**Sustainable housing, transportation and energy for Remote Communities in the Canadian Arctic**

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**Abstract**

The impact of climate change on coastal communities in the Canadian Arctic requires building more robust sustainable community infrastructure with less dependency on outside resources. The melting of permafrost and the erosion of shorelines due to both permafrost melt and increasingly violent storms in the Arctic Ocean as the ice cover decreases requires a redesign of Arctic communities if they are to be sustainable in the future. Housing can be built using a shell concept with greater flexibility of the support structures that enable simple methods of adjustment to cope with permafrost melt and also allows for the movement of the whole structure should the shoreline be endangered by the action of storms such as is the case in a number of communities located on the Arctic coast. Such housing can also be built with more efficient insulation and healthier air quality characteristics using new materials as well as novel approaches to air handling and heating systems. Mechanical and electrical systems should be designed to minimize future costs to upgrade or replace them as and when new technologies become cost effective. Currently the goal should be for housing that can be operated entirely by electricity generated renewably. Absence of interior structural walls will permit change of layout to meet changing needs. Although in this paper we do not cover food production, water and sewage for these remote Arctic communities, these are areas where great advances over current practice can be achieved with regard to energy use. The energy infrastructure of such communities, now based almost entirely on diesel generated electricity, can be made more secure by the inclusion of renewable energy such as wind, solar and ocean tidal/current sources. In the model proposed, electric and plugable hybrid vehicles including ATVs and snowmobiles would provide energy storage for the renewable energy sources made possible by using the battery capacity of this clean transportation system. This would be based on vehicle-to-building as well as the conventional building-to-vehicle charging systems. To optimize these systems, a smart micro-grid using smart grid technology is proposed based on developments now well underway. The possibility of creating a demonstration of these concepts in a remote community in the Canadian Arctic will be discussed and initial concepts proposed based on the characteristics of communities in Nunavut. Input from communities in Nunavut with regard to these concepts will be included in the paper.

**Keywords**: Permafrost; renewable energy; electric transportation; efficiency; smart grid; energy storage; energy security

**Résumé**

**Mots clés**

1. **Introduction**

Climate change in the Arctic is demonstrated by shrinking sea ice coverage in the summer months with much stormier Arctic Ocean conditions. The active layer of permafrost is increasing with impacts on buildings while shoreline erosion is causing the coastal communities in some cases to be relocated. All these factors are placing a strain on the existing infrastructure of these small but strategically vital communities scattered across Canada’s far north. This research is directed toward the utilization of more locally based renewable energy sources combined with the integration of advanced housing and transportation concepts to enable these communities to better adapt to the changing conditions of the Arctic under the influence of climate change.

Primary energy in remote Arctic communities such as those in Nunavut, Canada, is almost entirely derived from fossil fuel brought from the south by ship in the short open water season from July to October (1). Heating, transportation, and electricity production all depend on this imported fuel. The viability of these communities presently rests on the assumption that this dependency can continue even though the costs are now estimated at some $400M per year for a population of some 33,000 people (2). Should the economic situation change either due to higher fuel costs or to less funding being available from government sources, this system could break down and fuel could become unaffordable. The security of this energy system to support some 25 widely separated remote communities depends on the regular yearly delivery and safe storage of the fuel. In cases where this has not been possible, whole communities have had to be evacuated.

By providing an integration of renewable energy with smart micro grid technology, advanced housing designs and electric transportation, sustainable remote Arctic communities could be achievable. Using the characteristics of communities in Nunavut, a template for such sustainable communities has been created. An essential component for success is the full and active participation of the local community since there are life-style implications associated with this transition from fossil fuel dependency to truly sustainable communities. The Inuit historically were one of the most self-sufficient and innovative peoples in probably the most severe environment anywhere. In Nunavut, they make up the majority of the population and today, this young population is very open to new technology as they develop their communities and region. The economic argument for this proposed transition to sustainability becomes much stronger in the remote Arctic where real fuel costs can reach many times that in southern Canada. These communities therefore could provide a model of what could be achieved everywhere, but perhaps first in these remote regions, where social arguments, security and economics are the drivers.

