# Triblade Rotor Blades

Lund, Sweden, July 12, 2018


## 1 Executive summary

Rotor blades are causing big problems for wind power industry. They are expensive, they are heavy, and they are made in one piece. Both production and shipping pose significant challenges.

Winfoor has a solution. It is called Triblade and it is a disruptive technology for large scale wind turbine rotor blades. The unique technology lowers the costs for blades dramatically. It makes shipping easy and efficient. Blades become much lighter and they can be made in modules. Looking ahead, Triblade can also spearhead the development of next generation larger and more powerful wind turbines, by allowing for longer blades than today.

It is a game changing technology that can accelerate the transition to greater use of wind power worldwide and give Winfoor a unique opportunity on a global rotor blade market that is projected to reach $33 billion by 2025.

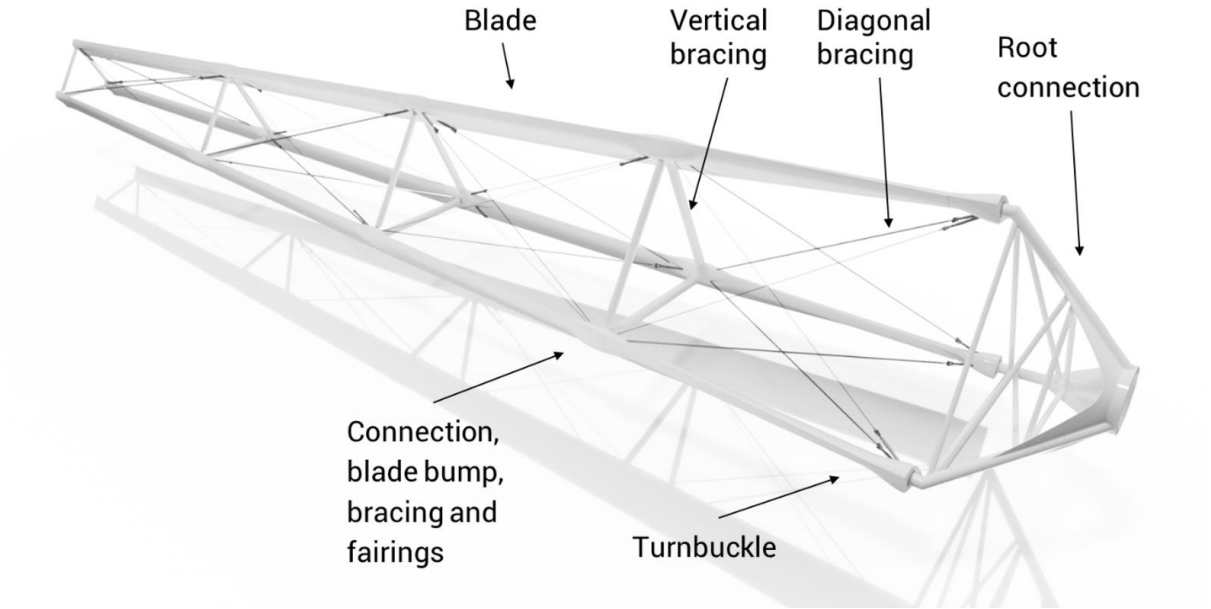
Winfoor is now in the process of raising funds for the final phase of taking Triblade to the market and to reach positive cash flow. We are looking to raise in total €22 million divided in two phases with €14 million, in the first phase, to enter the market through licensing followed by €8 million to set up own production.

We welcome investors of various kinds, such as turbine makers, utility companies, venture capital, and public funding. The plan is to close the financing round in 2018.

The company has so far raised in total €3.2 million for taking Triblade to the market.

# 2 3-in-1-blade technology

Triblade is a 3-in-1 blade. Three slender blades are linked together by supporting structure (bracing) to form a truss (framework). This makes it very stiff and lightweight.




