Nuclear Hydrogen for Peak Electricity Production and Commercial Sale

Charles Forsberg

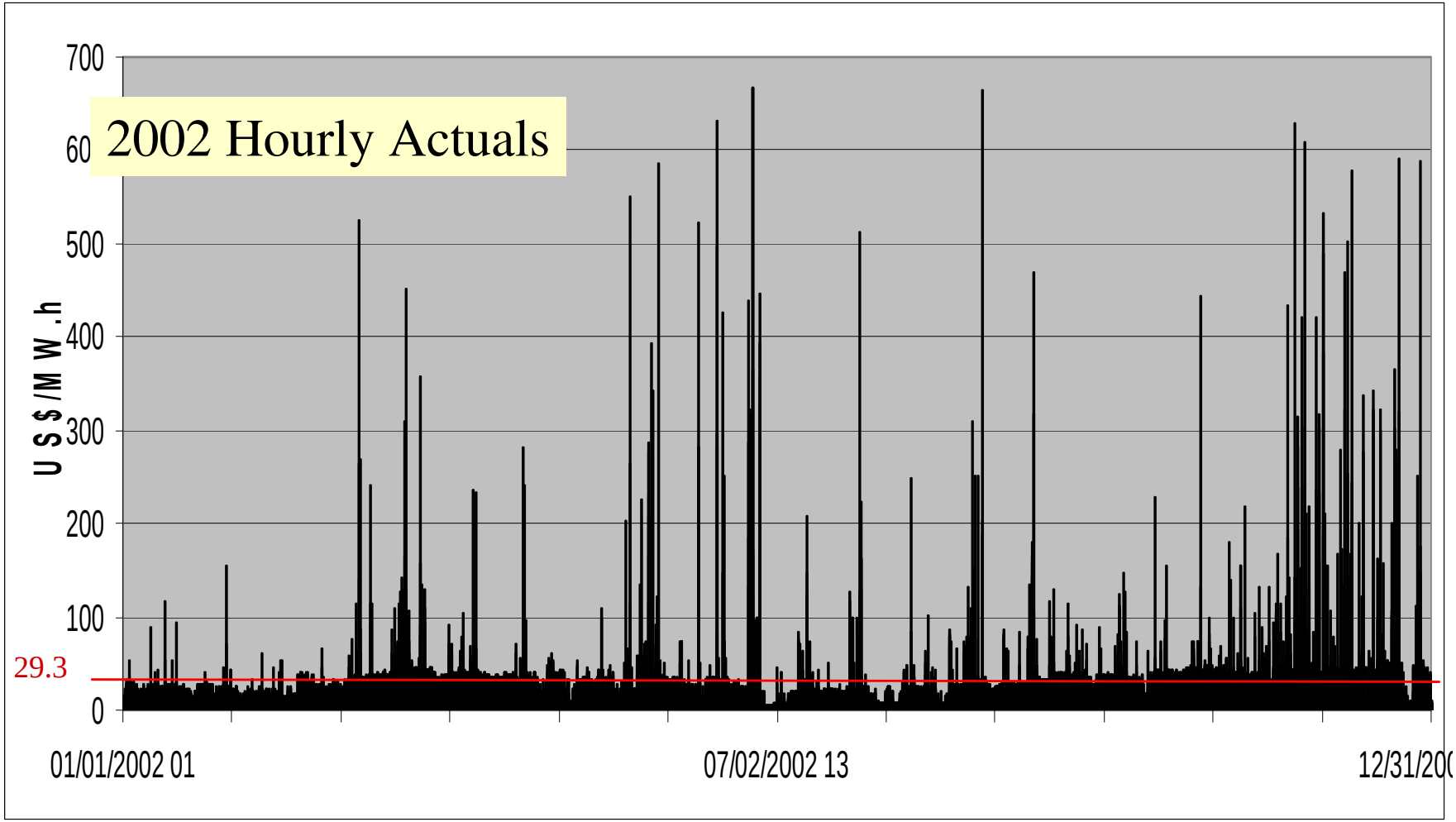
Oak Ridge National Laboratory
P.O. Box 2008; Oak Ridge, TN 37831-6165
Tel: (865) 574-6783; E-mail: forsbergcw@ornl.gov

American Nuclear Society 2004 Winter Meeting
Session: Hydrogen Production and Storage
Wednesday, November 17, 2004
Washington, D.C.

The submitted manuscript has been authored by a contractor of the U.S. Government under contract DE-AC05-00OR22725. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes. File name: PENS.ANS04

The Price (and Cost) of Electricity at Peak Times-of-Day is Very High

[Alberta Power Pool (US$/MW-h)]



Peak Power Requires Large Facilities

TVA Raccoon Mountain Pump-Storage Facility
For Peak and Intermediate Electric Power

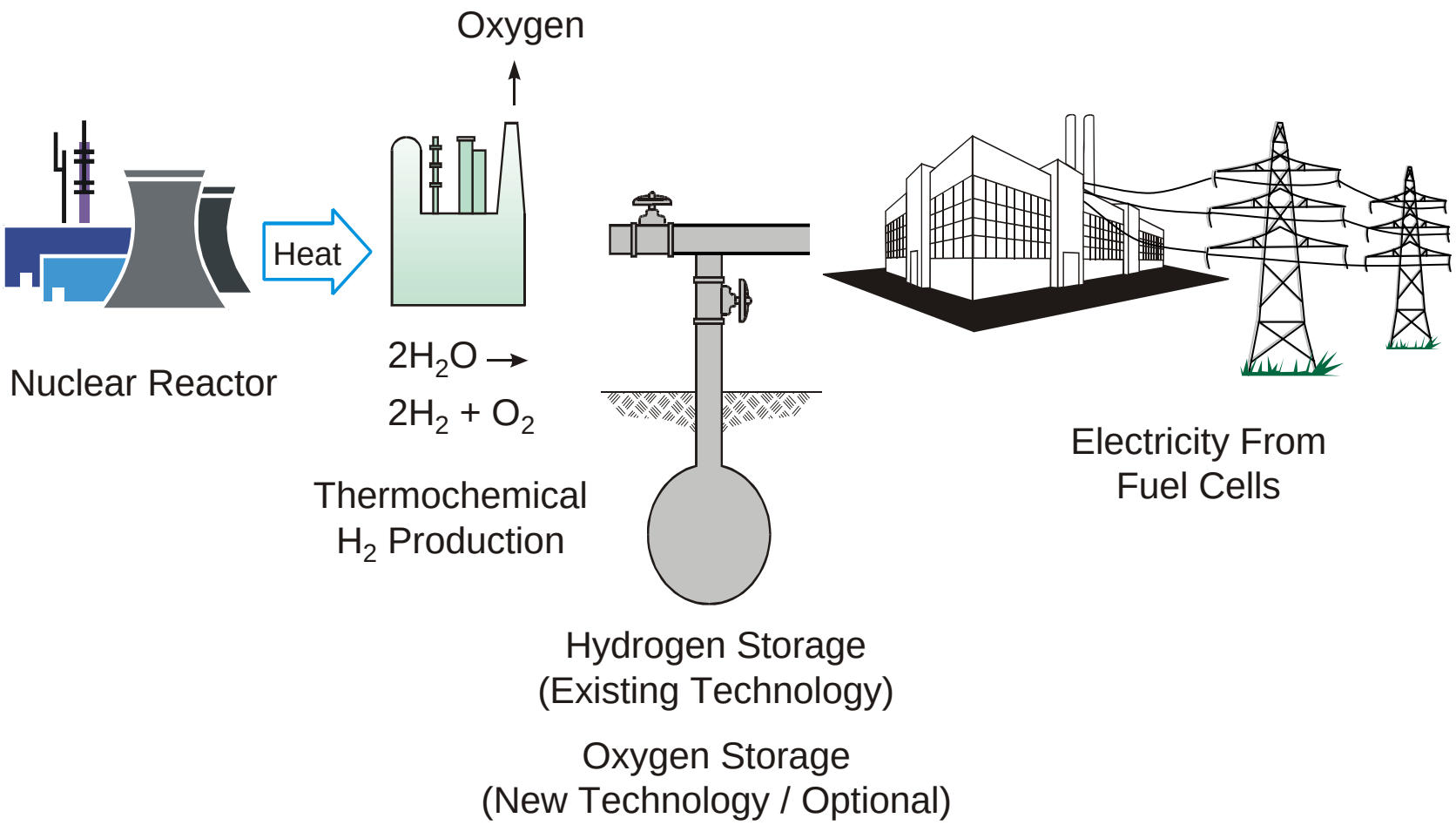
Courtesy of the Tennessee Valley Authority

