Integration of Nuclear Energy into Oil Sands Production

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Outline

- Current issues in Oil Sands Production
- Why Nuclear Energy ?
- Alternative Application Scenarios
- Nuclear Options Considered
- Specific Practical Nuclear Applications
- Challenges
  - Licensing
  - Public Acceptance
  - Safety
  - Staffing - Labor
- Economics
- Business Model
- Conclusions
- Recommendations

Current Issues

- Rapid Planned Growth
  - By 2020 – 5 million barrels per day
- Large consumer of natural gas
  - Price volitality
  - Impact on consumer
- CO_2 Emissions – 17% of total Canadian emissions by 2020
- Canadian Kyoto Protocol Compliance
- Water consumption
- Possible CO_2 tax or cap

Why Nuclear Energy ?

- Largely CO_2 emission free
- Price stability – low impact on rising fuel costs.
- High capacity factors – 90 %
- Cheaper than natural gas for long term.
- Long operating cycles – 18-24 months or on-line refueling
- Offsets high initial investment

Application Scenarios

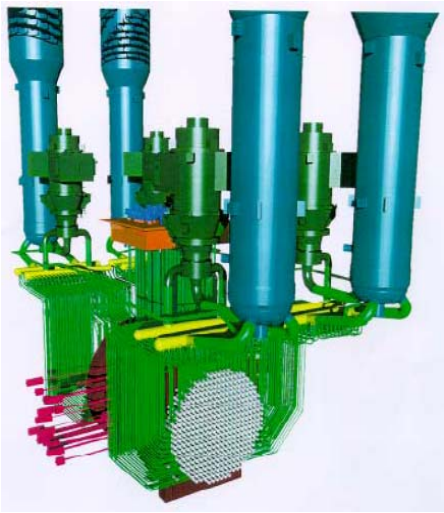
- Steam only
- Steam and Electricity
- Upgrading – Steam, electricity & hot water
- Steam, Electricity, Hydrogen and hot water
- Direct Mining – 20 %
- SAGD - 80 %

Nuclear Energy Plants Considered

- Enhanced CANDU 6
  - Advanced current technology AECL
- ACR 700
  - Next generation offering AECL
- Pebble Bed Modular Reactor
  - High temperature helium cooled
  - Being built in South Africa
  - PBMR-Westinghouse

Enhanced Candu 6

- Based on the CANDU 6
- Thermal efficiency 35%
- On-line refueling
- Steam cycle
- Calandria type reactor
- 1.7% Uranium enrichment
- 6 year construction time

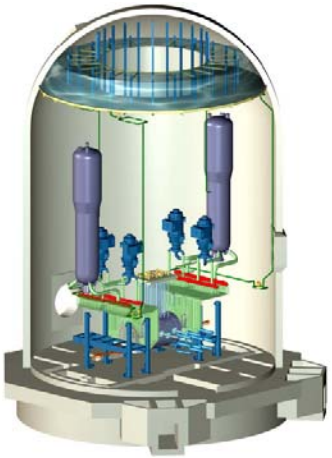


Enhanced CANDU 6

Enhanced CANDU 6 Reactor Operating Data	
Heat Output	2064 MWth
Electricity Output (max)	740 Mwe
Fuel	1.7% enriched uranium (UO_2)
Coolant	Heavy Water
Moderator	Heavy Water (65°C)
Secondary Side Fluid	Water
Secondary Side Inlet Temperature	187°C
Secondary Side Outlet Temperature	260°C
Secondary Side Steam Pressure	4.7 MPa

ACR-700

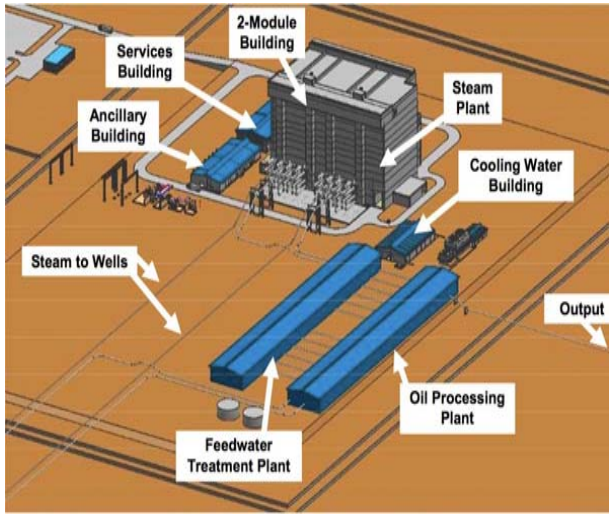
- Enriched Uranium
- Light Water Coolant
- Heavy Water Moderator
- Smaller Calandria
- Online Refueling
- More Economic to Build

