Hydrogen Futures, Nuclear Energy, and Separations

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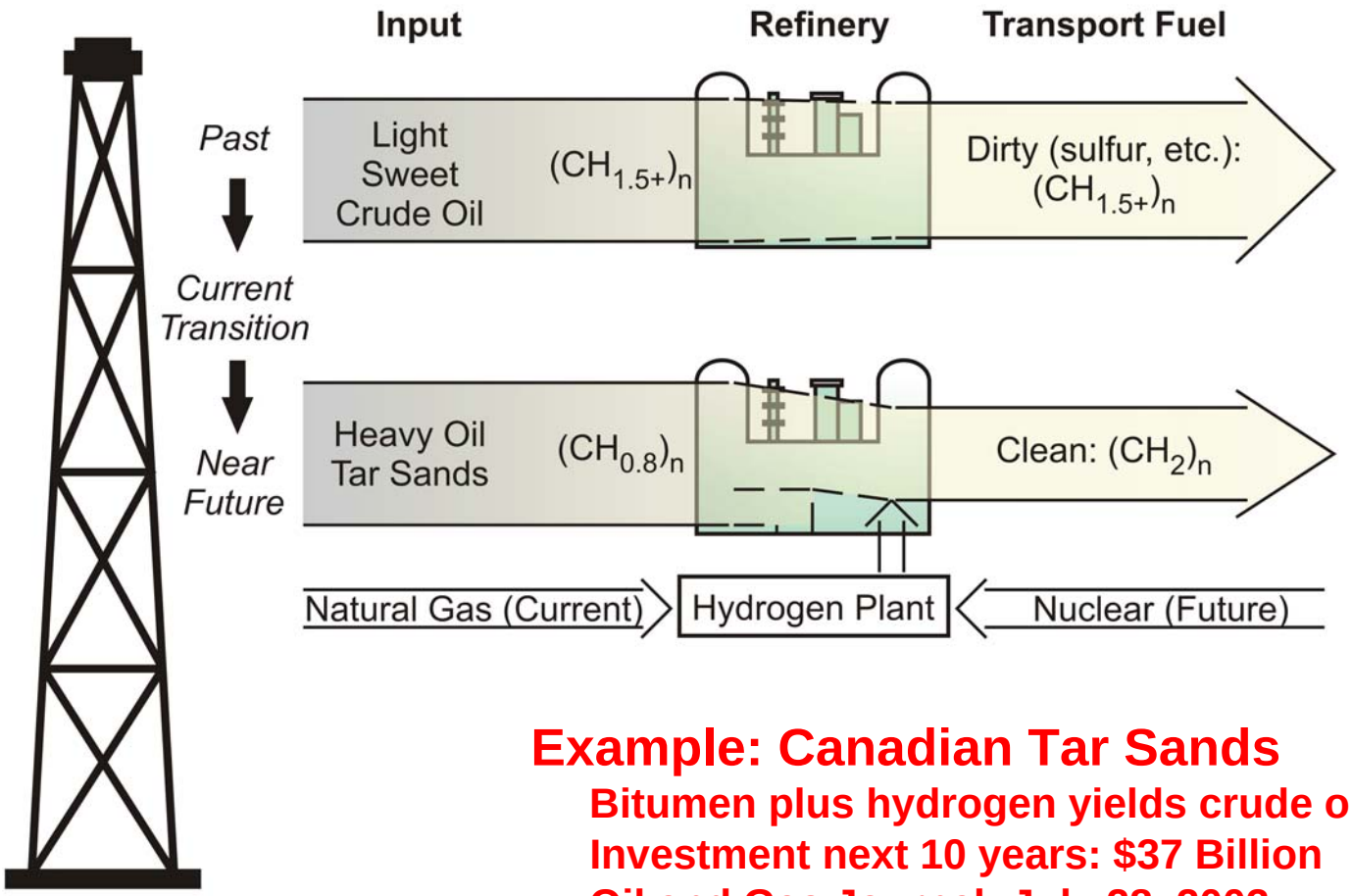
Hydrogen Futures

