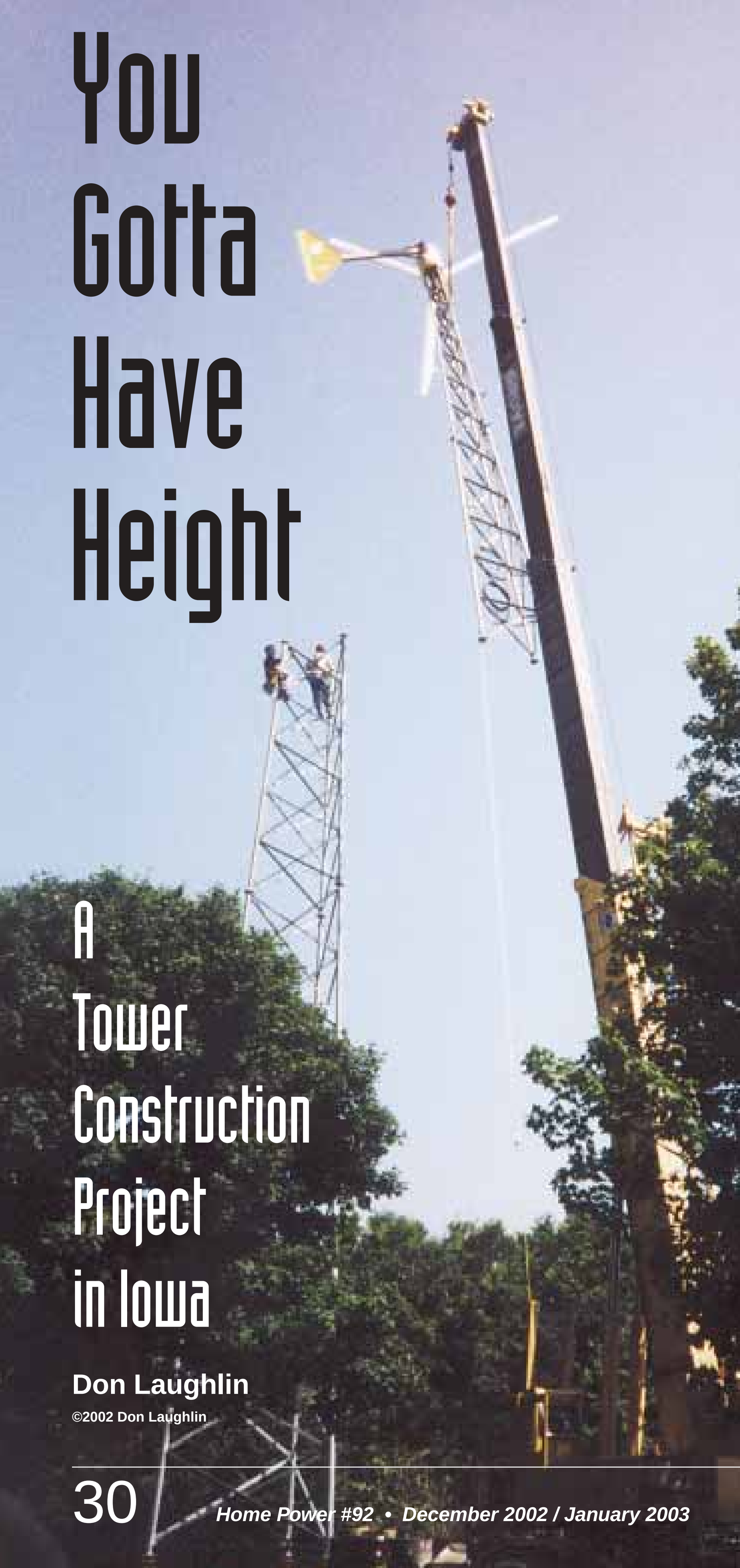
You Gotta Have Height

A Tower Construction Project in Iowa

Don Laughlin



Wind generated electricity has become relatively common in Iowa. Major wind farms are now in operation generating megawatt-hours of energy that is being bought by Iowa utilities. Small producers are furnishing their own electricity. At least one is selling excess to the utility. Over the past five years, I have become increasingly jealous of those who were actually doing it. I was only talking about it.

I finally succumbed to the urge and bought a Whisper 3000 (a discontinued turbine) still in the original packaging. While I made plans to put it up, my calculations kept showing me that I really would like to have more energy. Then one night while browsing around on eBay, I discovered a "10,000 watt wind generator, still on the skids." It turned out to be a Bergey Excel, and I couldn't resist the temptation.

