

## **Case R-3748-2010 – Distributor's 2011–2020 Supply Plan**

Expert witness of the Réseau national des Conseils régionaux  
de l'environnement (RNCREQ)

### **Analysis of wind-diesel alternatives for the design, planning, and operation of Quebec's autonomous grids PRINCIPLES, PROJECT BENCHMARKING, OUTLOOK, AND RECOMMENDATIONS**

*Photo courtesy of Dave Wheeler, Fair Isle, Shetland*

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## **Mandate**

Benchmark the use of wind-diesel systems outside of Québec and put forward a strategy for implementing this technology on a commercial scale.

## **Background**

In other cases, the RNCREQ focused on the peculiar situation of the Schefferville grid, in particular with respect to the high levels of unit consumption and losses. The intervenor intends to pursue its action aimed at eliminating or at least reducing the need to use thermal generation even in reserve.

In case R-3708-2009, the RNCREQ emphasized the high level of losses on certain autonomous grids and asked for explanations in this regard. In decision D-2010-022, the Régie asked the Distributor to specify the magnitude of these losses for each grid in the context of the next supply plan. The RNCREQ intends to analyze the information provided by the Distributor and make any relevant recommendations.

The RNCREQ notes that the Distributor appears to evince a degree of interest in wind-diesel technology, but that the pace of progress since the last supply plan leaves much to be desired. Given the economic and environmental benefits that would result from more limited use of thermal generating stations on these grids, it is surprising that the Distributor has not moved faster. The RNCREQ intends to address this issue by making reference, in particular, to the cost-effectiveness study submitted to the Régie in a previous case.

**Analysis of wind-diesel alternatives for the design, planning, and  
operation of Québec's autonomous grids**

**PRINCIPLES, PROJECT BENCHMARKING, OUTLOOK, AND RECOMMENDATIONS**

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# 1. Origin of wind-diesel technology and the hybrid systems industry for isolated communities

The use of local resources to satisfy the energy demands of isolated grids has a long history.

Beginning our examination of the alternatives exploited in the period immediately following the 1973 oil embargo, we can already see examples of innovation in the design engineering of the electric grids supplying isolated communities. These examples – which, on the conceptual level, compare very favourably with more recent or more modern commercial projects – allow for a deconstruction of design criteria all too often seen as immutable. The 1973 embargo gave a new push to the idea of energy independence, and it fired the creativity of those engineers who were in charge of energy supply to isolated communities.

To convey an idea of the prospects for changing the way that energy supply on the autonomous grids is planned, we feel the Fair Isle wind-diesel system is the best starting point.

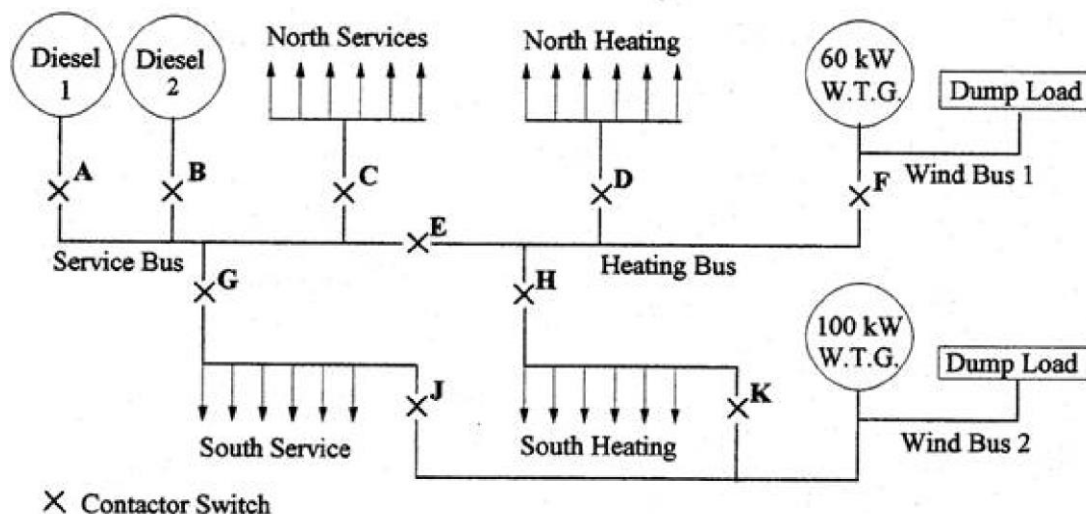
The story of this innovative commercial initiative begins in 1982 on Fair Isle, situated in northern Scotland halfway between the Orkney and the Shetland Islands. With the goal of reducing the high cost of all-diesel electricity brought on by spiking fuel prices, a 60-kW wind turbine (converter equipped with a synchronous machine) . The flagship project, financed by the island's administration and governmental development agencies, was the first of many wind-diesel programs worldwide, among them the one begun by the Institut de recherche d'Hydro-Québec (IREQ) in 1986. In hindsight, a case study of the Fair Isle system alone provides all of the conceptual material needed for an effective introduction to the fundamentals of planning the development of Québec's autonomous grids.

The Fair Isle project is a perfect illustration of what imagination and rigorous research can produce when they are applied to the development of creative energy engineering solutions. This commercial project, operated since 1982 by Fair Isle Electricity Company Limited (FIECo), has from the outset harnessed wind energy technology (fixed-pitch blades, synchronous machine), programmable relays, and an attractive pricing structure to develop a surprisingly simple grid, one whose operational characteristics remain to this day an inspiration for all grid designers.

In 1998, with the revenues generated by the facility and the assistance of organizations in Scotland, the Shetland Islands, and the European Union, FIECo (possibly the smallest public electric utility in the British Isles, serving only 80 residents) reinvested £350,000 in its energy infrastructure, refurbishing the first wind turbine and adding a second one rated 100 kW. In so doing it set up a unique commercial wind-diesel system that constitutes a successful example of the bold integration of standard electrical equipment in order to produce electricity at a reduced cost while guaranteeing energy security for the customers.

The following are the principal design characteristics of the system currently operated by FIECo on Fair Isle, the primary objective of which is to greatly reduce fuel consumption by the community:

- 1) **Prioritization of free fuel:** Integration of a high wind energy capacity (synchronous motors) capable of supplying the entire demand of the island when winds are sufficient. Diesel is essentially used as a backup energy system (20% of overall needs) on an annual basis.
- 2) **Harnessing of surplus wind energy (dual-energy heating mode)** to reduce the consumption of fossil fuels normally allocated for water and space heating in all-diesel mode.
- 3) **Grid stability/reliability:** The stability of the system is ensured by distributed heating loads, controlled by frequency-sensitive programmable relays, guaranteeing a balance of supply and demand at all times; additional heat-dissipating elements absorb the excess wind turbine production when all energy needs have been satisfied.
- 4) **Topological revision of grid engineering and operating practices vis-à-vis power routing:** Installation of the second distribution system dedicated to supplying the distributed electric heating loads of customers by wind turbine; modification of the grid operation plan, dual-energy pricing.
- 5) **Attractive pricing structure** encouraging the purchase of wind energy.



**Figure 2. Wind and diesel distribution schematic 1997**

Source: [http://www.fairisle.org.uk/FIECo/renewed/fig\\_1\\_2.htm](http://www.fairisle.org.uk/FIECo/renewed/fig_1_2.htm)

The average annual wind speed at the site is approximately 9 m/s. Wind energy supplies 85% of the community's needs in winter and 50% in summer, making this facility even today an uncontested leader in the use of renewable energy as a substitute for fossil fuel on autonomous grids. Together with an insulation program for the island's homes, the system has shown that it is possible to harness wind resources to greatly reduce dependence on costly imported fuels while minimizing the risk of oil spills and contributing to long-term energy cost stabilization.

With a functional diagram nearly elementary in its simplicity, this rugged system has proven its reliability for nearly 30 years. With its bold engineering choices and unusual operating modes, it already affords grid designers all the autonomy and uncompromising reliability of the best solutions to be found amid today's varied offering of so-called "hybrid" grid architectures and engineering.

The issue is, on balance, one of predicating investment decisions to an increasing extent on their capacity to buffer the autonomous grids from rising operating costs driven by the enduring upward trend in fuel prices. The builders of the Fair Isle project understood this reality in 1982. The project's detailed history (<http://www.fairisle.org.uk/FIECo/index.htm>) is emblematic of a strong technical/economic focus that attests to the wisdom of revamping the planning and operational practices applicable to autonomous grids. By doing so we can identify low-cost solutions that are innovative, viable, reliable, and economically sustainable over the long term.

### **1.1. Grid technology, structure, and economic issues**

It is helpful, when contemplating the complexity of the changes required to do this, to begin by discussing the issues that influence investment decisions relating to communities' energy needs. These issues are technological, structural, and/or economic nature, but there are complex interactions among them.

The relative weight of each issue varies according to the project at hand. When investments in energy infrastructure under consideration, each case must be assessed based on the initial conditions, the desired energy services, the project's time horizon, and the technical/economic offering available. The soundest decisions arise out of a stringent multi-criteria analysis of all aspects of the project. When it comes to planning energy systems from scratch, as may occur with some autonomous grids (e.g., new community, major overhaul, power station relocation), technological factors must be given central consideration in the opportunity costs analysis for each available option.

**Technological issues:** The history of a society is bound up with the history of its technology. The constant flux of technological evolution has long since proven to be an inexorable driver of change. New commercial products emerge, forcing established practices and methods to be revised. New technologies are taken on the strength of their proven capacity to offer new and effective solutions that result in lowered costs and improved means of achieving a desired result. Where electricity grids are concerned, this category of technological issues comprises the full range of technological options that can be incorporated into a grid. Manufacturers improve their products, new products enter the market, new technologies arrive bringing new possibilities and suggesting new approaches. A wide range of products are continually vying for dominance in fields as diverse as materials science, communications networks (WAN, LAN, IP), energy technologies (both supply and demand sides),

control and data acquisition systems, power electronics, real-time digital modeling and simulation of complex systems, programmable logic control, and so on. The possibility of harnessing certified products to meet increasingly complex needs, and to do so reliably, is a reality that influences our very ways of thinking. There is no question that technology alters our conception and construction of the world, of how systems should be designed, built, and operated. Electricity grids are no less beholden to technological change. For example, the rapid rise of “smart grid” investments among large electricity distributors has been a reality visible to all. In making these investments, distributors have grasped that the technical features of this paradigm offer new possibilities for integration of generation technologies (wind, solar) and usage-related technologies (demand-side management, real-time control, peak load reduction or shedding, dual energy), particularly in the area of distribution. They also offer additional flexibility for supply and demand management, yielding recurring economic benefits from grid operations.

In a context where a secure supply of low-cost fuel is no longer guaranteed, the catalogue of new options poses a challenge to the all-diesel paradigm that currently dominates the planning of Québec’s autonomous grids. This context forces us to consider equivalent alternatives in terms of investments and resources, paying particular attention as well to the opportunity cost of each decision. We discuss this point in detail in section 1.3.

Powerful design, optimization, and decision-making support tools have become common in all fields of engineering. Clearly, technological issues have a transformative power whose repercussions are economic, social, and structural. It is not uncommon to see the most sophisticated technologies quickly become established in societies where they have had minimal exposure. Baseload solar power and the cell phone are modern products that can offer a higher standard of living to less-developed populations who have never gone through the technological phase in which these services had to travel over wired networks.

**Structural issues:** This category subsumes issues relating to historical, cultural, institutional, organizational, and hierarchical phenomena. It is a complex set of issues; however, insofar as the “global village” is an increasingly technology-dependent metaphor, the cultural resistance of the past is rapidly giving way to curiosity about technologies perceived as potential sources of individual liberty. In this context, the resistance to change evinced by large organizations and institutions remains a complex and inscrutable matter. These entities operate within a hierarchical domain codified according to a mission that is rooted in a relatively rigid technological configuration. There is, after all, a service to be provided and responsibilities attaching to it. Though perhaps paradoxical, then, it is nonetheless true that large organizations evince the most insecurity in the face of new technologies. The inertia caused by their hierarchical organization of complex tasks makes these organizations reluctant to adopt new technologies, which tend to be perceived as threatening to the mission they are charged with carrying out.

While the vast resources wielded by these organizations give them the leeway to contemplate a wide range of projects, their decision-making processes encumber them when the time comes to forge ahead into new territory. Not all options are created equal.

In this report, we will not discuss the aspect of energy pricing in autonomous grids, except to point out its crucial importance as a lever for technological change through the price signal it sends to customers. Despite their deterrent features, the rate structures in effect for the autonomous grids north of the fifty-third parallel fall far below the real cost of supplying electricity service expressed in ¢/kWh (total avoided cost of 63.33 ¢<sub>2011</sub>/kWh for Nunavik according to the table on page 9 of ref (viii)). In addition to the brute fact of the recurring operating deficits generated by this rate policy, which have to be absorbed through rate increases for customers on the integrated system, we submit to the Régie that continually mopping up the deficits in this way may constitute a significant de facto structural bias, an expedient “out” that makes it seem less urgent to develop engineering solutions capable of reducing this deficit.

