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Study Objectives

- Objectives: to investigate the potential business case for establishing uranium conversion, enrichment and fuel fabrication facilities in South Australia
  
  - To estimate direct and indirect capital cost, fixed and variable operational costs for uranium processing facilities
  
  - To estimate lifecycle project cost of the facilities: engineering, construction, procurement, commissioning, operation and decommissioning
  
  - To establish investment justification based on possible service revenues
Fabricated LWR Fuel Cost: $1500 ~ $2000/kg

2014 U₃O₈ export price: $92.8/kg (Requires 8.7 kg of yellowcake for 1 kg of LWR fuel)

Question (in net present value):

Fuel sales cost – yellowcake cost ($807.36) – lifecycle processing facility cost = ?

Study goal: Estimate the levelized cost for uranium further processing
Base Case Scenarios

• Three Basic Cases
  • Conversion only
  • Conversion and enrichment only
  • Conversion, Enrichment and Fuel Fabrication

• 2 Types of Conversion Facilities, 3 Different Configurations
• 1 Enrichment Facility
• 2 Fuel Fabrication Facility Configurations

• There are total of 8 possible scenarios (16 base case scenarios when Brownfield and Greenfield assumptions are included)

• All facilities at single location but within separate fences
# 8 Base Case Scenarios

<table>
<thead>
<tr>
<th>Case</th>
<th>Conversion</th>
<th>Enrichment</th>
<th>Fabrication</th>
<th>Final Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wet</td>
<td>-</td>
<td>-</td>
<td>NU UF6, NU UO2</td>
</tr>
<tr>
<td>2</td>
<td>Wet</td>
<td>Centrifuge</td>
<td>-</td>
<td>LEU UF6, NU UO2</td>
</tr>
<tr>
<td>3</td>
<td>Wet</td>
<td>Centrifuge</td>
<td>90/10</td>
<td>LWR Fuel, PHWR Fuel</td>
</tr>
<tr>
<td>4</td>
<td>Wet</td>
<td>Centrifuge</td>
<td>100 LWR</td>
<td>LWR Fuel</td>
</tr>
<tr>
<td>5</td>
<td>Dry</td>
<td>-</td>
<td>-</td>
<td>NU UF6</td>
</tr>
<tr>
<td>6</td>
<td>Dry</td>
<td>Centrifuge</td>
<td>-</td>
<td>LEU UF6</td>
</tr>
<tr>
<td>7</td>
<td>Dry</td>
<td>Centrifuge</td>
<td>90/10</td>
<td>LWR Fuel, PHWR Fuel</td>
</tr>
<tr>
<td>8</td>
<td>Dry</td>
<td>Centrifuge</td>
<td>100 LWR</td>
<td>LWR Fuel</td>
</tr>
</tbody>
</table>

LEU = Low Enriched Uranium, NU = Natural Uranium
Financial Modeling

General Assumptions

Inputs:
- Prices
- Discount Rate
- Production
- Operating Costs
- Initial Capital Costs
- Capital Spending
- Sustaining Capital
- Working Capital
- Closure Costs
- Taxes

Discounted Cash Flow (DCF) Calculation

Outputs:
- NPV
- IRR
- Payback
- C1 Costs

Sensitivity:
- NPV
- IRR
The inputs to the model will be produced in the study:

- Fuel Service Revenue
- Production
- Initial Capital Cost (direct and indirect)
- Operating Costs (variable and fixed, plus sustaining capital)
- Closure Cost
High Level Assumptions

- Restrictive market
  - Insignificant quantities traded on exchanges
  - Majority of fuel sales are under long term contracts

- Potential fuel processing facilities do not impact:
  - Uranium production (mining)
  - Uranium demand
  - Conversion, enrichment and fuel fabrication ‘toll’ will be impacted
• Toll Service Model is adapted as the base case scenario
  • The facility is contractually obligated to process customer-owned uranium
  • Conversion, enrichment and fuel fabrication ‘services’ are sold; weak exposure to yellowcake commodity price changes
  • These services contracts are typically charged as a fixed price per kgU or per Separative Work Unit (SWU) adjusted for inflation
  • Most nuclear fuel service companies operate facilities under toll service model
    • Cameco
    • GE
    • KEPCO NF
Toll Services for Conversion

- USD $67/lb used for the base case
- CIBC World Markets Inc. long-term yellowcake price forecast, January 2015
- However, it is not a factor impacting the business case in toll service model
- Strong correlation exist between global UF6 price and yellowcake price → conversion service price is expected to be stable

\[ y = 2.6723x + 6.5562 \]
\[ R^2 = 0.9993 \]
Positive correlation found between spot SWU price and yellowcake price

- Enrichment revenue can be reasonably obtained
- Uncertainties includes secondary market supply and socio-political factors (Fukushima, Russian HEU, etc.)

Fuel fabrication price not easily correlated to yellowcake prices

- Long term private contracts
- Insignificant quantity traded on exchanges
- Strategic plants mostly linked to domestic nuclear power industry
Conversion, enrichment and fuel fabrication facilities modeled to process 10,000 tU/year

- Based on average value of high and low IEA global nuclear power generation capacity projection in 2030 (37% increase from 2014): 376.2 GW(e) → 518.6 GW(e)

- Also based on Australia maintaining the current uranium market share: 7,393 tU/year (2004 to 2014 average) → approx. 10,000 tU/year
• 2 mass throughput configurations based on global demand
  • 90%:10% split for LWR and PHWR fuel processing capacity sizing
  • 100% LWR fuel fabrication scenario is examined

• Current Installed Capacity (Approx. 93% LWR and 7% PHWR)
  • LWR: PWR - 257 GW(e), BWR - 75 GW(e)
  • PHWR: 25 GW(e)

