Using CFD to Predict the Performance of Innovative Wind Power Generators

COMSOL Conference Boston 2012

Boston Marriott Newton
Newton, MA 02466 USA
October 3-4, 2012

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1

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Using CFD to Predict the Performance of Innovative Wind Power Generators

Topics

1. Motivation
2. Possible Solutions
3. Model
4. Results
5. Conclusions

2

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Motivation

Is it possible to offer

Onshore & Offshore Commercial Buildings Urban Buildings Retail Stores Cruise Ships Consumer Products	Rapid Deployable Power for Soldiers · Schools · Naval Ships · Rural Communities **Affordable, Clean, Safe Energy for Everyone, Everywhere** Underdeveloped Countries ⇓ Economic Development	FEMA Homeland Security Emergency Power Generation Emergency Medical Disaster Power Generation Water Treatment Powering Hospitals

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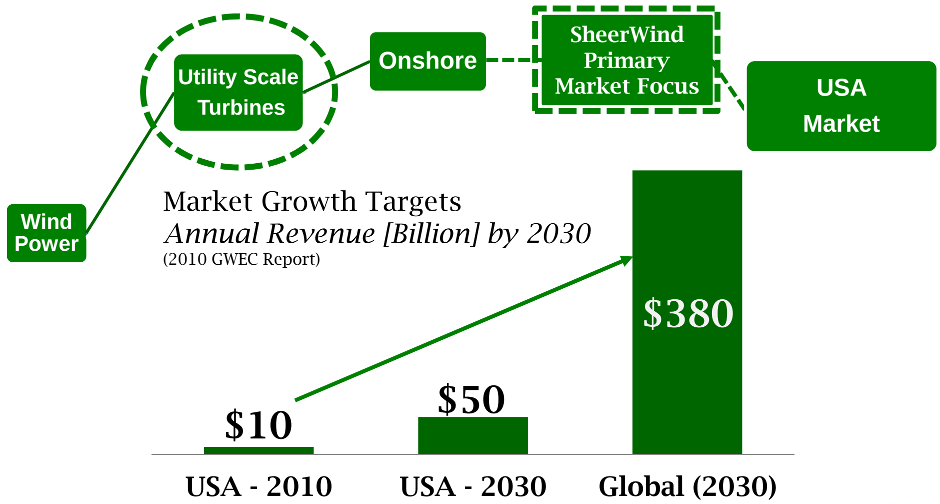
Wind Power Generation Market

Primary Market



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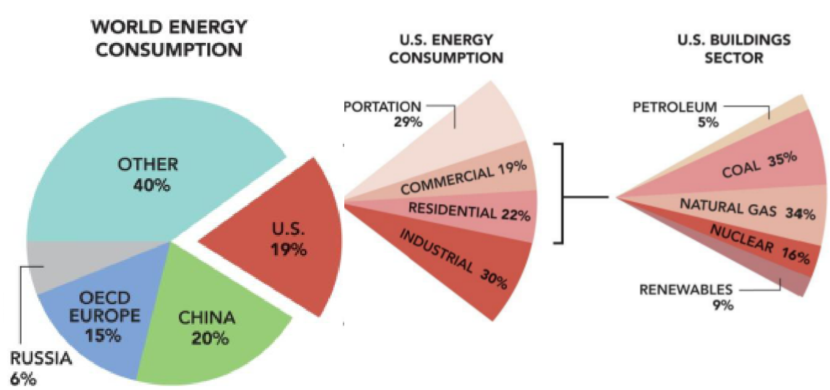
Energy Consumption

Energy Consumption (Source: 2011 DOE-NREL Report)

U.S. vs World & U.S. Consumption Breakdown



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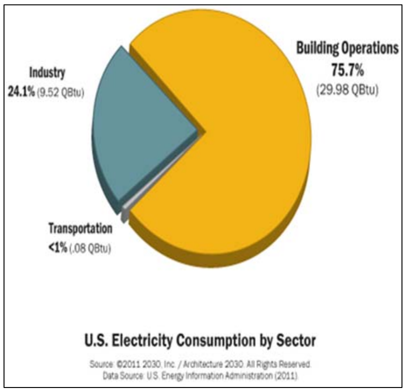
Energy Consumption by Buildings

Energy Consumption (Source: 2011 US Energy Information Administration Report)
Building Sector vs Industry & Transportation