Currently Under Construction

Massive Quantities of Hydrogen Are Used Today

Worldwide Production: 50 Million Tons/Year



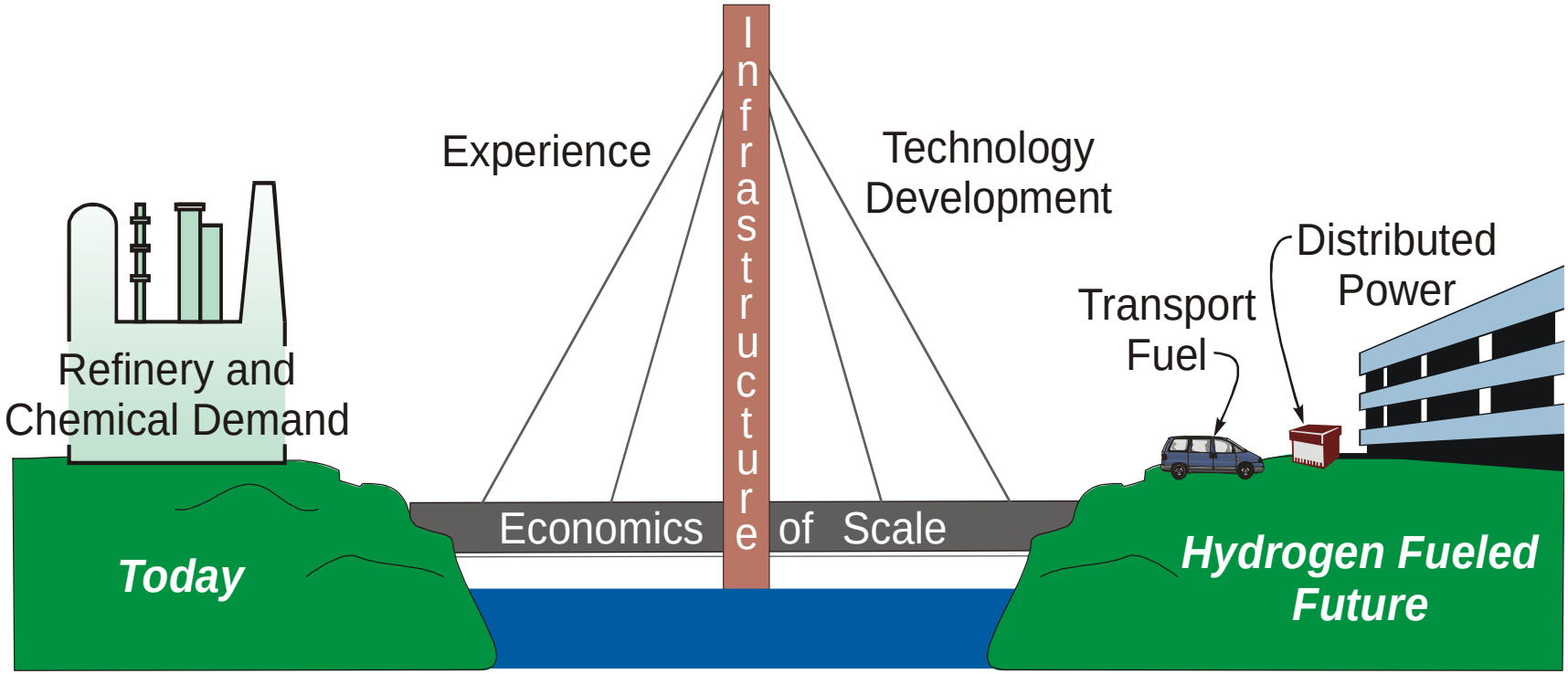
Example: Canadian Tar Sands

- **Bitumen plus hydrogen yields crude oil**
- **Investment next 10 years: $37 Billion**
- **Oil and Gas Journal: July 28, 2003**

Syncrude Canada Ltd.
Tar Sands Operations

(Tar Sands Exceed World's Conventional Oil Resources)

Growing H_2 Demand Creates a Bridge to the H_2 Economy



Nuclear Energy

Matches Requirements

No Greenhouse Gases

Nuclear Reactor Sizes Match H_2 Production

(Hydrogen Currently Made By Steam Reforming Natural Gas)