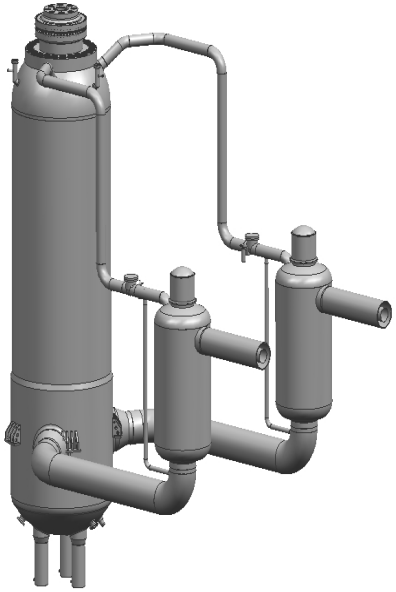


ACR-700 Reactor Operating Data	
Heat Output	2030 MWth
Electricity Output Gross (Net)	753 Mwe (703)
Fuel	SEU (2%)
Coolant	Water
Moderator	Heavy Water
Reactor Inlet Temperature	280°C
Reactor Inlet Pressure	13.3 MPa
Reactor Outlet Temperature	326°C
Reactor Outlet Pressure	12.1 MPa
Secondary Side Fluid	Light Water
Secondary Side Inlet Temperature	215°C
Secondary Side Outlet Temperature	281°C
Secondary Side Steam Pressure	6.4 MPa

Pebble Bed Modular Reactor

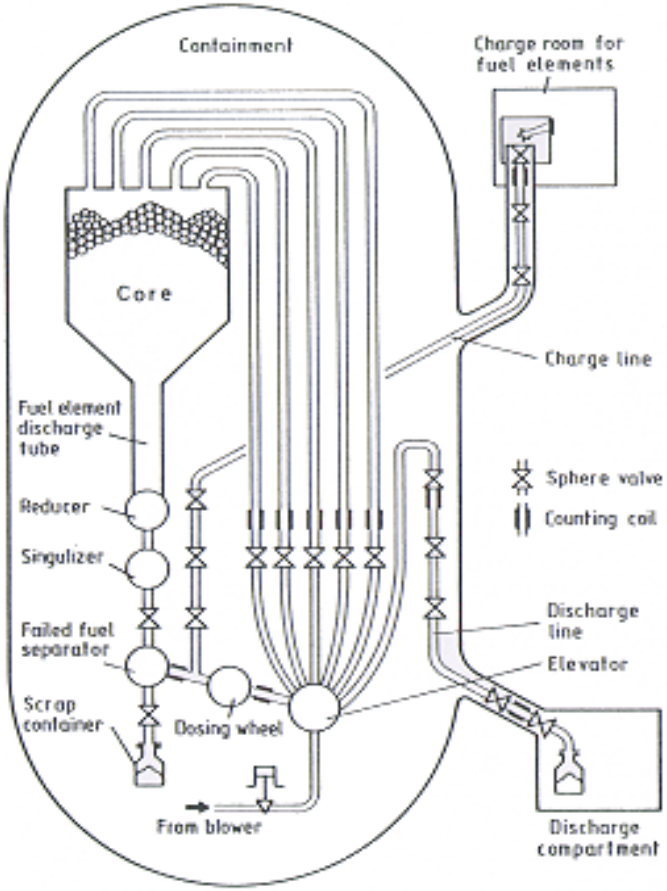
- 500 Mwth – 170 Mwe
- 750°C exit temperature
- Direct Brayton Cycle for electric production
- Efficiency – 41%
- 9% enriched
- Pebble Fuel – online refueling





