Power Generation Feasibility Study

For a mining operation and nearby town

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For a hypothetical mining operation and a nearby town

Summary

A feasibility study was conducted to introduce power to a mining operation and its nearby town. Based on the average load profile and the information on fuel prices, three technologies were assessed: Fuel Cell, Diesel and Gas Turbine. The fist part of the study was to understand the average daily load. The load profile shows three peaks, one in the morning, the other at noon and the third and highest peak in the evening. With the power conversion efficiency and part load efficiency curves the energy conversion efficiency of each technology was estimated. This allowed the estimation of the total energetic inputs requried to meet the load.

The fuels used with the three technologies where natural gas and medium fuel oil. The energy content for each fuel (considered here as 40 MJ/m^3 for natural gas; and 42.5 MJ/kg for medium fuel oil) was used to estimate the daily fuel consumption of the three technologies. The results show that Fuel Cell technology consumes less natural gas than the Gas Turbines. Diesel uses 10,942 litres of medium fuel oil every day.

Summary Table 1. Total Daily Consumption of the three technologies.

Daily Fuel Consumption		
Fuel Cell (m3)	**Diesel (L)**	**Gas Turbine (m3)**
7,269.38	10,942.55	24,963.10

A Life Cycle Cost Analysis (LCCA) for a period of 20 years was conducted to compare the total costs and energy production prices for the three available technologies. The LCCA results show that Fuel Cell are the most cost-effective alternative, even though it has the highest capital investment. The price per kWh for fuel cell was estimated at $ 0.11/kWh. Diesel was estimated at $0.16/kWh while Gas turbines is the most expensive of the three alternatives with a price of $0.27/kWh

Summary Table 2. Costs per kWh

Costs per kWh		
Fuel Cell	**Diesel**	**Gas Turbines**
$ 0.11	$ 0.16	$ 0.27

Alternatively a scenario considering two 5MW diesel generators was also considered. To replace one of the generators, the actual load profile needs to be understood to learn what the peak power requirements are. The costs of the new generator as well as the specific fuel consumption, derating factors and efficiency need to be taken in consideration to choose the best alternative. As a reccomendation for the replacement it is suggested that a 3.5MW diesel generator is chosen. This will increase the generator efficiency and increase its lifetime by working better loaded. The 3.5MW was chosen by estimating the generator output that will meet the load at 80% of its rated output in most number of hours per day. The average results were 3.5MW and thus the recommended alternative. Another option (if cost effective) would be to use a parallel hybrid system using a battery instead of a diesel generator.

Finally a sensitivity analysis was made to assess the change in fuel costs and O&M costs on the energy price per kWh for the three technologies. The sensitivity analysis shows steep slopes for changes in

fuel costs and gentle slopes for changes in O&M costs. This means that the price per kWh can be affected considerably by changes in fuel costs. Changes in O&M costs would not be so important on the price per kWh. Fuel cell seems to be the least sensitive to changes in fuel costs than the other two technologies. In conclusion the sensitivity analysis, the daily fuel consumption, life cycle cost analysis and price per kWh all show that fuel cell technology is the better choice from the three technologies assessed.

Load Profile

The average daily load profile for the mining operation was made using the data presented on table 1. The profile presents three peaks, one in morning, another around noon and the other one in the evening, where the energy demands are the highest.

