



IAEA

International Atomic Energy Agency

ABDAN Nuclear Summit
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Non-Electric Applications of SMRs

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Nuclear Power Technology Development Section

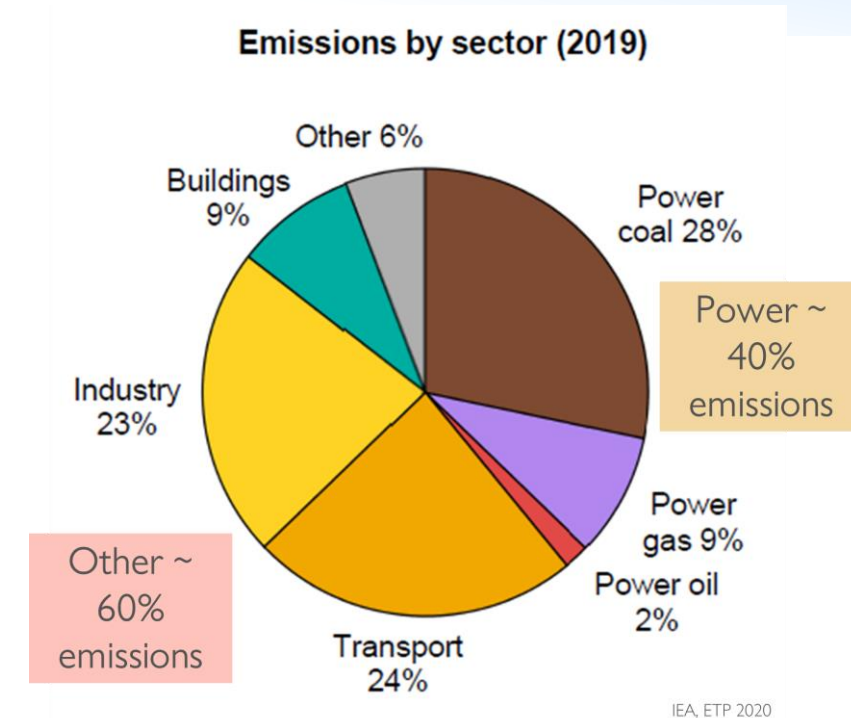
Division of Nuclear Power

Department of Nuclear Energy

Nuclear beyond electricity

The IAEA project on non-electric applications

- Most trajectories to net zero require massive amounts of low-carbon electricity but decarbonising the power sector will not be sufficient.
- Hence there is also a need for low carbon heat & low carbon fuels – and the technologies to produce them - for the “**hard to abate sectors**” that cannot be easily electrified (e.g. industry-steel, cement, marine & air transport, etc.).
- Nuclear energy’s low carbon heat potential mostly untapped until now.
- Non-electric applications have the potential to vastly increase the efficiency of nuclear generation, making good use of waste heat.



Size characteristics of the industrial heat market

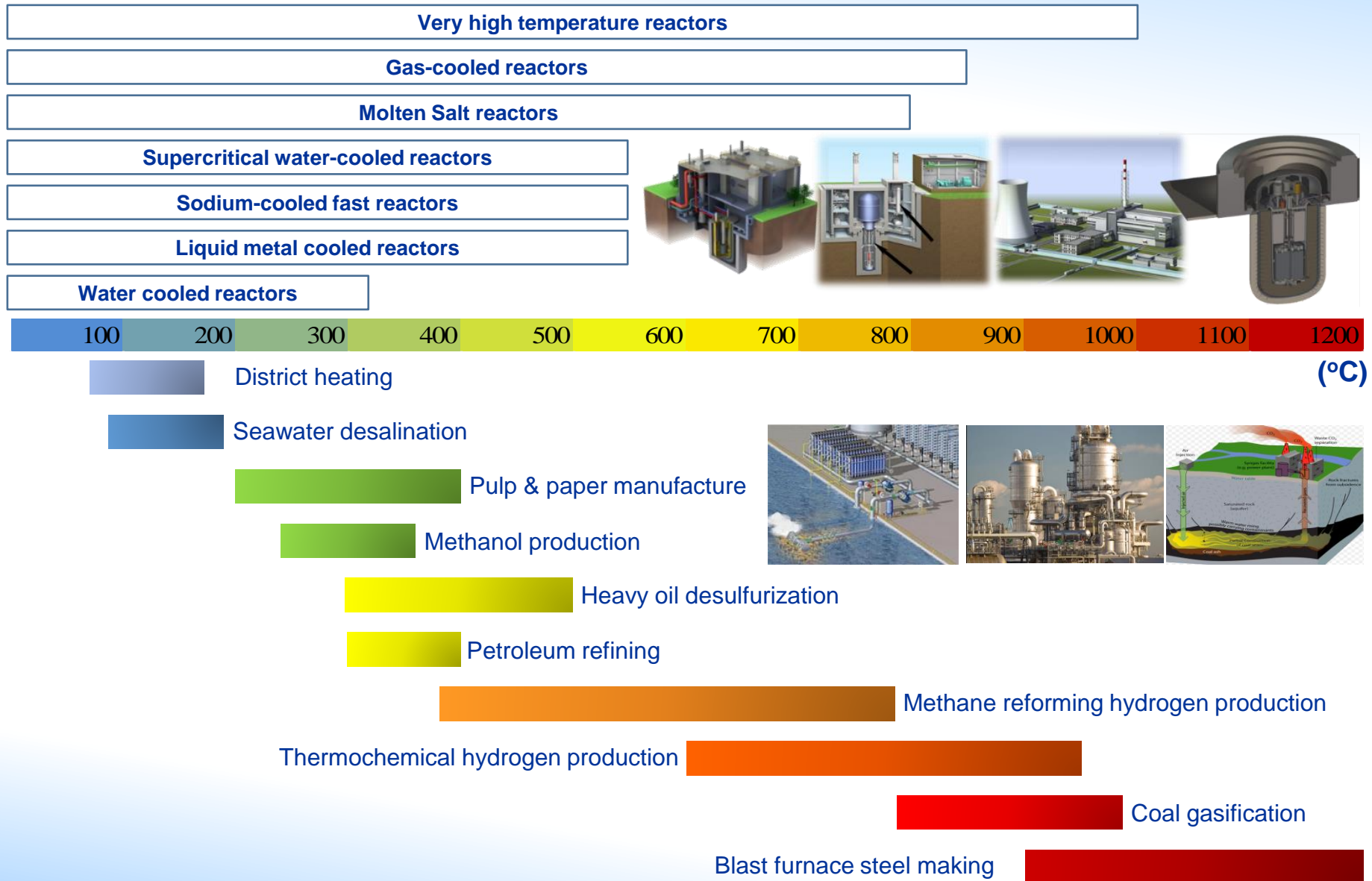
- 50% of the users for industrial processes require less than 10 MWth capacities.
- 40% require between 10 and 50 MWth.
- 99% of the users are included in the 1 to 300 MWth range, which accounts for about 80% of the total energy consumed.

