Final Technical Report
Wind Generator Project

DOE Award Number: DE-EE0000447
Project Period: July 1, 2014 to September 30, 2016


Principal Investigator(s):
Nathan Geisler; ngeisler@a2gov.org; 734-794-6430 x.43724
Brian Steglitz; bsteglitz@a2gov.org; 734-794-6000 x.43905

Recipient:
City of Ann Arbor
301 E. Huron St. P.O. Box 8647
Ann Arbor, MI 48107-8647

Project team member organizations:
Sub-recipient: Ann Arbor Hands-on Museum
Support partners:
Clean Energy Coalition
Great Lakes Renewable Energy Association
REcharge Labs
Woven Wind

March 20, 2017

Acknowledgments: This report is based upon work supported by the U.S. Department of Energy (US DOE) under Award No. DE-EE0000447.

Special acknowledgement to Gary Nowakowski, Technology Project Manager with the US DOE Wind Energy Technologies Office, Office of Energy Efficiency & Renewable Energy (EERE) for oversight and continuous help in advancement of the project through all phases.

Additional US DOE, EERE Support Acknowledgments:

Jayce Philpott
Michael Carella
Melissa Callaway
Laura Merrick
Jane Sanders

This project would not have been possible without these individuals' time and dedication to supporting wind energy education in Ann Arbor throughout the process and evolution of the grant.

Additional acknowledgement belongs to the Congressional offices of John Dingell and Debbie Dingell.

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List of Acronyms

AAHOM = Ann Arbor Hands-on Museum
US DOE = United States Department of Energy

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Executive Summary

All work products and related educational programming presented in this report and performed during the grant were possible with the generous support and ongoing guidance of the U.S. Department of Energy. The project owes particular acknowledgment to the Wind Energy Technologies Office, Office of Energy Efficiency & Renewable Energy (EERE). The Agency and individuals involved (See Acknowledgements, page 2) were instrumental in helping secure continued resources and guiding the project along to its ultimate course.

This grant was originally conceived as a wind turbine build project on City land with a related educational component. In July 2014, after challenges securing committed partners and finding suitable host sites, the project team presented a revised scope focused solely on educational programs for wind energy. As the home of the University of Michigan and a populace that is generally supportive of and informed on renewable energy technologies, there remained a strong opportunity to develop and cultivate wind energy awareness even if no local wind farm or large turbines appear in the nearby area.

With a renewed push to find the best local resource to move the project forward, from July 2014 through September 2016, the sub-recipient and project lead designee was the Ann Arbor Hands-on Museum (AAHOM) who organized wind energy education programming into the subtasks below. AAHOM brought a wealth of experience in both renewable energy education and exhibit fabrication to deliver standalone information highlighting wind energy and its role in present and future power generation. US DOE grant staff supported the re-worked scope of work and provided invaluable expertise, aid, and insights in shaping final work products and programs.

SUBTASK 3.1 **Portable Exhibits & Museum Permanent Display**	• AAHOM will create 5 portable table-top exhibits for touring use in community centers, schools, libraries, museums and at festivals.
SUBTASK 3.2 **Hands-On Activity and Demonstration Devices**	• AAHOM will create 5 demonstration devices to display aspects of how wind energy is generated, stored, distributed, and used in the power grid.
SUBTASK 3.3 **Educational Programs**	• AAHOM staff will deliver 36 outreach programs about wind as an alternative energy.
SUBTASK 3.4 **Participation in Three Regional Festivals**	• AAHOM will participate in 3 wind/energy festivals, including our portable exhibits, hands-on activities, and display of related items of interest to the wind community.

The project met or exceeded all of the above subtask activities within the final project period of performance.

Portable Exhibits: Completed

The following five exhibits were developed and are now on display at the AAHOM as of the writing of this report, while designed for temporarily travel to other institutions:

1) Wind Table
2) Flow Tank
3) Modifiable Wind Turbine (with removable blades)
4) Energy Storage (with wind animation praxinoscope)
5) Electrical Distribution Scenario Table

Accompanying display panels provide context and content linking all the exhibits as a cohesive whole

Demonstration Devices: Completed

Demonstration Devices developed for use during Educational Programs and Festivals/future events include:

1) Wind Tube
2) Air Vortex Cannon
3) Mini Wind Farm
4) Wind Hand Crank Generator
5) Construct a Turbine

Educational Programs: Completed

AAHOM, partners, and volunteers facilitated sixty-eight (68) in-classroom or school workshops, “Family Science Nights” at the Museum, and/or participatory “labs” and field trips. This number is nearly double the target of thirty-six (36) such programs originally set.

Participation in Regional Festivals (2016): Completed

AAHOM and partners were present during events and engaged attendees with the Demonstration Devices as well as prototypes of Exhibits at the following:

April 17, Ann Arbor Earth Day Festival (~3,000 attendees);
June 10 Ann Arbor Mayor’s Green Fair (~2,000 attendees);
June 24-25 Michigan Renewable Energy Fair (~1,000 attendees);
July 30-31 Detroit Maker Faire (Over 25,000 attendees).

During the grant, City staff met regularly with AAHOM staff for input and idea-development for the educational content delivered during Programs and Festivals and ultimately incorporated into Devices and Exhibits. US DOE staff also provided exceptional feedback during device and exhibit design as well as program content creation. Content development and demo-ing prototypes were the focus of the first year of the revised scope of work. The second year involved executing the programs and participating in the events and shifting to design and final device and exhibit fabrication. The City and AAHOM are very intent on carrying forward the successful work and taking full advantage of the products made and presented in Ann Arbor during the project. The Portable Exhibits will travel for a portion of 2016-17 to other science museums in the state, as well as schools and libraries, before returning to AAHOM for permanent use. As of this report, exhibits are on full display at the front entryway of the museum as the premier educational suite for visitors entering the building.

Introduction

Wind energy is a key component of 21st century energy production. As the nation and as states seek to diversify the sources of their electricity supply, wind generation has proven cost effective while occupying an increasingly large share of newly installed capacity. Both private development and renewable portfolio standards ("RPS") aided by production incentives have helped wind energy secure its place among more conventional, centralized power plant based generation.

The emissions-free benefits of wind generation help aid the general public support that accompanied the recent surge in wind energy installations within the United States. As with most technologies that are both less established and which can take up significant land area, wind energy is confronted with challenges in seamlessly occupying a greater share of production capacity in the US. The State of Michigan instituted a renewable portfolio standard in 2008 for 10% utility-owned renewable sources by 2015 and the majority was achieved by new wind farms. As a community, Ann Arbor is land-constrained, urbanized, and less suitable as a resource-base (e.g. moderate to low winds) for "wind farming", but nonetheless is a University town with a deep knowledge base and a citizenry demonstrating a high level of support for integrating more sustainable power sources into the power grid.

While originally conceived as a possible project to install a standing wind system, the scope of the grant evolved to a focus on: educational programming around wind energy, the development of accompanying portable devices, and permanent exhibit installations at the Ann Arbor Hands-On Museum (AAHOM), the primary partner and sub-recipient of the grant. AAHOM is a well-established and highly regarded local institution that has helped boost energy knowledge and awareness in coordination with the City's Energy Office in recent years. AAHOM brought a unique background and ability to distill information to general audiences as well as elementary and middle school "STEM" formats and classroom settings, which wound up as the focus audience for the ultimate content that was developed. The project also utilized a large base of expertise affiliated with the University of Michigan and student organizations as well as regional non-profits working in the renewable energy field. These partners and content-supporters included Woven Wind (an Engineering club at the University of Michigan), the Clean Energy Coalition (a local NGO and Clean Cities Coalition organization), the Great Lakes Renewable Energy Association (GLREA), and REcharge Labs, a regional renewable energy education non-profit. The US DOE grant project team's oversight and guidance allowed for creative ideas to culminate in the exceptional products that were ultimately constructed.

The primary deliverables for the project are as follows:

1) Portable Exhibits, 2) Demonstration Devices, 3) Educational Programs, 4) Participation in Regional Festivals

By the end of the project grant period (September 30, 2016), the grant produced or achieved the following within each project category:

Portable Exhibits

Five exhibits were developed and are on display at the AAHOM and are designed for temporary travel to other institutions: 1) Wind Table, 2) Flow Tank, 3) Modifiable Wind Turbine (with removable blades), 4) Energy Storage with Wind Praxinoscope, 5) Electrical Distribution Scenario Table, as well as accompanying display panels that provide context and content linking all the exhibits as a cohesive whole. Images and further detail of the devices is presented in Appendix A.

Demonstration Devices

Demonstration Devices developed for use during Educational Programs and Festivals/future events include: 1) Wind Tube, 2) Air Vortex Cannon, 3) Mini Wind Farm, 4) Wind Hand Crank Generator, 5) Construct a Turbine. Images and further detail of the devices is presented in Appendix B.

Educational Programs

AAHOM, partners, and volunteers facilitated 68 in-classroom or school wind energy workshops, “Family Science Nights” at the Museum, and/or participatory “labs”/field trips

Participation in Regional Festivals (2016)

AAHOM and partners were present during and engaged attendees with Demonstration Devices as well as prototypes of the permanent exhibits at the following: April 17, Ann Arbor Earth Day Festival (~3,000 attendees); June 10 Ann Arbor Mayor’s Green Fair (~2,000 attendees); June 24-25 Michigan Renewable Energy Fair (~1,000 attendees); July 30-31 Detroit Maker Faire (Over 25,000 attendees).

This grant created a first of its kind educational curricula that has been resoundingly successful within Ann Arbor and area school districts, as well as for attendees of several regional educational festivals, and the members and visitors of the Museum during the project. Programs are and will be offered after the project and, along with the physical exhibits, will be a treasured resource in the region for years to come.

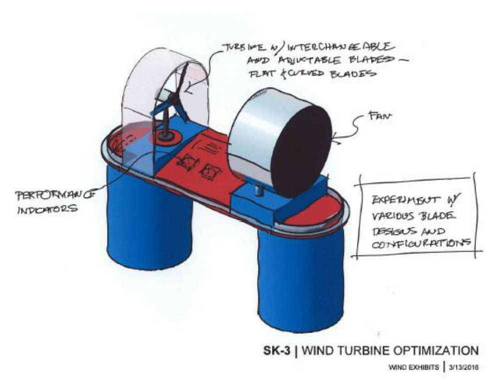
Background

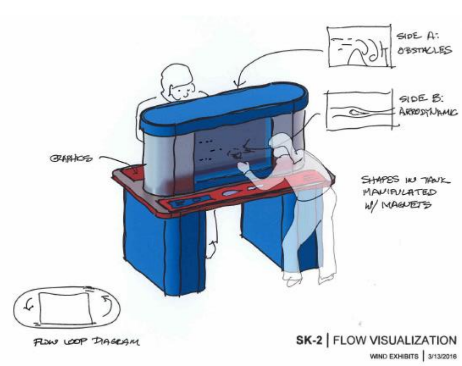
After initial efforts supported by the local District Congressional office to support a city wind installation in Ann Arbor were stalled after partner match commitments could not be secured, the City worked with the US DOE team on a modified project focusing on wind energy educational programs. Washtenaw County had recently done a wind resource study finding the local area to have moderate or low conditions conducive for large-scale wind turbines. In July 2014, the US DOE grant team accepted a modified proposal to retain the educational component of the original allocation for funds. The City approved an agreement with AAHOM to execute the education program with a period of performance out to September 30, 2016. Taking advantage of AAHOM's past experience building interactive science principles into exhibits and taking complex energy information down to an understandable level through outreach at schools and events became the emphasis of the City and AAHOM's project.

The City staff most engaged on the project were Nathan Geisler, Energy Programs Analyst, who has been working on energy efficiency programs with the City since 2009 and other land-use and environmental programs and organizations since 2002. Brian Steglitz is a senior utilities engineer for the City and Water Treatment Plant Manager and offered technical input as well as contract administration support in shifting the project's emphasis, and has worked for multiple decades in the engineering field. Matthew Naud is the City's Environmental Coordinator and has been with the City since 2001 after several years work in international and federal agency environmental consulting. The City's twelve-member citizen Energy Commission was also engaged during the grant and offered input and ideas.

AAHOM staff were led by Ari Morris, Assistant Director of Operations, with support and involvement from museum Director Mel Drum. The following additional AAHOM staff were highly involved and are educators, exhibit designers, and program leaders at the museum: Andrea Reynolds, Charles Stout, Cory Joyrich, Lorrie Beaumont, Sam McLaren. Ms. Beaumont, Ms. Reynolds, and Ms. McLaren were instrumental in developing and delivering the educational content and programs. To drive prototyping and construction of devices and exhibits Mr. Stout was joined by Larry Hutchinson of Hutchinson Studios, an expert exhibit fabricator involved in ongoing museum projects. Mr. Drum and Mr. Joyrich coordinated necessary administration and relationship building, alongside the facilitation and project coordination leadership of Mr. Morris.

Early Concept Sketches of Wind Energy Exhibits





Accomplishments

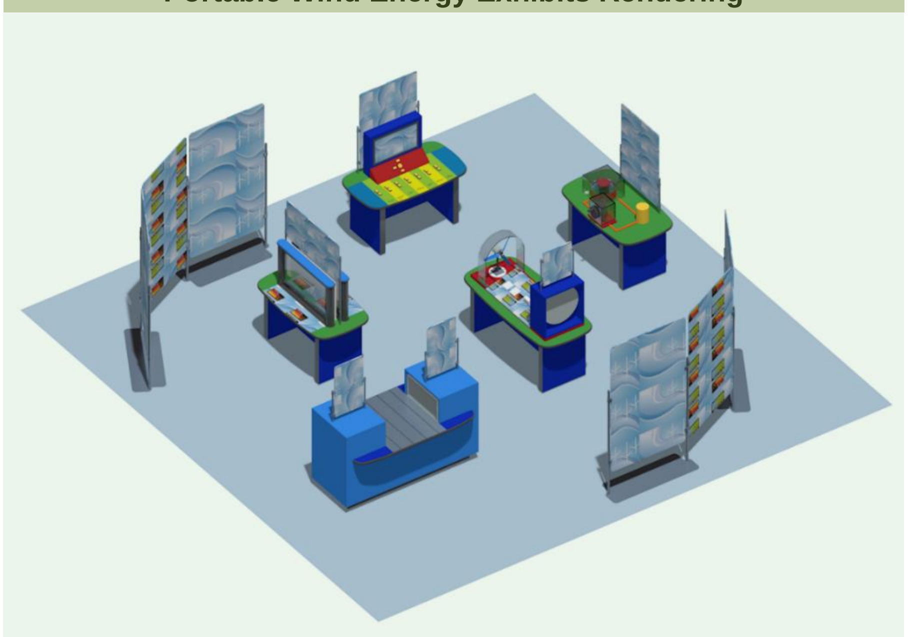
This project was highly successful in meeting the objectives of increasing awareness and understanding of wind energy's role in modern energy supply. In particular, concepts that can be daunting were effectively scaled to an elementary/middle-school audience, while at the same time helping the local school system to better incorporate renewable energy concepts in a classroom workshop setting. Energy is frequently part of the local school curricula at certain times of the school year and the programs and devices will be a valued aid for local teachers. By producing wind energy curricula and fabricating material supplies and devices that children and adults can experiment with, the project raised understanding both during the project period, but more importantly developed the template to build on for years to come. With the help of the US DOE team, the City, AAHOM and partners now offer new content that is replicable in other locations while also possessing interactive exhibits that will reside at one of this region's most accessible and highly visited educational venues. At the conclusion of the project, the five wind exhibits are in the front entryway to the museum.