In particular, we will examine electric cooperatives of Alaska and the Northwest Territories, where rates are based on the full cost of supplying power. Grid planners in these territories are, as we shall see, stepping up the search for engineering solutions that integrate new sources of power generation and energy efficiency into the conventional all-diesel supply scenario. Glaringly, though, it is the latter scenario which currently dominates all resource planning processes affecting the autonomous grids of Québec.

**Economic issues:** The economic arena constitutes the battleground on which the other two categories of issues square off in relation to any given project. It is the technical/economic (and financial) analysis that determines the affordability, the quality, and the quantity of services that a given infrastructure project will offer the community. Nowhere more than in the area of electricity grids, being public utility infrastructures, is the discussion more animated around the merits of the various competing technological options and variants. Energy grids, with electricity occupying a place of dominance among them, are certain to attract numerous and various sales pitches in response to a specific set of planning criteria set out as guidelines to the conduct of a technology-centered decision-making process. At that point, the technical/economic analysis must prevail over all other considerations, since it alone offers a venue in which the multiple intersecting dimensions of the problem can be accounted for. In the final analysis, the economic dimension is decisive, since it reflects all the constraints that must be taken into account in identifying the right project for the right context. These constraints are social, environmental, financial, and technological; they involve varied resources, long-term financial commitments, capital investment costs, operating and maintenance costs, and requirements to meet over a multi-year horizon, the structure of which depends on the technologies being implemented. The economic analysis must provide a solid answer to the obvious questions that must be asked about the multitude of projects vying to show their relevance as the ideal solution: What is the target objective? What are the applicable functional specifications? How can the expertise gained since the last time this project was the subject of an investment decision be best taken into account? What are the most significant parameters of the investment and operating costs of the different alternatives under study?

It is within this highly complex framework that a technical/economic analysis must be performed for the many variables affecting wind-diesel or other hybrid systems for the autonomous grids of Québec. We thank



the Régie for allowing us to present several hybrid system alternatives that illustrate the remarkable potential for recurring fuel savings offered by this dynamic branch of grid architecture, which substitutes local energy resources for increasingly expensive petroleum.

The objective of these wind-diesel hybrid solutions remains everywhere the same: to minimize the consumption of imported oil by favouring local energy sources, while guaranteeing a lower-cost, reliable and secure source of power to customers served by the autonomous grids.

## ***1.2. Classification of technologies applicable to the design of wind-diesel cogeneration systems***

The autonomous grids, it is clear, represent a privileged window on the technological changes taking place in the world of grid design. The structural changes that have divided the integrated system into its generation, transmission, and distribution functions, following the deregulation of electricity markets at the beginning of this century, are of no import here: it is in the very nature of the autonomous grids that all aspects of power generation, transmission, distribution, and consumption in isolated communities have to be accommodated within a single comprehensive process. From design to operation, electricity management on the autonomous grids is essentially a unified process due to the inherently local nature of the infrastructure.

It is this systemic nature of the autonomous grids that is particularly conducive to making changes to operational rules and practices in the course of a functional planning exercise. Therefore, these grids are particularly valuable as technological showcases of how innovative functional architectures can contribute to the balancing of energy supply budgets. It is hardly surprising that we currently see an explosion of innovation precisely in those places where the opportunity cost is most likely to result in operating profits (see the case of Sand Point, Alaska, section 2.1 of this report).

We begin by presenting an overview of the diverse range of technological tools (on both the demand and supply sides) that modern grid design and engineering have at their disposal. It is not within the scope of this study to present an exhaustive catalogue of all the commercial offerings available; we will compile here only a generic list of these components in order to convey an idea of the capacity ranges of the various commercial products available today as well as the functional configurations of their specific characteristics and uses. This list encompasses technologies that are now in great demand continent-wide as part of distribution grids designed around architectures associated with the portfolio of “smart grid” projects. But their cost-effectiveness is most clearly evident in the regions with the highest energy supply costs. As such, they are particularly advantageous for the majority of the autonomous grids, which can now choose from a gamut of increasingly competitive off-the-shelf products backed by commercial warranties.

Wind-diesel generating systems, often called hybrid wind-diesel systems (HWDS), belong to the large family of hybrid electric systems and can have varying architectures. A hybrid system may comprise different modules and technologies relating to generation, consumption, storage, power electronics (inverters, rectifiers, etc.), and metering/control features to meet the electricity and energy demands of communities.

Leaving aside diesel-fired generation technologies, which we will discuss later, we may group these commercial technologies into five functional categories that are managed according to a decision-making hierarchy built into the detailed operating program that is created by the system's designer. The operating system takes account of the characteristics of all the subsystems and manages decisions by taking into account the specified time periods, the response times specific to each of the subsystems, and the characteristics of the equipment.

**Generation components (energy and power contribution):**

**Photovoltaic** (dwellings, generating station rated 0.5–100 kW, annual LF of 15%).

**Wind** (insulated dwellings, generating station rated 0.1–5 MW, all types of mechanical-electric conversion systems (certain modules allow for control of voltage, reactive power, power setpoints, and rotor speed and pitch controls); annual LF of 20–40%; active market for modern machines (existence of a secondary market for reconditioned wind turbines).

**Hydro** (power station or reservoir; LF specific to each design);

**Demand-side components (active management of surplus wind generation; reduction in heating oil use through wind-based dual energy plus load-frequency regulation):**

“Smart grid” ceramic thermal storage systems – Steffes ETS modules, zoned or central domestic use (<http://www.steffes.com/>); 13 to 240 kWh of storage usable over 8–12 hours; \$30-60/kWh, \$100-200/kW, single phase or three-phase, programmable control, I/O, integrated LAN communication, programmable timers, manifolds, dedicated “green heating” (wind-PV) mode; wind electric heating: Chaninik Wind Group, Sand Point, Alaska. Centralized storage units for heat distribution systems (TDX, St. Paul Island, Alaska). Other thermal applications can be envisioned: freeze-protection for water systems, sewer systems, fire protection systems. Ice production modules (absorption refrigeration: Kotzebue, Alaska).

Charging of electric vehicles on autonomous grids: stability, operating reserve, load shifting functions: four-wheelers in St. Paul, Alaska.

Water desalination modules: Danvest project in Salisbury, Australia.

**Storage components (short-term, power quality + stability reserve):**

The demands made by specific equipment connected to the grid or necessitated by specialized applications may require the use of storage modules. For autonomous grids, these consist of short-term applications generally related to power quality and offering an operating reserve margin: protocols for adding and removing large loads, temporary support for system state changes, control of electrical transients. For microelectrification applications at isolated sites (PV system, e.g., batteries), the sizing of the system may require the use of proportionally greater electrochemical storage than in a grid designed to supply power to an entire community

(high-penetration wind-diesel system, for example).

**Flywheel/power electronics modules under autonomous or external control;** PowerStore flywheel, Capacity 18 MJ: performance  $\pm 500$  kW in 5 ms.

**Electrochemical storage modules:** Batteries/power electronics Modules.

**Linkage and coordination components for distribution:**

**Smart meter:** customer's energy portal, combining IP platform, LAN and WAN communications, input/output interface, displays, sensors, programmable control to take advantage of time-of-use pricing, peak management, performance optimization of generating equipment, load prioritization/shifting, operating reserve, etc. Various manufacturers.

**SCADA (Supervisory Control and Data Acquisition Systems) systems:** used to measure the system's sensitive parameters, for programmable digital control, and activation of specific functional command sequences managed at the level of subsystems through standardized (IP) communication protocols and appropriate communication networks (LAN, WAN, telecom, cable).

Communication and information exchange networks between dedicated digital controllers.

**Centralized grid operational and management features:**

The central supervision of the system is housed in the grid management program, which handles the continual variations in generated power and demand and coordinates decisions about energy routing over the grid in such a way as to guarantee the stability and reliability of the system in all of its operating modes (e.g., wind-diesel, all-wind, all-diesel, wind-hydro).

The whole arsenal of protective relays, teleprotection, and online remote control available today is marshaled in support of service reliability, and each modular subsystem can be included or not, depending on whether it possesses the grid operator's prescribed certifications in accordance with electric industry standards.

Reactive power can be controlled by dedicated electric machines (synchronous condensers) but, to take the example of wind power, several modern machines allow for control of the power factor and the line voltage at the interconnection point thanks to power electronics modules incorporated into their conversion systems.

**Centralized power routing/control:** Several manufacturers are competing to offer centralized control systems: SCADA, PLCs and system control hierarchy, power electronics, short-term electrochemical storage, operational programming (inflows-outflows, protection, stop/start, changes in system state, startup or shutdown delays, racks, automated changeover units, load and feeder control, etc.).

This generic list gives an idea of all the tools at the disposal of grid planners thanks to an ever-expanding array of electricity products (for both supply and demand sides) that also offers increasingly competitive specifications, certified performance guarantees, and prices as well as modular flexibility that can lead us to reconsider the rigidity of certain conventional planning criteria.

On this specific aspect, the operational flexibility that now allows for the lower-cost modular integration of the features presented in this section certainly deserves to be given in-depth consideration in the design of HP diesel-wind projects. Moreover, given the advances made in the areas of demand-side management, the conversion efficiency of modern diesel gensets, the use of surplus wind energy to power distributed secondary loads, and the consequent possibility of effectively lowering peak demand, there are excellent reasons to reconsider the operational relevance of the (N1)\*90% power reliability criterion. A comparison between the marginal cost of a kW of additional diesel capacity and that of a kW of “clippable” demand integrated into a HPNSDW system justifies, in our view, a comparative cost-benefit analysis of these two options, which can both claim to preserve the reliability of power service.

### ***1.3. Design and operation of wind-diesel cogeneration systems***

In the introduction, we presented a functional discussion of the wind-diesel project on Fair Isle in Northern Scotland. Due to the remarkable results yielded by this project, it has awakened a keen interest in the integration of new generation alternatives and has led several research centres around the world to embark on a range of studies focusing on the operational characteristics of a wide variety of wind-diesel systems.

The motivation is everywhere the same: to reduce the operating deficits of isolated electricity grids. At IREQ, work on this research topic began in 1985. Throughout the period from 1984 to 1994, an annual international conference on the subject alternated between Canada and the United States. It brought together researchers, engineers, and industry representatives around issues relating to system dynamics and the stability of wind-diesel grids, the relevance of using electrochemical or flywheel storage to guarantee grid reliability, or the need for forced startup of diesel gensets in a power deficit situation, among others.

Researchers and engineers from Amherst College (MA), Vermont-based companies (Enertech, Northern Power Systems), Colorado (National Renewable Energy Lab), Canadian institutions (Atlantic Wind Test Site, IREQ, York University, EMR Canada) and Europe (Rutherford Appleton Laboratory in England, Riso Laboratory in Denmark, Sintef in Norway) met to hammer out some classificational notions based on the operational characteristics of wind-diesel systems.

Initially there were two major classes of wind-diesel systems squaring off on the conceptual plane: systems with or without storage. The argument for storage was based on the risk of power outages taking place when the system switched from one operating mode to another (wind-diesel to all-wind, for example). Such transitions could create transients or surges that could be averted with the help of an energy reserve. But “reserve” means storage, and debate over the necessity of this design feature preoccupied the theorists of wind-diesel systems for some time.

This controversy persists today, even among large-grid experts. But one thing everyone agrees on is the length of time during which this storage would be needed: anywhere from a few seconds to a few minutes is sufficient to

manage these surges, which are mainly linked to startup or shutdown of generation units, equipment synchronization requirements in some instances, and fluctuations of generation and demand. Long-term storage (ranging from several hours to several days) is only needed to fulfil larger energy requirements associated with supplying energy demand on the system.

This assertion remains true regardless of the size of the energy system considered. One can easily understand why battery storage is necessary in the case of autonomous systems for very isolated sites (telecom stations, lighting for off-grid homes, pleasure craft). For example, a PV-powered lighting system is always connected to a battery so that solar energy can be stored up during the day and used to power the lights at night. This is an example of long-term storage, since the system has to be sized by comparing the statistics concerning sunless periods with the daily lighting load. Indeed, hydroelectric reservoirs on the main system play exactly the same role, since no one would want to depend on natural hydraulic inflows to meet their electricity needs. Annual and multi-annual reservoirs serve to manage seasonal and annual variations in hydraulic inflows vis-à-vis the aggregate annual variations in customer demand.

