Analysis and Engagement on Non-electric and Cogeneration Applications of Nuclear Energy

Dr. Chukwudi Azih and Mr Brent Wilhelm

28 August 2025

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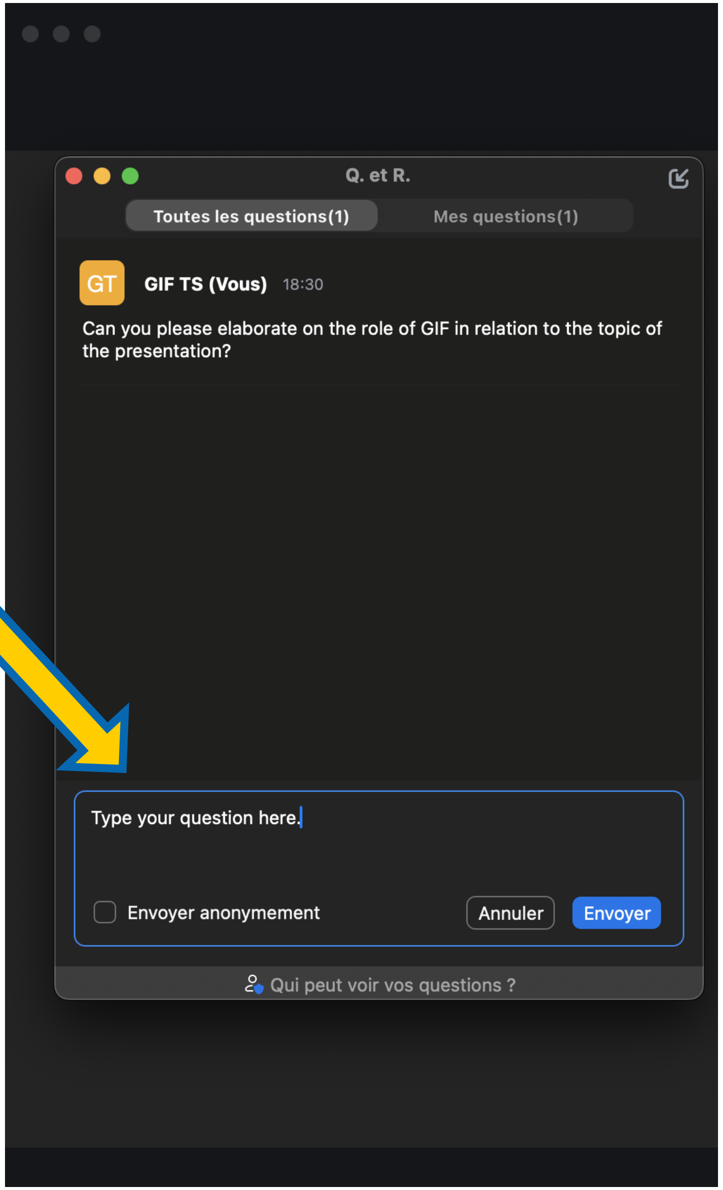

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Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

NEA
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Meet the Presenters

Dr. Chukwudi Azih is a Senior Research Scientist at Canadian Nuclear Laboratories and heads a Section at CNL that performs experimental investigations on high temperature and pressure scenarios in current and advanced nuclear reactors. He serves in a leadership role, from a technical standpoint, in areas of heat removal and utilization from CANDU reactors, GIF fleet of reactor designs, and SMRs. He is a Canadian representative in the Program Management Board for Thermal-Hydraulics and Safety of the GIF System Arrangement and in the Non-Electrical and Co-generation Applications of nuclear heat GIF Working Group. He applies his computational and experimental heat transfer expertise to lead efforts in developing technical understanding and facilities for active and passive heat removal systems for nuclear reactors, and thermal storage applications in integrated energy systems involving nuclear energy technology.

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Mr Brent Wilhelm is a Nuclear Energy Technology and Economics Analyst at the Nuclear Energy Agency and serves the GIF as Technical Secretary to the Non-Electric and Cogeneration Applications (NECA) Working Group and the VHTR system. Prior to this role, Brent worked for the Government of Canada as a Nuclear Science and Technology Advisor with Natural Resources Canada. Brent received both a MSc and BSc in Physics from the University of Guelph where he specialized in nuclear energy and planetary bulk geochemistry.

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Outline

- Overview of the GIF Non-Electric and Cogeneration Applications (NECA) Working Group (Azih)
- Summary of engagement with industry end users and regulators (Azih)
- Outcomes from “System Analysis: Hydrogen Production from Nuclear Energy” report (Wilhelm)

Non-Electric and Cogeneration Applications (NECA) Working Group
Overview

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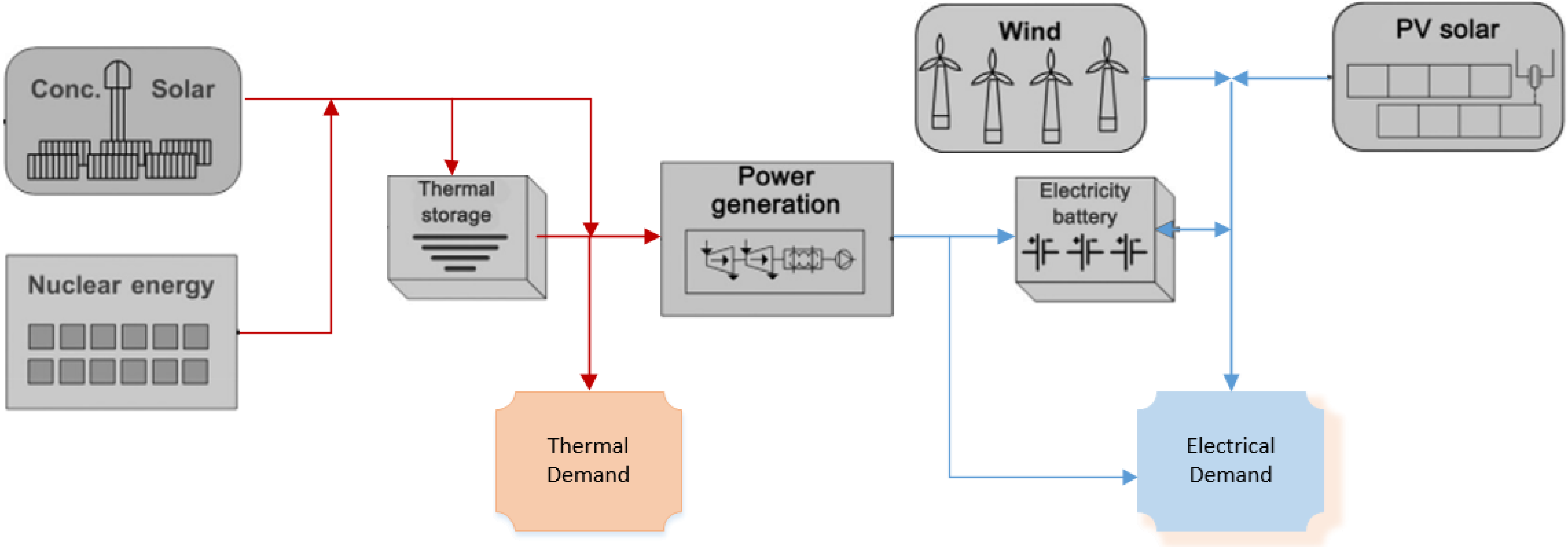
More Than Electricity



Adapted from: Handbook of Small Modular Nuclear Reactors 2021 Jan 1 (pp. 323-356). Woodhead Publishing

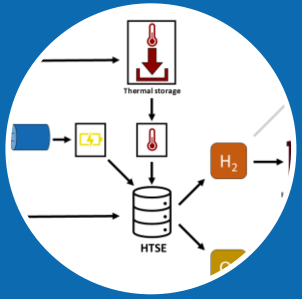
NECA WG Objectives

NECA WG Objectives

Biennial	In-person NECA workshops
Ad-hoc	Industrial in-person and virtual workshops
Bi-monthly	WG membership meetings
Annual	System analysis publications
Rolling updates	NECA database

