FROM ASTRONOMY TO INDUSTRY

ELF, ULF APPLICATIONS: BIOFOULING CONTROL OF SEAWATER INTAKE CULVERTS AT LAKVIJAYA COAL POWER STATION, SRI LANKA.

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ABSTRACT

The advancements in astronomical technologies, particularly in the domains of Ultra-Low Frequency (ULF) and Extremely Low Frequency (ELF), have transcended their original scientific purposes to address a wide range of industrial and environmental challenges. Technologies such as Charge-Coupled Devices (CCDs) and advanced imaging techniques, initially developed for astronomical observations, have found extensive applications in fields such as medical imaging, photography, and consumer electronics. However, the utilization of ULF and ELF frequencies represents a particularly significant crossover, offering innovative solutions to complex problems. This report examines the astronomical foundations of ULF and ELF technologies and their subsequent adaptation for industrial and environmental applications. A notable example is the application of ULF technology for biofouling control in seawater intake culverts at the Puttalam Coal Power Plant (Norochcholai Coal Power Plant or Lakvijaya Power Plant) in Sri Lanka. This solution, developed by Ecospec and ATS, leverages ULF frequencies to prevent the accumulation of marine organisms, thereby enhancing operational efficiency and reducing environmental impact. Ecospec, a green technology company, exemplifies the integration of scientific innovation with environmental stewardship. By prioritizing research and development, Ecospec has introduced cutting-edge technologies that not only address industrial challenges but also contribute to global sustainability efforts. The application of ULF technology for biofouling control is a testament to the potential of astronomical advancements to drive environmentally conscious solutions. Such innovations highlight the importance of interdisciplinary approaches in tackling contemporary environmental and industrial issues, ultimately fostering a more sustainable future.

Astronomical Approach | ELF | ULF

Extremely low-frequency (ELF) waves, ranging between 5 and 100 Hz, are of significant interest for submarine communication systems due to their unique propagation characteristics in seawater. The relatively weak absorption of electromagnetic radiation at these frequencies by seawater, combined with the prominent resonances of the natural cavity formed by the Earth and the ionosphere, makes this frequency range particularly attractive for long-range underwater communication (Barr et al., 2000). These properties enable ELF waves to penetrate deep into the ocean, facilitating reliable communication with submerged submarines. In contrast, ultra-low frequency (ULF) waves, typically in the millihertz to hertz range, play a critical role in the transmission of energy and momentum within magnetized plasma environments. ULF waves have been observed ubiquitously in the magnetospheres of various planets, including Earth, Saturn, and Jupiter (Southwood & Kivelson, 1981; Zarka et al., 2001). These waves are particularly significant for their role in radiation belt dynamics, where they contribute to both the energization and decay of high-energy particles trapped in planetary magnetic fields. For instance, ULF waves have been shown to modulate the radiation belts of Earth, Saturn, and Jupiter, influencing the distribution and behavior of charged particles in these regions (Elkington et al., 2003; Mann et al., 2013).

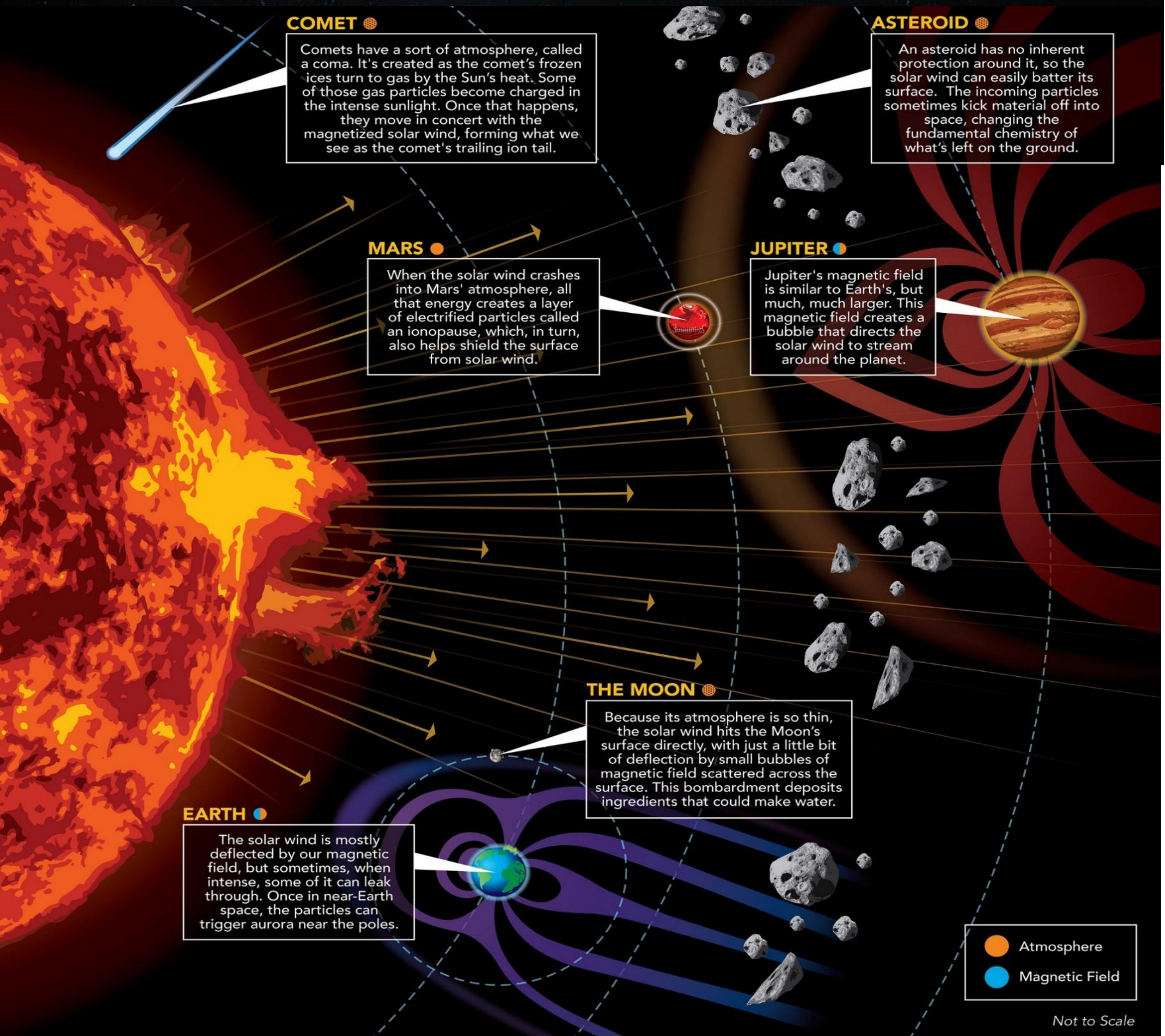
ULF waves can also manifest as field line resonances (FLRs), which have been observed in the magnetospheres of Earth, Mercury, Saturn, and Jupiter (Anderson et al., 1990; Glassmeier et al., 2004). These resonances occur when standing waves form along magnetic field lines, leading to localized plasma oscillations that can impact auroral processes and plasma distributions. For example, FLRs have been linked to the generation of auroral emissions and the modulation of plasma densities in the magnetospheres of these planets (Wright & Mann, 2006).

The generation mechanisms of ULF waves in planetary magnetospheres are often associated with solar wind interactions and plasma instabilities. These processes are common across different magnetospheric environments, but the specific dynamics of ULF waves can vary depending on the local plasma conditions and magnetic field configurations (Kivelson & Southwood, 1985). The similarities and differences in ULF wave behavior across these environments provide valuable insights into the fundamental physics of magnetospheric dynamics and the influence of environmental factors on wave propagation and interaction.

The study of ULF waves has been greatly advanced by the availability of extensive observational data from ground-based instruments and spacecraft missions. For example, ground-based networks such as SuperDARN and magnetometer arrays have provided detailed measurements of ULF waves at Earth (Greenwald et al., 1995). Similarly, spacecraft missions such as the Van Allen Probes, Arase, THEMIS, MESSENGER, Juno, and Cassini have enabled in-situ observations of ULF waves at Mercury, Earth, Jupiter, and Saturn (Mauk et al., 2013; Kasahara et al., 2018). These observations, combined with theoretical modeling, have been instrumental in advancing our understanding of ULF wave processes and their implications for magnetospheric physics.

Figure 01: When the solar wind encounters a planet or moon, its effects depend largely on the presence or absence of protective mechanisms such as an atmosphere, a magnetic field, or both. For example, planets like Earth, which possess a strong intrinsic magnetic field, are largely shielded from the direct impact of solar wind particles. The Earth's magnetosphere deflects the charged particles, channeling them toward the polar regions, where they interact with the upper atmosphere to produce spectacular auroras. Similarly, gas giants like Jupiter and Saturn, with their robust magnetic fields, exhibit similar deflection and auroral phenomena on a much grander scale. In contrast, celestial bodies lacking a significant magnetic field or atmosphere are more vulnerable to the direct impact of the solar wind. For instance, Mercury, despite its proximity to the Sun, has only a weak magnetic field and a tenuous exosphere. As a result, the solar wind can directly interact with its surface, contributing to the sputtering of material and the creation of a thin exosphere composed of atoms ejected from the planet's surface. Similarly, the Moon, which lacks both a global magnetic field and a substantial atmosphere, is bombarded by solar wind particles, which implant themselves into the lunar regolith and alter its chemical composition over time.Mars presents an intermediate case. While it lacks a global magnetic field, it possesses localized crustal magnetic fields that can partially deflect the solar wind. Additionally, its thin atmosphere provides some degree of protection, though not enough to prevent significant erosion of atmospheric particles over geological timescales. This interaction has played a crucial role in the evolution of Mars' climate and surface conditions.

Source: NASA's Goddard Space Flight Center/Mary Pat Hrybyk-Keith



ULF Waves Derived from Ground Magnetometer Measurements

Extremely Low Frequency (ELF) and Ultra-Low Frequency (ULF) electromagnetic fields (EMFs) represent a type of non-ionizing radiation characterized by their long wavelengths and low energy. These fields are part of the electromagnetic spectrum and are typically generated by both natural and anthropogenic sources. While concerns have been raised regarding potential health effects, current scientific evidence does not establish a causal link between ELF-EMF exposure and harmful health outcomes, including cancer. Common sources of ELF-EMFs include power lines, electrical wiring, and household appliances such as electric shavers, hair dryers, and electric blankets. ULF waves, on the other hand, occupy the frequency range between 300 hertz (Hz) and 3 kilohertz (kHz), corresponding to wavelengths from 1000 kilometers (km) to 100 km. In scientific disciplines such as magnetosphere physics and seismology, ULF waves are often defined within narrower frequency bands, such as 1 millihertz (mHz) to 100 Hz or 10 mHz to 10 Hz.

Health and Safety Considerations

ELF-EMFs are a subject of ongoing research due to their pervasive presence in modern environments. Despite widespread exposure, studies have not conclusively demonstrated adverse health effects from ELF-EMF exposure at levels encountered in daily life. Regulatory agencies and health organizations continue to monitor the scientific literature to ensure public safety.

Sources and Applications of ULF Waves

ULF waves are of particular interest in atmospheric and geophysical sciences. In magnetosphere studies, ULF waves are analyzed to understand phenomena such as geomagnetic pulsations, which are categorized into Pc2-Pc5 bands based on their frequency and period. These waves are also used in seismology to study Earth's crustal movements and in atmospheric science to investigate ionospheric dynamics. ULF data products are often derived from the 1-second SuperMAG dataset, a global network of magnetometers providing high-resolution geomagnetic field measurements.

Data Processing and Analysis

The derivation of ULF parameters involves advanced signal processing techniques. Using 1-second SuperMAG data, the following steps are employed:

1. **Component Selection**: The northward (N) and eastward (E) components of the geomagnetic field are used for analysis.

2. **Wavelet Analysis:** A 1-hour segment of geomagnetic data is analyzed using wavelet transforms to identify frequency components within the Pc2-Pc5 bands.

3. **Data Padding**: To minimize edge effects, 30 data points (15 minutes of data) are added to both ends of the 1-hour segment.

4. **Iterative Analysis:** The data segment is shifted forward by 1 hour, and the wavelet analysis is repeated.

5. **Parameter Calculation**: If a power peak is detected within the Pc2-Pc5 bands, key parameters such as amplitude (in nanoteslas, nT), period (in seconds), ellipticity, and azimuthal angle (in degrees) are calculated. Additional parameters, including the Q value, significance level, and component amplitudes, are also computed. If no peak is detected, these parameters are assigned a placeholder value of 999999.

6. **Power Spectral Density (PSD) Estimation**: The integrated power and slope of the PSD are estimated for each time segment, providing insights into the energy distribution of the ULF waves.

Caveats and Data Quality

While the SuperMAG dataset undergoes rigorous correction and validation, the quality of individual station data cannot be guaranteed. Users are encouraged to validate ULF data before use in publications, particularly for coastal stations where the conductivity of seawater may distort measurements—a phenomenon known as the coastal effect. When using SuperMAG-derived ULF data in publications or presentations, proper attribution is required to acknowledge the data source.

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History behind ELF & Alfvén wave

The Coronal Heating Problem

The coronal heating problem remains one of the most intriguing and unresolved questions in heliophysics. It centers on the perplexing observation that the solar corona, the outermost layer of the Sun's atmosphere, exhibits temperatures of approximately one million degrees Kelvin, significantly hotter than the Sun's surface, or photosphere, which measures only a few thousand degrees Kelvin. This phenomenon defies intuitive expectations, as one would anticipate a decrease in temperature with increasing distance from a heat source, particularly given that the photosphere is denser and presumably more capable of generating heat than the tenuous corona. In 1942, Swedish physicist Hannes Alfvén proposed a groundbreaking solution to this problem in his seminal paper published in *Nature*. He introduced the concept of electromagnetic-hydrodynamic waves, now known as Alfvén waves, which could transport energy from the photosphere to the corona, thereby heating it. Alfvén theorized that the Sun's conditions—a conducting plasma immersed in a magnetic field—were ideal for the generation and propagation of such waves. He explained that any motion of the conductive solar plasma within the magnetic field would induce electromotive forces (EMFs), generating electric currents. These currents, in turn, interact with the magnetic field to produce mechanical forces that alter the plasma's motion, creating a self-sustaining wave phenomenon. Alfvén described this as a "combined electromagnetic-hydrodynamic wave," capable of transferring energy across the solar atmosphere.

Alfvén's hypothesis not only provided a potential mechanism for coronal heating but also suggested a connection to other solar phenomena, such as sunspots. His work laid the foundation for modern studies of magnetohydrodynamics (MHD) and has inspired decades of research into the dynamics of the Sun's magnetic field and plasma. Despite significant progress, the coronal heating problem remains an active area of investigation, with Alfvén waves continuing to be a central focus in understanding the complex processes that govern the Sun's atmosphere and its extraordinary temperature distribution.

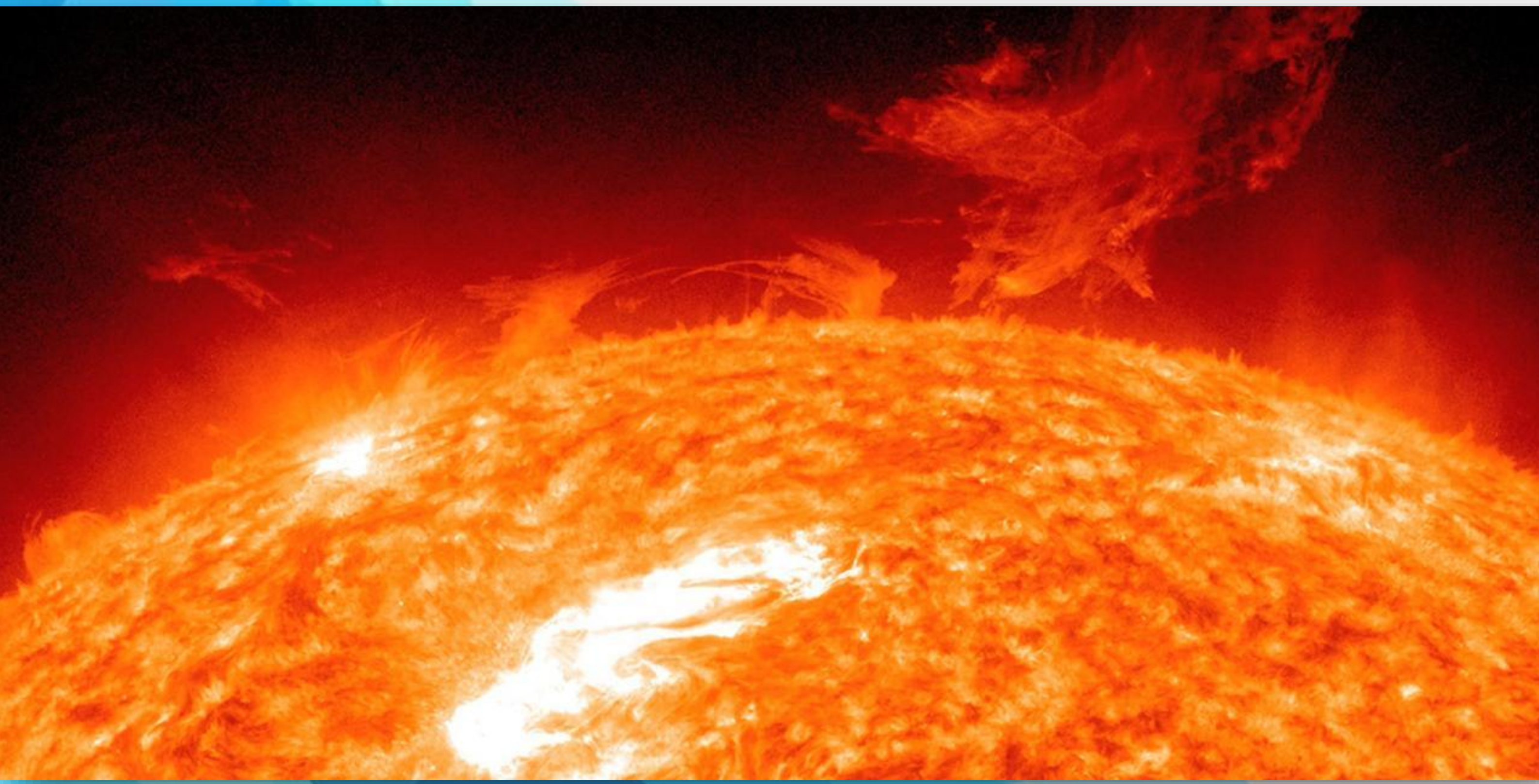


Figure 02: Explore views of active regions on the sun taken by NASA's Solar Dynamics Observatory. (https://svs.gsfc.nasa.gov/11473)

The Sun's convection zone, a region beneath the photosphere where energy is primarily transported by convection, is highly sensitive to the motion of the solar core due to the Sun's rotation. This sensitivity, combined with varying pressure gradients beneath the surface, generates electromagnetic fluctuations within the convection zone. These fluctuations induce random motions on the photospheric surface, producing Alfvén waves—magnetohydrodynamic waves that propagate through ionized plasma. Alfvén waves carry energy and can transport electrically charged plasma, playing a critical role in the dynamics of the solar atmosphere (De Pontieu & Haerendel, 1990; Tomczyk et al., 2007).

In the early 1990s, De Pontieu and Haerendel proposed a connection between Alfvén waves and spicules, which are transient jets of superheated gas observed in the Sun's chromosphere. They theorized that spicules are driven by the combined energy and momentum of their upward velocity and the transverse oscillatory motion of Alfvén waves. This hypothesis suggested that Alfvén waves could contribute to the transport of energy and mass into the solar corona (De Pontieu & Haerendel, 1990).

The first direct observations of Alfvén waves propagating toward the corona were reported by Tomczyk et al. in 2007. However, their study concluded that the energy carried by these waves was insufficient to account for the extreme temperatures of the solar corona, as the observed wave amplitudes were relatively low (0.5 km/s). This finding raised questions about the primary mechanisms responsible for coronal heating (Tomczyk et al., 2007). A breakthrough came in 2011 when McIntosh et al. observed highly energetic Alfvén waves with amplitudes of up to 20.0 km/s, over one hundred times greater than those reported in 2007. These waves, combined with energetic spicules, were found to carry sufficient energy to sustain the corona's million-Kelvin temperatures. The short period of these waves also facilitated more efficient energy transfer into the coronal atmosphere. Additionally, the 50,000-km-long spicules were suggested to play a role in accelerating the solar wind beyond the corona (McIntosh et al., 2011).

Further advancements in the study of Alfvén waves were made possible by high-resolution observations from instruments such as the Swedish Solar Telescope (SST) and the Hinode satellite. In 2009, Jess et al. reported the first direct detection of long-period (126-700 s) incompressible torsional Alfvén waves in the lower solar atmosphere using H-alpha line-width variations above chromospheric bright points. This discovery provided new insights into the role of Alfvén waves in the solar atmosphere (Jess et al., 2009). Subsequent studies revealed the existence of high-frequency torsional Alfvén waves in the Sun's chromospheric fine-structured flux tubes. In 2017, Srivastava et al. demonstrated that these high-frequency waves carry substantial energy, capable of heating the corona and contributing to the generation of the supersonic solar wind.

MIND-MELTING FACTS ABOUT THE SUN

National Aeronautics and Space Administration

MIND-MELTING FACTS

Temperature vs. Heat

In space, the temperature can be thousands of degrees without "feeling hot" to the touch. Why? *Temperature* measures how fast particles are moving, whereas *heat* measures the total amount of energy that they transfer. Since space is mostly empty, there are very few particles to transfer energy to your hand. Particles may be moving fast (high temperature), but if there are very few of them, they won't transfer much energy (low heat).

The Solar "Surface"

The Sun does not have a solid "surface"– as a giant ball of plasma, or ionized gas, the density gradually increases as you move towards the core. The layer you can see, called the **photosphere**, is just the layer that emits the most light in the visible part of the electromagnetic spectrum. In fact, there are three layers on top of it, but the visible light they emit is too faint to see. Except during a total solar eclipse, when the corona can be seen by the naked eye!

The Puzzle of Coronal Heating

As you walk away from a fire, you expect the temperature to go down. The Sun is quite different: the **corona**, the outermost layer of the Sun, is hotter than the layers immediately below it! Exactly how the corona gets so hot is one of the major unsolved puzzles of heliophysics.

SOLAR WIND

Solar Core

Temperature: More than 27 million °F
Density: 150 g/cm^3
(more than 10 times the density of lead)

Radiative Zone

Temperature: 3.5 million °F
Density: From 20 g/cm^3
(the density of gold)
to 0.2 g/cm^3
(less dense than water)

Convection Zone

Temperature: 3.5 million to 10,000 °F
Density: 2×10^{-7} g/cm^3
(.001% the density of air)

Photosphere (VISIBLE LAYER)

Temperature: 10,000 °F
Density: 10^{-9} g/cm^3
(.00001% the density of air)

Chromosphere

Temperature: 10,000 °F to 36,000 °F
Density: 10^{-12} g/cm^3

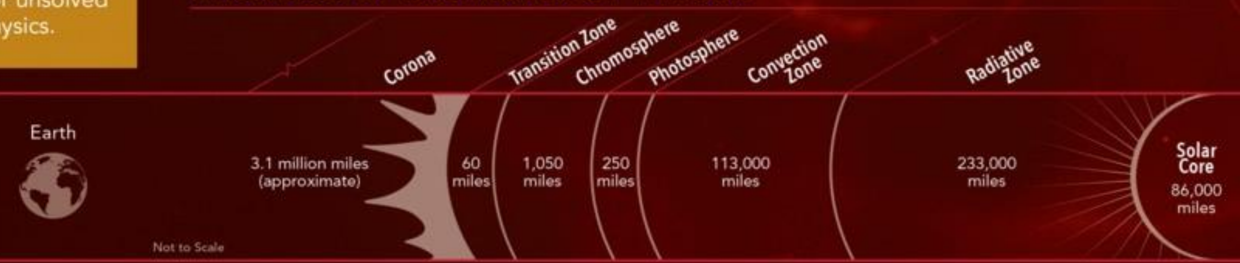
Transition Zone

Temperature: 40,000 °F to 1.8 million °F
Density: 2×10^{-13} g/cm^3

Corona (THE SUN'S ATMOSPHERE)

Temperature: 2 to 3 million °F
Density: 10^{-16} g/cm^3

THICKNESS OF EACH LAYER OF THE SUN



For more information, please visit:
https://science.nasa.gov/heliophysics

Biofouling Control of Seawater Intake Culverts at Puttalam Coal Power Plant

Figure 04: Capturing the impressive second seawater intake head at Lakvijaya Power Plant. A testament to engineering excellence and sustainable energy infrastructure. © Aravinda Ravibhanu, 2017

Figure 05: Barnacles and Slagle removed from the culverts of the Lakvijaya Power Plant. Each year, tons of barnacles are cleared to maintain optimal operations. © Aravinda Ravibhanu, 2017

Research Background

The Puttalam Coal Power Plant, located in the Puttalam District of the Northwestern Province in Sri Lanka, represents a critical infrastructure asset for the nation. Commissioned in early 2010, it is not only the first coal-fired power plant in Sri Lanka but also the largest, with a total generating capacity of 900 MW. As a cornerstone of the country's energy infrastructure, the plant plays a vital role in meeting the growing electricity demand and supporting economic development. However, the operation of such a large-scale facility comes with significant technical and environmental challenges, particularly in managing the cooling systems essential for power generation.

Cooling Systems and Seawater Utilization

In thermal power plants, cooling or condenser water is integral to the power generation process. The Puttalam Coal Power Plant, like many coastal power plants, utilizes seawater as a cost-effective and abundant cooling medium. To facilitate this, the plant is equipped with a purpose-built seawater transfer system. Seawater is drawn through three concrete culverts, each measuring 3 m × 3 m and extending approximately 400 m in length, before reaching the pump house. These culverts are designed to supply cooling water to the three separate power stations within the facility. The reliance on seawater, while economically advantageous, introduces the challenge of biological fouling, which can significantly impact the efficiency and reliability of the cooling system.

Biofouling: Challenges and Implications

Biofouling, the accumulation of marine organisms such as algae, barnacles, and mollusks on submerged surfaces, is an inevitable consequence of seawater usage. In the context of the Puttalam Power Plant, biofouling poses a serious threat to the operational integrity of the seawater intake system. The growth of marine organisms within the culverts can restrict water flow, reducing the effective cross-sectional area of the channels. In severe cases, fouling can extend to the condenser heat exchanger tubes, leading to blockages and impaired heat transfer efficiency. This can result in reduced power generation capacity or even unplanned plant shutdowns, with significant economic repercussions.

Moreover, biofouling can lead to under-deposit corrosion, a phenomenon where localized corrosion occurs beneath fouling deposits. This can cause leaks in the cooling system, exacerbating operational challenges and increasing maintenance costs. The conventional approach to mitigating biofouling involves chemical treatments, such as chlorination. While effective, these methods are associated with high operational costs and secondary environmental contamination, as the discharged chemicals can harm marine ecosystems.

Seeking Sustainable Solutions: ECOSPEC's BioMag System

In response to the challenges posed by biofouling, the Puttalam Coal Power Plant is exploring innovative and sustainable solutions. One promising technology is ECOSPEC's proprietary BioMag system, which employs Ultra-Low Frequency (ULF) electromagnetic wave technology to control biofouling. Unlike chemical treatments, the BioMag system offers a non-invasive and environmentally friendly approach to fouling control. The ULF electromagnetic waves disrupt the cellular processes of marine organisms, preventing their attachment and growth on submerged surfaces without the use of harmful chemicals.

The implementation of the BioMag system at the Puttalam Power Plant could provide several advantages:

1. **Operational Efficiency:** By maintaining unobstructed seawater flow, the system ensures optimal cooling performance, reducing the risk of power generation disruptions.

2. **Cost-Effectiveness**: The elimination of chemical treatments lowers operational costs and minimizes the need for frequent maintenance.

3. **Environmental Sustainability**: The non-chemical nature of the BioMag system aligns with global efforts to reduce the environmental impact of industrial operations, particularly in sensitive marine ecosystems.

The Puttalam Coal Power Plant is a vital component of Sri Lanka's energy infrastructure, but its reliance on seawater for cooling presents unique challenges, particularly in managing biofouling. The adoption of advanced technologies such as ECOSPEC's BioMag system represents a forward-looking approach to addressing these challenges. By combining operational efficiency, cost-effectiveness, and environmental sustainability, the BioMag system offers a compelling solution to ensure the long-term reliability and ecological compatibility of the Puttalam Power Plant's cooling systems. This case underscores the importance of integrating innovative technologies into industrial operations to achieve both economic and environmental objectives including cost-effective mothed. **(Table 01)**

Ampere consumption per hour (Only One plant)	(7200A × (85%) ×60×60 (Processing 60kg Cl^- per hour)
Voltage consumption per hour (Only One plant)	48Vdc
Approximate chlorine dosage for one plant per hour	60KG
Energy consumption for one canal per hour Energy consumption for one canal per day Energy consumption for 3 culvert (6 canals) per day | In optimum conditions only Approximately cost for 2 years | In optimum conditions only. Cleaning & maintainer cost (once in 2year) (Including divers' cost)	293.760 kWh (P=VI | 7200× 0.85 ×48 ×60×60/60×60) 7050.24 kWh (7200× 0.85 ×48 ×60×60/60×60 × 24) 42301.44 kWh (7200× 0.85 ×48 ×60×60/60×60 × 24 ×6) Domestic usage unit mean value 15.00 LKR for one unit and 1 USD =152 LKR **(2017)** [42301.44 kWh ×365× 15/ 152] × 2 =3,047,373.4736842 USD 20,000 USD **[Fixed charges and monthly fuel adjustment charges are not included -year 2017]**

Table 01: Exploring the Cost-Effective Chlorine Generation via Electrolysis: Insights into Extremely Low Frequency Applications and Fundamentals of Biofouling Control– Aravinda Ravibhanu, © 2017

Figure 06: Maintaining Chlorination Systems in Power Plants: A Critical Measure Against Biofouling. The chlorine-generating section of a power plant plays a vital role in preventing the growth of marine biota, which can lead to biofouling. Biofouling not only impairs equipment functionality but also significantly reduces plant efficiency. Effective chlorination is essential to mitigate these risks and ensure optimal operational performance. – Aravinda Ravibhanu © 2017

ULF Bio-Fouling Control

The presence of undesirable organisms on surfaces exposed to water, commonly referred to as bio-fouling, is a persistent and widespread issue affecting various industrial processes. Despite its long-standing prevalence, the industry continues to grapple with the absence of a comprehensive solution to effectively combat this challenge. Traditional methods, such as chemically assisted approaches including chlorination systems, remain widely used but are not without significant drawbacks. These methods often introduce secondary environmental and operational problems, raising concerns about their long-term sustainability.

In an era marked by growing environmental awareness and increasingly stringent regulatory standards, there is an urgent need for innovative solutions that not only achieve effective bio-fouling control but also align with eco-friendly principles. Conventional chemical-based treatments, which rely on toxic substances, are increasingly being restricted or prohibited in many countries due to their potential to cause serious environmental harm. This shift underscores the importance of developing alternative technologies that can deliver reliable performance without contributing to secondary pollution.

To address these challenges, a groundbreaking bio-fouling control solution has been developed: the **BioMag System**. This revolutionary system employs time-varying ultra-low frequency (ULF) technology, offering a true physical control mechanism that effectively mitigates bio-fouling without the use of harmful chemicals. Unlike conventional methods, the BioMag System operates on a non-toxic principle, ensuring compliance with stringent regulatory requirements while safeguarding the environment.

The BioMag System represents a significant leap forward in bio-fouling control, providing industries with a sustainable and efficient alternative to traditional chemical-based approaches. By embracing this innovative technology, businesses can not only meet their operational objectives but also contribute to a cleaner, greener future. As the global community continues to prioritize environmental stewardship, solutions like the BioMag System are poised to play a pivotal role in shaping a more sustainable industrial landscape.

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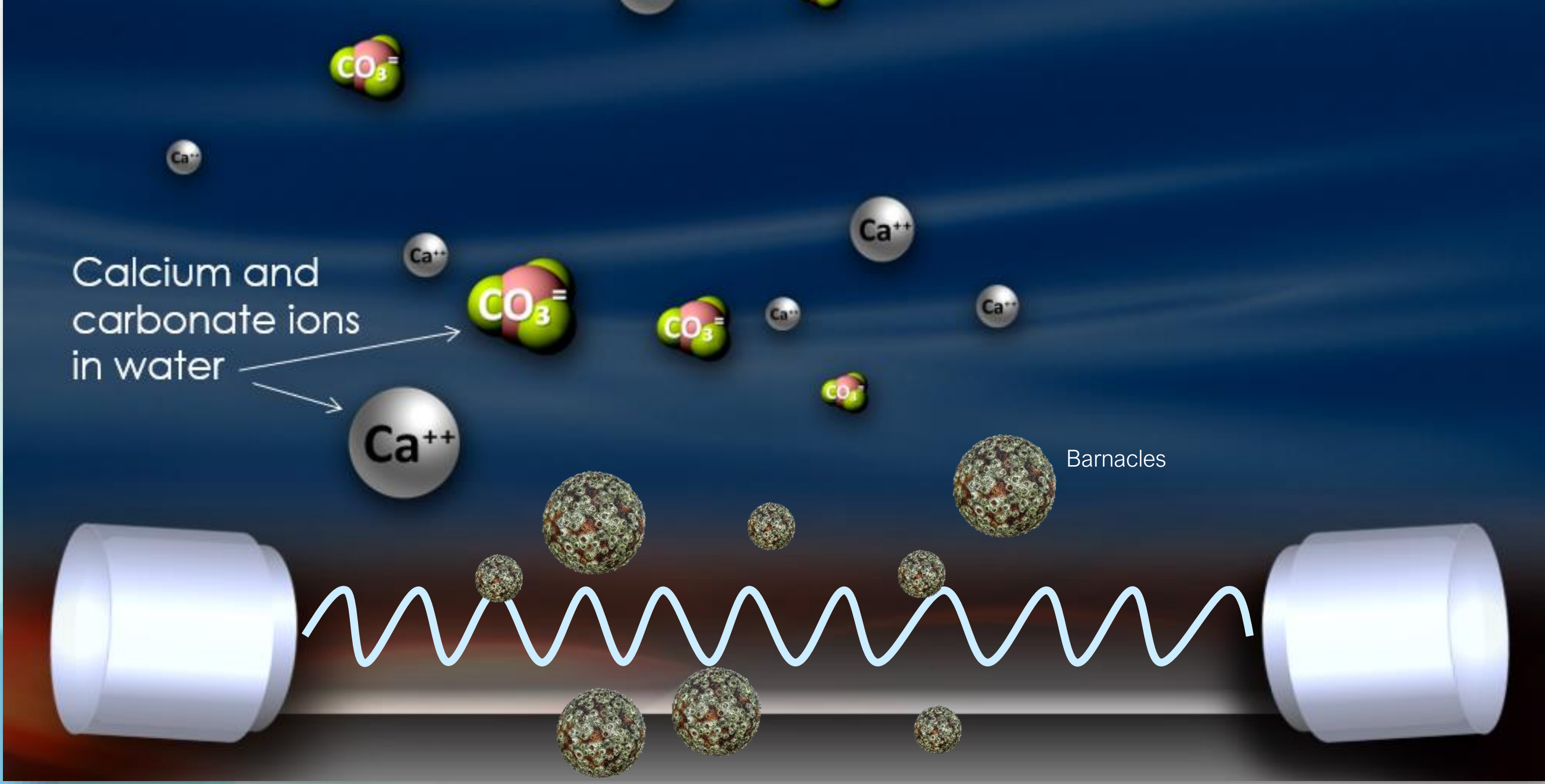


Figure 07: A model of Ulf processing for biofouling control. Ecospec ©2017

BioMag Control Methodologies

Basically, BioMag control method can be generally categorized into two main categories namely,

1. Hot Spot Protection method
2. Bulk Mainstream Protection Method

Hot Spot Protection Method

There are basically two modes can be configured under this particular control method. The first mode as illustrated in Figure 1 involves directly exciting immersed steel or metallic surfaces directly with specific bandwidth of ultra-low frequency electromagnetic wave in pulses form. In turn, the pulsed wave energy energizes the microscopic structure of the excited surface, causing the structure surface to resemble an "electrified" or "hot" surface to micro-organisms. Under such conditions, micro-organisms that tend to adhere to the surface will be deterred from anchoring themselves on these structure surfaces hence achieving an effective fouling control. Meantime, the energized state of the structure surface also inhibits the growth of bio-film and reduces the seeding sites for fouling to propagate.

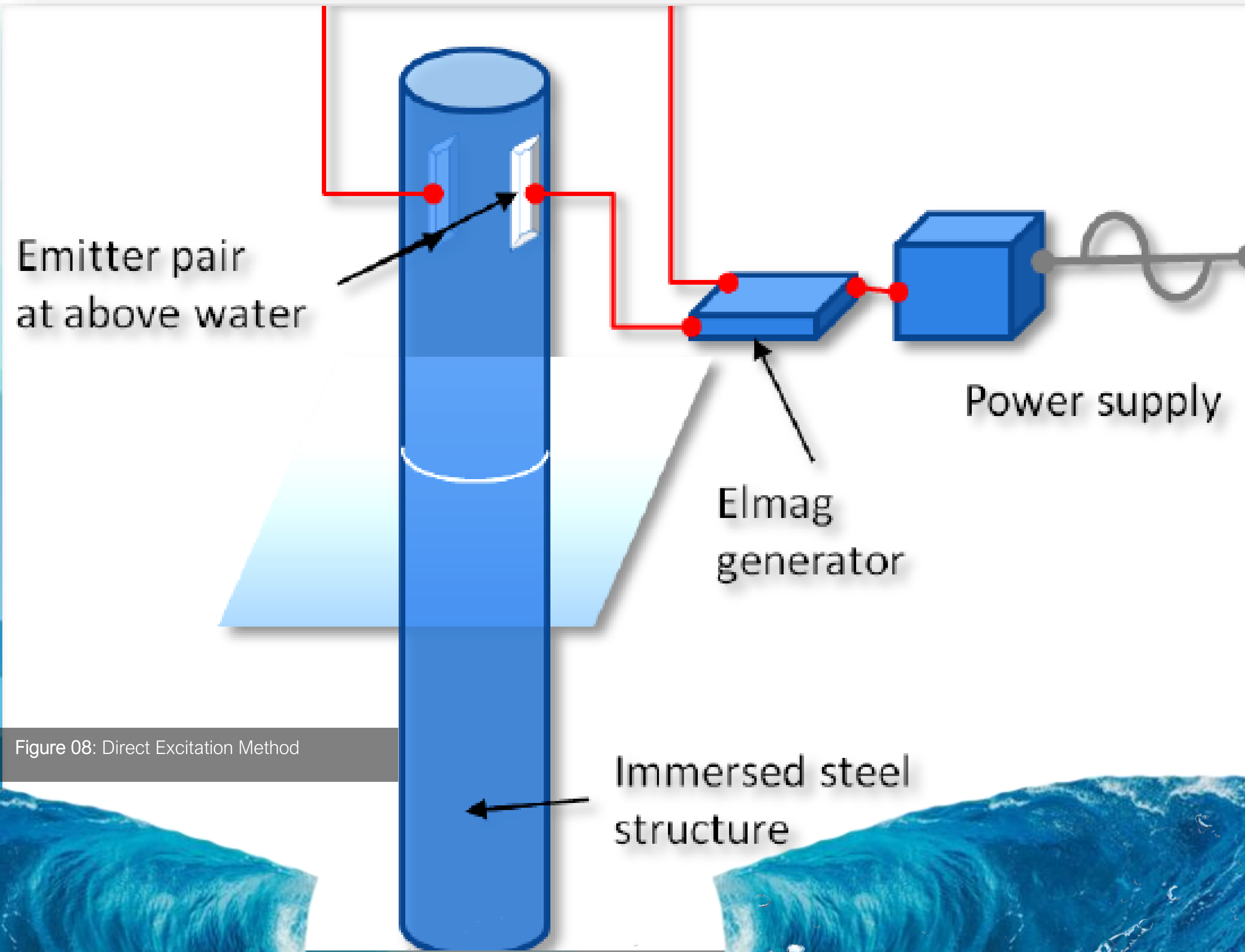


Figure 08: Direct Excitation Method

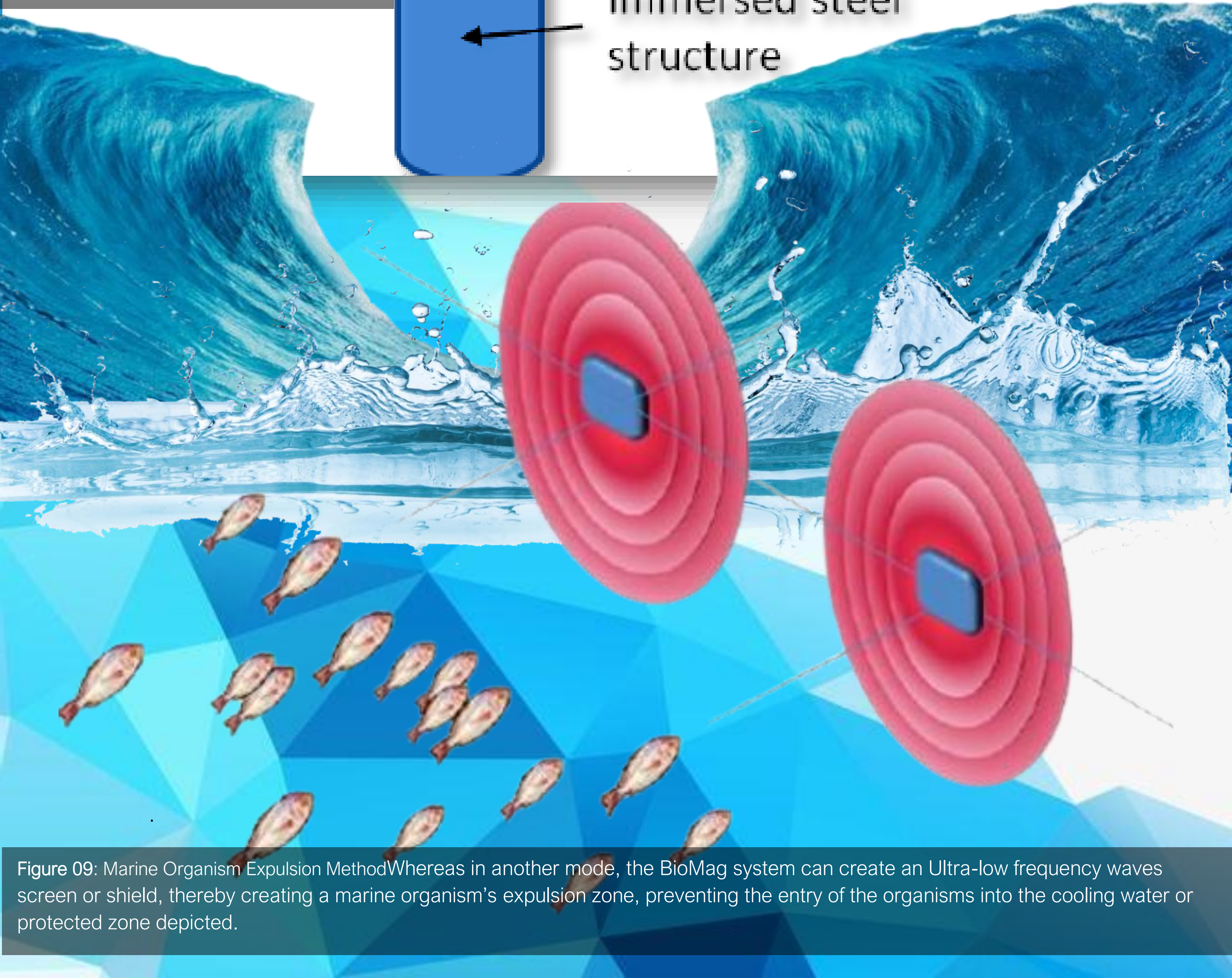


Figure 09: Marine Organism Expulsion MethodWhereas in another mode, the BioMag system can create an Ultra-low frequency waves screen or shield, thereby creating a marine organism's expulsion zone, preventing the entry of the organisms into the cooling water or protected zone depicted.

Bulk Main Stream Protection Method

Under the bulk mainstream protection method, an innovative extension of the established Ballast Water Treatment System (BWTS) is implemented. This advanced treatment approach employs an inline bulk water stream treatment process that utilizes ultra-low frequency to generate a wet plasma effect within the bulk water. This cutting-edge technology ensures a significant and instantaneous elimination of harmful organisms at the point of treatment. Additionally, it provides a residual treatment effect, enabling continued bio-fouling control downstream even after the water has exited the core treatment zone.

The process is designed to be highly energy-efficient, leveraging the principles of resonating frequency. This can be visualized as a harmonized system where the ultra-low frequency resonates with the water molecules, creating a wet plasma effect that effectively neutralizes pathogens and bio-contaminants. This method not only enhances the immediate treatment efficacy but also ensures sustained protection against bio-fouling, making it a robust and sustainable solution for ballast water management. By integrating these advanced principles, the system achieves optimal performance while minimizing energy consumption, aligning with modern environmental and operational standards.

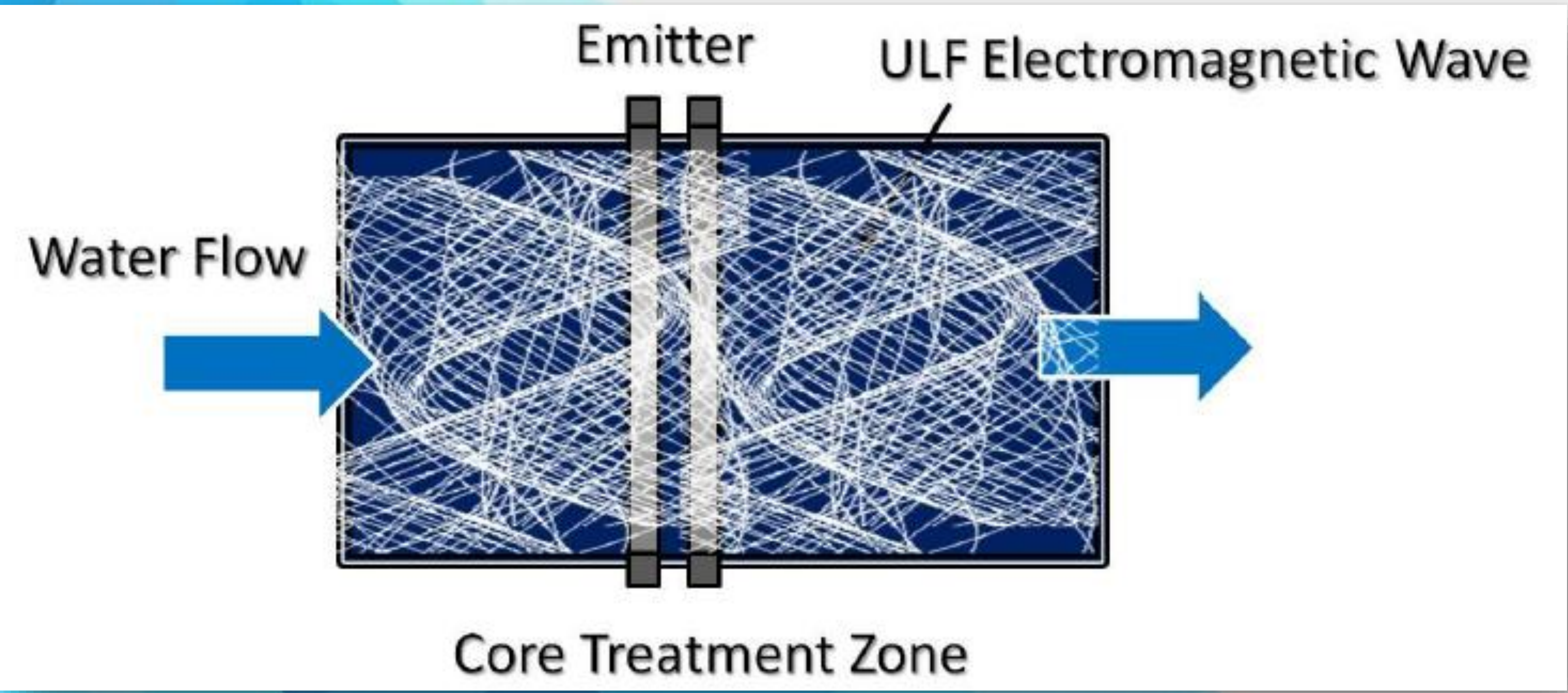


Figure 10: Illustration of an in line bulk water stream treatment by ULF induced wet plasma effect by Ecospec.

The BioMag system by EcoSpec represents a cutting-edge solution for bio-fouling control, offering unparalleled versatility and performance across various environments and circumstances. The system allows for the independent or synergistic combination of treatment methods to maximize bio-fouling control effectiveness. This adaptability ensures robust and consistent performance, making it a superior choice for tackling bio-fouling in diverse applications.

Beyond its exceptional bio-fouling control capabilities, the BioMag system distinguishes itself from other alternatives by providing secondary benefits, particularly in corrosion protection. The system facilitates the formation of a protective magnetite layer on steel surfaces, enhancing their durability. Additionally, it strengthens existing protective oxide layers on various metals, such as chromium oxide on stainless steel, cuprous oxide on copper alloys, and titanium oxide on titanium alloys. This dual functionality not only mitigates bio-fouling but also extends the lifespan of metal surfaces, reducing maintenance costs and improving operational efficiency.

Key Benefits of the BioMag System

True Physical Treatment: Utilizes non-chemical methods for effective bio-fouling control.

Robust and Consistent Performance: Delivers reliable results across diverse conditions.

Environmentally Friendly Free from toxic substances, ensuring minimal environmental impact.

Energy Efficient: Operates with low energy consumption, reducing operational costs.

Cost Effective: Eliminates the need for frequent maintenance and costly chemical treatments.

No Toxic Release: Ensures no discharge of harmful substances into the environment.

Corrosion Prevention: Avoids chlorine or metal ion-induced corrosion issues.

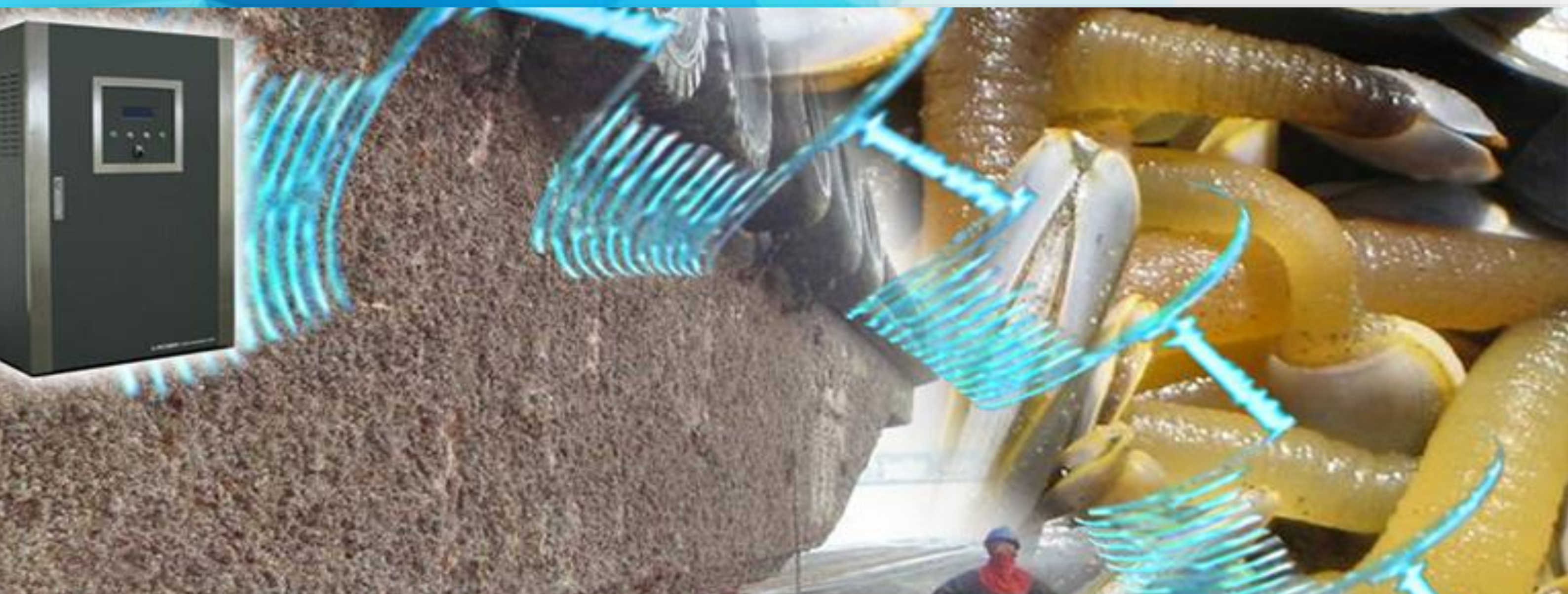
Enhanced Corrosion Protection: Forms and strengthens protective oxide layers on metal surfaces.

Comprehensive Water Channel Protection: Provides excellent internal protection against fouling with residual treatment effects.

Immunity-Free Solution: Eliminates the risk of immunity development in microorganisms.

Regulatory Compliance: Meets stringent discharge water regulatory criteria worldwide.

The BioMag system is a holistic solution that not only addresses bio-fouling challenges but also enhances the longevity and performance of metal surfaces. Its environmentally friendly, energy-efficient, and cost-effective design makes it an ideal choice for industries seeking sustainable and reliable bio-fouling control. By integrating advanced physical treatment methods with secondary corrosion protection, the BioMag system sets a new standard in the market, ensuring optimal performance and compliance with global regulatory standards.



Typical Configuration of BioMag System

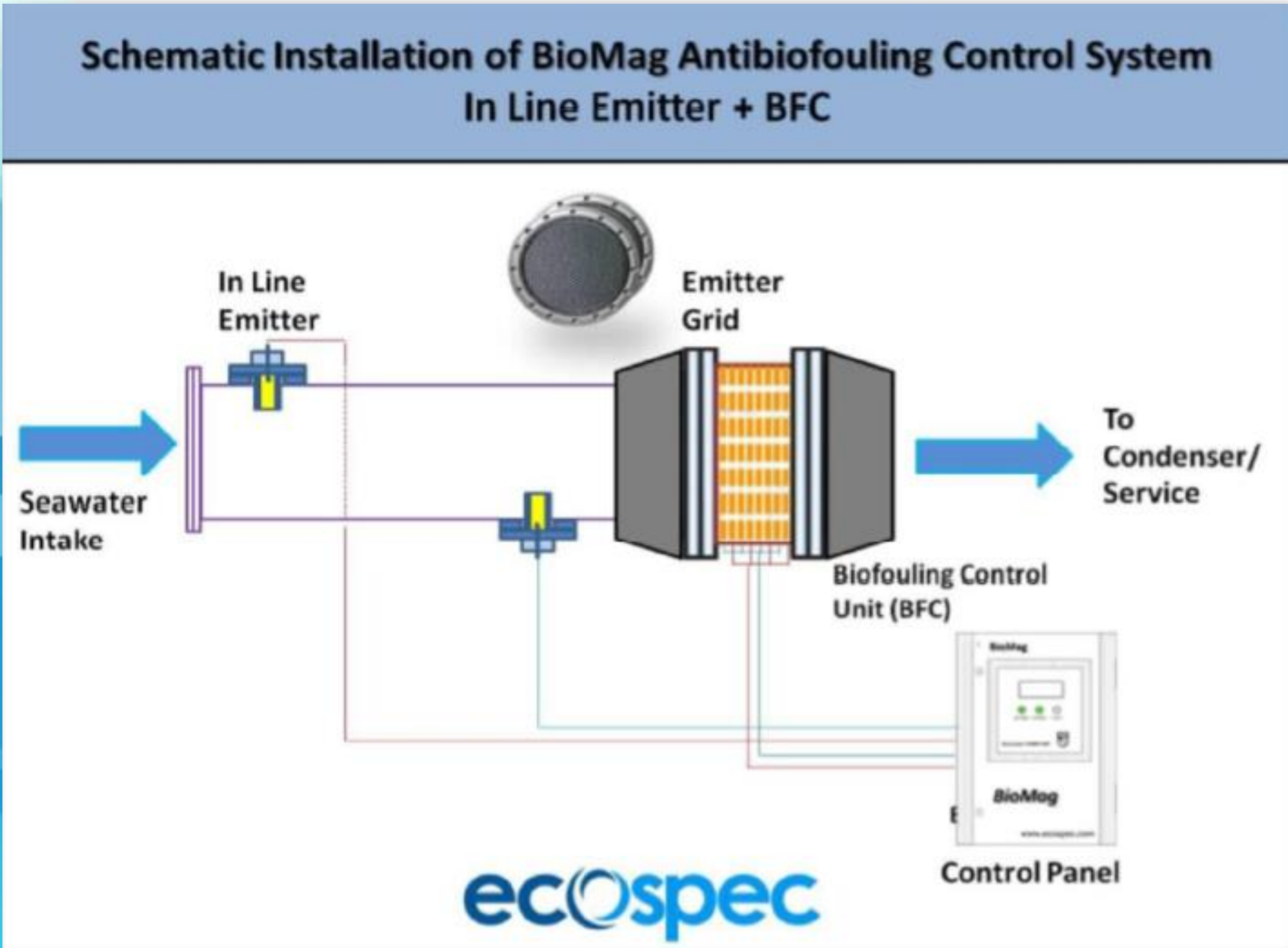


Figure 11: Typical BioMag Installation Schematic – An example of bulk main stream treatment scheme.

Figures 11 and 12 illustrate a generic BioMag system configuration, demonstrating its arrangement in two distinct methods. The BioMag system is designed for seamless installation on seawater intake channels, including pipelines, culverts, and other structures commonly utilized in industrial plants. The system employs Ultra-Low Frequency (ULF) waves to effectively address biofouling issues, ensuring optimal performance and longevity of downstream processes.

The BioMag system consists of two primary components:

1. *In-Line Emitter System*: This component is responsible for creating a marine organism expulsion zone, preventing the adhesion and entry of organisms into the seawater intake line.

2. *Bio-Fouling Control Unit (BFC):* Equipped with emitter grids, the BFC treats organisms in the bulk main stream, ensuring comprehensive biofouling control.

Together, these components provide a synergistic treatment effect, safeguarding downstream processes from fouling and maintaining system efficiency.

The in-line emitter system is mounted onto the pipe body using flange connections, with the emitter surface exposed to the flow stream. The placement of each emitter pair is optimized based on flow characteristics and pipe dimensions to ensure maximum effectiveness. Following the in-line emitter system, the BFC unit is installed. To enhance its functionality and prevent choking, a complementary filtering unit is typically incorporated upstream of the BFC to reduce particle load. For added protection, particularly to prevent clogging at the pump suction inlet, custom-designed box strainer emitters can be implemented. These localized solutions ensure complete and effective treatment in critical areas. The entire setup, as depicted in the accompanying images, exemplifies a hotspot protection scheme, showcasing the BioMag system's ability to deliver reliable and efficient biofouling control in industrial seawater intake systems.

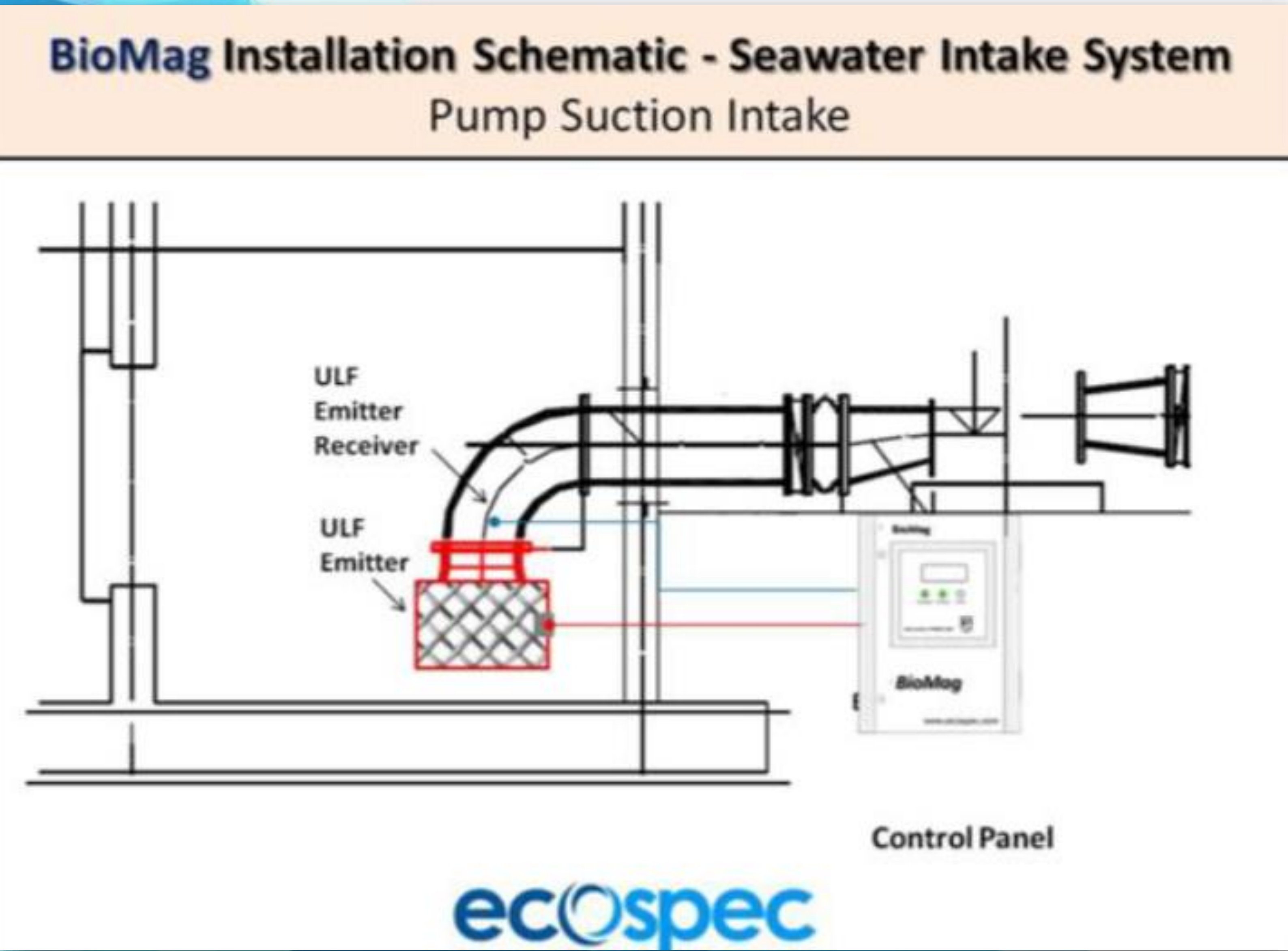


Image 12: Schematic Illustration of a strainer emitter bio-fouling control at pump suction inlet. An example of hot spot protection scheme.

Proposed BioMag System for Puttalam Coal Power Plant

In addressing the bio-fouling challenges within the Puttalam suction well and concrete culvert channel, the proposed solution involves the implementation of the BioMag system, utilizing a hot spot protection method. This innovative approach ensures effective control of bio-fouling organisms and prevents biological growth on critical infrastructure surfaces.

Suction Well BioMag System

The BioMag system installed in the suction well consists of 60 BioFouling Control (BFC) units strategically deployed across the top and bottom plates, as well as the side walls. These BFC units deliver Ultra-Low Frequency (ULF) treatment, effectively inhibiting the growth of bio-fouling organisms and maintaining the integrity of the suction well's internal wall surfaces. This ensures optimal performance and longevity of the infrastructure.

Culvert Channel BioMag System

For the 400-meter concrete culvert channel, the BioMag system incorporates 704 BFC units to provide comprehensive hot spot protection. This deployment is designed to safeguard the culvert walls from bio-fouling, ensuring uninterrupted functionality and structural durability.

Key Considerations for Implementation

The main contractor will be responsible for the safe and damage-free installation of cables connecting to the respective BFC units along the 400-meter culvert. Given the critical nature of the cable laying process, utmost care must be taken to avoid any damage to the cables, as even minor impairments could significantly reduce the treatment efficiency of the BioMag system. Proper planning, execution, and quality assurance measures are essential to ensure the system's optimal performance and long-term reliability.

By adopting the BioMag system, this project aims to achieve sustainable and effective bio-fouling control, enhancing the operational efficiency and lifespan of the Puttalam suction well and culvert channel infrastructure.

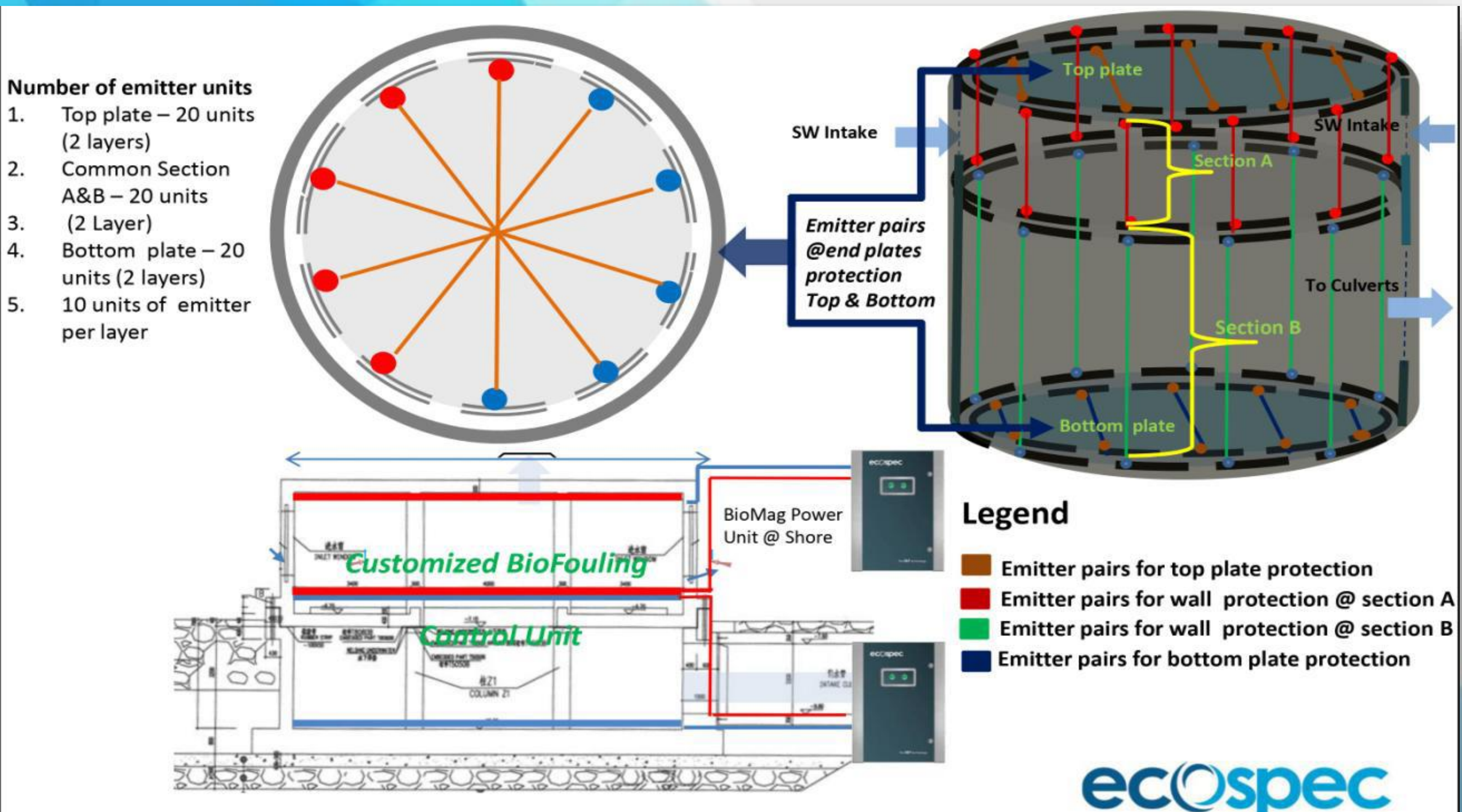


Image 13: Schematic Biomag for bio-fouling control SW Intake at Lakvijaya Power Plant 2017.

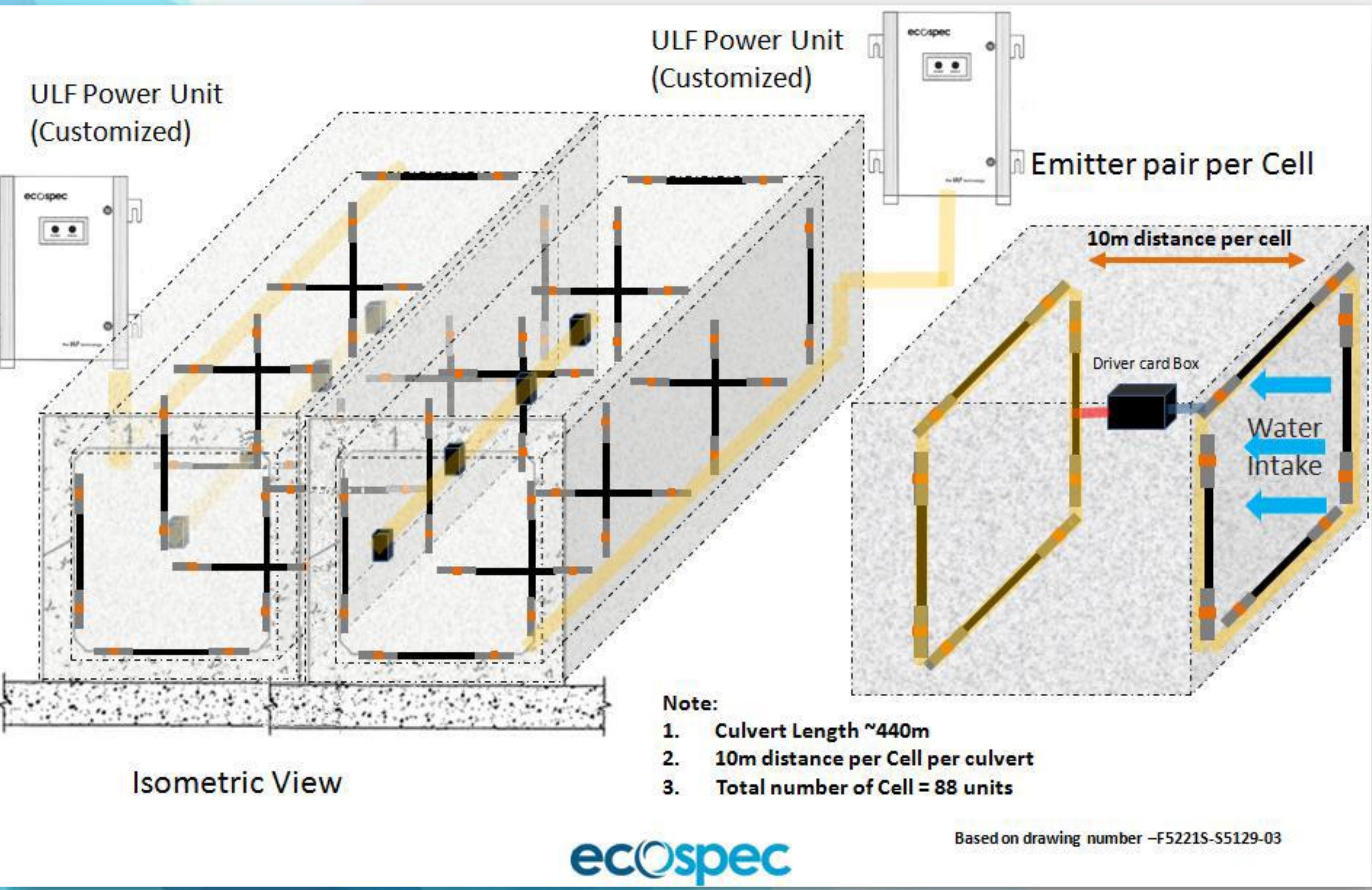


Image 14: Emitters installation layout for bio-fouling control SW Intake at Lakvijaya Power Plant 2017.

SUMMERY

Over the past few decades, transdisciplinary sciences have emerged as a significant catalyst for scientific progress. The most groundbreaking discoveries often occur at the intersection of multiple disciplines, where collaboration between fields fosters innovation and new insights. This has led to the emergence of intermediate fields such as mathematical physics, physical chemistry, biophysics, biochemistry, and geophysics, among others. In astronomy, for instance, astrophysics has long been a dominant field, but newer interdisciplinary areas like archeoastronomy, astrochemistry, astrobiology, and astroinformatics (closely linked to virtual observatories) are rapidly gaining traction. These fields exemplify how the integration of diverse scientific domains can lead to transformative advancements.

The influence of space-based data has also become increasingly significant across various scientific disciplines. As research on Earth reaches saturation in certain areas, many fields are turning to space-derived data to drive innovation. This trend suggests that in the near future, numerous scientific disciplines may establish dedicated space departments or collaborate closely with astronomers to expand their research horizons. The integration of astronomical data into other fields not only enhances scientific understanding but also opens new avenues for exploration and discovery.

Beyond the sciences, astronomy has also made a profound impact on culture and society. Astronomical themes are widely represented in literature, petroglyphs, and architecture, reflecting humanity's enduring fascination with the cosmos. Additionally, astronomy plays a pivotal role in scientific tourism, journalism, and the dissemination of popular science, contributing to public outreach and education. This multidisciplinary approach underscores the far-reaching influence of astronomy and its ability to bridge diverse areas of human knowledge and creativity.

One notable example of a multidisciplinary application is the use of Ultra Low Frequency (ULF) technology in astronomy and its potential to support research in other domains. For instance, ULF-based systems can be employed to sort and analyze complex datasets, such as questionnaires, across various fields. This highlights the versatility of ULF technology and its capacity to address challenges beyond its original scope.

Furthermore, the application of ULF technology extends to industrial and environmental solutions, as demonstrated by ULF BioMag. This innovative system offers unparalleled value in addressing bio-fouling in seawater cooling systems while providing enhanced corrosion protection. Unlike conventional methods such as chlorination, BioMag employs a non-toxic, eco-friendly approach that complies with regulatory requirements and aligns with global sustainability goals. Its energy-

efficient design minimizes environmental impact, mitigates the adverse effects of chemical treatments, and eliminates risks associated with immunity concerns. By adopting such technologies, industries can contribute to broader initiatives, such as the government of Sri Lanka's mandate to establish the country as a Green Destination.

In conclusion, the rise of transdisciplinary sciences has revolutionized the way we approach research and innovation. By fostering collaboration across fields and leveraging data from diverse sources, including space, scientists are able to tackle complex challenges and make groundbreaking discoveries. The integration of astronomical applications, such as ULF technology, into other domains exemplifies the potential of multidisciplinary approaches to drive progress. Moreover, solutions like ULF BioMag demonstrate how scientific advancements can address industrial and environmental challenges while promoting sustainability. As we move forward, the continued convergence of disciplines will undoubtedly play a critical role in shaping the future of science and technology.

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