Electrical power consumption
by market sector (2011)

2010 Building Energy Consumption in USA [TWh] & Market Value [$B], Energy Price: $0.1/KWh		
	Building Sector	Market Value [$B]
Total	**8,792**	**$879**
20% Renewable	**1,758**	**$176**

7

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8

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Possible Energy Solutions

Sources of Energy: Cost, Public Safety/Health, Environment

Line No.	Type of Power Generation Plant	Average Price per MWh (1000 KWh), $		Public Safety	Public Health	Environment
0	**Wind - INVELOX**	☺☺	**$69.00**	☺☺	☺☺	☺☺
1	**Hydro**	☺	**$89.90**	☺	☺	☹
2	**Natural Gas Fired**	☺	**$92.84**	☺	☺	☹
3	**Wind**	☺	**$96.80**	☺	☺	☹
4	**Geothermal**	☺	**$99.60**	☺	☺	☺
5	**Advanced Nuclear**	☹	**$112.70**	☹	☹	☹
6	**Coal**	☹	**$117.50**	☺	☺	☹
7	**Biomass**	☹	**$120.20**	☺	☺	☹
8	**Solar PV**	☹☹	**$156.90**	☺	☺	☹
9	**Solar Thermal**	☹☹	**$251.00**	☺	☺	☺
10	**Wind — Offshore**	☹☹	**$330.60**	☺	☺	☺

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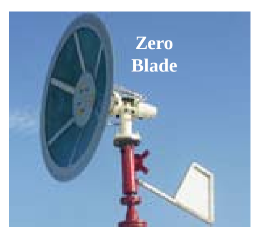
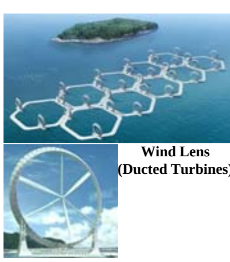
Possible Solutions: Wind Technologies


Traditional Wind Towers


Joby Energy

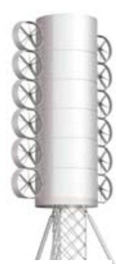

Megenn Power




Wind Lens
(Ducted Turbines)


Altaeros Energies


Makani Power


OptiWind

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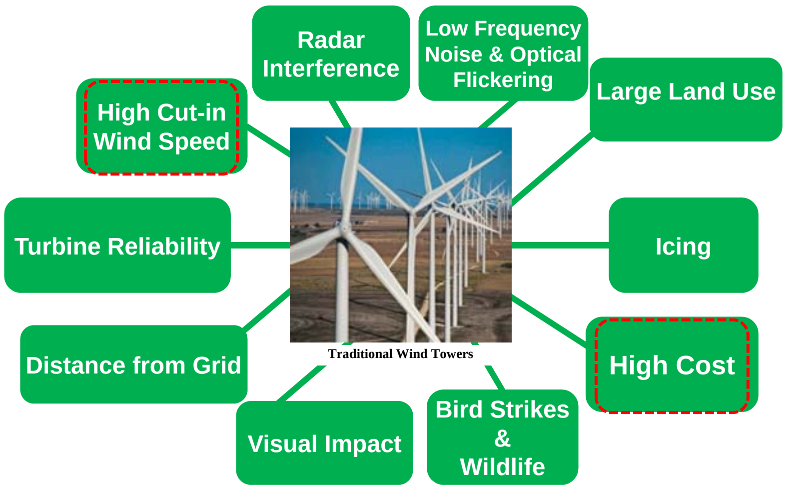
INVELOX Solves Traditional Wind Power Issues



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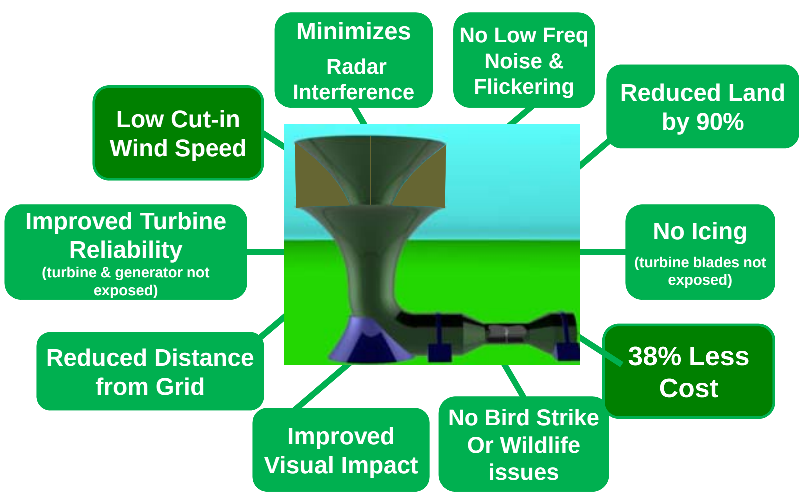
INVELOX Solves Traditional Wind Power Issues



