Energy consumption and GHG emissions at metal mines in Canada and the implications of Canadian climate change polices

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Masters of Applied Science (MASc) in Natural Resources Engineering

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THESIS DEFENCE COMMITTEE/COMITÉ DE SOUTENANCE DE THÈSE

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Title of Thesis Titre de la thèse	Energy consumption and GHG emissions at metal mines in Canada and the implications of Canadian climate change policies
Name of Candidate Nom du candidat	Smith, Connie
Degree Diplôme	Master of Science
Department/Program Département/Programme	MASc Natural Resources Engineering
Date of Defence Date de la soutenance	March 08, 2023

APPROVED/APPROUVÉ

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Abstract

The objectives of this research are to complete a review of energy consumption and greenhouse gas (GHG) emissions at metal mines in Canada, to understand the implication of Canadian climate change legislation for operations at these mines, and to assess practical actions mines can take to reduce their GHG emissions. The mining industry is an energy intensive but profitable industry that plays a critical role in the Canadian economy and the switch to a "green" economy. However, the reliance of the mining industry upon carbon rich fuels, the large and long term land use changes associated with mines sites, and the long life span of mining operations mean that the industry is an important contributor to climate change.

Keywords

energy management; energy audits; mining industry; energy reporting; energy benchmarking; GHG emissions; climate change; legislation; carbon tax; carbon incentives; GHG mitigation

Acknowledgement

Much gratitude goes to my supervisor, Professor Dean Millar. I truly appreciate the time, effort and expertise you shared. Thank you for this opportunity for personal growth. Similar appreciation goes to my supervisor at Natural Resources Canada, Doctor Michelle Levesque. I am grateful for the opportunity and support I have received to progress my career. Special thanks to Andrew Cooper at New Gold's New Afton Mine for providing me with the data and insights required to complete the energy audit of New Afton Mine. Also special thanks to my colleagues at CanmetMINING for your support and ice cream cake. Final thanks to my family and to my greatest friend, Grand Saluut.

Thank you,

Connie Smith

Table of Contents

List of Tables

List of Figures

List of Appendices

Nomenclature

Abbreviation	Term	Units
°C	degrees Celsius	
AC	alternating current	
BC	British Columbia	
BEV	battery-electric vehicle	
C	specific fuel consumption	kilograms per hour per engine horsepower
CAD	Canadian dollars	
CH_4	methane	
cm	centimeter	
CO_2	carbon dioxide	
CO_2e	carbon dioxide equivalent	
d	distance the truck was moved	metres
DC	direct current	
E	engine rating for the equipment	horsepower
f	conversion factor to convert kg force to newtons	newtons per kilogram force
FC	fuel consumed	litres
g	grams	
GDP	gross domestic product	
GGPPA	Greenhouse Gas Pollution Pricing Act	
GHG	greenhouse gas	
GJ	gigajoule	
GR	gross power rating of the truck provided by OEM	kilowatts
GWh	gigawatt hour	
GWP	global warming potential	
ha	hectare	
HP	horsepower	
hr	hour	
IPCC	in pit crusher and conveyor	
K	Kelvin	
kg	kilogram	
km	kilometre	
kt	kilotonnes	
$ktCO_2e$	kilotonnes of carbon dioxide equivalent	
kV	kilovolt	
kW	kilowatts	
kWh	kilowatt hour	
kWhe	kilowatt hour equivalents	
l	litres	
LF	load factor for engine	percent
LHD	load haul dump	
m	mass of truck	kilograms
m	metres	
m^3	metres cubed	
M CAD	million Canadian dollars	
MJ	megajoules	

Abbreviation	Term	Units
M l	million litres	
Mt	megatonnes or million tonnes	
$MtCO_2e$	megatonnes of carbon dioxide equivalent	
MW	megawatts	
N	number of trips to dump points	
n	engine efficiencies	percent
N_2O	nitrous oxide	
n.d.	no date	
OBPS	output-based pricing system	
OEM	original equipment manufacturers	
P	Power used by truck	kilowatts
R	fuel consumption rate	litres per hour
RR	total rolling resistance	percent
s	second	
S	specific fuel weight for diesel	kilograms per litre
SAG	semi-autogenous grinding	
T	traction effort	newtons
t	time spent on haul route	seconds or minutes
tCO_2e	tonnes of carbon dioxide equivalent	
TFC	total fuel consumed	litres
TJ	terajoules	
UNIPCC	United Nations' Intergovernmental Panel on Climate Change	
v	velocity of truck	metres per second
W	work to be done to move the truck	newton metres or joules
yr	year	

1 Introduction and outline

1.1 Motivation

Canada is not on track to meet climate change goals set by the federal government; most recently not meeting the Paris Agreement commitment for 2020 with emissions of 651 MtCO2e exceeding the target level of 638 MtCO2e for that year (Climate Action Tracker, 2021). It has been estimated that to lessen the impact of climate change, renewable energy must make up 60% of global energy use by 2030 and 77% by 2050 (Canadian Mining Journal, 2019). To meet global climate change goals, critical mineral supply chains need to be expanded ten fold by 2030 with hundreds of new critical mineral mines to be opened within this time frame and many in Canada (Lazenby, 2022).

However, the mining industry's reliance upon carbon rich fuels, the large and long term land use changes associated with mines sites, and the long life span of mining operations mean that the industry is an important contributor to climate change. Currently, the mining industry consumes roughly 50% of its energy in the form of electricity, which is partially renewable depending upon location, and the remainder from the direct consumption of fossil fuels (Canadian Energy and Emissions Data Centre, 2021). As global carbon emissions have significantly increased over the last century (US EPA, 2016), mining is experiencing economic, environmental, and societal pressures to evaluate their carbon footprint. Mineral development will need to occur in a cleaner, more sustainable way while meeting an increasing demand for those minerals necessary for the low carbon economy to function (Canadian Mining Journal, 2019; Government of Canada, 2018a). While the industry is working to reduce greenhouse gas (GHG) emissions, eliminating all the environmental impacts of mining is improbable given the timeframe (Canadian Mining Journal, 2019). This failure to meet emission targets suggests either a poor understanding of how emissions are produced by mines and/or ineffective climate change policies meant to guide large industry to reduce emissions.

1.2 Objective

The objectives of this research are to:

- Understand energy consumption at different types of metal mines in Canada,
- Understand GHG emission rates and profiles for those types of metal mines in Canada,
- Understand the climate change related regulatory landscape and its implication for the Canadian mining industry, and
- Identify the practicality of actions mines could take to reduce the GHG emissions from these mines.

To meet the objectives outlined above the following chapters are included in this thesis.

1.3 Thesis outline

Emissions from industry, including mining, are unlikely to decrease without sufficient political, societal, or financial reasoning to do so. Canadian climate change policies are political tools developed as a result of societal pressure; many work to reduce emissions through taxation of emissions or incentive funding of carbon reduction. Chapter 2 provides an overview of climate change, global climate change policies, and Canadian climate change goals established by the federal and provincial governments. This chapter is intended to provide context for carbon accounting analyses undertaken in later chapters that determine the impact of these policies upon operations at Canadian mines.

To understand the impacts of climate change policies upon the Canadian mining industry, it is necessary to understand how the industry consumes energy and what emissions are produced as a result. Chapter 3 provides a characterization of mining industry sector energy trends in Canada. This characterization includes a review of types of energy used and mine parameters impacting energy use by the mining sector. Using publicly available data, the energy consumption profile of the various metal mines sectors, including iron ore, gold and silver, and nickel and copper mines, in Canada is presented.

While a sector level review provides clarity around the scope of energy consumption and emission production by the mining industry in Canada, understanding how the mining method employed at a site (i.e., open pit versus underground mining or selective mining versus bulk mining) impacts energy consumption is necessary to understanding how emissions could be reduced at the site operations level. Chapter 4 provides an overview of energy use at Canadian mining operations including underground mines, surface mines, and block cave mines. Review of an energy audit completed for Garson Mine, an underground mine employing traditional mining methods, is presented. To improve understanding of energy consumption at surface mines, a case study involving Detour Lake Mine in Northern Ontario is presented. The focus of the case study is the main mining fleet including drills, shovels, trucks, dozers, etc. Diesel consumption was estimated using fuel consumption rates provided by the original equipment manufacturers (OEM) and assumed duty cycles. As the main haulage fleet consisting of CAT 795 trucks proved to be the major consumer of diesel, estimation of the energy consumption by the fleet was undertaken to validate the estimations produced using OEM provided fuel consumption rates. These alternative estimation methods were i) based on work required to move trucks and material over life of mine and an assumed engine efficiency, and ii) based on values for calculated work required to move trucks and material over the life of mine and a calculated load factor and OEM fuel consumption rates. The estimates of fuel consumed by the CAT 795 were used to assess GHG emissions in a later chapter.

Chapter 4 also presents a case study of energy use at New Afton Mine, an underground block cave mine in British Columbia (BC). The energy audit includes measured and estimated usage of all energy types consumed at the mine based upon measured data and is used to produce an energy consumption model of one of two block cave mines in Canada. This characterization will be used in the following chapter to determine carbon footprint.

Chapter 5 builds on the energy consumption estimates of the previous two chapters and provides an overview of direct and indirect sources of greenhouse gas emissions and carbon costs experienced by the Canadian mines that were subject of the preceding case studies. The characterization of GHG emissions includes the direct emissions from the main haulage fleet at Detour Lake Mine and direct and indirect emissions for energy consumption at

New Afton Mine. How the carbon taxation schemes experienced by mines in Canada vary based on location and resulting financial pressure to reduce emissions is reviewed using the two case study sites.

Canadian carbon policies are not limited to carbon taxation on fuel burned experienced by existing operations. Carbon accounting schemes are becoming increasingly wider in scope with new projects having to account for land use change emissions. Chapter 6 presents an estimation of greenhouse gas emissions from land use change at both Detour Lake Mine and New Afton Mine to understand the potential scope of these type of emissions. This includes emissions from vegetation removal and lost carbon sink potential from operations. Impacts of "like for like" rehabilitation and active remediation upon the estimated land use change emissions are investigated. Offsetting using habitat restoration projects undertaken by New Afton Mine are also discussed but framed around participation in various carbon incentive programs offered in BC.

Having gained a detailed understanding of how energy is consumed at the operational level by Canadian metal mines and how carbon policies apply in the preceding chapters, the intent of Chapter 7 is to review some viable alternatives the case study mines could employ to reduce their carbon footprints, carbon costs and increase carbon related revenue considering current climate change policy presented in Chapter 2. The chapter includes assessment of the following alternatives for the CAT 795 fleet at Detour: i) hydrogen fuel, ii) trolley assist system installation, and iii) an in-pit crusher and conveyor.

Similarly, Chapter 8 presents the alternatives considered for New Afton Mine which include replacing diesel haulage fleet with battery electric equivalents powered by a swapping battery strategy.

The final chapter presents a summary of the conclusions of the work around energy consumption and GHG estimations for metal mines in Canada. The chapter closes outlining future work to be undertaken to improve understanding around GHG emission reduction by the mining industry.

2 Climate change policy and effect on the mining industry

2.1 Introduction

Many countries are struggling to meet climate change goals and take effective action on climate change (Climate Action Tracker, 2021). To transition to cleaner technologies, mining of critical minerals must increase, but mining is an energy and emission intensive process (Lazenby, 2022). To tackle this dichotomy, many mining companies have begun to make commitments to reduce their carbon footprint and many have pledged to reach net zero GHG emissions by 2050 or sooner to be in line with global commitments (Canadian Mining Journal, 2021). To fully understand how mines in Canada can reduce their carbon emissions, it is essential to understand the strategies they can implement to move towards net zero mining and how these will be shaped by climate change policies and legislation.

The intent of this chapter is to provide an overview of global and Canadian climate change policies, from both federal and provincial Governments so that an appraisal of how they may impact the Canadian mining industry can be undertaken in later chapters.

2.2 Climate change

GHG are naturally occurring and contribute to the greenhouse effect in which the Earth's atmosphere acts like glass in a greenhouse trapping solar radiation. As the concentration of GHG increases in the atmosphere due to human activities, the ability for this radiation to leak back into space decreases resulting in global warming (Land Trust Alliance, 2021). Human activities, including the burning of fossil fuels, intensive agriculture, land clearing, among others, have been estimated to emit 11 billion of tonnes of GHG to the atmosphere per year (Land Trust Alliance, 2021). An increase of 2°C compared to pre-industrial global average temperatures is associated with serious negative impacts including an increased risk of dangerous and possibly catastrophic changes in the global environment (European Commission, 2019).

Figure 1 shows an increasing trend in historical GHG production by Canada. While Canadian GHG emissions are relatively small on a global scale, the impacts from global emissions are not restricted by geographical boundaries and the impacts from these are experienced in Canada (Government of Canada, 2021a). In an attempt to mitigate the impacts of these changes, Canada is participating in a number of climate change initiatives linked to global policies while implementing a number federal and provincial climate change strategies.

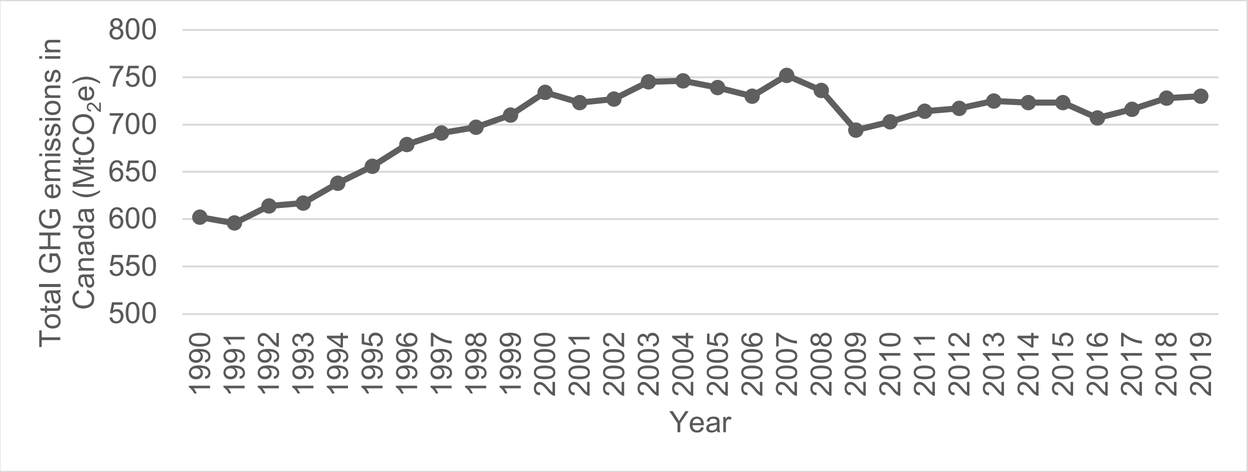

Figure 1. Historical GHG emissions by Canada (Government of Canada, 2021a)

2.3 Global climate change policy

Recent reports published by the UNIPCC recognized the need to keep warming well below 2°C and to pursue efforts to limit it to 1.5°C (Intergovernmental Panel on Climate Change, 2022). The UNIPCC indicated that to limit warming to this level by 2100 and avoid the worst impacts of climate change, the world would have to achieve net zero emissions by 2050 (Government of Canada, 2021b). Net zero does not mean reducing emissions to zero, but rather means maintaining a balance between GHG emissions produced and those removed from the atmosphere (Government of Canada, 2021b).

In 2016, the Paris Agreement was negotiated amongst 196 countries as part of the United Nations Framework Convention on Climate Change. The goal of this agreement is to limit global warming to between 1.5°C and 2°C through the reduction of GHG emissions (Government of Canada, 2021b). As part of this agreement, Canada is responsible for ratifying 1.95% of the total global GHG (United Nations, 2016).

2.4 Canadian climate change policy

To meet their commitments as part of the Paris Agreement, the Canadian government initially set a target to reduce GHG emissions to 30% below 2005 levels by 2030, with an additional goal of net zero emissions by 2050. A number of policies have been implemented in Canada to meet these goals and mitigate the effects of climate change.

2.4.1 Pan-Canadian Framework on Clean Growth and Climate Change

To achieve the goals of the Paris Agreement, Canada developed the Pan-Canadian Framework on Clean Growth and Climate Change. It relies on four pillars to meet a target of net zero emissions by 2050 including:

- Mandatory pricing on carbon pollution,
- Promote mitigation actions to reduce emissions,
- Promote adaptation and climate resilience, and
- Investment in clean technology, innovation and jobs (Government of Canada, 2016).

The strategy outlined in this Framework allows for Canadian provincial governments to set GHG emission reduction goals through provincial legislation; however, these goals and reduction initiatives must meet or exceed the minimum benchmarks for pricing carbon pollution established by the federal government and outlined in the federal Greenhouse Gas Pollution Pricing Act (GGPPA) (Government of Canada, 2016; Government of Canada, 2020a).

2.4.2 Greenhouse Gas Pollution Pricing Act

Mandatory carbon pricing came into effect in Canada in 2019 through adoption of the GGPPA that mandates that all Canadian provinces and territories must have a cap-and-trade system or a carbon tax in place. Otherwise, the federal pricing system applies in provinces that do not implement their own carbon tax or cap-and-trade system that meets the minimum federal pricing and emissions reduction standards (Osler, Hoskin & Harcourt LLP, 2021). The carbon pollution pricing legislations applied in Canada as of January 2022 are presented in Figure 2.

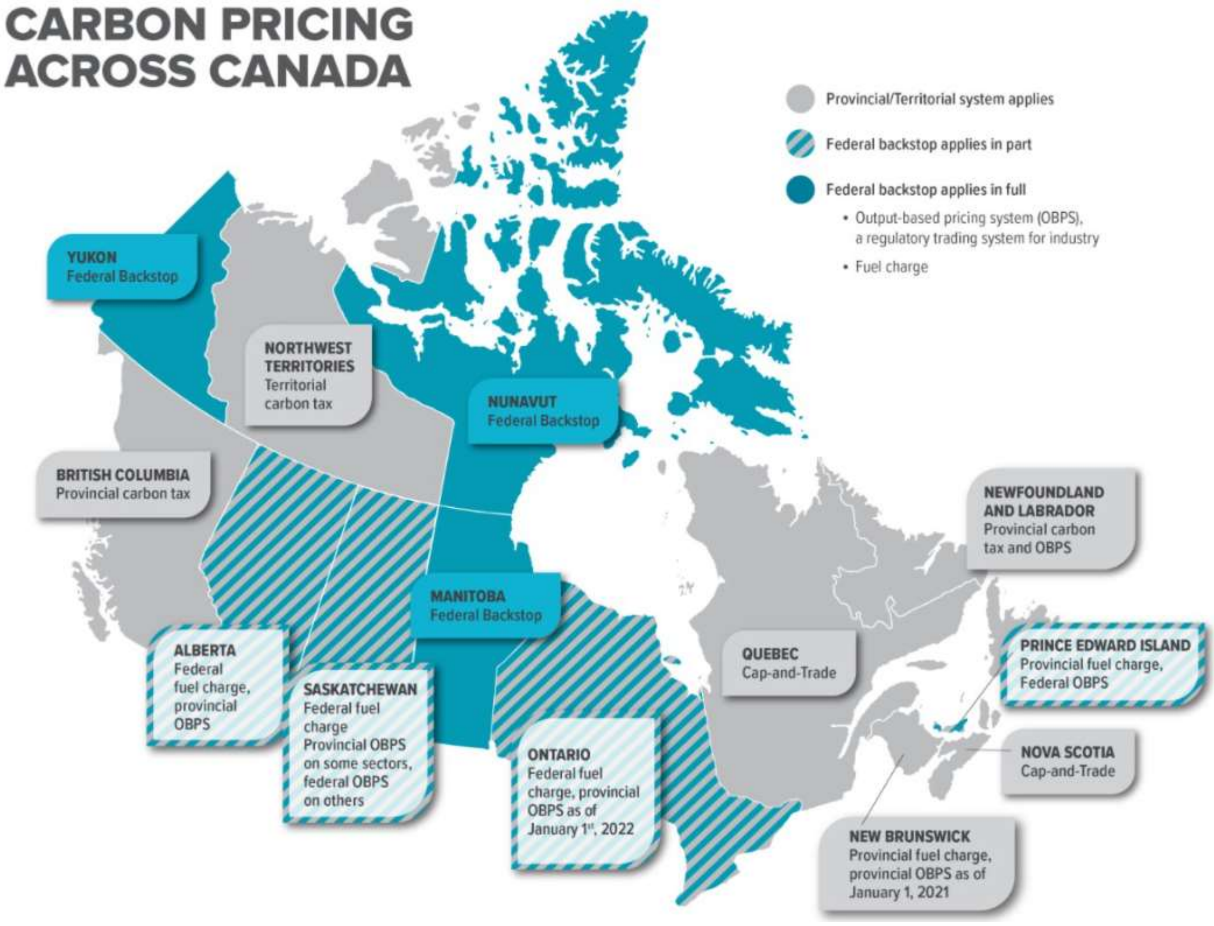

Figure 2. Carbon pollution pricing legislation in Canada (Government of Canada, 2022a)

At the time of writing, the federal GGPPA has two elements of direct relevance to this work that considers the mining industry:

- the fuel charge, which started at \$20 per tCO_2e in 2019 and increased by \$10 per year to \$50 per tCO_2e in 2022; and

- the output-based pricing system (OBPS), which requires industrial facilities to pay a carbon price if their annual reported emissions exceed 50,000 tCO_2e (Government of Canada, 2020a; Government of Canada, 2022b).

The fuel charge is applied to fuel producers and distributors who pay the tax directly to the Government of Canada. It is paid on fuels including gasoline, diesel (or "light fuel oil"), propane and natural gas among others, at a per volume rate defined in the Act that equates to the fuel charge for that year. For example in 2019, the fuel charge was $20 per tCO_2e which equated to charges of $0.0442 per litre for gasoline and $0.0537 per litre for diesel (or "light fuel oil") reflecting the carbon intensity of the various fuels. While the consumer will not pay the resulting fuel charges directly to the Government of Canada, they will likely be embedded in the fuel costs paid to their suppliers (Government of Canada, 2022b). Fuel producers and distributors pay the tax through a monthly reporting program (Kazaz et al., 2018).

The OBPS was developed as a distinct carbon pricing system for large industry that could experience a competitive risk if required to pay the federal fuel charge and to reduce the chance that these industries will invest in other locations with less stringent carbon taxation (Kazaz et al., 2018). It is intended to incentivize emission reduction efforts by large industry by applying a price per unit of carbon pollution on certain emission types if the facility reports emissions in excess of 50,000 tCO_2e in a year. A facility registered under the OBPS would generally not pay the charge on the fuels purchased as they would be subject to carbon pollution pricing on the portion of the emissions prescribed within the OBPS (Kazaz et al., 2018).

As stated, if the facility reports emissions in excess of 50,000 tCO_2e, the OBPS applies to their operations. These facilities are required to register with the federal government to remit payment should their actual emissions exceed an annual facility emissions limit also defined by the OBPS; this limit is defined separately from the 50,000 tCO_2e reported emissions limit that triggers application of the OBPS and is specific to each facility. The annual facility emissions limit is calculated using a unit based standard regulated within the OBPS and, for mines, annual production values (Government of Canada, 2021c). Mining industries that have applicable OBPS include coal, diamonds, iron, uranium, silver, platinum, palladium, base metals, and, of interest to this thesis, gold (Government of Canada, 2022b). For gold mines, the OBPS used to calculate the annual facility emissions limit has been established at 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2022b). Any eligible emissions in excess of this calculated limit are taxed as compliance obligations. Emission types that these standards are applied to include: stationary fuel consumption, industrial processes, venting, flaring, leakage, on-site transportation, waste, and wastewater (Government of Canada, 2022b).

Compliance obligations, or the amount of emissions the large emitter would pay a carbon pollution tax upon, are calculated by subtracting annual facility emissions limit described above from the total eligible emissions reported for the site annually. Emitters that produce more than their annual limit pay associated fees or apply earned or purchased credits. Emitters that emit less than their annual limit will earn credits that can be sold or used at a later time to cover excess emissions (Government of Canada, 2022b).

How the OBPS and fuel charges are applied to mines is discussed in more detail in Sections 2.6 and 2.7. It should be noted that, at the time of writing, the Government of Canada is proposing amendments to the GGPPA and OBPS that would impact carbon taxation for the mining industry. Firstly, amendments to the GGPPA would increase the yearly taxation rate increase from $10 to $15 per tCO_2e per year starting in 2023 meaning that the tax per tCO_2e would go from $65 in 2023 to $170 in 2030. Amendments to the OBPS would include a yearly declining or tightening rate of 1 to 2% applied to the production standards starting in 2023 with no end date and establish that a minimum of 25% of a facility’s compensation be made through payment versus surplus credits. Additionally, proposed amendments for metal and diamond mines would see the OBPS for these applied to operations that mine and mill the commodities rather than mine or mill as stated in the current regulations (Government of Canada, 2022b; Government of Canada, 2022c).

In addition to the policies discussed, the GGPPA also establishes a carbon offsetting program that allows for projects to be undertaken that for which the proponent can obtain offset credits for reduced or avoided carbon emissions or carbon capture (Government of Canada, 2020b). The policy around this program and what project are eligible is evolving at the time of writing but is discussed in more detail in Section 6.6.

2.4.3 Canadian Net-Zero Emissions Accountability Act

In 2019, it was noted by the federal government that Canada was not making enough progress to meet existing targets. With renewed focus, Canada committed to reducing its emissions between 40% to 45% below 2005 levels by 2030 (Climate Action Tracker, 2021). However, recent reporting (December 2020), suggests that Canada is on track to reduce emissions to 32% to 40% below 2005 by 2030 (Government of Canada, 2021b). Additionally, it has been estimated that Canada did not achieve its 2020 target with estimated emissions of 651 $MtCO_2e$ in 2020, exceeding the target level of 638 $MtCO_2e$ required to meet Paris Agreement commitments (Climate Action Tracker, 2021).

In 2021, the Canadian Net Zero Emissions Accountability Act was enacted which legislates Canada's commitment to net zero emissions by 2050 and associated 5 year targets to achieve this goal. It also formalizes the need for developing emissions reduction plans and additional reporting requirements (Climate Action Tracker, 2021; Government of Canada, 2021b). This Act was supported by recent revisions to the federal climate strategy *A Healthy Environment and A Healthy Economy* that contains policy to support funding for programs to promote emission reductions. However, it has been estimated that these measures are still not sufficient to meet the goals of the Paris Agreement as they would only lead to an emissions level in 2030 of 492 $MtCO_2e$ about 150 $MtCO_2e$ short of a 1.5°C compatible level (Climate Action Tracker, 2021).

2.4.4 Strategic Assessment of Climate Change

In 2019, the federal Impact Assessment Act came into force replacing previous versions of the environmental assessment legislation. One intention of enacting this legislation was to improve transparency and clarity of the impact assessment process (Government of Canada, 2020c). It also expanded the scope of effects to be considered during impact assessment of designated projects including, of interest to this thesis, the extent to which the effects of the designated project hinder or contribute to the Government of Canada's ability to meet its climate change targets (Government of Canada, 2020c). As new or expanding mining activity can be a designated project, it is important for the mining industry to be aware of their responsibilities for their projects undergoing this assessment.

According to the *Strategic Assessment of Climate Change* (Government of Canada, 2020c), its purpose is to quantify potential future GHG emissions from designated projects. Additionally, a plan is to be developed indicating how the proponent will achieve net zero by 2050 for those projects with a life span extending past 2050. When estimating the net GHG emissions for a project, estimates must include:

- Direct emissions or those generated within the scope of the project from fuel consumption (like diesel or gasoline), land use change, mobile and stationary equipment fuel combustion, emissions from the industrial process, and flaring, venting, and fugitive emissions, and
- Acquired energy GHG emissions or those associated with the generation of electricity, heat, steam or cooling; all purchased from a third party excluding.

These emissions are often referred to as Scope 1 and 2 emissions; greater detail on these can be found later in the thesis in Section 5.1. The following are counted to the negative as part of the quantification of net GHG emissions:

- CO_2 emissions that are captured and stored in a storage project,
- Any domestic GHG emissions that are avoided as a result of the project (e.g., replacing equipment with lower emitting versions) or those emissions removed as a result of mitigation measures employed by the proponent at the corporate level, and
- Offset credits including GHG emissions reduction or removals generated from work done by the proponent not as part of the permitting project with each credit representing one tCO_2e.

These quantifications will be completed for the whole project for new mines and only for the expansion activities for established projects that are considered designated projects. They will be based upon information required to be submitted as part of the detailed project description for the impact assessment process and could include: production capacities, project schedule, activities to be undertaken, and expected impacts (Government of Canada, 2019a). For those projects that require a mitigation plan to achieve net zero emissions by 2050, the plan must emphasize reduction of emissions at the source as early as possible in the project lifespan through the prioritization of the reduction of direct emissions and emissions from acquired energy, and the use of innovative technologies and best practices to mitigate emissions.

2.5 Provincial climate change policy

Given that one of the case studies discussed later in this thesis is located in British Columbia, climate related policy in this province is of particular interest and, for this reason, is discussed in some detail below. Ontario climate change policies were not included in this review even though the other case study site is located in that province. For the mine located in Ontario, the federal backstop legislation discussed in the preceding section is salient given that, at the time of writing, Ontario's *Greenhouse Gas Emissions Performance Standards* (an output based carbon taxation scheme similar to the OBPS) have been establish for gold mines at 7.21 tCO_2e per kg of gold produced; a value less stringent than the federal backstop value in the OBPS of 7.71 tCO_2e per kg of gold produced (Government of Ontario, 2021a).

In British Columbia, carbon pricing is mandated through a carbon tax only with no cap-and-trade system in effect. The British Columbia Carbon Tax was introduced in 2008; it taxes the purchase of fossil fuels (gasoline, diesel, natural gas, heating fuel, propane and coal), at a tax rate of $45 per tCO_2e as of April 1, 2021 with an increase to $50 per tCO_2e on April 1, 2022 (Government of British Columbia, n.d.).

Through this system, the carbon tax is applied across industrial and residential users alike (Harrison, 2019). This application, in addition to a lack of cap-and-trade system, was criticized as putting industrial sectors in the province, including the mining sector, at a competitive disadvantage to external competitors (Mansfield

Consulting Inc., 2020). In response, the CleanBC Program for Industry was implemented that directs an amount equal to the incremental carbon tax paid by industry above \$30 per tCO_2e into incentives for cleaner operations (Government of British Columbia, 2018). The program includes the CleanBC Industrial Fund that helps fund industries implementing emission reduction projects by investing a portion of carbon tax revenues to support development and capital expenses associated with those projects. Through this fund, provincial funding can be obtained for up to 90% of eligible costs to a \$25 million funding cap (Government of British Columbia, n.d.).

Relief from carbon taxation can also be obtained by industry in British Columbia through the purchase of offset credits. A ‘BC Offset Unit’ represents a tCO_2e that was either removed from or not released to the atmosphere as a result of direct, beyond business-as-usual, action by industry; these actions are verified by an accredited third party to ensure validity. Once an emission reduction project is undertaken by industry, the resulting eligible credits are purchased by the provincial government and tracked in an offset registry. These units can be purchased from the registry by other organizations that wish to meet emission targets and help finance incremental emission reductions and removals in the province (Government of British Columbia, n.d.). This policy is discussed in more detail in Section 6.7.

2.6 Carbon emission penalties according to the Greenhouse Gas Pollution Pricing Act for mines emitting more than 50,000 tCO_2e of emissions per year

Climate change policies being developed in Canada are intended to influence industry in two ways: i) by applying a penalty for carbon emissions and ii) by incentivizing de-carbonization of operations. The effectiveness of these policies will be considered as part of the case studies presented later in this thesis, but high-level implications are discussed here for context.

The GGPPA will act through the first mechanism. As discussed, mines reporting more than 50,000 tCO_2e of emissions per year may be required to pay fees based upon an OBPS that links allowable (i.e., not taxed) emissions to production. The unit based standards regulated within the OBPS were developed at a rate of 80 to 90% of the average of emissions intensity for industry that fit the criteria of the OBPS using emissions data from the federal Greenhouse Gas Reporting Program and industry provided production data (Government of Canada, 2022b). Figure 3 provides a generalized representation of the development of these unit based standards using gold mines as an example. For mining industries that have a unit based standard, the emission intensity was determined based upon reported emissions against production values for the commodity being mined.

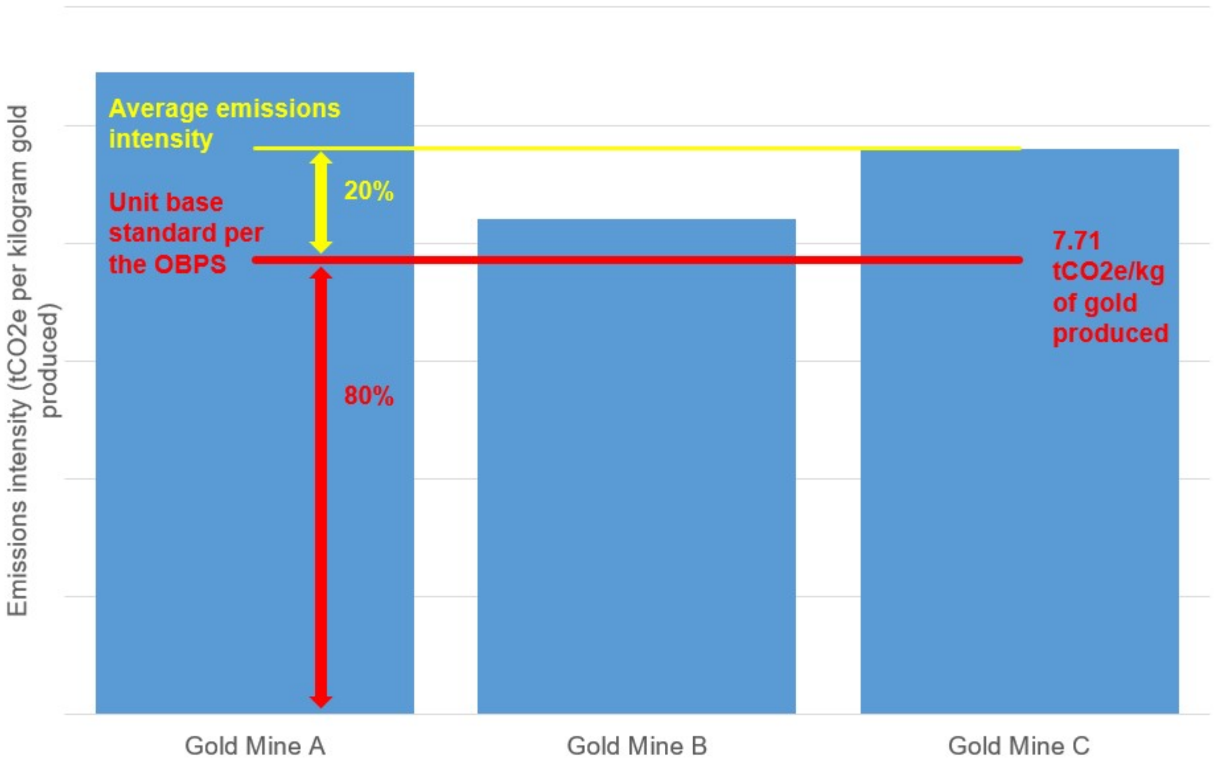

Figure 3. Development of output based standards for gold mines per the GGPPA (adapted from (Government of Canada, 2018b)

When reviewing the unit based standard for the production of gold and the associated reported emission rates in the Greenhouse Gas Reporting Program, only three gold mines of the 18 gold mines in Canada qualified for application of this standard due to emission levels in excess of 50,000 tCO_2e per year between the years 2014 and 2016 when the unit based standard was developed. These include Agnico Eagle's Meadowbank site, Kirkland Lake Gold's Detour Lake Project (the subject of a later case study in this thesis), and Canadian Malartic GP's Malartic Mine. All of these mines are large open pit mines located in remote areas in Canada with high production rates. Government of Canada staff confirmed that the unit based standard applied to qualifying gold mines was developed from data supplied by these sites (OBPS Operations Office, 2020).

Review of the most recent (2019) GHG reporting data available per the Greenhouse Gas Reporting Program shows seven gold mines exceeded the 50,000 tCO_2e of reported emissions trigger for the OBPS (Government of Canada, 2020d). These include the aforementioned three sites and New Gold's Rainy River Mine, Agnico Eagle's Meliadine Gold Project, Agnico Eagle's Hope Bay Project, and Newmont's Porcupine Gold Mines. As these mines are subject to the OBPS and yet also will pay a commercial distributor price for diesel, a rebate is applied on the price of diesel they are charged, the amount of which depends on the proportion of fuel charge contained with their distributors' prices

Table 1 provides a summary of mine type, reported emissions, and production values for these seven mines in 2019. Using these values, the compliance obligations for the mines to pay carbon pollution per the OBPS have been estimated. Not unexpectedly, the open pit operations report more emissions in general than the others. Also, those sites in the process of ramping up in 2019 (i.e., Rainy River) and ramping down (i.e., Meadowbank) had the greatest compliance obligations when considered against their reported emissions. This likely reflects lower production values suggesting that these sites could experience higher carbon taxation at times of already low cash flow.

As mines operate, their production profile (as defined by gold produced per the OBPS) may not exactly mirror their carbon emissions profile which relates to total tonnes mined. High production values can temper carbon compliance obligations (and carbon pollution taxation) making the relationship between actual emissions and the carbon tax paid by these sites covered by the OBPS indirect. High grade operations may experience lower compliance obligations while moving fewer tonnes than lower grade operations. This incentivizes mining out high grade reserves while making accessing lower grade ore less economically feasible with longer term implications to mine planning and resource classification. There may also be implications during ramp up and ramp down when profit from gold produced may be low compared to capital and operational expenses. While offset credits defined by the OBPS may be accrued during high production times to cover increased tax during ramping down, they would not be available for a typical operation during ramping up when operations may produce enough emissions to trigger compliance obligations per OBPS.

Table 1. GHG reporting emissions and OBPS compliance emissions for covered gold mines in 2019

Gold mine [1]	Mine type [2]	Reported GHG emissions (tCO_2e) [3]	Gold produced (kg)	Annual facility emissions limit prescribed by the OBPS (tCO_2e) [4]	Compliance obligations per OBPS (tCO_2e) [5]	Excess emission charges (M CAD) [6]	Compliance obligations as a portion of reported emissions [7]	Percent of reported emissions for all mines [8]	Percent of total compliance obligation emissions for all mines [9]
Detour Lake Project	Open pit	253,400	16,700	128,500	125,000	2.50	49%	25%	28%
Mine Canadian Malartic GP	Open pit	208,100	19,000	146,300	61,800	1.24	30%	21%	14%
Division Meadowbank	Open pit	186,400	6,000	45,800	140,600	2.81	75%	19%	31%
Rainy River Mine	Open pit	139,100	7,200	55,500	83,700	1.67	60%	14%	19%
Meliadine Gold Project	Hybrid	102,300	11,700	90,200	12,200	0.24	12%	10%	3%
Hope Bay Project	Hybrid	56,300	4,000	30,500	25,800	0.52	46%	6%	6%
Porcupine Gold Mines	Hybrid	51,400	6,400	48,800	2,700	0.05	5%	5%	1%
Totals		996,800	70,800	545,300	451,500	9.03	NA	100%	100%

1. Data on mines collected from Agnico Eagle, n.d.; Agnico Eagle, 2020a; Agnico Eagle, 2020b; Detour Gold Corporation, 2018; Government of Canada, 2020d; Hecht, 2020; and Mining Data Solutions, 2021a. All values in the table are rounded up to the nearest one hundred and any difference in calculated values are a result of this.
2. Hybrid refers to operations including surface and underground operations.
3. Reported for 2019 (Government of Canada, 2020d).
4. Calculated at 7.71 tCO_2e per kilogram of gold produced (Government of Canada, 2019b).
5. Calculated as reported emissions minus annual facility emissions limit prescribed by the OBPS (Government of Canada, 2019b).
6. At $20 per tonne in 2019 (Government of Canada, 2019b).
7. Compliance obligations per OBPS divided by reported emissions.
8. Reported emissions for the mine divided by a sum of reported emissions for all seven mines.
9. Compliance emissions for the mine divided by a sum of compliance emissions for all seven mines.

2.7 Fuel charges according to the Greenhouse Gas Pollution Pricing Act for mines emitting less than 50,000 tCO_2e of emissions per year

Unlike those gold mines included in the Section 2.6 above, mines emitting less than 50,000 tCO_2e per year do not trigger the OBPS. These facilities do not pay carbon tax directly to the Government of Canada in the form of compliance obligations. Instead, fuels sold to mines reporting less than 50,000 tCO_2e will be subject to the fuel charges outlined in the GGPPA that are applied directly to fuel consumed irrespective of production rates. As these mines will not pay the carbon tax directly, they will experience a price increase passed down by their fuel suppliers to cover the carbon tax that the supplier pays. The fuel prices will be increased by suppliers to cover the tax rates of \$20 per tCO_2e in 2019 increasing in \$10 per tCO_2e increments per year to up to \$50 per tCO_2e in 2022[1]. For perspective, this equates to a charge of \$0.1073 per litre of diesel (or "light fuel oil" per the GGPPA) in 2021 (Government of Canada, 2020a). When considering a mine currently paying \$0.80 per litre of diesel, this represents a potential increase in fuel cost of 13%. This carbon taxation will be experienced as increasing operational costs irrespective of production values by mines when they emit less than 50,000 tCO_2e per year.

As carbon rich fuels will increase in costs more than less carbon rich fuels, the fuel charge will pressure users to reduce consumption in general while possibly prioritizing the use of fuels with lower emission intensities. When considering the potential financial implications of such policies, it is increasingly important for mines to analyze potential mitigation scenarios for their carbon intensive activities.

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[1] At the time of writing, the Government of Canada is proposing amendments to the GGPPA that would increase the yearly taxation rate increase from \$10 to \$15 per tCO_2e per year starting in 2023 meaning that the tax per tCO_2e would go from \$65 in 2023 to \$170 in 2030.

2.8 Incentivizing de-carbonization for mines

Policies that incentivize de-carbonization do so through two mechanisms: i) prioritizing de-carbonization as part of the approvals process (e.g., the impact assessment process), and ii) providing a funding or revenue stream for work undertaken to reduce emissions.

At the federal level, through implementation of the *Strategic Assessment for Climate Change* as part of the Impact Assessment process, reduction and mitigation of carbon emissions are tied to the permitting process for new projects. Through this process, mines are encouraged to minimize their carbon footprint for all phases of their projects during feasibility and mine planning. Results of this minimization are presented during the impact assessment process for consultation and included in an effects assessment prior to any approvals or permits being issued. Going forward, it is possible that mines will consider more carbon-efficient operations into mine plans prior to breaking ground. Comparatively, if existing mines wish to reduce their carbon footprint they may have to expensively retrofit existing systems while concurrently balancing production goals.

Following the approval of such projects, GHG emission reporting requirements at both the federal and provincial/territorial levels ensure that projections made during the assessment process are validated and transparent. Conditions may be attached to project approvals to ensure reporting on the success of carbon mitigation measures with the respect to the net zero by 2050 goal (Wright, 2020). Beyond formalizing the link between production of a credible net zero plan to obtaining the permits and approvals required for a project, it is unclear what implications would result from a plan that was not implemented successfully.

Additionally, some government agencies are trying to facilitate the reduction of industrial carbon emissions by providing funding for projects that promote the retrofitting or optimization of existing systems. These programs can provide the capital funding needed to investigate and implement carbon efficient alternatives to existing processes. Additionally, programs that provide a source of continued revenue from carbon offsetting (i.e., revenue from emissions not produced by implementing a carbon efficient alternative or establishing a carbon reserve or sink) can be attractive if revenue is of significant value, offsetting projects are viable, and complement social license to operate initiatives for mining companies.

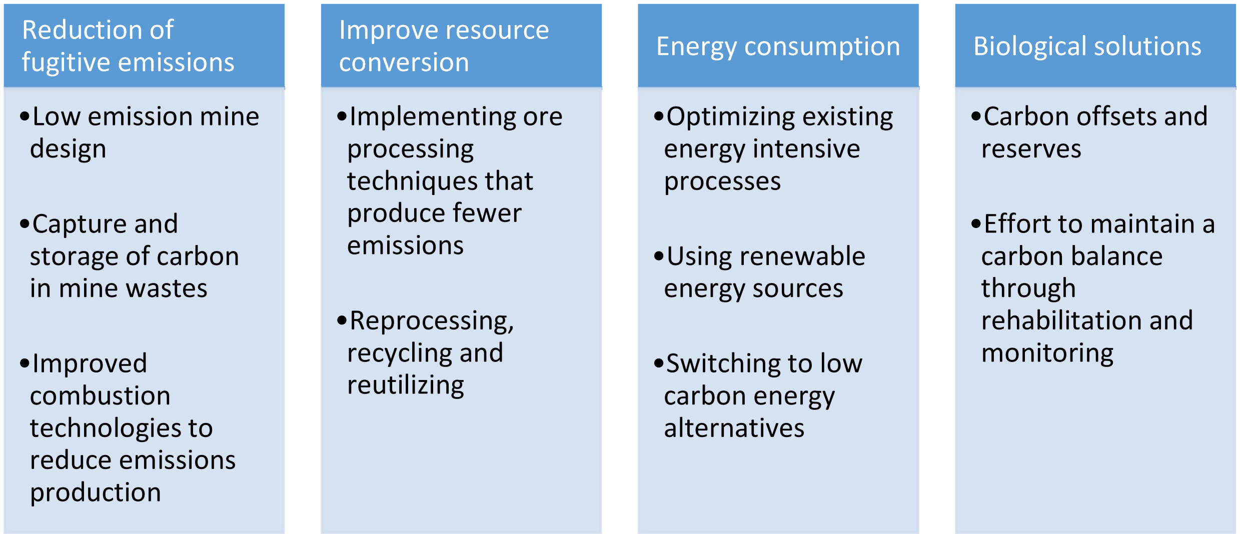
2.9 Strategies for mines to reduce GHG emissions in response to climate change policies

The Canadian federal government target of net-zero emissions by 2050 means there is an obvious need for all industry in Canada, including the mining industry, to reduce energy consumption. Carbon taxes that are intended to reduce carbon emissions through financial pressure will impact the industry. At the same time, there is increased demand for metals and minerals essential to develop clean technologies that will be necessary for transition to a greener economy, and increased demand for mining products generally, driven by fundamental economic development and growth.

However, there are challenges to decarbonization of the mining industry. As easily accessible, higher grade deposits are being exhausted, future mining will require going deeper, generally requiring more energy for recovery and, potentially, the excavation of more waste rock compared to ore. CO_2 emissions per tonne or ore, or per other unit mass of final product, will be tending to rise. In addition, demand for raw materials grows as population and economies grow meaning the amount of ore that needs to be mined and processed to meet this demand is increasing too (Azadi et al., 2020).

As this demand grows while climate change policy is evolving, miners will have to be aware and adaptable when planning and operating to maximize on demands for critical minerals and ease concerns of investors regarding financial risk associated with the need to meet changing net zero targets. Delevigne et al. (2020) suggests that investors will be increasingly concerned regarding decarbonization requirements. These investors are requiring that risk disclosures and strategies to reduce the carbon emissions be built into forecasts and feasibility reporting for mines. Such prioritization could eventually impact how reserves and resources are estimated. This financial pressure could prove to be an economic driver of change and carbon footprint reduction in addition to, or to a greater extent than, carbon taxation.

A number of strategies have been identified that could be implemented to reduce GHG emissions from industry generally which are presented in Figure 4 which is adapted from Azadi et al. (2020).



Reduction of fugitive emissions	Improve resource conversion	Energy consumption	Biological solutions
•Low emission mine design •Capture and storage of carbon in mine wastes •Improved combustion technologies to reduce emissions production	•Implementing ore processing techniques that produce fewer emissions •Reprocessing, recycling and reutilizing	•Optimizing existing energy intensive processes •Using renewable energy sources •Switching to low carbon energy alternatives	•Carbon offsets and reserves •Effort to maintain a carbon balance through rehabilitation and monitoring

Figure 4. Carbon reduction strategies that could be employed by mines (adapted from Azadi et al., 2020)

More specifically, strategies to reduce GHG emissions from mining projects include (US EPA, 2015):

- Improved energy efficiencies: improving mine infrastructure insulation, using more energy efficient mobile mining equipment,
- Energy conservation: reducing energy conservation through "on-demand" management systems such as ventilation, optimizing ore and waste haulage routes to reduce distance travelled,
- Fuel switching: adopting lower carbon energy sources through the use of new technologies such as battery electric mining vehicles or vehicles with hydrogen fuel cell powertrains,
- Carbon capture and sequestration: capturing carbon emissions from mine production processes and sequestering them within carbon sinks including underground spaces or within deposited mine wastes, and

- Changes in land use: minimization of new footprint with greenfield mine sites, incentives of rehabilitation of brownfield locations, active and progressive rehabilitation during mine operations.

Some of these strategies will be assessed through case studies in following chapters to determine effectiveness and practicality.

2.10 Chapter conclusions

As most supply chains are dependent to some extent on mined minerals, it is essential for the minerals industry to reduce carbon emissions for global climate change targets to be met (Kuykendall, 2020). The review of climate policies presented in this chapter highlights mechanisms meant to encourage adoption of carbon neutral processes into existing operations. While these are described as “the most comprehensive and aggressive climate policies that Canada has ever had”, Canada is not meeting global climate change commitments (Jones, 2023). This suggests that these policies are either insufficient, there is a basic misunderstanding of how these emissions are produced, or low carbon alternatives are not as effective as hoped. As energy usage is a significant operating cost and a contributor to GHG emissions from the mining industry in Canada, there are compelling economic and environmental reasons to have a better understanding of energy consumption at Canadian mines (Government of Canada, 2005a). To reduce emissions, mines will need to: i) understand their energy consumption profiles, ii) consider the emissions-friendly alternatives that exist, and iii) evaluate the financial and regulatory impact of carbon related legislation as it applies at their sites.

3 Mining industry sector energy trends

3.1 Introduction

Understanding energy consumption patterns typical of mining in Canada is essential to formulating methods to reduce energy use, operating costs, and GHG emission rates from mining; all of which will be essential to meet climate change goals for the industry and obtain approvals for future mines.

This chapter describes energy use by the metal mining industry in Canada at a consolidated sector wide level. It discusses types of energy used, factors affecting consumption, sector consumption trends over time, and how some of these things vary from Province to Province in Canada.

3.2 Types of energy used by the metal mining industry and parameters impacting consumption in Canada

3.2.1 Type and purpose of energy used

In very general terms, during mining, five types of energy are typically consumed:

- Electricity is used for processing ore, ventilation, hoisting, pumping, compressed air and drilling,
- Diesel is used to power medium and heavy duty equipment,
- Gasoline is used to fuel lighter duty equipment in surface mining,
- Natural gas and propane are typically used for heating, and
- Explosives are used during the excavation of waste and ore rock (Levesque, 2015).

Figure 5, which has been adapted from Katta et al. (2020) and Katta (2019), presents some detail on this usage and highlights the industry's reliance on electricity and diesel for many mine processes.

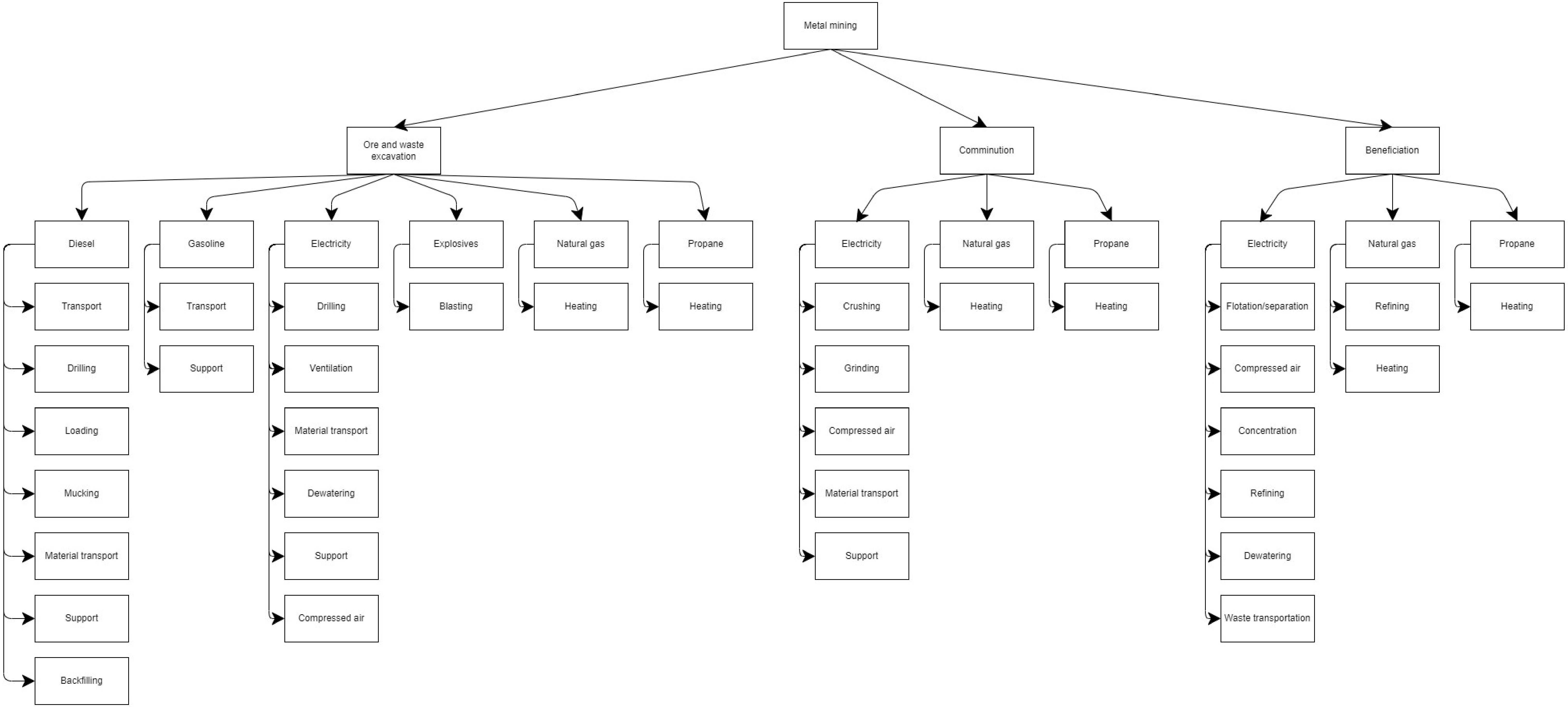


Figure 5. Energy use at metal mines in relation to mining activity and processes (adapted from Katta et al. (2020) and Katta (2019)

An alternative means of graphically denoting energy type and volume as well as end-use, or the cost center of end use, is a Sankey diagram. Figure 6 is from (Levesque, 2015) and depicts the energy consumption situation for Vale Canada's operations in Sudbury. The amount of energy is proportional to the width of the ribbon linking a source to a use. The ribbon colour denotes the energy type. Smelting and refining operations together present as "purification" in Figure 6. Multiple mines are represented in the mining end-use node.

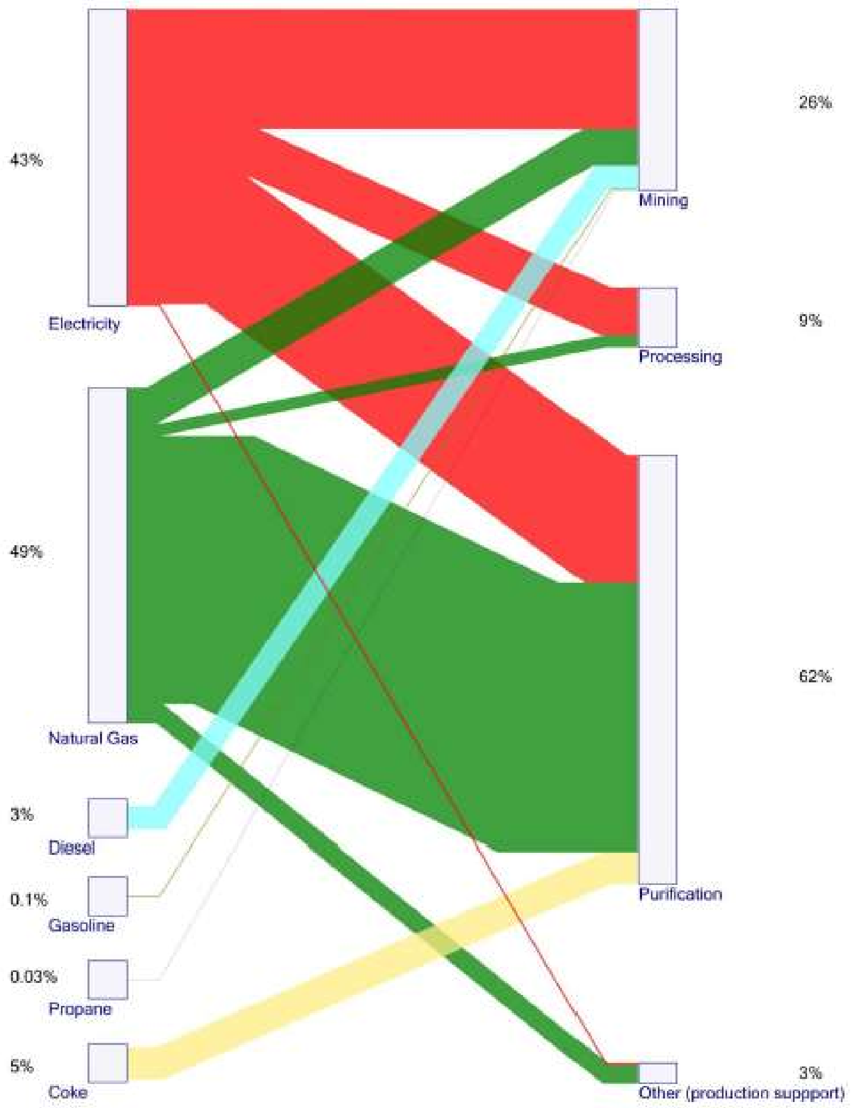


Figure 6. Sankey diagram illustrating the energy consumption of the mining process stages (Levesque, 2015)

For these operations, there is a heavy reliance upon electricity for mining and milling and natural gas for refining. This natural gas usage by Vale's furnaces highlights the energy intensity of, and the importance of carbon intensive energy sources to, the mineral processing purification stages of mining. However, energy consumption patterns will vary depending upon site and process specific parameters. For example, the smelting process can be fueled by other energy sources as demonstrated by the electrically powered furnaces operating at Glencore's Falconbridge Smelting facility also located in Sudbury, Ontario. A Sankey diagram for Glencore's operations in Sudbury would be 'redder' than Figure 6 because of the switch of energy type for their smelter.

3.2.2 Parameters impacting energy consumption

Rather than beneficiation, smelting or refining, this work aims to focus on the rock winning mining operations of mines, specifically. Many mines are also equipped with beneficiation facilities and so one of the first distinctions that must be made is a discrimination between energy consumed by rock winning and energy consumed in ore beneficiation.

Factors that help define energy use, that mines potentially have control over include: i) mine design (mining method) and plan, ii) material haulage and waste handling methods, iii) equipment selection and size of fleet, iv) beneficiation processes (if present), and v) fuel types consumed.

Mine operators do not have control over: i) the emissions intensity of the electrical grid that provides electricity to the site, ii) the mine location, iii) some energy costs, iv) orebody characteristics, and v) weather, all of which can have some bearing on energy expense. The impacts associated with the characteristics and mineralogy of the orebody and the remoteness and climate of where the mine is situated are presented in greater detail in Table 2.

By making switches of energy type used to execute specific mine processes, energy consumption and associated emissions can be reduced and, if these switches align with Government policy, will permit mine operators to access financial incentives (Friedman, 2021).

Table 2. Impact of mine characteristics upon energy consumption adapted from (Levesque, 2015)

Mine characteristic	Effect on energy consumption	Mining processes impacted
Orebody mineralogy and characteristics	Harder or denser ore will require more energy to process	Drilling, blasting, material transport, crushing, grinding
	Deeper and more dispersed orebodies will require more energy to access	Transport, material transport, support, ventilation, waste transport, dewatering, heating, mucking
	Lower grade ore will require more material to be excavated, transported and processed	Material transport, waste transport, crushing, grinding, drilling, blasting, compressed air, dewatering, ventilation, heating, mucking
	Host rock characteristics may require additional support and more detailing mine planning	Support, transport, material transport, ventilation, dewatering
	Smaller minerals require more processing to liberate	Crushing, grinding, floatation/separation, concentrating, refining, heating, waste transport
	Mineralogy affects the amount of energy required to process; harder minerals need more energy to be liberated	Crushing, grinding, floatation/separation, concentrating, refining, heating, waste transport
Mine location	Remote locations will require more energy to develop the site	Transport, material transport, support, heating
	Remote locations will require additional energy to be spent moving material and staff to and from site	Transport, material transport, waste transport, support, heating
	Remote locations may have limited access to less carbon intensive energy sources resulting in reliance on diesel, etc.	Transport, material transport, support, heating
	Locations in wet landscapes or areas with high ground water tables will result in more energy to be spent in water management	Transport, material transport, support, dewatering, heating
	Locations with limited waste management options will require waste to be deposited in ways that require energy intensive management (e.g., constructing lifts in tailings dams)	Waste transport, dewatering, material transport, transport

Mine characteristic	Effect on energy consumption	Mining processes impacted
	Mines located in more extreme climate zones will require energy to be spent heating, cooling, and as part of environmental management	Heating, dewatering, support

3.3 Energy usage by metal ore mines in Canada

The following includes a summary of energy consumption, emissions, and production values for metal ore mines in Canada that is publicly available through Canadian Energy and Emissions Data Centre (2021) and Government of Canada (2020e, 2020f, and 2020g) (the first which references the latter's data). Data for metal ore mines in Canada is presented below in an aggregated manner to provide an impression of overall industry consumption and disaggregated into i) gold and silver ore mines, ii) copper, nickel, lead and zinc ore mines, iii) iron ore mines, and iv) 'other metal ore mines'. Commodities grouped into 'other metal ore mines' include uranium-radium-vanadium ores, molybdenum ores, antimony ores, columbium ores, illmenite ores, magnesium ores, tantalum ores and tungsten ores. The energy consumption data presented is for the mining and beneficiation of these ores to concentrates and excludes any smelting or refining.

3.3.1 Energy consumption, production values and energy intensity of metal ore mining in Canada

In 2018, the latest complete statistical year at the time of writing, metal ore mines in Canada consumed approximately 33,792 gigawatt hours (GWh) of energy to produce 354,920 kilotonnes (kt) of milled ore while reporting emissions of 4,717 kt of carbon dioxide equivalent (ktCO$_2$e) resulting in an energy intensity of 95.2 kWh/t milled ore and production emissions intensity of 0.013 tonnes of carbon dioxide equivalent per tonne (tCO$_2$e/t) milled (Canadian Energy and Emissions Data Centre, 2021). It is important to note that these figures, although normalized by milled tonnes, nevertheless include energy consumed in waste handling and tailings management at mine sites. Overburden or stripping ratios significantly varying from the average implied in these sector wide figures, could mean that the values for individual mines could vary greatly. For the sector as a whole, the emissions intensity by energy type, and corresponding emissions are presented in Table 3 (Canadian Energy and Emissions Data Centre, 2021; Government of Canada, 2020e; and Government of Canada, 2020g).

Table 3. Energy use by energy type for metal ore mines in Canada in 2018 (Canadian Energy and Emissions Data Centre, 2021; Government of Canada, 2020e; and Government of Canada, 2020g)

Energy type	Amount used in 2018 (GWh)	Percent of total usage (%)	Emissions intensity ($ktCO_2e$ /GWh)	Emissions ($ktCO_2e$)[1]	Percent of total emissions (%)
Electricity	17,000	49.5%	0	0	0
Diesel	10,000	30.2%	0.26	2,700	57%
Coke	2,600	7.7%	0.40	1,000	22%
Heavy Fuel Oil	1,700	5.0%	0.27	500	9.7%
Natural Gas	1,100	3.3%	0.18	200	4.2%
Propane	1,100	3.2%	0.22	240	5.1%
Gasoline	280	0.8%	0.24	69	1.5%
Middle Distillates	58	0.2%	0.26	15	0.3%
Total	33,795	100%	0.14	4,717	100%

1. The sourced data considers electricity a carbon neutral source resulting in zero direct emissions from the metal ore mines and zero values in this table. Later in this thesis, emissions produced from the production of electricity via provincial and territorial grids as a result of the electricity consumed by mines is discussed (Sections 4.4 and 5.3).

The data sourced through the references for Table 3 considered electricity a carbon neutral energy source for mines if sourced from a provincial or territorial grid. Those emissions were taken to be *indirect* and hence ‘to belong to’ the producer of the electricity, rather than the consumer of the electricity at the mine site. This is the reason why the emissions amounts for electricity in Table 3 are nil. Such nuances become important when reviewing published data and can make reconciliation difficult between independent data sets purporting to report on the same topic matter.

The values for metal ore mines presented in Table 3 represent 3.6% of the total energy consumption by all industry in Canada in 2018 while producing 3.7% of total industrial GHG emissions for the same time period (Canadian Energy and Emissions Data Centre, 2021).

Energy consumption, production values, and emissions by the four metal mine sub-sectors in Canada between 2000 and 2018 are presented in Table 4. Calculated energy and emission intensities in relation to milled tonnes are also presented with the caveat that energy was also consumed to handle waste materials; as no data was available regarding the amount of waste handled, normalizing to total tonnes moved was not possible. More recent data was not included as various referenced data sets were not complete past 2018 at the time of writing.