AAHOM is planning to continue to expand the educational programming enabled by the grant, and leverage new opportunities. The local utility, DTE Energy, cooperated during the grant and facilitated a tour of an existing wind farm (cover photo) within their service territory, to inform and inspire exhibit and demonstration device design. Wind energy is likely to continue to serve an increasingly significant share of electricity and the City hopes that this project and work resulting in the future will aid utility efforts to diversify electricity supply with wind and other forms of renewable energy.

Portable Exhibits - Accomplishments

Below is a design rendering of the complete set of Portable Exhibits, immediately followed by a (partial) photo of the suite of exhibits on display at the Ann Arbor Hands-on Museum.

Portable Wind Energy Exhibits Rendering



Portable Wind Energy Exhibits on Display

The Exhibits were built during the grant period ending September 30, 2016 and are now on display, with plans for travel in 2017 and beyond to and from AAHOM. AAHOM received input from the City and partner organizations, as well as from the US Department of Energy grant team who received regular project updates.

The final constructed exhibits include: 1) Wind Table, 2) Flow Tank, 3) Modifiable Wind Turbine (with removable blades), 4) Energy Storage (with wind animation praxinoscope), 5) Power Grid Scenario Game, as well as accompanying display panels that provide content linking all the exhibits into a cohesive whole.

<u>Description of Exhibits</u>:

The **Wind Table** allows visitors to move small objects into positions to receive the force of fanned, one directional air. Objects on the table include wind sale cars, a vertical access turbine, and objects that can obstruct or impede air flow to the moveable objects.

The **Flow Tank** provides a visual for how fluid dynamics effectively demonstrate how wind current moves across objects, including the eddying effects produced. Users manipulate and reposition magnetized plastic implements from the outside of the transparent wall of the tank. Shapes include template turbine blades, a home, trees and other objects that, like the Wind Table, depict wind force in a visible and tangible way.

The **Modifiable Wind Turbine** mirrors the simpler turbine Demonstration Device. Each allow different shaped blades to be inserted into and out of a mock nacelle/axis. Users can add as few or as many blades as they wish to the horizontal axis, while a mounted reader shows the relative effect on “production,” as a fan generates constant wind toward the turbine.
The **Energy Storage** exhibit uses a hand-crank generator to run a praxinoscope that with enough speed animates the image of spinning wind turbines. After so many spins, “power” shifts to a cylinder, meant to represent a battery storing electricity, while a “flow” of LED lights show the direction of electricity. The battery lights up in successive rings of varied colors until full. The

wind turbine animation will continue to run and draw down the battery as a way to show the role of storage in wind energy systems, due to the variable nature of wind as an intermittent resource.

The **Power Grid Scenario Game** gives users the chance to explore how different sources of energy, including and in addition to wind energy, can factor into decisions around what type of energy source is more or less ideal under variable circumstances. This is one of the more complex exhibits both in design and as an interactive experience. Resource constraints, weather and other limitations like costs are presented to the user on a flat screen monitor and visitors must manage what proportion of different energy mixes best optimize the situation while not compromising or over-stretching the source for generation.

Appendix A contains several images of both design drawings and photographs of the final constructed exhibits.

<u>Demonstration Devices - Accomplishments</u>

Demonstration Devices were successfully fabricated and deployed for use during Educational Programs and Festivals during the grant period. The Devices made during the project were: 1) Wind Tube, 2) Air Vortex Cannon, 3) Mini Wind Farm, 4) Wind Hand Crank Generator, 5) Construct a Turbine.

This suite of devices are designed to conveniently pack-down and transport to schools and other facilities and augment content AAHOM developed with partner REcharge Labs, whose existing K-12 wind energy resource material was adapted and updated. AAHOM staff, along with volunteer support, delivered numerous educational sessions while observing and assisting use of the devices. Devices often served to help “lure” interest from passersby, such as the **Air Vortex Cannon**, frequently positioned slightly apart from other devices and near thoroughfares. The Cannon demonstrates the force of wind and typically sent a pulse of air to knock a light paper object from the head or hand of a visitor. Children and parents then draw closer to experiment with the full set of devices to gain a broader understanding of wind energy concepts. The vertical **Wind Tube** experiments with resistance and other physical aspects that factor into wind energy generation. Light objects are placed to hover within the tube or will quickly blow upwards. The **Hand-crank Generator** moves a two directional fan that can force small streamers in the direction generated by the faster of two participants. Interactive, competitive features within devices like this one help add excitement to the interaction and attempt to foster a greater willingness, through play, to absorb scientific concepts. The **Construct a Wind Turbine** device allows visitors to modify different blade designs and configurations to optimize turbine speeds (generated by a fan making constant “wind”), and helps transform the conceptual emphasis of the other devices into how design and experimentation determine wind turbine engineering and construction. The **Mini Wind Farm** device allows experimentation with the spatial dimension involved in arraying wind turbines, as users confront hills and other impediments to direct wind flow that reduce the speed or halt completely small moveable turbines. Full wind activates the mini turbines and lights-up a responsive LED light.

Images and detail of the devices are presented in Appendix B.

<u>Educational Programs – Accomplishments</u>
The wind energy educational programs were highly successful and participating teachers were very responsive when AAHOM first offered in-school visits and workshops for students. A sampling of advanced testimonials follows:

This is a great opportunity, and I'm so happy you offered it to us! My 6th grade Earth Science classes are working on wind as it relates to weather right now, so it would be a great connection! And my 7th grade Life Science classes are looking at how aspects of what we study in class connect to the big picture, so alternative energies is a great topic for them!
S. Frantom – Tappan Middle School

Thanks so much for thinking of us! We study energy in fifth grade.
J. Spiroff -Wines Elementary

Thanks so much for making this opportunity possible.
T. Othman - Lakewood Elementary

I teach energy to my students near the end of May and I would love for you to come in and talk to my students about wind energy. Thanks so much for reaching out!
S. Greenes – Tappan Middle School

We would love to have the Hands-on Museum come into our 6th grade classes at Slauson Middle School! We will be beginning our weather unit and the wind energy program will fit in perfectly with our curriculum.
T. Maglothin – Slauson Middle School

Thank you for providing this great opportunity for students in Ann Arbor.
J. Parkus – Pittsfield Elementary

Once the content for the programming was developed, 68 classroom workshops, labs, and Family Science Nights engaged local residents on wind energy concepts. AAHOM staff worked for several months prior to delivering the programs to refine the content. Due to the success of the programs, AAHOM has plans to continue wind energy education offerings in future school years.

Timeline of Major 2016 Educational Programs	
2/22/2016	Classroom Wind Workshop (x4) at Forsyth Middle School in Ann Arbor, MI
2/24/2016	Classroom Wind Workshop (x4) at Slauson Middle School in Ann Arbor, MI
2/29/2016	Classroom Wind Workshop (x4) at Slauson Middle School in Ann Arbor, MI
3/2/2016	Classroom wind workshop, (x4) at Slauson Middle School, Ann Arbor, MI
3/7/2016	Classroom wind workshop (x2) at Pittsfield Elementary School, Ann Arbor, MI
3/9/2016	Classroom wind workshop (x2) at Lakewood Elementary School, Ann Arbor, MI
3/9/2016	Classroom wind workshop at Bach Elementary School, Ann Arbor, MI
3/16/2016	Classroom wind workshop at Wines Elementary School, Ann Arbor, MI
3/16/2016	Classroom wind workshop (x5) at Tappan Middle School, Ann Arbor, MI
3/28/2016	Family Science Night at Childs' Elementary, Ypsilanti, MI
4/11/2016	Classroom wind workshop, (x2) at Allen Elementary School, Ann Arbor, MI
4/15/2016	Classroom wind workshop, (x2) at Bach Elementary School, Ann Arbor, MI
4/13/2016	Night at the Museum, Michigan State University Science Festival
4/18/2016	Classroom wind workshop, (x3) at Lawton Elementary School, Ann Arbor, MI
4/22/2016	Family Science Night at Bishop Elementary School, Ann Arbor, MI
4/26/2016	Family Science Night at Honey Creek Community School, Ann Arbor, MI
4/29/2016	Field trip wind lab class (x3) with Brenda Scott Academy of Theater Arts, from Detroit MI
4/30/2016	Field trip wind lab class with Schultz Elementary School, from Detroit MI
5/2/2016	Classroom wind workshop at Wines Elementary School, Ann Arbor, MI
5/4/2016	Classroom wind workshop at Wines Elementary School, Ann Arbor, MI
5/9/2016	Classroom wind workshop (x3) at Thurston Elementary School, Ann Arbor, MI
5/16/2016	Classroom wind workshop (x4) at A2-STEAM Elementary School, Ann Arbor, MI
5/18/2016	Classroom wind workshop (x4) at A2-STEAM Elementary School, Ann Arbor, MI
5/23/2016	Family Science Night at Creekside Intermediate School, Ann Arbor, MI
5/25/2016	Classroom wind workshop (x2) at Logan Elementary School, Ann Arbor, MI
5/31/2016	Family Science Night at A2-STEAM Elementary School, Ann Arbor, MI
6/3/2016	Family Science Night at Ann Arbor Open School, Ann Arbor, MI
6/3/2016	Classroom wind workshop (x4) at Tappan Middle School, Ann Arbor, MI
6/3/2016	Family Science Night at Go Like the Wind Montessori School, Ann Arbor, MI
6/13/2016	Classroom wind workshop (x3) at King Elementary School, Ann Arbor, MI

Participation in Regional Festivals (2016) - Accomplishments

The project met its intended target of exposure to over 30,000 festival/event attendees. These 2016 events included:

- April 17, Ann Arbor Earth Day Festival (~3,000 attendees)
- June 10 Ann Arbor Mayor's Green Fair (~2,000 attendees)
- June 24-25 Michigan Renewable Energy Fair (~1,000 attendees
- July 30-31 Detroit Maker Faire (Over 25,000 attendees)

Project team attendance and interactions with visitors aided the prototyping stage of exhibit development. Input from visitors ultimately shifted the direction and emphasis of multiple components and designs. AAHOM plans to bring the devices and exhibits back to several of these and other events in coming years.

Conclusion

This grant and support from the US Department of Energy enabled a new suite of exhibits and programs focused on wind energy to be fabricated and presented to audiences in a variety of local, educational settings. In particular, the grant was irreplaceable as a means of engaging children and parents on "STEM" concepts increasingly emphasized in K-12 education. Energy plays a significant role in all people's lives, even if they do not immediately recognize its impact. As older, centralized systems for electricity production give way to new technologies it will be important for the public to broaden their understanding of the role wind energy plays in providing reliable, cost-effective electricity. The materials developed during the project, thanks to the US DOE, would otherwise not exist, and the City of Ann Arbor now harbors a unique and lasting set of educational tools scalable to many communities in Michigan and elsewhere. AAHOM continues to promote the wind energy program in newly developed outreach materials, while forging ongoing partnerships to utilize the expertise gained during the wind energy project. The suite of devices and exhibits, as well as the educational guides for schools and teachers are readily transferable to many communities looking for a model and process to replicate.

Appendices

Appendix A – Portable Exhibit Renderings and Photographs of Constructed Exhibits

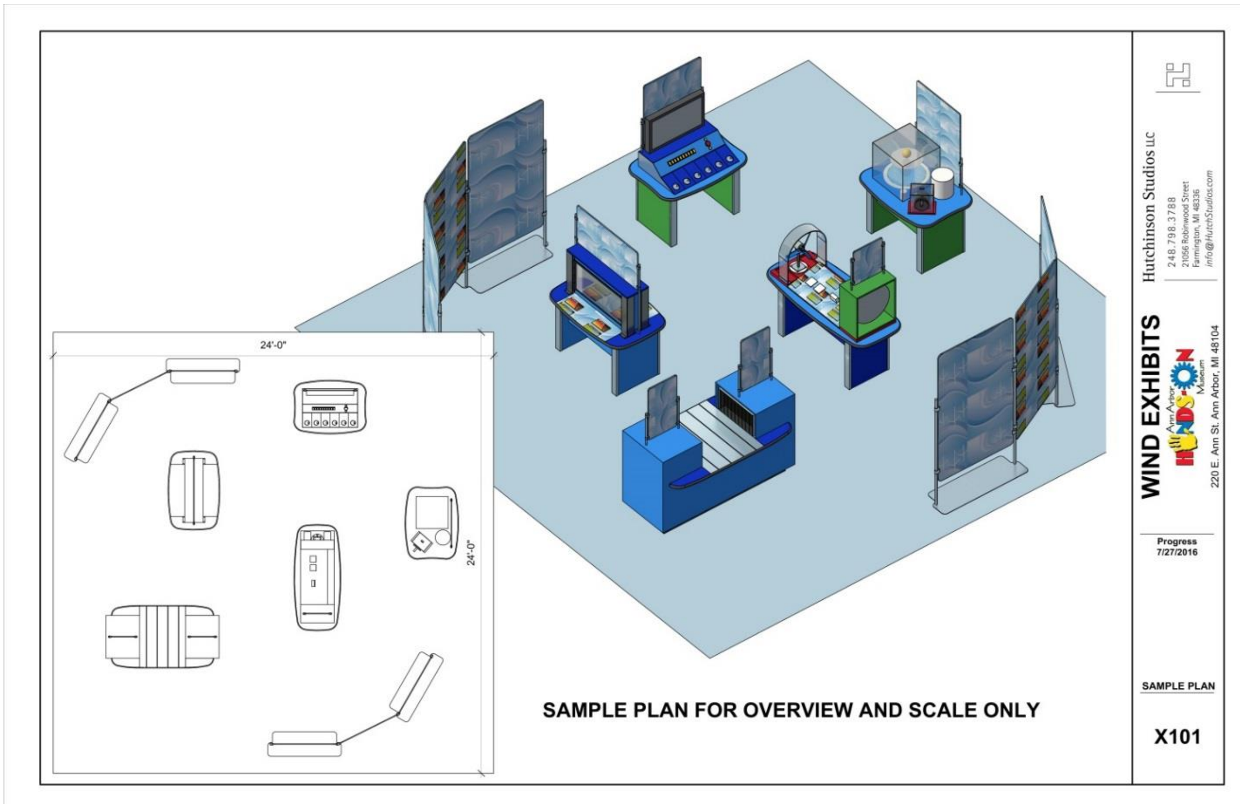
Appendix B – Demonstration Device Renderings and Image Gallery