*The nature of industrial heat market is highly fragmented,
hence very much suitable for SMR*

- Individual large users with energy intensive industrial processes (**Desalination, petrochemical, district heating...etc**) cover the remaining portion of the industrial heat market with requirements up to 1000 MWth, and exceptionally even more.

Large reactors for cogeneration in industrial parks

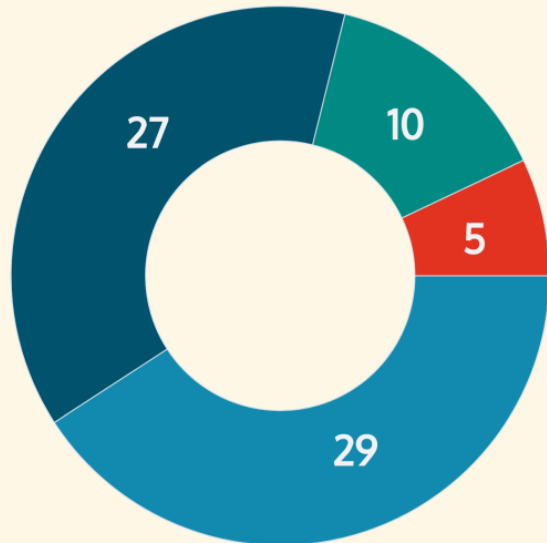
Reactor Technologies for Non-Electric Applications



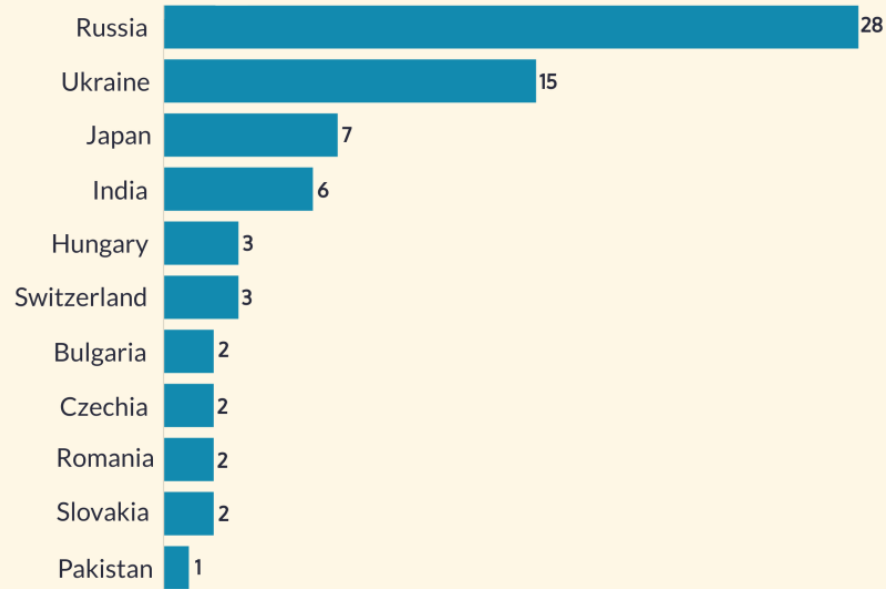
Non-electric Applications – Global Overview

Types of Non-Electric Applications
per reactor

■ Process and District Heating ■ Desalination
■ District Heating Only ■ Process Heat Only