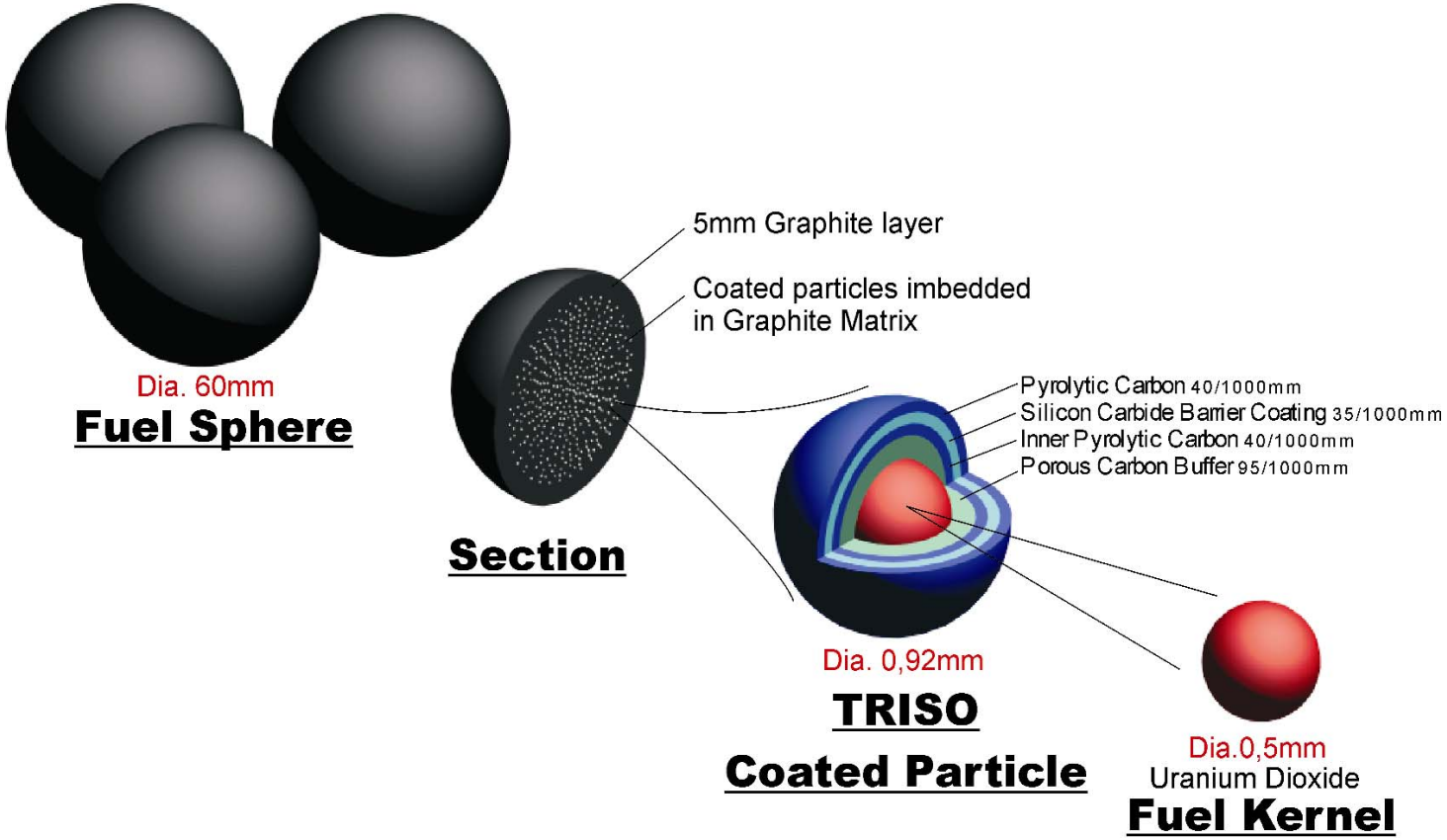
PBMR Reactor Operating Data	
Heat Output	500 MWth
Electricity Output (max, gross)	205 Mwe
Fuel	TRISO Fuel Pebbles
Coolant	Helium
Moderator	Graphite
Reactor Inlet Temperature	280°C
Reactor Inlet Pressure	8.5 MPa
Reactor Outlet Temperature	750°C
Reactor Outlet Pressure	8.2 MPa
Tertiary (Steam) Inlet Temperature	192°C
Tertiary (Steam) Outlet Temperature	318°C
Tertiary (Steam) Pressure	11 MPa

Pebble Bed Modular Reactor



- **400,000 pebbles in core**
- **about 4,000 pebbles handled by FHS each day**
- **about 350 discarded daily**
- **one pebble discharged every 30 seconds**
- **average pebble cycles through core 10 times**
- **Fuel handling most maintenance-intensive part of plant**

PBMR Fuel


Dia. 60mm
Fuel Sphere
5mm Graphite layer
Coated particles imbedded in Graphite Matrix
Section
Pyrolytic Carbon 40/1000mm
Silicon Carbide Barrier Coating 35/1000mm
Inner Pyrolytic Carbon 40/1000mm
Porous Carbon Buffer 95/1000mm
Dia. 0,92mm
TRISO
Coated Particle
Dia.0,5mm
Uranium Dioxide
Fuel Kernel

Specific Practical Applications Methodology

- Identify size of oil sands production field and facility (bbls/day of bitumen)
- Develop list of energy needs for each size facility.
- Determine reactor configurations that best match needs, steam, electricity and hydrogen
- Identify field limitations
  - Effective distance for piping steam/hot water
  - Field density for wells

Field Limitations Analysis

- Number of SAGD wells in a field
  - Data show that 8 wells per section is typical for a field
- Distance of pipeline for effective steam temperature and pressure from source.
  - 10 km based on heat loss analysis and expert opinion.

Steam Only - SAGD

Plant Type	Steam Production (bpd)
2030 MWth Enhanced CANDU 6	653,000
1895 MWth ACR-700	697,000
412 MWth PBMR	160,000

