NGNP in the U.S.

The Canon Institute for Global Studies

Climate Change Symposium

The Role of Nuclear Energy and Climate Change

With Special Focus on Heat Supply by HTGR and High-Level Radioactive Waste Treatment by Fast Breeder Reactor

Tokyo, Japan

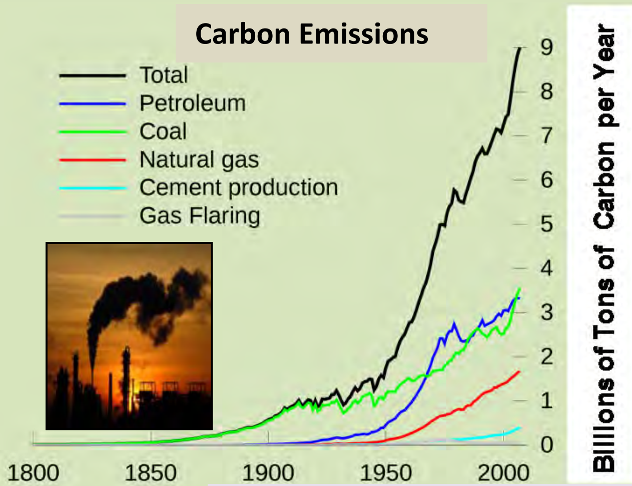
February 3, 2015

Matt Richards
Director, Engineering and Design
Ultra Safe Nuclear Corporation
mrichards@ultrasafe-nuclear.com

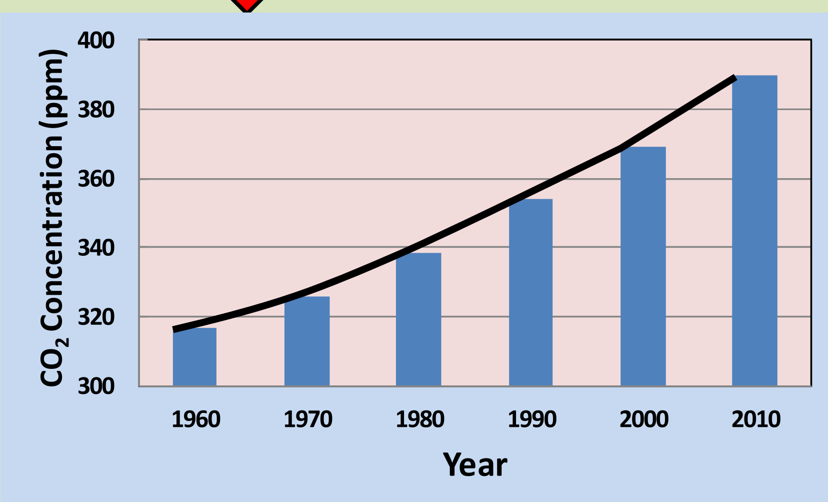
Outline

- **Greenhouse Gas Emissions and Global Energy Supply and Demand**
- **Next Generation Nuclear Plant (NGNP) Project**
  - History
  - Current Status
- **NGNP Industry Alliance (NIA)**
  - GEMINI Iniative with European Union
- **Modular High Temperature Gas Cooled Reactor (MHR) Design Concepts**
  - General design features and applications
  - MHR approach to safety in design
  - DOE NGNP Pre-Conceptual Design
  - DOE NGNP demonstration plant conceptual design
  - AREVA steam-sycle MHR concept
  - Other MHR concepts under development
  - Cost Estimates
- **NGNP TRISO Fuel Development Program**
- **NGNP Process Heat Applications and Market Assessments**
  - Target markets in North America identified in the 2012 NIA business plan
  - Displacing LNG used for electricity generation in Japan and the ROK
  - Nuclear steel manufacturing in Japan and the ROK
  - Displacing oil used for electricity generation and process heat in the KSA
- **Conclusions**
  - A Path Forward with International Collaboration

Increasing Use of Fossil Fuels Has Impacted the Global Carbon Cycle



Significant Increase in Atmospheric CO_2 Concentration



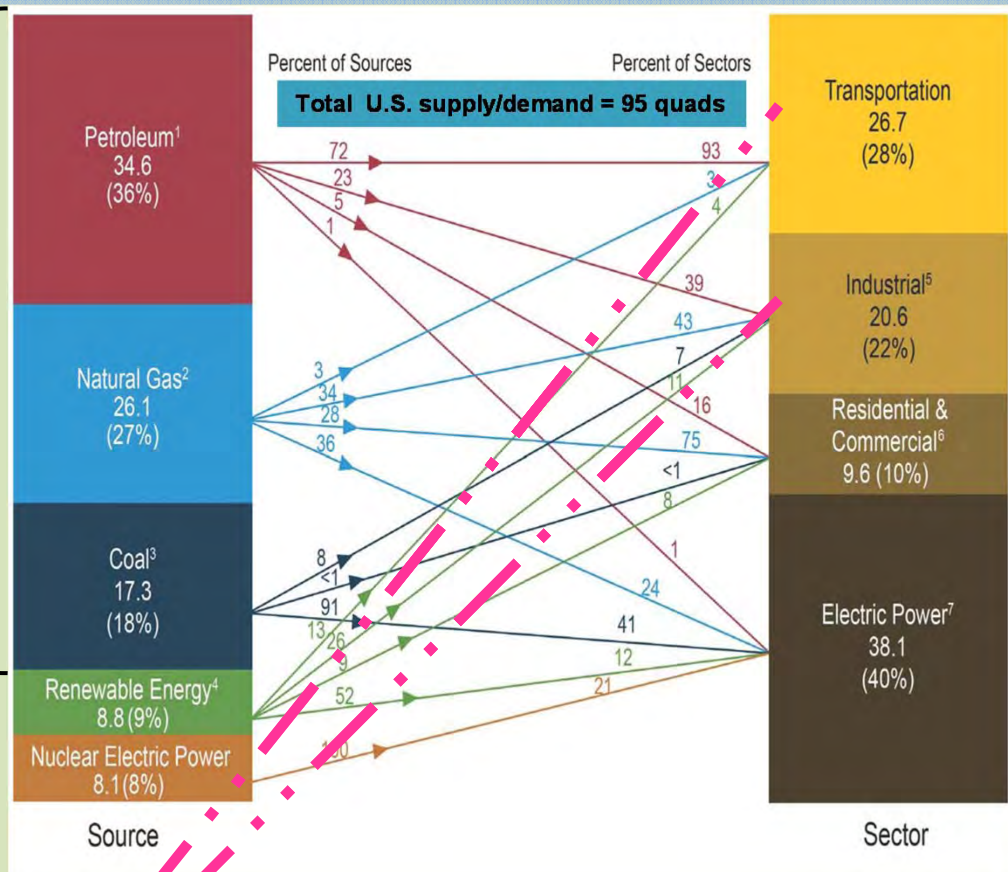
Rank	Country	Annual CO_2 Emissions (Billions of Metric Tons)	Percentage of Global Total
	World	29.88	100%
1	China	7.03	23.33%
2	United States	5.46	18.11%
3	European Union	4.18	14.04%
4	India	1.74	5.78%
5	Russia	1.71	5.67%
6	Japan	1.21	4.01%
7	Germany	0.79	2.61%
8	Canada	0.54	1.80%
9	Iran	0.54	1.79%
10	United Kingdom	0.52	1.73%
11	South Korea	0.51	1.69%

80%

Further increases in atmospheric CO_2 could have deleterious impacts on the global climate. Reducing CO_2 emissions should be a high priority for future energy policy.

U.S. Energy Supply and Demand (2012)

91% from Fossil Fuels



50% for Industry and Transportation

Globally, 78% of energy demand is in the industrial and transportation sectors.

Nuclear Process Heat ?

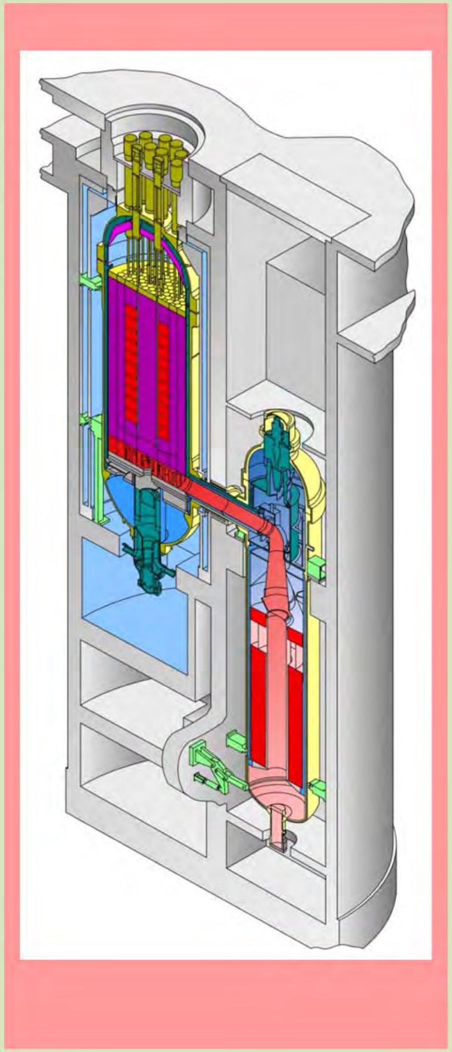
Can nuclear process heat reduce the use of petroleum, natural gas, and coal in the industrial and transportation sectors?

How Can We Reduce CO_2 Emissions?

- **Conservation and More Efficient Energy Use**
  - Can compensate for growth in demand to some extent
- **Carbon Capture and Storage (CCS)**
  - Technically feasible, but requires capturing, transporting, and storing very large quantities of CO_2
  - Negative economic impact
  - Potential safety issues with sudden release of a large quantity of CO_2
- **Increase Use of Renewable Energy**
  - Low energy density with limited applications, especially at high temperatures
- **Increase Use of Nuclear Energy**
  - Higher energy density than fossil fuels and renewables
  - Replace coal and natural gas in the electricity sector
  - Replace petroleum, natural gas, and coal in the industrial and transportation sectors
    - ➢ **Requires a next generation reactor with higher temperature capability and inherent safety**

NGNP History

- **Authorized by Energy Policy Act of 2005 (EPACT)**
  - Modular HTGR (MHR) concept based on R&D activities supported by Generation IV Nuclear Energy Systems
  - Funded through U.S. Dept. of Energy (DOE)
  - **Mission defined to produce electricity, hydrogen, or both**
- **Three Awards for Pre-Conceptual Design (2007)**
  - Westinghouse (Pebble-Bed Core)
  - General Atomics (Prismatic-Block Core)
  - Areva (Prismatic-Block Core)
- **Conceptual Design Studies (2008 – 2009)**
  - Various trade and special topics studies performed by all 3 vendor teams
- **Conceptual Design (2010 – 2011)**
  - **Based on market studies, mission changed to focus on nearer-term process steam and process heat applications**
  - Only General Atomics received a contract from DOE



NGNP Status (1/2)

- **Conceptual Design completed by General Atomics**
  - Conceptual Design Report and all major System Design Descriptions completed by December 2010.
- **Conceptual Design information provided to Nuclear Energy Advisory Committee (NEAC)**
- **NEAC Recommendations (June 2011)**
  - Accelerate formation of NGNP public/private partnership
    - Phased partnership should be pursued, with cost sharing requirements increased as uncertainties associated with NGNP deployment are reduced
  - Continue to engage NRC to ensure regulatory framework is ready for commercialization
  - Continue design activities to support PSAR level of detail
  - Expedite NGNP deployment efforts

NGNP Status (2/2)

- **Public/Private Partnership has not been established**
  - NEAC recommendations have not been implemented
- **Further design work is on hold**
- **DOE technology program has been very successful**
  - TRISO coated particle fuel technology has been successfully re-established in the U.S.
  - Fuel produced using commercial-scale equipment by U.S. vendor (B&W)
  - Excellent fuel performance during irradiation testing and accident-condition heating tests
  - Technology program continues, but with reduced funding
  - Less emphasis on nuclear hydrogen technology
- **NGNP Industry Alliance developing business plans**
  - International collaborations/agreements
- **In June 2014, GAO recommends DOE to develop strategy for resuming NGNP project**

NGNP Industry Alliance Limited

http://www.ngnpalliance.org/

DOW
SGL GROUP THE CARBON COMPANY
ConocoPhillips
USNC ULTRA • SAFE • NUCLEAR
Entergy
AREVA
Westinghouse
PTAC
TECHNOLOGY INSIGHTS
TOYO TANSO Inspiration for Innovation
Wyoming
GRAFTech International
MERSEN
Advanced Research Center
SRS COMMUNITY REUSE ORGANIZATION two states, one future
Manufacturing Excellence Consulting, Inc.

Mission: Commercialize High Temperature Gas-cooled Reactor (HTGR) technology and expand the use of clean nuclear energy within industrial applications while significantly reducing the dependence on premium fossil fuels in the future.

- **Collaborative agreement Korea Nuclear Hydrogen Alliance.**
- **Collaborative agreement with European Nuclear Cogeneration Industrial Initiative (NC2I).**

Selected NGNP Industry Alliance / MHR Milestones

- Studies of Waterford Louisiana site
- Application of MHRs in Canadian Oil Sands
- MHR assisted coal-to-liquids studies in 2 top U.S. coal states (Wyoming and Kentucky)
- Studies for use of MHR technology to provide energy for industrial process plant applications
- Work with U.S. Congress and Administration to maintain strong funding for MHTGR development work: approx. $600M since 2006
- Close coordination with the Idaho National Laboratory
  - Fuel/graphite program
  - DOE funding for business plans and other selected studies
- Potential partnership with Piketon, Ohio officials on siting of HTGR for possible “sister city” for NC2I GEMINI Initiative

DOE Awards Alliance
$3M Cost-Shared Contract

- One of 5 awards from $13M Total For Advanced Reactor R&D
- Alliance, AREVA, Westinghouse, Texas A&M, Ultra Safe Nuclear
- Reactor Building Response and Air Inventory During HTGR Depressurization Event
- Two year period of performance

GEMINI Initiative Under Consideration: Collaboration with EU/NC2I: www.gemini-initiative.com

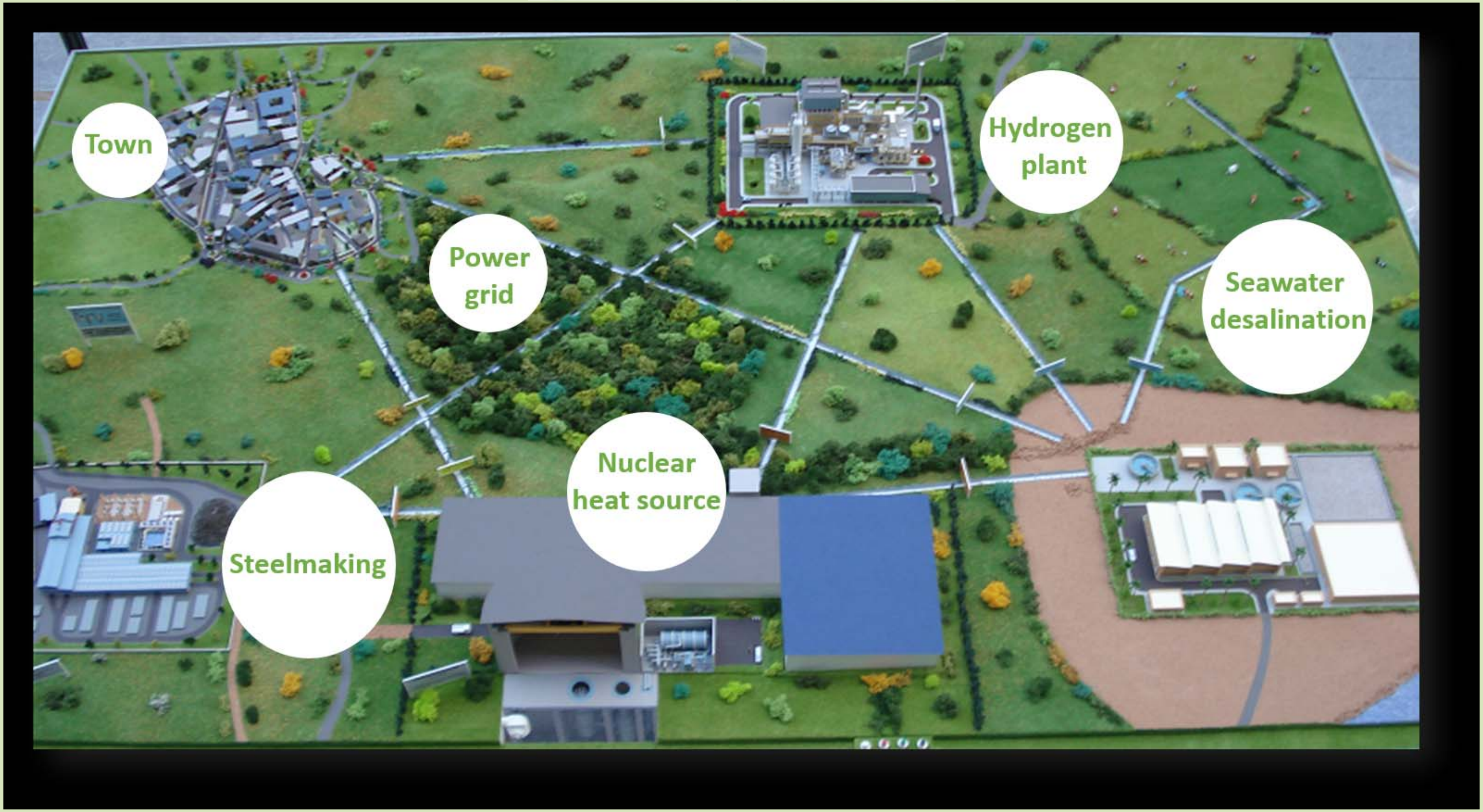
- **U.S. and EU industrial partners work with their governments under a collaborative arrangement**
  - Reduces each partner's cost of design, technology development, and licensing
  - 1/3 funding each by the U.S. and EU governments and 1/3 funding split among the U.S. and EU private sector participants
  - Combines the best engineering, manufacturing, and construction talents from both the U.S. and EU
  - Fully utilizes completed and ongoing R&D work performed in the U.S. and the EU, including coated-particle fuel, graphite, and high-temperature materials
  - Reduces risks and strengthens the attractiveness to potential investors through increased project stability from multi-government collaboration and investment
  - Increases global market opportunities
  - Makes significant contributions to energy security and reduced carbon emissions in both the U.S. and EU

NC2I Members

AREVA
e·on
Fortum
PROCHEM
Centrum výzkumu Řež s.r.o.
Research Centre Rez
NRG
AGH
BriVaTech
LIETUVOS ENERGETIKOS INSTITUTAS
MŰEGYETEM 1782

NC2I Vision for MHR Co-Generation

NC2I
Nuclear Cogeneration Industrial Initiative



NGNP INDUSTRY ALLIANCE LIMITED

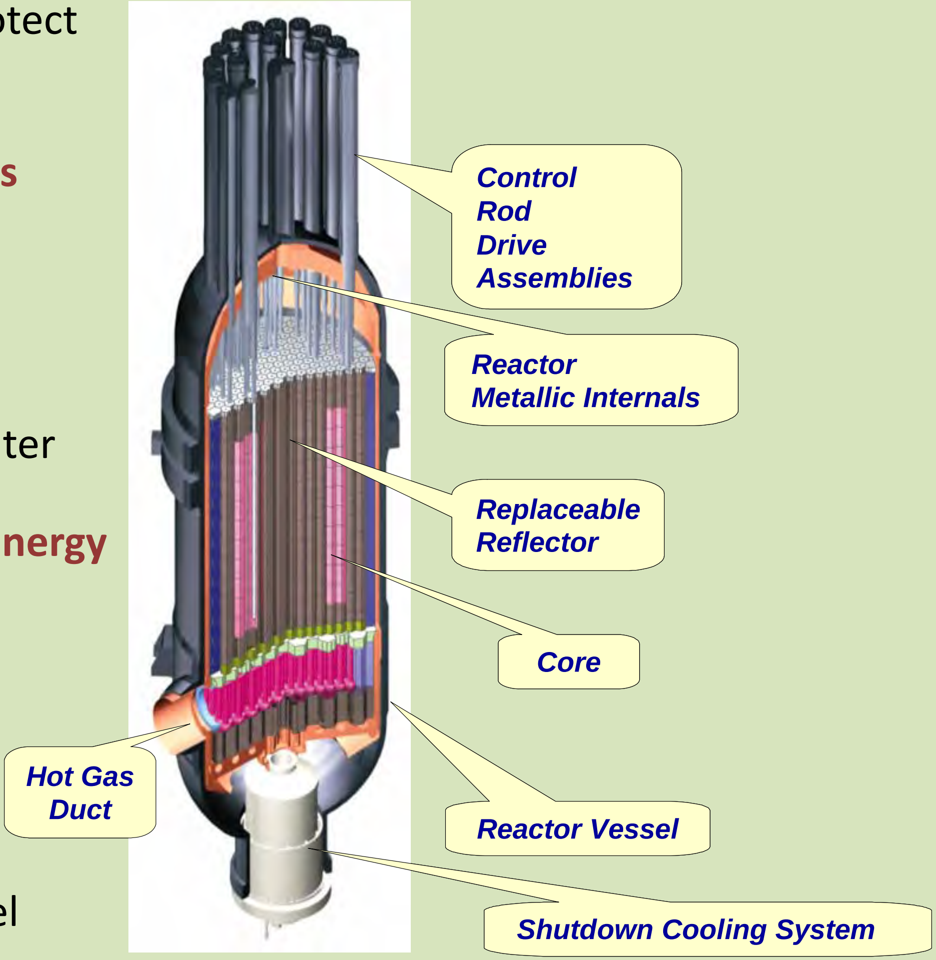
USNC ULTRA • SAFE • NUCLEAR

Piketon, OH: Potential U.S. Site for MHR Demonstration Plant

- **Very important to get potential communities, stakeholders, and end users involved early**
- **Portsmouth gaseous diffusion plant being decommissioned by DOE**
  - Local population supports nuclear energy and wants new mission to support local economy
  - Existing infrastructure available: land, transportation, geology, electricity, water
  - Favorable regional politics, including supportive Members of U.S. Congress
- **Piketon is potential "Sister City" for GEMINI Initiative with EU**
  - Is there a potential "Sister City" in Japan?