The three slender blades run more or less parallel to each other. They have approximately one third of the chord length (width) of a standard blade, so together they have the same chord length as a standard blade. The three blades are airfoil shaped and are the ones that drive the rotor. The supporting structure is called bracing and it runs between the blades both on the diagonal and perpendicular to the blades. The bracings that run perpendicular to the blades form triangles and are called vertical bracings. All bracings are streamlined to minimize drag. Triblade is rather wide at the end closest to the hub and therefor a transition for connecting it to the hub may be necessary. The transition is called root connection. Pitching of the three blades is done by rotating the entire Triblade in the same way as it is done with conventional blades. The design is similar to old type bi-planes from the early 1900s, where the planes had two wings on each side of the fuselage. While the

bracing introduces some additional drag, the close proximity of the three blades greatly improves the aerodynamic performance, giving Triblade outstanding energy conversion efficiency.

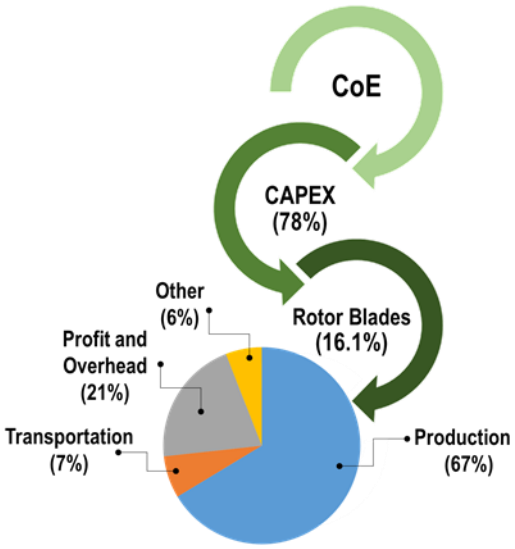
Truss structures are used in a wide range of large-span structures, such as bridges, cranes, roof beams etc. They have an optimal mechanical action since its members are mainly subjected to pure tension or compression, which results in structures having high stiffness and strength. These truss structures can be made of composite materials with very high strength to weight ratio such as glass fiber-reinforced plastic (GFRP) and carbon fiber reinforced plastic (CFRP) resulting in very lightweight large-span structures.

In Triblade the three slender blades are connected to the bracings at certain positions, called joints, to form a truss. Each blade can furthermore be divide along its length into separate blade segments that are connected to each other at these joints. The result is that Triblade can be assembled from smaller parts that are connected at the joints. This makes Triblade perfect for being made in modules. In fact, both production and shipping can be done in modules, dramatically lowering the cost of both. Assembling is done at or near the site of installation. Alternatively, Winfoor can ship Triblade in modules to the turbine maker for later assembly at their facilities. By keeping module sizes below 12m x 2m x 1m we can even ship Triblade easily and efficiently in ordinary containers on standard trains, trucks and ships. This is in stark contrast to standard blade transport that requires special vehicles and very complex and expensive logistical solutions, such as roadworks, shutting down traffic, and taking long detours to avoid bottlenecks in the road network.

Triblade IPR is today protected by four patent families and one design protection. An IPR strategy has been completed in cooperation with Awapatent, who is the leading patent firm in Scandinavia. To ensure a long-term success and to stay ahead of the competition, Winfoor will maintain and expand it IPR portfolio further over time.

# 3 Market needs and trends

Wind power is a fast-growing renewable energy source in Europe, where it is estimated to have accounted for over 10 % of the total electricity production in 2015. It is the second largest renewable energy source after hydro energy and offers the potential to deliver renewable electricity on a scale that would contribute significantly to the 2020 and 2030 EU renewable energy targets. Although it is one of the most cost effective renewable energy sources, it is capital intensive and reducing cost of purchase, installation, transportation and operations of wind turbines is top priority for the industry. Currently, the turbine accounts for the greatest proportion of total capital cost (CAPEX) in both onshore (65-84%) and offshore (30-50%) systems (IRENA, 2012). Furthermore, CAPEX represents 78 % of Cost of Energy (CoE) of wind power. Therefore, wind turbines are the biggest single cost for any wind power project, so it follows that the original equipment manufacturers (OEMs) would have the biggest impact on the CoE. However, OEMs can influence the CoE for wind projects in many other areas like operations and maintenance (OPEX) and maximized energy production for the site.




*Wind power CoE breakdown*

Up to 30% of the cost of a modern large-scale wind turbine is attributed to the rotor blades and up to 60% of that is material cost. Furthermore, blade production is very labor intensive, often engaging large portions of wind turbine makers work force. Rotor blades therefore has the potential to play a vital role in reducing the cost of wind turbines and ultimately CoE.