- **Pump water uphill at night**
- **Water through turbines to generate electricity when there is a high power demand**
- **1530 MW(e)**
- **Effectively a large storage "battery"**

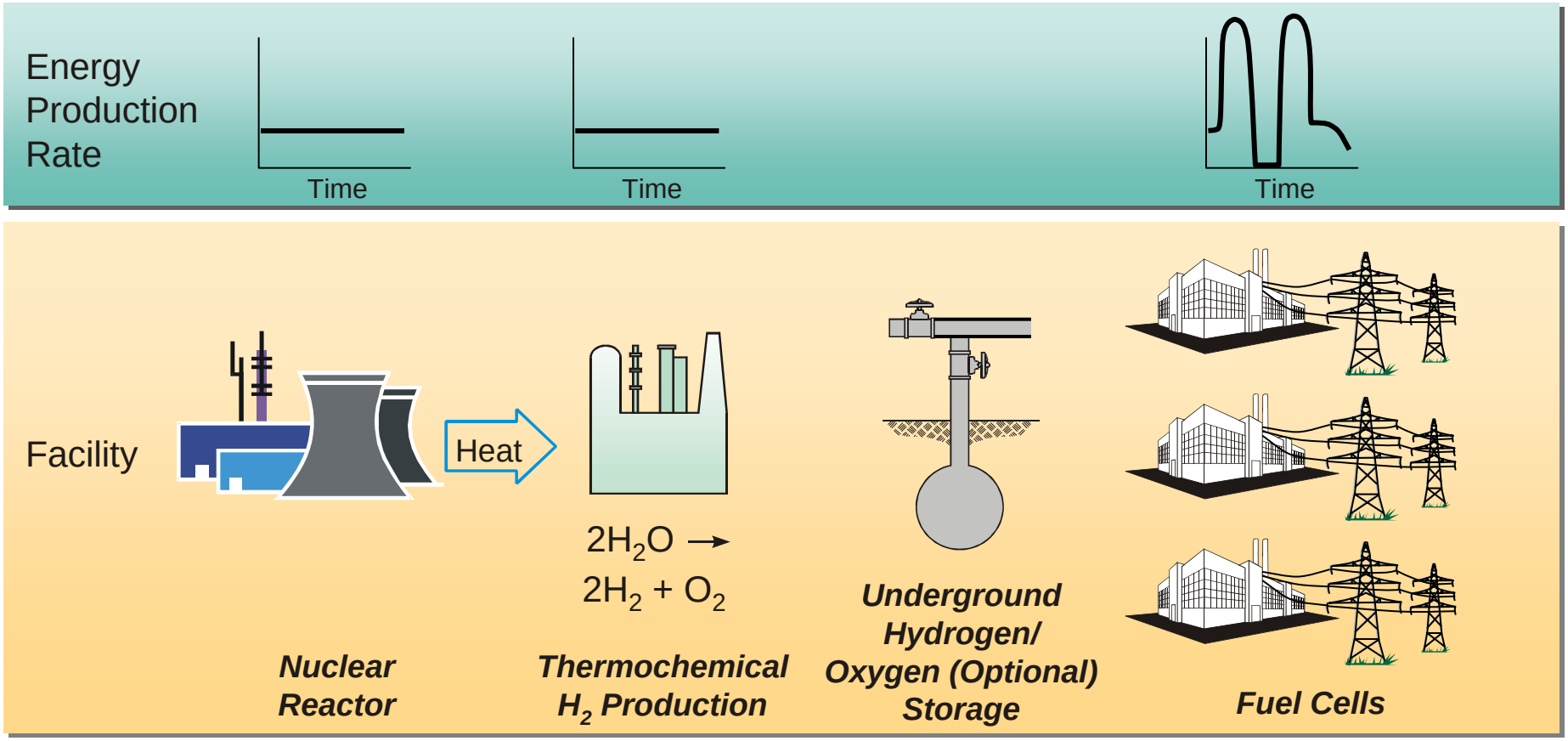
Nuclear Hydrogen may Provide Economic Peak Electric Power

- **Peak electricity is costly (high prices)**
- **Existing options to meet peak electricity demand:**
  - **Low capital-cost power production units for peak power (Gas turbines with natural gas)**
  - **Pumped storage (Example: Raccoon Mountain)**
- **Future option: Peak Electricity Nuclear System (PENS) uses the *unique characteristics* of nuclear hydrogen production systems**
  - **Produce low-cost hydrogen and oxygen**
  - **Sell high-priced peak electricity**
  - **Provide "spinning reserve" to electrical grid**

Components of a Peak Electric Nuclear System (PENS)



