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Harvest Ocean Energy Based on Airborne Wind Energy Systems

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ABSTRACT

Two thirds of the earth's surface is covered with water. Up to now, the huge amounts of energy available there have mainly been utilized in coastal areas only.

The aim of this work is to show how autonomously operating Airborne Wind Energy Systems (AWES) can make a significant contribution to the global energy supply.

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Introduction
Motivation
Every day, around 200,000 aircraft are on the move worldwide, carrying around 3.3 million passengers. According to the US government, international air traffic consumes more than 1 billion liters of paraffin every day, which equates to around 11,500 liters per second. In 2023, Airbus produced 735 and Boeing 528 aircraft. The economic lifespan can be up to 30 years. This means that the global aircraft fleet will be dependent on paraffin for decades to come. Only with Synthetic Aviation Fuel (SAF) can these aircraft be operated CO_2 neutral.

The aim of this thesis is to present a concept with which these necessary fuel quantities can be produced economically within the next ten years using airborne wind energy systems (AWES) offshore.

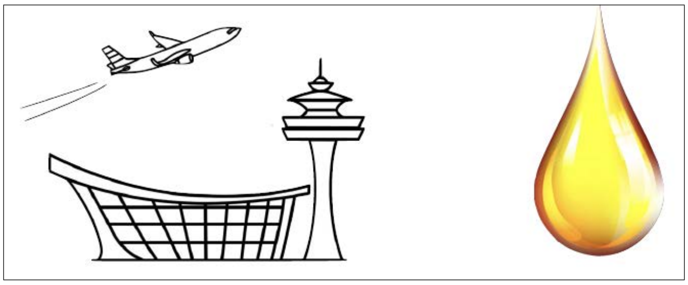


Figure 2.2.1: Synthetic Aviation Fuels (SAF)

The ParCy Harvest Ocean Energy Concept
Airborne Wind Energy Systems (AWES) have been under development for more than 15 years. Although the first systems have already reached market maturity, a market entry in the megawatt range is not yet in sight. One of the reasons for this is the difficulties in the take-off and landing phase. Carrying out this process automatically and reliably under all weather conditions is extremely demanding.

The ParCy Harvest Ocean Energy concept avoids this difficulty by launching the system only once and then allowing it to operate continuously in the air for a period of 5 -10 years. This is only possible because it can sail autonomously and freely on the world's oceans.

Optimum routes are calculated in central control centers on the basis of ten days active weather forecasts. These avoid weak and strong wind regions. The systems can thus always produce energy under optimal weather conditions with the best efficiency.

This requires underwater units that act as a balancing force for the kites and convert the electrical energy generated into hydrogen.

Autonomous refueling units transport the hydrogen produced to central supply vessels where it is further processed into synthetic fuel (SAF).

Kite Systems
Overview of possible Kite Systems
In principle, almost all kite systems available today can be used for the ParCy Harvest Ocean Energy concept.

There is strong cost competition in the energy sector. Solar power plants in Saudi Arabia are able to produce electricity for 1.1 cent per kilowatt hour. In future, airborne wind energy systems must also be able to produce electricity at this price. This extreme cost pressure has not been taken into account in the development of most AWES. They are not designed for automated series production and will be correspondingly expensive to manufacture.

In this paper we will investigate two systems that we believe can compete with other renewable energy sources.

As they are based on different principles, the underwater units must be adapted to the specific requirements of the systems.

Multi Wing Kite The wing concept proposed by the ParCy Group is based on an extruded polycarbonate wing. It is a lightweight construction that can produce a cost-effective wing from a small amount of material at high speed.

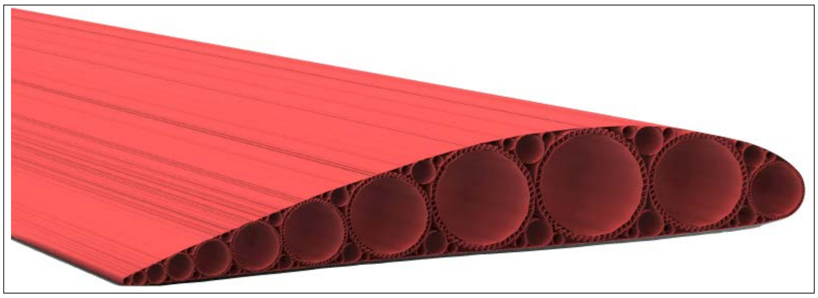
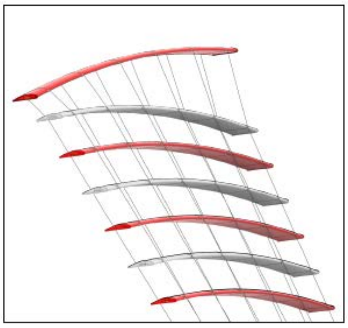


Figure 2.2.1: Extruded polycarbonate wing profile Foto: ParCy.Group

In offshore production facilities, they are to be assembled into a kite system immediately after manufacture. Only the top wing is used to control the entire system.



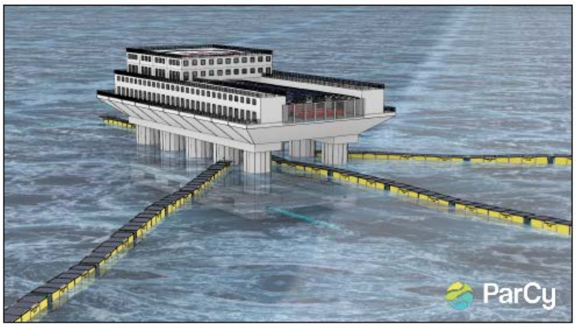


Figure 2.2.2: Multi Kite System **Figure 2.2.3:** Production Facility Foto: ParCy.Group

Rotation Kite
This very filigree-looking design principle has perhaps the greatest economic potential because it can generate an efficient rotational movement with a minimum amount of material.

Figure 2.3.1: Rotation Kite Foto: https://someawe.org

This photo shows a rotation kite with a holding kite [1]. Parallel to this development, there are considerations about using adjustable rotor blades, which could make the system more efficient. Daniel Unterweger from the University of Freiburg has been working on this [2].

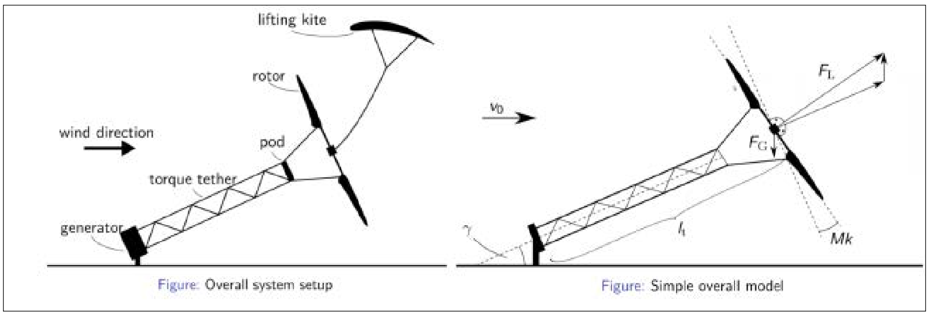


Figure 2.3.2: https://videoportal.uni-freiburg.de/video/Cyclic-Pitch-Control-of-a-Rotary-Kite-by-Daniel-Unterweger-/309653db6a29a6a97106238678f40514

Roderick Read from Windswept works on the same principle but with a slightly different design. Further research is needed to determine which approach is more suitable [3].

