Advanced High-Temperature Reactor for Hydrogen and Electricity Production

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UT-BATTELLE

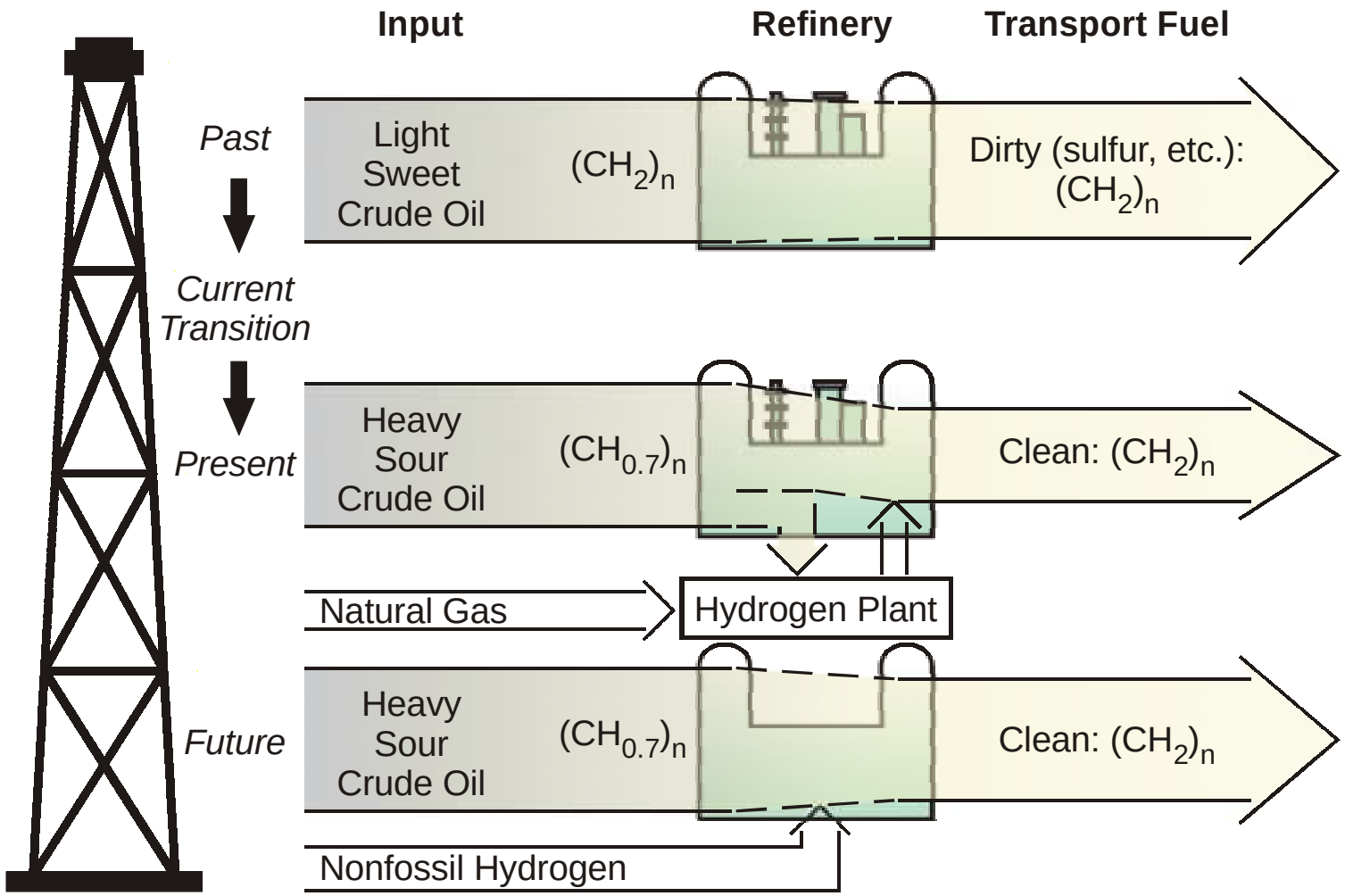
Outline

- **Why is a nuclear reactor needed to produce high-temperature heat?**
  - **Hydrogen**
  - **Electricity**
- **What is an Advanced High-Temperature Reactor (AHTR) ?**
- **What is the path forward?**