Reactors with Non-Electric Applications
by country



1%
OF AVAILABLE
NUCLEAR HEAT
HAS BEEN USED

Proven technology: about **70** reactors used in cogeneration and over **750** reactor-years experience

Activities of IAEA Project on Non-Electric Applications

IAEA Project on Non-Electric Applications

Education & Training Knowledge Transfer

- TC projects
- Training workshops

R&D

- Coordinated Research Projects (CRPs)
- Collaborating Centres

Events

- Technical Meetings
- Research Coordination Meetings
- Consultancy Meetings
- Webinars
- Conferences
- TWG-ND meetings

Tools & Toolkits

- HEEP
- DEEP
- DE-TOP
- WAMP
- Hydrogen Toolkit
- Desalination Toolkit [FRAMES]

Publications

- Technical Documents
- Nuclear Energy Series Docs
- Meeting Reports
- Peer-Reviewed Journals
- Conference Papers

Nuclear cogeneration

Publications

- **NES - Industrial Applications of Nuclear Energy (2017)**
- **NES - Opportunities for Cogeneration with Nuclear Energy (2017)**
- **NES - Guidance on Nuclear Cogeneration (2019)**

Upcoming:

- **Vendor and User Responsibilities in Nuclear Cogeneration Projects (NES)**
- **Nuclear cogeneration to support climate change mitigation and SDGs (NES)**

Tools & Toolkits

Identification of coupling configurations and analysis of heat extraction and power production

- **DE-TOP**

R&D

Coordinated Research Projects

Just started (March 23rd):

- **Role of Nuclear Cogeneration within the Context of Climate Change (2022-2026)**

Collaborating Centres:

- **Ontario Tech University (Canada) – launch event 02.11.2021**

Education & Training, Knowledge Transfer

- **Non-Electric Applications of Nuclear Power (ICTP NEM School, 28.06-09.07.2021)**
- **TC INT2021001: Supporting Member States' Capacity Building on Small Modular Reactors and Micro-reactors and their Technology and Applications – A Contribution of Nuclear Power to the Mitigation of Climate Change**

Events

- **Technical Meeting on Potential Schemes for Licensing Nuclear Cogeneration Plants (March 29-31, 2021)**
- **Webinar on Nuclear Heat to Decarbonize the Energy Sector (July 13, 2021)**
- **Technical Meeting on the role of nuclear cogeneration applications towards climate change mitigation (October 11-13, 2021)**

Upcoming

- **Technical Meeting on the Planning and Implementation of Nuclear Cogeneration Projects (May 30 – June 01, 2022)**
- **First Research Coordination Meeting on the Coordinated Research Project on Nuclear Cogeneration for Climate Change Mitigation (November 22-25, 2022)**

To be addressed

- **Review of the IAEA Milestones in the Development of a National Infrastructure for Nuclear Power to address aspects of nuclear cogeneration projects**
- **Safety approach for licensing of nuclear cogeneration projects**

Cross-links

- **IAEA wide platform on SMR and their applications**
- **TWG-SMR, TWG-GCR**
- **GIF**

Nuclear desalination and water management



Publications

- **TECDOC – New Technologies for Seawater Desalination Using Nuclear Energy (2015)**
- **NES – Efficient water management in WCR (2012)**
- **TECDOC – Status of Nuclear Desalination in IAEA Member States (2007)**
- **TECDOC – Economics of Nuclear Desalination (2007)**
- **TECDOC – Optimization of the coupling of nuclear reactors and desalination systems (2005)**
- **TECDOC – Status of design concepts of nuclear desalination plants (2002)**
- **TECDOC - Safety Aspects of Nuclear Plants Coupled with Seawater Desalination Units (2001)**
- **Tech Rep Series - Introduction of Nuclear Desalination (2000)**
- **TECDOC – Examining the economics of seawater desalination using the DEEP code (2000)**
- **TECDOC – Floating nuclear energy plants for seawater desalination (1997)**
- **TECDOC – Use of nuclear reactors for seawater desalination (1990)**

Tools&Toolkits

Identification of cost options for desalted water and/or power

- **DEEP (Desalination Economic Evaluation Programme)**

Identification of water needs in NPPs, and comparative assessment of various cooling systems)

- **WAMP (WATER Management Programme)**

Links to IAEA related activities

- **Nuclear Desalination Toolkit (a new version is to be released)**

R&D

Coordinated Research Projects (completed)

- **Optimization of the Coupling of Nuclear Reactors and Desalination Systems**
- **Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies**
- **New Technologies for Seawater Desalination using Nuclear Energy**
- **Application of advanced low temperature desalination systems to support NPPs and non-electric applications**

Events

- **Consultancy Meeting on developing plans for producing potable water using SMRs (Apr 27th, 2022)**

Upcoming:

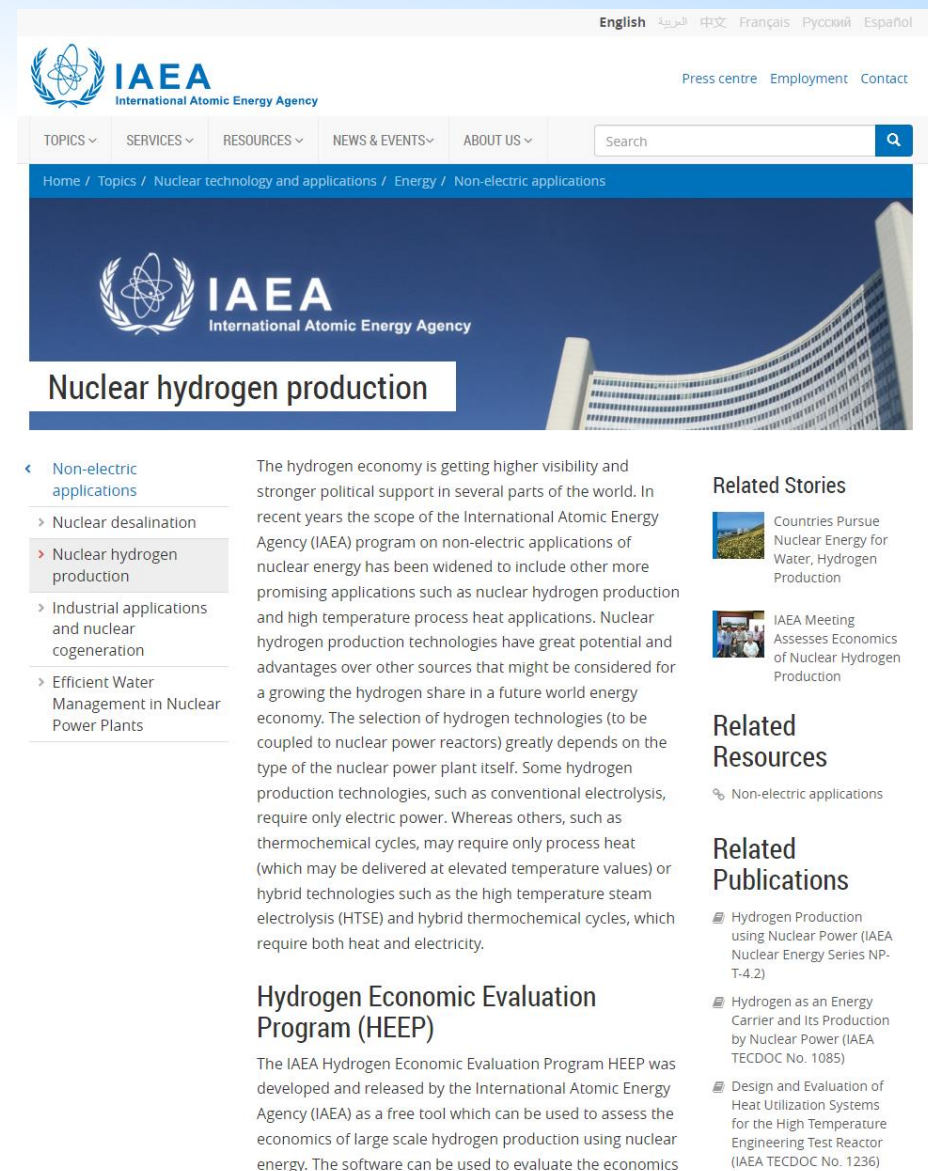
- **Meeting of the Technical Working Group on Nuclear Desalination (TWG-ND) (6-8 September 2022)**

In progress

- **Plan for producing potable water economically using small and medium-sized nuclear reactors (IAEA GC65 Resolution)**

IAEA hydrogen-related resources

- IAEA hydrogen webpage:
<https://www.iaea.org/topics/non-electric-applications/nuclear-hydrogen-production>
- Overall objective: support Member States in assessing options for hydrogen production using nuclear energy.
- Codes (HEEP, HydCalc, FRAMES);
- Hydrogen Toolkit;
- Publications;
- Meetings and events;
- Research and Development (CRPs).



The screenshot shows the IAEA website page for "Nuclear hydrogen production". The page features the IAEA logo and navigation menu at the top. The main content area includes a sidebar with a list of categories: "Non-electric applications", "Nuclear desalination", "Nuclear hydrogen production" (highlighted), "Industrial applications and nuclear cogeneration", and "Efficient Water Management in Nuclear Power Plants". The main text discusses the hydrogen economy and the IAEA program on non-electric applications of nuclear energy. It mentions that the scope has been widened to include other promising applications such as nuclear hydrogen production and high temperature process heat applications. The text also notes that the selection of hydrogen technologies depends on the type of nuclear power plant and that some technologies require only electric power, while others require process heat or both. The page also includes a section for "Related Stories" with two items: "Countries Pursue Nuclear Energy for Water, Hydrogen Production" and "IAEA Meeting Assesses Economics of Nuclear Hydrogen Production". There is also a "Related Resources" section with a link to "Non-electric applications" and a "Related Publications" section with three items: "Hydrogen Production using Nuclear Power (IAEA Nuclear Energy Series NP-T-4.2)", "Hydrogen as an Energy Carrier and Its Production by Nuclear Power (IAEA TECDOC No. 1085)", and "Design and Evaluation of Heat Utilization Systems for the High Temperature Engineering Test Reactor (IAEA TECDOC No. 1236)".