Figure 2.3.3: Roderick Read https://www.windswept.energy/technology

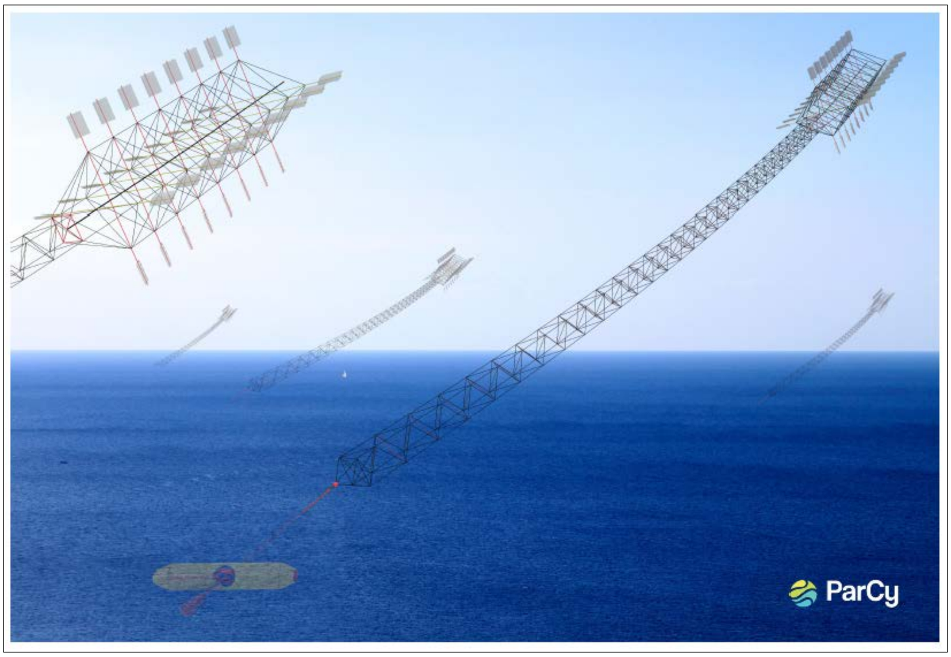


Figure 2.3.4: Rotation Kite Farm with Underwater Units Foto:: ParCy.Group

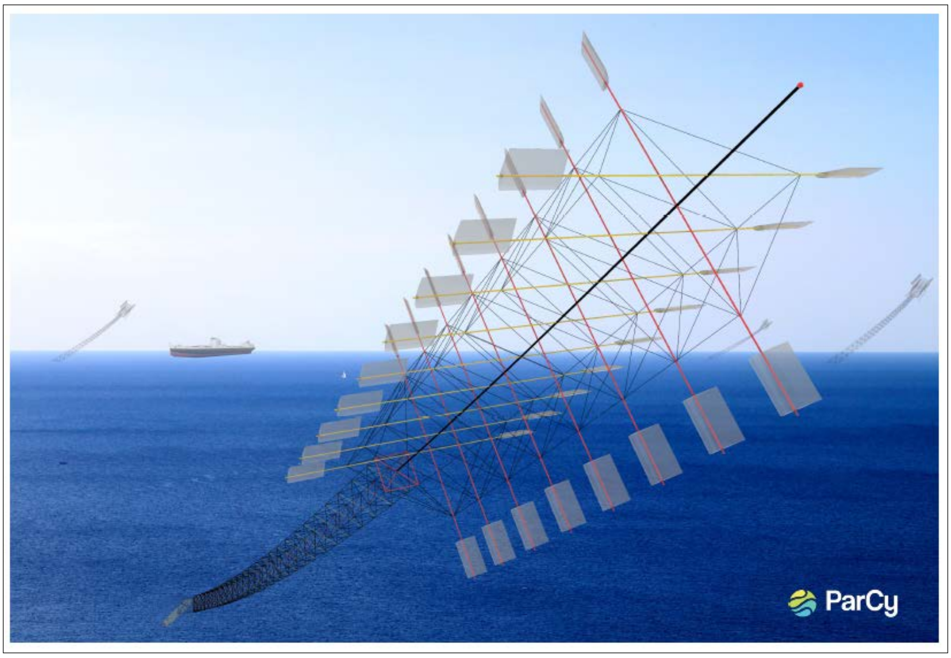


Figure 2.3.5: Rotation Kite with Adjustable Rotor Blades Foto: ParCy.Group

Production Plants

Floating Offshore Platform for Multi-Wing Kite Systems

Favorable energy costs can only be achieved with efficient production methods.

Design, materials, labour costs, automation, longevity and location costs are just some of the factors that are decisive for competitiveness with other forms of energy. For AWES that are still at an early stage of development, it is helpful to include these considerations in the planning.

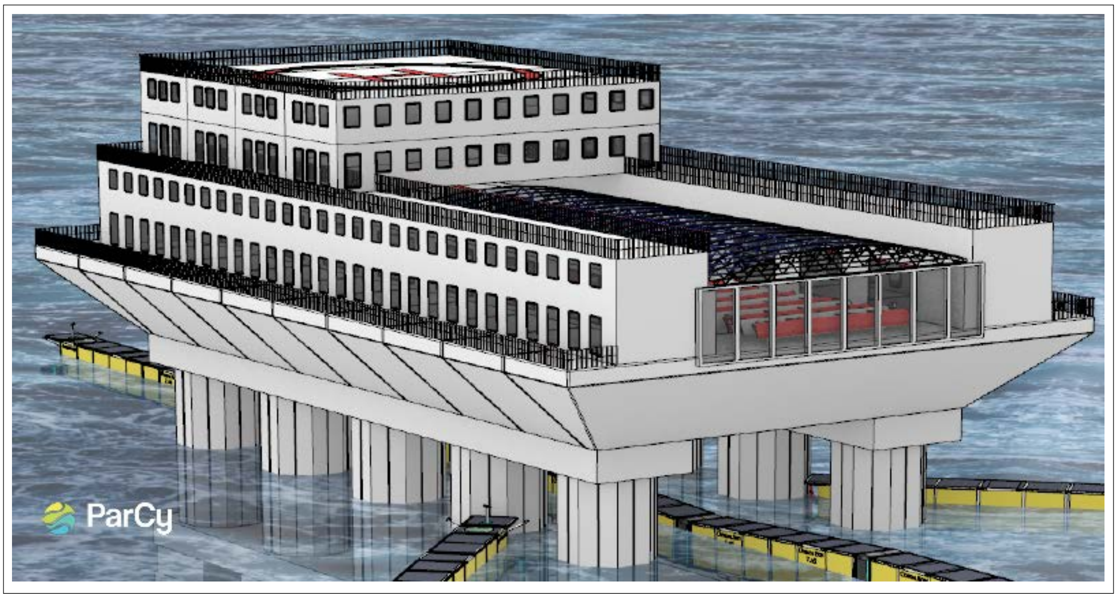


Figure 3.1.1: Production Plant Concept for Multi-Wing Kite Systems Foto: ParCy.Group

Extruders for the sash profiles are located in the side parts of the building. The system is assembled in the centre section. The roof construction can then be opened and fans are used to generate a powerful wind current that carries the kite system into the air. When connected to the underwater unit, it is expected to operate autonomously for 5-10 years without maintenance and produce 1 MW/h of power in the form of hydrogen.

