Fundamentals of Wind Energy

Paul Gipe, wind-works.org
Power in the Wind

\[ P = \frac{1}{2} \rho A V^3 \]

Where \( \rho \) is air density (kg/m\(^3\)), 
\( A \) is area (m\(^2\)), and 
\( V \) is velocity (m/s); thus 
\[ 2V^3 = 8P \]

Paul Gipe, wind-works.org
Seasonal Wind Distribution

Avg. Monthly Wind Speed (mph)

Month

Amarillo, Texas
Erie, Penn.
San Francisco, Calif.

Paul Gipe, wind-works.org
Rayleigh Wind Speed Distribution

Wind Speed Bin

Frequency of Occurrence %

0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Wind Speed Bin

5 m/s
6 m/s
7 m/s

Paul Gipe, wind-works.org
Increase in Wind Speed with Height

\[ V = V_0 \left( \frac{H}{H_0} \right)^\alpha \]

Wind Shear Exponent
- 0.1
- 0.14 (1/7)
- 0.2
- 0.25

Paul Gipe, wind-works.org
Increase in Power with Height

$P = P_0 \left( \frac{H}{H_0} \right)^{3\alpha}$

Wind Shear Exponent
- 0.1
- 0.14 (1/7)
- 0.2
- 0.25

Paul Gipe, wind-works.org
## Change in Wind Speed & Power with Height

<table>
<thead>
<tr>
<th></th>
<th>2 X Height</th>
<th>5 X Height</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind Speed</strong></td>
<td>1.1</td>
<td>1.25</td>
</tr>
<tr>
<td><strong>Wind Power</strong></td>
<td>1.35</td>
<td>1.99</td>
</tr>
</tbody>
</table>

1/7 (0.14), Low Grass Prairies

Paul Gipe, wind-works.org
Annual Energy Output (AEO) Estimating Methods

- **Back-of-the-Envelope (Swept Area)**
  Simple Approximation

- **Power Curve & Speed Distribution**
  Method Used by the Pros
  Accuracy Dependent Upon Data

- **Manufacturers’ Tables**
  Dependent Upon Honesty of Manufacturer

- **Software**
  Must Know Assumptions Used (RETScreen)

Paul Gipe, wind-works.org
Energy in the Wind
Annual Energy Output (AEO)
Annual Energy Production (AEP)

\[ \text{AEO} = \frac{1}{2} \rho A V^3 \eta \ (8,760 \text{ hrs/year}) \]

Paul Gipe, wind-works.org
Relative Size of Small Wind Turbines

Paul Gipe, wind-works.org
AEO for Small Wind Turbines
Per Square Meter of Swept Area

Average Annual Wind Speed (m/s)

Average Annual Wind Speed (mph)

Thousand kWh/year/m²
## Small Wind AEO

### Estimated Annual Energy Production for Small Wind Turbines

<table>
<thead>
<tr>
<th>Average Annual Wind Speed m/s</th>
<th>~mph</th>
<th>Power Density W/m²</th>
<th>Total Efficiency η</th>
<th>Average Annual Specific Yield kWh/m²/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>9.0</td>
<td>75</td>
<td>0.190</td>
<td>120</td>
</tr>
<tr>
<td>4.5</td>
<td>10.1</td>
<td>107</td>
<td>0.195</td>
<td>180</td>
</tr>
<tr>
<td>5.0</td>
<td>11.2</td>
<td>146</td>
<td>0.200</td>
<td>260</td>
</tr>
<tr>
<td>5.5</td>
<td>12.3</td>
<td>195</td>
<td>0.190</td>
<td>320</td>
</tr>
<tr>
<td>6.0</td>
<td>13.4</td>
<td>253</td>
<td>0.180</td>
<td>400</td>
</tr>
<tr>
<td>6.5</td>
<td>14.6</td>
<td>321</td>
<td>0.175</td>
<td>490</td>
</tr>
<tr>
<td>7.0</td>
<td>15.7</td>
<td>401</td>
<td>0.170</td>
<td>600</td>
</tr>
<tr>
<td>7.5</td>
<td>16.8</td>
<td>494</td>
<td>0.160</td>
<td>690</td>
</tr>
<tr>
<td>8</td>
<td>17.9</td>
<td>599</td>
<td>0.150</td>
<td>790</td>
</tr>
<tr>
<td>8.5</td>
<td>19.0</td>
<td>718</td>
<td>0.145</td>
<td>910</td>
</tr>
<tr>
<td>9</td>
<td>20.2</td>
<td>853</td>
<td>0.140</td>
<td>1,050</td>
</tr>
</tbody>
</table>

Note: Gross generation for a single turbine at hub-height wind speed, based on published manufacturer's data. Actual performance will vary.

