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SYNOBSIG Boost-ERC

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PRELIMINARY REVIEW OF POTENTIAL POWER SOURCES FOR THE SEA-FLOOR STATION

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SYNOBSIG Boost-ERC
Preliminary study of potential power sources for the sea-floor station

Abstract:

This document summarizes the different energy supply technologies usable to a sea-floor station, within the scope of the preparations for the SYNOBSIG project. More specifically, it is a preliminary study on the prospect of continuously powering a deep sea-floor station with 100W for 3 years, within the scope the SYNOBSIG project.

Key words :

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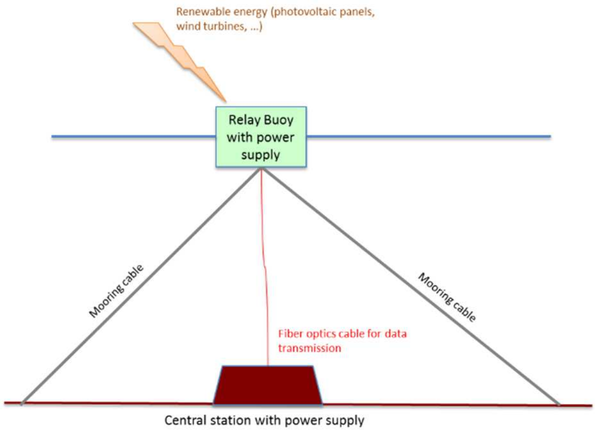
1 Requirements outlines

The desired outcome is to continuously power a deep sea-floor station with 100W for 3 years, i.e. 2.6MWh. The electrical voltage is yet to be specified.

The sea-floor station is connected to a surface buoy by a fiber optic cable for data transmission. The buoy is expected to be equipped with renewable energy production and storage apparatus (e.g. solar panels, wind turbines...).

The proposed 3-year lifespan requires the selection of reliable solutions without any maintenance requirement.



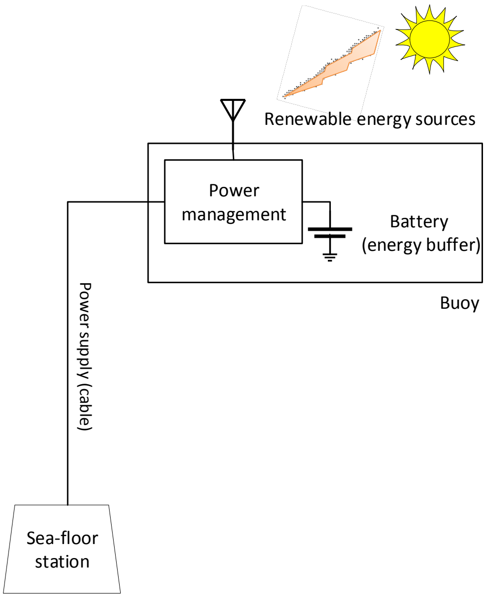
We distinguish two setups:

- The energy is transmitted down from the buoy (e.g. by cable...);
- The sea-floor station integrates its own energy source.

