JDP Transportation Solutions

Final Technical Report

Suitability of Small Zero-Emission Equipment for Use in Emergencies

Prepared for:
Serge Nadon
Physical Sciences Specialist
Environment and Climate Change Canada (ECCC)
(819) 938-4517

Prepared by:
Jeff Patten, P. Eng.
JDP Transportation Solutions
507 Fraser Ave. Ottawa, ON
613-596-3165

Project 2022-001

Document #: JDP-TR-2022-001

August 31st, 2022

COMMERCIAL CONFIDENTIAL
UNCLASSIFIED

EXECUTIVE SUMMARY

The Federal government is proposing to introduce zero-emission requirements for consumer market small spark ignition (SSI) engines which could result in a gradual decrease in availability of some new SSI tools. The use of these tools by emergency responders is not targeted by the regulations but could have an unintended consequence of reducing the ease with which they are currently purchased. The government wished to understand to what degree emergency responders are dependent on SSI tools to perform their work and how a shift to zero-emission tools could affect the way in which first responders do their work, and the safety of the individuals and properties being protected by first responders;

To better understand these issues a survey was administered. Thirty-seven individuals responded to the survey. These individuals came from different organizations related to first response representing rural and urban settings as well as several organizations with national coverage. Of the survey respondents, 26 were fire departments, four were search and rescue, one was police, one was towing and recovery, four were parks/wildland and one was a major tool manufacturer. The survey respondents represented communities with populations ranging from over one million to less than 5000.

The results of the survey were:

1. All respondents, except the tool manufacturer, indicated they currently operate at least one gasoline powered tool;

2. The tow and recovery company indicated that most of their tools are pneumatically (air) driven off the vehicle and they have very low reliance on gasoline powered tools;

3. The Canadian Coast Guard uses only two types of gasoline powered tools: dewatering pumps and generators;

4. Despite a reliance on SSI tools and a familiarity due to decades of use, survey respondents mentioned a broad array of challenges using SSI tools in their line of work. These included concerns relating to storage, mixing and transportation of fuels, toxic exhaust emissions, health and safety, maintenance and training requirements;

5. Conversely, many advantages of SSI were listed such as, the standardization of fuels, a lack of tether and good power to weight ratio;

6. 87% of the survey respondents had at least one zero-emission tool that was large enough to have an equivalent SSI counterpart (i.e. tools such as flashlights and cordless drills were not considered large enough);

7. Nearly every respondent already operated small battery electric hand tools, such as cordless drills, reciprocating saws and flashlights;

8. Many challenges were listed with respect to the use of zero-emission tools such as battery charging, run time, capital purchase finances, the proprietary nature of battery packs, charging in cold weather, needing a generator to charge all the batteries, tool power and tethered operation;

9. The following advantages were listed for zero-emission tools: the convenience of grab-and-go push button starting, confined space use, no exhaust fumes, no fuels to mix, reduced long term maintenance;

10. Of the five respondents who did not currently operate larger zero-emission tools, three indicated they would be willing to purchase zero-emission tools in the future. The remaining respondents could not commit, at this time, due to financial restrictions;

11. 100% of all respondents serving urban areas have already purchased at least one zero-emission tool whereas only 40% of respondents serving rural areas had done so. Of those respondents reporting as serving mixed urban and rural areas, 69% had purchased zero-emission tools;

12. Respondents from fire and all-hazard departments in rural areas made much mention of the role water pumps play in first response. Whereas most urban and suburban first responders can rely on hydrants and tanker/pumper trucks to provide water, many rural stations still rely on lakeside water pumps to provide water at a scene. This was listed by many rural stations as an impediment to broader electrification;

13. Wildland, park services and the Heavy Urban Search and Rescue task forces made more mention of the need for SSI tools due to the need for more power, longer bar length on chainsaws and longer runtimes compared to other respondents. They were reluctant to adopt zero-emission as they are rarely near AC power for charging and did not support the notion of carrying generators simply to charge batteries when their existing SSI tools perform the tasks satisfactorily. Search and rescue and wildland/park employees were the least optimistic regarding the adoption of zero-emission tools in the near term;

14. Small rural and northern communities were more likely to mention funding as an impediment to broader adoption of zero-emission tools. This includes not only price of the tools and batteries, but the support equipment such as generators and inverter-equipped trucks needed to charge the tools.

The results of the analysis were:

1. In general, zero-emission saws are lighter and less expensive than the SSI equivalent. However, overall cutting performance may not quite be at par with SSI tools at this point (based on blade size);

2. Hydraulic pumps are already available, and being used, in battery electric and corded form for use with extrication tools. Battery electric hydraulic pumps tended to be quieter, lighter, less expensive and offer similar performance than their SSI counterparts;

3. Exhaust fans are available in SSI, corded and battery electric in positive pressure and negative pressure varieties. Unlike some other tools, the SSI variants of fans were the least expensive compared to battery electric but were also the loudest and heaviest and contribute exhaust emissions in areas where the fan is working to clear smoky air;

4. Scene and tower lighting is also available in SSI, corded and battery electric. Lighting is one of the most obvious candidates for electrification as the lack of motor makes them

silent. Scene lighting in battery electric was found to be less expensive than SSI but not as powerful as SSI models;

5. Zero-emission tool purchase prices including batteries are typically somewhat lower than equivalent SSI, which aids in lowering life cycle costs given how much cheaper it is to recharge a zero-emission tool compared to the cost of premium pump gasoline;

6. Life cycle cost models illustrated the ten year life cycle costs of operating zero-emission chainsaws and rotary saws should be $700 and $500 less expensive, respectively, than similarly sized SSI saws;

7. All zero-emission tools are lighter than SSI counterparts of the same power class;

8. With the exception of rotary saws, all zero-emission tools are quieter than their SSI counterparts, some by a wide margin. Not only will noise levels at a scene be much reduced but long term exposure effects from noise should be reduced;

9. Runtime and charge time for zero-emission tools was very difficult to calculate as factors such as battery health, ambient temperature, battery size, charge type all have a dramatic effect on these features. Tool availabilities were calculated for zero-emission tools to estimate the number of batteries required to match the 90%+ tool availability of SSI at a scene. For some zero-emission tools, a total or five or six battery packs will be required to match the current 85% to 95% availability/runtime of SSI tools;

10. The time to recharge a battery pack was found to be affected by many factors such as: battery size, battery type, charger type, ambient and battery temperatures, battery health and state of charge (SOC);

11. First responders will have to understand (either via research or training) the effect that battery size and type and ambient temperature can have on tool performance and runtime. A conventional charger can take as much as four times longer to charge a battery compared to the newer types of fast-chargers. This could have a dramatic effect on tool availability if a first responder is expecting a fast charger but given a conventional charger instead. Batteries and chargers will have to be managed carefully to ensure the correct equipment is purchased and brought to scenes;

12. The way in which Li-Ion batteries are charged in extreme cold conditions could be a major impediment to adoption in the far north. Most chargers will automatically cease the charging process as soon as battery temperature drops below 0 deg C. First responders will have to develop novel ways to ensure batteries can be charged in warmed vehicles or tents;

13. Zero emission tools were found to be generally less expensive than SSI tools but the price of batteries could affect this in the future, but this cannot be predicted at this time;

14. The proprietary nature of battery packs could be a significant operational issue for first responders. Unlike fuels which can be shared between tools, most battery packs can only be used on one brand of tool. However, some interoperability of batteries has been observed and may evolve in the future;

15. Most battery electric tools have recharge to runtime ratios for their batteries in the range from as low as 2 to 1 to as high as 4 or 5 to 1. This will have to be clearly understood before arriving at a scene as high charge to run ratio devices will have their batteries on the charger for significant amounts of time rather than being used productively in the tool. These ratios will be even higher in cold ambient temperatures and could prevent a tool from achieving a desired recharge to runtime ratio with a reasonable number of back-up batteries;

16. Battery operated generators are on the market but have not been adopted by the industry owing to a lack of power and runtime or the fact that the technology is still too recent. None of the respondents indicated they were using zero-emission generators or zero-emission water pumps suitable for drawing water from lakes and rivers. Zero-emission water pumps and generators will likely not meet the required performance specifications in the next few years;

17. A potential compromise between gasoline and zero-emission tools emerged from the study: many respondents would be willing to adopt zero-emission hand tools, provided they could set up a fossil fuel powered generator to charge all the batteries to overcome the lack of an inverter-equipped vehicle close to the scene. Using portable generators could provide an opportunity to replace many gasoline powered tools with zero-emission tools to reduce the overall CO_2 footprint at a scene, even if the generator were to run continuously. Although somewhat counterintuitive, running an SSI generator for many continuous hours could still reduce emissions at a scene, provided enough SSI tools were replaced with zero-emission tools, be they corded or battery;

18. Emergency vehicles will become much more important in terms of tool charging in the future. Apparatus will need to be equipped with inverters and charging banks to support the potentially dozens of chargers that will be required at a scene;

19. Buying individual zero-emission tools may cost less than individual SSI tools but having to find funding to replace SSI tools that are still in good working order (or to purchase many tools at one time) may be a challenge;

20. The battery in a zero-emission tool begins to lose health/life the first time it is charged/discharged. The way tool manufacturers recommend charging battery packs for optimum life cycle performance conflicts with first response work. First responders will have to use, charge and discharge their tools in ways that maximizes performance at the scene but, potentially, at the detriment of battery health. This may cause first responders to purchase more battery packs than if they diligently followed the manufacturer's recommendations;

21. Nearly all first response organizations are managed and fiscally supported by some form of government (be it municipal, provincial or federal). As such, the policies regarding zero-emission tool adoption (or lack thereof) will often be dictated by the government body, rather than the end-users;

In summary, with the exception of water pumps and generators, the industry is ready to accept most zero-emission tools and there are reasonable work-arounds for many of the real and perceived challenges of migrating to zero-emission tools.

The consulting team identified four distinct issues that could pose a risk to public safety and will need to be very carefully considered by all departments before tools are approved, purchased and used:

a. The current lack of commonality between battery packs;
b. The difficulties charging in cold weather;
c. The current number of charged batteries that would be required to maintain a high tool availability; and
d. The high financial cost of replacing all current tools with zero-emission tools at once.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 ACKNOWLEDGEMENTS

The author would like to thank Tina Saryeddine and the Executive of the Canadian Association of Fire Chiefs (CAFC) for their valuable contributions to this project. The CAFC was very interested in participating in the study and became an early partner in the process. The CAFC agreed to be one of the technical committee members responsible for reviewing the technical report as well as providing general support to the researchers during the data collection phase. Many of the fire fighter survey interviews were coordinated through the CAFC and allowed the author to gain a much more diverse spectrum of participants than if acting alone.

The CAFC sent out email blasts outlining the details of the study and provided valuable input with regards to the distribution of survey participants from many of the provinces that had been difficult to contact by the consultants. Additionally, they provided industry specific details and clarified some terminology that were previously unknown by the author.

The contributions of the CAFC Executive Committee and their members is greatly appreciated and valued by the author.

The town of Meaford, Ontario provided survey responses but also provided detailed additional information to develop a case study in this report relating to battery electric tools.

The Ottawa International Airport Emergency Response Team invited the author to their facility for a guided tour and display of all their vehicles and power tools, in addition to the survey questionnaire session.

The City of Inuvik fire chief provided a virtual video tour of all the vehicles and tools in the station.

Retired Alberta fire commissioner Kevan Jess provided guidance and insight specific to the industry and reviewed the final report to ensure accuracy for industry terms and concepts.

The extra effort extended by these organizations is greatly appreciated.

The following 33 organizations agreed to participate in the study by providing 37 individual survey responses (some organizations felt the experiences of more than one employee could benefit the study). Their contributions are greatly appreciated by the author and Environment and Climate Change Canada:

- Township of Minden Hills, Ontario;
- City of Ottawa, Ontario;
- City of Vancouver, British Columbia;
- City of Red Deer, Alberta;
- Heavy Urban Search and Rescue (HUSAR), Task Force #1;
- HUSAR, Task Force #2;
- Ottawa Metro Towing and Recovery;
- Township of Deer Lake, Newfoundland
- City of Whitehorse, Yukon;
- Township of Lindsay, Ontario
- Township of Gibbons, Alberta;
- City of Brockville, Ontario;

- Township of Severn, Ontario;
- Alberta Fire Commissioner Kevan Jess (retired);
- City of Fredericton, New Brunswick;
- City of Montreal/HUSAR Task Force #6;
- Town of Inuvik, NWT;
- City of Levis, Quebec;
- City of Charlottetown, PEI;
- Paint Lake Provincial Park, MB;
- Meadow Lake, Saskatchewan;
- Parks Canada Wildland Fire Services;
- The Canadian Coast Guard Search and Rescue Group;
- Township of Morden, Manitoba;
- Siksika Nation, Alberta;
- Town of Grimshaw, Alberta;
- Town of Grand Falls Windsor, Newfoundland;
- Rural Municipality of Mountain, Manitoba;
- Lac Saint Anne, Alberta ;
- The Association of Yukon Fire Chiefs;
- The Ottawa International Airport Rescue (YOW-ARFF);
- Major tool manufacturer wishing to remain anonymous; and
- The City of Halifax, NS.

The author would like to thank the contributions of the research assistant, Mr. Alex Maddock who assisted with some of the interviews and performed the research related to equipment and tool specifications used for the Tables in Section 5 of this report. Mr. Maddock’s contributions are greatly appreciated.

2 INTRODUCTION AND BACKGROUND

2.1 Introduction

The emergency services sector relies heavily on many types of tools. Currently, emergency response tools powered by fossil fuels are excluded from emissions standards in Canada and the USA [1]. However, most of the tools available on the market meeting the performance requirements in this sector also comply with the emission standards. The Government of Canada is proposing to introduce zero-emission requirements for consumer market small spark-ignition (SSI) engines [1] which could result in a gradual and steady decrease in the availably of some SSI tools in the new sales market. Although emergency type small spark-ignition engine machines are not targeted by this standard, this could potentially have a secondary effect of making it more difficult for emergency response organizations to purchase SSI engine tools in the future.

There are many factors that must be considered when emissions regulations are created, or amended, since different transportation and stationary equipment sectors may be affected differently because of the proposed changes. The aim of this study is to explore how a reduction in availability of SSI engine tools could affect emergency services, should first responders become more reliant on zero-emission tools. The effect these changes could have on day-to-day operations of emergency services personnel who must purchase, operate, maintain and dispose of these pieces of equipment will also be considered.

Some of the Canada-specific factors relevant to emissions in the on-road, off-road, and emergency sectors have been presented below to provide context to this interim technical report.

2.1.1 Emissions Regulations, General

All internal combustion engines (ICEs) produce emissions via the exhaust system as well as through evaporation of the fuel from the tank and fuel lines. National emission standards specify the maximum level of pollutants allowed in exhaust gases discharged from engines and through evaporation. Tailpipe emission standards were initiated in California in the 1950s to control carbon monoxide (CO), and hydrocarbon (HC) emissions from gasoline engines [2]. Since that time, other pollutants, such as oxides of Nitrogen (NOx) and volatile organic compounds (VOC), have been added to the list of monitored substances [1]. Additionally, the monitoring has been extended to include diesel engines as well as off-road equipment (e.g. marine vessels or mining and agricultural equipment).

Historically, emissions standards in North America tended to be grouped into one of two broad categories: regulated and non-regulated. Non-regulated emissions comprised those emissions, such as CO_2, that were a direct by-product of burning a fossil fuel, that could not be directly reduced through mechanical or chemical means, such as catalyzers, traps or filters. Carbon dioxide is a known greenhouse gas (GHG) and has been linked to global warming, yet it is extremely difficult to reduce CO_2 while continuing to burn fossil fuels [3]. As a result of the direct link between burning fossil fuels and creating CO_2, CO_2 emissions have steadily increased in a period where other emissions have steadily decreased [4].

Conversely, regulated emissions were those emissions, such as CO, NO_x, hydrocarbons (HC), and particulate matter (PM), that were also a by-product of combustion but could be significantly reduced via various strategies such as catalysts, filters and traps, to name a few. A list of some of the regulated emissions traditionally monitored in Canada are shown in Table 1 [5].

Table 1: ICE traditional regulated exhaust pollutants [5]

Pollutant	**Source**	**Environmental and Health Effects**
Hydrocarbons (HC)	Unburned or partially burned fuel	Certain hydrocarbons are known to be carcinogenic or toxic. Reactions in air with other compounds may lead to the formation of ozone.
Carbon Monoxide (CO)	Incomplete combustion	Carbon monoxide can produce severe poisoning and/or death because it binds with hemoglobin in the blood, impairing its ability to transport oxygen.
Nitrogen Oxides (NO_X)	Reactions between oxygen and nitrogen	NO by itself is harmless. However, the oxidization to NO_2 can irritate lung tissue. NO_2 also combines with water to form nitric acid which can damage trees and other plants. Nitrogen oxides have also been categorized as a precursor to smog forming ozone.
Particulate Matter (PM)	Product of combustion predominantly from diesel engines	Scatters light, reducing visibility. Can be ingested into the lungs, which can be harmful to human health. In combination with ozone, is a component of smog.

However, due an increased awareness of the long-term damaging effects of CO_2, Canada has begun regulating CO_2 emissions for some sectors and types of equipment/vehicles, placing more responsibility on manufacturers/users to reduce CO_2, either via fuel consumption reduction or via the use of alternative power sources, such as bio-fuels or electrification. Furthermore, the reductions in air contaminant emissions (i.e. non CO_2 emissions) from transitioning SSI Engines to zero-emission would provide the bulk of the benefits in terms of cleaner air and reduced health impacts to humans in both the near-term and the long-term.

Engines tend to be coarsely grouped into categories such as spark ignition (SI) and compression ignition (CI) and these engines are then further classified for their sector, such as on-road and off-road. To date, the Canadian Federal government has spent significant effort mandating the reduction of tailpipe emissions for nearly all forms of on-road spark and compression ignition engines, resulting in significant reductions in traditional regulated emissions [4]. These reductions have largely been achieved via three-way catalytic converters, selective catalytic reduction (SCR), engine timing, filters and traps as well as fuel consumption reduction strategies such as low rolling resistance tires and reduced aerodynamic drag to name a few. Due to their small size, reductions of air contaminants from SSI engines has been, and continue to be more challenging, since weight and size considerations limit the ability to implement some of the after treatment strategies used for large categories.

Reductions in CO_2 emissions have also been achieved recently for road vehicles, but these reductions have been much less significant than the traditionally regulated emissions, since the only practical way to reduce CO_2 emissions is to burn less fuel or to burn an alternative fuel such as ethanol, or to not burn any fuel at all (i.e. use alternative technology such as electric motors). Due to their mass and volume, devices such as CO_2 scrubbers that reduce CO_2 without first reducing fuel consumption are not practical for passenger vehicles or handheld tools. It is for these reasons that reducing CO_2 emissions has been more challenging than some of the traditionally regulated emissions.

2.1.2 **Specific Challenges of SSI Emissions Regulations**

Traditionally, emissions regulations tended to focus primarily with on-road emissions, given the enormous population of engines in the on-road fleet (currently more than 25 million registered on-road vehicles in Canada according to Statistics Canada) [6] and the extent to which they are used on an annual basis. However, off-road small spark-ignition (SSI) engines, designed to be used for lawn and garden maintenance and other small mobile outdoor power equipment of 19 kW (25.5 HP) or less, also emit both greenhouse gases (GHGs) and the traditionally regulated air pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs) [1]. As with on-road vehicles, these substances are released into the surrounding atmosphere through the combustion and evaporation of fuel and contribute to climate change and air pollution and present health hazards for humans and affect other components of the environment [5] [7] [8] as shown in Table 1. According to Natural Resources Canada, [9] the off-road sector (which includes emergency SSI equipment) was responsible for approximately 8.6 Mt of CO_2e[1] in 2018, representing approximately 1.7% of Canada's total CO_2 output. [9]

Unlike passenger vehicles which must be licensed, SSI equipment is not registered with a provincial authority, therefore exact population and usage information is very difficult to acquire. In addition, fuel consumption data will be highly affected by the method in which equipment are used, and therefore, it is difficult to determine the exact fuel consumption and emission profile for any given piece of off-road SSI equipment. Additionally, the distribution of two stroke vs. four stroke equipment is not always easy to estimate thus making the estimation of emitted HC challenging. These factors, amongst others, contribute to the complexity of assessing environmental impacts that SSIs may have on Canadian air quality. Modelling is used to assist with the estimate of various emissions from SSI. These methods have inherent limitations and approximations but are improving with time and do allow regulators to monitor trends and evaluate the potential effects of these small engines.

As mentioned earlier, it has always been challenging to reduce emissions from small handheld tools since size and weight limitations make it difficult to install catalysts or traps on such devices without affecting the ability of a typical operator to hold, carry and work with it. Additionally, many older and some current handheld SSI engines use two stroke combustion (with associated high levels of HC) and rely on mixed fuel being metered through a carburetor and thus do not lend themselves to electronic fuel injection or other fuel saving devices/techniques that would make the devices too bulky and expensive for home use. The

[1] CO2e is a term for describing different greenhouse gases in a common unit

advantage of a two stroke engine for these applications being the smaller size and weight of the engine compared to a four stroke engine. Now that CO_2 is being considered as one of the pollutant for which emissions may be regulated there is more incentive to reduce CO_2 from all forms of fossil fuel powered devices, even handheld ones that have traditionally been powered by gasoline (four stroke) or a mix of gas and oil (two stroke).

2.1.3 **Small Spark Ignition Engines and Objectives of this Study**

Given that significant reductions in emissions of handheld devices may be impractical, it will be necessary to look for alternative forms of power. Since most SSI engine tools do not travel far from a charging device, the most obvious way to significantly reduce emissions from small spark-ignition engine tools is to replace them with similarly sized zero-emission tools that can be charged or powered on site. These tools are typically corded, powered by rechargeable battery packs, or a power take off (PTO) device that is driven by the clean diesel engine situated on a host vehicle (e.g. a Tier IV compliant fire truck engine that is used to power a generator, an inverter or a power takeoff). However, packaging, weight, size, power, battery charge time and battery reliability in Canada's cold weather have all been considered impediments to mass adoption of battery powered small power equipment. Corded electric devices also provide opportunity to achieve high levels of power output without harmful tailpipe emissions, however, the device must be tethered at all times to a 120/240V power source which can be, at best, aggravating and, at worst, completely impractical for the given emergency situation in which the operator is working (e.g. a forest fire). It is for these reasons that gasoline powered tools have been preferred over other types of tools for several decades. However, recent technology development have greatly improved electric motor power output as well as battery performance, triggering a slow but natural shift of consumer acceptance towards these more environment friendly options.

Another important factor to consider is the fact that small equipment such as lawn mowers and chain saws are used by many sectors such as residential, forestry, agricultural and mining, to name a few, where immediate and prolonged use is important but not necessarily critical to saving human lives. In other words, if a residential or business lawn mower's battery becomes depleted before the task is complete it is not a matter of life-and-death and the user must simply recharge the device before completing the task or replace the battery with a second pack that is, at least, partially charged.

Conversely, the first response/emergency services/rescue sector have unique challenges that are different than many other sectors, most notably the need to save lives and rescue people in a timely manner. Therefore, their equipment is considered amongst the most mission-critical and has not typically been subject to environmental emissions laws, owing to the higher priority of saving lives in an emergency, compared to reducing tailpipe emissions.

The aim of this study is to understand which zero-emission tools are used by first responders and to better understand if some SSI engine tools currently used by emergency and rescue services could be replaced by zero-emission devices. For example, could the typical SSI engine chainsaw (Figure 1) typically stored on an emergency services vehicle be replaced by a zero-emission chain saw and what differences would an operator experience with respect to power, torque, runtime, charge time, maintenance and functionally when compared to a traditional SSI engine chainsaw. Can zero-emission devices provide the same level of performance, power, cold weather use, equipment availability and lifespan for mission critical first response use where timeliness and saving lives are a part of the job?

Figure 1: Example of firefighter chainsaw/vent saw (image courtesy of Tempest.com)

Environment and Climate Change Canada (ECCC) would like to better understand how Canadian municipalities and other emergency/rescue services may be affected if various pieces of SSI engine equipment were gradually replaced by zero-emission equipment in keeping with upcoming emissions regulations. Would they gradually transition some, or all, of their tools to zero-emission or would they make use of regulatory exclusions to continue using SSI engine tools?

2.1.4 **Definition of Zero-emission**

For the purposes of this study the term 'zero-emission' refers to a product that does not itself produce emissions at its point of use. Many zero-emission tools can be charged from, or plugged into, a fossil fuel powered generator or an AC outlet being fed from a fossil fuel powered electricity generation plant. However, these are all still considered zero-emission since the tool itself is not producing emissions from an exhaust system/tailpipe, nor evaporative emissions from the fuel tank and fuel lines to power the engine, even if a generator is positioned close by.

2.1.5 **Emission Standards Exemptions**

A specific exclusion exists in the Canadian SSI Engine Emission Regulations for engines used in emergency and search and rescue. This exclusion is the same as the US EPA's rule for SSI engines as the two sets of regulations are aligned.

The California Air Resources Board (CARB) does not have the authority to regulate these machines nor agriculture and construction engines and therefore these machines are not subject to the more stringent emission standards implemented in California and not subject to the zero-emission standards that will start in California with the 2024 model year engines.

In December 2021, CARB approved updates to their Small Off-Road Engines (SORE) regulations to increase the stringency of air pollutant emissions standards. The updated regulations introduce zero-emission standards for all SORE, except generators and large pressure washers, for model year 2024 and later [12]. Zero-emission standards for large pressure washers take effect in model year 2028. The exhaust and evaporative emission standards for generators will become more stringent over model years 2024-2027, and by model year 2032, all new generators will need to meet zero-emission standards. Once implemented these standards will be the most stringent in North America. The machines listed in this section are not regulated by California's SORE regulations, and therefore not subject to zero-emission standards, because they are primarily used in agriculture or construction and the US Clean Air Act does not provide California with the authorities to regulate them.

Under the US Clean Air Act [1] handheld tools and tools with engines less than 25 hp are not considered to be construction and/or farming equipment. However, there are some pieces of equipment (25 hp and under) considered to be used in the agriculture, forestry and construction sectors that are known as "pre-empt" engines [11] [12] [13] because they still play a vital role in those industries. Since the California Air Resources Board (CARB) does not have the authority to regulate this equipment it will not be subject to zero-emission standards in California. Canada intends to continue excluding the types of tools used by the emergency services sector. The tools relevant to the emergency services sector are shown below. These tools will be analysed individually in subsequent sections of this report to better understand the role they play and the possible need for exemption in emissions regulations. However, it is not the intention of this report to influence how these devices become regulated. Rather, it is meant to inform and educate in terms of how the first response sector uses the various tools found in the list below.

The following is a list of tools exempt [11] [13] from California's zero-emission standard relevant to emergency services in Canada and studied in this report:

1. Chainsaws, 45 cc and above;
2. Drills;
3. Jackhammer;
4. Power pack: hydraulic;
5. Pumps, 40 cc and above;
6. Saws: concrete, masonry, cutoff;
7. Compressors; and
8. Light towers.

3 METHODOLOGY

The methodology used by the research team throughout the various phases of the project was as follows:

3.1 Task 0 Scope Definition: Candidates List

To gain insight into the experiences of how first responders acquire, maintain and use their tools, it was deemed necessary to contact current, and recently retired, emergency services personnel and administer a survey with questions relating to their opinions and experiences using gasoline and zero-emission tools.

The following emergency response sectors were initially considered as types of organizations that could be useful for the study:

1. Municipal Fire Departments;
2. Ambulance/Emergency Medical Service (EMS)/Paramedics;
3. Police /law enforcement;
4. Towing and recovery;
5. Snow removal;
6. Medivac helicopters (owned by municipalities not privately owned);
7. Disaster remediation;
8. Federal Search and Rescue;
9. Forest fire brigades; and
10. Park Rangers.

It was assumed that much of the equipment used by these sectors is owned by municipal governments, however, equipment that is owned by provincial and federal governments as well as private industry were also considered, in consultation with ECCC. Snowplows, ambulances and Medivac helicopters were removed from the list early-on in the project, leaving a maximum of seven response sectors to be studied.

Given the main propulsion engines of the emergency vehicles are not being studied as part of this project, it was assumed the following pieces of equipment were considered in-scope as part of the inventory to be studied as they all would be powered by a spark ignition engine less than 19 kW (25.5 hp) in size and independent of the vehicle on which they are stored or mounted:

1. Hydraulic Pumps;
2. Generators;
3. Compressors;
4. Water Pumps;
5. Chainsaws;
6. Concrete cutters;
7. Rotary cutters/K12;
8. Weed/grass trimmers;
9. Hydraulic Extrication/Rescue Tools (e.g. spreaders, cutters, etc).
10. Exhaust fans;
11. Scene/Tower lighting;
12. Jackhammers; and
13. Augers/Ice Cutters.

Very early in the process, the consultants contacted the Canadian Association of Fire Chiefs (CAFC) to create a diverse and representative list of candidates from the fire fighter sector who would be willing to participate in the study. The list of initially proposed survey candidates is shown in Section 3.2.1 as Table 3 and the list of actual participants is shown in Section 4 as Table 5.

3.2 Task 1 – Contacting Emergency Response Organizations

One of the first stages of the project was to develop a survey questionnaire that would be administered to various first responders. The results of the survey were then combined with the consultant's independent research to provide ECCC with as complete information and data as possible. The survey was drafted by the consultant team and subsequently reviewed, revised and approved by ECCC in late January 2022. The approved survey questions are shown in Table 2.

Table 2: Approved Survey Questionnaire

#	Question
1-1	Respondent Name
1-2	Email Address/Phone Number
1-3	Date and Time of Interview
2-1	What is the name of your organization?
2-2	What is your position within the organization?
2-3	What is the nature of your organization (e.g. fire, all hazards, EMS, maritime Search and Rescue (SAR)?
2-4	Do you respond to emergencies in primarily urban or rural settings?
2-5	Roughly how many citizens reside in your area of coverage?
2-6	How many stations/buildings do you manage or represent?
2-7	How many personnel/staff/employees are in your department/station?
2-8	What is the percentage breakdown between career staff and volunteer staff?
2-9	What types of emergency vehicles do you operate (e.g. fire engine, fire truck, pumper, aerial, ambulance, tactical vehicle, marine vessel, ATV, etc)
2-10	How many emergency vehicles do you currently own, manage or operate within the fleet?
3-1	Do you own/operate gasoline powered tools with engines less than 19 kW (25.5 hp) to be used on emergency scenes? (i.e. tools not powered by the emergency vehicle itself, for example: chain saws, cut off saws, generators). If no, proceed to Table 4. If yes, proceed to Q3-2.
3-2	If yes to Q 3-1, can you list the gasoline tools that that you or your organization manage? (Note: Must document details in Table 6)
3-3	In a typical/average month how often do you use gasoline power tools at an emergency scene?
3-4	In a typical/average month, how often do you start your gasoline powered tools at your facility to ensure they will work correctly at an emergency scene? Do you have a maintenance regime?
3-5	What are the biggest challenges or concerns with your gasoline powered tools? Please list as many as relevant: technical, financial, maintenance or logistical.
3-1	Do you own/operate gasoline powered tools with engines less than 19 kW (25.5 hp) to be used on emergency scenes? (i.e. tools not powered by the emergency vehicle itself, for example: chain saws, cut off saws, generators). If no, proceed to Table 4. If yes, proceed to

	Q3-2.
3-2	If yes to Q 3-1, can you list the gasoline tools that that you or your organization manage? (Note: please document details in Table 6)
3-3	In a typical/average week how often do you use gasoline power tools at an emergency scene?
3-4	In a typical/average week, how often do you start your gasoline powered tools at your facility to ensure they will work correctly at an emergency scene? Do you have a maintenance regime?
3-5	What are the biggest challenges or concerns with your gasoline powered tools? Please list as many as relevant: technical, financial, maintenance or logistical issues relating specifically to gasoline powered tools.
4-1	Do you currently operate any tools that are zero-emission (i.e. powered 100% by non-fossil fuels, battery or corded electric, fuel cell or other)?
4-2	If yes to Question Q4-1, can you list them. Enter details in Table 6.
4-3	If yes to Q4-1: what are the biggest challenges with your zero-emission tools? Lack of finances/resources, lack of confidence in the technology etc?
4-4	If yes to Q4-1: what have been the biggest advantages of using zero-emission tools thus far? Financial, convenience, lack of emissions, maintenance etc. List as many as relevant.
4-5	If no to Question Q4-1, have you, or would you in the future consider including zero-emission power tools in your emergency equipment?
4-6	If no to Question Q4-1, what has been the reason for not adopting some zero-emission tools? What are your concerns or impediments?
4-7	If no to question Q4-1, has your organization performed any field tests/trials zero-emission power tools?
4-8	If yes to Q4-7 when was the most recent trial/field test?
4-9	If yes to Q4-7, what type of equipment was tested?
4-10	If yes to Q4-7, what were your impressions of the equipment. What were your areas of confidence and what were the areas of concern?
4-11	If you had/have battery powered tools with sufficient number of battery packs, could you re-charge on scene with existing equipment/personnel? Would you need to designate someone whose sole duty was to charge equipment? Would you have to hire someone new?
5-1	Do you have any questions for the consultant team or ECCC?
5-2	Do you have anything else you'd like to add at this time? Do you have any comments you'd like us to pass along to the Federal government with respect this project?
5-3	Do you know of someone else who would be interested in helping us with this survey? Could you provide us their contact info.

Once the survey questions had been selected and approved, the consultant team, ECCC and the CAFC collaborated to produce an initial list of survey candidates (Table 3). It was important to suggest a list of candidates providing a reasonable level of diversity across Canada. This diversity is discussed in the following Section.

3.2.1 Survey Demographics

For the results of this survey to be useful it was deemed important to span various levels of government as well as multiple geographic, climatic and economic locations. Additionally, it was important to survey organizations from as many provinces and territories as possible to ensure any specific rules, or exclusions, that may apply only in some parts of the country were captured.

It was also deemed important to interview some of the product manufacturers to understand any existing limitations as well as forecasted near-term and mid-term innovations. Additionally, this provided an opportunity to discuss some of the opinion-based and contradictory answers given by the survey respondents to ensure the opinions of the users are tempered with the facts known by the organizations who design and manufacture the products. The approved preliminary candidate list is shown in Table 3, however, the final list of survey candidates differed greatly from that shown in Table 3 due mainly to willingness and availability to respond to the questionnaire in the timeframe allocated for the project as well as new potential sources of information being identified as the project unfolded.

The consultant team was not able to select a diverse sample of respondents in terms of age, gender, education, career experience or training. The respondents tended to be the fire chief or other high ranking official in whatever organization that agreed to participate in the study. Several respondents indicated that, in their opinion, the survey responses may be skewed towards an older generation of thinking since nearly all the respondents had worked with SSI for many years and that younger, less experienced, first responders might be more receptive to zero-emission tools. However, this type of human factors analysis was not part of the scope of this project and would have to be studied in a further phase of this work, if needed.

Table 3: Approved Preliminary List of Survey Respondents

#	Organization	Comment
1	Town of Minden, ON	Cottage Country in Ontario
2	City of Ottawa, ON	Very large geographic coverage. Urban and Rural
3	City of Vancouver, BC	Large urban and coastal setting
4	City of Red Deer, AB (Chief)	Urban setting in Western Canada. Chief perspective (see #7)
5	HUSAR #2 Calgary, AB	Heavy Search and Rescue for disaster relief
6	HUSAR #1 Vancouver, BC	Heavy Search and Rescue for disaster relief
7	City of Red Deer, AB (Local)	Perspective from maintainer/operator
8	Ottawa Metro Towing	Towing and Recovery Company in large urban setting
9	Deer Lake, NF	Rural setting in salt water environment
10	City of Whitehorse, YK	Rural and urban setting in the far north
11	City of Meaford, ON	Rural and urban setting in Ontario
12	Town of Lindsay, ON	Cottage Country in Ontario. All hazards
13	City of Gibbons, AB	Rural Alberta town
14	Canadian Towing Services Ottawa	Towing and Recovery
15	City of Charlottetown, PEI	Urban East Coast
16	City of Cold Lake AB	Urban setting in northern Alberta
17	City of Brockville, ON	Mid size town with cold and humid air.
18	City of Iqaluit, NU	Rural and Urban Northern Town
20	City of Maple Ridge, BC	Urban and rural BC
21	City of Moncton, NB	Urban East Coast
22	City of Montreal, PQ	Large Urban City
23	City of Ottawa Police	Heavy SWAT/Disaster vehicles

24	City of Regina, SK	Prairie urban and rural
25	City of St Johns, NF	Urban setting in salt water environment
26	City of Victoria, BC	Urban city in BC
27	City of Winnipeg, MB	Urban city in Central Canada
28	City of Yellowknife, NWT	Rural and Urban Northern Town
29	City of Yorkton, SK	Urban and Rural Saskatchewan
30	HUSAR #3, Toronto	Heavy Search and Rescue for disaster relief, Ontario Division
31	HUSAR #4, Manitoba	Heavy Search and Rescue for disaster relief, Manitoba Division
32	HUSAR #5, Halifax	Heavy Search and Rescue for disaster relief, East Coast Division
33	HUSAR #6, Montreal	Heavy Search and Rescue for disaster relief, Quebec Division
34	Makita Power Tools	Major manufacturer of power tools
35	Ontario Provincial Police (OPP)	SWAT vehicle, search and rescue vehicles and boats
36	Parks Canada	Forest services
37	Royal Canadian Mounted Police	SWAT vehicle, search and rescue vehicles and boats
38	Stihl Power Tools	Major manufacturer of power tools
39	City of Gatineau, PQ	Major urban Quebec city
40	Town of Dawson, YK	Remote northern town
41	City of Levis, PQ	Urban Quebec city
42	Town of Gracefield, PQ	Small cottage community in Quebec
43	City of Quebec City, PQ	Major urban Quebec city
44	Town of Inuvik, NWT	Remote northern town
45	Town of McNab/Braeside, ON	Rural Ontario
46	Town of St. Lazare, MB	Rural Manitoba
47	Town of Truro, NS	Rural town in NS
48	Canadian Coast Guard, East Coast	Search and rescue in oceans
49	Green For Life Environmental	Environmental Disaster Response/Remediation Company
49	Canadian Coast Guard, West Coast	Search and rescue in oceans
50	Laforge Environment	Environmental Disaster Response/Remediation Company

3.2.2 Conducting and Administering the Survey

The survey was conducted as follows:

1. A candidate list of respondents was created (Table 3). It was initially expected the list of candidates for this project would be 50 unique respondents. There was an initial influx of organizations willing to participate in the study. However, by May 2022 it was becoming more challenging to locate organizations willing to participate in the 20 minute survey. Ultimately, a total of 37 interviews were conducted across 34 unique organizations;
2. First contact was made with each respondent and a mutually agreeable date and time to conduct the interview was determined;
3. The format of the interview was agreed upon: MS Teams, Zoom, or phone call were the preferred method. One interview, at the Ottawa International Airport, was conducted in person;
4. One respondent indicated they were not available during business hours and completed the questionnaire via email;
5. The JDP team ensured that the respondents understood the nature of the work and how their answers may be used by ECCC;
6. All the questions were asked in order, one at a time;
7. The respondents’ answers were entered into a unique MS Word table;
8. The JDP team ensured that all the answers were completed to the best of the respondents’ capabilities;

9. The interviews ended once both parties were satisfied with the process and once it was clear the respondent had no further questions or comments about the process or how their information will be used. Most of the interviews took less than 30 minutes to complete;
10. Follow-up communications were sent to non-responsive organizations until an interview time had been agreed upon, or when it became clear the organization was not interested in participating in the survey; and
11. Follow-up emails were sent if detailed tool information was needed or if any of the answers were deemed confusing or potentially misleading.

3.2.3 **Analysing the Survey Results**

To ensure an unbiased analysis, none of the individual responses were combined or aggregated until all the survey responses had been saved onto unique response sheets. The use of MS Word for initial data entry was the preferred approach as it contains a reliable spell checker that was used to sanitize the information as it was being quickly written down during the interview. Once all the information had been collected and sanitized, it was copied into an aggregator spreadsheet so that data could be sorted and filtered in as many ways, as necessary, to fully understand the nature of the responses and develop trends and statistical results (See Section 4).

Once all the information had been aggregated into the spreadsheet it was possible to query the data and sort and filter it in any way to provide useful and relevant quantitative information to the study. Where possible, statistical functions such as mean, median, mode, maxima, minima and standard deviation were used to analyse the data set and produce meaningful tables of results. Where possible, mean and standard deviation were combined to determine what data sets were considered statistically significant compared to data that are more random and lacking in correlation.

4 SURVEY RESULTS

The survey was divided into four sections to organize the questions and concepts into logical categories. The results of each question, where relevant, have been presented in the sections below. Statistical results for each of the quantifiable answers have been presented. Trends, experiences, opinions and qualitative analysis have also been presented for the non-mathematical answers (e.g. in the opinion of four people, tool XYZ was felt to be more effective) but opinions have been tempered, with facts, where required.

