

Trends in Blade Repowering and Decommissioning

Mass determination and model prediction of retired blades from wind turbine repowering or dismantling using a GIS database

The Re-Wind Network

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Presentation Overview

1. The Re-Wind Network
2. Motivation
3. Identifying New, Dismantled, Repowered, & Not Repowered Turbines
4. Mass Estimation of Blades
5. Turbine & Blade Models due for Update
6. Broader Implications

Re-Wind

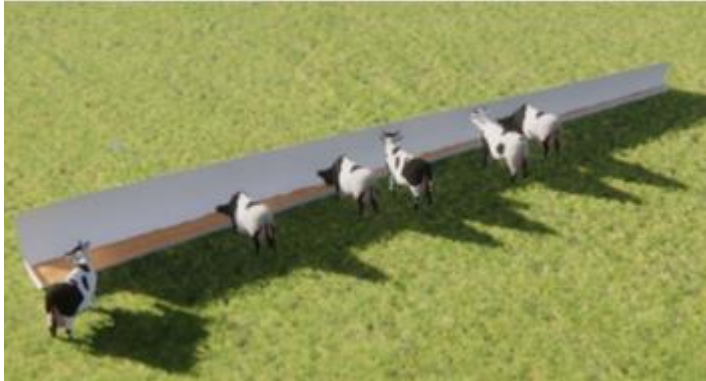
Driving Innovation in Wind Farm Decommissioning

- University College Cork, Queens University Belfast and Georgia Institute of Technology
- Blades can be reutilized into alternative structures upon end of life, such as girders for pedestrian bridges or poles for electric power transmissions lines



Draperstown, Ireland

Other Repurposing Concepts



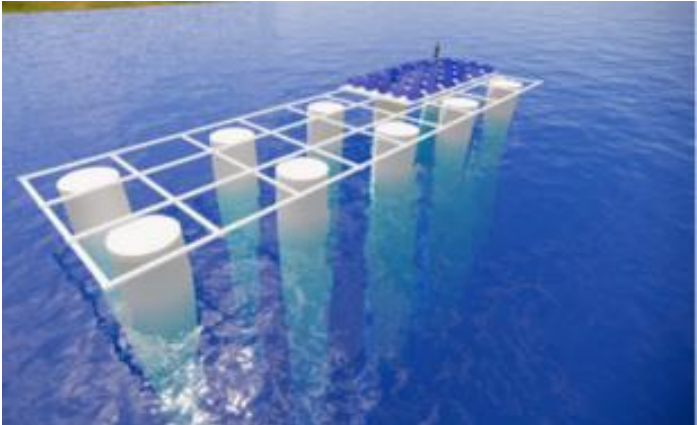
Blade Farm



Blade Jetty



Blade Barrier



Blade Platform



Motivation

- We need EoL Blades!
- What kind of blades are they?
 - Age?
 - Model?
 - Length?
 - Weight?
 - Where are they currently located?

Blade End-of-Life (EoL)

- When do we consider a blade to be at the EoL stage? Widely contended
 - Generally, after 15-25 years of operational life
 - “the *time* at which blades are no longer performing their original function on their original turbine.”
 - Does NOT equate to turbine end of life - Repowering

Tools & Methods

- Data used in this research was obtained from the **U.S. Wind Turbine Database**
 - U.S. Department of Energy (DoE), U.S. Geological Survey (USGS), and American Clean Power Association (ACP) jointly funded
 - March 2014 and July 2022 repositories used
- Data points collected by survey and confirmed via satellite imagery
- Main limitation was lack of thorough information for each turbine location
 - Rated capacity, rotor diameter, year online, manufacturer, or model

Tools & Methods

Missing Information

- 87% of 2014 turbines had capacity information listed
- 85% of 2014 turbines had rotor diameter listed

	I	J	K	L	M	N	O	P	Q	R	S
1	model	type_tower	decommiss	MW_turbine	total_cpcty	total_ht	tower_h	blade_l	rotor_dia	rotor_s_a	lat_DD
28782	NM48_750	monopole	no	0.75	11.25	84	60	24	48	1809.56	44.404292
28788	NM48_750	monopole	no	0.75	11.25	84	60	24	48	1809.56	44.399592
28843	NM48_750	monopole	no	0.75	1.5	79	55	24	48	1809.56	46.895092
28866	NM48_750	monopole	no	0.75	1.5	79	55	24	48	1809.56	46.895192
37728	NM48_750	monopole	no	0.75	0.75	79	55	24	48	1809.56	43.002693
42860	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.053895
42861	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.054795
42862	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.056395
42863	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.057195
42864	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.058195
42865	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.059395
42866	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.066095
42867	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.065095
42868	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.066395
42869	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.069295
42870	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.070395
42871	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.071395
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42873	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.072695
42874	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.073995
42875	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.074395
42876	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.075195
42877	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.075995
42878	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.076795
42879	NM48_750	monopole	no	0.75	80.25	74	50	24	48	1809.56	31.076795

