

**DESIGN CHALLENGES AND POSSIBLE BENEFITS
OF ELECTRIC/HYBRID UTILITY SNOWMOBILES**

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ABSTRACT

In the past 3 years, McGill University has emerged as a leader in electric and hybrid snowmobile designs. Over the course of those 3 years, different McGill prototypes have been used at the U.S. National Science Foundation's Summit Station in Greenland, early prototypes have pioneered a whole new category at the SAE Clean Snowmobile Challenge and more recent versions include the first plug-in series hybrid snowmobile presented at the event as well as the 2007 Wendigo Prototype, winner of the Best Zero-Emission Snowmobile, Best Design award and the competition's Innovation award.

This paper is based on McGill University's experience in electric and hybrid snowmobile design. It looks at the challenges in designing small, lightweight vehicles for use in cold weather. Past, current and future solutions implemented by the team to attempt to overcome these challenges are presented. Limitations of current hybrid and electric snowmobiles are discussed as well as energy efficiency and air pollution comparison between internal combustion engine, hybrid and electric snowmobiles. The comparative analysis of efficiency and air pollution is based on results obtained from simulations done using a modified version of Argonne National Lab's GREET model.

INTRODUCTION

For the past five years, students at McGill University have been modeling, simulating, designing, building and testing electric and hybrid snowmobile prototypes.

It all started with the design of an electric snowmobile prototype which was the first of its kind ever presented at the SAE Clean Snowmobile Challenge (SAE CSC). Three years later, McGill's latest electric snowmobile prototype was used successfully over a trial period of 2 months as a utility vehicle at the U.S. National Science Foundation's Summit Station. Summit station is one of the most isolated research bases on the planet. It is perched atop the Jakobshavn glacier in Greenland; the world's fastest moving glacier.

The experience and data gathered on electric snowmobiles over the years was key in the successful design of McGill's newest snowmobile prototype: a plug-in hybrid snowmobile. This proof of concept vehicle was unveiled as a demonstration prototype at the 2007 SAE CSC. After successful concept validation, the plug-in snowmobile's hybrid powertrain was implanted into a Formula Hybrid race car less than two months after the 2007 SAE CSC. This allowed the snowmobile's hybrid powertrain to undergo more testing despite the warm weather. The Formula Hybrid race car, equipped with the plug-in hybrid snowmobile's powertrain, dominated the inaugural SAE Formula Hybrid competition, winning 3 out of 5 events, on its way to the overall title. This result shows great promise for the future of the plug-in hybrid snowmobile powertrain.

The latest performance results of these new snowmobile technologies may hint towards technological changes in the future of the snowmobiling world. Some of the limiting factors, however, are cost as well as some physical and technological barriers. That being said, the unique characteristics of these new snowmobile technologies give them an edge over conventional snowmobiles in a number of applications.

In the short term, electric snowmobiles could potentially open the possibility of motorized utility snow travel in places where emissions are a major issue. In the medium term, plug-in hybrid snowmobiles have the potential of meeting the needs of most utility snowmobile uses and part of the touring snowmobile uses while at the same time improving vehicle fuel economy, lowering vehicle emissions and noise production.

This paper looks at some of the biggest technical and physical challenges in implementing electric and

plug-in hybrid powertrains into a snowmobile application. It investigates the possible benefits of electric and plug-in hybrid technology on fuel/energy use and emission production. Lastly, it gives a brief overview of the latest McGill University snowmobile prototypes.

ENERGY DENSITY... THE SNOWMOBILE REALITY

“Why is the design of a practical electric snowmobile such a challenge?” The answer to this question is simple: energy density.

Snowmobiles, unlike road vehicles, do not operate on a solid and unchanging surface. They operate in various snow conditions. Depending on the type of snow and level of compaction, snowmobiles will sink to a lesser or greater extent into the media in which they operate. The interaction between the snowmobile and the snow is affected by the vehicle's weight. Along with snowmobile handling and performance characteristics, fuel efficiency is one of the aspects affected by vehicle weight.

