HTGR Technology Course for the Nuclear Regulatory Commission

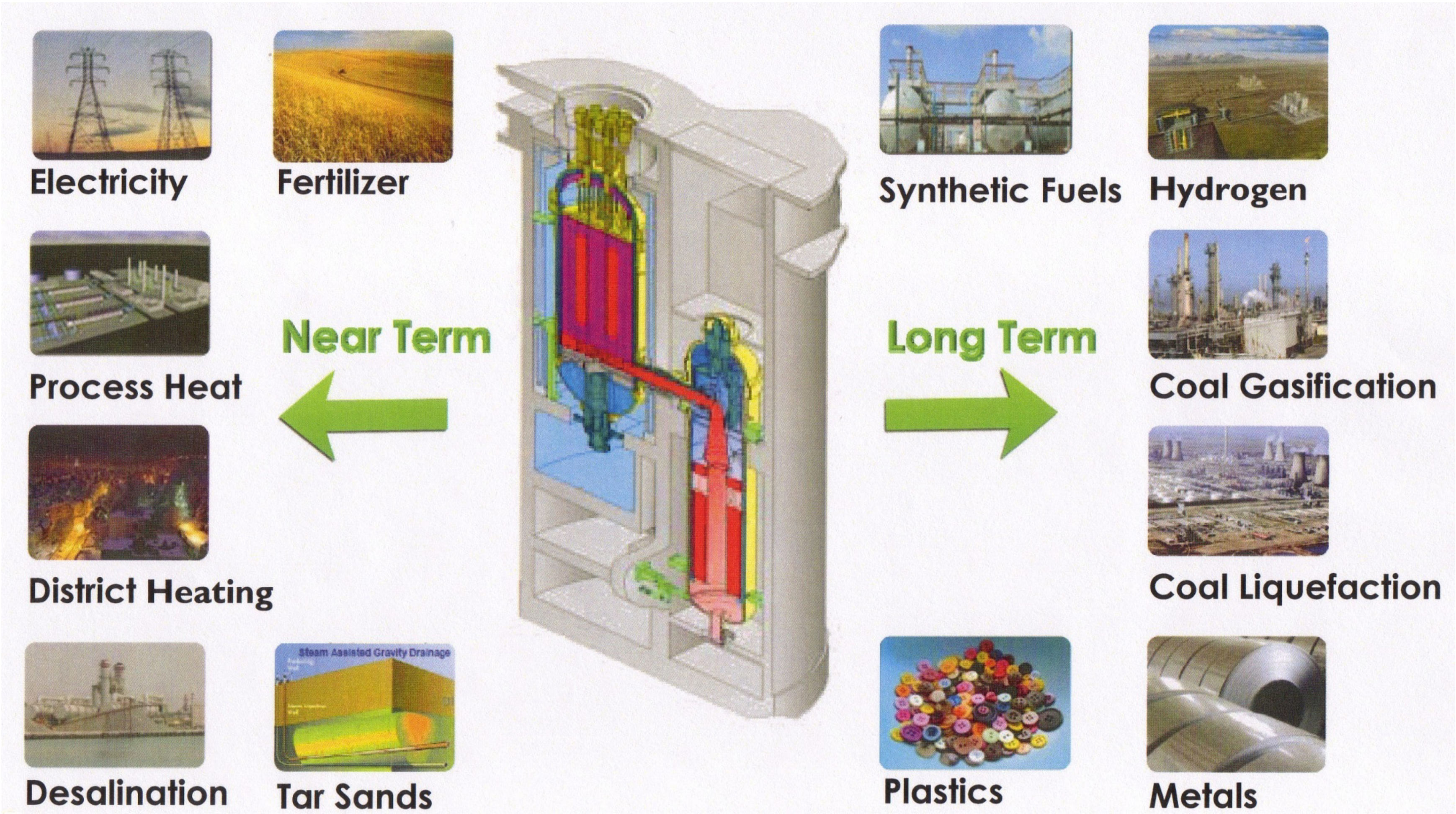
May 24 – 27, 2010

Module 5e
Thermal-Fluid Aspects of Process Heat Coupling

