

Appendices

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Appendix 1: Economic Analysis

TiPro Process		Key parameters affecting the cost and quality of TiAl produced by TiPro process								
The University of Waikato		Project Number				Sheet 1				
ECONOMIC ANALYSIS		REV	DATE	BY	APVD	REV	DATE	BY	APVD	
Form XXXX-YY-ZZ										
Kenneth Sichone Hamilton Case Description		Capital Cost Basis Year 2013						Units <input type="radio"/> English <input type="radio"/> Metric		
		On Stream 8,064 hr/yr						335.98 day/yr		
REVENUES AND PRODUCTION COSTS		CAPITAL COSTS		CONSTRUCTION SCHEDULE						
	\$/yr		\$	Year	% FC	% WC	% FCOP	% VCOP		
Main product revenue	22000000	ISBL Capital Cost	2858202	1	100.00%	100.00%			35 wt% combustion synthesis product recycled for TiO ₂ Recovery	
Byproduct revenue	1695566	OSBL Capital Cost	285820	2		100.00%	100.00%	100.00%	TiO ₂ Recovery products included in by-product revenue	
Raw materials cost	13531523	Engineering Costs	943207	3		100.00%	100.00%	100.00%	Assume 65% Plant Yield	
Utilities cost	1430602	Contingency	628804	4		100.00%	100.00%	100.00%	TiO ₂ Recovery inputs included in consumables	
Consumables cost	497853	Total Fixed Capital Cost	4716033	5		100.00%	100.00%	100.00%		
VCOP	13764412	Working Capital	1198658	6		100.00%	100.00%	100.00%		
Salary and overheads	992860			7+		100.00%	100.00%	100.00%		
Maintenance	142910								Mtce costs = 5% of ISBL - (Towler p.377)	
Interest	473175								Assume 8% Interest rate on capital	
Royalties	110000								Assume 0.5 % of TiAl revenue - i.e about US\$220/T TiAl produced - (Towler p.384)	
FCOP	1718945									
ECONOMIC ASSUMPTIONS										
Cost of equity	0.1125	Debt ratio	0.55	Tax rate	0.28					
Cost of debt	0.0440	Plant Yield	0.65	Depreciation method	Straight-line					
Cost of capital	0.1565			Depreciation period	10 years					
									Towler p.397-403 & http://www.newzealandnow.govt.nz/investing-in-nz/rules-law/taxes	
CASH FLOW ANALYSIS										
All figures in \$ unless indicated										
Project year	Cap Ex	Revenue	CCOP	Gr. Profit	Deprcn	Taxbl Inc	Tax Paid	Cash Flow	PV of CF	NPV
1	5914692	0	0	0	471603	-471603	0	-5914692	-5114303	-5114303
2	1198658	22000000	15483358	6516642	471603	6045039	1692611	3625373	2710575	-2403728
3	1198658	22000000	15483358	6516642	471603	6045039	1692611	3625373	2343774	-59954
4	1198658	22000000	15483358	6516642	471603	6045039	1692611	3625373	2026610	1966656
5	1198658	22000000	15483358	6516642	471603	6045039	1692611	3625373	1752365	3719021
6	1198658	22000000	15483358	6516642	471603	6045039	1692611	3625373	1515231	5234252
7	0	22000000	15483358	6516642	471603	6045039	1692611	4824031	1743374	6977626
8	0	22000000	15483358	6516642	471603	6045039	1692611	4824031	1507457	8485083
9	0	22000000	15483358	6516642	471603	6045039	1692611	4824031	1303465	9788549
10	0	22000000	15483358	6516642	471603	6045039	1692611	4824031	1127077	10915626
11	0	22000000	15483358	6516642	0	6516642	0	6516642	1316503	12232129
12	0	22000000	15483358	6516642	0	6516642	0	6516642	1138351	13370480
13	0	22000000	15483358	6516642	0	6516642	0	6516642	984307	14354787
14	0	22000000	15483358	6516642	0	6516642	0	6516642	851109	15205896
15	0	22000000	15483358	6516642	0	6516642	0	6516642	735935	15941831
16	0	22000000	15483358	6516642	0	6516642	0	6516642	636347	16578177
17	0	22000000	15483358	6516642	0	6516642	0	6516642	550235	17128412
18	0	22000000	15483358	6516642	0	6516642	0	6516642	475776	17604188
19	0	22000000	15483358	6516642	0	6516642	0	6516642	411393	18015581
20	-1198658	22000000	15483358	6516642	0	6516642	0	7715301	421153	18436734
ECONOMIC ANALYSIS										
Average cash flow	5678666 \$/yr		NPV	10 years	10915626 \$		IRR	10 years	62.0%	
Simple pay-back period	1.04156351 yrs			15 years	15941831 \$			15 years	63.3%	
Return on investment (10 yrs)	91.19%			20 years	18436734 \$			20 years	63.4%	
Return on investment (15 yrs)	97.52%		NPV to yr	1	-5114303 \$					

