Nuclear Energy for Oil Sand Production

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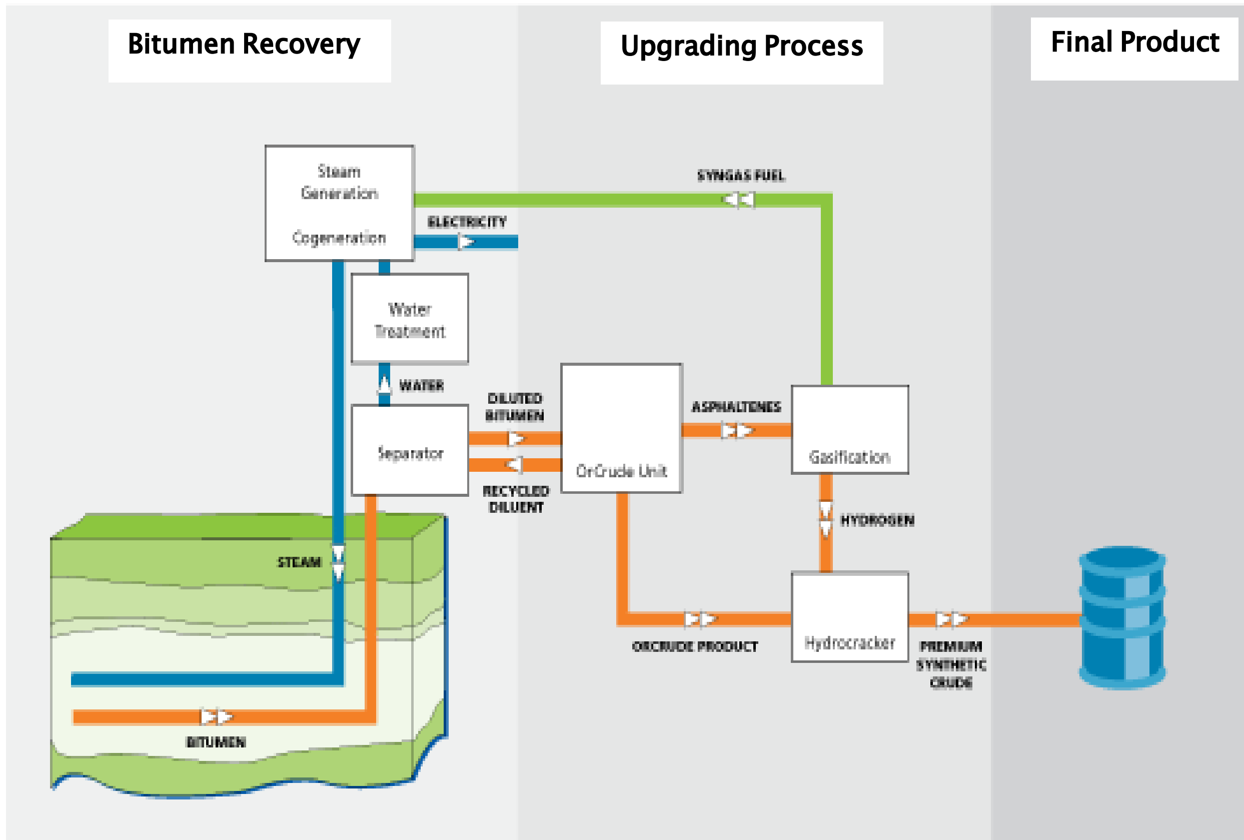
Canadian Oil Sands

- There are an estimated 1.7 x 10^{12} barrels of bitumen in northeast Alberta, of which about 3.0 x 10^{11} barrels are recoverable with current technology.
- Recovering bitumen and converting it to synthetic crude oil is an energy-intensive process. The principal source of this energy is hydrocarbon combustion.

