3.1 GW of Short Turbines Could be Added to the San Gorgonio Pass Wind Resource Area[1]

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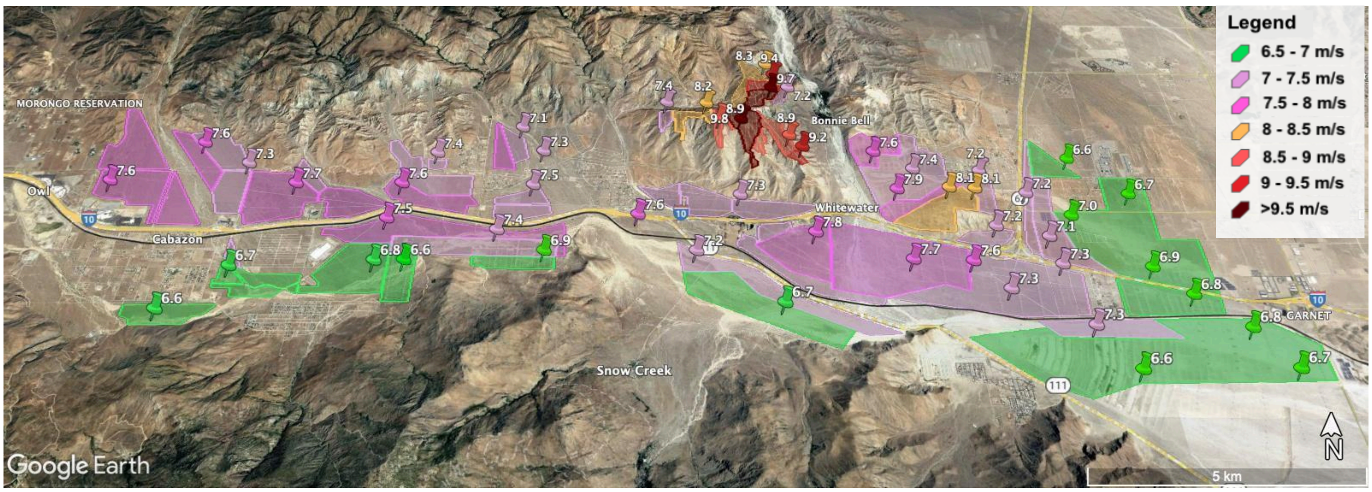

Image 1. Wind speed zones >6.5m/s (14.5mph) in the San Gorgonio Pass Wind Resource Area at 66' (20m) above ground level

Executive Summary

One of the most legendary wind resource areas in California is the San Gorgonio Pass (SGP). Some of the first wind turbines were installed here in the early 1980s. It quickly grew to hold over 600 MW of **horizontal axis wind turbines** but has had no significant increases in capacity in decades. Yet under and around the traditional turbines blows one of the world's best wind resources. Current wind turbines take advantage of wind above 100 feet (30m) off the ground, but are not designed to use mid-level wind, which blows 15 to 100' (5 to 30m) above ground.

With shorter **vertical axis wind turbines** that are built to handle the turbulence without structural problems, a full build out of the wind resource area can be achieved. This new report shows that adding VAWTs to the resource area could increase energy output by 377%, generating enough **energy to power more than 1.4 million[2] California homes each year.**

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[1] Land in and outside of wind farms where the average annual wind speed exceeds 6.5m/s (14.5 mph) at 66' (20m) above ground level. See Methodology for more information.

[2] The average annual electric consumption per Californian household is ~7,000 kWh.