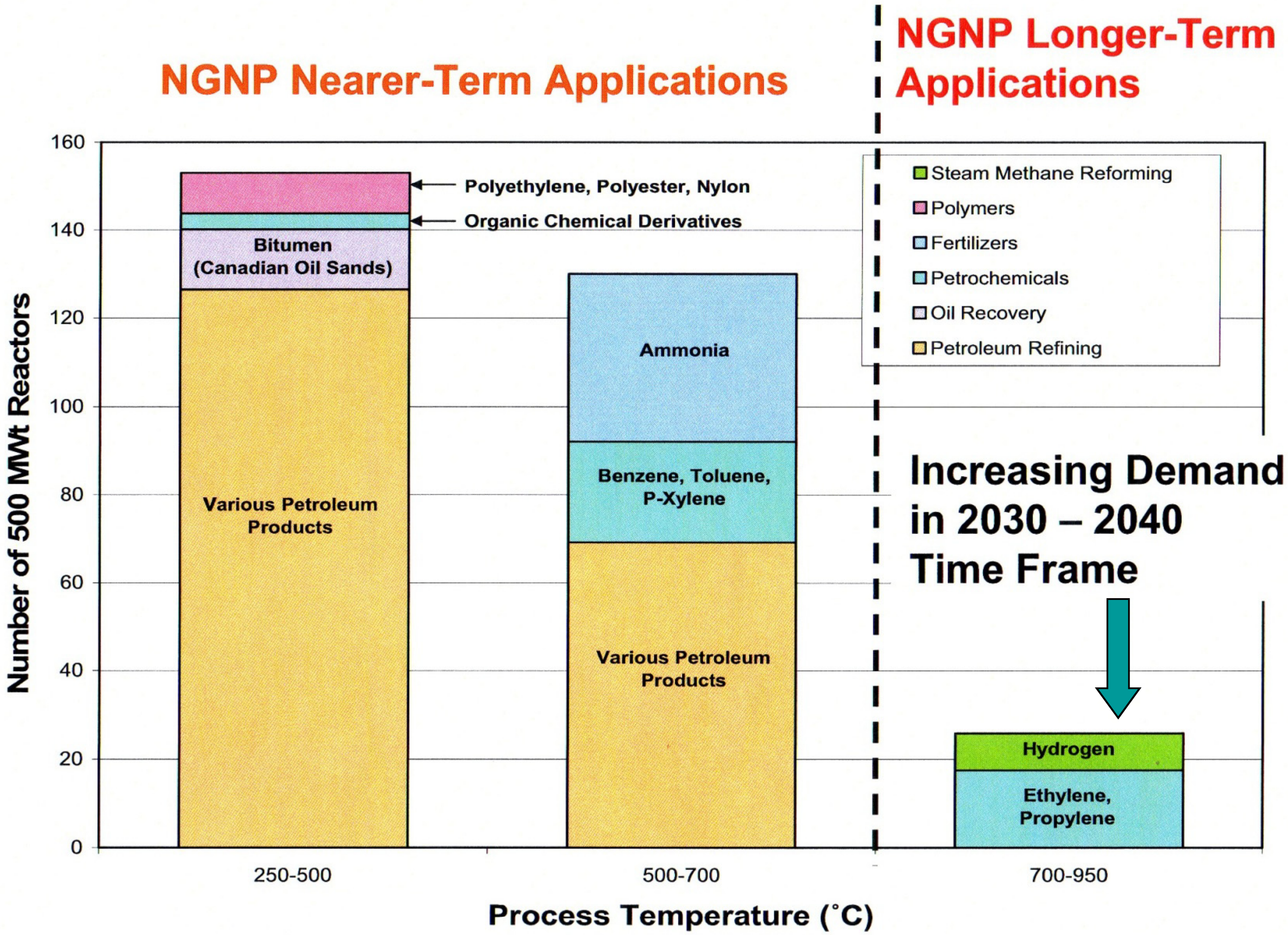
Outline

- Overview of process heat applications
- Selection of point design conditions
- Control / transient considerations
- Summary

