Potential Economic and Operational Benefits and Impacts Of Trolley Assist In Open Pit Mining

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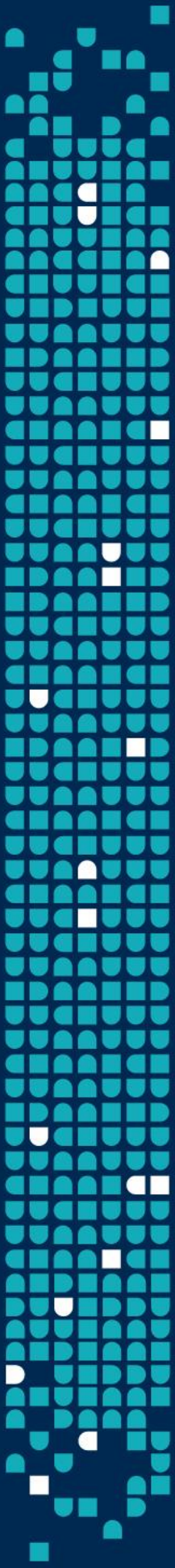

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Executive Summary

In a diesel-electric haul truck, a diesel engine is used to drive an alternator that produces the energy required to power electric wheel motors. Trolley Assist ("TA") allows a diesel-electric haul truck to bypass the diesel engine entirely when in TA mode so that electric power can be supplied directly by overhead lines. The result is an increase of approximately 10km/hr. in loaded up-ramp travel speed, as well as the substitution of diesel fuel with cheaper and cleaner electrical energy. This improved grade performance can have a significant impact on truck productivity, personnel requirements, fuel consumption, and operating and capital costs.

Although TA systems have been available for over 40 years and despite interesting operational and environmental benefits (reduced CO2, NOx, noise emissions, etc.), few operations have employed them. The decision to install a TA system is heavily dependent on the size and overall mine plan of an operation. Additionally, these systems involve significant capital investments and require technical expertise to efficiently design, plan and maintain them.

This paper will analyze some of the economic, operational and planning implications and benefits of installing TA at large open pit operations in Canada based on studies completed by BBA.

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Introduction

In an age of increasing environmental awareness, the electrification of transportation and reduction in fossil fuel related emissions have become a hot topic and focus for consumers and producers alike. In open pit mining, the application of an electrically powered loading unit is relatively common, however few mines employ TA systems to help power their haulage fleets. Similar to electrically powered street cars or rail cars in some major cities, TA allows dieselelectric haul trucks to idle their large diesel engines and directly draw power from overhead catenary lines.

TA is typically employed on long up-hill segments where it allows for increased rate of travel and greatly reduced fuel consumption. Because haul trucks will spend a large portion of the haul cycle on the uphill loaded segments in a deep open pit, on-grade performance can have a significant impact on truck productivity, personnel requirements, truck fleet requirements and project operating and capital costs. Depending on the project, TA systems can provide significant environmental and productivity benefits with a relatively small capital expenditure.

Nevertheless, the amenability of an operation to the application of a TA system is highly dependent on the specific characteristics of each operation and explains why few operations around the world employ a TA system. In today's volatile and investment-weary commodities market, the environmental, productivity and operating cost benefits of TA systems can potentially provide companies with improvements in both existing operations and potential projects. This paper will provide an overview of the factors, benefits and costs to be considered when evaluating the application of TA in an open pit mining operation, based on studies completed by BBA for open pit mining projects in Canada.

Trolley Assist Fundamentals

Haul trucks move around using one of two types of propulsion systems and can be either fully mechanical or diesel-electric powered. In a typical diesel-electric haul truck, a diesel engine is used to drive an alternator that produces the energy required to power electric wheel motors. The electrical energy produced by the alternator is first fed to a control cabinet that will condition the output of the alternator and supply the

appropriate voltage and current to the wheel motors to produce the desired torque and speed. Mechanical drive trucks instead supply mechanical energy from the diesel engine to the wheels via a transmission. Regardless of the type of truck, the speed of the haul truck when travelling uphill with a full payload is typically limited by the horsepower delivered by the onboard diesel engine. In the case of diesel-electric trucks, the electric wheel motors of the truck may have available output power that cannot be fully used due to insufficient input power being supplied by the diesel engine. Additionally, due to the mass of both the empty trucks and their payloads, uphill loaded haulage segments can result in instant fuel consumption rates in excess of 500 L/hr., depending on the truck class.