In order to increase the efficiency, to reduce maintenance cost and to extract more energy from wind turbines the trend is to make wind turbines larger. However, as the length of current rotor blades increase, their cost and weight increase at a faster rate than the turbine's potential power output, making it not economically viable to produce turbines beyond a certain size. At the same time, as blades get longer, they are becoming increasingly more difficult to manufacture and transport. In fact, transportation of heavy and long blades is a major problem setting the limit for land-based wind turbines to around 3 MW.

In fact, the increasing size of wind turbine rotors has resulted in new challenges with regard to manufacturing process (requiring larger moulds and costlier processes), structural integrity and transportation (increase of the cross-sections dimensions and weight). Therefore, it is of great interest to reduce the weight of blades to be able to continue constructing longer blades. Blades are made predominantly of composites, or reinforced plastics – essentially fibers of a stiff material such as glass, carbon or wood – bound together by an epoxy or polyester resin. The two most common material used are GFRP and CFRP, both combining high stiffness with low density and good fatigue resistance. However, and independently of the material used, when blade length increases, stiffness considerations begin to dominate blade design. This issue is especially relevant for blades longer than 60m in order to prevent the blades from deforming or striking the turbine tower. In these cases, extra material to provide stiffness is used, thereby increasing rotor weight, which further complicates design and increase manufacturing and transportation costs.

In summary, our market research shows that

- Reducing total cost of energy is top priority for the wind industry.
- A long-standing trend is that wind turbines get bigger and bigger.
- Up to 30% of the turbine cost is the rotor cost and more than half of that is material cost.

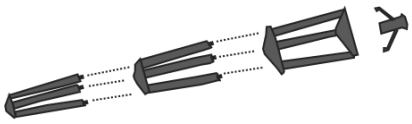
- There are major problems associated with producing and shipping long and heavy blades and these grow of course with the blade length.
- Production of rotor blades is to a large extent manual work.

The result is that the technical and commercial performance of wind turbines is limited by current rotor blade technology. To overcome this problem new design approaches are needed. By introducing a new blade technology that reduces cost of production and shipping, makes blades lighter, is modular, and allows for longer blades, Triblade has the potential to lower the cost of energy and to accelerate the transition to greater use of wind power worldwide.

# 4 Triblade benefits

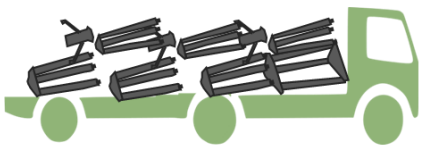
Based on its material composition and structural design, in particular the modularity and truss structure, Triblade can be regarded as a ground-breaking technology, which has several advantages compared to current market offerings. The unique technology lowers the costs for blades dramatically and, in the end, the total cost of wind energy. It makes shipping easy and efficient. Blades become much lighter and they can be made in modules. Looking ahead, Triblade can spearhead the development of next generation larger and more powerful wind turbines, by allowing for longer blades than today. In particular, the modular design lets us optimize both production and transportation and it is considered a key success factor for Triblade.

It is a game changing technology that can accelerate the transition to greater use of wind power worldwide and give Winfoor a unique opportunity on a global rotor blade market.



- Specification
  - **Cheaper** – manufacture and shipping
  - **Modular** – module size below 12x2x1m
  - **Lighter** – up to 80% less material
  - **Longer** – more than 50% longer

