WIND POWER

ANNUAL RESEARCH AND INNOVATION AGENDA 2019

MEGAVIND

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INTRODUCTION

Welcome to Megavind Annual Research and Innovation Agenda 2019.

Megavind - Denmark's national partnership for wind energy representing both industry and research organisations - acts as a catalyst and initiator of a strengthened strategic agenda for research, development and demonstration (RD&D). The Annual Research and Innovation Agendas from Megavind are an annual update of the research and innovation landscape for the Danish wind energy sector. It communicates emerging trends in wind energy RD&D and policies and gives strategic recommendations that are essential to Danish (and European) public and private stakeholders.

In the first annual agenda from 2017, we identified four megatrends influencing the wind energy community globally and we outlined the basic framework for what has now become an ongoing discussion within the sector and with the public funding programmes about the direction of wind energy research and innovation in Denmark.

In the 2018 Annual Research and Innovation Agenda we dug deeper into the framework needed to create a vibrant RD&D ecosystem. Particular focus in the second agenda was on defining five Innovation Drivers and six R&I Themes that were derived from the internal RD&D roadmaps in the industry (see next page).

In this third iteration of the Annual Research and Innovation Agenda, Megavind focuses on the following key priorities for the sector:

1. Production and industrialisation
2. Test and demonstration facilities
3. The right competences
4. The green transition
5. Floating wind power systems
6. Funding

There is a close link between manufacturing on the one hand and research, development and demonstration on the other, because the design of a wind turbine and components must include considerations about efficient manufacturing and end products with high reliability. The efficiency of the various parts of the loop is enhanced when there is a short physical distance between production, test facilities and a competent work force in the various parts of the work process.

0-series production[1], test and competences are 3 essential factors for a thriving national sector. If any of the three legs are weakened: if 0-series production moves out of Denmark, if the home market disappears or test facilities and competences are not available, then the sector will be weaker and less competitive.

1) 0-series production is the final part of the design phase. The production process for the new component is tested to ensure that production is ready for series production and the component can be produced as planned volume- and timewise.

Megatrends

Competitive, industrialised and global industry
Subsidy-free and technology neutral tenders
Integrated energy systems based on distributed generation sources
Digitalisation

Innovation drivers

Increase performance and efficiency
Decrease technical and financial risks
Increase the system value of wind power
Shorten the time to market
Address environmental and regulatory barriers to the market

Research, development and demonstration themes

Any research, development or demonstration project should fit in the matrix below and address these questions

What Megatrend(s)? Which Innovation Driver(s)? Incremental or radical innovation? High or low Technology Readiness Level (TRL) research? Short/long time and budget frame? Where in life cycle phase?

Research, development and demonstration themes	Onshore	Offshore	Floating
1. Wind, waves, soil and siting			
2. Wind turbine technology			
3. Foundations & substructures			
4. Electrical infrastructure & grid integration			
5. Environment & consenting			
6. Logistics & decommissioning			

Supported by human resources and test and demonstration facilities.

The factors described above are the basic requirements for a successful sector and for maintaining the position as leading global wind power hub. But the sector must also address dynamic and potentially game changing topics – and Megavind has zoomed in on 3:

FLOATING WIND POWER: Firstly, the rapid development in floating wind power makes it a central RD&D theme to be addressed. Floating wind power was included in last year's agenda as one of three technology markets, but significant investments in demonstration projects around the world now call for special attention from the Danish wind energy sector.

GREEN TRANSITION: Secondly, the urgent green transition globally reflected in the Paris Agreement on climate change and the ambition to keep increase in global warming below 1.5 °C, locally translated into a pressing Danish goal of reaching 70% CO_2 reduction by 2030 require drastic changes especially in the energy sector and heavy power consuming sectors e.g. agriculture as well as air, sea and road transport. Power2X and storage solutions will take part in paving the way for a green transition.

LEADING RD&D FACILITIES: Thirdly, global competition to attract investments in technology development and RD&D programmes in the renewable energy field has increased dramatically. On a regularly basis, private companies active in the Danish RD&D environment and Danish wind sector are approached by foreign governments, authorities, associations and research facilities to attract investments and local RD&D presence.

In light of the increasing global competition and the urgent climate agenda, the activities described above should be supported by an agile funding system. Denmark has a tradition for thinking across disciplines, thinking in system solutions and for a pragmatic spirit of working together to find the best solutions. Let us use these skills to maintain and develop Denmark as a global hub for wind power systems research and development.

To support the focus areas mentioned above, Megavind recommends five actions. The actions are followed up by three new Megavind strategic initiatives targeting parts of these recommendations.

Megavind recommendations

1 THE GREEN RESEARCH BILLION

Megavind recommends that the Danish government allocates DKK 1 billion for energy research already in 2020 with a prioritised focus on wind energy research on all Technology Readiness Levels (TRL).

2 A CONCERTED EFFORT IN FLOATING WIND ENERGY

Megavind recommends that a strategic, concerted Danish effort in floating wind energy is set up to accelerate and coordinate activities in this area and establish Danish competences in selected areas of floating wind power systems.

3 COMPETENCES FOR THE FUTURE

The sector should start a process to harvest the potential for improved collaboration between industry and universities on matching courses with emerging sector needs and better conditions for student internships.

4 AN INTERNATIONAL WORK FORCE

The industry should have easier access to recruiting foreign competent employees. The legislative barriers preventing the companies accessing the right competences even if these are found internationally should be removed.

5 SUCCESS THROUGH DIVERSITY

The sector should focus on increasing diversity and actively promote “more women in science” as well as encourage social, cultural and competence diversity.

