Nuclear Hydrogen Applications for the Production of Synthetic Crude

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Outline

- Hydrogen requirements for oil sands
- Integrated Facility
- Hydrogen production processes
  - Steam-Methane Reforming
  - Partial Oxidation
  - Electrolysis

Bitumen upgrading processes

- Advantages of an Integrated Facility
- Conclusions

Hydrogen Requirements for Oil Sands

- Oil production from Alberta Oil Sands higher than conventional production (1.1 million b/d in 2006)
- Upgrading a barrel of bitumen requires 2.4 – 4.3 kg hydrogen
- Projected need for hydrogen: 11 kt/d by 2040

Hydrogen Production Processes

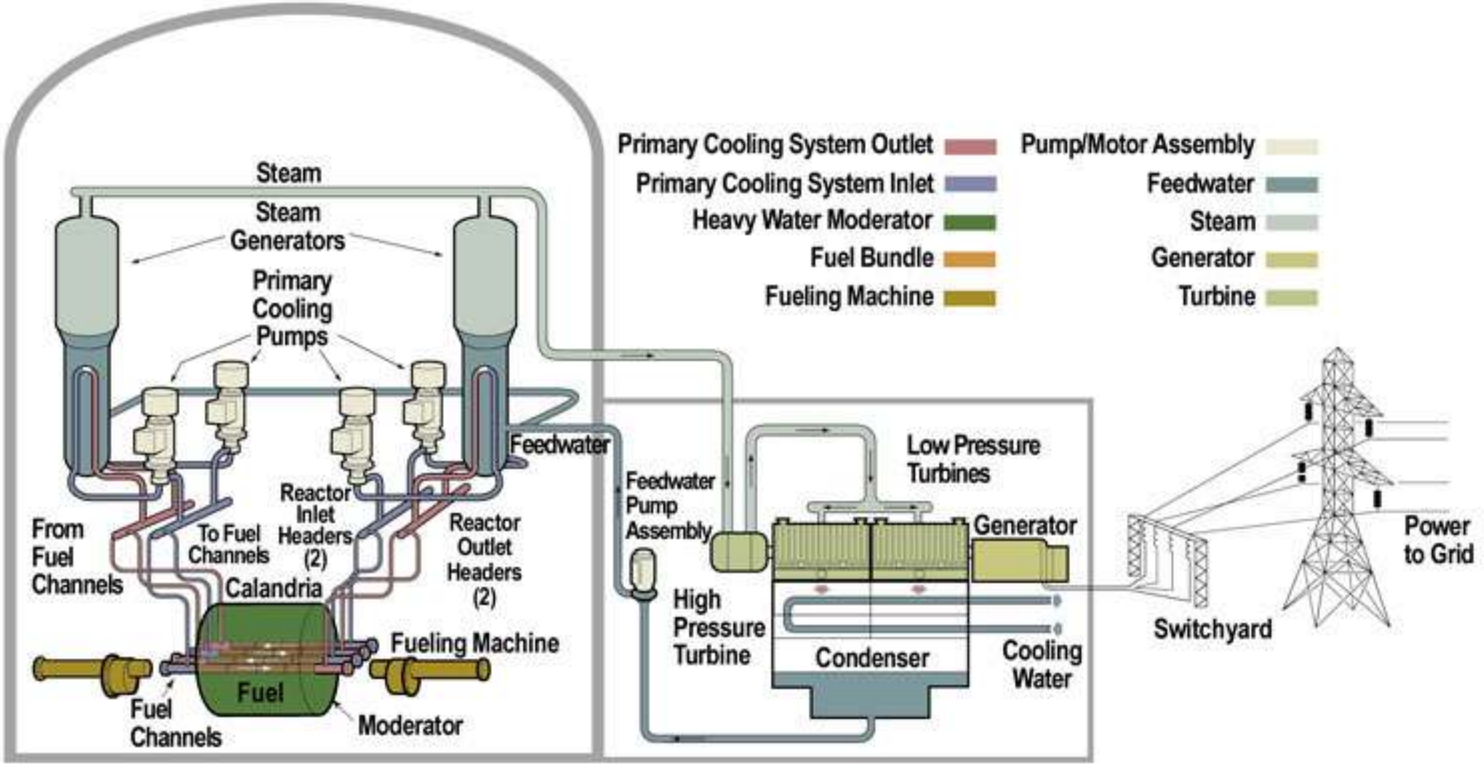
- Steam-Methane Reforming
  - 200 million SCFD (182 t/d)
  - Uses natural gas as feedstock and heat source
  - Produces 11 tonnes of CO_2/ tonne H_2
- Partial Oxidation of Heavy Hydrocarbons
  - Gasify coke or asphaltenes
  - Product gas contains H_2S, CO_2