To help assess the energy required to mine the ore from the data presented in Table 4, the energy and emission intensities for the various metal ore mines are also presented as graphs in Figure 7 below. Production rates represented as annual milled tonnes of ore vary widely between industries: iron and copper, nickel, lead and zinc mines mill the most tonnes on average and 'other metal mines' mill the least. Energy consumption mirrors these production trends but it is unclear what impact waste mining or handling has upon these energy consumption values as such data was not available. Additionally, ore grades corresponding to the production rates as annual milled tonnes were not available for these industry-level statistics. However, all mines types show an increasing trend in production with the exception of 'other metal ore mines' that present a decreasing trend. Not unexpectedly, production rates reflect commodity pricing. For most commodities considered, higher prices were observed in 2006 to 2013 with some metals experiencing a price drop in 2008 to 2009. During these time periods, there are corresponding increases and decreases in energy consumption and mining rates as production rates were likely increased to take advantage of higher prices (Levesque, 2015). The exceptions are commodities like uranium and molybdenum (included in 'other metal ore mining') whose prices and production values have been low or in decline since 2008 and likely related to international policies on nuclear energy production (Singh, 2018).

When considering energy and emission intensities in relation to production represented by milled tonnes presented in Figure 7, 'other metal ore mines' prove to have the highest and most variable energy and emission intensities with copper, nickel, lead and zinc mines the lowest and most consistent. Both intensities for iron ore mines are decreasing from high emission intensities noted prior to 2010. This may reflect effort by these mines effort to reduce reliance upon heavy fuel oils and coal for energy (Tigue, 2020). Intensities for gold and silver mines increase most notably between 2010 and 2013. As mentioned by Levesque (2015), this could correspond to increasing effort to mine existing works (i.e., increased haul distances) especially during high prices experienced during 2011 to 2013 which may have resulted in producers altering mine plans to optimize quick extraction resulting is less efficient mining when prices declined. However, without corresponding information on ore grades, haul distances, mine depths, etc. it is difficult to make conclusions from this aggregated data.

Table 4. Energy, production, emissions data and intensities of the various types of metal mines in Canada from 2000 to 2018 (Canadian Energy and Emissions Data Centre, 2021)

	Iron ore					Gold and silver					Copper, lead, nickel and zinc					‘Other metal ore’				
Year	Energy consumed (GWh)	Tonnes milled (kt)	Emissions (ktCO$_2$e)	Energy intensity (kWh/t milled)	Emissions intensity (tCO$_2$e/t milled)	Energy consumed (GWh)	Tonnes milled (kt)	Emissions (ktCO$_2$e)	Energy intensity (kWh/t milled)	Emissions intensity (tCO$_2$e/t milled)	Energy consumed (GWh)	Tonnes milled (kt)	Emissions (ktCO$_2$e)	Energy intensity (kWh/t milled)	Emissions intensity (tCO$_2$e/t milled)	Energy consumed (GWh)	Tonnes milled (kt)	Emissions (ktCO$_2$e)	Energy intensity (kWh/t milled)	Emissions intensity (tCO$_2$e/t milled)
2000	11,000	94,000	2,400	120	0.025	4,000	41,200	360	90	0.009	6,000	97,900	670	70	0.007	1,000	12,000	200	120	0.017
2001	9,000	75,000	2,000	120	0.027	4,000	41,400	390	90	0.009	7,000	94,400	720	70	0.008	2,000	13,900	300	170	0.021
2002	9,000	75,000	2,000	120	0.027	4,000	41,700	390	100	0.009	6,000	87,600	650	70	0.007	3,000	16,800	280	170	0.017
2003	11,000	86,000	2,400	130	0.028	4,000	42,800	370	90	0.009	6,000	83,100	580	70	0.007	2,000	20,000	240	100	0.012
2004	10,000	79,000	2,100	120	0.027	4,000	41,800	350	90	0.008	6,000	87,400	610	70	0.007	2,000	19,300	200	90	0.011
2005	11,000	86,000	2,400	120	0.028	4,000	40,500	330	90	0.008	7,000	101,300	750	70	0.007	2,000	19,400	220	90	0.012
2006	10,000	92,000	2,600	110	0.028	3,000	41,100	300	90	0.007	6,000	94,400	690	70	0.007	2,000	19,600	260	100	0.013
2007	10,000	84,000	2,500	120	0.030	4,000	39,600	320	90	0.008	7,000	90,300	780	80	0.009	2,000	20,300	260	100	0.013
2008	12,000	94,000	2,800	130	0.030	4,000	38,200	310	100	0.008	8,000	95,000	910	80	0.010	2,000	17,300	290	120	0.017
2009	10,000	84,000	2,200	120	0.027	4,000	41,700	260	90	0.006	6,000	85,700	730	70	0.009	2,000	12,600	240	130	0.019
2010	12,000	102,000	2,600	110	0.025	4,000	43,100	410	90	0.009	7,000	88,300	830	80	0.009	2,000	13,500	220	120	0.016
2011	11,000	103,000	2,500	110	0.024	5,000	34,700	500	130	0.014	7,000	96,300	900	80	0.009	2,000	15,400	260	120	0.017
2012	12,000	113,000	2,500	110	0.022	5,000	37,800	580	140	0.015	8,000	110,700	1,030	80	0.009	2,000	20,100	270	100	0.013
2013	11,000	125,000	2,300	90	0.018	7,000	55,100	760	120	0.014	9,000	109,300	1,080	80	0.010	2,000	20,800	280	100	0.013
2014	11,000	126,000	2,100	90	0.016	7,000	64,300	890	120	0.014	9,000	124,400	1,120	70	0.009	3,000	23,500	340	110	0.014
2015	11,000	120,000	2,200	90	0.018	7,000	68,000	880	110	0.013	9,000	129,900	1,110	70	0.009	2,000	5,200	270	370	0.051
2016	11,000	118,000	2,200	90	0.019	8,000	69,100	870	110	0.013	10,000	158,500	1,130	60	0.007	2,000	4,700	190	340	0.041
2017	11,000	121,000	2,200	90	0.018	8,000	72,100	1,010	120	0.014	10,000	156,000	1,160	70	0.007	2,000	5,800	190	270	0.033
2018	13,000	145,000	2,200	90	0.015	9,000	83,300	1,200	110	0.014	10,000	121,600	1,220	80	0.010	1,000	5,500	150	240	0.028
Average	11,000	101,000	2,300	110	0.024	5,000	49,300	550	100	0.011	8,000	105,900	880	70	0.008	2,000	15,000	250	160	0.02

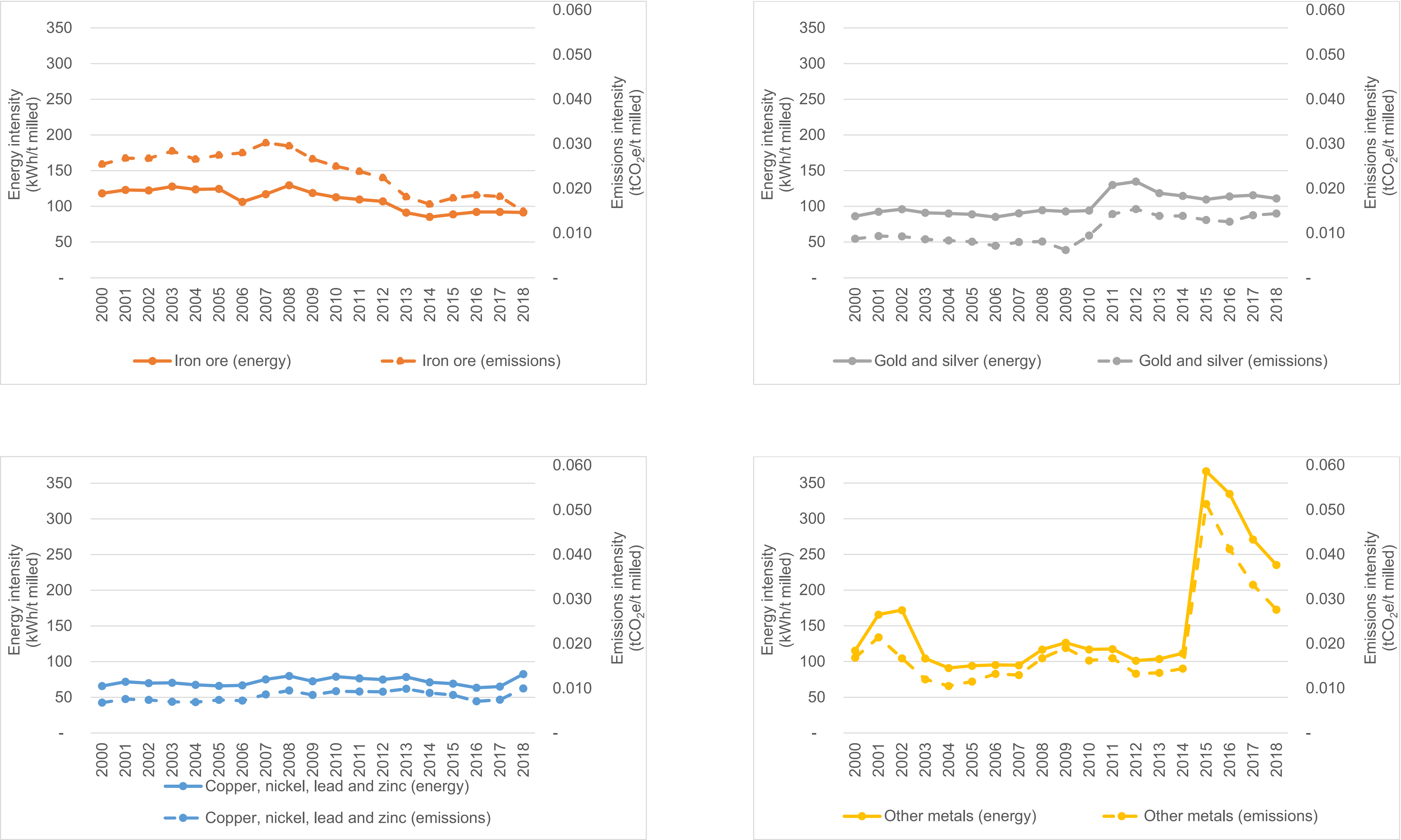


Figure 7. Energy and emission intensities in relation to production for the various metal mines in Canada between 2000 and 2018 (Canadian Energy and Emissions Data Centre, 2021)

3.3.2 Energy consumption by energy type for metal ore mines in Canada

Figure 8 details the different types of energy that were consumed by the various metal ore mine types in Canada in from 2000 to 2018. They were presented in (Levesque, 2015) and have been updated with additional data (Canadian Energy and Emissions Data Centre, 2021). To provide context about the emissions values and how they are impacted by energy type consumed, the GHG emissions for the mines have also been presented.

The values presented demonstrate the mining industry’s reliance upon electricity and fossil fuels to provide its energy needs. Reliance upon coke and heavy fuel oils are decreasing potentially being replaced by increasing consumption of electricity and diesel (Tigue, 2020) which corresponds to the decreasing and stable intensities of the iron ore and copper, nickel, lead, and zinc industries presented in Figure 7. Of particular note are the yearly values regarding diesel, light fuel and kerosene usage presented in Figure 8 with some mine types (gold and silver) obtaining up to 42% of their energy needs from these fuels in 2018. Due to diesel’s high emissions intensity, it correspondingly constitutes to 58% of total emissions by these mines (Canadian Energy and Emissions Data Centre, 2021). As indicated in Levesque (2015), these fuels are associated with haulage and ventilating underground workings, this could suggest an increased haulage effort by the mines (particularly the gold and silver mines), but without information on mines depths and haulage distances, this is not confirmed.

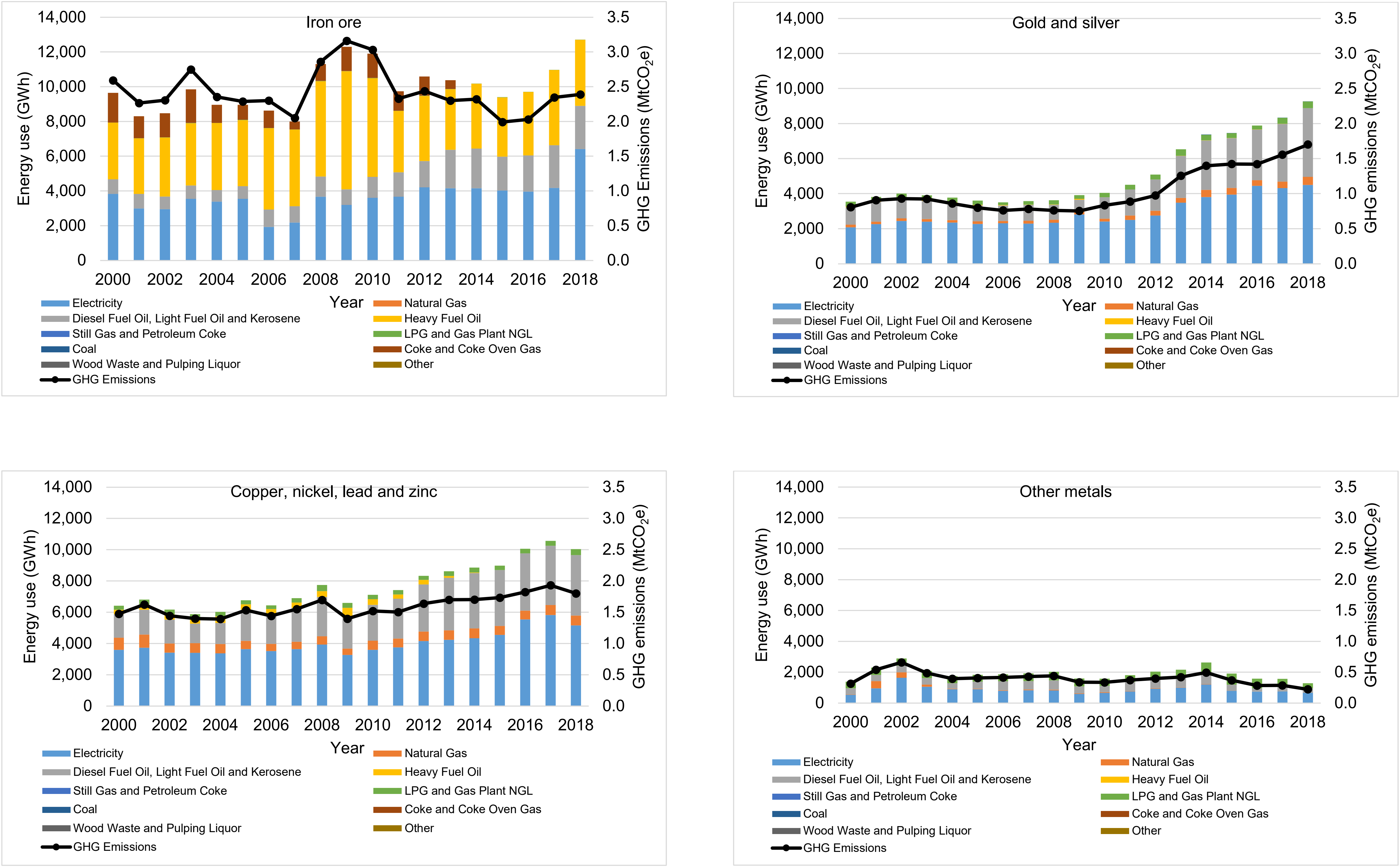


Figure 8. Energy use by type and emission for the various metal mines in Canada between 2000 and 2018 (Canadian Energy and Emissions Data Centre, 2021)

3.3.3 Energy consumption considering commodity mined and location

The province or territory a mine is located within will impact its carbon footprint as the carbon intensity of energy supplied varies based on location. To garner a better understanding of the impact of location, a review of the mineral statistics of operating mines in 2017 was completed. The year 2017 was selected because, at the time of writing, data for that year was most complete allowing for a review of how energy consumption was impacted by mine commodity and geographical location. During the time period under consideration, there were 63 metal mines operating in Canada; a breakdown of their location is presented in Table 5.

Table 5. Metal mines in Canada in 2017 by commodity and province or territory (Canadian Energy and Emissions Data Centre, 2021; Government of Canada, 2020e)

Province or territory	Number of mines	Iron ore mining	Gold and silver ore mining	Copper, nickel, lead and zinc ore mining [1]	Other metal ore mining
Newfoundland and Labrador	5	2	1	2	
New Brunswick	1			1	
Quebec	20	1	12	4	3
Ontario	18		13	4	1
Manitoba	4		1	2	1
Saskatchewan	5		1		4
British Columbia	7			7	
Yukon	1				
Nunavut	2	1	1	1	
Total	63	4	29	21	9

1. Includes 13 copper-zinc ore mines, 7 nickel-copper ore mine, and 1 lead-zinc ore mine.

In 2017, these mines produced 355 million tonnes of milled ore while using 31,440 GWh of energy or 88.6 megawatt hour per kilotonne (MWh/kt) of ore milled; this represents 3.2% of energy used by all industry in Canada during the same time period (Canadian Energy and Emissions Data Centre, 2021; Government of Canada, 2020f). The same data set indicates that the mining industry emits 6.1 $MtCO_2e$ including electricity related emissions (or 3.4% of total Canadian industrial emissions) or 4.2 $MtCO_2e$ excluding electricity related emissions (or 2.7% of total Canadian industrial emissions) (Government of Canada, 2020f). A breakdown of total and average energy consumption, energy costs, GHG emissions and value by mine sector in 2017 is presented in Table 6 which suggests:

- Iron ore mines in Canada are large, productive mines that consume large amounts of energy while emitting corresponding amounts of GHG, but are showing improved energy and emissions intensity over time comparatively when considering milled tonnes produced,
- Individual gold and silver mines are much smaller operations with smaller energy consumption and GHG emission rates, but the gold and silver mining industry is showing increased energy and emissions intensities suggesting that mining of these ores is requiring increasing effort,
- Individual copper, nickel, lead and zinc mines in Canada are comparatively mid-sized operations in respect to energy cost and profitability with consistent energy and emission intensities, and
- ‘Other metal ore mines’ are small operations but declining production is making mining of these ores increasingly energy and emissions intensive.

To investigate the impact of location upon energy consumption, the same data referenced in Table 6 was considered by province or territory where available. In Figure 9, energy consumption by energy type for metal ore mines in the various provinces in Canada is presented on the left and corresponding emissions from the consumption of this energy is presented on the right; both were adapted from Levesque and Acuña (2021). It should be noted that no data was reported for mines in the Northwest Territories or the Yukon although three mines were reported as being located in these territories in 2017. Also, the source data was not disaggregated to mine type by province.

Table 6. Energy consumption by mine type for metal ore mines in Canada in 2017 (Government of Canada, 2020e), (Canadian Energy and Emissions Data Centre, 2021).

Mine sector	Total energy consumed (GWh) [1]	Average energy consumption by mine (GWh) [2]	Total energy costs (M CAD) [3]	Average energy cost by mine (M CAD) [4]	Total GHG emissions (ktCO_2e) [5]	Average GHG emissions by mine (ktCO_2e) [6]	Total gross domestic product (M CAD) [5]	Average gross domestic product by mine (M CAD) [6]	Total ore milled (kt) [5]	Average ore milled by mine (kt) [6]
Iron ore mining	8,600	2,100	389	97	2,200	550	5,420	1,355	21,000	30,000
Gold and silver ore mining	8,300	300	506	17	1,000	40	5,260	181	72,000	2,000
Copper, nickel, lead and zinc ore mining	10,600	500	646	31	1,200	60	7,100	338	156,000	7,000
Other metal ore mining	1,600	200	99	11	200	20	1,340	149	6,000	640
Total or average	29,000	500	1,640	26	4,600	70	19,130	304	355,000	5,600

1. There was a noted discrepancy for total energy consumed by metal ore mines for 2017 from the various data sources. Disaggregated data sourced from Government of Canada (2020e) reproduced in the table above indicated a lower energy consumption than that quoted in the previous paragraph from Government of Canada (2020f) and Canadian Energy and Emissions Data Centre (2021). From review of the data, differences appear to be limited to how light fuel oil, heavy fuel oil, middle distillates, gasoline, and liquid petroleum are reported. The source of the discrepancy is unclear, but for the following analysis data from Government of Canada (2020e) will be used.
2. Average energy consumption was calculated by dividing the total energy consumption reported in this table with the number of mines reported in the preceding table.
3. As reported in Government of Canada (2020e).
4. Calculated as per note 3 using reported costs.
5. As reported per Canadian Energy and Emissions Data Centre (2021).
6. Calculated as per note 3 using reported data from Canadian Energy and Emissions Data Centre (2021).

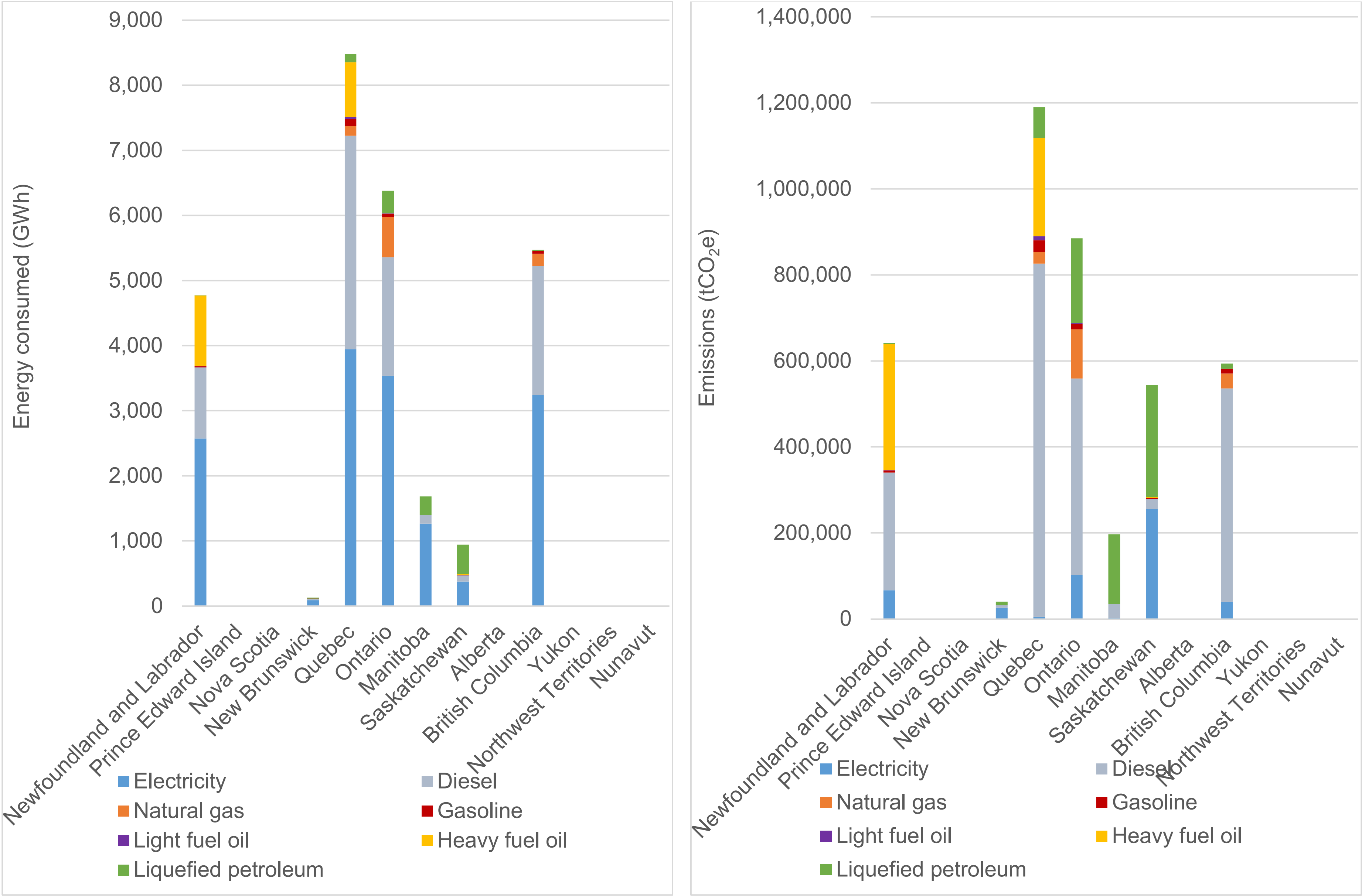


Figure 9. Energy consumption (left) and GHG emissions (right) in 2017 by metal mines by type and province (Government of Canada, 2020e; and adapted from Levesque and Acuña, (2021))

As expected, given the number of mines located in each, the mining industries in Quebec and Ontario had the highest energy consumption in total in 2017 followed by the mining industry located in British Columbia. Also, large, productive iron ore mines located in Newfoundland and Labrador consumed correspondingly large amounts of energy. GHG emissions by province shows large emissions from Quebec and Ontario with the consumption of diesel in Quebec resulting in higher emissions from these mines. The footprint of the mining in Quebec is likely due to the number of mines in the province in 2017 with those mines appearing to be energy intensive types (iron ore mines, gold and silver mines, and copper, nickel, lead and zinc mines). Reliance of mines in Manitoba and Saskatchewan upon liquefied petroleum resulted in high emissions when compared to energy consumption.

3.4 Chapter conclusions

The data presented in this chapter confirms that mining is an energy intensive process no matter the commodity mined. The intensity of energy consumption, and to some relation carbon emission rates, of a mine are a function of a number of parameters, including location, accessibility to low carbon energy sources (i.e., the electrical grid), and mining sector. While the presented data confirms that energy requirements are increasing, it also confirms that GHG emissions intensity from some metal mines in Canada are showing decline in recent years. While this decrease is helping mines meet climate change goals, it could also indicate that easy operational changes to reduce the carbon footprint of these sites are close to being exhausted. As additional GHG emission reductions may require a higher level of investment by these mines, understanding exactly how a mine uses energy at the operational level is necessary and discussed in the Chapter 4.

4 Energy use in Canadian mining operations

4.1 Introduction

The sector level review of energy consumption in Chapter 3 provides an understanding of the scope of energy consumption and emission production by the mining industry in Canada. To effectively reduce emissions, it is necessary to understand how operational decisions at the site level impacts energy consumption. Understanding energy use at a mine can be limited by the lack of metered data, uninformed estimates or poor correlations between production and energy consumption. Canada's ability to meet net-zero targets by 2050 could be impacted. According to the United Nations' Intergovernmental Panel on Climate Change (UNIPCC), lack of data is a key challenge to meeting these targets (Intergovernmental Panel on Climate Change, 2022; Katta, 2019).

This chapter describes energy use by the metal mining operations in Canada considering mining method. Energy consumption has been disaggregated to the greatest extent possible.

4.2 Underground mines in Canada employing selective mining methods

The case studies presented in this thesis include a large open pit mine and an underground block caving mine. As these bulk mining methods are typically associated with high production rates, a review of energy consumption data found in literature for underground mines in Canada employing selective mining methods was undertaken to present a complete picture of the sector.

4.2.1 Parameters that define energy consumption patterns for underground mines in Canada

Publicly available disaggregated data that provide a detailed breakdown of energy consumption at the process or equipment level are limited, possibly in part, due the need for discretion when sharing commercially sensitive data. However, energy consumption at underground mines in Canada has been characterized as:

- electricity consumption - 65% to 73% of total energy consumed at the mine site,
- energy used to move equipment and material including diesel and gasoline - 16% to 20% of energy consumed, and
- energy used for heating or cooling - 11% to 15% of energy consumed (Kalantari et al., 2020).

An analysis of energy consumption of eleven underground mines in Canada was completed by Natural Resources Canada in 2005 and provides a deeper understanding of energy use at such facilities during the year 2000 (Government of Canada, 2005b). A Sankey diagram was prepared from the data presented in the report (Figure 10) for 10 of the 11 underground bulk mines included in the study. These included five base metal mines and five gold mines. All facilities had both underground operations and above ground milling/beneficiation operations.

The report included an aggregated energy consumption value in kWh equivalents (kWhe) for each mining process. It is understood that this value is aggregated from energy consumption data for the sites including electricity, diesel, gasoline, explosives, propane, natural gas, and light fuel oil; however, data by energy type was not presented in the report. For the aggregated energy consumption, estimates were normalized to tonnes of ore hoisted from each underground operation and tonnes milled for each above ground milling operation. Again, data was not available regarding total tonnes moved to reflect the energy consumed to handle waste.

To prepare the Sankey diagram, these values were averaged for the 10 underground operations (five gold and five base metal mines) and expressed as kWhe per tonnes of ore hoisted. For the energy consumption data for the above ground operations at the underground mines, the reported data differentiated between mine sector (gold versus base metal mine) so that it was possible to present aggregated data by mine sector in the Sankey diagram where it is presented as kWhe per tonnes milled.

From the Sankey diagram, the energy intensive mining processes become readily apparent. For underground operations, these include: ventilation, hoisting, drilling, mucking and underground support (Government of Canada, 2005a).

For the above ground operations at base metal mines, separation, flotation and grinding proved to require the most energy based on the data provided. Similarly for the gold mines surveyed, extraction, refining, and grinding required the bulk of the energy consumed by above ground operations (Government of Canada, 2005a).

As details on the mines included in the study were limited (i.e., depths, haulage methodologies, mining method, energy types consumed, etc.), it is difficult to infer how representative this energy use pattern is for the majority of Canadian underground mines where operational variability will affect energy use. It is also unclear from the report what activities are included as underground support and mill support, but major energy consumption values to ventilate the mines and move material is not unexpected.

While this data provides a high level overview of energy consumption at underground Canadian mines, the sample size is small. Without mine specific details or energy sources it is difficult to be certain of general conclusions regarding the GHG emissions of these mines. A further disaggregation of data by fuel type and production step is required to understand the GHG emission potential of the mining process and to identify carbon intense activities. Such data is required to compare and prioritize GHG mitigation options and to provide a benchmark to measure any positive energy and environmental effects from implementing such mitigation strategies (Katta, 2019).

To address these problems, an energy audit completed at Vale's Garson Mine located in Sudbury, Ontario in 2014 was reviewed. This audit was completed as part of a thesis completed for the Natural Resource Engineering program at Laurentian University by Mallett (2014) and summarized by Levesque (2015).

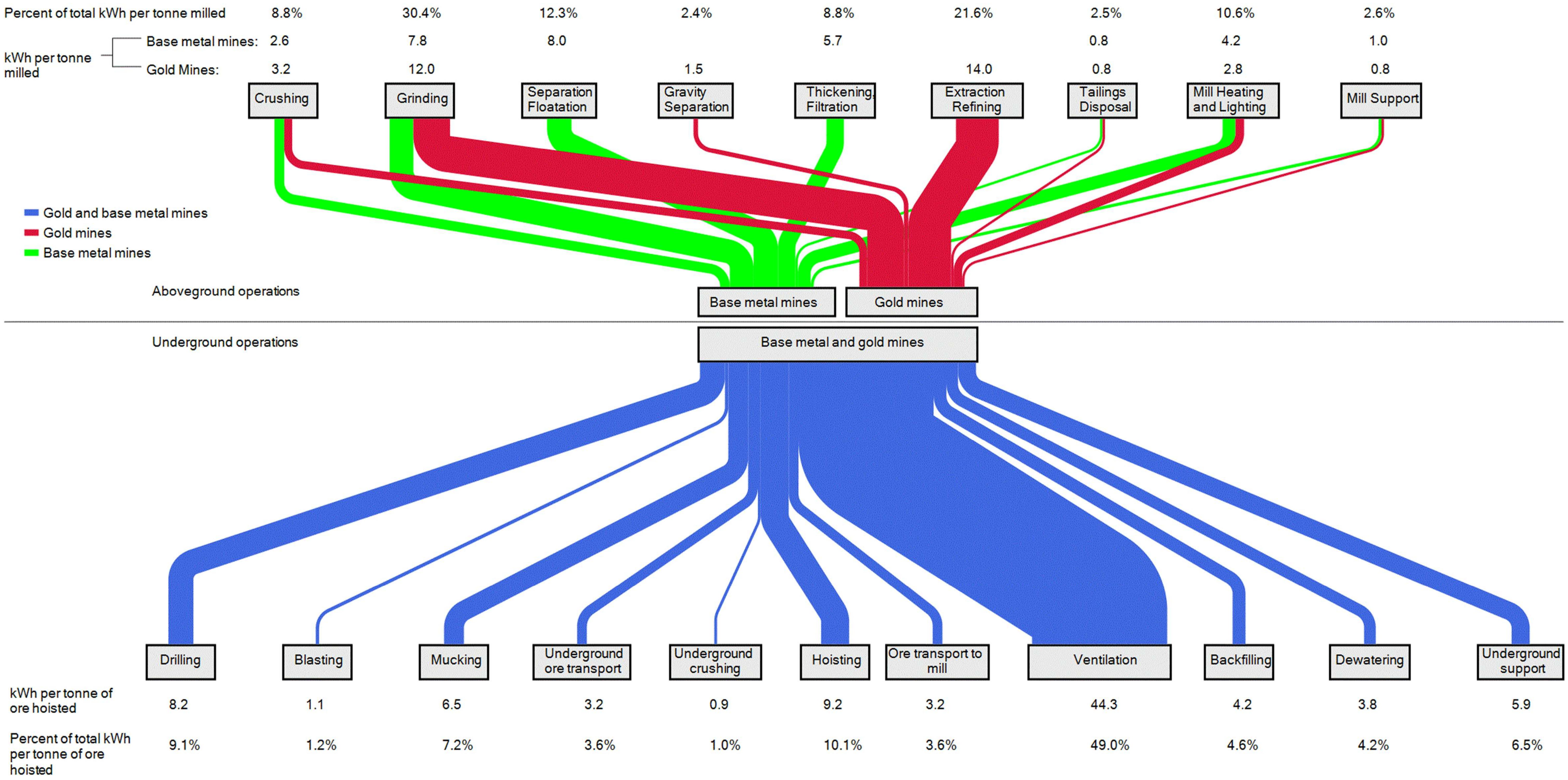


Figure 10. Sankey diagram of average energy consumption of underground gold and base metal mines in Canada in 2000 (prepared from data presented in Government of Canada (2005a))

4.2.2 Energy audit of Garson Mine

Unless otherwise referenced, the following provides an overview of findings of the energy audit completed by Mallett (2014), presented by Levesque (2015) and revisited by Millar (2015); the overview focuses on underground operations with the exclusion of energy consumption for processing and purification.

Garson Mine is an underground mine consisting of three orebodies that are accessed via a ramp and a shaft to 1,288 m depth. Commodities mined on site include nickel and copper and other fine metals (Mining Data Solutions, 2021b). Orebodies are mined using blast hole stoping and upper retreat methods with a production rate of 616 kt of ore hoisted in 2019 and a daily ore mining rate of 2,195 tonnes per day in in 2016 (Millar, 2015; Mining Data Solutions, 2021b).

At the time of the energy audit, the equipment fleet consisted of 68 pieces of equipment including drills, bolters, scissor lifts, scoops and haul trucks, personnel transports, etc. which consume diesel fuel and electricity. Mined material is excavated and transported to ore passes from where it is collected and fed to a rail tramming system. Ore is crushed underground and hoisted out via a skip hoist both of which consume electricity. The ventilation system includes 16 main and booster fans and 54 auxiliary fans. The ventilation system is powered by electricity and uses natural gas for heating when required. Support equipment of note that consume electricity include 5 compressors that supply the underground operations with compressed air, 7 dewatering pumps, and 2 backfill plants.

Following the inventory of equipment and processes on site consuming energy, the audit was completed by reviewing energy invoices, metered data and estimating energy consumption for individual pieces of equipment or processes. Estimates were based upon power ratings, assumed load factors, duty cycles, and general knowledge of energy consumption at mines. The only metered data included the natural gas consumption to provide heating of ventilated air and the electricity consumption by the compressors and dewatering pumps representing only 22% of the energy consumption on-site.

The resulting Sankey diagram including estimated GHG emissions is presented in Figure 11. Energy consumption at the site excluding milling was estimated to be 226.5 MWh/kt (Millar, 2015). Using the data presented in Figure 11 and nickel (the main product at the mine) and gold grades for the site of 1.39% nickel and 0.49 grams of gold per tonne of ore, an average annual emissions intensity of 0.078 tCO_2e per tonne of ore hoisted, 0.003 tCO_2e per pound of nickel produced, or 0.16 tCO_2e per gram of gold produced was calculated (Vale, 2022).

Firstly, it confirmed that ventilating the underground infrastructure is an energy intensive process; the carbon intensity of a ventilation system depends upon the airflow demand and amount of heating required as well as the energy sources and grid that supplies the electricity, but overall, 71.8% of the energy consumed by the mine services the mine ventilation system.

Secondly, while consuming 10.5% of the total energy in the form of diesel, underground loading and haulage equipment is associated with 33% of the GHG emissions. Some flexibility may be found within the mobile equipment fleet to reduce GHG emissions at the mine by employing alternative fuels, adopting different material handling methods, or equipment types.

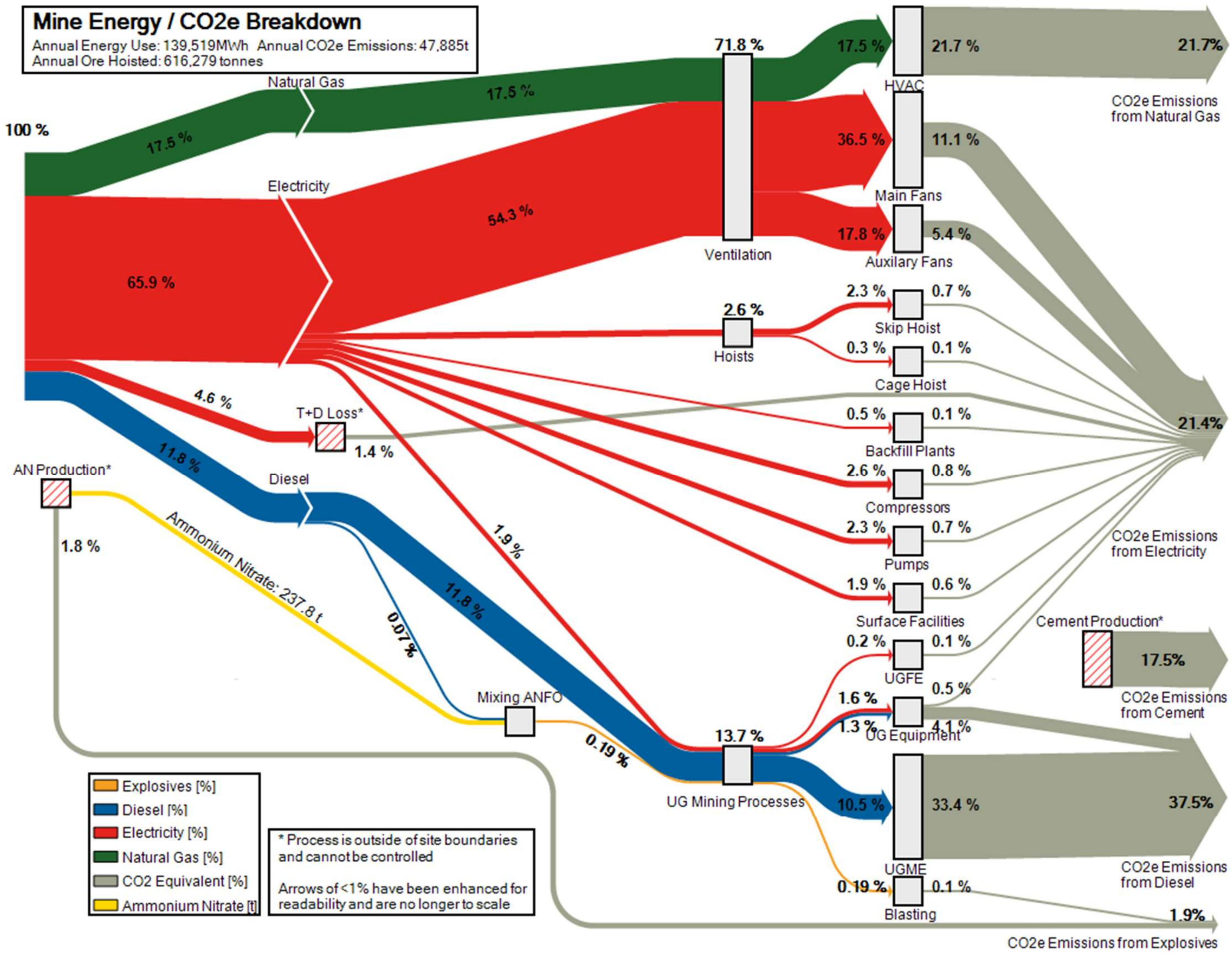


Figure 11. Sankey diagram of energy consumption at Vale's Garson Mine in Sudbury, Ontario (diagram from Millar (2015), and incorporating data from Mallett (2014) and Levesque (2015))

4.3 Surface mining in Canada

An analysis of energy consumption of nine open-pit mines in Canada completed by Natural Resources Canada in 2005 provided a deeper understanding of energy use at those facilities during the year 2000 (Government of Canada, 2005b). The study included three iron ore operations, four gold mines, and the mining only data for two oil sands operations. Figure 12, taken directly from the report, gives an overview of how energy is consumed during the mining and milling processes aggregated across the sites. The data below is the average energy consumption per stage of production. The report did not provide a breakdown of energy consumption by mine type so no conclusions could be drawn regarding energy consumption differences between commodities being mined.

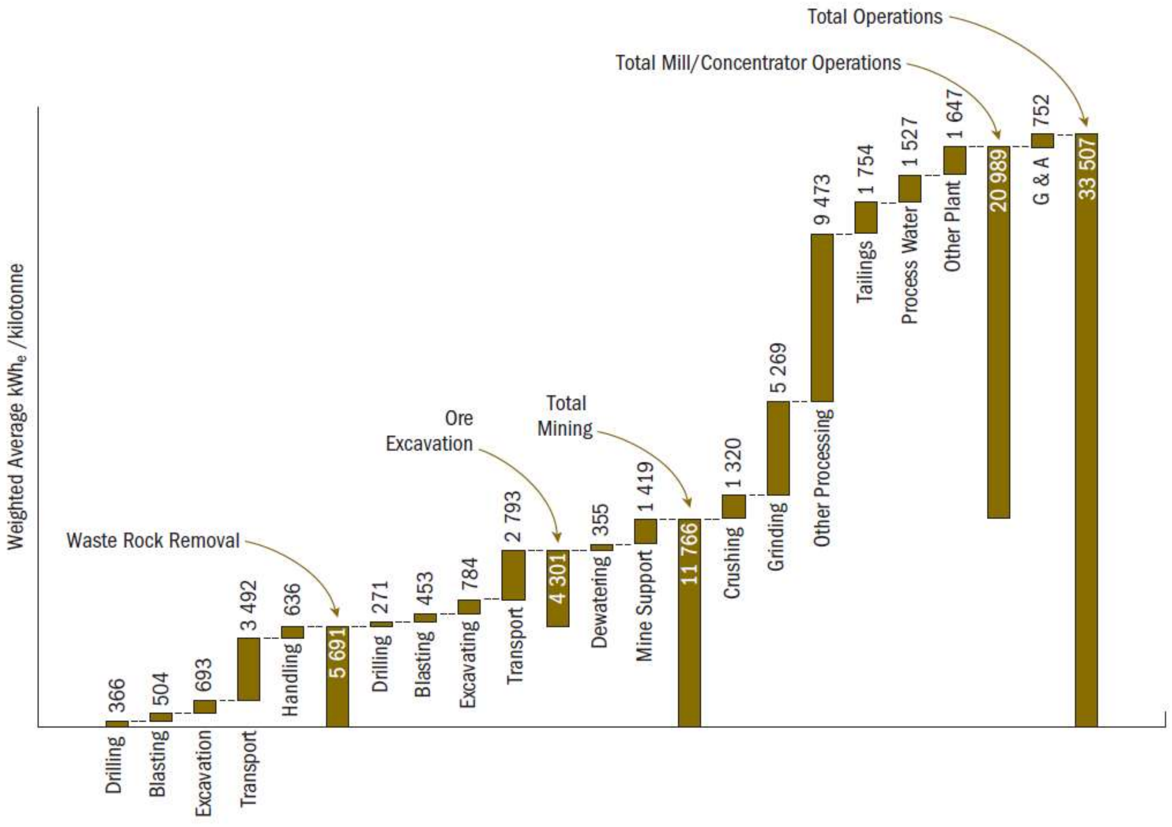


Figure 12 Average mining energy consumption per stage of production for some iron, gold and oil sands open pit mines in Canada in the year 2000 (Government of Canada, 2005b)

For the sites considered 5.9 MWh/kt milled were consumed on average to mine and handle waste whereas 4.3 MWh/kt milled were consumed to mine and handle ore which perhaps reflects that, generally, smaller equipment is used to deal with waste materials than ore materials in mining. Total energy intensity for mining was 11.8 MWh/kt milled, comminution was 6.6 MWh/kt milled whereas energy consumed for ‘other processing’ which could include classification, separation (flotation), dewatering and drying amounted to 9.5 MWh/kt milled. The total beneficiation energy consumption amounted to 21.0 MWh/kt milled on average, over the 10 mines considered in the study.

An important deficiency in this data is that the type of energy consumed to support each of the processes is not disclosed. This means that it is not possible to assess sources of emissions in the surface mining process to help mines assess the viability of alternatives to reduce their carbon footprints. However, it may be generally accepted that material transport at these surface mining sites will be typically associated with the consumption of carbon rich fuels (e.g., use of diesel powered fleet of mining trucks as part of a shovel/truck material handling system).

To get a more detailed picture, one must consider individual mining operations specifically. As an example, this is done in the next section.

4.3.1 Sankey Diagram for an open pit Canadian mine

The Sankey diagram presented in Figure 13 is for a surface mining operation, with a ratio of ore:waste of 1:5.1 for a recent year of operation (Millar, 2022). All but a very small fraction of diesel consumed at the mine is purposed toward the mining operation with an energy intensity of 7.9 MWh/kt mined waste and ore, equivalent to 40.5 MWh/kt ore milled. The latter metric is significantly higher than the 11.8 MWh/kt milled of the prior section, most likely reflecting the stripping ratio of the exemplar mining operation of this section and its dependence on diesel. In the mill fed by the surface mining operation, the dominant form of energy consumed is electricity with an intensity of 35.5 MWh/kt milled. This is higher than the average of 21.0 MWh/kt from the prior section and, mostly likely, the disparity correlates with liberation size compared with that for the prior average. In this instance, the mining operation is slightly more energy intensive than the milling operation.

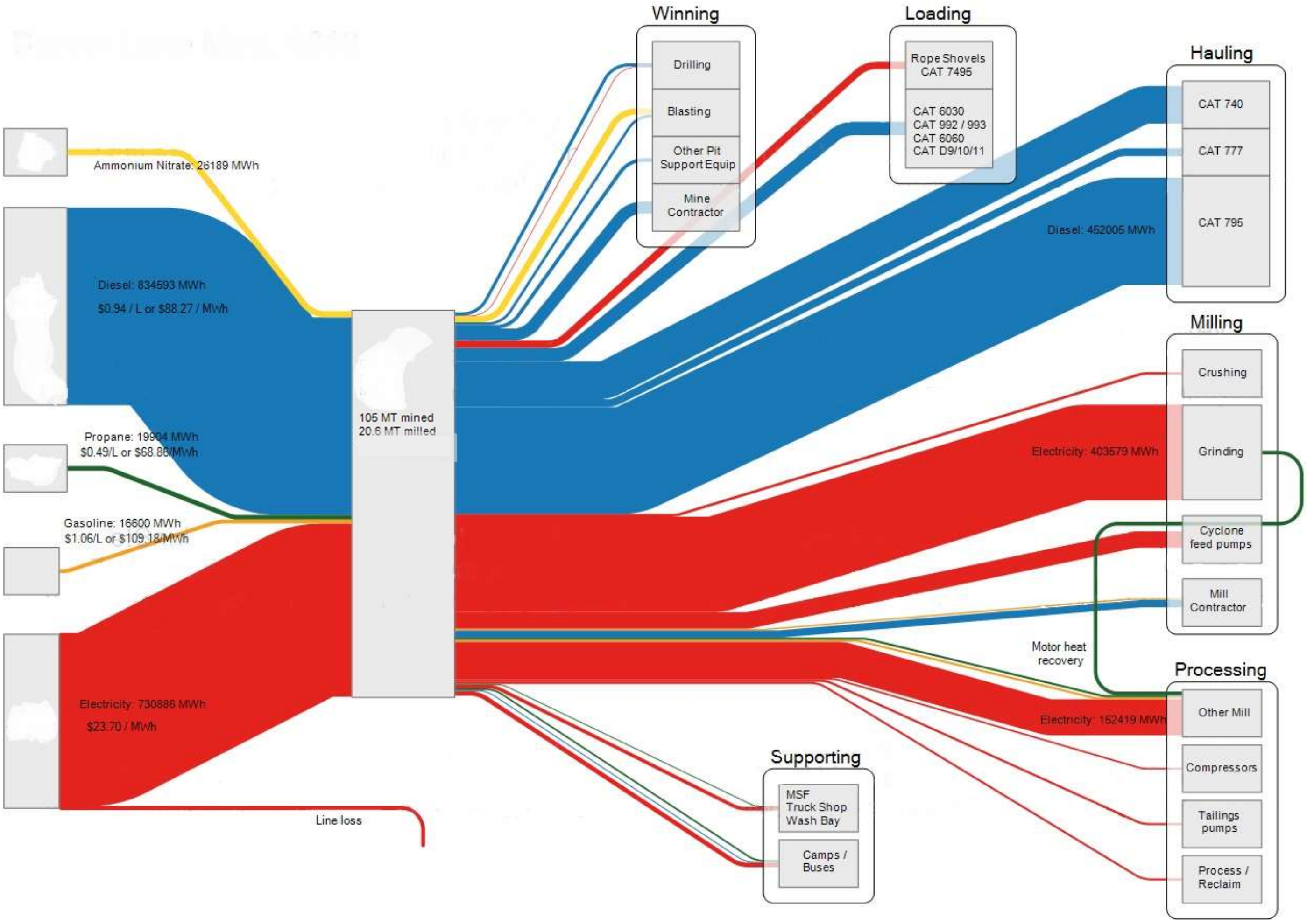


Figure 13. Sankey diagram for a large open pit mine in Canada (Millar, 2022)

In terms of GHG emissions, those associated with the electricity consumed would be indirect and thus ‘owned’ by the electricity producer. GHG emissions associated with the diesel consumption 'belong to’ the operator, and are incurred on the mining side of the operation, with most arising from haulage. To address GHG emissions, the focus must thus be on assessing diesel fuelled haulage, and this will hold for most open pit mines.

4.3.2 Robust estimation of diesel usage at a large open pit mine

Gold is a mineral mined at both open pit and underground operations in Canada. Due to lower grades and stripping ratios, large volumes of material are typically moved and processed at open pit mines in comparison to underground mines meaning that diesel consumption per tonne of rock mined is, on the whole, higher (Engeco, 2021). Having a robust way to estimate diesel usage will ensure that mine operators can confidently plan for balancing emissions with carbon offsets.

In the following sections, two distinct methods to assess the reliability of diesel consumption estimations will be presented in order that they can be compared. The methods will be explained with reference to a case study mine: Detour Lake Mine which is a large open pit gold mine in Northern Ontario operated by Agnico Eagle. The intent of this exercise is to check rapid estimation methodologies that are typically employed by mine planners or regulators using specific details on expected haulage patterns and paths detailed in public domain mining plans and equipment schedules, to confirm (or otherwise) the accuracy of any GHG emission estimates. This characterization will be used in following chapters to determine carbon footprint and assess GHG emissions mitigation alternatives.

4.3.3 Approaches and boundaries of analysis

Fuel consumption was estimated in two ways. Firstly, diesel consumption by the main mining fleet was estimated using fuel consumption rates provided by original equipment manufacturers (OEM), using assumed load factors, duty cycles and shift patterns gleaned from review of the technical report for the site titled *Detour Lake Operation Ontario, Canada NI 43-101 Technical Report* prepared in 2018 (further referred to as “the 43-101 report”). Part of the analysis focused on fuel consumed by a portion of the main mining fleet: the haulage fleet made up of CAT 795 trucks that move waste rock and ore from the main pit to the various dump points. These trucks proved to be the major consumers of diesel on site, and thus are the principal emitters of GHGs.

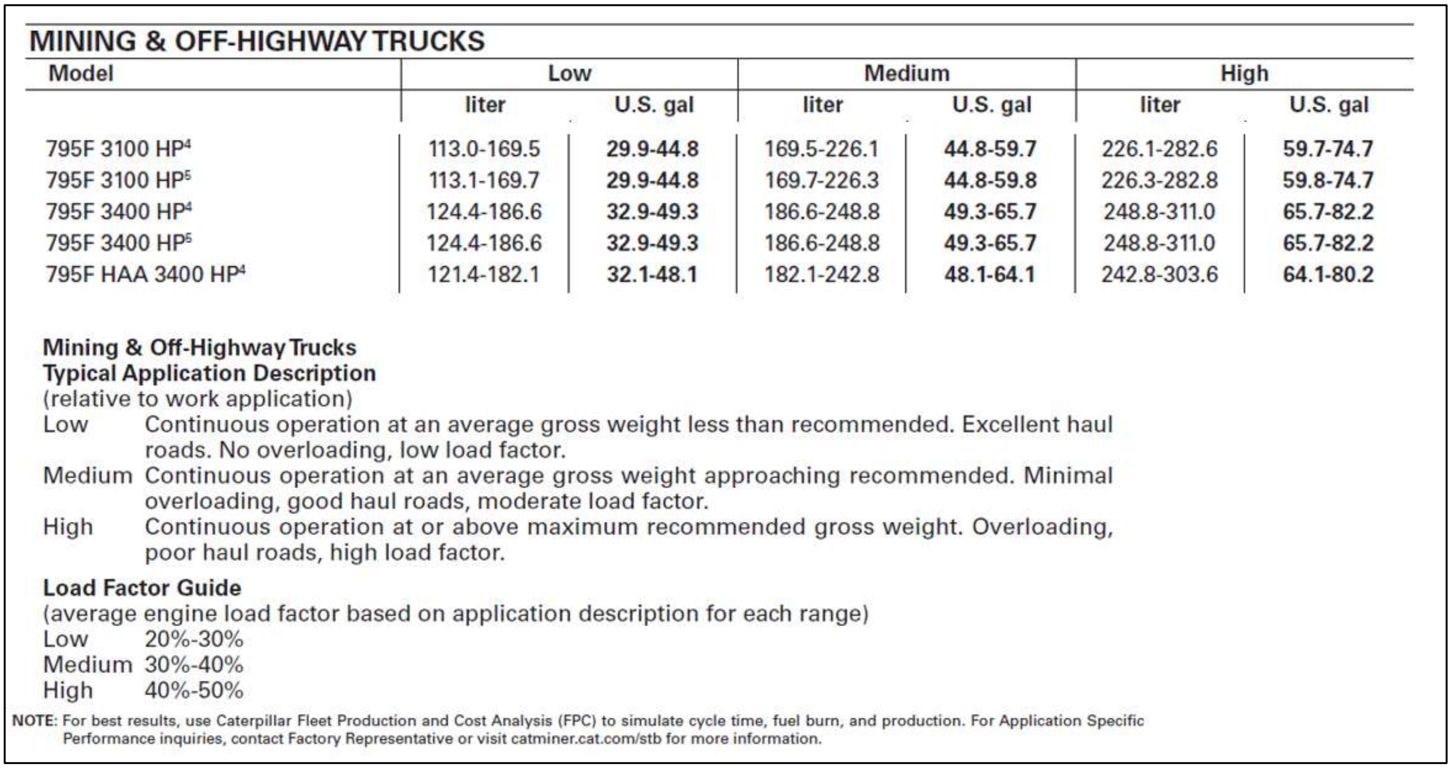
Then, to verify the accuracy of diesel consumption estimates by these large consumers, fuel consumption by the CAT 795 fleet was estimated again from first principles calculations. The same fleet specifications are adopted with a prescription of expected haulage routes (including elevations, grades and rolling resistances), haulage speeds and haulage cycles. This was done to assess the validity of fuel consumption estimates using OEM fuel consumption rates and to better understand the work needed to be done to mine the site using fuel alternatives (presented in later chapters).

The scope and spatial boundaries considered for this energy analysis includes activities undertaken by the main mining fleet mining the main and ancillary open pits and the main haulage fleet at Detour Lake Mine moving ore and waste from the main open pit to various waste piles and ore pile on site. The temporal boundary is limited to 2019 to 2040 (i.e., the current pit design to end of planned production for the mine).

4.3.4 Estimates using OEM fuel consumption rates

Fleet details were obtained for the main mining fleet from the 43-101 report. The main mining fleet included drills, primary loading units, trucks, excavators, graders, dozers and loaders. Fleet size by make and model for the main mining equipment over the life of the mine (from 2018 to 2040) is reproduced in Table 7.

For each equipment type, it was determined if they consumed electricity or diesel, and fuel consumption rates were estimated for those consuming diesel. For Caterpillar equipment, this was done by referencing fuel consumption rate tables and load factor guides in the Caterpillar Performance Handbook 48 (Caterpillar, 2018a). The engine load factor was defined as the portion of the rated engine power that is utilized during work process and it was estimated for each type of equipment used at Detour Lake Mine based upon work load described for the equipment in the 43-101 report (Klanfar et al., 2016). For most equipment, these factors were assumed to be medium to high. An example of the fuel consumption tables provided in the Caterpillar Performance Handbook 48 is presented in Figure 14.



MINING & OFF-HIGHWAY TRUCKS

Model	Low		Medium		High	
	liter	U.S. gal	liter	U.S. gal	liter	U.S. gal
795F 3100 HP[4]	113.0-169.5	**29.9-44.8**	169.5-226.1	**44.8-59.7**	226.1-282.6	**59.7-74.7**
795F 3100 HP[5]	113.1-169.7	**29.9-44.8**	169.7-226.3	**44.8-59.8**	226.3-282.8	**59.8-74.7**
795F 3400 HP[4]	124.4-186.6	**32.9-49.3**	186.6-248.8	**49.3-65.7**	248.8-311.0	**65.7-82.2**
795F 3400 HP[5]	124.4-186.6	**32.9-49.3**	186.6-248.8	**49.3-65.7**	248.8-311.0	**65.7-82.2**
795F HAA 3400 HP[4]	121.4-182.1	**32.1-48.1**	182.1-242.8	**48.1-64.1**	242.8-303.6	**64.1-80.2**

Mining & Off-Highway Trucks
Typical Application Description
(relative to work application)

Low	Continuous operation at an average gross weight less than recommended. Excellent haul roads. No overloading, low load factor.
Medium	Continuous operation at an average gross weight approaching recommended. Minimal overloading, good haul roads, moderate load factor.
High	Continuous operation at or above maximum recommended gross weight. Overloading, poor haul roads, high load factor.

Load Factor Guide
(average engine load factor based on application description for each range)

Low	20%-30%
Medium	30%-40%
High	40%-50%

NOTE: For best results, use Caterpillar Fleet Production and Cost Analysis (FPC) to simulate cycle time, fuel burn, and production. For Application Specific Performance inquiries, contact Factory Representative or visit catminer.cat.com/stb for more information.

Figure 14. Fuel consumption table for the CAT 795 mining truck from Caterpillar Performance Handbook 48 (Caterpillar, 2018a).

Table 7. Main mining equipment fleet summary (maximum per period) at the Detour Lake Mine (Detour Gold Corporation, 2018).

Equipment type	Fleet	Periods by Year								
		2018 - 19	2020 - 21	2022 - 23	2024 - 26	2027 - 29	2030 - 32	2033 - 35	2036 - 38	2039 - 40
Atlas Copco D65	Drills	4	4	4	4	5	5	1	1	0
Atlas Copco DPV271		5	5	5	4	4	3	1	1	0
Atlas Copco EPV271		3	3	3	3	3	3	3	3	1
Atlas Copco DM45		2	2	2	2	3	3	2	2	0
CAT 6030	Primary Loading Units	2	2	2	3	3	3	3	2	0
CAT 6060FSD		3	3	3	2	2	3	2	1	0
CAT 6060FSE		2	2	2	2	2	2	2	2	2
CAT 7495		2	2	2	2	2	2	0	0	0
CAT 777	Trucks	15	16	17	24	24	26	23	21	4
CAT 795		36	38	39	39	38	40	24	27	13
CAT 349	Excavators	2	2	2	2	2	2	1	1	1
CAT 385		5	6	5	7	7	7	6	6	4
CAT 16M	Graders	3	3	3	4	4	4	2	2	1
CAT 24M		1	1	1	1	1	1	1	1	1
CAT D9	Dozers	2	2	2	2	2	2	2	1	2
CAT D10		5	5	5	5	5	5	5	5	1
CAT D11		5	5	5	7	8	8	7	7	1
CAT 844K		2	2	2	2	2	2	2	2	1
CAT 980K	Loaders	2	2	2	2	3	3	1	1	1
CAT 992		1	1	1	1	1	1	1	1	0
CAT 993		2	2	2	2	2	2	2	2	1
Totals		104	108	109	120	123	127	91	89	34

For the Atlas Copco drills, fuel consumption rates were estimated from white papers specific to the equipment or by relating fuel consumption rates to the horsepower rating of the engine in question using the following equation:

$$R = \frac{C \cdot E}{S} \tag{1}$$

where R is the fuel consumption rate expressed in litres consumed per hour (Atlas Copco, 2022). The variable C is the specific fuel consumption that is a measure of the conversion of chemical energy to mechanical energy by an engine expressed as measure of flow rate (Sforza, 2014). For the drill rigs, a value of 0.18 kilograms per hour per engine horsepower was used (Khan, 2011 and Hale, 2003). The variable E is the engine rating for the equipment in horsepower and S is the specific fuel weight for diesel and a value of 0.83 kilograms per litre was used (Speight, 2011).

Using these selected or calculated fuel consumption rates, fuel consumption was then calculated using the fleet numbers presented in Table 7 while assuming 360 days a year of operation, operating at 20 hours per day and 23 years of operation. Availability and utilization rates were also applied to reflect realistic mine operational practice. Availability was defined as the portion of time the equipment is able to be used for its intended purpose and utilization as the portion of time the equipment was actually used for its intended purpose (Dunn, 1997). Publicly accessible availability and utilization rates for equipment used at the mine site was limited to shovel productivity for the CAT 7495 and CAT 6060 rope shovels; these values ranged between 54% and 87% availability and 74% and 79% utilization (see Table 8) (Detour Gold Corporation, 2018). Availability rates between 77% and 80% and utilization rates between 50% and 80% were used for all other equipment listed in Table 7 and were selected based upon work descriptions found in the 43-101 report.

Table 8. Availability and utilization of the shovels for part of 2018 (Detour Gold Corporation, 2018).

	CAT 7495		CAT 6060	
2018	Availability (%)	Utilization (%)	Availability (%)	Utilization (%)
January	78	75	69	74
February	76	75	69	74
March	54	77	81	77
April	83	78	73	78
May	83	79	87	78

A graphical representation of the methodology described above is presented in Figure 15. The right hand side of the flow chart depicts the methodology used when the fuel consumption rates are supplied by the OEM and are a related to an estimated load factor. The left hand side of the flow chart depicts the methodology used when such fuel consumption rates are not known and need to be calculated using the engine rating and the specific weight of the fuel being used as in (1).

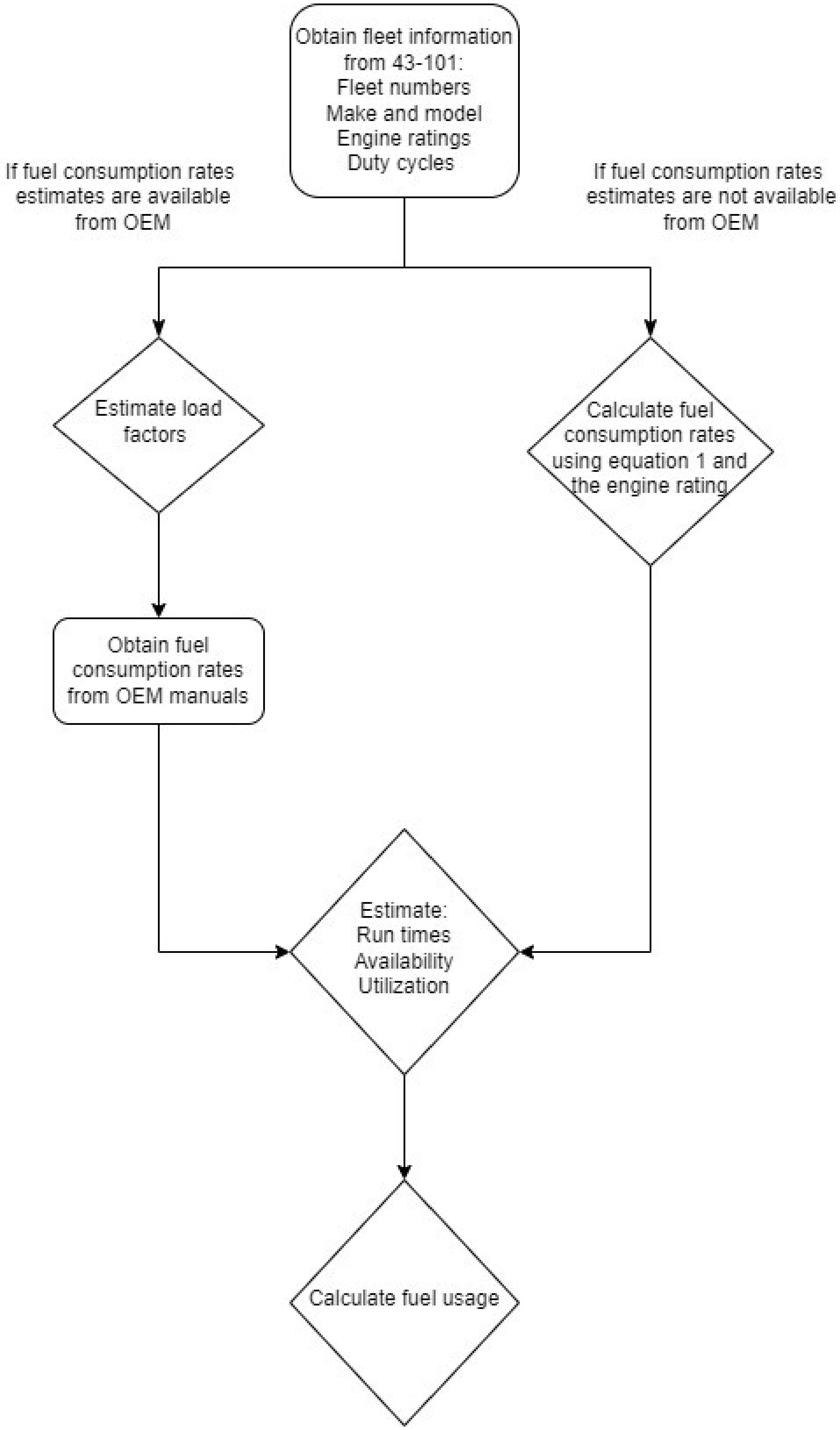


Figure 15. Methodology used to estimate fuel consumption using OEM provided fuel consumption rates, assumed load factors and duty cycles.