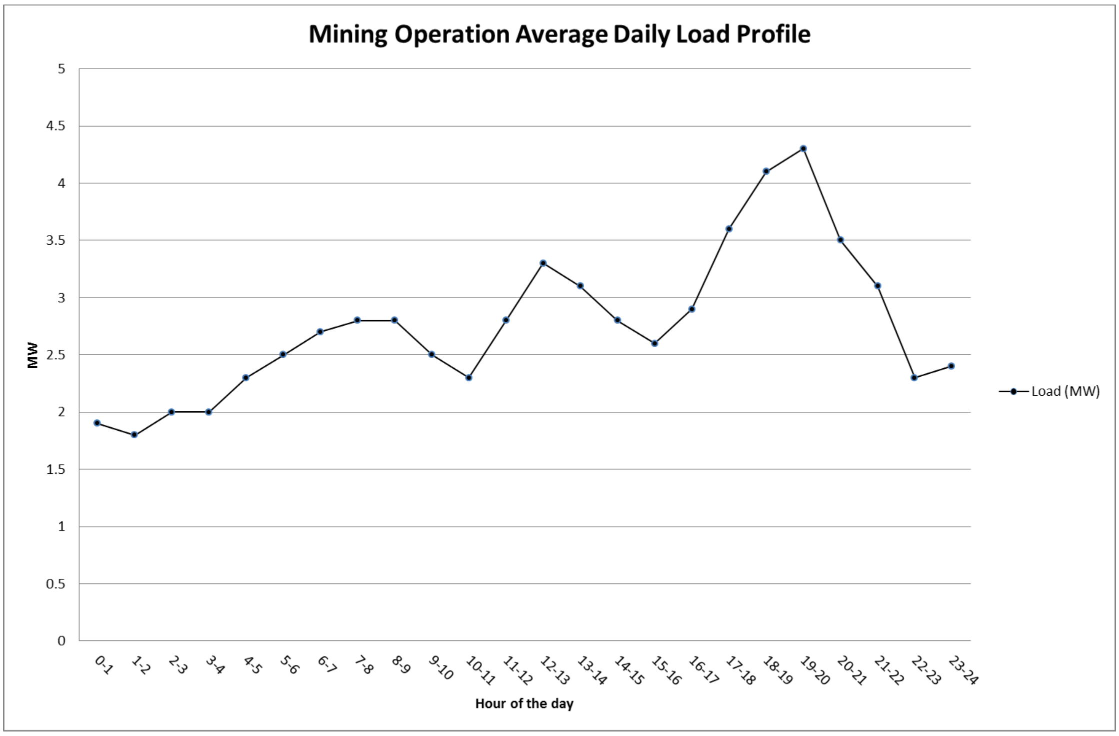

Figure 1. Average daily load profile for the mining operation.

Energy Needed to Meet Load

Based on the power conversion and relative part load efficiency curves (Figure 3 and 4, Annex 1), the energy needed to meet the load was estimated. Table 1 presents the results for the energy input needed to meet the average daily load profile in MW per hour. The same procedure was used for the three systems.

Table 1. Energy conversion efficiencies and energy inputs needed to meet the average daily load profile in MW per hour.

Eff(L)= Relative Part Load Efficiency x Eff(R)

$$Energy\ in = \frac{Energy\ out\ (Load)}{Eff\,(L)}$$

Hour of Day	Load (MW)	Rated Output %	Relative Part load efficiency			Efficiency at Rated Load Eff(R)			Efficiency (L)			Energy in (MW)		
			Fuel Cell	Diesel	Gas Turbine	Fuel Cell	Diesel	Gas Turbine	Fuel Cell	Diesel	Gas Turbine	Fuel Cell	Diesel	Gas Turbine
0-1	1.9	38	1.20	0.90	0.62	0.70	0.50	0.30	0.84	0.45	0.19	2.26	4.22	10.22
1-2	1.80	36	1.20	0.91	0.60	0.70	0.50	0.30	0.84	0.46	0.18	2.14	3.96	10.00
2-3	2.00	40	1.20	0.95	0.65	0.70	0.50	0.30	0.84	0.48	0.20	2.38	4.21	10.26
3-4	2.00	40	1.20	0.95	0.65	0.70	0.50	0.30	0.84	0.48	0.20	2.38	4.21	10.26
4-5	2.30	46	1.20	1.00	0.75	0.70	0.50	0.30	0.84	0.50	0.23	2.74	4.60	10.22
5-6	2.50	50	1.20	1.02	0.76	0.70	0.50	0.30	0.84	0.51	0.23	2.98	4.90	10.96
6-7	2.70	54	1.20	1.06	0.78	0.70	0.50	0.30	0.84	0.53	0.23	3.21	5.09	11.54
7-8	2.80	56	1.18	1.07	0.80	0.70	0.50	0.30	0.83	0.54	0.24	3.39	5.23	11.67
8-9	2.80	56	1.18	1.07	0.80	0.70	0.50	0.30	0.83	0.54	0.24	3.39	5.23	11.67
9-10	2.50	50	1.20	1.02	0.76	0.70	0.50	0.30	0.84	0.51	0.23	2.98	4.90	10.96
10-11	2.30	46	1.20	1.02	0.79	0.70	0.50	0.30	0.84	0.51	0.24	2.74	4.51	9.70
11-12	2.80	56	1.18	1.07	0.80	0.70	0.50	0.30	0.83	0.54	0.24	3.39	5.23	11.67
12-13	3.30	66	1.18	1.05	0.88	0.70	0.50	0.30	0.83	0.53	0.26	4.00	6.29	12.50
13-14	3.10	62	1.18	1.05	0.85	0.70	0.50	0.30	0.83	0.53	0.26	3.75	5.90	12.16
14-15	2.80	56	1.18	1.07	0.80	0.70	0.50	0.30	0.83	0.54	0.24	3.39	5.23	11.67
15-16	2.60	52	1.20	1.02	0.79	0.70	0.50	0.30	0.84	0.51	0.24	3.10	5.10	10.97
16-17	2.90	58	1.19	1.05	0.85	0.70	0.50	0.30	0.83	0.53	0.26	3.48	5.52	11.37
17-18	3.60	72	1.15	1.05	0.90	0.70	0.50	0.30	0.81	0.53	0.27	4.47	6.86	13.33
18-19	4.10	82	1.10	1.05	0.95	0.70	0.50	0.30	0.77	0.53	0.29	5.32	7.81	14.39
19-20	4.30	86	1.10	1.05	0.95	0.70	0.50	0.30	0.77	0.53	0.29	5.58	8.19	15.09
20-21	3.50	70	1.15	1.05	0.85	0.70	0.50	0.30	0.81	0.53	0.26	4.35	6.67	13.73
21-22	3.10	62	1.18	1.05	0.85	0.70	0.50	0.30	0.83	0.53	0.26	3.75	5.90	12.16
22-23	2.30	46	1.20	1.00	0.75	0.70	0.50	0.30	0.84	0.50	0.23	2.74	4.60	10.22
23-24	2.40	48	1.20	1.00	0.75	0.70	0.50	0.30	0.84	0.50	0.23	2.86	4.80	10.67
Total	**66.40**											**80.77**	**129.18**	**277.37**