For example, with the same power draw, McGill's electric snowmobile will go roughly 50% faster on the road (equipped with special wheeled skis) than on the snow (normal configuration). Knowing that even in road vehicles the energy density of batteries vs. the energy density of gasoline is one of the biggest hurdles to overcome, this quick statistic gives a general idea of how much of an issue this becomes in the case of a snowmobile. The following section investigates and illustrates the issue of energy density (batteries vs. gasoline) in snowmobiles.

Using a value of 8760 Wh/l¹ as the energy available in gasoline and looking at the size of the fuel tanks offered by the 4 main snowmobile manufacturers on their utility models it can be seen in Table 1 that on average, by taking the fuel tank size of one utility snowmobile model from each major manufacturer, their utility snowmobiles carry 358,722 Wh of energy on-board. As a basis for comparison, the 2007 McGill Electric Snowmobile Team's prototype carries 3240Wh of energy.

Table 1: On-board energy of gasoline powered utility snowmobiles

Vehicle	Fuel Volume (l)	Energy On Board (Wh)
Arctic Cat Bear Car 570	49.2 ²	430,992
Polaris 340 LX	44.6 ³	390,696
Ski-Doo Skandic Tundra	34 ⁴	297,840
Yamaha Venture Multi-Purpose	36 ⁵	315,360
<i>Average</i>	40.95	358,722

Table 2: Energy Density of Common Battery Technologies

Battery Technology	Gravimetric Energy Density (Wh/kg)	Volumetric Energy Density (Wh/l)
Pb-A ⁶	33.5	76.2
Ni-Cd ⁷	54	95
NiMH ⁸	60	155
Li-Ion ⁹	105	284

Using a mass of 0.73 kg/l (6.1 lb/gal)¹⁰ as the volumetric mass of gasoline, the weight of the average 358,722 Wh of energy carried on-board those snowmobiles is 29.9 kg (65.8lbs).

In comparison to the gasoline numbers, Table 2 looks at the energy density of 4 of the main battery technologies mature enough for use in electric snowmobiles: lead- acid (Pb-A), Nickel Cadmium (Ni-Cd), Nickel Metal Hydride (NiMH), and Lithium-Ion (Li-ion).

As Table 2 shows, the “raw” energy density of battery technologies is nowhere near the “raw” energy density of gasoline.

Why is it termed the “raw” energy density? It is termed the “raw” energy density because the numbers in Table 2 only consider the energy density of the batteries themselves. For a very accurate comparison between energy density of batteries and gasoline one should also account for the weight and volume of the containment chamber or other means of holding the gasoline and batteries on board. To that must be added the difference in weight and volume of energy transfer systems (i.e. Fuel pump and tube vs. battery management system and heavy gage copper wire). Lastly, the reduction in battery energy density related to cold temperature and high discharge rates should be taken into account for a true comparison between battery technology and gasoline. Taking all these factors into account can be termed the “net” energy density comparison. In general, the “net” energy density comparison will be worse for the batteries than the “raw” energy density comparison.

The rest of this section looks at how, even with the best battery technology available today and with extremely clever designs that could somehow bring “net” energy density difference to approach “raw” energy density difference, building an electric snowmobile in 2007 that can rival the performance aspects of today's gasoline snowmobiles is an incredibly difficult challenge.

In a best case scenario, as seen in Table 3, in order to have as much energy on-board an electric snowmobile as on a gasoline powered snowmobile, one would have to carry over 2800kg (6173lbs) of batteries. With new utility snowmobiles such as Ski-Doo's Tundra weighing 172kg (379lbs) (dry weight)¹¹, this represents a “fuel” weight 16.5 times larger than the weight of the vehicle itself. Adding to that the fact that unlike liquid fuels, the mass of the batteries will not diminish as energy is consumed, it is clear that such a vehicle to fuel weight ratio is not suitable for a snowmobile.

Table 3: Head-to-head energy carrier (EC) comparison

Energy Carrier (EC)	Gasoline	Li-Ion Batteries	NiMH Batteries	NiCd Batteries	Lead Acid Batteries
Vehicle	Ski-Doo Tundra				
Dry Weight	172 kg				
Energy On-Board	297,840 Wh				
EC Volume	34 l	10,49 l	19,22 l	31,36 l	39,10 l
EC Weight	24.8 kg	2,837 kg	4,965 kg	5,516 kg	8,892 kg
Ratio: EC Weight / Vehicle Dry Weight	0.144	16.5	28.9	32	51.7

Table 3 only takes into account the energy on-board and not the efficiency of the 2 drive systems. The efficiency of the electric drive system is often seen as one of its main advantages over the Internal Combustion Engine (ICE). The question is, how much can the difference in efficiency compensate for the on-board energy difference.