With TA, two pantographs are mounted to the front of the truck so that electric power can be collected from overhead trolley lines (Figure 1). A TA system allows a diesel-electric haul truck to bypass the diesel engine entirely when hooked up to the system, so that electric power can be supplied directly to the control cabinet by overhead lines.

Figure 1: Haul Truck Connected to Trolley Assist

Trolley Assist Electrical Infrastructure Requirements

While the electrical infrastructure required for a TA system will vary depending on the specific application, the system is generally comprised of the following main electrical components:

1. Additional 34.5 kV feeder(s) at the 149-34.5 kV main substation.
2. Dedicated 34.5 kV distribution lines, using 477 kcmil ACSR conductors, would connect the main substation to each of the in-pit mobile (container type) traction substations.
3. Mobile traction substations located alongside the fixed catenary system. Each of these container substations would convert 34.5 kV AC power into 2600 V DC.
4. A fixed catenary system would be installed within the pits, providing 2600 V over a maximum distance of 500 m on either side of each mobile traction substation under regular operation.
5. Each truck would be modified in order to install a pantograph assembly at the front of the trucks to collect power from the overhead lines.

Productivity, Cost and Environmental Benefits of Trolley Assist

The TA system presents evident productivity and cost benefits that make the system interesting for some mining operations.

- As a result of no longer being limited by the output of its diesel engine, the haul truck will be able to maximize the output of its wheel motors. In addition, TA trucks are usually equipped with more powerful wheel motors and thus, the speed of a haul truck when travelling loaded uphill on a trolley system will increase by approximately 10km/hr. (depending on the truck model and effective ramp grade), resulting in increased productivity per truck.

- The increased productivity will result in a reduced truck fleet requirement and corresponding lower manpower costs

- The use of electricity supplied by the overhead TA wires has the benefit of reducing the fuel consumption per haul for the truck, as the diesel engine is idling when connected to the trolley system.
- The decreased load factor on the diesel engine contained within the haul truck should also result in an increase in the number of hours between engine repairs and overhauls.

These benefits can be translated into a cost saving of 22$/hr., as shown in Table 1.

Table 1: Cost savings due to reduced fuel consumption and maintenance

	Without Trolley Assist:	With Trolley Assist:
Operator:	40$/hr.	40$/hr.
Repairs and PM:	136$/hr.	130$/hr.
Engine Repair Savings:		6$/hr.
Fuel Consumption:	192$/hr.	166$/hr.
Electricity Consumption:		10$/hr.
Total Cost:	368$/hr.	346$/hr.
Savings: 22$/hr.		

The decrease in fuel consumption due to the use of a TA network has the effect of reducing the environmental emissions from diesel combustion. Undeniably, for every liter of diesel fuel combusted, ~2.7kg of CO_2 is produced. Large open pit mining projects can require anywhere from 30 to 90 million liters of fuel per year, resulting in 162k t of CO_2 exhausted into the atmosphere. The TA could reduce these emissions by 10 to 30% in addition to reducing NOx and diesel particular matter emissions (DPM).

While there are currently no costs related to CO_2, NOx and DPM emissions in the mining industry, increasingly stringent environmental regulations and expectations could see the introduction of taxes on emissions in the near future. There might also be potential government funding for green mining solutions.

Challenges of Implementing a Trolley Assist System

Trolley Assist Implementation, Maintenance and Planning

The TA system involves the installation and maintenance of a network of overhead catenary cables, cable supports and DC and AC substations, which can create additional risks and complexity for an operation. The maintenance of these systems requires additional skilled labour to help ensure a high level of system availability. In addition, planning is required to ensure that the ramp segments to be used for TA are available during the designated period and that installation, maintenance and removal activities do not interfere with normal mining operations. Because the installation, maintenance and removal of TA infrastructure represent additional steps beyond the typical mining sequence, delays in these activities can negatively impact mining productivity and consequentially project economics.

