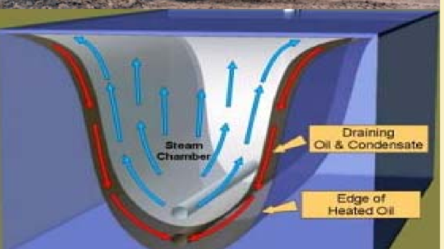

Small Nuclear Steam Generators for Alberta's Bitumen Resources

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Western Focus Seminar
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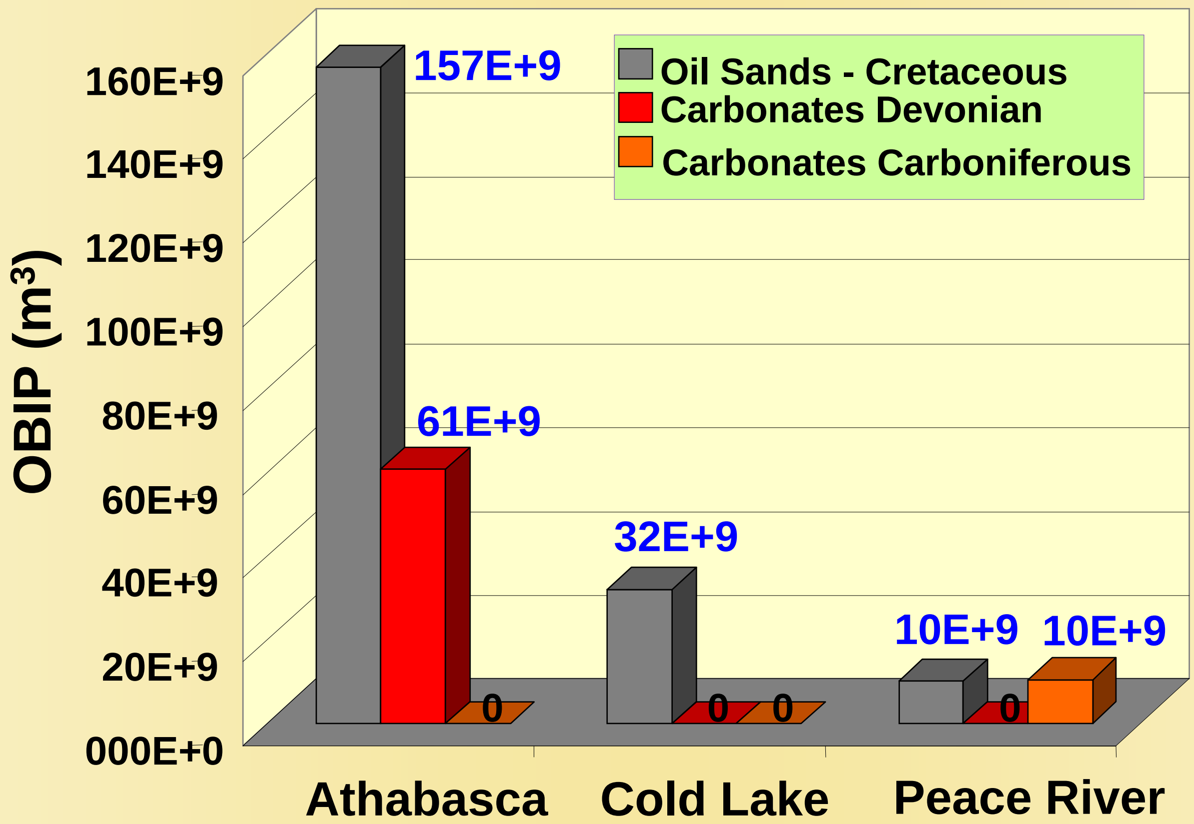
Alberta Bitumen Outlook



Carbonates - 71 billion m^3 of bitumen

- Grosmont formation contains 71% of Alberta's bitumen carbonate reserves

Bitumen: In-Place Volumes and Reserves ($10^9 m^3$)

Recovery method	Initial volume in-place	Initial established reserves	Cumulative production	Remaining established reserves	Remaining established reserves under active development
Mineable	16.1	5.59	0.58	5.01	2.95
In situ	254.2	22.80	0.28	22.53	0.39
Total	270.3 (1 701)[a]	28.39 (178.7)[a]	0.86 (5.4)[a]	27.53 (173.2)[a]	3.34 (21.0)[a]

[a] Imperial equivalent in billions of barrels.

