APPENDIX D: FURTHER PROCESSING–ANALYSIS OF VIABILITY AND ECONOMIC IMPACTS

1. ANALYSIS OF VIABILITY—COMMISSIONED STUDY

This study, undertaken by Hatch Pty Ltd, assessed the business case and provides quantitative analyses for establishing facilities in South Australia that provide further processing services—uranium conversion, enrichment and fuel fabrication. These services have been suggested as having potential to add value to the state's exports of uranium oxide concentrates.

The study assessed the potential returns on investment of establishing the facilities in South Australia. It estimated the revenues and lifecycle costs of a range of uranium processing facilities with the capacity to process volumes equal to Australia's uranium production.

ASSUMPTIONS AND INPUTS

Further processing services

The study analysed several different types of uranium conversion, enrichment and fuel fabrication services, either on a standalone basis or in various combinations, including as vertically integrated activities, as shown in Figure D.1.

Facility capacity

As a baseline the analysis used a capacity based upon Australia's current share in the market for uranium oxide concentrate, comprising both its average output and growth to 2030 consistent with an expansion in global nuclear capacity. That growth in capacity is consistent with the commitments made by countries prior to the 2015 Paris Climate Change Conference in their intended nationally determined contributions (INDCs).[1]

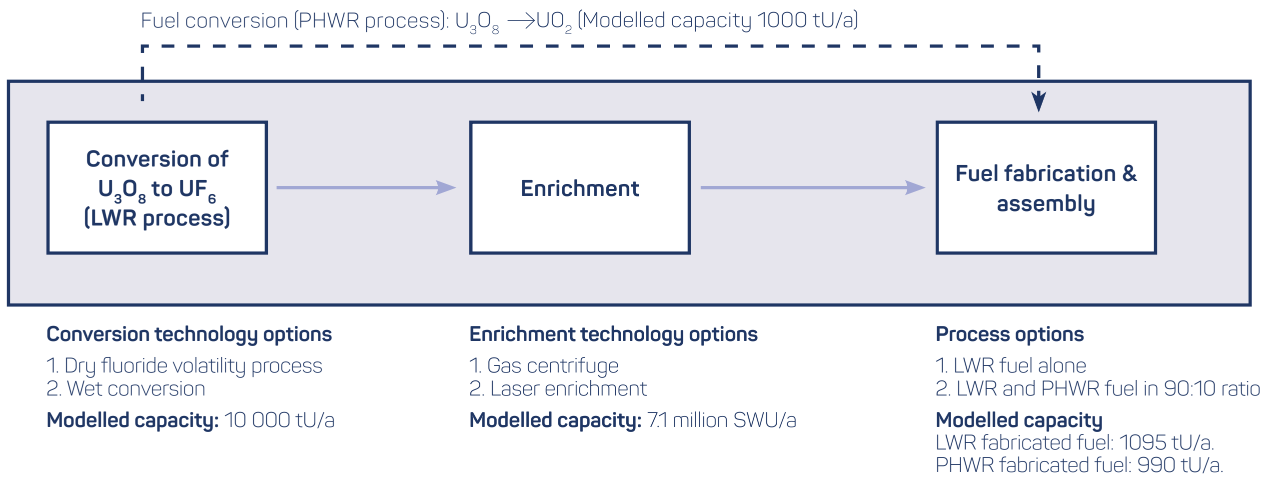
Table D.1 compares the capacity of the facilities addressed in the assessment to current global installed capacity and to relevant currently operating facilities. It shows that while the increment to current global capacity would be between 8 per cent and 17 per cent for the light water reactor (LWR) fuel, the increment to the heavy water reactor (HWR) fuel production capacity would be 23 per cent.