As the implementation of TA at a site allows equipment planners to reduce the required size of the haul truck fleet, as compared to a diesel-only scenario, it becomes increasingly important to ensure a high level of availability of the TA network. Underutilization or lower than planned availability of a TA system with a "leaner" TA truck fleet would compound material movement shortfalls, as less spare equipment will be available to make up production. Sudden changes in the required mining sequence would also be limited or affected by the TA infrastructure and smaller TA fleet.

Impact on In-Pit Haul Roads

As a consequence of the implementation of the TA lines, ideally the widths of the applicable haul roads should be increased to ensure that an additional traffic lane is available in case of installation, maintenance or repairs to the trolley lines or for haul trucks that are unable to connect to the trolley lines due to missing or damaged pantographs. While not absolutely required, the extra lane should allow for an operation to maximize the use of the trolley lines and minimize delays to non-trolley mining operations. At a minimum, haul roads would need to be widened to accommodate the TA infrastructure within the pit.

In the case of a 38 meter wide haul road used for the 320 t class haul trucks where a trolley line is installed, a suggested haul road width of 51 meters was used. This increase

assumes a 12 m wide running width for the additional lane and 3 extra meters to account for any infrastructure and support structures required by the TA. An example of a trolley equipped haul road crosssection is presented in Figure 1.

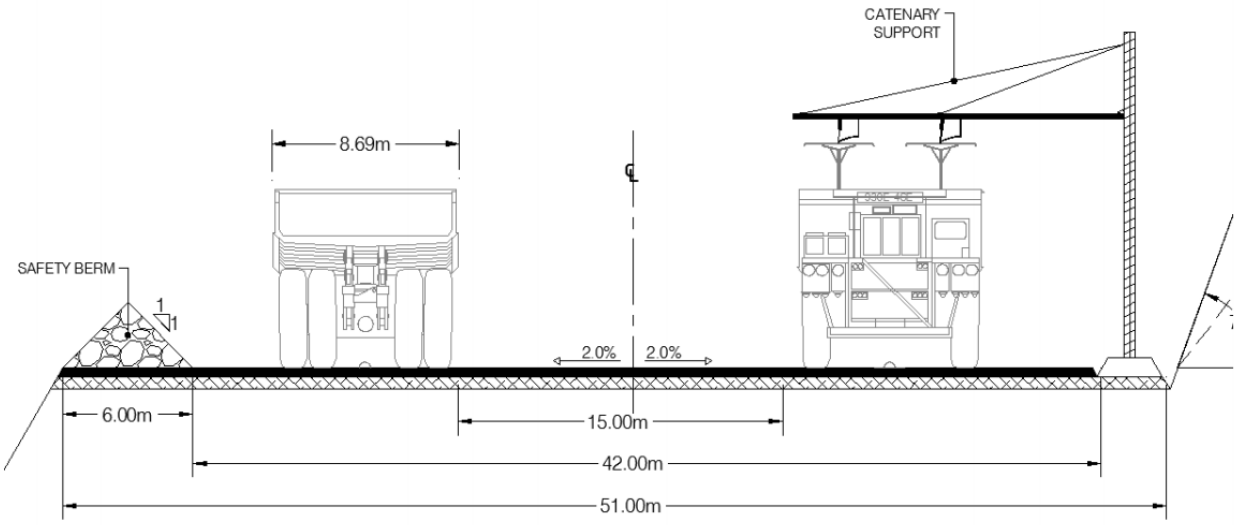

Figure 1: Haul road cross section with trolley assist infrastructure

As a result of these wider haul roads, a proportional increase in haul road construction costs (both initial and sustaining) can be expected for TA segments versus those without. Wider haul road requirements will impact the waste rock quantities in the pit as the pit wall would need to step out slightly for the same ore content or would alternatively result in some ore loss if roads are widened towards the inside of the pit.

The quality of the connection between a haul truck and the overhead lines relies on the mine being able to maintain a well graded road surface free of large debris and ruts, which can cause the pantographs of a truck to lose contact with the overhead lines, possibly resulting in arcing and the truck being rejected from the trolley line. Failure to maintain good road conditions will result in reduced trolley savings (due to reduced trolley usage) and increased trolley costs (due to pantograph and trolley line damage).