Integrated Facility

- Integrated facilities common in oil industry
  - Refineries contain hydrogen plants
  - Share infrastructure
  - Heat recovery options
  - Minimize water use

- Conceptual design of integrated facility
  - Nuclear Reactor
  - Electrolytic Hydrogen Plant
  - Bitumen Upgrader

Nuclear Reactor – ACR-1000



- Light water cooled
- Reactor outlet 325º C, 12.1 MPa(g)
- Steam 278ºC, 6.4 MPa(g)

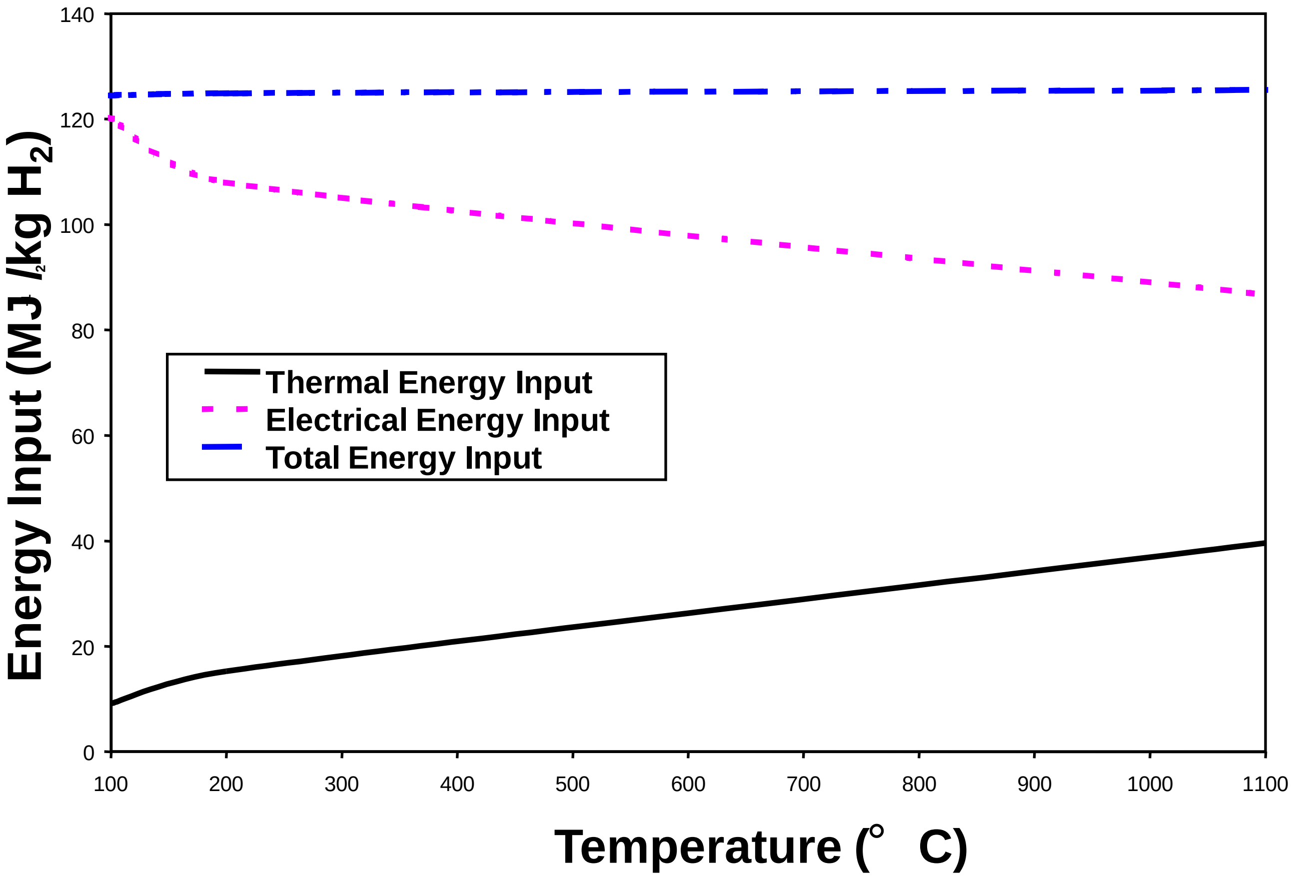
Water Electrolysis

- Well-established technology
- Electricity requirement 50-70 kWh/kg H_2 produced
- Ambient pressure cells – up to 500 Nm^3/h
- High pressure (1 MPa) cells - up to 120 Nm^3/h
- Thermal-to-hydrogen efficiency ~27% when combined with nuclear reactors