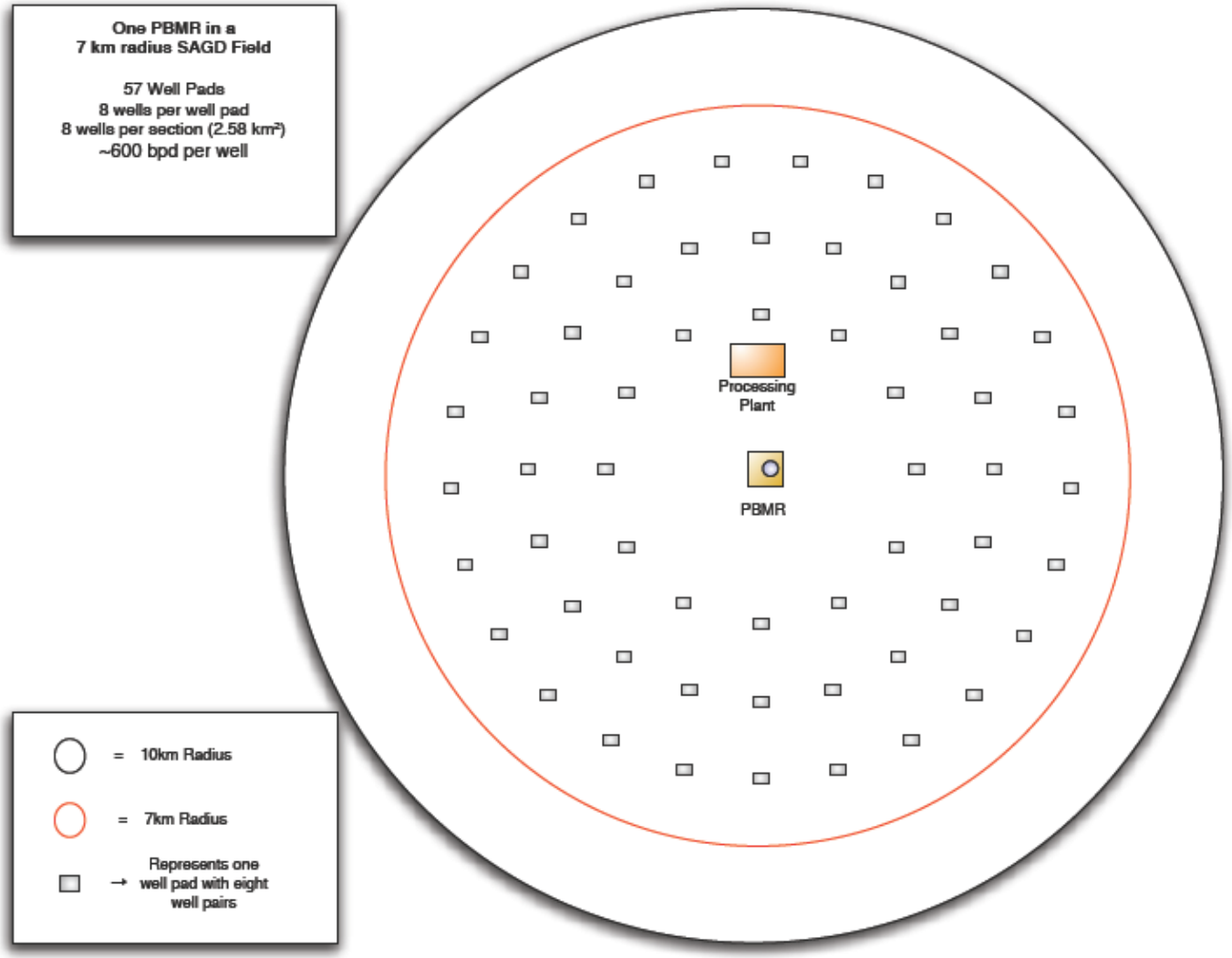
Nuclear Energy Integration

Reactor(s)	Oil Sands Site	Input Provided
2 PBMRs	100k bpd SAGD	Steam and Electricity
4 PBMRs	200k bpd SAGD	Steam and Electricity
3 PBMRs	100k bpd SAGD with Upgrading	Steam, Heat, and Electricity
1 CANDU 6 or 1 ACR-700 or 3 PBMRs	200k Direct Mining	Steam, Heat, and Electricity

Nuclear Energy Integration

Reactor(s)	Oil Sands Site	Input Provided
3 PBMRs	200k Direct Mining with Upgrading	Steam, Heat, and Electricity
Enhanced CANDU 6	Any	Electricity
ACR-700	Any	Electricity
ACR-1000	Any	Electricity
PBMR	Any	Electricity

SAGD Steam 54K bbls/d



Hydrogen

- Using nuclear energy only, the only possible means is electrolysis
- Research underway to use thermo-chemical processes – NGNP
- Best current use of nuclear is to use nuclear heat for steam methane reforming – saves some natural gas and CO_2 emissions.

Hydrogen Electrolysis

Nuclear Reactor	Electrolysis H_2 Capacity (kg/day)	Barrels of Syncrude
Enhanced CANDU 6	355,200	66,767
ACR-700	361,440	67,940
ACR-1000	576,000	108,271
One-Unit PBMR	98,400	18,496
Two-Unit PBMR	196,800	36,992
Four-Unit PBMR	393,600	73,984

Challenges

- Licensing
  - No HTGRs have been licensed in Canada
  - CANDU's should be easier to license
  - Licensing non-CANDU technology is possible due to the new licensing process. (Risk informed)
- Public Opinion
  - Dependent on technology chosen and education campaign
  - Global warming helping nuclear acceptance

Challenges continued

- Labor costs and shortage
- Need a labor plan for construction and operations
  - Similar to Chinese housing plans
- Transportation of large heavy components
- Weather for construction
- Designs for limited oil sands field lifetime
  - Convert to electric production

Safety

- Record of industry excellent
  - One minor western exception – Three Mile Island – no offsite contamination or injuries
  - Chernobyl – not western reactors
- Advanced designs use more passive safety features such as the PBMR's no melt-down core.
- Most designs limit size of emergency planning zone to site boundary

Economics

- Difficult to find reliable figures
- References: CERI report – "Electricity Generation Technologies: Performance and Cost Characteristics" 2005 prepared for the Ontario Power Authority
- Pebble bed nth of a kind target for capital
- Recent commodity price increases
- Difficult to make apples to apples comparison
- For capital assumed overnight engineering, procurement and construction costs

