CANDU Nuclear Plant Configured for Multiple Oil Sands and Power Applications

CNS Annual Conference
Calgary, Alberta

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May 31 – June 3, 2009

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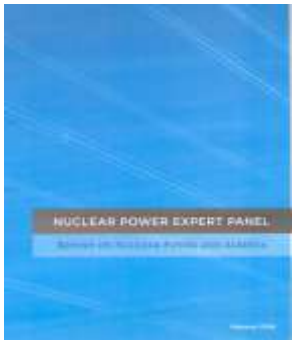
Alberta

Background

4600 MW to 9500 MW **of new electricity generation could be required by 2024.**



Demand for electricity for oil sands operations alone could reach *3200 MW* by 2030

A positive outcome from public consultation on the Nuclear Power Expert Panel Report should enable the Alberta Government to endorse nuclear in Alberta

Proposition

Oil prices are rising slowly and the Alberta economy will recover its strong growth over the next 12 to 24 months

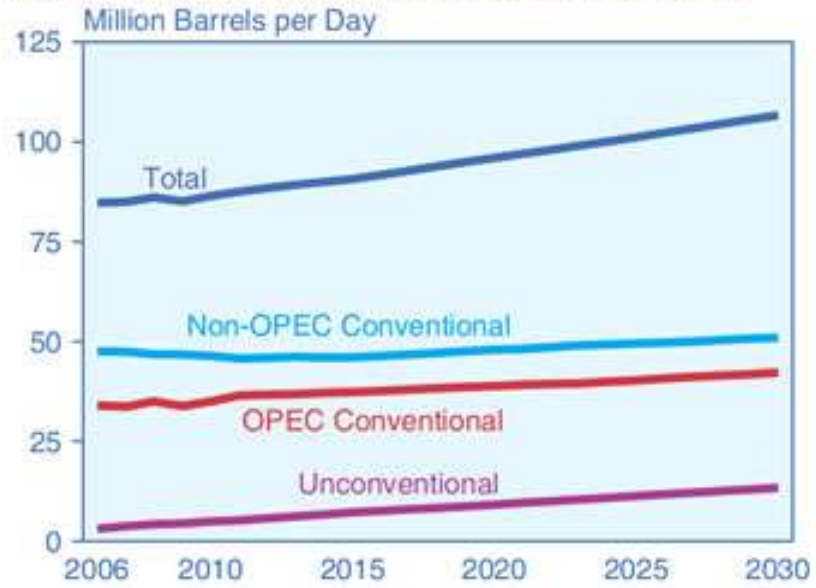
Market Drivers

“De-carbonizing” of the oil sands will encourage producers to look at low GHG extraction technologies and energy sources

World Oil Demand & Unconventional Fuels

Global Oil Demand

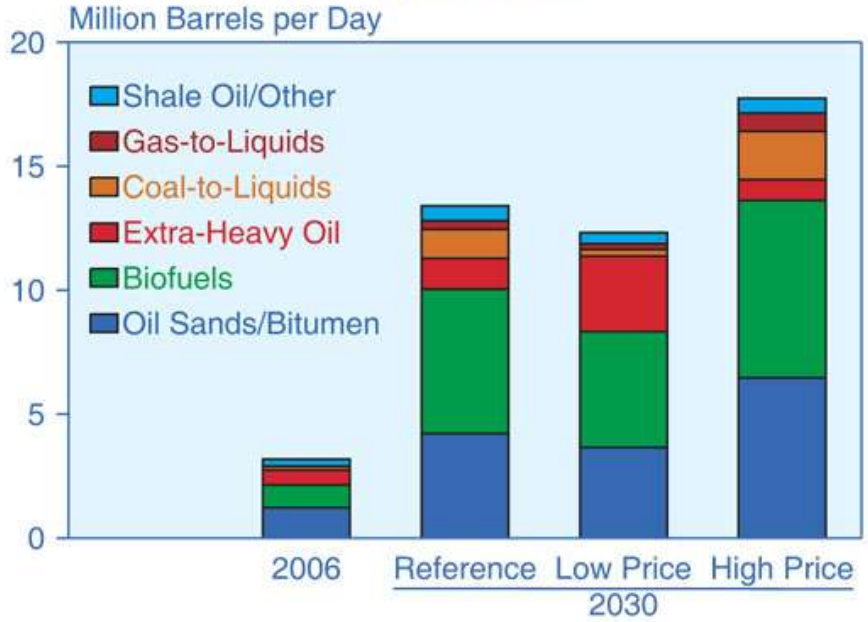
Figure 4. World Liquids Production, 2006-2030



Sources: **2006:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, Generate World Oil Balance Model (2009).