MHR Design Features Are Well Suited for Multiple Applications

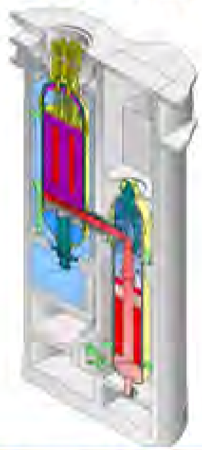
- **Passive and Inherent Safety**
  - No active safety systems required to protect public and investment
  - No evacuation plans required
  - **Can be located near industrial end users**
- **Competitive Economics**
  - Elimination of active safety equipment
- **High Thermal Efficiency**
  - **Siting Flexibility**
  - Lower waste heat rejection, reduced water cooling requirements
- **High-Temperature Capability with Flexible Energy Outputs**
  - Electricity
  - **Process heat/steam**
  - **Hydrogen**
- **Flexible Fuel Cycles**
  - LEU, Pu, TRU, Thorium
  - Very high burnup capability of TRISO fuel
  - Fuel cycle synergy with fast reactors



The MHR Can Transition to Higher Temperature Applications

Near Term: SC-MHR

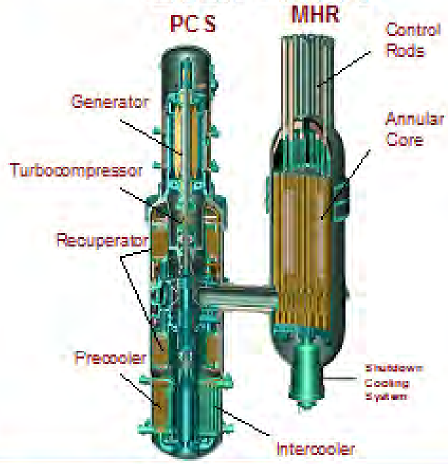
2020 - 2025



- 700 – 750°C outlet temperature
- Co-generation of steam and electricity
- Users: chemical process industry, refineries, steel manufacturers

Mid Term: GT-MHR

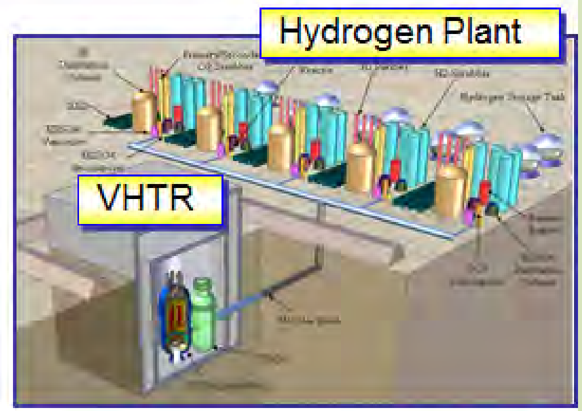
2025 - 2030



- 850°C outlet temperature
- High efficiency (~48%) electricity
- Users: utilities
- Enabling technology: gas turbine

Longer Term: PH-MHR

2030 - 2040



- 900 - 950°C outlet temperature
- High temperature process heat
- Users: hydrogen producers, chemical process industry, refineries
- Enabling technology: high temperature IHX

Fundamental Requirements for Inherent Safety Define the MHR Concept

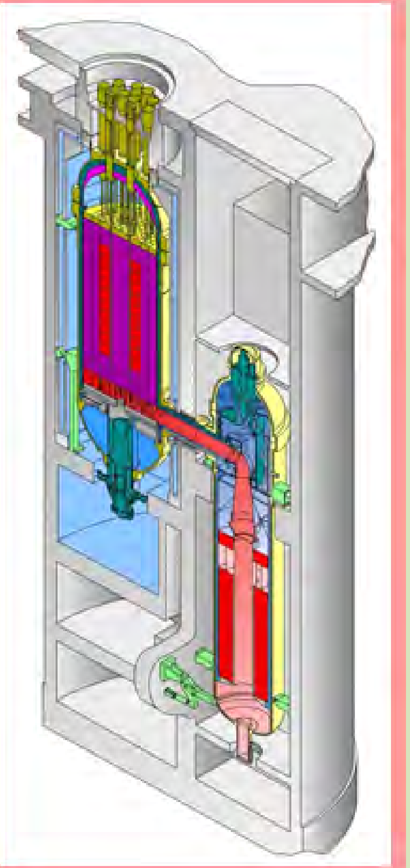
Fundamental Requirements

- A reactor core meltdown shall be physically impossible, regardless of the severity of the accident and its initiating events.
- The reactor shall rely only on the laws of nature and passive, inherently safe design features to prevent a core meltdown and achieve safe shutdown conditions.
- No public evacuation shall be required because of radioactivity released during any accident, regardless of its severity.

Design Features

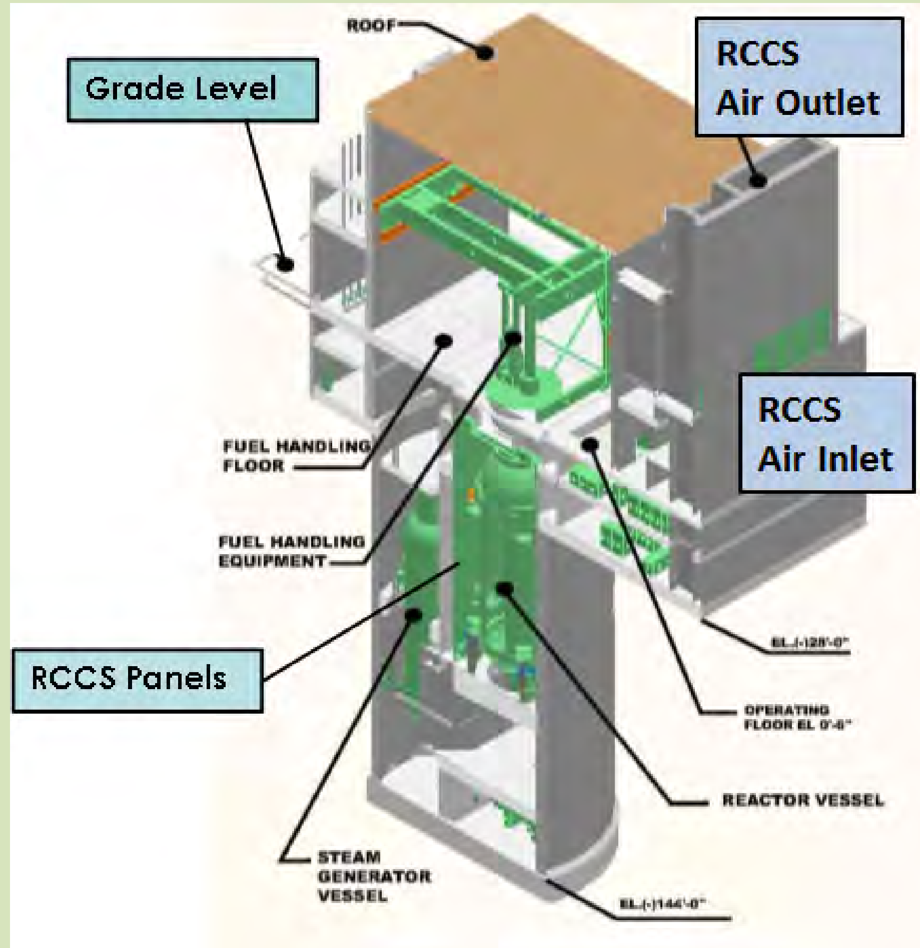
- Ceramic, coated-particle fuel
  - Maintains integrity during loss-of-coolant accident
- Annular graphite core with high heat capacity
  - Enhances heat transfer and Limits temperature rise during loss-of-coolant accident
- Low power density
  - Maintains acceptable temperatures during normal operation and accidents
- Inert Helium Coolant
  - Reduces circulating and plateout radioactivity

Design Concept



Release Barriers
(Functional Containment Approach)

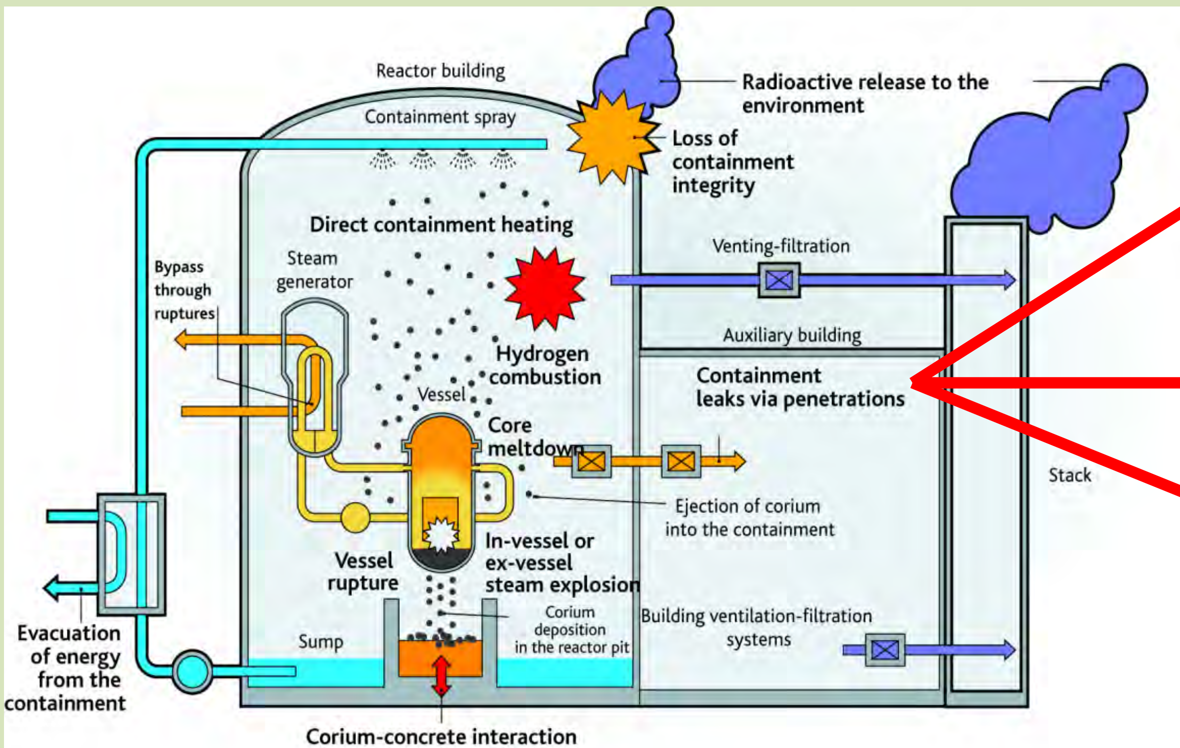
1. **Fuel Kernel**
2. **TRISO Coating System**
3. **Fuel Compact / Graphite**
4. **Primary Coolant Pressure Boundary**
    - Helium Purification System removes gaseous and volatile fission products
    - Condensable fission products plateout on helium-wetted surfaces
5. **Reactor Building: Vented Low Pressure Containment (VLPC)**
    - VLPC provides best safety response for MHR slow heatup transients
    - Eliminates driving force for radionuclides released from fuel during the slow heatup

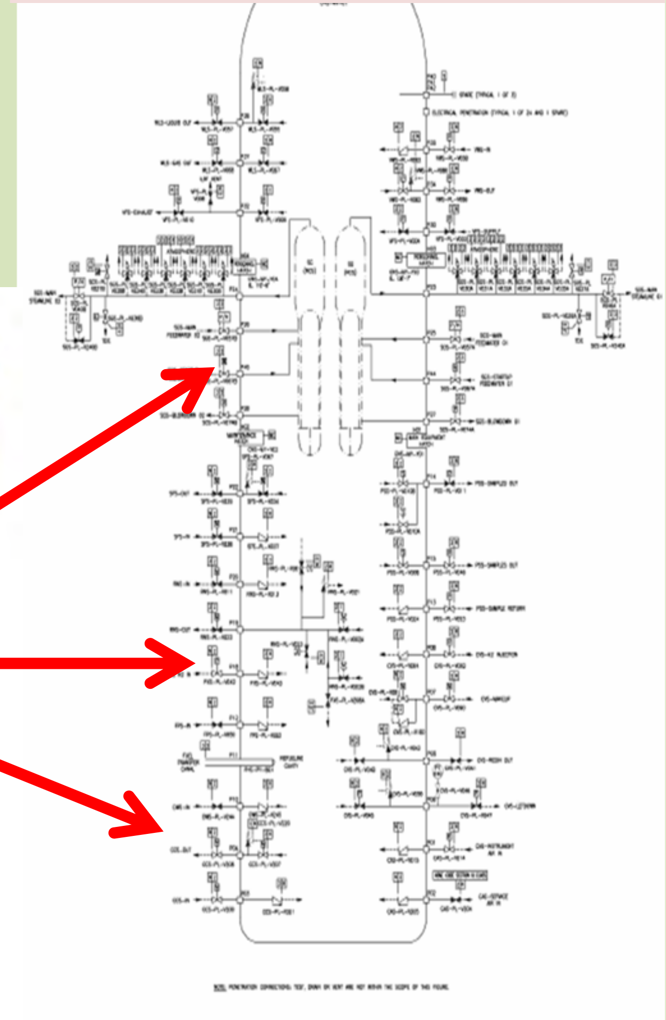


High-pressure containments have many penetrations that can fail during a severe accident

During unmitigated severe accidents, the LWR reactor building is the primary barrier to radionuclide release and is designed as a high-pressure containment structure for that purpose.

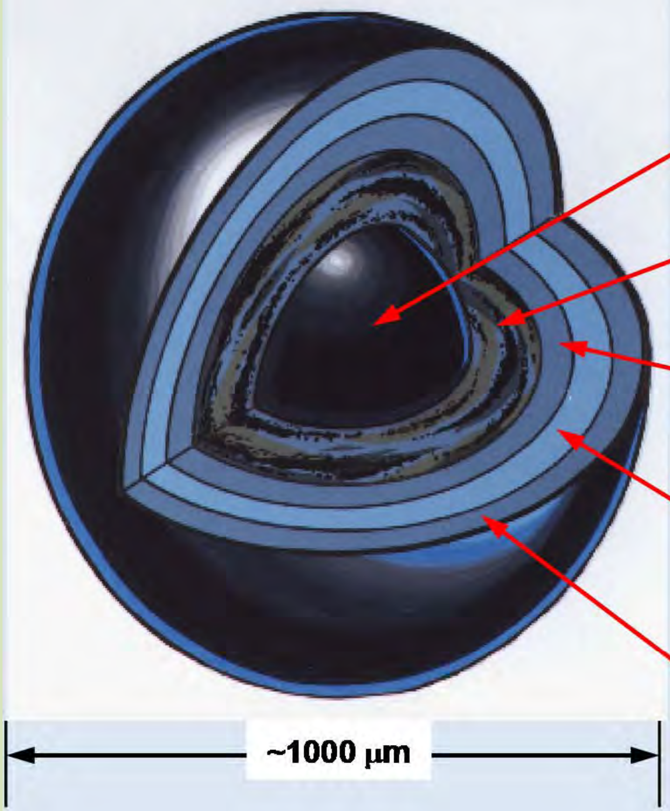
AP1000 Containment Penetrations





TRISO Coated Particle Fuel Provides Primary Containment of Radionuclides

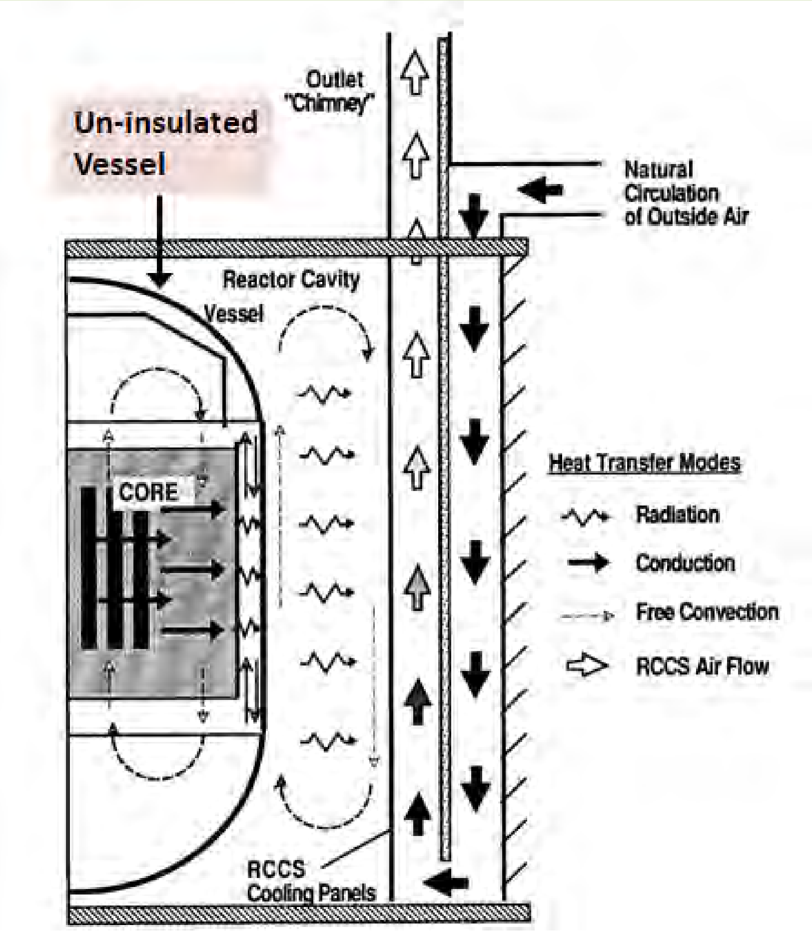
The TRISO Coating System is an Engineered Structure



- **Fuel Kernel**
  - **Provides fission energy**
  - **Controls oxygen potential**
- **Buffer layer (porous carbon layer)**
  - **Provides void volume for gaseous fission products and CO**
  - **Accommodates kernel swelling**
  - **Attenuates fission recoils**
- **Inner Pyrocarbon (IPyC)**
  - **Protects kernel from Cl attack during SiC layer deposition**
  - **Reduces tensile stress in SiC**
  - **Retains gaseous fission products**
- **Silicon Carbide (SiC)**
  - **Primary load bearing member**
  - **Retains gaseous and metallic fission products**
- **Outer Pyrocarbon (OPyC)**
  - **Reduces tensile stress in SiC**
  - **Retains gaseous fission products**
  - **Protects SiC from chemical attack by coolant impurities**