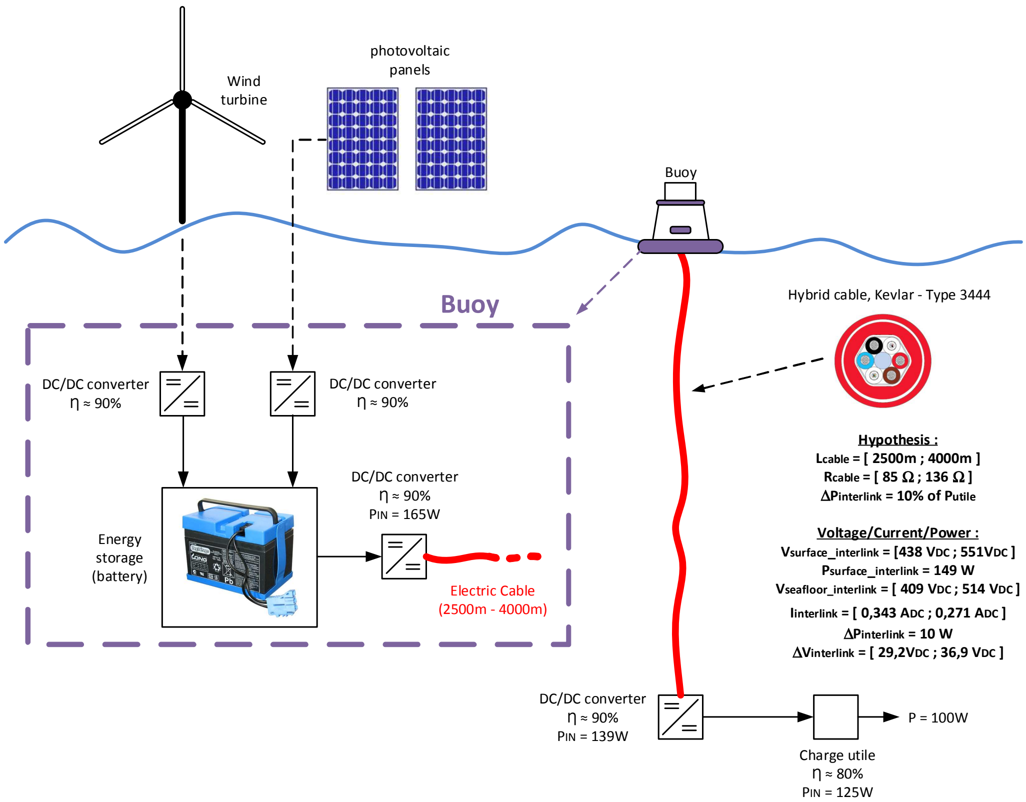
2 Energy transmission from the surface buoy

2.1 Cable

There will already be a physical link between the sea-floor and the surface. Indeed, a fiber optic cable will be necessary for the data transfer. A suggested solution is to add electric conductors to the existing fiber optic cable in order to power the station.



Assuming a maximum 10% loss in the cable and a copper conductor section of 1mm², this result in an electrical tension between 420 and 550V DC. A pre-sizing guide is detailed in the diagram below.



As an example, the *MacArtney Type 3444 hybrid cable* would be fit for purpose. With an overall diameter of 15.5mm, it contains several fiber optics and 4x 1mm² conductors. On the basis of this cable, it is possible to use 2 pairs of conductors, and thus ensuring a redundancy in the power delivery system or a reduction of the electrical voltage.

MacArtney
UNDERWATER TECHNOLOGY

Hybrid cable, Kevlar Type 3444

Construction characteristics

Fibre optic element (MM)	Loose tube with 4 multi-mode optical fibres 50/125 µm with Kevlar reinforcement and polyolefin sheath. 3 mm diameter Fibre colour: grey, white, red, black.
Fibre optic element (SM)	Loose tube with 4 single mode optical fibres 9/125 µm with Kevlar reinforcement and polyolefin sheath. 3 mm diameter Fibre colour: blue, orange, green, brown
Conductor	1.0 mm² stranded tinned copper conductor insulated with polyofin 3 mm diameter. Conductor colour: blue, black, red, brown (4 each)
Filler	Filler element
Inner jacket	Polyurethane jacket. Colour red
Strength member	Kevlar braiding
Outer jacket	Polyurethane jacket. Colour red

Mechanical characteristics

Diameter	15.50 mm ±0.40 mm
Weight in air	235 kg/km nom
Weight in seawater	42 kg/km nom
Min. bending radius	230 mm
Min. breaking strength	15 kN
Depth rating	5,000 m
Operating temperature range	-20°C - +80°C

Electrical and fibre optical characteristics

Operating voltage	1,000 V DC
max attenuation	3.00 dB at 850 nm for multi mode fibre 0.80 dB at 1300 nm for multi mode fibre 0.40 dB/km at 1,300 nm for single mode fibre 0.25 dB/km at 1,550 nm for single mode fibre

A system analysis, integrating all operation constraint (mooring constraints, depth, deployment…), must be realized in order to define all requirements concerning this cable.

