
Technical Report

Literature Review on Global Renewable Energy Projects Using Transportation Infrastructure

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# Table of Contents

1. Introduction ..................................................................................................................................... 5
2. Renewable Energy Projects on Transportation Infrastructure ........................................................ 6
3. New Concepts and Techniques ...................................................................................................... 12
5. Conclusions .................................................................................................................................... 17
6. References .................................................................................................................................... 17

Appendix A: Summary of Renewable Energy Projects............................................................... 20
List of Figures

1. Solar panels installed at Canopy Airport Parking. (Source: Car Stations) ........................................... 7
2. Solar/wind hybrid powered street light installed in Minnesota ............................................................ 8
3. Oregon solar highway. (Source: Oregon Live.com) .................................................................................. 9
4. Solar-powered lighting at El Paso airport, TX (Source: www.elpasotexas.gov) ................................. 9
5. Solar cell parking lot in Bordentown, NJ (Source: The Green Optimistic) ........................................... 10
6. Solar freeway (Source: Inhabitat.com) ..................................................................................................... 11
7. Rainbow Bridge in Tokyo (Source: ACTIVE Corporation) ....................................................................... 12
8. Solar road panel (Source: Solar Roadways) ............................................................................................ 12
List of Tables

1. SAMMA indicators of project outcomes ................................................................. 5
2. Barriers to developing small wind systems identified by AWEA .............................. 6
3. Performance comparison of rechargeable batteries ................................................. 8
1. Introduction

Sustainable transportation systems will substantially benefit by using the existing transportation infrastructure as a backbone to generate renewable energy. Most of the current research in sustainable transportation deals with renewable fuels, but very few investigate renewable energy projects on roadway infrastructures. In this literature review, the existing projects using transportation infrastructure for generating renewable energy are discussed, highlighting their economic, social, and environmental impacts.

The Sustainable Mobility, policy Measures and Assessment (SAMMA) program in Europe defined some indicators to evaluate projects outcomes in improving transportation sustainability (1), as shown in Table 1. Both transport operation cost and resource use are selected as outcome indicators. Renewable energy power generation systems on transportation infrastructures can offset the energy expense of transportation operation and reduce the consumption of energy from fossil fuel. This will finally help to achieve the goal of sustainable transportation.

Table 1. SAMMA indicators of project outcomes.

<table>
<thead>
<tr>
<th>Economic Indicators</th>
<th>Environmental Indicators</th>
<th>Social Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td>Resource use</td>
<td>Accessibility and affordability</td>
</tr>
<tr>
<td>Transport operation cost</td>
<td>Direct ecological intrusion</td>
<td>Safety and security</td>
</tr>
<tr>
<td>Productivity/Efficiency</td>
<td>Emissions to air</td>
<td>Fitness and health</td>
</tr>
<tr>
<td>Costs to economy</td>
<td>Emissions to soil and water</td>
<td>Livability and amenity</td>
</tr>
<tr>
<td>Benefits to economy</td>
<td>Noise</td>
<td>Equity</td>
</tr>
<tr>
<td></td>
<td>Waste</td>
<td>Social cohesion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Working conditions in transport sector</td>
</tr>
</tbody>
</table>

Wind is a clean energy source and has been used in many industries. The energy production of small wind turbines with a rated capacity of 100 kilowatts or less has reached 100 megawatts in the United States of America with a staggering 15% growth in the year 2010 (2). The typical site for small wind systems is in rural areas, because the best wind resources are strong over flat landscape. Urban and suburban areas have many buildings, trees, signs, and other obstacles which disrupt available wind resources. Dutton et al. (3) studied the feasibility of using small wind turbines in urban areas, and points out the challenges of turbine designs for urban environments and nontechnical issues such as zoning restrictions, financing, and safety. AWEA identified the barriers to small wind system development in the roadmap for the small wind turbine industry in 2002 (4). These barriers are listed in Table 2. In recent years, significant effort has been put forth to meet both technological and policy barriers. Energy plus roadways would be another significant step in that direction. With the development of turbine technologies and power system designs to maximize available wind resources, small wind turbines can achieve the desired performance in urban and suburban areas. Federal tax credit and state level incentives, such as net metering, help to make small wind projects competitive, especially in areas with
high electricity prices. The Database of State Incentives for Renewable Energy & Efficiency (DSIRE) provides available incentive information for the whole country (5).