Interestingly, Table 4 shows that even if the electric snowmobile's drive system used the best batteries available and was 100% efficient, the ICE snowmobiles would have to be powered by engines with an efficiency of less than 1% for the two technologies to be equal in terms of range and performance with the same mass of energy carrier (EC) on-board.

Table 4: Comparison of required technological efficiencies for equivalent vehicle performance using different energy carriers

Energy Carrier (EC)	Gasoline	Batteries (Li-Ion)
Vehicle	Ski-Doo Tundra	
Dry Weight	172 kg	
Energy Carrier Weight	24.8 kg	
Energy On-Board	297,840 Wh	2,604 Wh
Hypothetical Efficiency for Equivalent Performances	0.87%	100%
Energy Used to Propel the Vehicle	2,604 Wh	

Table 5 shows the weight difference in what can be considered an optimistic case scenario as seen from the electric vehicle's point of view. Even in this best case scenario, the electric snowmobile would need to carry over 18 times the weight of its gasoline counterparts to compete with it on a given distance at a given speeds/accelerations, in given conditions.

Table 5: Energy carrier weight difference taking into account vehicle efficiency (optimistic scenario as seen from electric vehicle)

Energy Carrier (EC)	Gasoline	Batteries (Li-Ion)
Vehicle	Ski-Doo Tundra	
Dry Weight	172 kg	
EC Weight	24.8 kg	448kg
Energy On-Board	297,840 Wh	47,027 Wh
Hypothetical Efficiency for Equivalent Performances	15%	95%
Energy Used to Propel the Vehicle	44,676 Wh	

Despite being much more efficient than its gasoline counterparts at the vehicle level, the electric technology starts with a handicap well above 100:1 when it comes to the energy density of some of today's best electric energy carriers vs. gasoline. Thus, in designing an electric snowmobile one must find applications which benefit from the technology and in which the vehicle's low energy to weight ratio (relative to gasoline snowmobiles) can either be minimized or even taken advantage of (ex: grooming cross-country ski trails is often done with a snowmobile towing a heavy sled).

WELL-TO-TRACK (WELL-TO-WHEEL)

Solely based on energy density, it is difficult for one to imagine an electric snowmobile being used in a given application when internal combustion engine (ICE) snowmobiles are an option. However, one must remember that ICE snowmobiles are not always an option and that even in certain applications for which ICE snowmobiles are an option, high power outputs over prolonged periods of time may not necessarily be require.

In cases where vehicles must emit zero emissions during their use, the lower energy density of batteries versus that of gasoline becomes a secondary issue. In these cases, (ex: Summit Station, various locations in Europe) the challenge is then not to try and compete directly with the gasoline snowmobile but to fine tune the electric snowmobile so that it is well adapted for the type of performance required by this application.

In cases where ICE snowmobiles can potentially be used but energy efficiency and/or emissions are a dominant issue, a comparative analysis of both technologies can be made. This section looks at the energy efficiency and the emissions of ICE snowmobiles and puts them into context with a comparison to passenger vehicle energy efficiencies and emissions. Following that, the ICE snowmobile fuel cycle energy efficiency and emissions are then compared to the electric snowmobile's energy efficiency and emissions.

Methodology

A modified version of Argonne National Laboratory's GREET model version 1.7 is used to obtain fuel cycle energy efficiency and emissions.

The GREET model has been designed to compare road vehicles using different technologies, one against the other, on a standard drive cycle. It looks at energy consumption and emissions both during the vehicle use and the fuel production process. For this exercise, the part of the GREET model which calculates energy consumption and emissions during the fuel production process is assumed to be valid for the production of fuel for snowmobiles. However, the fuel consumption and emission values of the baseline vehicle during use are not valid for the snowmobile. Thus, in order to use the GREET model for this exercise, a snowmobile drive cycle must be defined and both fuel consumption and emission values for this defined cycle must be compiled.

