H2-MHR Conceptual Designs Based on the SI Process and HTE

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H2-MHR Conceptual Designs are Being Developed

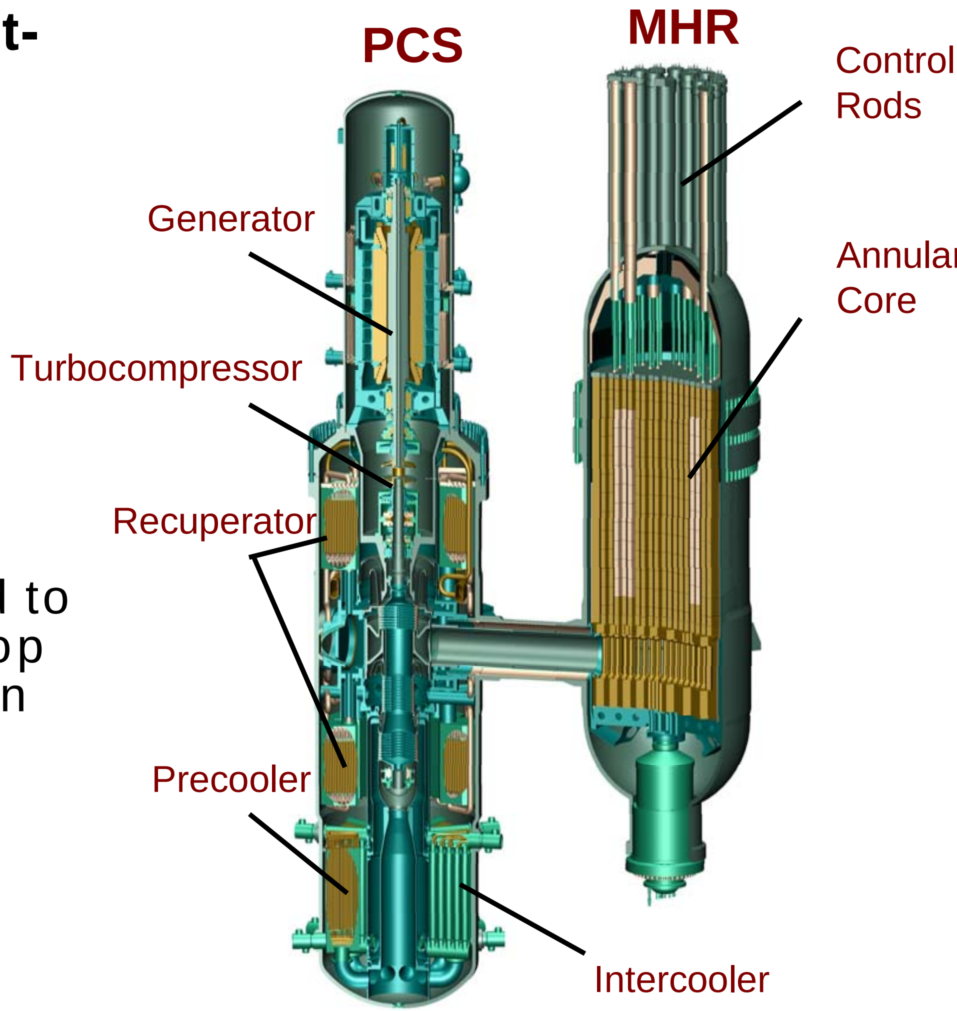
- **3 year DOE NERI project with GA, INL, TAMU, & Entergy**
  - Develop conceptual designs of "H2-MHR" hydrogen production plants
  - Initial focus on integration of MHR and Sulfur-Iodine-based hydrogen production plant
  - Conceptual design also being developed for integration of MHR with High Temperature Electrolysis
  - FY-05 is last year of project

- **Participation in Related NERI/I-NERI Projects:**
  - Centralized Hydrogen Production from Nuclear Power: Infrastructure Analysis and Test Case Design Study (SRNL, GA, Entergy, ANL, Univ. S. Carolina)
  - High Efficiency Hydrogen Production from Nuclear Energy: Laboratory Demonstration of S-I Water Splitting (SNL, CEA, GA)

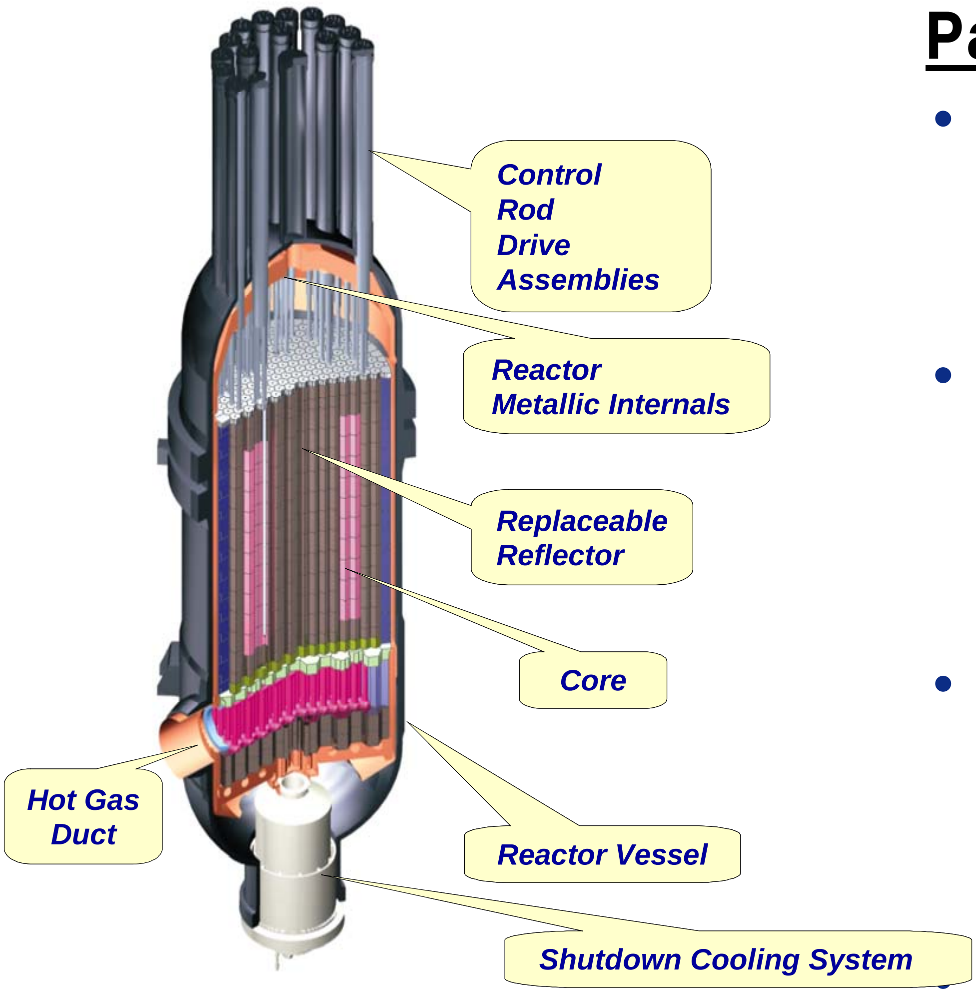
- **Additional Cooperation/Coordination with Various other Projects**
  - UNLV High Temperature HX Project
  - Private collaborations with Fuji Electric / Toshiba
  - HTE Technology Development at INL