For several years, I have been an avid member of the Iowa Renewable Energy Association (I-RENEW), an educational organization that uses demonstrations and workshops to get the RE message out. In planning my wind generator installation, it was a given to use the installation as a teaching tool. What follows is not about my wind-electric system, but the adventures of getting my new wind generator up in the air.

Siting Process
Two facts govern siting a wind generator.

1. The energy in the wind is proportional to the cube of the wind velocity ($P \sim V^3$).
2. Over most terrain, the higher you go, the higher the velocity.

From these two facts, you can say that height is of the essence. Increasing tower height is the easiest way to increase output of a wind-electric system. The most common error in wind-electric installations is using too short a tower.

Our home is on about four acres. The general topography in all directions is gently rolling farm fields. Elevation changes are usually no more than 70 feet (21 m) in any quarter mile. Prevailing winds are from the northwest. The west half of our place is fairly well covered with walnut trees that are now about 30 feet (9 m) high. The east half is windbreak, pasture, and lawn, with large shade trees and buildings.

The highest spot on the acreage is near the southwest corner among the walnut trees. This would be my first choice site. But this site is the farthest distance from the house and would require a long wire run of more than 1,000 feet (300 m). The next highest site is only 125 feet (38 m) north of the house, right next to the wind break. We decided that this was the best place for our tower considering the topography and wire run.

I first thought of a tilt-up tower because I liked the idea of working on the generator on the ground. But a tilt-up needs a large open area because the guy wires must be in the clear as the tower tilts up. For a 90 foot (27 m) tower, the guys would need 45 feet (14 m) on all sides. A fixed, guyed tower would present the same need for clear space. Either one of these choices would mean cutting out too many trees. Our final decision was to use a freestanding tower.

Locating a wind generator close to or among trees needs careful thought. Wind blowing against a grove of trees rises to form a turbulent zone that can be many feet thick. Above that, however, is a zone of smooth accelerated air. A generator should never be located in a turbulent area, and it is best to get it into the faster zone. The standard guideline is to be 30 feet (9 m) above anything within 500 feet (150 m).

A 100 foot (30 m) tower would put my generator above the turbulent zone and into the acceleration zone far into the future. I have a 300 foot (91 m) long windbreak and a grove of walnut trees directly west of the tower site. The land with walnut trees slopes downhill away from the tower. I don't expect either the walnuts or windbreak trees to get more than 60 feet (18 m) tall.

Tower Found—Too Short
Once the site was determined, my search for a freestanding tower began. I located a used, 80 foot (24 m) Rohn SSV not 5 miles away in a shed, mostly disassembled. This would not put me high enough above the walnut grove to the west and the maple trees to the south. I needed to add 20 feet (6 m) to the tower. The top of the Rohn tower tapered to the plate to which I would bolt the generator. There was no way to go higher on that end. So I had to add 20 feet to the bottom.

The Rohn company was helpful, and agreed to build a bottom 20 foot (6 m) section. If I would send all the markings stamped into the steel plates of the tower I had, they would find those markings on their plans and build to fit. Unfortunately, the tower had been discontinued, and they could not find matching drawings.

The Only Choice—Build It
A friend and structural engineer, Larry Marsh, encouraged me to build the bottom 20 foot (6 m) section myself. He offered to do the design work. He needed the taper of the existing tower and the thrust on the propeller at whatever wind velocity was to be our design

Don's homemade, 20 foot bottom section (black, background) is attached to the original Rohn, 20 foot bottom section (silver, foreground).

The homebuilt base section's geometry was extrapolated downwards from the Rohn's original bottom section. The structural design was the same.

limit. Bergey Windpower Company said that the thrust on the Excel was 2,000 pounds (900 kg) in winds up to 125 mph (56 m/s).

To get the taper of the tower, Larry took measurements from the top 20 feet (6 m), the only section fully assembled at that point. By projecting 80 feet (24 m) down, he estimated the dimensions of the base. From these, he calculated stresses and steel sizes needed for that size base, tower height, and thrust.

The plan was simple, and as it turned out, adequate. I would build a section with features matching the existing Rohn. The section would have three legs with braces between them, with 1 inch (25 mm) thick, flat steel flanges welded on both ends of the leg. These flanges would bolt to the Rohn flanges at the top, and to the foundation piers at the bottom. This meant steel pipe for the three corners, with angle iron braces. I planned to follow the same pattern of bracing as the original tower, so that the transition from Rohn to homebuilt would not be obvious.