• Annual natural uranium demand by LWR and PHWR (94% LWR and 6% PHWR)
  • LWR: 59,000 tU/year (6,500 tU/year finished product)
  • PHWR: 3,500 tU/year (3,500 tU/year finished product)
Model Facility Sizes in Global Context

- Conversion facility: 10~13% of the global capacity in 2030
- Enrichment facility (7 million SWU): 8~10% of the global capacity in 2030
- Fuel fabrication facility will add 8~9% LWR fuel capacity and 23% PHWR capacity (90/10 case) to the global market

<table>
<thead>
<tr>
<th></th>
<th>Current Demand</th>
<th>Current Capacity</th>
<th>90/10 Facility</th>
<th>100 LWR Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWR</td>
<td>6,500 tHM</td>
<td>13,600 tHM</td>
<td>1,073 tHM</td>
<td>1,204 tHM</td>
</tr>
<tr>
<td>PHWR</td>
<td>3,000 tHM</td>
<td>4,300 tHM</td>
<td>980 tHM</td>
<td>0</td>
</tr>
</tbody>
</table>
Capital Cost Estimates

- The majority of capital cost will incur during procurement and construction stages.
- Based on existing commercial facilities for conversion, enrichment, and fuel fabrication and assembly.
- The most capital and operating cost intensive mechanical equipment are identified and costs are individually estimated.
- Small equipments such as pumps and valves are calculated as percentage values of Direct Costs.
- The capital costs for electrical, I&C and civil/structural components are estimated as percentage value of building and site Direct Costs.
• Major consumables and energy costs are individually calculated or scaled from similar facilities.
• Labour costs, including general maintenance and security, are scaled from similar facilities.
• The majority of labour cost will incur during procurement, construction, commissioning and operation phases.
Project Cost Estimates

- Project costs (BOM and labour for engineering, construction, commissioning) are estimated from Hatch’s EPCM experience in similar chemical, mechanical and high tech mechanical plants.
- Nuclear cost and productivity factors are applied whenever required.
- Regulatory and licensing costs calculation assumes that the requirements will be similar to the Canadian requirement.
  - South Australia and Saskatchewan in Canada share many similarities: yellowcake exporter, absence of fuel processing facilities, low population density, etc.
- Decommissioning cost will be based on projected decommissioning costs of similar facilities.
• Reference plant costs will be calculated in the currency of the country they are presently located in.

• The costs will be adjusted for South Australian local conditions.

• The World Bank purchasing power parity ratios will be applied whenever direct SA costs cannot be obtained for certain plant components and labour.

• Cost estimates are order of magnitude calculations and they are based on several assumptions made in this study.
Reference Plants - Conversion

- Conversion facilities are essentially chemical plants
- Two technologies examined
- Wet Conversion Reference Plants
  - Blind River Refinery Facility, Canada (U₃O₈ → UO₃)
  - Port Hope Conversion Facility, Canada (UO₃ → UO₂, UO₃ → UF₆)
- Dry Conversion Reference Plant
  - Honeywell Uranium Hexafluoride Processing Facility, Metropolis, USA (U₃O₈ → UF₆)

Photo credit: Cameco corporation
Reference Plants - Enrichment

- Second generation technology (gas centrifuge) considered
  - First generation technology (Gas diffusion process) phased out

- GC plant is essentially a mechanical plant

- Gas Centrifuge Reference Plant
  - Urenco USA facility, New Mexico, USA
  - Urenco TC-21 centrifuge used as the cost modeling basis

photo credit: US Department of Energy/Wikimedia Commons
Conversion, pellet production and assembly examined

- UF6 → UO2 conversion: Integrated Dry Route (IDR) process
- Pellet production and fuel assembly for LWR and PHWR fuel
  - For LWR fuel, AP1000, EPR and GE BWR assembly considered
  - For PHWR, CANDU 37 element is considered

Reference Plants
- Cameco Plant, Canada
- Westinghouse Plant, USA
- KNF Plant, Republic of Korea

Photo credit: KEPCO NF
Site Infrastructure Assumptions

- **Road requirement**
  - Industrial truck access, approximately 40 t per day (based on 10,000tU per year)
  - Rail not required

- **Power requirement**
  - Approximately 80 MW(e) (10 MW for conversion, 50 MW for enrichment, 20 MW for fuel fabrication)

- **Labour requirement**
  - Approx. 2,000 people (500 for conversion, 250 for enrichment, 1200 for fuel fabrication)

- **Water requirement**
  - Approx. 1,550,000 m$^3$/year (900,000 m$^3$ for wet conversion, 250,000 m$^3$ for GC, 400,000 m$^3$ for fuel fabrication facility)

- **Site Considerations (Brownfield and Greenfield Estimates)**
  - Access to 275 kV transmission line
  - Access to nearby port facility
  - Co-location with other nuclear facilities (NPP, Waste Repository)
  - Near existing uranium production facility
Project Risk Contingency Assessment

• The following methods will be utilized to identify the contingency factors for the facilities

  • Identification of project risks affecting CAPEX, OPEX, facility schedule
    • Risks will be identified and captured in the risk register.
    • Examples: construction, licensing/regulatory, availability of skilled labour, infrastructure, technology strategy, contracting strategy (EPC vs. EPCM), etc.

  • Cost impact will be quantitatively assessed.
    • Impact will be ranged to evaluate the most likely, optimistic and pessimistic scenarios
    • Monte Carlo Simulation to determine contingency level for project risks

  • Schedule contingency will be qualitatively assessed.
Exclusions

The study excludes the following considerations:

- Cost for regulatory and legal framework setup
- Socio-political factors
- Secondary supply
- Inter government negotiation and treaties
- Cost for marketing and customer relations
- All cost factors that will be incurred outside of the facilities boundary
- Any other classified information
Thank you.