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Small Hydropower, Another Source of Renewables for Australian Underground Mining?

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Abstract

The mining sector in Australian consumes around 500 petajoules per year which is 10% of Australia's total energy usage. It is predicted that the Australian mining sector's long-term energy intensity will be increased due to falling of average ore grade and overburden increasing. Wind and solar have been considered as main renewable resources which can be utilized by mining sector in Australia to generate power. Based on water supply system at an underground mine, another source of renewables, small hydropower has been discussed. Utilizing of Break Tanks at water supply system of underground mines is a recommended practice. The results of this work showed that installation Pump as Turbine (PaT) at inlet of the Break Tanks at an underground mine can recover more than 300 kW energy, annually generates up to 2.5 GWh electricity, save up to AU$ 0.7 million of mine annual electricity costs and reduces CO_2 emission. In addition to several hydraulic advantages of utilizing Break Tanks in an underground mine water supply system, energy recovery is another benefit which should be considered as well.

Keywords: Underground Mining; Renewable Energy; Break Tank; Pump as Turbine (PaT)

Nomenclature

E	Available Energy [Watt]
g	9.8 m/S^2
h	Net Head = Available Head-Pipe Head-loss [m]
IMEC	International Mining Engineering Consultants
HDPE	High-density Polyethylene
LPG	Liquefied Petroleum Gas
OD	Outer Diameter[mm]
PaT	Pump as Turbine
PN	Nominal Working Pressure Rating[bar]
Q	Inlet Water Flowrate [m^3/S]
ρ	Water Density [Kg/m^3]

Introduction

The mining sector in Australian consumes around 500 petajoules per year which is 10% of Australia's total energy usage. As mining volumes increased in Australia, the mining sector electricity consumption has risen around 6.0% per annum over the last decade [1,2]. Diesel (41%), natural gas (33%), and grid electricity (22%) are the main energy sources which generate electricity for Australia's mining sector while a mixture of other refined fuels, biofuels, renewables, LPG and coal are the rest of the energy sources for the electricity generation at the mining sector [3]. Over the last decade, the diesel contribution has fallen from 49% to 41% and been massively replaced by grid electricity and natural gas, due to infrastructure development and volatility of the oil prices [2]. It is predicted that the Australian mining sector's long-term energy intensity will be increased due to falling of average ore grade and overburden increasing (over the last 30 years, the average grade has halved, and overburden doubled) [4].

Development of batteries and electric equipment, which allow diesel consumed in mining site and logistics to be increasingly swap with a combination of electricity generation and energy storage, is gradually leading to disappear distinction between energy (the summation of plant diesel, electricity, explosives, etc.) and electricity. It is expected that electricity generation and storage in the mining sector will be more important due to transition to 'all electric' mining. Historically, the "favoured fuel source" of Australian mining sector is diesel along with natural gas, however the concept of an 'all-electric mining' integrating renewables, batteries and traditional energy was building momentum [2].

Logistics and fossil fuel price volatility are outside the control of most mine owners but have a remarkable impact on the economic ability of the mining sector (Figure 1). The mining sector in Australia and the Australian Government have acknowledged the environmental impacts and risk of the fossil fuels and are encouraging the renewable electricity adoption and energy efficiency measures [2]. The Australian mining sector has recently discovered that there is a cleaner, cheaper and smarter way to power their operations, and the mining industry is now appearing as the source of the next boom in renewables investment [5]. Mining sectors need to understand the advantages and disadvantages of each renewable energy technology versus the specific power supply needs of the sector. More renewable energy means more competitive and clean energy and provide bigger hedge versus future grid or fuel price volatility, but at the same time means more complex energy management system [6].