Unfortunately, unlike passenger cars, snowmobiles do not have standard drive cycles specifying vehicle speed over time. The most standard cycle used in the snowmobile industry is the one used for emissions testing. This cycle is a modal cycle. Measurement of emissions is done at five different predefined engine load cases (given percentage of engine rated speed and torque) and emissions are measured for each one. Emissions from each load case are then multiplied by a percentage factor (all five % factors adding up to 100%) and the emissions values obtained for each load case are then summed up. Unfortunately, this method of measuring emissions does not yield fuel consumption and emission values on a per distance basis. Since the GREET Model's key input in terms of vehicle use are fuel consumption in miles per gallon and emissions in grams per mile, a valid methodology and data had to be found to obtain these values for snowmobiles on a per mile basis.

The chosen methodology was to use the standard snowmobile emissions modal test and correlate each mode with a vehicle speed. Then using the speed of each mode and the weight factor of each mode, the time to travel a mile was calculated. Once the time required to travel a mile was known, and given the modal factors, the emissions, and the fuel flow per mode; fuel consumption and emissions on a per distance basis could be computed.

Yellowstone National Park and the Montana Dept. of Environmental Quality ordered a number of tests on snowmobiles in 2002¹². Among those tests, the standard modal emissions test was performed on two different 4-stroke stock snowmobiles (2002 Arctic Cat 4-Stroke Touring & 2002 Polaris Frontier 4-stroke). An attempt was made to correlate a vehicle speed with each test mode for both vehicles. By using this data and the methodology previously outlined, fuel consumption and emissions per distance traveled were obtained. The results for both snowmobiles were averaged out and the resulting fuel

efficiency and emission results were used as the values for the baseline vehicle in the GREET model simulation for the snowmobile.

The assumptions used for all vehicle simulations (car and snowmobile) were those of simulation year 2010 with the following modifications:

- 1- Fuel: 99.9% of fuel used was conventional gasoline (GREET would not let reformulated gasoline % drop to 0 so it had to be at least a minimum of 0.1%)
- 2- Electricity production was changed to User Defined. The GREET model divides possible electricity production methods into 6 categories. Hydroelectric power production does not have its own category, thus in the context of a country which has a high amount hydroelectric power, the “other” category accounts for a large percentage of electricity production. The values used are given in Table 6 below. They reflect Canadian electricity production in 2003 based on the latest statistics from the International Energy Agency.
- 3- Fuel consumption and emissions used for the gasoline powered snowmobile are those calculated based on the methodology previously outlined.

Table 6: Canadian Electricity Production by Type¹³

Canadian Electricity Production						
Oil	Natural Gas	Coal	Nuclear	Biomass	Other	Total
3%	6%	19%	13%	2%	57%	100%

Results

The results of the GREET analysis are presented in the Tables 7 and 8. In preparing these results, the following notes must be made:

- During vehicle operation, the GREET model calculates CO₂ emissions based on the vehicle's fuel consumption. However, since the amount of unburnt fuel in the snowmobile is much higher than in a car, the model overestimates the CO₂ emissions. Thus the CO₂ emissions values during snowmobile use in the result table are not the GREET results, they are values found using the same methodology as the other emissions values.
- The GREET model divides volatile organic compounds (VOC) into 2 categories: exhaust and evaporative. The result tables above only shows exhaust VOC. It is also worth noting that snowmobiles will normally operate on winter blend fuel. This factor was not taken into account in this analysis.
- The GREET model classifies particulate matter (PM) in 2 different size categories. It also normally looks at PM produced from tire and brakes separately from PM produced by fuel combustion. The data available for the snowmobile did not look at PM from brake and track. Also, it did not differentiate between the sizes of the particles. Thus the PM values for the car represent the sum of the fuel combustion PM of both sizes from the model.
- While the only known electric or plug-in snowmobiles in use in Canada at this time are operated in Quebec (over 90% of electricity produced via hydro power), the electricity production distribution used in the model looks at the whole country. Thus the model gives projected values for fuel consumption and emissions if electric snowmobiles were in use at a greater scale and their distribution followed distribution of power across the country.