Appendix 2: Process Costing

Total Production - tpa	500
Plant Availability - %	92.05
Operating Time - Hours	8064
Plant Overall TiAl Recovery - %	80
Evaporator H ₂ O Recovery - %	90
Evaporator Heat Recovery - %	60

Material	US\$/T	T/T TiAl		% TiAl Yield																	
				10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	
Input				10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	
TiO ₂	3500	1.0671		3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735	3735
Al	2000	0.8411		1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682	1682
CaH ₂	8000	1.238		9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904	9904
Ca	3500	1.179		4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127	4127
CaO: CaCl ₂ Wt Ratio			0.0851																		
CaCl ₂	330	0.88		58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
HCl (33 Wt% conc)	259	6.50		1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684	1684
H ₂ O	1.98	0.09		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labour (1 Met, 2 Operators)	US\$/T			993	993	993	993	993	993	993	993	993	993	993	993	993	993	993	993	993	993
Power - kW/T TiAl	US\$/kWh	kWh/T TiAl	MJ/T TiAl																		
Milling ¹	0.09384	2079	7486	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195	195
Preheat ²	0.09384	14178	51040	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330
Purification	0.09384	14178	51040	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330	1330
Evaporator	0.09384	55	200	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Total Production Cost - US\$		11.79830609		25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044	25044
US\$/T TiAl	CaH ₂ Reduction			250439	166959	125220	100176	83480	71554	62610	55653	50088	45534	41740	38529	35777	33392	31305	29463	27827	27827
	Ca Reduction			151399	100933	75700	60560	50466	43257	37850	33644	30280	27527	25233	23292	21628	20187	18925	17812	16822	16822
Product	US\$/T	T/T TiAl		Effect of % TiAl Yield on Production Cost - US\$/T TiAl																	
TiAl	44000	1		4400	6600	8800	11000	13200	15400	17600	19800	22000	24200	26400	28600	30800	33000	35200	37400	39600	39600
Al ₂ O ₃	1800	0.9081																			
Al Credit (ex O ₂ Reduction)	2000	0.2179		44	65	87	109	131	153	174	196	218	240	262	283	305	327	349	371	392	392
Total Revenue				4444	6665	8887	11109	13331	15553	17774	19996	22218	24440	26662	28883	31105	33327	35549	37771	39992	39992
Gross Profit	CaH ₂ Reduction			-20600	-18379	-16157	-13935	-11713	-9491	-7270	-5048	-2826	-604	1618	3839	6061	8283	10505	12727	14948	14948
	Ca Reduction			-10696	-8475	-6253	-4031	-1809	413	2634	4856	7078	9300	11522	13743	15965	18187	20409	22631	24852	24852