Upcoming strategies

1. Megavind will initiate a mapping of competences in the Danish value chain and deliver recommendations to improve opportunities, conditions and cooperation between companies.
2. Megavind will publish a strategy mapping the need for new Danish test facilities covering both components, turbine and wind farm.
3. Megavind will publish a strategy focusing on grid, storage, Power2X and hybrid solutions.

PRODUCTION AND INDUSTRIALISATION – INDUSTRY STANDARDS

The four megatrends influencing wind energy that Megavind identified in the 2017 Annual Research and Innovation Agenda, set the scene for how the Danish wind power hub needs to adapt to maintain its position. In this 2019 annual agenda, special focus is on the megatrend "a competitive, industrialised and global industry" and the threats and opportunities it presents to Danish companies, in particular the many sub-suppliers to OEMs and utilities.

The long track record in wind power means that there is a detailed knowledge of components and systems in the Danish value chain. This knowledge can be marketed and utilised better both in the interaction with national and global partners and more specifically in an improved interaction with OEMs and utilities. The Danish value chain is in a unique position to find technology and process solutions that are tailored and tested to standard requirements, enabling delivery of unmatched quality and modularised solutions.

Industry standards

The wind energy industry is still relatively young compared to the automotive or aviation industry, but it is "coming of age". A clear sign of this is the discussions on industry standards for components and systems where the specification is not critical to share with competitors. Examples of wind turbine components that could be standardised are yaw gears, tower, bolts and cast iron quality for e.g. hubs. Boat landings for offshore wind turbines, design requirements for monopiles and calculation of cable burial depths are examples of areas outside the wind turbine where companies discuss standard solutions to reduce costs[2].

How does standardisation work?

The term standardisation covers both public standards (IEC, ISO, DS, DIN etc.) as well as standardised products, i.e. an attempt to gain advantages by minimising the number of variants. Public standards often describe requirements for quality and safety. Standards and standardisation can occur from various types of processes:

- De facto standardisation that typically occurs when a market-leading player defines standards and others subsequently use these.
- Industry standards based on cooperation between players in a certain industry or sector without participation from standardisation institutions.
- Public standards managed by international (IEC, ISO), European (EN) and national (DS, DIN) standardisation organisations.

2) Find more examples in the Hot or not list in the Megavind publication on standardisation: https://megavind.winddenmark.dk/standardisation

PHOTO: FIBERLINE

PHOTO: WIND DENMARK

Standards ensure more uniform products that are produced according to a standardised specification and set of requirements. It is a natural proces in a maturing industry and an overall benefit for the value chain but it also involves a risk of altering the competetive position of existing companies.

Exploit the full potential of industry standards

The 2018 Annual Research and Innovation Agenda had the subtitle "exploiting the full potential of wind energy", referring to the potential for further development and continued reduction of costs, thus increasing the value of wind power.

Industry standards are key to continued cost reduction while also ensuring the quality of components and services. Standardisation and industrialisation go hand in hand, and despite concerns from suppliers, the trend is inevitable and needs to be addressed head on.

As a sector, we need to define industry standards that on the one hand minimise the cost of components, improve functionality, increase flexibility, increase reliability and ensure quality in production, while on the other hand, enable sub-suppliers to design and produce these quality products in a fair, transparent and competitive environment.

Experience from other sectors and the ongoing work on standardisation in Megavind[3] show that this requires standardisation that focuses on functional requirements, documentation, validation and performance rather than detailed component specifications from OEMs and utilities.

In essence, as an example it is about describing the size of the hole you want, not the size, colour and material of the drill that is needed to make it. This way the suppliers are set free in the "product development" process to design the best solutions in the competition with other suppliers.

Industry standards will open the innovation space and enable sub-suppliers to position quality products on an international market. This requires research and innovation abilities to design and develop new solutions.

To further address these challenges and opportunities, Megavind has initiated a strategy process that maps the Danish value chain with special focus on supplier positioning and competences. The expected output will be recommendations on how to operationalise these new processes.

