Energetyka jądrowa w Polsce

synergia węglowo – jądrowa

Ludwik Pieńkowski
Środowiskowe Laboratorium Ciężkich Jonów
Uniwersytet Warszawski
pienkows@slcj.uw.edu.pl

Synergia przemysłu węglowego i energii jądrowej

- Objawy kryzysu energetycznego: rosnące ceny gazu i ropy naftowej oraz groźby niestabilności dostaw tych paliw
- Nowe technologie: metoda przezwyciężenia kryzysu
- Wysokotemperaturowy reaktor jądrowy dla czystych technologii węglowych: skoncentrowanie w Polsce europejskich badań będzie elementem naszego bezpieczeństwa
- Programu badawczy będzie stabilizująco oddziaływać na rynek paliw
- Wykształci naukowców i inżynierów dla racjonalnych decyzji o drogach budowy energetyki jądrowej w Polsce
- Stworzy mechanizm wsparcia dla energetyki jądrowej przez polskie górnictwo, które w innej sytuacji mogłoby postrzegać energetykę jądrową jako konkurencję dla energetyki węglowej, która jest i przez długie lata będzie podstawą naszego bezpieczeństwa energetycznego

Wysokotemperaturowy reaktor dla Polski

- Hel chłodzący reaktor osiąga temperaturę 900 °C
- Moc cieplna reaktora nie przekracza kilkuset MW

Ciepło z reaktora do przerobu węgla na paliwa gazowe i płynne

Pierwszym etapem produkcji benzyny syntetycznej jest zgazowanie węgla:

$C + H_2O \rightarrow CO + H_2$

W kolejnych etapach gaz syntezowy prowadzi się syntezę wodoru z tlenkiem węgla:

$2H_2 + CO \rightarrow CH_3OH$

$17H_2 + 8CO \rightarrow C_8H_{18} + 8H_2O$

SYNERGISTIC HYDROGEN PRODUCTION BY NUCLEAR-HEATED STEAM REFORMING OF FOSSIL FUELS

Masao Hori	Nuclear Systems Association
Kazuaki Matsui	The Institute of Applied Energy
Masanori Tashimo	Energy Think Tank Co
Isamu Yasuda	Tokyo Gas Co

The 1st COE-INES International Symposium
INES-1
November 1, 2004
Tokyo, JAPAN

Ratio of heat of reaction to heat of combustion of produced hydrogen in steam reforming reaction of representative fossil fuels / hydrocarbons

Fossil Fuel / Hydro-carbon	Representative Component's Molecular Formula	Steam Reforming Reaction Formula	Heat of Reaction / Mole of Hydrocarbon [kJ/mol-HC]	H_2 Heat of Combustion / Mole of Hydrocarbon [kJ/mol-HC]	Heat of Reaction / H_2 Heat of Combustion [%]
Natural Gas	C_1H_4	$CH_4+2H_2O \rightarrow CO_2+4H_2$	165.0	968	17.0
LPG	C_4H_{10}	$C_4H_{10}+8H_2O \rightarrow 4CO_2+13H_2$	486.6	3146	15.5
Naphtha	C_6H_{14}	$C_6H_{14}+12H_2O \rightarrow 6CO_2+19H_2$	739.3	4598	16.1
Kerosene	$C_{12}H_{26}$	$C_{12}H_{26}+24H_2O \rightarrow 12CO_2+37H_2$	1433.0	8954	16.0
Coal	C_1	$C+2H_2O \rightarrow CO_2+2H_2$	90	484	18.6

Synergy of Fossil and Nuclear

1+1=3

- Most discussions of future global energy supply anticipate continued use of fossil fuels to some extent for a century or so while reducing carbon dioxide emission. The synergistic production of hydrogen using both energy sources could enable nuclear energy to improve the efficiency with which valuable fossil fuel resources are consumed.
- With all these benefits, the synergistic blending of fossil fuels and nuclear energy to produce hydrogen can be an effective solution for the world until competitive thermo-chemical water splitting processes are available.

