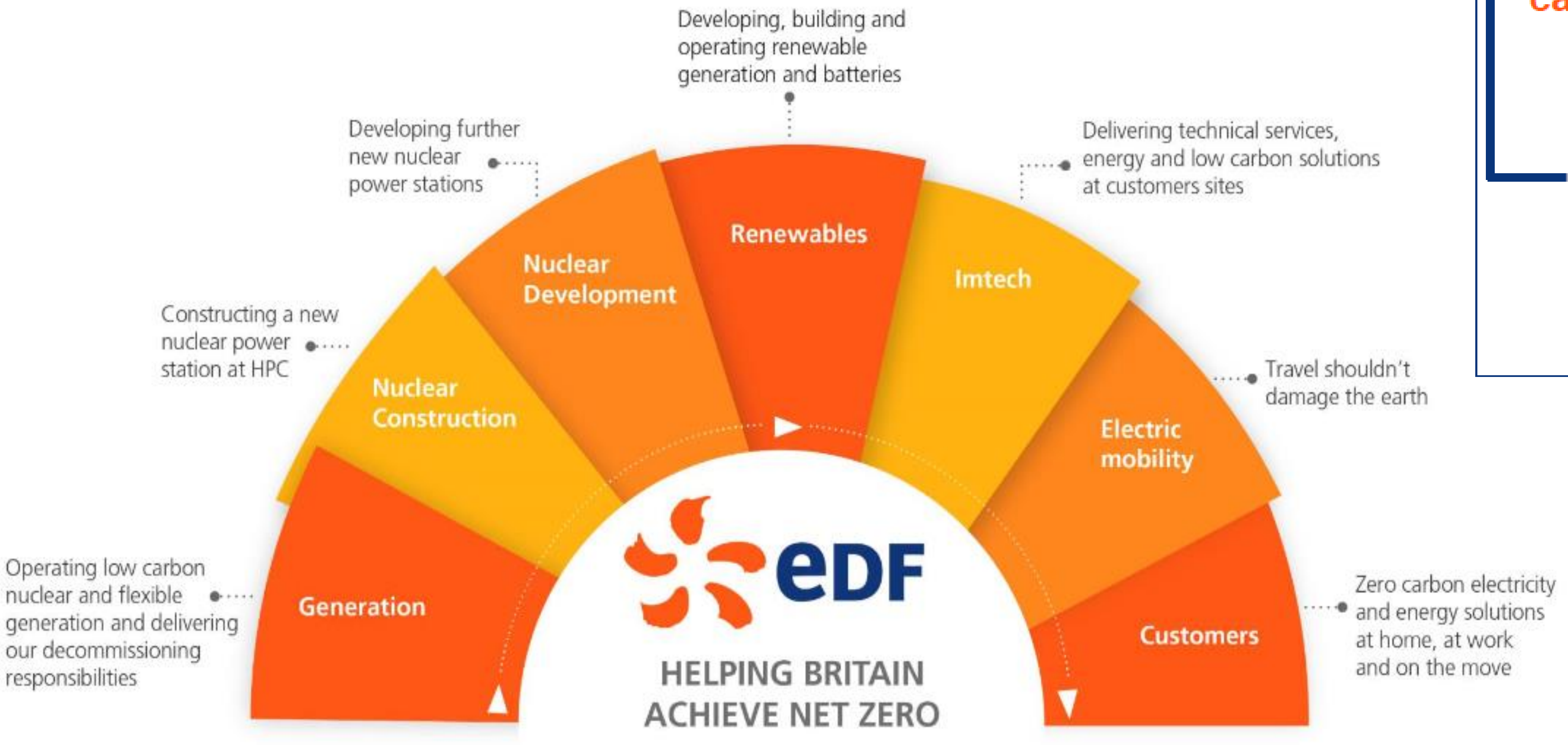
EDF R&D UK Centre

EDF Group & EDF UK

Our *raison d'être* is to build a net zero energy future

hynamics
EDF GROUP





McPhy
Driving clean energy forward

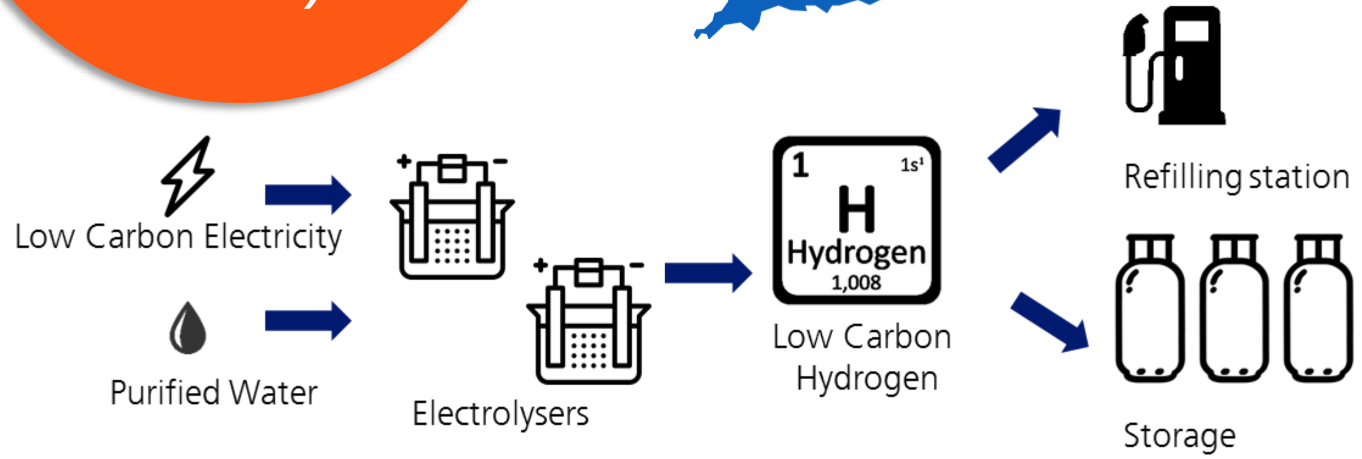
eifer
European Institute for Energy Research by EDF and KIT

Hydrogen to Heysham (H2H)

Main Drivers

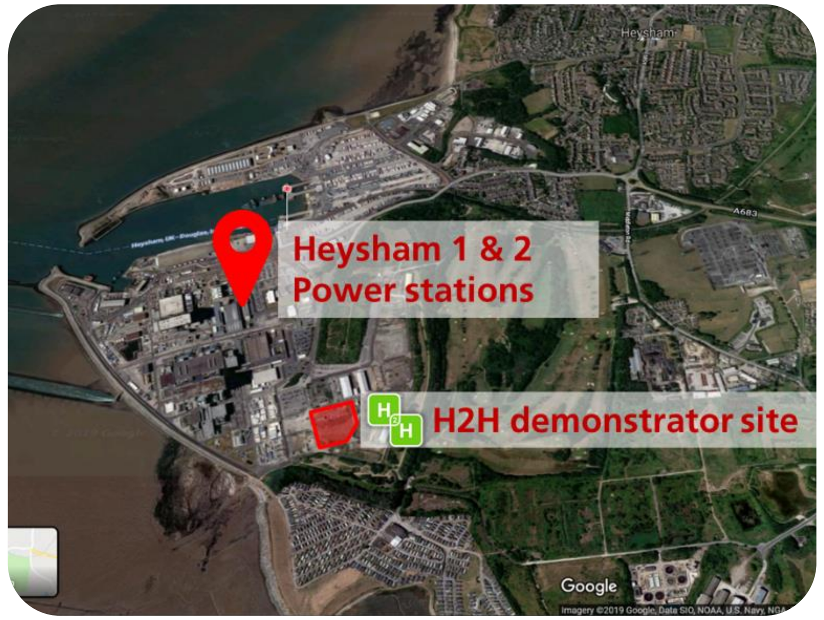
- *Hydrogen is emerging as a vital energy vector in the UK energy system*
- *Nuclear & Renewables is best placed to supply the low-carbon electricity for hydrogen production*
- *Hydrogen is already used at nuclear sites and can supply the local demand*

Max. Daily Production
800 kg H2
(350 bar HRS)



Project Goal: Feasibility assessment on the viability of low carbon hydrogen production by electrolysis using nuclear generated electricity at the Heysham nuclear power station

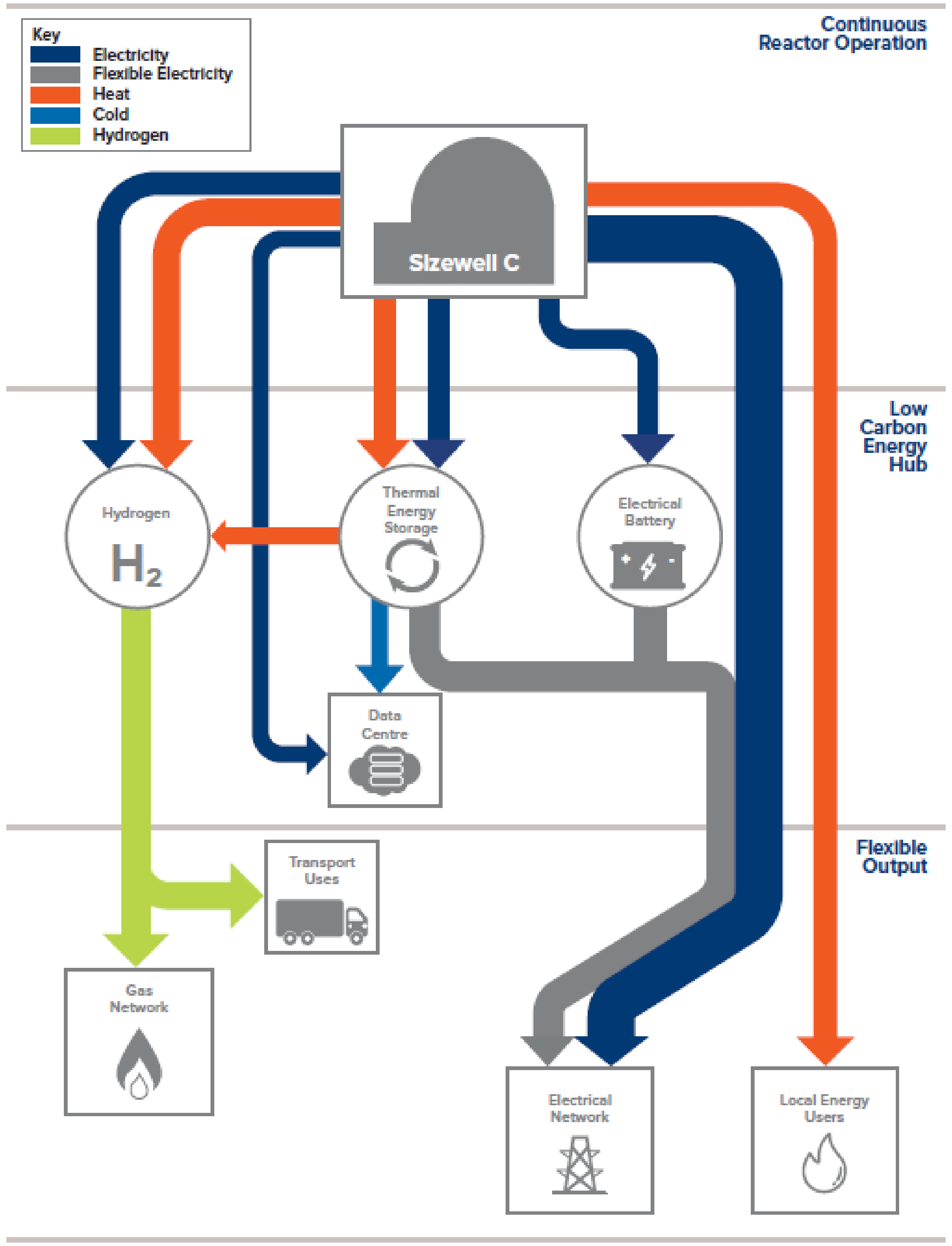
- Site outside licensed area
- Safety and Security
- Accessibility for end users
- Services: water and electricity



Department for Business, Energy & Industrial Strategy

Hydrogen at Sizewell C

Sizewell C Energy Hub



Sizewell C
Doing the power of good for Britain

EOI issued to test hydrogen production from nuclear with a view to producing 800kg of H2 per day

Ambition is to scale up hydrogen production leveraging high temperature steam electrolysis by making use of waste heat from the steam turbine

