

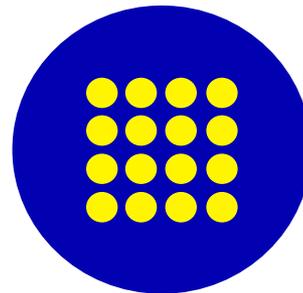
# **BNFL/Westinghouse's Perspective on the Nuclear Hydrogen Economy**

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**Westinghouse**



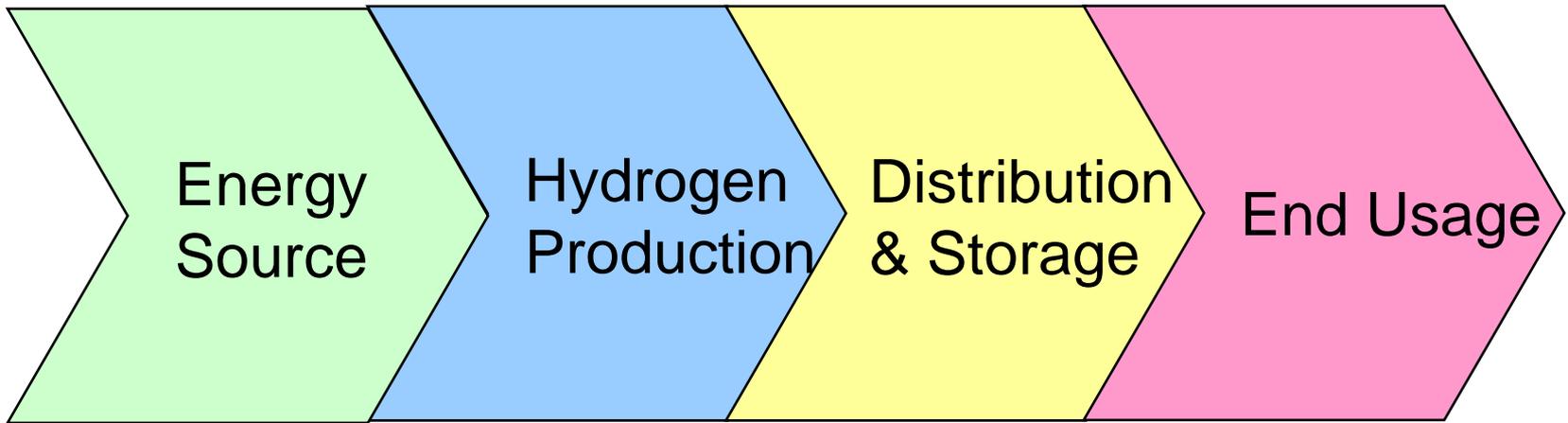
**BNFL**



- **BNFL/Westinghouse is a large, international supplier of products and services for nuclear industry**
- **Employs 23,000 people in UK, US, Europe, Far East**
- **Turnover £2.3bn in FY03/04**
- **Supplies Utilities and Governments & consists of**
  - Westinghouse**
  - Nuclear Sciences & Technology Services**
  - Spent Fuel Services**
  - British Nuclear Group**
  - BNFL Inc**

# Hydrogen Economy Supply Chain

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Scope of Nuclear Technology  
Interest

# Why nuclear?

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- Nuclear offers:
  - a near-zero emissions option
  - demonstrated and established technology
  - long-term stability on generation cost
  - Applications for both electricity & high temperature heat generation
  
- High Temperature Gas-Cooled Reactor Technology offers:
  - Outlet temperature > 800°C
  - Inherently safe technology
  - Small / modular reactors to cope with grid & deployment issues

# H<sub>2</sub> Production via Nuclear

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- Electrolysis

- For reactor systems with high outlet temp (700-900°C) this could replace some of demands on electrical energy requirements with thermal energy.
- This would improve the efficiency and reduce production cost