Kotzebue Alaska is a coastal community of just over 3000 people located in NW Alaska with an electrical supply based on a hybrid wind/diesel system that currently includes 17 wind turbines with a maximum capacity of 1.14MW (3). The peak loads in Kotzebue are from 3-4 MW (3). The community was concerned about the cost of diesel fuel which from 2002 had risen from $1.5M to $6M in 2008 and this hybrid system was their response. There are current plans to increase wind generation capacity to 2.94 MW that will meet most peak power requirements (3). There are also plans for the installation of an energy storage system based on flow batteries which will provide the capability to load level the demand as well as increasing the percentage of wind penetration in the hybrid/diesel system (3). Kotzebue provides a good example of a medium sized remote Arctic community that has mobilized the population in support of renewable energy to save money and provide secure energy in the long term and offer the local population job opportunities locally and outside where their capabilities are in demand as other communities move toward sustainable technologies. It should be recognized that the Kotzebue Electric Association is a cooperative utility owned by the community. This has enabled local initiatives to succeed where in other jurisdictions such as Nunavut, where there is a government owned utility, Quillik Energy, with a monopoly on power generation throughout the Territory, it is more difficult to make changes based on such local efforts. However, Quillik Energy is working toward the introduction of more renewable energy in particular hydro power is being considered for Iqaluit the largest community in Nunavut (4). To implement an integrated sustainable energy plan as proposed in this paper would clearly require support from the Territorial utility as well as from the Government of Nunavut. It is with this knowledge that our paper is offered in order to stimulate discussion and hopefully interest in demonstration projects that will move communities in Nunavut toward the often stated goal of community sustainability in the Arctic.

1. **Impacts of climate change on communities**
	1. **Marine weather conditions**

As part of the International Polar Year (IPY) Fisheries and Oceans Canada (FOC) led a project on the impact of severe Arctic storms and climate change (5). The increasing frequency of such storms is of concern to northern coastal communities that depend on the sea for food, local transportation and delivery of fuel from the south. As the summer sea ice extent has decreased, the influence of wind and waves has become much more pronounced, to the extent that small boats which were adequate in the past are no longer safe for fishing and hunting from these coastal communities. It has been shown in these studies that wind is increased by the open water compared to sea ice covered waters by as much as 14 km/h with surface currents also being enhanced.

* 1. **Shoreline erosion and storm surges**

It is clear from a number of studies that bigger waves occur due to more open water and that storms are having a greater impact on the coastline in the Arctic as a result of the reduction in sea ice due to climate change. In fact, in September 1999, a storm surge occurred that covered 132 km2 of the Mackenzie Delta with salt water and caused serious damage to vegetation which has not recovered in over 10 years since the event. Research into this storm surge indicated that there had never been such an event previously in at least over the past 1,000 years (6,7).



Figure 1 – Storm damaged coast of the Beaufort Sea at Tuktoyaktuk

Coastal erosion is also an important factor in many Arctic communities such as in Tuktoyaktuk as seen in the Figure above where wave action and storm surges will require relocation of buildings in the community.

* 1. **Permafrost melting**

There is much evidence on the impacts of climate change on permafrost in northern coastal Canada (8). Arctic communities are built on permafrost as well as industrial infrastructure such as oil and gas installations including pipelines and these are already being affected by the melting permafrost that seriously impacts the stability of these structures. The figure below shows the vast extent of the permafrost in northern Canada.