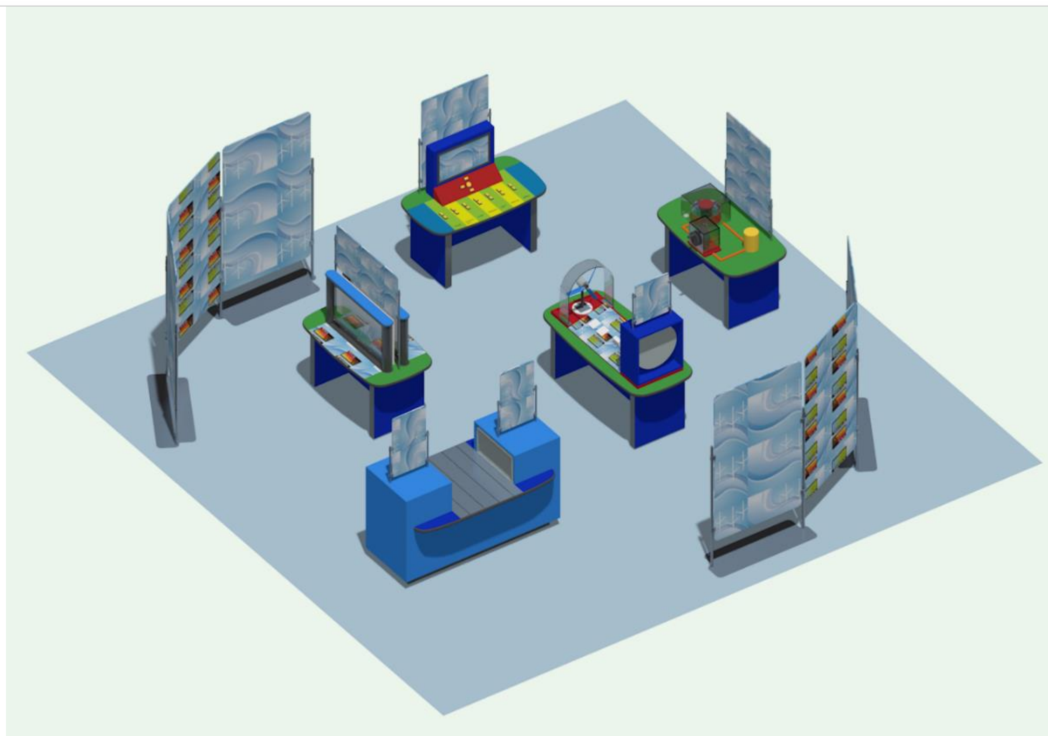
Appendix C – Standing Exhibit Panel Graphics and Content

Appendix D – Image Gallery from Participation in Regional Festivals and Events

Appendix A – Portable Exhibit Renderings and Photographs of Constructed Exhibits

Full Wind Energy Exhibit Suite Rendering and Constructed Exhibits

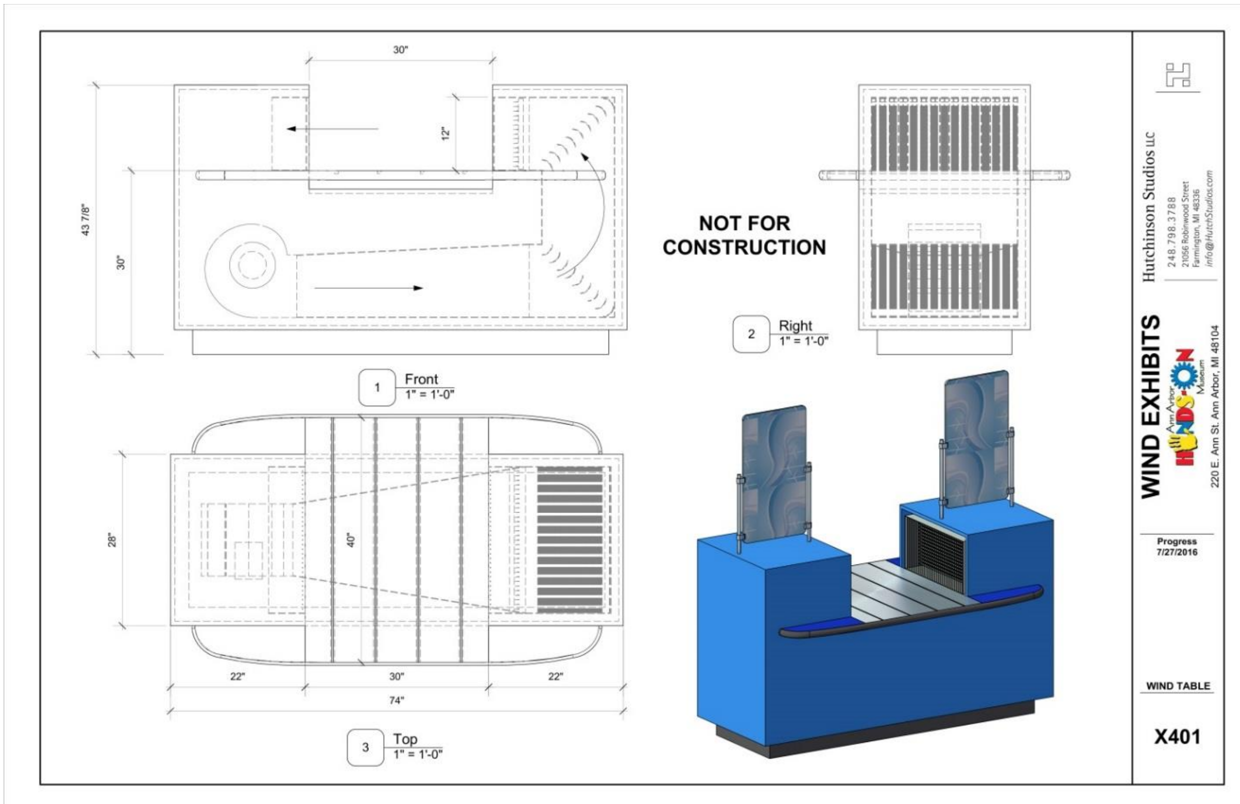


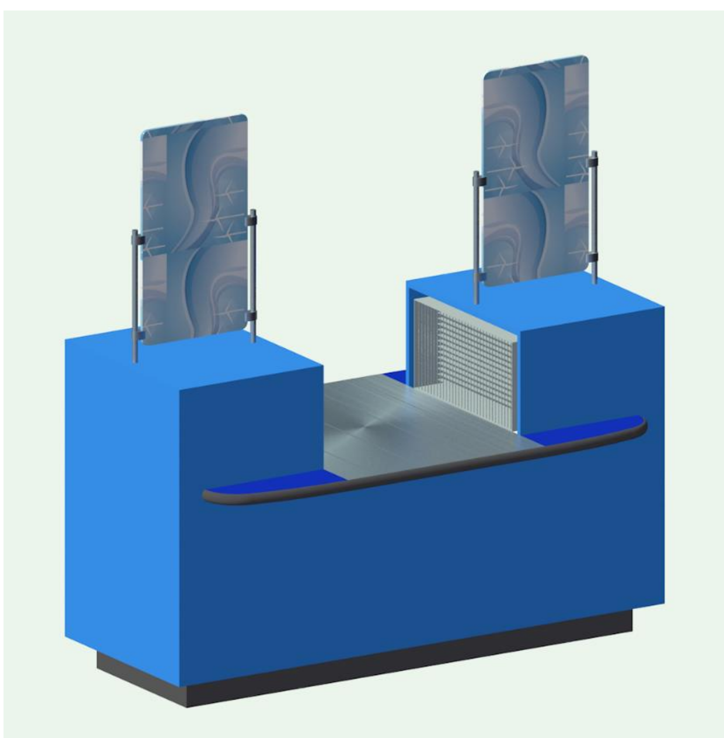



EXPERIMENT
EDUCATE
EXPLORE
THE FUTURE OF
WIND
POWER
FLOW


EXPERIMENT
EDUCATE
EXPLORE
explore
experiment
educate
GETTING THE MOST
ABOUT
TURBINES
FLOW

Wind Table Rendering and Constructed Exhibit

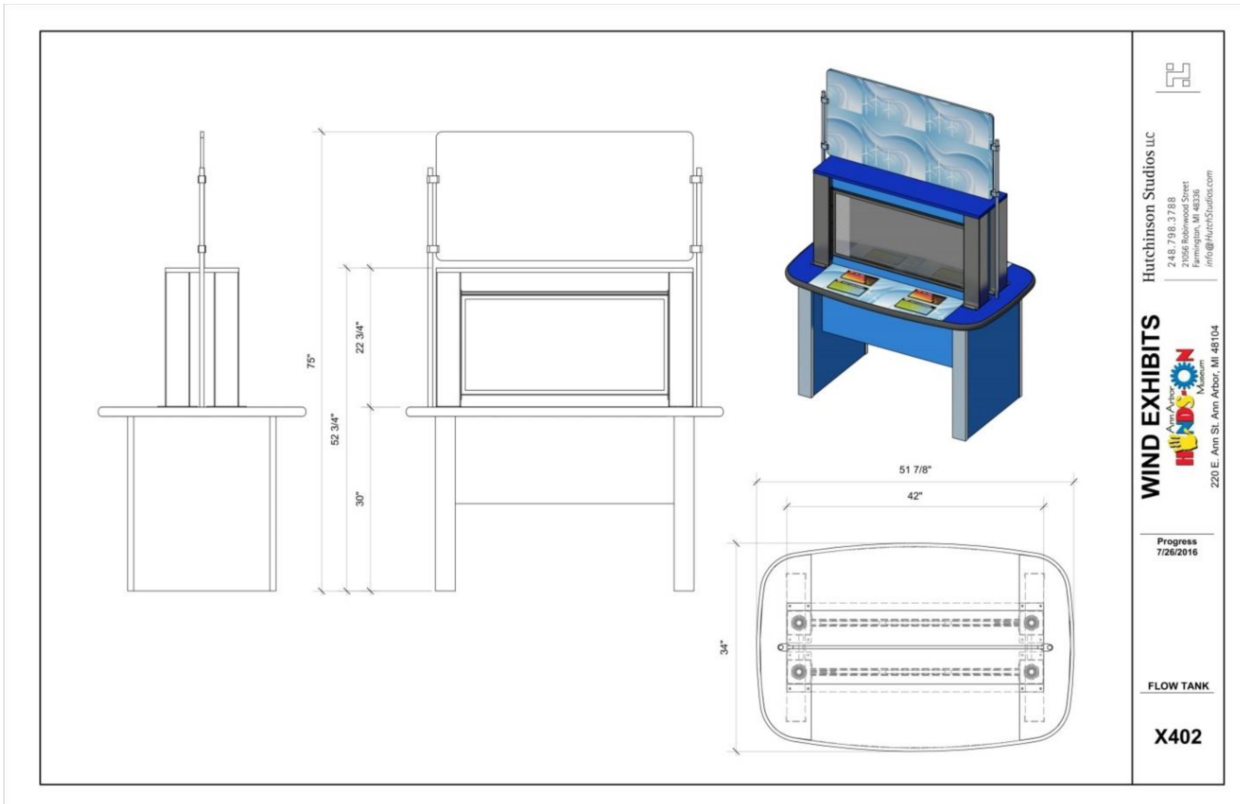


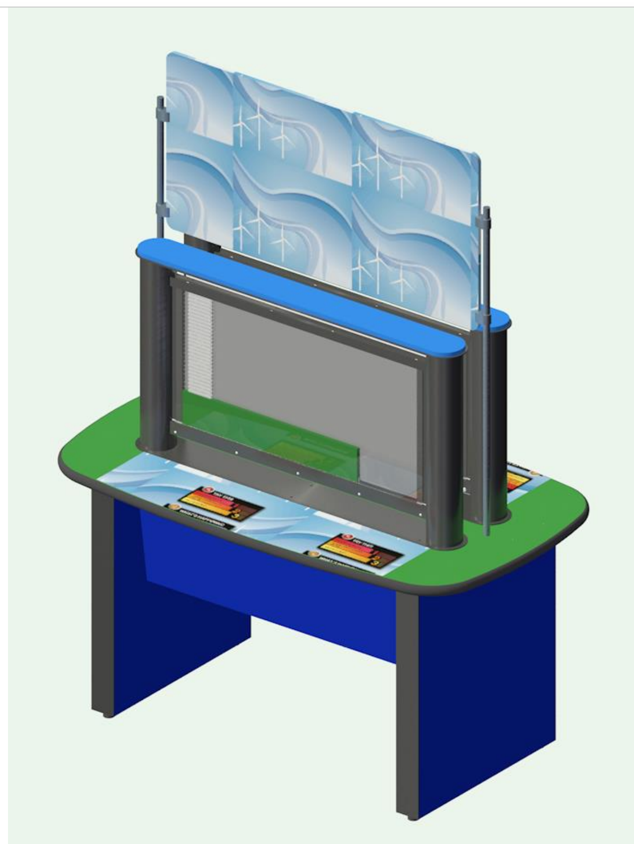



WIND
IS STUFF
TRY THIS!