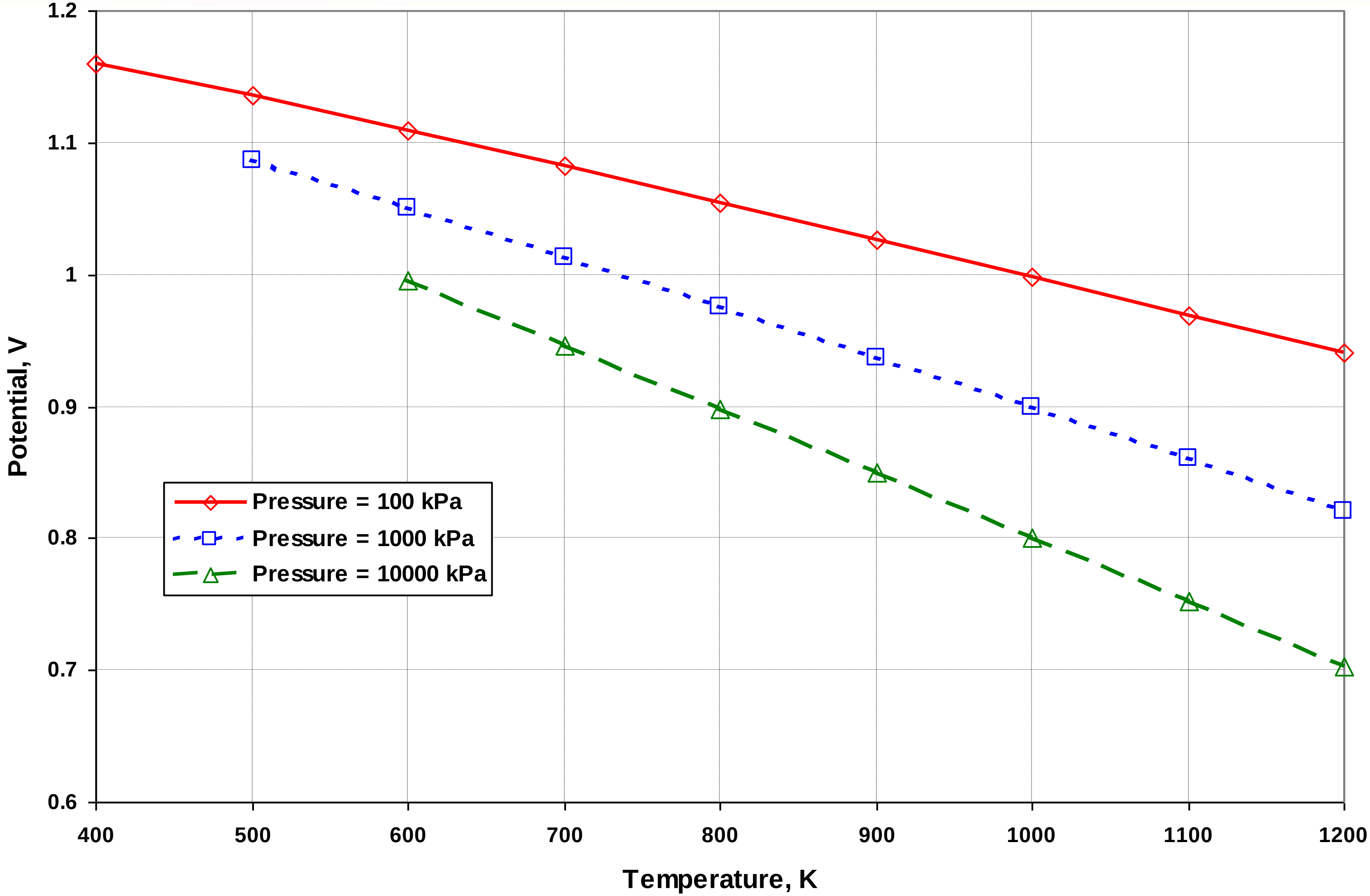
Steam Electrolysis

- Uses electrical and thermal energy to split water
- Better performance at higher temperature
  - Decreased electrical overpotentials
  - Increased gas diffusivity
  - More rapid kinetics
  - By-product: high temperature thermal energy
- Thermal-to-hydrogen efficiency ~33% when combined with nuclear reactors
- Temperature limit ~ 850ºC due to materials

