High Temperature Reactors for Hydrogen Production

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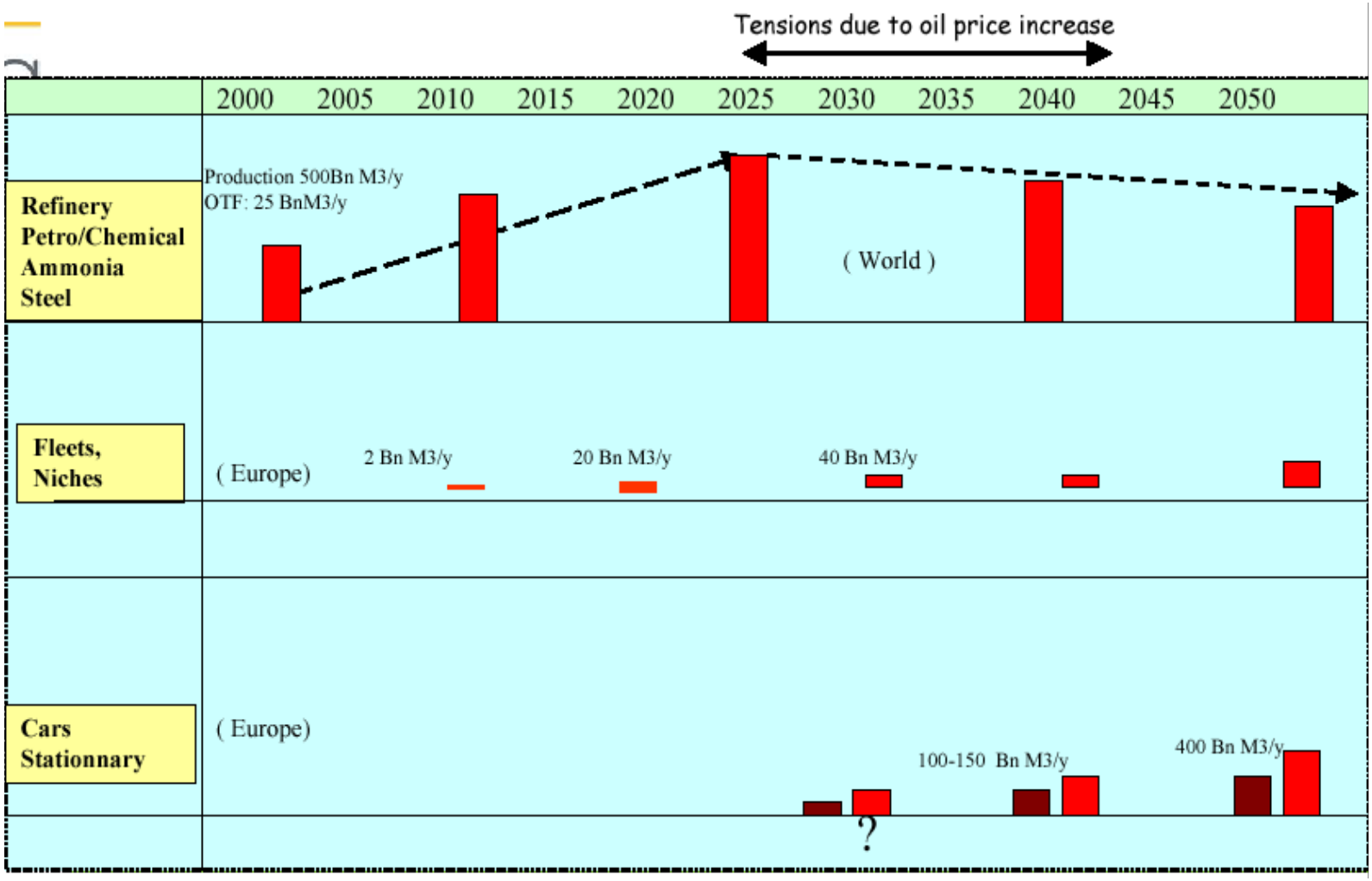
H_2 Market Assessment by EC High Level Group



Nuclear Hydrogen

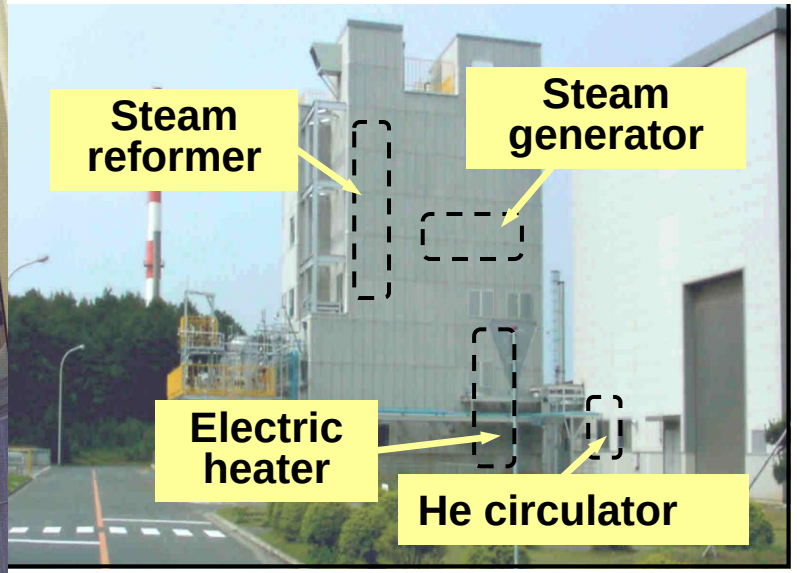
Driving forces for the use of nuclear energy in the hydrogen economy:

- Nuclear energy can be taken to produce hydrogen at a large scale to replace CO_2 emitting fossil fuels;
- Thus fossil reserves will be saved for later use in environmentally friendly applications;
- Energy security from extended fuel reserves and independence from foreign oil uncertainties.

Short-Term Option: SMR

Jülich, Germany

Steam Methane Reforming appears to be a reasonable first step



Oarai, Japan

- most widely applied conventional production method
- savings of ~ 35%, if process heat is from nuclear
- tested under nuclear conditions in pilot plants in both Germany and Japan

Short-Term Option: Electrolysis

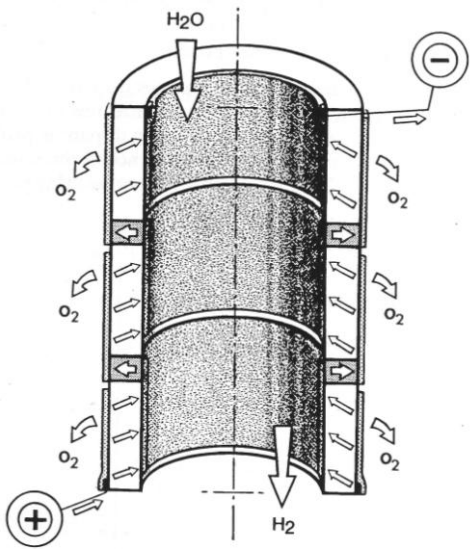
- Electrolysis ideal for remote and decentralized H_2 production
- Off-peak electricity from existing NPP (if share of nuclear among power plants is large)