Unconventional Production Forecast

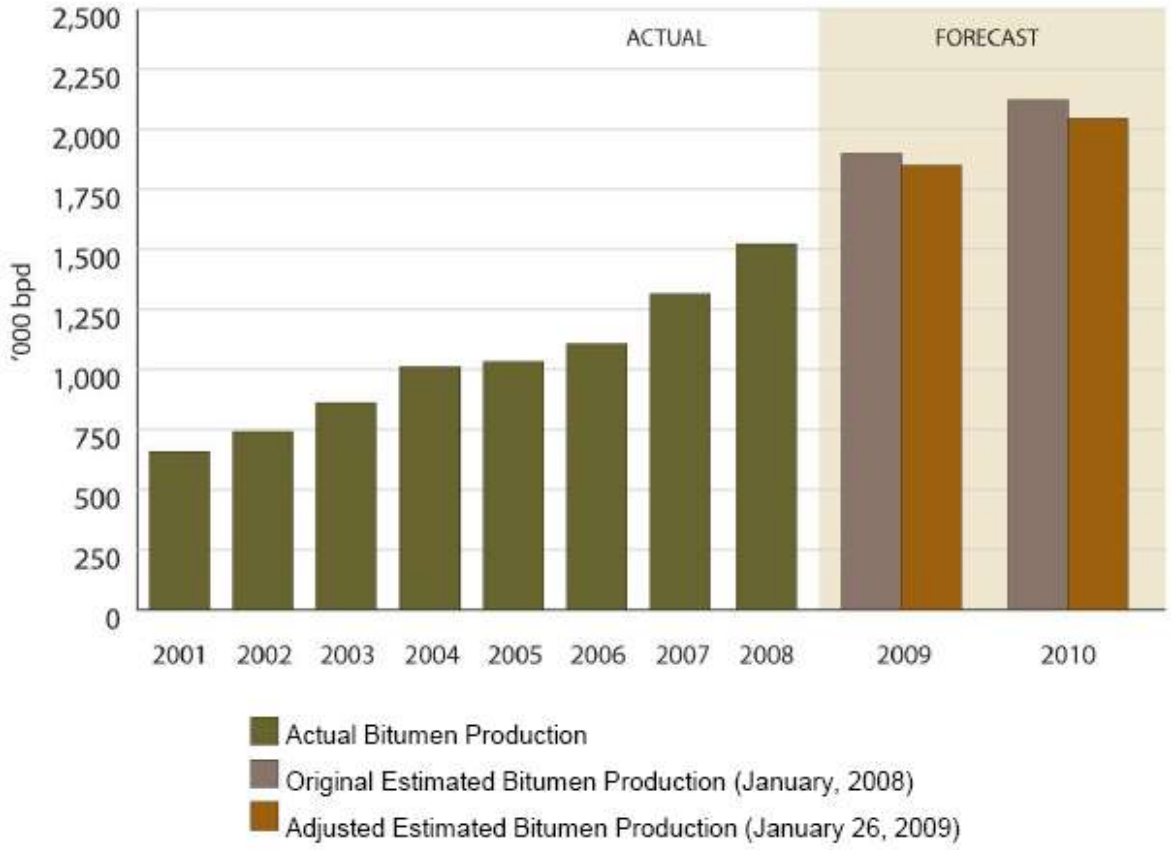
Figure 27. World Production of Unconventional Liquid Fuels, 2006-2030



Sources: **2006:** Energy Information Administration (EIA), Office of Energy Markets and End Use. **2030:** EIA, Generate World Oil Balance Model (2009).