The extruders have a production speed of around 1 m/min. This means that 120 meters can be produced in 1 hour. With a width of 2.50 meters, this is 300 m². We assume that it should be possible to start a system every 4 hours.

The targeted annual production of 2,000 systems is roughly equivalent to the energy output of two nuclear power stations.

Floating Offshore Platform for Rotary Kite Systems

An annual production target of 2,000 units is also being set for the *Rotation Kites*. It is a floating tower that operates in temperate regions, such as the Mediterranean, where the waves are not so high. A system should also be launched every 4 hours and the tower must be turned into the wind for this. Partial automation is planned. The uppermost wings are mounted on the ground first and then pulled upwards piece by piece until the total length of around 250 meters is reached. It is then connected to the *Underwater* Unit and the crane moves it out of the tower. The generators or electric motors of the *Underwater Unit* rotate the system. When the wind forces are sufficient, the assembly rope is released and the *Rotation Kite* remains in the air until the end of its service life. It is an ambitious goal to build such a production facility, but compared to a nuclear power plant, which costs around €10 billion, it seems realistic. Especially as the installed systems produce around 2,000 MW of electricity per year.

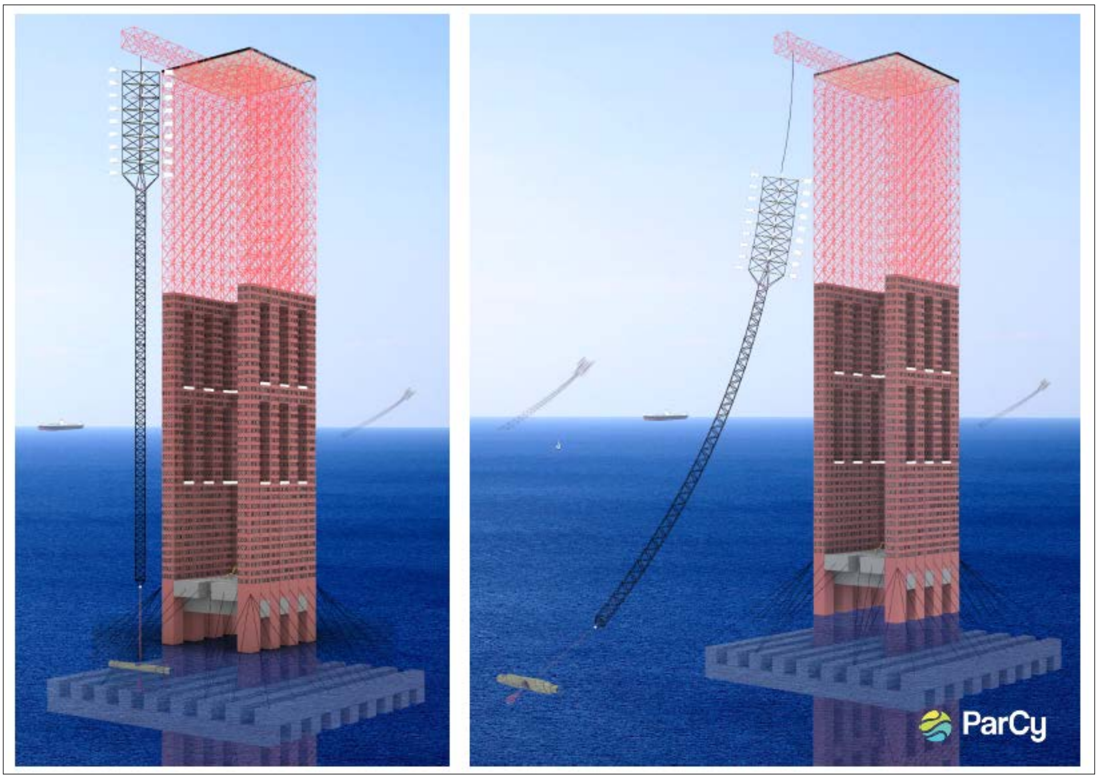


Figure 3.1.1: Production Plant Concept for Multi-Wing Kite Systems Foto: ParCy.Group

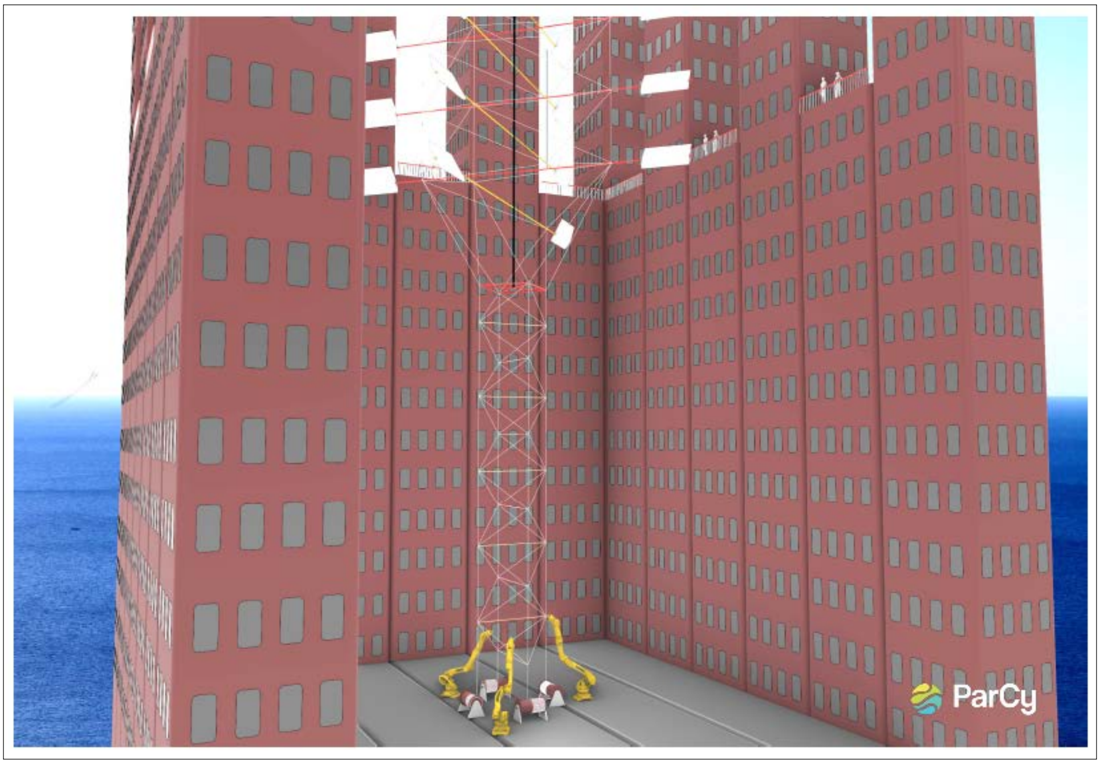


Figure 3.1.1: Production Plant Concept for Multi-Wing Kite Systems Foto: ParCy.Group

Underwater Unit for Hydrogen Production

System Variants for Multi Wing Kite

The two variants have different operating principles. The Multi Wing Kite is connected to the *Underwater Unit* via a rope. Only tractive forces that pull the *Underwater Unit* through the oceans can be transmitted. A relatively high speed is required so that the turbines can produce sufficient power. The water resistance of the unit reduces the overall efficiency of the system. However, the high speed makes it easier to reach the areas where the optimum wind speeds prevail.