Rapid Growth Is Expected in Industrial Hydrogen (H_2) Demand

- **Growing H_2 demand**
  - **Production uses 5% of U.S. natural gas plus refinery by-products**
  - **If nuclear energy were used to meet the H_2 demand in 2010, the nuclear fleet for H_2 production would exceed the current use**
- **Changing refinery conditions are driving the H_2 demand**
  - **More heavy crude oils (limited supplies of high-quality crude)**
  - **Demand for clean fuels (low sulfur, low nitrogen, non-toxic fuels)**
  - **Changing product demand (less heating oil and more gasoline)**
- **If nonfossil sources of hydrogen are used, lower-value refinery streams can be used to make gasoline rather than hydrogen—reduced oil imports**
- **Development of nonfossil hydrogen sources lays the groundwork for the hydrogen economy**

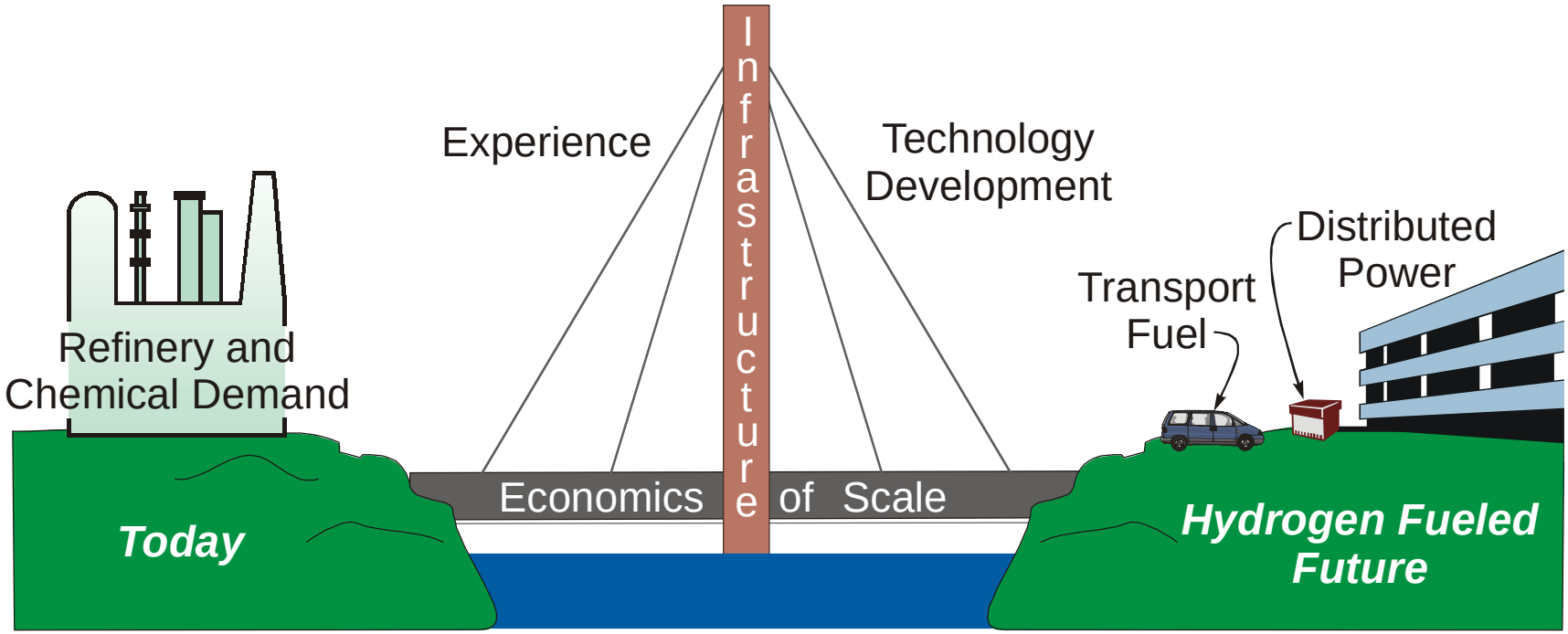
Increased Use of More-Abundant Heavy Crude Oils Reduces Refinery Yields, Unless Nonfossil Hydrogen Is Used



Multiple Benefits with Nonfossil Economical Sources of Hydrogen

- **Increased transport fuel yields per barrel**
  - **Lower-value oil components converted to transport fuel rather than to hydrogen**
  - **Reduced import of crude oil and natural gas**
- **Greater use of heavy crude oils**
  - **More abundant with lower costs**
  - **Western Hemisphere suppliers (Venezuela Canada, and the United States)**
- **Lower carbon dioxide emissions**

