

Cameron Henry
Environmental Studies 206
Professors Hank Art and David Dethier
5.13.08

Ergometer Co-Generation Using Micro Wind Turbines

Introduction

Rowers are capable of generating and expending a great deal of energy each time they complete a stroke on a rowing machine (or ergometer). This project endeavors to create a system that allows an athlete the ability to generate electrical energy when using a rowing machine. Concept2 rowing machines are the ones most commonly used nationwide by colleges, high school, club programs, and fitness centers and thus will be the machine used in the assignment. I believe that with the proper technology, ergometers could produce usable energy and help to cut down on some of Williams' energy and financial costs. Furthermore, this project strives to create a relatively low-cost, easily replicable system which other rowers and teams could install to reduce their carbon footprint.

Basic Human Energetics and Energy Output

As different socioeconomic, genetic, and environmental backgrounds lead to vast disparities in body size and composition in adults, it is no small task to try and measure the average total energy expenditure (TEE) of the human adult. TEE can be defined as the average amount of energy spent over a typical 24 hour period. A person's basal metabolic rate (BMR) is the smallest possible amount of energy utilized at rest. It is measured under controlled and standardized conditions which include rest, fasting,

mental state, immobility, and thermoneutrality. It is important to consider TEE in terms of someone's BMR as the BMR of an adult constitutes approximately 45-70% of his or her TEE depending on whether the individual is active or sedentary respectively. It is then possible to understand the energy required to sustain activity other than the BMR, calculated in kilocalories per day (kcal/day) or mega joules per day (MJ/day). Thus, the physical activity level (PAL) is a measure of TEE for 24 hours, expressed as TEE/BMR and therefore, $BMR \times PAL = TEE$.¹ Last, the physical activity ratio (PAR) is an energy cost of an activity per unit of time, expressed in terms of BMR thus: energy spent in activity/BMR for the specific unit of time.² The following table assembles a number of calculations of TEE for various lifestyles for individuals of a certain population group.

Main daily activities	Time allocation (hours)	Energy cost^a PAR	Time × energy cost	Mean PAL^b multiple of 24-hour BMR
Sedentary or light activity lifestyle				
Sleeping	8	1	8.0	
Personal care (dressing, showering)	1	2.3	2.3	
Eating	1	1.5	1.5	
Cooking	1	2.1	2.1	
Sitting (office work, selling produce, tending shop)	8	1.5	12.0	
General household work	1	2.8	2.8	
Driving car to/from work	1	2.0	2.0	
Walking at varying paces without a load	1	3.2	3.2	
Light leisure activities (watching TV, chatting)	2	1.4	2.8	
Total	24		36.7	36.7/24 = 1.53

¹ Joint FAO/WHO/UNU Expert Consultation. "Human Energy Requirements." Rome, 2001. 9, 35.

² Ibid., 8.

Active or moderately active lifestyle				
Sleeping	8	1	8.0	
Personal care (dressing, showering)	1	2.3	2.3	
Eating	1	1.5	1.5	
Standing, carrying light loads (waiting on tables, arranging merchandise) ^c	8	2.2	17.6	
Commuting to/from work on the bus	1	1.2	1.2	
Walking at varying paces without a load	1	3.2	3.2	
Low intensity aerobic exercise	1	4.2	4.2	
Light leisure activities (watching TV, chatting)	3	1.4	4.2	
Total	24		42.2	42.2/24 = 1.76
Vigorous or vigorously active lifestyle				
Sleeping	8	1	8.0	
Personal care (dressing, bathing)	1	2.3	2.3	
Eating	1	1.4	1.4	
Cooking	1	2.1	2.1	
Non-mechanized agricultural work (planting, weeding, gathering)	6	4.1	24.6	
Collecting water/wood	1	4.4	4.4	
Non-mechanized domestic chores (sweeping, washing clothes and dishes by hand)	1	2.3	2.3	
Walking at varying paces without a load	1	3.2	3.2	
Miscellaneous light leisure activities	4	1.4	5.6	
Total	24		53.9	53.9/24 = 2.25

^a Energy costs of activities, expressed as multiples of basal metabolic rate, or PAR, are based on Annex 5 of the previous consultation's report (WHO, 1985) (see also Annex 5 of this report).