Procedure to estimate energy to meet the load

Fuel Cell Efficiency Hour 0-1

$$Eff(L) = Relative\ part\ load\ efficiency\ x\ Efficiency\ at\ rated\ load$$

$$Eff(L) = 1.20\ x\ 70$$

$$Eff(L) = 84\%$$

Energy in

$$Eff(L) = \frac{Energy\ out}{Energy\ in}$$

$$Energy\ in = \frac{Energy\ out\ (Load)}{Eff(L)}$$

$$Energy\ in = \frac{1.9\ \text{MW}}{0.84}$$

$$Energy\ in = \mathbf{2.26\ MW}$$

2.26 for hour 0-1 that means **2.26 MWh**

Diesel Efficiency Hour 0-1

$$Eff(L) = Relative\ part\ load\ efficiency\ x\ Efficiency\ at\ rated\ load$$

$$Eff(L) = 0.9\ x\ 50\%$$

$$Eff(L) = 45\%$$

Energy in

$$Eff(L) = \frac{Energy\ out}{Energy\ in}$$

$$Energy\ in = \frac{Energy\ out\ (Load)}{Eff(L)}$$

$$Energy\ in = \frac{1.9\ \text{MW}}{0.45}$$

$$Energy\ in = \mathbf{4.22\ MW}$$

4.22 for hour 0-1 that means **4.22 MWh**

Gas Turbine Efficiency Hour 0-1

$$Eff(L) = Relative\ part\ load\ efficiency\ x\ Efficiency\ at\ rated\ load$$

$$Eff(L) = 0.62\ x\ 30$$

$$Eff(L) = 18.6\%$$

Energy in

$$Eff(L) = \frac{Energy\ out}{Energy\ in}$$

$$Energy\ in = \frac{Energy\ out\ (Load)}{Eff(L)}$$

$$Energy\ in = \frac{1.9\ \text{MW}}{0.186}$$

$$Energy\ in = \mathbf{10.22\ MW}$$

10.22 for hour 0-1 that means **10.22 MWh**

Daily Fuel Consumption

The daily fuel consumption for the three technologies was estimated based on the energy needed to meet the load. Table 3 shows the result from the daily fuel consumption in cubic meters for natural gas and litres for medium fuel oil. The assumptions of energy content for the fuel are presented in Table 2, fuel specifications.

Table 2. Fuel specifications.

Fuel	Specifications		
	Energy Content	**Density[3]**	**Fuel Cost**
Natural Gas[1]	40MJ/m^3		$ 15.00 per GJ
Medium Fuel Oil[2]	42.5 MJ/kg	1000 kg/m^3	$ 0.72 per L

[1]Energy 2000 A National Energy Policy Paper, Department of Primary Industries and Energy. Australia Government Publishing Service, Canberra 1998
[2] Based on BS 2869:2010+A1:2011 Fuel oils for agricultural, domestic and industrial engines and boilers.
[3] Based on BS 2000:365 at 15^{o}C

Procedure to estimate daily fuel consumption

Fuel Cell Natural Gas Consumption Hour 0-1

The energy needed in MJ was obtained from the energy needed to meet the load in MW.

$$2.26 \text{ MWh x} \frac{1000\ kWh}{1 \text{ MWh}} = 2260\ kWh\ x\ 3.6 \frac{MJ}{kWh} = 8136\ MJ$$

With the energy needed in MJ the amount of Volume of natural gas needed to meet the load can be estimated.

$$8136\ MJ\ x\ \frac{m^3}{40\ MJ} = \mathbf{203.4\ m^3}$$

Medium Fuel Oil Consumption Hour 0-1

The energy needed to meet the load was converted from MWh to kWh and to MJ for each hour

$$4.222 \text{ MWh x} \frac{1000\ kWh}{1 \text{ MWh}} = 4222\ kWh\ x\ 3.6 \frac{MJ}{kWh} = 15199.2\ MJ$$

The energy content of medium fuel oil was used to estimate the mass of medium fuel oil needed to meet the load.

$$15199.2\ MJ\ x\ \frac{1\ kg}{42.5\ MJ} = 357.63\ kg$$

The volume of the medium fuel oil was estimated using the density and transforming the volume in cubic meters to litre.

$$357.63\ kg\ x\ (\frac{m^3}{1000\ kg}) = 0.36\ m^3\ x\ 1000\frac{L}{m^3} = \mathbf{357.63\ L}$$

Gas Turbine Natural Gas Consumption Hour 0-1

The same procedure as the fuel cell was used to estimate the natural gas consumption in the gas turbine.

$$10.22\ \text{MWh x}\frac{1000\ kWh}{1\ \text{MWh}} = 10220\ kWh\ x\ 3.6\frac{MJ}{kWh} = 36792\ MJ$$

The volume of natural gas used by the gas turbine to meet the load was calculated using the energy content of natural gas

$$36792\ MJ\ x\ \frac{m^3}{40\ MJ} = \mathbf{919.8\ m^3}$$

Summary of Total Daily Fuel Consumption of the three technologies.

Daily Fuel Consumption		
Fuel Cell (m3)	**Diesel (L)**	**Gas Turbine (m3)**
7,269.38	10,942.55	24,963.10

Table 3. Daily Fuel Consumption for fuel cells, diesel generators and gas turbines.