Reactor Operates Continuously, Fuel Cells Operate at Peak Demand



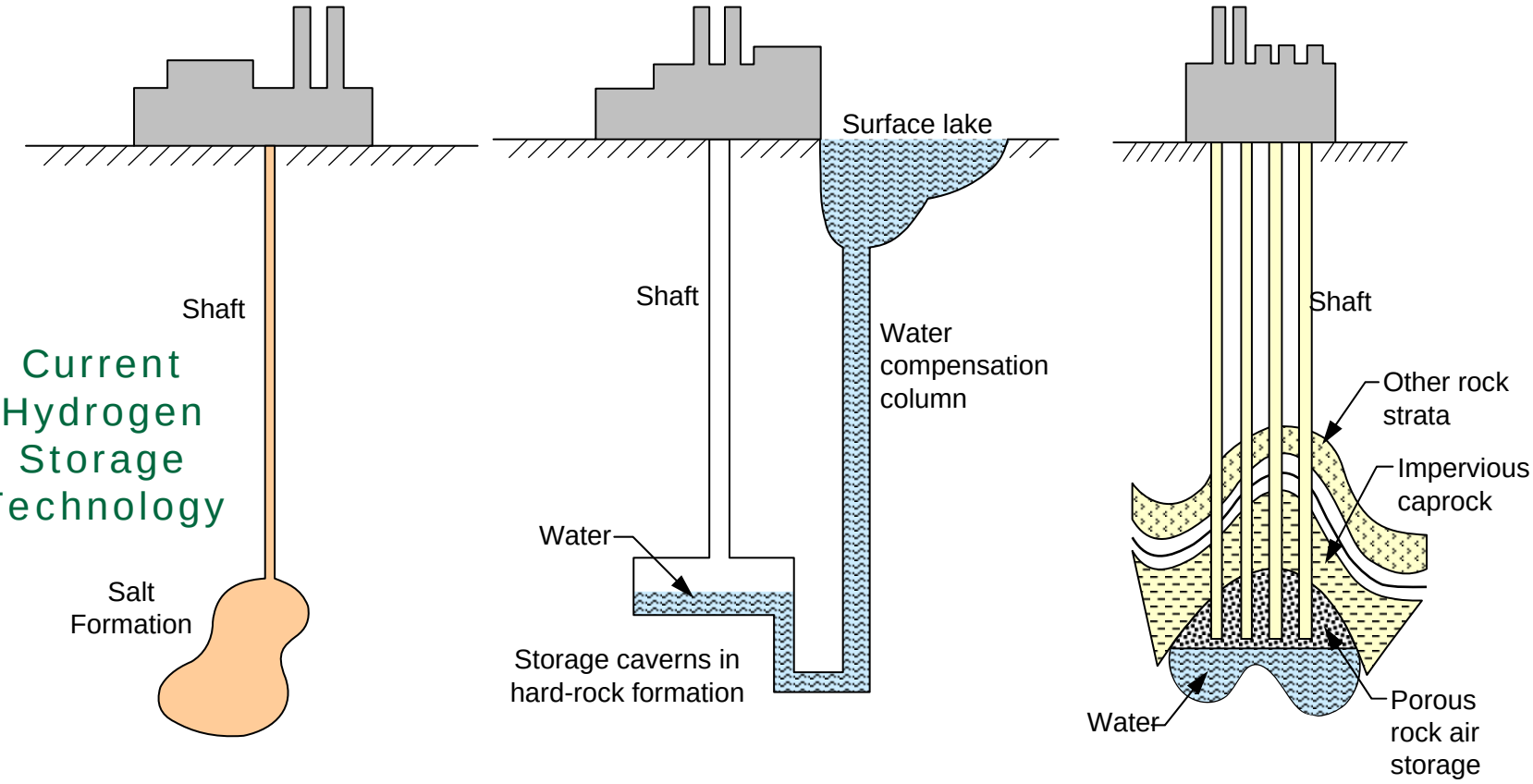
Cost/kw	$$$$	$$	$	$

Several Factors Indicate Potentially Viable Economics for PENS

- **Economics-of-scale [1000 MW(e) or more of peak power]**
  - **Hydrogen production**
  - **Low-cost underground hydrogen and oxygen storage**
  - **Large scale fuel-cell complex**
- **Electrical production costs from fuel cells are expected to be less than from gas turbines (the competition)**
  - **Peak electrical power generation requires low capital cost per kW(e) because the power plant operates only a fraction of the year at times of peak electrical demand**
  - **DOE fuel-cell goals are for capital costs <20% of gas turbines**
  - **Fuel cell projected efficiency (70%) is greater than that for gas turbines (50%)**
  - **But, fuel cells require hydrogen (premium fuel) for high efficiency**
- **Fuel cells using oxygen have significantly lower costs than fuel cells operated on air**
  - **Improved fuel cell efficiency**
  - **Reduced fuel-cell capital costs by a factor of 3**

Hydrogen can be Stored Economically Underground *on a Large Scale*

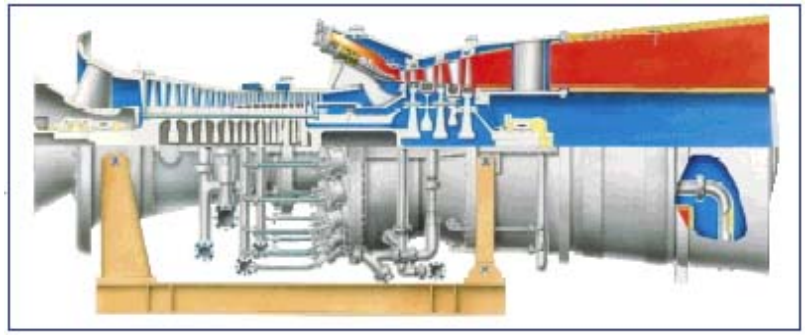
(8 Trillion ft^3 of Natural Gas Storage in the U. S.)

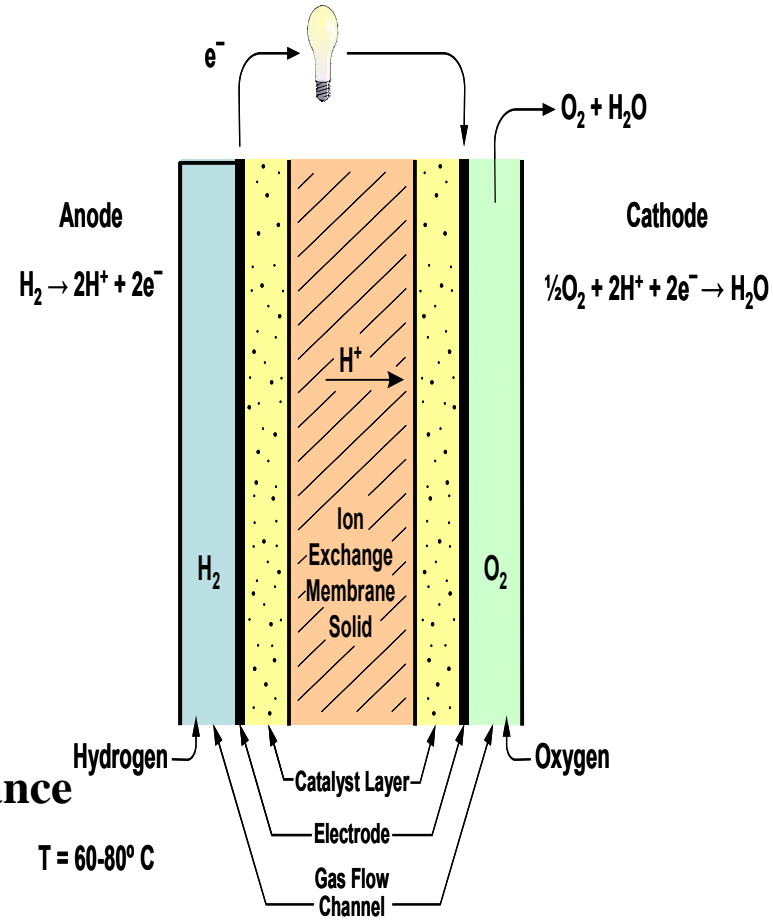


Current Hydrogen Storage Technology

No existing methods to store hydrogen cheaply on a small scale

Unlike Gas Turbines, Fuel Cell Cost is Reduced by use of Oxygen Rather than Air





↑ **Brayton Power Cycles**
- **Materials limit peak temperature**
- **Oxygen not a benefit (Heat engine)**

Fuel Cells →
- **Mass transfer limits performance**
- **Oxygen (rather than air) boosts performance**

PENS Provides Spinning Reserve

- **Utilities keep "extra" power plants on line to provide replacement electricity if a power plant goes off-line for any reason**
  - **This "extra" capacity is called spinning reserve**
- **The East-coast blackout was partly a consequence of a shortage of spinning reserve**
- **PENS can provide spinning reserve**
  - **Fuel cells capable of going from no load to full power in a fraction of a second**
  - **Major existing fuel-cell commercial market is providing "instant" backup power for critical operations**
  - **Potentially major economic benefit but very difficult to quantify**