Diesel estimates based upon fuel consumption rates related to assumed engine load factors for the main mining fleet at the Detour Lake Operation are presented in Table 9. Interannual variation is the result of fleet numbers for each equipment type changing over the life of mine as presented in Table 7. For example, the fleet of 36 CAT 795 in use at the mine in 2019 were assumed to have a medium high engine load factor to account for the effort of moving material up ramp resulting in a fuel consumption rate of 270 litres per hour per the Caterpillar OEM manual (refer to Figure 14). In addition to assumed availability and utilization of 80% each and working 360 days a year for two 10 hour shifts a day, it was estimated that this fleet of trucks consumed 45 million litres of diesel in 2019. In 2020, the number of CAT 795 increases to 38 and with the other assumptions remaining the same as 2019, it was estimated that the fleet consumed 48 million litres per year or 95.9 million litres for 2020 and 2021 as presented in Table 9.

Table 9. Estimated diesel consumption for the main mining fleet at the Detour Lake Operation

Equipment type	Fleet	Fuel consumption rate	Availability	Utilization	Fuel consumption in the mining periods by year (M l)									Totals (M l)
		(l/hr)	(%)	(%)	2019	2020 - 21	2022 - 23	2024 - 26	2027 - 29	2030 - 32	2033 - 35	2036 - 38	2039 - 40	
Atlas Copco D65	Drills	117	80%	80%	2.20	4.40	4.40	6.60	8.25	8.25	1.65	1.65	-	37.41
Atlas Copco DPV271		190	80%	80%	4.46	8.91	8.91	10.70	10.70	8.02	2.67	2.67	-	57.05
Atlas Copco EPV271		Electric	80%	80%	-	-	-	-	-	-	-	-	-	-
Atlas Copco DM45		103	50%	80%	0.60	1.21	1.21	1.81	2.72	2.72	1.81	1.81	-	13.91
CAT 6030	Primary Loading Units	215	80%	80%	2.01	4.02	4.02	9.04	9.04	9.04	9.04	6.03	-	52.23
CAT 6060FSD		400	80%	78%	5.47	10.93	10.93	10.93	10.93	16.40	10.93	5.47	-	81.99
CAT 6060FSE		Electric	80%	78%	-	-	-	-	-	-	-	-	-	-
CAT 7495		Electric	77%	77%	-	-	-	-	-	-	-	-	-	-
CAT 777	Trucks	63	85%	80%	4.69	10.01	10.63	22.52	22.52	24.39	21.58	19.70	1.45	137.49
CAT 795		270	80%	80%	45.41	95.87	98.39	147.59	143.80	151.37	90.82	102.18	18.98	894.42
CAT 349	Excavators	59	85%	80%	0.59	1.17	1.17	1.76	1.76	1.76	0.88	0.88	0.34	10.30
CAT 385		82	85%	80%	2.04	4.88	4.07	8.55	8.55	8.55	7.33	7.33	1.88	53.17
CAT 16M	Graders	39	85%	80%	0.58	1.16	1.16	2.32	2.32	2.32	1.16	1.16	0.22	12.42
CAT 24M		78	85%	80%	0.39	0.77	0.77	1.16	1.16	1.16	1.16	1.16	0.45	8.19
CAT D9	Dozers	58.1	80%	80%	0.54	1.09	1.09	1.63	1.63	1.63	1.63	0.81	0.63	10.67
CAT D10		112	80%	80%	2.62	5.23	5.23	7.85	7.85	7.85	7.85	7.85	0.61	52.93
CAT D11		112	80%	80%	2.62	5.23	5.23	10.99	12.56	12.56	10.99	10.99	0.61	71.77
CAT 844K		73	80%	80%	0.68	1.36	1.36	2.05	2.05	2.05	2.05	2.05	0.39	14.04
CAT 980K	Loaders	29	80%	80%	0.27	0.54	0.54	0.81	1.22	1.22	0.41	0.41	0.16	5.58
CAT 992		121	85%	80%	0.60	1.20	1.20	1.80	1.80	1.80	1.80	1.80	-	12.01
CAT 993		140	85%	80%	1.39	2.78	2.78	4.17	4.17	4.17	4.17	4.17	0.80	28.60
Totals					77.15	160.78	163.12	252.28	253.03	265.27	177.93	178.12	26.52	1,554

Over the life of mine, it is estimated that 1.6 billion litres of diesel will be used by the main mining fleet with peak consumption occurring between years 2024 and 2032; this corresponds to excavations occurring in both the main pit and ancillary, smaller open pits to the north and west of the main Detour Lake Pit (referred to as the North and West Pits). Over the life of the mine considered as part of this study (i.e., from 2019 to 2040), it has been estimated that 2,034 Mt will be excavated from the various pits with 470 Mt being ore. Given the consumption, this equates to 3.35 litres of diesel per production tonne or 0.77 per tonne of material moved or \$2.68 and \$0.62 of diesel cost per tonne of ore and total material moved respectively when a diesel cost of \$0.80 per litre is assumed (as per the 43-101 report). In diesel usage alone, the consumption and productivity data indicate that the energy intensity of the haulage operation alone is 8.7 MWh/kt on average. While not specified in the 43-101 report, it has been assumed that equipment listed in Table 7 is not used for construction of the tailings management area, surface operations maintenance, explosives, and mine contractors.

Of specific interest to this analysis are the CAT 795s that provide the main hauling effort moving waste and ore from the Detour Lake Pit and consume 58% of the estimated diesel usage on site. In total, the CAT 795 are estimated to consume 894 million litres of diesel over the life of mine using OEM fuel consumption rates which equates to 40.7 million litres in an average year.

4.3.5 Fuel consumption of the CAT 795 per haulage cycle

As demonstrated in the preceding section, fuel consumption by major movers at a mine can be estimated using OEM provided fuel consumption rates and a knowledgeable estimation of load factors and duty cycles for the equipment. Unfortunately, actual consumption values were not found in the publicly available data to assess the accuracy of this estimation. In an effort to validate these estimates, two additional estimates of fuel consumed by the CAT 795 fleet (the major diesel consumer) at Detour Lake Mine were completed using first principles and actual work done based on distance travelled by the trucks.

To estimate fuel consumption for the primary movers at the Detour Lake Mine, the CAT 795 haul truck, haul distances and grades that these trucks would traverse to move material to the various ore and waste dump points were estimated. The CAT 795 trucks move material from the main pit, the Detour Lake Pit, to the low/high grade ore stockpile, the north rock pile where potentially acid generating waste rock is collected, and the south waste rock pile where non-acid generating waste rock is collected. The location of these dump points in relation to the main pit and assumed haul routes are presented in Figure 16.

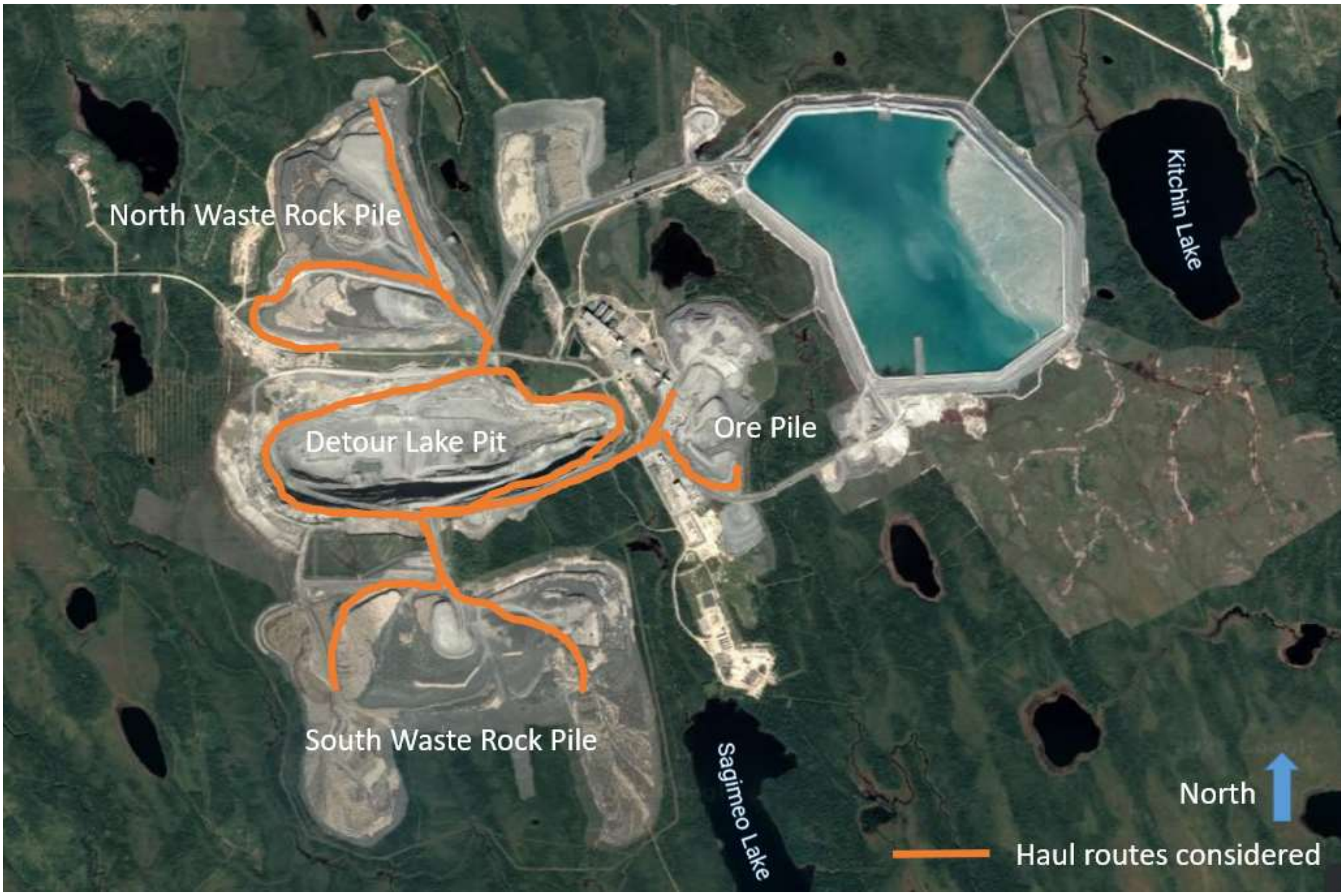


Figure 16. Main pit and dump point locations and assumed haul routes at the Detour Lake Mine site (Google Earth, 2021a).

Total travel distances for the haul trucks included ramp distances that varied with mining phase and haul routes from the pit to the dump points that are likely relatively consistent over the life of the mine. Haul distances from the pit exits and entrance points to the various dump points were estimated by tracing and measuring the visible haul roads on Google Earth; these haul roads were assumed to have level grade. As depicted on Figure 16, there appeared to be various viable haulage routes visible on Google Earth imagery of the site. As no information was available regarding actual routes taken or any constraints on truck travel (e.g., one way routes, etc.), an average distance was assumed to each dump point from the viable alternatives. It was assumed that trucks hauling one-way from the pit exit to the north waste rock pile, south waste rock pile, and ore pile would travel on average 3,215 m, 3,700 m, and 3,120 m, respectively.

Ramp distances in the Detour Lake Pit were calculated by measuring the ramp distances on end of period mine production plan views found in the 43-101 report. Figure 17 shows the progression of the ramp and pit limits between 2019 and 2040; ramp distances increase as the pit gets deeper over time. Ramp grades were described in the 43-101 report as being 6% to 8% on curves and 10% on straight-aways. These grades, in addition to the measured ramp distances, were used to calculate the actual ramp distances trucks would have to travel to reach the pit exits from loading points. As noted for the haul routes, there appeared to be a number of routes the trucks could take to traverse the pit ramp. By averaging these, it was estimated that ramp distances would vary from 1,496 m in 2019 up to 4,824 m in 2040 (refer to Table 12 in the next section for estimated ramp distance for each phase of mine life).

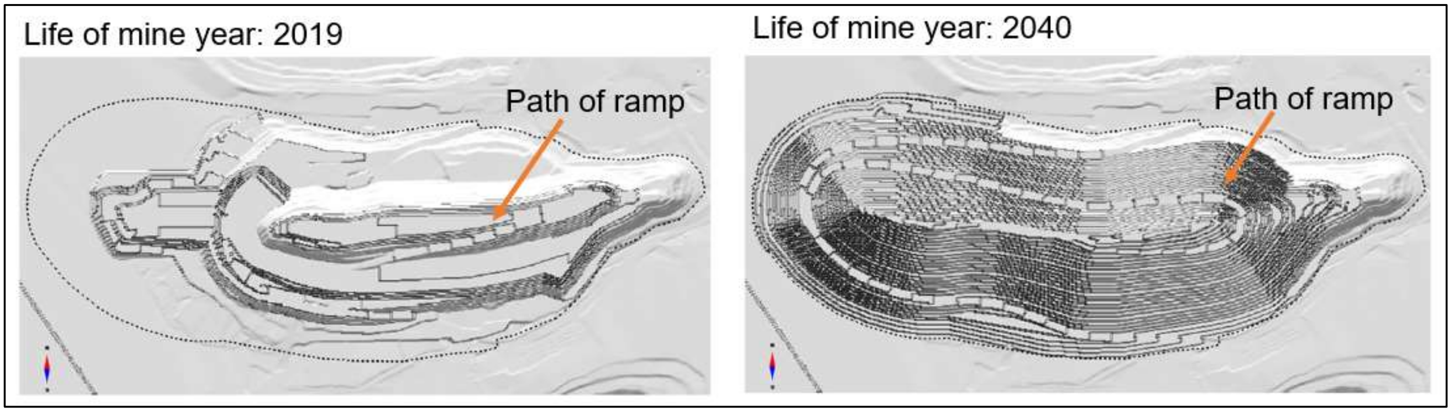


Figure 17. Outline of Detour Lake Pit in 2019 (left) and 2040 (right) showing construction of the ramp over time (Detour Gold Corporation, 2018).

Hauling velocities for the CAT 795 are specified in the 43-101 report and vary depending upon task being performed including hauling up ramp empty, hauling down ramp empty, etc. (Table 10). These velocities were used in conjunction with the estimated haul distances to estimate haulage times. Haul times for each phase of mine life are presented below in Table 11 and Table 12 in detail but varied from 37 minutes to 76 minutes per round trip depending upon dump point and pit depth.

Table 10. Velocities of the CAT 795 depending on task being performed (Detour Gold Corporation, 2018).

Hauling activity	Loaded (m/s)	Empty (m/s)
Flat in pit	6.9	6.9
Flat on pile	7.5	8.9
Flat Ex Pit	8.9	9.7
10% Uphill	3.1	6.4
10% Downhill	6.7	6.7

A rolling resistance, or the resistance required to overcome the gravel surface of the road, of 3% was assumed for all haulage routes on the flat (Hustrulid et al., 2013). Total rolling resistances on the ramp were calculated by the addition of the grade of the ramp (between 6% and 10% per the 43-101 report) to the rolling resistance of 3% to overcome the gravel surface of the road and ramp (Figure 18).

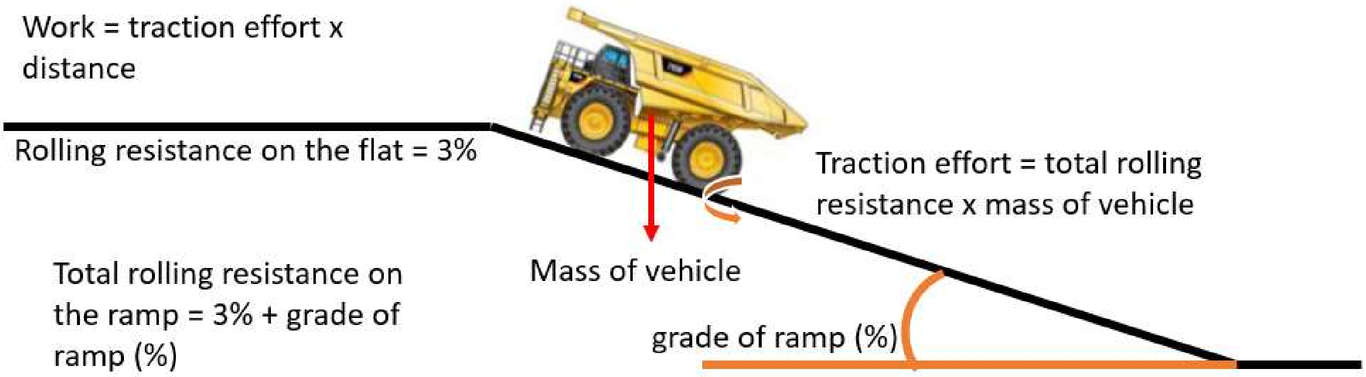


Figure 18. Calculation of total rolling resistance and work required to move the CAT 795 on the haul route

Using the mass of the CAT 795 presented in the Caterpillar Performance Handbook for both an empty and full payload and the rolling resistances, the traction effort to turn the wheels of the truck and move it forward were calculated using the following equation:

$$T = m \cdot RR \cdot g \tag{2}$$

where T is the traction effort to move the truck in newtons (N), m is the mass of the truck of 570,166 kilograms (kg) full and 251,993 kg empty, RR is the total rolling resistance, and g is acceleration due to gravity. The traction effort, in conjunction with the actual distances the truck is to be moved on the haul route, were used to calculate the work to be done to move the truck per trip to the various dump points per the equation:

$$W = T \cdot d \tag{3}$$

where W is the work required to move the CAT 795 in joules and d is the distance travelled in metres. The time spent on the haul route (t) was calculated using the distance travelled (d) and the velocity (v) for that specific activity (i.e., travelling up the ramp full) per equation:

$$t = d/v \tag{4}$$

Using the aforementioned equations, the diesel a CAT 795 would consume to travel from the main pit to the dump points and return to the main pit is presented in Table 11 assuming a 36% efficiency for the diesel engine and drive train (Caterpillar, 2021a; Nino Vega, 2020). A fuel consumption rate of 1 litre per hour was assumed when travelling down ramp empty and during loading and dumping; as no mechanical energy is required to move the truck as part of these activities, this fuel consumption rate was assumed to cover engine idling.

Table 11. Energy required by the CAT 795 to travel from the main pit entrance to the dump points and back using an assumed engine efficiency

Dump point	Travel distance [1] (m)	Time spent on travelling [2] (hr)	Work required to overcome traction effort [3] (kWh)	Diesel consumed by CAT 795 [4] (l)
North waste rock pile	3,215	0.19	216	55
South waste rock pile	3,700	0.22	249	63
Ore pile	3,120	0.19	210	53

1. Travel distance from main pit entrance to the various dump points and is an average of the possible routes observed on available imagery.
2. Time spent by the CAT 795 travelling from pit entrance to dump point and back to the pit entrance per trip.
3. Work required to overcome traction effort to move a CAT 795 from pit entrance to dump point and back loaded and unloaded per trip.
4. Diesel consumed by CAT 795 to travel from main pit entrance to dump point and back per trip assuming an efficiency of 36% for the engine and drive train (Caterpillar, 2021a; Nino Vega, 2020).

Similarly, the energy requirements for the CAT 795 to travel up and down the ramp in the main pit were calculated and are presented in Table 12 for the various phases of the mine life that reflect the increasing ramp distances as pit depth increased.

Table 12. Energy required by the CAT 795 to traverse the ramp at various phase of mine life using an assumed engine efficiency

Phase of mine life	Ramp distance (m) [1]	Time spent on ramp (hr) [2]	Work required to overcome traction effort [3] (kWh)	Diesel consumed by CAT 795 to do work of traverse the ramp [4] (l)
2019 to 2021	1,496	0.14	839	77
2022 to 2025	1,507	0.14	845	77
2026 to 2028	2,613	0.24	1,466	134
2029 to 2031	2,914	0.26	1,635	149
2032 to 2034	3,266	0.30	1,832	167
2035 to 2037	4,321	0.39	2,424	221
2038 to 2040	4,824	0.44	2,706	247

1. Travel distance is an average of the number of potential routes that appeared viable on available imagery.
2. Time spent by the CAT 795 travelling up and down the ramp in the pit only per trip.
3. Work required to overcome traction effort to move a CAT 795 up and down the ramp in the pit loaded and unloaded per trip.
4. Diesel consumed by CAT 795 to travel up and down the ramp per trip assuming an efficiency of 36% for the engine and drive train (Caterpillar, 2021a; Nino Vega, 2020).

4.3.6 Determining the number of trips to the various dump points required over the life of mine

Having produced estimates of fuel consumed per haulage cycle, calculation of the total fuel consumed requires estimate of the number of haulage cycles per year, or over the mine life, as well as identification of whether a haulage cycle is a waste cycle or an ore cycle.

The number of trips to each dump point required over the life of the mine were calculated for the CAT 795 trucks based upon yearly mining rates of waste and ore from the Detour Lake Pit presented in the 43-101 report and the payload capacity of the truck. Trips to the north and south waste rock piles were calculated based on a cited 17% of the waste rock produced being acid generating and being sent to the north waste rock pile with the remainder sent to the south waste rock pile (Detour Gold Corporation, 2018). All ore was assumed to go to the low and high grade ore stockpile.

It should be noted that while the 43-101 report indicates that the CAT 795 trucks are dedicated to hauling from the Detour Lake Pit, additional haul trucks are used on site. These include the CAT 740 that are used to haul overburden, and the CAT 777 trucks that are the main haul trucks for the smaller North and West Pits. However, review of the numbers of CAT 777 trucks on site for given mining periods and the mining plan for the North and West Pits suggests that the CAT 777 trucks also haul from the Detour Lake Pit. Assuming this, the amount of material hauled by the CAT 795 was reduced when appropriate (i.e., CAT 777 have fleet numbers when the North and West Pits are not or only partially operational). A table providing a breakdown of material moved and trips taken to the various dump points accounting for supplementary use of the CAT 777 is presented in Appendix A.

Total fuel consumed was then calculated per equation (5) using the number of trips and fuel required per trip as calculated above:

$$TFC = \sum N \cdot FC \tag{5}$$

where TFC is the total fuel consumed over the life of the mine in litres, N is the number of trips to the respective dump points to move all the material mined, and FC is the fuel consumption per haul route to the respective dump points and presented in Table 11 and Table 12. The methodology described above is presented below in Figure 19.

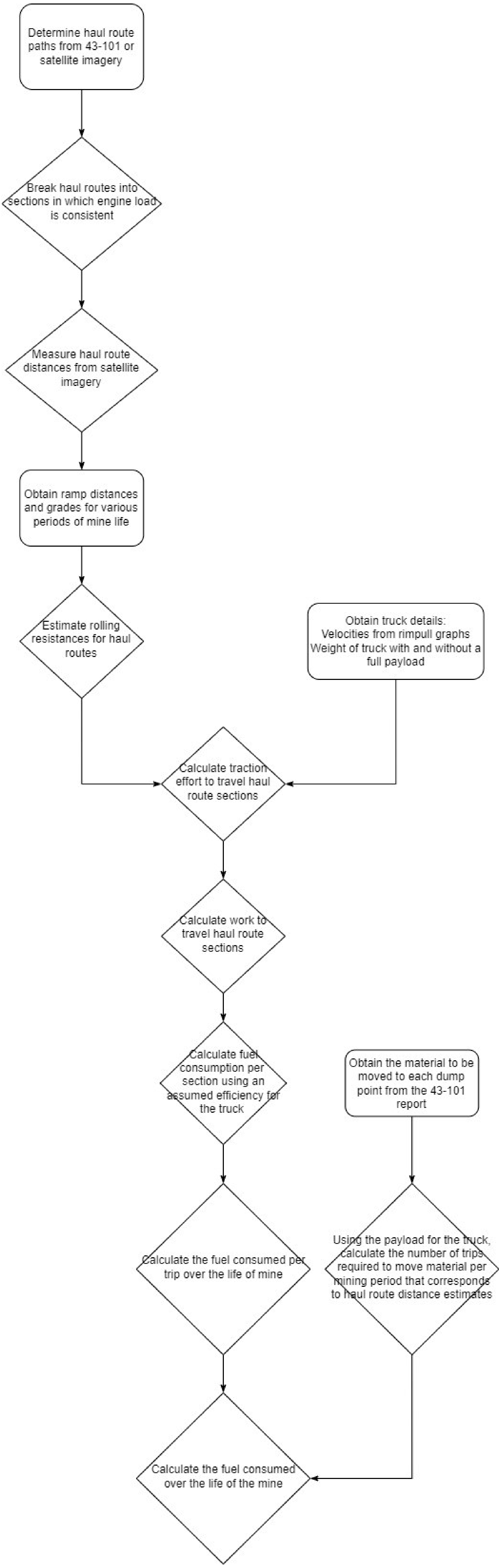


Figure 19. Methodology to calculate fuel consumed using first principles and assumed engine efficiencies

4.3.7 Comparison of fuel consumption estimates

The resulting fuel consumption estimates are presented in Table 13 for the CAT 795 fleet using the two methodologies:

1. OEM provided fuel consumption rates (in this case from the Caterpillar Performance Handbook) and estimated engine load factors, and,
2. first principles estimation from haul road distances, routes, elevations and grades with an assumed engine and drive train efficiency together with a schedule of ore and waste production.

Table 13. Yearly fuel consumption estimates for the CAT 795 estimated via all methodologies

Operating year	Fuel consumption estimates for the CAT 795 fleet			
	Caterpillar Performance Handbook [1] (M l)	First principles and assumed engine efficiencies [2] (M l)	Difference [3] (M l)	Percent variance [4]
2019	45.41	45.44	-0.02	-0.1%
2020	47.93	47.27	0.66	1.4%
2021	47.93	48.64	-0.70	-1.5%
2022	49.20	48.29	0.91	1.8%
2023	49.20	48.41	0.79	1.6%
2024	49.20	47.33	1.86	3.8%
2025	49.20	38.83	10.37	21.1%
2026	49.20	56.72	-7.52	-15.3%
2027	47.93	57.87	-9.94	-20.7%
2028	47.93	57.94	-10.01	-20.9%
2029	47.93	53.37	-5.43	-11.3%
2030	50.46	56.32	-5.86	-11.6%
2031	50.46	52.14	-1.68	-3.3%
2032	50.46	45.13	5.33	10.6%
2033	30.27	31.50	-1.23	-4.1%
2034	30.27	30.77	-0.50	-1.7%
2035	30.27	44.25	-13.98	-46.2%
2036	34.06	41.22	-7.16	-21.0%
2037	34.06	31.76	2.30	6.8%
2038	34.06	27.30	6.76	19.9%
2039	16.40	17.37	-0.98	-5.9%
2040	2.58	2.69	-0.11	-4.3%
Total	894.42	930.56	-36.14	-4.0%

1. Calculated per Section 4.3.4 and Figure 15 using fuel consumption rates provided by the OEM and an estimation of load factor and previously presented in Table 9
2. Calculated per Section 4.3.6 and Figure 19 using work required per trip and an assumed engine efficiency
3. Difference determined using OEM provided fuel consumption rates and an estimation of load factor (per note 1) minus methodology in preceding column
4. Calculated as the difference between methodologies related to fuel consumption estimates calculated per note 1

Review of the resulting variances indicates broad consistency between the estimation methods. However, both methodologies are sensitive to the decisions made by the estimator. Fuel consumption rates established from the Caterpillar Performance Handbook with assumed availability and utilization as per Figure 15 are sensitive to the correct engine load factor estimation and do not consider constant duty sections of the haulage cycle and their respective distances and grades. The user must have some awareness of the load the equipment they are estimating for will experience otherwise the accuracy of their estimates may be poor. For the first principles approach, poor determination of haul distances and grades within the Figure 19 methodology introduces a potential source of estimation sensitivity to the methodology.

Irrespective of these sensitivities and based upon resulting fuel consumption estimates, the methodologies employing first principles does appear to validate (consistency between life of mine values) the use of OEM fuel consumption rates if the estimator has some knowledge of equipment load factor. Interannual variation could be the result of the number of trips assigned per year not reflecting fleet numbers changing. While more labour intensive than use of OEM provided fuel consumption rates, the first principles approach does have the advantage of a more considered estimate and could lead to determination of overall engine load factor if this is unknown. This could result in a more accurate fuel consumption rate estimate when compared with the range of rates the user could select from by using the Caterpillar Performance Handbook as presented above.

However, confirming the accuracy of either estimation approach requires measured data of fuel consumption from the haulage fleet which is not publicly available for the case study site.

4.3.8 Surface mining summary

When compared to the energy intensity selective underground mining at Garson Mine in Section 4.2.2 of 226.5 MWh/kt milled, the large open pit surface mine presented in Figure 13 had a much lower energy intensity of 79 MWh/kt milled due to bulk mining processes. With the currently broadly adopted mining technologies, mine design and operating practices, surface mining processes are dominated by diesel consumption during haulage activity with a diesel consumption intensity of around 8 MWh/kt of ore or waste mined. If energy intensity is reported per tonne (or kt) of ore mined, or ore milled, then the energy consumption figures for the mining operation will be dominated by the mine stripping ratio. As GHG emissions associated with electricity consumed via a grid connection are attributed to the producer of the electricity in Canada, for open pit mines, GHG emissions relate to diesel consumed on site, which in turn are dependent on materials transport of rock from pit to waste piles or ore stockpiles. Accurate estimation of diesel consumption for haulage processes, is key to understanding expected GHG emissions from open pit mines. Two independent methodologies to estimate diesel consumption from haulage fleets in open pit mines have produced estimates that are consistent with one another. The methodology adopting first principles estimation is probably more suitable when subsequent phases of investigation of mitigation of GHG emissions is to be pursued, that may involve fuel switching. Ultimately, to verify either methodology explored herein, and to assess energy use reduction and GHG mitigation potential for the minerals sector, complete and quality data on energy use at the production stage level accounting for fuel and technology use is required (Katta, 2019).

4.4 Energy consumption at a block cave mine

Block cave mining is a bulk underground mining method which offers the advantage of production rates up to 30,000 to 100,000 tonnes per day that are comparable with those of surface mining operations (typically between 20,000 and 100,000 but up to 170,000 tonnes per day in Canada) (Dunbar, 2012; Geoengineering.com, 2018).

In comparison to underground mines employing more selective mining methods with typically lower production rates up to a maximum of 20,000 tonnes per day, block caves need to be considered separately from an energy and carbon management point of view, because the currently adopted technologies and typical operating practices are quite different. Simply the higher production intensity via block caving (the economies of scale) could present lower energy intensities than underground mining using selective methods and possibly also, lower overall energy consumption than surface mining (Villa, 2020), (Dunbar, 2012). However, block caving is a mining technique that is not suited to all orebodies, so it is not an underground mining technique that can universally replace other underground mining methods.

From the standpoint of considering the energy consumed by underground mining operations, because of the at least one order of magnitude disparity in mine production intensities, aggregating energy data from block cave mines with energy data from underground mines adopting more selective mining processes (such as those at Garson Mine) could lead to skewing of discernable trends and challenges in interpretation.

For the purpose of energy and carbon management in mines, it is asserted that it is more appropriate to consider three broad categories of mining technique:

- Underground mining operations
- Surface mining operations
- Block cave mining operations

The first two sections of this Chapter have concerned energy consumption in mines of the first two types. To complete the Canadian mining sector energy management picture in this section a case study of energy consumption at New Afton Mine will be presented. This is a block caving gold mining operation in British Columbia. It is one of two block cave mines operating in Canada. It is hoped that its analysis will thus present a reasonably representative characterization of this segment of mining practice within the Canadian mining industry. As energy consumption data was provided by mine staff, it was possible to complete a high-level energy audit and allowing for a limited analysis of emissions.

4.4.1 Purpose and boundaries of analysis

The purpose of this energy analysis is to i) provide an overview of energy consumption at New Afton Mine and ii) identify large energy consumers for the purpose of a GHG mitigation analysis in later sections. This analysis includes data on energy consumption provided by site staff, information gleaned from publicly available technical reports for the site, and estimates based upon energy consumption rates. The scope of the analysis includes all energy forms consumed on-site: electricity, diesel, natural gas, gasoline, propane, and explosives.

The spatial boundary considered for this analysis includes the area confined within the boundaries of the New Afton property. Consumption reported below from 2012 to 2020 is based predominately upon measured data supplied by site staff (Cooper, 2020). The remainder from 2021 to 2030 (the end of mine life) are energy estimations based upon measured energy consumption patterns unless otherwise specified.

4.4.2 Outline description of the New Afton block cave mining operation

The New Afton Mine is a copper-gold mine located near Kamloops, British Columbia owned and operated by New Gold Inc. In development since 2007, in operation since 2012 and mined using block caving methods, it is an underground mine that operates at the site of a former open pit mine (New Gold Inc., 2021). With probable reserves on site including 1.00 million ounces of gold, 2.8 million ounces of silver, and 802 million pounds of copper, the mine is expected to produce 85,000 ounces of gold and 75 million pounds of copper per year until its end of mine life in 2030 (RPA, 2020).

4.4.2.1 Mine infrastructure

At the time of writing, two orebodies are in production (Orebodies B1 and B2 also referred to as Lift 1) with additional orebodies coming online in 2021 (Orebody B3) and in 2023 (Orebody C Zone) (Figure 20). The mine has a target production rate of 15,600 tonnes per day (RPA, 2020). The block caving method used on site involves undermining the orebody, causing it to progressively collapse under its own weight eventually resulting in large areas of subsidence on surface (Geoengineering.com, 2018).

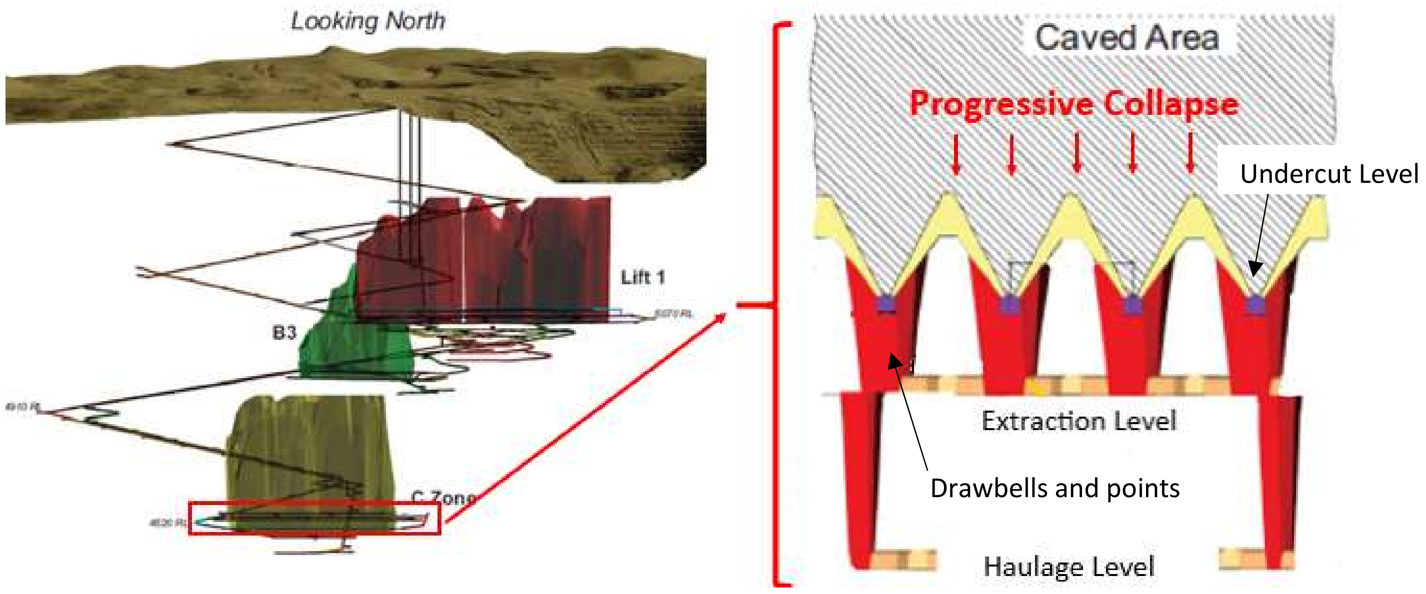


Figure 20. Orebody layout and mining method at New Afton Mine (RPA, 2020)

To access the ore bodies, the following major mine infrastructure has been constructed or installed (RPA, 2020):

- Ramps, declines, undercut drifts, extraction drifts, haulage drifts, access drifts, and ore and waste passes to the haulage level
- Gyratory crusher and back up jaw crusher in the mine and a conveyor system from gyratory crusher to surface
- Belt plow on conveyor at surface for segregation of waste
- Refuge stations and Alimak elevator as emergency exit
- Mine dewatering system
- Mine communication system including telephone, radio network, asset tracking system, and video monitoring systems
- Monitoring and control systems for pumps, fans, and ore pass conveyors
- Electrical power distribution system
- Explosives magazines
- Underground maintenance shop and fuel station
- Mine ventilation fans and associated raises and auxiliary distribution systems

The following figures (Figure 21 and Figure 22) are included to provide an overview of the underground and surface layout of the mine and its' infrastructure.

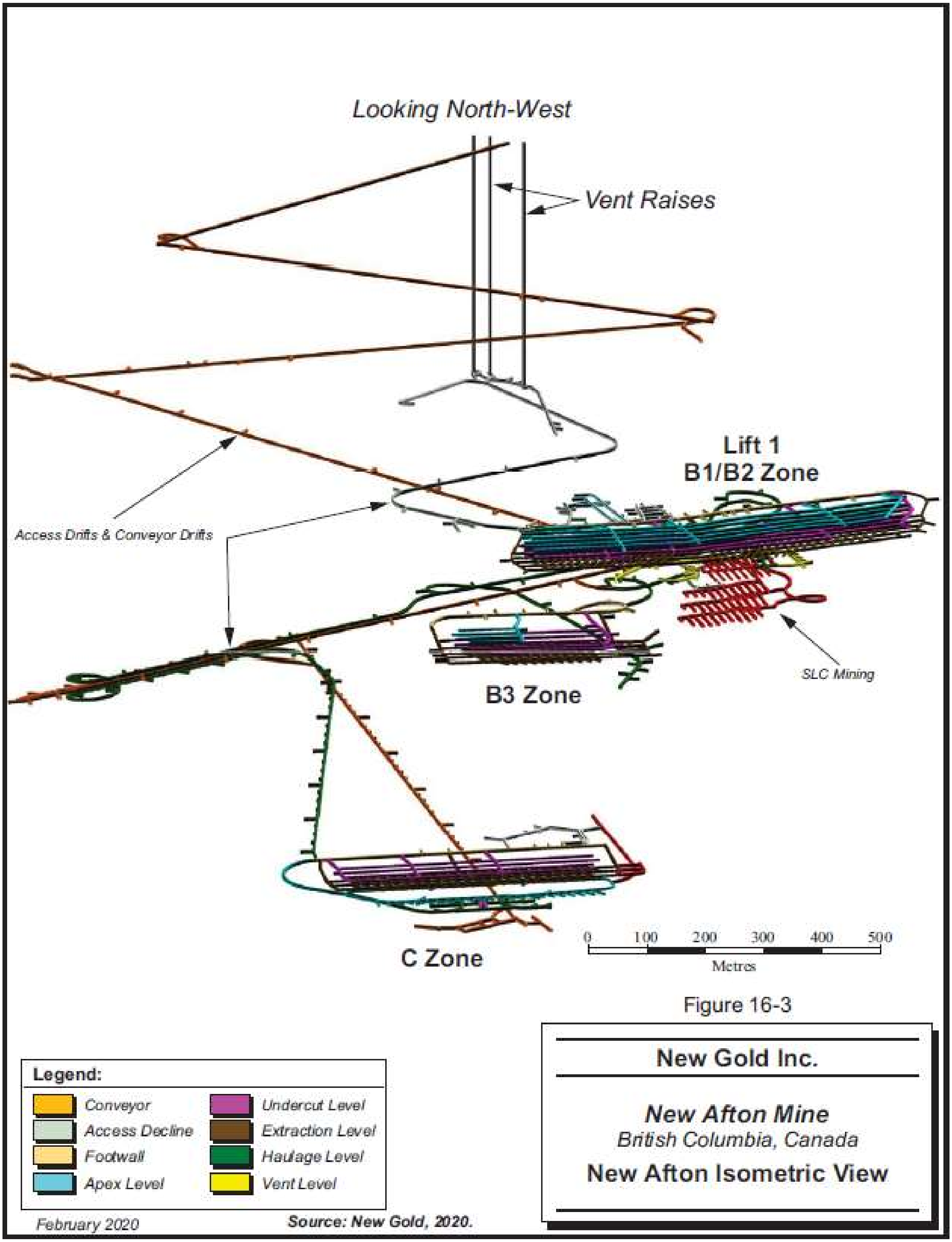


Figure 21. Underground layout of New Afton Mine (RPA, 2020)

Figure 22. Surface infrastructure of at New Afton Mine (RPA, 2015)

4.4.2.2 Underground materials handling

The typical layout of the production levels is presented in Figure 20. Caving of each orebody is initiated via blasting of undercuts on the respective undercut level. Extraction occurs at drawpoints on the extraction levels (one for each orebody) located below the undercut levels from which ore is continuously drawn via scoops or load, haul, dumps (LHD) (assumed to have 10t capacity (Caterpillar, 2018b)). Material is moved from extraction levels to haulage levels via ore passes with one ore pass dedicated to each undercut. These ore passes have capacities that range between 250 to 950 tonnes depending on location. The maximum tram distance from any drawpoint to the local ore pass is 150 m. Waste material extracted from the cave is also handled through these ore passes and stockpiled into two waste storage bays with a combined capacity of 4000 tonnes on the haulage level (RPA, 2020).

Ore and waste are then hauled by LHD and trucks and dumped directly to the underground crushing and conveying system. Run of mill ore is crushed to minus 150 mm (more typically 90 mm) via a 1.1m by 1.8 m, 447 kW gyratory crusher with double dump pockets and a capacity of 15,000 tonnes per day (Cooper, 2020; FLSmidth, 2021; and RPA, 2020). A back up jaw crusher is also located underground with a capacity of 6,700 tonnes per day (RPA, 2020).

Material from the crusher is fed to a series of 4 conveyor belts installed in conveyor declines/drifts that transport material to surface (Table 14). The conveyor system is suspended from the ceiling, or back, of a series of conveyor declines that allow vehicle travel underneath. Peak capacity for the system is 1,200 tonnes per hour but more typically averages 1,000 tonnes per hour. The system can be run remotely through shift change but will shut down once belts are emptied.

Table 14. Particulars of the conveyor system at New Afton Mine (Cooper, 2021)

Conveyor	Length (m)	Grade (%)	Motor rating (kW)
U2	1,179	16.9	Two at 522
U3	1,180	16.7	Two at 522
U4	839	16.7	Two at 447
U5	647	16.7	Two at 447

For the new orebodies coming on-line, material will be trucked from the B3 zone up the ramp to the gyratory crusher and a second crusher will be installed in the C zone and the conveyor systems will be extended to collect material from this crusher (RPA, 2020). Waste is moved up the conveyor system in batches and diverted to waste stockpiles on surface using plows on the conveyor system (RPA, 2020).

4.4.2.3 Ventilation

The ventilation system consists of a push-pull system with three intake and three exhaust fans (see Figure 23). Three 596 kW fans are located in the three intake shafts (one fan per shaft) and three 447 kW fans in the three exhaust raises; air is also exhausted out the conveyor portal. Intake rate through the three parallel shafts is 543 m^3/s. Based upon diesel consumption at the mine in 2020 and assuming a mine ventilation requirement of 0.06 m^3/s per kW as prescribed by the provincial government, this intake rate exceeds the estimated ventilation rate requirement of 463 m^3/s (Cooper, 2020 and Government of British Columbia, 1997).

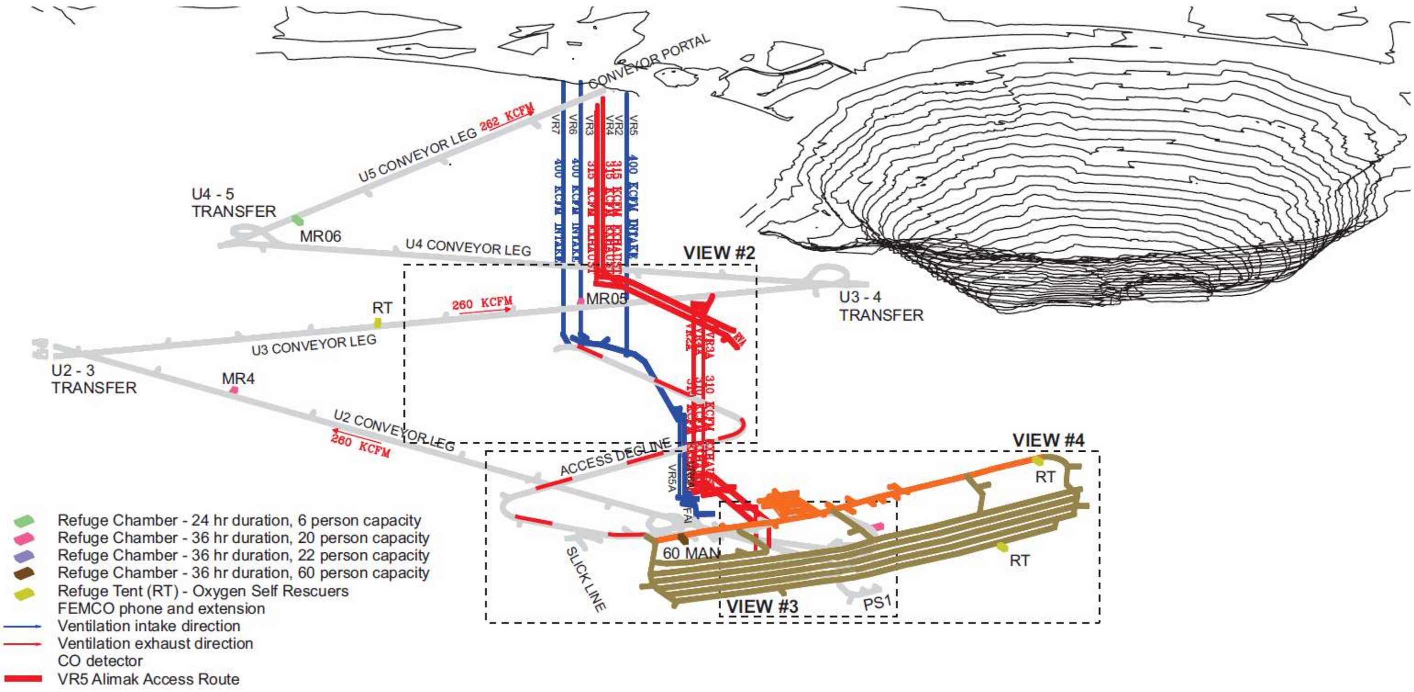


Figure 23. Underground layout of New Afton Mine circa 2015 showing main ventilation shafts (RPA, 2015)

At the top of the decline this flow is split with most going down the access drift to the B1 and B2 zones. All major production areas are supplied via flow through ventilation design while development areas in the mine are supplied via auxiliary ventilation (RPA, 2020). New orebodies will also be supplied by this system as they come on line. Fresh air will be supplied to each new orebody via access and haulage drives and newly constructed raises with auxiliary fans used to supply work areas. These areas will be exhausted via newly constructed raises to the existing exhaust raises and conveyor drive (RPA, 2020).

4.4.2.4 Water management

Due to local conditions, the mine has a negative net water balance and pumps water from Kamloops Lake (roughly 4 km to the northwest of the mine) as needed. This water is used for process water, dust suppressant, fire control, and drilling. Current water license allows for a maximum collection rate of roughly 292 m^3/hr with a proposed increase to 420 m^3/hr being considered to accommodate increased mining activity as new orebodies come on-line.

Mine and ground water is collected by a dewatering system that reports to the tailings storage facility (RPD, 2020). The system collects mine water, water that has entered the mine through the breakthrough to the pit, and groundwater inflow. Additionally, the Afton pit has been dewatered and surrounding wells are used to facilitate dewatering. The mine dewatering system includes multiple sumps and three pumping stations in series with two 240 m^3 capacity, 149 kW vertical sumps located at the bottom of B1/B2 development. Sumps outflow to a dewatering system of three booster stations along a 200 mm dewatering line (Cooper, 2021).

The system cycles three times every 24 hours running for two hours. Groundwater inflow and mining water consumption adds 20 m^3/hr to the system and discharge pumping rate is estimated to be 13 m^3/hr with an additional 10 m^3/hr discharged with the ventilation air via evaporation (RPA, 2020). The maximum pumping rate of the system is 150 m^3/hr but typically operates at 90 m^3/hr. Recovered water is pumped to the tailings storage facility along with the tailings slurry (RPA, 2020).

4.4.2.5 Processing

Once transported to surface via the conveyor system, waste and low grade ore (i.e., between 0.82 to 0.75% copper and 0.34 to 0.68 grams per tonne gold) is diverted from the mill feed to dedicated stockpiles. High grade ore discharges to a 120,000 wet metric tonne live capacity stockpile from which ore is sent to two 1.8 m by 11 m apron feeders into a three stage grinding circuit in the on-surface mill. This circuit consists of a primary 5,220 kW semi-autogenous grinding (SAG) mill, a secondary 5,220 kW ball mill and a tertiary 2,200 kW vertimill. Ground material then enters a multi-stage flotation circuit, including a regrinding circuit, that separates metal bearing minerals from barren rock material (tailings). Tailings are diverted to on-surface tailings facilities and separated minerals are dewatered to form a concentrate in the concentrate thickener. The resulting concentrate is then hauled off site to the Port of Vancouver for shipping (RPD, 2020). An overview of the process flow diagram for the site is presented in Figure 24.

4.4.2.6 Surface infrastructure

The surface infrastructure at the mine includes:

- Administration and operating/technical offices, security posts and a first aid room and ambulance
- Mine rescue equipment and facilities
- Fresh water supply (4 km pipeline to Kamloops Lake and pumphouse)
- Concrete batch plant and a shotcrete batch plant on surface near the mine portal
- Sub-station and connection to the BC Hydro grid for power
- Surface maintenance shop, warehouse, and fuel storage facility
- Main mine fans
- Compressor building
- Control room for automated tramming on the extraction level (5,070 m elevation)

4.4.2.7 Waste management

There are two active and one historical tailings storage facilities on site as shown in Figure 22. The New Afton Tailings Storage Facility is the main active facility and was constructed in 2013 and is currently receiving thickened tailings. There is an auxiliary tailings storage facility on site to provide contingency tailings and water storage. The historical tailings storage facility was used to store tailings when the open pit was in operation on site from 1976 to 1997 (RPA, 2020).

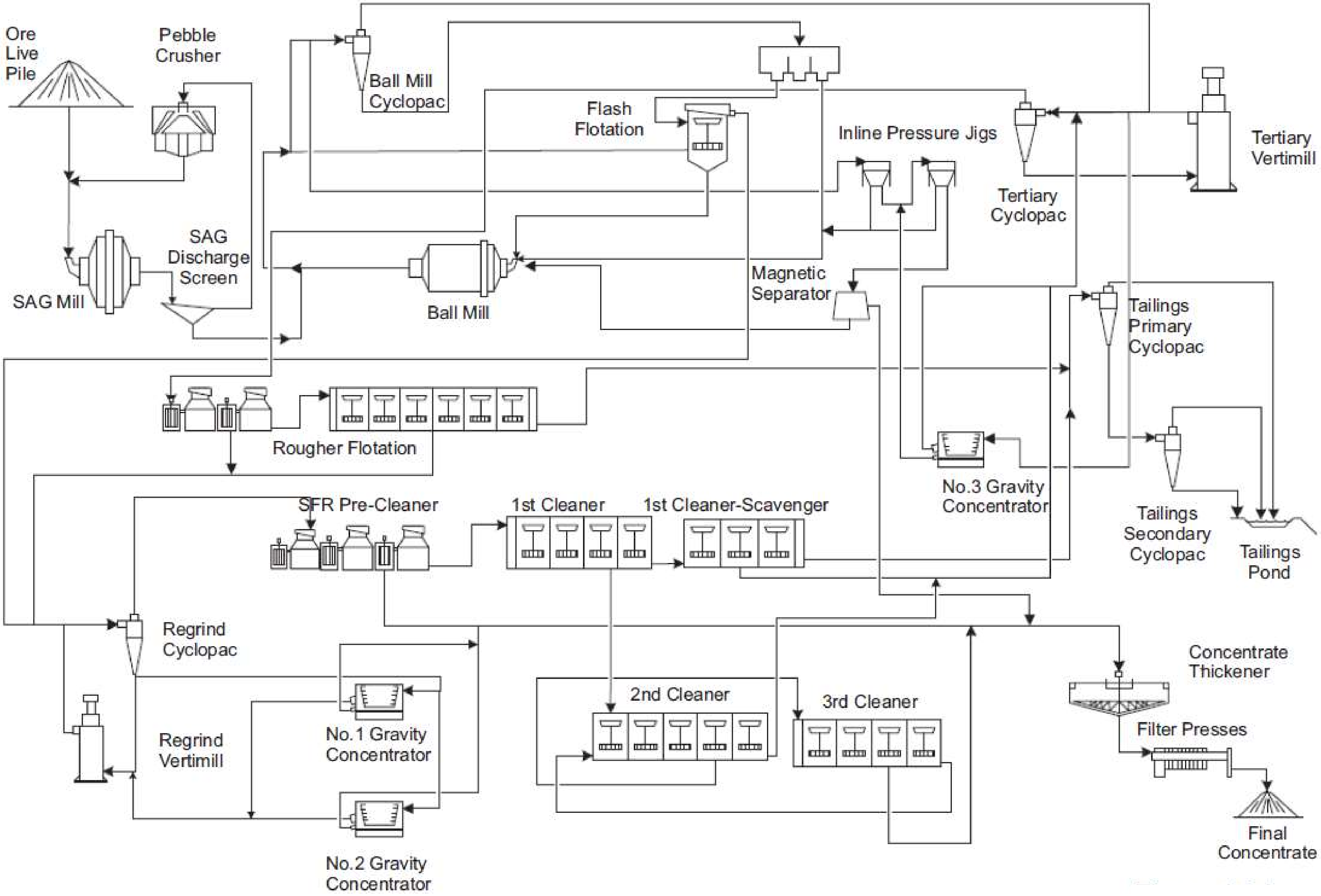


Figure 24. Simplified milling process at New Afton Mine (RPA, 2020)

4.4.3 Measured energy consumption by energy type

A summary of major energy consumption on site between 2012 and 2020 was provided by mine staff and included: i) annual energy consumption aggregated by end use including grinding, flotation, tailings, crushing and conveying, ventilation, mobile equipment, compressed air, and cooling systems, and ii) by energy type including electricity, diesel, gasoline, natural gas, propane and explosives (Cooper, 2020). Yearly measured energy consumption totals and the resulting GHG emissions are presented in Table 15. For this time period, production and energy consumption peaked in 2017 at 5.99 million dry tonnes consuming 324 GWh.

The average energy intensity for the mine is 57.8 MWh/kt milled, lower than the sector average from 2012 to 2018 (data to 2020 was not available) of 115 MWh/kt milled (Table 4); both energy intensities are for the mining and beneficiation of ore to concentrate. Similarly, the emissions intensity at New Afton Mine between 2012 and 2020 is also low at an average of 0.004 tCO_2e/milled t (or 0.015 tCO_2e per gram of gold produced) when compared to the gold and silver mining industry on whole at 0.014 tCO_2e/milled t between 2012 and 2018. It should be noted that New Afton emissions include direct emissions from energy produced on site, and indirect emissions from energy produced off site (electricity). However, it is not known if the industry value of 0.014 tCO_2e/milled t includes both types of emissions or direct emissions only. It was also not possible to discern open pit from underground mine energy consumption in the industry data presented in Chapter 3. However, comparing to the energy intensity of mining at Garson Mine of 226 kWh/t prior to milling indicates that New Afton operations may indeed be less energy intense than other underground operations.

Table 15. Measured energy consumption and resulting GHG emissions at New Afton Mine between 2012 and 2020 (Cooper, 2020)

Calendar year (Year)	Life of mine year (Year)	Milled (M t)	Electrical (GWh)	Diesel (GWh)	Natural Gas (GWh)	Gasoline (GWh)	Explosives[1] (GWh)	Propane (GWh)	Total energy (GWh)	Energy intensity (kWh/t milled)	Total emissions[2] (tCO_2e)	Emissions intensity (tCO_2e/t milled)
2012	1	2.00	90.6	42.7	8.5	1.41	1.44	1.09	146	72.9	16,600	0.008
2013	2	4.09	186	41.9	13.0	1.44	0.79	0.30	243	59.6	16,100	0.004
2014	3	4.76	197	35.4	19.5	1.26	0.67	0.18	254	53.3	15,700	0.003
2015	4	5.10	219	38.1	14.4	1.10	0.38	0.15	273	53.6	15,700	0.003
2016	5	5.77	239	51.1	15.4	1.19	0.47	0.13	307	53.2	18,200	0.003
2017	6	5.99	246	54.6	21.4	1.21	0.35	0.16	324	54.0	20,200	0.003
2018	7	5.35	220	39.7	18.7	1.10	-	0.18	280	52.2	15,800	0.003
2019	8	5.58	233	64.3	19.9	1.18	0.39	0.18	319	57.1	22,200	0.004
2020	9	5.53	236	67.7	16.6	1.16	0.89	0.26	323	58.3	27,100	0.005
2021[3]	10	4.89	229	62.6	17.4	1.08	1.05	0.24	311	63.7	29,500	0.006
Total		49.07	2,097	498	165	12.1	6.43	2.87	2,780		251,300	
Average		4.91	210	49.8	16.5	1.21	0.64	0.29	278	57.8	25,100	0.004

1. Measured explosive consumption in 2018 was reported as zero. It is unclear if this is a reporting error or if it reflects the use of explosives predominately for lateral development with no lateral development occurring in 2018.
2. Direct emission from energy produced on site (consumption of hydrocarbons, etc.) and indirect emissions from energy produced off site (electricity).
3. These values were not provided by site staff, but were collected from Mining Data Solutions (2022), inferred from GHG reporting Government of British Columbia (n.d.), and sustainability and financial reports produced by New Gold (New Gold Inc., 2022)

As expected, there is a strong, positive relationship between energy consumption and production rates (Figure 25) with 53% of the energy consumed on surface in the mill and tailings management areas and the remainder consumed underground (Cooper, 2020).

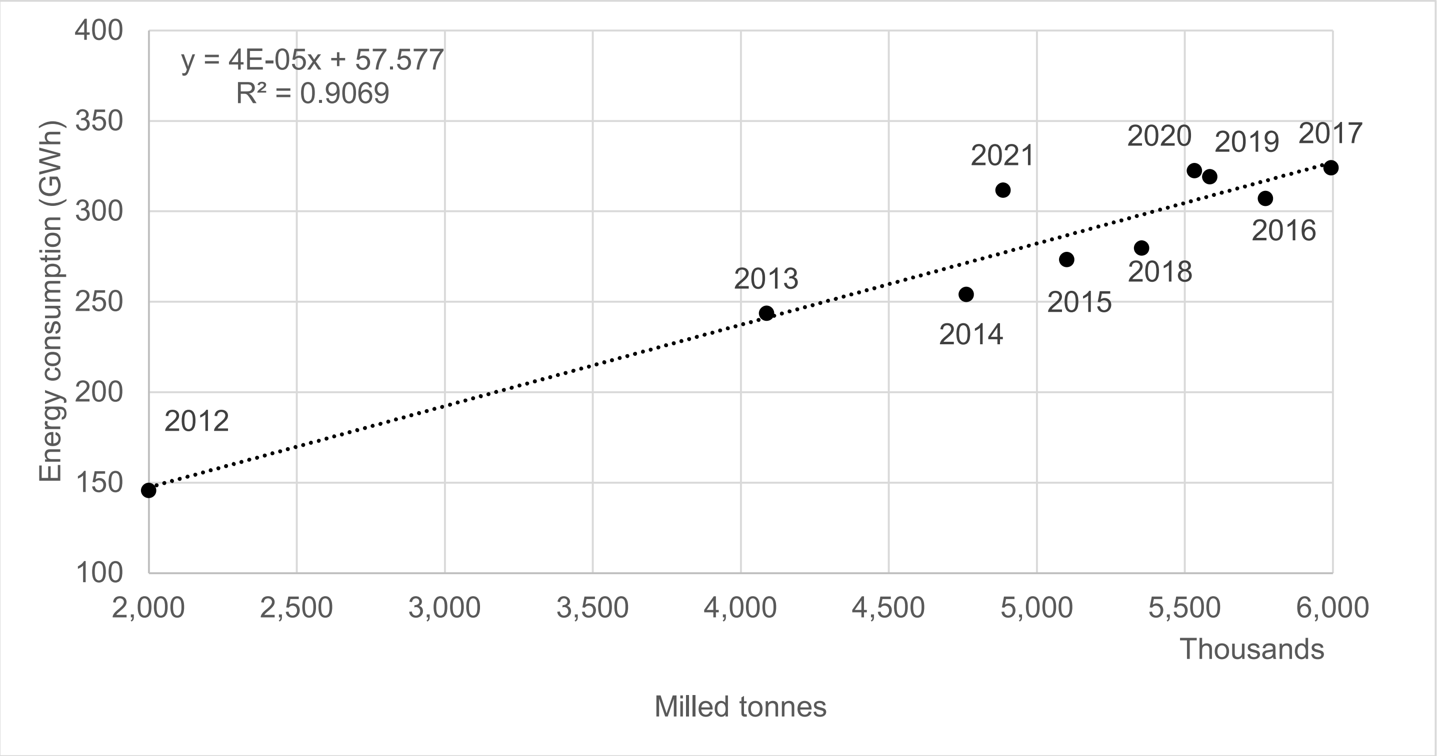


Figure 25. Measured energy consumption in relation to milled tonnes at New Afton Mine between 2012 and 2021 (Cooper, 2021).

4.4.3.1 Estimated disaggregated energy consumption

To provide further insight on disaggregated energy use at the mine, energy consumption was estimated for the mobile equipment fleet listed in the 43-101 report and other major stationary equipment where detail on power ratings was available to make such estimates in a reasonable manner (RPA, 2020).

Estimates for mobile equipment were made for both diesel consumption and electrical consumption for that equipment that may tram using a diesel engine but operate most of the shift on electricity; these included jumbos and drills. These estimates are presented in Table 16. Power ratings for the diesel engines and electric motors were determined from vehicle specifications provided by the equipment manufacturers (Caterpillar, 2021b;

Kubota Canada, 2021; MacLean Engineering, 2021; and Sandvik, n.d.). Diesel engine efficiency was assumed to be 35% for all equipment and a 94% electric motor efficiency was assumed for the equipment with electric motors; assumed load factors are presented in Table 16 (Barnes and Miller, 2002; nuclear-power.com, n.d.; Skawina, 2019; and Varaschin and De Souza, n.d.). Availabilities and utilities were taken from the 43-101 report or literature and duty cycle information was gleaned from the 43-101 report and other publicly available information for the site (Arputharaj, 2015; RPA, 2015; and RPA, 2020). It was assumed that all equipment operated for 360 days per year. Resulting energy consumption estimates for diesel were converted to litres consumed assuming that combusting one litre of diesel produces 10.6 kWh of energy (Deep Resource, 2012).

Table 16. Estimated energy consumption of the mobile fleet at New Afton Mine in a year

Equipment information					Duty cycle information					Energy consumed per year		
Type	Model	Diesel power rating (kW)	Electric motor power rating (kW)	Quantity	Load factor	Availability	Utility	Diesel (hours per day)	Electric (hours per day)	Diesel (litres)	Diesel (MWh)	Electricity (MWh)
Drill jumbo	Sandvik two boom	110	150	4	60%	81%	60%	2	16	24,900	260	3,800
Rock bolter	Tamrock/Sandvik Bolters	74	70	6	60%	84%	60%	2	16	26,100	280	2,700
LHD	Sandvik LH410	220		2	78%	84%	60%	16	-	267,800	2,840	
	CAT R1600	208		10	78%	84%	60%	16	-	1,266,200	13,420	
	CAT R2900G	305		4	78%	84%	60%	16	-	742,500	7,870	
Truck	CAT AD45	447		7	78%	88%	60%	16	-	1,993,600	21,130	
Long hole drill	Sandvik DL 420 & 430	110	90	3	60%	81%	60%	2	16	18,700	200	1,700
Explosives	Emulsion & ANFO Loaders	97	37	1	60%	80%	60%	2	16	5,400	60	200
Concrete mixer	Transmixers	144		5	60%	75%	60%	4	16	75,400	800	
Shotcrete	Normet Sprayers	74	70	3	60%	80%	50%	4	16	20,700	220	1,300
Utility	Scissor deck, boom truck & other	144		8	40%	80%	50%	2	16	35,800	380	
	Maclean Blockholer	144		1	50%	80%	60%	2	16	6,700	70	
	CAT Skid Steer	50		2	50%	80%	48%	12	-	22,300	240	
	CAT 140 M Grader	136		2	50%	80%	48%	12	-	60,800	650	
	CAT TH407 Telehandler	75		4	40%	80%	48%	4	-	17,800	190	
	CAT 930G IT Loader	111		4	40%	80%	48%	4	-	26,500	280	
	Kubota tractor/loader	56		2	40%	80%	48%	16	-	26,700	280	
	Personnel vehicles	100		33	40%	80%	20%	10	16	204,800	2,170	
Total										4,842,496	51,330	9,839

Resulting estimates were then compared to the energy consumption totals for the year 2020 for significant energy users provided by site staff indicating a 3% difference between measured and estimated totals for underground diesel usage (50,025 MWh of measured diesel consumption in 2020 (Cooper, 2021)). It was assumed that all 123 pieces of equipment listed in the 43-101 report operated underground and consumed diesel although it is feasible that some equipment listed consume gasoline (e.g., personnel vehicles). Site staff also confirmed that measured diesel was consumed by contractors expanding the tailings impoundment area, but this equipment did not seem to be included in the equipment list in the 43-101 report and will be addressed later in this chapter (Cooper, 2021). When reviewing these estimates it is unsurprising that the majority of the diesel is estimated to be consumed by equipment associated with material handling; specifically, the LHD and trucks.