It was important to receive responses from not only a broad array of first response organizations, but also a diverse cross section of provinces, climatic conditions as well as urban and rural settings. Table 4 illustrates the respondent diversity with respect to location and setting for each of the organizations who agreed to participate in the survey. Table 5 shows the final list of all cities/towns/organizations who agreed to participate in the study.

Table 4: Regional Diversity of Respondents

Region	Rural	Urban	Total
Newfoundland	2	0	2
New Brunswick	0	1	1
PEI	1	0	1
Nova Scotia	0	1	1
Quebec	0	1	1
Ontario	3	4	7
Manitoba	1	1	2
Saskatchewan	1	0	1
Alberta	2	3	5
BC	0	1	1
Yukon	1	1	2
NWT	0	1	1
Nunavut	0	0	0
Total Fire/All Hazards	**11**	**14**	**25**
Federal Search and Rescue	0	4	4
Provincial Fire Marshal	0	1	1
Towing and Recovery	0	1	1
Tool Manufacturers	0	1	1
Medivac	0	0	0
Police/SWAT	0	1	1
Airport/ARFF	0	1	1
Disaster Remediation	0	0	0
Parks/Wildland	3	0	3
Total Non Fire	**3**	**9**	**12**
Grand Total	**14**	**23**	**37**

Table 5: List of Survey Respondents

	Organization/Jurisdiction	Type of Organization
1	Town of Minden Hills, ON	Fire Department
2	City of Ottawa, ON	Fire Department
3	City of Vancouver, BC	Fire Department
4	City of Red Deer, AB (Chief)	Fire Department
5	HUSAR TF #2 – Calgary	Heavy Search and Rescue
6	HUSAR TF #1 – Vancouver	Heavy Search and Rescue
7	City of Red Deer, AB (Training)	Fire Department
8	Ottawa Metro Towing, Ottawa, ON	Towing and Recovery
9	Town of Deer Lake, NF	Fire Department
10	City of Whitehorse, YK	Fire Department
11	Town of Meaford, ON	Fire Department
12	Town of Lindsay, ON	Fire Department
13	Town of Gibbons, AB	Fire Department
14	City of Brockville, ON	Fire Department
15	Town of Severn, ON	Fire Department
16	Province of Alberta	Provincial Fire Marshall (retired)
17	City of Fredericton, NB	Fire Department
18	HUSAR TF #6 – Montreal	Heavy Search and Rescue
19	City of Inuvik, NWT	Fire Department
20	City of Levis, PQ	Fire Department
21	City of Charlottetown, PEI	Fire Department
22	Paint Lake Provincial Park (#1), MB	Park/Wildland Fire
23	Town of Meadow Lake, SK	Fire Department
24	Parks Canada Wildland Services	Park/Wildland Fire
25	Canadian Coast Guard SAR	Federal Search and Rescue
26	Town of Morden, MB	Fire Department
27	Siksika Nation, AB	Fire Department
28	Town of Grimshaw, AB	Fire Department
29	Town of Grand Falls Windsor, NF	Fire Department
30	Paint Lake Provincial Park (#2), MB	Fire Department
31	Rural Municipality of Mountain, MB	Fire Department
32	Lac Ste. Anne, AB	Fire Department
33	Golden Horn, YK	Fire Department
34	Ottawa Police Department	Police
35	Anonymous Tool Manufacturer	Major tool manufacturer
36	Ottawa Airport ARFF	Airport Rescue (ARFF)
37	City of Halifax, NS	Fire Department

According to the National Fire Protection Association's (NFPA) Fire Profile 2018 report [14] there were approximately 3 672 fire departments in Canada in 2016. It is not expected that this number would have changed significantly since that time. Twenty five unique fire departments were interviewed as part of this study, representing 0.68% of total departments in Canada.

For ease of review and analysis, the results of each question have been presented separately in this Section.

4.1 Questions 1-1 through 1-3 and 2-1 to 2-2

Questions 1-1 through 1-3 and 2-2 dealt with tombstone data regarding the survey respondent, the date of the survey and the city/town/organization being represented. The individual responses to these questions are not relevant to the conclusions therefore they have not been presented here. However, they will be delivered separately to ECCC for their archives and possible future work.

4.2 Question 2-3

Question 2-3 asked respondents to describe the nature of their organization. The purpose of this question was to make relationships between tool specific questions, to group those answers with the various types of organizations taking place in the survey. The results of this question are shown in Table 6.

Table 6: Responses to Question 2-3

Type of Service	Number of Respondents	Percent of Total
All Hazards*	22	59%
Fire Department	4	11%
Forestry/Parks/Wildland	3	11%
Search and Rescue	3	8%
Police	1	3%
Marine/Coast Guard	1	3%
Towing and Recovery	1	3%
Equipment Manufacturer	1	3%
Airport Rescue (ARFF)	1	3%
Ambulance/Paramedic/EMS	0	0%
Environmental Remediation	0	0%
Total	37	100%

** For the purposes of this study, 'all hazards' refers to an organization responding to, at a minimum, emergencies relating to fire, rescue, extrication and medical but can also include other emergencies as needed.*

Of the 37 respondents, 70% were either fire departments or all-hazard departments. Of the 26 respondents who were representing what would typically be thought of as a fire department that responds to structural building fires, 22 identified as also responding to one, or more, of the following types of emergencies thus making them an 'all hazards' or 'multi hazards' organization:

- Wildland/grass fires;
- Vehicle accidents/extrication;
- Medical/EMS;

- Water and ice rescue;
- Confined space rescue; and
- Hazardous materials (Hazmat).

4.3 Question 2-4

Question 2-4 asked if respondents provided a service primarily in a rural or urban setting. The purpose of this question was to understand if there was a possible correlation between differences in tool purchasing and tool-use for rural and urban locations. The results of this question are shown in Table 7 with more complex analysis in follow on sections. Some respondents (e.g. the Canadian Coast Guard and tool manufacturers) were excluded from this table as they serve the entire nation rather than one specific area.

Table 7: Responses to Question 2-4

Setting	Number of Respondents	Percent of Total
Mix of rural and urban	13	35%
Rural	10	27%
Urban	9	24%
Not relevant/National/Marine	5	14%
Total	37	100%

Of all 37 respondents, 35% identified as being a mix of rural and urban setting, 27% identified as being strictly rural whereas 24% identified as servicing strictly urban. Fourteen percent of the respondents represented organizations where the definition of rural or urban was not relevant or meaningful.

This will have relevance to some of the later analysis where correlations are made between station location and tool use/preference.

4.4 Question 2-5

Question 2-5 asked roughly how many citizens reside in the area of coverage for that particular organization. As with urban and rural settings, an attempt was made to determine if zero-emission tools are more likely to be found by organizations that serve larger rather than smaller populations. The results of this question are shown in Table 8.

Table 8: Responses to Question 2-5

Population Size (# residents)	Number of Respondents	Percent of Total
More than 1 000 000*	7	19%
500 000 to 1 000 000	5	14%
250 000 to 500 000	2	5%
100 000 to 250 000	2	5%
50 000 to 100 000	2	5%
10 000 to 50 000	11	30%
Less than 10 000	8	22%
	37	100%

*Includes three respondents with national coverage area and a nationwide manufacturer

Of the seven organizations serving a population greater than one million residents, five were organizations serving an entire province or the entire nation (e.g. the Canadian Coast guard and the HUSAR groups who, despite having provincial home bases, can be called upon to respond to emergencies in any province or country, if needed). If these more global organizations are ignored, the mean population size was found to be 199,710, the largest response was the City of Ottawa which declared a coverage population of over 1,000,000[2] residents and the smallest value was 3,200 in the northern community of Inuvik, NWT.

4.5 Question 2-6

Question 2-6 asked respondents to indicate how many buildings or stations their department operated. The results of this question are shown in Table 9:

Table 9: Responses to Question 2-6

Number of Stations (#)	Number of Respondents	Percent of Total
More than 20	2	5%
15 to 20	1	3%
10 to 15	0	0%
5 to 10	5	14%
2 to 4	10	27%
One (1)	17	46%
Not applicable	2	5%
Total	37	100%

The largest number of stations was found to be the City of Ottawa with 47 while many rural communities had only one station. The mean number of stations was 5.4. There was some correlation between the number of residents in any given community and the number of stations being reported. For urban areas this was roughly one station for every 20,000 to 30,000 residents whereas this value was between 3000 and 7000 residents per station in rural areas. This stands to reason since many communities have less than 3000 residents but still require one fire station. This will be useful for understanding how many tools would be required to outfit all the stations in any given community size.

[2] The City of Ottawa is considered a composite station with urban, suburban and rural stations, with a mixture of career, on-call and volunteer fire fighters.

4.6 Question 2-7

Question 2-7 asked respondents to indicate how many personnel/staff reported into the department/station. The results of this question are shown in Table 10:

Table 10: Responses to Question 2-7

Number of Staff (#)	Number of Respondents	Percent of Total
0 to 25	5	14%
25 to 50	14	38%
50 to 100	2	5%
100 to 200	6	16%
200 to 500	4	11%
More than 500	2	5%
Not applicable	4	11%
Total	37	100%

There was a wide variation in the number of personnel associated with each organization. The lowest number was 15 in the town of Grimshaw, Alberta and the highest was 1,500 personnel at the City of Ottawa. The total number of personnel associated with all the fire departments surveyed for this project was approximately 4,782 staff. The distribution of career versus volunteer staff is discussed in the next section.

4.7 Question 2-8

Question 2-8 asked respondents to indicate, of the staff discussed in Question 2-7, the percentage breakdown between salaried career staff versus volunteer staff. For the purposes of this study, career staff represent those staff receiving a living salary to perform their emergency services duties whereas volunteer staff are those personnel who do not receive a living salary or receive 'on call' payment for their time at a scene or do not receive any payment at all. The results of this question are shown in Table 11:

Table 11: Responses to Question 2-8

Percentage of Career Staff (%)	Number of Respondents	Percent of Total
100%	16	43%
80 to 99%	0	0%
60 to 79%	3	8%
40 to 59%	1	3%
20 to 39%	0	0%
1 to 19%	9	24%
None (0%)	6	16%
Not applicable	2	5%
Total	37	100%

*It was not relevant for two respondents to answer this question

Of the 37 responses, more than 43% of the stations reported having a staff that was 100% career, or paid employees making a living salary. Conversely, six stations reported having 100% volunteer staff. These stations tended to be small rural departments with very small populations of residents in their area of coverage. Many stations reported having one paid chief with all the other staff being volunteer or “paid on call”. The national distribution of career versus volunteer fire fighters [14] is shown in Table 12 and illustrates a fairly large discrepancy between the national data and the survey respondents of this project/report, highlighting an over-representation of urban versus rural departments, when compared to the national data. As a result, extra care was taken to analyse the information provided by small rural departments to ensure any potential rural-specific issues were properly addressed.

Table 12: National Statistics for Career and Volunteer Fire Fighters [14]

Career at Station	Amount	Percent of Total
100% Career	66	2%
Mostly Career	44	1%
Mostly Volunteer	501	14%
100% Volunteer	3061	83%
Total	3672	100%

The results of this question indicate that many first responders are not employees of the organisation providing them with the tools being analysed in this report but rather, are volunteers. This could impact their ability to request funding for new tools. The financial challenges faced by many of the respondents have been discussed in subsequent sections of this report.

4.8 Question 2-9

Question 2-9 asked respondents to indicate what types of emergency vehicles they operated. The results of this question are shown in Table 13. Note, the total number of vehicles in the fleet was posed in Question 2-10.

Table 13: Responses to Question 2-9: What Types of Vehicles do you Operate?

Vehicle Type/Class*	Number of Respondents	Percent of Total
Rescue Trucks	24	64%
Pickup Trucks	21	57%
Pumpers	16	43%
Engines	14	38%
Boats/Vessels/Inflatables/Zodiac	16	32%
Tankers	12	32%
Platforms/Aerials	10	27%
Trucks	9	24%
ATV	9	24%
UTV	9	24%
Tenders	6	16%
Ski Doos	6	16%
Wildland Brush Fire Trucks	5	14%
Stick Ladders	5	14%
Semi Trailers/Dry van cargo trailers	4	11%

Medic/EMS	4	11%
Hazmat	3	8%
Quints	2	5%
Foamers	1	3%
Towers	1	3%
Airport Rescue (ARFF)	1	3%
Total	37	100.0%

This question, although not directly related to tools and emissions, was posed to understand the various ways in which tools, fuels and batteries are stored and transported to an emergency scene and the types of vehicles that would be expected to store, and possibly charge, all the tools and accessories required to operate zero-emission equipment.

There was a wide variety of vehicles included in the responses including many forms of heavy apparatus such as pumpers, ladders, tenders, aerials, buckets, platforms, quints and support equipment such as pickup trucks, SUVs, light and heavy rescue trucks. Some of the less common equipment included Utility Terrain Vehicles (UTV), All Terrain Vehicles (ATV), skidoos, Zodiacs and EMS vehicles. The HUSAR teams operate heavy haul highway trucks and trailers rather than traditional fire apparatus and the lone towing company in the survey reported operating many classes of tow trucks, recovery vehicles and heavy wreckers.

The wide variety of vehicles shown in Table 13 will be useful when analysing the amount of space required to carry tools and a potentially growing amount of support equipment to a scene.

4.9 Question 2-10

Question 2-10 asked respondents to indicate how many emergency vehicles they operate, and if possible, to provide a count per vehicle type. The results of this question are shown in Table 14:

Table 14: Responses to Question 2-10, Fleet Size and Makeup

Number of Vehicles (#)	**Number of Respondents**	**Percent of Total**
More than 50	7	19%
21 to 50	4	11%
11 to 20	8	22%
6 to 10	11	30%
1 to 5	6	16%
Not applicable	1	3%
Total	37	100.0%

The total number of vehicles per organization correlated well with the number of stations and the population of the surrounding area. In general, most organizations had one vehicle for every three to four thousand residents in their area of coverage. This provides a reasonable way to estimate the number of tools that will be required to fully equip all the vehicles in any given community size which could be useful as an estimate of national inventory of tools required.

4.10 Question 3-1

Question 3-1 asked respondents to indicate if they operated gasoline powered tools with engines less than 19 kW (25.5 hp). This was a simple “yes” or “no” question where an answer of ‘yes’ would trigger follow-on questions and an answer of ‘no’ would end this section of the survey. The results of this question are shown in Table 15.

Table 15: Responses to Question 3-1, Gasoline Tool Ownership

Do you use Gasoline Tools (Yes/No)	Number of Respondents	Percent of Total
Yes	36	97%
No	0	0%
Unsure/Other/Not Applicable	1	3%
Total	37	100%

Every respondent indicated they currently operate at least one piece of gasoline powered equipment with an engine with rated power of less than 25.5 hp. The exact listing of these classes of tools is illustrated in the next Section. The ‘not applicable’ response refers to the tool manufacturer.

4.11 Question 3-2

Question 3-2 asked respondents to list all the types of gasoline power tools currently operated in the fleet if they answered ‘yes’ to Q3-1. The results of this question are shown in Table 16:

Table 16: Responses to Question 3-2, Gasoline Tool Types

Type of Gasoline Tools	Number of Respondents	Percent of Total
Chainsaws	32	94%
Water Pumps	29	85%
Generators	29	85%
Rotary/K12 Saws	23	68%
Positive and Negative Exhaust fans	21	62%
Extrication Tools	19	56%
Hydraulic Pumps	17	50%
Scene Lights	8	24%
Heaters	5	15%
Cutters and Spreaders	4	12%
Jackhammers/Concrete breakers	4	12%
Augers	4	12%
Not Applicable	1	3%
Total Organizations	34	100%

With the exception of the manufacturer, every respondent indicated having at least one gasoline powered tool located in/on emergency vehicles. The most popular tools were chainsaws (94% of respondents), water pumps (85%) as well as generators (85%), rotary/K12 rescue saws (68%) and exhaust fans (62%). Other tools such as extrication tools, hydraulic pumps, scene lights and heaters were mentioned, but by fewer than 60% of respondents. The two respondents who did not indicate using chainsaws were the Canadian Coast Guard and the towing and recovery company as neither of these organizations tend to work with wood as part of their day-to-day tasks.

In addition to being useful as a list of current gasoline tools, this became the baseline for comparison with zero-emission tools: in other words, only tools that compete directly with the tools in Table 16 were included as part of the list of zero-emission tools. This was an important way to exclude some of the respondents' smaller out-of-scope tools, such as zero-emission flashlights and reciprocating saws.

4.12 Question 3-3

Question 3-3 asked respondents to indicate how often they started their gasoline powered tools at an emergency scene (i.e. not for maintenance and training purposes).

Table 17: Responses to Question 3-3, Scene Startups Frequency

Frequency of Startup at Scene	Number of Respondents	Percent of Total
Daily	4	12%
Several Times Per Week	8	24%
Weekly	8	24%
Bi-weekly	1	3%
Monthly	8	24%
Several times per year	2	6%
Other/Unknown	3	9%
Total	34	100%

There was a wide variation in the frequency of startups at emergency scenes but this was very well correlated with the size of the community in which the respondent operated (i.e. large cities use their gasoline tools at least 7 times a week whereas some very small communities may not use them more than once or twice a month). Note that the two answers of 'several times per year' were from the two federal search and rescue HUSAR task forces who only respond to major search and rescue emergencies not more than seven times per year (and quite often as little as two to three times per year). The frequency of use for gasoline tools is an indicator of how much time is spent maintaining tools with regard to corrective and preventive maintenance. Tools that are infrequently used require much more preventative maintenance with respect to fuel stabilization and carburetor protection, whereas tools that are used frequently require more corrective maintenance to wear items such as spark plugs and air filters. This will be important for the life cycle costs presented in Section 5.5.

4.13 Question 3-4

Question 3-4 asked respondents to indicate how often they started their gasoline powered tools purely for maintenance or training purposes (i.e. not at an emergency scene). The purpose of this question was to understand how much effort is currently being expended for maintenance of gasoline tools. The results of this question are shown in Table 18:

Table 18: Responses to Question 3-4, Maintenance Start Up Frequency

Frequency of Maintenance Startup	Number of Respondents	Percent of Total
Daily	4	11%
Weekly	17	46%
Every two weeks	2	5%
Monthly	8	22%
Did not respond/Not Applicable	6	16%
Total	37	100%

The results indicated that gasoline powered tools are started more often, on average, for routine maintenance than for actual scene use. Over 50% of the respondents indicated they are currently starting all their gasoline tools at least once a week as part of routine preventative maintenance checks and emergency preparedness. However, a small number of respondents indicated they only do these checks once a month. For example, the HUSAR groups tend to start their gasoline powered tools less often than once a week as most of their tools are locked inside storage facilities and are only used five to six times a year for major emergencies when there is slightly more time to prepare than a conventional fire hall who must respond immediately. This was listed as a potential threat to their ability to respond quickly to emergencies since their gasoline powered tools tend to sit much longer than those tools of conventional fire departments. This was listed as a major risk to carburetor gumming and blockages.

Some maintenance activity related to blade condition will likely exist for any type of saw, be they gasoline or zero-emission. However, routine startups to ensure that SSI carburetors are not gummed up will not be required for zero-emission tools. There is essentially no reason to start a zero-emission tool between use other than to confirm the power level on a battery, which can be done with the visual charge indicator bars found on nearly all modern battery packs.

Routine maintenance and system check tests were listed as major source of frustration with gas powered tools by many respondents.

Switching to zero-emission tools could greatly reduce the amount of time spent starting and checking on tool health while at the station.

4.14 Question 3-5

Question 3-5 asked respondents to indicate the challenges and benefits they have faced in the past with their gasoline powered tools. The respondents were asked to consider the following broad topics: finances, logistics, maintenance, performance, safety, emissions and training but were not shown any of the specific topics shown in the table below as it was deemed important to allow free thought from the respondents. Table 19 illustrates the challenges that were listed by the respondents, sorted by the following categories:

1. Fuels;
2. Health and Safety;
3. Performance;
4. Logistics/Tool use; and
5. Maintenance and Training.

Table 19: Responses to Question 3-5, gasoline powered tool, challenges, and issues

Concern/Issue with Gasoline Tools	Number of Responses	Percent of Total
FUELS	40	
Managing all the fuel mixes/premium fuel/stabilizers/2 stroke vs. 4 stroke	16	40.0%
Storing Fuels in Cabinets on Trucks/Gas spills	14	35.0%
Transporting an explosive fuel to a fire/Hazmat	7	17.5%
Availability of gas at 3 AM in remote locations	2	5.0%
Disposal of stale/bad fuel	1	2.5%
HEALTH AND SAFETY	19	
Emissions/Exhaust/Smells/Fumes	10	52.6%
Noise/Noise Pollution/Long term hearing loss	4	21.1%
Long Term Health Risks/Spills on Personal Protective Equipment (PPE) and clothing	4	21.1%
Too much power for inexperienced operators	1	5.3%
PERFORMANCE	13	
Cold starting problems	5	38.5%
Hard to start/need compression bypass/must be strong to start	4	30.8%
Too heavy/weight	3	23.1%
Tool is drawing in smoke from the scene into the carb resulting in mal function	1	7.7%
LOGISTICS/WORKING	10	
Can't use inside confined spaces/buildings	4	40.0%
Requirement to start tools on the ground and carry them up ladders idling	3	30.0%
Positive pressure fans cleanse the air inside a building while simultaneously forcing toxic exhaust into the same building.	3	30.0%
MAINTENANCE AND TRAINING	14	
Maintenance/Breakdowns/Repairs/Spark plugs	12	85.7%
Training newer staff on how to use very powerful tools	2	14.3%

Given the complexity of some of the answers provided in Table 19, an expanded description of gasoline tool challenges and advantages (be they real or perceived) have been described in the following two sections, based on the concepts listed in Table 19:

4.14.1 Challenges of Gasoline Powered Tools

Despite their ubiquitous use and availability, there are specific challenges when using gasoline powered tools. Many challenges were listed by the respondents either as direct responses to the consultants' questions or as part of dialogue between questions or in the final opinions section of the interviews. Question 3-5 provided a variety of answers ranging from 'there are no negative issues' to a myriad of technical and logistical challenges.

The most prevalent concerns related to the broad topic of storing, transporting, mixing and purchasing all the various fuels and oils needed to operate all the tools in the station. For some larger stations the number of tools and fuels mixes can be daunting. Some of the specific concerns relating to fuels were as follows:

- Some tools are four stroke, other tools are two stroke at 25 to 1 oil ratio while others are 50 to 1 oil ratio. This presents a significant logistical issue for first responders to purchase, store, mix and monitor three types of fuels in separate containers, not only at the station but at a scene. Additionally, less experienced staff do not always understand the nuances of fuel mixing and preservation;

- Running a two-stroke engine with pure untreated gasoline will destroy the tool in a matter of minutes. This creates extra pressure on first responders to ensure the correct fuel is being used in each tool. Less experienced staff are not always aware of these subtleties and could unknowingly destroy a tool at a scene by adding incorrect fuel;

- Many older engines should not be operated with current 87 pump octane as it generally contains at least 5% to 10% ethanol which can damage seals and gaskets in older engines, shortening their life span or reducing engine compression/power. Additionally, ethanol blended gasolines contain more oxygen than pure gasoline meaning the tool will run "lean", causing performance and durability issues since carburetors do not possess the ability to alter the fuel/air ratio like a fuel-injected engine can. This means operators must purchase 91 pump Octane or greater, or use additives or use special long term tool fuels like Aspen^{R} fuels. All of these factors create extra burden and costs on the department;

- It is not difficult to find fuel at, say, 3 AM in a large urban centre. However, some respondents from small rural areas pointed out that finding fuel in the middle of the night can be very challenging and can pose a significant risk to operations should they not bring adequate volumes of fuel to a scene;

- Untreated gasoline only lasts approximately five months before it must be disposed of. This was listed as a major logistical and environmental challenge as many litres of fuel are needlessly discarded every year due to risk of going stale and providing reduced performance at a scene.

The second most prevalent responses had to do with health and safety:

- The loud noises created by gasoline tools cause hearing loss and health concerns for fire fighters and casualties. These health concerns can be short term (e.g. ringing in the ears), and long term (e.g. permanent hearing loss). A explanation of how the decibel scale is interpreted is presented in Section 6.3;

- The exhaust created by gasoline tools require respirators and can have long term health effects for fire fighters. Exhaust stream is also very aggravating and dangerous for the casualty being rescued;

- Short term exposure to gasoline-soaked coveralls and gloves and the long term cancer risks from gasoline fumes and vapours;

- The weight of tools being carried up ladders was listed as possible risk, however, this is not necessarily unique to gasoline powered tools;

Other challenges listed included:

Fire fighters, by definition, are typically working around hazardous, explosive and hot environments. Bringing an explosive fuel to an already hazardous scene is an added risk. Similarly, fire fighters working in rural areas often set up high powered gasoline water pumps in grassy fields next to a lake or river to draw large volumes of water to fight a fire when hydrants are not available. These engines tend to have very hot exhaust pipes/mufflers that can set the grass on fire if the scene is not adequately prepared. Not only does this present a risk to fire fighters but it also wastes valuable time as fire fighters must cut down the grass where the pump has been set up to prevent fires.

One comment mentioned by four respondents related to the conundrum of power and risk. While many respondents indicated in other questions that they liked the high power of gasoline powered tools, some respondents indicated in Q3-5 that the high power of some gasoline powered tools posed a safety risk to newer and less experienced operators. This creates a conflict for some respondents as they desire the high power of some tools but acknowledge it comes with a health and safety risk.

Emergency vehicles have a finite amount of storage space and having fuel leaking onto storage trays contaminates what is already a confined space and requires special care when cleaning. Also, transporting fuel on a moving vehicle is, in itself, a hazardous situation.

One clear disadvantage of gasoline powered tools relates to the device itself emitting toxic emissions such as carbon monoxide, and Oxides of Nitrogen (see Section 1). For example, the use of positive pressure exhaust fans are intended to clear the air inside a building of toxic, dangerous and hot fumes yet, when gasoline fans are used, the device itself is emitting toxic emissions into the area. Similarly, gasoline powered tools cannot be used indoors or in confined spaces.

It is standard safety practice in the industry to start an SSI tool on the ground before attempting to climb a ladder to prevent a first responder from struggling with the starting procedure while standing on a roof. This can waste precious time at a scene.

Gasoline tools require significant effort to maintain in terms of replacing spark plugs and ensuring carburetors do not become gummed-up while not in use. Additionally, four stroke tools require oil changes.

Fire fighters, by definition, work in smoky environments, yet gasoline powered tools require a steady stream of clean air/oxygen to feed the carburettor. Drawing in smoky air reduces the power output of a gasoline powered tool (or can even cause the engine to stall and stop working). Using a chainsaw to cut an opening in a roof will often result in large plumes of smoke being released directly into the intake of the gasoline tool, thus robbing it of power.

Gasoline engines can be very difficult to start at extremely cold temperatures. Cold start and hot start procedures can be very different.

Although most chainsaws have special carb floats that allow them to work upside down, not all gasoline powered tools work upside down.

4.14.2 Advantages of Gasoline Powered Tools

The following attributes were listed as advantages of gasoline powered tools:

1. Although there are differences between various grades of fuel with respect to octane and detergents etc, gasoline powered tools will generally run on any gasoline brand and do not require proprietary fuels sourced from one station (e.g. Shell vs. Esso vs. Petro Canada). As one responded stated, "*gasoline has been gasoline for 100 years*". And although this statement is not entirely true in terms of lead and ethanol content, it is true in the sense that fuel has generally always been standardized across brands at any given moment in time;

2. Fuel can be sourced at any local gasoline station and brought to the scene 24 hours a day (although this relates to populated urban centers and can actually be the opposite in sparsely populated Northern communities where first responders rely on stockpiles of fuel or rely on local farmers for fuel [15]);

3. When a gasoline power tool runs out of fuel, it can take less than a minute to refuel it. As long as there are portable fuel containers filled with the correct fuel there is no reason to ever run out of power on a scene and the wait time between complete exhaustion of a tool and 100% refueled can be less than a minute;

4. Gasoline tools have very high power and good power to weight ratios. If gross power is required, a gasoline powered tool will almost always provide the highest available power (see Section 6 for specifications and references);

5. There is virtually no limit to the amount of power than can be designed into a tool with a gasoline engine. From the smallest weed whacker to the largest water pump, a gasoline engine can, and does, exist to perform the task. The technology is very mature and scalable to almost any application, be it hand-held 3 hp chainsaw or a 25 hp stationary water pump. When high power is required there is always a gasoline tool designed to do the job;

6. Gasoline tools have fuel tanks that are easily scaled to the size of the tool. This may not be an issue for stationary equipment but it is an issue for handheld tools. A high powered gasoline tool can still have a relatively small fuel tank since refill times are so short;

7. Gasoline tools are never tethered to a power source which can be a nuisance for first responders and pose a tripping hazard;

8. Although some gasoline tools can be difficult to start in extreme cold weather, once they are started their range is generally not affected by temperature. If, say, a chainsaw can run for 20 minutes at +20 deg C it will also run for approximately 20 minutes at -20 deg C, provided it can be started.

9. Gasoline tools are generally transported to the scene in heated vehicles making the first start fairly easy, however, subsequent cold starts can be problematic, particularly in the far north;

10. Gasoline tools are designed with very simple mechanical components that can be adjusted or tuned on scene. Many fire fighters are accustomed to performing minor repairs and tuning of a gasoline tool at a scene.

4.15 Question 4-1

Question 4-1 asked respondents to indicate if they currently operate any zero-emission tools. As with Question 3-1, the question was a simple 'yes/no'' type. Follow-on questions regarding the ownership experience with zero-emission tools were posed if the answer to Q4-1 was a 'yes' whereas follow on questions regarding why an organization had declined to migrate to zero-emission tools were asked if the answer was 'no'. Note that some organizations responded yes to this question but when asked about the types of tools, indicated it was limited to flashlights, reciprocating saws and cordless drills which do not qualify for a 'yes' in this question as there are no gasoline equivalents to these tools and therefore these tools cannot represent a shift towards zero-emission tools.

Table 20: Responses to Question 4-1, Operation of Zero-emission Tools

Zero-emission Tools (Yes/No)	Number of Respondents	Percent of Total
Yes	32	87%
No	5	13%
Unsure/Other	0	0%
Total	37	100%

A total of 32 respondents (87%) identified as having at least one zero-emission tool from a class of tool that is also available in fossil fuel powered. The types, and quantities, of zero-emission tools have been discussed in further detail in the next section.

4.16 Question 4-2

Question 4-2 asked respondents to list what types of zero-emission tools they operated, if they answered 'yes' to question 4-1. All information was gathered and sorted, even if some of the tools were deemed out-of-scope by virtue of not having a gasoline powered equivalent (e.g. rechargeable flashlights). The results have been shown in Table 21.

Table 21: Responses to Question 4-2, Zero-emission Tool Census if "Yes" to Q4-1

Type of Zero-emission Tools*	**Number of Respondents**	**Percent of Organizations**
Extrication Tools/Jaws of Life**	18	50%
Scene Lights	15	42%
Fans/Exhaust/Positive Pressure Fans	12	33%
Cutters/Spreaders/Sheers	5	14%
Chainsaws	3	8%
Jackhammers/Concrete breakers	3	8%
Heaters	3	8%
Rotary Saws/K12	2	6%
Hydraulic Pumps	2	6%
Water Pumps	1	3%
Augers	1	3%
Generators	0	0%
*Reciprocating saws/"Sawzall"****	22	61%
Cordless Drill/Impact guns	20	56%
Circular Saw	14	39%
Rechargeable flashlights	18	50%
Grinders	13	36%
Total	**36**	**100%**

*Devices in italics are included for sake of completeness but deemed out of scope as there are no equivalent gasoline powered devices
** Jaws of life is a trade name of Hurst Tools that has become synonymous with the proper term 'extrication tools' or 'rescue tools'
*** Sawzall is a trade name of Milwaukee Tools that has become synonymous with the proper term "reciprocating saw".

The results of this question are core to the purpose of this project as they define the current state of acceptance for zero-emission tools. Some of the findings were:

- No respondents indicated they were using high power water pumps. The one 'yes' response to water pumps was for very small fluid transfer pumps not capable of pumping water from a lake;

- No respondents indicated they were using zero-emission generators other than equipment permanently mounted to a vehicle which was out of scope for this project;

- Many of the tools listed as being 'zero-emission' were in fact too small for inclusion in the core summary as they do not represent a shift to zero-emission tools from gasoline or diesel tools (e.g. reciprocating saws and flashlights);

- The most popular zero-emission tool used by respondents were the family of tools encompassing spreaders, cutters and extrication tools (Jaws of Life);

- Positive and negative pressure fans and exhaust equipment were also listed by 33% of respondents. The use of gasoline powered fans represents a conflict for first responders as the exhaust fumes are often blown into the very building they are attempting to clear of smoky air. In these instances, zero-emission tools have reduced the level of toxic fumes inside buildings, solving a chronic industry problem with virtually no negative side effects.

- Rotary saws and chainsaws were only listed by three and two respondents respectively, illustrating a general lack of acceptance or availability of these items by the industry.

4.17 Question 4-3

Question 4-3 asked respondents to indicate the challenges they have faced in the past with their zero-emission tools. The respondents were asked to consider the following broad topics: finances, logistics, health and safety, maintenance, performance and training but were not shown any of the specific topics shown in the table below as it was deemed important to allow free thought from the respondents. The base number of respondents for this table is 26, rather than 37, as some respondents indicated they did not have any zero-emission tools and therefore had no specific experiences or opinions to share on the topic. The responses are shown in Table 22 where the percent is based on a denominator of 26.

Table 22: Responses to Question 4-3, Challenges with Zero-emission Tools

Specific Challenge with Zero-Emission Tools	**Number of Respondents**	**Percent of Total (based on 26 ‘yes’ at Q4-1**
BATTERIES AND CHARGING		
Runtime/Battery Life at the scene	16	62%
Reduced Long Term Battery Life/Life span/Battery Cycling	9	35%
Having to ensure batteries are always charged before arriving at scene	6	23%
Battery health is hard to understand	5	19%
Remembering to bring all batteries to the scene	5	19%
Batteries dying in remote locations without ability to charge	4	15%
Proprietary nature of battery packs for every manufacturer	4	15%
Annoyance of needing to bring a generator/find AC power on site to recharge batteries if power was not available on the truck.	3	12%
Storage of many batteries on the truck and in the station	2	8%
Batteries can get lost in the snow	1	4%
Batteries get wet from fire hose and don't work	1	4%
Takes time to recharge compared to refueling with gas	1	4%
FINANCES/COSTS	12	
The cost of new batteries kills the long term return on investment (ROI)	7	27%
So much equipment to replace at once is impossible to afford/No budget	5	19%
LOGISTICS/OPERATIONS	15	
Cold weather use reduces performance/run time/battery life	9	35%
Performance is not at par with gasoline in terms of power	5	19%
Heavy/Difficult to handle in the field	3	12%
Cords are a trip hazard	1	4%
When airplane transport is required, airlines may object to flying with the batteries in cargo hold	1	4%
MAINTENANCE	2	
Maintenance on the cords	1	4%
Staff can't repair even minor issues due to complex electronics	1	4%

This question drew a significant number of answers as well as a very diverse spectrum of experiences with zero-emission opinions. Some of the highlights were as follows:

- The most common concerns revolved around the issues of reduced runtime, managing battery packs, constantly changing battery packs. These issues have been described separately as follows:
    - Reduced runtime: Many respondents indicated their battery electric tools simply did not last as long at an emergency scene compared to what they were used to with gasoline tools. This concern was twinned with the annoyance of having to

bring a generator to a scene or searching for 120V outlets to charge rather than the simplicity of using portable fuel containers for gasoline tools;

  - Managing battery packs at a scene: Many respondents indicated that they had become accustomed to having a few portable fuel containers of fuel at a scene but found it challenging to manage the number and diversity of battery packs required to manage all their e-tools. Responses varied from the volume of packs to the different types of packs to losing packs in snow banks to concerns around wet battery packs and the reduction in runtime when batteries are cold;

  - Changing battery packs: Some e-tools require users to plug in the entire tool rather than remove a battery pack, thus creating a logistics challenge and a loss of availability of the tool while it is charging. Others indicated that they simply had no place to plug in their e-tools while on scene because there were no 120V outlets and their trucks lacked inverters that are generally only available on newer vehicles;

  - Concern regarding the long term life of battery packs that, when purchased new, will produce a runtime of, say, 20 minutes and, within less than two years of ownership, can only provide a runtime of, say, 10 minutes. This was a major concern for many respondents who combined this sentiment with the cost of new batteries as a major impediment towards mass adoption. The topic of research into battery life is discussed in Section 6.10;

- Many respondents indicated a strong willingness to using many forms of zero-emission tools but could not afford to purchase the tools with their current budget. Many respondents indicated that budgets for capital expenses were very limited and switching to zero-emission tools at this time was cost-prohibitive. Some respondents used this question as a time to state '*if the government wants use to use e-tools they need to give us the money to do so*';

- Many respondents were very frustrated with the proprietary nature of battery packs and chargers developed by each of the manufacturers. As one respondent stated, "we have to manage four brands of battery packs whereas gasoline is standardized across brands". This point is extremely valid as despite the various grades of gasoline available at fuel stations, gasoline is not proprietary and nearly any gasoline powered tool can run on nearly any gasoline brand. This issue could continue to be a major limiting factor for wider adoption of battery electric tools by emergency response crews until such time as tool manufacturers develop some type of generic battery pack system. However, this is not likely to happen in the near future. This topic is discussed in more detail in Section 6.7;

- Respondents living in more northern communities cited poor performance in cold weather as a major source of frustration with battery performance and a limiting factor to wider adoption at their stations as well as the risk of losing packs in the snow.

4.18 Question 4-4

Question 4-4 asked respondents to indicate the biggest advantages they experienced with their zero-emission tools. The respondents were asked to consider the following broad topics: finances, logistics, maintenance, performance and training but were not shown any of the specific topics shown in the table below as it was deemed important to allow free thought from the respondents. The responses are shown in Table 23 grouped with the following sub headings:

1. Performance;
2. Health and Safety;
3. Gasoline/Mix; and
4. Maintenance.

Table 23: Responses to Question 4-4, Advantages with Zero-emission Tools

Advantages of Zero-emission (# residents)	**Number of Respondents**	**Percent of Total (from 26)**
PERFORMANCE		
Grab and Go/Flexibility/Portability/Convenience	18	69%
No Cords/Tripping hazards/Tethers*	12	46%
Push button start	5	19%
Lightweight and balanced/better ergonomics/Crews don't burn out as fast due to lower weight compared to SSI	4	15%
Corded tools can work all day if you have a generator	3	12%
Can work in confined spaces	3	12%
Less training	1	4%
Instantaneous Power/Max torque at 0 rpm	1	4%
Performance is not altered in very smoky environment	1	4%
Can start on the roof (no need to carry idling tool)	1	4%
HEALTH AND SAFETY		
No fumes/emissions	8	31%
Quiet/No hearing damage or loss	6	23%
Safer	1	4%
No hot mufflers starting grass fires	1	4%
NO GASOLINE/MIX		
No fuel to mix	5	19%
No fuel to buy	5	19%
Not spilling gas on PPE	4	15%
No fuel to store	2	8%
MAINTENANCE		
Less Maintenance/Fewer breakdowns	4	15%
Total	26	100%

*Respondents may have confused zero-emission with battery electric as many zero-emission tools can be tethered.

Respondents listed a variety of advantages they had experienced while comparing their existing zero-emission tools with their existing gasoline powered tools. The most commonly listed advantages were:

1. Nearly 70% of respondents indicated they appreciated the way an electric tool can simply be picked up and started with the push of a button without any need to choke the engine, add fuel or pull a high tension rip cord multiple times. Specifically, zero-emission tools can be safely and quietly carried up a ladder in the off position and then easily started, with the push of a button, on the rooftop, when required;

2. Many respondents discussed the freedom of using battery electric tools without being tethered to a generator as an advantage of zero-emission tools. However, respondents may have been unclear that corded tools are, in fact, a subset of zero-emission tools therefore this response would only apply to battery electric tools;

3. Many respondents listed the storing, mixing and transporting multiple portable fuel containers of gasoline as a major impediment to the logistics of first response. Some respondents admitted being confused about all the various mixes that must be brought to a scene and that some staff required refresher training to understand all the nuances of two-stroke engine operation. None of these steps are needed with zero-emission tools and this was listed as a very significant advantage of zero-emission tools;

4. Heath and safety issues were mentioned frequently in terms of emissions for first responders, emissions for the casualty, the long-term effects of being exposed to gasoline fumes and gasoline soaked PPE;

5. Noise pollution and the long term effects of loud tools being operated so close to the first responders' ears were listed as major concerns for gasoline tools and are less of a concern with zero-emission tools. Some gasoline powered chainsaws emit noise in the 117 dBA range which can be extremely harmful to human health (see Section 6.3 for details of tool noise specifications). Similarly, there is less noise for the casualties and neighbours to be exposed to during emergency operations;

6. Many respondents indicated that zero-emission tools are much easier to maintain, do not breakdown as frequently and likely have lower overall life cycle costs (although the life cycle cost information was anecdotal in nature and not supported by actual financial data). See Section 5.4 for life cycle cost estimates;

4.19 Question 4-5

Question 4-5 asked the respondents who had answered 'no' to Question 4-1 if they would consider trialing or testing zero-emission tools in the future. The responses to this question are shown in Table 24.