Hydrogen Plant Size

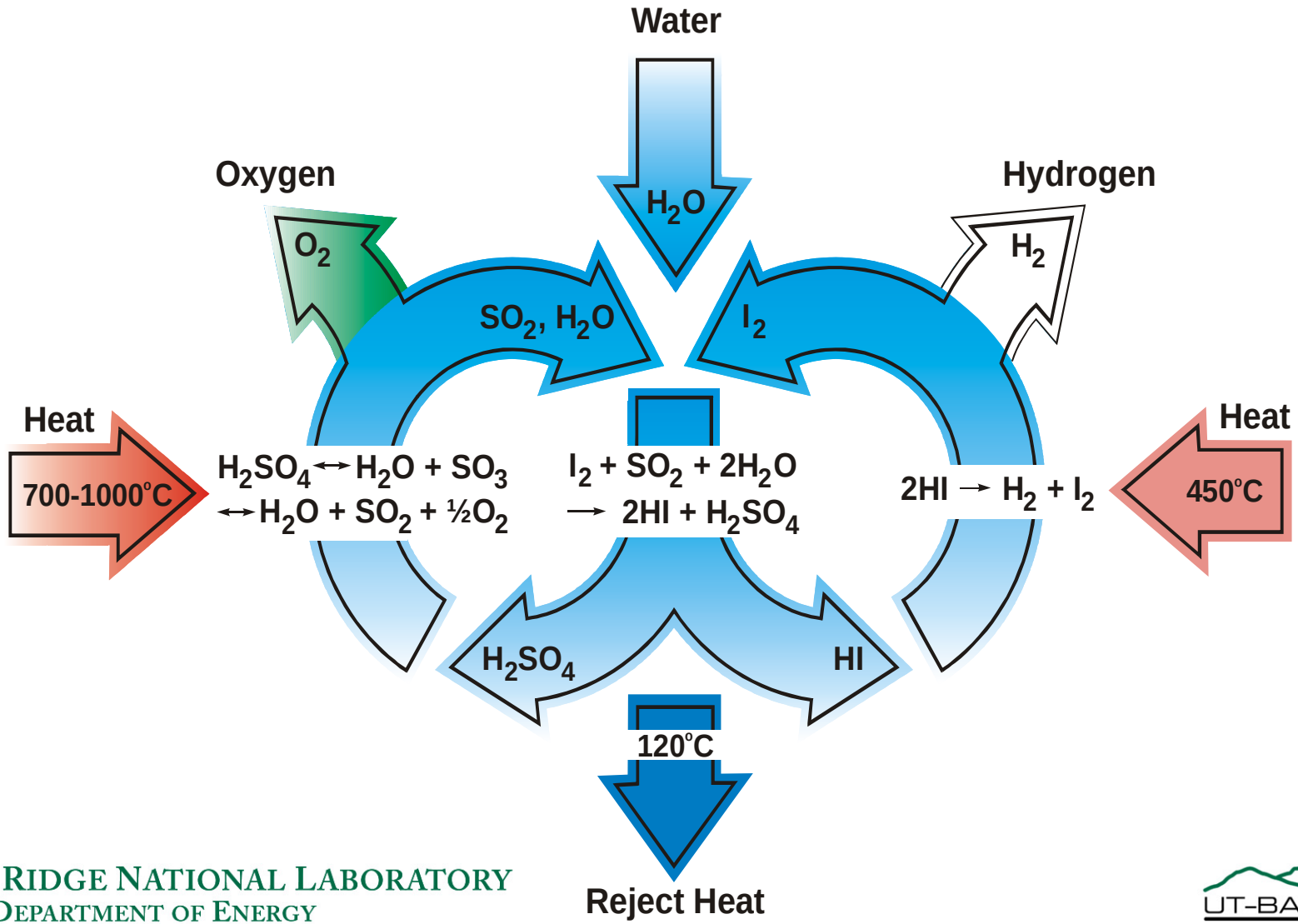
H_2 Plants	Energy to Produce H_2 (50% Efficient)
5.7×10^6 m^3/d (Existing)	1600 MW(t)
8.0×10^6 m^3/d (Future)	2400 MW(t)

Time

Nuclear Reactor

2000–4000 MW(t)

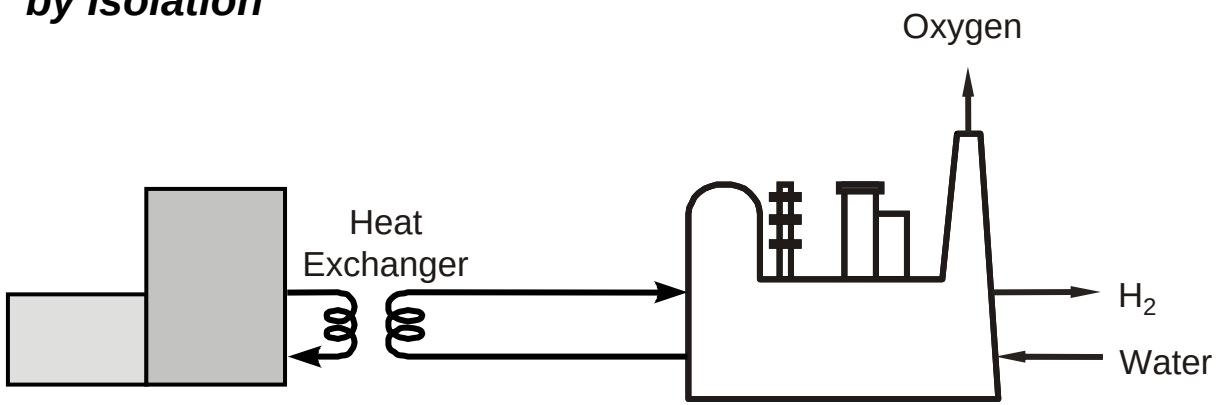
Thermochemical Processes Use Nuclear High-Temperature Heat and Water to Produce H_2



Thermochemical Hydrogen Facilities May Require Physical Separation From the Nuclear Reactor

Nuclear Safety by Isolation

Hydrogen Safety by Dilution



Loop Heat Transfer Comparison [50 MW(t)]

Characteristic	Salt	Helium
Pressure (bar)	1	70
Velocity (m/s)	4	40
Temperature Drop (°C)	200	200
Pipe Diameter (m)	0.25	1.2
Relative Pumping Power	1	45