^b PAL = physical activity level, or energy requirement expressed as a multiple of 24-hour

BMR.

^c Composite of the energy cost of standing, walking slowly and serving meals or carrying a light load.

Table 1. This table shows average calculations of TEE for three lifestyles: sedentary/light, active/moderately active, and vigorous/vigorously active. Units are as follows: Time is measured by hours while Energy Cost is measured in MJ. The averages are composed from individuals in a certain population group. The data is not fool-proof; in fact, many of the individuals that were used in study were Italian men with relatively high BMR values. In addition, the closed-circuit calorimetry method may overestimate the oxygen consumption and energy expenditure levels of the subjects.³

In order to determine the caloric intake required by an individual to sustain whatever lifestyle he or she leads, one must multiply the PAL by the BMR. Table 2 is a classification of lifestyles based solely on PAL values.

Category	PAL value
Sedentary or light activity lifestyle	1.40-1.69
Active or moderately active lifestyle	1.70-1.99
Vigorous or vigorously active lifestyle	2.00-2.40*

* PAL values > 2.40 are difficult to maintain over a long period of time.

Table 2. This table classifies lifestyles based on the PAL values. Once average PAL and BMR values of a population are known, it is then possible to determine the average energy requirement for that population.⁴

The above information is relevant as the work that this project relies on revolves around the rowers and fitness gurus who utilize the ergometer in to practice and stay in shape. People in the “vigorous or vigorously active” category are probably the only ones who could sustain such exercise for long, although “active or moderately active” individuals are capable of using an ergometer as well. In order to fuel such output, an

³ Ibid., 36, 37.

⁴ Ibid., 38-40. For more in-depth information related to the daily energy requirement for men and women (further separated by age groups), please see the Human Energy Requirements article, pages 39-46. There are detailed tables showing calculations regarding the daily energy requirement as a factor of BMR (or PAL) and body weight.

athlete of such caliber needs to consume at least 4,000 Calories daily, if not more. This is a measure of consumption rather than output, the latter of which I am trying to harness.

To determine how many calories go into exercise versus maintaining the other body functions, the following example provides insight into the problem.

Vigorous or vigorously active individual: If this PAL was from a male population, 20 to 25 years old, with mean weight of 70 kg and mean BMR of 7.30 MJ/day (1 745 kcal/day), $TEE = 2.25 \times 7.30 = 16.42$ MJ (3 925 kcal), or 235 kJ (56 kcal)/kg/d.⁵

This individual, who is representative of the average male rower at Williams, would have to consume approximately 1,745 kcal/day just to maintain his BMR. Approximately 2,200 kcal/day are necessary for him to continue competing at the collegiate level.

From personal experience, the Concept2 rowing machine (models C & D) is a thoroughly effective machine. It works a great deal of muscles in the legs, where most of the power is coming from, the back, and the arms. Working out on this machine is strenuous, but the results are noticeable and a large variety of measurements can be gauged by the built-in computer (which *is* powered by the machine). The computer not only keeps track of distanced rowed and time, but also Calories per hour burned, measured with a basic equation which takes into account the rower's weight, and wattage per stroke produced. The latter feature is what I am interested in as it is a pure measure of power. True, it is the peak amount of power during a rower's stroke (which occurs at the beginning of it). We must keep in mind that the machine measures watts, not watts hours which are a measurement of power over a period of time. Strong rowers are capable of pulling strokes (for brief periods of time) that produce 300-400 watts. Over the course of an hour, Justin Moore, the Williams College Women's Crew coach,

⁵ Ibid., 36.

estimates that a man can generate 200 watts per stroke for an hour while a woman can generate about 160 watts per stroke over an hour.⁶ Thus, a man could create 200 watt hours while a woman could produce 160 watt hours. This is no exaggeration – during my testing for this project, the subject maintained an average of 237 watts per stroke. Great potential energy exists here.