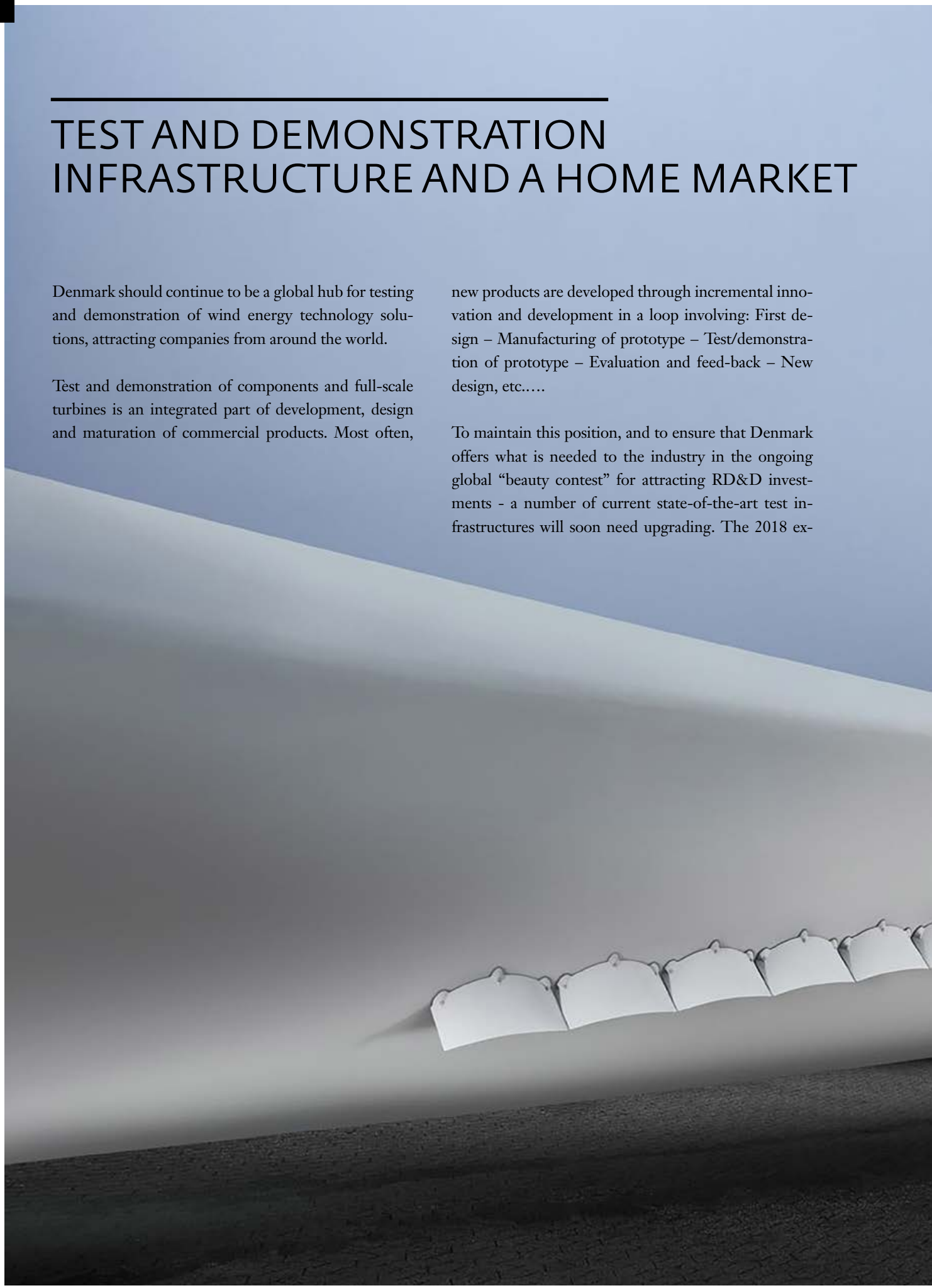
3) https://megavind.winddenmark.dk/standardization

TEST AND DEMONSTRATION INFRASTRUCTURE AND A HOME MARKET

Denmark should continue to be a global hub for testing and demonstration of wind energy technology solutions, attracting companies from around the world.

Test and demonstration of components and full-scale turbines is an integrated part of development, design and maturation of commercial products. Most often, new products are developed through incremental innovation and development in a loop involving: First design – Manufacturing of prototype – Test/demonstration of prototype – Evaluation and feed-back – New design, etc.….

To maintain this position, and to ensure that Denmark offers what is needed to the industry in the ongoing global "beauty contest" for attracting RD&D investments - a number of current state-of-the-art test infrastructures will soon need upgrading. The 2018 ex-



pansion of the national test sites for wind turbines at Høvsøre and Østerild was a critical step, but more prototype and 0-series test sites with flexible installation requirements are needed. Also, the facilities for nacelle and blade testing may need upgrading to accommodate +10 MW turbines. LORC is building the world´s largest nacelle test facility and Blaest has completed a 120 m blade test set up but this may not be sufficient for future needs.

More and bigger test infrastructures are, however, not the only way forward. With the advent of MW turbines, there will also be a need for better modularised and virtual testing in lab or at sub-component level. Call it 'smart testing'. A good example of this is the need for new grid test facilities, where advanced lab-scale test infrastructures is the way to go.

Denmark has been able to attract wind RD&D centers from major wind power companies because of the available know-how and facilities as well as a qualified group of suppliers. But our capabilities are also increasingly built on our position in a strong network of competence hubs in the countries around the North Sea that provide services to the industry and a market at GW scale. It is a position that should not be taken for granted. Therefore, a new strategy specifying the need for "full-scale" facilities is needed.

As a next step, Megavind will initiate an update of the test infrastructure mapping done in 2016[4] to identify gaps, required updates and new possibilities and deliver a report with recommendations for test and demonstration.