Capital and operating costs

Lifecycle costs were estimated for the development of further processing facilities in South Australia, including each of the five project phases—design, construction, commissioning, operation and decommissioning—as well as waste management.[2]

To estimate capital costs for each of the facilities and the combination of facilities, major equipment and material inventories were developed using process flowcharts for each facility type. These components and materials costs were then individually priced using standard chemical engineering plant cost evaluation methods and commercially available material cost databases.[3]

For each of these facilities, detailed cost estimates were also developed for supporting transport infrastructure (access to roads and port facilities) and for accessing electricity and gas distribution networks. These estimates were made for a hypothetical brownfield location that was assumed to be



tU/a = tonnes of uranium per annum
LWR = light water reactor
PHWR = pressurised heavy water reactor
SWU = separative work unit

Figure D.1: Conversion, enrichment and fuel fabrication processes and technology assessed

Table D.1: Comparison of modelled facility capacities to current global installed capacity and to capacity of commercially established facilities

Facility	Global installed capacity (2015)	Modelled facility capacity	Increment to current global capacity (%)	Comparable commercially established facilities
Light water reactor process				
Conversion to UF_6	59 100 tU/a	10 000 tU/a	17	Canada: Port Hope, Cameco wet conversion facility (12 500 tU/a) USA: Metropolis, Illinois Converdyn dry conversion facility (17 600 tU/a)
Enrichment	57 million SWU	7.1 million SWU	12	France: Georges Besse II gas centrifuge enrichment facility (7–7.5 million SWU)
Fuel fabrication	13 600 tU/a	1095 tHM/a	8	USA (several): Columbia, Westinghouse facility (1150 tU/a)
Pressurised heavy reactor process (no enrichment)				
Conversion to UO_2	4320 tU/a[a]	1000 tHM/a	23	Canada: Port Hope, Cameco (2800 tU/a)
Fuel fabrication	4320 tU/a	990 tHM/a	23	France: Georges Besse II gas centrifuge enrichment facility (7–7.5 million SWU)

[a] Based on World Nuclear Association 2015 figures
Notes: tHM/a = tonnes of heavy metal per annum, SWU = separative work unit, tU/a = tonnes of uranium per annum
Source: World Nuclear Association

near existing supporting infrastructure and a hypothetical greenfield location that was assumed to be 30–50 km from these facilities. Potential cost synergies from the collocation of further processing facilities were not included, which suggests that further reductions in costs could be achieved.[4]

For operating and other project lifecycle costs, estimates were drawn from technical literature, historical projects, calculations based on process requirement analyses, and financial, environmental and regulatory compliance reports of commercially established facilities.[5]

Estimated capital costs for further processing facilities (base case) are presented in Table D.2. Capital and operating cost estimates were able to be made with greater certainty for the commercially proven wet conversion, gas centrifuge and fuel fabrication processes. The dry conversion technology (with only one operational facility) and laser enrichment technology (not yet commercially proven),[6] have substantial cost uncertainties even though they are estimated to require significantly smaller capital investments than the wet conversion and gas centrifuge processes respectively.

Table D.2: Lifecycle capital and operating costs for LWR processing facilities (2015 A$)

	Wet conversion	Dry conversion	Gas centrifuge enrichment	Laser enrichment	LWR fuel fabrication
Capital costs	$437.4m	$247.2m	$7623.0m	$2616.0m	$977.7m
Operating costs (per year)	$98.0m	$66.0m	$82.0m	$83.0m	$243.0m
Plant design capacity (per year)	10 000 tU	10 000 tU	7.1m SWU	7.1m SWU	1095 tU

Notes: tU = tonnes of uranium, m = million, LWR = light water reactor, SWU = separative work unit
Source: Hatch

Table D.3: Spot and long-term average prices for uranium conversion and enrichment services, 2015

Service	Spot price (A$)	Long-term average price (A$)
Conversion (A$/kgU)	8.4	20.8[a]
Enrichment (A$/SWU)	77.9	182[b]
LWR fuel fabrication (A$/kgHM)	N/A	409
PHWR fuel fabrication (A$/kgHM)	N/A	136

[a] Long-term average price
[b] Over the period 2005–11
Notes: US$1 = A$0.77, kgU = kilograms of uranium, kgHM = kilograms of heavy metal, LWR = light water reactor, PHWR = pressurised heavy water reactor, SWU = separative work unit
Source: Hatch

Revenues

Assessments of viability required determining a range of prices that could be used to estimate revenues that a prospective facility developed in South Australia might secure.

