# Nuclear Hydrogen Production: Scoping the Safety Issues

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Canadian Nuclear Society
Ottawa Chapter


# Nuclear Hydrogen Production (NHP)
# Scoping the Safety Issues

***Hydrogen Use Will Rise Sharply in Fossil Fuel Sector (Alberta).***
***Need for Process Heat to extract crude from Oil Sands will grow.***

*Nuclear Hydrogen Production (and Heat) is Especially Attractive*

*Reduces Emissions ($CO_2$). But:*
*Electro- Thermo-Chemical + Nuclear: Unprecedented.*
*Incremental Risk (i) Chemical Plant ($SO_2$) (ii) Onsite storage $H_2$ ; $O_2$*

## ***Preliminary, Foresighting Analysis***

*Preliminary PSA-type Analysis of Incremental Risk:*

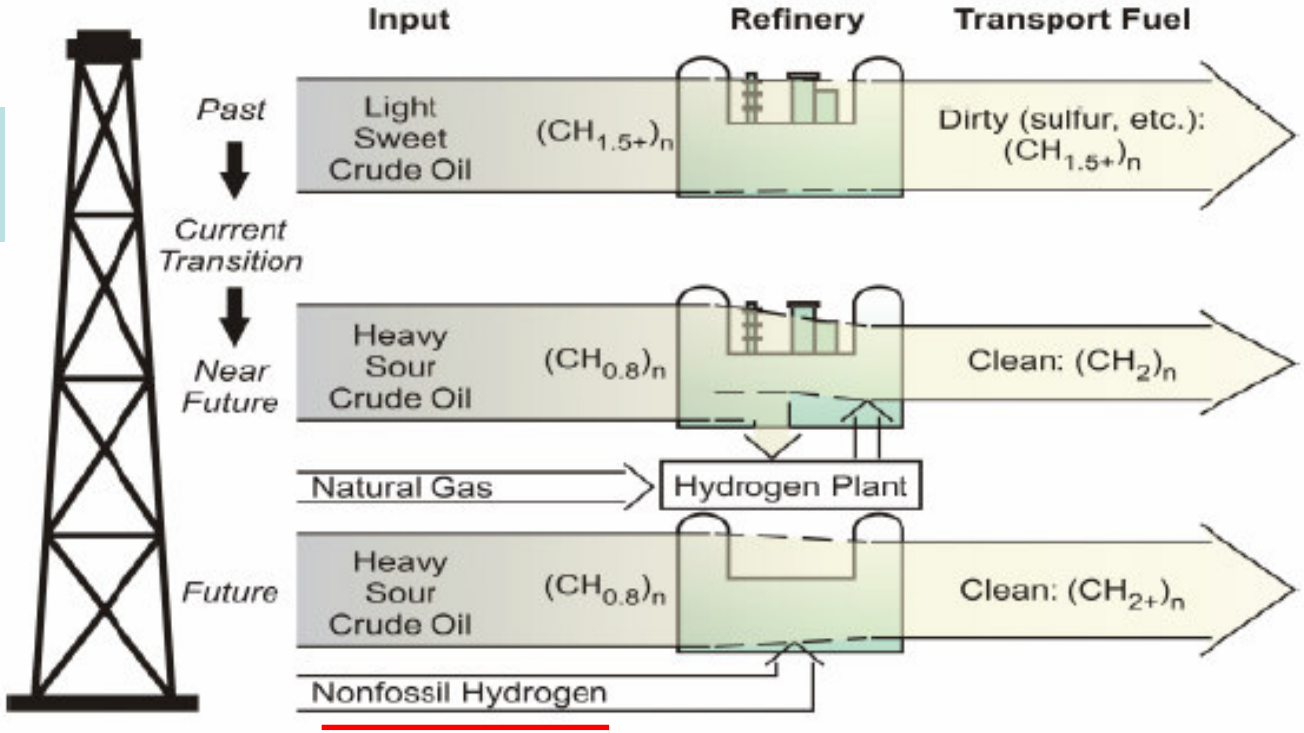
*(Detailed PSA-type Analysis required of Chemical Plant as well.)*
*Currently Hydrogen in Widespread use in N-plants (BWRs PWRs)*
*Can be generated in LOCA (metal-water interactions etc) Tritium*

***This Talk: Incremental Risk from generating Hydrogen near N-plant.***

# Before we get to a full-fledged H2E, Hydrogen Use in Fossil Fuel Industry will Rise

## Crude Oil Quality Change

Forsberg 2001





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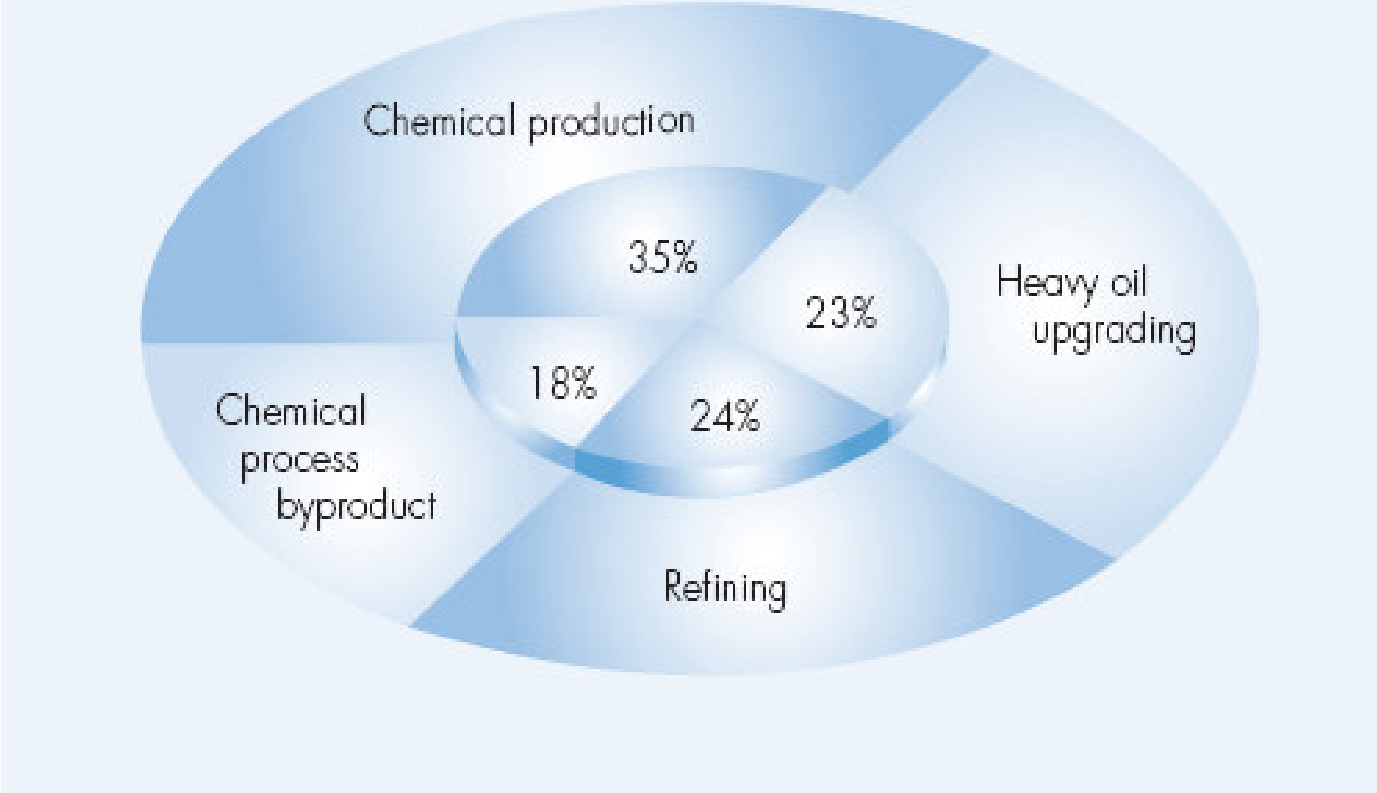
# Hydrogen Usage in Canada (CHA 2007)