Table 24: Responses to Question 4-5, Would you Trial Zero-emission Tools

Would you consider zero-emission tools (If no to Q4-1)	**Number of Respondents**	**Percent of Total**
Yes	3	60%
No	0	0%
Maybe/unsure	2	40%
Total	5	100%

Three respondents who indicated they did not currently use zero-emission tools said they would test and eventually integrate zero-emission tools into their station once the financial and performance issues had been resolved. These respondents represented small rural stations lacking the financial resources to purchase zero-emission tools until such time as the performance and battery range were guaranteed to be on-par with that of gasoline tools. The other respondents had no plans to test zero-emission tools in the foreseeable future but did not categorically state they would never try them.

4.20 Question 4-6

Question 4-6 asked the eight respondents who answered 'no' to Question 4-1 to indicate why they had not adopted zero-emission tools to date. Table 25 lists all types of concerns listed for zero-emission tools.

Table 25: Question 4-6, Why have you not Adopted Zero-emission Tools to Date?

Rationale for not using Zero-emission Tools	**Number of Respondents**	**Percent of Total**
Gasoline tools are more reliable	2	25.0%
Cost	1	12.5%
Performance of Water Pumps	1	12.5%
Battery Failure	1	12.5%
Keeping Batteries Charged	1	12.5%
Batteries must be used to stay healthy	1	12.5%
Maneuverability	1	12.5%
Concerned about committing to just ZE in the field	1	12.5%
Too many types of batteries to buy and manage	1	12.5%
Total	8	100.0%

Only a few answers were provided for this question and all the responses dealt with one of two subjects: costs and performance. Those organizations who chose to answer this question felt that their municipality did not have the necessary funds to support a migration to zero-emission tools, or they had a general lack of confidence in the power and performance of the tools/batteries, or both.

4.21 Question 4-7

Question 4-7 asked respondents to indicate if they had conducted field tests or trials of zero-emission tools in the past. This question was asked to all respondents, regardless of their answer to Question 4-1. The responses to this question are shown in Table 26.

Table 26: Have you Undertaken Field Trials for Zero-emission Tools

Have you Trialed (Yes/No)	Number of Respondents	Percent of Total
Yes	21	60%
No	14	40%
Total	35	100%

Approximately 60% of the respondents indicated they had experienced some form of field test or trial with a zero-emission tool manufacturer in the past few years. Some of the respondents indicated that sales staff from fire equipment manufacturers were constantly engaging them to discuss the latest products whereas other respondents felt that it was up to them to contact sales staff. In general, sales staff from manufacturers and re-sellers tended to be more aggressively selling their products in urban centres rather than in smaller rural communities. Many respondents indicated that visits from tools sales personnel slowed down considerably during the COVID pandemic.

4.22 Question 4-8

Question 4-8 asked respondents to indicate when the most recent trial or field test was conducted with zero-emission tools, provided the answer to Question 4-7 was 'yes'. The responses to this question are shown in Table 27.

Table 27: Responses to Question 4-8, When did you Last Experience a Field Test/Trial

Test/Trial Date	Number of Respondents	Percent of Total
Too long ago/can't recall	2	10%
2015	1	5%
2016	1	5%
2017	0	0%
2018	2	10%
2019	3	15%
2020	6	30%
2021	4	20%
2022	1	5%
Total	20	100%

Five of the 20 respondents (25%) indicated they had experienced at least one field test or demonstration with zero-emission tools recently, during COVID in 2021 and 2022. But the remaining 75% of the respondents indicated that the most recent field test had taken place before the COVID 19 travel restrictions were put in place. Only two respondents indicated their most recent field test was so long ago they could not recall the year.

Anecdotally it appears as though the various travel restrictions have greatly reduced the ability or desire for sales staff to perform field tests and equipment demonstrations on site at a fire hall. It is not known if this trend will continue once COVID restrictions are relaxed in 2022 and 2023. Again though, it is worth mentioning that several respondents indicated that emergency services equipment sales representatives can be very persistent at making sales calls and demonstrating the abilities of their equipment.

4.23 Question 4-9

Question 4-9 asked respondents to indicate what zero-emission tools were trialed, provided the answer to Question 4-7 was 'yes'. A list of all the tools used during manufacturer trials are shown in Table 28.

Table 28: Responses to Question 4-9, What zero-emission tools were trialed?

Which Tools were Trialed	Number of Respondents	Percent of Total
Extrication/Jaws of life	11	55%
Positive Pressure Air Fans	2	10%
Chainsaws	2	10%
Scene Lights	2	10%
K12/Rotary saws	1	5%
Battery Generators	1	5%
Hydraulics	1	5%
Total	20	100%

The most demonstrated zero-emission tool was the family of tools used for extrication. These sales staff seemed to have made the most inroads into the stations to attempt to sell their product. Several respondents indicated that they purchased products directly after being a part of the field tests and trials as they were so impressed with the technology and felt zero-emission extrication tools were just as powerful as gasoline powered ones.

4.24 Question 4-10

Question 4-10 asked respondents to indicate either their specific or overall impressions of the zero-emission tested equipment, provided the answer to Question 4-7 was 'yes'. The general impressions of the 20 respondents regarding the tested tools are shown in Table 29.

Table 29: Responses to Question 4-10, What was your impression of the tested tools

Concerns and Positive Remarks with Tested Tools	**Number of Respondents**	**Percent of Total**
CONCERNS		
Not powerful enough	6	30%
Battery Life	2	10%
Not enough runtime to cut trees all day long	2	10%
Reduced performance/battery life in cold weather	2	10%
Need inverters on the trucks and [we] don't have those now	1	5%
Storage space for batteries on the trucks	1	5%
Risk of battery Fires	1	5%
Managing multiple types battery packs	1	5%
Too heavy	1	5%
POSITIVE REMARKS		
Overall they liked it so they purchased	3	15%
Lighter Weight	2	10%
Compact/small	2	10%
Grab and Go	2	10%
Technology has improved a lot in the past 15 years	1	5%
Quiet	1	5%
Battery life indicator	1	5%
Instant Power	1	5%
Don't need to run back to the truck if you have spare batteries on your person	1	5%

There was a broad array of answers for this question but battery life, costs and power were the most popular answers of areas of concern that may have resulted in organizations not procuring e-tools after the trial. Many positive comments were also given regarding the ease of use and "grab and go" features of zero-emission tools.

4.25 Question 4-11

Question 4-11 asked respondents to indicate if they could adequately charge battery packs at an emergency scene with current staff or if they would have to hire additional personnel to perform these tasks. The results of this question are shown in Table 30.

Table 30: Responses to Question 4-11, Charging on Scene

Could you Charge/Recharge Batteries with Current Staff	Number of Respondents	Percent of Total
Yes, but we would need better equipment	13	38%
Yes, it could be done with existing staff/existing vehicles	11	32%
Not sure/Unsure/Unknown	8	24%
No, we would have to hire new staff	2	6%
Total	34	100%

This question produced a wide array of answers from a simple 'we will make it work' to 'we are very concerned about how this will affect logistics at a scene and it could be a major problem'. However, the majority of respondents indicated they would adapt to the situation and ensure that staff are properly trained on the use of batteries on a scene. Many respondents also indicated one of the most important ways to deal with this issue will be to buy emergency vehicles equipped with large banks of inverters and 120V power ports to assist with the logistical challenge of charging batteries or operating corded tools. Portable generators were also listed as a means to transition from gas to zero-emission battery management. The truck of the future concept is described in Section **Error! Reference source not found.** and the role that generators will have to play is described Section 8.1.

4.26 Case Study: Municipality of Meaford, Ontario

Nearly every organization interviewed for this project indicated they had high power tools fueled by both gasoline and batteries. However, one municipality, Meaford, Ontario, claimed to have replaced all their higher power gasoline tools with zero-emission equivalents except for water pumps and large generators. In terms of commitment to zero-emission tools they were the only survey respondent who had voluntarily converted to battery electric for all their cutting and ventilation tools.

The staff at Meaford had discussed the transition to zero-emission tools for some time but were unable to commit to battery electric tools based on a lack of funding and lack of confidence with tool power and runtime. This was a commonly expressed sentiment by many respondents. However, the Meaford Fire Department received a cheque from Fire Marque[3] in 2020 to compensate them for several very large fires they had fought the year before. The senior management team consulted with fire fighters and eventually agreed to direct the funds towards a complete suite of zero-emission batter electric power tools including drills, chainsaws, lighting, fans, K12 rotary saws, flashlights etc. They considered various manufacturers such as Dewalt, Milwaukee, Husqvarna and Stihl and eventually chose one of these manufacturers primarily based on the dealer network in their city thus allowing them better options for maintenance, spare parts and future purchases of that same make of tool. Similarly, it was deemed important to commit to one manufacturer for the sake of battery commonality (Section 6.8). As described in Section 6.8.12 there was some concern about spreading the purchasing over many fiscal years for fear they could end up with tools from various manufacturers, each with a different

[3] Fire Marque is a Canadian company providing funding to fire departments based on the recovery of insurance payouts. For more information visit firemarque.com

battery technology. Staff were initially reluctant to use the new battery electric chainsaws, however, it did not take long before staff began choosing the zero-emission tools over their gasoline counterparts on the basis of weight, ease of use and lack of need for refueling. The concept of a ‘grab-and-go’ tool was deemed very attractive for fire fighters preparing for a scene.

The experiences of Meaford, Ontario are a good example of how zero-emission tools can be successfully used in fire fighting provided research is performed to understand which tools can be used for which applications. In other words, it may be too early to commit to zero-emission generators and water pumps, however, there is a clear precedent for at least one fire department committing to one battery electric manufacturer and having great success to the point where gasoline tools are only used if zero-emission tools are not available. The Chief in Meaford went on to describe that many of his personnel were initially concerned about run time and power, yet, fire fighters only use saws briefly to perform a specific task then the saws are usually set aside for hours at a time.

It should be noted that Meaford is located in central Ontario and receives diverse summer and winter weather conditions but generally does not experience the types of extreme winter weather conditions of the far north. Therefore, these experiences may not be relevant for search and rescue, parks and wildland fire organizations or first response work in the far north, where charging on-demand might be more challenging than in locations such as Meaford.

4.27 Compound Statistics

The previous sections addressed each question individually. The following sections deal with some selected compound statistics whereby the results of two questions are combined to determine trends or correlations.

4.27.1 Rural versus Urban Use of Electric Tools

Questions 2-4 and 4-1 were combined to form a compound statistic to understand if zero-emission tools had been more accepted in urban or rural locations. The aggregated data is shown in Table 31.

Table 31: Acceptance of zero-emission tools, rural vs. urban

Setting	Yes	No
Rural	4 (40%)	6 (60%)
Urban	9 (100%)	0 (0%)
Rural and Urban	9 (69%)	4 (31%)

Of the nine organizations located in urban centres, all of them had adopted at least one form of zero-emission tool that was big enough to be considered a replacement for a tool that was previously available in gasoline (i.e. not, say, a cordless drill). By contrast, only 40% of organizations located in rural areas had adopted at least one zero-emission tool larger than a reciprocating saw. As could be expected, organizations located in mixed rural and urban areas had an acceptance level between urban and rural of 69% with at least one zero-emission tool larger than a reciprocating saw.

This agrees with two comments relating to sales in rural areas and the available budget in small rural areas, as follows:

1. Many respondents located in rural settings indicated they do not receive regular visits from zero-emission sales and marketing staff. Conversely, nearly all organizations located in urban areas receive many calls from equipment sales staff trying to see the latest version of zero-emission tools;

2. Nearly every respondent, particularly fire chiefs, mentioned challenges securing funding for large scale purchase of zero-emission tools. However, this sentiment was much stronger in small rural areas where capital funding for tools can be exceedingly low compared to large urban cities.

Additionally, many rural respondents indicated a lack of 120V power supply when working at a scene, which becomes an impediment to adopting zero-emission tools, regardless of funding.

4.27.2 **Other Compound Results**

Some of the other indices were as follows:

1. Respondents in rural areas were more likely to discuss the role that water pumps play in their operations. It is common for rural fire fighters to draw water from a lake for hours at a time. Rural and suburban first responders will also often use tenders (tanker trucks) whereas urban fire fighting rely more heavily on hydrants;

2. Wildland fire and park services personnel were more likely to mention chainsaw run time, bar length and horsepower as a key area of concern compared to urban respondents. Urban respondents tended to discuss the importance of chainsaws but also acknowledged once they have achieved their goal of venting and gaining entry into a building they can usually set the chainsaw aside. Wildland fire fighters commonly have to cut down large numbers of trees making the performance of saws a key issue;

3. There was a strong link between the nature of area of coverage (i.e. rural vs. urban) and the type of staff (i.e. career versus volunteer). Most urban stations reported nearly 100% career staff at all stations whereas most rural stations reported a very high percentage (sometimes 100%) of volunteer staff. It was very common for rural departments to report one career chief with the rest of the staff being volunteer.

5 TOOL SPECIFICATIONS

Section 4 dealt with the experiences and opinions of the survey respondents but it was equally important to review the factual specifications of the tools mentioned by the respondents. This allowed a data driven comparison between existing gasoline powered tools and zero-emission tools with respect to aspects such as power, weight, run time, noise, user features, maintenance and costs.

It would not be practical to list every make and model of power tool presented in the surveys, however, generic classes of gasoline powered tools that were discussed by many operators, with the corresponding zero-emission tools, have been presented below, in no particular order:

5.1 Saws

Generally, there are four types of powered saws marketed to first responders: chainsaws, rotary saws and reciprocating saws [16] being the three primary types. Pole saws also have some relevance to the first response industry but are much less commonly used. The four types of powered saws have been described in more detail below. Note: for the purposes of this study a fuel and oil mixture of 50:1 has been assumed for all two stroke engines where the gasoline is assumed to have a density of 0.748 kg/l [17] and the mix oil is assumed to have a density of 0.866 kg/l [18] for a combined density of 0.75 kg/l.

5.1.1 **Chainsaws**

One of the most discussed tools was the gasoline powered traditional chainsaw and the modified chainsaw that becomes a vent saw with an adjustable depth gauge that increases safety and can be set to minimize cutting structural members such as trusses and rafters (example shown in Figure 2). Chainsaws play a critical role in emergency services for multiple reasons, most notably for cutting ventilation holes in roofs and walls as well as cutting access ports to allow personnel to enter a locked/secured scene, or to create an avenue for casualties to exit. Additionally, in more rural and parkland areas, chainsaws are used to clear brush, fell trees that may be obstructing access or, in severe cases, to fell a row of trees to create a fire break to halt the progress of a forest fire. Traditionally, gasoline chainsaws have been used to greatly reduce fire fighter fatigue and reduce cut time, compared to unpowered tools, but can be difficult to start and heavy to carry [16].

Figure 2: Example of firefighter chainsaw/vent saw (image courtesy of Tempest.com)

An exhaustive list of gasoline chainsaws currently on the market would not be relevant to this study therefore only chainsaws commonly used by first responders are listed in Table 32. Similarly sized battery electric chainsaws have been shown in Table 33. Note that corded chainsaws do exist but have been excluded as very few first responders would choose to use a corded chainsaw as the tether prevents them from doing their work and this downfall far outweighs the advantages of quasi-unlimited runtime.

The following attributes are considered important and worth considering when choosing a chainsaw. Some of these attributes have been highlighted in Table 32:

1. Weight;
2. Chain speed (rpm);
3. Noise;
4. Run time;
5. Bar size/length;
6. Initial price;
7. Life cycle costs;
8. Battery lifespan (zero-emission only);
9. Cutting time; and
10. Fuel consumption/CO_2 emissions.

Table 32: Commonly Used SSI Chainsaws in the Emergency Services Sector*

Make	**Model**	**Bar Size (in)**	**Rated Power (kW)**	**Displ (cc)**	**Noise** (dBA) Pow/Pre**	**Weight (kg)**	**Fuel Tank (l)**	**Price ($)**	**Fuel Cons (l/hr)**
Echo	CS7310P [33]	20 to 32	4.1	73.5	117/107	6.7	0.80	$1289	2.33
Echo	CS620P [34]	16 to 27	3.8	59.8	114/103	6.3	0.64	$610	N/A
Husqvarna	562 XP [35]	15 to 28	3.5	59.8	116/106	6.1	0.66	$1029	2.32
Husqvarna	395 XP [36]	16 to 28	4.9	94.0	114/102	7.9	0.90	$1529	3.07
Husqvarna/Ventmaster	572 XP [37]	15 to 28	4.3	70.6	118/107	6.6	0.76	$1300	2.35
Husqvarna/Ventmaster	576 XT [38]	16 to 20	4.2	74.0	114/105	6.6	0.70	$1600	2.33
Stihl	MS362 [39] [40]	16 to 25	3.5	59.0	117/106	5.6	0.60	$1100	1.84
Stihl	MS461R [41]	20	4.5	76.5	117/105	7.2	0.77	$2139	N/A
Stihl	MS462 R CM [42]	16 to 36	4.5	72.3	119/108	6.5	0.71	$1439	2.39
Stihl	MS500i [43]	16 to 32	5.0	79.2	119/106	6.5	0.77	$1699	N/A
Stihl	025	15 to 18	2.2	45.1	N/A	4.6	0.47	$429	N/A
Super Vac/Makita*	SV3/EA7900 [44] [45]	16 or 20	4.3	78.5	NA/105	9.5/9.8	0.75	$2864	2.67
Minimum	**N/A**	**15**	**2.2**	**45.1**	**102*** **	**4.6**	**0.470**	**$429**	**1.84**
Maximum	**N/A**	**36**	**5.0**	**94.0**	**108*** **	**9.8**	**0.900**	**$2864**	**3.07**
Mean	**N/A**	**18**	**4.0**	**69.8**	**105*** **	**6.6**	**0.703**	**$1431**	**2.41**

*The Supervac SV3 is marketed as a SuperVac product but uses a Makita engine
** Sound power vs. sound pressure is explained in Section 6.3
*** From an operator's perspective, noise pressure at the ear will be taken as most relevant

Note that all chainsaws listed in Table 32 have engines greater than 45 cc in size, making them currently exempt of CARB standards (see Section 2.1.5). For the near term there will likely not be any pressure to reduce the use of these tools.

As seen in Table 32, the typical first response chainsaw has a 4.0 kW, 70 cc engine, weighing 6.6 kg and putting out a sound level at the operator's ear of 105 dBA with a fuel tank capacity of 0.7 litres burning 2.41 litres per hour. These mean values for chainsaws will be used in the next Section to compare the performance of zero-emission tools with gasoline tools.

Table 33 shows similar specifications for zero-emission chainsaws suitable for first response work and currently available at major retailers. Nearly all saws have many possible battery choices. The batteries shown in brackets in column 2 of the table are representative of the standard battery suggested by the manufacturer, but larger or smaller batteries can be used, if desired, by the operator with corresponding changes in run time, charge time and initial cost. Run time and re-charge time have not been shown in this table as the factors such as battery size and type of charger can drastically change these performance measures thus creating comparisons that are not equitable, and potentially misleading. The runtime of a gasoline tool can be easily predicted as the fuel tank size generally remains the same throughout the life of the tool. This allows for comparisons between tools with regard to runtime. The same cannot be said for battery electric tools where a small 1 Ah battery can be used on one day and replaced with a much larger, say, 8 Ah battery the next day, providing a runtime that could be approximately eight times longer. This makes runtime comparisons between tools pointless and potentially misleading.

Table 33: Battery Electric Chainsaws Sized for use in the Emergency Services Sector

Make	**Model**	**Bar Size (in)**	**Noise** (dBA) (Power/pres)**	**Weight (kg)**	**Tool Cost ($)**	**Battery Cost ($)***	**Total Cost ($)**
Milwaukee	2727 (18V/1x6 Ah)	16	NA/87	6.3	$500 [46]	$400 [47]	$900
Makita	LXT-XCU04Z (2x18V-5 Ah)	16	NA/89	5.5	$580 [48]	$369 [49]	$949
Dewalt	DCCSS677 (60V 9Ah)	16 to 20	NA/75	7.9	$369 [50]	$429 [51]	$798
Ryobi	RY40580 (1 x 40V 4 Ah)	18	NA/99	6.7	$298 [52]	$418 [53]	$716
Echo	CCS-58V (1 x 58V 4 Ah)	16	NA/88	6.2	$567 [54]	$360 [55]	$927
Stihl	MSA 220 C-BQ (1xAP300)	16	NA/86	5.4	$549 [56]	$500 [57]	$1049
Husqvarna	540i XP (1xBLi300)	12 to 16	106/95	4.8	$889 [59]	$610 [58]	$1499
Minimum	**N/A**	**12**	**75.0**	**4.80**	**$298**	**$360**	**$716**
Maximum	**N/A**	**20**	**99.0**	**7.90**	**$889**	**$610**	**$1499**
Mean	**N/A**	**16**	**88.4**	**6.11**	**$536**	**$440**	**$976**

* Battery costs are for a set of two batteries as one battery does not allow for proper cycling at a scene
** Sound power vs. sound pressure is explained in Section 6.3

Most battery electric chainsaws have a slightly shorter bar length than their gasoline counterparts, although many models do have options from which to choose. This reduction in bar length would not be a concern when attacking a structure fire but could be a concern for forest fire fighting. The mean noise level is significantly less than that of gasoline (88.4 dBA vs. 105 dBA). The weight of battery electric chainsaws is very similar to that of gasoline. These features have been described in more detail in the following section.

5.1.2 **Rescue/Rotary/Cutoff/K12 Saws**

Nearly every respondent listed rotary saws in their current inventory. Rotary saws use a round metal blade to cut through a variety of substances such as wood, concrete or metal. Different blades are used to cut through different materials and must be changed to optimize the cutting time through each material. A typical rotary saw is shown in Figure 3 and a listing of the more common tools is shown in Table 34.

Figure 3: Example of firefighter rotary/K12 saw (image courtesy of Firehooks.com)

Table 34: SSI Gasoline Engine Rotary Saws used in the Emergency Services Sector

Make	**Model**	**Blade Diameter (in)**	**Rated Power (kW)**	**Displ (cc)**	**Noise (dBA) Power/Pres****	**Weight (kg)**	**Fuel Tank (l)**	**Price**	**Fuel Cons (l/h)**
Stihl	TS 410 [60]	12	3.2	66.7	109/98	9.5	0.71	$1,529	N/A
Stihl	TS 800 [61]	16	5.0	98.5	114/101	12.7	1.20	$2,199	N/A
Husqvarna	K 960 Rescue [64]	12/14/16	4.5	93.6	116/104	13.5	1.00	$2,469	N/A
Husqvarna	K 1270 [62]	14/16	5.8	118.8	117/104	13.7	1.25	$2,794	1.75
Husqvarna	K 770 [63]	14	3.7	73.5	115/101	10.1	0.80	$1,225	1.08
Makita	EK7651H* [65]	14	3.0	75.6	NA/93*	12.9	1.10	$1,329	1.60
Makita	EK8100 [66]	16	4.2	81.0	NA/100	10.6	1.10	$1,393	2.27
Super Vac	SVC4-14 [67]	14	3.2	60.7	NA/100+ est	8.9	0.70	$4,612	N/A
Hilti	DSH 600-X [68]	12	3.2	63.3	NA/102	9.9	0.87	$1,449	N/A
Hilti	DSH 900-X [69]	14/16	4.3	87.0	NA/102	12.0	0.90	$2,099	N/A
Echo	CSG-7410 [70]	14	3.2	73.5	NA/101	10.7	0.70	$2,346	N/A
Partner/Husq	K 970/K12/K14 [71]	12/14/16	4.54	95	NA/100	10.3	1.00	$2,855	1.39
Minimum	**N/A**	**12**	**3.0**	**61**	**93**	**8.9**	**0.7**	**$1,225**	**1.08**
Maximum	**N/A**	**16**	**5.8**	**119**	**104**	**13.7**	**1.2**	**$4,612**	**2.47**
Mean	**N/A**	**14**	**4.0**	**83**	**100.5**	**11.1**	**0.9**	**$2,269**	**1.61**

*Four stroke engine
** Sound power vs. sound pressure is explained in Section 6.3

Based on the survey results and the market research, the typical first response SSI gasoline rotary saw has a blade diameter of 14 to 16 inches, weighs just over 11 kg, with a fuel tank capacity of just under a litre, a fuel consumption rate of 1.61 litres per hour and a measured noise level of 100.5 dBA at the operator's ear and a printed power rating of 4.0 kW and a cost of over $2200. The Makita four stroke model is, naturally, the quietest (and slightly skews the sound data) but also the least powerful in the group. Zero-emission rotary saws are listed in Table 35.

Table 35: Zero-Emission Powered Rotary Saws used in the Emergency Services Sector

Make	**Model**	**Blade Diameter (in)**	**Noise (dBA) Power/Pres****	**Weight*** (kg)**	**Tool* Only Price**	**Battery Price* ($)**	**Total Cost ($)**
Stihl	TSA 230 (36V AP 300) [72]	9	114/103 [80]	5.7	$549 [83]	$500 [57]	$1049
Husqvarna	K 535i (BLi300) [73]	9	NA/100.5	3.5	$670	$600 [58]	$1270
Husqvarna	K4000 (120V Corded) [74]	14	NA/95.0	7.6	$950	N/A	$950
Husqvarna	K1 Pace (94V B380X) [144]	12 and 14	NA/101.9 [81]	7.4	$1546 [84]	$2000 [87]	$3546
Makita	DCE090T2X1 [75] (2x5Ah)	9	NA/103.0	6.3	$799	$369 [49]	$1199
Milwaukee	2786-22HD (18V 2x12 Ah) [76]	9	N/A	11.3	$849	$400 [47]	$1249
Milwaukee	MXF314-2XC (72V 1x XC406) [77]	14	N/A	14.6	$1300	$1600 [88]	$2900
Dewalt	DCS690X2 20V/9Ah 60V 3Ah [78]	9	NA/103.6 [82]	4.9	$829 [85]	$420 [88]	$1269
Hilti	DSH 600-22 (2xB22170) [79]	9	N/A	10.2	$1049 [86]	$350 [86]	$1399
Minimum	**N/A**	**9**	**95.0**	**3.5**	**$549**	**$350**	**$ 950**
Maximum	**N/A**	**14**	**103.6**	**14.6**	**$1,546**	**$2,000**	**$3,546**
Mean	**N/A**	**9**	**101.1**	**7.9**	**$948**	**$780**	**$1,648**

* Battery costs are for a set of two batteries as one battery does not allow for proper cycling at a scene and some may be in US dollars
** Sound power vs. sound pressure is explained in Section 6.3
*** It is not always clear if weights are listed with or without battery

Currently, rotary saws are offered by many major manufacturers in battery electric or corded version, with 9 inch and 14 inch being the two common blade sizes. The research team did not find a 16 inch blade currently on the market to compete with the largest gasoline powered rotary saws. The typical zero-emission rotary saw has a variety of available battery packs, emits 101.1 dBA of noise at the operator's ear and costs approximately $1700 including the tool and batteries and chargers. However, note that researching specifications for battery powered tool can be extremely confusing as some prices and weights are not clearly defined as being inclusive or exclusive of battery packs. For two pack systems this can lead to wide variations in price and weight which should be clearly understood before purchase time.

Corded rotary saws benefit from endless runtime but some can trip standard 15 amp breakers and may require a 20 amp breaker for high demand use.

5.1.3 **Reciprocating Saws**

Reciprocating saws (often incorrectly referred to by the trade name “Sawzall”) use a straight metal blade (Figure 4) that is driven back and forth in a linear cutting motion where speed is measured not in revolutions per minute, but strokes per minute/second. These saws have many uses but in the context of first response are often used to cut metal during vehicle extrication. None of the respondents listed gasoline reciprocating saws in their current inventory as this type of tool rarely, if ever, is driven by a gasoline engine. Reciprocating saws are generally already zero-emission (either corded electric or battery electric). Nearly every respondent listed this as a zero-emission tool but they will not be discussed further in this report as they do not represent a shift from SSI to zero-emission.

Figure 4: Example of Corded Reciprocating Saw (image courtesy of Bosch Tools)

5.1.4 **Pole Saws**

Pole saws typically use the same type of SSI engine and blade as a conventional chainsaw but are separated by a long pole where the source of power is close to the operator. These devices are typically marketed and sold to power utility workers and forestry experts who need to clear branches that are out of reach. None of the survey respondents listed pole saws in their current inventory but they are included in this report as an SSI tool that could potentially be used by first responders and could lend itself well to being zero-emission in the future. Power utility workers are not necessarily thought of as first responders, however, in any widespread power outage their services are critical to the proper function of any community. An example is shown in Figure 5 and specifications of select pole saws are shown in Table 36 illustrating their relatively low powered engines, compared to conventional chainsaws.

Figure 5: Example of SSI Pole Saw (image courtesy of Husqvarna Tools)

Table 36: Specifications of Selected SSI Pole Saws

Make	**Model**	**Bar Size (in)**	**Rated Power (kW)**	**Displacement (cc)**	**Noise** (dBA) Pow/Pre**	**Weight (kg)**	**Fuel Tank (l)**	**Price ($)**	**Fuel Cons (l/h)**
Stihl	HT 135	12	1.4	36.3	N/A	7.9	0.51	$999	N/A
Stihl	HT 105 [90]	12	1.05	31.4	N/A	7.9	0.51	$929	N/A
Husqvarna	525DEPS [91]	12	1.0	25.4	107/91	7.4	0.49	$1499	0.53
Minimum	**N/A**	**12**	**1.0**	**25.4**	**91**	**7.4**	**0.49**	**$929**	**0.53**
Maximum	**N/A**	**12**	**1.4**	**36.3**	**91**	**7.9**	**0.51**	**$1499**	**0.53**
Mean	**N/A**	**12**	**1.2**	**30.9**	**91**	**7.7**	**0.50**	**$1142**	**0.53**

Stihl also offers a 36V battery electric version [92] and has a sound level of 83 dBA at the operator’s ear and is 1.3 kg lighter than its gasoline equivalent and costs $699 without a battery pack and approximately $1199 with two battery packs [57].

5.2 Pumps

There are two classes of pumps commonly used by first responders: hydraulic pumps and water pumps, and each have been described in greater detail in the following sections.

5.2.1 Hydraulic Pumps

Hydraulic pumps may be used for countless industrial processes but in the context of first response, hydraulic pumps are generally used to power extrication tools including spreaders, cutters, rams or combination tools. The most common types of SSI hydraulic pumps are shown in Table 37 while zero-emission models are shown in Table 38. Figure 6 illustrates how the SSI (left) and zero-emission 220V corded (right) hydraulic pumps looks nearly identical to the untrained eye.

Figure 6: Example of Extrication Hydraulic Pumps (image courtesy of Hurst.com)

Table 37: Commonly Used SSI Hydraulic Pumps in the Emergency Services Sector

Make	**Model**	**Rated Power (kW)**	**Noise (dBA)**	**Weight (kg)**	**Cost ($)**	**Fuel Tank (l)**	**Fuel Consump. (l/hr)**
TNT (Honda GXH50) [93]	BT 1.5 Nitro Pump	1.6	N/A	12.9	$4538 [97]	0.72	0.88 [102]
TNT (Honda GX200) [94]	BT 6.5	4.9	N/A	36.5	$6441 [98]	3.60	1.70 [103]
Holmatro	SR 10 PC 1 E	1.6	N/A	15.2	$7 635 [99]		0.9
Holmatro	SR 20 PC 2 CORE	2.2	85 dBA [96]	23.2	$9 661 [99]	1.70	N/A
Holmatro	DUO PUMP SR 40 PC 2	4.1	N/A	37.0	$10 711 [99]	3.00	N/A
Hurst [95]	P 635 SG (Figure 6)	2.4	80 dBA	32.7	$10 104 [100]	0.77	N/A
Champion Rescue (Honda 6.5 hp)	PW-65	4.8	N/A	31.3	N/A	3.10	1.7 [103]
Amkus (Honda GX100)	GH2B-MCH	2.1	N/A	27.0	$8 570 [101]	0.77	0.9
Minimum		**1.6**	**80**	**12.9**	**$4 538**	**0.76**	**0.9**
Maximum		**4.8**	**85**	**37.0**	**$10 711**	**3.60**	**1.7**
Mean		**3.0**	**82.5**	**26.7**	**$7 027**	**2.06**	**1.3**

The typical SSI extrication hydraulic pump has a rated power of 3 kW and a mass of 26.7 kg with a noise signature of 82.5 dBA, a fuel consumption of 1.3 litres per hour and costs $7,000. All the tools listed in Table 37 are 4-stroke since they are not hand held tools therefore weight is not as critical a specification. Noise specifications were very difficult to obtain but the use of four stroke engines should make this class of tool quieter than, say, chainsaws and the results for the Hurst unit demonstrate this.

Table 38: Commonly Used Battery Hydraulic Pumps in the Emergency Services Sector

Make	**Model**	**Battery Pack**	**Rated Power (kW)**	**Mass (kg)**	**Noise (dBA)**	**Tool Cost ($)**	**Battery Cost ($)**
Milwaukee	2774-20	18V Milwaukee 8 Ah	N/A	15.0	N/A	$6 298 [107]	$540 [111]
Enerpac	XC1201M	28V Milwaukee 3 Ah	0.37	9.0	N/A	$3 214 [104]	$370 [112]
Enerpac	XC1402M	28V Milwaukee 3 Ah	0.37	10.0	N/A	$4 027 [106]	$370 [112]
Enerpac	ZC3908JB	28V Milwaukee 3 Ah	1.0	33.3	N/A	$6 953 [105]	$370 [112]
Yale	PYB-1.0	Hitachi Li-Ion 5 Ah	N/A	6.4	N/A	$1 871 [110]	$340 [113]
Weber Rescue	B-Compact ECO	28V Milwaukee 5 Ah	N/A	12.0	N/A	N/A	
Holmatro	GBP10EVO3 (backpack)	28 V Li-Ion BPA 286	N/A	7.5	74	$8292 [99]	$1324 [99]
Holmatro	SPU 16 BC CORE	36V Li-Ion BPA 36-1	N/A	17.4	N/A	N/A	N/A
Lukas	P 605 OE	Hurst 25.2V -9 Ah	1.0	13.7	N/A	N/A	N/A
Amkus	iC500	Dewalt Flexvolt 60V	N/A	10.1	71	N/A	$450 [101]
Minimum			**0.37**	**9.0**	**71**	**$1871**	**$370**
Maximum			**1.0**	**33.3**	**74**	**$8292**	**$1324**
Mean			**0.69**	**13.4**	**72.5**	**$5109**	**$562**

The typical battery powered hydraulic extrication pump has a power rating of 0.69 kW, a mass of 13.4 kg and a cost of $5 700 including battery packs and is quite a bit quieter than their gasoline counterparts at 72.5 dBA. Some use their own battery designs while others piggyback on the battery packs of other manufacturers.

Table 39: Commonly Used Corded Hydraulic Pumps in the Emergency Services Sector

Make	**Model**	**Power Source**	**Rated Power (kW)**	**Mass (kg)**	**Noise (dBA)**	**Cost ($)**
TNT	ET- 4.0 [114]	220V	2.6	45.4	N/A	N/A
Holmatro	SR 20 HC 2 R	220V	1.8	32.8	N/A	N/A
Hurst	P635 SE	220V	N/A	36.7	N/A	$10 104 [150]
Hurst	P650 4E	220V	4.0	58.0	83* [115]	N/A
Amkus	240SS	220V	N/A	98.4	N/A	$28 050
Minimum		**220V**	**1.8**	**32.8**	**83**	**$10 104**
Maximum		**220V**	**4.0**	**98.4**	**83**	**$28 050**
Mean		**220V**	**2.8**	**58.7**	**83**	**$19 000**

*Full load at a distance of 1 m

The typical corded electric hydraulic extrication pump operates on 220V, has a power rating of 2.8 kW, a mass of 59 kg. Only one sound rating could be found, at 83 dBA.

5.2.2 **Water Pumps**

Water pumps (Figure 7) pump water from one location to another, or from one elevation to another. Urban fire fighters can generally find a reliable source of high pressure water from hydrants or from tanker trucks. However, rural fire fighters rarely have access to hydrants near a scene and sometimes tanker trucks are not available or cannot be positioned in the optimal location, therefore emergency response teams set up high powered water pumps beside a river or lake (see Figure 8) to draw water for fighting fires, sometimes (according to survey respondents) for many consecutive hours.

Figure 7: Gasoline Powered Water Pump (image courtesy of abcfireandsafety.com) [23]

Figure 8: Fire fighter Operating SSI Water Pump (image courtesy of Youtube.com) [23]

Table 40: Examples of Commonly Used SSI gasoline Water Pumps

Make	Model	Flow (l/min)	Rated Power (kW)	Disp (cc)	Weight* (kg)	Noise dBA	Tank Size (l)	Price ($)	Fuel Cons (l/h)
BE	HP2013	530	8.7	389	31.5	N/A	6.1	N/A	
Honda (GX160)	WH20XTC	500	3.6	163	23.5	99 [118]	3.1	$979	1.4 l/h
Yamaha	YP20G	640	3.0	175	29.0	N/A	4.5	N/A	N/A
Waterous	Floto [147]	530	6.0	134	19.1	107 [119]	4.7	$3831	3.76 l/h
Waterous	PB18-4025B	950	13.0	570	61.2	94	0.77	N/A	
Waterax	Rancher125 [117]	303	1.6	49.4	92.0	91 [120]	3.1	N/A	0.65 l/h
AMT	2MP5HR	606	3.6	163		N/A	5.3	N/A	N/A
CET	PFP-9HPHND-EM	757	6.3	270	52.0	N/A	3.1	N/A	N/A
Forester	NFF2	360	8.7	389	34.0	N/A	6.1	$2820	N/A
Enduraplas (Honda GX160)	Fire Ranger	454	3.6	163	106.6	99 [118]	3.6	N/A	1.4 l/h
King Canada	KCG-2WPG	466	5.2	208	22.6	N/A	3.4	N/A	N/A
Champion	100192	583		196	25.0	N/A	3.1	N/A	N/A
Echo	FP-2126	477	4.1	196	59.0	N/A	6.1	$1280	N/A
Minimum		**303.0**	**1.6**	**49.4**	**19.1**	**91**	**0.77**	**$979**	**0.65**
Maximum		**757.0**	**8.7**	**570.0**	**106.6**	**107**	**6.10**	**$3831**	**3.76**
Mean		**531.5**	**4.6**	**223.0**	**46.0**	**98**	**4.07**	**$2227**	**1.80**

*Weight taken without water (i.e. dry weight)

The research team could not find any battery electric zero-emission water pumps matching the power and flow of the gasoline models shown in Table 40. Corded water pumps are available in many sizes and flow rates, however, given the nature of rural fire fighting, a corded water pump is not practical unless a generator is co-located with the pump. This would likely be cost prohibitive and logistically challenging in terms of carrying bulky equipment over potentially long distances.

5.2.3 **Fans**

First responders make extensive use of fans to exchange air into and out of a building. There are two types of fans [141] commonly used in the industry: positive pressure and negative pressure. Positive pressure ventilation fans are used to force clean air into a building. Typically, they are high powered fans that are set up six to eight feet away from a large opening with the air flow directed towards the inside. They are used to force high volumes of air into a building to force smoke, unburned gases and heat to exit via another door or opening to be rejected to the ambient air outside the structure. Conversely, negative pressure fans are typically set up near a window or door and are used to draw smoky, toxic and hot air out of the building and exhaust to the ambient air outside. Even though they are marketed as different devices, for the purposes of equipment analysis and comparison in this study they are essentially the same product, with slightly different applications. Nonetheless, they have been shown separately in the Tables below.

Figure 9: Fire fighter Operating SSI Fan (image courtesy fireapparatusmagazine.com) [121]

Table 41: SSI Gasoline Powered Positive Pressure Exhaust Fans Specifications

Make	Model	Size (in)	Rated Power (kW)	Noise (dBA)	Mass (kg)	Fuel Tank Size (l)	Price ($)	Fuel Cons (l/h)
Ramfan (Honda GX200) [122]	GX400	21	4.1	99	40	3.1	$4819	1.7 [102]
SuperVac (Honda GX200) [123]	720G4-H	20	4.1	N/A	42	3.1	$4217	1.7 [102]
Leader (Honda GX200) [124]	MT245	22.4	4.1	96	52	3.1	$5831	1.7 [102]
Tempest (Honda GX200) [125]	DD-21-H-5.5	21	4.1	97.5	43	3.1	$3781	1.7 [102]
Minimum		**20**	**4.1**	**96**	**40**	**90**	**$3781**	**1.7**
Maximum		**22.4**	**4.1**	**99**	**52**	**120**	**$5831**	**1.7**
Mean		**21.1**	**4.1**	**97.5**	**44.25**	**106.7**	**$4662**	**1.7**

The typical gasoline powered positive pressure fan has a fan diameter of 21 inches with a rated power of 4.1 kW, putting out 97.5 dBA of noise, weighs over 44 kg, with a runtime of close to 120 minutes and a price of over $4600.

