Renewable Energy Sources Evaluation

Beverly, Massachusetts

Matt Tormey
Research Objective

• Explore and evaluate the potential for renewable energy sources in a New England community
• Evaluate two of three renewable sources: biomass, wind, solar
• Community Selected: Beverly, Massachusetts
• Follow an evaluation that was done in Poultney, Vermont and published in Renewable Energy Journal
• This article was used as an outline for renewable sources in Beverly
Location

- Northeast Region of Massachusetts
- Essex County
- Coastal City
- Borders Manchester, Wenham, Danvers, and Salem
- Established 1626
Demographics

• Total Population = 39,862 People
• Median Age = 38.3 Years Old
• 96% White
• Household Population = 37,692 Residents
• Housing Units = 16,275
• Actual Homes = 7,764

• 9 Schools
• 3 Fire Stations
• City Hall / Police Station
• 2 Libraries

Source: US Census 2000
## Energy Usage

### Massachusetts
- Total Electricity Consumption = 54 Trillion kWh in 2009
- Population = 6,547,629
- Electricity Consumption Per Capita = 8,302 kWh
- Cost per kWh = 14.27 cents, 4.65 cents higher than National average

### Beverly
- Total Electricity Consumption = 330 Million kWh in 2009
- Population = 39,862
- Electricity Consumption Per Capita = 8,302 kWh
- Cost = $47,224,328

Sources: EIA and US Census 2000 & 2010
Major Industries and Land Uses

- Primarily Residential
- Some Commercial
- Some Industrial
- Cummings Center
- Downtown Areas Mix of Residential and Commercial
- Parks and Playgrounds
- Few Ponds and Streams
- Coastal Beaches
Solar Now Inc.

- President Jimmy Carter Administration
- Authorized the construction of 8 experimental solar research facilities
- Dr. John W. Coleman Greenergy Park, located next to Beverly High School
- One of the largest of the 8 facilities and the only one still active
- Has been providing power to Beverly High School for 30 years

- Small wind turbine was installed to complement the solar panels
- Currently run by Solar Now Inc.

Source: www.solarnow.org
Solar Now Inc.

Pictures Taken By Matt Tormey 5/1/11
Cabot Street Apartment Building

Picture Take By Matt Tormey 5/1/11
# Data Needed for Analysis

**Shapefiles**
- Town Polygons
- Essex County Land Use
- 50 Meter Wind Speed Classification
- Parcel Polygons
- Protected Space Polygons
- Wetland Polygons
- 2000 Census Block Data Layer

**Other**
- Digital Elevation Model (DEM) 1/3 ARC
- Orthographic Photos 15 cm Resolution
Methodology For All Renewables

• Download All Data from Internet Sources (Mass GIS, USGS)
• Re-project All Data to Massachusetts State Plane Mainland Coordinate System if needed
• Cut Away Excess Data Outside of Beverly
• This streamlines the rest of the process by minimizing the data and reducing potential errors
Biomass Fuel In Beverly

Criteria
- Ruled out Agriculture
- Slopes Must be $\leq 20\%$
- Classified as Forest
- No Bodies of Water or Wetlands
- No Protected Space
- No Open Space
- No Conservation Land
- Parcel Size Over 2 Hectares
- Final Polygon Size Over 2 Hectares
- 1 ha = 70 odt, 1 odt = 15 million Btu, 3412 Btu = 1 kWh

Methodology
- Isolate Land Classified as Forest from the Land Use Shapefile
- Eliminate All Slopes $> 20\%$
- Exclude All Protected/ Open/ Conservation Land
- Exclude All Bodies of Water and Wetlands
- Eliminate All Parcels $< 2$ Hectares
- Eliminate All Remaining Polygons $< 2$ Hectares
- Calculated Acreage, Biomass Yields and Energy Content
# Biomass Tables

## Forest Acreage

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Forest Land</td>
<td>1390 ha</td>
</tr>
<tr>
<td>Slope &gt; 20%</td>
<td>87 ha</td>
</tr>
<tr>
<td>Open Space Excluded</td>
<td>375 ha</td>
</tr>
<tr>
<td>Parcel Size &lt; 2 ha</td>
<td>353 ha</td>
</tr>
<tr>
<td>Polygons &lt; 2 ha</td>
<td>39 ha</td>
</tr>
<tr>
<td>Total Excluded</td>
<td>854 ha</td>
</tr>
<tr>
<td>Remaining Forest Land</td>
<td>536 ha</td>
</tr>
</tbody>
</table>