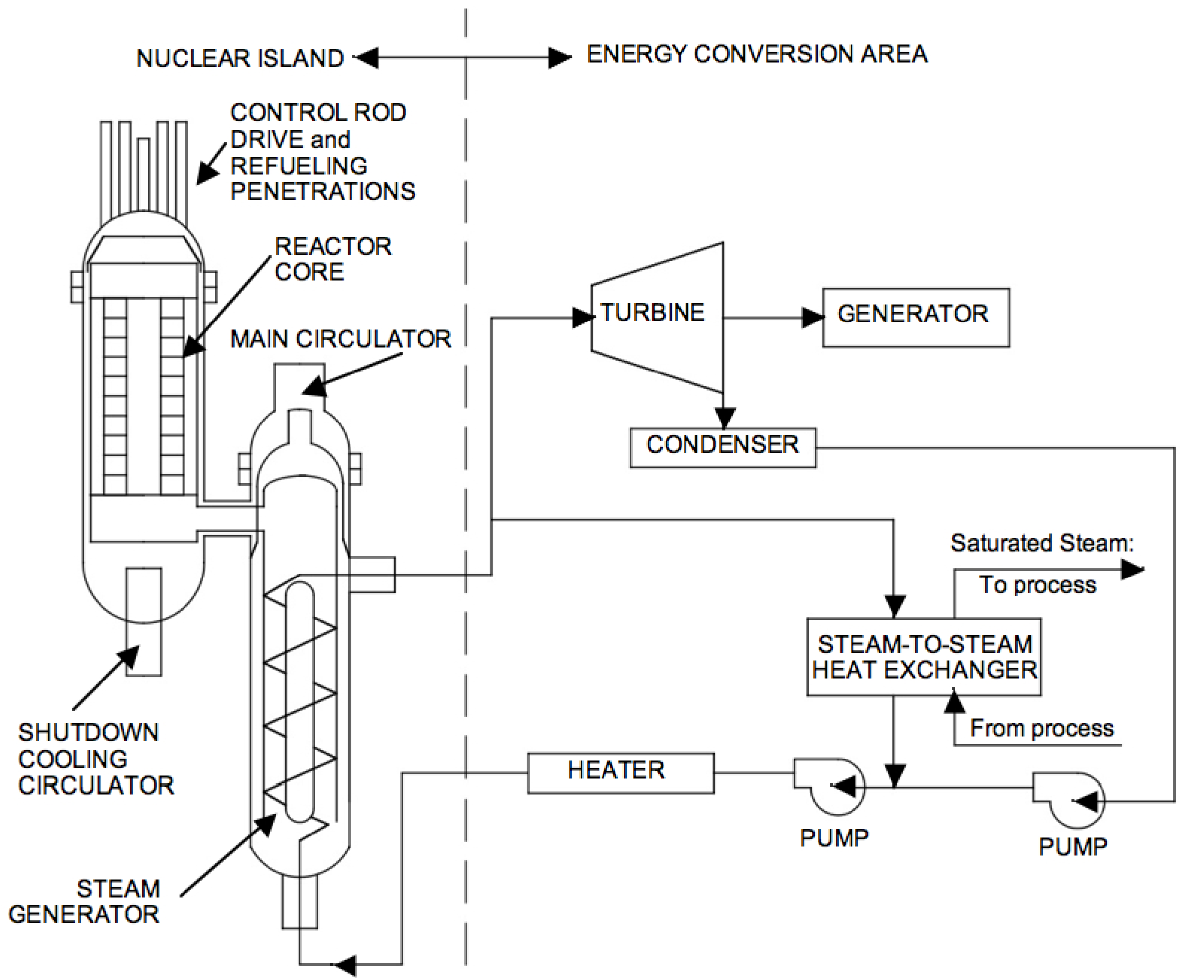
HTGRs Can Be Used for Production of a Wide Variety of Energy and Commercial Products