**Total Canadian Production is expected to rise from 800K tons to 2.8 M tons in 2020**

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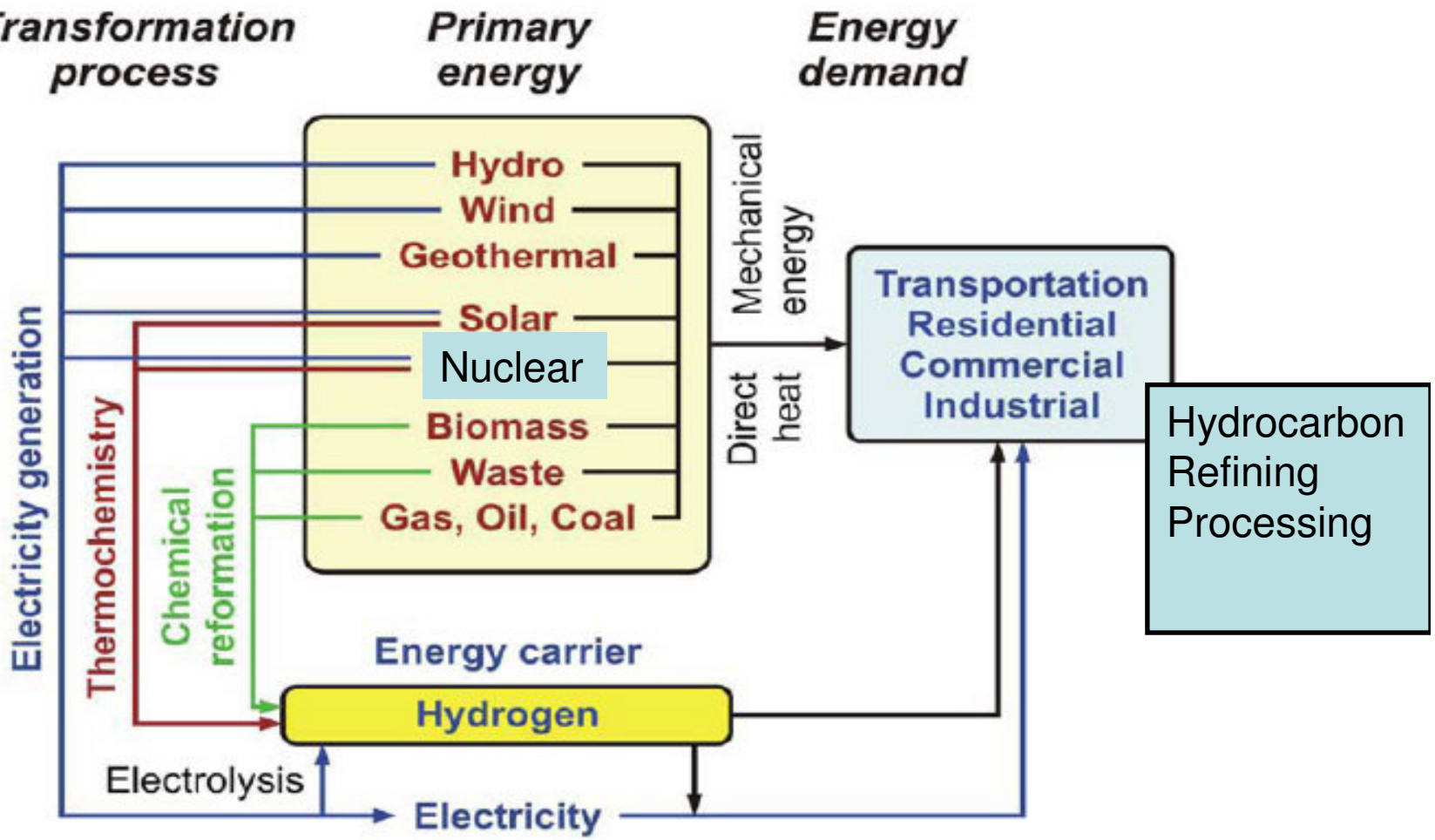
# Nuclear Hydrogen Production
# Canadian Developments

- **Alberta**
  - Bruce Power buys Energy Alberta Corporation November 2007
  - Strong interest from Oil Sands Industry in Nuclear Power
  - For Electricity, Process Heat **and Hydrogen**
  - Oil Sands Extraction, Coal Liquefaction, Synthetic Fuels

- **Ontario**
  - Bruce Power considering Nuclear Hydrogen Production
    - For Off-Peak Energy Utilization - announced Fall 2006.

# Hydrogen Economy: Production, Demand and Supply

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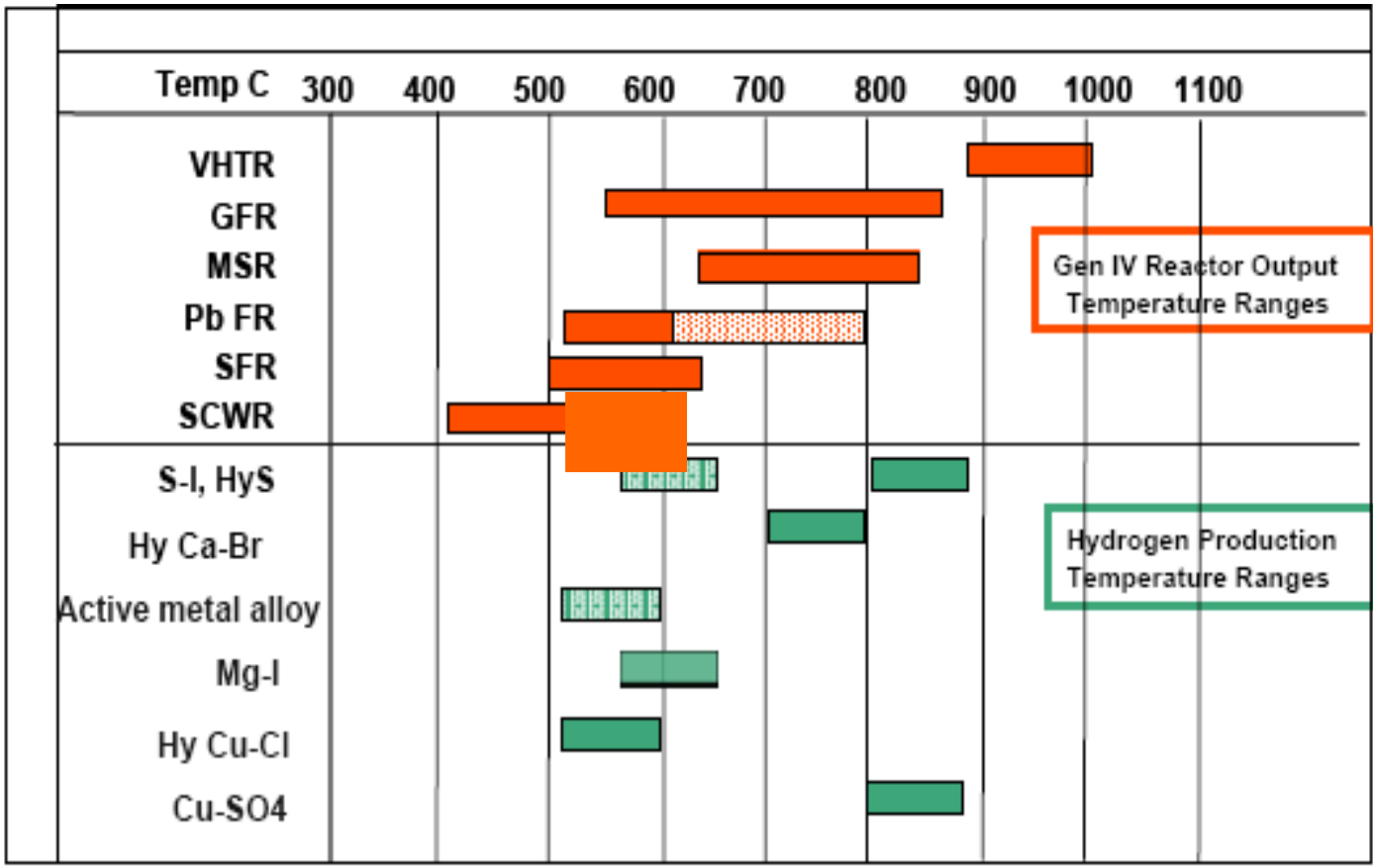
# Operating Ranges of Gen-IV Concepts & Hydrogen Production Technology Requirements