The essential point to understand with regard to the operation of a wind-diesel system, whether it is a retrofit or a new system, is that the cost of all the equipment beyond what is strictly associated with the diesel portion of the system, including of course the wind turbines, must be covered by:

- 1) fuel savings;
- 2) additional revenues from the use of the surplus wind power;
- 3) the market value of the environmental externalities and possibly also of the economic spinoff benefits to the community.

Prioritizing wind generation, with its no-cost fuel, minimizes the need to consume costly imported fuel. What this also entails is the imperative of finding the economically optimum level of wind penetration by identifying ways to take advantage of all the available surplus wind power. Increasingly promising modules now make it possible to achieve this at ever more competitive costs.

Denmark and Canada have been the pioneers of no-storage or “high penetration” wind-diesel solutions, which are the only solutions that can achieve the goal of maximally reducing fuel consumption in the autonomous grids.

In the field of systems in which energy sources such as wind and diesel are paired, the concept of “**wind penetration**” is found expressed as a **power ratio** (installed wind capacity as a percentage of peak demand) or an **energy ratio** (wind energy as a percentage of annual requirements). An additional remark has to be made for the case of high-penetration systems in which surplus wind generation can serve to further reduce the need for heating fuel thanks to secondary modules operated in dual-energy mode. These can be centralized heat storage systems, as on St. Paul Island (Alaska), or distributed systems, as on Fair Isle (Scotland). Where surplus electricity is taken advantage of, it is preferable to distinguish the fuel reduction associated with priority demand

from the reduction linked to heating-driven demand (which is not normally supplied by the diesel plant). Since the goal is to optimize the overall reduction in fuel consumption, an indicator of the contribution of local energy sources expressed as a percentage of total energy consumed annually in the community would be more descriptive.

Thus, to maximize fuel savings, the HPNSWD (hi-penetration no-storage wind-diesel) scenario leads to an unconditional preference for investment in no-cost fuel technologies (including negawatts of course) before any investment in short-term storage facilities (batteries, flywheels), which have no inherent value for reducing fuel consumption in an autonomous grid, especially given the considerable investment demanded and the limited lifespan, not to mention the fact that the storage-discharge cycle necessarily entails energy losses. Generally speaking, the storage of a significant volume of energy is only cost-effective when the marginal cost of energy over one day, for example, varies more than the cost of storing/discharging this volume of energy over the same period, which allows a monetary advantage to be derived. This condition does not hold on an autonomous grid, so this type of storage can at best be justified for functions related to power quality control or scheduled transients (switching on of a heavy load drawing a large amount of current that would normally disrupt the frequency momentarily).

The updated HPNSWD scenario developed at IREQ over the period 1986–1999 originates from this line of thinking. HPNSWD, that is, represented the smallest possible technological change, in operational terms, for the autonomous grids. It constituted the technological step forward that was at once the most “natural” and the most cost-effective from an operational standpoint.

In terms of storage, though, the solution appearing most appropriate continued to be fossil fuel, an energy reserve of very high caloric density (about 40 MJ/l), which can be used as a backup at any time.

The RD&D project explored a technologically realistic solution for effecting a significant reduction in diesel fuel consumption with a view to minimizing the operating deficit of Québec’s autonomous grids. In 2004, the cost of diesel fuel supply in Nunavik was around \$9.5 million, or 53.8% of Hydro-Québec’s operating costs. Nunavik, among all the autonomous grids served by Hydro-Québec, accounted for 45.1% of total diesel fuel purchases and 16.4% of total electricity sales (ref. 7).

The design of HPNSWD systems is essentially guided by two overarching considerations:

1) **A priority on wind generation (free fuel):** The **diesel gensets can be stopped** when wind generation alone can power priority electricity demand. It follows that **optimal wind penetration is obtained** not by restricting the operation of the diesel plant but **by an economic analysis** that takes account of fuel costs, local wind potential, HP wind-diesel infrastructure costs, demand growth, rising fuel costs, fuel savings, operating and maintenance costs, lifecycle extension for the diesel gensets, etc.

2) **Maintaining quality electricity supply to customers:** a **load-frequency regulator** balances supply and

demand at all times by acting on dump loads to absorb generated power surpluses (surplus wind energy can be taken advantage of when it replaces the fuel consumption associated with non-electric uses such as space and water heating; dual-energy triggered in the presence of wind generation). A **control system** provides for the orderly management of transitions between the three operating modes of the system: all-wind, all-diesel, and wind-diesel.

[Legend:]

Features of an HPNSWD system

High	Generation	Use
Operational priority	Wind turbines	Village demand
	Generator	
	Clutch	
	Engine	
Low	Gensets	Secondary loads
	Control	Regulator

Source: B. Saulnier and R. Reid, *L'éolien: Au coeur de l'incontournable révolution énergétique*, ISBN 978-2-89544-145-8 (Québec: Multimondes, 2009), 432 pp.

Appendix 1 provides further details on the history of Hydro-Québec's HPNSWD project.

In essence, HPNSWD makes it possible to realize greater fuel savings than with wind-diesel systems operated in “fuel saver” mode, which are associated with the class of low-penetration wind-diesel systems (less than 20% replacement of reference annual priority diesel-fired generation). For reference, the 5 MW pilot project that Hydro-Québec plans to implement in Îles-de-la-Madeleine (IDLM) in 2013 falls into the “fuel saver” category, and its penetration will amount to about 10% of electricity demand in IDLM.

The dump load (23,000-l hot water tank) and its regulator, TDX System, St. Paul Island, Alaska (source: ref. 7)

With the HPNSWD scenario, it is easily possible to halve the diesel fuel needed to meet electricity demand, or reduce it even more if the design of the wind-diesel system and the operating plan for the generating facilities fully reflects the first of the two overarching considerations described above. By 1982, the Fair Isle project (see section 1) was already pointing the way towards what could be technically achieved.

With HPNSWD, it is of course necessary to preserve the backup generating capacity that will be needed to meet the basic needs of the community during windless periods, but it entails major changes, primarily in operational practices and in how the diesel gensets are used. What with the unavoidable reality of rapidly burgeoning operating deficits, the status quo of diesel as the main power source is no longer a viable option. Clearly, the traditional market for the one will become the new market for the other. The transition to this new equilibrium cannot happen without some resistance.

The way HPNSWD works lengthens the lifespan of diesel gensets. Less fuel burned, shorter operating times, and less maintenance all translate into postponed investment in new gensets. HPNSWD also entails financial rebalancing in terms of the investments devoted to wind and the evolution of the autonomous grids in question.

One of the thorniest aspects of the discussion between the proponents of maximal fuel reduction and the operators of the existing diesel gensets



has to do with the operating regimen recommended by the manufacturers and its possible impacts on the warranty coverage. It is known that prolonged use of diesel at low loads causes condensation of combustion residues (bore glazing) and that this increases friction and ultimately erodes the efficiency of the machine. The solution to this problem is also known: burn off these deposits by running the engine at higher temperatures. The discussion has been ongoing for 25 years. But during this period we have learned some practical things about diesel engines from research done in the various laboratories where they have tended to be run “cold.” These lessons have helped further the conversation with diesel genset manufacturers. Here is how Per Lundsager, who directed the wind-diesel program from 1984 to 1990 at the Riso Laboratory in Denmark, analyzed this operational issue for the experimental genset that was in service for 20 years before being replaced in 2004; it had been operated for long periods at low loads, indeed often at 0% (ref. 4):

Several diesel manufacturers (Caterpillar, Detroit Diesel, and others) participated in one of the wind-diesel workshops a few years ago. I asked them straight out whether they would sell me a machine with their usual warranty for a project in which I would use it at zero load, and they answered: “Sure, that’s what we’re here for, but we would impose certain conditions.” They would require me not to push diesel in a “negative load” situation (compression mode). I believe that by keeping lines of communication open with the manufacturers, it is possible to operate a system down to 0% load under the manufacturer’s typical genset warranty, provided their instructions are followed – for example, as expressed in terms of the running time necessary at full load in order to “clean” the machine after it has run for a time at zero load.

There are other diesel solutions on the market that would make it possible to fully meet the manufacturer’s requirements. These consist of making accommodations, when designing a wind-diesel retrofit for an existing diesel system, for the use of lower-capacity diesel gensets, or gensets designed for variable-speed operation.<sup>1</sup>

Certain observations in the conclusion of the 2008 technical/economic study on wind-diesel systems for the autonomous grids (reference (i), p. 6) lead one to believe that the cost-effectiveness of wind-diesel projects in Québec’s autonomous grids could be significantly increased if the minimum requirements for the diesel gensets set by the operator were lowered further in light of the comments quoted above:

- At Cap-aux-Meules, increasing this parameter from 50% to 63%, in deference to the operational realities at the site, considerably decreased the optimal penetration and cost-effectiveness;
- In Nunavik, when this parameter was lowered to 30%, the effect was the opposite. It should moreover be

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<sup>1</sup> See, for example, the information sheet on low-load diesel - wind/diesel 320 kW at <http://www.pcorp.com.au/images/pcorp-pdfs/low-load-diesel-product-specification.pdf>; this is a Detroit Diesel Series 60 400-kVA unit designed for a 16-year life cycle and capable of operating for prolonged periods at 7% (23 kW) of its rated capacity. The product is specifically designed for HP wind-diesel applications.

noted that only at Inukjuak does there appear to be an advantage to installing a small backup thermal genset, given their high cost of installation.

[Legend:]

Fuel consumption by ZA40S diesel gensets at Cap-aux-Meules

Consumption (kWh/l)   Consumption (l/h)

Power (kW)

Figure 12 of reference (xi), reproduced above for the purposes of the “cold temperature” argument, shows that the characteristic efficiency available for the diesel gensets in service in Îles-de-la-Madeleine (Sulzer ZA40S, rated 11.45 MW) is relatively flat over the 3.8–11.5 MW range. The 63% used in study (i) corresponds to the beginning of the 4.5 kWh/l plateau and at a load of 7.2 MW.

The safe range of operation at Inukjuak should also apply to Cap-Aux-Meules. Thermodynamic theory obliges us to question the validity of arguments to the effect that the combustion of 900 litres of fuel per hour in such an engine operating at an electrical efficiency of 33% could constitute an unacceptably “cold” operating temperature threshold in Îles-de-la-Madeleine. A review of the annual power generation archives for each of the Îles-de-la-Madeleine gensets would help clarify the physics of this alleged constraint once and for all.

Furthermore, the strict application of the 7.2-MW minimum load criterion established for the existing diesel gensets at Cap-aux-Meules would have direct impacts on the cost-effectiveness of the 5-MW wind project planned for the islands, since this operating constraint could force the wind park to sacrifice some of the power it generates. What this amounts to is insisting that polluting fuel be burnt instead of using the available wind resource to replace that fuel.

In a context of fast-rising fuel costs, a close analysis of the different diesel load options down to 0% would serve to quantify the impact of diesel genset operating constraints on the cost-effectiveness of wind-diesel for grids such as those of Îles-de-la-Madeleine, Akulivik, and Inukjuak. It is important at the outset to clarify the economic sensitivity of the wind-diesel scenarios with respect to the key operational variables that enable the fuel reduction objectives targeted by HP wind-diesel systems to be attained.

[Legend:]

NPV (\$million <sub>2004</sub> )	Sensitivity study – Inukjuak	
	Displacement of NPV for a 5¢/kWh value placed on surplus energy	Reference case:
	Ratio with respect to reference case	<ul style="list-style-type: none"> <li>- 3 0.66-MW turbines</li> <li>- Project life cycle: 20 years</li> <li>- Mean annual wind speed (at 25 m): 8.0 m/s</li> <li>- Diesel genset maintenance: \$36.37/h</li> <li>- Fuel: <math>\Delta_{\text{annual}}</math> mean + 2.1% (incl. inflation, 70.5¢/l in 2005)</li> <li>- Fixed portion of installed cost: \$1,670,000</li> <li>- Wind turbine maintenance: 3.0¢/kWh</li> <li>- Discount rate: 5.20%</li> <li>- Variable portion of installed cost: \$2122 k/kW</li> <li>- Surplus energy: \$0.0/kWh</li> <li>- Reserve: 10%</li> <li>- Minimum diesel load: 50%</li> </ul>

Sample sensitivity analysis of the net present value (NPV) of a HPNSWD project in 2003, ref. (ii), p. v

The following remark suggests as well that such a sensitivity study could helpfully clarify the opportunity cost analysis of several HPNSWD projects:

In addition, it should be noted that the analyses do not provide for putting a value on the surplus energy.  
[ref (i), p. 6]

While robustness, reliability, and simplicity remain imperatives of functional grid design, these imperatives do not stand in the way of designing and implementing innovative HPNSWD systems – systems that can help curtail the long-term operating deficit without any sacrifice of service quality.

## 2. International developments and benchmarking of wind-diesel projects of interest for Québec's autonomous grids

The number and diversity of wind-diesel projects in progress around the world are such that we have deliberately chosen to limit our research to those with direct relevance to our climate.