From US DOE EIA Energy Outlook May 2009

Projected Oil Sands Production



[1]*Bitumen forecast for all Alberta oil sands projects – original estimate (January, 2008) and adjusted estimate per public announcements (January 26, 2009)*

Source: CAPP and Nichols Applied Management

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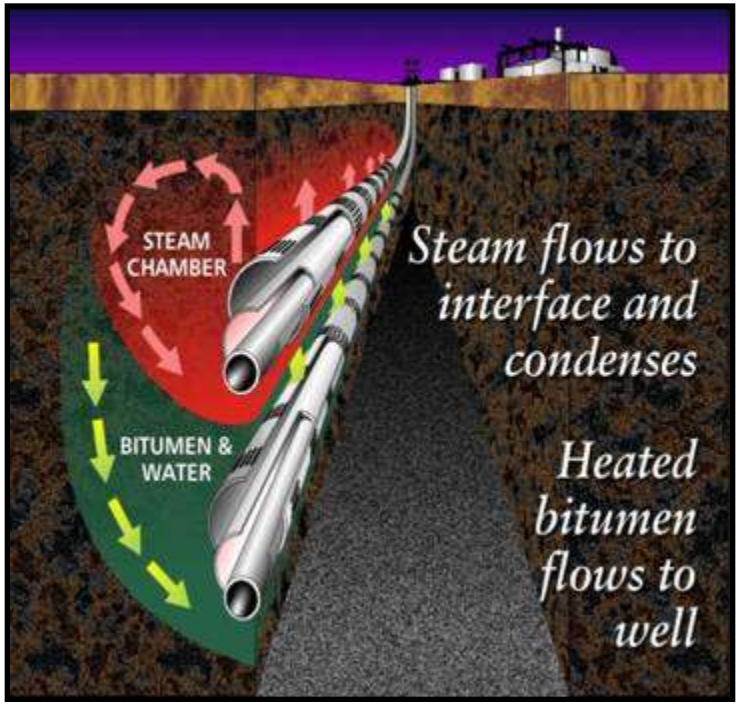
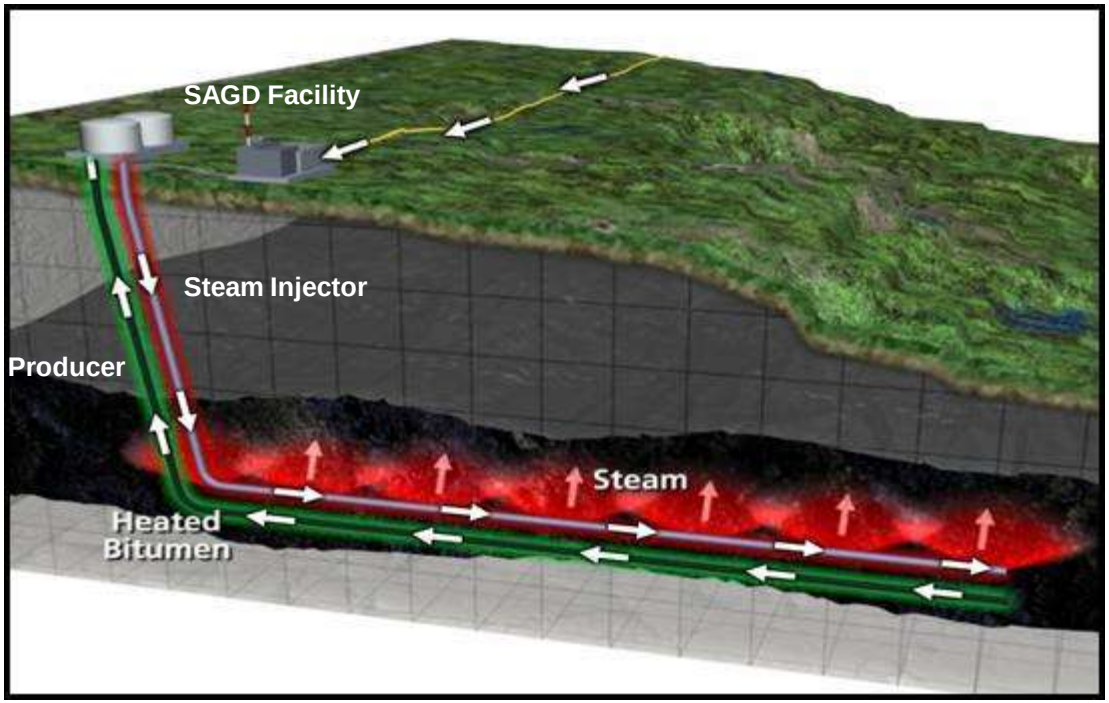
Steam Assisted Gravity Drainage (SAGD) Bitumen Extraction





Source: Canadian Heavy Oil Association / Suncor Energy

Alternatives to Conventional SAGD

- SAGD with carbon capture
- SAGD with coal gasification and carbon capture
- SAGD with nuclear steam
- Solvent or inert gas injection
- In-situ combustion
- Electro-thermal heating