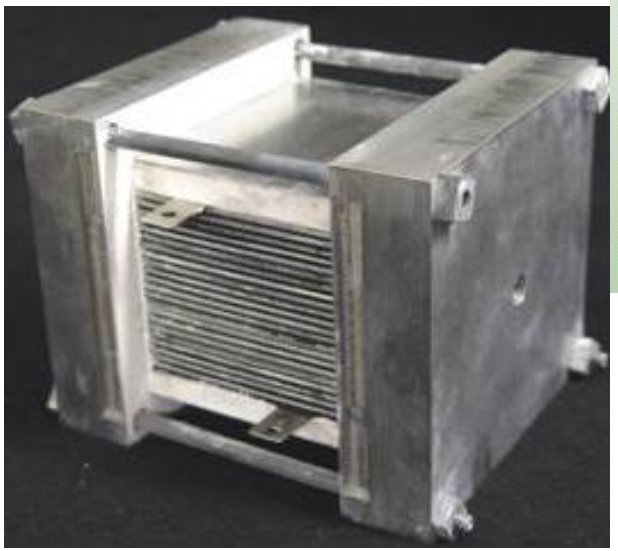
200 m^3/h

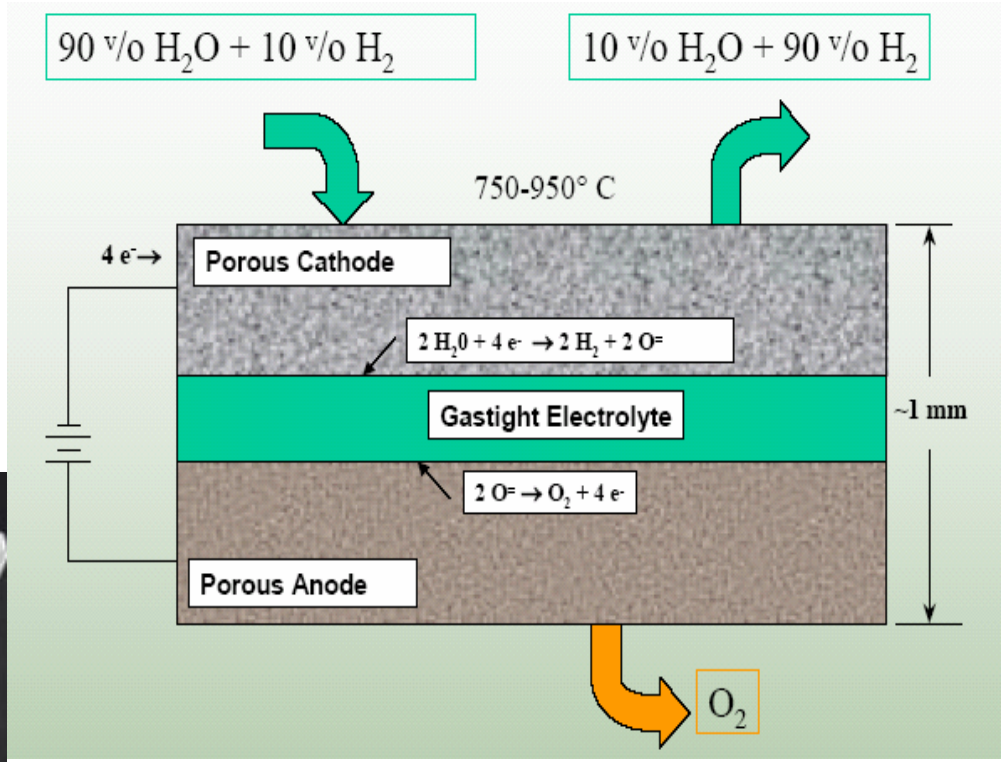
- As fossil fuels become more expensive, the use of nuclear outside base load becomes more attractive

Long-Term Option: HT-Electrolysis

- Increased efficiency
- Reduced electricity needs
- Capitalize from SOFC efforts