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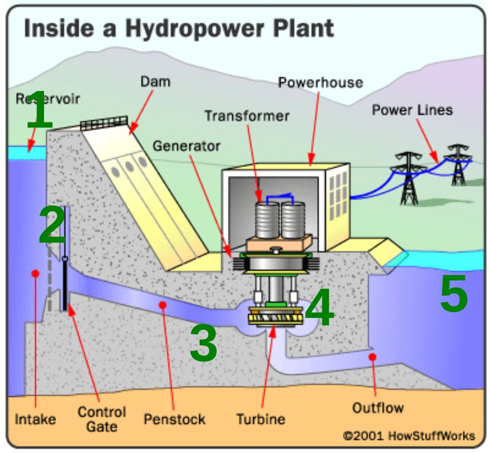
How it Works

INVELOX Operates Similar to **Hydropower**

1. Water intake
2. Water is channeled
3. Water accelerates
4. Hydro power conversion system
5. Excess water discharged



13

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How it Works

INVELOX Operates Similar to Hydropower

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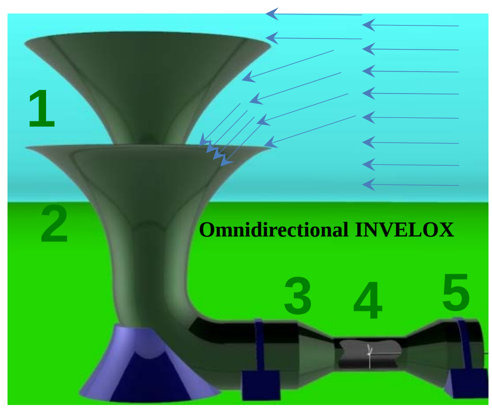

14

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Design Parameters for Wind Power Generation
Higher Towers & Longer Turbine Blades

Higher Tower → Higher Wind Speed → More Power

Longer Blades → More Power

Power proportional to $(\text{Wind Speed})^3$

Power proportional to $(\text{Turbine Radius})^2$

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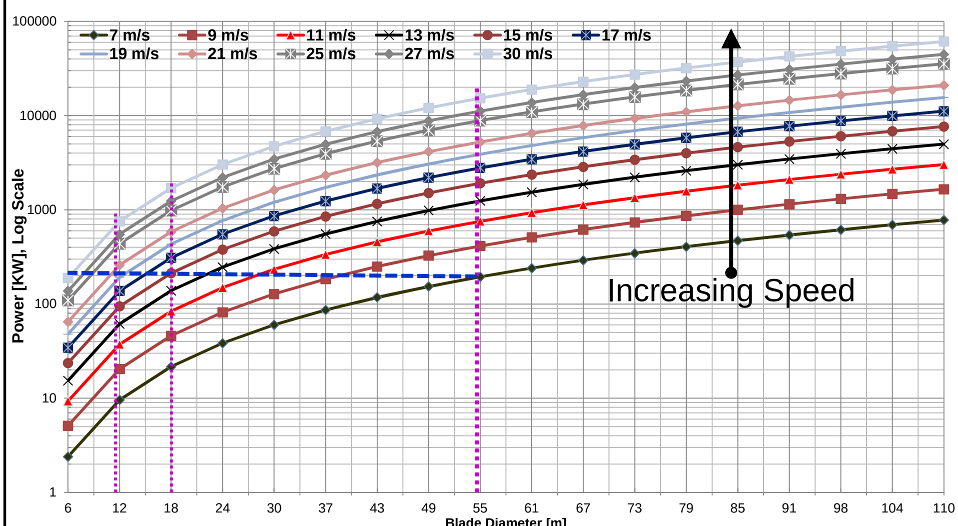
Power versus Wind Speed and Blade Diameter



