Totaro&Associates

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com

Reduction of Cost of Energy Through Innovation

Patent Landscape Analysis Helps Define Wind Turbine Technology Trends

by Philip Totaro, CEO & Principal, Totaro & Associates

Utility scale wind turbines have become so technologically advanced that they have improved the cost of energy of wind enough to become more mainstream than ever before and compete with today's conventional energy sources. The resultant reduction in cost of energy (COE) has been the result of two governing forces: public policy and technological innovation. This paper will explore what technological trends have emerged thus far and what might be in store for the future direction of wind turbine technology. Policy and governmental R&D support will continue to be essential, and barriers to wind technology commercialization must be broken down.

Two years ago, we decided to conduct an investigation of the patent landscape to see what technological trends have emerged thus far and what we might be able to infer for the future direction of wind turbine technology.

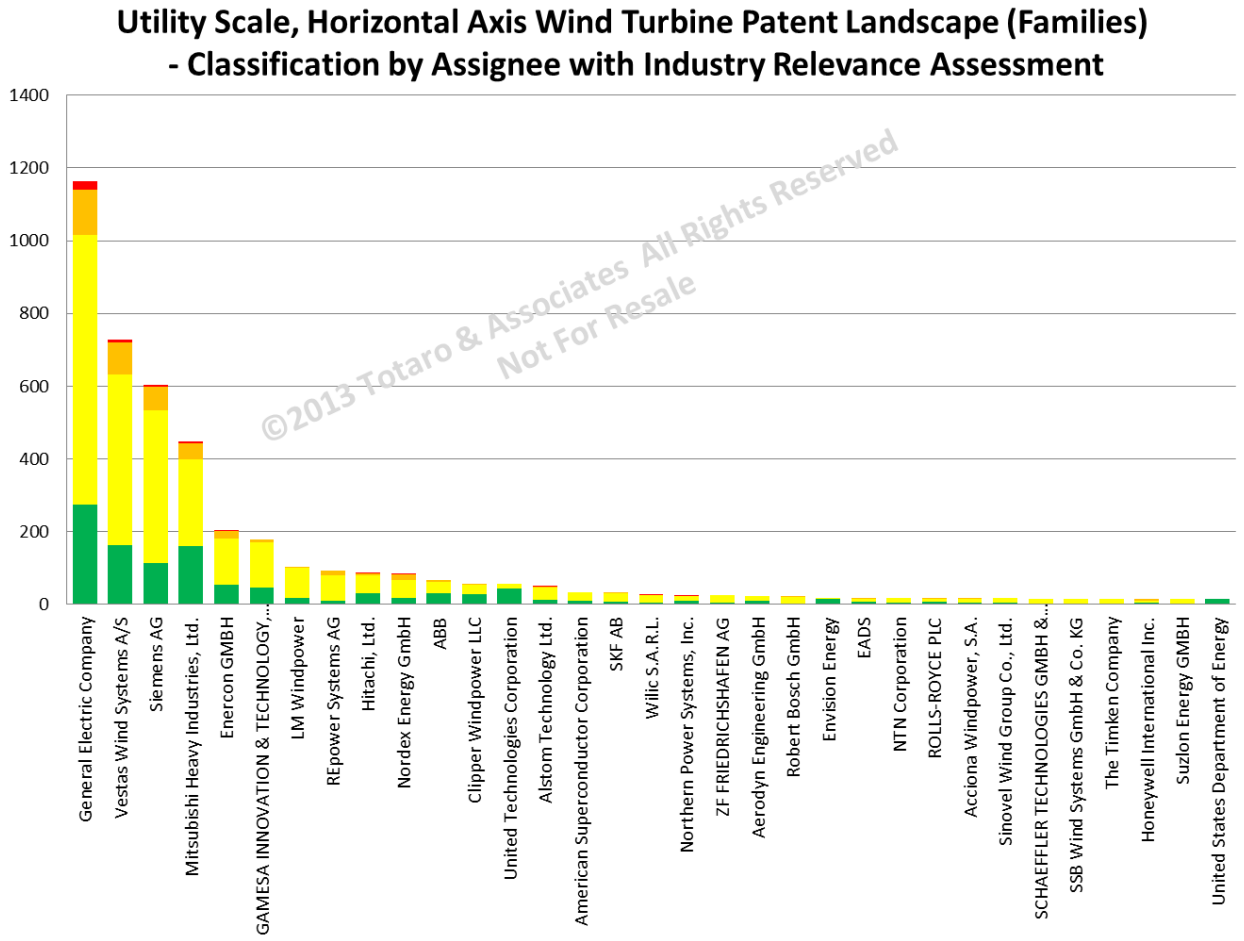
At that time, we decided to limit the assessment to the most prevalent sector of wind turbine technology – utility-scale, horizontal-axis wind turbines, as this is most reflective of the mainstream industry. However, we leave the possibility open to include small and medium scale, vertical axis, building and rooftop, as well as ducted rotor turbines in the future.

The search was conducted utilizing a comprehensive approach, as well as thorough examination of results. Patent database and search portals were used which cover over 90 worldwide jurisdictions, and results for all jurisdictions were harmonized to provide comprehensive portfolio analysis. We first identified a set of keywords which would provide an all-inclusive set of search results. We also identified patent classes to search in order to ensure that relevant results would not be omitted. Lastly, a set of assignees of over 1,080+ companies who have currently or previously produced wind turbine technology / components was searched for all relevant filings.