Hy4Fleets

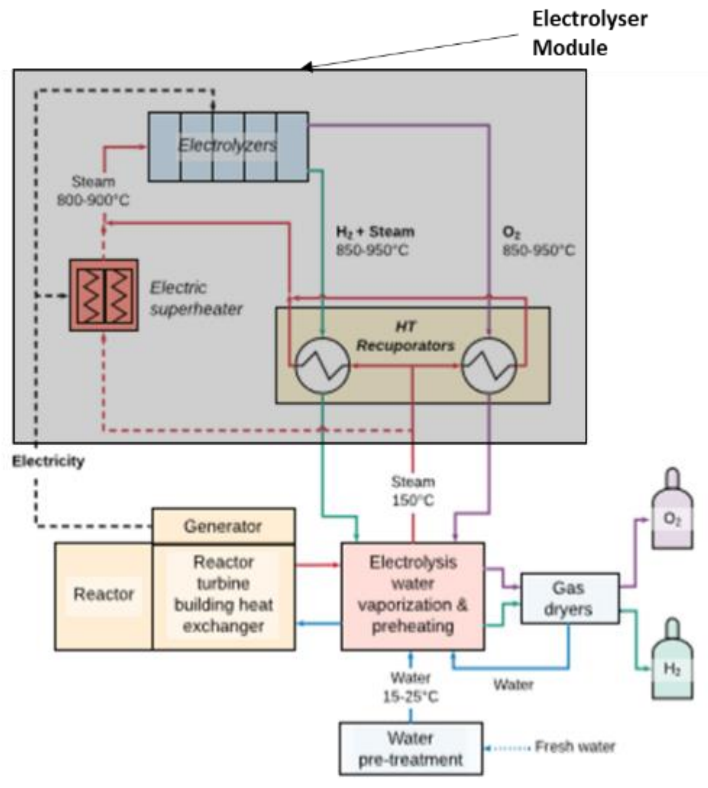
UKRI Innovate UK

What’s Next?

Support ambition of 5GW of low-carbon hydrogen production capacity by 2030

Investing in a pipeline of large nuclear including Hinkley Point C & Sizewell C

Also exploring opportunities to develop Small Modular Reactors (SMR) and Advanced Modular Reactors (AMR)



sunfire

High temperature steam electrolysis offers the most efficient approach for producing Hydrogen from nuclear using process waste heat as an alternative to direct electrolysis but requires investment to scale up


Thank You

ROSATOM

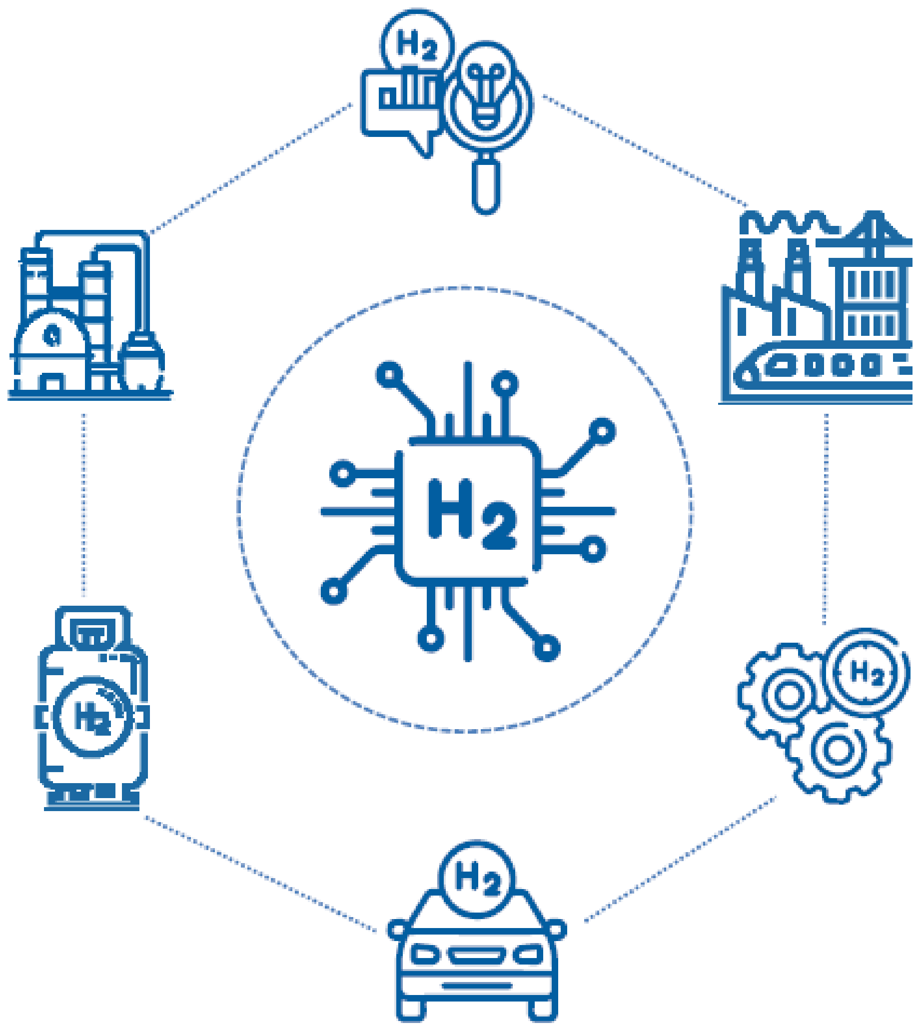
ROSATOM APPROACH TO HYDROGEN ENERGY PROJECTS DEVELOPMENT

Anton Moskvin

Vice President, Marketing and business development
Rusatom Overseas

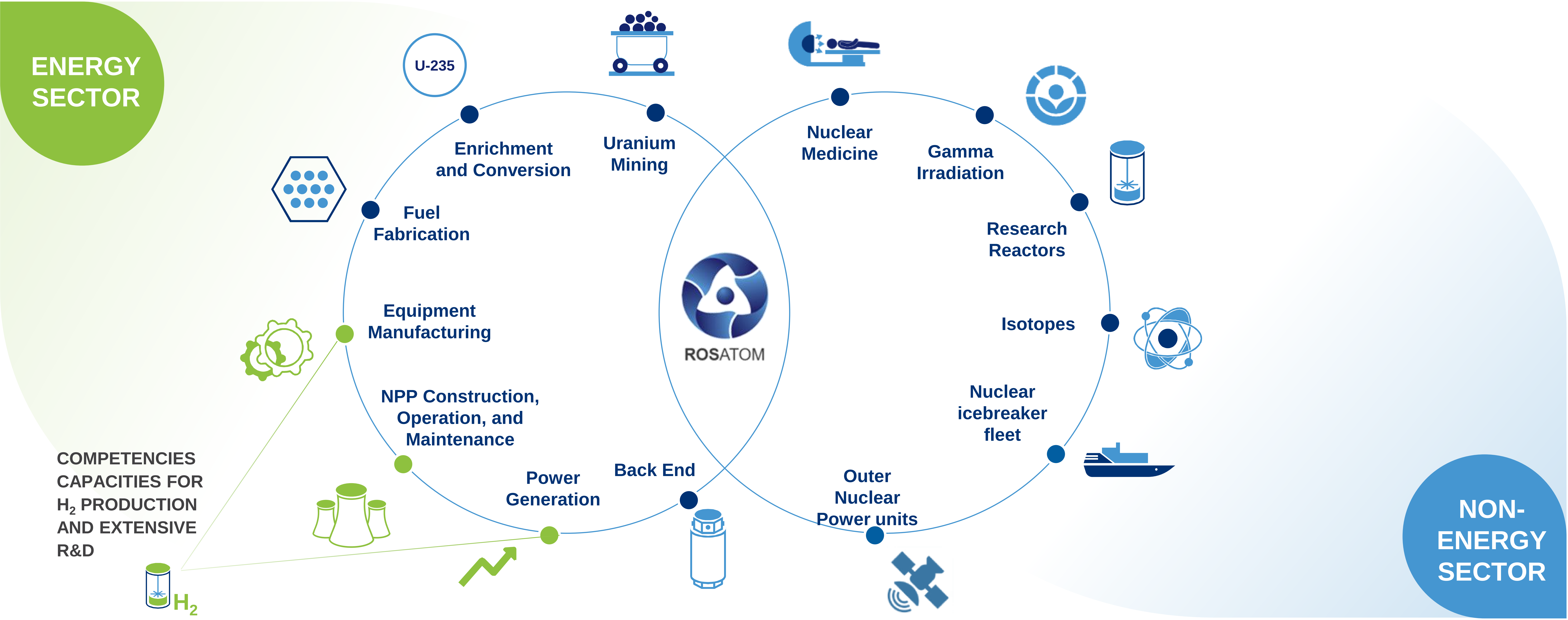
Hydrogen energy development roadmap in Russia

The Russian Government approved the "Plan of hydrogen energy development in the Russian until 2024“ that provides the measures of State support for the projects of hydrogen production, storage, transportation and use



The Plan includes the implementation of the Program for hydrogen production at nuclear power plants developed by the State Atomic Energy Corporation “Rosatom”.
This Program includes large-scale environmentally friendly hydrogen production technologies development on the basis of high temperature gas-cooled reactors and on the basis of large scale NPPs.

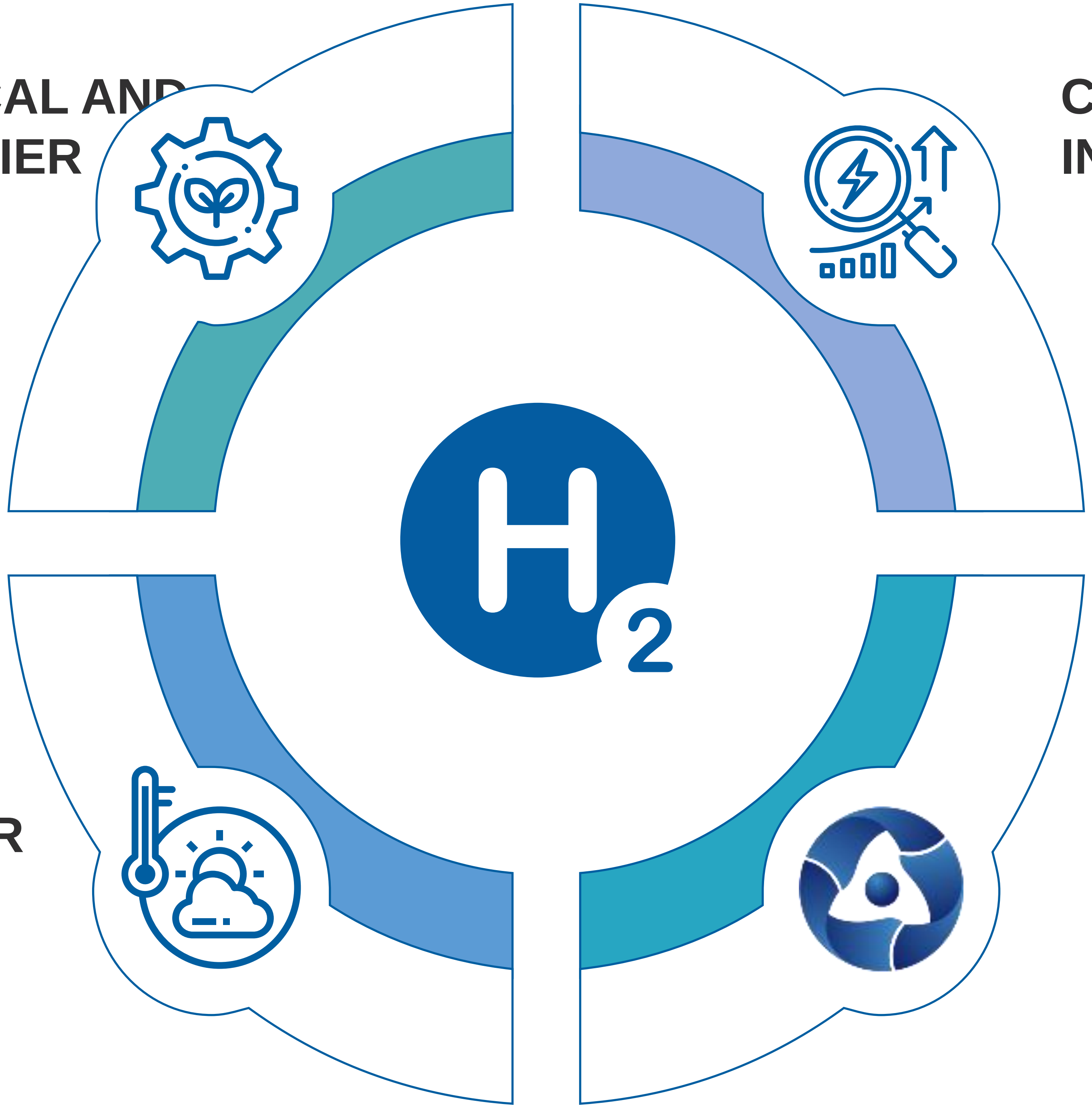
Rosatom competences go beyond energy sector