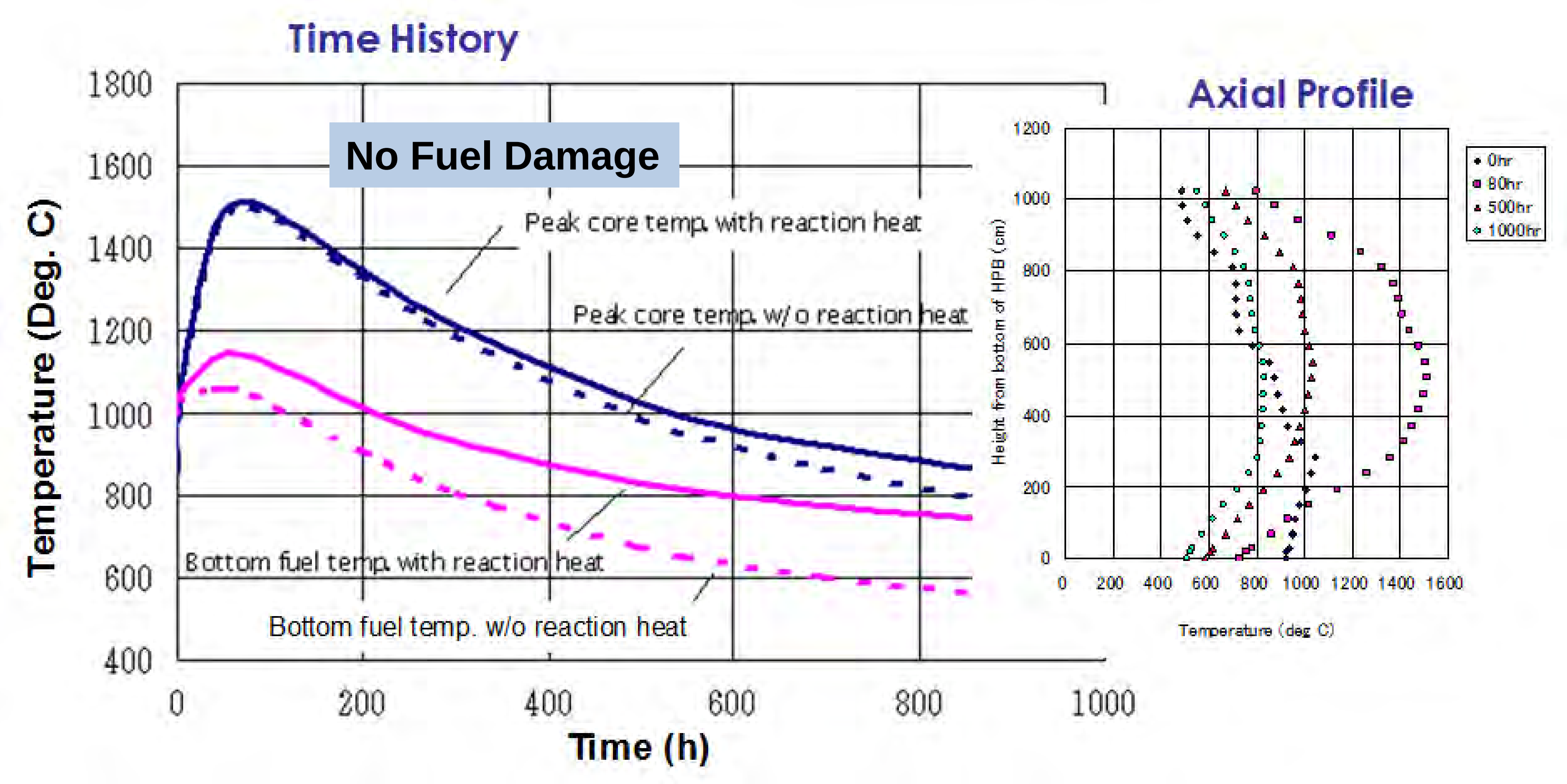
MHR Has Both Passive and Inherent Safety Features

- **During a LOCA, decay heat is removed by the passive Reactor Cavity Cooling System (RCCS).**
- **MHR inherent safety features include:**
  - High temperature, ceramic coated particle fuel
  - Annular graphite core with high heat capacity and large surface area for heat transfer
  - Relatively low power density
  - Inert helium coolant, which reduces circulating and plateout activity
  - Negative temperature coefficients of reactivity
  - Multiple barriers to the release of radionuclides



The MHR is Inherently Safe Even for Beyond Design Basis Accidents

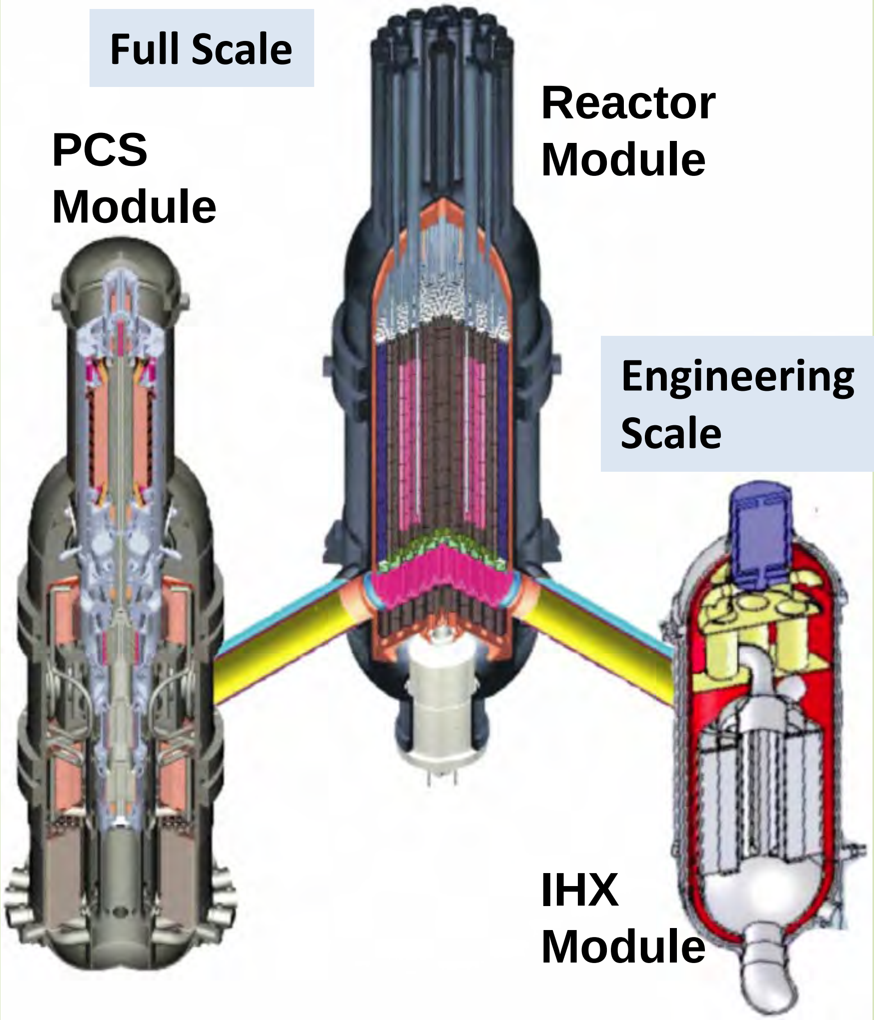
Complete system depressurization with air ingress into the graphite core



Key safety feature – very slow transient

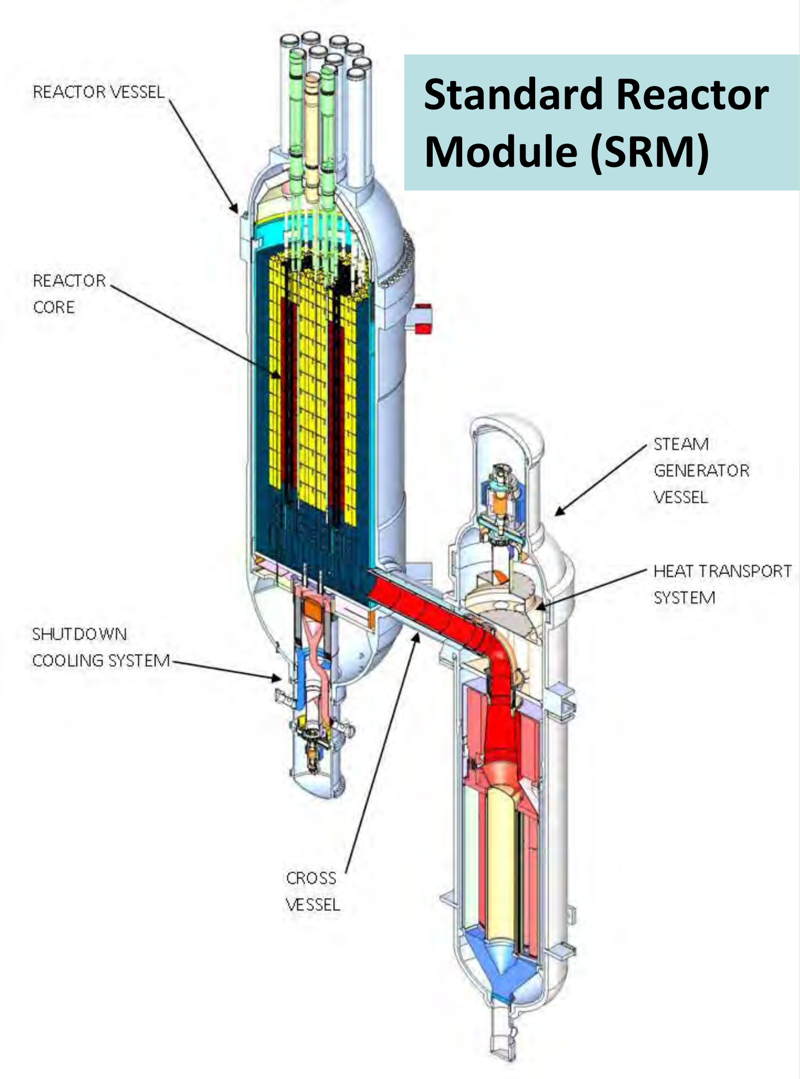
NGNP Pre-Conceptual Design (2007)

Reactor Power Level	600 MW(t)
Coolant Inlet Temperature	510°C - 590°C
Coolant Outlet Temperature	950°C
Primary System Pressure	7 MPa
Power Conversion	Full Scale Direct Brayton Cycle with Integrated PCS
Primary/Secondary Coolant	Helium/Helium
IHX Type/LMTD	Ref.: Printed Circuit/25°C Backup: Helical Coil/91°C
Hydrogen Production Demonstration	SI: 60 MW(t) HTE: 4 MW(t)
Heat Rejection	Dry Cooling Tower

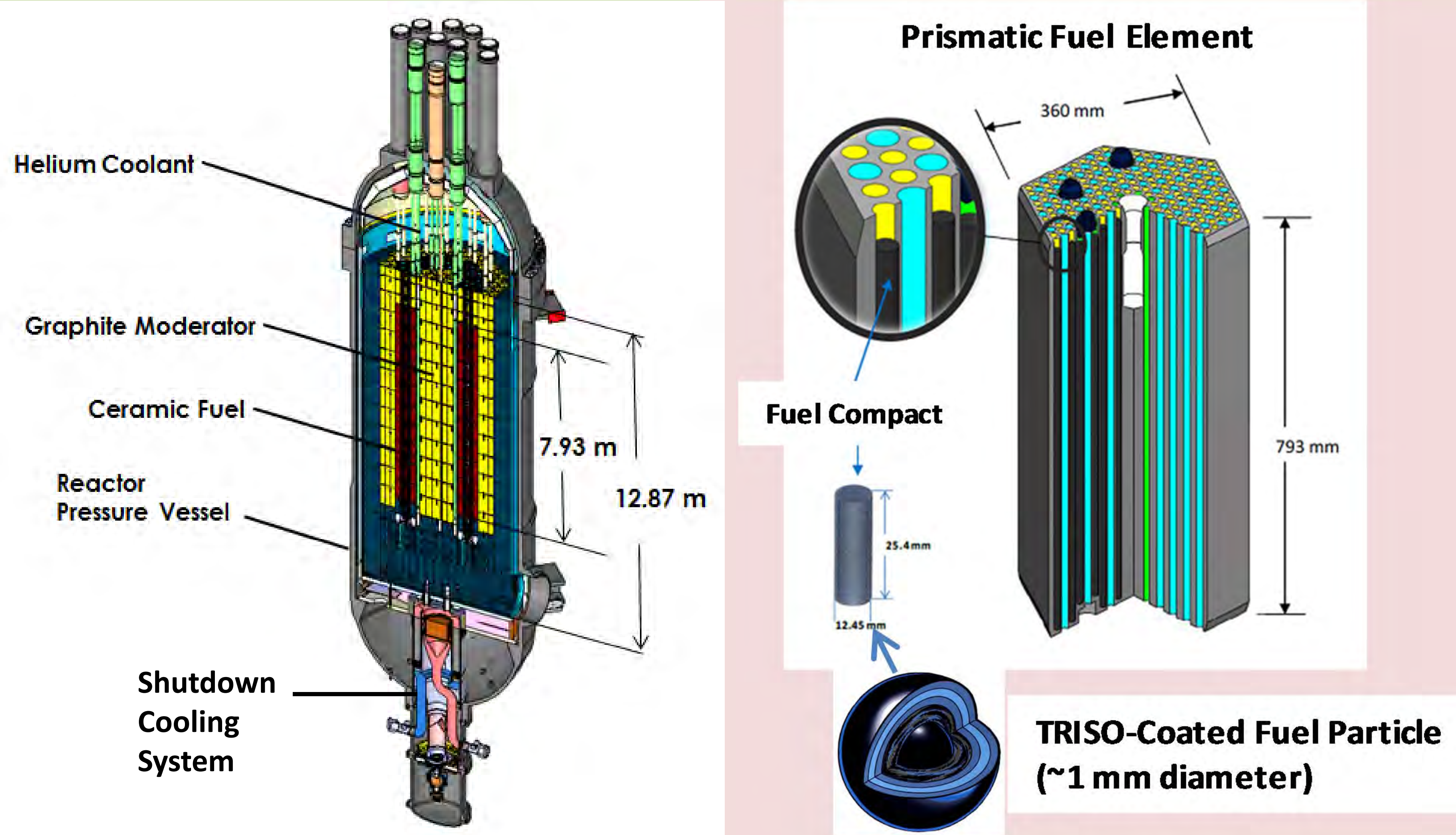


DOE NGNP Conceptual Design is the Steam-Cycle Modular Helium Reactor (SC-MHR) (2010)

- **Based on legacy design concepts from the 1980s**
- **Reactor power level: 350 MW(t)**
- **Reactor inlet/outlet temperature: 290 °C /725°C**
- **Primary helium pressure: 7 MPa**
- **Co-generation of process steam and electricity**
- **Nominal plant production parameters:**
  - Gross electricity: 68 MW(e)
  - Net electricity: 56 MW(e)
  - Steam export: 80 kg/s [238 MW(t)]



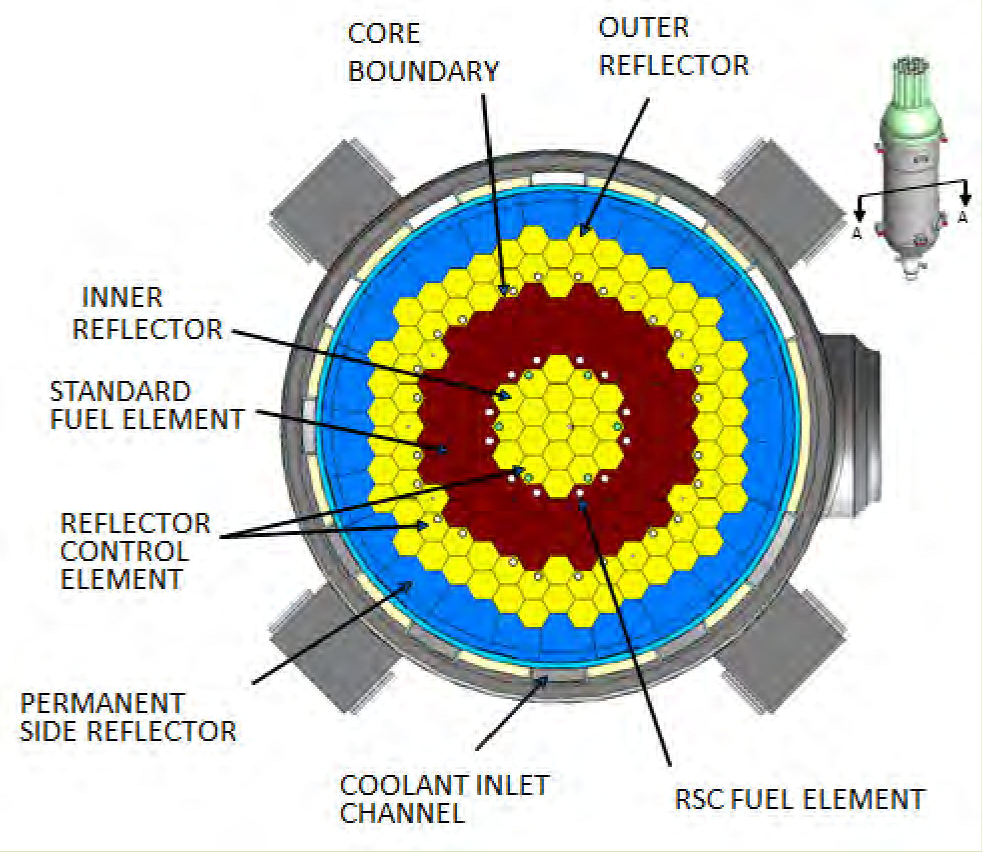
SC-MHR Reactor System



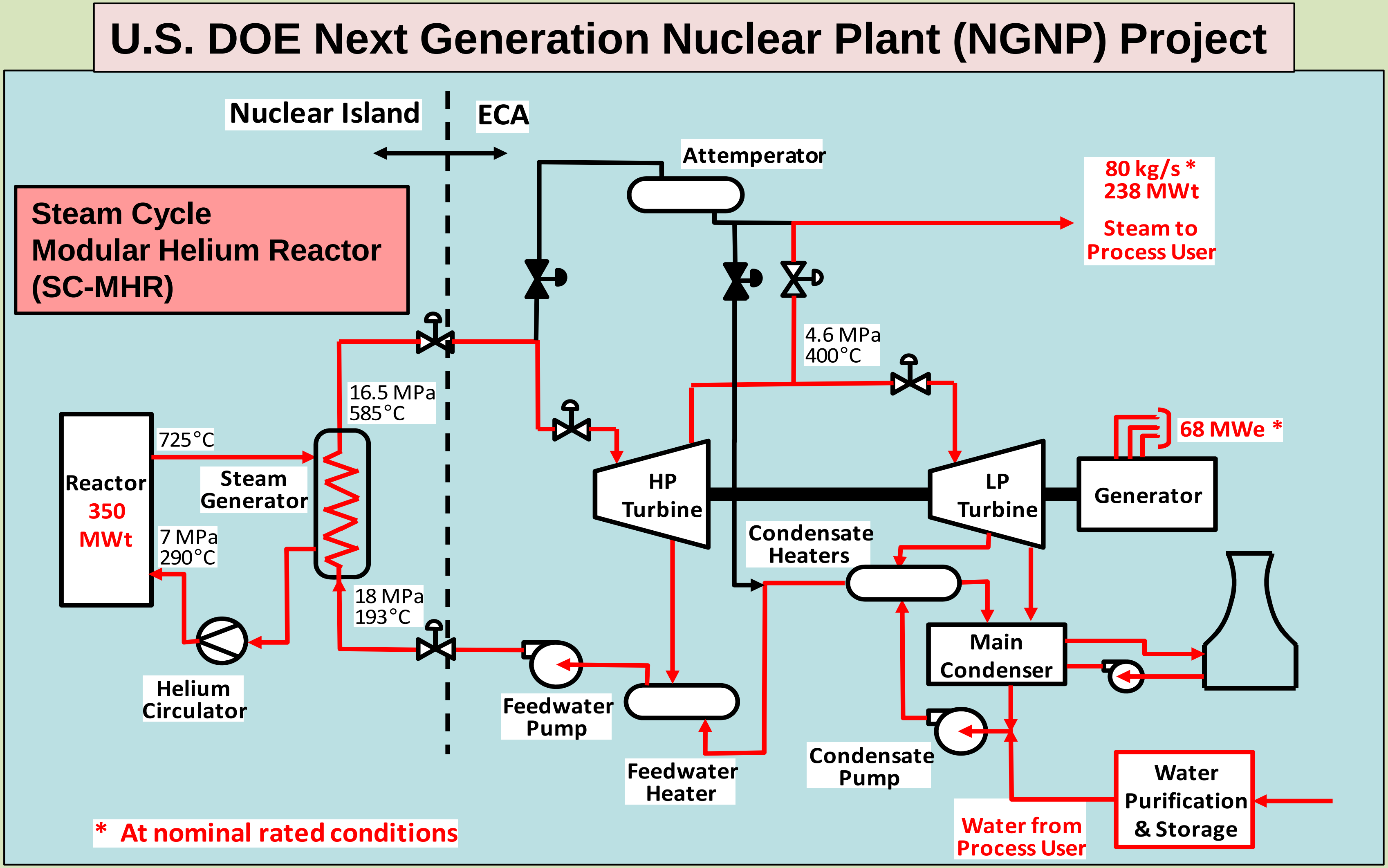
Annular Fuel & Reflector Arrangement Enable Inherent Safety during LOCA

Inner reflector is an unfueled region with large heat capacity.
Annular active core increases radial heat transfer area (R^2 effect).