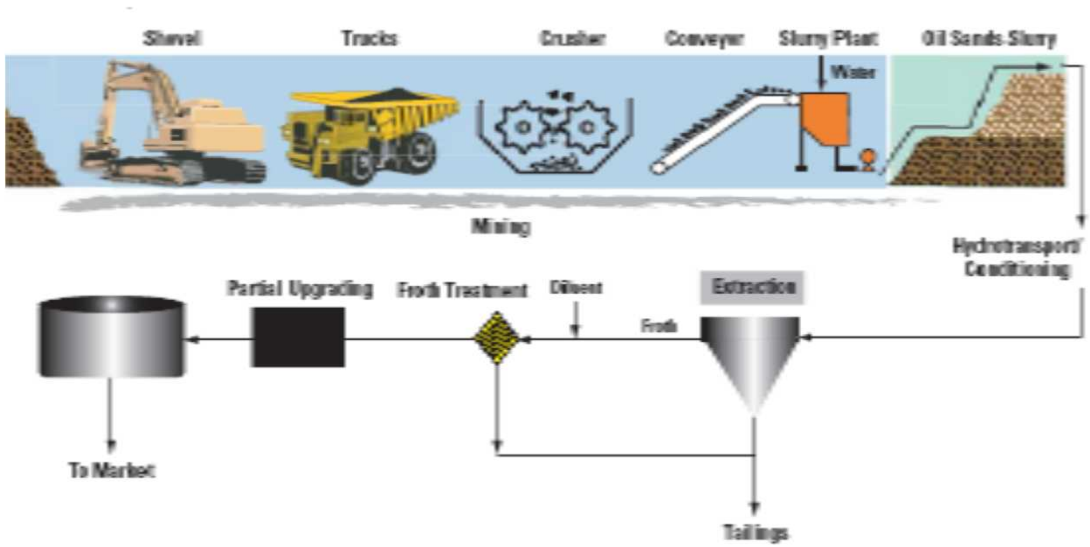
Oil Sand Production

Phases of Production

- Bitumen Recovery
  - Mining and Extraction
  - SAGD
  - CSS
  - Emerging Technologies of VAPEX & THAI
- Upgrading
- Transportation to Market



Mining



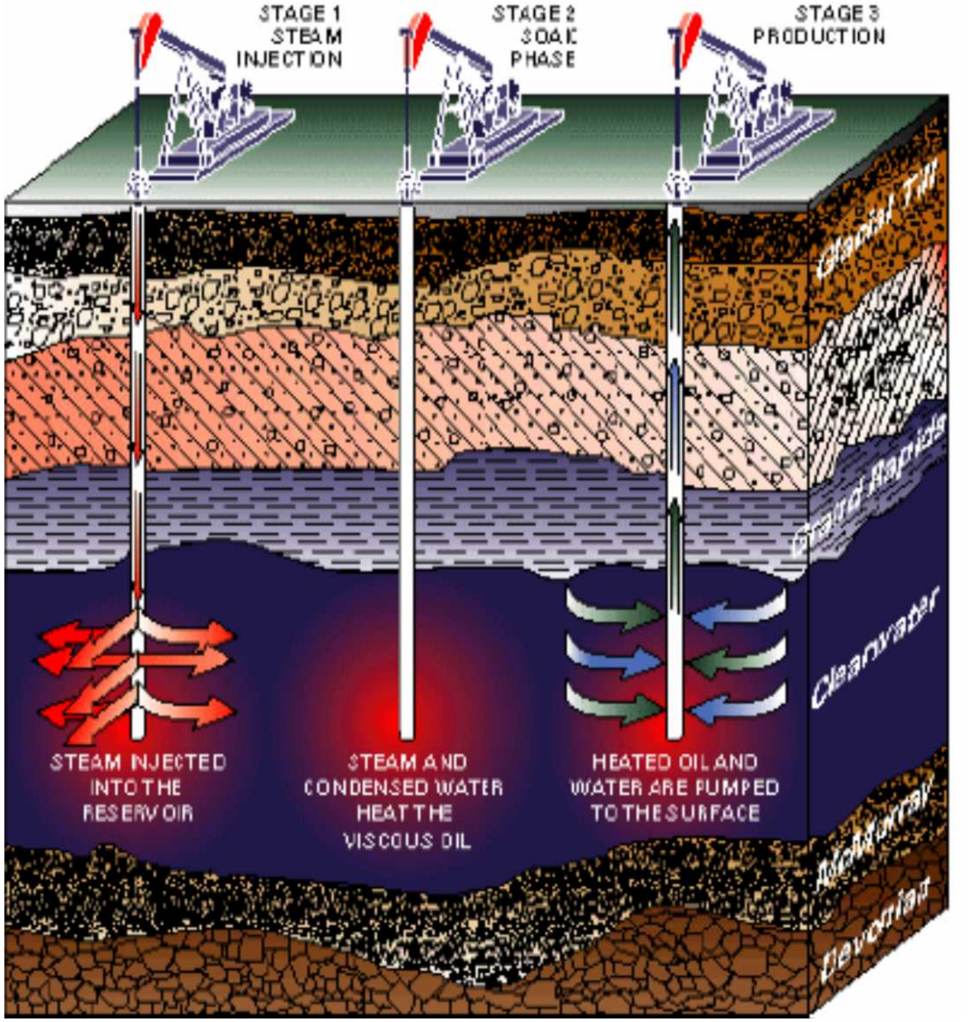
About 20% of the oil sands are buried shallow enough to recover through mining. The oil sand is soaked in hot water to release the bitumen, which is upgraded to SCO.