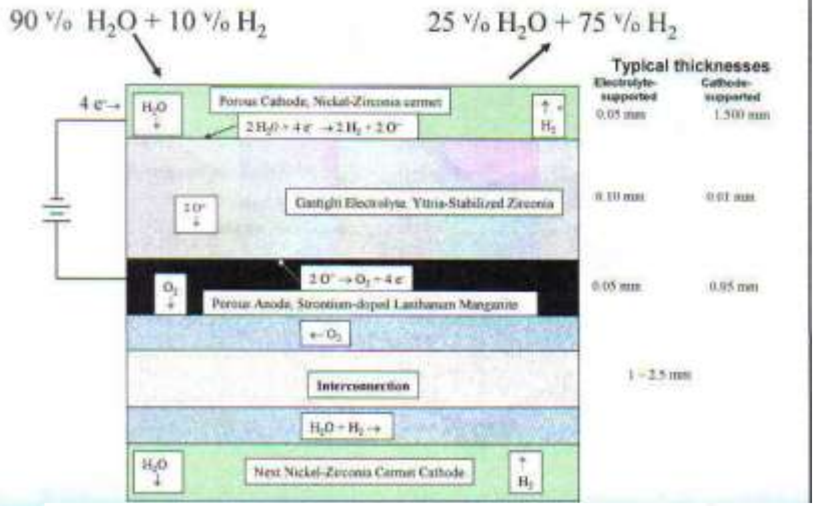
Energy Input for Steam Electrolysis

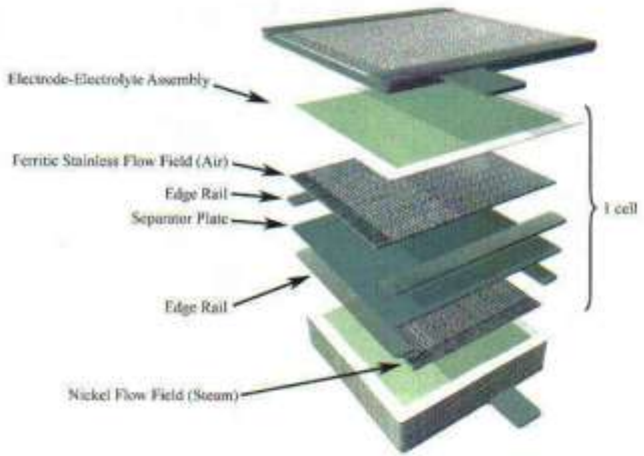


Steam Electrolysis



Steam Electrolysis

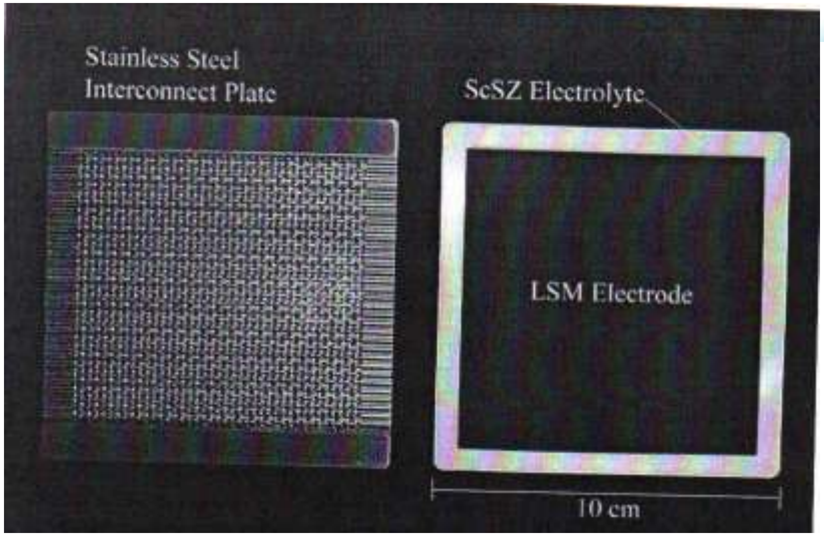




25-cell stack used in 1000-hour test Jan. 4 – Feb. 16, 2006