Alaska was the obvious choice for wind-diesel benchmarks that can shed light on the possibilities for wind-diesel in the autonomous grids of Quebec in both Nunavik and Îles-de-la-Madeleine.

We also chose to look at Ramea Island for what it can teach us about the operation of wind-diesel systems since it operates in a maritime climate similar to that of IDLM and is only a little further away than Gaspé. The island, on the south coast of Newfoundland near Port aux Basques, is home to a privately developed project built in 2004 that has now been service for over seven years. It is exclusively financed by operating revenues under an

energy purchasing contract with Nalcor.

There are other projects, of course, but these are amply sufficient to present a general outline of the wind-diesel variants in service today, as well as the equal variety of policy frameworks in which they evolve, in terms of the structural incentive programs that assisted in bringing them into being. With each year, the economic sense of having installed these systems becomes increasingly clear, with rising fuel prices continually confirming the intelligence of the investment decisions made by their developers.

Since no industry can develop without a suitable and coherent regulatory framework, it is necessary to present a brief discussion of these issues as they apply to the development of wind-diesel projects. In this regard, the state of Alaska has a truly exemplary set of regulatory institutions. Alaska has 181 rural communities in which diesel provides 94% of the power.

### ***2.1. Government policy, structural support for the wind-diesel industry, technological development assistance programs, financial incentives***

In Alaska, the following institutions specifically regulate the structured development of wind-diesel projects and hybrid systems appropriate to the varied needs of the communities served (ref. 6).

**Alaska Energy Authority (AEA)** <http://www.akenergyauthority.org/>

Mission:

Reduce the cost of energy in Alaska

**Alternative Energy and Energy Efficiency (AEEE)**, a program of the Alaska Energy Authority (AEA)

[http://www.akenergyauthority.org/programsalternative\(2\).html](http://www.akenergyauthority.org/programsalternative(2).html)

This program manages and financially supports projects and initiatives representing US \$188 million of Alaska state and federal funds. Eligible projects must aim to reduce the cost of electricity and heating in Alaska communities while guaranteeing the security and reliability of the supply. Images of wind-diesel projects in which AEA had a hand are available at the following link:

<http://www.akenergyauthority.org/programwindssystem.html>

**Alaska Center for Energy and Power (ACEP)**

Mission:

To meet the applied research needs of the state and of local communities by working to develop, improve, demonstrate, and ultimately commercialize and market technologies providing practical solutions to concrete problems.

To leverage external resources (grants, private sector, national laboratories, other universities, etc.) so as to meet Alaska's energy challenges.

To act as an impartial agent on behalf of the communities and agencies of Alaska in order to arrange for prudent investments in reasonable and coherent energy projects that contribute to the residents' long-term quality of life.

**Alaska Wind-Diesel Application Center (WiDAC), Alaska Center for Energy and Power, University of Alaska, Fairbanks**

<http://www.uaf.edu/acep/alaska-wind-diesel-applic/about-widac/>

**Mission:**

To support the large-scale deployment of the most cost-effective wind-diesel technologies in order to reduce and/or stabilize the cost of energy in Alaska's rural communities.

To provide Alaska's rural communities with the information necessary to assess, implement, and operate appropriate, optimized, viable wind-diesel energy systems and to develop the human resources necessary for this purpose.

**Alaska Wind-Diesel Test Center (AWIDITC), Alaska Center for Energy and Power, University of Alaska, Fairbanks**

<http://www.uaf.edu/acep/alaska-wind-diesel-applic/>

**Mission**

To work to increase the penetration of wind-diesel systems through improvements at the level of control, storage, and low-load operation of diesel gensets.

**Alaska Village Electric Cooperative (AVEC), <http://www.avec.org/>**

We mention this power utility here for the considerable structural role it is currently playing in the deployment of HP wind-diesel technologies in Alaska. AVEC is a non-profit power company. It belongs to the customers it serves in 53 scattered communities of interior and western Alaska. AVEC's geographical coverage makes it the largest electricity distribution cooperative in the world.

By late 2009, AVEC had installed wind capacity in several communities: Toksook Bay (300 kW), Kasigluk (300 kW); Selawik (264 kW), Savoonga (200 kW), Hooper Bay (300 kW), Chevak (400 kW), Gambell (300 kW), Mekoryuk (200 kW), and Quinhagak (300 kW). In 2010, it added a fourth wind turbine at Toksook Bay, while four new units were recently installed at Emmonak. In 2009, net wind generation totaled 1.93 GWh, representing savings of over 550,000 litres of diesel fuel. At 2009 prices of about US \$0.80/l, this amounted to a \$441,000 decrease in the fuel purchasing budget.

In 2009, AVEC purchased 19.3 million liters of diesel fuel and aims to save 25% of this volume in 2018 through energy efficiency and renewable energy programs. Source: [http://www.avec.org/renewable-energy-projects/Wind\\_program\\_brief\\_recap\\_03-2010.pdf](http://www.avec.org/renewable-energy-projects/Wind_program_brief_recap_03-2010.pdf)

AVEC has now adopted a design rule for its electricity supply systems according to which its new diesel stations

have to be “wind-ready” so that wind turbines can be brought on stream at any time without the need for major reconfiguration.

As of 2009, Alaska had 21 hybrid system projects for a total installed wind capacity of 13,100 kW.

Source: Keith, K., “Alaska Isolated Wind-Diesel Systems: Performance and Economics,” 2011 International Wind-Diesel Conference, March 8-11, Girdwood, Alaska

These projects total approximately US \$87 million, including more than \$23 million from Native-owned corporations and private capital. Average cost since the beginnings of the program in 1995: US \$10,200 per installed kilowatt (across all systems, 2009 portrait). The cost of wind inventoried in a recent study (ref. 12) commissioned by the Alaska Energy Authority on the wind power experience shows that the wind costs of Alaska’s currently operating (1995–2009 cohort) projects vary from US \$5,000–12,000 per kW of installed capacity for the sum total of projects enjoying a high-quality wind resource (annual load factor of 30% or more), which corresponds to a capital cost of generation of \$0.17–0.40/kWh in a context where the fuel cost is US\$0.60–1.40/l.

The report distinguishes the cases of HP wind-diesel systems with costs below \$0.10/kWh, as for example the Pillar Mountain project (Kodiak Island) built in 2009.

## **2.2. The Arctic climate and wind turbine manufacturers**

The biggest Arctic challenge facing the wind industry concerns the adaptation of wind turbines to the Arctic climate. Wind turbines have to assure guaranteed reliability even as they cope with the issues raised by the harsh climate, where the combination of extreme cold, frost, and violent winds can pose major maintenance challenges. Manufacturers wishing to be certified for this environment have to draw upon the best available knowledge for subsystem design in order to succeed: materials, electronics, lubrication, electromechanical protection, sensors, and SCADA all have to meet the most exacting specifications imaginable. A specific knowledge of climate statistics helps optimize the economic productivity of the machines in all climates. For example, by drawing on what statistical cross-comparisons between extreme cold and strong winds can teach us in terms of available energy volumes, it is possible to determine whether the cost of designing for any specified extreme condition becomes prohibitive or not, in which case alternative methods can be used.

Extended periods of ice or frost at persistent low temperatures can interrupt wind turbine operation for rather long periods. This is a recurring theme of interest to various designers of Arctic wind systems and has been the subject of ongoing, internationally collaborative research (hydrophobic surfaces, heated blades). An idea of this work and the recommendations arising from it can be gleaned from the website devoted to the subject by the International Energy Agency (IEA) at <http://arcticwind.vtt.fi/> (refs. 10–11).

Certain wind-diesel projects in Alaska now have a track record over 15 years with varied systems of different levels of complexity, derived during a period of growth, consolidation, and accelerated technological development in the wind industry. Of course, the driver of growth in the world wind market is the strong demand for wind turbine products integrated into the major continental electricity grids in every country. The commercial offering of wind generation systems has evolved a great deal since 1995, as can be seen in the rated capacity and performance specifications of modern commercial machines.<sup>2</sup> Pitch-controlled, variable-speed, direct-

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<sup>2</sup> The average unit capacity of all the machines operating in the world went from 200 kW at year-end 1997 to 1.06 MW at year-end 2009. The average unit capacity of all the wind turbines installed annually around the world went from 550 kW at year-end 1997 to 1.6 MW at year-end 2009. By 2009, wind turbines under 750 kW were classified in the small wind turbine market segment and had been reduced to only 1.1% of the market. Over 82% of the wind power market at year-end 2009 was held by machines rated 1.5–2.5 MW (ref. 13).

drive machines with integrated reactive power control, not to mention remote control and programmable functionalities, were extremely rare in 1995, at a time when the automation of even diesel-fired power stations was the exception rather than the rule.

The extensive experience acquired with wind-diesel systems designed for large grids, and the technological advances they have made possible, are now feeding a new growth phase with offshoot products targeting the more specialized market of today's autonomous grids. The 50- and 60-kW wind turbines of the 1995 cohort, which made possible the development of HPNSWD technology, are gradually being replaced by a new 2010 cohort consisting of machines whose performance and reliability are comparable to those of machines used for large grids. These new machines are being offered for this specific market by an ever-growing number of manufacturers with an evolving range of capacities. Some of the leading-edge products are already able to draw upon the experience of the several dozen commercial units commissioned in the Arctic in the last decade.

A resale market for reconditioned wind turbines exists today. The last decade has seen the arrival in America of quite a few Danish machines from the 1995 cohort; they were supplanted in Europe by a new generation of taller, more powerful, more efficient, more cost-effective commercial wind turbines. Since the relatively moderate winds of Europe limited the wear and tear on these machines, they have been pressed into service on this side of the Atlantic with a decent life span ahead of them. Machines of this type are currently in service in Alaska and Canada. But this will not be a stable long-term market because the original manufacturers will be ceasing to support these models and dedicating their efforts to more advanced ones. Spare parts are becoming harder to obtain and more expensive. Luckily, through the ever-surprising operation of that technological innovation which is transforming the world, modern commercial machines are paving the way for growth in the wind-diesel market that will give it a momentum as new as the machines taking their place among the panoply of efficient commercial alternatives offering the prospect of massive reductions in fuel consumption. The “free” locally available fuel offered by the wind option is now part of the solution rather than part of the problem.

### ***2.3. Portraits of existing wind-diesel projects***

Kotzebue, Alaska: low-penetration wind-diesel

Kotzebue, a community north of the Arctic circle with a population of some 3000, is the regional capital of northwestern Alaska. The Kotzebue Electric Association (KEA), a non-profit cooperative with 840 members, is in charge of providing power to the community. Its diesel-fired power station, with an installed capacity of 11 MW (6 diesel gensets) has delivered up to 22 GWh in recent years. Minimum demand at Kotzebue is around 750 kW, while the peak is in the vicinity of 4 MW. Since 1995, KEA has played an active role as a leading developer of wind facilities for Arctic environments. Its first wind turbines came on stream in 1997 (3 AOC 15/50). Its wind park now has 17 50-kW turbines (15 AOC 15/50 + Entegrité EW15/50), 1 V-17 (65 kW), and 1 Northwind 100/19 (100 kW) for a total installed capacity of 1.14 MW.

Despite relatively limited wind speeds (mean annual speed of 5.5 m/s according to 1998–2004 observations), the wind turbines have typically supplied 3.5% of Kotzebue's needs, saving 180,000 l of fuel every year.



After nearly 15 years of experience with wind power, KEA imminently plans to install two DirectWind DW 54/900 kW (EWT) turbines, which are pitch-controlled variable-speed direct-drive machines. Manifestly, this is the result of a strategic decision to make wind power the power source of choice for the future. KEA's leadership continues to impart new momentum to this wind-diesel technology.

### **Toksook Bay, Alaska: wind-diesel system (25% penetration)**

Toksook (pop. 560) is a village in southwestern Alaska. Average demand is 400 kW. The local grid is operated by the Alaska Village Electric (AVEC) cooperative and includes three Northwind 100/19 wind turbines, which came on stream in early 2006. The wind turbines are dispatched according to an operating mode that is adjusted for the operating levels of the diesel gensets and where distributed heating loads absorb surplus wind generation as needed. Wind, with an availability rate of over 95%, supplies 24% of annual demand. A fourth wind turbine was installed in 2010. The project, carried out in conjunction with a major overhaul of the local grid, is aimed at reining in the rising costs of electricity generation (avoided fuel cost: \$0.34/kWh in 2009–2010), driven by rising fuel prices.

### **St. Paul, Alaska: high-penetration wind-diesel system**

TDX Power, a subsidiary of the Native-owned Tanadgusix corporation, has been operating an autonomous wind-diesel system since 1999. The system serves the airport industrial complex on St. Paul Island (Pribilof Islands, Bering Sea, Alaska). TDX wanted to reduce its overall energy costs for heating and electricity without compromising service quality and reliability.