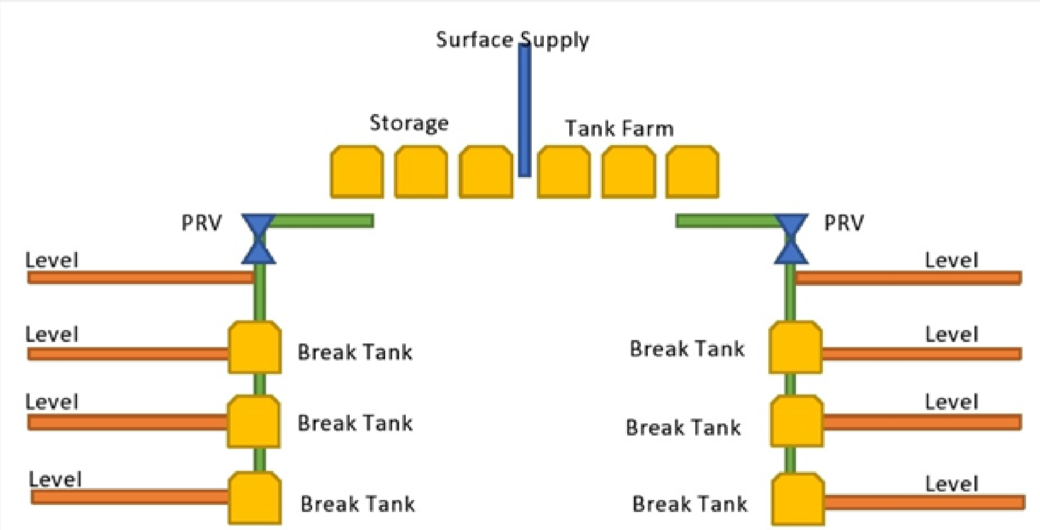

Figure 1: Generalized Water Supply Schematic of an Underground Mine.

Wind and large-scale solar PV are economically feasible and technically mature technologies which can be utilized to decrease a mine's reliance on fossil fuels for power generation. Solar PV has some practical advantages for mining application compare to the wind, but currently technical and commercial considerations limited its adoption into the mining sectors [2]. Solar or wind energy cost high capital investment but they need very limited operating expenses. With significant upfront investments, mine owners need to have a mid- or long-term strategy to benefit the net value of renewable energy whether the owner decides to invest himself, or to enter into a medium to long-term Power Purchase Agreement (PPA) with an entity who will develop and invest in the renewable power plant [6].

Wind and solar are now competitive with fossil fuels on an un-subsidised Levelised Cost of Electricity (LCOE) and capital cost basis [7]. On a LCOE basis, wind and on-grid large-scale solar PV are one of the lowest cost sources (<AU$80/MWh) and with anticipating of further decreases, their capital costs are becoming competitive with diesel or gas generator (costs of the PV module have dropped 80% since 2008 and cost of the onshore wind dropped by 50% since 2009) [8]. The combination of comparable capital cost and low LCOE is making wind and solar PV attractive in short-term economic metrics [2] (Figure 2).

As solar PV and wind are the intermittent sources, this limitation can overcome by utilizing hybrid system to ensure a reliable electricity supply via combination of renewable sources with fossil fuel-based generation. Automated hybrid control systems can help to minimize electricity costs by maximizing the use of low-cost renewable electricity. Large-scale hybrid systems are becoming more attractive in the mining sector. Combined diesel with wind or solar PV systems, with capacities up to 47MW diesel/9.2MW wind and 19MW diesel/10MW solar PV have been recently installed in Australia and Canada [2].

In general, energy storage is currently uncompetitive with fossil fuels for most energy shifting applications. However, the electric vehicles and global attention of renewable energies has led to remarkable research and development in the storage field. It is forecasted that the capital costs of most storage technologies

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will fall by around 25%-50% over the next 5 years due to improvements of design and chemistry, manufacturing scale and reduction of material costs [2]. As mentioned, wind and solar have been considered as main renewable resources which can be utilized by mining sector in Australia to generate power. This work discuses another source of renewables, small hydropower, which can be an alternative renewable resource for hybrid electricity systems at underground mines in Australia (Figure 3).

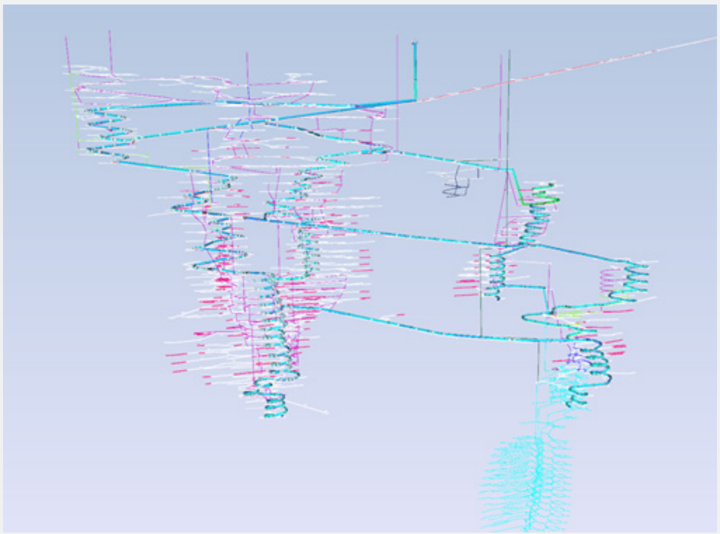

Figure 2: Isometric View of Water Supply System Model at Gossan Hill Mine, Western Australia.