2 x 60-cell stacks tested at Ceramatec, SLC

Initial rate: 1.2 Nm3 H2/hr
final: 0.65 Nm3 H2/hr
2040 hours, ended 9-22-06
>900 hrs in co-electrolysis



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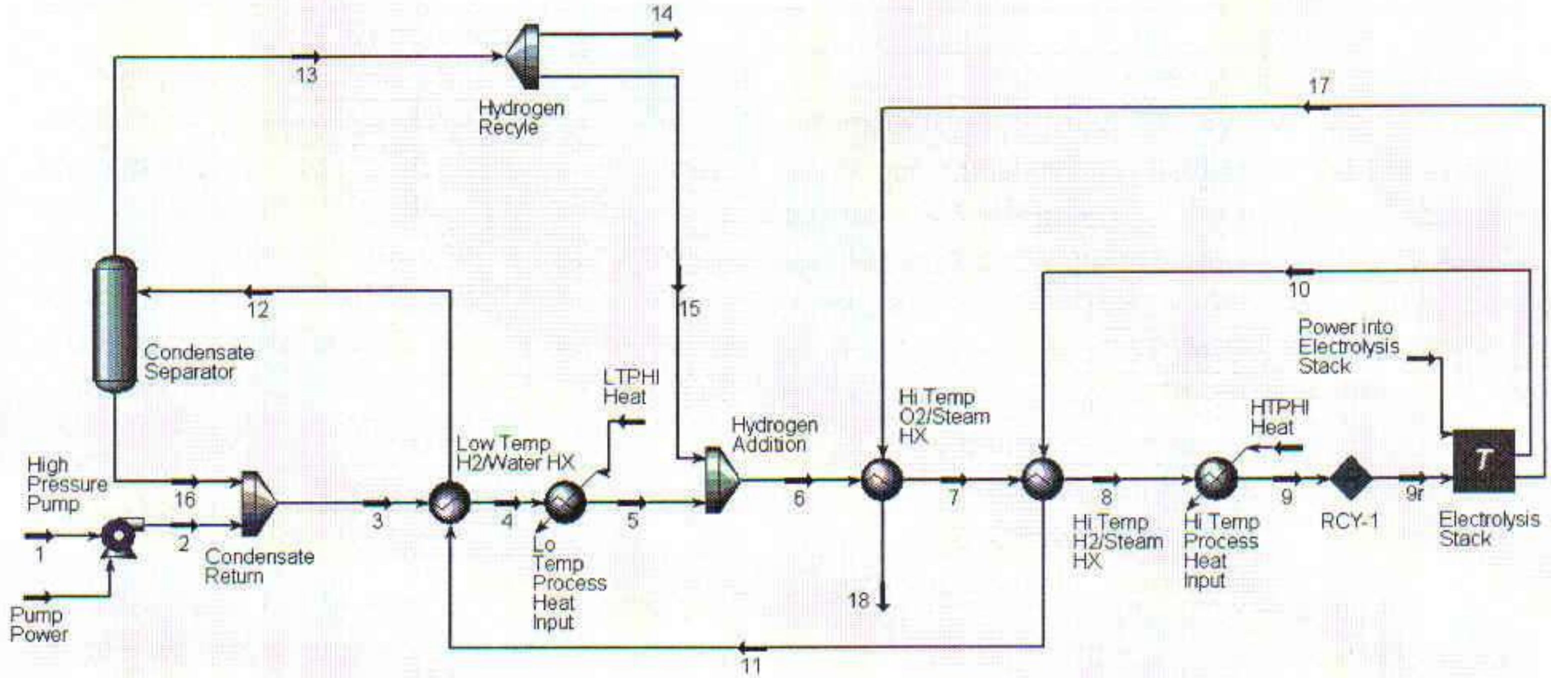
Integrated ACR-1000 and Steam Electrolysis