Table 42: Corded Positive Pressure Exhaust Fans Specifications

Make	Model	Size (in)	Rated Power (kW)	Noise (dBA)	Mass (kg)	Runtime (min)	Price ($)
Ramfan	XP500 [151]	18	1.10	96	33	Unlimited	$3633
SuperVac	720-EVS [152]	20	1.12	N/A	39	Unlimited	$4561
Leader	ESV245 [153]	22.4	2.20	88.7	53	Unlimited	$8435
Tempest	VS-21-G-1.5 [154]	21	1.18	90	45	Unlimited	$4513
Blowhard	BH-20 [155]	20		84	28	Unlimited	$3590
Minimum		**18**	**1.1**	**84.0**	**28**	**N/A**	**$3633**
Maximum		**22.4**	**2.2**	**96.0**	**53**	**N/A**	**$8435**
Mean		**20.35**	**1.4**	**90.0**	**42.5**	**N/A**	**$5286**

The typical corded positive pressure fan has a fan diameter of 20.4 inches with a rated power of 1.4 kW, putting out 90.0 dBA of noise, weighs over 43 kg, with an unlimited runtime (assuming a reliable AC power source is available) and a price of over $5200. Compared to gasoline, these tend to be more expensive, quieter and approximately the same weight with the advantage of never needing to be recharged or refueled as long as a steady source of AC power is available. AC power is almost never available from the building subject to the fire fighting, therefore this power must be sourced from a generator, a vehicle or from an adjacent building.

Table 43: Battery Electric Positive Pressure Exhaust Fans Specifications

Make	**Model**	**Battery Make and Size**	**Size (in)**	**Rated Power (kW)**	**Noise (dBA)**	**Mass (kg)**	**Runtime (min)**	**Tool Price ($)**	**Batt Price ($)**
Ramfan	EX150Li	2x 52V 8 Ah	18	1.4	N/A	36	45	$5215 [126]	~$3200*
SuperVac	V20-BD-SP	2xDewalt 60V-9Ah	20	0.75	N/A	28	40	$6600 [127]	~$1000*
SuperVac	V20-BL-SP	2xMilwaukee 28V-12Ah	20	0.75	N/A	28	50	$6600 [127]	~$1200*
SuperVac	V20-BH-SP	2xHurst EXWT-9 Ah	20	0.75	N/A	30	60	$6600 [127]	~$1000*
SuperVac	V20-BK-SP	2xMakita XGT 5 Ah	20	0.75	N/A	28	50	$6600 [127]	~$1000*
Leader	E-Fan 18"		18	0.65	N/A	23.6	70	N/A	N/A
Blowhard	Quickee	Lithium Polymer Battery	20		87 @ 10 ft	21	45	$4600 [128]	~$1000*
Blowhard	Commando		24		91	28	45	$6062 [129]	~$1000*
Tempest	VS-1.2D		18	0.65	83.7	23.3	40	$7032 [130]	$1083
Minimum			**18**	**0.65**	**83.7**	**21**	**40**	**$4600**	**$1000**
Maximum			**24**	**1.4**	**91**	**36**	**70**	**$7032**	**$3200**
Mean			**19.8**	**0.81**	**87.2**	**27.32**	**49.44**	**$6163**	**$1310**

*The tool requires two batteries to operate therefore four batteries have been priced

The SuperVac line of battery operated fans shown in the above table can be configured to run on the following types of battery packs: DeWalt, Makita, Milwaukee and Hurst. This allows much greater flexibility to purchase fans that are compatible with existing power tools. They are also designed to run on shore power (i.e. corded) for a $425 premium (as identified by the code 'SP' in the model numbers) again allowing for more flexibility of use.

The typical battery electric positive pressure fan has a fan diameter of 19.8 inches with a rated power of 0.81 kW, putting out 87.2 dBA of noise, weighs over 27.3 kg, with a runtime of just under 50 minutes and a price of over $6400 with all batteries and charger(s) included. Compared to gasoline, these tend to be more expensive, quieter and substantially lighter (27 kg vs. 44 kg).

Table 44: SSI Powered Negative Pressure Exhaust Fans Specifications

Make	Model	Size (in)	Displac (cc)	Rated Power (kW)	Noise (dBA)	Mass (kg)	Fuel Tank (l)	Price ($)	Fuel Cons (l/h)
SuperVac (Honda GX200)	GP187S [109]	18	196	4.1	95	34.5	3.1	N/A	1.7
Tempest (Honda GX200)	GB-18-S-5.5 [156]	18	196	4.1	95	36.8	2.0	N/A	1.7
Minimum		**18**	**196**	**4.1**	**95**	**34.5**	**2.0**		**1.7**
Maximum		**18**	**196**	**4.1**	**95**	**36.8**	**3.1**		**1.7**
Mean		**18**	**196**	**4.1**	**95**	**35.4**	**2.5**		**1.7**

Data for gasoline powered negative pressure fans was very sparse. Two 18 inch fans were found, each putting out 4.1 kW (from the same type of Honda engine) with an average mass of over 35 kg.

Table 45: Corded Negative Pressure Exhaust Fans Specifications

Make	Model	Size (in)	Rated Power (kW)	Noise (dBA)	Mass (kg)	Price ($)
SuperVac	P200S	20	0.75	N/A	38.5	$2739
Tempest	EB-16	16	1.12	N/A	30.0	$1516
Ramfan	EFC150x	16	1.1	90.2	25.0	$3084
Minimum		**16**	**0.75**	**90.2**	**25.00**	**$1516**
Maximum		**20**	**1.12**	**90.2**	**38.64**	**$3084**
Mean		**17.3**	**0.99**	**90.2**	**31.21**	**$2447**

Three corded negative pressure fans were found, ranging from 16 to 20 inches in size with mean motor size of 1.0 kW, putting out 90.2 dBA of noise and weighing over 31 kg.

The research team did not find any battery-electric negative fans for sale at this time.

5.3 Scene/Tower Lighting

Some respondents listed scene lighting as one of their current gasoline powered tools. First responders often perform their duties at night or in confined spaces therefore it is important to have a reliable source of high powered, and aimable, lighting. Scene lighting designed for shorter, smaller scenes is typically mounted on top of emergency apparatus such as aerials, engines and rescue trucks (Figure 10). However, for longer or more geographically complex scenes, first responders will often make use of towed lighting. Towed scene lights are typically mounted on top of a mast and may be raised or lowered and aimed in whatever manner is required to illuminate the scene. A typical mast mounted scene light is shown in Figure 11 and some of the common makes and models are listed in Table 46.

Figure 10: Vehicle mounted scene lights (image courtesy of Fire Apparatus Magazine) [131]

Figure 11: Towed SSI light tower (image courtesy of Generac mobile products) [132]

Table 46: Gasoline Powered Scene/Tower Lights Specifications

Make	**Model**	**Disp (cc)**	**Rated Intensity (Lumens)**	**Noise (dBA)**	**Mass (kg)**	**Runtime (min)**	**Fuel Tank (l)**	**Price ($)**	**Fuel Cons (l/hr)**
Lentry	1STARX	49.4	20 000	50	27.5	420	2.27	$ 6,116	0.7 [133]
Lentry	2STARXX	121	40 000	57	45.5	468	3.6	$ 10,062	1.1 [134]
Lentry	2SPECXXX	121	84 000	57	47	348	3.6	$ 16,664	1.1 [135]
Tele-lite	TEU-1.LEDTL6	49.4	15 000	50	20.5	240	2.27	$ 3,509	0.7
Tele-lite	NOVA-LITE [136]	196		65	63.6	366	9.84	$ 6,099	1.1
Akron	Scene Star	49.4	20 000	50	15.9	240	3.6	$ 4,401	0.7
Minimum		**49.4**	**15 000**	**50**	**15.9**	**240**	**2.27**	**$3 509**	**0.7 l/hr**
Maximum		**196**	**84 000**	**65**	**63.6**	**468**	**9.84**	**$16 664**	**1.1 l/hr**
Mean		**97.70**	**35 800**	**54.8**	**36.7**	**347.00**	**4.19**	**$7 808**	**0.9 l/hr**

The typical gasoline powered tower lighting package provides over 35 000 lumens of lighting intensity, emitting a noise of 54 dBA with a runtime of 347 minutes and a cost of over $7800.

Table 47: Battery Electric Scene/Tower Lighting Specifications

Make	**Model**	**Voltage**	**Rated Intensity (Lumens)**	**Noise (dBA)**	**Mass (kg)**	**Runtime (min)**	**Tool Price ($)**	**Battery Price* ($)**
Dewalt	DCL079R1	20	3000	0	10.84	660	$ 319 [137]	$339 [149]
Dewalt	DCL074	20	5000	0	4.65	660	$ 269 [139]	$339 [149]
Milwaukee	2120-20	18	5400	0	N/A	420	$ 598	$400
Milwaukee	2150-20	18	9000	0	N/A	210	$ 549	$400
Makita	DML814	18	3000	0	7.2	180	$ 399 [140]	$400
Makita	DML810	18	5500	0	13.9	1080	$ 499 [141]	$400
Foxfury	Nomad 360		8800	0	11.1	180	$ 3,043	N/A
Foxfury	Nomad Transformer		17600	0	24.25	180	$ 8,331	N/A
Pelican	9440	14.4	5300	0	7.3	90	$ 1,689	N/A
Pelican	9460	12	12000	0	27.7	180	$ 3,329	N/A
Streamlight	PORTABLE SCENE LIGHT EXT	12	5300	0	25.5	240	$1,489	N/A
Minimum		**12**	**3000**	**0**	**4.7**	**90**	**$ 269**	**$339**
Maximum		**20**	**17600**	**0**	**27.7**	**1080**	**$ 8,331**	**$400**
Mean		**16.7**	**7263.6**	**0**	**14.7**	**370.91**	**$1,865**	**$380**

*The price for two batteries is included

Battery powered scene lighting tends to be much less expensive than gasoline powered models. However, the lighting intensity is significantly less than that of gasoline at just over 7200 lumens compared to over 35 000 for gasoline. This is discussed in the next Section.

5.4 Generators

Generators were one of the most commonly listed SSI tools in the survey and least commonly listed item in zero-emission. Generators play a crucial role in first response as they are light enough to be located close to any scene and can power up many devices requiring various forms of AC power.

Table 48: Gasoline Powered Generator Specifications

Make	**Model**	**Rated Power (W)**	**Noise (dBA)**	**Mass (kg)**	**Runtime at Max amp (h)**	**Fuel Tank (l)**	**Price ($)**	**Fuel Cons (l/h)**
Honda	EB2200iTC	2 200	52.5	21.1	3.2	3.6	$1499	1.125
Honda	EM5000S3CT2	5 000	72	102.2	8.1	23.5	$2999	2.901
Honda	EB10000C1	10 000	72	183	5.4	31.0	$6199	5.741
Yamaha	EF2000IS	2 000	56	21	4.2	4.2	$1349	1.000
Yamaha	EF5500DE	5 500	74	103	9.0	26.0	$2249	2.889
Yamaha	EF7200DE	7 200	74.5	102	8.0	26.0	$2499	3.250
Champion	100414	2 000	53	21	7.0	4.2	$799	0.594
Champion	100247	5 500	74	72.6	7.5	22.7	$899	3.027
Champion	201043	9 500	74	94	6.5	29.17	$1500	4.488
Minimum		**2 000**	**52.5**	**21.0**	**3.2**	**3.6**	**$799**	**0.594**
Maximum		**10 000**	**74.5**	**183.0**	**9.0**	**31.0**	**$6199**	**5.741**
Mean		**5 433**	**66.9**	**80.0**	**6.5**	**18.9**	**$2221**	**2.779**

Generator specifications were extremely varied as power output can be as low as 2000 W or as high as 10 000 W which can have a dramatic effect on cost, noise, weight and fuel consumption. The typical generator was found to have a power rating of over 5000 Watts, a noise signature of just under 67 dBA with a mass of 80 kg and a run time of 6.5 hours. However, generators can be purchased with the power and size needed for the task and the data found in Table 48 are representative of a very small sample to illustrate the range of performance. Of the respondents who provided technical information regarding their current SSI generators, most stated they had generators in the 3.5 kW to 6 kW range which is typical of what can be classified as 'mid-range' generators. Many fire departments have begun to include separate small diesel driven, engine driven or hydraulically driven generators on fire apparatus to reduce the need for portable generators and provide reliable AC power, on scene, typically with power ratings between 5 kW and 15 kW.

Battery electric generators were not mentioned by any respondents, however some models are available (see Table 49). These zero-emission generators are fairly new to the market and may not be known by first responders or not yet trusted as a technology. Also, battery electric generators tend to have modest power ratings, ranging from 1 kW to 5 kW (although this is more than adequate for charging zero-emission tool batteries).

Table 49: Battery Powered Generator Specifications

Make	**Model**	**Running Power (kW)**	**Fuel Type**	**Battery Size (kWh)**	**Weight (kg)**	**Price ($)**
Bluetti	AC200P	2.0	Electric/Solar	2.000	27.2	$2,259
EcoFlow	DELTA Power Station	1.8	Electric/Solar	1.260	14.0	$1,899
EcoFlow	DELTA Max	2.4	Electric/Solar	2.020	21.8	$2,599
EcoFlow	DELTA Pro	3.6	Electric/Solar	3.600	45.0	$4,499
EGO Power	PST3040	2.0	Electric	1.680	13.7	$799
EGO Power	NEXUS PORTABLE	2.0	Electric	1.680	13.7	$1,699
Goal Zero	Yeti 1000X	1.5	Electric/Solar	0.983	14.4	$1,730
Goal Zero	Yeti 1500X	2.0	Electric/Solar	1.516	20.7	$2,660
Goal Zero	Yeti 3000X	2.0	Electric/Solar	3.032	31.6	$4,260
Goal Zero	Yeti 6000X	2.0	Electric/Solar	6.071	48.1	$6,800
Jackery	Explorer 1500	1.8	Electric/Solar	1.534	15.5	$1,999
Kohler	enCUBE	1.4	Battery (Solar)	1.200	49.4	$1,391
Portable Electric	Voltstack 5k	4.8	Electric	5.6	150.0	$28,875
Minimum		0.12		0.983	13.7	$799
Maximum		3.60		6.071	150.0	$28 875
Mean		1.14		2.475	35.7	$4 728

5.5 Tool Life Cycle Costs

The phases of tool life have been described below in terms of how they could compare between SSI and zero-emission with regards to capital costs, life cycle costs, performance, and disposal. The information found in this section is taken from theory, specification tables, marketing documents, research and this project's survey responses, all referenced accordingly. Finally, a life cycle cost model is presented for chainsaws.

5.5.1 Original Purchase Price

Original purchase price is difficult to report owing to the vast number of makes and models of tools and battery packs. Additionally, it is difficult to compare tools against one another since a very advanced SSI tool will be more expensive than a lesser zero-emission tool whereas the reverse can also be true when a very high end zero-emission tool is compared to a lower end SSI. The mean prices for all the types of tools shown in the previous section have been shown in Table 50 below, but the reader is cautioned that prices are presented for comparison purposes but may change at any time depending on many market factors. Note also that negative and positive pressure fans have been combined into one line item.

Table 50: Mean Price for Various Tools (2021/2022 prices)

Tool	Gasoline	Corded	Battery
Chainsaw	$1 431	N/A	$976
Rotary/K12 Saw	$2 269	$950	$1 735
Ventilation Fans	$4 662	$3866	$6 400
Scene/Tower Lighting	$7 808	N/A	$1 910
Hydraulic Pumps	$10 104	N/A	$5 672
Total for one complete set	$26 274	N/A	$16 663

Tool costs were fairly scattered but, for the most part, zero-emission tools were found to be, on average, less expensive for the original purchase price when compared to SSI tools. Chain saws, rotary saws, scene lighting and hydraulic pumps all tended to be less expensive, even when the price of two batteries was included. Water pumps and generators were excluded from the analysis as they did not lend themselves well to electrification for emergency response at this time. When the averages were summed, a complete suite of gasoline tools was found to be over $26 000 whereas battery electric were closer to $17 000. In this instance, the point is not to define the exact costs, as there are limitless combinations of tools, battery packs and options that could make Table 50 very confusing to understand. Rather, the point was to demonstrate that purchasing new zero-emission tools is generally not more expensive than their SSI counterparts.

Many respondents rightfully pointed out that it will be very expensive to replace all their SSI tools with equivalent zero-emission tools, however, it will not be more expensive than purchasing SSI tools. Rather, it is the justification of locating funds to replace tools that may not yet be at end of life that is more concerning to respondents. Many of them indicated a preference for using zero-emission tools, but not until their current SSI tools have reached end of life.

5.5.2 **Storage on a Vehicle or in a Building**

Many respondents indicated that storage of fuel and SSI tools on a truck poses a significant logistical challenge particularly as it relates to fuel spills. This would not be an issue with zero-emission tools. Although there are many issues related to storage of tools, none of these issues parlay into financial costs and have not been accounted for in the model below. However, until water pumps and generators are all zero-emission, some amount of fuel will need to be stored on vehicles.

5.5.3 **Scheduled Preventative Maintenance (PM)**

One of the greatest advantages that zero-emission tools have over SSI tools is preventative maintenance. The following preventative maintenance items are performed on SSI tools to ensure continued and effective use of the tool. None of these procedures are required for zero-emission tools, be they corded or battery. If chainsaws are taken as an example, only periodic cleaning, chain sharpening and bar maintenance are required PM for a zero-emission device.

Spark plugs: Although spark plugs typically can remain in a modern car's engine for as long as 160,000 km they tend to be replaced quite frequently in SSI tools to ensure clean starts and due to the way in which fuel can go stale in SSI that sit more than they are used. For the purposes of the models below it has been assumed that a $5 spark plug is required every year for each SSI tool. This frequency was corroborated by many of the survey respondents who indicated they tend to replace spark plugs more often than the manufacturer's suggested interval to ensure peak tool performance.

Oil changes/Oil mix: Four stroke tools require oil changes just as a vehicle does whereas two stroke tools require regular addition of mixed oil to the gasoline. Failure to maintain the oil levels or perform oil changes will drastically reduce the life of the engine and cause capital expenses to be much higher than necessary. For the purposes of the model below, a volume of 1/50th the volume of gasoline has been allotted for two stroke SSI and 1 Litre of oil has been budgeted for four stroke oil changes, per year per SSI tool. A cost of $8 per litre has been estimated for synthetic oil.

Air filters: All SSI require some form of air filter to ensure the incoming air does not contain dirt and debris that would score or scratch the cylinder walls and other components of the ICE. A cost of $5 per year per SSI has been budgeted for the models below.

Fuel Stabilizers: Fuel suppliers generally warn consumers that after four to five months of inactivity a fuel should be stabilized with a conditioner fluid. Many respondents indicated they do not always know how much fuel will be required per month nor do they know how much fuel will be stored in various mixes. Additionally, some organizations such as the HUSAR Task Force groups only response to three or four events a year and fuel stabilization is a major logistical issue that must be dealt with. For the purposes of this study a value of $5 per year of stabilizer per tool has been allocated.

5.5.4 **Corrective Maintenance (CM)**

It is complicated to capture all the possible corrective maintenance (CM) actions that could occur on any piece of SSI over its lifetime. However, it is fair to assume that any piece of SSI will require significantly more CM than its zero-emission counterpart. Repairs related to gummed up carburetors, adjusting ignition, brake and clutch components and overhauls are all items that would not generally be required with a zero-emission device. Unlike preventative maintenance which can easily be represented with, say, $20 a year in predicted parts there is no easy way to predict the value of the CM every year on an SSI. Additionally, most SSI will go through CM cycles where some years are very high and others are very low. Of course this can be made more stable with rigorous PM. One academic example of corrective maintenance costs for SSI chainsaws is shown in in the next Section.

An operator of an SSI powered tool who is knowledgeable in small engines can sometimes coddle a poorly running engine to get a small measure of functionality, depending on the symptoms of poor performance. However, battery electric tools generally run or don't run; there is often no middle ground as high-performance battery tools use computer controlled motors and have algorithms and sensors to protect the motors and batteries from potential damage.

Battery tools won't need the same frequency of care that SSI tools do. There are no spark plugs to check & replace, no carburetors to clean & adjust, no gasoline & oil to mix, fewer seals & gaskets to leak, and fewer moving components (recoil starter, clutches, brakes, etc.) that require regular maintenance. The trade-off is that when battery tools do need care, it is generally more expensive. While tools themselves are quite robust and can last a long time, the batteries that power them do need to be periodically replaced. These batteries are quite expensive and are usually a significant percentage of the tool's initial cost.

5.5.4.1 Study of Corrective Maintenance Costs

A 2013 study [19] published in the Croatian Journal of Forest Engineering reviewed the maintenance and repair history of 44 chainsaws used in the forestry industry in Northern Italy. The saws typically had more than 3,000 hours of use over their life cycle of 6 to 9 years. The average maintenance costs for the tools were found to be 820 Euro each ($1 088 CND), representing about 120% of the initial capital investment. The study included three Stihl and four Husqvarna chainsaws ranging from 1.6 kW to 5.2 kW, which nicely captures the range and types of chainsaws shown in Table 32 of this report. The following findings were drawn from the Croatian study:

1. The average number of maintenance actions was 31 for a service life of 3 175 hours;
2. The most common maintenance issues related to the engine and the carburettors (45%);
3. The costs for each maintenance action varied between $10 and $68;
4. Corrective maintenance costs for saws in the range of 3.2 to 4.0 kW ranged between $0.17 and $0.60 per hour of run time for an average of $0.33 per hour;
5. The breakdown for repairs was listed as follows:

    a. Engine: 27%;
    b. Carburetor: 18%;
    c. Overhaul: 17%;
    d. Chain and Bar: 13%;
    e. Ignition System: 12%

f. Safety Devices: 6%;
g. Crankcase: 4%; and
h. Starter: 3%.

Of the corrective maintenance items listed in the previous section, only the chain and bar (13%) and safety devices (6%) are relevant to zero-emission chainsaws. Based on the inputs described above, a 10 year life cycle model is presented below, showing four separate ownership streams: a very expensive gasoline chainsaw, a very inexpensive gasoline chainsaw, a zero-emission chainsaw with many battery replacements and a zero-emission chainsaw with modest battery replacements. These factors were chosen because the biggest variability in gasoline powered tools is the initial purchase prices whereas the biggest variability in battery electric tools is the cost and replacement frequency of the battery packs.

5.5.4.2 Battery Replacement as part of CM

One aspect of CM that must not be overlooked is that of battery replacement for zero-emission tools. Much has been discussed about the ease of use of battery electric tools and their lack of maintenance requirements. However, it is not feasible to assume a battery electric tool could be useful for, say, 10 years in the first response industry without at least one complete battery replacement. Even a cautious homeowner meticulously following the manufacturer's guidelines will eventually need to replace the battery packs. The nature of first response work may cause sub optimal battery cycling and charging at the incorrect temperature at a scene meaning that most battery electric tools will need a complete battery replacement once every, say, 3 to 5 years depending on use and ambient conditions. Some survey respondents indicated a noticeable degradation in battery power after just two years of operation.

Corded tools have the least amount of CM as they do not have a fuel system to maintain nor do they require battery replacements.

5.5.5 **Use at an Emergency Scene**

The way in which tools are used at an emergency scene have been described in great detail throughout the body of this report and will not be repeated here. For the purposes of this study, the costs associated with use at an emergency scene relate entirely to the fuel and charge required to run the tools at the scene. It is assumed that no maintenance is required while working at a scene.

5.5.6 **End of Life Recycling and Disposal**

Most tools have some expenses related to disposal. Gasoline tools must be drained and cleaned of all fluids and zero-emission battery tools must have their batteries disposed of in a responsible manner. For the purposes of the model below, the disposal costs for all tools has been assumed to be equal and therefore is not included in the analysis.

5.5.7 **Life Cycle Cost Analysis: SSI Chainsaw vs. Zero-emission Chainsaw**

A relatively basic ten year life cycle cost analysis was performed for SSI chainsaws and battery electric chainsaws. The assumptions and results were as follows:

Assumptions:

- 10 year life span for both;
- Yearly use of 50 hours for both;
- Yearly spark plug and air filter replacement for the gasoline tool;
- Fuel consumption of 2.4 litre per hour for the gasoline tool;
- Yearly consumption of 50 litres of gasoline;
- Yearly 1 litre of mix oil for gasoline (i.e. 50:1 mix);
- Corrective maintenance actions at $0.33 per hour of runtime [19] for gasoline tools;
- Corrective maintenance actions that are 19% that of gasoline for the zero-emission tools;
- Yearly battery charging of 100 hours for the battery electric tool;
- Gasoline cost of $2.00 per litre;
- Mix oil cost of $8.00 per litre;
- Electricity cost of $0.12 per kWh based on charging from the grid. (Note: this becomes more complex if charging from a generator that is already running at the scene but burning a fossil fuel); and
- Corded chainsaws have been ignored as they do not have an assured future in the industry.

Table 51: Estimated 10 Year Life Cycle Costs for Chainsaws, High-Low Analysis

Item	**Gasoline (low)**	**Gasoline (high)**	**Battery Electric (low)**	**Battery Electric (High)**
Initial Purchase	$429	$2 864	$716	$1 499
Preventive Maintenance	$100	$100	$0	$0
Corrective Maintenance	$165	$165	$31	$31
Battery Replacement	$0	$0	$738	$1 220
Mixed Fuel/Charge/Electricity	$2 490	$2 490	$180	$180
Total	$3 184	$5 589	$1 665	$2 930
Mean	$4 387		$2 298	

The analysis shown in Table 51 presents four scenarios where scenario 1 is the least expensive gasoline chainsaw and scenario 2 is the most expensive gasoline chainsaw but all other operational expenses are held constant for scenarios 1 and 2. Scenario three is the least expensive battery electric chainsaw with the least expensive battery packs being replaced twice over the 10 year life cycle. Scenario four is the most expensive battery electric chainsaw with two complete battery replacements over the life cycle with all other operational expenses held constant. As could be expected there is a wide variation in life cycle costs depending on the make and model of saw selected. The mean expected ten year life cycle costs for all gasoline chainsaws shown in Table 32 is $4 387 and for the electric saws shown in Table 33 is $2 298 for battery electric.

Based on the assumed inputs, it is possible that a zero-emission chainsaw could be less than half the cost to operate over a ten year life cycle, for a total projected savings of more than $2,000 per saw, largely based on the contribution of fuel costs. The model assumes two complete battery pack replacements but even with four complete replacements the costs could still be roughly the same as gasoline. These numbers assuage some of the concerns mentioned by the industry regarding the way in which battery replacements could negate any cost savings of owing a zero-emission tools. The lack of fuel and reduced maintenance costs should make owning a zero-emission chainsaw less expensive over a ten year period. Particularly as pump gasoline prices are rising to never before seen levels (more than $2.30 for premium unleaded at the time of report preparation) while battery pack prices are dropping every year (or said another way, consumers may purchase more powerful packs for the same price as before).

5.5.7.1 Life Cycle Cost Analysis: Two Stroke SSI Rotary Saw vs. Zero-emission Chainsaw

A similar life cycle costing was performed for SSI and zero-emission rotary/K12 saws using the same assumptions and the same maintenance data as the chainsaws. The only real difference in the two studies being the original purchase price and the price of the batteries and the fuel consumption of the SSI tool, which was assumed to be 1.61 litres per hour of mixed fuel. The results are shown in Table 52.

Table 52: Estimated 10 Year Life Cycle Costs for Rotary Saws, High-Low Analysis

Item	Gasoline (low)	Gasoline (high)	Battery Electric (low)	Battery Electric (High)
Initial Purchase	$1 225	$4612	$950	$3546
Preventive Maintenance	$100	$100	$0	$0
Corrective Maintenance	$165	$165	$31	$31
Battery Replacement	$0	$0	$738	$2000
Mixed Fuel/Charge/Electricity	$1 610	$1,610	$180	$180
Total	$2 680	$6 067	$1 929	$5787
Mean	$4 374		$3 858	

Again, there was a wide variability of prices but, on average, the zero-emission rotary saws should be approximately $500 less expensive to operate over a ten-year time period than the SSI equivalent.

For each of the examples developed in this section the battery electric tools were found to be, on average, less expensive to operate than their SSI counterparts. Chainsaws and rotary saws were used as examples as they both represent tools that are currently available but not widely used by first responders. It is expected that analyses of other equipment, such as scene lighting and hydraulic pumps would yield similar results as each of them requires fuel and maintenance that are not required with zero-emission tools.

6 MARKET RESEARCH AND PERFORMANCE ANALYSIS

The survey responses dealt with a myriad of opinions, experiences and statements of fact. Many of the responses were qualitative in nature, such as “I find the tool very heavy”. To quantify the specifications of the tools and confirm or refute the opinions of the respondents, a full market research and performance specifications analysis was performed to ensure decisions could be made based on documented manufacturer data. The following sections compare the printed specifications, independent of costs, of gasoline and zero-emission tools to dispel any myths or conflicting opinions.

To prioritize the list of tools, Table 16 and Table 21 were combined to provide a comparison between the types of gasoline tools that were reported versus zero-emission tools. Table 53 is sorted in descending order of prevalence of gasoline tools with the corresponding zero-emission tool shown to the right with its percent response.

Table 53: Tool Priorities Based on Survey Response Rate

Type of Tool	Gasoline Use	ZE Use
Chainsaws	32	3
Water Pumps	29	1
Generators	29	0
Rotary Saws/K12	23	2
Fans/Exhaust/Positive Pressure Fans	21	12
Extrication Tools/Jaws of Life	19	18
Hydraulic Pumps	17	2
Scene Lights	8	15
Heaters	5	3
Cutters/Spreaders	4	5
Augers	4	1
Jackhammers/Concrete breakers	4	3

As expected, the higher horsepower tools tended to be more highly reported in gasoline format whereas the lower power tools tended to be a blend of both gasoline and zero-emission. The most notable trends were as follows:

- Scene lighting was the only zero-emission tool that is currently used more than its gasoline counterpart;

- 100% of all generators reported in the study were gasoline powered. This is clearly an item that is either not available to first responders or is available but not trusted by the sector;

- Despite the widespread availability of zero-emission chainsaws by many manufacturers, there were very few zero-emission chainsaws and rotary/K12 saws. It would appear there is still a reluctance on the part of the industry to adopt zero-emission high power saws;

- Heaters, fans, scene lights and hydraulically driven extrication tools were split between gasoline and zero-emission. All of these devices tend to be lower in power and thus can be designed with various forms of input power;

- Nearly all water pumps were listed as being gasoline powered. Even though two water pumps were listed as being zero-emission, the respondents indicated the pumps were very low power helper pumps rather than high power pumps capable of pushing large volumes of lake water to a fire;

- No respondents listed using gasoline powered air compressors other than the towing and recovery operator who indicated that their compressors were driven off the vehicles' engines;

6.1 CO_2 Emissions

There is no sense in comparing emissions of gasoline powered tools to those of zero-emission tools as, the name implies, zero-emission tools do not create emissions at the usage site. However, when comparing how CO_2 emissions of small tools compare to gasoline generators that are operating expressly for the purpose of charging batteries or powering corded zero-emission tools it will be important to quantify the level of emissions produced by the more common tools used by first responders. These values will be important inputs for the discussion and Case Studies in Section 7 of this report.

Table 54: Average emissions and fuel consumption for classes of SSI engines

Class of Tool	**Fuel Consumption (l/h)**	**CO_2 (kg/h)**
Chainsaws	0.8 to 3.1 litres per hour	2 to 7.4 kg/h
Rotary saws/K12	1 to 2 litres per hour	2.4 to 4.8 kg/h
Exhaust Fans	1.7 litres per hour	4.1 kg/h
Extrication Tools	0.9 to 1.7 litres per hour	2.1 to 4.1 kg/h
Generators	0.3 to 1.7 litres per hour	1 to 4.1 kg/h
Scene lights	0.7 to 1.1 litres per hour	1.7 to 2.6 kg/h
Water Pumps	0.65 to 3.76 litres per hour	1.6 to 9.0 kg/h

In general, the fuel consumption data were retrieved from manufacturer data sheets and then CO_2 emissions per hour values were calculated using the formula of 2.41 kg of CO_2 being generated for every litre of gasoline burned and 2.67 kg/l for diesel. There was a large variety of emissions and fuel consumption rates amongst all the SSI tools, particularly for generators and water pumps which had a large range of engine size. Handheld tools, due to their compact design, tended to have a narrower range of emissions with nearly all handheld devices burning approximately 1 to 2 litres per hour of fuel. Larger more stationary tools may have larger tanks and larger engines and thus burn upwards of 4 litres an hour, or more. However, for the purposes of rough calculations, it is fair to state that most first response SSI tools burn between 0.7 and 2 litres of fuel per hour. These values will be used later for some of the case studies.

6.2 Weight

Weight was one attribute that caused confusion when analysing the results, as some respondents indicated their gasoline tools were lighter than zero-emission tools whereas other respondents indicated the opposite. The mean of the weights, taken from the Tables in Section 4, are summarized in Table 55. The weights include a full tank of fuel for the gasoline models and the requisite number of batteries for the zero-emission tools.

Table 55: Average mass of various classes of SSI and Z-E tools

Class of Tool	**Gasoline (kg)**	**Zero-Emission (kg)**	**Difference (kg)**
Chainsaws	7.0	5.3	2.3
Rotary saws/K12	11.1	7.9	3.2
Exhaust Fans	44.0	27.0	17.0
Extrication Pumps	26.7	13.7	13.0
Scene lights	37.0	15.0	18.0
Mean	**25.16**	**13.78**	**10.7**

In the field of first response, lighter is highly desirable for hand-held tools as it reduces fatigue and effort carrying tools to and from the site and up ladders etc. All classes of battery electric tools tended to be lighter than their gasoline counterparts. However, it should be noted that some types of battery powered tools (most notably scene lights) had substantially less output compared to SSI, with a corresponding reduction in weight.

Despite being more complex electrically, battery tools are simpler mechanically as they do not require the mass of metallic engine parts required in an SSI tool (engine block, cylinder liners, pistons, connecting rods, valves etc). A gasoline fueled chainsaw (or K12 saw) will have a clutch so the engine can be started without engaging the tool, and a brake to stop the tool, but a battery tool manages both with the electric motor and generates 100% of its torque at 0 rpm. The tool draws no power while "idling" thus the motor is not energized and does not require a clutch. For braking, the motor is used for regenerative braking, converting the tool's kinetic energy into electrical energy, or by actively driving the motor in reverse. In both cases, the electric motor provides a convenient, wear-free equivalent to their mechanical counterparts, resulting in a mechanically simpler tool (which can help in not only weight reduction, but reliability). Battery electric devices do not require a push primer, a choke, a recoil unit and pull start, all of which should make the zero-emission tool lighter.

Another aspect related to tool mass/weight is balance point. The weight and balance of a gasoline powered tool changes as the fuel is drawn down whereas the weight and balance of a battery electric tool never changes (unless a different size of battery is selected). Manufacturers of zero-emission tools have an advantage that battery packs may be placed strategically to improve balance points for their tools whereas SSI manufacturers must place the tank in the safest position, relative to the exhaust components which can lead to tools that are not as balanced as zero-emission tools.

When it comes to tool weight, zero-emission tools will most of the time be lighter than a similar size gasoline engine tool.

6.3 Noise/sound

All survey respondents who mentioned tool noise levels, indicated their zero-emission tools were quieter than similarly sized gasoline tools and nearly all respondents indicated that one of the downsides to SSI tools is noise. However, this information was anecdotal in nature and not based on results obtained via a calibrated sound measurement device.

There is a distinction between sound power level and sound pressure level that should be understood in the context of manufacturer's printed specifications. Bruel and Kjaer are a well established company in the sound measurement field and they define sound pressure and sound power on their website [27] as follows:

> "*Sound power is the total airborne sound energy radiated by a source per unit of time"*
>
> whereas
>
> "*Sound pressure is the result of sound sources radiating energy that is transferred into a specific environment and measured at a specific location".*
>
> *In effect, sound power is the cause and sound pressure is the effect".*

For the purposes of understanding how sound can affect a first responder's health, it would normally be more important to understand the value of the sound pressure at the operator's ear(s) rather than the absolute noise power emanating from the machine. Note also, that a first responder may be holding a high noise tool like a chainsaw but there may be many other sources of noise nearby which all add up to provide even more total noise pressure than the sound pressure caused by the tool in the first responder's hands. Similarly, the tool may not be very close to the operator's ear but it could be much closer to a casualty's ear which could cause distress or long term pain for the casualty.

As an example, a review of major chainsaw manufacturers' websites (see Tables in Section 4) revealed the average noise pressure at the operator's ear area was 105 dBA for gasoline powered chainsaws while the average for battery electric chainsaws was 88.4 dBA. The maximum posted value for gasoline powered was 117 dBA for three Stihl model chainsaws whereas the loudest battery electric chainsaw was the Husqvarna 540i at 95 dBA. The greatest sound reduction caused by electrification was found to be for scene lighting where a gasoline powered engine that indirectly powers lights via a generator/alternator is replaced with a set of batteries that directly power the lights without any need for a motor thus, making scene lights essentially silent.

Although many of these noise level values seem fairly similar, one must recall that the decibel scale is logarithmic which means small numerical differences represent large differences to the operator. To understand how the human ear perceives a difference in measured sound level, one must use the following formula:

1) Measured sound level 1 – Measured sound level 2 = X
2) Exponent Y = X/10
3) Difference = 10^Y

An example relevant to this study is presented as follows:

1) Typical gasoline chainsaw sound pressure level: 105 dBA

2) Typical battery electric chainsaw sound pressure level: 88.4 dBA

3) 105.0 – 88.4 = 16.6

4) Y = 16.6/10

5) Y = 1.66

6) Difference = $10^{1.66}$

7) Difference ~ 45.7

In practical terms, a tool giving a sound pressure of 105 dBA (SSI) at the operator's ear is perceived as being more than 45 times louder than a tool emitting 88.4 dBA (zero-emission).

A study [20] performed by the faculty of forestry at Bursa Technical University in Turkey analysed the noise emissions from a Stihl MS250 chainsaw to understand how these noise emissions might affect the workers using the saws. In the Turkish report they presented all the known health hazards resulting from exposure to noise which generally agree with similar findings by Yale University [26] who state that long term hearing loss may occur after prolonged exposure to 80 to 90 dBA. Table 56 outlines the range of noise levels and the range of expected results due to the exposure while Table 57 illustrates the maximum daily exposure times for healthy living from two sources, firstly the Turkish study [20] and secondly from the Occupational Health and Safety pages from hearing conservation website [28]. These two sources displayed values that were nearly all different by a factor of 2 therefore both have been presented knowing the current acceptable levels will likely fall in between these two values for most organizations.

Table 56: Effects on Human Health from Various Sound Levels

Noise Level (dBA)	**Expected Result**
0 to 35	Non destructive noise
36 to 65	Annoying noise that may disturb sleep
66 to 85	Annoying and mentally damaging leading to ear disorders
86 to 115	Causes mental and physical harm and leading to psychological disease
116 to 130	Hazardous noise causing deafness
131 to 150	Very dangerous noise, unbearable without protection
Greater than 150	Immediate ear damage

Table 57: Maximum Recommended Exposure Times to Various Sound Levels

Noise Level (dBA)	Maximum Recommended Exposure Time (Hours) [20]	Maximum Recommended Exposure Time (Hours) [28]
90	4	8
95	2	4
100	1	2
105	0.5	1
110	0.25	0.5
115	0.125	.25 or less

The physical effects of excessive noise exposure are well understood and immediately obvious to the operator who feels the pressure in their ears over the short term or could experience hearing loss over the long term. However, the authors of the Turkish study [20] also made mention of the less obvious physical and psychological effects of excessive noise exposure. These can include such conditions as high blood pressure, slowing of neural reactions, irritability and a reluctance to perform work of a similar nature in the future. Nearly all these side effects affect the operator, however, in the context of first response work, reluctance to use a tool due to noise exposure could have an effect on a casualty at a scene.

Based on the research, it is generally accepted that 85 dBA is the limit for safe exposure whereas anything above 90 dBA has been shown to all but guarantee some risk to the operator and levels above 115 will cause permanent hearing loss if purpose-built ear protection is not worn [20]. Some of the tools shown in this report have printed noise levels at or above 115 dBA and are therefore considered high risk tools for hearing loss.

In the Turkish study, the saw had a printed sound pressure level of 99 dBA at the operator’s ear and a total sound power level of 111 dBA. The actual measurements recorded during the study showed a sound level of 95.4 dBA (between 88.6 dBA and 100.8 dBA sample) during the undercut stage of felling and 86.7 dBA (between 84.9 dBA and 91.8 dBA sample) during the backcut stage. The study concluded that the operator is exposed to varying degrees of noise pressure depending on the operation and it is expected that this would also be true for first response work where the angle and distance between the saw and the operator could vary tremendously depending on the task. Therefore, an operator can never experience more than the printed sound level power from the saw but they can receive less, depending on their proximity to the tool. All of this assumes only one source of noise in the immediate area therefore the addition of other tools being operated by other first responders will obviously add to the overall ambient noise levels at the scene.