Why hydrogen energy development is in focus of Rosatom development

IS UNIVERSAL, ECOLOGICAL AND EFFICIENT ENERGY CARRIER AND STORAGE

CAN BE APPLIED IN TRANSPORT, INDUSTRY AND ENERGY



- ✓ CAN BE PRODUCED WITH NPP ELECTRICITY and BE CO_2 - FREE
- ✓ OVER 45 YEARS OF EXPERIENCE IN NUCLEAR FACILITIES FOR HYDROGEN PRODUCTION DEVELOPMENT

CAN BECOME A TOOL FOR CLIMATE CHANGE MITIGATION

Rosatom is developing own technologies along the supply chain

H_2 PRODUCTION | H_2 STORAGE AND ACCUMULATION | H_2 TRANSPORTATION | H_2 POWER GENERATION FACILITIES and CONSUMPTION | SALES

Rosatom is working on hydrogen R&D areas, focusing on hydrogen production:

LOW-CARBON H_2 PRODUCTION

- Electrolysis
- SMR, CCS
- HTGR

H_2 INFRASTRUCTURE

- High-pressure cylinders

H_2 CONSUMPTION

- Hydrogen fuel-cells

Nuclear technologies for low carbon hydrogen production

ROSATOM

NEAR TERM SOLUTIONS

ELECTROLYSIS WITH NPP ELECTRCITY

1

- Utilizing Rosatom NPPs **excess energy for electrolysis**;
- **Electrolysis based on renewable energy** sources of Rosatom (wind)
- **Research , development and partnerships** are required to develop electrolyzers

LONG TERM SOLUTION

NPP WITH HTGR

2

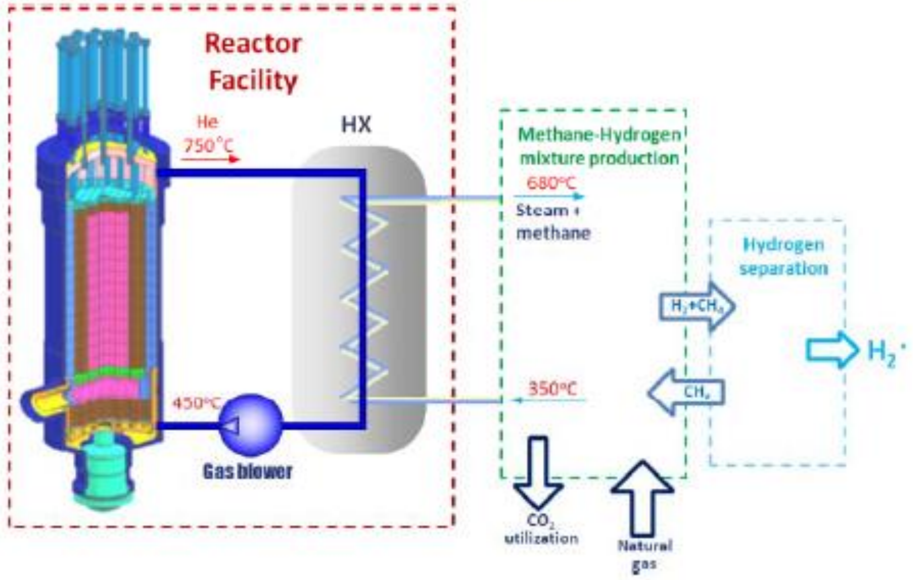
- **NPP unit with a HTGR** and a chemical process unit for large-scale hydrogen production;
- **Research and development** on the reactor installation is planned for **2019-2024**;
- **Partnerships** (Russian and/or international) for **CCUS TECHNOLOGY d**evelopment.
- Russia has **one of the lowest natural gas prices in the world** which can reduce the cost of hydrogen production by methane steam reforming at HTGR

HTGR – High potential energy for hydrogen production

ROSATOM

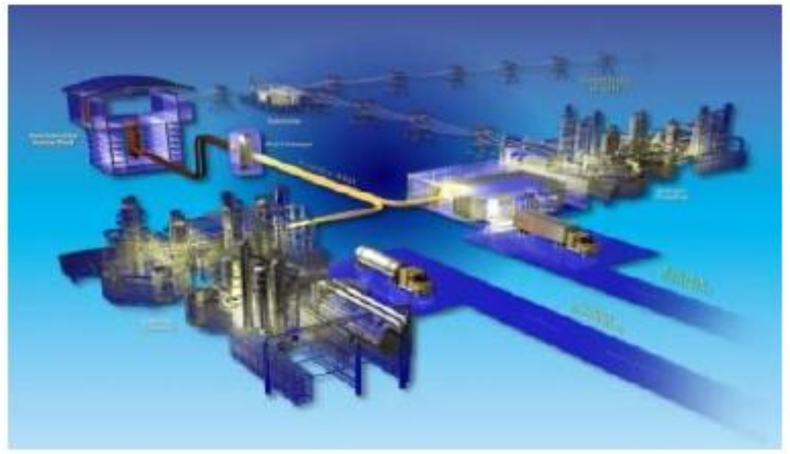
Great experience accumulated in development of gas cooled reactor systems in Russia

- ✓ high-qualified team of developers (scientific basis, design approaches, technology, manufacturing)
- ✓ R&D infrastructure (experimental facilities)
- ✓ knowledge base management



Ongoing developments

- ✓ designing a Nuclear Power Technological Unit with HTGR as an efficient response to market need in low carbon hydrogen
- ✓ HTGR is designed as an innovative combination of known components ensuring efficiency, availability of resources, and safety
- ✓ high Technology Readiness and Manufacture Levels



Low carbon hydrogen supply chain

ROSATOM

- ELECTRO-/THERMAL ENERGY SOURCES
- RAW MATERIALS
- H_2 PRODUCTION INCLUDING HTGR OPTION
- H_2 STORAGE AND ACCUMULATION
- H_2 TRANSPORTATION
- H_2 POWER GENERATION FACILITIES AND CONSUMPTION INFRASTRUCTURE
- SALES CHANNELS

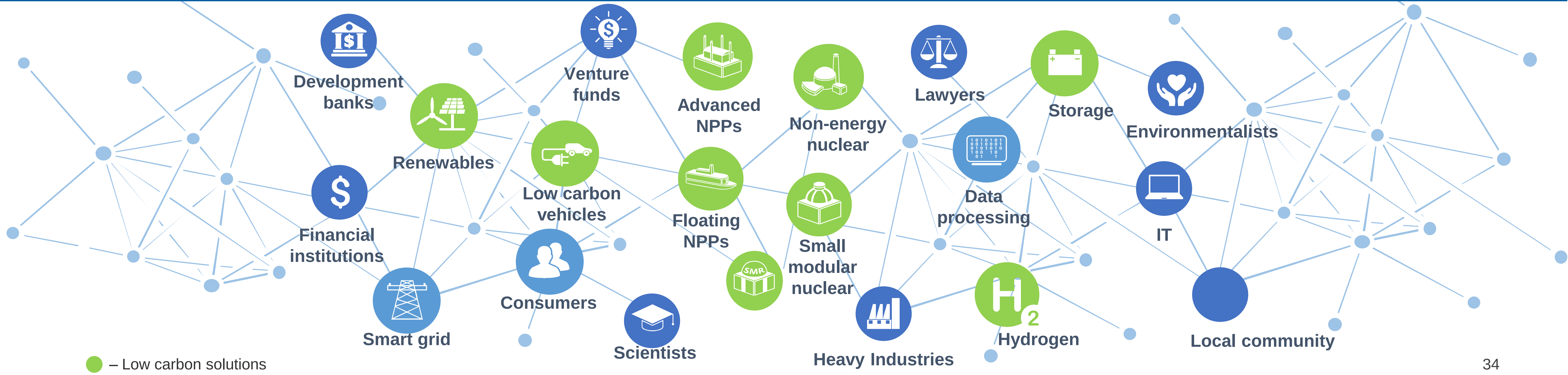
ROSATOM

Carbon-neutral and cost-effective **NUCLEAR POWER TECHNOLOGIES** can significantly contribute to **low carbon HYDROGEN SUPPLY CHAIN development AND BOOST HYDROGEN MARKET**

Sustainable energy ecosystem

ROSATOM

- ✓ Both **nuclear power and hydrogen energy** have to become part of the emerging global low-carbon energy-ecosystem.
- ✓ In the upcoming years the desire to decarbonize the energy sector will bring us to efficient energy systems where **nuclear power, renewables, hydrogen energy, storage technologies and other clean power solutions** will join hands to make the sustainable world a reality



Thank you for your attention

Anton Moskvin
Vice President, Marketing and business development
Rusatom Overseas

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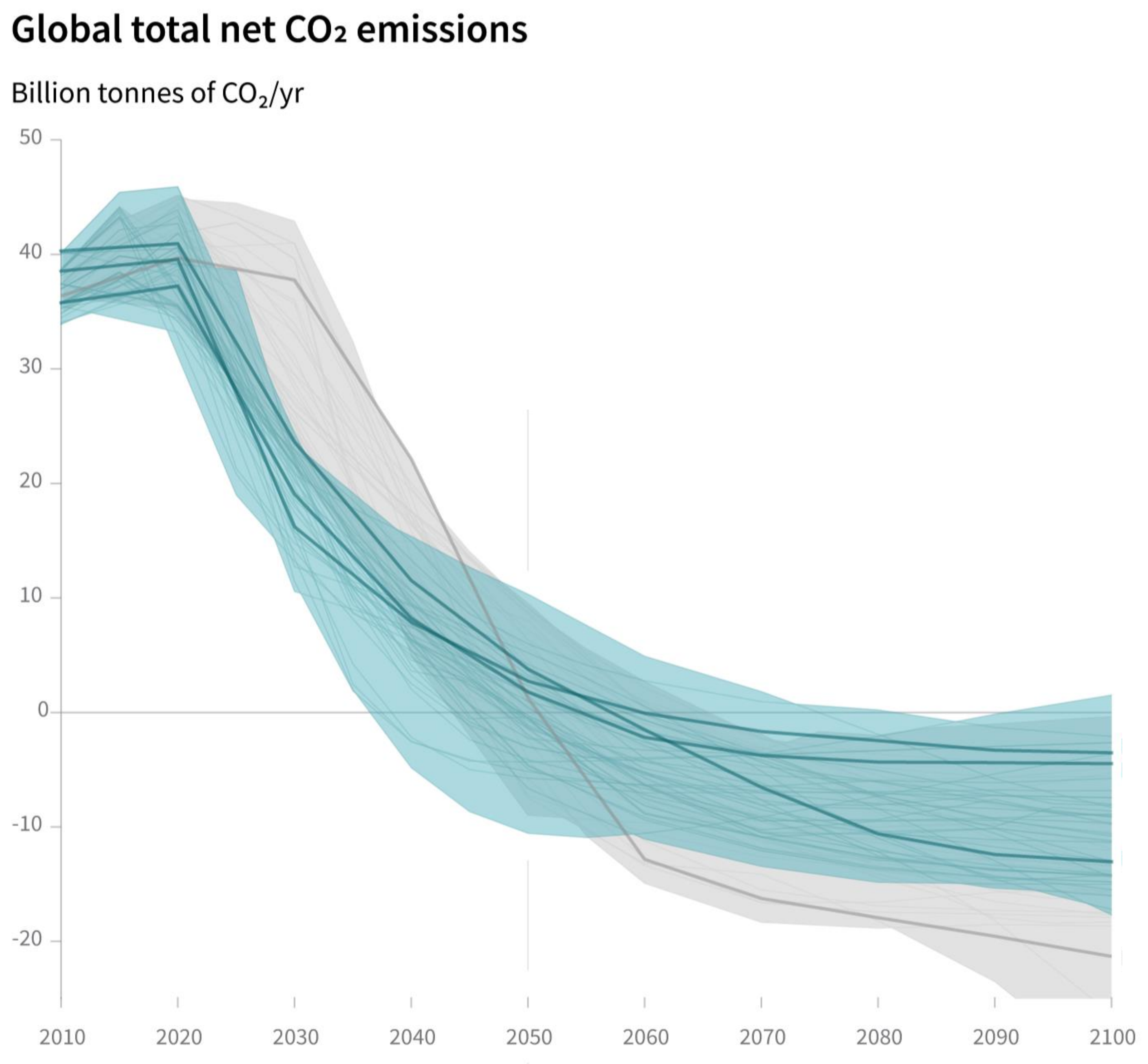
INNOVATION FOR CLIMATE