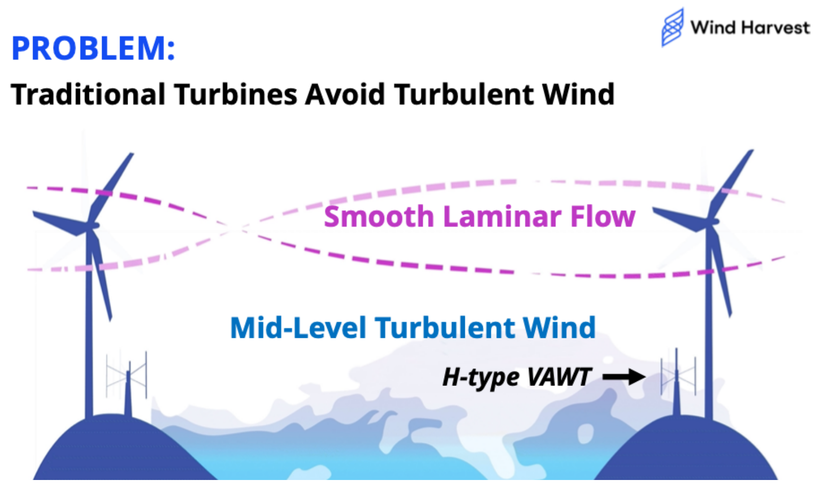


Image 2: Turbulence and Turbine Types[3]

Table 1. Capacity and GWh with Vertical Axis Wind Turbines (VAWTs) in the San Gorgonio Pass Wind Resource Area

		Capacity	Annual Energy
		(GW)	Production (GWh/yr)[4]
HAWT	Existing Wind Farms	0.68	2,661
VAWT	Existing Wind Farms	1.80	5,713
VAWT	Outside of Wind Farms	1.33	4,327
Combined Potential		**3.81**	**12,700**

Table 2. Capacity and Annual Energy Production (AEP) of Horizontal Axis Wind Turbines (HAWTs) in SGP Wind Farms

Wind speed		HAWT Existing	HAWT Existing
m/s	MPH	Capacity (MW)	AEP (GWh/yr)
7 - 7.5	15.7 - 16.8	120	401
7.5 - 8	16.8 - 17.9	273	1,014
8 - 8.5	17.9 - 19	172	703
8.5 - 9	19 - 20.1	81	361
9 - 9.5	20.1 - 21.3	16	78
> 9.5	>21.3	20	105
Total		**682**	**2,661**

[3] How VAWTs like *Wind Harvesters* operate in turbulent wind
[4] Assumes 196’ (60m) hub height

1.8 GW of H-type Turbines Could be Added to Existing Wind Farms

Wind Harvest analyzed **66 feet** (20 meter) above ground wind speeds in the SGP Wind Resource Area using publicly available location information and predictions from UL Solution's Windnavigator. We found that the 682 MWs[5] of **existing** wind farms could add 1,807 MWs of short, *Wind Harvester*[6] H-type VAWTs underneath the existing turbines and could be completed much sooner than new onshore or offshore wind farms. This land is already zoned for wind turbines. Access roads and security fences have already been installed. For "capacity factor enhancement" projects, they already have the transmission infrastructure.

Table 3. Potential to add H-type VAWTs to Existing Wind Farms

Wind speed		Area		Potential	Annual Energy
m/s	MPH	Hectares	Acres	Buildout (MW)	Production (GWh/yr)
6.5 - 7	14.5 - 15.7	1,447	3,575	822	2,296
7 - 7.5	15.7 - 16.8	963	2,380	548	1,741
7.5 - 8	16.8 - 17.9	466	1,151	265	936
8 - 8.5	17.9 - 19	175	433	90	349
8.5 - 9	19 - 20.1	62	152	28	117
9 - 9.5	20.1 - 21.3	23	57	10	44
> 9.5	>21.3	88	218	46	230
Total		**3,224**	**7,967**	**1,807**	**5,713**

Based on the mid-level wind speeds in the zone and the annual energy production of VAWTs, a buildout of VAWTs under existing HAWTs could produce an additional 5,713 GWh of electricity per year to the 2,661 GWh of electricity generated now.

264% Increase in Capacity by Adding an Understory of VAWTs

VAWTs like *Wind Harvesters* can significantly increase the capacity of the existing footprint of land. Based on the simple calculation of MWs over the almost 8000 acres of wind farms, the San Gorgonio Pass has an existing energy density of 20 W/m^2 or 0.08 MW per acre. Specific

[5] US Wind Turbine Database

[6] *Wind Harvesters* will complete third party certification and be installed in projects in 2024.

wind farms such as the Cabazon Wind Farm can be significantly higher at 32 W/m^2 or 0.13 MW per acre. (*See the analysis in the appendix*).