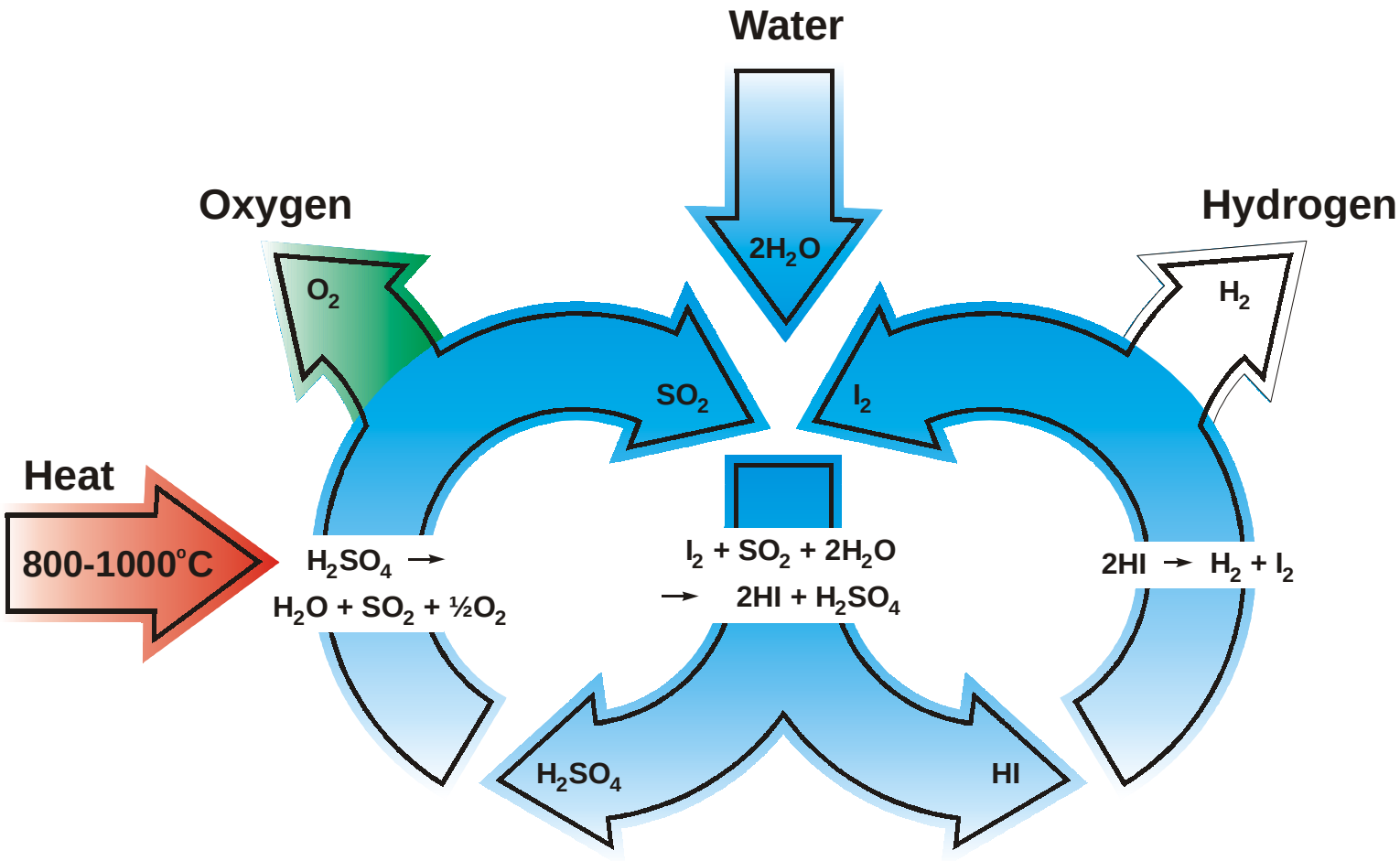
The Growing Industrial Demand for Hydrogen Creates a Bridge to the Hydrogen Economy