Figure 2 – A north-south section showing permafrost from the Beaufort Sea to the Alberta border (9)

* 1. **Energy costs and options in the north**

The National Energy Board has provided an overview of energy use in the Canadian Arctic (10). In conclusion this report quotes from the Government of Nunavut Energy Strategy (11):

*“While opportunities for making real and positive changes in the energy sector are great, some difficult decisions lie ahead. Real solutions will require positive changes in consumer behaviour, government operations and cooperation among governments, departments and agencies. Education about true energy costs and the environmental consequences of energy choices is critical. Displacement of some of the fossil fuels Nunavummit use by other source will result in favourable environmental impacts and also should result in a portion of the economic benefit of energy being retained in Nunavut, even if the overall cast of energy is not significantly decreased. Currently, energy represents a financial and environmental burden, but by taking a clear and careful look at our energy options, Nunavummiut can develop energy as a tool and a resource for Nunavut’s future.”*

In the NWT of Canada, the Arctic Energy Alliance (AEA) is an organization that provides a coordinating role for the many agencies and groups with an interest in energy and conservation services (15). They have fostered efficiency in buildings and supported the introduction of renewable energy based on solar, wind and wood in the boreal regions of the Territory. These efforts are supported by the Territorial Government and the AEA offers training at the community level in energy conservation concepts and implementation of new energy systems. Their programs are attractive to communities and industrial participants through direct savings that can be made by making use of energy more efficiently and by moving away from expensive fossil fuels to locally available fuels and renewable energy sources such as solar. Such an organization would be of value particularly in Nunavut which is totally dependent at this time on expensive fossil fuel imports.

1. **New and innovative housing options**

Climate change is forcing unprecedented rates of change, which in turn need to be matched by unprecedented implementation of innovation. That isn’t happening. This section of the paper describes innovative housing.

 Much of northern housing is deplorable This, in no small part, is because they wear out quickly for many reasons not least because the typical northern house is a mere hybrid of its southern equivalent. It has not been thoroughly re-engineered to suite the unique conditions that prevail in remote cold regions. Houses which wear out fast and need replacing, a burgeoning population growth, and the need to upgrade housing conditions to counter severe medical problems, especially respiratory diseases, is a necessity if these communities are to survive the impacts of climate change. There is an opportunity to build houses and associated infrastructure that will offer lasting housing that sits lightly on the tundra.

If energy to operate housing, and other buildings, is to exclude fossil fuels, and there is no combustible biomass available – as there is in the boreal zone - then the only practical option is to use electricity. It is assumed that steering (unprocessed) arctic oil or gas to isolated communities is not going to become viable in the foreseeable future, and anyway increasingly viable renewable energy sources should preclude that option anyway. Though an all electric house is technically possible, and is nearly achieved in isolated research stations, availability and the price of oil made it uneconomic until recently. However, is now appropriate to plan for net zero energy housing in cold remote communities; setting conditions that facilitate introduction of appropriate technologies as they become viable.

The route to independence from oil lies through balancing the gradual implementation of most cost-effective ways of:

* increasing renewable supply and passive energy input
* reducing demand
* interfacing supply and demand with short and long-term energy storage.

and doing this in the context of starting with a mixed bag of existing houses, centralized diesel generated electricity and individual oil-fired space and water heating.

**Increasing renewable supply and passive energy input**

The only sources of renewable energy in the Arctic can come from, dammed rivers; river- tidal-, or ocean- flows; wind or solar. In each of these realms year by year advances in cost effectiveness are being realized. The keys to implementing them is to minimize the inhibiting influence of installed systems and refining product and system designs to suite the harsh condition prevailing in the north.

Increasing passive energy input is a challenge since the effectiveness of the process is typically dependent on using thermal mass, a phenomenon scarce in arctic homes apart from the water and wastewater held in tanks. More promising is the potential for phase change energy storage. Furthermore the need to orient glazing to the south will be countered in many house sites by the preference to orient sight lines dependent on local topography.

**Reducing demand**

A further aspect of the issue is bound up in the issue of embodied energy and investment. Before mapping how to transition from oil dependence to independence it is essential to consider the investment in and life expectancy of housing. Housing typically degrades rapidly in the north for many reasons, with many of those reasons being correctable.