Aggregation of these results and elimination of duplicates as well as false positives has now led to a total set of over 27,500 issued patents and published pending applications from over 62 worldwide patent jurisdictions dealing with utility-scale, horizontal-axis wind turbines.

With the results grouped by assignee (or patent owner), it should come as no shock to industry watchers who are the top assignees for these patent filings. The assignee chart below shows the number of patent families held by each company. The patent families represent individual inventions covered by multiple common patent applications filed worldwide, including divisional and continuation applications. For the sake of compactness, only those with 15 or more patent families were included in the chart.

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com



Next, the search results were read and analyzed to determine a keyword classification that indicates the specific technology and component to which the patented invention denotes. The component literally refers to the wind turbine component, i.e. blade, tower, generator, gearbox, etc. The technology refers to the nature of the improvement, and deals with such topics as performance improvement, reliability enhancement, manufacturing tools or processes, safety as well as grid compliance. The search results are presented in a format in which each individual patent filing was assessed and classified, and all results were grouped by patent family. The 27,500+ global filings can be aggregated into 6,755 patent families of relevance which have been identified and evaluated thus far.

Additionally, an assessment of the relevance of each patent filing to the industry was performed and results were classified as Low, Medium, Medium/High, and High. Definitions of this classification method are below. The assessment of industry relevance serves the purpose of indicating the degree to which the patent owner has asserted their patent rights in the past or would be able to seek licenses or otherwise enforce the patent due to usage of that patent protected technology by their competition.

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com

Low	Medium	Medium/High	High
Patent / Application is not relevent to the pervasive set of technologies and products in the industry.	May have been relevant in the past or is simply not broadly applicable. Multiple methods of design around exist.	Important filings which the industry needs to be cognizant of, but these can likely be avoided / mitigated.	Critical filing which has been asserted, licensed or enforced, or is otherwise highly likely to be in the future due to claim breadth.

The following excerpt from the patent landscape is indicative of the keyword classification and relevance assessment methodology. The family members were evaluated individually, and differences in the design intent of each patent filing is noted in the keyword assignment.

Title	Component	Sub-Component	Technology	Sub-Technology	Relevance to Utility-scale WTG Industry	
ARTICULATED WIND TURBINE BLADES	Blade	Variable Diameter	Load Mitigation		L	
POWER CONVERTER SYSTEM AND METHODS OF OPERATING A POWER CONVERTER SYSTEM	Controls & Sensors	Converter	Frequency / Voltage Regulation		H	Did they bother to search for prior art? This is just a patent application on a converter.
METHOD FOR FEEDING A MULTIPHASE ELECTRIC NETWORK AND ASSOCIATED CIRCUIT ARRANGEMENT	Controls & Sensors	Converter	Frequency / Voltage Regulation		M-H	I believe this individual phase control of a grid connected turbine is already known in the industry.
FAULT RIDE THROUGH SWITCH FOR POWER GENERATION SYSTEM	Electrical	Converter	Frequency / Voltage Regulation	LVRT	M	

In acknowledging that the application of these keywords and the assessment of relevance are both subjective, it should therefore be clear that this landscaping activity requires a certain level of technological and wind industry domain expertise. This technical domain expertise is the key area where the plethora of other lists of wind and/or 'clean-tech' related patent filings, which have been developed by IP search companies or law firms in the past, have all fallen short.

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com

Also, this assessment of relevance should be an indication of the proverbial landmines to watch out for when navigating a new technology or product through the landscape, and these results have already been used in freedom to operate investigations. There are numerous instances of infringement which we have identified during the course of our landscaping efforts that remain largely unknown to the OEMs or unaddressed through licenses or other means of risk mitigation.

The risk profiles which were developed based on the data set explore the relevance of each patent family and individual filing to a particular OEMs turbine architecture. They provide turbine OEMs, financiers, developers and insurance providers with clarity as well as a quantification of IP risk. This can defray project risks related to possible patent infringement.

The landscape has also shown a vast number of areas in which relevant prior art was discovered which was not cited by the inventor(s) or examiner(s) during the patent prosecution process. Further complicating matters, there are also numerous instances where the inventors clearly should have known about the existence of the prior art references, but chose not to cite them anyway in their newly filed patent applications. This leaves the door open to the possibility of invalidation of many patents due to inequitable conduct, which could have been avoided.

The industry relevance results indicate that only ~1% of issued patents are a high impact on the entire industry as a whole, with another ~7% which may become relevant in the future. The remaining ~92% of filings are merely providing companies with basic defensive IP protection.

General Electric Company (GE) controls not only the largest number of patent families, but the largest percentage of all wind-related IP with over 17% of patent filings. All combined, the top 6 patent holders hold 49.4% of patent filings. Only 60 patent families out of 6,755 catalogued thus far comprise technology which is broadly applicable to products and services offered commercially within the industry worldwide.