- ACR-1000 steam temperature ~ 278ºC
- Electrical resistance heating is required to increase the temperature to > 800ºC
- An optimized flow sheet developed for integration of HTE with ACR-1000 - to maximize efficiency
- ~15% of steam from ACR-1000 is used for thermal heating of HTE loop
- Overall thermal-to-hydrogen efficiency estimated to be ~33% - compared to ~27% for conventional electrolysis

Dedicated ACR-1000 to H_2 Production

- ACR-1000 = 3070 MW_{th}, 1087 MW_e
- Produce 232 000 Nm^3/h using water electrolysis
  - Comparable in size to SMR
- Produce 275 000 Nm^3/h using steam electrolysis
  - Reduce electricity output to 920 MW_e
  - Use 810 MW_e for H_2 production

Integrated ACR-1000 and Steam Electrolysis



Bitumen Upgrader

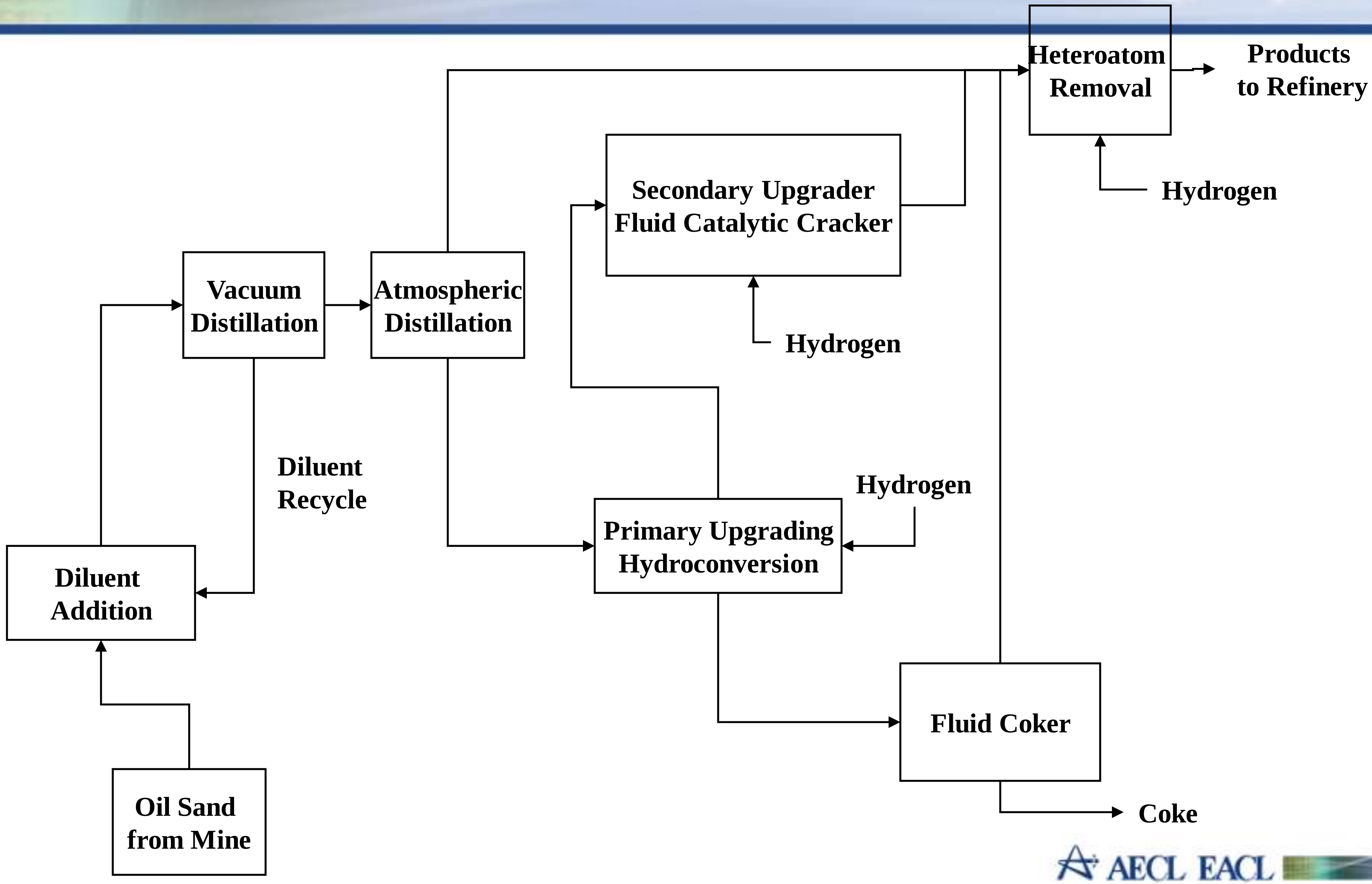
- Upgrade bitumen into synthetic crude oil
  - Refined like conventional oil into gasoline, diesel fuel, etc.
  - Produce a stable product with no heavy fractions
  - Reduce S, Ni, V content