The energy density of VAWTs varies on the topography. In flat areas, like the Cabazon Wind Farm, VAWTs can reach a density of 0.24 MWs/acre (59W/m^2). The analysis shows that on average, VAWTs can increase the capacity in *existing* SGP wind farms by 264%, from 682 MW to 2,489 MW.

GWh per acre varies based on wind speed and type of technology. When VAWTs are placed close together and can utilize the “coupled vortex effect”[7], they can achieve the 45% or greater efficiencies that large HAWTs have. This analysis assumes that HAWTs are 5% more efficient than VAWTs at the same wind speeds.

This analysis shows that the output of existing wind farms (2,661 GWh) would increase by 5,713 GWh with a full build out of VAWTs in their “understories.”

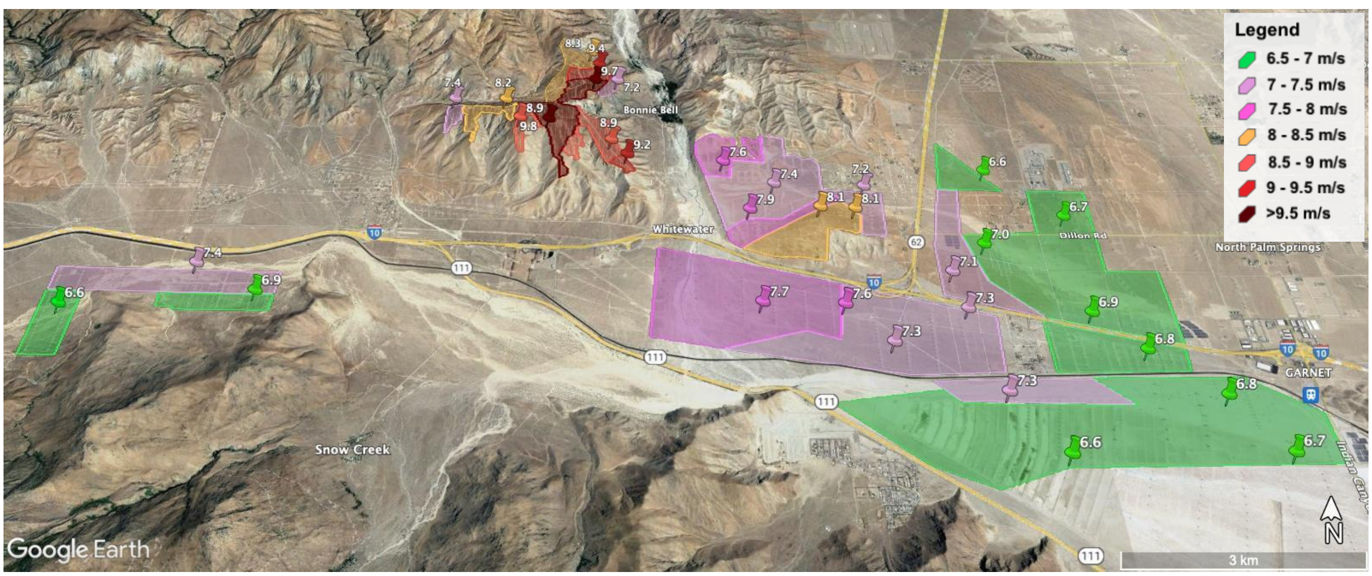


Image 2. Wind speed zones >6.5m/s (14.5mph) in existing wind farms at 66’ (20m) above ground level

Note: *Research[8] from Stanford, CalTech and other universities on VAWTs in wind farms predicts that vertical mixing from understories of VAWTs will bring faster moving wind into the rotors of the HAWTs. As a result, the HAWTs energy output could increase by 10%. This is in addition to the increase in the land’s Annual Energy Production that would be generated from the understory of VAWTs. This analysis does not include any additional expected output by HAWTs.*

[7] The Coupled Vortex Effect occurs when two H-type VAWTs are placed very close to each other. Blockage by the blades forces wind to around turbines. The diverted wind enters the gap and speeds up and also speeds up through the neighboring rotors.
[8] Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms

1.33 GW of H-type VAWTs Could be Added Outside of Existing Wind Farms

Many windy areas in the SGP have not been developed because of concerns over the visual impacts that more 300’ (91m) to 500’ (152m) tall turbines would have. It is possible that there won’t be the same opposition to turbines that can be as short as 60’ (18m) tall.