Relevance	GE			Vestas			Siemens			Mitsubishi			Total Industry	
	No. of Patents & Apps	% of GE Portfolio	% of Total Industry	No. of Patents & Apps	% of Vestas Portfolio	% of Total Industry	No. of Patents & Apps	% of Siemens Portfolio	% of Total Industry	No. of Patents & Apps	% of MHI Portfolio	% of Total Industry	No. of Patents & Apps	% of Total Industry
High	22	**1.9**	**36.7**	9	1.2	15.0	5	0.8	8.3	4	0.9	6.7	60	0.9
Medium/ High	124	10.7	**25.0**	88	12.0	17.7	66	10.9	13.3	46	10.1	9.3	496	7.3
Medium	742	63.9	20.3	471	64.2	12.9	420	69.5	11.5	243	53.4	6.6	3,664	54.2
Low	274	23.6	10.8	166	22.6	6.5	113	18.7	4.5	162	35.6	6.4	2,535	37.5
Total	**1,162**	**100**	**17.2**	**734**	**100**	10.9	**604**	**100**	8.9	**455**	**100**	6.7	**6,755**	**100**

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com

While most companies are in-line with industry averages in terms of overall portfolio distribution of Low, Medium and High risk filings, GE's High risk patents as a percentage of their overall portfolio is double the industry average at 1.9% vs. 0.9%. Their portfolio also comprises over 36% of all High risk patents, showing a concerted effort to gain a tactical and commercial advantage through capturing and aggressively enforcing IP rights.

Also notable is that top-tier companies have a combined High and Medium/High set of filings which is above the industry average of 7.3%. This confirms the strong correlation between investment in both R&D and IP protection, and the commercial success of the top-tier companies due to the reduced CapEx and more energy production from the turbines comprising those patent protected technologies.

Tangible value predominately exists on the Low and Medium impact patents if those companies are seeking equity investment, or sale / divestment and their patent portfolio will require valuation, or alternatively they are licensing their portfolio to a partner or third party.

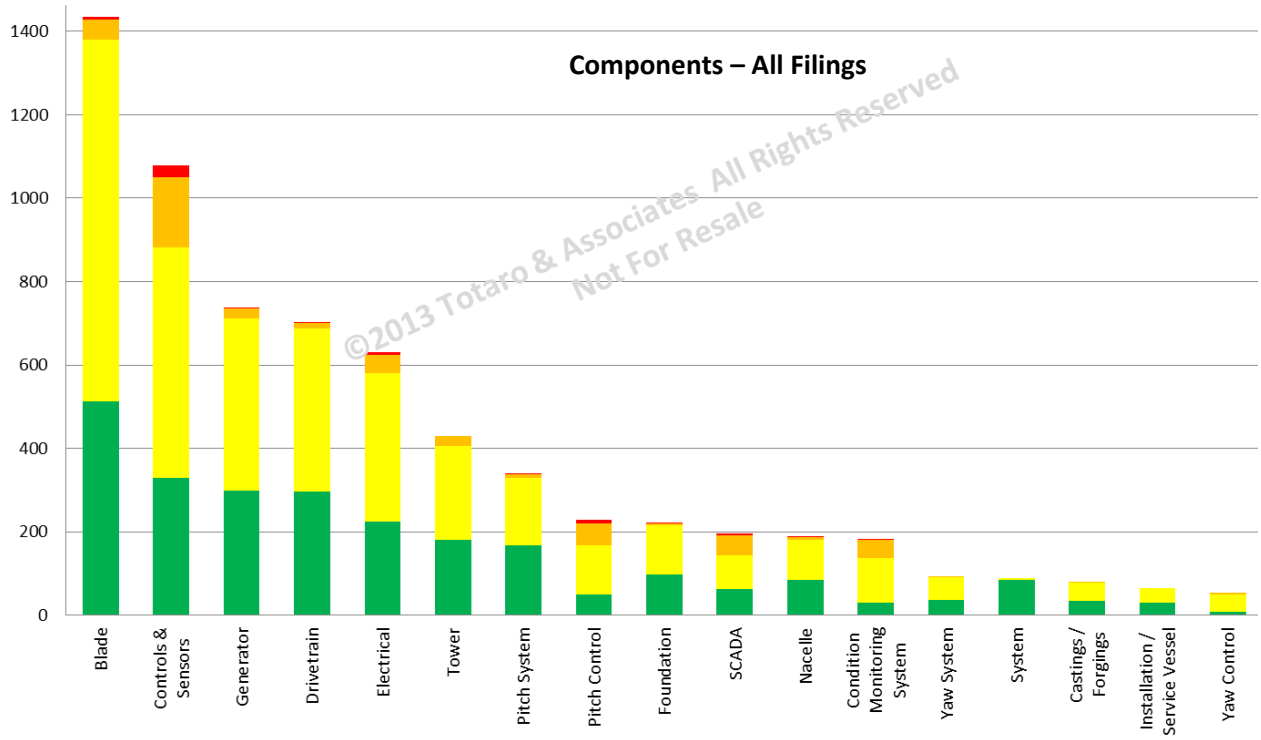
The heat map of the filing dates for the set of issued patents and pending applications confirms that the majority of filings have occurred in the past decade or so, with all expired patents having been moved to the low category now that they are public domain. This is reflective of the shared influence of public policy on technology adoption and the subsequent cost efficiencies enabled by widespread deployment of wind turbines.

