Integrated Oil Sands and Nuclear Process Economics

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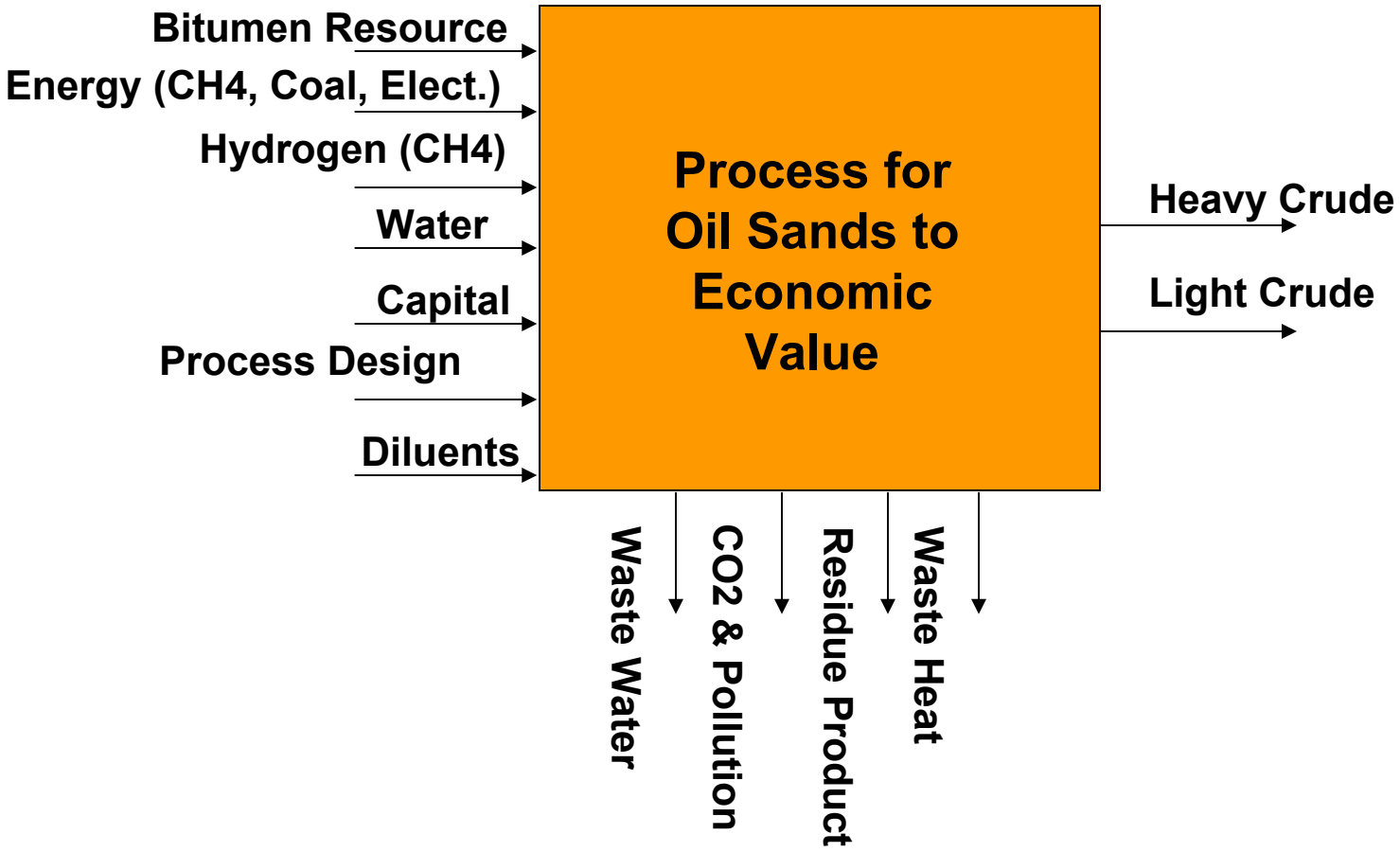
Oil Sands Value Chain



Oil Sand Process Issues

- Energy Costs and Possible Flexibility Constraints
- CO2 Emissions and Costs (Going to $100/t?)
- CH4 Constraints and Costs (Heat and H2)
- Capital Constraints (Use Advanced Manufacturing?)
- Labor Constraints (Use Autonomous Systems?)
- Energy Costs Increase Labor and Capital Costs (Embodied 30-40%)
- Water Constraints
- Diluent Constraints
- Material Waste Streams/Tailings