- **Mining presently accounts for approximately 65% of bitumen extraction.**
- **Mining creates an environmental mortgage around land restoration.**
- **About 0.2 gJ/b is needed to create upgrader feedstock.**
- **CO_2 emission = 10 kg/b**

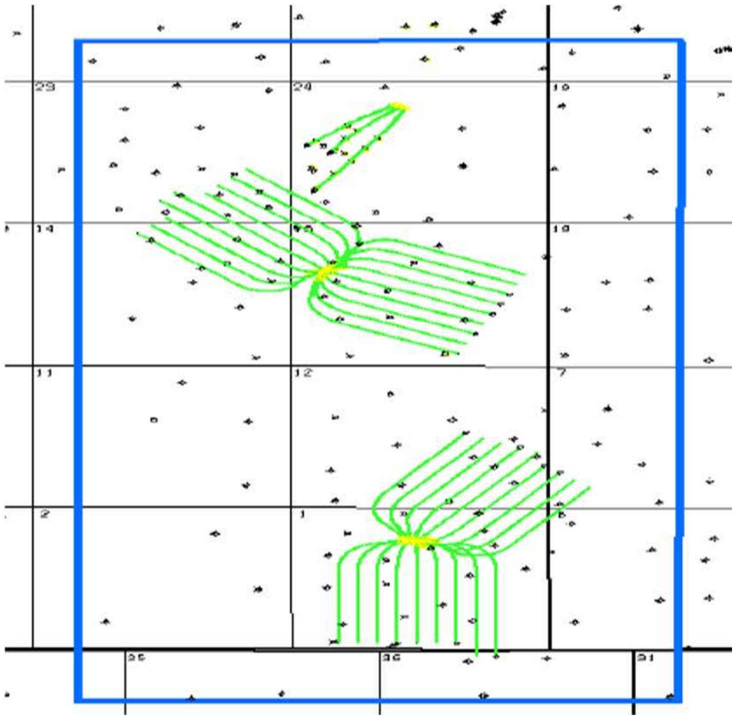
Cyclic Steam Stimulation (CSS)

Cyclic Steam Stimulation uses steam piped vertically into the formation to lower the viscosity of the bitumen. Steam injection is cyclic, requiring a three-stage process.

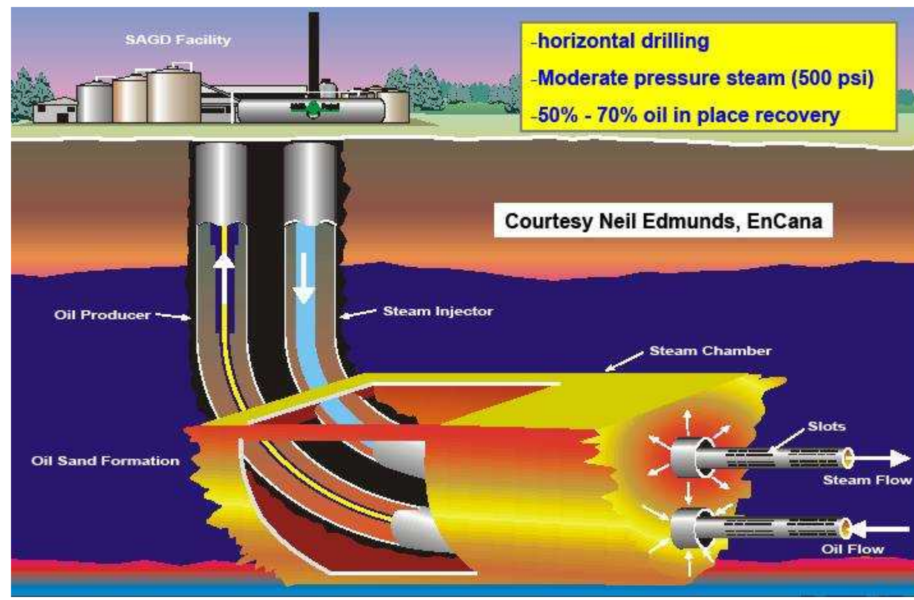
- **Typical CSS Cycle**
  - Injection (4 – 6 weeks)
  - Soak (4 – 8 weeks)
  - Production (3 – 6 weeks)
- Requiring about 1.0 gJ/b
- 20 – 25% recovery rate
- Uses about 350°C steam



Steam-Assisted Gravity Drainage



Steam-assisted Gravity Drainage (SAGD) uses steam piped horizontally into the subsurface formation to lower the viscosity of the bitumen. Bitumen flows to a well that is approximately 5 meters lower and is brought to the surface, where it is separated from the water/steam.

