In Situ Production of Monopropellant Hydrazine

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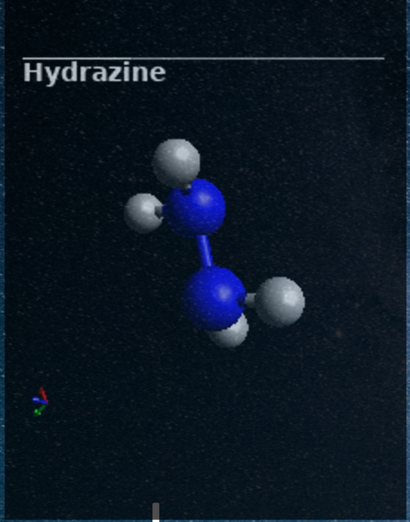
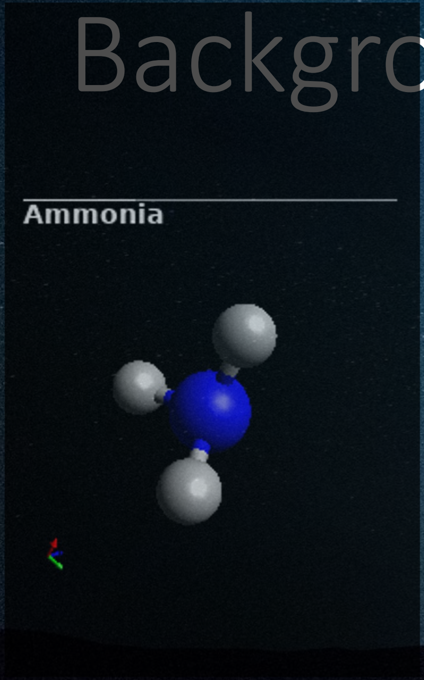
Project Background





- Monopropellant hydrazine (N_2H_4) used as a satellite propellant due to simplicity of catalytic decomposition to produce thrust
- Discovery of ammonia (NH_3) in cryogenic lunar polar soils could enable in-situ lunar hydrazine production through chemical synthesis
- Peroxide Process:
  - $2NH_3 + H_2O_2 \rightarrow H_2NNH_2 + 2H_2O$

Design Objectives

In-situ lunar hydrazine production for satellite and spacecraft launch sites

Design of a stand-alone, integrated hydrazine production system that will utilize input power, water, and ammonia to produce hydrogen and hydrogen gas (in space or on Earth)