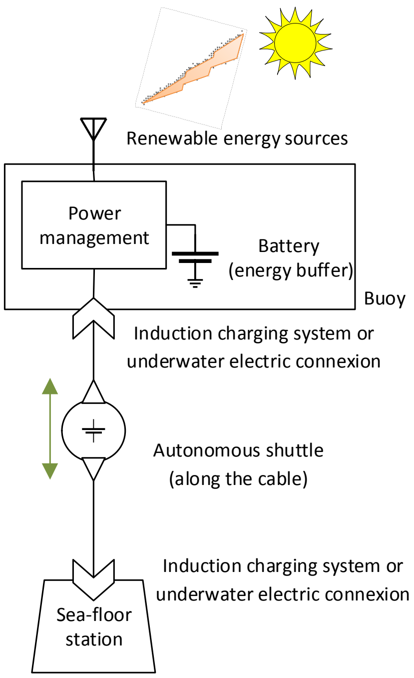
Besides, this solution involves a larger buoy integrating renewable energy sources (solar panels, wind turbines) and an energy buffer (battery) that must be well designed in order to power the sea-floor station whatever meteorological conditions.

2.2 Autonomous « shuttle »

If powering the station by cable is not possible, an energy transmission vector, shuttling between the surface and the station could be considered.

Examples of possible solutions (cf. the diagram):

1. A "shuttle" along a cable (anchored or otherwise)
2. An autonomous underwater vehicle (AUV)



This solution has a certain number of technological barriers:

- Power transmission :
  - Underwater electric connection/disconnection to the buoy and the sea-floor station – not feasible considering the operational constraints
  - Underwater inductive transmission
- The autonomous shuttle vector must be entirely automated with a very high level of reliability to allow it to function for 3 years without any interventions.

Moreover, the overall efficiency remains low and probably below 50% with the 2 stages of inductive transfers and the loss in the two successive battery charges. As a consequence, it is necessary to take into account the additional energy required for the transfer between the station and the surface. For a rotation every 5 days, 12kWh will need to be stocked at the station, yet the necessary energy at the surface is approximately 28kWh (the efficiency of the inductive charge is around 70%[1]).

This solution does not appear to be practical due to its low overall efficiency, the necessary developments and the potential unreliability.

[1] McGinnis, T., Henze, C. P., Conroy, K., "Inductive Power System for Autonomous Underwater Vehicles," Oceans 2007, 1-5, 29 September 2007 - 4 October 2007

3 Self-sufficient sea-floor station

3.1 Primary Lithium-ion battery

This is the favored solution for most of the energy independent underwater observatories. Presently, the most appropriate technology is $LiSoCl_2$ primary battery to maximize the energy capacity.

WILPA1122 battery pack[2] – currently used in Ifremer's observatories

	ENERGY						POWER			HIGH TEMPERATURE	
	LS 14250	LS 14500	LS 17330	LS 17500	LS 26500	LS 33600	LSH 14 Light	LSH 14	LSH 20	LSH 20-HTS	LSH 20-150
Cell size	1/2 AA	AA	2/3 A	A	C	D	C	C	D	D	D
Cell construction	Bobbin	Bobbin	Bobbin	Bobbin	Bobbin	Bobbin	Spiral	Spiral	Spiral	Spiral	Spiral
Nominal voltage	3.6 V	3.6 V	3.6 V	3.6 V	3.6 V	3.6 V	3.6 V	3.6 V	3.6 V	3.6 V	3.6 V
Nominal capacity	1.2 Ah	2.6 Ah	2.1 Ah	3.6 Ah	7.7 Ah	17.0 Ah	3.6 Ah	5.8 Ah	13.0 Ah	11.0 Ah	14.0 Ah
Max. continuous current	35 mA	50 mA	25 mA	100 mA	150 mA	250 mA	1.3 A	1.3 A	1.8 A	1.0 A	300 mA
Max. pulse discharge rate	0.1 A	0.25 A	0.12 A	0.25 A	0.3 A	0.4 A	2.0 A	2.0 A	4.0 A	3.0 A	0.5 A
Max. outside diameter	14.55 mm	14.55 mm	16.5 mm	17.13 mm	26.0 mm	33.4 mm	26.0 mm	26.0 mm	33.4 mm	33.4 mm	32.05 mm
Max. height	25.15 mm	50.3 mm	33.4 mm	50.9 mm	50.4 mm	61.6 mm	50.4 mm	50.4 mm	61.6 mm	61.6 mm	61.7 mm
Typical weight	8.9 g	16.7 g	14.4 g	21.9 g	48 g	90 g	51 g	51 g	100 g	100 g	104.5 g
Operating temperature range	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 60 / + 85°C	- 40 / + 150°C