ENERGY INNOVATION FOR A PROSPEROUS PLANET

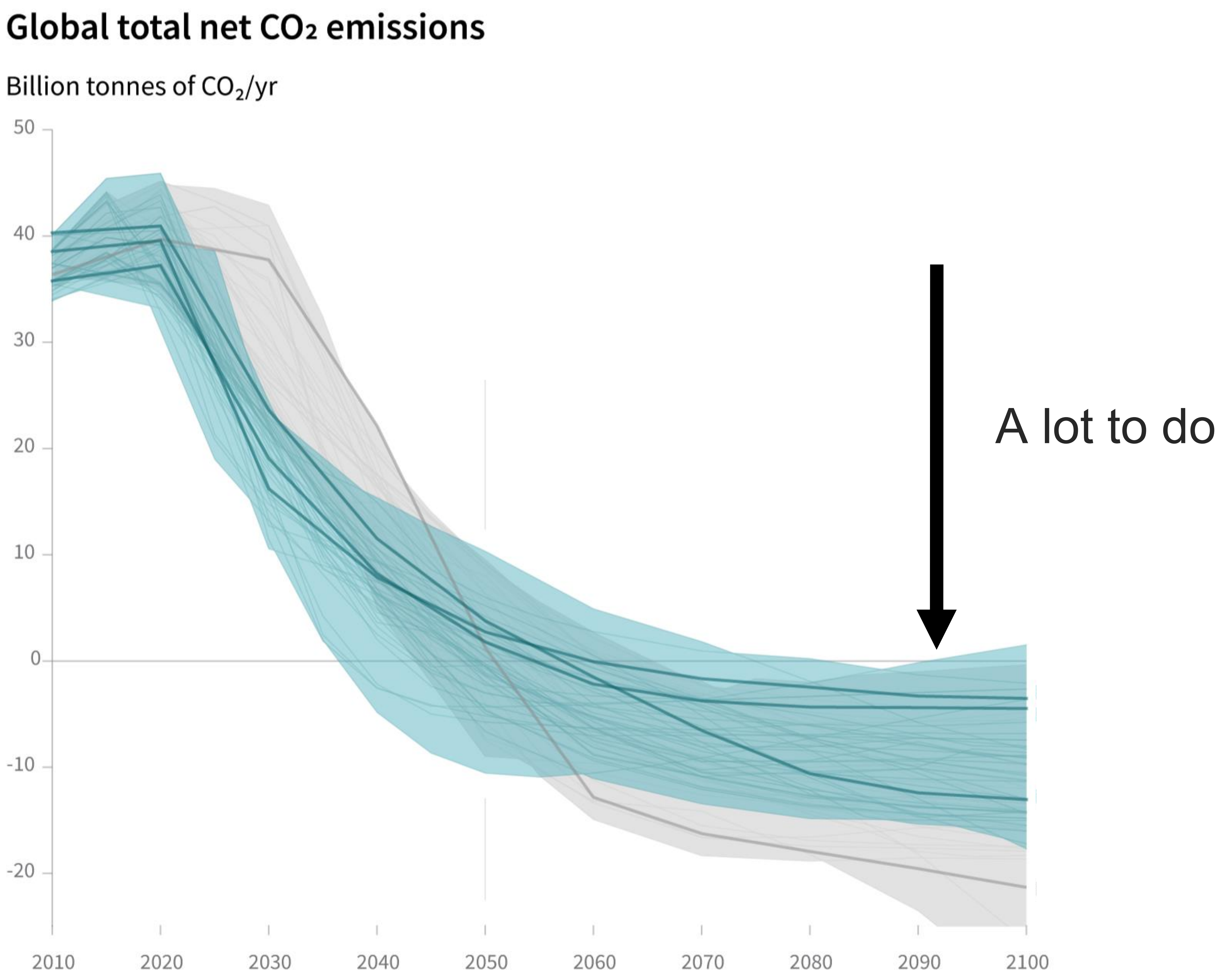
December 2020

TERRA PRAXIS

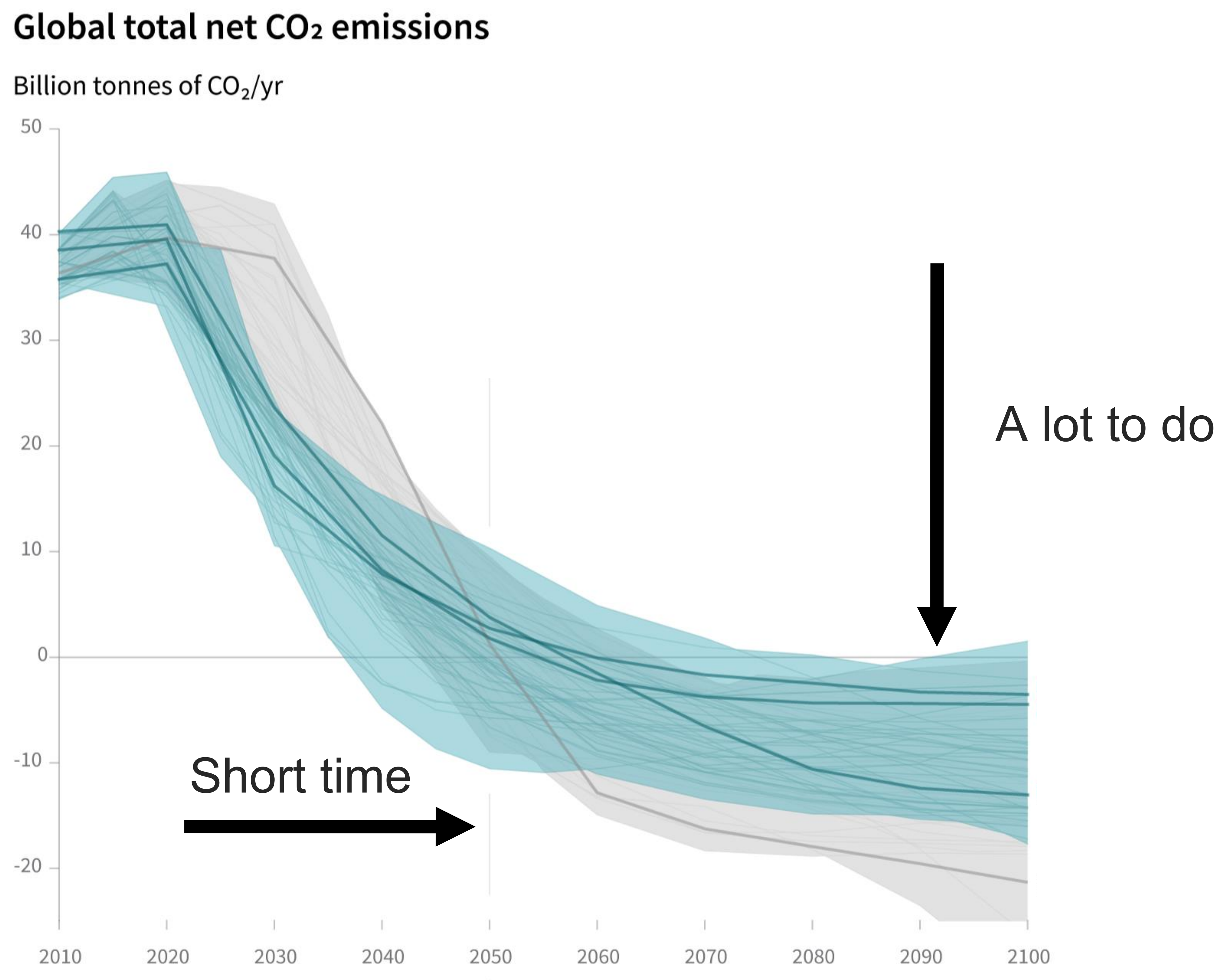
This is Where We Need to Go



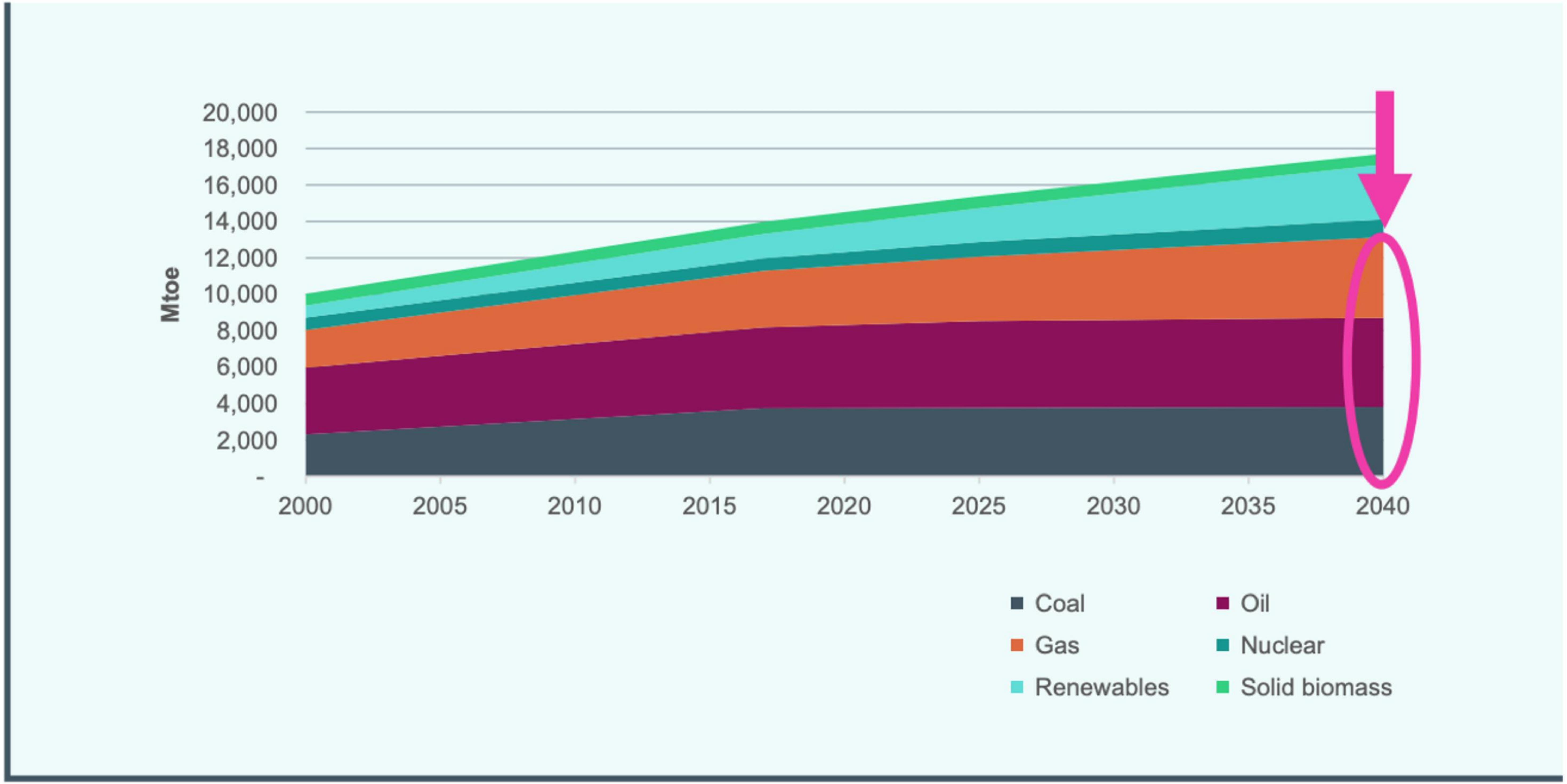
We Have a Lot to Do



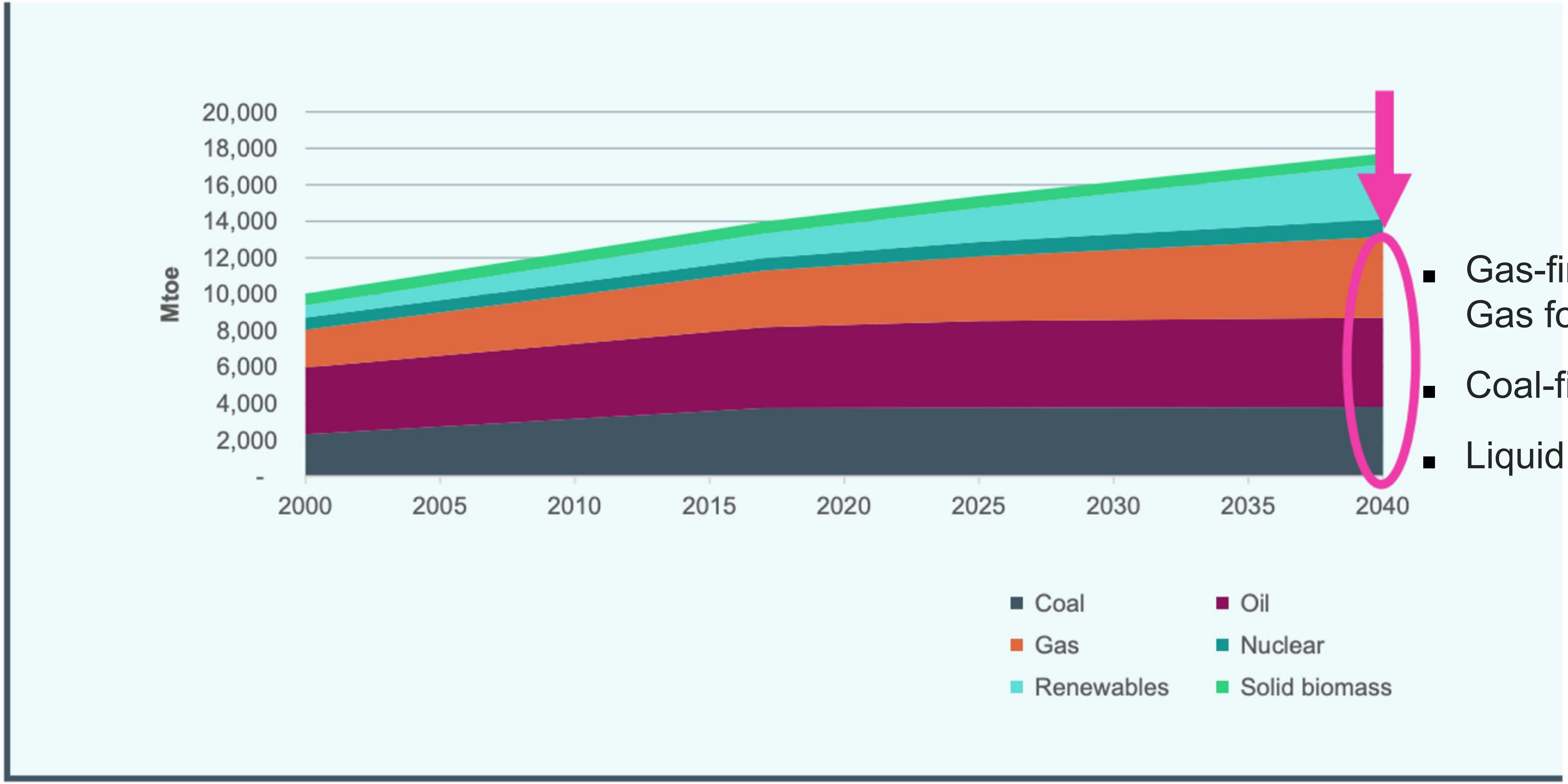
We Don’t Have Much Time



Stated Policies Scenario: World Energy by Source (IEA 2018)

