

PHOTOVOLTAIC NOISE BARRIER – CANADA

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ABSTRACT: Photovoltaic noise barriers (PVNB) have been in use in Europe since 1989. Thus far, in Canada, despite a massive transport system and a high per capita use of vehicles, no building integrated photovoltaic projects of this type have been undertaken. This paper discusses various issues that affect the potential for uptake of PVNB within Ontario's provincial highway system. Provincial highway infrastructure is categorized according to orientation, estimates are made regarding the placement of existing noise barriers and the potential for PVNB retrofit or replacement projects, as part of this existing infrastructure base, is explored. Solar radiation is calculated for various tilts and azimuths and results on potential energy yields are presented. Boundary conditions, in respect of issues such as standards and policy, are evaluated in an effort to understand better the prospects for PVNB implementation. This work, funded by the Ontario Ministry of Transport (MTO), will continue. It is hoped that the final report will provide the foundations for a future demonstration phase of PVNB technology at sites in Ontario and, eventually, throughout North America.

Keywords: PVNB, Grid-Connected, PV System, Evaluation

INTRODUCTION

Despite the environment benefits, the installation flexibility and the fast international growth over recent years, solar energy use through photovoltaic (PV) systems remains small in Canada with just 11 MW of potential installed (IEA, 2005). To get the benefits of photovoltaic electricity generation and make it more economically viable in short-term, it is necessary to find particular situations that give advantages to photovoltaics over other options of energy supply.

Solar energy generation using PV systems reaches its best potential within a decentralized structure offering advantages like low transmission losses or optimum utilization of local energy resources. In densely populated areas, distributed large scale electricity generation plants are possible through PV systems integrated in roofs, walls of commercial and industrial buildings, and through the integration of PV in new or existing sound barriers on the transportation system.

PV technologies on noise barriers have been demonstrated in Europe as a feasible application of renewable energy technology. In a building integrated context, PVNB adds the value of energy generation when it is incorporated into an existing structural component. These photovoltaic plants or systems combine the needs of clean energy with traffic noise mitigation. The PV can be installed on existing noise barriers, that serve as physical support for the PV modules and improving sound abatement, or it can be integrated with the structures of planned noise barriers. In the integration situation, there is the possibility of prefabrication of the PV and noise barrier substructures.

The objective of this study is to approximate the PVNB potential on highways under Ministry of Transportation of Ontario (MTO) responsibility. This work is funded by the MTO's 2004 Highway

Infrastructure Innovation Funding Program.

The estimations of the potential for PV in noise barrier applications in Ontario, reported in this paper, are based on the existing transport network and on the possibility of future retrofits or replacements. The analysis undertaken thus far in the project includes:

- A background study of the literature on PVNB technologies has been undertaken.
- Geographical Information Systems (GIS) software has been used to summarize and breakdown the provincial highway system into categories based on speed limit, annual average traffic volumes and road orientation. This information is used in estimating PVNB potential based on road suitability and design constraints.
- Solar radiation, according to tilt, azimuth and road orientation has been used to evaluate potential solar energy yields.
- Noise legislation for various jurisdictions has been compared and discussed.
- Safety issues and constraints emerging from noise barrier standards have been investigated.
- Some programs and incentives for renewables are presented to give an overview of the renewable energy policy situation in Ontario and Canada.

The following paper summarizes the analysis thus far.

BACKGROUND OF PVNB

The first photovoltaic plant on a noise barrier, shown in Figure 1, was installed in Switzerland in 1989 on an existing sound barrier structure along the A13 motorway in the Swiss Alps (Nordmann and Clavadetscher, 2004). It was a 100kWp plant funded by the Swiss National Energy Research and by the German Federal Ministry of Education, Science, Research and Technology, in a long-term Swiss/German project to explore this PV application. The integration of sound barriers and PV's was developed to improve the economic viability of PV.

