Evaluation of Renewable Energy Alternatives for Highway Maintenance Facilities

SJN: 134706

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### Background

- A considerable annual energy budget is used for heating, lighting, and operating ODOT maintenance facilities.
- Such facilities contain vehicle repair and garage bays, which are large open spaces with high heating demand in winter.
• ODOT is trying to reduce its energy consumption to lower its bills and lower its environmental impact through the use of Renewable Energy Technologies (RETs).
• RETs have numerous applications and benefits; however, the success of their implementation depends on a detailed assessment of a variety of factors including physical, economic, and institutional and requires an adequate selection process.
• The research developed a three-phase selection process for evaluating RETs and designed a decision support tool for use in each phase.
Main Goal

- The main goal of the project was to recommend strategies for ODOT maintenance facilities that will reduce energy costs and reduce greenhouse gas (GHG) emissions.
The research team conducted the research work in seven major tasks:

1. Collecting data on maintenance facilities’ energy consumption and energy capture technologies currently employed in ODOT maintenance facilities.
2. Conducting a comprehensive literature review on renewable energy alternatives, their available resources in Ohio and their associated advantages/disadvantages.
3. Selecting case studies of ODOT maintenance facilities and conducting on site assessment.
4. Identifying and analyzing potential renewable energy best practices.
5. Developing Applicability Matrices for the selection of RET projects.
6. Developing a Life Cycle Costing Analysis (LCCA) methodology for the evaluation of RET.
7. Making final recommendations for implementing RETs at ODOT maintenance facilities.
These research tasks and their deliverables are summarized.
Although the rest of the presentation focuses more on the results, the next few slides briefly discuss some of the research tasks in more detail.
• Data Collection: It is very important to gather site-relevant data before recommending strategies for reducing energy use and costs (Federal Energy Management Program, 2010a).

• The research team collected and analyzed an extensive amount of detailed information about some of Ohio’s existing highway maintenance facilities. The collected data included (1) utility bills, (2) energy usage and costs, (3) site location (address, longitude and latitude), (4) square footage, (5) typical number of occupants, (6) functional use (office, garage, warehouse), (7) unusual features, (8) age, condition of roof (9) atypical energy needs, (10) availability of land for renewable energy installations and (11) two complete sets of construction documents for two maintenance facilities.
• ODOT has provided the University of Cincinnati (UC) with electricity and gas usage data for 13 of its maintenance facilities in districts 2, 6 and 9.

• The 13 facilities were selected based on age and include the newest ODOT maintenance facilities.

• ODOT and the research team have decided to evaluate energy usage of the newest facilities as those facilities are less likely to be replaced in the near future and as such are good candidates for implementing renewable energy projects.
Facilities Analyzed

- **District 2 Facilities**
  - Seneca County Garage
  - Williams County Garage
  - Ottawa County Garage
  - Wood County Garage

- **District 9 Facilities**
  - Pike County Garage
  - Lawrence County Garage
  - Scioto County Garage

- **District 6 Facilities**
  - Marion County Garage
  - Fifth Avenue Outpost Garage
  - Franklin County Garage
  - Morrow County Garage
  - Delaware County Garage
  - Pickaway County Garage
Total Energy Consumption (Gas and Electric) – Pike County Garage

**Total Energy Use**

- Monthly (KWh)
- Dates: Jan-10 to Aug-12

Dr. Hazem Elzarka
• Maintenance facilities primarily consists of vehicle repair bays (which are large open spaces with high clearance)

• They have a number of unique attributes that contribute to an energy use profile that is quite unlike most other commercial buildings.

• Because the vehicle bays are often a main driver of total energy consumption, the maintenance facilities typically have high ventilation demand, high heating demand in winter, and generally, no or little cooling in summer.
As shown in Figure 1, the 2003 Commercial Building Energy Consumption Survey (CBECS) identifies the main drivers of energy use in the vehicle service category as **heating** and **lighting**, followed by **process loads**, which are categorized as “Miscellaneous” in Figure 1.

Process loads are generally the equipment used in the servicing or repair of vehicles, including compressed air systems, welding, and any number of power tools used.
Because the literature indicated that most of the energy used by maintenance facilities was used on HVAC systems, it was important to collect weather data since weather impacts the energy consumption of HVAC systems.

We collected heating degree days and cooling degree days for all 13 facilities evaluated.
Degree days

- Heating Degree Day (HDD): The number of degrees that a day's average temperature is below 65°F Fahrenheit.
- Cooling Degree Day (CDD): The number of degrees that a day's average temperature is above 65°F Fahrenheit and people start to use air conditioning to cool their buildings.
Degree days- Pike County Garage

**HDD**

**CDD**
Surveys

- Organized Survey in following sections:
  - General Facility Information
  - Occupants/ Facility Manager Opinions
  - Metering and Emergency Generator Information
  - Heating Equipment
  - Cooling Equipment
  - Lighting System
  - Building Systems Controls
  - Energy Consuming Equipment Conditions and O&M procedures
  - Energy Efficiency and Conservation
  - Renewable Technologies
Sent out surveys to 13 maintenance facilities

Received all 13 completed surveys.
### Surveys

<table>
<thead>
<tr>
<th>Facility</th>
<th>Built</th>
<th>Area (Sq Ft)</th>
<th>Total Energy Use Indices Jan 2010 to Jan 2012</th>
<th>Energy Use Indices Jan 2010 to Jan 2012</th>
<th>Hours/Week</th>
<th>Occupants</th>
<th>Building Control Systems</th>
<th>Energy Efficiency</th>
<th>Heating Systems</th>
<th>Cooling Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seneca County Garage</td>
<td>1997</td>
<td>36325</td>
<td>0.95</td>
<td>0.27</td>
<td>0.68</td>
<td>40</td>
<td>23</td>
<td>No</td>
<td>None</td>
<td>Gas Fired Furnace, Standard Radiant Heaters</td>
</tr>
<tr>
<td>Williams County Garage</td>
<td>1997</td>
<td>36325</td>
<td>0.82</td>
<td>0.34</td>
<td>0.47</td>
<td>40</td>
<td>24</td>
<td>No</td>
<td>None</td>
<td>Gas Fired Furnace, Standard Radiant Heaters</td>
</tr>
<tr>
<td>Ottawa County Garage</td>
<td>1991</td>
<td>28000</td>
<td>0.85</td>
<td>0.53</td>
<td>0.32</td>
<td>40</td>
<td>22</td>
<td>Occupancy, Thermostat</td>
<td>None</td>
<td>Gas Fired Make up Air Unit, Standard Radiant Heaters</td>
</tr>
<tr>
<td>Wood County Garage</td>
<td>1986</td>
<td>18400</td>
<td>1.72</td>
<td>0.41</td>
<td>1.31</td>
<td>42.5</td>
<td>26</td>
<td>No</td>
<td>None</td>
<td>Standard Radiant Heaters, Boilers, Waste Oil Burner</td>
</tr>
</tbody>
</table>

Table 4.2, Summary of survey results for ODOT district 2.

- Based on survey results, selected 5 facilities for site visits
- Facilities were selected to represent different sizes and ages.
Site Visits

- Three objectives of visit

1. Review Drawings to identify major energy consuming equipment
2. Walk the facility with a facility personnel who is familiar with existing systems and review the usage of the following systems:
   - Lighting
   - Building Envelope
   - HVAC
   - Equipment
3. Evaluate the feasibility of the building/site for implementing renewable energy strategies
# Site Visits

<table>
<thead>
<tr>
<th>Facility</th>
<th>District</th>
<th>Year Built</th>
<th>Square Footage</th>
<th>Site Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pike County Garage</td>
<td>9</td>
<td>2008</td>
<td>27,857</td>
<td>10</td>
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<tr>
<td>Seneca County Garage</td>
<td>2</td>
<td>1997</td>
<td>36,325</td>
<td>12</td>
</tr>
<tr>
<td>Fifth Avenue Outpost Garage</td>
<td>6</td>
<td>2005</td>
<td>5,110</td>
<td>4</td>
</tr>
<tr>
<td>Franklin County Garage</td>
<td>6</td>
<td>2002</td>
<td>22,307</td>
<td>9</td>
</tr>
<tr>
<td>New Lucas County Garage</td>
<td>2</td>
<td>2013</td>
<td>-</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 4.6, List and characteristics of the facilities selected for site visits.

