IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Economics of HTR

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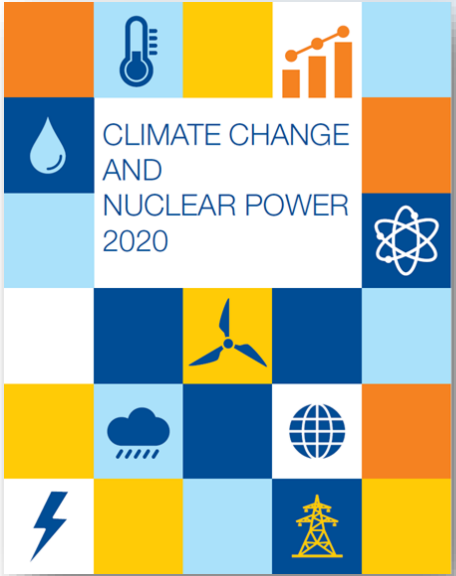
High Temperature Reactors for deep decarbonisation: the Polish example
From the Gemini+ research project towards demonstration
25 November 2020

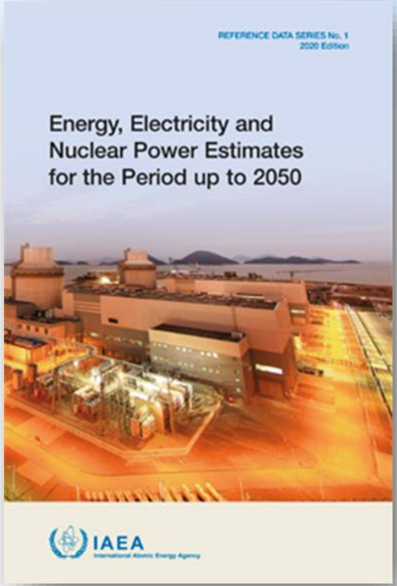
Outline

- Relevant IAEA activities
  - PESS and NPTDS sections
  - Launch of CRP on Economics of SMRs (including HTRs)
- Decarbonising beyond power
  - Towards “Net Zero” goals
  - Non-power applications of nuclear energy
- Economics
  - nuclear cogeneration
  - H2 production
- Integrated Energy Systems (Hybrid Nuclear Renewables)
  - Coupling through electricity and hydrogen
  - Coupling through electricity, heat and hydrogen (HTR case)
- Macro-economic impacts of nuclear programmes
- Conclusions

Planning and Economic Studies Section

- Energy Planning support to Member States
- Nuclear power projections to 2050
- Technical and economic analysis of nuclear power and integrated nuclear/renewables systems
- Assessing contribution of nuclear energy to Climate Change mitigation
- Water-Energy Nexus, Resilience and adaptation to CC



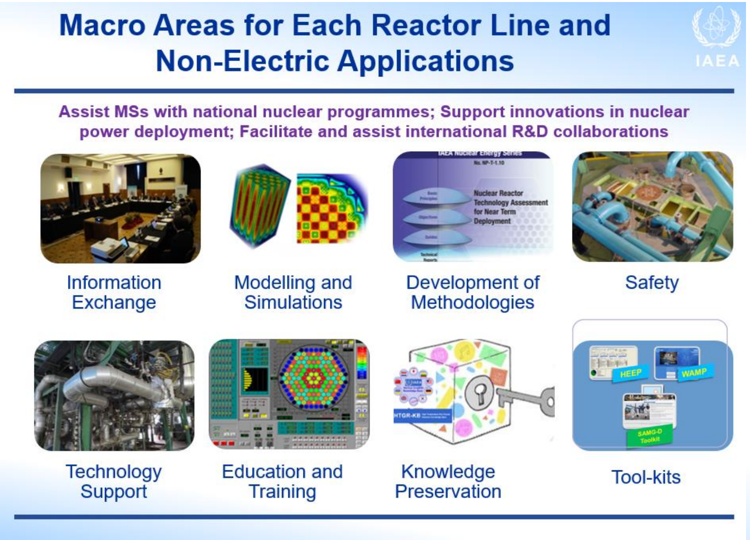


https://www.iaea.org/topics/nuclear-power-and-climate-change/climate-change-and-nuclear-power-2020

https://www.iaea.org/publications/14786/energy-electricity-and-nuclear-power-estimates-for-the-period-up-to-2050