WIND
IS STUFF
Myth
Reality
EXPLORE
FLOW

Wind **Flow Tank** Exhibit Rendering and Constructed Exhibit

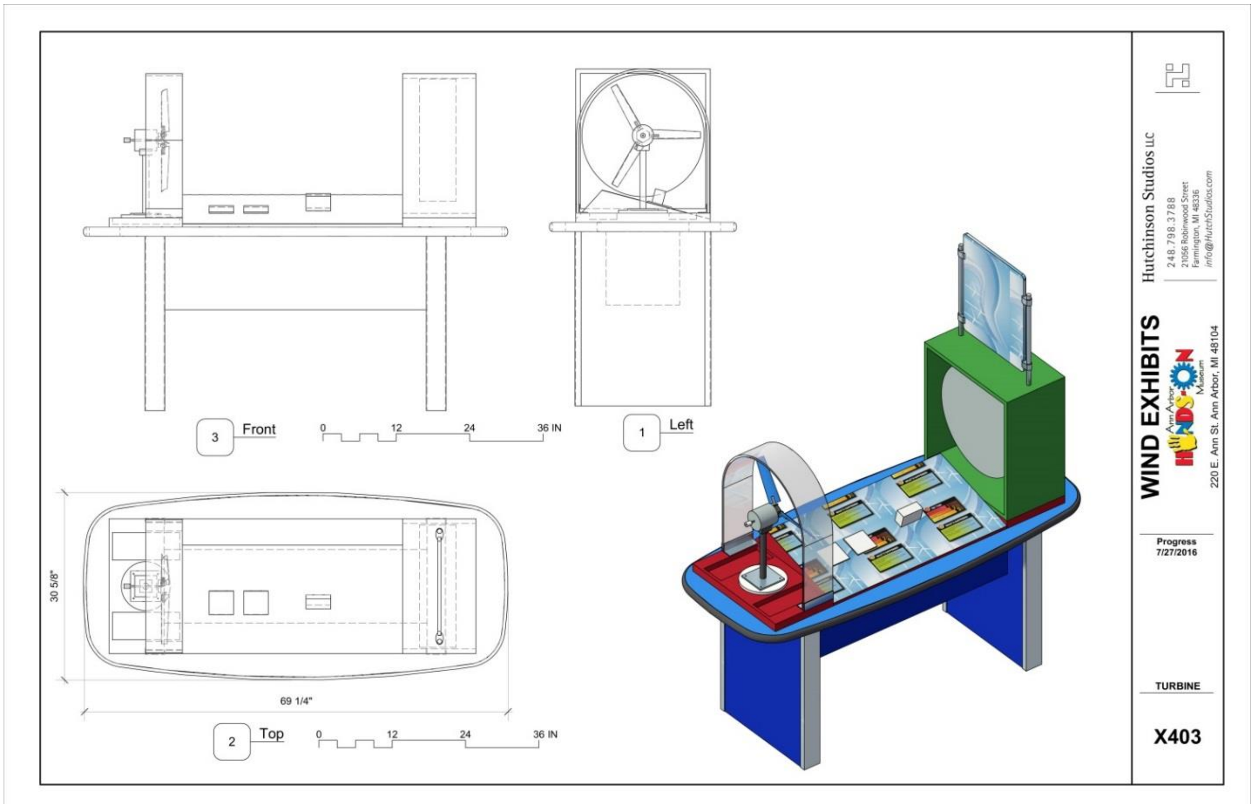


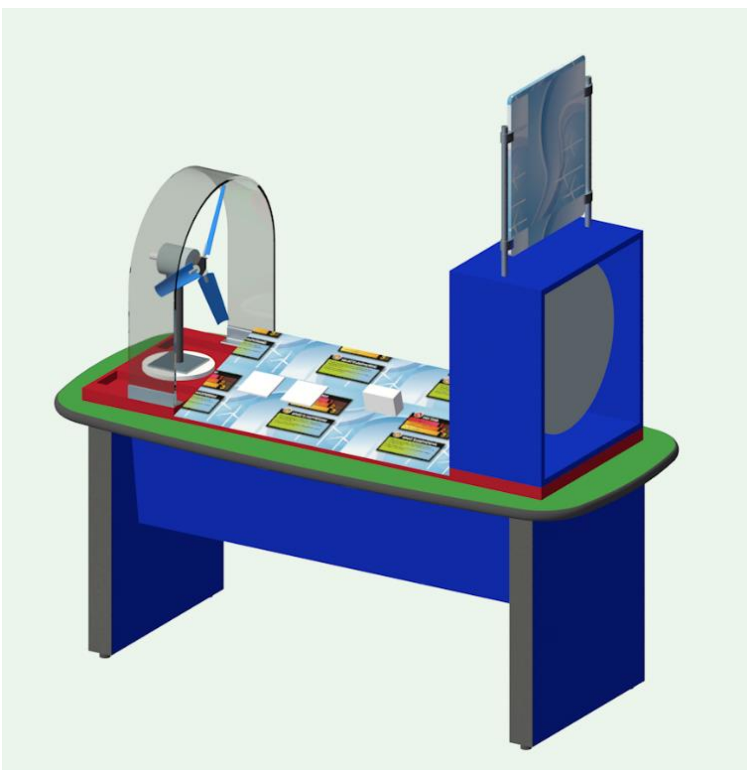



GOING WITH THE
FLOW
Wind moves much like water. It flows around objects, and those objects can change its speed and direction.
Discover Science


GOING WITH THE
FLOW
Discover Science Assistance Fund

Adjustable **Wind Turbine** Exhibit Rendering and Constructed Exhibit

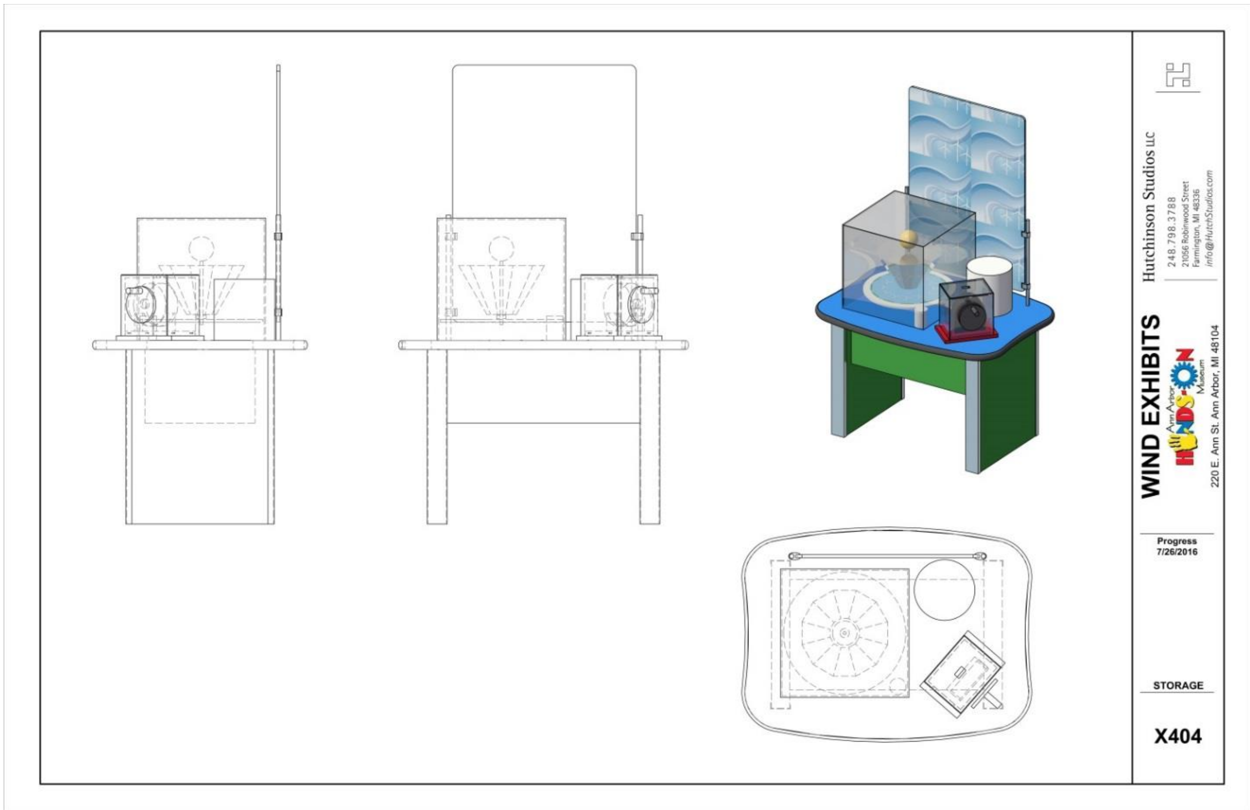


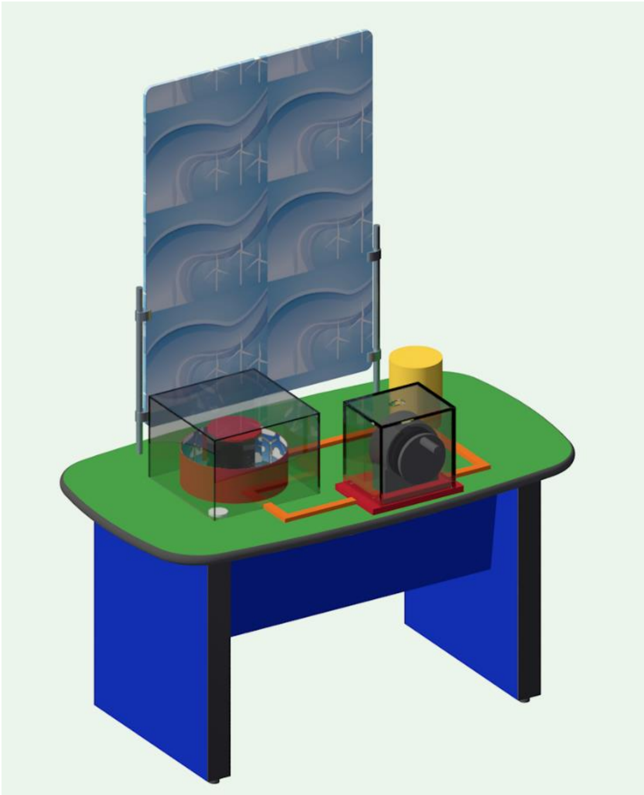



TRY THIS!
TEST A DESIGN
1. Set up your turbine design.
2. Select the type and number of blades and mount them on the hub at your desired angle.
3. Set the load to "0."
4. Turn on the fan.
Observe the speed (RPM) and power (watts). Now change the load. WHAT HAPPENS?
Turn off the fan and repeat the experiment with a different configuration. Remember, changing just one variable for each test will allow you to understand what each variable does. How does the turbine's performance change?
ELECTRICAL LOAD
FAN ON/OFF


GETTING THE MOST
SMALL
WIND
TURBINES
FARMS

Renewable **Energy Storage** Praxinoscope Rendering and Constructed Exhibit

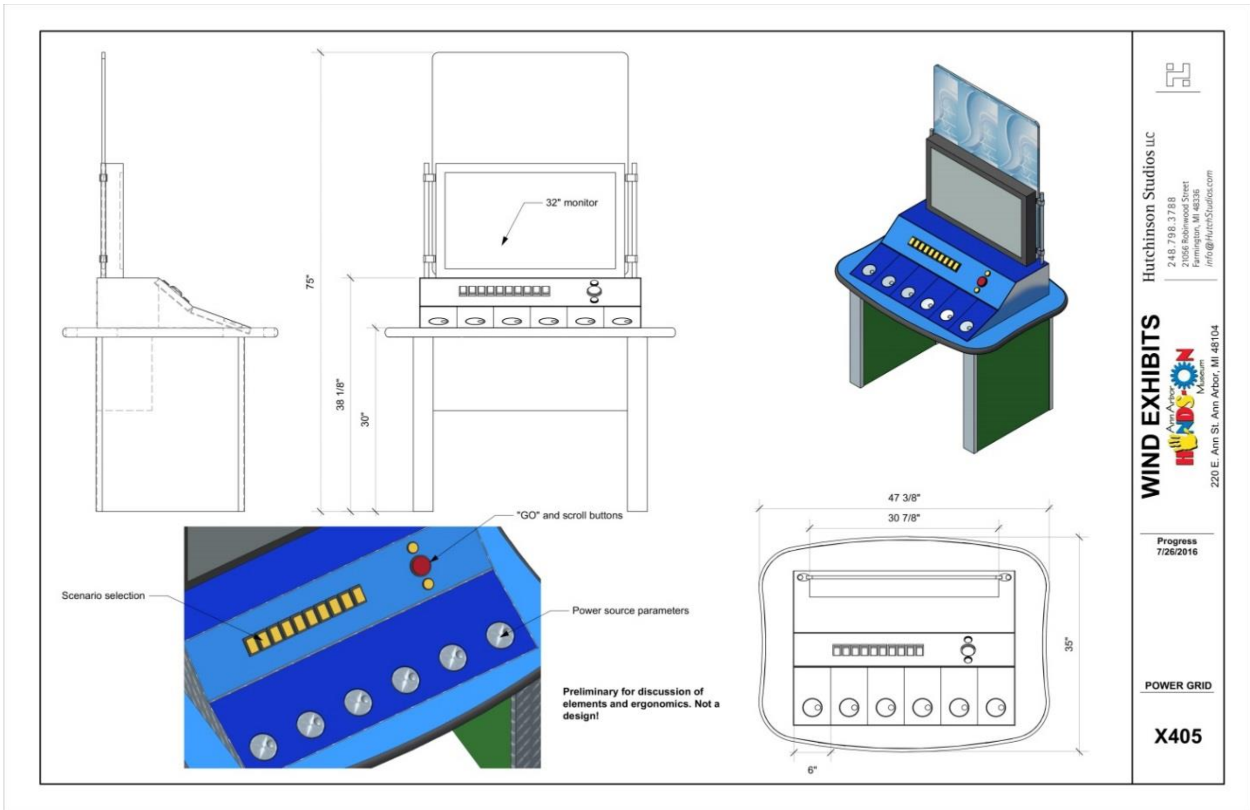





educate
SHIFTING WINDS
what is
WIND


educate
SHIFTING WINDS
what is
WIND

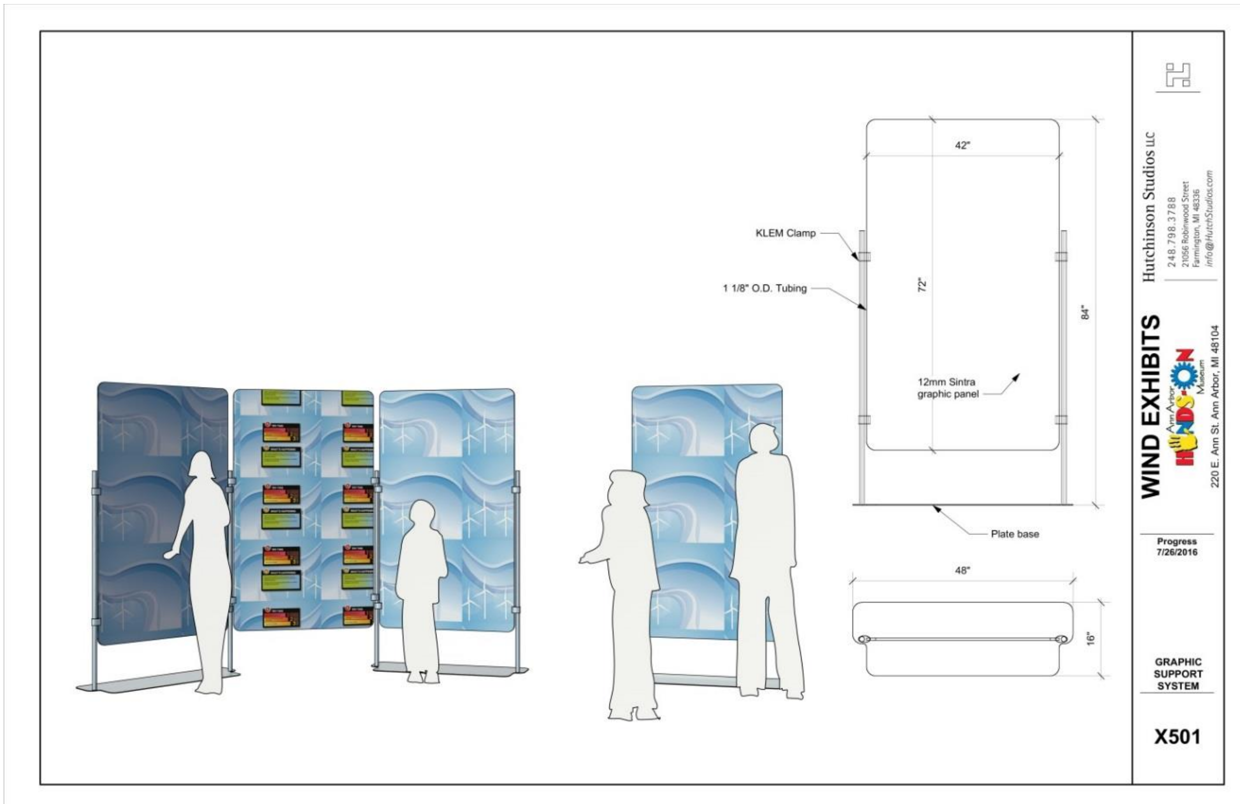
Power Grid Scenario Game Rendering and Constructed Exhibit




renewable energy, such as wind power, by 2015—and power producers have met that goal. Another rule says that utilities need to use and pay for extra electricity created by small, privately owned generators.
Michigan's first large-scale wind turbine was installed in Traverse City in 1996. The state's first wind farm was set up in 2008 in the state's "Thumb" area, where there is open land and a fair amount of wind. There are now more than 20 wind farms operating in Michigan, with more being planned and built. There are also about 300 small wind turbines connected to the grid in the state. Overall, wind accounts for about 40% of the electricity generated by renewable sources in Michigan (2016).
Michigan companies make towers, blades and generators for wind turbines, and about 140 companies in the state are part of the wind industry.
Maintenance - December, Present Day
Solar
WIND
COAL
STORAGE
GAS
SOLAR
NUCLEAR
HYDRO