Non-Electric and Cogeneration Applications of Nuclear Energy (NECA) WG

Scope and membership



Conduct system analysis with respect to KPIs

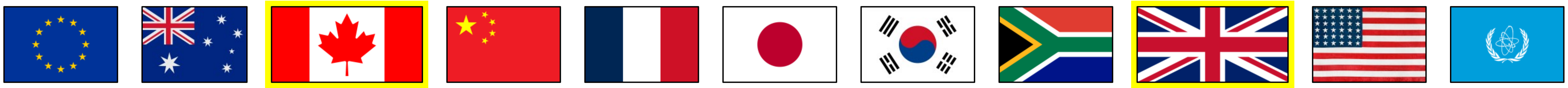
Engaging industrial end-users

Maintain the Non-Electric Applications Public Database

Support regulatory readiness on non-electric applications of nuclear energy systems

Continue international collaboration (IAEA, IEA, NEA, WNA)

Coordinate relevant activities across GIF systems and working groups



History of Non-Electric and Cogeneration Applications of Nuclear Energy

- **More than 70 reactors with over 750 reactor-years globally of experience as of 2019**
  - Accounts for less than 0.5% of the total nuclear thermal output of over 440 reactors
  - Mostly water-cooled reactors

- District Heating:
  - 43 reactors have been used, ~500 reactor years
  - Average 5% thermal output; range 5 to 240 MWth
  - Typically, <150ºC
- Desalination of water
  - 17 reactors have been used, ~250 reactor years
  - Mostly using thermal processes (multi-effect distillation and multi-stage flash), <130ºC
- Industrial Process Heat
  - >10 reactors
  - Typically based on medium pressure steam, <250ºC

GIF – "Position Paper on Non-Electric Applications of Nuclear Heat", 2022

IAEA - "Opportunities for Cogeneration with Nuclear Energy" NP-T-4.1, 2017

IAEA - "Guidance on Nuclear Energy Cogeneration" NP-T-1.17, 2019

NEA – "Beyond Electricity: The Economics of Nuclear Cogeneration", 2022

History: District heating

43 reactors have been used, ~500 reactor years: some examples

Country	Plant	Application	Status
China	Haiyang NPP – PWR Qinshan NPP – PWR	1 million residents (1,200 MW_t) 4 thousand residents	2020 – Operating 2021 – Operating
Czechia	Temelin NPP – PWR	8 thousand residents	2020 – Operating
Hungary	Paks NPP – PWR	20 thousand residents (40 MW_t) - 5 km	1982 – Operating
Romania	Cernavoda NPP – PHWR	18 thousand residents (46 MW_t)	1996 – Operating
Russia	Kola NPP – PWR Smolensk NPP – RBMK KLT-4S Floating – PWR	232 MW_t - 11 km 30 thousand residents (<520 MW_t) – 5 km 70 MW_t	1973 – Operating 1982 – Operating 2020 – Operating
Switzerland	Beznau NP – PWR	11 towns (<80 MW_t) – 130 km network	1984 – Operating
Canada	Bruce A NPP – PHWR	15 MW_t , 6 km	1972 – 2006

History: Desalination

17 reactors have been used, ~250 reactor years: some examples

Country	Plant	Application		Status
China	Hongyanhe NPP – PWR Haiyang NPP – PWR Tianwan NPP – PWR	Reverse osmosis (RO) Thermal process/RO Reverse osmosis	~10,000 t/day ~36,000 t/day	2021 – Operating 2021 – Demonstrated 2024 – Operating
India	Kudankulam NPP – PWR Madras Station – PHWR	Thermal process Thermal process/RO	~7,600 t/day ~6,300 t/day	2012 – Operating 2002 – Operating
Japan	Ehime Ikata-3 – PWR Fukui Ohi 4 – PWR Fukui Takahama – PWR	Reverse osmosis Reverse osmosis Thermal process	~2,000 t/day ~2,600 t/day ~1,000 t/day	1994 – Operating 1989 – Operating 1983 – Operating
Pakistan	Karachi NPP – PHWR	Thermal process/RO	~2,000 t/day	2009 – Operating
Russia	Rostov NPP – PWR	Thermal process	~9,600 t/day	2010 – Operating
USA	DCPP NPP – PWR	Reverse osmosis	~2,500 t/day	1985 – Operating
Kazakhstan	Mangyshlak NPP – SFR	Thermal process	~80,000 t/day	1972 – 1999