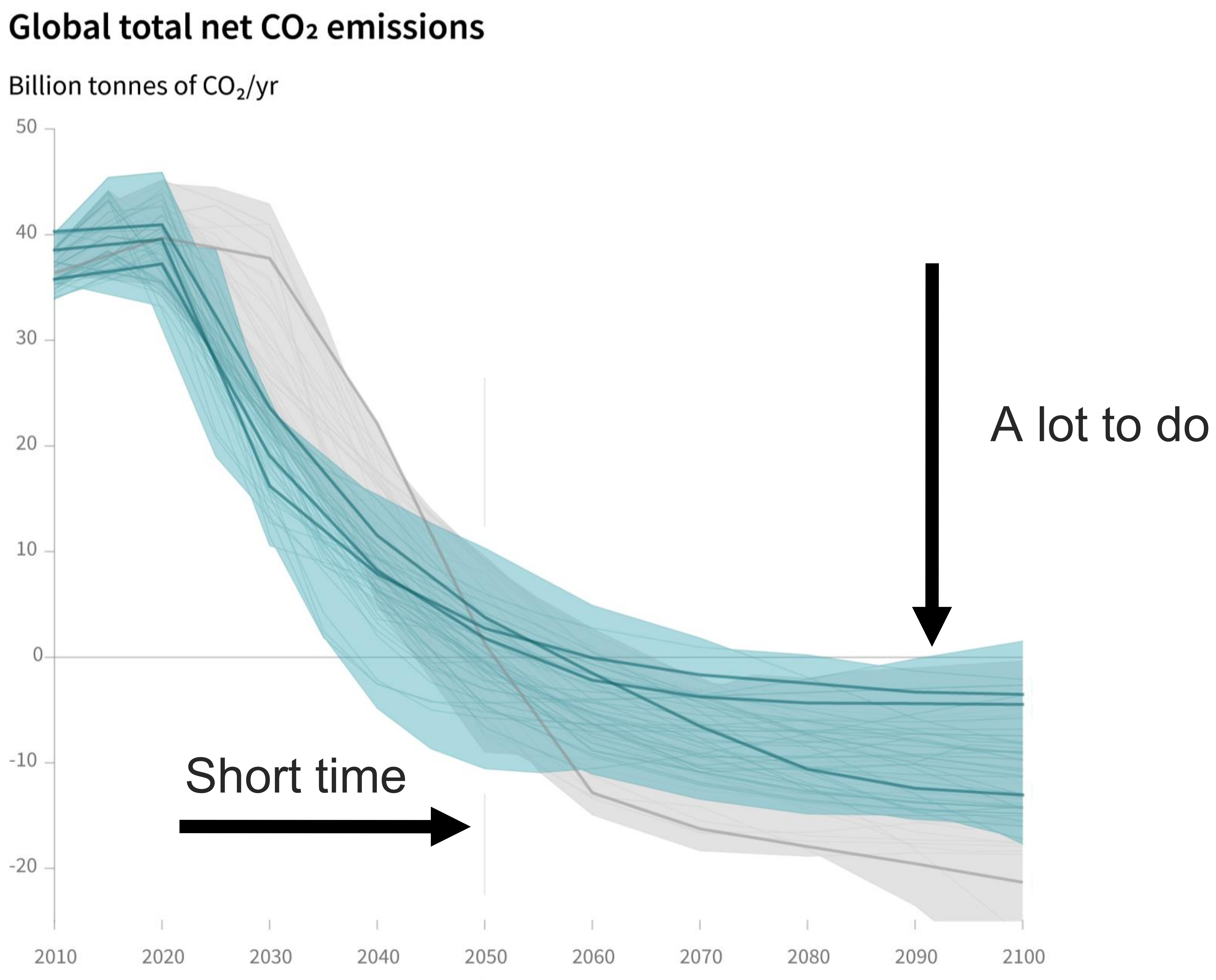


Stated Policies Scenario: World Energy by Source (IEA 2018)



- Gas-fired power plants
  Gas for industry
- Coal-fired power plants
- Liquid fossil fuels

This is What We Need to Do



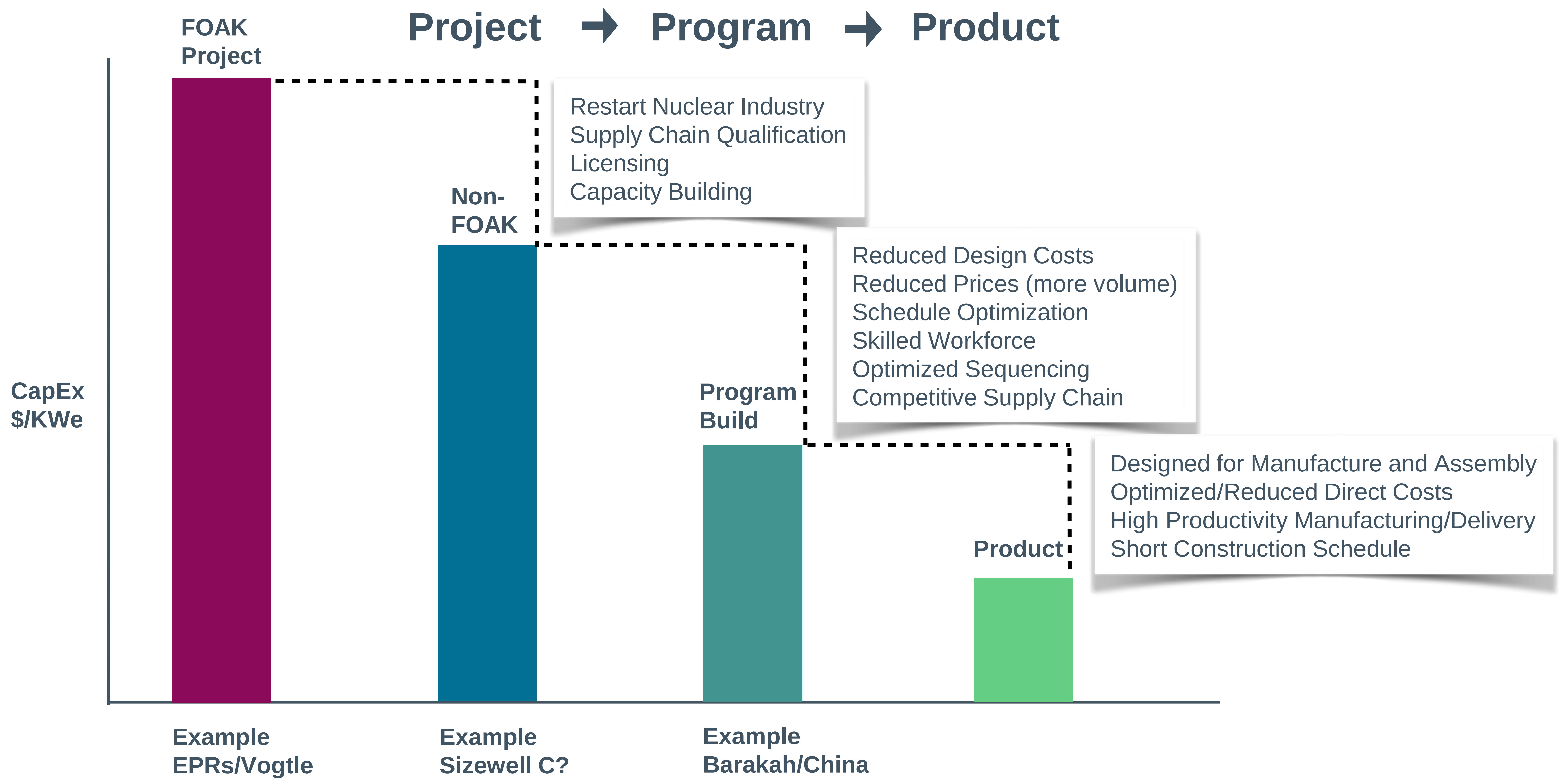
- Repower all coal plants
- Replace flexible gas plants
- Replace gas for industrial heat
- Replace liquid fossil fuels