IAEA hydrogen-related meetings and events

- IAEA GC65 side event:
Innovations in the Production and Use of Nuclear Hydrogen for a Clean Energy Transition,
September 21, 2021.
- *3rd Research Coordination Meeting on Assessing Technical and Economic Aspects of Nuclear Hydrogen Production for Near Term Deployment*,
15-17 November 2021.
- *Technical Meeting on Assessing Technologies that Enable Nuclear Power to Produce Hydrogen*, 7–9 Dec 2020.
- *Technical Meeting on the Role of Nuclear Hydrogen Production in a Low Carbon Economy*, Apr 8-10 2019.
- TM “*Developing a Roadmap for the Commercial Deployment of Nuclear Hydrogen Production*”
(jointly organized with PESS, April 5-7), to be followed by a CM on 8-10 June, 2022.



Upcoming

- International Workshop on the Role of Low Carbon Hydrogen for a Net Zero Energy System – June 22-24, Aix-en-Provence, France, IAEA + CEA + IEA, PESS + NPTDS.
- World Energy Hydrogen Conference (WHEC) - International Hydrogen Energy Association + Ontario Tech University organize the conference in cooperation with the IAEA - Istanbul, Turkey, 26-30 June, 2022.

IAEA hydrogen-related R&D (Coordinated Research Projects)

- Coordinated Research Projects (CRP 2018-2022):

“Assessing Technical and Economic Aspects of Nuclear Hydrogen Production for Near-Term Deployment”.

Upcoming

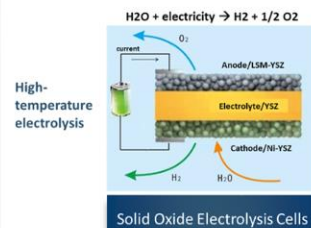
- New CRP (2022-2026): *“Role of Nuclear Cogeneration for sustainable development”*

For nuclear cogeneration, with a focus on advanced nuclear hydrogen production, on advanced desalination using nuclear energy, district heating and industrial uses:

- Development of approaches, case studies, and supporting data for techno-economics assessment;
- Identification and development of technological aspects and advances to increased competitiveness;
- Quantify benefits of nuclear waste heat utilization on the water impact of nuclear installations and resulting environmental benefits for water bodies and climate change;
- Identification of risk factors, uncertainties and best practices in nuclear cogeneration projects to guide Member States' informed decision on the deployment of such projects.

Solid Oxide Electrolysis Cells (SOEC)

- The raw material: pure water, hydrogen consumption: $\sim 3\text{kWh}/\text{Nm}^3\text{H}_2$
- Industrial waste, nuclear energy, and



MLSR

IS-process development in JAEA (update)



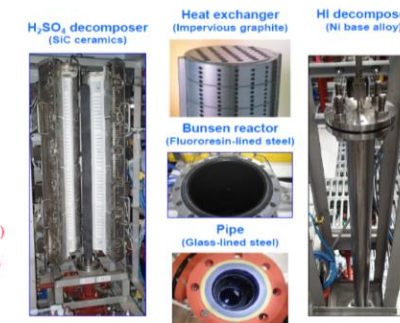
- Structural materials for each process environment from corrosion tests

Liquid phase

- SiC ceramic (H₂SO₄ decomposer and reboiler) (-400°C)
- Graphite (impervious) (EED and heat exchanger for HI solution) (25 - 200°C)
- Fluororesin-lined steel (tank, pipe and heat exchanger for low temp.) (25 - 100°C)
- Glass lined-steel (tank and pipe) (25 - 200°C)

Gaseous phase

- SiC ceramic (H₂SO₄ decomposer) (400 - 900°C)
- Ni base alloy (HI decomposer and pipe for HI gas) (100 - 500°C)
- JIS SUS316 (Utility system) (RT)



IAEA hydrogen-related publications

- TECDOC - *Hydrogen as an Energy Carrier and its production by Nuclear Power*, (1999)
- NES - *Hydrogen Production using Nuclear Power*, (2012)
- TECDOC - *Examining the Techno-economics of Nuclear Hydrogen Production and Benchmark Analysis of the IAEA HEEP Software* (2018).

Upcoming

- TECDOC - *Outcomes of the CRP Assessing Technical and Economic Aspects of Nuclear Hydrogen Production for Near-Term Deployment*.
- NES - *Nuclear cogeneration towards climate change mitigation and sustainable development goals*.
- NES - *Vendor and user requirements and responsibilities in nuclear cogeneration projects*.
- NES - *Roadmap for the Commercial Deployment of Nuclear Hydrogen Production*, Summarizing the results of the corresponding TM & CM.

IAEA hydrogen-related tools and toolkits



- HEEP: Techno-economic assessments of hydrogen generation options.

New version released on the IAEA website since Nov 2021 (improved GUI and sensitivities studies)

https://www.iaea.org/sites/default/files/22/01/2021-11-21_setup_heel.zip

- HydCalc: Hydrogen production cost calculator with nuclear and other technologies.

<https://www.iaea.org/sites/default/files/18/07/hydcalc.zip>

- Toolkit on nuclear hydrogen.

<https://www.iaea.org/sites/default/files/20/04/nuchydtoolkit.zip>

- FRAMES: Integrated assessment of energy systems, including for H₂ production.