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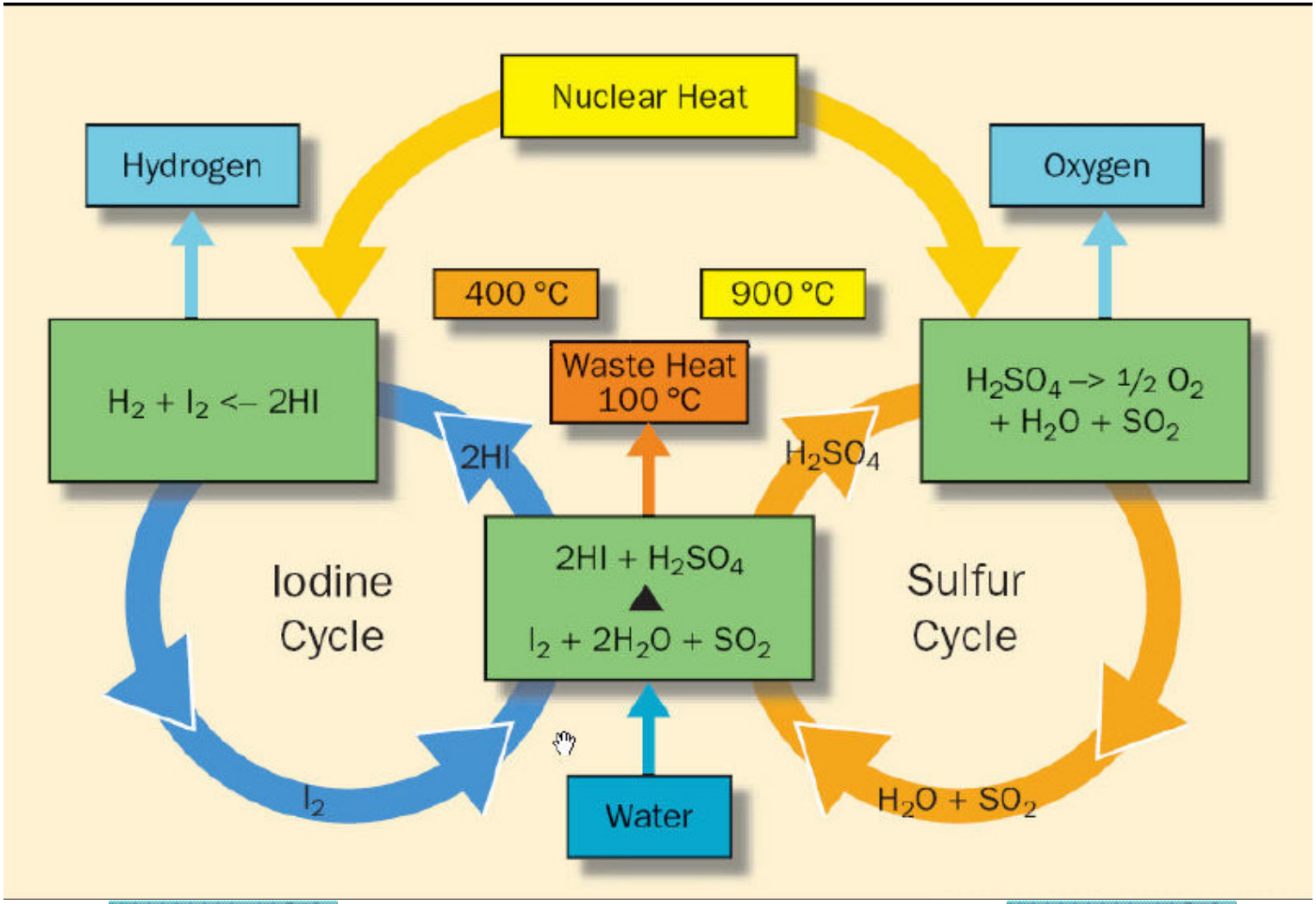
# The Sulphur-Iodine Cycle (US, EU, Japan)

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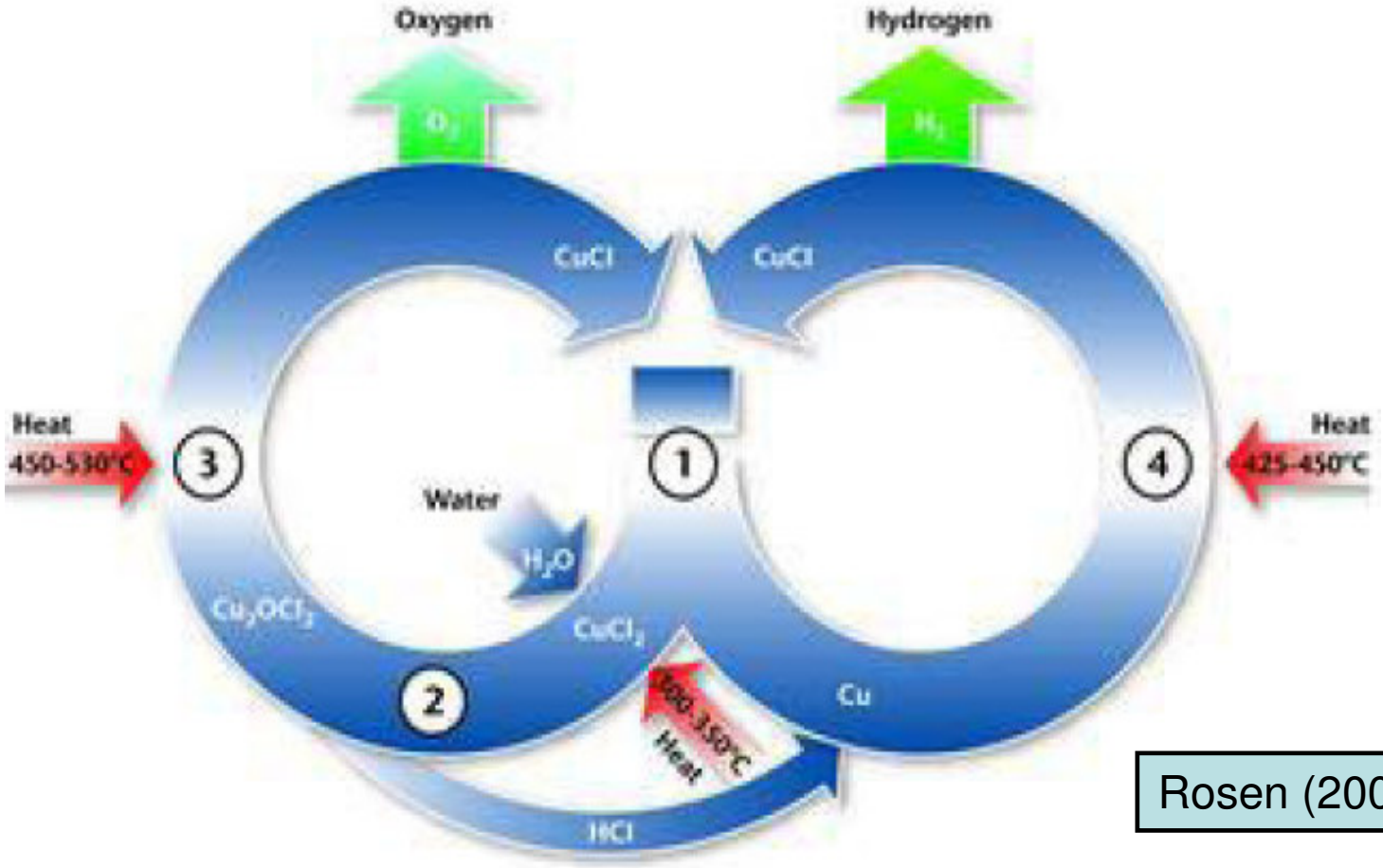
# The Copper-Chlorine Cycle