Typical values relative to cells stored for one year or less at + 30°C max ; Performances vary according to discharge characteristics (current, duration, frequency), temperature conditions, storage conditions prior to usage and applications acceptable minimum voltage.

SAFT primary battery datasheet

On the basis of the LS33600 unit from the supplier SAFT (one of the industrial leaders in batteries), 43 000 cells must be assembled in order to obtain the desired 3-year autonomy. This represents a total of almost 4 tons of batteries at a cost of 900k€. Additionally, these cells cannot withstand underwater pressure, and it is thus necessary to integrate batteries in a resistant enclosure.

Only the pouch cell technology is pressure tolerant and forgoes the need of a resistant enclosure. Nevertheless, pouch cells are used for Li-ion accumulators and not for the primary batteries. The feasibility of developing a custom $Li\text{-}SOCl_2$ battery solution in a flexible packaging would need to be considered. However, safety aspects and the regulations for Li-ion batteries are such that the development costs will be prohibitive for the project.

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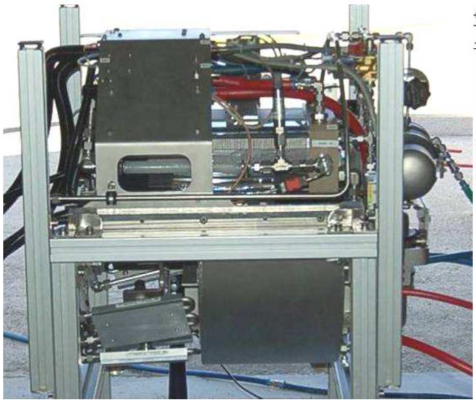
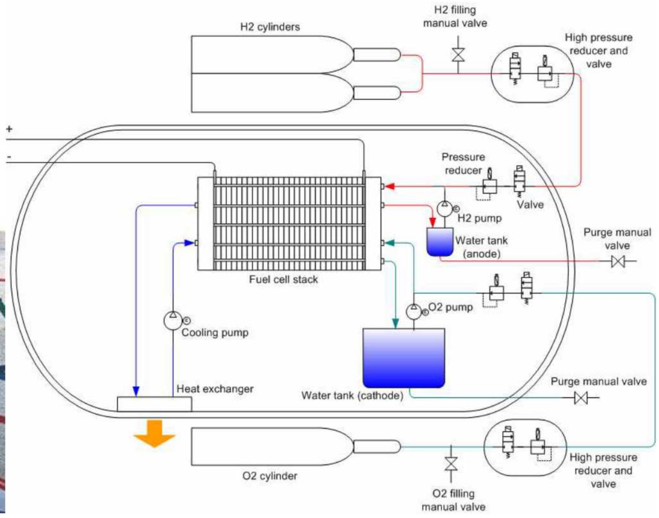
[2] Modular pack developed by Williamson Electronique to power self-sufficient observatories to the standards defined by the R&D unit (Department of Physical Resources and Deep Sea Ecosystems) of Ifremer.

3.2 The H_2/O_2 Fuel cell

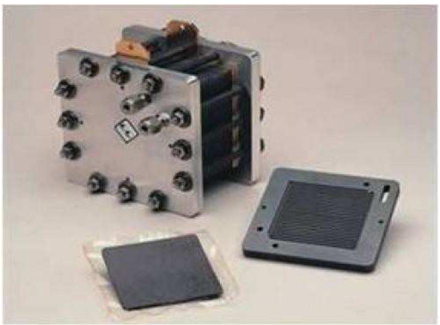
Beyond a certain energy capacity (>100kWh), the fuel cell solution becomes pertinent and deserves to be considered. Several fuel cell systems have been developed to power underwater devices, namely by JAMSTEC (for Urashima[33]) and by Ifremer (for Idef[X] for the ANR PACSM project[4]).