Table 7: Energy Use and Emissions of Gasoline Vehicles

Item	GAS CAR Wh/km or grams/km			GAS Snowmobile Wh/km or grams/km			Relative Energy Use and Emissions (snowmobile relative to car)		
	Well to pump	Vehicle Operation	Total	Well to pump	Vehicle Operation	Total	Well to pump	Vehicle Operation	Total
TOTAL ENERGY	184	853	1037	345	1599	1945	188%	188%	188%
Fossil Fuels	176	853	1029	330	1599	1929	188%	188%	188%
Coal	24	0	24	45	0	45	188%	100%	188%
Natural Gas	61	0	61	114	0	114	188%	100%	188%
Petroleum	91	853	943	170	1599	1770	188%	188%	188%
CO ₂	47	224	271	89	372	461	188%	167%	170%
VOC	0.077	0.076	0.153	0.145	1.554	1.698	188%	2049%	1111%
CO	0.040	2.328	2.367	0.074	26.613	26.687	188%	1143%	1127%
NO _x	0.132	0.088	0.220	0.248	2.927	3.175	188%	3340%	1444%
PM	0.036	0.009	0.045	0.067	0.031	0.098	188%	333%	218%

Table 8: Energy Use and Emissions of Gasoline and Electric Snowmobiles

Item	GAS Snowmobile Wh/km or grams/km			Electric Snowmobile Wh/km or grams/km			Relative Energy Use and Emissions (Electric snowmobile relative to gasoline snowmobile)		
	Well to pump	Vehicle Operation	Total	Well to pump	Vehicle Operation	Total	Well to pump	Vehicle Operation	Total
TOTAL ENERGY	345	1599	1945	333	457	790	96%	29%	41%
Fossil Fuels	330	1599	1929	173	237	410	52%	15%	21%
Coal	45	0	45	117	161	279	259%	INF	613%
Natural Gas	114	0	114	34	47	81	30%	INF	71%
Petroleum	170	1599	1770	21	29	50	12%	2%	3%
CO ₂	89	372	461	134	0	134	150%	0%	29%
VOC	0.145	1.554	1.698	0.013	0.000	0.013	9%	0%	1%
CO	0.074	26.613	26.687	0.042	0.000	0.042	57%	0%	0%
NO _x	0.248	2.927	3.175	0.168	0.000	0.168	68%	0%	5%
PM	0.067	0.031	0.098	0.216	0.000	0.216	320%	0%	219%

Discussion

Prior to looking at the details of the results obtained in the two fuel cycle comparative analysis, a quick note must be made to emphasize that this analysis should not be confused with a full cycle analysis. In order to have full cycle analysis one needs to add another dimension to the fuel cycle analysis: energy use and emissions due to the making, maintenance and discarding of the vehicles and infrastructure for fuel production and delivery. In the case of gasoline vs. electric snowmobiles, some key differences would be energy use and emissions produced from battery manufacture and disposal vs. oil and coolant manufacture and disposal. Another one would be the manufacture and disposal of the electric motor and wires vs. the gasoline engine and all its sub systems (exhaust, fuel delivery, ignition, etc). Lastly the amount of electronic components used in each vehicles and their nature should be assessed in a full cycle analysis.

Car vs. Snowmobile

Since it was assumed that the same well-to-pump analysis could apply to both the car and the snowmobile, one must concentrate on the differences during vehicle use of Table 7 to get a feel for the differences between both types of vehicles. Right away, at the top of Table 7, the higher power demand of snowmobiles compared to road vehicles mentioned early in the first section of this report is visible in the total energy used per driven kilometer. The snowmobile uses almost twice the amount of energy per distance traveled despite the fact that the snowmobiles weight roughly a quarter of the weight of a sub-compact car. In terms of emissions, the snowmobile produces more of all the emissions under investigation than the car on a per km basis with the highest one being NO_x production with more than 30 times the emissions of a car per kilometer.

However, if looked at on a per year basis, using the values from Table 7 and statistical information from the International Snowmobile Manufacturer Association (ISMA)¹⁴ and the U.S. Department of Energy¹⁵ (snowmobile average travel of 2,178 km/yr & car average travel of 12,374 km/yr), 4-stroke snowmobiles actually emit less CO₂ and PM than a conventional car on average per year. But even when viewed on a per year basis, snowmobiles still emit much more VOC, CO and NO_x than a conventional car.