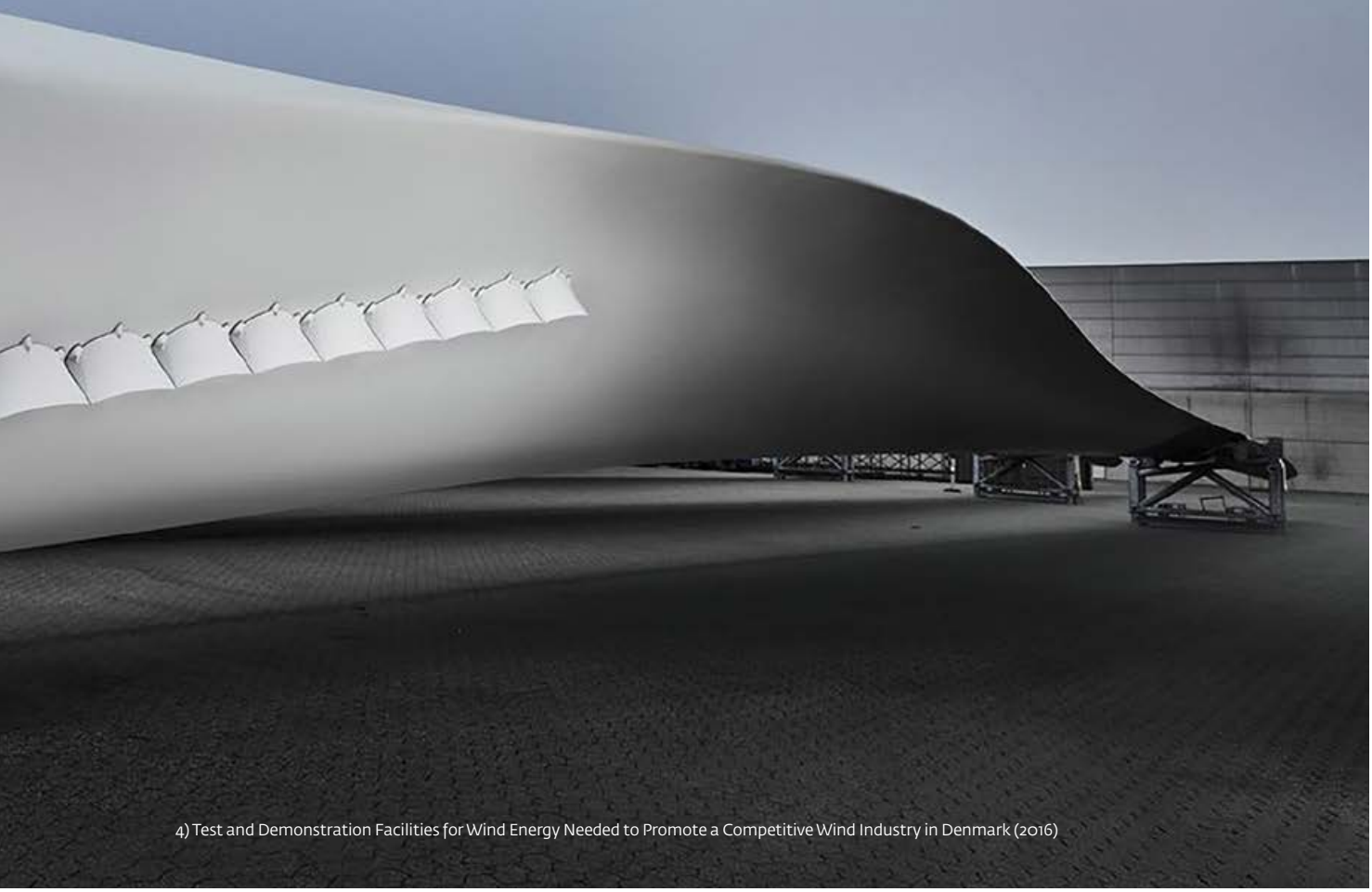


PHOTO: LM WIND POWER

4) Test and Demonstration Facilities for Wind Energy Needed to Promote a Competitive Wind Industry in Denmark (2016)

COMPETENCES

In most modern industries, human resources are the key to success. Therefore, it is critical that the Danish wind industry continuously has access to needed competences and resources and can hire and attract skilled candidates both from other countries and from the universities in Denmark and abroad. Today, the industry is dependent on recruiting employees outside Denmark and a study made by Wind Denmark[5] shows an increasing dependency on employees with an international background from 8% in 2008 to 14% in 2016. These employees are well educated, 67% have an academic education of some sort: 42% hold a master's degree and the rest have a short or medium term academic education.

The same study shows that the share of women in the Danish wind sector has dropped from one in four employees in 2008 to one in five employees in 2016.

A study conducted in 2018 by the Danish Association of Engineers (IDA) concludes that Denmark will need 10,000 Science, Technology, Engineering and Mathematics (STEM) candidates by 2025. The Danish wind industry has an interest in Denmark allowing foreign students close collaboration with Danish universities to ensure that the content of the curriculum is relevant for the industry and attractive for students. The wind industry is global also with respect to recruitment therefore the Danish wind industry sees a lot of benefits from having international students coming to Denmark to study at Danish universities.

Highly qualified engineers are essential to the wind energy industry and its continued development, but the shortage of competences runs deeper than the need for more engineers. Metal workers, welders, mechanics, industry technicians and electricians are all in high demand in a growing sector. Part of the gap will need to be covered by international employees as is already the case, but we also need to improve recruitment from vocation colleges to universities.

Furthermore, the wind energy sector needs a holistic approach to attract, retain and retrain employees. Here the role of universities in creating vibrant educational environments through world class research and innovation should be considered as well. The wind sector also needs to put a special attention on attracting more women employees.