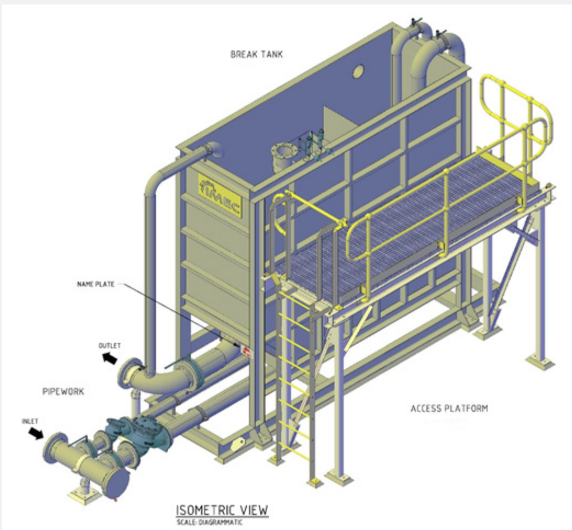

Figure 3: Typical Break Tank Isometric View (designed by IMEC).

Water Supply System of Underground Mines and Available Hydro-Energy

The water supply system is typical to many underground mines in Australia. In general, the reticulation of raw water underground is transferred via a gravity fed system. The layout of the system is common to most underground raw water distribution systems in that

a) A Supply System, often in the form of a header tank above ground, which either via gravity or is pumped into the mine.

b) An Underground Bulk Storage System, to store water underground in the event of upstream supply problems as well as manage peak demand spikes, and

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c) A Distribution system, often just standard HDPE pipelines, throughout the mine, with "Break Tanks" and pressure reduction valves strategically placed to both manage the pressures the system produces (due to differential static heads), as well as manage localized demands.

Given the water is transferred via gravity, the deeper it travels the more the pressure increases. For this reason, pressure reduction valves are installed in various locations, with Break Tanks serving a similar purpose (system break back to atmospheric pressure). As the main supply HDPE lines are extended down the decline, take-offs to the various levels then tee off. Generally, the system is depicted as per the schematic below:

It is recommended by most professionals that open to atmosphere 'Break Tanks' is utilized as pressure reduction equipment for water supply system at underground mines. These tanks serve as pressure reset devices, as they 'break' the pipelines into individual segments and allow the pipelines to be exposed to atmosphere. Further they provide localized surge capacity within their proximity, allowing for short bursts of high demand to be managed by the tank itself. Installing level-controlled break tanks, every 80-120m vertically, connected via 100mm diameter HDPE lines, is common practice for water supply system of underground mines in Australia. If we assume that the Break Tanks connected via OD 110 PN 12.5 HDPE pipe, which is very practical in underground mining, then based on the pipe working pressure, the Break Tanks can be located every 120m vertically. As the pipe route at an underground mine usually follows the driveways, the pipe physical length between every two tanks should be much longer than 120m and can be expanded up to 800m. The level of the water inside each tank usually controls with closed-open level control valves.

Figure 4 shows the pressure loss through OD110 PN 12.5 HDPE lines (100m pipe) versus different flowrates which calculated by using Darcy-Weisbach equation where Darcy friction factor obtained from Colebrook equation approximations suggested by Cheng [9]. If all available head between two tanks(120m) is used to transfer water to the downstream tank, more than 40 L/s can be delivered to the downstream tank during filling time (around 45 L/s). However, with attention to the tank surg capacity and flowrate requirement of the mine activities which feeds by the downstream tank, the filling time of the tank can be increased, and inlet flowrate can be decreased. Therefore, part of the available head at the tank inlet can be exploited as energy via deploying energy recovery devices at inlet of each Break Tank.