4.4.4 Energy consumption by end use

Based upon power ratings provided by site staff, energy consumption for stationary equipment was also estimated (Table 17) (Cooper, 2020). An electric motor efficiency of 94% was assumed and duty cycle details were assumed based on descriptions in the 43-101 where available and inferred as typical for the industry where not (Skawina, 2019 and U.S. Department of Energy, 2014). It was assumed that the equipment would operate 360 days of the year. The resulting estimates were compared to measured values provided at the location level by mine staff for 2020 indicating a 3% difference (Cooper, 2020).

Table 17. Estimated energy consumption of the stationary equipment at New Afton Mine in 2020

Stationary equipment				Duty cycle	Energy consumption
Location	Type	Motor rating (kW)	Quantity	hours per day	Electricity (MWh/annum)
Grinding	SAG mill	5,593	1	24	45,400
	Ball mill	5,593	1	24	45,400
	Tertiary vertimill	2,237	1	24	18,200
	Cyclone feed pump	746	1	24	6,100
	Pebble crusher	447	1	24	3,600
Tailings	Tailings pumps	522	3	10	5,300
Crushing and Conveying	Conveyor [1]	3,878	1	16	21,000
	Gyratory crusher	447	1	16	2,400
Ventilation	Supply fans	597	3	22	13,300
	Exhaust fans	447	3	22	10,000
	UG fans	1,119	1	22	8,300
Mill Compressors	Compressors	261	3	20	5,300
Mill Cooling	Cooling units	93	1	10	300
Total					184,679

1.This motor rating is a summation of those described in Table 14

4.4.4.1 Variables impacting energy consumption

To establish relationships between energy consumption and mine operation at the New Afton site, a review of past site activity was undertaken to determine the impact upon the reported energy consumption from 2012 to 2021. Activities or variables thought likely to impact energy consumption at New Afton Mine included:

- Production Effort – For the purpose of this analysis, production effort was expressed as measured milled tonnes per year provided by site staff. Review of the 43-101 reports indicated that production effort ramped up from mid-2012 to roughly 13,000 tonnes per day by mid-2013 and then increased following a mill capacity increase to 15,000 tonnes per day in 2015.

- Tailings Construction – Tailings construction on site has been undertaken multiple times by contractors and diesel consumption for this purpose has been identified in some measured data provided (Cooper, 2021). Tailings construction on site is expected to wrap up in 2021.

- Development Effort – Information on site development was limited and a mix of actual development reported in the 43-101 and scheduled development that was not confirmed to have been completed. Years in which development effort was assumed to be high was during mine ramp up in 2012 and 2013 and as new orebodies were developed in 2019 and 2020. No lateral development occurred in 2018.
- Heating Degree Days – Heating of the ventilated air using natural gas is required when local temperatures were below 2 degrees Celsius based on information provided by site staff (Cooper, 2021). Propane was also used for heating of surface buildings not supplied with natural gas.

Given that the site operates as a block caving facility, the 43-101 report suggests mining depth and hauling distances offered minimal variability over the time period being considered and not likely to result in significant variability in the measured energy consumption. A summary of activities at the mine with the potential to impact energy consumption is presented in Table 18 where the intensity of the activity is represented by colour: orange, yellow, green, and no colour representing high, moderate, low and minimal intensity, respectively. This intensity was inferred from the 43-101 reports for the site, quarterly and annual reporting, and sustainability reports produced by New Gold (New Gold Inc., 2022; RPA, 2015; and RPA, 2020).

Table 18. Site activities at New Afton Mine expected to impact energy consumption

Year	Development effort	Production effort	Tailings construction
2011	Ramp up Lift 1 development	No production	Construction of New Afton Tailings Storage Facility
2012	Ramp up Lift 1 development	Production commences mid-year	Construction of New Afton Tailings Storage Facility complete by mid-year
2013	Sustaining development of Lift 1	Nameplate production achieved mid-year Mill capacity 13,000 tonnes per day	Dam raise
2014	Sustaining development of Lift 1	Mill capacity of 13,000 tonnes per day Mill expansion	Dam raise
2015	Sustaining development of Lift 1	Mill capacity of 13,000 tonnes per day until mid-year Mill expansion completed mid-year with new capacity of 15,000 tonnes per day	Geomembrane installation and dam raise
2016	Sustaining development of Lift 1		Dam raise
2017	Sustaining development of Lift 1		
2018	No development		No diesel consumed by tailings contractors was reported, but dams raised annually until 2021
2019	Minimal development until mid-year when development commences on B3 and C Zone		Dams raise
2020	Development of B3 and C Zone		Dams raise
2021	Development of C Zone	New orebodies brought on-line	Tailings construction wraps up

4.4.4.2 Establishing relationships to predict energy consumption

As presented in Figure 25, a strong, positive relationship between measured energy consumption and production effort expressed as milled tonnes was confirmed. However, review of the scatter of the data points and the activities outlined in Table 18 suggest complexities within this relationship warranting investigation to better understand energy consumption at block cave mines. Data presented in graphs in this section is produced from the measured data presented in Table 15 unless otherwise specified.

4.4.4.2.1 Electricity

Reviewing measured data, electricity consumption proved to have a strong, positive relationship to milled tonnes similar to that shown for all energy consumed on site in Figure 25. This is not unexpected given that electricity is the most consumed energy type on site and the mill is the major consumer of electricity, but outliers were observed as a result of ramping up during 2012 and 2013. Considering intensity of both variables as a function of time improved the relationship by normalizing the production occurring during the ramp up years (Figure 26).

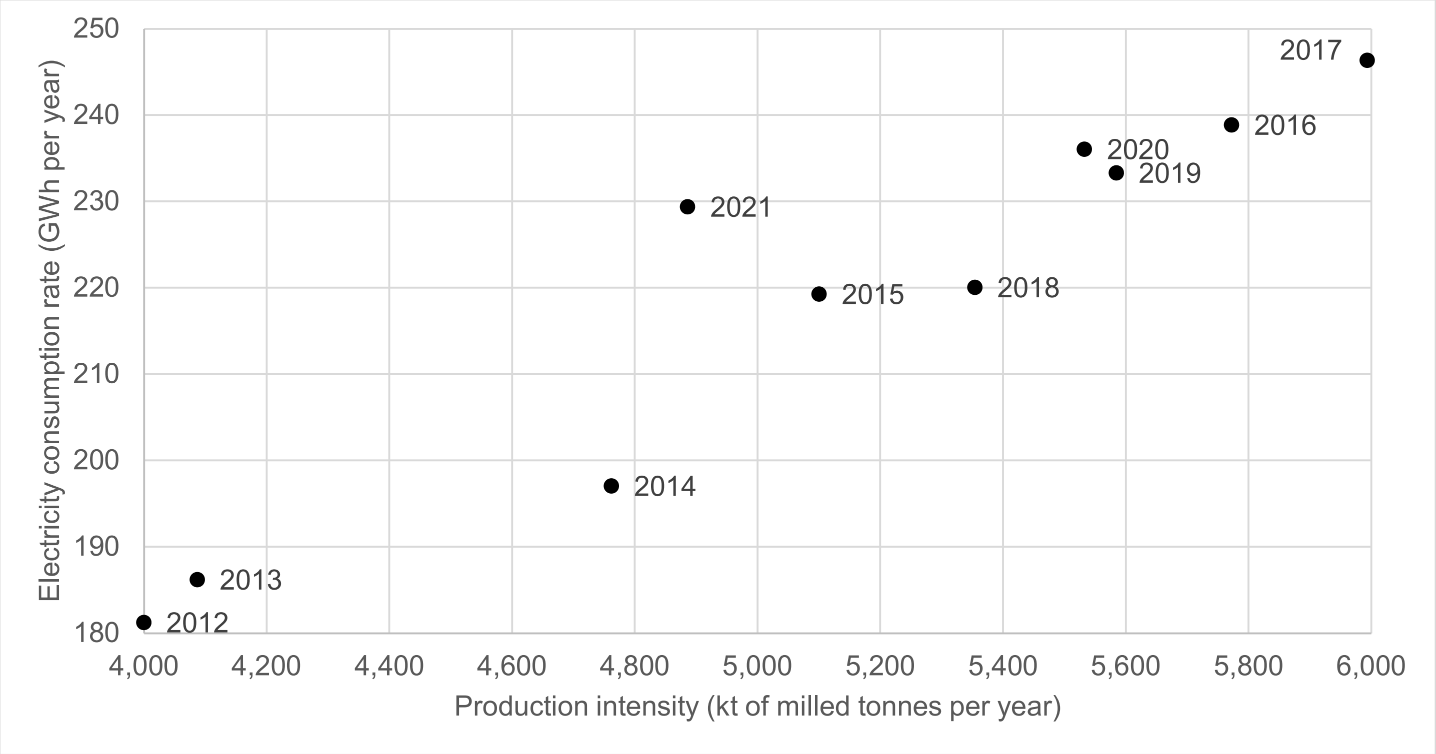


Figure 26. Electrical energy consumption rate at New Afton Mine between 2012 and 2021 in relation to production intensity

It is known that a mill upgrade was completed by mid-2015 when capacity increased from 13,000 tonnes per day to 15,000 tonnes per day. Review of Figure 26 and grouping the data points by mill capacity suggests the rate of consumption of electricity in relation to production intensity changes following this upgrade. To better understand the impact of the mill upgrade upon energy efficiency, electricity energy consumption was normalized to milled tonnes produced (referred to as specific electricity consumption) and plotted against production intensity defined again as milled tonnes normalized by time (Figure 27).

Reviewing Figure 27, the impact of the mill upgrade upon electricity consumption at New Afton Mine becomes more clear with increased efficiency of milling process post-2015 upgrade resulting in data points being located to the lower right of the plot (i.e., less energy consumed per milled tonne while producing more tonnes) and the data points prior to the mill upgrade being located to the left of the plot with the ramp up years of 2012 and 2013 being least efficient in the upper left (i.e., more energy consumed per tonne to produce fewer tonnes). Lines defining these mill capacity regimes are included with blue lines representing a mill capacity of 13,000 tonnes per day and orange lines representing a mill capacity of 15,000 tonnes per day. Of these, solid lines represent suspected typical operation at these two mill capacities with low production operations for each being represented by coarse dashed line to the left and below the solid line and higher production operations by the fine dashed line to the right and above the solid line. Where a given year plots between these lines likely depends upon production interruptions, push by planners to meet operational targets, or increased consumption of electricity by other mining processes.

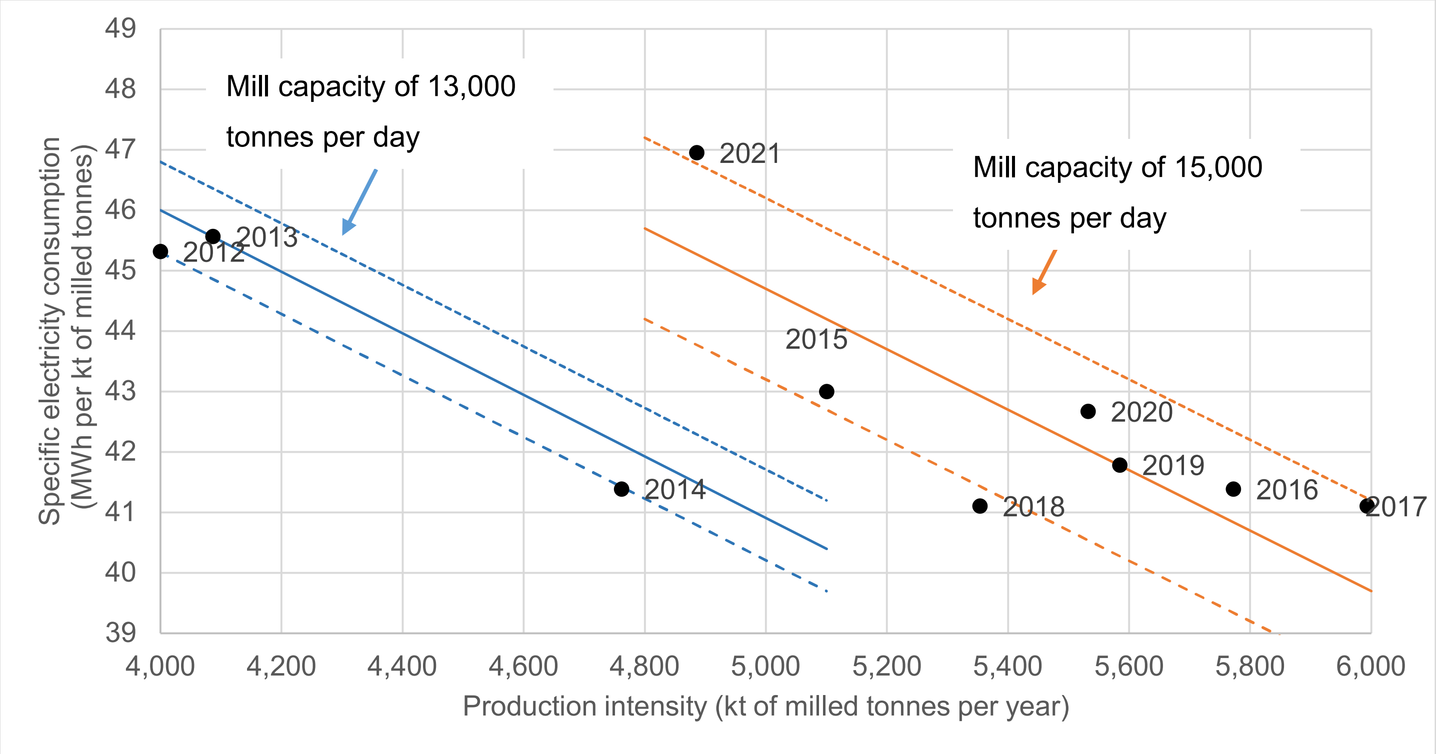


Figure 27. Specific electrical energy consumption at New Afton Mine between 2012 and 2020 in relation to production intensity

4.4.4.2.2 Diesel

Second to electricity, diesel is the other most consumed energy type. As diesel is consumed on site to support production efforts, development effort, and tailings construction, the relationship between diesel consumption and production represented as milled tonnes as presented in Table 15 is poor. To understand diesel consumption on site better, each consumption variable was considered separately by disaggregating the total diesel consumption based on information summarized in Table 18.

As outlined in Table 18, no lateral development occurred in 2018 and while tailings construction did, diesel consumed by the tailings contractors was not included in the measured diesel total for the year. This meant that the measured diesel consumption for 2018 of 0.69 litres per milled tonne represented production effort only. Using this value and measured milled tonnes, the diesel consumption for production effort was estimated for 2012 to 2021. To estimate the diesel consumed by the development effort, a consumption rate (litres per development metre) was estimated by dedicating the remaining measured diesel consumption not accounted for by tailings construction and production effort between 2012 to 2021 to development and relating that volume of diesel to the development activity inferred from the review of site activities summarized in Table 18. This produced a diesel consumption rate of 229 litres per development metre that was used to estimate diesel consumption by development effort for each year using yearly advancement values. Finally, diesel consumed by tailings construction was estimated for 2012 to 2021 by subtracting the estimated production effort and development effort diesel volumes from the measured diesel values for each year. As the review of site activities indicated that tailings construction occurred in 2012 and 2018 but no diesel consumption for tailings was reported, some diesel consumption was estimated for tailings construction during these years based on other consumption rates. Total estimated diesel consumption for each year from 2012 to 2021 was calculated by summing diesel estimated for production effort, development effort, and tailings construction. These values are present in Figure 28 normalized to time and plotted against production intensity represented by milled tonnes normalized to time.

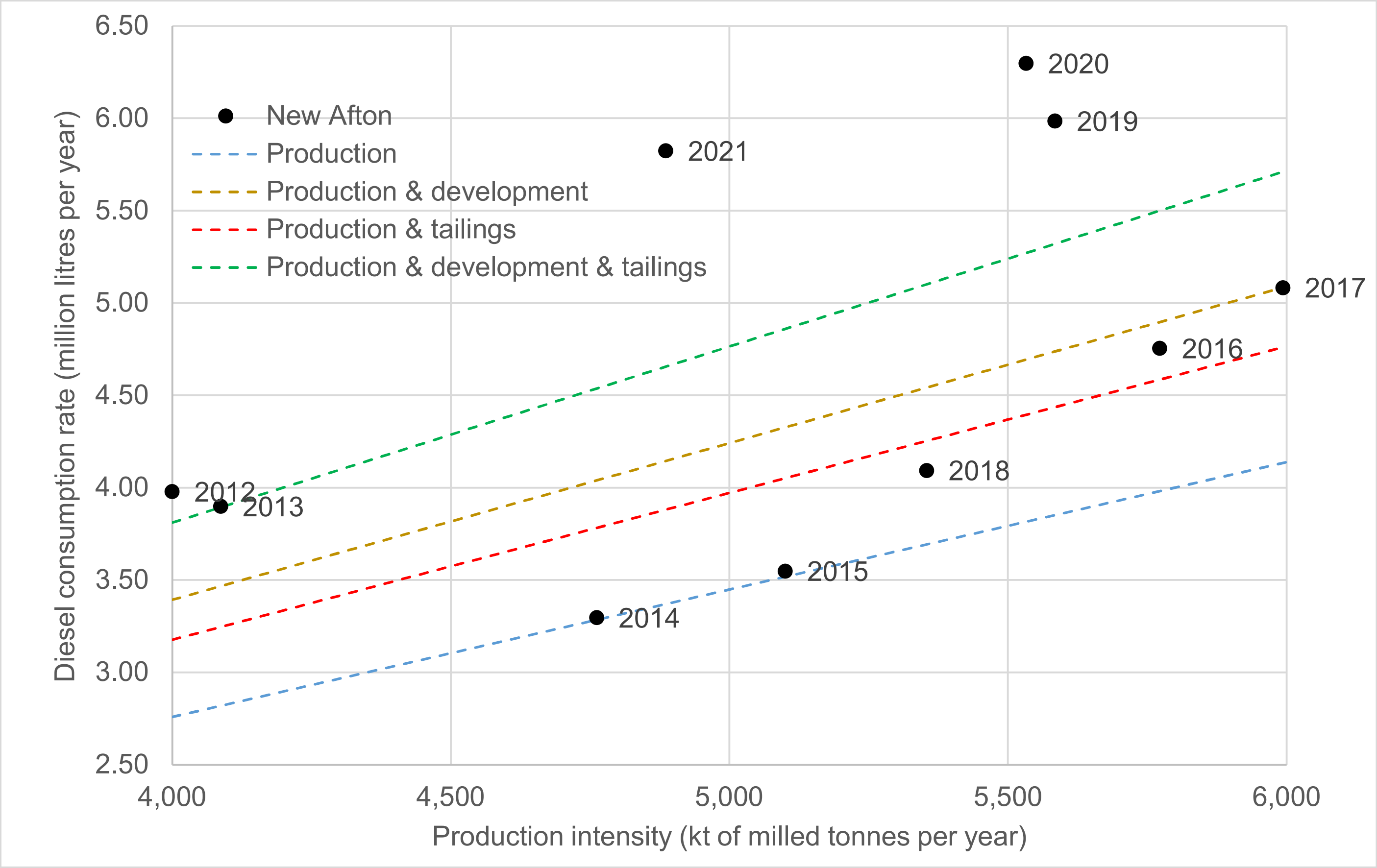


Figure 28. Estimated diesel consumption rate at New Afton Mine between 2012 and 2021 in relation to production intensity

Relating these estimated values to production represented by milled tonnes produced specific consumption rates for each variable of 0.69 litres of diesel per milled tonne for production effort, 0.16 litres of diesel per milled tonne for development effort, and 0.10 litres of diesel per milled tonne for tailings construction or 0.95 litres of diesel per milled tonne for all combined. These rates, in conjunction with the production intensities between 2012 and 2021 reported for the site, were used to produce the dashed lines on Figure 28.

Where the annual diesel consumption data points plot with respect to these lines defining production, development and tailings construction intensity compares well with the known site activities for these years presented in Table 18. Specifically, recent years where new ore bodies are being brought on-line and tailings construction occurs are plotting well above the production, development and tailings intensive line (green dash line) and years, like 2014 and 2015, where sustaining production during mill capacity expansion was prioritized are plotting at the production intensive line (blue dash line). It should be noted that the assumed diesel consumption for tailings construction in 2018 means that the that data point plots above the production intensive line defined by the measured diesel consumption for this year that reflects only production as previously mentioned. This correspondence between the data points and defined intensity lines suggests that these consumption rates represent a good model of diesel consumption for this block cave mine.

4.4.4.2.3 Natural gas

Natural gas is used at New Afton Mine for mine operations (predominately the heating of ventilated air for underground operations), mill operations, and surface and tailings operations. Using measured consumption data and a published greenhouse gas emissions profile for the site, it has been estimated that 41% of the consumed natural gas is used for mine operations, 32% for mill operations, and 24% for surface and tailings operations (with 3% uncertainty) (Cooper, 2021 and New Gold Inc., 2022). While natural gas is used for heating the mill, surface and tailings operations, little detail is available regarding disaggregated use. Site staff have indicated that ventilation fan heaters for underground operations typically only operate in winter when temperatures drop below 1°C, with one heater having a heating setpoint of 5°C and the other two have a heating setpoint of 2°C.

Considering this, the relationship between natural gas consumption and heating degree days was investigated for a number of heating degree day temperatures ranging from 2ºC to 40ºC for measured monthly consumption data in 2020 and annual consumption data from 2012 to 2021 (BiZEE Software, 2022). The relationship proved strongest (and comparable) for heating degree day temperatures of 7ºC and 3.5ºC and are presented for 7ºC in Figure 29 and Figure 30. It should be noted that the trend line is the same for both figures as it was developed considering the best fit to an aggregated data set including measured monthly consumption in 2020 and annual data between 2012 and 2021. Data was separated into two figures presenting monthly and annual data for presentation purposes but the trend line is a continuation from the monthly data to the larger consumption values of the annual data and shows good fit to both.

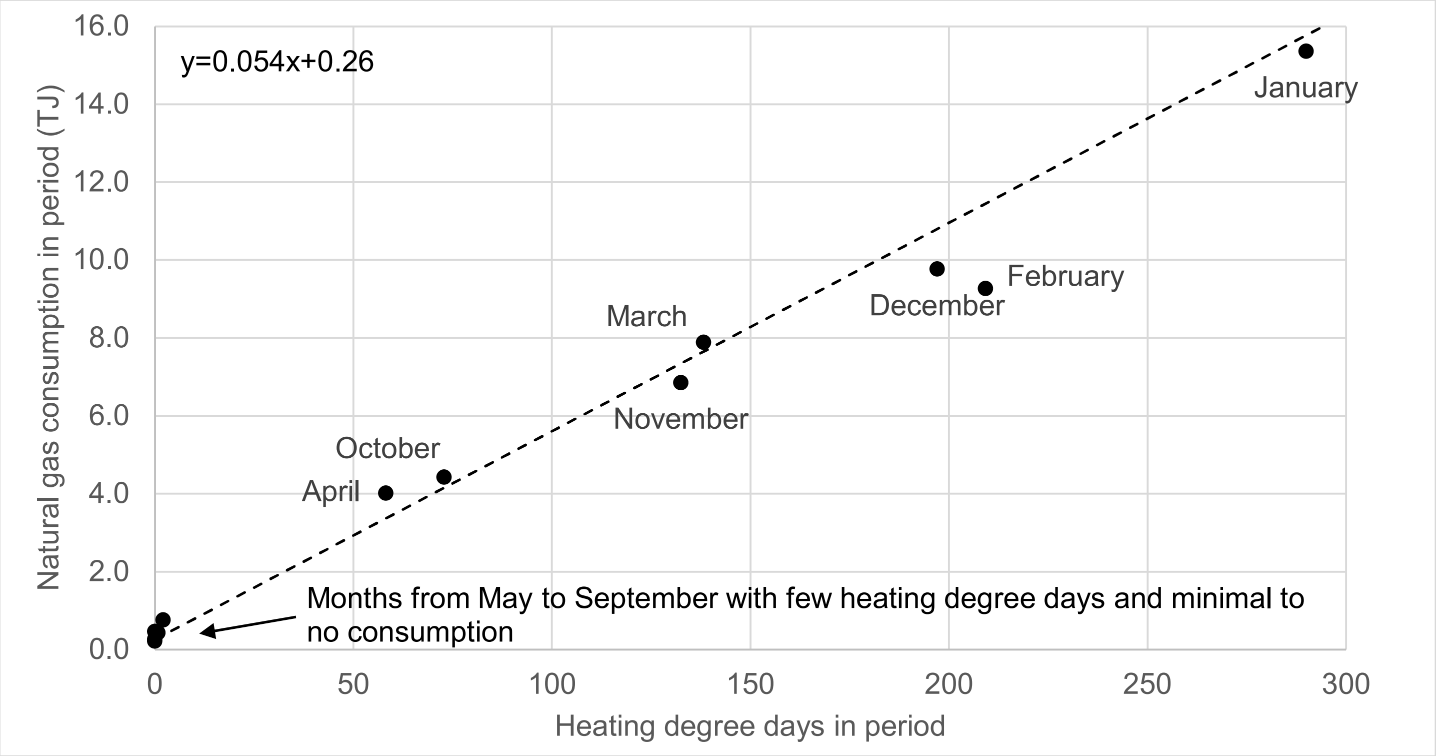


Figure 29. Measured monthly natural gas consumption at New Afton Mine in 2020 in relation heating degree days below 7ºC (BiZEE Software, 2022 and Cooper, 2020)

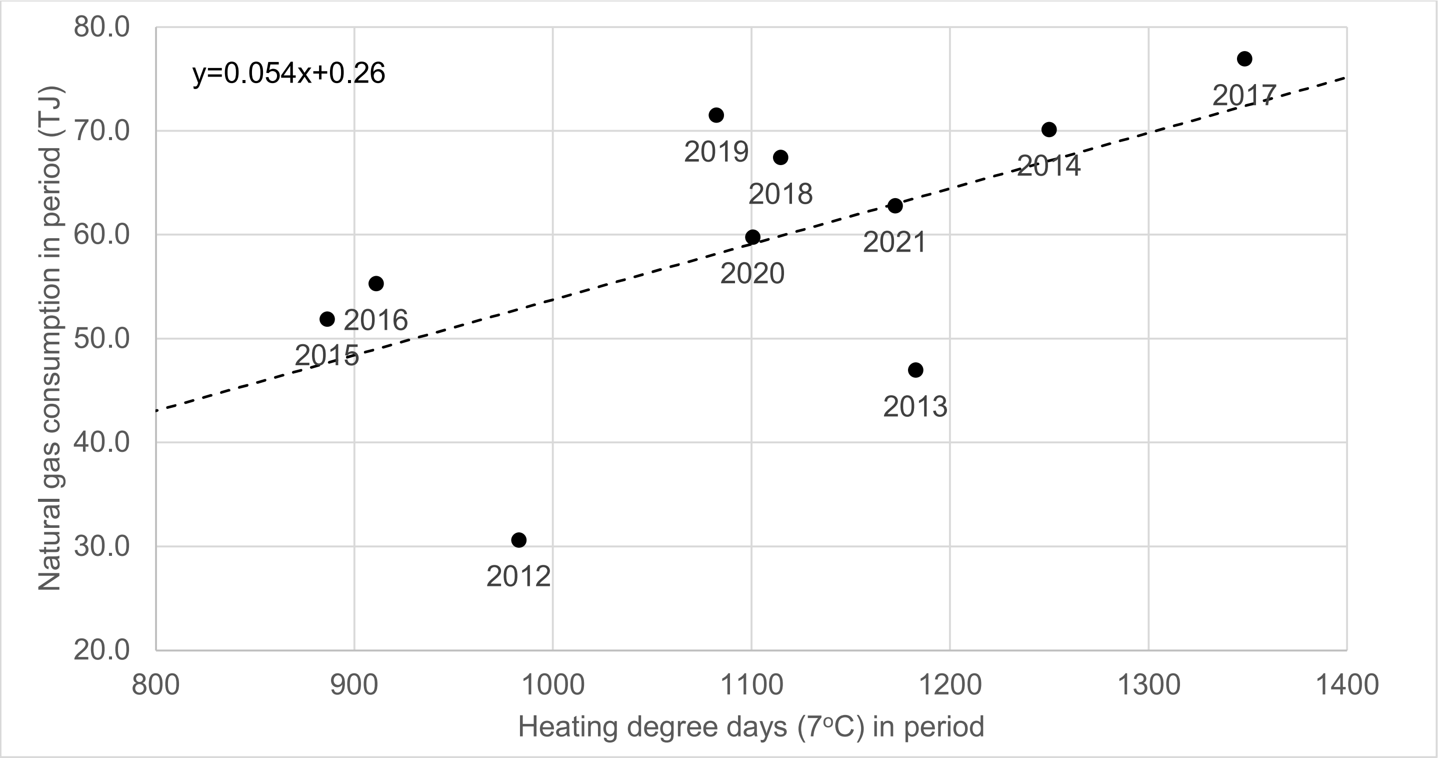


Figure 30. Measured annual natural gas consumption at New Afton Mine from 2012 to 2021 in relation heating degree days below 7oC (BiZEE Software, 2022 and Cooper, 2020)

4.4.4.2.4 Gasoline

With the exception higher consumption in 2012, 2013, and less so 2014, gasoline consumption shows minimal variation between years or based on production rates. This is not unexpected given that gasoline is consumed by surface vehicles only which were likely more active during ramp up years of 2012 to 2014 until the mill upgrade in 2015. When removing these years from the data set, a slightly positive relationship is observed between gasoline consumption and milled tonnes (Figure 31).

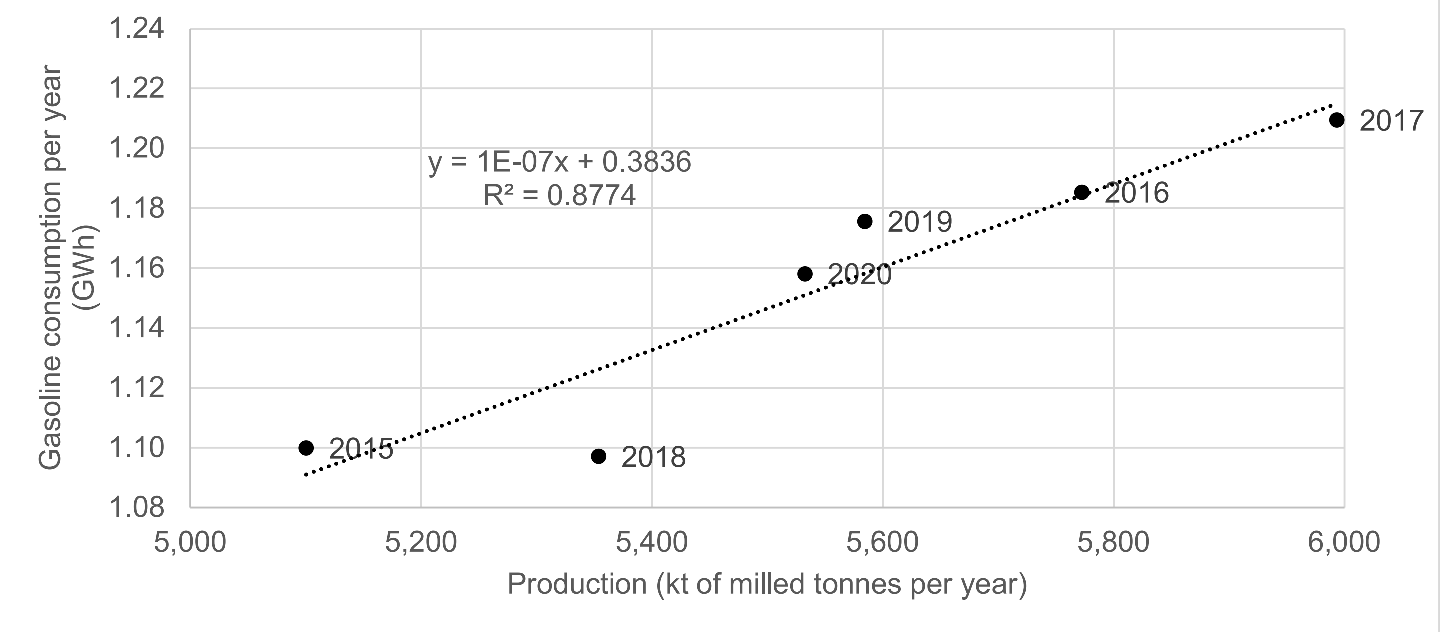


Figure 31. Measured gasoline consumption at New Afton Mine between 2015 and 2020 in relation to milled tonnes (Cooper, 2020 and RPA, 2020)

4.4.4.2.5 Explosives

Explosives at New Afton Mine are used predominately for development given that the block caves are intended to be self-propagating once initiated. The relationship between measured yearly consumption of explosives proved to have a strong, positive relationship to both development metres advanced gleaned from technical and annual reports for the site (Figure 32) and development diesel estimated in Section 4.4.4.2.2.

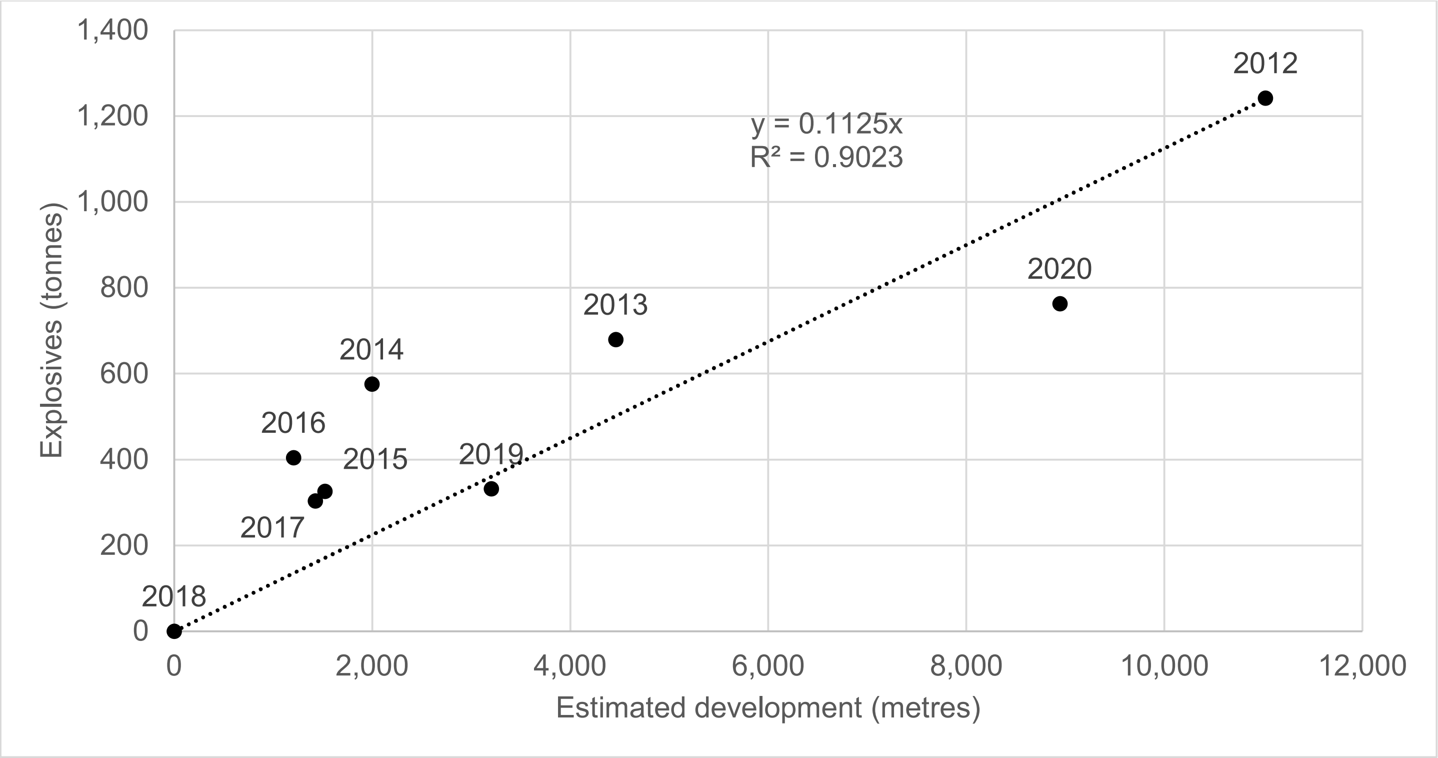


Figure 32. Measured explosives consumption at New Afton Mine between 2012 and 2020 in relation to lateral development metres (Cooper, 2020 and New Gold Inc., 2022)

4.4.4.2.6 Propane

Propane is used on site to heat buildings on surface where natural gas is not available (Cooper, 2021). Relationships between propane consumption and heating degree days were investigated in a similar manner as for natural gas but consumption rates proved to not have an obvious correlation. It is assumed that this is because propane is being used to fuel portable heaters at temporary locations such as contractor trailers and workspaces. Review of yearly consumption values confirm this as propane consumption is highest during ramp up years of 2012 and 2013 when more temporary heating requirements would have been required for contractors on site doing ramp up related work (Figure 33).

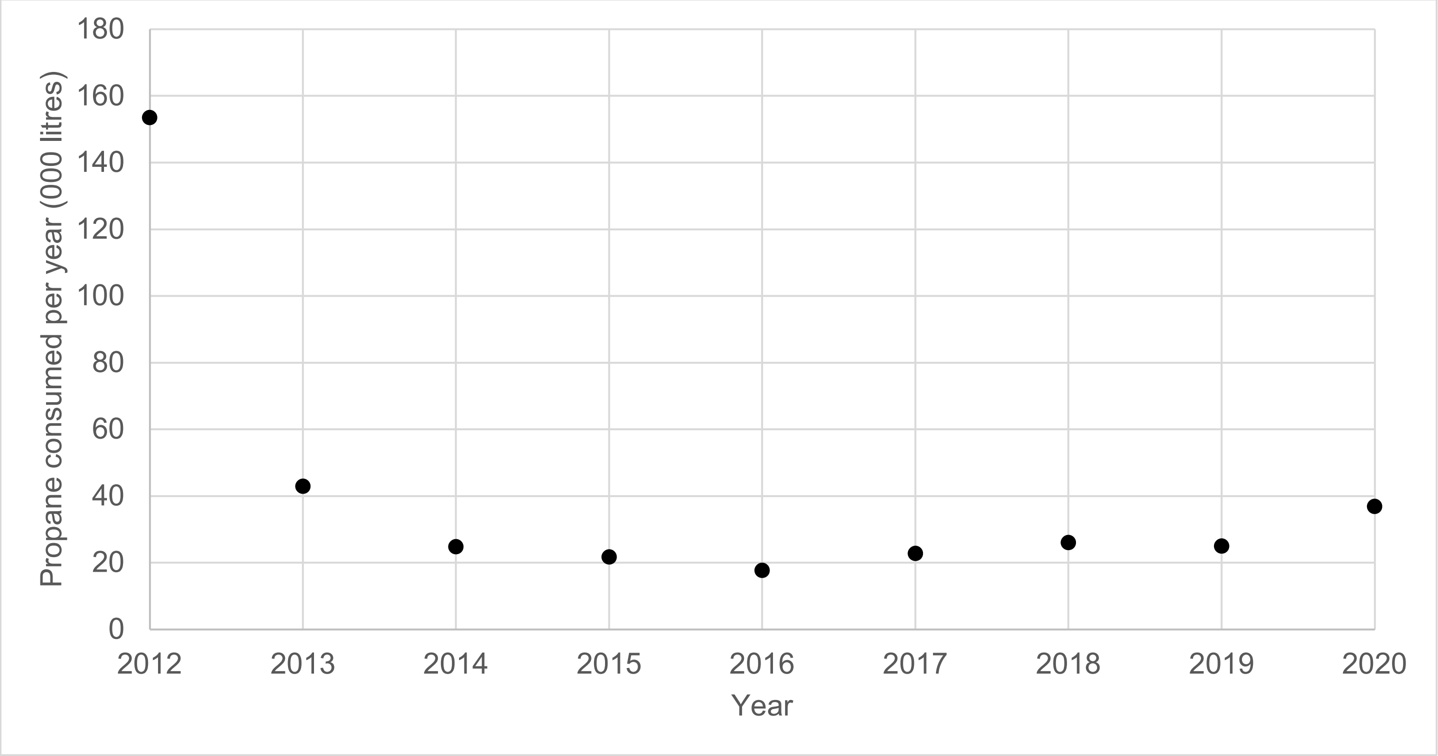


Figure 33. Measured propane consumption at New Afton Mine between 2012 and 2020 (Cooper, 2020)

4.4.4.2.7 Energy relationships summary

The relationships investigated highlighted distinct energy consumption intensities dictated by production effort, development effort, and tailings construction for the major energy types used (e.g., electricity and diesel) at this block cave mine. Understanding around the impact of mining parameters like those discussed above could be improved for the site. Access to historical mine plans outlining actual development and production values at a more granular level could provide insight to the impact of mining planning upon energy consumption. Energy consumption data aggregated at the monthly level could provide greater insight into seasonal consumption patterns. Additionally, a multivariate analysis could highlight the impact of a number of these parameters upon energy consumption by type. However, such analysis were beyond the scope of this review but could be considered for future work.

4.4.4.3 Predicting energy consumption from future production estimates

For predicting future energy consumption (and ultimately GHG emissions) for electricity, diesel, gasoline, and explosives, the relations presented in the previous sections were used in conjunction with the future production and development estimates presented in the 43-101 with the assumption that 2022 to 2023 would be years with high development effort and production effort as the new orebodies come on line. Post-2023 it was assumed that development effort would ramp down between 2024 and 2026 and the remainder of the mine life would be production focused (RPA, 2020). Additional diesel consumption for tailings construction was not predicted as tailings construction wrapped up in 2021 (RPA, 2020). The presented relationship between natural gas consumption heating degree days below 7ºC was also used with an average of the heating degrees days between 2012 and 2021(BiZEE Software, 2022). For propane, an average yearly consumption value was determined from the measured data from 2013 to 2020 (excluding the outlier from start up year 2012).

The resulting predicted future energy consumption values for the remaining mine life are presented Table 19. Values from 2012 to 2021 presented for all columns are measured and provided by mine staff or gleaned from reporting by New Gold (Cooper, 2020 and New Gold Inc., 2022). Milled tonne values from 2022 to 2030 are as presented in the 43-101 report. Energy consumption values from 2022 to 2030 in Table 19 were estimated as described above.

Table 19. Measured and estimated energy consumption and production values for the life of New Afton Mine

Calendar year[1]	Life of mine year	Milled	Electrical	Diesel	Natural Gas	Gasoline	Explosives[2]	Propane	Total energy	Energy intensity
Year	Year	M t	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kWh/t milled
2012	1	2.00	90.6	42.7	8.5	1.41	1.44	1.09	146	72.9
2013	2	4.10	186	41.9	13	1.44	0.79	0.3	243	59.6
2014	3	4.80	197	35.4	19.5	1.26	0.67	0.18	254	53.3
2015	4	5.10	219	38.1	14.4	1.1	0.38	0.15	273	53.6
2016	5	5.80	239	51.1	15.4	1.19	0.47	0.13	307	53.2
2017	6	6.00	246	54.6	21.4	1.21	0.35	0.16	324	54.0
2018	7	5.40	220	39.7	18.7	1.1	-	0.18	280	52.2
2019	8	5.60	233	64.3	19.9	1.18	0.39	0.18	319	57.1
2020	9	5.50	236	67.7	16.6	1.16	0.89	0.26	323	58.3
2021[3]	10	4.90	229	62.6	17.4	1.08	1.05	0.24	311	63.7
2022	11	4.60	215	41.5	16.7	0.85	0.62	0.18	275	59.6
2023	12	4.70	218	42.6	16.7	0.86	0.55	0.18	279	58.9
2024	13	4.70	217	42.1	16.7	0.85	0.19	0.18	277	59.1
2025	14	4.60	216	41.7	16.7	0.85	0.01	0.18	275	59.3
2026	15	5.10	226	37.5	16.7	0.9	0.04	0.18	281	54.9
2027	16	5.10	226	37.4	16.7	0.9	0.00	0.18	281	54.9
2028	17	4.90	222	35.9	16.7	0.87	0.00	0.18	275	56.1
2029	18	4.70	216	34.0	16.7	0.85	0.00	0.18	268	57.5
2030	19	1.00	62.1	7.0	16.7	0.48	0.00	0.18	86	90.4
Total		88.50	3,913	818	315	19.5	7.84	4.49	5078	
Average		4.70	206	43	17	1.03	0.44	0.24	267	59.4

1. Measured and reported values are presented for years 2012 to 2021 and values from 2022 to 2030 are predicted.
2. Measured explosive consumption in 2018 was reported as zero. It is unclear if this is a reporting error or if it reflects the use of explosives predominately for lateral development with no lateral development occurring in 2018.
3. These values were not provided by site staff, but were collected from Mining Data Solutions (2022), inferred from GHG reporting (Government of British Columbia, n.d.), and sustainability and financial reports produced by New Gold (New Gold Inc., 2022).

4.4.5 Sankey Diagram for a Canadian block cave mine

The Sankey diagram was prepared employing a bottom up and top down energy audit approach similar to that advocated by Levesque (2015). The measured values were used to produce a Sankey diagram of energy consumption at the site for 2020 in a top down manner (Figure 34). Additionally, to more accurately depict downstream energy end use in Figure 34, estimates of energy consumption for known mining processes were made to fill gaps in reported data and reported consumption was disaggregated where possible. This bottom up analysis refined the understanding of how energy was consumed by operations at New Afton Mine. Specifically, electricity to pump freshwater from Kamloops Lake to the site, to operate the shotcrete batch plant, and seasonal heating (trace lines for pipes, etc.) represented by seasonal variations in electricity consumption was estimated. As stated in Levesque (2015), the intent of this review was to improve the accuracy of the estimated data during a bottom up energy audit by matching consumption to total end use consumption of the facility. In this case study, it allowed for disaggregation of 95% of the measured energy consumption to estimated downstream end use. The remaining 5% unaccounted for is in the form of electricity and is suspected to be used for heating.

Figure 34 highlights the use of diesel and electricity to support material handling underground at New Afton Mine and electricity to supply the mill on surface. When compared to the Sankey diagram produced for underground operations at Garson Mine (Figure 11), where most energy was consumed ventilating the mine and a lower proportional reliance on diesel, this Sankey diagram reflects the underground infrastructure and the bulk mining production rates of the block cave and is more similar to that of the open pit mine presented in Figure 13. Also, given the carbon intensity of diesel fuels, it suggests there may be opportunities for optimization of the material handling system at the site to reduce energy consumption by and emissions from the primary movers.

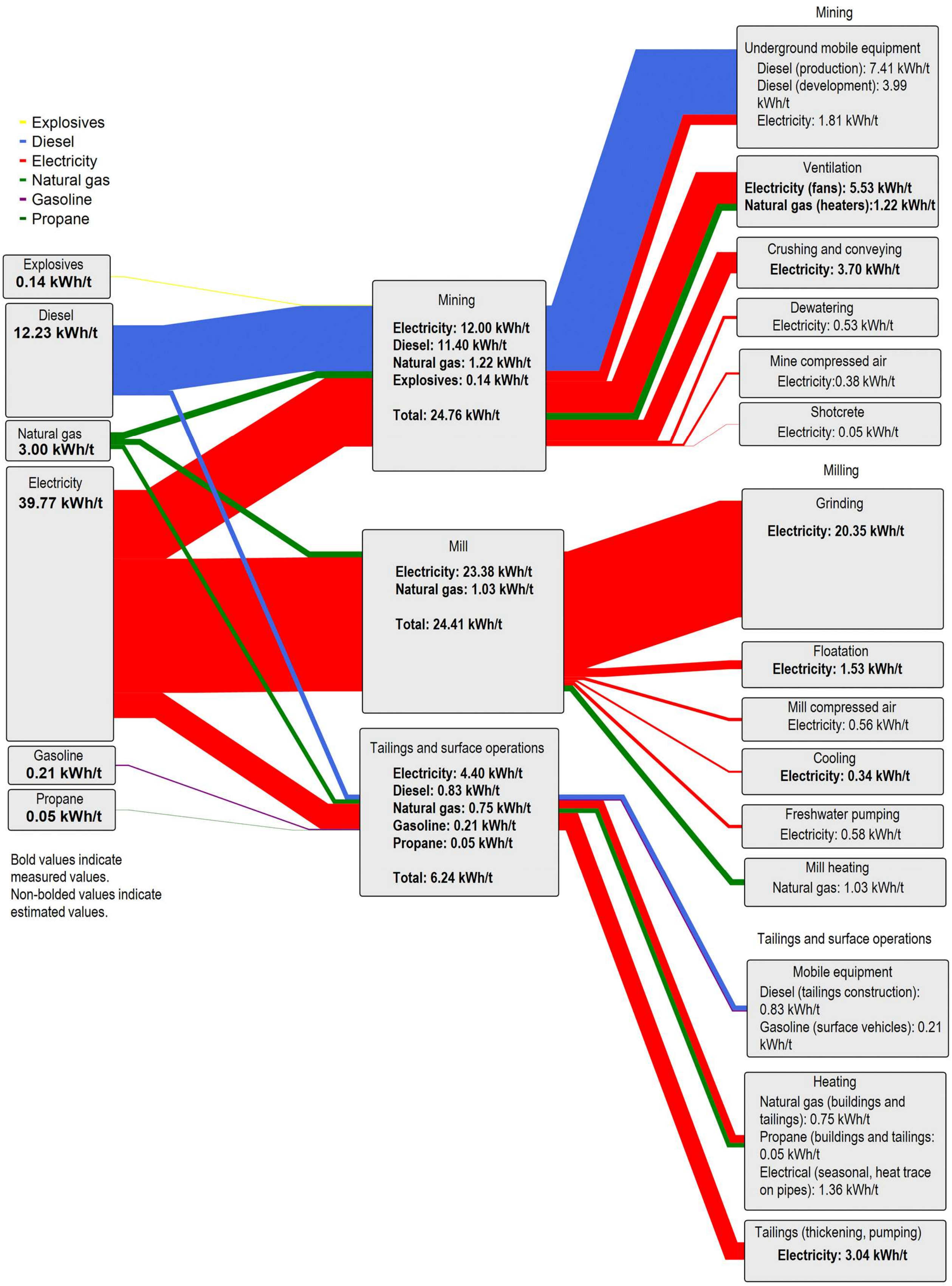


Figure 34. A Sankey diagram of measured and estimated energy consumption for 2020 at New Afton Mine allocating 95% of all energy consumed with the unallocated 5% being electricity.

4.5 Chapter conclusions

A summary of energy intensity for the mines reviewed in this chapter is presented in Table 20. Of interest is the higher energy intensity of Garson Mine employing underground selective mining compared to the bulk mining methods of open pit mining at Detour Lake Mine and block cave mining at New Afton Mine. It was also noted that the energy intensity of operations at Garson Mine are higher than the average for metal ore industry of 115 MWh/kt milled reported in Table 4. Operational similarities between the bulk mining methods were also obvious when reviewing the Sankey diagrams for these operations (refer to diagrams listed in Table 20). Not surprisingly, for both Detour Lake Mine and New Afton Mine, material processing and material handling consumes most of the energy on-site with electricity (the major energy source on site) being consumed by the mills and conveying system and diesel being consumed by LHDs, shovels, and trucks. Diesel is also consumed by trucks at the open pit mine to move large volumes of waste. The Sankey diagram for Garson Mine highlighted the need of this underground selective mining operation to supply heated, ventilated air to a complicated underground infrastructure.

Table 20 Energy intensity by mining method for underground selective, open pit, and block cave mining

Mine	Mining method	Energy consumption (MWh/kt milled)	Section in thesis	Sankey diagram	Reference
Garson Mine	Underground selective mining	226.5	Section 4.2.2	Figure 12	(Levesque, 2015; Mallett, 2014; and Millar, 2015)
Surface Mine	Open pit mining with truck haulage	79.0	Section 4.3.1	Figure 13	(Millar, 2022)
New Afton Mine	Block cave mining	57.8	Section 4.4.3	Figure 34	(Cooper, 2020)

As suggested in Levesque (2015), energy consumption at mines is impacted by mine depth, hauling distances, production rate, and heating and cooling requirements. Supporting this, the energy audit for New Afton Mine also highlighted how site activities impacted these variables and understanding these activities improves understanding energy consumption. For New Afton Mine, it was possible to discern the impact of production, development and tailings construction intensive activities upon diesel consumption at the mine between 2012 to 2021. These relationships, in addition to those developed for electricity, gasoline, natural gas, propane, and explosive consumption presented in this chapter produced a preliminary model of energy consumption at one of the two block cave mines in Canada.

Review of the estimated energy consumption at the individual level (i.e., Sankey diagrams) indicated that opportunities to economize energy consumption are likely limited given the nature of the milling process; a major consumer of electrical energy for mines. Assuming that such energy consuming ancillary services including ventilation and the provision of compressed air have been optimized, opportunity to significantly reduce energy consumption, and therefore potentially GHG emissions, may be limited to consideration of less carbon intense fuel alternatives to diesel. Such an analysis will be presented in following chapters.

5 Direct and indirect sources of greenhouse gas emissions at Canadian mines

5.1 Introduction

Chapter 4 produced an improved understanding of energy consumption at the operational level. It is necessary to review what emissions are produced from this consumption to understand what climate change policies may apply and, ultimately, how these emissions can be reduced. As mentioned in Chapter 2, implementation of the *Strategic Assessment of Climate Change* requires predicted GHG emissions for projects extending past 2050 to be quantified for projects undergoing the federal impact assessment process highlighting the importance of improving the understanding around emissions from mines (Government of Canada, 2020c). While direct emissions have predominately been the focus of GHG reporting requirements for mining companies to date, understanding the scope of indirect GHG emissions is becoming increasingly important as the global community moves towards net-zero supply chains.

The Greenhouse Gas Protocol was developed to standardize the way the GHG emissions referenced above are measured and further categorizes emissions into three scopes. These are described below in relation to the mining industry (emission types are also discussed in in Section 2.4.4):

- Scope 1 emissions or direct emissions are those emissions from a mining company's own operations. The most typical examples of these at mines include, but are not limited to, the consumption of diesel, propane, natural gas on-site during operation.

- Scope 2 or indirect emissions are those emissions produced from energy purchased by a miner and typically include electricity consumed via the grid delivery but produced off-site.

- Scope 3 emissions are also indirect emissions; however, they are produced by assets not owned or controlled by the mine but in its value. These emissions are not within the Scope 1 or 2 boundary and can include transportation of supplies or goods by non-company owned vehicles, processing of sold products by other industries, employee commuting, etc. and are sometimes referred to as value chain emissions (PricewaterhouseCoopers, 2021 and World Business Council for Sustainable Development and World Resources Institute, 2005).

This chapter is intended to, firstly, use the energy consumption estimates established previously to determine Scope 1 and 2 GHG emissions from this consumption and discuss the relevant carbon taxation schemes for the two case study sites in Chapter 4. The resulting benchmarks of GHG emissions will be used to assess mitigation activities and alternatives to reduce the carbon intensity of the subject operations. Additionally, application of federal back stop carbon pricing outlined in the GGPPA described in Chapter 2 will be applied to the GHG emissions estimates to characterize the financial impact upon the industry[2].

Secondly, other carbon emissions not likely to be directly taxed through the GGPPA but with potential to be assessed during impact assessments will be investigated for both case study sites in this chapter. The intent of this is to assess emissions for mines in the context of Scope 1 and 2 emissions and highlight potential concerns of miners who may be required to account for these emissions.

The outline for this chapter is as follows:

- carbon emissions and carbon taxation of diesel consumption (Scope 1 emission type) of the mining fleet at Detour Lake Mine,
- carbon emissions and related charges for operation of New Afton Mine expressly for the consumption of diesel, gasoline, natural gas, and propane (Scope 1 emission types) and electricity (Scope 2 emission type), and
- carbon emissions from trucking of concentrate from New Afton Mine to the Port of Vancouver (Scope 3 emission type).

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[2] At the time of writing, the GGPPA included carbon pricing with rates until 2022, but it is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.

5.2 Carbon emissions from, and carbon taxation of diesel consumption of, the main mining fleet at Detour Lake Mine

5.2.1 Purpose and boundaries of analysis

The emissions intensity for Detour Lake Mine, a high producing, large open pit mine, was calculated to be 0.002 tCO_2e per tonne of material moved or 0.015 tCO_2e per gram of gold produced (Kirkland Lake Gold, 2021); low when compared to the emission intensity of Garson Mine of 0.16 tCO_2e per gram of gold produced. However, gold being a by-product of nickel production at Garson Mine, the emission intensity of 0.003 tCO_2e per pound of nickel produced is more reflective of carbon production at the mine employing underground selective mining. As established in Section 4.3.2, the bulk mining operation consumes large amounts of energy and it is important to understand the resulting emissions profile. One of the major energy consumers at the Detour Lake Mine is the main mining fleet including the CAT 795 and 777 haulage trucks, drills, shovels, graders, and dozers. The purpose of this carbon emissions analysis was to use the estimated fuel consumption values for the main mining fleet at Detour Lake Mine presented in Table 9 to understand how this consumption contributes to the carbon footprint of the mine throughout its life. Both fuel charges and OBPS excess emissions charges of the federal GGPPA[3] (as described in Chapter 2) were calculated for the fuel consumption estimates for the main mining fleet although, as discussed later, only the latter applies to this mine.

The scope and spatial boundaries considered for this carbon emissions analysis includes activities undertaken by the main haulage fleet at Detour Lake Mine moving ore and waste from the main and ancillary open pits to various waste piles and ore pile on site. The temporal boundary is limited to from 2019 to 2040 (i.e., the current pit design to end of planned production for the mine). This temporal boundary was selected to investigate the costs and

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[3] At the time of writing, the GGPPA included carbon pricing with rates until 2022, but it is understood that the Government of Canada has proposed to increase these rates by \$15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.

benefits of a large operating pit retrofitting their haulage system to reduce GHG emissions part way through life of mine operations.

5.2.2 Carbon emissions from the main mining fleet

Using the fuel consumption estimates for the main mining fleet (including trucks, drills, shovels, graders, etc.) presented in Table 9, the cost and tCO_2e emitted from consuming the fuel was calculated assuming a fuel cost of $0.80 per litre as described in the 43-101 report and assuming that 2.7 kg of CO_2 is produced for every litre of diesel combusted. With these assumptions, it was estimated that Detour Lake Mine will spend $59 million on fuel for the main mining fleet in an average year while producing 199,825 tCO_2e from this consumption. Using production data provided in the 43-101 for the whole site (ancillary and main pits) between 2019 and 2040 a total of 467 Mt of ore and 2,035 Mt of material (ore and waste) will be mined on site, this equates to a diesel cost (excluding any carbon taxation) of $0.65 per tonne of material moved and $2.65 per tonne of ore moved.

The estimated fuel consumption, fuel charges, and OBPS excess emission charges calculated to operate the main mining fleet for each year of operation are presented in Table 21.

Table 21. Calculated carbon pricing charges for the main mining fleet on site based on estimated fuel consumption and standards established per the federal Greenhouse Gas Pollution Pricing Act.

Year	Estimated fuel consumption main mining fleet				Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg) [1]	Fuel consumed by main mining fleet (M l) [2]	Fuel cost (M CAD) [3]	CO_2 produced by combusting fuel consumed by the main mining fleet (t) [4]	Potential fuel charge rate (CAD/l) [5]	Potential fuel charges (M CAD) [6]	Annual facility emissions limit prescribed by the OBPS (kt) [7]	Predicted total reported emissions (kt) [8]	Compliance obligations per OBPS (kt) [9]	Charge per tonne CO_2e (CAD/tonne CO_2e) [10]	Excess emission charge (M CAD) [11]	Difference between carbon related charges (M CAD) [12]
2019	16,700	77.2	61.7	208,300	0.05	4.14	128	253	125	20	2.50	-1.64
2020	16,600	80.4	64.3	217,100	0.08	6.47	128	267	139	30	4.17	-2.30
2021	17,600	80.4	64.3	217,100	0.08	6.47	136	267	132	40	5.28	-1.20
2022	17,700	81.6	65.3	220,200	0.11	8.75	137	274	138	50	6.88	-1.87
2023	17,700	81.6	65.3	220,200	0.11	8.75	136	274	138	50	6.91	-1.84
2024	17,300	84.1	67.3	227,100	0.13	11.28	133	274	141	50	7.06	-4.22
2025	18,200	84.1	67.3	227,100	0.13	11.28	140	274	134	50	6.72	-4.56
2026	17,600	84.1	67.3	227,100	0.13	11.28	136	274	139	50	6.94	-4.34
2027	17,200	84.3	67.5	227,700	0.13	11.31	132	267	135	50	6.75	-4.56
2028	17,500	84.3	67.5	227,700	0.13	11.31	135	267	133	50	6.63	-4.68
2029	17,400	84.3	67.5	227,700	0.13	11.31	134	267	133	50	6.65	-4.66
2030	18,400	88.4	70.7	238,700	0.13	11.86	142	281	140	50	6.99	-4.87
2031	19,700	88.4	70.7	238,700	0.13	11.86	152	281	130	50	6.48	-5.38
2032	19,600	88.4	70.7	238,700	0.13	11.86	151	281	130	50	6.50	-5.36
2033	19,100	59.3	47.5	160,100	0.13	7.95	147	169	22	50	1.08	-6.88
2034	18,800	59.3	47.5	160,100	0.13	7.95	145	169	24	50	1.21	-6.74
2035	20,600	59.3	47.5	160,100	0.13	7.95	159	169	10	50	0.51	-7.44
2036	22,100	59.4	47.5	160,300	0.13	7.96	170	190	20	50	1.00	-6.96
2037	23,000	59.4	47.5	160,300	0.13	7.96	177	190	13	50	0.64	-7.33
2038	24,400	59.4	47.5	160,300	0.13	7.96	188	190	2	50	0.10	-7.86
2039	19,900	22.9	18.3	61,900	0.13	3.07	153	91	-62	50	0.00	-3.07
2040	7,600	3.6	2.9	9,700	0.13	0.48	59	14	-44	50	0.00	-0.48
Total	404,600	1,554	1,240	4,196,000		189.2	3,253	4,989	1,870	0	91.0	-98.2

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Estimated per methodology described in Chapter 4.
3. Cost of fuel assumed to be $0.80/l as presented in the 43-101 report.
4. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO2 (Government of Canada, 2014).
5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act (Government of Canada, 2020a) at the time of writing. It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate
6. Application of fuel charge rates to the estimated fuel consumption. As stated, Detour Lake Mine should not incur these charges as the site triggers the OBPS given reported emission rates (refer to Chapter 2 for additional information).
7. Determined by applying the Output Based Pricing System defined in the Greenhouse Gas Pollution Pricing Act of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b).
8. Determined based upon actual reported emissions for 2019 and scaled to estimated consumption to the remainder of the mine life (Government of Canada, 2020d).
9. Predicted total reported emissions minus annual facility emissions limit prescribed by the OBPS. Negative values represent potential offset credits available.
10. Charge per tonne of excess CO_2e emissions calculated per the Output Based Pricing System (Government of Canada, 2019b). See note 5 regarding charge rates used for this analysis.
11. Charges resulting from the excess emissions defined by the Output Based Pricing System resulting from the operation of the main mining fleet.
12. Difference between carbon taxation between what would be incurred if the fuel charges were applied to purchase fuel compared to those actually incurred due to OBPS charges. Negative values indicated a lower carbon taxation rate by application of the OBPS for industry.

As the site is expected to emit more than 50,000 reported tCO_2e per year, the OBPS charges will apply and fuel consumed on site will be exempt from the fuel charges. Application of the OBPS to the fuel consumption estimate for the main mining fleet results in carbon related charges of $4.3 million in an average year with the potential for offset credits produced in 2039 and 2040. In total, the mine is likely to incur $91 million in carbon related charges over the life of the mine which is a 7.3% increase in life of mine fuel costs to power the main mining fleet. This equates to additional costs of $0.04 per tonne of material moved and $0.19 per tonne of ore moved.

In Table 21, both the fuel charge and the OBPS charges per the GGPPA are presented for comparative purposes. Application of the fuel charge as outlined in the GGPPA to the estimated fuel consumption suggests that Detour Lake Mine could pay $9.1 million dollars in an average year if these charges were passed on at cost by the fuel supplier (i.e., if the OBPS did not apply). This would result in carbon fees in excess of $189 million over the life of the mine (or a 15% increase in fuel related costs). Comparing this value to the $91 million incurred through the application of the OBPS highlights the carbon taxation savings for large emitters through application of the GGPPA.

5.2.3 Carbon emissions from the haulage fleet

In Chapter 4 it was shown that the CAT 795 trucks that haul material from the main pit at Detour Lake Mine to the various dump points are the major consumers of diesel fuel on the site. As the alternatives considered will focus on alternative fuels for or alternatives to operation of the CAT 795 trucks, a similar exercise as described in the previous section was undertaken considering only the fuel estimated to be consumed by the CAT 795. The GGPPA carbon taxation scheme presented in Table 21 was also applied to the estimated fuel consumption for the CAT 795. The estimated CO_2e emissions are presented below in Table 22 with a detailed yearly cost breakdown to fuel and operate the CAT 795 fleet presented in Table 64 in Appendix B where it has been estimated that Detour Lake Mine will spend $715 million dollars to fuel the CAT 795 fleet over the life of the mine equating to $34 million in an average year in diesel costs.