5) Competences in the Wind Industry, May 2019

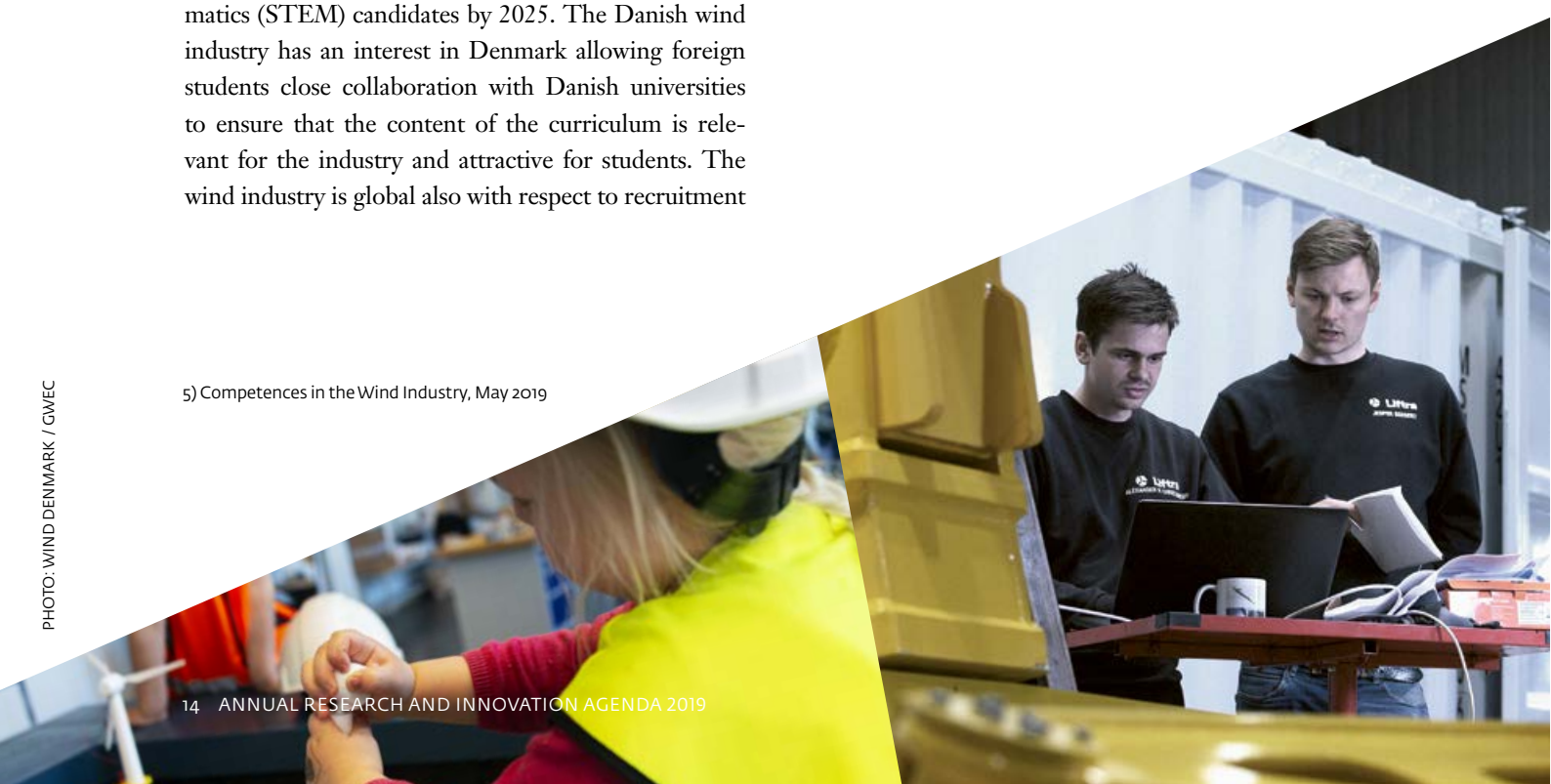


PHOTO: WIND DENMARK / GWEC

Megavind recommendations

1. The industry should have easier access to recruiting skilled foreign employees. The majority of foreign employees are well educated and are in shortage on the Danish labour market. The legislative barriers preventing the companies accessing the right competences even if these are found internationally should be removed.

2. The sector should start a process to harvest the potential for improved collaboration between industry and universities on matching courses with emerging sector needs and better conditions for student internships.

3. The sector should focus on increasing diversity and actively promote "more women in science" as well as encourage social, cultural and competence diversity.

PHOTO: WELCON

4

NEW FRONTIERS AND GAME CHANGERS

The sector has come a very long way in developing a technology that is now one of the key solutions to combat global warming. This position also opens numerous new and challenging opportunities and Megavind has chosen to focus on two of the most apparent in this year's annual agenda – floating wind power systems and the system value of wind energy in the green transition. Both hold the potential of catapulting the market for wind power to a whole new level where the demand for wind energy solutions will increase significantly.

1) Floating wind power systems

One of the most significant developments in recent years is the progress in development of floating foundations for wind turbines. Floating wind power has the potential to open markets in offshore areas where bottom-fixed is not possible. Countries like Japan, US, France, Norway and Portugal etc. with a steep descending seabed all have - or are planning - demonstration projects with different technology solutions.

Ten years ago, most experts in the business saw floating wind energy as far too expensive and only a couple of prototypes were appearing. In a not distant future, the installed capacity of demonstration sites worldwide will exceed 100 MW and a couple of 200 MW projects have recently been announced to be built by 2025 in the Canary Islands and South Korea.

By 2030, global installation of floating wind power could increase significantly. Five to ten years from now, we may well have large commercially driven floating power plants in large markets such as the US, off the European Atlantic coast, the Mediterranean, Far East as well as the North Sea.

Danish companies were first with onshore wind energy and Denmark has led the way for bottom fixed offshore. Danish companies should be part of the future of floating wind energy. Danish and European strategic research programmes were very successful in accelerating wind energy development in the 1990's when the technology was still immature.

Floating wind energy would benefit from a similar approach. The sector needs a holistic understanding of the design of a floating wind power system and the installation and operation of this. A concentrated effort is also needed to innovate and demonstrate new installation processes, O&M on floaters and deep-water monitoring inspections etc. An example of new challenges to be solved is that service vessels can no longer jack-up to change a 100+ tonne component at 150 m because of the water depth, so new processes and vessels must be developed.