While growing the energy system to supply the developing world

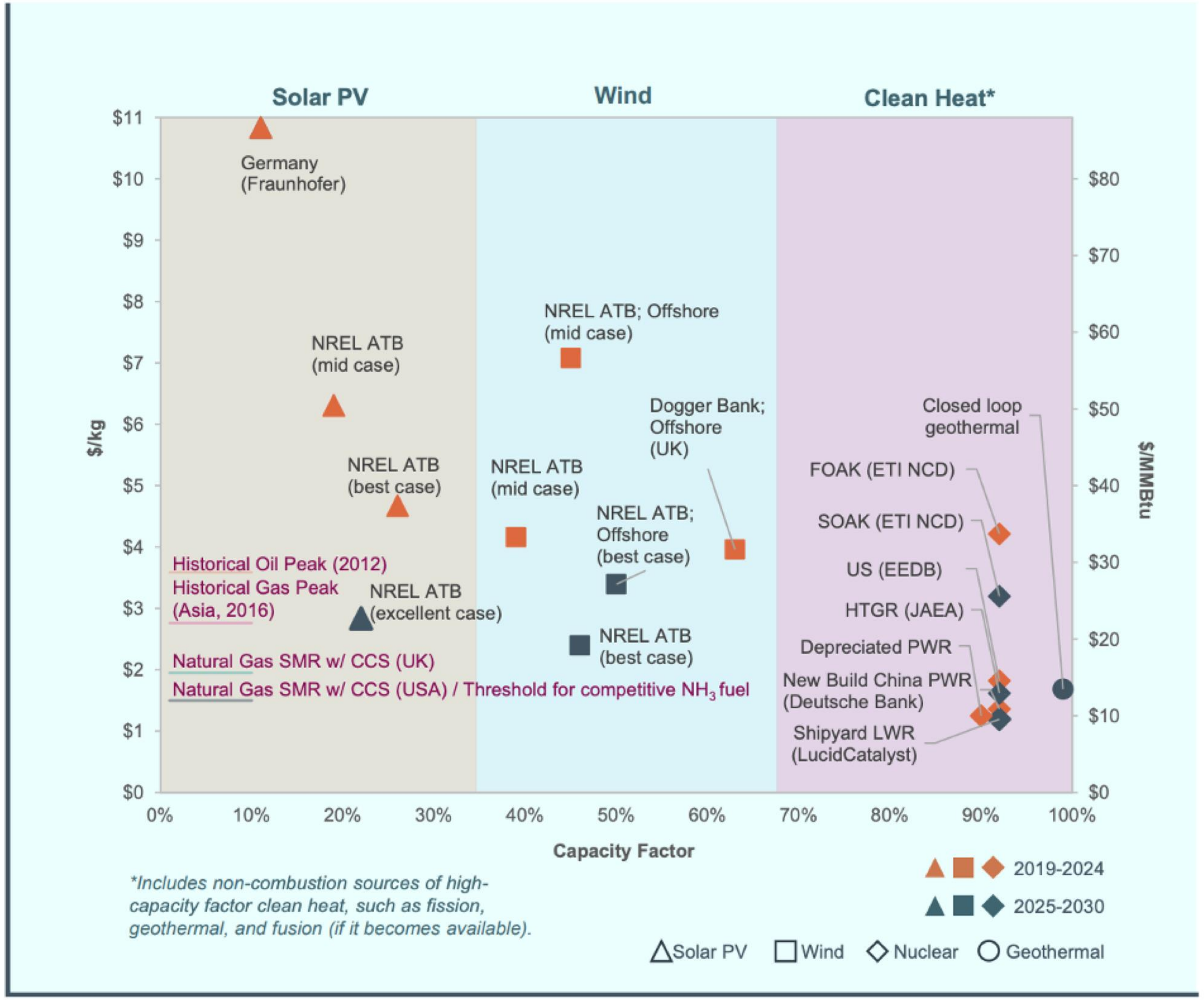
Our Climate Solutions need to be Impossible Burgers

- Drop-in substitute: cost & performance
- Leverages existing infrastructure
- Cost-competitive
- Not dependent on behaviour change
- Scale applicable to market size
- Rapidly deployable