Figure 4.1.1: Underwater Unit for Multi Wing Kite Foto: ParCy.Group

System Variants for Rotation Kite

For rotary kite systems, the Underwater Unit must have a high water resistance. The rotation is converted into electricity in generators and into H_2 in electrolysers.

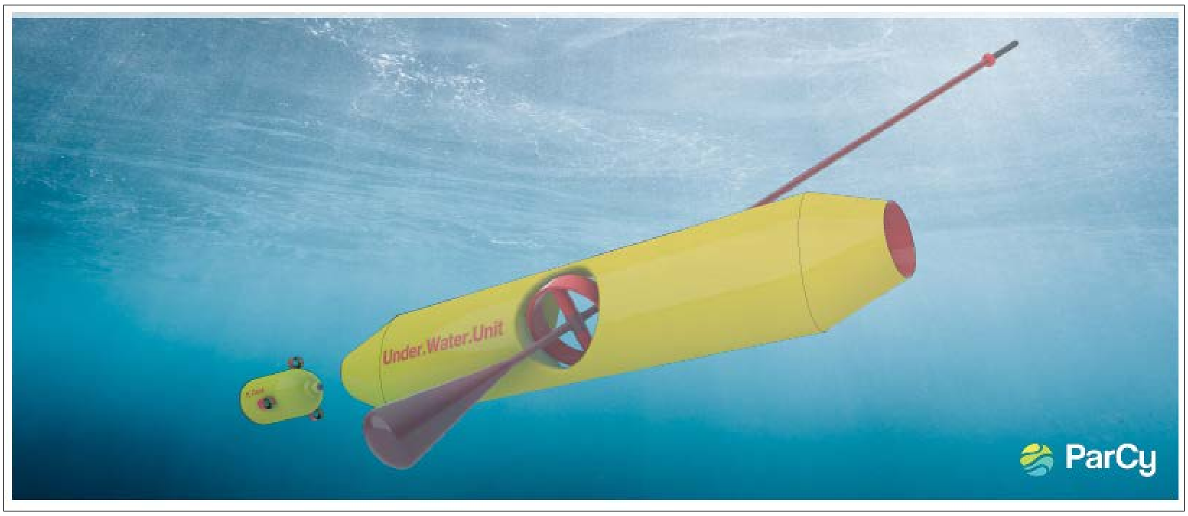


Figure 4.1.1: Underwater Unit for Rotation Kite Foto: ParCy.Group

AEM Electrolysis

Enapter produces large quantities of small electrolysers that are assembled into large systems. This approach makes it possible to develop systems for different requirements [4]. The air cooling system seen on the roof would be replaced by a more efficient water cooling system in the *underwater* unit proposed by the ParCy.Group.

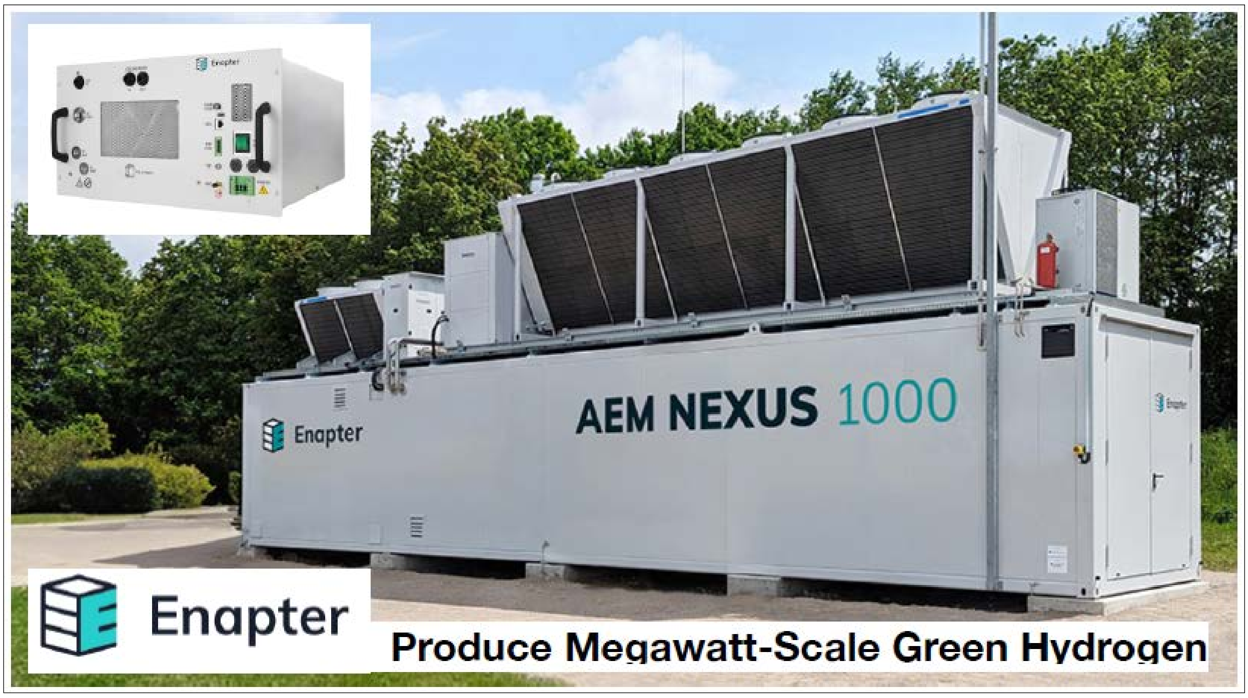


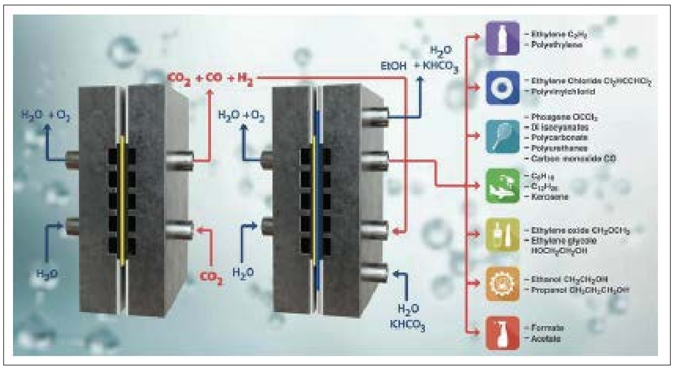
Figure 4.3.1: https://www.enapter.com/aem-electrolysers/aem-nexus/ Foto Enapter

Favourable Nickel-Electrode Electrolyser
The project, led by Prof. Dr Enno Wagner, Professor of Mechatronic Design and Technical Mechanics at the Frankfurt University of Applied Sciences (Frankfurt UAS), is developing electrolysis systems that work with electrodes that do not require expensive and rare precious metals [5].

https://www.frankfurt-university.de/de/news/n-frankfurt-uas-aktuelles/wasserstoff-produktion-in-der-heimischen-garage-1/

Tandem Electrolyser
The TU Berlin has developed a promising tandem electrolyzer. These processes could be used to realize chemical conversion processes more easily [6]. However, it has not yet reached market maturity.

https://www.tu.berlin/ueber-die-tu-berlin/profil/pressemitteilungen-nachrichten/co2-als-nachhaltiger-rohstoff



Most Efficient Hydrogen System
The company Hysata now promises the commercial production of the world's cheapest hydrogen [7]. With an efficiency of 95% and favourable production costs for electrolysis, it is taking the widespread use of hydrogen a big step forward.