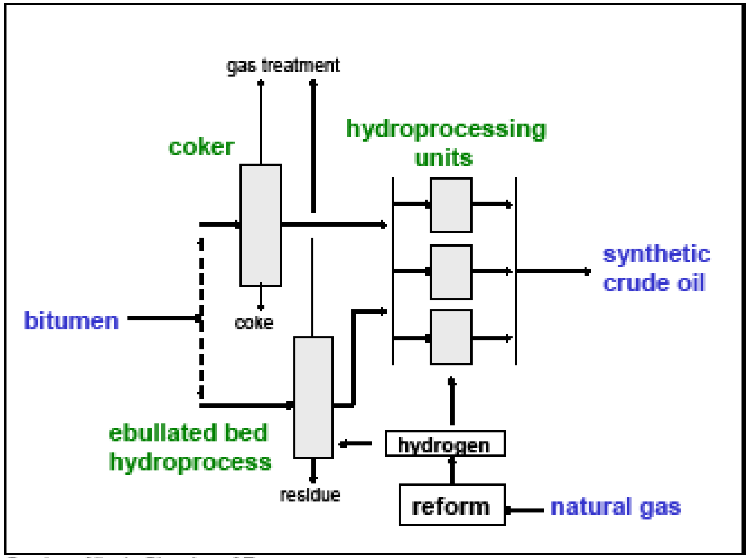


- **SAG is a continuous process**
- **Requires about 1.1 gJ/b**
- **40 – 70% recovery rate**
- **Oil flow is proportional to effective length**
- **Uses about 300°C steam @ 500 psi**

Bitumen Upgrading to Synthetic Crude Oil

- Upgrading consumes natural gas both as a fuel and as a source of H_2
- Natural gas consumption is approximately 0.5 GJ/b 480 cf/b

- Upgrading is typically a two-step process:
  - Primary upgrading is largely based on coking, but catalytic processes are increasing. This step leaves significant sulphur and nitrogen compounds.
  - Secondary upgrading uses large hydro-treaters to produce synthetic crude oil (SCO).
- SCO production consumes approximately 1 x 10^3 sef/b H_2



