Urban Energy Generation & Storage

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Introduction

- As of 2011, 82% of US population lives in "urban areas"
  - At least 1000 people per square mile
  - Energy intensity in these locations is amplified
    - Schools, health care, appliances, energy supply, transportation, food, clothing, water, and sewage
- In order to continue growth trends, a redesign of the city landscape is necessary
- Examples will be US based, specifically Chicago

The City Process

- Energy - Electricity
- Fresh water
- Food
- Natural Gas and Oil

- Productivity
- Wealth
- Happiness
- Innovation

- Waste Heat
- Garbage
- Sewage

Energy Sources

- Solar PV
- Wind turbines
- Energy storage utilization
- Mass recycling, composting and sewage reclamation programs
- Methane regeneration

Redesign – Energy Sources

- Solar PV on tall buildings
- Electrochromic technology
- http://www.onyxsolar.com/
- http://www.nsf.gov/news/special_reports/science_nation/sprayonsolar.jsp
- Chicago is perfectly positioned with long north/south arrangement to capture rays from rising/setting sun
- Potential Energy Generated
  - Capacity factor
  - Total area of tall buildings (>30 stories)
  - Utilization factor

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PV Buildings

$$P = \left(\frac{Avg\ Area}{bldg}\right)(\#bldgs)\left(\frac{W}{m^2}\right)\gamma * \alpha$$

- Where:
  - Feasibly, 300 bldgs tall enough
  - γ is capacity factor: 0.4 (% of day collected)
  - α is utilization factor: 0.1 (aka efficiency)
- Calculated power available: **43 MW**

Redesign – Energy Sources

- Wind capture in the "windy city"
  - Using modern wind turbines on building roofs
    - Vertical Axis Wind Turbines
  - Large scale wind farm in Lake Michigan
    - 3-5 MW turbine systems
- Rain capture from lake affect precipitation
  - Use in fresh water
  - More appropriate for energy storage

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VAWT

- Positioning VAWT on top of bldgs will allow direct power utilization
- Can be converted to electricity or used for pump storage
- On top of same 300 buildings, apply VAWT concept for feasibility study

Figure 2. Hybrid Darrieus and Savonius self starting Neoga turbine on top of a building.

Figure 3. Experimental concept for a vertical sail wind machine with a 3 kW rated output.

VAWT Power Generation

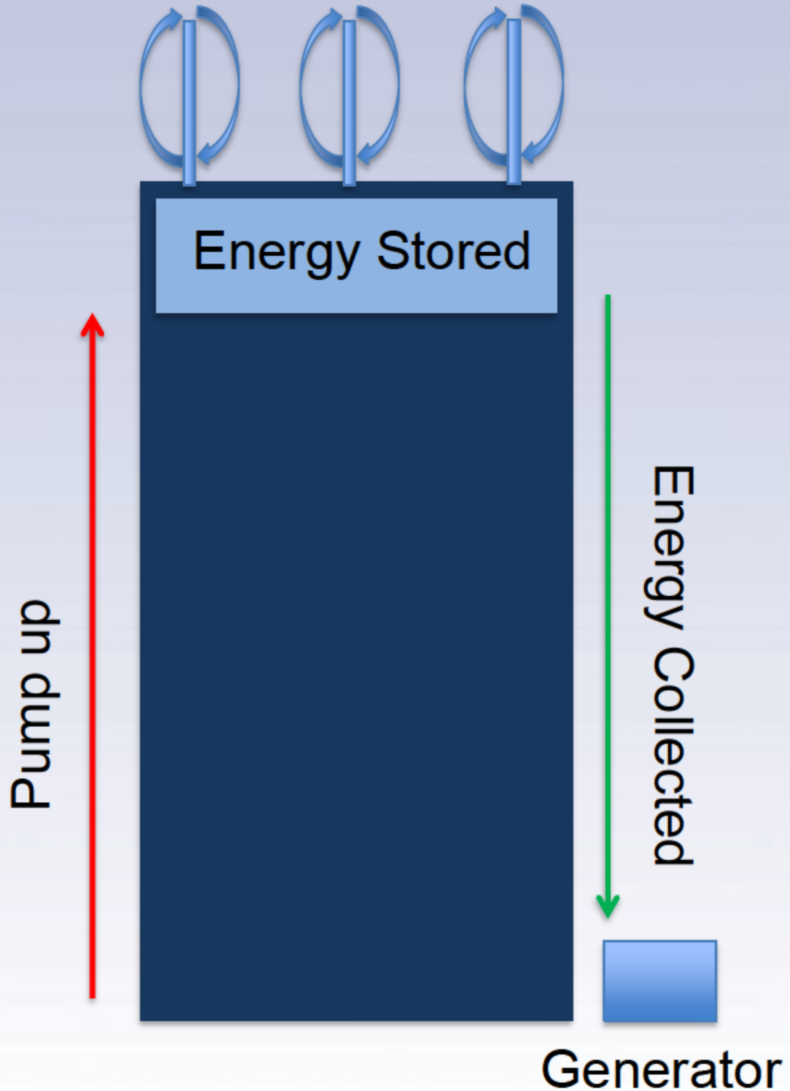
$$P = (\#bldg)\left(\frac{\#turbines}{bldg}\right)\left(\frac{W}{turbine}\right)\beta$$