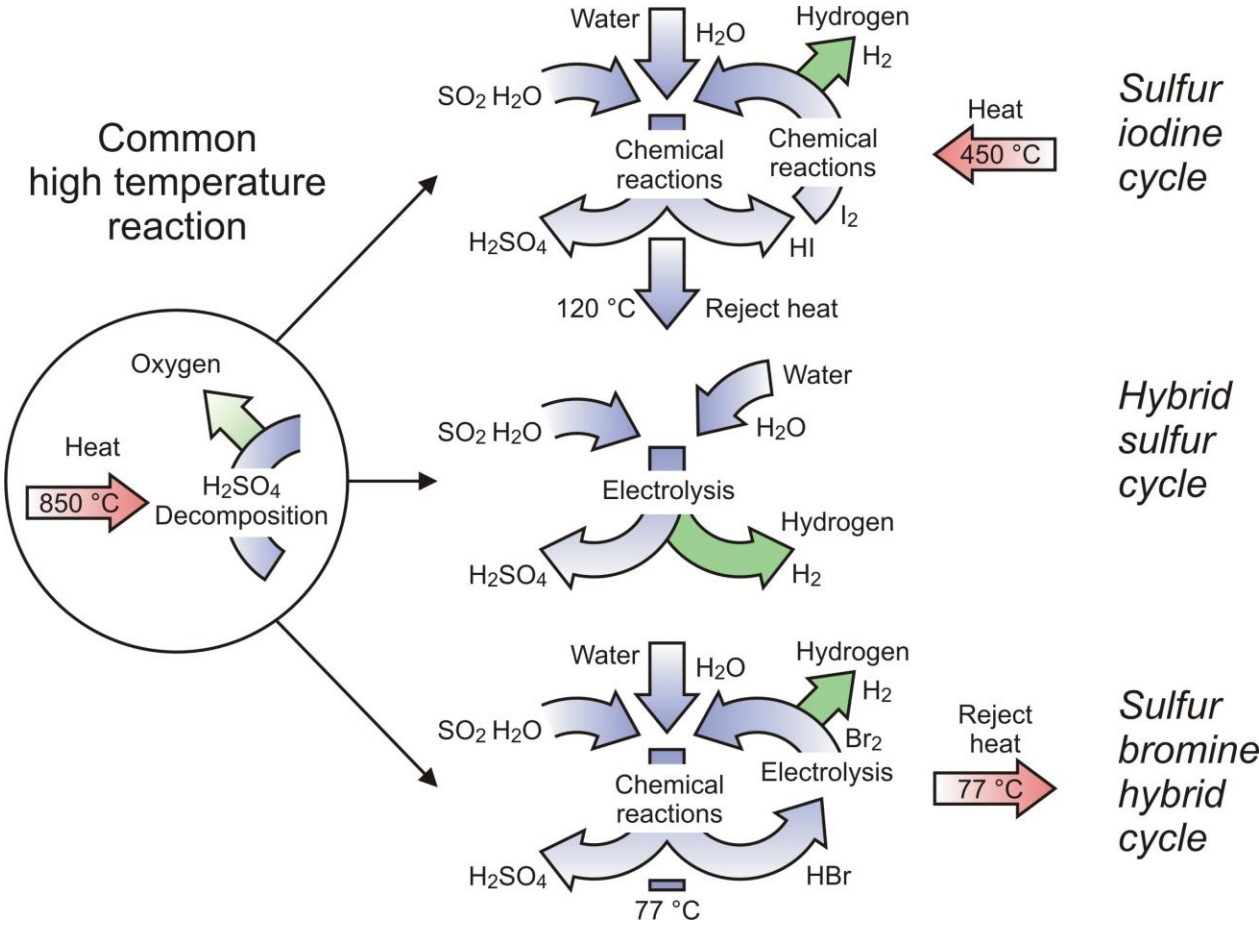




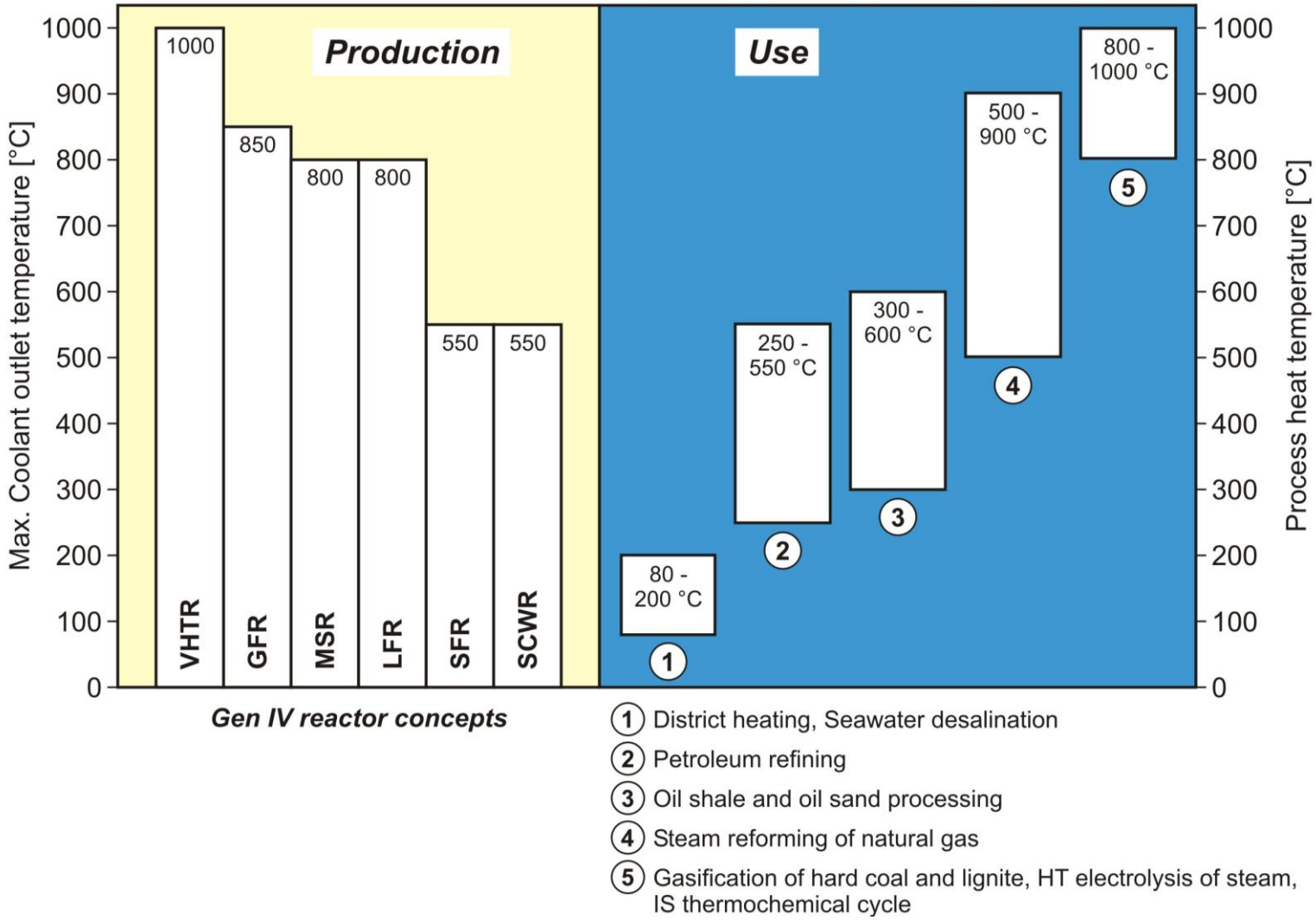


Long-Term Option: Thermochemical Cycle

- Top candidates: Ca-Br (UT-3), S-I
- Common reaction of H_2SO_4 splitting
- Different coolants (molten salt, gas, liquid metal) in intermediate circuit