Rapid Recent Rise in Copper Prices

Cost Assumptions - Basic Inputs

General Inflation	2.00%
Term, years	40 Nuclear, 20 Natural Gas
Federal Tax Rate	22.1%
Provincial Tax Rate	8.00%
Debt Ratio	50%
Loan Term, yrs	40
Interest Rate	8.00%
Equity Return	14.75%; 12.71%
Prop Tax & Insurance	1.50%
Tax Life, Years	20
Declining Balance Rate	100%
Real Return	12.50%; 10.50%

Natural Gas Plant Assumptions

Capital Charge Rate	0.1524
Generation (MWe)	100
Overnight $/kWe	1050 in Edmonton
Construction Period	2 years
Construction Interest	12.71% on ½ of construction period escalation of overnight costs
O&M	$11 million per year
Heat Rate (btu/kWh)	6800
Natural Gas Price	Varies

Enhanced CANDU 6 Assumptions

Capital Charge Rate	0.1444
Generation (MWe)	728
Overnight $/kWe Electric in Ontario	3375 (CERI)
Overnight $/kWe in Edm (electric)./Ft. M (steam)	4050/3150
Construction Period	6 years
Construction Interest	14.75% on construction capital outlay sequence - yr1: 8%, yr2: 21% yr3: 27.1%, yr4: 19.6%, yr5: 12%, yr6: 7.2%, yr7: 5.1% (CERI)
O&M	$90 million per year (CERI)
Nuclear Fuel Cost	3.75 $/MWh (CERI)

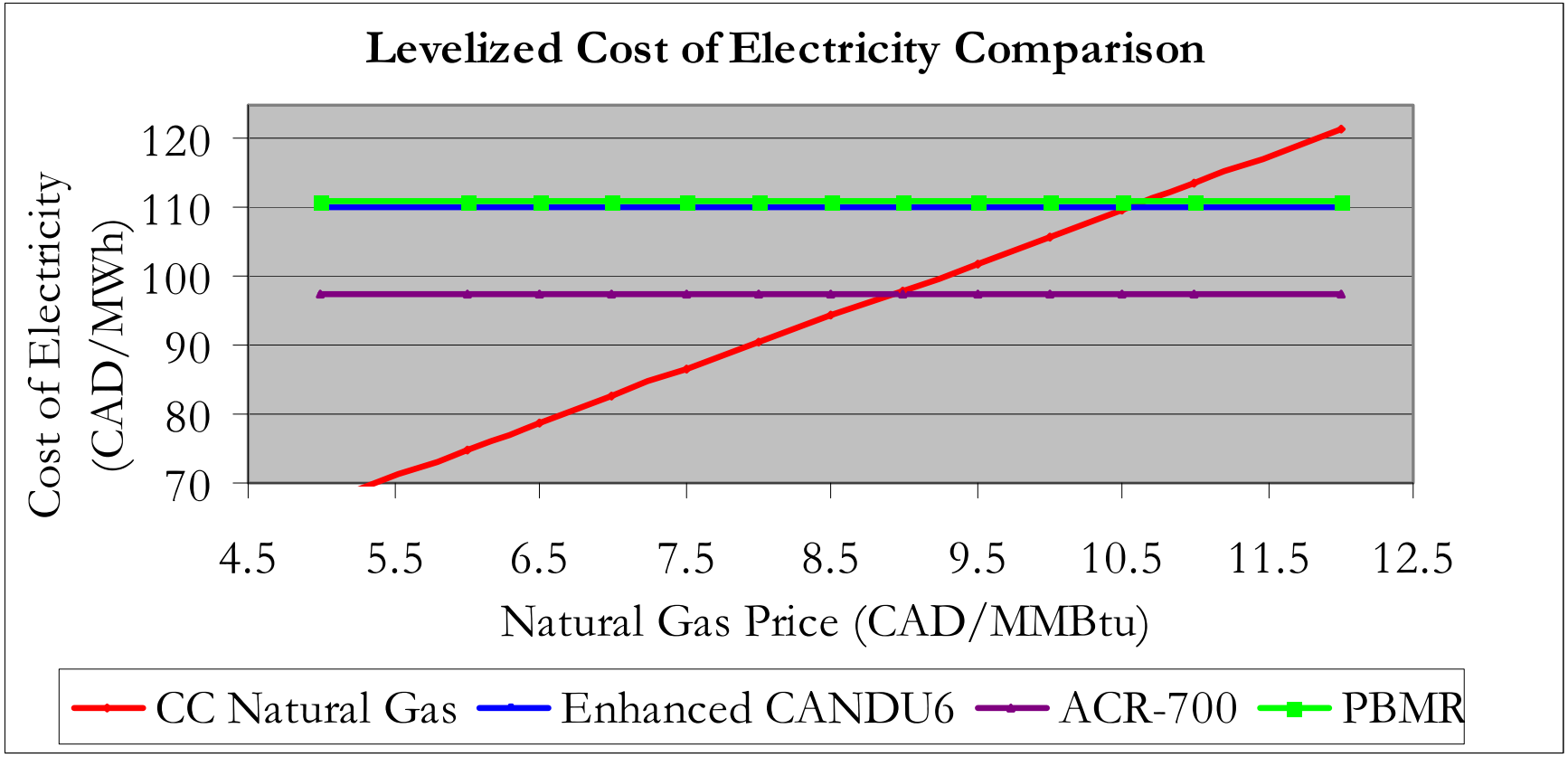
ACR-700 Assumptions

Capital Charge Rate	0.1444
Generation (MWe)	703
Overnight $/kWe in Ontario	2740 (CERI)
Overnight $/kWe in Edm (electric)./Ft. M (steam)	3288/2558
Construction Period	6 years
Construction Interest	14.75% on construction capital outlay sequence - yr1: 8%, yr2: 21% yr3: 27.1%, yr4: 19.6%, yr5: 12%, yr6: 7.2%, yr7: 5.1% (CERI)
O&M	$100 million per year (CERI)
Nuclear Fuel Cost	5.45 $/MWh (CERI)