Gasoline vs. Electric Snowmobile

On a well-to-pump basis, the electric snowmobile uses almost the same amount of energy as the gasoline snowmobile. However, on a vehicle use basis, it uses 3.5 times less energy. On the complete fuel cycle the electric snowmobile uses almost 2.5 times less energy than its gasoline counterpart. Overall, the electric snowmobile uses close to 5 times less energy from fossil fuels than the gasoline snowmobile. The types of fossil fuels used by each vehicle also vary largely in quantity. The use of natural gas is relatively similar for both cases with the electric snowmobile using 71% the amount of the gasoline snowmobile. However the use of coal and petroleum is very different for each vehicle. The electric snowmobile is the biggest user of coal with just over 6 times the amount used per driven kilometer, but the gasoline snowmobile uses up over 33 times more petroleum than the electric snowmobile per driven km!

The amount of energy used by each vehicle and the different energy production methods used have a direct impact on the emissions results. Thus, given the large amount of coal used in the production of electricity to power the snowmobile, it is no surprise to see that the snowmobile's complete fuel cycle produced over twice the amount of particulate matter than the gasoline snowmobile's fuel cycle. However, the large reliance of the gasoline snowmobile on burning petroleum products throughout its fuel cycle means that it produces 3.5 times more carbon dioxide than the electric snowmobile. It also produces 20 times more NO_x, 100 times more VOC and many hundreds of times more CO than the electric snowmobile per driven km on a complete fuel cycle basis.

VEHICLE DESIGN

Electric Snowmobile

As previously mentioned, electric snowmobiles cannot directly compete with high performance gasoline snowmobiles (racing and mountain models for example which can easily produce 140HP stock). The energy density of electrical alternatives to gasoline does not make this practical. However, in light utility applications in which long range between recharges is not an issue, an electric snowmobile can be a practical solution. It is worth noting that according to the ISMA¹⁶, 1 in 5 snowmobilers use their snowmobiles predominantly for utility purposes. Thus, in designing a successful electric snowmobile, one must take into account the needs of this segment of the snowmobile world demographic. Another potential market for electric snowmobiles is a completely new one: the zero-emission snow transportation market. This market covers areas in which conventional gasoline utility snowmobile cannot be used or are very highly regulated due to emissions. The introduction of electric snowmobiles to this new market is what McGill believes to be the main short term outlet for this technology.

The latest McGill electric snowmobile prototype was designed specifically for such an application, namely, use as a zero-emission utility snow vehicle for science support at the U.S. NSF's Summit Station.

Performance targets for the application were a minimum of 16km of range at moderate speeds and a towing capacity of over 500kg (mass on trailer sled). Other key needs of the application (some of which were only discovered after initial on site testing) include, absolute reliability (no way of getting

new parts anytime soon on the glacier!), an easy to use/stable/maneuverable/forgiving vehicle (most users have never touched a snowmobile), and immunity to extreme cold (-40C at night in May...).

What the team found to be the best avenue to reach the performance targets of the applications while satisfying the specific needs was to start with one of the lightest snowmobile chassis available on the market and ensure that all components in the vehicle are being used to the full range of their capacity. Thus, the electric drive system is sized just right for the application and this allows the vehicle to use a minimal amount of batteries. As a result of this, the team was able to produce an electric vehicle which weighed 225 kg. That is less than most snowmobiles on the market today when full of fluids (fuel, oil coolant). The positioning of the vehicles components is such that it has a lower center of gravity (CG) than most utility snowmobiles. The combination of low weight and low CG were key design features required to have a stable/maneuverable/forgiving vehicle. The ease of use criteria were fulfilled with design features such as an on-board charger, simple controls, and a single receptacle for all AC powered electronics. For both ease of use reasons and reliability reasons, every effort was made to try and keep as much of the original gasoline snowmobile drivetrain parts as intact as possible. Lastly, the solution to the battery temperature management problem posed by the extreme cold was found after monitoring the battery pack's temperature over a period of 2 weeks and correlating the temperature with the vehicle's whereabouts. Based on this, it was determined that a single heating, element inside the snowmobile cab, activated only on recharge was sufficient to get the required performance out of the batteries.

