Applications of Nuclear Energy to Oil Sands and Hydrogen Production

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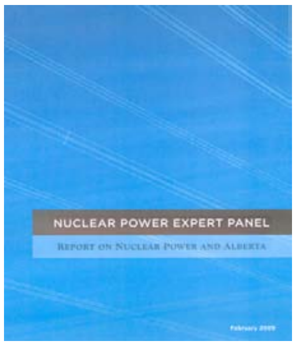
AECL EACL

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 would enable the Alberta Government to endorse nuclear in Alberta

Proposition

Oil prices are rising and the Alberta economy will recover its strong growth

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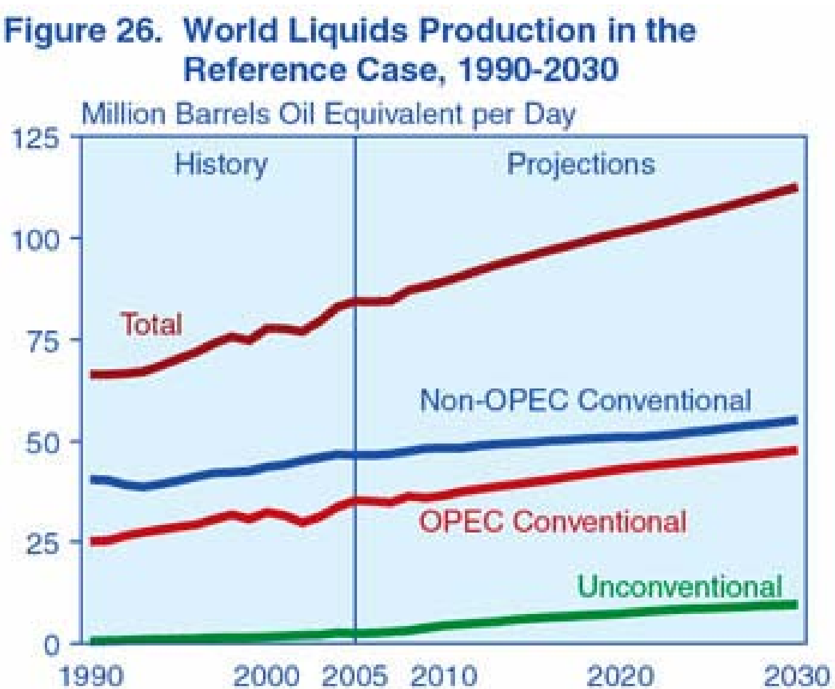
Market Drivers

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

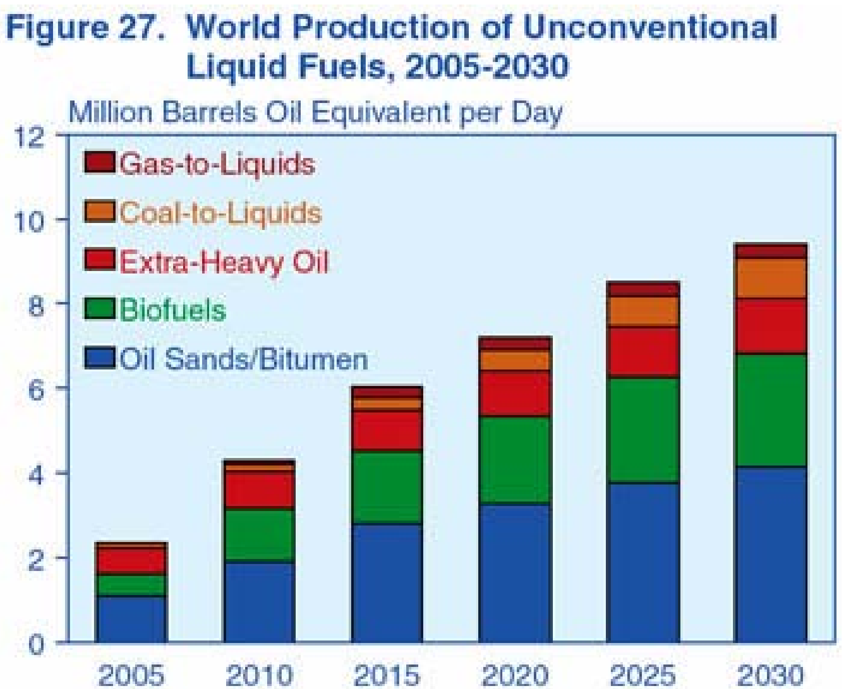
World Oil Demand & Unconventional Fuels

Global Oil Demand



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea.. **Projections:** EIA, Generate World Oil Balance Model (2008).