Energy Content of Fuel		
1 Natural Gas	40	MJ/m3
2 Medium Fuel Oil	42.5	MJ/kg Density 1000kg/m3

Energy in (MW) x 1000

Energy in (kWh) x 3.6

Hour of Day	Load (MW)	Rated Output %	Energy in (MW) Fuel Cell	Energy in (MW) Diesel	Energy in (MW) Gas Turbine	Energy kWh Fuel Cell	Energy kWh Diesel	Energy kWh Gas Turbine	Energy MJ Fuel Cell	Energy MJ Diesel	Energy MJ Gas Turbine	Daily Fuel Consumption Fuel Cell (m3)	Daily Fuel Consumption Diesel (L)	Daily Fuel Consumption Gas Turbine (m3)
0-1	1.9	38	2.26	4.22	10.22	2,261.90	4,222.22	10,215.05	8,142.86	15,200.00	36,774.19	203.57	357.65	919.35
1-2	1.80	36	2.14	3.96	10.00	2,142.86	3,956.04	10,000.00	7,714.29	14,241.76	36,000.00	192.86	335.10	900.00
2-3	2.00	40	2.38	4.21	10.26	2,380.95	4,210.53	10,256.41	8,571.43	15,157.89	36,923.08	214.29	356.66	923.08
3-4	2.00	40	2.38	4.21	10.26	2,380.95	4,210.53	10,256.41	8,571.43	15,157.89	36,923.08	214.29	356.66	923.08
4-5	2.30	46	2.74	4.60	10.22	2,738.10	4,600.00	10,222.22	9,857.14	16,560.00	36,800.00	246.43	389.65	920.00
5-6	2.50	50	2.98	4.90	10.96	2,976.19	4,901.96	10,964.91	10,714.29	17,647.06	39,473.68	267.86	415.22	986.84
6-7	2.70	54	3.21	5.09	11.54	3,214.29	5,094.34	11,538.46	11,571.43	18,339.62	41,538.46	289.29	431.52	1,038.46
7-8	2.80	56	3.39	5.23	11.67	3,389.83	5,233.64	11,666.67	12,203.39	18,841.12	42,000.00	305.08	443.32	1,050.00
8-9	2.80	56	3.39	5.23	11.67	3,389.83	5,233.64	11,666.67	12,203.39	18,841.12	42,000.00	305.08	443.32	1,050.00
9-10	2.50	50	2.98	4.90	10.96	2,976.19	4,901.96	10,964.91	10,714.29	17,647.06	39,473.68	267.86	415.22	986.84
10-11	2.30	46	2.74	4.51	9.70	2,738.10	4,509.80	9,704.64	9,857.14	16,235.29	34,936.71	246.43	382.01	873.42
11-12	2.80	56	3.39	5.23	11.67	3,389.83	5,233.64	11,666.67	12,203.39	18,841.12	42,000.00	305.08	443.32	1,050.00
12-13	3.30	66	4.00	6.29	12.50	3,995.16	6,285.71	12,500.00	14,382.57	22,628.57	45,000.00	359.56	532.44	1,125.00
13-14	3.10	62	3.75	5.90	12.16	3,753.03	5,904.76	12,156.86	13,510.90	21,257.14	43,764.71	337.77	500.17	1,094.12
14-15	2.80	56	3.39	5.23	11.67	3,389.83	5,233.64	11,666.67	12,203.39	18,841.12	42,000.00	305.08	443.32	1,050.00
15-16	2.60	52	3.10	5.10	10.97	3,095.24	5,098.04	10,970.46	11,142.86	18,352.94	39,493.67	278.57	431.83	987.34
16-17	2.90	58	3.48	5.52	11.37	3,481.39	5,523.81	11,372.55	12,533.01	19,885.71	40,941.18	313.33	467.90	1,023.53
17-18	3.60	72	4.47	6.86	13.33	4,472.05	6,857.14	13,333.33	16,099.38	24,685.71	48,000.00	402.48	580.84	1,200.00
18-19	4.10	82	5.32	7.81	14.39	5,324.68	7,809.52	14,385.96	19,168.83	28,114.29	51,789.47	479.22	661.51	1,294.74
19-20	4.30	86	5.58	8.19	15.09	5,584.42	8,190.48	15,087.72	20,103.90	29,485.71	54,315.79	502.60	693.78	1,357.89
20-21	3.50	70	4.35	6.67	13.73	4,347.83	6,666.67	13,725.49	15,652.17	24,000.00	49,411.76	391.30	564.71	1,235.29
21-22	3.10	62	3.75	5.90	12.16	3,753.03	5,904.76	12,156.86	13,510.90	21,257.14	43,764.71	337.77	500.17	1,094.12
22-23	2.30	46	2.74	4.60	10.22	2,738.10	4,600.00	10,222.22	9,857.14	16,560.00	36,800.00	246.43	389.65	920.00
23-24	2.40	48	2.86	4.80	10.67	2,857.14	4,800.00	10,666.67	10,285.71	17,280.00	38,400.00	257.14	406.59	960.00
Total	**66.40**		**80.77**	**129.18**	**277.37**	**80,770.89**	**129,182.86**	**277,367.83**	**290,775.21**	**465,058.29**	**998,524.17**	**7,269.38**	**10,942.55**	**24,963.10**

[1] Energy 2000 A National Energy Policy Paper, Department of Primary Industries and Energy. Australia Government Publishing Service, Canberra 1998

[2] Energy content based on BS 2869:2010+A1:2011 Fuel oils for agricultural, domestic and industrial engines and boilers. Density based on BS 2000:365 at 15°C

Life Cycle Costing Analysis (LCCA)

Initial fuel costs

The initial fuel costs of each technology where transformed to costs per kWh. This data was used in the life cycle costing analysis to estimate fuel costs per year.