History: Industrial Heat

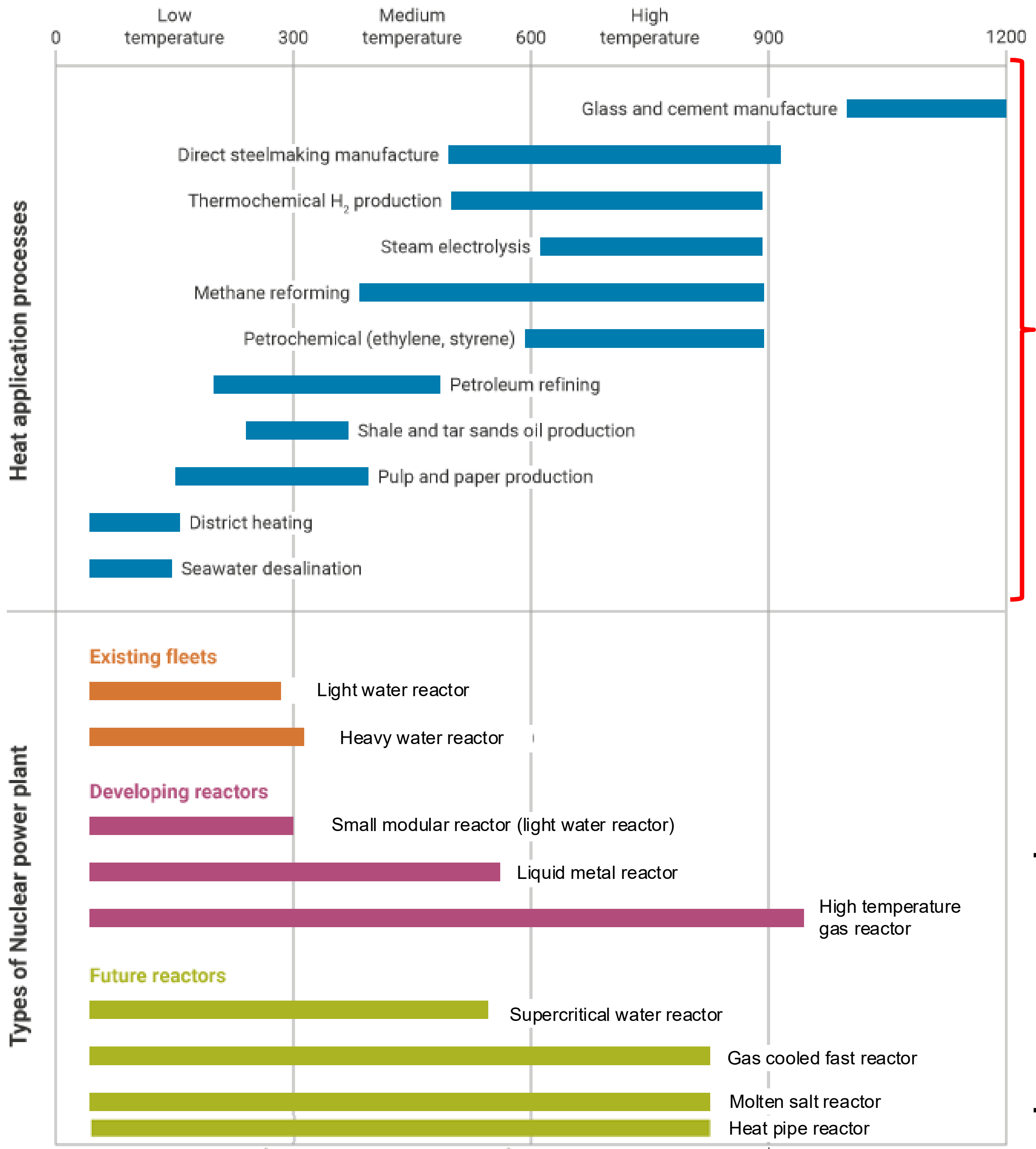
Over 10 reactors have been used

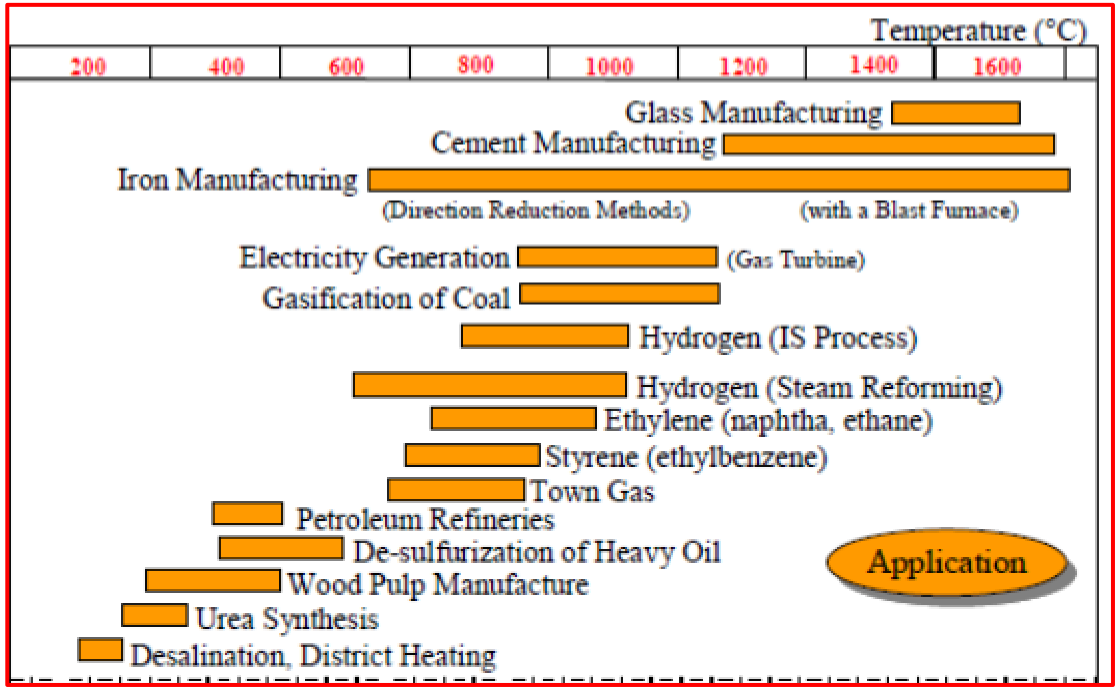
Country	Plant	Application	Status
China	Tianwan NPP – PWR	Petrochemical – 248°C, 600 t/h steam	2024 – Operating
Switzerland	Beznau NPP – PWR Gösgen NPP – PWR	Paper – 60 t/h steam Cardboard – 200°C, 45 MWt, 70t/h steam	1984 – Operating 1979 – Operating
Canada	Bruce A NPP – PHWR	Heavy water – 750 MW_t plastic, agriculture, ethanol – 72 MW_t	1972 – 2006
Germany	Stade – PWR	Salt refinery – 270°C, 60 t/h steam	1984 – 2003
Norway	Halden – BWR	Pulp/Paper mill – 20 MW_t, 60 t/h steam	1964 – 2018

Heat Applications

IAEA - "Opportunities for Cogeneration with Nuclear Energy" NP-T-4.1, 2017

GIF – "Generation IV Roadmap – Crosscutting Energy Products R&D Scope Report", 2022





GIF reactors

Non-Electric Applications Public Database

Initial database completed in 2023 and comprises an initial inventory of NEANH activities.

Global repository of activities relevant to non-electric applications coupled with nuclear energy systems.

Database includes information on relevant activities in the following areas:

1. Case Studies
2. Collaborative initiatives
3. Past or existing demonstration projects (or relevant commercial systems)
4. Planned demonstrations or commercial systems
5. Modelling tools

Plans to finalise digital database in 2025

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In-person workshops

Biennial Workshops

October 3, 2022. Toronto Ontario Canada. 150 participants.

- **Held in conjunction with the GIF industry Forum**
- **Co-organised by the International Framework for Nuclear Energy Cooperation**
- **On the margins of the Gen-IV and Small Reactors (G4SR) conference.**
- Key Findings:
  - There are historic precedents for coupling other technologies with nuclear technology.
  - There is a significant need for the development and sharing of detailed data by relevant parties, including by building demonstration projects.
  - In addition to high temperature heat, there is significant demand for heat applications below 550ºC.
  - There are a range of options for owner-operator models. Energy end-users do not desire to own and operate a reactor themselves or deal with the waste produced.
  - Uncertainties were voiced over costs and regulatory processes.

Biennial Workshops

April 26, 2024. Busan, Korea. 75 participants.

- **Hosted by Korean Nuclear Industry Association (KAIF) and the Korea Nuclear International Cooperation Foundation (KONICOF)**
- **Co-organised with Korea Atomic Energy Research Institute (KAERI)**
- **On the margins of the Korea Atomic Power (KAP) Annual Conference.**
- Key Findings:
  - Coordination among international initiatives to share information and leverage complimentary interests.
  - Honest communication about readiness and timelines of this technologies to build confidence.
  - End users emphasize commercial viability via demonstration. There is strong demand for large-scale clean heat.
  - Analysis of the overall hydrogen value chain and integrated system operation is needed to identify the competitiveness of nuclear energy to produce hydrogen.
  - There are existing tools that could help industrial end users assess the opportunity in nuclear, including through research institutions in GIF member countries and the IAEA.

April 2024 Workshop on Non-Electric and Hybrid Applications of Nuclear Energy

Special Sessions

- **May 2023,** Sustainable Nuclear Energy Technology Platform (SNETP) forum workshop on Non-Electric and Hybrid Energy Systems in Gothenburg, Sweden.
- **January 2024,** 1st Joint IEA-GIF Meeting on H2 from Nuclear Energy and NEANH System Analysis workshop in Idaho Falls, USA.
- **February 2024,** Senior Industry Advisory Panel **(**SIAP) Special Session on NEANH in Ottawa, Canada.
- **January 2025,** 2nd Joint IEA-GIF-NEA Workshop on H2 from Nuclear Energy and Joint System Analysis Workshop in Paris, France.

Engagement with industry end users and regulators

2025 Engagement Activities

Industrial End-User Virtual Workshop

Focus on regulatory readiness perspectives

17-18 June 2025

NECA Deep Dive

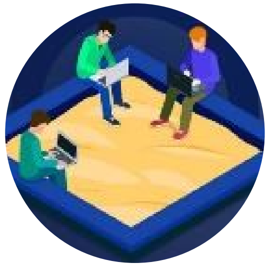
On the margins of the EG/PG meeting in Busan, Korea