Notes

- Assuming 1.10 kW for 1h HEMM = 1.10 kWh/529 gTiAl (Name Plate Motor Rating)
- Assuming 15 kW for 30 minutes = 7.5kWh/529 gTiAl (Experiment Setting)
- Assuming 15 kW for 30 minutes = 7.5kWh/529 gTiAl (Alloy purification -O₂Reduction Experiment Setting)
- Assume US\$44/kgTiAl from Froes at http://www.uobabylon.edu.iq/eprints/publication_10_14475_394.pdf
- Assume US\$18/kgAl₂O₃ from <http://www.indexmundi.com/commodities/?commodity=aluminum>
- Assume US\$0.80 = NZ\$ 1 from TV3 Exchange Rates on 12 August 2013
- Assume Labour Cost NZ\$ 496430 from File:\THESIS\CALCULATIONS\....
- Assume Leach Water:CaCl₂ Mass Ratio = 1:1

Appendix 3: Equipment List

Qty	Description	Equipment No.	Capacity Unit	Type	Power Consumption	Unit	Unit Cost NZ\$	2013 Installed Cost NZ\$	Lang Factor	Main Plant Item Dec 2004 Cost	Over-design Factor	
TiO₂ Powder:												
1	TiO ₂ Enclosed Bag Breaker	1-TP-001	667 tpa				45625	80756	1.77			Flexicon Corporation (Australia) PTY Ltd. Purchase price Quotation
1	TiO ₂ Screw Feeder	1-TP-002	1.000 tph		0.104	kW		0	2.11	1243		Flexicon Corporation (Australia) PTY Ltd. Purchase price Quotation
1	TiO ₂ Load Cell	1-TP-003						0	1.21			
1	TiO ₂ Hoist	1-TP-004	1 t					0	2.04			
1	1 t TiO ₂ Lifting Frame	1-TP-005	1 t					0	2.04			
1	TiO ₂ Silo	1-TP-006	72 t					0	2.37			
1	TiO ₂ Bag Filter	1-TP-007	0.020 tph					0	2.37			
Aluminium Powder:												
1	Aluminium Enclosed Bag Breaker	2-TP-008	526 tpa				45625	80756	1.77			Flexicon Corporation (Australia) PTY Ltd. Purchase price Quotation
1	Aluminium Screw Feeder	2-TP-009	0.065 tph		0.036	kW		0	2.11	1243		Flexicon Corporation (Australia) PTY Ltd. Purchase price Quotation
1	Aluminium Load Cell	2-TP-010						0	1.21			
1	Aluminium Hoist	2-TP-011	1 t					0	2.04			Use 6-TP-037
1	1t Aluminium Bag Lifting Frame	2-TP-012	1 t					0	2.04			Use 6-TP-038
1	Aluminium Silo	2-TP-013	5 t					0	2.37			Flexicon Corporation (Australia) PTY Ltd. Purchase price Quotation
	Aluminium Bag Filter	2-TP-014	10.520 tph				15000	22125	1.48			Flexicon Corporation (Australia) PTY Ltd. Purchase price Quotation
1	Control Panel	2-TP-014	0.001 tph				8875	13091	1.48			Flexicon Corporation (Australia) PTY Ltd. Purchase price Quotation
Shared:												
1	Al/TiO ₂ Feed Blend Chute	3-TP-015	0.148 tph					0	1.21			
1	HEMM Mill	3-TP-016	0.148 tph	Stirred Mill	129	kW		121422	2.74	42216		
1	Al/TiO ₂ Composite Conveyor	3-TP-017	0.148 tph	Screw	0.042	kW		0	2.37			
1	Al/TiO ₂ Composite Load Cell	3-TP-018						0	1.21			
1	100t Press	3-TP-019						0	2.37			
1	Induction Furnace Feed Conveyor	3-TP-020	0.148 tph					0	2.37			
1	Jaw Crusher Apron Feed Conveyor	3-TP-021	0.148 tph					0	2.37			
1	Jaw Crusher	3-TP-022	0.148 tph					65002	2.74	22600		
1	Jaw Crusher Screen	3-TP-023	0.222 tph				3657	3657	2.74			Over-designed to 0.5 tph Ref. Cost estimation handbook for the Australian Mining Industry p.118-125
1	Secondary Crusher	3-TP-024	0.148 tph	Rod & Roll	129	kW		58742	2.74	20424		Assume same power but lower milling intensity as 3-TP-015 (HEMM Mill)
1	Milled Product Chute	3-TP-025	0.148 tph					0	1.21			
1	Milled Product Chute Load Cell	3-TP-026						0	1.21			
1	Reduction Furnace Feed Chute	3-TP-027	0.148 tph					0	1.21			
1	Combustion Furnace	3-TP-028	0.148 tph		879	kW		279296	2.74	97107		