Reaktor wysokotemperaturowy do produkcji wodoru z wody

W temperaturze 900 °C wodór można wydajnie i bez emisji CO_2 produkować w procesach pośrednich (na przykład w cyklu siarkowym) z wody:

$$2H_2O \rightarrow 2H_2 + O_2$$

Nie wodór z węgla, a wodór dla węgla

HYDROGEN AND SYNTHETIC HYDROCARBON FUELS – A NATURAL SYNERGY*

K. Schultz[1], L. Bogart[2], G. Besenbruch[1], L. Brown[1], R. Buckingham[1], M. Campbell[1], B. Russ[1], and B. Wong[1]

General Atomics, P.O. Box 85608, San Diego, CA 92186
Consultant to GA, 7982 Chaucer Dr., Weeki Wachee, FL 34607

* Work supported by General Atomics

GENERAL ATOMICS

Coal is a possible source of synfuel

- Synfuel by Coal Gasification:

Gasification	$2C + {}^1/_2O_2 + H_2O \Rightarrow 2CO + H_2$
Water gas shift	$CO + H_2O \Rightarrow H_2 + CO_2$
F-T reaction	$CO + 2H_2 \Rightarrow CH_2 + H_2O$
Net reaction	$2C + H_2O + {}^1/_2O_2 \Rightarrow CH_2 + CO_2$

- Process uses 2 C and half an O_2 and makes one CO_2 for every CH_2 produced

- Replacing oil with coal synfuel would triple current coal use and double current CO_2 production

Addition of H_2 improves the coal synfuel process

- Synfuel by Coal Gasification + H_2 from Water-splitting:

Gasification	$C + {}^1/_4O_2 + {}^1/_2H_2O \Rightarrow CO + {}^1/_2H_2$
Water-splitting	${}^3/_2H_2O + \text{Energy} \Rightarrow {}^3/_2H_2 + {}^3/_4O_2$
F-T reaction	$CO + 2H_2 \Rightarrow CH_2 + H_2O$
Net reaction	$C + H_2O + \text{Energy} \Rightarrow CH_2 + {}^1/_2O_2$

- Carbon need cut in half compared to synfuel from standard coal gasification, and *no* CO_2 is produced.

A source of CO_2 would make synfuel very attractive

- Synfuel by CO_2 Capture + H_2 from Water-splitting:

Reverse Water Gas Shift	$CO_2 + H_2 \Rightarrow CO + H_2O$
F-T reaction	$CO + 2H_2 \Rightarrow CH_2 + H_2O$
Water-splitting	$3H_2O + \text{Energy} \Rightarrow 3H_2 + {}^3/_2O_2$
Net reaction	$CO_2 + H_2O + \text{Energy} \Rightarrow CH_2 + {}^3/_2O_2$

- No coal is needed and one CO_2 is consumed for each CH_2 produced
- When the CH_2 is burned, the process is carbon-neutral