This was my first experience at building a major steel structure. I was keenly aware that in a couple of months, a crane would be lowering a 40 foot (12 m) section of tower down onto what I was about to build. With friends and acquaintances and a US$150 per hour crane crew watching, where would I hide if the bolt holes didn't match? Not only did the holes between the sections have to match, but my section had to hold the 80 foot (24 m) Rohn absolutely vertical—that is, the center line vertical, not the tapered sides of the tower. Each side had to have exactly the same slope. There is no place to put a level on a three-sided, tapered tower, whether on its side or standing.

Designing the Homebuilt Section

Our design called for three, 5 inch, schedule 40 steel tubes for legs. Off-the-shelf steel comes in 21 foot (6.4 m) lengths, so that determined the height. Each tube was to have an 8 by 8 by 1 inch (20 x 20 x 2.5 cm) steel flange welded onto each end. The $^7/_8$ inch (22 mm) holes for $^3/_4$ inch (19 mm) bolts near the corners of these flanges would mate with the Rohn tower at the top, and the homebuilt foundation legs at the bottom. Each flange had a large hole in the center to fit the outside diameter of the 5 inch tubing. By slipping the end of the tube three-fourths of the thickness into the flange, two continuous beads could be welded around the circumference of the tube.

Larry had calculated that the flanges could be welded onto the ends of the tubes with a single bead—without cutting the 5 inch (13 cm) hole in the plates—and still give adequate strength. But the galvanizing requires no

The 40 foot sections were assembled horizontally. Tripods, a winch, and block and tackle were used to position the 300 pound legs for welding.

closed cavities, so the large holes were needed to leave the inside of the tubes accessible.

Preparing the Steel
With so many holes to drill, it was important to make jigs so that we would not have to mark each hole with a center punch. This was easily done by clamping steel guides on the drill press table. For drilling two holes in the brace-plates, the guides were clamped on so that the piece could be flipped over after one hole, and the second could then be drilled.

For the three pairs of end flanges that were to mate, I clamped each pair together and drilled through 2 inches (5 cm) of steel for each hole. These mated pairs were coded with a center punch mark on the edge to keep them paired. Braces could not be jigged, so each hole had to be marked, center punched, and drilled.

My drill press is a small one, so many pilot holes were used to work up to a large one. In the case of the largest holes, it took four smaller bits before the 7/8 inch (22 mm) bit could be safely used. Drilling in steel should always be done with care. Bits should be kept sharp, work should be clamped securely to the table, and cutting oil should be used.

Constructing the Homebuilt Section
To allow the braces to be bolted to the corner tubes, we welded, on edge, 7 by 2 1/2 inch (18 x 6 cm) plates onto the tubes. Five pairs of plates, spaced 4 feet, 11 inches (150 cm) apart, were spaced 60 degrees around the circumference of each tube. Each plate had two holes to receive the ends of two braces, and was aligned so that it could receive braces from an opposite tube.

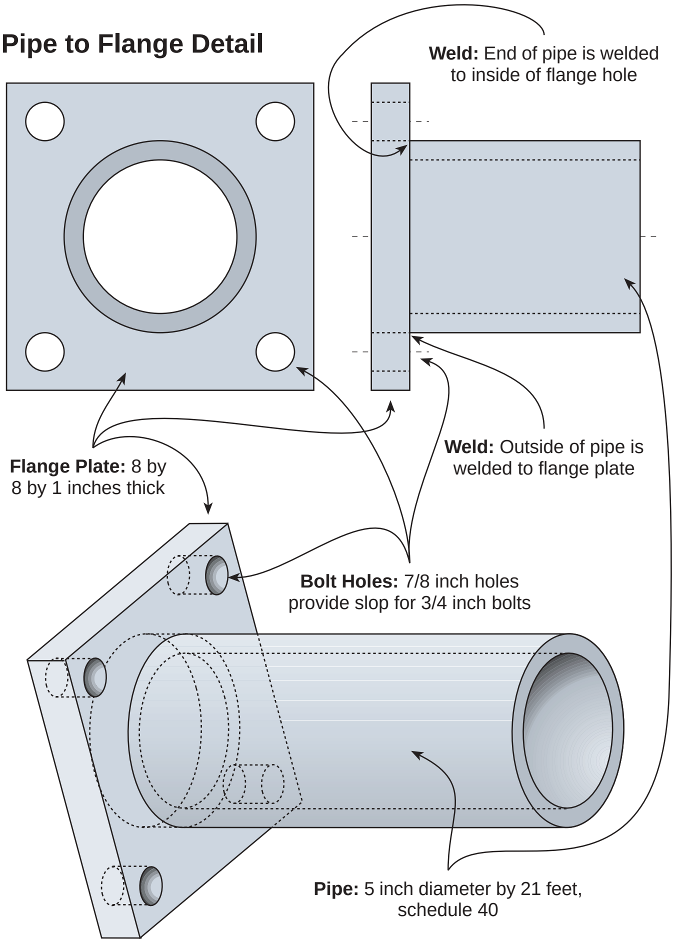
Welding these plates onto the 5 inch, schedule 40 tubes caused them to warp. The center of each tube was displaced from a straight line by about 1/2 inch (13 mm). The only consequence was that the braces were all unique to a place on the tower, and had to be measured, cut, drilled, and marked for that place.