October 13-17, 2025

Regulator Virtual Workshop

Informed by end user engagement

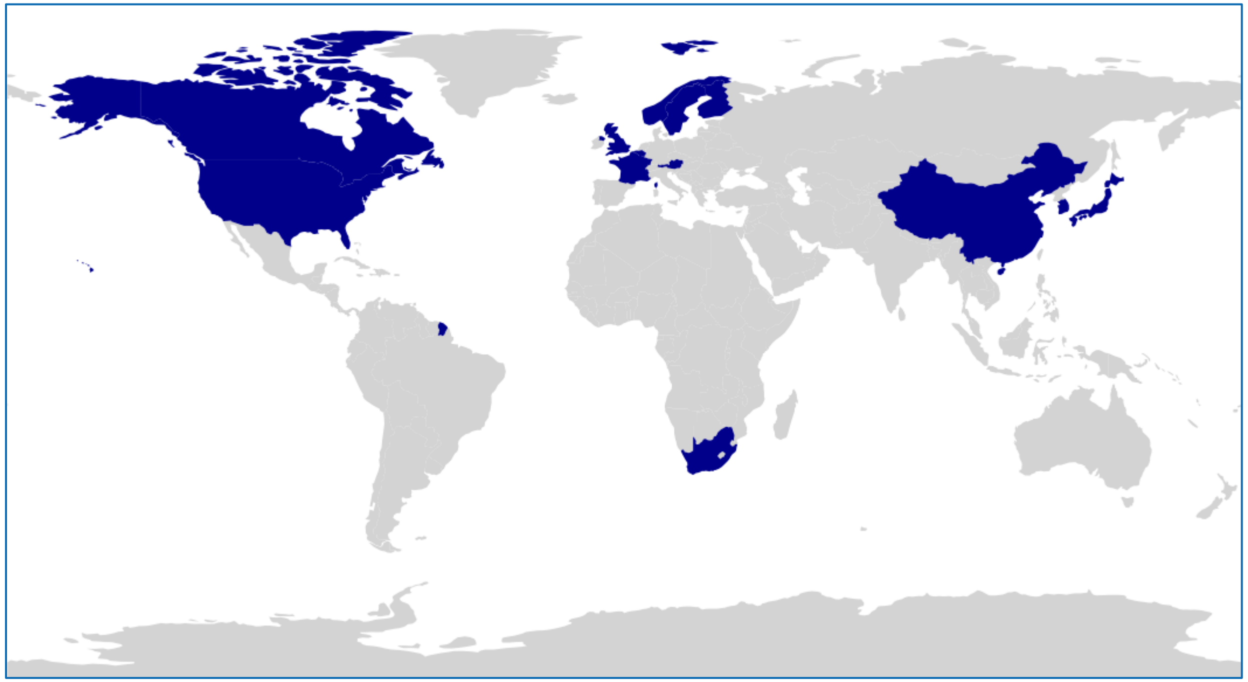
12-13 November 2025



Non-Electric & Cogeneration Virtual Workshop with End Users

- This two-day virtual event brought together industrial energy end users, regulators, and technology vendors to discuss non-electric and cogeneration applications of nuclear energy
- Invitation-only, following Chatham house rules to enable open discussion and information sharing
- Sessions:
  1. Operational experience with non-electric systems
  2. District heating and industrial heating networks
  3. Diversity of non-electric and cogeneration applications of nuclear energy
  4. Opportunity for process industries

Geographic distribution of the 74 attendees in 14 countries:



Participation from: United Kingdom (15), France (15), Canada (11), Korea (7), United States (7), and China (5), as well as participation from Sweden, South Africa, Norway, the Netherlands, Japan, Austria, Finland, and Belgium.

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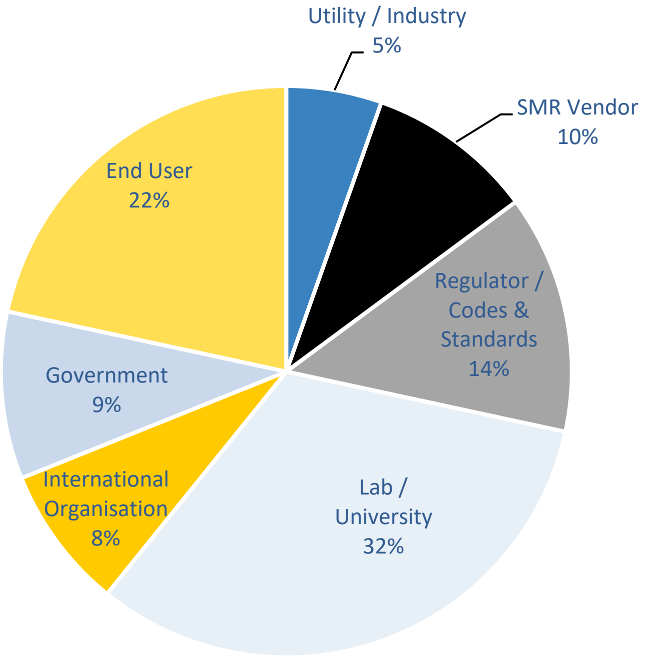
www.gen-4.org/resources/events/non-electric-cogeneration-virtual-workshop-end-users

Non-Electric & Cogeneration Virtual Workshop with End Users

Key findings

- CHP is mature but deployment depends on local conditions
- Experience from past and current projects shows that close physical and functional integration between reactors and industrial facilities requires coordination between multiple industries
- Demonstration projects critical for confidence and regulatory clarity
- Process industries well-positioned for FOAK projects
- Public trust and policy evolution are essential

Audience composition:



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Non-Electric & Cogeneration Virtual Workshop with End Users

- Full workshop summary available on the event webpage:
  - www.gen-4.org/resources/events/non-electric-cogeneration-virtual-workshop-end-users
- The NECA WG continues to engage with end users bilaterally to:
  - support regulatory engagement activities in November 2025
  - Update the programme of work for NECA starting from 2026

Workshop Proceedings GEN IV International Forum — Expertise | Collaboration | Excellence

Non-Electric & Cogeneration Virtual Workshop with End Users

WORKSHOP SYNOPSIS AND FINDINGS

17-18 June 2025; 13:00–16:00 CEST
Virtual

Contents

Workshop Overview and Key Findings

Key Insights from the Workshop

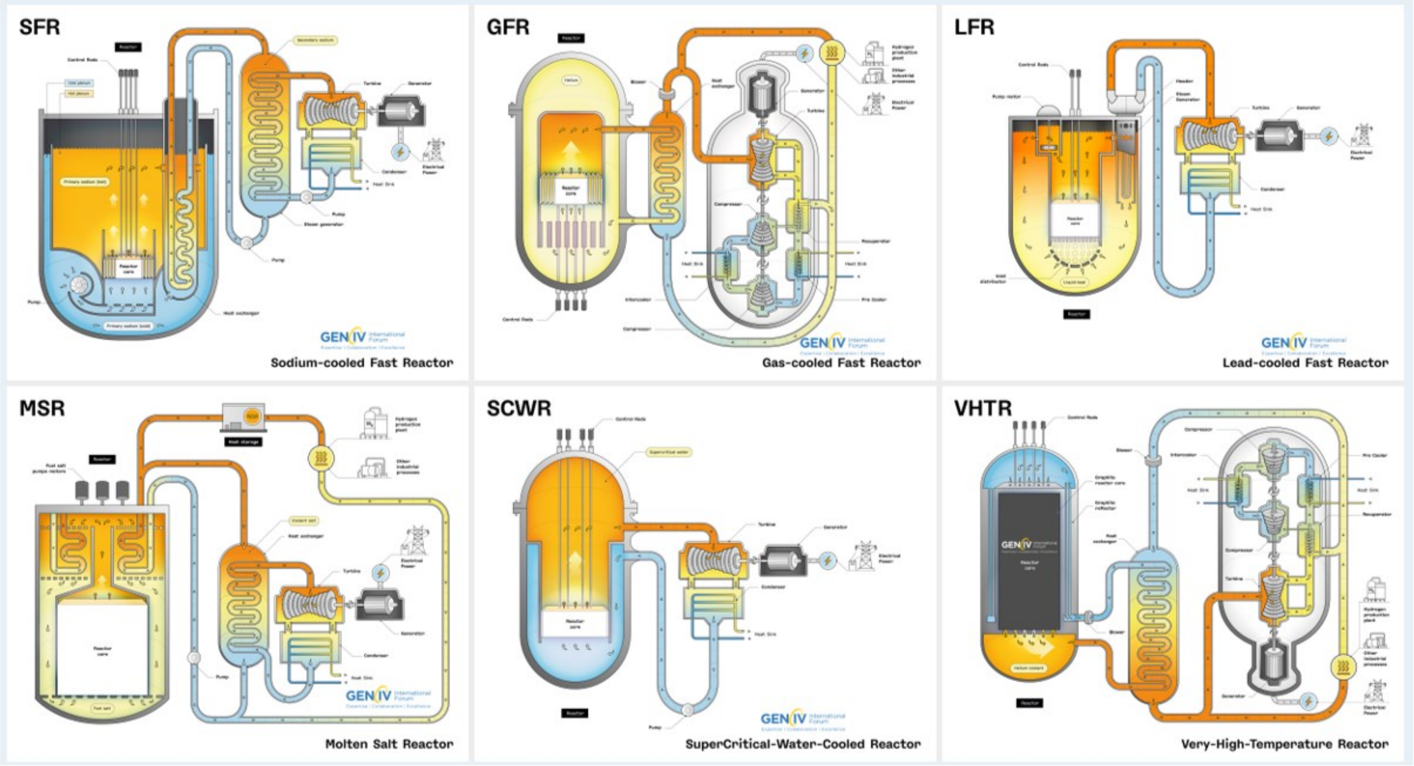
- Nuclear heat has broad industrial relevance. There are many potential applications: district heating, hydrogen, food and drink, cement, asphalt, mining, chemicals, potash, and more. Many have distinct temperature, pressure, and integration requirements.
- Combined heat and power using nuclear energy is technically mature, but deployment depends on local infrastructure and regulation. Past and current projects demonstrate feasibility, but factors such as siting, grid interaction, market changes, and permitting complexity influence their replicability today.
- Large-scale deployment of nuclear steam for industrial use is already occurring in China and government supported demonstrations are planned in other polities such as Japan. Demonstration projects are useful to build confidence and demonstrate the regulatory and financial pathways to commercial projects.
- There are "low-hanging fruit" where technical coupling is expected to be simple, including low-temperature electrolysis and district heating in certain jurisdictions.
- Process industries familiar with complex and large-scale infrastructure projects may be best positioned to lead early deployments. Sectors such as chemicals and oil and gas may be better suited to succeed with first-of-a-kind (FOAK) projects due to their experience with high-risk capital projects and onsite energy supply and demand management.
- Public trust and local engagement remain essential. Gaining social license requires proactive, transparent engagement.