SAGD Economics (CERI Estimates)

- Oil prices will need to recover in order to justify “greener” sands production strategies
- The Canadian Energy Research Institute (CERI) has recently projected that using steam from a large NPP could add ~US $10/barrel +/- to the cost of synthetic crude oil (SCO)
  - Greater if natural gas prices stay low (ie shale gas comes thru)
  - Less if natural gas prices stay increase (as most predict)
  - Less if carbon penalties are imposed on producers
    - US $60 /Tonne CO2 tax -> US $5/barrel cost increase
- Nuclear can be competitive under a number of scenarios if the other hurdles can be overcome

SAGD GHG Emissions

- **Comparison of CO_2 releases:**
  - ⇨ **Coal: 850 tonnes/million kWh**
  - ⇨ **Oil: 700 “**
  - ⇨ **Natural Gas: 550 “**
  - ⇨ **Nuclear: ~ 0 “**

- **Saving of 5 Mt CO_2/year vs natural gas for one equivalent 3200 MWth steam generation plant (reference case of ACR-1000 unit)**

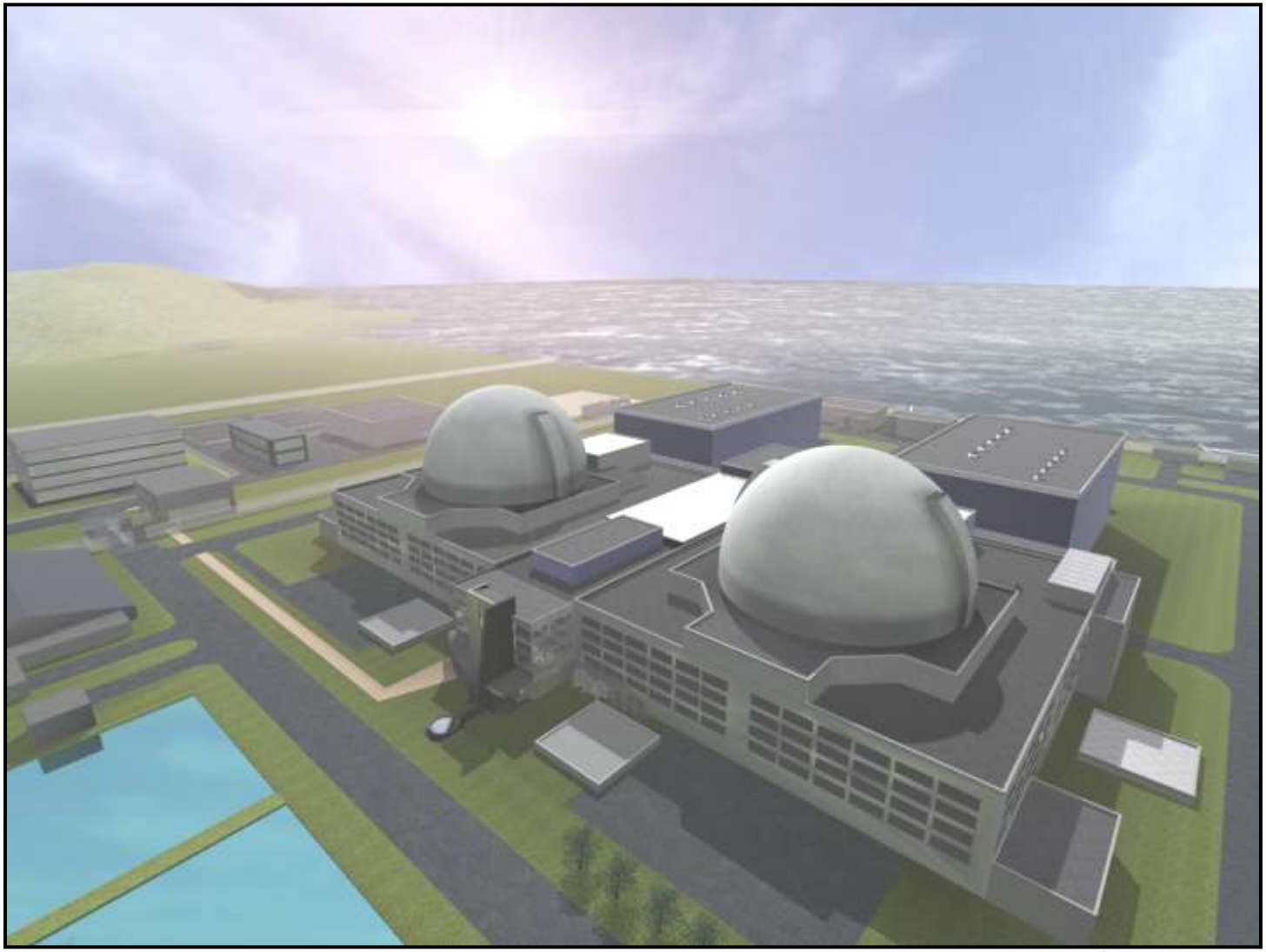
- **Nuclear can help meet oil sands GHG intensity reduction targets**