Photovoltaics integrated to sound barriers save costs on the noise barrier side. Working as the sound abatement material, the support structure of the noise barrier can support the PV panels decreasing the BOS (Balance Of System) costs in PV installations. This added value cost saving improves the overall PV project feasibility.



Figure 1: PVNB along the A13 in Switzerland

Some others advantages of PVNB include:

- the double use of land resources - because the land on the edge of highways can be used for noise abatement and also to place the PV modules for electricity generation;

- the public perception of ownership and a community pride in having clean energy generation and a commitment to environmental preservation (Remmer,2004);
- easy access for installation and maintenance;
- the possibility of being close to densely populated and industrialized areas where both noise abatement needs and energy demand are high;
- being grid-connected systems, the use of batteries is not necessary, and
- environmentally friendly energy production resulting in associated improvements in air quality and reductions in greenhouse gas emissions.

In 1996, a competition for noise barrier designers was held in Germany and Switzerland resulting in the construction of six PVNB plants of 10kWp each. The prototypes were constructed to explore some aspects of noise abatement and energy generation such as sound absorption and reflection, and PV inclination. Figure 2 shows different configurations of PVNBs. The zigzag, cassette and shingles configuration have better sound absorption properties than the top mounted and vertical designs.

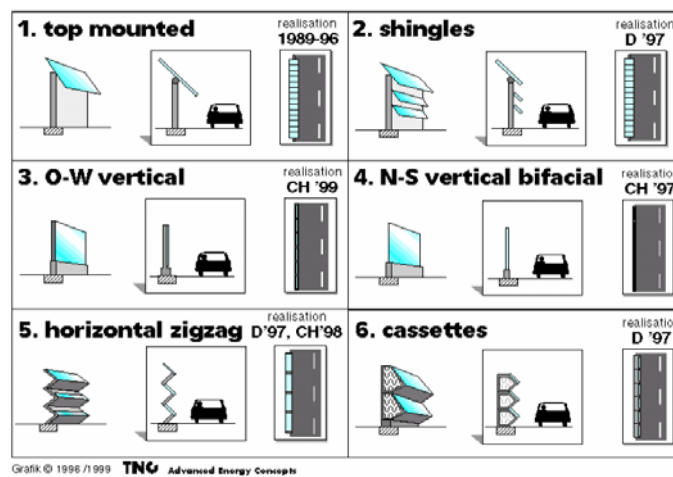


Figure 2: PVNB Designs and Realization Dates (Nordmann and Froelich, 2000).

Top mounted configurations are used to upgrade existing noise barriers. The noise abatement is best when the PV faces the road but the PV installation, in this case, is also limited by the free width needed along the highway.

Though there has been a low level of uptake, the shingles configuration is an inexpensive approach to retrofitting of existing barriers, particularly where improvements to the noise abatement levels are required. This configuration exhibits high sound absorptive qualities but the self shading effect must be considered during the PVNB design.

The bifacial configuration is designed to be used for a North-South road orientation. The bifacial modules are sensitive to solar radiation on both the front and back sides. In both bifacial and East/West vertical configurations, the photovoltaic modules can act as the structure of the wall to abate the noise and as a reflective noise barrier. Measurements of the noise reduction properties of the bifacial modules integrated with noise barriers have shown the same abatement levels as with previous levels of replaced noise barriers (Nordmann et. al, 1998).

The Zigzag and cassette configurations have experienced a high level of integration in the European context. Their excellent noise absorption qualities depend on the materials used and the inclination. In general, the PV modules can be tilted in a range from 35° to 75° depending on the site and the configuration applied. Good air ventilation has been shown to effect performance and energy production.

In some European countries, noise abatement is required by legislation thus contributing to the increase in new noise barrier installations and the potential for new PVNBs. At present, there are 850kWp of PVNB in operation in Europe, and an estimated generating capacity potential of approximately 800MWp or 680GWh of electricity per year (Nordmann and Clavadetscher , 2004).