www.gen-4.org/resources/events/non-electric-cogeneration-virtual-workshop-end-users

Systems Analysis

6 × 3 × 6

Reactor Systems



X

Reactor Size

X

Applications

- ✓ Cogeneration application
- ✓ Hydrogen production
- ✓ Seawater Desalination
- ✓ Process heat
- ✓ Synthetic Fuel and Chemicals
- ✓ Cooling applications

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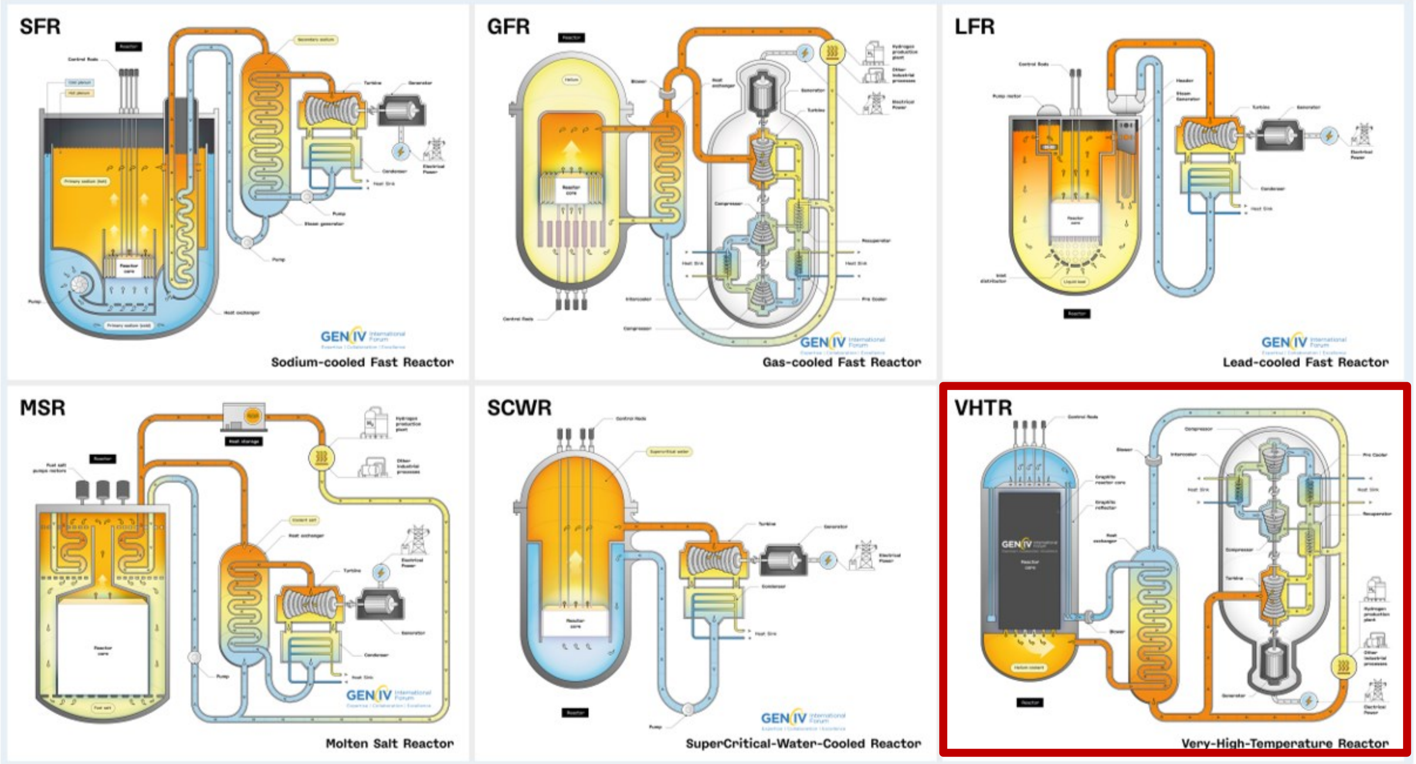
NECA report

System Analysis: Hydrogen Production from Nuclear Energy

Systems analysis

6 × 3 × 6

Reactor Systems



X

Reactor Size

X

Applications

- ✓ Cogeneration application
- ✓ Hydrogen production
- ✓ Seawater Desalination
- ✓ Process heat
- ✓ Synthetic Fuel and Chemicals
- ✓ Cooling applications

Systems analysis approach

Type 1 - Objective system modelling and analysis

- Assessment of generic system scenario using existing modelling tools
- Modelling inputs and assumptions were provided to modelling teams in GIF and NEA member countries
- "Crowd-sourced" modelling exercise

Type 2 - Subjective survey of system readiness

- Leverage existing frameworks
- Seeks expert views on the status or readiness of each system
- Identifying gaps associated with specific systems
- Could identify challenges that are common regardless of country

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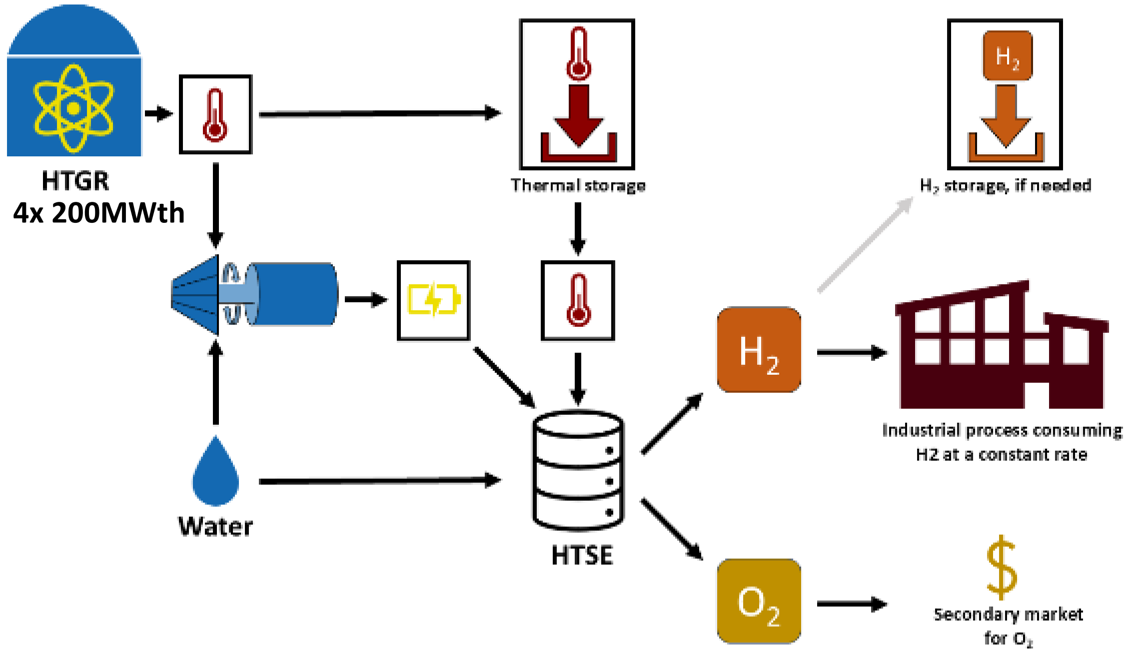
Modelling scenario