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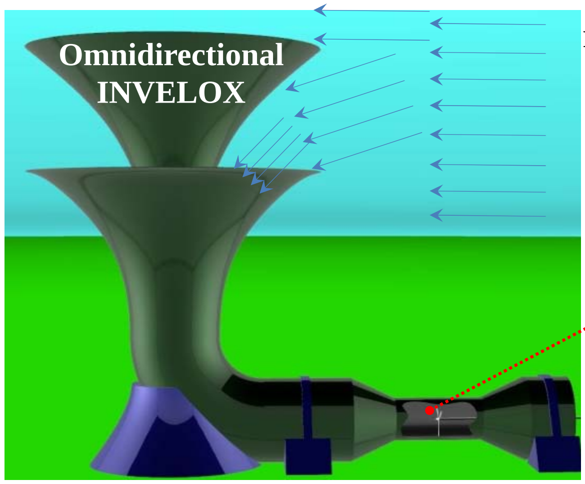
Example: Increased in Velocity

Assume Speed Ratio of 4 = Venturi Speed/ Free Stream Wind



Free Stream Wind Speed:
7 m/s [15 mph]

Venturi Wind Speed:
28 m/s [60 mph]

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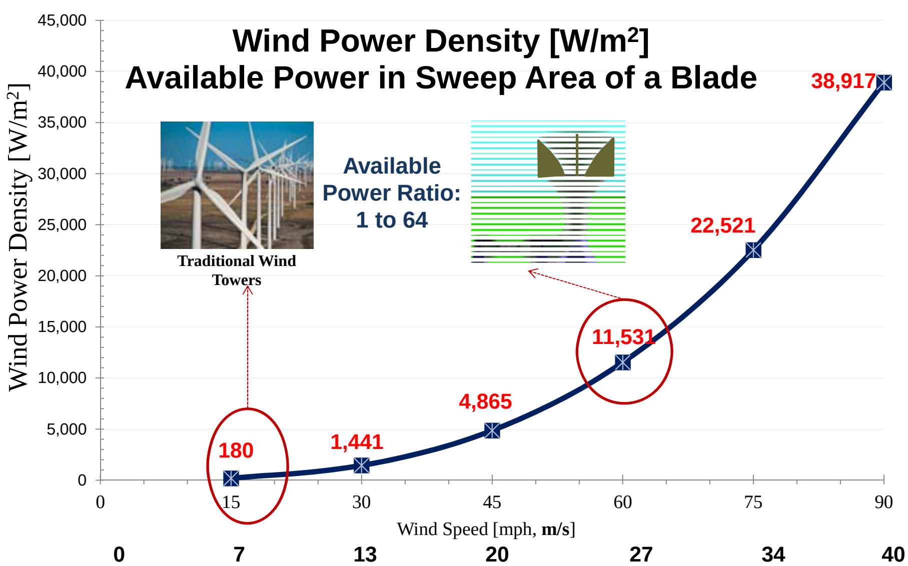
Power Density versus Wind Speed



18 SHEERWIND

Using CFD to Predict the Performance of
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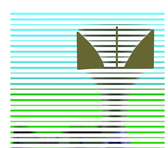
Computational Fluid Dynamics (CFD)

1) Solid Model of INVELOX
2) Virtual Wind Tunnel
3) Boundary Conditions
4) Input & Output