Natural Gas: $ 15.00 per GJ

$$\frac{\$15}{GJ}\ x\ \frac{1GJ}{1000MJ}\ x\ \frac{3.6MJ}{kWh} = \$\ 0.054\ per\ kWh$$

Medium Fuel Oil: $ 0.72 per L
Energy Content: 42.5 MJ/Kg
Density: 1000 kg/m^3

$$\frac{\$0.72}{L}\ x\ \frac{1000L}{m^3}\ x\ \frac{1m^3}{1000kg}\ x\ \frac{kg}{42.5MJ}\ x\ \frac{3.6MJ}{kWh} = \$0.061\ per\ kWh$$

Fuel Cell LCCA

The data inputs for the fuel cell LCC where estimated as follows:

Fuel Cell Capital Costs

$$\$1{,}300.00\ x\ 5000kW = \$\ 6{,}500{,}000.00$$

Fuel Cell Major Maintenance

$$\$\ 300.00\ x\ 5000kW = \$\ 1{,}500{,}000.00\ x\ 3\ times\ (20\ year\ period) = \$4{,}500{,}000.00$$

Fuel Cell General Operating and Maintanance (O&M) per year

$$\$0.025\ per\ kWh\ x\ (66.4\ MW\ x\ 1000\ kW\ x\ 365\ days) =$$

$$\$605{,}900.00\ x\ 20\ years = \$\ 12{,}118{,}000.00$$

Natural Gas Fuel Costs per year

$$\$\ 0.054\ per\ kWh\ x\ \mathbf{80{,}770.89}\ kWh\ needed\ per\ day\ x\ 365\ per\ year =$$

$$\$\ 1{,}591{,}994.28\ \ x\ 20\ years = \$\ 31{,}839{,}885.60$$

The total costs calculated divided by the total kWh produced in the analysis period provide the costs per kWh.

$$\frac{\$54{,}957{,}885.60}{484{,}720{,}000} = \$\ \mathbf{0.11\ per\ kWh}$$

Table 4. Life Cycle Costs of Fuel Cell Technology for a period of 20 years.

Fuel Cell Life Cycle Costing Analysis

Year	Captial Costs	Major Maintanance	General O&M	Costs of fuel kWh	Total Costs	kWh Produced	Costs per kWh Total Costs/kWh Produced
0	$ 6,500,000.00						
1			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
2			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
3			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
4			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
5		$ 1,500,000.00	$ 605,900.00	$ 1,591,994.28		24,236,000.00	
6			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
7			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
8			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
9			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
10		$ 1,500,000.00	$ 605,900.00	$ 1,591,994.28		24,236,000.00	
11			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
12			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
13			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
14			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
15		$ 1,500,000.00	$ 605,900.00	$ 1,591,994.28		24,236,000.00	
16			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
17			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
18			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
19			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
20			$ 605,900.00	$ 1,591,994.28		24,236,000.00	
Total	**$ 6,500,000.00**	**$ 4,500,000.00**	**$ 12,118,000.00**	**$ 31,839,885.60**	**$ 54,957,885.60**	**484,720,000.00**	**$ 0.11**

Diesel LCCA

The data inputs for the Diesel Generator LCC where estimated as follows.

Diesel Capital Costs

$$\$900.00\ x\ 5000kW = \$\ 4{,}500{,}000.00$$

Diesel Major Maintenance

$$\$\ 450.00\ x\ 5000kW = \$\ 2{,}250{,}000.00$$

Diesel General Operating and Maintanance (O&M) per year

$$\$\ 0.030\ per\ kWh\ x\ (66.4\ MW\ x\ 1000\ kW\ x\ 365\ days) = \$\ 727{,}080.00$$

$$= \$\ 727{,}080.00\ x\ 20\ years$$

Medium Fuel Oil Costs per year

$$\$0.061\ per\ kWh\ x\ 129{,}182.86\ kWh\ needed\ per\ day\ x\ 365\ per\ year = \$\ 2{,}876{,}256.37$$

$$= \$\ 2{,}876{,}256.37\ x\ 20\ years$$

The total costs calculated divided by the total kWh produced in the analysis period provide the costs per kWh.

$$\frac{\$78{,}816{,}727.43}{484{,}720{,}000} = \$\ \mathbf{0.16\ per\ kWh}$$

Table 5. Life Cycle Costs for Diesel Technology for a period of 20 years.