Paul Gipe, wind-works.org
Small Wind AEO Example

- Aircon 7.1 m
- Area = 40 m²
- @ 6.5 m/s hub height avg. wind speed
- Yield: ~500 kWh/m²/yr
- 40 m² x 500 kWh/m²/yr ~20,000 kWh/yr

Paul Gipe, wind-works.org
Sample Power Curve Calculation

Power Curve

Kilowatts

Wind Speed (mph)

Paul Gipe, wind-works.org
Sample Power Curve Calculation
Speed Distribution

Hours per Year

Wind Speed (mph)

Paul Gipe, wind-works.org
Sample Power Curve Calculation

Annual Energy Production

Paul Gipe, wind-works.org
Why Small Wind in California? What is the Purpose or Objective?

• Lawn Ornament?
  “Whirlygigs are Cheaper”

• LEED Points?

• Break Even?
  At Least Not “Lose My Shirt”

• Make Money?
  How Much? What is Profitable Enough?

• Customer Demands It?
  “Despite What I Tell Him”

Paul Gipe, wind-works.org
Small Wind for California

• **Product Choice Limited**
  Only 3-4 Products Worthy of Consideration

• **Sites Limited**
  Geographic Diversity Problematic
  High Desert Good
  Coastal Sites Good
  Urban Agglomerations Not Good
  Central Valley Not Good

Paul Gipe, wind-works.org
CEC Emerging Renewables

- Traditional Stepped Subsidy
- Two Tranches
  - $2,500/kW < 10 kW
  - $1,500/kW > 10 kW < 30 kW
- Product Must be Certified to Qualify
- No Measurements & No Monitoring
- Bureaucratic & Cumbersome

Paul Gipe, wind-works.org
CEC Emerging Renewables Results

- $8 million in Subsidies for Small Wind in 11 Years

Paul Gipe, wind-works.org
Tehachapi, California
California Small Wind Program Results

- Since 1999--11 Years
- Total Installed: 560 units
- Total Installed: 3.6 MW!
- Average: 50 units/yr; 250 kW/yr
- No Performance Data!
- No Reports!

Paul Gipe, wind-works.org
<table>
<thead>
<tr>
<th>Size</th>
<th>Subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 kW</td>
<td>$2,500/kW</td>
</tr>
<tr>
<td>&gt;10 kW&lt;30 kW</td>
<td>$1,500/kW</td>
</tr>
</tbody>
</table>

Paul Gipe, wind-works.org
## CEC Small Wind “Buy Down”

### 15 kW Example

<table>
<thead>
<tr>
<th>Size</th>
<th>Subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 kW</td>
<td>10 kW X $2,500/kW</td>
</tr>
<tr>
<td>&gt;10 kW&lt;30 kW</td>
<td>5 kW X $1,500/kW</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

Paul Gipe, wind-works.org
## California Small Wind Subsidy Calculation

Bergey 10 kW

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed cost</td>
<td>$65,000</td>
</tr>
<tr>
<td>CEC Buy Down</td>
<td>-$25,000</td>
</tr>
<tr>
<td>Sub Total</td>
<td>$40,000</td>
</tr>
<tr>
<td>Federal ITC (30%)</td>
<td>-$12,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$28,000</strong></td>
</tr>
</tbody>
</table>

80-foot (24 m) guyed tower

Paul Gipe, wind-works.org
California Small Wind Subsidy Calculation
Skystream 3.7 (1.8-2.4 kW)

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed cost</td>
<td>$18,000</td>
</tr>
<tr>
<td>CEC Buy Down</td>
<td>-$6,000</td>
</tr>
<tr>
<td>Sub Total</td>
<td>$12,000</td>
</tr>
<tr>
<td>Federal ITC (30%)</td>
<td>-$3,600</td>
</tr>
<tr>
<td>Total</td>
<td>$8,400</td>
</tr>
</tbody>
</table>

33-foot, 10 m tower.

Paul Gipe, wind-works.org
CEC & DyoCore: A Cautionary Tale

- DyoCore Solar 1.2 m Diameter
- 1.1 m² Swept Area
- “Rated Power: 1,600 W!
- Comparable Turbines
  - Ampair: 300 W
  - Air Breeze: 200 W
  - Actual: 125 W

Paul Gipe, wind-works.org
CEC & DyoCore: A Cautionary Tale

• Result?
  CEC Subsidies = Cost of Turbine
  A Wind Turbine “for Free” = Irresistable
  CEC Flooded with Rebate Applications
  Program Suspended (Temporarily)
  CEC Initiates Action Against Dyocore

Paul Gipe, wind-works.org
CEC & DyoCore: A Cautionary Tale

- DyoCore Over-rated by 10 Times
- Just Shy of World Wind Hype Record
- AEO Estimate = More Energy Than in the Wind
- CEC Now Requires Turbine Certification

Paul Gipe, wind-works.org
Who Was Responsible?