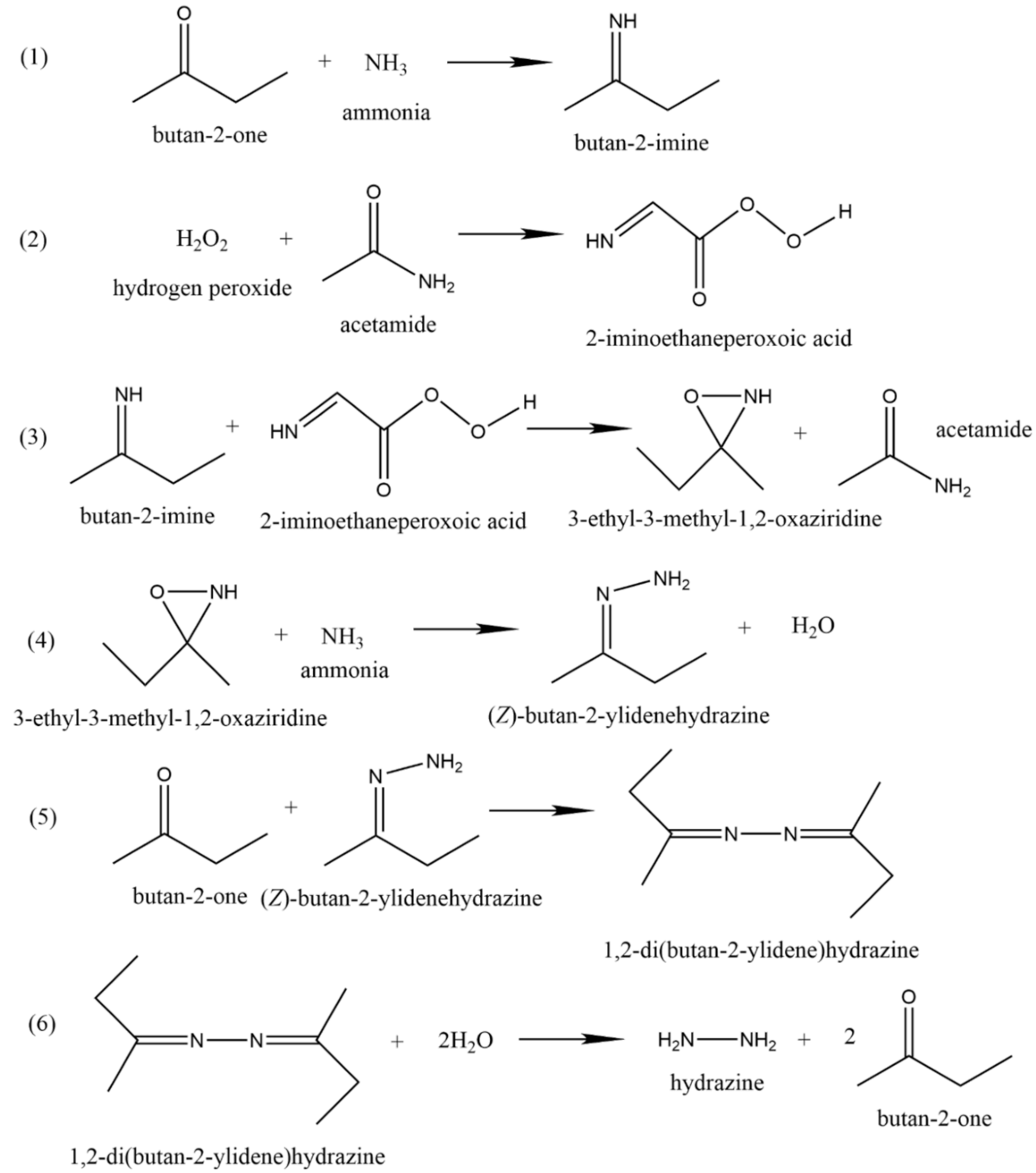
Produce 98.5 wt% 1000 kg hydrazine per month assuming continuous operations

Unit operations: chemical reactions, phase