Nuclear Power Technology Development Section

- Advanced reactors including SMRs
- Non-electric applications of nuclear energy



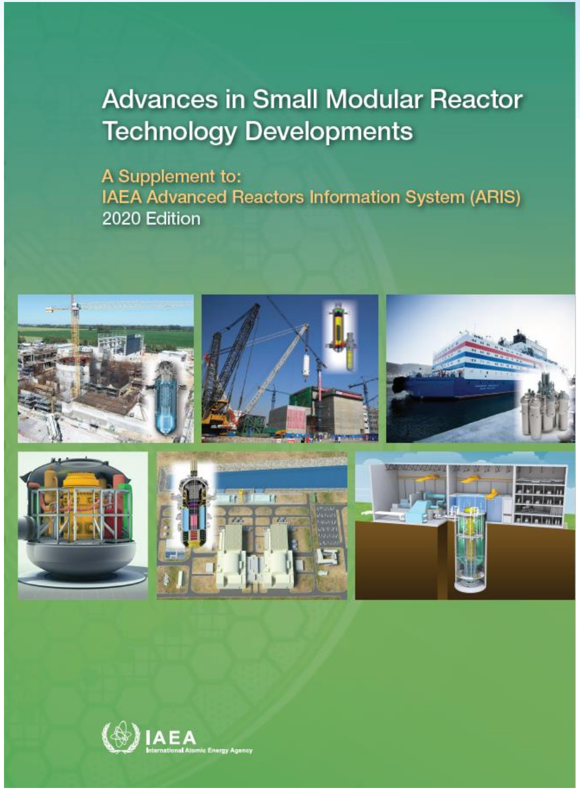
Small Modular Reactors

2020 Edition

- **Economics based on “serial production”**, modular design with factory fabrication, etc

Latest IAEA Booklet on Advanced in SMR Technology Developments:

- Design description and main features of **72** SMR designs being updated (56 in 2018)
- SMRs are categorized in types based on coolant type/neutron spectrum:
  - Land Based Water-cooled Reactors
  - Marine Based Water-cooled Reactors
  - **High Temp gas cooled reactors**
  - Fast Reactors
  - Molten Salt Reactors
  - Micro reactors



https://aris.iaea.org/Publications/SMR_Book_2020.pdf

Coordinated Research Project on the Economics of SMR

- Areas of investigation
  - Market research
  - Analysis of the competitive (non-nuclear) landscape
  - Project planning, cost forecasting and analysis
  - Project structuring, risk allocation and financial valuation
  - Business planning and business case demonstration
  - Economic cost-benefit analysis

- Activities
  - 75+ proposals received so far
  - About 50 proposals selected
  - First Meeting of the CRP to take place in Vienna on **December 7-11, 2020**

New CRP: Economic Appraisal of Small Modular Reactor (SMR) Projects: Methodologies and Applications (I12007)

The IAEA is launching a 3-year, Coordinated Research Project (CRP) focusing on the economics of SMRs, including micro-reactors, by providing Member States with an economic appraisal framework for their development and deployment.

New Coordinated Research Project

Saied Dardour, IAEA Department of Nuclear Energy
Frederik Reitsma, IAEA Department of Nuclear Energy

MAR 25 2020

Significant advances have been made on Small Modular Reactors, some of which will use pre-fabricated systems and components to reduce construction costs and shorten delivery schedules.

Small Modular Reactors (SMRs), with electrical power up to 300MW per

Related Stories

IAEA Launches Technical Working Group on Small, Medium Sized or Modular Nuclear Reactors

IAEA SMR Regulators' Forum Shares Experiences on New Reactors

New IAEA Self-Assessment Methodology and Enhancing SMR Licensing Discussed at Regulatory Cooperation Forum

Related Resources

Small modular reactors

Small Modular Reactor (SMR) Regulators' Forum

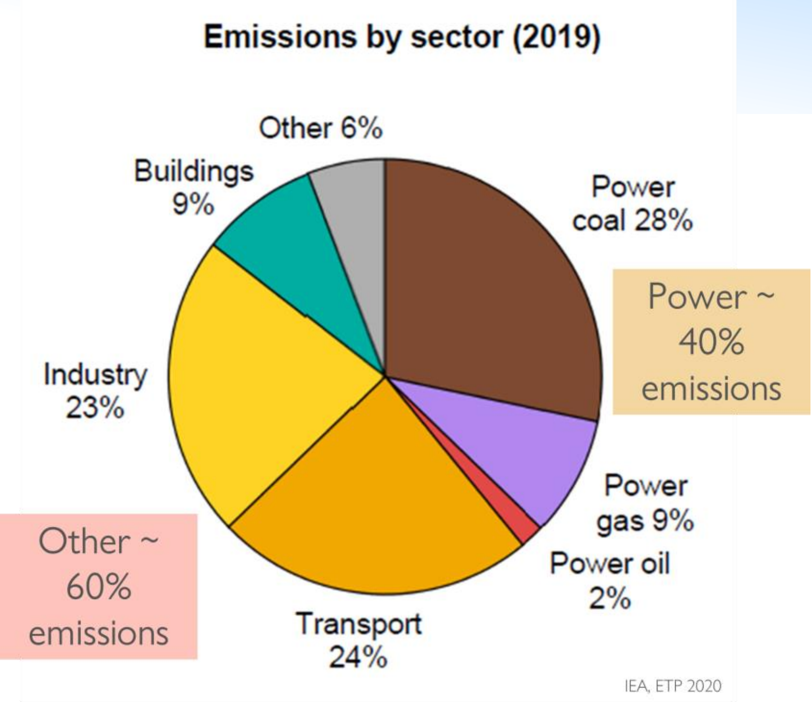
Expect data and analysis on economics of HTR (contribution from China, Japan, Indonesia, Poland, S. Africa, US)