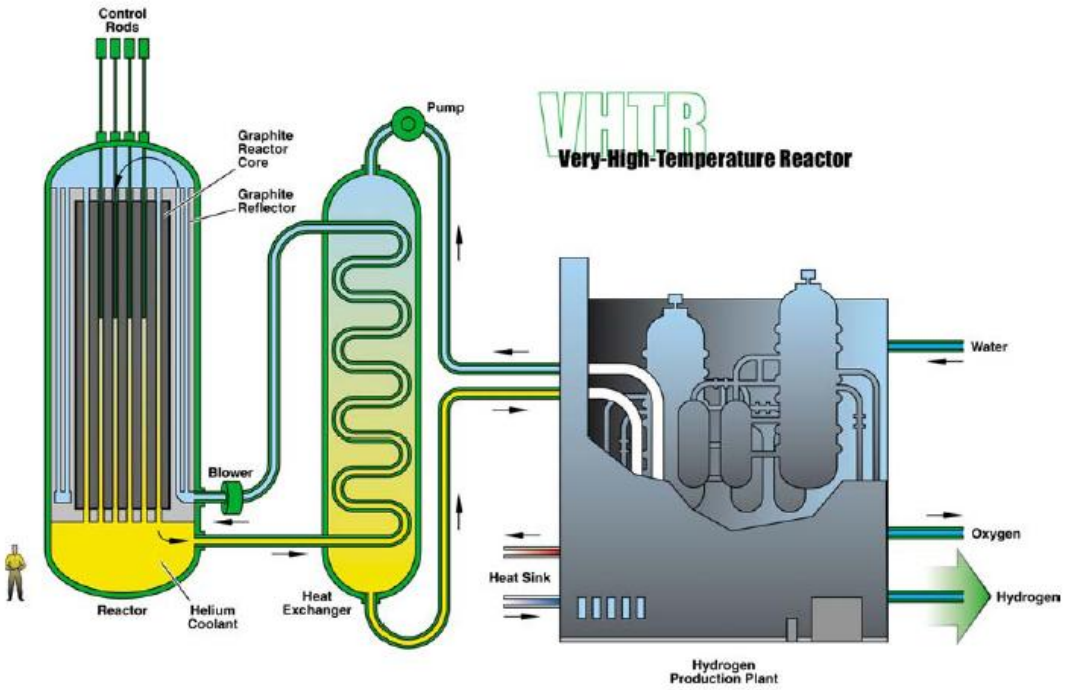


Temperature Ranges Provided and Required

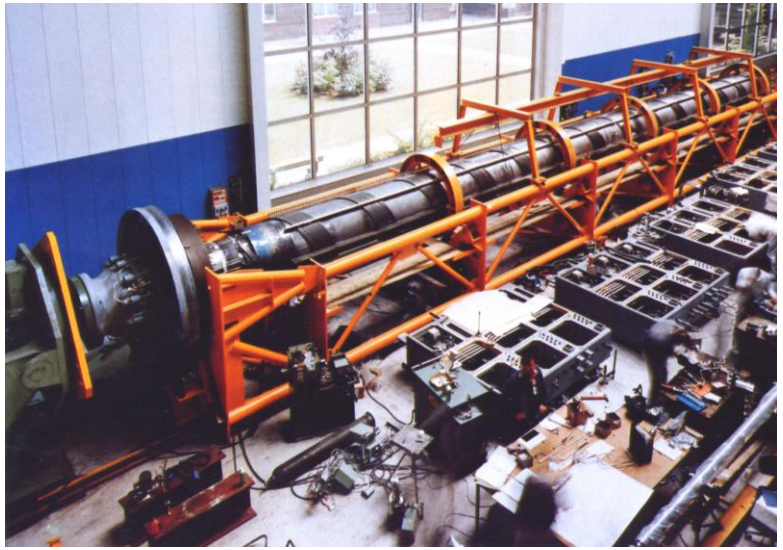


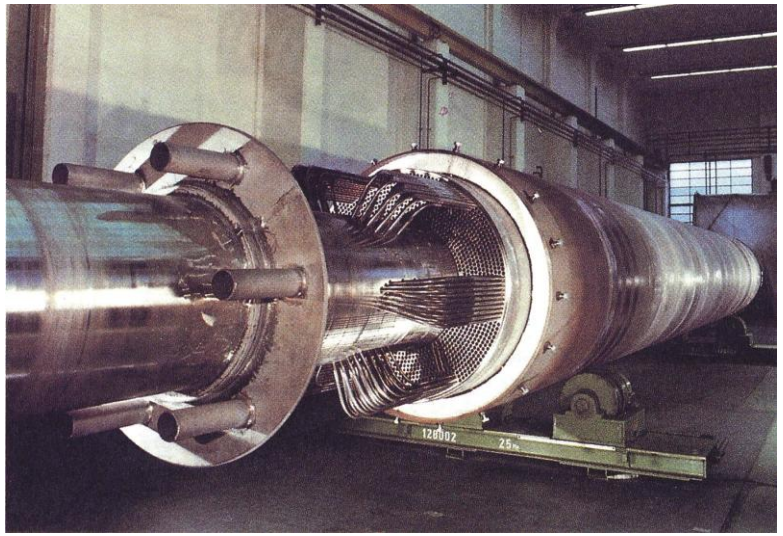
GenIV Nuclear Reactor: VHTR

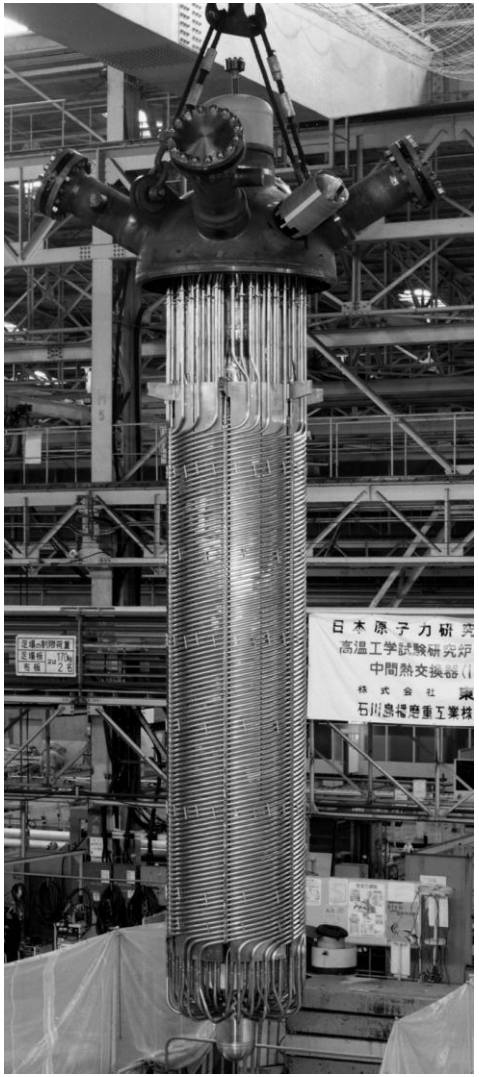
- 400-600 MW(th) for electricity and process heat production;
- Helium-cooled, graphite-moderated, thermal neutron spectrum;
- Gas outlet temperature of 900-1000 °C;
- IHX for heat transfer to H_2 production plant or gas turbine.