Model

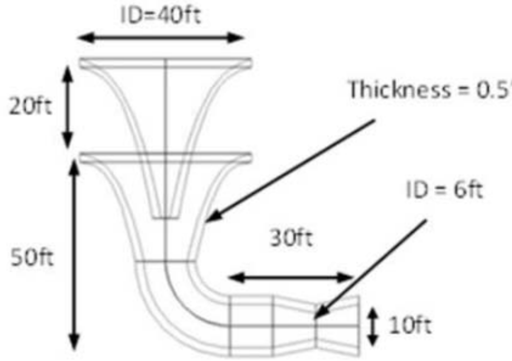


Figure 3 Detailed dimensions and geometry of omnidirectional INVELOX

21

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COMSOL Model

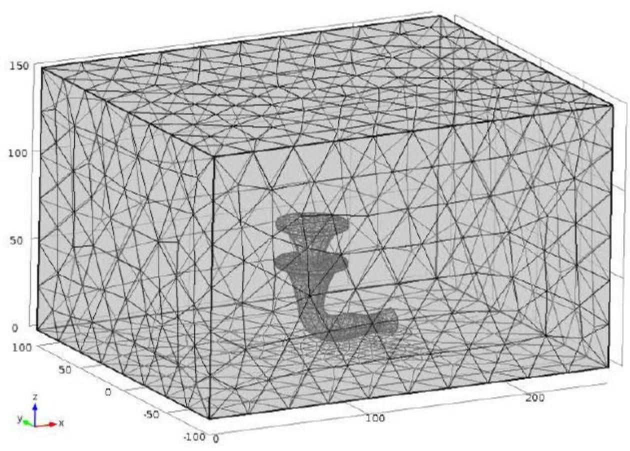

Figure 4 CFD model of INVELOX

22

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Using CFD to Predict the Performance of Innovative Wind Power Generators

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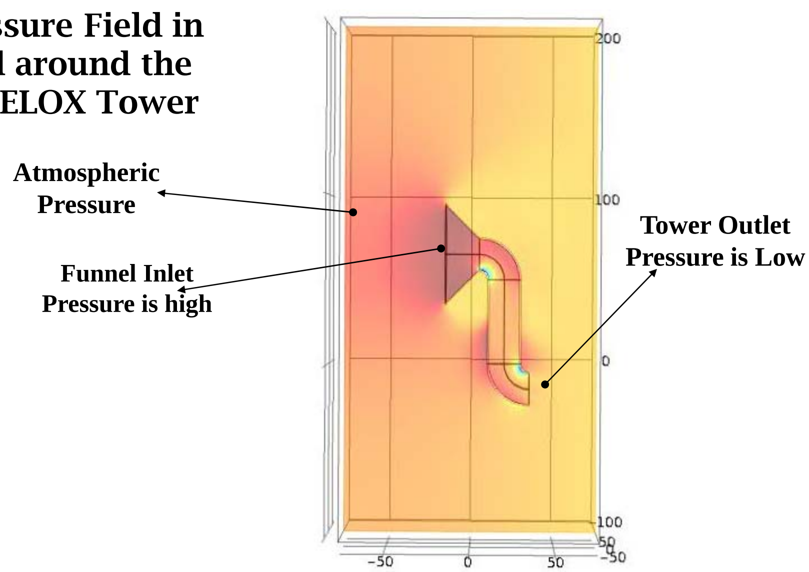
Computer Models & Simulations

Pressure Field in and around the INVELOX Tower



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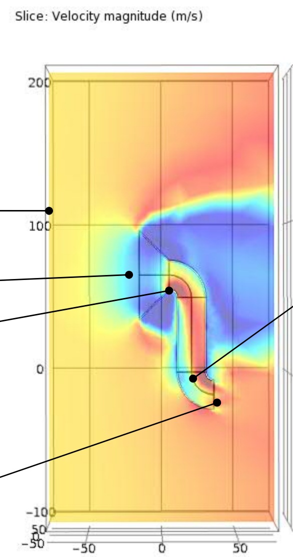
Computer Models & Simulations

Velocity Field in and around the INVELOX Tower

Wind Speed
15 mph

Funnel Inlet Speed-
Min:4, Max:10 mph

Speed at 1st Bend –
Min:10, Max:33 mph



at 2nd Bend –
Min:9 mph
Max:33 mph

Tower Outlet Speed-
Min:15, Max:24 mph

52% increase

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Computer Models & Simulations

Energy Balance at 6.7 m/s (or 15 mph) Free Stream Wind
Energy Density : J/m^3

Stage	Static Pressure Energy (PE)	Dynamic Pressure Energy (KE)	Total Energy (PE+KE)
Free Stream	**100,000**	**27**	**100,027**
At the Intake	100,021	6	100,027
At the End of Intake Funnel (1st Bend)	99,967	60	100,027
At the End of 2nd Bend	99,967	60	100,027
Right Before Exit (Turbine Location)	**99,967**	**60**	**100,027**
Far from Exit	100,000	27	100,027

Ratio of Dynamic Energies:
Turbine Location / Free Stream = 2.23 (or 123%)

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Computer Models & Simulations