Towards net-zero emissions

- Decarbonising the power sector will not be sufficient.
- Need to decarbonize other sectors, representing 60% of emissions today:

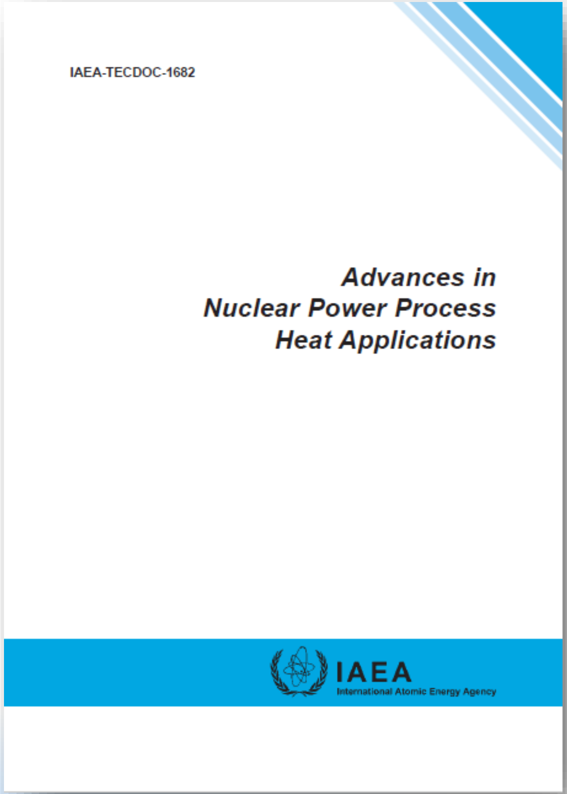
- **Electrification** whenever possible (so increased demand for clean electricity)
- Need for **low C heat sources** (eg. fossil + CCS, nuclear heat, solar thermal)
- Use of **low C fuels**, including hydrogen, produced from clean electricity

→ **Sector Coupling / integrated systems**



3 low-carbon energy vectors: electricity, heat, hydrogen

Non-electric applications: Process Heat, Desalination



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Advances in Nuclear Power Process Heat Applications

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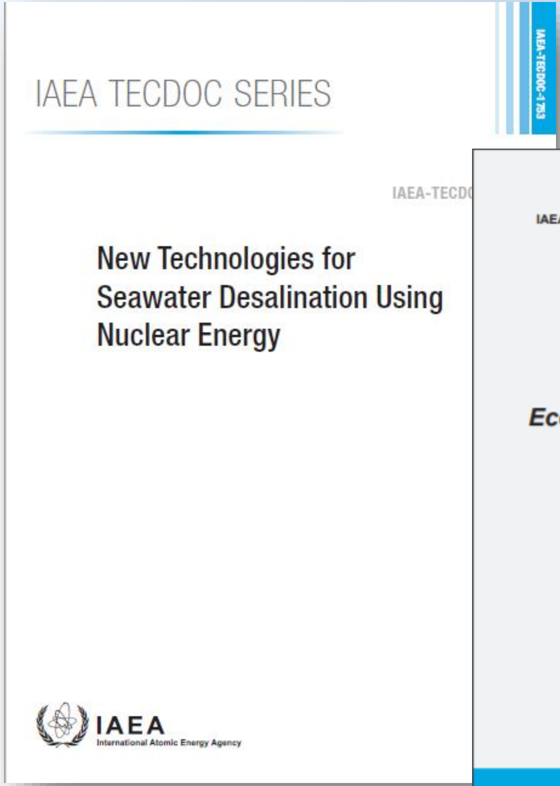

IAEA-TECDOC-1753

IAEA TECDOC SERIES

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New Technologies for Seawater Desalination Using Nuclear Energy