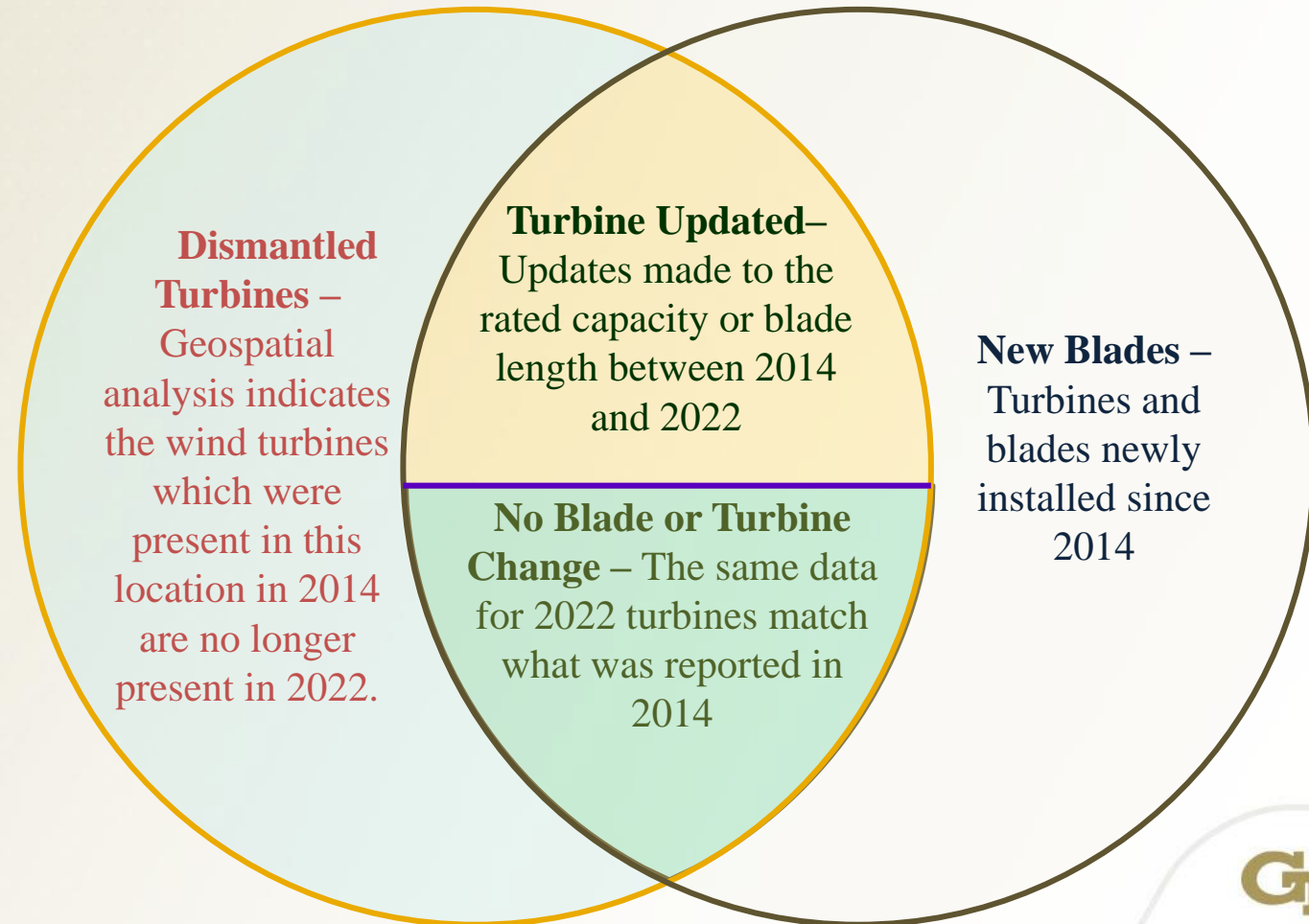
$$\frac{\text{Sum of Reported Mass}}{\text{Actual Percent Reported}} = \frac{\text{Total Mass}}{100\% \text{ Reported}}$$