Similar systems exist for bikes which allow users to generate 125 to 250 watts depending on the individual and efficiency of the system. The Pedal-a-Watt bicycle stand was so effective that it was used by a number of people over the course of several days to generate enough energy to power part of the Super Bowl show.⁷ The basic set-up is as follows: a stationary bike is used to spin a rotor connected to a generator which produces energy. That energy is then stored or transported as needed to power typical appliances like televisions, computers, stereos, or more intricate events like the Super Bowl.

Utilizing Micro Wind Turbines

After contacting Concept2 to see if anybody else was thinking along similar lines and might be able to impart advice, I received a less than encouraging email stating that it is unlikely that a similar generator could be built for an ergometer that could be attached to the flywheel (the rotating fan) and not alter the characteristics of the machine. As my intentions are to create something that helps the environment but does not affect the way rowers and coaches monitor individual efforts, this approach does not seem entirely plausible currently.

⁶ Justin Moore, personal communication, April 4, 2008.

⁷ It took 42 people 4 days to generate the energy used by the Fox Sports pre-game show and Amp Energy event. <http://humanenergy.ampenergy.com/> (accessed 4.14.08). Energy was stored in massive battery banks which were then used to power the show.

Instead of using a rotor attached to the flywheel, I propose using micro wind turbines to generate energy. They are small, lightweight, and relatively inexpensive. Developed by Hong Kong University and Lucien Gambarota (Motorwave Ltd.), a row of eight turbines only costs \$240 and can be disassembled as needed.⁸ The diameter of the turbines is only 25cm. If the wind turbines were put on a stand, they could be placed in front of the flywheel. Since the turbines only need wind speeds of 2m/s to operate and generate electricity, such positioning would allow them to function well.⁹ I do not anticipate that this would increase the drag for a rower at all due to their lightweight and portable nature (if it is a problem, just move the wind turbine back). Figure 1 is a diagram of what a row of turbines look like.

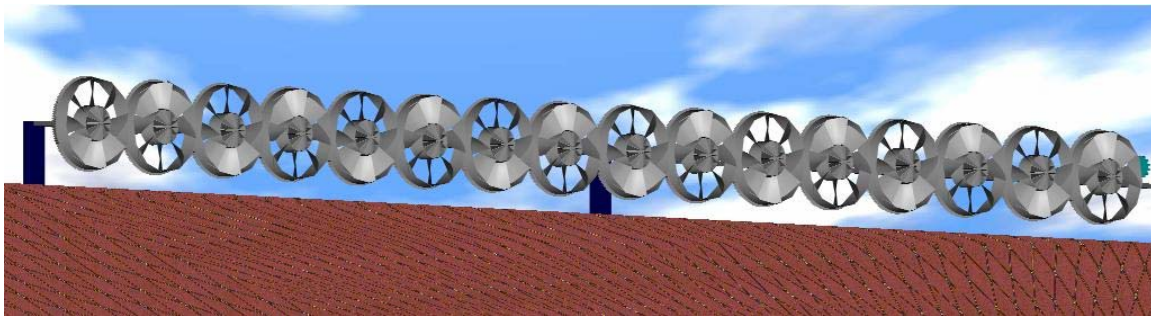


Figure 1. This is an image showing a row of twenty low-wind speed turbines, which would cost \$420 for the set. This amounts to \$21 per turbine, a low price for renewable technology. A portion of this money would go back to Hong Kong University to fund more research pertaining to alternative energy technology. The low-wind speed version of these turbines is rated at 170W with a wind speed of 10m/s. Therefore, each individual unit is capable of about 8.5W. Potential output of the entire set is between 12 and 100 unregulated volts.¹⁰

According to Levesque's article, a one square meter array of the turbines (4x4) could generate 131 kWh/year given a constant wind speed of 5m/s. Therefore, one turbine

⁸ Tylene Levesque. "MICRO WIND TURBINES: Small Size, Big Impact." March 21, 2007, <http://www.inhabitat.com/2007/03/21/micro-wind-turbines-small-size-big-impact/>. (accessed 4.16.2008) and Motorwind, <http://store.motorwavegroup.com/20-microturbine-with-generat.html> (accessed 5.9.2008)

⁹ Levesque.