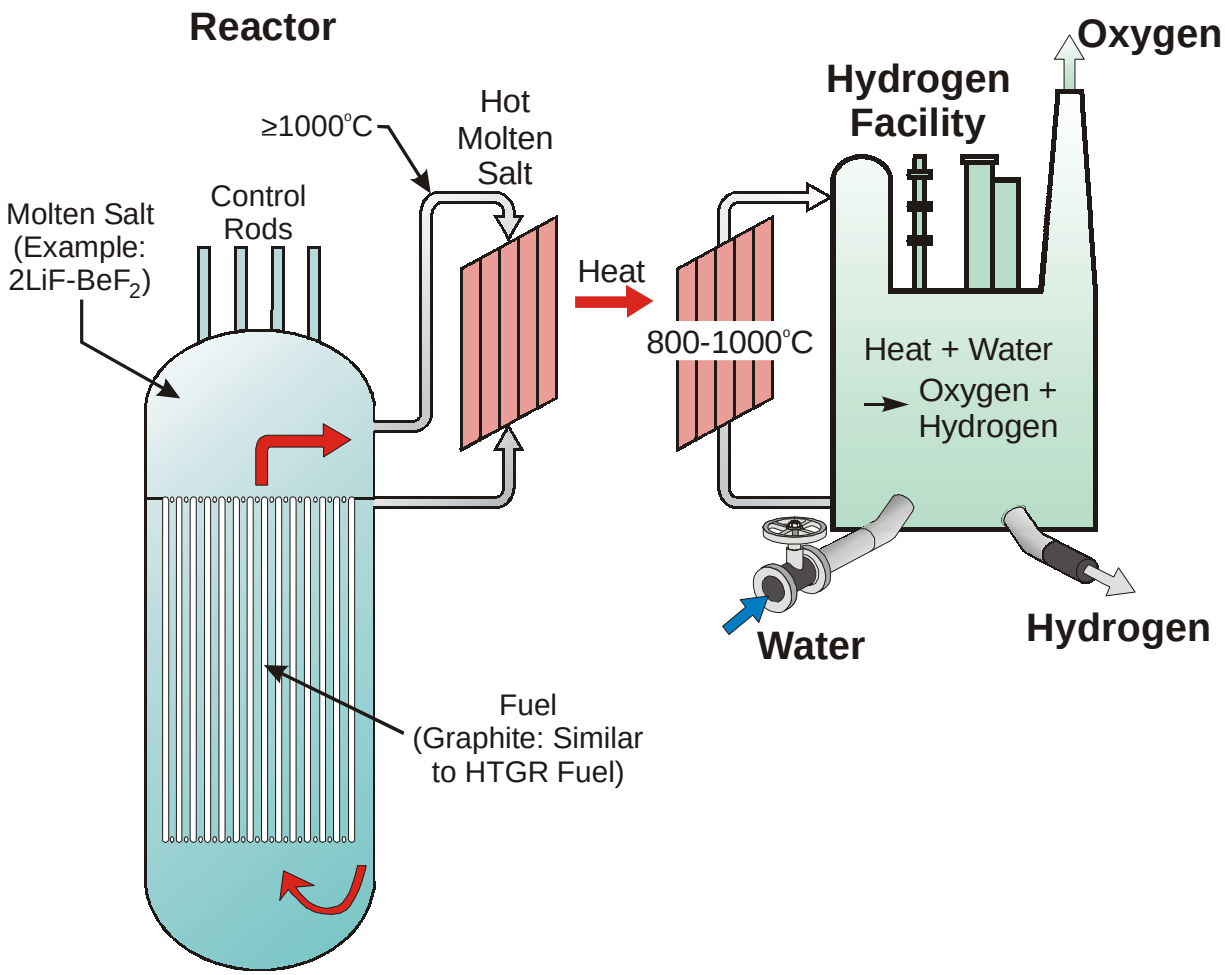
Hydrogen Can Be Produced with Heat from a Nuclear Reactor

- **Heat + water ⩾ hydrogen (H_2) + oxygen (O_2)**
- **Uranium fuel costs are lower than those of natural gas**
- **Characteristics of hydrogen from water**
  - **Projected efficiencies of >50%**
  - **High-temperature heat is required: 800 to 1000ºC**
  - **Existing commercial reactors can not produce heat at these high temperatures**
  - **An alternative reactor concept is required**

Chemical Processes Convert High-Temperature Heat and Water to Hydrogen and Oxygen