Appendix 3 contd.

Qty	Description	Equipment No.	Capacity Unit	Type	Power Consumption	Unit Cost NZ\$	2013 Installed Cost NZ\$	Lang Factor	Main Plant Item Dec 2004 Cost	Over-design Factor
Flotation Plant:										
	Total Cost						56154			
Fluxes (Ca and CaCl₂):										
1	Ca Storage	4-TP-029					0	2.74		
1	CaCl ₂ Storage	4-TP-030					0	2.74		
1	Reduction Furnace	4-TP-031	0.243 tph		879 kW		279296	2.74	97107	
Shared:										
1	Leach Vessel Agitator	5-TP-032	0.486 tph	3.8 m ³	2.2 kW		28788	4.28	6396	
0	Forklift		1.500 t				16100	1.00		
1	Decanter	5-TP-033	0.135 kg/s				565494	4.28	125639	
	Leach Water Pump	5-TP-034	0.005 tph	Diaphragm			212	3.76	54	2.0
1	Slurry Pump	5-TP-035	0.486 tph	Centrifugal			8308	3.76	2101	
1	Alloy Drier/ Oven	5-TP-036	0.062 tph	10 m ³ Oven			67514	4.28	15000	
CaCl₂ Regeneration:										
	Hoist HCl	6-TP-037					2026	1.00		
	HCl Mixing Tank	6-TP-038					0	2.98		
	HCl Solution Dosing Pump	6-TP-039	0.504 tph				3886	2.98	1240	2.0
	HCl Transfer Pump	6-TP-040					3886	2.98	1240	2.0
	HCl Storage Tank	6-TP-041	12 t				5119	2.98	1634	
	HCl Sump Pump	6-TP-042		Centrifugal			8308	3.76	2101	
	CaCl ₂ Evaporator	6-TP-043	0.2 tph				1088264	4.28	241786	1.6
Total Plant Installed Cost							2858202			

(1.75 m dia x 1.75 m h) Mixer - Agitator, Heavy duty open Tank Refer to Metso H/book also
http://www.aucklandforktruckhire.co.nz/Vehicles_for_sale.aspx - Retrieved 15/09/2013

Over-design to 3m³/h

<http://www.rotechequipment.co.nz/site/rotech/files/Section%205/FDH%2018-515.pdf> - Retrieved 15/09/2013

Over-design to 1m³/h

Over-design to 1m³/h

Polyethylene storage vessel

Over-design to 3m³/h

Screw feeder mass flow over-design to 1.0 kg/sec (3.6 tph) to accommodate minimum crusher size Ref. SCENZ :R W Bouman, S B

ISBL Capital Cost	2858202	Ref. Towler & Sinnott p.309
OSBL Capital Cost	285820	40% of ISBL cost - Ref. Towler & Sinnott p.309
Engineering Cost	943207	30% of ISBL + OSBL cost - Ref. Towler & Sinnott p.310
Contingency	628804	20% of ISBL + OSBL cost - Ref. Towler & Sinnott p.311
Total Fixed Capital Cost	4716033	Ref. Towler & Sinnott p.308
Working Capital	1198658	7 weeks' cost of production less 2 weeks' feedstock costs - Ref. Towler & Sinnott p.392; Production cost based on 85% plant yield; Ref. Process Costing Worksheet
Total Investment Cost	5914692	