* Foundations that isolate structures from the damaging stresses imposed from permafrost melting
* Structures that are stiff enough to withstand relocation as climate change and other reasons become more likely to require this.
* Mechanical and electrical systems that are retrofit-ready to be upgraded as more efficient technologies are proven to fit the rugged conditions. Clustering of houses around utility modules that supply heat and power is an obvious and proven avenue in this regard. On-site water reclamation; centralized potable water supply and effluent treatment being very energy intensive.
* Test facilities that encourage innovation but not implementation before thorough evaluation and modification to ensure full suitability.
* Designs that above all are adaptable for difficult to forecast and sure to change conditions.

 A further note on the decentralization of electricity and power generation: whilst introducing multiple utility modules will require greater maintenance time its duplication and redundancy enhances system reliability against freezing in the dark.

Practices that inhibit following this implementation:

* Centralized electrical power generation because frequently it is not possible to utilize a significant proportion of engine waste-heat. The investment in the centralized plant inhibits investment in close to point-of-demand heat and power generation; and is not conducive to incremental implementation of system upgrading.
* Housing structures and foundation systems that are not fit for purpose.

**Interfacing supply and demand with short and long-term energy storage**

 Smoothing between both a variable supply and demand requires energy storage, most obviously in the form of battery storage. As elsewhere referred to this could at least in part for short term storage be associated with implementation of EVs. Winter increase in demand and reduction in, of at least solar derived supply, points to the need to encourage the development of cost effective seasonal storage. Deep water compressed air storage offers intriguing potential for longer-term energy storage.

**An innovative house concept**

Structure:

* The shell of high insulating large, high strength to weight ratio Structural Insulated Panels (SIPs). This leaves freedom to place and relocate interior walls as demands change since they are all non load bearing. Using SIPs results in lasting airtightness.
* Fit out can be the responsibility of local trades, bringing local employment opportunity.
* The floor can be much closer to grade since the floor is suspended from a king truss in the ceiling structure.
* The whole structure is supported on 3 adjustable foundations to facilitate level maintenance but more importantly renders a structure immune from the strains that are otherwise induced from permafrost caused ground movement. Furthermore this design lends itself to relocation without damage to the structure; increasingly likely in arctic scenarios, and eliminates the need for landscaping to accommodate a foundation
* The structure is dimensionally stable enough to contemplate later upgrading with Vacuum Insulated Panels (VIPs), and vacuum windows, when they become cost effective.

Heating:

* Eventually space heating will be in-floor electrical resistance heating. However counter- intuitive this may sound, the energy demand in a highly insulated house built in the NWT is so low that this has been found to be the most economic method.
* Similarly, water heating will be by resistance heating.
* The option, and bridging technology to the above, is to cluster houses around utility modules that house pairs of small diesel generators to provide heat and power for the surrounding houses. The pairing provides reliability; Canada is already an established pioneer in this technology.
* Controlled by the smart grid, household systems could provide discretionary loads for available ‘surplus’ electric supply e.g., heating of water or other heat storage mass, when renewable energy from such a source as wind was available and in excess of community demand.

Ventilation

It is crucial to maintain a healthy indoor air quality. Avoidance of mold and other moisture problems is imperative and far more achievable with a maintainable airtight structure; and with increasingly effective energy recovery ventilators

Electricity:

The above mentioned utility modules provide the bridge to renewable energy delivered via mini smart grids. The generator can fulfill a continuing roll to meet peak demand and stand-by capacity.

**Form of housing**

Figure 3, shows the elements of a single storey house, the type preferred by a large majority of northerners. Whereas the foundation system and form of structure lends itself most efficiently to this simple house forms it can be adapted to storey- and-a-half, two stories and modest sized multiple housing units that may offer efficiencies in construction and operation.



Figure 3 - New housing concept for permafrost regions in the Arctic

**Broader picture**

Whilst the above description of the evolution of housing applies specifically to arctic housing, it is substantially applicable to all cold remote regions especially the many inland First Nations communities located at the end of winter roads. The economic benefits for collaboration of all the regions, within Canada and internationally are obvious.

