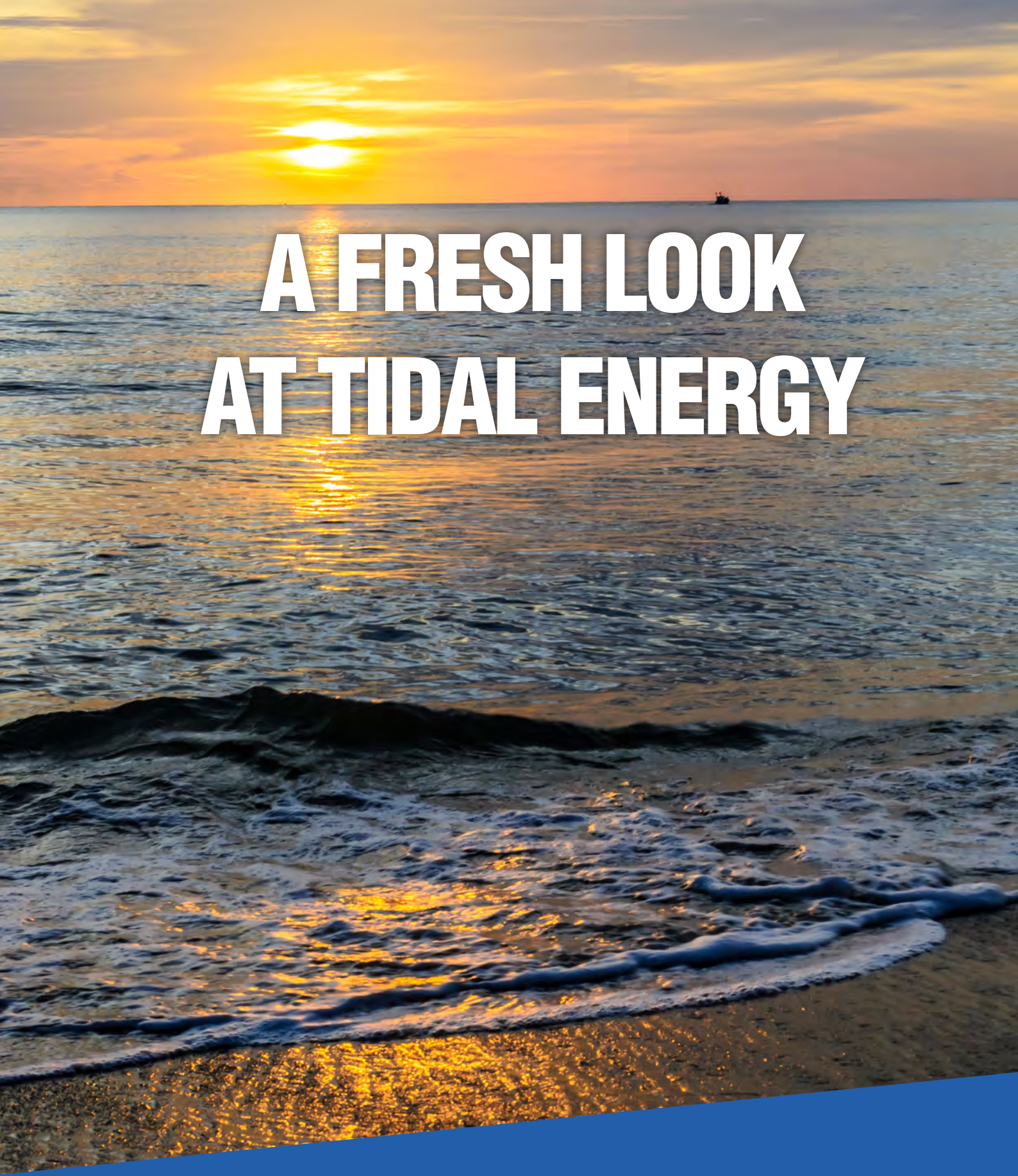


# A FRESH LOOK AT TIDAL ENERGY

## AN OPPORTUNITY FOR THE FRENCH TERRITORIES

SHF

# *Fendre les flots*
## *Cutting through the waves*

“**Les marées reviennent chaque jour avec les gazettes**
*The tides come back every day as regular as clockwork*
**Leur force allume les réverbères et les lanternes**
*Their force lights up streets and houses*
**elles poussent leurs ardeurs contre la falaise**
*they throw themselves against the cliffs*
**elles l’étripent en font des fleurs minérales à leur aise**
*and strip them, making mineral flowers with ease*
**elles poussent leurs bataillons de béliers et de brebis**
*they push their battalions of battering rams and white sheep*
**enfantant les galets rares et autres débris**
*creating rare pebbles and other debris*
**ainsi va le monde et la lune en tourniquant**
*this is the way of the world and the moon as it turns*
**ainsi va la mer seule et une montant et baissant**
*this is the way of the sea as it rises and falls*”