---

<table>
<thead>
<tr>
<th>Facility Name:</th>
<th>ODOT Region:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODOT Region:</td>
<td>Date:</td>
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</table>

<table>
<thead>
<tr>
<th>Address:</th>
<th>Facility Representative:</th>
<th>Phone:</th>
<th>Email:</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phone:</th>
<th>Email:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Facility Name:</th>
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<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODOT Region:</td>
<td>Date:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location:</th>
<th>Corrective Action Request / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Check Point Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Are doors/windows kept closed during heating and cooling season?</td>
</tr>
<tr>
<td></td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>2.</td>
<td>Are building walls too hot/cold candidate for insulation?</td>
</tr>
<tr>
<td></td>
<td>YES NO N/A Location:</td>
</tr>
<tr>
<td>3.</td>
<td>Is weather stripping found to be adequate around windows/doors? (reduce air leak)</td>
</tr>
<tr>
<td></td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>4.</td>
<td>Are windows types adequate (e.g. single pane, double pane, high performance windows)?</td>
</tr>
<tr>
<td></td>
<td>YES NO N/A Location:</td>
</tr>
<tr>
<td>5.</td>
<td>Are windows placed correctly? (i.e. majority of windows facing south)?</td>
</tr>
<tr>
<td></td>
<td>YES NO N/A</td>
</tr>
<tr>
<td>6.</td>
<td>Are there signs of deterioration of building envelope (siding deterioration, masonry</td>
</tr>
<tr>
<td></td>
<td>fluorescence, window fogging, and</td>
</tr>
<tr>
<td></td>
<td>YES NO N/A Location:</td>
</tr>
<tr>
<td></td>
<td></td>
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</table>
## Site Visits

**Light Meter,**
**Carbon Monoxide Meter,**
**Carbon Dioxide Meter,**
**Temperature and Humidity Meter,**
**Range Finder,**
**FLIR Infrared Camera**

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature</th>
<th>Relative Humidity</th>
<th>CO2 (ppm)</th>
<th>Light level (fc)</th>
<th>CO</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Equipment</th>
<th>HP</th>
<th>Number</th>
<th>Phase</th>
<th>volt</th>
<th>Wire</th>
<th>HP</th>
<th>Number</th>
<th>Phase</th>
<th>volt</th>
<th>Wire</th>
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<tbody>
<tr>
<td>Air Compressor</td>
<td>15</td>
<td>3</td>
<td>1</td>
<td>208</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Vehicle Lift Console</td>
<td>20</td>
<td>3</td>
<td>1</td>
<td>208</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Ton Crane</td>
<td>8.3</td>
<td>3</td>
<td>1</td>
<td>208</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pressure Washer</td>
<td>7.5</td>
<td>3</td>
<td>1</td>
<td>208</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Ton Monorail</td>
<td>2.94</td>
<td>3</td>
<td>1</td>
<td>208</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>OH Doors</td>
<td>0.75</td>
<td>1</td>
<td>6</td>
<td>120</td>
<td></td>
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<td></td>
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<tr>
<td>Vehicle Exhaust Reel</td>
<td>0.33</td>
<td>1</td>
<td>2</td>
<td>120</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Grinder</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck Tire Changer</td>
<td>1</td>
<td>1</td>
<td></td>
<td>120</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ice Machine</td>
<td>1</td>
<td>1</td>
<td></td>
<td>120</td>
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<td></td>
<td></td>
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<tr>
<td>Air Dryer</td>
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<td>1</td>
<td></td>
<td>120</td>
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<td></td>
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<td></td>
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<tr>
<td>Parts Washer</td>
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<td>1</td>
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<td>120</td>
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<td>Band Saw</td>
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<td>120</td>
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<tr>
<td>Shop press</td>
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<td>2</td>
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<td>120</td>
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<td>Fuel Island</td>
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<td>1</td>
<td></td>
<td>208</td>
<td>#12</td>
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<td></td>
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<tr>
<td>Salt dome</td>
<td>3</td>
<td>1</td>
<td></td>
<td>208</td>
<td>#6</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Calcium Tank</td>
<td>1</td>
<td>1</td>
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</table>

<table>
<thead>
<tr>
<th>Misc. Equipment</th>
<th>Williams County</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

*Note: The table above lists the equipment and their specifications.*
Key Results

- Energy use profiles for ODOT maintenance facilities
- Energy efficiency recommendations
- Three phase process for the selection of RETs
- Best practices for implementing RETs
Key Results

- Energy use profiles for ODOT maintenance facilities
- Energy efficiency recommendations
- Three phase process for the selection of RETs
- Best practices for implementing RETs
Monthly electrical energy consumption

- Charts showing the monthly electrical energy consumption for each of the 50 maintenance facilities were developed.

- A general observation for all facilities analyzed was that the December to March months consumed more electricity, signifying that electricity expenses associated with heating the facilities in the winter months were greater than the cooling demands in the summer months.

![Electricity Use](image)
Monthly natural gas consumption

- Charts showing the monthly natural gas consumption for each of the 13 maintenance facilities were developed.

- A general observation for all facilities analyzed was that the December to March months consume the majority of natural gas to heat the facility in the winter. Only small amounts of natural gas are used in the summer months to provide hot water.
Monthly total energy consumption

- Natural gas consumption in ccf was multiplied by a conversion factor (1ccf = 29.3 kWh) to determine the consumption in kWh.

- Once again, a general observation for all facilities analyzed was that ODOT maintenance facilities use much more total energy in winter than in summer to meet heating requirements.

![Total Energy Use Graph]

*Figure 2.9. Pike county garage – total monthly energy consumption (kWh).*
Correlation of Energy Consumption with Weather Data

- The degree days’ charts were superimposed over the monthly energy use charts to identify any correlation between degree days and electricity and natural gas consumption.
- The natural gas consumption tends to follow the heating degree days trend steadily throughout the year. Natural gas is primarily used for space heating and hot water.
Correlation of Energy Consumption with Weather Data

- It was expected that the electricity consumption would follow the cooling degree days since the mechanical cooling is achieved with electrical air conditioning systems in the summer.
- However, the electricity consumption didn’t follow the cooling degree days completely although in the summer, electricity slightly increase as the number of cooling degree days increase.

*Figure 2.15: Cooling degree days and electricity consumption for Pike County Garage*
Correlation of Energy Consumption with Weather Data

• When electricity consumption was plotted together with heating degree days, it was noticed that electricity usage significantly increases with the increase in heating degree days in winter.

• Electricity is used more in the winter to run the exhaust fans used in building ventilation. These exhaust fans are not used in the summer since overhead doors are open in the summer to naturally ventilate the maintenance facilities.
Table 2.7 shows that although electricity account for 75% of the total energy cost, it only provides 43% of the total energy consumed. This trend was evident in all of the 13 facilities analyzed and can lead to the following conclusions:

- The source of most of the energy used in ODOT facilities is natural gas (57% for Pike County Garage). Natural gas is primarily used for space heating and hot water.
- Space heating requirements account for the majority of energy needs.
- The price of natural gas is relatively low compared to electricity.
- With current low prices, ODOT facilities should continue using natural gas for space heating if conventional fossil systems are to be used.
- A steep rise in natural gas price would have a large effect on the energy costs.
Key Results

- Energy use profiles for ODOT maintenance facilities
- Energy efficiency recommendations
- Three phase process for the selection of RETs
- Best practices for implementing RETs
Energy efficiency recommendations

• Energy efficiency strategies often have a quicker payback and higher return on investment than renewable energy projects and will lead to lower energy costs and reduced greenhouse gas emissions.
• The less efficient the building is, the greater the potential of energy efficiency improvements. As energy efficiency improves, additional efficiency projects have less of an impact, and renewable energy systems become the more appealing investment (NCHRP, 2013)
• Energy efficiency strategies have been identified for the heating and lighting systems, process equipment, and operation procedures. The energy efficiency strategies have been categorized as quick fixes or long term solutions.
• Quick fixes are those that would not require any substantial costs and could sometimes be achieved just with simple workforce behavioral changes. Long term fixes are those that would require some capital investment and typically include equipment replacement.
At 55 percent, heating accounts for the largest portion of the total energy cost in a maintenance facility. By adopting these energy saving steps, heating energy can be reduced significantly.