**Manufacture and Supply**

SIPs are bulky and therefore expensive to transport. The prospect of manufacturing theses panels in the north has been proposed. The low density foam insulation can be generated from the ingredient chemicals that only require a small fraction of the foam and would be far less to ship. If it were straightforward it would already be done that way. However, the stars may be nudged into alignment to realize the potential that this concept encompasses.

Much inter-related with location of manufacture is the impending metamorphosis of means of transportation. The advantages of lighter than air craft have long been recognized as a means of freighting goods and people economically; a means that would have particular values where the maintenance of good runways for aircraft is a challenge, to name just one matter.

New materials, improved engines, better weather forecasting, ability to design complex structures using computer aided design are bringing closer the day when hybrid air ships will become viable, drastically changing remote region economics, security and a host of other factors that define remote communities.

1. **Sustainable energy and housing infrastructure integration with transportation**

We tend to categorize our energy in terms of sources (e.g., oil, hydro, solar) and end use (e.g., home heating, industrial, transportation). However, other means of categorizing energy are at least as important: dispatchable vs. non-dispatchable; how well the energy form can act as energy storage; the carbon content; renewable vs. finite; impact on health. For this conference, the key characteristics are the greenhouse gas emissions and waste heat generated in the production and consumption of energy.

Energy is essentially fungible, that is, we can exchange one kind of energy for another. If oil becomes expensive as a heating fuel, we can substitute other energy forms (e.g., natural gas, propane, electricity, solar, geothermal, biomass) to achieve the same desired outcome (warmth). While we have a barrier to adoption in the form of infrastructure investment in the industrialized world that tends to inhibit such changeovers, a strong price signal can drive fairly rapid change (e.g., the shift from heating oil to natural gas as a home heating fuel in new residential construction in southern Canada).

We recognize that oil is losing its place as the transportation fuel of choice because we can no longer afford it in terms of simple cost, reliability of supply, or impact on the environment or human health. We recognize the burning of carbon-based fossil fuels is a major driver behind climate change, and are now beginning to truly understand that climate change is not about global warming, but is about weather volatility that may actually shorten growing seasons rather than extend them (due to late spring and early fall frosts) and storm systems which are larger and more powerful, doing more damage, than we allow for based on 10,000 years of relatively stable climate patterns that are the fundamental platform that supports all life on this planet as we know it.

We are on the cusp of seeing a massive shift in our road-going fleet away from oil to other fuels. While much is made of natural gas as the new transportation fuel of choice, actual sales suggest that the shift is actually going toward electric drive - including plug-in hybrid vehicles. Electric Vehicles (EV) have a major advantage over natural gas and hydrogen vehicles - the electric fueling infrastructure is largely already in place.

Many vehicle owners do not recognize the degree to which their liquid fuel vehicles are already dependent on electricity to provide their fuel. Oil well pumps are typically powered electrically. Oil refineries and upgraders are large consumers of electricity (13). Pipelines are frequently powered by electricity. The fuel is generally delivered to the vehicle via electric pump. Internal combustion engines typically use an electric motor to start the engine, and electric spark to ignite the fuel. Monitoring and control systems to operate all of the above are generally electric. In cold climates, electric heaters are used on engine blocks and batteries to keep them warm enough to be able to start the fossil fuel engine.

Oil refineries are such large consumers of electricity that several analysts - including the U.S. Department of Energy - conclude that a modern electric car can travel farther on a kWh of electricity than a gasoline car can travel on the gasoline refined by using the same kWh of electricity (14). That does not include the electricity used to extract and transport crude oil, nor to deliver refined products to the end user.

All- electric and plug-in hybrid electric vehicles could bring a number of advantages to a remote (off the continental electrical grid) community, especially one in a cold climate such as the Canadian Arctic.

No exhaust emissions (carbon dioxide, soot, nitrous oxides, carbon monoxide, toxins, carcinogens are all associated with burning gasoline and diesel fuel) means higher albedo for snow and ice downwind from the community, thus slowing the spring melt of snow and ice cover. Such pollution is often trapped over the communities leading to very poor air quality due to the atmospheric conditions in the Arctic. Such vehicles will be quieter. The vehicles do not need block heaters or to idle to stay warm enough to restart.