*Raymond QUENEAU*

# PREFACE

## RE-OPENING THE TIDAL OPTION: BOLD BUT REALISTIC

**Is France ashamed of its tidal energy?** It's a valid question in view of the ambivalent attitude to a form of energy that is completely renewable, predictable and abundant. We are proud to acknowledge the pioneering industrial success of the Rance plant, but perplexed and sometimes even hostile to the popular belief that no new sites can be envisaged.

This ambivalent perception has even been set down in the national vision: the report of the inter-ministerial audit on renewable marine energies published in March 2013[1] recognizes its technological maturity and its potential. However, the questions of environmental and societal acceptability are highlighted as a major disincentive for considering it as a future option.

**The SHF is convinced that this energy has a future.**

In 2015, re-engaging with its initial missions, the Société Hydrotechnique de France (SHF) decided to set up a working group called "New tidal energy" to take another look at the fundamentals of this powerful source of energy and redefine modern and responsible conditions for its development.

Bringing together more than twenty experts and specialists, it offered thoughts, data and proposals for actions to re-open the tidal option, a mature technology with great potential for innovation. This working group highlighted the conditions for the feasibility and viability of new projects in a modern and innovative approach, without any concessions on the questions of their environmental integration.

The goal of this booklet is to put tidal energy back into a framework that has evolved considerably since the commissioning of La Rance plant. It offers a summary of our work[2], setting out our convictions and the keys to the success of future projects: global territorial integration, optimised environmental integration, innovation to drive development and a lucid, transparent economic assessment.

On the basis of this work, the SHF is convinced that tidal energy is a major asset for the energy transition, to enrich the mix of low-carbon energy sources. The French territories are amongst the first committed to implementing this transition in the field and we believe that tidal energy is an asset for economic, social and ecological development.

We would like to thank all those who contributed to the "New tidal energy" booklet, divided into 3 themed sub-groups led by C. Le Visage (Sea & Coastal Strategies President), A. Rabain (Consultant) and L. Deroo (President of ISL-Ingénierie)[3]. We hope that this booklet will enlighten all the regional and national players and decision-makers regarding this wonderful source of energy.

**Olivier METAIS**
(Grenoble-INP)
President of the SHF

**Pierre-Louis VIOLLET**
President of the SHF's BCST

**Denis AELBRECHT**
(EDF-CIH) "New tidal energy" working group leader

*[1] Ministry of Ecology, Energy and Sustainable Development / Ministry of Economic Affairs. Marine renewable energies audit report (March 2013). N° 2013 / 008693-01 / CGEDD*
*[2] The full report on the work carried out by the "New tidal energy" working group is available on the SHF website: www.shf-hydro.org*
*[3] A full list of the working group's themed sub-groups is given on the last page of this booklet*

# CONTENTS

## MINI GLOSSARY

**CAPEX:** *CAPital EXpenditure Investment needed to develop a project.*

**MSFD:** *Marine Strategy Framework Directive*

**PRC:** *Environmental integration approach for projects on the basis of: Prevention, Reduction, Compensation*

**MEP:** *Multiannual energy programme*

**TEP:** *Technically exploitable potential*

**IRR:** *Internal rate of return*

# TIDAL ENERGY
## HIGH UNTAPPED DEVELOPMENT POTENTIAL

**10 000 - 20 000 TWh / yr**
**Theoretical global resource[4]**

**1250 TWh / yr**
**Technical Exploitable Potential (TEP)**

**1 TWh / yr**
**Current effective production**

**or only 0.005%** of the theoretical global resource and 0.08% of the TEP.
**A significant margin for development exists: much remains to be done!**