Haul trucks must be able to maintain a narrow range of alignment between the pantographs and the overhead line. Operator training is critical to ensure usage of the TA system is maximized and potential damage limited to the pantographs of the truck and overhead cables. Improperly aligned trucks could potentially cause the

pantographs of the truck to snag on the overhead cables, which could result in damage to long segments of overhead line.

Impacts on Mining Sequence

Due to the capital expenditures required to implement a trolley line, attempts should be made wherever possible to maximize the length of time ramp segments are available for TA, minimizing the frequency of line removal and re-installation. In addition to reducing the removal/installation costs, having a relatively stable set of trolley lines minimizes disruptions on the mining operation and reduces the loss of trolley usage during installation or removal.

Mine plans can be adjusted to include larger/wider mining phases to increase the lifetime of TA enabled ramp segments, however this will typically involve realignment of the mine plan and advancing of waste stripping for the larger pit phases. Attempting to maximize the use of the trolley system through the adjustment of the mine plan does not necessarily equate to improved overall project economics, as the increased TA savings must be weighed against the economic impact of advanced stripping.

Load Management

As trucks connecting and disconnecting from the overhead lines can be considered to be discrete power loads, continual monitoring of the load connected to the trolley grid is required to eliminate excessive fluctuations in electrical power demand and to ensure the maximum power draw is not exceeded. As the price paid for electricity is dependent on both the maximum power demand (peak load) and power consumption (quantity of energy consumed), users of TA systems should attempt to level electrical demand from the TA system through the use of dispatching tools and/or an additional variable "make-up" electrical load. Since unmanaged power demand from a TA system can be extremely variable, proper power management is crucial to avoid excessive peak demand charges that would increase the price paid for electricity and negatively impact the economics of the system.

Mine Plan Amenability to Trolley Assist

Mine plans should be examined on a period by period basis to estimate the "life" of ramp segments in the pit and their suitability for the installation of a TA segment. Ramp segments should only be considered potentially suitable for TA if they are a minimum of 500 m long and remain in use for at least 2 years. Based on the schedule of the TA line

installation as determined by the mine plan, the quantity of material to be transported on each trolley line must be estimated. These quantities should be adjusted according to the mining sequence and the likelihood that a TA line would be used to bring the material to its intended destination.

Depending on the site layout and size of the operation, it may also be possible to install trolley lines external to the open pit on hills and/or material stockpiles. While the economics of TA for a particular study or operation can only be ascertained by completing a detailed economic analysis, in general, a mine plan that maximizes the kilometer-tonnes moved via the trolley lines will see the greatest positive impact from TA.

Trolley Assist Capital and Operating Costs

On a recent TA project conducted by BBA for an operation in Canada, the following capital costs were obtained or assumed for the TA system:

Table 2: Obtained or assumed capital costs for trolley assist system

Expenditure	Capital Cost
New trolley line installation	1.2M$/km
Trolley line re-installation	600K$/km
Trolley line removal	150K$/km
DC substation unit cost	2.3M$ per unit
Main AC substation distribution infrastructure	400K$/pit
AC line from main substation to pit center	300K$/km
AC line drops from pit center to DC substations	800K$/km
Trolley EPCM	2.0M$
Truck pantograph cost	400K$/truck
Trolley system spares (pantographs, traction substation(s) and trolley line and supports)	

The following operating costs were estimated for the TA system:

Table 3: Obtained or assumed capital costs for trolley assist system

Expenditure	Operating Cost
Annual substation inspection:	2K$/yr
Annual trolley line inspection:	50K$/km/yr
Trolley line and substation maintenance:	0.86$/trolley-km

Trolley Assist Economics and Sensitivity

Based on the capital and operating costs presented earlier, an economic evaluation over the life of mine (LOM) was conducted by BBA. Figure 3 shows the costs and savings on operating and capital costs (OPEX and CAPEX) for a sample TA project.