**Quick Fixes**

- When available, make sure vehicle exhaust reel is used in winter to limit CO generation and automatic start of large exhaust fans and gas using make up air unit.
  - Also better for mechanics and highway workers health
Quick Fixes

• When available ensure garage exhaust fans are controlled by CO sensors and do not override this control strategy.
Quick Fixes: Effectively use HVAC controls

• Use weekend and night setbacks on HVAC in offices or conditioned buildings
• Look for unoccupied areas being heated or cooled, and switch off heating or cooling.
• Check that heating controls are not set too high or cooling controls set too low.
Quick Fixes: Control infiltration.

- Replace worn weatherstripping and caulking to ensure windows and doors are airtight.
  - Exterior doors and windows
  - Doors between offices and garages
Quick Fixes: Maintenance.

- Regular maintenance of heating, ventilation, cooling, and refrigeration systems—including changing filters regularly—is important for good operation and to avoid energy waste.
Long Term Fixes: Test and Balance.

- Room furthest from HVAC is hot, closest to HVAC is freezing.
- Room furthest from furnace is cold, closest to furnace is too hot.
Long Term Fixes: Heat Recovery Ventilator (HRV)

- On cold winter days, the unit significantly helps heat the outdoor air coming into the building. The warm exhaust air (return air) heats up the plate heat exchanger on the way out of the building. When the cold outdoor air hits the warm plate heat exchanger, it gets conditioned up to 70% of the way to the return air temperature.
Long Term Fixes: Use efficient equipment (only when replacement is needed)

- Choose high efficiency condensing furnaces and unit heaters (92+ efficiency) and high efficiency air conditioners (EER 11.5+ for larger units, SEER 14+ for smaller units).
Heating EE opportunities

Long Term Fixes: Hydronic radiant floor heating (for new buildings).

- Heat to the space is provided by hot water supplied through pipes embedded in floors.
- The uniform temperature distribution from floor heating increases comfort and reduces room air temperature stratification.
- Radiant floor systems provide the same comfort level in the working zone at a lower room air temperature during the heating season. This results in reduced ventilation and infiltration losses.
Heating EE opportunities

Long Term Fixes: Thermal separation of functional areas.

- ODOT maintenance facilities typically have 5 different types of functional areas.
Long Term Fixes: Thermal separation of functional areas.

• Three of these functional spaces; (1) maintenance area, (2) garage area and (3) truck washing area, are combined into one large area.
• They are heated to the same temperatures even though they have different heating requirements; The maintenance area should be heated in the winter to a comfortable temperature (70°C to 72°C) that enables the mechanics to safely and comfortably work.
• On the other hand, the garage space, (typically the largest space) should only be heated to (50°C or 55°C) and it would still achieve the intended objective of melting the snow and ice off of trucks to protect them from rust, and ensure a more efficient snow/ice clearing operations in the winter.
• When these two areas are combined, the more stringent heating requirements have to be used for both areas.
Long Term Fixes: Thermal separation of functional areas.

- By thermally separating the different functional areas, a significant amount of energy used for heating the facility could be saved.
- This strategy has been adopted in the “New Lucas” County Garage.
- Separating the truck washing area from the rest of the facility had an added benefit of reducing corrosion effect of the used wash water that is mixed with salt.
- Such salt-mixed water caused corrosion of structural steel in some of the visited facilities.
- Some ODOT facility personnel also reported that the salt mixed water caused rusting of their personal vehicles.
Long Term Fixes: Waste oil heater.

• One gallon of waste oil has the same heat content as 1.4 ccf of natural gas.

• Annual cost savings resulting from using a waste oil heater can be calculated knowing the following:
  Annual savings = \( V_{wo} \times ((1.4 \times C_g) - R_{wo}) \)

  \begin{itemize}
  \item \( C_g \) = Cost of natural gas = $1/ccf (typical current cost for ODOT facilities)
  \item \( V_{wo} \) = Volume of waste oil generated each year by facility = 500 Gallons (assumed)
  \item \( R_{wo} \) = Revenue generated from selling used oil $0.5/Gallon (assumed)
  \end{itemize}

• Then the annual savings from using a waste oil heater would be $450.
Lighting EE opportunities

At 17 percent, lighting accounts for a large portion of the total energy cost in a maintenance facility. Efficient lamps, fixtures, and controls save money and improve working conditions.

**Quick Fixes**

- Switch off unnecessary lights; rely on daylighting whenever possible.
  - Added advantage in summer: less heat
## Quick Fixes

- Use occupancy sensors to turn light off when no one is in room (This is specially important because highway workers are in the facility for a short time)
- Use photo sensors to turn electric light off when there is enough daylight
- Use Dimmers to reduce lighting when not needed
- Reduce ambient lighting and complement with task lighting
Lighting EE opportunities

Long term fixes: Replace MH lamps in Garage with High Intensity Fluorescent (HIF)

• Choose T5HO or Super T8 linear fluorescent fixtures in place of metal halide options to use less energy for the same amount of light and better color rendering, in addition to uniform light distribution
  • Ability to add energy saving occupancy sensors (shorter start and restrike time)

Figure 4.25. Before and after pictures of a Trident Seafood facility where MH lamps were replaced with HIF lamps (Seattle Government- Energy Smart Services).
Quick Fixes

• Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety.
• Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.
• Fix compressor leaks
Quick Fixes

• Encourage “energy conservation” behavior
• Encourage facility personnel to report leaks of water (both process water and dripping taps), and compressed air. Ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.
• Encourage other environment-friendly habits, such as recycling and using recycled or “green” materials.
Long term Fixes

• Seek input from facility personnel when designing new projects.
Key Results

- Energy use profiles for ODOT maintenance facilities
- Energy efficiency recommendations
- Three phase process for the selection of RETs
- Best practices for implementing RETs
Three phase process for RET Selection

<table>
<thead>
<tr>
<th>INTRODUCTION</th>
<th>RESEARCH OBJECTIVES</th>
<th>RESEARCH APPROACH</th>
<th>RESULTS</th>
<th>CONCLUSIONS &amp; RECOMMENDATIONS</th>
<th>IMPLEMENTATION</th>
</tr>
</thead>
</table>

- The research concluded that the factors which influence the feasibility of a RET project can be categorized into 3 categories: (1) statewide/institutional factors, (2) project physical factors, and (3) project financial factors.
- To be able to effectively assess the 3 categories of factors, the research team developed a 3-phases screening/evaluation process and developed a decision support tool for use in each phase.
The first phase of the screening/evaluation process is performed at the state level and considers the statewide/institutional factors that are similar throughout Ohio.

These factors for example include energy prices and facilities’ energy use profiles.

- Compared to other states, energy prices in Ohio are reasonable. Although good for Ohioans, reasonable energy prices make RET projects less feasible and make energy efficiency projects more practical.

- Energy use profiles for ODOT maintenance facilities are comparable; with space heating accounting for the majority of the energy demand. Therefore any energy efficiency or RET project should first consider reducing heating requirements.
The research team developed and used a state level decision matrix to rank RET projects at the state level. The State Level matrix provides a high level comparison of RETs and ranks them based on their overall applicability in highway maintenance facilities in Ohio. This matrix provides an initial screening mechanism without considering specific site conditions.

The research team used an excel spreadsheet to develop the state level matrix. The spreadsheet consists of several tabs.