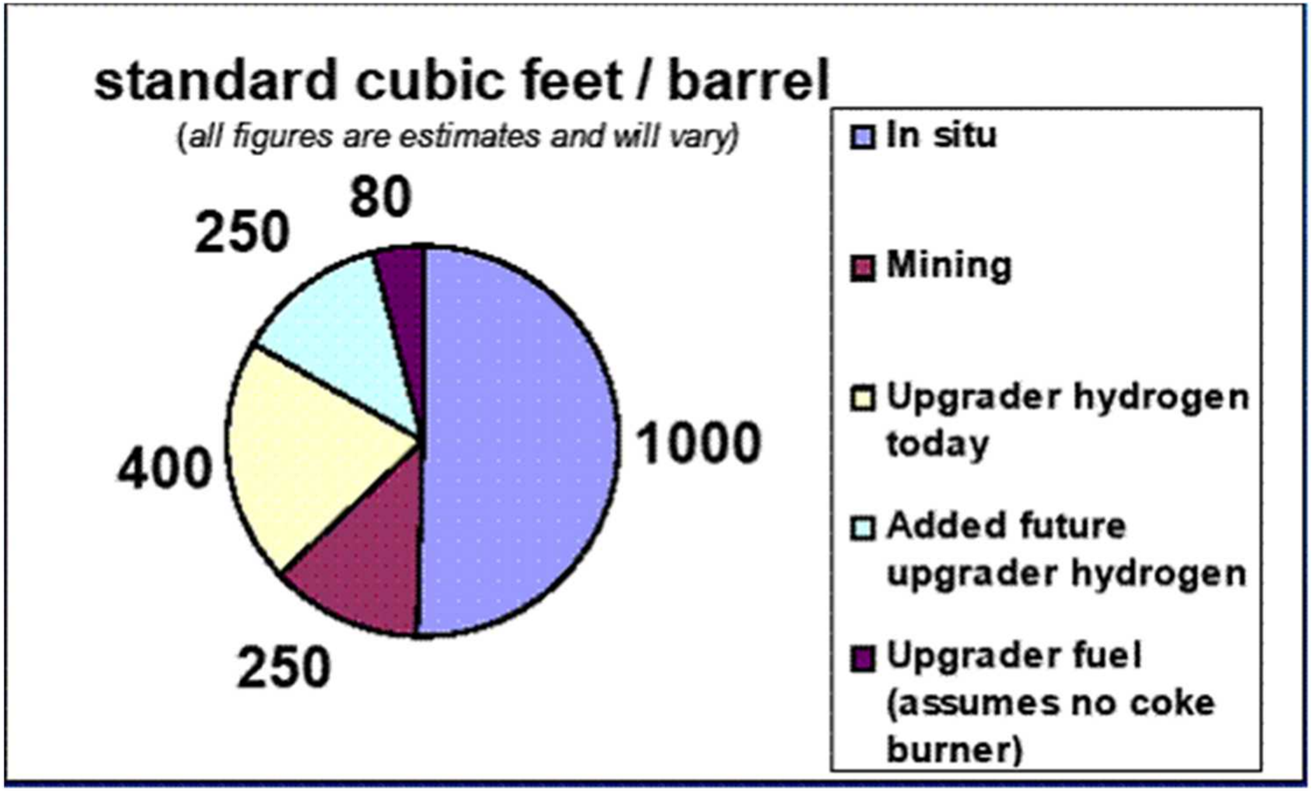
Courtesy Alberta Chamber of Resources

What About Transportation?