Number of 500 MW(t) HTGR Modules Required to Meet Non-Electric Demands



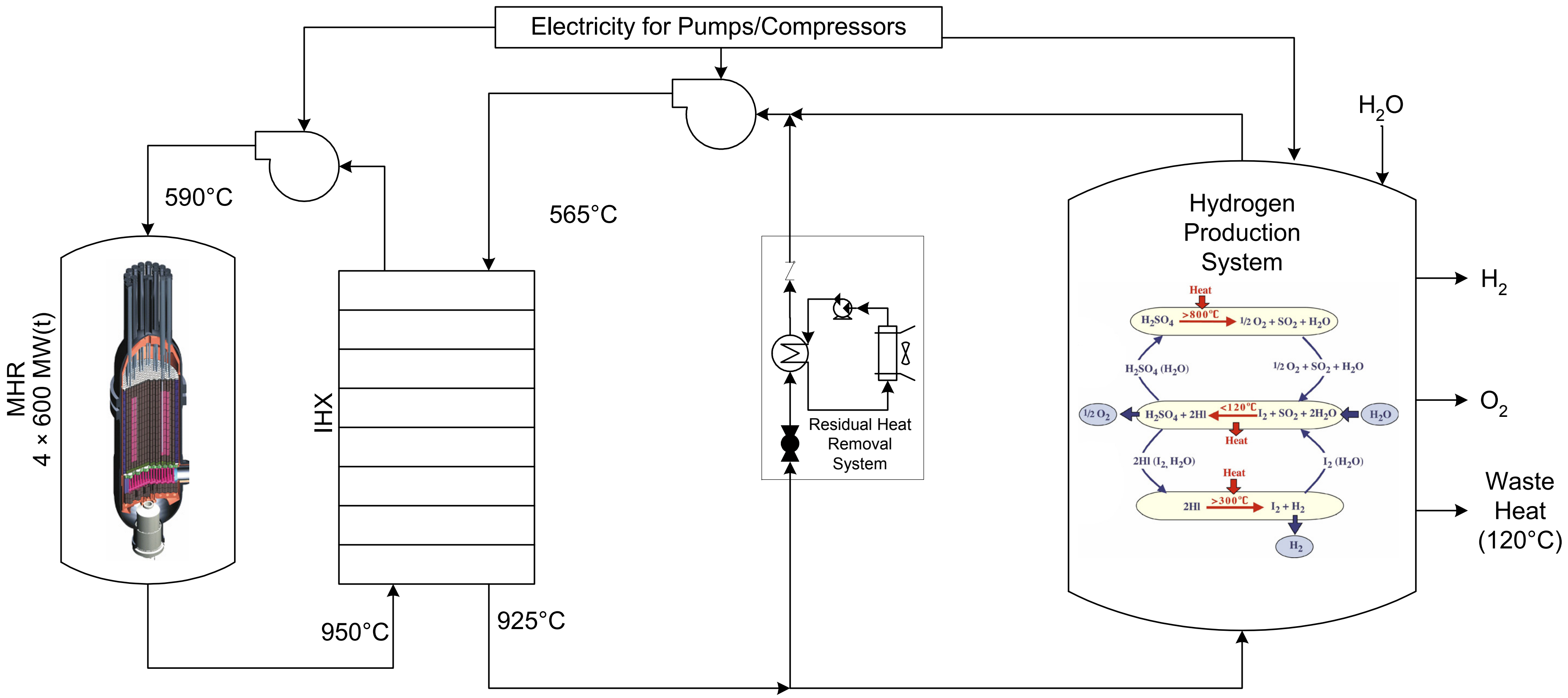
A First Step – the HTGR for Process Steam and Cogeneration