However, there are even more gains for a remote community in the use of electric vehicles, especially if the community embraces smart micro-grid techniques to increase the efficiency of the power generation system and local renewable energy sources. Diesel generators are only efficient in a small portion of their power generation range; underloads or overloads degrade system efficiency and possibly longevity. By using the electric vehicle fleet as an additional load at times of low demand, system efficiency is improved. By using the EV charging load as a non-essential load (load-shedding) at times of high demand, generating system efficiency can be maintained by avoiding overload conditions.

As oil prices worldwide continue to rise, renewable energy sources have become less expensive per unit of energy delivered than conventional fossil fuels. Recent material from Australia shows that unsubsidized renewable energy is less expensive than new-build coal- and gas-fired power stations (15). When you consider that Australia is a coal-producing nation, and that most of its major cities are seaports - open year-round, this should mean that renewables are even more cost-effective for many remote Canadian communities, which typically don’t have year-round deepwater ports.

It is possible to go further, and use the energy stored in the electric vehicle to power houses (V2H) in the event of power outages, power other buildings (V2B) in the event of emergencies, or even to power the grid (V2G) at times of peak demand. In large southern communities the latter will likely prove impractical as the peak demand time coincides with traffic rush hour (weekday mornings and late afternoons), precisely when most of these vehicles will be on the roads, and therefore not accessible to the grid. However, that is the easy, inexpensive part. While the V2G model is somewhat feasible at an electric transmission level, proponents have not yet substantively addressed the issues around compensating the vehicle owner for the electricity taken from their vehicle to support the grid. The power can only be supplied to the utility when the utility wishes to receive it, which requires communication to both the vehicle operator and the vehicle itself at a machine to machine interface level. The utility may need to implement special controls behind the outlet to prevent back-feeding when they do not wish to receive the energy. The utility operator has to be able to identify which vehicle is supplying the power and via which electrical connection. Then, the connection point has to be metered to determine how much power was received. To date, EVs are not being shipped with 2-way power transfer systems. Charging systems are one-way devices (grid to vehicle). Assuming a grid-quality power inverter is installed on the vehicle (as an after-market modification), most available conventional outlets in the community (North America) are rated for 115-volts and 15 amps. To ensure the reverse flow does not create any problems in the local circuit wiring, and to safeguard the vehicle battery, it is likely that the power level will be in the order of 1 kW only. This is not expected to be an everyday occurrence; if it was, the utility should increment its generating capacity. However, before the vehicle owner will be compensated, the utility and the owner will have to be able to reconcile the amount of electricity supplied, the agreed payment rate and account information. There are formidable costs associated with the metering, recording, reconciling, billing and payment for these amounts of electricity, which will likely be in the order of several kWhs per vehicle per month.

In a small community, the need for all that accounting may be less of an issue. First, the vehicles will typically have much shorter distances to travel, allowing more of their stored energy to be available to support the grid. Second, the vehicles are more likely to be connected to the grid when needed as travel times are shorter. Third, in a remote community, one is unlikely to encounter an EV which has travelled in from another community, which might have a different electricity billing arrangement, requiring inter-company transactions. Fourth, in a small community, there may be less concern about compensating vehicle owners to the cent for power supplied to the grid, especially if a lower rate is charged to them for off-peak charging (an increasingly popular practice in larger centres to entice customers to use more power at low demand times and less power at high demand times). Time-of-use pricing is easy to implement once a smart grid and smart meters are in place. Small communities should be more attractive places to implement V2G arrangements than large urban centres, if they can agree to dispense with the need for accounting to the cent for every Wh transferred. If the alternative is to install an additional large diesel generator to meet peak demand, the economics of encouraging V2H grid support at high demand times may be quite attractive.