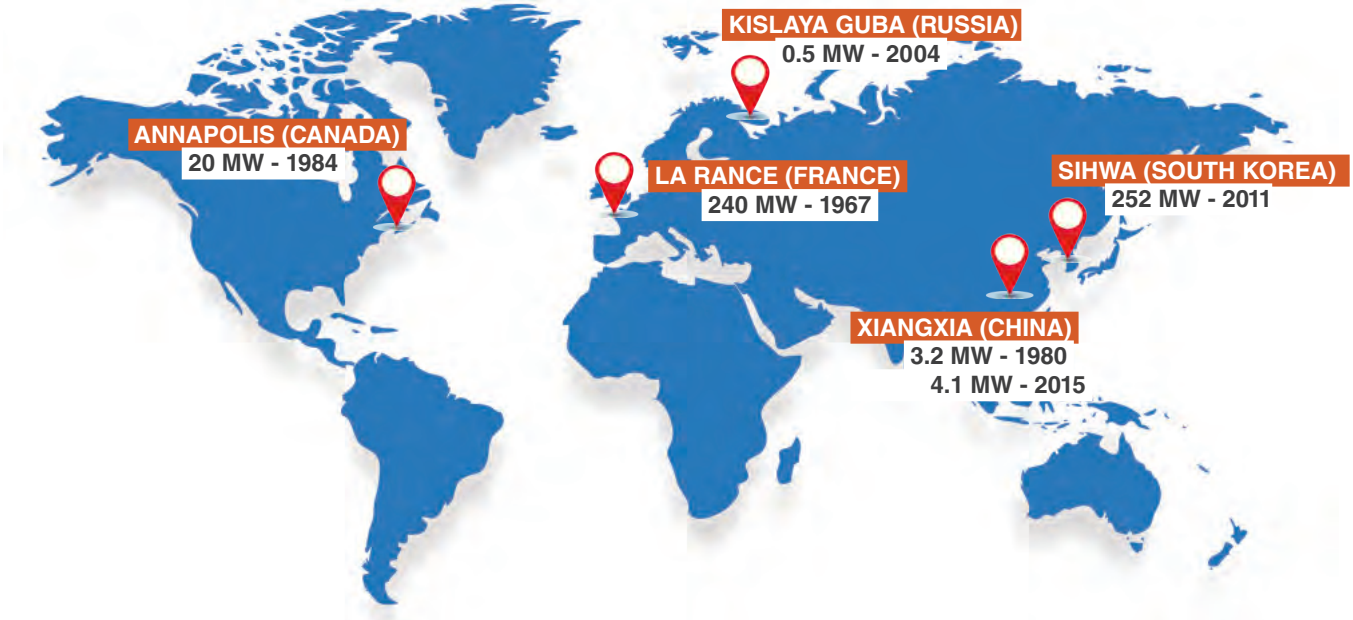
**Benchmark[5]**

**1 TWh / yr =**

0.2% of France's total annual electricity consumption

consumption of 300,000 people *(individuals + professionals, not including major industries or small-and medium-sized businesses)*

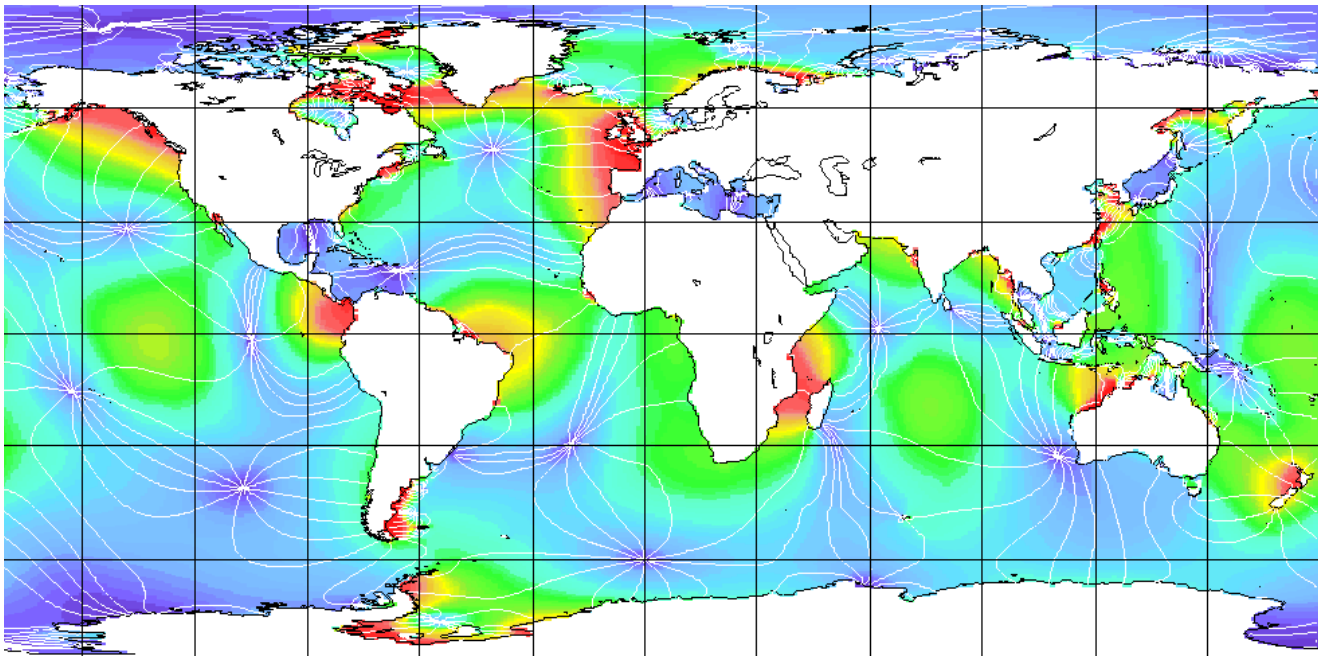
## 5 industrial-sized installations are currently in operation worldwide:




*[4] The IPCC's special report on renewable energies (SRREN, IPCC 2012 Cambridge Univ. Press) mentions the theoretical resource (in power) of 1 - 3 TW, that can be converted into annual energy in a range of 10,000 to 20,000 TWh.*
*See also the data from the International Energy Agency's specific renewable tidal energy group on - https://www.ocean-energy-system.org*
*[5] According to RTE (the French transmission system operator) statistics in 2015: electricity consumption production: www.rte.fr*

**The schemes at La Rance (France) and Sihwa (South Korea) produce the majority of global industrial production.** La Rance provides around 0.5 TWh/yr, which corresponds to the annual consumption of a town of approximately 150,000 people.

The countries with significant tidal energy potential are the United Kingdom, France, Canada, India, Russia, China, Korea and Argentina… but other countries also have moderate tidal ranges where innovative technologies could be applied: the Netherlands, Denmark…



*Amplitude of the M2 tidal wave (semidiurnal lunar influence) showing zones with high potential - ©LEGOS Toulouse*

## The French regions, considerable assets and requirements:

**Potential sites:** one of the best tidal energy resources, initially concentrated in the Channel/North Sea, but with potential in other regions for new turbine or plant technologies (e.g.: Tidal Garden): Brittany (South Finistere, Morbihan), Pays de la Loire, Nouvelle Aquitaine (Charentes).

**New tidal energy projects could satisfy the many challenges of essential coastal requirements:**

- **Securing renewable energy supplies** for highly populated sites
- **Protecting the coastline** from the risks of erosion and coastal flooding
- **Fighting the risk of industrial impoverishment** in some areas,…

# TIDAL ENERGY
## HOW DOES IT WORK?

Tidal energy works by extracting the potential and/or kinetic energy associated with tidal water movements. It is totally renewable and totally predictable.

It is exploited:

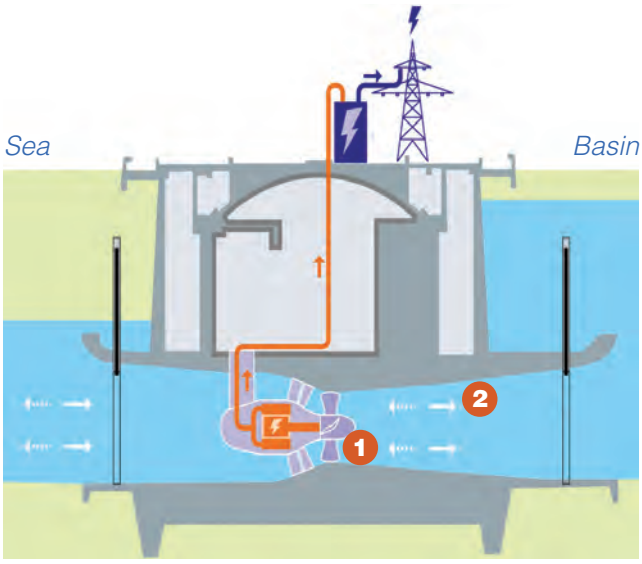
» either by using the potential energy between the sea and a basin, produced by the temporary storage of the movement of water masses in the basin: this is the principle of tidal energy,

» or by using the kinetic energy of the tidal currents directly: this is the principle of marine turbines in the open sea.