Applications

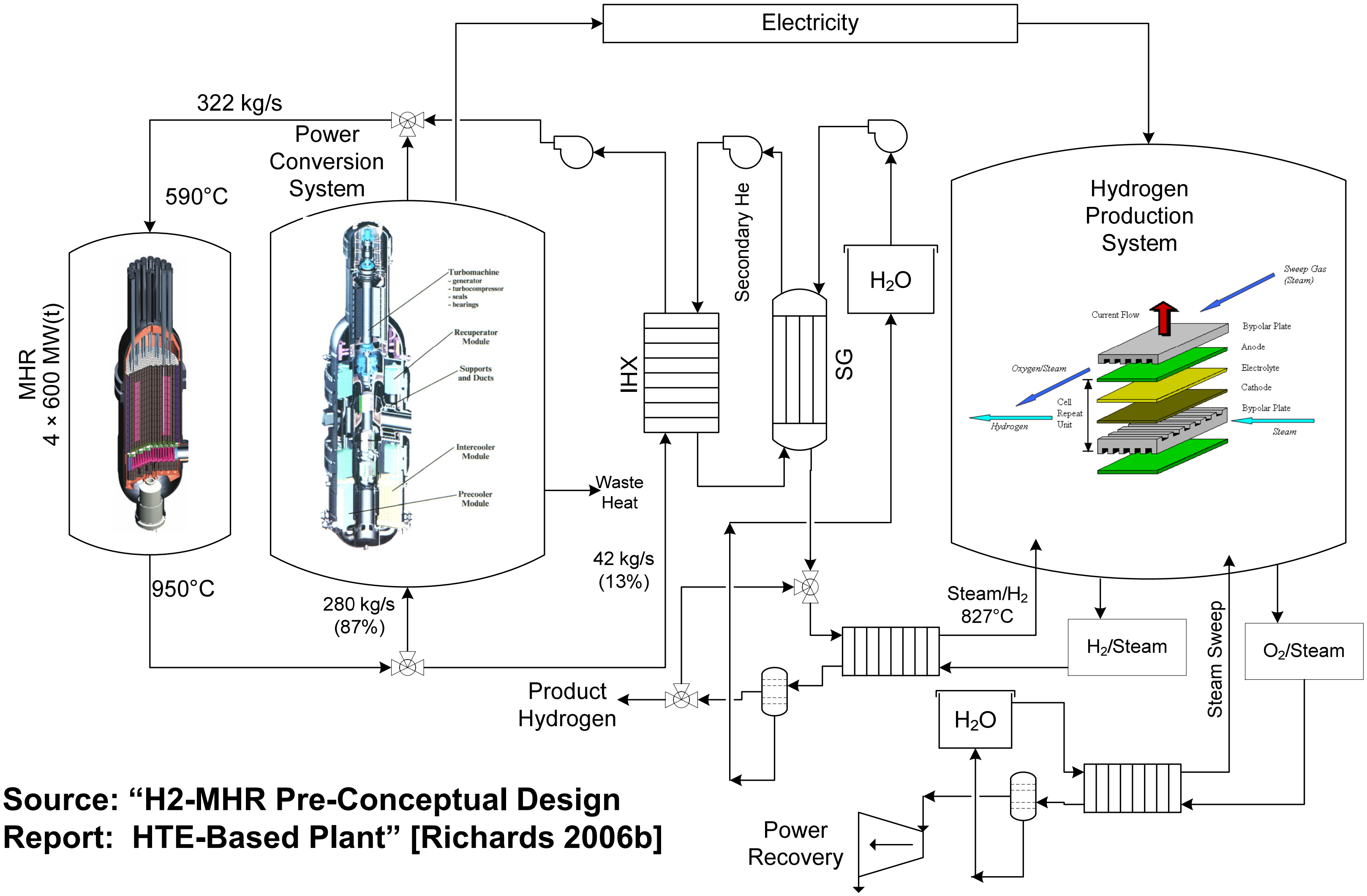
- Heavy oil recovery
- Oil from tar sands
- Industrial process steam
- Coal liquefaction
- Coal gasification

Multi-Module VHTR Plant for SI-Based Hydrogen Production



Source: "H2-MHR Pre-Conceptual Design Report: SI-Based Plant" [Richards 2006a]