Given that the average battery electric chainsaw is significantly quieter than the gasoline counterparts it stands to reason that hearing loss as well as other health effects would be less of an issue compared to gasoline tools of the same size. However, at an average noise level of 88 dBA there are still long term health risks to prolonged exposure to zero-emission chainsaws and proper hearing protection should still be used, regardless of the type of chainsaw being used in the types of power class discussed in this report. Selected tool type sound pressure levels are shown in Table 58.

Table 58: Average Sound Pressure Specifications of SSI and Z-E tools

Class of Tool	Average Sound Pressure at Operator's Ear (Gas)	Average Sound Pressure at Operator's Ear (Zero-Emission)	Perceived Difference at the Operator's Ears (X)
Chainsaws	105 dBA	88.4 dBA	45 times
Rotary saws/K12	100.5 dBA	101.1 dBA	1.15 times
Positive Pres Exhaust Fans	97.5 dBA	87.2 dBA	10.7 times
Negative Pres Exhaust Fans	95.0 dBA	90.2 dBA	3 times
Scene lights	54.8 dBA	Negligible/ 0 dBA	Infinite
Generators	66.9 dBA	Negligible/ 0 dBA	Infinite
Water Pumps	98.0 dBA	Not available at this time	N/A

It is beyond the scope of this report to quantify the potential long-term improvements to human health because of the noise emissions of various pieces of equipment, but nearly all forms of zero-emission tools generate less noise, some much less, than their SSI cousins (rotary saws being the exception). This should parlay into real health and safety benefits not only for first responders but potentially also to casualties. Many respondents listed noise as a negative side effect of using SSI tools.

With respect to noise emissions, zero-emission tools are almost always quieter than the SSI tool they replace, some by a wide margin.

6.4 Runtime

None of the respondents indicated their zero-emission tools could operate for as long as their gasoline counterparts, however, this is anecdotal in nature and may not be based on comparing tools of similar power and performance under the same conditions. One of the challenges of calculating runtime for tools such as chainsaws is the cyclic nature of their use. Chainsaw runtime can be reported based on various types of on/off cycling and cutting various hardness and thicknesses of wood and at various load levels. This makes it difficult to make an equitable comparison between two or more different makes and models.

Similarly, a tool manufacturer may list their tool as having, say, a 40 minute runtime with a 5 Ah battery, however, the operator will receive a fraction of this run time should they use a 1 Ah battery instead, even if the battery was fully compatible with the given tool. For these reasons, it is virtually impossible to compare the runtime of a gasoline tool to its zero-emission counterpart.

Although tempting to use as data for this report, the research team avoided the use of Youtube video performance tests, as none of them were conducted in a scientific manner and could have led to incorrect or biased conclusions. In each of these videos, runtime comparisons were conducted with batteries of different capacities thus leading to potentially erroneous conclusions.

As a result of this ambiguity it is critical to consider the metric of "charge to use" ratio as the defining factor for zero-emission run time. This is the arithmetic ratio of how long it takes to recharge a battery compared to how much useful time it delivers to the tool as a result of that 100% state of charge. As an example, a battery pack that requires 1 hour to charge and delivers 20 minutes of useful tool life would have a ratio of 3 to 1. This metric is not often used for gasoline tools as it only takes a minute to refuel an SSI tool.

As an example of the potential for confusion when buying a saw, take the Stihl TSA 230 battery powered cut off rotary saw. The Stihl website lists two very different theoretical run times for the same TSA 230 saw: 15 minutes for the AP 180 battery and 75 minutes with the much more expensive AR900 backpack battery. Each pack delivers power at 36V but the total amount of available energy is very different (178 Wh for the AP180 and 891 Wh for the AR 900). Additionally, the price is reflective of the power difference with the smaller battery listing at $199 and the large pack at $1079 as of report preparation.

Users and purchasers must realise that manufacturers' claims of high run time may be associated with very large and expensive battery packs as shown in Figure 12 that may also conflict with the self contained breathing apparatus already strapped to the backs of first responders. Operators will have to perform cost benefit analyses and suitability analysis to make educated purchases with respect to battery packs. Additionally, the concepts of run time and recharge time are very different and must be calculated separately and then combined to produce an overall tool availability. The way in which runtime could affect first response work is explained in Section 6.9.

Figure 12: Example of Battery Backpack (image courtesy of Stihl.com)

Table 59: Average Runtime of Selected SSI tools

SSI Tool	Expected Runtime
Chainsaws	17 to 22 minutes
Rotary saws/K12	29 to 42 minutes
Exhaust Fans	1.5 to 2.0 hours
Extrication Pumps (Table 36)	48 minutes to 2 hours
Generators	3 to 9 hours
Scene lights	3 to 8 hours
Water Pumps (Table	1.3 to 4.7 hours

The information found in Table 59 will be considered the benchmarks for comparison against zero-emission tools in terms of run time and tool availability from full charge to depletion as these are the runtimes that first responders have become accustomed to experiencing.

6.5 Recharge Time

The amount of time required to recharge zero-emission tool batteries at a scene was listed as one of the biggest concerns of first responders. Survey respondents indicated they normally show up to a scene with gasoline supplies varying from 10 litres to 30 litres, or more, depending on the size and number of vehicles deployed to the emergency. Conversely, many respondents indicated they do not currently stock enough battery packs to avoid charging during the emergency. Additionally, some respondents indicated a general lack of understanding relating to battery state of charge (compared to reading a fuel level in a gasoline tool) and how best to cycle their battery packs to ensure not only health at the scene but battery longevity.

Corded electric tools plugged into the grid's AC supply never require refuelling. Generators and vehicles used to power corded tools may require re-fueling. Gasoline powered tools generally take less than a minute to refuel from empty, assuming fuel is located close at hand. Swapping a dead battery pack with a charged battery pack generally takes less than 30 seconds. However, the time to recharge the battery in a battery electric tool is more difficult to quantify as there are wide variations in battery size, battery health and battery state of charge, each potentially altering the time it takes to re-charge a battery (or to prevent full charge). Sites such as Youtube.com and various tool blogs are filled with testimonials and non-scientifically conducted examinations of battery recharge time with results that are scattered and presented in a potentially biased manner preventing them from inclusion in this report.

The concept of 'recharge' requires defining as it can mean different things to different people, or can mean different things in different situations. Additionally, it is important to understand there is a difference between battery replacement/swapping time and charging time. Each of which are used in tool availability calculations. Another complication is compatibility: all four stroke SSI tools will operate on the same pump gasoline and a fleet of two stroke SSI tools can generally be operated on one, or at most two, blends of fuel and oil. Battery operated tools may be managed with one type of battery pack, or many types of battery packs depending on the number of manufacturers.

In terms of SSI tools, the following attributes must be considered: the tool's fuel tank, the fuel, the portable fuel container and the gasoline station/vendor. In terms of time, the following must be considered: the time to acquire the fuel, the time to move the fuel from the safe zone to the site of the emergency and the time to pour the fuel into the tool's on-board tank. Throughout this report it is assumed that first responders will show up to a scene with enough portable fuel containers filled with fuel to last the entire emergency and that all these containers are located within the collapse/safe zone which would normally be less than 100 m from the actual emergency. However, this may not always be the case as some scenes last for days (e.g. HUSAR type work) while others may be located many hundreds of meters (or possibly kilometers) from the stockpile of fuel (e.g. a fire occurring in a Provincial Park or at sea).

In terms of battery electric tools, the following attributes must be considered: the tool's battery pack, the charging base and the charge/current flowing into and out of the battery. In terms of time, there is the time for the charging base to charge the pack from 0% state of charge (or whatever is considered "dead") to 100% state of charge and the time it takes to remove a pack and replace it with a charged pack. The number of batteries is also a variable, as well as the number of charging bases.

A comparison may be drawn as follows: gasoline to an SSI is as charge is to a battery-electric tool and the portable fuel container is to SSI what the battery pack is to battery electric tools. The portable fuel container and the battery pack hold the fuel whereas the gasoline and the charge are the fuel. But, to make fair comparisons between SSI and battery electric in terms of re-charge time it is necessary to understand the total amount of fuel on site and the total number of batteries on site. In other words, re-fuel/re-charge times become irrelevant if enough fuel and batteries are on site but for the sake of calculations this can be highly variable and can greatly affect comparative results. Many respondents indicated they always have fuel on site but they do not always have sufficient quantities of batteries to ensure a steady supply of 100% charged packs, however, as zero-emission tools become more popular this will undoubtedly change. Similarly some respondents indicated they felt that having multiple portable fuel containers on site is much cheaper than having many batteries on site, given the current cost of batteries.

The concept of re-charge time is highly variable and abstract unless all the variables are known. It is for this reason that tool 'availability' is the more important metric in terms of what first responders will experience at a scene. The concept of tool availability has been explored in depth in Section 6.9 and is a better way to compare zero-emission tool performance versus that of SSI.

In terms of SSI, the time to re-fuel a tool can be affected by the following factors:

- The size of the fuel tank;
- The distance between the collapse/safe zone and the actual emergency;
- The volume of fuel brought to the site;
- The distance between the scene and the closest fuel station that is open at the time of need;

In terms of battery electric, the time to re-charge a battery can be affected by the following factors:

- Battery size (e.g. 1 Ah vs. 5 Ah);
- The type of battery (e.g. Li-Ion vs. Ni Cad)
- The type of charger (i.e. quick charge vs. regular charge);
- Temperature/Ambient conditions;
- The health of the battery;
- The battery state of charge (SOC) at the beginning of the recharge cycle; and
- The number of compatible batteries at the site.

Most of these topics are described in separate sections below:

6.5.1 **Battery Size**

As could be expected, battery size plays a very significant role in charge and run times and although it is not perfectly linear, it is roughly linear, so a rough correlation between pack size and charge time may be made. For example, on its website [138], Makita lists the following charge times for their line of XGT fast chargers:

- 2.5 Ah = 28 minutes (11.2 minutes per Ah);
- 4.0 Ah = 45 minutes (11.3 minutes per Ah); and
- 5.0 Ah = 50 minutes (10.0 minutes per Ah).

Similarly, Milwaukee makes the following claims for its batteries, with more examples shown in Table 60 below:

- 3.0 Ah CP203 = 45 Minutes (15 minutes per Ah); and
- 6.0 Ah XC406 = 90 Minutes. (15 minutes per Ah).

The Makita values have been plotted in Figure 13 to illustrate the nearly linear relationship between charge time and battery size, in amp-hours. Given that the ratio between charge time and run time would be critical to first response, it stands to reason that the 5.0 Ah pack, in the example above, would be the pack of choice. Its recharge rate of 10 minutes per Amp Hour is less than the other two packs, by a fairly slight amount, and would provide the longest runtime of the three. Ultimately, first responder will want to use batteries that have the longest runtime with the lowest recharge to use ratio (or lowest time to recharge per Ah). But what must be noted is that throughout this report there is frequent mention of battery packs in the 5 Ah to 9 Ah range which have been specifically selected for their application with higher power tools but these larger batteries will require upwards of 50 minutes to recharge using standard chargers, in the best of conditions.

First responders will have to understand the relationship between battery size and charger type to estimate the recharge to use ratio for any combination of tool. Using the currently available specifications, the following charge time per battery amp hour (i.e. size of battery) has been developed:

- Using a standard charger: 18 to 25 minutes per Amp Hour;
- Using a fast charger: 10 to 16 minutes per Amp Hour;
- Using a super charger: 5 to 6 minutes per Amp Hour;

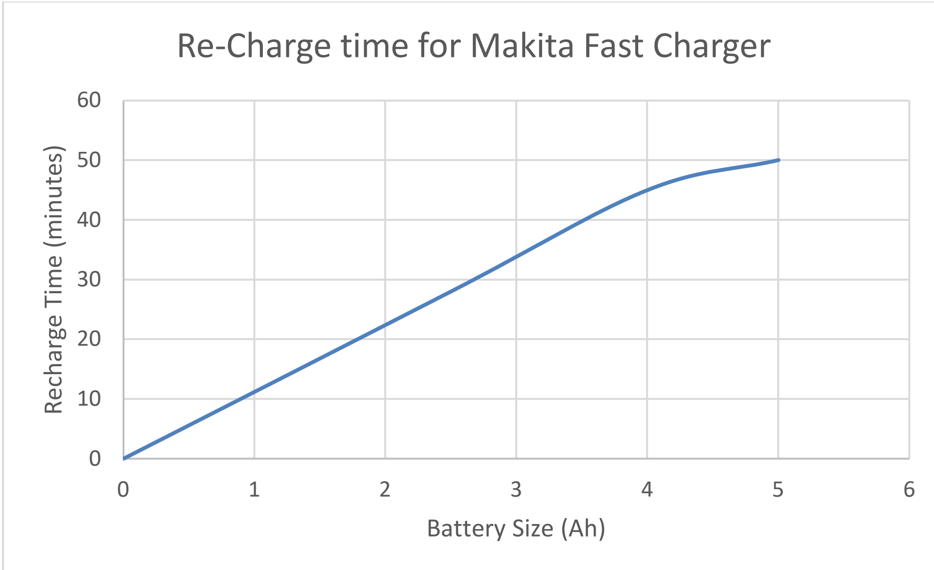

Figure 13: Charge Time vs. Battery Size (data courtesy of Makita.com)

When considering these issues as they relate to on road vehicles, one of the main drawbacks of a long-range battery electric vehicle is the corresponding long re-charge time (assuming the owner consistently uses the same level of charging). Although battery swapping in road vehicles is being explored, currently road vehicles have but one integral battery pack. Unlike vehicles, a battery electric tool can, in theory, be run indefinitely if the operator has enough charged batteries close at hand. If say, a tool's battery pack has a runtime of 20 minutes and a recharge time of 60 minutes, an operator need only have three battery packs and two charger cradles and the tool should be able to run continuously with proper coordination by the operator. Therefore, for emergency services, it is not so much the runtime that is critical but the number of batteries and charging stands that are required to provide an equivalency of runtime with a gasoline powered tool. The concept of 'range anxiety' that has prevented the mass adoption of battery electric vehicles should not exist in first response work, provided staff plan ahead with the correct number of batteries and chargers to maintain tool use.

Along with recharge time comes the metric of 'Use to recharge ratio' which is a unitless measure of how much useable run time an operator will receive for every unit of time used to charge the unit.

6.5.2 **Battery Type**

There was a time when operators had to choose between Li-ion batteries and Ni-Cad batteries. However, at the time of report preparation only Li-Ion batteries are being sold as viable options for large battery electric tools. Battery chemistries may change in the future which could alleviate some of the challenges associated with charging Li-Ion in cold weather but these advancements are not forecasted in the near term. First responders wishing to maximize the performance and longevity will need proper training to fully understand the correct handling and charging techniques for Li-Ion batteries. Many of these features have been described in the following sections.

6.5.3 **Type of Charger**

Most major tool manufacturers now offer standard chargers and rapid/fast charger. Milwaukee has recently announced a third charger called the super charger which greatly accelerates charge times for some of its battery packs. Milwaukee's claims [145] are shown in Table 60 with the caveat that charge times are highly variable depending on various parameters such as state of charge and ambient/battery temperature.

Table 60: Printed Charge Times for Various Types of Milwaukee Battery Chargers

	M18 HD12.0 (min)	**M18 XC8.0 (min)**	**M18 XC6.0 (min)**	**M18 CP3.0 (min)**	**M18 HD9.0 (min)**	**M18 XC 5.0 (min)**	**M18 CP2.0 (min)**	**M12 XC3.0 (min)**	**M12 CP2.0 (min)**
Super	60	45	35	35	103	60	25	46	30
Fast	130	83	64	35	103	60	25	46	30
Normal	241	153	119	65	184	105	42	55	43

Given the variability of charge times shown in Table 60 it will be very important for first responders and procurement officers to understand what charger they are acquiring and how this could affect tool availability, or the number of batteries required to achieve a desired availability. For example, with the M18 HD 12.0 Ah battery, an unsuspecting purchaser could erroneously tell a fire chief they will only need 60 minutes to charge their batteries but if they mistakenly purchase the normal charger, this time will be 241 minutes, more than four times longer.

Care must be taken to understand the ramifications of charger type and how this will affect tool availability at a scene. Failure to understand charge time could result in much higher costs due to the purchase of many more batteries than expected to achieve a forecasted tool availability or a reduced runtime and tool availability.

6.5.4 **Ambient and Battery Temperature**

The challenges of cold ambient temperature and battery performance are twofold: the way in which the tool behaves while in use and, the way in which the batteries recharge. On its website, Hurst claims that their 25.2V batteries function down to -20 C [108] but make no reference to power degradation or recharging at cold temperatures. Even as a best case scenario working at -20 C, this will not be sufficient for many emergency scenes all over Canada. Several respondents in rural and northern communities indicated it is very common for them to respond to scenes at ambient temperatures below -30 C and they must remain there for hours at a time with no hope the temperatures will climb. This is a potentially significant issue that will need to be addressed as it is not practical for first responders to cover up battery packs while in use or remove packs temporarily to store them in their PPE. Personnel are used to the convenience of gasoline tools that work at any temperature, once they are started. Cold starting of SSI tools was listed as a source of frustration by respondents who indicated that SSI tools often need to be stored in vehicles between use to ensure starting at temperatures below -20 C. This strategy may need to be employed for battery electric tools as well to ensure optimum performance and charging. However, this will not allow battery electric tools to work for extended periods of time in ambient temperatures that are simply too cold for continuous operation. Cold starting SSI tools at extremely low temperatures is challenging but once the tool is started it should run at any temperature as long as it is fed with gasoline.

Battery temperature can greatly affect charge performance for Lithium Ion batteries [29]. Li-Ion can be fast charged from 5 deg C to 45 deg C, however, most chargers will automatically cease the charging process as soon as battery temperature drops below 0 deg C as internal damage will occur due to plating of metallic lithium on the anode. Even at 5 dec C the charge rate should be reduced. In a study performed in 2016, researchers in Australia [25] performed testing and developed a cold weather model to predict the effects of temperature on battery charge time, battery performance and battery state of charge. They determined that the internal impedance effect can significantly affect the performance of the battery to the point where capacity was reduced to 7% to 23% of the cell's original charge level (100%). They pointed out that this degradation in available power would not be acceptable for many applications.

Conversely, Li-Ion can be charged at relatively high temperatures, but this can affect the life span of the battery pack and most chargers will automatically turn off at temperatures above 50 deg C to prevent both cylindrical and pouch style packs from damage.

Battery and ambient temperatures could be a significant factor for charging capabilities for first responders working in subzero temperatures. First responders do not have the luxury of working indoors or delaying their work until the weather warms up. For first responders to achieve the types of charge times advertised by manufacturers it will be critical to setup charge stations inside vehicles or inside heated tents that maintain equipment above a pre-determined level, as is already done with portable radios and other current types of battery powered tools.

In a worst case scenario, all the batteries at a scene could be discharged and so cold they cannot be charged until such time as they are warmed up. This could cause, at best frustration, and at worst, a risk to human health for casualties at a scene. This issue will have to be well understood and backup plans involving the use of gasoline tools, for at least the near term, may be required in locations where temperatures routinely dip below zero and chargers cannot be kept warm.

6.5.5 **Battery Health/Age**

All Lithium-ion batteries begin to lose health the moment they undergo their first charge/discharge cycle. This slow decline in health continues until the battery has undergone so many charge/discharge cycles it becomes unusable for any user requiring a certain level of performance or run time. This phenomenon exists for cell phones as well as they quite often need to be replaced due to an inability to hold a charge even though all other features remain fully functional.

Tests conducted by Cadex [30] on 11 types of Lithium-ion cell phone batteries concluded that, on average, most cells will go from 95% capacity to 75% capacity after as few as 300 to 500 cycles. For some cell phones this can happen is less than two years but would likely require many years to achieve for the types of tools used in first response. However, some very busy departments did claim to use their power tools every day, which could result in over 300 charge cycles per year which has the potential to alter the life cycle costs of zero-emission tools should batteries require replacement every two years.

6.6 The Compromise of Battery Charge Time and Battery Lifespan

On its website, Dewalt tools [148] describes what owner/operates should do to maximize battery health and lifespan. Some of their tips include:

1. Batteries should not be left to become totally depleted before they are put on the charger. Rather, a battery should be placed on the charger the moment the operator notices a degradation of performance;

2. Li-Ion power tool batteries tend to not suffer from ‘memory’ since the duty cycles of most tools are sufficiently variable the batteries cannot ever have a memory like cell phone batteries which tend to discharge at the same rate every single day;

3. Dewalt suggests the following sequence of events for optimum charging and battery lifespan:
    1) Remove the battery from the tool when the tool experiences a power loss;
    2) Let the battery sit for two hours;
    3) Place the battery in the charger;
    4) Allow the battery to charge at room temperature for eight hours;

4. Batteries must be charged between 4 C and 40 C;

5. Inverter type generators are designed to provide ‘clean’ power to safely charge electronics whereas conventional generators can provide ‘dirty’ power that can damage sensitive electronics. However, according to their website, all current Dewalt batteries can be charged with conventional or inverter type SSI/diesel generators. This would be an important feature to note when zero-emission tools are integrated into an organization’s existing fleet of equipment;

Many of these manufacturer recommendations, meant to prolong battery life, are in direct conflict with first response work, particularly ones related to slow charging at room temperature. Many first responders indicated concerns related to the life span of batteries yet they will be unwittingly breaking many of the recommendations meant to prolong battery life as a result of the nature of their work. It will not be practical for first responders to charge batteries slowly at room temperature and they may, from time to time, allow a tool to become totally depleted. Even though battery lifespan may suffer from some of these practices, it is not likely that first responders will be able to alter their usage rates as completing a task will always be more important than tool longevity while the task is being completed.

6.7 World Supply of Lithium

A representative from a major tool manufacturer indicated the world supply of lithium could affect tool prices in the future. Lithium is not a plentiful element in the world and its distribution is closely controlled and monitored as many industries rely on a steady supply of lithium. Lithium is used for batteries in the smallest of handheld devices as well as full size pickup trucks. As supplies diminish, this could severely affect the price of tools since automobile manufacturers can outbid tool manufacturers for lithium since the profit margin for, say, a $40,000 vehicle is much higher than for, say, a $300 power tool. As a result of this, tool manufacturers may need to research alternate power sources, or consumers may be faced with higher tool prices as the price of lithium rises to reflect the lower stocks. Improved recycling practices and development of new Lithium supplies in North America could help alleviate this issue.

6.8 Proprietary Battery Pack Architecture

Nearly every major manufacturer markets its own line of proprietary battery pack and battery pack charging system. None of these architectures are interchangeable thus requiring operators to either own a vast array of charging stations, or to commit entirely to one brand of tools to have 100% interoperability amongst all its tools. The proprietary nature of battery packs was one of the major negative aspects listed by many of the respondents. Some of the major types of charging systems are shown in the subsections below.

6.8.1 **Voltage Systems**

The pack voltages currently provided by some of the battery electric manufacturers are listed in Table 61.

Table 61: Currently available type of battery packs

Manufacturer	**Li-Ion Voltages Offered**
Milwaukee	USB, 4V, 12V, 18V, 28V (M Fuel), 72V MX
Ryobi	18V (One +), 40V
Dewalt	20V, 40V, 60V/120V (Max)
Husqvarna	36V, 40V
Makita	10.8V, 12V, 14.4V, 18V/36V, 40V/80V
Stihl	36V
Hurst	25.2V
Holmatro	28V
Echo	58V
Bosch	18V (Power for All)

6.8.2 **Milwaukee**

Milwaukee Tools uses the “M” battery system of battery packs, as shown in Figure 14 which includes 12V, 18V and 28V packs. Milwaukee battery chargers can be used to charge 12V and 18V batteries simultaneously. Milwaukee also carries a line of high voltage packs which operate at 72V and can be used for high power tools such as generators (Figure 15).

Figure 14: Examples of Milwaukee Battery Packs

Figure 15: Examples of Milwaukee MX 72V Battery Packs

6.8.3 **Dewalt**

Dewalt has phased out its 18V line in favour of a multi pack 20V, 60V system, all with latching mechanism that is similar, but not directly interchangeable with Milwaukee and Makita. Dewalt has developed a system of interoperability which allows 20V and 60V batteries to be used on any tool and some may be used in series to provide higher voltage (e.g. two 60V batteries combined in series to make 120V). Examples of Dewalt Flexvolt batteries are show in Figure 16.

Figure 16: Examples of DeWalt Flex Volt Battery Packs

6.8.4 **Ryobi**

Ryobi currently use the One + 18V battery pack system with an input stem latch that is entirely different than any other manufacturer as well as the newer 40V slide model. A photo of a One + 18V stem battery is shown in Figure 17 and its latest 40V slide battery is shown in Figure 18. Not only are these two designs not interchangeable with other manufacturers' packs, they are not interchangeable with each other in Ryobi products.

Figure 17: Example of 4 Ah Ryobi One + Battery Pack

Figure 18: Example of 2 Ah Ryobi 40V Slide Battery Pack

6.8.5 **Hurst**

Hurst manufactures the brand name 'Jaws of Life' and uses a proprietary 25.2V power pack. One of their batteries is shown in Figure 19 (ebay).

Figure 19: Example of Hurst Battery Pack

6.8.6 **Husqvarna**

The Husqvarna system is shown below and can only be used in Husqvarna tools. See Figure 20.

Figure 20: Example of Husqvarna Battery Pack

6.8.7 **Makita**

The Makita system is visually similar to that of Milkwaukee and Dewalt but not interchangeable with either of those other system. An example is shown below:

Figure 21: Examples of Makita 5 Ah Battery Packs

6.8.8 **Stihl**

Stihl uses the AI, AP and AK systems of battery packs which bear no resemblance to other companies and are not interchangeable in any way. Some of their battery packs are shown in Figure 22:

Figure 22: Examples of Stihl Battery Packs

6.8.9 **Narrow versus Broad Manufacturer Tool Availability**

Note: the following paragraph is meant to demonstrate a market point and should in no way be construed as JDP Transportation Solutions, or its principal, endorsing any particular product or manufacturer.

Historically, if a first response organization wished, they could purchase tools based on reputation (be it real or perceived) of being the best in that specific class of tool. As an example they could select a Stihl chainsaw, a Husqvarna rotary saw, a Blowhard fan, a Honda generator and so on. Given that they all ran on gasoline, they could use each piece of equipment without any concern for sourcing energy. However, the recommendations in this report clearly indicate it would be preferable to commit to one manufacturer for all battery electric tools for the sake of battery commonality but this creates a product issue as many manufacturers such as Husqvarna and Stihl produce a relatively narrow line of cutting tools whereas manufacturers such as Makita, Milwaukee, Dewalt and Ryobi each manufacture literally hundreds of types of tools. It will become more and more difficult for first responders to justify purchasing narrow manufacturer product-lines such as Echo, Stihl and Husqvarna if that company's battery pack is proprietary and they do not offer a line of tools that include flashlights, cordless drills, reciprocating saws, circular saws etc. The broader tool manufacturers will likely begin to claim a much greater market share of first response tools and first responders may be frustrated if they know they should purchase based on commonality rather than the actual preferred tool for the job (again, be it real or perceived). This could result in a difficult decision between the best tool for the job and one with battery pack commonality.

6.8.10 **Battery Pack Sharing**

To combat the issues discussed in the previous section, some narrow product line manufacturers source their battery packs from another company's proprietary line of battery packs. One example of this is the line of extrication tools sold by Amkus. Their battery electric extrication tools use various sizes and styles of Dewalt battery packs. This may alleviate some of the concerns regarding proprietary battery pack architecture if a single manufacturer's battery pack can be used across a variety of product lines, which would reduce the number of batteries required at a scene. Using this as an example, an organization could purchase an entire suite of Dewalt tools as well as Amkus extrication tools and know they could use the batteries in all of their tools, from flashlights to high pressure extrication pumps.

6.8.11 **Conversion Kits**

Despite the proprietary nature of all the battery packs shown in this Section, re-sellers do manufacture conversion kits for using one manufacturer's pack in another one's tools. However, these only assist with tool use and do not allow for one manufacturer's pack to be charged with another manufacturer's charger. Additionally, many of these devices can power up more than two different companies' battery packs and thus are only practical if an organization has two different types of tools, say, for example Milwaukee and Dewalt. Canadian Tire has recently marketed a system called "PWR POD" that can be used as an interchange system, but only between Mastercraft, Simoniz, Woods and Motomaster products. Ideally, any one organization would commit to one brand of tools to allow for maximum charging flexibility at a fire scene but it apparent that manufacturers are beginning to acknowledge the need for battery conversion kits. An example of a Dewalt/Milwaukee multi charger is shown in Figure 23.

Figure 23: Example of Dewalt and Milwaukee Multi Pack

With regards to battery packs, many respondents indicated the lack of commonality was a major impediment to their operation or would force them to commit to one brand. Even committing to one brand was not seen as an ideal solution as many manufacturers will change their own designs every five to ten years under the guise of performance enhancements but this, of course, increases revenue for the company at the same time. The ideal tool for many emergency situations is un-tethered and immediately fueled with a generic fuel. Gasoline tools enjoy both features, whereas corded electric and battery electric have but one each. However, it is not likely the Federal Government will be able to mandate a generic battery power pack integration format in the next five to ten years as the industry would not be able to accommodate this after spending so much R and D on developing their individual systems. Only something like a Canadian Standards Association (CSA) national standard would allow such a common architecture to be developed, but this is not likely to happen in the near to mid term.

6.8.12 Battery Packs and Government Tool Procurement

Whereas gasoline and corded tools each run on generic and ubiquitous power sources, battery electric tools are almost all operated on some form of proprietary battery pack, sometimes more than one per manufacturer. This could lead to a troubling situation for many first response organizations. Unlike private industry, governments are tied to strict procurement and contracting rules and processes. The exact details of these rules are outside the scope of this report, however, it is fair to state that Federal, provincial and municipal governments all have to abide by some form of competitive process for procurement to ensure the receiving organization does not act with bias when selecting a product, in this case a tool, or suite of tools. A typical procurement bid process would proceed as follows:

1. The organization identifies the product requirements in a written document;
2. The manufacturers bid on the request for products, based on the specifications outlined in the document;
3. The organization rates the bids for technical merit;

4. The technical scores are reviewed and ranked; or those bids that are not technically compliant are rejected;
5. The low bidder is selected from the list of technically compliant bids (or some combination of technical and price scoring where the low bidder receives 100% on the financial score);
6. The winner is then invited to sell their product to the organization, in this case, say, a municipality with a fire department.

The following two hypothetical scenarios have been presented as plausible outcomes of two very different requests for tools. The town of Pleasantville needs five different types of power equipment: chainsaws, rotary saws, scene lighting, ventilation fans and water pumps. Due to the high cost of first response tools and the very limited budget of the small town, the Mayor has indicated these plans must span five fiscal years. In each scenario the fire department launches five successive requests for proposal (RFP) in five successive fiscal years to ensure they have replaced all their tools over the next five years. In each scenario, the following types of tools are needed in the next five years and contracts are won as follows:

- 2024: Chainsaw contract won by Manufacturer 1;
- 2025: Rotary saw contract won by Manufacturer 2;
- 2026: Scene lighting won by Manufacturer 3;
- 2027: Fans won by Manufacturer 4; and
- 2028: Water pumps won by Manufacturer 5.

Scenario 1, gasoline tools: Although this may not be ideal in terms of training, maintenance and spare parts, these are typically not concerns at an emergency scene. Regardless of the number of manufacturers who may have won these bids, all the tools run on the same fuel: pump gasoline (be it two stroke mix or four stroke pure).

Scenario 2, battery electric tools: Now consider the same manufacturers won each of these same competitions, but this time with battery electric tools. In this scenario, the first responders must manage five different types of battery packs at an emergency scene. Not only does this present a huge logistical challenge, it poses a safety risk to casualties as the source of power cannot be interchanged, whereas gasoline can be interchanged (so much so that four stroke gasoline can be transformed into two stroke gasoline in less than a minute). In scenario two, if the chainsaw runs out of power, the battery pack from, say, the rotary saw cannot be interchanged.

Several respondents noted they would be willing to carry one extra battery pack on their PPE/jackets a spare which would be seen as a huge advantage over gasoline in that fire fighters are expressly forbidden from carrying gasoline on their person, for obvious reasons. However, this advantage is quickly lost if they would have to carry multiple manufacturer’s proprietary packs. The current size of battery packs makes it impractical for first responders to carry multiple battery packs in their PPE, however, this could change in the future as battery technology allows packs to become much smaller..

In order to ensure reverse compatibility with existing tools, organizations will have to write requests for proposals that include requirements for battery compatibility. Otherwise, there is risk that organizations may end up with many different types of battery packs with each yearly tool purchase. End-users and contracting authorities will have to collaborate on this topic to ensure first responders do not become mired in the logistics of managing, say, five different types of battery packs as a result of contracting and supply rules.

6.8.13 **Charging Architecture Standard**

The concept of universal charging architecture is not unique to power tools. Charge ports and cabling also exist in the cell phone and electric vehicle industries where much standardization work has already been accomplished. The same kind of effort could help alleviate some of the issues that have been identified above. Examples from other sectors are provided below.

6.8.13.1 Electric Vehicles

Although electric vehicles are largely out of scope for this project, a similar situation could have existed in the automotive industry if all electric vehicle manufacturers designed unique and proprietary charging stations and cabling. However, as a result of work by many governing bodies and some planning there are only a handful of electric vehicle charging protocols for each level of charging.

Level 1: Standard 120V outlet common to all homes and businesses in North America;

Level 2: SAE J1772 and Tesla; and

Level 3: Tesla, CCS (J1772 expanded) and CHAdeMo.

Not only are there many fewer standards when compared to battery electric tools but some of the different protocols may be used with each other via the use of adapters. The adaptors are as follows:

- An adapter to charge a Tesla from CHAdeMo sold for a cost of $450;
- There are no adaptors between CCS and CHAdeMo meaning many charging stations must carry both these features;

6.8.13.2 Cell Phones

Over the past twenty years there have been at least five cell phone charge cables that are all incompatible with each other: micro USB, Type A, Type B, Type C and Apple Lightning. As charging cords and charging protocols evolve all but two of these have disappeared for conventional cell phones and personal electronic devices: USB C and Apple lighting. Despite only having two cords, the European Union (EU) has recently launched a program to develop an EU standard that would eliminate the use of various types of cell phone charger systems in favour of a single architecture, most likely the USB-C.

The EU cited a desire to increase sustainability and reduce electronic waste across all 27 member nations [143] as the driving force behind the initiative.

6.9 Tool Availability and Runtime Comparisons

Vehicle or equipment availability is a term that is used to define the percentage of time a piece of equipment, or fleet of vehicles, is available for use as opposed to the percentage of time the equipment is not available for use. For example, in the urban transit industry it is a measure of how often a fleet of buses is available compared to when they are in the garage for maintenance or inspections. The term has been modified slightly for this report to define the percentage of time a tool could be used compared to the percentage of time it is not available due to recharging/re-fueling. A tool availability of 100% is next to impossible to achieve but organizations can put measures in place to achieve near-100% levels with proper planning.

Tool availability for SSI equipment is well understood and relatively easy to calculate but it will be important to understand what conditions will need to exist for a piece of battery powered equipment to at least match its SSI equipment equivalent in terms of unit availability. As stated earlier, any zero-emission tool can achieve near 100% availability but the number of batteries required for any tool to achieve this goal must be calculated in advance, for all environmental conditions.

Small gasoline tools have a wide range of fuel tank sizes, ranging from about 0.6 litre for the smallest of chainsaws to more than 30 litres for a large generator. However, despite this wide variation in size, it is relatively simple to estimate the time it takes to refuel any gasoline tool mentioned in this study. Unless there are complications, most gasoline powered tools can be re fueled in one to two minutes, depending on the fuel tank size. Additionally, the time it takes to refuel a tank is not affected by temperature or the general condition of the tool itself nor can you reduce fill times by purchasing more expensive tools. The time to fill a gasoline tank is highly predictable and relatively quick for all forms of SSI tools. Several survey respondents indicated they shut down equipment before re-fueling but must routinely perform hot-refuels and must manage the risks of fuel being spilled on hot exhaust components via the use of articulating/reticulating spouts/nozzles which can be aimed directly into the tank. Additionally, first responders receive frequent training regarding the dangers of hot-refuels. This risk is not present with zero-emission tools.

Corded tools have the highest tool use availability rate, provided a reliable source of 120/240 VAC power is available. As long as the tool can receive power and it does not incur any maintenance breakdowns its availability will be 100% at an emergency scene.

Unlike gasoline and corded tools, there is no simple formula for the time it takes to recharge a battery pack. Battery packs studied in this project come in sizes ranging from 1 Ah to 12 Ah and not only would a 12 Ah pack take approximately 8 to 12 times longer to charge than a 1 Ah pack, factors such as state of charge, charger type and temperature can also greatly affect the charge time. For these reasons it is difficult to estimate tool availability as the recharge times can vary tremendously. As shown in Section 6.5, many battery packs require somewhere between 1 to 4 times on the charger compared to the runtime in the tool. This factor will be used in the following calculations:

6.9.1 **Availability: Gasoline Powered Saws vs. Battery Electric Saws**

6.9.1.1 Gasoline Tools

In this example, the data for a variety of gasoline powered chainsaws and rotary saws are shown in Table 62 and Table 63, respectively, where the data points are as follows:

- Tank size: Manufacturer's printed tank size, taken from specification tables;
- Fuel Burn Rate at WOT: Tested fuel consumption rate at wide open throttle (WOT), taken from specification tables;
- Fuel Burn Rate at WOT: The value in column three converted to litres per hour using the assumption that fuel mixed with oil has a density of 0.75 kg/litre;
- Tank Depletion Time at WOT: The tank size found in column 1 of each Table divided by the value in column 4 divided by 60 minutes per hour, to acquire a runtime for each saw, expressed in minutes of runtime for a complete fuel tank.

Table 62: Runtimes of Various Chainsaws

Model	**Tank Size (litres)**	**Fuel Burn Rate at WOT (kg/hr)**	**Fuel Burn Rate at WOT (l/hr)**	**Run Time at WOT (min)**
Echo CS7310P	0.80	1.75	2.33	20.6
Husqvarna 562	0.66	1.74	2.32	17.1
Husqvarna 395	0.90	2.30	3.07	17.6
Husqvarna 572	0.76	1.76	2.35	19.4
Husqvarna 576	0.70	1.75	2.34	18.0
Makita EA7900	0.75	2.00	2.67	16.9
Mean	**0.76**	**1.88**	**2.51**	**18.3**

Table 63: Runtimes of Various Rotary Saws

Model	**Tank Size (litres)**	**Fuel Burn Rate at WOT (kg/hr)**	**Fuel Burn Rate at WOT (l/hr)**	**Run Time at WOT (min)**
Husqvarna K1270	1.25	1.31	1.75	42.9
Husqvarna K770	0.80	0.81	1.08	44.4
Husqvarna K970	1.00	1.04	1.39	43.3
Makita EK7651H	1.10	1.20	1.60	41.3
Makita EK8100	1.10	1.70	2.27	29.1
Mean	**1.05**	**1.21**	**1.62**	**40.2**

As seen in Table 62 and Table 63, chainsaws and rotary saws typically used by first responders have runtimes of approximately 18 minutes and 40 minutes, respectively, at wide open throttle (WOT). These values are highly variable depending on the type of product being cut and the way in which the operator manages the throttle trigger, however, for the purposes of this study runtimes of 18 and 40 minutes will be used as a reasonable assumption.

Using the data from Table 62, all the chainsaws would require three full re-fuels (at minutes 18, 36 and 54) in one hour of WOT operation and would have some fuel remaining after that first hour. Individual results would vary but, in general, most conventional SSI chainsaws would have tool availability at a scene as follows:

60 minutes – (2 minutes x 3 refuels) = 54 minutes

54 minutes/60 minutes = 90% available

Even if refueling were to take three minutes, the tool availability would still be 85%. A chainsaw availability of between 85% and 90% is then taken as the baseline as what first responders have become accustomed to, also noting that this availability is not affected in any way by temperature or the size of the saw.

Similarly, for rotary saws, the following availability may be calculated based on the need for one full re-fuel during the first hour of operation:

60 minutes – (2 minutes x 1 refuel) = 58 minutes

58 minutes/60 minutes = 96.7% available

These calculations assume the portable fuel container are very close to the location of the required refuel. As the distance between the portable fuel container and the scene increases, the tool availability decreases. Some examples illustrating how the time to retrieve fuel affects availability are shown in Table 64 where a ten minute delay to retrieve fuel can change a chainsaw's availability from 90% to 40% and that of a rotary saw from 97% to 80%. However, several survey respondents indicated that fuel is generally stored as close as possible to the scene to minimize travel time, or a fully fueled backup tool may also be positioned close to the scene.

Table 64: Availability of Saws Based on Proximity to Fuel Source

Time to Retrieve Fuel	**Time to Refuel**	**Chainsaw Availability**	**Rotary Availability**
0 min	2 mins	90.0%	96.7%
1 min	2 mins	85.0%	95.0%
2 min	2 mins	80.0%	93.3%
3 min	2 mins	75.0%	91.7%
4 min	2 mins	70.0%	90.0%
5 min	2 mins	65.0%	88.3%
6 min	2 mins	60.0%	86.7%
7 min	2 mins	55.0%	85.0%
8 min	2 mins	50.0%	83.3%
9 min	2 mins	45.0%	81.7%
10 min	2 mins	40.0%	80.0%

6.9.1.2 Battery Electric Tools

If a similar approach were to be taken for battery electric tools, availability could be estimated as follows, using an assumption that changing a battery pack takes less than one minute (in reality, if a pack is close at hand it takes less than 10 seconds).