¹⁰ Ibid.

could produce about 8.2 kWh/year. Motorwind maintains that the daily production of an 8 turbine array could be as much as 1.2 kWh if there is a wind speed of 10m/s. If one turbine were added to each ergometer, of which there are 32 at Williams, and over the course of winter training (2 hours per day for four months), I am hopeful that it might be possible to produce a target of 100 kWh/season.

C Breeze

I would recommend channeling the wind in such a way that it becomes concentrated. This would then lead to higher wind speeds which would let the turbines generate more electricity. There is one product on the market which might suit the needs of the project. The C-Breeze, produced by PS Sport, is positioned around the Concept2 ergometer's flywheel so it concentrates the air back towards the athlete in order to cool off the individual. It should be possible to arrange this device so it faces away from the rower and towards the turbine where, if properly positioned, it might be able to take advantage of wind speeds greater than 10m/s. Each unit costs \$35, therefore an initial investment of \$1120 would be required to outfit Williams College's 32 ergometer.



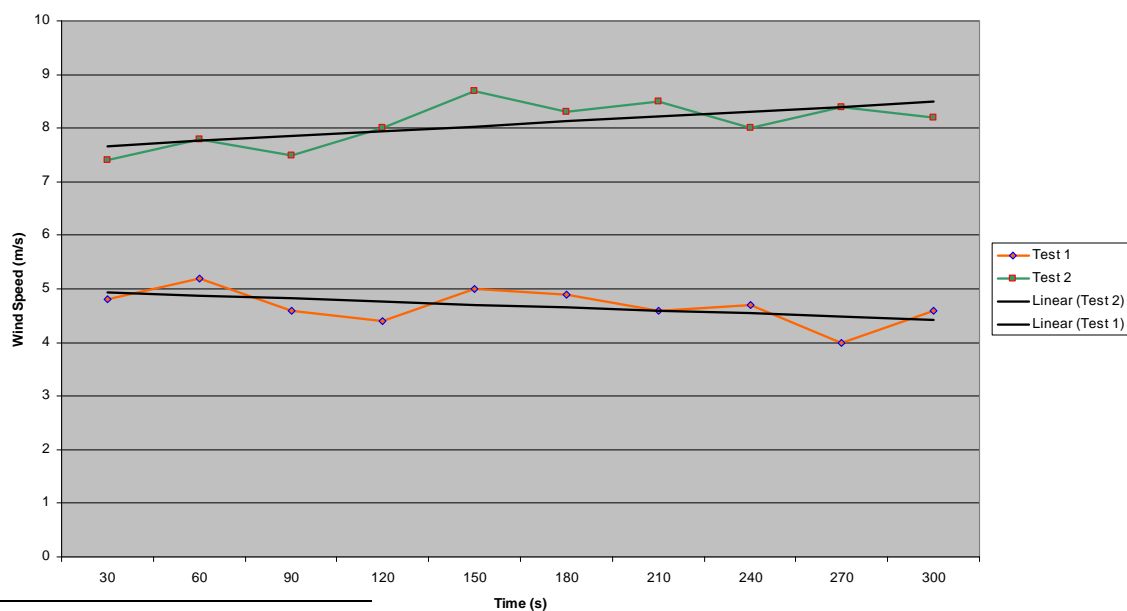
Figure 5. These pictures depict the concentrated airflow generated by the C Breeze. The inventor claims that this device can produce wind speeds greater than a 14" fan on high setting, however, this assertion seems disputable. It does do an adequate job of

concentrating airflow though, and should be considered for the project to get the most out of the rowing machines.¹¹

Testing the Feasibility of the Project

I was unable to procure Motorwind turbines to test the efficiency of this system and determine whether or not it would actually work. Therefore, in order to test the feasibility of the project, I used a handheld anemometer to measure the wind field around the rowing machine. The preliminary results I obtained by these tests were promising and impart several important lessons.

I performed three basic tests. The first was to determine the wind speed generated by a rower who performed at an hour pace. I chose this pace since more energy will be produced over a longer period of time, allowing the athlete to create more energy. The rower pulled two five minute pieces, rowing 24 strokes per minute. His average wattage per stroke during each test was 237 watts. I was shocked by the consistency he achieved during the workout, and grateful as it made for more uniform testing. The results of the first tests are shown below in Figure 2.