• Small Wind Turbine Industry
  Still No Certified Turbines in US

• CEC
  Capital Subsidies (Grants) Wrong Choice

• DyoCore

• Consumers
  Falling for “Too Good to be True”
Skystream
Minimum Payment Needed

Skystream, Alexandria, Indiana

Paul Gipe, wind-works.org
Skystream Tariff Needed

Assumptions

• 3.7 m Diameter, 11 m2
• 2.4 kW
• $18,000 Installed
• Yield from SWP Estimates*
• Annual Expenses: 4%

* Not Independently Verified.
Paul Gipe, wind-works.org
## Skystream Tariff Needed

### Chabot Profitability Index Method

<table>
<thead>
<tr>
<th>Average Weighted Cost of Capital Before Tax</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equity</strong></td>
<td><strong>ROE</strong></td>
</tr>
<tr>
<td><strong>Return on Equity</strong></td>
<td>13.0%</td>
</tr>
<tr>
<td><strong>Debt</strong></td>
<td>80%</td>
</tr>
<tr>
<td><strong>Interest on Debt</strong></td>
<td>6.94%</td>
</tr>
<tr>
<td><strong>Nominal AWCC</strong></td>
<td>0.0815</td>
</tr>
<tr>
<td><strong>Inflation</strong></td>
<td>3.0%</td>
</tr>
<tr>
<td><strong>AWCC real</strong></td>
<td>5.0%</td>
</tr>
</tbody>
</table>

Paul Gipe, wind-works.org
**Skystream 3.7 Tariff No Subsidies**

$\sim$\$0.45/kWh

<table>
<thead>
<tr>
<th>Assumptions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>kW</td>
</tr>
<tr>
<td>Rotor Diameter</td>
<td>m</td>
</tr>
<tr>
<td>Specific Installed Cost</td>
<td>$/m2</td>
</tr>
<tr>
<td>Federal ITC Rate</td>
<td></td>
</tr>
<tr>
<td>Annual Expenses</td>
<td>Kom on installed cost</td>
</tr>
<tr>
<td>Equity</td>
<td></td>
</tr>
<tr>
<td>Return on Equity</td>
<td>ROE</td>
</tr>
<tr>
<td>Interest on Debt</td>
<td></td>
</tr>
<tr>
<td>Loan Term</td>
<td>n years</td>
</tr>
<tr>
<td>Inflation</td>
<td></td>
</tr>
<tr>
<td>Generation</td>
<td>kWh/yr</td>
</tr>
<tr>
<td>Profitability Index Target</td>
<td>PI NPV/I</td>
</tr>
</tbody>
</table>

Paul Gipe, wind-works.org
Skystream Tariff Needed
$0.17-$0.45/kWh at 6 m/s

Paul Gipe, wind-works.org
Endurance (E3120 50 kW) Tariff

- 19 m Diameter, 290 m²
- 50 kW
- $400,000 Installed
- $1,400/m²
- Annual Expenses: 4%
Endurance (E3120 50 kW) Tariff

Paul Gipe, wind-works.org
Paying for Performance Leads to Maturity

• After 30 Years
  Time for Small Turbine Industry to Grow Up

Paul Gipe, wind-works.org
Capital Subsidies are Poor Public Policy

New Federal Subsidies Distort the US Small Wind Market: Or How to Increase the Power of the Skystream 3.7 with the Stroke of a Pen

November 14, 2008
By Paul Gipe

- Capital Subsidies Are Not Good Public Policy

Background

On October 3, 2008 the US Congress passed The Emergency Economic Stabilization Act (TARP), otherwise known as the banking bailout package. The bill also included $150 billion in renewable energy subsidies that trade associations and industry lobbyists had labored over for years.

The subsidies were, for the most part, in the form of tax credits on the capital invested, that is, an Investment Tax Credit (ITC) based on the cost of the system. For the first time in at least two decades, small wind turbines were included in the technologies that qualified for the ITC. The ITC will be available for eight years.