Table 22. Fuel estimated to be consumed by the CAT 795 fleet in comparison to the main mining fleet.

Operating year	Fuel consumed by mining fleet (M l) [1]	Fuel consumed by CAT 795 (M l) [2]	Percentage of fuel consumed by CAT 795 compared to mining fleet	CO_2 produced by combusting fuel consumed by mining fleet (kt) [3]	CO_2 produced by combusting fuel consumed by CAT 795 (kt) [3]
2019	77.2	45.4	59%	208	123
2020	80.4	47.9	60%	217	129
2021	80.4	47.9	60%	217	129
2022	81.6	49.2	60%	220	133
2023	81.6	49.2	60%	220	133
2024	84.1	49.2	59%	227	133
2025	84.1	49.2	59%	227	133
2026	84.1	49.2	59%	227	133
2027	84.3	47.9	57%	228	129
2028	84.3	47.9	57%	228	129
2029	84.3	47.9	57%	228	129
2030	88.4	50.5	57%	239	136
2031	88.4	50.5	57%	239	136
2032	88.4	50.5	57%	239	136
2033	59.3	30.3	51%	160	82
2034	59.3	30.3	51%	160	82
2035	59.3	30.3	51%	160	82
2036	59.4	34.1	57%	160	92
2037	59.4	34.1	57%	160	92
2038	59.4	34.1	57%	160	92
2039	22.9	16.4	72%	61.9	44.3
2040	3.6	2.6	72%	9.7	7.0
Total	1,554	894.4	58%	4,196	2,415

1. Estimated using OEM fuel consumption rates and assumed duty cycles for the main mining fleet (including trucks, shovels, drills, graders, etc.) as described in the 43-101 per Chapter 3.
2. Estimated using OEM fuel consumption rates and assumed duty cycles for the main haulage fleet consisting of CAT 795 trucks as described in the 43-101 per Chapter 3.
3. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO_2 (Government of Canada, 2014).

5.2.4 OBPS offers less carbon tax for large scale gold producers

Review of the CO_2 emissions estimate values for Detour Lake Mine highlights the following:

- Should a mine emit in excess of the 50,000 tCO_2e trigger of the GPPA so that the OBPS applies, the site can still experience carbon related charges on Scope 1 energy consumption of significant financial impact (up to a 7% increase related to fuel charges alone).
- However, in this instance, carbon taxation per the OBPS is markedly less than if the fuel charges had been applied as they would have been if the emissions trigger had not been exceeded. Carbon taxation potentially applied to the purchase of diesel fuel to operate the main mining fleet at Detour Lake Mine has been estimated to be 52% less per application of the OBPS taxation scheme than application of the fuel charges taxation scheme outlined in the GGPPA and experienced by smaller emitters.

5.3 Scope 1 and 2 carbon emission projections and associated taxation for the life of New Afton Mine

5.3.1 Purpose and boundary of analysis

The purpose of this analysis was to estimate the carbon emissions associated with the measured and predicted energy consumption at New Afton Mine. The analysis includes energy consumption associated with Scope 1 and 2 emission types and parts of this analysis will be used to inform a mitigation alternatives analysis presented in Chapter 8 of this thesis.

The spatial boundary considered for this carbon emissions analysis includes the area subject to potential effects from the carbon emissions on site and will be confined within the boundaries of the New Afton property. The temporal boundary is the life of mine from 2012 to 2030.

5.3.2 Carbon emissions from operational energy consumption

For the analysis of New Afton Mine, direct Scope 1 carbon emissions on site are attributed to the consumption of natural gas, diesel, gasoline, propane and explosives. Indirect Scope 2 carbon emissions on site are attributed purely to the consumption of electricity. To estimate carbon emissions for this energy consumption, emission factors typical for consumption of these energy types in British Columbia were used (Table 23) (Government of British Columbia, 2014).

Table 23. Emission factors for various Scope 1 and 2 energy types consumed at New Afton Mine

Scope	Energy type	Emissions factor[1]	Unit
1	Natural Gas	49.75	kgCO_2e/GJ
	Diesel	2.679	kgCO_2e/litre
	Gasoline	2.31	kgCO_2e/litre
	Propane	1.54	kgCO_2e/litre
	Explosives	0.189	kgCO_2e/kg
2	Electricity	40.1	tonnes CO_2e/GWh

1. Emission factors were taken from Government of British Columbia, 2014. Also, unlike Table 3, emissions from the production of electricity via the provincial grid are being considered as indirect emissions.

These emission factors were then multiplied against measured (years 2012 to 2020) and estimated (years 2021 to 2030) energy consumption for each type presented in Table 19 in Section 4.4.4.3. The resulting yearly emissions estimates are presented for Scope 1 emission types and 2 emission types in Table 24 and Table 25, respectively. For comparative purposes, actual Scope 1 emissions reported by New Afton Mine to the provincial GHG inventory are also presented (Government of British Columbia, 2021). As mentioned in Section 4.4.3, the average emissions intensity for Scope 1 and 2 emissions at New Afton Mine is 0.004 tCO_2e/milled t (or 0.015 tCO_2e per gram of gold produced).

An estimate of costs of consuming the Scope 1 fossil fuels (e.g., gasoline, diesel, natural gas, and propane) is provided. This cost estimate excludes explosives as the applicable carbon taxation does not apply to explosives; however, the emissions from explosives are presented in Table 24 as they are a source of GHG. For this estimation it was assumed that diesel costs $1 per litre, natural gas costs $3.90 per GJ, gasoline costs $1.65 per litre, and propane costs $1.10 per litre (Cooper, 2020; Fortis BC, 2021; GlobalPetrolPrices.com, 2021; and Government of Canada, 2009). The cost estimate is rudimentary and does not reflect variability in these prices over the life of the mine but is intended only to give a scope of cost to reference carbon taxation against. Additionally, the relevant carbon taxation rate per British Columbia's Carbon Tax has been applied to the fossil fuels consumed on site (i.e., gasoline, diesel, natural gas, and propane, but not explosives) (Government of British Columbia, n.d.).

Table 24. Scope 1 or direct estimated GHG emissions, energy costs and taxation from burning fossil fuels at New Afton Mine

Year	Life of mine year	GHG emissions from Scope 1 energy consumption [1]							Scope 1 energy consumption	British Columbia's Carbon Tax [3]	
		Natural Gas	Diesel	Gasoline	Propane	Explosives Total	Estimated total [1]	Reported [2]	Estimated fuel costs [3]	Taxation rate	Taxation amount
		(tCO$_2$e)	(tCO$_2$e)	(tCO$_2$e)	(tCO$_2$e)	(tCO$_2$e)	(tCO$_2$e)	(tCO$_2$e)	(M CAD)	(CAD/tCO$_2$e)	(M CAD)
2012	1	1,523	11,452	367	236	235	13,600	13,200	4.51	40	0.53
2013	2	2,337	11,225	373	65	128	14,000	13,600	4.38	40	0.55
2014	3	3,488	9,489	327	39	109	13,300	13,100	3.81	40	0.52
2015	4	2,581	10,214	285	33	62	13,100	12,800	3.96	40	0.51
2016	5	2,750	13,685	308	28	76	16,800	16,300	5.19	40	0.65
2017	6	3,827	14,632	314	35	57	18,800	18,400	5.61	40	0.73
2018	7	3,354	10,631	285	39	0	14,300	14,000	4.17	40	0.56
2019	8	3,557	17,228	305	39	63	21,100	20,600	6.49	40	0.82
2020	9	2,973	18,126	301	56	144	21,500	20,800	6.77	40	0.83
2021	10	3,117	15,626	260	52	171	19,100		6.29	45	0.86
2022	11	2,993	10,357	204	39	101	13,600		4.27	50	0.68
2023	12	2,993	10,640	207	39	89	13,900		4.38	50	0.69
2024	13	2,993	10,503	204	39	30	13,700		4.33	50	0.69
2025	14	2,993	10,409	204	39	2	13,600		4.29	50	0.68
2026	15	2,993	9,349	216	39	7	12,600		3.91	50	0.63
2027	16	2,993	9,347	216	39	0	12,600		3.91	50	0.63
2028	17	2,993	8,964	209	39	0	12,200		3.76	50	0.61
2029	18	2,993	8,497	204	39	0	11,700		3.58	50	0.59
2030	19	2,993	1,745	115	39	0	4,900		1.00	50	0.24
Totals		56,444	212,119	4,907	974	1,275	274,444		84.6		12.1

1. Emissions are based on reported energy consumption from 2012 to 2021 provided by site staff or in annual reporting and energy consumption estimated in Chapter 4 for 2022 to 2030 (refer to Table 19) (Cooper, 2020 and New Gold Inc., 2022). Estimated totals include Scope 1 emissions associated with burning fossil fuels and no emissions associated with explosives or electricity consumption.
2. GHG emissions are as reported by New Afton Mine as part of the provincial GHG inventory (Government of British Columbia, 2021a). These include only Scope 1 emissions associated with burning fossil fuels and no emissions associated with explosives or electricity consumption.
3. Applied to all energy sources presented in the table with the exclusion of explosives.

Table 25. Scope 2 or indirect estimated GHG emissions for New Afton Mine

Calendar year Year	Life of mine year Year	Electricity (tCO_2e)
2012	3,600	3,600
2013	7,500	7,500
2014	7,900	7,900
2015	8,800	8,800
2016	9,600	9,600
2017	9,900	9,900
2018	8,800	8,800
2019	9,300	9,300
2020	9,500	9,500
2021	9,200	9,200
2022	8,600	8,600
2023	8,700	8,700
2024	8,700	8,700
2025	8,600	8,600
2026	9,100	9,100
2027	9,100	9,100
2028	8,900	8,900
2029	8,700	8,700
2030	2,500	2,500
Totals		153,300

In an average year, fossil fuel cost to operate New Afton Mine (including all the mobile equipment fleet) is estimated to be \$4.5 million while emitting on average 14,400 tCO_2e per year. This equates to a fuel cost of \$0.96 per tonne of ore moved. On average, New Afton Mine will pay \$0.6 million per year in carbon tax which equates to \$0.14 per tonne of ore moved. Costs associated with carbon taxation represent a 14% increase in the fossil fuel costs. Mine staff report an average emission intensity 3.6 kg CO_2e per dry tonne which is comparable to the average emissions intensity of 3.1 kg CO_2e per dry tonne calculated from the values in Table 24 and Table 25 (Cooper, 2020).

5.3.3 Carbon emissions of the main haulage fleet

Material haulage alternatives will be considered for the site that have the potential to mitigate some GHG emissions resulting from production at New Afton Mine. The main haulage fleet includes 16 LHD and 7 haulage trucks (RPA, 2020). Based on estimates presented in Chapter 4, of the 123 pieces of equipment on site, these are the major consumers of diesel. As the alternatives considered will focus on alternative fuels for the operation of haulage equipment, the carbon emissions and costs to operate the haulage equipment were estimated. Using the yearly energy consumption estimated for this equipment per Section 4.4.3, the energy requirements consumed by the individual machines per shift were calculated and are presented in Table 26.

Table 26. Energy consumption and production of the diesel fleet per shift (RPA, 2020)

Type	Model	Quantity	Diesel engine output power rating (kW)	Energy produced by engine to do work per shift[1] (kWh)	Energy consumed by the engine to do work each shift[2] (kWh)	Diesel consumed by the engine each shift[3] (litres)
LHD	Sandvik LH410	2	220	690	1,971	186
	CAT R1600	10	208	652	1,864	176
	CAT R2900G	4	305	956	2,733	258
Truck	CAT AD45	7	447	1,467	4,193	396
Totals				4,708	13,451	1,269

1. These values represent the energy outputted by the engine in individual machines to do work required each 10 hour shift (assumed to operate 8 of the 10 hours) based upon the yearly energy consumption estimates presented in Table 16 in Chapter 4.
2. Using the assumed minimum energy requirements to complete the work required of the equipment calculated in the previous column, the actual energy consumed by the equipment to do the work was calculated assuming a 35% engine efficiency of the diesel engine (nuclear-power.com, n.d. and Varaschin and De Souza, n.d.).
3. The volume of diesel consumed to produce the energy determined in the previous column was determined assuming that combusting one litre of diesel produced 10.6 kWh of energy (Deep Resource, 2012).

Consumption of diesel by the haulage fleet using the values above was estimated to be 4.27 million litres of diesel per typical year; this is comparable to the value of 4.09 million litres (or 88%) of the reported 4.6 million litres of diesel consumed by non-tailings related activity on site assumed to be consumed by the haulage fleet as predicted in Table 16 in Chapter 4.

Tonnes of CO_2e emitted from combustion of the diesel powering the haulage fleet using an emission factor of 2.7 kg CO_2e per litre of diesel (Government of British Columbia, 2014) was estimated to be 11,439 tCO_2e per average year. For 2020, this consumption would have fuel purchase costs estimated to be \$4.2 million and carbon tax costs on that fuel (at the rate of \$45 per tCO_2e) of \$0.51 million or 12% of fuel costs.

5.3.4 Conclusions

Review of the CO_2 emissions values above estimated highlights the following:

- Like the open pit mine presented above, diesel consumption is a major contributor to reported Scope 1 emissions.
- Uncertainties regarding energy consumption can make it difficult to come to a fulsome understanding of the emission potential for a mining project.
- Application of a flat carbon taxation rate resulted in this small emitter (by GGPPA standards) to potentially experience a 14% increase in cost associated with purchasing fuel whereas application of the OBPS at a large emitting site (as presented in the previous case study) resulted in a smaller 7% increase.

5.4 Scope 3 carbon emissions

5.4.1 Purpose and boundaries

The purpose of this carbon emissions review was to create a more fulsome understanding of other relevant emissions for the mining operations and to this end some Scope 3 emissions associated with operations at New Afton Mine were investigated. Scope 3 emissions are often referred to a value chain emissions and are outside the control of the company itself. As mentioned in Section 5.1, these can include emissions from downstream processing of commodities sold by a mine and transportation of supplies, goods, employees, amongst others. For this review, those emissions produced as a result of transporting the resulting concentrate from the New Afton Mine site to the Port of Vancouver by a contractor were estimated. This analysis provides an overview of the potential climate related impacts of other parts of the mining supply chain not currently considered during net zero assessments and outside the direct control of the miner but represent only a portion of the Scope 3 emissions associated with mining in general. The spatial boundary for this analysis is limited to the fuel consumption associated with trucking the concentrate from New Afton Mine to the Port of Vancouver for shipping to smelters overseas. No consideration was given to the carbon footprint of overseas shipping as it is unclear which international ports receive the concentrate from New Afton Mine. The temporal boundary for this analysis was for the life of the mine from 2012 to 2030.

5.4.2 Transportation of concentrate from New Afton Mine

As indicated in the previous 43-101 report, concentrate is moved from site via truck to the Port of Vancouver. Site staff reported that in 2020, approximately 2,890 loaded concentrate hauls were made from the site to the Port of Vancouver using 45 tonne capacity trucks (Cooper, 2021 and RPA, 2015). Using this information and the measured and predicted yearly production rates for the site, the total number of concentrate tonnes to be trucked off-site was estimated assuming that milling and floatation results in production of concentrate that is 2.3% of the mill feed by weight (lower than the 3% suggested in the 43-101 report for the site but calibrated to 2020 trip numbers provided by site staff (Cooper, 2021 and RPA, 2015`). Based on these values and using the assumed capacity of the trucks, the number of trips from site to the Port of Vancouver was calculated by year and daily trips per year.

The distance for a round trip from site to the Port of Vancouver was determined to be 710 km. Using an emissions factor for freight trucking of 63.8 g CO_2e per tonne*km, the resulting emissions from trucking concentrate to the Port of Vancouver were estimated (Table 27) (CN, n.d.).

Table 27. Estimated Scope 3 emissions related to trucking concentrate produced at New Afton Mine off-site

Calendar Year	Life of mine year	Mill feed (M t)	Concentrate produced (t)	Transportation related emissions		
				Truck trips per year	Truck trips per day	Tonnes CO_2e
2012	1	2.00	47,000	1,040	3	1,890
2013	2	4.09	96,000	2,130	6	3,870
2014	3	4.76	111,900	2,490	7	4,510
2015	4	5.10	119,900	2,660	7	4,830
2016	5	5.77	135,700	3,020	8	5,460
2017	6	5.99	140,800	3,130	9	5,670
2018	7	5.35	125,800	2,800	8	5,070
2019	8	5.58	131,200	2,920	8	5,280
2020	9	5.53	130,000	2,890	8	5,240
2021	10	4.89	114,800	2,550	7	4,620
2022	11	4.61	108,400	2,410	7	4,370
2023	12	4.74	111,400	2,480	7	4,490
2024	13	4.68	110,000	2,440	7	4,430
2025	14	4.64	109,000	2,420	7	4,390
2026	15	5.12	120,400	2,680	7	4,850
2027	16	5.12	120,300	2,670	7	4,850
2028	17	4.91	115,400	2,570	7	4,650
2029	18	4.66	109,400	2,430	7	4,410
2030	19	0.96	22,500	500	1	910
	Totals	88.5	2,080,000	52,000		83,700

When compared to other Scope 1 and 2 resulting from operations at New Afton Mine emissions, it is obvious that Scope 3 emissions can be a significant source of CO_2e from operating mines (Table 28).

Table 28. Estimated carbon emissions by type over the life of New Afton Mine

Carbon emission type	Tonnes CO_2e over the life of mine	Percent of total emissions
Scope 1[1]	274,000	54%
Scope 2[2]	153,000	30%
Scope 3[3]	84,000	16%
Total	535,000	100%

1. Direct emissions from burning diesel, natural gas, gasoline, and propane on site between 2012 and 2030.
2. Indirect emissions from electrical energy purchased by New Afton from the provincial electrical grid (emissions produced off-site and attributed to the grid) between 2012 and 2030.
3. Partial indirect emissions from the value chain for the mine including transportation of concentrate from the mine to the Port of Vancouver by a trucking contractor only. This only represents a portion of the Scope 3 emissions for the operation.

Choices made at the mine planning and development stage also have the potential to impact Scope 3 emissions from downstream commodity production that would typically be beyond the scope of carbon accounting for permitting purposes. The high-level analysis of CO_2e from trucking of concentrate off the mine site, and beyond the typical carbon reporting requirements for a mine, indicated that carbon emissions from these activities could represent a 16% increase over the life of mine Scope 1 and 2 carbon emissions. As mentioned, these only represent a portion of the Scope 3 emissions for mining.

5.5 Chapter conclusions

Carbon taxation, if of significance, can act as a financial driver for greenhouse gas emission mitigation. Two carbon taxation schemes were reviewed as part of this chapter. Firstly, carbon taxation tied to an emission trigger and production values was investigated and secondly, a flat carbon taxation on hydrocarbon consumption was reviewed. Both taxation schemes increase the cost of doing business for mines. For the sites considered, application of a flat taxation rate saw costs to fuel the mobile fleets increase between 14% (New Afton Mine) and 15% (Detour Lake Mine). For the site that exceeded emission triggers resulting in production related penalties in lieu of the flat taxation rate (Detour Lake Mine), these costs only increased by 7% over baseline fuel costs (an 8% reduction from the flat taxation rate that would apply without the emission trigger taxation scheme for large emitters).

While this alternative carbon taxation scheme for large emitters is meant to protect the Canadian economy from such industries relocating to countries with more lenient carbon polices, it comes at the cost of reduced financial pressure to reduce carbon consumption to meet climate change commitments. Additionally, the high level analysis of only some of the Scope 3 emissions associated with New Afton Mine highlights the importance of understanding value chain emissions for a product to make effective carbon reduction decisions given the significance of Scope 3 emissions in comparison to Scope 1 and 2. As Canada struggles to meet climate change commitments it is likely that a better understanding of upstream, on-site, and downstream carbon emissions will be required if carbon reduction policies are to be effective.

6 Carbon emissions and land use change in mining

Canadian carbon policies are not limited to carbon taxation on fuel burned. According to the *Strategic Assessment of Climate Change,* new mines will need to broaden the scope of their carbon accounting practices to include supply chain emissions (like those discussed in Section 5.4) and land use change emissions (Government of Canada, 2020c). Carbon is retained in terrestrial ecosystems in live biomass, decomposing organic matter, and soil with carbon being exchanged with the atmosphere via photosynthesis, respiration, decomposition, and combustion (Intergovernmental Panel on Climate Change, 2003). Land use change resulting from human activity that impacts the vegetation and soil within the system decreases this ability to store carbon (Yang et al., 2003). During mine start up, rapid land use change occurs where native vegetation and soil is stripped from the landscape to accommodate mine infrastructure. Conversion of native forest or wetland to open pits, waste rock piles, tailings impoundment areas, parking lots, and other infrastructure will reduce carbon storage in vegetation and soil.

Some active remediation may occur during the life of mine; however, the bulk of the site will remain mostly devoid of vegetation until mine closure. At closure, effort will be undertaken by the mining companies to remediate their sites to an acceptable land use, preferably to pre-mining conditions. At a minimum, remediated land use is expected to be aesthetically similar to surrounding land conditions and to function as a self-sustaining ecosystem (Canary Research Institute, n.d.). However, given topographical and hydrological changes resulting from mining activity (i.e., deposition of wastes into low lying areas and remnant, flooded open pits remaining on the landscape, etc.), a “like for like” remediation with respect to land use is often not possible. As a result, mining can result in permanent reduction in carbon storage capacity when considering land use change emission factors.

6.1 Purpose and boundaries

The purpose of this analysis is to provide an overview of the potential climate related impacts of emissions and loss of carbon sequestration potential associated with land use change at the case study mine sites. Using emission potential from vegetation clearing during construction, loss of carbon sequestration potential during the life of mine, and carbon sink potential during site rehabilitation, carbon emissions associated with development of both the case study sites, Detour Lake Mine and New Afton Mine, were estimated. The spatial boundaries for this analysis included the mine site and off-site locations where mines had undertaken carbon offsetting activities through habitat restoration projects. Temporal boundaries for the analysis were from start of construction through to remediation (where the information was available).

6.2 Estimating land use change related emissions at Canadian mines

As Detour Lake Mine is a large open pit and New Afton Mine is an underground mine, analysis of these two sites provides the advantage of understanding the impact of these two mining methods upon land use change. The sites exist in contrasting terrestrial ecosystems: Detour Lake Mine being located in the boreal moist climate zone and New Afton being located in the cool temperate dry climate zone (Intergovernmental Panel on Climate Change, 2000). Both were constructed on brownfield sites where previous mining activity had occurred; however, expansion into undisturbed native vegetation occurred to accommodate waste disposal.

For both sites, satellite imagery for the mines showing land use change over time was reviewed starting from just prior to the point of construction for the current operations. New Afton Mine was operated as an open pit mine from 1977 to 1997 and Detour Lake Mine operated as a historical open pit/underground operation from 1983 to 1999 (Kirkland Lake Gold, 2021 and RPA, 2020). Current operations for each site commenced in development in 2007 at New Afton Mine and 2011 at Detour Lake Mine (Kirkland Lake Gold, 2021 and RPA, 2020).

The following figures (Figure 35 and Figure 36) show brownfield conditions at the time of construction (left image) and current conditions for each site (right image); to establish the scope of current development, outlines of the historical mining activity have been superimposed upon satellite imagery of current site conditions.

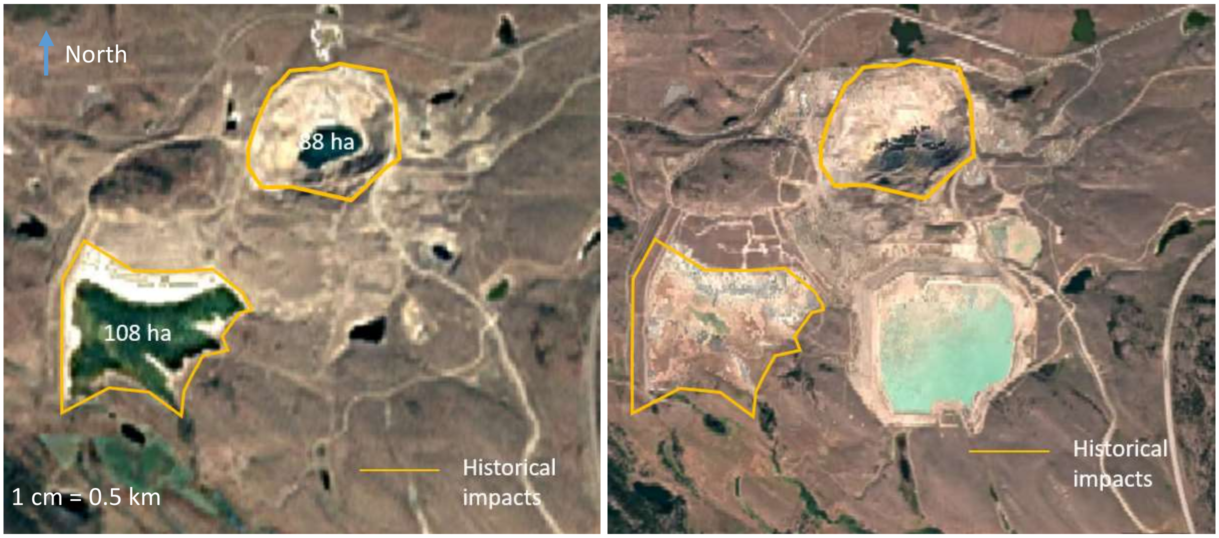

Figure 35. Historical impacts of previous mining activity at New Afton Mine (left photo: circa 2007, right photo: circa 2020) (Google Earth, 2021b).

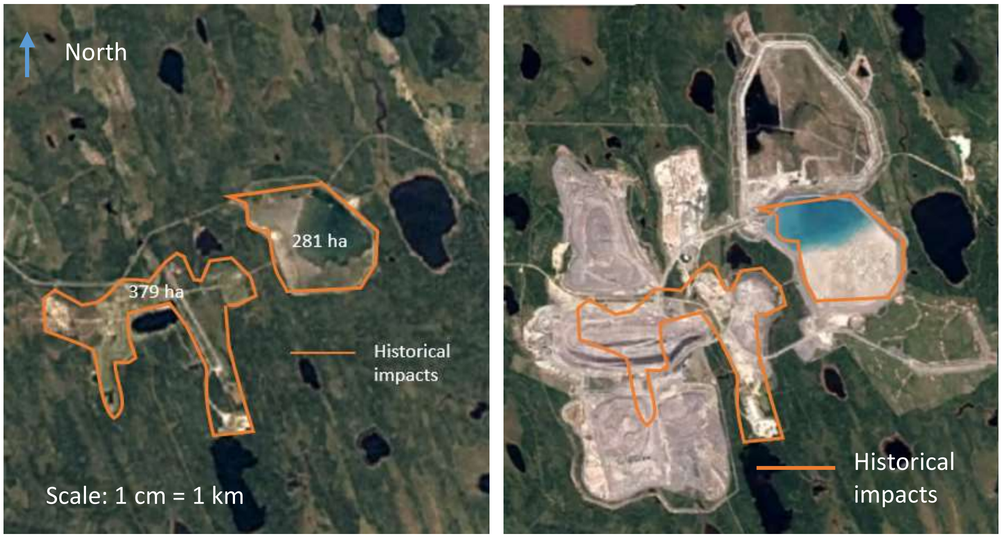

Figure 36. Historical impacts of previous mining activity at Detour Lake Mine (left photo: circa 2009, right photo: circa 2020) (Google Earth, 2021).

From these images it has been inferred that at construction:

- The majority of the New Afton Mine site consisted of grasslands with the exception of a historical open pit (88 ha) that was not vegetated and a historical tailings area (108 ha) that appears to have been partially flooded.

- The majority of the Detour Lake Mine site was forested to sparsely forested with some wetland areas with the exception of an area of historical mine infrastructure (379 ha) that appears to be sparsely vegetated and a historical tailings area (281 ha) that appears to have been partially vegetated and included wetland areas.

To understand land use changes from current operations, using available images for the sites and general knowledge of site construction gleaned from the 43-101 reports for both sites, land use change and associated areas were estimated up to the end of mine production life (Detour Gold Corporation, 2018; RPA, 2020). The resulting land impacts are presented in the following figures (Figure 37 and Figure 38) on the most current satellite images for each site.

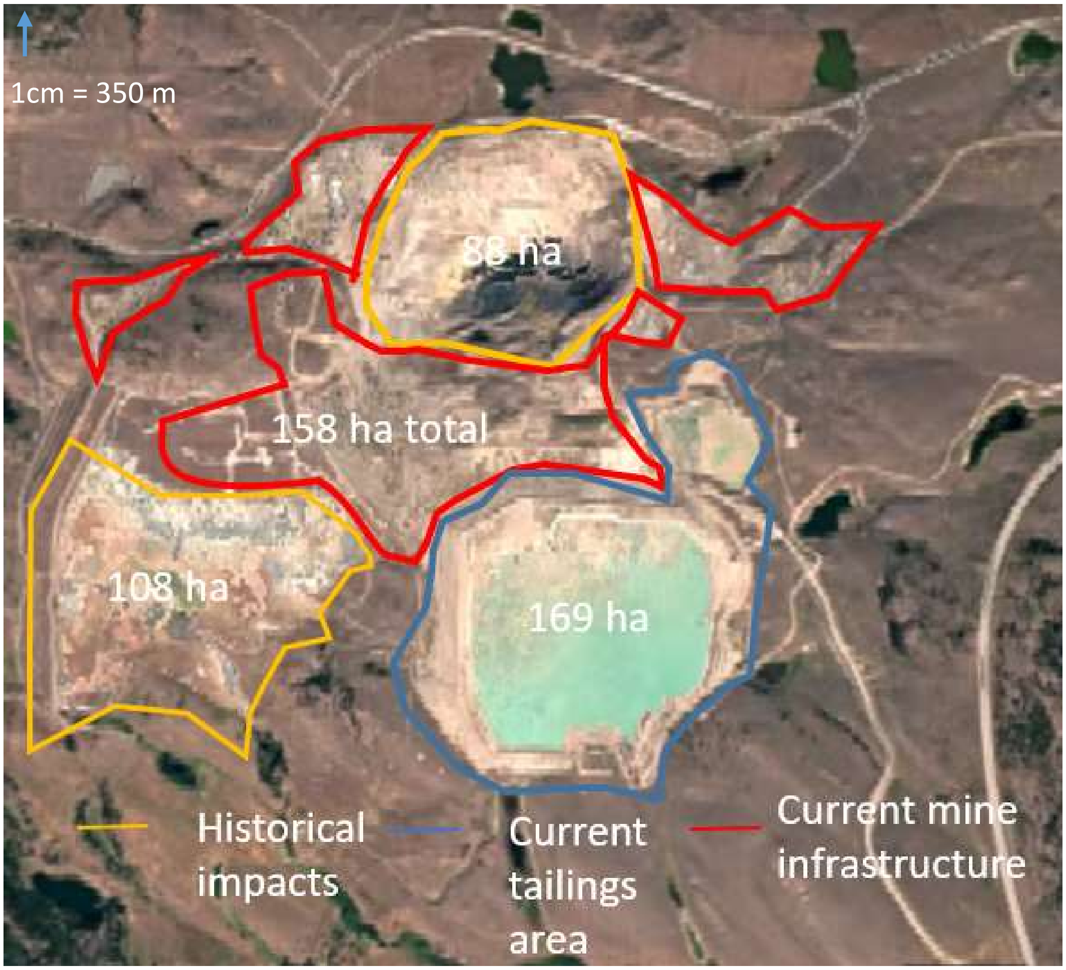

Figure 37. Estimates of current land use change at New Afton Mine (Google Earth, 2021b)

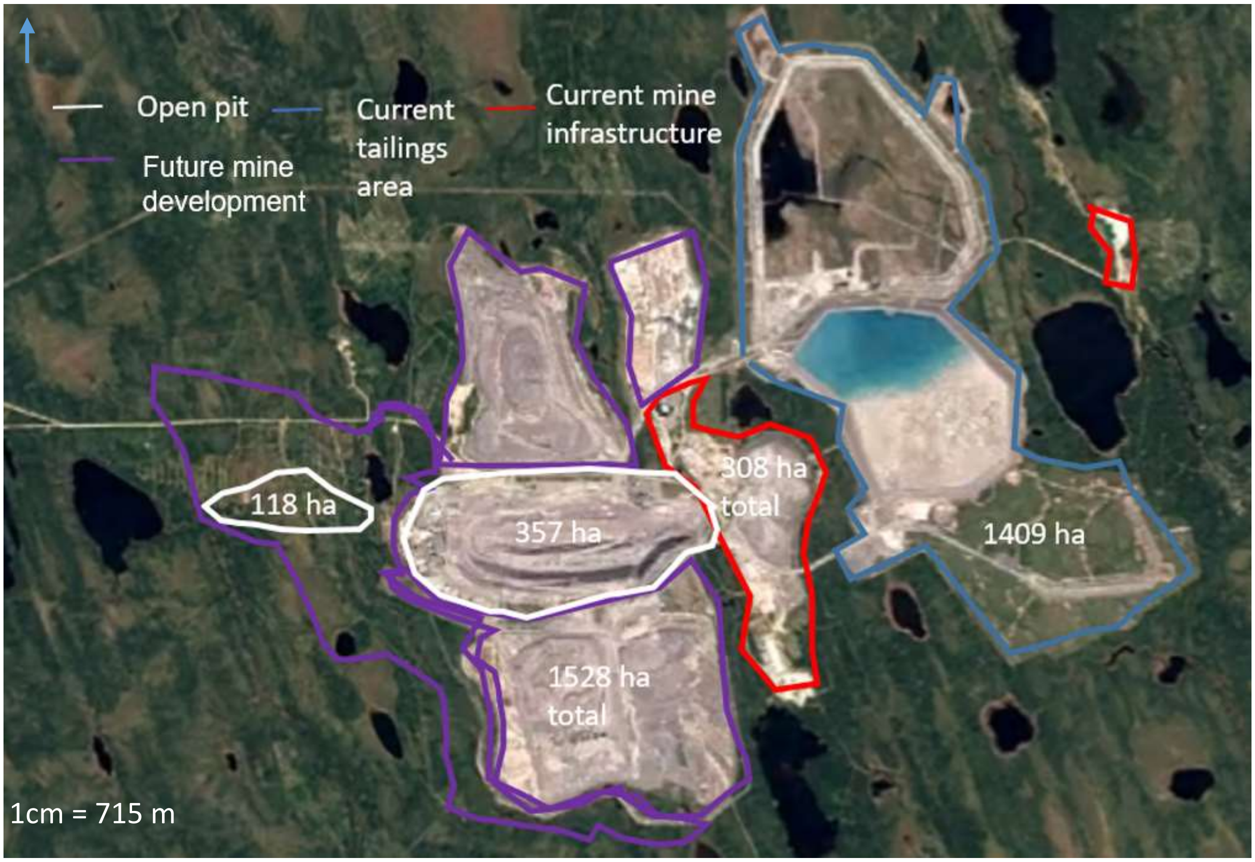

Figure 38. Estimates of current land use change at Detour Lake Mine (Google Earth, 2021)

Reviewing these images, it can be inferred that:

- The construction of additional mine infrastructure (158 ha) and new tailings impoundment areas (169 ha) at the New Afton Mine site results in the removal of native grassland at the site below the area impacted by historical mining activity.
- The construction of two new open pits (475 ha), new mine infrastructure (308 ha), a new tailings impoundment area (1409 ha), and waste disposal areas (1528 ha) at Detour Lake Mine result in the removal of boreal forest vegetation and wetland vegetation. Although it should be noted that, unlike at New Afton Mine, some of the new land use impact at Detour Lake Mine encompasses the historical mining areas and will result in the removal of what has been assumed to be predominately grassland vegetation in these areas.

To determine areas to be rehabilitated, closure tasks mentioned in the 43-101 reports were used to estimate areas to be remediated using site figures and current satellite imagery as described above. It was assumed that no rehabilitation efforts that contribute to carbon sequestration would be undertaken in open pits, areas of subsidence, or tailings areas with wet covers and these areas were excluded. It was also assumed that rehabilitation to original native vegetation cover type would not be undertaken in all disturbed areas. For example, where significant grade change had occurred in areas that were originally wetland, rehabilitation would involve planting of native grasses more suitable to the drier soils of the infilled low lying areas.

From the reports and satellite imagery for the sites, it was inferred that at closure:

- Mine infrastructure would be removed from the New Afton Mine site and the areas (158 ha) would be revegetated to native grasslands, tailings areas (new and historical) would continue to be wet cover areas, and the open pit and area of subsidence would be fenced off but not rehabilitated.
- Mine infrastructure would be removed from the Detour Lake Mine site and that area (308 ha) would be rehabilitated to a mix of forest and grassland. Waste disposal areas (1528 ha) and tailings areas (1409 ha) will be rehabilitated to grass cover. Open pit areas will not be rehabilitated with vegetation.

A summary of these land use changes are presented in the next section (Section 6.3) in Table 29 and are used to determine the emissions resulting from biomass change on site. Two forms of carbon accounting will be considered for the sites: firstly, GHG emissions from removal and subsequent rehabilitation of the vegetation biomass resulting from activities associated with operation and closure of the site by current operators, and secondly, carbon sequestration potential of the site over the life of the mine in the face of land use change. The following section (Section 6.3) describes the first where removed biomass is assumed to be oxidized and emit carbon to the atmosphere as a result. Section 6.4 describes that latter where the carbon not trapped in vegetation that would have remained on site had the mine not been constructed is considered as a loss of carbon sequestration potential.

6.3 GHG emission from vegetative biomass change

A methodology for estimating GHG emissions resulting from vegetative biomass change as a result of land use change has been developed by the UNIPCC. This methodology involves complex carbon budget modelling relying on a depth of understanding of biomass change from land use change that has occurred to determine emission factors and resulting carbon release (Intergovernmental Panel on Climate Change, 2003 and Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013). This analysis will adopt the terminology and application of emissions factors outlined in the UNIPCC's *Good Practice Guidance for Land Use and Land-use Change and Forestry* into a modified methodology more typically applied when estimating GHG emissions for future land use change as described in Seabridge Gold Inc. and Rescan Environmental Services Ltd (2013).

As per the simplified methodology, it is assumed that the flux of CO_2 to or from the atmosphere from land use change is equal to the changes in carbon stocks in the existing biomass and soils (Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013). In this case (as outlined in detail in Section 6.2 and summarized in Table 29), land was assumed to change i) from native vegetation (grasslands at New Afton Mine and sparse forest, wetland and grassland at Detour Lake Mine) ii) to settlement[4] during mine construction and operation (no vegetation and described as "area converted to mine infrastructure during construction" in Table 29) and iii) vegetation through rehabilitative work at end of mine life (return to grassland at New Afton and rehabilitation to grassland for Detour Lake Mine and described as "area reclaimed and revegetated at closure" in Table 29). For some areas, restoration back to native vegetation was not possible (e.g., open pit mines, tailings areas, etc.) resulting in the net land use change at the end of mine life described in Table 29 to which emission factors per net hectare of land changed have been applied. Emission factors for the land types considered were obtained from literature for the various climate zones described (refer to Table 29 for references). A summary of these emissions in relation to Scope 1 and 2 emissions for each mine is presented later in Section 6.5.

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[4] These land use types are defined by the UNIPCC in the referenced methodology. Details are provided in notes of Table 29, but the use of the UNIPCC term settlement refers to areas from which vegetation has been removed. For mines, these are areas where mine infrastructure like open pits, tailings areas, roads, and buildings have been constructed.

Table 29. Land use change and resulting GHG emissions for the two mine sites

Mine	Land use type [1]	Area converted[2] (ha)	Area reclaimed[3] (ha)	Net land use change at end of mine life (ha)[4]	Emission factor (tCO_2e/ha) [5]	Emissions due to land use change (tCO_2e) [4,5]	Total emissions due to land use change (tCO_2e)
New Afton	Grassland	327	158	169	12	2,027	2,027
Detour Lake	Sparse forest	3,037	62	2,975	300	892,533	895,220
	Wetland	282	-	282	128	36,063	
	Grassland	402	3,518	(2,781)	12	(33,376)	

1. Land use types were defined as:
    - Grassland – generally dominated by perennial grasses and distinguished from forest by lack of canopy and dominated by below ground carbon contained in roots and soil organic matter; vegetation includes grasses, herbs and low shrubs (Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013 and Stantec Consulting Ltd., 2020).
    - Sparse forest – dominated by tree species and presence of a canopy, but with less biomass than forest (due to bedrock impacted growing conditions; above ground and below ground carbon storage; vegetation includes needled coniferous and broad-leafed trees (Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013).
    - Wetland – permanently or recurrently saturated area that allow for riparian and wetland vegetation to be established ((Intergovernmental Panel on Climate Change, 2003 and Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013).
2. Area converted to mine infrastructure during construction.
3. Area reclaimed and revegetated at closure.
4. Numbers in brackets represent efforts to remediate (i.e., area reclaimed from settlement to land use types in note 1).
5. Emission factors were adopted from (Ducks Unlimited Canada, 2015; Intergovernmental Panel on Climate Change, 2003; Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013; and Stantec Consulting Ltd., 2020).

There is an obvious contrast between the mine sites when considering carbon emissions from land use change and a number of factors contribute to this. Detour Lake Mine has a footprint at construction of 3,721 ha, over 10 times greater than that of New Afton Mine with a footprint of 327 ha. Land types also varied between the sites. As mentioned, New Afton Mine is located in a cool temperate dry climate zone with arid, desert like habitat. The site prior to construction was dominated by grassland and while details on the remediation plans are limited, they focus around revegetating the site with grassland species. Irremediable land, including subsidence areas in and around the historical open pit, represents a significant portion of the site disturbance.

Detour Lake Mine is dominated by vegetation and soil types typical of the boreal forest and site construction will result in a land use change from sparse, boreal forest and wetland. Remediation on site will be limited by the presence of the large open pits and will focus on naturalizing roads and removing mine infrastructure. Additionally, the waste areas will be revegetated, but not to pre-development conditions. Instead, they will be vegetated with grass species typical to the area. However, unlike at the New Afton Mine site, historical mine infrastructure and tailings impoundment areas will be rehabilitated as part of the closure plan for Detour Lake Mine. These efforts to reclaim historically impacted areas result in the operators of Detour Lake Mine undertaking more rehabilitation by area than they impact as part of current operations. However, they are counter balanced by reclamation of the rest of the site to grasslands; a much less carbon dense biomass type than the native forest and wetlands contributing to net land use change emissions from the site.

6.4 Carbon sequestration potential of the sites over the life of mine

In addition to the carbon stored in plant matter removed or added to the sites through activities undertaken by the mining companies discussed in the previous section (Section 6.3), vegetation has the potential to remove atmospheric carbon through annual growth and decay cycles. Carbon is converted into biomass as plants grow then into soil carbon when plants die and the resulting litter decays into the soil (Sharma et al., 2021). The carbon can remain as soil organic material for years but is released through carbon respiration by microorganisms in the soil or through soil disturbance (Carleton University, 2021). This analysis will consider the change in this carbon sequestration potential as annual cycles of vegetative growth and decay are interrupted as the mines are developed.

For each site, the historical satellite imagery was used to calculate the amount of area from which vegetation has been removed as the site was developed as described above. For each vegetation type, values for the sequestration potential (i.e., the amount of CO_2e converted into plant biomass through the consumption of atmospheric carbon dioxide) were selected from a review of literature. The values for each are as follows:

- Grassland – 0.74 tonnes CO_2e per hectare per year (Tallgrass Ontario, 2021)
- Wetland – 3.09 tonnes CO_2e per hectare per year (Hansen, 2009), (Sharma et al., 2021)
- Forest – 12.78 tonnes CO_2e per hectare per year (Hansen, 2009), (Sharma et al., 2021)

The resulting loss of CO_2e sequestration potential for each mine site is presented graphically below (Figure 39 and Figure 40). The green line on these figures depicts the amount of carbon as CO_2e that would be trapped by annual cycle of plant growth and decay. The other lines below the green line represent the amount of carbon trapped by the vegetation that remains on site during construction and operation or is planted during rehabilitation efforts; the difference between these and the green line is the lost carbon sequestration potential. The patterns of both graphs reflect increasing vegetation removal during mine construction and start up until peak operations when expansion and land use change plateaus. GHG sequestration increased near the end of mine life to reflect remediation activities during site closure. It is likely that both sites will undertake progressive rehabilitation over the life of the project, however, details regarding such plans or how long site remediation will take were not available and are not reflected on the graphs of Figure 39 and Figure 40.

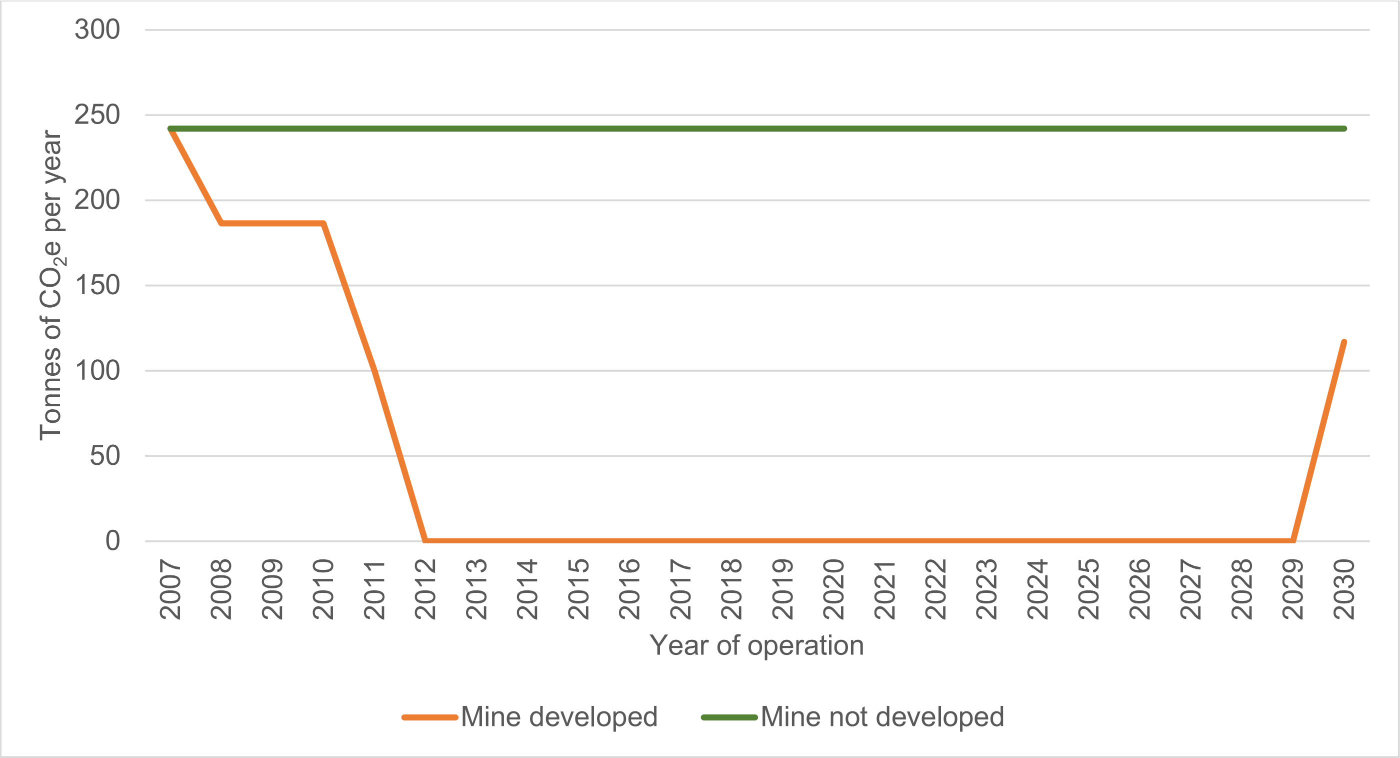

Figure 39. Amount of GHG emissions not sequestered due to loss of vegetation due to land use change over the life of mine at New Afton Mine.

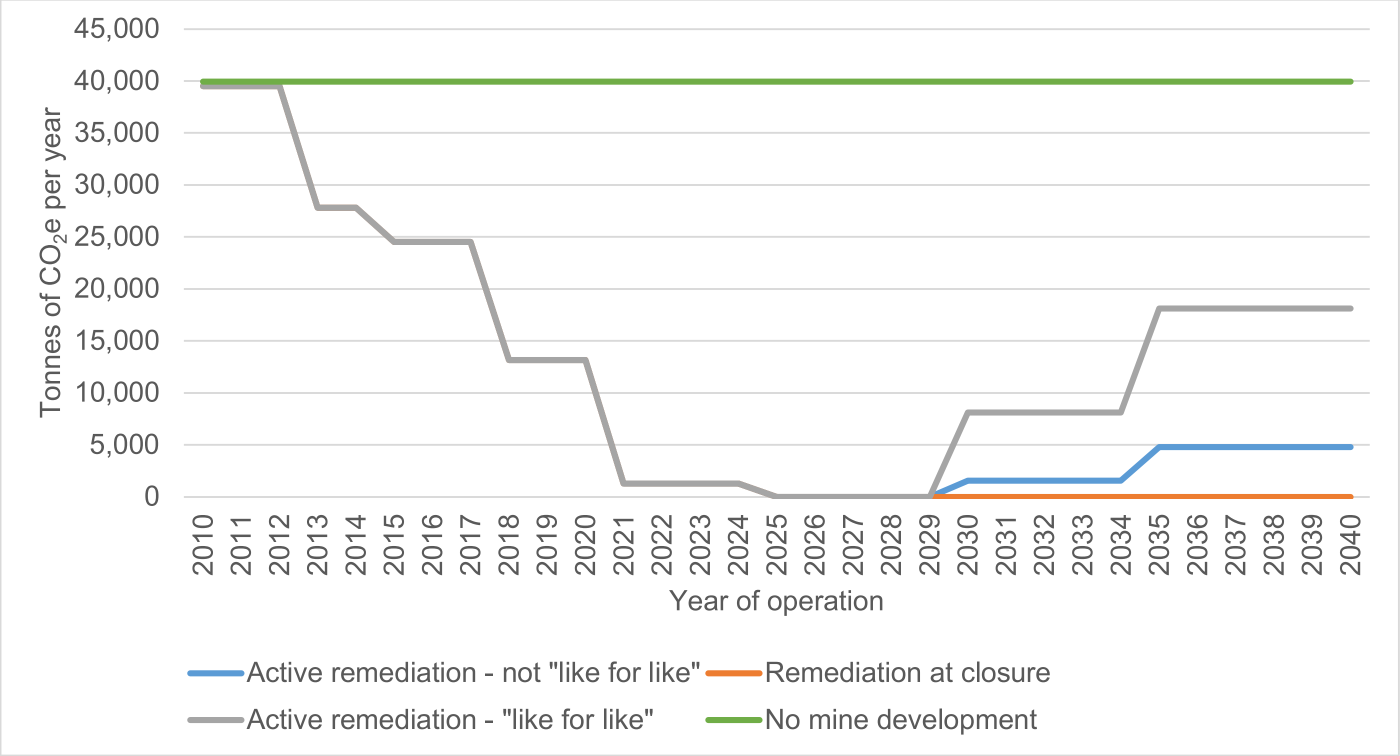

Figure 40. Amount of GHG emissions not sequestered due to loss of vegetation due to land use change over the life of mine at Detour Lake Mine.

From development of each site to closure and remediation occurring after closure, the total lost potential for sequestration of CO_2e resulting from the removal of vegetation over the life of the mine is as follows:

- New Afton Mine – 4,791 tonnes of CO_2e or 1.1% of the total CO_2e emitted from energy consumed during operations during this same time period
- Detour Lake Mine – 946,559 tonnes of CO_2e or 12% of the total CO_2e emitted from energy consumed during operations from 2013 to 2040

Post-closure and following assumed remediation works, loss of sequestration potential is 169 tonnes of CO_2e per year for New Afton Mine and 476 tonnes of CO_2e per year for Detour Lake Mine due to net land use changes.

6.5 Life of mine land use change related climate impacts

As indicated above, there are two types of carbon related impacts from land use change caused by mining: i) emissions caused by the removal and oxidation of biomass during construction, and ii) the carbon not trapped by native vegetation that would have remained on site should the mine not have been constructed referred to as the lost carbon sequestration potential. By presenting both as tCO_2e, it is useful to compare the emissions from land use change to total Scope 1 and Scope 2 GHG emissions from the burning of fossil fuels and consumption of electricity during operations (Table 30). Scope 1 and 2 GHG emissions in Table 30 were calculated from reported consumption of energy consumed by the mines where this information was available. Where not available, consumption was estimated based on reported consumption and production schedules. For New Afton Mine, this included GHG emissions related to electricity, diesel, natural gas, gasoline, propane and explosives consumed during site operations from 2012 to 2030 and totaled roughly 427,744 tonnes CO_2e (as previously reported in Table 24 and Table 25). For Detour Lake Mine, this included GHG emissions related to electricity, diesel, natural gas, gasoline, propane and explosives consumed during site operations from 2013 until 2040 and totaled 7,659,722 tonnes CO_2e. Based on this, emissions from land use change represents 0.5% and 12% of these combined Scope 1 and 2 GHG emissions for New Afton and Detour Lake Mines, respectively. When considering lost carbon sink potential over the life of the mine (i.e., the carbon not trapped in annual cycles of vegetative growth and decay due to the native vegetation being removed to construct the mine), the values are of similar scope being 1.1% and 12% of Scope 1 and 2 GHG emissions for New Afton Mine and Detour Lake Mine, respectively.

Table 30. A summary of land use related parameters for both mine sites

Emissions related parameter	New Afton Mine	Detour Lake Mine [1]
Scope 1 and 2 GHG emissions (tCO_2e)	427,744	7,659,722
Net land use change from mining (ha)[2]	169	476
GHG emissions associated with land use change and biomass removal (tCO_2e)	2,027	895,220
Land use change emissions as a proportion of Scope 1 and 2 GHG emissions (%)	0.5	12
Lost carbon sequestration potential from lost plant growth (tCO_2e)	4,791	946,559
Lost carbon sequestration potential as a proportion of Scope 1 and 2 GHG emissions (%)	1.1	12

1. For Detour Lake Mine, Scope 1 emissions include those reported for 2013 to 2018 and those estimated and reported as predicted total reported emissions in Chapter 5 (Government of Canada, 2020h). Scope 2 emissions were determined assuming that connection to the grid was utilized at maximized capacity and an assumed emission factor for the grid of 77 g CO_2e per kWh (Detour Gold Corporation, 2018 and Electricity Map, 2022).
2. This value is a sum of the areas presented in Table 29 and represents total net land use change but does not reflect land use type but does reflect the areas not rehabilitated and revegetated (e.g., areas that remain open pit or uncovered tailings impoundment areas).

Review of these values highlights the following:

- While total footprint of disturbance plays a large role in resulting emissions, this analysis showed that net change in land use type was most impactful when mining resulted in transition from a biomass intense ecosystem, such as forested land, to a mining site when compared to less biomass intense classifications, like arid desert.
- Remediation plans also play a key role in reducing net emissions as remediation to a less biomass intense land use classification may be more easily achieved, but the associated loss of carbon sequestering capacity can have long term effects upon the ecosystem's ability to moderate GHG emissions.
- Active site remediation during operation is important to reducing impacts and emissions from land use over the life of mine which can span multiple decades. Consideration of the rate of impacted or developed

and remediated land use is important during mine planning to reduce yearly land use related emissions from mine sites during operation.

- Appropriate remedial land use targets are key to reducing land use change related emissions from the site. Passive remediation plans may be insufficient to meet sustainability goals of the mining companies, involved government, and local stakeholders.
- For mines developed on historical brownfield sites, new operators will likely bear some responsibility for remediation of historical impacted areas at closure. This could result in a positive net land use change and a negative emissions profile for the site over the life of mine depending upon the carbon accounting scheme used. Under these conditions, it seems plausible that such works may be applicable under carbon offsetting programs if they exist which could offer an incentive to operate in brownfield areas promoting remediation of historical sites.

6.6 How land use change emissions and lost carbon sequestration potential are considered against taxation policy

Currently, emissions from land use change at mines are not taxed, but when considered in a context of general carbon emissions reduction, these specific sources of emissions are important for two reasons. First, and as mentioned in Section 2.4.4, new or expanding mines that are considered ‘designated projects’ in the Impact Assessment Act will be required to outline how the operation will achieve net zero emissions by 2050. As part of the *Strategic Assessment of Climate Change*, land use change emissions will be counted against the net emissions of a project meaning that these projects will need to reduce land use emissions in addition to the more obvious emissions from burning fossil fuels. Secondly, some carbon taxation schemes, such as the OBPS and carbon taxation policies in British Columbia, allow for emitters to generate offset credits from projects they undertake that avoid or reduce emissions or capture carbon (Government of British Columbia, n.d. and Government of Canada, 2020b). Each credit counts as one tCO_2e being removed from the atmosphere and can be sold or remitted against unavoidable emissions. Policy around what type of projects are eligible to generate such offsets is still evolving but will likely include soil carbon enhancement and forest management projects which are both relevant to mine rehabilitation and the potential to reduce or avoid emissions from land use change. An example of such an initiative is discussed in more detail in the following Section 6.7.

6.7 Biodiversity conservation efforts by New Afton Mine and the potential for carbon offsetting

Ecosystems with higher biomass, such as forests, actively sequester carbon dioxide equivalent gases (CO_2e) from the atmosphere in plant biomass, dead organic matter, and soil. Through photosynthesis, plants within these ecosystems fix carbon dioxide; this fixation will exceed the release of CO_2 as plants grow resulting in a net uptake from the environment. During decomposition, the carbon will be released back to the atmosphere from the dead plants (Freedman et al., 2009). Changing the character of the ecosystem in a way that impacts vegetation and soil will impact the ability of the system to store carbon (Yang et al., 2021). One way to reduce atmospheric concentrations of greenhouse gases (GHG), specifically CO_2, is to conserve or enhance biomass carbon in the living biomass or dead organic matter of these systems (Freedman et al., 2009). Currently, terrestrial ecosystems absorb a significant but declining portion of anthropogenic GHG emissions; however, projections indicate that this capacity will decrease as global warming progresses (Freedman et al., 2009).

Most current global warming policies recognize the importance of these ecological sinks in climate change mitigation and promote accounting frameworks to reduce emissions through land use change. These policies (like the OBPS and carbon taxation policies in British Columbia), encourage projects that conserve ecological sinks or enhance fixation so that they can be used to generate carbon credits (Freedman et al., 2009). These projects can also include the restoration of productive natural ecosystems in areas where anthropogenic land use has resulted in reduced carbon sequestration (Freedman et al., 2009). These tradable credits are marketable and can be used by emitters to compensate for GHG emissions they could not reduce to meet emission targets.

As discussed in Section 2.5, the Government of British Columbia manages a carbon offsetting program through which the province will purchase offset credits that represent a tonne of CO_2e that was either removed from or not released to the atmosphere as a result of direct—beyond business as usual—action by industry (Government of British Columbia, n.d.). These units can be purchased from the registry by other organizations that wish to meet emission targets (Government of British Columbia, n.d.). For mines undertaking conservation or rehabilitation projects beyond the scope of site remediation outlined in their closure plans, the sale of resulting carbon offset credits could provide some relief from carbon taxation depending upon the scope and scale of the projects in question.

6.7.1 Purpose and boundaries of this analysis

The purpose of this analysis was to review conservation efforts being undertaken by New Afton Mine and determine the revenue from potential sale of carbon offsetting units to the Government of British Columbia to assess the scope of carbon taxation relief from the current accounting framework.

The boundaries of this analysis are conservation efforts being undertaken by New Afton Mine determined from the review of publicly available sustainability reporting for the site. These include two projects: the formation of the Warner Philip Conservation Area and a wetland restoration project (MineralsEd, 2021 and New Gold Inc., 2020). The details associated with each are outlined in the following sections.

6.7.2 Warner Philip Conservation Area

The Warner Philip Conservation Area is a 260 ha area located 20 minutes south of Kamloops. Historically operated as ranch land, this acreage was designated as a biodiversity reserve through a conservation covenant. The intent of the conservation plan is to protect tracts of native grasslands, Ponderosa pine woodlands, savannah, wetlands, shallow ponds and provide habitat for threatened grassland fauna (Nature Conservancy Canada, 2020). Conservation of this property will ensure restoration of native grasslands on the former ranchland.

While this project was undertaken by a number of partners in addition to New Afton Mine, for the purpose of this analysis, it has been assumed that all resulting carbon offset credits will be attributed to New Afton Mine (Nature Conservancy Canada, 2020).

6.7.3 Wetland restoration

As reported in New Afton Mine's 2020 sustainability report, New Afton Mine partnered with BC Wildlife Federation to protect a 1.3 ha wetland located north of the mine site adjacent to Kamloops Lake. Impacts to this area include over grazing of the wetland by cattle. Fencing was installed around to wetland to allow for passive wetland restoration (New Gold Inc., 2020). As with the project above, this project was undertaken in partnership with other local stakeholders, but for the purpose of this analysis, it has been assumed that all resulting carbon offset credits will be attributed to New Afton Mine.

6.7.4 Conservation efforts and land use change emissions

To determine the impact of these conservation efforts and the potential revenues from any resulting carbon offset units sold via British Columbia's emission offsetting program, the land use change accounting methodology as employed previously in Section 6.3 was applied to the described conservation projects. It was assumed that land use changed from cropland to grassland at the Warner Philip Conservation Area and from cropland to wetland at the wetland restoration site.

As before, this analysis adopted the terminology and application of emission factors outlined in the IPCC's *Good Practice Guidance for Land Use and Land-use Change and Forestry* into a modified methodology more typically applied when estimating GHG emissions for future land use change as described in (Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013).

For the analysis presented in Section 6.3, emission factors were applied to the net land use change resulting from removal of native vegetation to convert the site to settlement (i.e., mine site) and then the partial rehabilitation of the sites back to native conditions or ecologically acceptable alternatives. In this analysis, vegetation on site was assumed to change from cropland to grassland and wetland, respectively. The emissions factors were calculated by subtracting the emission factor for the conversion of cropland to settlement of 9.8 tCO$_2$e per hectare from those for the conversion of settlement to grassland (12 tCO$_2$e per ha) and wetland (128 tCO$_2$e per ha) (Ducks Unlimited Canada, 2015; Intergovernmental Panel on Climate Change, 2003; Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013; Stantec Consulting Ltd., 2020; and Tubiello et al., 2016). The resulting GHG emission reductions are presented in Table 31 and as in Seeley (2019), the average provincial purchase price of \$12 per tonne of CO$_2$e was applied to net emissions due to emissions avoided due to rehabilitative land use change.

Table 31. Revenue from carbon offsetting projects undertaken by New Afton Mine

Biodiversity offset	Land use type prior to offset project[1]	Land use type as a result of offset project[1]	Area reclaimed (ha)	Percentage of net land use change area[2]	Emission factor[3] (tCO$_2$e/ha)	Emissions avoided due to rehabilitative land use change (tCO$_2$e)	Revenue from carbon offset credits[3] (at \$12/ tCO$_2$e)
Warner Philip Conservation Area	Cropland	Grassland	260	154%	2.2	575	\$6,895
Wetland restoration	Cropland	Wetland	11.3	6.7%	118.2	1,336	\$16,029

1. Land use types were defined as:

- Cropland – annual or perennial cropland or pasture (Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013).
- Grassland – generally dominated by perennial grasses and distinguished from forest by lack of canopy and dominated by below ground carbon contained in roots and soil organic matter; vegetation includes grasses, herbs and low shrubs (Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013 and Stantec Consulting Ltd., 2020).
- Wetland – permanently or recurrently saturated area that allow for riparian and wetland vegetation to be established (Intergovernmental Panel on Climate Change, 2003 and Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013).

2. Represented as a percentage of the total net land use change for the site of 169 ha (Table 29) which is the 327 ha of grassland converted to mine during construction minus the 158 ha of this area rehabilitated to grassland at closure on the New Afton Mine site.
3. These emissions factors were calculated by subtracting an emission factor for the conversion of cropland to settlement of 9.8 tCO$_2$e per hectare from those for the conversion of settlement to grassland (12 tCO$_2$e per hectare) and wetland (128 tCO$_2$e per hectare) (Ducks Unlimited Canada, 2015; Intergovernmental Panel on Climate Change, 2003; Seabridge Gold Inc. and Rescan Environmental Services Ltd., 2013; Stantec Consulting Ltd., 2020; and Tubiello et al., 2016).
4. This value is the total over the life of mine.

Reviewing the resulting revenues presented in Table 31 from sale of the carbon offset units produced as part of the conservation projects undertaken by New Afton Mine shows a small return when compared to the $12.2 million in carbon taxes estimated to be paid by the mine from 2012 to 2030 (refer to Table 24 in Section 6.3.2).

This is due to two factors: the scale of the remediation efforts and land use changes undertaken. The conservation efforts undertaken, while providing important reserves of native grasslands, are small in footprint with compared to other similar conservation projects included in the BC Carbon Registry. Significant carbon sequestering projects on the registry involved conservation of hundreds of thousands of hectares compared to the few hundred described above (Government of British Columbia, n.d.). Also, these more impactful projects occur in ecosystems with greater biomass richness than the ecosystems surrounding New Afton Mine meaning that emission factors for those sites are much higher than the conversion of cropland to grassland and wetland being undertaken by New Afton Mine. While conservation of the natural biodiversity of native grasslands is an important conservation effort in this area of British Columbia, current carbon accounting frameworks that rely solely on biomass availability will devalue these efforts when compared to similar effort undertaken in more heavily vegetated or forested areas.

6.8 Chapter conclusions

The analysis completed in this chapter indicates that the amount emissions resulting from land use change and the lost carbon sink potential due to mine construction is a function of the mine operational footprint, the carbon richness of the mine location, and the rehabilitation effort and timing. Depending upon the land types being impacted and the scale of the physical footprint of the mine, carbon related impacts from land use change represented up to 24% of the Scope 1 and 2 emissions for the sites considered. While not currently taxed, these emissions are considered towards the net emissions of new of expanding mining projects triggering federal impact assessments. More importantly, the carbon emissions reduced or avoided or captured through well planned site construction and remediation plans may be eligible for carbon offset programs, but the policy around these is still evolving at the time of writing. If eligible offsets produced from managing site construction to avoid vegetation removal or through remedial planting could be a source of carbon revenue and count against carbon produced from more obvious emissions sources like burning fossil fuels.