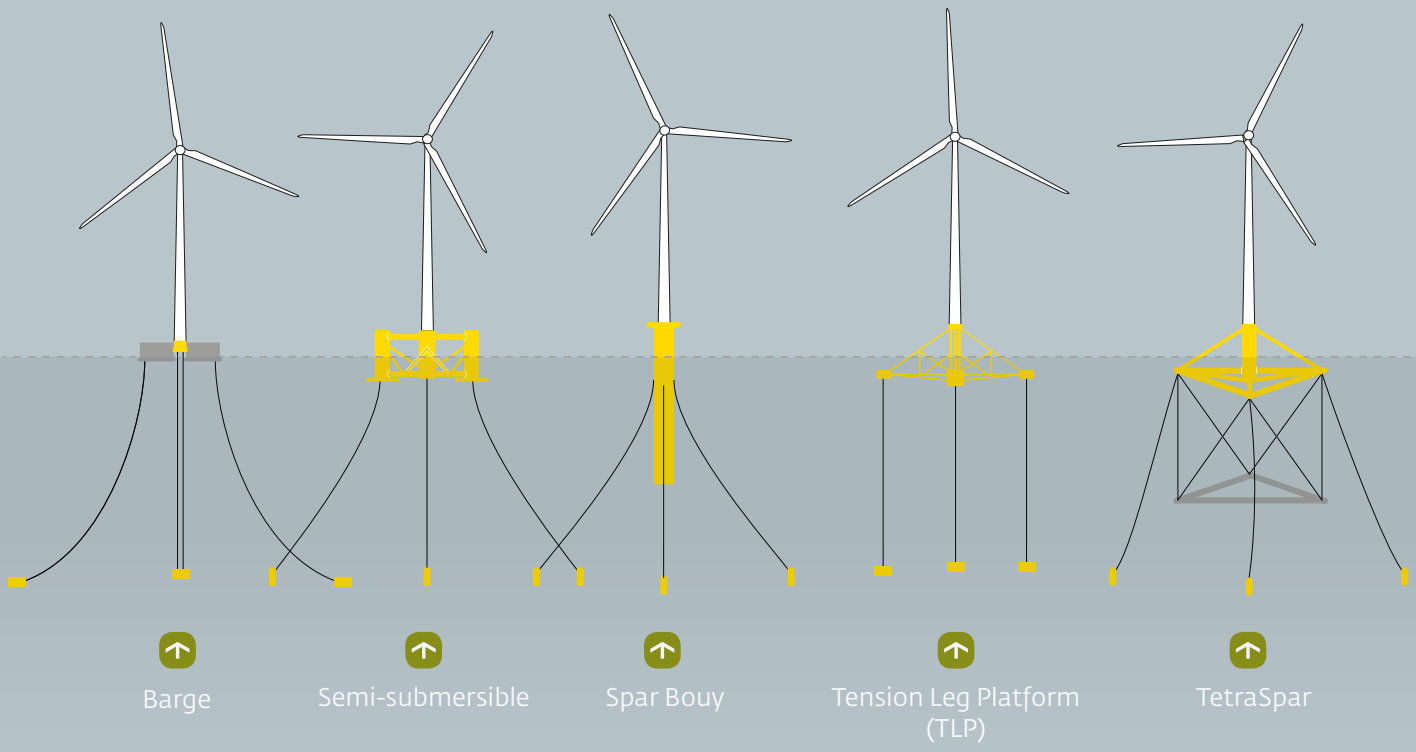
The sector has already initiated RD&D projects, in the form of new calculation models for floating wind power and the Danish floater concept, TetraSpar, that will be mounted with a 3.6 MW turbine off the Norwegian coast in 2020.

This is only a small first step, Megavind recommends that a strategic, concerted Danish efforts in floating wind energy is set up to accelerate and coordinate activities in this area and establish Danish competences in selected areas of floating wind power systems.

2) The green transition – Power2X, integration, electrification and storage

In June 2019, the new Danish government set a target of lowering the Danish CO_2 emission by 70% in 2030 compared to 1990 level. To reach this goal, a radical transition is needed for all sectors. Wind energy is one of the apparent technology solutions with regard to an increased electrification of transport and heating (electrical cars and heat pumps). Dedicated storage facilities are needed that can store energy when there is no wind.

Floating wind power systems



Megavind recommendation

Megavind recommends that a strategic, concerted Danish effort in floating wind energy is set up to accelerate and coordinate activities in this area and establish Danish competences in selected areas of floating wind power systems.

However, powering direct electrification is one way that wind energy can contribute to the green transition.

The significant cost out delivered by the wind energy sector over the last 5 years, means that wind energy is now a valid solution used in electrolyses and pyrolysis processes used to produce hydrogen and by-products like e.g. ammonia and E-fuels for e.g. air traffic. The conversion of electricity to other forms of energy is known as Power2X technologies and it is a crucial element in solving the storage challenge in a fully decarbonised energy system.

The green transition poses unique opportunities for dominant sectors to form cross sector cooperation to demonstrate large scale solutions.