The system was built by Northern Power Systems of Vermont in collaboration with the Institut de recherche d'Hydro-Québec (IREQ), which built the load-frequency controller for the system. This subsystem, which balances supply and demand in a wind-diesel system at all times, controls the switching and shedding of secondary heating elements in hot water tanks. Equipped at the outset with a Vestas V27 (225 kW), two 150-kW diesel gensets, a synchronous condenser, a 6000-gallon hot water tank, and a programmable command system allowing for fully automated operation, it is the first commercial system based on HPNSWD technology to be put into service.

Electricity demand at the site is about 85 kW, but the wind-diesel cogeneration system also supplies power for space heating at the airport complex. In 2011, TDX Power commissioned two more Vestas V-27 (225 kW) wind turbines as part of an expansion designed to progressively connect its grid to that of the City of St. Paul Municipal Electric Utility. The installed cost of these two new machines is approximately US \$650,000 (transportation, foundations, site installation, and connection included). Once these turbines are connected, minimum power demand on the system made up of the two grids will be 400 kW, and the turbines will displace diesel fuel at that point.

Courtesy of Northern Power Systems - source: TDX 525 kW Wind/Diesel Hybrid CHP System

<http://www.akenergyauthority.org/programwindsystem.html>

Operating Report 2003–2008: St. Paul Island, Alaska

Period: 2003–2008	Average 2003–2008
Total wind generation	625.8 MWh/year
Electricity displaced by wind generation	194.6 MWh/year
% of wind generation serving demand	32%
% of year when wind turbine was running	56%
% of power demand supplied by wind	27%
Diesel fuel saved (power demand)	55,513 litres/year
Fuel saved (combustion efficiency: 80%) (note 1)	49,725 litres/year
Total fuel volume saved	105,238 litres/year
% fuel savings. [(savings/(purchases+ savings))]	42%
Hours when diesel is off (note 2)	2008 hours/year
% of year when diesel is off	23%

Note 1: All the heating fuel saved is displaced by wind.

Note 2: Never more than one diesel genset running.

Source: J. Coleman, Renewables Program Manager, TDX Power, April 2011

The table above, based on cumulative data for 2003–2008, gives the wind contribution to the wind-diesel cogeneration system in place on St. Paul Island. All the figures are reported on a mean annual basis over this period.

### **Sand Point (project developed by TDX Power)**

The architecture of this HP wind-diesel project is based on advanced metering devices incorporating data processing and a command/control system based on the IP communication platform. Here is a brief description of the system:

- Average electricity demand: 700 kW
- Wind turbines: 2 Vestas V-39 turbines with 1 MW of installed capacity
- Secondary controlled (and dispatchable) loads: 750 kW
- Control of automated diesel gensets

The goal is for renewables to displace 750,000 litres (40%) of the fuel currently being consumed to supply demand, and some 60,000 additional litres of heating fuel thanks to the surplus wind energy.

See also: <http://www.uaf.edu/acep/alaska-wind-diesel-applic/wind-projects-in-alaska/>

### **Unalakleet (project developed by Unalakleet Valley Electric Coop)**

Situated 150 km southeast of Nome in western central Alaska, the community of Unalakleet (pop. 750) began work on a HP wind-diesel project in 2008 and brought the facility on stream in spring 2010. The system includes six Northwind 100-kW wind turbines.

The project aims to generate 1.5 GWh annually and to eliminate 428,000 l/year of fuel (700 kT of avoided CO<sub>2</sub> emissions). It exploits surplus wind power by using secondary electric loads to provide for the community's heating needs.

The project cost of \$5.75 million is shared between AAEEA, the Norton Sound Economic Development Corporation, and the Unalakleet Corporation.

### **Kokhanok (a project of Kokhanoc Electric)**

In 2008, the cost of fuel in Kokhanok, a community located at the near end of the Aleutian peninsula, reached US \$2.00/l, leading to a community decision to invest in renewables.

With its two V-17 wind turbines (90 kW), reconditioned in 2010 by Halus Power Systems, the system (engineered by Marsh Creek of Anchorage), aims to cut the diesel fuel normally used to generate electricity by 30–50%. The diesel-fired power station is composed of four diesel gensets (2 x 160 kW, 1 x 115 kW, 1 x 60 kW), an electrochemical storage system (336 kWh with a 200 kVA inverter), a synchronous condenser (240 kvar), and a hot water unit equipped with 240-kW electric heating elements designed to reduce heating oil consumption for the school complex.

The total cost of US \$1.94 million was financed by the Rural Utility Services (RUS) program of the United States Department of Agriculture (USDA). The project comprised a substantial upgrade of the command/control system for the existing power station, including the installation of a remote supervision and operational command module. The new HP wind-diesel system was inaugurated in October 2010.

**Chaninik Wind Group; development/demonstration project financed by the Tribal Energy component of the Energy Efficiency & Renewable Energy (EERE) program of US Department of Energy (DoE).**

Source: [http://apps1.eere.energy.gov/tribalenergy/projects\\_detail.cfm/project\\_id=137](http://apps1.eere.energy.gov/tribalenergy/projects_detail.cfm/project_id=137)

Driven by the rising costs of fuel for essential uses such as cooking and heating, there is considerable emerging potential for energy substitution at the present time. In several villages of the Calista region in Alaska, annual heating demand accounts for nearly 60% of total fuel consumption across all uses (electricity, transportation, and heating). Twice as much fuel is consumed for heating as for electricity. Chaninik Wind Group Villages brings together four Native villages (pop. 1750) where heating oil retailed for US \$1.83/l in 2008: Kongiganak, Kwigilliingok, Tuntutuliak, and Kipnuk. The “village wind heat” concept is quickly being put in place to provide for local energy security.

The project is financed by the US Department of Energy. Fifteen reconditioned WindMatic S-17 wind turbines rated at 95 kW were brought on stream in three of these villages in 2010; three more will start up in the village of Kipnuk in 2011.

The system involves the use of dual energy thermal modules (electric heat stoves) so that surplus wind power can be incorporated into a Smart Grid-type operating mode (IP platform). The 500 customers can choose their source of supply, taking advantage of the lower rates associated with surplus wind generation as they wish. The wind power generated is managed in such a way as to improve the quality of the electricity service and the efficiency of the diesel gensets. Targeted fuel economies are 40% and will supplant 750,000 l of fuel (more than 250,000 l

associated with power generation, the rest used to meet residential heating needs).

### **Kodiak, Pillar Mountain wind project (developed by Kodiak Electric Association)**

The power system in service on Kodiak Island in southern Alaska is a hybrid autonomous hydro-wind-diesel system powering a load ranging from 11 MW (minimum) to 25 MW. The Terror Lake hydro-complex, equipped with two 11.25-MW turbines, meets 80% of the electricity requirements. The facility has been owned by the Kodiak Electric Association since 2002. The installation of three 1.5-MW wind turbines at a cost of US \$21.4 million (4.8 kS/kW of installed wind capacity) in the summer of 2009 reduced the contribution of diesel from 20% to 11% at a wind generation cost of US \$.07/kWh. This is the first time wind turbines of this type have been installed on the isolated grids of Alaska.

The system is operated in such a way that wind generation in excess of that which is needed to shut down the diesel gensets is matched with the hydro plant, which supplies the balance of the power requirements, the idea being to optimize the storage capacity of the Terror Lake reservoir. The Kodiak Electric Association is currently studying the implementation of three new wind turbines with the same rated capacity.

### **Ramea, Newfoundland: project financed and developed by Frontier Power Systems (FPS) IPE**

Built on Ramea Island (off the southern coast of Newfoundland near Port aux Basques), this HP wind-diesel project was designed in 2002. It was built and commissioned in September 2004 by a private firm. It has been in service for more than seven years and is financed exclusively out of the revenues derived from the power it generates. This revenue derives from an energy purchase contract with Nalcor designed to reduce diesel fuel consumption by the power station in this community of 350 people. The system includes six 65-kW WindMatic wind turbines reconditioned by FPS, which supply the electricity demand (baseload 250 kW, peak 1200 kW). Annual power consumption is 4.5 GWh. The diesel plant consists of three 925-kW gensets. Total project cost: \$1.3 million, or less than \$3,500/kW of installed capacity.

A heating load of 192 kW absorbs surplus wind power and maintains the frequency of the system while balancing supply and demand in wind and wind-diesel modes. The surplus energy does not give rise to any additional valuation. The minimum load on the diesel gensets is set at 30% of the rated capacity by the operator Nalcor. When this threshold is reached, the controller of the diesel plant intervenes to stop a wind turbine.

Management of the wind park is fully automated and the wind power generated supplants 10–15% of annual fuel requirements every year. The purchase price is established according to the avoided fuel cost (delivered to the site) of power generation. The fuel cost, which was \$0.43/l in 2004 when the facility came on stream, is now reaching \$1.00/l, such that the price paid for wind power has been increasing year over year

for more than seven years: “the bank takes its cut.”

Photo and diagram courtesy of Carl Brothers, Frontier Power Systems

### 3. Outlook and prospects

Please refer to chapter 10 of reference (2), pp. 266–85, for a discussion of technological developments specific to electricity grids. Today's deregulated electricity markets are leading us into one of the most decisive reflections on technology since the advent of the electricity grid itself in the last century. A profound transformation is underway, particularly due to the gradually increasing prominence of the operational functionalities of the Smart Grid paradigm in the investments choices being adopted by a growing number of Western utilities. These utilities have reached a turning point in the planning and operation of the infrastructure they use for power generation (greenhouse gas emission reduction policies, RPS, pollution limits, etc.), transmission (NIMBY, routing constraints, uncertainties related to gas price volatility), and distribution (rising demand and service costs, congestion).

With rising fuel prices severely affecting the Distributor's operating budgets for the autonomous grids, the planning rules in effect for these grids do not appear to have come to grips with the implications of these new technologies in terms of opportunity costs, particularly on these grids. There is no longer any appreciable doubt that the technological status quo, deeply rooted as it is in the all-diesel paradigm, is causing the annual operating deficit of the autonomous grids to spiral out of control. This phenomenon is forcing the planner to rethink the whole energy question for remote communities.

Research and development efforts are focusing on energy generation scenarios providing for 100% energy self-sufficiency. Such systems are not yet in the same realm as the commercial generation systems discussed above. Still, by virtue of the bold prospect of energy independence that they hold out, these systems deserve to be presented here because the RD&D element is indispensable at this stage. As an example of this type of system, we briefly present the case of a project constituting an R&D extension of the commercial project on Ramea Island described in the preceding section. This is a collaboration between Nalcor, Memorial University (Newfoundland), the University of New Brunswick, and Natural Resources Canada (CanMET). The partners propose to develop a wind-hydrogen-diesel system for the autonomous grids. The R&D project is designed to make possible the combination of commercial or pre-commercial products in an energy system intended for deployment on the autonomous grids.

The project combines an electrolytic generator and a hydrogen storage facility, hydrogen-powered gensets, and 300 kW of additional wind capacity. In 2009, Nalcor installed 3 NW-100 kW and the wind-hydrogen part of the partners' project. The hydrogen will be produced from the surplus wind power. Since the system is designed to supplant a high proportion of diesel fuel, it will be necessary to provide for a hydrogen storage capacity that can meet several days of energy requirements, which poses some cost-related challenges given the low efficiency of the electrolysis-storage-power generation cycle. Initial testing of the system is ongoing. The possibility of a demonstration project at Cape Dorset is in the evaluation phase (ref. 15).

### **3.1. Growth of the international market**

Grid technology architecture is evolving as we write. It is being implemented rapidly on the scale of the integrated system, as growing investments in smart-grid technology demonstrate. This transformation is underway and has reached a point from which there is no turning back. The autonomous grids are an ideal place for these technologies to be implemented, as the sample projects presented in this section illustrate.

On this note, there are clear conceptual parallels between the grid projects that have been developed under the smart-grid paradigm in the villages of Sand Point and Chaninik Wind Group (Alaska), on the one hand, and the one put in place by the city of Boulder (SmartGrid City, <http://smartgridcity.xcelenergy.com/>), on the other.

Source: Meiners, D., IES LLC, “Chaninik Wind Group Wind Heat Smart Grid,” International Wind Diesel Conference, 8–11 March 2011, Girdwood, Alaska

The success of these projects on the autonomous grids where they are now being implemented will entrain conventional continental grid planning into an irreversible set of changes.

The driver of this trend in the autonomous grids is the search for a viable energy future in which green power has pride of place. This free, omnipresent power source is the only viable resource that can replace formerly cheap fossil fuels as they become increasingly uncompetitive.