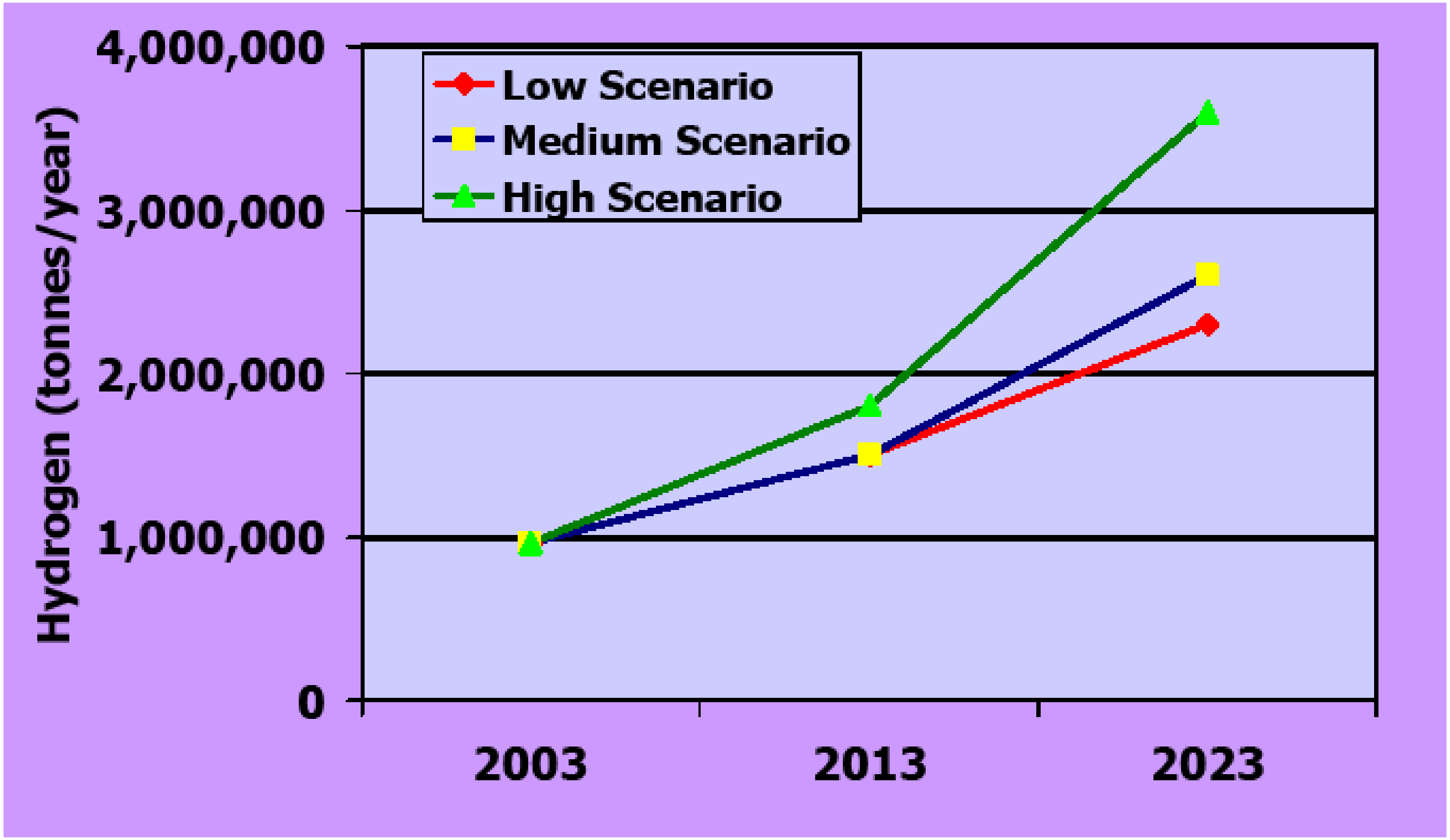
Compressor Stations Can Be Expensive

Need of Natural Gas

Recovery and upgrading of bitumen from the oil sands consume large amounts of natural gas, electricity, and hydrogen. Natural gas is the main source of energy and hydrogen [historical origin].

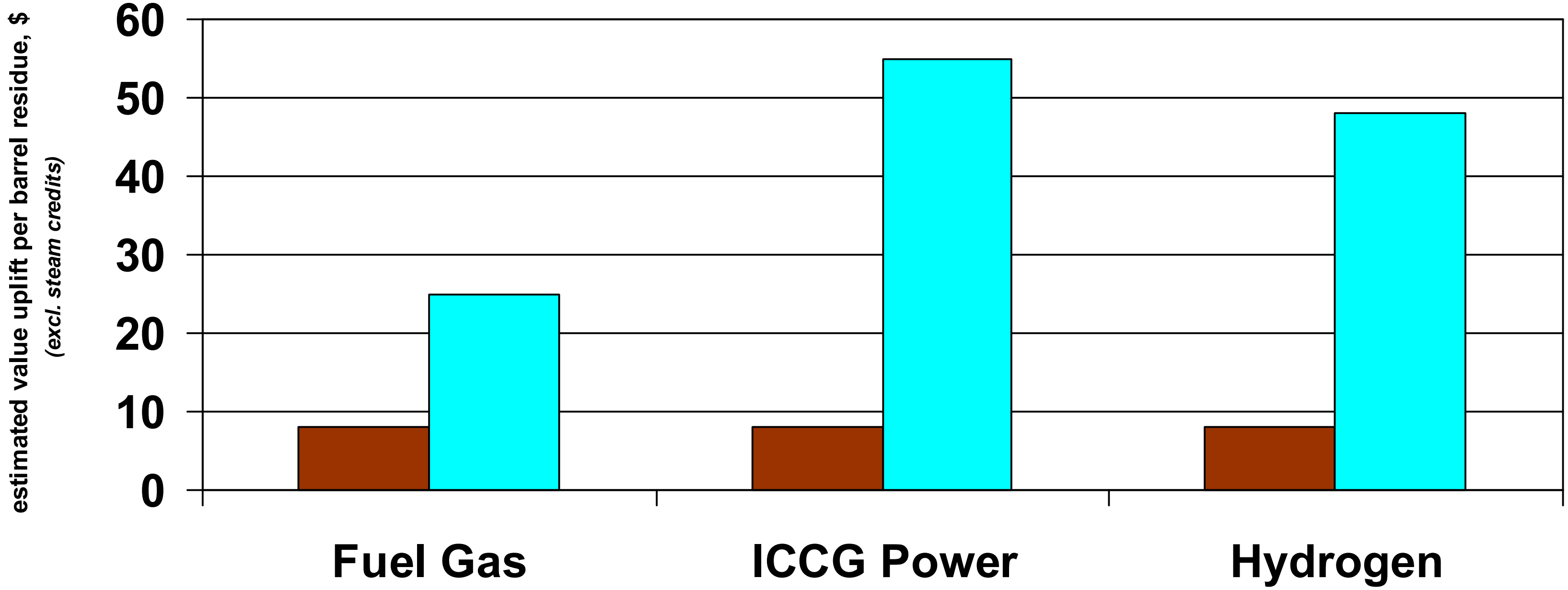


Oil Sands Hydrogen Demand Scenarios



Source: Canadian Hydrogen. Current Status and Future Prospects, Dalcor Consultants & Intuit Strategies, August 2004

Projected CO_2 Emissions



Assumptions:

- **residue value $8 per barrel**
- **Natural Gas $5 per GJ**
- **Hydrogen @ 0.64 x Natural Gas**
- **Power $0.06 per KW -h**