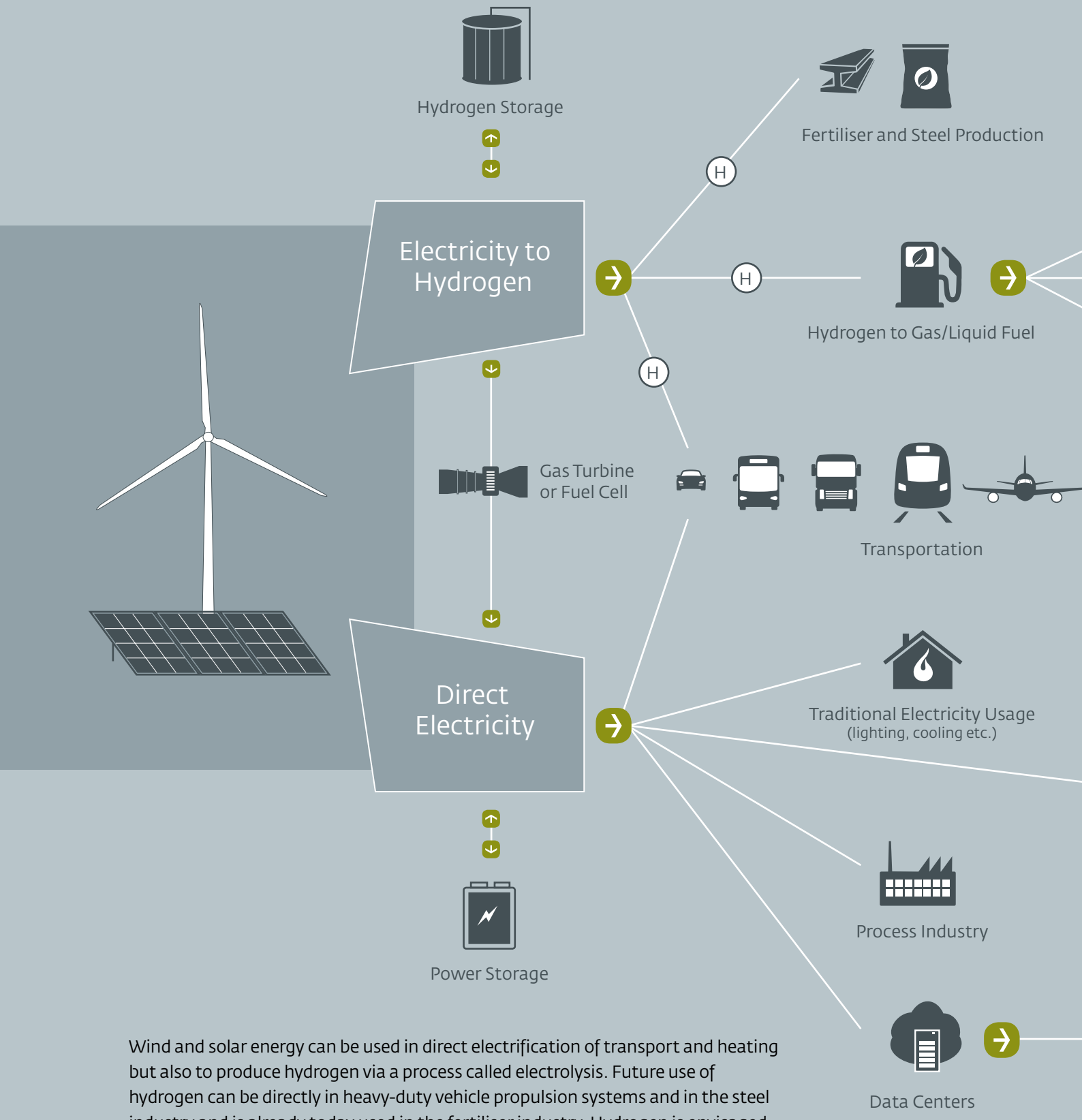
Examples are:

- Shipping sector: Ammonia, liquid hydrocarbons or biofuels can replace marine fuel oil e.g. in cargo shipping.
- Agricultural sector: Ammonia or methanol could replace diesel in large agricultural machines e.g. tractors, harvesters etc.
- Heavy transport sector: Ammonia or methanol could replace diesel in heavy good vehicles, mobile cranes etc.
- Air traffic and agricultural sector: Climate neutral aviation fuel based on straw and slurry from animals
- District heating: Replace thermal generators with heat pumps powered by renewable electricity

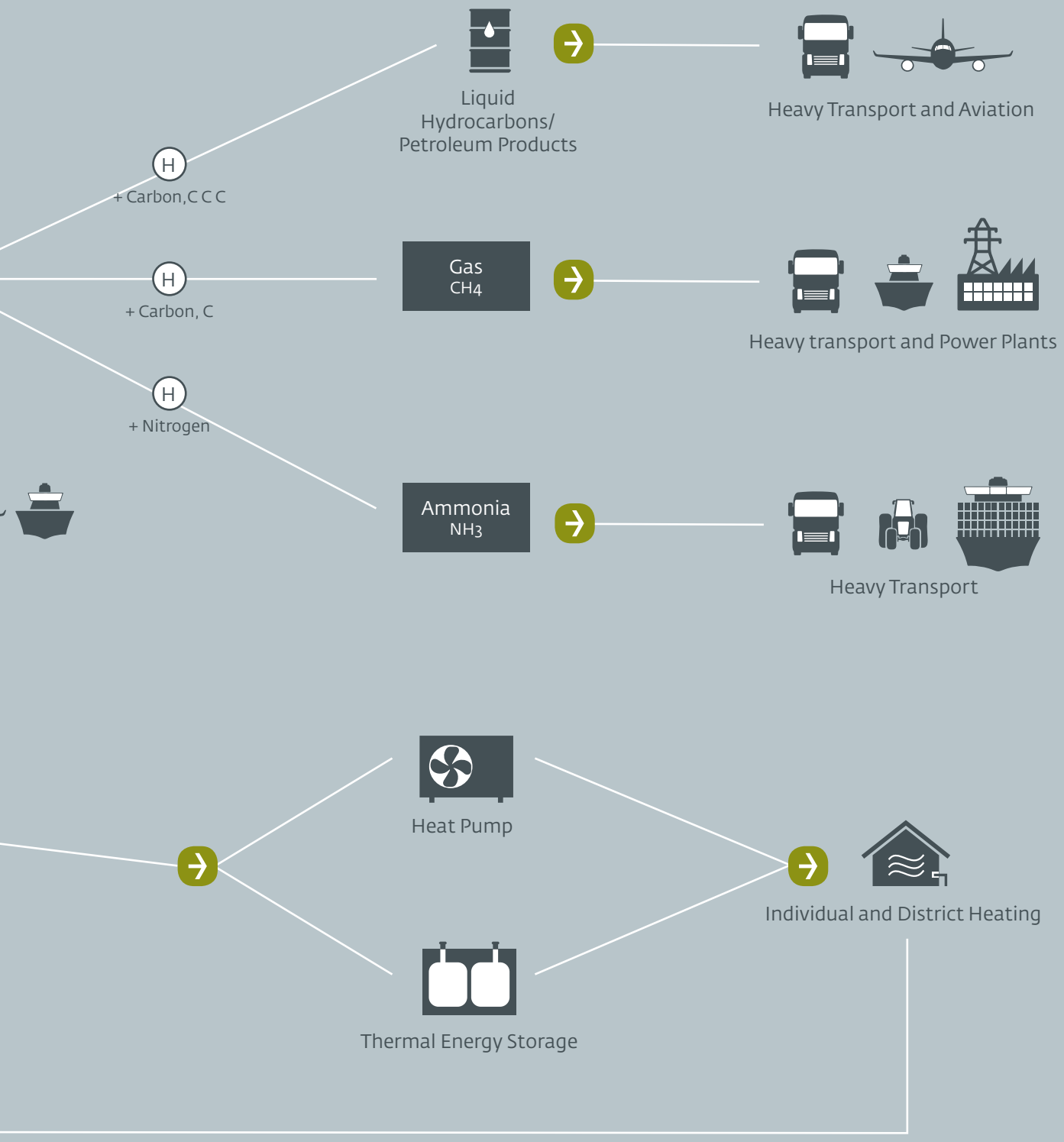
Wind turbine technology can already deliver the power needed for these production processes, but in order to drive down costs of dedicated Power2X production, new prototype, test and demonstration facilities for E-fuel production in both small and larger scale are needed.