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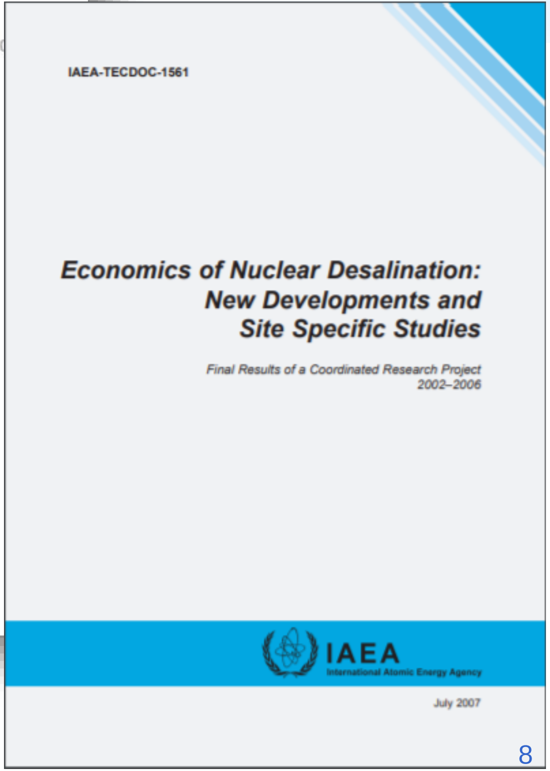
International Atomic Energy Agency



IAEA-TECDOC-1561

Economics of Nuclear Desalination: New Developments and Site Specific Studies

Final Results of a Coordinated Research Project 2002–2006

IAEA
International Atomic Energy Agency

July 2007

Non-electric applications: District Heating

- Decades of experience, in Russia, Hungary, Switzerland, etc
- In June 2020, the new **Floating Nuclear Power Plant** Akademic Lomonosov, powered by two SMR units, provided 1st heat to Pevesk district (1st grid connection in Dec 2019)
- In November 2020, **Haiyang NPP** (AP1000) started delivering commercial DH

Source: http://fnpp.info/

Haiyang begins commercial-scale district heat supply

20 November 2020

Share

China's Haiyang nuclear power plant in Shandong province has officially started providing district heat to the surrounding area. A trial of the project - the country's first commercial nuclear heating project - was carried out last winter, providing heat to 700,000 square metres of housing, including the plant's dormitory and some local residents.

A pipeline carrying heated water from the Haiyang plant (Image: SPIC)

Source: WNN

Economics of cogeneration (electricity + other)

- Considerations:
  - Cost Allocation
  - Net Present Value
  - Exergy
  - Profitability analysis, etc
  - Proximity NPP – users (issue of cost of transport infrastructure)
  - **IAEA tools** for cost evaluation: HEEP (Hydrogen), DEEP (Desalination)

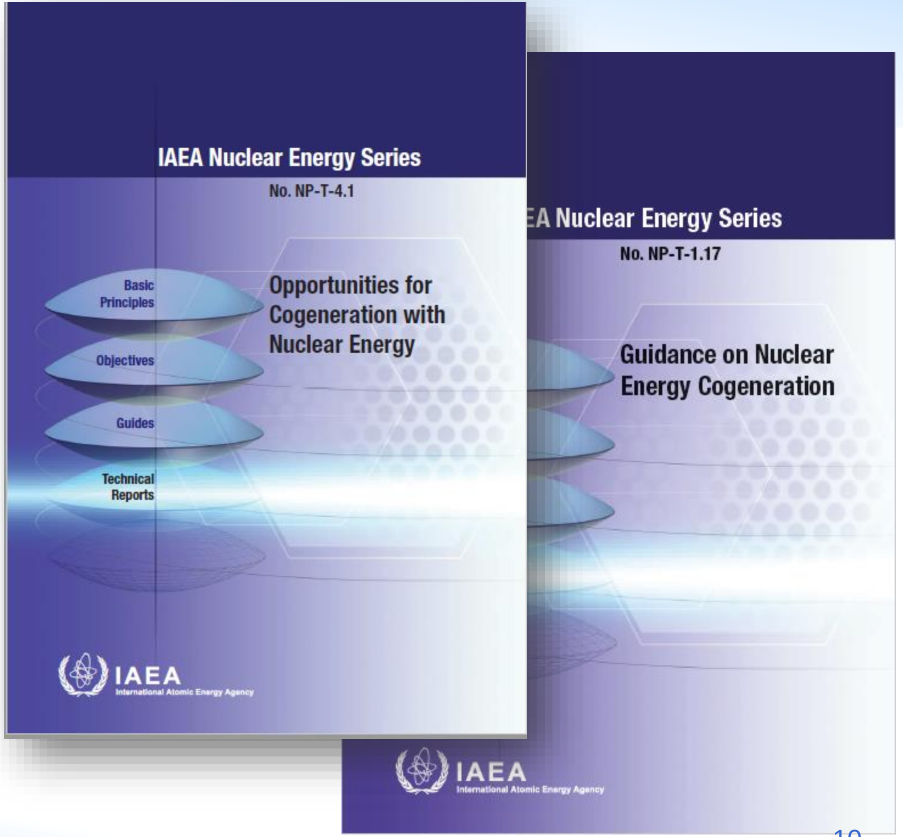
- Also issue of stability of production costs (favorable to nuclear vs. fossil fuel alternatives)