- Steam Reforming Process

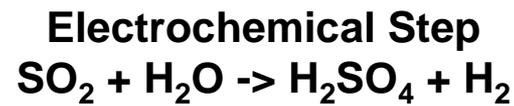
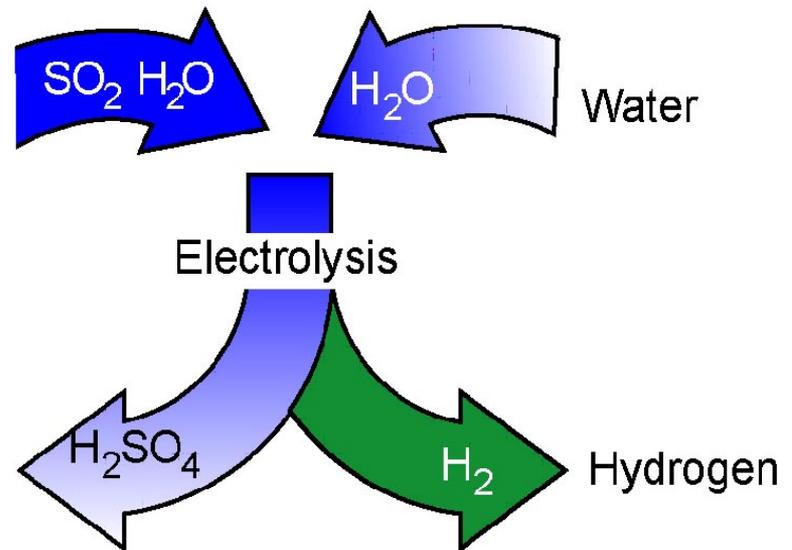
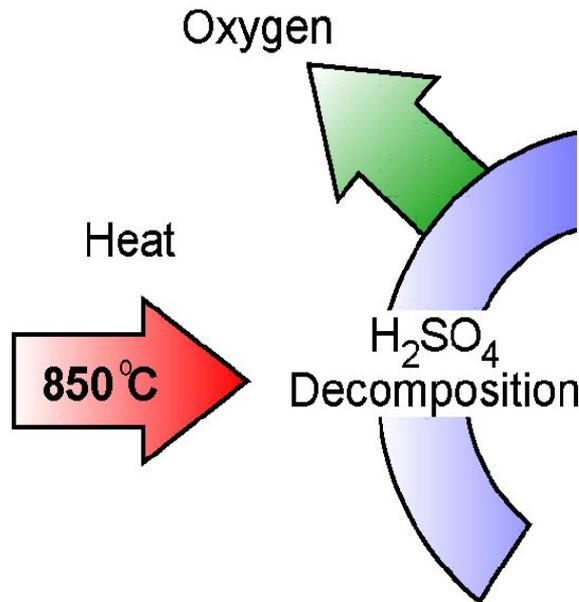
- Requirements on natural gas can be significantly reduced by using nuclear heat

- Thermochemical Cycles

- Production of hydrogen without generation of CO<sub>2</sub>
- Potential for long term low stable cost

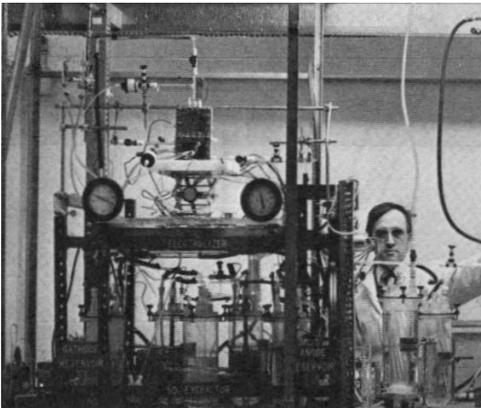
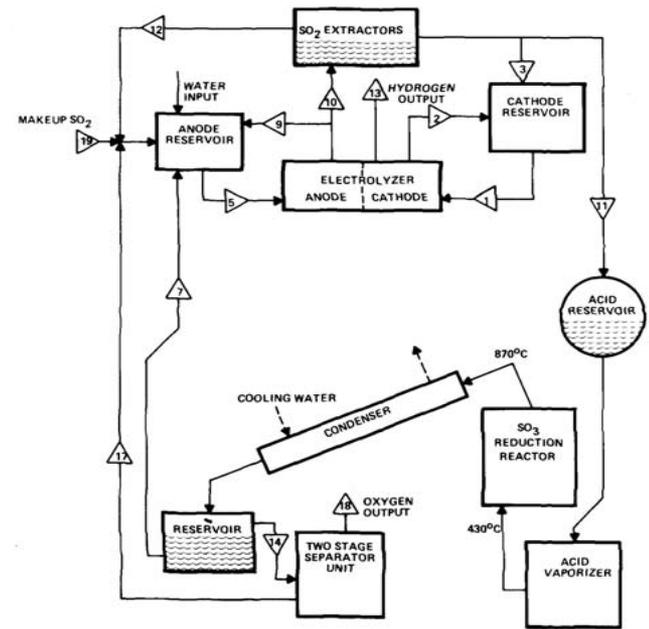
# The Westinghouse Sulphur Cycle