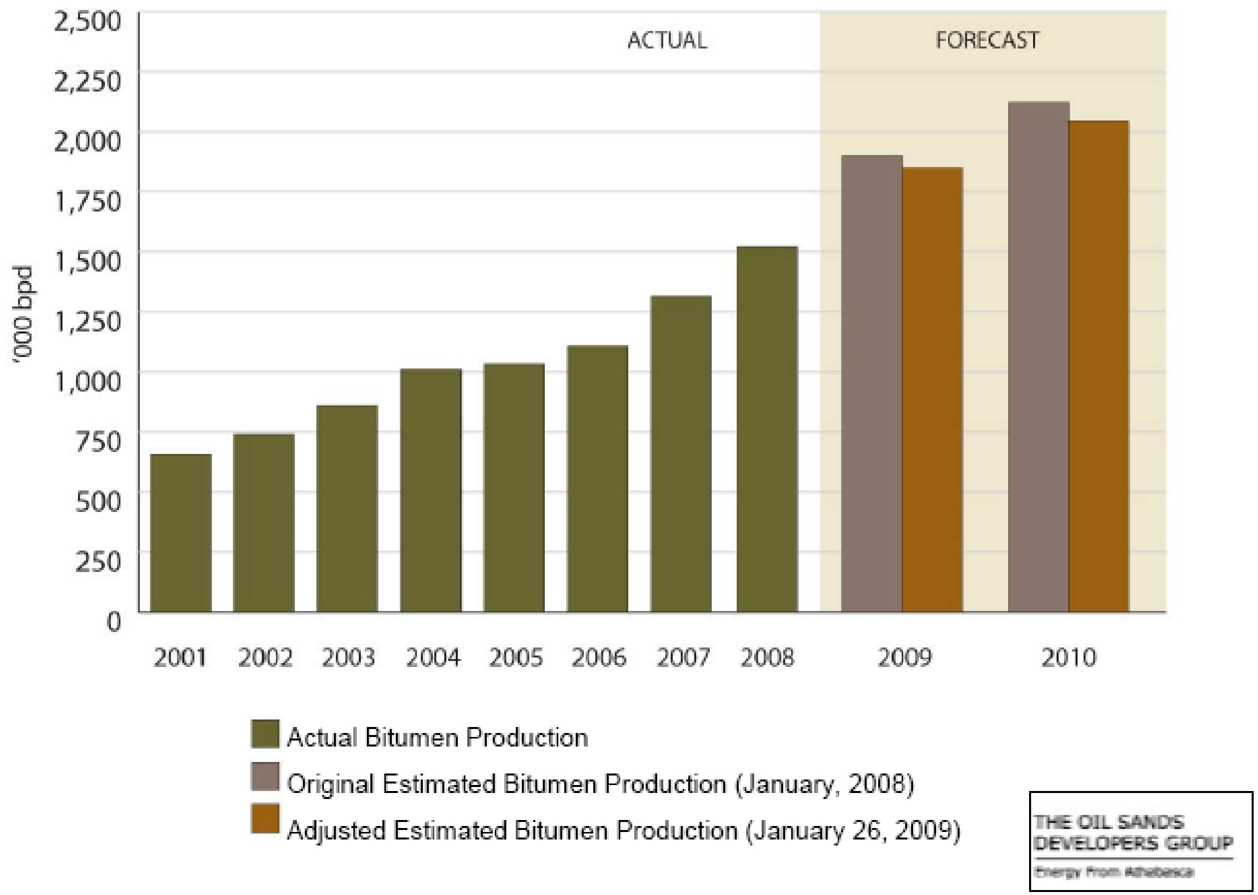
Unconventional Production Forecast



Sources: **2005:** Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea. **Projections:** EIA, Generate World Oil Balance Model (2008).