Uranium conversion, enrichment and fuel fabrication services are not traded in meaningful quantities on a commodity exchange.[7] However, prices of actual transactions are available and from them a long-term average price can be determined. Both spot and long-term average prices for conversion and enrichment are presented in Table D.3.

An assessment of viability undertaken on the basis of the long-term average price assumes that either new supply would meet new demand or displace an existing supplier.

In comparison with prices for conversion and enrichment, estimates for fuel fabrication services are more difficult to establish, given that they are based on negotiated long-term contracts and there is no spot market. The analyses undertaken used financial and purchasing reports published by utilities KEPCO (South Korea) and Ontario Power Generation (Canada) to estimate an average price.[8] The long-term average prices used are set out in Table D.3.

RESULTS OF VIABILITY ANALYSIS

Overall, viewed on a standalone basis, the financial assessments suggested that most further processing facilities were not viable. Those based on currently used and proven technologies were at best marginal investments, and in many cases had negative returns.[9] Positive returns were indicated for facilities that used proprietary or unproven technologies, although that assumed significant investments were made to demonstrate and commercialise those technologies, but no estimate of these investments were made or included as part of the analyses.

Those outcomes are reflected in Figure D.2, which shows facilities assessed to be viable in the upper-right quadrant. They were assessed to be viable if they were profitable with an internal rate of return of 10 per cent—the amount a private investor would expect to receive on an investment.

The relative viability of each of the processing technologies for LWR fuel as standalone facilities is presented in Figure D.2.[10]

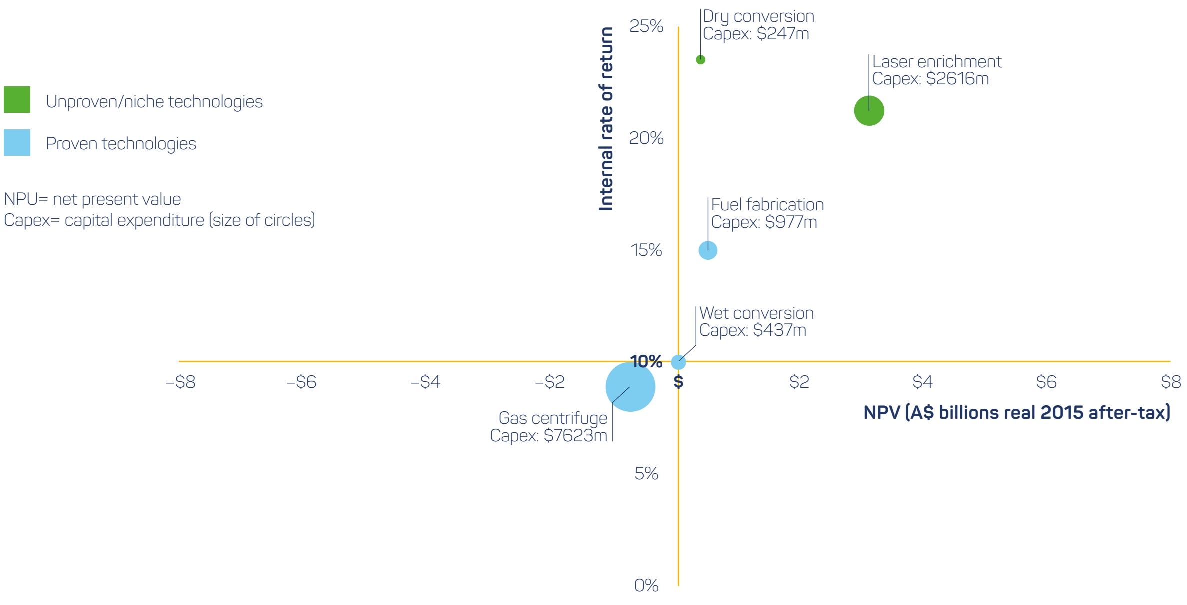


Figure D.2: Commercial viability of standalone facilities

Conversion

While the wet conversion process is marginal but negative, the dry conversion process is very profitable, as shown in Table D.4.