## Forest Estimate of Biomass Yields (odt)

<table>
<thead>
<tr>
<th></th>
<th>Low (0.1%)</th>
<th>Medium (0.5%)</th>
<th>High (1.0%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (70 odt/ha/year)</td>
<td>37.50</td>
<td>187.50</td>
<td>375.00</td>
</tr>
</tbody>
</table>

## Forest Estimate of Energy Content (Btu)

<table>
<thead>
<tr>
<th></th>
<th>Low (0.1%)</th>
<th>Medium (0.5%)</th>
<th>High (1.0%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (70 odt/ha/year)</td>
<td>562,500,000</td>
<td>2,812,500,000</td>
<td>5,625,000,000</td>
</tr>
</tbody>
</table>
Wind Energy In Beverly

Criteria
- Slopes $\leq 60^\circ$
- Wind Classification $\geq 2$
- No Bodies of Water
- No Wetlands
- No Protected Space
- No Open Space
- No Conservation Land
- Turbine Height of 50 Meters
- Average Tree Height Roughly 30 meters
  - Three most common trees in Beverly
    - Eastern White Pine (80’-100’)
    - Red Maple (60’-90’)
    - Eastern Hemlock (100’)

Methodology
- Isolate Wind Classifications $\geq 2$
- Eliminate All Slopes $> 60^\circ$
- Exclude Wetlands
- Exclude Protected/ Open/ Conservation Land
- Select 3 points from the remaining locations
- Viewshed Analysis Performed with Turbine Heights of 50 meters
- Used DEM
- Layered resulting viewshed on top of 2000 Census Blocks
- Calculated Population Affected and Area

Source: Massachusetts Land Owners Association
### Wind Tables

#### Area Figures in Beverly, MA

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Area</td>
<td>4,006 ha</td>
</tr>
<tr>
<td>Slope &gt; 60 Excluded</td>
<td>342 ha</td>
</tr>
<tr>
<td>Protected Space Excluded</td>
<td>543 ha</td>
</tr>
<tr>
<td>Wetlands Excluded</td>
<td>164 ha</td>
</tr>
<tr>
<td>Wind Class &lt; 2 Excluded</td>
<td>511 ha</td>
</tr>
<tr>
<td>Total Excluded</td>
<td>1,560 ha</td>
</tr>
<tr>
<td>Total Available Lands</td>
<td>2,446 ha</td>
</tr>
</tbody>
</table>

#### Wind Turbine Site 1

<table>
<thead>
<tr>
<th>Approx. Location</th>
<th>Block # 2,004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Blocks Affected</td>
<td>154 out of 605</td>
</tr>
<tr>
<td>Total Viewshed Area</td>
<td>403 ha</td>
</tr>
<tr>
<td>Total Population Affected</td>
<td>2,478 Residents</td>
</tr>
</tbody>
</table>

#### Wind Turbine Site 2

<table>
<thead>
<tr>
<th>Approx. Location</th>
<th>Block # 9,001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Blocks Affected</td>
<td>245 out of 605</td>
</tr>
<tr>
<td>Total Viewshed Area</td>
<td>651 ha</td>
</tr>
<tr>
<td>Total Population Affected</td>
<td>6,147 Residents</td>
</tr>
</tbody>
</table>

#### Wind Turbine Site 3

<table>
<thead>
<tr>
<th>Approx. Location</th>
<th>Block # 5,014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Blocks Affected</td>
<td>142 out of 605</td>
</tr>
<tr>
<td>Total Viewshed Area</td>
<td>409 ha</td>
</tr>
<tr>
<td>Total Population Affected</td>
<td>2,271 Residents</td>
</tr>
</tbody>
</table>
Solar Radiation In Beverly

Criteria

- Buildings Owned by the City of Beverly
- 9 Schools
- 3 Fire Stations
- 2 Libraries
- City Hall / Police Station
- Radiation for 2011
- 50% Rooftop Availability
- 16% Efficiency
- 90% Transmission Rate