The image displays two software interfaces. The top interface is HEEP (Mandatory details of all plants and facilities), showing various input fields for financial and operational parameters. The bottom interface is HydCalc (Hydrogen Production Calculator), showing a user-defined calculation for hydrogen production cost.

HEEP - [Mandatory details of all plants and facilities]

View Additional inputs Help Exit

Finance Details

Discount rate (%): 5 Inflation rate (%): 1

Ignore "Inflation"

Equity % : Debt % : Borrowing interest (%) : Tax Rate (%) : Depreciation period (yrs) : Construction (yrs) : 5

30 : 70 : 10 : 10 : 20

Facilities to be considered for evaluation

Nuclear Power Generation Hydrogen Generation

Nuclear Power Plant Details

Use Library Utility Read from Library Create new Library Update NPP Library

List of nuclear plant files in the library: APWR1117, APWR360

Parameter	Value	Add. Data
Thermal rating (MWth/unit)	3385	Edit
Heat for H2 plant (MWth/unit)	0	Edit
Electricity rating (MWe/unit)	1117.05	Edit
Number of units	2	Edit
Initial fuel load (kg/unit)	75000	Edit
Annual fuel feed (kg/unit)	25000	Edit

Hydrogen Generation Plant Details

Use Library Utility Read from Library Create new Library Update H2GP Library

List of hydrogen plant files in the library: CE04, CE08

Location of H2 Generation Plant: Co-located Away from NPP

Parameter	Value	Add. Data
H2 generation per unit (kg/yr)	1.26E+08	Edit
Heat consumption (MWth/unit)	0	Edit
Electricity required (MWe/unit)	719	Edit
Number of units	1	Edit

HydCalc - Hydrogen Production Calculator

Select hydrogen production technology: Steam Methane Reformation

Select feedstock price/basis of estimation: \$6.86/MMBtu

Adjusted feedstock price, please use comma as separator:

Calculate Enter the amount and unit of hydrogen demand: 1 kg

The estimated cost of the hydrogen demand is: \$ 1.9

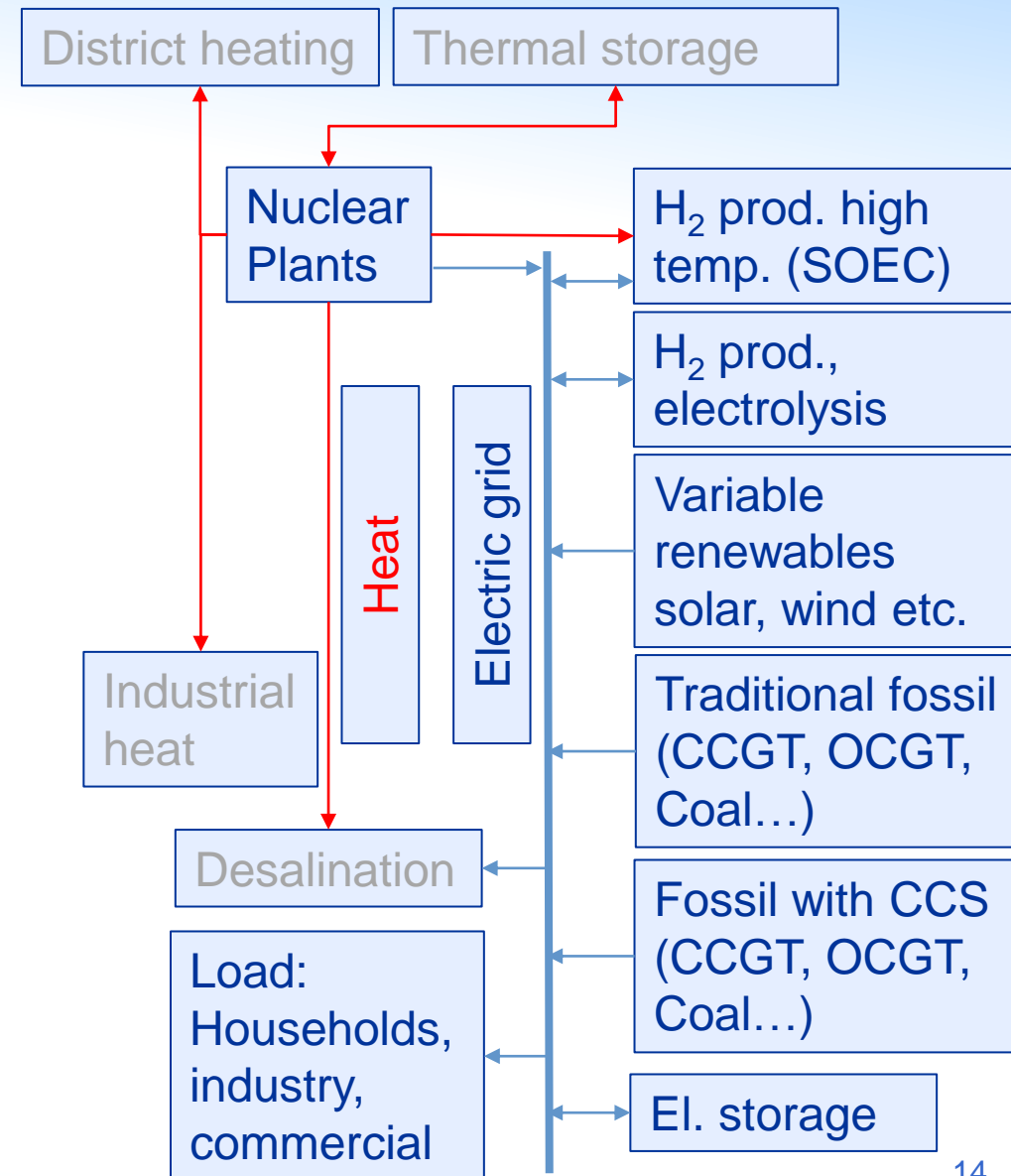
Using life cycle assessment, the average of CO2 released is: 11.6 kg