Appendix 4: Flotation Capital Cost

Assume:

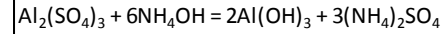
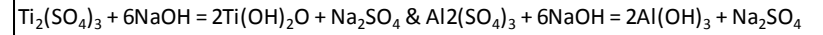
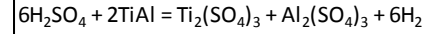
1. Flot Test 5 Kinetics Results
2. Cost of total flot equipment = 0.5 times total cost of Flotation Plant p.150 - 1
- (Newell, 1990) from AUSIMM Monograph 20,
3. Flot cell volume = 1.5 m^3
4. Flot cell 1992 price = AUD 12200
4. Mechanical Flot cell

Rougher Retention volume	7 min
Solids feed rate	0.065 tph
Pulp flow at flotation density (30%)	$0.217 \text{ m}^3/\text{h}$
Rougher flotation volume	0.0253 m^3

Total cost of Flotation Plant	NZ\$ 56154
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Appendix 5: Cost of TiO₂ Recovery

Material	Price US\$/T	Emperical		Stoichiometric	
		T/T Composite	US\$/T Composite	T/T Composite	US\$/T Composite
Input					
Composite		1.000			
H ₂ SO ₄	200	2.000	400	1.744	349
NaOH	320	5.250	1680	1.423	456
NH ₄ OH (28 wt%)	300	17.857	5357	2.227	668
NaF	750	0.025	19	0.025	19
Total Direct Materials Cost - US\$		26.132	7456		1491
Product	US\$/T	T/T Composite			
TiO ₂	3000	0.601	1803	0.601	1803
Al ₂ O ₃	600	0.291	175	0.291	174.6
Total Revenue		0.892	1978	0.892	1978
Gross Profit			-5478		487



Appendix 6: Lang Factors

Details	Grass-roots Plants								
	Solids Processing			Solid-Fluid Processing			Fluid Processing		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Equipment (Delivered)	1	1	1.00	1	1	1.00	1	1	1.00
Equipment, Installation	0.19	0.23	0.21	0.39	0.43	0.41	0.39	0.43	0.41
Piping	0.07	0.23	0.15	0.3	0.39	0.35	0.3	0.39	0.35
Structural Foundations	0	0	0.00	0	0	0.00	0	0	0.00
Electrical	0.13	0.25	0.19	0.08	0.17	0.13	0.08	0.17	0.13
Instruments	0.03	0.12	0.08	0.13	0.13	0.13	0.13	0.13	0.13
Battery-limits Building and Service	0.33	0.5	0.42	0.26	0.35	0.31	0.26	0.35	0.31
Excavation and site preparation	0.03	0.18	0.11	0.08	0.22	0.15	0.08	0.22	0.15
Auxilliaries	0.14	0.3	0.22	0.48	0.55	0.52	0.48	0.55	0.52
Total Physical Plant	1.92	2.81	2.37	2.72	3.24	2.98	2.72	3.24	2.98
Field Expense	0.1	0.12	0.11	0.35	0.43	0.39	0	0	0.00
Engineering	0	0	0.00	0.35	0.43	0.39	0.41	0.41	0.41
Direct Plant Costs	2.02	2.93	2.48	3.42	4.10	3.76	3.13	3.65	3.39
Contractor's Fees, Overhead, Profit	0.3	0.33	0.32	0.09	0.17	0.13	0.17	0.17	0.17
Contingency	0.26	0.26	0.26	0.39	0.39	0.39	0.36	0.36	0.36
Total Fixed-Capital Investment	2.58	3.52	3.05	3.90	4.66	4.28	3.66	4.18	3.92