### **3.2. Lessons learned and impact on good planning practices: the power reliability issue**

We will undoubtedly have to pay somewhat more at the outset to profit from these hybrid energy systems, at least until we reach a point where enough lessons have been learned for the downward effect on costs to be felt. Public electricity utilities might deliberately choose to wait for costs to come down – but how can this happen if the utilities themselves do not develop a cohesive strategy for exploring ways to reduce their costs? This is surely the big lesson to be drawn from the numerous wind-diesel projects carried out in Alaska over more than 15 years. Thanks to these projects, it can be stated today that a new branch of power grid architecture and engineering is finding its place in the complex domain of grid planning. Along with it have come new practices that have cast doubt on truths once considered unshakable.

With wind, it is now possible to dispel some of the uncertainty surrounding future energy supply costs, to reduce dependency on imported solutions and, most important, to guarantee delivery of the required volumes of energy. The installation of wind turbines to meet basic heating needs may prove to be a simple, viable, cost-effective alternative when the cost of diesel fuel has become prohibitive. But in order to implement this alternative economically in the autonomous grids, it will first be necessary to remove the obstacles to even considering the possibility of electric heating, and make room for the dual-energy technologies which energy price trends are making necessary.

What would even be the point of a diesel genset in a modern power station where the fuel cost in a community is so prohibitive that the residents have to turn down their furnace settings just to make ends meet? Under such conditions, the very idea that diesel could ever have been justified, even at a time when a certain grid reliability criterion made such investments seem pertinent, is incomprehensible now given the alternatives these investments could have financed. Energy demand continues to grow, conventional resources are running out, and their costs will make their use prohibitive. The economic equation that governed planning in the last century no longer obtains. For the production of energy and electricity, natural fossil fuels are becoming increasingly uncompetitive. This is already a fact in many areas, such as the ones covered by the autonomous grids. The solutions of the past will not be able to support the energy needs of these communities indefinitely. This is what the Native people of Chaninik are teaching us today.

Even at \$5000/kW of installed capacity and a 25% annual load factor, the cost of wind generation is \$0.15–0.20/kWh, maintenance included. This is already significantly lower than the cost of diesel-based generation on the majority of Québec's autonomous grids.

Given the ceaseless rise in fuel costs, it is incumbent upon all those responsible for the autonomous grids to develop a cohesive strategy for making the necessary structural changes.

## 4. Arguments concerning the opportunity cost of a HP wind-diesel investment in Akulivik

This section of the report analyzes the investment project related to the construction of a new diesel-fired power station in Akulivik. This project was recently filed with the Régie for approval. The purpose of this analysis is to identify the desirable elements of this project from the standpoint of a HP wind-diesel application for all the autonomous grids of Nunavik.

In reference (iii), p. 15, l. 4, it is stated that a new commercial diesel genset can expect to achieve an efficiency of 3.76 kWh/l, as compared with the typical efficiency of the gensets currently operating in Akulivik (3.53 kWh/l). Over the period 2016–2036, the fuel savings associated with this improved efficiency would total “some 1.7 million litres, which would result in savings of slightly over \$3.5 million (current dollars).” This amounts to savings of some \$2 million<sub>2011</sub> (vi, response to question 7.3, table on p. 14).

[Legend:]

Consumption (kWh/l)

Power (kW)

Source: ref. (ii)

According to ref. (iii), p. 19, l. 13–14, the Distributor expects fuel costs in Akulivik to increase by more than 75% between 2016 and 2030 (252 residential and agricultural customers in 2020 according to the Distributor’s projection, Table A-7.2.1.A of Appendix 7, p. 47 of 75 of ref. (x)): “from \$1.46/l in 2016 to \$2.57/l in 2030.”<sup>3</sup> The current forecast fuel cost for 2016 has doubled since the 2003 forecast for that same year (ref. (ii), p. 19, Table 5). While in 2003 the projected annual fuel cost increase was practically nil over a 20-year horizon, we are now looking at a projection, based on the current assumption of annual growth at a constant rate (net of CPI) of 4%, that fuel costs will double every 18 years. If this pattern holds, by the end of the lifecycle of this facility in 2041 (25 years starting in 2016, according to ref. (iii), p. 15, l. 15), the fuel cost (net of CPI) will have reached

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<sup>3</sup> According to the Distributor’s statements appearing in another section of the same document, (iii), p. 15, l. 10, this represented a cost in current dollars (inflation assumption not mentioned) corresponding to an annual 4% increase in the fuel supply cost.

\$3.89/l, for an avoided fuel cost of \$1.03/kWh generated.

At the cost of \$1.46/l projected by the Distributor for 2016, the share of the avoided energy cost strictly associated with fuel (assuming the stated efficiency of 3.76 kWh/litre) will be 39.36¢/kWh. To a reasonable observer, this projection is in and of itself a powerful price signal that should induce us to look actively for energy alternatives that can help us minimize fuel consumption. In 2036, the avoided fuel cost will be 68.35¢/kWh ( $\$2.57/l = 3.76 \text{ kWh/l}$ ), according to the Distributor's forecast.

Clearly, fuel cost represents the lion's share of the Distributor's avoided energy cost.

A clarification is necessary here in order to grasp the magnitude of the opportunity cost entailed by the project to build the new Akulivik power station. In reference (vi), p. 14 of 23, in response to question 7.3 from the Régie concerning the total discounted cost of this project for 2011–2036 in ¢/kWh (2011 dollars) (R-3756-2011; Application for approval to build a new diesel-fired power station in Akulivik), the Distributor presents a table establishing this value at 48.7¢/kWh (2011 dollars). According to the information provided with this table, this value essentially corresponds to the investments only. That is, 48.7¢/kWh leaves out the fuel cost, typically the largest component of the operating costs for a diesel-fired power plant.

Factoring in the 1.7 million litres of fuel saved as a result of the improved efficiency of the new plant over the period 2016–2036, the Distributor (in the scenario it proposes for Akulivik) will still, according to our calculation, have to purchase around 25 million litres of fuel over this period (assuming an all-diesel scenario). These purchases will cost about \$57 million in total (in current dollars for comparability with the fuel cost forecast provided by the Distributor), corresponding to around \$30 million present value (in 2011 dollars but for commissioning in 2016). In the table mentioned above, the Distributor announces fuel purchase savings of \$2 million (2011 dollars) directly associated with the improved efficiency of the diesel gensets over the life of the project. This is certainly a step in the right direction, but it cannot hide the fact of a continually increasing annual operating deficit caused by the rising costs which the Distributor projects. A very different approach is needed to counter the longer-term effects of this inexorable market trend – a trend over which the Distributor has no control.

Since fuel makes up a sizeable and growing share of avoided costs as defined by the Distributor and recognized by the Régie, it is perfectly clear that without radical changes in the planning and operating practices that typify current decision-making processes, the accrued deficit on the autonomous grids will continue to grow without cease.

But the wind-diesel projects ongoing in various North American communities, notably in Alaska, and involving a variety of grid architectures operated in accordance with innovative operating modes, lead one to believe that it is possible not only to alter the course of things in this area, but also to realize considerable savings when all is said and done. The Distributor's efforts to improve the efficiency of its diesel gensets are laudable, no doubt, but the real gains have to be made now using methods for reducing fuel consumption that take advantage of all locally available energy potentials.

[Legend:]

Operating deficit for autonomous grids, 2005–2010

(for 2011, the amount is a projection)

Annual deficit (in million current dollars)

Year

Source: ref. (xii)

If the Distributor has the will to reverse the trend towards marked growth in the deficit for the autonomous grids, which trend is clear for all to see, then it is absolutely essential to change course on planning and design engineering practices for these grids. These changes are difficult, to be sure, but they are not impossible – as the projects described in this report concretely attest.

#### **4.1. Akulivik: *planning to grow the operating deficit?***

To conclude this argument about the need to stem the growth in the Distributor's operating deficit for the autonomous grids, we believe that the idea of building a new power station such as the one proposed by the Distributor for Akulivik represents an investment whose opportunity cost has to be taken into account. There are decisions that bind society, for good or ill, to a future course. These decisions demand that engineering options be analyzed from now on in a manner that gives preponderant weight to the matching of energy requirements. The power requirements argument remains valid, to be sure, but the question is how to meet them – and answering that question forces us to review options other than augmenting our diesel generation capacity. Yet the Distributor, in its application to the Régie (ref. (iv), R-3756-2011), provides no other justification for what it is proposing.

The case of Akulivik raises several fundamental questions in this regard. We submit to the Régie that it is indispensable to consider the fundamentals when contemplating the phenomenal increase in costs and operating

deficits that the Distributor's proposal presages for this Nunavik community. We believe that the exact same difficulties will arise everywhere in Nunavik. Therefore, it is relevant to consider the key facts of the case at hand as they relate to the supply plan for these grids.

The investment under consideration has a total discounted cost of \$35.2 million (2010 dollars), giving rise to operational capacity of 1148 kW versus requirements of 800 kW in 2020 (iii). The outcome is an estimated capital investment of \$30,000/kW (operational base of 1148 kW). If the investment is taken instead to apply to the 800-kW projected power requirement, then the result is \$44,000/kW. If this cost is applied to the Distributor's Akulivik customer base (252 residential and agricultural customers in 2020, according to the forecast given in Table A-7.2.1.A of Appendix 7, ref. (x), p. 47), the result is an investment of \$175,000 per customer to install new capacity. All one has to do is transpose this nominal investment to the scale of the integrated system for everyone to agree on the absolute need to find creative solutions that can satisfy the power reliability criterion at a lower cost.

And we also have to consider operating costs. Just the fuel portion of the avoided energy cost, calculated on a nominal basis from the Distributor's figures (3.38 GWh in 2016, 223 customers, 3.76 kWh/l, \$1.46/l), leads to a recurring annual cost of about \$6000<sub>2016</sub> per customer for fuel alone.

Imagine now that this money, instead of being spent on fuel year after year, is invested in an energy system in which energy efficiency, active demand-side management, and optimum use of local energy sources are integrated into design and planning requirements with a view to maximally reducing fuel purchases in the community.

The financial parameters of the Akulivik project, as provided by the Distributor (iv), including a long-term discount rate of 5.913% (consisting of 35% equity at 7.849% and 65% debt at 4.870%, operation over 25 years) correspond to a present value factor of 12.89. Ignoring for a moment the residual value of the assets making up this new energy infrastructure, we would have an engineering project with a nominal total discounted cost slightly less than \$77 000 per customer, or approximately \$15 million<sub>2016</sub>. We think a capital investment of this magnitude constitutes a powerful incentive for finding innovative planning and operating practices for the autonomous grids. This avoided fuel cost alone justifies a detailed consideration of alternative projects for these grids. If half of this amount were devoted to investments that would recurrently halve the fuel consumption entailed by the all-diesel option, we would already be on the road to a viable long-term energy future. And in fact the Distributor, in the table of potential CO2 emission reductions for Akulivik at the 2020 horizon (reference (vii), p. 29 of 43), appears to acknowledge this percentage as a realistic target.

It is obvious to us that, as the magnitude of the capital investments and the fuel costs implied by the Distributor's proposal for Akulivik becomes clear, it becomes imperative to give diligent consideration to solutions that can keep the operating budgets for the autonomous grids within reasonable bounds over time.

It does not appear that the Distributor, in the types of project engineering it currently prefers, is taking advantage of the supply- and demand-side management potential offered by hybrid grids and technologies such as

those presented in this report. Yet today, these technologies offer tangible alternatives that are conducive to far more innovative approaches to planning for the power reliability criterion. These technologies offer the prospect of bringing the long-term operating deficit under control.

#### 4.1. History of wind-diesel systems for the Akulivik autonomous grid: 1995–2011

We conclude this section, which calls on the Distributor to reconsider its approach to planning for the autonomous grids, by reviewing the case of the village of Akulivik from 1995 to date, starting from an observation appearing in the report of the working group in reference (v), p. 3, concerning the review of energy alternatives for Akulivik. “For the time being, the diesel option is the only preferable option for this village. However, the wind option seems likely to show promise within a decade.” In 1995, the Akulivik site had a wind resource of comparable quality to that of Umiujaq. The working group found Akulivik to be the second-most promising site (after Quaataq) for a wind-diesel implementation.<sup>4</sup>

Reference (ii) indicates that the 2004 update on the Akulivik wind-diesel project indicated that there would be a marginal return on such an investment (\$28,000 NPV for a \$3.33 million<sub>2004</sub> investment, with 6,045,000 l of avoided fuel consumption over 20 years in a scenario where fuel cost remained stable at \$0.71<sub>2003</sub>/l over the entire period analyzed, i.e. 2005–2024) and confirmed the quality of the wind resource at the site.

Reference (i) contains the 2008 update for all the Nunavik villages served by the Distributor. For Akulivik, the investment is much more attractive: NPV of \$239,000 (at 4.8% ROI) on a total investment of \$5.97 million. While this is still a modest return, it is realized now in a scenario where the investment cost has risen by 80% with respect to 2003. Clearly, then, because of the significant increase in fuel costs (\$1.15<sub>2008</sub>/l, plus 3% anticipated annual growth) in the updated economic analysis for this village, the fuel savings over the 20-year period analyzed more than cancel out the factors that have increased capital cost since 2003 (roads, lines, machine costs, sizable decline in wind potential).