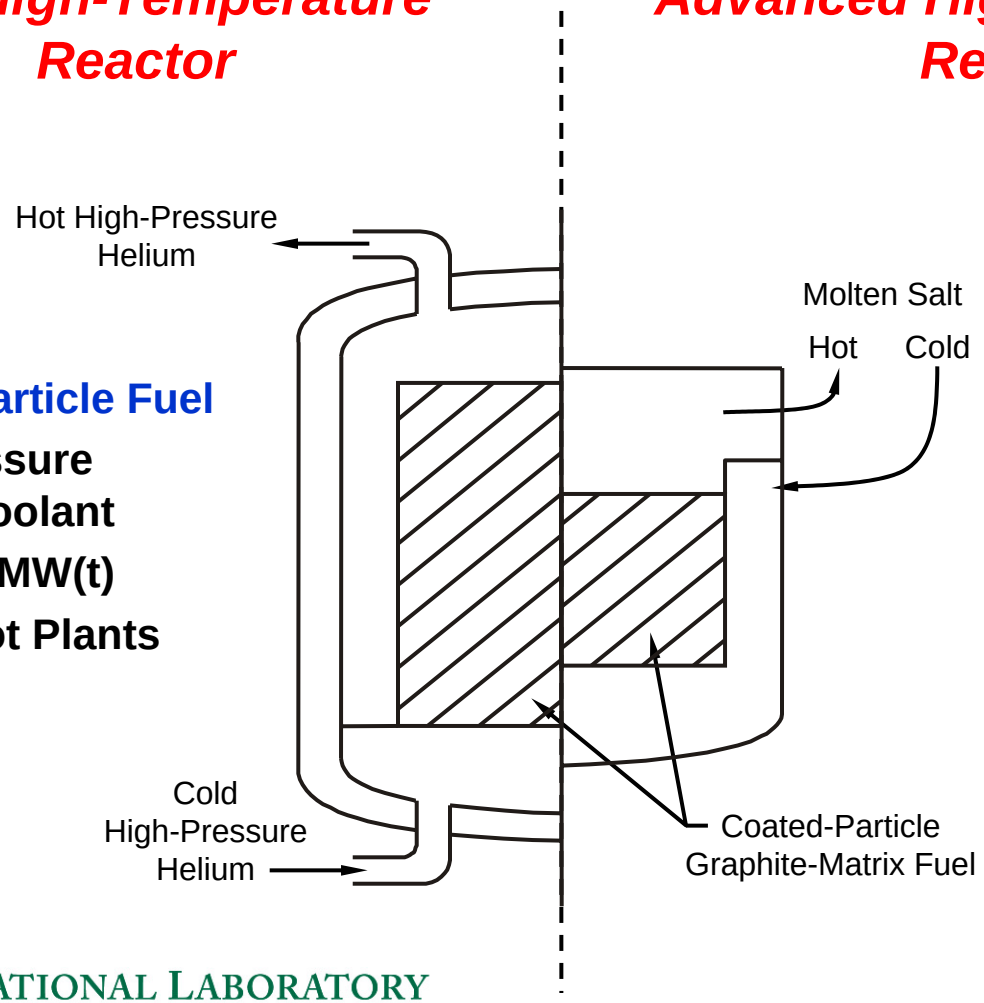
Two Nuclear Reactor Options Can Produce the Required High-Temperature Heat

Very-High-Temperature Reactor

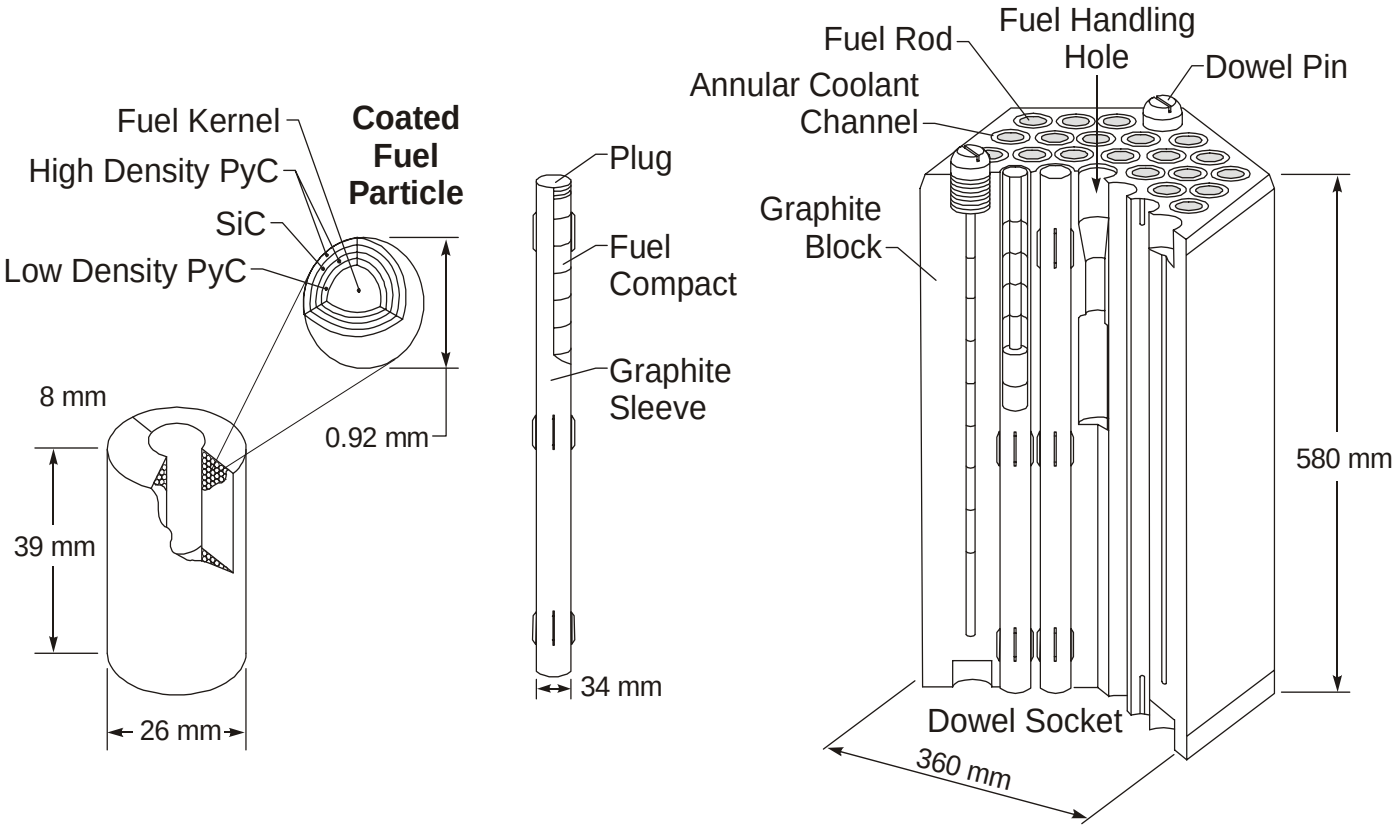
- **Coated-Particle Fuel**
- **High-Pressure Helium Coolant**
- **Size: 600 MW(t)**
- **Small Pilot Plants**