separations, product separation and storage

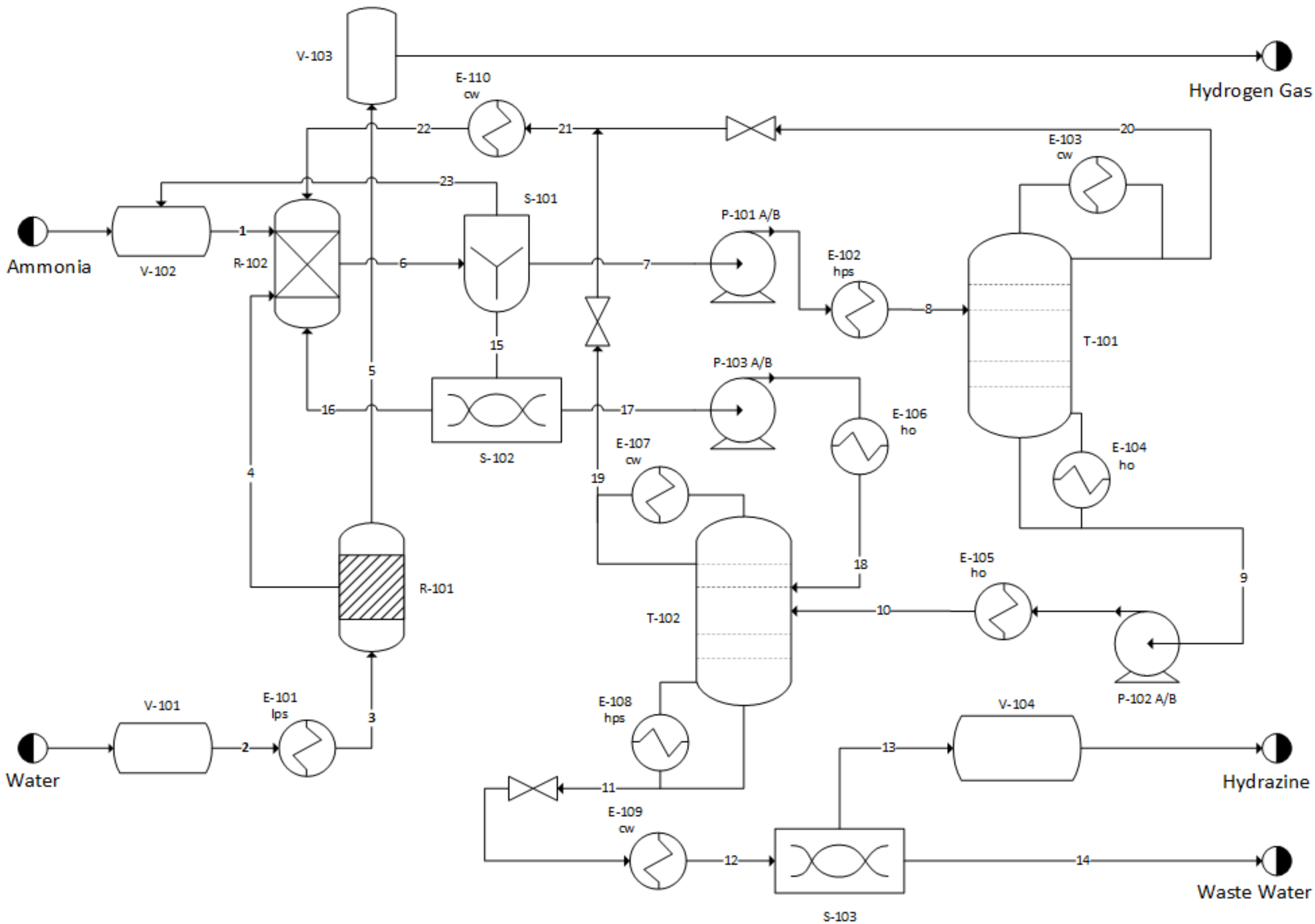
Remote operations preferable for terrestrial applications and essential for lunar applications