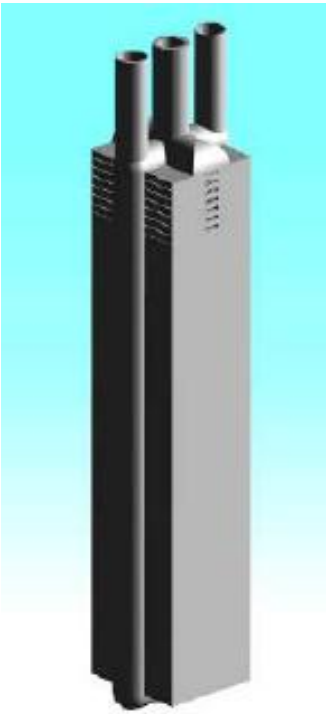


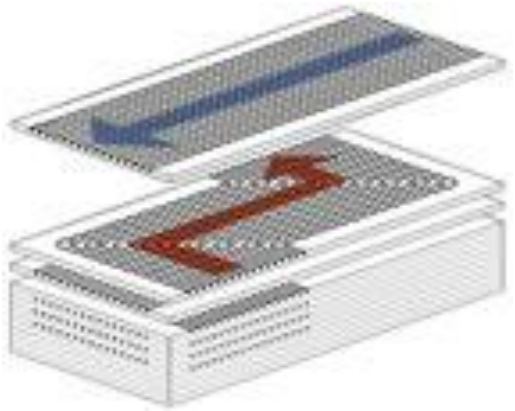
Intermediate Heat Exchanger



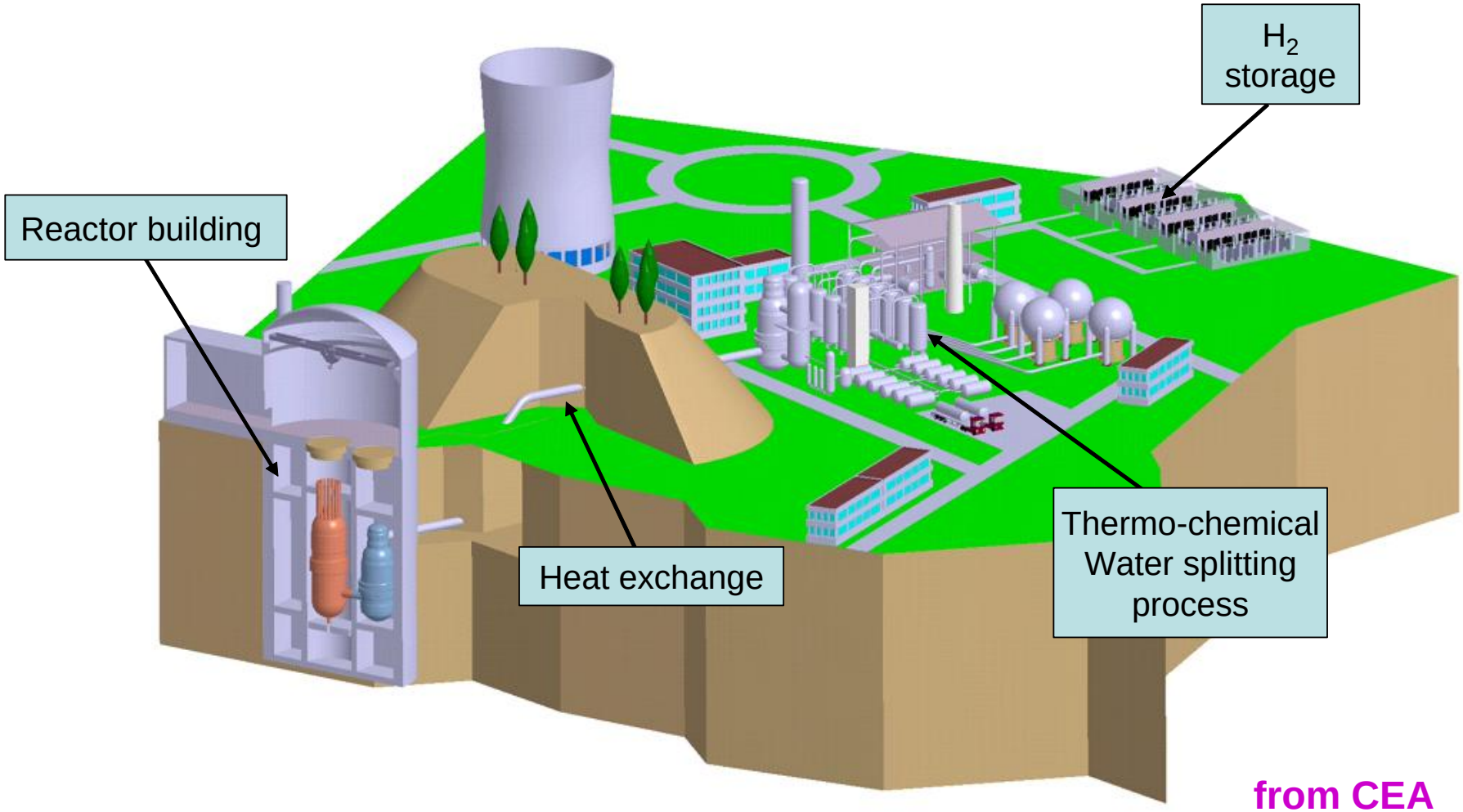








Potential Arrangement of 600 MW VHTR for H_2 Production



from CEA