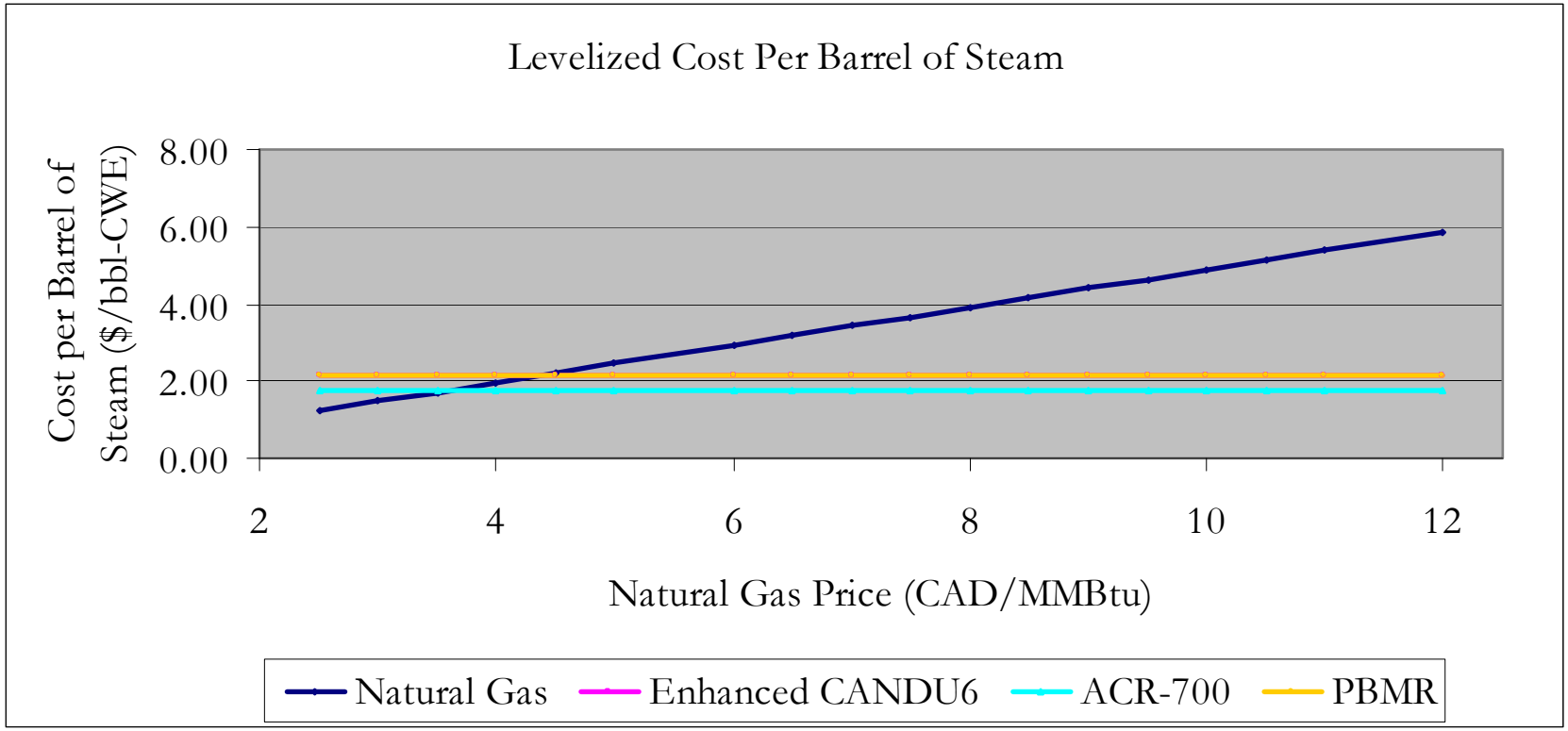
PBMR Assumptions

Capital Charge Rate	0.1444
Generation (MWe)	172
Overnight $/kWe	3750
Overnight $/kWe in Edm (electric)./Ft. M (steam)	4800/3733
Construction Period	3 years
Construction Interest	12.71% on ½ of construction period escalation of overnight costs
O&M	$10.5 million per year
Nuclear Fuel Cost	21.25 million $/year