Conclusions

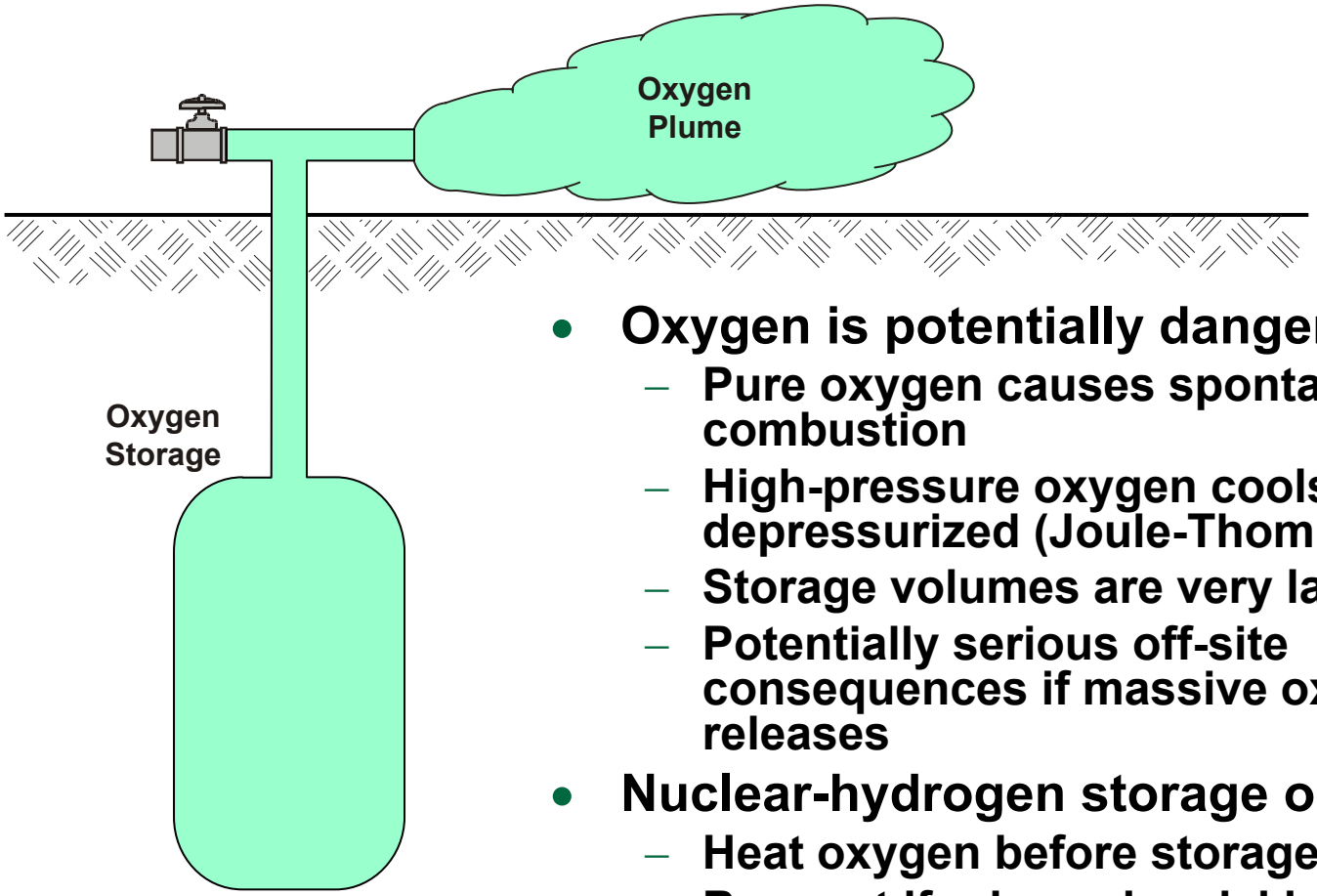
- **PENS is a way to introduce nuclear hydrogen without a massive infrastructure**
  - **Everything is inside the utility fence**
  - **The products are peak electric power and spinning reserve, known markets**
  - **Market size is equivalent to the existing nuclear enterprise**
- **Match low-cost nuclear production with high-cost product: peak electricity**
  - **Critical economic challenge: Low cost fuel cells relative to gas turbines**
  - **If projected air fuel-cell cost reductions occur, economics are highly favorable**
  - **Oxygen significantly reduces fuel cell costs**

Backup Slides
Backup Slides
Backup Slides

Raccoon Mountain: TVA 1530 MW(e) Pump-Storage Facility Powerhouse

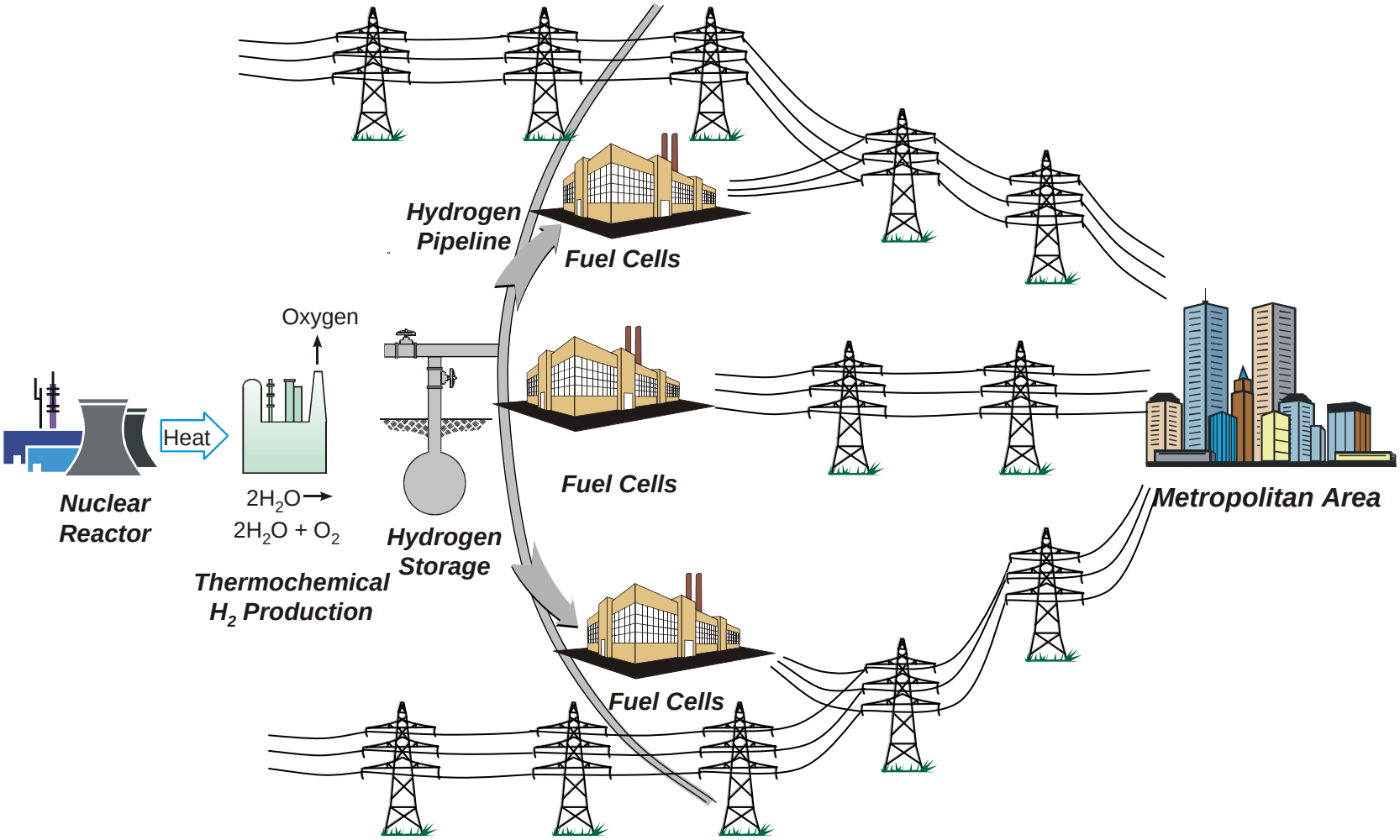
Courtesy of the Tennessee Valley Authority