		Filing History - All Patent Families, by Filing Year																						
Industry Relevance		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
High	60									2	1	1	1	2	3	3	3	4	6	4	11	7	11	1
Medium / High	496				1			2	3	2	2	5	5	11	17	20	22	24	43	57	70	95	89	28
Medium	3664			2	2	7	11	5	7	13	24	30	40	60	83	90	126	121	229	391	607	724	728	364
Low	2535	22	25	18	14	18	25	10	10	17	18	49	61	87	81	91	104	97	139	192	229	351	326	183
Total	**6755**	22	25	20	17	25	36	17	20	34	45	85	107	160	184	204	255	246	417	644	917	1177	1154	576

The keyword classification shows interesting, albeit somewhat recognizable trends to industry watchers, but it also indicates certain areas which may present "whitespace" for patent protection. Obviously the blades, gearboxes, generators, and electrical systems of the wind turbines are the largest areas of focus historically, because these components represented the largest piece of turbine CapEx and they presented the greatest opportunity for COE reduction.

Beyond that, it will be seen from the technology keyword classification that blades, drivetrain and electrical have also been the most problematic for turbine manufacturers and sub-component suppliers when it comes to component reliability, so they have garnered a great deal of attention and innovation to improve quality and performance. The emergence of controls towards the top of the list is a more recent industry trend in which turbine OEMs endeavor to optimize turbine performance while operating within the design envelope.

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com



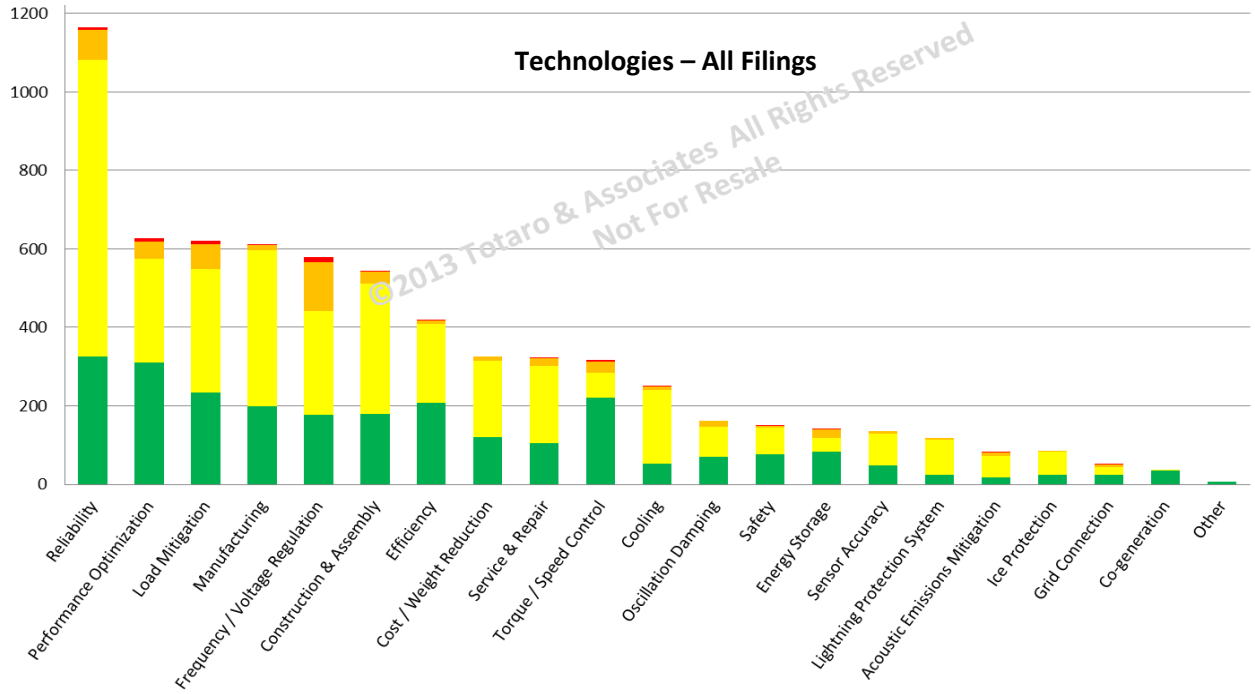
As previously mentioned, the trend of attempting to improve reliability and efficiency of wind energy conversion has been the predominant focus of the industry over the past 2 decades. It has been this focus which has resulted in the COE reduction as well as the reliability enhancement seen in that time frame. Fleet-wide availability of wind turbines has been dramatically improved, with most OEMs now quoting a 97 - 98% availability guarantee in their turbine supply agreements, as well as providing more sophisticated instruments like production-based availability (PBA) guarantees. The improvement of component reliability as well as the development of fleet management tools has enabled PBA to become a win-win for the turbine OEMs and the wind park owner / operators.

Additionally, performance optimization has been, and will continue to be near the top of the list since the efficient conversion of mechanical energy into electrical is the intent of this technology.