¹¹ Photo courtesy of <http://www.ps-sport.net/>.

Figure 2. This graph shows the results of my first test, during which Ben Howard rowed two five minute pieces. The x-axis is time, measured in seconds, while the y-axis is wind speed measured in meters per second. I took measurements every 30 seconds during the tests over a period of five minutes. The first test, in orange, resulted in an average wind speed of 4.6m/s (10.3mph). The second test, in green, resulted in an average wind speed of 8.1m/s (18.1mph); this is a 75% from the first test. The difference is accounted for by the angle of the anemometer. During the first test, it was held flush towards the flywheel, while in the second test, it was held at a 45° angle. Since the air coming off the flywheel is projected upwards at an angle, not straight out from the machine, it makes sense that the anemometer was able to capture more wind at a significantly higher speed when held at the correct angle.

The second test measured wind speed as it related to stroke rate (strokes per minute or spm). I went into the test believing that wind speed and stroke rate were directly proportional; as stroke rate increased so would wind speed. Figure 3 demonstrates the correlation and supports my hypothesis.

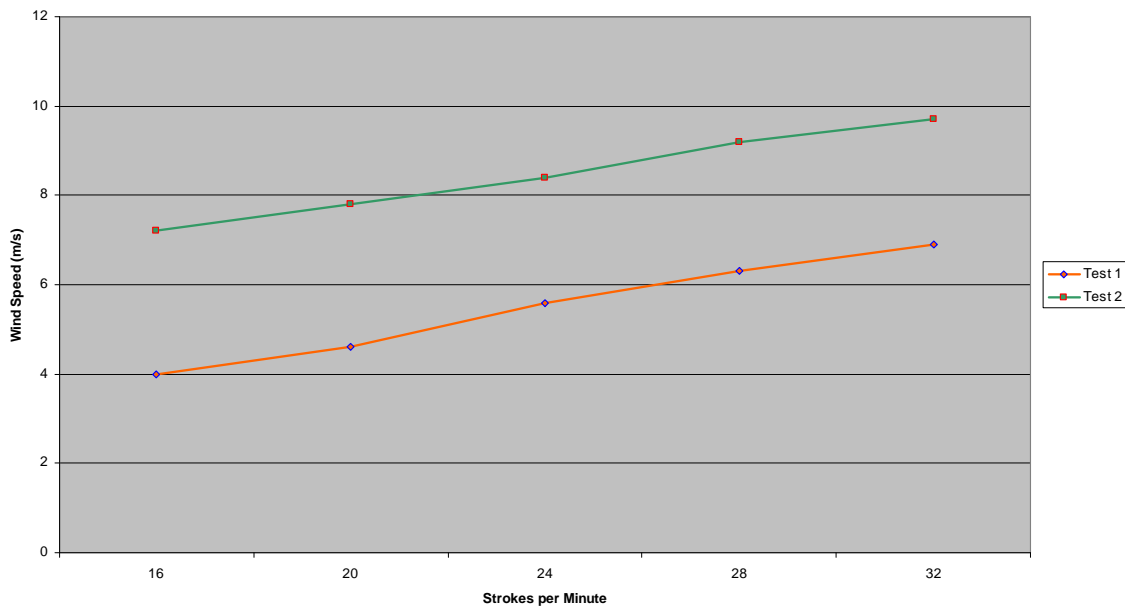


Figure 3. This graph shows how closely related stroke rate and wind speed are. The first test is represented again by the orange line while the second is shown by the green line. As in the first test, the difference is the tilt of the anemometer. The x-axis is strokes per minute while the y-axis is wind speed (m/s). At 16 strokes per minute (about one stroke every four seconds), the wind speed generated is 4m/s or 7.2m/s depending on the angle of the anemometer. Every time the rower increased the stroke rate by 4, the wind speed increased by .6-8m/s on average. While it would be nice for a rower to maintain 32spm

for an hour and generate much more energy, it is not a long-term pace since it tires out the athlete too quickly. Based on these tests, it seems that 24spm is a good compromise, generating a great deal of wind speed, but allowing an individual to practice for a sustained period of time, creating the most energy possible. We should remember that the increased wind speed is not only due to greater effort on the rower's part, but also because during a stroke, the peak amount of wind produced is at the beginning of the stroke, and decreases as the rower returns to a neutral position. Thus, at 16spm, this lag time is much longer than that of 32spm.