From US DOE EIA Energy Outlook June 2008

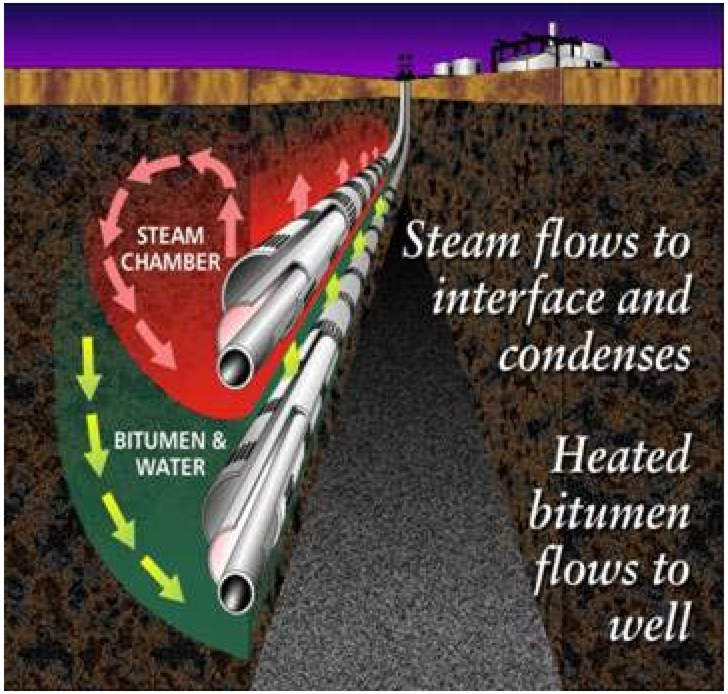
Projected Oil Sands Production

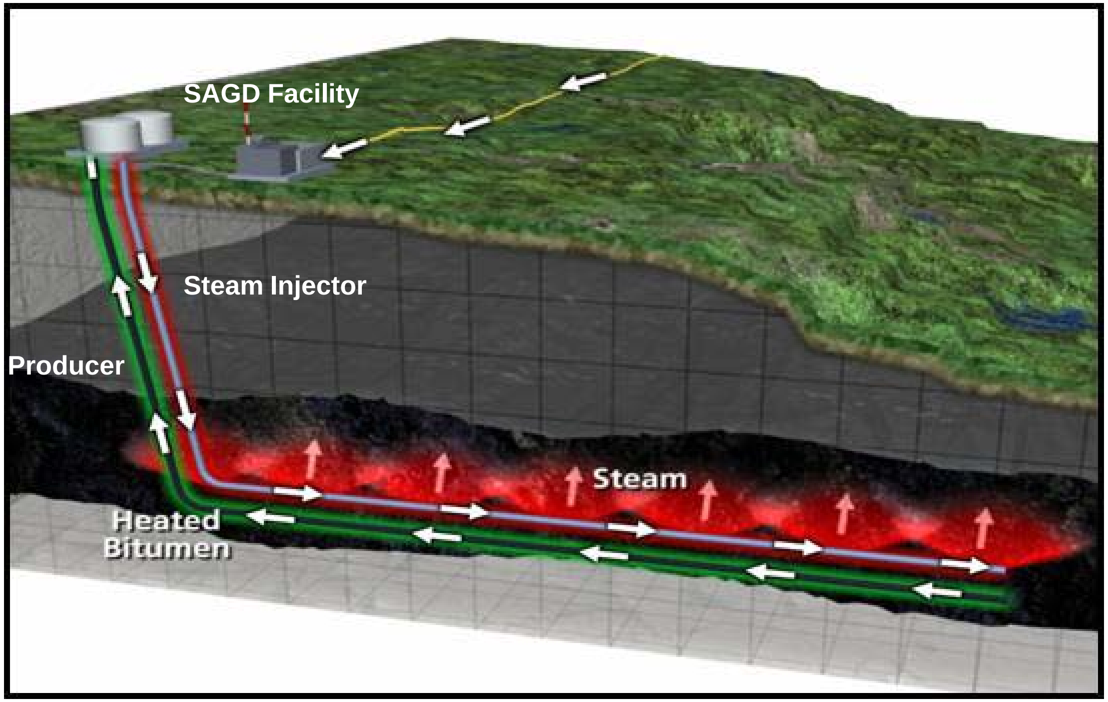


[1]Bitumen forecast for all Alberta oil sands projects – original estimate (January, 2008) and adjusted estimate per public announcements (January 26, 2009)

Source: CAPP and Nichols Applied Management

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 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 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*:**

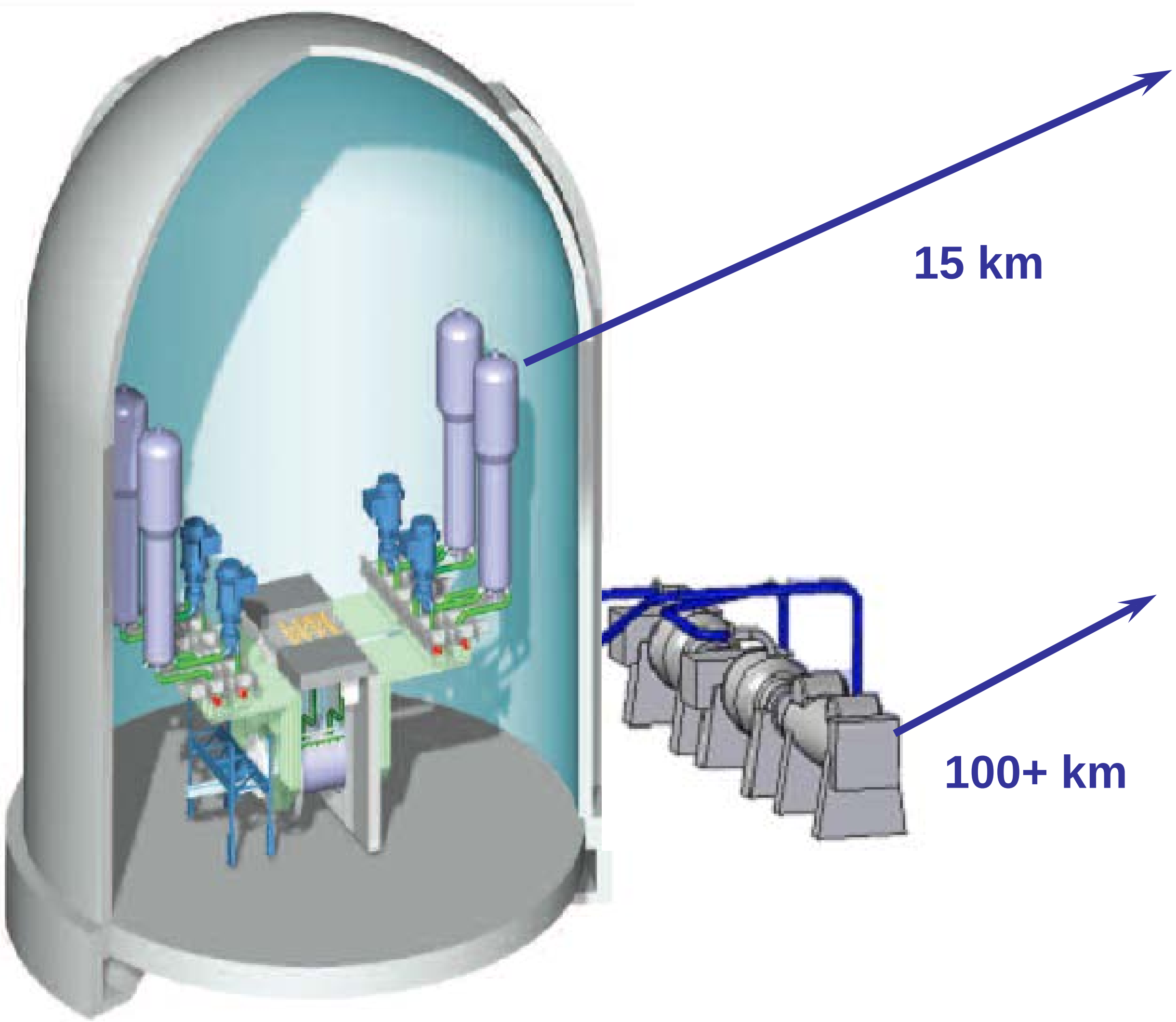
  - **"The introduction of nuclear energy into the Oil Sands region will be a lengthy and expensive process**
    - **The timing is likely post 2025.**