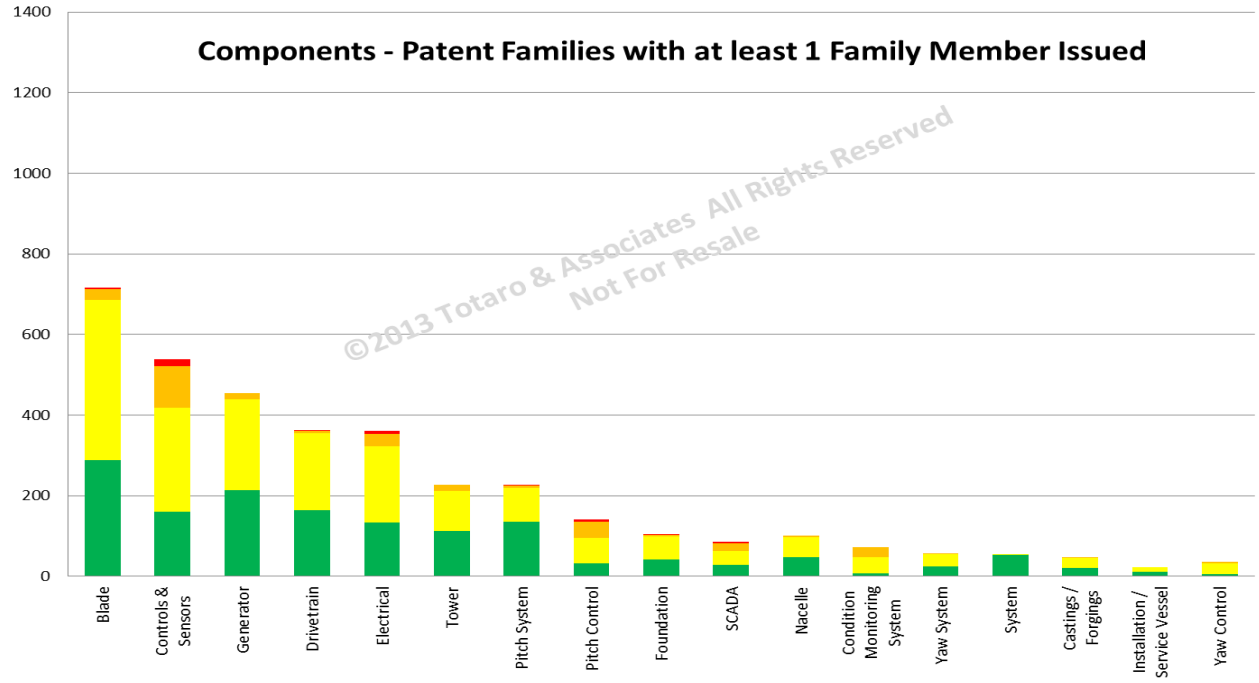
Now with turbines getting bigger in physical size as well as nameplate rating, we can see that manufacturing, load mitigation and construction are emerging thrusts. Shipping turbines in modular sections and assembling on-site at a wind farm will be an important area of investigation for land based turbine manufacturers. Component size has increased to such an extent that transportation of whole blades, towers, and nacelles under bridges and through tunnels is reaching its' limits. Even offshore component size is pushing the limits of installation vessels. Additionally, with commodity prices still fluctuating we see many manufacturers attempting to take weight / material and therefore cost out of their products.

Interestingly, offshore specific technology comprised less than 200 patent families in the landscape and presents one of the greatest areas of growth potential.

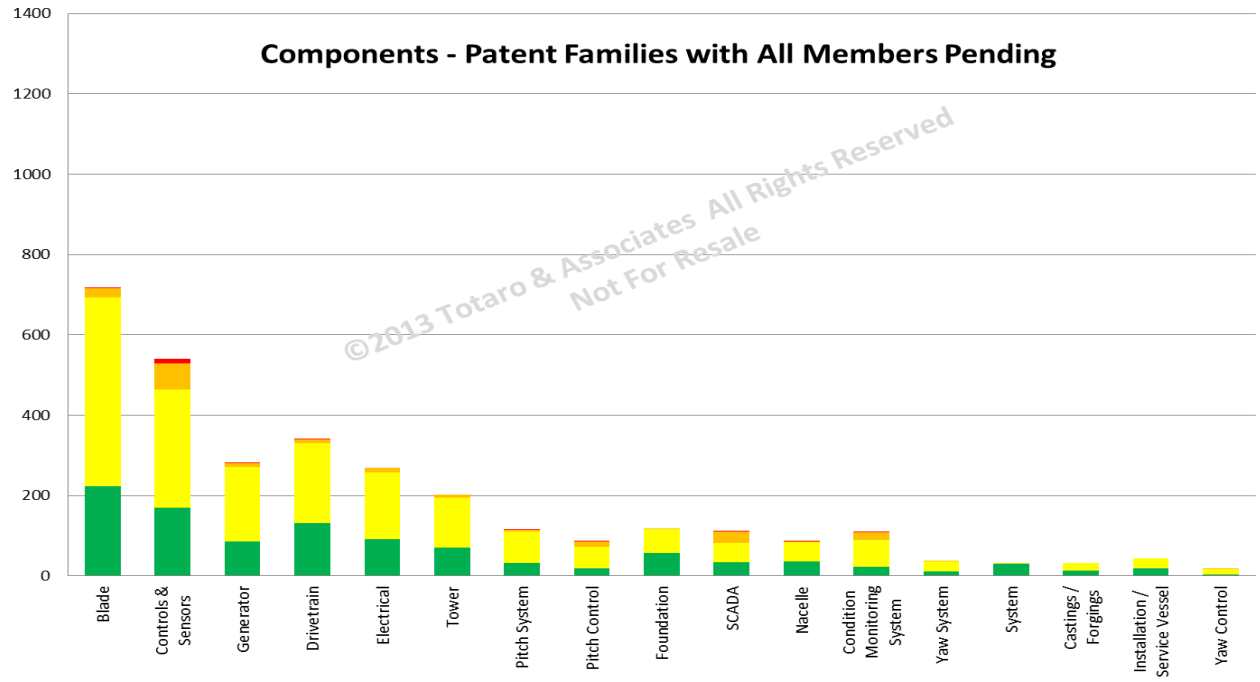
1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com