Co = LCOE, ΔE = electricity loss

$$cH = (C' - C_0) + c_0(E_0 - E') = \Delta C + c_0 \Delta E$$

Cost of cogenerated product (= LCOH x H produced)

Cost of plant modification



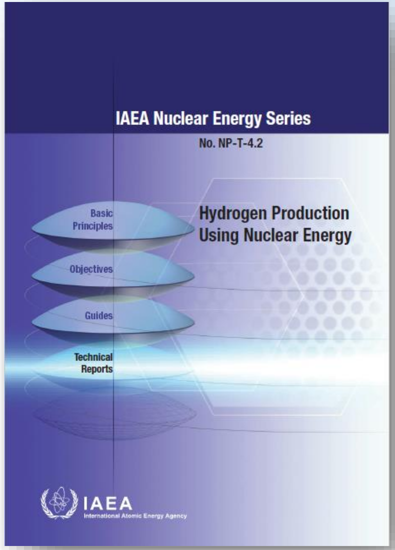
Case of Hydrogen

Over 96% of world H_2 produced from fossil fuels. How to produce "clean" / Low Carbon Hydrogen:

- Low temperature electrolysis with low carbon electricity (renewables, **nuclear**)
- High temperature steam electrolysis (**current or advanced reactors incl. HTR**)
- Thermo-chemical splitting (**advanced reactors incl. HTR**)

Economics of hydrogen production depend on a wide variety of parameters such as scale and availability of the plant, cost of feedstock, efficiency of the technology employed, state of development (i.e. early stage or mature) and physical distance to end use markets

For H_2 produced from electrolysis to be competitive on a heating-value basis against fossil-fuel reforming would require very high CO2 prices (100-200 €/t)



Comparison of different H2 production methods

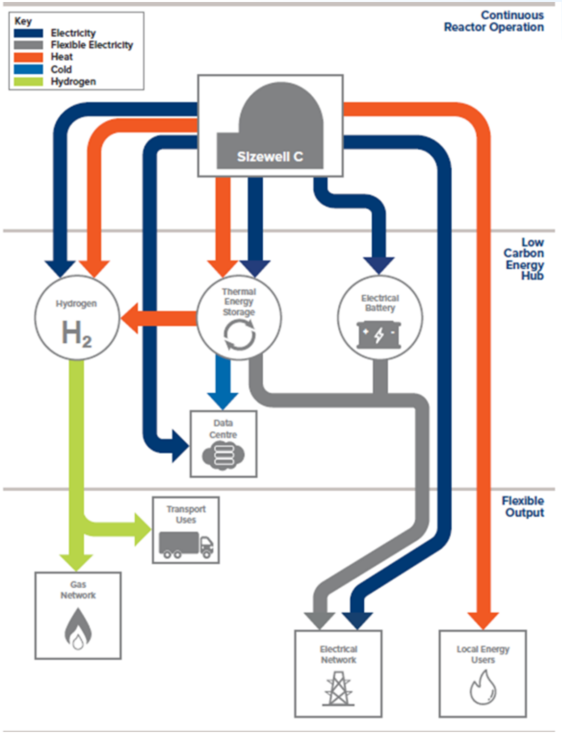
Process	Energy source	Feedstock	Capital cost (M$)	Hydrogen cost ($/kg)
SMR with CCS	Standard fossil fuels	Natural gas	226.4	2.27
SMR without CCS	Standard fossil fuels	Natural gas	180.7	2.08
Solar PV electrolysis	Solar	Water	12–54.5	5.78–23.27
Solar thermal electrolysis	Solar	Water	421–22.1	5.10–10.49
Wind electrolysis	Wind	Water	504.8–499.6	5.89–6.03
Nuclear electrolysis	Nuclear	Water	–	4.15–7.00
Nuclear thermolysis	Nuclear	Water	39.6–2107.6	2.17–2.63
Solar thermolysis	Solar	Water	5.7–16	7.98–8.40
Photo-electrolysis	Solar	Water	–	10.36