ONTARIO HIGHWAY NETWORK

Transportation is a major contributor to greenhouse gas emissions in Canada, contributing to 28% of overall energy use and 67% of petroleum product consumption (NRCAN, 2005). The potential for the integration of photovoltaics (PV) into existing and proposed noise barriers in Ontario's provincial highway system is the focus of this paper.

The Canadian transportation network, including federal, provincial and municipal roads, has a length of 901,903 km, measured on a two-lane equivalent basis (Forman et al., 2003). The Ontario province has a transportation network with almost 15,000 km of provincial highways and 7 million road motor vehicles registered (Statistics Canada, 2005).

All Ontario roads, federal, provincial and municipal, are plotted on a GIS map. However, given the focus, only provincial roads are considered for this study.

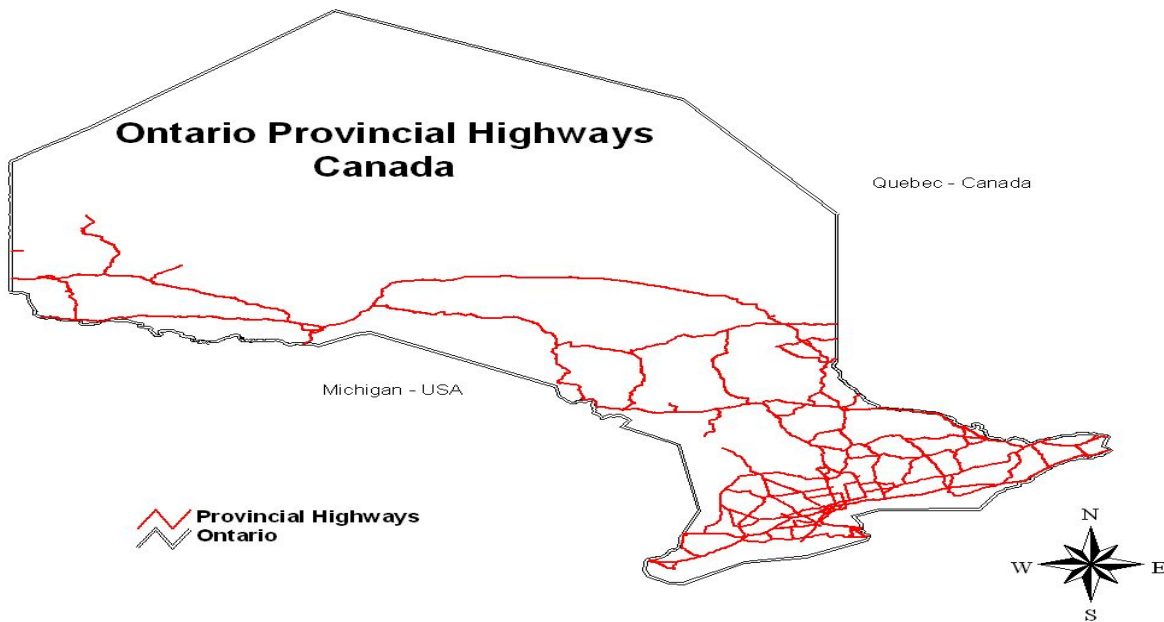


Figure 3: Ontario Provincial Highway Network

Figure 3 shows all provincial roads in Ontario and illustrates, by their distribution, the population densities in various parts of the province. As can be seen, population density and road concentration is highest in southern Ontario and, hence, the potential for noise barrier installations and for the retrofitting of existing noise barriers, is also highest in southern Ontario.

Figure 4 shows the roads in the south of the province that meet both the traffic noise and road orientation criteria set out in the following points:

- **Traffic noise:** The highways of southern Ontario connect the main cities of the province and in doing so pass through or close by many suburban communities. All roads shown in Figure 4 have an average annual daily traffic volumes ranging from 45,000 to 400,000, and a speed limit of 80 km/hour to 100 km/hour (MTO, DMTI Spacial, 2005). These roads, which include the Queen Elizabeth Way (QEW), 400, 401, 403, 404, 410, 417, 427, 6 and 7, have a total length of 3,720km.
- **Road Orientation:** Using the GIS software, roads are classified into three groupings; roads with an East–West orientation (EW); roads with either an South-East, North-East, South-West, or North-West orientation (SEW), and roads with a North-South (NS) orientation. The QEW, 401, 417, 427 and highway 7 have the best orientation for future implementation of PVNB.