The state level matrix compares different RET alternatives and ranks them based on 5 criteria: (1) environmental attributes, (2) reliability, (3) practicality, (4) maintenance, and (5) cost effectiveness.
**Evaluation Criteria**

- **Environmental attributes**: We considered the emissions reduction potential of the RET both during the manufacturing process during the operation. We also considered other environmental impacts such as site disturbance, ground water pollution, noise pollution, and social impacts.
- **Reliability**: We considered the maturity of the technology, its typical useful life, typical warranties, and ability to meet requirements without interruption.
- **Practicality**: We considered ease of construction/installation, special code/zoning requirements, availability of renewable resources in Ohio, and whether technology matches ODOT maintenance facilities’ energy demands’ patterns.
- **Maintenance**: We considered the complexity of required maintenance activities and their frequencies and costs.
- **Cost effectiveness**: We looked at the economic feasibility (both initial cost and total life cycle cost).
### Environmental Attributes

<table>
<thead>
<tr>
<th>Technology</th>
<th>Environmental Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Ventilation Preheating</td>
<td>1. Solar air reduces the amount of fossil fuel required to heat ODOT facilities in the winter which are typically heated using natural gas. Life cycle costing analysis performed by the research team as further described in Chapter 7 showed that each $12 of SAH collector approximately saves 1.76 ccf of natural gas each year. Each ccf of natural gas saved from SAH saves approximately 12 lb of CO2. 2. Solar energy is a renewable and free energy source 3. Since solar air heating reduces the costs associated with supplying more fresh air to a building, it encourages building operators to supply the appropriate amount of fresh air to the building thus improving indoor air quality. 4. By supplying the appropriate amount of fresh air to the building; SAH eliminates problems associated with negative air pressure in some ODOT facilities. Negative building air pressure occurs when the ventilation system exhausts more than the air brought in to the building. Negative building air pressure causes infiltration of cool air as well as annoying air currents through doorways and corridors.</td>
</tr>
<tr>
<td>Grid connected PV systems</td>
<td>There are many environmental benefits in using PV modules for generating electricity in ODOT maintenance facilities: 1. The lifetime emissions of GHG resulting from generating electricity using PV modules are 5 to 10 times less than if the same quantity of electricity is produced with fossil fuels. These emissions only occur during manufacture of the PV modules. The energy used in the manufacturing process of the PV modules is generated twenty times over during their useful lifetime. During operation, PV-modules produce no harmful emissions. 2. PV modules don't make any noise when generating electricity. This is a significant advantage when compared to a diesel or gasoline fired generator. 3. Solar energy is a renewable and free energy source. 4. Because PV modules generate electricity at the site of electrical consumption, they reduces both energy (kWh) and capacity (kW) losses in the utility distribution network.</td>
</tr>
<tr>
<td>Grid connected Wind systems</td>
<td>Wind turbines are reliable. NREL estimates that a financial return on investment is achieved in less than 10 years for systems providing electrical loads. The prolonged lifetime of these systems makes the payback period short, with a 25-30 year service life. The PV system can last 25 to 40 years, one of the highest useful lives of any of the RET technologies available in the market place. The financial return on investment is achieved in less than 10 years for systems providing electrical loads. The prolonged lifetime of these systems makes the payback period short, with a 25-30 year service life.</td>
</tr>
</tbody>
</table>
### Technology

<table>
<thead>
<tr>
<th>SAH systems are very practical as they are:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Easy to construct since there are no storage tanks or heat exchangers involved, which reduces complexity and costs.</td>
</tr>
<tr>
<td>- The solar collector can be installed on walls of different configurations. It can be installed on the entire wall or on part of the wall. Although it is easier to install a solar collector on a wall that has now windows or doors, wall openings can be accommodated.</td>
</tr>
<tr>
<td>- The amount of solar energy collected by the SAH system correlates well with ODOT heating demands; the vertical solar collector catches more sun during the winter, when the sun is low in the sky. Heating demands increase significantly in the winter in ODOT facilities because of the cold weather and longer hours of operation in case of snow storms.</td>
</tr>
<tr>
<td>- The color of the collector should be dark, but it does not have to be black. Most dark colors will not significantly reduce the collector output and thus provide flexibility to the design team for integrating the collector with the architectural design.</td>
</tr>
</tbody>
</table>

### Practicality

<table>
<thead>
<tr>
<th>Solar Ventilation Preheating</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV is a simple technology that can be easily installed in ODOT maintenance facilties. PV modules can easily be mounted on the roof of a structure. Roof mounted PV systems are very practical in ODOT maintenance facilities since they typically have large roof areas. They can also be mounted on the ground or on the building walls. When mounting PV modules on the roof of an existing building it is important to ensure that the roof is able support the additional weights of the modules and support structures and that the roof’s life is at least as long as the expected life of the PV modules. Roof mounted PV modules are more practical in new construction projects since roof life is typically longer than in existing projects. On existing projects, roof mounted PV systems may not be practical if roof is oriented east or west. Another advantage of a PV system is its modularity. PV is a scalable technology that can be put into place quickly and in any increment desired. PVs’ modularity permits the owners to start with a small system and add capacity over the years, in response to changes in the demand for electricity or the availability of capital. For ODOT facilities, the solar load correlation is negative since sunny periods coincide with lower than average electric loads during the summer. Although this is not a major concern for grid connected PV modules, it should be taken into consideration when sizing the PV system in order not to oversize the system. PV systems are very suitable for distributed integration with the utility grid because of the simplicity of these systems, their modularity and reliability. The distributed approach is potentially more suitable for Photovoltaics since it overcomes a major disadvantage of centralized PV power plants, in that distributed systems can be mounted on roofs and facades, whereas the cost of a large tract of land for a central PV power plant can be very significant.</td>
</tr>
</tbody>
</table>

### Maintenance

<table>
<thead>
<tr>
<th>Solar Ventilation Preheating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar air heating systems require little additional maintenance. The steel collector has the same maintenance requirements of the steel cladding it replaces, and can be repainted if necessary. The summer bypass damper is operated similar to other dampers in the ventilation system. Building ventilation fans need the same maintenance regardless of whether they draw air through a solar collector or a regular intake. The flow of warm air dried the space behind the collector, making it an uninviting environment for insects. The flow rate per unit area of collection is too low to draw dirt, pollen, dust, and snow towards the wall. Thus they do not clog the collector’s perforations and do not significantly lower the efficiency of the collector.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grid connected PV systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV systems contain few components and have very basic operating and maintenance procedures. The PV system, unlike wind turbines, bio mass systems or generators, is simple, very reliable, and can be maintained by people who have no background in power systems. This is particularly important for ODOT maintenance facilities which may not have adequate staff with proper expertise to operate complex power systems.</td>
</tr>
</tbody>
</table>
# 1st Phase of RET Selection process - tool

<table>
<thead>
<tr>
<th>Technology</th>
<th>Cost Effectiveness</th>
<th>New versus Existing Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solar Ventilation Preheating</strong></td>
<td>Properly designed and installed SAH systems have one of the shortest payback periods of any of the available RET technologies when incentives are not considered. On new projects, SAH systems may have simple payback periods as low as two to five years depending on the cost of the energy source they replace. The solar air heating system will last for decades, and continue to generate savings after it has paid back its initial costs. Solar air heating is most cost-effective when employed in new construction where the collector replaces some of the regular building cladding and allows the use of less expensive wall cladding material as a backing, reducing the net cost of the solar system. Also on new projects, the building ventilation system will be designed and situated so as to facilitate integration of the solar collector, avoiding additional ducting and fans. The next most cost-effective application of SAH is on retrofit projects that aim to renovate or repair an existing exterior wall, improve interior air quality, or eliminate negative air pressure problems. On these retrofit projects, the SAH system will benefit from the cladding credit, but may require minor modifications to the existing ventilation system.</td>
<td></td>
</tr>
<tr>
<td><strong>Grid connected PV systems</strong></td>
<td>Without financial incentives grid connected PV systems often have paybacks of 20 years or more, depending on the price of electricity saved. Simple payback periods are expected to decrease in the future as PV system costs continue to decrease and electricity rates continue to increase. It is important to use the most recent costs of PV modules when evaluating their economic feasibility. PV systems are much more feasible by taking advantage of available financial incentives and by selling solar renewable energy credits; payback periods can be as low as 6 years. The net cost of PV installations can also be reduced by using the modules to replace part of the building facade or roof, thereby saving on the cost of conventional materials. Such installations are referred to as building integrated photovoltaic (BIPV). Several PV manufacturers are BIPV modules which can be incorporated into buildings as standard building components such as roofing tiles and curtain walls. This helps reduce the relative cost of the PV power system by the cost of the conventional building materials. A large cost advantage of PV system in general is that the sun, the fuel for PV systems, is free, and thus protected from the price volatility that is always a concern with fossil fuels. Grid connected PV systems can successfully be implemented on both new and existing buildings. PV systems have some advantages when employed in new construction since the building can be oriented due south to optimize the PV system's energy performance. Also on new projects, if BIPV systems are used, the BIPV modules will replace some conventional building materials and will reduce the net cost of the BIPV system. On existing buildings, for roof-mounted PV installations, the roof should be in good condition. It should be able to support the additional weight of the modules and should last for the expected service life of the PV modules.</td>
<td></td>
</tr>
</tbody>
</table>
• The “RET General Info” contains a discussion of how each RET alternative performs against each evaluation criteria.