Methodology

- Calculate Solar Radiation for year 2011 using DEM
- Digitize Selected Buildings and created new vector file using Ortho Photos
- Calculate Rooftop Area
- Perform Zonal Statistics using the radiation and Digitized Buildings
- Combine Tables and Perform Calculations
<table>
<thead>
<tr>
<th>Building Name</th>
<th>Total Rooftop Area (m²)</th>
<th>Available Rooftop Area 50% (m²)</th>
<th>Zonal Radiation (WH/m²/yr)</th>
<th>Radiation on Building (KWh/m²/yr)</th>
<th>Energy Captured By Panels 16% (KWh/m²/yr)</th>
<th>Energy After 90% Transmission Rate (KWh/m²/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Hall/Police Station</td>
<td>864</td>
<td>432</td>
<td>1,202,419</td>
<td>519,445</td>
<td>83,111</td>
<td>74,800</td>
</tr>
<tr>
<td>Ayers Elementary School</td>
<td>6,180</td>
<td>3,090</td>
<td>1,200,685</td>
<td>3,710,116</td>
<td>593,619</td>
<td>534,257</td>
</tr>
<tr>
<td>Beverly High School</td>
<td>20,771</td>
<td>10,386</td>
<td>1,201,701</td>
<td>12,480,267</td>
<td>1,996,843</td>
<td>1,797,158</td>
</tr>
<tr>
<td>Briscoe Middle School</td>
<td>5,565</td>
<td>2,783</td>
<td>1,204,906</td>
<td>3,352,651</td>
<td>536,424</td>
<td>482,782</td>
</tr>
<tr>
<td>Centerville Elementary School</td>
<td>5,725</td>
<td>2,863</td>
<td>1,191,552</td>
<td>3,410,818</td>
<td>545,731</td>
<td>491,158</td>
</tr>
<tr>
<td>Cove Elementary School</td>
<td>6,357</td>
<td>3,179</td>
<td>1,205,520</td>
<td>3,831,796</td>
<td>613,079</td>
<td>551,771</td>
</tr>
<tr>
<td>Farms Library</td>
<td>462</td>
<td>231</td>
<td>1,210,979</td>
<td>279,736</td>
<td>44,758</td>
<td>40,282</td>
</tr>
<tr>
<td>Fire Department (Central Station)</td>
<td>486</td>
<td>243</td>
<td>1,215,573</td>
<td>295,384</td>
<td>47,261</td>
<td>42,535</td>
</tr>
<tr>
<td>Fire Department (Farms Station)</td>
<td>335</td>
<td>168</td>
<td>1,211,846</td>
<td>202,894</td>
<td>31,477</td>
<td>29,230</td>
</tr>
<tr>
<td>Fire Department (North Beverly)</td>
<td>288</td>
<td>144</td>
<td>1,210,730</td>
<td>174,345</td>
<td>27,885</td>
<td>25,106</td>
</tr>
<tr>
<td>Hennah Elementary School</td>
<td>6,722</td>
<td>3,361</td>
<td>1,205,993</td>
<td>4,053,344</td>
<td>648,535</td>
<td>583,682</td>
</tr>
<tr>
<td>Library</td>
<td>1,460</td>
<td>730</td>
<td>1,206,191</td>
<td>880,519</td>
<td>140,883</td>
<td>126,795</td>
</tr>
<tr>
<td>McKeown Elementary School</td>
<td>2,884</td>
<td>1,442</td>
<td>1,202,291</td>
<td>1,735,145</td>
<td>277,623</td>
<td>249,861</td>
</tr>
<tr>
<td>Memorial Middle School</td>
<td>4,871</td>
<td>2,485</td>
<td>1,206,883</td>
<td>2,999,709</td>
<td>479,953</td>
<td>431,958</td>
</tr>
<tr>
<td>North Beverly Elementary School</td>
<td>5,855</td>
<td>2,918</td>
<td>1,199,308</td>
<td>3,498,982</td>
<td>559,837</td>
<td>503,853</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td><strong>68,905</strong></td>
<td><strong>34,453</strong></td>
<td><strong>18,077,578</strong></td>
<td><strong>41,425,192</strong></td>
<td><strong>6,628,031</strong></td>
<td><strong>5,965,228</strong></td>
</tr>
</tbody>
</table>
Centerville School Digitized Sample
Results

- Potential for 1,666,178 kWh to be produced from biomass burning yearly
- Potential for 5,965,228 kWh to be produced from rooftop solar panels yearly
- Accounts for roughly 2% of Beverly’s electricity consumption
- A higher percent can be achieved by installing wind turbines in the eastern most part of Beverly
- Only 15 buildings were selected for solar panels which means more electricity can be produced with more buildings
- If the solar panels only power their own buildings, residents still benefit because they are paid for by tax payers
- Overall benefit by reducing electricity produced by Salem Power Plant
References


Questions?