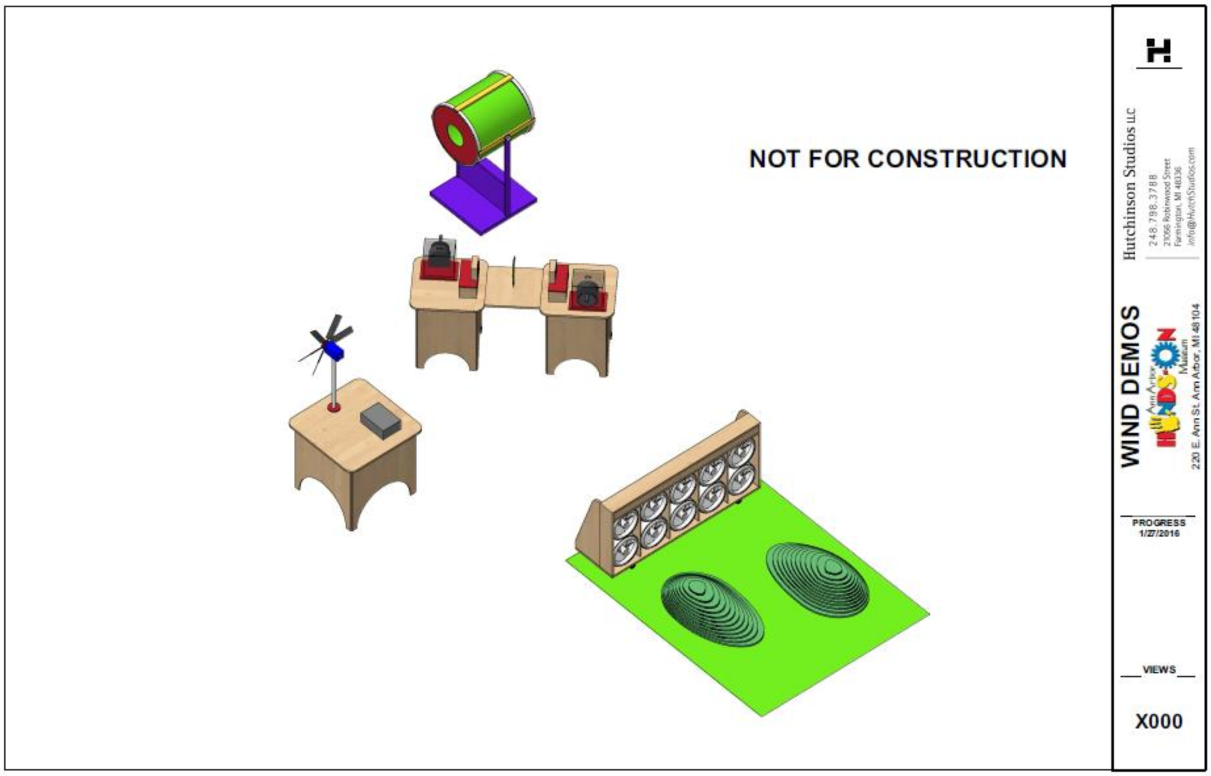

THE GRID
A BALANCING ACT
in Michigan
WIND
POWER
POWER
POWER

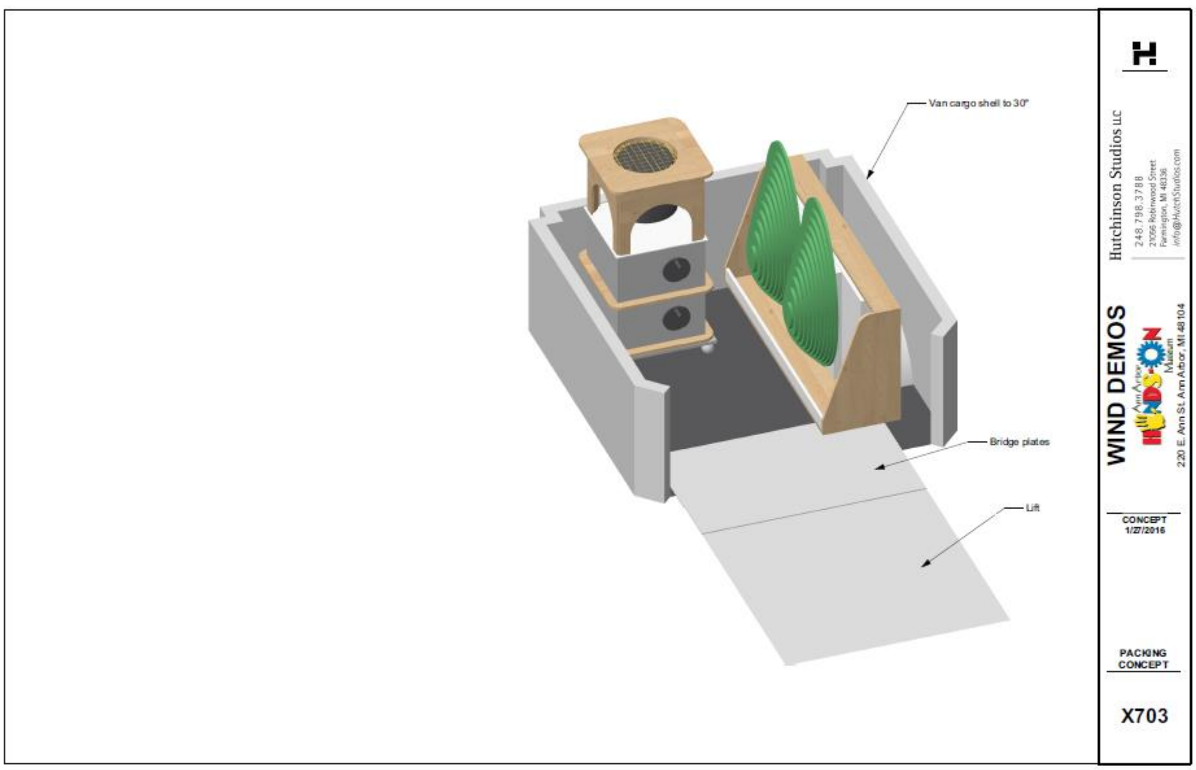
Wind Energy Exhibits **Standing Exhibit Panels** Scale Rendering



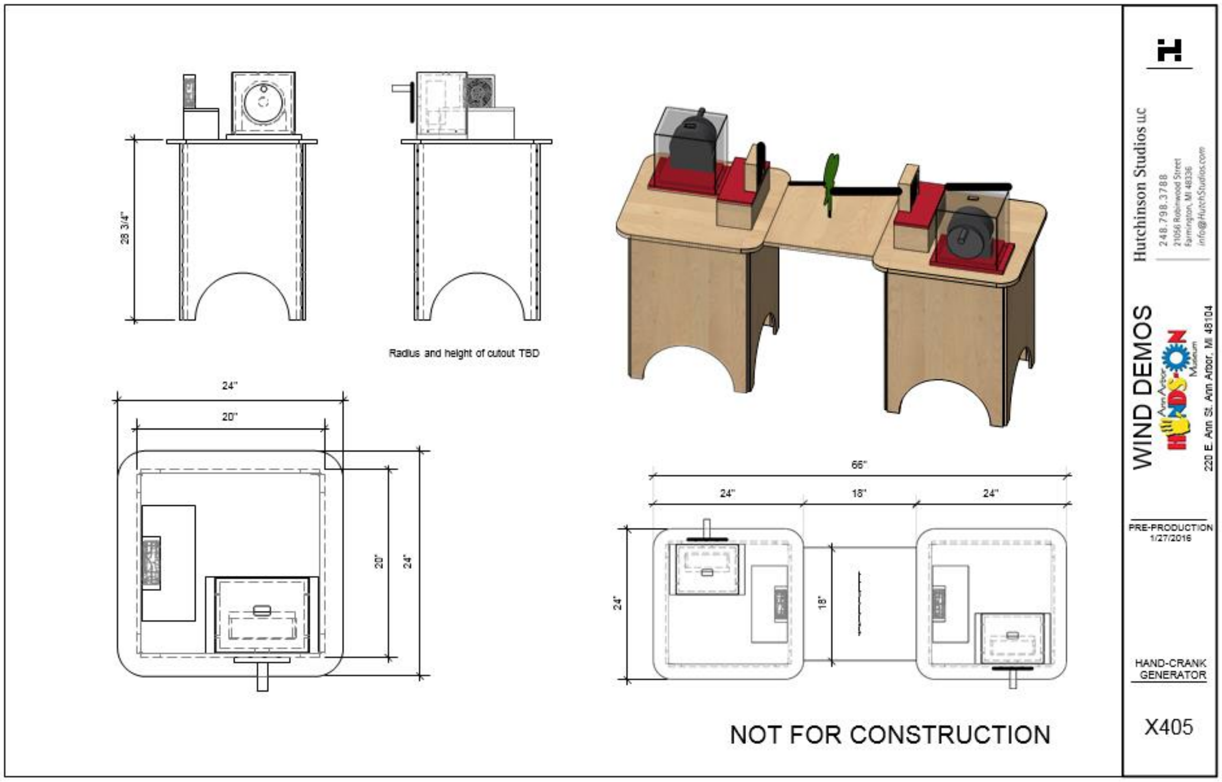
Appendix B – Demonstration Device Renderings and Image Gallery

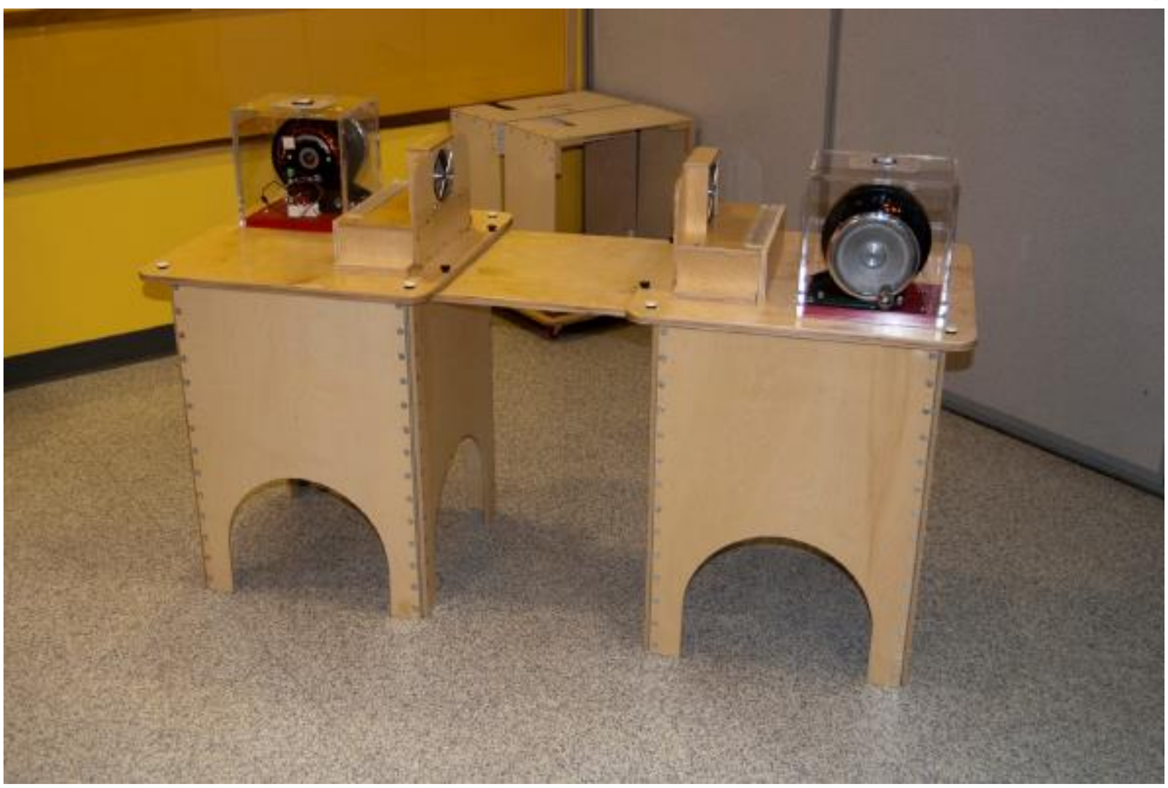
Suite of Demonstration Devices and Transport Assembly