Of note here is that the Distributor’s most recent (2011) forecast for Akulivik in reference (iii) acknowledges a 33% anticipated annual increase in fuel costs with respect to the cost used in the 2008 calculation. This phenomenon of accelerating fuel cost increases militates in favor of a radical change in how the development of the autonomous grids is planned. Anyone can see that the fundamentals of petroleum supply

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<sup>4</sup> Quaataq: In its report, the working group (v) identified the Quaataq project as the one with the lowest risk for HQ’s first wind-diesel implementation. The conclusion of the report clarified this choice as follows: “The project to begin with is certainly the Quaataq wind-diesel project. The main reasons why are the research maintenance costs, the low cost and small scale of the project and, finally, the possibility of quick delivery.” The report (v) concludes: “It should be kept in mind that, once acquired, this expertise will be exportable, serving the best interests of HQ and Québec society.

are now and will continue to be contingent on a level of geopolitical volatility that confounds even the most experienced analysts of these markets.

These major changes in the Distributor's fuel cost forecast since the 2004 update are such that if they were to be retroactively applied to the Akulivik project in its 2003 version, they alone would have yielded additional NPV on the same order of magnitude as the total investment cost associated with the project in 2003!

What this means is that the marked exacerbation of the financial risks associated with fuel supply in the autonomous grids calls for an immediate reorientation of the entire engineering process towards an approach favoring the use of local energy resources with a view to maximally reducing dependence on increasingly costly fuel. It forces us now to emphasize massive reductions in fuel consumption when planning energy infrastructure for the autonomous grids. What it also means is that to stick to the status quo when planning for the autonomous grids is the surest recipe for the most dire cost increases imaginable. Finally, it means unfortunately that with energy demand on the rise, the more this necessary change is postponed, the more the operating deficit for the autonomous grids will increase.

It would be irresponsible to refrain from making the immediate and extensive efforts necessary to set this new course and completely rethink the planning and operational rules applicable to the autonomous grids. We must invest in alternatives to fuel consumption without delay. We believe that rising fuel prices should be seen as an urgent inducement to overhaul the planning of power generation for the purposes of projects to be implemented on the autonomous grids.

We submit that this observation, based as it is on a strict analysis of the relevant costs, is an unassailable assessment of what is needed for the autonomous grids.

#### ***4.2. Opportunity costs in Nunavik: the case of Akulivik***

The Distributor's application to build a new power station in Akulivik at a cost of \$35.2 million<sub>2010</sub><sup>5</sup> depreciated over the years 2010–2036 constitutes a major investment in this community. The Distributor's own projections confirm that to maintain the diesel status quo in Akulivik at this time – even with the marginal savings to be derived from the higher efficiency of the new diesel gensets – would be to lock the autonomous grids into a cycle of uncontrollably rising deficits.

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<sup>5</sup> In year 1 after commissioning (2016), the total discounted investment cost of the new facility reached \$37.3 million<sub>2010</sub>. The residual value of the plant in 2036, estimated by the Distributor at \$5.267 million<sub>2010</sub> (\$21.96 million<sub>2036</sub>), brings the total discounted cost to \$35.2 million.

Region	Power class	Grid	2008 peaks (kW)	Mean wind speed at 10 m (m/s)	Initial penetration (%)	Investment - wind/diesel installation (x \$1000)	Optimal NPV (x \$1000)	ROI at optimal NPV (%)	Benefit - cost
Nunavik	Small								
	Medium								
	Large								

We wish to draw the Régie's attention to a key aspect of the financial equation being played out in Akulivik that concerns the opportunity costs of wind-diesel: according to the last update (from 2008; ref. (i), Table 2, p. 5) on wind-diesel prospects for Nunavik, Akulivik is the only one of the nine Nunavik villages classed under 1 MW to still offer a potential return on investment (the 2003 study identified a total of five, with Akulivik just making the cut; ref. (iii), Table 10, p. 30). It is important to reiterate here that Umiujaq, the village with the best wind resource (along with Akulivik), as identified in the conclusions of the Laflamme report of 1996 (ref. (v), p. 47), fell off the wind-diesel radar screen in the wake of the 2008 wind-diesel analysis (ref(i)).

According to the trend indicated by these analyses, done over a 12-year period, the construction of a new diesel-fired power station in Akulivik could indeed send the signal that technological improvements are impossible for this power class. In view of the continual growth in the Distributor's operating deficits for the autonomous grids, we regard this prospect as having grave implications.

We submit to the Régie that in this context, the very concept of return on shareholder's equity in an all-diesel status quo scenario for the autonomous grids would be the height of financial absurdity. We believe that the experiences presented in this report concretely illustrate that it is indeed possible to do things differently, at a lower cost, and with no energy security consequences for the customers.

#### **4.3. Akulivik: the technical and economic stakes**

A reading of the statements contained in the Distributor's application to build a new power station in Akulivik leads one to wonder about the Distributor's attitude towards generation alternatives for the autonomous grids.

A second Nunavik wind-diesel pilot project is still planned for Akulivik. The ultimate purpose of the pilot projects is to implement wind-diesel in those Nunavik communities where an economic benefit is foreseen (vii, p. 25 of 43, l. 14–16).



Based on the results of the pilot projects in Akulivik and Kangiqsualujjuaq, the Distributor will in due course implement wind-diesel in those autonomous grids of Nunavik where it is economically advantageous to do so, provided such projects are favourably received by the communities in question (vii, p. 27 of 43, l. 11–14).

A demand reduction program was considered but not retained, since it would not have served to postpone additions of capacity to the Akulivik power station. This community heats with fuel oil and has no major dispatchable loads. The analysis of demand reduction measures will, however, be presented as part of the application for approval of a new thermal power station in Akulivik. (vii, pp. 34–5 of 43).

(Note: Concerning this last excerpt, the Distributor will clarify the scope of these “demand reduction measures” in February 2011 in the context of application R-3756-2011: “the existing rate scheme discourages the use of electricity for space and water heating... there is no significant potential for measures relating to these uses, nor for electricity consumption management measures or other efficient energy use measures. The residual potential for energy savings is covered by the Distributor’s programs. The impact of these programs is already included in the demand forecast for the territory. It is, however, insufficient to postpone or significantly reduce the additional power requirements of the Akulivik station. Thus, the implementation of new programs in due course has no influence over the Distributor’s decision to build a new plant” (iii, p. 8, l. 10–16 and p. 9, l. 1–8)).

At the 2013 horizon, the Distributor will pursue the steps taken to implement two wind-diesel pilot projects in Kangiqsualujjuaq and Akulivik.... The wind-diesel pilot project in Akulivik will be launched at the right time to bring it on stream one year after the arrival of the new power station. This strategy lessens the risks associated with the commissioning of the two projects. The power station will be fully functional before the arrival of the wind pilot project. Given these considerations, it is planned to bring the Akulivik wind-diesel pilot project on stream no earlier than 2016 (vii, p. 36 of 43, l. 8–15).

Moreover, the Distributor, having been approached by the community of Inukjuak, is in discussions with the Pituvik Landholding Corporation for a project to purchase energy from an 8-MW hydroelectric facility. If this project goes ahead, the existing thermal power station should be kept in cold reserve in order to fulfil the reliability criterion (vii, p. 36, l. 16–20).

The Inukjuak hydro project would replace the entirety of the thermal power produced by the existing power station (vii, p. 28, l. 19–20).

At the 2020 horizon: Including the projects planned for the 2013 horizon, more than half the existing power stations will need to increase their power by 2020 in order to meet customer requirements, even if the energy efficiency programs and deterrent pricing schemes are maintained. Capacity will have to be added at Inukjuak, Kangiqsualujjuaq, Kangiqsujuak, Kangirsuk, Puvirnituq, Salluit, Tasiujaq, and Umiujaq (vii, p. 36, l. 24–6).

The tone of these statements corroborates the reality of the small-steps strategy that emerges from an analysis of the Distributor’s decisions with respect to wind-diesel over the last 15 years or more (in this regard, see also Appendix 1 of this report: “Chronology of Hydro-Québec’s experience with wind-diesel systems, 1986–2011”).

As far it is possible to determine from the exhibits submitted by the Distributor, the Akulivik project exhibits all the unfortunate characteristics of technological inertia. Rather than heeding the dictates of technological innovation and embarking on a forward-looking planning process, one in which Akulivik points the way along what has become an unavoidable new learning curve, the Distributor clearly states its intention to postpone the wind-diesel integration presaged in the “pilot” phase until 2016 at the earliest.

In the Distributor’s current planning process for the autonomous grids, one has to wonder whether the Distributor has the will to work diligently to reduce the risk of rapidly accelerating operating deficits linked to foreseeable volatility in fuel costs. We contend that the case of the Akulivik power station constitutes a groundless refusal to come to terms with the natural technological evolution observed in the planning of power distribution for autonomous grids, and in fact for the integrated system as well.

Doesn’t the conception of the Akulivik project as a technological showcase for HP wind represent an opportunity for technological leadership of which the Distributor can take advantage at a lower cost than the scenario it proposes?

Even if only the avoided fuel cost is included as a first approximation, shouldn’t distributed self-generation technologies for residential power in Nunavik be given similarly favourable economic treatment to that of the self-generation program in effect for the integrated system? Considering the lessons that the Distributor has learned through the administration of this program on the integrated system (where its lack of success is clearly tied to poor prospects for economic viability due to insufficient avoided costs), it can readily be granted that projects unviable on the integrated system could easily become viable on the autonomous grids. These are the questions we think the Distributor has to answer today.

The obligation to carry out detailed design work for these options would help rebuild the planning practices guide for the autonomous grids and set the table for the technological evolution that must take place in the engineering of all energy projects for these grids. It would seem that the Distributor implicitly recognizes the feasibility of this evolution in the case of the hydro option under discussion in Inukjuak (see Appendix 1 and ref. 3, pp. 14–15), but that it has so far failed to exhibit similar open-mindedness with regard to wind-diesel projects, without adducing any valid technical or operational grounds for such special treatment.

On the basis of the avoided cost criterion (ref. (ix), p. 11 and table on p. 12 of 21), hasn’t the active search for options for Nunavik become the only credible guarantee of long-term energy security? Wouldn’t it be completely justified to send this very signal in a case where the Régie is set to rule on the most prudent investment options for Nunavik in the coming years? We believe that the Régie’s decision will have major repercussions in terms of the signal it sends about the direction it intends to impart to efforts to reverse the trend of inexorably rising rates, given the imminent growth in the operating deficit for the autonomous grids and the structural inertia characteristic of the Distributor’s engineering projects.

In view of the successful projects documented in this report, we firmly believe that a new technical/economic course must be charted without delay.

## **5. Observations and recommendations on wind-diesel systems**

### **5.1. Observations**

The planning done for the autonomous grids shows the signs of technological inertia. The power reliability criterion is leading to investments in diesel-fired equipment that constitute structural barriers to the necessary technological transition towards wind-diesel systems in Nunavik.

These massive investments in diesel-fired power stations remain in thrall to the all-diesel paradigm and are feeding into structural increases in the operating deficit (see the arguments put forward in the application to build the Akulivik diesel-fired power station, R3756-2011).

The Distributor gives every sign of having abdicated its responsibilities as a planner vis-à-vis the technological advances needed to provide for long-term control over the operating deficits on the autonomous grids. It does so by putting forward the idea that the rate policies in effect for the autonomous grids are somehow sacrosanct.

Yet there are proven, risk-free technological solutions by which the necessary transformation can be effected. We submit to the Régie that major structural biases are the reason why the Distributor's decision-making processes have given rise to year upon year of diesel-based investment proposals, and that if nothing is done to remedy the problem, these biases will lock the autonomous grids into a cycle of skyrocketing operating deficits – a development that is clearly already well underway.

Solutions to be implemented:

A much more aggressive HP wind-diesel approach, one that is committed to making use of advanced, commercially available technology (advanced metering, IP, LAN, WAN, IP-based relay control, SCADA, distributed or centralized digitally controlled heating modules, storage modules via VÉ, diesel gensets that can be operated from zero to full load, etc.) and aims for a massive reduction in fuel consumption on the autonomous grids:

Advantages of this strategy:

- Enhances energy security (wind generation).
- Greatly reduces fossil fuel consumption (use of surplus wind power).
- Stabilizes energy prices; controls and caps the operating deficit.
- Alleviates GG emissions and oil spill risks.

Makes optimal use of distribution infrastructure and increases the operating reserve.

Provides for operational flexibility: dump load, optimization of diesel operation plan, peak limiting, load anticipation and shifting.