Table 2. Barriers to developing small wind systems identified by AWEA.

<table>
<thead>
<tr>
<th>Technology Barriers</th>
<th>Policy Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near-term</td>
<td>Lack of federal incentives</td>
</tr>
<tr>
<td>High cost of wind turbines</td>
<td>Restrictive zoning</td>
</tr>
<tr>
<td>Insufficient product reliability</td>
<td>NIMBY and environmental concerns</td>
</tr>
<tr>
<td></td>
<td>Excessive interconnection requirements and unequal billing policies</td>
</tr>
<tr>
<td></td>
<td>Undervaluation of green energy</td>
</tr>
<tr>
<td></td>
<td>Disincentives in the tax code</td>
</tr>
<tr>
<td>Mid-term</td>
<td>Lack of more state-based incentives</td>
</tr>
<tr>
<td>Turbine productivity hampered by power electronics issues</td>
<td>Lack of sustained national incentives</td>
</tr>
<tr>
<td>Domestic market requirement</td>
<td>Lack of interconnection standards</td>
</tr>
<tr>
<td>Quiet operation</td>
<td>Lack of national models for net metering and zoning rules</td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
</tr>
<tr>
<td>Need for better technology tools</td>
<td></td>
</tr>
</tbody>
</table>

2. Renewable Energy Projects on Transportation Infrastructure

An exhaustive effort was made to list experiences gained from existing projects that use transportation infrastructure to generate renewable energy. A list of both national and international projects in this area can be found in Appendix A. It should be noted that all of the existing projects are isolated applications as compared to the proposed system which would be a smart grid system. In the following paragraphs the projects are described in more detail.

Wind Power Projects

Maryland State Highway Administration (MD SHA) installed a small vertical wind turbine to light an LED overhead sign in Western Maryland in 2007 (6). The installed project cost was $10,000. The wind turbine is designed to be used for over 20 years and cut 80% of the electricity cost of the LED sign.

In June 2009, MD SHA installed another wind turbine pilot renewable energy project (7). Based on wind assessments conducted by the Maryland Energy Administration, MD SHA installed a 60-foot tall small wind turbine at the back parking lot of the Westminster Maintenance Facility in Carroll County. This project aims to determine the feasibility and the effectiveness of using wind energy to help power SHA facilities. A wind turbine was chosen for this project because of the ease of installation, cost, and maintenance compared to other technologies. The project cost $25,000 and produces an average of 700 kWh per month. It claims to reduce 1,400 lb. of CO₂ every month, which would otherwise be produced by fossil fuels. The designed life of the turbine is 20 to 25 years.

Massachusetts transportation and environmental officials plan to install a 400-ft.-tall wind turbine with a rated capacity of 1500 kilowatts at a 68-acre, state-owned site adjacent to the Massachusetts
Turnpike’s Blindfold Rest Area (8). This site was chosen based on the size of the land, its proximity to the electrical grid, and its high elevation. The expected wind energy production is 3,000 MWh every year. The production would be enough to provide electricity to approximately 400 households. The production will be sold to Western Massachusetts Electric Company or another utility provider. Solaya Energy will design, construct, and finance the wind turbine system. It will lease the land and pay rent equal to 3.5% of the annual power sales, or approximately $16,600 for the first year of operation. The Turnpike Authority is guaranteed a minimum rent of $15,000 each year over the 20-year lease period.

All of these wind energy projects create a new funding source for a transportation operation, as well as promote local economies. As estimated by NREL, a 100 megawatt wind energy project can create 495 local jobs during construction and 21 long-term jobs; and 20 operations would bring total economic benefit of $136 million (9).

**Hybrid Wind/Solar Power Projects**

Wind resources vary by time of day and season. Wind and solar are found to compensate each other. In recent years, many parking facilities have been designed to use both wind and solar energy. Canopy Airport Parking in Denver, CO, opened in Nov. 2010, is said to be the greenest parking facility in the world (10). The parking lot is built with 16,900 watts solar arrays (Figure 1), a 9600 watts wind turbine farm, and geothermal energy generation. The renewable energy technologies help in building an energy savings of 70% compared to a similar building without the energy saving additions and provides free charging to electric and hybrid vehicles at the parking lots.