Synfuel Cost estimates are encouraging

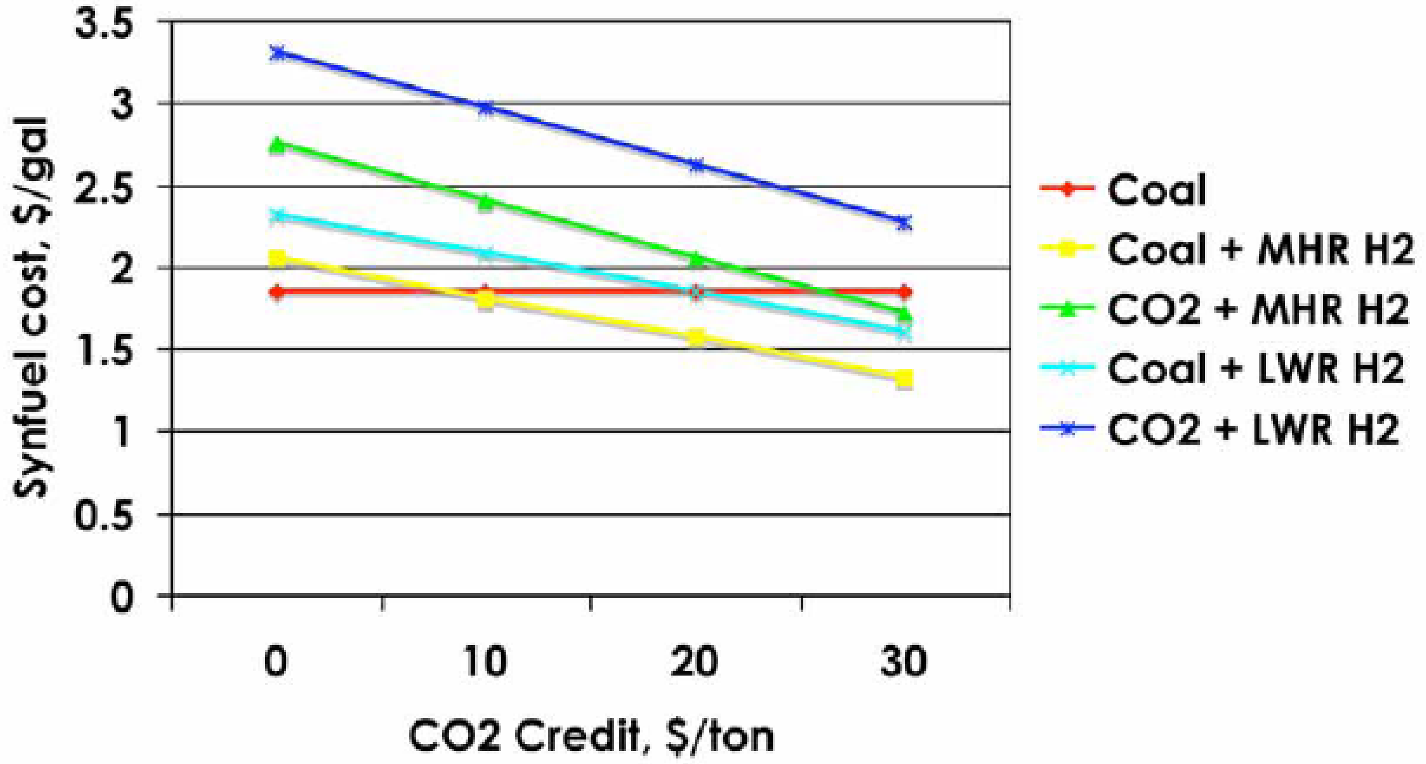
Estimated Cost of Synfuel, $/gallon (with/without $30/ton CO_2 credit)

Process	External Hydrogen Source		
	None	Modular Helium Reactor + S-I Process	Light Water Reactor + Electrolysis
Coal gasification + F-T	1.85*	-	-
Coal gasification + H_2 from water + F-T	-	1.32 / 2.06	1.61 / 2.36
CO_2 capture + H_2 from water + F-T	-	1.72 / 2.75	2.28 / 3.31

*: Coal gasification synfuel cost estimated from Rentech study (http://www.rentechinc.com/process-technical-publications.htm)

but with $30/ton coal and 10% interest rate,

The CO_2 credit is a key parameter



- A modest CO_2 credit allows H_2 synfuel to compete with coal synfuel

Hydrogen and Synfuel have Natural Synergy

- Addition of H_2 to the synfuel process can eliminate CO_2 production, allowing coal-based synfuel to replace oil with no increase in CO_2
- H_2 plus capture of CO_2 can allow synfuel production and use while cutting CO_2 release in half
- With modest CO_2 credit, H_2 can save money over conventional synfuel processes
- H_2 use in synfuels can be a bridge to the Hydrogen Economy

RAPHAEL JOURNAL n° 1
March 2006

Editorial

ReActor for Process heat,
Hydrogen And ELectricity generation

(Very) High Temperature Reactor (HTR/VHTR):
Small size,Big potential

FP6 project **RAPHAEL** addresses the viability and performance of an innovative system for the **next generation of power plants**, the **Very High Temperature Reactor (VHTR)** , which can supply both **electricity** and **heat** for industrial applications, including for **hydrogen production**.