H_2 Production through HTSE using HTGR

- Beginning in January 2024, members of GIF and the NEA Hydrogen Value Chains Working Group worked to create a common set of modelling inputs

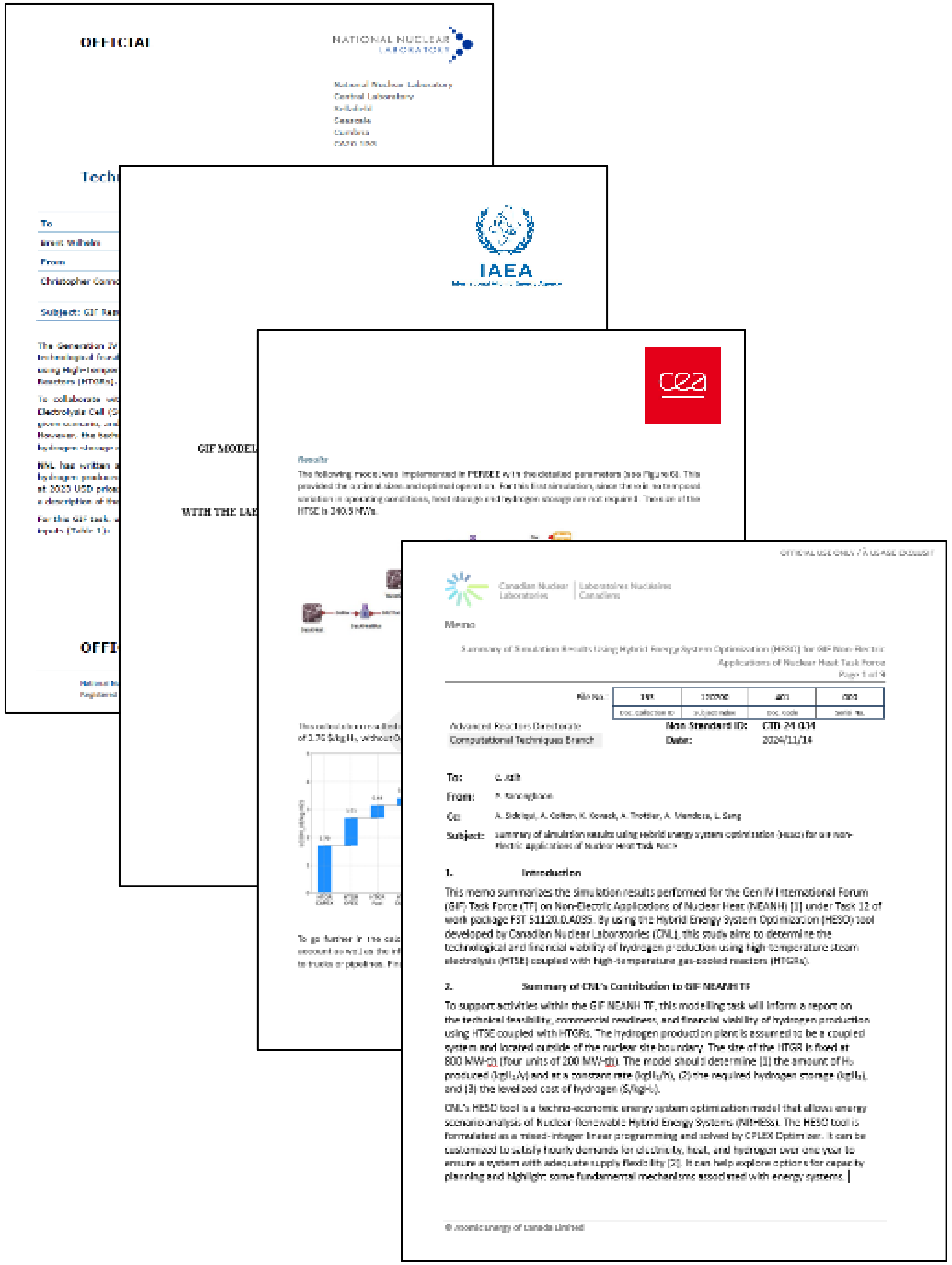


	Variable / Description	Value	Unit
	HTGR Variables		
Reactor details	Power rating	4 units x 200 (800 MWth total)	MWth
	Outlet temperature	750	deg C
	Outlet pressure	7.02	MPa
	Configuration	Prismatic	
	Power conversion efficiency	45	%
	Capacity factor	90	%
	Fuel enrichment level	19.75	% U235
	Refueling timeline	24	month
Construction	Plant lifetime	40	year
	Years to construct	3	year
Financial	Overnight Capital Costs	$ 6,000.00	USD/kWe
	O&M Costs	$ 25.00	USD/MWh
	Annual fuel costs	Not available	
	Decommissioning and decontamination costs	Not available	
	Annual Interest Rate	5	%
	Thermal Storage and Thermal Transport		
	Intermediate heat medium temperature	565	deg C
	Intermediate heat medium pressure	16	MPa
	Thermal Energy Storage (TES) fluid	Solar Salt	
	TES configuration	Two-tank	
	Levelised cost of storage	0.447	Euro / kWh
	Distance between NPP and hydrogen production	1	km
	HTSE Variables		
HTSE details	Capacity factor	90	%
	Current Density	0.5 to 1.5	A/cm^2
	Electricity consumption	38	kWh/kg-H2
	Thermal energy consumption	10	kWh/kg-H2
	Stack lifetime	4.5	year
	Water consumption	72.6	kg/s
	Feedwater temperature	185-225	deg C
	Stack operating pressure	1 to 5	bar
	Stack operating temperature	765	deg C
	Stack degradation rate	1.378	%/1000 hr
Construction	Hydrogen Production Plant Lifetime	35	year
	Years to construct	3	year
Financial	Overnight Capital Costs	Not available	$M
	Annual O&M Costs	Not available	$M / year
	Market price for secondary O2 market	0.09	$ / kg O2
	Annual Interest Rate	5	%

Type 1 - Objective system modelling

- The following modelling teams have delivered results, which are in this report version:
  - UK NNL technoeconomic model
  - IAEA HEEP model
  - CNL HESO model
  - France PERSEE model

Additional groups still plan to complete a model and will provide results in the near future for a V2 of the report (CNL CIPAM code, Gemini 4.0, and G4ECONs)