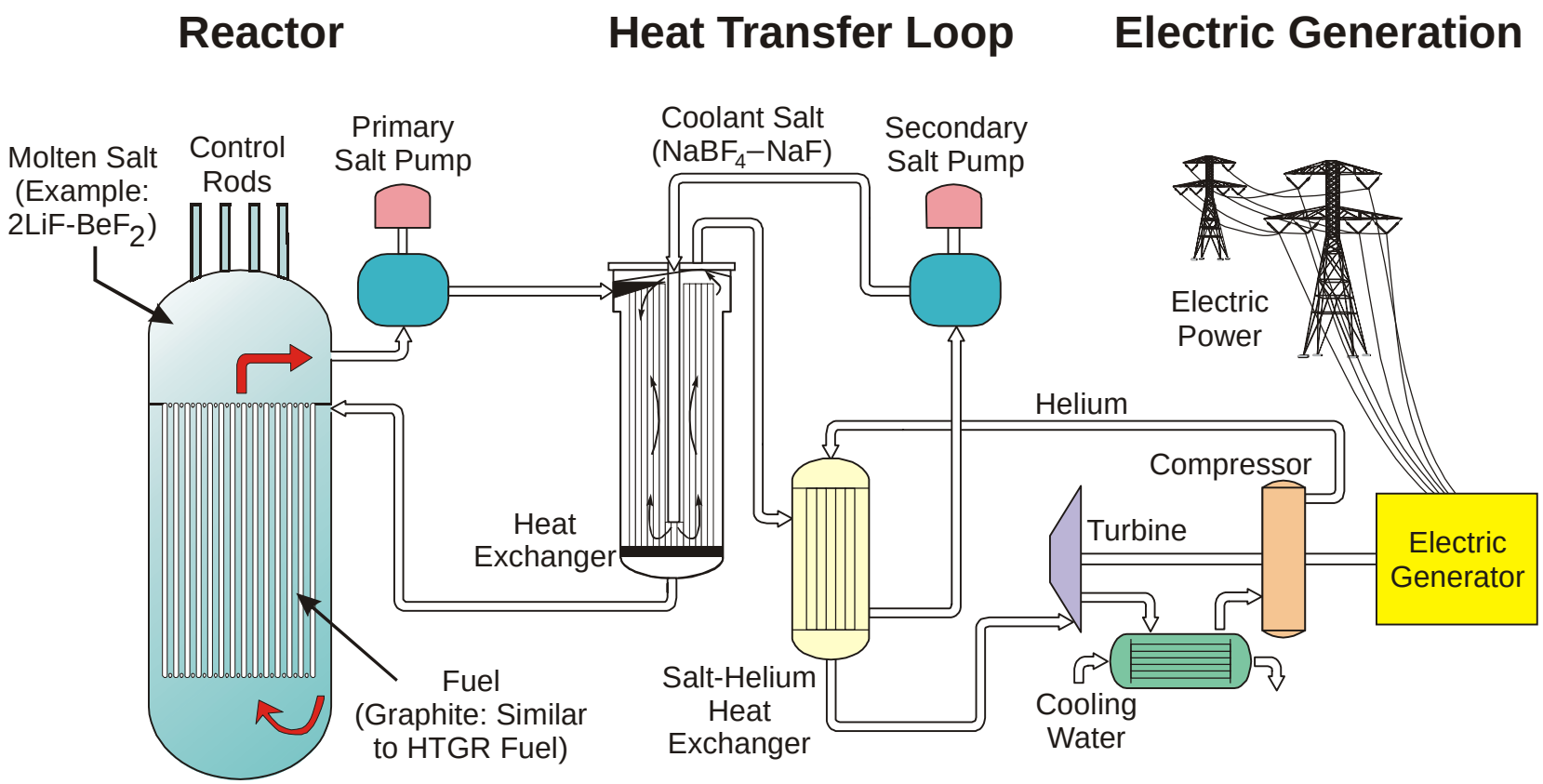
Advanced High-Temperature Reactor Coupled to a Hydrogen Production Facility