New and improved recovery in-situ processes required:

- In situ recovery (e.g. SAGD):
  - "Commercial infancy"
  - Technological development still required to accelerate in-situ maturity and adoption
- Some reservoirs are currently considered uneconomic:
  - Geology or other physical features (e.g. thin sands)
  - New recovery processes need to be developed to address these unexploited resources
- More than 25% of Alberta's bitumen is in bitumen carbonate reservoirs
  - Currently no economically viable recovery process
- The technological challenge is to:
  - Develop recovery processes that are technically and economically feasible, while
  - Balancing against the other emerging (emerged) stakeholder challenges

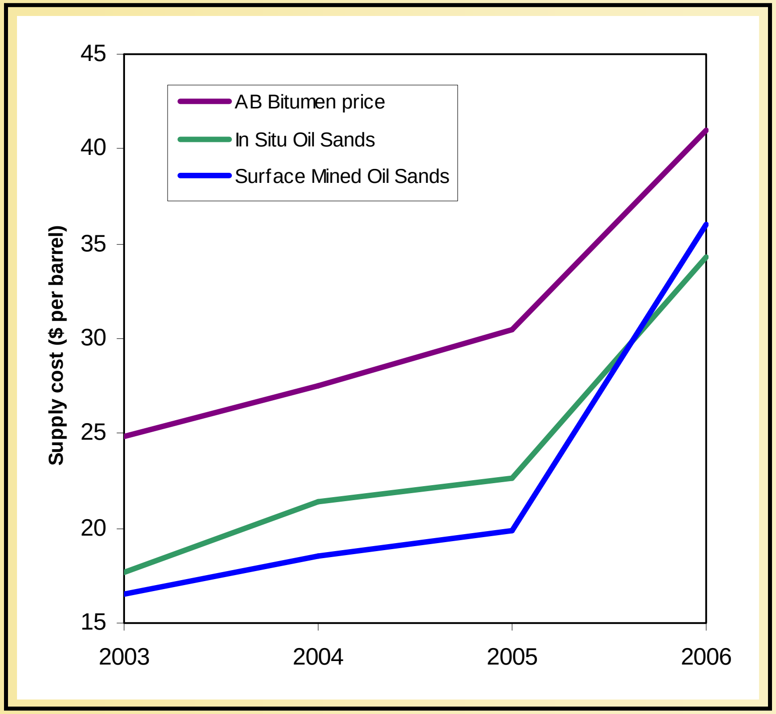
Emerged Challenges

Rising Costs

- Improve oil sands processing to reduce bitumen losses, minimize maintenance issues, and optimize efficiency
- Develop and implement new processes that require less energy input
- Develop and implement smaller, more modular processes that require less infrastructure and thus less initial capital expenditure

Minimizing Environmental Impacts:

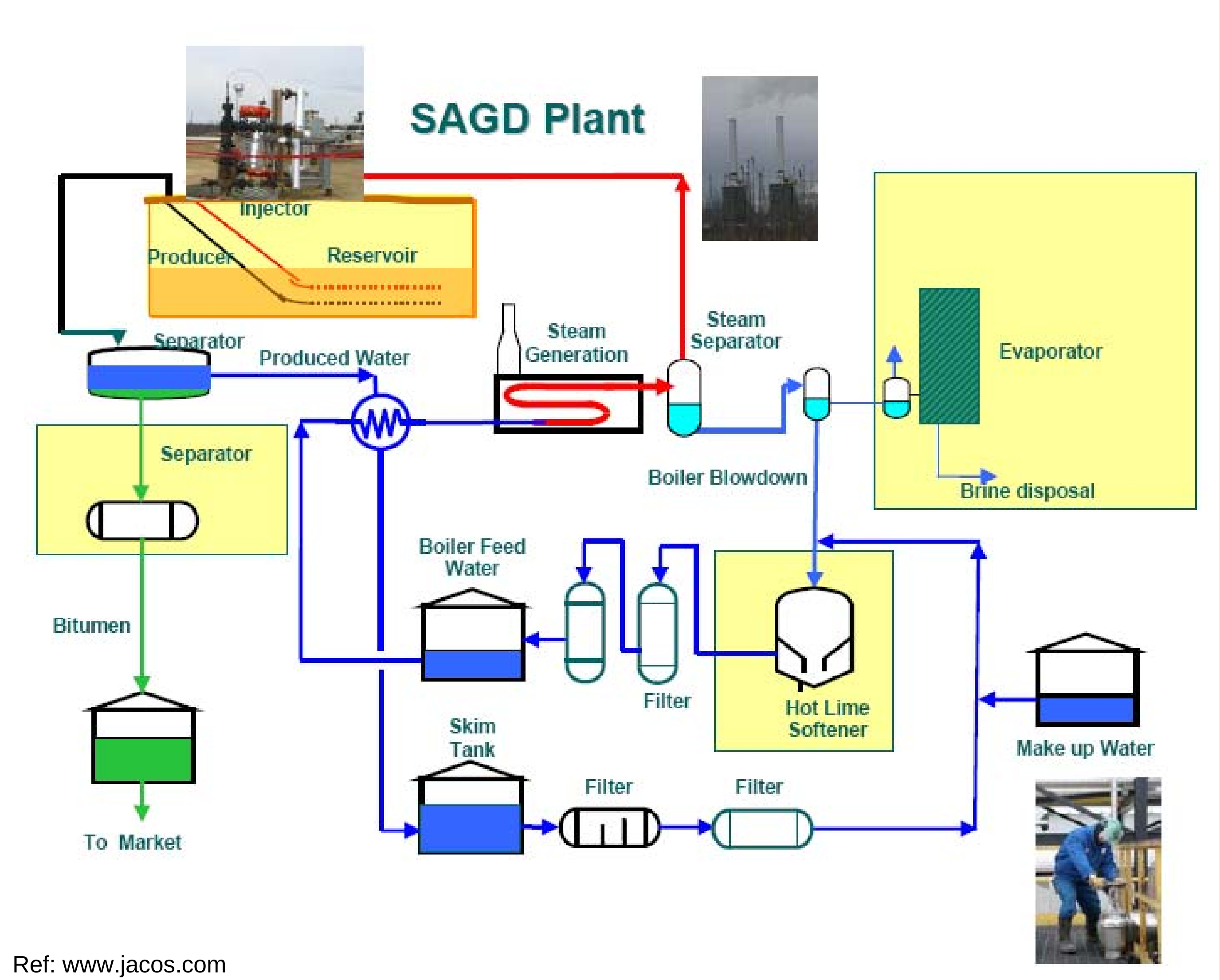
- Land:
  - Technological advances are required to develop processes that have less impact,
  - emergence of in situ oil sands recovery is key to meeting this challenge.
- Air:
  - Development of processes that minimize and eliminate air pollutants
  - Greenhouse gases
- Water:
  - Between 2-4 barrels of water are needed to produce a barrel of synthetic crude oil from bitumen.
  - Currently 90-95% of the water is recycled, but significant volumes of fresh water are still used



Possible Energy Sources for Oil Sands

Energy Source	Conversion System
– Natural Gas	Combustion & steam reforming
– Coal – Bitumen – Residues	Conventional combustion Circulating fluidized bed Gasification
– Uranium	Nuclear/steam/electrolysis
– Geothermal (HDR)	Steam