GT-MHR Provides Springboard to the H2-MHR

- **MHR coupled to a direct-cycle Brayton power-conversion system**
- **600 MW(t), 102 column, annular core, prismatic blocks**
- **Concept developed initially in the U.S.**
  - Technology transferred to Russia to further develop design for Pu disposition
  - Similar concept being developed in Japan (JAEA GTHTR300)



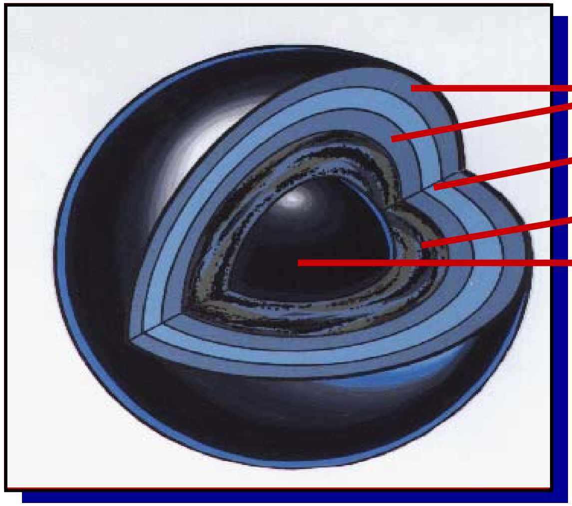
The MHR is a Passively Safe Design



Passive Safety Features

- **Ceramic, coated-particle fuel**
  - Maintains integrity during loss-of-coolant accident
- **Annular graphite core with high heat capacity**
  - Helps to limit temperature rise during loss-of-coolant accident
- **Low power density**
  - Helps to maintain acceptable temperatures during normal operation and accidents
- **Inert Helium Coolant**
  - Reduces circulating and plateout activity

Ceramic Fuel Retains its Integrity Under Severe Accident Conditions and is an Ideal Waste Form for Permanent Disposal



TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).

PARTICLES

COMPACTS

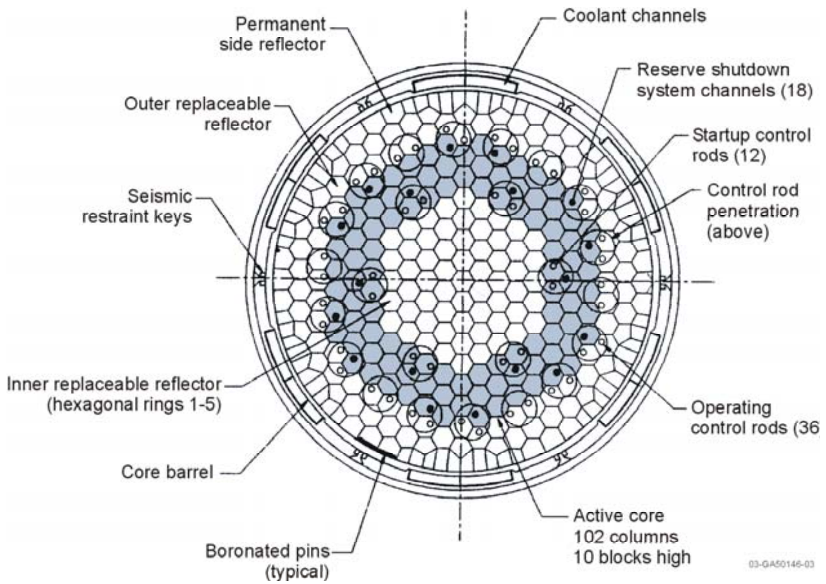
FUEL ELEMENTS

Reactor Design is Being Optimized for Higher Temperature Operation

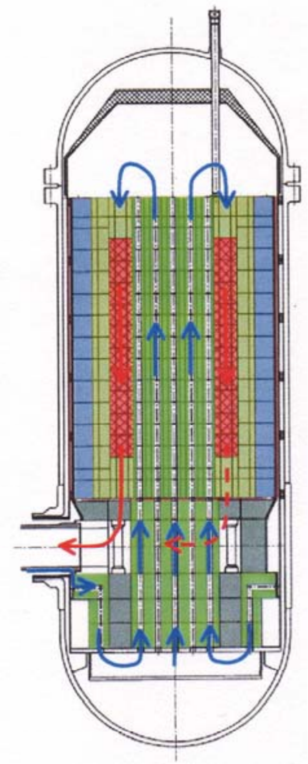
- **Optimize Power Distributions**
  - Fuel placement or sandwich shuffling refueling schemes to reduce "age" component of power peaking
  - Improved zoning of fissile/fertile fuel ratio and burnable poison
  - Use control rods in inner and outer reflector
    - Reduce radial component of power peaking
    - Temperature limitations may require C-C clad rods
- **Optimize Thermal Hydraulic Design**
  - Reduce bypass flow
    - Core restraint and sealing devices to minimize gaps
    - Reduce or eliminate flow in control-rod channels using C-C rods
    - Goal is to reduce bypass flow fraction from about 0.2 to about 0.1
  - Alternative Inlet Flow Configurations
    - Reduce vessel temperature
    - Route flow through inner and/or outer reflector
- **Use Higher-Temperature Metals, C-C Composites for Reactor Internal Components**

Alternative Inlet Flow Configurations Can Reduce Vessel Temperatures

Reference GT-MHR (channel box)

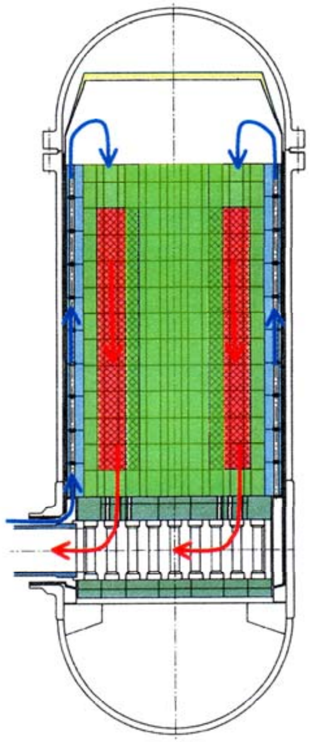


Inner Reflector



(a)

Permanent Side Reflector



(b)

ATHENA code used to assess alternative flow configurations

Inner reflector configuration removes significant heat capacity, resulting in higher fuel temperatures during accidents