Conclusions of PTAC Study

- **PTAC (Petroleum Technology Alliance Canada) completed a study on alternatives to replace natural gas use in oil sands development which concluded that:**
  - **"The introduction of nuclear energy into the Oil Sands region will be a lengthy and expensive process"**
    - **The timing is likely post 2025.**
  - **The Project duration, including site selection, environmental assessment, licensing and construction could span over 15 years.**
  - **A practical way of utilizing the existing commercial NPP designs for use in the Oil Sands region would be to adopt a 'utility' approach for the delivery of energy (in the form of steam and electricity) to multiple Oil Sands facilities, and for providing electricity to the Alberta power grid."**

(Source: National Engineering Summit, 19-21 May 2009, Montreal)

ACR-1000® – Multiple Energy Streams



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Oil Sands Applications

- In 2004 to 2007 AECL performed site specific studies with several oil sands producers on deployment of ACR and EC6 units in northern Alberta in a steam/electricity configuration
- Studies concluded that CANDU energy output is technically feasible and economically competitive for oil sands applications
  - Design can be adapted for minimal water consumption
  - Structures can be adapted to climate and geology
  - New issues in nuclear licensing could be managed
  - Modular assembly minimizes construction challenges
  - Steam can be economically transported up to 15 km

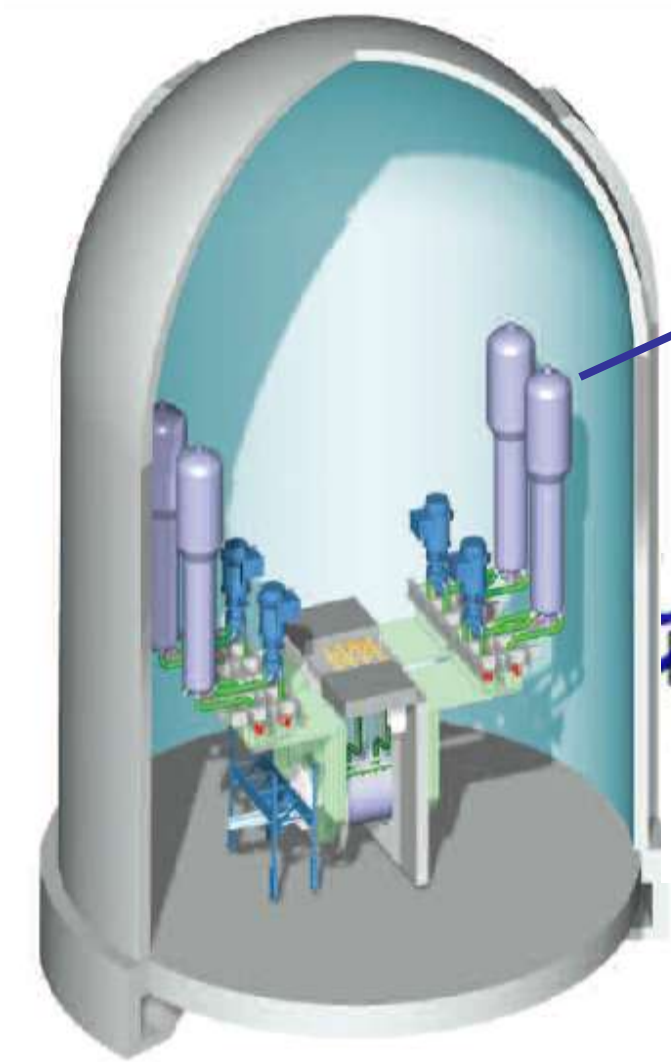
Oil Sands Applications – What's Next

- **A 1000 MWe NPP (steam output only) can support a 300,000 barrels/day in-situ production facility**
  - **Most SAGD facilities in 30,000 to 50,000 BPD range**

solution =

- **ACR-1000 configured to provide both steam and electricity in a COGEN mode:**
  - ***Steam ⇒ SAGD applications***
  - ***Electricity ⇒ utility grid and process applications***
  - ***Electricity ⇒ hydrogen ⇒ bitumen upgrading***