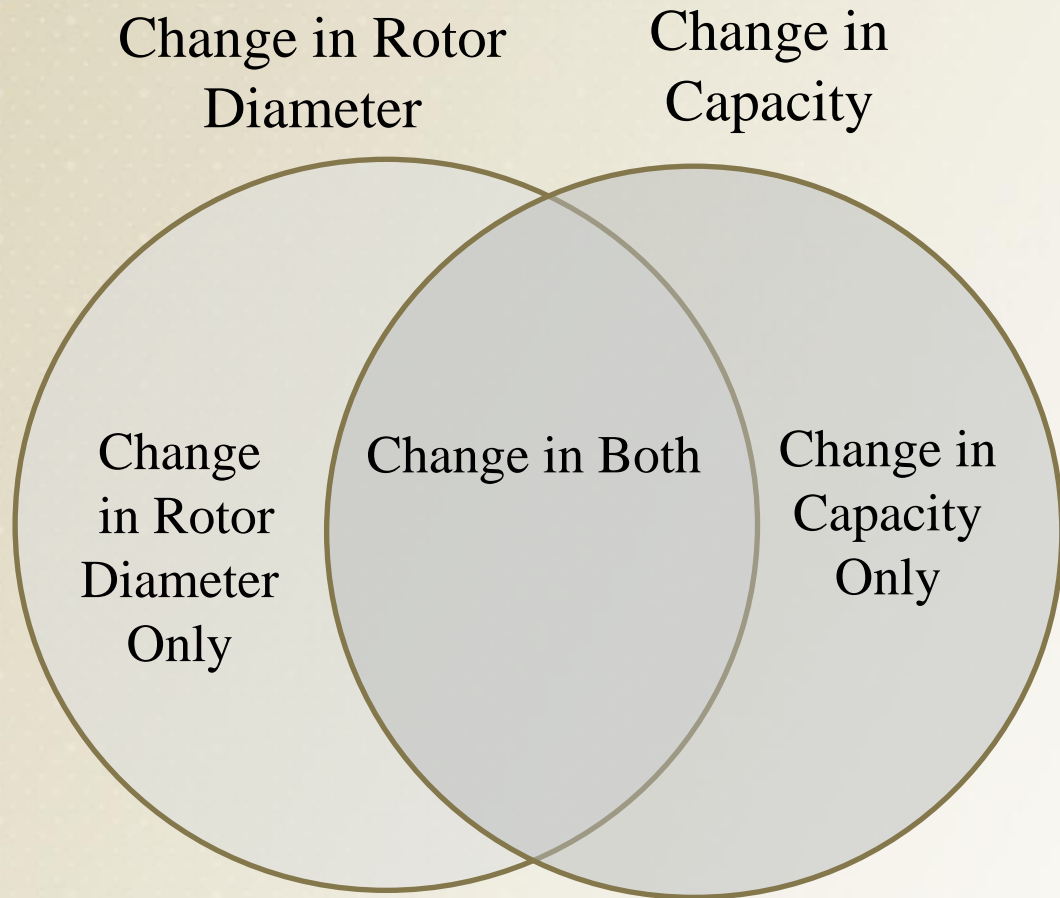


Identifying New, Dismantled, Repowered, and Not Repowered Turbines

2014 USWT Database 2022 USWT Database

How can we identify the pool of turbines we think are most in need of or most likely due for repowering in the near future?
What Constitutes repowering?





What constitutes repowering?