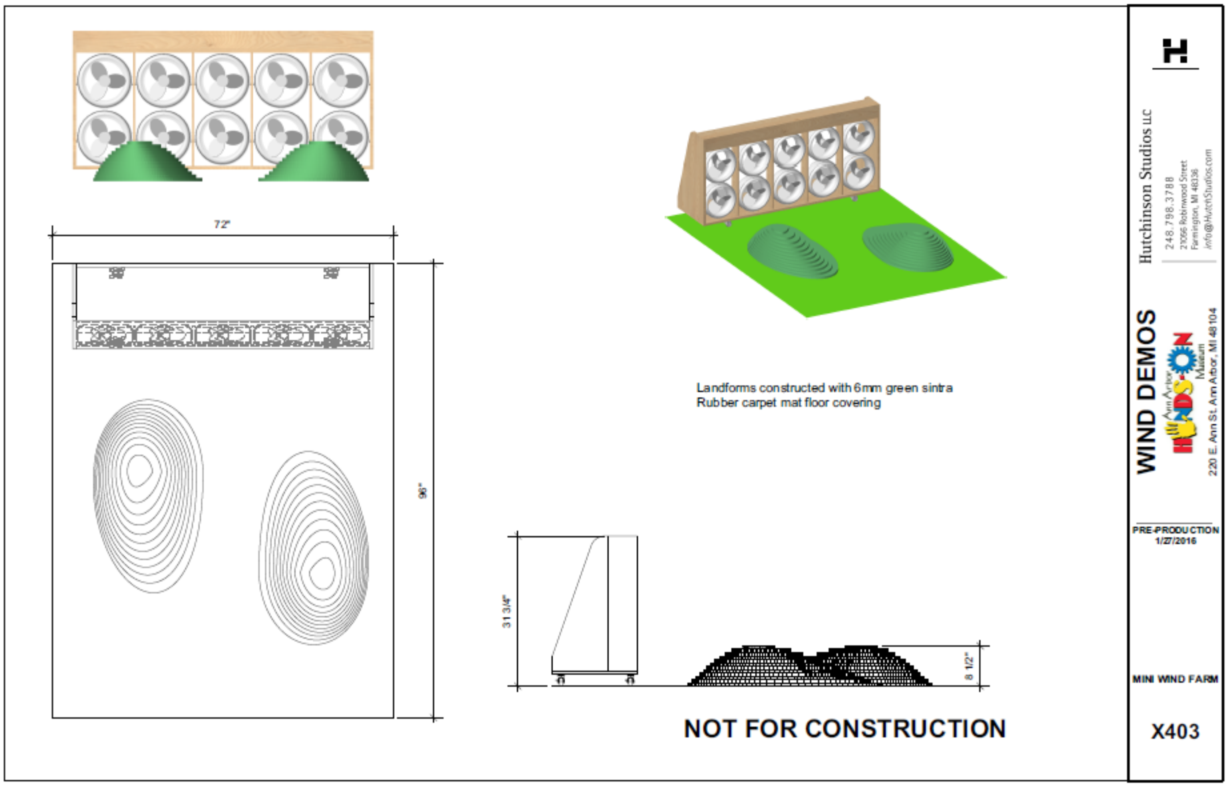


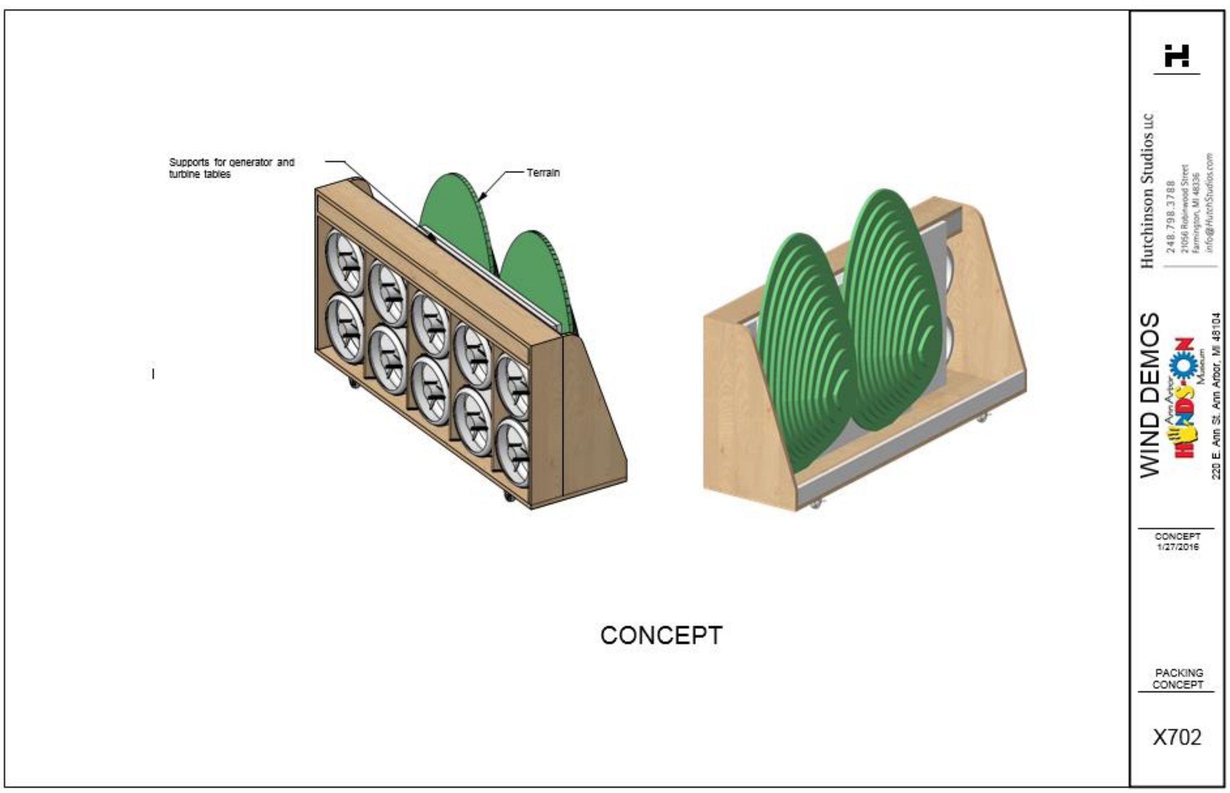
Hand-crank Generator



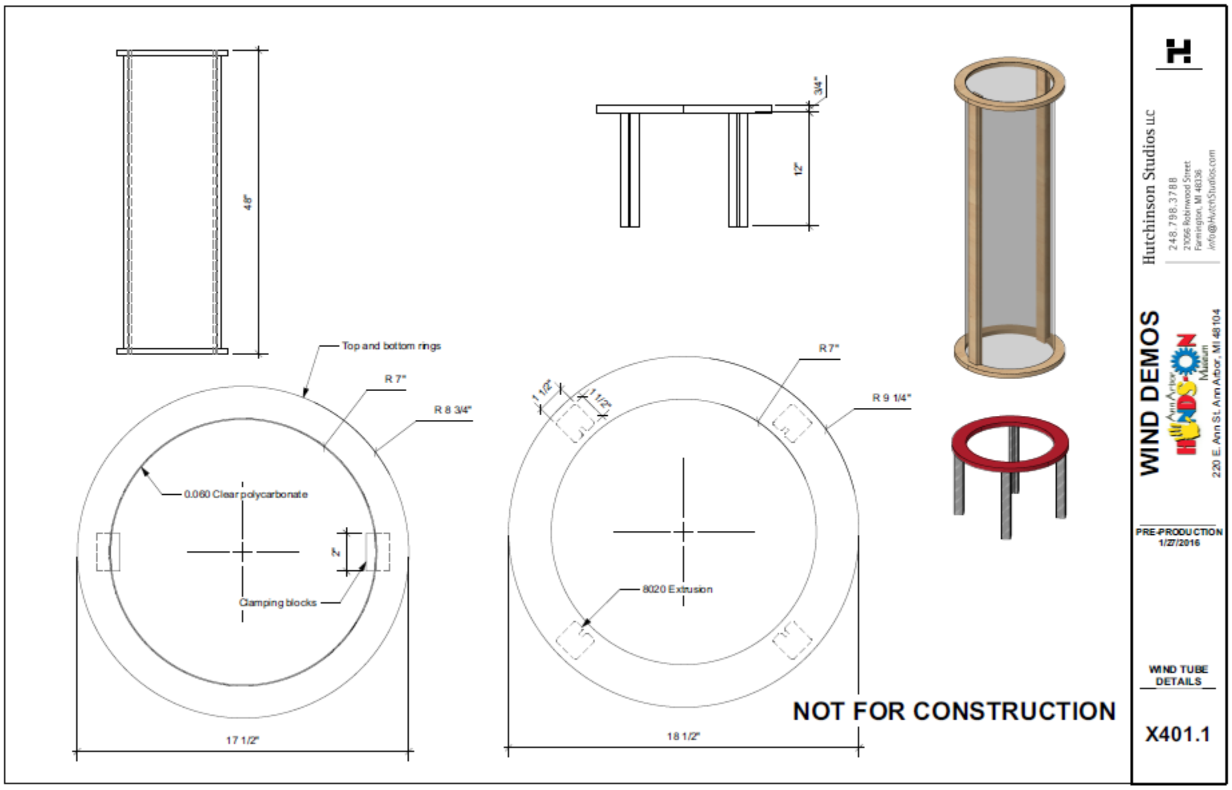


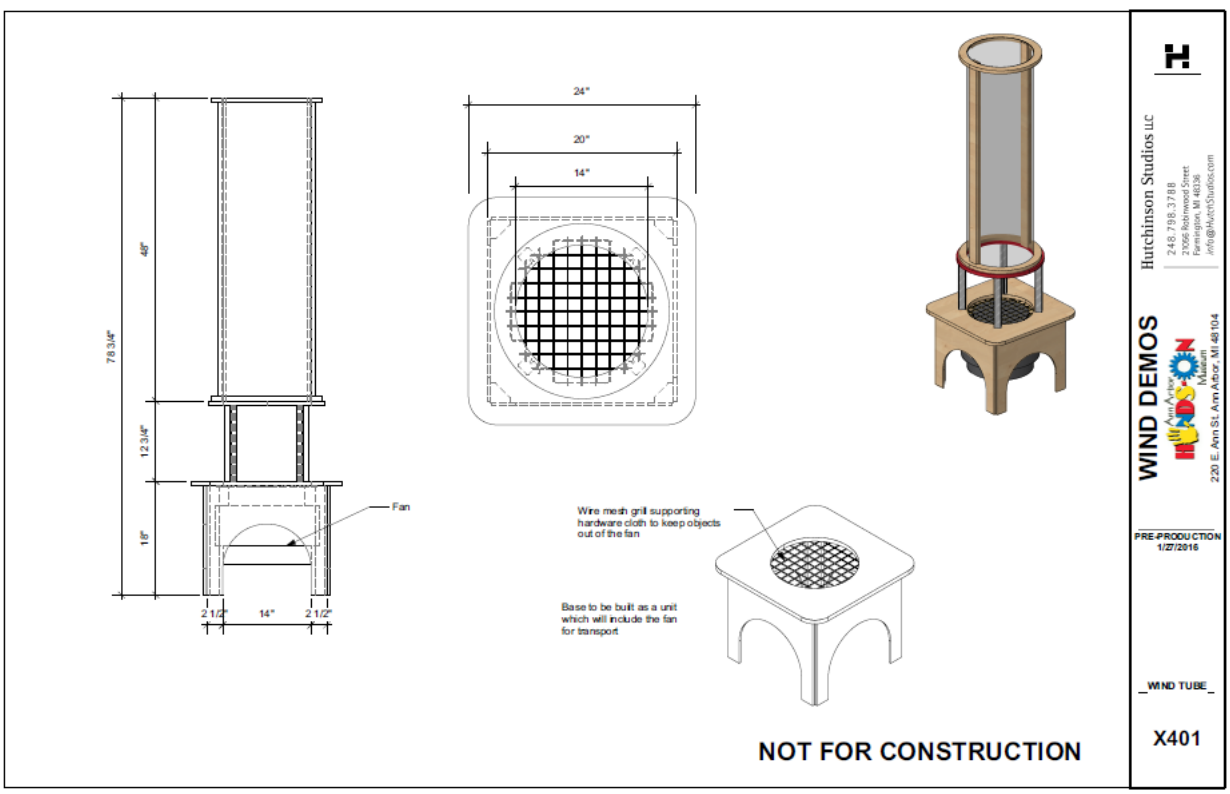
Mini Wind Farm





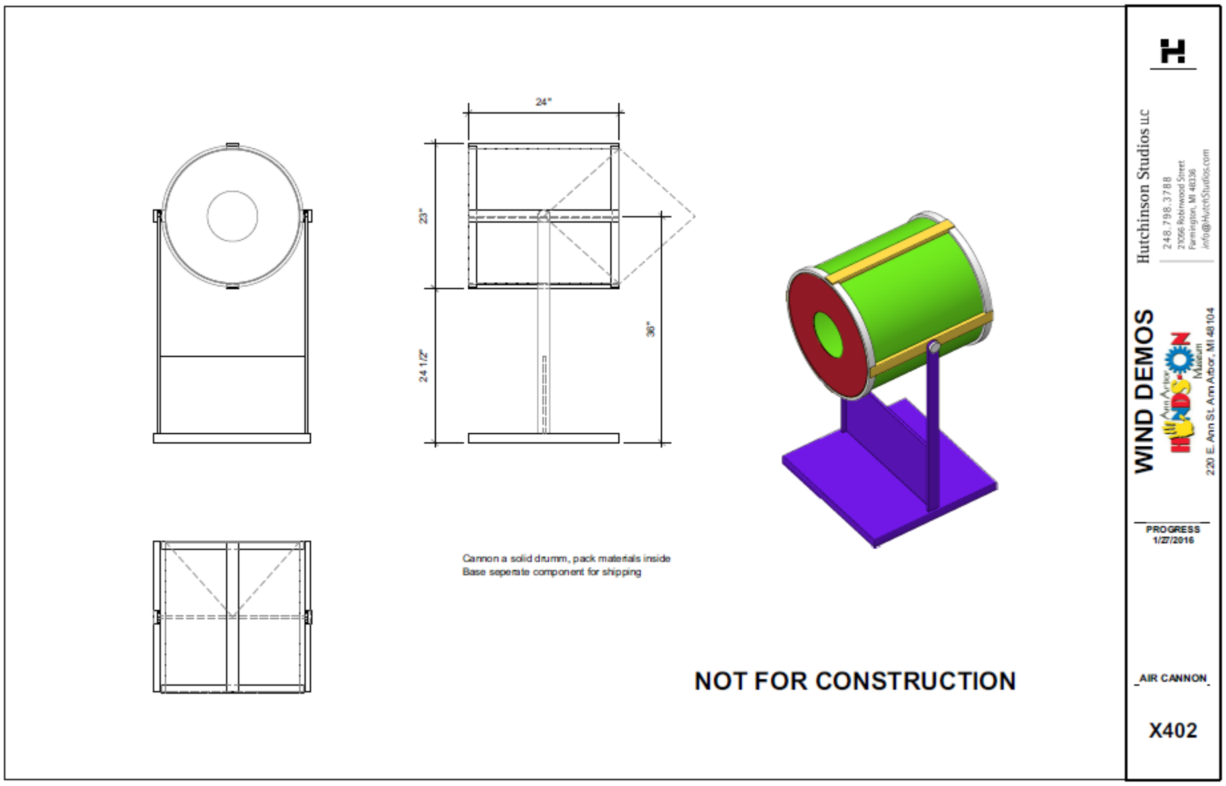
Wind Tube


48"
3/4"
12"
Top and bottom rings
R 7"
R 8 3/4"
0.060 Clear polycarbonate
2"
Clamping blocks
17 1/2"
1 1/2"
1 1/2"
R 7"
R 9 1/4"
8020 Extrusion
18 1/2"
NOT FOR CONSTRUCTION
Hutchinson Studios LLC
248.798.3788
21056 Robinwood Street
Farmington, MI 48336
info@HutchStudios.com
WIND DEMOS
220 E. Ann St. Ann Arbor, MI 48104
PRE-PRODUCTION
1/27/2016
WIND TUBE DETAILS
X401.1


78 3/4"
48"
12 3/4"
18"
Fan
2 1/2"
14"
2 1/2"
24"
20"
14"
Wire mesh grill supporting hardware cloth to keep objects out of the fan
Base to be built as a unit which will include the fan for transport
NOT FOR CONSTRUCTION
Hutchinson Studios LLC
248.798.3788
21056 Robinwood Street
Farmington, MI 48336
info@HutchStudios.com
WIND DEMOS
220 E. Ann St. Ann Arbor, MI 48104
PRE-PRODUCTION
1/27/2016
WIND TUBE
X401