  - **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 <u>'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."</u>**

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

CANDU Flexibility



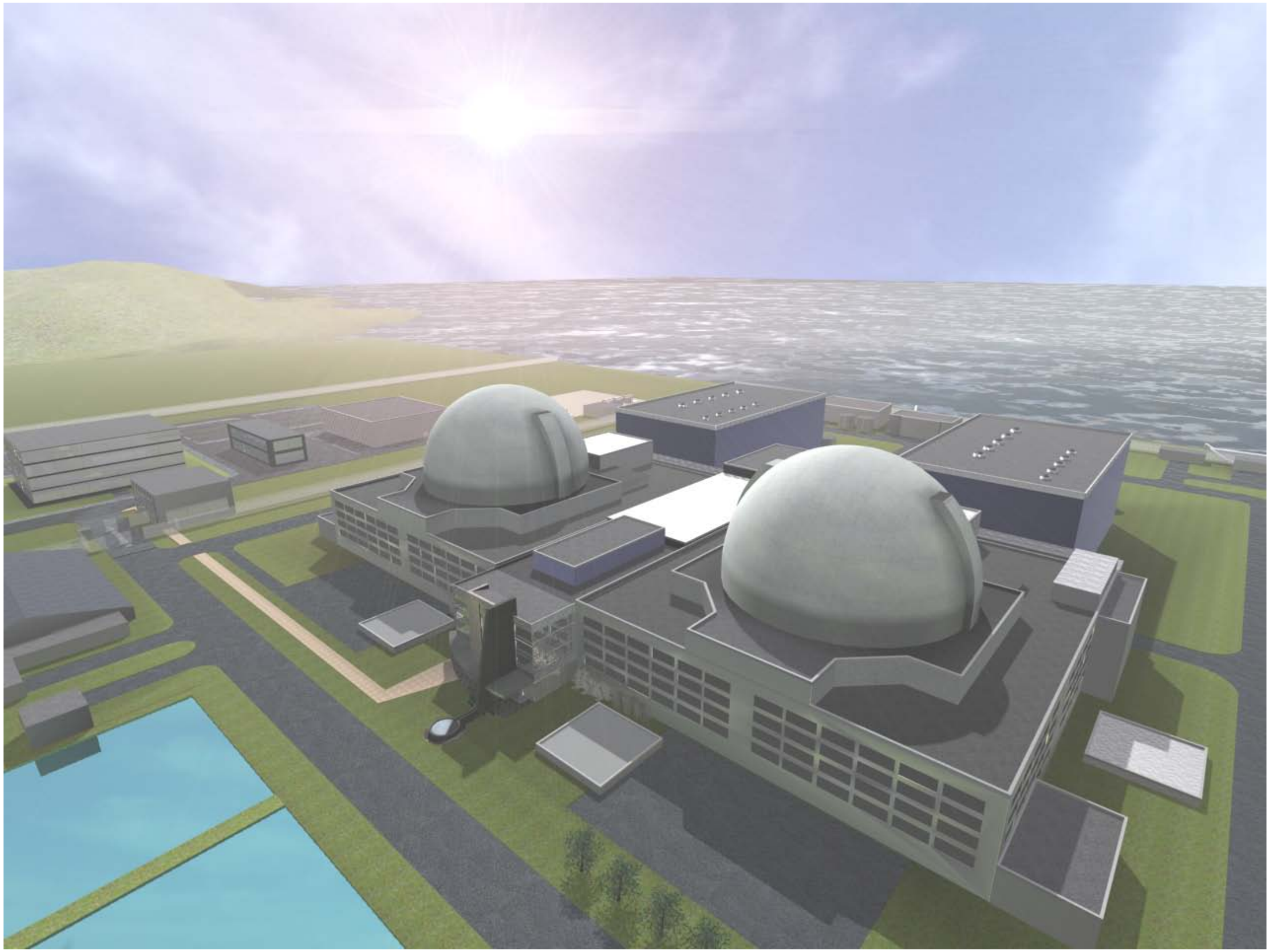
Steam

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

Electricity

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

ACR-1000 – Multiple Energy Streams



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 =

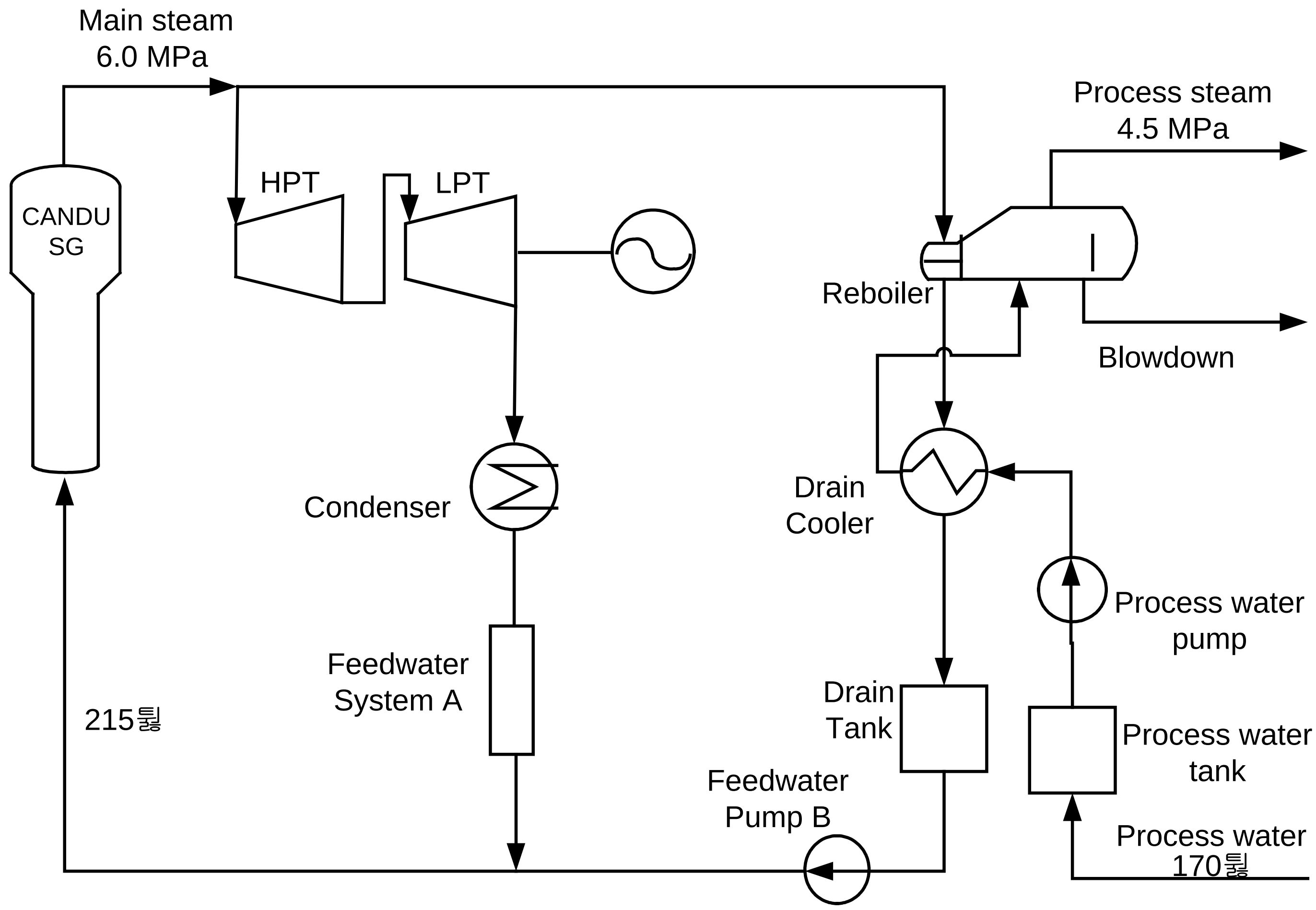
- **ACR-1000 configured to provide both steam and electricity in a COGEN mode:**
  - ***Steam ⇒ SAGD applications***
  - ***Electricity ⇒ utility grid and process applications***
  - ***Electricity ⇒ Hydrogen ⇒ bitumen upgrading***