- Increase in blade length of **more than 2 meters**

OR

- Increase in turbine rated power capacity of **more than 20 kW**

2022

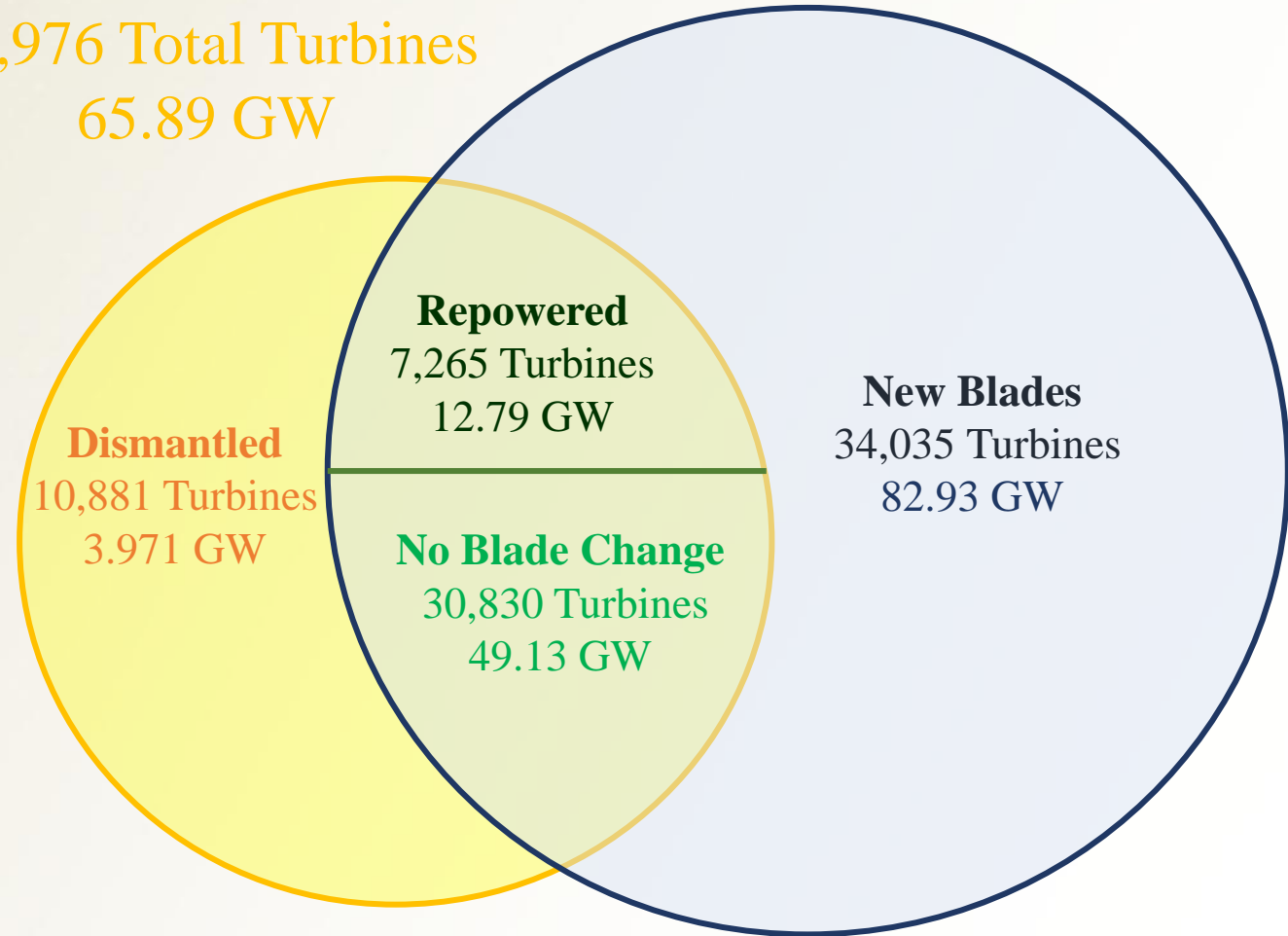
72,130 Total Turbines

144.9 GW

2014

48,976 Total Turbines

65.89 GW



All Blades Classified as Repowered

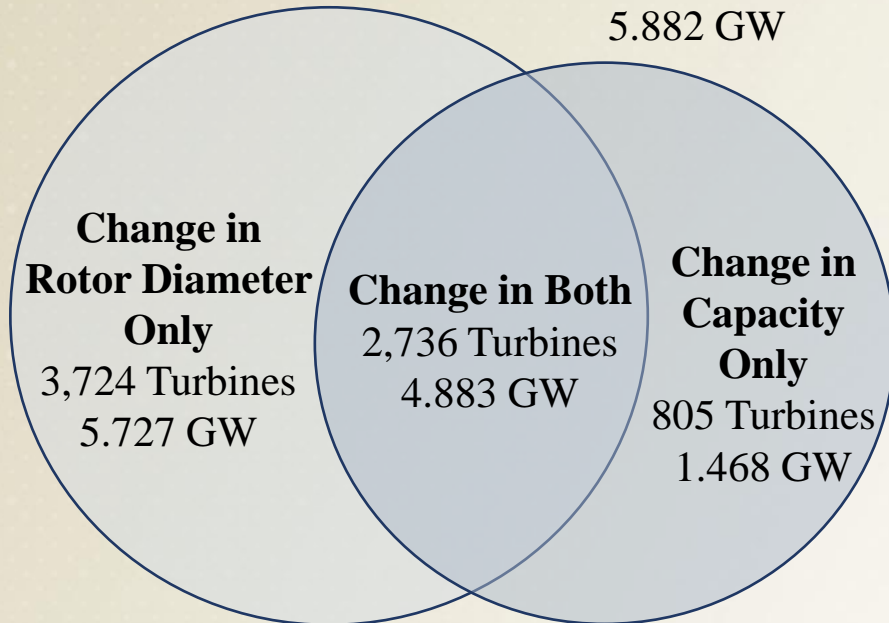
7,265 Turbines

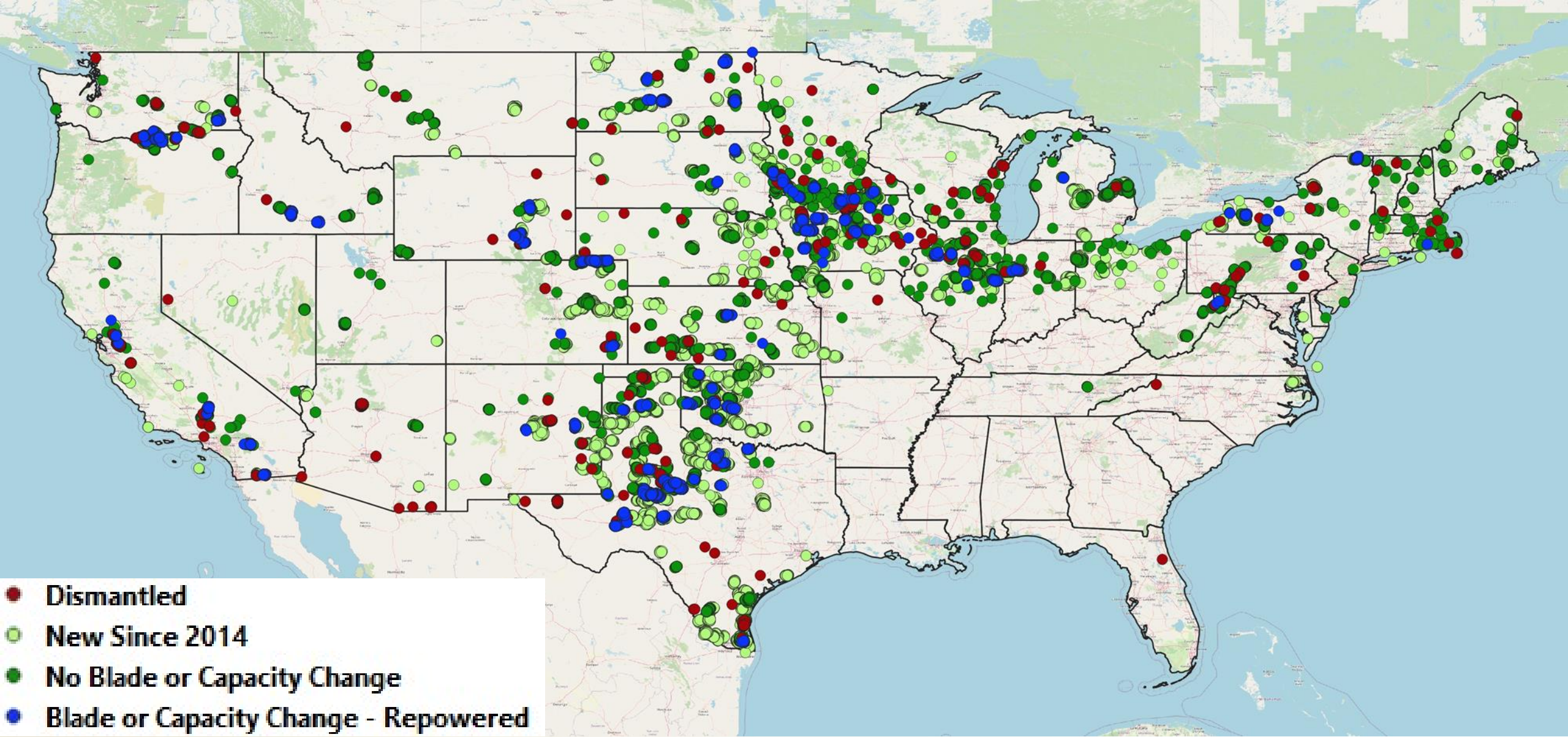
12.79 GW

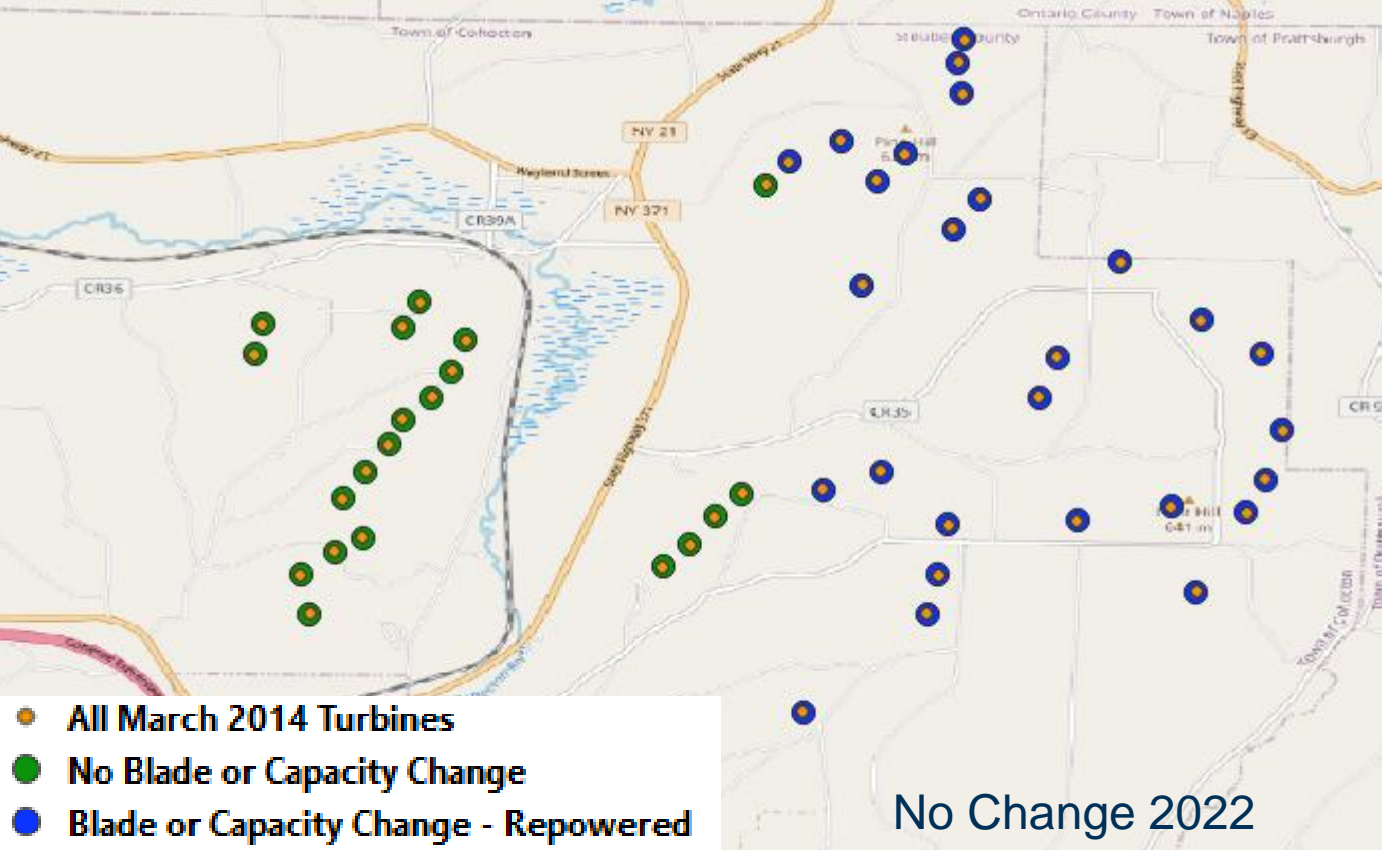
Change in Rotor Diameter

6,460 Total Turbines
10.84 GW

Change in Capacity
3,541 Total Turbines
5.882 GW







- All March 2014 Turbines
- No Blade or Capacity Change
- Blade or Capacity Change - Repowered

2014 data

unique_id	34805.000000
site_name	Dutch Hill
total_turb	15.000000
on_year	2009
year_range	no
on_year_s	2009.000000
manufac	Clipper
model	C96
type_tower	monopole
decommiss	no
MW_turbine	2.500000
total_cpcy	37.500000
total_ht	126.700000
tower_h	80.000000
blade_l	46.700000
rotor_dia	96.000000
rotor_s_a	7238.220000