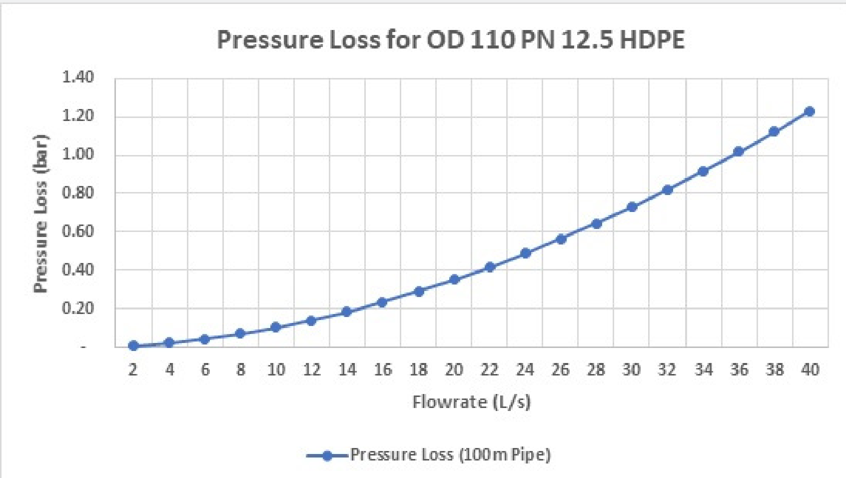

Figure 4: Pressure Loss through OD110 PN 12.5 HDPE Lines.

The available energy at inlet of each tank is calculated from below equation:

$$E = \rho \times g \times Q \times h \quad (1)$$

Where,

$E = Availible\ Energy[Watt]$

$\rho = Water\ Density = 1005 \frac{Kg}{m^3}$

$g = 9.8 \frac{m}{S^2}$

$Q = Inlet\ Water\ Flowrate\ [\frac{m^3}{S}]$

$h = Net\ Head = Availible\ Head\ (120m) - Pipe\ Headloss[m]$

Table 1 presents the available energy at the inlet of the downstream tank for different flowrates. By deploying an energy recovery device with duty point around flowrate=25L/s and Head=79m at inlet of each Break Tank, the maximum energy can be exploited during filling time while 25L/s of water delivered to the tank.

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Table 1: Available Energy at The Inlet of the Downstream Tank for Different Flowrates.

Flowrate (L/s)	Pipe Head-loss (m)/100m	Pipe Head-loss (m)/800m	Net Head (m)	Available Energy (kW)
10	0.98	7.84	112.16	11.05
12	1.36	10.89	109.11	12.9
14	1.8	14.38	105.62	14.56
16	2.29	18.3	101.7	16.03
18	2.83	22.64	97.36	17.26
20	3.43	27.4	92.6	18.24
22	4.07	32.58	87.42	18.94
24	4.77	38.15	81.85	19.35
26	5.52	44.13	75.87	19.43
28	6.31	50.49	69.51	19.17
30	7.16	57.25	62.75	18.54
32	8.05	64.4	55.6	17.52
34	8.99	71.93	48.07	16.1
36	9.98	79.84	40.16	14.24
38	11.02	88.13	31.87	11.93
40	12.1	96.8	23.2	9.14

Hydro Turbines Vs. Pump as Turbine (PaT) for hydro-energy recovery

As discussed in previous section, an energy recovery device with duty points around flowrate=25 L/s and Head=79 m is required at the inlet of each Break Tank to recover maximum energy. Figure 5 shows the general operational range of different types of hydro-turbines, Pelton, Francis and Kaplan turbines, for small and mini hydropower solutions. In general, the Pelton turbine is utilized for high-head, low-flow application. As the hydro-turbine chart at Figure 5 shows the Pelton turbine cannot meet the duty point which is required at the inlet of the Break Tank (flowrate=25 L/s and Head=79m).

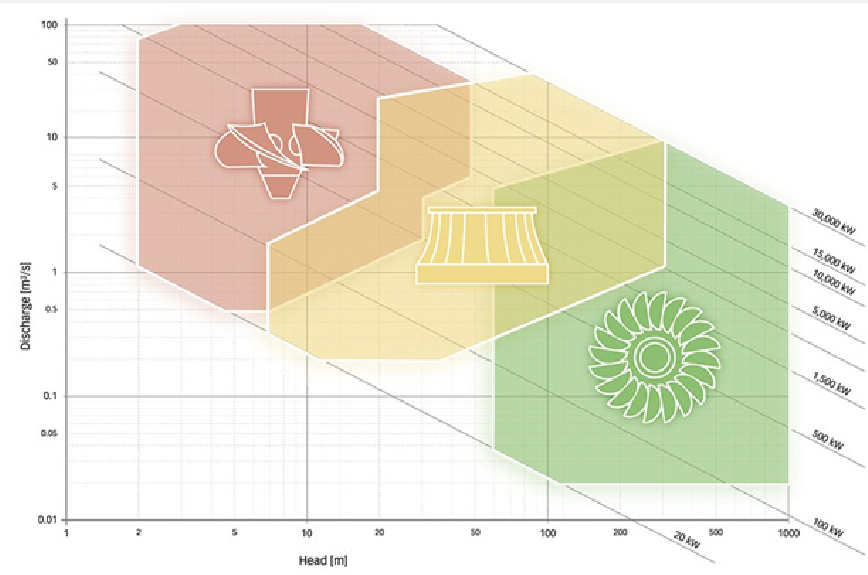

Figure 5: Operational Range of Different Types of Hydro-Turbine for Small and Mini Hydropower Solutions [10].

