Wildlife and Wind Energy: An Emergy Analysis of Bird and Bat Impacts at Maple Ridge Wind Farm

David Riposo and Patrick Kangas

ABSTRACT

Climate change associated with industrial activity threatens environmental and economic systems worldwide. Wind power is one of several technologies that collectively could mitigate many of the adverse effects of global climate change if deployed at sufficient scale. The objective of this study was to explore wind energy-related wildlife impacts. Emergy analysis was performed to explore the total environmental costs and benefits of the Maple Ridge Wind Energy Facility in common units. Analysis suggests that the emergy of wildlife impact is small relative to the emergy yield of the facility. Implications of these results on the energy landscape of the future are discussed.

PROBLEM STATEMENT

Though often conflated, the words ‘renewable’ and ‘sustainable’ are not synonymous. Some renewable energy technologies are not sustainable. For example, scholarship suggests that making ethanol from corn has a low energy yield per unit energy input and that production processes rely on non-renewable resources such as coal, natural gas, and oil. Thus, despite the renewable feedstock, these ethanol products may be no more sustainable than the non-renewable fuels on which they depend.¹

Wind turbines are comprised of several components. Each of these incurs an energy cost and environmental impact. The tower and support structures are made of steel and may be taller than 100 m. The tower sits on a foundation typically comprised of steel reinforced concrete. The nacelle features a generator, gear system, main shaft, yaw system, flanges, and other components. Each of these components must be manufactured from primary materials, transported to the site, and assembled into turbines that must be connected to the grid and maintained over the project life cycle by highly trained operation and maintenance personnel.

Wind turbines also exact a toll on bird and bat populations. There is little scholarship exploring this phenomenon; however, government agencies and project developers have explored the issue in detail. The Government Accountability Office authored a seminal meta-analysis on the subject (GAO, 2005). Studies reviewed by GAO suggested bird and bat impacts associated with wind development were regionally severe. California was marked by impacts to raptor populations. West Virginia and Pennsylvania had high levels of bat mortality. Impacts in the rest of the country were less severe.

¹ There is debate about the sustainability of biofuels. Regarding corn-based ethanol for example, Pimentel (2003) contends that it has a low net energy yield. However, Farrell (2006) argues it has a positive net energy yield and “can contribute to energy and environmental goals.”
Figure 1. System diagram of adverse wildlife impact associated with wind energy development.

Figure 2. Energy systems diagram of the Maple Ridge Wind Energy Facility.

**METHODOLOGY**

Emergy analysis facilitates the comparison of diverse economic and ecological goods and services in common units. It’s therefore a tool well suited to evaluating the relative sustainability of electricity generation technologies like wind. Several studies have developed emergy yield ratios (EYRs) for wind energy (e.g., Odum 1976; Brown and Ulgiati, 2002), but none have examined modern turbines. The study by Brown and Ulgiati (2002) examined a wind farm featuring five 500 kW machines constructed for the municipality of Bologna, Italy by Riva Calzoni in 1996. Several other types of energy generation systems have been examined using emergy techniques (e.g., Odum, 2000; Brown and Ulgiati, 2002; Carraretto, 2004; Wang, 2005).

This study will employ emergy techniques to evaluate the Maple Ridge Wind Energy Facility in comparison to other types of electricity generation technology in order to gauge the sustainability of wind power relative to other electricity generation technologies.

Lenzen’s meta-analysis of 73 wind EROI studies (2002) suggests that wind energy technologies offer a favorable energy return. Different methods were used for many of the studies; many different turbine types and sizes were evaluated. Contemporary analyses offered more favorable energy returns than older studies. Studies of larger turbines offered more favorable returns than smaller turbines. For example, energy return ranged from just less than 1 for a 3 kW turbine in 1981 to more than 30 for a
1.5 MW manufactured in India in 1999. The few EYR analyses that have been performed on wind (Odum 1976; Brown and Ulgiati, 2002) also suggest that the technology is sustainable. Therefore, it is hypothesized that an evaluation of Maple Ridge Wind Energy Facility will suggest the facility is sustainable relative to other electricity generation technologies and that incidental takes of birds and bats do not substantially impact sustainability characteristics.

Maple Ridge Wind Energy Facility near Lowville, New York served as the target system for both the EROI and emergy analyses. Maple Ridge features 195 Vestas V82 1.65 MW turbines. Each turbine is about 80 m tall and features a swept rotor area of 5,281 m2 (Vestas, 2007). Maple Ridge is the largest wind energy facility in New York State.