Oxygen Storage Safety is a Concern: Nuclear Heat ay Eliminate Safety Concern



- **Oxygen is potentially dangerous**
  - **Pure oxygen causes spontaneous combustion**
  - **High-pressure oxygen cools when it is depressurized (Joule-Thompson effect)**
  - **Storage volumes are very large**
  - **Potentially serious off-site consequences if massive oxygen releases**
- **Nuclear-hydrogen storage option**
  - **Heat oxygen before storage by 20 to 40ºC**
  - **Buoyant if released, quickly diluted**
  - **No off-site risk**
  - **Viable with nuclear heat**

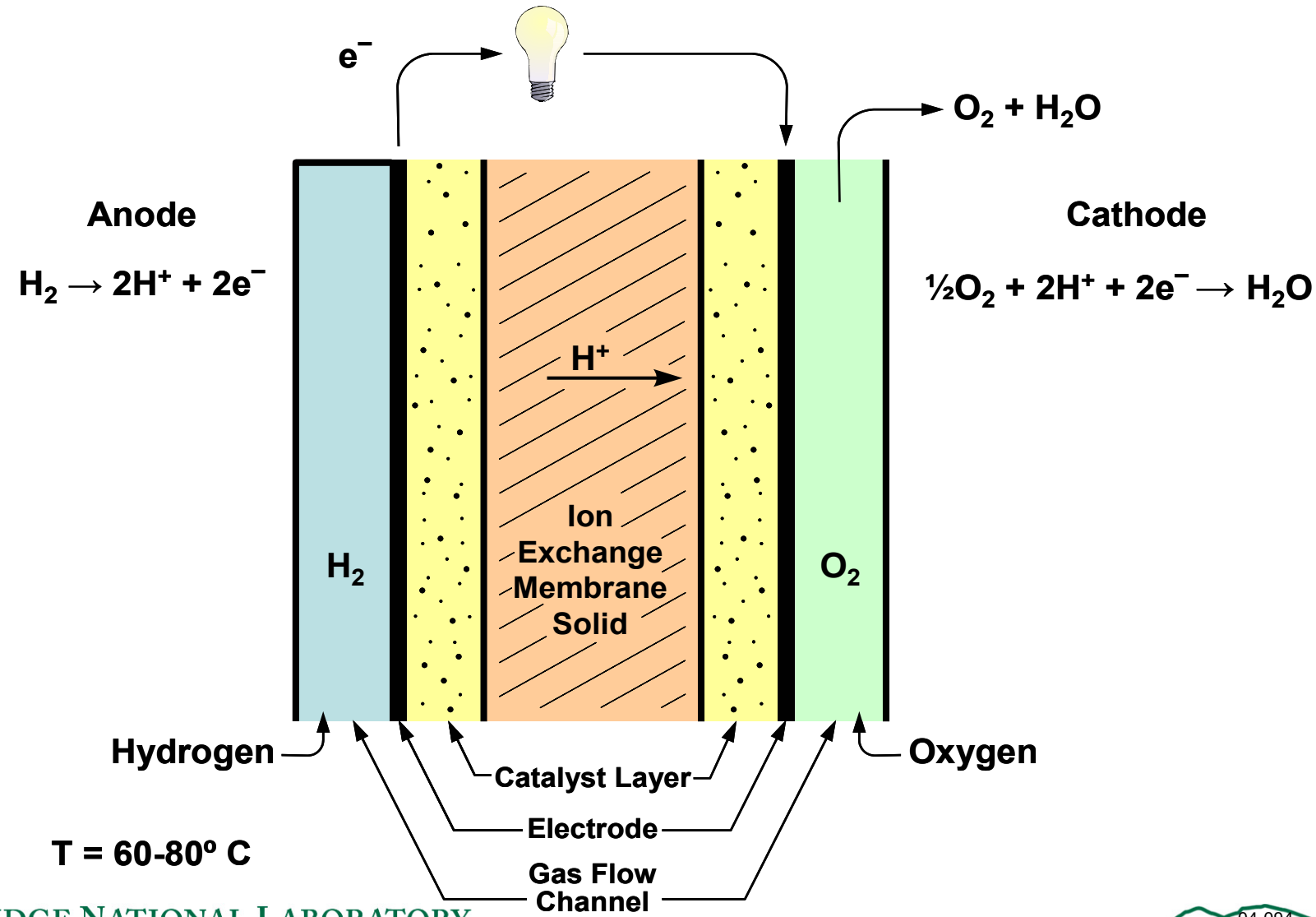
PENS may have Several Large Fuel-Cell Sites