Hysata

https://hysata.com/news/hysata-announces-111m-usd-series-b-investment-round/

Seawater Desalination
Fortunately, there has been intensive research and development work on hydrogen production in recent years [8].

At the University of Adelaide's Professor Shizhang Qiao and Associate Professor Yao Zheng from the School of Chemical Engineering, for example, they have succeeded in producing hydrogen directly from seawater without desalination.

(https://www.adelaide.edu.au/newsroom/news/list/2023/01/30/seawater-split-to-produce-green-hydrogen)

As an alternative to this method, small desalination systems for boats have been available for many decades that work very reliably and cost-effectively.

Hydrogen Transport with Underwater Tanks

Transporting hydrogen is a very challenging topic. Whether in pipelines, in solids, cooled or under high pressure, all these methods are cost-intensive.

For the concept presented here, we propose autonomous high-pressure tanks which, like small submarines, transport the hydrogen from the underwater units to the accompanying ship. They are equipped with batteries and three electric propellers, which also take over the pre-steering function.

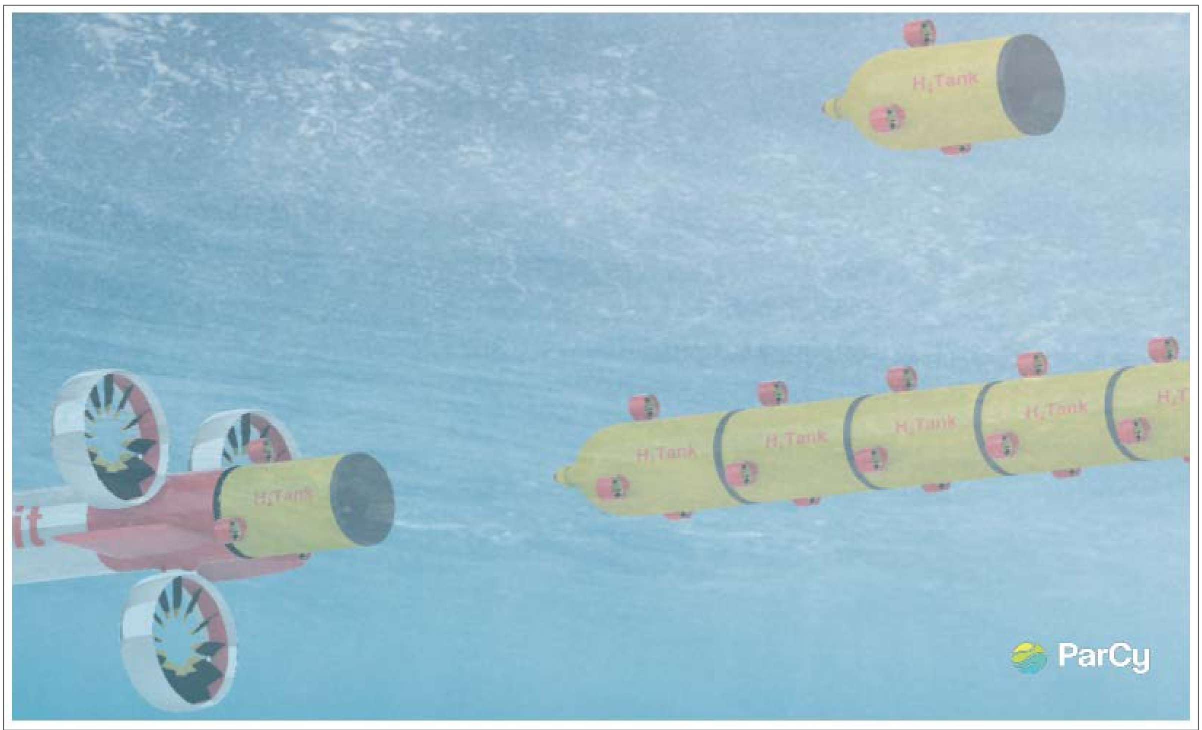


Figure 4.4.1: Autonomously Operating Hydrogen Tank Foto: ParCy.Group

Independently Operating AWE-Farms

Weather Forecast and AI-Supported Route Planning

Without the precise weather forecasts available today, the ParCy Harvest Ocean Energy concept would not be possible. Based on long-term forecasts, it is possible to calculate optimum routes for the airborne wind energy farms. Weak wind and strong wind regions are avoided. This allows the kite systems to fly for years without interruption and produce energy
with optimum efficiency.