- Replaces thermal decomposition of water (requiring > 2500°C) with several partial reactions
- Westinghouse cycle is simpler than other thermal cycles



# Westinghouse Sulphur Cycle - History

- Initial development by Westinghouse between 1973-83 with DoE support from 1976 to 1983
- Development of electrolyser components & the  $\text{H}_2\text{SO}_4$  decomposition reactor
- Integrated laboratory demonstration in 1978 produced 120 L/hr  $\text{H}_2$
- Development of commercial design / flowsheets, including process optimisation and integration with nuclear energy source
- Economic assessments



# Advantages of the Westinghouse Sulphur Process compared to other cycles

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- Expected efficiency >50%
- Fewer materials issues (no use of corrosive halides)
- More scalable (minimal heat and mass transfer design issues)
- Economic scale factors better than for other cycles
- Operable process already defined
- Increased safety / ease of integration with nuclear plant

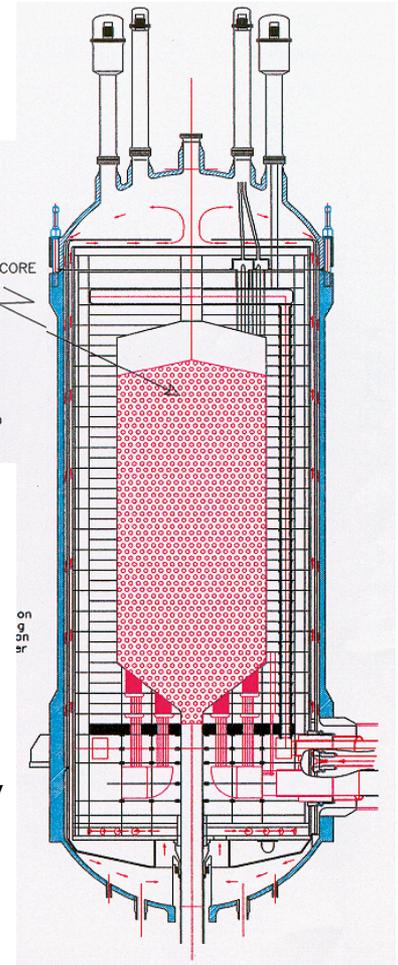
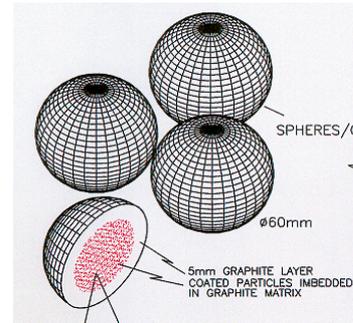
# High Temperature Reactor Technology