MHR
GENERAL ATOMICS

H2-MHR Point Design Options Have Been Evaluated

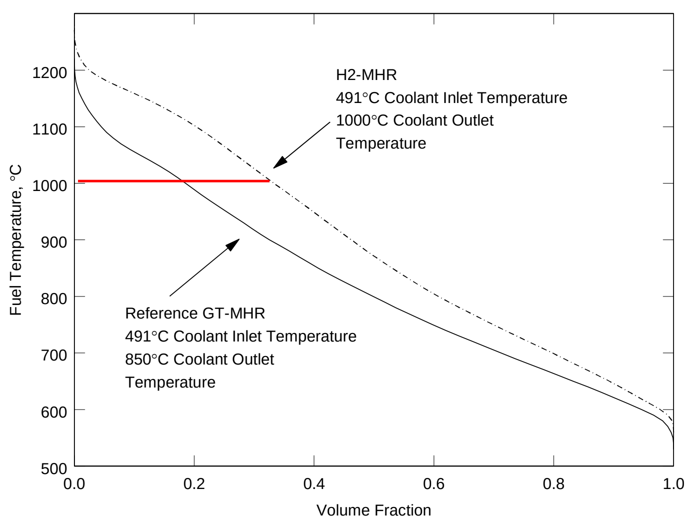
	GT-MHR	H2-MHR Orificed Core	H2-MHR Optimized Core
Power Level (MW_t)	600	600	600
Helium Inlet Temperature (°C)	490	490	590
Helium Outlet Temperature (°C)	850	1000	950
Coolant Flow Rate (kg/s)	320	226	320
Core Pressure Drop (kPa)	~50	~50	>50

Orificed Core: Use of fixed orifices in upper/lower reflector
Optimized Core: Possible limited use of fixed orifices on "cold" columns for additional design margin on fuel temperatures

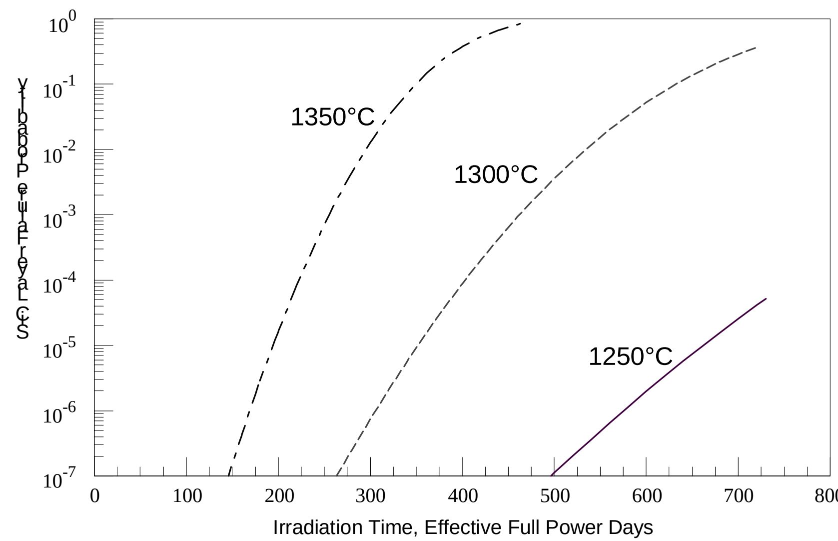
Core Nuclear / Thermal Hydraulic Optimization – Scoping Studies

	Flow Control Scheme		
	None	Optimized by POKE	Optimized by POKE
Inlet Coolant Temperature (°C)	640	640	490
Coolant Flow Rate (kg/s)	320	320	225
Average Outlet Coolant Temperature (°C)	1000	1000	1000
Maximum Fuel Temperature (°C)	1309	1204	1239
Maximum Outlet Coolant Temperature (°C)	1124	1030	1042
Core Pressure Drop (kPa)	69	100	48

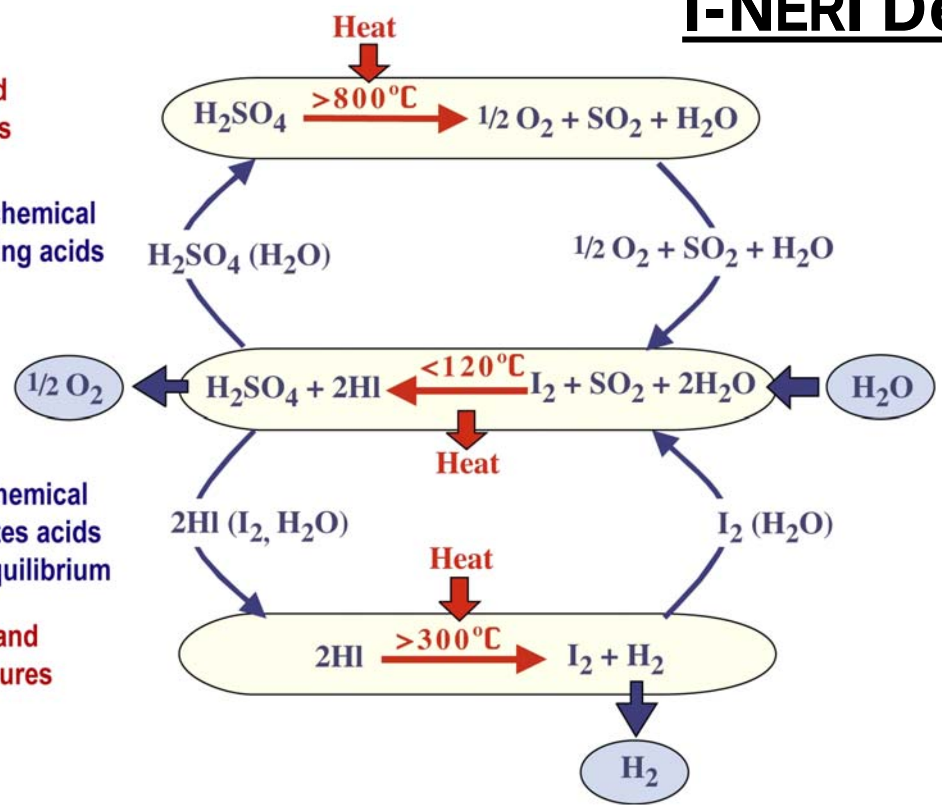
Fuel Temperatures



Fuel Performance



Sulfur-Iodine Cycle



Sulfuric acid is concentrated and decomposed at high temperatures

Excess water shifts chemical equilibrium by hydrating acids

Bunsen reaction produces acids and releases waste heat to the environment at low temperatures

Excess iodine shifts chemical equilibrium and separates acids by liquid-liquid phase equilibrium