Source: OSTRM

Nuclear Energy for Oil Production

PROS

- Nuclear Power Produces Little Greenhouse Gases
- Stable and Predictable Cost
- Allows Alternative Uses for Natural Gas
- Easily Sized to the Application
- Electricity is a By-Product

CONS

- New Technology to SCO Product
- High Capital Investment
- Politically Difficult to Sell
- Accidents Can Be Both Financially and Politically Expensive

One Option for Oil Sand Production

A network of small (50 – 200 MW) liquid metal-cooled fast reactors could substantially reduce natural gas consumption and greenhouse gas emissions in SCO production

- Commercially available
- Inherently safe
- Small footprint
- Fuel could be very inexpensive
- Could close the nuclear fuel cycle
- Long refueling cycle
- Low operating overhead

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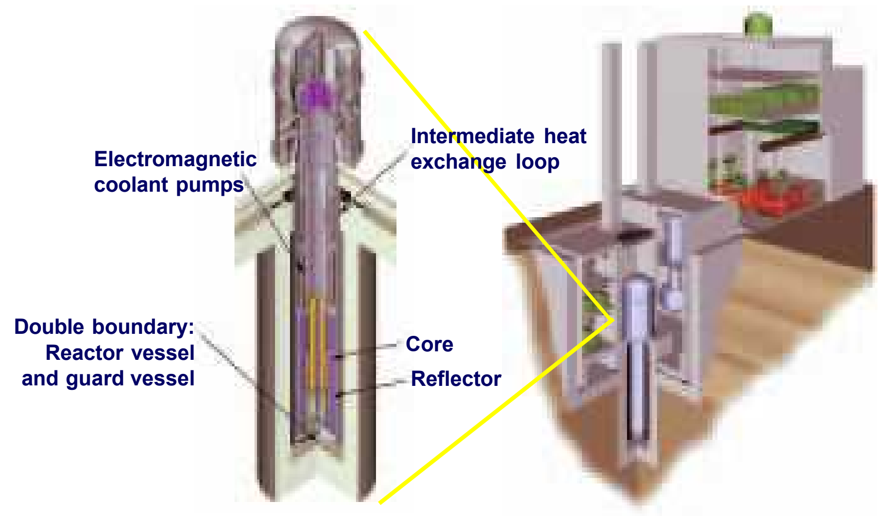
Case Study: Upgrader

- **Consider a 30,000 bl/d upgrader**
- **Energy needed is .5 GJ/bl or about 175 MW for the plant**
- **This demand could be produced by two 90 MW thermal Liquid Metal Fast Reactors**
- **The Toshiba 4S currently in licensing with the NRC is 30 MW thermal and a 100 MW thermal was designed at the same time.**
- **Argonne National Laboratory and General Electric both have completed FBR designs in this power range**

Yukon Town Studies Option – 30 Years of Clean Nuclear Energy

- Present cost of power through diesel generators is over $1/kW-hr
- 4S power is projected to be $.04-.05/kw-hr
- The Alaskan governor has asked Toshiba to consider building 4 or 54S plants in Alaska

- Toshiba 4S (super-safe, small, simple) reactor capital costs $20-30M
- Toshiba held their first presentation with the NRC October 23, 2007
- Toshiba, Westinghouse, RCRIEPI, and Argonne National Laboratory have a partnership
- Design approved by 2011 with combined license by 2012



The Toshiba 4S features a sodium-cooled reactor that requires no refueling during its 30-year life-span.

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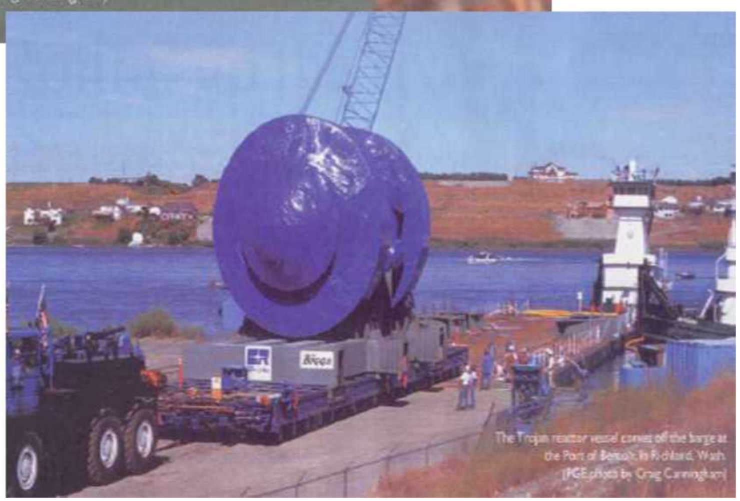
After 30 Years

About the decommissioning after 30-year operation

The barge, reactor vessel on board, makes its way up the Columbia River. (PGE photo by Craig Cunningham)



The Trojan reactor vessel comes off the barge at the Port of Benton in Richland, Wash. (PGE photo by Craig Cunningham)

1. **Fuel**

   Long-term geologic repository in Yucca Mountain site.