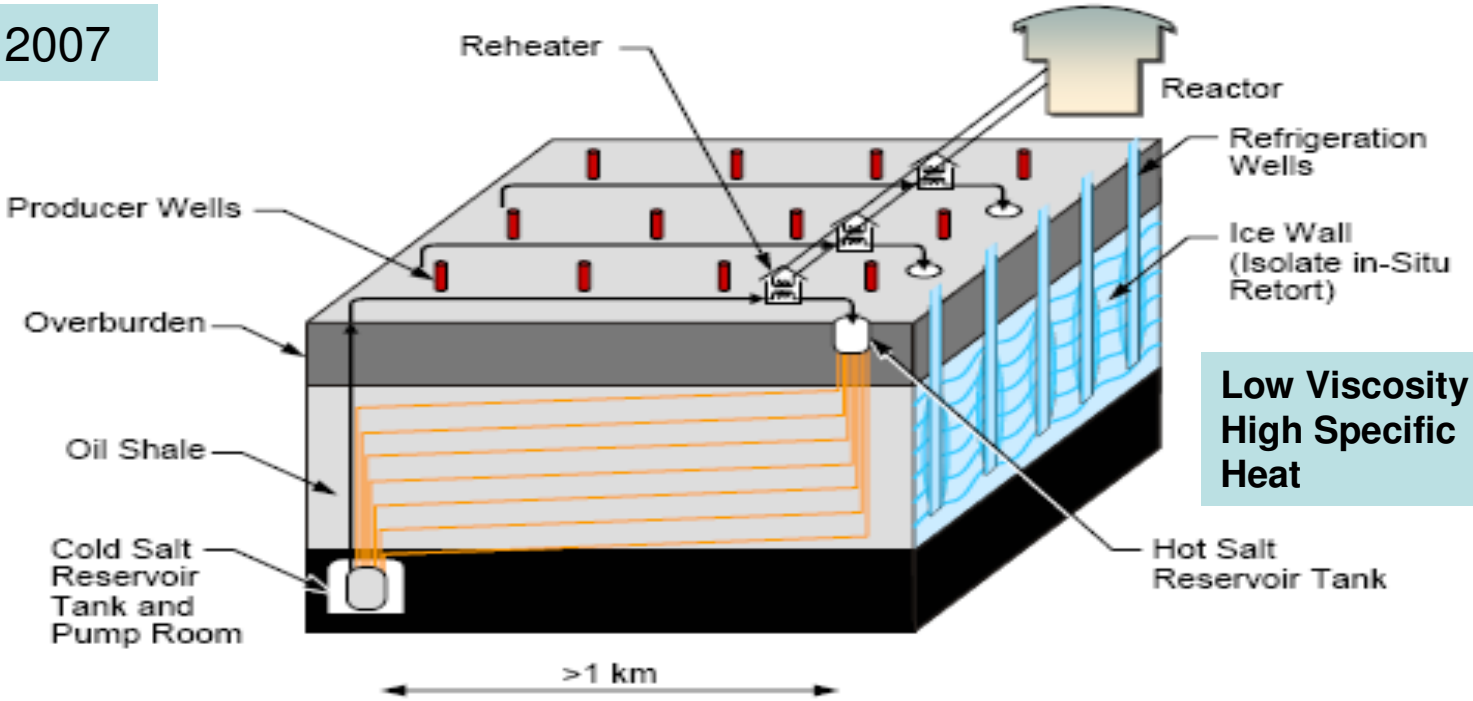

Rosen (2006)