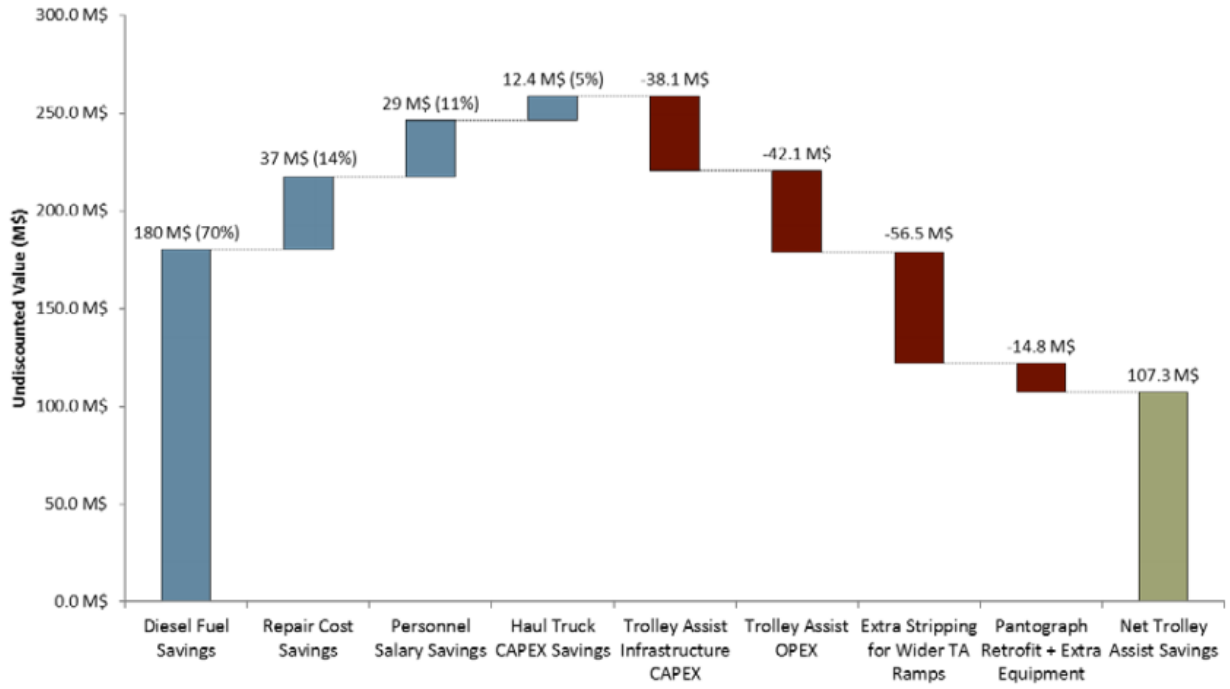

Figure 2: Example of estimated trolley assist savings over LOM

The following graph shows that the TA system economics are most sensitive to changes in fuel price, the utilization of the TA system and to a lesser extent the capital cost of the TA system. On the other hand, the electricity cost, TA pantograph cost and TA Opex costs have a less significant impact on NPV over the life of a project.