PACSM fuel cell developed by AREVA SE for Idef[X] AUV

The power of 100W suggests a small fuel cell stack weighing around 1kg.



[3] Toshio MAEDA, Fuel cell AUV "URASHIMA", Mitsubishi Heavy Industries, Ldt. Technical, Review Vol.43 n°1 (January 2006)

[4] E. Raugel, V. Rigaud, "Sea experiment of a survey AUV powered by a fuel cell system", AUV2010, Monterey, USA

Most of fuel cell works with air as oxidant. Underwater application implies the use (and the storage) of pure oxygen. H2-O2 fuel cell requires a specialized supplier and a custom design[5] (e.g. CEA or AREVA SE). Nevertheless, the technology already exists and could meet the needs of the project.

It will probably be necessary to integrate several fuel cells that will succeed each other to ensure a power production during 3 years (2-4 batteries should be sufficient depending of the chosen technology).

Development efforts will be mainly focused on the gas management. The target autonomy being high, the gas storage will therefore be a crucial point. With a high efficiency fuel cell system (high electrochemical efficiency, no gas loss, optimized auxiliaries[6] for a low electric consumption), it will be necessary to store almost 2000 Nm^3 of Hydrogen and 1000 Nm^3 of Oxygen. In addition, the storage must hold internal pressure but also withstand the external environmental pressure. It will therefore be necessary to develop appropriate storage solutions. A preliminary study shows that H2/O2 storage will be around 13-15 tons, if applied at a depth of 2000m and probably greater than 20 tons at 6000m depth.

Different innovative solutions could be studied to optimize gas storage:

Hydrogen storage:

- The metallic hydrides used for the hydrogen storage (mature technology but with thermal management and mass issues to be considered for large scale application)
- The water-aluminum reaction for hydrogen production[7] (less mature, newer technology - TRL4)

Oxygen storage

- The O_2 storage in liquid form (−182,96°C) that could reduce the storage volume to $1.2m^3$ (without the cryogenic equipment and mechanical enclosure)
- Hydrogen peroxide reaction[8]. It will be necessary to store almost 1 ton of hydrogen peroxide, which will need to be diluted to guarantee stability (amounting to a volume of 1300 liters). A similar approach is used for the Al-H_2O_2 batteries developed by Kongsberg (see below).

In addition to the gas storage, other issues must also be taken into account when using a fuel cell:

- The safety aspects during the installation phase due to the large quantity of hydrogen.
- The gas management for the under pressure operation and in anaerobic conditions is very specific and requires preliminary testing (the feedback from projects such as PACSM is still very important on this topic and is a major advantage):
    - Recovery and storage (or draining) of the water resulting from the electrochemical reaction (approximately 700-800 liters)
    - The necessity of very high gas purity for the anaerobic operation (very complex gas purge due to external pressure)

[5] Many fuel cells are developed for atmospheric application. The choice of membranes, materials and designs (gas distribution) are therefore optimized for air and not with pure oxygen.

[6] Auxiliaries for the fuel cell system : valves, pumps, converters

[7] cf : http://www.ga.com/websites/ga/images/products/power_and_energy/ALPS_data_0617.pdf :
General Atomics studies this concept to power an AUV with fuel cells. Coupled with the weak TRL, several technological barriers must be added to the targeted usage, such as:
- The capacity to store 4 to 6 tons of Aluminum under stable and corrosion-free conditions during 3 years.
- The management of the reaction products and the hydrogen purity.

[8] Hydrogen peroxide decomposition reaction: $2H_2O_2 \rightarrow 2\ H_2O+O_2$. Being unstable, the hydrogen peroxide must be at a maximum concentration of 70% - a dilution to 50% is preferred to lower risks.