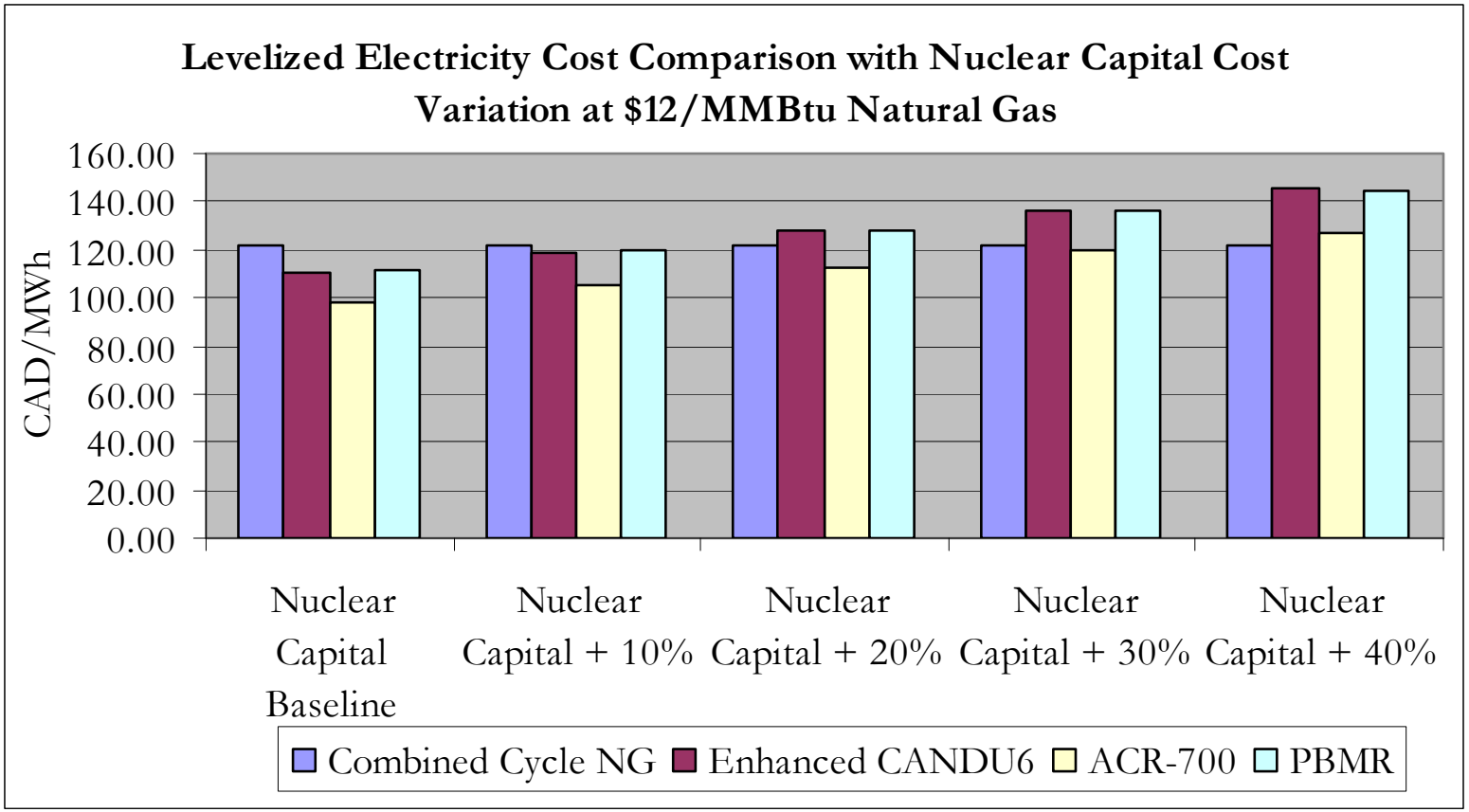
Table of Results for Electricity



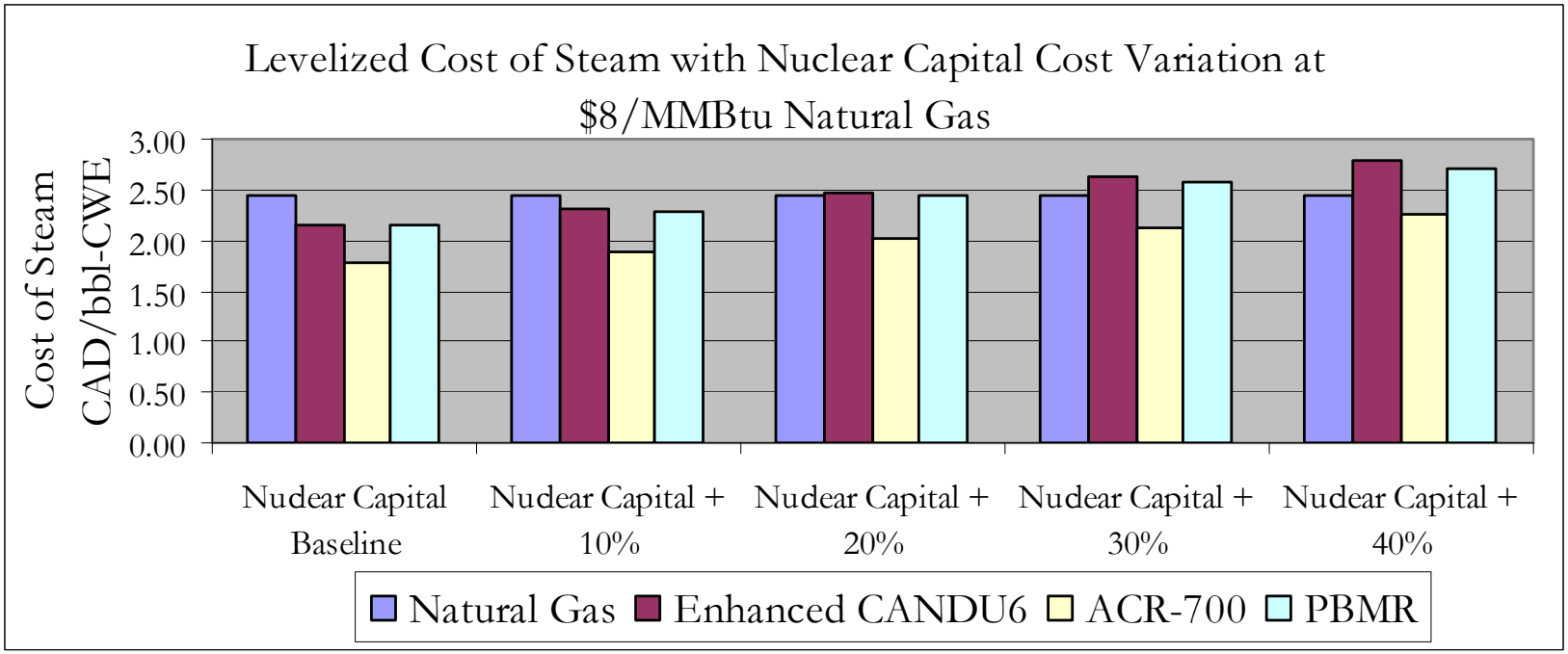
Cost for Steam Only



Capital Cost Sensitivity Study for Electricity



Capital Cost Sensitivity Study for Steam



Cost for Steam Only

- The breakeven price of Natural Gas for the PBMR:

  $7/MMBtu (Canadian)

- The levelized cost for each reactor is :

  CANDU6: 2.79 ($/barrel of steam)
  ACR700: 2.25
  PBMR: 3.40

Table of Results for Electricity

- The breakeven price of Natural Gas for the PBMR:

  $13/MMBtu (Canadian)

- The levelized cost for each reactor is ($/MWh):

  CANDU6: 128
  ACR700: 112
  PBMR: 134

Business Model

- Oil sands companies not expected to be nuclear plant operators
- May be investors
- Limited liability companies formed to provide energy on a contract basis
- Similar to present situation

Greenhouse Gas Savings in Representative Reactor Scenarios

Reactor(s)	Oil Sands Site	Input Provided	GHG savings in metric tons of CO_2e per yr	Lifetime (40 yr) GHG savings in metric tons CO_2e
2 PBMRs	100k bpd SAGD	Steam and Electricity	3.3×10^6	131×10^6
4 PBMRs	200k bpd SAGD	Steam and Electricity	6.6×10^6	262×10^6
3 PBMRs	100k bpd SAGD with Upgrading	Steam, Heat, and Electricity	4.0×10^6	158×10^6
1 CANDU 6 or 1 ACR-700 or 3 PBMRs	200k Direct Mining	Steam, Heat, and Electricity	1.8×10^6	70×10^6

Greenhouse Gas Savings in Representative Reactor Scenarios

Reactor(s)	Oil Sands Site	Input Provided	GHG savings in metric tons of CO_2e per yr	Lifetime (40 yr) GHG savings in metric tons CO_2e
3 PBMRs	200k Direct Mining with Upgrading	Steam, Heat, and Electricity	3.1×10^6	124×10^6
Enhanced CANDU 6	Any	Electricity	2.7×10^6	208×10^6