Hydrogen iodide is concentrated and decomposed at moderate temperatures

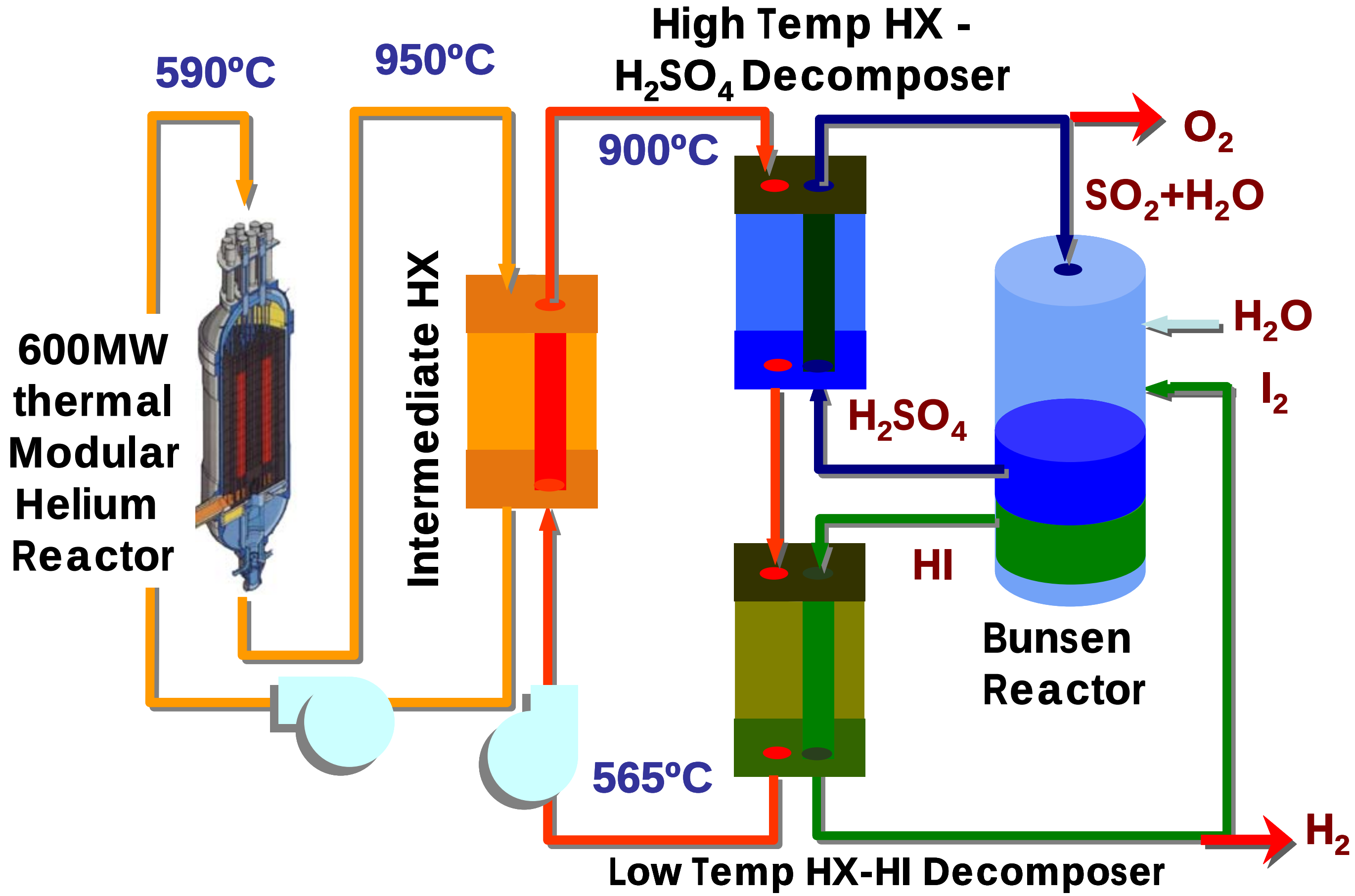
I-NERI Demonstration

Sandia

CEA

GA

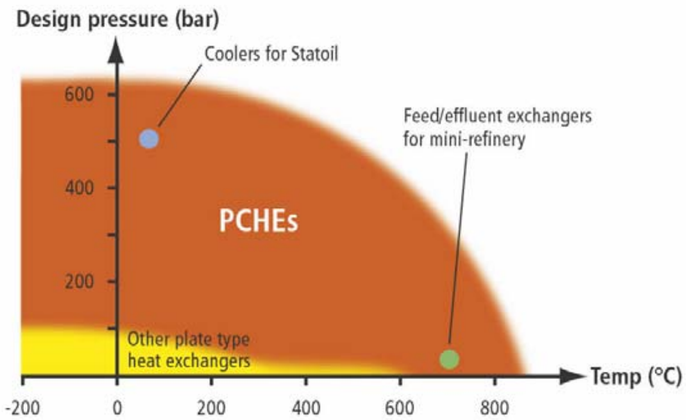
MHR Coupled to S-I Thermochemical Water Splitting



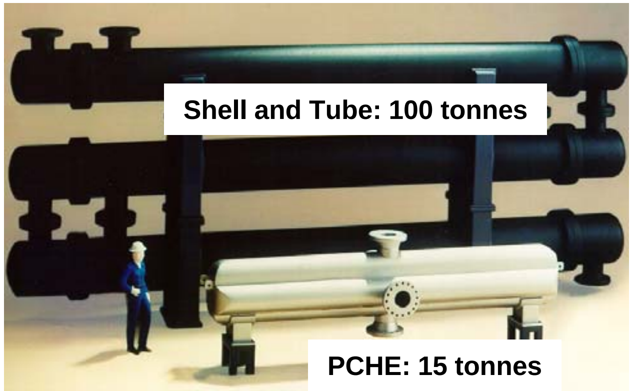
Aspen flowsheet evaluations show efficiencies of about 45% based on HHV of H_2

Conceptual IHX Design has Been Developed Based on HEATRIC Printed Circuit Heat Exchanger (PCHE)

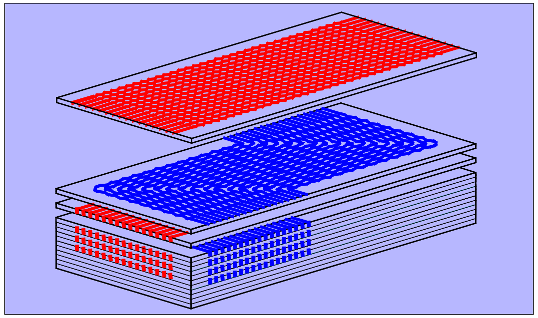
High Temperature and High Pressure Capability