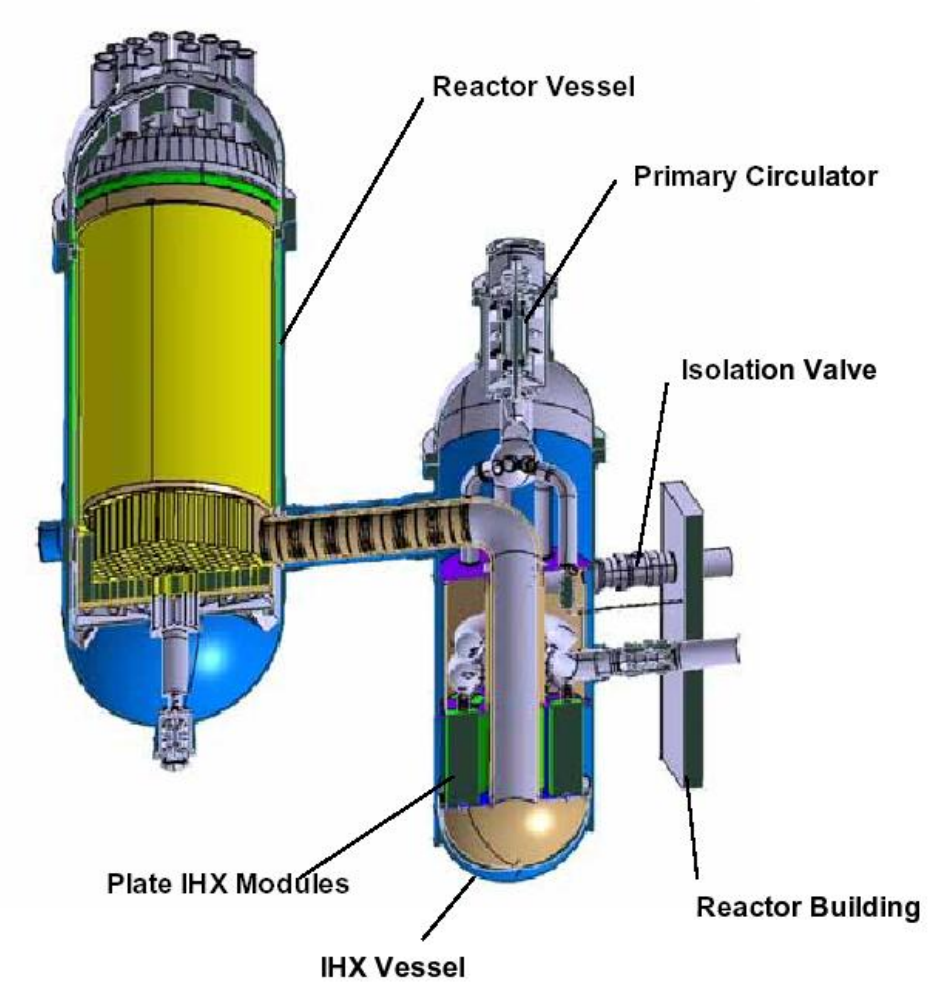
Nuclear H_2 R&D Projects in France

- **ANTARES**

indirect cycle block-type reactor
850°C coolant exit temperature

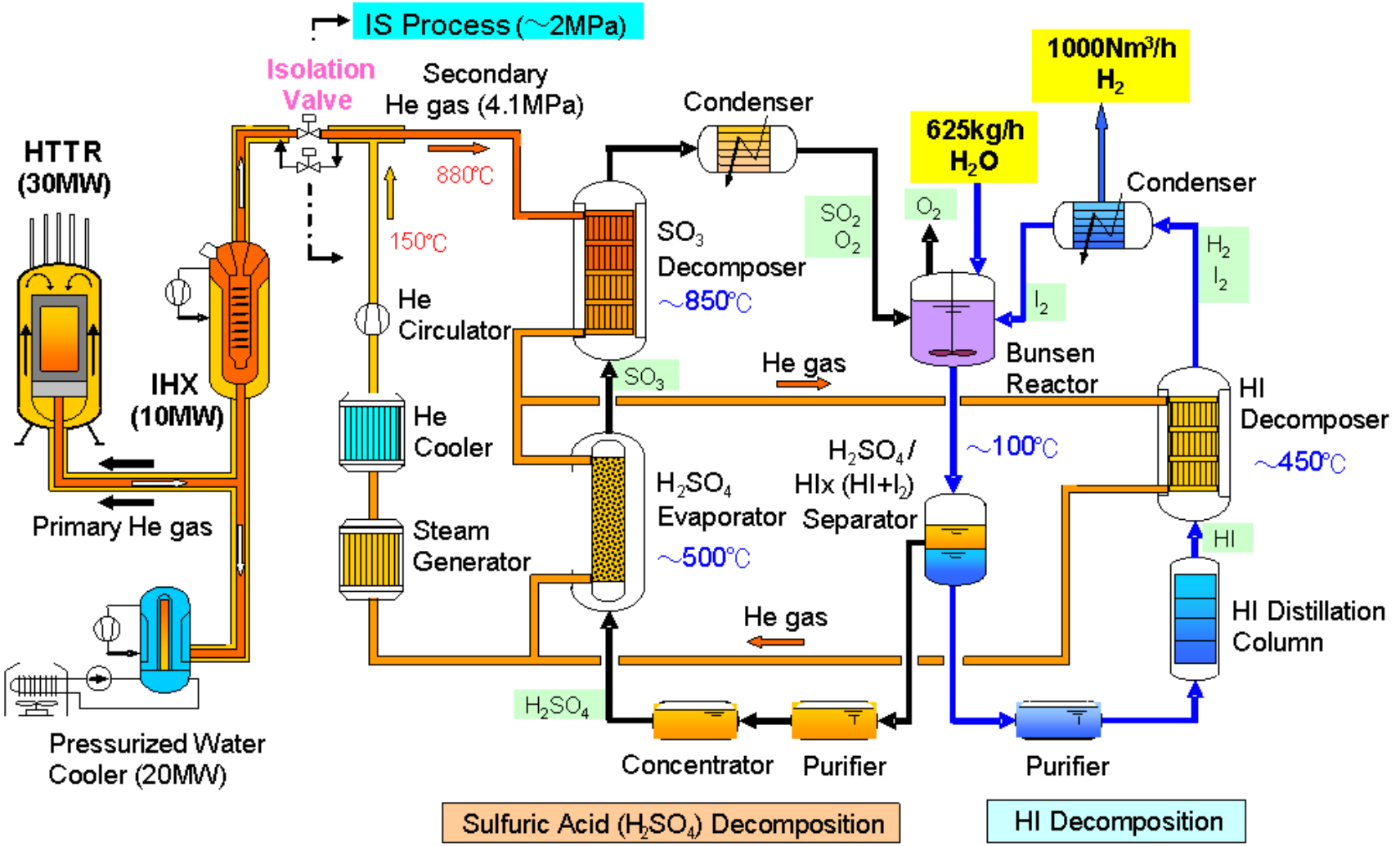
for electricity/H_2 cogeneration:
~1000°C coolant exit temperature