HTR

Source: M. Kayfeci et al., Chap. 3 Hydrogen Production, in Solar Hydrogen Production, Academic Press, 2019

IAEA Publication (in preparation)

- On Business Case Opportunities for Nuclear Production of Hydrogen (with existing reactor technologies)
- Utilities:
  - Arizona Public Service Company (Palo Verde NPP)
  - Exelon
  - EDF Energy
  - Vattenfall
  - Rosatom
  - Foratom
  - EPRI
- Motivation:
  - Diversify revenues (when electricity prices are too low)
  - Contribute to clean energy objectives
- System approach needed to assess costs and benefits
- Concept of "Energy Hub" – EDF Energy in the UK



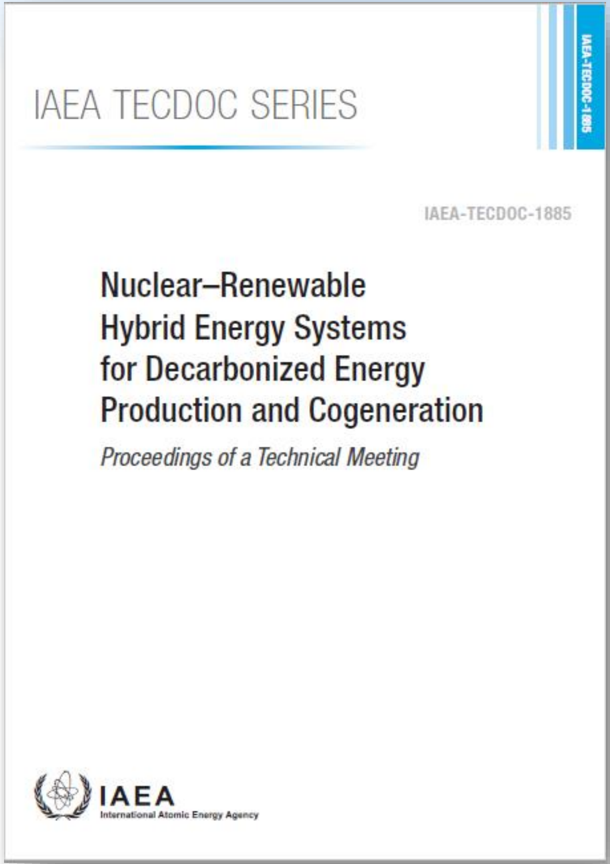
Source of figures: Sizewell C Energy Hub brochure prepared by Mott MacDonald

Integrated Energy Systems (Hybrid Energy Systems)

- How to design low carbon energy systems using all possible low carbon technologies:
  - Renewables
  - Nuclear
  - Fossil with CCS

- Coupling of the power sector with the non-power sector through 3 low carbon energy vectors:
  - Electricity
  - Heat
  - Hydrogen

- Economics of such systems requires sophisticated modelling approaches, able to inform on interactions between generation technologies, grid, energy storage and demand:
  - Optimize in terms of CO_2 emissions and overall costs
  - The value (economics) of a given technology depends on what is present in the system



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Nuclear–Renewable Hybrid Energy Systems for Decarbonized Energy Production and Cogeneration