2. **Reactor**

   Transport and disposition in accordance with US experience.

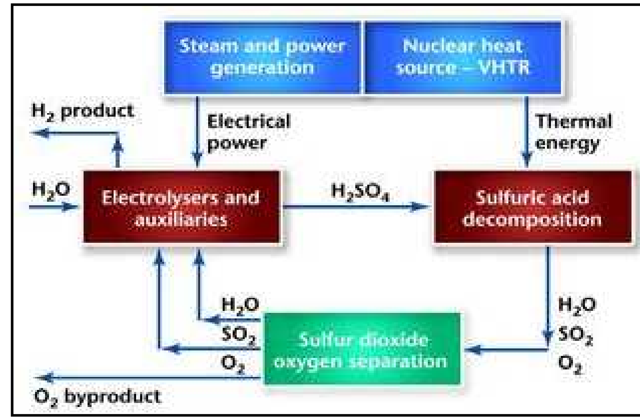
3. **Sodium, buildings & substructure**

   Reutilized for next 4S installation.

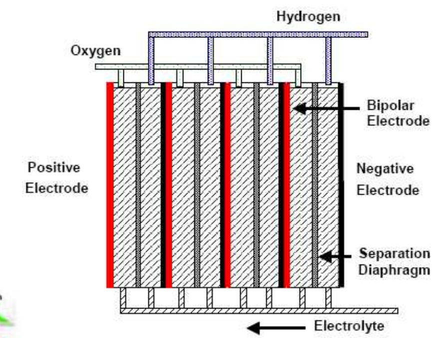
Reference photos: http://www.nucleartourist.com/systems/rv_trip.htm

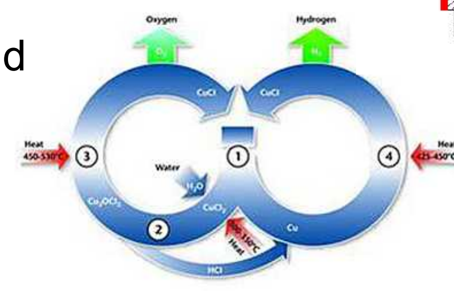
Hydrogen Production

- Local H2 production for upgrading, conservation of CH4, and elimination of CO2 (from SMR or proposed coal gasification).
- On-site-reactor allows H2 use "on-demand at mine-site or up-grader.
- Joint/mixed operation of electrical generation, H20 splitting, and process heat as needed.



- GCR and LMR can support higher efficiency for electrolysis and higher temperatures for thermochemical process.
- Highest efficiency, high-temperature-steam electrolysis requires Solid Oxide Electrolysis Cell. Conventional electrolysis uses high-efficiency Proton Exchange Membrane. Engineering optimization still required.
- Thermochemical process needs material studies and optimization.
- Thermochemical (50% efficiency: Sulfur-Iodine)
- Electrochemical (45% efficiency: Brayton Cycle)
- Low-temperature Cu-Cl cycle (45% efficiency)





clear-based hydrogen production in a thermochemical Cu-Cl cycle

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Liquid Metal Reactors Have a Long History

- **Experimental Breeder Reactor (EBR I) 1951 (INEEL Site)**
- **Used NaK as Coolant**
- **Produced First Electric Power**
- **Pumped by Electromagnetic Pumps**
- **Operated for 12 Years**
- **Maximum Outlet Temperature was 350°C**

EBR I Was Followed by a Series of Other Liquid Metal Cooled Reactors

- **EBR II (Na cooled, 62.5 MWt)**
- **SEFOR (Na cooled, 20 MWt Commercial Power Reactor)**
- **FERMI I (Na cooled, 300 MWt Commercial Power Reactor)**
- **FFTF (Na cooled, 400 MWt Test Reactor)**

Other Countries Have Liquid Metal Reactors

- **Russia (BN5, BOR 60, BN350, BN600)**
- **Japan (MONJU)**
- **United Kingdom (DFR, PFR)**
- **France (Rapsodie, Phenix, Super Phenix)**