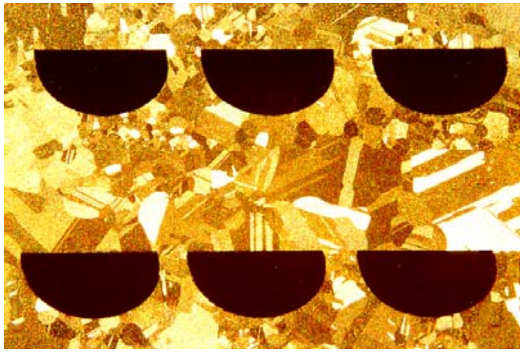
Compact, Lighter-Weight Design

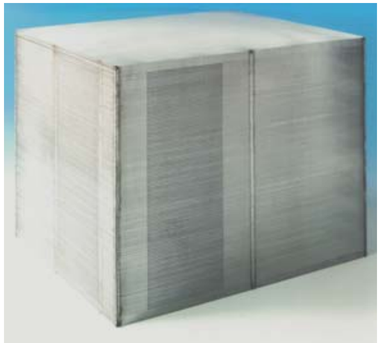


Stacked Plates with Counterflow



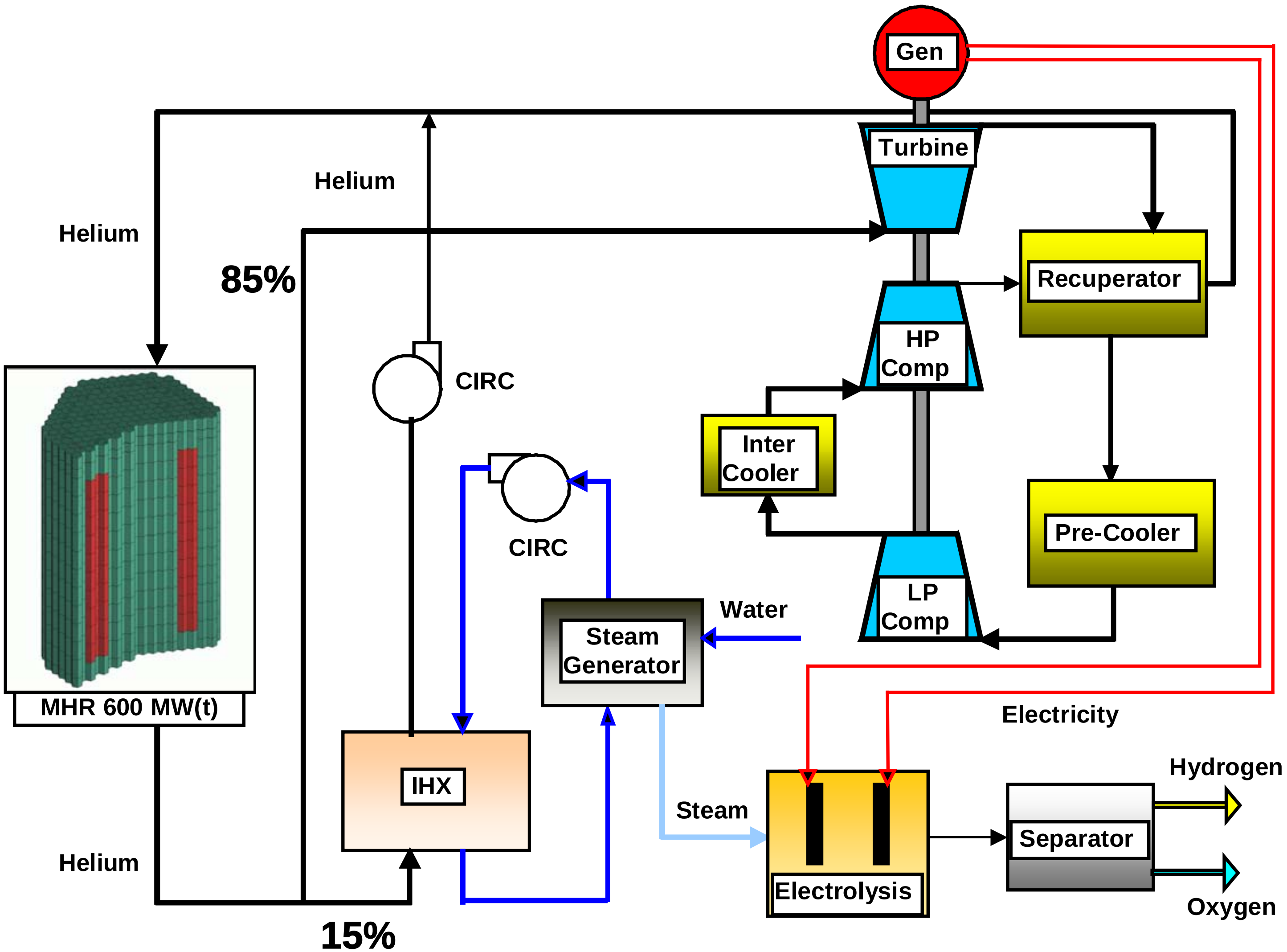
Diffusion Bonding Restores Properties of Base Metal