Proceedings of a Technical Meeting

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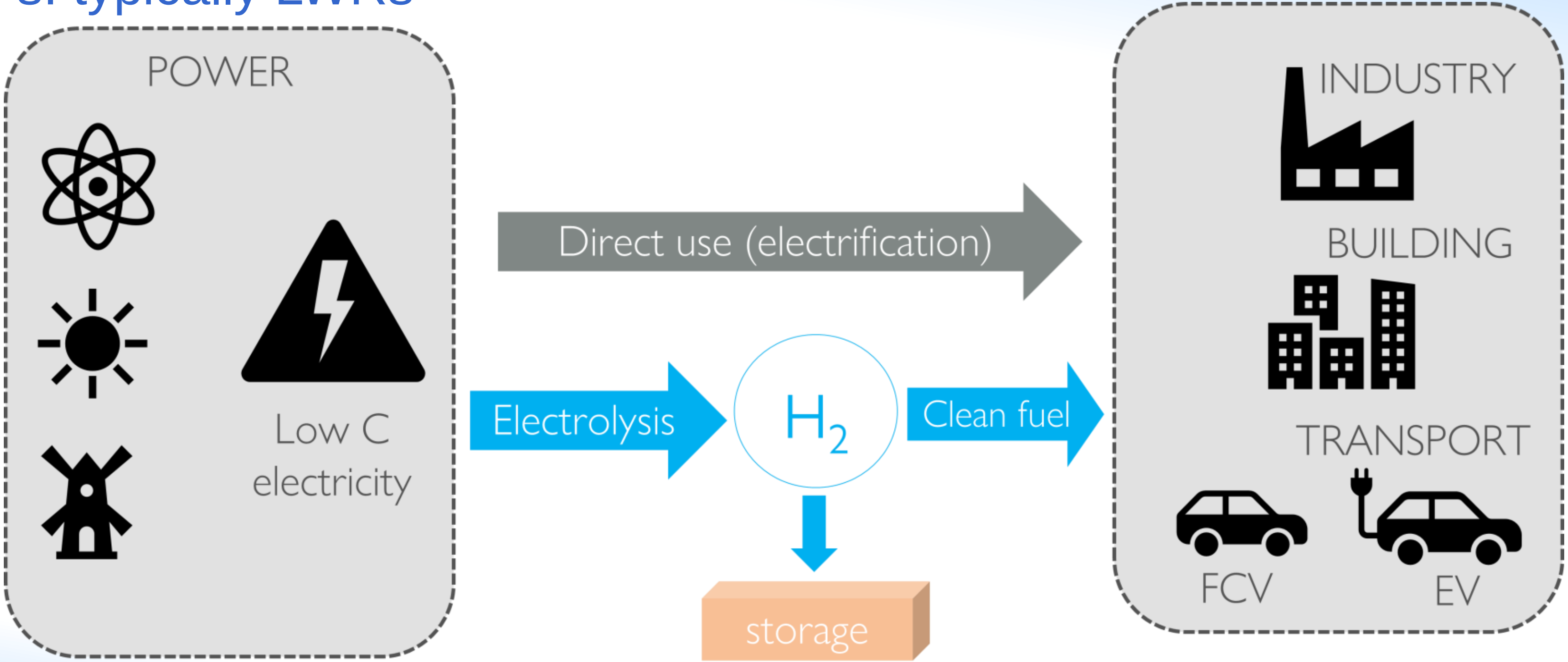
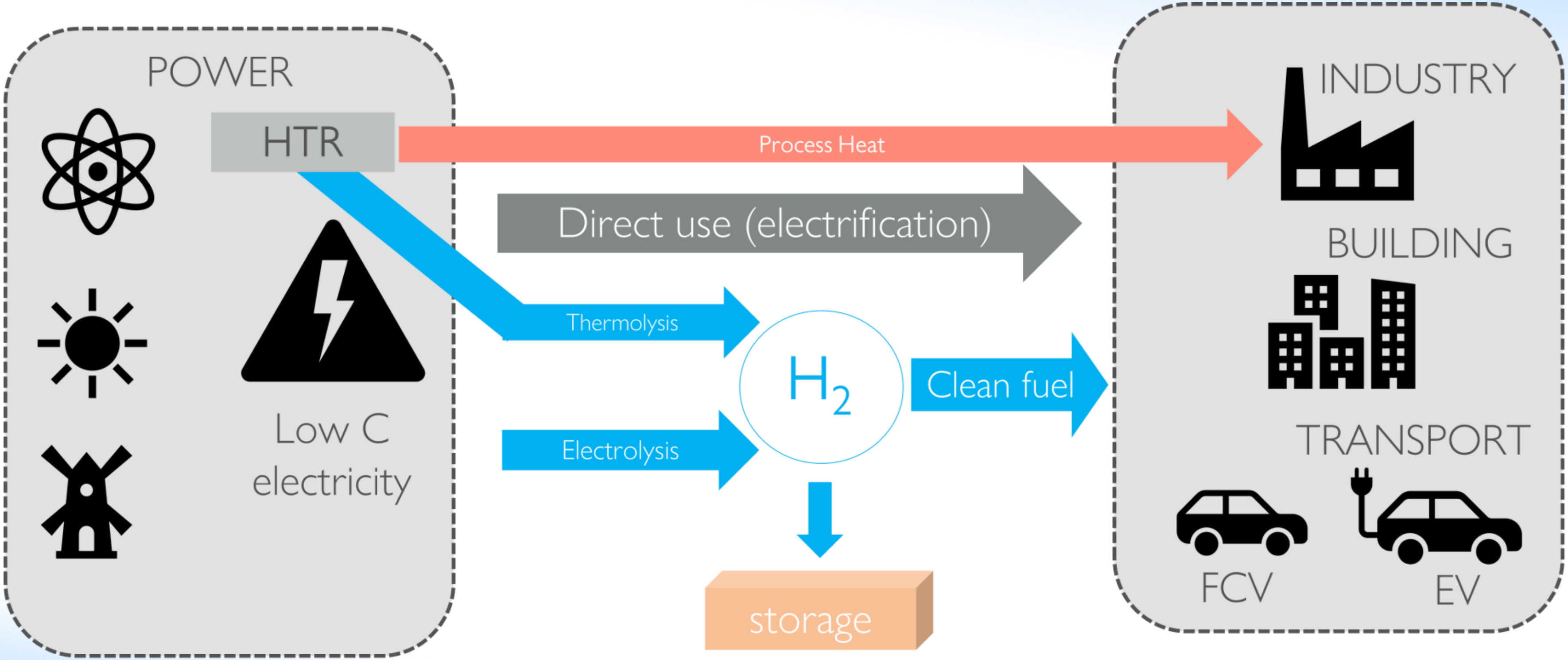
Coupling via Electricity and Hydrogen (electrolysis)