When the battery pack in an EV reaches a point where it is no longer adequate for the transportation mission (typically after more than 10 years of use), it will likely still have something like 80% of its original capacity left. Rather than shipping such batteries away to be recycled, they could be re-purposed in the community as an additional level of electrical storage available to the electricity generator for load levelling and peak-shaving, and as emergency backup power (16). Only after the batteries are no longer adequate for other uses in the community would they need to be shipped out for recycling. Until such time as such surplus secondary batteries become available, flow batteries could be used to improve the efficiency of the diesel generation facility and store energy from local renewable energy sources until it is needed (17). Flow batteries store energy in a charged electrolyte fluid which can be stored for months with high recovery efficiency. Flow batteries can be used in conjunction with the old EV batteries to increase overall on-line power capacity.

Electric vehicles can also be designed to better suit the Arctic environment. Enhancements such as duo-pane windows with imbedded grid defrosters, dehumidifiers to extract moisture, seat and steering wheel warmers, space-efficient thermal insulation for the cabin and battery pack, lubricants with lower viscosity at low temperatures and use of cabin and drive-train preconditioning are all available technologies, but not in common use in our vehicle fleet. These kinds of measures will further reduce the energy consumption of the electric vehicle. In cold weather conditions, it is not unusual to use a block heater consuming approximately 500 watts for many hours a day to ensure an internal combustion engine will start. The same amount of energy, say 5 kWh used in 10 hours - which does not propel the ICE vehicle so much as a centimetre - could propel the EV 25 kilometres, enough to cross the main portion of Iqaluit from end to end 4 times. (That is not the range of the EV, which is well in excess of 100 km per charge. It is just the distance the EV can travel by using the same amount of electricity efficiently instead of heating an engine block.) Smartphone applications make it easy to implement vehicle time of charging patterns and initiate pre-trip vehicle conditioning. On-board GPS systems make it easier to locate vehicles in the event assistance is required.

The fact that the block heaters have been accommodated in cold communities for decades means that the charging infrastructure is already in place. Higher capacity charging outlets may be desired for heavy vehicles or those frequently travelling long distances. This can also be addressed by using plug-in hybrid vehicles. Still, for the majority of vehicle charging needs in small communities, regular access to ordinary 115-volt, 15 or 20-amp outlets is likely sufficient - enough to provide over 100 km worth of recharging each day for a mid-size sedan EV.

Electric vehicles are not just cars and light trucks. They can include snowmobiles, ATVs and boats. (One of the authors has an electric tractor and boat, and has had electric motorcycles in the past.) The Canadian Department of Defence is currently developing electric snowmobiles (18), and electric snowmobiles have been used successfully on glaciers in Greenland (19).

EV capabilities are continuing to grow. The Tesla Model S, now commercially available, can travel over 450 kilometres on a charge, and SuperChargers permit it to refuel in minutes. This is done using renewable solar energy (20).

We recognize that remote communities tend to resist change due to the risks associated with changing from proven systems. However, in Canada’s Arctic, climate change is bringing those changes, whether the communities wish them or not. The changes we are proposing will not happen overnight, but the response to climate change has to be started. Existing infrastructure and technology will be retained - even after new alternatives are proven superior - to provide backup capacity and because it is likely cheaper to leave these structures in place than to remove them.

If the community embraces renewable energy sources such as hydro, wind power, ocean current, geothermal or solar, the battery capacity - either in vehicles or separately managed by the electricity supplier - can be used to store energy from when it is being generated until it is required. This makes it more attractive for communities to embrace locally produced, sustainable energy sources. Using this local energy to displace imported energy reduces the amount of money leaving the community to pay for fuel while also creating local jobs in the installation, maintenance and operation of the local energy plants. It also makes the community more self-sufficient and resilient.

In remote communities, it typically takes a lot of energy just to move the needed fuel from distant refineries to the community. Reducing the amount of fuel required reduces the energy needed to transport that fuel proportionally.