Paul Gipe, wind-works.org
## Worldwide Small Wind Tariffs

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>kW Range</th>
<th>Tariff ($/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portugal</td>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td></td>
<td>0.49</td>
</tr>
<tr>
<td>Britain 1.5 kW-15 kW</td>
<td></td>
<td>0.44</td>
</tr>
<tr>
<td>Israel &lt;50 kW</td>
<td></td>
<td>0.44</td>
</tr>
<tr>
<td>Britain &gt;15 kW&lt;100 kW</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>Israel &lt;15 kW</td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>Greece &lt;50 kW</td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>Switzerland &lt;10 kW</td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>Italy &lt;1 MW</td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>Vermont &lt;15 kW</td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td>Hawaii &lt;100 kW</td>
<td></td>
<td>0.14</td>
</tr>
<tr>
<td>Slovenia &lt;50 kW</td>
<td></td>
<td>0.13</td>
</tr>
<tr>
<td>Denmark &lt;25 kW Maximum</td>
<td></td>
<td>0.11</td>
</tr>
</tbody>
</table>

Paul Gipe, wind-works.org
Small and Household-size Wind Turbines

- General
  - Small Turbine Product Reviews
- Small Turbine Testing
  - Wulf Small Wind Turbine Test Field Results
- Inventions & Questionable Wind Turbines
  - Worst Turbine Install in History
  - Rooftop & Urban Wind
  - Vertical Axis Wind Turbines
  - Shrouded & Ducted Wind Turbines
- Feed-in Tariffs for Small Wind
- Accidents & Safety
- Reviews
- Auf Deutsch
- En Français
- More on Small Turbines
Summary: Small Wind for ZNE

• Unlikely Economic
  Under Current Conditions

• Site Unlikely Suitable
  Need Good Exposure
  Need Good Wind

• Use Only Certified Turbines
  Few Available at this Time

• Better Alternatives Exist
  Solar PV
  Community Ownership

Paul Gipe, wind-works.org
Community Wind

• Greater Acceptance
• More Power More Quickly
• More People Involved Locally
• More Money Locally
• More Jobs Locally

Paul Gipe, wind-works.org
What is Community Wind?

- **Local**
  Rooted in and Responsible to the Community

- **Locally Owned**
  Cooperative, First Nation, Farmer-Owned

- **Commercial-Scale Generation**

- **Small Projects Making a Big Difference**

Paul Gipe, wind-works.org
Why Community Wind?

- Participation = Greater Acceptance
- Distributed = Greater Resiliency
- Clean & Green (Mostly)
- Human Scale
- Enables Local Ownership
- New Cash Crop For Farmers
Lynetten Co-op København

- 7 x 600 kW
- 4 Owned by Co-op
- 3 Owned by Municipal Utility

Paul Gipe, wind-works.org
Wieringemeer
Noord Holland

- 5 x 600 kW
- Co-owned
  1/2 by Two Farmers
  1/4 by NEG-Micon
  1/4 by Utility
Middelgrunden Co-op København

- 20 x 2 MW Off-shore
- 1/2 Owned by Co-op
- 1/2 Owned by Utility
- 8,500 Investors
- €570 per Share
- Visible from Christiansborg Palace
German Co-ops (Bürgerbeteiligung)

• +200,000 Own Shares
• 80% Schleswig-Holstein
• 90% Nordfriesland Amt

Schauinsland, Germany

Paul Gipe, wind-works.org
German Ownership of Renewables in 2010: 53,000 MW

- Individuals: 40%
- Farmers: 11%
- Developers: 14%
- Utilities: 13%
- Investment Funds: 11%
- Industrial: 9%
- Others: 1%

www.unendlich-viel-energie.de
Paul Gipe, wind-works.org
Ownership of Renewables in Germany 2010

• 51% Farmers & Individuals
• Own 27,000 MW!

Wind, Solar, & Biogas
German Ownership of Wind in 2010: 27,000 MW

- Individuals: 52%
- Farmers: 21%
- Developers: 7%
- Utilities: 16%
- Investment Funds: 2%
- Industrial: 2%

14,500 MW ~$30 Billion!

www.unendlich-viel-energie.de
Paul Gipe, wind-works.org
## Co-Op & Farmer-Owned Wind

<table>
<thead>
<tr>
<th>Country</th>
<th>Farmer</th>
<th>Co-op</th>
<th>Corporate</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>60%</td>
<td>5%</td>
<td>35%</td>
</tr>
<tr>
<td>Germany</td>
<td>10%</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>Denmark</td>
<td>64%</td>
<td>24%</td>
<td>12%</td>
</tr>
<tr>
<td>Great Britain</td>
<td>1%</td>
<td>1%</td>
<td>98%</td>
</tr>
<tr>
<td>Spain</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Dave Toke, University of Birmingham, 2005, 2008