Energy Balance at 15 m/s (or 34 mph) Free Stream Wind
Energy Density : J/m³

Stage	Static Pressure Energy (PE)	Dynamic Pressure Energy (KE)	Total Energy (PE+KE)
Free Stream	100,000	135	100,135
At the Intake	100,106	29	100,135
At the End of Intake Funnel (1st Bend)	99,834	301	100,135
At the End of 2nd Bend	99,834	301	100,135
Right Before Exit (Turbine Location)	**99,834**	**301**	**100,135**
Far from Exit	100,000	135	100,135

Ratio of Dynamic Energies:
Turbine Location / Free Stream = 2.23 (or 123%)

27

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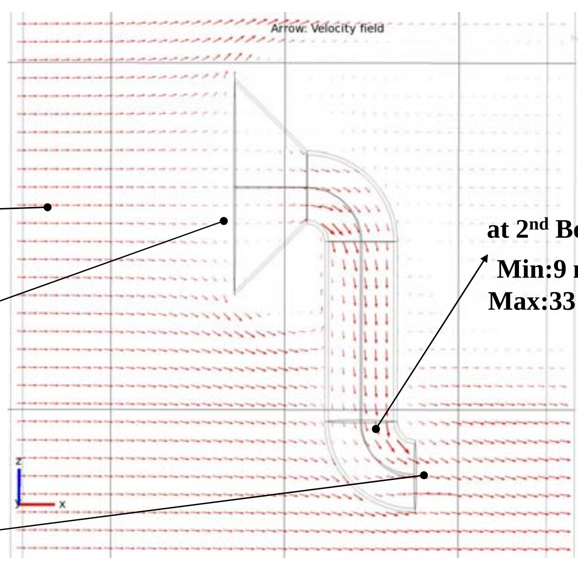
CFD Models & Simulations

Velocity Field in and around the INVELOX Tower



Wind Speed 15 mph

Funnel Inlet Speed- Min:4, Max:10 mph

at 2nd Bend – Min:9 mph Max:33 mph

Tower Outlet Speed- Min:15, Max:24 mph

52% increase

28

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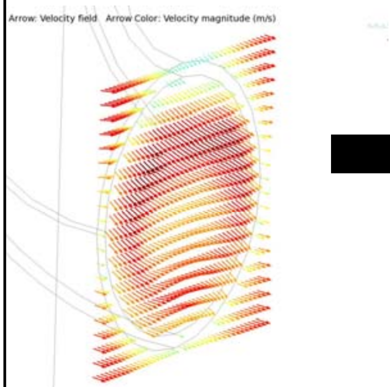
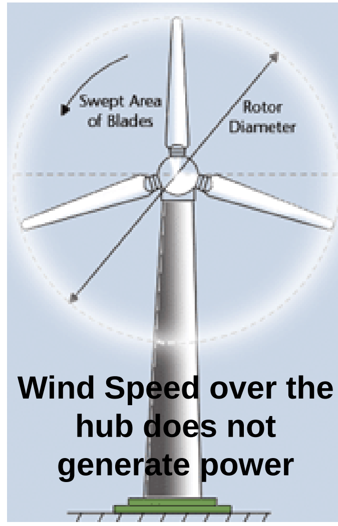


Capable of Creating Donut-Shaped Velocity Profile at Turbine Location



Wind Speed over the hub does not generate power

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CFD (Computational Fluid Dynamic) Model Comparison between Two Independent Models

1. **ANSYS CFD was utilized by CCNY**
   (CCNY = City College of New York)
2. **COMSOL CFD was employed by QRDC**
   (QRDC is an R&D Company in Chaska, MN)
3. **A virtual wind tunnel was constructed to examine the performance of an INVELOX system**
4. **The results are in agreement**

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CFD (Computational Fluid Dynamic)
Model Comparison between Two Independent Models

The Model

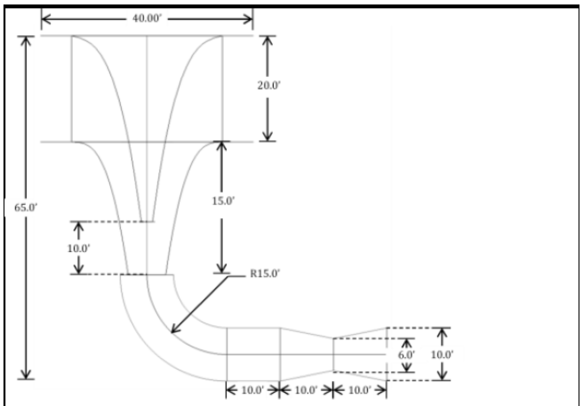

Figure 1 – Solid model with dimensions

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CFD (Computational Fluid Dynamic)
Model Comparison between Two Independent Models