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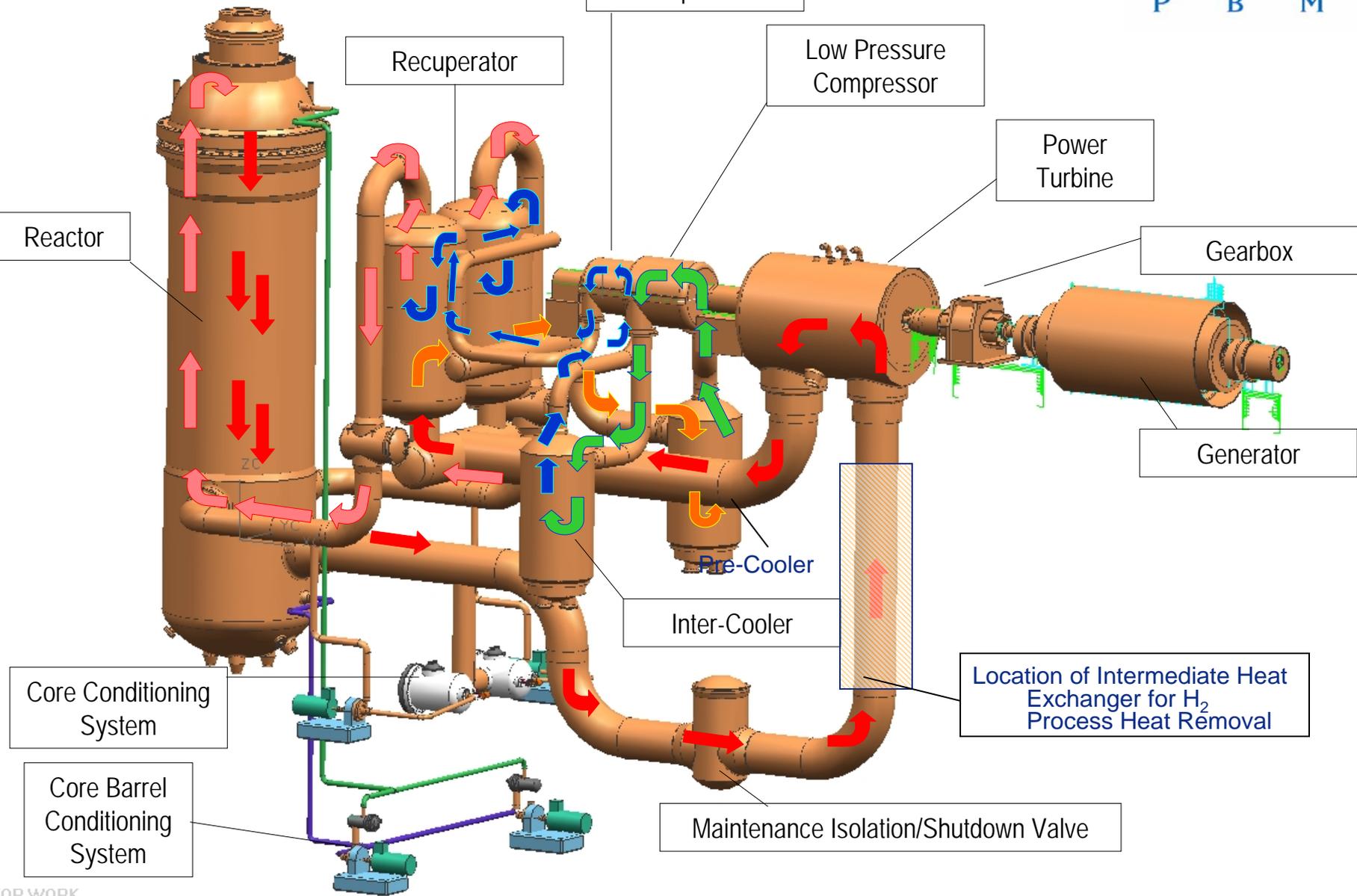
- Significant international interest in HTR Technology:
  - Pebble Bed Modular Reactor (PBMR) in South Africa
  - HTR-10 and HTR-PM in China
  - HTTR in Japan
  - NGNP in US at Idaho
  - Significant interest in S. Korea
  - General Atomics development with GT-MHR
  - France actively pursuing R&D with major development plans
- Proven technology historically developed in Europe (Dragon, AVR, THTR, HTR- Modul) and US (Fort St Vrain)

# Pebble-Bed Modular Reactor (PBMR)

- Small (~400 MWt) modular pebble bed HTR
  - helium cooled, graphite moderated
  - direct cycle gas turbine
  - no secondary steam circuit
  - high outlet temperature: 900°C
    - good thermal efficiency (~ 42%)
    - flexibility for alternative applications
  - high fuel average burnup (~ 80 GWd/tU initially, higher later)
  - very high degree of inherent safety
- Design based on European proven technology demonstrated in 1970s & 1980s
- Direct cycle technology introduced by PBMR