Horizon Energy and PPM Energy published a report (PPM Energy and Horizon Energy, 2007) regarding bird and bat impacts at Maple Ridge in the preceding year. The U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (ACE), New York State Department of Environmental Conservation, developers (PPM and Horizon), and others reviewed methodology for the analysis. An independent firm conducted the analysis. Adverse wildlife impacts associated with 120 of the facility’s 190 turbines were included in the study. Iterative carcass surveys were performed in the vicinities of each of the turbines throughout the 2006 season. A total of 123 avian carcasses were observed. There was one raptor fatality attributed to rotor collision (Falco sparverius, an American Kestral). Twenty-six species of songbirds, one ruffed grouse, and two Canada Geese were also killed by rotor collisions. There were no carcasses of threatened or endangered species observed. A total of 326 bat carcasses were observed. Five species of bats were observed. No carcasses of threatened or endangered bats were observed. All species observed have been designated by the International Union for Conservation of Nature and Natural Resources as “species of least concern” (PPM Energy and Horizon Energy, 2007). Researchers performed mortality transects at certain turbines every 7 days, others every 3 days, and others daily throughout the season. The greatest numbers of mortality incidents were recorded at turbines searched daily. At turbines searched daily, there were 9.59 bird deaths/turbine/season and 24.53 bat deaths/turbine/year (PPM Energy and Horizon Energy, 2007). Transformities were developed for bird and bat populations in the region. Emergy values were calculated.

Riposo (2008) calculated emergy indices for the Maple Ridge Wind Energy facility. Table 1 summarizes this analysis. Appendix A provides assumptions and calculations. This analysis was employed herein to: 1) explore the sustainability implications of Maple Ridge Wind Energy facility relative to other electricity-generating facilities, and 2) quantify the impact of incidental takes on the facility’s sustainability characteristics.

Horizon Energy and PPM Energy published a report (PPM Energy and Horizon Energy, 2007) regarding bird and bat impacts at Maple Ridge in the preceding year. The U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (ACE), Environmental Design and Research (EDR), New York State Department of Environmental Conservation, developers (PPM and Horizon), and others reviewed methodology for the analysis. An independent firm conducted the analysis. Adverse wildlife impacts associated with 120 of the facility’s 190 turbines were included in the study. Iterative carcass surveys were performed in the vicinities of each of the turbines throughout the 2006 season. A total of 123 avian carcasses were observed. There was one raptor fatality attributed to rotor collision (Falco sparverius, an American Kestral). Twenty-six species of songbirds, one ruffed grouse, and two Canada Geese were also killed by rotor collisions. There were no carcasses of threatened or endangered species observed. A total of 326 bat carcasses were observed. Five species of bats were observed. No carcasses of threatened or endangered bats were observed. All species observed have been designated by the International Union for Conservation of Nature and Natural Resources as “species of least concern” (PPM Energy and Horizon Energy, 2007). Researchers performed mortality transects at certain turbines every 7 days, others every 3 days, and others daily throughout the season. The greatest numbers of mortality incidents were recorded at turbines searched daily. At turbines searched daily, there were 9.59 bird deaths/turbine/season and 24.53 bat deaths/turbine/year (PPM Energy and Horizon Energy, 2007). The mean biomass of birds impacted at Maple Ridge in
Table 1. Emergy analysis of Maple Ridge Wind Energy Facility (from Riposo, 2008).

<table>
<thead>
<tr>
<th>Note</th>
<th>Item</th>
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<td>j</td>
<td>1.59 E5</td>
<td>7.80 E21</td>
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</table>

2006 was 14.4 g dry weight. This figure excludes one 6 kg wild turkey discovered by researchers that may have been killed by a turbine. Walter (1979) indicates that the energy content of bird biomass is about 20,000 J/g. Therefore, energy lost to the system due to bird mortality may be calculated as follows:

\[(9.59 \text{ birds killed/turbine/season})(195 \text{ turbines})(14.4 \text{ g dry weight/bird})(20,000 \text{J/g})(20 \text{ years})\]