This outcome is in large part a result of the dry conversion process being simpler and requiring fewer processing steps than the wet process—which means that, in the assessments, it has lower capital and operating costs.[11] However, it is important to note that the dry conversion facility carries far greater technical risks.

Table D.4: Project net present value (NPV) for standalone conversion facilities (A$ millions 2015)

Facility	NPV at A$21 per kgU
Wet conversion	-1
Dry conversion	383

Note: kgU = kilograms of uranium
Source: Hatch

Enrichment

Gas centrifuge enrichment is not viable under most realistic future scenarios.[12] In comparison, laser enrichment, if it could be commercially demonstrated at scale, could be highly viable as a disruptive technology. The assessment did not take into account the potentially substantial costs associated with proving commercial feasibility.[13] If it could be, the analysis suggests it would have a substantial competitive advantage over existing producers.[14]

The comparison of the viability of enrichment by gas centrifuge and laser enrichment can be seen in Table D.5.

Table D.5: Project net present value (NPV) for standalone enrichment facilities (A$ millions 2015)

Facility	NPV at A$182 per SWU	NPV at A$78 per SWU
Gas centrifuge enrichment	-709	-5013
Laser enrichment	3114	-1191

Note: SWU = separative work unit
Source: Based on data supplied by Hatch

Fabrication

A fuel fabrication facility manufacturing light water fuel would be viable if contracts could be secured at or above the current estimated prices (approximately US$315 per kilogram of heavy metal (HM)[15]). However, the fabrication of both light and heavy water reactor fuel in a 90:10 ratio in a hybrid facility was found to be less profitable.[16]

SENSITIVITY–VERTICAL INTEGRATION OF TWO OR MORE SERVICES

The analysis was also undertaken on the basis that two or more services might be integrated. That was undertaken for the following reasons:

- Because of the distances involved to export large quantities of uranium concentrate from South Australia to existing uranium conversion suppliers, it is considered uneconomic for the converted product to be returned to the state for enrichment and/or fuel fabrication.
- Standalone fuel fabrication facilities would not be expected to be developed without there being a supplier to a domestic nuclear power plant market, and would therefore—if located in South Australia—need to be associated with conversion and enrichment facilities.[17]

Table D.6 presents a summary of the estimated project returns from investment in various combinations of vertically integrated facilities grouped on the basis of whether they rely on proven technologies (wet conversion and gas centrifuge enrichment) or unproven/niche technologies (dry conversion and laser enrichment). A profitable outcome is shown by a rate of return greater than 10 per cent. A sensitivity analysis was also undertaken to address the risks respectively of significant cost overruns or an adverse market, where the price is significantly lower than the long-term average.

Integrated facilities based on proven technologies that also included fuel fabrication yielded a higher rate of return, than when conversion and enrichment were considered on a standalone basis; however, they were still not viable. Integrated facilities based on unproven or niche technologies, with the qualifications stated above, were viable. It can also be seen that they were less sensitive to adverse market conditions or cost overruns.