- Steps in bitumen upgrading
  - Pretreatment
  - Primary upgrading
  - Secondary upgrading
  - Heteroatom removal
    - Atoms other than C and H (e.g., S, N, O, V, Ni)

Composition of Bitumen and Crude Oil

	Athabasca Bitumen	Conventional Light Crude	Synthetic Crude Oil
Density, kg/m^3	900	793	870
Kinematic Viscosity, m^2/s	7000	5	
Sulfur, wt %	4.9	0.5	0.11
Nitrogen, wt %	0.5	0.1	0.3
Naptha (82-177ºC)		25	16
Mid-distillate (177-343ºC)		40	49
Gas Oil (>343ºC)		24	33

Bitumen Upgrading Facility



Primary Upgrading

- Increase H/C ratio
- Break C-C bonds – at least 410-420ºC
- Fluidized catalyst bed
- Add H_2 at pressure of 7-10 MPa
- Single reactor – conversion of 60%
- Requires ~2 kg H_2/barrel
- Not always successful in cracking heavy hydrocarbons
  - Thermal process – coking
    - > 500 ºC and pressure > 10 MPa

Secondary Upgrading

- Break longer chain hydrocarbons into smaller pieces
- Fluid catalytic crackers
  - Commonly used in refineries
  - 470-510 ºC
  - Requires ~0.2 kg H_2/barrel

