Joint NEA/IAEA Expert Workshop

"Technical and Economic Assessment of Non-Electric Applications of Nuclear Energy"

Past NEA activity and objectives of the workshop

Henri PAILLERE

Non-electricity products of Nuclear Energy (2004)

- 25-page report reviewed by the NDC.
- Structure:
  - Current status and future prospects for nuclear non-electricity energy products
  - Supply potential for nuclear non-electricity energy products
  - Strategic issues for development and deployment
  - **Findings and Recommendations**

Non-electricity products of Nuclear Energy (2004)

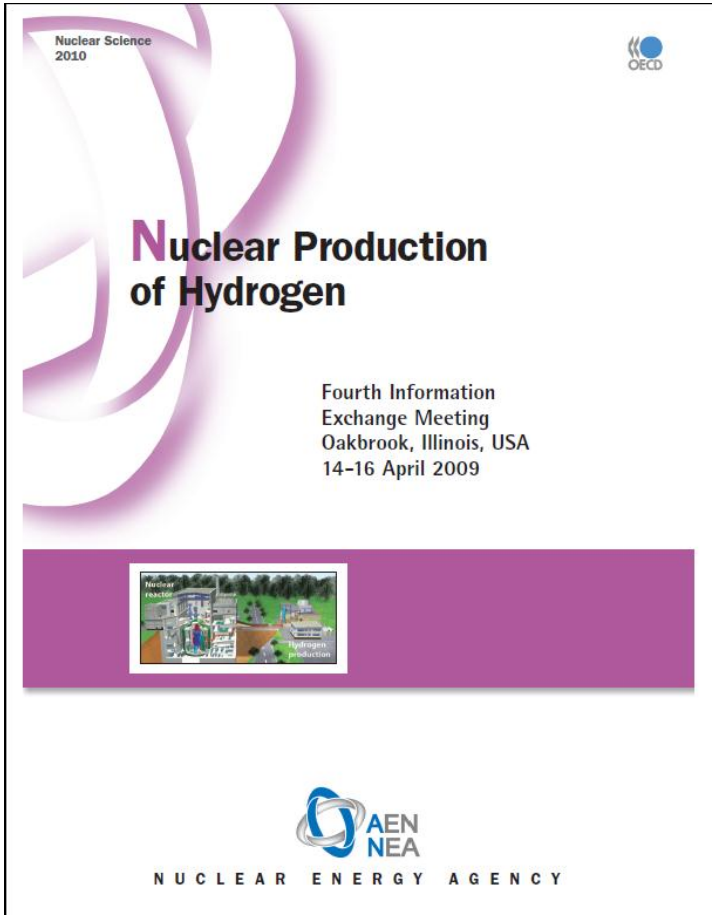
- **Findings and Recommendations:**
  - If the potential of non-electric applications of nuclear energy is so high, why has its deployment been so limited?
  - Limited data, market information, technology assessment not comprehensive → preliminary findings & recommendations.

1. Need to understand better the markets & increase communication with stakeholders
2. Establishing a interest group (with links to developing countries/markets)
3. Depending on demand (distributed vs. centralised), nuclear technology solutions will vary (small (modular) reactors vs large units). Nuclear energy sector needs to be involved in the development of "end applications".
4. Need for demonstration projects.
5. Competitiveness of non-electric products is essential
6. Involvement of governments & international co-operation

Nuclear production of Hydrogen

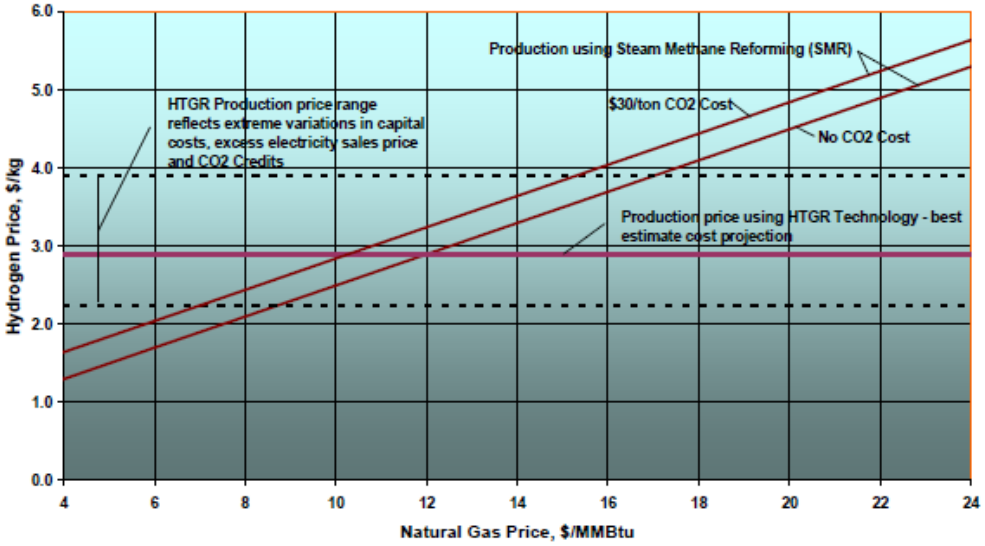
- **Proceedings of 4 Information Exchange Meetings:**
  - **2000, 2003, 2005 and 2009**
  - **2009:** Contents:

I. Programme Overview
II. High-Temperature Electrolysis
III. Thermochemical sulphur process
IV. Thermochemical copper chloride and calcium bromide processes
V. **Economics and market analysis of hydrogen production and use**
VI. Safety aspects of nuclear hydrogen production



Economics and market analysis of hydrogen production and use (1/3)

- **Nuclear H2 production – a utility perspective.** *(US Utility Entergy)*
  - Belief that HTGR can compete with fossil fuel for process heat supply, and that nuclear H2 production can become competitive on the bulk market (with respect to steam methane reforming)



  - Interest of Entergy also related to fact that its NPP sites are located near existing H2 pipeline infrastructures.
  - Market assessment for process heat applications justify further RD&D
  - BUT commercial viability nuclear H2 production still unclear (lack of specificity in cost and economic modelling) → uncertainties in investment and O&M cost assumptions AND operational & deployments risks.

Economics and market analysis of hydrogen production and use (2/3)

- **Alkaline and high temperature electrolysis for nuclear hydrogen production** *(AREVA, France)*
  - use of HTR with 600ºC outlet temp. combined with electric heating to reach 900ºC conditions. (reduction of cost of developing new reactor technologies)
- **The production of hydrogen by nuclear and solar heat** *(FZJ/DLR, Germany)*
  - nuclear vs. renewables for H2 production
  - solar H2 more competitive than nuclear for small plants (< 100 MWth) … (competition is not just with fossil fuels?)
- **NHI* economic analysis of candidate nuclear hydrogen processes** *(SNL/INL/DOE, US)* *(* Nuclear Hydrogen Initiative)*
  - objective to compare the costs of H2 production processes
  - tool development (H2A model, discounted cash flow rate of return methodology)
  - Input (HTGR): nuclear heat $ 20-30/MWth-h / electricity $ 60-75/Mwe-h
  - large uncertainties in cost of technologies → uncertainty in H2 selling price output (but HTSE always more competitive than Sulfur-Iodine or Hybrid Sulfur cycles)
  - more work needed (also to compare with other technologies)

Economics and market analysis of hydrogen production and use (3/3)

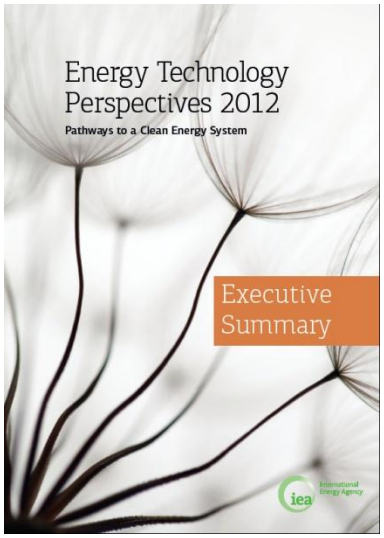
- **Market viability of nuclear hydrogen technologies: quantifying the value of product flexibility** *(ANL/MIT)*
  - Financial model based on real options theory to assess profitability of different nuclear H2 production technologies in evolving electricity and H2 markets
  - Model quantifies the value of the option to switch between H2 and electricity production, depending on what is more profitable to sell.
  - Electrochemical processes (high pressure water electrolysis HPE or high temperature steam electrolysis HTE) > thermochemical processes (since electricity used for electrolysis can be sold to electricity market in periods of high electricity prices) → product flexibility increases market viability

Hydrogen production process	Nuclear reactor type	Product flexibility?
High-pressure water electrolysis (HPE)	Advanced light water reactor (ALWR)	Yes
High-temperature steam electrolysis (HTE)	High-temperature gas-cooled reactor (HTGR)	Yes
High-temperature sulphur-iodine cycle (SI)	High-temperature gas-cooled reactor (HTGR)	Pure hydrogen
Hybrid sulphur thermo-electrochemical cycle (HyS)	High-temperature gas-cooled reactor (HTGR)	Fixed hydrogen and electricity production

Technology	Product flexibility?	Levelised cost [$/kg]	Expected profit [M $]	Expected value of flexibility [M $]
HPE-ALWR	Yes	2.98	283	266
HTE-HTGR	Yes	2.93	295	212
SI-HTGR	No	3.26	-348	0
HyS-HTGR	No	2.97	19	0

Role of nuclear energy in decarbonisation scenarios: example of IEA's ETP (2050)

- Nuclear energy is primarily considered as a low carbon electricity-generation technology.
- Besides nuclear power, no other application is identified as a potential candidate technology to lower the GHG emissions of the non-power sector (transport, heating & cooling)
- Special chapter on potential role for hydrogen in ETP 2012 but hardly any mention of nuclear
  - The added value of hydrogen lies in its potential for flexibility: it can be produced from different sources, either renewable sources or in combination with CCS, in small- and large scale applications
- Benefit of non-electric applications in terms of GHG emissions?