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Pump as Turbine (PaT) technology is taking the field in different small-hydro energy recovery solutions [10]. Williams [11] discussed economic and practical advantages of utilizing PaTs instead of micro hydro turbines in medium-head sites. Due to the possibility of PaTs application in different situations and to its less expensive cost than turbines, this technology has been rapidly improved in the recent decade [10]. Larger operation range of heads and flowrates, low investment costs, variable installation possibilities, extensive range of products and materials, easier availability of spare parts like seals, bearings and easier installation can be summarized as some advantages of using PaTs instead of micro hydropower turbines [12,13].

In most cases, it is possible for PaT systems to achieve the same high level of pump efficiency in conventional operation. The efficiency of a double-entry volute casing pump is approximately 85%. At Best Efficiency Point (BEP), the PaT runs as smoothly as a pump in conventional mode. The outgoing flow is almost vortex-free, and noise, wear and pipe vibration are very low [14]. Figure 6 presents choice of different pumps for PaT applications. According to required operational range at the inlet of the Break Tank (flowrate=25 L/s and Head=79m) Radial Flow PaT or Multistage Radial Flow PaT may be used.

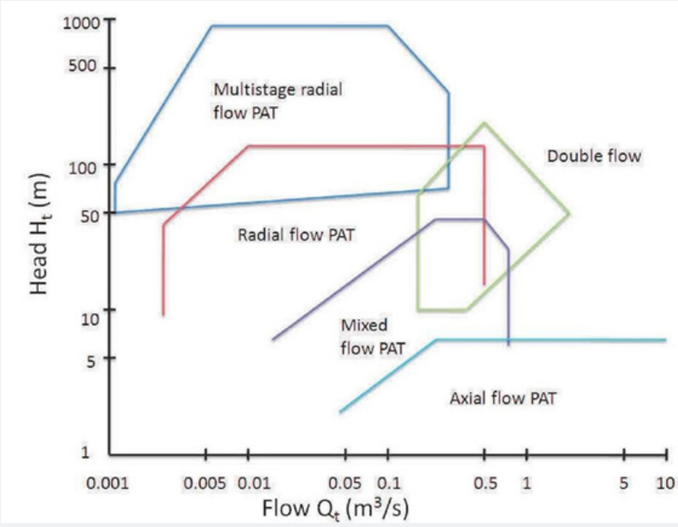

Figure 6: Choice of pumps for PaT applications [16].

Economical Evaluation

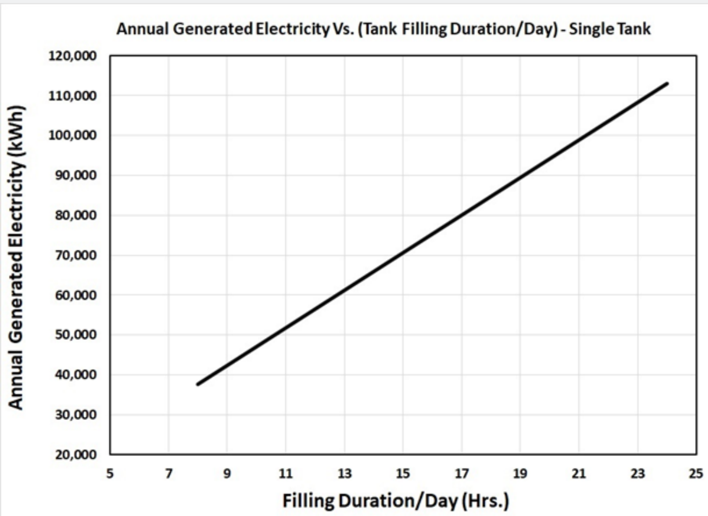

Figure 7: Possible Annual Generated Electricity by a PaT at Inlet of a Break Tank.

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As explained in section 2, the maximum available capacity of hydropower at inlet of a Break Tank is around 19.5 kW. By taking to account the PaT efficiency (70%) and generator efficiency (95%), the maximum achievable capacity is around 12.95 kW.