To calculate emergy lost to the system due to bird mortality, one must first calculate a transformity for birds. Bird transformity may be calculated by dividing the emergy of food consumed by the bird population by the bird energy flow. Energy flow in this context is defined as the total metabolic energy use plus biomass accretion per unit area. Holmes and Sturgis report the average annual energy intake of birds to be 73,858 kcal/ha/yr. Insects were assumed to be the primary forage for the birds in the vicinity of Maple Ridge. The Golden Crowned Kinglet is an insectivore (Holmes and Sturgis, 1979). Since this is the most impacted species, the aforementioned assumption is fair. The transformity for insects was obtained from the literature (Cohen, 2004) to determine emergy of food consumed. Holmes and Sturgis (1979) also present the average of total avian respiration plus net production for an experimental forest with species diversity comparable to Maple Ridge. The authors found annual avian energy flow to be 51,701 kcal/ha/yr. Figure 3 illustrates how the emergy associated with bird impact is derived from this data.

The median biomass of bats impacted at Maple Ridge in 2006 was 27 g dry weight. Bat biomass is assumed to have energy content comparable to that of birds. Walter (1979) indicates that the energy
The content of bird biomass is about 20,000 J/g. Therefore, energy lost to the system due to bat mortality may be calculated as follows:

\[
(24.53 \text{ bats killed/turbine/season})(195 \text{ turbines})(27 \text{ g dry wt/bat})(20,000 \text{ J/g})(20 \text{ yrs})
\]

To calculate emergy lost to the system due to bat mortality, one must first calculate transformity for bats. Bat transformity may be calculated by dividing the emergy of food consumed by the bat population by the bird energy flow. Energy flow in this context is defined as the total metabolic energy use plus biomass accretion per unit area. de la Cueva Salcedo (2005) determined that the diet of the Hoary Bat consists primarily of moths and other insects. Reddy estimated that the Hoary Bat consumed about 262,800 insects per year. Vshivkova (2003) determined an average energy density of 1895 j/g dry weight for certain moths. The transformity for insects was obtained from the literature (Cohen, 2004) to determine emergy of food consumed. There are few authoritative studies regarding the population ecology of the Hoary Bat, though studies of behavioral ecology suggest they are solitary and have large home ranges (e.g., Shump and Shump, 1982). A modeling tool available through the Foothills Model Forest Network (Foothills Model Forest, 1999; pg HOBA-2) proposes that Hoary Bats thrive at a population density of two individuals per hectare on agricultural land. Figure 4 illustrates how the emergy associated with bat impact is derived from this data.

EYR is the emergy cost of the yield produced per unit of emergy contributed by the main economy (seJ/seJ). In an electricity generation context, emergy cost is a function of renewable (R) and non-renewable resources (N) consumed in the construction, operation and maintenance of the facility and the goods and services purchased to support the facility (F). In an electricity generation context, emergy yield (Y) refers to electricity generation.

RESULTS

Figure 5 illustrates where Maple Ridge falls among energy generating technologies in terms of Emergy Yield Ratio. EYR values for other energy generating facilities were gathered from Odum.
Figure 4. Emergy of bat impact at Maple Ridge.

Figure 5. Emergy Yield Ratio (EYR) for energy generating technologies with Maple Ridge highlighted in bold.
The dark grey bars represent data gathered from Brown and Ulgiati (2003) and the light grey bars represent data gathered from Odum (1996).

Total renewable inputs to the Maple Ridge system are $2.26 \times 10^20$ sej. $R$ is comprised of wind, land appropriation, and wildlife impact (see Table 1, items 1-4). Wildlife impact is small relative to $R$. Total bird and bat impact is $3.55 \times 10^17$ or less than one percent of the total renewable input. Total yield of the Maple Ridge system is $7.8 \times 10^21$. Emergy associated with total bird and bat impact is a negligible percentage of the total emergy yield.

These data suggest that the Maple Ridge Wind Energy Facility has a high emergy yield relative to other electricity-generating technologies. They suggest that wildlife impacts are small relative to the emergy yield. These data support the hypothesis that Maple Ridge is a sustainable enterprise and that incidental takes of birds and bats do not substantially impact sustainability characteristics.

**CONCLUSION**

Although Maple Ridge earns high marks for sustainability, wildlife issues will impact the wider wind industry. The magnitude of wildlife impact will increase as wind energy facilities proliferate into migratory flyways and critical habitat. Endangered species will be impacted with increased frequency and regional biodiversity may be threatened. The transformity of endangered species is higher than that of common species (Personal communication, Mark Brown, 3 January, 2008), so the cumulative impact of this phenomenon could be significant in emergy terms.