In-Situ SAGD Steam System



Ref: www.jacos.com

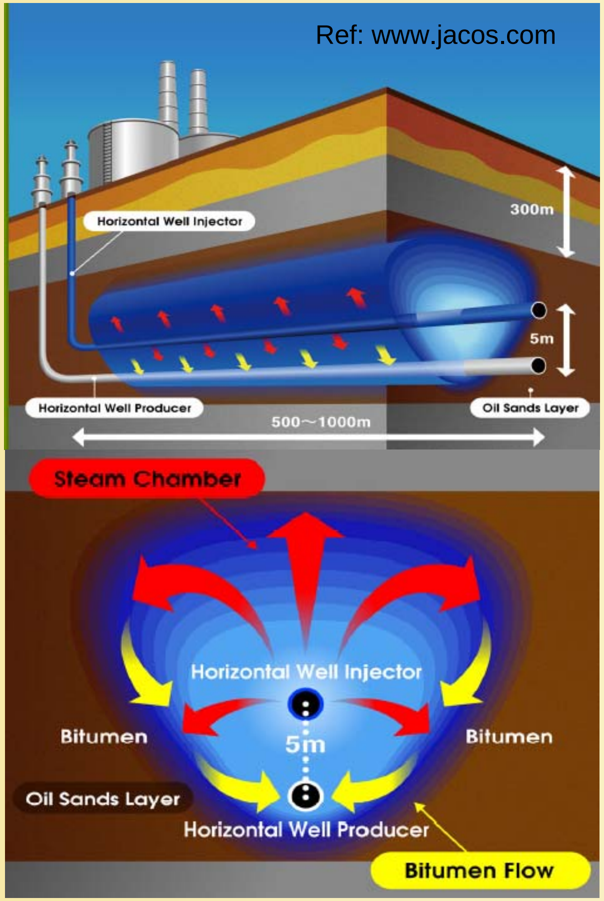
Reservoir Conditions

		High Quality	Low Quality
Reservoir Quality			
	Bitumen Gravity (°API)	8	8
	Continuous Pay Thickness (m)	35	15
	Porosity (%)	35	31
	Bitumen Saturation (%)	85	71
	Effective Vertical Permeability (Darcies)	5	2.5
	Bitumen Viscosity (mPa.s)	1,000,000	3,000,000
Performance			
	Recovery of Original Bitumen in Place	65	50
	Cumulative Steam Oil Ratio	2	2.8
Design			
	Deth to resevoir top (m)	200	200
	Effective Horizontal Well Length (m)	750	750
	Inter-well Spacing (m)	150	100
	Peak Production Rate per well-pair (m^3/d)	245	95

Example: In-Situ Oil Sands Operation

- 60,000 Barrels bitumen/day
- Steam Required: 34,000m^3/day
- SOR – 3.5
- Steam Temperature: 250-290°C
- Steam Pressure - 3 MPa

This would require a plant on the order of ~1000 MWt, comprised of a single reactor or several smaller reactors. Gen-III reactors are at least 3 times larger. Heating the water with electricity would require 3X power



Commercial Nuclear Energy by the Numbers

- Outstanding safety record in North America
- No emissions during operations; ~75% of US emissions-free generation
- Lowest life cycle GHG emissions
- Reliable—high capacity factor
- 10% of US capacity generates 20% of electricity
- 17 applications to USNRC for 26 new units

Nuclear System Integration Challenges (Special Considerations for Oil Sands)

- Transport of components to (remote) site
- Licensing for a new application
- Inexperience with the reactor design
- Efficient generation and transport of heat to the working site
- Refuelling
- Cogeneration operation
- Disposition after site plays out
- Workforce
- Logistics of operation