The PaT utilizes at the inlet of the Break Tank generates electricity just during tank filing. Most of underground mines especially the gold mines in Australia operates 24 hours per day, 365 days per year. However, filling duration of a Break Tank during a day can be varied depend to activities at different parts of the mine. Figure 7 shows the possible annual generated electricity (365 days mine operation) by a PaT at the inlet of a Break Tank for different tank filling durations per day.

The potential saving of electricity cost by using PaT at inlet of a Break Tank is totally depend to the electricity price paying by the mine. The price ranges from <$0.10/kWh for grid electricity, $0.10/kWh–$0.30/kWh for electricity derived from pipeline gas, and $0.15/kWh–$0.30/kWh (after rebates) for electricity generated by off-grid diesel or gas, have been reported for electricity price in Australia by Australian Renewable Energy Agency (ARENA) [2]. Maximum annual saving of mine electricity cost can be achieved by using PaT at the inlet of a Break Tank for the mines which powered by different sources has been reported at Figure 8.

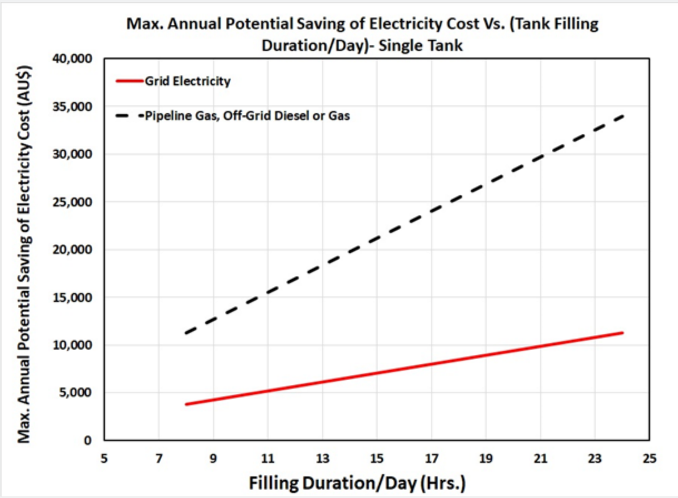

Figure 8: Maximum Annual Saving of Mine Electricity Cost by Using PaT at Inlet of a Break Tank.

Figure 7 and Figure 8 show the annual generated electricity and annual saving cost which are achievable by one Break Tank. It is very practical that the water supply system of an underground mine includes 15 to 25 Break Tanks. Therefore, by using PaT at inlet of all Break Tanks, the maximum available capacity of hydropower in an underground mine can be between 195 kW to 325 kW; Annual generated electricity by small hydropower and maximum annual saving of electricity cost in an underground mine can be increased up to 2.5 GWh and AU$0.7 million, respectively.

Hydropower at the inlet of the break tank is the intermittent source. This limitation can overcome by utilizing hybrid system or energy storage. To calculate the payback ratio (period) for utilizing PaT at the inlet of a Break Tank, the cost of battery storage to store the generated electricity for one day with 80% depth of discharge and 1.05 inefficiency factor, has been taken to account as upfront investment cost as well. In 2019, battery prices have fallen 87% in real terms to US$156/kWh, while were above US$1,100 per kilowatt-hour in 2010. According to the latest forecast from research company Bloomberg NEF (BNEF), average prices will be close to US$100/kWh by 2023. It looks very promising which the price will be reduced even further, from US$100/kWh down to US$61/kWh by 2030 [15].

Table 2 presents the investment cost for utilizing a proper PaT, which explained in section 2, at the inlet of single Break Tank. Figure 9 shows the minimum payback ratio for utilizing the PaT system including the battery bank at the inlet of single Break Tank versus different tank filling durations per day for the mines which powered by different sources. While the payback ratio is around 2 years for the mines powered by pipeline gas or off-grid diesel/gas, it is around 6.5 years for the mines connected to the grids. However, in future years by dropping the battery price, the payback ratio should be even much less than the values reported in Figure 9.

Environmental Advantages

Figure 10 shows the specific carbon dioxide emissions of various fuels and Table 3 presents emission factors for consumption of purchased electricity or loss of electricity from the different grid across Australia. Based on the reported values at Figure 7 and Table 3, Figure 8 presents the annual CO_2 emission

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reduction can be achieved by recovering hydro-energy at inlet of single Break Tank at mines which powered by different grids across the Australia or different off-grid systems [16-19]. It is notable that Figure 8 reports CO_2 emission reduction just for single Break Tank and as explained previously, water supply system of an underground mine usually includes 15 to 25 of Break Tanks.