**REFERENCES**


APPENDIX A

1. National Renewable Energy Lab (1986) National Renewable Energy Laboratory describes the 1/7 power rule whereby wind speed aloft may be calculated based on anemometer measurements:
   \[ \frac{u}{u_0} = \left( \frac{z}{z_0} \right)^{1/7} \]
   where, \( u \) = the wind speed at a reference height, \( u_0 \) = the wind speed at a height \( z \)
   \( z_0 \) = height for which wind speed is under investigation

   AWS Truewind (2007) indicates that wind resource is class 3 throughout the installation. AWEA (2007) indicates that class three resource is characterized by, on average, 6.7 m/s winds at 50 m. Hub height of the Maple Ridge turbines is 82m (Vestas, 2007). Given these data points, one can calculate the wind speed at hub height using the 1/7 power law.
   \[ \frac{6.7}{u_0} = \left( \frac{50}{82} \right)^{1/7}, \quad u_0 = 7.2 \]

   Using this velocity, I can calculate the power in the area swept by the rotor.
   \[ P = \frac{1}{2} \cdot \rho \cdot \text{Area} \cdot V^3, \quad P = 235,425,966 \, W, \quad P = 41,246,629,251.61 \, kWh \text{ incident over project lifecycle}, \quad P = 1.48E+17 \, J \text{ incident over project lifecycle}, \quad \text{Wind energy not used} = (1 - 0.6) \times 1.2E6 \, W \times 31.5E6 \, sec/yr \times 195 \text{ turbines} \times 20 \text{ yrs} = 8.95E+17 \, J \]

2. Hectares directly appropriated = 84 (Horizon Wind, 2007). Land cover class = pasture, livestock (author’s observations, Winter, 2006). Empower density of pastureland with livestock = 8 E14 (Brown and Vivas, 2005). This is the value for “Woodland Pasture (with livestock)”. Emergy lost to land appropriation = (84 ha)*(8. E14 sej/ha/yr)*(20) = 1.34 E18 sej.

3. Appendix B suggests that the Hoary Bat (Lasiurus cinereus) is by far the most adversely impacted bat species. This species will be used as a proxy for the bat impact at Maple Ridge. There are few authoritative studies regarding the population ecology of the Hoary Bat, though studies of behavioral ecology suggest they are solitary and have large home ranges (e.g., Shump and Shump, 1982). Foothills Model Forest, 1999; pg HOBA-2 suggests 2 individuals per hectare on disturbed land. This comports with Shump and Shump’s contention that the Hoary Bat has a large home range.


   Bats killed by Maple Ridge over facility lifecycle = 95,667 (PPM Energy and Horizon Energy, 2007, p. 3). Assumed energy content of biomass similar to bird biomass. Energy content of biomass 20,000 j/g (Walter, 1979; pg 178-180). Lifecycle energy lost to the system = (20 yrs) * (95,667 + 1.56E6 sej/j)
bats/yr)(27 g average weight)(20,000 j/g) = 5.16 E10 j. Lifecycle emergy lost to the system = (5.16 E10 j)/(1.56 E6 sej/j) = 8.03 E16 sej.

4. Average annual energy intake or birds is 3.09 E11 j/yr (Holmes RT and Sturgies FW, 1974). Assumed most birds adversely impacted by the Maple Ridge facility are insectivores. Cohen (2004) reports transformity of “large aquatic insects” as 6.37 E4 sej/j. The emergy of food for birds is 1.97 E16 sej/ha. Total avian energy flow 51,701 kcal/ha/yr (Holmes RT and Sturgies FW, 1974, p. 191). This represents average of total avian respiration plus net production for the years 1969-1973. Transformity, Birds = (1.97 E16 sej/ha)/(51701 kcal/ha/yr * 4184 j/kcal) = 5.16 E06. Birds killed by Maple Ridge facility per year = 1,870 (PPM Energy and Horizon Energy, 2007, p. 3) [9.59 birds per turbine (high estimate) *195 turbines]. Mean biomass per bird = 14.43 (see Appendix A). Lifecycle biomass lost to the system = (1,870 birds per year)(14.43 g/bird)(20 years) = 539,682 g/20 years. Energy content of bird biomass = 20,000 j/g (Walter, 1979; p. 178-180). Lifecycle energy lost to the system = (26,984)(20,000) = 1.07 E10 j. Emergy lost to the system = (1.07 E10 j)/(5.16 E06 sej/j) = 5.22 E16 sej.