Although it is tempting to use the manufacturer's runtime and charge time data they can be very misleading as runtime is highly affected by the size of the battery pack and not all manufacturers use the same pack size for their comparisons. Similarly, recharge times are very unpredictable as they can be affected by the type of charger and the temperature of the pack and the surrounding air as well as the age and general health of the battery. For these reasons, manufacturer runtime estimates were ignored and in their place calculated tables of many runtimes and recharge times were created to allow the reader to see the possible range of tool availabilities and the number of batteries that may be required to match the runtime and availability of SSI tools. The tables below were created as follows:

In scenario one, shown in Table 65, a battery electric tool is being operated with only one battery pack. The battery pack begins at 100% state of charge (SOC) and the operator uses the tool until it is depleted, then places the battery on the charger until it is fully charged again. This cycle is repeated for a period of two hours (120 minutes). In this scenario the tool's availability is quite low.

In scenario two, shown in Table 66, a battery electric tool is being operated with two battery packs. The two battery packs begin at 100% SOC and the operator alternates between using the tool with battery #1, then recharging pack #1 while using pack #2 and so on and so on. In this scenario there are times when both packs are on the charger, thus reducing tool availability but availability is much higher than with one pack.

Scenario three, shown in Table 67, and scenario number four, shown in Table 68 were developed using the same methodology as with two battery packs, but with three and four battery packs, respectively.

Again, it is important to note that runtime itself is not nearly as important a metric as availability. An SSI chainsaw may only have a runtime of 18 minutes but has a tool availability of over 90% in one hour as long as little as 5 litres of fuel is nearby.

The research team noted some tools require one battery, some require two batteries simultaneously, while others can run on one or two batteries. Note that in the tables below, the terms '1 pack' or '2 pack' refers to the number of complete swap overs therefore if a tool requires two battery packs to be installed simultaneously into the tool for normal operation, the term '1 pack' would actually mean two individual battery packs for both run time and charge time, and so on.

Table 65: Tool Availability, Various Run and Recharge Times, One Battery Pack

		Battery Recharge Time, 10 minute increments. One Battery Pack											
		10	20	30	40	50	60	70	80	90	100	110	120
Tool Run Time (min)	10	50%	33%	25%	25%	17%	17%	17%	17%	17%	17%	8%	8%
	15	63%	50%	38%	38%	25%	25%	25%	25%	25%	17%	13%	13%
	20	67%	50%	50%	42%	33%	33%	33%	33%	25%	17%	17%	17%
	25	75%	63%	50%	42%	42%	42%	42%	33%	25%	21%	21%	21%
	30	75%	67%	50%	50%	50%	50%	42%	33%	35%	25%	25%	25%
	35	83%	67%	58%	58%	58%	50%	42%	33%	29%	29%	29%	29%
	40	83%	67%	67%	67%	58%	50%	42%	33%	33%	33%	33%	33%
	45	83%	75%	75%	67%	58%	50%	42%	38%	38%	38%	38%	38%
	50	83%	83%	75%	67%	58%	50%	42%	42%	42%	42%	42%	42%
	55	92%	83%	75%	67%	58%	50%	46%	46%	46%	46%	46%	46%
	60	92%	83%	75%	67%	58%	50%	50%	50%	50%	50%	50%	50%

Table 66: Tool Availability, Various Run and Recharge Times, Two Battery Packs

		Battery Recharge Time, 10 minute increments. Two Battery Packs											
		10	20	30	40	50	60	70	80	90	100	110	120
Tool Run Time (min)	10	100%	92%	83%	75%	67%	58%	50%	42%	33%	17%	17%	17%
	15	100%	92%	83%	75%	67%	58%	50%	42%	33%	25%	25%	25%
	20	100%	100%	92%	83%	75%	67%	58%	50%	42%	33%	33%	33%
	25	100%	100%	92%	83%	75%	67%	58%	50%	42%	42%	42%	42%
	30	100%	100%	100%	92%	83%	75%	67%	58%	50%	50%	50%	50%
	35	100%	100%	100%	92%	83%	75%	67%	58%	58%	58%	58%	58%
	40	100%	100%	100%	100%	92%	83%	75%	67%	67%	67%	67%	67%
	45	100%	100%	100%	100%	92%	83%	75%	75%	75%	75%	75%	75%
	50	100%	100%	100%	100%	100%	92%	83%	83%	83%	83%	83%	83%
	55	100%	100%	100%	100%	100%	100%	92%	92%	92%	92%	92%	92%
	60	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 67: Tool Availability, Various Run and Recharge Times, Three Battery Packs
s

		Battery Recharge Time, 10 minute increments. Three Battery Packs											
		10	20	30	40	50	60	70	80	90	100	110	120
Tool Run Time (min)	10	100%	100%	96%	92%	88%	83%	79%	75%	71%	67%	63%	59%
	15	100%	100%	100%	96%	92%	88%	83%	79%	75%	71%	67%	63%
	20	100%	100%	100%	100%	96%	92%	88%	83%	79%	75%	71%	67%
	25	100%	100%	100%	100%	100%	96%	92%	88%	83%	79%	75%	71%
	30	100%	100%	100%	100%	100%	100%	96%	92%	88%	83%	79%	75%
	35	100%	100%	100%	100%	100%	100%	100%	96%	92%	92%	92%	92%
	40	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	45	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	50	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	55	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	60	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 68: Tool Availability, Various Run and Recharge Times, Four Battery Packs

	Battery Recharge Time, 10 minute increments. Four Battery Packs												
		10	20	30	40	50	60	70	80	90	100	110	120
Tool Run Time (min)	10	100%	100%	100%	92%	83%	75%	67%	67%	67%	67%	67%	67%
	15	100%	100%	100%	100%	96%	92%	88%	83%	79%	75%	71%	67%
	20	100%	100%	100%	100%	100%	100%	92%	88%	83%	79%	75%	71%
	25	100%	100%	100%	100%	100%	100%	100%	96%	92%	88%	83%	83%
	30	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	35	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	40	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	45	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	50	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	55	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	60	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

The data shown for chainsaws are tailored to the fuel tank size of SSI chainsaws whereas the four tables above do not represent data from any one tool manufacturer and apply to any battery electric tool, not just chainsaws, with any battery size. The tables include a wide range of possibilities and are bounded with some specifications that may not currently be available, but presented to show the full boundaries of actual and potential operation. Studying the tables, one could make the following observations:

1. Some combinations of charge and run time are unrealistic, such as 60 minutes of runtime with only 10 minutes of charge time but have been included to capture possible future technology advancements. Similarly, it is not normal to require 120 minutes of charging for 10 minutes of runtime but this is plausible in extremely cold weather and has been shown to illustrate the effect on availability;

2. Having just one battery pack is not practical for first response as it only allows 90%+ tool availability for tools that can operate at WOT for more than 50 minutes, which is not expected under most conditions and could never be counted upon in emergency situations. Very few, if any, manufacturers are currently offering high powered tools with runtimes over 50 minutes at WOT and certainly not with charge times of 10 minutes;

3. Even with two battery packs, run times of less than 25 minutes or recharge times of more than 25 minutes will not provide first responders with the tool availability they are used to. With two battery packs, a recharge to run time ratio of 1 to 1 is required to maintain 100% availability. This type of performance is typically only found with fast charge systems;

4. Having three battery packs greatly improves tool availability but availability could be lower than expected for run times less than 20 minutes or re-charge times greater than 30 minutes. With three battery packs, the recharge to runtime ratio cannot be higher than about 2 to 1 to assure 100% availability. This is the type of performance that some, but not all, battery chargers may provide;

5. Having four battery packs, improves the situation again, but availability could be lower than expected for run times less than 15 minutes or re-charge times greater than 40 minutes. With four battery packs, the re-charge to runtime ratio can be as high as 3 or 4

to 1 which allows for a fairly slow charge rate and is typical of even conventional chargers;

6. It is not until an operator has six batteries that a tool availability of 100% can be all but guaranteed for any situation. In order to achieve SSI-like tool availability for any given situation it is best to review the charts above and ensure that operation can fall within any of the cells with entries at, or approaching, 100% if full tool availability is required;

7. Operators will have to bear in mind that a steady supply of batteries is useless without an appropriate number of chargers. Given that no tool on the market provides enough batteries to achieve 100% availability in their original kit, there will be an added financial burden to purchase extra batteries ($100 to $500) and chargers ($100 to $300) to achieve the types of availabilities discussed in this section. However, unlike gasoline, these are assets rather than consumables;

8. The tables above assume that someone is paying attention to the battery charge levels and constantly monitoring and swapping batteries between the tool and the chargers. This may require assignment of duties that are currently outside the scope of first response work. This question (4-11) was posed in the interview and some respondents indicated they were concerned with this facet of battery tool logistics whereas other respondents indicated they would learn to deal with this via training and re-assignment of duties.

Some first responders indicated that finding gasoline at 3 AM is much more difficult than charging batteries at 3 AM whereas other respondents indicated the reverse, saying they were never far from an all but guaranteed supply of gasoline, 24 hours a day. Given that tool availability is based on a supply of reliable energy it will be important for operators to understand which form of energy can be more easily obtained in the middle of the night, if tool availability is critical 24 hours a day.

Also note that recharge times will be higher and run times will be lower, possibly by a wide margin, in extremely cold temperatures meaning that a tool availability of, say, 90% in ideal conditions could, in reality, be much lower than 90%. In a worst case scenario, the tool would function upon arrival at the scene and none of the batteries could be recharged upon first depletion due to cold temperatures. In such cases, a heated battery charging area would be required to maintain the desired availability levels.

Several respondents mentioned that first response is not a business of satisfying one client and then resting. Rather, no matter how much energy and time is expended at one scene they must all be prepared for the next scene, which could be minutes after leaving the previous scene. Long recharge times were listed as not acceptable for first response since there is not a predictable dwell time between occurrences and driving back to the station with, say, 20 depleted batteries could be problematic for the next occurrence.

The concept of proprietary battery packs is also key to this issue: if a first responder were to suddenly lose power in a battery electric tool and ask a co worker for a replacement battery but the co worker was using a tool from another manufacturer there would be no way for the two to share power. Similarly, it is common in suburban and rural areas for multiple fire departments from different jurisdictions to respond to a given scene, making it even more likely that different types of incompatible battery packs would be found at one scene. All the calculations above assume a steady supply of the only type of battery that fits with that given tool. Unlike gasoline, energy sharing is not possible between manufacturers.

It is expected that these calculated values will provide the most valuable insight into what types of equipment could be electrified without sacrificing equipment availability and response time to an emergency. Run time is a major barrier to battery electric tool adoption and many other features will be seen as irrelevant to first responders if the runtime is not adequate and purchasing enough batteries to provide the desired runtime availability will be key to operator acceptance and public safety.

6.10 Battery Life Cycle/Degradation Over Time

Many respondents mentioned how battery life span could, and would, affect their decision making regarding the purchase of battery electric tools compared to corded or gasoline tools. The way in which batteries degrade over time and the way in which this could affect the tool's return on investment is described in this section.

6.10.1 General

One of the pitfalls of gasoline tool ownership centers around the constant need for clean fuel (mixed or clear) and the maintenance requirements to ensure the carburetor remains free of varnish and gum. Many survey respondents listed 'grab and go' as one of the biggest advantages of zero-emission tools compared to the labour intensive ownership requirements of similarly sized gasoline tools. For many respondents, the labour requirements of owning SSI tools and attempting to start the tools in cold conditions created significant frustration when rapid deployment is important.

However, the 'grab and go' convenience of a battery electric tool can change as the tool's battery pack ages, thus causing issues in terms of charge retention and power delivery. Many respondents indicated dissatisfaction of how the performance of their current battery packs changed over time. Some cited less than two years between peak performance and unsatisfactory performance. The following section outlines the reasons behind these phenomena.

Batteries tend to degrade in one of two ways:

1. Inability to hold charge, and
2. Increasing internal resistance.

The inability for a battery to hold a charge represents the end-of-life (EOL) condition, however long before a lithium-ion battery reaches its EOL, the internal resistance will increase to a point that makes the battery unsuitable for high-demand, high-output applications, representing a functional EOL. It is important to note that a battery at its functional EOL for a high-demand application (e.g. a 20" bar chainsaw needed for forestry work) may still be perfectly serviceable for lower demand application, such as a cordless drill required to drill a few holes at the station.

For the utmost performance in high-demand applications, each cell within a battery pack must have as low an internal resistance as possible. This internal resistance is known as the

equivalent series resistance (ESR) and is ideally zero, however this is not possible in reality. When new, a high-quality Li-ion cell has a very low ESR, typically on the order of a few milliohms or less. As a battery ages through use, each cell's ESR increases over time.
During discharge, this ESR dissipates real power and causes the battery pack to heat up. For batteries with low ESR, this heat can help the battery achieve slightly improved performance as the increased temperature causes the internal battery chemical reactions to occur faster. However, as the ESR increases over the life of the battery, too high of an ESR will cause the battery terminal voltage to decrease, eventually causing the tool to shut down automatically, even with a fully charged battery.

Typically, battery tools have protection logic built-in to prevent deep discharging the battery and causing damage. This protection typically monitors the battery terminal voltage and shuts down at a specific cut-off voltage. Unfortunately, the tool is unable to distinguish between low-voltage caused by an old, high-ESR battery, and low-voltage caused by deep-discharge. This can cause frustration for the operator as a "freshly charged" (but old and worn) battery keeps activating the automatic shutdown of the tool.

The primary cause of this "wear", via increased ESR, is via repeated rapid charging. When charging a Li-ion battery, ions move from the cathode to the anode due to the externally applied charging voltage. The anode of a Li-ion battery is typically made from graphite and as ions move (intercalate) into the graphite lattice, the graphite anode expands slightly. During low-rate charging, these ions move "slowly", finding intercalation sites gradually, and causing the anode to expand slowly and evenly. During high-rate charging, the external charge voltage is higher, which forces ions into intercalation sites quickly and causes uneven expansion of the graphite anode lattice. This uneven expansion can lead to nanometer scale cracking of the lattice, and these cracks reduce the conductivity of the anode, increasing the ESR.

Somewhat counterintuitively, high-rate discharging has little effect on the "wear" of a battery, though the self-heating of a battery under high-rate discharge can also cause the ESR to increase, though this is generally temporary and a function of temperature.

6.10.2 Battery Pack Construction

Although the inner workings of battery packs are beyond the scope of this report, it is important to understand the basic principles of pack construction and the current and future trends. The two major types of construction are described below.

6.10.2.1 Cylindrical Cells

One detail that isn't always apparent to users looking at their rectangular battery pack is that conventional packs are constructed of several smaller cylindrical cells (See Figure 24) to achieve the desired performance characteristics. The nominal voltage of a single Li-ion cell is approximately 3.6 volts; though this depends on the exact chemistry of the cell. These individual cells are then connected in series to achieve the desired pack voltage (e.g. five cells connected in series make an 18 V nominal pack). The series connected cells are then connected in parallel to increase capacity and power output. Batteries labeled as "high-output", or similar, often have two or three series strings connected in parallel.

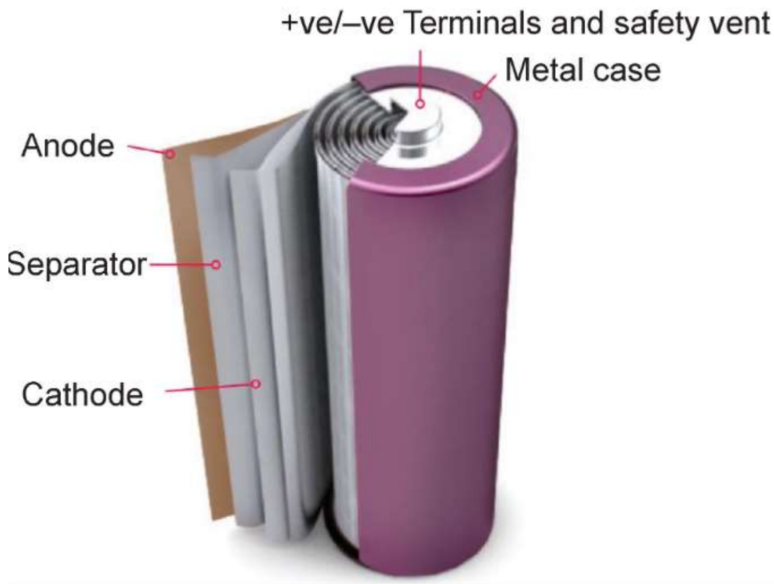

Photo courtesy of Johnson Matthey

Figure 24: View of Cylindrical Li-Ion Cell

In order to maximize the performance and longevity of a battery pack, the individual cells need to have their voltages match the other cells in a pack as closely as possible. When charging, each cell's voltage needs to be monitored to ensure even and complete charging. Balance charging is a key enabler for ensuring a battery pack maintains a high level of performance throughout its useable life. The circuitry responsible for balance charging is often incorporated directly into the battery pack itself and integrated as part of the battery management system. Because of this, it is not possible to know if a battery is equipped with balance charging without disassembling the pack and examining its construction carefully.

6.10.2.2 Pouch Cells

Pouch cells deliver the same power as cylindrical cells but do so in an architecture and construcion that is quite different. Based on the way in which battery cells are arranged in a typical mobile phone battery pack, a pouch pack is made up of layers of flat material laying on top of each other, as seen in Figure 25. One of the survey respondents who wished to remain anonymous described how his company had recently begun selling a very small number of tools with the pouch cell technology and went on to state that pouch cells will be the standard for power tools in the future but he did not state what the timelines might be for full migration to this technology. The purported advantges of pouch packaging are as follows:

- The power output is the same as a cylinder;
- A more compact and efficient way to package batteries. Two cylinders pressed together naturally create a gap between them which cannot be filled with battery thus creating wasted or unused space. A pouch cell maximizes space claim and provides much more energy density per cubic inch of pack space;
- Can provide up to twice the lifespan due to heat rejection and even charging;

- Up to 50% more power for the same design envelope;
- Stacking the cylinders doesn't work well in terms of heat transfer because heat gets trapped between the cells and electronics are required to protect the cells. With the pouch technology the cells can be stacked in a flat layer and heat transfer can be distributed more evenly; and
- Heat can be managed more efficiently to prevent thermal overload. This allows the tool to deliver more power with less impedance with a thermal event.

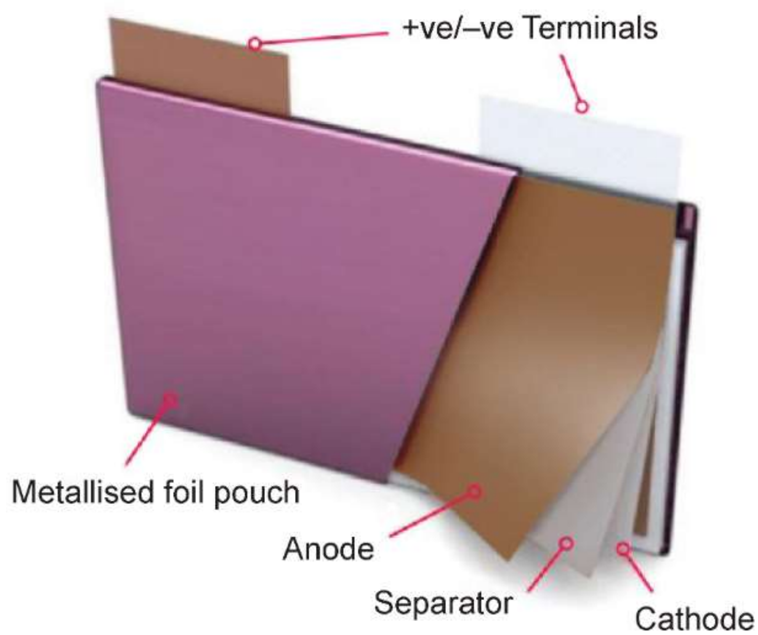

Photo courtesy of Johnson Matthey

Figure 25: View of Pouch Li-Ion Cell

The industry is slowly migrating towards the use of pouch style battery packs (as are used in cell phones) rather than cylindrical cells. This should improve heat transfer and battery life for Li-Ion packs but at this time very few manufacturers are offering pouch style batteries.

6.10.3 Battery Life/Return on Investment

One piece of "advice" still occasionally encountered is making sure a battery is fully discharged before charging to prevent battery "memory". This was generally true for older chemistries such as Ni-Cd and Ni-MH, but this practice persists yet this can cause more harm than good for Li-ion batteries. Lithium-ion batteries do not experience "memory" like other chemistries, and the current best practice is to charge early, charge often and charge slowly. Lithium-ion batteries are better suited to handling many shorter charging cycles, as opposed to fewer but longer charging cycles. Many respondents indicated they did not fully grasp the concepts of battery cycling and how to best manage a battery to maximize its lifespan while still achieving peak performance on a scene and may require training to ensure optimum battery cycling. Additionally, respondents who were concerned with finances indicated a concern that any financial gains via the lack of need for gasoline would be quickly negated by the regular need for expensive battery packs.

First responders will have to read their owner's manuals very carefully and understand how charging cycles can affect battery life and return on investment. The financial return on investment of any battery electric tool will be severely affected if batteries are bought more often than predicted by the manufacturer and could turn a cost savings into a cost increase. Care and proper cycling techniques will be required to preserve the lower operating costs of zero-emission tools.

7 TECHNOLOGY GAPS

The market research information gathered in Section 6 identified the products and technologies currently available on the market in terms of gasoline, corded and battery electric tools. From that review came a series of technological gaps and products that are not mature enough for first response use at this time. Despite the fact that many respondents indicated costs as the biggest impendent to adoption of zero-emission tools, tool costs have not been addressed in this section as they tend to become adjusted due to market forces as well as technology advancements.

Zero-emission tools tend to be lighter, cheaper, quieter and easier to start and use compared to SSI tools. Despite all of these advantages there are still significant technological challenges that must be overcome before there is wider adoption in first response. The most important technology gaps have been identified and explained as follows:

7.1 Water Pumps

Many respondents not only mentioned water pumps as one of the key weaknesses of zero-emission tools but some listed this as their number one impediment to mass adoption of zero-emission tools. Water pumps are often required to work for hours at a time, usually several hundred meters from rescue vehicles or any fixed source of AC power, meaning water pumps must be powered by gasoline or a generator that is positioned next to the water pump. The research team could not find any commercially available battery operated water pump that could perform the types of duties required by first responders, be they land based, or water based. Significant technology developments in terms of power and runtime will be required before battery electric water pumps could be used in the manner in which gasoline pumps are currently used.

Another concept that should be considered is alternate fuel sources for water pumps. If zero-emission water pumps cannot be designed in the near term there could still be reductions in CO_2 emissions via water pumps that are operated by propane, natural gas, clean diesel or fuel cells. However, the shifting of emission from CO_2 to methane, a GHG 25 times [31] more potent than CO_2 at trapping the earth's heat, should be fully considered before such a shift should occur. Fuels such as dimethyl ether (DME) [21] have shown potential to reduce GHGs but it is not likely that DME will be available for small tool use in the near to mid term.

Operating corded water pumps from a vehicle 120VAC receptacle is not practical as many rural first responders must draw water from a lake that is hundreds of meters away from the parked vehicle. It would not be practical to expect that extension cords could be run that long or that the vehicle could provide guaranteed 120VAC, at full current for many consecutive hours.

According to a major tool manufacturer, wishing to remain anonymous, high powered battery electric water pumps with runtimes appropriate for first response will not be available in the next five years.

7.1.1 **Losing 'Prime'**

Most pieces of equipment can be unpowered for brief periods of time with no resulting loss of performance, once the device is re-powered. However, this is not the case with water pumps. For water pumps to work correctly they must first be 'primed' with water to avoid air being pumped into the system and the resulting loss of pressure and flow. Once a pump has been primed and is operational it is generally not advisable to un-power the pump, as it may require an operator to re-prime the pump, which can consume valuable time at a scene. For these reasons, SSI water pumps have very large fuel tanks to maintain a lengthy run time, and when required, first responders generally perform 'hot refuels' while the pump engine remains running to ensure they do not lose 'prime' in their pumps. Performing a 'hot-swap' of battery packs (i.e. replacing a battery pack without interrupting power supply) is only possible with devices that have more than one battery pack (and only if one of the battery packs is still above zero SOC at the time of swapping). This feature will be important when selecting zero emission water pumps in the future.

7.2 Generators

Battery powered generators are a curious conundrum in that they can provide AC power in an area where conventional AC current is not available, yet, AC power is periodically required to charge the generator's batteries. They can provide much needed AC power relief, but then they require the very power, currently not available, in order to continue to be useful.

Many of the arguments made for zero emission water pumps in terms of runtime and power are similar to those for generators except that some generators are currently available in a variety of zero-emission designs. Some zero emission generators can also be complemented with solar panels to extend their run time, however, sunlight is not always available at an emergency scene.

Table 49 in Section 5.4 showed the specifications of seven manufacturers' zero emission generators, ranging from 1.4 kW to 4.8 kW steady state operating power. The two largest in the list are the EcoFlow Delta Pro and the Portable Electric VOLTstack 5k.

The EcoFlow Delta Pro which, itself, can deliver 3600 Watts of continuous power, or can be combined with other units to provide 25 kW of power. They claim to be able to charge the unit in any one of five ways but make no mention of runtime once fully charged:

1. Standard Canadian 120V/15 amp outlet 2.7 hours;
2. Standard European 240V/15 amp outlet 1.9 hours;
3. Proprietary 240V outlet 1.8 hours;
4. EV Charging 1.7 hours
5. AC plus Solar plus Smart Generator Less than two hours.

Figure 26: Battery/Solar Generator (photo courtesy of ecoflow.com)

Portable Electric also offers a zero-emission generator that delivers 27 kW of continuous power with a battery of 80 kWh. It was not included in Table 49 because it is outside of the 19 kW scope of this study but this type of heavy duty generator could provide significant levels of AC power at emergency scenes lasting days, or weeks. The unit is mounted on a trailer and is priced at over $200k. The size and price of this unit would likely be problematic at this time but as technologies mature it is likely the size and, most certainly, the price would shrink. A photo of the VOLTstack 30k being loaded on a trailer is shown in Figure 27.

Figure 27: VOLTstack 30 being loaded on a flatbed trailer

Battery powered generators show great promise and may be useful in residential applications where solar arrays may be erected in the daytime to ensure a few hours of power in the evening. Solar charging is not practical for first response work as emergency deployments can occur at any time of day and in any weather condition. These devices better lend themselves to being charged when homes are not experiencing a power outage and then saved for use during a power outage (as was experienced in winter 1998, summer 2003, fall 2018 and spring 2022 in Eastern Ontario and Western Quebec). However, there is good reason to suspect the smaller devices could not deliver the type of multi hour high power AC current required to power, say, a large fire fighting water pump.

In theory, it would be possible to imagine a scenario where the battery generator is fully charged at the station, then brought to a scene for the express purpose of charging batteries. In this scenario the tools are zero-emission and the method of charging the tools is also zero-emission. However, with a recharge time of two hours it is not clear what would happen if the generator's power became depleted while tool batteries were being charged, leaving not only the generator out of service but stranding all the other tools as well. In a first response scenario it is not clear how these generators would become charged unless a steady source of AC power could be found, which is what is needed to charge the batteries anyway, thus resulting in a very circular situation that appears to be 'green' but is in fact just non-sensical.

For the near term, there is no realistic expectation that first responders could use battery generators for anything other than the shortest and least taxing of emergencies for low current applications like battery chargers. Significant technological advancements will need to occur before zero-emission generators will have the power and runtime to be trustworthy at an emergency scene, and even then, search and rescue teams like the HUSAR task forces will likely not be able to trust this form of power in a multi-day/week deployment. Currently, search and rescue teams, who deploy for many days in scenarios without any form of available AC power, have the option of using SSI tools or some combination of SSI and zero-emission tools provided they also have SSI generators on-site. However, there is good reason to suspect that, in time, larger zero emission generators will become more available, less expensive and technologically capable of delivering the power required on-site to charge zero-emission tools.

7.3 Cold Weather Battery Charging

Battery temperature can greatly affect charge performance for Lithium Ion batteries [29]. Li-Ion can be fast charged from 5 deg C to 45 deg C, however, most chargers will automatically cease the charging process as soon as battery temperature drops below 0 deg C as internal damage will occur due to plating of metallic lithium on the anode. Even at 5 dec C the charge rate should be reduced.

Battery and ambient temperatures could be a significant factor for charging capabilities for first responders working in subzero temperatures. First responders do not have the luxury of working indoors or delaying their work until the weather warms up. For first responders to achieve the types of charge times advertised by manufacturers it will be critical to setup charge stations inside vehicles or inside heated tents that maintain equipment above a pre determined level.

In a worst case scenario, all the batteries at a scene could be discharged and so cold they cannot be charged until such time as they are warmed up. This could cause, at best frustration, and at worst, a risk to human health for casualties at a scene.

Research will have to be conducted to determine if other battery chemistries could have charging regimes that are more conducive to cold weather charging.

This issue will have to be well understood and backup plans involving gasoline tools may be required in locations where temperatures routinely dip below zero and chargers cannot be kept warm.

The charge cycling techniques that optimize the useable life span of Lithium-Ion batteries are in direct conflict with the nature of first response work. Li-Ion likes to be slowly charged over many hours, at a certain temperature range whereas first responders will typically want to use a tool until it no longer can provide any power and then re-charge as quickly as possible so that the battery can be used again. Additionally, first responders do not have the luxury of placing the battery to charge in, say, a heated garage or basement while they do work in frigid temperatures. Batteries will need to be charged at whatever ambient temperature is prevailing that moment with the inside of an emergency vehicle being the only way to charge at the manufacturer's recommended temperature. None of this is an issues with gasoline powered tools.

Much work still needs to be done in terms of lithium-Ion charge preferences in Canada's cold weather otherwise first responders will be purchasing many more battery packs than forecasted, reducing the ROI of the tool(s).

7.4 Cold Weather Runtime

Similar to cold weather charging, is the issue of cold weather runtime. According to BatteryUniversity.com [31] a battery with a nominal rating of 2.8 Ah (a size that is typical for smaller tools) will provide 2.8 Ah of useable charge at 40 deg C but just under 1.5 Ah at -20 deg C (Figure 28). This is a significant degradation in available energy and could result in first responders experiencing performance and runtime issues that could affect their work. To make matters worse, as runtime for pack #1 decreases, the operator must select a second battery pack that will itself not last if the first pack and so on until all available battery packs are charging rather than being used.

Not only does cold weather reduce a battery pack's available runtime power, but frigid conditions can crack the internal architecture of the pack, thus affecting its ability to function and charge correctly. A study [24] performed by the US Department of Energy SLAC National Accelerator Laboratory revealed how cold temperature can create new cracks in the cathode or enlarge existing cracks. They concluded that storing and use at subzero temperatures can reduce the available state of charge of the battery by 5% for every 100 charge cycles. This might be more problematic for cell phones but could still pose a longevity and performance risk to first responders.

All these factors will cause concern for first responders who cannot control the ambient temperatures in which they work. More work will need to be done to develop batteries that can operate at extreme temperatures and still provide reasonable performance, run times and reliability for first response work where tool failure can affect public safety. Alternately, methods such as heaters or insulation will need to be developed to maintain battery temperature if advancements in battery chemistry technology are not made.

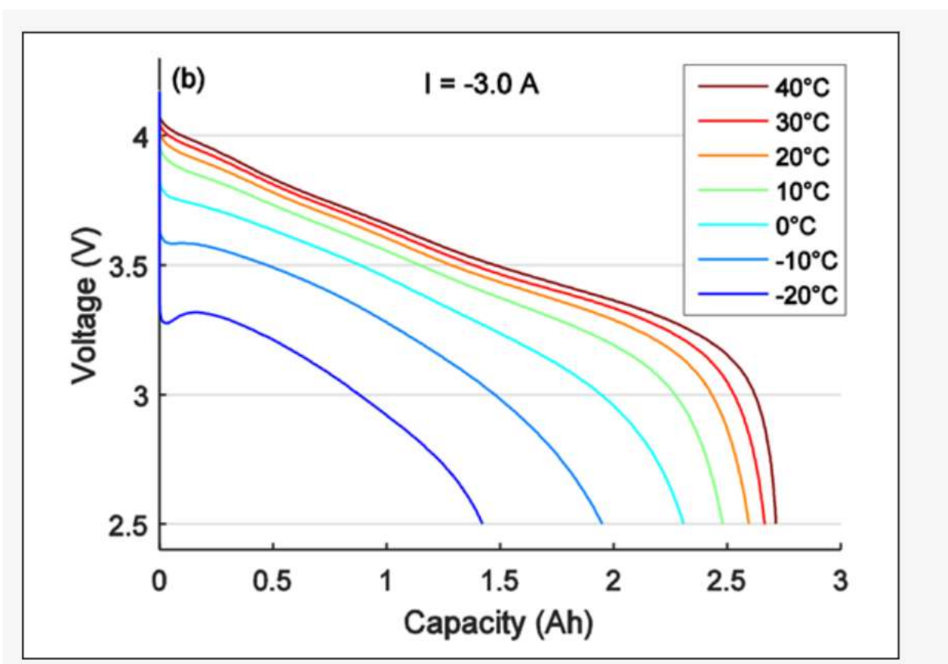

Figure 28: Discharge Capacity of Lithium-Ion Batteries vs. Temperature

7.5 Other Potential Gaps

Many respondents raised concerns regarding the safety of storing Lithium-Ion batteries. Li-Ion batteries are a known fire risk and have been known to spontaneously combust, causing very hot fires. Many respondents are concerned that the risks of fire from storing gasoline will now be replaced with the risk of storing fire prone Lithium-Ion batteries. Fire fighters have already had exposure to Li-Ion fires and stated they are a very different type of fire that requires special attention to products and techniques for safe extinguishing. Despite these concerns, Li-Ion batteries are currently being used in billions of cell phones around the world with very low instances of spontaneous combustion. Some respondents indicated a concern regarding flying commercially with their zero-emission tools and how the airlines would react to placing large Li-Ion batteries in their cargo holds;

Some respondents indicated a concern regarding the use of electric tools that could become submerged in the water being used by first responders thus creating an electric shock risk for operators;

8 DISCUSSION

8.1 Shifting GHGs from SSI Tools to SSI Generators

Shifting from SSI tools to zero-emission tools is relatively straightforward in commercial and residential settings where AC power is readily available and charge time is less critical. However, emergency responders may, or may not, have access to reliable AC power while at a scene and cannot commit to zero-emission tools without readily accessible reliable AC power. There is a potential solution that could allow a large reduction of the use of handheld gasoline powered tools thus advancing Canada's goals for GHG reduction and providing cleaner air. However, this might only be achieved in the near-term via a greater reliance on gasoline or diesel powered generators that could be running for many hours at an emergency scene solely for the purposes of battery charging or running corded tools.

The author had a lengthy discussion with a retired Fire Commissioner from Alberta who described three common types of deployments: short term, medium term and long term. Each of these has specific logistical challenges with regards to power and re-fuelling. They have been described below:

> Short term: An emergency scene that lasts one to three hours and all tools can be used as needed with the tank of fuel or the battery they arrived in. In this scenario the emergency responders are busy but the scene does not tax the runtime of the devices.
>
> Mid term: An emergency scene that lasts more than a few hours but less than a day. In this scenario there is not enough time to set up an additional dedicated logistics network to monitor fuel and charge levels yet the scene lasts long enough that fuel tanks and batteries will require replenishing several times. Typically, this would be performed by the responders themselves and then they would return to working with the tools.
>
> Long term: An emergency scene that lasts days, or possibly weeks. This may include fire but could also include collapsed buildings, floods or earthquake response where first responders are performing search and rescue tasks. In this scenario the tools could require significant number of refuels/re-charge but there is enough time and enough resources to set up dedicated charging stations/tents, generators or recruit the assistance of other organizations whose sole purpose could be to assist with the creation and operation of a charging network.

Some first responders indicated a specific concern regarding mid-term emergency scenes. They explained there is not enough time to set up the logistics of dedicated charging stations and create a coordinated effort to ensure batteries were being charged in a timely manner yet there is sufficient time that some battery operated tools would become depleted while the tool was still required to perform a life saving task. In such a scenario it will be critical to find ways to quickly and reliably recharge zero-emission tools, possibly via the use of fossil fuel powered generators that may need to operate throughout the entire duration of the scene. Additionally, at very cold temperatures it may not be possible to set up heated tents to house the battery chargers.

Despite the potential continued need for a fossil fuel powered tool, from a regulatory perspective, it may be easier to monitor and manage emissions from generators because it becomes a single source piece of equipment rather than a scene filled with dozens of GHG and air pollutant emitting two stroke SSIs. Additionally, since generators are quasi-stationary equipment, it is possible to design generators with heavier features such as four stroke, SCR, traps, catalytic converters and mufflers. Small hand tools become too heavy to use when these features are added and have never been appropriate candidates for GHG reduction strategies. Even if generators were to run longer at a scene they could be designed to operate in a regime that is much cleaner than the gasoline tools that were replaced by zero-emission tools, particularly for traditionally regulated emissions such as CO, NOx, PM and THC. This may be seen as an intermediate step to full adoption of zero-emission tools and some examples have been created in the following sections to illustrate this point.

8.1.1 **Scene Case Studies**

Several case-studies have been developed to illustrate these fuel and emissions reductions options:

8.1.1.1 Case Study 1: Short Duration Scene

Scene a) An SSI chainsaw and SSI fan operating for a period of one hour over a two hour period; or

Scene b) A zero-emission chainsaw and zero-emission fan operating for one hour over a two hour period and charged using SSI generator running continuously for two hours; or

Scene c) A zero-emission chainsaw and zero-emission fan being used for one hour over a two hour period and charged using the inverters on the idling vehicle;

In each of these scenes, a truck has been left idling for the entire time to power up accessories, pumps and inverters. It is assumed the engine is 10 to 12 litre, 400+ hp, Tier IV compliant, EPA California clean diesel engine.

For these scenarios, the estimated specification for the required tools are shown in Table 69.

Table 69: Specifications for Tools Used in Case Study #1

Piece of Equipment	**Power (kW)**	**Fuel Consumption (l/h)**	**CO_2 Emissions (kg/hour)**
Gasoline Generator	3.4	0.8	1.93
SSI Chainsaw	4.0	1.86	4.48
SSI Fan	4.1	1.70	4.10
Tier 4 Diesel Truck Engine	300	4.0 (at high idle)	10.68

Most generators will consume between 0.1 and 0.3 litres per hour per kW of generated power. For the purposes of this example, a 3,400 Watt generator consuming 0.80 litres of gasoline per hour (i.e. 0.23 litres/kW) will be used to recharge the batteries that will be needed to operate the zero-emission tools.

Scene a) It is assumed the chainsaw will consume a modest 1.86 litres per hour of two stroke mix gasoline and the fan will consume 1.7 litres of fuel per hour and the truck will consume approximately 4 litres per hour at idle.

Chainsaw: 1.86 litres x 1 hour = 1.86 litres
1.86 litres x 2.41 kg/litre = 4.48 kg CO_2

Fan: 1.7 litres x 1 hour = 1.7 litres
1.7 litres x 2.41 kg/litre = 4.10 kg CO_2

Truck: 4.0 litres x 2 hours = 8 litres
8.0 litres x 2.67 kg/litre = 21.36 kg CO_2

The two tools will consume a combined total of 3.56 litres of gasoline and they will emit a total of 8.58 kg of CO_2

The generator was not turned on in this scenario but the truck idled for two hours and consumed 8 litres of diesel and emitted 21.36 kg of CO_2.

Therefore, the total fuel consumed in this scene was 1.86 l + 1.7 l + 8 l (diesel) = 11.56 litres and the CO_2 footprint for this scene is 21.36 kg + 8.58 kg = 29.94 kg

Scene b) It is assumed the chainsaw and fan will have their batteries charged from a gasoline powered generator that will operate continuously for two hours.

Chainsaw: The chainsaw is zero-emission and therefore will emit 0 kg CO_2;

Fan: The fan is zero-emission and therefore will emit 0 kg CO_2;

Generator: 0.8 l/h x 2 hour = 1.6 litres
1.6 litres x 2.41 kg/litre = 3.86 kg CO_2

Truck: 4.0 litres x 2 hours = 8 litres
8.0 litres x 2.67 kg/litre = 21.36 kg CO_2

The generator was turned on and produced 3.86 kg of CO_2 in this scenario and the truck idled for two hours and consumed 8 litres of diesel and emitted 21.36 kg of CO_2.

Therefore, the total fuel consumed was 1.6 l + 8 l = 9.6 litres and the CO_2 footprint for this scene is 21.36 kg + 3.86 kg = 25.21 kg

Scene c) It is assumed the chainsaw and fan will have their batteries charged from the diesel powered truck that will operate continuously for two hours.