Advanced High-Temperature Reactor

- **Coated-Particle Fuel**
- **Atmospheric-Pressure Molten Salt Coolant**
- **Size: To 2400 MW(t)**
- **New Concept**

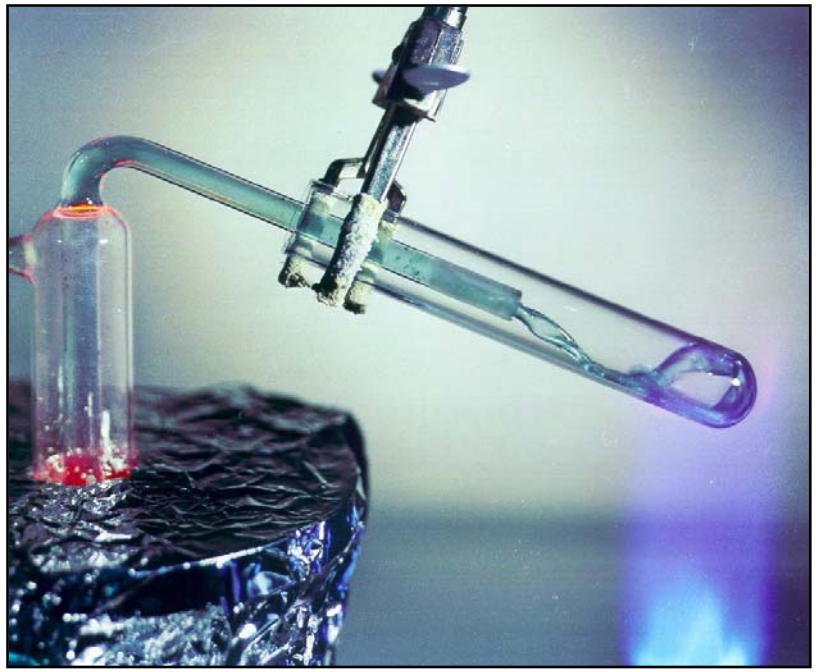


Reactor Options Limited by Fuel: Only One Type of Demonstrated High-Temperature Fuel