Chemical Reactions

- Reactions 1-5 carried out in series in one reactor
- Catalyzed homogeneous gas-liquid-liquid reaction
- Reaction 6 in reactive distillation column



Process Flow Diagram



Anticipated Markets

Orbital Refueling Market: Refueling of commercial and military satellites (lifetime extension). Hydrazine valued as high as $350,000/kg for this application. An option to salvage an already depreciated satellite can lead to high margins for owners.

Potential terrestrial customers (NASA, USAF-USSF) with a need for lean manufacturing for onsite supply of hydrazine. Negates shipping costs.

Terrestrial Economic Spinoff Analysis

Terrestrial value of Hydrazine is ~$100/lb. Continuous operation at 1000kg/month would yield $2,650,000/yr

Operating costs total to $783,000/yr. Includes costs of labor, feedstocks, and power.

Depreciation modeled using 12 yr MACRS, 26% tax rate

NPV = $2,870,000, IRR = 116%

Next Steps

- Modeling/Development of microchannel reactor for production of ketazine intermediate
- Additional lunar market analysis
- Analyze feasibility of peroxide production method
- Bench scale testing of overall process

Questions?

Supplemental Slides

Sizing

Equipment Code	Number Required	Number Spares	Equipment Name	Equipment Type	Description	Factor #1	Factor #2	Factor #3	Factor #4	Materials of Construction
V-101	1		Water Storage	Process vessels - Horizontal	1=Diameter [m]; 2=Height [m]; 3=Pressure [barg]; 4=Volume [m3]	0.8	2.4	1	1.2	CS
V-102	1		Ammonia Storage	Process vessels - Horizontal	1=Diameter [m]; 2=Height [m]; 3=Pressure [barg]; 4=Volume [m3]	0.6	1.8	1	0.5	CS
V-103	1		Hydrogen Gas Storage	Process vessels - Vertical	1=Diameter [m]; 2=Height [m]; 3=Pressure [barg]; 4=Volume [m3]	0.7	2.1	1	0.8	CS
V-104	1		Hydrazine Storage	Process vessels - Horizontal	1=Diameter [m]; 2=Height [m]; 3=Pressure [barg]; 4=Volume [m3]	1	3	1	2.4	SS
P-101	1	1	T-101 Prep Pump	Pumps - Positive displacement	1=Total fluid power [kW]; 2=Efficiency; 3=Discharge pressure [bar-g]; 4=Shaft power per Unit [kW]	0.0063	0.3	6	0.021	SS
P-102	1	1	T-102 Ketazine Prep Pump	Pumps - Positive displacement	1=Total fluid power [kW]; 2=Efficiency; 3=Discharge pressure [bar-g]; 4=Shaft power per Unit [kW]	0.0162	0.3	20	0.054	SS
P-103	1	1	T-102 Water Prep Pimp	Pumps - Positive displacement	1=Total fluid power [kW]; 2=Efficiency; 3=Discharge pressure [bar-g]; 4=Shaft power per Unit [kW]	0.0361	0.3	20	0.120	SS
E-101	1		R-101 Prep Heater	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	0.08	0	1	0.080	SS shell/SS tube
E-102	1		T-101 Prep Heater	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	0.279	5	38	0.279	SS shell/SS tube
E-103	1		T-101 Condenser	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	0.024	2	5	0.024	SS shell/SS tube
E-104	1		T-101 Reboiler	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	1.26	5	38	1.260	SS shell/SS tube
E-106	1		T-102 Water Prep Heater	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	3.16	19	38	3.160	SS shell/SS tube
E-107	1		T-102 Condenser	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	0.187	0	19	0.187	SS shell/SS tube
E-108	1		T-102 Reboiler	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	9.25	19	38	9.250	SS shell/SS tube
E-109	1		Product Cooler	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	0.8	0	0	0.800	SS shell/SS tube
E-110	1		Ketazine Reactor Recycle Cooler	Heat exchangers - Double pipe	1=Total Area [m2]; 2=Shell pressure [barg]; 3=Tube pressure [barg]; 4=Area per Unit [m2]	0.66	0	5	0.660	SS shell/SS tube
S-101	1		Gaseous/Organic/Aqueous Decanter	Decanter - Vessel	1=Diameter [m]; 2=Height [m]; 3=Pressure [barg]; 4=Volume [m3]	0.205	0.616	0	20.4	SS
S-102	1		Acetimide Membrane	Membrane - Chitosan	1=Total Area [m2]	26				SS
S-103	1		Hydrazine Membrane	Membrane - Polystrene	1=Total Area [m2]	774				SS
R-101	1		PEC Water Splitter Reactor	Reactors - Jacketed agitated	1=Volume [m3]; 4=Volume per unit [m3]					CS
R-102	1		Ketazine CSTR	Reactors - Jacketed agitated	1=Volume [m3]; 4=Volume per unit [m3]	0.025			0.025	SS
T-101	1		Ketazine Column	Towers - Tray & Packed	1=Diameter [m]; 2=Height [m]; 3=Pressure [barg]; 4=Volume [m3]	0.1	4.467	5	0.0351	SS
T-102	1		Hydrazine Column	Towers - Reactive Tray	1=Diameter [m]; 2=Height [m]; 3=Pressure [barg]; 4=Volume [m3]	0.19	4.83	19	0.1369	SS
TRAY-101	29		Ketazine Column's Trays	Trays - Sieve	1=Diameter [m]; 4=Area per tray [m2]	0.1			0.0	SS
TRAY-102	37		Hydrazine Column's Trays	Trays - Sieve	1=Diameter [m]; 4=Area per tray [m2]	0.19				SS