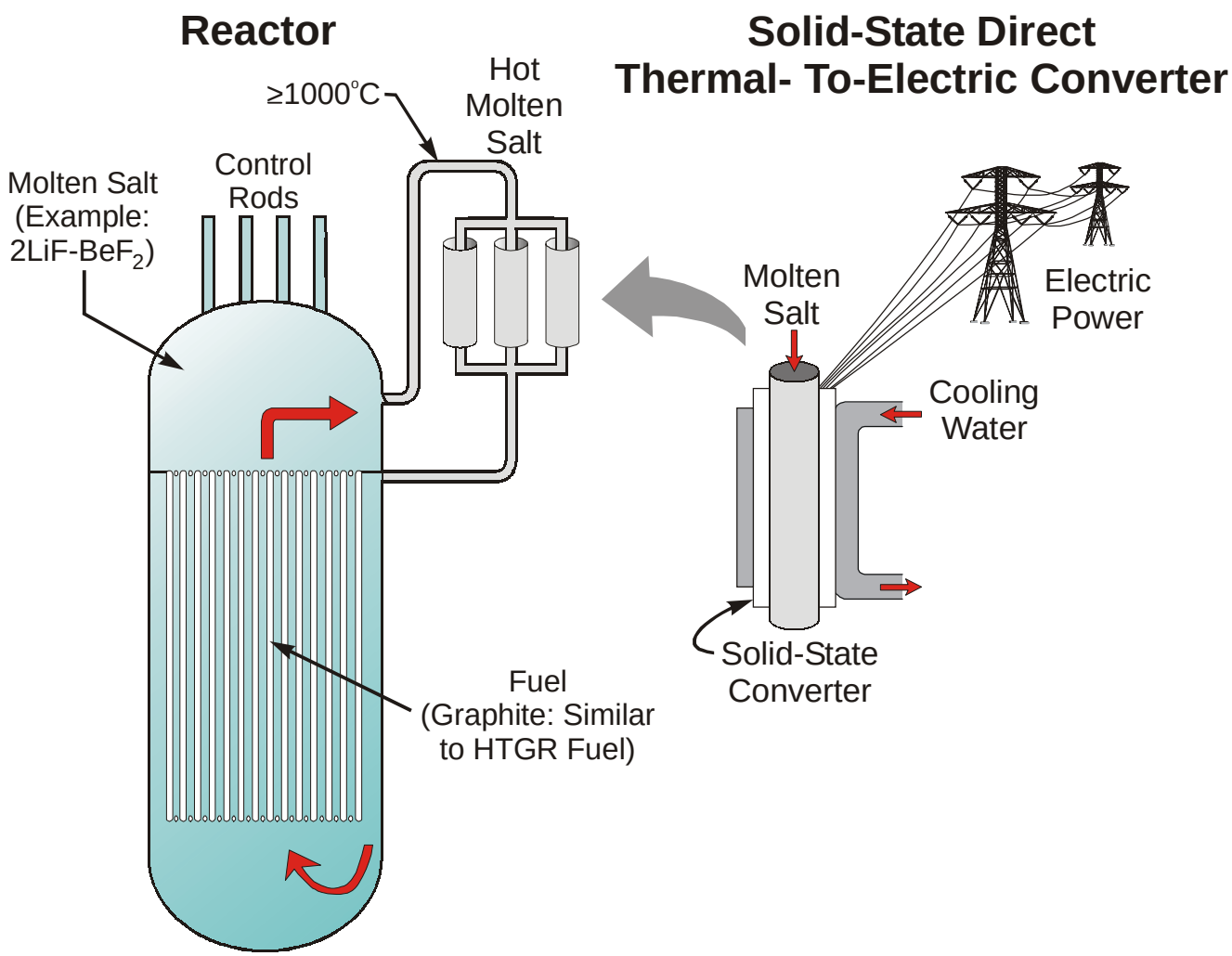
High Temperatures Create New Options For Production of Electricity

- **High-efficiency helium gas-turbine cycles**
  - **Conversion efficiency >50% at 1000ºC**
  - **Provide isolation of power cycle from the reactor using low-temperature-drop heat exchangers**
  - **Use advanced gas-turbine technology**
- **Direct thermal to electric production**
  - **No moving parts (solid-state) methods to produce electricity from high-temperature heat**
  - **Radically simplified power plant**
  - **Potential for major cost reductions**
  - **Longer-term option—solid-state technology is in an earlier stage of development**

The AHTR May Enable High-Efficiency (>50%) Electricity Production with an Advanced Brayton Cycle



The AHTR May Enable the Longer-Term Option of Direct Conversion of Thermal Energy to Electricity