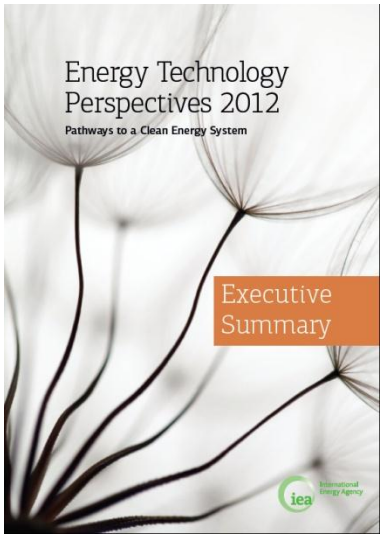
Role of nuclear energy in decarbonisation scenarios: example of IEA's ETP (2050)

- Hydrogen generation:

Table 7.2 Levellised costs of hydrogen-generation technologies, ranges depend on scale

Generation technology	CCS	Deployment phase (USD/kg)	Established market (USD/kg)
Natural gas steam reforming (small and large scale)	No	1.9 to 3.6	1.7 to 2.8
Natural gas steam reforming (large scale only)	Yes	~1.8	~1.8
Coal gasification	No	~1.1	~0.7
Coal gasification	Yes	~1.4	~1.1
Electrolysis (average mix, small and large scale)	-	4.9-5.5	5.0-5.5
Electrolysis from wind (on-shore)	-	~7.0	~3.9
Electrolysis from solar	-	~10	~4.9
Biomass gasification (small and large scale)	No	1.9-3.5	1.6-2.8
Biomass gasification (large scale only)	Yes	~2.1	~2.1
Thermochemical separation, nuclear	-	~3.5	~1.5
Thermochemical separation, solar	-	~7.0	~3.5

Note: Cost calculations are based on a discount rate of 8%. Fuel prices are based on the 2DS. Oil prices are USD 78/bbl in 2010 and USD 87/bbl in 2050. Coal prices are USD 3.4/GJ in 2010 and USD 2.1/GJ in 2050. Gas prices are USD 4.2/GJ in 2010 and USD 6.6/GJ in 2050. For biomass-based options a biomass price of USD 6/GJ has been assumed. The price of CO_2 is not reflected in this table.