lat_DD	42.516092
long_DD	-77.498197
state	NY
county	Steuben

unique_id	34804.000000
site_name	Cohocton Wind
total_turb	35.000000
on_year	2009
year_range	no
on_year_s	2009.000000
manufac	Clipper
model	C96
type_tower	monopole
decommiss	no
MW_turbine	2.500000
total_cpcy	87.500000
total_ht	126.700000
tower_h	80.000000
blade_l	46.700000
rotor_dia	96.000000
rotor_s_a	7238.220000
lat_DD	42.505992
long_DD	-77.447197
state	NY
county	Steuben

No Change 2022

faa_ors	36-020463
faa_asn	2019-WTE-7669-OE
usgs_pr_id	34805
eia_id	56633
t_state	NY
t_county	Steuben County
t_fips	36101
p_name	Dutch Hill/Cohocton
p_year	2009
p_tnum	50
p_cap	125
t_manu	Clipper
t_model	C96
t_cap	2500
t_hh	80
t_rd	96

Repowered 2022

faa_ors	36-020431
faa_asn	2019-WTE-7651-OE
usgs_pr_id	34804
eia_id	56634
t_state	NY
t_county	Steuben County
t_fips	36101
p_name	Dutch Hill/Cohocton
p_year	2009
p_tnum	27
p_cap	67.5
t_manu	GE Wind
t_model	GE2.5-116
t_cap	2500
t_hh	80
t_rd	116