If Economic, PENS is the Ideal Nuclear Hydrogen Market

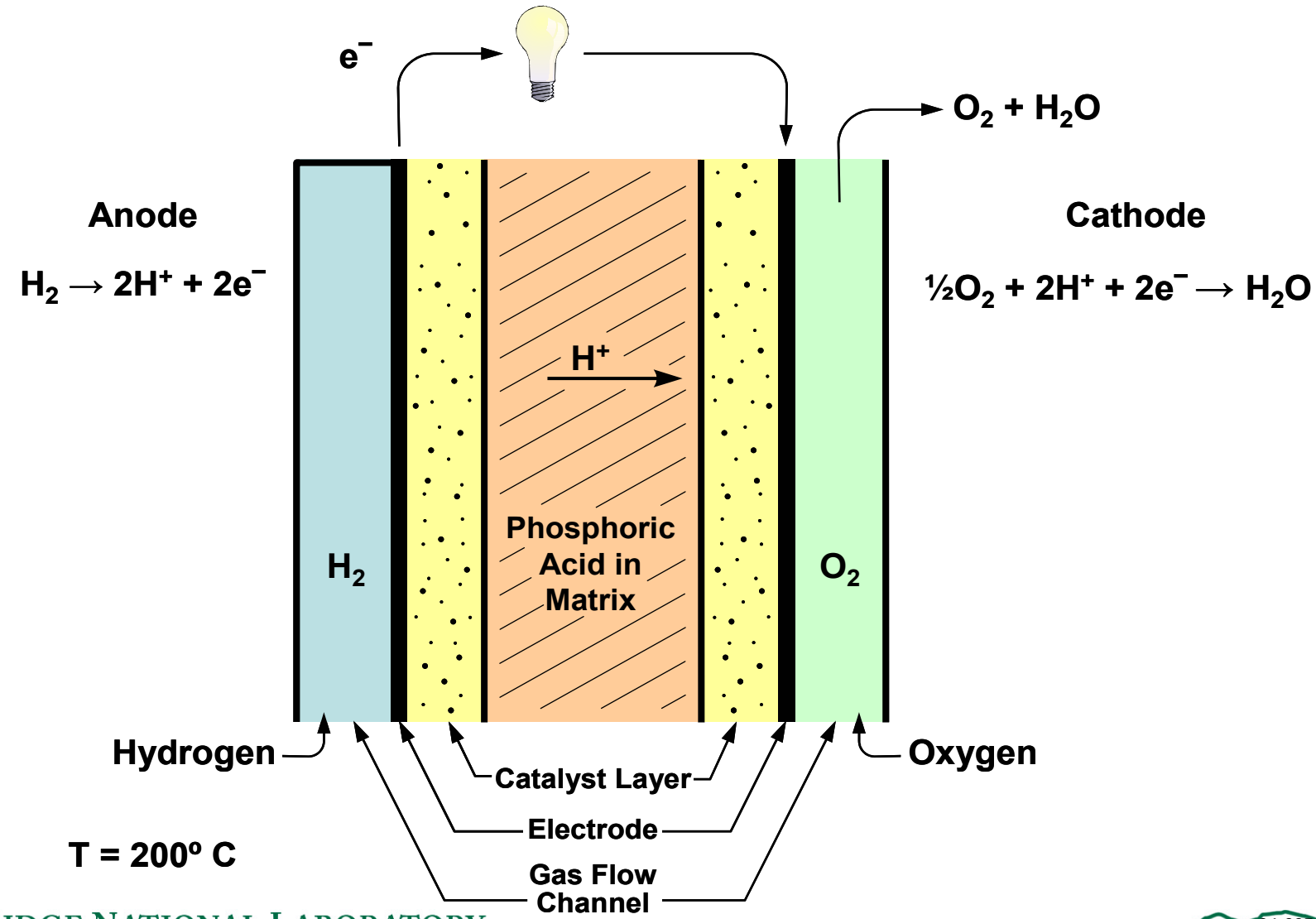
- **Nuclear-hydrogen reduces fuel-cell costs**
  - **PENS economics depends upon cheap fuel cells**
  - **Large economics-of-scale in the fuel-cell complex**
  - **Low capital-cost and high-efficiency fuel cells based on nuclear-hydrogen system inputs to the fuel-cell complex**
    - **Hydrogen**
    - **Oxygen (rather than air)**
    - **Heat for safe oxygen storage**
- **If PENS is economically viable:**
  - **Existing peak and intermediate electricity market, no chicken and egg introduction problem for hydrogen**
  - **Compatible with utility operations**
  - **Single application (independent of all other uses) sufficient to fully justify development of nuclear hydrogen**