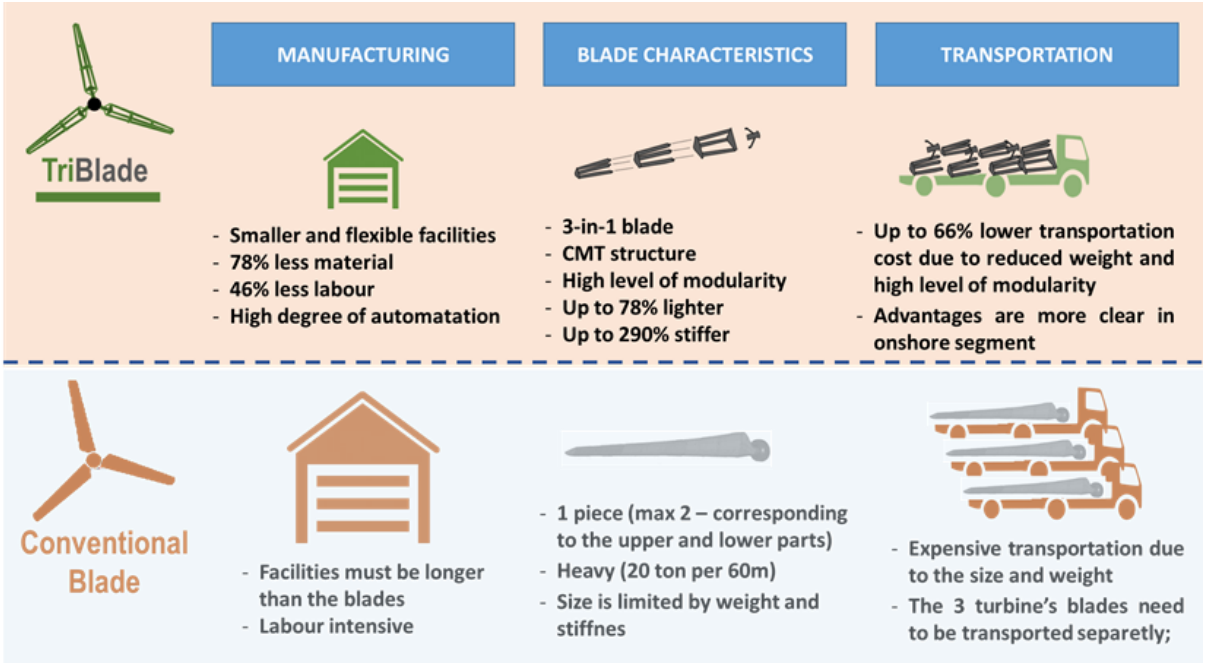
- Manufacturing – 65% lower cost
  - Smaller and flexible facilities
  - High degree of automated production



- Transportation – 65% lower cost
  - Low weight and modular approach reduce cost.
  - Standard trucks and containers
  - Assembling at or near site of installation.

**For manufacturing**, smaller and more flexible production facilities can be used. The production can be highly automated. We estimate that manufacturing costs can be reduced by an astonishing 65%, clearly in line with industry priorities.

**For transportation**, standard trucks and containers can be used to ship Triblade in modules. Assembling is done at or near the site of installation. Shipping costs can also be reduced by 65%.




*Limitations of competing technologies compared with Triblade.*

Using the same material as in standard rotor blades, Triblade will allow rotor blades to be longer (more than 50%), stiffer (up to 290%) and lighter (up to 78%). Furthermore, the reduced costs for production and shipping implies that **Triblade will reduce CoE by 13% - 15.5%**. This level of CoE reduction represents a remarkable improvement, leveraging an entirely new paradigm and outlook for the wind power industry, since typically only a 1-6% reduction of CoE has resulted from earlier major developments in this industry.

Triblade technology is compatible with standard wind turbines. The technology is deemed most suitable for the large-scale wind turbine segment, with blade lengths reaching over 60m. This is the most significant segment within the wind power market and the technology would fit well with standard wind turbines made by the leading manufacturers. The modular design will make it possible to use longer blades for land-based turbine and make it possible to install wind turbines at sites that were earlier inaccessible due to logistics problems.

With the Triblade concept, the wind power industry will be well-positioned to address and offer solutions that meet the market trends and needs mentioned above. The market trends and needs have created a business opportunity that can be addressed by the Triblade concept, giving a strategic and decisive competitive advantage to end-users that adopt the technology.

To sum-up, Triblade project has the potential to significantly alter the economics and scale of wind power, playing an important role in increasing installed base worldwide, driving the next generation of larger and more powerful wind turbines. The new technology is expected to facilitate 20MW wind turbines. By using a single large turbine instead of several smaller ones, OPEX will also be reduced. The introduction of a modular design will allow easier shipping and installation and give access to sites that were previously inaccessible. It reduces shipping costs dramatically and allows for standardized shipping in containers and on ordinary trucks and ships.

# 5 The team

The Winfoor team consists of

- Rikard Berthilsson, CEO, Winfoor
- Rickard Norenstam, Technical project leader
- Kent Persson, Professor in Structural Mechanics, Lund University
- Seven product developers, MSc.