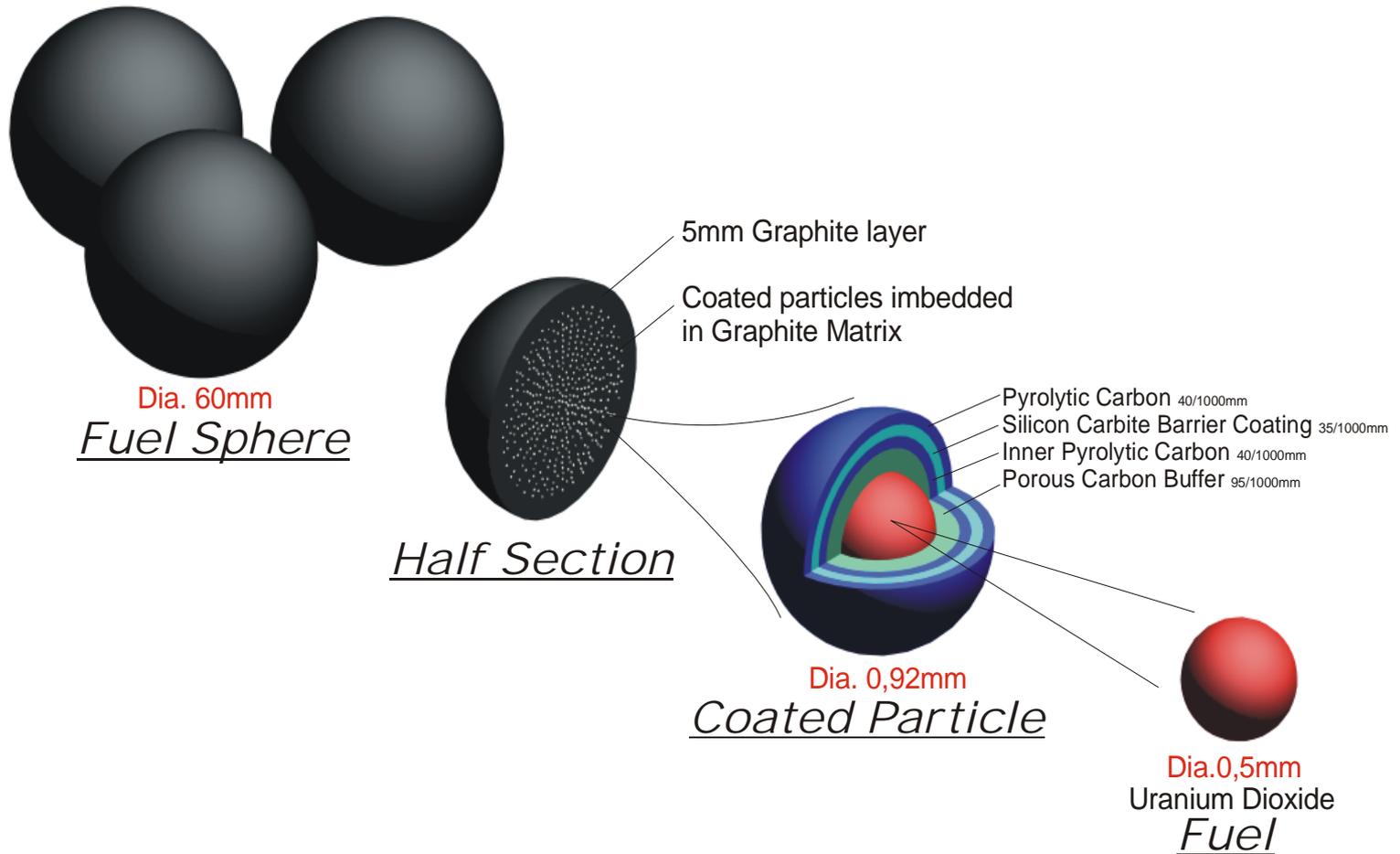


# PBMR Layout



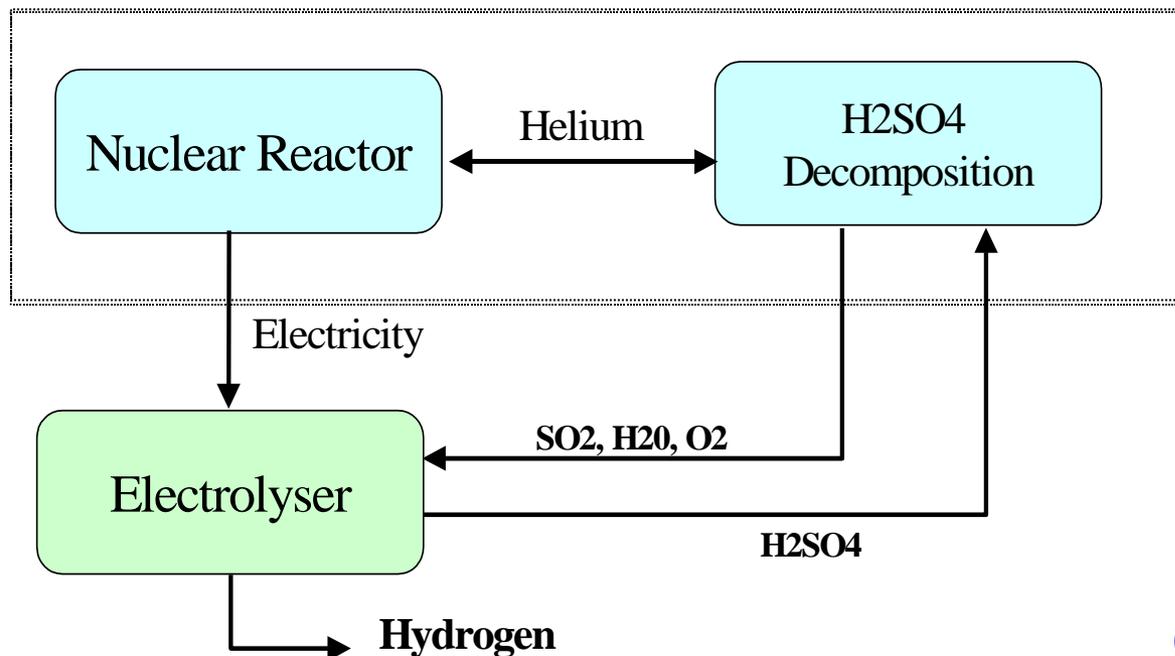