CANDU Flexibility



15 Km

Steam

- Bitumen Extraction (SAGD)
- Thermal Hydrogen Production
- Other Steam Applications

100+ Km

Electricity

- Grid Sales
- Resistance Heating (oil sands / carbonates)
- Hydrogen Production
- Electric Boilers for small SAGD

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Oil Sands Applications

- **ACR-1000 BOP would be configured to operate at high capacity factor while supplying both electricity and steam**

Bruce A & B with Heavy Water Plant

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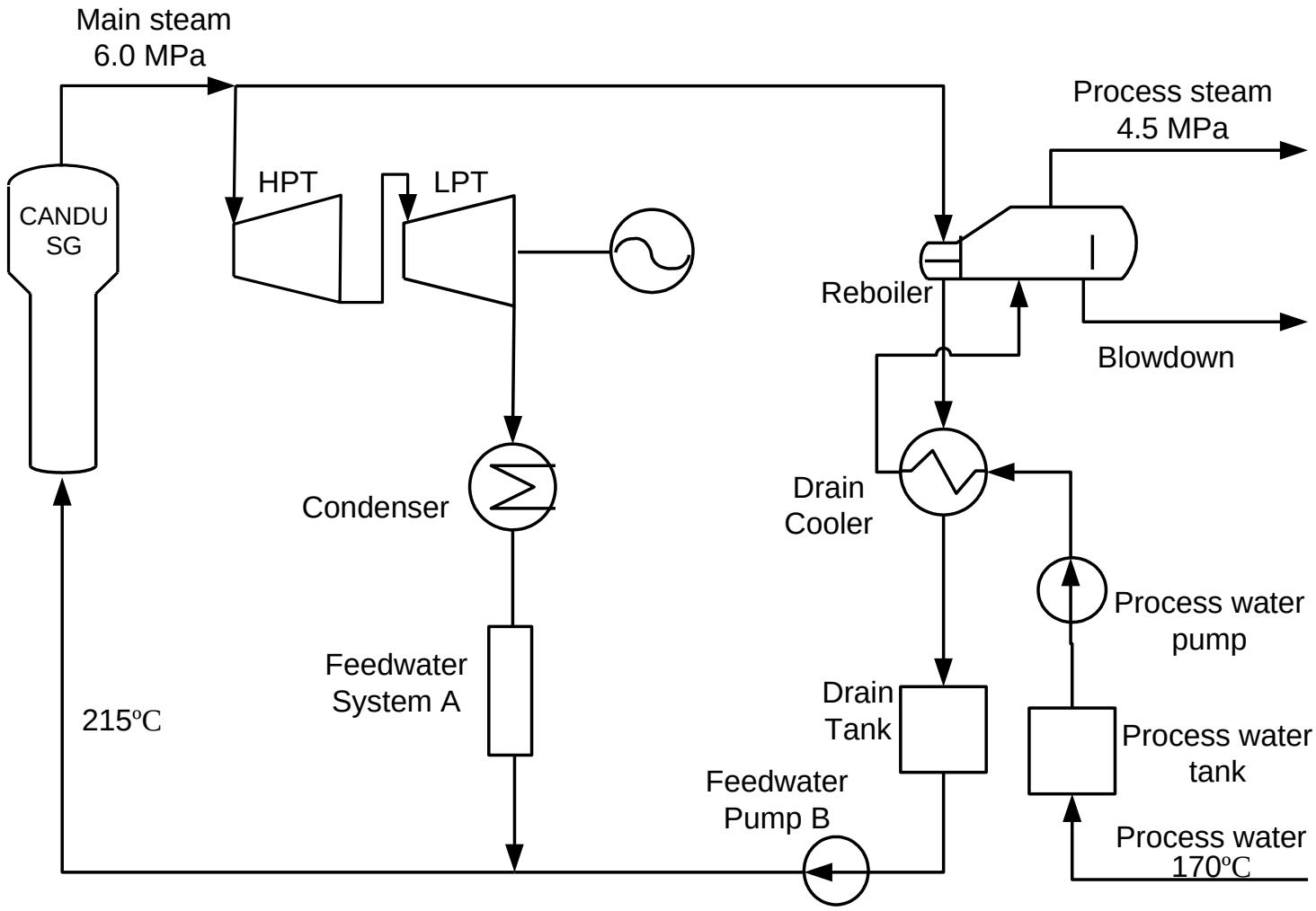
Design Concept – ACR-1000 SAGD Application