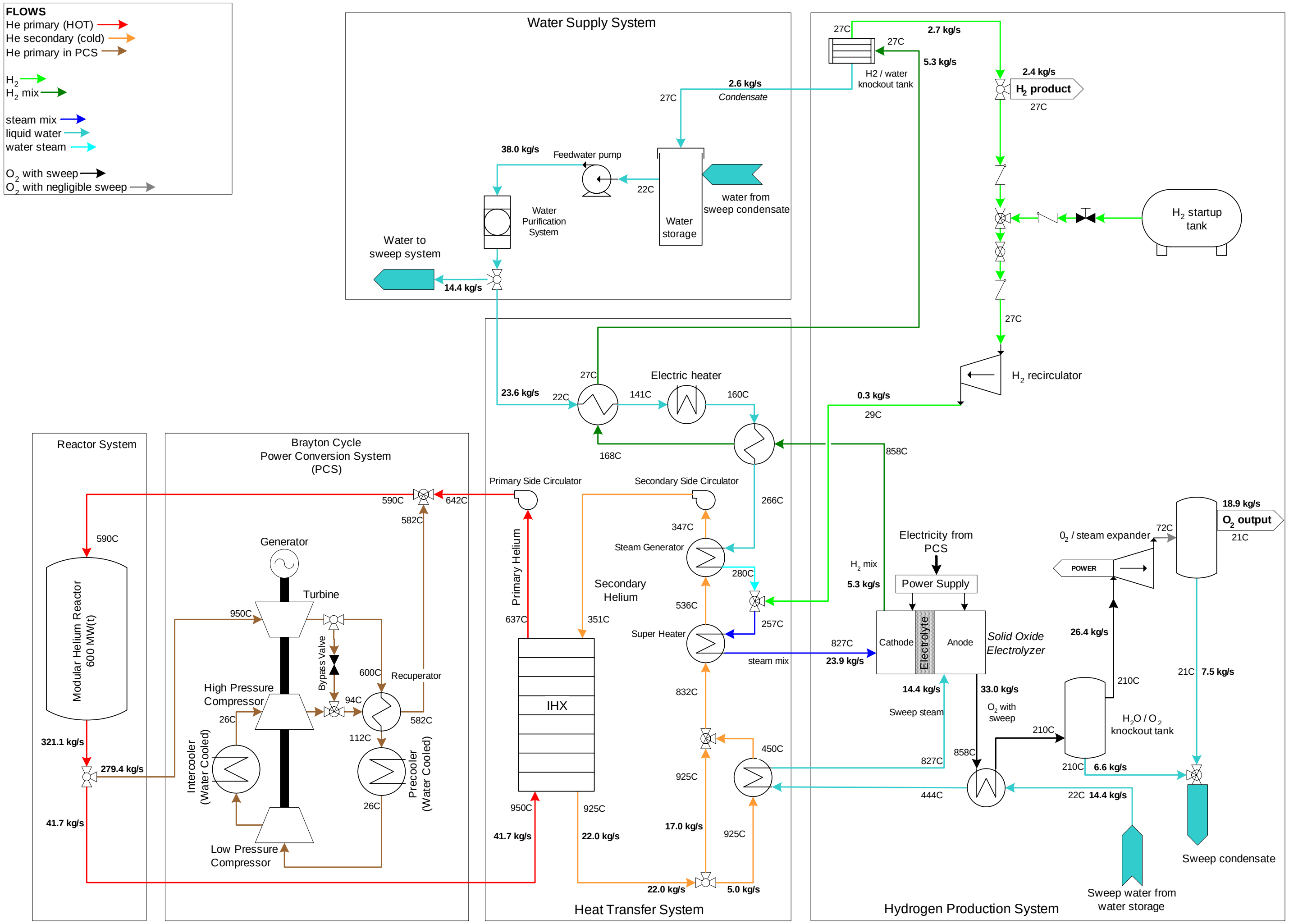


PCHEs using higher temperature alloys are currently being developed by HEATRIC. 600 MW(t) IHX would consist of 40 15-MW(t) modules.

MHR Coupled to High-Temperature Electrolysis



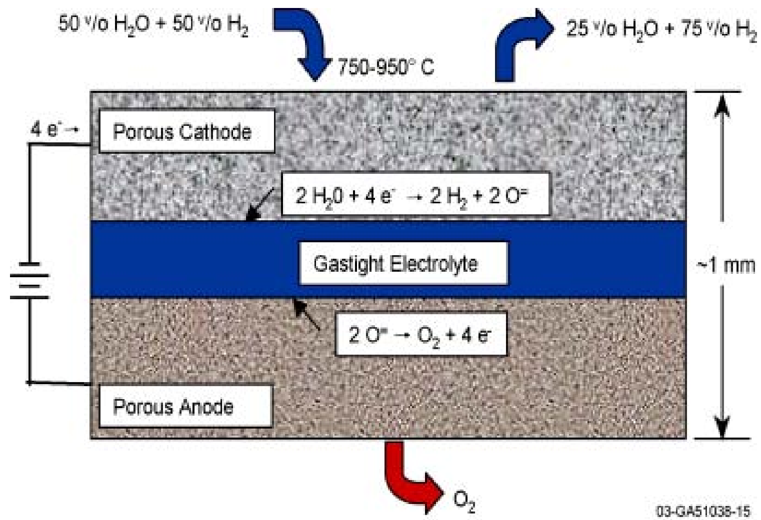
HTE-Based H2-MHR Flowsheet



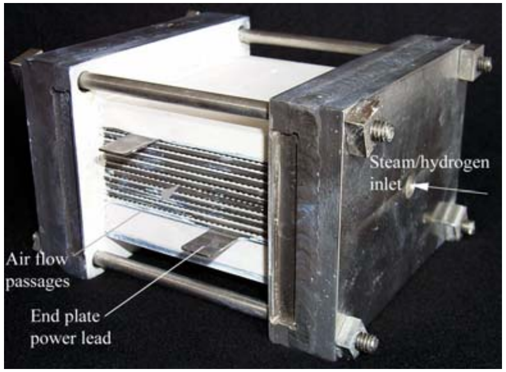
Results of HTE Flowsheet Using HYSYS Process Simulation Software

MHR Module Thermal Power	600 MW(t)
MHR Coolant Outlet Temperature	950°C
PCS Power Generation	312 MW(e)
PCS Thermal Efficiency	52%
Thermal Power Supplied for Hydrogen Production	68 MW(t)
SOE Process Temperature	827°C
Power Supplied to SOE Modules	292 MW(e)
Hydrogen Production Rate	2.36 kg/s
Hydrogen Production Efficiency (based on HHV of H_2)	55.5%
Auxiliary Power Generation	9.3 MW(e)
Overall Process Efficiency	59.9%

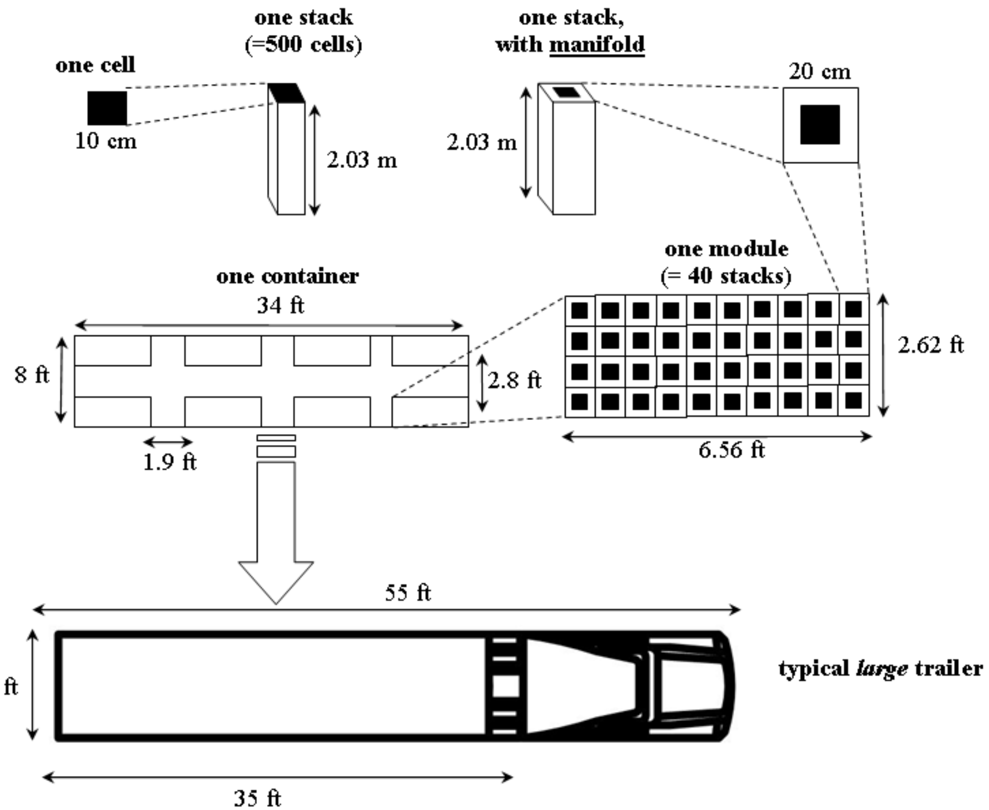
Solid Oxide Electrolyzer Technology Has Been Successfully Tested