The last test determined the relationship between wind speed and distance from the ergometer. I thought that as one increased the distance from the machine, the wind speed would decrease as the area it had to dissipate increased dramatically. The results illustrated by figure 4 supported this hypothesis as well.

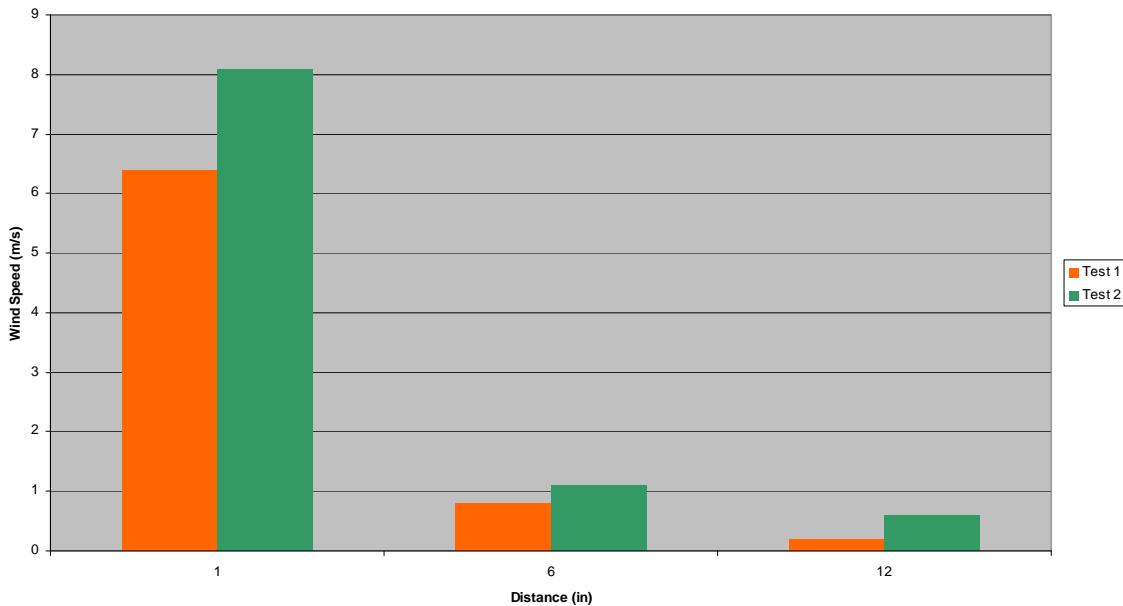


Figure 4. This graph demonstrates the relationship between wind speed and distance from the rowing machine. Once again, the first test is in orange, the second in green. The difference between these tests, as in the previous tests, was the angle of the anemometer. The x-axis is distance from the rowing machine (measured in inches), while the y-axis is wind speed (m/s). If the anemometer was held one inch from the fly wheel, it registered a wind speed of 6.4m/s or 8.1m/s respectively. At six inches away, the wind speed dropped to .8m/s and 1.1m/s. At 12 inches away, the wind speed was .2m/s and .6m/s. Remember, these micro turbines require a wind speed of 2m/s to generate energy. Therefore, it is imperative that they be set up as close to the machine as possible. When asked if the anemometer led to an increase in drag, possibly altering the performance of the ergometer, the rower replied that there was no noticeable difference.

Lessons from the Tests

The test results are significant and suggest that this micro turbine and ergometer co-generation system would be feasible. We should remember though that the anemometer is about four times smaller in diameter than the wind turbines are, so their output might be different from what was measured. In order to obtain the highest wind speed possible, the turbines should be placed about one inch from the ergometer at a 45° angle. Therefore, they will have the best chance to capture the most wind possible coming off of the flywheel.

What to Do with this Energy?