NPPs: typically LWRs



Coupling via Electricity, Heat and and Hydrogen

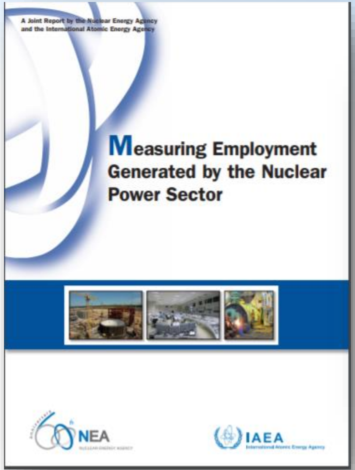
NPPs: typically LWRs + HTRs

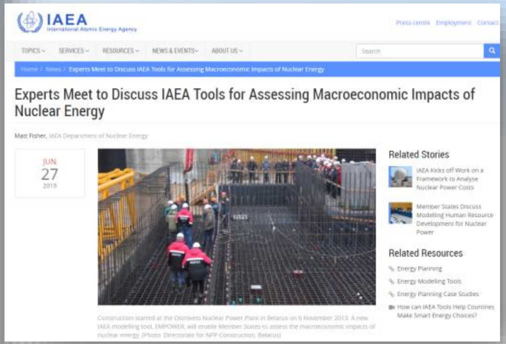


3 low-carbon energy vectors: electricity, heat, hydrogen

Macro-economic impacts of nuclear programmes

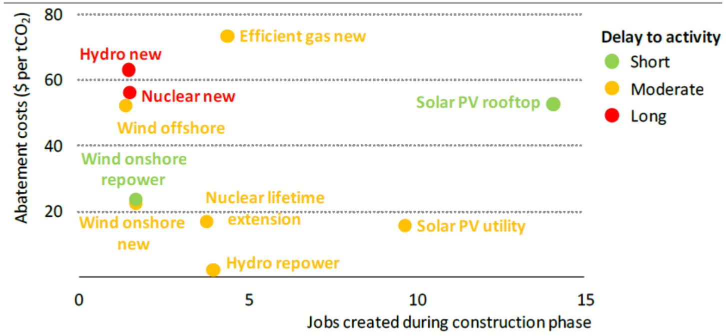
- Energy transition: transformation of energy sectors:
  - Importance of energy policies, level-playing field, taxonomy, green deal, financing support, etc
  - Competition between technologies
  - Socio-economic impacts and accompanying measures (e.g. reconversion)
- Macro-economic impacts of nuclear programmes:
  - Job creation (direct, indirect)
  - Other effects (importance of long-term power supply at stable production costs) – e.g. PPAs with energy-intensive industries
- Post-covid recovery plans and energy transition
  - IEA Sustainable Recovery Report (2020): 4.5 jobs are created per $million invested in LTO projects, or twice more employment than onshore wind
  - For new nuclear, situation comparable to off-shore wind





EMPOWER

Figure 2.3 ▷ Job creation per million dollars of capital investment in power generation technologies and average CO_2 abatement costs



Take-aways

- Challenge of decarbonizing the whole energy sector requires all low carbon technologies
- Nuclear: existing + advanced reactors (SMRs incl. HTRs)
- Economics of existing nuclear: “economy of scale” (+ cost reduction measures)
- Economics of SMRs: “economy of serial production”
  - Economics of HTRs: multiple revenue streams
- HTRs provide unique characteristics that should make this technology attractive from an economic point of view:
  - **Ability to provide all 3 low carbon energy vectors, electricity, heat and hydrogen**
  - **Flexibility to switch / adapt to market conditions – will be an important advantage**
- Besides technological costs specific to HTRs, the “value” to the system needs to be assessed using sophisticated modelling