Electricity Offtake

- **Wholesale energy sales to the provincial power grid**
- **Dedicated power supplies to various oil sands facilities (recovery, processing and upgrading)**
  - **Electrolytic hydrogen plants to supply bitumen upgraders**
  - **Resistance-heating for carbonate shale extraction**
  - **Electric boilers to supply steam for small dispersed in-situ bitumen extraction facilities**

Longer term (?)

- **In-situ electro-thermal heating for bitumen extraction**

Hydrogen Supply to Upgraders

- **Most industrial hydrogen is generated by Steam Methane Reforming (SMR) process using natural gas feedstock**
- **The hydrogen cost for SMR is very sensitive to the price of natural gas**

Texas Gulf Coast formula used to estimate hydrogen costs

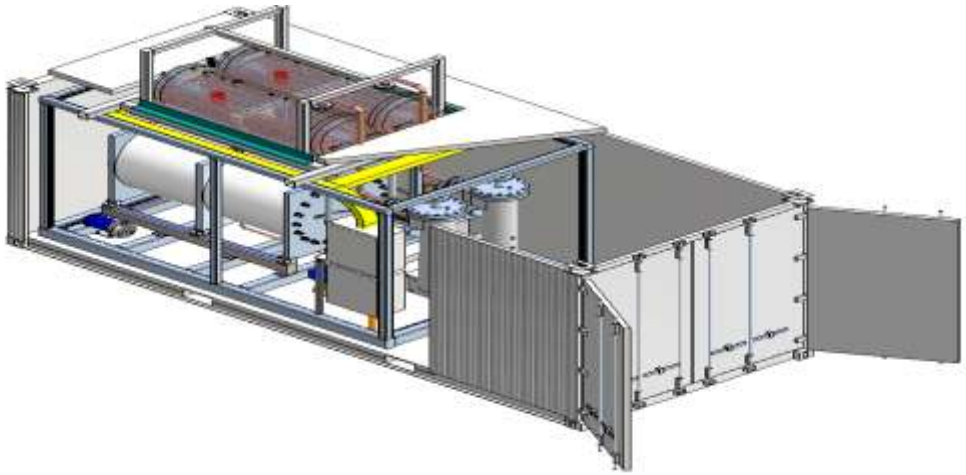
$$C_{H_2} = \$0.15/kg + 0.29\ MBtu/kg \cdot C_{NG}$$

Hydrogen from Electrolysis

- **Is electrolytic hydrogen price competitive?**
  - ✓**Yes – by using intermittent H2 production withoff-peak electricity prices**
- **Can intermittent production meet continuous supply requirement?**
  - ✓**H_2 storage in underground caverns**
    - **ICI has used caverns at Teesside UK for 30 years**
- **Is electrolytic hydrogen environmentally friendly?**
  - ✓**Avoids 8 kg CO2 per kg of H2 produced (cf SMR)**
  - ✓**Electrolytic H2 (with nuclear) for 250,000 BPD upgrader – saves 2.5 Mt CO2/a**

Electrolysis Technology

- **Standard electrolysis modules simplifies shipment, installation and servicing**
- **Larger units, lower cost, high efficiency**