Multi-Module VHTR Plant for HTSE-Based Hydrogen Production

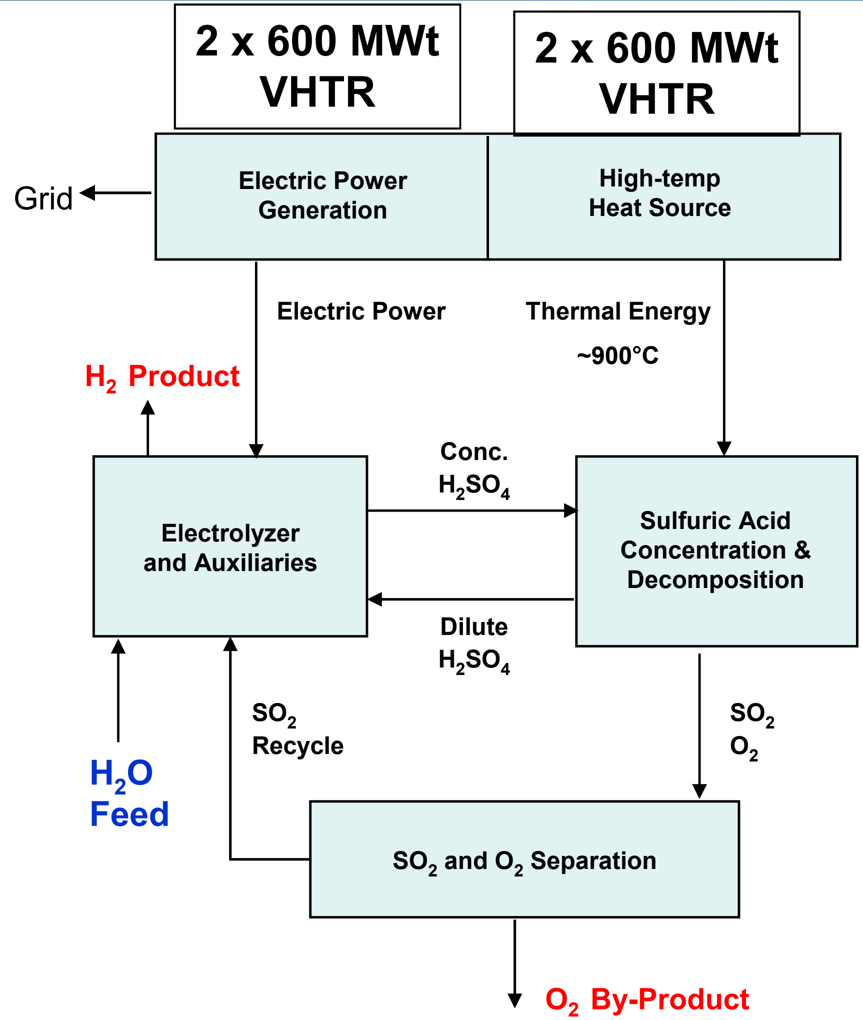


Source: "H2-MHR Pre-Conceptual Design Report: HTE-Based Plant" [Richards 2006b]

Multi-Module VHTR Plant for Hybrid-Sulfur-Based Hydrogen Production

- **Requires electric & thermal input**
- **VHTRs can supply high temperature (~900°C) heat source and electricity**
- **Thermochemical system has three main processing units**
  - SO_2-depolarized electrolyzers
  - Sulfuric Acid concentration and decomposition
  - SO_2/O_2 separation

Source: [Summers 2006]



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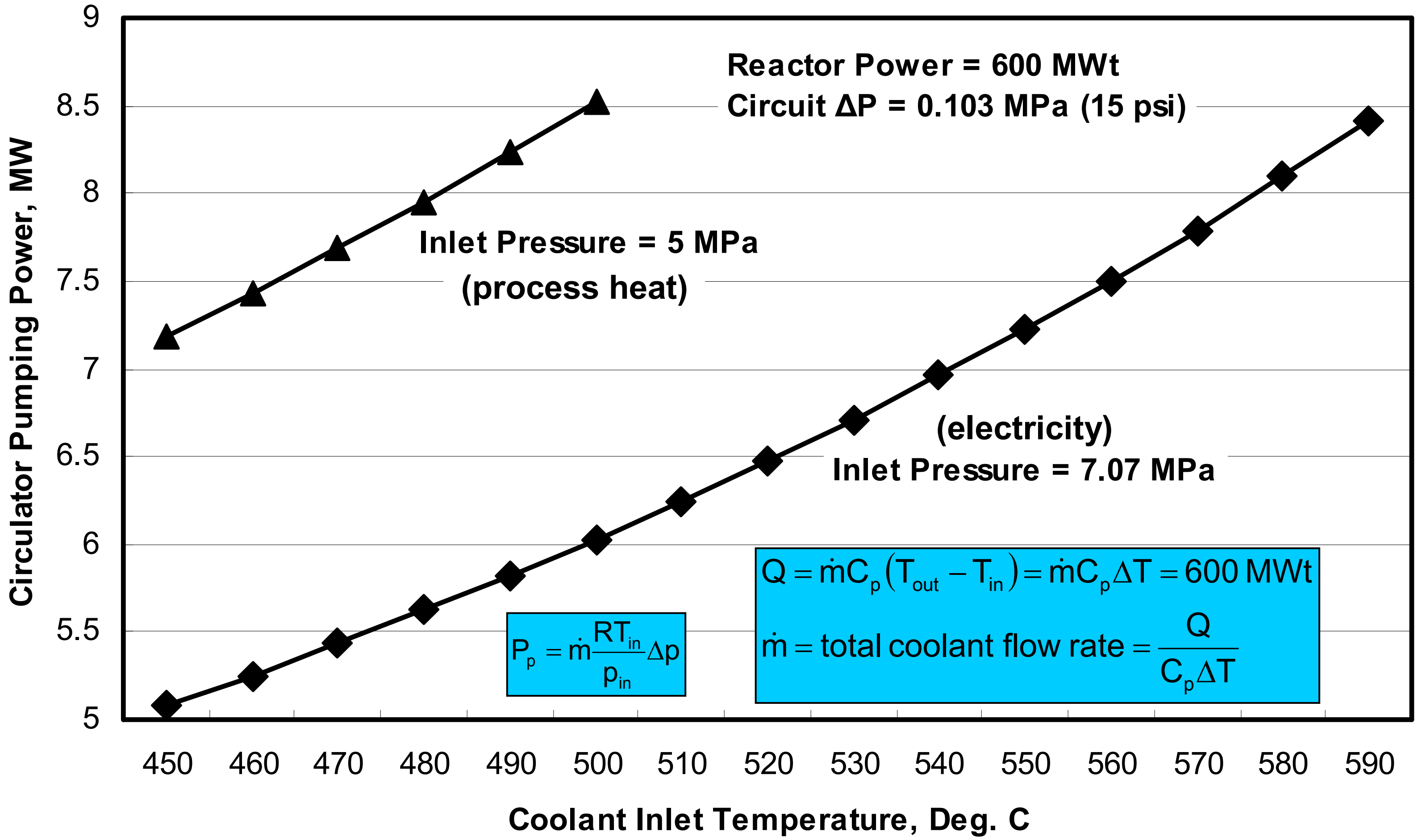
Selection of Point Design Conditions