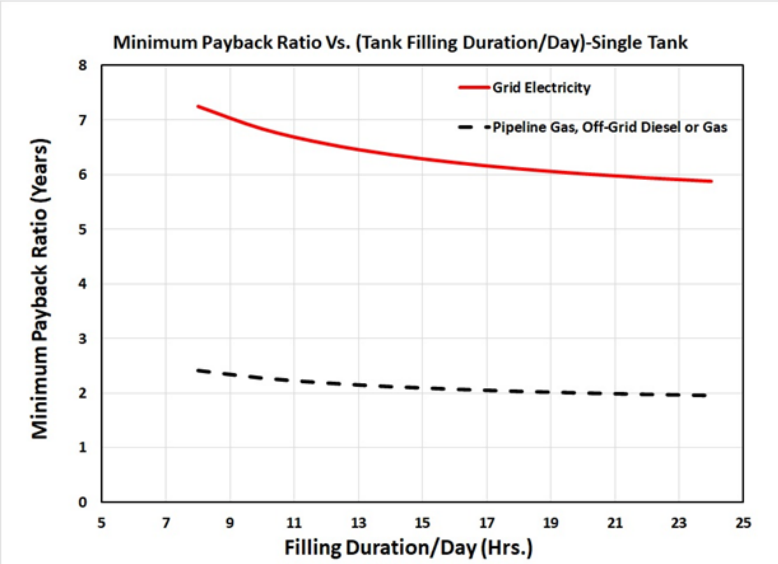

Figure 9: Minimum Payback Ratio for Utilizing PaT System at Inlet of Single Break Tank Vs. Different Tank Filling Durations Per Day.

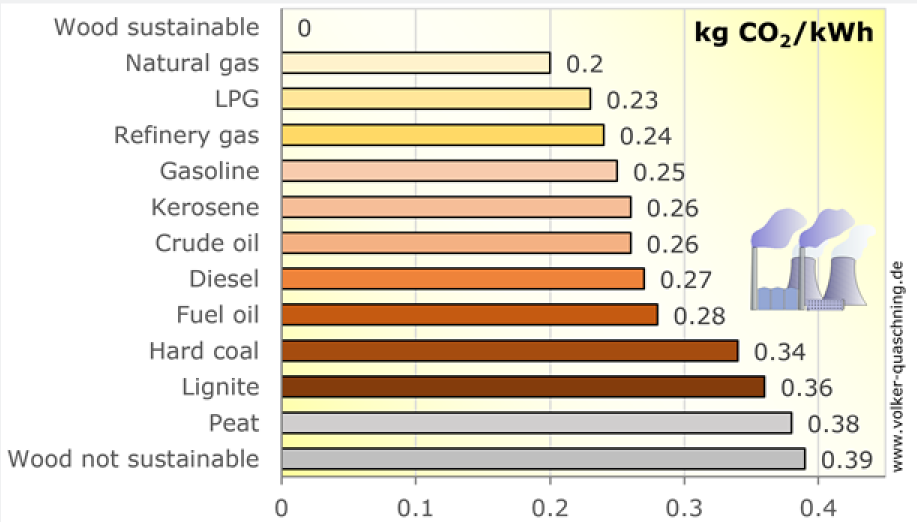

Figure 10: Specific Carbon Dioxide Emissions of Various Fuels [18].

Table 2: Investment Cost for Utilizing PaT at Inlet of Single Break Tank.

Item	Cost (AU$)
PaT	11,000
Battery Bank (one day storage with 80% depth of discharge and 1.05 inefficiency factor)	137/kWh
Installation	10% of Capital Cost

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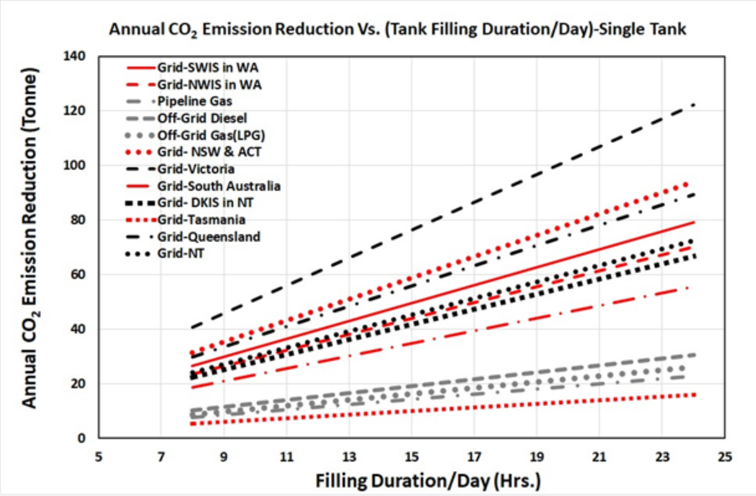

Figure 11: Annual CO_2 Emission Reduction by Recovering Hydro-Energy at Inlet of Single Break Tank.