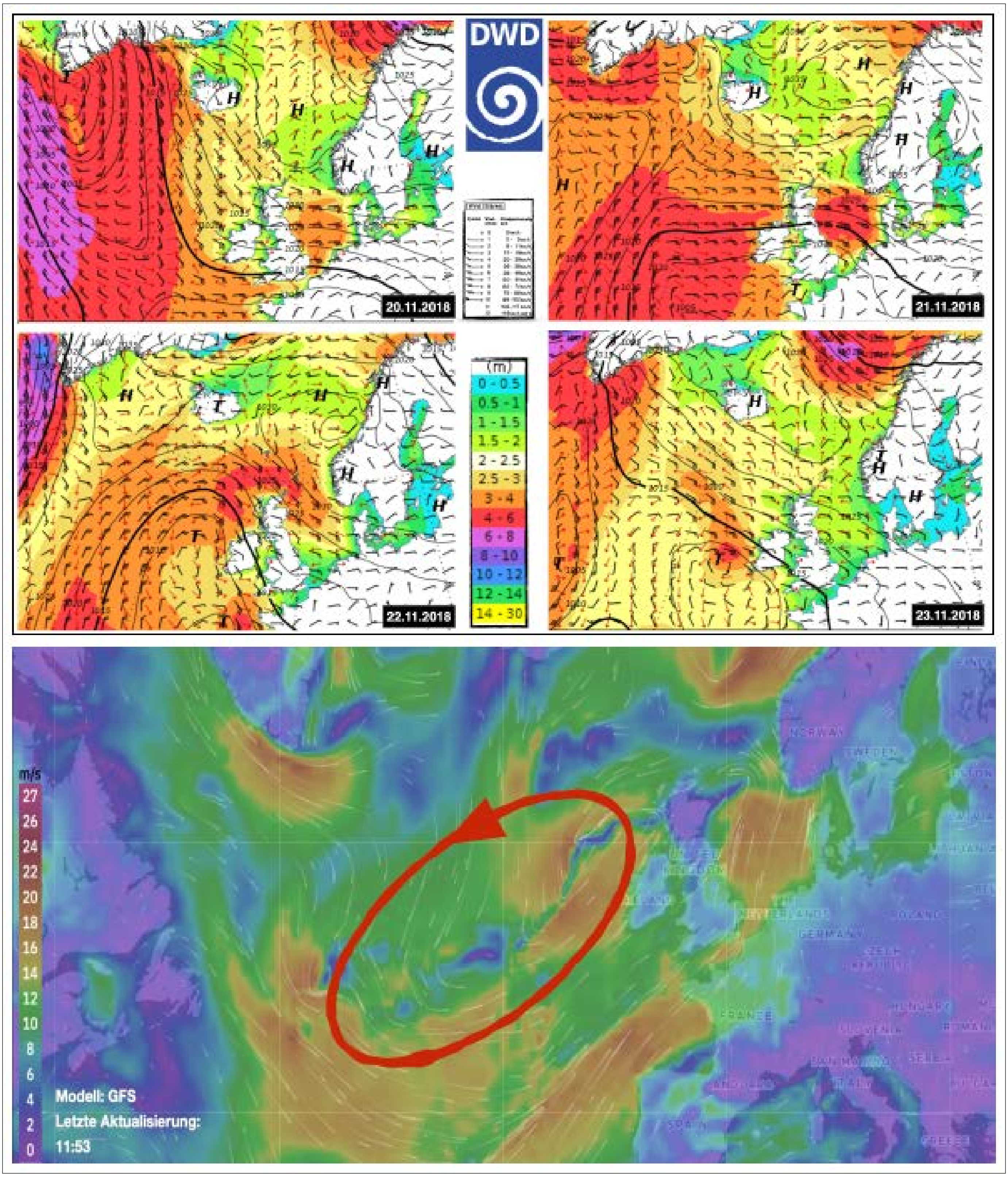


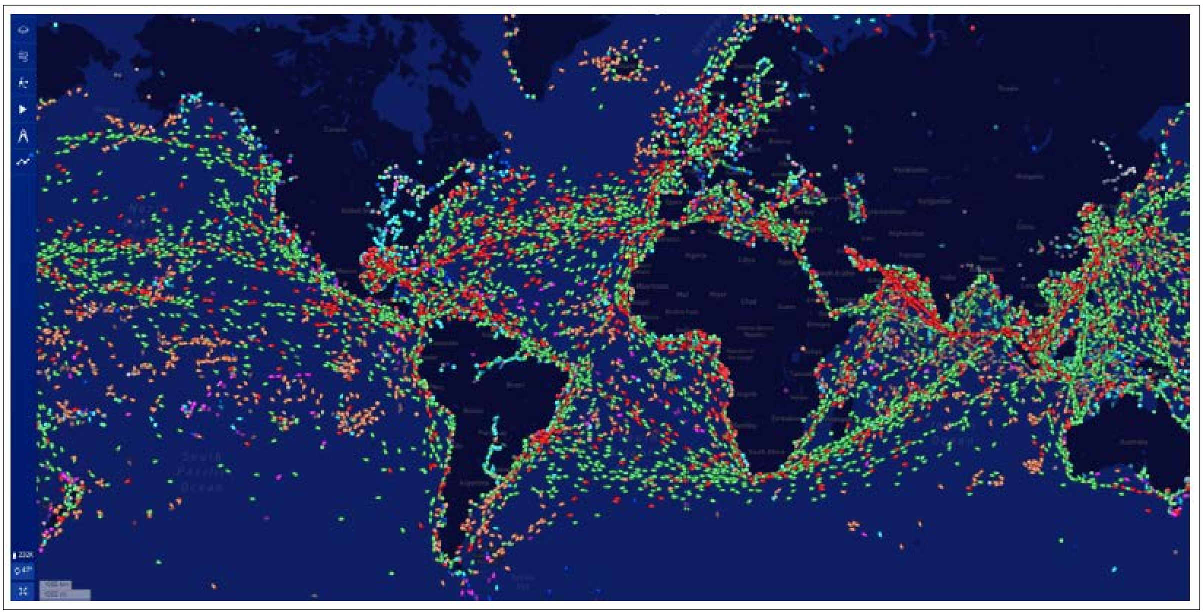
Figure 4.4.1: Weather Forecast Foto: Deutscher Wetterdienst

Management and Control of AWE-Farms

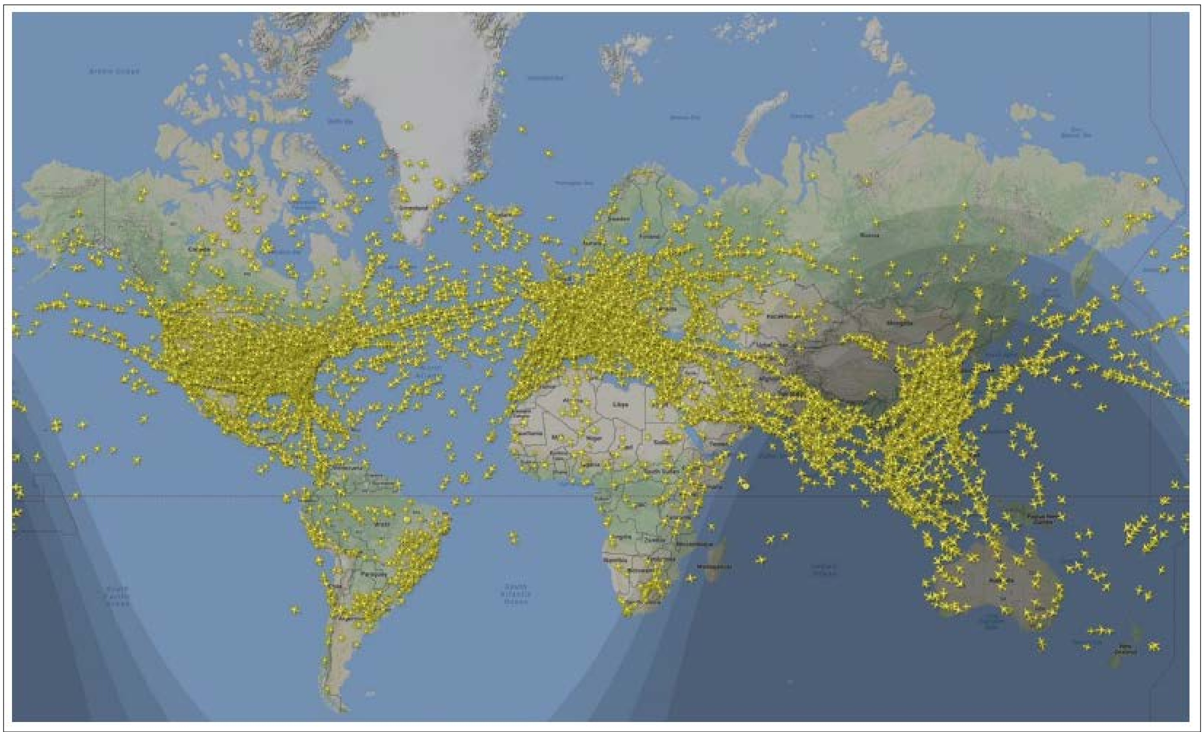
Fossil energy sources must be replaced by renewable, generated energy. The Harvest Ocean Energy concept shows how large quantities can be produced. The oceans offer the space to operate millions of systems there.