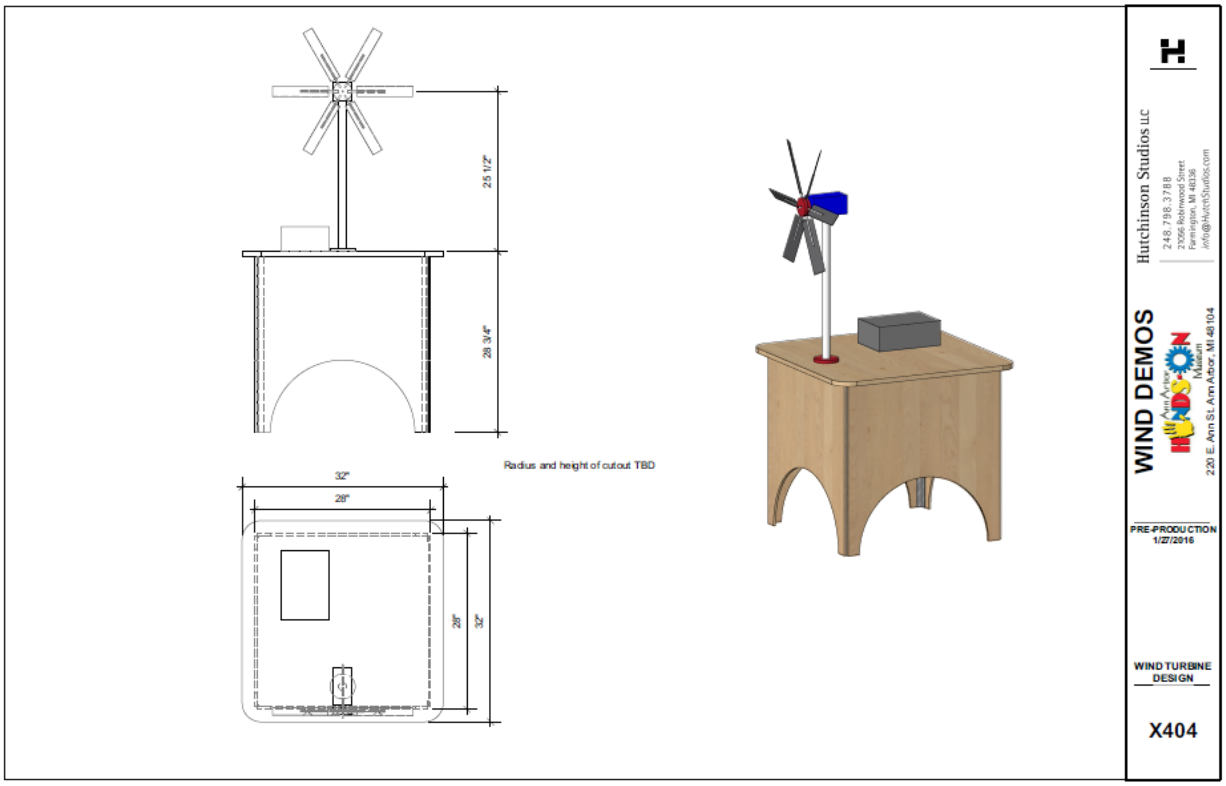

ScienceWorks
2

Air Cannon


24"
23"
24 1/2"
36"
Cannon a solid drumm, pack materials inside
Base seperate component for shipping
NOT FOR CONSTRUCTION
Hutchinson Studios LLC
248.798.3788
WIND DEMOS
220 E. Ann St. Ann Arbor, MI 48104
PROGRESS
1/27/2016
AIR CANNON
X402


Driving
America
The impact of cars on our lives

Wind Turbine



Appendix C – Appendix C – Wind Exhibit Standing Panel Graphics and Content

The content and graphics below accompany the permanent exhibits and function to establish the context and guide visitor interactions.

WIND PROJECT Page 1 Interactive Copy FINAL FOR PRODUCTION - 20160927

E1:
Wind is "Stuff"
Moving air is made up of various gas molecules. When the molecules run into an object, they can make that object move around.
[Side A]
Try This
1. Use the "telltale"—the pole with the flags—to see the movement of the air at different spots on the table. Is it the same all over?
2. Place the telltale on the table. Slowly move the barrier to shield it from the wind. What happens when you move the barrier from side to side, or closer and farther away from the telltale?
[Side B]
Try This
1. Place the vertical axis turbine on the table and notice how it turns.
2. Can you change its speed or direction by redirecting the air flow with the barrier?
Visit the "Going with the Flow" exhibit to see how water flow can help us understand wind.
E2:
Going with the Flow
Wind moves much like water. It flows around objects, and those objects can change its speed and direction.
[Tank #1: Site Side]
Try This
1. How does the flow behave when there is nothing in its path?
2. Put a house or tree on the ground. What does it do to the flow?
What kind of location would be good for a wind turbine? Engineers put turbines in open places that have smooth-flowing air.
[Tank Side #2: Laminar vs. Turbulent flow]
Try This
1. Place the shapes into the flow one at a time. What happens?
2. Is the flow smoother or more turbulent with different shapes? Can you change it?
The shape of a turbine blade (or anything else designed to move through the air) affects how well it works. Some shapes and positions produce more turbulence than others. For turbine blades, engineers try to use shapes that create less turbulence and work more efficiently.

WIND PROJECT Page 2 Interactive Copy FINAL FOR PRODUCTION - 20160927
Visit the “Wind is Stuff" exhibit for another look at how wind moves.
E3:
Getting the Most Out of the Wind
Wind turbines may look simple. But to work well, they have to be designed just right.
Try this
Test a Design
1. Set up your turbine design.
2. Select the type and number of blades and mount them on the hub at your desired angle.
3. Set the load to “0.”
4. Turn on the fan.
Observe the speed (RPM) and power (watts). Now change the load. What happens?
Turn off the fan and repeat the experiment with a different configuration. Remember, changing just one variable for each test will allow you to understand what each variable does. How does the turbine’s performance change?
[Instrument Panel]
RPM
Revolutions per minute (or RPM) is a measure of how fast the turbine rotates.
Watts
Watts are a measure of the work that electricity can do, like powering the lights in your house.
Electrical Load
Load is the work being done by electricity, in things such as lights, toasters and electric motors. Use this knob to adjust the electrical load on your turbine. As the load increases, the turbine has to work harder and generate more electricity.
E4:
Dealing with the Shifting Winds
Wind comes and goes. But by storing the energy it provides, we can have electricity whenever we need it.

WIND PROJECT Page 3 Interactive Copy FINAL FOR PRODUCTION - 20160927

Try This

1. What happens when you turn the crank?
2. When the red light turns on, you have reached the praxinoscope's full speed. What happens then? What happens when you crank harder?
3. How high can you charge the battery? What happens when you stop cranking?

We need to store wind-generated electricity for times when there is no wind. There are a number of ways to do that, such as batteries, pumping water uphill and spinning flywheels. Today, batteries are the most common way to store electricity from small, local turbines.

[Deck Panel]

Generator

When you turn the crank, you generate electricity. That energy can be used to do work.

Load

This praxinoscope—an animation device—uses electricity to turn. It is represents the "load," or work that needs to be done by the electricity.

Battery

Batteries are common electrical storage devices. They store the electricity they receive, and can release the energy later to do work.

E5:

The Grid: A Balancing Act

Wind power is one of several sources of electricity. Utilities need to consider many factors when managing power from all these sources on the grid.

WIND POWER

HARVESTING WIND

Wind is moving air, and it holds energy that can move things. Wind energy can push sailboats, lift kites, and blow down trees. It can also be used to turn windmills, or wind turbines that generate electricity.

Wind is starting to become an important energy source in Michigan, generating nearly 5% of our state's electricity. Utility companies have set up "wind farms" here. These have many huge wind turbines that can generate large amounts of electricity—one turbine might supply enough electricity to power 1,000 houses. People can also use their own smaller wind turbines to make electricity to power their homes and businesses.

Why are people interested in wind power? For one thing, it provides a clean source of energy that doesn't pollute the air or water. It is also renewable—it doesn't get used up like coal or natural gas, which are often burned to generate electricity. And it can be less expensive than some other power sources. The wind is a free "fuel."

ENERGY IN MICHIGAN

This project was funded with the generous support of the U.S. Department of Energy's Office of Energy Efficiency & Renewable Energy, Wind Energy Technologies Program. Special recognition also belongs to U.S. Representatives John and Debbie Dingell.

Wind is air that moves from high-pressure areas of the atmosphere to low-pressure areas. Those pressure differences are caused by the sun's heat being absorbed unevenly by the earth, creating uneven air temperatures. The warmer air rises, and colder air rushes in to replace it.

Wind energy has been put to work by people throughout history. Sailing ships were used on the Nile River in Egypt about 5,400 years ago. About 1,000 years ago, windmills for grinding grain and pumping water were used in Persia. The first windmill that generated electricity was built in Scotland in 1887.

Modern turbines are engineered to take full advantage of the power of wind and are far more efficient than those older windmills. As wind passes by, the shape of the wind generator's blades creates pressure differences that move the blades. That turns a shaft connected to a generator, which makes electricity.

what is WHAT IS ***what is***

WIND?

VARIES OVER OVER TIME + PLACE

Winds change for a number of reasons. For example, during the day, land heats up more quickly than water. That creates uneven air temperatures. The warmer air rises, and the cooler air over the water moves in. Then, the wind is coming from the water to the land. At night, the wind reverses direction, because the land cools more quickly than the water.

Wind changes with the seasons, too. In Michigan, March is usually a windy month. That's when colder air from the north meets warmer air coming from the south—and the pressure differences create wind.

When winds are slower, wind turbines produce less electricity. To make sure there is enough electricity when it's needed, wind-generated electricity can be stored in batteries. Or, wind energy can be used to pump water to an uphill location. When more electricity is needed, the water is released, and the flow is used to turn generators. Utilities can also use other forms of generation, such as natural gas or solar energy, to fill in when the winds are slow.

WIND
WIND
WIND

ABOUT

Wind turbines have three major parts. The tower that provides support, the blades that spin, and a box behind the blades called a "nacelle." The nacelle holds the generator that makes electricity.

Most large wind turbines used by utilities have three blades and "monopole" towers, which are large tubes of steel often taller than a 20-story building. They look something like a giant house fan. The blades can be up to 180 feet long, and they are made of special composite materials that are strong but light, so the wind can turn them more easily. The nacelles are the size of a school bus.

Wind turbines do more than just spin. They have sensors that read the speed and direction of the wind, and they use small motors to turn them to face the wind as it changes. The angle of the blades can be adjusted to help the wind turbine work efficiently in faster or slower winds. Or, the blades and wind turbines can turn away from the wind if it gets too strong.

W I N D

TURBINES

SMALL

WIND TURBINES

Sometimes, small wind turbines are used to produce electricity for a house, a school or a business. These vary in size, but an average windmill for a home is about 80 feet tall.

For a small wind turbine to power a house, the average wind speed in the areas needs to be at least 12 mph. It's important to put these wind turbines in open fields or other places where there are no obstacles to block the winds. Even nearby houses and trees can slow the wind down.

If a home is connected to the grid—the power lines that move electricity from place to place—the homeowner can get extra electricity from the power company when there is not enough wind. On the other hand, if a home's wind turbine generates extra electricity, that power can be sent to the utility for use in other places. And if a home is not connected to the grid, the homeowner can store power in batteries for later use.

WIND FARMS

When wind turbines are set up in a group, it's called a wind farm. In a wind farm, many turbines work together to act like a powerful generating plant.

Wind farms may include more than 100 large wind turbines spread over hundreds of acres. One tower requires about half an acre of space. However, the towers have to be built far apart, because one tower can "steal" wind from another.

To decide where to put a wind farm, developers set up towers holding wind-measuring instruments —called anemometers—and then track wind speeds for a year or more. They also study whether the wind farm will affect the area's birds, bats and endangered species. The wind turbines are usually placed so that farmers can continue to use as much of the land as possible.

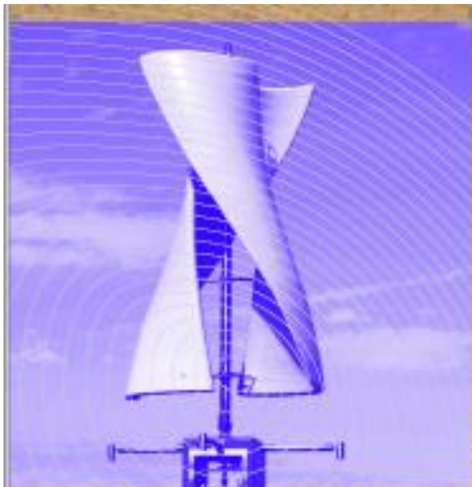
In Michigan, half the wind farms are owned by utilities like DTE and Consumers Energy, and half are owned by private developers. The private developers can sell the power they generate to the utilities, who then deliver it to their customers around the state.

The state of Michigan has established a number of rules that affect our use of wind power. For example, state policy said that 10% of our electricity should come from renewable energy, such as wind power, by 2015—and power producers have met that goal. Another rule says that utilities need to use and pay for extra electricity created by small, privately owned generators.

Michigan's first large-scale wind turbine was installed in Traverse City in 1996. The state's first wind farm was set up in 2008 in the state's "Thumb" area, where there is open land and a fair amount of wind. There are now more than 20 wind farms operating in Michigan, with more being planned and built. There are also about 300 small wind turbines connected to the grid in the state. Overall, wind accounts for about 40% of the electricity generated by renewable sources in Michigan (2016).

Michigan companies make towers, blades and generators for wind turbines, and about 140 companies in the state are part of the wind industry.