Process Choices

- Criteria for selection of nuclear system (Or for alternative system)
  - Recognize energy as <u>part</u> of process value chain
  - Need to think of "whole system" integration
  - Need comprehensive thinking to maximize economic efficiency of system.
- Economically Recover Everything Possible
  - Reduced cost for refinery implies better price from refiner.
  - Release natural gas to markets
  - Make waste into product

Status Quo Process Costs

- 1.5 bbl of oil-equivalent input per bbl "product" to pipeline.
  - A 25% to 35% "excess" energy input per product output
  - A 10-15% product loss in coke and recovery
- Costs a 20% premium on pipeline transport due to viscosity.
- Electricity transmission and distribution costs are 20-30% of industrial prices
- Obtain a $30/bbl premium on sweet or 30% premium (Daily Canadian Energy Report)
- High cost energy input for low value energy outputs

Technology/Process Choice Modularity I

- **Technology Spiral-Development**
  - **Technology will continue to change and improve. Why lock in old costs?**
  - **Path is planned with infrastructure and economics**
  - **Lease and switch-out when better tech available**
  - **Used/Depreciated tech has (reduced cost) market-value/use**

Technology/Process Choice Modularity II

- **System-Independent Modules**
  - **Failsafe w/ Replaceability, operability, reliability**
    - **Accidents do not affect resource or process**
    - **Plug and Play / Plop and Op**
    - **Neither BOP or Reactor are inter-dependent**
    - **A redundant module failure does not shut down system**
  - **Need to decouple economies-of scale**
  - **Can allocate costs across value chain components**
  - **Can use renewable or "advanced" energy source in future**

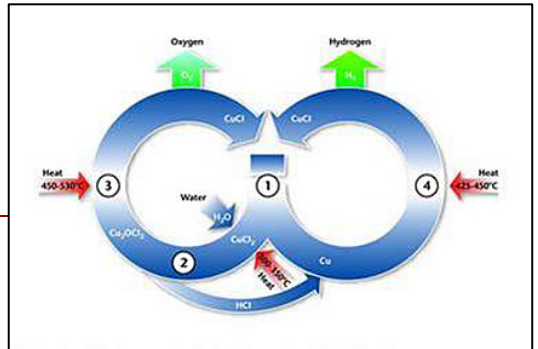
Disruptive Systems View

- Use H2 to convert all C or CO2 to fuel (e.g. from petroleum coke)
- Dramatic improvement of energy product per tonne of "ore."
- Coke-based ethanol is "subsidized" green fuel.
- Avoid all use of CH4 in production
- No CO2 emissions
- CO2 for HCAGD: Hot-CO2-Assisted Gravity Drainage (Easy separation and low viscosity?)

Hydrogen Process

- H2 as energy carrier; not as energy
- C as H2 carrier to make liquid fuels
- Local H2 production
  - Enhanced upgrading
  - Conservation of CH4
  - Elimination of CO2 from SMR
  - Elimination of CO2 from fuel burning
  - Conversion of coke and waste into product
  - Conversion of C & CO2 to high quality fuel
  - Chemical process improvement?

Hydrogen Production



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

- **Sulfur-Iodine Cycle, CuCl Cycle, or high electrical efficiency electrolysis**
  - **Thermo-chemical costs (with expected improvement) are 1 to 1.5 times current costs of H2 from SMR (@$3.50/GJ natural gas)**
  - **Electrolysis is 2.0 to 3.0 times more expensive.**

- **Natural gas is now $7-$8/GJ**
- **Stored H2 is NOT a fuel for making peak electricity!**

Reactor-Enabled Oil-Sands Process

- **Reactor system as source of electricity, and of H2, hot CO2, and steam, in any pressure/temperature, and in any proportions**
  - **Maybe no electric generation**
  - **Modules for H2; Modules for heat**
  - **High-Efficiency (reduce water needs, lower costs)**
  - **Sized for actual/current need**
  - **O2 and electric-heat to go above reactor temperature.**