Diesel Life Cycle Costing Analysis

Year	Captial Costs	Major Maintanance	General O&M	Costs of fuel kWh	Total Costs	kWh Produced	Costs per kWh Total Costs/kWh Produced
0	$ 4,500,000.00						
1			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
2			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
3			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
4			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
5			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
6			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
7			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
8			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
9			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
10		$ 2,250,000.00	$ 727,080.00	$ 2,876,256.37		24,236,000.00	
11			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
12			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
13			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
14			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
15			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
16			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
17			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
18			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
19			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
20			$ 727,080.00	$ 2,876,256.37		24,236,000.00	
Total	**$ 4,500,000.00**	**$ 2,250,000.00**	**$ 14,541,600.00**	**$ 57,525,127.43**	**$ 78,816,727.43**	**484,720,000.00**	**$ 0.16**

Gas Turbine LCCA

The data inputs for the Gas Turbine LCC where estimated as follows:

Gas Turbine Capital Costs

$$\$700.00\ x\ 5000kW = \$\ 3{,}500{,}000.00$$

Gas Turbine Major Maintenance

$$\$\ 600.00\ x\ 5000kW = \$\ 3{,}000{,}000.00$$

Gas Turbine General Operating and Maintanance (O&M) per year

$$\$\ 0.030\ per\ kWh\ x\ (66.4\ MW\ x\ 1000\ kW\ x\ 365\ days) = \$\ 727{,}080.00$$

Natural Gas Fuel Costs per year

$$\$0.054\ per\ kWh\ x\ 277{,}367.83\ kWh\ needed\ per\ day\ x\ 365\ per\ year = \$\ 5{,}466{,}919.85$$

The total costs calculated divided by the total kWh produced in the analysis period provide the costs per kWh.

$$\frac{\$130{,}379{,}996.97}{484{,}720{,}000} = \$\ \mathbf{0.27\ per\ kWh}$$

Summary of the LCC for the three technologies

Costs per kWh		
Fuel Cell	**Diesel**	**Gas Turbines**
$ 0.11	$ 0.16	$ 0.27

Table 6. Life Cycle Costs for Gas Turbine Technology for a period of 20 years.

Gas Turbine

Year	Captial Costs	Major Maintanance	General O&M	Costs of fuel kWh	Total Costs	kWh Produced	Costs per kWh Total Costs/kWh Produced
0	$ 3,500,000.00						
1			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
2			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
3			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
4			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
5			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
6			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
7			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
8			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
9			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
10		$ 3,000,000.00	$ 727,080.00	$ 5,466,919.85		24,236,000.00	
11			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
12			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
13			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
14			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
15			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
16			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
17			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
18			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
19			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
20			$ 727,080.00	$ 5,466,919.85		24,236,000.00	
Total	**$ 3,500,000.00**	**$ 3,000,000.00**	**$ 14,541,600.00**	**$109,338,396.97**	**$ 130,379,996.97**	**484,720,000.00**	**$ 0.27**

Alternative Scenario using Two Diesel Generators

In the situation where one of two 5MW diesel generators are meeting the same load, and one would need replacement the following factors should be considered.

- Costs of new diesel generator
- Costs of maintanance and operation of the new generator
- New generator efficiency
- Peak power requirements and the daily load profile: (The actual load profile is not known and can have higher peak loads not shown in the average daily load profile).
- Derating factors of the new diesel generator
- Specific daily fuel consumption of the new set.
- Spinning reserve needed.

One recommendation is to change the 5MW diesel generator for a 3.5MW. In this situation the 3.5MW diesel would operate during low load periods at a higher rated outputs. The 5MW generator set can be used to meet the higher loads in peak hours.

To estimate the generator set output we answered the following question:

What is the generator output in order for it to run at 80% of its rated output to meet the given load? 80% was used because it would also allow this generator to work at higher loads in case spinning reserve is needed.

$$\text{Rated output} = \frac{\text{Load}}{Generator\ output} x\ (100)$$

$$\text{Generator output} = \frac{\text{Load}}{Rated\ output} x\ (100)$$

$$\text{Generator output} = \frac{1.9}{80\%}\ x\ 100$$

$$\text{Generator output} = 2.4$$

The values for each hour were then averaged (table 7). The average for the 24 hour period so that the generator set work at 80% of its rated output is 3.5MW

Table 7. Rated outputs from a 5MW and a 3.5MW Diesel Generator Sets.

			Genset output = Load/Rated Output	
Hour of Day	**Load (MW)**	**Rated Output % 5MW Diesel**	**Generator output at 80%**	**Rated Output % 3.5 MW Diesel**
0-1	1.9	38	2.4	**54**
1-2	1.80	36	2.3	**51**
2-3	2.00	40	2.5	**57**
3-4	2.00	40	2.5	**57**
4-5	2.30	46	2.9	**66**
5-6	2.50	50	3.1	**71**
6-7	2.70	54	3.4	**77**
7-8	2.80	56	3.5	**80**
8-9	2.80	56	3.5	**80**
9-10	2.50	50	3.1	**71**
10-11	2.30	46	2.9	**66**
11-12	2.80	**56**	3.5	**80**
12-13	3.30	**66**	4.1	**94**
13-14	3.10	**62**	3.9	**89**
14-15	2.80	**56**	3.5	**80**
15-16	2.60	52	3.3	**74**
16-17	2.90	**58**	3.6	**83**
17-18	3.60	**72**	4.5	**103**
18-19	4.10	**82**	5.1	**117**
19-20	4.30	**86**	5.4	**123**
20-21	3.50	**70**	4.4	**100**
21-22	3.10	**62**	3.9	**89**
22-23	2.30	46	2.9	**66**
23-24	2.40	48	3.0	**69**
Average		**55**	**3.5**	**79**

The other option that can be used if cost-effective would be to use a a parallel hybrid system. A life cycle costing analysis would need to be done in order to compare the changes in costs per kWh for this alternative technology.