plate or printed circuit IHX
as the only really novel component



Nuclear H_2 R&D Projects in Japan

HTTR + S-I to become the world's first nuclear H_2 production plant



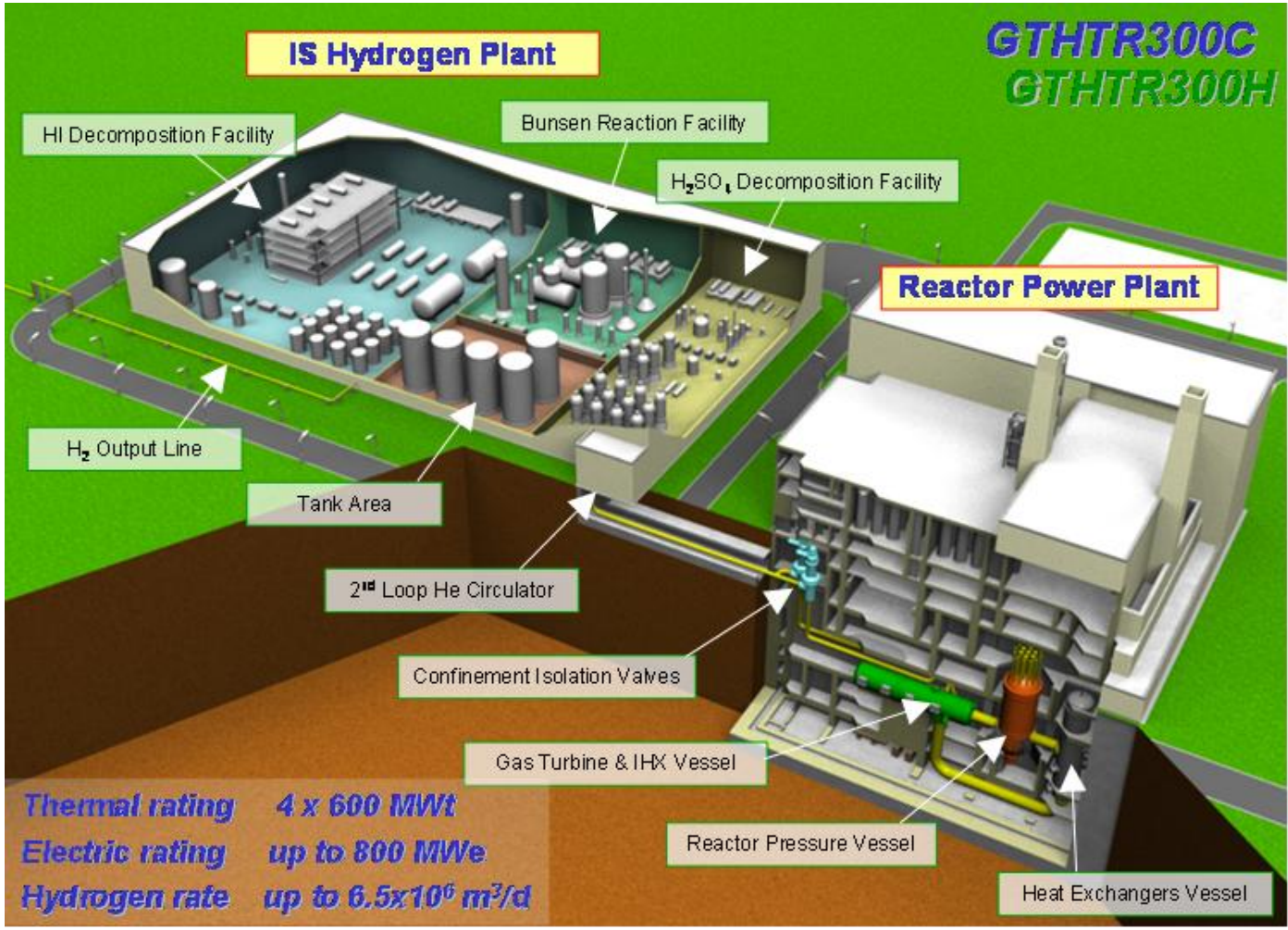
Nuclear H_2 R&D Projects in Japan

- **GTHTR300H**

direct cycle,
block-type core
950°C at coolant exit

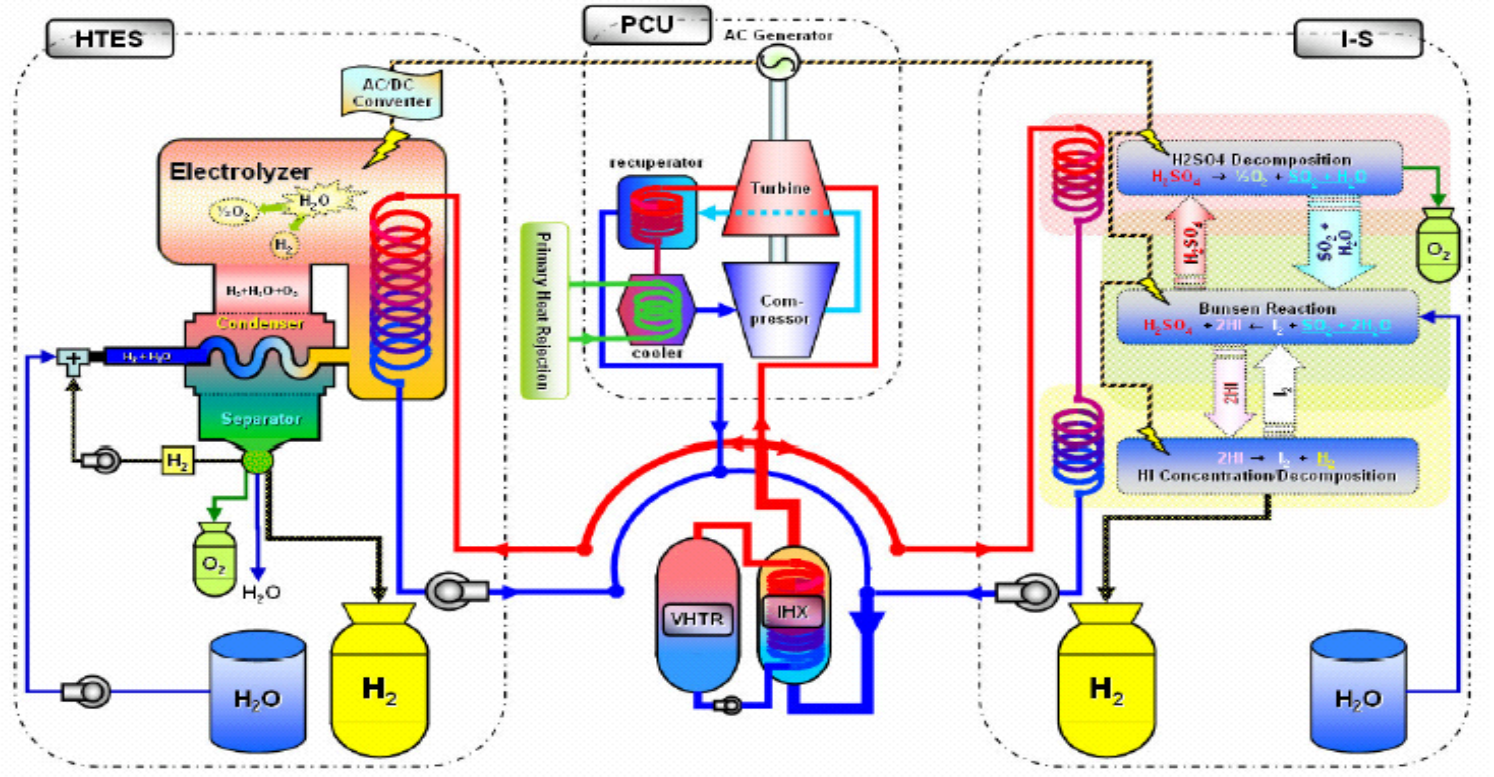
168 MW(th) for the sulfur-iodine process for 24,000 Nm^3/h of H_2

plus 202 MW(e)



Nuclear H_2 R&D Projects in Korea

- **Nuclear Hydrogen Development and Demonstration** (NHDD) project
  600 MW(th) block core or 400 MW(th) pebble core
  3 H_2 options: S-I, HTE, MMI (methane-methanol-iodomethane)