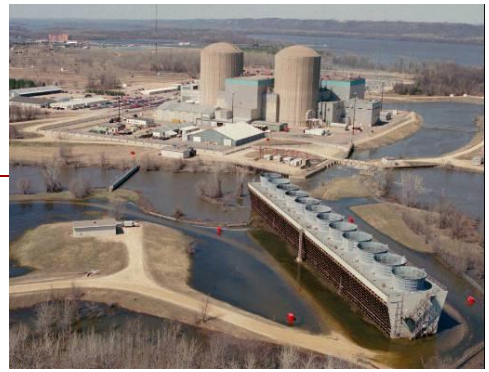
Economies of Scale

- Decouple economies of scale by:
  - Integrated-system view
  - Advanced manufacturing
- Advanced (factory) manufacturing for:
  - Reduced costs
  - Minimal contingency
  - Short construction time
  - Maximum reliability
  - Smart sensors/autonomous control
- Modular Sizing
  - Small footprint
  - Short pipe-runs to process
  - Minimize containment, foundation, structural support

Nuclear versus Alternatives

- Current nuclear "designs" are in the $0.03 to $0.045 /kWh range. ($0.01 to $0.015/kWt)
- Capital costs are in the $1000-$1500/kWe range (comparable with coal and cheaper than renewable)
- Nuclear fuel costs are (no-risk) fixed for 20-60 years.
- Coal capital costs are typically 30-40% of "total costs"
- Nuclear capital costs are typically 60-70 % of "total costs"
- Nuclear needs to add decommissioning costs that make nuke and coal "all-in" costs comparable
- $/kWh*100 ≈ $/GJ = $/MMBtu ≈ $/Mcf in kWt terms
  - Natural Gas and Coal are too expensive to use as fuel

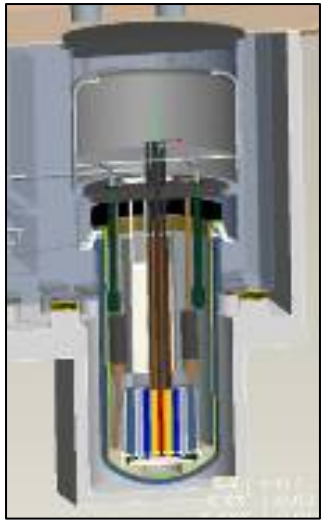
Large Generation Plants



- Have Economy of Scale, but..
  - Fixed in (wrong) place
  - Transmission costs and LONG steam runs
  - Rigid output = Rigid plant operation
  - Rigid output = No load-following on grid
  - Larger economic risk from single (failure) expensive device
  - Greater leap of tied-up capital
  - Have excess cogeneration

Replaceable LMFR Example

- Super-critical CO2 Brayton Cycle
  - High temperature
  - High efficiency electricity
  - Process heat (water splitting)
  - Steam or CO2 heat exchanger
- Fast Fuel is not used up
  - Not fueled on site (20-30 years)
  - Can use CANDU and LWR “waste” fuel.
  - Paid to take waste fuel
  - Fuel is leased and reusable
- Small, Low Pressure Reactor
  - Accident flow is in; not out
  - Process and product remain safe in failures
  - Automated load-following
  - No decommissioning/clean site



LMFR Infrastructure Compatibility/Flexibility

- FMFR can share its fuel with CANDU
- Breeding-ratio eliminates uranium-mining emissions
- Joint/mixed operation of generation, H20 splitting, and process heat, as needed to optimize value.

- Load-Following for added value
  - Base-load = $40/MWh
  - Load-Follow = (5000hr*$40+3000hr*$65+760hr*$180)/8760hr = $61/MWh
  - Natural gas NOT needed for peak power on grid.
  - Local use has no T&D costs

Allow use of Coal and Gas

- Coal gasification with O2, then H2, to make fuel without producing CO2 emissions.
- No CO2 sequestering needed, no GHG costs
- O2 available to increase temperatures for chemical process or allow added industry.
- O2 to change refinery chemistry ops?
- Upgrade CO2, and all CO2 emissions can be virtually eliminated.
- Use any and all high-concentration CO2 gas streams
- HCAGD may allow use of natural gas resource around Oil Sand resources

Backup Slides

Hydrogen Economics

Economic assumptions span a wide range

Description	GT-MHR	MHR alone	SI-H_2 Cycle	H_2-MHR
Total Overnight Cost, $M	1,290 ($1120/kWe)	968	504 - 1,008 ($210-420/kWt)	1,472 - 1,976
Operating Cost, $M/year	127	95.3	33.6 - 67.2	128.9 - 162.5
Efficiency — production	48%			40 - 60%
Efficiency — electrolysis	65 - 95%			
Electrolysis Unit Cost	$288M–1.2B ($250-1000/kWe)			

Joint GA/SNL/UK Study 2002