Type 1 - Objective system modelling

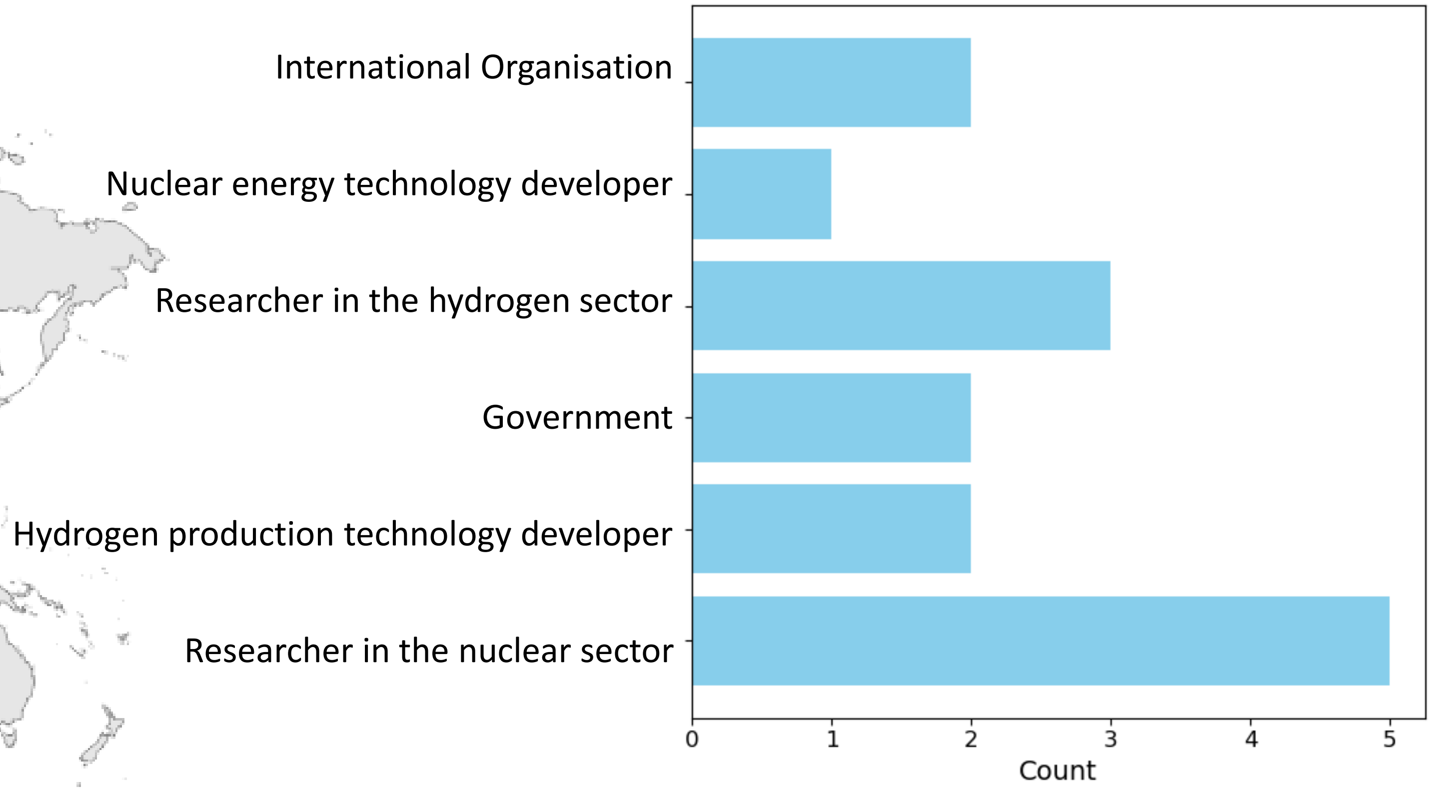
Results and discussion

	LCOH ($/kgH2)	LCOH + O2 sales ($/kg$H_2$)	H_2 produced (kgH_2 per year)	Model notes
UKNNL Literature value	3.53			Previous work - FOAK under different conditions
UKNNL model			**70.4 M**	No storage
IAEA HEEP	3.89	**3.17**	**66.8 M**	Existing HEEP libraries, no storage
CNL HESO Scenario #1	4.52	**3.72**	**55.6 M**	No storage
CNL HESO Scenario #2	6.47	5.67	65.5 M	Hydrogen storage
CNL HESO Scenario #3	7.09	6.29	65.5 M	Thermal energy storage
CEA PERSEE model	3.76	**3.04**	**70.7 M**	No storage

- Results converged towards reasonably similar values (both in cost and quantity)
- Comparison of codes was successful for this simple case – deviations and limitations would be more evident with a more specific case

Type 2 – System readiness survey

Results: Demographics



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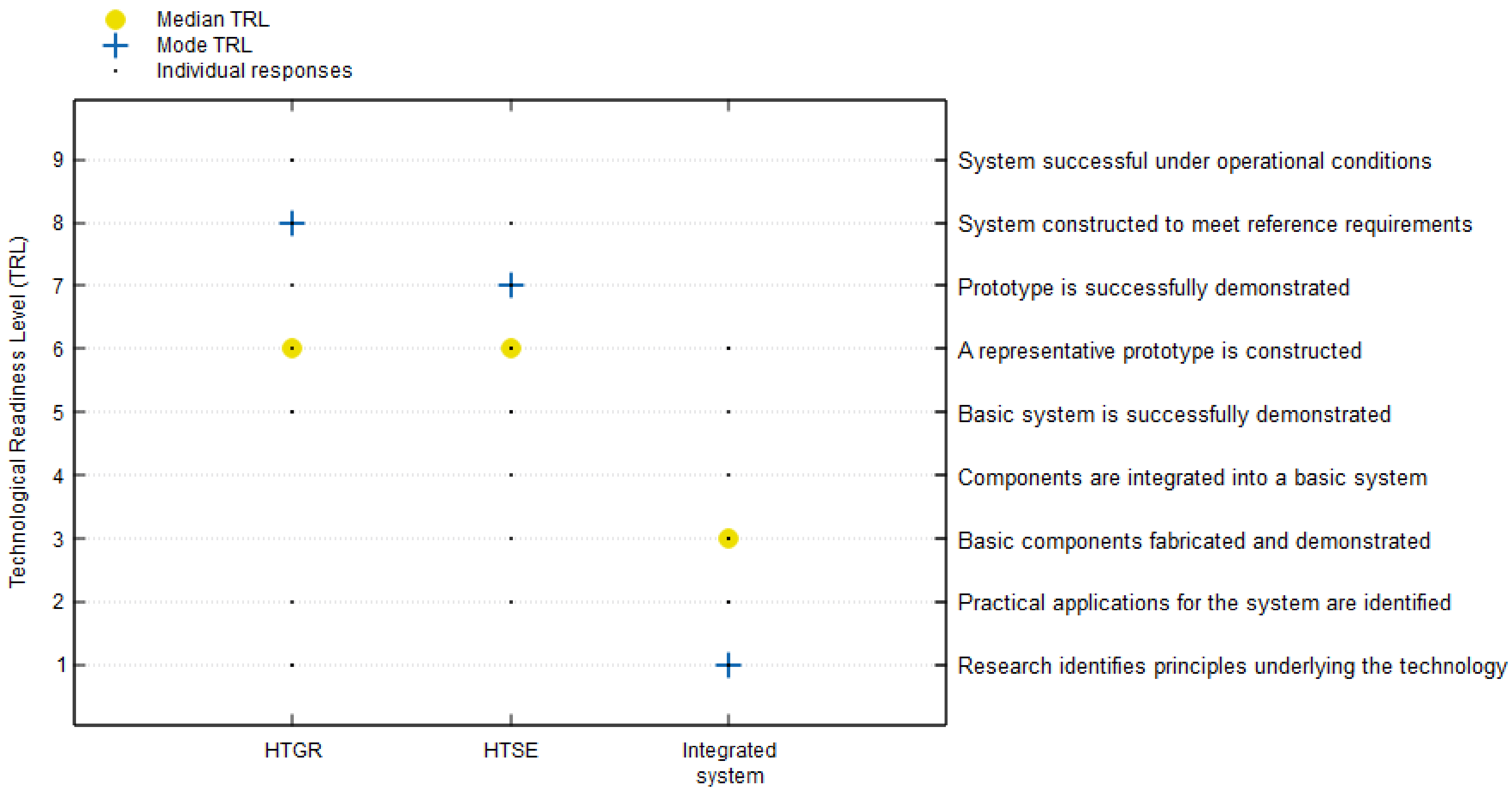
Type 2 – System readiness survey

Results: Technological Readiness

Observations

- Individual technologies are ready:
  - Evidence of commercial HTGR
  - Commercial HTSE systems, but scale needs to be demonstrated
- Integration is not ready (TRL ~1). There is a need to demonstrate integrated systems, including at scale.