Braces between tubes were bolted flat—a low plate on one tube to a higher plate on the other tube. This made a zig-zag pattern of braces up the tower. The bases of the tower legs were about 11 feet (3.4 m) apart, and braces varied in length from about 12 feet to 8.5 feet (3.6–2.6 m).

All bolts used in the tower were ASTM grade A325. This is a hardened, structural steel bolt with a heavy head designed for oversized holes. The ones I used were hot-dipped galvanized.

Finding Perfect Alignment
My plan was to assemble the bottom 20 foot (6 m) Rohn section out in the driveway with the big end toward the

Pipe to Flange Detail



garage. When all the bolts were in place and tightened down, including the ones where the braces cross, I assumed that this would be a rigid structure. It should be the same size and shape, whether on its side or standing. Knowing the flexibility of steel, this was a scary assumption, but the best I could do.

A solidly welded bead makes things as near “cast in stone” as you can get. It was essential that the tower sections be assembled and aligned before welding began. Three flanges were bolted onto the bottom of the Rohn section. Two legs were lying on the ground, so it was easy to slide two, 5 inch, schedule 40 tubes into them. They were slid in to a depth of 3/4 inch (19 mm) and rotated so the lower brace-plates were horizontal. They were carefully aligned with the Rohn corners. Then braces were measured, cut, drilled, and bolted into place. Care was taken that the tubes neither fell out of the end flanges nor slid farther in. It was important to maintain the ledge for welding the tube to the flange.

Getting that third tube in place was a challenge! Each tube weighed 300 pounds (136 kg). All three had to be held exactly in place before welding. In addition, the upper tube had to be solid enough, before its braces were in place, to support a ladder, so we could climb up

Alignment is crucial for the tower pieces to fit together and to be structurally sound. But a three-legged, tapered tower has no plumb component, so string lines were used to create a center line for reference.

to bolt the braces on. To do this, I built two temporary tripods with a winch on one and a block and tackle on the other.

Then came the final challenge to my homebuilt construction. The tower sits on three angle iron legs (4 x 4 x $^3/_8$ inches x 8 feet long; 100 x 100 x 10 mm x 2.4 m long) cast into the concrete foundation to form piers. Each of these legs has an 8 inch (20 cm) square by 1 inch (25 mm) thick flange welded flat to each end. Leveling bolts are located between the bottom tower flanges and the leg flanges.

These foundation legs do not taper with the tower, but are vertical and parallel to each other. This forms a slight angle with the tower. For the tower to stand plumb, this angle must be exactly the same for all three sides. This was accomplished by bolting the three foundation legs onto the unwelded tower flanges, and aligning accurately before welding.

The Rohn and homebuilt sections and foundation legs were laid out in position. For alignment purposes, a cross-sectional center point was located at four levels. These were: bottom of the foundation legs, bottom of the homebuilt section, and bottom and top of the Rohn section. The point was located by finding the center between each set of two legs, and stretching a string from that point to the center of the opposite leg.

By doing this for each leg, the three lines should cross at a center point. These four center points were needed to form a straight line down the center of the tower. With blocks, shims, and a jack, the tower was jockeyed around until the four center points lined up. This turned out to be easier than I had expected. Now the brace bolts for the homebuilt section could be tightened down, and the tube ends could be tack welded to their flanges.

The tack welds consisted of three short beads, spaced as evenly as possible around the circumference. Once this was done, the three tubes and all braces were carefully disassembled and removed from the Rohn, so as not to strain the tack welds. Final welding was done with the tubes laid out on sawhorses and rolled, so that the work was always on top. A trip to a galvanizing plant produced a shiny, new, 21 foot (6.4 m) tower section ready for assembly.