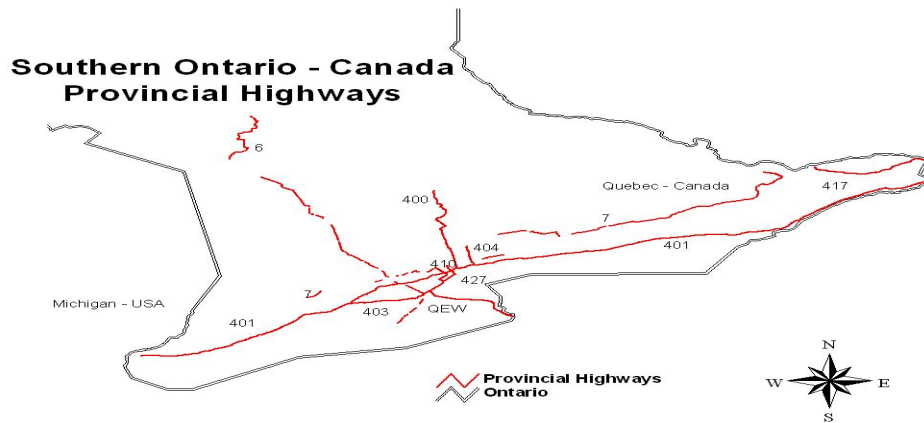


Figure 4: Provincial highways of Southern Ontario that meet both traffic noise and road orientation criteria for the implementation of PVNB

Figure 5 gives an overall summary of highway lengths broken down according to orientation. Percentages of total length are also illustrated and, later, used to fortify assumptions made regarding the PV generating potential of existing noise barriers.

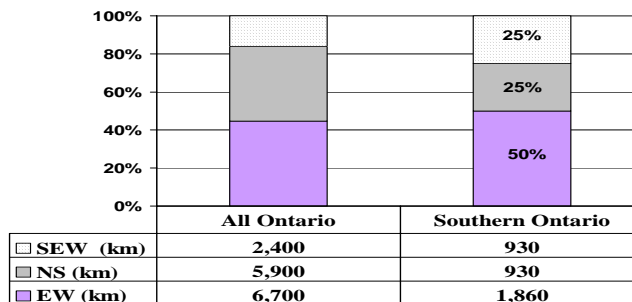


Figure 5: Provincial Ontario highway breakdown by orientation, length and percentage of total length

This separation of roads, by orientation, allows investigation of noise barrier design solutions, such as those shown in Figure 1:

- EW and SEW roads are best suited to the use of PV mounted on the noise barrier, either in a top-mounted or shingled configuration, and angled, in a southerly direction. These EW and SEW possibilities make up approximately 50% and 25%, respectively, of provincial highways in southern Ontario.
- Roads with a NS orientation may be able to incorporate bifacial PV technologies.

ESTIMATING THE POTENTIAL FOR PVNB BASED ON EXISTING INFRASTRUCTURE

In Ontario, there are currently 155 km of noise barriers along provincial highways. Every year, approximately 5 km of noise barriers are either constructed or replaced on the provincial highway network (MTO, 2004). A large percentage of noise barriers in Canada are made of concrete, and the rest are constructed using wood, earth mounds, or metal. Heights are generally in the 3 to 5 m range. As mentioned earlier in this paper, noise barriers can be designed to be reflective or sound-absorbent. When the roadway cross-sections are large without houses across the road from the noise barrier, multi-

reflection barriers are not a problem. In this case of reflective noise barriers, the sound-absorber layer is omitted and the sound properties are only related to the transparent substrate of the PV.