The overall objectives of HTR/VHTR in the present phase are:

2. Assessing technologies of the first step in advanced HTR development
3. Exploring promising options for higher performances (VHT above 950°C, higher burnup).
4. Developing technologies for coupling the nuclear reactor with industrial process heat applications

http://www.raphael-project.org

Status of HTR/VHTR development in the world

HTR-TN High Temperature Reactor Technology Network

- Projects of industrial demonstrators are already running in many different countries, with large public funding support and with large related R&D programmes:
  - PBMR in South Africa
  - GT-HTR 300 in Japan
  - HTR-PM in China
  - NHDD in South Korea
  - GT-MHR in Russia and US
  - NGNP in US

  The starting of operation in all these projects is before the end of next decade
- **What about Europe?**

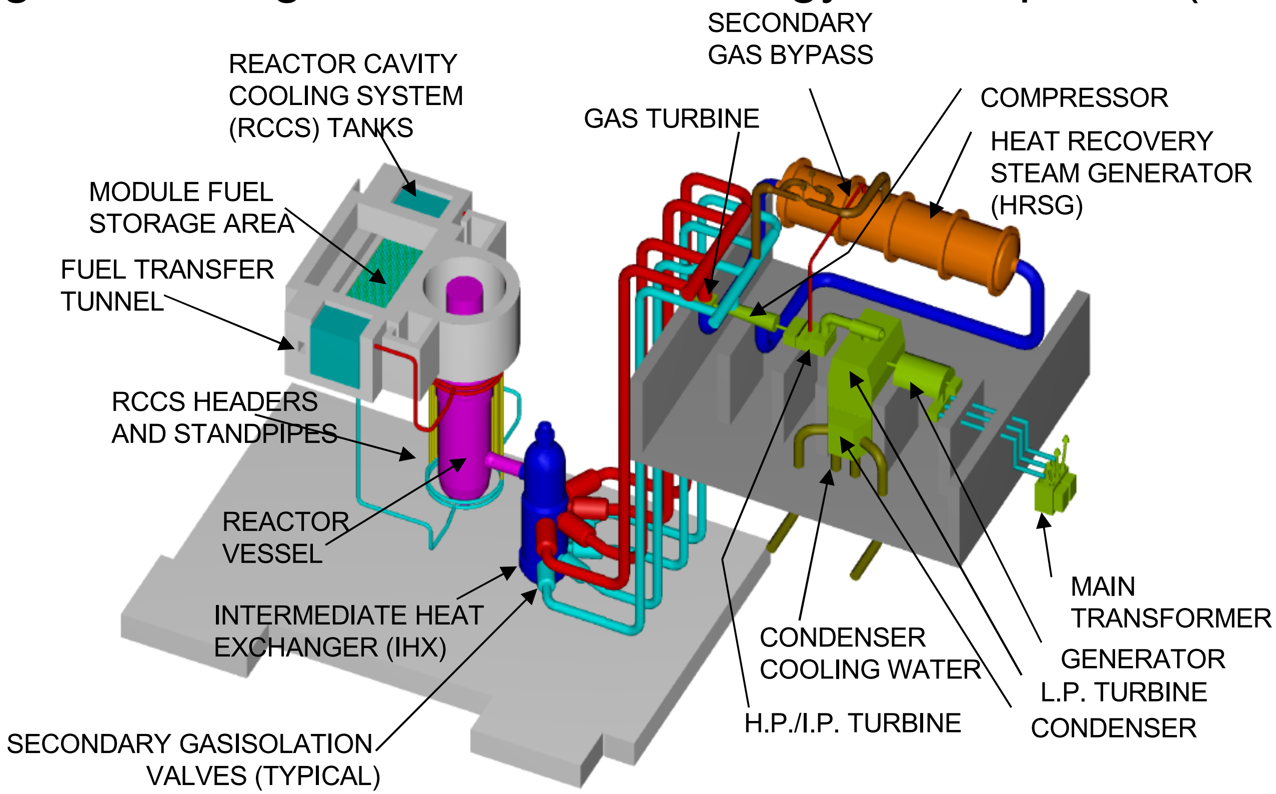
Status of HTR/VHTR development in Europe