Preparing Tower Sections to Mate

Towers are designed with oversized holes for the express purpose of making connections easier. A $^3/_4$ inch (19 mm) bolt requires a $^7/_8$ inch (22 mm) hole. But even with sloppy holes, there is not much room for error between legs cast in concrete and the rigid tower. Also, no one wants to fight with misaligned holes while strapped to the side of a tower many feet above the ground.

For good alignment between the legs in the concrete and the bottom of the homebuilt section, a solid, rigid template was of utmost importance. I made one of scrap angle iron and flat plate, with four, $^7/_8$ inch (22 mm) holes in the three corners. I didn't skimp on holes for bolting to the tower and legs. Twelve, $^7/_8$ inch holes provided a reliable connection. To get its dimensions, the template was sandwiched between the top of the foundation legs and the bottom tower flanges while alignment was being done. Then, to pour the piers, the template was used to get the exact placement of the legs.

Building the Foundation

The tower rests on a concrete foundation. The bottom of the foundation, 7 feet (2.1 m) below ground level, is a square concrete slab, 15 feet (4.6 m) on a side and 2 feet (0.6 m) thick. Integral with the slab, via lots of heavy rebar, are three steel and concrete piers. The walls of the excavation served as forms for the slab, but the piers were formed with Sonotubes. These are round, waxed cardboard tubes. They are removed by cutting them apart once the concrete has set.

It has been said that a good backhoe operator can “pick your teeth” with his machine. The skill of our operator was used to form the excavation so that no forms were needed for the slab. The sides were kept plumb, and 15 feet (4.6 m) apart. With a laser level, the bottom was kept flat and at a depth of about 7 feet (2.1 m). We hit water and dumped in a yard of gravel to make walking possible. With a laser level, an orange line was sprayed on the clay sides to mark the top of the concrete pour.

Two layers of rebar were laid on a 12 inch (30 cm) grid. One was spaced 20 inches (51 cm) above the other with short pieces of vertical rebar. These extended down to the gravel and stood on bricks to take the weight. All rebar crossings were wired together.

The three piers, with the steel foundation legs embedded, were an integral part of the whole foundation. These angle iron legs were stood on end and set down into the rebar grid. They were braced with stakes in the bank. For each pier, six pre-bent, #7 rebars ($^7/_8$ inch; 22 mm diameter reinforcing rods) were maneuvered into place. These permanently tied the piers securely to the slab. Circular rebar loops, spaced 12 inches (30 cm) apart up the piers, were wired securely to the six vertical bars. The template was bolted to the top of the legs so they would be in exactly the right place to mate with the tower.

Three concrete and rebar piers, poured around 8 foot angle iron legs, are embedded in the foundation.

The tower foundation is a 15 foot square slab, 2 feet thick, buried 7 feet deep.

The 18.75 cubic yards of concrete was poured in two stages. The 15 foot (4.6 m) square by 2 foot (0.6 m) thick base was poured first. Then the template was removed to allow placement of the 18 inch (46 cm) diameter cardboard forms (Sonotubes) around the legs. The template was replaced, and the second pouring filled the Sonotubes. The template was kept in place until the backfilling was done to be sure nothing moved.

Tower Costs

A good tower, with a solid foundation, is not a low-cost item. Checking a wind generator manufacturer’s Web site and looking at the costs of equipment does not tell the whole story. The wind generator itself generally represents less than 50 percent of the cost of the complete system, and sometimes much less.

Different tower sites will have a variety of different costs. For instance, I had to build a driveway with three loads of gravel to get the crane in and out. Excavation and foundation expenses (whether for freestanding or tilt-up towers), crane rental, electrical wiring down the tower and into the power room, instrumentation (anemometer and amp-hour meter, if you want them), and labor costs will vary.

Laying the foundation is not a trivial operation. Setting up the rebar grid, leveling the feet, and pouring the concrete require skilled labor. You might save a lot of headaches and even money by hiring a competent contractor. The hourly wage will be high, but he or she will work quickly and efficiently. And then you can be sure that your investment will not lean in the first 100 mile per hour wind that comes your way.

Erecting the Tower

One of the requirements for a successful hands-on workshop to erect a freestanding, 100 foot (30 m) tower with a 10 KW Bergey wind generator is a windless day.

This is no time for misaligned bolt holes!