Add CO2 Tax 50 \$/tonne

The CO2 adjusted estimation cost of hydrogen demand is: \$ 2.4

FRAMES: purpose/status/planned extensions

- Growing interest in integrated energy systems (Member States and IAEA), in particular with nuclear & renewables and with Non-Electric Applications
- IAEA is developing an in-house capability (FRAMES)
- Can quantify the value that nuclear brings to integrated systems, and inform policy
- Complete H₂ model, with 4 production methods.
- Other non-electric applications (desalination, thermal storage, district heating, industrial heat, etc.) on the drawing board.
- FRAMES is well suited to quantify the synergisms of non-electric applications and nuclear energy.

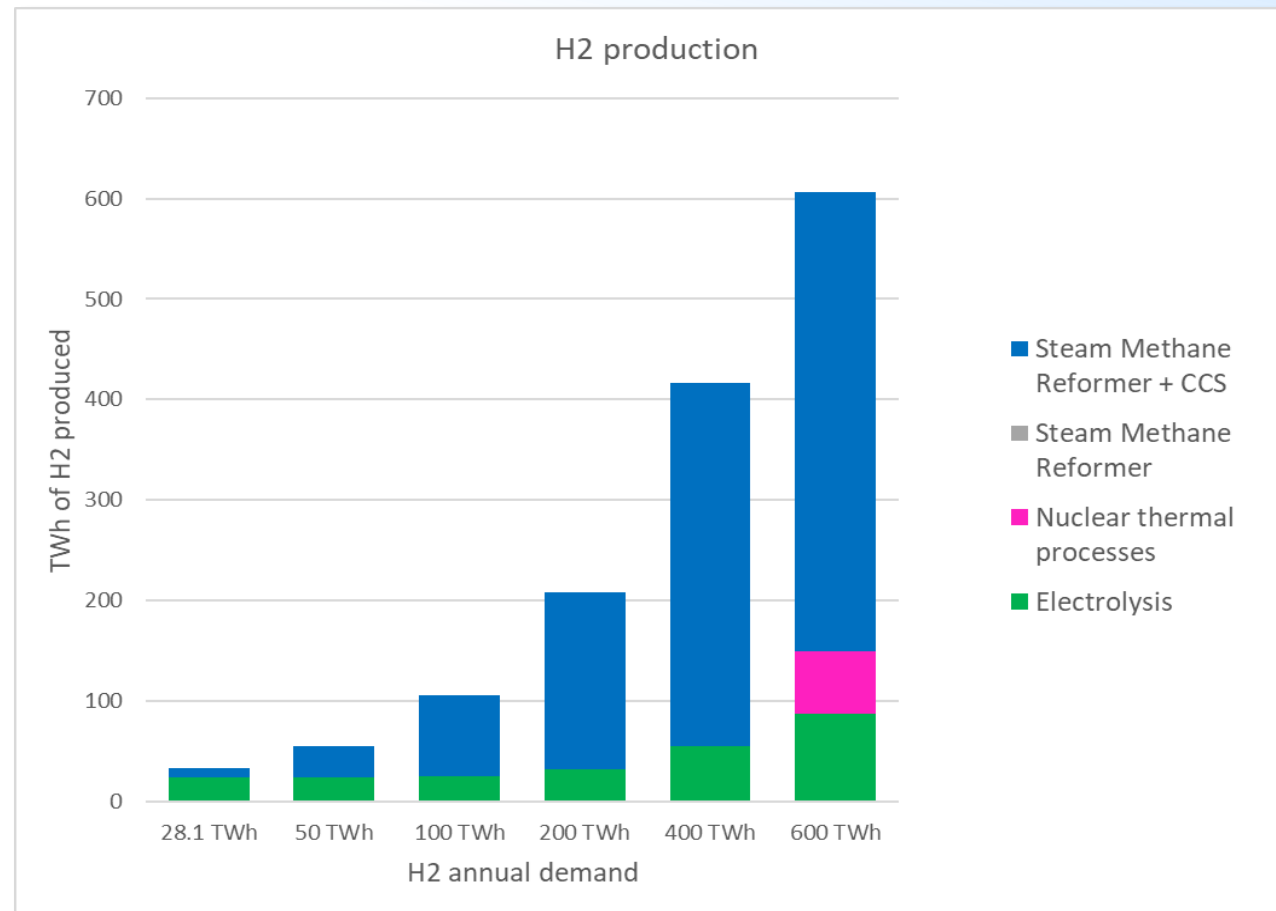


Four H₂ production options in FRAMES

- Conventional steam methane reforming (SMR) of natural gas;
- Steam methane reforming of natural gas with CCS (i.e. blue hydrogen);
- Low temperature electrolysis using grid electricity (PEM or Alkaline);
- High temperature processes using nuclear heat. It can be thermochemical cycles (e.g. S-I, Cu-Cl etc.) or high temperature steam electrolysis (HTSE).