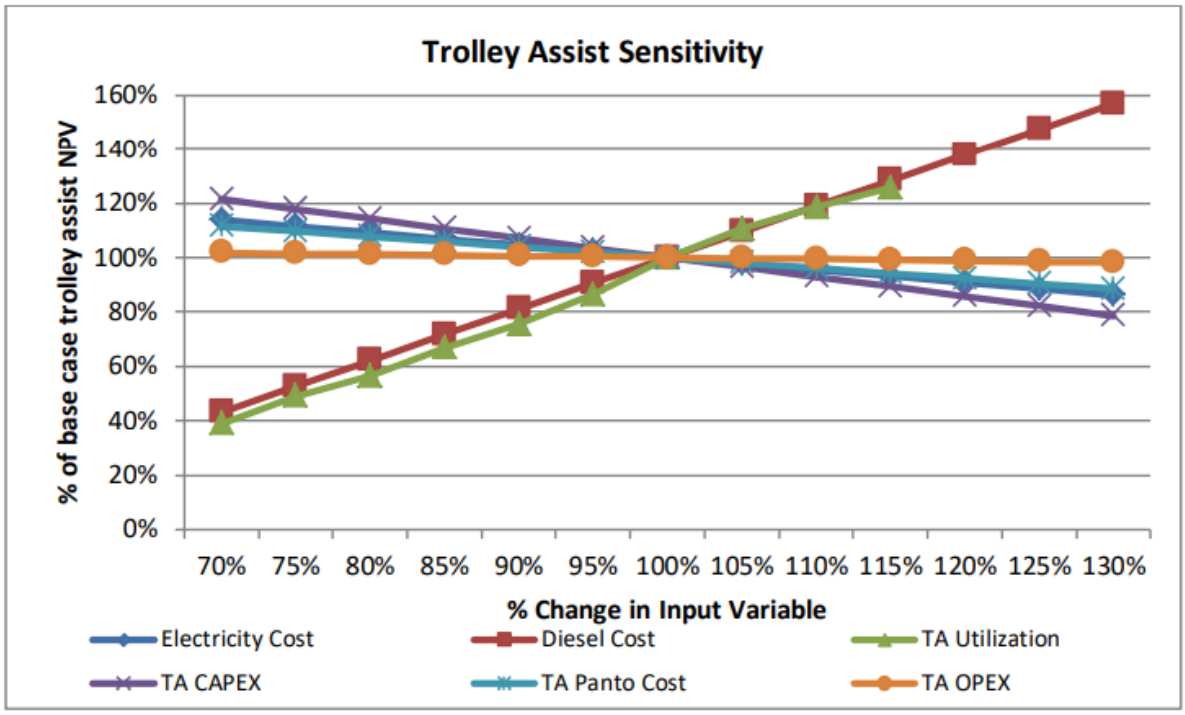

Figure 3: Example of sensitivity analysis on trolley assist

Discussion and Conclusions

The cost savings related to TA are primarily derived from:

- Increased haul truck productivity due to increased speed on uphill loaded segments (+10km/hr. on average);
- Decreased fuel consumption when hooked up to TA as the diesel engine is idling;
- Replacement of expensive diesel fuel with cheaper electrical energy sources on TA;dam operation.
- Reduced truck maintenance costs and anticipated reduction in truck engine operating costs per period due to a lower engine load factor;
- Reduced truck fleet requirements and corresponding lower manpower costs due to increased productivity per truck;

These cost savings are, however, partially offset by the costs associated with the installation, maintenance and proper use of the TA system:

Installation, relocation and removal of trolley overhead wires, supports and electrical infrastructure (DC substations, switches, AC lines, etc.);

- Maintenance and operating costs related to TA equipment (lines, pantographs, etc.)
- Installation of pantographs on each haul truck;
- Additional TA maintenance and engineering personnel;
- Increased haul truck ramp width and correspondingly higher open pit waste stripping.

BBA has completed multiple trade-off studies and TA scenarios for large open pit mining projects in Canada that have indicated that the installation of TA is cost-effective under current market conditions and that there is a small gain in the NPV of a project if the system is installed. However, while the implementation of a TA system would likely have a positive impact on overall project economics, the estimated economic benefits of such as system is of relatively small significance to a new or proposed operation. The implementation of a TA system also involves relatively important operational constraints and risks, and would add additional complexity to a fledgling operation. As such, it is

important to understand the trade-off between the potential risks and rewards of the system to the overall.

Most mine plans do not permit the installation of a trolley line until several years after the start of production as:

The mine becomes more stable and longer live ramp segments are developed.

- More opportunity exists to further study the impact of TA implementation following the start of production and allows for a better understanding of site characteristics when evaluating a TA system.
- A preliminary evaluation of the system would help avoid equipment compatibility issues later in the mine life.
- Once a commitment to TA is made, a continuous effort must be made to efficiently operate and maintain the system in order to meet production targets. Failures to use the system as budgeted can have a compound effect on the productivity and economics of a mine.

While the implementation of TA at a mining operation does present some interesting operational and environmental benefits, the decision to implement the system depends on multiple factors:

- The economics of TA are highly sensitive to the amenability of a mine plan to the installation of long lived trolley segments that will handle the maximum possible tonnage coming out of a pit.
- The potential of the TA system is sometimes limited when paired with vertically aggressive (high sinking rate), short lived mining phases and ramp systems and/or a short mine life. These conditions can limit both the installed length of the TA line(s) and the number of trolley tonne-kilometers that can be planned for each trolley line.
- The economics of TA are greatly influenced by changes in the price differential between diesel and electricity. As such, the economic valuation of TA is dependent on the longterm price assumptions used. Conversely, any increase in the differential between the price of diesel fuel and electrical energy would have a positive impact on the economic merits of a trolley system.