The MTO and University of Guelph (UofG) will be working together to establish a summary indicating the exact location and design of these 155 km of existing provincial noise barriers. This paper estimates the potential for PVNB based on the nearer term possibility that existing noise barriers may be retrofitted or replaced. The methodology may also be applied to other possibilities such as the 5 km per year of new construction along the provincial highway network. To calculate these estimates of potential the following steps are taken:

- the orientation and percentage breakdowns of Southern Ontario highways, shown in Figure 5, are used to, similarly, create the categories, orientation and length, for the 155 km of existing noise barriers.
- solar irradiance values, based on azimuth and tilt angles, are summarized in Figure 6. These values are used to determine the average annual irradiance reaching the surface of the PV.

ANNUAL IRRADIATION ESTIMATES FOR TORONTO, ONTARIO

Toronto is the major urban centre of southern Ontario. As such, suburban sprawl that necessitates the use of noise barriers spreads outward from Toronto. Estimates of annual solar irradiation for Toronto, over a range of tilt and azimuth angles, are summarized in Figure 5. These estimates are derived using the RETScreen® model for Photovoltaic projects.

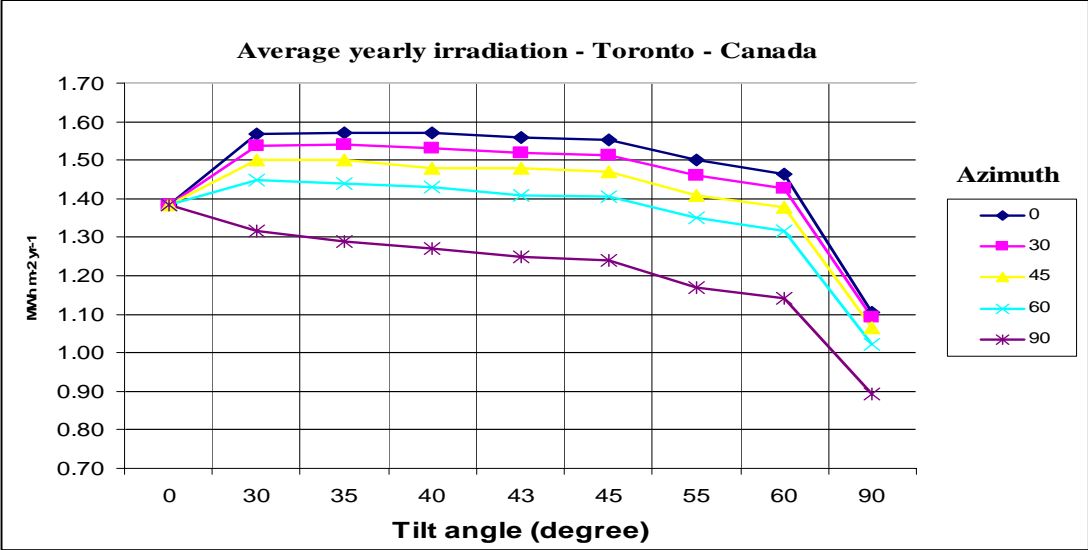


Figure 6: Average yearly irradiation on a tilted surface – Toronto, Ontario, Canada – latitude 43.7

As can be seen in Figure 6, the best PV module orientation is to the south (azimuth zero) at a tilt angle range between 30° to 45°. These tilt angles also help to avoid snow and dust accumulation on the panels. Values of average yearly irradiance are taken from Figure 6 for the azimuth angles relating to the road categories created: EW, azimuth angle of 0°; SEW, azimuth angle of 30°; N, azimuth angle of 90°. These values are summarized in Table I. The estimated energy yield for the 155 km of existing noise barriers is then calculated according to the following PVNB system design assumptions:

- For top-mounted and shingle designs, designs most easily implemented as retrofits to existing EW and SEW roads, an overall PV system efficiency of 11% is assumed. This assumption is conservative for now and does not take into consideration issues of performance and field experience. This will be the focus of work to come.