Table 3: Indirect Emission Factors for Consumption of Purchased Electricity from Different Grids across Australia [19].

State or Territory	Emission factor kg CO_2-e/kWh
New South Wales (NSW) and Australian Capital Territory (ACT)	0.83
Victoria	1.08
Queensland	0.79
South Australia	0.49
South West Interconnected System (SWIS) in Western Australia (WA)	0.7
North Western Interconnected System (NWIS) in Western Australia (WA)	0.62
Darwin Katherine Interconnected System (DKIS) in the Northern Territory (NT)	0.59
Tasmania	0.14
Northern Territory (NT)	0.64

Conclusion

Wind and solar have been considered as main renewable resources which can be utilized by mining sector in Australia. However, small hydropower is another source of renewable can generate electricity for underground mines in Australia (Figure 11). Utilizing of Break Tanks at water supply system of underground mines is a recommended practice. Installing PaT systems at inlet of the Break Tanks which need low upfront investment cost, can recover more than 300 kW energy, annually generates up to 2.5GWh electricity and save up to AU$ 0.7 million of mine annual electricity costs for an underground mine in Australia.

In addition to several hydraulic advantages of utilizing Break Tanks in an underground mine water supply system, energy recovery is another benefit which should be considered as well. As electricity generation and storage in the mining sector going to be more important due to transition to 'all electric' mining, all available sources to power the mining sector are getting more value. Utilizing the Break Tanks as part of an underground mine water supply system, provides an extra source of energy for underground mines. In the close future, by rapid development of battery storage and hybrid power system technologies, utilizing a PaT at inlet of the Break Tank may be a common practice at underground mining.

References

1. Australian Government Department of Industry, Innovation and Science. (2016) Australian Energy Update, Canberra, September.
2. Australian Renewable Energy Agency (ARENA) (2017) Renewable Energy in the Australian Mining Sector White Paper (20062017 Rev. 2).
3. Australian Bureau of Statistics (2017) Energy Account Australia 2014-2015 (4604.0).
4. Bye AR (2011) Case Studies Demonstrating Value from Geo-metallurgy Initiatives, 1st AusIMM International Geo-metallurgy Conference (GeoMet).
5. https://reneweconomy.com.au/miners-see-50-renewables-as-standard-but-are-aiming-for-100-100/.
6. https://www.australianmining.com.au/features/renewables-are-a-no-brainer-for-the-australian-mining-sector/.

How to cite this article: Amir B T, Robert M. Small Hydropower, Another Source of Renewables for Australian Underground Mining?. Insights Min Sci technol.2021; 2(4): 555595. DOI: 10.19080/IMST.2021.02.555595.

7. Lazard (2016) Levelized cost of energy analysis – version 10.0.

8. Liebreich M (2016) Bloomberg New Energy Finance Summit - In search of the miraculous.

9. Cheng N (2008) Formulas for Friction Factor in Transitional Regimes. Journal of Hydraulic Engineering 134(9): 1357-1362.

10. Rossi M, Righetti M, Renzi M (2016) Pump-as-Turbine for Energy Recovery Applications: The Case Study of An Aqueduct. Energy Procedia 101: 1207-1214.

11. Williams AA (1996) Pumps as Turbines for Low-Cost Micro Hydro Power. Renewable Energy 9(1-4): 1227-1234.

12. Agarwal T (2012) Review of Pump as Turbine (PaT) for Micro-Hydropower. International Journal of Emerging Technology and Advanced Engineering 2(11).

13. Andritz Gmbh, Pumps Used as Turbines Booklet.

14. https://www.ksb.com/centrifugal-pump-lexicon/turbine-mode/328156.

15. https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/?sf113554299=1.

16. https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php.

17. (2017) Commonwealth of Australia, Department of the Environment and Energy. National Greenhouse Accounts Factors.

18. Andritz Hydro Gmbh, Small and Mini Hydropower Solutions Booklet.

19. Teuteberg B (2010) Design of a Pump-As-Turbine Microhydro System for an Abalone Farm. Final Report for Mechanical Project 878, Department of Mechanical and Mechatronic Engineering, Stellenbosch University, March.

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