# Related Applications
# Liquid Salt as Heat Transport Fluid instead of SAGD

## Nuclear-Heated In-Situ Oil-Shale Conversion Process

### Liquid-Salt Heat-Transport Loop

Forsberg 2007




**Low Viscosity**
**High Specific Heat**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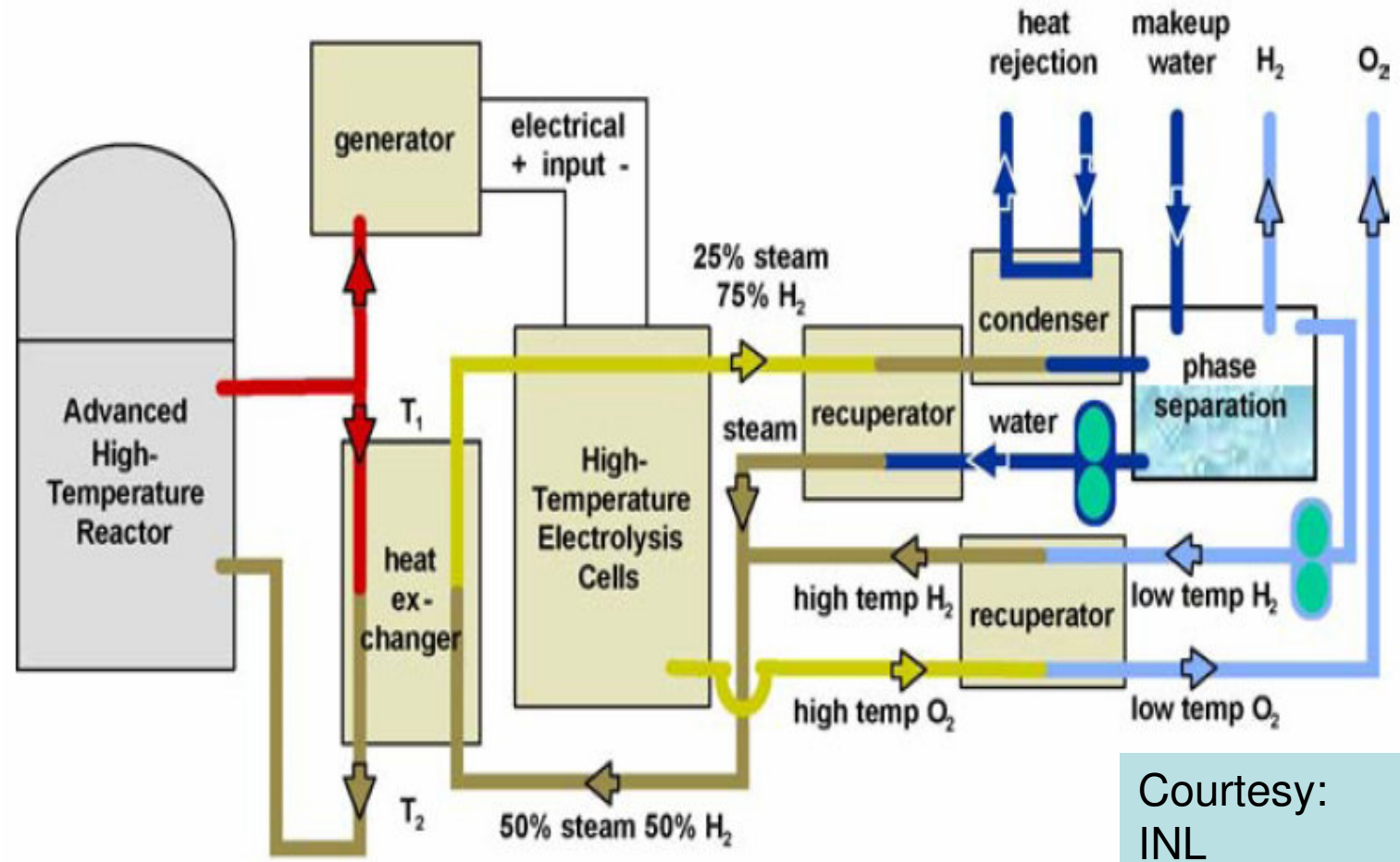
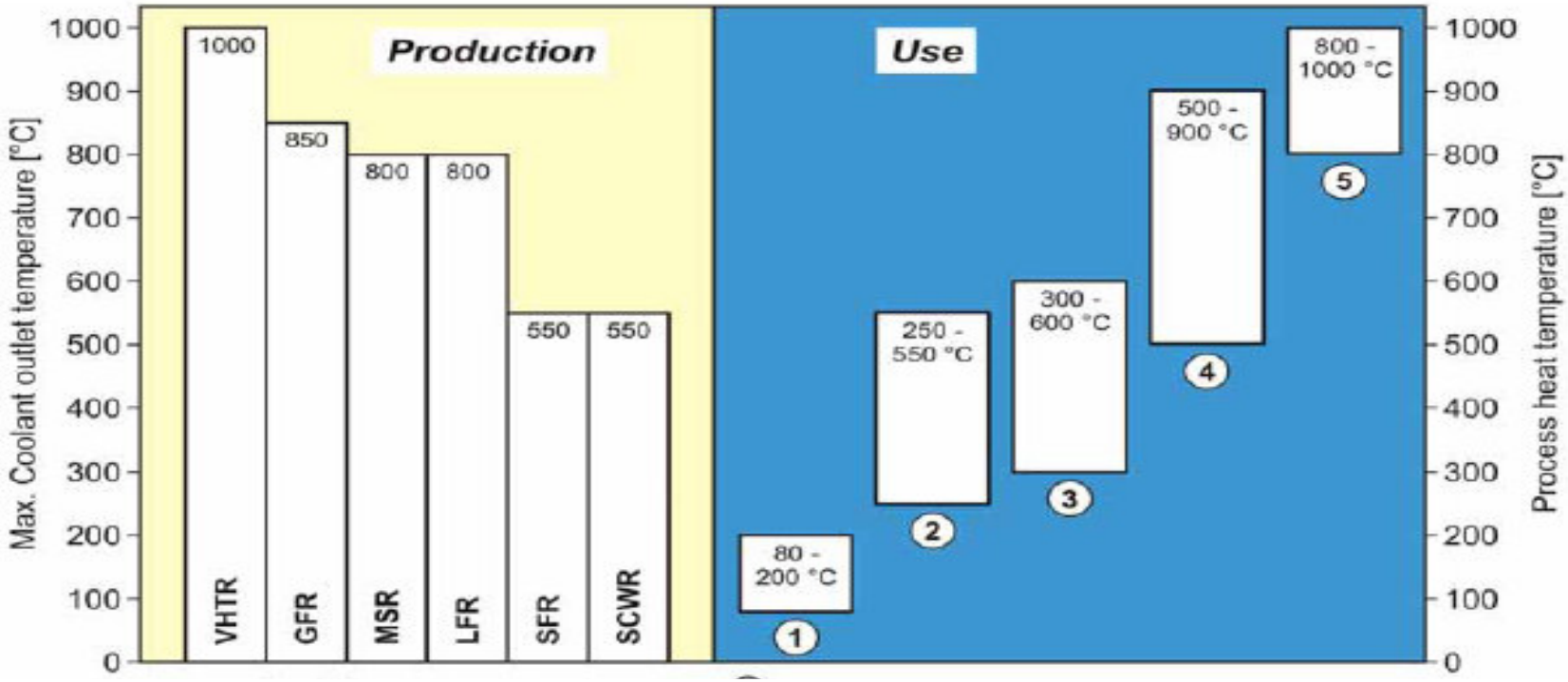
# Conceptual Schematic of a Nuclear-powered High Temperature Electrolysis Plant