- Bifacial assumptions are based broadly on the work of Thomas Nordmann et al, and are taken from the paper, “First Experience with a Bifacial PV Noise Barrier” (Nordmann et al,2000).

The results summarized in Table I offer a conservative estimate of the potential for PVNB in Ontario based on existing noise barriers and, apart from the bifocal calculation, are not technology specific. Future work, undertaken for the MTO, will explore technology specific issues in detail.

| Road Orientation/Azimuth | Road Length (km) * | Average Irradiance in the Plane of the Array (MWh/m ² /yr) | PVNB Design | Estimated Energy Yield (GWh/yr) |
|--------------------------|--------------------|-----------------------------------------------------------------------|-------------|---------------------------------|
| EW/0 | 77.5 | 1.56 | Top mounted | 13.3 |
| | | | Shingles | 20 |
| SEW/30 | 38.75 | 1.53 | Top mounted | 6.5 |
| | | | Shingles | 9.8 |
| NS/90 | 38.75 | 0.9 | Bifacial | 5 |

Table I: PVNB potentials for existing noise barriers *calculated using (percentage of Southern Ontario roads with that orientation) x (total 155km of existing noise barriers)

BOUNDARY CONDITIONS FOR ONTARIO

Noise barrier legislation and standards, in combination with government support for renewables, effect the potential for uptake of PVNB. Given the slow inertia relating to such boundary issues, adequate attention will ensure that their development favors PVNB technologies. The following sections summarize the initial findings of this study.

Noise Pollution Legislation

Photovoltaic noise barriers depend on noise legislation and its enforcement. In Canada, “The Environment Protection Act” defines vibration and sound that can cause health “adverse effects” as a contaminant. Adverse effects are defined as harm or material discomfort to any person, or an adverse effect on the health of any person, or loss of enjoyment of normal use of property.

In Ontario, the provincial Ministry of Environment has created guidelines for noise control in land-use planning; Guideline LU-131. In this guideline, environment classes and noise limit levels are specified. There is also a specific directive issued by the MTO, called QST A-1, for the control of provincial highway noise and its effect on adjacent noise sensitive areas. The provincial government gives permission and assists municipalities in the creation and implementation of municipal plans and noise control by-laws to abate individual sources of noise.

Table II presents a summary of legislated noise pollution limits for a variety of jurisdictions. As can be seen in Table II, the Ontario acceptable noise levels are high compared to those limits set by some European countries (Urban Transport and the Environment, p.181). They are also higher than those specified by the World Health Organization (WHO). In general, noise standards for Ontario are set low, noise levels are high, and enforcement of the standards is weak. It is the case in all jurisdictions that levels of enforcement are weak. Greater levels of enforcement would lead to positive increases in noise barrier construction.

| Country | Residential Noise Levels |
|----------------|---------------------------------|
| Canada | 55 dBA |
| Germany | 49 dBA |
| Switzerland | 45 dBA |
| Netherlands | 40 dBA |
| WHO | 45 dBA |

Table II: Noise pollution Levels

In Ontario, noise levels are considered during the design and construction of new highways. But regulation protects existing highway infrastructure ahead of any new residential construction. This means that new residences or residential suburbs constructed close to highways and subject to high levels of noise may not request the province to construct noise barriers but must construct these themselves. This construction may be undertaken by the resident or the developer (Estrin, 2004).

Noise Barriers Standards

Quality properties of PVNB are not only evaluated by electrical or acoustical purposes, but also depend on safety, visual impact and maintenance (L.Schirone et al, 2003). Possible car crashes and fire propagation must be accounted for during the PVNB specification and design. Electrical safety concepts like extra low dc current increase the overall costs due to the need for decentralized module inverters.