Friday, June 29, 2001 dawned clear and calm. After introductions among the thirteen people gathered to study wind technology, siting, politics, problems, and opportunities, Dennis Pottratz introduced the three-day schedule. By then, the small crane had arrived to set up the 21 foot (6.4 m) homebuilt section. The foundation, with three piers protruding from the ground, had been poured a month before.

The tower had been previously assembled on the ground in three partially completed horizontal sections. The workshop crew got the experience of finishing the assembly, and making sure the alignment was perfect for the sections to be mated. They mounted the Excel, with the blades and tail, and the anemometer to the top 40 foot (12 m) section of tower. All bolts were tightened and double nutted. Tail fin bolts were torqued to 20 foot-pounds, and the blade nuts to 150 foot-pounds. The three, #2 (33 mm^2) copper wires to come down the tower were coiled and tied to the bottom of the top section.

This section, the middle 40 feet (12 m), and the 21 foot (6.4 m) homebuilt section, were positioned for the cranes to hook on above their center of gravity and lift into place. When the homebuilt section was put together, it became apparent that some of the twelve bolt holes didn't fit the template exactly. This is the triangular steel pattern used to transfer the exact position of the holes from the lower tower flanges to the legs in the piers before they were cast in concrete.

After loosening brace bolts on one side, a come-along encouraged the holes to line up. Super tightening of the brace bolts seemed to make a reliable match. During the workshop, I watched anxiously as the crane lowered my homebuilt section onto the foundation legs—all twelve leveling bolts dropped into place!

By Saturday morning, when the tall crane came for the final lift, there was still little air movement. By noon, as we were in the final stages of bolting down the top 40 feet, a slight breeze had come up. Three men, working at the 60 foot (18 m) level, where the wind velocity was much greater, struggled more than two hours to get the last four of the twelve bolts in place.

While tower work was going on, others were cleaning out the trench for the underground lines from the tower to the house, and laying the three, #2 (33 mm^2) copper wires. Still others were working in the battery room mounting switches, the voltage control system, inverter, and connecting the entire system. In perfect accord with our needs, the final day of the workshop arrived with a brisk breeze. We could observe the production of electricity, and watch the batteries charge at about 35 amps at 120 VDC nominal.

The workshop crew in front of the 10 KW Bergey Excel on the completed 100 foot Rohn/homebuilt tower.

Laughlin Tower Costs

Manufactured Tower & Crane	*Cost (US$)*
Rohn tower, 80 foot, used	$2,000
Crane	1,260
Used Tower Total	$3,260
Homebuilt Tower Section, 21 feet	
Sandblasting, galvanizing, trucking	$1,036
Bolts, nuts, washers	707
Welding	680
3 tubes, 5 inch, 21 feet, Sched. 40	414
Angle iron for braces, 2 1/2 x 2 1/2 x 3/16 in.	340
9 flange plates, 1 inch steel, 8 x 8 inches	98
19 steps, Rohn	70
Miscellaneous	57
New Section Total	$3,402
Excavating, Base, Landscaping, Driveway	
Labor	$1,250
Concrete, 19 yards	1,209
Rebar	865
Gravel, 3 loads	666
Backhoe work	229
Sonotubes	170
Black dirt, 1 load	100
Skip loader rental	60
Excavating & Misc. Prep Total	$4,549
Grand Total	$11,211

The workshop program included a handout with topics on wind characteristics with relation to trees, buildings, and open land. We discussed the advantages, disadvantages, and costs of different towers available. Dennis presented data and costs for different wind generators on the market. We discussed safety and lightning protection, and the crew installed the best known grounding system for the tower. The workshop concluded to the satisfaction of all that a very professional wind-electric system had been installed.

I'm often asked, "What is the payback on this huge expense?" I answer the question by reciting the costs of SUVs and vans, all in the US$20 to $30 thousand range. Then my question is, "Did you ever hear of a normal person calculating the payback on their SUV?" Of course not.

Payback is the wrong question to ask. People spend money for what they perceive to be important. I perceive increasing the use of renewable energy to be of supreme importance. The task facing the renewable energy community is to educate society to shift its spending priorities from energy-consuming items to perhaps equally expensive items that are sustainable. Power boats can be replaced with sailboats, SUVs with compact hybrid cars, and on and on. A just and secure society will not be low cost. I want to furnish a model of what can be done.

Access

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A325 hot-dipped galvanized bolts

Sonoco, North Second St., Hartsville, SC 29550
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gaye.lloyd@sonoco.com • www.sonoco.com
Sonotubes

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Schedule 40 tubing & angle iron