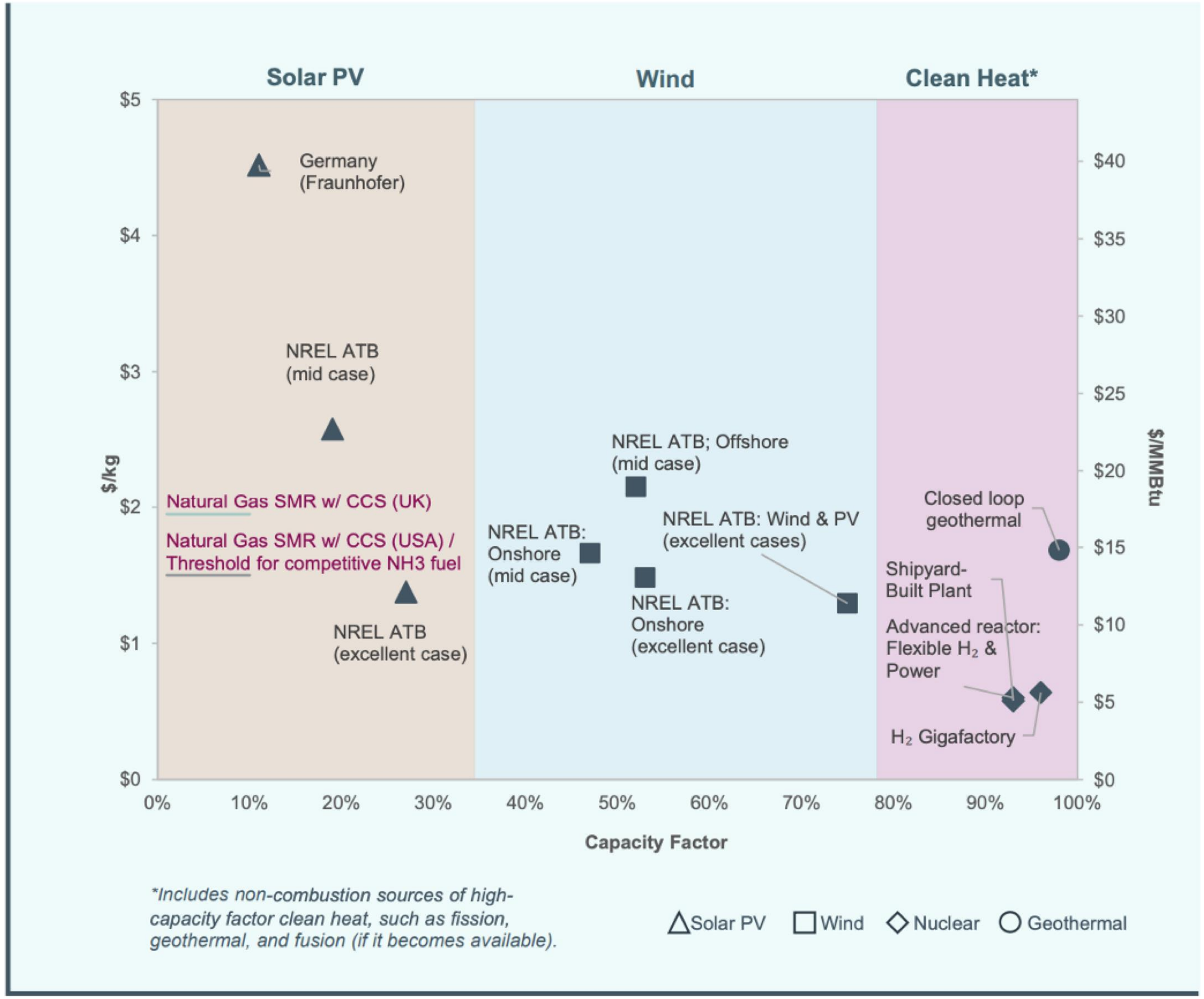
Pathway to Low Cost



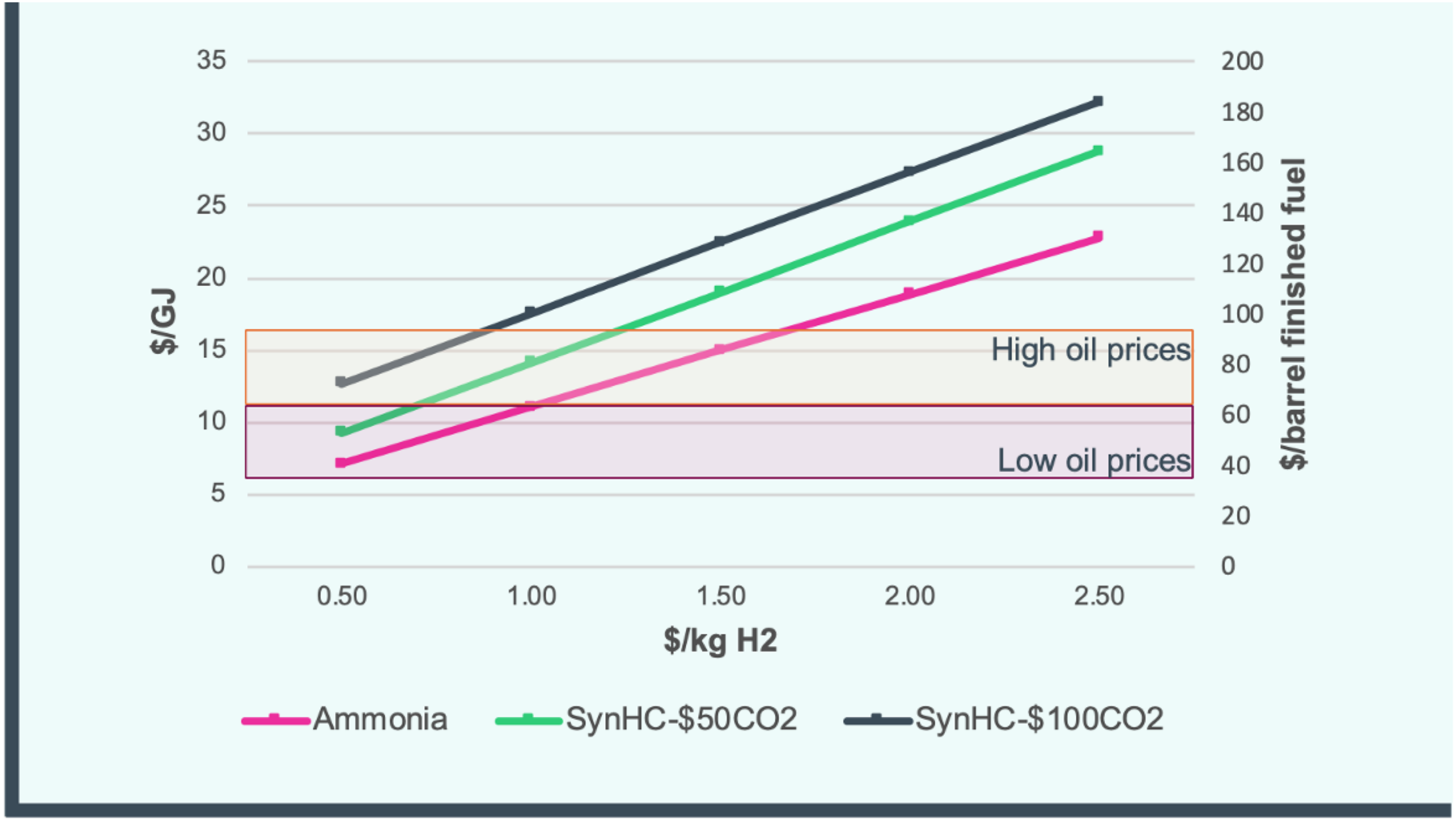
Hydrogen Production Costs: 2020–2030



Hydrogen Production Costs 2030 - 2050



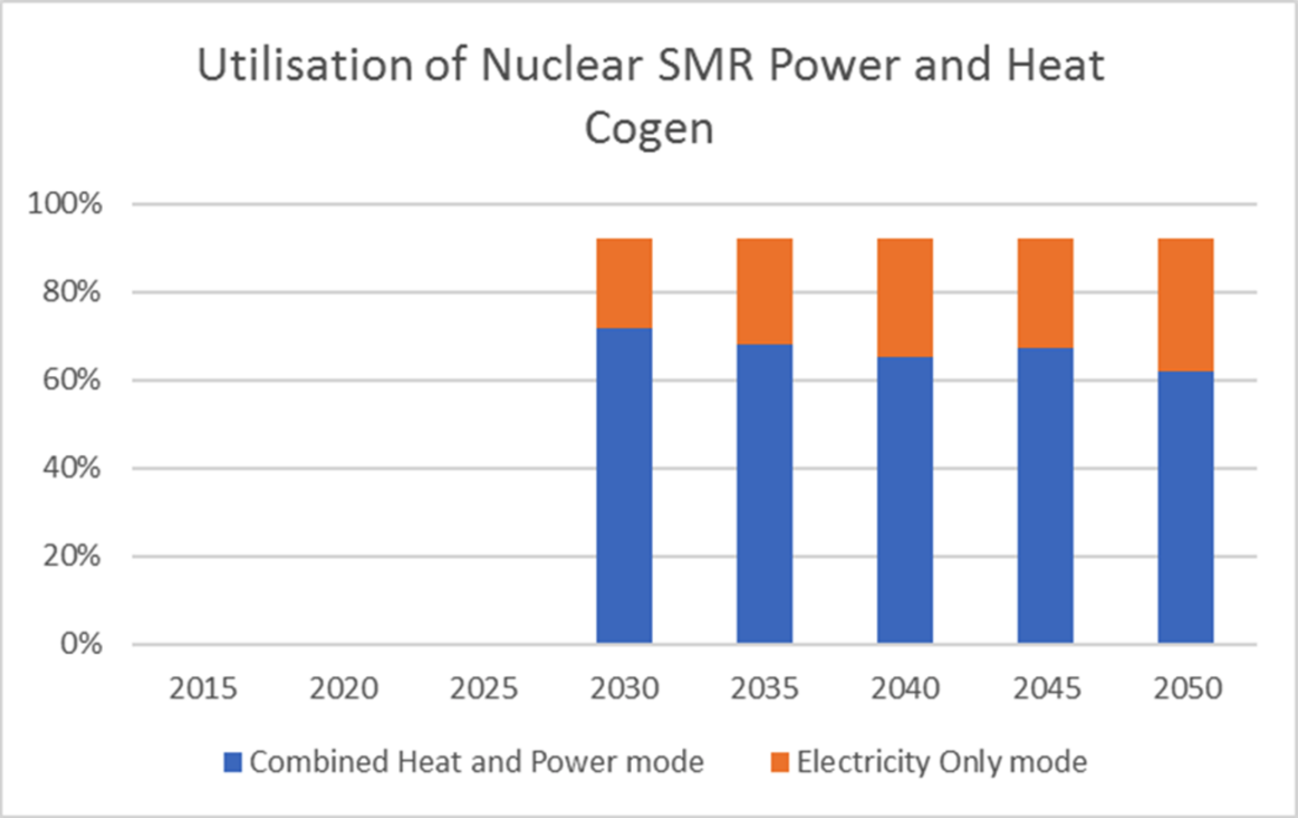
Cost: Oil price 'guardrails' of the hydrogen economy ($0.50–$1.50/kg)

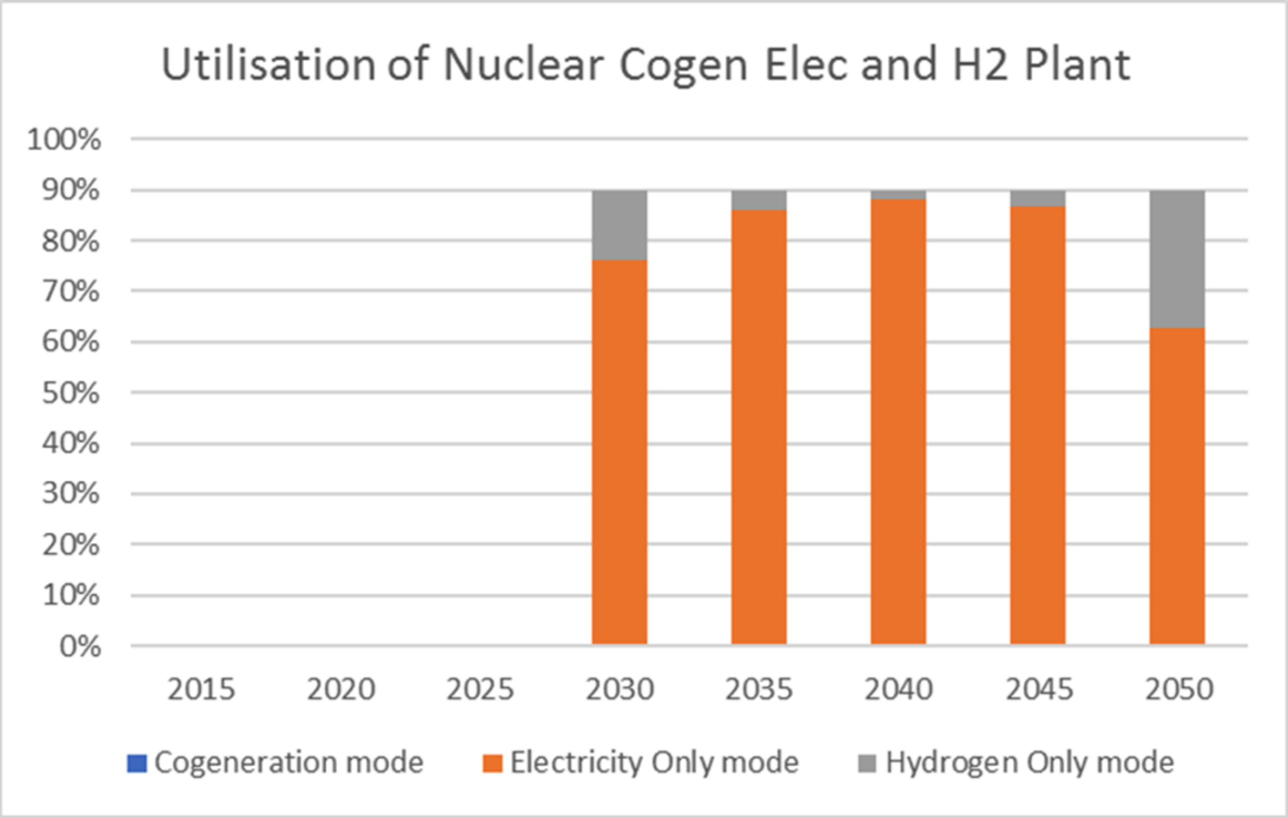


Refinery-Scale Hydrogen/Synfuel Gigafactory

Flexible Cogeneration of Power, Heat, and Hydrogen is Attractive for Future Markets

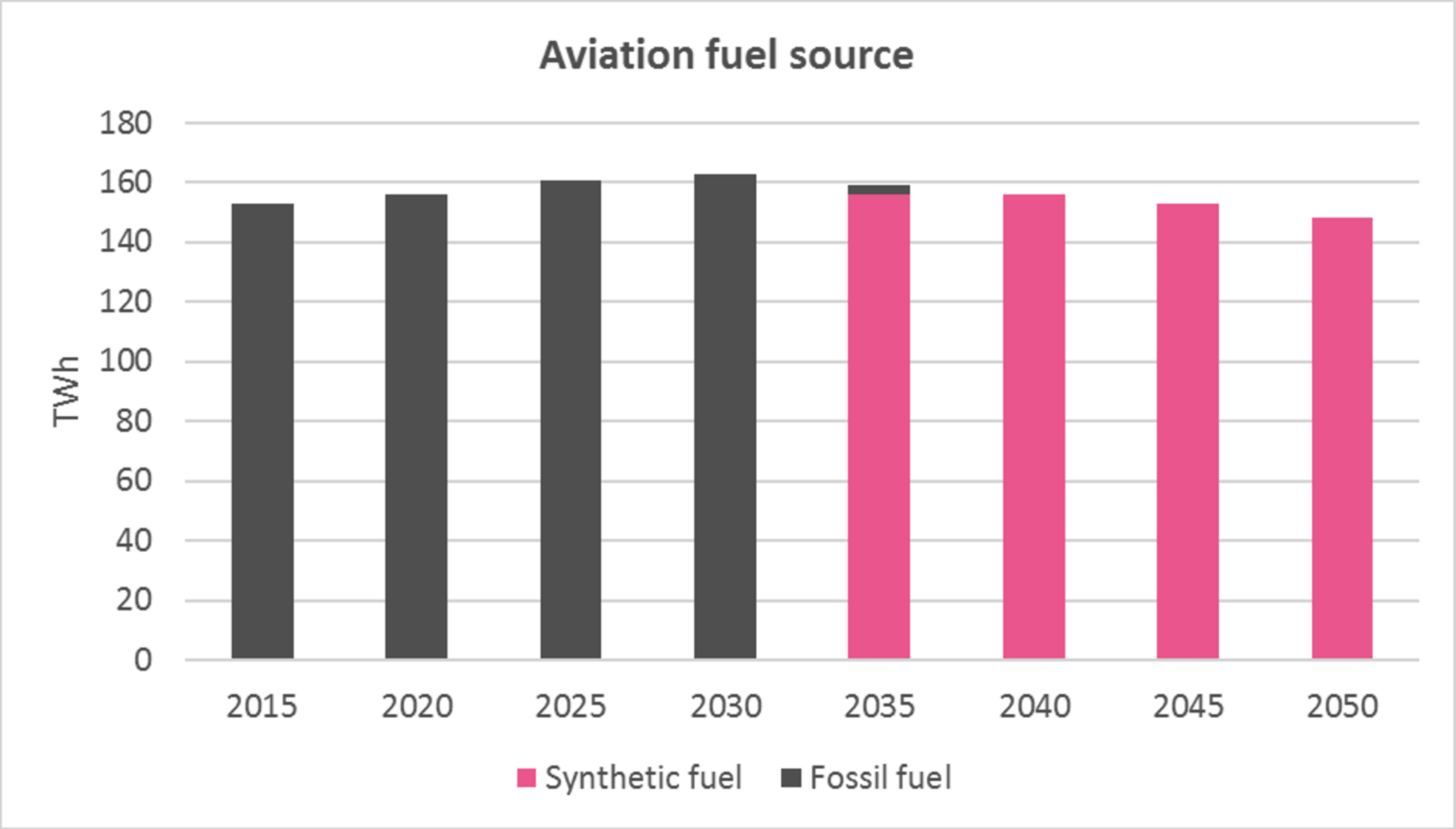
SR2 – LWSMR and Gen IV Utilisation in 2050 (Run 228)





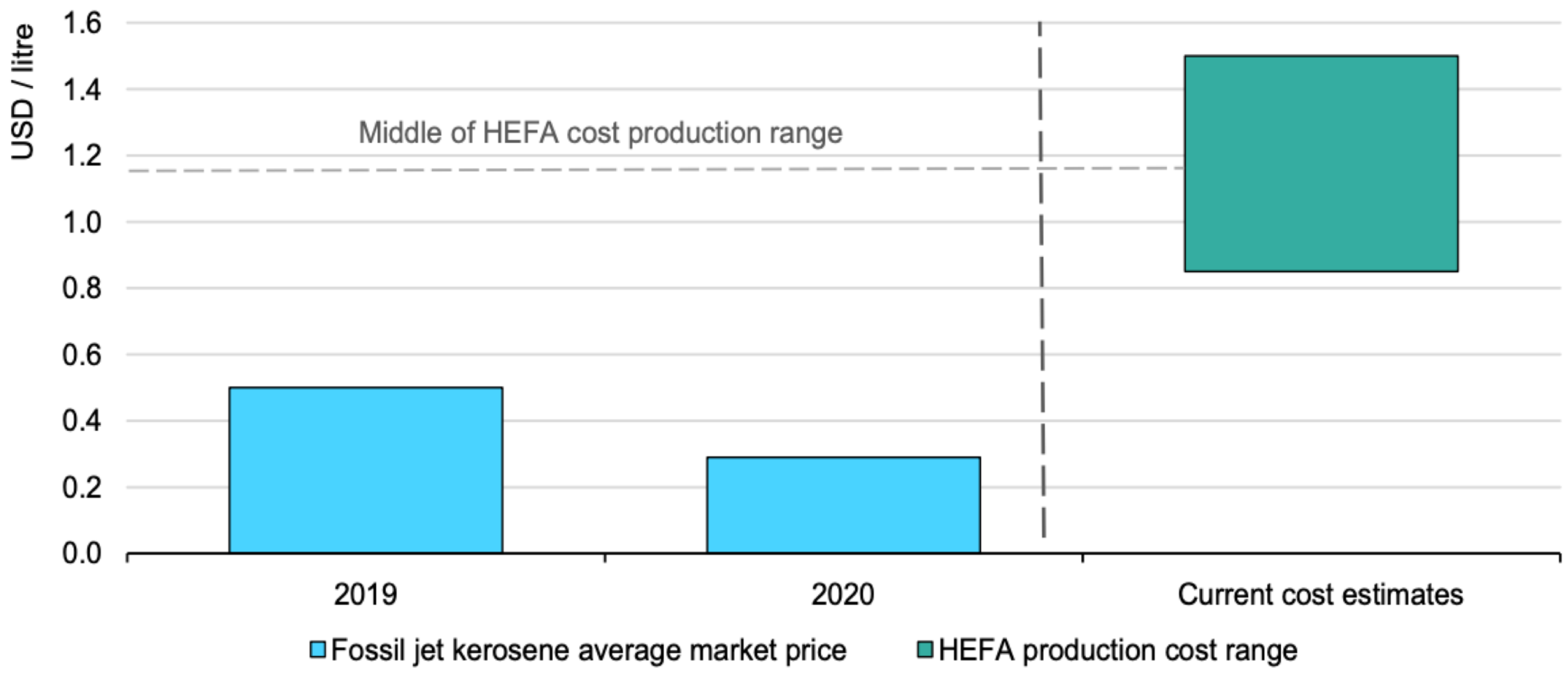
Hydrogen Gigafactory with Synfuel Plant Replaces Fossil Aviation Fuel