Courtesy: INL

# Gen-IV Reactor Outlet Temperatures
# Possible Non-Electric Uses




(1) District Heating, Seawater Desalination. (2) Petroleum Refining. (3) Oil Sand Processing. (4) Nuclear Steam Methane Reforming. (5) S-I Cycle, High Temperature Steam Electrolysis, Coal Gasification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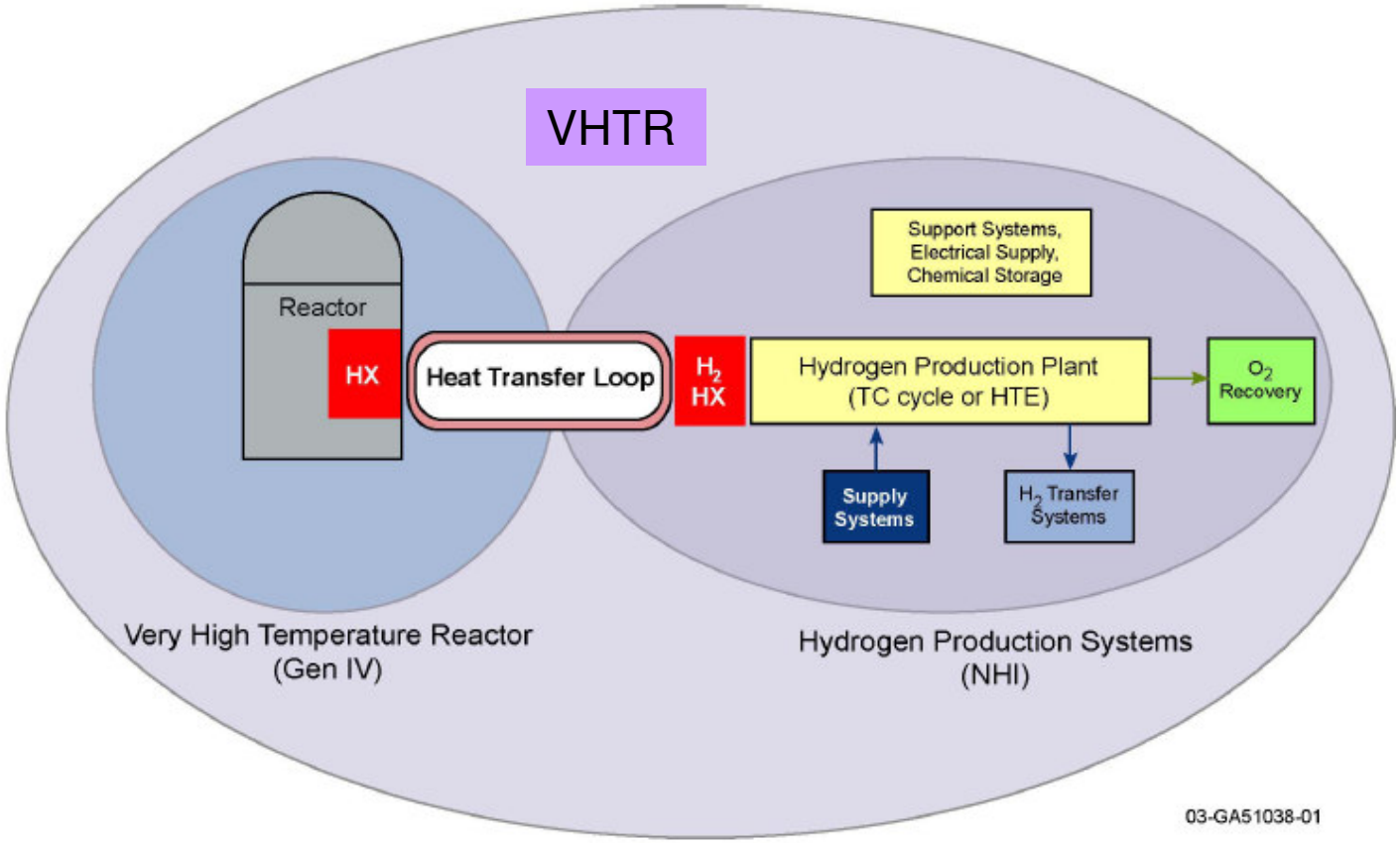
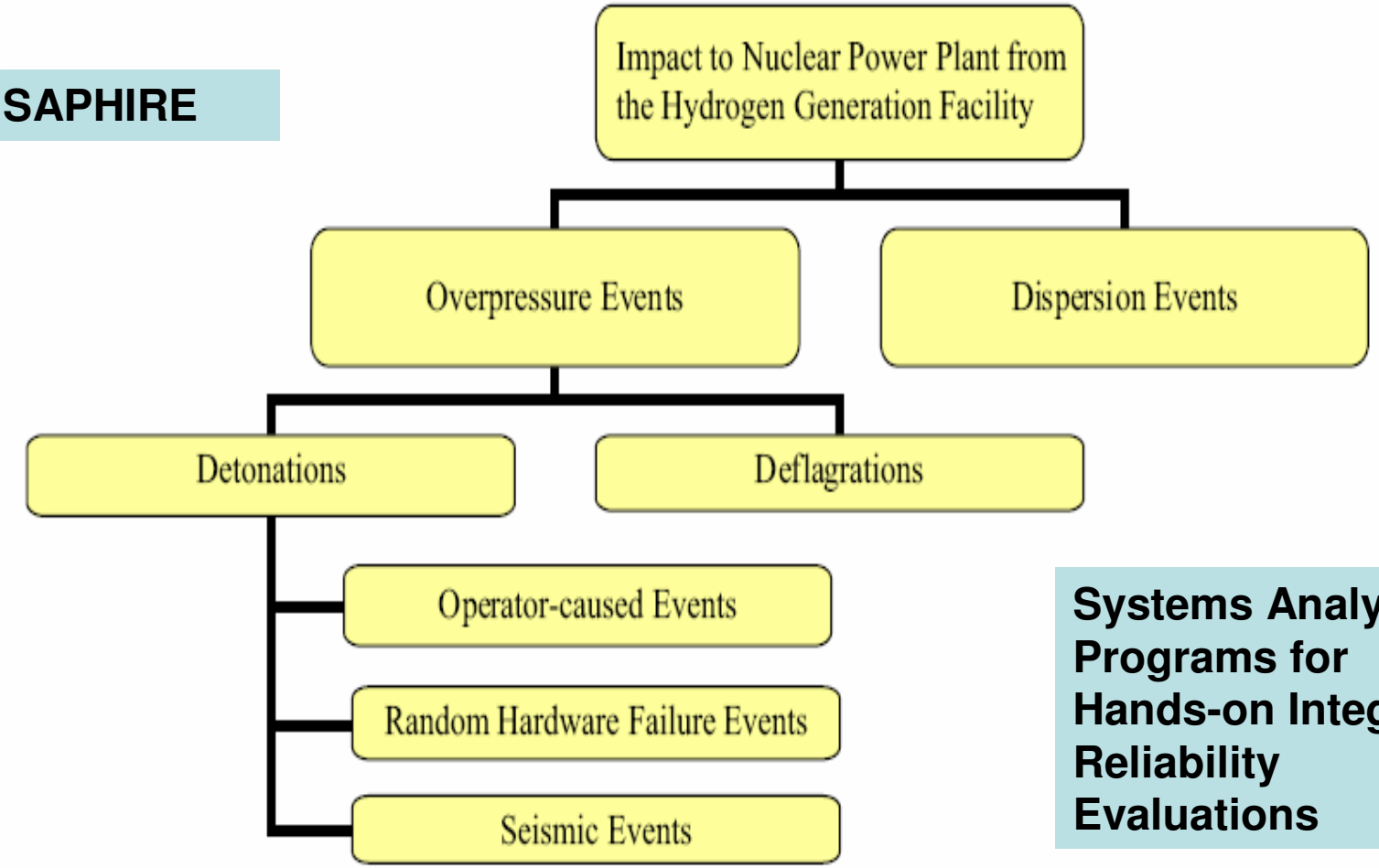
# Schematic of Nuclear Reactor Coupled to Hydrogen Plant