HTR-TN
High Temperature Reactor Technology Network

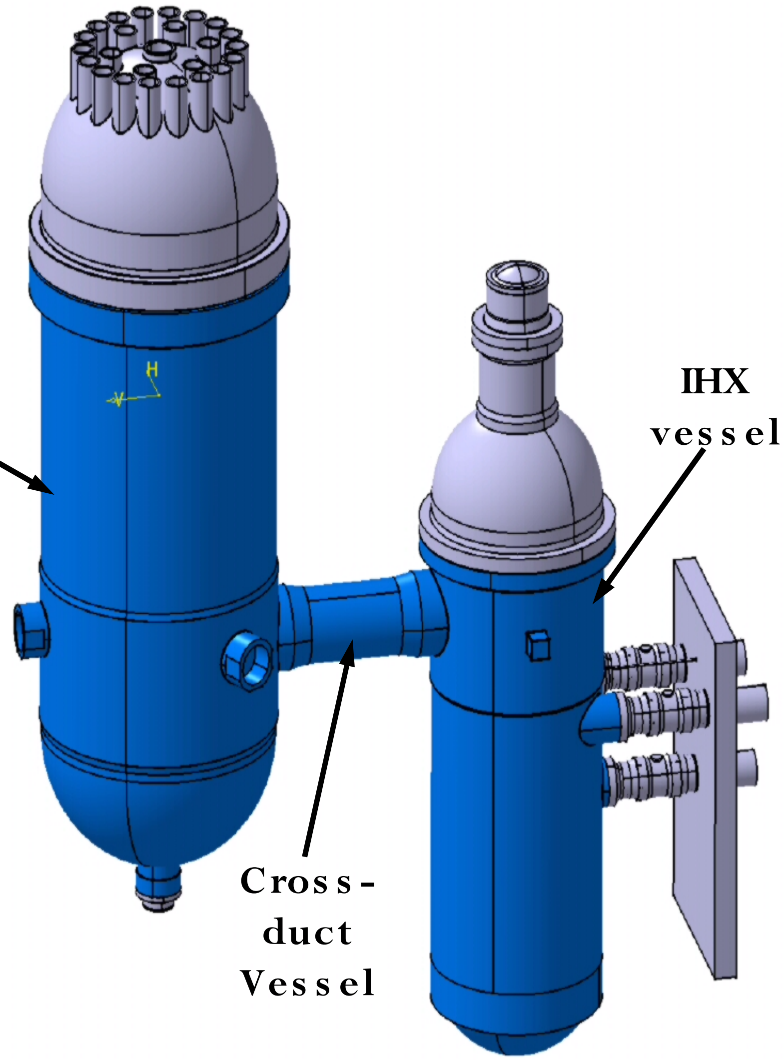
For the time being in Europe there are

- A prototype project, ANTARES, from AREVA and a participation of different European organisations to PBMR
- A European programme of generic HTR technology development (FP5, FP6)