![Figure 1. Solar panels installed at Canopy Airport Parking. (Source: Car Stations).](image)

In another project, researchers from the University of Minnesota developed a self-sustaining solar/wind hybrid powered street light to study the benefit of renewable energy in supplying rural ITS applications.
The system was installed in the Minnesota Department of Transportation’s District-1 parking lot and consists of a 130 watt solar panel and a 400 watt small wind turbine, as shown in Figure 2. A two-year field test found that wind can provide supplementary energy when solar energy is not sufficient to power the lighting applications. On many rainy and snowy days when solar radiation is deficient, wind is strong and can provide alternative energy resources. This study also suggests that a solar/wind-powered system is cheaper than a grid–tied system for most remote ITS applications. A solar/wind generator along with sufficient battery storage can provide a reliable power source for remote ITS applications.

Figure 2. Solar/wind hybrid powered street light installed in Minnesota.

Solar Power Projects

In recent years, the use of photovoltaic (PV) solar energy technology for electric power generation and distribution has been accommodated within the highway right-of-way in several European countries as discussed in the next section. In the United States, the first solar highway project was conducted by the Oregon Department of Transportation (12). A ground-mounted PV array was installed at the interchange of I-5 and I-205 and connected to the power grid for clean electricity generation and distribution. The project was finished in Dec. 2008 at a cost of $1,280,000 with annual electricity production of 112,000 kWh.
In another project, the Hawaii DOT plans to install a solar photovoltaic power system at Lihu‘e Airport (13). The systems are expected to produce 1,200,000 kWh of energy each year. Over the 20-year system lifetime, the arrays will offset up to 26 million lb. of CO$_2$ emissions, which is the equivalent of removing more than 1,400 cars from the road.

The airport operations officials in El Paso, TX, installed solar-powered lighting in the facility’s long-term, overflow parking lot (14), as shown in Figure 4. The project was completed in March 2010 at a cost of $330,000, which is about 60% less than a standard lighting installation. The solar lighting project for the 2,200 space parking lot was funded through the airport capital improvement budget. The solar lighting is estimated to save the city $40,000 per year in electricity costs.
A 1 megawatt solar cell parking lot of the Manheim, NJ, Auto Dealers Exchange in Bordentown, NJ, is constructed in 2010 (15). More than 5,000 photovoltaic panels are installed within a total area of 104,000 sq. ft. The panels are tied in to one single meter via 11 separate inverters. The system is connected to the grid and will generate more than 1,000 megawatts per year, which is roughly the amount required to power 114 households. The reduction of 1,900,000 lb. of CO₂ is equivalent to the annual emissions from 158 cars.

Figure 5. Solar cell parking lot in Bordentown, NJ (Source: The Green Optimistic).

Many “green rest areas” or “Eco-Friendly Rest Areas” along the national highways are designed as energy saving buildings, like the I-89 Green Rest Stop in Sharon, VT, and the rest areas on U.S. Highway 287 west of Chillicothe, TX. Some of the green rest areas also have renewable energy production facilities. The North Carolina Department of Transportation opened the Northwest North Carolina Visitor Center on Oct. 1, 2009, which is located on the northbound side of U.S. 421 in North Wilkesboro (16). The cost of the 10,030 sq. ft. green rest area was $12 million. It has roof-mounted solar panels to preheat water for restrooms. Fourteen photovoltaic panels installed atop the building are expected to produce nearly 4,400 kWh per year.

The SpeedInfo company uses solar-powered Doppler radars in its wireless network to collect traffic flow information in many metropolitan areas in the U.S. (23). The sensors are attached to transportation infrastructure, such as traffic poles, and the real-time traffic data is sent via the AT&T® Wireless network.

International Applications

Renewable energy projects are developed all over the world. Solar power seems to have a wider implementation. The following paragraphs discuss a few international sites using transportation infrastructure to produce renewable energy.
Germany is installing 2700-kilowatt solar panels on the 2700 meters of the roof of the tunnel of its A3 highway (17). The first phase of construction was completed in 2009. The company, Goldbach-Hoesbach, purchased the land from the German government. The projects will be connected to the power grid. The €11 million ($15 million) investment is expected to be paid back through cost savings over 16 years.