WIND POWER POWER POWER in Michigan

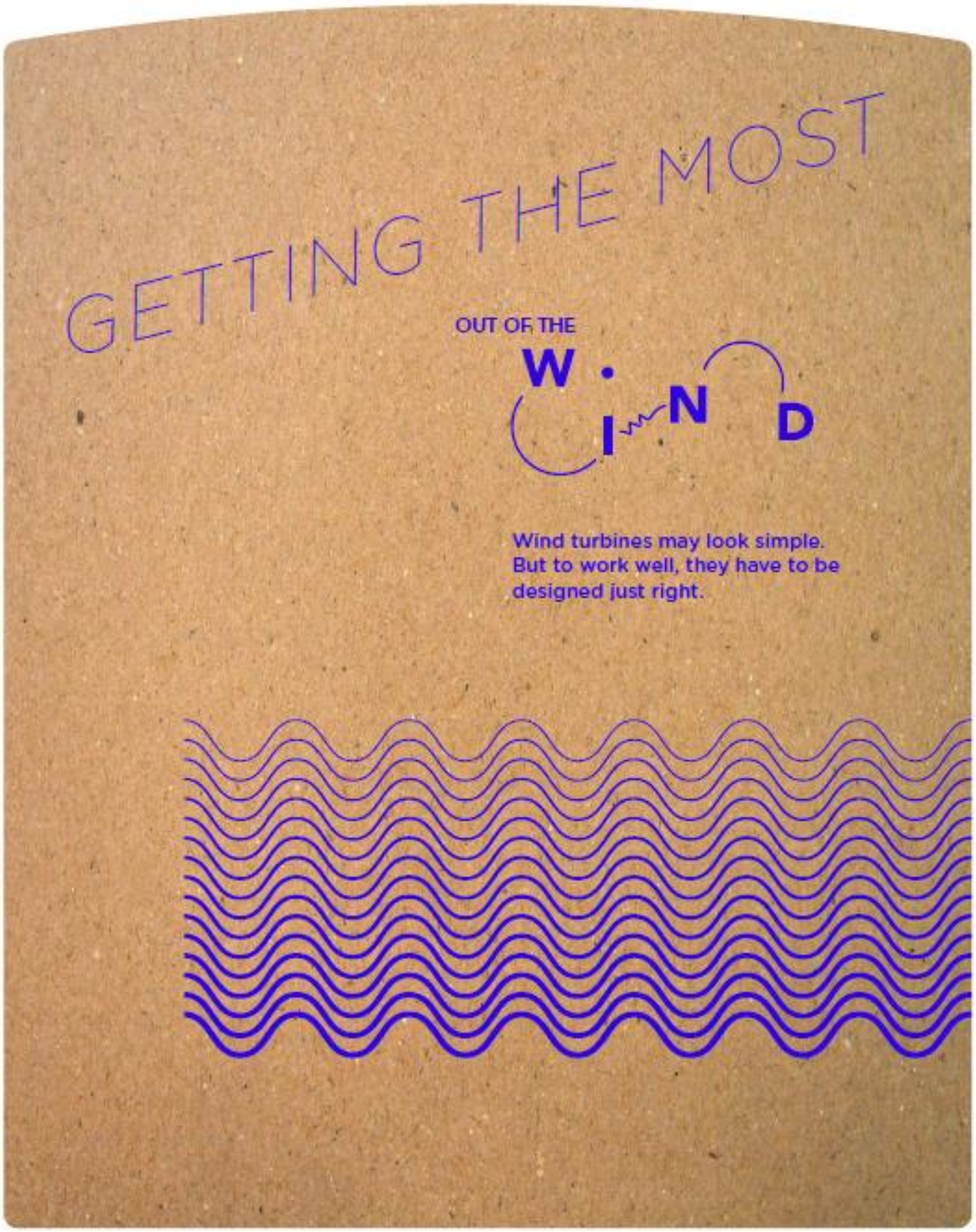


THE FUTURE OF WIND POWER

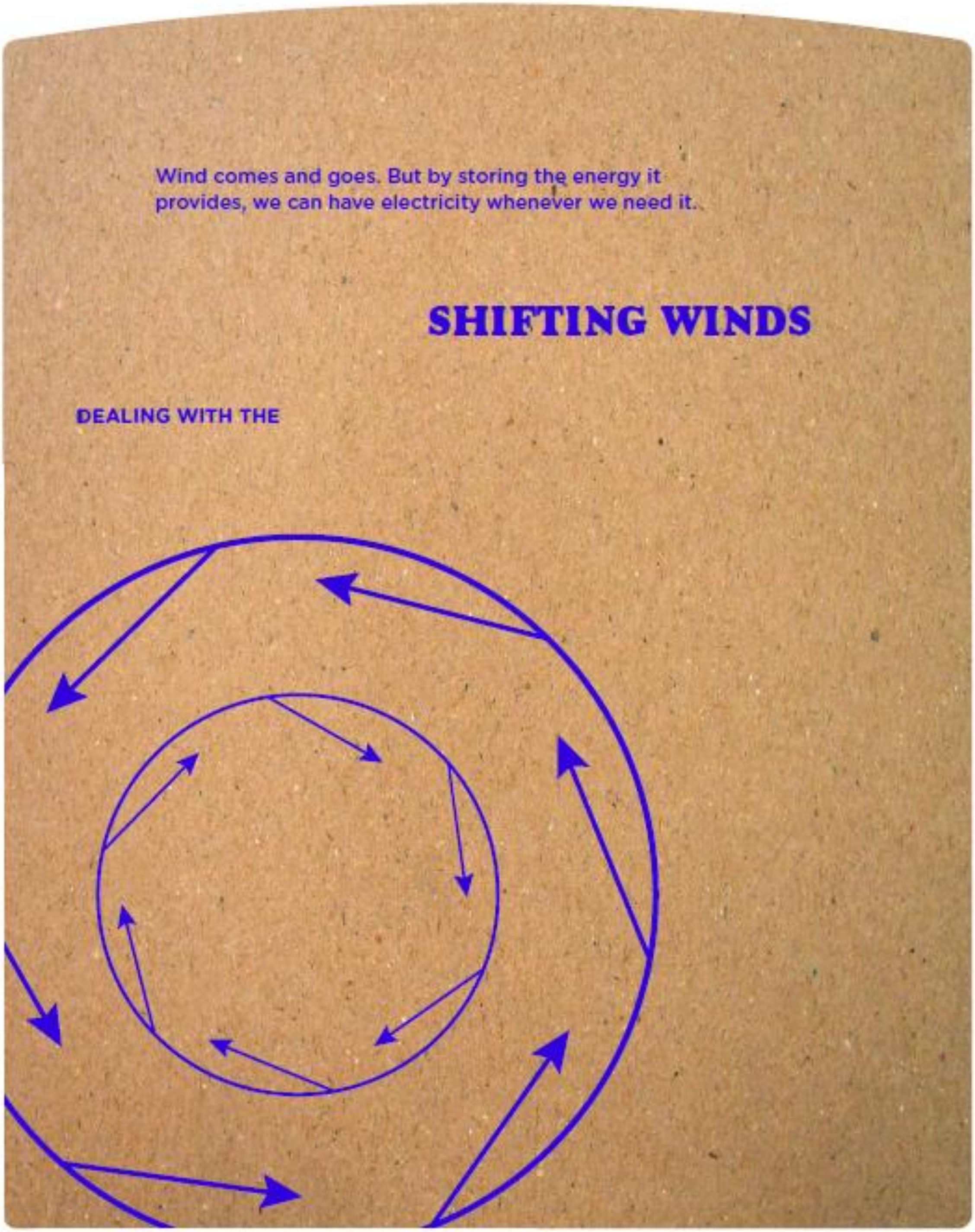
Wind power has proven to be an inexpensive and reliable resource, and it can be an important source of electricity. How important? In Denmark, wind provides 42% of the country's power. In the state of Iowa, it generates 31% of the state's power.

More wind farms are coming to Michigan. Also, the state is surrounded by the Great Lakes, making offshore wind turbines an important potential power source. Offshore winds are stronger and more consistent than inland winds.

Meanwhile, wind power technology is improving. Turbines are getting larger and more efficient, and towers are getting taller. The ability to predict winds is getting better. Some developers are creating floating wind turbines that could be used far from shore, where the water is too deep to build towers. And many companies are researching entirely new approaches to capturing wind energy. As the technology gets better, wind power will be used in more and more places—making the future of wind power bright.


GETTING THE MOST
OUT OF THE
WIND
Wind turbines may look simple. But to work well, they have to be designed just right.

Turbine



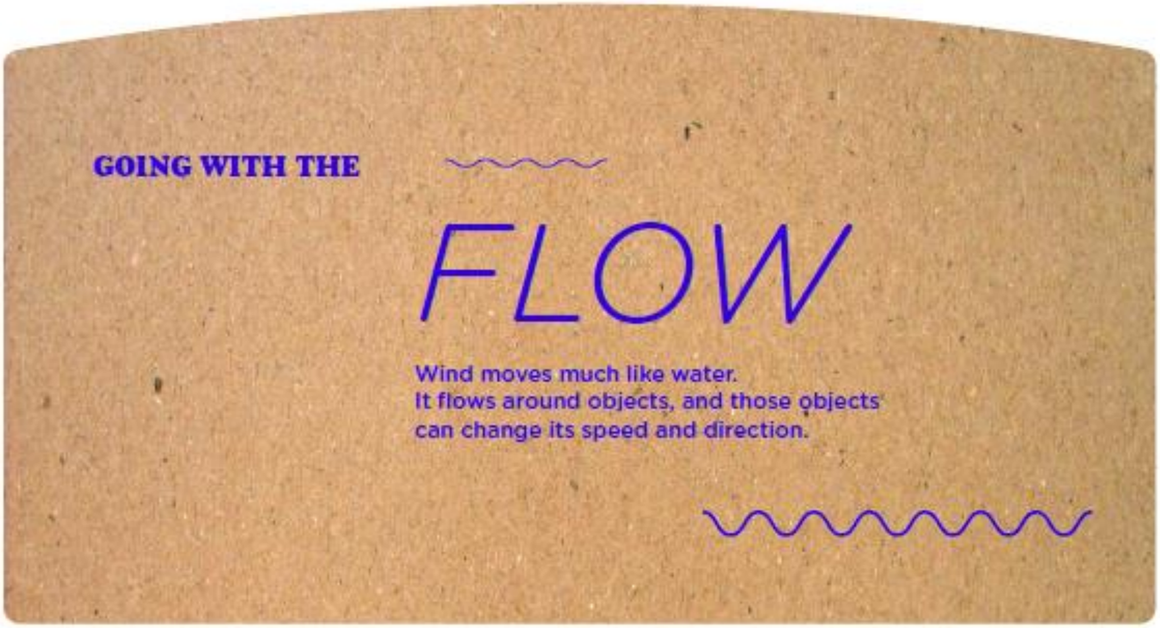
Energy Storage

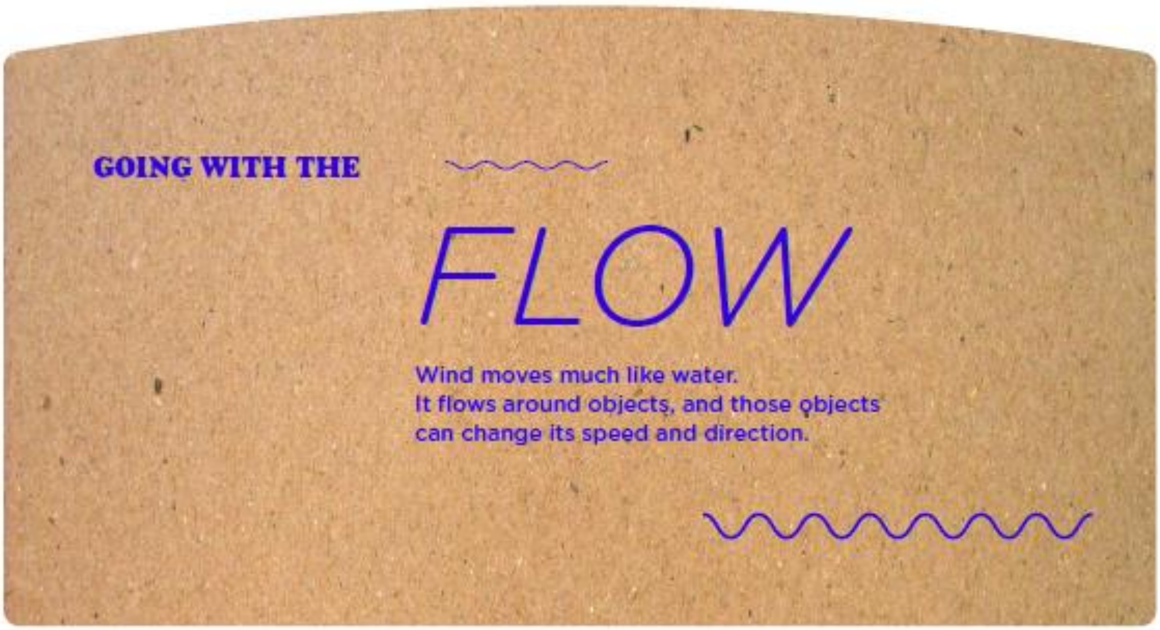
THE GRID

A BALANCING ACT

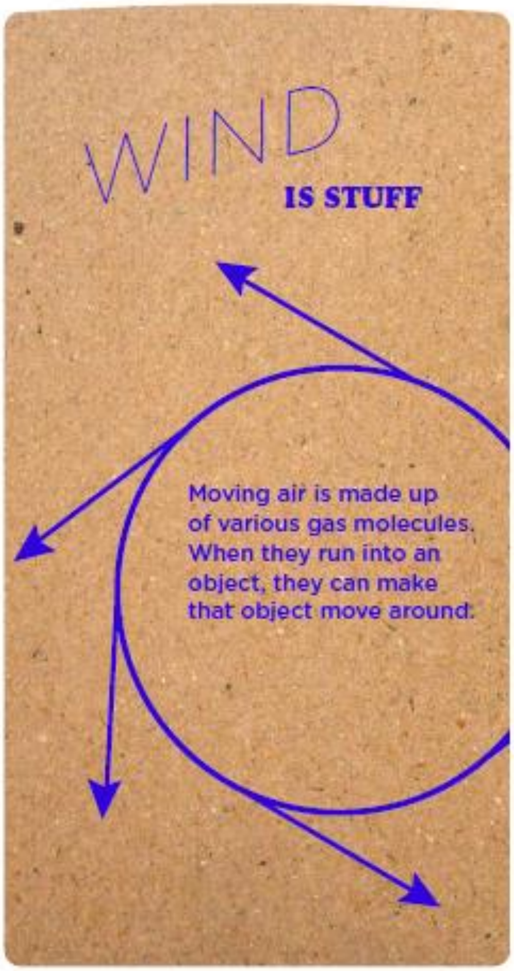
Wind power is one of several sources of electricity. Utilities need to consider many factors when managing power from all these sources on the grid.

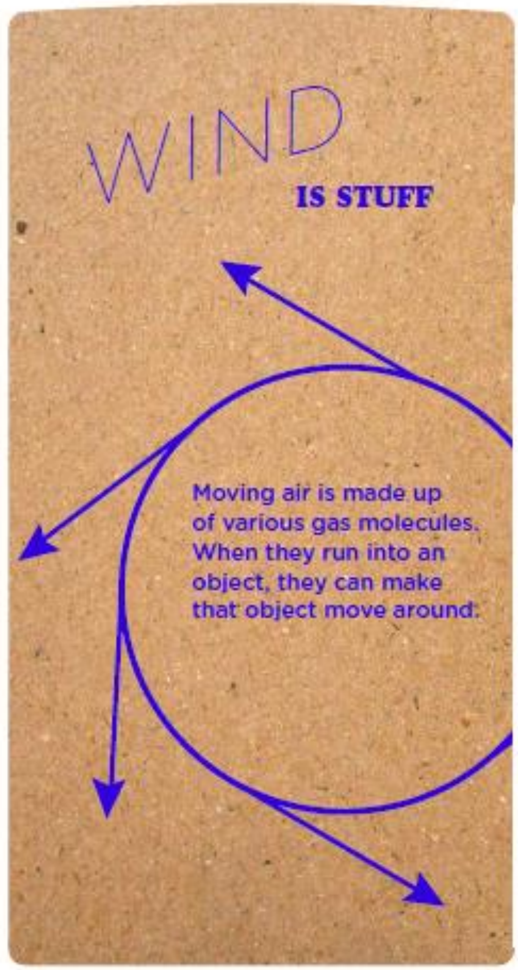
Power Grid


GOING WITH THE
FLOW
Wind moves much like water.
It flows around objects, and those objects
can change its speed and direction.


GOING WITH THE
FLOW
Wind moves much like water.
It flows around objects, and those objects
can change its speed and direction.

Fluid Flow


WIND
IS STUFF
Moving air is made up of various gas molecules. When they run into an object, they can make that object move around.


WIND
IS STUFF
Moving air is made up of various gas molecules. When they run into an object, they can make that object move around.

Wind Table

Appendix D – Image Gallery from Participation in Regional Festivals and Events

(Note: AAHOM obtained releases from parents/guardians for all images obtained during the grant project and appearing in this report.)


PA Crossings


WEST
COASTIN'


E Huron
OILERS


SLAUSON
SCIENCE OLYMPIAD


tembec
TemPlus