The MTO is committed to quality and safety within its transportation network. Ontario’s highways are the safest in Canada and, according to statistics from 2002, second only to Massachusetts in North America (MTO, 2004). In 2004, there were 257 highway car crashes involving noise barriers in Ontario (accounting for 2% of all accidents involving fixed objects along highways). All potential costs and hazards associated with PV installation along highways will need to be carefully assessed ahead of implementation.

In Ontario, standards for noise barriers specifying acoustic, mechanical and safety requirements have been set by the MTO using standard SSP599F01. This standard, accessible from the MTO website, deals with materials such as concrete, metal, wood and glazing materials. New standards or specifications may be necessary to cover the integration of new materials or devices like photovoltaics on noise barriers. At this point in time, the evaluation of new materials and processes are undertaken by highway agencies themselves. New product evaluation, given its nature as an agency task, will allow staff to become familiar with photovoltaics and solar energy systems in general. Such familiarity, despite any drawbacks relating to time, should lead to a broad acceptance and continuing innovation in the use of PVNB in North America.

Photovoltaic Government Support

Of the 11 MWp of PV plants installed in Canada, only 3% are grid-connected applications (OME, 2005). In 2003, off-grid plant installation grew by 18% and grid-connected installations by 10%. Comparing with some countries in Europe, Canada is in the early stages of developing the conditions necessary to promote distributed generation and grid-connected PV. However, both on the provincial level, in Ontario, and on a federal level, there are positive pushes to bring renewable generation and energy conservation solutions into the supply mix.

The Ontario government has committed to the closing down of all of its coal-fired generating plant by 2007. As part of this commitment, the Ontario government took two RFPs through to the approval stage in 2004. “Renewables I” called for 300 MW of new renewable energy supply and approved 400 MW of new projects. A second RFP for 2,500 MW of new clean generation and demand-side projects was also launched. On April 19, 2005, the government announced two new renewable RFPs. The first calls for up to 1,000 MW of new renewable energy supply from generation facilities between 20 MW and 200 MW (‘Renewables II’). ‘Renewables III’ will be issued in draft form in June 2005, and seeks up to

200 MW of new renewable energy supply from generation facilities under 20 MW (Dignard-Bailey, 2004). Whilst the reverse auction, electricity market approach inherent in the RFP process does not favor PV, these initiatives are a strong indicator of the level of support that is building for renewable generation in Ontario. The renewables industry has also been lobbying government to consider the implementation of advanced renewable tariffs and government response is positive (OME, 2004).

The Ontario governments' target to increase the province's renewable energy generation capacity to 1,350MW, by 2007, is supported by the Canadian federal governments' commitment to the Kyoto protocol. In 2003, the government of Canada created a program called "Canadian Program on Decentralized Energy Production" operating within Natural Resources Canada. This program targets the development of Cleaner Fossil Fuels, Advanced Efficiency Technology, the Hydrogen Economy, Bioenergy and Decentralized Energy. Others initiatives launched to promote the development of renewables include the Renewable Energy Deployment Initiative (REDI), Sustainable Development Technology Canada (SDTC), Climate Change Action Plan for Canada and MicroPower Connect. This list of federal initiatives is by no means complete but does illustrate the strength of commitment, to both research and implementation, coming from both federal and provincial levels of government in Canada. Such commitment is extremely positive in regard to the prospects for PVNB demonstration.

CONCLUSIONS

Photovoltaic noise barriers (PVNB) have been in use in Europe since 1989. Thus far, in Canada, despite a massive transport system and a high per capita use of vehicles, no building integrated photovoltaic projects of this type have been undertaken. The initial findings of this study lay a foundation but there is much work still to be done.

The project will now proceed towards a more detailed analysis of existing sites. Over the next year, work will include the modeling of a variety of system designs and configurations for chosen sites, analysis of performance and economics for such systems and development of preliminary specifications with a view to the needs of future standards as well as to the prospects for PVNB demonstration. It is hoped that this feasibility work will provide the foundations for a future demonstration phase of PVNB technology at sites in Ontario and, eventually, throughout North America.

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