Summary Results
Free Stream Wind Speed: 6.7 m/s (or 15 mph)

Model	Mesh Size	Duct Diameter [ft]	Nozzle Diameter [ft]	Average Velocity [m/s]	Maximum Velocity [m/s]	Volumetric Flow [m^3/s]	Mass Flow [kg/s]
CCNY	Normal	10.0	6.0	**10.6**	**12.1**	28.2	34.5
QRDc	Normal	10.0	6.0	**10.6**	**12.1**	29.6	36.3
	Fine	10.0	6.0	**11.7**	**13.1**	30.5	37.4

Speed Ratio Based on Average Speed: 1.6
Speed Ratio Based on Maximum Speed: 1.8

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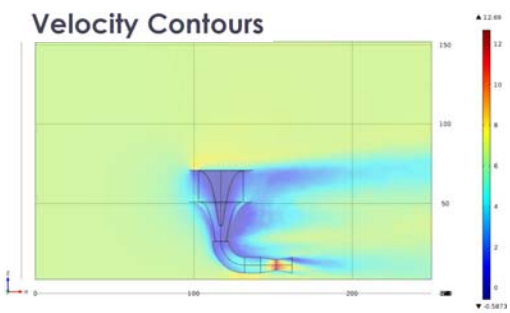
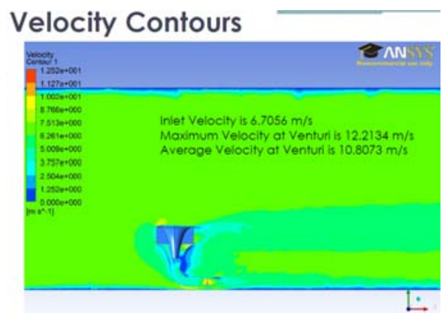
CFD (Computational Fluid Dynamic)
Model Comparison between Two Independent Models

Summary Results





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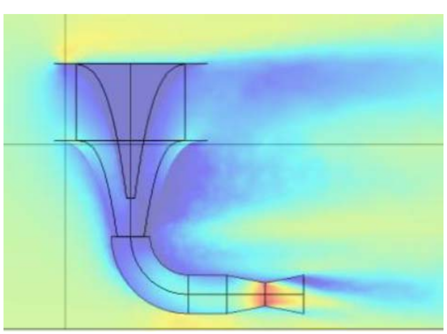
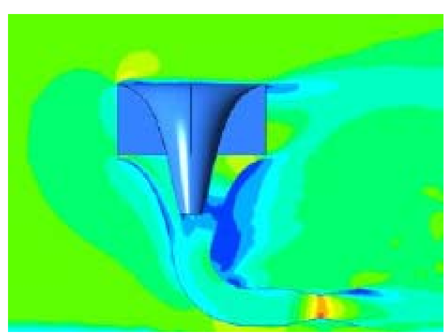
CFD (Computational Fluid Dynamic)
Model Comparison between Two Independent Models

Summary Results - Close-up





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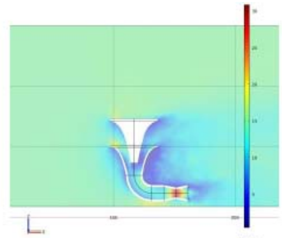
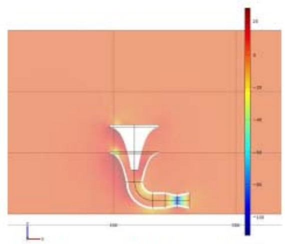
CFD (Computational Fluid Dynamic) - Additional Results Using COMSOL Model