Heteroatom Removal

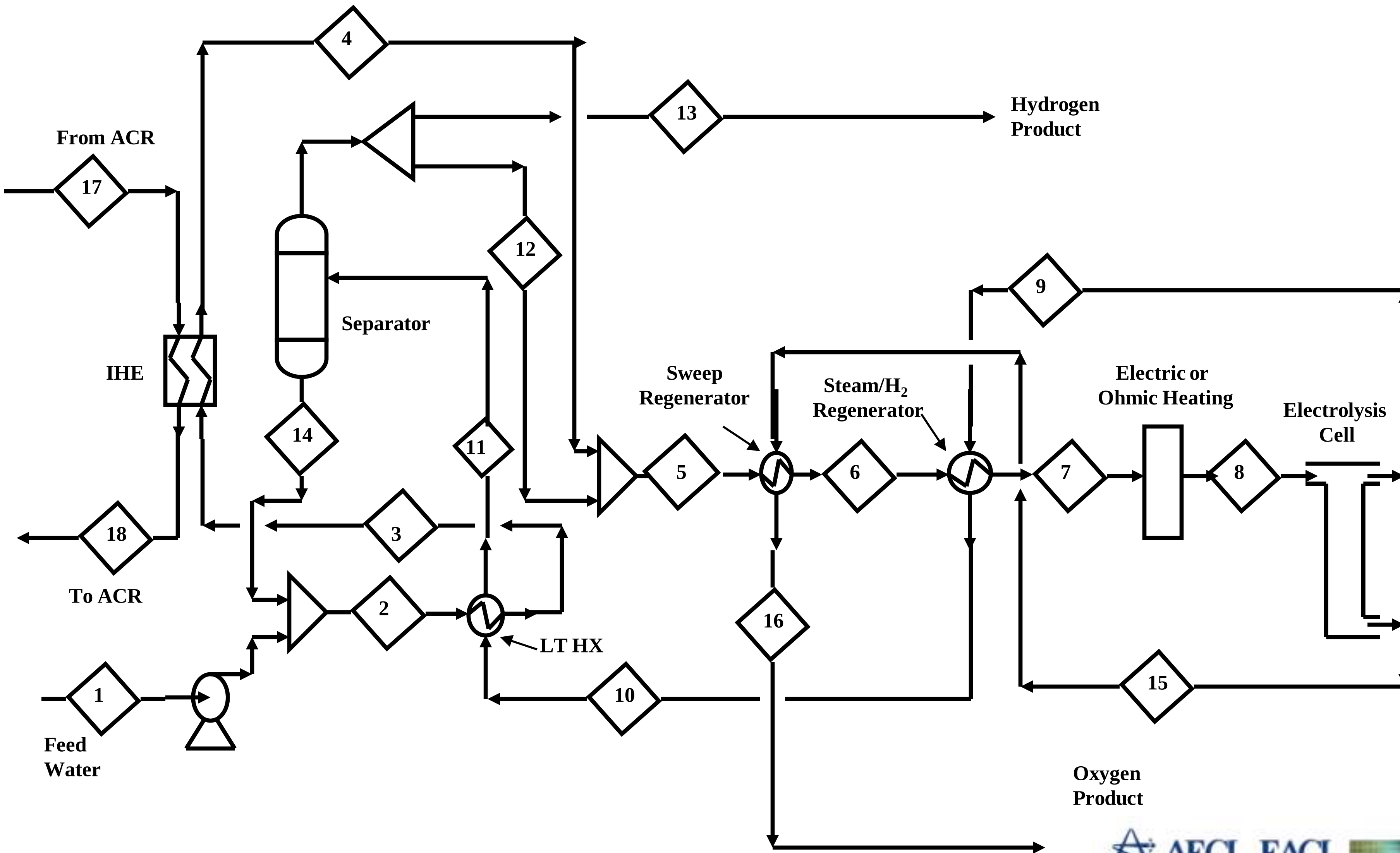
- Saturates the hydrocarbon molecules
- Removes S, N, O
- Fixed bed reactor
  - Temperature of 300-400 ºC
  - Increasing pressure enhances N removal
  - Requires up to 2 kg of H_2/barrel

Advantages of Integrated Facility

- ACR-1000 can produce steam and/or electricity
  - Provide process heat
    - Bitumen extraction processes
    - Electrolysis plant
    - Bitumen upgrader
- Steam electrolysis operates at 5 MPa and 825 ºC
  - Less H_2 compression required
  - Process heat
    - Oxygen Stream
    - Heteroatom Removal Unit
- Minimize the amount of fresh water used in process
- Optimization of integrated complex just beginning

Questions?

Integrated ACR-1000 and Steam Electrolysis



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