Mass Estimation of Blades

- Estimates based on **rated capacity** of turbines blades are installed on
 - Low estimate 10 tonnes per MW
 - High estimate 15 tonnes per MW
- Estimates based on **length of blade**

Albers H, Greiner S, Seifert H, and Kuehne U, 2009, "Recycling of wind turbine rotor blades. Fact or fiction?", *DEWI-Magazin*, vol. **34**

Jensen J P and Skelton K, 2018, Wind turbine blade recycling: Experiences, challenges and possibilities in a circular economy, *Renew. and Sust. Energy Rev., Elsevier*, **97**, pp. 165-176, <https://doi.org/10.1016/j.rser.2018.08.041>

Mass Estimation of Blades – Capacity vs. Blade Length

Group	No.	Blade Lengths		
	Turbines	10 Tonnes/ MW	15 Tonnes/ MW	Estimate in Tonnes
2022 Turbines	72,130	1,449,000	2,173,500	2,132,800
2014 Turbines	48,976	658,900	988,350	883,480
New	34,035	829,300	1,243,950	1,344,100
Dismantled	10,881	39,710	59,565	49,844
Not Repowered- No Change	30,830	491,300	736,950	605,830
Repowered - Change in Blades OR Capacity	7,265	127,900	191,850	192,960

Equation Source	Equation (where y is material weight in Kg)
WindPACT Baseline – Baseline blade mass curve	$y = 0.1452x^{2.9158}$
LM Wind Glassfiber – Advanced blade mass curve	$y = 0.4948x^{2.53}$
Emma Delaney PhD Thesis Blade Weight Equation	$y = 0.0036x^2 + 0.0258x$
Franco Arias PhD Thesis Blade Weight Equation (weight of composite material only, ~85% of total blade weight)	$y = 0.002x^2 + 0.0733x - 0.6588$

Mass Estimation of Blades – Length Equations

Group	WindPACT Equation, Weight in Tonnes	LM Equation, Weight in Tonnes	Delaney Equation, Weight in Tonnes	Arias Equation, Weight in Tonnes
2022 Turbines	2,994,000	2,190,000	2,132,800	1,705,100
2014 Turbines	956,680	765,100	883,480	713,890
New	2,091,700	1,475,100	1,344,100	1,050,700
Dismantled	35,944	31,786	49,844	34,602
Not Repowered - No Change	678,130	541,590	605,830	504,571
Repowered - Change in Blades or Capacity	187,000	245,530	192,960	157,160

Mass Estimation of Blades – Change in Weight

Change With Blade Length Estimate

	Weight in Tonnes in 2014	Weight in Tonnes in 2022	% Change in Weight
Repowered – Change in Blades OR Capacity	154,050	192,960	25.26

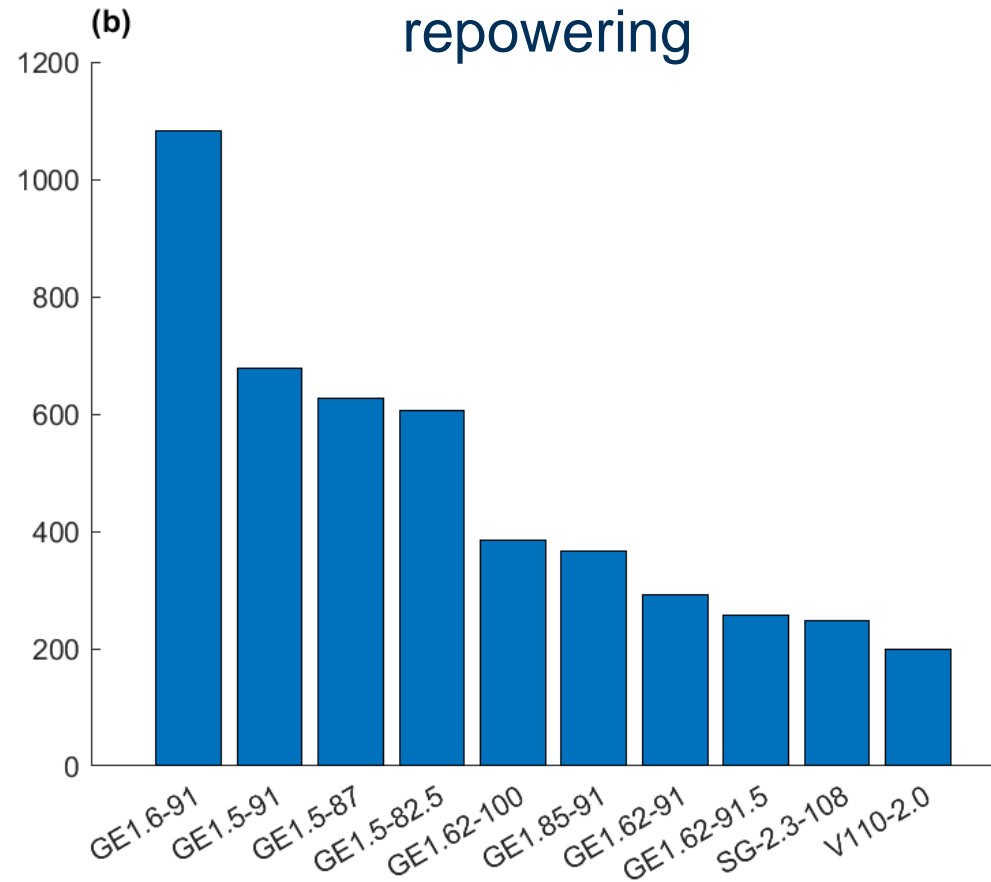
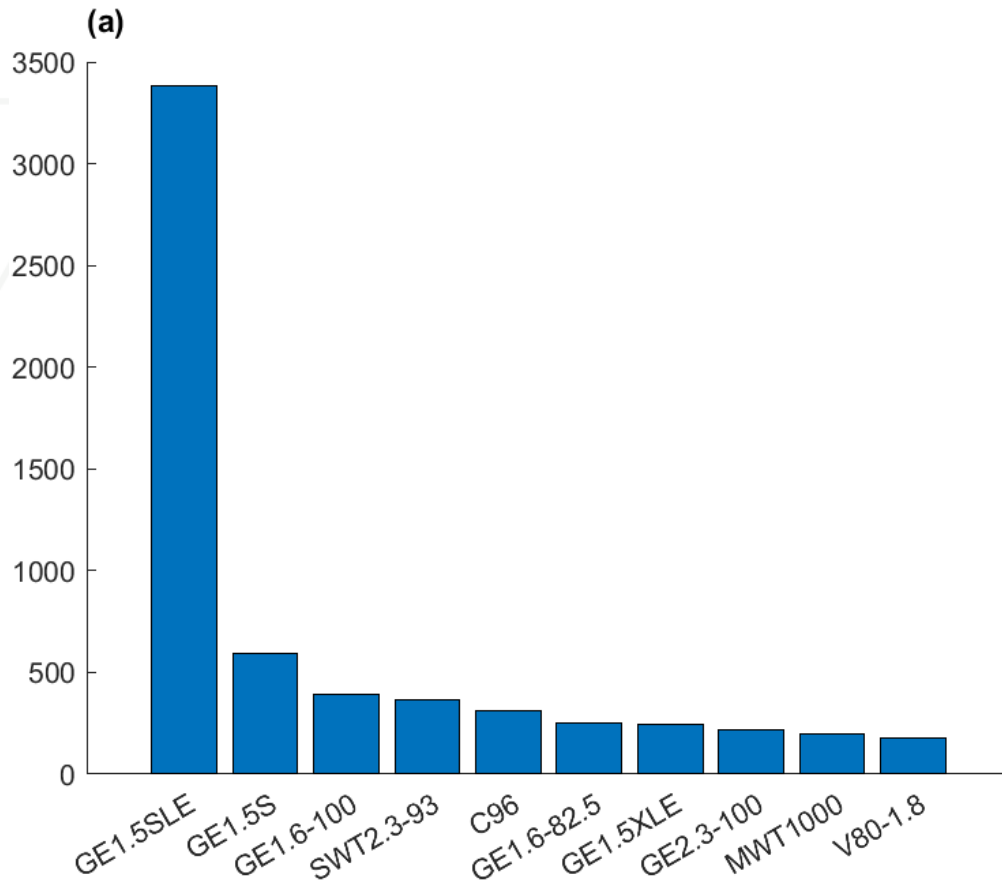
*Estimated with Delaney Blade Weight Equation