Table D.6: Internal rates of return for vertically integrated facilities

Facilities internal rate of return (after tax, real basis)	Conversion, enrichment and fuel fabrication		Conversion and enrichment	
	Proven technologies	Unproven/niche technologies	Proven technologies	Unproven/niche technologies
Baseline scenario: Reference capex estimate, market recovers	9.4%	19.3%	7.8%	20.3%
No market recovery	4.2%	11.3%	1.9%	10.0%
Cost overrun	6.5%	12.0%	5.1%	12.0%
Worst case scenario: Cost overrun, no market recovery	2.2%	6.2%	<1.0%	4.8%

Source: Hatch

2. ANALYSIS OF ECONOMIC IMPACTS —COMMISSIONED STUDY

Economic modelling using a general equilibrium model was undertaken by Ernst and Young to assess the potential effect on the wider South Australian economy of investments being made in further processing facilities. It estimated changes in key measures of economic activity such as gross state income, gross state product, wages and employment.

The modelling undertaken used the transparent, peer-reviewed model maintained by the Victoria University Centre of Policy Studies known as the Victoria University Regional Model (VURM).[18] *This model has been used widely in Australia to assess the effects of investments made in one part of the economy on economic activity more broadly.*

ASSUMPTIONS AND INPUTS

The potential macroeconomic impacts of providing further processing services were assessed by assuming private investment in conversion and enrichment facilities in 2024 for operational commencement in 2030.[19]

It was assumed that a combined investment was made in conversion and enrichment facilities based on proven technologies. Investment in fuel fabrication facilities was not assessed as it was considered that, in the timeframe to 2030, it would not be feasible to establish a sufficiently broad technical skills base to capture market share.

The investment in further processing facilities was assumed to be made in an international market where Australia had implemented a carbon price to meet the abatement targets agreed at the Paris Climate Change Conference.[20]

RESULTS OF ANALYSIS OF ECONOMIC IMPACTS

The combination of conversion and enrichment facilities was estimated to generate annual export revenues for South Australia of A$657m in current terms.

Investment in further processing facilities in South Australia was also estimated to deliver modest but positive outcomes of an additional 0.5 per cent in 2030 for the South Australian economy, as shown in Table D.7.

In the two years prior to commencement of operations, the construction work force would peak at approximately 4000 persons employed on a full time equivalent basis, but this would decline to 1000 persons over the operational phase.[21]

Table D.7: Impact of investment in conversion and enrichment facilities on South Australian economy

	2029–30	2049–50
Gross state income	A$898m (0.65%)	A$794m (0.39%)
Gross state product	A$671m (0.47%)	A$914m (0.45%)
Wages	0.09%	0.02%
Total employment	1013	1000
Direct employment	210	324

Source: Ernst & Young

NOTES

1 Hatch, *Final report: Quantitative analyses and business case for the development of uranium conversion, enrichment and fuel fabrication*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, 2015, section 3.6.1, table 3.4, http://nuclearrc.sa.gov.au/

2 ibid., section 5, http://nuclearrc.sa.gov.au/

3 ibid., pp. vi, section 5, pp. 42–63.

4 ibid., section 7.3, p. 71.

5 ibid., p. vi.

6 ibid., p. vii

7 ibid., section 9.1.2, p. 106.

8 ibid., section 9.1.7, p. 108.

9 ibid., section 9.2, pp. 110–128, section 9.3, pp. 128–131.

10 Nuclear Fuel Cycle Royal Commission internal analysis using Hatch financial model.

11 Hatch, *Final report: Quantitative analyses and business case*, section 4.2.3, pp.34–5.

12 ibid., pp. 111, 115, figure 9.4.

13 ibid., section 4.3.2.1, p.38.

14 ibid., section 9.2.4, p. 115.

15 ibid., section 9.1.7, p. 108.

16 ibid., section 9.2.5, p. 115.

17 ibid., section 2.3.3, p. 11.

18 Ernst & Young, *Computational general equilibrium modelling assessment*, report prepared for the Nuclear Fuel Cycle Royal Commission, Adelaide, February 2015, sections 2.3, 2.4, http://nuclearrc.sa.gov.au/

19 ibid., section 4.2.1.

20 ibid., section 3.2, table 7.

21 ibid., section 6.2.2, figure 57.

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions