Appendices E to J

Appendix D: see The Musk Prize see www.thecomingsfoundaion.org

Appendices E-H page

Appendix E: Bay Engineering Inc https://www.bayengineeringinc.com

Naval Architecture Computer programs Including USACOE Naval Architectural Analysis, computer generated & faired hull lines, hull & appendage design, hydro-statics, hull girder strength, speed & power analysis, ship's motion studies, intact & damage stability analysis, lightship surveys, inclining experiments, trim & stability manuals, loading manuals & weight engineering.

Marine Engineering Including main propulsion and auxiliary equipment selection and sizing, propulsion shafting including vibration and alignment analysis, anti-pollution system design, HVAC systems, hydraulic systems, machinery space arrangements and layout, diesel exhaust scrubbers, purchase technical specifications and test and trial memorandum.

Structural Design Including scantling design in accordance with classification society requirements, hull strength & scantling reassessment, spud design, equipment foundation design, wood, steel & aluminum structural design.

Finite Element Analysis Structural Analysis (both linear and non-linear) using finite element methods in 3D, including stress, vibration, buckling, and fatigue analysis, optimizing the structural design.

Outfitting Design Including vessel general arrangements, navigation visibility, mooring, towing & anchor handling arrangements, cargo/stores handling design, ladder/stairway design, door/closures/gangway design, accommodations, commissary & public space arrangements, lifesaving & rescue boat arrangements, fire control & safety plans.

Mechanical Design Including bulk cargo materials handling system design, pneumatic conveying and self-unloading conveyor design.

Piping Design Including system diagrams with size & material, fluid flow analysis, piping arrangements, ballast water treatment system feasibility & design application, system modules & pipe spools, naval vessel fire-fighting & chilled water systems.

Electrical/Electronic System Design Including ships power and lighting systems, electrical systems for manned as well as unmanned engine rooms, electronic communications and shipboard aids to navigation.

Software Technology We Utilize AutoCAD, Rhino, Ship Constructor, MARIN, RISA-3D, FEMAP, NavCad, AutoDesk Nastran, NX Nastran, General HydroStatics, pipeflow, PIPE-FLO PROFESSIONAL, Propeller Series Package

Contact Phone 920.743.8282   253 North First Avenue Sturgeon Bay, WI 54235

Appendix F: Vertical Axis Wind Turbines (VAWT)

A OAE ship is useless if it produces more CO_2 than it sequesters. Thus, in addition to solar panels and fuel cells ours will be outfitted with wind turbines of the Vertical Axis Wind Turbine (VAWT) type as opposed to the Horizontal Axis Wind Turbines (HAWT).

VAWT Advantages

VAWTs have fewer parts than HAWTs. That means fewer components to wear out and break down. Also, the supporting strength of the tower doesn't need to be as great, because the gearbox and generator are near the ground. Parts for controlling pitch and yaw aren't needed either. They ae also much shorter and compact than HAWTs. In addition, the turbine doesn't have to be facing the right wind direction. In a vertical system, air flowing from any direction or speed can rotate the blades. Therefore, the system can be used to generate power in gusty winds.

Other benefits include:

Safety for workers: Maintaining generators, gearboxes, and most of the mechanical and electrical parts of the structure do not require scaling the tower because these aren't mounted on top. Lifting equipment and climbing gear aren't needed either.

Scalability: The design can be scaled down to small sizes, even as small as what will fit on an urban rooftop. In addition, VAWTs are:

Cheaper to produce than HAWTs.

More easily installed compared to other wind turbine types.

Transportable from one location to another.

Equipped with low-speed blades, lessening the risk to people and birds.

Function in extreme weather, with variable winds and even mountain conditions.

Permissible where taller structures are prohibited.

Quieter to operate, so they don't disturb people in residential neighborhoods.

According to the Institution of Mechanical Engineers, vertical axis wind turbines are more suited for being installed **in denser arrays**. Up to 10 times denser than horizontal models, they can be clustered into arrays that even create turbulence from one turbine to another, which helps increase the flow around them. Therefore, the wind speeds up around each one, increasing the power-generated. A low center of gravity also makes these models more stable for shipboard use.

Since the vertical design allows engineers to place the turbines closer together, **a row or two of them can be placed on a ship**. In contrast, if horizontal wind turbines are close to one another this can create turbulence and reductions in wind speed that affects the output of neighboring units.

A 2017 report in the Journal of Renewable and Sustainable Energy, cited by Phys.org, noted that although vertical axis wind turbines produce less energy per tower, they have the potential to generate **as much as 10 times more power over a comparative area** of land when placed in arrays.

Disadvantages of VAWTs

Not all of the blades produce torque at the same time, which limits the efficiency of vertical systems in producing energy. Other blades are simply pushed along. There is also more drag on the blades when they rotate. Although a turbine can work in gusty winds, that is not always the case; the low starting torque and dynamic stability problems can limit functionality in conditions the turbine wasn't specifically designed for.

Since the wind turbines are lower to the ground, they do not harness the higher wind speeds often found at higher levels. However, it is more practical to install a vertical system on a level base.

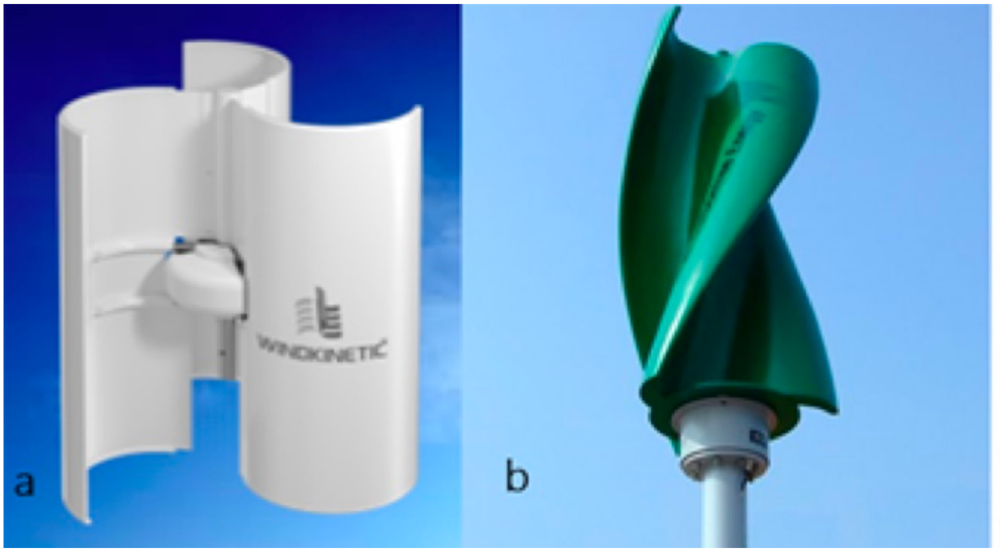
Vibration can be an issue at times, and even increase the noise produced by the turbine. Air flow at ground level can increase turbulence, thereby increasing vibration. This can wear out the bearings. At times, this can result in more maintenance and therefore more costs associated with it. In earlier models, blades were prone to bending and cracking, causing the turbine to fail.

The following review is based on:
Kumar, P.M. et al. (2019) A Review on the Evolution of Darrieus Vertical Axis Wind Turbine. Journal of Power and Energy Engineering 7:4 April. (see article for references).

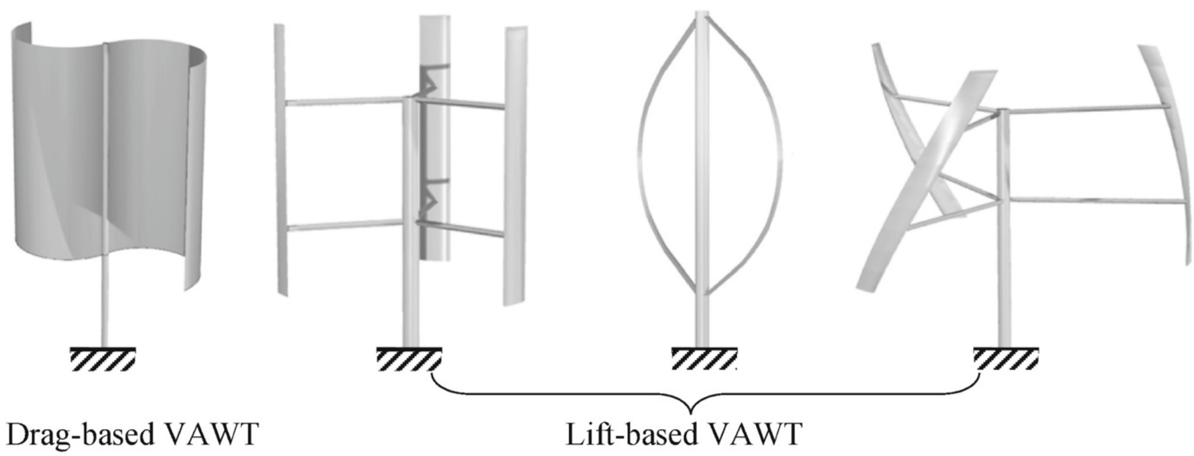
See also: **Liu, J. et al (2019). Review on the technical perspectives and commercial viability of vertical axis wind turbines. Ocean Engineering 182:608-626.**

Various configurations of VAWT have been assessed in terms of reliability, components and low wind speed performance. This review was envisioned as an information hub for the major developments in VAWT and its technical advancements.

Savonius turbines. The early VAWTs are based on the aerodynamic drag. The reverse drag was eliminated by covering the advancing blade to generate net torque. Later, it was realized that the lift force is more efficient than drag and in order to achieve sufficient lift, the blade shape has to be different on the top and bottom side. Lift based **Darrieus turbine** was invented by G.J.M. Darrieus, a French aeronautical engineer in 1925 and subsequently obtained a U.S. patent in 1931.



(a) Savonius turbines with Straight bucket [19] ; (b) Darrieus type Helical buckets



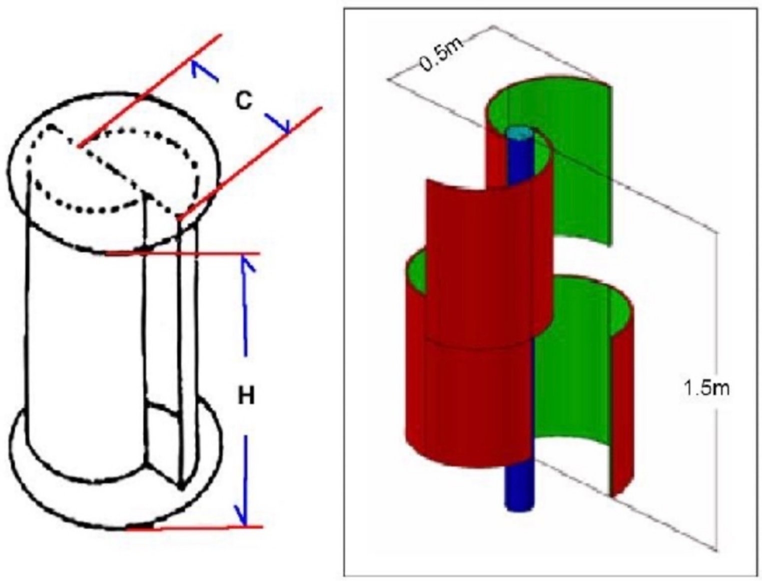
Schematic view of different types of VAWTs from left to right: S-type Savonius wind turbine, straight-type, troposkien-type, and helical-type Darrieus wind turbine (Liu et al, 2019).

Though Darrieus built smaller models to establish his invention, a 7-kW power generation model was built in 1950 by Morel. As the research on VAWT gained momentum during early 1980s numerous configurations have been conceived and put to test. Due to early failures and limited funding compared to HAWT, various innovative concepts have not been fully explored or not commercialized.

The evaluation of wind turbines is categorized into three, based on their power capacities: less than 50 kW are small scale wind turbines, whereas medium scale wind turbines have their power capacities in the range of 50 kW to 500 kW. Power capacity above 500 kW is termed as large or utility-scale wind turbines.

In typical VAWT, the blades are arranged vertically and rotate around the vertical axis. Some of the niche advantages of Savonius turbines are insensitive to the wind direction, ease of maintenance by placing the drive train components on the ground, low manufacturing cost of blades and reduced tower height. Savonius turbines tend to be less efficient (~15%) than the Darrieus turbines.

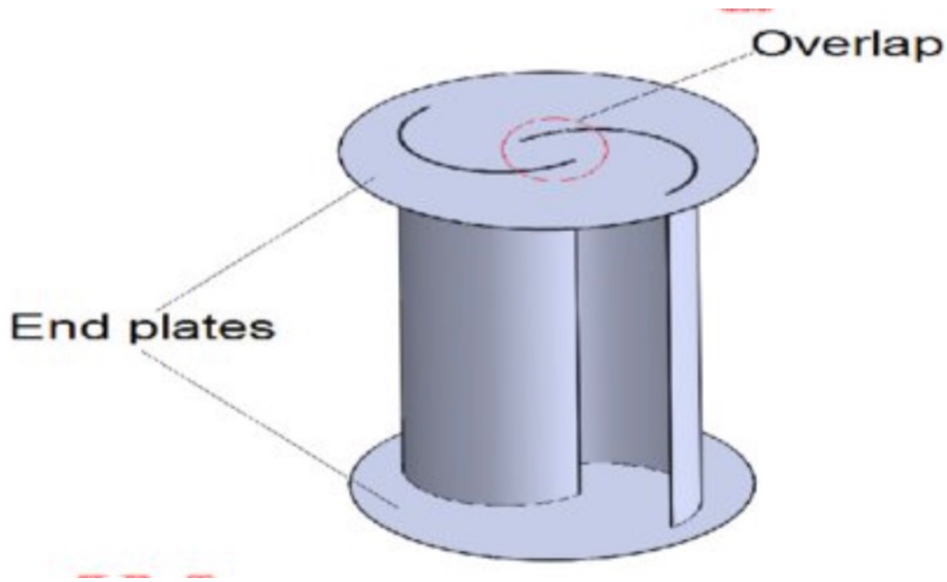
Overlap ratio is shown in following figure. It is the **ratio of the diameter of the rotor blade to the distance which the blades overlap.** For buckets of semi-circular cross-section, the appropriate overlap ratio is **20 to 30%**. The overlap ratio for this designed wind turbine was 30%.



Overlap ratio

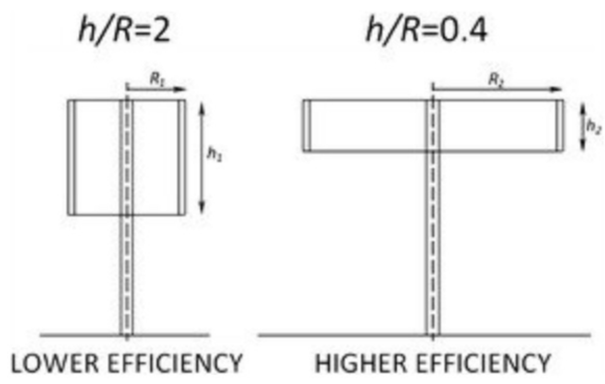
According to Kamoji, the maximum power coefficient decreases with increase in overlap ratio, whereas the experimental study by Alexander reveals that, the efficiency increases with the overlap ratio for the tested values of −0.07 to 0.22. The maximum efficiency of the Savonius turbines hovers around 18%. The maximum commercially available Savonius turbine has the power capacity of 10 kW manufactured by Wind Side. Compared to HAWT, Savonius turbines have much better prospects in terms of return on investment in low wind.

End plates are shown in the following figure.



Research shows that the end plate significantly improves the power performance by preventing the fluid flowing over the blades thus maintaining the pressure difference between the concave and the convex side over the height of the rotor. Sivasegaram conducted an experimental investigation on the effect of the end plate and found that optimum end plate diameters are 1.1 times the rotor diameter. The maximum efficiency of the Savonius turbines hovers around 18%. Compared to HAWT, Savonius turbines have much better prospects in terms of return on investment in low wind. In addition, VAWT's supporting tower is shorter than HAWT's one.

The **aspect ratio** can be defined as the ratio between the height to the diameter of the rotor. It was concluded through experimental results that the efficiency increases as the aspect ratio increases.

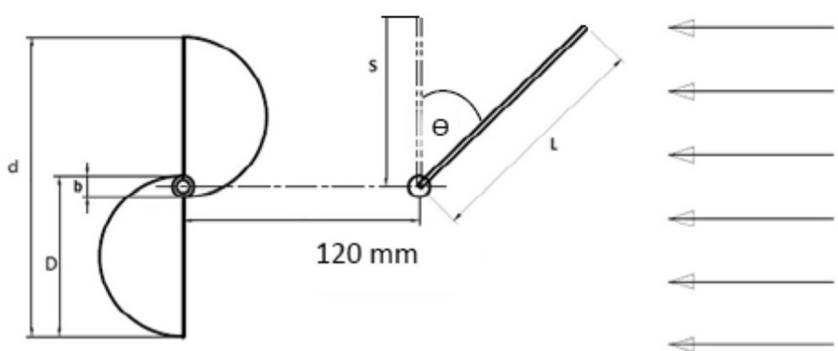


Reynolds Number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities.

The plume from this candle flame goes from laminar to turbulent. The Reynolds number can be used to predict where this transition will take place.

Torque is the rotational equivalent of linear force. Just as a linear force is a push or a pull, a torque can be thought of as a twist to an object around a specific axis.

Obstacle Plate Experimental studies have been carried out to assess the capability of an obstacle located upstream of a Savonius wind turbine to improve the power generated by the rotor.



Schematic illustration of the turbine and flat plate obstacle upstream of the returning blade (Putri et al, 2019)

The obstacle plate and the Reynolds number have little influence on the rotational speed of the loaded turbine. On the other hand, **the torque of the turbine is strongly influenced by the opening angle of the obstacle**. The studies reveal that the obstacle opening angle strongly influences the acting torque, where the maximum torque takes place at θ = 40° regardless of the Reynolds number (Putri et al, 2019). The obstacle plate used to reduce the negative moment on the convex side of the blade by directing the wind towards the concave side tends to increase the wind load, though the deflecting plate increases the efficiency to 27%. For small wind turbines, the wind load is calculated based on the frontal area. The frontal area of the Savonius rotor does not change in the event of high winds.

Numerous experimental studies have established the critical parameters of the turbine such as effect of end plates, optimum end plate diameters, effect of aspect ratio, influence of bucket spacing, bucket overlap, number of buckets, number of stages, interference of shat, effect of deflecting plate, helical and straight blades.

Savonius turbine to reduce the wind load and have achieved notable success. As the concave shape of the Savonius buckets has the drag coefficient of ~2.2, whereas the cylinder has the drag coefficient of ~0.47, converting the semicircular buckets to cylindrical shape was proposed as a solution by Patrick-Leroy. The linkages attached to the center shaft rotate the semicircular buckets to one cylinder. Though the experimental studies reveal that the wind loads are reduced by 20% - 30%, the cylinder at high winds will induce von Karman vortices which will compound the wind loading with alternating moment and vibrations. **Telescopic Savonius Turbine (TST)** was proposed as a potential solution to curtail the wind load as shown as follows.

The telescopic turbine is able to expand and retract based on wind conditions. The ability of the turbine to modify its frontal area in accordance with the wind speed helps the wind turbine to maintain its power and wind loads within the acceptable limits. Numerical simulation shows that the wind load of TST can be reduced by ~60% compared to conventional Savonius turbine. Savonius turbines are not preferred for the power capacity more than 10 kW due to the higher wind loads which demand heavier support structures.

Straight bladed Darrieus Turbine The straight bladed Darrieus turbine is the simplest of the type as they are easier to manufacture, transport and assemble on the turbine. Numbers of blades for a given power capacity are based on the average wind speed on the installation site, rpm of the machine and starting characteristics. A two-straight bladed Darrieus rotor is commonly referred as **H-Rotor** and more than two-bladed turbines are referred as **Giromill** as shown in below.

(a) High solidity Giromill; (b) H-rotor; (c) Two-stage Giromill; (d) High aspect ratio Darrieus turbine.

Though in most cases the blades are parallel to the axis of rotation, delta rotor, diamond rotor, V or Y rotor was reported to have their blades inclined to the axis of rotation. The maximum coefficient of performance (Cp) of a straight bladed turbine is in the range of 0.25 - 0.35. The Cp of the turbine is highly influenced by the solidity of the turbine defined by the ratio between the blade area to the swept area. Solidity can be increased by increasing the number of blades or increasing the chord length of the blades. The solidity of a straight bladed Darrieus rotor has a major impact on the starting characteristics of the turbine.

The experimental study by Baker shows that **the static torque coefficient is higher for three bladed turbines compared to a two-bladed turbine**. The blade mounting struts can be steel tubes which reduces the manufacturing cost and available in a wide range of diameters with various wall thicknesses. Straight bladed Darrieus turbines are not preferred for urban applications due to its lower performance in low and turbulent winds. Unable to self-start at wind speeds below 4 m/s is a major drawback hindering these turbine installations on rooftop. The past studies on self-starting reveal that the flow detachment from the blades at low Reynolds number (Re) and high Angle of Attack (AoA) results in the generation of low lift significantly reducing the net torque.

Another shortcoming of smaller Darrieus turbines is the rotational speed. Darrieus turbines are comparatively slow rpm machines than HAWT. The increased generator size for the same power capacity leads to an increase in cogging torque, offering higher resistive
The straight bladed Darrieus turbines are commercially available in power capacities from 500 W to 1.5 MW.

Helical Darrieus Turbine The helical turbine was proposed by Gorlov in 1995. Compared to the straight bladed turbine, helical bladed turbine offers noteworthy advantages such as enhanced self-starting capability, low noise, increased blade life, low vibrations and reduced peak stress in the blades. The self-starting capability is improved by the reduction of AoA and the ability of the blades to accelerate beyond the dead band.

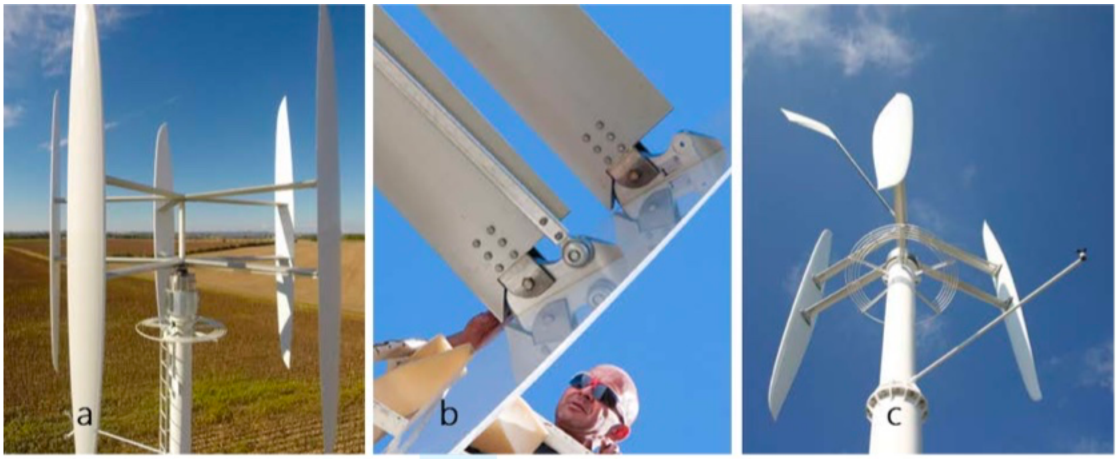
J-Bladed Turbine As self-starting and the low-speed behavior are crucial for a small wind turbine, Darrieus community is in constant search for a solution that can address the above said challenges. J-profile was conceived by researchers and later adopted by manufacturers around the world. The J-Profile on the blade is formed by removing a portion on the pressure side of the airfoil. The opening length and position along the chord is a parameter for optimization based on the prevailing wind speed.

Curved Bladed Turbine The curved bladed rotor was derived from the phi rotor developed during the earlier days of VAWT. The primary difference between the curved bladed rotor and the phi rotor is that the ends of blades are attached to the tower in the case of phi rotor, whereas in the curved bladed rotor it is free. The curved blades are attached to the tower through struts. Phi rotor design is prevalent for turbines of capacity more than 50 kW, the curved rotor designs are suitable for small turbines of capacity ~10 kW.

Curved blade assembled on turbine

Electrical Start Darrieus Turbine For maximum energy output, it is necessary for the turbine to accelerate to the rated rpm in a shortest possible time. Wind turbines are either connected to the electrical grid or to an energy storage system such as battery and in either case, it is possible to use the energy to accelerate the rotor to the rated rpm. Since most of the turbines use direct drive permanent magnet generator [PMG], Liu proposed a solution in which the generator can operate as a motor during starting and low wind. As the rotor accelerates beyond the dead band and gains sufficient rpm, it can operate as a generator producing power.

Blade Pitching Darrieus Turbine Blade pitching was once proposed for large wind turbines, as integrating the system in small wind turbine is costly and complex. Due to the advent of actuation systems and reduced cost of the associated electronics, pitching system can be implemented in small Darrieus turbines of capacity as low as 10 kW.



Blade Pitching Darrieus Turbine

Combined Savonius and Darrieus VAWT

This type of wind turbine combines two types of blades, the S-shaped Savonius-Vanes (viewed from above) and the curved arerofoil Darrieus-Blades (shape of an egg-beater).

Whereas the Savonius-Vanes are drag-driven, the Darrieus-Blades will experience a lifting force when wind is blowing across the turbine. Since a pure Darrieus Wind Turbine is (mostly) not able to start without an initial net rotational force, the Savonius-Vanes are added to make the turbine self-starting. This system is omnidirectional and does not need special yaw mechanisms to rotate itself towards the wind direction (Meziane et al, 2019; Pallotta, A.et al, 2020).

Other Literature

de Vries, (2021). Recently published research by Oxford Brookes University suggests that H-shape Darrieus vertical-axis turbines (VAWTs) installed a certain way could outperform "traditional propeller-type" wind turbines or HAWTs in offshore wind farms.

When set closely interspaced in pairs, VAWTs increase each other's performance by up to 15%, the UK-based institute said in its press release, triggering much media attention. Business publication Forbes wrote in May: "A recent discovery by engineers of Oxford Brookes University's School of Engineering, Computing, and Mathematics could change the design of offshore wind farms forever."

The university's research team, led by Iakovos Tzanakis, a professor in technology, design and environment, used extensive computer simulation for the in-depth study "This study evidence that the future of wind farms should be vertical," Tzanakis said. "Vertical-axis wind farm turbines can be designed to be **much closer together**, increasing their efficiency and ultimately lowering the prices of electricity. In the long run, VAWTs can help accelerate the green transition of our energy systems, so that more clean and sustainable energy comes from renewable sources."

The researchers argue that VAWT's in wind-farm array do not suffer from HAWT-related turbulent wake issues created by the first row, which decrease the output of the rows of turbines behind by up to 40%. Using vertical rather than horizontal-axis machines would not only eliminate this problem, they suggest, but the VAWTs would actually enhance each other's performance.

Two similar-size rotors were used for the research, with the second rotor placed the length of three rotor diameters downstream. The maximum increase in power output — compared with two units each operating in isolation — was achieved with the second rotor placed at a 60-degree array angle (ß) to the prevailing wind direction.

Another variable the team introduced was letting the two rotors either co-rotate in the same direction or counter-rotate, whereby the counter-rotating pair performed better only at smaller array-angles of around -30 to +30 degrees. Minimum power output is logically achieved when the wind blows directly over the two rotors positioned in line relative to the prevailing wind direction (0 degrees).

A main disadvantage compared with modern, large-scale HAWTs is much lower aerodynamic efficiency. The Oxford Brookes University report states a maximum pressure coefficient (Cp) in the 35-40% range, compared with nearly 50% for HAWT. Lead author Joachim Toftegaard Hansen explained that the team chose an **H-type Darrieus** rotor shape with a 20-metre rotor diameter (65 ft) for the analysis. This study is **relevant to the use of VAWTs on ships, suggesting a number of turbines placed fairly close together could be used.**

The purpose of this review is to provide some background to the subject of Vertical Axis Turbine design. The critical subject is what is available commercially and which of those commercial machines are ideal for adding electrical power to the OAE ship? There are a lot of vertical wind turbines for the home, but all of these are less than 1 kW and 12-to-24-volt output. A 5kW or greater with a 120v or greater output is needed. The following are some commercial examples.

Commercial VAWTs with 5 kW+

The following link provides an extensive listing of the different commercial companies the sell various types of VAWTs. Most are less than 5 kW.
https://www.energy-xprt.com/products/?keyword=vertical+axis+wind+turbine+(VAWT)

The following are some examples of 5kW or greater VAWTs. It will be up to the naval architects designing our OAE ship to choose the best option.

1. 4navitas Vertical Axis 55kW Wind Turbine

This VAWT offers a very reliable, efficient and cost-effective alternative to conventional Horizontal Axis Wind Turbines. Vertical Axis Wind Turbines are less intrusive visually, even in areas such as National Parks and Areas of Outstanding Natural Beauty. These turbines are quieter, more bird and bat-friendly and are less expensive to maintain compared to horizontal turbines.

The 4N-55 is a 55 kW, rated vertical axis wind turbine. Three years in development, the radical new design is manufactured in the UK and incorporates a wealth of patented design features, which greatly enhanced power generating output at low wind speeds and significantly reduce the total costs of ownership. The design team includes world leading aerodynamic, mechanical and electrical engineers. Emphasis on low maintenance. Most of the serviceable components are at ground level.

4Navitas (Green Energy Solutions) Ltd, Disley Close, Whitehills Business Park, Blackpool, Lancashire, FY4 5FN, United Kingdom. Telephone: +44 (0)1253 530 680
Fax: +44 (0)1253 530 868 Email: info@4navitas.com

4navitas Vertical Axis 55kW Wind Turbine

Technical Data and Specifications

Electrical Data

90 KW induction motor
400 volts
Multiple poles
Converter: active front end regenerative full-scale converter
Closer loop feedback
Design safety: G59, EMC directive BS EN 61800-3 machinery directive 60204-1

Operating Data

Rated power: **55 kW**
Maximum power: 65 kW
Cut in wind speed: 7 mph
Cut out wind sped: 55 mph
Survival winds speed: 133 mph

Physical Data

Mill diameter: 14 m or 45 ft
Blade length: 14 m or 45 ft

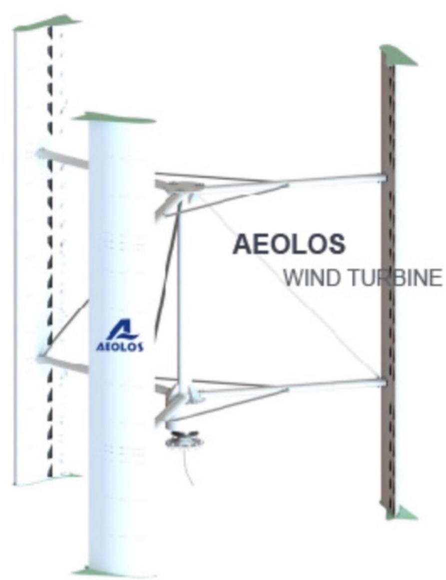
Number of blades: 5 (3 for higher wind speeds)
Nominal rpm: 34
Braking system: regenerative braking with dual fil-safe mechanical breaking and hurricane load stationary parking brakes.
Tower type: tubular mast
Height: Hub height 23 or 30 m (98 ft)
Design specification: IEC 61400 – 2 wind turbine standard
Power up sequence: self-starting
Electrical housing: external IP54 enclosure with internal IP2X protection
Ul patents: 2517246, 2553069, 2555965

If the **4navitas** 4N-55, **55 kW** turbine is chosen we would work with the company to significantly lower the height and width and make the components resistant to seawater. The height would be easy to decrease, just shorten the tower.

Placing 4 **4navita** on the ship would provide 220 kW. This, plus the output from solar cells might be sufficient to run both the motors and the electrolysis on the ship. The final details will be left to the electrical engineers involved in the ships design.

2. Aeolos-V 10kW vertical wind turbine

Aeolos 10kW vertical axis wind turbine is a low start wind speed, quiet, safe and reliable vertical wind turbine. Aeolos 10kW vertical axis wind turbines were widely applied for building, small farm, schools, supermarkets, home and other low noise area. The blades were made by aluminum alloy with a special aerodynamic design. This design will limit the max rotating speed to 260rpm even the wind speed is 30m/s or 40m/s. It is safer and more reliable than traditional vertical axis wind turbine.



Specifications

Rated Power	10kW
Maximum Power	12kW
Output voltage	300/380V
Rotor height	19.7 ft
Rotor diameter	18.0 ft
Star-up speed	5.6 mph
Rated wind speed	24.6 mph
Survival wind speed	117.4 mph
Generator	Permanent Manet Generator
Generator Efficiency	>.96
Turbine weight	1,499 lbs.
Noise	<45dB
Temperature range	-20^{oC} to +50^{o}C
Lifetime	20 years
Warranty	5 yrs.

Aeolos-V 10kW price & brochure , please contact sales@windturbinestar.com

3. Windspire

Their vertical axis wind turbines come in many sizes and shapes from 750-watt wind turbine up to our **5kW** wind turbine. Affordable, attractive, and Ultra Quiet, creating clean energy from the natural wind. Every wind turbine Is Completely Made in Reedsburg, Wisconsin, USA. All wind turbines are available in custom colors. Prices start at $5,995.

Light weight, high powered, and encased in a rugged housing for long life. An advanced wind turbine generator that took years to develop and test. All of our wind turbines can be installed on-grid or off-grid. For an on-grid connection we use Inverters specifically matched to our wind turbine controller. Designed, tested and fabricated at our facilities in Wisconsin, to exacting standards and the highest in technological advances.

5kW Vertical Axis Wind Turbine Specifications:

- Rated Maximum Output: 5.4kW
- Annual Output: 9400 kwh @ average 12.5 mph wind speed
- Voltage Output: 240 VAC Split Phase
- Cut in Wind Speed: 10 mph
- Cut out Wind Speed: 35 mph
- Survival wind Speed: 110 mph
- Wind Blades: 3 blades in three tiers total 9 blades
- Rotor Diameter: **7.0 feet**
- Height: 32 feet
- Weight: 1450 lbs.
- Construction: All Metal, Special powder coatings
- Braking: Dynamic Diversion Load and Stop Switch

Advantage: 5kW and small diameter. Could place many in rows on the ship.
Disadvantage tall but could order shorter ones.

4. Astralux – Their products range from 5 kW to 100 kW with increasing size with increasing output. The total eight tends to be twice the rotor height suggesting the height can be significantly decreased by decreasing the tower height.

VAWT 5 kW. Vertical Axis Wind Turbine 5 kW wind turbine is one of the smallest in their product range and designed serve energy needs of approximately 2 households. It can be used in homes or cottages, may run heating in small farm. Energy, generated by this turbine may charge batteries, connected directly to heating device or connected via inverter to the grid. This 5kW turbine, may be installed on open place (field or elevation), or roof of the garage or house. It can fully substitute your need for external electricity supply as a source of energy for heating and hot water or charging batteries thus reducing your expenses.

Specifications

Total height – 7 m 22 ft

Rotor height- 4 m **13 ft**

Rotor diameter- 6 m 19 ft

Area occupied (square) – 81 sq. m. (can be installed on existing structure)

Minimal working speed- 1.5 m/s

Nominal working speed – **9.5** m/s

Materials – steel, aluminum and composite plastics

Turbine does not require careful maintenance, repair and preservation during its entire lifetime

The turbines have a service life of more than 100 years.

VAWT 10 kW Total height – 7 m Rotor height- 4 m (13 ft) Rotor diameter- 8 m Area occupied- 180 sq. m. (can be installed on existing structure) Minimal working speed- 1.5 m/s Nominal working speed – 10.5 m/s Materials – aluminum and composite plastics. This VAWT can be used in homes, small business and farming communities allowing them to heat their homes and water.

This appears to offer the maximum power/rotor height suitable to ships.

VAWT 20KW Total height – 11 m Rotor height (36 ft) – 6 m Rotor diameter (20 ft) – 12 m Area occupied – 410 sq. m. (can be installed on existing structure) Minimal working speed – 1.5 m/s Nominal working speed – 10.5 m/s. Materials – aluminum, steel and composite plastics Turbine does not require careful maintenance, repair and preservation during its entire lifetime.

VAWT 50 kW Total height – 18 m Rotor height 59 ft – 10 m Rotor diameter – 20 m Area occupied – 1,130 sq. m. Minimal working speed – 1.5 m/s Nominal working speed – 10 m/s Power on wind speed of 2 m/s – 0.4 kW Materials – aluminum, steel, concrete and composite plastics Turbine does not require careful maintenance, repair and preservation during its entire lifetime.

VAWT 100 kW This turbine can produce enough energy to power 15-25 homes. Total height – at least 22 m Rotor height 72 ft– 12 m Rotor diameter – 24 m Area occupied – 1,630 sq. m. Minimal working speed – 1.5 m/s Nominal working speed – 9.5 m/s Power on wind speed of 2 m/s- 0.7 kW Materials – aluminum, steel, concrete and composite plastics Turbine does not require careful maintenance, repair and preservation during its entire lifetime

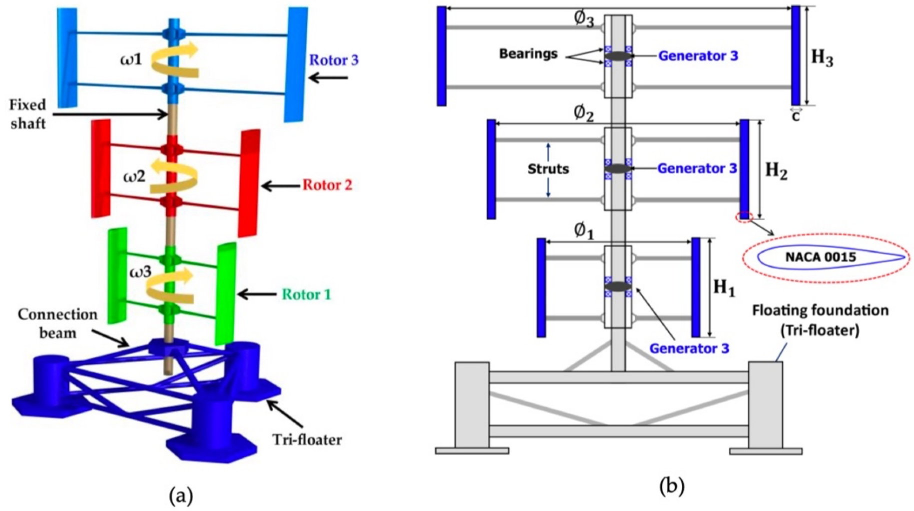
5. Vertogen Ltd manufacturer of Variable Pitch Vertical Axis Wind Turbine. After 10 years of investment and development by an innovative UK Company we are now offering an opportunity for partners to join us in the final stages to refine, build and roll out on global basis. A design that will impact and reach across the globe to make a true difference to All and the Environment. https://youtu.be/wqQWg9rvTak

Power output available on request.

6. 3 Stage Darrieus VAWT (Dabachi, M.A. et al. 2020).

This article presents a new concept of floating Darrieus-type straight-bladed turbine with three-stage rotors. A double-multiple stream tube (DMST) model is used for aerodynamic simulations to examine several critical parameters, including, solidity turbine, number of blades, rotor radius, aspect ratio, wind velocity, and rotor height. This study also allows to identify a low solidity turbine ($\sigma = 0.3$), offering the best aerodynamic performance, while a two-bladed design is recommended. Moreover, the results also indicate the interest of a variable radius rotor, as well as the variation of the height as a function of the wind speed on the aerodynamic efficiency.

Solidity is the ratio of total rotor planform area to total swept area. Low solidity (0.10) = high speed, low torque.



This version was designed as a floating VAWT.

Appendix G: Final Stage Grinders

Efficiency of Comminution (grinding) and the Machines to do it.

One of the major problems with EW is the energy cost of grinding the rocks. There has been a considerable amount of research devoted to making this more energy efficient. Since the machines that perform the initial grinding at the mine are usually quite large, they are best suited for onsite use, with the possibility of using renewable energy sources. Here we primarily examine those machines that could be used on an OAE ship, or onsite for EW on croplands. Here the goal is to find the best methods to perform the final stage of **fine and ultrafine grinding** that is small enough to have several on the ship. One option is the use of ball mill machines discussed below.

What is a Ball Mill?

A ball mill is a type of grinder used to grind bulk material into **nanosize** particles using different sized balls. The working principle is simple**;** impact and attrition size reduction takes place as the ball drops from near the top of a rotating hollow cylindrical shell. It consists of a hallow cylinder containing balls, mounted on a metallic or rubber frame such that it can be rotated along its longitudinal axis. The balls which could be of different diameters occupy 30 – 50 % of the mill volume and its size depends on the feed and mill size. The large balls tend to break down the coarse feed materials and the smaller balls help to form fine product by reducing void spaces between the balls. Ball mills grind material by impact and attrition.

The degree of milling in a ball mill is influenced by,

a. Residence time of the material in the mill chamber.
b. The size, density, and number of the balls.
c. The nature of the balls (hardness of the grinding material)
d. Feed rate and feed level in the vessel.
e. Rotation speed of the cylinder.

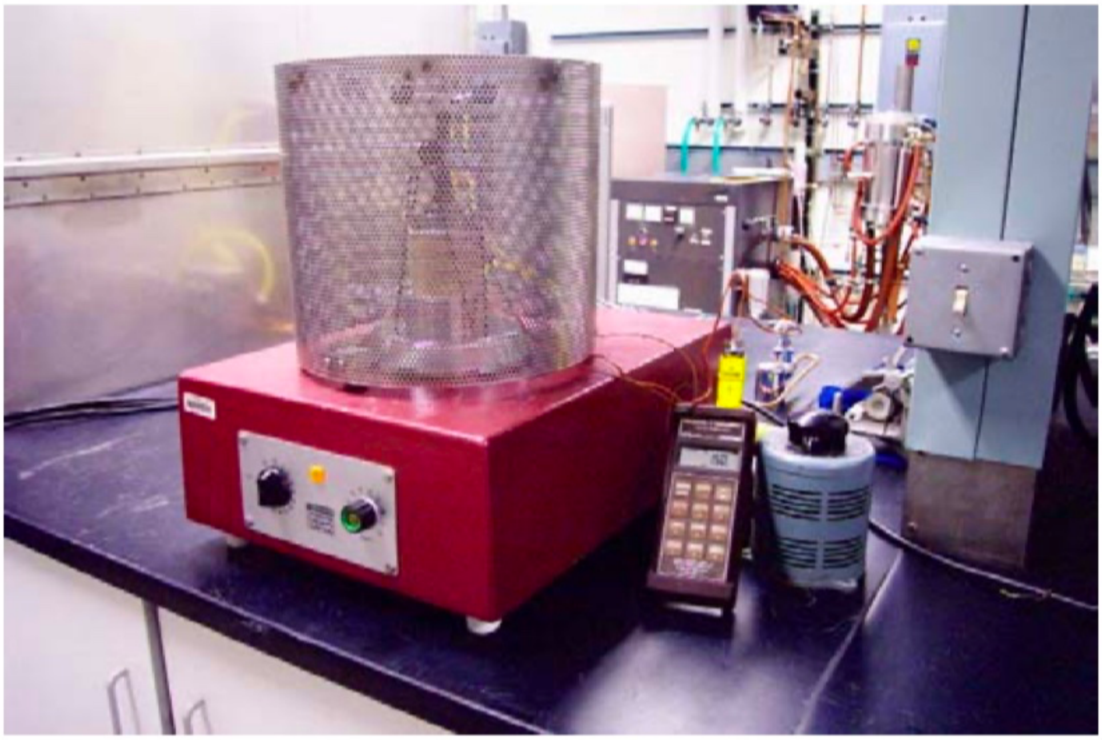
Advantages of Ball Mills

a. It produces very fine powder (particle size less than or equal to 10 microns).
b. It is suitable for milling toxic materials since it can be used in a completely enclosed form.
c. Has a wide application.
d. It can be used for continuous operation.

Disadvantages of Ball Mills

a. Contamination of the product may occur as a result of wear and tear which occurs principally from the balls and partially from the casing.
b. High machine noise level especially if the hollow cylinder is made of metal, but much less if rubber is used.
c. Relatively long milling time.

McKelvy, M.J. (2005) Described a **controlled temperature ball mill grinding system** used at ASU for thermomechanical studies.



Francioli (2015) provided an extensive review of the variables and mathematics of comminution. **Grinding media (ball) size is the variable that affects power consumption and particle breakage the most.** The use of bigger balls results in a more efficient breakage, especially of coarse particles. It also decreases power consumption however this effect may be linked to the high lifter height used. The following figure shows a large ball size grinder with lifters.

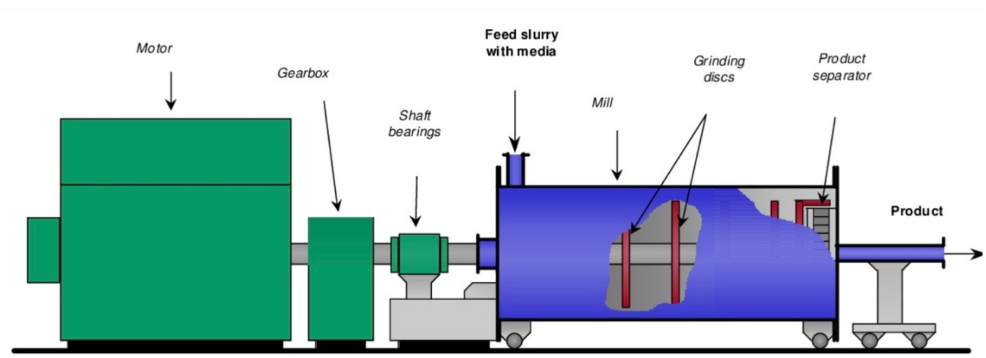
A ball mill grinder with large balls and large lifters on the inner wall.

Lifters prevent slipping of the product (charge) in the mill, reducing the amount of energy wasted during the grinding process and improving the breakage mechanism by enhancing the number of collisions. The dimensions of the lifters have great influence in charge motion and grinding efficiency. An older additional review ball mills was provided by Fuerstenau, and Abouzeidb (2002).

Wet vs Dry Grinding Wet grinding in tumbling mills is more efficient than dry grinding (Fuerstenau and Sullivan, 1962). One reason for this is that water is adsorbed on the newly created surfaces and prevents the fines from agglomerating. The second reason is that the fine particles produced during comminution remain suspended in the aqueous medium, thereby increasing the chance for the coarser particles to be broken by the tumbling media.

Batch Ball Mill A batch ball mill is a grinding mill into which a charge of ore and water is placed and is ground to completion of the required comminution.

IsaMill A need for economy and for high-grade but fine-grained ore processing have forced the mining industry to look for more efficient processes. IsaMill Technology for **ultra-fine and fine grinding** is one such process employed at several mining operations in Australia including Mount Isa Mines Limited in Australia. The Isamill is **energy-efficient.**



While the large size of the IsaMill raises questions as to whether it is suitable for ship-board use, there is a high likelihood that a smaller versions could be produced.

Stirred Mill A vertical stirred media grinding mill uses a grinding chamber filled with small beads whereby comminution takes place by attrition between the beads. The stirring effect is caused by rotating discs mounted on a shaft located along the central axis of the mill. In a stirred mill, a central paddle wheel or impellor armature stirs the media at speed from 100 to 1500 rpm. Stirred mills often consist of stirrers mounted on a rotating shaft

Attritor Stirred Ball Mill (Gao, et al, 2011) is a stirred ball mill with a simple and effective method of grinding and dispersing fine and homogenous material quickly. The Attritor can operate wet or dry, introduce inert atmospheres, operate at controlled temperatures, and vary grinding speed. Results are repeatable from one grind (batch) to another so the attritor is ideal for pilot plant and scale up studies. The material and media are agitated by a shaft with arms rotating at high speed. This causes the media to exert both shearing and impact forces on the material resulting in an extremely fine material. The laboratory scale Attritor is much faster than conventional mills. The unit can use carbon steel, stainless steel, chrome steel, tungsten carbide or ceramic balls as grinding media. No premixing is necessary, and ingredients can be added at any time during the grinding process. The Attritors are designed for media ranging from 1/8” to 3/8” and run at 100 to 500 rpm.

Attritor by Sepor, Inc. 718 Fries Ave, Willington, CA 90744

Some of the features are:

- Variable shaft RPM
- Adjustable agitator shaft height to accommodate different size grinding media.
- Bottom discharge grid with valve for easy sampling and discharge.
- Tank slides forward and tips @ 90 degrees for media discharge and fast cleaning.
- Jacketed for cooling (or Heating)
- Quick disconnects for cooling water.
- VFD – Variable speed drive system

Its relatively small size and ability to produce extremely fine material makes the Attritor Stirred Ball Mill an excellent candidate for ship-board use and onsite use of EW on croplands.

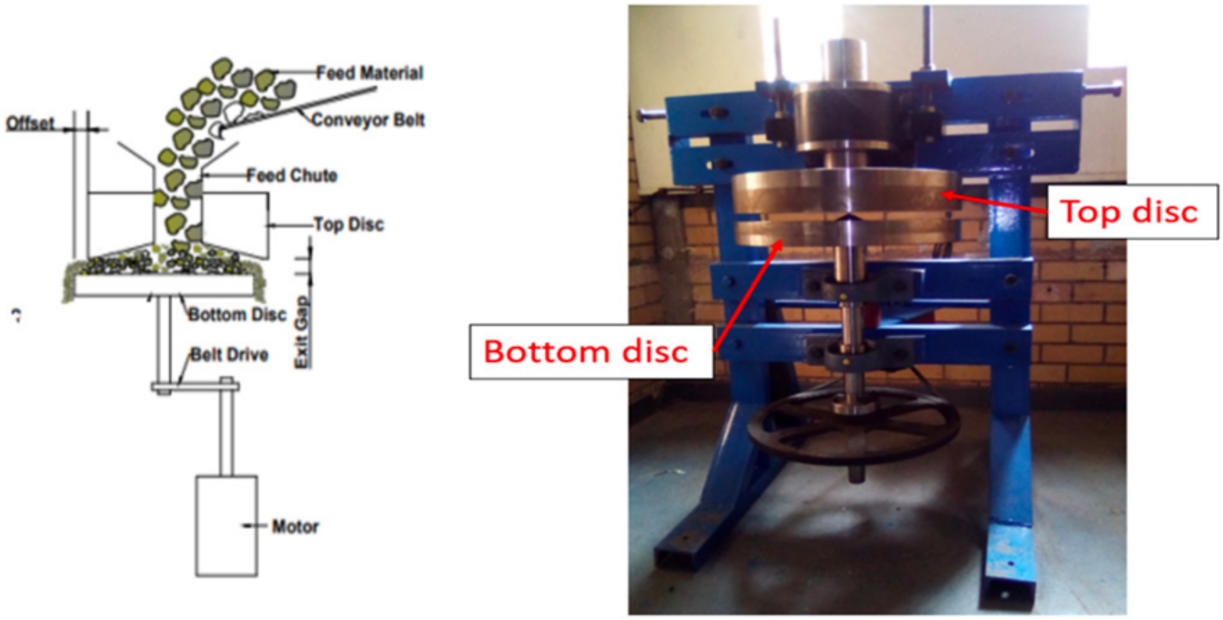
Nphipulile et al, (2021). Comminution is, at present, a relatively inefficient process with only a small fraction of the energy, meant for size reduction, being used to effect breakage, with the rest being lost in different forms of energy, such as heat, sound, mechanical losses, and others. A novel crusher, known as the **rotary offset crusher (ROC)**, was invented in 2002 by Michael Hunt, Henry Simonsen, and Ian Sinclair, but failed to garner enough support to progress to production. The original design concept was recently rekindled, and a laboratory version of the crusher has been built and commissioned at the University of the Witwatersrand, South Africa. The crusher is simple in design, with two cylindrical discs that are parallel to each other, and, as the name implies, there is an offset between the vertical axes of the discs. The top disc has a conical section on its lower face, and this creates a crushing zone between the opposite faces of the two spinning discs. Centrifugal motion transports particles through the crushing zone. Batch experiments have been conducted with quartz at various crusher settings (discs offset, rotational speed, and vertical exit gap) for various feed size distributions. The indications so far suggest that the disc speed is a key factor affecting the performance. Size reduction ratios as high as 11 were recorded from experiments with quartz at a speed of 830 r/min. Conventional crushers are characterized by low reduction ratios in the range of 3:1 and 10:1.

Fragmentation of rocks in comminution equipment occurs due to three mechanisms – impact, compression, and abrasion. In the ROC, the rapid variation of the gap between the crushing discs during each revolution as particles are transported away from the center to the crusher periphery will subject particles to cyclic impulses of compressive forces. At this point it can only be hypothesized that both impact, due to rapid movement of the discs, and compressive loading are possible.

Compression breakage, which dominates in the high-pressure grinding roll (HPGR) and vertical roller mill (VRM), is said to be energy-efficient (see many references in article). The ROC under development at the University of the Witwatersrand, has the potential advantage of reducing equipment size as energy can be concentrated in a small space simply by increasing the rate of rotation of the discs, which aids both particle transportation and comminution frequency.

The ROC is a novel crushing device that exploits the centrifugal motion of particles **between two off-center, high-speed spinning discs** and the consequential closure and opening of the hollow conical space in the upper disc due the discs being off-center.

As shown in the following there is an offset between the vertical axes of the crusher discs. This horizontal offset of the top disc relative to the bottom disc produces a change in the geometry of the crushing zone during rotation. The horizontal offset between the discs is adjusted by sliding the top disc support structure.



Working diagram for the rotary offset crusher (left) and photograph showing the discs (right)

The ROC is a new device with many of its aspects yet to be understood, and thus an experimental program has been initiated to establish what drives the capacity of this machine. The crusher has been instrumented to provide information about the process.

The small size of the ROC makes it an additional consideration for ship-board use.

Attrition milling is simple and effective. Feed material is placed in a stationary tank with the grinding media. A rotating shaft with arms or discs then agitates the material and media. Both impact and shearing action result in size reduction as well as homogenous particle dispersion with very little wear on the tank walls. The discs of an attrition mill are generally in a vertical position so that materials not capable of reduction can pass by gravity out of the grinding area. However, in some cases they are in a horizontal position with the bottom disc contain various sized holes allowing the milled fraction to pass through. There are many types commercially available.

Centrifugal Grinders The high speed cutter assembly of the centrifugal grinder pump performs over 3,200 cutting operations per second. Its product is an extremely fine slurry (not sludge) that is over 96% water. Since this slurry is almost all water, it pumps like water and is therefore able to take advantage of the unique operating characteristics of the centrifugal pump. Using seawater this slurry with fine particles might be ideal for OAE operations.

In summary, the above review shows there are several options for grinding ultramafic rocks to a fine or ultrafine size for use both on ships and land. Some research will be necessary to determine which is the best to reduce ultramafic rocks to a fine powder.

Appendix H: Photovoltaics on Floats

If the dense array of solar panels placed on the OAE ship, plus the vertical axis wind turbines, plus the fuel cells and possibly OTEC, are not enough to supply the ship's electricity to power the propellors, electrolysis, and other electrical needs, an additional potential power source could be floating photovoltaic panels pulled behind the ship. There are many floating solar farms in the Orient, so the technology has been invented and widely used. However, the majority of these are for fresh water or very calm saltwater inlets and bays. A few companies market photovoltaic floats for the ocean. The following are some examples different methods of floating photovoltaics.

NRG Energy

NGR Floating solar.
Houston Headquarters: NRG Energy, Inc. 910 Louisiana St, Houston, TX 77002
phone 715-537-3000.

Takiron Engineering

Topper Floating Solar PV Mounting Manufacturer Co., Ltd.
A Branch of **Xiamen Topper Technology Co., Ltd.**
Address: No. 879, Xiahe Road, Siming, Xiamen, Fujian, P. R. China. 361004
Tel: 0086 592 5819200
Email: sales@topvsolar.com
Website: https://www.floatingsolarmounting.com/

Scotra

SCOTRA

New world on the water

Marina, floating bridge, floating house and floating PV

Specialized company for floating system-Scotra builds everything on the water.

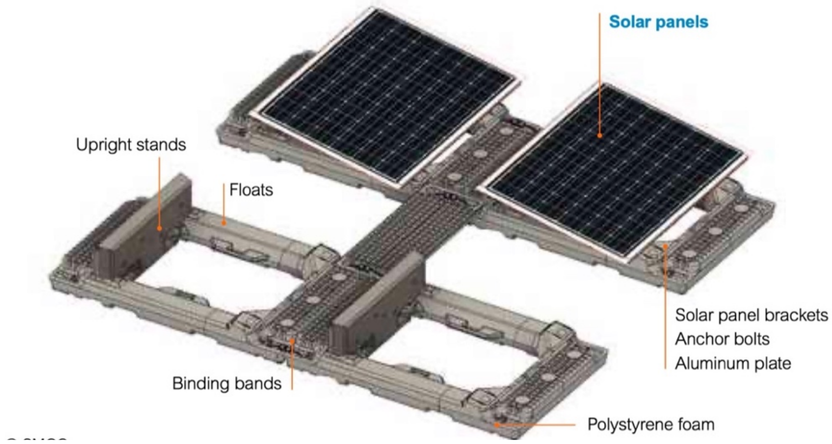
17 Patents for floating PV

8 patents for floating leisure facility

6 design registrations for floating PV

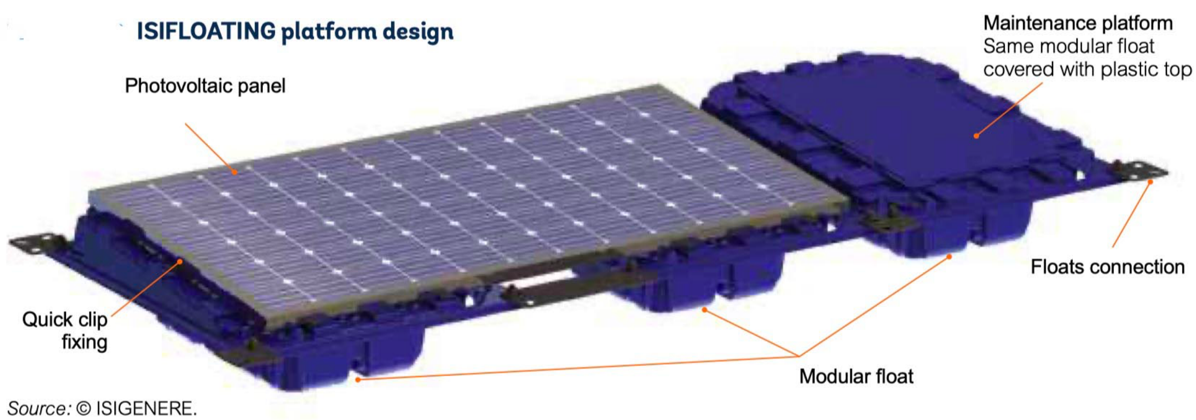
More than 1,400 references of mooring & anchoring
With unrivaled technical abilities and plenty of experience on the water
World best company in floating system field
Scotra opens new paradigm on water for future
322, Tera Tower, 167, Songpa-daero, Songpa-gu, Seoul, Republic of Korea
T +82-2-402-0591 F +82-2-2054-8291

Sumitomo



Sumitomo Mitsui Construction Co., Ltd.
2-1-6, Tsukuda,Chuo-ku,Tokyo 104-0051,Japan

Isifloating Platform



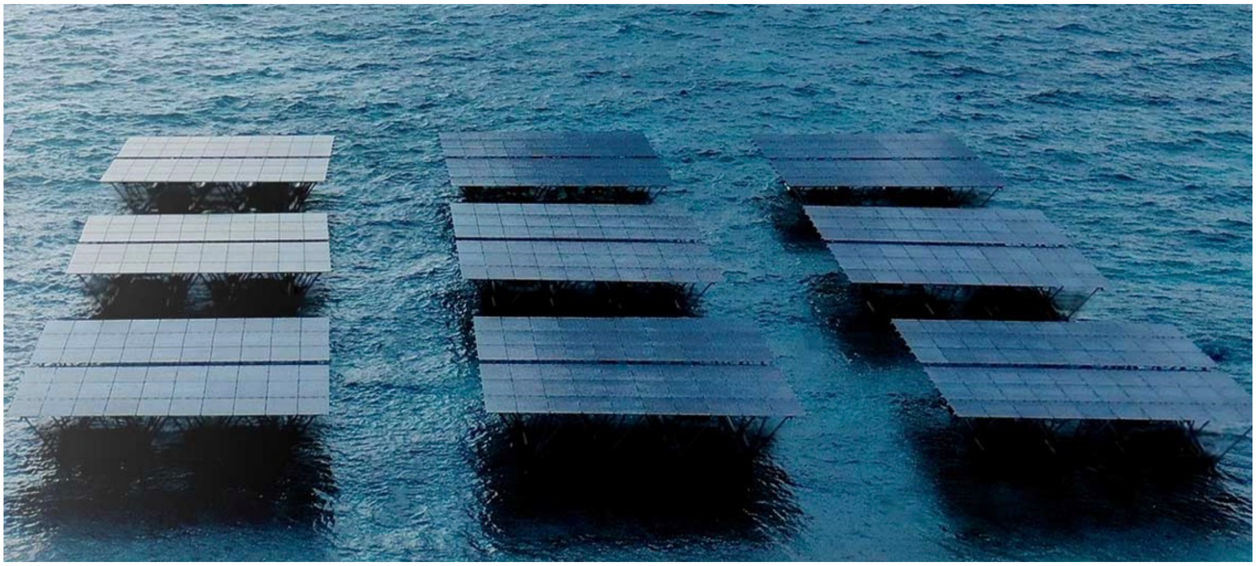
Beneixama – España

C/ Chapaprieta Nave 5. P.I La Casilla
03460 – Beneixama (Alicante)
Write to us and we will get back to you as soon as possible

isifloating@isigenere.com

SolarSea - Floating Solar Systems

In 2014, Swimsol launched the world's **first floating solar solution for the sea**. SolarSea™ is a commercial renewable energy product that creates space for solar panels on the sea surface.



SolarSea™ consists of separate floating platforms of 196m² that can be arranged in a system of any required size. Each platform is equipped with 25 kW of marine grade solar panels.

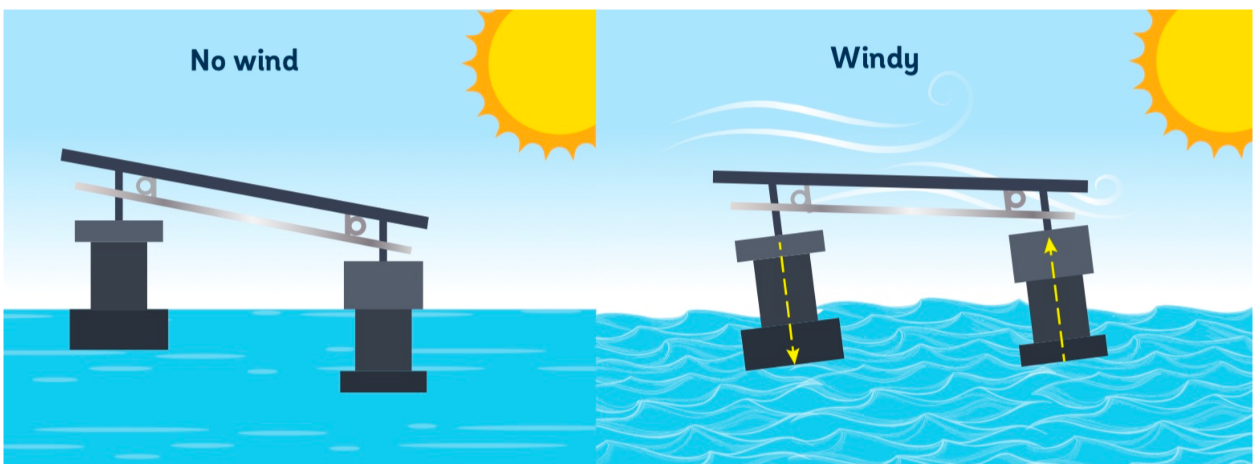
Patented Floating Solar Structure The development of the unique floating solar platform took more than four years of computer simulations, tests, and trials with the help of Vienna University of Technology. The platform can survive waves of tropical shallow water lagoons, as well as the currents, tides, extreme UV, humidity and is corrosion-proof.

Working with electronics in the tropical marine environment is a challenge. We, therefore, searched for high-quality components, subjected them to stress testing and selected only the best for our systems. We use heavy-duty, high-performance panels developed specifically for tropical marine regions, and our systems have a lifetime of around 30 years.

"We wanted to bring solar energy to places where there is no space on land for the panels. So, we put them on the seawater" – Martin Putschek, Managing Director.

SolarSea Goldeggasse 2/3, 1040 Vienna, Austria

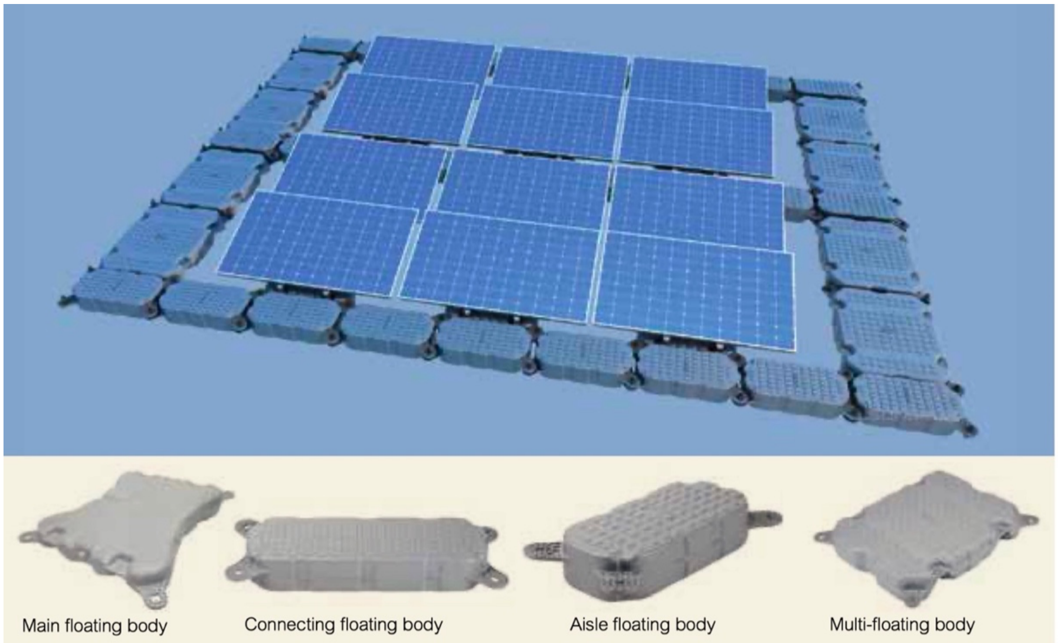
Solaris



SolarisFloat is a Portuguese business group with an international presence in more than 70 countries, primarily operating in the ICT sector, but also in complementing areas that reinforce and enhance the value of the solutions offered to the market.

Made of modular floating platforms with tracking capabilities, this floating photovoltaic solar system is a modular, detachable, scalable, reliable solution, with an easy installation process.

Solaris Synergy (Israel) Ltd.



Sungrow Source: © Sungrow.

Sungrow USA Corporation
Phoenix Arizona
+1 833 747 6937
techsupport@sungrow-na.com

These platforms by eight different companies represent many different approaches to floating photovoltaics and a huge amount of combined research. Despite all of the innovation involved, none of them may be ideally suited to pulling a floating photovoltaic behind a ship. There are three issues involved.

1. First, it will be necessary to determine if an additional power source is even necessary.

2. Second, if it is determined that it is necessary, would it be best to have the naval engineers who are designing the OAE ship, review what these companies have done and design their own floating photovoltaic platform?

3. Alternatively, we could contract with one of the companies whose platforms is closest to being suitable for the needs of the ship and have them design a platform that is best suited for use with OAE ships.

Appendix J: A 3-site Research Project

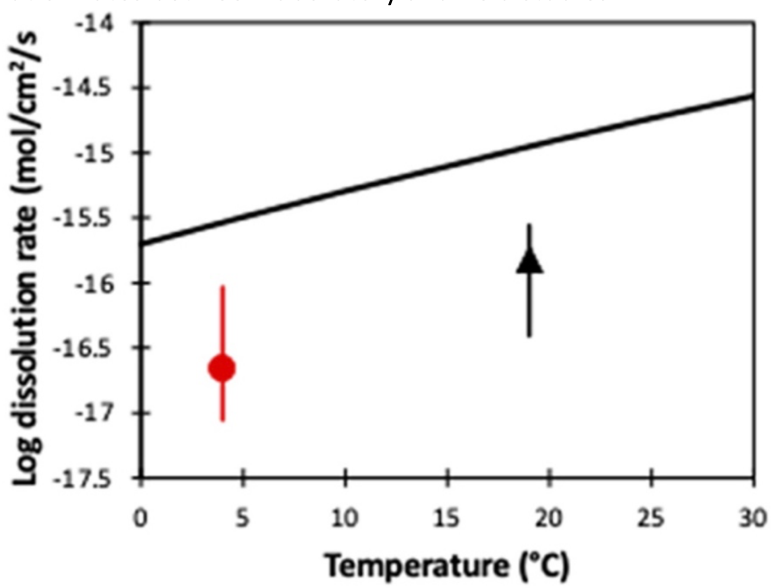
(We initially included this in the document. But several subsequent research reports have covered much of this ground, allowing us to focus on designing eOAE ships.)

The Basic Plan Essentially this research proposal will set up three field research plots. One in a **wet, tropical rapid weathering hot spot, one in a wet temperate site, and one in a dryer temperate site.** We propose that the wet tropical site will be in Ecuador, Columbia or Central America, the wet temperate site in Mississippi, Alabama, Georgia or Florida, and the drier temperate site in a Midwestern state.

Field studies, rather than laboratory research into weathering is critical since it is known that laboratory-based rates can be **1 to 5 orders of magnitude greater than those measured in the field** (White, 1995, White and Brantley, 2003; Maher et al., 2004; Maher, 2010; Zhu, 2005).

The opposite side of the issue comes from **Schuiling - The rate of olivine weathering, an expensive myth.** He claims the opposite, that **the rate of olivine weathering in nature is much faster than the laboratory**. The reader is referred to his web site for a discussion of why he feels this way. **White, A.F. (1995)** reported the weathering for two minerals, oligoclase and hornblende, where data on rates was available for both "soil" and "experimental". **The rates for soil were 1 to 4 orders of magnitude lower than for experimental rates.**

Pogge von Strandmann et al (2022) provided the following diagram illustrating the differences in dissolution rates between laboratory and field studies.



From Pogge von Strandmann et al, (2022). The top line represents dissolution rates of olivine at different temperatures based on laboratory studies. The black triangle represents the dissolution rate for field studies at about 19^{o}C while the red circle represents the slower field rate at 4^{o}C.

These studies and their opposing opinions illustrate one of the reasons why a **3-Site Research Project is important**. Before describing the project, a review of the methods of testing weathering rates is relevant.

Testing Weathering Rates In the field, mineral dissolution rates can be quantified by analyzing river water chemistry in a watershed (April et al., 1986), studying weathering rinds (Sak et al., 2004), or by determining a mineral or chemical depletion profile throughout a soil column samples (White and Brantley, 2003). Testing river water is clearly not suitable for the 3-site study since the conditions at each size are quite different.

Weathering rinds are defined as discolored and permeable crusts enriched in immobile oxides (i.e., Fe_2O_3, TiO_2 and Al_2O_3) relative to un-weathered cores. Measuring weathering rind thickness is easily done in the field making rinds an effective tool for determining the relative degree of surficial deposit weathering. This technique is most suited to large non-pulverized rocks. It will not be suitable for particles in the 1 to 30 um range.

Thus, **analyzing core samples (White and Brantley 1995, 2003) is clearly best suited to produce results that can be compared between the three sites and is suitable for small particle size.** The average **silicate weathering rate R** (mol/m^2/s) or (mol m^{-2}s^{-1}) is commonly defined by the relationship

$$R = Q/St \qquad \text{Eq 1}$$

where Q is the moles of a mineral reacted, S (m^2) is the surface area and t (in seconds) is time.

As an example, column studies, using freshly prepared Panola Granite, produced ambient plagioclase weathering rates that decreased parabolically over 6 years to a final rate of 7.0×10^{-14} mol/m^2/s (White and Brantley, 2003).

Methods included solid-state compositions determined by X-ray fluorescence analyses (XRF), alkalinity and pH measured using an auto-titrator, and **solute cations** were determined by **ICP/MS - Inductively Coupled Plasma Mass Spectrometry.** This is an analytical technique that can be used to measure elements at trace levels in fluids. This has replaced older techniques such as atomic absorption and atomic emission.

Weathering rates are normalized to the surface areas of the reacting silicates, based either on gas sorption isotherms (BET) or geometric estimates (GEO). BET values are incorporated into almost all the experimental rate data.

BET refers to **Brunauer–Emmett–Teller** theory that aims to explain the physical adsorption of gas molecules on a solid surface and serves as the basis for an important analysis technique for the **measurement of the specific surface area of materials.** The observations are very often referred to as physical adsorption or physisorption.

In 1938, Stephen **B**runauer, Paul Hugh **E**mmett, and Edward **T**eller published the first article about the BET theory in the Journal of the American Chemical Society. The BET theory applies to systems of multilayer adsorption and usually utilizes probing gases (called the adsorbent) that do not chemically react with material surfaces as adsorbates (the material upon which the gas attaches to and the gas phase is called the adsorptive) to quantify specific surface area. **Nitrogen** is the most commonly employed gaseous adsorbate used for surface probing by BET methods. For this reason, standard BET analysis is most often conducted at the boiling temperature of N_2 (77 K). Other gases have included argon, carbon dioxide, and water Wikipedia. A Quantachrome NovaWin BET Analyzer can be used to determine pore volume and surface area of the mineral samples using the BET method.

The scale of geometric surface area measurements, using microscopic techniques such as SEM (Dorn, 1995) and AFM (Brantley et al., 1999), is orders of magnitude greater than the atomic scale of the BET methods. This discrepancy is responsible for consistently higher reported BET surface areas compared to geometric estimates. The calculated weathering rates are inversely related to the surface area (Eq 1). This difference partly explains why most of the natural rates, based on geometric estimates, are faster than experimental rates based on BET estimates. A general relationship of decreasing weathering rate with increasing time was clearly evident for plagioclase (White and Brantley, 2003).

Some workers have suggested that geometric (GEO) rather than BET surface areas may be more representative of reactive surface areas in the weathering environment (White et al., 1996; Gautier et al., 2001). If such a situation is true, the question is raised as to whether the large apparent decreases in weathering rates with time are artifacts based on a normalization using BET measurements which overestimate actual increases in reactive surface area with time.

Other methods and instruments (Swanson, 2014).

• A laser-based particle sizer (Beckman Coulter, Inc., LS 13 320 MW) to determine the mean particle size and particle size distributions.

• Wavelength Dispersion X-Ray Fluorescence (WD-XRF, Pananalytical Axios).

• X-Ray Diffraction (XRD 3000, Inel Inc.) in the range of 20º and 80º and CuKα radiation (λ = 1.5406 Å) to determine the chemical compositions and the crystalline structures of the mineral samples, respectively.

• Loss of Ignition (LOI) test to quantify the water content in the mineral samples.

Common Laboratory Given the wide range of expensive instruments required, using a university lab already set up makes the most sense. A single, common laboratory for the analysis of soil samples throughout the study should be located in the US. We would incorporate such a laboratory as an integral part of the study with input into the study design.

Types of rock Three different classes of ultramafic and mafic rocks will be studied – **olivine, serpentine and basalt.**

Particle Size is an important variable to be tested in the 3-site studies. Average sizes of 1 um, 10 um, 30 um and ≥ 100 um seem reasonable. If it proves difficult to sort the samples into different particle sizes, they may be separated on the basis of the duration of grinding followed by a determination of the range of sizes in the sample. Alternatively, with **attrition grinding** the size of the particles will be set by the size of the pores in the pore plate.

Grinding method There will be a need to choose the best method of producing small particle sizes, such as ball mills plus attrition grinding. One question for serpentines will be - is there a need for concurrent grinding in the presence of heat? If so, this would require the purchase or development of an apparatus combining the two. As shown in the **Appendix G. Final Stage Grinders** the ACU group developed such a machine for laboratory studies. A much larger one would be required for field studies. See also below under encouraging creativity.

Use of tailings Some of the macro-plots will be used to test the utility of using tailings as a source of EW rocks.

Test for microorganisms such as bacteria, viruses and fungi which can play an important role in EW. Metagenomic analysis of soil DNA samples may be the best method to do this. We may need to include a microbiologist on the staff to do these analyses. This person would do the testing at all three sites.

Testing the effect of fungi on dissolution rates R. D. Schuiling (2013) has suggested that the dissolution rates of olivine as determined in the laboratory grossly underestimates the speed actual rate in the soil in nature because it fails to consider the effect of fungi on the dissolution. He stated, “One may wonder why there is such a large discrepancy between laboratory experiments, showing low rates of weathering, and the real world, where weathering rates are 100 times larger. The answer is relatively simple. Higher plants live in symbiosis with mycorrhizal fungi in and around their root system. These fungi secrete low molecular organic acids like acetic acid, malic acid and oxalic acid that rapidly attack mineral grains in the soil (Van Schöll et al, 2008). This liberates mineral nutrients that are subsequently taken up by the higher plants. In turn, the higher plants “reward” the fungi by providing them sugars. Lichens act in a similar way by secreting oxalic acid that “eats” the underlying rock (Wilson et al, 1981). In the laboratory, mycorrhizal fungi and lichens are absent, and this is the reason why the abiotic reaction rates that were found in the laboratory are much lower than weathering rates in nature.”

Schuiling based his rates on dissolution of olivine in natural conditions on studies of a lateritic crust in Conakry Guinea. Laterite is an iron rich iron-rich insoluble red residue of the dunite after deep tropical weathering. It no longer contains silica, magnesium, or calcium oxides. These were completely leached out during the weathering process (Percival,1965). This somewhat roundabout method needs to be verified by direct studies of olivine weathering in natural soils, something our 3-site study will do.

In the meantime, Schuiling makes an interesting point. At a minimum this suggests that we need a mycologist on the team to both test for the presence of fungi in our different test plots and more importantly, determine if seeding the test plot with the appropriate fungi spores could assist in the more rapid dissolution of the ultramafic rocks spread on both cropland and non-cropland. If it is possible, for example, to increase the dissolution from 100 years to one year, this would be a game changer.

Different species of fungi produce different rate of rock eating (Van Schöll et al, 2008), which is another reason for having a mycologist on the team. Studies of the effect of different species on the dissolution rates of olivine and serpentine would be an important adjunct to the 3-site study. Determining which fungi species are most effective at assisting the dissolution of olivine and serpentine could be undertaken both at the 3-site research site and independently of this site. The Comings Foundation may fund such studies.

Articles as a Source of Methods Several articles contain detailed descriptions of some of the methods that will need to be used in these studies. The report of Amann et al (2020), Swanson (2014), and White and Brantley (2003) are good examples.

Uniformity of All Study Sites. For accurate comparison of the results at each site it will be critical that studies at each of the three sites be carried out in an identical fashion. Thus, they will all use the same source of olivine, serpentine and basalt, the same common laboratory for analyses, and the same research plan. The level of nickel and chromium will be determined before being used. An exception to this uniformity is listed below under Encouraging Creativity.

Solar Panels. A portion of the acreage will be set aside for solar panels. Renforth (2012) calculated that it would require 1.5 GJ to grind 1 ton of olivine to 1 um or less. In the conversion of GJ to kWh, 1 GJ = 278 kWh. One acre (4,000 m^2) of modern solar panels can produce 4,000 kWh of electricity. Since there will be other needs for electricity such as testing the value of pretreatment of serpentines with heat, we anticipate that the placement of solar panels on one-half acre of land should be adequate. It the area is windy wind turbines could also be used.