Fuel Compact **Fuel Rod** **Fuel Block**

Only Two Coolants Are Compatible With High-Temperature Fuel



Helium

Molten Fluoride Salts

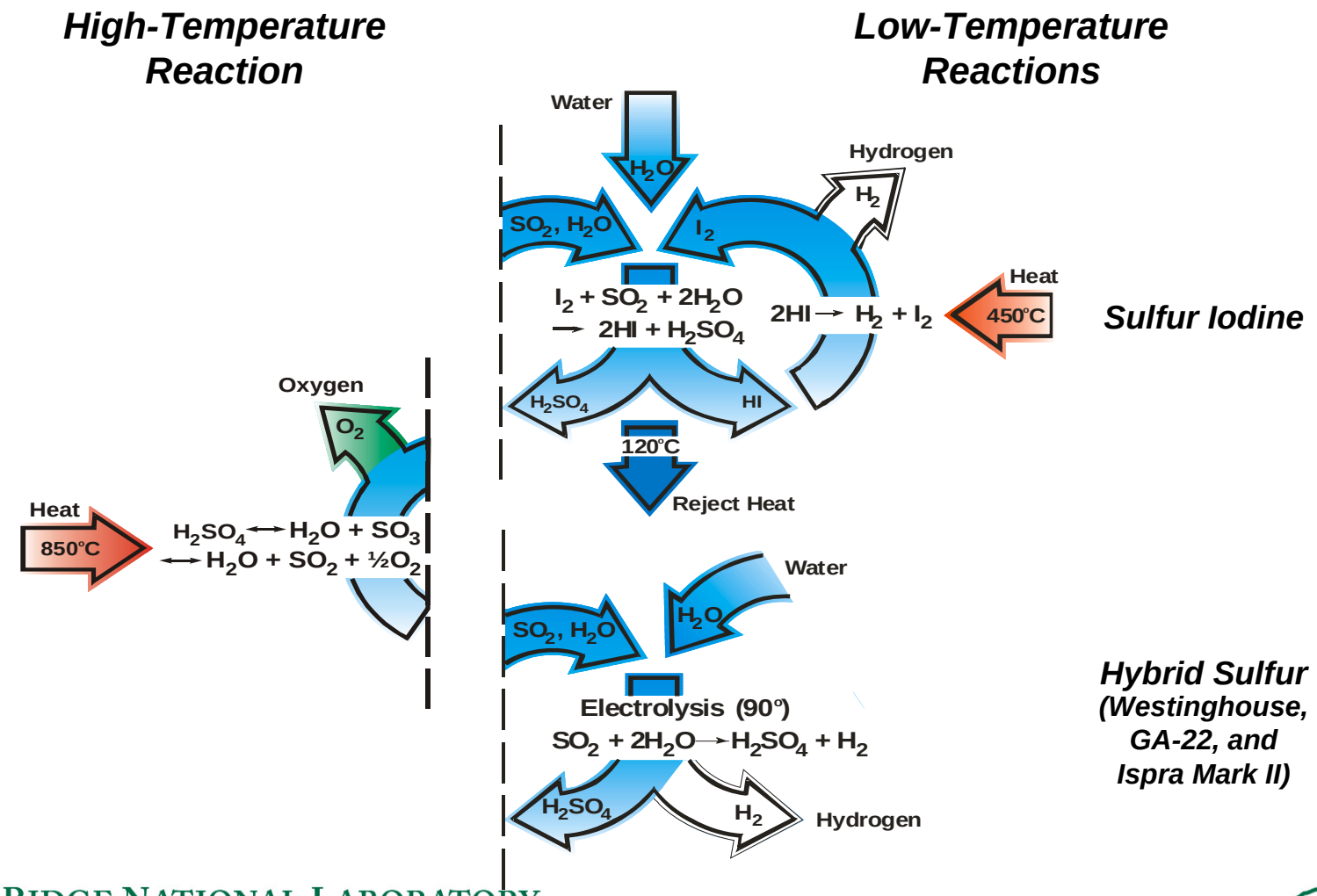
Separations

(Thermochemical Cycles In A Few Decades May Contain The Largest Separations Processes)