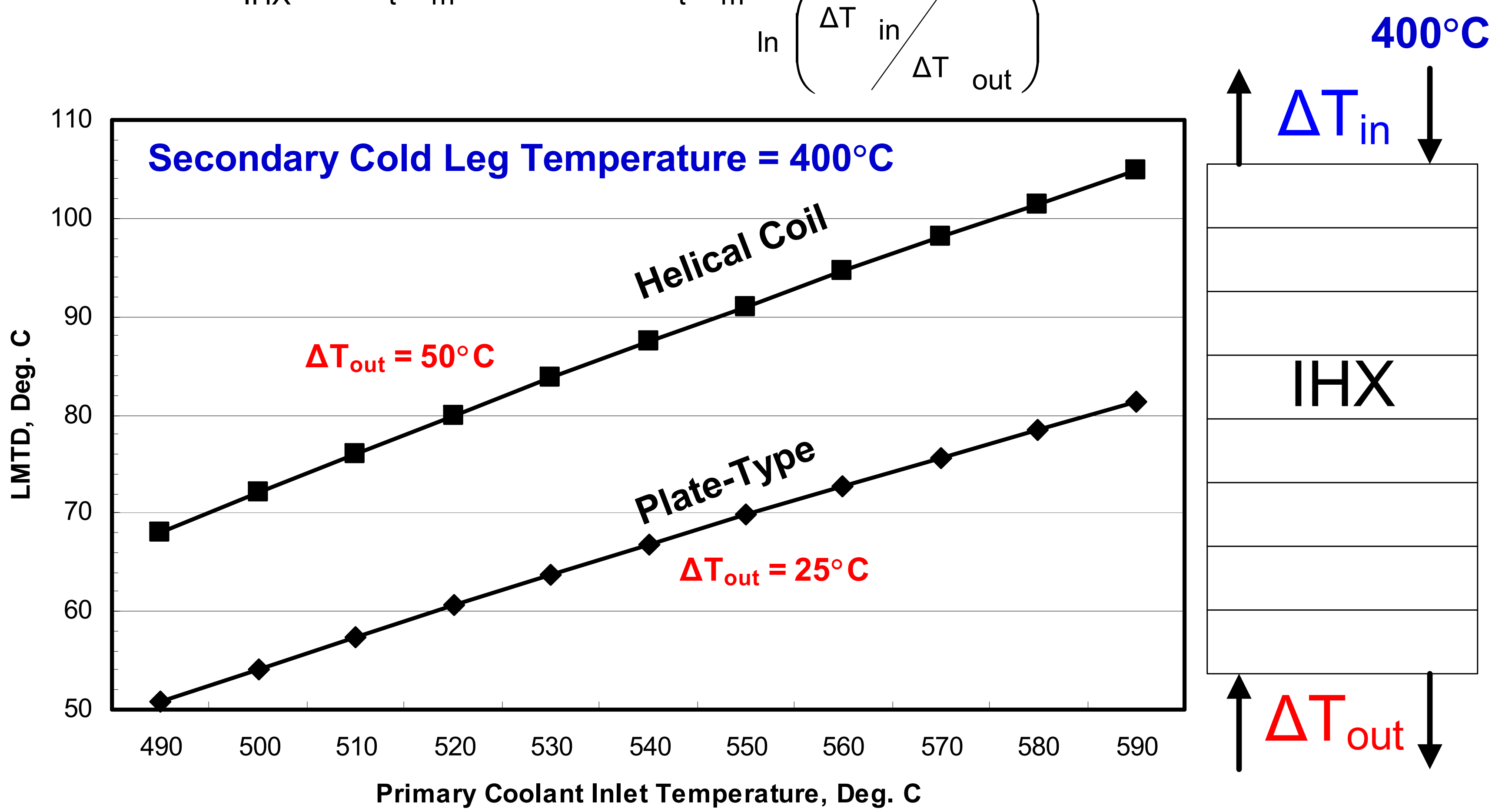
- **Coolant outlet temperature**
  - Must be sufficiently high to generate process heat/steam to drive the application of interest
  - Materials considerations for SG/IHX
  - Impact on IHX size (LMTD)
- **Coolant pressure**
  - Desirable to minimize ΔP across heat exchanger surfaces (HX stresses/lifetimes)
  - Impact on required pumping power
  - Impacts on efficiency/thermodynamics of the process heat application
- **Coolant inlet temperature**
  - Impact on required pumping power
  - Impact on IHX size (LMTD)
  - Impact on reactor vessel temperature