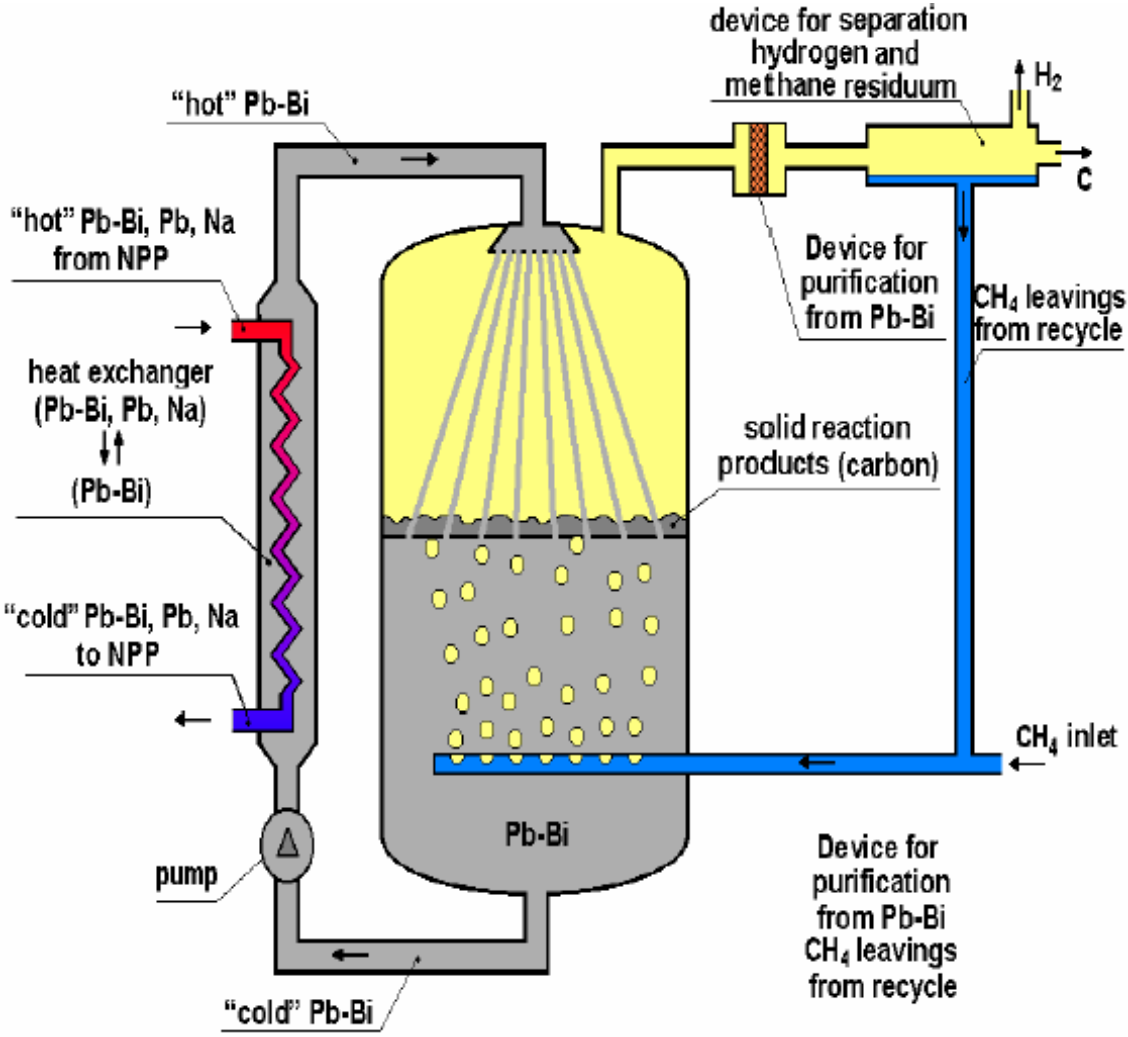


Nuclear H_2 R&D Projects in Russia

- **LMCFR for direct-contact methane decomposition**

metal/metal IHX

secondary coolant lead-bismuth @ ~ 700°C



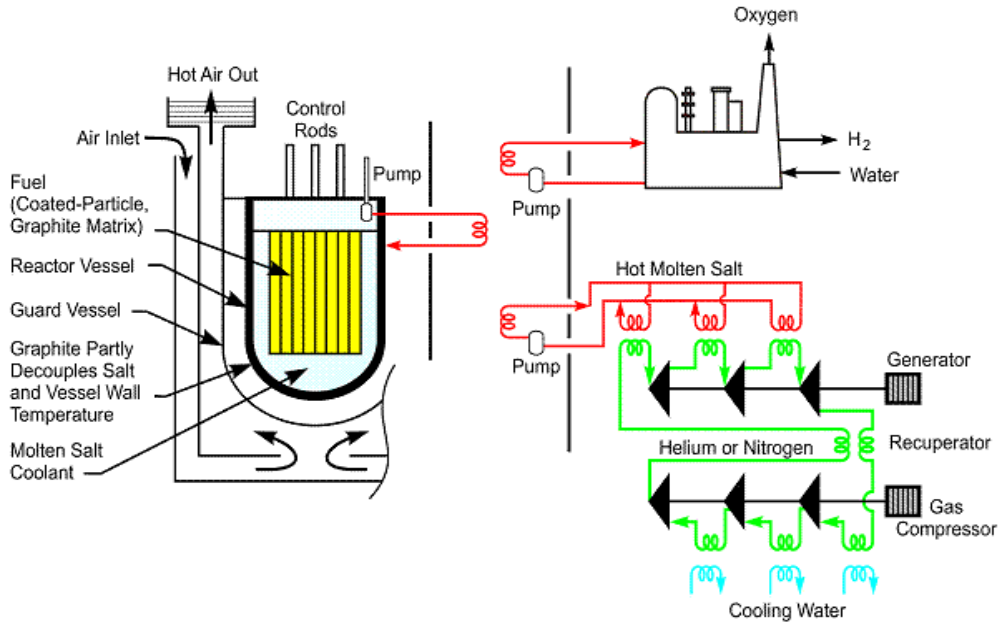
Nuclear H_2 R&D Projects in the USA

- **H2-MHR**
  based on 600 MW GT-MHR, H_2 production by S-I or HTE,
- **STAR-H2** (Secure Transportable Autonomous Reactor Hydrogen)
  400 MW heavy liquid metal cooled fast reactor, sec. coolant „FLiBe“
  to produce, apart from H_2, electricity and potable water
- **AHTR** (Advanced High Temperature Reactor)

  up to 4000 MW(th)

  coolant is liquid fluoride salt
  @ 700-1000°C

  H_2 via S-I at lower temp.
  using membrane techn.



RAPHAEL - Integrated Project in FP6

- RAPHAEL is acronym for „Reactor for Process Heat, Hydrogen and Electricity Generation“
- 35 partners, coordinated by Framatome-ANP
- Focus on VHTR technological developments needed for industrial reference designs in the areas of reactor physics, safety, fuel and fuel cycle back-end, materials, components, system integration
- RAPHAEL started April 15, 2005

RAPHAEL Objectives

- Assessment of fuel technologies for a VHTR at 900-1000°C with burnup > 15%FIMA;
  (Irradiation tests in Petten: HFR-EU1 and -EU1bis)

- Explore promising options for development of a GCR above 1000°C.

  1000°C: no problem for fuel
  conceivable for direct cycle
  not feasible for metallic components (IHX)

EU Contracts on Hydrogen in FP-6

Project	Topic	Coordinator	EU Funding [M E]
HYTHEC-STREP	Thermochemical cycles	CEA (F)	1.9
CHRISGAS-IP	H_2 rich gas from biomass	Växjo Uni (S)	9.5
Hi2H2-STREP	HT electrolysis	EDF (F)	0.9
HYWAYS-IP	European hydrogen roadmap	LBST (G)	4.0
NATURALHY-IP	Infrastructure H_2-natural gas mixes	Gasunie (NL)	11.0
STORHY-IP	Storage for on-board applications	Magna Steyr (A)	10.0
HYSAFE-NE	Research in safety issues	FZK (G)	7.0
ZEROREGIO-IP	H_2 fuel cell fleet demonstration	Infraserv (G)	7.5
PREMIA-SSA	Effectiveness of demo initiatives	VITO (B)	1.0
HYICE-IP	Internal combustion engines	BMW (G)	9.0

Conclusions (1/2)

- **A significant and steadily growing H_2 market exists already.**
  chemical industries, conversion of "dirty" fuels, transport, stationary
- **Most H_2 production technologies can be connected to nuclear primary energy, all have their benefits and drawbacks.**
  saving fossil reserves, lower tension on Europe's need for energy imports
- **Next generation NPP must provide more than just electricity.**
  process heat and process steam according to industrial needs

Conclusions (2/2)

- **Near-term and long-term options for nuclear hydrogen production**
  - LT electrolysis, nuclear steam reforming, most components developed
  - HT electrolysis, thermochemical cycles, still R&D level
- **European Union activities**
  - Hydrogen: HYWAYS, HYTHEC, HYSAFE
  - Nuclear: MICANET, RAPHAEL (fuel, spent fuel, materials, code qualification)
- **Other international activities**
  - HTTR, HTR-10
  - GIF (ambitious R&D programs in various countries for concepts to bring nuclear hydrogen to the market)

Thank you
for your kind attention !

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