Improved Separations Can Greatly Improve Thermochemical Cycles

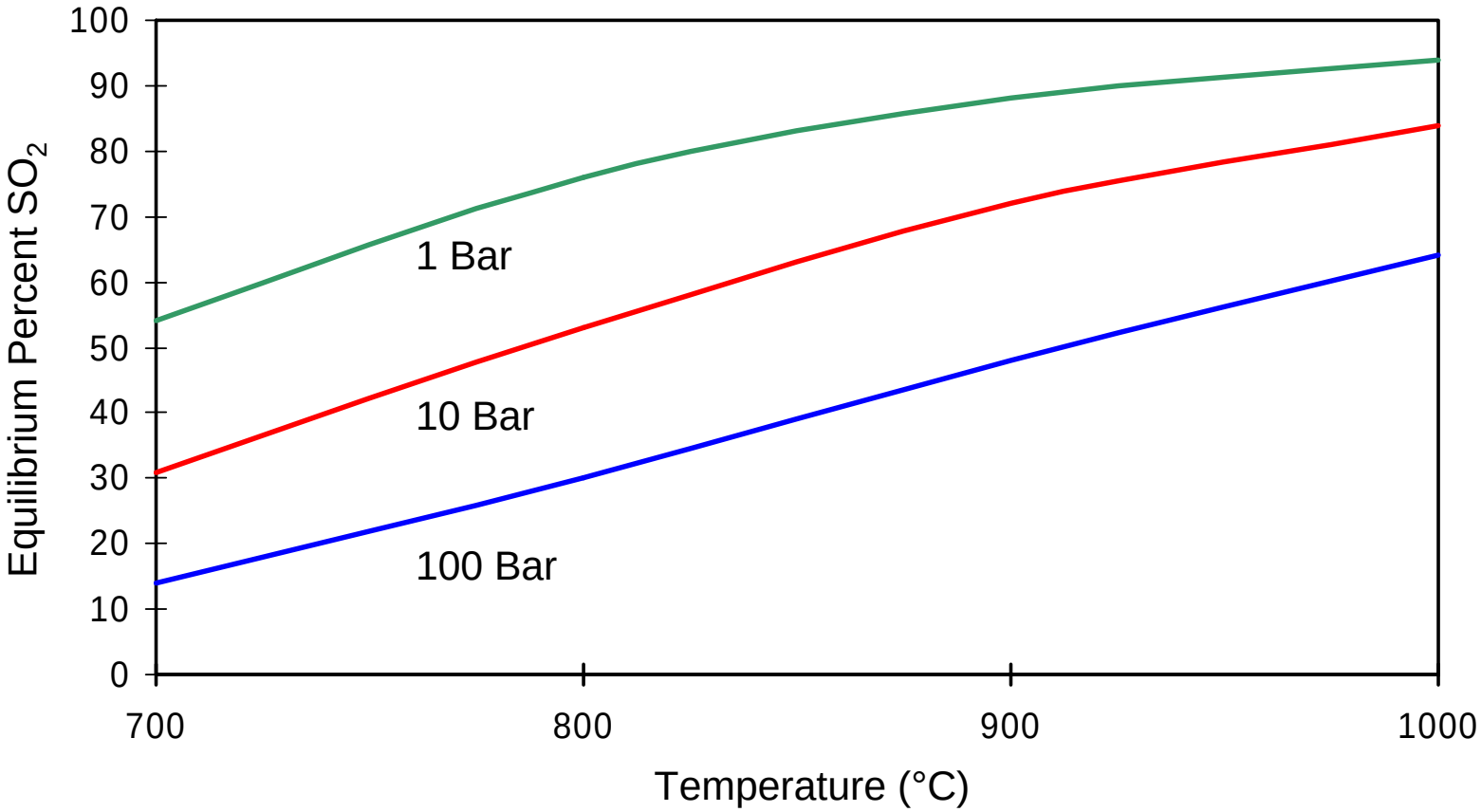
Example: Sulfur Cycles

A Major Challenge With Sulfur Thermochemical Cycles Is The High-Temperature Sulfuric Acid Decomposition Step



Driving The High-Temperature Reaction To Completion Requires High Very Temperatures

$$(H_2SO_4 \Leftrightarrow SO_3 + H_2O \Leftrightarrow SO_2 + H_2O + 1/2\ O_2)$$



One Solution Uses Separations

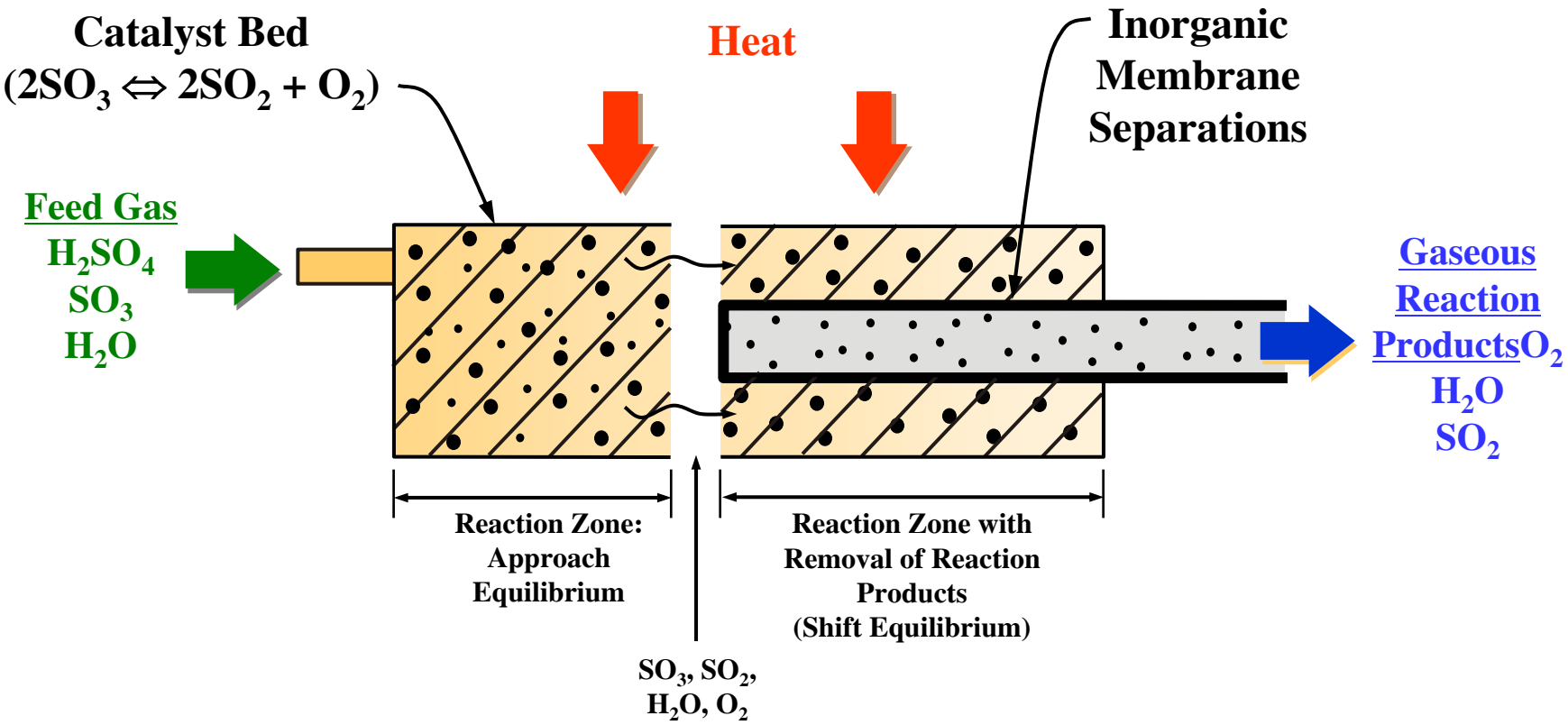
- **Push equilibrium high-temperature reaction to completion by removing reaction products**