Active core height	7.93 m
Fuel ring inner diameter	1.65 m
Fuel ring outer diameter	3.51 m
Number of fuel columns	66
Number fuel blocks	660
U-235 enrichment	15.5%
Inner reflector control rods	6
Outer reflector control rods	24
Reserve shutdown channels	12
Time to refuel	21 days
Fuel cycle length	530 EFPD
Total fuel residence time	1060 EFPD
Avg. fuel burnup at discharge	85 GW-d/t



SC-MHR Simplified Flow Diagram



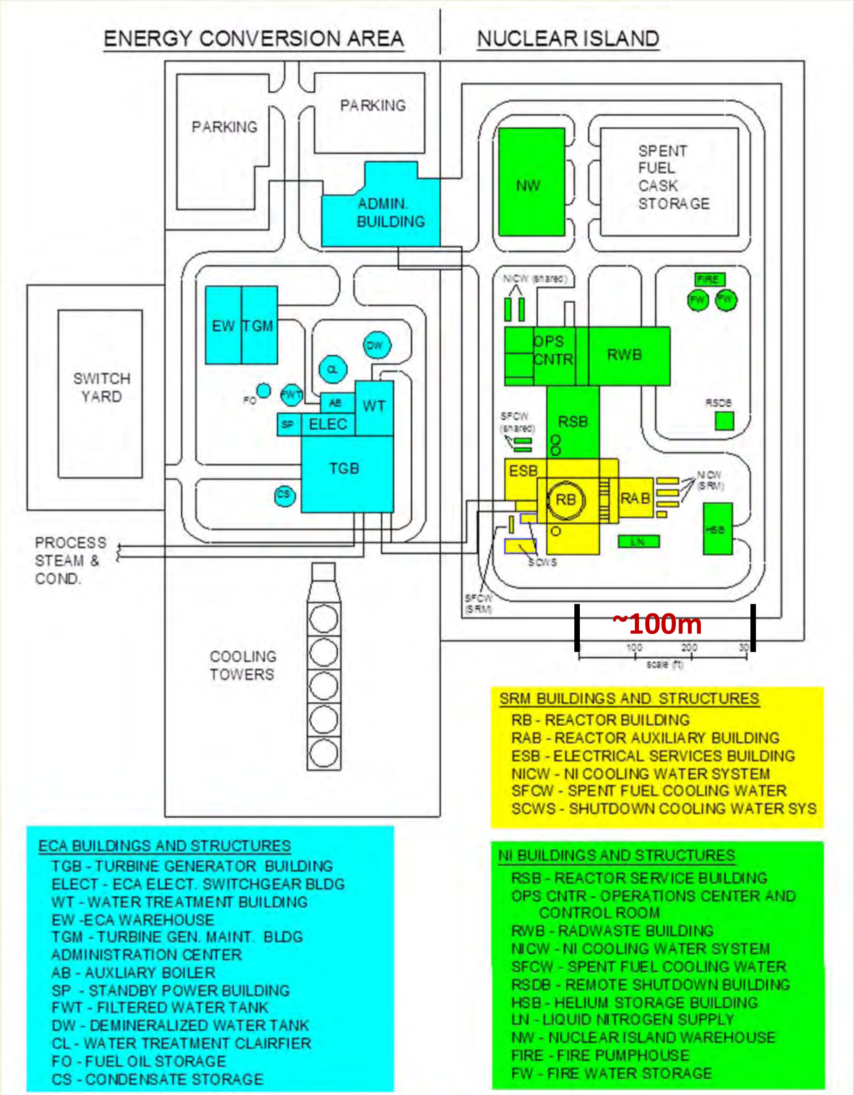
Co-Generation Boosts Thermal Efficiency

Reactor Thermal Power	350	MWt
Thermal Power to Steam Generator	352	MWt
Steam Sold to User	238	MWt
Thermal Energy Allocated to Electricity	115	MWt
Electricity Produced (Gross)	67.9	Mwe
Assumed House Load (10%)	6.8	MWe
Electricity for Sale (Net)	61.1	MWe
Effective Electrical Efficiency (Based on Net)	**53%**	
Total Energy Product	299	MWe+MWt
Effective Plant Efficiency (Product/Production)	**85%**	

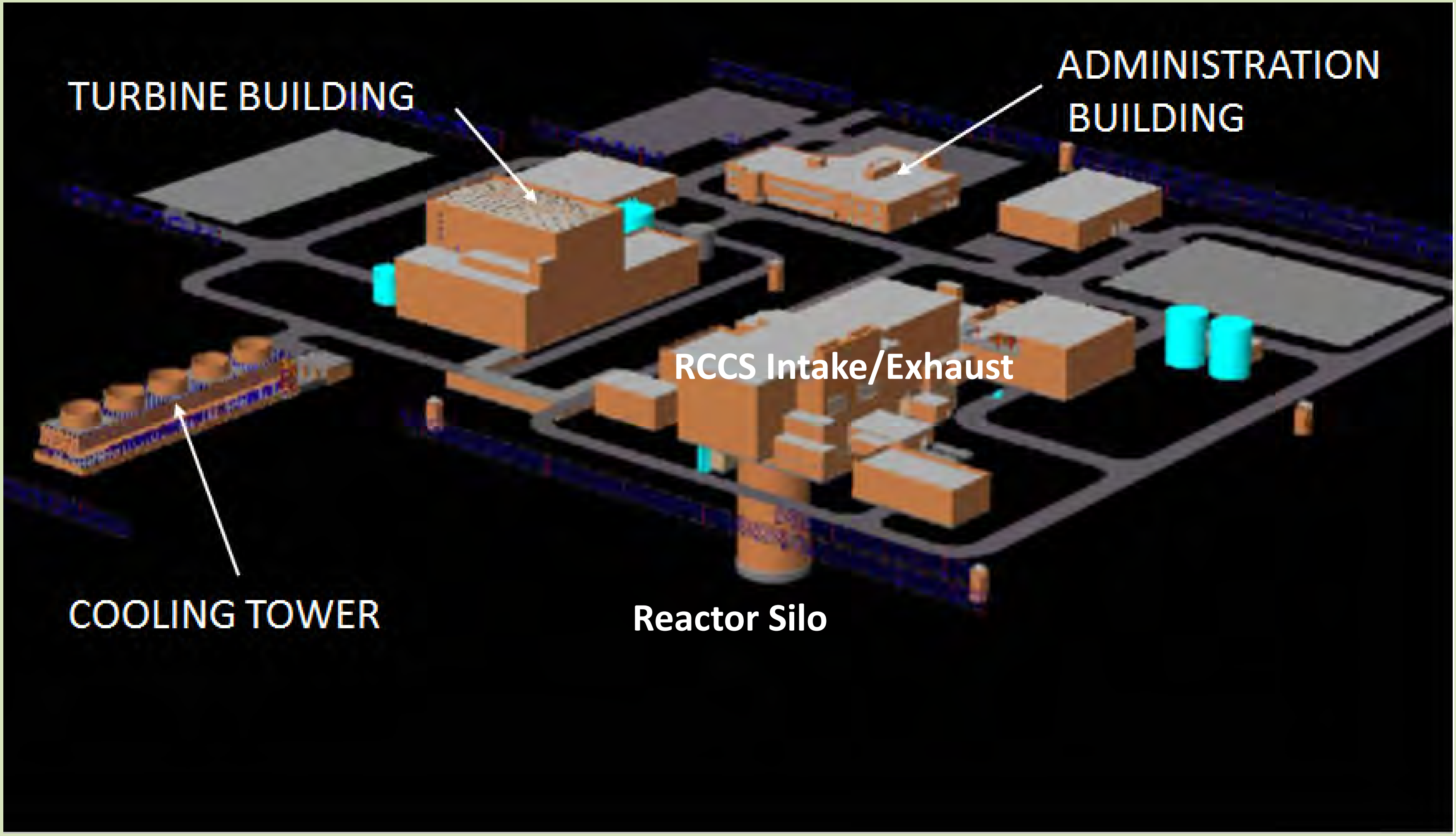
- **More efficient use of nuclear heat**
- **More efficient use of nuclear fuel**

SC-MHR General Plant Layout

- **SC-MHR Demonstration Plant consists of the Nuclear Island (NI) and Energy Conversion Area (ECA)**
- **ECA with conventional equipment separated from NI providing:**
  - Ability to design the ECA area as a non-nuclear safety facility at reduced cost
  - Flexibility to accommodate different ECAs with the same basic NI design, allowing for NI replication
  - Limiting entries to the NI to a minimum number of personnel, enhancing security provisions



Plant 3D Layout from CAD Models

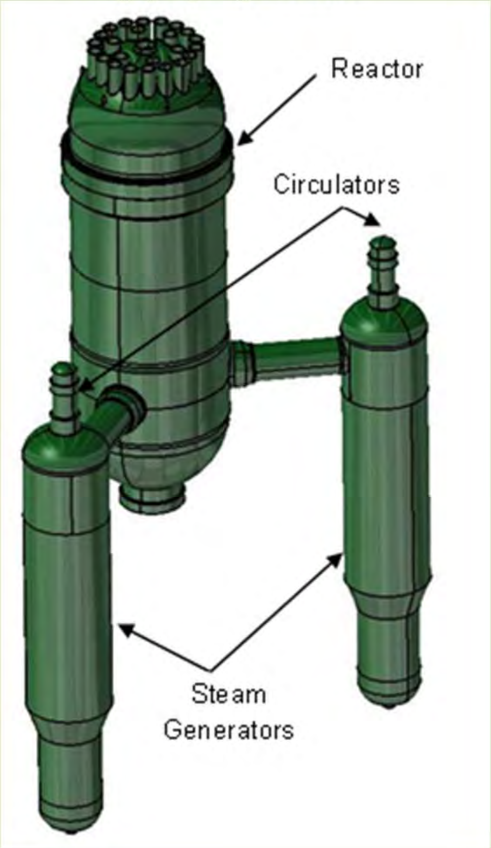


NGNP Conceptual Design 3-D Model Animation (Created from Engineering Drawings and 3-D CAD Models)

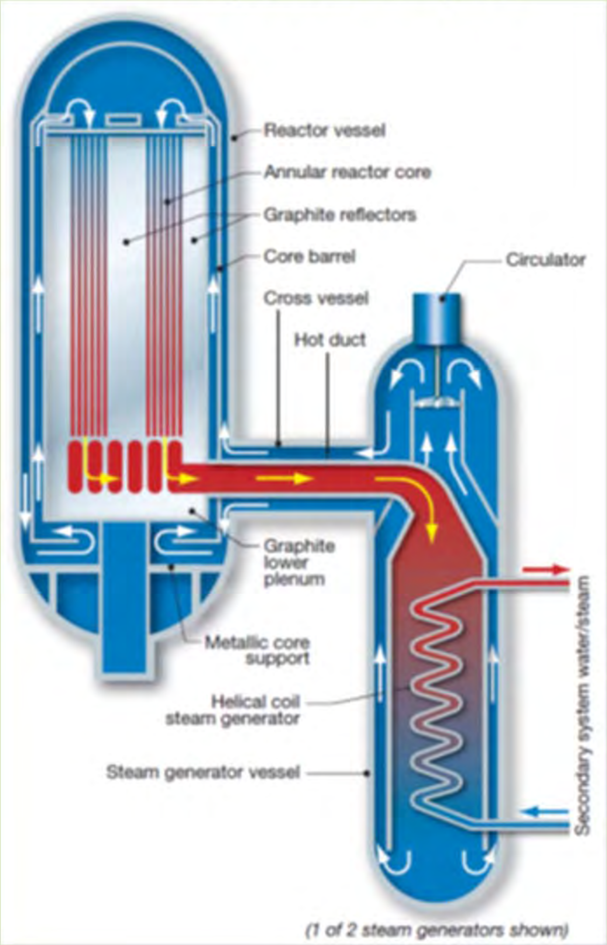
AREVA Steam-Cycle MHR Concept

- Co-generation of steam and electricity
- 625 MWt
- 750°C helium coolant outlet temperature
- 550°C steam temperature

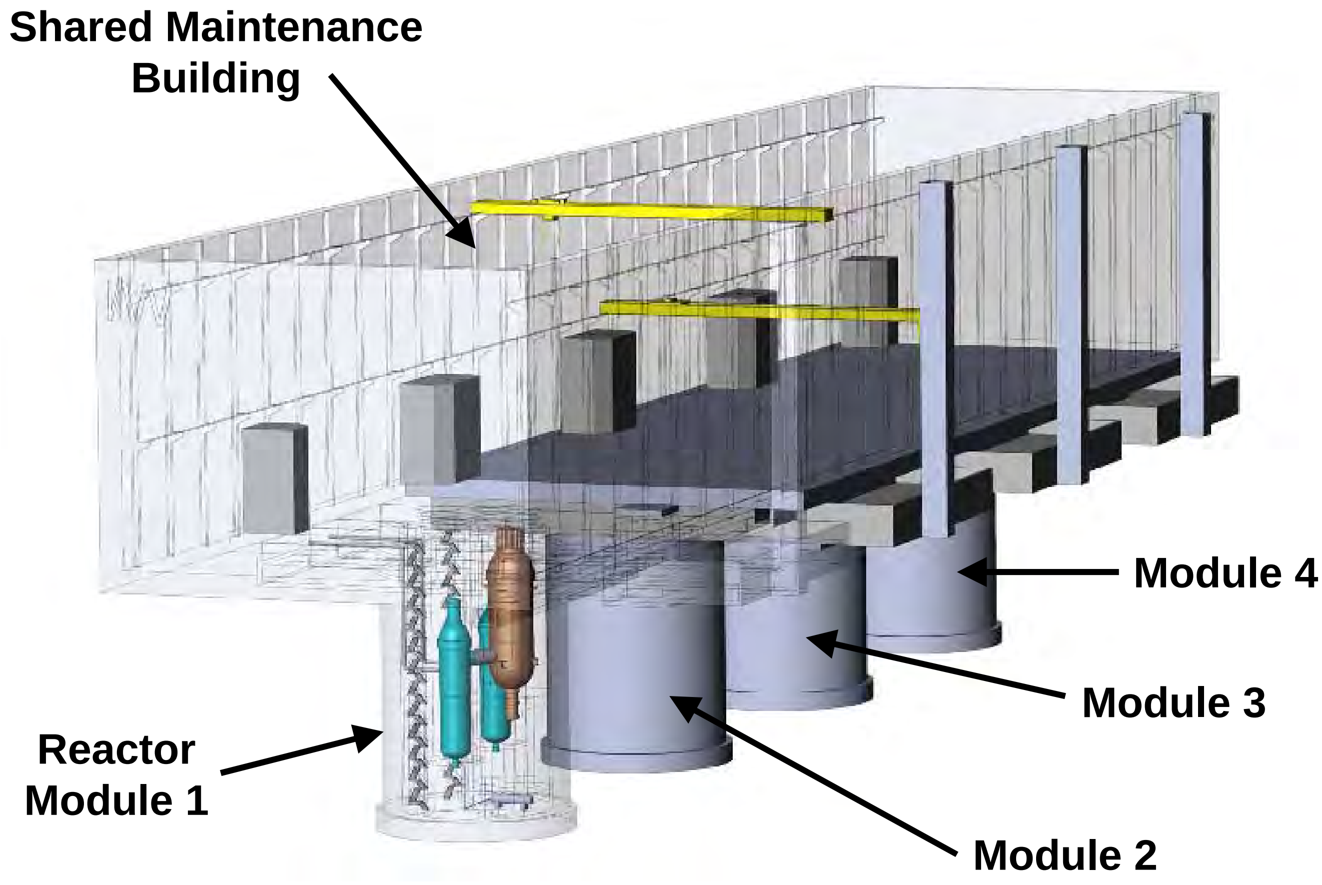
Nuclear Process Steam Supply System



Primary Circuit Layout

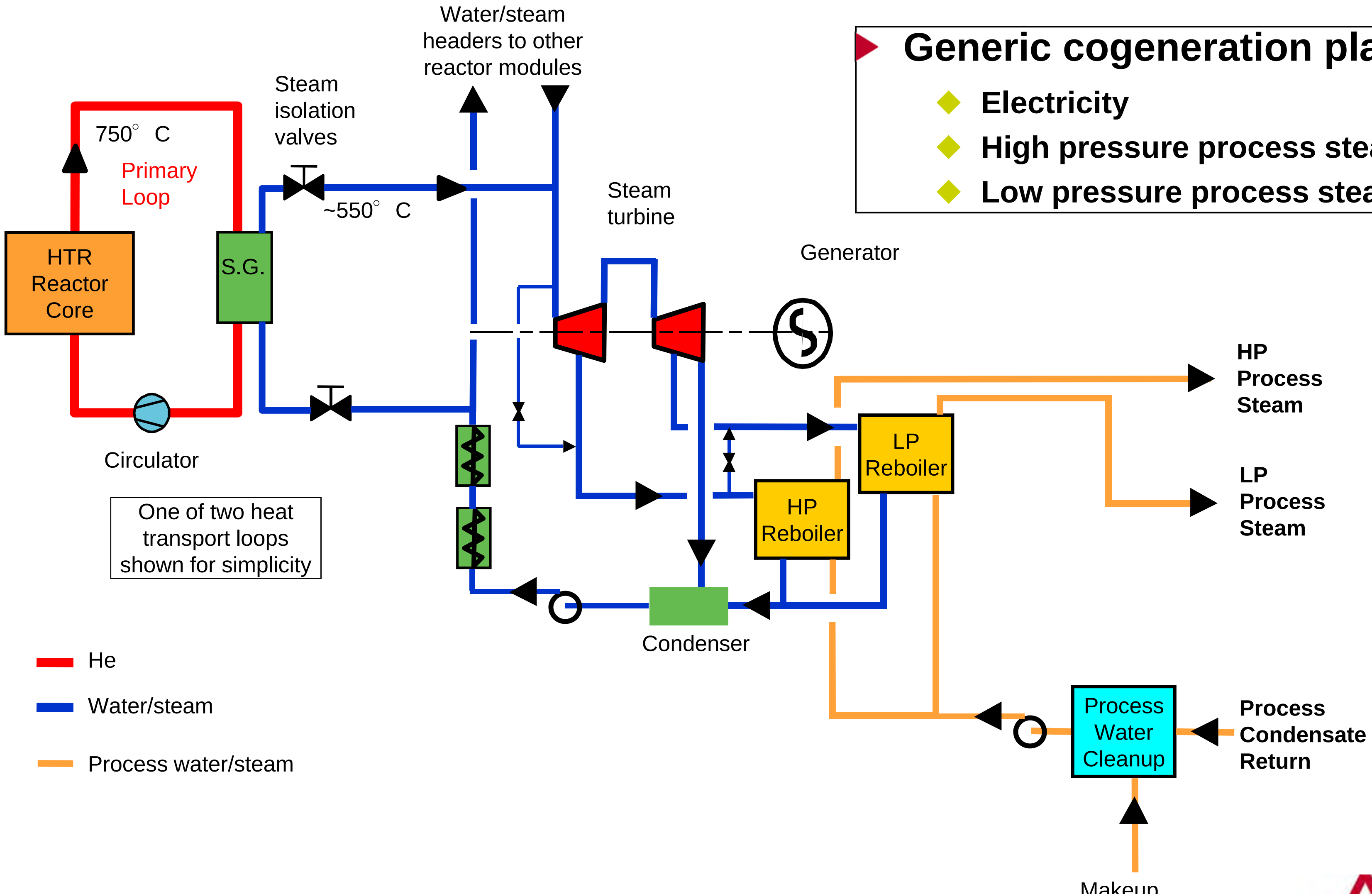


Independent Reactor Modules Arranged to Share Site Facilities



Single Reactor Module Design Supports Many Applications

- **Generic cogeneration plant**
  - **Electricity**
  - **High pressure process steam**
  - **Low pressure process steam**