- It is not possible to calculate any economic gain from a reduction in emissions due to the installation of a TA system. However, this could represent an opportunity for companies to seek governmental incentives or subsidies to help develop a greener mining industry.
- The ultimate decision to implement TA in the future feasibility study or mining operation is dependent on a company's internal forecast and evaluation of future diesel fuel and electricity prices, environmental benefits related to TA and/or any governmental incentives related to the system.

As illustrated in Figure 4, historical trends support a much higher oil price inflation rate as compared to the rate associated with electrical power. If this trend continues going forward, it is foreseeable that the economics of TA will continue to improve as the fuel savings resulting from TA increase in value relative to the electrical energy costs required to move the trucks along trolley lines.

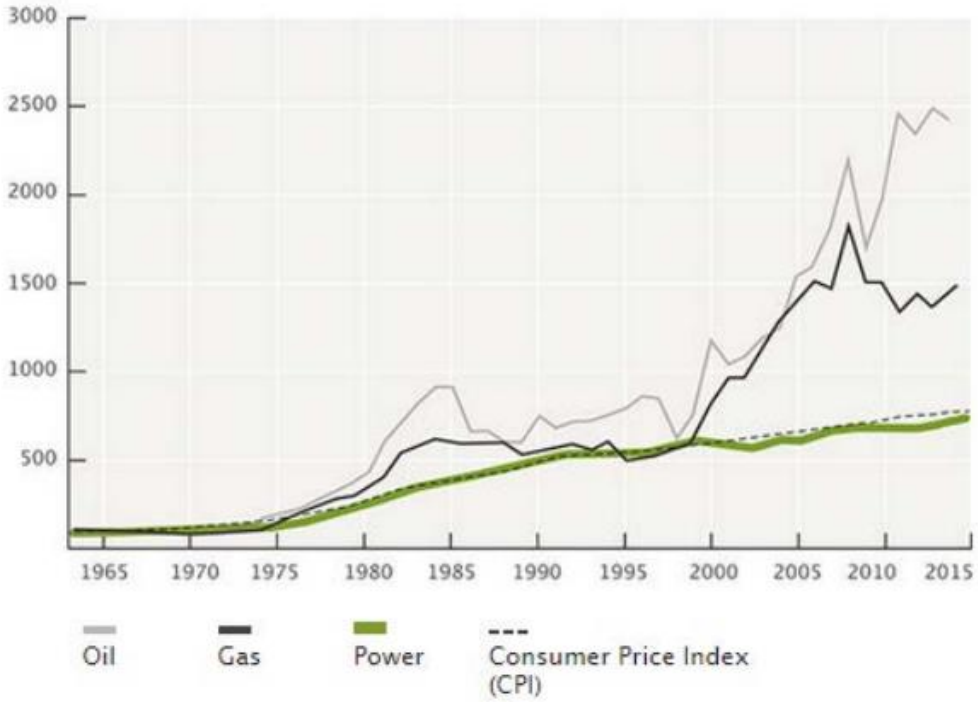

Figure 4 : Inflation and trend in energy prices in Quebec[1]

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References

HITACHI, Hooking up to the grid, 2010, http://hitachiconstruction.com

HUTNYAK, David, Trolley Assist, 2004, www.hutnyak.com

[1] HYDRO QUEBEC, Inflation and trend in energy prices in Quebec, 2015, http://www.hydroquebec.com

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Isabelle Leblanc holds the position of Department Manager of the Mining group and is actively involved in the training of junior engineers and trainees, as well as the auditing of projects. Ms. Leblanc joined BBA in 2007 as a junior engineer, after obtaining her Bachelor's degree in mining engineering. She studied at two different universities and has gained strong technical skills and considerable knowledge of the optimization software and the development of open pit mines.

Since starting at BBA, she has participated in many economic preliminary assessments, as well as PreFeasibility and Feasibility studies for gold, silver, copper, lithium and iron projects.

Her expertise covers a wide range of activities including pit optimization and design, mine planning, 'trade off' studies, equipment selection, Opex and Capex cost estimation, financial analysis and the preparation of NI 43-101-compliant reports. Ms. Leblanc also provides technical support to mine operations, specifically for equipment selection and long- to medium-range planning activities.

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