Oil Sands Applications

- **ACR-1000 BOP would be configured to operate at high CF when supplying both electricity and steam**

Bruce A & B with Heavy Water Plant

Design Concept – ACR-1000™ SAGD Application



Electricity Streams

- **Wholesale energy sales to the provincial power grid**
- **Local power supplies to oil sands facilities (processing and upgrading)**
- **Transmission to remote oil sands facilities:**
  - **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 Golf Coast formula used to estimate hydrogen costs

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

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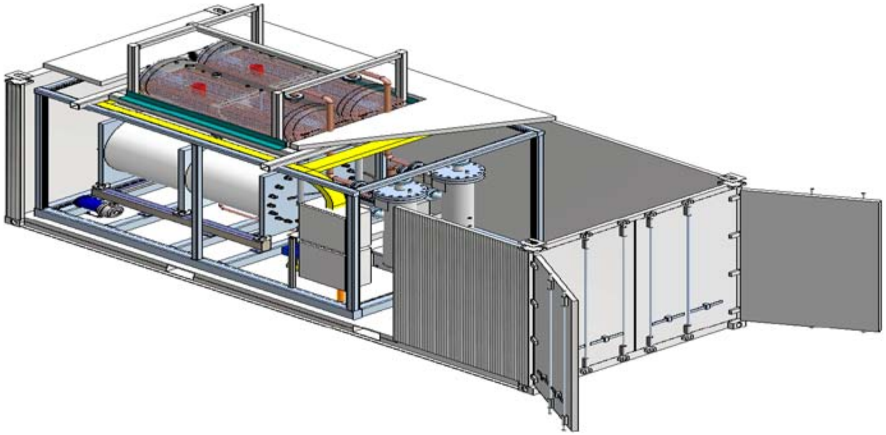
Hydrogen from Electrolysis