Table 4. VAWTs that Could be Added Outside of Existing Wind Farms

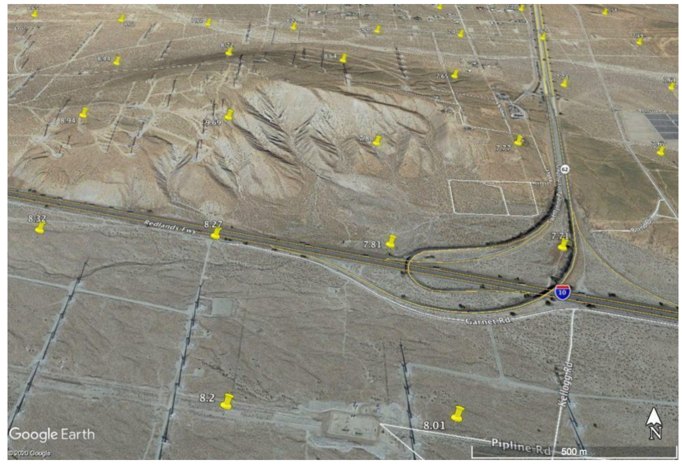
Wind speed		Area		Potential	Annual Energy
m/s	MPH	Hectares	Acres	Buildout (MW)	Production (GWh/yr)
6.5 - 7	14.5 - 15.7	481	1188	273	763
7 - 7.5	15.7 - 16.8	837	2069	476	1,513
7.5 - 8	16.8 - 17.9	1021	2522	580	2,051
Total		**2339**	**5779**	**1329**	**4327**

We found that potentially available areas outside of existing farms could hold 1.33 GWs of short VAWTs. Based on the mid-level wind speeds outside of wind farms and the annual energy production of *Wind Harvester*s (see Appendix 2), adding VAWTs throughout the area mapped in Image 3, would produce 4,327 GWh of electricity per year.

Image 3. Wind speed zones >6.5m/s (14.5mph) outside of existing wind farms at 66’ (20m) above ground level

Methodology: How was VAWT density calculated?

1. This image shows a subset[9] of the wind speed predictions from UL Windnavigator at at 66' (20m) above ground level, which is the proposed hub height of VAWTs that could be installed around the HAWTs. Wind Harvester VAWTS would be 87' (26.5m) tall, which is well below the bottom sweep of most modern HAWTs.



2. The topography and existing infrastructure were analyzed using Google Earth to determine the feasible areas for H-type turbines within each wind speed area.