The Australian renewable energy retailer, Going Solar, created the concept of installing solar panels in highways as sound barriers (18). The biggest advantage of this project is that the footprint is minimal as the solar panels are mounted vertically as shown in Figure 6. The first highway installation was completed on the Tullamarine Calder Interchange in Australia. The solar sound barrier comprises 500 meters of photovoltaic panels that are attached to a public display showing the project’s power output. The project provides 25 kilowatts of peak power output and is expected to produce 18,700 kilowatts per year, which is enough to cover its cost in about 15 years. The electricity generated is consumed by nearby residential areas. With the solar panels, the sound barrier provides noise reduction with aesthetic appeal, cost effectiveness, and environmental sustainability.

![Figure 6. Solar freeway (Source: Inhabitat.com).](image)

In Italy, there is a plan to build the world’s first totally solar highway between the cities of Catania and Syracuse in Nov. 2010 (19). The approximately 19 miles of highway will use photovoltaic panels to power all of the highway's systems including tunnel fans, lights, road signs, and emergency telephones. The project’s estimated cost is around $81 million, and it is expected to generate 12 million kWh of solar power annually.

The Vauxhall Cross Bus Interchange in London, United Kingdom, was built in 2005 at a cost of about $5.8 million (20). “Hybrid” solar modules (168 Sanyo 180W) were installed onto the interchange’s canopy and generate 30% of the energy required to power the 24-hour bus station area. The Walworth Bus Garage in London also has 744 solar panels on the roof to generate 38,500 kWh of electricity each year.

The Rainbow Bridge in Tokyo, Japan, shown in Figure 7, is illuminated with 444 solar-powered lamps that change color with the seasons (21).
These renewable energy projects on transportation infrastructure can change the role of the transportation industry from big energy consumer to energy provider while creating green collar jobs for local communities.

3. New Concepts and Techniques

There has been a significant technological innovation in recent years that can be instrumental in achieving the goals of “green” transportation.

The Solar Roadways project develops a solar roadway by combining a series of structurally engineered solar panels (22), as shown in Figure 8. The aim is to replace all existing transportation infrastructure such as roads, parking, etc., with Solar Road Panels that collect energy and provide sensor data. It is proposed to save excess energy in or alongside the roadway. The solar panel will consist of three layers: 1) a road surface layer made of translucent glass which is able to provide strength and traction yet pass sunlight, 2) an electronic layer which collects power from sensors and hosts some circuitry, and 3) a base plate layer for power and data distribution. The first prototype of a 12-ft. by 12-ft. road panel was built in February 2010.
Another renewable application in ITS is portable traffic signal systems powered by solar panels. These products have been available on the market for many years. Solar arrays and small wind turbines have historically been used in rural areas or off-grid systems. Many new technology innovations can help the use of renewable energy in urban transportation systems.

Scientists in Korea have developed the On-Line Electric Vehicle System, which uses electric magnetic field sensing on a power supply line that is installed under the road and supplies power to electric vehicles wirelessly (24). With the new wireless charging techniques, it’s possible to charge electric/hybrid vehicles on the road using renewable energy sources generated and distributed along the roadway systems.

The Green Roadway (TGR) project developed technology portfolios to provide patented alternative energy systems for installing massive solar, wind, geothermal, and electric vehicle infrastructure systems along roadways (25). Power from roadway energy systems may be used to supply vehicle charging stations, homes, and businesses or be delivered to the grid. TGR’s exclusive licenses have been obtained by individual states via sealed bid auction since July 2009. Ten states have obtained the TGR license to date. These technology portfolios will contribute to a new standard of renewable energy applications in transportation.

New Energy Technologies Inc. has developed a prototype of MotionPower™ which generates electricity by vehicle movement. It underwent field tests at a Burger King drive-thru in Hillside, New Jersey, in 2009 (26). The MotionPower™ system is currently under development. It can potentially be installed at intersections, toll booths, rest areas, and drive-thrus to produce energy by vehicles traveling every day. A similar technology has been tested in the United Kingdom. The electrokinetic road ramp developed by the UK Highway Energy System can generate electricity when vehicles pass the articulated plates placed in the road (27). The output of the generator varies from 5 to 10 kilowatts depending on the frequency and weight of traffic. A UK supermarket chain, Sainsbury's, installed the electrokinetic plates in its car parks in 2009, expecting to produce 30 kilowatts of electricity per hour to power the store’s checkouts. If these kinds of technologies are mature and widely used, the vehicle miles travelled will bring immense economic and environmental benefits.