ACR-700	Any	Electricity	2.7×10^6	107×10^6
ACR-1000	Any	Electricity	4.3×10^6	170×10^6
PBMR	Any	Electricity	0.7×10^6	26×10^6

Conclusions

- Nuclear energy is a viable alternative to the use of natural gas in the oil sands industry.
- Depending on application, PMBR and various CANDU options have advantages – Determinants:
  - PBMR good for steam for typical oil sands field – 50-100,000 bbls/day
  - CANDU good for large scale electric production – likely not in Ft. McMurray due to construction costs
  - ACRs good for large fields (200,000 bbls/day) and electric production but limited due to low pressure and well density possible in field.

Conclusions Continued

- Economic analysis appears to show lower costs of energy when compared to expected natural gas prices.
- The CO_2 emission avoidance for every 100,000 bbls/day production amounts 131 x 10^6 tonnes per year
- Timeline for development of first application is at least 10 years.
- Public acceptance requires special effort
- Regulator needs to be prepared to license new reactor technologies including advanced CANDUs and PBMRs.
- Present business models for energy suppliers would work with nuclear
- Oil sands company investment in nuclear technologies will be important to jump start industry.

Recommendations

- Establish a public outreach program on nuclear energy and alternatives
- Develop specific site conceptual designs for real oil sands development projects
- Develop a workforce plan for licensing (regulatory readiness), construction and operation.
- Develop an industry wide energy strategy sharing or co-owning facilities such as central electric generating plants and hydrogen production facilities.