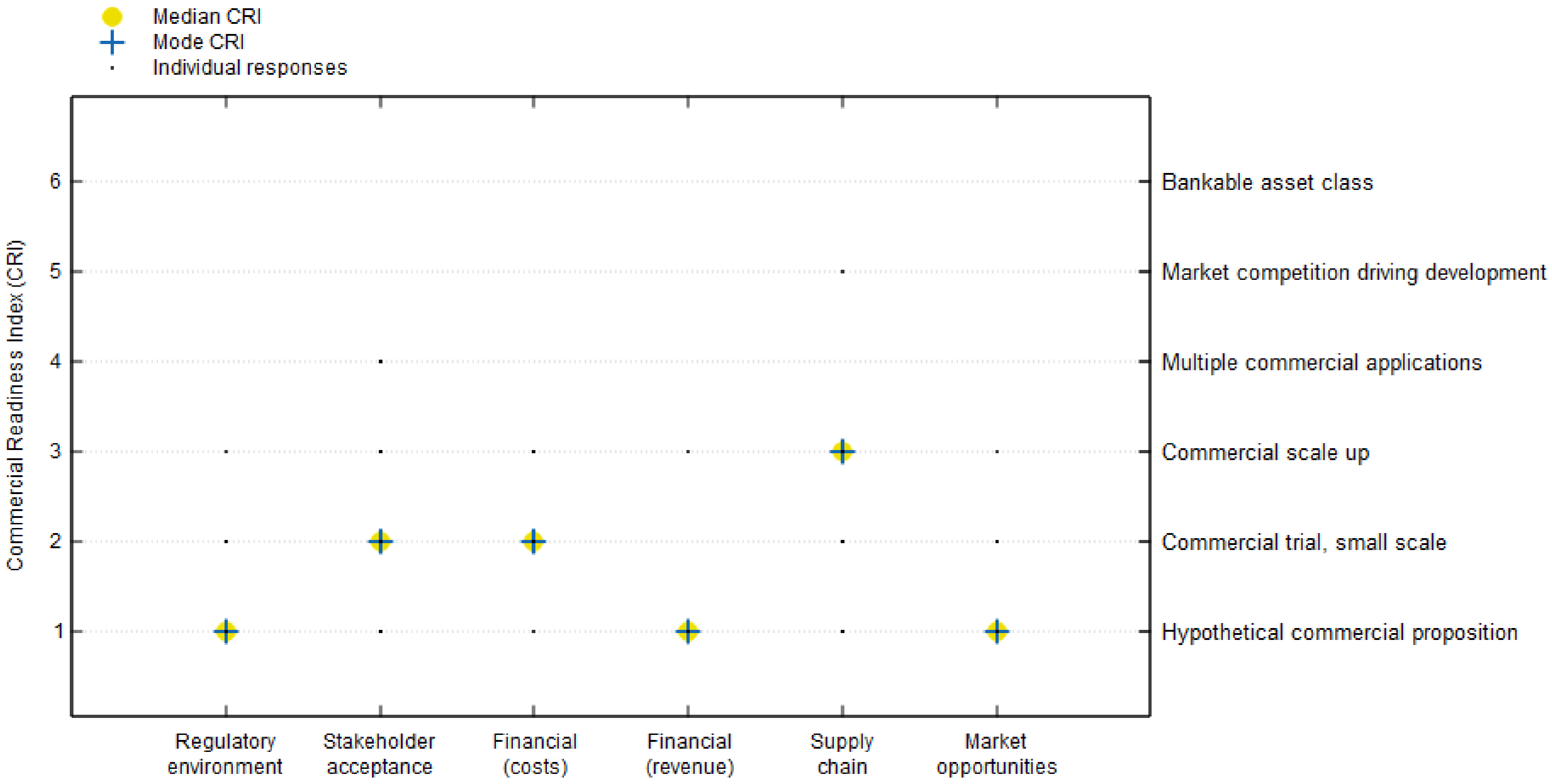


Type 2 – System readiness survey

Results: Commercial Readiness

Observations

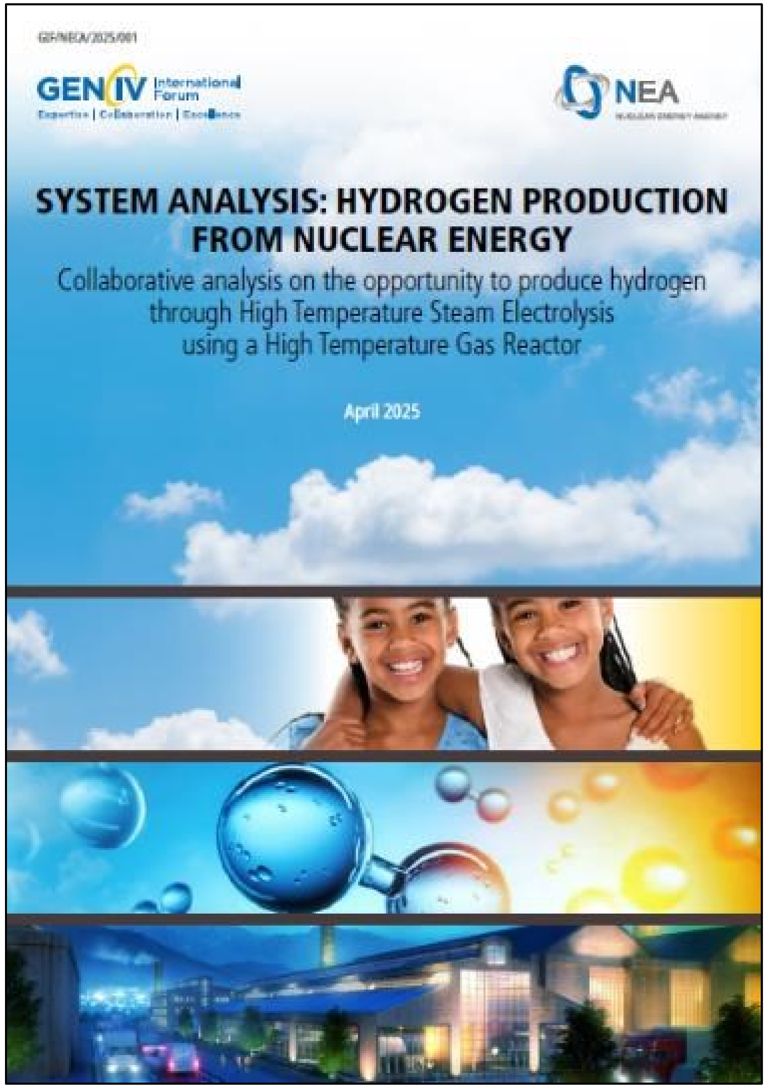
- The largest perceived **gaps** are related to:
  - regulatory readiness
  - uncertainty regarding cost and revenue data
  - Identifying market demand
- Variability in **timeline** estimates:
  - ~2028-2035 for an integrated demonstration
  - ~2040-2050 for an integrated commercial system



Some findings and recommendations

- The opportunity for nuclear hydrogen is compelling for a large, undisturbed demand for H_2 at a single point of consumption.
- Clear role for LWRs, but increased efficiency expected for mature GenIV technologies.
- Integration very challenging - merging two technologies that are not yet commercial is a challenge
  - Recommendation to integrate HTSE with existing LWRs at scale first to improve integration TRL
- HTSE is a very modular technology. Learning curve expected to “level-off” around 200MW
  - Recommendation to demonstrate a 200MW HTSE system to reach commercial maturity
- There has been recent activity among regulators in the UK, USA, Canada, France, and others.
  - Recommendation to share knowledge among regulators
  - Recommendation for NEA WGNT to consider a HTSE system in regulatory sandbox initiative

First NECA system analysis report now available



This System Analysis report contains detailed results and analysis from the crowd-sourced system analysis and expert questionnaire.

The report was co-published with the Nuclear Energy Agency, with significant contributions from the NEA Hydrogen Value Chains Working Group (H2VAL)

The report is available now on the GIF website:

- www.gen-4.org/resources/reports/system-analysis-hydrogen-production-nuclear-energy

Future version of this report anticipated in early 2026

Version 2 of the hydrogen report with additional input and modelling outputs provided by :

- Gemini 4.0 programme after its completion
- GIF G4ECON after adapting model
- CNL model using CIPAM code

Questions?

Upcoming Webinars

Date	Title	Presenter
24 September 2025	3S interfaces of a pebble-bed small modular advanced reactor	Dr. Bryan van der Ende, Canadian Nuclear Laboratories (CNL), Canada
08 October 2025	Science for the safe disposal of nuclear waste – a German perspective	Dr. Francesca Quinto and Dr .Frank Heberling, Karlsruhe Institute of Technology, Germany
05 November 2025	Severe accidents in Sodium Fast Reactors: Safety Study Approach, Prevention and Mitigation by Design	Dr. Frederic Bertrand, Commissariat a l'Energie Atomique et aux Energies Alternatives (CEA), France