• It was important to include this discussion so that the decision maker using the matrix understands how the research team arrived at the score assigned to each RET alternative for each criterion.

• This tab also includes additional guidance information on how the feasibility of a given RET will vary based on whether the project is new construction or a retrofit of an existing building.

• The Final report contains more details such as the chart showing simple payback for solar space heating.
The “RET Ranking NB” contains a list of all RETs evaluated, scores with regards to the various ranking criteria, an overall weighted score and rank (compared to other RETs weighted score) for new buildings.
1st Phase of RET Selection process - conclusions

- Because electricity prices are currently more expensive than natural gas, RETs that reduce electricity consumption were generally found to be more economically feasible under present market conditions. These systems include solar photovoltaic and wind turbines.

- An exception to this general rule is the use of solar air heaters particularly if implemented on new construction projects.

  - Although a solar air heater reduces consumption of relatively inexpensive natural gas, its reasonable initial cost makes it one of the most feasible renewable energy technologies for ODOT maintenance facilities.
Since the feasibility of implementing RET technologies depends on whether the project is a new project or a retrofit, two state level decision matrices were developed; one for new construction projects and the other for existing buildings.

The “RET Ranking EB” tab shows the ranking of RETs for existing buildings.
New vs. Existing Buildings

- There was a need for including a separate tab for evaluating existing buildings since the feasibility of implementing RET technologies may change with existing buildings.
- For example, solar air heating is most cost-effective when employed in new construction since the collector replaces some form of regular building cladding, reducing the net cost of the solar system.
- Thus SAH has a higher score for cost effectiveness in “RET Ranking NB” than it does in “RET Ranking EB”.

Dr. Hazem Elzarka
1st Phase of RET Selection process - conclusions

- Solar air heating (SAH) and solar PV systems, in general, have the best potential in ODOT maintenance facilities.

- SAH systems reduce energy required for space heating which is currently provided by natural gas and as such their use can be a hedge against future increases in natural gas prices.

- SAH systems are most financially attractive in new construction where simple payback periods can be as low as 8 years.
• The capital costs of PV systems are high, but their operation and maintenance costs are very low. Typical payback periods for PV systems in Ohio are 25-30 years without considering financial incentives and/or selling solar renewable energy credits (SREC)s.

• The use of financial incentives and the ability to sell SRECs can significantly improve the economic feasibility of grid connected PV systems and reduce their payback periods to 7 years, but will require special arrangements.

• Such arrangements include involving a third party to take advantage of available incentives/tax credits and certifying the PV system with the proper agencies.
1st Phase of RET Selection process - conclusions

- A large cost advantage of PV systems in general is that the sun, the fuel for PV systems, is free, and thus protected from the price volatility that is always a concern with fossil fuels.

- Wind energy systems also have a similar advantage since the wind is free. However, wind energy systems’ performance significantly depends on wind speeds which are adequate only in some parts of Ohio, and they are more complex to maintain compared to PV systems.
1st Phase of RET Selection process - tool

- The “Resources” tab contains listings of manufacturers; and links to technology briefs, case studies, and reports..

<table>
<thead>
<tr>
<th>Rank</th>
<th>Technology</th>
<th>Other Case Studies</th>
<th>Popular Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Solar Ventilation Preheating</td>
<td>Selection Matrix/Case Studies/Other Case Studies/Booth_Hall_SolarWallCaseStudy_Y11.pdf</td>
<td>Solar Air Heating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection Matrix/Case Studies/Other Case Studies/SolarWall:SolarArticulatingBattery.pdf</td>
<td>Enerconcept Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection Matrix/Case Studies/Other Case Studies/SolarWall:SolarArticulatingBattery.pdf</td>
<td>Gram</td>
</tr>
<tr>
<td>4</td>
<td>Grid connected PV systems</td>
<td>Selection Matrix/Case Studies/FEMP Case Studies/Generating Energy at Channel Islands National Park.pdf</td>
<td>Conserva Engineering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection Matrix/Case Studies/FEMP Case Studies/Generating Energy Projects at NREL.pdf</td>
<td>Matrix Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection Matrix/Case Studies/FEMP Case Studies/Solar is Saving, Energy for the Alfred A. Arroyo U.S. Courthouse.pdf</td>
<td>Sunergy Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection Matrix/Case Studies/FEMP Case Studies/Solar is Saving, Energy for the Alfred A. Arroyo U.S. Courthouse.pdf</td>
<td>Sharp</td>
</tr>
<tr>
<td>5</td>
<td>Grid connected Wind Turbines</td>
<td>Selection Matrix/Case Studies/FEMP Case Studies/Generating Wind Energy Projects at NREL.pdf</td>
<td>Suntech</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection Matrix/Case Studies/FEMP Case Studies/Generating Wind Energy Projects at NREL.pdf</td>
<td>First Solar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection Matrix/Case Studies/FEMP Case Studies/Solar is Saving, Energy for the Alfred A. Arroyo U.S. Courthouse.pdf</td>
<td>Sun Power</td>
</tr>
</tbody>
</table>
1st Phase of RET Selection process - tool

- Several case studies for each technology are easily accessed from the spreadsheet.
The “Ranking criteria” tab contains more detail on the ranking criteria and the weights assigned to each criteria. Initially, the research team assigned equal weights to each of the five evaluation criteria (20%). However, the decision maker using the matrix can easily change the weights to match his/her project’s specific conditions. This will obviously change the overall score for each RET.
### Changing weights assigned to each criterion

- For example, if a decision maker knows that he/she has access to an experienced maintenance staff, then he/she should reduce the weight assigned to the maintenance criterion since maintenance is not going to be an issue.

- If on the other hand, the facility is located in an area where experienced maintenance personnel are not readily available, than the decision maker should increase the weight assigned to the maintenance criterion in order to select a system that requires less maintenance.

- Once the weights assigned to each criterion have been adjusted and a new ranking of the RETs established, the decision maker should use the site level decision matrix to evaluate if the top 3 RETs from the state matrix are good candidates at the project level and deserve further evaluation using life cycle costing assessment techniques.
As discussed above, the state level matrix provides an overall ranking of the studied RETs as they generally apply to highway maintenance facilities in Ohio.

It should be noted however that a RET may have a high overall ranking in the State level matrix, yet it is not suitable for a particular project.

For example, installing a large wind turbine to generate electricity from renewable wind energy may have a high overall ranking in Ohio but may not be suitable for an urban highway maintenance facility or not suitable for a facility where the majority of energy used is in the form of natural gas.

The site level matrix provides guidance for when a particular RET should and should not be selected under various specific site conditions, energy usage patterns and facilities goals.
### 2nd Phase of RET Selection process

- The **site level matrix** provides guidance for when a particular RET should and should not be selected under various specific project physical conditions.