Plug-in Hybrid Snowmobile

The first section of this paper showed how the high energy density of gasoline is a must in order to have the performance of most high end snowmobiles on the market. The second part of the paper looked at some possible benefits of electric snowmobiles in a Canadian context. McGill's latest snowmobile prototype is an attempt at combining both the high energy density of gasoline and the possible benefits of an electric snowmobile into one. Achieving this within the space and weight constraints of a snowmobile is a considerable challenge.

Building on what the team knows best, a series hybrid configuration was the chosen drivetrain architecture for the proof of concept plug-in hybrid snowmobile. This first plug-in hybrid snowmobile had more than double the power of the latest electric snowmobile prototype. Its configuration allowed the driver to run in three different modes: hybrid (battery + E10 generator), electric (battery only) and gas (E10 generator only). This proof of concept prototype had a very large battery pack and a relatively small generator. As a result, the snowmobile was heavy, unstable and difficult to maneuver. However, the prototype did what it was built to do: validate the concept of the self regulating DC generator around which the series plug-in hybrid system was designed. The idea behind the self regulating DC generator was to design and build a gasoline powered source of electricity to supplement the vehicle's battery power. The goals in the design of this generator were to obtain the most compact system possible. The end result was a DC generator which can be supplying power directly to the snowmobile's motor drive, the snowmobile's battery pack, or both instantaneously and seamlessly without the use of current or voltage regulating systems between these components. The team achieved this by designing and assembling a generator system that weights less than 30kg and can produce up to 5kW of power. McGill's first plug-in hybrid snowmobile is already history and design work on its successor is already well underway. Now that the proof of concept has been validated, the approach taken in the design of this new PHEV is the same which was taken for the design of the latest electric snowmobile sent to Summit Station:

- 1- Determine target performance
- 2- Design the drivetrain so that all components are being used fully (i.e. no extra power or energy needs to be carried on-board)

3- Eliminate all unnecessary weight and distribute the remaining weight in the most stable way possible

CONCLUSION

Snowmobiles, by nature, require much more power to travel a given distance than road vehicles. However the difference in emissions between snowmobiles and road vehicles is not proportional to the extra power needed to travel a given distance with the snowmobile relative to a car: snowmobiles produce much more emissions than they consume power per kilometer relative to road vehicles. Based on a fuel cycle analysis, electric and plug-in hybrid technology can help reduce snowmobile emissions and fuel consumption. Unfortunately, the high power requirement of most snowmobiling applications makes it very difficult to incorporate technologies with low energy density into this type of vehicle. Nevertheless, a certain number of existing applications and some possible new ones could potentially benefit from electric snowmobiles despite their drawbacks. McGill University has acquired the knowledge base and experience to address the needs of these applications. It is believed that a broader number of applications could benefit from plug-in hybrid snowmobiles than from electric snowmobiles. McGill University is currently acquiring the knowledge base and experience to address the needs of these applications

¹ The Physics Factbook™ Edited by Glenn Elert -- Written by his students
<http://hypertextbook.com/facts/2003/ArthurGolnik.shtml> [Feb 07]

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⁸ Calculated using Cobasys NiMH online spec sheet: www.cobasys.com/pdf/faq/faq.html [Feb 07]

⁹ Calculated using LTC's 45AH-602050 online spec sheet: www.lithiumtech.com/StandardCells.html
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¹⁰ Calculated from: The Physics Factbook™ Edited by Glenn Elert -- Written by his students
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¹² [www.deq.state.mt.us/cleansnowmobile/publications/reports/Lab_Testing_of_Snowmobile_Emissions-\(July%202002\).pdf](http://www.deq.state.mt.us/cleansnowmobile/publications/reports/Lab_Testing_of_Snowmobile_Emissions-(July%202002).pdf) [May 07]

¹³ www.iea.org/Textbase/stats/electricitydata.asp?COUNTRY_CODE=CA&Submit=Submit [Apr 07]

¹⁴ www.snowmobile.org/pr_snowfacts.asp [Jul 07]

¹⁵ Calculated from: http://cta.ornl.gov/data/tebd26/Edition26_Chapter04.pdf [Jul 07]

¹⁶ http://www.snowmobile.org/pr_snowfacts.asp [Jul 07]