5. Concrete consumed = 1.57 E11 g (Vestas, 2006). Transformity 1.44 E9 sej/g (Buranakarn, 1998), Emergy = (1.57 E11)(1.44 sej/g) = 2.26 E20 sej.


7. Fiberglass and composites consumed = 2.57 E9 g (Vestas, 2006). Includes fiberglass, epoxy, and balsawood framing materials for blades. Transformity = 7.64 E9 sej/g (Buranakarn, 1998). Emergy = (2.57 E9 g) (7.64 E9 sej/g) = 1.93 E19 sej.

8. Aluminum consumed = 2.51 E9 g (Vestas, 2006). Transformity = 1.27 E10 sej/g (Buranakarn, 1998; p. 143). Emergy = (2.51 E9 g)(1.27 E10 sej/g) = 3.19 E19 sej.

9. Copper consumed = 2.96 E8 g (Vestas, 2006). Transformity = 6.8 E10 (Buenfil, 2001; pg 197). Emergy = (2.96 E8 g)(6.8 E10 sej/g) = 2.01 E19 sej.

10. Cast iron consumed = 5.71 E9 g (Vestas, 2006). Transformity = 3.38 E9 (Odum, 1996; pg 186). Emergy = (5.71 E9 g) (3.38 E9 sej/g) = 1.93 E19 sej.


13. Plastics consumed = 2.1 E9 g (Vestas, 2006; pg 16-17). Transformity = 3.8 E8 (Lagerberg and Brown, 1999, pg 429). Emergy = (2.1 E9 g)(3.8 E8 sej/g) = 7.98 E17 sej.

14. Paint consumed = 2.2 E6 g (ABB Power Transmission, 2003). Transformity = 1.5 E10 (Buranakarn, 1998, pg 199). Emergy = (2.2 E6 g)(1.5 E10 sej/g) = 3.3 E16 sej.

15. Wood consumed = 1.5 E7 g (ABB Power Transmission, 2003). Transformity = 8.08 E8 (Buranakarn, 1998, pg 69). Emergy = (1.5 E7 g)(8.08 E8 sej/g) = 1.21 E16 sej.

16. Insulation consumed = 6.5 E6 g (ABB Power Transmission, 2003). Transformity = 1.5 E9 (Brown and Ugliati, 2002; pg 327). Emergy = (6.5 E6 g)(1.5 E9 sej/g) = 9.75 E15 sej.

17. Porcelain consumed = 2.65 E6 g (ABB Power Transmission, 2003). Transformity = 3.06 E9 (Brown and Buranakarn, 2003; pg 13). Used value for “Ceramic tile with recycled glass”. Emergy = (2.65 E6 g)(3.06 E9 sej/g) = 8.11 E15 sej.

18. Capital cost of the Maple Ridge Wind Energy Facility was $350 million and included trucking and shipping costs (fuel, labor) and all construction costs (D’Estries, 2007). The emergy to dollar ratio for the year the facility was constructed was 8 E11 sej/$. Emergy associated with services = ($350 million)*8 E11 sej/$ = 2.80 E20 sej.

19. O&M FTE = 40 (William Moore, PPM Energy, Personal communication, May 2007. Mr. Moore was the lead project developer for the Maple Ridge facility. Data regarding FTE is proprietary and changes over the project lifecycle due to unpredictable circumstances, but Mr. Moore indicated that
‘40’ is a good estimate.) Lifecycle man years = 40 * 20 years = 800. Energy per man year = 2.8 E17 (Odum, 1996; pg 232). Used value for “College Grad.” Emergy = (800 man yr)(2.8 E17 sej/man yr) = 2.24 E20 sej.

20. Assumed decommissioning labor will be identical to construction labor. Labor (Construction) includes trucking, crane and rigging, longshore, and other construction operations. (William Moore, PPM Energy, Personal communication, May 2007). Data regarding employment is proprietary, but Mr. Moore agreed that ‘300’ is a good estimate. Comports with estimates in other sources, e.g., Alliance for Clean Energy New York, 2007. (William Moore, PPM Energy, Personal communication, May 2007). Construction lasted about a year according to Mr. Moore. Assumed 1.5 years to provide a conservative estimate of emergy associated with labor. 450 man years. Energy used per man year = 9.4 E16 (Odum, 1996; pg 232). Used value for “School,” i.e., not college graduates. Emergy = (450 man yrs)(9.4 E16 sej/man yr) = 5.64 E19 sej.