Electric vehicles will create a lot of opportunities for remote communities to reduce their dependence on imported petroleum fuels, reduce their greenhouse gas emissions and reduce their overall energy use (keeping more money in the community. Coupled with a smart micro-grid, EVs will allow remote communities to embrace local, renewable energy sources, increasing self-reliance, self-sufficiency and local employment, largely related to green jobs.

1. **Proposed Nunavut community demonstration**

In looking at Nunavut communities, Pangnirtung is located on a fiord on the southern coast of Baffin Island with a population of 1550 in 2012 and with a median age of 23.0, and has some 500 private dwellings (21). The community is almost entirely Inuit. The road system in the community is quite limited since the hamlet areal extent is only 7.7 km2 which is characteristic of nearly all 26 communities in Nunavut. There were 3,529 road vehicles registered in Nunavut in 2007 which would suggest by population that there would be in the order of 166 in Pangnirtung (22). In addition there would be several hundred ATVs and snowmobiles in the hamlet as well as the fleet of small craft associated with fishing and hunting from the hamlet.

This community has indicated an interest in conducting an energy audit as an initial step in creating a community energy strategy. Senior members of this community have participated with RESTCO in helping to create energy research and demonstration program plans for the new Canadian High Arctic Research Station in Cambridge Bay (CHARS). It is intended that the concepts outlined above that show the power of integrated planning involving energy, housing and transportation be demonstrated in a community such as Pangnirtung. For such a demonstration to succeed, the full cooperation and participation of the community is the first step. RESTCO has begun this process which we expect to take a number of years by engaging with the community at the earliest stages of conceptual planning. It is noteworthy that in Kotzebue Alaska, the initial wind/diesel system was discussed in the mid 1990s and the community is still working on improving and adding additional features to their energy system in 2013. It is also important to recognize that in the Canadian Arctic there are more layers of government and larger utility entities to deal with in terms of advancing new concepts in community infrastructure. However, Nunavut is a relatively new entity and has already demonstrated that it is looking for new approaches to governance which we are hopeful will lead in the next few years to the creation of more sustainable communities in this region of Canada as the north is faced by the most dramatic evidence of climate change in the country. The Figures below illustrate the situation today and in future.

Such a community demonstration project would start from a baseline snapshot, and then start introducing the various components in a measured way to establish, not only the behaviour of new components, but their interaction with the existing community. As a remote community, the local grid is under local control, and not subject to impacts from distant points (e.g., the north-eastern US plus Ontario blackout in August 2003). The innovative housing system we propose would be introduced in small numbers, along with EVs of multiple types. All of these would be monitored for a year and compared to control versions of the existing types for analysis. Lessons learned would be incorporated into a second generation of housing, vehicles and systems. Over a period of years, refined versions of each would be introduced into the mix, with continuing evaluation to arrive at best practices. Earlier versions would not be removed, but would continue to provide usable housing and transportation while continuing to be monitored. These learnings and technologies can be applied to other communities for their benefit - economic, environmental, health and social. These activities do not preclude parallel work on local food production, water supply and sewage management systems.



Figure 4 – A present day Arctic community energy system (left) and a future system (right)

1. **Summary and Conclusions**

Climate change in the Arctic is clearly in evidence and adaptation by communities is already taking place. Ice roads are no longer feasible or their extent and useful life is shrinking. Storm conditions in the open water season are becoming a hazard for local small boat operators. The secure provision of fossil fuel to coastal communities and safe storage of these fuels due to melting permafrost is also a concern. A number of conclusions are suggested from this study:

* Local involvement in energy planning with Territorial Government support is the initial step in moving toward sustainable Arctic communities
* A multi-faceted approach that looks at housing, energy and transportation and the systems that can be created by merging these elements of infrastructure will lead to more sustainable and resilient communities economically driven by the actual cost structures found in the Arctic
* Involving the local community in the earliest stages of concept development and planning will lead to the greatest local benefit in education in new skills and job creation in areas of greatest grown expected in the next decades
* Fostering these concepts in the Canadian Arctic could lead to commercial opportunities throughout the circumpolar regions which are all suffering the same impacts from climate change as found in Canada’s north
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