This requires control centers in which the systems are monitored and controlled using intelligent software.

Just as anyone can track the position of ships and aeroplanes online today, it will also be possible to control the autonomously operating AWE farms.



https://www.marinetraffic.com/blog/wp-content/uploads/2022/02/MarineTraffic_Ship-Tracking-Definition-1920x1080.png



https://www.reisereporter.de/reisenews/tracker-misst-rekordtag-im-flugverkehr-200-000-flieger-in-der-luft-ZKVCGHHFNAI67ZD3DVBA4NUJ7Q.html

Support Vessel with Synthetic Aviation Fuel Production
Synthetic Aviation Fuel (SAF) Production
The market demand for sustainable aviation fuel is high. Because only with SAF is it possible to reduce CO_2 emissions in aviation in the short term.

Sustainable Aviation Fuel (SAF) is a key element in reducing CO_2 emissions and defossilising aviation worldwide. The EU has included the increased use of SAF in its plans for a climate-neutral Europe by 2050. Part of these plans is the ReFuelEU Aviation initiative [9].

(https://www.consilium.europa.eu/de/press/press-releases/2023/10/09/refueleu-aviation-initiative-council-adopts-new-law-to-decarbonise-the-aviation-sector).

It regulates a SAF blending requirement for fuels supplied to EU airports. The plan is to gradually increase the minimum proportion of sustainable aviation fuel: from 2 % in 2025 to 6 % in 2030 and up to 70 % in 2050.

For investments, this legal requirement is a solid basis for calculation.

Sustainable Aviation Fuel (SAF) can be produced in different ways. For this concept, we believe that production from regeneratively produced hydrogen and CO_2 makes the most sense. We propose burning waste and filtering the CO_2 out of the flue gases.

What are the arguments in favor of this approach?

CO_2 could also be filtered out of the air, but this is very energy-intensive. Another option is to transport it by ship from land to the AWE farms.

To do this, the CO_2 would have to be liquefied. Cooling it down to -35° again requires additional energy and special ships are needed.

It is much easier to transport waste, especially as this could reduce the pollution of large parts of the world. For example, a market for substitute fuels made from waste could be created in Africa. This would create an incentive to collect and process waste (preferably plastic waste).

Figure 6.1.1: Plastic Waste on a Beach in Ghana dpa
https://media1.faz.net/ppmedia/w1240/aktuell/1259364351/1.9086807/1900x850/plastikmuell-kennt-keine.jpg.webp

Substitute fuels have a calorific value comparable to that of coal. The energy produced during combustion can be used to supply the chemical conversion process to SAF with additional energy.

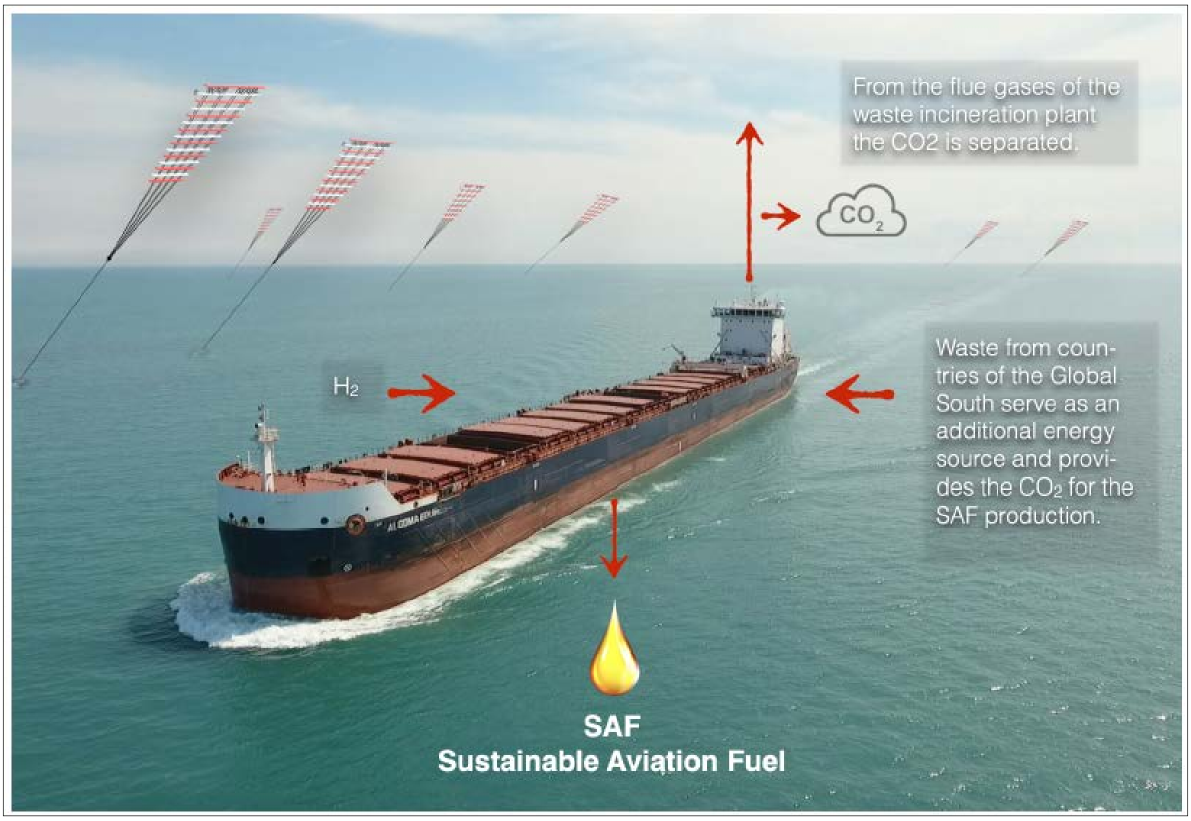
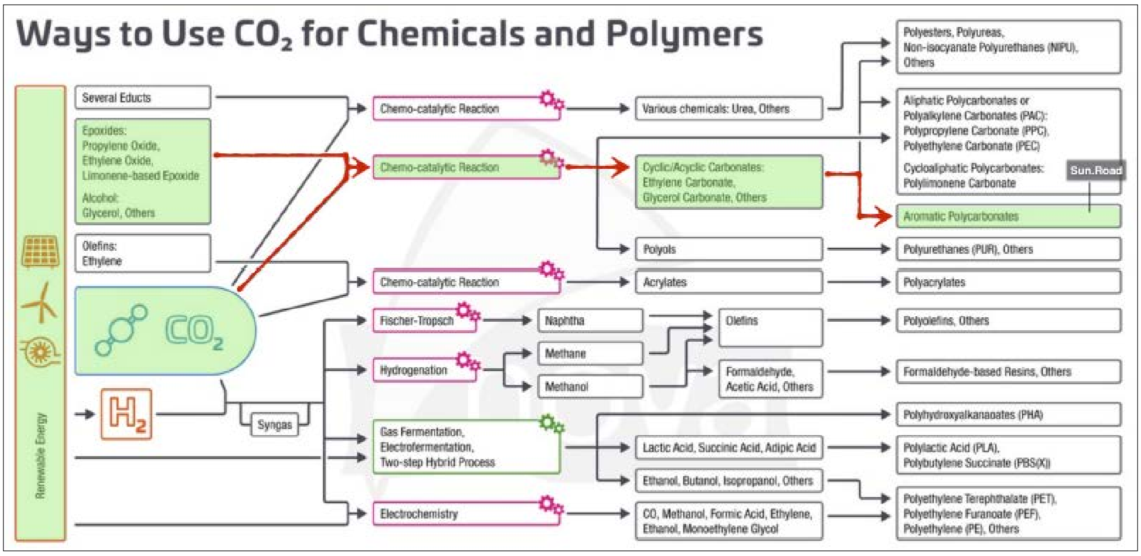