10-Cell Stack Tested at INL



4-MW(e) Trailer Module

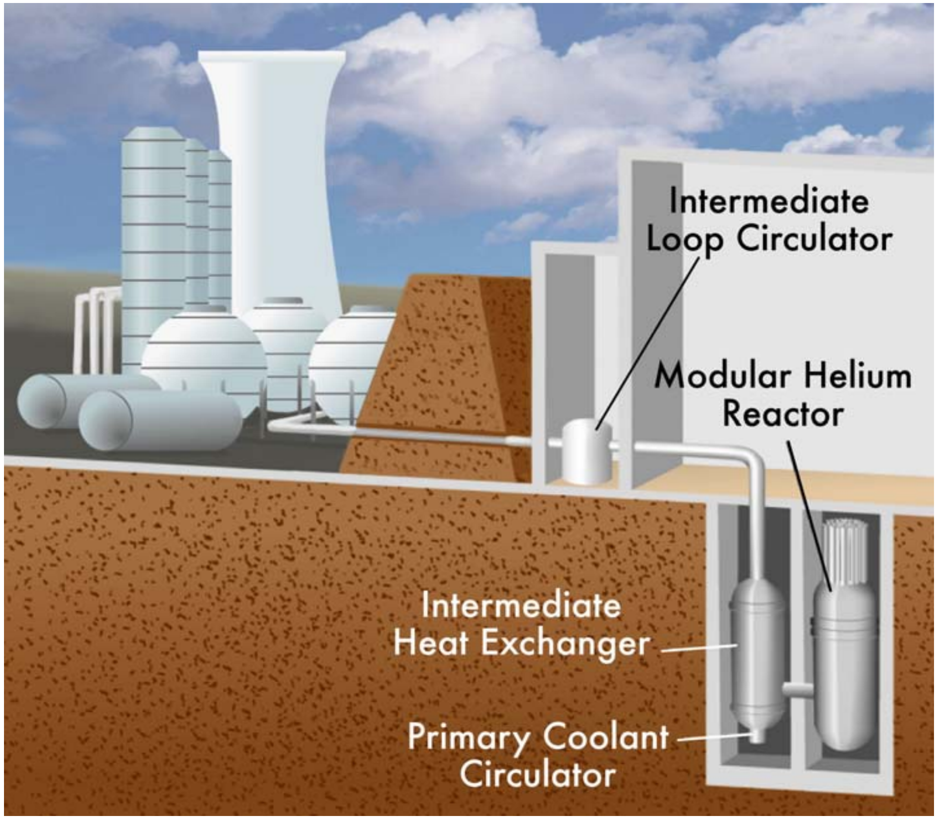


MHR

GENERAL ATOMICS

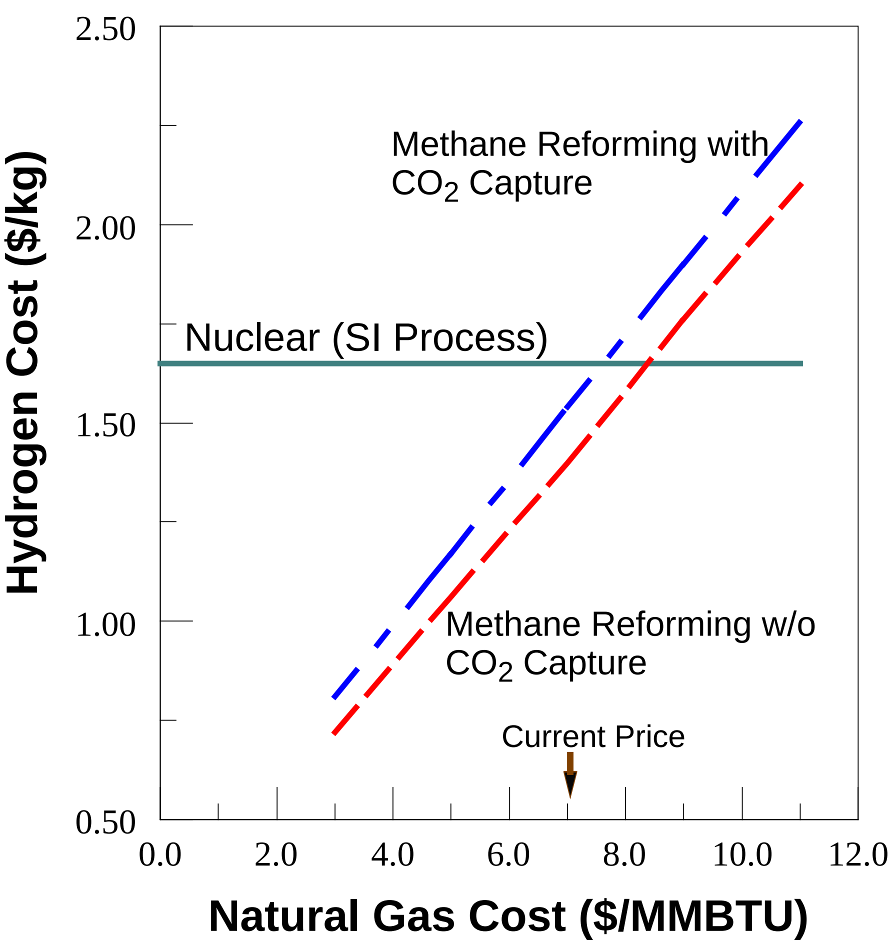
Hydrogen Plant Will Not Impact Passive Safety

- **Licensing issue of most concern is co-location of MHR and Hydrogen Plant**
  - Passive safety of MHR allows co-location
  - Earthen berm provides defense-in-depth
- **Other reactors located in close proximity to hazardous chemical plants and transportation routes**
  - NRC allows risk-based approach
  - INL recommends 60 to 100 m separation distance



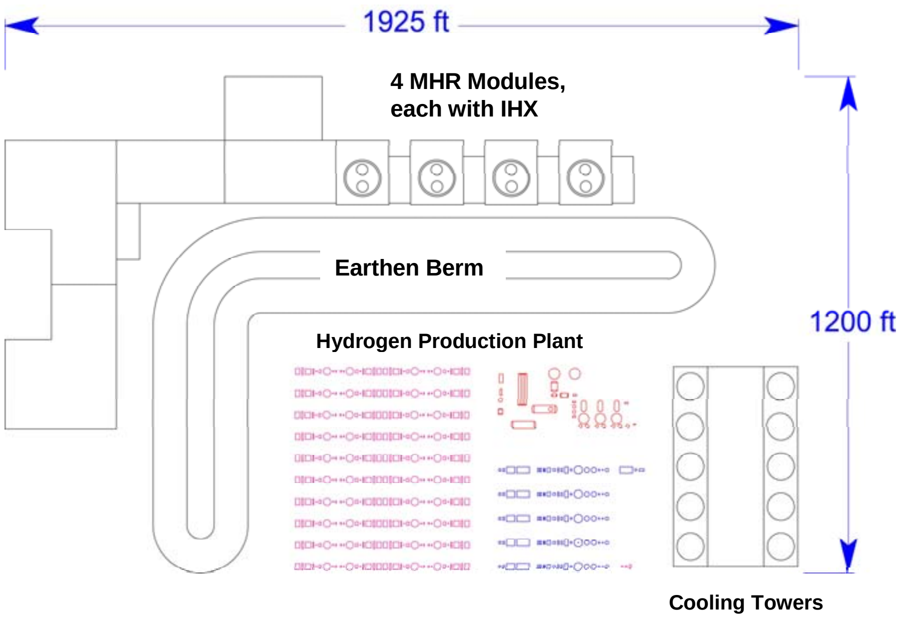
Economics for Nuclear Hydrogen Production are Competitive With Steam-Methane Reforming