# PBMR fuel design

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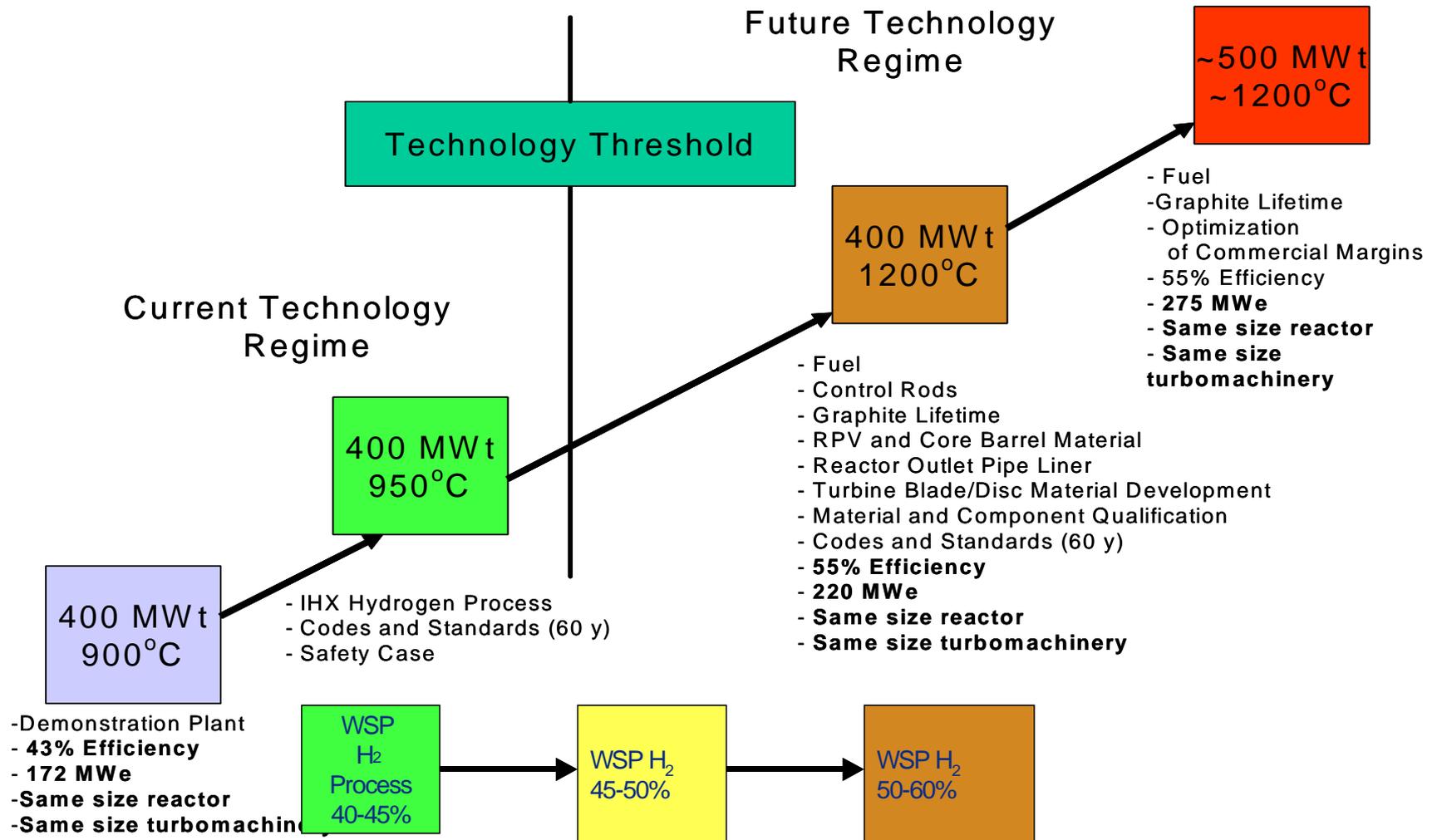