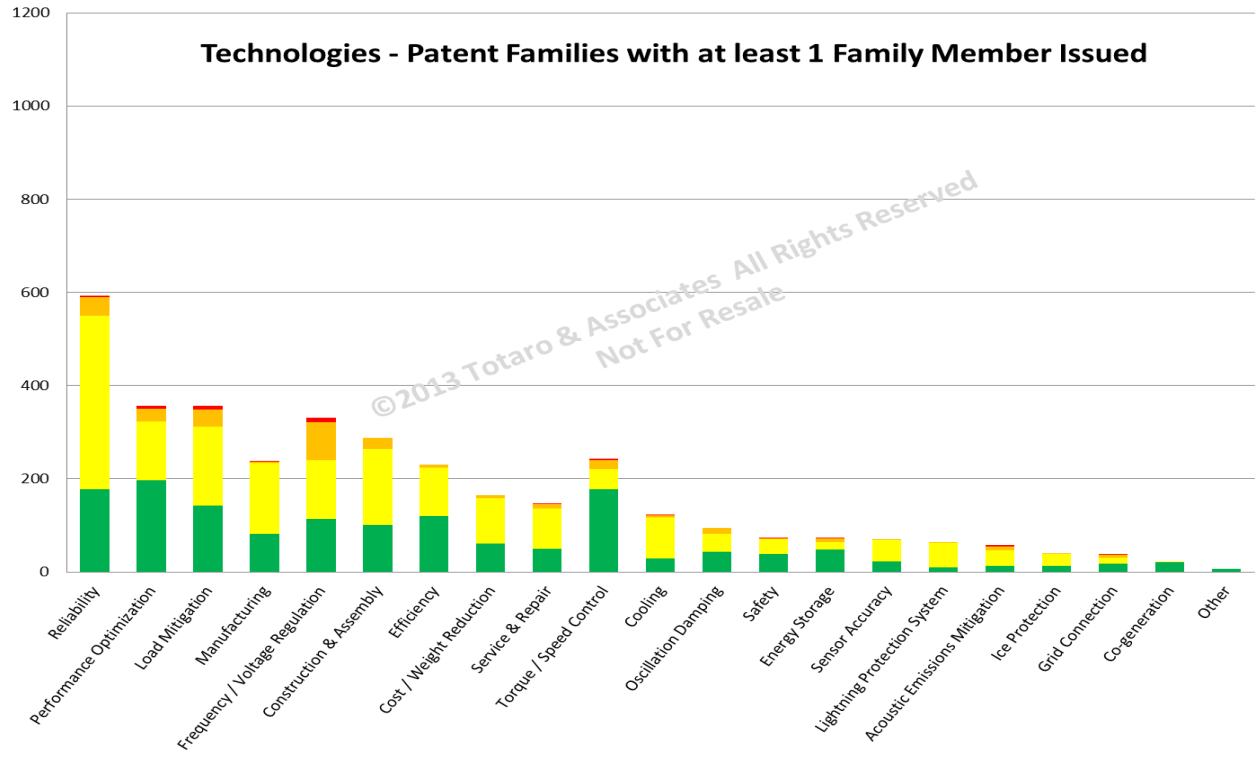
A comparison of the issued patents in their portfolio vs. the pending applications reveals some interesting trends as well. The differences between the two charts indicate areas where innovation has occurred in the past (the issued patents) vs. more recently (the pending applications). From this comparison it is clear that component developments have historically been directed towards blades, gearboxes, generators and electrical systems, with newer filings directed towards controls and a continuing focus on blade performance enhancements.