- **Electrolytic hydrogen is price competitive**
  - **–using intermittent H_2 production with off-peak electricity prices**
- **Intermittent production meets continuous supply requirement**
  - **H_2 storage in underground caverns**
    - **ICI has used caverns at Teesside UK for 30 years**
- **Electrolytic hydrogen is environmentally friendly**
  - **Avoids 8 kg CO_2 per kg of H_2 produced (cf SMR)**
  - **Electrolytic H_2 (with nuclear) for 250,000 BPD upgrader – saves 2.5 Mt CO_2/a**

Electrolysis Technology

- **Standard electrolysis modules simplifies shipment, installation and servicing**
  (reference Hydrogenics Corp)
- **Larger units, lower cost, high efficiency**



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

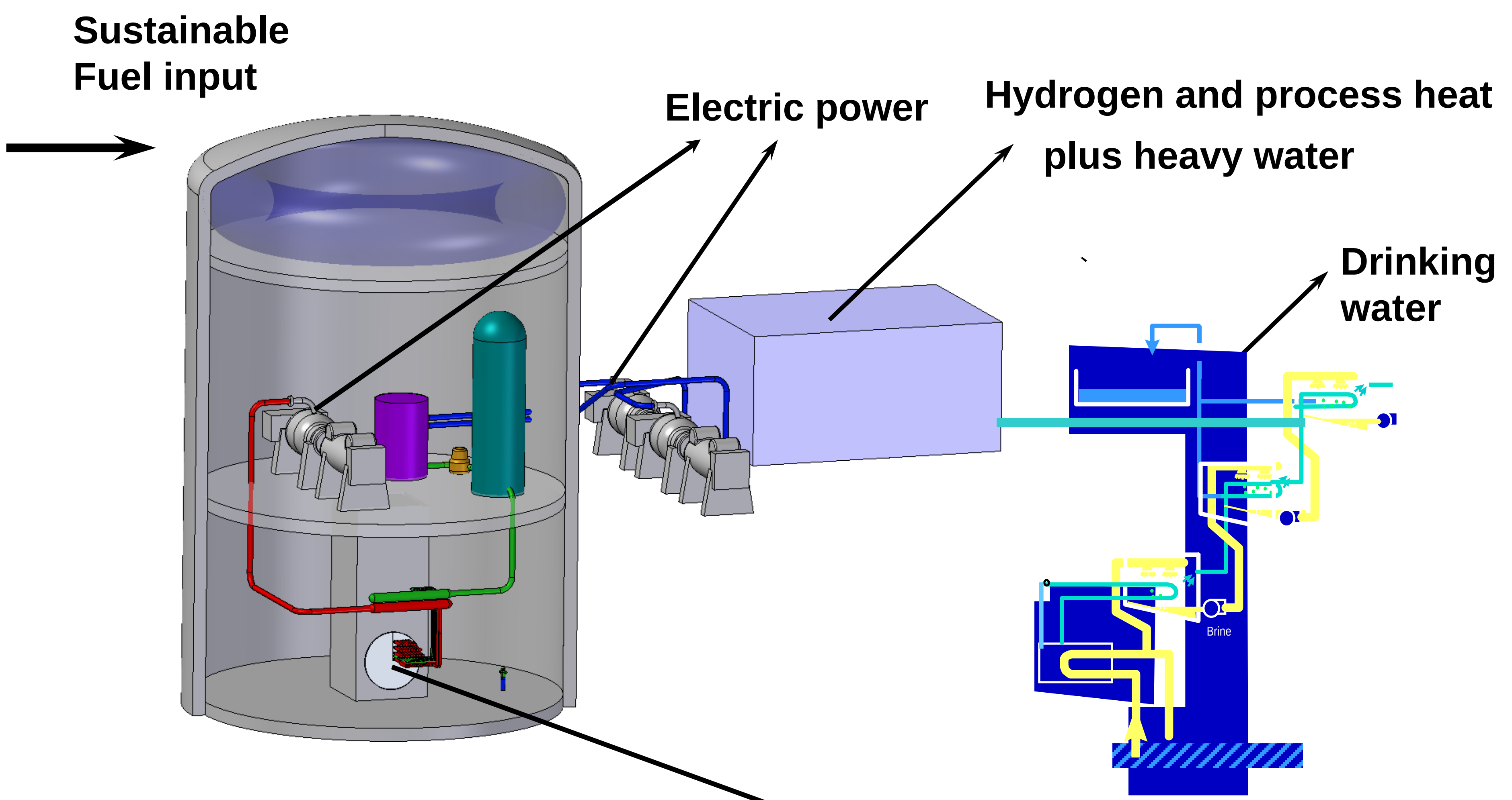
Nuclear Challenges

- **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?**

Launching the Hydrogen Economy

- ***AECL's stress in the near term has been placed on practicality of launching the Hydrogen Economy with distributed electrolysis***
- **Showing that this can be competitive with off-peak electricity from Generation III+ reactors**
- **Can also incorporate some input energy from wind**
  - **Which is not competitive on its own**
- **Complements deployment of nuclear to displace coal-fired stations currently used for intermittent demand**
- **In the longer term utilize Generation IV cogeneration systems**
- **Develops a demand foundation for subsequent expansion toward centralized H_2 production, pipeline distribution and distributed cogeneration**
  - **Not either/or but a complementary pairing**