- These conditions include building orientation, solar radiation, wind speed, shading from trees, terrain, condition of roof, and zoning requirements.
The spreadsheet consists of two tabs for favorable conditions and unfavorable conditions:

<table>
<thead>
<tr>
<th></th>
<th>Favorable Conditions</th>
<th>Unfavorable Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Existing Buildings - Favorable Conditions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Focus On Utilizing Technologies That Benefit From These Characteristics</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Available and adequate roof space, facing south or near south</td>
<td>X X</td>
</tr>
<tr>
<td>3</td>
<td>Available and adequate ground space that is not obstructed or surrounded by obstacles such as structures or tall trees</td>
<td>X X X X</td>
</tr>
<tr>
<td>4</td>
<td>Available space for storage of batteries and wiring to connect to RETs (if system generates excess energy)</td>
<td>X X</td>
</tr>
<tr>
<td>5</td>
<td>Structure roof is capable of supporting additional loads and is not subject to replacement in the near future</td>
<td>X X</td>
</tr>
<tr>
<td>6</td>
<td>Available and unobstructed exterior wall facing south or near south</td>
<td>X X</td>
</tr>
<tr>
<td>7</td>
<td>Adjustments to garage ventilation systems at southern wall will be uncomplicated</td>
<td>X X</td>
</tr>
<tr>
<td>8</td>
<td>No major shading obstructions in the southern portion of the facility site</td>
<td>X X</td>
</tr>
<tr>
<td>9</td>
<td>No concerns of structure aesthetics with the addition of RETs</td>
<td>X X</td>
</tr>
<tr>
<td>10</td>
<td>High need for hot water at the facility</td>
<td>X</td>
</tr>
<tr>
<td>11</td>
<td>Facility is in need of a new water heater</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>Water tank location will be easily connected to a rooftop or ground area system</td>
<td>X</td>
</tr>
<tr>
<td>13</td>
<td>Site has available space for excavation and soil installation</td>
<td>X</td>
</tr>
<tr>
<td>14</td>
<td>Site has a lake or pond to utilize geothermal energy</td>
<td>X</td>
</tr>
<tr>
<td>15</td>
<td>No nearby airports or other facilities that would restrict height of RET construction</td>
<td>X</td>
</tr>
<tr>
<td>16</td>
<td>Neighbors are far enough away to not be disturbed by sight or noise concerns</td>
<td>X</td>
</tr>
<tr>
<td>17</td>
<td>No environmental or zoning restrictions to RET construction</td>
<td>X</td>
</tr>
<tr>
<td>18</td>
<td>Facility has no limiting setbacks or spatial issues due to the proximity of roads or other structures</td>
<td>X</td>
</tr>
<tr>
<td>19</td>
<td>Easily available and cheap local fuel source</td>
<td>X</td>
</tr>
</tbody>
</table>
The spreadsheet consists of two tabs for favorable conditions and unfavorable conditions.
Factors affecting feasibility: PV

- Type of PV modules
- Orientation of Modules
  - Optimal performance is achieved for PV arrays that are south oriented
- Tilt angle
  - Best when modules tilted at an angle, with respect to the horizontal, about equal to the latitude.
- In general tilt angles of +/- 10 degrees from latitude, and orientations of +/- 30 degrees from true south do not appreciably change performance.
- Solar interferences on site: Shading analysis should be performed using solar path charts.
PV feasibility – Pike County Garage

- Garage built in 2009
- Type of PV modules
  - Large roof area: any type can be used
- Orientation of Modules
  - PV arrays should be south oriented.
  - PV on main building will be east or west oriented (Not good)
  - PV can potentially be installed on storage building (SE)
- Shading
  - Building and land areas are generally unshaded and provide solar access (good)
PV feasibility – Seneca County Garage

- Garage built in 1997
- Type of PV modules
  - Large roof area: any type can be used
- Orientation of Modules
  - PV arrays would be south oriented (perfect).
- Shading
  - Building and land areas are generally unshaded and provide solar access (good)
Factors affecting feasibility: Solarwall (SAH)

- Orientation
  - The Solar Wall should be south facing (true south), although orientations within 30 degrees of true south will still provide adequate solar energy capture.

- Solar interferences on site: Shading analysis should be performed using solar path charts.

- Architectural integration
Solarwall (SAH) feasibility: Pike County Garage

- **Orientation**
  - The Solar Wall should be south facing (true south), although orientations within 30 degrees of true south will still provide adequate solar energy capture.
  - South Wall is about 10 degrees of true south (good)

- **Shading**
  - South wall is unshaded (good)

- **Architectural integration**
  - Possible
Solarwall (SVH) feasibility: Seneca County Garage

- Orientation
  - South Wall is oriented south (good)
- Shading
  - South wall is shaded by shed (not good)
- Architectural integration
  - Not Possible
Factors affecting feasibility: Wind

- **Wind resources**
  - Wind speed (mph) and Wind Power Density (W/m²)
  - Power output from wind turbines increases exponentially with wind speed

<table>
<thead>
<tr>
<th>Wind Power Classification</th>
<th>Resource Potential</th>
<th>Wind Power Density at 50 m (W/m²)</th>
<th>Average Wind Speed at 50 m (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Marginal</td>
<td>200–300</td>
<td>12.5–14.3</td>
</tr>
<tr>
<td>3</td>
<td>Fair</td>
<td>300–400</td>
<td>14.3–15.7</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
<td>400–500</td>
<td>15.7–16.8</td>
</tr>
<tr>
<td>5</td>
<td>Excellent</td>
<td>500–600</td>
<td>16.8–17.9</td>
</tr>
<tr>
<td>6</td>
<td>Outstanding</td>
<td>600–800</td>
<td>17.9–19.7</td>
</tr>
<tr>
<td>7</td>
<td>Superb</td>
<td>&gt; 800</td>
<td>&gt; 19.7</td>
</tr>
</tbody>
</table>
Factors affecting feasibility: Wind

- Terrain
  - The most favorable turbine location at a given site will typically be at the highest elevation, have the smoothest land cover, and have few obstructions in the direction of the prevailing wind.
  - Terrain is considered in analysis through Wind Shear Value which has a significant impact on turbine Capacity factor.
  - The CF represents the actual annual energy output of a turbine as a fraction (or percentage) of the energy that the turbine would produce at full capacity.
  - There should be adequate space to place the turbine away from obstructions to prevent turbulent airflow.

<table>
<thead>
<tr>
<th>Land Cover Type</th>
<th>DSAT Terrain Roughness Category</th>
<th>Wind Shear Value (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Ice, open pavement, snow, level beach, water</td>
<td>Ice or pavement</td>
<td>0.08</td>
</tr>
<tr>
<td>b. Grass</td>
<td>Cut grass</td>
<td>0.15</td>
</tr>
<tr>
<td>c. Agricultural</td>
<td>Cropland/agricultural</td>
<td>0.21</td>
</tr>
<tr>
<td>d. Scattered</td>
<td>Scattered trees and hills</td>
<td>0.29</td>
</tr>
<tr>
<td>e. Sparse</td>
<td>Sparse forest</td>
<td>0.34</td>
</tr>
<tr>
<td>f. Suburban</td>
<td>Scattered buildings and suburban</td>
<td>0.34</td>
</tr>
<tr>
<td>g. Dense forest (50-100ft)</td>
<td>Dense forest</td>
<td>0.44</td>
</tr>
<tr>
<td>h. Urban</td>
<td></td>
<td>0.44</td>
</tr>
</tbody>
</table>

Table 3.1 Different types of terrain and their associated wind shear values (The Cadmus Group, 2012).

Figure 3.8. Obstacle clearance parameters for wind turbines (Source: http://www.smallwindtips.com/tag/tower-height/).
2nd Phase of RET Selection process

Preliminary Wind feasibility – Pike County Garage

- Wind resource: poor
- Terrain:
  - Scattered (Wind Shear Value = 0.29) (average)
- Possibility of good wind turbine location
  - Yes
2nd Phase of RET Selection process

Preliminary Wind feasibility – Seneca County Garage

- Wind resource: Marginal - fair
- Terrain:
  - Scattered (Wind Shear Value = 0.29) (average)
- Possibility of good wind turbine location
  - Yes
The third phase of the selection/evaluation process uses a Life Cycle Costing Assessment (LCCA) methodology to determine the economic feasibility of a RET project that passed the first two screening phases.

The LCCA considers the project financial factors that may have an impact on the economic feasibility.