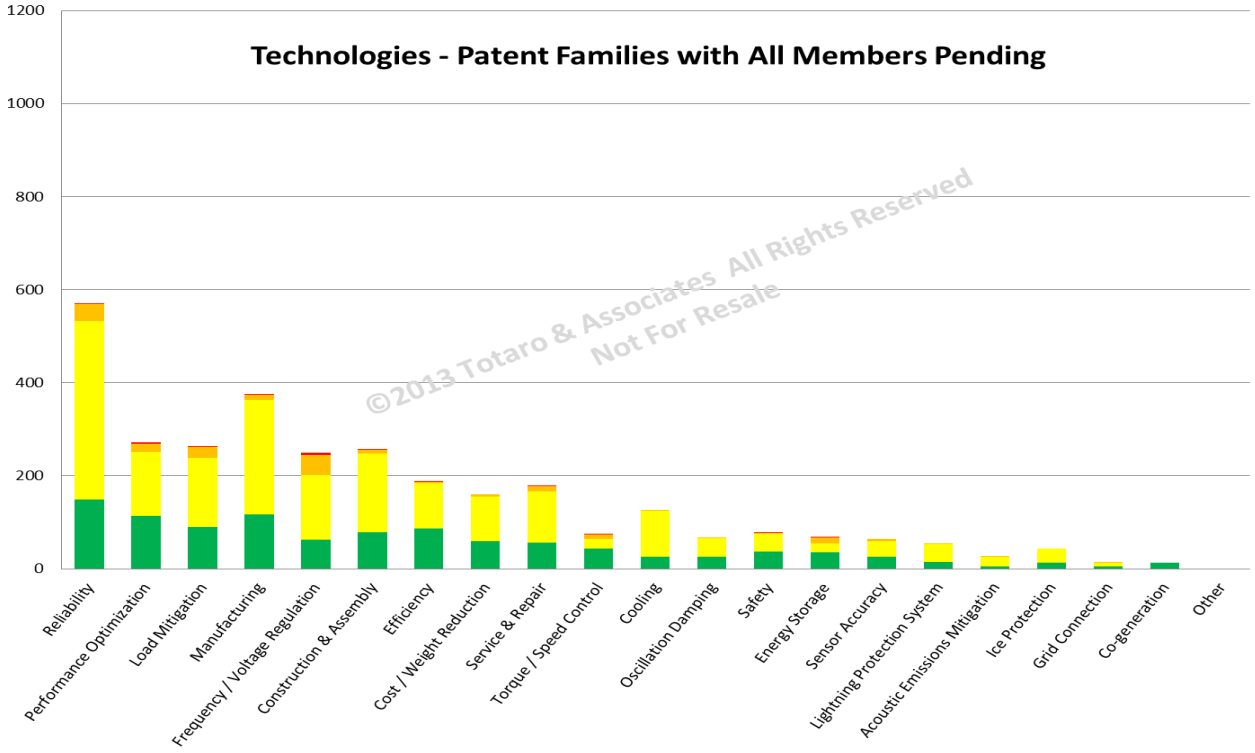
1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com



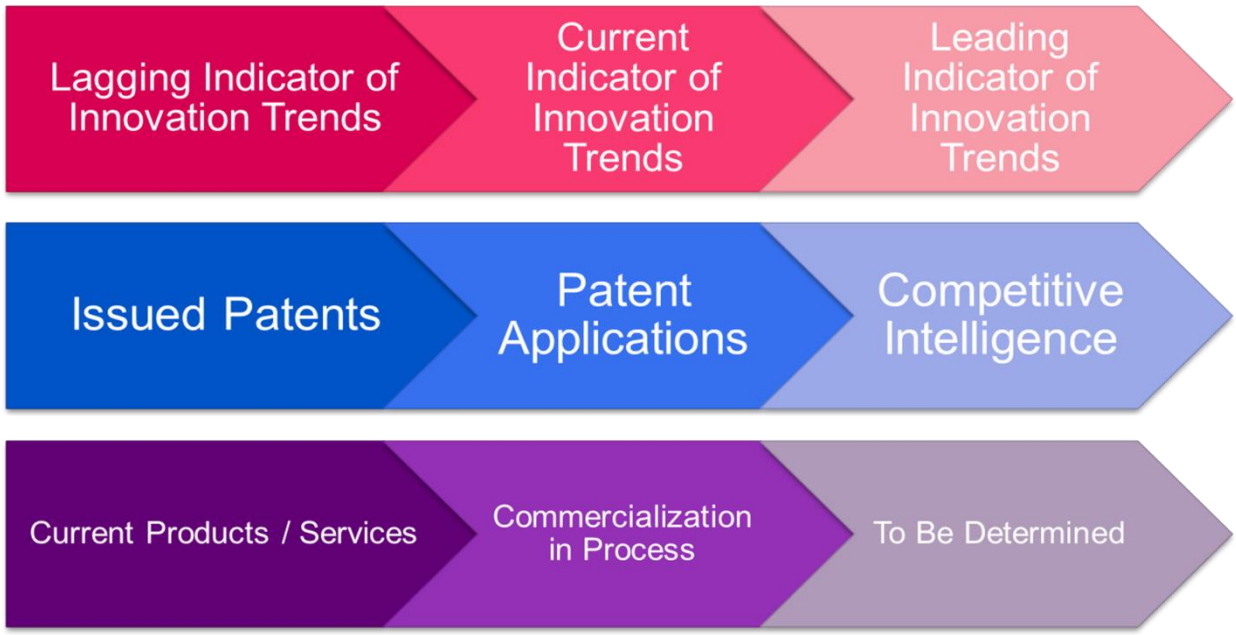
We also offer a comparison of the technology keyword breakdown. It is clear that technology developments have historically been directed towards component reliability, torque / speed control, frequency / voltage regulation, performance optimization and load mitigation, with newer filings directed towards manufacturing, construction and O&M.



1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com



The patent landscape analytics, as well as extensive analysis of forward looking competitive intelligence helps shape our view of future technology trends for the industry.



The following are what we believe to be the emerging trends in wind turbine technology, and therefore patent protection:

- **Component Weight Reduction** (i.e. maintaining tower head mass ratio) – transportation across land and sea of increasingly heavy components

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com

  - Advanced materials such as low cost carbon and hybrid fabrics for blades, graphene-based power electronics and alternatives to rare earth magnet materials.
  - Load mitigation tech / controls, especially incorporation of forward-looking capabilities like LIDAR as well as model based controls and anticipatory controls.