21. Assumed decommissioning fuel use will be identical to construction labor. Fuel (Shipping and Trucking) includes diesel and gasoline for trucking and bunker fuel for shipping. Tower sections comprise the great majority of a turbine’s shipped weight. The Vestas Environmental Statement (Vestas, 2004; pg 93) indicates that tower section are manufactured in and exported from the factory in Varde, DK. Assumed all turbine components were manufactured in and exported from Varde facility. Author’s observations, September 2005, indicate that tower components arrived at the Port of Oswego. GIS analysis indicated 3165 nautical miles from Varde, DK to Oswego, NY. 3165 nm = 5862 km. Freihofer, 2006; pg 1 indicates 25 ships arrived from 2005-06. The author of this thesis observed several ships from the Beluga Fleet in the Port of Oswego unloading turbine components during this interval. The Beluga Revolution and other ships of similar size were observed in the Port of Oswego in the Fall of 2005 (See Figure XXXX). Beluga Group, 2007 indicates that R-Class heavy lift carriers like the Revolution consume 29 mega tons of “Intermediate Fuel Oil” (bunker fuel) per day when cruising at 18 knots (~33 km/hr). [(5862 km)/(33 km/hr*24 hrs/day)]*(29 metric tons/day)*(25 ships)(2 trips per ship) = 1.7 E10. Transformity of shipping fuel = 2.95 E9 (Carrarretto, 2004; pg 2209). Emergy, shipping fuel = (1.7 E10 g)(2.95 E9 sej/g) = 5.02 E19 sej. Trucking distance, Port of Oswego to Lewis County construction site = 75 miles (authors estimate). Freihofer, 2006; pg 1, indicates that the facility is comprised of (i.e., rolled of the docks as) 1755 independent pieces. Author’s observations indicate that blades must be shipped dedicated trucks, but that many nacelles and other components may be shipped in the same truck. Estimated 1000 total truck trips to deliver the 1755 independent pieces. 2000 total trips including return trips. (150 miles)(2000 one-way trips) = 300,000 miles. Estimate mpg of 7. 300,000/7 = 42,857 gallons. Fuel weight = 1.42 E8 g (used fuel weight calculator at changinggears.com). Transformity = 2.95 E9 sej/g (Carrarretto, 2004; pg 2209). Emergy, trucking fuel = (1.42 E8 g)(2.95 sej/g) = 4.18 E17. Author observed Ford Ranger pickup trucks escorting 18-wheelers to the construction site. FuelEconomydb.com, 2007 indicates that the Ford Ranger gets about 24 mpg in mixed highway, city driving conditions. Freihofer, 2006; pg 1 indicates that a blade truck requires three escorts while other trucks require only two. The 195 turbines at Maple Ridge have 585 total blades (585*3). Blades require dedicated trucks. Therefore 415 18-wheelers required only two escorts. [(415 18 wheelers)(2 escorts each)(150 miles)]+[585 18 wheelers)(3 escorts each)(150 miles)] = 387,750. Total fuel use, escort = (387,750 miles)/(24 mpg) = 16.156 gallons. Fuel weight = 4.5 E7 (used fuel weight calculator at changinggears.com). Transformity = 2.95 E9 sej/g (Carrarretto, 2004; pg 2209). Emergy, escort fuel = (2.4 E7 g)(2.95 E9 sej/g) = 1.3 E17 sej. Total emergy of fuels used = (5.02 E19)+(4.18 E17)+(1.3 E17) = 5.52 E19 sej.

22. Nameplate capacity of wind power plant = 312.75 MW. Maple Ridge is a new facility with 195 turbines. Capacity factor has fluctuated widely as technical problems have arisen, and then been resolved (William Moore, personal communication, May 2007). Tester (2006) indicates that 0.33 is a rule-of-thumb capacity factor for terrestrial wind farms. Estimated lifecycle energy production = 1.2 E6 W (31.5 E6 sec/yr)(0.33) (195) (20 yrs) = 4.92 E16 J Transformity = 1.59 E5 (Odum ,1996; pg 187). Emergy = (4.9 E16 j)(1.59 E5 sej/j) = 7.8 E21 sej.