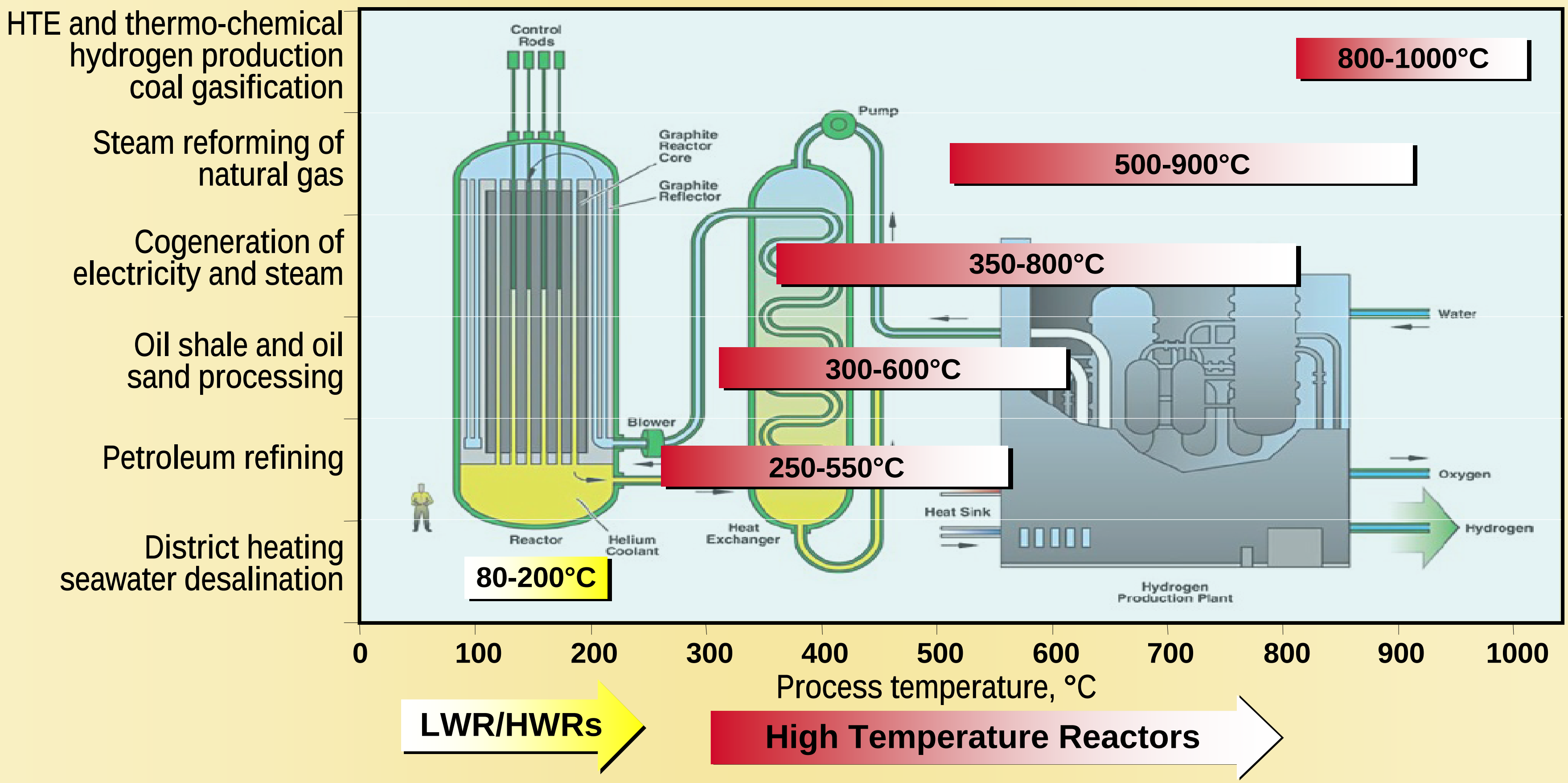
Reactor Size Classifications

- The International Atomic Energy Agency (IAEA) defines (based on electrical output):
  - Small and medium-sized reactors (SMR):
    - Small reactor: <300MWe
    - Medium reactor: 300 to 700MWe
  - Large reactor: >700MWe
- According to IAEA, 139 of 442 commercial power reactors in current operation are SMRs
- Deliberately Small Reactors (DSRs)
  - Designs that do not scale to large sizes but capitalize on their size to achieve specific performance characteristics
  - "SMR" has also been used for "Small Modular Reactors"