How much land will be needed? Macro- and Mini plots. This can best be estimated from the bottom up. We start with the proposed size of each individual test plot. We believe that a plot 8 meters on a side is reasonable i.e., 64 m^2, is reasonable for the average test plot. These are called **macroplots**. In addition, some macroplots will be divided into four **miniplots** each 4 m on a side for 16 m^2 (somewhat less since there will be a ½ meter path between the internal parts of the miniplots).

Each 64 m^2 plot should be surrounded on all four sides with a 4-meter-wide border to allow safe separation of each test plot and room to walk and drive tractors between them. Since adjacent plots share borders, this is equivalent to 2 more meters around each for a plot total size of 12 m on a size or 144 m^2.

Five different crops: none, corn, wheat, barley, and alfalfa.

Five different rock sizes: 0 (no rocks), 1 um, 10 um, 30 um, 100 um and >300 um. As above these may represent different grinding times producing groups with an average of particle size.

Four different rocks: olivine, basalt, and serpentine, and none.

We would multiply this by 1.5 this to provide plenty of micro-plots – 400 of them in all. We do not anticipate using all of them but better to have too many than too few.

Thus 5 x 5 x 4 x 1.5 = 150 macro-plots x 144 m^2 for a total of 21,600 m^2. We would double that to have land for solar panels and buildings (storage, test labs, administration and lodging. Thus, the total area = 43,200 m^2 = 10.6 acres per site.

Since this is not a large amount of land, we would buy it rather than lease it. This way it would allow the studies to go on for many years, if we wished.

How much does the land cost? An acre of land in the U.S. ranges from about $2,500 in Mississippi to about $8,500 in Illinois, or $25,000 to $85,000 per research plot in the U.S. The prices are somewhat comparable in Ecuador.

Specialized Mini plots The average test plot will be 8 m on a side. However, we will also set aside a large number of 4 m on a side mini plot (4 per 8 m plot) with a two-foot path between the internal boundaries. This makes it possible to answer a number of specialized questions with the minimum use of land. The following are some examples of this use of mini plots:

• **Maximum thickness of rock**? What is the maximum thickness of olivine that can be placed on croplands or non-croplands and still sequester CO_2? The findings in Oman (Fox, 2021) suggested that the layers can be very thick. This could be tested by using several miniplots each covered with increasing amounts of olivine ground to different sizes. This might show, for example, that in a weathering hot spot, olivine can be spread very thickly and still sequester CO_2. It would also determine that maximum thickness that could be applied in the wet temperate and dry temperate sites. **This could result in a dramatic decrease in estimates of the amount of land required to successfully sequester CO_2.**

• **Methods of increasing thickness of sequestering rock on non-croplands.** If one were trying to maximize the amount of finely ground ultramafic that could be used to sequester CO_2, one question is whether there was some type of **supporting matrix** that could hold multiple layers the fine rock powder thus increasing their exposure to the air. If, for example, this could lead to a 10-fold increase in efficiency, instead of using 100 acres only 10 acres would be needed. Pondering this question has led us to the possibility that **the best matrix would be more coarsely ground rocks with the fine powder spread between them.** This would be especially useful on non-croplands. Multiple microplots could be devoted to determining the best size of the larger rocks and the maximum ratio between the two.

This raises the possibility that we could fund independent research into the question - Is it possible to develop an inexpensive matrix that would dramatically increase the amount of pulverized olivine exposed to the air?

• **Effect of ultramafic rocks on different soils?** The following type of soils could be brought in from around the world: acid, oxisol, ultisol and other, to test for the effectiveness of ultramafic rocks to convert them to being usable for crops. Given the small size of the miniplots the amount of soil brought in would be small. This would avoid the need to set up additional studies in other countries or areas with these soils.

• Effect of added water? The formula for the dissolution of ultramafic rocks includes 4 moles of water. Since water is so critical, one or more of the mini plots will be treated with various levels of watering. This will probably be most informative for the Midwest sites. This may indicate the maximum effective rate of watering.

• **Role of fungi and bacteria**? Different miniplots could be seeded with certain fungi or microorganisms to test their effect of the rate of dissolution of the rocks.

• **Effectiveness of *Alyssum* plants to extract nickel**? Several mini plots could be planted with varying amounts of *Alyssum* to determine its effectiveness in extracting nickel from crushed olivine and serpentines. Periodic core samples of soil will be tested for Ni and Cr. We will also attempt to determine if electrolysis techniques can be used to extract nickel from the ground rocks. Surhoff (2022) listed a number of other plants that are Ni accumulators.

• **Effect of ultramafic rocks on growing vegetables**? The emphasis in the few field studies reported has been on the effect of ultramafic rocks on grains such as wheat, corn, and barley. A number of mini plots could be set aside to test the effectiveness of ultramafic rocks on vegetables such as lettuce, carrots, potatoes, strawberries, squash, and others.

• **The need for pretreatments of serpentines?** The majority of laboratory studies on the dissolution of serpentines have suggested the need for pretreatments such as heat, acid, concurrent grinding, and others. A number of mini plots could be used to determine the effectiveness of these pretreatments versus only grinding. There are two considerations: are the pretreatments advantageous and if so, are they economically feasible? If they have high energy needs can the solar panels cover it?

• **Encourage Creativity with Site Specific Research.** In addition to the research done in the same way by all sites, some of the microplots can be used by the PI's and their staff to test their own pet ideas, such as testing different types of pre-treatments, different types of grinding, different types of crops, etc. If these seem promising, in the following years they will also be performed at all sites.

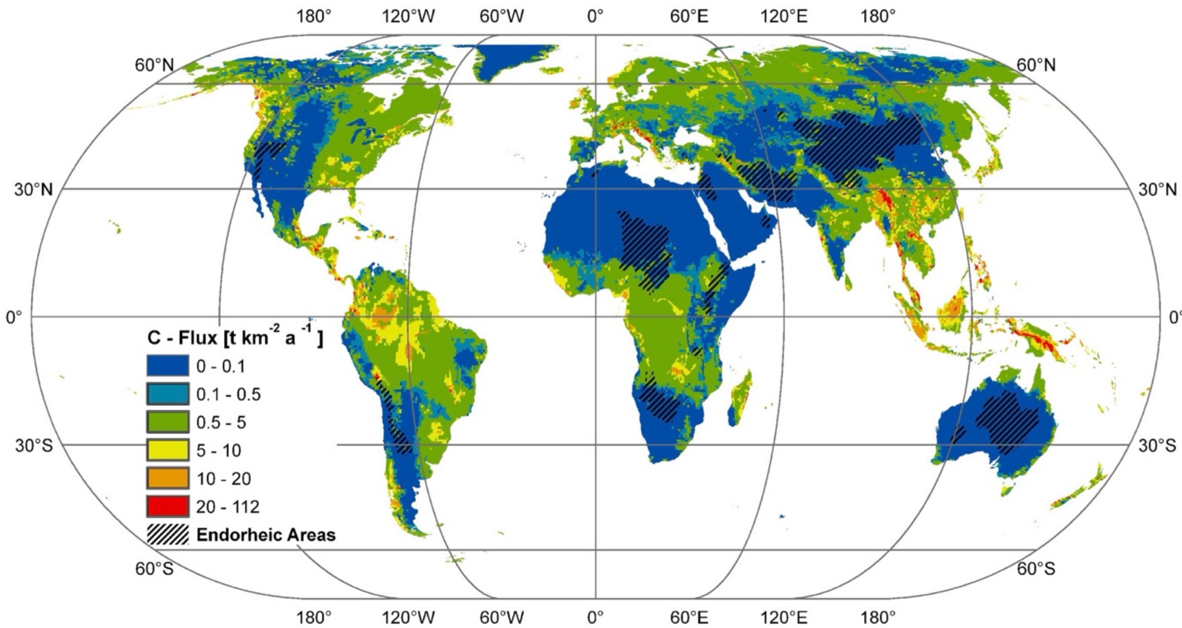
• **Effect of Climate Rocks on Lawns.** This would involve planting grass in a miniplots and examining the progress of climate rock dissolution.

Ecuador's Contribution For the purpose of national pride we would encourage Ecuador to fund and staff the research site in their country. The PI's for each of the three plots and for the whole project will all play a role in the final design and execution of the 3-site research.

Goals The following are some of the questions and goals:

- Examine four different crops treated and untreated on macro-plots.
- Have many additional macroplots for research flexibility.
- Have multiple microplots for a wide range of studies including a range of vegetables, different pre-treatments, grinding methods and other.
- Determine the percent improvement in crop growth for the different crops.
- Can serpentines be used with grinding only or are other pretreatments needed?
- Compare the weathering rate of olivine versus serpentine versus basalt at each site.
- Compare the weathering rates for different sized particles.
- Determine the ideal particle size for both olivine and serpentine and basalt.
- Determine the ideal method of grinding. Roller mills, attrition grinding, centrifugal grinding, and others singly or in tandem. Also examine wet or dry grinding or both.
- Determine if concurrent grinding with heat is required for serpentines or if grinding alone is adequate.
- Determine the amounts of nickel and chromium, and other metals that are leached into the soil.
- Determine if plants such as *Alyssum* can be used to sequester nickel and if that nickel can be economically recovered.
- Determine if electrolysis or other methods can be used to extract Ni and Cr from the ground particles.
- Do we need to hire an experienced soil chemist and soil microbiologist to assist with or run the studies?
- Determine the degree of increase in weathering in the hot spots compared to temperate wet and temperate dry spots. Focusing on moist tropics has been stated to produces 29 times more rapid weathering than dry, temperate climates, and focusing on tropical "weathering hot spots" leads up to a further 5-10-fold increase in weathering (see above). This suggests that the exclusive use of hot spots would produce a weathering rate of 29 x 5 or 145 x that of temperate dry areas in the US. Clearly these would be the areas to use. This might dramatically change some of the above negative thoughts about EW. This research would determine if this degree of increase in EW is valid.

Where would the hot spot test site be located? Hartmann et al (2009a) published **hot spot map for the world**.



This shows that some potential hot spots for this study, in the Western Hemisphere, are in Columbia, Ecuador and Central America.

Duration of Study The studies of White and Brantley (2003) had an unusually long duration of 6 years. We anticipate that with much smaller particle sizes, the duration of the study needed to return good data can be considerably shorter, such as 2 to 4 years. However, it is also likely that important information will be obtained by continuing the studies for longer periods of time. We do not believe it will be necessary to wait for these longer times to begin EW in countries throughout the world. **The 3-site study will inform ongoing EW with information on the relative value of focusing on weathering hot spots, optimal particle size, methods of grinding, methods of removing nickel if necessary, and other results.**

Advisory Group. We propose to engage with a number of the authors of previous studies (above) to serve as advisors on the study. We hope that one of these advisors will become the PIs for the study or suggest a suitable candidate. We will also need associate PI's monitoring each site. In the **Carbon 180 Zero then Negative** - The Congressional Blueprint for Scaling Carbon Removal, May 2021, proposed as their action #11 - Create an RD&D program for enhanced CO_2 mineralization. **This would be just such a research program**. If the resources of the Comings Foundation are not adequate to cover these research expenditures, outside funds would be welcome.

There are several advantages of funding such studies through a private foundation.

1. If the foundation develops a sizable endowment and runs on the return on investments, some types of research can run for much longer periods of time than usually allowed by federal grants. If our advisory team feels that continuing the 3-site research for longer periods of time would be productive, with an adequate endowment, we could do so.

2. Funding is very nimble and can respond quickly to changes in direction dictated by results.

3. Probability of funding is certain. Probability of federal funding is uncertain.