3. The potential VAWT buildout is calculated to be 57W/m^2 or 0.23 MWs per acre based on these factors:

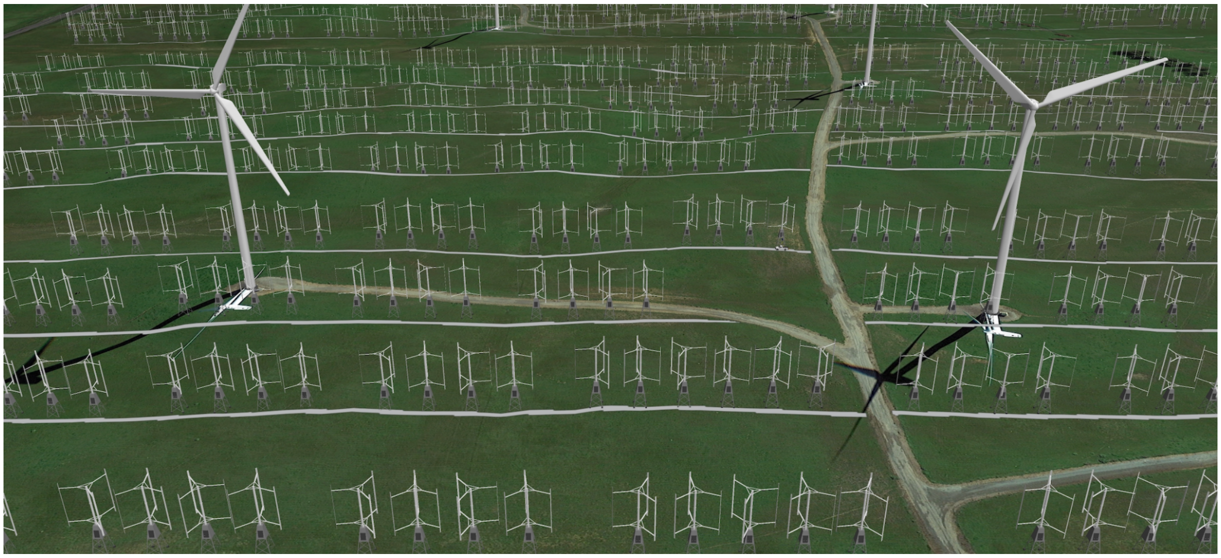
    a. The distance between rows of H-type VAWTs is set at 5X their rotor height. For this analysis, 43' (13m) tall rotors were used. This scales so if the rotors were 66' (20m) tall, the rotor swept area of VAWTs per acre would be roughly the same.

    b. In a row of VAWTs, it is assumed that neighboring turbines are installed 3' (1m) apart from each other. Arrays of seven VAWTs are separated by a 85' (26m) gap to allow for bird passage if needed.[10]

4. The UL Windnavigator data was independently reviewed by renowned wind industry meteorologist Rich Simon. He used wind speed data sets collected over decades in the wind farms to verify the Windnavigator predictions. His analysis showed that Windnavigator overestimated wind speeds by 0.59 m/s (1.3 mph) in flat land and underestimated it in the hilly areas by 0.1 m/s (0.2 mph). The mid-level wind speeds in this report were adjusted to match Simon's data.

5. This report assumes that VAWTs in the wind rich area of the San Gorgonio Pass are only installed on flatter land:
    a. 98' (30m) away from roads
    b. 492' (150m) away from residences
    c. 348; (100m) away from facilities and freeways
    d. 0.5 miles (800m) away from the Pacific Crest Trail
    e. In areas with wind speeds greater than 6.5m/s (14.5mph) at 66' (20m) above ground level.

[9] For all the wind speeds included in this report, please contact us for the kmz file with all the wind speed pins.
[10] VAWTs are 3 dimensional with slower tip speeds than HAWTs. Ornithologists predict they will cause fewer impacts on birds and bats than the 2d HAWTs with tip speeds often over 67m/s (150 mph).



Recommendations

1. The DOE and CEC should fund the evaluation of how harvesting mid-level wind in the resource area could:
   a. Increase capacity factors from wind farms with and without new transmission lines.
   b. Extend the life of HAWTs under which the VAWTs are installed.
   c. How motion detection technology with VAWT pilot projects could speed up the environmental review of bird and bat impacts from large-scale installations.
   d. How much can fields of VAWTs increase the energy output of HAWTs when installed together

2. The California Energy Commission should provide immediate grant funding to analyze and model how much additional energy its wind resource areas could produce with arrays of VAWTs strategically placed under and around them in the State's Wind Resource Areas. Modeling should be specific to each wind farm area as issues that could affect the synergy between the two types of turbines include:
   a. How the inversion layer impacts wind speeds and rejuvenation rates,
   b. How the high density "congestion" problems of HAWT wakes may be affected by the physics of how VAWT wakes draw fast moving wind towards the ground.
   c. How the intense heat in the Pass affects thermals and if VAWTs exacerbate or alleviate the associated problems the heat thermals cause for HAWTs.