**Rikard Berthilsson** is CEO and founder of Winfoor AB. The Triblade technologic concept was formulated and designed by him. He is also cofounder and former CEO of Cognimatics AB, that employed some 15 people in Sweden and USA. He built and led Cognimatics during a period of 13 years until it was sold to Axis Communications in 2016. At the time of sale, he was the main shareholder of the company. Cognimatics developed software for artificial intelligence technology for surveillance cameras. He is also cofounder and former CEO of Decuma AB that employed some 30 people. Decuma was sold to Zi Corporation in 2004. The company developed technology for hand writing recognition software for hand held devices. At the time of sale, the company supported Western, Chinese, Japanese, Korean and Arabic hand writing. His research interests include applied mathematics, modelling and simulations, energy technology, and mechanics. He has written or co-authored more than 20 scientific papers. He has co-supervised several PhD students, and master thesis students. He was awarded the Chester Carlsson prize from the Swedish Royal Engineering Academy for his work on handwriting recognition. He has extensive experience from managing business development teams and R&D projects.

**Kent Persson** has extensive experience in structural design and analysis in composite materials. Since 2005 Kent have been (sub)project leader for research projects within structural mechanics-related projects with a turnover of approximately €1.5M (this amount is the amount granted to the university and equals also to the amount of which he has been responsible for as project leader). Kent is deeply involved in Triblade, contributing with his management experience and broad knowledge of the wind turbine market, with extensive experience in business development and expertise in structural mechanics of wind turbines.

Throughout the development of Triblade Winfoor has maintained a close cooperation with Lund University and in particular the departments of Structural Mechanics and Fluid Mechanics. This has ensured that the Triblade technology rests on a sound scientific foundation.

To bring Triblade successfully to the market, Winfoor has also formed strategic partnerships with

- **Nordex**: *Nordex is one of the world's leading producers of onshore wind power systems. Our guiding principle is to harness the wind intelligently. This we achieve by never ceasing in our search for new and better technical solutions. Our skills include the development and production of wind turbines, project development and construction of turn-key wind farms as well as maintenance and service.*
- **Marstrom Composite**: *Marstrom Composite is the leading composite manufacturer in Sweden and has expert competence in producing products in composite material, production development and structural mechanics for a broad variety of industries, such as wind turbines, defense, aerospace, marine and automotive. Marstrom Composite has the facilities needed to implement a high degree of automated and streamlined low cost production of Triblade.*

Finally, the reference group includes several of the world leading wind turbine manufacturers and electric utility companies.