Types of SMRs by Coolant

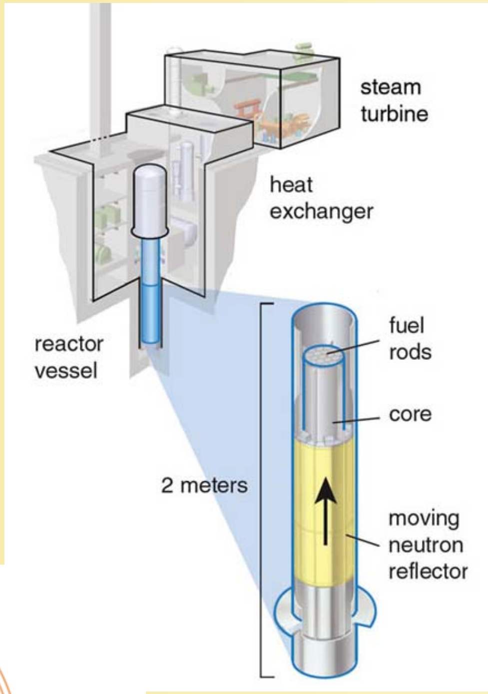
- LWR: Light Water Reactor
- SFR: Sodium Fast Reactor
- LFR: Lead Fast Reactor
- GCR: Gas Cooled Reactor (high temp. reactor)
- VHTR: Very High Temperature Reactor
- HWRs? Heavy Water Reactor
- Other

Applications as a function of temperature



SMR concepts being developed internationally

- United States of America
- Russia
- Japan
- France
- India
- Argentina
- South Korea
- China



Ref: www.americanscientist.org/issues/pub/a-nuke-on-the-yukon/1
Ref: www.hyperionpowergeneration.com/

SMR Attributes

- Modular fabrication and construction logistics
  - Fabrication
  - Transportation
  - Construction
- Plant Safety
  - Inherent safety features
  - Assured decay heat removal
- Operational flexibilities
  - Site selection
  - Load demand
  - Grid stability
  - Water usage
  - Demand growth
  - Plant economics
  - Total project cost
  - Economy of scale
  - Investment risk

Overview of the Generation IV Systems

System	Neutron Spectrum	Fuel Cycle	Size (MWe)	Missions	R&D Needed
Sodium Cooled Fast Reactor (SFR)	Fast	Closed	300-1500	Electricity, Actinide Management	Advanced recycle options, Fuels
Very-High-Temperature Reactor (VHTR)	Thermal	Open	250	Electricity, Hydrogen, Process Heat	Fuels, Materials, H_2 production
Gas-Cooled Fast Reactor (GFR)	Fast	Closed	1200	Electricity, Hydrogen, Actinide Management	Fuels, Materials, Thermal-hydraulics
Supercritical-Water Reactor (SCWR)	Thermal, Fast	Open, Closed	1500	Electricity	Materials, Thermal-hydraulics
Lead-Cooled Fast Reactor (LFR)	Fast	Closed	50-150 300-600 1200	Electricity, Hydrogen Production	Fuels, Materials
Molten Salt Reactor (MSR)	Epithermal or Fast	Closed	1000	Electricity, Hydrogen Production, Actinide Management	Fuel treatment, Materials, Reliability

http://www.gen-4.org/Technology/systems/index.htm

Summary

- Application of nuclear technology to the oil sands will be a commercial decision
- There may be some role for R&D, but it is too early to determine what the needs are
- Licensing is the major barrier to introduction of SMRs
- Lots of interest; stay tuned to see what develops

Contact Information

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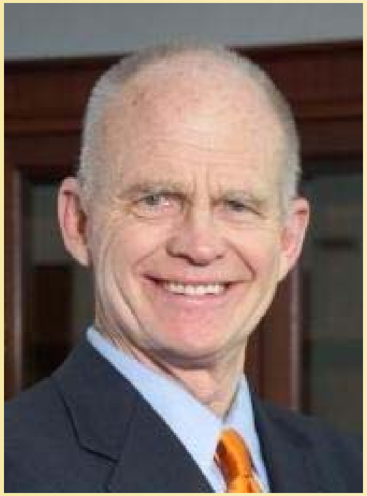

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