These factors include initial costs, incentives, maintenance and replacement costs.

The LCCA calculates a suite of financial indicators to assess the profitability of the project.
3rd Phase of RET Selection process - tool

RETScreen Software

- [http://www.retscreen.net](http://www.retscreen.net)

- RETScreen (Renewable Energy Technology Screening software) conducts detailed LCCA analysis for projects and performs prefeasibility and feasibility studies to compare traditional energy sources to RET alternatives.

- RETScreen reduces the cost of doing prefeasibility and feasibility studies and enables more potential projects to be screened.
3rd Phase of RET Selection process - tool

RETScreen’s LCCA model

- LCCA model is very powerful and is capable of (1) considering all life cycle costs associated with design alternatives (2) accounting for various financial parameters and (3) performing several financial analyses.
3rd Phase of RET Selection process - tool

RETScreen Financial Analysis

- Can consider incentives, rebates, inflation rate, fuel escalation rate, debt ratio, debt interest rate, rate of electricity exported to grid, equipment depreciation for tax purposes, and greenhouse gas reduction income.

- RETScreen calculates a suite of financial indicators including simple payback, equity payback, internal rate of return (IRR), and net present value (NPV). RETScreen also displays a cumulative cash flow graph.
• The report includes results from several LCC analyses performed for the 3 most promising RETs for ODOT maintenance facilities as identified by the research; namely solar air heating systems, grid connected PV systems and grid connected wind energy systems.

• It is important to note that different decision-makers use different financial indicators to assess the life cycle cost feasibility of their projects.
  • For example, an investor might seek a ROI in excess of 8%, and a company might want a positive net present value at a discount rate of 10%.
  • The payback period is often used by small firms that may be cash poor. A project with a short payback period, but a low rate of return, is preferred over another project with a high rate of return, but a long payback period.
  • An acceptable payback also depends on the project’s owner. An institutional owner typically accepts payback periods in the 5 to 10 year range, whereas a private owner may require a payback period of 5 years or less.
### 3rd Phase of RET Selection process – PV case studies

<table>
<thead>
<tr>
<th>INTRODUCTION</th>
<th>RESEARCH OBJECTIVES</th>
<th>RESEARCH APPROACH</th>
<th>RESULTS</th>
<th>CONCLUSIONS &amp; RECOMMENDATIONS</th>
<th>IMPLEMENTATION</th>
</tr>
</thead>
</table>

- Since the cost-effectiveness of grid connected PV systems depends on financial incentives, two LCCAs of grid connected PV systems are discussed in the case study.
- The first LCCA is for a proposed retrofit of the Seneca county garage where the roof is properly oriented for optimal PV performance and where financial incentives were not considered. The second LCCA considers financial incentives for the proposed retrofit of Seneca county garage.
In order to perform a LCC analysis for a grid connected PV system, the system need to be designed to estimate its size and expected performance.

- RETScreen includes a large database of solar radiation so the user needs only enter the PV module’s nominal capacity (20 kW), the collector’s orientation (0) and tilt angle (35 degrees).

- In addition to design parameters, the LCCA also requires an estimate of life cycle costs (LCC) associated with PV system. These include initial cost, replacement cost, maintenance cost, service life, and electricity escalation rate. Initial cost of PV modules are about $3000/kW of nominal capacity and annual maintenance costs are about $20/kW/year.

<table>
<thead>
<tr>
<th>LCCA design parameters</th>
<th>Without Incentives</th>
<th>With Incentives</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV nominal kW</td>
<td>20 kW</td>
<td>20 kW</td>
</tr>
<tr>
<td>Cost $/kW</td>
<td>3,000 $/kW</td>
<td>3,000 $/kW</td>
</tr>
<tr>
<td>Annual maintenance $/kW</td>
<td>20 $/kW</td>
<td>20 $/kW</td>
</tr>
<tr>
<td>Inverter replacement cost in years 10,20</td>
<td>10,000 $</td>
<td>10,000 $</td>
</tr>
<tr>
<td>Electricity cost ($/kWh)</td>
<td>0.13 $/kWh</td>
<td>0.13 $/kWh</td>
</tr>
<tr>
<td>Azimuth</td>
<td>0 °</td>
<td>0 °</td>
</tr>
<tr>
<td>Tilt</td>
<td>35 °</td>
<td>35 °</td>
</tr>
<tr>
<td>Electricity escalation rate</td>
<td>5 %</td>
<td>5 %</td>
</tr>
<tr>
<td>Inflation rate</td>
<td>2 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Discount rate</td>
<td>2 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Project Life</td>
<td>30 years</td>
<td>30 years</td>
</tr>
<tr>
<td>Incentives</td>
<td>0 %</td>
<td>30 %</td>
</tr>
<tr>
<td>SREC ($/kWh)</td>
<td>0 $/kWh</td>
<td>0.1 $/kWh</td>
</tr>
<tr>
<td>Calculated area for PV modules</td>
<td>1270 sf</td>
<td>1270 sf</td>
</tr>
</tbody>
</table>
3rd Phase of RET Selection process – PV case studies

- RETScreen calculates the energy generated annually and the capacity factor. The capacity factor is the ratio of the average power produced by the power system over a year to its rated power capacity.

### LCCA financial results

<table>
<thead>
<tr>
<th></th>
<th>Without Incentives</th>
<th>With Incentives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity factor</td>
<td>14.20 %</td>
<td>14.20 %</td>
</tr>
<tr>
<td>Annual electricity generated</td>
<td>24.8 MWh</td>
<td>24.8 MWh</td>
</tr>
<tr>
<td>Total initial cost of PV system</td>
<td>60000 $</td>
<td>60000 $</td>
</tr>
<tr>
<td>Simple payback</td>
<td>21.2 years</td>
<td>7.9 years</td>
</tr>
<tr>
<td>Equity payback</td>
<td>16 years</td>
<td>6.5 years</td>
</tr>
<tr>
<td>IRR equity</td>
<td>6.3 %</td>
<td>17 %</td>
</tr>
<tr>
<td>Net Present Value</td>
<td>54,402 $</td>
<td>193,711 $</td>
</tr>
<tr>
<td>Annual Life Cycle savings $/yr</td>
<td>2,429 $/year</td>
<td>8,605 $/year</td>
</tr>
<tr>
<td>Benefit/Cost ratio</td>
<td>1.91</td>
<td>4.21</td>
</tr>
<tr>
<td>GHG reduction cost ($/tCO2)</td>
<td>-174 $/tCO2</td>
<td>-619 $/tCO2</td>
</tr>
<tr>
<td>Net Annual GHG reduction</td>
<td>14 tCO2/year</td>
<td>14 tCO2/year</td>
</tr>
<tr>
<td>Net GHG reduction (30 years)</td>
<td>420 tCO2</td>
<td>420 tCO2</td>
</tr>
</tbody>
</table>
Key Results

- Energy use profiles for ODOT maintenance facilities
- Energy efficiency recommendations
- Three phase process for the selection of RETs
- Best practices for implementing RETs
RET incentives

- [http://www.dsireusa.org/](http://www.dsireusa.org/)
- Business energy investment tax credit (30% of up-front cost for systems that are placed into service by December 31, 2016)
- As a state agency, ODOT may be ineligible for many of these federal incentives. Private developers, however, can take advantage of them.
- This becomes a key consideration in deciding whether to fund projects directly or enter into a contract with a third party to be able to take advantage of federal incentives
Best practices for implementing RETs

RET incentives

- [http://energizeohio.osu.edu/incentives](http://energizeohio.osu.edu/incentives)

- Before planning on receiving an incentive it is a good practice to confirm that it will still be offered when the project is completed and that the project can still apply for it