Effect of Pressure and Coolant Inlet Temperature on Circulator Pumping Power



Effect of Primary Coolant Inlet Temperature on IHX LMTD

$$Q_{IHX} = A_t U_m LMTD = A_t U_m \frac{\Delta T_{in} - \Delta T_{out}}{\ln\left(\Delta T_{in} / \Delta T_{out}\right)}$$



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Control / Transient Considerations

- **Flow sheet of the process application**
  - Efficient use of process heat (recuperation, etc.)
  - Stable control of heat and mass balances with respect to small disturbances in temperature of supplied heat [Kubo 2008]
- **Impact of chemical plant transients**
  - Should not affect safety of HTGR
  - Thermal absorber system (e.g. SG) in chemical plant can mitigate rapid fluctuations in HTGR helium temperatures during loss of heat load event events [Nishihara 2006], [Sato 2007]
    - Prevention of automatic scram of HTGR during loss of heat load events (impacts on overall plant availability)

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Summary

- The MHTGR can play an important role for near-term and long-term process heat applications
  - Industrial process steam
  - Oil from tar sands
  - Heavy oil recovery
  - Coal liquefaction
  - Coal gasification
  - Hydrogen production
- The impacts on point design conditions must be evaluated for coupling the HTGR to specific process heat applications
- The coupled plant design must ensure stable control of the process heat application
- The coupled plant design should have negligible impact on the safety case for the nuclear plant
- The chemical plant should be designed to minimize the impacts of loss of heat load events on operation of the nuclear plant

Suggested Reading

- [Shenoy 1995] A.S. Shenoy, "Modular Helium Reactor for Non-Electric Applications of Nuclear Energy," GA-A22701, General Atomics, San Diego, CA, November 1995
- [MPR 2008] 'Survey of HTGR Process Energy Applications, MPR-3181, Rev. 0, MPR Associates, Inc., Alexandria, VA, May 2008
- [Richards 2006a] M. Richards, et al., "H2-MHR Pre-Conceptual Design Report: SI-Based Plant," GA-A25401, General Atomics, San Diego, CA, April 2006
- [Richards 2006b] M. Richards, et al., "H2-MHR Pre-Conceptual Design Report: HTE-Based Plant," GA-A25402, General Atomics, San Diego, CA, April 2006
- [Nishihara 2006] T. Nishihara and Y. Inagaki, "Development of Control Technology for the HTTR Hydrogen Production System," Nuclear Technology, Vol. 153, pp. 100-106, January 2006
- [Summers 2006] W. Summers and M. Gorensek, "Nuclear Hydrogen Production Based on the Hybrid Sulfur Thermochemical Process, "proceedings of ICAPP '06, Reno, NV, June 4-8, 2006, paper 6107
- [Sato 2007] H. Sato, et al., "Conceptual Design of the HTTR-IS Hydrogen Production System – Assumed Abnormal Accidents Caused by the IS Process," Proceedings of the 15th International Conference on Nuclear Engineering, Nagoya, Japan, April 22-26, 207, paper ICONE15-10150
- [Kubo 2008] S. Kubo, et al., "A Simulation for Closed Cycle and Continuous Hydrogen production by a Thermo-Chemical Water-Splitting IS Process," Proceedings of the 16th Pacific Basin Nuclear Conference, Aomori, Japan, October 13-18, 2008, paper P16P1391