3.3 The Alkaline Aluminium Hydrogen Peroxide Semi-Fuel Cell

The Alkaline Aluminium Hydrogen Peroxide Semi-Fuel Cell is developed by FFI [9] and Kongsberg to power the AUV HUGIN3000[10]. This semi-fuel cell uses a circulating alkaline electrolyte (Potassium hydroxide electrolyte, KOH), aluminium anodes and maintains the oxidant concentration in the electrolyte by continuously adding hydrogen peroxide (HP) to the electrolyte. In each cell, the electrochemical reaction[11] between aluminium and oxygen produced by HP decomposition generates an electric current with a voltage around 1.3V/cell.

This technology uses only solid aluminium and liquid reactants (HP and KOH) that are stored in plastic bags at ambient pressure. It's a pressure tolerant solution and does not need a resistant enclosure, such as H_2/O_2 fuel cell or primary battery.

During the operation, a small amount of electrolyte is continuously released from the semi fuel cell and mixed with seawater. After dilution and reaction with seawater, the resulting mixture is a milky white, weakly alkaline suspension of aluminium and magnesium hydroxide, calcium carbonate and calcium magnesium carbonate. This mixture is classified as "environmentally harmless" by the Norwegian Environmental Protection Agency, but the environmental impact for a long term stationary application has to be studied.

Semi Fuel Cell developed by Kongsberg

A preliminary sizing, scaling up from Kongsberg's solution, shows that to provide 2.6MWh, a large quantity of reactants is needed:

- ~ 3.2 tons of Aluminium
- ~ 4.4 tons of HP (50%)
- The quantity of KOH to be defined depending on amount to be released during the 3 years operation (4.6 tons?)

3.4 Sea water lithium battery

The sea water - lithium battery is an emerging technology, developed by PolyPlus Battery. This technology has been tested on gliders[12]. It is still a work in progress with interesting potential outcomes. But the gap between the small quantities of generated energy today and the needs for the sea-floor station is too large. In addition, the biofouling could be a key issue for a 3 years operation.

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[9] FFI : Norwegian Defence Research Establishment

[10] Øistein Hasvold, Kjell Håvard Johansen, Karstein Vestgaard, "The Alkaline Aluminium Hydrogen Peroxide Semi-Fuel Cell for the Hugin 3000 Autonomous Underwater Vehicle", AUV 2002, USA, June 2002

[11] Overall reaction : $2\ Al + 3\ H_2O_2 + 2\ OH^- = 2\ Al(OH)_4^-$

[12] Russ E. Davis, Jeffrey T. Sherman, "Evaluating a Lithium-Seawater Battery on Gliders", Instrument Development Group, Scripps Institution of Oceanography, La Jolla, California, 2016

4 Summary

Energy storage on the sea-floor is only viable if the energy requirement is drastically reduced (e.g. intermittent power). For a few hundred kWh, Li-ion batteries or even fuel cells (or semi fuel cells) could be available with a sufficient reliability, if some technological issues are previously solved. Nevertheless, for several MWh, the volumes and weights needed seem too significant. Furthermore, the safety and reliability aspects have to be taken into account for a maintenance-free and autonomous operation during 3 years.

As a physical fiber optic link between the sea-floor and the surface is required, the option of an electro-optical cable appears to be the most pertinent solution (see table below).

Solution	Type	TRL[13]	Specific developments	Inconvenience/risks
Câble	Energy transmission	9	None	Physical link between the sea-floor and surface
Shuttle	Energy transmission	5-6	Underwater inductive charge The shuttle system	Low overall efficiency Low overall reliability for long term operation
Battery	On-board storage	7-8	None	
Fuel Cell	On-board storage	5-6	H2/O2 storage Specific fuel cell system	Gas management for underwater and long term operation Safety aspect during deployment phase Mass and volume needed
Al-H2O2	On-board storage	5-6	Scale up of the Kongsberg technology	Amount of reactants Environmental impact? Reliability?
Li-seawater	On-board storage	4-5	?	Very low TRL Biofouling

[13] TRL : Technology readiness level