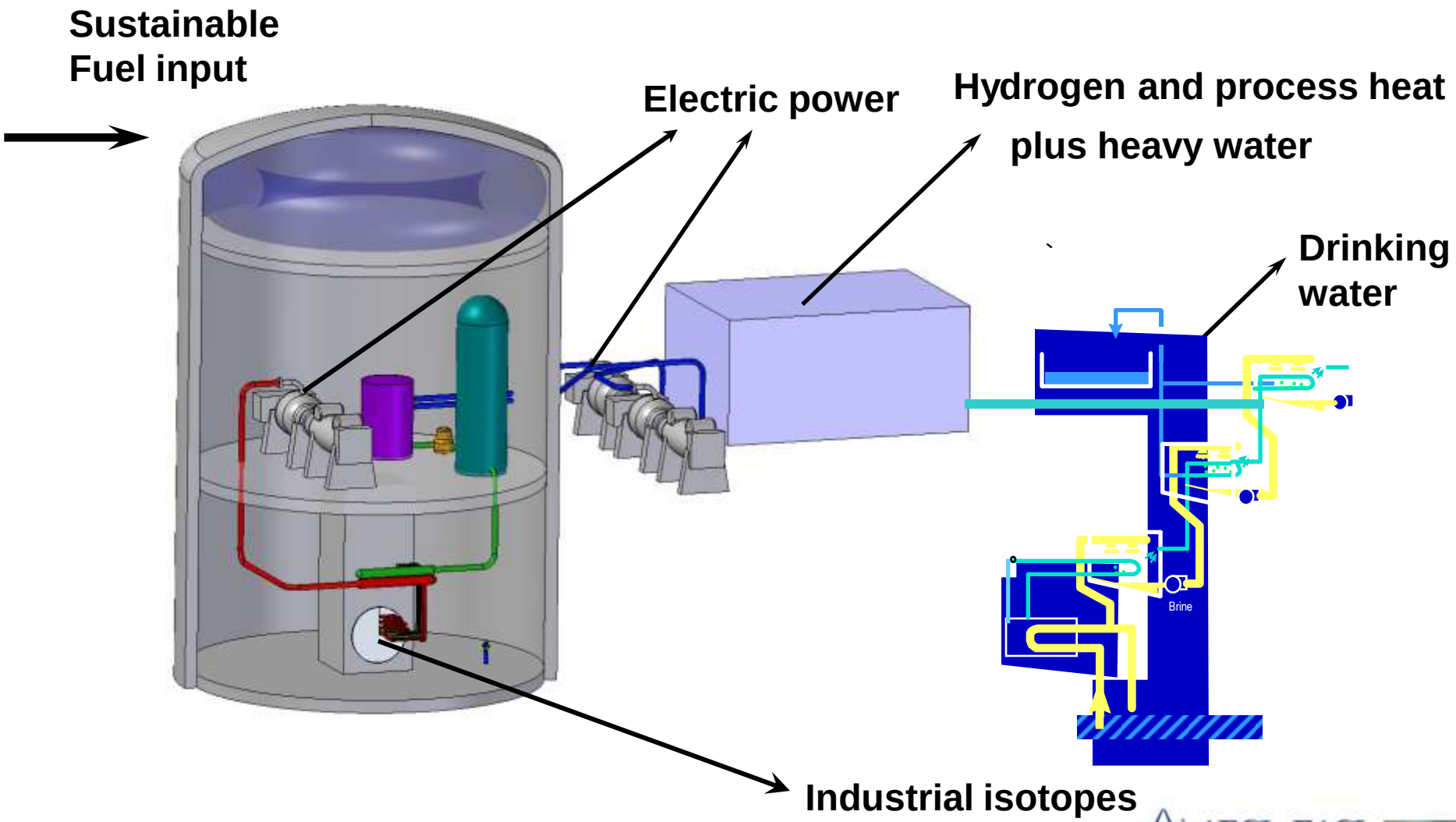
- **High temperature electrolysis holds promise of high efficiency and lower cost hydrogen**

Source: Hydrogenics Corp

Nuclear Challenges

- Government and public support
- Local and First Nations support
- Site selection
  - Need access to water, oil sands, and transmission
- Oil industry acceptance
  - Alberta is carbon country
- Economics
  - Impacted by oil and gas prices, labor costs
  - Need long-term contracts for steam and electricity
- Nuclear owner/operator – Bruce Power Alberta?

Post 2025: Generation IV National Program
Small-Size CANDU Ultra PTR ("SuperCandu")



Conclusions

- **ACR-1000 (or Enhanced CANDU 6) can provide both thermal and electrical energy to a range of oil sands applications**
  - **Energy that can be economically competitive for oil sands applications under various scenarios**
- **ACR-1000 energy enables reduction in the GHG emission intensity for a variety of oil sands recovery and upgrading applications**
- **ACR-1000 energy source can be available by 2020**
  - **With Alberta Govt. and oil industry cooperation**
- **CANDU Gen IV "SuperCandu" will be a good fit for longer term oil sands developments**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