- **Turbine Reliability**
  - Drivetrain / turbine architecture (fewer gearbox stages)
    - Elimination of gearbox - direct drive
  - Simplified electrical component design – solid state power electronics

- **Fleet Management / O&M**
  - Deployment of condition based maintenance solutions (CBMS) with emphasis on:
    - Calculating component damage accumulation
    - Calculating remaining useful component / system life
    - Turbine output optimization based on remaining useful life
    - Trend analysis of SCADA data
    - Predictive maintenance scheduling
    - Spares demand scheduling

- **Performance Optimization** – Optimal energy production regardless of prevailing conditions
  - "Maximum energy, all the time"
  - Site-specific design and assessment tools
  - Derate / Uprate control capabilities
  - Integration of turbine controls with the condition monitoring system (CMS)
  - Blade aero / structural performance – flaps, vortex generators, plasma actuators

- **"Grid Friendly"** – ensuring wind parks operate much like conventional energy plants today, where output can be throttled and grid fluctuations can be absorbed, etc.
  - Medium voltage converters
  - Enhanced low-voltage ride through (LVRT) and VAR support
  - Energy storage for time shifting, black start and grid smoothing
  - Mitigation of grid harmonics and sub-synchronous inductance

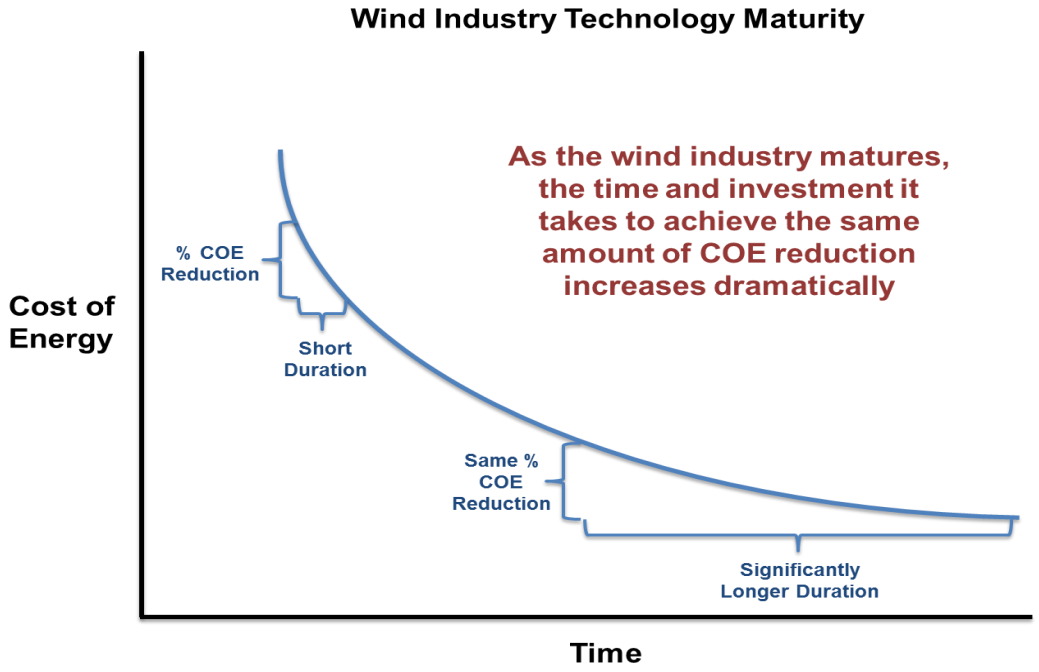
- **Component Size and Transportability**
  - Sectional components such as blades and towers
  - 'Self-erecting' capabilities
  - On-site assembly procedures while maintaining component quality / integrity

- **Offshore**
  - Custom installation vessels and methods
  - Load mitigating foundations – floating, jacket, monopole and gravity base
  - Co-generating foundation structures

The landscape also reveals numerous areas of technology development which have significant potential for reduction in COE, but the technology is facing substantial hurdles to commercialization, such as blade flaps, multi-piece blades, medium-speed gearboxes, remote

1322 Anacapa St
Santa Barbara, CA 93101
Phone: +1-805-405-3947
info@totaro-associates.com

service and inspection technologies, self-erecting towers, and offshore installation methods. To keep reducing COE there will need to be enormous R&D expenditure to get even a 5 - 10% improvement going forward, due to diminishing returns being reached in turbine CapEx.



Also contributing significantly to the commercialization gap are project financiers who do not incentivize the development and introduction of new technologies and products due to associated technical and commercial risks. This leaves turbine OEMs and key component suppliers to vendor-fund prototypes, form JVs, partner with developers / customers or seek external investment, all of which can be expensive propositions.

Whatever the future may actually hold, the promise of clean energy is here. Innovation continues to drive change.

About Totaro & Associates

Totaro & Associates is a market research, patent brokerage, and innovation strategy consulting firm with services tailored to clients' needs under the expert leadership of the company's Founder, CEO and Principal, Philip Totaro. We are regarded worldwide as the foremost experts on wind industry technology and intellectual property matters. We have helped cultivate and disposition over 450 innovations, and our assessments have led to over 250 issued patents. Our strategic market analysis has led to the funding justification of over US$500M in R&D investment and the development of multi-million dollar product and service offerings. We have provided legal and technical due-diligence for over US$1B in M&A. To find out more or get in touch please visit www.totaro-associates.com.