Other MHR Concepts Under Development

- **Republic of Korea**
  - Working on HTGR technology and nuclear hydrogen production for over a decade
  - Research and development program has been established to develop key technologies and design codes/methods
  - In 2012, the Nuclear Heat and Hydrogen (NuH_2) design project was initiated by Korea Atomic Energy Research Institute (KAERI) in collaboration with Korean industry
- **Japan**
  - Japan Atomic Energy Agency (JAEA) has been developing the GTHTR300 (electricity generation) and GTHTR300C (co-generation of electricity and hydrogen) concepts
  - JAEA also operates the high temperature engineering test reactor (HTTR), which is an operational, engineering-scale (30 MWt) prototype of the MHR
- **China**
  - China has established the High Temperature Reactor – Pebble-bed Module (HTR-PM) project
  - The HTR-PM project has enjoyed strong support from the Chinese government and has proceeded to the construction phase, with pouring of first concrete in December 2012

Comparison of NGNP Demonstration Module Cost Estimates

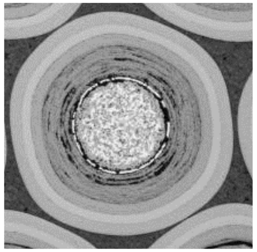
DEMONSTRATION MODULE COSTS	PLN-2970 INL One Plant Est (Table 2-1), '09 M$	2012 Business Plan (Table 2-2 Re-ordered), '11 M$		AREVA Cost Est (Table 2-3 Re-ordered), '13 M$	
Cost Item					
Technology Development	**452**		**316**		**260**
Plant Design (Engineering)					
Conceptual/Preliminary Design		280		270	
Final Design		200		311	
Site-specific Engineering		100		64	
Subtotal	**562**		**580**		**645**
Licensing					
Through Preparation of Application		165			
Const Permit, License App Review		65			
FOAK Licensing				140	
Design Certification				70	
Subtotal	**246**		**230**		**210**
Procurement & Construction (Demo Module)					
Equipment & Infrastruc Dev		648		175	
Equipment Procurement		432			
Construction		625			
Matls, Equip. Installation Labor				1459	
Subtotal	**1727**		**1705**		**1634**
Start Up Testing	**54**		**55**		**11**
Initial Operations					
Demo Module 1st Core				168	
Demo period O & M		348		356	
Demo Inpections, Tests & Mods		75		73	
Subtotal	**422**		**423**		**597**
Income during Initial Operations	**-264**		**-265**		**-177**
Grand Totals	**3200**		**3044**		**3180**

AREVA Cost Estimates for FOAK & NOAK SC-HTGR Plants

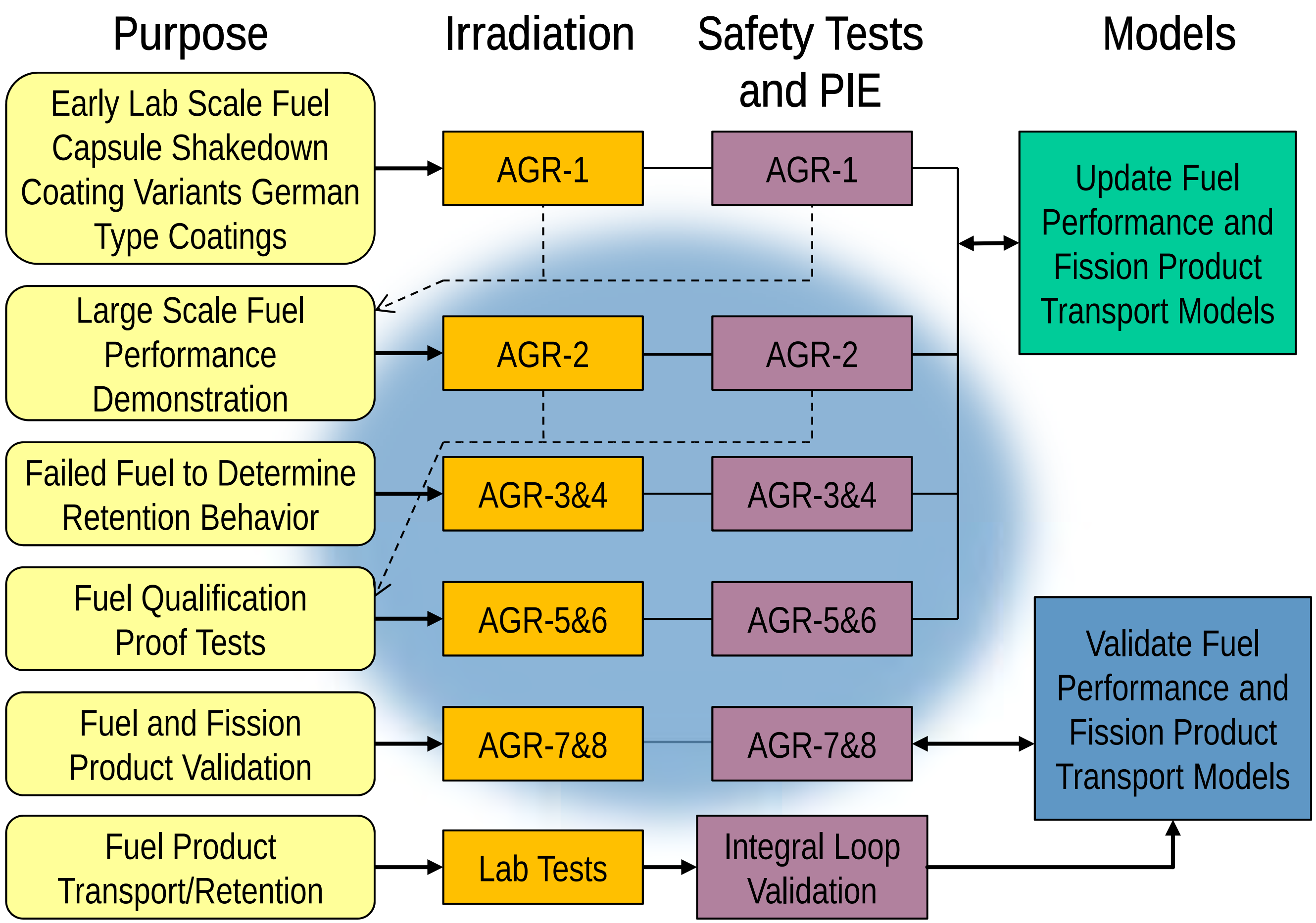
ACTIVITY	First Demo Module	FOAK Modules 2,3 &4
	$M	$M
FOAK Plant		
Conceptual Design	$97	$0
Preliminary design	$173	$0
Final Design	$311	$0
FOAK Engineering during const.	$64	$118
Mtls, Hdw, Inst. Labor	$1,459	$4,086
Licensing (FOAK)	$140	$0
Startup Testing	$11	$32
Inspection Test Mod (Unit 1)	$73	$0
FOAK O&M (See Note below)	$356	$119
Initial Fuel (FOAK) Plant	$168	$505
Design Certification	$70	$0
Equip. & inferastructure development	$175	$0
Total	$3,097	$4,860

Note: Demo O&M is for 1 year pre-operation + 2 years operations
FOAK O&M is per year

ACTIVITY	NOAK 4-Module Plant
	$M
NOAK Plant	
NOAK Engineering	$134
Construction Engineering	$128
Mtls, Hdw, Inst. Labor	$4,159
COLA	$42
Total (without fuel)	$4,463



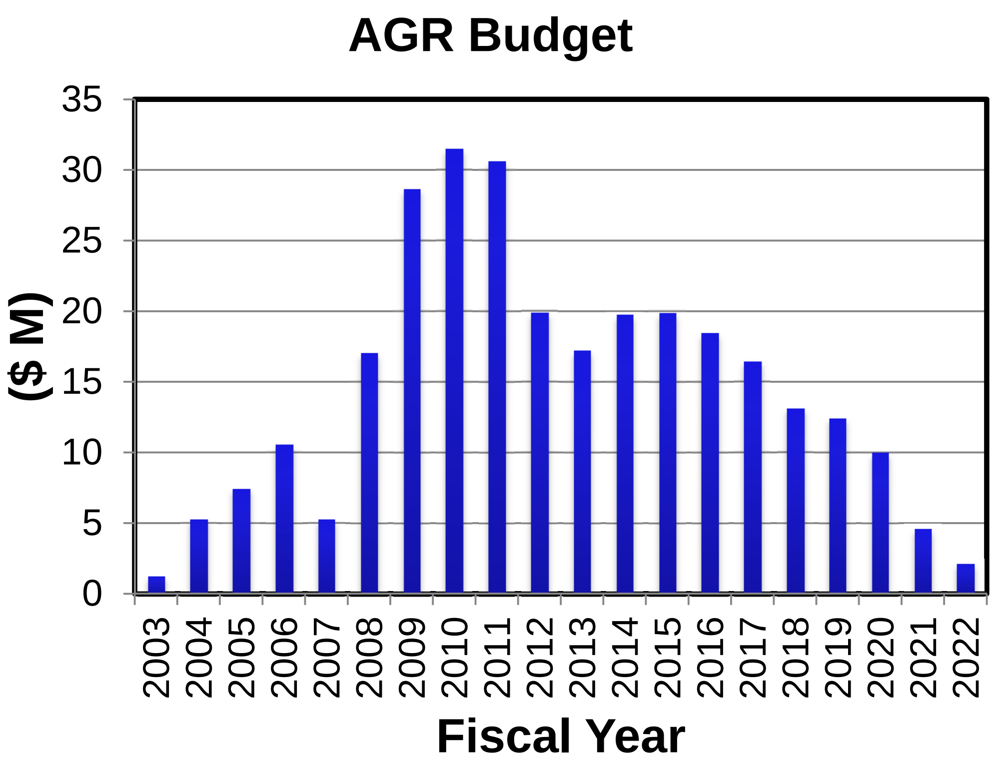
Overview of AGR Program Activities

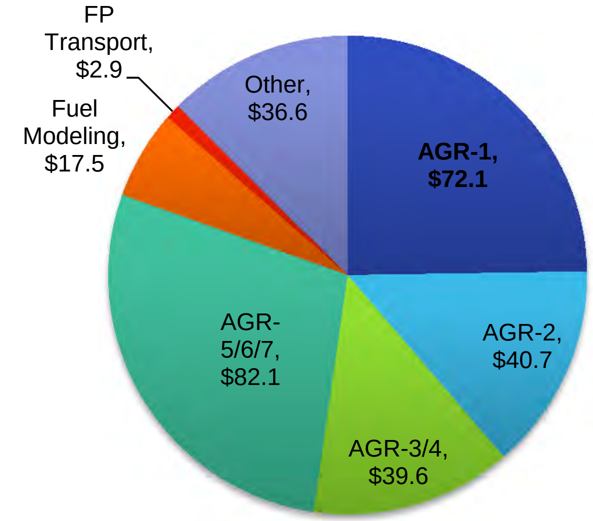


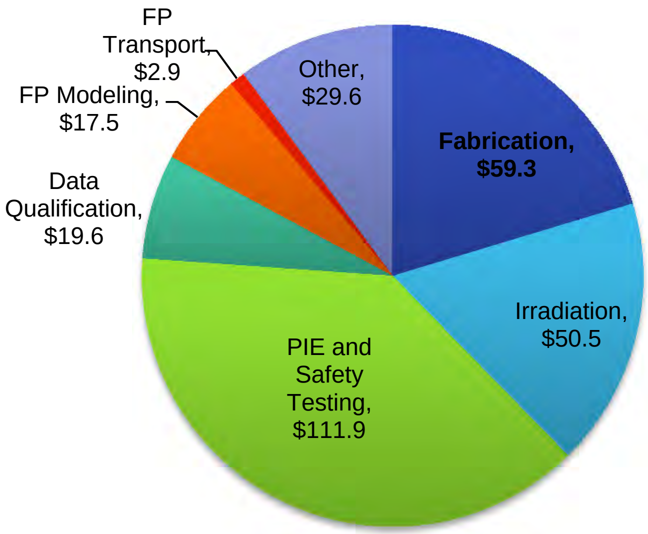
Moisture and air ingress effects are part of AGR-5/6 PIE

AGR Budget - $291.4 M

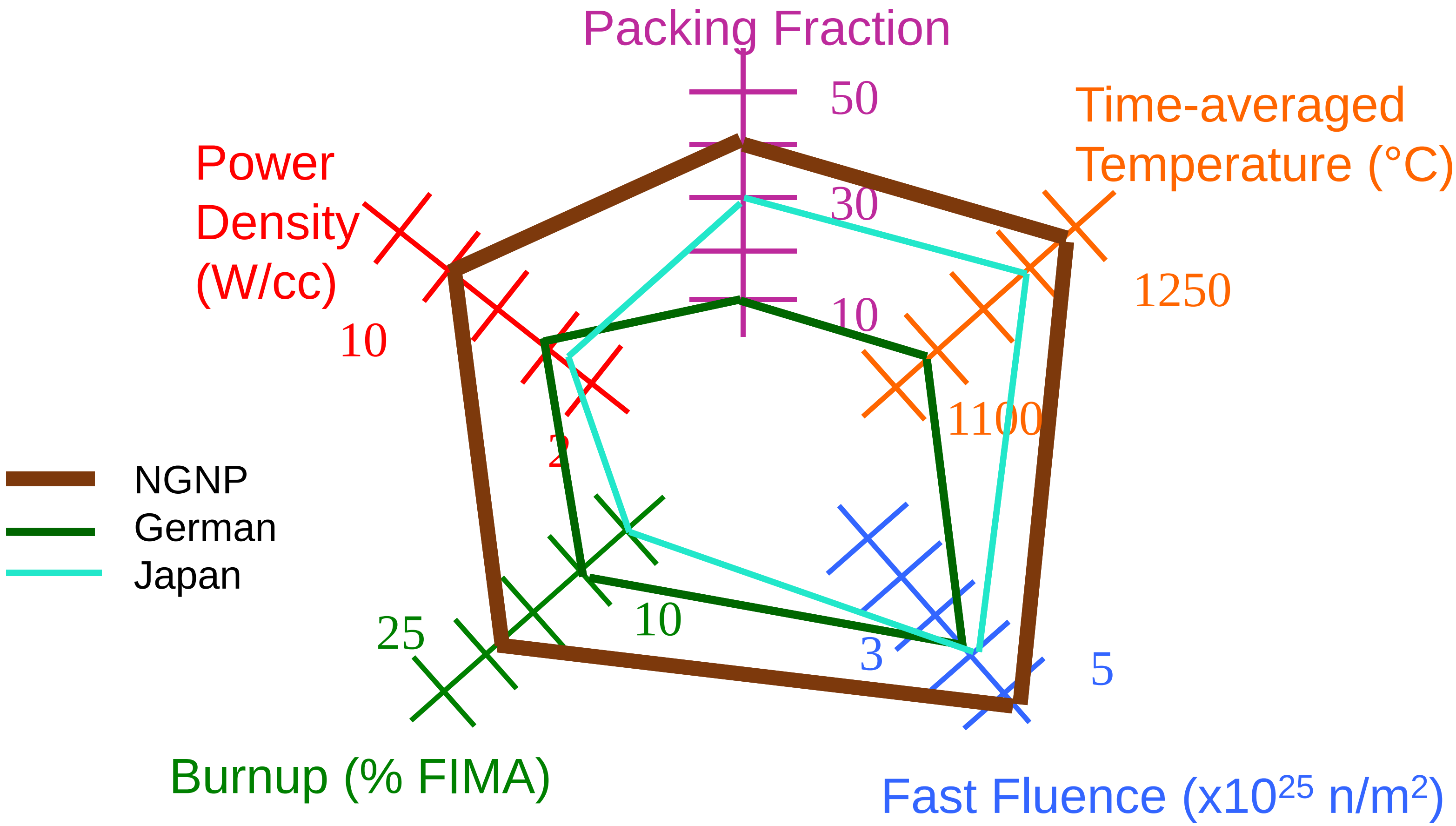
- Based on actuals through FY13 and estimates going forward in ($ M)
- Includes (a) equipment development costs as well as actual technical tasks, (b) facility upgrades, (c) software licenses and (d) project management





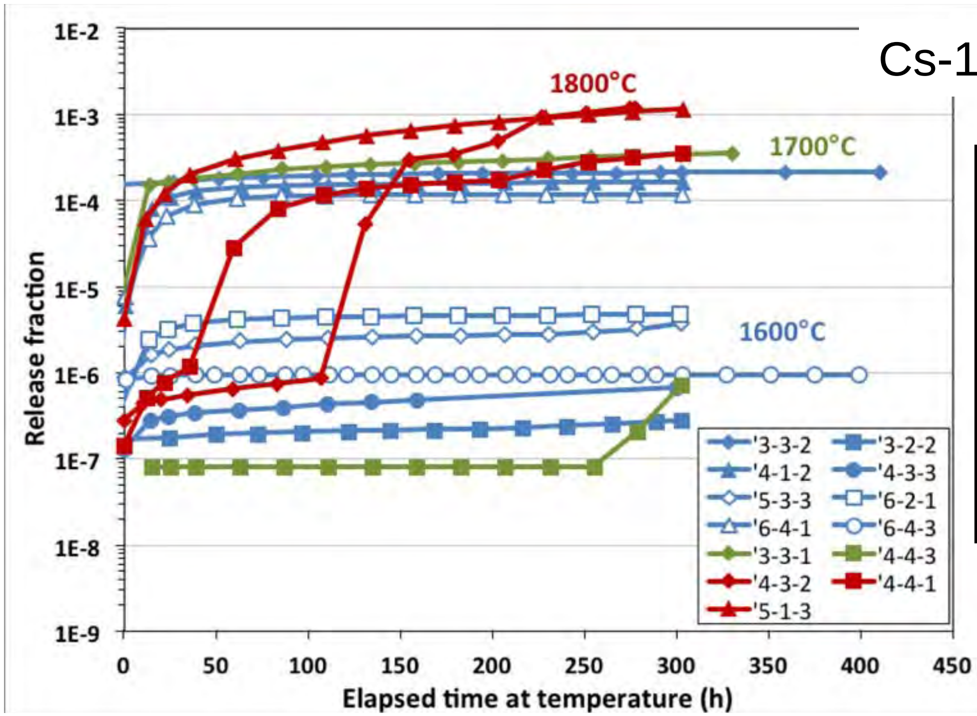


Performance Envelope for NGNP TRISO Fuel is More Aggressive than Previous German and Japanese Fuel Qualification Efforts

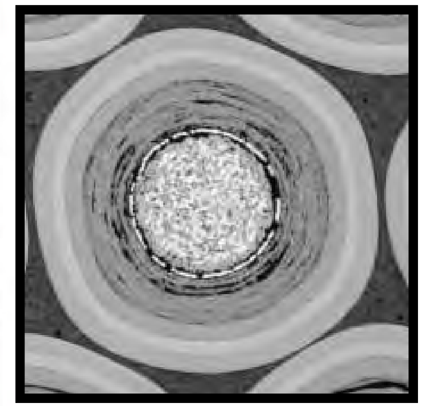


Radar plot of five key parameters of fuel performance

AGR-1 Safety Testing shows outstanding performance up to 1800°C for hundreds of hours – combination of good coatings and UCO