# Master Logic Diagram for Hydrogen Disruption Scenarios (Smith 2006, INL)

**SAPHIRE**




**Systems Analysis Programs for Hands-on Integrated Reliability Evaluations**

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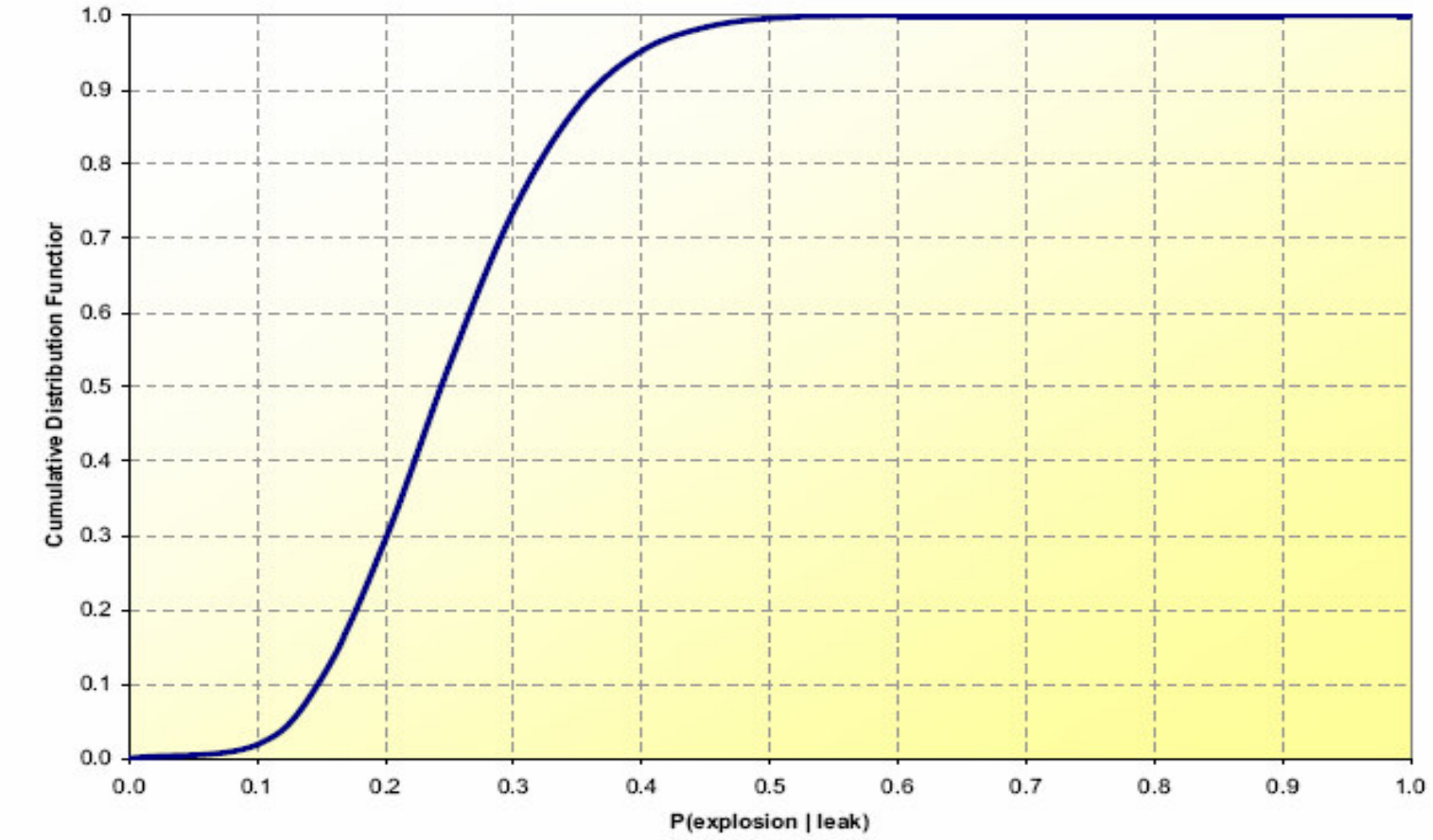
# Conditional Probability of an Explosion Given a Hydrogen Leak




History + Physics-based model

25% of Leaks resulted in Explosions

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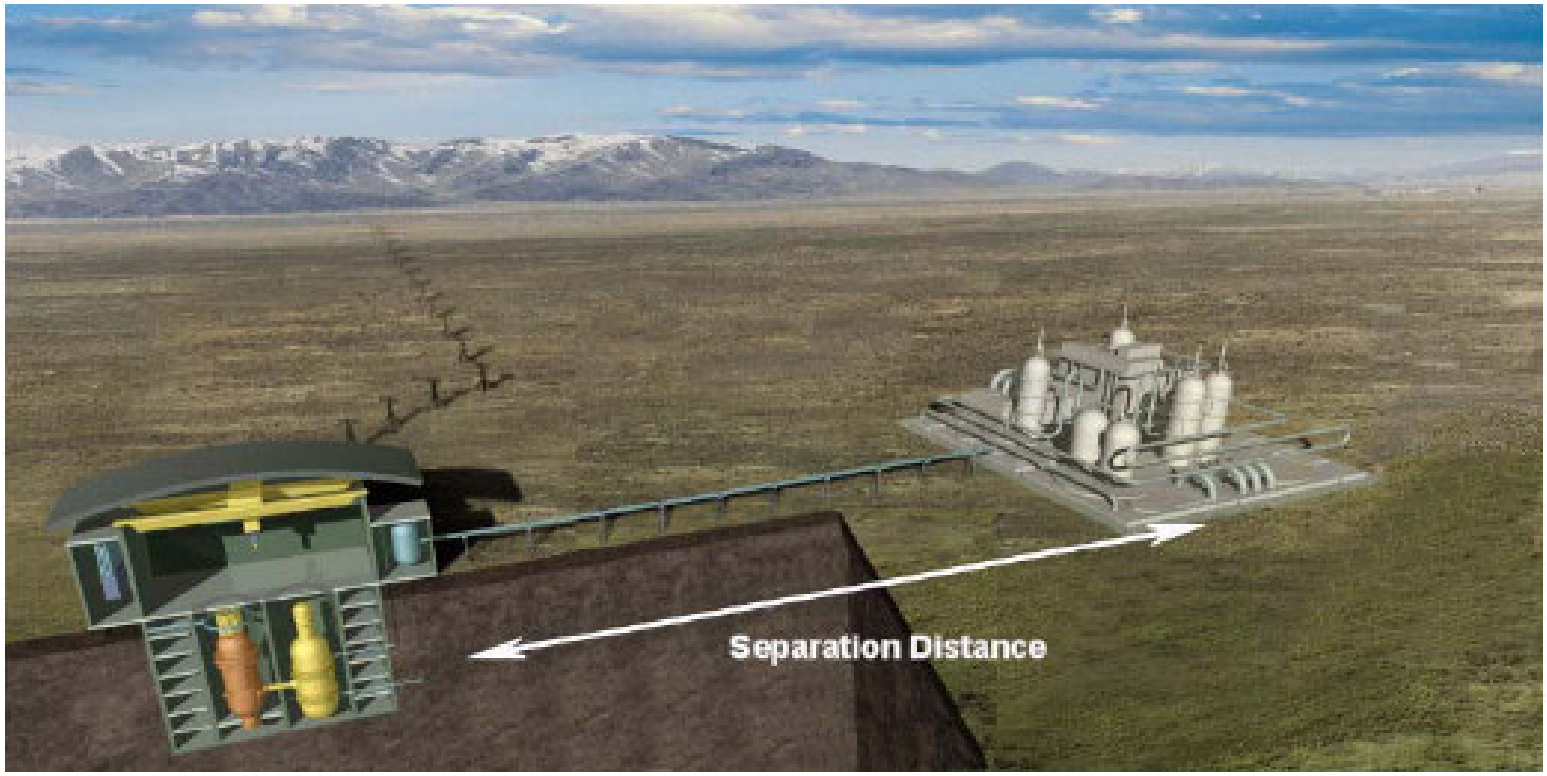
# 1. Separation Distance between Nuclear and Thermochemical Plants




**C. Smith, S. Beck and W. Galyean**, "Separation Requirements for a Hydrogen Production Plant and High Temperature Nuclear Reactor", INL-EXT-05-00137, October 2006.