The proposed EPRTL may use a battery to store green electricity generated by the wind/solar hybrid power system (HPS). Compared to its peers, a battery is the most cost-effective, energy-efficient, and flexible energy storage technology. There are many different types of batteries based on the chemical processes applied and design chosen, e.g., lead-acid battery, NiCd battery, NiMH battery, Li-ion battery, etc. A survey has been conducted to compare different types of rechargeable batteries in terms of cost, service life, maintenance requirement, charge/discharge efficiency, self-discharge, safety, environmental impacts, etc., which will be used as a guide for selection of appropriate battery storage for the EPRTL. The following is a summary of today's popular batteries.
**Nickel-Cadmium (NiCd) Battery:** It has a moderate energy density. Nickel-cadmium contains toxic metals. Due to the memory effect, it should be fully discharged before charging in order to get full capacity. The major advantages of the NiCd battery are:

- Low cost
- Good overcharge endurance
- Excellent quick charge performance
- Long cycle life
- Extensive temperature range
- Mid-degree self-discharge
- Good safety performance

**Nickel-Metal-Hydride (NiMH) Battery:** It has a higher energy density compared to the NiCd battery at the expense of reduced cycle life, higher self-discharging rate, and shorter cycle life. Therefore, it should always be kept in a charged condition when using or storing it. The NiMH battery has no toxic metals. It is viewed as a stepping stone to lithium batteries. The major advantages of the NiMH battery are:

- Good quick charge performance
- Low cost
- High drain electronic devices
- No pollution
- Extensive temperature range
- Good safety performance
- No memory effect for easy charging and usage

**Lead-Acid Battery:** It is the oldest rechargeable battery and is the most economical for larger power applications where weight is of little concern. The major advantages of the lead-acid battery are:

- Very low cost and simple to manufacture
- Mature, reliable, and well-understood technology
- Good safety performance

**Lithium-Ion (Li-Ion) Battery:** It is the fastest growing battery offering a high energy density and low weight. A protection circuit is needed to limit voltage, temperature, and current for safety considerations. The major advantages of the li-ion battery are:

- High operation voltage
- High energy density
- Long cycle life
- No pollution
- Light weight
- Very low self-discharge rate
- Fast charging capability
**Polymer Lithium-Ion (Li-Polymer) Battery:** It is similar to the Li-ion battery but has a higher power density.

**LiFePO4 Battery:** It is one of the latest technologies in the family of Lithium batteries. The LiFePO4 battery outperforms the traditional Li-Ion battery:

- Extraordinary long cycle life
- Higher discharging current
- Extremely safe/stable chemistry-high intrinsic safety, no explosion, and will not catch fire under collision, when overcharged, or if short circuited
- Wide working temperature range from -20°C ~+70C
- Very fast charge

Table 3 compares the performance of major rechargeable batteries. Based on this comparison, the following recommendations are made for selecting batteries for this project. If capital cost is the major concern, then lead-acid batteries are recommended. Otherwise, LiFePO4 batteries are recommended, which are environmental friendly and have a long cycle life, high energy density (light weight), low capital cost per cycle per Wh, low maintenance cost, high charge/discharge efficiency, and low self-discharge rate (low energy loss).