Change With Turbine Capacity Estimate

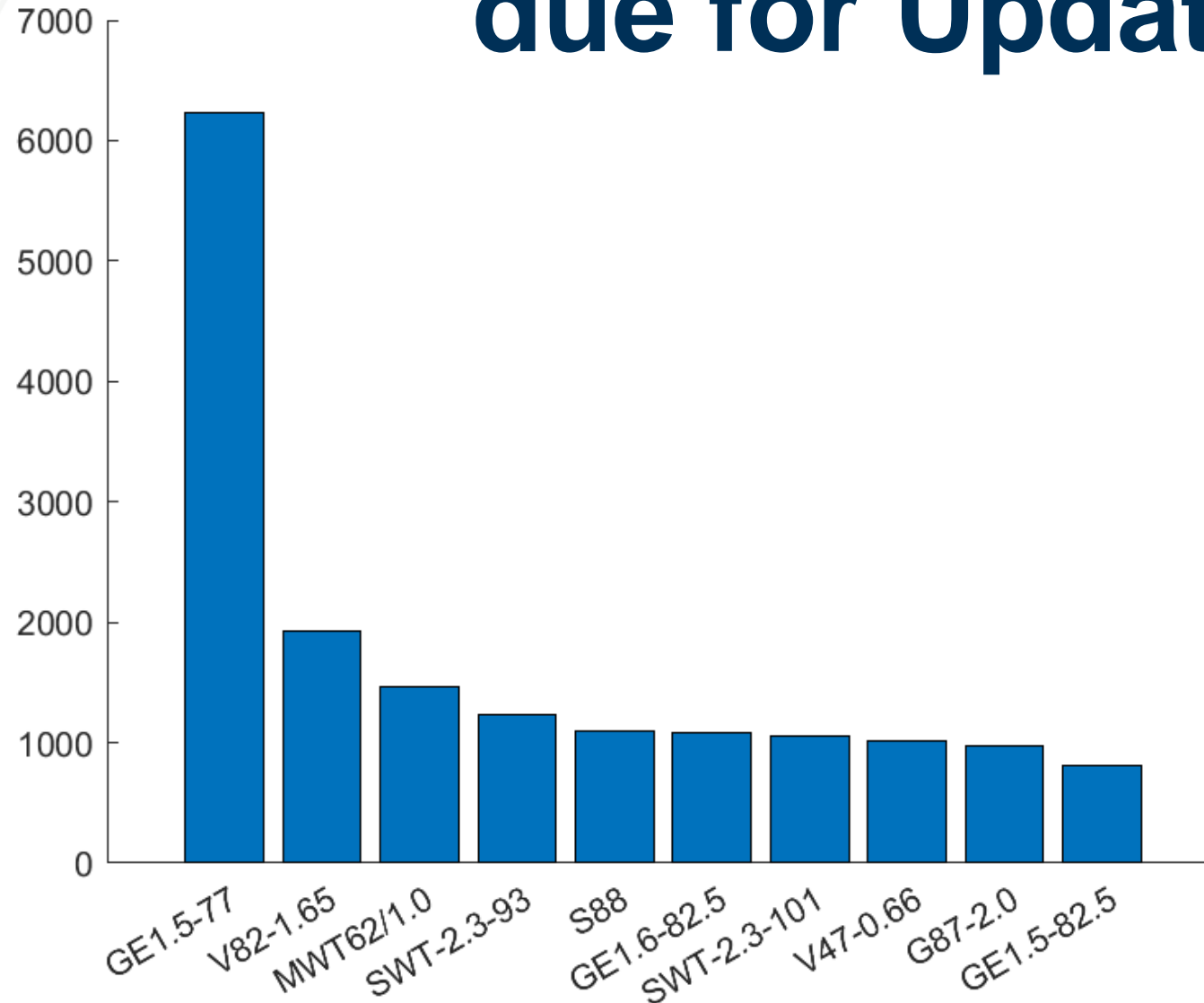
	10 Tonnes/ MW in 2014	15 Tonnes/ MW in 2014	10 Tonnes/ MW in 2022	15 Tonnes/ MW in 2022	%Change in Weight
Repowered – Change in Blades OR Capacity	123,300	184,950	127,900	191,850	3.731