While the eligibility rules of the carbon credit trading systems, like that in place in British Columbia, will favour other types of projects over the current biodiversity efforts being undertaken by New Afton Mine, these projects will have non-carbon related co-benefits related to the conservation of natural ecosystems (Freedman et al., 2009). The conservation of biodiversity resulting from these efforts will have societal importance and contribute to the Mine's on-going social license to operate. These efforts will create goodwill with local stakeholders and contribute to sustainability goals and reporting by the mine.

Overall, undertaking off-site biodiversity offsetting projects for the purpose of carbon unit trading to offset emissions from mining impacts will require projects to be of significant land area for benefits to impact a mine's emissions balance in a meaningful way. Land use emission factors are higher for biomass intense land use types resulting in a larger potential "payback" for remedial efforts. If a mine is located in a naturally low biomass ecosystem, this could mean that biodiversity offsetting efforts may be undertaken by the mine further afield where offsetting work will result in the sale of more carbon offsetting units, but too much flexibility in such policies could result in impacts being accrued in greenfield, remote environments with remedial benefit redirected to more urban areas. This could work against efforts by the mine to create goodwill with stakeholders local to the mine.

7 Material haulage alternatives at Detour Lake Mine

7.1 Purpose and boundaries of this analysis

Chapters 4, 5, and 6 provided an overview of energy consumption at the operational level for the case study mines considered. With this improved understanding of how energy is consumed by the various mining activities, a review of operational alternatives can be undertaken to determine if the carbon footprint of these mines can be reduced. The purpose of the alternatives analysis presented in this chapter is to review the operation of a haulage system at an open pit mine in Canada and determine the viability of alternative haulage methods and fuel sources. To do this, public facing information regarding the mining fleet, operations, and production rates for the Detour Lake Mine near Cochrane, Ontario were used. The site's connection to the Hydro One electricity transmission network allows for consideration of a number of alternative haulage systems dependent upon the affordable electricity provided by this grid.

As the motivation for this analysis is to assess alternative technologies that lower CO_2e, emissions, and those at Detour Lake are principally associated with waste and ore haulage, technologies that are cost, energy and carbon competitive with the CAT 795 haulage fleet are its focus. Reduction of estimated diesel consumption and related emissions will be the goal of this analysis. Electric-powered, heavy-duty trucking solutions suited to the operating and climatic conditions at open pit mines in Canada are considered alongside others that offer the materials handling capacity required, including alternative fuel types or alternate conveying systems (Propulsion Québec, 2020). Battery electric operation of haul trucks was not considered practical for the scale of this surface operation.

The scope and spatial boundaries considered are the same as for the energy and carbon analyses of earlier chapters except, for simplification and commensurate with the publicly available information, only operation of the CAT 795 making up the main haulage fleet moving ore and waste from the main open pit to various waste piles and ore pile on site is considered. The temporal boundary is limited to from 2019 to 2040 (i.e., the current pit design to end of planned production for the mine). All costs are presented in Canadian dollars; costings used were converted to Canadian dollars and adjusted to 2020 prices as necessary. Where used, a cost for diesel of $0.80 per litre and a cost for electricity of $25 per MWh was used as these costs were defined in the 43-101 report for the site.

7.2 Base case diesel consumption at Detour Lake Mine

Consumption estimates determined in Chapter 4 are adopted as the base case benchmark. Between 2019 and 2040, it is estimated that 1.55 billion litres of diesel will be used by the main mining fleet with peak consumption occurring between years 2024 and 2032. This corresponds to excavations occurring in both the main pit and ancillary, smaller open pits to the north and west of the main Detour Lake Pit (referred to as the North and West Pits). The CAT 795 mining trucks that provide the main hauling effort to move waste and ore from the Detour Lake Pit and consume 58% of the estimated diesel usage by the main mining fleet. Using the OEM fuel consumption rates, the CAT 795 trucks are estimated to consume a total of 894 million litres of diesel between 2019 and 2040 (Table 9); this equates to 2.41 million tCO_2e of Scope 1 emissions over the same period (Table 22). This corresponds to an average annual consumption of 42.6 million litres with 0.55 litres burned for every tonne of material moved from the main pit by the CAT 795.

Cost as well as CO_2 emissions will be considered. In addition to the diesel cost, there will be operating cost and capital costs for truck replacement. Direct costing for CAT 795 trucks was not found in literature, but capital costs for similar units (CAT 797 and CAT 793) varied between $2.9 and $6.7 million (Ben-Awuah, 2017; Huffman, 2000; Kalantari et al., 2020; and Stantec Consulting Ltd., 2019). Using these, an average capital cost of $4.7 million per CAT 795 was assumed. Costs presented in Ben-Awuah (2017) and Stantec Consulting Ltd. (2019) suggested that operating costs per year per truck was on average 48% of the capital cost so a yearly operating costs of $2.3 million per truck was assumed. The operating costs were assumed to include maintenance, labour, parts and tires, but not fuel as this is dealt with separately. A replacement interval of 6 years was assumed for the CAT 795 fleet. Using these costs and assumptions, the cost to operate the existing fleet was determined and is presented in Table 32. These will be the benchmarks against which alternatives will be considered. A detailed, itemized yearly cost breakdown is presented in Appendix B.

Table 32. Estimated base case capital and operating costs for the diesel powered CAT 795 fleet

Cost type	Life of mine	Average year	Per production tonne	Per total tonne moved
Capital (CAD)	496,000,000	23,000,000	1.32	0.31
Operating (CAD)	1,637,000,000	77,000,000	4.35	1.01
Energy (CAD)	715,000,000	34,000,000	1.90	0.44
Total (CAD)	2,848,000,000	135,000,000	7.58	1.75

7.3 Powering the CAT 795 fleet with hydrogen fuel cells

Hydrogen has the potential to contribute to Canada's GHG reduction goals (Government of Canada, 2020i). In mining applications, hydrogen can be used in a fuel cell in electric vehicles, which can have improved efficiency over their diesel counterparts with minimal emissions from the vehicle (Government of Canada, 2020i). For material handling in mining, use of hydrogen fuel cells could reduce reliance upon diesel. Cost, availability, and practicality (i.e., technological readiness at the scale needed) of fuel cells and their required infrastructure will be considered to determine whether the complexity of fuel production/supply will hinder uptake as suggested by the Government of Canada (2020i). As mining companies implement efforts to decarbonize, they must do so without limiting the effectiveness of their production function. Hydrogen has the flexibility to deal with some of these challenges; Fúnez Guerra et al., (2020) present a heavy duty application case study.

For this analysis, two methods of hydrogen production were considered: i) delivery of liquid hydrogen to the site from a depot via truck and ii) production of gaseous hydrogen onsite. For each, the hydrogen distribution and storage necessities on site were considered.

It was further assumed that the diesel powered CAT 795 would be retrofitted with hydrogen fuel cells that would produce electricity on-board to power the existing electric motors on the trucks; the CAT 795s in use at Detour Lake Mine already employ a diesel-electric drive system. A diesel powered engine that supplies power to an alternator which delivers electrical power to two electric motors mounted on the rear axle via a power electronics module (including an inverter and converter) that converts the alternating current electricity to direct current then to three phase alternating current electricity. The electric motors, one dedicated to each rear wheel, provide the motive power to turn the wheels (Caterpillar, 2021a). A simplified schematic of the electric drive is presented in Figure 41; estimated efficiencies of the various engines, converters, and motors are presented in red (Caterpillar, 2021a and Nino Vega, 2020). Based on these, a cumulative efficiency for the diesel powered electric drive is 36%.

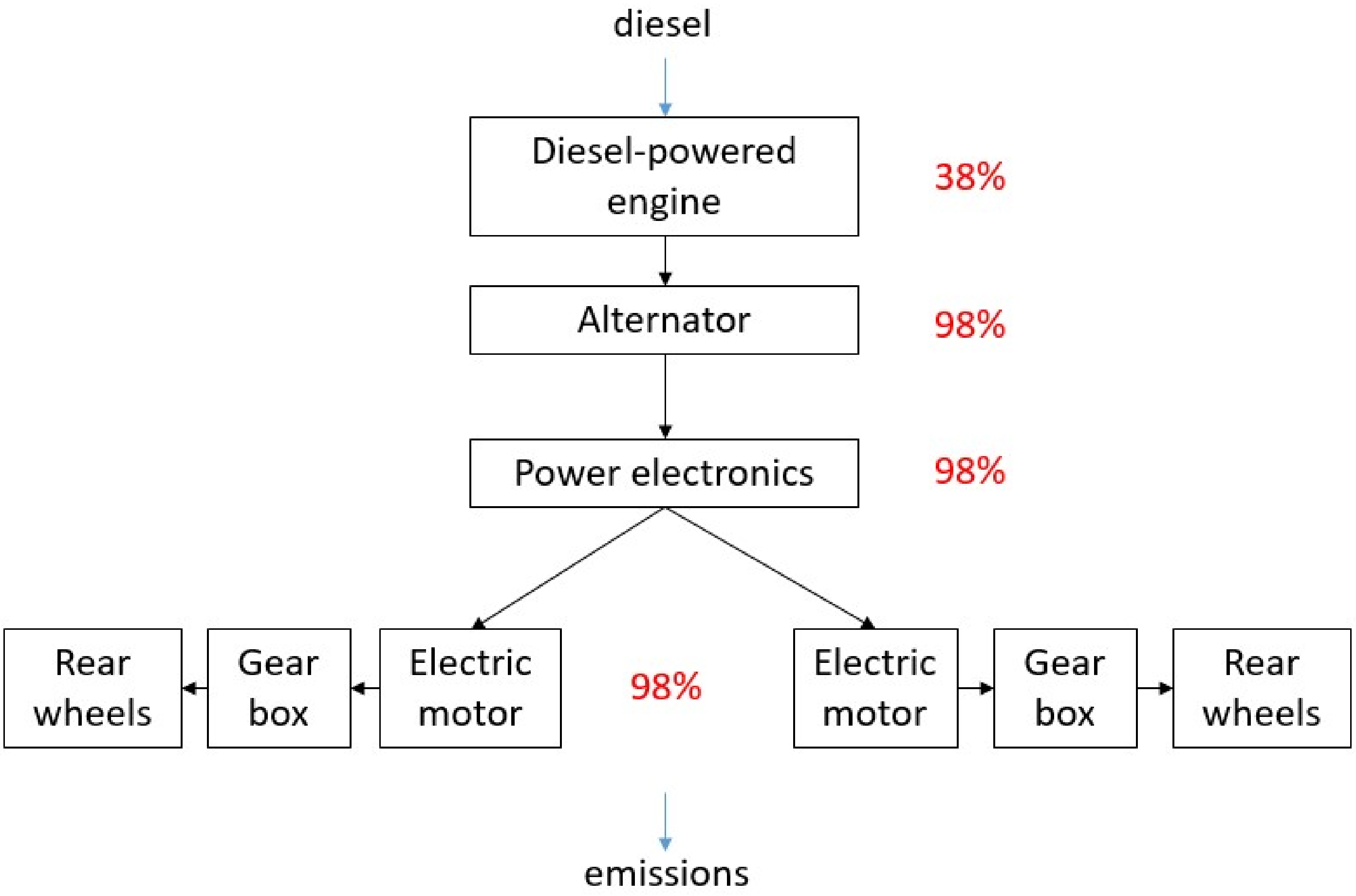

Figure 41. Electric drive system in the CAT 795 used at Detour Lake Mine (Caterpillar, 2021b and Nino Vega, 2020)

To consume hydrogen in lieu of diesel to power the CAT 795 fleet, the electric drive system would have to be retrofitted to include a fuel cell that would power the electric motors by converting hydrogen gas to electricity directly (Dippo et al., 2009). The Proton Exchange Membrane fuel cell type is the most commonly used and has been proven in underground mining applications (Bétournay, 2019). A simplified schematic of a fuel cell is presented in Figure 42. As depicted, the fuel cell includes two electrodes separated by an electrolyte capable of carrying an electrical charge. The hydrogen fuel is consumed at the anode where it produces protons that travel towards that cathode through the electrolyte and electrons that also travel to the cathode through a circuit producing electricity in the process. At the cathode, oxygen is also consumed (sourced from air around the vehicle) to produce waste water and heat when combined with the hydrogen (Adolf et al., 2017).

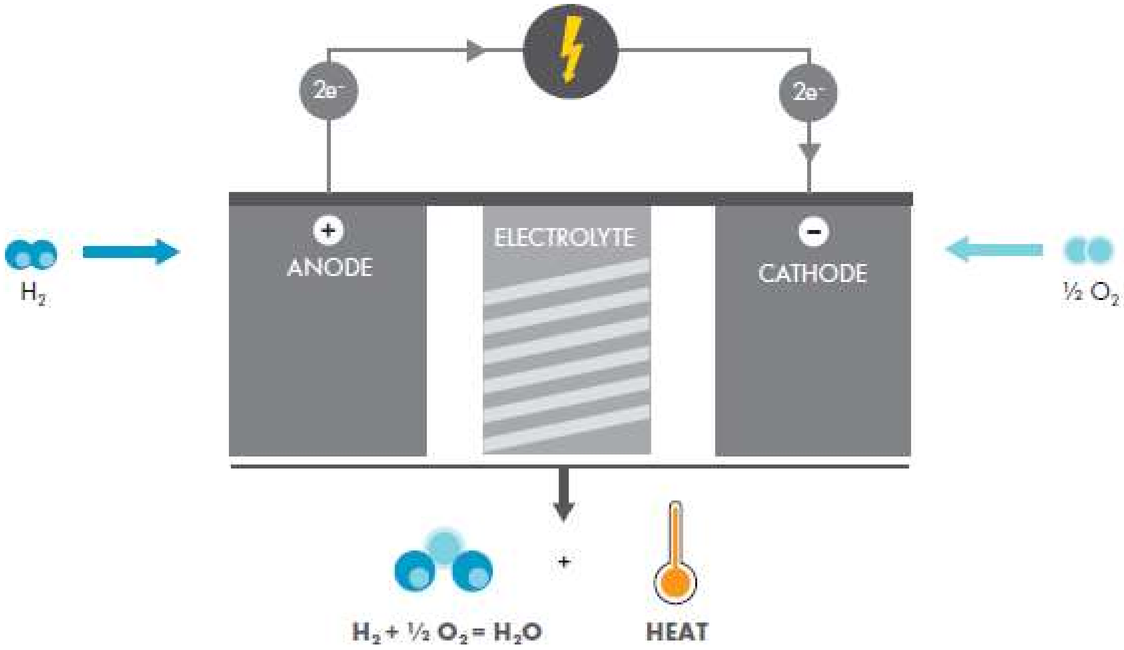

Figure 42. Hydrogen fuel cell simplified schematic (Adolf et al., 2017)

To use hydrogen fuel cells to power the CAT 795, the electric drive system would need to be retrofitted to exclude the diesel powered engine and include the fuel cell and associated converters. The remainder of the power system will remain the same. A simplified schematic of the hydrogen fuel cell powered electric drive system is presented in Figure 43 including estimated efficiencies. When compared to diesel engines, the efficiency of a fuel cell can vary between 40% and 60% depending upon the electrolyte used and sensitivities to fuel impurities, corrosion from high operating temperatures, CO_2 in the air, and the fuel cell type (Adolf et al., 2017 and Office of Energy Efficiency and Renewable Energy, n.d.). Assuming use of polymer electrolyte membrane fuel cells typically used to meet heavy duty demands and efficiencies of 60%, the cumulative efficiency for this system is estimated to be a maximum of 56% (Office of Energy Efficiency and Renewable Energy, n.d.).

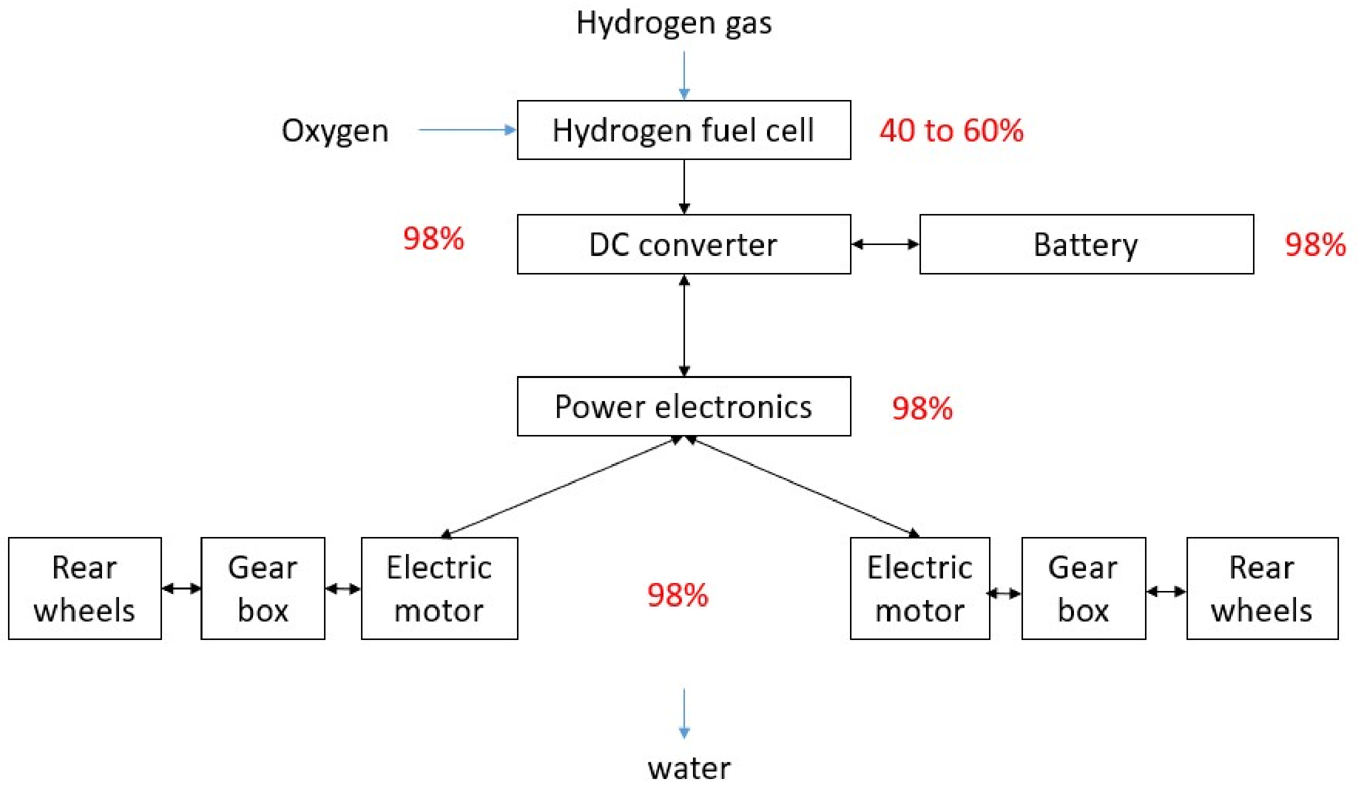

Figure 43. Simplified schematic of the hydrogen fuel cell powered electric drive system of CAT 795 (Adolf et al., 2017 and Nino Vega, 2020)

To operate the existing fleet of CAT 795 there will be costs to retrofit with fuel cells and hydrogen storage tanks. Costs to retrofit the existing fleet were adapted from those in Kalantari et al. (2020) and were assumed to be $4.3 million per truck (i.e., cost to install fuel cells on existing trucks) an appreciable saving on the fleet replacement cost of $7.0 million per truck (i.e., cost to purchase CAT 795 truck with a hydrogen fuel cell already installed) every five years (considered in Sustaining CAPEX). Operating costs (excluding fuel) for the hydrogen powered CAT 795 were assumed to be the same as the diesel powered trucks.

Capital and operating cost to operate a hydrogen powered CAT fleet over the life of mine were determined to be $957 million and $1,637 million, respectively. The additional capital costs represent a 90% increase over equivalent costs for the diesel powered fleet and is due predominately to the capital outlay to install fuel cells into the existing trucks.

When comparing the energy density of diesel and hydrogen fuel, diesel has an energy density of 46 MJ per kg compared to hydrogen's energy density of 120 MJ per kilogram which is roughly three times that of diesel. This means that 1 kg of hydrogen used in a fuel cell provides roughly the same energy of a gallon (or 3.78 litres) of diesel (RMI, 2019). When comparing the efficiency of the system, fuel cells are roughly 30 to 50% more efficient than diesel engines with efficiency ranging between 40 and 60% (Adolf et al., 2017; Ballard Motive Solutions, n.d.; and Fúnez Guerra et al., 2020). Given this, it is estimated that for every 7.5 to 8 litres of diesel consumed, one kg of hydrogen would be required to do the same work (Fúnez Guerra et al., 2020 and LeBlanc, 2021).

The established benchmark for diesel consumption by the CAT 795 fleet has been estimated to be 894 million litres of diesel over the life of mine or an average annual consumption of 42.5 million litres with 0.47 litres burned for every tonne of material moved from the main pit. The amount of hydrogen required to fuel the CAT 795 fleet was estimated be 5.7 million kg per year on average or 0.07 kg of hydrogen per tonne moved. A consumption rate per day for hydrogen fuel was calculated from these values to determine supply needs (on average 16 tonnes per day). As stated, two methods of hydrogen supply were considered: delivery of liquid hydrogen by truck and production of hydrogen gas on-site via water electrolysis. The footprint for hydrogen storage (either on board on in depot) depends on whether it is stored as a cryogen or a compressed gas.

7.3.1 Liquid hydrogen delivery to site by truck

For the site in question, delivery of hydrogen would require production of large quantities of hydrogen at an off-site, centralized location most likely through bulk production like steam methane reforming that uses natural gas to produce hydrogen and other by-products including carbon dioxide (Bétournay, 2019). Purification is also likely required to remove these by-products from the hydrogen fuel to maintain the useful life of the fuel cells (Hatch, 2006). It was assumed that hydrogen would be delivered to site by truck given the remote location of the site, the capital expense, and approvals required makes installation of a pipeline a less practical alternative. It was also assumed that the hydrogen would be delivered in liquid form as it has a higher energy density compared to hydrogen gas and, under certain conditions, could offer a lower cost for higher volumes (Connelly et al., 2019). Liquefying hydrogen is completed in three steps (compression, cooling, and expansion) and requires that the gas be cooled to cryogenic temperatures through a liquefaction process (Bétournay, 2019).

Once compressed, there are two steps involved in cooling. It needs to be pre-cooled below its inversion temperature of 80 Kelvin (K) using a liquid nitrogen bath and a heat exchanger. A second heat exchanger is used to further reduce the temperature of hydrogen to 40 K. A throttling process is employed to allow the hydrogen to expand to a low pressure of slightly above atmosphere during which it further cools to 20 K and partially liquefies. Liquid is then separated from the vapour with the cold vapour redirected to heat exchangers for cooling prior to being recycled through the process (Connelly et al., 2019). The hydrogen product would then typically be filled into a cylinder, pack of cylinders, or tube trailer using a high-pressure filling station and trucked to the location of use. To maintain hydrogen in a liquid state for delivery, these trucks will be required to have cryogenic storage capacity (Hatch, 2006). From the truck, the hydrogen would be pumped to on-site cryogenic storage tanks (Bétournay, 2019 and Hatch, 2006).

There are additional safety and storage complexities at the mine sites when using liquid hydrogen that may require dedicated, skilled staff to facilitate than those considered in the study presented above. Liquid hydrogen transportation is most applicable for the sites where demand is less than 4 tonnes of hydrogen per day and sites are within a 1,500 km radius of the hydrogen production site (Bétournay, 2019). While the hydrogen demand calculated at Detour Lake Mine would be well in excess of this (on average of 16 tonnes per day) and currently no bulk production or bulk storage is known to exist within 1,500 km of the site, this alternative was investigated to fully illuminate the supply chain issues that will be faced by high production, open pit mining operations in Canada generally, not just Detour Lake.

To estimate the cost of having hydrogen delivered to the site, the distribution scenario presented in Figure 44 was considered. Given the volume of hydrogen required at site, it was assumed that hydrogen would be delivered in liquid form by the supplier requiring transportation in cryogenic tankers and stored on site in tanks permitting a few days of fuel storage. There was assumed to be additional complexity to the handling of liquid hydrogen on site resulting in high capital and operating cost and potentially requiring mine staff with specialized knowledge. Additional surface infrastructure for operations using liquid hydrogen include cryogenic storage tanks and associated vaporizers and compressors to allow for state change to gaseous fuel (Bétournay, 2019). To avoid some of these costs and complexities, liquid hydrogen could be dispensed directly from the storage tanks to liquid storage fuel tanks on the mining trucks. However, at the time of writing, onboard storage units that use liquid hydrogen are less well developed than those that store hydrogen gas. While they are expected to have weight and volume advantages, onboard liquid hydrogen storage systems are unproven with unknown costs and consequently are not considered for this analysis (Burke and Fulton, 2022).

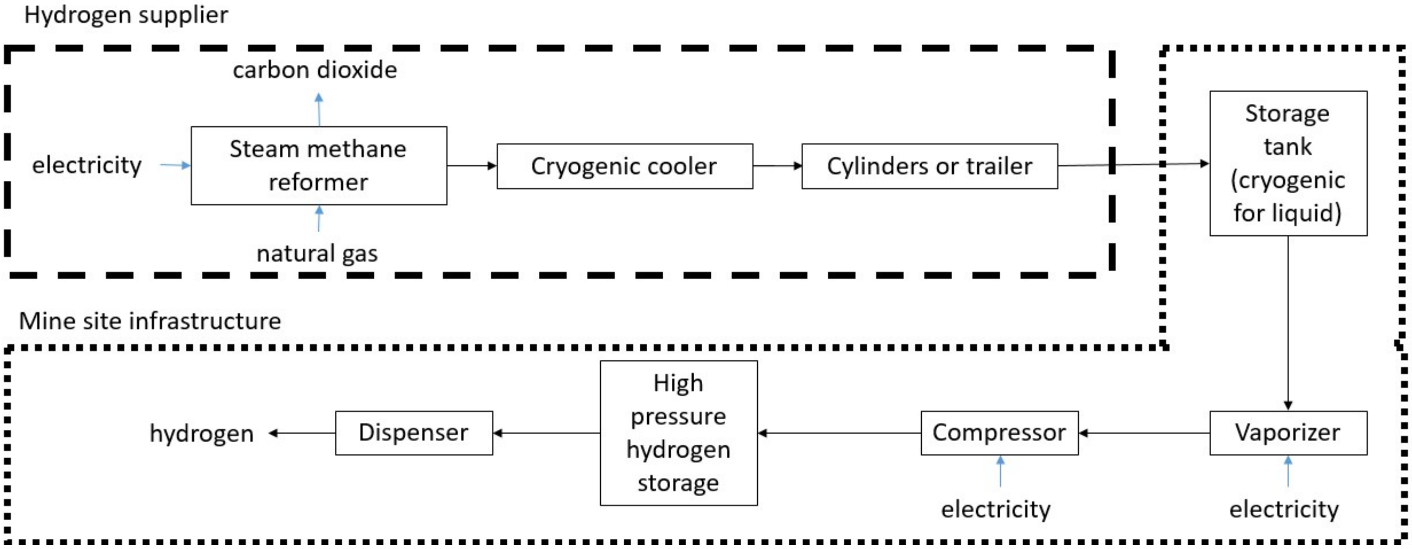

Figure 44. Hydrogen delivery and distribution system for fuel delivered from a centralized location to site.

For the above system, the following design parameters were applied and are based upon a review of Bétournay (2019); Connelly et al. (2019); Fúnez Guerra et al. (2020); Hatch, (2006); and Parks et al. (2014) (Table 33). Dispensers with a filling rate of 0.5 kg of hydrogen gas per minute were included as per Hatch (2006); however, Parks et al. (2014) suggests a filling rate of 2 kg of hydrogen per minute is possible. The cost estimate presented in this section uses a filling rate of 0.5 kg of hydrogen per minute to provide a conservative estimate of filling times and capital costs.

Table 33. Design parameters for the distribution system for the use of liquid hydrogen.

Infrastructure	Design parameter
Cryogenic storage	Sized for two days of storage at peak storage requirements.
Vapourizer	Sized for the average daily consumption rate of approximately 16 tonnes per day.
Compressor	Need to compress full capacity of storage tanks over two day period.
High pressure storage	May include different high pressure requirements but are required to hold two days worth of hydrogen fuel and to facilitate distribution.
Distribution	Each unit has 2 nozzles and fill rate of 0.5 kg of hydrogen/minute.

A study of supply chain costs to supply hydrogen fuel for light duty vehicles at a rate of 27,000 kg per day was undertaken by the US Department of Energy in 2019 to determine the associated costs in California. It determined that dispensing and liquefaction would be the most expensive aspect of the production of hydrogen fuel for this purpose, representing 51% and 30% of total costs respectively (Connelly et al., 2019). A detailed breakdown of these costs are presented in Figure 45. As this study estimated costs associated with the production of hydrogen for sale at various dispensing stations at a commercial scale, of interest to this thesis are the costs excluding commercial dispensing stations; namely costs for production, liquefaction, terminal, and trucking. These costs were equivalent to $6.06 per kilogram and will be compared to a similar analysis completed for Detour Lake Mine (Connelly et al., 2019).

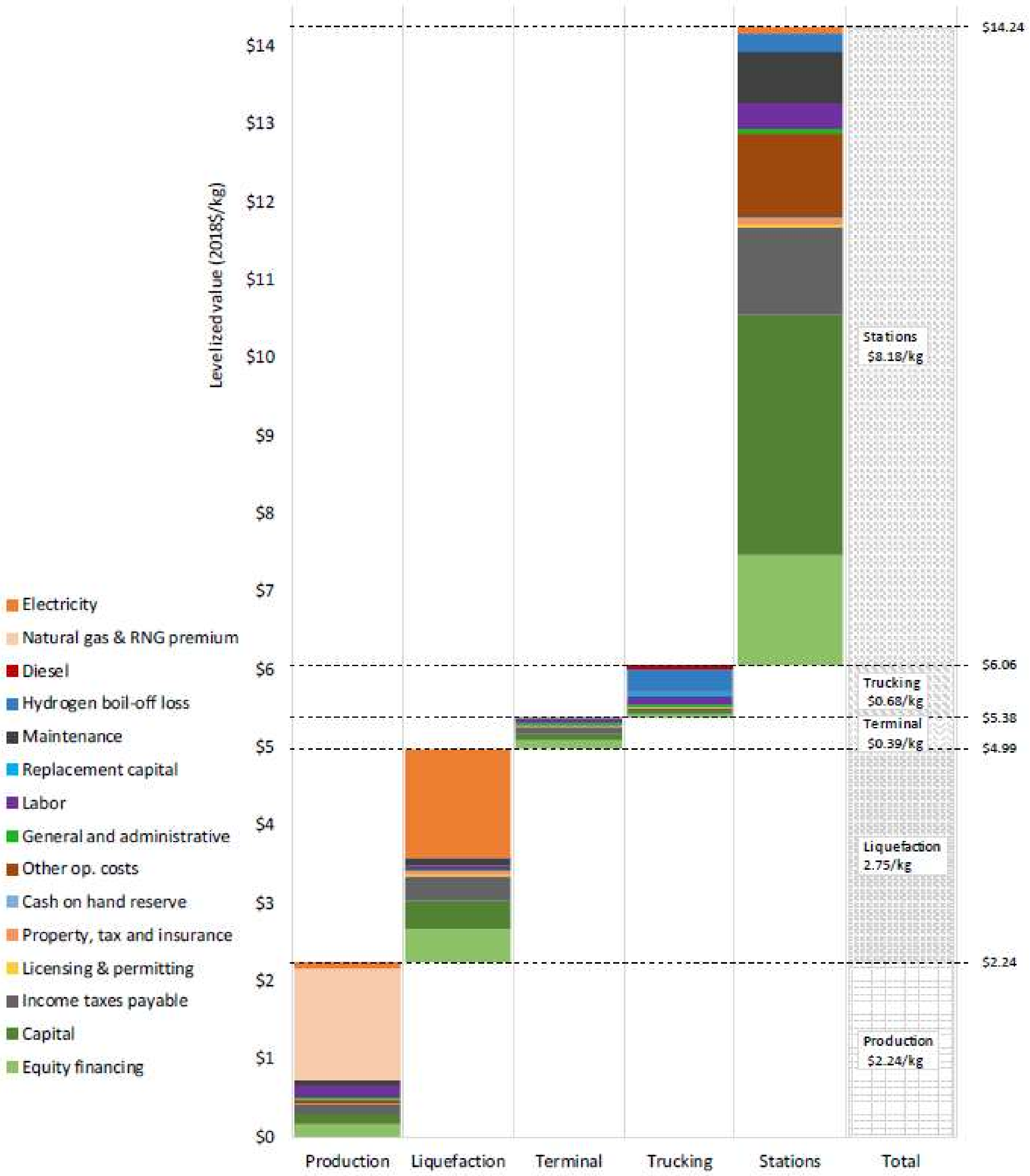

Figure 45. Estimated costs associated with the production of liquid hydrogen for light duty vehicles in California (Connelly et al., 2019)

To estimate the cost to install and operate the hydrogen distribution system outlined in Figure 44 per the design parameters listed in Table 33, unit costs were obtained from a review of literature availble with preference given to costing found for Canadian mine sites where possible; these are presented in Table 34. Where pricing found was for commercial distribution systems, which have a higher costs over industrial equivalents, the lower of the costs were selected for this analysis if a range of costs were found. It was observed that the researched unit costs varied greatly; especially for operation of the distribution systems where they varied from \$0.16 per kilogram to \$2.97 per kilogram (Fúnez Guerra et al., 2020; Hatch, 2006; and Parks et al., 2014). A similar variation was observed for estimated electrical consumption by the distribution system being between 2 to 8.3 kWh per kilgoram (Christensen, 2020 and Parks et al., 2014). Unit cost values presented in Table 34 are averages of these cost ranges where applicable.

Costs to purify the liquid hydrogen have been assumed to be included in the supplier's cost. To determine the captial cost of the distribution system it has been assumed that individual dispensing units capable of dispensing gaseous hydrogen at a rate of 0.5 kg per minute will be used requiring a total of 21 dispensing units to be installed at a cost of \$134,000 each (Hatch, 2006). As noted, a faster fill rate of 2 kg per minute was suggested by Parks et al. (2014) at a cost of \$214,000 per dispensing unit. This would decrease the required dispensing units to 6 which would cause operational issues when filling a fleet of the size used at Detour Lake Mine. To provide a conservative costs estimate and operational flexibility, the lower cost dispensers were selected. Energy required to operated the storage and distribution system was determined based on the amount of hydrogen consumed by the CAT 795 in a year and energy requirements of similar systems described in Christensen (2020) and Parks et al. (2014). Based on these and considering the requirements of the proposed system, it was assumed that 4.5 kWh of electrical energy would be required per kilogram of hydrogen distributed. This was based on a review of similar systems described in Christensen (2020) and Parks et al. (2014) and rated considering the compression requirements of the proposed system. It should be noted that it was not possible to discern electrical costs from the operating cost rates presented in the literature as they lacked sufficent detail to do so. However, for this analysis, the lower range of operating costs presented in the literature reviewed was assumed and electrical cost were calculated seperately based upon the energy consumption rate above.

Captial costs to install the distribution system once are also presented in Table 34. Most capital costs were assumed to be incurred in year 1 of this analysis in 2019, but additional capital costs to replace the distribution sytsem were assumed to be incurred again in 2029 at the end of their expected life (Hatch, 2006).

Table 34. Cost used when estimating costs associated with liquid hydrogen delivery to site (Bétournay, 2019; Connelly et al., 2019; and Hatch, 2006).

Type		Unit cost (CAD)	Cost for one time installation (CAD)
Capital costs	Vapourizer	208/kg of hydrogen	3,100,000
	Cryogenic storage tank	5,000/m^3 of hydrogen	1,060,000
	Compressor	1,155/m^3 of hydrogen	9,900,000
	High pressure storage	616/kg of hydrogen	14,600,000
	Distribution	134,000/per dispenser unit	2,800,000
Operating costs	Hydrogen costs	6.74 kg of hydrogen	
	Delivery fee	1.08 kg of hydrogen	
	On-site storage and distribution	1.36 kg of hydrogen	

With these assumptions, a summary of estimated costs to operate the CAT 795 fleet at Detour Lake Mine from 2019 to 2040 using liquid hydrogen is presented in Table 35. The estimated capital costs include the costs to retrofit the trucks, replace the trucks every five years, and install a storage and distribution system. Operating costs include costs to operate the trucks, to have hydrogen delivered, and to operate the distribution system. Energy costs include costs for liquid hydrogen and electricity to power the distribution system. A detailed, itemized yearly cost breakdown is presented in Appendix B.

Table 35. Estimated costs to delivery liquid hydrogen to Detour Lake Mine

Item	Life of mine total	Average year	Per production tonne	Per total tonnes moved
Hydrogen consumed (kg)	119,000,000	5,678,000	0.3	0.1
Number of deliveries required	49,700	2,366		
Capital costs (CAD)	994,000,000	47,000,000	2.65	0.61
Operating costs (CAD)	1,927,000,000	92,000,000	5.13	1.19
Energy costs (CAD)	817,000,000	39,000,000	2.17	0.50
Total	3,739,000,000	178,000,000	9.95	2.30

As mentioned, use of the faster dispensing system (2 kg per minute versus 0.5 kg per minute) would reduce the number of required dispensers and associated life of mine capital costs in Table 35 by $3.1 million. Additionally, a two day storage capacity was suggested by Fúnez Guerra et al. (2020) and is reflected in the design parameters in Table 33. However, the 43-101 report for Detour Lake Mine indicates tanks providing a seven day storage capacity for diesel are located on site. To increase the storage capacity of the hydrogen distribution system to provide a similar capacity would result in additional capital costs of $89.5 million.

It should also be noted that the estimates in Table 35 assume that a centralized supply is located within a reasonable distance of the Detour Lake Mine site (i.e., within 500 km). The closest likely location would be Timmins, Ontario; however, a supply depot of this capacity is not currently located there. At the time of writing, the largest capacity supplier of liquid hydrogen is located roughly 1000 km away—in Quebec. It has also been assumed that delivery will be completed via specialized 9,000 gallon (or 34,000 litre) tankers with a capacity of 2,400 kg of liquid hydrogen.

A comparative summary table of costs for all alternatives considered against the benchmark diesel powered fleet costs is presented in Section 7.6.

7.3.2 Production of gaseous hydrogen on site

For sites requiring large volumes of hydrogen (typically greater than 4 tonnes of hydrogen per day), on-site production may be more economical (Bétournay, 2019). Gaseous hydrogen can be produced through the installation and operation of electrolyzers. Electrolyzers produce hydrogen by passing electricity through two electrodes separated by an electrolyte; water is a required input and oxygen is produced as a by-product (Dippo et al., 2009). In an alkaline electrolyzer, as considered in this analysis and depicted in Figure 46, the cathode loses electrons into the electrolyte and hydrogen gas is produced from the dissociation of the water. At the anode, the electrons are absorbed producing oxygen from the dissociated water. A membrane prevents the mixing of oxygen and hydrogen gas but allows for anions from the dissociated water to travel as needed (Adolf et al., 2017). This method has smaller production rates than the previously mentioned steam methane reformer but is advantageous when a steady supply is required and if electricity is available at a low cost (Bétournay, 2019). Efficiency is determined by the amount of electricity needed to produce an amount of hydrogen and is currently around 60% to 80% and is a function of sensitivity to CO_2 in the fuel and air, electrolyte management, and membrane conductivity. Combining electrolyzers, hydrogen production can be adapted to meet the energy needs of a site (Adolf et al., 2017).

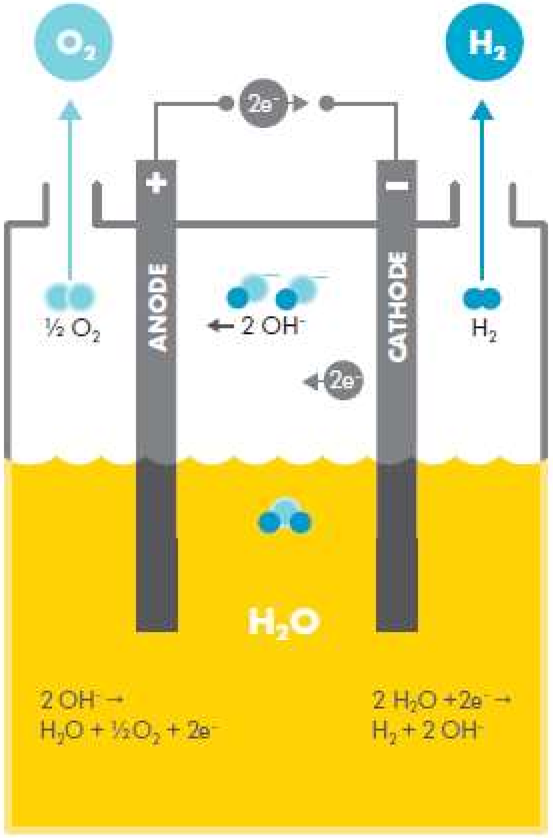

Figure 46. Simplified schematic of an alkaline electrolyzer (Adolf et al., 2017)

The basic arrangement of a hydrogen production facility includes generation, storage, a distribution system, and dispensing system. To estimate the costs of installing such infrastructure and producing hydrogen on site, the infrastructure presented in Figure 47 was considered essential. In this scenario, all production of hydrogen gas was assumed to occur on site for the purpose of fueling the CAT 795. As the site is connected to the provincial electrical grid and does not have access to natural gas piplelines, an alkaline electrolyzer was selected as the hydrogen production plant.

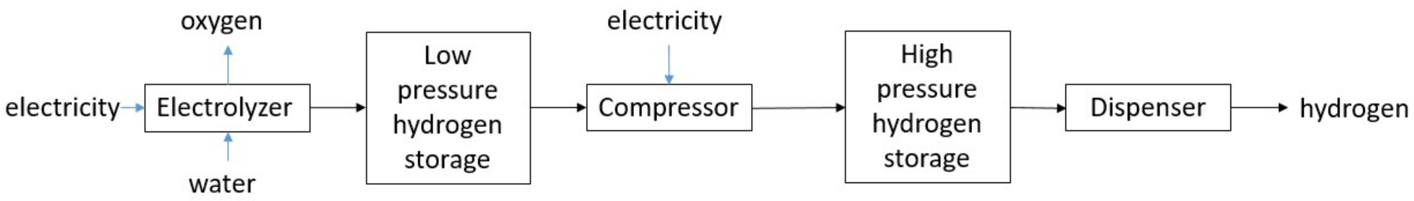

Figure 47. Production, distribution and storage infrastructure to produce hydrogen gas on site.

The number of electrolyzers required was determined by using the estimated kilograms hydrogen consumed on site per day and converting this value to kilowatt hours using the assumption that one kilogram of hydrogen is equivalent to 33.6 kWh of energy (RMI, 2019). An electrolyzer efficiency rate of 80% was assumed (Bétournay, 2019). A 10 MW electrolyzer is currently the largest available commercially and these have a capacity of producing 4500 kg of hydrogen per day (Fuel Cells Bulletin, 2019). Using the hydrogen consumption estimates for the site per day in conjunction with this value, the number of electrolyzers for the site was determined to be three to five 10 MW electrolyzers depending upon the mining phase. It was assumed that these would have a life span of 10 years (Kalantari et al., 2020).

The infrastructure included in the storage and distribution system was selected and modelled after that presented in Bétournay, (2019); Fúnez Guerra et al. (2020); and Hatch (2006); the design parameters considered are presented in Table 36. It should be noted that the referred to analyses were completed for underground operations with lower hydrogen consumption rates than would be needed at Detour Lake Mine. As mentioned in Section 7.3.1, there are some potential alternatives to these design parameters. Specifically, Parks et al. (2014) suggest a faster filling rate for the distribution system is possible (from 0.5 to 2 kg per minute); in this case study it would add additional capital costs and potential operational issues due to fewer dispensers for the fleet. Also, the cost estimate provided in this section is for a system that provides two day storage capacity as suggested by Fúnez Guerra et al. (2020). However, as per the 43-101 report, Detour Lake Mine currently stores seven days of diesel on site; cost to increase the storage capacity of this distribution system for hydrogen to seven days will be provided.

Table 36. Design parameters for the storage and distribution systems for hydrogen gas produced on site

Infrastructure	Design parameter
Electrolyzer	Determined based on hydrogen consumption assuming one 10MW electrolyzer can produce 4500 kg of hydrogen per day with a 10 year service life.
Low pressure storage	Sized for two days of storage at peak storage requirements; same pressure as gas produced from electrolyzer.
Compressor	Need to compress full capacity of low storage tanks over two day period.
High pressure storage	May include different high pressure requirements but are required to hold two days worth of hydrogen fuel and to facilitate distribution.
Distribution	Each unit has 2 nozzles and fill rate of 0.5 kg of hydrogen/minute.

To size the storage systems, the maximum daily consumption rate of hydrogen was selected for each mining period of the main pit at Detour Lake Mine and used to determine storage requirements; the resulting requirements are presented in Table 37. Instead of installing a system to handle peak capacity, it was assumed that it would be phased up or down at intervals during the mine life. For this estimate, the high pressure storage system was costed to include a larger at high pressure and a smaller at very high pressure installed in parallel. Fúnez Guerra et al. (2020) indicates that use of such a cascade system of high pressure storage, although with additional capital expense, improves efficiency by reducing the use of electricity at the compressor stage. In Table 37, the combined storage of the two high pressure systems is equal to that of the low pressure system and allows for two days storage.

Table 37. Capacity requirements of the hydrogen gas storage and distribution system.

	Infrastructure	Low pressure storage requirements (kg of hydrogen)	High pressure storage requirements (kg of hydrogen)	Very high pressure storage requirements (kg of hydrogen)	Flow rate requirements for compressor (m^3/hr)
Mining period years	2019 to 2023	36,000	23,700	12,600	8,500
	2024 to 2032	37,000	24,000	13,000	8,700
	2033 to end of project	25,000	16,000	8,800	5,900

Capital and operating costs used to determine the estimated cost for production of gaseous hydrogen on site are presented in Table 38. Costs for the infrastructure were either scaled up from those presented in Bétournay (2019); Fúnez Guerra et al. (2020); Hatch (2006); and Kalantari et al. (2020) on the basis of consumption rates or by applying a generalized costing for similar commercial facilities from Christensen (2020) and Parks et al. (2014) and as reported in the previous section. It has been assumed that operational costs include costs associated with water, maintenance and personnel. Water used by the system was assumed to be freshwater supplied from East Lake like process water for the mill per the 43-101 report; however, this water would require deionization. A water demand of 9 l per kg of hydrogen would require 164,000 l of water per day at peak and 1.07 billion litres over the remaining life of mine; deionization of this water was assumed at a cost of $0.004 per litre (Saulnier et al. 2020 and Water Innovations Inc., n.d.). Electrical consumption of the electrolyzer and storage and distribution system have been calculated separately. Electrolyzer electricity consumption was determined using estimated consumption based on number of electrolyzers, hydrogen requirements by mining period, an assumed electrolyzer efficiency of 80%, and duty cycle of 22 hours a day for 360 days per year. It was also assumed that 4.5 kWh per kilogram of hydrogen consumed by the CAT 795 each year would be required to operate the distribution system (Christensen, 2020 and Parks et al., 2014).

Table 38. Costs use to estimate hydrogen production on site at Detour Lake Mine

Type		Unit cost (CAD)	Cost for one time installation (CAD)
Capital costs	Electrolyzer	1,397/KW	13,970,00/electrolyzer
	Low pressure storage	339/kg of hydrogen	12,000,000
	Compressor	1,155/m^3 of hydrogen	9,800,000
	High pressure storage	1,170 to 616/kg of hydrogen	29,500,000
	Distribution	134,000/per dispenser unit	2,800,000
Operating costs	Electrolyzer (CAD/kg)	1.59/kg of hydrogen	
	On-site storage and distribution (CAD/kg)	3.81/kg of hydrogen	

Using the hydrogen requirements, costings, and design requirements for hydrogen gas production on site, the total capital and operating costs were determined and are presented in Table 39. As before, the estimated capital costs include the costs to retrofit the trucks to operating using hydrogen fuel cells. A detailed, itemized yearly cost breakdown is presented in Appendix B.

Table 39. Estimated capital and operating costs associated with producing hydrogen gas on-site to fuel the CAT 795 fleet at Detour Lake Mine

Item	Life of mine total	Average year	Per production tonne	Per total tonnes moved
Hydrogen consumed (kg)	119,000,000	5,700,000	0.3	0.1
Capital costs (CAD)	1,200,000,000	57,500,000	3.21	0.74
Operating costs (CAD)	2,280,000,000	108,000,000	6.07	1.40
Energy costs (CAD)	224,000,000	10,700,000	0.60	0.14
Total	3,710,000,000	177,000,000	9.87	2.29

A comparative summary table of costs for all alternatives against the benchmark diesel powered fleet is presented in Section 7.6.

7.3.3 Additional considerations for the use of hydrogen to power the CAT 795 fleet

Considering just the operating and capital costs presented, use of hydrogen on site at Detour Lake Mine, with cost ranging between \$9.95 per production tonne for delivery and \$9.87 per production tonne for production on site, seems a like more expensive alternative to diesel consumption at \$7.58 per production tonne. However, there are additional considerations, some beyond the mining company's control, to assess to fully understand feasibility. These include capacity of the electricity transmission and distribution grid, need for a specialized infrastructure and labor force, and availability of required technology.

Currently, the Detour Lake Mine is connected to Ontario's electricity grid via a 230 kilovolt (kV) transmission line can supply 120 MW of power (Government of Ontario, 2021b). While the electrical consumption profile of the equipment on site is not readily available in public facing documents, given the various mills and processing infrastructure on site, it is likely that power draw may approach the limits of the connection. Installation of four 10 MW electrolyzers may represent a constant draw on the electrical supply to the site that is beyond the capacity of the existing infrastructure and power supply. Additionally, the energy demand of the distribution system during fueling could push capacity limits depending upon the fueling strategy used.

Availability of required technology may also be a hindrance to use of hydrogen at large open pit mines like Detour Lake Mine. Firstly, the analysis presented above assumes availability of 10 MW electrolyzers to produce the sufficient required amounts of hydrogen gas. While electrolyzers of this capacity are being tested (Fuel Cells Bulletin, 2019), typical electrolyzers are more in the 3.5 to 4 MW range which would require the installation of numerous electrolyzers to meet demand. Beyond the complexity of multiple storage tanks, compressors, vapourizers, etc. described above as being needed to provide the fleet with sufficient volumes of hydrogen fuel, dispensing of the fuel is complicated by the need for the dispensers to be designed to provide fuel at the pressure required by the on-vehicle storage tanks (Adolf et al., 2017). Filling rates may also be a limiting factor for the practicality of hydrogen fuel at large open pit mines. Viable filling rates from dispensers range between 0.5 to 2 kg per minute (Adolf et al., 2017; Bétournay, 2019; and Parks et al., 2014). With a demand of 220 kg per CAT 795 per shift, filling time would be the better part of two hours for each truck to operate for a full shift. It should be noted that advancements in onboard storage tanks for liquid hydrogen (rather than the gaseous systems considered here) could also result in improved dispensing rates between 2 and 4 kg per minute but further development is required at the time of writing (Burke and Fulton, 2022).

As installation of the hydrogen production infrastructure described above will require the installation of extensive infrastructure and considering the hazards associated with production of hydrogen, there will likely be additional staffing requirements to crew the production plant. While not included as part of this estimate, it is likely a number of full time positions for skilled workers will be required. As mentioned, water will be required to fuel the electrolyzers. While multiple freshwater water sources are named in the 43-101 report for the site, no information on the volume of water taking or the capacity of existing systems is supplied so it is unclear if this new demand would require upgrades to the water management infrastructure on site. It is expected that additional electricity will be required to pump this new demand also.

Equipment manufacturers will be required to commit to developing commercially available hydrogen-powered equipment where development costs for unproven technology continue to be a challenge in this sector as are operating risks (Government of Canada, 2020i). Current PEM fuel cell rated capacities are maximized in the 800 kW range for mining applications and would require a three times scale up to power a CAT 795 (Pocard, 2021). On-vehicle hydrogen storage options include cryogenic tanks that maintain hydrogen in its liquid form which requires super cooling to negative 263°C or compressed gas tanks that store gaseous hydrogen between 241 and 690 bar (Kantola, 2021). It is unclear at this time if the volume of hydrogen gas required to be stored on the CAT 795 is practical without having to replace payload with fuel tanks or require too frequent refueling stops. To operate for a full shift, roughly 220 kg of hydrogen would be required which equates to approximately a 9,000 litre compressed gas tank; the current tank size on the CAT 795 is 3,600 litres meaning tank capacity would need to be scaled up 2.5 times (Caterpillar, 2018a and Kantola, 2021). Use of liquid hydrogen would reduce the required tank capacity to 3,100 litres, but since fuel cells require fuel feed to be at ambient pressures (i.e., gaseous hydrogen), the super-cooled liquid hydrogen stored in the tanks would need to undergo a phase change on-board requiring necessary vapourizers to be installed (Kantola, 2021). Work is underway to develop such a system but is lacking technical readiness to be included in this analysis (Burke and Fulton, 2022). Also, if retrofitting a diesel power plant on a truck for this purpose, additional batteries would need to be installed on-board to store electrical energy produced (as per Figure 43).

While it is possible to produce sufficient quantities of hydrogen to fuel the fleet, delivery and storage considerations in addition to the increased cost and operational effort of the required technology may limit the benefit of this fuel alternative when compared to traditional diesel-power.

Not considered so far in this analysis are the implications of emissions from and carbon taxation on these alternatives. Those will be discussed in Section 7.6.

7.4 Installation of a trolley assist system to power the CAT 795 up ramp

As well as consuming electricity generated on board, the CAT 795 can utilize electrical power directly from overhead trolley supply lines (Mazumdar, 2011). The diesel engine rating powering the CAT 795 is rated at 2.54 MW; however, the rating of the electrical motors that actually drive the wheels of the vehicle is 4.75 MW (Caterpillar, 2021c). A truck trolley system can substitute electricity use for diesel fuel consumption to power these motors, at least for some parts of their duty cycle (specifically, while being loaded, uphill – the leg consuming the most energy by far) (Mazumdar, 2011).

Some evaluated systems indicate that use of these systems can increase travel speeds up to 44%, reduce travel time by 16%, and result in 85% energy savings for each trip (Kawalec et al., 2020 and Valenzuela Cruzat and Aníbal Valenzuela, 2018). Overall, fuel consumption can be reduced by 50 to 60% and emissions can be reduced 1.7 to 2.0 times when compared to diesel haul trucks (Kawalec et al., 2020 and Khazin et al., 2018). A recent study completed by Caterpillar showed that use of their trolley assist increased the speed of the CAT 795 on the flat from 14 km/h to 28 km/h (Caterpillar, 2021c). Suppliers suggest a 40% speed increase travelling up-grade is achievable through use of a trolley assist system (Stantec Consulting Ltd., 2019). These improved travel rates can result in additional benefits of increased production, reduced truck fleet requirements, and lower manpower costs as well as energy and emissions savings. Additionally, the decreased load factor on the diesel engine combined with improved road maintenance to operate the trolley assist system could correspond to increased longevity of the engine and up to a 10% reduction in parts and maintenance costs (Janusauskas et al., 2014 and Stantec Consulting Ltd., 2019).

A trolley assist system allows a diesel-electric haul truck to by-pass the diesel engine entirely by connecting the truck to overhead trolley lines via pantographs mounted on the truck (Janusauskas et al., 2014). Electricity is supplied to these lines from the electrical power supply on site. Infrastructure for a trolley assist system generally includes: trolley or catenary system consisting of catenary lines and support poles, traction substations (AC and DC), a trolley mast mounted high voltage supply, the trolley box mounted on the truck deck, and safety features like lighting and load height checks (Caterpillar, 2021c and Mazumdar, 2011). Additional details on typical voltages required can be found in Janusauskas et al. (2014) but are not considered in great detail beyond grid capacity for the purpose of this high level cost comparison.

A trolley assist system has been designed by Caterpillar to support tucks with electric drive systems like the CAT 795 used at Detour Lake Mine. For the purpose of this analysis, a simplified case study involving the installation of a trolley assist system to facilitate haulage from the main pit to the main on-surface haul roads at Detour Lake Mine was completed. The case study involved two scenarios: i) the installation of a trolley assist system on the main ramp into the Detour Lake Mine main pit, and ii) the construction of a tunnel through the pit wall during year 2022 and installation of the trolley assist system in that tunnel.

7.4.1 Trolley assist system installation on the main pit ramp

When considering installation of the trolley assist system on the main ramp, trolley installation was assumed to be completed in three phases as the ramp in the pit extended to accommodate increasing pit depth. Installation events were as follows:

- installation of the trolley assist system in 2019 included 2,850 m of catenary system, three DC substations, the main AC infrastructure and lines, and the installation of pantographs on 36 trucks,
- extension of the trolley assist system in 2025 included an additional 1,650 m of catenary system, 1,000 m of AC line drops, and one DC substation,

- extension of the trolley assist system in 2035 included an additional 1,000 m of catenary system, 1,000 m of AC line drops and one DC substation, and
- Trolley line maintenance including reinstallation at a rate of 500 m per year.

Capital expenditures considered included trolley line installation costs, costs to install substations to convert AC power supplied by the grid to DC power for the trolley system to operate, costs to install AC distribution lines, and costs to install pantographs on the existing and new CAT 795. Operating costs included line maintenance, line inspections, and increased ramp maintenance to ensure a consistent grade and distance between the ramp surface and catenary system (Janusauskas et al., 2014). These cost and design requirements were predominately sourced from Benardos et al. (2013); Caterpillar (2021c); Janusauskas et al. (2014); Ranggård and Mäki (2020); Stantec Consulting Ltd. (2019); Tannant and Regensburg (2001); and (Wietschel et al., 2019), and are summarized below in Table 40.

Table 40. Capital costs for the installation of a trolley assist system in Detour Lake Pit

Infrastructure	Cost	Design requirement
New trolley line installation	$1,880,000 per km	Catenary lines are DC conductors connected directly to the DC substations to supply power to the trucks via pantographs installed on the trucks. The lines are supported by a system of support poles placed approximately every 40 m on the side of the road designated for uphill travel. The catenary lines are cantilevered over the haul route by a quarter of its width. Assumed to be installed in phases over three events in 2019, 2025, and 2035.
Trolley line removal	$150,000 per km	The trolley assist system requires maintenance this includes removal and reinstallation of the line at regular intervals. Maintenance occurs at a rate of 500 m per year.
Trolley line re-installation	$600,000 per km	The trolley assist system requires maintenance this includes removal and reinstallation of the line at regular intervals. Re-installation typically required at a rate of 500 m per year.
DC substation unit cost	$3,500,000 per unit	Located near the trolley line and provides DC current 500 m either side (i.e., placement every 1 km). They are fed from the AC sub-station and convert the AC power to 2,600 V DC power for the trolley lines. Total number depends on length of route and number of trucks to be operated at the same time. Assumed to be installed in phases over three events in 2019, 2025, and 2035.
Main AC sub-station distribution infrastructure	$4,000,000 per trolley assist system	Directs AC power from the local power grid for use by the smaller DC substations along the trolley system. Typically, only one is required per system.
AC line from main substation to pit center	$300,000 per km	Assumed to be installed once during the life of the trolley assist system.
AC line drops from pit center to DC substations	$300,000 per km	Assumed to be installed in phases over three events in 2019, 2025, and 2035.
Trolley Engineering, procurement, construction, and management	$2,000,000	Incurred once at the beginning of the installation.
Yearly inspections	$52,000 per year	Yearly occurrence.
Additional ramp maintenance	$90,000 per year per km	Additional ramp maintenance required to maintain consistent clearances for catenary system was assumed to result in a 10% increase over typical ramp maintenance costs of $900,000 per year per km. Only the additional costs above typical maintenance are considered in this costings estimate.
Truck pantograph cost	$434,000 per truck	Installed on each truck and it connects to the catenary lines via carbon brushes. The attachments are integrated with the truck system and controls so that the hand over from diesel to electric power when connecting with the system is automatic. When powered by electricity, the diesel engine idles to support auxiliary systems and to quickly resume duty at the end of the trolley assist system. Safety features like quick-drop features on the truck, additional lighting, and load height check systems are also installed. It was assumed that this cost would be incurred during each fleet renewal every 6 years.

The following figure (Figure 48) shows the typical construction of a haulage road incorporating a trolley assist system. According to the 43-101 report for Detour Lake Mine, the main haulage ramp entering the main pit is 40 m wide, roughly 3.5 times the width of the largest piece of equipment travelling the ramp; that being the CAT 795 (Detour Gold Corporation, 2018). As this design already incorporates two lanes, construction of a dedicated lane for the trolley assist system is not required to be included as a capital cost given that the system can be installed in the existing uphill lane.

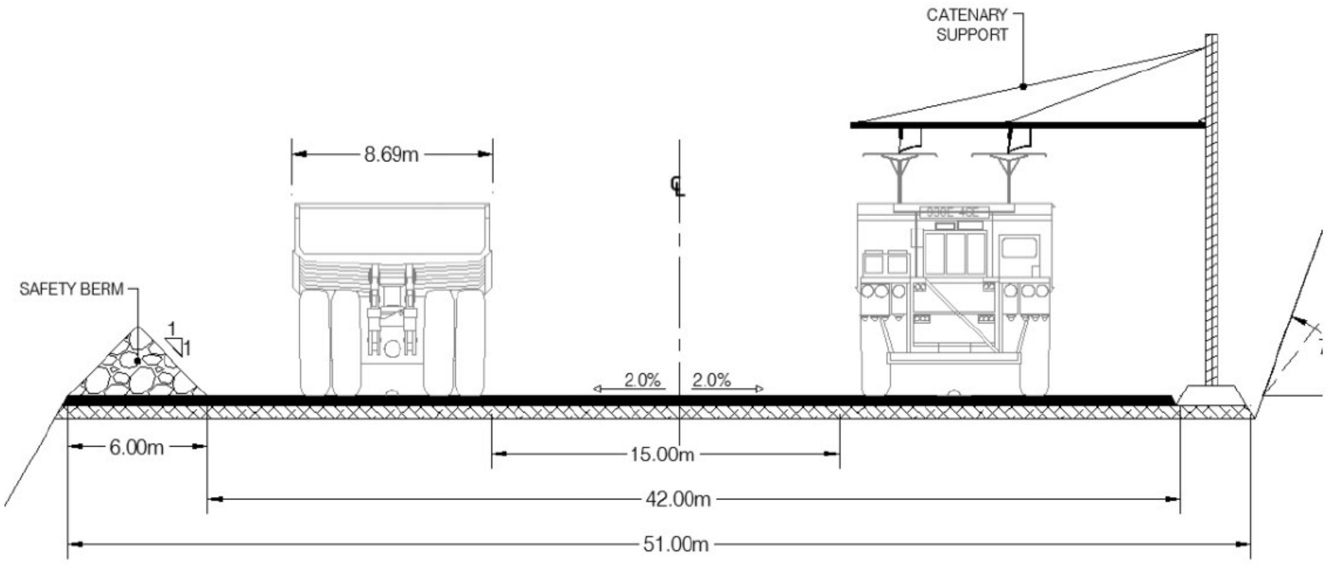

Figure 48. Haulage road construction incorporating a trolley assist system (Janusauskas et al., 2014)

Drawing on the methodology detailed in Section 4.3.5, the operational costs for the trolley assist system considered the reduction in diesel consumption that would result from using the trolley assist system for all uphill haulage performed by all CAT 795 on the main pit ramp as well as the electricity consumption to do so. Additional operational benefits associated with use of a trolley assist system include potential reduction in fleet size, reduced truck maintenance costs, and increased haulage speeds allowing for increased production rates (Janusauskas et al., 2014 and Mazumdar, 2011). Limited information was available regarding speed limits for the operation of the CAT 795 on site other than what is described in Table 10 and it is unclear if they were established due to operational or safety constraints. So to provide a conservative estimate of the benefits of the trolley assist system, it was assumed that the number of trucks required throughout the mine life would remain the same, but the impacts of potentially increasing speed limits and the associated reduction in fleet numbers on capital expense and operating expense were also considered.

While reviewed literature indicates fuel consumption rates could decrease up to 85% through use of the trolley assist system at mines in general, to determine fuel consumption reduction if a trolley assist system was employed at Detour Lake Mine a high level analysis of work required to move material was completed (Khazin et al., 2018). The amount of diesel fuel (in litres) required for each part of a round trip from the main pit to the three dump points on site were calculated for the CAT 795; these parts included: i) travelling up ramp full, ii) travelling to the dump point full, iii) travelling back to the pit empty, and iv) travelling down the ramp empty. This calculation was completed using the velocities specified in the 43-101 for the CAT 795 based on activity (Table 10) to determine time spent traversing the various parts of the round trip. This amount of time, in conjunction with fuel consumption rates determined based on estimated load factor as specified in the Caterpillar Performance Manual, were used to determine the fuel consumed on each part of the round trip to the various dump points. A fuel consumption rate of 1 l/hr was used for trips made by the trucks when travelling down the ramp empty as this rate was determined sufficient to account for idling of the truck when no hauling effort is required being the y intercept value of plots of engine load factor to fuel consumption rate provided by the manufacturer (as per Figure 14) (i.e., when the load factor on the engine was 0%, the fuel consumption rate was 1 l/hr) (Esfahanian, 2014).

To determine the reduced fuel consumption through use of the trolley assist system, the same fuel consumption rate to account for the idling of the truck was applied to the part of the round trip that included travelling uphill with a full payload. This was done because the energy required to move the full truck uphill would be provided by electricity through the trolley assist system, but the truck would still be required to idle its diesel engine to power auxiliary systems in the truck and to facilitate quick transitions on and off the trolley assist system. Fuel consumption was then determined for the round trip to each dump point for each scenario (i.e., fuel consumption travelling up ramp via diesel consumption and via trolley assist) and is presented in Table 41. The fuel consumed using only diesel power varied with mine life and increasing pit depth. Once the diesel consumed on the ramp was replaced with electrical power, the diesel consumption reflected only that used to move the truck from the pit to the dump points and back resulting in consistent consumption over the life of the mine. Diesel required to idle the truck while travelling the ramp was minimal.