Chainsaw: The chainsaw is zero-emission and therefore will emit 0 kg CO_2;

Fan: The fan is zero-emission and therefore will emit 0 kg CO_2;

Generator: The generator is turned off

Truck: 4.0 litres x 2 hours = 8 litres
8.0 litres x 2.67 kg/litre = 21.36 kg CO_2

The truck idled for two hours and consumed 8 litres of diesel and emitted 21.36 kg of CO_2.

Therefore, the total CO_2 footprint for this scene is 21.36 kg

Table 70: Results of Case Study #1

Scenario	**Gasoline Consumed**	**Diesel Consumed**	**CO_2 emitted**
SSI and Truck	3.56 litres	8 litres	29.94 kg
ZE and Generator and Truck	1.6 litres	8 litres	25.21 kg
ZE and truck	0 litres	8 litres	21.36 kg

In these three scenarios, the use of zero-emission tools lowered the theoretical CO_2 footprint at the scene by as much as 4 to 8 kg. It is also worth noting that these calculations are strictly for CO_2 emissions and do not in any way address emissions such as HC, THC, NOx and PM. The emissions from the two stroke chainsaw alone would likely have more non CO_2 contaminants than the 10 litre diesel truck engine therefore there are significant gains to be made with respect to those emissions, but they cannot be quantified in this report as they cannot be represented by a simple formula, as is the case with CO_2.

Actual lab testing would be required to quantify all the air contaminant emissions from these scenarios. Obviously it stands to reason that these savings are highly dependent on the amount of time the chainsaw and fans are operational.

8.1.1.2 Case Study 2: Mid length Scene

Scene a) SSI chainsaws, K12 saws and fans operated for a variable amount of time over a period of twelve hours while a truck idles; vs.

Scene b) Zero-emission chainsaws, K12 saws and fans operated many times each over a period of twelve hours and charged using SSI generators while a truck idles; vs.

Scene c) Zero-emission chainsaws, K12 saws and fans operated many times each over a period of twelve hours and charged using the idling diesel truck;

In each of these scenes, the truck has been left idling for the entire time to power up accessories, pumps and inverters. It is assumed the engine is 10 to 12 litre, 400+ hp, Tier IV compliant, EPA California clean diesel engine.

For these scenarios, the estimated specification for the required tools are shown in Table 71

Table 71: Specifications for Tools Used in Case Study #2

Piece of Equipment	Size (kW)	Fuel Consumption (l/h)	CO_2 Emissions (kg/hour)
Gasoline Generator	3.4	0.8	1.93
SSI Chainsaw	4.0	1.86	4.48
SSI Rotary Saw	4.0	1.33	3.20
SSI Fan	4.1	1.70	4.10
Tier 4 Diesel Truck Engine	300	4.0 (at high idle)	10.68
Total		9.69	24.39

Most generators will consume between 0.1 and 0.3 litres per hour per kW of generated power. For the purposes of this example, a 3400 Watt generator consuming 0.80 litres of gasoline per hour (i.e. 0.23 litres/kW) will be used to recharge the batteries that will be needed to operate the zero-emission tools.

Scene a) It is assumed the chainsaw will consume 1.86 litres per hour of two stroke mix gasoline and the fan will consume 1.7 litres of fuel per hour and the rotary saw will consume 1.33 litres per hour.

Chainsaw: 1.86 litres x 1 hour = 1.86 litres per hour
1.86 litres x 2.41 kg/litre = 4.48 kg CO_2 per hour

Rotary Saw: 1.33 litres x 1 hour = 1.33 litres per hour
1.33 litres x 2.41 kg/litre = 3.21 kg CO_2 per hour

Fan: 1.7 litres x 1 hour = 1.7 litres per hour
1.7 litres x 2.41 kg/litre = 4.10 kg CO_2 per hour

Truck: 4.0 litres x 1 hour = 4 litres
4.0 litres x 2.67 kg/litre = 10.68 kg CO_2 per hour

In this scene, the use of the three gasoline tools was varied significantly and the use of the diesel truck was held constant for the entire 12 hour scene and the generator was not used. The results are shown in Table 72.

Table 72: Fuel and GHG Emissions Results for Case Study #2

Time Used	1 hour		3 hours		5 hours		7 hours		9 hours		11 hours		12 hours	
Item	Fuel (l)	CO_2 (kg)	Fuel (l)	CO_2 (kg)	Fuel (l)	CO_2 (kg)	Fuel (l)	CO_2 (kg)	Fuel (l)	CO_2 (kg)	Fuel (l)	CO_2 (kg)	Fuel (l)	CO_2 (kg)
Chainsaw	1.86	4.5	5.58	13.4	9.3	22.4	13.02	31.4	16.74	40.3	20.46	49.3	22.32	53.8
Fan	1.70	4.1	5.1	12.3	8.5	20.5	11.9	28.7	15.3	36.9	18.7	45.1	20.4	49.2
Rotary Saw	1.33	3.2	3.99	9.6	6.65	16.0	9.31	22.4	11.97	28.8	14.63	35.3	15.96	38.5
Generator	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Truck	48	128.2	48	128.2	48	128.2	48	128.2	48	128.2	48	128.2	48	128.2
Total	52.89	139.9	62.67	163.5	72.45	187.1	82.23	210.7	92.01	234.2	101.79	257.8	106.68	269.6

The range of CO_2 emissions was from 139.9 kg for a scene where the truck idled for 12 hours and the tools were only used for one hour to a maximum of 269.6 kg for a scene where the truck idled for 12 hours and the tools were also used for 12 hours (which is likely impractical but possible).

Scene b) It is assumed the saws and fan will have their batteries charged from a gasoline powered generator that will operate continuously for 12 hours and the truck will also idle for 12 hours. For the purposes of this study the fuel consumption of the generator is held constant even though in reality it will vary depending on the applied plug load.

Saws: The saws are zero-emission and therefore will emit 0 kg CO_2;

Fan: The fan is zero-emission and therefore will emit 0 kg CO_2;

Generator: 0.8 l/h x 1 hour = 0.8 litres
0.8 litres x 2.41 kg/litre = 1.93 kg CO_2 per hour;

Truck: 4.0 litres x 1 hour = 4 litres
4.0 litres x 2.67 kg/litre = 10.68 kg CO_2 per hour

In this scene, the use of the three zero-emission tools was varied significantly but their emissions are not affected by runtime. The use of the diesel truck and the generator were held constant for the entire 12 hour scene. The results are as follows:

Three zero-emission tools: 0 litres of fuel
0 kg of CO_2

Generator: 12 hours x 0.8 litres = 9.6 litres
10.6 litres of gasoline x 2.41 kg/l = 23.14 kg CO_2

Truck 12 hours x 4 litres = 48 litres
48 litres of diesel x 2.67 kg/l = 128.16 kg CO_2

Total emissions of CO_2 = 23.14 kg + 128.16 kg = 151.3 kg

This exercise demonstrates that running the generator and the truck for 12 straight hours produces less CO_2 compared to scene a) for all scenarios except where each of the three powertools are operated for anything less than 1.96 hours (i.e. between the 1 hour and 3 hour marks shown in Table 71). In a mid length scene such as this there could be real CO_2

emissions savings by using zero-emission tools and charging with a generator or the truck even if those devices idle for many hours.

Scene c) It is assumed the saws and fan will have their batteries charged from the diesel powered truck that will operate continuously for 12 hours.

Saws: The saws are zero-emission and therefore will emit 0 kg CO_2;

Fan: The fan is zero-emission and therefore will emit 0 kg CO_2;

Generator: The generator is turned off and will emit 0 kg CO_2;

Truck 12 hours x 4 litres = 48 litres
48 litres of diesel x 2.67 kg/l = 128.16 kg CO_2

Total emissions of CO_2 = 128.16 kg

In these three scenarios, the use of zero-emission tools lowered the theoretical CO_2 footprint at the scene by as much as 12 to 141 kg although using the generator fulltime in scene B did increase carbon emissions if tools are used for less than an hour. It is also worth noting that these calculations are strictly for CO_2 emissions and do not in any way address emissions such as HC, THC, NOx and PM. The emissions from the two stroke chainsaw and rotary saw alone would likely have more non CO_2 contaminants than the 10 litre diesel truck engine therefore there are significant gains to be made with respect to those emissions, but they cannot be quantified in this report as they cannot be represented by a simple formula, as is the case with CO_2. The results in Table 73 illustrate that many scenarios using zero-emission tools will reduce the CO_2 footprint even if generators and vehicles are running for extended periods of time. Additionally, generators are quieter than chainsaws and rotary saws, and they can be set further away from the operators, thus reducing fatigue and irritation for the operators.

Table 73: Results of Case Study #2

Scenario	**Gasoline Consumed**	**Diesel Consumed**	**CO_2 emitted**
SSI and Truck	4.89 to 58.68 l	48 litres	140 kg to 270 kg
ZE and Generator and Truck	9.6 litres	48 litres	151.3 kg
ZE and truck	0 litres	48 litres	128.2 kg

Actual lab testing would be required to quantify all the air contaminant emissions from these scenarios. Obviously it stands to reason that these savings are highly dependent on the amount of time the saws and fans are operational.

8.1.1.3 Case Study 3: Long term Scene

Scene a) SSI chainsaws, extrication tools, K12 saws, lighting and fans all used extensively for a period of three days; vs.

Scene b) SSI chainsaws, extrication tools, K12 saws, lighting and fans all used extensively for a period of three days; and charged using SSI generators.

Scene c) SSI chainsaws, extrication tools, K12 saws, lighting and fans all used extensively for a period of three days; and charged using the diesel truck.

In each of these scenes, the fire truck has been left idling for the entire time to power up accessories, pumps and inverters. It is assumed the engine is 10 to 12 litre, 400+ hp, Tier IV compliant, EPA California clean diesel engine.

For these scenarios, the estimated specification for the required tools are shown in Table 74.

Table 74: Specifications for Tools Used in Case Study #3

Piece of Equipment	**Size (kW)**	**Fuel Consumption (l/h)**	**CO_2 Emissions (kg/h)**
SSI Generator	3.4	0.80	1.93
SSI Chainsaw	4.0	1.86	4.48
SSI Rotary Saw	4.0	1.33	3.20
SSI Fan	4.1	1.70	4.10
Tier 4 Diesel Truck Engine	300	4.0 (at high idle)	10.68
SSI Tower Lights	3.1	0.90	2.17
SSI Extrication Pump	3.0	1.3	3.13

Most generators will consume between 0.1 and 0.3 litres per hour per kW of generated power. For the purposes of this example, a 3 400 W generator consuming 0.80 litres of gasoline per hour (i.e. 0.23 litres/kW) will be used to recharge the batteries that will be needed to operate the zero-emission tools.

Scene a) It is assumed the chainsaw will consume 1.86 litres per hour of two stroke mix gasoline and the fan will consume 1.7 litres of fuel per hour and the rotary saw will consume 1.33 litres per hour.

Chainsaw: 1.86 litres x 1 hour = 1.86 litres per hour
1.86 litres x 2.41 kg/litre = 4.48 kg CO_2 per hour

Rotary Saw: 1.33 litres x 1 hour = 1.33 litres per hour
1.33 litres x 2.41 kg/litre = 3.21 kg CO_2 per hour

Fan: 1.7 litres x 1 hour = 1.7 litres per hour
1.7 litres x 2.41 kg/litre = 4.10 kg CO_2 per hour

Extrication Pump: 1.3 litres x 1 hour = 1.3 litres per hour

1.3 litres x 2.41 kg/litre = 3.13 kg CO_2 per hour

Tower Lights: 0.9 litres x 1 hour = 0.9 litres per hour
0.9 litres x 2.41 kg/litre = 2.17 kg CO_2 per hour

Truck: 4.0 litres x 1 hour = 4 litres
4.0 litres x 2.67 kg/litre = 10.68 kg CO_2 per hour

In this scene, the use of the five gasoline tools was varied significantly and the use of the diesel truck was held constant for the entire 36 hour scene and the generator was not used. The results are shown in Table 75.

Table 75: Fuel and GHG Emissions Results for Case Study #2

Time Used	**1 hour**		**5 hours**		**10 hours**		**15 hours**		**20 hours**		**25 hours**		**36 hours**	
Item	**Fuel (l)**	**CO_2 (kg)**	**Fuel (l)**	**CO_2 (kg)**	**Fuel (l)**	**CO_2 (kg)**	**Fuel (l)**	**CO_2 (kg)**	**Fuel (l)**	**CO_2 (kg)**	**Fuel (l)**	**CO_2 (kg)**	**Fuel (l)**	**CO_2 (kg)**
Chainsaw	1.86	4.48	9.30	22.41	18.60	44.83	27.90	67.24	37.20	89.65	46.50	112.07	66.96	161.37
Fan	1.70	4.10	8.50	20.49	17.00	40.97	25.50	61.46	34.00	81.94	42.50	102.43	61.20	147.49
K12 Saw	1.33	3.21	6.65	16.03	13.30	32.05	19.95	48.08	26.60	64.11	33.25	80.13	47.88	115.39
Generator	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lighting	0.90	2.17	4.50	10.85	9.00	21.69	13.50	32.54	18.00	43.38	22.50	54.23	32.40	78.08
Hydraulics	1.30	3.13	6.50	15.67	13.00	31.33	19.50	47.00	26.00	62.66	32.50	78.33	46.80	112.79
Truck	144.00	384.48	144.00	384.48	144.00	384.48	144.00	384.48	144.00	384.48	144.00	384.48	144.00	384.48
Total	151.1	401.6	179.5	469.9	214.9	555.3	250.4	640.8	285.8	726.2	321.3	811.7	399.2	999.6

The range of CO_2 emissions was from 401 kg for a scene where the truck idled for 36 hours and the tools were only used for one hour to a maximum of 1000 kg for a scene where the truck idled for 36 hours and the five tools were also used for 36 hours (which is likely impractical but possible).

Scene b) It is assumed all the tools will have their batteries charged from a gasoline powered generator that will operate continuously for 36 hours and the truck will also idle for 36 hours. For the purposes of this study the fuel consumption of the generator is held constant even though in reality it will vary depending on the applied plug load.

Tools: The tools are zero-emission and therefore will emit 0 kg CO_2;

Generator: 0.8 l/h x 1 hour = 0.8 litres
0.8 litres x 2.41 kg/litre = 1.93 kg CO_2 per hour;

Truck: 4.0 litres x 1 hour = 4 litres
4.0 litres x 2.67 kg/litre = 10.68 kg CO_2 per hour

In this scene, the use of the five zero-emission tools was varied significantly but their emissions are not affected by runtime. The use of the diesel truck and the generator were held constant for the entire 36 hour scene. The results are as follows:

Three zero-emission tools: 0 litres of fuel
0 kg of CO_2

Generator: 36 hours x 0.8 litres = 28.8 litres
28.8 litres of gasoline x 2.41 kg/l = 69.4 kg CO_2

Truck 36 hours x 4 litres = 144 litres
144 litres of diesel x 2.67 kg/l = 384.48 kg CO_2

Total emissions of CO_2 = 69.4 kg + 384.48 kg = 453.9 kg

This exercise demonstrates that running the generator and the truck for 36 straight hours produces less CO_2 compared to scene a) for all scenarios except where each of the five powertools are operated for anything less than 4.05 hours. In a long length scene such as this there could be real CO_2 emissions savings by using zero-emission tools and charging with a generator or the truck even if those devices idle for many hours. In short, as more and more SSI tools are used and for longer run times, the more it makes sense to replace all of them with one SSI generator and the reduction in CO_2 emissions can be very high.

Scene c) It is assumed the tools will have their batteries charged from the diesel powered truck that will operate continuously for 36 hours.

Tools: The tools are zero-emission and therefore will emit 0 kg CO_2;

Generator: The generator is turned off

Truck 36 hours x 4 litres = 144 litres
144 litres of diesel x 2.67 kg/l = 384.48 kg CO_2

Total emissions of CO_2 = 385 kg

In these three contrived scenarios, the use of zero-emission tools lowered the theoretical CO_2 footprint at the scene between -21 kg to 546 kg, depending on tool use. Using zero-emission tools can actually increase the carbon footprint at a scene if generators and trucks are operated non stop. However, as the number of displaced SSI tools increases and as first responders learn to manage the operation of their generators, there is a real potential for GHG emission reduction (see Table 76).

It is also worth noting that these calculations are strictly for CO_2 emissions and do not in any way address emissions such as HC, THC, NOx and PM. The emissions from the two stroke chainsaw and rotary saw alone would likely have more non CO_2 contaminants than the 10 litre diesel truck engine therefore there are significant gains to be made with respect to those emissions, but they cannot be quantified in this report as they cannot be represented by a simple formula, as is the case with CO_2. The results in Table 76 illustrate that many scenarios using zero-emission tools will reduce the CO_2 footprint even if generators are running for extended periods of time. Additionally, generators are quieter than the chainsaws and rotary saws they replace and they can be set further away from the operators.

Table 76: Results of Case Study #3

Scenario	**Gasoline Consumed**	**Diesel Consumed**	**CO_2 emitted**
SSI and Truck	7.1 to 615 litres	144 litres	401.6 kg to 1866 kg
ZE and Generator and Truck	28.8 litres	144 litres	453.9 kg
ZE and truck	0 litres	144 litres	384.5 kg

Actual lab testing would be required to quantify all the air contaminant emissions from these scenarios. Obviously, it stands to reason that these savings are highly dependent on the amount of time the saws and fans are operational.

The calculations shown in the preceding sections may be over simplified but they are meant to demonstrate how using a single generator, or vehicle, to allow the removal of many SSI tools could reduce CO_2 at a scene. The level of reduction will be directly proportional to the number of tools displaced from the scene by a generator. Additionally, many of these tools are two-stroke with their inherent high hydrocarbon emissions whereas the generator replacing the tools will almost assuredly be four stroke which do not, by design, burn oil (although some four stroke generators may burn trace amounts of oil either by design or as a result of engine wear).

These scenarios using battery tools and a generator or inverters on emergency vehicles do not lend themselves to all situations. In some cases, bringing all the required batteries and a generator as part of the equipment is simply not practical. Also, not all emergency vehicles are equipped with inverters as some currently used vehicles date back to the 1980s. Also, these scenarios would only be useful in situations where the generator or truck can be positioned reasonably close to the scene or to the source of water (depending on the need). Therefore, such solutions would not make sense for forest fires or other situations where the vehicle could not be positioned in the optimum location. In these situations it will still be preferable to have gasoline powered hand tools that may be fueled rapidly on demand, in-situ and the vehicle would be seen more as a ‘home base’ for shift changes and logistics meetings.

9 TOOL SPECIFIC CONCLUSIONS

The overall conclusions of the research project are presented in Section 10 whereas this Section outlines the conclusions specific to each class of tool.

The aim of this project was not to compare one manufacturer's products against another's, however, it was very much of interest to understand which types of zero-emission tools are considered ready for use now, which ones may need some minor technology maturation and which ones will require a significant level of advancement before considered practical for first-response work.

Each of the following classes of tool have been described in terms of its technology readiness as it applies to all forms of first response studied in this project.

9.1 Mature Zero-Emission Tools Currently in use

The following zero-emission tools are currently being used by many of the survey respondents and do not appear to have many drawbacks in terms of performance. These tools are technologically mature and could likely be used by nearly all first responders except perhaps severe and remote search and rescue situations. It is conceivable that in the next five years many first response department in Canada will be using at least some of the following tools:

9.1.1 Scene Lighting

The group of equipment comprising scene lights, tower lights and flashlights tend to draw relatively low amounts of power (particularly those with light emitting diodes [LED]) and are commonly found in corded, and less so in battery-electric, configurations. Approximately 33% of respondents indicated they operated at least some form of zero-emission scene/tower lighting. None of the survey respondents described scene lighting as something that needs to be gasoline powered. In general, corded lighting can be plugged into the truck or a generator for the duration of a scene and battery-operated LED lighting lasts sufficiently long that none of the respondents indicated they were disappointed in the run time of their lighting products. Since lighting is generally positioned and left in one location for hours at a time, scene lighting is not considered a 'hand tool' and lends itself well to being corded since first responders are not aggravated by walking around with a tether. Most zero-emission tools are quieter than their SSI counterparts but zero-emission scene lighting is completely silent as there are no motors or generators whatsoever.

With the exception of performing work deep in a forest or for extended search and rescue operations, where 120V power is not available, there are practically no impediments to using zero-emission scene lighting and it is already well accepted in the industry. The complete lack of noise and stationary nature of the device makes them an obvious choice for being zero-emission.

9.1.2 **Positive and Negative Pressure Ventilation/Exhaust Fans**

For the purposes of this study, positive and negative pressure fans have been grouped together since the direction of air flow is not linked to the source of power. Approximately 44% of respondents indicated they operated at least some form of zero-emission ventilation/exhaust fan. None of the survey respondents described fans as something that needs to be gasoline powered and nearly all respondents pointed out the industry irony of trying to clear a building of toxic fumes by using a tool that, itself, can blow toxic exhaust fumes back into a building (albeit much less than the fumes already in the building as a result of the emergency). The arrival of zero-emission fans is generally considered to be a welcome addition to the arsenal of tools use by first responders.

In general, corded fans can be plugged into the truck or a generator for the duration of a scene and battery-operated fans last sufficiently long that none of the respondents indicated they were disappointed in the run time of their fan products. Since fans are generally positioned and left in one location for at least some portion of time, fans lend themselves well to being corded as they are not a hand tool and therefore first responders are not aggravated by walking around with a tether.

There are virtually no drawbacks to using zero-emission fans. Unlike scene lighting, fans still need a motor but zero-emission fans tend to be quieter than SSI models. Zero emission fans are portable, lightweight and most importantly they do not blow toxic exhaust fumes into the very building that the fans are trying to cleanse and have already been widely accepted in the industry.

9.1.3 **Extrication Tools**

Extrication tools can be powered by gasoline, corded electric or battery electric. However, they all have one thing in common: the source of power does not directly act on the tool, rather they rely on the source of power to activate hydraulics which then actuate the tools. Many of the respondents indicated they had partially, or totally, switched from gas-over-hydraulic to battery-over-hydraulic for their suite of extrication tools. Zero-emission extrication tools appear to be one of the most actively marketed tools by industry sales staff and most respondents indicated they are extremely pleased by the performance and runtime of their zero-emission extrication tools.

Given that most extrication takes place on public roadways it is likely that extrication tools can easily be plugged into the truck or the truck could be used to re-charge the batteries needed for battery operated tools.

Zero-emission extrication tools appear to be mature and well accepted in the industry and there appear to be very few, if any, limitations of the product at this time unless the extrication is to take place deep in a forest which is fairly rare given that extrication generally is performed on, or near, roads.

9.1.4 **Reciprocating Saws and Other Hand Tools**

Although not entirely within scope of the project it is worth noting that nearly all survey respondents indicated they have already migrated to battery electric for many types of hand tools. In these cases, not only are the tools not SSI but they are not tethered to a power source either, thus providing zero-emission with maximum flexibility without sacrificing any performance.

1. Reciprocating saws/Sawzall;
2. Drills/Impact guns;
3. Circular saws;
4. Flashlights; and
5. Grinders.

The battery technology will continue to develop for all of these tools with continued improvements in light-weighting, run time and battery voltage (e.g. convertible 40V and 60V systems). It is anticipated that nearly every organization will have a full complement of these tools in battery electric in the next few years, if not already. Additionally, with proper planning, organizations can commit to one manufacturer of heavy duty tools as well as lighter duty tools and use one family of batteries that should be interchangeable for many years.

9.2 Tools Currently Being Used by Some First Responders

This is the most complex category, as the tools in this section seem to be useful and applicable to some forms of first response but less so for other forms of first response. The use, or non-use, of these tools over the coming years will be difficult to predict as many survey respondents indicated resistance to changing over to these tools, for reasons that may be real or perceived. They include:

9.2.1 **Chainsaws**

For the purposes of this study, chainsaws included any saw with a chain revolving around a fixed bar and does not include the class of tools known as rotary cutters or K12 saws which use a circular blade (see next Section).

Unlike fans and lighting, it is not practical for chainsaws to be corded for first response work. Chainsaws, more than any other tool, must be highly portable so that first responders can climb onto roof tops to create ventilation holes or access ports. Therefore, they must be either gasoline or battery-electric to be useable and accepted by the industry.

Only 11% of respondents indicated they currently use some form of zero-emission chainsaw. Many respondents indicated they had a basic mistrust of the runtime and power for chainsaws and that some of the saws they trialed were not adequate for their needs (again, be it actual or perceived).

Based on the survey results it appears that many first responders could perhaps envision the use of zero-emission chainsaws for creating ventilation holes in roof tops and for basic entry into homes. The actual amount of time a chainsaw is running and cutting is generally quite low at most fire scenes. They must be ready for use at a moment's notice but the actual amount of time it is operational is quite low. For these instances the use of battery electric does make sense, provided the power was adequate.

However, Park Services and Wildland Fire Services all agreed that battery electric chainsaws are not currently suitable for felling large trees needed to create fire breaks. Fire breaks allow fires a chance to slow their progress, which, ultimately can greatly reduce the emissions of CO_2 from the burning trees. Handheld gasoline powered chainsaws for wildfires may actually greatly reduce emissions rather than increase them. Additionally, chainsaws used for felling trees must operate for much longer periods of time therefore runtime is an issue much more so than, say, for an urban dwelling fire. Forestry experts are used to using chainsaws with bar lengths up to 30 inches and beyond. It may be some time before zero emission chain saws are available in these lengths and with the associated power required to fell large mature trees.

More than any other tool in this survey, chainsaws are on the cusp of broader acceptance in first response, yet they are generally not currently accepted at this time.

Chainsaws with 40V and 60V battery packs are becoming more and more commonplace and it is reasonable to expect that within the coming years the technology will be sufficiently mature to assuage the fears of many of the respondents. However, it may still be many years before battery electric chainsaws can be used with confidence for felling large trees in remote areas where fire breaks must be created without delays.

9.2.2 **Rotary/K12 Saws**

For the purposes of this study, rotary and K12 saws included any saw with a circular steel blade and does not include the class of tools known as chainsaws (see previous Section).

Unlike fans and lighting, it is not practical for rotary saws to be corded for first response work. Like chainsaws, rotary saws must be highly portable so that first responders can climb onto roof tops or in and around obstacles that may have tripping or cut hazards with cords. Therefore, they must be either gasoline or battery-electric to be useable and accepted by the industry.

Only 16% of respondents indicated they currently use some form of zero-emission rotary/K12 saw. Many respondents indicated they had a basic mistrust of the runtime and power for saws and that some of the saws they trialed were not adequate for their needs (again, be it actual or perceived).

Based on the survey results it appears that many first responders could perhaps envision the use of zero-emission rotary saws at many types of emergency scenes. They must be ready for use at a moment's notice but the actual amount of time the saw is operational can be quite low. For these instances the use of battery electric saws does make sense, provided the power was adequate.

Like chainsaws, rotary saws are on the cusp of broader acceptance in first response, yet they are generally not currently accepted at this time.

Rotary saws with 40V and 60V battery packs are becoming more and more commonplace and it is reasonable to expect that within the coming years the technology will be sufficiently mature to assuage the fears of many of the respondents for nearly all forms of work.

9.3 Tools Currently Not Being Used by First Responders

Zero-emission water pumps and generators are currently not available or used by first responders due to a lack of power and runtime and a technological mistrust of a product that is still new to the market. The development time is likely between five to ten years at the earliest for these tools to be even somewhat useful for use by first responders. It will be some time before these tools gain broader acceptance in the industry and, like many topics discussed in this report, will likely become accepted in urban centres long before they are accepted in rural locations and for search and rescue purposes.

10 Overall Conclusions

The following general conclusions are based on the results of the survey and of the analysis of the data and market research conducted between January and August 2022. The conclusions are grouped by functional categories:

1. The Federal government is proposing to introduce zero-emission requirements for consumer market small spark ignition (SSI) engines which could result in a gradual decrease in availability of some new SSI tools. The use of these tools by emergency responders is not targeted by the regulations but could have an unintended consequence of reducing the ease with which they are currently purchased. The government wished to understand to what degree emergency responders are dependent on SSI tools to perform their work and how a shift to zero-emission tools could affect the way in which first responders do their work, and the safety of the individuals and properties being protected by first responders;

2. To better understand these issues, a 32 question survey was created and targeted towards many types of first response organizations. In all, 37 different respondents from 34 different organizations provided responses to the survey. Fifteen represented organizations in rural areas and 20 were from urban areas and two represented all of Canada;

3. Of the survey respondents, 26 were fire departments, four were search and rescue (three land one marine), one was police, one was towing and recovery, four were parks/wildland and one was a major zero-emission tool manufacturer. The survey respondents represented communities with populations ranging from over one million to less than 5000;

4. All the respondents reacted positively to the survey and ECCC's initiatives and applauded the government's willingness to look ahead into the potential issues but cautioned that change must be slow and based on technology maturity in this sector. Many of the respondents had much to say regarding their experiences and opinions of all forms of tools and expressed many concerns related to the adoption of zero-emission tools in their sector;

5. 100% of the first responders had at least one gasoline powered tool. These included chainsaws (94% of respondents), water pumps (85%), generators (85%), rotary saws (68%), fans (62%), extrication tools (56%), hydraulic pumps (50%), scene/tower lights (24%), heaters (15%), jackhammers (12%) and augers (12%);

6. 63% of respondents indicated using their gasoline tools more than once a month while the remining 37% indicated using tools not more than once per month. Several respondents in the search and rescue sector indicated they only use their gasoline tools several times per year;

7. 57% of respondents indicated starting all their gasoline tools at least once a week to ensure proper operation. The remaining respondents started their gasoline tools on a bi-weekly or monthly basis;

8. One tow and recovery company was interviewed and they indicated that most of their tools are pneumatically driven off the vehicle and they had a very low reliance on gasoline powered tools. Towing and recovery companies tend to do nearly all their work within several meters of their vehicle therefore most of their tools can be driven off the vehicle itself. As a result they are not likely a candidate for focus on SSI reduction;

9. The Canadian Coast Guard uses only two types of gasoline powered tools: dewatering pumps and generators. These are, however, the two classes of tools that have been identified in this report as not ready for zero-emission in first response work. It is not likely that the Coast Guard will be able to commit 100% to zero-emission tools in the near term as their search and rescue capabilities depend too heavily on equipment that does not lend itself to electrification, despite the coast guard's desire to have a 'green' fleet of tools;

10. Despite a reliance on SSI tools, survey respondents mentioned a broad array of challenges with using SSI tools in their line of work. These included concerns relating to fuels, health and safety, tool performance, logistics, maintenance and training. Some of the significant issues included:

    a. Managing and mixing many types of fuels for two stroke and four stroke equipment;
    b. Storing, transporting and disposing of fuels;
    c. Arriving at an already dangerous scene with an explosive product;
    d. Noise and exhaust emissions;
    e. Long term health risks;
    f. Cold starting;
    g. Reduced performance due to smoky intake air;
    h. Can't use inside confined spaces (particularly for exhaust fans);
    i. Need to start SSI tools the ground as opposed to on a rooftop for safety;
    j. Breakdowns and maintenance of spark plugs, air filters, clutches, brakes;
    k. Trainig new staff how to use powerful tools and properly mix fuels;
    l. Difficult to use an SSI fan to clear the air in a building if the tool itself is creating toxic exhaust.

11. Similarly, many advantages of SSI tools were mentioned:

    a. Unlike battery packs, fuel is standardized across brands and can be used in any SSI tool;
    b. In urban centres, fuel can be readily found 24 hours a day;
    c. When speed is important, even the largest SSI can be re-fueled in less than a minute;
    d. Very high power to weight ratio and good performance once the tool is started;
    e. Power and runtime are generally not affected by cold temperatures (although starting can be);
    f. Lack of tether provides maximum flexibility and maneuverability;
    g. Can be maintained and repaired by staff.

12. 87% of the first responders had at least one zero-emission tool that was large enough to have an equivalent SSI counterpart (i.e. tools such as flashlights and cordless drills were not considered large enough). These included extrication tools (50%), scene lights (42%), fans (33%), cutters (14%), chainsaws (8%), jackhammers (8%), heaters (8%), rotary saws (6%),hydraulic pumps (6%), water pumps (3%) and augers (3%). Nearly every respondent had some form of small battery electric hand tool, such as cordless drills, reciprocating saws, flashlights;

13. No respondents indicated they were using zero-emission water pumps or generators;

14. Zero-emission rotary/K12 saws and chainsaws, although readily available on the market, were only listed by three and two respondents respectively. It appears as though these devices have not yet been widely accepted in the industry;

15. As with SSI tools, many challenges were listed with respect to the use of zero-emission tools, grouped by topics such as batteries/charging, finances and operations:

    a. Proprietary nature of battery packs means owning four tools could result in four different battery packs;
    b. Runtime is too short and battery life at a scene is unpredictable;
    c. Some batteries will not charge in sub-zero temperatures;
    d. Lifespan of batteries is hard to predict and much shorter than advertised;
    e. Remembering to bring all the batteries and having to ensure batteries are always charged and ready to use at a scene;
    f. Battery health and state of charge is not easy to understand and manage;
    g. Needing a generator or a vehicle inverter to charge batteries;
    h. Takes so much longer to recharge compared to refuelling an SSI tool;
    i. The cost of new batteries ruins the ROI of the tool;
    j. Too expensive to replace all the SSI with zero-emission at this time;
    k. Cold weather performance and charging;
    l. Performance is not at par with most SSI used in emergency work;
    m. Cords are a trip hazard (although not an issue with battery electric);
    n. Staff can’t repair tools due to complex electronics.

16. Similarly, many advantages of zero-emission tools were mentioned and grouped by categories such as performance, health and safety, lack of gasoline:

    a. Nearly all respondents indicated the convenience of ‘grab and go’ and pushbutton starting, even on a rooftop;
    b. Can be used in confined spaces and fans do not blow toxic exhaust into the very building they are trying to cleanse;
    c. Performance is not altered in smoky environments;
    d. Battery electric tools are not tethered (although this is actually an advantage relative to another form of zero-emission, not SSI);
    e. No fumes, no exhaust and much less noise pollution;
    f. No hot exhaust systems to start a grass fire;
    g. No fuels to mix and manage and dispose;
    h. Less maintenance, no spark plugs and air filters to manage;
    i. In theory should be less expensive to own over the entire life cycle.

17. Of the five respondents who did not currently operate zero-emission tools, three indicated they would be willing to purchase zero-emission tools in the future and the other two stated they could not commit at this time due to financial restrictions but did not rule out the possibility either. These respondents had a broad array of reasons for not having adopted zero-emission tools to date, including costs, performance, reliability, battery charging and the lack of battery pack commonality;

18. 60% of respondents indicated they had performed some type of manufacturer sponsored field tests or trials for zero-emission equipment. Many respondents indicated that COVID 19 restrictions had greatly reduced the number of visits from tool manufacturer sales representatives. Extrication and rescue tools were listed as being the most popular tool for testing and trialing with many respondents indicating they purchased the tools because the results of the trials were so positive;

    a. Some of the concerns resulting from the zero-emission tools trials were:

        i. Not powerful enough;
        ii. Battery life;
        iii. Not enough runtime to cut trees all day long;
        iv. Cold weather use;
        v. Our trucks don't have inverters;
        vi. Storage space on vehicles and apparatus;
        vii. Battery fires;

    b. Some of the positive remarks resulting from the trials were:

        i. Compact, lighter weight;
        ii. Grab and go;
        iii. Technology seems to have improved a lot;
        iv. Battery life indicators are now very common;
        v. Quiet, instant power with no exhaust;

19. The last question asked respondents to describe if they would have to hire new staff or alter the way in which they respond to emergencies based on the need to manage and charge multiple batteries at a scene. The responses were as follows:

    a. 38% said yes they could manage it but would need better trucks and apparatus;
    b. 32% said yes this could be done with existing staff and vehicles and they were not concerned;
    c. 24% said it was unclear at this time; and
    d. 6% said no they could not manage charging with current staffing assignments.