Polymer Electrolytic Fuel Cell

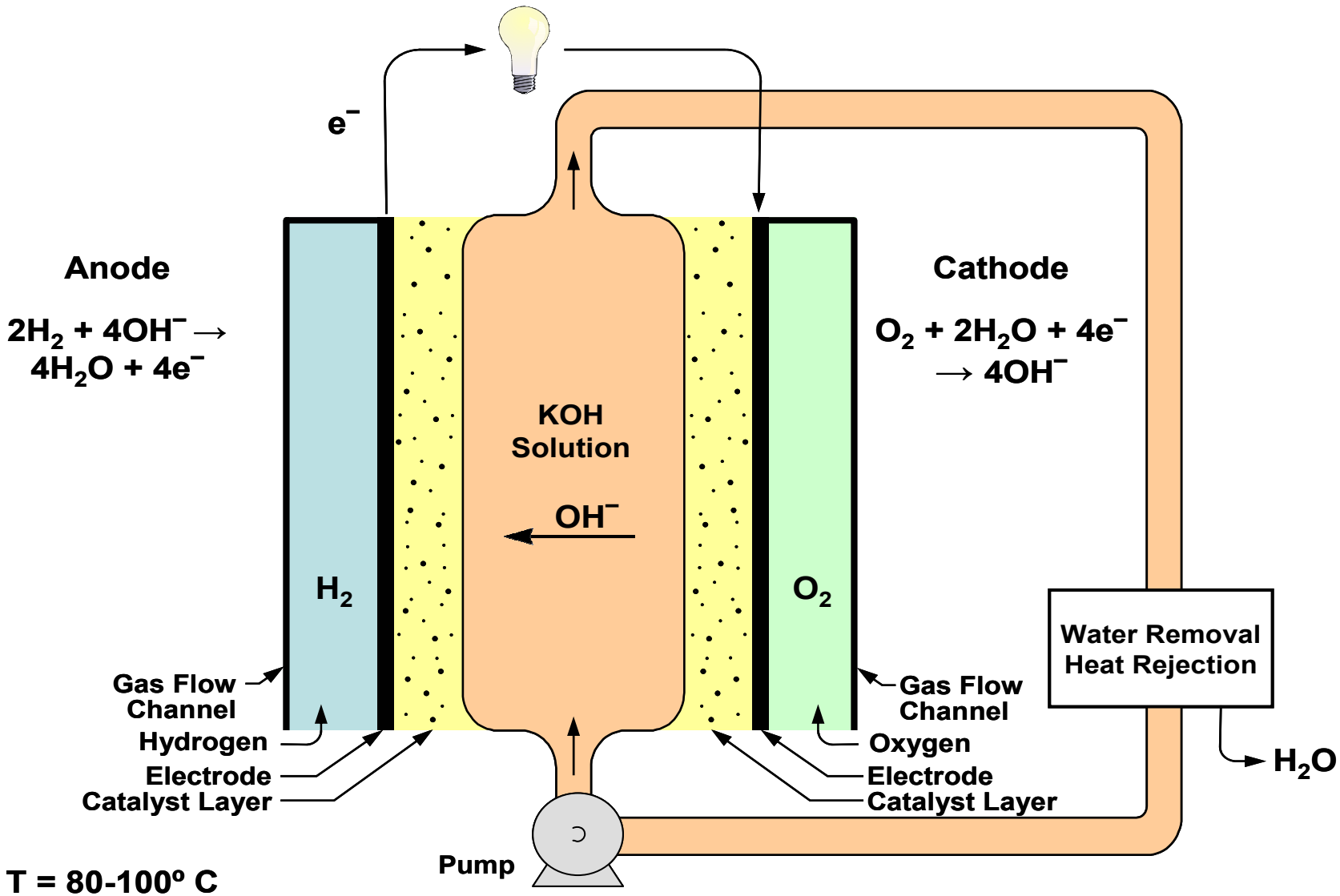


T = 60-80º C

Phosphoric Acid Fuel Cell

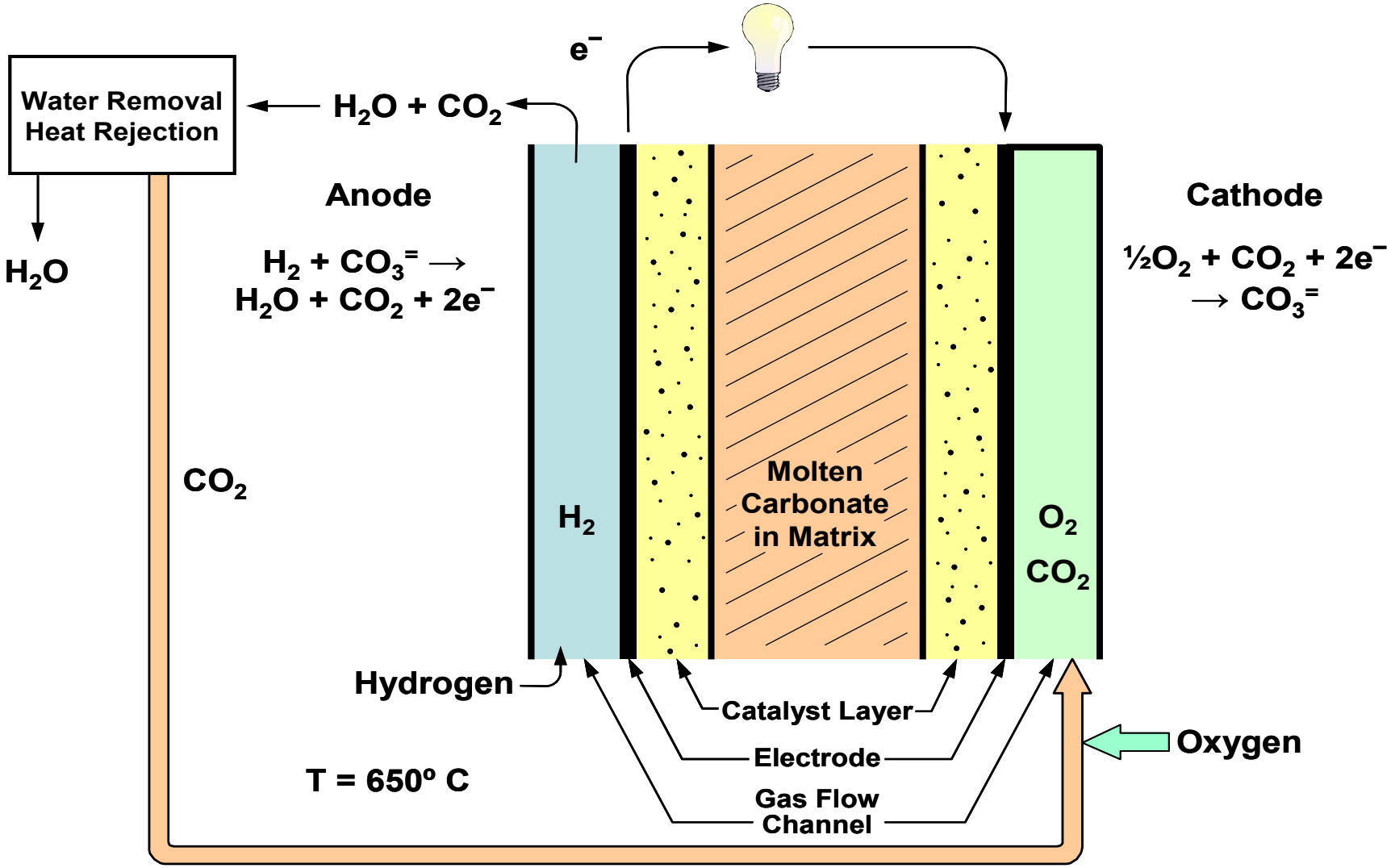


Alkaline Fuel Cell

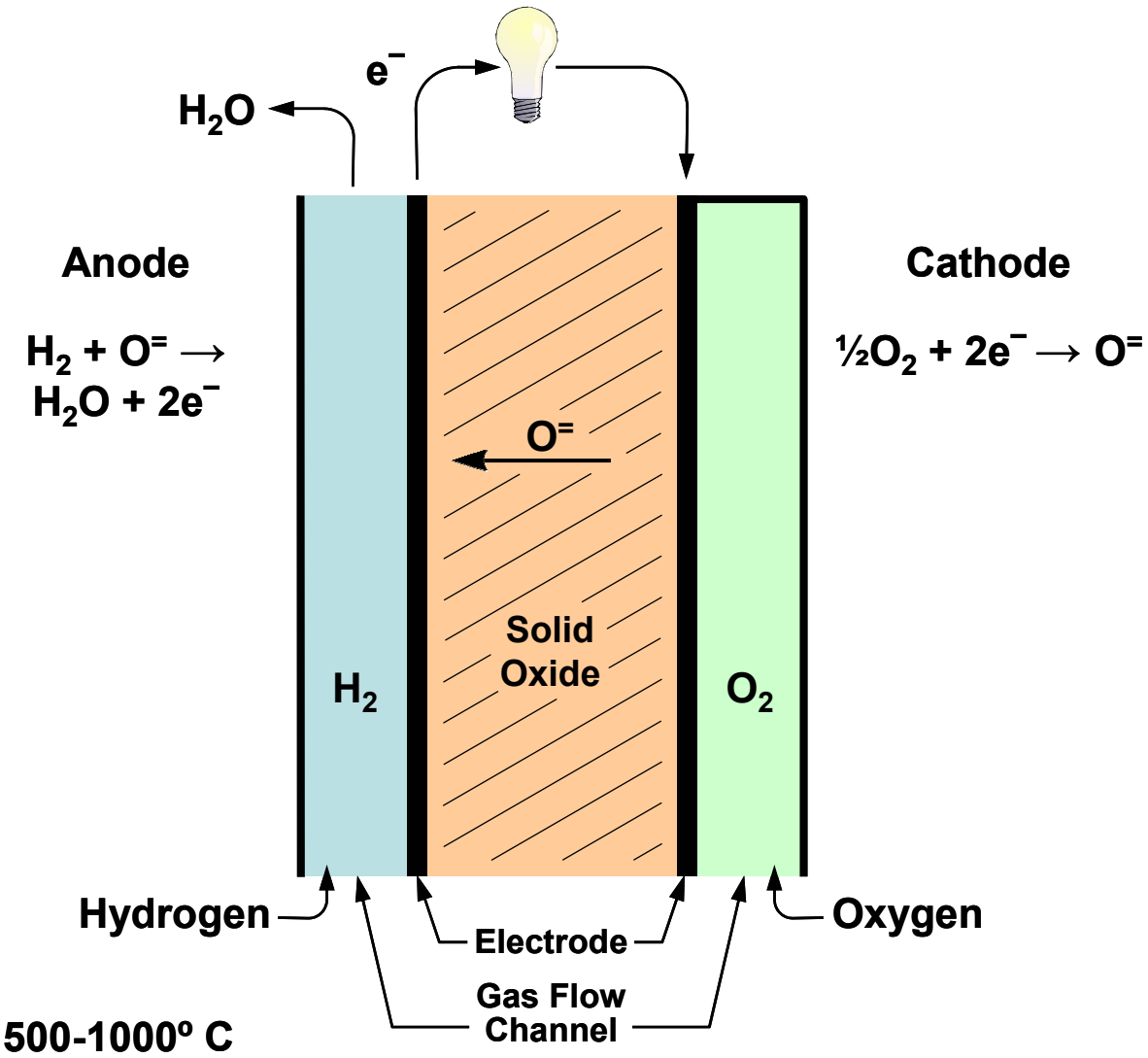


T = 80-100º C

Molten Carbonate Fuel Cell

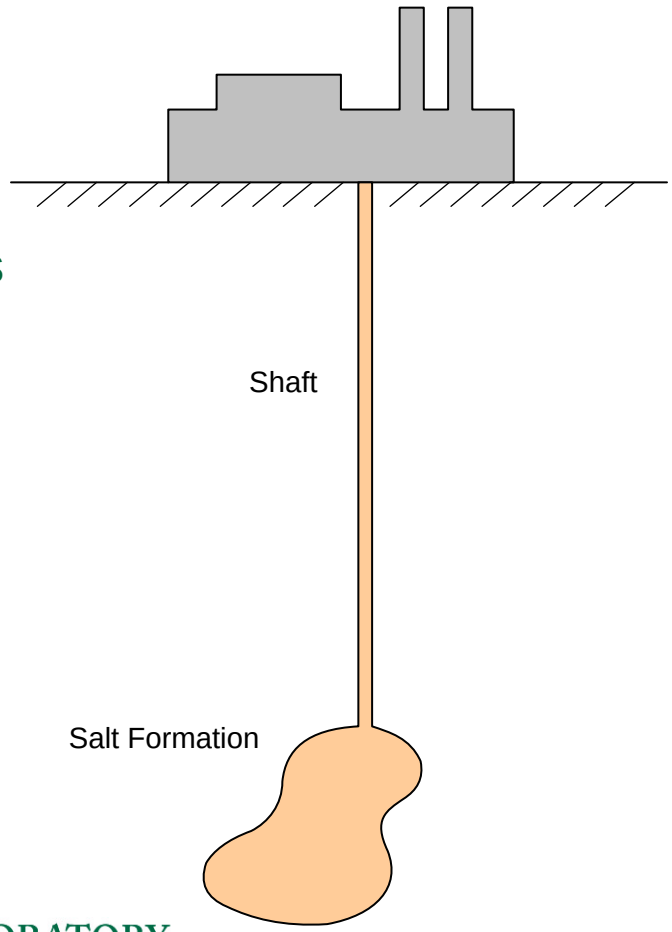