<table>
<thead>
<tr>
<th>Incentive Name</th>
<th>Available Funding</th>
<th>Technology</th>
<th>Specific Requirements</th>
<th>DSIRE Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEP Ohio - Renewable Energy Credit (REC) Purchase Program</td>
<td>Solar: $262.5/REC, Wind: $34/REC</td>
<td>Photovoltaic, Wind</td>
<td>AEP Customer. Solar-Wind systems must have a rated capacity of 100kW. Installed after Jan 1, 1998</td>
<td>Link</td>
</tr>
<tr>
<td>Commercial Custom Project Rebate Program</td>
<td>$0.08/kWh - $100/kW (50% of cost up to $300,000)</td>
<td>Energy Efficient Building Equipment</td>
<td>Equipment must be new and not covered by other AEP incentive</td>
<td>Link</td>
</tr>
<tr>
<td>Commercial Energy Efficiency Rebate Program</td>
<td>Various Rebates by Equipment</td>
<td>Energy Efficient Building Equipment</td>
<td>Equipment must be new</td>
<td>Link</td>
</tr>
<tr>
<td>Commercial New Construction Energy Efficiency Rebate Program</td>
<td>Various Rebates (Max: 50% of cost up to $50,000)</td>
<td>Energy Efficient Building Equipment</td>
<td>Equipment must be new</td>
<td>Link</td>
</tr>
<tr>
<td>Commercial Self Direct Rebate Program</td>
<td>Up to $45,000 business entity, $22,000 project</td>
<td>Energy Efficient Building Equipment</td>
<td>Equipment must be new. Must use more than 700,000kWh. Projects since 2008</td>
<td>Link</td>
</tr>
<tr>
<td>Renewable Energy Technology Program</td>
<td>Solar: $1.50/Watt, Wind: $0.275/kWh, Max: Res $60.50 or $12000, NonRes $60.50 or $25000, Res: Wind $50 or $7500, NonRes: Wind 40% or $12000</td>
<td>Photovoltaic, Wind</td>
<td>Customers must use the AEP net metering, and all equipment must comply with AEP Requirements.</td>
<td>Link</td>
</tr>
</tbody>
</table>

Table 5.1: List of incentives offered by the AEP Ohio.
Best practices for implementing RETs

Project Procurement / Contracting Best Practices

• Power purchase agreements (PPA)
  • PPA works on the basis of a private developer agreeing to fund, install, own, operate, and maintain customer-sited RET project. The customer signs an agreement to purchase the produced electricity from the developer through a long term contract (10 to 30 years) with specified energy prices
  • A PPA allows a facility pursuing a renewable energy system to place all capital costs on the developer
  • PPAs are driving most commercial PV installations
  • PPAs allow a RET project to take advantage of incentives that they would normally not be able to, such as the business energy investment tax credit, which leads to reduced energy costs.
Best practices for implementing RETs

Project Procurement / Contracting Best Practices

- Energy savings performance contracts (ESPC)
  - Typically used for financing energy efficiency projects
  - The agency contracts with an energy services company (ESCO) to implement an energy efficiency for one of its facilities.
  - Using an ESPC requires no up-front costs for the governing agency. Rather, the ESCO incurs all costs of implementing various energy projects, and then receives payment based on the resulting energy savings.
  - A measurement and verification professional is needed to verify estimated savings are taking place.
Best practices for implementing RETs

Selling RECs and SRECs

Selecting RET project team members

Managing RET project

Technology specific best practices
- PV systems
- Solar air heating systems
- Wind
- Solar hot water
- Biomass heating systems
- Ground source heat pumps
• The main objective of the research was to recommend strategies for reducing energy costs and associated GHG emissions in ODOT maintenance facilities.

• The research team has determined that the source of most of the energy used in ODOT maintenance facilities is natural gas and that space heating which accounts for the majority of energy needs are provided by natural gas.

• Natural gas prices are currently low but a sharp increase in their prices will significantly increase ODOT energy bills.
• Energy efficiency strategies often have a quicker payback and higher return on investment than renewable energy projects and will lead to lower energy costs and reduced greenhouse gas emissions.

• The research has recommended several energy efficiency strategies for existing and new ODOT facilities.

• Energy efficiency strategies have been identified for the heating and lighting systems, process equipment, and operation procedures. The energy efficiency strategies have been categorized as quick fixes or long term solutions.
Conclusions: RET Feasibility

- Because of low energy prices in Ohio, renewable energy projects in general have long payback periods.
- Economic feasibility significantly depends on site conditions
- Other reasons that may make RET projects in Ohio viable
  - Economic incentives
  - Hedge against inflation
  - Reducing Carbon footprint/ Net zero buildings
  - Comply with policies/regulations
- For new buildings, even if the initial analyses indicate that a solar energy system is not cost-effective, it may be beneficial to incorporate features that will facilitate the addition of solar systems at a later time.
Conclusions: RET Selection

• Because electricity prices are currently more expensive than natural gas, RETs that reduce electricity consumption were generally found to be more economically feasible under present market conditions. These systems include solar photovoltaic and wind turbines.

• An exception to this general rule is the use of solar air heaters particularly if implemented on new construction projects.

  • Although a solar air heater reduces consumption of relatively inexpensive natural gas, its reasonable initial cost makes it one of the most feasible renewable energy technologies for ODOT maintenance facilities.
• The research concluded that the factors which influence the feasibility of a RET project can be categorized into 3 categories: (1) statewide/institutional factors, (2) project physical factors, and (3) project financial factors.
• To be able to effectively assess the 3 categories of factors, the research team developed a 3-phases screening/evaluation process and developed a decision support tool for use in each phase.
There are several benefits to implementing the recommended RET systems as early as possible.

As these systems become more prevalent, the economic values of the renewable energy credit (REC) they generate decrease and the financial incentives offered by utilities expire.

Furthermore, there is currently a 30% tax credit for eligible RET systems that are placed into service by December 31, 2016.

Although ODOT as a state agency is not eligible for this tax credit, it can still indirectly take advantage of it by involving a private developer through a power purchase agreement (PPA)
• Some recommended energy efficiency strategies require energy modeling and daylight modeling software for proper evaluation.
  • These strategies include the thermal separation of functional areas and the use of daylighting strategies.
  • They are only applicable to new buildings but can potentially reduce energy consumption significantly.
  • The use of energy modeling and daylight modeling were beyond the scope of this project and the research team recommends a second phase of the project where such software is utilized for proper assessment.
Recommendations for future research

- If power purchase agreements and alternative financing options are used as recommended in Chapter 5, it is important to develop best practices for ODOT to use based on experiences of other state, federal agencies. Such best practices would be developed in Phase 2 of the research.
• Reducing energy cost and GHG emissions is a continuous on-going process
• The research team recommends that the University of Cincinnati continue working with ODOT on an on-going basis to help ODOT meet their energy cost reduction needs. This will:
  • Ensure the energy consumption data is complete
  • Identify any negative trends in energy consumption in a timely manner
  • Ensure that implemented energy efficiency and/or renewable energy strategies are achieving anticipated results
  • Ensure proposed best practices are being implemented
  • Provide measurement and verification support in case ESPC contracts are used
  • Provide support when detailed LCCA evaluations are needed for proposed projects.
  • Provide support when energy modeling and daylighting studies are needed during the design of new facilities.
• ODOT maintenance facilities consume a significant amount of energy annually (more than $2M as estimated by the research team), The proposed UC involvement will cost less than 2% of this annual budget and is expected to save much more than it costs.
Recommended energy efficiency quick fixes should be implemented immediately

- Quick fixes are those that would not require any substantial costs and could be achieved even with simple workforce behavioral changes.

- Implementing quick fixes will require training.

Long term heating energy efficiency recommendations should be implemented on all new projects and major renovations of existing projects.

- Re-lamping of maintenance facilities should occur every 5 years.
Some recommended energy efficiency strategies require energy modeling and daylight modeling software for proper evaluation.

- These strategies include the thermal separation of functional areas and the use of daylighting strategies.
- They are only applicable to new buildings but can potentially reduce energy consumption significantly.
RET Selection

• It should be emphasized that the economic feasibility of an RET which depends on several project physical and financial factors can only be established through a detailed LCCA analysis.

• Results from several LCCA studies for RET implementations on existing ODOT facilities were performed and included in Chapter 7. However, it is important to perform a “new” detailed LCCA analysis for any RET project other than those included in Chapter 7.

• The research team recommends using the RETScreen software for the LCCA evaluation.
Discussions and Questions
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