Megavind is already looking into these potentials and will publish RD&D recommendations on Power2X.

ELECTRIFICATION



Wind and solar energy can be used in direct electrification of transport and heating but also to produce hydrogen via a process called electrolysis. Future use of hydrogen can be directly in heavy-duty vehicle propulsion systems and in the steel industry and is already today used in the fertiliser industry. Hydrogen is envisaged to be used to produce a variety of gaseous and liquid fuels such as ammonia, methane, methanol or jet fuel to substitute heavy fuel oil, jet fuel and diesel in sectors that are hard to electrify such as shipping, aviation, heavy-duty trucking.


Liquid
Hydrocarbons/
Petroleum Products
Heavy Transport and Aviation
H
+ Carbon,C C C
H
+ Carbon, C
Gas
CH4
Heavy transport and Power Plants
H
+ Nitrogen
Ammonia
NH3
Heavy Transport
Heat Pump
Individual and District Heating
Thermal Energy Storage

5

FUNDING

It is easy in retrospect to draw a straight line showing the development in the size of wind turbines, towers, blades etc. and the decreasing cost of wind energy. The problem is that it narrows our perspective and promotes incremental thinking. The ability of the industry to stay ahead of the LCOE curve to maintain competitiveness is due to the step-by-step improvements through incremental research and innovation. However, the ability of the wind energy sector to exceed expectations to the technological and economic development is also due to capacity in the sector for radical innovation.

Wind energy is a mature technology and the sector has achieved remarkable cost out results over the last 5 years. However, there are still a significant LCOE reduction potentials to be exploited. The bill payed to curb global warming will be significantly smaller if the price of wind energy electricity can be lowered even further and there are still low hanging fruits to be picked on all technology readiness levels in the industry.

In 2018, Germany invested DKK 700m, Holland 228m and Japan 470m in wind energy R&D according to the latest figures from IEA Wind TCP.[6] Holland has doubled its investments compared to 2107. In comparison, Denmark invested DKK 180m. Internationalized Danish companies also benefit from these investments, but as a global wind energy systems RD&D hub, Denmark should not be complacent about the mounting competition to attract companies and competences. Together with the multimillion investments in in-house RD&D and at the Danish research institutions, the Danish public co-funding programmes play a critical role in ensuring a Danish sector standing firm in a global competition on technology development.

The 2018 Annual Research and Innovation Agenda outlined what Megavind sees as the framework for a vibrant research and innovation system. The combination of innovation drivers to assess the impact of RD&D and the R&I themes providing overall guidance for research areas is a good and simple framework for evaluating research.

Innovation drivers and R&I themes should be the general framework for assessing. But in certain areas, Denmark needs to draw on the lessons from the early development of wind power and adapt a more strategic programme-driven approach. Floating wind power systems is a good example of an area where pre-competitive research needs to be brought together in a common framework to improve synergies and enable companies to draw on the advancement of knowledge in their development of new commercial products.

A rapid continuing reduction in LCOE from wind energy will mean that the cost of the green transition based on wind energy generated electricity will be significantly less than if investments are delayed.

In the latest energy agreement from June 2018, the plan is to gradually increase annual government RD&D funding for energy technology from DKK 580m in 2020 to DKK 1 billion in 2024.

Megavind recommends that the Danish government allocates DKK 1 billion for energy research already in 2020 with a prioritised focus on wind energy research on all Technology Readiness Levels (TRL). A part of this investment should be dedicated to a Danish programme or node-based center for research, development and demonstration in floating wind power systems.[7]

6) IEA Wind TCP: The International Energy Agency Wind Technology Collaboration Programme
7) Decentralised organisation with expert competences located at various universities

Megavind recommendation

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PHOTO: DTU WIND ENERGY

MEGAVIND RECOMMENDATIONS

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PHOTO: ØRSTED

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