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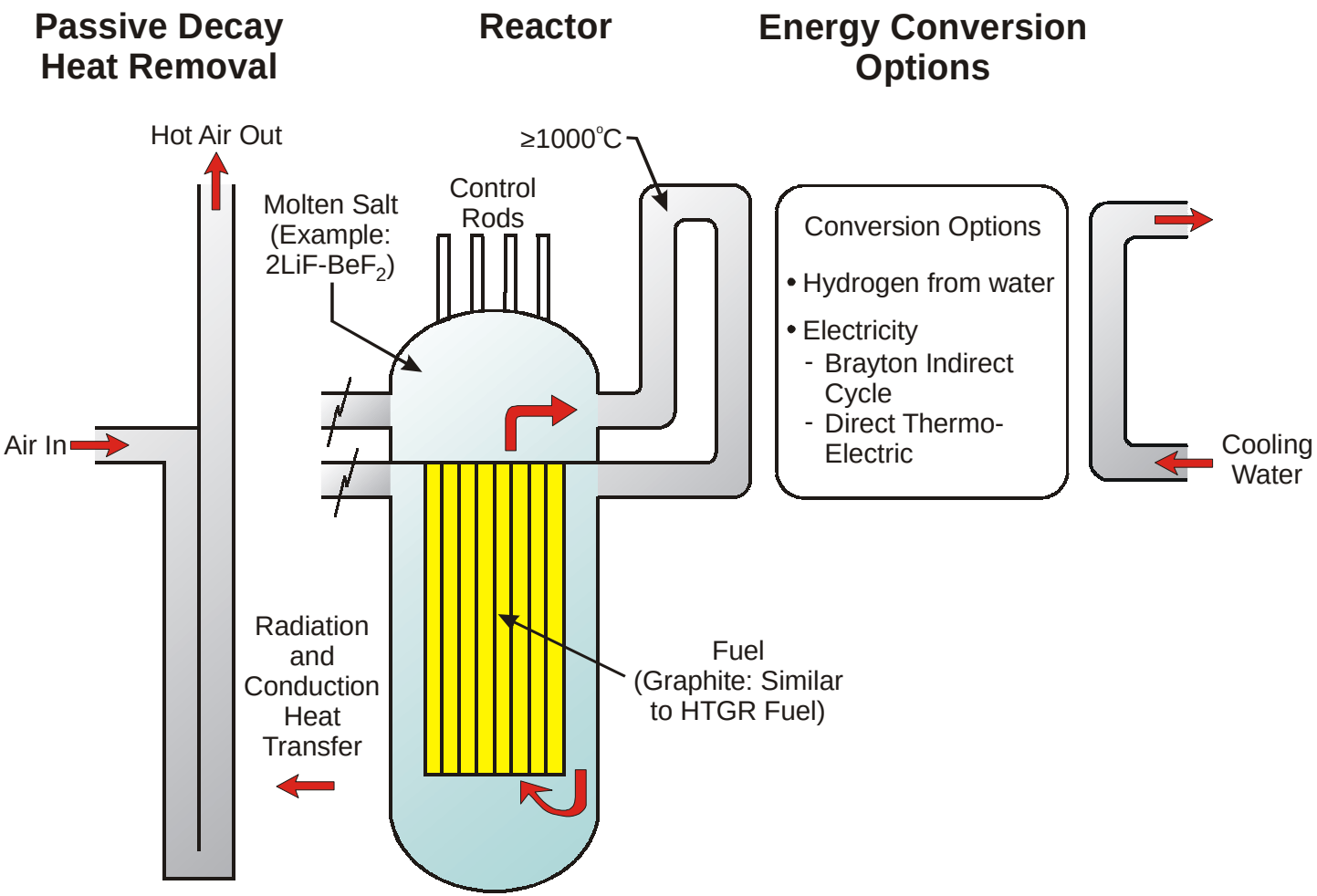
Desired Reactor Characteristics to Produce High-Temperature Heat

- **Low-pressure system (atmospheric)**
  - **Metals become weaker at higher temperatures**
  - **Low pressures minimize strength requirements**
- **Efficient heat transfer**
  - **Need to minimize temperature drops between the nuclear fuel and application to deliver the highest-temperature heat**