Appendix 7: Electricity Prices

Electricity Prices (Real 2009 Prices)								
Calendar Year	Residential (Incl GST) ¹	Commercial (Excl. GST)	Industrial (Excl. GST)	National Average ²	Residential (Incl GST) ¹	Commercial (Excl. GST)	Industrial (Excl. GST)	National Average ²
cents per kWh					\$/GJ			
1974	10.99				30.52			
1975	9.90	PPI deflator unavailable before 1979.			27.50	PPI deflator unavailable before 1979.		
1976	11.08				30.79			
1977	13.33				37.03			
1978	13.41				37.26			
1979	15.56	24.81	12.13	16.24	43.23	68.91	33.69	45.11
1980	15.38	22.83	11.44	15.97	42.73	63.43	31.79	44.35
1981	14.62	21.25	10.75	15.20	40.60	59.04	29.86	42.23
1982	14.17	20.47	10.55	14.73	39.35	56.86	29.31	40.93
1983	13.59	19.95	10.07	13.97	37.75	55.42	27.97	38.81
1984	13.09	19.03	9.60	13.43	36.37	52.86	26.67	37.31
1985	13.29	19.00	9.74	13.61	36.92	52.77	27.06	37.80
1986	14.01	20.14	10.40	13.87	38.92	55.95	28.90	38.52
1987	14.23	20.62	10.27	13.40	39.52	57.27	28.53	37.23
1988	14.77	20.55	10.22	13.50	41.02	57.07	28.38	37.50
1989	14.48	19.51	9.63	13.10	40.22	54.20	26.74	36.38
1990	13.94	18.67	9.12	12.45	38.72	51.85	25.33	34.57
1991	14.45	18.29	9.13	12.37	40.13	50.81	25.36	34.37
1992	14.97	17.78	9.28	12.57	41.59	49.38	25.79	34.93
1993	15.51	16.83	9.08	12.50	43.09	46.75	25.21	34.73
1994	16.08	16.24	8.76	12.38	44.68	45.11	24.32	34.38
1995	16.28	15.84	9.18	12.33	45.21	44.00	25.51	34.26
1996	16.91	16.04	9.07	12.49	46.98	44.56	25.19	34.68
1997	17.67	15.96	8.94	12.60	49.09	44.34	24.82	35.01
1998	17.16	15.36	9.65	12.64	47.67	42.66	26.80	35.12
1999	17.30	14.68	8.88	12.29	48.04	40.77	24.65	34.15
2000	16.83	13.73	8.34	12.00	46.76	38.15	23.16	33.33
2001	17.53	13.25	8.36	12.45	48.68	36.81	23.23	34.57
2002	18.41	13.53	8.98	12.87	51.13	37.58	24.94	35.75
2003	19.44	14.86	10.05	13.74	54.00	41.27	27.91	38.16
2004	20.79	15.33	9.99	14.21	57.76	42.58	27.75	39.47
2005	21.55	15.70	10.73	14.96	59.87	43.62	29.79	41.56
2006	22.35	15.37	10.32	15.28	62.07	42.68	28.67	42.45
2007	23.46	15.36	10.63	15.70	65.17	42.65	29.53	43.61
2008	23.77	14.78	10.76	16.33	66.03	41.06	29.88	45.37
2009	24.44	15.64	11.73	17.08	67.89	43.44	32.58	47.45

Notes:

¹ Residential prices were created using the CPI all groups deflator, whereas Commercial and Industrial real prices were created using the PPI Inputs all groups deflator. Care should be taken when comparing real residential prices to the other time series'.

² National average prices are calculated as residential (including GST), commercial and industrial prices (excluding GST) weighted by consumption.

Retrieved on 7 Apr 2013 from:

Source: <http://www.med.govt.nz/sectors-industries/energy/electricity/prices/historic-electricity-prices>