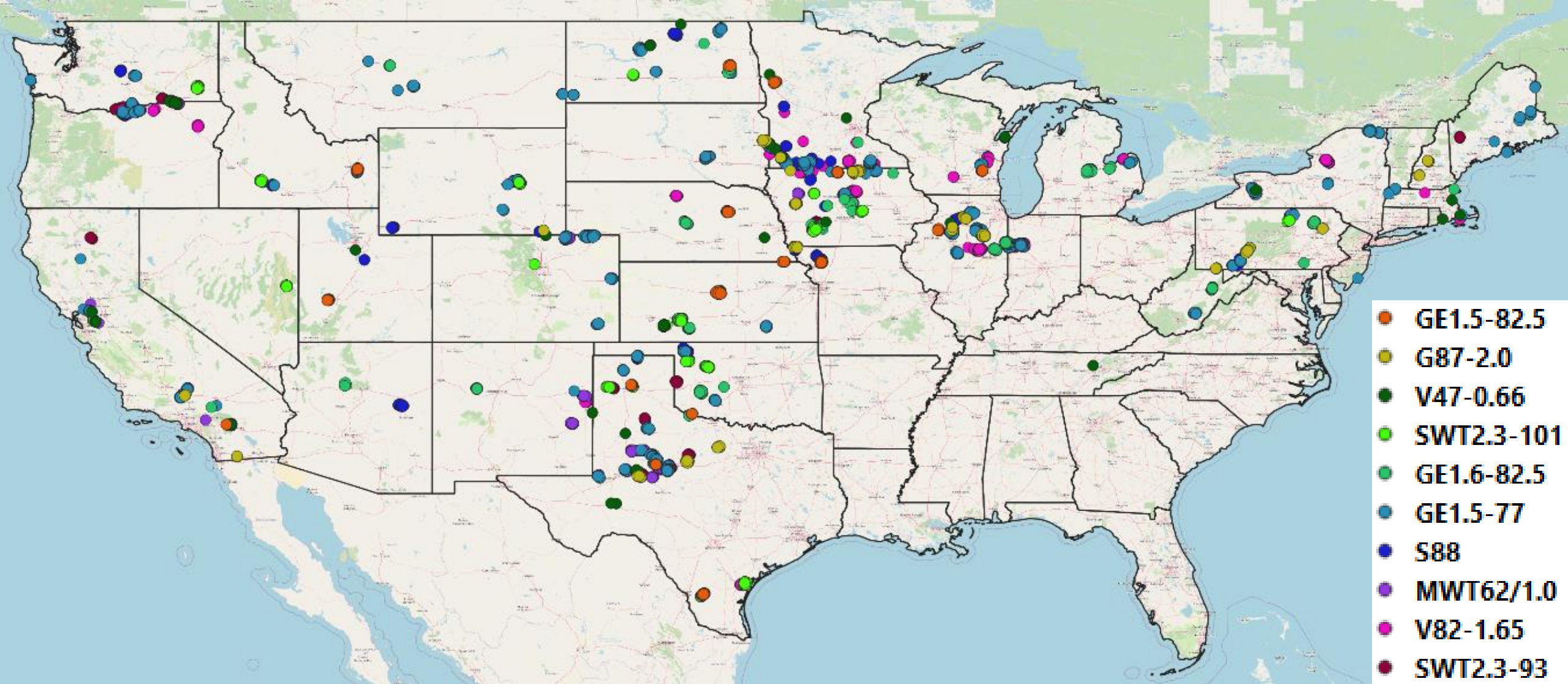
Turbine and Blade Models due for Update

(a) the 2014 turbine models that were updated and (b) the 2022 turbine models that are the result of repowering



Turbine and Blade Models due for Update





Turbine and Blade Models due for Update

Discussion & Implications

- Making predictions on the type and total mass of blades coming out of service helps stakeholders plan for uses and processing procedures
 - 163,010 to 244,515 tonnes of blade waste currently in landfills or sent to EoL processing
 - In the next decade or so an additional 491,300 to 736,950 tonnes of blade material can be expected to enter waste streams
- Capacity-based estimates are no longer sufficient to determine weight of blade material
- GE1.5 MW turbines associated with the GE37 blade model, which represent 9.23% of current online blades and roughly 99,350-149,025 tonnes of material, are most widely identified for future repowering projects