# Why PBMR and Westinghouse H<sub>2</sub> Process ?

- Both PBMR and Westinghouse H<sub>2</sub> technologies have been demonstrated
- PBMR provides temperature and power levels to produce high efficiency hydrogen through the Westinghouse Hydrogen process.
- Process allows separation of Hydrogen production from nuclear plant
- No highly corrosive halides in hydrogen generation process



# Matching evolutionary paths of HTR Technology & Hydrogen Production Process



# A gas-cooled reactor technology path

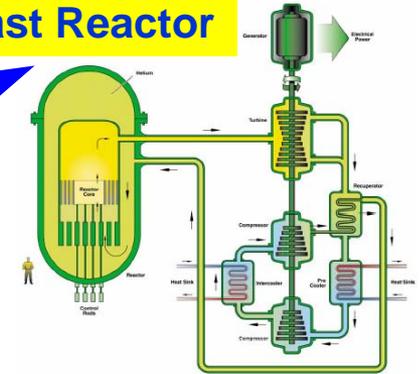
Diagram shows natural development for gas cooled systems & technology challenges to be addressed

**ETDR**

**GFR R&D**

fuel materials & fabrication  
materials for high fluence  
fuel cycle technology  
safety systems

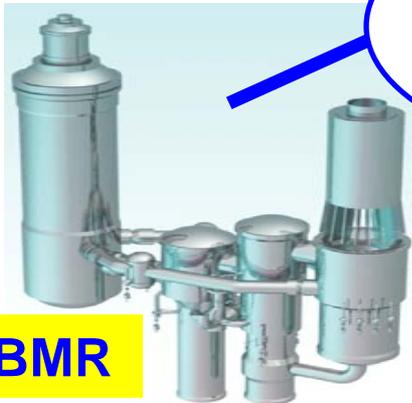
**Gas-cooled Fast Reactor**



**NGNP / VHTR R&D**

fuel materials & fabrication  
high temperature materials  
hydrogen production technology  
graphite technology

**VHTR**



**PBMR**

**Idaho NGNP**



# Key Technology Development Areas

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- Integration with nuclear heat source
  - Thermal coupling method, associated technologies (e.g. HX, materials)
  - Operational considerations (e.g. pressure balancing requirements)
- Integrated Process Demonstration of Hydrogen Generation Process
  - Pilot loop applying prototype materials at proposed operating conditions
- Regulatory Considerations
- Economic Assessment with updated process materials & costs



# BNFL/Westinghouse Experience

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- Significant historical capability in:
  - Fuel Manufacture
  - Gas-cooled reactor technology
  - Graphite technology
- Active involvement in the PBMR South African project
- Provides links between BNFL/W & Sheffield University, University of South Carolina and Savannah River National Laboratory
- Development of HTR Nuclear physics and fuel performance capability
- Involvement in international collaborative activities such as US DoE's Generation IV programme



# Required Governmental Support

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- Recognise benefits of nuclear and its role in hydrogen economy
- Fund a wider range of R&D activities supporting nuclear hydrogen production
- Support collaborative research activities
- Propose long term integrated vision
- Develop technology roadmaps
- Support regulatory studies on issues associated with nuclear plants for hydrogen generation