	SI-Based Plant	HTE-Based Plant
Capital Costs ($M)		
Reactor System	1030	1284
Hydrogen System	738	TBD – Depends on SOE unit costs
O&M Costs ($M/yr)		
Reactor System	27.8	34.6
Hydrogen System	70.9	TBD – Probably less than SI plant
Hydrogen Cost ($/kg)	1.65	TBD



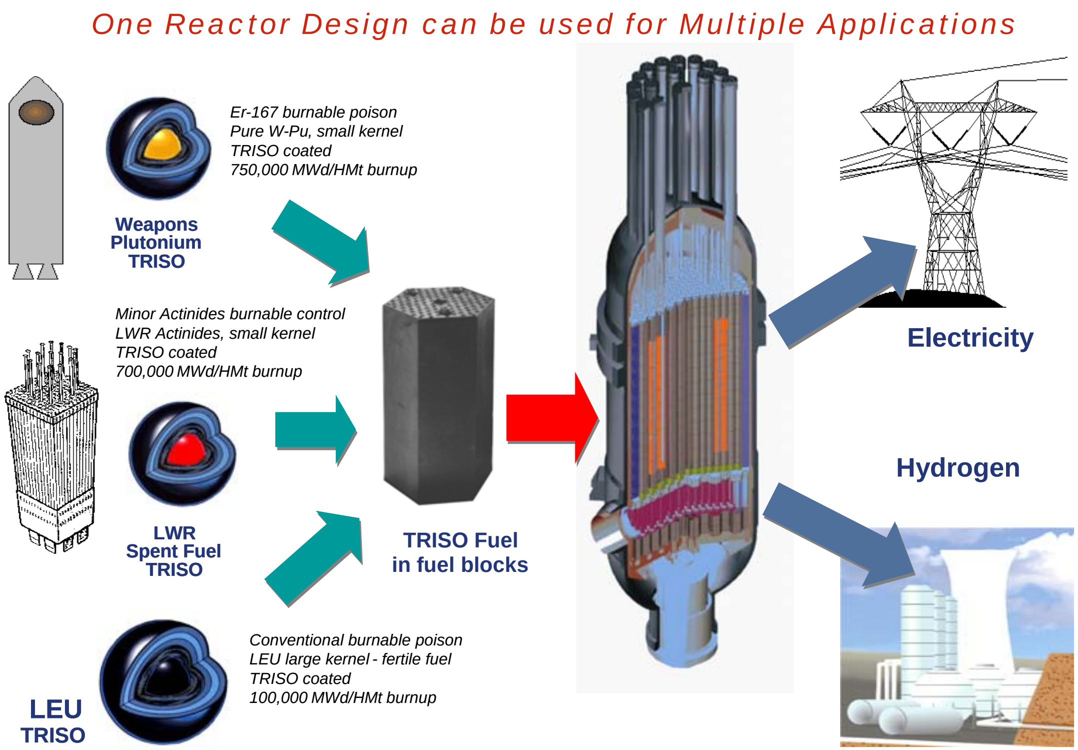
H2-MHR 4-Module Reference Design

- Standard MHR (850°C) or VHTR (950°C - 1000°C) reactor
- Intermediate Heat Exchanger (IHX) in adjacent cavity
- Intermediate heat transport loop
- MHR Passive Safety maintained
- H_2 plant separation by berm
- Non-nuclear H_2 plant
- 600 MWt $\Rightarrow$ 200 tons/day hydrogen production



CONCLUSIONS

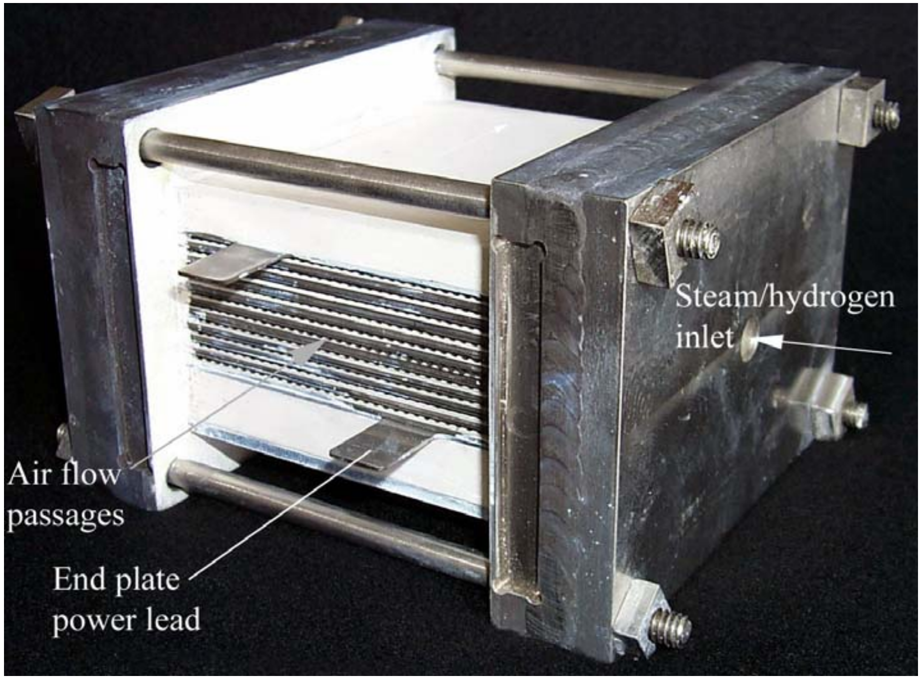
- **MHR is well suited for hydrogen production**
  - Passively safe reactor design
  - Produces high temperature heat needed for SI process and HTE
  - Proof of principle for both SI process and HTE have been demonstrated
  - Both SI process and HTE show potential for economical production of hydrogen without producing carbon dioxide
- **MHR technology can be applied to other missions**



Thank you for your kind attention.

Solid Oxide Electrolyzer Technology Has Been Successfully Tested

10-Cell Stack Tested at INL



Requirements for a 600 MW(t) MHR Module

Cell Area	
Individual Cell Width	10 cm
Individual Cell Active Area	100 cm^2
Total Number of Cells	12 x 10^6
Total Active Cell Area	120,000 m^2
Cell Thickness	
Electrolyte	10 µm (Scandia Stabilized Zirconia)
Anode	1500 µm (Strontium Doped Lathanum Manganite)
Cathode	50 µm (Nickel Zirconia Cermet)
Bipolar Plate	2.5 mm (Stainless Steel)
Total Cell Thickness	4.06 mm
Stack Dimensions	
Cells per Stack	500
Stack Height	2.03 m
Stack Volume	0.0203 m^3
Stack Volume with Manifold	0.0812 m^3
Number of Stacks	24,000