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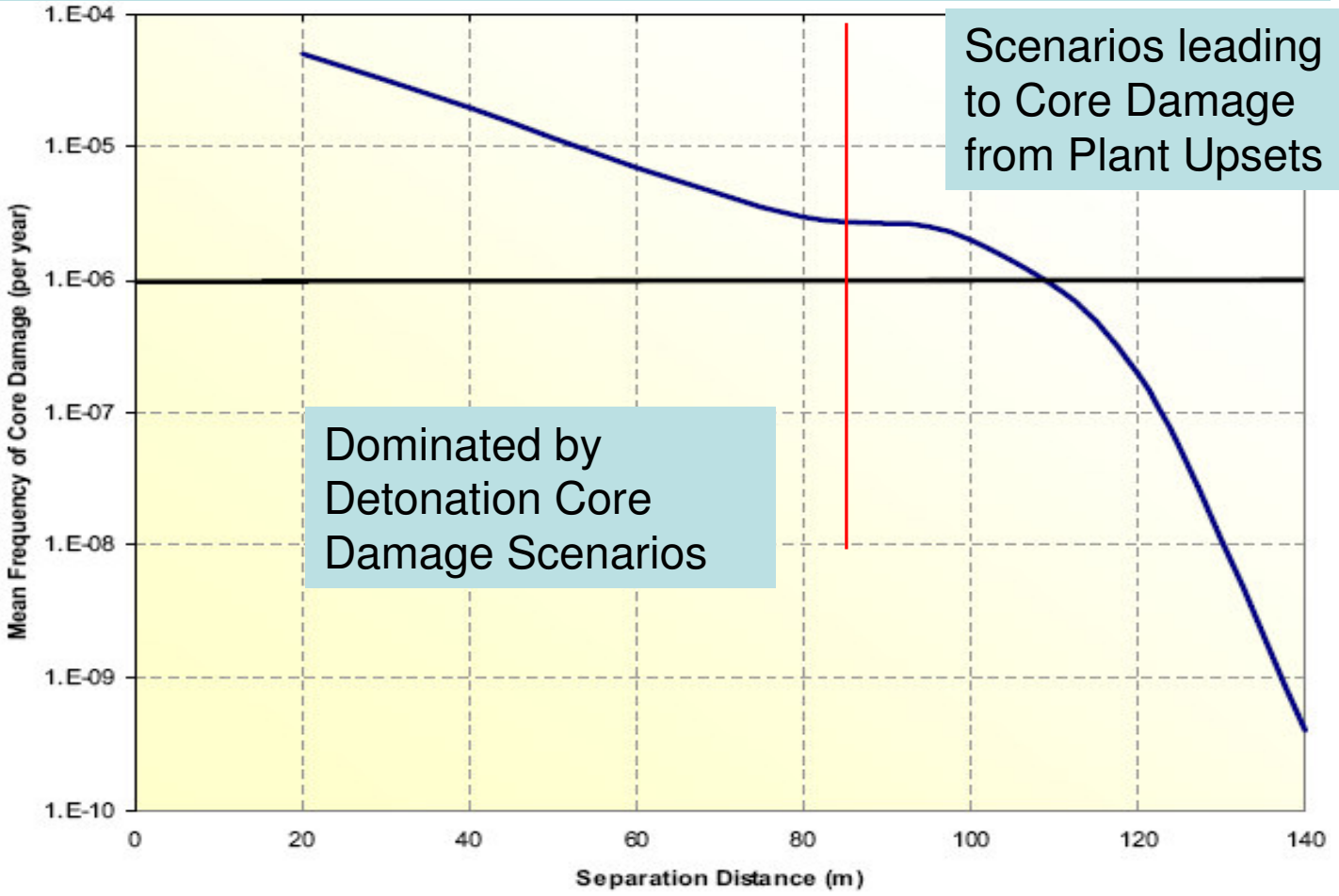
# Core Damage Risk as a Function of Separation Distance

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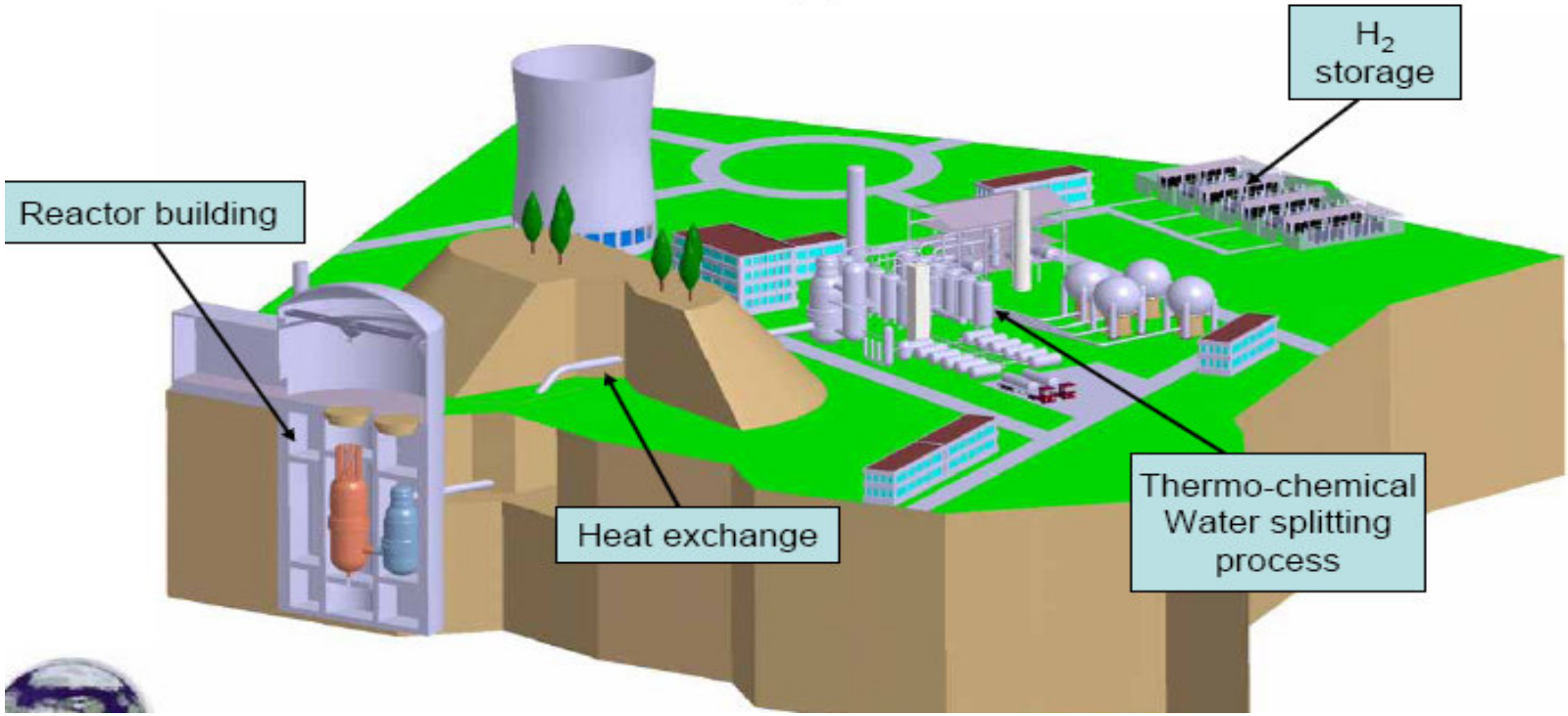
# Summary of Case Studies (Smith, Beck, Galyean 2006)

| Case | Description | Mean Core Damage Frequency (per year) | Mean Chemical Dispersion Frequency (per year) |
|---|---|---|---|
| Nominal | No mitigating features and the separation distance set at 60 m | 7E-6 | 3E-3 |
| 1. | Varying the separation distance between the nuclear and hydrogen production facilities | Figure | 3E-3 |
| 2. | Constructing an earthen barrier between the nuclear and chemical facilities | 4E-10 | 3E-3 |
| 3. | Constructing the nuclear facility primarily underground | 4E-10 | 3E-3 |
| 4. | Constructing blast panels near the chemical facility to dampen overpressure events | 4E-10 | 3E-3 |
| 5. | Constructing the chemical facility primarily underground | 8E-11 | 8E-4 |
| 6. | Moving the nuclear plant control room offsite | 7E-6 | Releases no longer impact control room |

# Potential Arrangement of 600 MW VHTR for $H_2$ Production




**Verfondern (2006)**

# INL Study Recommendations Regarding Nuclear Hydrogen Plants

Other recommendations from the INL study include:

- A 100 kg on-site limit for Hydrogen storage.
- Quickly Pipe out as produced.
- Use of double-walled pipes for hydrogen transport
- Location of the nuclear plant control room outside of the dispersion zone for chemical release.