- Where:
  - β is utilization factor (0.5)
  - 3 kW per turbine is used (efficiency accounted for here)

– Calculated power available: **13.5 MW**

Pumped Energy Storage

- Designate two floors of buildings to pumped water storage
- Buildings require pumps to move water up floors already
- Utilize HAWT to pump water for storage
- Capture precipitation
- Can also dampen swaying



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Potential Stored Energy

$$P = (\#bldg)\left(\frac{Volume}{bldg}\right)\left(\frac{m}{Volume}\right)(H)g$$

- Where:
  - H is average height
  - Volume is (average bldg width^2)*(2 stories)
- Calculated Energy stored: 7.063 GJ

- **Conceivable power output: 150 MW**
  - 500 kW generator at each building
  - full stored capacity would last 48 hours per building

Lake Michigan HAWT

- Lake Michigan has excellent wind resources
- Cost limited
- Pushback from lake conservationists

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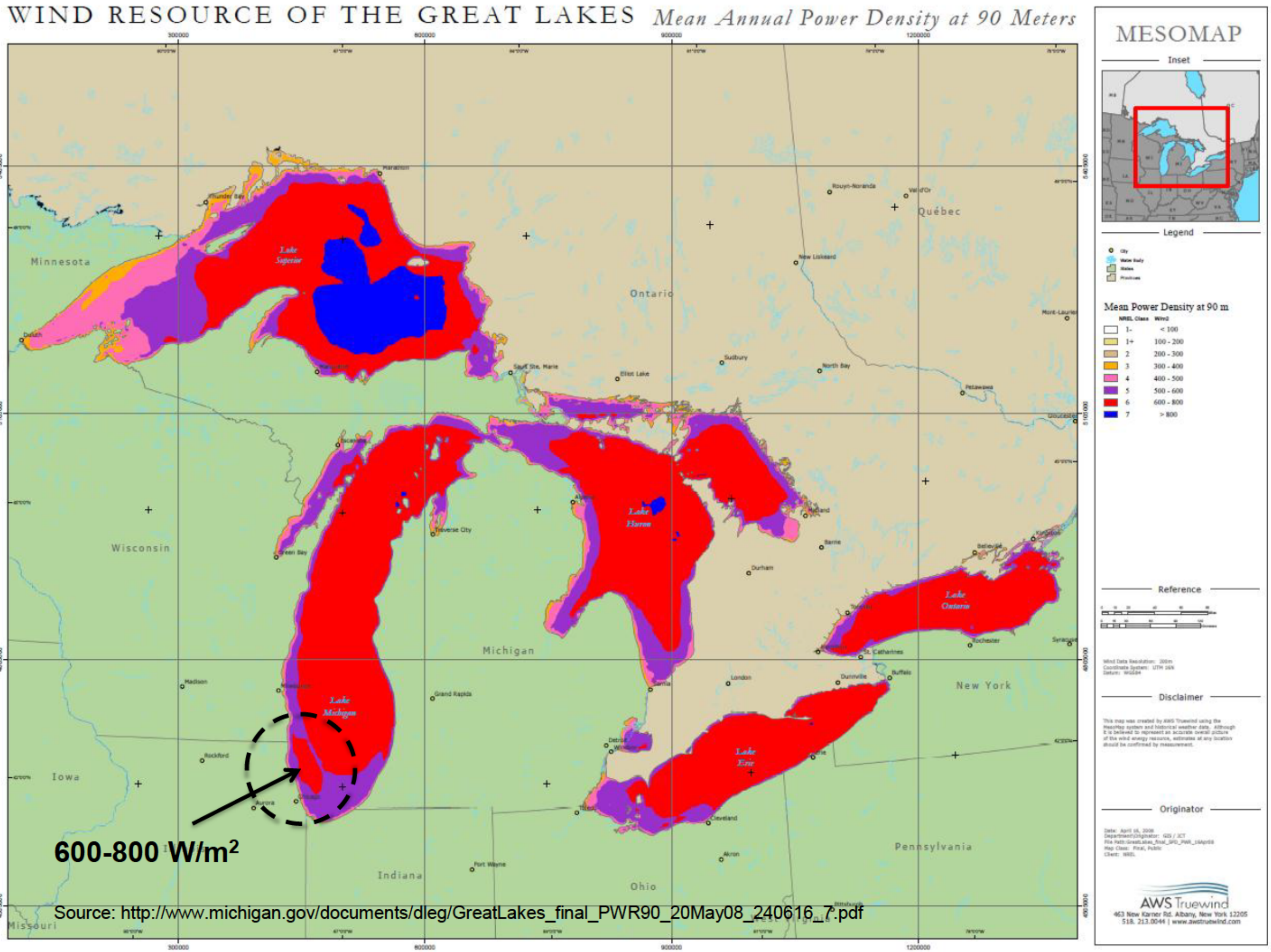

Source: http://www.michigan.gov/documents/dleg/GreatLakes_final_PWR90_20May08_240616_7.pdf

HAWT Power Output

$$P = (\#turbines)(Avg\ P)(\beta)\eta$$

- Where:
  - β is utilization factor (0.5)
  - 300 turbines
  - 3 MW normal output per turbine
  - η is power loss efficiency (0.7)
    - » Due to line loss
- **Conceivable power output: 315 MW**

Total Power Available

- Total Power available with treatment thus far:
  - 47 MW (PV)
  - 13.5 MW (HAWT)
  - 150 MW (max output from Pumped Storage)
  - 315 MW (VAWT)

- 525.5 MW available