# 6 Operational activities

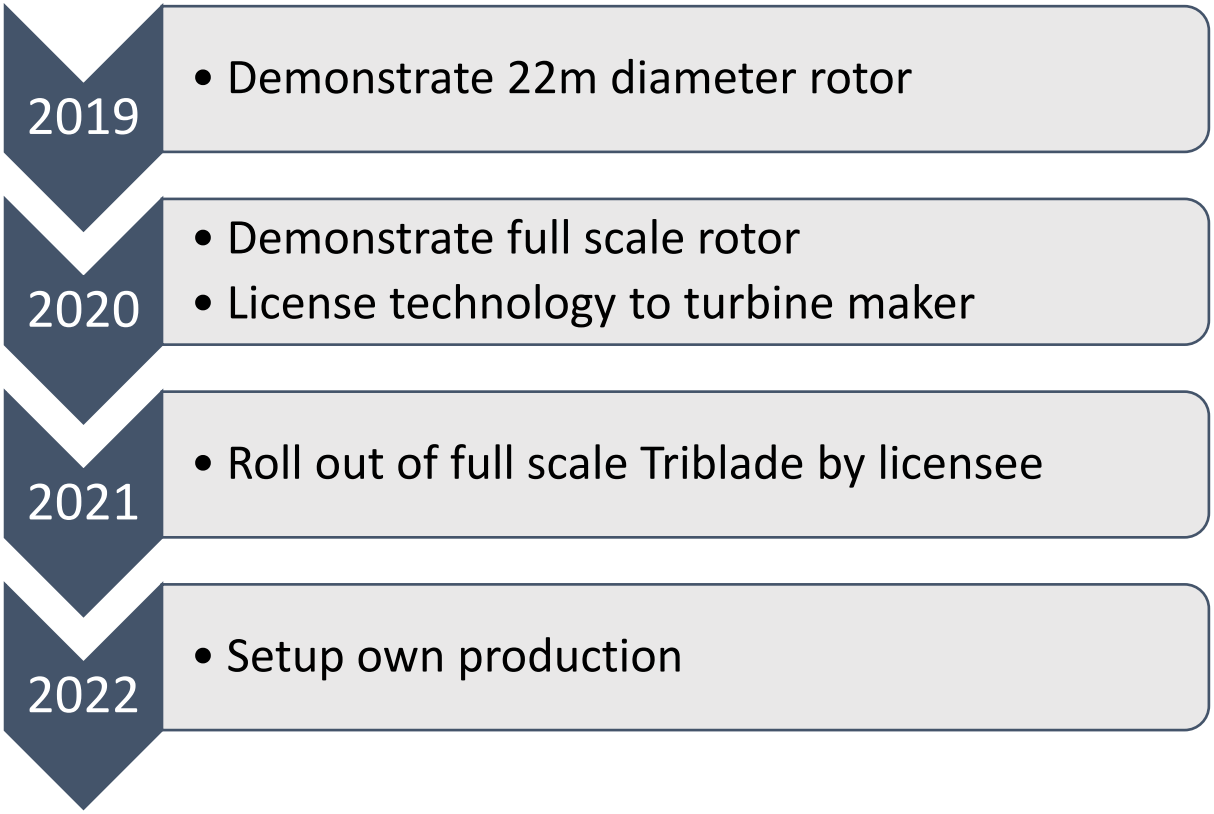
Winfoor has put a lot of effort into research and development for Triblade. The company has done lab testing (in for example wind tunnels) and real-world testing. In 2016 a 7.4m diameter Triblade rotor was demonstrated under real-world conditions on a wind turbine. The results showed that the technology works as expected and that the power output is in line with predicted values.

*Pilot demonstration of a 7.4m diameter Triblade rotor on a test turbine.*

Later this year we will demonstrate a 22m diameter Triblade on a wind turbine. It is three times the size of our first demonstration, but still not full size. The scale up project to a 22m rotor is funded by the EU commission program SME Instrument. It is a two-year project that started in October 2017. Project activities include production scale-up, product and production testing, demonstration and optimization, and preparation for market uptake. The project will finalize the technical development, demonstrate the technology under real-world conditions, and lay the foundation for market uptake. The project is done in cooperation with Marstrom Composite. The reference group includes the utility companies Vattenfall and E.ON. and several leading wind turbine makers such as Nordex and Suzlon. The remaining turbine makers are not mentioned here due to confidentiality reasons.

# 7 Roadmap and go-to-market strategy

Our go-to-market strategy is to start licensing the technology to a selected turbine maker who will roll out Triblade on their turbines. It is a scalable and cost-efficient business model that has global reach. Later on, we will follow up with our own manufacturing. Below is the roadmap.




According to the go-to-market strategy, we intend to enter the market through licensing the technology to a selected turbine maker in 2020. The strategy includes building and demonstrating a full-scale Triblade rotor (over 100m diameter) on a turbine. The full-scale demonstration will be done in cooperation with the turbine maker that will license the technology. By 2022 we will set up our own production.

We need money for the licensing strategy in 2019 and for setting up own production in 2021.

# 8 Financing

The company has so far raised in total €3.2 million for taking Triblade to the market.

Out of this, Winfoor received €2.1 million from the EU Commission (the SME Instrument call) for the scale up project mentioned above. The remaining amount has been raised from the Swedish agencies Vinnova, Mistra and the Swedish Energy Agency.

We are now in the process of raising funds for this final phase of the project. The money will be used to implement the roadmap, to scale up the organization and to reach positive cash flow by 2023.

We are looking to raise in total €22 million divided in two phases

- Phase 1: 2019 – 2021, €14 million to enter the market through licensing.
- Phase 2: 2021 – 2023, €8 million to set up own production.

We welcome investors of various kinds, such as turbine makers, utility companies, venture capital, and public funding.

We would like to close the financing round in 2018.

To summarize, the main benefits of Triblade are low production cost, low shipping cost, easy shipping, and the ability to make longer blades.

# 9 Contact

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