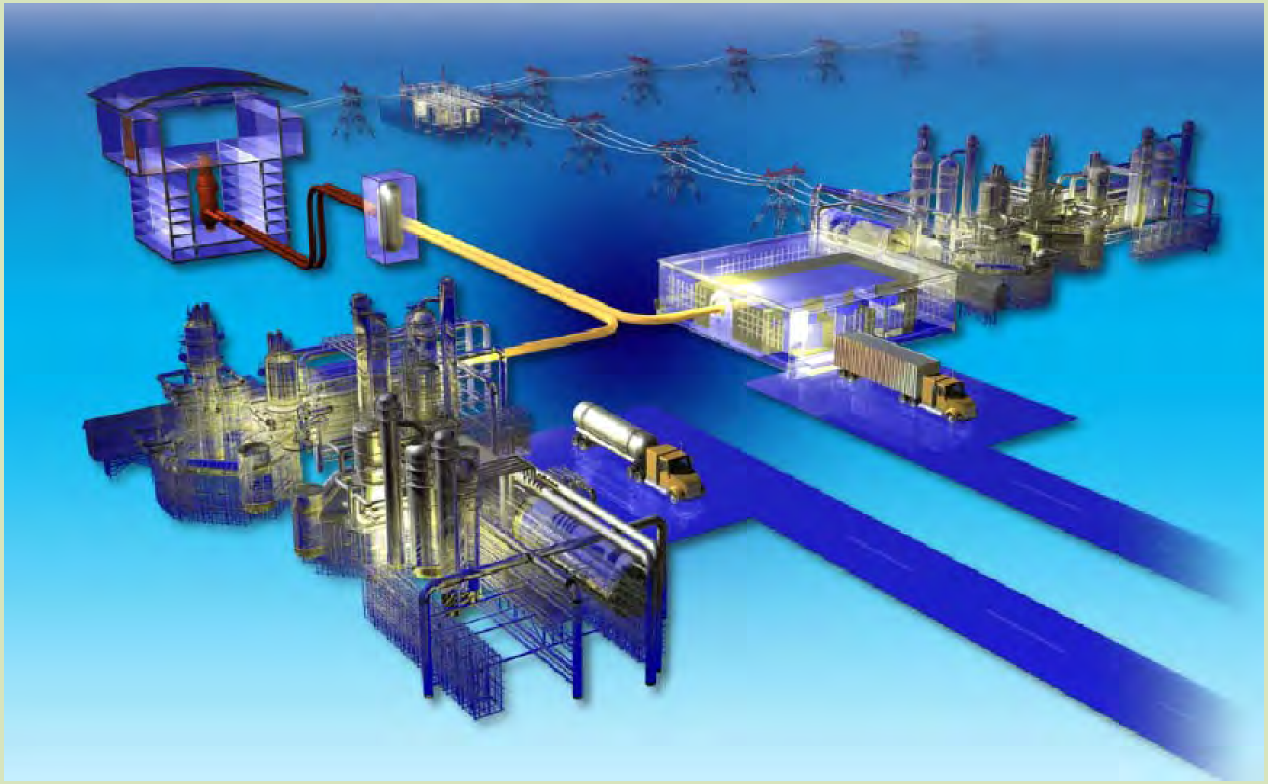
Cs-134



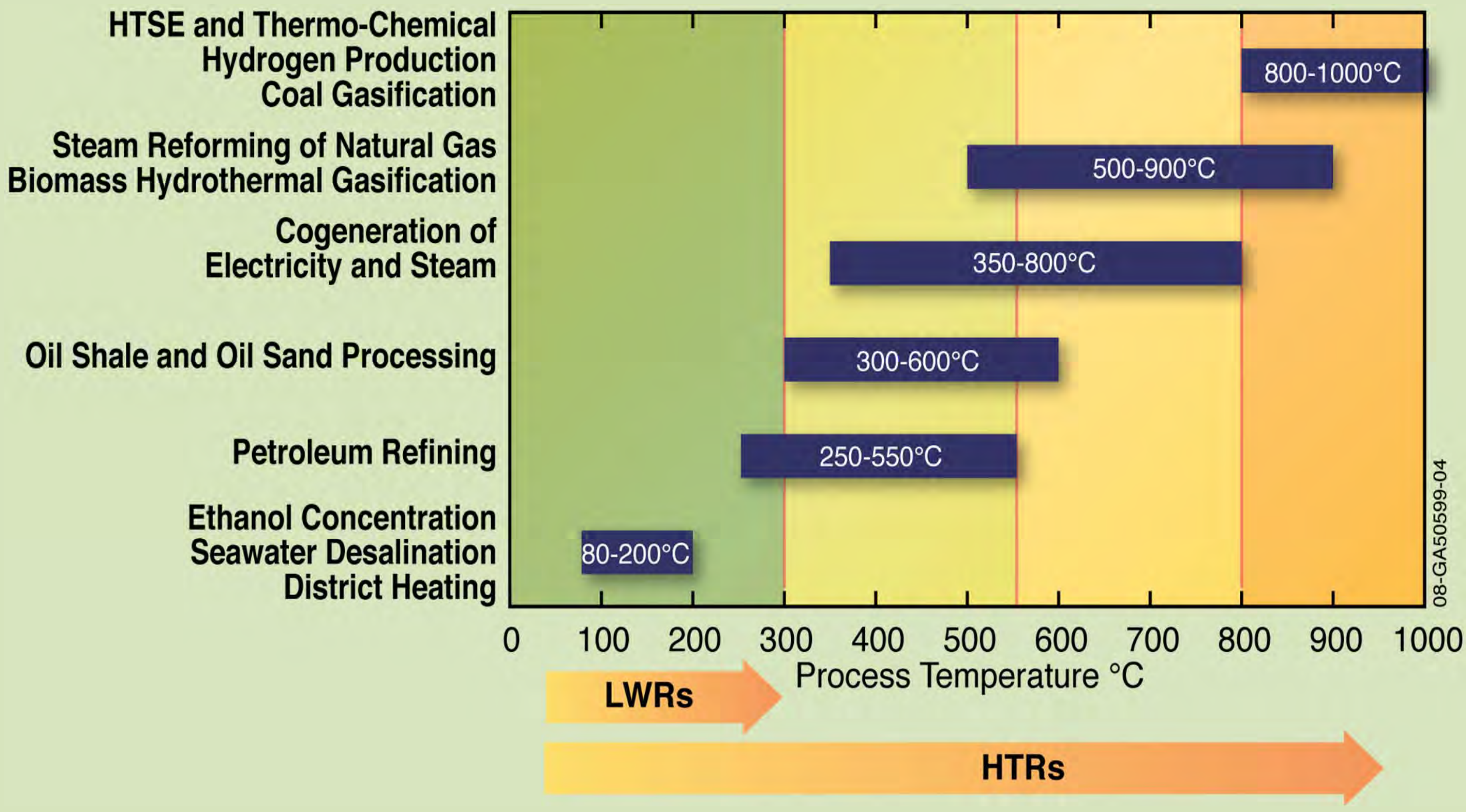
- Heat fuel compacts and monitor the release of fission products
- Building a database of fission product release behavior at 1600–1800°C (**Kr-85, Ag-110m, Cs-134, Cs-137, Eu-154, Eu-155, Sr-90**)
- 14 AGR-1 compacts tested to date (March 2014)

NGNP Process Heat Applications and Market Assessments

- Target markets in North America identified in the 2012 NIA business plan
- Displacing LNG used for electricity generation in Japan and the ROK
- Nuclear steel manufacturing in Japan and the ROK
- Displacing oil used for electricity generation and process heat in the KSA



Process Heat Opportunities Increase with Temperature



Many Industrial Applications Are a Good Match for MHRs

- Petroleum Refining
  - Employs many processes that require large quantities of heat at temperatures ranging from 250 – 950°C.
- Oil Recovery
  - Enhanced oil recovery using high pressure, high temperature steam
  - Bitumen extraction and upgrading (oil sands)
  - Kerogen retorting and upgrading (oil shale)
- Coal and Natural Gas Derivatives
  - Coal gasification
  - Coal liquification
  - Steam-Methane reforming to produce syngas
  - Methanol production
- Hydrogen Production
  - Transportation and industrial sectors
- Ethylene Production
- Steel Manufacturing
  - Requires hydrogen and electricity

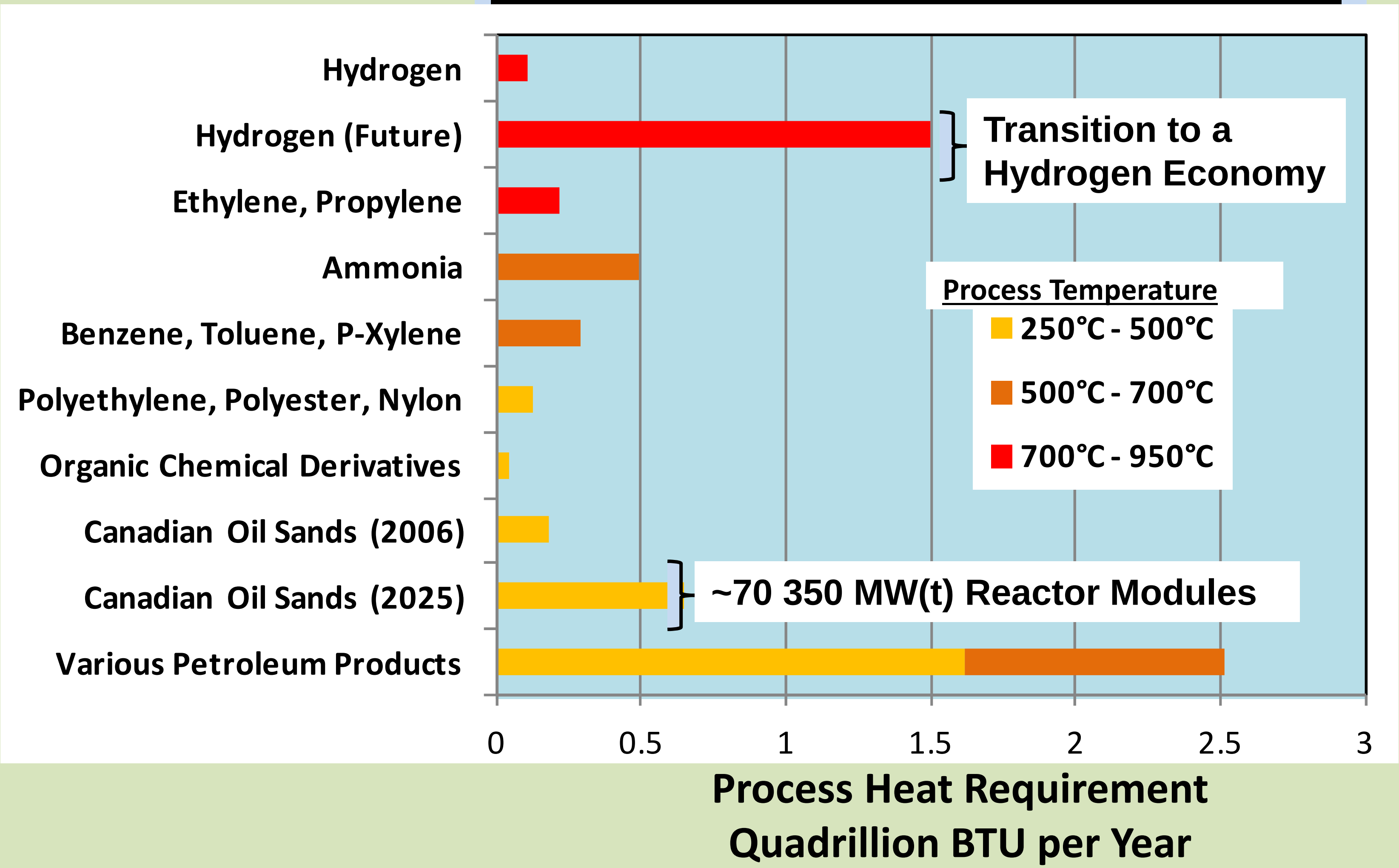
We use a lot of fossil energy to make more useful forms of fossil energy.

A first step is to use nuclear energy to make these more useful forms of fossil energy.

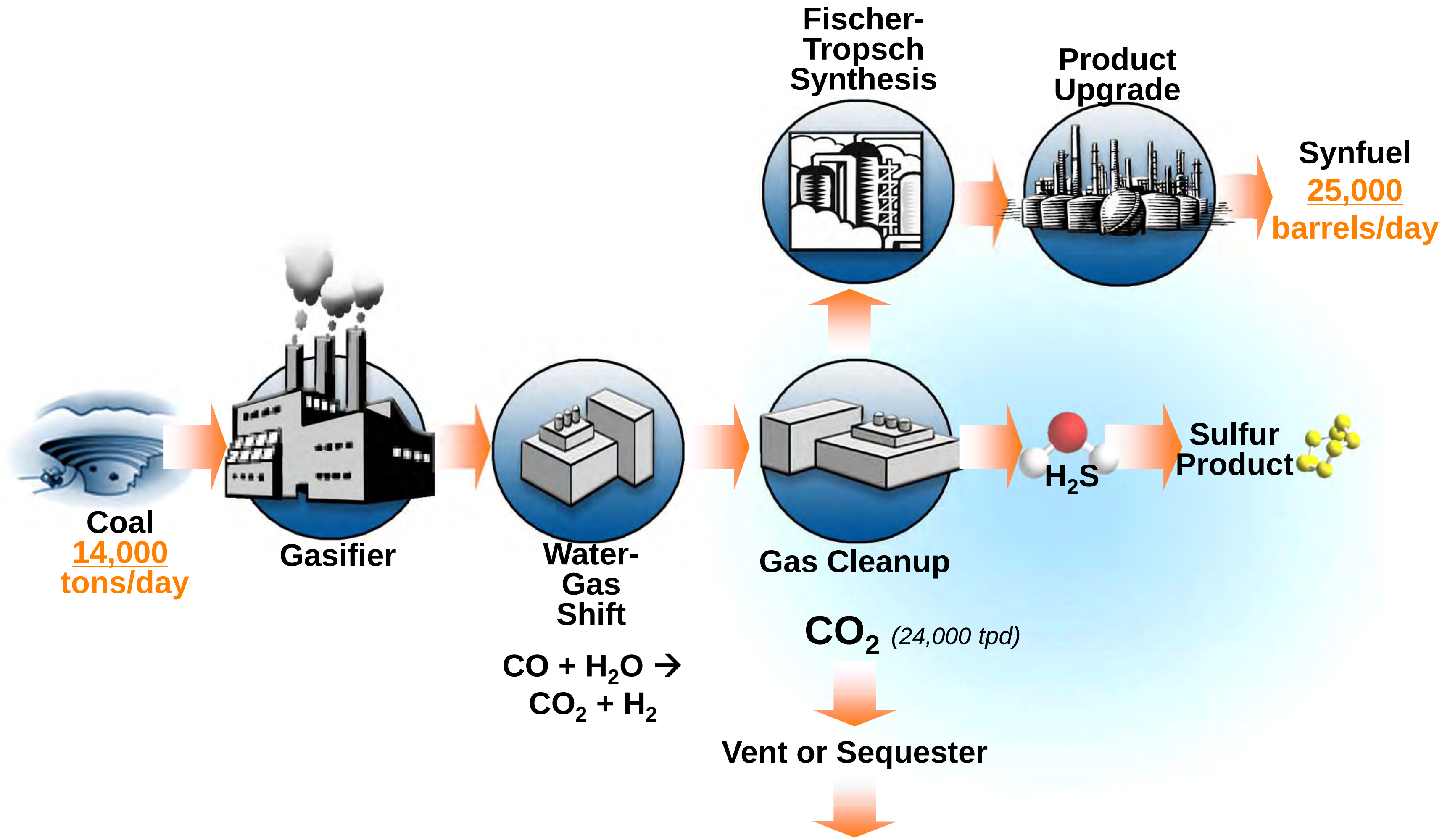
In the longer term, we can transition from fossil fuels to hydrogen, when the technologies for hydrogen utilization (e.g., fuel cells) become more economical.

Modular HTRs Can Supply the High-Temperature Heat for Many Industrial Applications