Costing

Equipment Code	Base Cost per Unit [$]	Base Cost Total [$]	Base Cost Year	Base Cost Index	Escalated Base Cost Total [$]	B1	B2	F-Materials	F-Pressure	F-Bare Module	Purchased Equip Cost [$]	"Base" Bare Module Cost [$]	Bare Module Cost [$]
V-101	$3,863	$3,863	2001	397.0	$5,985	1.49	1.52	1.00	1.00	3.01	$5,985	$18,016	$18,016
V-102	$2,825	$2,825	2001	397.0	$4,377	1.49	1.52	1.00	1.00	3.01	$4,377	$13,175	$13,175
V-103	$2,851	$2,851	2001	397.0	$4,417	2.25	1.82	1.00	1.00	4.07	$4,417	$17,978	$17,978
V-104	$5,166	$5,166	2001	397.0	$8,004	1.49	1.52	3.10	1.00	6.20	$24,813	$24,092	$49,641
P-101	$1,594	$3,188	2001	397.0	$4,939	1.89	1.35	2.70	1.00	5.54	$13,336	$16,004	$27,340
P-102	$1,530	$3,060	2001	397.0	$4,741	1.89	1.35	2.70	1.17	6.16	$14,989	$15,361	$29,196
P-103	$1,590	$3,180	2001	397.0	$4,927	1.89	1.35	2.70	1.17	6.16	$15,577	$15,963	$30,341
E-101	$957	$957	2001	397.0	$1,482	1.74	1.55	2.70	1.00	5.93	$4,002	$4,877	$8,783
E-102	$1,506	$1,506	2001	397.0	$2,333	1.74	1.55	2.70	1.00	5.93	$6,300	$7,677	$13,825
E-103	$601	$601	2001	397.0	$931	1.74	1.55	2.70	1.00	5.93	$2,514	$3,064	$5,517
E-104	$2,354	$2,354	2001	397.0	$3,647	1.74	1.55	2.70	1.00	5.93	$9,847	$11,999	$21,610
E-106	$2,949	$2,949	2001	397.0	$4,569	1.74	1.55	2.70	1.00	5.93	$12,337	$15,032	$27,072
E-107	$1,317	$1,317	2001	397.0	$2,041	1.74	1.55	2.70	1.00	5.93	$5,509	$6,713	$12,090
E-108	$3,677	$3,677	2001	397.0	$5,697	1.74	1.55	2.70	1.00	5.93	$15,382	$18,743	$33,755
E-109	$2,077	$2,077	2001	397.0	$3,218	1.74	1.55	2.70	1.00	5.93	$8,689	$10,587	$19,067
E-110	$1,968	$1,968	2001	397.0	$3,049	1.74	1.55	2.70	1.00	5.93	$8,233	$10,032	$18,066
S-101	$1,522	$1,522	2001	397.0	$2,358	1.49	1.52	3.10	1.00	6.20	$7,309	$7,096	$14,622
S-102													$1,300
S-103													$38,700
R-101		$0	2001	397.0	$0	1.49	1.52	3.10	1.00	6.20	$0	$0	$17,152
R-102	$1,785	$1,785	2001	397.0	$2,766	1.49	1.52	3.10	1.00	6.20	$8,573	$8,324	$17,152
T-101	$1,181	$1,181	2001	397.0	$1,830	2.25	1.82	3.10	1.00	7.89	$5,672	$7,447	$14,440
T-102	$1,550	$1,550	2001	397.0	$2,401	2.25	1.82	3.10	1.00	7.89	$7,443	$9,772	$18,948
TRAY-101	$114	$3,306	2001	397.0	$5,122					2.00	$0	$0	$10,244
TRAY-102	$411	$15,207	2001	397.0	$23,561					2.00	$0	$0	$47,123
Area 100		**$66,089**			**$102,396**						**$185,304**	**$241,952**	**$525,150**

[2]

Utilities

Block	Duty (kW)
E-101	0.339
E-102	1.55
E-103	-2.05
E-104	1.73
E-106	14.4
E-107	-23.42
E-108	13.68
E-109	2.31
E-110	2.49
P-101	0.0063
P-102	0.0162
P-103	0.0361
R-101	11.55
R-102	4.02

Component	Cost ($/kJ) or ($/kg) or ($/m2)	Annual Cost ($/yr)
lps	1.90E-06	$20.31
hps	2.50E-06	$1,200.89
cw	2.12E-07	$199.60
ho	3.50E-06	$1,785.89
el	2.15E-05	$10,597.91
Ammonia	0.4	$13,896.82
Water	2.60E-04	$18.90
Acetamide	5	$65,981.19
MEK	1.04	$16,403.98
Chitosan Membrane	50	$1,300.00
Polystrene Membrane	50	$77,360.00
	Total	$188,765.49

Economic Forecast

End of Year:	Time 0	1	2	3	4	5	6	7	8
Revenue:			2,645,544	2,645,544	2,645,544	2,645,544	2,645,544	2,645,544	
Salvage value:									131,288
Operating costs:			-784,150	-784,150	-784,150	-784,150	-784,150	-784,150	
Operating profit			1,861,394	1,861,394	1,861,394	1,861,394	1,861,394	1,861,394	131,288
Tax:			-466,895	-449,828	-449,828	-449,828	-466,895	-483,962	-34,135
Net Income:			1,394,499	1,411,566	1,411,566	1,411,566	1,394,499	1,377,432	97,153
Capital costs:	-210,060	-315,090							
Land:	-169,000								
Working Capital:		-105,030							
After-Tax Cash Flow:	-379,060	-420,120	1,394,499	1,411,566	1,411,566	1,411,566	1,394,499	1,377,432	97,153
Cumulative Cash Position:									

Tax rate: 26%

IRR:	113.0%
NPV:	5,601,417
Minimum ROR:	6.7%

Depreciation Rate:		4	5	6	7	8
		12.50%	25.00%	25.00%	25.00%	12.50%

Capital cost 525150