AREVA
ANTARES



Base options of the Framatome ANP design

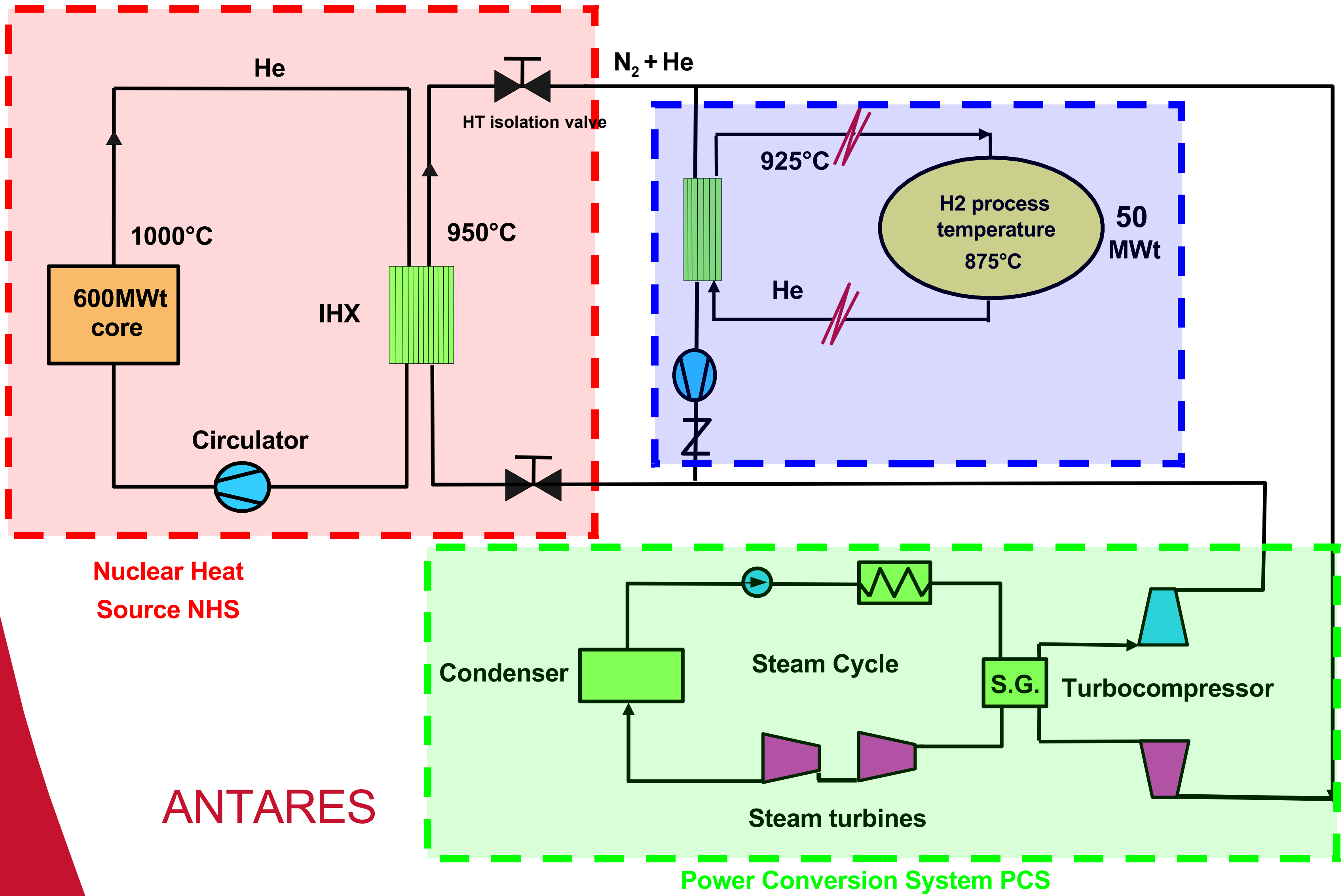


Dominique HITTNER

HTR-VHTR Project R&D manager
Framatome ANP

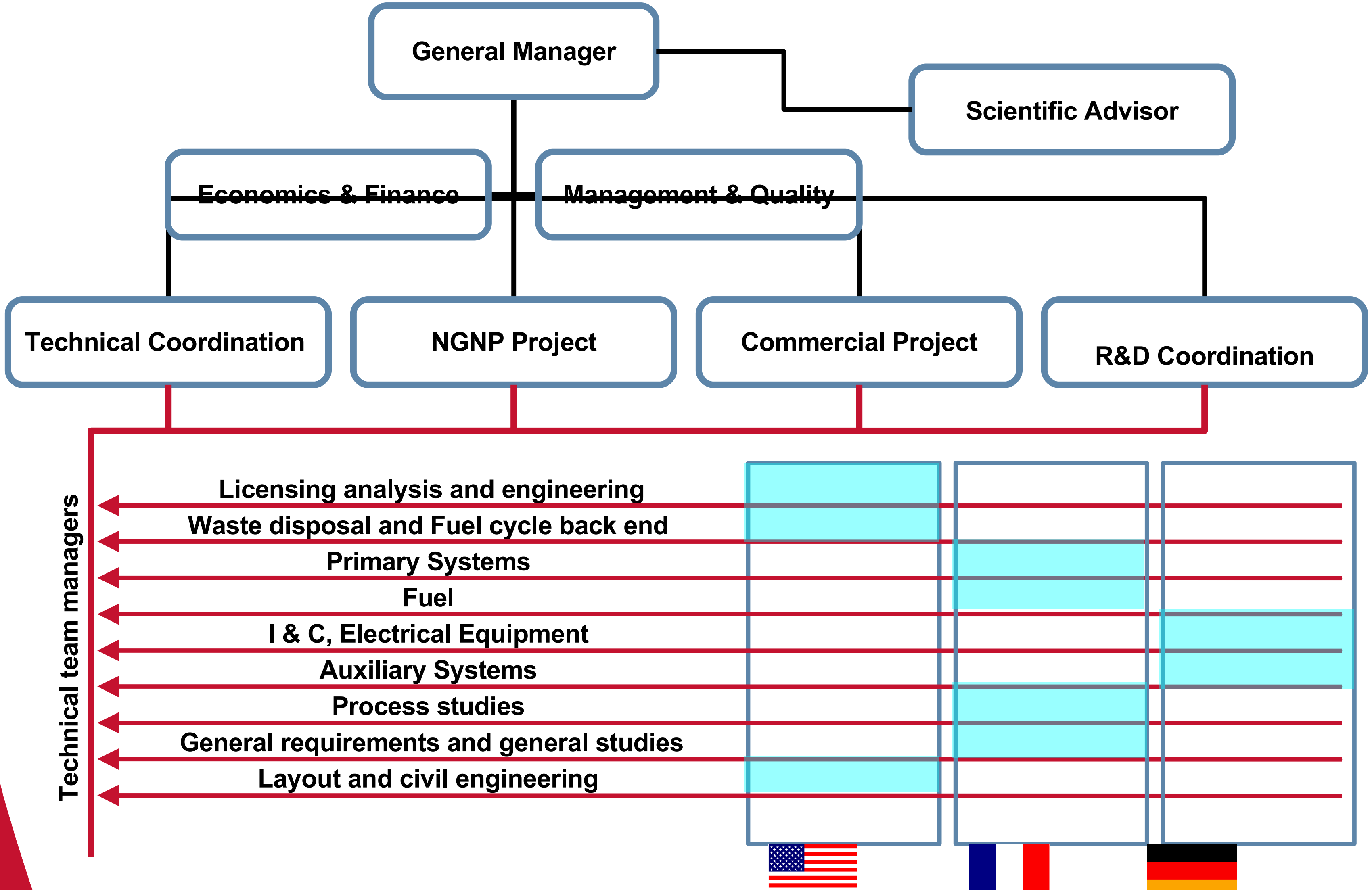
ANTARES

Arrangement for Electricity and Hydrogen Cogeneration



ANTARES

V/HTR Project Organization



⇒ ***The Framatome ANP HTR/VHTR ANTARES project is an international project***

United States Senate Committee on
Energy & Natural Resources

Full Committee Hearing: Next Generation Nuclear Plant Project
Monday, June 12, 2006

Dr. Regis Matzie, Westinghouse Electric Company, Senior Vice President and Chief Technology Officer Westinghouse Electric Company:

High temperature reactors can be used to provide environmentally friendly process heat for a broad range of applications, including **syngas production, coal-to-liquid** petroleum conversion, and hydrogen production. […] We do not have to wait for the development of hydrogen distribution and storage systems. We do not have to develop an economical hydrogen-fuelled car. Instead, we can use the existing industrial infrastructure of the chemical and transportation sectors. **This will help stabilize fossil fuel prices**. This would help our nation become less dependent on foreign imported fossil fuels at a time when energy security is prominent in our minds and would make a significant additional contribution to greenhouse gas reduction. […] the Pebble Bed Modular Reactor program can be of help to the Next Generation Nuclear Plant program because this design is already being reviewed by the U.S. Nuclear Regulatory Commission. [...] To fully launch the Next Generation Nuclear Plant program to demonstrate nuclear co-generation with the objective of completion of the **demonstration reactor within 10 years** through the establishment of a public private partnership, including strong international cooperation.

http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Hearing&Hearing_ID=1562

United States Senate Committee on Energy & Natural Resources

Full Committee Hearing: Next Generation Nuclear Plant Project
Monday, June 12, 2006

Mr. Tom Christopher, Areva, Inc., Chief Executive Officer AREVA, Inc.:

Our ANTARES reactor design is envisioned to serve these future markets and is a High Temperature helium cooled graphite moderated Reactor, or HTR. Thanks to its indirect cycle, this **HTR is able to produce process heat** at temperatures well above those of the current fleet of light water reactors. This process heat may be able to offset heat currently produced by fossil fuels in a broad range of industrial applications. For example, in the coming decades, we see a growing need for alternate liquid fuels. To augment traditional petroleum sources, alternate sources such as Alberta oil sands, Western oil shales and **conversion of coal to liquids** may become significant contributors to our transportation fuel mix. These all consume large quantities of process heat and hydrogen. Conversion of cellulosic biomass to ethanol also requires significant process heat. In place of fossil fuels presently used to provide the process heat for these applications, nuclear reactors may be able to provide the necessary energy. This would avoid significant amounts of carbon dioxide emissions and further consumption of fossil fuel.

http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Hearing&Hearing_ID=1562