FRAMES allows to study the relative competitiveness of the four processes under different sets of assumptions: CO₂ emission limits, costs of the various technologies, etc.

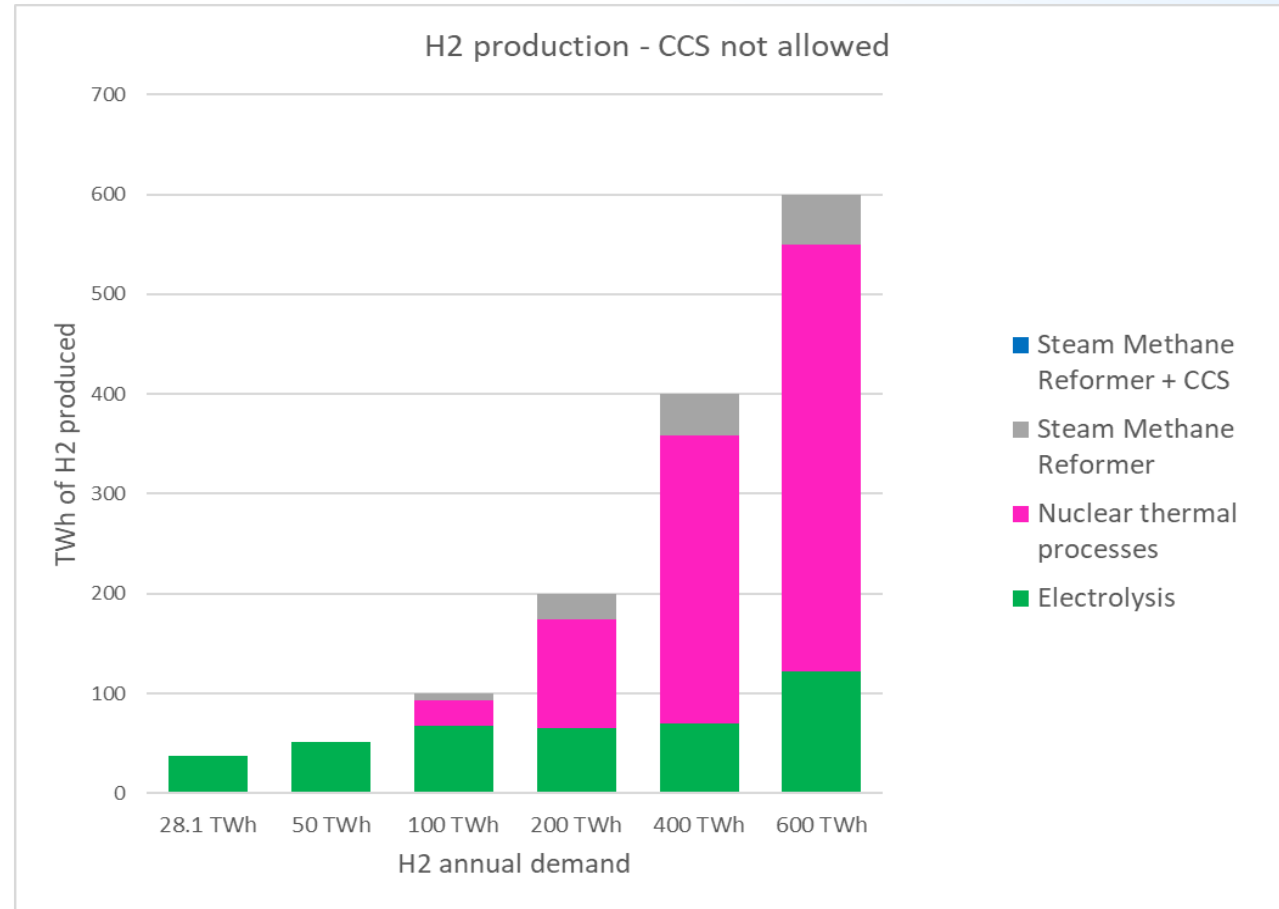
Steam methane reforming with CCS plays the leading role in producing large amounts of H₂



The high level of SMR deployment depends on some key assumptions:

- Fugitive CH₄ emissions from SMR+CCS have not been considered.
- High CO₂ capture rate (90%)
- Natural gas price (~\$6/MMBTU).

In the absence of CCS, nuclear plays the leading role in producing low-carbon H₂ through the use of nuclear heat



These results depend on the relative cost of the various low-carbon technologies.



IAEA

International Atomic Energy Agency



8 December 1953



1 to 23 October 1957



11 December 1957



1959



10 December 2005



1958 to 1979



23 August 1979

Thank you for your attention!

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Atoms for Peace and Development...