Sensitivity Analysis

A sensitivity analysis was conducted to see the effect of fuel costs and general operation and maintenance costs on the final fuel prices. The results for the three technologies is summarised in table 8 and figure 2.

Table 8. Sensitivity analysis table showing how the change in fuel costs and O&M costs affect the price per kWh.

	% Change in costs per kWh				% Change in costs per kWh		
% Change in Fuel Costs	Diesel	Fuel Cell	Gas Turbine	% Change in O&M Costs	Diesel	Fuel Cell	Gas Turbine
-50%	-36%	-29%	-42%	**-50%**	-9%	-11%	-6%
-30%	-22%	-17%	-25%	**-30%**	-6%	-7%	-3%
-10%	-7%	-6%	-8%	**-10%**	-2%	-2%	-1%
0%	0%	0%	0%	**0%**	0%	0%	0%
10%	7%	6%	8%	**10%**	2%	2%	1%
30%	22%	17%	25%	**30%**	6%	7%	3%
50%	36%	29%	42%	**50%**	9%	11%	6%

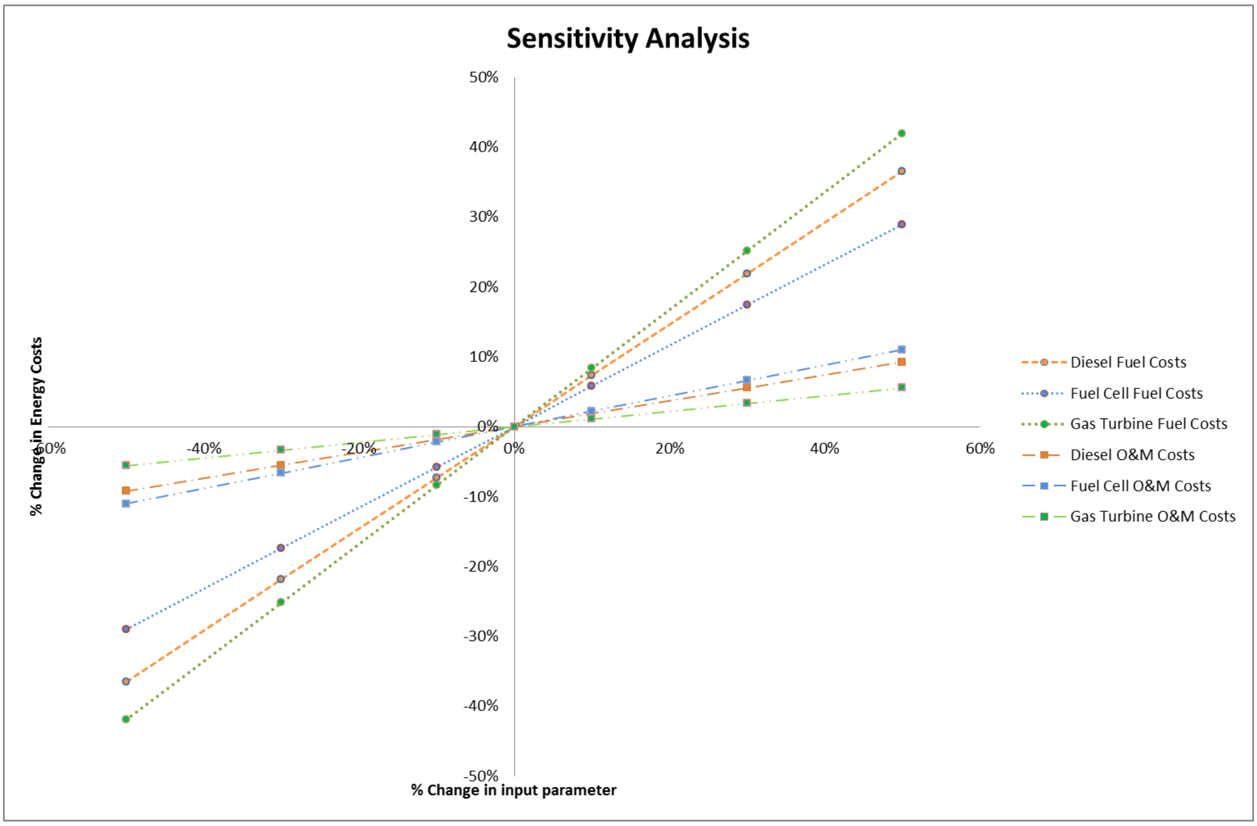

Figure 2. Sensitivity Analysis for the three technologies.

Sensitivity Analysis Conclusions

The steep slopes on the sensitivity analysis shows that variation in fuel costs have a very strong impact on the energy price per kWh. A 10% increase in fuel costs can change the energy price by 6% for Fuel Cell, 7% for Diesel and 8% for Gas Turbine. On the other hand the gentle slopes for the O&M cost variation are an indicator that this parameter does not affect considerably the final price of energy produced per kWh. For example a 10% change in O&M changes the price per kWh produced by 2% for Fuel Cell, 2% for Diesel and 1% for Gas Turbine.