$$H_2SO_4 \Leftrightarrow SO_3 + H_2O \Leftrightarrow SO_2 + H_2O + 1/2\ O_2$$

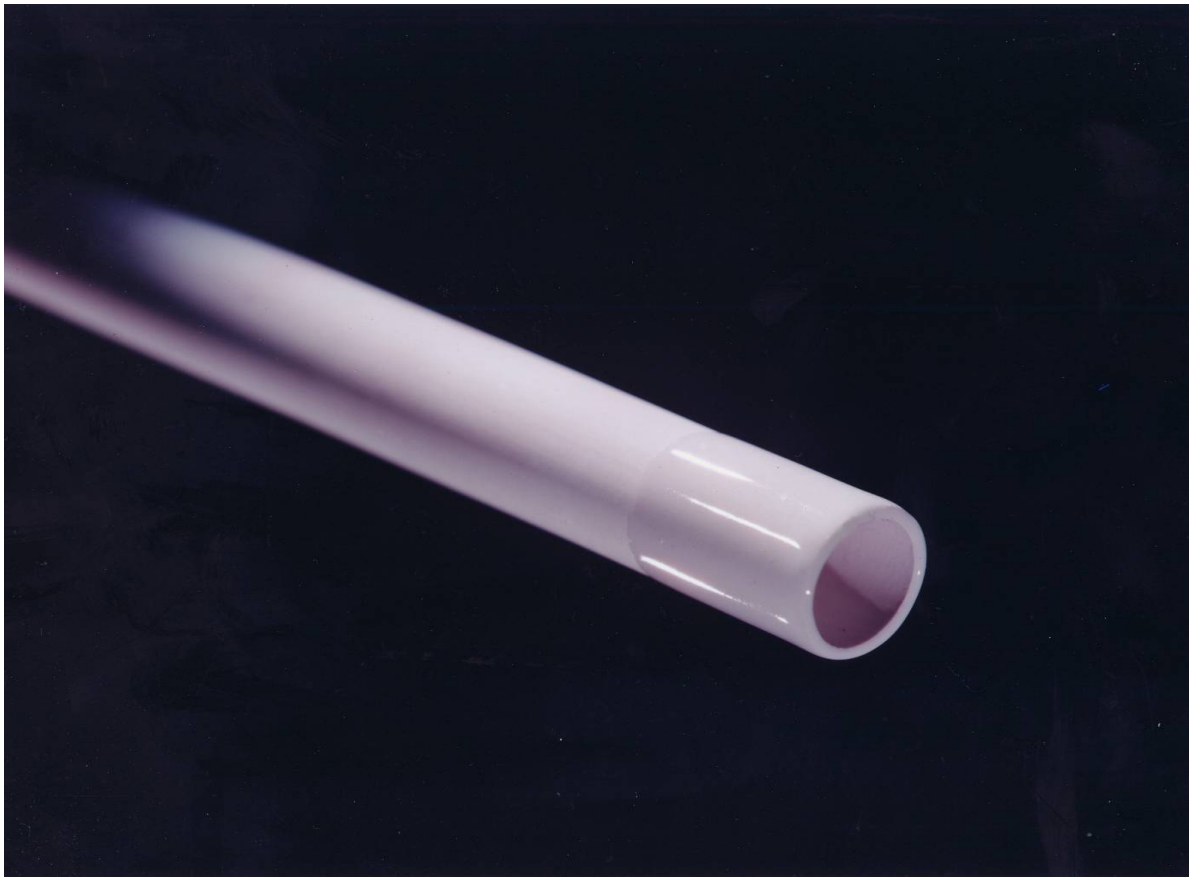
- **Membrane separation of O_2, H_2O, and SO_2 from SO_3 drives reaction to the right allowing high conversion at lower reaction temperatures**

Potential to reduce peak temperature to between 650 and 750°C

Conceptual System For Idealized Sulfur Thermochemical Inorganic Membrane Chemical Reactor



Inorganic Membranes For Thermochemical Sulfur Cycles



Conclusions

- **The hydrogen economy is coming**
  - **It is under construction at your local refinery**
  - **It will expand out with time**
- **Nuclear energy is a major hydrogen generation option**
- **Separations is a critical issue for all hydrogen production technologies**