Table 41. Diesel fuel consumption per round trip to each dump point using diesel power and the trolley assist system.

Life of mine period	Year	Diesel fuel consumption per round trip to dump point using diesel power (l)			Diesel fuel consumption per round trip to dump point using trolley assist system installed on the main pit ramp (l)		
		North Waste Rock Pile	South Waste Rock Pile	Ore Pile	North Waste Rock Pile	South Waste Rock Pile	Ore Pile
	2022	194	202	193	53	61	52
	2025	276	284	284	53	61	52
	2035	326	334	324	53	61	52

Reduced fuel consumption per round trip through use of the trolley assist system was then determined by subtracting the percent of the fuel spent travelling up the ramp via trolley assist (i.e., just using a fuel consumption rate to account for idling of the truck) from the fuel spent travelling up the ramp if the truck was powered by its diesel engine alone. For example, in 2019 prior to trolley assist system installation one round trip to the North Waste Rock would have required the CAT 795 to consume 194 litres of diesel using its diesel powered engine with 73% of these 194 litres consumed on the ramp with a full payload (or 141 litres used on the ramp). If a trolley assist system was installed on site in 2019, the same trip would require only 53 litres of diesel as most of the energy to move the truck with a full payload up the ramp would be provided by electricity through the trolley assist system (i.e., 194 litres for the whole trip minus 141 litres used on the ramp). This would mean that of the 53 litres consumed, only 0.4% would have been consumed on the ramp with a full payload to keep the truck idling.

Based on this analysis, it was determined that diesel fuel consumption following the installation of a trolley assist system would be on average 17% to 28% of diesel consumption established in the base case. This range reflects varied consumption depending upon the year (i.e., ramp depth) and dump point. This reduced consumption rate was then applied to the base case diesel consumption estimates for the CAT 795 fleet presented in Chapter 4 to revise the life of mine diesel consumption total.

Electricity consumption to operate the trolley assist system was also considered as an operating cost. To determine the amount of electricity consumed to power travel of the CAT 795 up ramp with a full payload, the work required to do so was calculated using the distance travelled up ramp, the weight of the truck with a full payload and the rolling resistance encountered per equation (3) in Section 4.3.5. A rolling resistance of 13% was used to account for the resistance of the material making of the ramp: 3% for gravel of the ramp and 10% to account for the grade of the ramp which is the maximum grade described in the 43-101 report and the maximum grade for which a trolley assist system can be used for the CAT 795 (Caterpillar, 2022; Detour Gold Corporation, 2018; and Hustrulid et al., 2013).

The resulting work required represented the effort required per trip was expressed in kWh. To determine this effort over the life of mine, the number of trips to the various dump points was determined based upon the amount of ore and waste to be moved identified in the 43-101 report; it was assumed that a minimum of 17% of the waste was acid generating and would be transferred to the North Waste Rock Pile (Detour Gold Corporation, 2018). To calculate the potential electrical costs associated with this consumption, an electricity cost of $25 per kWh was assumed and an 8.5% transmission and distribution line loss was also assumed (Bartłomiejczyk et al., 2016). As before, the cost to purchase diesel was assumed to be $0.80 per litre.

The summary of the resulting costs are presented below in Table 42. A detailed, itemized yearly cost breakdown is presented in Appendix B.

Table 42. Estimated costs to install and operate a trolley assist system on the ramp of the main pit

Item	Life of mine total	Average year	Per production tonne	Per total tonnes moved
Capital costs (CAD)	$596,000,000	$28,000,000	$1.59	$0.37
Operating costs (CAD)	$1,655,000,000	$79,000,000	$4.40	$1.02
Energy costs (CAD)	$269,000,000	$13,000,000	$0.72	$0.17
Total	$2,520,000,000	$120,000,000	$6.70	$1.55

A comparative summary table of costs for all alternatives against the benchmark diesel powered fleet is presented in Section 7.6. As noted, the values in Table 42 do not consider a reduction in fleet numbers due to increased speeds of the CAT 795 trucks when on the trolley assist system. However, if the CAT 795 trucks travel at the maximum design speed of 7.8 m/s on the trolley assist system, it reduces the travel time per trip between 25% and 34% depending upon the dump location and pit depth. This translated to reduction in fleet numbers offered potential savings in capital and operating expenditures of $140 million and $359 million, respectively, reducing the cost per production tonne of $5.37 and cost per total tonne moved of $1.24.

7.4.2 Trolley assist system installation in pit wall tunnel

Haul road maintenance requirements to support a trolley lane are more onerous than a typical ramp; the target elevation and slope of the ramp needs to be kept even to maintain the required clearance for the cantilevered catenary system. During the winter, snow and gravel build up can result in haul road elevation changes. Additionally, operation in northern climates can result in icing of the lines causing inconsistency of the behaviours of the system and lighting requirements to ensure safe operation (Ranggård and Mäki, 2020). In the previous section, the additional cost above typical ramp maintenance to maintain the ramp to the standard required to operate the trolley assist system on the ramp was estimated to be $8.1 million over the life of the mine. Given the location of the mine in Northern Ontario, installation of the trolley assist system within a tunnel constructed through the pit wall was also considered to mitigate these issues.

For this analysis, it was assumed that the CAT 795 fleet would be operated using diesel powered engines up ramp per the mining plan presented in the 43-101 report until the year 2022 when the tunnel and trolley assist system would be installed. The tunnel would be excavated in the eastern wall of the pit minimizing the distance travelled by the trucks from the shovels to the mill. Review of satellite imagery for the site and the mining plans presented in the 43-101 report indicates that the pit wall slope in this area varies between a 6% and 25% grade. Design parameters for the tunnel in this location include an 8.9% grade and an actual haul distance of 339 m with a 30 m vertical rise. It has been assumed that after installation of the tunnel, the 3,330 m of ramp that was used to haul material between the commencement of mining and 2022 would no longer be used by the CAT 795. Figure 49 gives a representation of what this installation would look like post-2022.

Figure 49. Installation of the trolley assist system through the pit wall via a tunnel in year 2022

Capital and operating costs were calculated as per the previous section with additional costs of tunnel construction at $58,000 per metre (Benardos et al., 2013). The tunnel would be excavated to a 50 m width and 15 m height to accommodate two lanes allowing for the trucks to return via the tunnel also. Given the reduced length of required trolley assist system, capital costs for the system only included one each of the AC and DC substations. Operationally, it was assumed that, once the tunnel was installed, the CAT 795 would travel from the shovel to the entrance of the pit under diesel power when they would engage to the trolley assist system. After travelling up ramp powered by electricity, they would disengage from the trolley assist system at the top of the ramp and travel to the various dump points under diesel power. The return trip to the shovel would also be under diesel power.

Reduced diesel fuel consumption was calculated as per the methodology described in the previous section but considering reduced distance of the trolley assist system in the tunnel versus along the entire ramp. This is presented below in Table 43. It was determined that diesel fuel consumption following the installation of a trolley assist system and tunnel in the year 2022 would be between 35% to 70% of diesel consumption if the fleet was operated as described in the 43-101 under diesel power depending upon the year and dump point. This reduction in diesel consumption was not as great at that reported for installation of the trolley on the main ramp in Section 7.4.1 of 17% to 28% of the base case diesel consumption and is due to trucks having to travel a greater distance from the shovel to the tunnel entrance in the pit under diesel power.

Table 43. Diesel fuel consumption per round trip to each dump point using diesel power and the trolley assist system installed in a tunnel through the pit wall.

Life of mine period	Year	Diesel fuel consumption per round trip to dump point using diesel power (l)			Diesel fuel consumption per round trip to dump point using trolley assist system installed in a tunnel (l)		
		North Waste Rock Pile	South Waste Rock Pile	Ore Pile	North Waste Rock Pile	South Waste Rock Pile	Ore Pile
	2019	194	202	193	194	202	193
	2025	276	284	284	135	143	133
	2035	326	334	324	184	192	183

Electrical consumption and costs were calculated considering the amount of work required to move a CAT 795 with a full payload up the tunnel. This was determined to be 85 kWh per trip based upon the power rating of the CAT 795 engine and an assumed distribution loss on the trolley assist system of 8.5% (Bartłomiejczyk et al., 2016). The total electricity consumption by the trolley assist system was determined by considering the number of trips required to excavate the main pit based on mining plan information provided in the 43-101 report and the payload of the CAT 795. A summary of the resulting total costs are presented Table 44. However, a detailed break down of yearly costs, energy consumption and truck trips in presented in Appendix B.

Table 44. Estimated costs to install and operate a trolley assist system in an excavated tunnel through the eastern wall of the main pit

Item	Life of mine total	Average year	Per production tonne	Per total tonnes moved
Capital costs (CAD)	588,000,000	28,000,000	1.56	0.36
Operating costs (CAD)	1,643,000,000	78,000,0000	4.37	1.01
Energy costs (CAD)	424,000,000	20,000,000	1.13	0.26
Total	2,655,000,000	126,000,000	7.06	1.63

A comparative summary table of costs for all alternatives against the benchmark diesel powered fleet is presented in Section 7.6. As in Section 7.4.1, the values in Table 44 do not consider a reduction in fleet numbers due to increased speeds of the CAT 795 trucks when on the trolley assist system. However, if the CAT 795 trucks travel at the maximum design speed of 7.8 m/s on the trolley assist system through the tunnel in the pit wall, it reduces the travel time per trip between 20% and 34% depending upon the dump location and pit depth. This translated to reduction in fleet numbers offering potential savings in capital and operating expenditures of $108 million and $277 million, respectively, and a cost per production tonne of $6.04 and per total tonne moved of $1.40.

7.4.3 Additional considerations for the installation of a trolley assist system at Detour Lake Mine

When compared to the cost per production tonne to operate the diesel powered CAT 795 fleet as described in the 43-101 report of $7.58, both conservative estimates of trolley assist system options considered appear to be viable lower cost alternatives. These alternatives are viable because Detour Lake Mine is connected to the provincial electrical grid. As stated previously, currently the Detour Lake Mine is connect to the provincial power grid and can be supplied 120 MW of power (Government of Ontario, 2021b). Based on electricity consumption rates, at peak operation the trolley assist system will require an additional 35 MW of power upon the system. Using publicly available information about the site, it is not possible to assess if this additional power requirement will exceed capacity of the supply system.

A similar but more detailed analysis undertaken to assess haulage alternatives for oil sands operations in western Canada identified that the maximum capacity of substations is roughly 11 MW based on current technologies (Stantec Consulting Ltd., 2019). Such a substation has the ability to power between one and four haulage trucks of similar power rating and capacity as the CAT 795 over a distance of 850 m. However, the simultaneous operating times for these trucks is not consistent. Such a substation would have the capacity to power up to two trucks continuously, 3 trucks for 10 minutes and 4 trucks for 1 minute of simultaneous operation. Based on this and the travel distances and travel speeds, it has been estimated at each truck in the CAT 795 fleet would be required to make roughly 7 trips per shift with 49% of the time spent travelling up ramp. Given this, it is likely that if the trolley assist system is installed on the main ramp, 17 CAT 765 would have to operate simultaneously to meet production targets which could potentially exceed the capacity of the substations. Additionally, as trucks will be frequently engaging and disengaging from the system, the variable power draw on the system risks introducing harmonic distortion in the system and may require additional filters to ensure that performance does not degrade or maintenance costs do not increase (Afonso et al., 2020).

However, there is the potential to mitigate this power draw through the use of regenerative braking as the truck travels down ramp with an empty payload. Regenerative braking with an electric drive vehicle allows for electricity to be produced through the capture of kinetic energy when travelling down ramp. This energy can either be stored in a battery or fed back in the electrical distribution system if the infrastructure exists (Artisan Vehicles, 2021). Operating the trucks on the trolley assist system may also offer maintenance cost savings of up to 10% costs for diesel powered operation (Stantec Consulting Ltd., 2019).

Due to the additional infrastructure requirements, the haul route for which the trolley assist system is to be installed should be planned in advance to reduce the number of times the track needs to moved, re-installed, or modified to optimize savings. Expansion of the pit will require additional trolley lines and may require additional substations (Khazin et al., 2018). As trucks will potentially be travelling at greater speeds than when operating on diesel, consideration should be given to planning curves in the haul route. Loading times for the trucks should also be considered to reduce power fluctuations in the system (Khazin et al., 2018). Given the intolerance of variation in grade and elevation of the planned haul routes, road conformity will be a priority and potentially require grading equipment to be equipped with a high precision machine guidance system (Ranggård and Mäki, 2020).

As Detour Lake Mine is an existing operation with an established mine plan, it may be difficult to optimize the savings offered via installation of such a system. For example, pre-excavating the area in which the tunnel is to be installed to a greater depth ahead of mine plan would allow the tunnel to be extended increasing diesel savings substantially over time. This would mean that the trucks would also be travelling downhill from the active benches to the tunnel entrance for a number of years until the mine plan excavations caught up with the pre-excavated area of the tunnel entrance potentially allowing for regenerative braking offering more energy savings.

7.5 Installation of an in pit crusher with conveyor

The final hauling alternative considered as part of this analysis was an in pit crusher and conveyor (IPCC). Multiple IPCC scenarios were considered to move material from the crusher to the various dump points; these involved installation of a traditional conveyor: i) up the pit wall, ii) along the main ramp, and iii) through a tunnel excavated in the pit wall.

IPCC presents advantages associated with reduced maintenance costs, diesel consumption, continuous operation, reduced labour requirements, and lower energy consumption. However, these benefits are potentially offset by the requirement to actively consider crusher locations during mine operation (Nunes et al., 2019). Cost comparison alone is not the complete picture for mine planners when considering installation of an IPCC. While it is estimated that the operating cost of an IPCC can be less than one third of a truck haulage system, the additional capital costs associated with installation can reduce these savings to 50% of a truck haulage system (Dean et al., 2015). Efficiency of an IPCC system must also consider material characteristics and pit topography. While a conveyor system may allow for continuous operation, failure of the system can result in production grinding to a halt if no haulage alternatives exist (Werk et al., 2017). However, in this analysis, some CAT 795 will remain to allow for partial production to continue.

Work force reduction is another potential cost saving associated with the use of an IPCC when compared to truck haulage. It has been estimated that fixed IPCC (of unspecified capacity) typically require 80 staff to maintain and operate depending upon conveyor size. When compared to a truck requiring 7 staff each to maintain and operate, depending upon fleet sizes, labour requirements of the haulage system could be greatly reduced (Dean et al., 2015). However, such labour reductions at an established operation could have implications beyond costs alone. Resulting reduced fleet size can also increase the safety of a mine site given the reduced potential of vehicular collisions (Dean et al., 2015).

Design considerations for a conveyor system include placement of the crusher and use of a fixed, semi-movable or movable crusher. IPCC are more efficient in deeper open pits where material needs to be hauled over great vertical distances. Locating the crusher at or below the working face reduces further the cost of uphill haulage to the crusher (Werk et al., 2017). Locating the crusher to allow for short haulage distances by truck can have added flexibility while optimizing the cost saving of the conveyor (Werk et al., 2017). Additionally, the lump size (or the maximum dimension of the largest lump) of the material being transported by conveyor should not exceed one third of the belt width. Given this, in pit crushers need to be sized adequately. However, if the stripping ratio is low, there may be some cost savings considering the crushing and conveying of ore while continuing to truck waste (Ben-Awuah, 2017). Based on the mine phase plans presented in the 43-101, it was determined that installation of an in pit crusher in the year 2022 would allow for the crusher to be installed at a fixed location to maximize the size of the crusher. This crusher location was used for all conveying scenarios presented below.

7.5.1 Overland belt conveyors with in-pit conveyor up pit wall

To assess the potential cost savings associated with installing an IPCC at Detour Lake Mine, the location of the in pit crusher and paths the overland conveyors could take to the various dump points were estimated (Figure 50). For this scenario and based upon mine plans presented in the 43-101 report, the overland conveyor leaving the pit would haul material a vertical height of 100 m and at an average grade of 14% (within the maximum grade of 25% which is suggested as maximum design considerations (Ben-Awuah, 2017)).

Figure 50. Location of the in pit crusher and path of the traditional conveyors to the various dump points.

The rate at which material would have to be conveyed from the pit was determined based upon production targets outlined in the 43-101 report. When considering waste material, it was assumed that 17% of the waste was potentially acid generating and would be directed to the North Waste Rock Pile and the remainder would be directed to the South Waste Rock Pile. As it was assumed that the IPCC would be installed after 2022, no material was expected to be moved to the overburden piles. The rate at which material is to be moved by the conveyor system is presented in Figure 51; these material movement rates are used as a design consideration for all scenarios presented in this section.

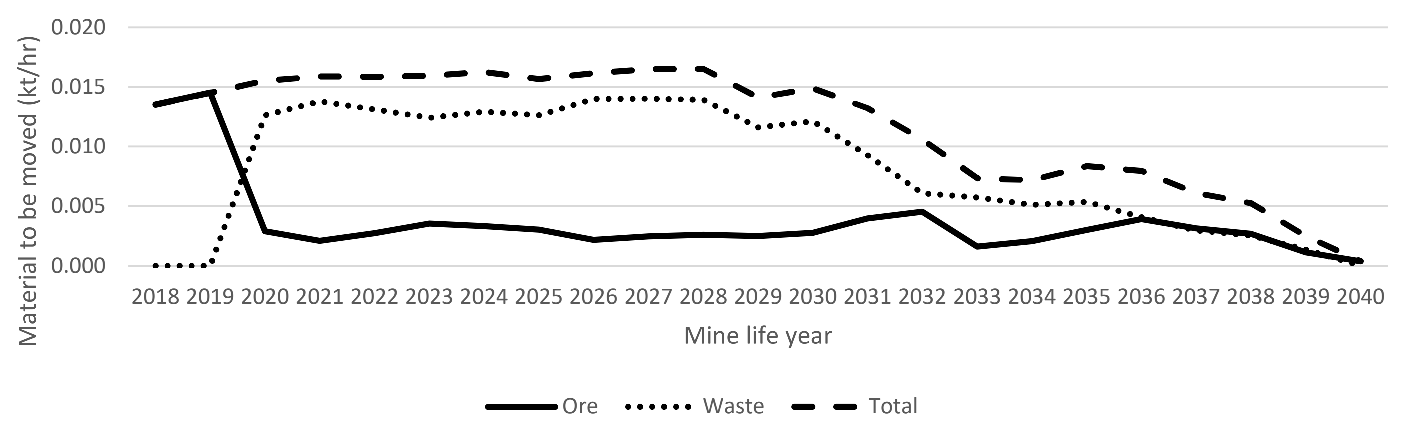

Figure 51. Material to be moved by the conveyor system over the life of mine.

Maximum standard conveyor belt widths available were determined to be 3.2 m but belts with a 2.0 m width are more typical (Conveyor Equipment and Manufacturers Association, 2002), (International Organization for Standardization, 2012). Conveyor belt widths and motor sizes selected are presented in Table 45 and were dependent upon the amount of material to be moved per hour (Queen’s University, 2016), (Pooley Inc., n.d.). Given the required rate at which material needs to be moved and the maximum width of commercially available belts, three separate conveyors operated in parallel will be required to move material from the pit to the ore pile and to the south waste rock pile. Of note, this conveying system requires a similar energy consumption rate as was measured for the conveying system at New Afton Mine of 0.001 kWh per tonne per metre (presented in Section 4.4.5).

Table 45. Design considerations for the traditional conveyor system to move material from an in pit crusher to the various dump points.

Conveyor section	Type	Distance (m)	Maximum tonnes per hour	Minimum total combined belt width (m)	Motor size (kW)	Motor size (HP)
In pit conveyor	sloped	320	16,200	4.78	5,369	7,200
Ore pile conveyor	overland	560	4,000	1.17	1,342	1,800
South waste rock conveyor	overland	2,000	10,900	3.20	3,579	4,800
North connector conveyor	overland	890	2,000	0.66	746	1,000
North waste rock conveyor	overland	900	2,000	0.66	746	1,000

Assuming a maximum individual belt width of 2.5 m would mean that the maximum lump size (or the largest dimension of the largest lump) of the material to be conveyed would be approximately 800 mm since belt width should be not greater than 3 to 5 times the lump size (Queen's University, 2016). The limits imposed by the conveying system on material size introduces some inefficiencies in the system with respect to crushing. Currently, the primary crusher to receive ore in the mill is a 1.5 m by 2.9 m gyratory crusher with a feed size of 1,200 mm. It has a capacity of 5,000 tonnes per hour and with an assumed availability of 80% has a capacity of 96,000 tonnes per day (Kirkland Lake Gold, 2021). This maximum lump size handled by the conveying system is smaller than the required feed size for the primary crusher in the mill but not smaller than the required 80% passing size of 165 mm that is the primary crusher's product (Kirkland Lake Gold, 2021). This means that the primary crusher in the mill will be oversized if a conveyor system is adopted. However, some efficiencies could be gained by re-deploying the primary crusher to the pit but would be done at the risk of production interruptions in the mill. It also means that if an in pit crusher is installed, extra effort will be spent crushing all types of material (ore and waste) to a small enough size to be handled by the conveyor belts, but as depicted in Figure 13, crushing is a relatively small energy consumer when looking at the beneficiation process.

The maximum throughput required of roughly 16,000 tonnes per hour described in Table 45 limits the type of in pit crusher that can be installed on site to double roll or low speed sizer crusher if a single installation is required. However, both are typically used in medium to soft rock applications and may not be suitable for Detour Lake Mine site (Utley, 2011). Installation of two 1500 kW gyratory crushers would be applicable in this hard rock setting to meet the design considerations as they have a maximum capacity of 10,000 tonnes per hour with a feed size of 1,500 mm and product size of 50 to 300 mm plus (Utley, 2011). At the time of writing, one 1600 kW gyratory crusher with a crushing rate of 17,000 tonnes per hour is being developed (Metso Outotec, 2021). However, it was difficult to determine the capital costs for this so the cost estimates below are for the installation of two 1500 kW gyratory crushers. While there are additional capital costs associated with the installation of two in pit crushers with capacity exceeding production rates by 20%, being able to continue production (at an albeit reduced rate of 63% of production requirements) should one in pit crusher fail has operational advantages.

It proved difficult to find capital and operating cost estimates in the literature that are applicable to as large of an operation as Detour Lake Mine. Where available, such capital and operating costs were adapted from those found in literature by scaling up using the design parameters of the larger conveyors and crushers required; these are presented in Table 46. These costs were calculated from those presented in Ben-Awuah (2017); Radlowski, (1988); Queen's University (2016); Western Mine (2006); and Werk et al. (2017). A scale coefficient of unity was used to establish the relationship between the design parameters and the costs rather than the 6/10th rule of thumb that accounts for economy of scale where increase in equipment capacity is often greater than the increase in costs (Tribe and Alpine, 1986). This provides a conservative cost estimate considering uncertainties regarding scaling units for conveying systems where quoted scaling factors were between 0.65 and 0.87 (Whitesides, 2020). Tribe and Alpine (1986) suggests these scaling units can vary greatly (in cases, in excess of unity) based on the difference in capacity and by equipment type. Electrical costs are included in the operational costs and were calculated based upon motor sizes, an assumed duty cycle of 360 days per year at 22 hours per day. A load factor was determined from a review of expected energy consumption presented in Werk et al. (2017) and was estimated to be 50%. It was assumed that 200 m of conveyor belt would have to be replaced every year.

Table 46.Captial and operating costings for the in-pit crusher and traditional conveyor system.

Infrastructure	Type	Capital costs	Operating costs per hour
In pit crushers	fixed	$23,400,000 each	$1,800
In pit conveyor	sloped	$31,000 per linear metre	$1,498
Ore pile conveyor	overland	$5,900 per linear metre	$367
South waste rock conveyor	overland	$16,000 per linear metre	$4,427
North connector conveyor	overland	$3,300 per linear metre	$253
North waste rock conveyor	overland	$3,300 per linear metre	$257
Conveyor belt replacement		$12,000 per linear metre	

An additional advantage of an IPCC system is that the number of CAT 795 trucks required for material handling from the main pit will be reduced as they will only be required to move material from the active bench to the fixed location of the in pit crusher. Trips from the pit up the ramp to the various dump points by the trucks will not be required as material will be conveyed overland by conveyor to each point. To determine the fleet size required for in pit material movement, the ramp distance from the active bench to in-pit crusher was estimated based upon the bench height between 10 m to 12 m and ramp grade of 10% reported in the 43-101 report. Based on these values, it was estimated that the actual ramp distance travelled from the shovel to the in pit crusher would increase by 122 m each year of mine life. Using the CAT 795 travel speeds reported in the 43-101 of 3.1 m/s when travelling up ramp with a full payload and 6.7 m/s down ramp with no payload, the time the CAT 795 spent on the ramp per trip was calculated; it was assumed that filling and dumping of the truck would take 5 minutes total.

The number of trips required to meeting the maximum feed rate of the in pit crusher previously reported of 16 kt per hour was determined using the payload reported for the CAT 795 of 318 tonnes which was calculated to be 52 trips per hour (Caterpillar, 2018a). Using the number of trips required to meet the hourly feed rate for the in pit crusher and the time per trip, the number of CAT 795 trucks needed to meet this hourly feed rate was determined. The results of this analysis are presented in Table 47.

Table 47. Required fleet size of CAT 795 to move material from the active bench to the in pit crusher.

Mining year	Ramp Distance to in pit crusher(m)	Time to go up loaded (s)	Time to go down empty (s)	Time to fill and dump (s)	Total time per trip (s)	Total time per trip (hr)	Number of trucks needed
2022	122	40	18	300	358	0.10	5
2023	244	80	37	300	417	0.12	6
2024	367	120	55	300	475	0.13	7
2025	489	160	73	300	533	0.15	8
2026	611	200	92	300	592	0.16	9
2027	733	240	110	300	650	0.18	9
2028	856	280	128	300	708	0.20	10
2029	978	320	147	300	767	0.21	11
2030	1100	360	165	300	825	0.23	12
2031	1222	400	183	300	883	0.25	13
2032	1344	440	202	300	942	0.26	14
2033	1467	480	220	300	1000	0.28	14
2034	1589	520	238	300	1058	0.29	15
2035	1711	560	257	300	1117	0.31	16
2036	1833	600	275	300	1175	0.33	17
2037	1956	640	293	300	1233	0.34	18
2038	2078	680	312	300	1292	0.36	19
2039	2200	720	330	300	1350	0.38	19
2040	2322	760	348	300	1408	0.39	20

Diesel consumption for the fleet sizes reported above was calculated by scaling the previously reported diesel consumption for the existing fleet in Table 9 in Section 4.3.4 with the new, reduced fleet numbers presented in Table 47. Diesel cost was assumed to be $0.80/l as described in the 43-101 report. Resulting costs to operate the reduced CAT 795 fleet and to install and operate the IPCC is presented in Table 48. A detailed, yearly cost breakdown is presented in Appendix B.

Table 48. Capital and operating cost estimate for the in pit crusher and conveyor system.

Item	Life of mine total	Average year	Per production tonne	Per total tonnes moved
Capital costs (CAD)	306,000,000	14,600,000	0.81	0.19
Operating costs (CAD)	1,877,000,000	89,400,000	4.99	1.16
Energy costs (CAD)	372,000,000	17,700,000	0.99	0.23
Total	2,556,000,000	122,000,000	6.80	1.57

As mentioned, as economies of scale were not applied to the estimates for the conveying system, costs in Table 48 are likely conservative. Review of economic scaling factors for conveying systems suggests the rule of thumb scaling factor of 0.6 is high so an average of conveyor-specific scaling factors found in Whitesides (2020) was applied. Using this average scaling factor of 0.8 would reduce the estimated capital and operating costs for the conveying systems by $172 million or 6.7%, reducing the cost per production tonne and cost per total tonne moved to $6.34 and $1.47, respectively. A comparative summary table of costs for all alternatives against the benchmark diesel powered fleet is presented in Section 7.6.

7.5.2 In pit conveyor installed in a tunnel through the pit wall

There are operational concerns associated with automated material handling systems in Northern Ontario including icing, additional lighting, and maintenance requirements. In an effort to reduce these impacts upon production, installing the sloped in pit conveyor in a tunnel excavated through the east wall of the pit was examined (Figure 52). As before, it was assumed that the tunnel would be installed in the year 2022 and be 339 m long at a grade of 8.9%. The tunnel dimensions were reduced from the previous tunnel design (50 m wide and 11 m high) to accommodate one truck and the three in pit conveyor belts to be operated in parallel (21 m wide by 11 m high). Only a tunnel installation through the pit wall was considered as it would reduce the slope of the in-pit conveyor and provide weather protection for operation of this critical conveyor. Tunnel installation was not considered for the overland conveyors travelling from the exit of the main pit to the various dump points due to excavation costs being prohibitive. Additionally, it would allow for flexibility to incorporate additional conveyors to collect material from the West and North pits more easily if desired.

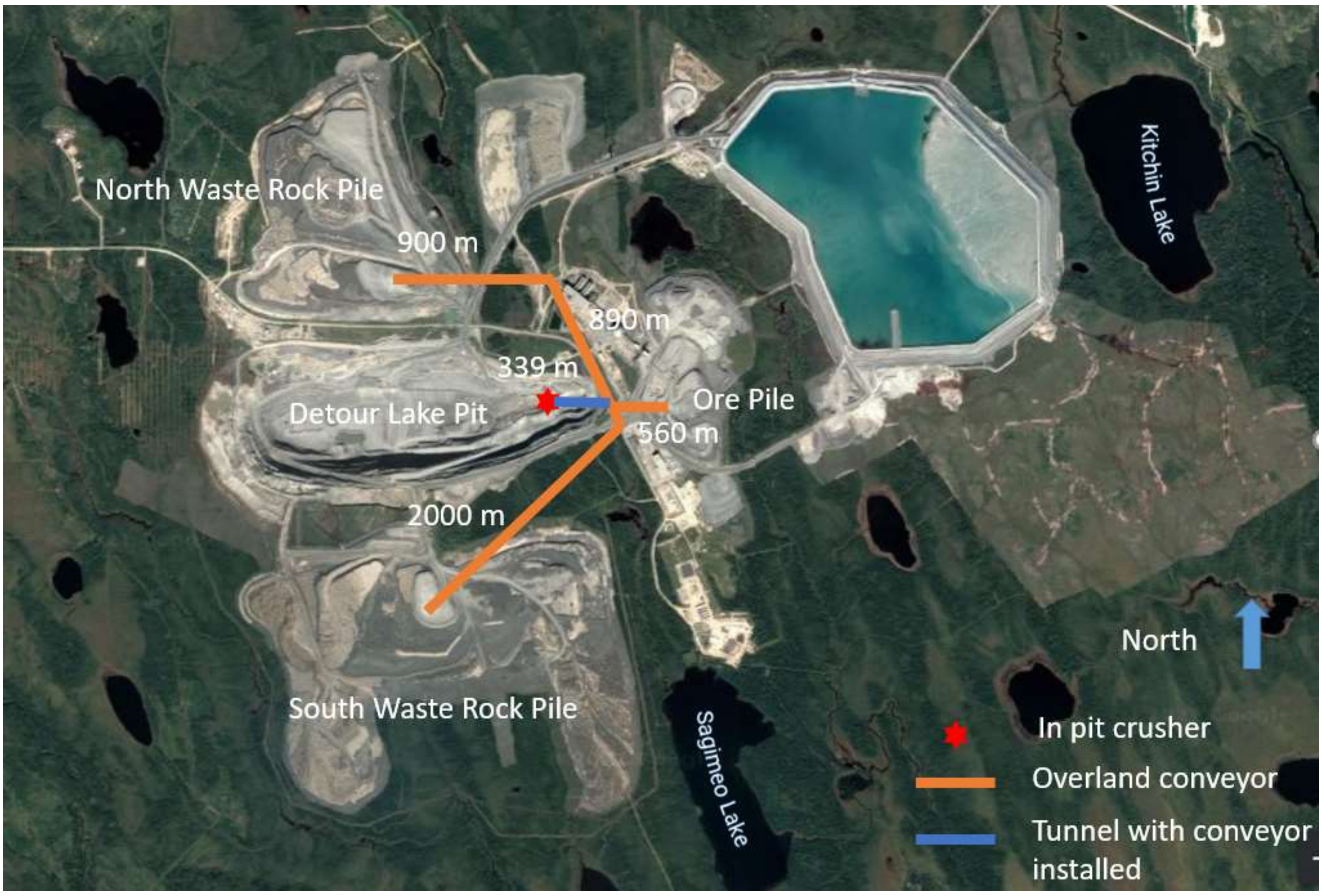

Figure 52. Installation of overland conveyors and in pit conveyors through a tunnel in the pit wall

The cost to install the tunnel was estimated to be $24,500 per m for a total cost of $8.3 million plus the capital cost of $0.6 million to install an additional 19 m of in pit conveyor (Benardos et al., 2013). As indicated, it was difficult to discern operational cost for conveyor system for such a large operation from literature. It was assumed that the required motor size for the in pit conveyor through the pit wall would be the same as that for the conveyor installed up the pit wall per the previous scenario. Given this, the capital and operating costs used in the previous section were also used to determine costs for this scenario (Table 49).

Table 49. Capital and operating cost estimate for the in pit crusher and conveyor system via a tunnel excavated in the pit wall.

Item	Life of mine total	Average year	Per production tonne	Per total tonnes moved
Capital costs (CAD)	325,000,000	15,000,000	0.86	0.20
Operating costs (CAD)	1,900,000,000	90,000,000	5.05	1.17
Energy costs (CAD)	375,000,000	18,000,000	1.00	0.23
Total	2,600,000,000	124,000,000	6.92	1.60

Values presented in present a conservative estimate of these costs. When a scaling factor is applied to capital and operating costs like in Section 7.5.2, these costs are reduced by $127 million or 4.9% with the cost per production tonne and cost per total tonne moved reduced to $6.58 and $1.52, respectively. A comparative summary table of costs for all alternatives against the benchmark diesel powered fleet is presented in Section 7.6.

7.5.3 In pit conveyor installed along the main ramp

As mentioned, the installation of the in-pit conveyor up the pit wall analyzed in Section 7.5.1 is within the design specifications of the sloped conveyor, however, there may be operational concerns regarding the required grade and safety concerns for staff working in and around the installation. An additional scenario was analyzed where the in-pit conveyor was installed along the main ramp (Figure 53).

Figure 53. Location of in pit crusher and path of the overland conveyor along the main ramp to the various dump points.

The path of the conveyor was selected to ensure that it would be a permanent installation along a path that meets design requirements of the main ramp (i.e., grade not greater than 10%) and because of this differs from the path of the main ramp presented in the 43-101 report. The resulting in-pit conveyor installation would be 4300 m in linear length. The required motors to drive the conveyor was scaled up from that presented in previous sections to have a cumulative power requirement of roughly 14,000 kW and it has been assumed that multiple motors of lesser ratings will be installed along the length of the conveyor (e.g., at junction points). Given the scale of the capital installation, the cost per linear metre of in pit conveyor was scaled back to $14,883 based on costings from Western Mine (2006) and Queen's University (2016). All other cost considerations remain the same as presented in Section 7.5.1.

Resulting costs to operate the same reduced CAT 795 fleet as described in Section 5.3.5.1 and to install and operate the IPCC with the in-pit conveyor installed per Figure 53 is presented in Table 50. A detailed, yearly cost breakdown is presented in Appendix B.

Table 50. Capital and operating cost estimate for the in pit crusher and conveyor system with the in-pit conveyor installed along the main ramp.

Item	Life of mine total	Average year	Per production tonne	Per total tonnes moved
Capital costs (CAD)	358,000,000	17,000,000	0.95	0.22
Operating costs (CAD)	4,673,000,000	222,000,000	12.43	2.88
Energy costs (CAD)	391,000,000	19,000,000	1.04	0.24
Total	5,422,000,000	258,000,000	14.42	3.34

When a scaling factor is applied to capital and operating costs like in Section 7.5.2, these conservative costs are reduced by $953 million or 18% with the cost per production tonne and cost per total tonne moved reduced to $11.89 and $2.75, respectively. A comparative summary table of costs for all alternatives against the benchmark diesel powered fleet is presented in Section 7.6.

7.5.4 Additional considerations for the installation of an in pit crusher and automated conveying system at Detour Lake Mine

Some considerations for the installation of an in pit crusher and conveying system have been mentioned above. As with the other alternatives considered, there are uncertainties regarding technical feasibility of this alternative to a diesel powered trucking fleet. As mentioned, the amount of material to be moved to meet production targets as presented in the 43-101 report is high when compared to other case studies reviewed. Crushers currently available to accommodate these throughput requirements in a hard rock environment are limited meaning that multiple crushers will likely have to be installed; however, this will provide resiliency should one require repairs. A fixed in pit crusher installation was selected for this analysis to allow for installation of two more typically sized gyratory crushers. A fixed installation means additional capital costs to install the crushers and create permanent dump points for the remaining CAT 795 and use of a fixed crusher reduces the potential for flexible operation to adapt to any changes in the mining plan. As mentioned, this design dictated that the fixed crusher be installed in 2022 at the pit bottom elevation at that time. This design choice will require full trucks to travel up hill at increasing distances to dump at the crusher as the pit will be continuously excavated until 2040. Relocating the crusher between 2022 and 2040 or excavating out the crusher location at initial installation in 2022 has the potential reduce operational costs and the cost per tonne of material moved further.

As stated in Section 7.5.1, the in pit crusher selected is capable of reducing the ore to the size necessary (P80 of 165 mm) to by-pass the primary crusher in the mill and allow ore to be fed directly to the secondary crusher. Removal of the primary crusher in the mill could provide capital and operational savings not considered in this analysis. However, there is an operational limit imposed by the size of material that can be accepted by the conveying system which is a function of belt width. Since both ore and waste will be handled by the conveying system, the in pit crushers will have to reduce waste to a size that can be handled by the conveying system (i.e., 800 mm for the conveyors selected in this analysis). The crushing costs for waste as a result of the installation of this system would be a novel operational expense when compared to the operations described in the 43-101 report as the shovel and trucks may be able to accommodate larger material sizes.

In addition to the capacity issue of the currently available conveying systems, consideration has to be given to the electrical power required to move the material. While it has been noted that the site is connected to the HydroOne power grid with a connect capacity between 85 MW and 120 MW, it is unclear how much capacity there is within the connection for additional power draw. Operating the IPCC could result in an additional power requirement of up to 17 MW or more depending upon the need for supplemental drives to be installed on the conveyors should any restarting underload problems arise (Wheatley and Rubel, 2020). However, some capacity could be gained should the primary crusher in the mill be removed in lieu of the in pit crusher installations.

In general, it has been suggested that a different approach to planning and design must be adopted to accommodate a fixed IPCC as there is limited flexibility within the system. As a fixed pit wall, tunnel or ramp is required to accommodate a conveyor and permanent infrastructure must be built in the pit to accommodate the crushers and dump points, careful consideration should be taken when sequencing excavations. An IPCC system is less flexible with respect to maneuverability, scalability, and resilience to system failure. Trucking and shoveling can often accommodate the effects of poor mine planning more readily and maybe more able to access higher value ore more quickly or on demand (Nehring et al., 2018). As Detour Lake Mine is an operating site with an established mine plan accommodating a truck fleet, the implications of the decreased flexibility of an IPCC may not be captured by a cost analysis alone.

7.6 Total costs, carbon related charges, and conclusions associated with the material handling alternatives

To better understand the impact of reduced diesel consumption on material handling costs and carbon related charges, the total carbon related charges as established in the GGPPA were calculated for each material handling alternative considered as part of this analysis[5]. These charges were selected to be indicative of likely carbon related charges experienced by the mine as, at the time of writing, the GGPPA applies as a federal back stop legislation while the Ontario-specific legislation is being approved.

These charges were calculated for both taxation schemes within the Act. The application of the fuel charges was limited to the consumption of diesel for each alternative as the consumption of electricity or hydrogen is not taxed

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[5] At the time of writing, the GGPPA included carbon pricing with rates until 2022, but it is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates outlined in the GGPPA at the time of writing were considered with the 2022 rates applied to the end of mine life as appropriate.

as part of the legislation being considered. As mentioned in Chapter 2, the fuel charges are not paid directly by the consumer to the federal government but are to be embedded within the price of fuel charged by the supplier. What is provided in the following is a summary of these potential charges that would be passed down to Detour Lake Mine from their fuel suppliers if they did not exceed the 50,000 tCO2e trigger of the OBPS. By exceeding this emissions limit, the Output Based Pricing System will apply and fuel purchased to run the fleet will be exempt from the flat taxation rate of the fuel charges. For example, in 2019 Detour Lake Mine reported emitting 253,327 tCO2e per federal GHG reporting mandates (Government of Canada, 2020d). For the same year, it has been estimated that the CAT 795 fleet emitted 122,612 tCO2e moving material from the main pit as part of this analysis which is 48% of this reported value. Once the 50,000 tCO2e trigger is exceeded, the allowable (i.e., tax exempt) emissions from the site are calculated based on the prescription of 1 tCO2e for every 7.71 kg of gold produced. The actual emissions (in this case, projected emissions based upon emitting history) produced in excess of this allowable limit are taxed as a rate per tonne.

How these charges were applied are presented in more detail on the yearly breakdowns of capital, operating and carbon related cost tables presented in Appendix A for each alternative. These tables provide the cost schedule for both the OBPS and fuel charges for the life of mine as defined in the GGPPA even though only the OBPS related taxes apply. This was done to provide context around the financial differences of the two tiered taxation scheme.

A summary of the resulting costs including capital, operating, and carbon related charges for all the alternatives are presented in Table 51 below with the base case for comparison. Capital and operating costs are those presented in the previous sections and include the costs to purchase and install any equipment required for the alternatives and the costs to operate the materials handling alternatives (including costs to operate and maintain the CAT 795 fleet). Carbon related costs were calculated as outlined in the GGPPA as described above.

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Table 51. Total costs including carbon related charges for each haulage alternative

Item	Diesel powered CAT 795 fleet	Hydrogen powered CAT 795 fleet		Trolley assist system to move CAT 795 fleet		In-pit crusher and conveyor		
	Base case	Liquid hydrogen delivery	Gaseous hydrogen produced on site	On main ramp	Through tunnel in pit wall	On pit wall	Through tunnel in pit wall	On the main ramp
Capital cost - CAT 795 fleet (M CAD)	496	957	957	542	542	165	165	165
Capital cost - infrastructure (M CAD)	-	37	250	54	46	142	160	193
Capital cost - total (M CAD)	**496**	**994**	**1,207**	**596**	**588**	**306**	**325**	**358**
Diesel consumed between 2019 to 2040 (M litres)	894	-	-	198	519	420	420	420
Operating cost - diesel (M CAD)	716			159	415	336	336	336
Electricity consumed between 2019 and 2040 (GWh)	-	537	8,952	4,410	347	1,423	1,545	2,190
Operating cost - electricity (M CAD)		13	224	110	9	36	39	55
Hydrogen consumed between 2019 and 2040 (kt)		119	119					
Operating cost - hydrogen delivery or production (M CAD)		933	189					
Operating cost - CAT 795 fleet (M CAD)	1,637	1,637	1,637	1,637	1,637	796	796	796
Operating cost - infrastructure excluding fuel and electricity (M CAD)		162	454	18	6	1,082	1,104	3,878
Operating cost - total (M CAD)	**2,353**	**2,745**	**2,504**	**1,924**	**2,067**	**2,249**	**2,275**	**5,065**
Capital and operating cost - total (M CAD)	**2,849**	**3,739**	**3,711**	**2,520**	**2,655**	**2,556**	**2,600**	**5,422**
Capital and operating cost - per production tonne moved by the CAT 795 fleet (CAD)	7.58	9.95	9.87	6.73	7.06	6.80	6.92	14.42
Capital and operating cost - per total tonne moved by the CAT 795 fleet (CAD)	1.75	2.30	2.29	1.56	1.63	1.57	1.60	3.34
CO_2 produced by via materials handling system (kt) [1]	2,415	-	-	536	1,402	1,135	1,135	1,135
Carbon cost - fuel charge total (M CAD) [2]	109			23	59	47	47	47
Carbon cost - excess emission charge per the Output Based Pricing System (M CAD) [3]	91	2.5	2.5	21	53	31	31	31
Carbon cost - total (M CAD)[4]	**91**	**2.5**	**2.5**	**21**	**53**	**31**	**31**	**31**
Capital, operating and carbon cost - total (M CAD)[5]	**2940**	**3,742**	**3,714**	**2,541**	**2,708**	**2,586**	**2,630**	**5,453**
Capital, operating and carbon cost - per production tonne moved by the CAT 795 fleet (CAD)	7.82	9.95	9.88	6.76	7.20	6.88	7.00	14.51
Capital, operating and carbon cost - per total tonne moved by the CAT 795 fleet (CAD)	1.81	2.30	2.29	1.56	1.67	1.59	1.62	3.36

1. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO_2 (Government of Canada, 2014).
2. Fuel charges applied to the amount of diesel consumed based on the GGPPA at the time of writing (Government of Canada, 2020a). A proposed rate increase by $15 per tCO_2e starting in 2023 until 2030 was not considered..
3. Due to Detour Lake Mine exceeding the annual emissions trigger of 50,000 tCO_2e, fuel purchased would be exempt from the fuel charges in lieu of the production related charges of the OBPS.
4. Charge per tonne of excess CO_2e emissions calculated by applying the Output Based Pricing System defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b).
5. Includes only the OBPS related charges as the site is exempt from fuel charges due exceeding the annual emissions trigger of 50,000 tCO_2e.

Review of the above shows:

- Based upon capital and operation cost considerations alone, use of a trolley assist system on the main ramp or installation of an IPCC along the pit wall or through a tunnel in the pit wall are the most cost effective ways of moving material from the main pit. While this conclusion is supported by the mine indicating an intention to undertake a cost benefit analysis of installing trolley assist system in the 43-101 report, installation of an IPCC is also a viable alternative for the site given similar costs expected to install and operate the system using conservative estimates. Design choices made as part of this analysis, like installation of a fixed crusher requiring trucks to travel up fully loaded from the shovels, location of the portal at a lower elevation, etc., could be reassessed to provide further operational savings.

- When considering the amount of CO_2 produced by the various material handling scenarios, both of these involving hydrogen had the lowest carbon footprints followed by use of a trolley assist system on the main ramp or installation of an IPCC. However, the carbon emissions accounting was limited to the hydrocarbons produced by each scenario on-site and did not reflect any upstream emissions (e.g., diesel spent delivering hydrogen to the site, carbon intensity of the electrical grid).

- When compared to the flat taxation rate of the fuel charge experienced by smaller emitters, the production related OBPS taxation scheme offers a lower taxation rate for all scenarios except either of the hydrogen fuel options. Review of reported emissions for the site indicate that even by completely eliminating GHG emissions from operation of the CAT 795 fleet, total emissions for the site are still in excess of the 50,000 tCO_2e trigger of the OBPS. However, actual emissions are only predicted to exceed the prescribed emissions limit until 2030 when Detour Lake Mine would be able to redeem unused emissions as offset credits.

However, cost alone will not define the practicality of the options considered. Installation of a trolley assist system appears to be the most practical alternative to a diesel-powered fleet especially when installed on the main ramp. This alternative offers substitution of diesel consumption with electrical power directly with minimal new infrastructure investment with the potential for reduced fleet requirements in the future. While application of this technology in open pits in northern climes is limited, trials are being undertaken with success (Ranggård and Mäki, 2020). A trolley system has been developed by Caterpillar; the same manufacturer as the truck fleet (Caterpillar, 2021c). IPCC systems were cost comparable to the trolley assist system for capital, operating, and carbon. Installation of the IPCC would require multiple systems and crushers to be installed and operated in parallel to handle the required capacity for this site; however, these systems were economical when adapted to the existing mine plan. Additional operational savings could be gained by optimizing the location of the fixed crusher to reduce upgrade haul distances for the CAT 795 as the design location will result in increasing haul effort as the pit is continuously excavated.

Use of hydrogen on site has a number of technological issues associated with it including lack of a centralized high capacity production facility to supply liquid hydrogen and the lack of electrolyzers and distribution systems to provide hydrogen at the scale and speed required. Additionally, on-truck hydrogen storage options have questionable applicability at the scale required. It is also likely that the carbon cost of delivery of liquid hydrogen to site is under-represented given that the focus of the analysis was carbon emission production through the consumption of diesel on-site and neglected to consider the consumption by delivery trucks. Use of hydrogen provides an opportunity to have a low carbon footprint but was complicated by lack of suppliers and trucking requirements for off-site production and limited capacity for electrolyzers for on-site production. The capacity of dispensing technology also limited the viability of the hydrogen scenarios considered.

As indicated previously, both use of a trolley assist and hydrogen gas production on-site rely heavily upon electricity and it is unclear at this time if there is sufficient capacity within the existing feed from the provincial electrical grid to accommodate these systems. The trolley assist system as assessed in this thesis may be limited by the capacity of commercially available substations requiring additional capital costs to be incurred. It is also unclear if this limited capacity would affect the number of haul trucks that could be on the trolley assist system concurrently. This may be less of an issue for the shorter trolley assist system that access the pit through a tunnel in the pit wall; this shorter track may be capable of accommodating more trucks due to shorter travel distances but some carbon reduction benefits are lost.

Other operational considerations would need to be further investigated to determine the viability of each option include: the impact of local climate (i.e, harsh winters) upon operation, need for flexibility to accommodate changes in the mine plan, impacts of maintenance and operation upon mining staff and scheduling.

7.7 Conclusions

As indicated by Azadi et al. (2020) there are a number of actions a mine can undertake to reduce their carbon footprint including the reduction of fugitive emissions, increase the efficiency of resource conversion, decrease energy consumption, and biological solutions. Climate change goals set by the Canadian government are meant to provide the legislative and financial push for mines to consider operational alternatives to reduce the GHG emissions linked to their operations. Selecting an appropriate response to this policy-based call to action is dependent on a number of variables including: mine location, mining method, dependence on diesel, connection to provincial and territorial electrical grids, cost, life of mine, and financial incentives.

The GHG mitigation alternatives considered in this chapter provided some insights into what carbon-related gains could be made through decreased energy consumption. Review of the haulage alternatives for Detour Lake Mine highlighted the impact of location upon adopting emerging "green" technologies as benefits of fuel alternatives were out-weighed by the cost, both financial and carbon-related, of getting the fuels to the site. While emerging technologies, like hydrogen fuel, offer vastly reduced emission rates over diesel consumption, the convenience and ease of use of diesel can make it the preferred alternative. Capital costs of developing and adopting emerging, greener technologies is a barrier.

As many of the alternatives considered in this chapter relied upon access to low cost electricity, it will be important to keep electrical costs low as demand will increase if these greener alternatives are adopted. Both Detour Lake Mine and New Afton Mine (subject of the next chapter) have upgraded the capacity of their connection to the electrical grid as their operational demands have increased. Subsidizing such infrastructure improvements may promote adoption of emerging technologies that rely on electrical power. This will be especially true for remote mines that currently do not have access to an electrical grid. As application of forgiving taxation schemes for large emitters, like the OBPS discussed in Section 5.2, may not provide the leverage required for the adoption of low carbon operations, facilitating access to low carbon energy may be of interest to policy makers. It is also essential for energy sources supplying provincial and territorial grids be as carbon neutral as possible allowing for the trickle down of any net-zero power production into the supply chain.

8 Fuel switching analysis for the main haulage fleet at New Afton Mine

8.1 Purpose and boundaries of this analysis

Even cursory inspections of the Sankey diagrams in Figures 11, 13 or 34 demonstrate that the most significant CO_2 emissions in mining operations arise from diesel consumption associated with ore and waste haulage. As there are limited electric powered, heavy-duty trucking options currently available that meet the operating and climate conditions at open pit mines in Canada, the alternatives considered for Detour Lake Mine, a large, high production open pit mine, focused on alternative fuel types or alternative conveying systems (Propulsion Québec, 2020). The purpose of the analysis in this Chapter is to review viability of a carbon emission reduction project for underground mines. Battery electric operation of the haul truck was not considered practical for the scale of such a surface operation but is considered herein for underground application at New Afton Mine.

The influence of carbon policy is also considered. Analysis is undertaken in the context of participating in the provincially funded incentive programs described in Chapter 2 to determine value for the mining company, to determine whether the policy constitutes a meaningful driver. For these purposes alone, a fuel switching project is considered in which all LHDs vehicles and 45 tonne haulage trucks used on the main haulage level at the mine are assumed converted to/replaced by battery-electric vehicle (BEV) equivalents. With the exception of two electric tethered LHDs, this fleet predominately operates using diesel only at present (RPA, 2020).

The analysis includes:

- A review of the estimate of current diesel consumption costs for operation of the fleet for the status quo presented in Chapters 4 and 5,
- An estimate of costs to convert the fleet to BEV,
- Cost reductions to the above when considering participation in CleanBC Industrial Fund and through the selling of B.C. carbon offset units to the province.

The scope and spatial boundaries considered are the same as for the energy and carbon analyses of the previous chapters except only operation of the main haulage fleet consisting of 16 LHD and 7 haulage trucks are considered (RPA, 2020). The temporal boundary is limited to remaining life of mine (assumed to be 9.5 years from 2021 to 2030).

8.2 Base case energy consumption by the haulage fleet at New Afton Mine

As described in more detail in Section 5.3.3, yearly energy consumption for the main haulage fleet at New Afton Mine was calculated based upon an assumed duty cycle and estimated to be 4.27 million litres of diesel per typical year with a total of 40.6 million litres consumed for the remaining mine life (from 2021 to 2030). To determine energy and carbon costs associated with this consumption, cost of $1.00 per litre of diesel was assumed based upon information provided by site staff (Cooper, 2020) and a tax rate of $45 per tonne CO_2e was applied to the emissions (Government of British Columbia, n.d.). To determine energy costs for electrical consumption the following costs were used: a basic charge of $0.1266 per kWh was assumed, a transmission charge of $0.05073 per kWh, and a tax rate of 13% (B.C. Hydro, 2021a; B.C. Hydro, 2021b; and Cooper, 2020). According the B.C. Hydro rate information, the site will also pay a demand charge of $8.679 per kW per month (B.C. Hydro, 2021b). It is expected that this is paid at a rate of 27.5 to 31.5 MW per month to reflect current electrical consumption (RPA, 2020). An emission factor of 40.1 tonnes CO_2e per GWh was used for electrical consumption during this analysis (Government of British Columbia, n.d.).

Switching from a diesel fuel to an alternative power source to fuel the main haulage fleet may have the added advantage of reduced ventilation requirements due to reduced diesel particulate matter and heat. To understand these reduced costs by alternative, the cost to operate the ventilation system has also been considered for each scenario. To do so, it was assumed that the total ventilation requirement for the site was a result of operating the mobile equipment described in the most recent 43-101 report and presented in Table 16 of Section 4.4.3 of Chapter 4. The estimated yearly consumption for the main haulage fleet of 4.27 million litres was 92% of the 4.64 million litres of diesel reported to be consumed on site excluding diesel used by contractors for tailings construction

(Cooper, 2021). Using the measured electricity consumption by the ventilation system of 30.6 GWh, the amount of electricity required to operate the ventilation system due to the operation of the haulage fleet each year was assumed to be 92% of this value or 28.1 GWh.

The resulting cost estimates and emissions for operation of the haulage fleet from 2021 to 2030 are presented in Table 52.

Table 52. Estimated costs and emissions associated with operation of the diesel haulage fleet at New Afton Mine from 2021 to 2030.

Equipment	Current operating regime		
	Energy cost (M CAD)	Emissions (tCO_2e)	Carbon tax (M CAD)
LHD fleet	21.6	57,900	2.6
Truck fleet	18.9	50,700	2.3
Ventilation	53.0	10,700	0.4
Total	94.0	119,000	5.4

These will be the benchmarks against which alternatives will be considered. The energy costs to operate the LHD and truck fleet with fuel between 2021 and 2030 are estimated to be $2.12 per milled tonne and $1.94 per tonne moved.

8.3 Cost of switch to BEV

When determining total capital costs for conversion of the fleet to BEV, battery pack capacity, charging strategies and requirements were considered. Using the same duty cycle assumptions to calculate the yearly energy consumption of the mobile equipment presented in Table 16 in Section 4.4.3 of Chapter 4 and the output power ratings of the various diesel engines, the amount of work done by the individual pieces of equipment in a shift was calculated and then totalled based upon the number of each respective piece of equipment outlined in Table 16. Using these values and an assumed 94% electric motor efficiency (Varaschin, 2016), the minimum amount of energy to be delivered by the battery packs per shift was determined. These values are presented in the following table. As most of the existing equipment was to be converted to battery electric, drivetrain losses were considered to be equivalent between diesel and electric operations and, therefore, not included in the energy required totals. Additionally, as diesel engine output power ratings were used, it was not necessary to consider energy losses due to the efficiency of the diesel engine when determining how much work was being done by the fleet per shift (i.e., this does not reflect diesel energy consumed, but the mechanical work energy produced by the machine to complete the material handling work).

Table 53. Electrical energy consumed by the BEV fleet to do work per shift.

Type	Diesel engine output power rating (kW)	Energy required to do work per shift per machine[1] (kWh)	Electrical energy consumed to do work per shift per BEV[2] (kWh)
LHD	220	690	731
	208	652	691
	305	956	1,013
Truck	447	1,467	1,555
Totals		3,766	3,990

1. This value was calculated assuming the equipment was operated an 8 hour shift (to allow for travel time for personnel), utility of 60%, availability of 84% for the LHDs and 88% for the trucks, and an engine load factor of 77.8%.It was totaled based on numbers of each respective pieces of equipment outlined in Table 16. Engine efficiency was not considered as this was determined to be the work done to handle the material rather than the energy consumed by the machines.
2. Using the value calculated in note 1, the electrical energy that would need to be supplied by the battery packs during a shift per LHD or truck was calculated assuming a 94% motor efficiency for the electric motor.

It was assumed that LHDs would be retrofitted with battery packs and new trucks would be purchased outright as retrofitting costs would be comparable to purchase costs. Available individual battery pack capacity is expected to range between 200 and 400 kWh, indicating that either multiple battery packs will be required or they will have to be charged multiple times per shift (GMG Group, 2018). Regenerative braking was not considered for any of the haulage equipment as all haulage routes were assumed to have minimal grade change. Assuming 600 kW fast charger(s) were used on site, the amount of time spent charging the vehicles per shift was determined based upon the electrical energy required by each motor to do the work done during a shift (Table 54).

Table 54. Charging times for the BEV fleet assuming use of a 600 kW fast charger

Type	Diesel engine output power rating (kW)	Electrical energy consumed to do work per shift per machine[1] (kWh)	Power required by the electric motor in each BEV to do the work per shift[2] (kW)	Selected battery pack size[3] (kWh)	Running time of the selected battery pack[4] (hours)	Time machine spends operating per shift[5] (hours)	Number of battery packs needed per shift per machine[6]	Number of battery packs needed per shift for the BEV fleet[6]	Time spent charging each battery pack per machine[7] (hours)	Total charging time per shift for the fleet (hours)[7]
LHD	220	731	91	200	2.2	4.0	2	4	0.3	1.2
LHD	208	691	86	200	2.3	4.0	2	17	0.3	5.8
LHD	305	1013	127	300	2.4	4.0	2	7	0.5	3.4
Truck	447	1555	194	400	2.1	4.2	2	14	0.7	9.6
Totals		3990						42	1.8	20.0

1. This value was established as electrical energy consumed by the electric motor to do the work presented in Table 53.
2. This value was calculated from the electrical energy consumed by the motor to do the work per note 1 over an 8 hour shift (to allow for travel time for personnel) (i.e., electrical energy supplied in kWh divided by length of shift in hours).
3. Available individual battery pack capacity is expected to range between 200 and 400 kWh; size was selected based on energy needs and payloads (GMG Group, 2018).
4. Running time of the selected battery pack was determined by dividing the selected battery pack size by the power required per note 2.
5. Time the equipment spends actually operating was determined assuming an 8 hour shift (to allow for travel time for personnel) and 84% availability for the LHD, 88% availability for the trucks, and 60% utility rates for both established in the previous sections (Arputharaj, 2015).
6. The number of battery packs needed per machine was determined considering the actual running time of the equipment by the running time of the selected battery packs and established in previous columns. The total number of battery packs required each shift to operate the whole fleet using the number of equipment outlined in Table 16 of Section 4.4.3 and includes two LHD with 220 kW diesel engine output power ratings, ten LHD with 208 kW diesel engine output power ratings, four LHD with 305 kW diesel engine output power ratings, and seven trucks with 447 kW diesel engine output power ratings.
7. Time spent charging each battery pack was determined considering the battery pack size in kWh as a portion of the charging rate of 600 kW. The total time to charge all the battery packs in the fleet for each shift was calculated using the number of equipment outlined in Table 16 of Section 4.4.3.

Based on the assumptions above, it will take approximately 20 hours to charge all the battery packs required to fuel the BEV fleet for a shift with each battery pack being charged once per shift. Given this, it was assumed the installation of three fast charging stations would allow for flexible recharging of equipment and would increase power requirements for the site by 1.8 MW. Charging station costs applied were two part: installation of battery chargers and construction of charging stations on the haulage level underground.

For the purpose of this analysis, capital costs to install battery packs on the LHDs, purchase new BEV haul trucks, construct three charging stations on the haulage levels with battery swapping cranes, and to purchase spare battery packs were estimated based on a review of similar costs presented in literature. Installation of the charging stations was costed at $1 million each with excavation of the charging station bay estimated at $471,000 (Table 55). It should be noted that battery replacement due to degradation was not considered in the capital cost estimations. Assuming the battery packs will be operable for roughly 2,500 charging cycles, based upon the charging rate of once per shift per battery pack, each battery pack is assumed to last 3.3 years (Iracabal, 2021). With battery pack costs estimated to be $165,000, this could be an additional cost of $15.2 million assuming two replacement events over the remining mine life (Schatz et. al., 2017).

Table 55. Capital costs associated with the conversion of the diesel fleet to BEV.

Equipment	Capital costs (CAD/unit)	Reference
Battery pack installation on LHD	545,000	(Medatech, 2020), (Varaschin, 2016), (Stantec Consulting Ltd., 2019)
Charging station construction on haulage level	1,470,000	(Medatech, 2020)
Crane installation to allow for battery packs to be swapped	225,000	(Medatech, 2020)
Purchase costs for spare battery packs (per kWh)	475	(Medatech, 2020)
Truck cost	1,043,000	(Varaschin and De Souza, n.d.), (Stantec Consulting Ltd., 2019), (Wietschel et al., 2019)

The total estimated capital costs to swap the haulage fleet from diesel to BEV are presented below (Table 56).

Table 56. Total capital cost for conversion of the fleet to BEV

Equipment	Total capital costs (M CAD)
Battery pack installation on LHD	8.70
Charging station construction on haulage level	4.40
Crane installation to allow for battery packs to be swapped	0.68
Purchase costs for spare battery packs	2.70
Truck cost	7.30
Total	23.8

8.4 Participation in the CleanBC Industry Fund

Recently, capital cost funding of CleanBC Industry Fund projects was temporarily increased to 90% for the 2021 funding cycle (Government of British Columbia, 2021b). However, review of past CleanBC Industry Fund projects funded by the province suggests that funding is more typically in the range of 50% of capital costs which was the previous maximum funding available with a cap of $25 million (Government of British Columbia, n.d.). Given that the capital funding increase to 90% is a temporary measure to spur such projects during the global pandemic, the more typical funding value of 50% was assumed for this project.

As BEV do not produce diesel particulate matter that needs to be dissipated by the mine ventilation systems, it is suggested that use of BEV in lieu of their diesel counterparts underground can reduce ventilation airflow demands by 40% to 80% and reduce fan power by 60% to 80% (SRK Consulting, 2022; Varaschin and De Souza, n.d.; and Varaschin, 2016). The remaining volume of ventilated air would provide for heat and dust dissipation. As this analysis considers only a partial conversion of the underground fleet to BEV at New Afton Mine, a conservative estimate of 20% reduction on airflow demand was assumed. This resulted in a power reduction (power consumed is proportional to the cube of volumetric flow rate) and was applied using the power usage provided by mine staff and attributed to the diesel fleet as described in Section 4.4.3. This reduced ventilation requirement would result in a decrease in the power consumption on site by 1.6 MW which would counterbalance the aforementioned increased power demand to charge the BEV fleet of 1.8 MW resulting a net power demand increase of 0.2 MW.

To allow for some flexibility, an increased demand of 0.5 MW as assumed as a result of switching the fleet to BEV.

Energy costs to operate the equivalent BEV fleet were determined based on the estimated electrical energy requirements as presented in Table 53. In addition to the electrical rate charges described in Section 8.2, a demand charge of \$8.679 per kW per month was included in the cost estimate at a rate of 0.5 MW; this rate represents the additional power demand for charging the BEV fleet using a fast charging strategy (B.C. Hydro, 2021b). The demand charge was not applied to electrical costs for the ventilation requirements as it was included in the base case. Similarly, emissions associated with operating a BEV fleet were determined using the emissions factor of the grid at 40.1 tonnes CO_2e per GWh (Government of British Columbia, n.d.). Resulting costs and emissions are presented in Table 57.

Table 57. Capital and operating costs associated with switching the fleet to BEV and participating the CleanBC Industry Fund.

Equipment	BEV powered fleet and participating in CleanBC Industry Fund			
	Capital costs[1] (M CAD)	Energy cost (M CAD)	Emissions (tCO_2e)	Carbon tax (M CAD)
LHD fleet		18.7	3,400	0.15
Truck fleet		15.5	3,000	0.13
Ventilation		28.0	5,500	0.25
Total	11.9	62.2	11,900	0.53

1. The total capital expense for the fleet of \$23.8 million is presented in Table 56. The capital cost presented in this table are those same costs reduced by 50% if funded as part of the provincial CleanBC Industry Fund.