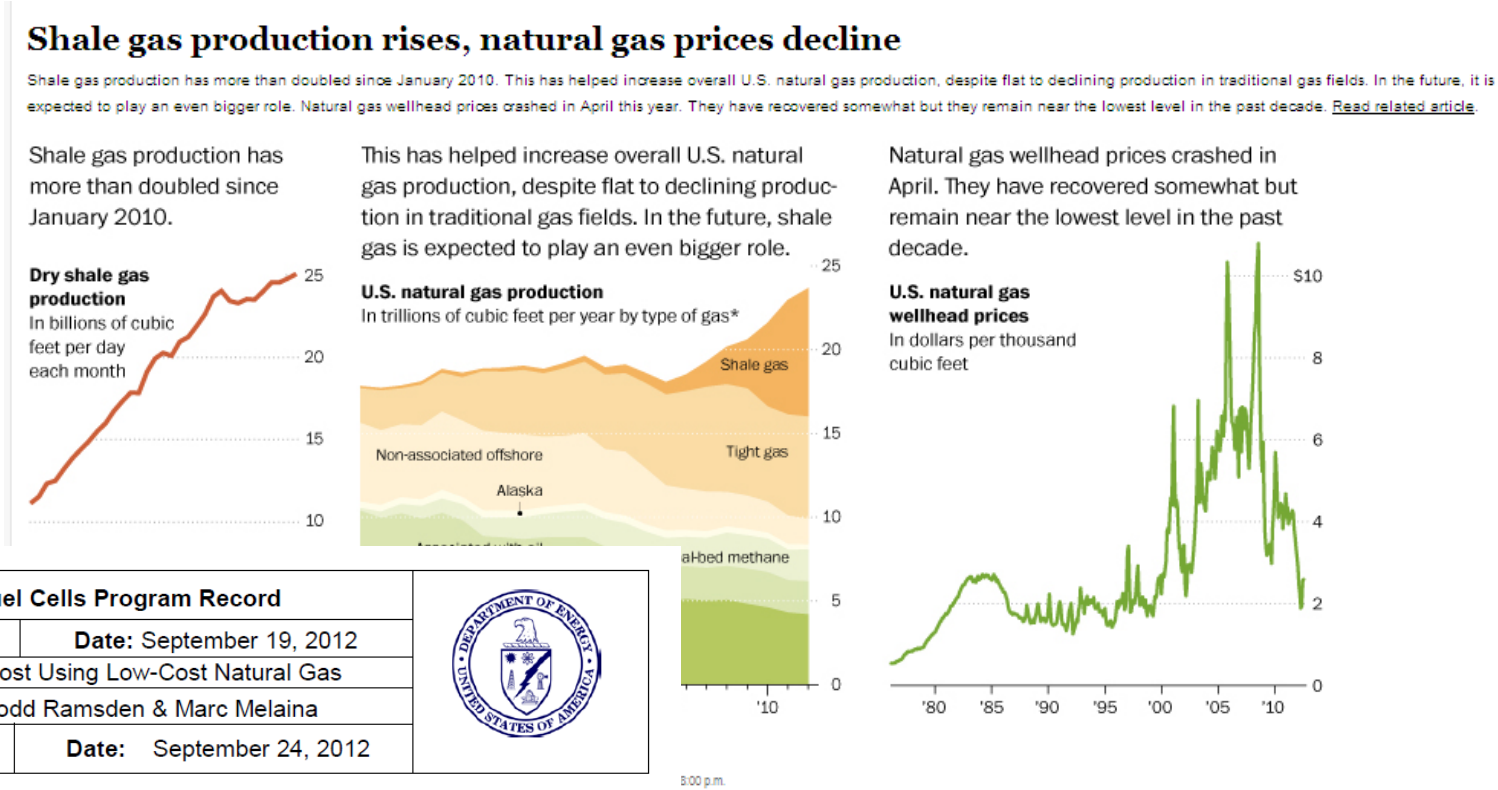


Context of the current workshop

- Changes:

  - Role of nuclear energy post Fukushima (energy policies, public acceptance)
  - Hydrogen economy never happened
  - Price of gas has fallen dramatically (North America)
  - Economic crisis (with NPP representing a huge investment)
  - International consensus/decisions/commitments on GHG reductions lacking
  - Strong expansion of renewables, effect on dispatchable technologies, need for flexibility and storage, synergies or competition?

  - In the mid to long term, impact of climate change (eg. water scarcity), urgency of decarbonising the whole energy sector, not just the power sector?



DOE Hydrogen and Fuel Cells Program Record	
Record #: 12024	**Date:** September 19, 2012
Title: Hydrogen Production Cost Using Low-Cost Natural Gas	
Originator: Sara Dillich, Todd Ramsden & Marc Melaina	
Approved by: Sunita Satyapal	**Date:** September 24, 2012

Item:

Hydrogen produced and dispensed in distributed facilities at high-volume refueling stations using current technology and DOE's Annual Energy Outlook (AEO) 2009 projected prices for industrial natural gas result in a hydrogen levelized cost of $4.49 per gallon-gasoline-equivalent (gge) (untaxed) including compression, storage and dispensing costs. The hydrogen production portion of this cost is $2.03/gge.

In comparison, current analyses using low-cost natural gas with a price of $2.00 per MMBtu can decrease the hydrogen levelized cost to $3.68 per gge (untaxed) including compression, storage and dispensing costs. The production cost portion of hydrogen produced at distributed retail stations could decrease to $1.21 per gge.

Falling gas prices → increased competitiveness of steam methane reforming to produce H2

Some key questions

- Why have non-electric applications of nuclear not developed more
  - Technology? Economics? Need?
- Are there clear drivers for non-electric uses and if so have messages addressed to policy makers been clear and intelligible?
- Is there a consensus on methodologies to assess the economic benefits, if any, of non-electric applications of nuclear?
- What should be included in the analysis? What is the system to be assessed and compared?
  - (Reactor + Application + Back-up + Storage/Transport of Product) vs. "fossil-fuel" equivalent system
- What does the industry think? Utilities, Vendors, "end users"?

Objectives

- Identify main technological, economic or other challenges
- Reach consensus among invited experts on:
  - critical issues that need to be solved
  - methodologies to assess the viability of non-electric applications of nuclear
  - priorities for future development, demonstration, …
  - recommendations for further work, including RD&D, analytical work and modelling, … as well as communication to various stakeholders

- Importance of Q&A sessions, role of session chairs to gather & encourage input
- Ouput of workshop will be summarised in a report to be presented to the NDC at its next meeting → further work of NEA