## **5.2. Recommendations**

**In light of the fuel cost-related information provided in the Akulivik case, among other items, RNCREQ recommends that the Régie ask the Distributor to update the report on wind-diesel for the Nunavik and Îles-de-la-Madeleine grids.**

**Depending on the results of this update, the Régie should then ask the Distributor to lay out a strategy for the deployment of HP wind-diesel technology in the autonomous grids with a view to greatly reducing fuel consumption and keeping the looming operating deficit for the autonomous grids from spiraling out of control. RNCREQ suggests that the Régie ask the Distributor to submit this strategy for approval by the Régie before the end of 2011.**

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## Appendix 1: Chronology of Hydro-Québec's experience with wind-diesel systems, 1986–2002

For the first time in 1986, the concept of high-penetration no-storage wind-diesel (HPNSWD) systems was identified by the Institut de Recherche d'Hydro-Québec (IREQ) as a promising energy supply scenario for customers not connected to the integrated system. In November 1986, Hydro-Québec erected the 65-kW BONUS wind turbine in Kuujuaq. The purpose of the project was to demonstrate the feasibility of bringing a commercial wind turbine on stream in fuel saver mode on a diesel-based northern grid. The project was part of a broader focus on diversifying energy sources for the isolated grids. The monitoring program met the targets and the turbine's availability was 98% in its first year of service.

The course taken by HPNSWD systems at Hydro-Québec has been inflected by numerous changes since 1988 in terms of the administrative responsibility for RD&D on the isolated grids where this technology applies.

Between 1986 and 1995, four project mandates were carried out. It should moreover be noted that the project has, since its beginnings, taken place within the operational framework of the client-supplier approach, which meant a tightly controlled RD&D context in terms of project management and the mandates obtained. The work on wind-diesel systems has been presented in the context of numerous conferences, publications, and reports.

In 1988, the power generation sector roundtable recommended that wind turbines be made a technological development priority for the isolated grids served by Hydro-Québec. From 1990 to December 1994, the internal budgets for the project came successively from the VPPR of the Infrastructure Group and the Grid and Infrastructure Planning Branch, a division of the head office (DPRÉ by its French acronym).

After initial evidence obtained by IREQ in October 1990 demonstrated the technical feasibility of the HPNSWD scenario, it gradually became necessary to demonstrate the technology at a realistic scale. Starting in the summer of 1992, the project began moving towards this new goal with the inauguration of a fruitful collaboration with the Atlantic Wind Test Site (AWTS) on Prince Edward Island.

At the time of its approval in 1992, this project aimed to develop and demonstrate a representative HPNSWD system for a typical village on an isolated grid. The project was found to respond adequately to the concerns of the Montmorency region in terms of demonstration, training, and expertise. It offered high added value since it was carried out with contributions from the staff and equipment of AWTS and on a shared-cost basis between HQ and Natural Resources Canada. A collaborative project to be carried out with AWTS was prepared and NRCan guaranteed financial support to the project, which was consistent with national wind energy priorities. The collaborative project was approved in a recommendation to the Executive Vice-President, Planning in



August 1992. NRCan also announced its involvement by purchasing a wind turbine for installation at AWTS and covering the costs incurred by AWTS when it made major modifications to the diesel gensets it had recovered from a previous project in Sudbury (Indal Technologies), for which new specifications had been established by IREQ.

From 1992 on, the project was carried out in close collaboration with AWTS and sponsored by Natural Resources Canada and the VPPR of the Infrastructure Group. In the spring of 1994, the VPPR was reorganized to become the DPRÉ, and the outcome was to transfer the HPNSWD file to the Montmorency region. Responsibility for the isolated grids was transferred to the Matapédia region shortly afterward. This grouping of HQ's activities concerning the autonomous grids led to the creation of the Gaspé Peninsula and Autonomous Grids sector (GRA by its French acronym), which reported to the Matapédia region and was headquartered in Gaspé. As of 1 June 1994, then, technology budgeting for wind-diesel systems came under the responsibility of the GRA sector.

The full-scale demonstration of HPNSWD by the IREQ team was successfully completed in 1994 at ATWS. This success was officially recognized and celebrated at the AWEA/CanWEA wind-diesel symposium in June 1994 on Prince Edward island, in the presence of delegates from around the world.

At the same time, a HPNSWD steering committee was struck by the Matapédia Division, which was responsible for power supply to the autonomous grids of Québec. The committee was made up of representatives from the Montmorency region, the Boreal sector (which became GRA), the Purchasing Branch, the Technology Division and IREQ, the Environment and Communities Division, the Private Generation Branch, and the Matapédia region. A technical/economic feasibility study of HPNSWD systems developed by IREQ was carried out from September 1994 to January 1996 by this working group, spearheaded by the planning group for the Montmorency region. The committee's recommendations clearly established the technical feasibility and economic viability of this option for the autonomous grids. Subsequently, the committee's mandate was enlarged to encompass a review of hydro or wind alternatives for the 14 northern villages. This study was completed in January 1996 (ref. (vi) of the "References" section of this report). The committee concluded that wind-diesel technology was viable for 8 of the 14 villages of Nouveau-Québec served by Hydro-Québec and proposed that Quaqtaq be chosen for a pilot project to start the implementation of the technology throughout the autonomous grids of Nouveau-Quebec.

The report included a recommendation to the working group's steering committee to carry out this first project. In late April 1996, this recommendation was rejected by the Matapédia region, which transferred responsibility for the file to the Generation Planning Division of the Generation and Transmission group. This decision included a recommendation to produce a master plan for the entire wind power file at Hydro-Québec. The recommendation was to be followed ("but not before 1997," as per the decision) by a reactivation of the Quaqtaq project. A new pre-feasibility study was produced by the Planning Group of the Hydro-Québec Infrastructure Group in 1998; this study concluded that the capital cost would be 2.7 times higher than the cost estimated by the steering committee in the HPNSWD file created in 1994.

In 1999, the first commercial installation of a HPNSWD system was brought on stream by Northern Power

Systems (NPS), an American turnkey contractor mandated by TDX Corporation of St. Paul Island, Alaska (Bering Sea). IREQ, under a collaboration agreement with NPS, acted as a business partner for the design aspects, the modeling needed to size the St. Paul Island HPNSWD system, and by supplying the load-frequency regulator required to allow the system to operate in either wind-diesel or wind-only mode. This system is still operational today and has never been the object of any recalls since it came on stream.<sup>6</sup>

In the wake of this first commercial project, it seemed justifiable to revise the cost estimate for the Quaqtaq project by the Planning Group of the Infrastructure Group with reference to the new economic facts to be derived from the St. Paul Island HPNSWD project. This study, sponsored by the Grids (Distribution) Division, was commissioned from NPS and completed in August 2001. The NPS study implicitly confirmed that the 1995 recommendation by the working group on the technical/economic feasibility of HPNSWD for the autonomous grids of Québec was still valid six years later. The analysis of the study and the recommended follow-up to it were presented to the client (VPR – HQ-Distribution) in a report delivered in August 2001.

In May 2002, the Operations Core Group of the Distribution Platform (the HQD-IREQ decision-making body resulting from a restructuring of the supervisory frameworks for the execution of RD&D projects and given responsibility for ensuring compatibility between the objectives of IREQ's projects and the strategies of the Hydro-Québec business units), requested a presentation on the proposed follow-up plan for this dossier at HQ.

Further to this presentation, the Operations Core Group asked for an update of the economic study done in 1995 by the working group headed by J.-P. Laflamme in light of the results of the 2001 NPS study, giving consideration to two types of wind turbines and different levels of wind penetration. This update showed that there would be a potential economic benefit to be derived in six communities. The presentation of these results at the Hydro-Québec Distribution Grid Innovation Platform in December 2003 included two recommendations: a wind speed measurement program in the three most promising villages (Inukjuak, Kuujuaapik, and Kangisualujuaq) and the preparation of a call for tenders deliverable in March 2005 for an initial wind-diesel project (estimated cost of Inukjuak project: \$8.04 million; NPV: \$2.5 million).

In December 2003, an economic pre-feasibility study of a wind-diesel scenario for the Îles-de-la-Madeleine grid was commissioned from IREQ by the Autonomous Grids Branch (DRRA). The ensuing report, delivered in February 2004, concluded that an optimal project would comprise 29.7 MW of wind capacity at a cost of \$73 million with a NPV of \$6 million (\$16 million assuming a value could be placed on the GG reduction credits, and \$20 million if 20% of the capital cost were funded under the federal Technology Early Action Measures program). Interest in the wind projects was clearly expressed by several community economic actors (in Nunavik and IDLM) in 2004 and 2005, when several specific partnership requests and service offers were submitted to the DRRA.

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<sup>6</sup> Information confirmed in April 2011 in a private communication with J. Coleman, former CEO OF NPS.

In May 2005, the DRRA was weighing three approaches to the implementation of the wind-diesel projects proposed for Inukjuak and Îles-de-la-Madeleine: 1) HQD as general contractor, 2) HQD purchasing energy from a private generator, or 3) HQD in a public-private partnership (PPP). The second and third options were fraught with difficulties at that time since Bill 116 does not allow the DRRA to purchase energy from a private generator, much less to enter into a partnership with such a generator. An amendment to Bill 116 would require the validation of HQD's exclusive right to supply electricity.

In June 2005, the DRRA 1) commenced work on a new wind-diesel project on Île d'Entrée (IDLM) as a pilot phase of a preliminary stage in the implementation of the Inukjuak project, and 2) put out a call for tenders for wind speed data collection on the site in question. The Île d'Entrée project was abandoned in June 2006 after it failed to obtain support from the local community. The population of Îles-de-la-Madeleine was then consulted on wind energy development in March 2007.

In 2007, the Pituvik Landholding Corporation (Innavik project, <http://www.innavik.com/>) commissioned a pre-feasibility study for a run-of-the-river hydro project (8 MW, 2 turbines) in Inukjuak from the firm RSW Inc. The project, costing over a period of 20 years, aims to meet the entirety of the community's basic power requirements, with the surplus power used to satisfy a large proportion of heating demand ("80 to 50%"). The information available for the construction of the facility (without 25-kV 10-km line, without reinforcement of the distribution grid, without modification of the centralized control system, and without the modifications necessary for dual-energy operation of customer-owned fuel heating systems) yields an investment cost of \$48–80 million, corresponding to a unit power generation cost of 30–75¢/kWh (ref. 3, p. 7) and fuel savings of up to 2.45 million litres annually (ref. 3, p. 15). Based on the Distributor's fuel cost forecast for Nunavik ((iii), p. 19, l. 13–14), this represents monetary savings of \$3.55 million<sub>2016</sub>.

The project to install 5 MW of wind energy in Îles-de-la-Madeleine in "fuel saver" mode is planned for 2011. Since these are modern commercial wind turbines comparable to the one currently being installed in the integrated system, the Distributor plans to sign a contract to purchase wind energy with a generator who will potentially be involved in a partnership with the community. The generator (and the community, if it is involved) would be the owner of the wind park while the Distributor would own the wind-diesel system. Hydro-Québec put out a call for pre-selection of submissions (call for submissions no. 13369333) for the study and implementation of a wind-diesel system in conjunction with a 5 MW facility in Îles-de-la-Madeleine (peak demand of 40 MW, annual consumption of 182 GWh in 2010, anticipated mean annual growth of 1.3%) in February 2010. The wind park is to come on stream in 2013.

Hydro-Québec put out a call for pre-selection of submissions (call for submissions no. 13369204) for the study and implementation of a wind-diesel system in conjunction with a 600–700 kW facility in Kangiqsualujjuaq (peak demand of 750 kW, consumption of 4 GWh in 2010, anticipated mean annual growth of 2%) in March 2010. The wind park is to come on stream in 2013.

As of April 2011, the business model selected by the Distributor for wind-diesel in the autonomous grids

is as follows:

The Distributor has defined the business model for wind energy in Nunavik, which is different from the model applicable to Îles-de-la-Madeleine. For Nunavik, the Distributor will own the wind park and the wind-diesel system. This decision is justified by several factors, such as remoteness, logistical difficulties, small grid size, and the use of lower-capacity wind turbines than on the integrated system. These factors narrow the profit margin and lessen the attractiveness of these projects to prospective developers. In this context, the Distributor seeks to work with a firm that is experienced with this type of project. The Distributor thus issued a call for submissions, followed by a call for proposals with a view to selecting an experienced firm that can contribute to the success of northern wind projects. The successful candidate firm will be known by the end of 2010. This firm will be in charge of the design, delivery, and installation of the wind-diesel system and the wind park, as per the contents of its proposal. The competing firms are the same ones that submitted proposals for the Îles-de-la-Madeleine wind-diesel project (viii, p. 35, l. 12–25).

Photo: Wind park on St. Paul Island, Alaska

Photo: Wind park on St. Paul Island, Alaska