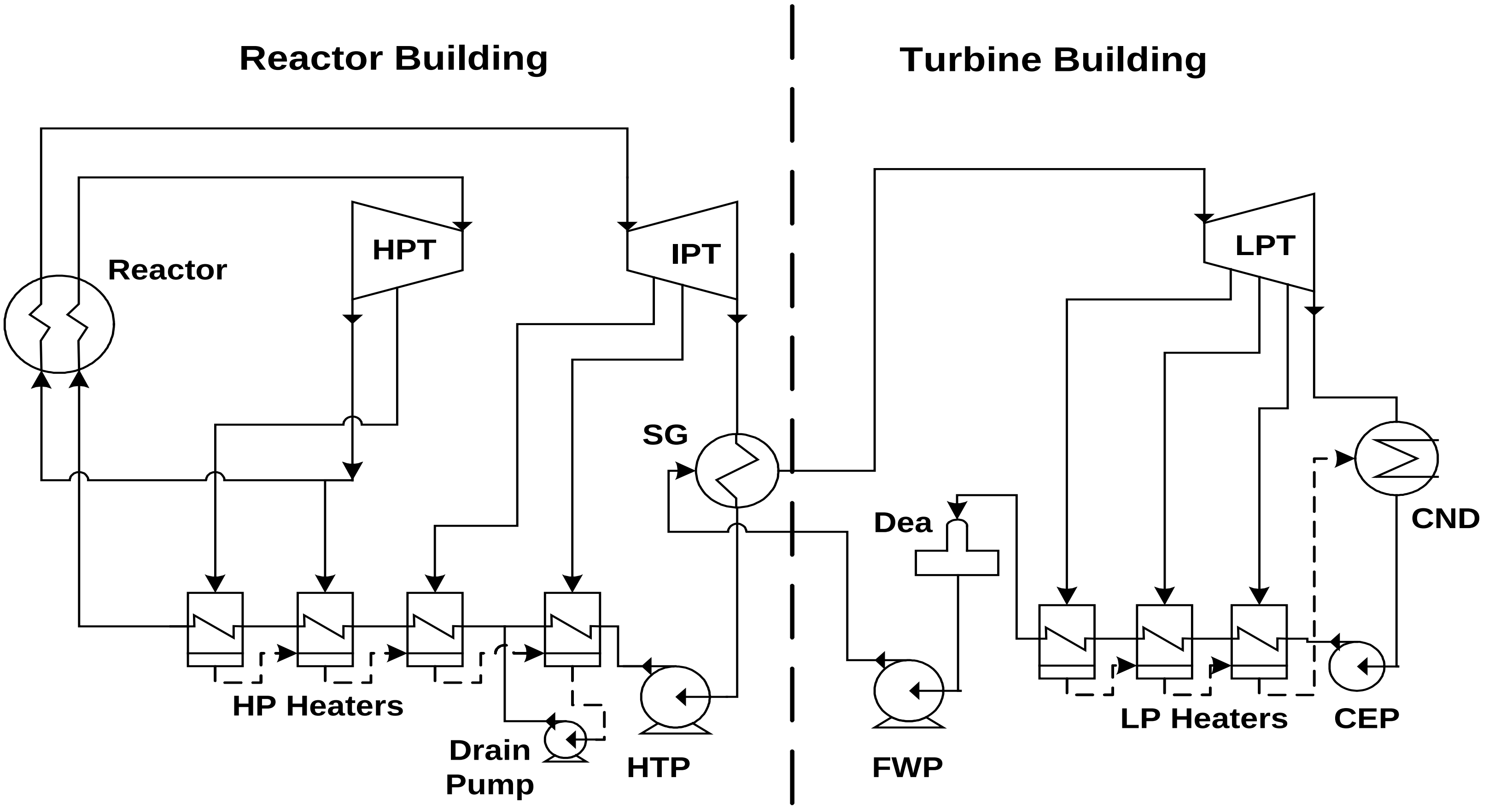
Post 2025: Generation IV National Program
Small size CANDU Ultra PTR ("SuperCandu")