In terms of technology fuel cells would seem to be a better option for investment as they are the least sensitivity to fuel costs. A 50% change in fuel costs has a 29% in the energy price per kWh in comparison to gas turbine (a 50% change in fuel costs produces a 42% change in energy price per kWh). Also the LCC shows that although the capital costs of fuel cell technology is more expensive than the other alternatives the total life cycle cost is less. Because it is a more efficient technology it consumes less fuel and is more competitive to produce the same amount of energy.

Gas turbines on the other hand are the most sensitive to the change in fuel costs. Even though it has the lower capital costs, the total LCC is the highest of the three technologies. Furthermore it has a lower energy efficiency and the costs of energy production are higher. This produces the highest energy costs per kWh of the three technologies.

The sensitivity analysis also shows that diesel technology is the midpoint between fuel cell and gas turbine. This can also be said for the final energy price per kWh produced, capital investment and O&M costs.

It is thus recommended that fuel cell technology is chosen for the power generation of the mining operation and town.

Annex 1

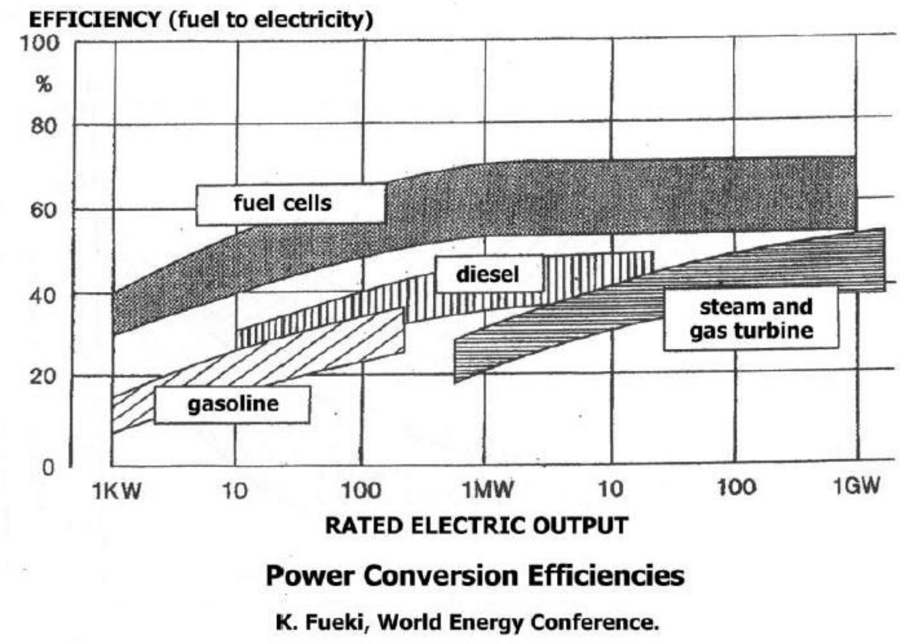

Figure 3. Power Conversion Efficiency.

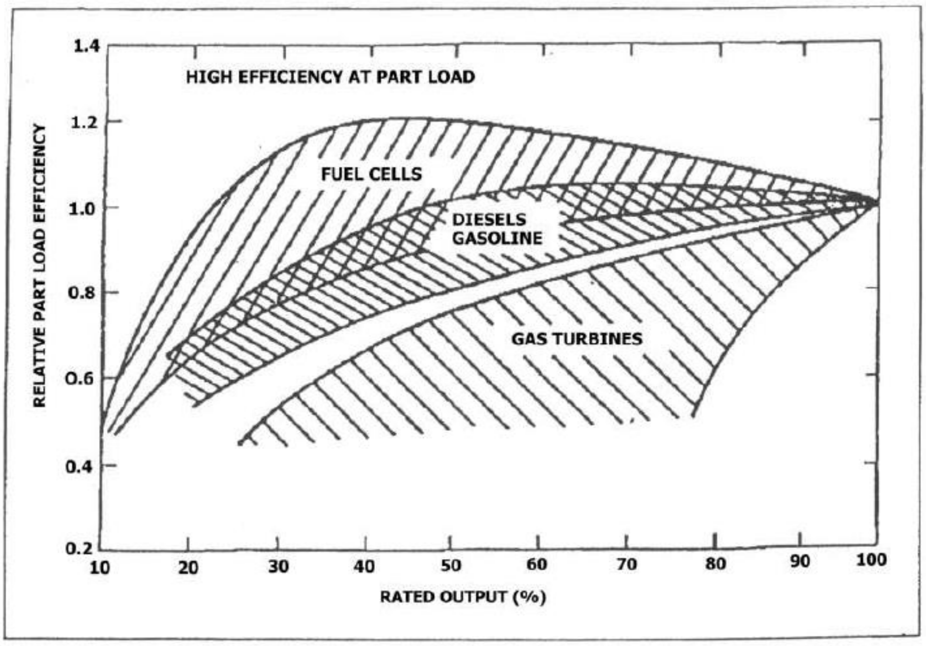

Figure 4. Relative Part load efficiencies