3. Determine which wind farms would be best to install pilot projects. Topography matters. HIlls like in the Alta Mesa, ridge lines along the Whitewater River, flat land near the steep slopes and other factors will need to be accounted for. To properly map out and determine the best locations of VAWTs in the SGP will require data collections using strategically placed VAWT pilot projects and sophisticated modeling.

4. Fund the evaluation of how using the mid-level wind resource in the San Gorgonio Pass could:
    a. Increase capacity factors from each property with and without new transmission lines.
    b. Extend the life of HAWTs under which the VAWTs are installed.
    c. How motion detection technology with VAWT pilot projects could speed up the environmental review of bird and bat impacts from large scale installations.

Conclusion

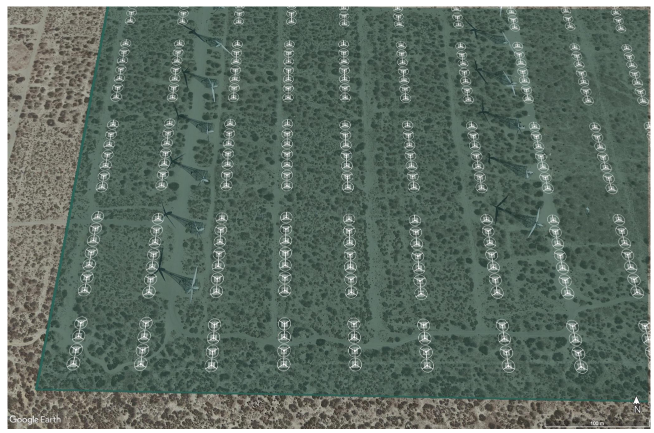
California and Riverside County and its citizens and businesses would benefit greatly from the buildout of even a small percentage of the 10GWs of mid-level wind energy in the San Gorgonio Pass. New short VAWTs will soon be available to handle the turbulent, high energy winds. When they are, more jobs, property and other taxes, and lower cost energy could soon benefit the region and the state.

Appendix

1. Estimating Capacity Density

The most western wind project in the San Gorgonio Pass is the Cabazon Wind Farm. It currently has 79 MWs of HAWTs on its 618 acres. This is a capacity density of 32W/m^2 or 0.13 MW per acre. An understory of VAWTs would increase this by 151 MW for a total of 230 MW. The density of VAWTs would be 59W/m^2 (0.24 MW per acre) for a combined project density of 91W/m^2 (0.37 MW per acre).

Current HAWT Capacity Density (W/m2)	32
VAWT Added Capacity Density (W/m2)	59
Potential Combined Capacity Density (W/m2)	91



The image to the right shows a section of a potential buildout of VAWTs. The existing HAWTs (Zond Z50s with a capacity of 750kW each) are seen as shadows between the second and third and seventh and eighth rows of VAWTs. The distance between rows of HAWTs is 984’ (300m). The distance between rows of VAWTs is five times their rotor height as modeling shows at this distance, wind speeds return to full strength and the wake from the VAWTs is gone[11]. In this analysis, 230’ (70m) between rows was used.

2. *Wind Harvester* VAWT Annual Energy Production (AEP)

This table uses power performance data from the *Wind Harvester* Model 3.1 prototype at the UL Advanced Wind Turbine Testing Facility in Texas. It assumes a 15% increase in AEP because pairs of H-type VAWTs placed close together gain the benefit of the coupled vortex effect.[12]