SCWR Steam Cycle Considerations

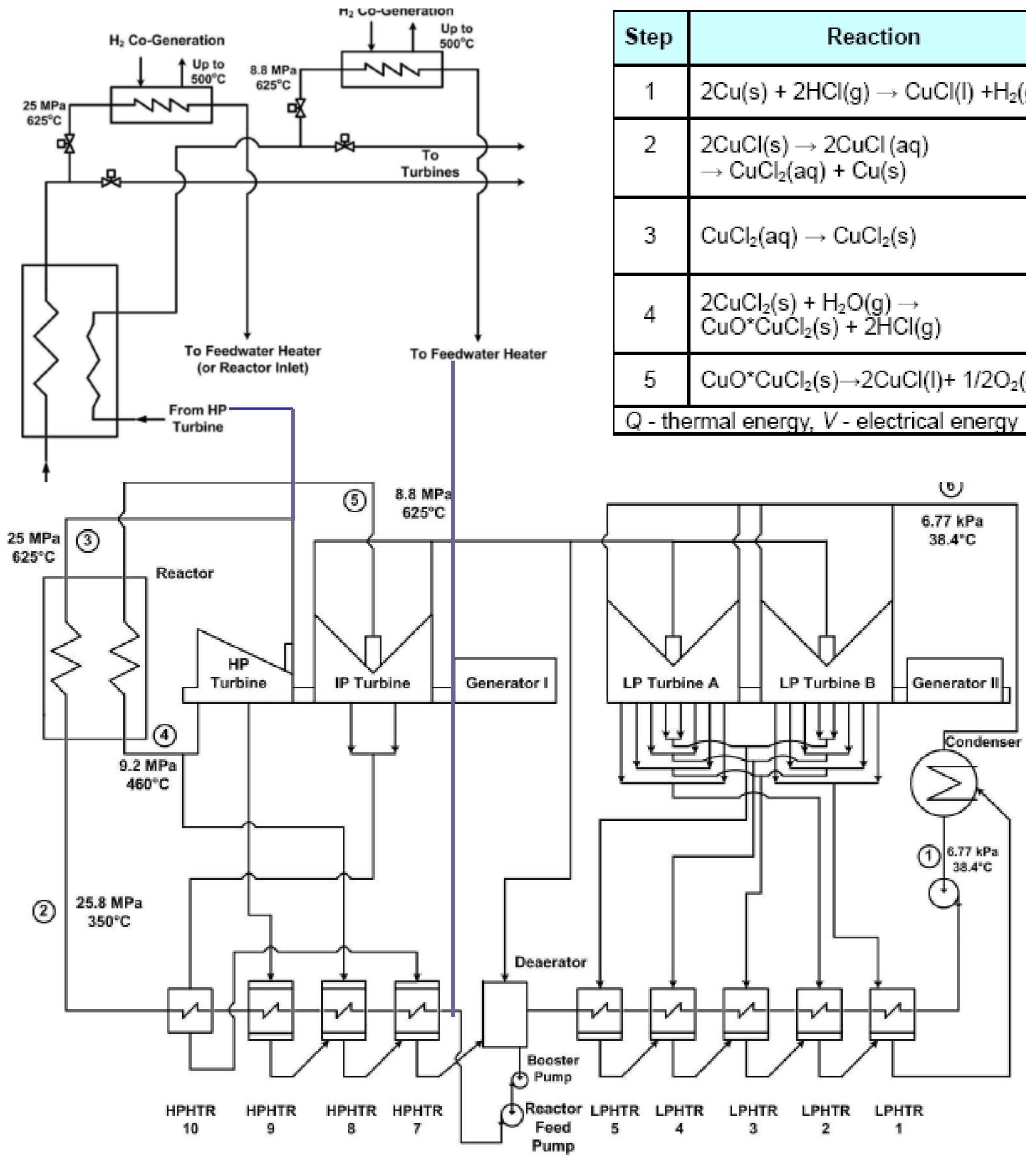
- Objective: maximize cycle efficiency
- Reheat or Non-Reheat
  - This will affect the reactor design requirement and steam cycle arrangement.
- Direct or indirect cycle
  - This has no effect on the reactor design, but will affect system configuration and turbine choice and options.
  - Traditional CANDU and PWR plants use indirect cycle, and BWR plants use direct cycle.
  - New thermal (coal) plants utilize ultra-supercritical turbines

SCWR Reheat Dual Cycle Option: schematic



HPT & IPT Located in R/B

Hydrogen cogeneration from "SuperCandu"
(Ref: Naidin et al, ICHP, UOIT, 2009)



Step	Reaction	Temperature Range (°C)	Feed/Output	
1	$2Cu(s) + 2HCl(g) \rightarrow CuCl(l) + H_2(g)$	430 – 475	Feed: Output:	Electrolytic Cu + dry HCl + *Q* H_2 + CuCl(l) salt
2	$2CuCl(s) \rightarrow 2CuCl(aq)$ $\rightarrow CuCl_2(aq) + Cu(s)$	Ambient (electrolysis)	Feed: Output:	Powder/granular CuCl and HCl + *V* Cu and slurry containing HCl and $CuCl_2$
3	$CuCl_2(aq) \rightarrow CuCl_2(s)$	<100	Feed: Output:	Slurry containing HCl and $CuCl_2$ + *Q* Powder/granular $CuCl_2$ + H_2O/HCl vapors
4	$2CuCl_2(s) + H_2O(g) \rightarrow CuO{*}CuCl_2(s) + 2HCl(g)$	400	Feed: Output:	Powder/granular $CuCl_2$ + $H_2O(g)$ + *Q* Powder/granular $CuO{*}CuCl_2$ + 2HCl (g)
5	$CuO{*}CuCl_2(s) \rightarrow 2CuCl(l) + 1/2O_2(g)$	500	Feed: Output:	Powder/granular CuO* $CuCl_2(s)$ + *Q* Molten CuCl salt + oxygen

Q - thermal energy, *V* - electrical energy

Strategy for the Oil Sands

Strategy – Near Term

Utilize existing commercial NPPs in cogen mode to supply:

- **electricity**
  - **grid**
  - **electrolytic hydrogen plants**
  - **electric heating of oil bearing rocks**
  - **electric boilers for smaller and remote SAGD projects**
- **Steam**
  - **larger and local SAGD projects**

Strategy – Longer Term

Explore feasibility of deploying emerging high temperature reactors for other cogen projects by evaluating:

- **Licensing**
- **Siting**
- **Infrastructure requirements**
- **Siting**
- **Interface with SAGD operations**

Conclusions

- **CANDU can provide both thermal and electrical energy to a range of oil sands applications**
- **In near term Gen III+ ACR-1000 energy is economically competitive for oil sands applications**
- **Nuclear energy enables reduction in the GHG emission intensity for a variety of oil sands recovery and upgrading applications**
- **GenIV SCWR in the longer term can provide co-generation of steam, hydrogen and electricity**

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