As presented in the table above, converting the fleet from diesel to BEV can result in reduced emissions and carbon taxes when compared to operating the fleet using diesel (Table *52*). Participating in the CleanBC Industry Fund can result in considerable costs savings; however, current provincial policy excludes any reduced carbon emissions from provincially funded projects from being purchased as part of the B.C. carbon offset units program (Thrift, 2021). As fuel switching projects are eligible for funding as both a CleanBC Industry Fund project and as an emission offset project, it is necessary to determine if capital funding of the fuel switching is more financially beneficial than revenue from carbon offsets over the remaining life of the mine.

8.5 Revenue generated from the purchase of carbon offset units

As in Chapter 2, a B.C. carbon offset unit represents a tonne of CO_2e that was removed from or not released to the atmosphere as a result of work undertaken by the project proponent (Government of British Columbia, n.d.). These tradable credits can be used by emitters to compensate for GHG emissions they could not reduce to meet emission targets. Purchasing offset credits pays for an offset project at another location and offset credits are typically produced from reforestation, conservation, or renewable energy projects (SPEC, 2021). In British Columbia, the provincial government manages purchase and sale of offset credits. Eligible projects and resulting credits are included in a provincial registry; credit purchase prices range from \$7 to \$15 per tonne of CO_2e depending upon the project (Government of British Columbia, n.d.). According to recent reports on offset projects completed between 2010 and 2014 in British Columbia, the province has invested \$53 million for the purchase of roughly 4.5 million tonnes of offsets at an average price of \$12 per tonne of CO_2e (Seeley, 2019).

Review of the projects on the provincial registry of offset projects indicates that the carbon emission reduction from conversion of the diesel fleet at New Afton Mine to BEV would be eligible for purchase by the provincial government as offset credits. When considering estimated CO_2e emissions from operating the existing diesel fleet compared to those estimated to be emitted from a BEV equivalent haulage fleet presented in the previous sections, fleet conversion will result in an emission reduction of approximately 107,510 tonnes of CO_2e over the life of the mine. Resulting energy and capital costs and carbon offset revenues for the life of mine are presented in Table 58. Revenue resulting from purchase of emissions offsets was calculated assuming a purchase price of \$12 per tonne of CO_2e (Seeley, 2019). Without funding from the CleanBC Industry Incentive Fund, capital costs were assumed to be \$23.8 million for conversion of the fleet and installation of battery charging stations.

Table 58. Costs and revenues associated with conversion of the haulage fleet to BEV and participation in provincial carbon offset programs.

Equipment	BEV powered fleet and selling carbon offsets					
	Capital costs (M CAD)	Energy cost (M CAD)	Emissions (tCO_2e)	Carbon tax (M CAD)	Emissions offsets (tCO_2e)	Revenue from carbon offset credits (M CAD)
LHD fleet		18.7	3,400	0.15	54,500	0.65
Truck fleet		15.5	3,000	0.13	47,800	0.57
Ventilation		28.0	5,500	0.25	5,000	0.06
Total	23.8	62.2	11,900	0.53	108,000	1.29

8.6 Considerations for implementing the fleet operating scenarios

Not included in the cost analyses for conversion of the fleet to BEV above are costs associated with upgrades of electric grid supply capacity to the mine site required to accommodate supply of electricity for BEV operation. Currently, the site is supplied via a 31.5 MW connection to the B.C. Hydro grid via a 1.1 km transmission line from the nearest grid substation. Recent expansions have resulted in power use on site to increase from 27.5 MW to 31.5 MW. An additional increase is expected to occur as additional orebodies are brought on-line in 2024 (RPA, 2020).

Employing a charging strategy using three 600 kW fast chargers as described in previous sections will result in a power demand increase of 1.8 MW that will be offset by a reduced power demand from the ventilation system of 1.6 MW; for the purpose of this analysis a net power demand increase of 0.5 MW has been assumed to allow for some flexibility. Given the capacity restrictions being maximized by the current 31.5 MW power demand, an additional upgrade to the 1.1km transmission line would be required to account for this additional demand.

Costs associated with this feed capacity upgrade were difficult to estimate using publicly available information, but review of available estimates suggest the upgrade costs could range between $311,000 and $344,000 (Carvalho et al., 2013; Mongrid et al., 2020; and NRECA International, Ltd., 2000). These estimates reflect the nominal distance from the closest substation. Cost to upgrade the power supply could be higher if additional infrastructure including substations or transformers are required. While it is not possible to determine the infrastructure needs from the publicly available information for this site, these additional costs could range between $0.36 and $2.3 million (BBA, 2014 and Romero et al., 2014).

8.7 Cost comparison of operating scenarios and funding opportunities

The resulting total operating and capital costs considering the various fleet operating scenarios described in the previous sub-sections are presented in Table 59. Capital costs associated with electrical supply upgrades are not included as some upgrades are required when new ore bodies come on-line in 2024 and could potentially be absorbed as part of that expansion.

Table 59. Total costs associated with the various fleet operating scenarios including carbon revenues and funding opportunities

Fleet operation scenarios	Total costs (including revenues and funding)
Current operating regime	$99,500,000
BEV powered fleet and participating in CleanBC Industry Fund	$74,600,000
BEV powered fleet and selling carbon offsets	$85,200,000
BEV powered fleet and participating CleanBC Industry Fund and selling of carbon offsets concurrently [1]	$73,300,000

1. While this scenario is not viable as participation in the CleanBC Industry Fund excludes the selling of carbon offsets resulting from the funded project it is presented to provide context around the policies of implementing the taxation scheme.

As presented, conversion of the diesel fleet in question to a BEV fleet has a number of advantages. Firstly, energy demands are reduced by 58% (Table 60) and energy costs are reduced by 32%. Secondly, GHG emissions and costs in the form of carbon tax are both reduced by 91%. Capital investment required for fleet conversion is the driving variable to determine economic benefit of the alternative fleet operation scenarios considered. Incentive programs that promote GHG emission reduction through funding of capital costs proved to be the most economically beneficial.

Table 60. Energy consumption and emissions per year of the various operating scenarios

Operating scenario	Current operating regime	BEV powered fleet
Electricity consumed by fleet (MWh/year)[1]		17,000
Diesel consumed by fleet (MWh/year)[2]	45,000	
Electricity to provide ventilation for haul fleet (MWh/year)[3]	28,000	14,000
Total energy consumed (MWh/year)	73,000	31,000
Scope 1 and 2 emissions (tCO_2e/year)	13,000	1,300

1. No electricity was assumed to be required to operate the diesel powered haul fleet. The electricity required to operate the BEV powered fleet was calculated based upon the electrical energy consumption estimate per BEV presented in Table 53.
2. Diesel consumed by the fleet was based on estimates of diesel consumption per machine presented in Table 53.
3. Electrical energy required to ventilate the underground works with a BEV fleet was calculated based on measured ventilation energy requirements and assuming a conservative flow reduction of 20% per Section 8.4.

However, these conclusions are dependent upon the cost of energy. Where electricity is significantly more costly when compared to diesel, operation of the diesel fleet would prove more economical than when considering more carbon neutral alternatives including BEV adoption. Of the provincial funding opportunities, offsetting capital costs of installation proves more economical than sale of carbon offset units over the life of the mine; this is likely a function of the short remaining mine life of 9.5 years considered in this analysis. While current policy precludes industry from taking advantage of both the CleanBC Industry Fund and revenue from carbon offsets concurrently, review of the costs associated with a scenario that allows industry to participate in both funding streams proves most economical of the scenarios considered. Consideration of a policy change to allow industry to take advantage of both incentives could spur the adoption of emission reduction strategies into mine plans for new operations with longer operating lives where sale of resulting carbon offsets would be more advantageous.

8.8 Sensitivity to costing variables

To further understand the impact of participation in the various government initiatives and the variable cost of diesel, a sensitivity analysis was completed for the following three alternatives: i) the current diesel-fuelled operating regime, ii) the BEV powered fleet and selling carbon offsets, and iii) the BEV powered fleet and participating the CleanBC Industry Fund. For each, the relevant variables were flexed within ranges probable to occur either during the life of mine or legislative scope. For example:

- diesel prices were varied in \$0.30 increments from \$1.00 per litre to \$1.60 per litre,

- the carbon tax was varied from the current \$45 per tonne CO_2e to of \$50 per tonne CO_2e (the only legislated increase set to occur in B.C. in April 2022) and from \$65 to \$80 (proposed increases to occur in 2023 and 2024), and

- carbon offset prices were varied from \$12 per tonne CO_2e offset to \$15 per tonne CO_2e (the top end of prices currently occurring) in \$1.50 per tonne CO_2e increments.

The resulting costs for these scenarios are presented in Table 61 and sorted from lowest to highest.

Table 61. Sensitivity of cost to diesel costs, carbon tax, and carbon offset price variables by operating regime.

Operating regime	Total cost (M CAD)	Carbon offset unit price (CAD/tCO$_2$e)	Carbon tax (CAD/tCO$_2$e)	Diesel cost (CAD/l)
BEV powered fleet and participating in BC Clean Industry Fund	74.6		45	
BEV powered fleet and participating in BC Clean Industry Fund	74.6		50	
BEV powered fleet and participating in BC Clean Industry Fund	74.7		65	
BEV powered fleet and participating in BC Clean Industry Fund	74.8		80	
BEV powered fleet and selling carbon offsets	84.9	15.00	45	
BEV powered fleet and selling carbon offsets	84.9	15.00	50	
BEV powered fleet and selling carbon offsets	85.0	15.00	65	
BEV powered fleet and selling carbon offsets	85.0	13.50	45	
BEV powered fleet and selling carbon offsets	85.1	13.50	50	
BEV powered fleet and selling carbon offsets	85.1	15.00	80	
BEV powered fleet and selling carbon offsets	85.1	13.50	65	
BEV powered fleet and selling carbon offsets	85.2	12.00	45	
BEV powered fleet and selling carbon offsets	85.2	12.00	50	
BEV powered fleet and selling carbon offsets	85.2	13.50	80	
BEV powered fleet and selling carbon offsets	85.3	12.00	65	
BEV powered fleet and selling carbon offsets	85.4	12.00	80	
Current operating regime	99.5		45	1.00
Current operating regime	100.0		50	1.00
Current operating regime	101.7		65	1.00
Current operating regime	103.3		80	1.00
Current operating regime	111.7		45	1.30
Current operating regime	112.2		50	1.30
Current operating regime	113.8		65	1.30
Current operating regime	115.5		80	1.30
Current operating regime	123.8		45	1.60
Current operating regime	124.4		50	1.60
Current operating regime	126.0		65	1.60
Current operating regime	141.4		80	1.60

Review of this analysis shows that:

- No matter the diesel price considered, operating the diesel fleet proved more expensive than operating the BEV fleet for the various scenarios.

- For all carbon tax rates, carbon offset prices, and diesel prices considered, participation in the CleanBC Industry Fund to have the capital cost of converting the haulage fleet to BEV offset in part is most cost effective followed by conversion of the fleet to BEV and selling resulting carbon offset units.

8.9 Conclusions

A number of conclusions can be drawn from review of the hypothetical fuel switching project at New Afton Mine:

- Of the incentive programs currently offered by the Government of British Columbia, programs that contribute to offsetting capital costs associated with the fleet conversion would be most likely to provide incentive for the project to be undertaken.

- The sale of carbon offsetting units resulting from the fleet conversion could be of sufficient scale to provide incentive for the project to be undertaken given current carbon taxation schemes and current diesel costs.

- Policy that precludes the sale of carbon offset units resulting from a partially provincially-funded capital conversion of the fleet could dissuade industry from undertaking such projects with limited operational savings associated with them. While in this analysis, the limited life of mine considered made sale of carbon offset units a nominal source of revenue for the mine, projects with longer life spans could produce enough carbon offset units to make such projects operationally attractive.

9 Discussion and conclusions

9.1 What was learned and research highlights

The mining industry is an energy intensive but profitable industry consuming roughly 3.6% of the energy and emitting 3.7% of the GHG while producing 5% of the total GDP by industry in Canada (Government of Canada, 2022d and The Mining Association of Canada, 2021). Essential to supplying critical minerals to the “green” economy, mines must also reduce the carbon footprint of their operations. The objectives of this research were to complete a review of energy consumption and GHG emissions at metal mines in Canada, to understand the implication of Canadian climate change legislation for operations at these mines, and to assess practical actions mines can take to reduce their GHG emissions.

This research confirmed that producing metals and minerals with a net zero carbon footprint is not a simple undertaking. Review of energy consumption by the mining industry at the sector level confirmed a reliance on carbon rich fuels and a geographic implication to energy consumption. Those mines with access to electrical grids showed lower GHG intensities depending upon the generating energy type supplying the grid (e.g., hydroelectricity, nuclear generation, natural gas, etc.). Those mines located in remote areas have a reliance on carbon rich fuels.

This research also highlighted the impact of mining method upon energy and emission intensity of mining. At all mines reviewed, large amounts of energy were consumed by material handling and milling. Underground operations had an added energy burden of ventilating underground workings. The advantage of bulk mining methods became obvious when considering energy and emission intensities; the larger total footprint of these operations being offset by higher production rates. Table 62 provides a summary of the various intensities of the mine types reviewed as part of this thesis. These benchmarks can be applied to other case studies and energy audits or used to monitor sector data to determine trends in energy and GHG reduction.

Table 62 Benchmark of energy and emission intensity for the various mining methods reviewed

Mine	Mining method	Energy consumption (MWh/kt milled)	Emissions intensity (tCO_2e/t)[1,2]	Emissions intensity by production unit[1]	Sections in thesis	References
Garson Mine	Underground selective mining	226.5	0.078	0.003 tCO_2e /pound of nickel produced[3]	Section 4.2.2	(Levesque, 2015; Mallett, 2014; and Millar, 2015)
Surface Mine	Open pit mining with truck haulage	79.0	Not available	Not available	Section 4.3.1	(Millar, 2022)
Detour Lake Mine	Open pit mining with truck haulage	Not available	0.002	0.015 tCO_2e/gram of gold produced	Section 5.2.1	(Kirkland Lake Gold, 2021)
New Afton Mine	Block cave mining	57.8	0.008	0.015 tCO_2e/gram of gold produced	Section 4.4.3	(Cooper, 2020)

1. Emissions include scope 1 and 2 types for all sites and include measured and reported per the references and predicted emissions per Table 30.
2. How production with respect to material moved was publicly reported varied by site. For Garson Mine, energy intensity is MWh per tonne of ore hoisted; for the surface mine, it is MWh per tonne of material moved (ore and waste); and for New Afton Mine, it is for MWh per tonne of material mined (ore and waste). Total energy consumption for Detour Lake Mine was not available in the public domain so not reported here.
3. Gold production at Garson Mine is a by-product of nickel production so the emission intensity of the underground selective mining at the site is expressed normalized to nickel. The emission intensity for Garson Mine normalized to gold production is 0.16 tCO_2e/gram of gold produced, but considering the emissions in relation to gold production may over-represent the intensity of the operations.

In addition to these benchmarks, methodologies to understand energy consumption established in this thesis can facilitate future energy audits. A procedure was developed using publicly available information to estimate diesel consumption for open pit mines. For this analysis, disaggregated energy consumption was estimated based on fuel consumption rates and assumed duty cycles resulting in small inconsistencies between measured and estimated consumption. As material handling, especially using trucks, is a major source of GHG emission from mining operations, being able to accurately predict diesel consumption for future mining plans will be increasingly important for mines across Canada.

The energy audit of New Afton Mine resulted in an energy model for the block cave mine that was used to predict future energy use based upon operational parameters. This model was built upon well defined data provided from a high quality energy management program at the mine. It highlighted the relationship between major processes such as production, development, and tailings construction and energy consumption by type and can be used to predict energy consumption and GHG emissions for other block cave mines. As highlighted in Table 62, this bulk mining method offers low energy and emission intensities that may be important for new mines that will be required to operate with a net zero footprint.

The main mechanisms to reduce emissions implemented within the regulatory landscape of interest to the mining industry are carbon taxation followed by incentive programs to promote greener operations. GHG emissions from direct energy consumption by industry, or Scope 1 emissions, are the main focus of carbon reduction policies so far. One of the case studies presented focused on diesel consumption at Detour Lake Mine and confirmed that taxation schemes within these regulatory frameworks shelter large emitters from flat taxation rates. The production related taxation rates regulated within the OBPS of GGPPA have the benefit of reducing global competitive pressures from production of the same commodities in countries with less stringent environmental policies. This short-term gain from reduced carbon taxation fees is counterbalanced by reduced pressure for these emitters to adopt greener operational processes. This potentially delays carbon reduction further jeopardizing Canada's ability to meet climate change targets.

New regulatory tools, like the *Strategic Assessment of Climate Change* requirements that are part of the impact assessment process, are beginning to include consideration of Scope 2 and 3 and other indirect emissions from projects with a focus on how these emissions will impact longer term goals associated with achieving net zero emissions by 2050. Emissions from land use change at mine sites and Scope 3 emissions are often not quantified but this research proved that these sources of emissions can be significant. As it becomes more likely that consumers will be required to report on emissions from supply chains, understanding of these indirect emissions from mining will be increasingly important as well as reducing them.

9.2 Needs identified

The evolution of the regulatory landscape around climate change goals is a source of uncertainty for mines as regulatory changes could impact long term mine plans and feasibility conclusions. While methods to predict fuel consumption based on assumed duty cycles and OEM supplied fuel consumption rates proved reliable, the importance of understanding the impact of the mine plan and changes resulting from production and construction pressures was observed when developing the energy model for New Afton Mine. There is limited publicly available disaggregated data describing energy consumption at metal mines in Canada to improve this understanding. What is easily accessible is data disaggregated to the sector level (i.e., by commodity) with little or no consideration given to mining method or process unique to the various operations as a result. To make effective policy to promote GHG reduction, data may have to be disaggregated in a more refined manner and consider those energy consumption patterns also unique to the various mine types in Canada.

This research confirmed the importance of "greener" material handling methods to reduce emissions from mines. Material handling was one the major energy consuming processes at the mines in addition to milling. As outlined by Levesque (2015), energy savings associated with milling has been well investigated and there may be less opportunity for further innovation. All material handling methods reviewed as part of this thesis had at least a partial reliance on diesel and the alternative analyses indicated potential cost benefits associated with employing cleaner technologies. However, potential GHG emission mitigation alternatives reviewed highlighted how reducing energy consumption at mines can be complicated by technological readiness of low carbon alternatives (e.g., hydrogen fuel cells). Adoption of these alternatives requires commitment of substantial amounts of capital. Within mining companies, projects of multiple types (e.g., energy saving, drilling for new orebodies, upgrade of process equipment) have to compete for company capital resources. Pay back of energy projects from reduced carbon taxation as well as process improvement is important in this context. Incentive programs that provide capital funding can be sufficient to drive rapid fundamental operational change.

An effective, alternative incentive funding source for mining projects could be the relatively under-utilized carbon offsetting regime. At time of writing, an offsetting program for carbon credits accrued by large emitters emitting less than their allowable limit per the OBPS is being developed (Government of Canada, 2022b). Programs that offer carbon offset credits for habitat restoration or biodiversity offsetting projects have been investigated in this work. Evidence suggests that industrial carbon capture projects have mixed success and are often abandoned

(Carleton University, 2022). However, in the right location (i.e., ecosystems with a rich biomass), habitat restoration projects, including restoration of impacted land to native vegetation, can offer good dividends when considering carbon taxation. These projects often have additional benefits of increasing access to habitat, regulating runoff, cooling effects for local environment, etc. Some programs in existence go so far as to pay areas to be set aside as reserves (Government of British Columbia, n.d.). This research confirmed in that the price per tonne paid for carbon offset by these projects is likely too low at existing rates to make this a viable carbon taxation reduction scheme for mines.

9.3 Future work

While the objectives of this research were met, based on the needs identified above there is opportunity for future work to increase knowledge around energy use and ways to reduce GHG emissions for mining operations in Canada. Firstly, an improved ability to predict emissions based upon proposed mining activities is required. To this end, measured, disaggregated data is required at the equipment level to allow for multivariate analyses to determine parameters that impact energy consumption and can be used in future modelling GHG emissions. Secondly, this data can also be used to fill gaps in data sets used to complete life cycle assessments for mined commodities improving GHG estimations for supply chain. A critical review of available data sets and potential data sources is required. Finally, a socio-economic analysis should be completed on funding programs for carbon reduction efforts for large emitters. Balances between reduced taxation and capital funding and impacts to local communities should be explored, but reconsideration around carbon taxation relief for large industrial emitters as carbon reduction programs are implemented globally may be necessary.

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Appendix A: Material moved from the main pit at Detour Lake Mine to the various dump points

Table 63. Material moved by CAT 795 to the various dump points and trips required (Detour Gold Corporation, 2018)

Operating year	Total mined from all pits (Mt)	Strip ratio	Number of CAT 795	Number of CAT 777 available to work in the main pit	Proportion of material moved from the main pit by CAT 795	Ore moved from main pit by CAT 795 (Mt)	Waste moved from main pit by CAT 795 to North Waste Pile (Mt)	Waste moved from main pit by CAT 795 to South Waste Pile (Mt)	Total amount of material moved by CAT 795 (Mt)	Number of trips by the CAT 795 to the ore pile	Number of trips by the CAT 795 to the North Waste Pile	Number of trips by the CAT 795 to the South Waste Pile	Total number of trips by the CAT 795
2019	117.5	4.2	38	15	90%	20.3	14.5	70.9	105.8	63,923	45,641	222,836	332,400
2020	123	4.4	38	16	89%	20.4	15.2	74.4	110.0	64,011	47,880	233,768	345,659
2021	125.8	6.6	39	16	90%	14.8	16.7	81.3	112.8	46,643	52,334	255,512	354,489
2022	125.5	4.8	39	17	89%	19.3	15.7	76.8	111.8	60,582	49,435	241,358	351,374
2023	126.2	3.5	39	17	89%	25.0	14.9	72.6	112.4	78,519	46,719	228,097	353,334
2024	128.8	3.9	39	24	85%	22.4	14.9	72.5	109.8	70,430	46,695	227,983	345,109
2025	124	4.2	39	0	100%	17.3	12.4	60.3	90.0	54,401	38,843	189,643	282,888
2026	127.9	6.5	39	0	100%	12.4	13.7	66.8	92.8	38,905	42,990	209,891	291,785
2027	130.6	5.7	38	0	100%	14.2	13.7	66.9	94.8	44,469	43,091	210,384	297,944
2028	130.8	5.4	38	0	100%	14.8	13.6	66.5	95.0	46,625	42,802	208,974	298,401
2029	111.7	4.6	40	0	100%	14.5	11.3	55.3	81.1	45,505	35,585	173,737	254,827
2030	117.9	4.4	40	0	100%	15.8	11.9	57.9	85.6	49,809	37,258	181,904	268,971
2031	104.8	2.3	40	0	100%	24.1	9.4	46.1	79.6	75,820	29,646	144,740	250,206
2032	83.9	1.3	24	0	100%	27.7	6.1	29.9	63.7	87,090	19,247	93,971	200,308
2033	58.1	3.6	24	0	100%	9.6	5.9	28.7	44.1	30,155	18,455	90,102	138,711
2034	56.9	2.5	24	0	100%	12.4	5.2	25.6	43.2	38,813	16,496	80,538	135,847
2035	66.2	1.8	27	0	100%	18.0	5.5	26.8	50.3	56,446	17,273	84,331	158,050
2036	63.1	1	27	21	82%	25.9	4.4	21.5	51.8	81,370	13,833	67,537	162,741
2037	48.4	0.9	27	21	82%	20.9	3.2	15.6	39.7	65,699	10,052	49,077	124,828
2038	41.5	0.9	13	21	69%	15.0	2.3	11.2	28.5	47,214	7,224	35,269	89,707
2039	19.7	1.2	13	4	92%	8.2	1.7	8.2	18.1	25,902	5,284	25,798	56,985
2040	3.1	0	13	4	92%	2.9	-	-	2.9	8,967	-	-	8,967
Total	2,035					375.9	212.2	1,035.9	1,623.9	1,181,301	666,779	3,255,451	5,103,530

Appendix B: Yearly cost breakdown of haulage alternatives considered for Detour Lake Mine

Table 64. Yearly breakdown of capital, operating, and carbon costs to operate the diesel powered CAT 795 fleet

Year		Estimated fuel consumption for material handling using CAT 795						Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg) [1]	Number of trucks [1]	Capital costs for CAT 795 (fleet replacement every six years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Fuel consumed by CAT 795 (M l) [2]	Fuel cost (M CAD) [3]	CO_2 produced by combusting fuel consumed by CAT 795 (kt) [4]	Potential fuel charge (CAD/l)[5]	Fuel charge total (M CAD)[6]	Annual facility emissions limit prescribed by the OBPS (kt)[7]	Predicted total reported emissions (kt)[8]	Compliance obligations per OBPS (kt)[9]	Charge per tonne CO_2e (CAD/tonne CO_2e)[10]	Excess emission charge (M CAD)[11]	Difference between carbon related charges (M CAD)[12]
2019	16,655	36		81.7	45.4	36.3	123	0.05	2.44	128	253	125	20	2.50	0.06
2020	16,641	38		86.3	47.9	38.3	129	0.08	3.86	128	267	139	30	4.17	0.31
2021	17,576	38		86.3	47.9	38.3	129	0.08	3.86	136	267	132	40	5.28	1.42
2022	17,746	39		88.5	49.2	39.4	133	0.11	5.28	137	274	138	50	6.88	1.60
2023	17,661	39		88.5	49.2	39.4	133	0.11	5.28	136	274	138	50	6.91	1.63
2024	17,293	39	183	88.5	49.2	39.4	133	0.13	6.60	133	274	141	50	7.06	0.46
2025	18,172	39		88.5	49.2	39.4	133	0.13	6.60	140	274	134	50	6.72	0.12
2026	17,605	39		88.5	49.2	39.4	133	0.13	6.60	136	274	139	50	6.94	0.34
2027	17,179	39		88.5	47.9	38.3	129	0.13	6.43	132	267	135	50	6.75	0.32
2028	17,491	38		86.3	47.9	38.3	129	0.13	6.43	135	267	133	50	6.63	0.20
2029	17,435	38		86.3	47.9	38.3	129	0.13	6.43	134	267	133	50	6.65	0.22
2030	18,370	40	187	90.8	50.5	40.4	136	0.13	6.77	142	281	140	50	6.99	0.23
2031	19,703	40		90.8	50.5	40.4	136	0.13	6.77	152	281	130	50	6.48	-0.29
2032	19,646	40		90.8	50.5	40.4	136	0.13	6.77	151	281	130	50	6.50	-0.27
2033	19,107	24		54.5	30.3	24.2	81.7	0.13	4.06	147	169	21.6	50	1.08	-2.98
2034	18,767	24		54.5	30.3	24.2	81.7	0.13	4.06	145	169	24.2	50	1.21	-2.85
2035	20,581	24		54.5	30.3	24.2	81.7	0.13	4.06	159	169	10.2	50	0.51	-3.55
2036	22,056	27	126	61.3	34.1	27.2	92.0	0.13	4.57	170	190	19.9	50	1.00	-3.57
2037	22,991	27		61.3	34.1	27.2	92.0	0.13	4.57	177	190	12.7	50	0.64	-3.93
2038	24,380	27		61.3	34.1	27.2	92.0	0.13	4.57	188	190	2.02	50	0.10	-4.47
2039	19,901	13		29.5	16.4	13.1	44.3	0.13	2.20	153	91.5	-62.0	50	0.00	-2.20
2040	7,598	13		29.5	2.58	2.06	6.97	0.13	0.35	58.6	14.4	-44.2	50	0.00	-0.35
Total	421,947		496	1,637	894	716	2,415		109	3,253	4,989	1,870		91.0	199

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Estimated per methodology described in Chapter 4 using fuel consumption rates provided by the OEM and assumed duty cycles.
3. Cost of fuel assumed to be \$0.80/l as presented in the 43-101 report.
4. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO_2 (Government of Canada, 2014).
5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act at the time of writing (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by \$15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
6. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
7. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
8. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
9. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
10. Charge rates presented in the GGPPA that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year (Government of Canada, 2020a).
11. Charge per tonne of excess CO_2e emissions calculated per note 9.
12. The difference between fuel charges per note 6 and production related charges in note 11 and highlights the savings associated with application of the production related OBPS in lieu of a flat taxation rate on fuel consumed.

Table 65. Yearly breakdown of capital, operating, and carbon costs to operate the CAT 795 fleet using liquid hyrdogen delivered to site

Year		Estimated costs for material handling using hydrogen to fuel the CAT 795												Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg)[1]	Number of trucks[1]	Capital costs for CAT 795 (retrofit the first year and fleet replacement every five years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Hydrogen consumed by the CAT 795 (kt)[2]	Number of liquid hydrogen deliveries[3]	Delivery costs (M CAD)	Capital cost for hydrogen storage and dispensing system (M CAD)	Hydrogen cost (M CAD)	Operating costs for hydrogen storage and distribution system (M CAD)	Electricity consumed by the hydrogen storage and distribution system (GWh)	Electrical costs (M CAD)	CO_2 produced by materials handling system (kt)[4]	Potential fuel charge (CAD/l)[5]	Fuel charge total (CAD)[6]	Annual facility emissions limit prescribed by the OBPS (kt)[7]	Predicted total reported emissions (kt)[8]	Compliance obligations per OBPS (kt)[9]	Charge per tonne CO_2e (CAD/tonne CO_2e)[10]	Excess emission charge (M CAD)[11]	Difference between carbon related charges (M CAD)[12]
2019	16,655	36	156	82	6.05	2,523	6.54	31.50	40.81	8.23	27.2	0.61	-	0.05	0.00	128	131	2.31	20	0.05	0.05
2020	16,641	38		86	6.39	2,663	6.90		43.08	8.69	28.8	0.72	-	0.08	0.00	128	138	9.68	30	0.29	0.29
2021	17,576	38		86	6.39	2,663	6.90		43.08	8.69	28.8	0.72	-	0.08	0.00	136	138	2.46	40	0.10	0.10
2022	17,746	39		89	6.56	2,733	7.08		44.21	8.91	29.5	0.66	-	0.11	0.00	137	142	4.78	50	0.24	0.24
2023	17,661	39		89	6.56	2,733	7.08		44.21	8.91	29.5	0.74	-	0.11	0.00	136	142	5.44	50	0.27	0.27
2024	17,293	39	274	89	6.56	2,733	7.08		44.21	8.91	29.5	0.74	-	0.13	0.00	133	142	8.28	50	0.41	0.41
2025	18,172	39		89	6.56	2,733	7.08		44.21	8.91	29.5	0.74	-	0.13	0.00	140	142	1.50	50	0.08	0.08
2026	17,605	39		89	6.56	2,733	7.08		44.21	8.91	29.5	0.74	-	0.13	0.00	136	142	5.88	50	0.29	0.29
2027	17,179	39		89	6.39	2,663	6.90		43.08	8.69	28.8	0.72	-	0.13	0.00	132	138	5.52	50	0.28	0.28
2028	17,491	38		86	6.39	2,663	6.90		43.08	8.69	28.8	0.72	-	0.13	0.00	135	138	3.12	50	0.16	0.16
2029	17,435	38	267	86	6.39	2,663	6.90	5.94	43.08	8.69	28.8	0.72	-	0.13	0.00	134	138	3.56	50	0.18	0.18
2030	18,370	40		91	6.73	2,803	7.26		45.34	9.14	30.3	0.76	-	0.13	0.00	142	145	3.61	50	0.18	0.18
2031	19,703	40		91	6.73	2,803	7.26		45.34	9.14	30.3	0.76	-	0.13	0.00	152	145	-6.67	50	-	-
2032	19,646	40		91	6.73	2,803	7.26		45.34	9.14	30.3	0.76	-	0.13	0.00	151	145	-6.23	50	-	-
2033	19,107	24		54	4.04	1,682	4.36		27.21	5.49	18.2	0.45	-	0.13	0.00	147	87	-60.2	50	-	-
2034	18,767	24	169	54	4.04	1,682	4.36		27.21	5.49	18.2	0.45	-	0.13	0.00	145	87	-57.6	50	-	-
2035	20,581	24		54	4.04	1,682	4.36		27.21	5.49	18.2	0.45	-	0.13	0.00	159	87	-71.5	50	-	-
2036	22,056	27		61	4.54	1,892	4.90		30.61	6.17	20.4	0.51	-	0.13	0.00	170	98	-72.0	50	-	-
2037	22,991	27		61	4.54	1,892	4.90		30.61	6.17	20.4	0.51	-	0.13	0.00	177	98	-79.2	50	-	-
2038	24,380	27		61	4.54	1,892	4.90		30.61	6.17	20.4	0.51	-	0.13	0.00	188	98	-89.9	50	-	-
2039	19,901	13	91	30	2.19	911	2.36		14.74	2.97	9.8	0.25	-	0.13	0.00	153	47	-106	50	-	-
2040	7,598	13		30	0.34	143	0.37		2.32	0.47	1.5	0.04	-	0.13	0.00	59	7	-51.1	50	-	-
Total	421,947	-	957	1637	119	49,690	128.74	37.44	803.78	162.06	536.7	13.26	-		0.00	3,253	2,575	-545		2.52	2.52

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Diesel fuel requirements were estimated per methodology described in Chapter 4 using fuel consumption rates provided by the OEM and assumed duty cycles. Required hydrogen was calculated based on the assumption that for every 7.5 to 8 litres of diesel consumed, one kg of hydrogen would be required to do the same work (Fúnez Guerra et al., 2020b and LeBlanc, 2021).
3. It has been assumed that delivery will be completed via specialized 9,000 gallon (or 34,000 litre) tankers with a capacity of 2,400 kg of liquid hydrogen.
4. Consumption of hydrogen by the fuel cells assumed to produce no emissions.
5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act at the time of writing (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
6. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
7. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
8. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
9. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
10. Charge rates presented in the GGPPA (Government of Canada, 2020a) that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year.
11. Charge per tonne of excess CO_2e emissions calculated per note 9.
12. The difference between fuel charges per note 6 and production related charges in note 11 and highlights the savings associated with application of the production related OBPS in lieu of a flat taxation rate on fuel consumed.

Table 66. Yearly breakdown of capital, operating, and carbon costs to operate the CAT 795 fleet using gaseous hydrogen produced on site

Year		Estimated costs for material handling using hydrogen to fuel the CAT 795													Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg)[1]	Number of trucks[1]	Capital costs for CAT 795 (retrofit the first year and fleet replacement every five years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Hydrogen consumption rate per day by the CAT 795 (kg per day)[2]	Number of 10 MW electrolyzers required	Capital cost for electrolyzers (M CAD)	Operating cost for electrolyzers (M CAD)	Electricity consumed by the electrolyzers (GWh)	Capital cost for hydrogen storage and dispensing system (M CAD)	Operating costs for hydrogen storage and distribution system (M CAD)	Electricity consumed by the hydrogen storage and distribution system (GWh)	Electrical costs (M CAD)	CO_2 produced by materials handling system (kt)[3]	Potential fuel charge (CAD/l)[4]	Fuel charge total (CAD)[5]	Annual facility emissions limit prescribed by the OBPS (kt)[6]	Predicted total reported emissions (kt)[7]	Compliance obligations per OBPS (kt)[8]	Charge per tonne CO_2e (CAD/tonne CO_2e)[9]	Excess emission charge (M CAD)[10]	Difference between carbon related charges (M CAD)[11]
2019	16,655	36	156	81.7	16,819	4	55.9	9.61	396	54.5	23.0	27.2	10.6		0.05		128	131	2.31	20	0.05	0.05
2020	16,641	38		86.3	17,754	4		10.1	396		24.3	28.8	10.6		0.08		128	138	9.68	30	0.29	0.29
2021	17,576	38		86.3	17,754	4		10.1	396		24.3	28.8	10.6		0.08		136	138	2.46	40	0.10	0.10
2022	17,746	39		88.5	18,221	5		10.4	495		25.0	29.5	13.1		0.11		137	142	4.78	50	0.24	0.24
2023	17,661	39		88.5	18,221	5		10.4	495		25.0	29.5	13.1		0.11		136	142	5.44	50	0.27	0.27
2024	17,293	39	274	88.5	18,221	5		10.4	495	55.8	25.0	29.5	13.1		0.13		133	142	8.28	50	0.41	0.41
2025	18,172	39		88.5	18,221	5		10.4	495		25.0	29.5	13.1		0.13		140	142	1.50	50	0.08	0.08
2026	17,605	39		88.5	18,221	5		10.4	495		25.0	29.5	13.1		0.13		136	142	5.88	50	0.29	0.29
2027	17,179	39		88.5	17,754	4		10.1	396		24.3	28.8	10.6		0.13		132	138	5.52	50	0.28	0.28
2028	17,491	38		86.3	17,754	4		10.1	396		24.3	28.8	10.6		0.13		135	138	3.12	50	0.16	0.16
2029	17,435	38	267	86.3	17,754	4	55.9	10.1	396		24.3	28.8	10.6		0.13		134	138	3.56	50	0.18	0.18
2030	18,370	40		90.8	18,688	5		10.7	495		25.6	30.3	13.1		0.13		142	145	3.61	50	0.18	0.18
2031	19,703	40		90.8	18,688	5		10.7	495		25.6	30.3	13.1		0.13		152	145	-6.67	50	0	0
2032	19,646	40		90.8	18,688	5		10.7	495		25.6	30.3	13.1		0.13		151	145	-6.23	50	0	0
2033	19,107	24		54.5	11,213	3		6.41	297		15.4	18.2	7.88		0.13		147	87.1	-60.2	50	0	0
2034	18,767	24	169	54.5	11,213	3		6.41	297		15.4	18.2	7.88		0.13		145	87.1	-57.6	50	0	0
2035	20,581	24		54.5	11,213	3		6.41	297		15.4	18.2	7.88		0.13		159	87.1	-71.5	50	0	0
2036	22,056	27		61.3	12,614	3		7.21	297		17.3	20.4	7.94		0.13		170	98.0	-72.0	50	0	0
2037	22,991	27		61.3	12,614	3		7.21	297		17.3	20.4	7.94		0.13		177	98.0	-79.2	50	0	0
2038	24,380	27		61.3	12,614	3		7.21	297		17.3	20.4	7.94		0.13		188	98.0	-89.9	50	0	0
2039	19,901	13	91	29.5	6,074	2	27.9	3.47	198		8.32	9.84	5.20		0.13		153	47.2	-106	50	0	0
2040	7,598	13		29.5	956	1		0.55	99.0		1.31	1.55	2.51		0.13		58.6	7.43	-51.1	50	0	0
Total	421,947	-	957	1,637			139.7	189	8,415	110	454	537	224				3,119	2,575	-545		2.52	2.52

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Diesel fuel requirements were estimated per methodology described in Chapter 4 using fuel consumption rates provided by the OEM and assumed duty cycles. Required hydrogen was calculated based on the assumption that for every 7.5 to 8 litres of diesel consumed, one kg of hydrogen would be required to do the same work (Fúnez Guerra et al., 2020b and LeBlanc, 2021).
3. Consumption of hydrogen by the fuel cells assumed to produce no emissions.
4. Charge rates presented in the Greenhouse Gas Pollution Pricing Act at the time of writing (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
5. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
6. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
7. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
8. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
9. Charge rates presented in the GGPPA (Government of Canada, 2020a) that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year.
10. Charge per tonne of excess CO_2e emissions calculated per note 8.
11. The difference between fuel charges per note 5 and production related charges in note 10 and highlights the savings associated with application of the production related OBPS in lieu of a flat taxation rate on fuel consumed

Table 67. Yearly breakdown of capital, operating, and carbon costs to operate the CAT 795 fleet using a trolley assist system on the main ramp

Year		Estimated fuel consumption for material handling using a trolley assist system on the main ramp											Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg)[1]	Number of trucks[1]	Capital costs for CAT 795 (fleet replacement every six years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Diesel consumed by CAT 795 (M l)[2]	Diesel cost (M CAD)[3]	Number of trips	Capital cost to install the trolley assist system (M CAD)	Operating costs for the trolley assist system (M CAD)	Electricity consumed by the trolley assist system (GWh)	Electrical costs (M CAD)	CO_2 produced by materials handling system (kt)[4]	Potential fuel charge (CAD/l)[5]	Fuel charge total (CAD)[6]	Annual facility emissions limit prescribed by the OBPS (kt)[7]	Predicted total reported emissions (kt)[8]	Compliance obligations per OBPS (kt)[9]	Charge per tonne CO_2e (CAD/tonne CO_2e)[10]	Excess emission charge (M CAD)[11]	Difference between carbon related charges (M CAD)[12]
2019	16,655	36		81.7	12.8	10.3	332,400	40.4	0.31	208	5.19	34.6	0.05	0.69	128	165	36.9	20	0.74	0.05
2020	16,641	38		86.3	13.5	10.8	345,659		0.68	216	5.40	36.5	0.08	1.09	128	175	46.2	30	1.39	0.30
2021	17,576	38		86.3	13.5	10.8	354,489		0.68	221	5.53	36.5	0.08	1.09	136	175	39.0	40	1.56	0.47
2022	17,746	39		88.5	13.9	11.1	351,374		0.68	219	5.48	37.5	0.11	1.49	137	179	42.3	50	2.11	0.62
2023	17,661	39		88.5	13.9	11.1	353,334		0.68	221	5.52	37.5	0.11	1.49	136	179	42.9	50	2.15	0.66
2024	17,293	39	199	88.5	13.9	11.1	345,109		0.68	215	5.39	37.5	0.13	1.86	133	179	45.8	50	2.29	0.43
2025	18,172	39		88.5	9.82	7.86	282,888	7.40	0.83	279	6.97	26.5	0.13	1.32	140	168	28.0	50	1.40	0.08
2026	17,605	39		88.5	9.82	7.86	291,785		0.83	288	7.19	26.5	0.13	1.32	136	168	32.4	50	1.62	0.30
2027	17,179	39		88.5	9.57	7.66	297,944		0.83	294	7.34	25.8	0.13	1.28	132	164	31.4	50	1.57	0.28
2028	17,491	38		86.3	9.57	7.66	298,401		0.83	294	7.35	25.8	0.13	1.28	135	164	29.0	50	1.45	0.16
2029	17,435	38		86.3	9.57	7.66	254,827		0.83	251	6.28	25.8	0.13	1.28	134	164	29.4	50	1.47	0.19
2030	18,370	40	205	90.8	10.1	8.06	268,971		0.83	265	6.63	27.2	0.13	1.35	142	172	30.8	50	1.54	0.19
2031	19,703	40		90.8	10.1	8.06	250,206		0.83	247	6.17	27.2	0.13	1.35	152	172	20.5	50	1.03	-0.32
2032	19,646	40		90.8	10.1	8.06	200,308		0.83	197	4.94	27.2	0.13	1.35	151	172	21.0	50	1.05	-0.30
2033	19,107	24		54.5	6.04	4.84	138,711		0.83	137	3.42	16.3	0.13	0.81	147	103	-43.9	50	0.00	-0.81
2034	18,767	24		54.5	6.04	4.84	135,847		0.92	134	3.35	16.3	0.13	0.81	145	103	-41.2	50	0.00	-0.81
2035	20,581	24		54.5	5.25	4.20	158,050	6.18	0.92	190	4.76	14.2	0.13	0.70	159	101	-57.4	50	0.00	-0.70
2036	22,056	27	138	61.3	5.90	4.72	162,741		0.92	196	4.90	15.9	0.13	0.79	170	114	-56.1	50	0.00	-0.79
2037	22,991	27		61.3	5.90	4.72	124,828		0.92	150	3.76	15.9	0.13	0.79	177	114	-63.3	50	0.00	-0.79
2038	24,380	27		61.3	5.90	4.72	89,707		0.92	108	2.70	15.9	0.13	0.79	188	114	-74.0	50	0.00	-0.79
2039	19,901	13		29.5	2.84	2.27	56,985		0.92	68.7	1.72	7.67	0.13	0.38	153	54.9	-98.6	50	0.00	-0.38
2040	7,598	13		29.5	0.45	0.36	8,967		0.92	10.8	0.27	1.21	0.13	0.06	58.6	8.64	-49.9	50	0.00	-0.06
Total	421,947		542	1,637	198	159	5,103,531	54.0	17.7	4,410	110	536		23.4	3,253				21.4	44.7

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Estimated per methodology described in Chapter 4 using fuel consumption rates provided by the OEM and assumed duty cycles.
3. Cost of fuel assumed to be $0.80/l as presented in the 43-101 report.
4. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO2 (Government of Canada, 2014).
5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act at the time of writing (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
6. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
7. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
8. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
9. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
10. Charge rates presented in the GGPPA that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year (Government of Canada, 2020a).
11. Charge per tonne of excess CO_2e emissions calculated per note 8.
12. The difference between fuel charges per note 5 and production related charges in note 10 and highlights the savings associated with application of the production related OBPS in lieu of a flat taxation rate on fuel consumed

Table 68. Yearly breakdown of capital, operating, and carbon costs to operate the CAT 795 fleet using a trolley assist system through a tunnel in the pit wall

Operating year		Estimated fuel consumption for material handling using a trolley assist system to move the CAT 795										Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg)^{1}	Number of trucks^{1}	Capital costs for CAT 795 (fleet replacement every six years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Diesel consumed by CAT 795 (M l)^{2}	Diesel cost (M CAD)^{3}	Capital cost to install the trolley assist system (M CAD)	Operating costs for the trolley assist system (M CAD)	Electricity consumed by the trolley assist system (GWh)	Electrical costs (M CAD)	CO_2 produced by materials handling system (kt)^{4}	Potential fuel charge (CAD/l)^{5}	Fuel charge total (CAD)^{6}	Annual facility emissions limit prescribed by the OBPS (kt)^{7}	Predicted total reported emissions (kt)^{8}	Compliance obligations per OBPS (kt)^{9}	Charge per tonne CO_2e (CAD/tonne CO_2e)^{10}	Excess emission charge (M CAD)^{11}	Difference between carbon related charges (M CAD)^{12}
2019	16,655	36		81.7	45.4	36.3					123	0.05	2.44	128	253	125	20	2.50	0.06
2020	16,641	38		86.3	47.9	38.3					129	0.08	3.86	128	267	139	30	4.17	0.31
2021	17,576	38		86.3	47.9	38.3					129	0.08	3.86	136	267	132	40	5.28	1.42
2022	17,746	39		88.5	34.3	27.4	45.7	0.08	30.0	0.75	92.6	0.11	3.68	137	234	97.4	50	4.87	1.19
2023	17,661	39		88.5	34.3	27.4		0.34	30.1	0.75	92.6	0.11	3.68	136	234	98.0	50	4.90	1.22
2024	17,293	39	199	88.5	34.3	27.4		0.34	29.4	0.74	92.6	0.13	4.60	133	234	101	50	5.04	0.44
2025	18,172	39		88.5	24.0	19.2		0.34	24.1	0.60	64.8	0.13	3.22	140	206	66.3	50	3.31	0.10
2026	17,605	39		88.5	24.0	19.2		0.34	24.9	0.62	64.8	0.13	3.22	136	206	70.6	50	3.53	0.32
2027	17,179	39		88.5	23.4	18.7		0.34	25.4	0.64	63.1	0.13	3.13	132	201	68.6	50	3.43	0.30
2028	17,491	38		86.3	23.4	18.7		0.34	25.5	0.64	63.1	0.13	3.13	135	201	66.2	50	3.31	0.18
2029	17,435	38		86.3	23.4	18.7		0.34	21.7	0.54	63.1	0.13	3.13	134	201	66.6	50	3.33	0.20
2030	18,370	40	205	90.8	24.6	19.7		0.34	22.9	0.57	66.4	0.13	3.30	142	212	70.0	50	3.50	0.20
2031	19,703	40		90.8	24.6	19.7		0.34	21.3	0.53	66.4	0.13	3.30	152	212	59.7	50	2.99	-0.31
2032	19,646	40		90.8	24.6	19.7		0.34	17.1	0.43	66.4	0.13	3.30	151	212	60.2	50	3.01	-0.29
2033	19,107	24		54.5	14.8	11.8		0.34	11.8	0.30	39.8	0.13	1.98	147	127	-20.3	50	0.00	-1.98
2034	18,767	24		54.5	14.8	11.8		0.34	11.6	0.29	39.8	0.13	1.98	145	127	-17.7	50	0.00	-1.98
2035	20,581	24		54.5	10.7	8.58		0.34	13.5	0.34	29.0	0.13	1.44	159	116	-42.6	50	0.00	-1.44
2036	22,056	27	138	61.3	12.1	9.66		0.34	13.9	0.35	32.6	0.13	1.62	170	131	-39.4	50	0.00	-1.62
2037	22,991	27		61.3	12.1	9.66		0.34	10.7	0.27	32.6	0.13	1.62	177	131	-46.6	50	0.00	-1.62
2038	24,380	27		61.3	12.1	9.66		0.34	7.65	0.19	32.6	0.13	1.62	188	131	-57.3	50	0.00	-1.62
2039	19,901	13		29.5	5.81	4.65		0.34	4.86	0.12	15.7	0.13	0.78	153	62.9	-90.5	50	0.00	-0.78
2040	7,598	13		29.5	0.91	0.73		0.34	0.77	0.02	2.47	0.13	0.12	58.6	9.90	-48.7	50	0.00	-0.12
Total	421,947		542	1,637	519	415	45.7	6.14	347	8.68	1,402		59.0	3,253	3,976	857		53.2	112

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Estimated per methodology described in Chapter 4 using fuel consumption rates provided by the OEM and assumed duty cycles.
3. Cost of fuel assumed to be $0.80/l as presented in the 43-101 report.
4. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO2 (Government of Canada, 2014).
5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act at the time of writing (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
6. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
7. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
8. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
9. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
10. Charge rates presented in the GGPPA (Government of Canada, 2020a) that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year.
11. Charge per tonne of excess CO_2e emissions calculated per note 8.
12. The difference between fuel charges per note 5 and production related charges in note 10 and highlights the savings associated with application of the production related OBPS in lieu of a flat taxation rate on fuel consumed

Table 69. Yearly breakdown of capital, operating, and carbon costs to operate the CAT 795 fleet and an IPCC system along the pit wall

Year												Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg)[1]	Number of trucks[1]	Capital costs for CAT 795 (fleet replacement every six years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Diesel consumed by CAT 795 (M l)[2]	Diesel cost (M CAD)[3]	Capital cost to install the IPCC (M CAD)	Operating costs for the IPCC (M CAD)	Electricity consumed by the IPCC (GWh)	Electrical costs (M CAD)	CO_2 produced by materials handling system (kt)[4]	Potential fuel charge (CAD/l)[5]	Fuel charge total (CAD)[6]	Annual facility emissions limit prescribed by the OBPS (kt)[7]	Predicted total reported emissions (kt)[8]	Compliance obligations per OBPS (kt)[9]	Charge per tonne CO_2e (CAD/tonne CO_2e)[10]	Excess emission charge (M CAD)[11]	Difference between carbon related charges (M CAD)[12]
2019	16,655	36		81.7	45.4	36.3					123	0.05	2.44	128	253	125	20	2.50	0.06
2020	16,641	38		86.3	47.9	38.3					129	0.08	3.86	128	267	139	30	4.17	0.31
2021	17,576	38		86.3	47.9	38.3					129	0.08	3.86	136	267	132	40	5.28	1.42
2022	17,746	5		11.6	6.42	5.14	98.4	56.9	74.9	1.87	17.3	0.11	0.69	137	159	22.1	50	1.11	0.42
2023	17,661	6		13.4	7.47	5.97	2.41	56.9	74.9	1.87	20.2	0.11	0.80	136	162	25.6	50	1.28	0.48
2024	17,293	7	31.6	15.3	8.51	6.81	2.41	56.9	74.9	1.87	23.0	0.13	1.14	133	165	31.3	50	1.56	0.42
2025	18,172	8		17.2	9.56	7.65	2.41	56.9	74.9	1.87	25.8	0.13	1.28	140	167	27.3	50	1.37	0.08
2026	17,605	8		19.1	10.6	8.48	2.41	56.9	74.9	1.87	28.6	0.13	1.42	136	170	34.5	50	1.73	0.30
2027	17,179	9		21.0	11.3	9.08	2.41	56.9	74.9	1.87	30.6	0.13	1.52	132	169	36.2	50	1.81	0.29
2028	17,491	10		22.8	12.7	10.2	2.41	56.9	74.9	1.87	34.3	0.13	1.70	135	172	37.4	50	1.87	0.17
2029	17,435	11		24.7	13.7	11.0	2.41	56.9	74.9	1.87	37.1	0.13	1.84	134	175	40.6	50	2.03	0.19
2030	18,370	12	54.8	26.6	14.8	11.8	2.41	56.9	74.9	1.87	39.9	0.13	1.98	142	185	43.5	50	2.18	0.19
2031	19,703	13		28.5	15.8	12.7	2.41	56.9	74.9	1.87	42.7	0.13	2.12	152	188	36.1	50	1.80	-0.32
2032	19,646	13		30.4	16.9	13.5	2.41	56.9	74.9	1.87	45.6	0.13	2.26	151	191	39.3	50	1.97	-0.30
2033	19,107	14		32.3	17.9	14.3	2.41	56.9	74.9	1.87	48.4	0.13	2.40	147	136	-11.8	50	-	-2.40
2034	18,767	15		34.1	19.0	15.2	2.41	56.9	74.9	1.87	51.2	0.13	2.54	145	138	-6.35	50	-	-2.54
2035	20,581	16		36.0	20.0	16.0	2.41	56.9	74.9	1.87	54.0	0.13	2.68	159	141	-17.5	50	-	-2.68
2036	22,056	17	78.1	37.9	21.1	16.8	2.41	56.9	74.9	1.87	56.9	0.13	2.82	170	155	-15.2	50	-	-2.82
2037	22,991	18		39.8	22.1	17.7	2.41	56.9	74.9	1.87	59.7	0.13	2.96	177	158	-19.6	50	-	-2.96
2038	24,380	18		41.7	23.1	18.5	2.41	56.9	74.9	1.87	62.5	0.13	3.10	188	161	-27.4	50	-	-3.10
2039	19,901	19		43.5	24.2	19.4	2.41	56.9	74.9	1.87	65.3	0.13	3.24	153	113	-40.9	50	-	-3.24
2040	7,598	20		45.4	3.97	3.18	2.41	56.9	74.9	1.87	10.7	0.13	0.53	58.6	18.2	-40.4	50	-	-0.53
Total	421,947		165	796	420	336	142	1,082	1,423	35.6	1,135		47.2	3,253	3,710	591		30.6	77.9

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Estimated per methodology described in Chapter 4 using fuel consumption rates provided by the OEM and assumed duty cycles.
3. Cost of fuel assumed to be $0.80/l as presented in the 43-101 report.
4. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO_2 (Government of Canada, 2014).
5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act at the time of writing (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
6. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
7. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
8. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
9. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
10. Charge rates presented in the GGPPA (Government of Canada, 2020a) that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year.
11. Charge per tonne of excess CO_2e emissions calculated per note 8.
12. The difference between fuel charges per note 5 and production related charges in note 10 and highlights the savings associated with application of the production related OBPS in lieu of a flat taxation rate on fuel consumed

Table 70. Yearly breakdown of capital, operating, and carbon costs to operate the CAT 795 fleet and an IPCC system through a tunnel in the pit wall

Year												Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg)[1]	Number of trucks[1]	Capital costs for CAT 795 (fleet replacement every six years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Diesel consumed by CAT 795 (M l)[2]	Diesel cost (M CAD)[3]	Capital cost to install the IPCC (M CAD)	Operating costs for the IPCC (M CAD)	Electricity consumed by the IPCC (GWh)	Electrical costs (M CAD)	CO_2 produced by materials handling system (kt)[4]	Potential fuel charge (CAD/l)[5]	Fuel charge total (CAD)[6]	Annual facility emissions limit prescribed by the OBPS (kt)[7]	Predicted total reported emissions (kt)[8]	Compliance obligations per OBPS (kt)[9]	Charge per tonne CO_2e (CAD/tonne CO_2e)[10]	Excess emission charge (M CAD)[11]	Difference between carbon related charges (M CAD)[12]
2019	16,655	36		81.7	45.4	36.3					123	0.05	2.44	128	253	125	20	2.50	0.06
2020	16,641	38		86.3	47.9	38.3					129	0.08	3.86	128	267	139	30	4.17	0.31
2021	17,576	38		86.3	47.9	38.3					129	0.08	3.86	136	267	132	40	5.28	1.42
2022	17,746	5		11.6	6.42	5.14	113	58.1	81.3	2.03	17.3	0.11	0.69	137	159	22.1	50	1.11	0.42
2023	17,661	6		13.4	7.47	5.97	2.64	58.1	81.3	2.03	20.2	0.11	0.80	136	162	25.6	50	1.28	0.48
2024	17,293	7	31.6	15.3	8.51	6.81	2.64	58.1	81.3	2.03	23.0	0.13	1.14	133	165	31.3	50	1.56	0.42
2025	18,172	8		17.2	9.56	7.65	2.64	58.1	81.3	2.03	25.8	0.13	1.28	140	167	27.3	50	1.37	0.08
2026	17,605	8		19.1	10.6	8.48	2.64	58.1	81.3	2.03	28.6	0.13	1.42	136	170	34.5	50	1.73	0.30
2027	17,179	9		21.0	11.3	9.08	2.64	58.1	81.3	2.03	30.6	0.13	1.52	132	169	36.2	50	1.81	0.29
2028	17,491	10		22.8	12.7	10.2	2.64	58.1	81.3	2.03	34.3	0.13	1.70	135	172	37.4	50	1.87	0.17
2029	17,435	11		24.7	13.7	11.0	2.64	58.1	81.3	2.03	37.1	0.13	1.84	134	175	40.6	50	2.03	0.19
2030	18,370	12	54.8	26.6	14.8	11.8	2.64	58.1	81.3	2.03	39.9	0.13	1.98	142	185	43.5	50	2.18	0.19
2031	19,703	13		28.5	15.8	12.7	2.64	58.1	81.3	2.03	42.7	0.13	2.12	152	188	36.1	50	1.80	-0.32
2032	19,646	13		30.4	16.9	13.5	2.64	58.1	81.3	2.03	45.6	0.13	2.26	151	191	39.3	50	1.97	-0.30
2033	19,107	14		32.3	17.9	14.3	2.64	58.1	81.3	2.03	48.4	0.13	2.40	147	136	-11.8	50	0.00	-2.40
2034	18,767	15		34.1	19.0	15.2	2.64	58.1	81.3	2.03	51.2	0.13	2.54	145	138	-6.35	50	0.00	-2.54
2035	20,581	16		36.0	20.0	16.0	2.64	58.1	81.3	2.03	54.0	0.13	2.68	159	141	-17.5	50	0.00	-2.68
2036	22,056	17	78.1	37.9	21.1	16.8	2.64	58.1	81.3	2.03	56.9	0.13	2.82	170	155	-15.2	50	0.00	-2.82
2037	22,991	18		39.8	22.1	17.7	2.64	58.1	81.3	2.03	59.7	0.13	2.96	177	158	-19.6	50	0.00	-2.96
2038	24,380	18		41.7	23.1	18.5	2.64	58.1	81.3	2.03	62.5	0.13	3.10	188	161	-27.4	50	0.00	-3.10
2039	19,901	19		43.5	24.2	19.4	2.64	58.1	81.3	2.03	65.3	0.13	3.24	153	113	-40.9	50	0.00	-3.24
2040	7,598	20		45.4	3.97	3.18	2.64	58.1	81.3	2.03	10.7	0.13	0.53	58.6	18.2	-40.4	50	0.00	-0.53
Total	421,947		165	796	420	336	160	1,104	1,545	38.6	1,135		47.2	3,253	3,710	591		30.6	77.9

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
2. Estimated per methodology described in Chapter 4 using fuel consumption rates provided by the OEM and assumed duty cycles.
3. Cost of fuel assumed to be $0.80/l as presented in the 43-101 report.
4. Calculated based on the assumption that combusting 1l of diesel produces 2.7 kg of CO2 (Government of Canada, 2014).
5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act at the time of writing (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
6. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
7. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
8. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
9. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
10. Charge rates presented in the GGPPA (Government of Canada, 2020a) that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year.
11. Charge per tonne of excess CO_2e emissions calculated per note 8.
12. The difference between fuel charges per note 5 and production related charges in note 10 and highlights the savings associated with application of the production related OBPS in lieu of a flat taxation rate on fuel consumed

Table 71. Yearly breakdown of capital, operating, and carbon costs to operate the CAT 795 fleet and an IPCC system through along the main ramp

Year												Greenhouse Gas Pollution Pricing Act							
	Gold produced (kg)[1]	Number of trucks[1]	Capital costs for CAT 795 (fleet replacement every six years) (M CAD)	Operating costs for CAT 795 (labour maintenance and parts) (M CAD)	Diesel consumed by CAT 795 (M l)[2]	Diesel cost (M CAD)[3]	Capital cost to install the IPCC (M CAD)	Operating costs for the IPCC (M CAD)	Electricity consumed by the IPCC (GWh)	Electrical costs (M CAD)	Difference between carbon related charges (M CAD)[12]	Potential fuel charge (CAD/l)[5]	Fuel charge total (CAD)[6]	Annual facility emissions limit prescribed by the OBPS (kt)[7]	Predicted total reported emissions (kt)[8]	Compliance obligations per OBPS (kt)[9]	Charge per tonne CO_2e (CAD/tonne CO_2e)[10]	Excess emission charge (M CAD)[11]	Difference between carbon related charges (M CAD)[12]
2019	16,655	36		81.7	45.4	36.3					0.06	0.05	2.44	128	253	125	20	2.50	0.06
2020	16,641	38		86.3	47.9	38.3					0.31	0.08	3.86	128	267	139	30	4.17	0.31
2021	17,576	38		86.3	47.9	38.3					1.42	0.08	3.86	136	267	132	40	5.28	1.42
2022	17,746	5		11.6	6.42	5.14	158	204	115	2.88	0.42	0.11	0.69	137	159	22.1	50	1.11	0.42
2023	17,661	6		13.4	7.47	5.97	1.98	204	115	2.88	0.48	0.11	0.80	136	162	25.6	50	1.28	0.48
2024	17,293	7	31.6	15.3	8.51	6.81	1.98	204	115	2.88	0.42	0.13	1.14	133	165	31.3	50	1.56	0.42
2025	18,172	8		17.2	9.56	7.65	1.98	204	115	2.88	0.08	0.13	1.28	140	167	27.3	50	1.37	0.08
2026	17,605	8		19.1	10.6	8.48	1.98	204	115	2.88	0.30	0.13	1.42	136	170	34.5	50	1.73	0.30
2027	17,179	9		21.0	11.3	9.08	1.98	204	115	2.88	0.29	0.13	1.52	132	169	36.2	50	1.81	0.29
2028	17,491	10		22.8	12.7	10.2	1.98	204	115	2.88	0.17	0.13	1.70	135	172	37.4	50	1.87	0.17
2029	17,435	11		24.7	13.7	11.0	1.98	204	115	2.88	0.19	0.13	1.84	134	175	40.6	50	2.03	0.19
2030	18,370	12	54.8	26.6	14.8	11.8	1.98	204	115	2.88	0.19	0.13	1.98	142	185	43.5	50	2.18	0.19
2031	19,703	13		28.5	15.8	12.7	1.98	204	115	2.88	-0.32	0.13	2.12	152	188	36.1	50	1.80	-0.32
2032	19,646	13		30.4	16.9	13.5	1.98	204	115	2.88	-0.30	0.13	2.26	151	191	39.3	50	1.97	-0.30
2033	19,107	14		32.3	17.9	14.3	1.98	204	115	2.88	-2.40	0.13	2.40	147	136	-11.8	50	0	-2.40
2034	18,767	15		34.1	19.0	15.2	1.98	204	115	2.88	-2.54	0.13	2.54	145	138	-6.35	50	0	-2.54
2035	20,581	16		36.0	20.0	16.0	1.98	204	115	2.88	-2.68	0.13	2.68	159	141	-17.5	50	0	-2.68
2036	22,056	17	78.1	37.9	21.1	16.8	1.98	204	115	2.88	-2.82	0.13	2.82	170	155	-15.2	50	0	-2.82
2037	22,991	18		39.8	22.1	17.7	1.98	204	115	2.88	-2.96	0.13	2.96	177	158	-19.6	50	0	-2.96
2038	24,380	18		41.7	23.1	18.5	1.98	204	115	2.88	-3.10	0.13	3.10	188	161	-27.4	50	0	-3.10
2039	19,901	19		43.5	24.2	19.4	1.98	204	115	2.88	-3.24	0.13	3.24	153	113	-40.9	50	0	-3.24
2040	7,598	20		45.4	3.97	3.18	1.98	204	115	2.88	-0.53	0.13	0.53	58.6	18.2	-40.4	50	0	-0.53
Total	421,947		165	796	420	336	193	3,878	2,190	54.8	77.9		47.2	3,253	3,710	591		30.6	77.9

1. As detailed in the 43-101 report (Detour Gold Corporation, 2018).
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5. Charge rates presented in the Greenhouse Gas Pollution Pricing Act (Government of Canada, 2020a). It is understood that the Government of Canada has proposed to increase these rates by $15 per tonne of CO_2e starting in 2023 until 2030. For this analysis, only those rates currently outlined in the GGPPA were considered with the 2022 rates applied to the end of mine life as appropriate.
6. Calculated by applying the charge rates per note 5 to the estimated fuel consumption.
7. Determined by applying the OBPS defined in the GGPPA of 7.71 tCO_2e for every kilogram of gold produced (Government of Canada, 2019b). Carbon taxes will be applied to yearly emission in excess of these amounts.
8. Calculated based upon emissions estimated for the CAT 795 in relation to the reported emissions for the site in 2019 (Government of Canada, 2020h). The resulting rate of 48% was applied to the estimated emissions for the CAT 795 between 2020 and 2040.
9. Predicted total reported emissions minus Annual facility emissions limit prescribed by the OBPS; negative values represent an opportunity to sell unused emissions as offset credits.
10. Charge rates presented in the GGPPA (Government of Canada, 2020a) that are applicable for relevant facilities that emit more than 50,000 tCO_2e per year.
11. Charge per tonne of excess CO_2e emissions calculated per note 8.
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