20. The town of Meaford, ON was the only organization in the survey who had already committed 100% to zero-emission tools with the exception of water pumps and generators. According to their chief, the staff are now ignoring the gasoline tools in favour of the battery electric tools. In order to achieve their zero-emission goals they committed to one major manufacturer thus allowing them battery interoperability;

21. 100% of all respondents serving urban areas have already purchased at least one zero-emission tool whereas only 40% of respondents serving rural areas had done so. Of those respondents serving mixed urban and rural areas, 69% had purchased

zero-emission tools. It appears as though rural departments have been less willing, or able, to purchase zero-emission tools than their urban counterparts. A lack of funding, fewer sales calls and less pressure from senior management/city council to be 'green' were cited as the main reasons that rural departments have been slower to adopt;

22. Respondents in rural areas made much mention of the role water pumps play in first response. Whereas most urban first responders can rely on hydrants and tanker/pumper trucks to provide water, many rural stations still rely on lakeside water pumps to provide water at a scene. This was listed by many rural stations as an impediment to broader electrification;

23. Wildland, park services and the Heavy Urban Search and Rescue task forces made more mention of the need for SSI tools due to the need for more power, more bar length on chainsaws, longer runtimes compared to other respondents. Respondents who routinely work for days, or weeks, at a time in hostile and remote locations were very adamant that zero-emission tools were not suitable for their line of work. They were very reluctant to adopt zero-emission as they are rarely in close proximity to a reliable source of AC power for charging and did not like the idea of carrying an extra generator simply to charge batteries when the SSI tools are already performing the tasks in a satisfactory manner. Of all survey respondents, search and rescue and wildland/park employees were the least optimistic regarding the adoption of zero-emission tools in the near term;

24. Small rural and northern communities were more likely to mention funding as an impediment to broader adoption of zero-emission tools. This includes not only price of the tools, but the support equipment such as generators and inverter-equipped trucks needed to charge the tools. Although large city centers are also under pressure to reduce costs, there was less concern about funding than in rural areas;

25. Zero-emission saws are lighter and less expensive than the SSI equivalent. However, zero-emission saws tend to be slightly smaller in terms of bar length and cutting wheel diameter meaning overall cutting performance may not quite be at par with SSI tools at this point. This will likely improve in the coming years;

26. Hydraulic pumps are readily available in battery electric and corded for use with extrication tools. Battery electric pumps tended to be quieter, lighter, less expensive and offer similar performance than their SSI counterparts ;

27. Exhaust fans are available in SSI, corded and battery electric in positive pressure and negative pressure varieties. Unlike some other tools, the SSI variants of fans were the least expensive compared to battery electric but were also the loudest and heaviest. Regardless of cost, first responders list fans as one of the most obvious and necessary candidates for electrification as SSI tools are counterproductive as they blow toxic fumes into the very building they are trying to cleanse/evacuate;

28. Scene and tower lighting is also available in SSI, corded and battery electric. Lighting is one of the most interesting candidates for electrification as there is literally no noise from a zero-emission light stand as there are no motors, let alone an SSI engine. Scene lighting in battery electric was found to be less expensive than SSI but not as powerful as SSI models;

29. Price difference between SSI and zero-emission are hard to quantify owing to the vast array of makes, models and trim levels. Also, the choice between a 1 Ah battery and, say, an 8 Ah battery can have a dramatic effect on costs. Additionally, gasoline is considered an operational consumable cost whereas battery packs are seen as a capital expense before the tool is even used, making the costs for zero-emission artificially high at the time of purchase. Despite all this, zero-emission purchase prices including batteries are typically somewhat lower than equivalent SSI, which aids in lowering life cycle costs given how much cheaper it is to recharge a zero-emission tool compared to the cost of premium pump gasoline. Premium pump gasoline was mentioned often as a mean of avoiding the use of ethanol infused fuels in carburetted engines;

30. A 10 year theoretical life cycle cost comparison model was created between SSI and zero-emission chainsaws. Using assumed duty cycles of 50 hours per year and a variety of other assumptions based on survey input, it was determined that, on average, the ten year life cycle costs of operating a zero-emission chainsaw should be $700 less expensive than a similarly sized SSI saw. A similar exercise was conducted for rotary saws and the savings were found to be closer to $500, in favour of the zero-emission saw. All of these comparisons included mid-life battery replacements;

31. An inventory of SSI tools commonly used in the first response sector revealed that most SSI tools burn between 1 and 2 litres of fuel per hour, although some larger equipment like pumps and generators will be higher. This equates to CO_2 emissions of between 2 and 6 kg per hour of operation in SSI;

32. All zero-emission tools are lighter than SSI counterparts of the same power class. Saws tended to be 2 to 3 kg lighter whereas fans, pumps and lights were as much as 13 to 18 kg lighter than their SSI counterparts. This is a significant savings in terms of weight being carried by first responders;

33. With the exception of rotary saws, all zero-emission tools are quieter than their SSI counterparts, some by a wide margin. Not only will noise levels at a scene be much reduced but long term exposure effects should be reduced;

34. Runtime was very easy to calculate for SSI tools as it is merely the fuel burn rate multiplied by the volume of fuel in the tank, and this is largely independent of ambient conditions. However, the runtime for zero-emission tools was very difficult to calculate as factors such as battery health, ambient temperature, battery size, charge type all have a dramatic effect on charge time. For these reasons, direct comparisons were not made in the report. Rather, tool availabilities were calculated for zero-emission tools to estimate the number of batteries required to match the 90%+ tool availability of SSI at a scene. It is estimated that SSI tools have availability between 85% and 95%. Corded tools also have availability that can approach, or reach, 100%;

35. The time to recharge a battery pack was found to be affected by many factors such as: battery size, type of battery, charger type, ambient and battery temperatures, battery health and state of charge (SOC);

36. First responders will have to understand (either via research or training) the effect that battery size and type can have on performance and runtime. A battery of, say, 1 Ah will provide significantly less runtime than that of, say, an 8 Ah battery. These details will have to be understood at purchase time so that runtime matches their needs. Similarly, charger type can play a significant role in tool availability. A conventional charger can take as much as four times longer to charge a battery compared to the newer types of fast-chargers. As an example, one brand of fast charger requires only 60 minutes to charge a 12 Ah battery that would take 241 minutes to charge in a conventional charger. This could have a dramatic effect on tool use if a first responder is expecting a fast charger but given a conventional charger instead. Batteries and chargers will have to be managed very carefully to ensure the correct equipment is purchased and brought to scenes;

37. Lithium-Ion is now essentially the exclusive battery chemistry used in all the tools discussed in this survey. Until newer chemistries are developed, Lithium-Ion will be the standard as it does not have ‘memory’ and can be charged many times before experiencing power and runtime losses;

38. The way in which Li-Ion batteries are charged in extreme cold conditions could be a major impediment to adoption in the far north. Li-Ion can be fast charged from 5 deg C to 45 deg C, however, most chargers will automatically cease the charging process as soon as battery temperature drops below 0 deg C as internal damage will occur due to plating of metallic lithium on the anode. Even at 5 dec C the charge rate should be reduced. This could have a very detrimental effect on first response if many batteries are set up at a scene for charging, only to discover the charger has shutdown with a ‘cold battery’ error code. First responders will have to develop novel ways to ensure batteries can be charged in warmed vehicles or tents otherwise tool availability could be low, or zero, at very cold scenes. In cases like this, backup SSI tools will be required to assure tool availability;

39. Zero emission tools were found to be generally less expensive than SSI tools but the price of lithium could affect this in the future but this cannot be predicted at this time;

40. The proprietary nature of battery packs could be a significant operational issue for first responders. The nature of government procurement could lead to first response departments owning, say, 10 tools with 7 different types of battery packs. Respondents, view this as an impediment to broader adoption of zero-emission tools. First responders will have to pay close attention to battery pack architecture to ensure they can maximize interoperability. Conversion kits are available but have limited use as they cannot be used for charging;In time, it may be necessary to do in the tool industry what was done in the electric vehicle and cell phone industries where, currently, there are at most, two to three charging architectures per industry. The number of battery styles and architectures will surely result in difficulties for the first response sector and efforts should be put in place to standardize battery architecture so that first responders are selecting the best tool for the job, rather than the tool with the most convenient battery pack;Most battery electric tools have recharge to runtime ratios for their batteries in the range from as low as 2 to 1 to as high as 4 or 5 to 1. This will have to be clearly understood before arriving at a scene as high charge to run ratio devices will have their batteries on the charger for significant amounts of time rather than being used productively in the tool. These ratios will be even higher

in cold ambient temperatures and could prevent a tool from achieving a reasonable recharge to runtime ratio;

41. Tool availability and run time/charge time ratios were calculated for scenarios with one, two, three and four battery packs with variable charge times and run times. For most scenarios and tool specifications, four to six battery packs may be required to match the tool availability of SSI tools. This will improve over time as battery packs become more powerful and charge times are reduced. For tools that have intermittent use this will not be an issue;

42. Water pumps are a critical tool in first response, particularly in rural areas, but are not currently available in zero-emission (at least not in the power and runtime required). Similarly, battery operated generators are on the market but have not been adopted by the industry owing to a lack of power and runtime or the fact that the technology is still too recent. None of the respondents indicated they were using zero-emission generators or zero-emission water pumps suitable for drawing water from lakes and rivers. Zero-emission water pumps and generators likely will not meet the required performance specifications in the next few years;

43. A potential compromise between gasoline tools and zero-emission tools emerged from the study: many respondents would be willing to adopt zero-emission hand tools, provided they could set up a fossil fuel powered generator to charge all the batteries to overcome the lack of an inverter-equipped vehicle close to the scene. Using portable generators could provide opportunity to replace many gasoline powered hand tools with zero-emission tools without sacrificing the ability perform life saving response duties and reduce the overall CO_2 footprint at a scene, even if the generator were to run continuously at the scene. However, zero-emission water pumps would probably remain unavailable for many years. One generator can be used to charge the batteries for literally dozens of zero-emission tools, all with just one tailpipe. Additionally, most, if not all, current generators are four stroke meaning a four stroke engine could be replacing many two stroke engines, thus reducing emissions of hydrocarbons, possibly by a large amount. Although somewhat counterintuitive, running an SSI generator for many continuous hours could still reduce emissions at a scene, provided enough SSI tools were replaced with zero-emission tools, be they corded or battery. Some crude CO_2 reduction calculations were performed as part of this study to demonstrate this point but more refined models would be required to validate and quantify all air emissions from these scenarios;

44. Emergency vehicles will become much more important in terms of tool charging in the future. Apparatus will need to be equipped with inverters and charging banks to support the potentially dozens of chargers that will be required at a scene. Some urban departments are currently receiving their first all electric vehicles which will have the capacity to charge tools using the on board battery, or a small APU style diesel engine. In either case, the emissions will be reduced from that of the combined fleet of SSI tools being displaced;

45. The Heavy Search and Rescue respondents (HUSAR) had the greatest level of concern regarding electrification of tools. They are commonly deployed for days, or weeks, at a time that may, or may not, have 120V/240V power for recharging and thus indicated a higher than average dependence on gasoline powered tools compared to urban fire operations. They raised significant concern about performing

their duties with exclusively zero-emission tools at this time unless they could use and carry as many SSI generators as needed to recharge;

46. Significant up-front capital would be required to replace all the current SSI tools with zero-emission tools. Many respondents were less concerned about tool performance and the life cycle costs of zero-emission tools and much more concerned regarding the capital cost of purchasing so many tools. Buying individual zero-emission tools will cost less than SSI tools but having to find funding to replace SSI tools that are still in good working order will be the challenge. Some respondents felt the government should provide financial incentives to do so;

47. Lithium-Ion batteries are found in nearly all current battery-electric power tools. However, Li-Ion battery packs cannot be charged at temperatures less than 0 deg C because most chargers will automatically cease the charging process as soon as battery temperature drops below 0 deg C. This may pose a severe risk to first response as many survey respondents indicated they often respond to emergencies at ambient temperatures between -30 and -40 deg C. Given the extreme low temperatures in parts of Canada for prolonged periods of the year, this point and associated risk will have to be considered strongly by first responders. Battery packs would have to be charged inside vehicles or inside heated tents in order to assure the types of tool availabilities calculated in this report;

48. The battery in a zero-emission tool begins to lose health/life the first time it is charged/discharged. This degradation can be very slow and take years, but it is an unavoidable consequence of using Li-Ion batteries. Consumers can safeguard against these effects by following the charging best practices such as slow charging overnight, charging at room temperature. However, while working at an emergency scene, first responders will not have the luxury of following all the manufacturers' charging best practices. The way in which first responders use tools may often be in direct conflict with charging best practices which will undoubtedly reduce battery lifespans thus requiring the unexpected purchase of expensive battery packs. Currently, Li-Ion battery packs cost between $100 and $400 each, depending on size and power. Fortunately, it is possible to purchase just the battery packs and use existing chargers;

49. Nearly all first response organizations are managed and fiscally supported by some form of government (be it municipal, provincial or federal). As such, the policies regarding zero-emission tool adoption (or lack thereof) will often be dictated by the government body, rather than the end-users;

50. In summary, the industry is ready to accept most zero-emission tools and there are reasonable work-arounds for many of the real and perceived challenges of migrating to zero-emission tools. There are four distinct issues that could pose a risk to public safety and will need to be very carefully considered by all departments before tools are approved, purchased and used:

    a. The current lack of commonality with battery packs;
    b. The difficulties charging in cold weather;
    c. The current number of charged batteries that would be required to maintain a high tool availability; and

d. The high financial cost of replacing all current tools with zero-emission tools at once.

11 Possible Follow-On Work

Based on the analysis of the gathered data, the following potential areas of further study were identified:

1. Further study into how the proprietary nature of battery pack architecture could affect broader adoption of zero-emission tools for emergency response;

2. Explore the possibility of developing a standard for battery architecture;

3. Collect more information on the risks and likelihood of Lithium-Ion fires compared to gasoline fires for small tools;

4. Look into potential benefits that incentives for the purchase of zero-emission tools could have in assisting with the transition of the sector;

5. Further refine models and calculations to validate and better quantify potential emissions reductions of different operational scenarios using zero-emission tools;

6. Collect more information on cold weather battery performance and technologies to increase runtime and preserve battery life in Canada's cold weather; and

7. Collect more information on the long term reliability of zero-emission tools.

12 REFERENCES

The following references were reviewed and cited in the report. This section has been divided into two headings: traditional academic references that should not change over time; and product information website links that, although useful and current at the time of report preparation, will likely change, or disappear, in time.

12.1 Traditional/Academic References

1. Environment and Climate Change Canada. (2021). ECCC Bid Solicitation 5000060776-1 "*Suitability of Zero-emission Equipment for use in Emergencies*". Published 2021-11-10;

2. Toma, E; Patten, J.D. (2013). *Canadian Stationary Diesel Market Study: Effects of Tier 4 Regulations*, National Research Council of Canada, Technical Report ST-GV-TR-0008;

3. The Economist. (2014); Retrieved from http://www.economist.com/blogs/economist-explains/2014/02/economist-explains-16;

4. Natural Resources Canada. (2021) Retrieved from https://www.nrcan.gc.ca/energy/efficiency/communities-infrastructure/transportation/idling/4419;

5. Booz, Allen & Hamilton. (2000). *Protype Evaluation of New Technology Buses for MBTA*. Technical Report Rev. 5;

6. Statistics Canada. (2021). Vehicle Registration Census Database. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701;

7. Patten, J.D., (2009). *New Flyer Fuel Cell Bus Climate Testing*, National Research Council Canada, Technical Report CSTT-HVC-TR-161;

8. Government of Canada. (2021). *Health Impacts of Air Pollution in Canada – Estimates of Premature Deaths and Nonfatal Outcomes.* Report., catalogue no. H144-51/2021E-PDF. 56 pp. Retrieved from https://publications.gc.ca/collections/collection_2021/sc-hc/H144-51-2021-eng.pdf;

9. Natural Resources Canada. (2018). Environmental Statistics. Retrieved from https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=aaa&juris=ca&rn=3&page=0;

10. Environment and Climate Change Canada. (2022). Emissions Inventory. Retrieved from https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html;

11. California Air Resource Board (CARB) Website, About Small Off Road Engine (SORE); Retrieved from https://ww2.arb.ca.gov/our-work/programs/small-off-road-engines-sore/about;

12. California Air Resources Board (CARB. (2022). List of Pre Empt Devices: Retrieved from https://ww2.arb.ca.gov/sore-list-determine-preempt-road-applications;

13. California Air Resources Board (CARB). (2022). Determination of Pre-empt applications. Retrieved from https://ww2.arb.ca.gov/sore-list-determine-preempt-road-applications;

14. Haynes, Hylton and Stein, Gary. (February 2018). NFPA Research. Canadian Fire Department Profile, 2014-2016, National Fire Protection Association;

15. Email from Kevan Jess, CAFC advisor and former Alberta Fire Commissioner to Jeff Patten, August 25, 2022;

16. Connecticut Fire Academy, Recruit Fire Fighter Program. (2014). Retrieved from https://portal.ct.gov/-/media/CFPC/files/NEW-ITEMS-2019/Uploaded-Files/Instructor-Lesson-Plans/Uploaded-Files/Unit-9/911-Firefighter-Tools--Equipment-Instructors-Guide.pdf

17. Engineering Toolbox Fuel Densities, Retrieved from: https://www.engineeringtoolbox.com/fuels-densities-specific-volumes-d_166.html;

18. Mobil 1 Mix Oil Specifications. (2022). Retrieved from https://www.mobil.com/en-au/passenger-vehicle-lube/pds/ap-xx-mobil-2-stroke-oil;

19. Calvo, Angela & Manzone, Marco & Spinelli, Raffaele. (2013). *Long Term Repair and Maintenance Cost of some Professional Chainsaws*. Croatian Journal of Forest Engineering. 34. 265-272;

20. Tas, Inanc & Akay, Abdullah. (2018). Analysis of Noise Level Caused by a Chainsaw During Tree Felling Operations. Bursa Technical University, Faculty of Forestry, Bursa, Turkey;

21. Patten, JD, McWha, T,. (2015). Dimethyl Ether Fuel Literature Review. National Research Council of Canada. Technical Report ST-GV-TR-0032. Retrieved from https://nrc-publications.canada.ca/eng/view/ft/?id=b22a2fd1-f2fc-40d9-a6f4-cf109f3ea344;

22. Population of Cities in Canada. (2022). Retrieved from https://worldpopulationreview.com/countries/cities/canada;

23. Testing the Waterax B2X Water Pump. (2016). Waterax Corporation. Retrieved at https://www.youtube.com/watch?v=7vrpJC85Dac;

24. Jizhou Li et al. (Aug 2021). *Advanced Energy Materials*. Technical Report 10.1002/aenm.202102122. US Department of Energy, SLAC National Accelerator Laboratory;

25. Aris, Asma Mohammed, Shabani, Bahman. (2016). *An Experimental Study of a Lithium Ion Cell Operation at Low Temperatures*; University of Melbourne, Australia;

26. Decibel Level Comparison Chart. (2009). Yale University Health and Safety Retrieved from https://ehs.yale.edu/sites/default/files/files/decibel-level-chart.pdf;

27. Sound Power and Sound Pressure Explained. (2022). Bruel and Kjaer Corporation. Retrieved from https://www.bksv.com/en/knowledge/blog/sound/sound-power-sound-pressure;

28. Decibel (Loudness) Comparison Chart. (2022). Hearing Conservation Organization. Retrieved from https://www.hearingconservation.org/assets/Decibel.pdf;

29. Low Temperature Charging of Li-Ion Batteries. (2019). Battery University.com Retrieved from https://batteryuniversity.com/article/bu-410-charging-at-high-and-low-temperatures#:~:text=During%20charge%2C%20the%20internal%20cell,performance%20noticeably%20with%20Li%2Dion;

30. Cycle Testing Various Li-Ion Batteries. (2016). Cadex Electronics, Richmond, BC. Retrieved from https://www.cadex.com/technology/our-technologies;

31. The United States Environmental Protection Agency (2022). *The Importance of Methane.* Retrieved from https://www.epa.gov/gmi/importance-methane;

32. Discharging at High and Low Temperatures. (2019). Battery University.com: Cold Weather Use. Retrieved from https://batteryuniversity.com/article/bu-502-discharging-at-high-and-low-temperatures;

12.2 Technical Specification and Pricing References

33. Technical Specifications for Echo CS7310. Retrieved from https://lawnmowerhosp.com/product/echo-cs7310-chainsaw-2177;

34. https://cms-yamab.sdch.develondigital.com/uploads/site/catalogue/5bb3a824bc21192bdd3e3012/ECHO_catalogue_2022.pdf;

35. Technical Specifications for Husqvarna 562. Retrieved from https://www.husqvarna.com/ca-en/chainsaws/562xp-gw/;

36. Technical Specifications for Husqvarna 395. Retrieved from https://www.husqvarna.com/ca-en/chainsaws/395xp/;

37. Technical Specifications for Husqvarna 572. Retrieved from https://www.husqvarna.com/ca-en/chainsaws/572xp/;

38. Technical Specifications for Husqvarna 576. Retrieved from https://gardensurge.com/husqvarna-576-xp-review/;

39. Technical Specifications for Stihl 362. Retrieved from https://www.stihl.com/STIHL-power-tools-A-great-range/Chainsaws/Petrol-chainsaws-for-forestry/22255-131/MS-362-C-M.aspx;

40. Technical Specifications for Stihl 362. Retrieved from https://www.ciampelli.com/en/stihl-ms-362-c-m-petrol-chainsaw-with-bar-and-chain-45-cm_pr88.php

41. Technical Specifications for Stihl 461. Retrieved from https://robertkee.ie/site/uploads/pdfs/stihl-chainsaw-pdfs/stihl-ms461-chainsaw-specification-sheet.pdf

42. Technical Specifications for Stihl 462. Retrieved from https://www.stihl.com/STIHL-power-tools-A-great-range/Chainsaws/Petrol-chainsaws-for-forestry/279876-131/MS-462-C-M.aspx

43. Technical Specifications for Stihl MS500i Retrieved from https://www.forestry.com/editorial/equipments/stihl-ms-500i-test-first-chainsaw-fuel-injection/;

44. Technical Specifications for Supervac chainsaws. Retrieved from https://supervac.com/rescue-saws/gas-powered-chainsaws/;

45. Technical Specifications for Makita chainsaws. Retrieved from https://makita.ca/index2.php?event=tool&id=3273&catid=40

46. Technical Specifications for Milwaukee 2727 Chainsaw. Amazon.com. Retrieved from https://www.amazon.ca/Milwaukee-2727-20-Fuel-Chainsaw-Tool/dp/B07FRRFR47;

47. Technical Specifications for Milwaukee M18 Battery Packs. The Home Depot. Retrieved from https://www.homedepot.ca/product/milwaukee-tool-m18-18v-lithium-ion-high-output-starter-kit-with-2-6-0-ah-battery-packs-and-charger/1001628251;

48. Technical Specifications for Makita XCU04Z. Amazon.ca. Retrieved from https://www.amazon.ca/Makita-XCU04Z-Lithium-Ion-Brushless-Cordless/dp/B07781633N;

49. Technical Specifications for Makita Battery Chargers. Amazon.ca. Retrieved from https://www.amazon.ca/Makita-Y-00359-Charger-Battery-BL1850B/dp/B01MDKWI32/ref=pd_lpo_3?pd_rd_i=B01MDKWI32&psc=1;

50. Technical Specifications for Dewalt 60V Chainsaw. The Home Depot. Retrieved from https://www.homedepot.ca/product/dewalt-60v-max-flexvolt-lithium-ion-cordless-brushless-16-inch-chainsaw-tool-only-/1001530916;

51. Technical Specifications for Dewalt Battery Packs. The Home Depot. Retrieved from https://www.homedepot.ca/product/dewalt-20v-60v-max-flexvolt-lithium-ion-battery-pack-9ah-2-pack-/1001032332;

52. Technical Specifications for Ryobi 40V 18 inch Chainsaw. The Home Depot. Retrieved from https://www.homedepot.ca/product/ryobi-40v-hp-brushless-cordless-18-inch-chainsaw-tool-only-/1001613236;

53. Technical Specifications for Ryobi 40V Li-Ion Battery. Amazon.ca. Retrieved from https://www.amazon.ca/Ryobi-40V-Lithium-Ion-Battery-OP4040/dp/B07QYH36TC/ref=sr_1_12?crid=3619MOL1WNG3D&keywords=ryobi+40v+battery+2+pack&qid=1655899058&s=hi&sprefix=ryobi+40v+battery+2+pack%2Ctools%2C76&sr=1-12;

54. Technical Specifications for Echo 16 inch chainsaw. Amazon.ca. Retrieved from https://www.amazon.ca/ECHO-16-in-Cordless-Chainsaw/dp/B01AL69EPE/ref=sr_1_1?crid=1EWKS8GS8Q7KP&keywords=CCS-58V&qid=1655899134&s=hi&sprefix=ccs-58v%2Ctools%2C70&sr=1-1;

55. Technical Specifications for Echo 58V Li-Ion Battery. Echo.com. Retrieved from https://www.echopartsonline.com/Echo-58v-Battery-CBP58V4AH-OEM/;

56. Technical Specifications for Stihl MSA 220 Chainsaw. Stihl Corporation. Retrieved from https://en.stihl.ca/STIHL-Products/Battery-Power-Made-by-STIHL-/Battery-Chain-Saws/2110374-87564/MSA-220-C-BQ.aspx;

57. Technical Specifications for Stihl Batteries. Stihl Corporation. Retrieved from https://m.en.stihl.ca/STIHL-Products/Battery-Power-Made-by-STIHL-/Batteries/261723-1592/AP-300.aspx

58. Technical Specifications for Husqvarna Battery Packs. Gardenland.com. Retrieved from https://www.gardenland.com/product/husqvarna-bli300-lithium-ion-battery/;

59. Technical Specifications for Husqvarna 540i Chainsaw. Husqvarna Corporation. Retrieved from https://www.husqvarna.com/au/chainsaws/540i-xp-without-battery-and-charger/

60. Technical Specifications for Stihl TS 410 saw. Stihl Corporation. Retrieved from https://www.stihl.com/STIHL-power-tools-A-great-range/Cut-off-machines-and-concrete-cutters/Cut-off-machines/21367-510/TS-410.aspx;

61. Technical Specifications for Stihl TS800 saw. Stihl Corporation. Retrieved from https://www.stihl.com/STIHL-power-tools-A-great-range/Cut-off-machines-and-concrete-cutters/Cut-off-machines/21208-510/TS-800.aspx;

62. Technical Specifications for Husqvarna K1270 saw. Husqvarna Corporation. Retrieved from https://www.husqvarna.com/ca-en/power-cutters/k1270/

63. Technical Specifications for Husqvarna K770 saw. Husqvarna Corporation. Retrieved https://www.husqvarna.com/ca-en/power-cutters/k770/

64. Technical Specifications for Husqvarna K960 saw. Alltools.com. Retrieved https://www.alltools.com.au/product/husqvarna-k960-14inch-ring-cutter

65. Technical Specifications for Makita EK765H saw. Makita Corporation. Retrieved https://www.makitatools.com/products/details/EK7651H

66. Technical Specifications for Makita E8100H saw. Makita Corporation. Retrieved https://www.makitatools.com/products/details/EK8100

67. Technical Specifications for Supervac SVC414. Supervac Corporation. Retrieved https://supervac.com/wp-content/uploads/2019/06/SVC414Sht.pdf

68. Technical Specifications for Hilti 7124 saw. Hilti Corporation. Retrieved https://www.hilti.ca/c/CLS_POWER_TOOLS_7124/CLS_GAS_SAW_SUB_7124/CLS_GAS_SAW_7124/r13340238

69. Technical Specifications for Hilti 7124 saw. Hilti Corporation. Retrieved https://www.hilti.ca/c/CLS_POWER_TOOLS_7124/CLS_GAS_SAW_SUB_7124/CLS_GAS_SAW_7124/r11460425

70. Technical Specifications for Echo 7410 Saw. Echo Corporation. Retrieved https://www.echo.ca/Products/Cut-Off-Saw/CSG-7410

71. Technical Specifications for Partner K12FD saw. Thefirestore.com. Retrieved https://www.thefirestore.com/Partner-K-12FD-Fire-Rescue-Saw

72. Technical Specifications for Stihl TSA 230saw. Stihl Corporation. Retrieved https://en.stihl.ca/STIHL-Products/Battery-Power-Made-by-STIHL-/Battery-Cut-off-Machine/240781-1609/TSA-230.aspx

73. Technical Specifications for Husqvarna K535 saw. Husqvarna Corporation. Retrieved https://www.husqvarna.com/ca-en/power-cutters/k535i/;

74. Technical Specifications for Husqvarna K4000 saw. Husqvarna Corporation. Retrieved https://www.husqvarna.com/ca-en/power-cutters/k4000/;

75. Technical Specifications for Makita 3574 saw. Makita Corporation. Retrieved https://www.makita.ca/index2.php?event=tool&id=3574

76. Technical Specifications for Milwaukee 2786-22HD saw. Milwaukee Corporation. Retrieved https://www.milwaukeetool.ca/Products/Power-Tools/Concrete/2786-22HD

77. Technical Specifications for Milwaukee MXF314 saw. Milwaukee Corporation. Retrieved https://www.milwaukeetool.ca/Products/Equipment/Cutting/MXF314-2XC

78. Technical Specifications for Dewalt 60V Cutoff Saw. Dewalt Corporation. Retrieved https://www.dewalt.com/product/dcs690b/60v-max-9-brushless-cordless-cut-saw-tool-only?tid=577701

79. Technical Specifications for Hilti 7124 cutoff saw. Hilti Corporation. Retrieved https://www.hilti.ca/c/CLS_POWER_TOOLS_7124/CLS_GAS_SAW_SUB_7124/CLS_BATTERY_CUTOFF_SAW_7124/r13693257?combo_content=6cce06881c5d8b01ec39ae36503a5615&itemCode=2251533

80. Technical Specifications for Stihl TSA 230 saw. Stihl Corporation. Retrieved https://www.stihl.co.nz/STIHL-Products/Concrete-Cutters-and-Cut-Off-Machines/Battery-Electric-Cut-Off-Saw/240781-1629/TSA-230-tool-only.aspx

81. Technical Specifications for Husqvarna K1 Pace saw. Husqvarna Corporation. Retrieved https://www.husqvarnaconstruction.com/ae/power-cutters/k1pace/?article=970445801

82. Technical Specifications for Dewalt 230mm cutoff saw. Dewalt Corporation. Retrieved https://www.dewalt.com.au/products/dcs690x2-xe--54v-xr-flexvolt-230mm-cut-off-saw-2-x-9ah

83. Technical Specifications for Stihl TSA 230 saw. Stihl Corporation. Retrieved https://en.stihl.ca/STIHL-Products/Battery-Power-Made-by-STIHL-/Battery-Cut-off-Machine/240781-1609/TSA-230.aspx;

84. Technical Specifications for K1 Pace Saw. Acecutting.com. Retrieved https://acecutting.com/collections/battery-hand-held-saws/products/k1-pace-battery-14-husqvarna-power-cutter;

85. Technical Specifications for Dewalt 9 in cutoff saw. The Home Depot. Retrieved https://www.homedepot.ca/product/dewalt-60v-max-flexvolt-lithium-ion-cordless-brushless-9-inch-cut-off-concrete-saw-tool-only-/1001558037

86. Technical Specifications for Hilti DSH600 saw. Protoolreviews.com. Retrieved https://www.protoolreviews.com/hilti-nuron-battery-cut-off-saw-dsh-600-22/

87. Technical Specifications for Husqvarna Pace 94 saw. Wolfswinkel.com. Retrieved https://www.wolfswinkel.shop/forest-garden-park-machines-accessories/husqvarna-machinery/husqvarna-battery-tools/husqvarna-pace-94-volt-system

88. Technical Specifications for Milwaukee XC406 battery pack. The Home Depot. Retrieved https://www.homedepot.ca/product/milwaukee-tool-mx-fuel-lithium-ion-redlithium-xc406-battery-pack/1001514218

89. Technical Specifications for Dewalt DSC690X2 saw. Amazon.ca. Retrieved https://www.amazon.ca/Dewalt-DCS690X2-FLEXVOLT-Cordless-Brushless/dp/B07JGL7J89/ref=pd_lpo_2?pd_rd_i=B07JGL7J89&psc=1

90. Technical Specifications for Stihl pole pruner HT105. Stihl Corpotaration. Retrieved https://www.stihlusa.com/products/pole-pruners/professional-pole-pruners/ht105/#specifications;

91. Technical Specifications for Husqvarna Pole Saw 525. Bayleysonline.com. Retrieved Husqvarna 525DEPS (25.4cc) Dielectric Pole Saw with 12" Bar & Chain (MAD SAW) (baileysonline.com)

92. Technical Specifications for Stihl Battery Powered Pole Saw HTA 135. Ciampelli.com. Retrieved https://www.ciampelli.com/en/perche-d%e2%80%98elagage-professionnelle-a-batterie-hta-135-systeme-ap-stihl-sans-batterie-ni-chargeur_pr872.php

93. Technical Specifications for BT1.5 hydraulic pumps. Shopify.com. Retrieved https://cdn.shopify.com/s/files/1/1538/2347/files/BT1.5-01.pdf?1529532169611238319

94. Technical Specifications for BT6.5 hydraulic pumps. Shopify.com. Retrieved https://cdn.shopify.com/s/files/1/1538/2347/files/BT6.5-01.pdf?18370453389978706966

95. Technical Specifications for Hurst hydraulic pumps.. Retrieved Hurst Jaws of Life Magazine - Powered by PageTurnPro.com

96. Technical Specifications for Spartan SR-20-PC CORE. Spartan Fire Corporation. Retrieved from https://spartanfire.com/wp-content/uploads/2019/01/SR-20-PC-2-CORE-Spec-Sheet-Letter-US-Standard_72dpi_612x792px_G_NR-9389.pdf

97. Technical Specifications for TNT hydraulic pumps. Firstoutrescue.com. Retrieved https://www.firstoutrescue.com/rescue-extrication/tnt-rescue-tools/tnt-high-pressure-pumps.html

98. Technical Specifications for TNT hydraulic pumps. Firstoutrescue.com. Retrieved https://www.firstoutrescue.com/rescue-extrication/tnt-rescue-tools/tnt-high-pressure-pumps/bt-6-5-simo.html;

99. Technical Specifications for Holmatro hydraulic pumps. Holmatro Corporation. Holmatro Rescue Equipment Pricing List, July 2021. *July 2021-Price List.pdf*. Homatro, Glen Burnie, MD., 21061 USA;

100. Hurst Jaws of Life 2021 Price List, 5000 psi Tools and Accessories. Effective 1/1/2021. *Hurst 2021 5,000 PSI MSRP Price List-Effective 1.1.21.pdf*; https://www.hgacbuy.org/products-and-services/view-product?productid=22072;

101. Amkus Rescue Systems Price List, Effective July 1, 2021. *2021 Amkus Price List HGAC (7-1-21).pdf*; https://www.hgacbuy.org/products-and-services/view-product?productid=22101;

102. Technical Specifications for BT 1.5 Hydraulic Pump. Secureservercdn.net. Retrieved https://secureservercdn.net/104.238.71.33/lv1.22d.myftpupload.com/wp-content/uploads/2021/11/BT-1.5.pdf;

103. Technical Specifications for Honda GX200 Engines. Graftonpowerproducts.com. Retrieved https://www.graftonpowerproducts.com.au/listing/honda-gx200-engine/

104. Technical Specifications for Enerpac Pump XC1201M. Enerpac Corporation. Retrieved XC1201M, Cordless Hydraulic Pump, 3/2 Valve, 60 in3 Usable Oil, Batteries and Charger Not Included | Enerpac

105. Technical Specifications for Enerpac Pump ZC3908JB. Enerpac Corporation. Retrieved ZC3908JB, Cordless Hydraulic Pump, 4/3 Valve, 1.75 gallon Usable Oil, Battery and Charger Included, 115V | Enerpac

106. Technical Specifications for Enerpac Pump XC1402M. Enerpac Corporation. Retrieved XC1402M, Cordless Hydraulic Pump, 4/3 Valve, 120 in3 Usable Oil, Batteries and Charger Not Included | Enerpac

107. Technical Specifications for Milwaukee 10,000 psi pump. Enerpac Corporation. Retrieved Milwaukee Tool M18 FORCE LOGIC 18V Lithium-Ion Cordless 10,000 PSI Hydraulic Pump (Tool On... | HEADER_META_TAGS.SITE_NAME (homedepot.ca)

108. Technical Specifications for Jaws of Life Batteries. Hurst Corporation. Retrieved https://www.jawsoflife.com/rescue-products/accessories/batteries/ewxt-rescue-batteries

109. Technical Specifications for Supervac Smoke Ejector Fans. Supervac.com. Retrieved from https://supervac.com/smoke-ejectors/#gasSmoke

110. Technical Specifications for Yale cordless pump. SafetyLiftingGear.com. Retrieved from https://www.safetyliftingear.com/products/yale-1ltr-cordless-battery-powered-pump/cm-pyb-1-0-rs

111. Technical Specifications for Milwaukee 8.0 aH battery pack. The Home Depot Corporation. Retrieved from https://www.homedepot.ca/product/milwaukee-tool-m18-18v-lithium-ion-extended-capacity-xc-high-output-8-0-ah-redlithium-battery-pack/1001513101

112. Technical Specifications for Milwaukee Red M28 lithium battery pack. The Home Depot Corporation. Retrieved from https://www.homedepot.ca/product/milwaukee-tool-m28-28v-redlithium-battery-pack/1000523881;

113. Technical Specifications for Hitachi HIT 338890. Atlas Machinery. Retrieved from https://www.atlas-machinery.com/Hitachi/HIT-338890

114. Technical Specifications for TNT Rescue ET-4.0. TNT Rescue Corporation. Retrieved from https://tntrescue.com/product/et40/

115. Technical Specifications for Hurst P650. Manualslib.com. Retrieved from https://www.manualslib.com/manual/1317412/Hurst-P-650.html?page=60#manual

116. Technical Specifications for Ministrike Pump. ABCFireandsafety.com. Retrieved from https://www.abcfireandsafety.com/product-p/wtx-ministrikerpump.htm

117. Technical Specifications for Waterax Rancher. Waterax Corporation. Retrieved from https://waterax.imgix.net/products/documents/RANCHER-125N%20Data-sheet.pdf

118. Technical Specifications for Honda GX Engines. Honda Engines North America. Retrieved from https://cdn.powerequipment.honda.com/engines/pdf/news/2011-honda-launches-all-new-mid-gx-engine-lineup.pdf#:~:text=Enhancements%20to%20the%20muffler%2C%20the%20breather%20valve%20and,dual%20silent%20spec%20Current%20Honda%20GX160%3A%20102%20dbA

119. Technical Specifications for Waterous F-2603 pumps. Waterous Company. Retrieved from https://www.waterousco.com/media/pdfs/F-2603.pdf

120. Technical Specifications for Waterax Rancher Water Pump. Manualzz.com. Retrieved from https://manualzz.com/doc/2984026/rancher-quick-guide;

121. Image and Description of Exhaust Fans. Fireapparatusmagazine.com retrieved from https://www.fireapparatusmagazine.com/fire-apparatus/ventilation-equipment-ranges-from-compact-to-very-large/#gref

122. Technical Specifications for Ramfan GX400 with Honda GX200 engine. Ramfan Corporation. Retrieved https://www.ramfan.com/resource-hub/data-sheet/GX400.pdf

123. Technical Specifications for Supervac 720G4H. Supervac Corporation. Retrieved from https://supervac.com/wp-content/uploads/2015/07/720G4H.pdf

124. Technical Specifications for Tempest MT245 Fans. Tempest Corporation. Retrieved from https://tempest.us.com/gas-driven-fan-mt245-30135-cfm-open-air/

125. Technical Specifications for Tempest Direct Drive Fans. Tempest Corporation. Retrieved from https://tempest.us.com/direct-drive-gas-power-blower/

126. Technical Specifications for Ramfan EL6500 fan. Industrialstop.com. Retrieved from https://www.industrialstop.com/products/ramfan-el6500-ac-dc-battery-powered-ppv-fan

127. Technical Specifications and Pricing for Super Van V20-BD Fire-End.com. Retrieved from Super Vac V20-BD | Fire-End & Croker.

128. Technical Specifications for Blowhard Quickee. Northrdidgefire.com. Retrieved https://www.northridgefire.com/blowhard-quickee-20-high-flow-jet-ppv-fan-ac-dc.html

129. Technical Specifications for Blowhard Commando. Blowhard Corporation. Retrieved from https://www.aoe.net/blowhard-commando/;

130. Technical Specifications for Tempest VS 1.2D Battery Powered Fan. Firstoutrescue.com. Retrieved from https://www.firstoutrescue.com/equipment/fans/fans-electric/tempest-vs-1-2d-battery-powered-blower.html

131. Image of Apparatus Mounted Scene Lighting. Fireappartusmagazine.com. Retrieved from https://www.fireapparatusmagazine.com/fire-apparatus/new-developments-in-fire-scene-lighting/;

132. Image of Towed Scene Lighting. Generac Corporation. Retrieved from https://www.generacmobileproducts.com/products/light-towers;

133. Technical Specifications for Ventry 1 Star. Ventry Corporation. Retrieved from https://ventry.com/products/1starx-lentry-single-led-generator-light?_pos=1&_sid=3ff5fafaf&_ss=r

134. Technical Specifications for Ventry 2 Star XX. Ventry Corporation. Retrieved from https://ventry.com/products/2starxx-lentry-dual-led-xt-generator-light?_pos=1&_sid=1a9d42abd&_ss=r

135. Technical Specifications for Ventry Specxxx. Ventry Corporation. Retrieved from https://ventry.com/products/2specxxx-lentry-generator-light-with-triple-tall-leds?_pos=1&_sid=d46172e5e&_ss=r

136. Technical Specifications for Tele Lite Nova EU-6500. Tele Lite Corporation. Retrieved from http://www.tele-lite.com/viewProducts.asp?prodID=134;

137. Technical Specifications for Dewalt Cordless Tripod Light. Amazon.com. Retrieved from https://www.amazon.com/DEWALT-DCL079R1-Cordless-Tripod-Light/dp/B077ZKKDW5

138. Technical Specifications for Makita DC40RA rapid charger. Makita Corporation. Retrieved from https://www.makitatools.com/products/details/DC40RA

139. Technical Specifications for Dewalt Connect Yellow Light. Amazon.com. Retrieved from https://www.amazon.com/DEWALT-DCL074-XJ-DCL074-XJ-Luz-Connect-Yellow/dp/B07NTVGPJY/ref=sr_1_2?crid=DHEB6AWHZ5TC&keywords=dewalt+dcl074&qid=1659411474&sprefix=dewalt+dcl+074%2Caps%2C88&sr=8-2

140. Technical Specifications for Makita DML814 Light. Amazon.com. Retrieved from https://www.amazon.ca/Makita-DML814-Li-Ion-3-Way-Lumens/dp/B09GTMBSRJ/ref=sr_1_1?crid=35FB2JRI1WV5R&keywords=makita+dml814&qid=1659499120&sprefix=makita+dml814%2Caps%2C79&sr=8-1;

141. Technical Specifications for Makita DML810 Light. Amazon.com. Retrieved from https://www.amazon.ca/Makita-DML810-Lithium-Ion-Cordless-Upright/dp/B0899D41G7/ref=sr_1_1?crid=2EBTAZM3UPRZC&keywords=makita+dml810&qid=1659499229&sprefix=makita+dml810%2Caps%2C69&sr=8-1;

142. Exhaust Fan Use. Firefightingincanada.com online magazine. Retrieved from https://www.firefightingincanada.com/june-2011-8659/#:~:text=These%20types%20of%20fans%20are,to%20create%20a%20wind%20tunnel.

143. News article: EU to standardize cell phone chargers. CBC.ca. Retrieved from https://www.cbc.ca/news/business/eu-charge-phones-1.6482185#:~:text=European%20Union%20officials%20said%20they,cut%20down%20on%20electronic%20waste.

144. Technical Specifications for Husqvarna K1 Pace Saw. Eschsupply.com. Retrieved from https://shop.eschsupply.com/Husqvarna-K1-PACE-14-Battery-Saw

145. Technical Specifications for Milwaukee super charger. Protoolreview.com. Retrieved from https://www.protoolreviews.com/milwaukee-m18-super-charger/

146. Technical Specifications for Amkus GH2B-MCH Power Unit. Amkus Corporation. Retrieved from https://amkus.com/Amkus/media/Resource-Library/lap-011_04.pdf

147. Technical Specifications for Waterous Floto Pump. Waterous Corporation Retrieved from https://www.waterousco.com/media/wysiwyg/docs/product-literature/motor-pumps/f1130_floto_pump.pdf

148. Best practices for best battery life. Dewalt.com. Retrieved from Dewalt Tools, Lithium-Ion FAQ website: https://www.dewalt.com/why-dewalt/featured-articles/best-practices-for-battery-life

149. Technical Specifications for Dewalt 20v MAX XR Battery Pack. The Home Depot. Retrieved from https://www.homedepot.ca/product/dewalt-20v-max-xr-lithium-ion-premium-battery-pack-6ah-2-pack-/1001529230

150. Technical and Pricing Specifications for Hurst P635 SE pump. Alexair.net. Retrieved from https://www.alexair.net/p635-sg-high-pressure-simo-electric-220v-power-unit.html

151. Technical Specifications for Ramfan XP500. Intrinsicallysafestore.com. Retrieved from https://intrinsicallysafestore.com/product/explosion-proof-fan-ramfan-xp500-18-inch/

152. Technical Specifications for Supervac 720 Fan. Wfgear.com. Retrieved from https://www.wfgear.com/p-14917-supervac-720evs-fan-electric-variable-speed-ppv-free-shipping.aspx

153. Technical Specifications for Leader ESV245. Leader Corporation. Retrieved from https://www.leader-group.company/en/firefighting-equipment/fire-ventilators/electric-fans/electric-fan-esv245-49050-m3h

154. Technical Specifications for Tempest VSG fans. Tempest.com. Retrieved from https://tempest.us.com/variable-speed-electric-power-blower-vsg/

155. Technical Specifications for Blowhard fans. Blowhard.com. Retrieved from https://www.blowhardfans.com/our-fans/

156. Technical Specifications for Tempest fans. Tempest.com. Retrieved from https://tempestlive.wpengine.com/wp-content/uploads/2020/09/GBS-3.5-4.8-16-Manual.pdf