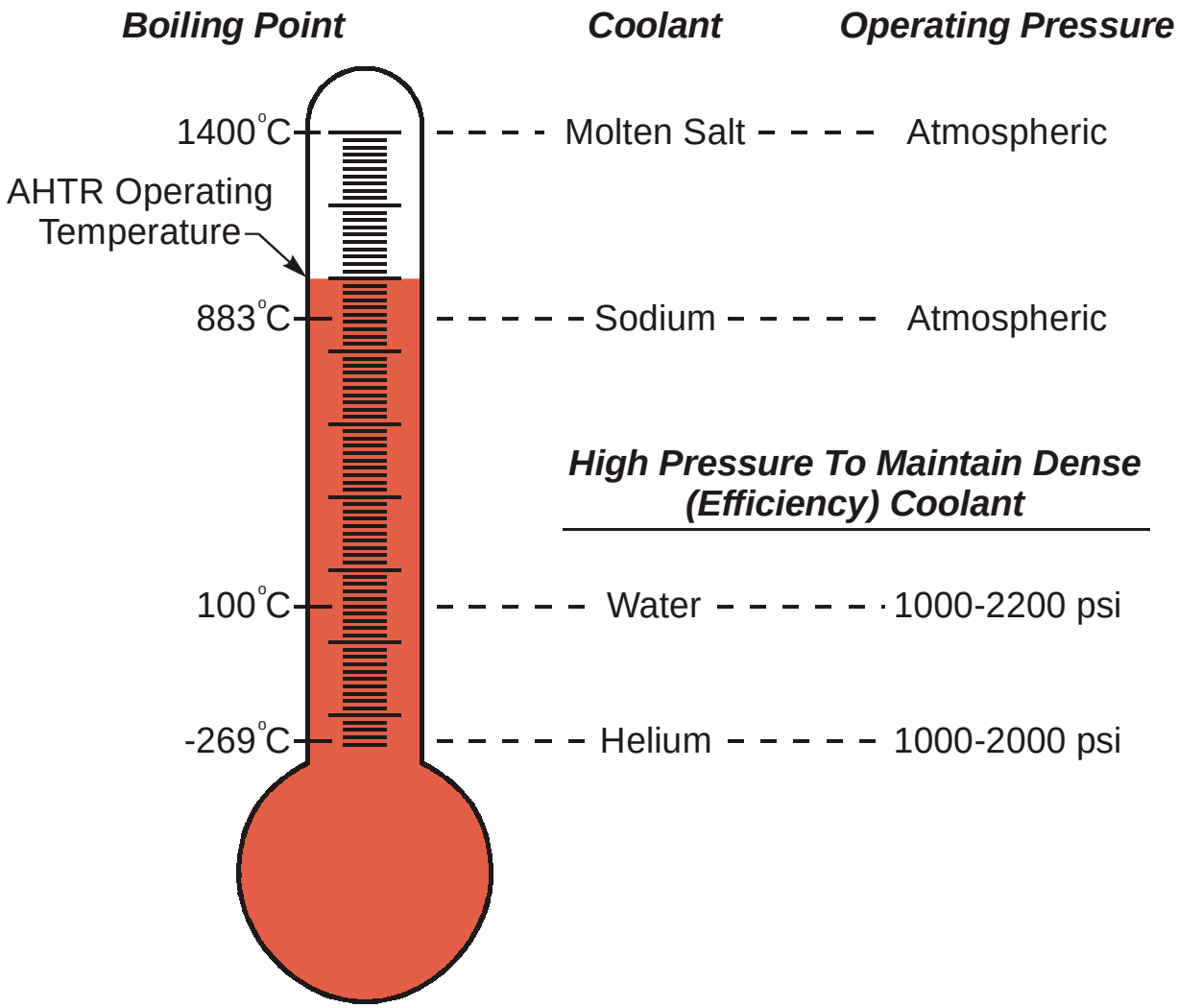
Advanced High-Temperature Reactor



The AHTR Combines Two Different Technologies To Create an Advanced Reactor Option

- **Graphite-matrix fuel**
  - **Demonstrated operation at an operating limit of ~1200ºC**
  - **Same fuel technology planned for modular gas-cooled reactors**
- **Molten salt coolant ($2LiF\text{-}BeF_2$)**
  - **Very low pressure (boils at ~1400ºC)**
  - **Efficient heat transfer (similar to that of water, except it works at high temperatures)**

Molten Salt Coolants Allow Low-Pressure Operations at High Temperatures Compared With Traditional Reactor Coolants



The Safety Case for the AHTR

- **Low-pressure (subatmospheric) coolant**
  - **Escaping pressurized fluids provide a mechanism for radioactivity to escape from a reactor during an accident**
  - **Low-pressure (<1 atm) salt coolant minimizes accident potential for radioactivity transport to the environment**
- **Good cooling characteristics provide added safety margins for many upset conditions**
- **Passive decay-heat-removal system similar to that proposed for other advanced reactors**
  - **Heat conducts outward from fuel to pressure vessel to passive vessel-cooling system**
  - **Power limited to ~600 MW(t)**

Development Challenges for the AHTR

- **AHTR uses some demonstrated technologies**
  - **Fuels**
  - **Coolant**
- **AHTR requires advanced technology**
  - **High-temperature materials of construction**
  - **Optimized system design**
  - **Heat exchangers**
  - **Hydrogen and energy conversion systems**

Proposed Activities

- **Better define hydrogen production requirements by working with the refinery and chemical industries**
- **Develop initial conceptual design for hydrogen and electricity production**
- **Examine key technical issues**

Conclusions

- **Economic methods to produce hydrogen from nuclear power may provide multiple benefits**
  - **Increased gasoline and diesel fuel yields per barrel of crude oil with reduced dependence on foreign oil**
  - **Long-term pathway to a hydrogen economy**
- **High-temperature heat allows for new, more-efficient methods to produce electricity**
- **An economic high-temperature, low-pressure nuclear reactor is required to obtain these benefits**