High-Temperature Solid-Oxide Fuel Cell



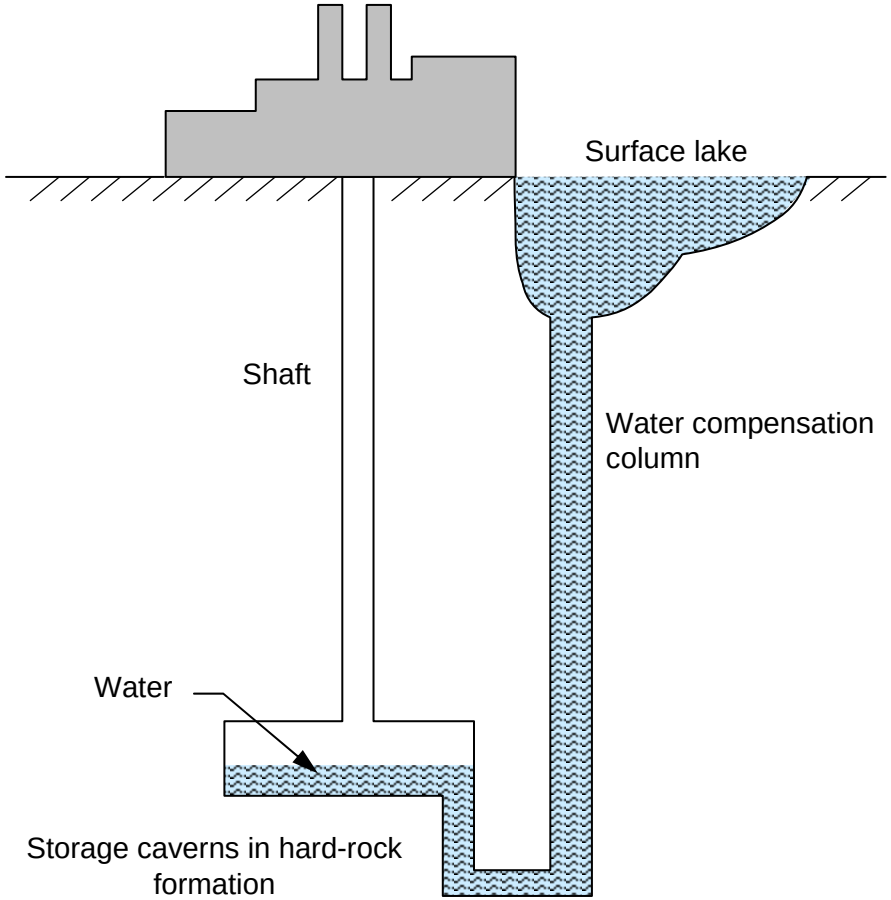
Underground Hydrogen Storage in Salt Caverns: Existing Technology

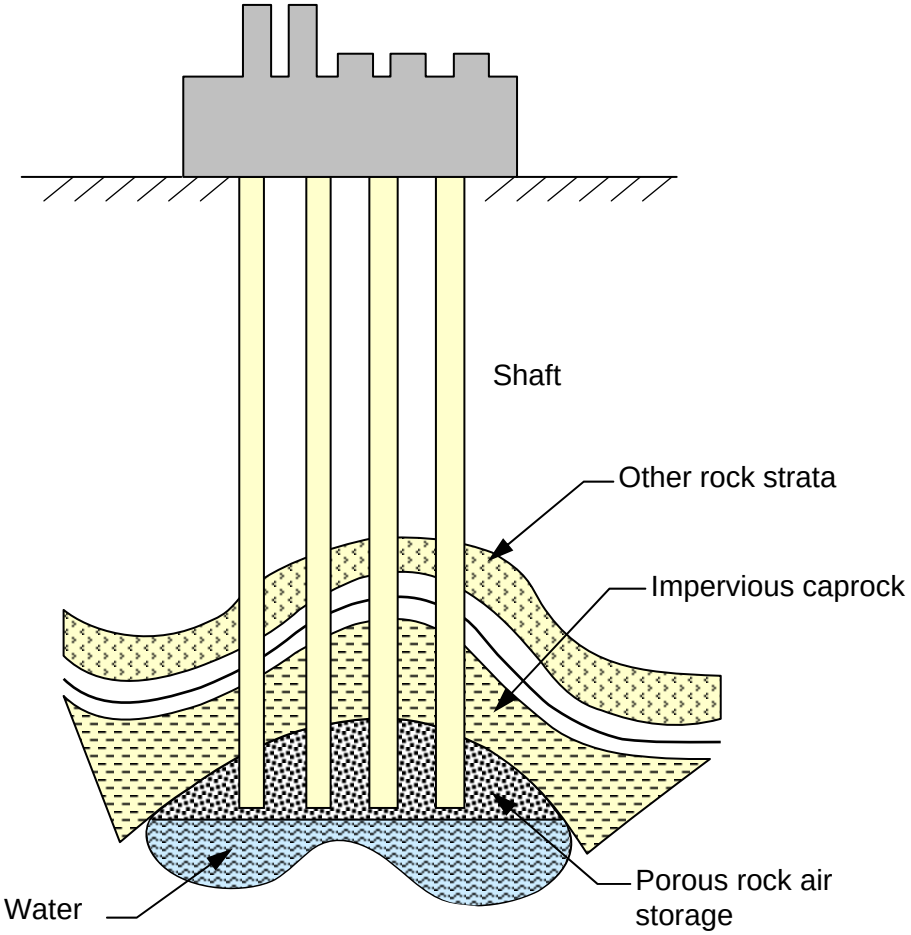
Salt Formations



Underground Hydrogen Storage in Hard Rock

Hard Rock Formations



Underground Hydrogen Storage in Porous Geology

Porous Media Formations