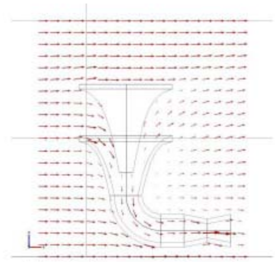


(a) Velocity Field in the x-z plane

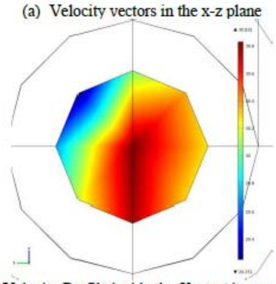


(b) Pressure Field in the x-z plane

Figure 5 Velocity and pressure field in x-z plane at the center of INVELOX



(a) Velocity vectors in the x-z plane



(b) Velocity Profile inside the *Venturi* in y-z plane

Figure 6 Velocity vector and profile

35

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CFD (Computational Fluid Dynamic) - Additional Results Using COMSOL Model

With Supporting Columns

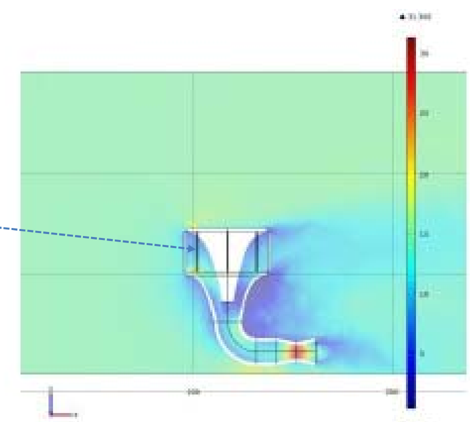

Figure 7 Velocity field in the x-z plane

36

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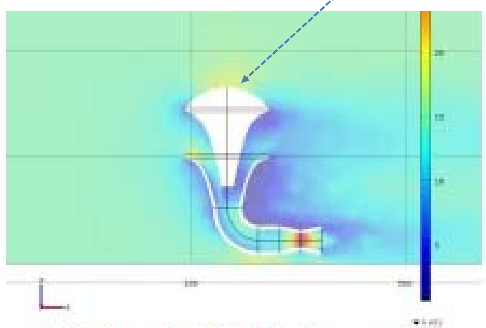
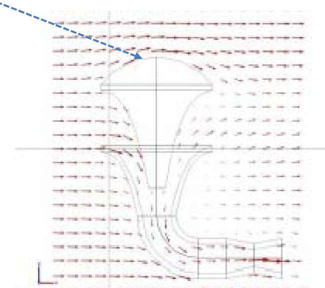
CFD (Computational Fluid Dynamic) - Additional Results Using COMSOL Model

Dom-Shaped Top



(a) Velocity field in the x-z plane



Velocity vectors in the x-z plane

Figure 8 Influence of a dome top on the velocity fields of INVELOX

37

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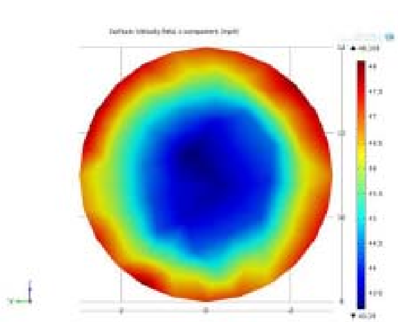
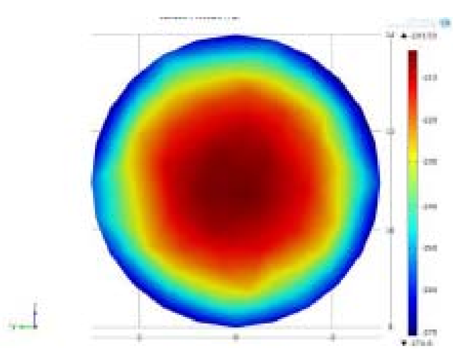
CFD (Computational Fluid Dynamic) - Additional Results Using COMSOL Model

Dom-Shaped Top



(a) Velocity profile inside the *Venturi* in y-z plane



(b) Pressure field inside the *Venturi* in the y-z plane

Figure 10 Velocity and pressure field in y-z plane inside the *Venturi*

38

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Using CFD to Predict the Performance of
Innovative Wind Power Generators

1) It was shown that INVELOX can be designed to capture and accelerate wind to speed ratios of 2 and 3 for omnidirectional INVELOX without and with fins, respectively.
2) Increasing wind speed by a factor of 2 or 3, results in increased power output by a factor of 4 to 8.
3) It was further shown that COMSOL is an effective computational tool to model and analyze the INVELOX systems.