**Table 3: Performance comparison of rechargeable batteries**

<table>
<thead>
<tr>
<th></th>
<th>Li-ion</th>
<th>Li-polymer</th>
<th>LiFePO4</th>
<th>NiMH</th>
<th>NiCd</th>
<th>Lead acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle life (times)</td>
<td>300~800</td>
<td>500~1000</td>
<td>&gt;2000</td>
<td>500~1000</td>
<td>500~1500</td>
<td>~300</td>
</tr>
<tr>
<td>Weight energy density (Wh/kg)</td>
<td>140~160</td>
<td>160~200</td>
<td>120~140</td>
<td>60~120</td>
<td>45~80</td>
<td>30~50</td>
</tr>
<tr>
<td>Volume energy density (Wh/l)</td>
<td>320</td>
<td>400</td>
<td>300</td>
<td>200</td>
<td>150</td>
<td>80</td>
</tr>
<tr>
<td>Cost ($/Wh)</td>
<td>~1.1</td>
<td>~1.25</td>
<td>~1.2</td>
<td>~1.0</td>
<td>~1.4</td>
<td>~0.2</td>
</tr>
<tr>
<td>Cost per cycle per Wh referred to lead acid battery</td>
<td>1.5~2.0</td>
<td>1.5~2.0</td>
<td>0.15~0.25</td>
<td>1.2~1.4</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Fast charge time</td>
<td>1 h or less</td>
<td>1 h or less</td>
<td>0.5 h or less</td>
<td>2 h to 4 h</td>
<td>~1 h</td>
<td>8 h to 16 h</td>
</tr>
<tr>
<td>Overcharge tolerance</td>
<td>Low. Cannot tolerate trickle charge.</td>
<td>moderate</td>
<td>low</td>
<td>moderate</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>Operating temperature (°C) (discharge only)</td>
<td>-20~60</td>
<td>-20~60</td>
<td>-20~70</td>
<td>-20~60</td>
<td>-40~60</td>
<td>-20~60</td>
</tr>
<tr>
<td>Memory effect</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Environmental impact</td>
<td>Ok</td>
<td>Ok</td>
<td>Good</td>
<td>Good</td>
<td>Bad</td>
<td>Not good</td>
</tr>
</tbody>
</table>
Comparison of Batteries and Flywheels

Flywheels may provide an alternative to batteries in some energy storage applications. The technologies of flywheels and batteries have been greatly advanced during the last decade. For example, the flywheels produced by Beacon Power (28) represent the latest advancements in flywheel technologies. They are a good alternative to batteries for large-scale utility applications, such as frequency regulation, peak power support, and mitigation of wind/solar intermittence. However, batteries are a better choice for the EPRTL in this project. This can be justified by the following.

First, the energy loss of flywheels is much higher than batteries. The mechanical efficiency of the Beacon Power flywheels is 97%. This means that if a 5 kWh flywheel system is used for the traffic signals at one intersection, 3.6 kWh of energy will be lost in the flywheel every day in order to maintain the flywheel rotation at the nominal capacity for backup. On the other hand, the energy loss of batteries is mainly the self-discharge loss. For example, the self-discharge loss of lithium batteries is less than 5% per month. This means that if the 5 kWh flywheel system is replaced by a lithium battery system, less than 0.001 kWh of energy will be lost in the battery every day in order to maintain it at the nominal capacity.

Second, for small-scale applications (e.g., the EPRTL of this project), the footprint and weight of a flywheel system are larger than a battery. For example, a 5 kWh lithium battery made by A123 Systems (29), a US company producing batteries with one of the latest lithium cell technologies, is weighted at 180 lb. On the other hand, the rotor of a 25 kWh Smart Energy 25 flywheel made by Beacon Power is over 2,500 lb. Including other components of the flywheel system, the total weight per 5 kWh will be over 500 lb., which is much more than that of a battery system. Moreover, the construction of a flywheel system is more complicated than a simple plug-in battery. For example, flywheels are usually required to be embedded in the ground to halt any material that might escape the containment vessel. Since the installed flywheel system is close to the walkways of the intersection, noise would be a concern.
Third, the control and power conversion (a high and adjustable speed electric machine drive system is needed) of a flywheel system are more complicated than a battery system. As a result, flywheels are not an economically efficient solution to small-scale energy storage, e.g., the EPRTL of this project.

The fourth issue is the flexibility for system scaling. Battery systems are constructed using small cells and, therefore, can be constructed flexibly into systems with different power capacities. However, flywheels are commonly made with a power capacity which is not flexible for small-scale applications. For example, the basic flywheel unit of Beacon Power is 25 kWh which may be an optimal design when taking into account various factors; but it is too big for our project.