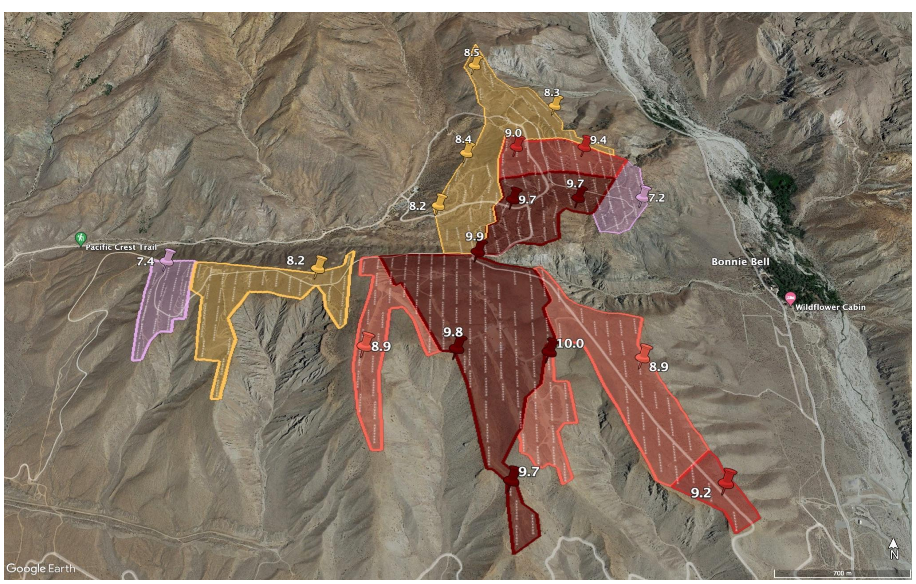
Wind speed		Turbine	Per MW	Capacity
m/s	MPH	MWh/yr	MWh/yr	Factor
6.5	14.5	181	2,586	29.5%
7.0	15.7	210	3,000	34.2%
7.5	16.8	235	3,357	38.3%
8.0	17.9	260	3,714	42.4%
8.5	19.0	285	4,071	46.5%
9.0	20.1	310	4,429	50.6%

[11] Dr. Marius Paraschivoiu, Concordia University
[12] The Coupled Vortex Effect

3. *Wind Harvester* Sized VAWT - Theoretical Density Calculation[13]

Generator size	0.07	MW	70	kW	
Rotor diameter	13	meters	43	feet	
Rotor height	13	meters	43	feet	
Rotor Swept Area	169	m2	554	ft2	0.41 kW per m2
Center of Rotor	20	meters	66	feet	Above ground level
Distance between turbines in array	1	meter	3.3	feet	
Length of array	97	meters	318	feet	7 H-type VAWTs each 43’ (13m) wide with 3’ (1m) between turbines
Distance between arrays in row	26	meters	85	feet	The space between arrays assumes that it is needed for bird passage. The gap between arrays is 2 turbines wide.
Distance between rows	70	meters	230		Rows of VAWTs can be installed as close as 5X the rotor height and realize the same wind speed as the upwind row.
Theoretical density assumption	57	W/m2	17	W/ft2	Estimated average VAWT capacity by surface area, which may vary ± 25% based on terrain.
	0.23	MW/acre	147	MW/mi2	

4. VAWT Potential in the Alta Mesa Area of the San Gorgonio Pass



13 Density of VAWTs scales. For example, a VAWT with a 2x rotor height would have half the number rows.

The Alta Mesa area in the northern part of the San Gorgonio Wind Resource Area to the west of the Whitewater River is one of the windiest spots in the US. It currently holds three wind farms with a total capacity of 33MW. Adding an understory of VAWTs like *Wind Harvesters* to these wind farms has the potential to increase capacity from 33MW to 171MW. The image above shows what this could look like.

For the Alta Mesa area, VAWTs are assumed to have a higher capacity generator per rotor swept area. This calculation used 75kW generators and not the 70kW generators that have been used in the calculations for the rest of the wind resource area.

Wind speed		Area		Potential	Annual Energy
m/s	MPH	Hectares	Acres	Buildout (MW)	Production (GWh/yr)
6.5 - 7	14.5 - 15.7	0	0	0	0
7 - 7.5	15.7 - 16.8	26	64	14	46
7.5 - 8	16.8 - 17.9	0	0	0	0
8 - 8.5	17.9 - 19	93	229	34	134
8.5 - 9	19 - 20.1	59	147	30	126
9 - 9.5	20.1 - 21.3	23	57	11	51
> 9.5	>21.3	86	212	49	243
Total		**287**	**709**	**138**	**600**