Initially, I had hoped to help heat the swimming pool, saving a great deal of energy and money. After talking with Ken Jensen and Thomas Laureyns about the idea, they said that Chandler Athletic Facility and Lasell Gymnasium were far too complicated to achieve this goal. They instead suggested that I investigate the night-time emergency exit lighting and if the project could power LED lights required to illuminate the required one foot-candle in front of each exit. Mr. Jensen had LED arrays which had the capacity to last for 75,000 hours and run on only a few watts (1-3) when operated. Therefore, with the system that I am proposing, it seems much more realistic to try and power the exit lighting rather than heat the swimming pool. However, while this sounds great, this endeavor would require storage of the energy via battery power. Mr. Jensen noted that a basic lead-acid battery would be the best option. I am not sure though that using batteries is the best idea as the storage and transfer of energy invariably leads to energy loss. Furthermore, if the batteries do not consistently maintain their charge, their lifespan decreases significantly. It would not be in our best interests to have to continuously

purchase these batteries since that would diminish the returns on our initial investment and increase the payoff time for the project. Last, I would prefer avoiding throwing out a large number of lead-acid batteries as they are quite toxic and detrimental for the environment.

Perhaps the best use of this energy would be to directly add it to the power grid. While it might be a bit complicated and could require some invertors, it should not be overly difficult to connect to system to the nearest circuit breaker. The process would utilize standardized parts and procedures, so most anybody could replicate it. While this avenue could be a little expensive and lead to a long payoff, it does the most good at an institutional level – supplying electricity and reducing energy costs.

Other Potential Crew-Related Uses for the Wind Turbines

The Williams College crew teams have access to a water tank during the winter which is located in Chandler Athletic Facility. The tanks have circular systems for the water to flow, eliminating the possibility of wasting much water. In traditional tanks, the water is circulated by the rowers themselves rather than mechanically. This is the system used at Williams. While I have never used the system myself, I think that the water could be used to operate the wind turbines much like the wind. If the generator is waterproofed (which is possible), then the turbines should be able to produce energy using water.

Obstacles would include how effectively the rowers propel the water in the tanks which might lead to reduced efficiency of the turbines.

Is this Project Worth Pursuing in the Long Term?

This project demonstrates that capturing the energy generated by rowers on ergometers is possible. While at best these turbines might only generate several hundred kilowatts over the course of a year, this can still reduce a building's carbon footprint. Indeed, this project is not ideally suited for use at an institutional level as its impact will be small. However, the energy generated would be much more appropriately used in a boathouse which is seasonally used and does not require large amounts of energy. An individual could also benefit from such a system and perhaps use the energy to charge appliances or provide power to his or her home. I believe that this project is worth pursuing in the long term as it requires little initial investment (\$1120 for C Breeze, \$840 for 40 turbines) besides the ergometers, which Williams has, and the circuitry needed. Remember, the intent of this project was not to create the silver bullet which solves the College's energy problems, but rather something that contributes to the overall solution – a piece of the puzzle if you will.

REFERENCES

- Concept2 Rowing. Email communications with author. April 9 and May 5, 2008.
- Food and Agriculture Organization of the United Nations, World Health Organization, and United Nations University. "Human Energy Requirements." Rome: FAO Corporate Document Repository, 2004.
<http://www.fao.org/docrep/007/y5686e/y5686e00.htm>
- Jensen, Ken. Interviews by author. Williamstown, MA, April 16 and May 5, 2008.
- Laureyns, Thomas. Interview by author. Williamstown, MA, April 16, 2008.
- Levesque, Tylene. "MICRO WIND TURBINES: Small Size, Big Impact." March 21, 2007. <http://www.inhabitat.com/2007/03/21/micro-wind-turbines-small-size-big-impact/>.
- Moore, Justin. Interview by author. Williamstown, MA, April 4, 2008.
- Motorwind. "20 Turbines Set." 2007. <http://store.motorwavegroup.com/20-microturbine-with-generat.html>
- Pepsico, Inc. "Human Energy Powers Super Bowl Pre-Game Show." 2008.
<http://humanenergy.ampenergy.com/>
- .