Paul Gipe, wind-works.org
Ontario’s Feed-in Tariffs

• No Subsidies or Grants
• Costs Borne by Ratepayers
  Not Taxpayers—More Egalitarian
• Community Wind Bonus
  Farmers Qualify ($0.01 CAD/kWh)
• Aboriginal Bonus ($0.015/kWh)

Paul Gipe, wind-works.org
Potential per Ontario Farm

- 2MW Turbine, 80 m Ø, 80 m Tower
- ~$5 million CAD Installed
- ~4 million kWh/Year (~6.5 m/s)
- ~$500,000 CAD/yr @ $0.145/kWh
- Simple Payback: ~10 Years
- After Payback: ~$500,000 CAD/yr

Paul Gipe, wind-works.org
Skibsted Fjord, Denmark
Stromrebellen (Electricity Rebels)

- Democratizing Generation
- Creating Local Investment
- Creating Local Jobs
- Creating Opportunity--and Hope
- Denmark, Germany, and France, Minnesota, Ontario and . . . ?

Paul Gipe, wind-works.org

Friedrich-Wilhelm-Lübke-Koog, Germany
Anton Bro
Thyborøn-Harboøre Vindmøllelaug

• Near Offshore
• Share Cooperative
• 4 x 2 MW
• 35 Million kWh/yr
• All Information Public
  on the Web

Paul Gipe, wind-works.org
Josef Pesch, Fesa

- 45 MW
- 60 million kWh/yr
- Just One of Many
Heinrich Bartelt, Dardesheim

- 62 MW Wind
- 380 kW Solar PV
- 5% Royalties
  - 1% for Nearby Villages
  - 2% for Landowners with Turbines
  - 2% for Landowners without Turbines

Paul Gipe, wind-works.org
François Pélissier, Erélia

- Le Haut des Ailes, Lorraine
- 32 MW

Objectives
- New Jobs Locally
- New Opportunity Locally
Community Wind

Is North America Being Left Behind?

• No
  Time to Get It Right
• It’s Not Easy Here
  Frustrating? Yes!
• Only the Beginning
  Minnesota & Ontario
Jim Young
One Tough Hombre
Medicine Bow, WY

• Rebuilt 65 kW
• Developed Project

Paul Gipe, wind-works.org
Phil Littler
Shafer Systems
Iowa

- 500,000 kWh/yr
- Local Landmark
- One Person Can Make a Difference

Paul Gipe, wind-works.org
Toronto’s WindShare . . . A Pioneer in Canada

Paul Gipe, wind-works.org
... And North America
WindShare
Toronto, Canada

• First Urban Turbine in N.A.
• Co-Owned
  WindShare Co-op
  450 Members
  Toronto Hydro
• Prominent Location
• Highly Visible
• Highly Popular

Paul Gipe, wind-works.org
Schleswig-Holstein, Germany
Conservative Government

• Doubling Land Area for Wind
• Raising Renewables from 50% to 100%
• Highest Density of Wind in Germany
• Highest Percent Locally Owned
• Wind Generates More than Coal, Oil, & Gas Combined
  Only Nuclear Produces More

Paul Gipe, wind-works.org
Schleswig-Holstein, Germany
Conservative Government
2015 Targets

- Wind: 3,000 MW to 5,000 MW
- ~Triple Solar PV
  540 MW to 1,400 MW
- Biogas: 300 MW*
  from 600 Plants

*Biogas USA: 50 MW in 2009.

Paul Gipe, wind-works.org
The Farmers of Nordfriesland

- 0.5% of California
  2,000 km²; 165,000 Population
- 850 MW of Wind
  90% Community-Owned
  6,000 Investors (4% of Population)
  <1% of Land
- 1.3 TWh/yr
  More than Altamont, More than San Gorgonio
  ~Tehachapi Pass
  €100 million ($150 million)/yr

Paul Gipe, wind-works.org
Friedrich-Wilhelm-Lübke-Koog, Germany
Electricity Rebels--the Rallying Cry

“Wind is a Local Resource. It is Our Resource. And We Want to Make Money from it.”--Wolfgang Paulsen (Stromrebelle)
Move From
A Culture of Consumption
to
A Culture of Conservation

--Ontario Premier Dalton McGuinty

Paul Gipe, wind-works.org

Montfort, Wisconsin
Move From A Nation of Consumers to A Nation of Producers

Paul Gipe, wind-works.org
Lackawanna, New York
No Time for Half-Measures

No Time to Lose

Paul Gipe, wind-works.org
We Need A Lot More Wind . . .

Matane, Quebec

Paul Gipe, wind-works.org
A Lot More Solar

Paul Gipe, wind-works.org
A Lot More Renewable Energy Technology for Life*

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