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Power Needed

- To calculate power needed:

$$P = (\#pop)(Avg\ E)\left(\frac{1\ hr}{3600\ sec}\right)$$

- Where:
  - Illinois, average monthly consumption is 770 kWh
  - Potential Population affected sized at 5 million

- Calculated power needed (residential only): **1069 MW**

Continuing Calculations

- Using very conservative estimates:

$$\frac{P_{generated}}{P_{needed}} = \frac{525.5\ MW}{1069\ MW} = 49.15\%$$

- We can reduce a city's dependence on outside energy by almost 50%

Fiscally Responsible?

- PV modules show least ROI on capital
  - Significant reductions in cost per kWh will be necessary to justify expense
  - Higher efficiencies
- Buildings will have to be upgraded for new storage technologies
- Costs for Wind turbines are most competitive
  - Capital, operational & maintenance

Vision Revisited

- A future where city planners come together with architects, engineers and private enterprise to plan a framework for city to constantly evolve from
- Lay the foundation for a constantly evolving technological base

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City 2.0 Project

- Http://www.thecity2.org/
- Modifying the city:
  - For better access
  - Superior infrastructure
  - Modularity
  - Better resource distribution
  - Energy independence and redundancy
  - Higher quality of living
  - Higher efficiencies
  - More community involvement

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Sources

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