Figure 6.1.2: SAF Production on an Escort Vessel Foto: ParCy.Group

As the global demand for air travel continues to grow, it is all the more important to harmonize flying with climate protection. Aviation accounts for 3.06% (2023) of global CO_2 emissions. Other basic chemical substances can also be produced from CO_2 + H2. The table shows that almost all plastics can be produced from it [10].



www.co2-chemistry.eu7.0

Second Life

Thinking in Cycles

The development of an airborne wind energy system is actually complicated enough. Taking into account upstream and downstream relationships makes the design process even more complex. Of course, it is also much more exciting. If people want to integrate themselves into natural cycles, which they must if they want to survive, then we must not shy away from complex interrelationships in our work.

Upstream Circuits
Which relationships are relevant?

Collecting rubbish to make a living, protect the environment and produce fuel for aeroplanes is an example of such a network of relationships.

Electric cars are just starting to enter the market. It won't be long before they reach the end of their lives. Many of the components can be used in airborne wind energy systems. The electric motors are certainly the most important [11]. Using them as generators is certainly an economical and ecological prospect.

There are also sensible applications for the batteries [12].

Unfortunately, I cannot judge to what extent the sensors, computers and electronic components can till be used. There may certainly be a use for LEDs from the lighting systems.

https://imgr1.auto-motor-und-sport.de/Audi-e-tron-S-Sportback-169Inline-e8c49fdf-1703045.jpg

https://assets.meinauto.de/image/upload/q_auto:eco/f_auto/dpr_1.0/c_scale,h_543,w_1136/v1/website/pics/landingpages/ratgeber/e-auto-akku-vw

Downstream Cycles
The ambitious goal is to operate the Airborne Wind Energy Systems for 5-10 years without maintenance, offshore under harsh weather conditions. It will be very difficult to repair the kites during operation. If a component fails, a completely new system will be necessary. 99% of the components will still have a use value. Recycling is a possibility, but there are better applications for the time being.

The wing profiles of the kites are made of extruded polycarbonate, which has a life expectancy of at least 20 years. Carbon tubes and ropes with high tensile strength are then used. Greenhouses can be built from these materials. Add solar panels and you have a solar power station. With minor modifications, low-cost kits can be developed that can be transported very compactly by lorry.

The underwater units with the electrolysers for hydrogen production should have a life expectancy of at least 20 years. After their offshore deployment, with a careful maintenance plan they can supplement decentralized solar power plants in securing the regional energy supply and be operated for another 20 years.

They are adapted to the new European container dimensions (Big Box W 2.55 x H 2.9 x L 14.9 m) and can therefore be easily transported by truck.

The Green Wall in Africa
There are regions of the world where living conditions and food production are extremely precarious. This often forces people to leave their homes. The areas south of the Sahara are particularly affected by climate change and desertification.

The "Great Green Wall of Africa" project was adopted by the African Union in July 2005.

Based on the idea of building a line at least 15 kilometers wide and 7,775 kilometers long of trees from west to east through the African desert.

from west to east across the African desert (from Dakar to Djibouti), the concept of the Great Green Wall developed into a mosaic of interventions to address the challenges of the people of the Sahel.

challenges facing the people of the Sahel and the Sahara.

In a greenhouse, or rather an indoor farm, all the necessary food can be produced anywhere in the world with minimal water consumption.

They can make a major contribution to solving many problems.

Figure 7.4.1: A Contribution for Africa's Green Wall Foto: ParCy.Group

Although indoor farms are not the central topic of this article, the analysis of the correlation the connection with the kite systems resulted in feedback to the kite development. One example will illustrate this.

AWES are in conflict with air traffic. Good visibility can help to avoid accidents. This is why the kite wings were initially designed in the colors white and red.

Transparent wings are more suitable for greenhouses or hall roofs. It is not important for the kite function. For Second Life use, it plays a decisive role.

Figure 7.4.2: Indoor Farm aus Kite Komponenten Foto: ParCy.Group7.5

Material Cycle

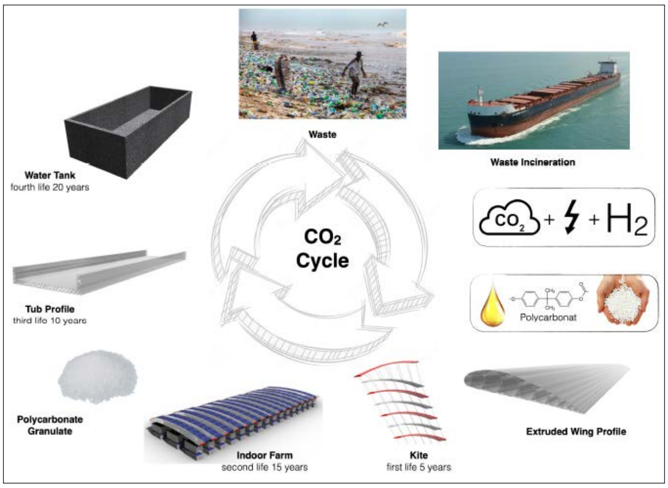


Figure 7.5.1: Material cycle Foto: ParCy.Group

Summary and Outlook

Cooperation

At the Airborne Wind Energy Conference in Madrid 2024, stakeholders from the community came together to exchange ideas. It is interesting to see how many different approaches are being pursued, how complex the topic is and how complicated the individual sub-areas are. It is very pleasing to see the commitment and enthusiasm with which the goal of producing sustainable energy is being pursued. A great deal of research and development will still be necessary before the megawatt range is reached. It is probably only a matter of time before competitive energy prices are achieved.

Financing

At present, the speed of development is blocked by chronic underfunding of the individual projects. This will probably continue to be the case until it is proven that airborne wind energy is more favorable than the use of fossil fuels. New sources of financing will then be developed that can ensure exponential growth.

The offshore concept presented here for the generation and production of airborne wind energy systems shows that rapid scaling is possible.

There is enough space on the oceans for countries, individual companies or even private individuals to produce their own energy sustainably.

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