Potential Applications in North America

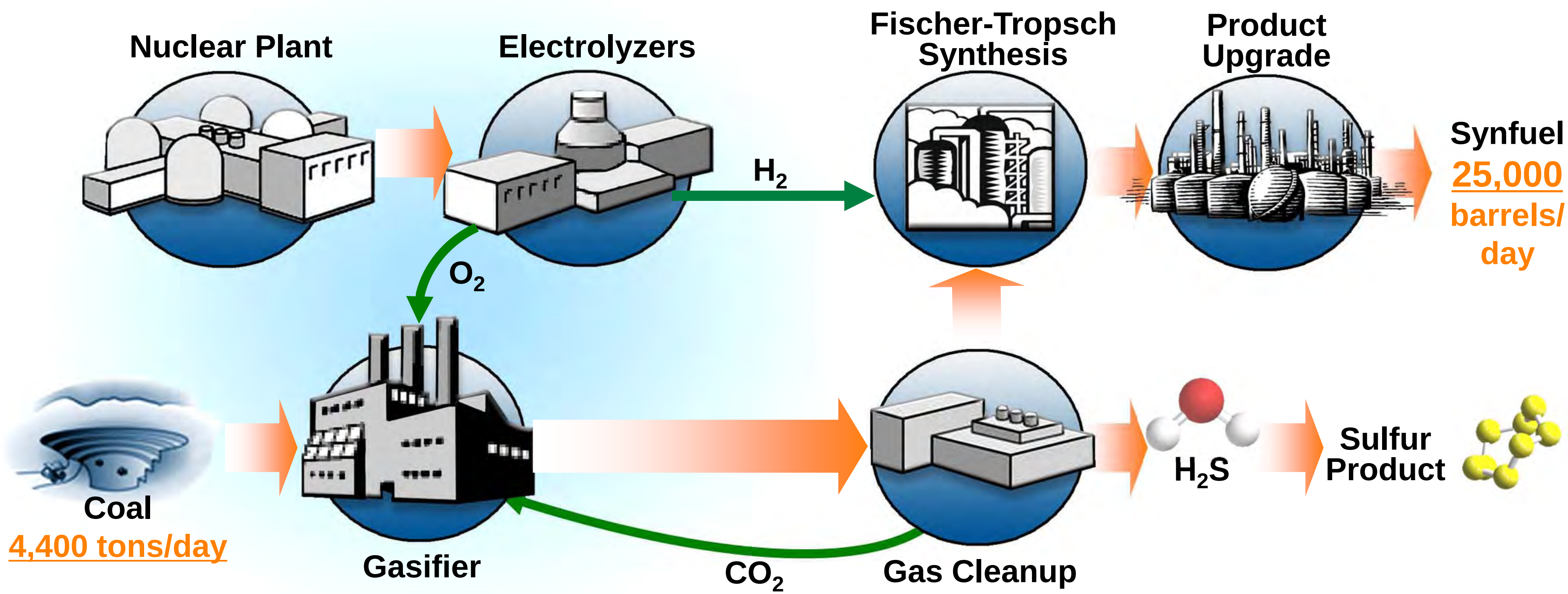


Carbon Conversion - Conventional Coal to Liquids



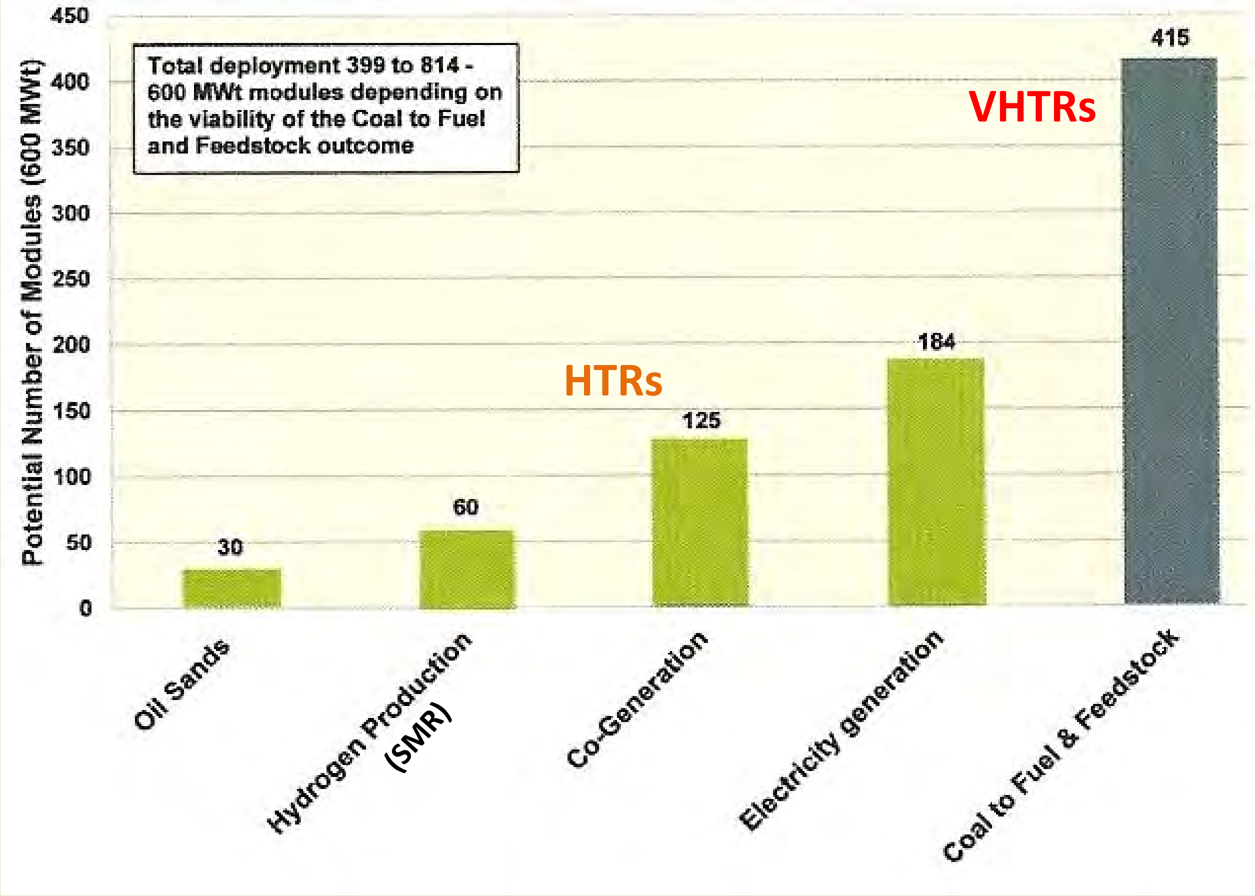
$CO + H_2O \rightarrow CO_2 + H_2$

Carbon Conversion - Nuclear Hybrid Coal to Liquids



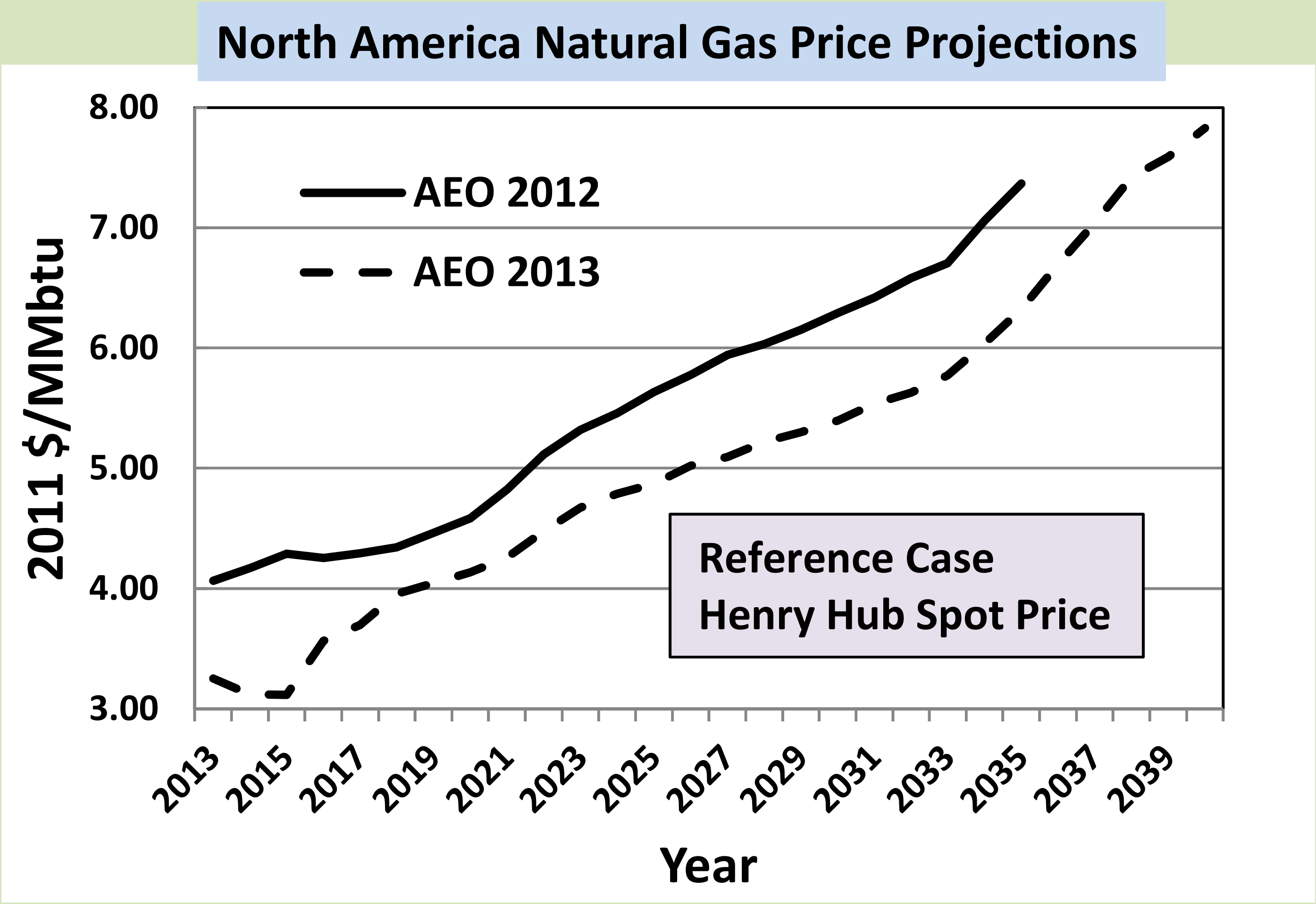
- Hybrid systems use 70% less carbon
- Little carbon is converted to CO_2
- Small amount of CO_2 is recycled to Gasifier
- No CO_2 emissions

Target Markets in North America (2012 NIA Business Plan)



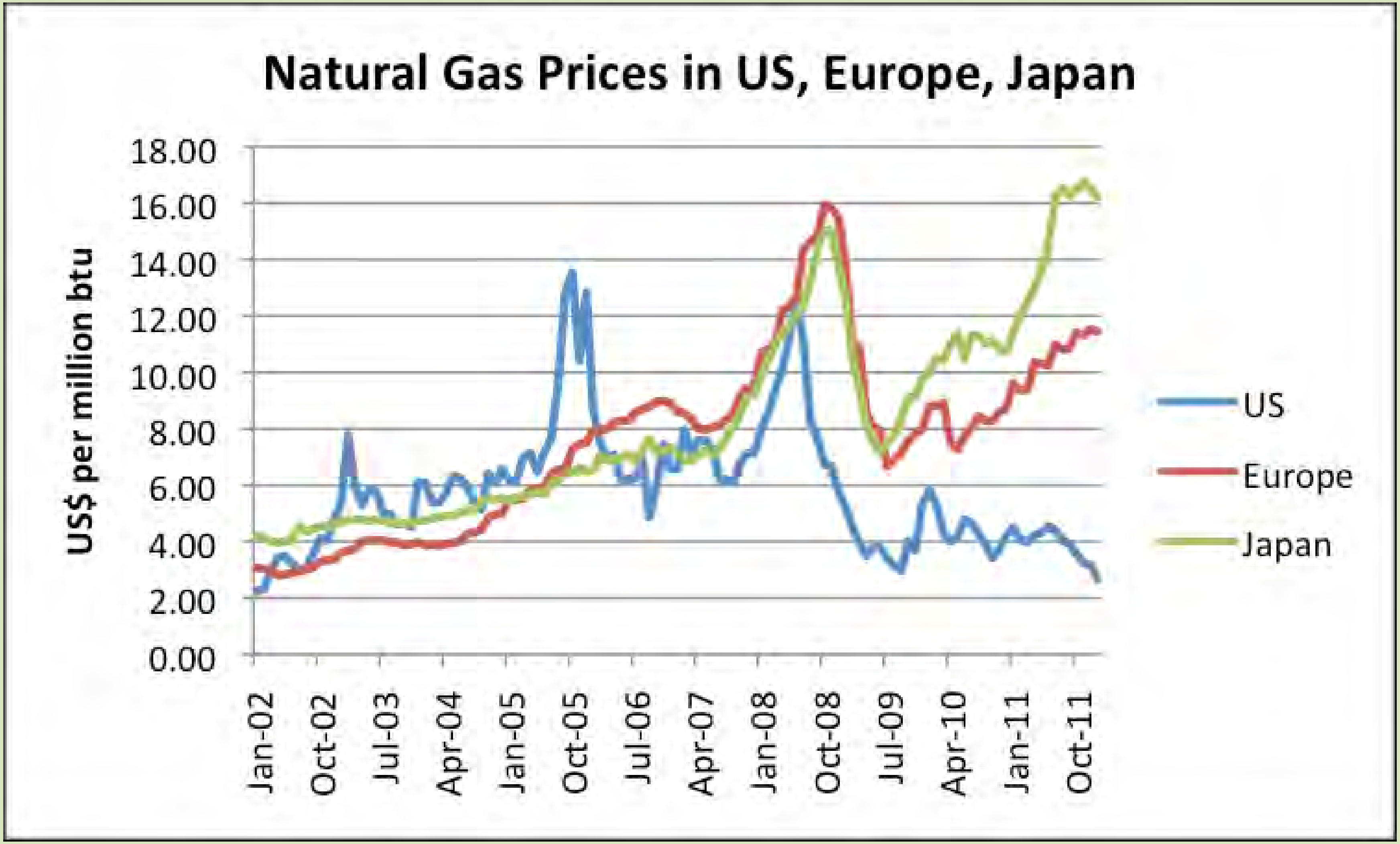
At current coal and natural gas prices in the U.S., Idaho National Laboratory (INL) has projected synthetic transportation fuels and other liquid products is competitive with crude oil prices at approximately $70/barrel and higher.

Natural Gas is the Competition

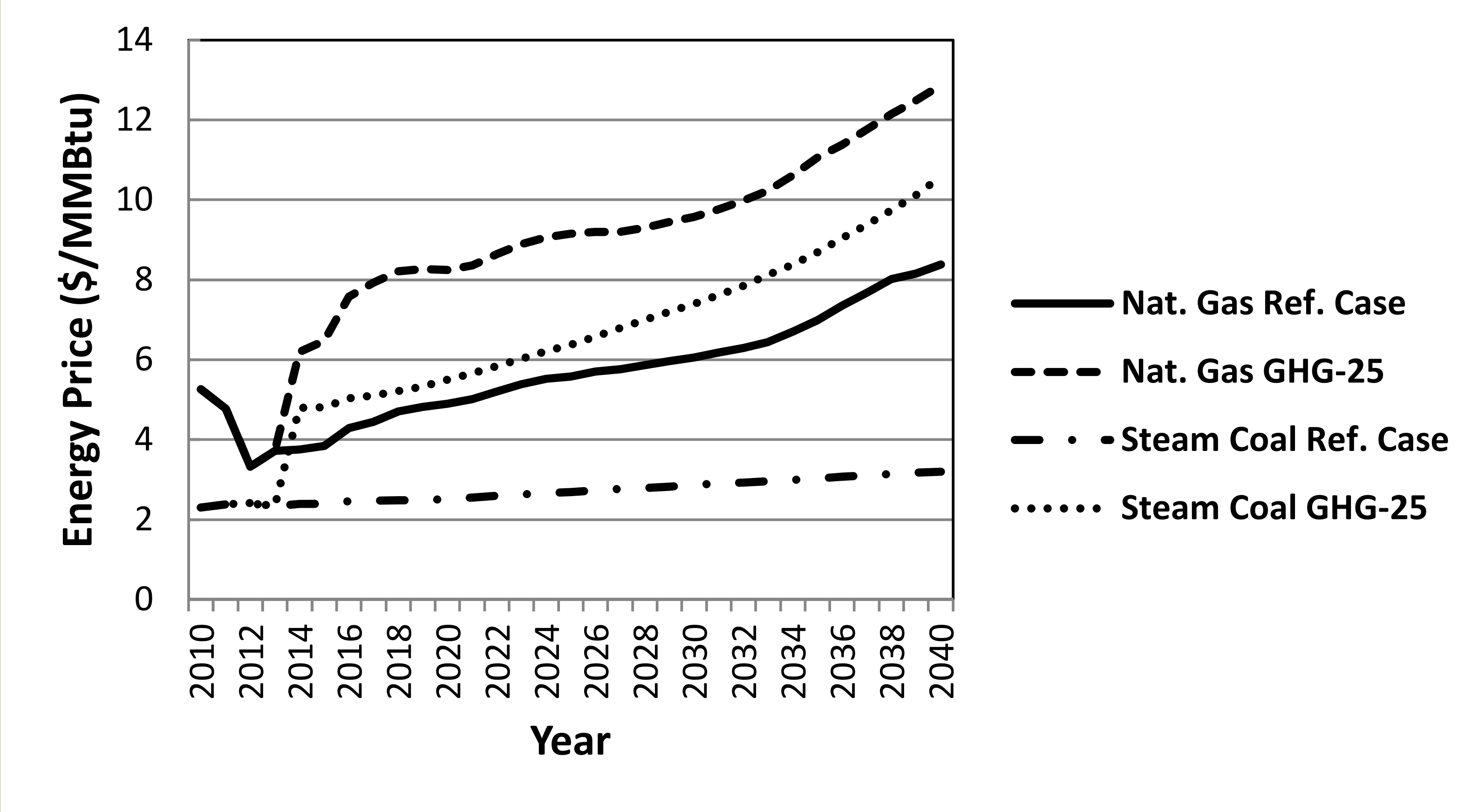


SC-MHR competitive with natural gas prices in the $6 - $8/MMBTU range.

Natural Gas Prices Have Been Very Unstable



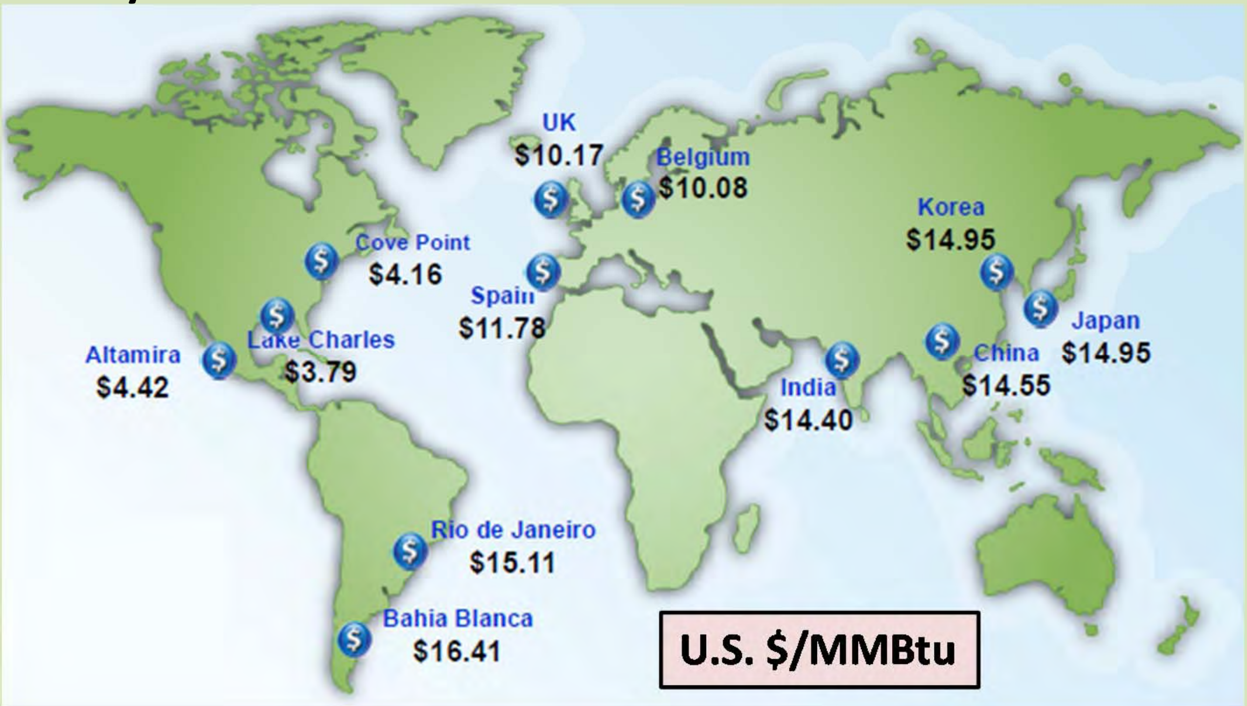
Effect of Carbon Tax on Natural Gas and Coal Prices



Carbon tax increases 5%/yr from $25/tonne CO_2 in 2014 to $90/tonne CO_2 in 2040.

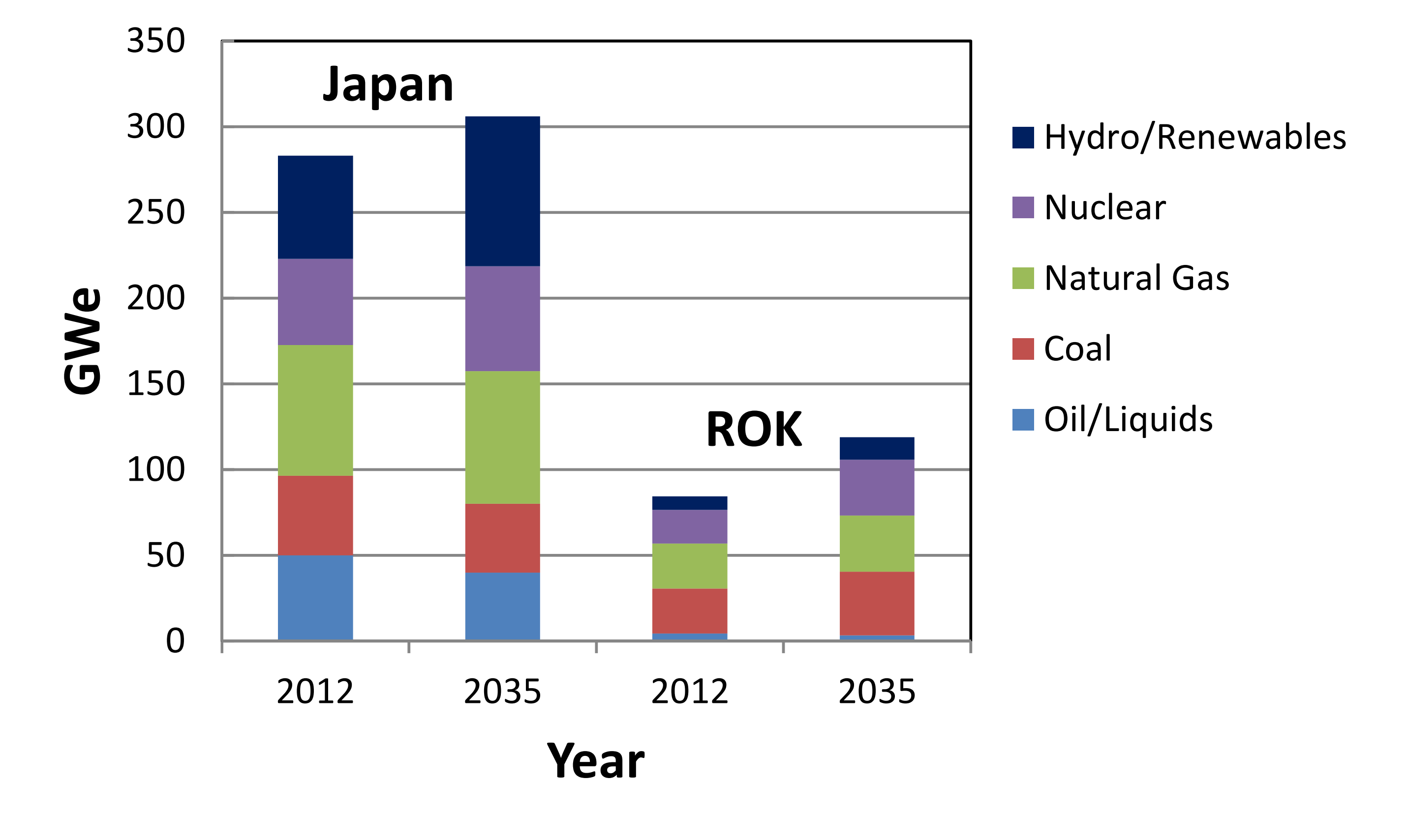
Displacing LNG for Electricity in Korea and Japan