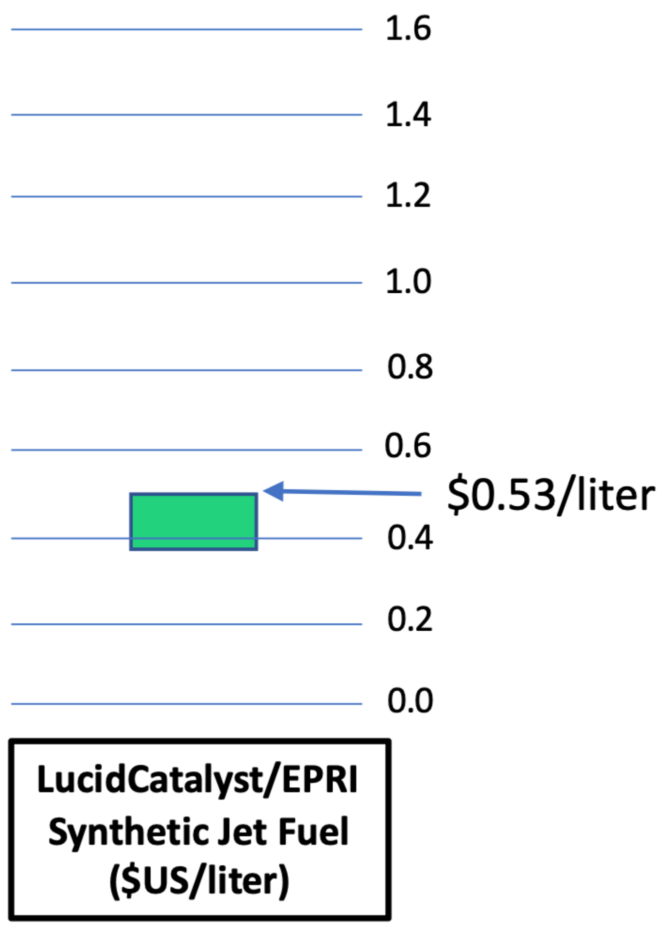
Liquid Synthetic Fuel Production - Run 310



IEA: Sustainable Aviation Fuel Projected Costs Compared to EPRI Synthetic Jet A Fuel

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

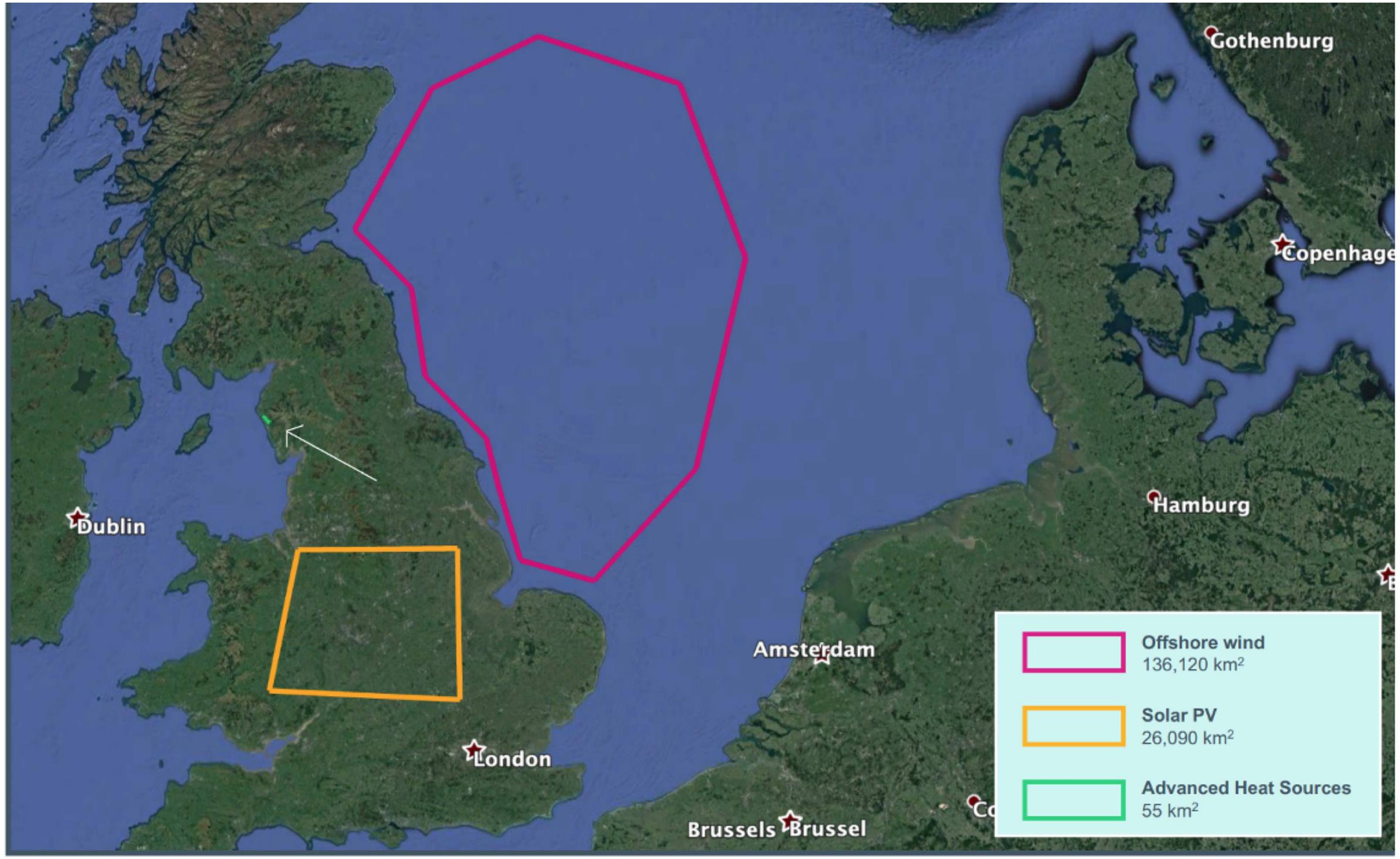




Source

Electric Power Research Institute (EPRI) Report: *Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors.* December 2020

Land Area Requirements for Meeting Current UK Oil Consumption from Hydrogen

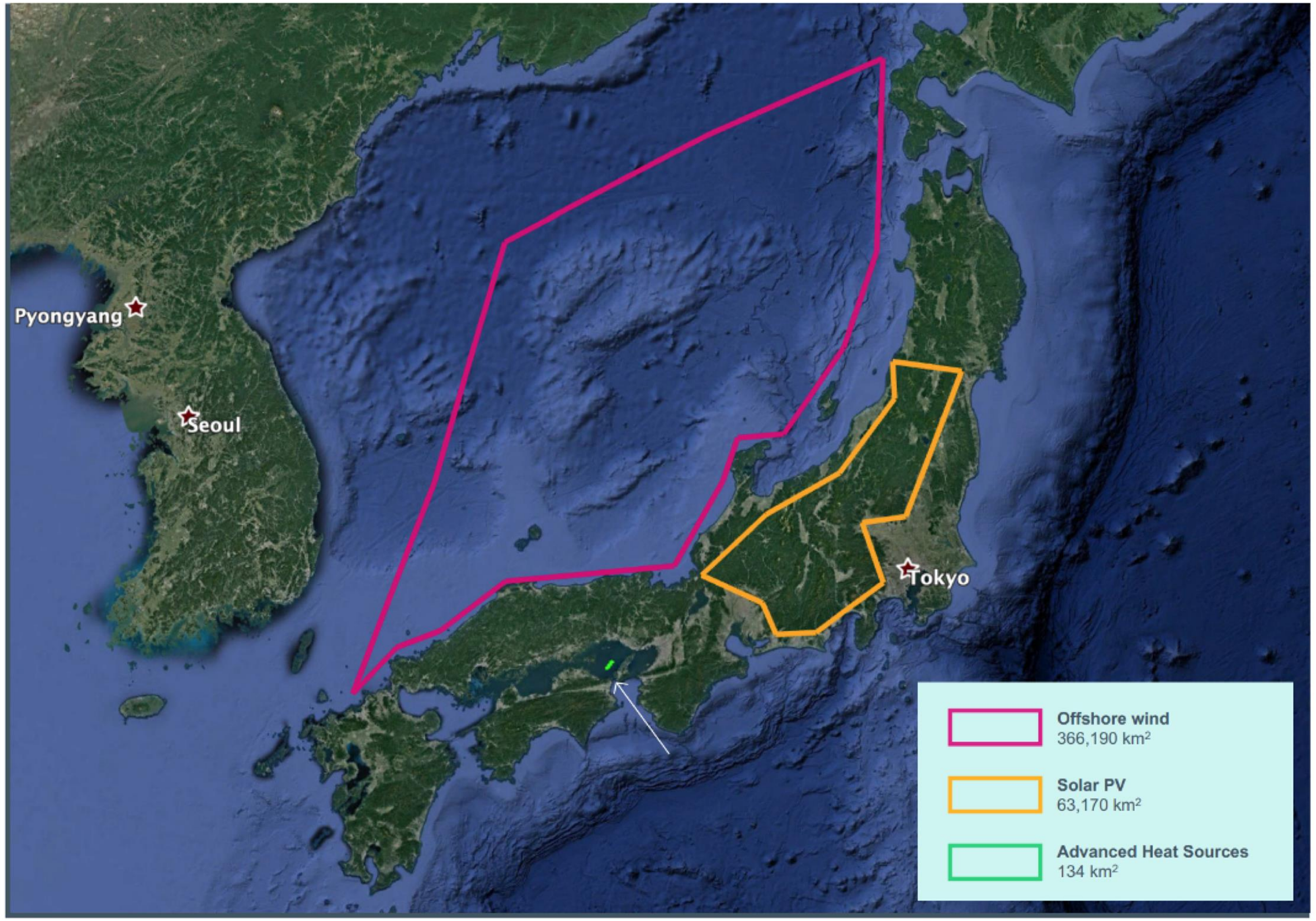


Each colored outline represents the total area that would be required for the siting of each type of resource if it were to be the only one used to generate enough hydrogen to replace current oil consumption in the UK.

TerraPraxis / Innovation for Climate

Comparing area required to replace the UK's current oil consumption with hydrogen generated from either wind, solar, or advanced heat sources

Land Area Requirements to replace Japan's Current Oil Consumption with Hydrogen



Each colored outline represents the total area that would be required for the siting of each type of resource if it were to be the only one used to generate enough hydrogen to replace current oil consumption in Japan.

Comparing area required to replace the Japan's current oil consumption with hydrogen generated from either wind, solar, or advanced heat sources

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

FPSO for Hydrogen, Power, Ammonia, Desalination

ENERGY INNOVATION FOR A PROSPEROUS PLANET

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TERRA PRAXIS

THE NEW NUCLEAR WATCH INSTITUTE

The synergy of the hydrogen economy and nuclear energy

17 December 14:00 – 15:30 GMT

Q&A Discussion

chaired by Tim Yeo

Please use the Q&A button to ask questions.

Charles Hart	Senior Researcher, The New Nuclear Watch Institute
Elina Teplinsky	Advisor, Global Nuclear, Clean Air Task Force Partner, Pillsbury Winthrop Shaw Pittman LLP
Dr Tariq Dawood	Lead Engineer Asset Management, Nuclear & Renewables, EDF R&D UK Centre
Anton Moskvin	Vice President for Marketing and Business Development, Rusatom Overseas
Kirsty Gogan	Co-founder, TerraPraxis

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