One of the advantages of flywheels is that they can be charged and discharged at high power rates. This is very useful for certain large-scale utility applications, such as peak power support and mitigation of ramp change of wind power. For example, Beacon Power’s 25 kWh Smart Energy 25 flywheel can be discharged at 100 kW, which is four times the rated capacity. However, fast discharge is not a requirement for the energy storage in this project. In addition, the latest batteries can also be discharged at high power rates. For example, the A123 battery cells can be continuously discharged at 35C, i.e., 35 times the rated capacity.

5. Conclusions

Renewable energy has great potential in the transportation sector, and it is a rapidly evolving field. There is still a lack of a standard policies and measure of effectiveness tools for using existing transportation infrastructure to generate renewable energy. Most of the current deployments are individual efforts by state or local agencies to test a new technology. There is a strong need to document these scattered efforts and provide some guiding business models that can be followed for such implementation. There is also a need for developing guidelines for assessing economic, social, and environmental impacts.

6. References


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## Appendix A: Summary of Renewable Energy Projects

<table>
<thead>
<tr>
<th>Year</th>
<th>Project Name</th>
<th>Energy Source</th>
<th>Installed Capacity</th>
<th>Cost</th>
<th>Utility Saving</th>
<th>CO₂ Reduction</th>
<th>Ownership</th>
<th>Design Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Vauxhall Cross Bus Interchange in London</td>
<td>Solar</td>
<td>30kw</td>
<td>$5,800,000</td>
<td>Generate 30% of the energy required to power the 24-hour bus station</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>MD SHA LED sign lighting</td>
<td>Wind</td>
<td></td>
<td>$10,000</td>
<td>Cut 80% of the electricity cost of the LED sign</td>
<td></td>
<td>MD SHA</td>
<td>Over 20 years</td>
</tr>
<tr>
<td>2008</td>
<td>University of Minnesota street light</td>
<td>Wind/solar</td>
<td>130 watts solar panel, a 400 watts small wind turbine</td>
<td></td>
<td>Sufficient to power the lighting applications</td>
<td></td>
<td>Mn DOT</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Oregon Solar Highway</td>
<td>Solar</td>
<td></td>
<td>$1,280,000</td>
<td>112000kWh/year; provides 28% of power for the interchange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Australian highways sound barriers panels</td>
<td>Solar</td>
<td></td>
<td></td>
<td>18,700kWh/year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>MD SHA pilot renewable energy project</td>
<td>Wind</td>
<td>700kw/month</td>
<td>$25,000</td>
<td>700kWh/month</td>
<td>1,400 lb./month</td>
<td></td>
<td>20-25 years</td>
</tr>
<tr>
<td>2009</td>
<td>Photovoltaic power system at Lihu’e Airport</td>
<td>Solar</td>
<td></td>
<td></td>
<td>1,200,000kW/year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>Northwest North Carolina Visitor Center</td>
<td>Solar</td>
<td></td>
<td>$12,000,000</td>
<td>4,400 kWh/year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>Project Name</td>
<td>Energy Source</td>
<td>Installed Capacity</td>
<td>Cost</td>
<td>Utility Saving</td>
<td>CO2 Reduction</td>
<td>Ownership</td>
<td>Design Life</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------</td>
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<td>----------------------------------</td>
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<td>----------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>2009</td>
<td>Germany's A3 highway</td>
<td>Solar</td>
<td>2,700kw</td>
<td>$15,000,000</td>
<td></td>
<td></td>
<td></td>
<td>Paid back through cost savings over 16 years</td>
</tr>
</tbody>
</table>
| 2010 | Massachusett's Turnpike       | Wind                    | 1500kw             | 3,000,000 kWh/year;  
$15,000 each year over the 20-year lease period | Solaya Energy, Massachusetts Turnpike owns land |
| 2010 | Canopy Airport Parking        | Wind/ solar/ thermal    | 16,900 watts solar arrays (Figure 1), a 9600 watts wind turbine | Saving 70% compared to a similar building without the energy savings additions; provide free charging to electric and hybrid vehicles |
| 2010 | El Paso airport lighting      | Solar                   | $330,000           | Electricity saving $40,000 per year | city El Paso |
| 2010 | Solar cell parking lot in Bordentown | Solar | 1 megawatt | More than 1000 megawatts per year | 1,900,000 lb./year |
| 2010 | Italy solar highway           | Solar                   | $81,000,000        | 12,000,000 kWh/year |