May 2013 World LNG Landed Prices at Selected Locations



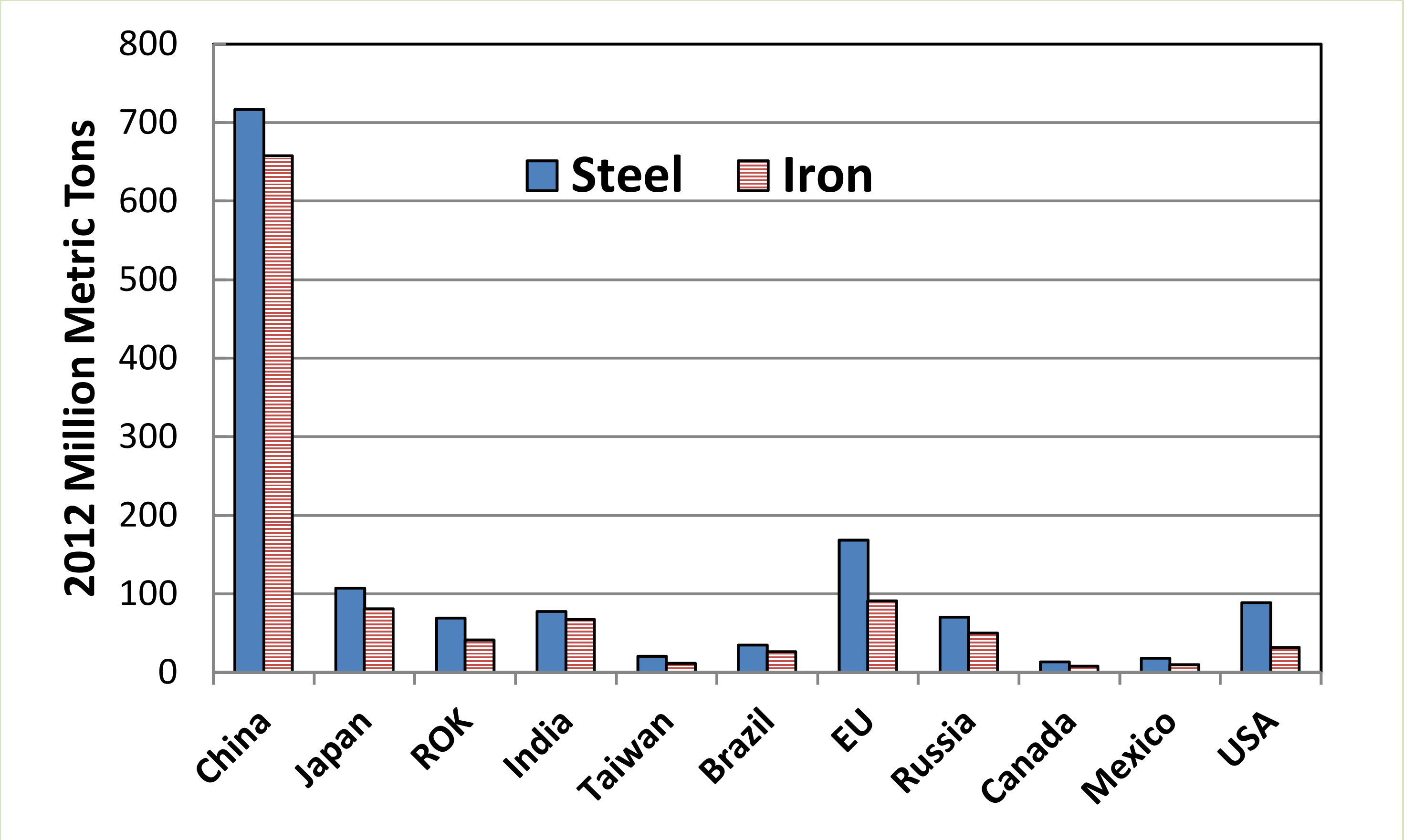
- **Japan and Korea are World's No. 1 and No. 2 importers of expensive LNG (~$15/MMBtu)**
- **One GWe corresponds to about four, 600-MWt MHR modules, assuming a steam-cycle thermal efficiency of about 40%**

Electricity Generation Mix Projections in Japan and the ROK Indicate Expanded use of LNG for Next 20 Years



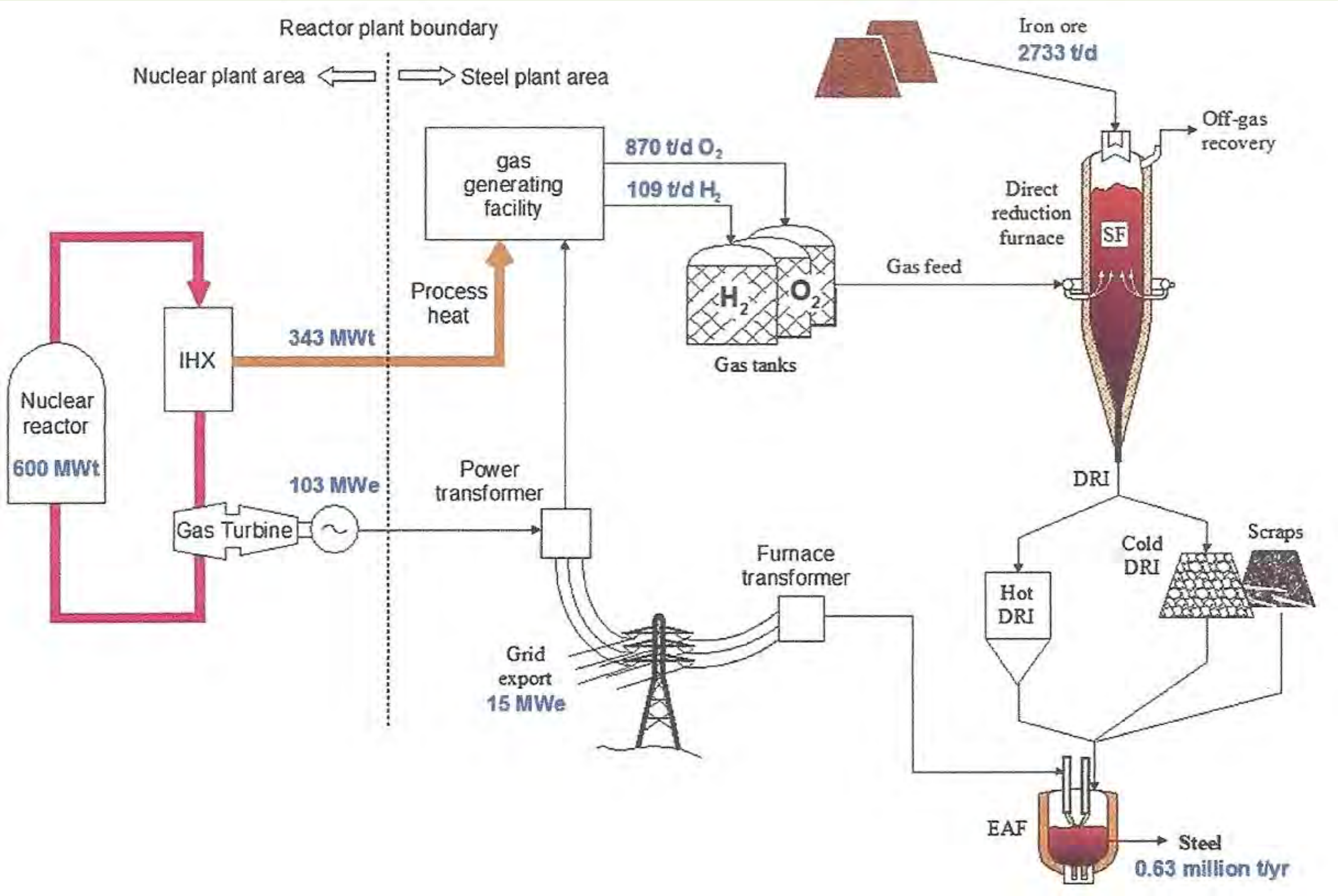
A 20% penetration of the LNG electricity market in Japan and Korea would account for about 80 600-MWt MHR modules

Nuclear Steel Manufacturing in Korea and Japan

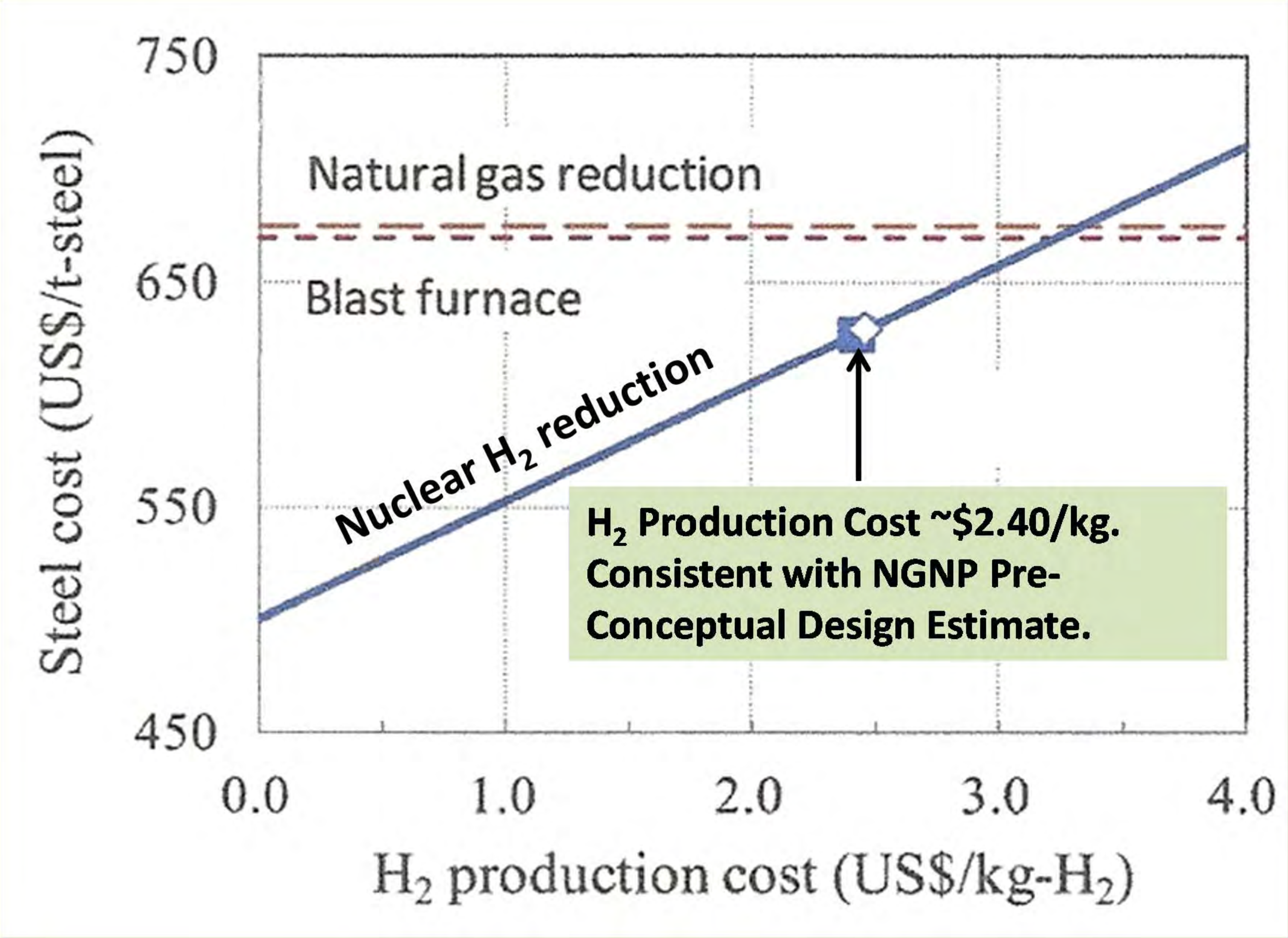


- Iron and steel production in 2012 was dominated by China but with substantial production in Japan, Korea, and the EU
- Iron-ore reduction is one of the largest sources of CO_2 emissions

JAEA Concept for Nuclear Steel Manufacturing



Cost Comparison of Steel Production Methods Illustrates Sensitivity to Hydrogen Production Costs

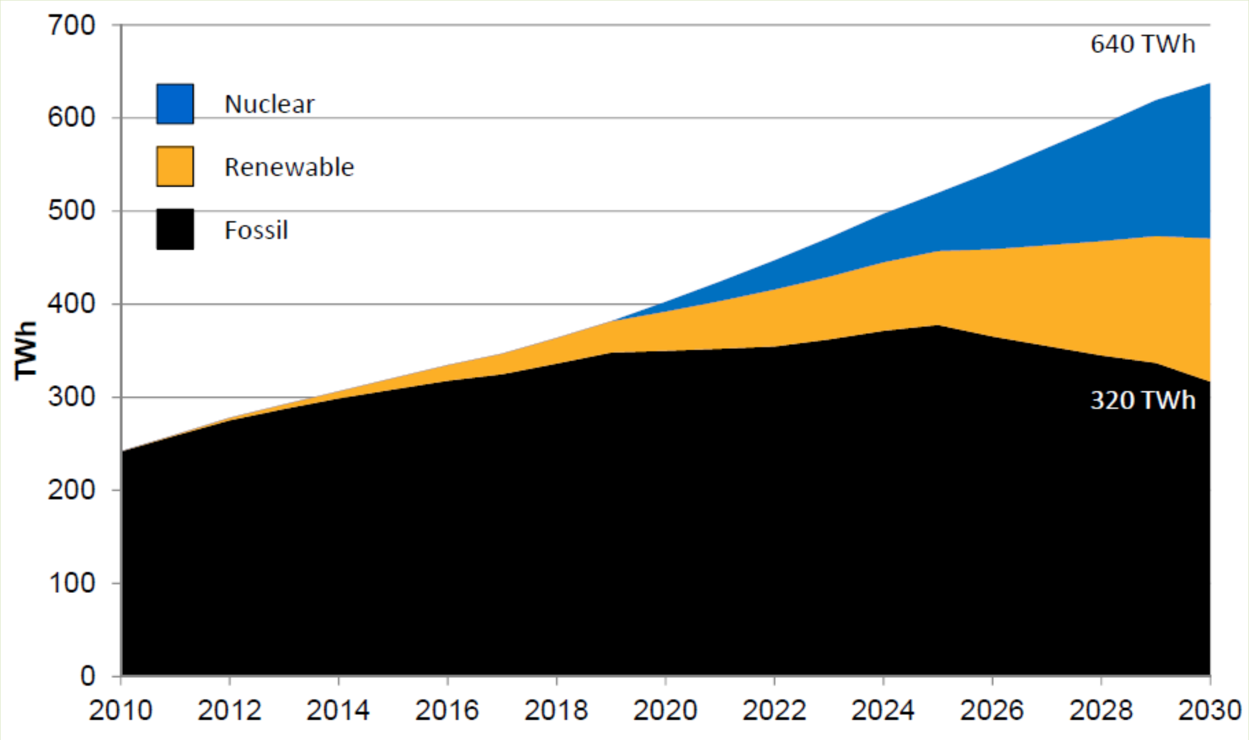


Market Potential for Nuclear Steel Manufacturing

- **Japan produces about 80 million metric tons of iron per year**
  - Results in about 140 million metric tons of CO_2 emissions per year.
    - Assuming pre-Fukushima nuclear capacity, iron production in Japan contributes 10% - 12% of its CO_2 emissions and represents a significant portion of its fossil fuel imports.
  - Eighty million metric tons of iron produced per year corresponds to about 130, 600-MWt GTHTR300C modules (or about 80 GWt)
- **ROK produces about 40 million metric tons of iron per year**
  - Results in about 70 million metric tons of CO_2 emissions per year
  - 40 million metric tons of iron produced per year corresponds to about 65, 600-MWt VHTR modules (about 40 GWt).

Displacing Oil Used for Electricity Generation and Process Heat in the Kingdom of Saudi Arabia

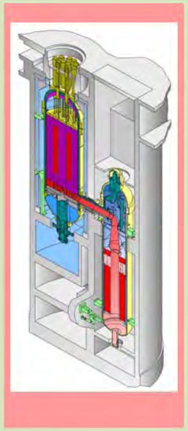
KSA Plan to Offset Fossil Energy with Nuclear and Renewable Energy



- **KSA plans to provide 17.6 GWe of nuclear energy by 2030**
- **MHRs could provide a significant portion of the KSA demand, especially at inland locations with limited or no availability of cooling water**

Conclusions (1/2)

- **The world continues to rely heavily on fossil fuels**
  - We need a global energy policy with reduced carbon emissions that does not compromise the high standard of living enjoyed by much of the world
- **Nearly 80% of the world's energy demand is in the industrial and transportation sectors**
  - We need a transition from fossil fuels in these sectors
- **MHRs are well suited for replacing fossil fuels**
  - Well established next-generation technology
  - **High temperature (700 – 950°C) capability matches requirements for transportation and industrial energy sectors**
  - **Inherently safe, meltdown-proof design**
  - Can be located close to end users of process heat/steam
  - High thermal efficiency
  - Can be located in areas with limited cooling water supply
  - Can be the basis for an emissions-free hydrogen economy
  - Excellent technology for export, especially to developing nations
  - Efficient fuel cycle synergy with fast reactors for developed nations



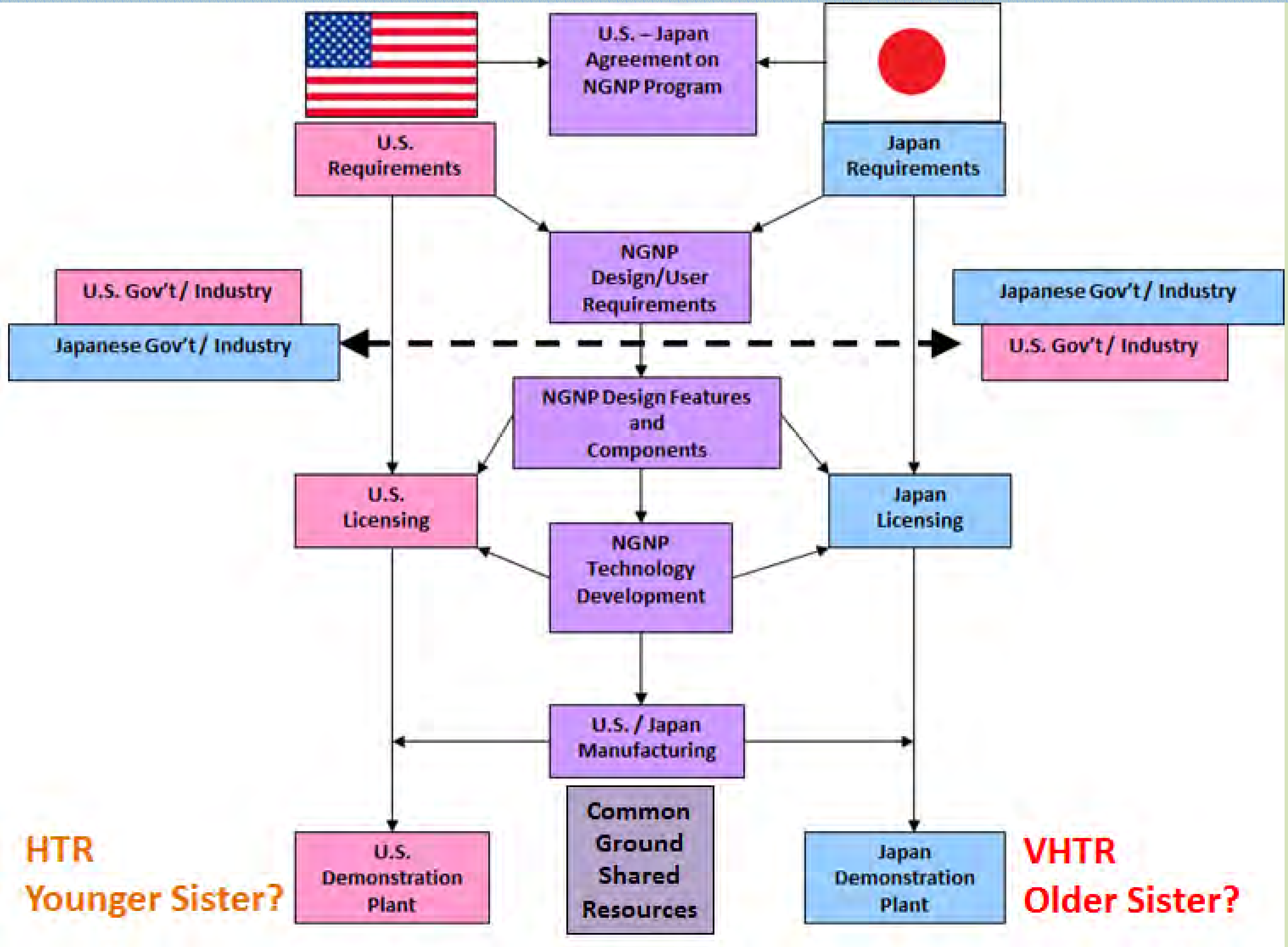
Conclusions (2/2)

- **Markets exist today for economical deployment of a large number of steam-cycle MHRs for electricity and process heat**
  - Korea and Japan with high LNG price and established MHR programs
  - KSA using heavily subsidized oil for energy needs
  - Other locations with high fossil fuel costs
- **Low NG prices in N. America inhibit expansion of any nuclear technology**
  - MHRs may be competitive for projected NG prices in the 2030 time frame
  - Carbon taxes improve economic case for MHRs
- **Good market potential for future higher-temperature applications**
  - Nuclear steel manufacturing
  - Synthetic fuels
  - Hydrogen for fuel-cell vehicles and industrial applications

Path Forward

- **Primary obstacle is the high level of funding needed to complete technology development, licensing, and construction of the first-of-a-kind demonstration module**
  - About $3B is required
  - Requires a significant level of government support to mitigate financial, technical, and regulatory risks
  - This is not unexpected for any new nuclear technology
- **International collaboration can pool government and private sector resources**
  - EPACT encourages DOE to pursue international collaboration
  - NGNP Alliance exploring initiatives with EU, Korea, and Japan
  - **There is much common ground to share resources, capabilities, and technologies to develop and demonstrate the world's best HTR and VHTR.**

Potential Model for U.S./Japan Collaboration on NGNP



ご静聴、ありがとうございました.

Plum
Blossom Festival
Kairakuen, Mito

Thank you for your kind attention.