**Innovative approaches can combine these two physical principles, like the concept of Tidal Garden,** developed later on in this booklet.

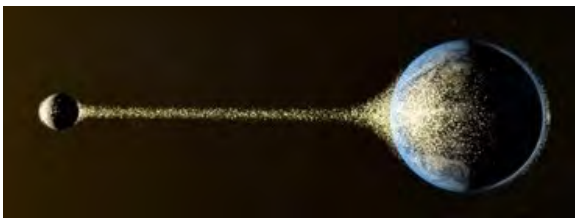
The energy can be extracted in a single part (usually as the tide ebbs) of the high tide / low tide cycle – **we call this the single effect (or "single action")** 1

Or it can be extracted on both the ebb and flow parts of the cycle – **we then call it double effect (or "double action")** 2




*Operating principle of a tidal energy scheme*

**THE TIDAL PHENOMENON:**



The gravitational movements of the moon and the sun relative to Earth cause a swelling of the waters at the surface of the seas and oceans.

These movements materialise with periodic variations to one degree or another of the levels and currents, according to diurnal or semi-diurnal cycles (high tide and low tide cycles) and according to seasonal lunar cycles (spring and neap tides) and even solar-lunar cycles linked to the relative position of the moon and the sun (we use the term "syzygy").Terrestrial rotation and the shapes and sizes of bays also have an impact on the amplitude of the phenomenon.

The operating mode, and therefore the cycle of variations of water height in the basin, are the result of a compromise between:

» energy optimisation

» a respect of environmental objectives, expressed as constraints or limitations of the levels reached in the basin (min/max), level gradients, periods of slack water, etc.

### What energy can be extracted on a given site?

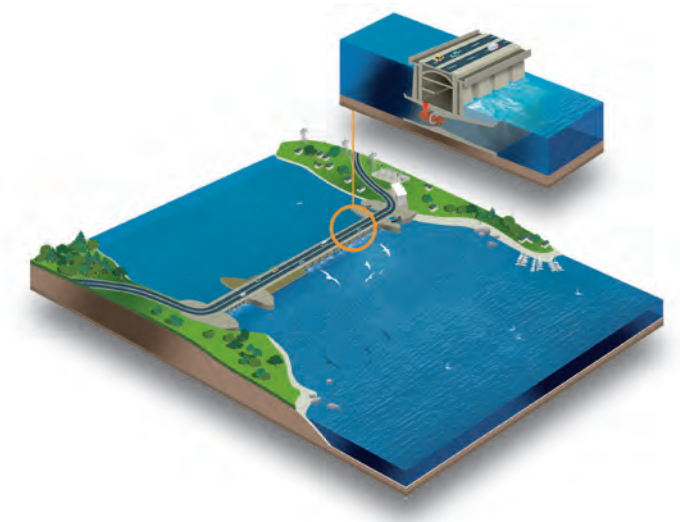
Markers for a basin with a surface S ($km^2$) and a mean tidal range $H_m$ (in m)

| | | |
|---|---|---|
| $H_m$ = **7 m** | ▶▶ | E ≈ **40 GWh/yr/km²** |
| $H_m$ = **5 m** | ▶▶ | E ≈ **20 GWh/yr/km²** |
| $H_m$ = **3.5 m** | ▶▶ | E ≈ **10 GWh/yr/km²** |

# 4 STANDARD DIAGRAMS
# OF TIDAL SCHEME SOLUTIONS

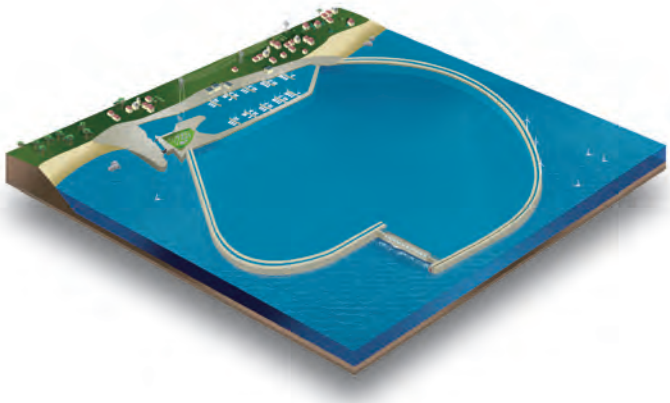
## DAM IN AN ESTUARY

Like La Rance



## COASTAL LAGOON

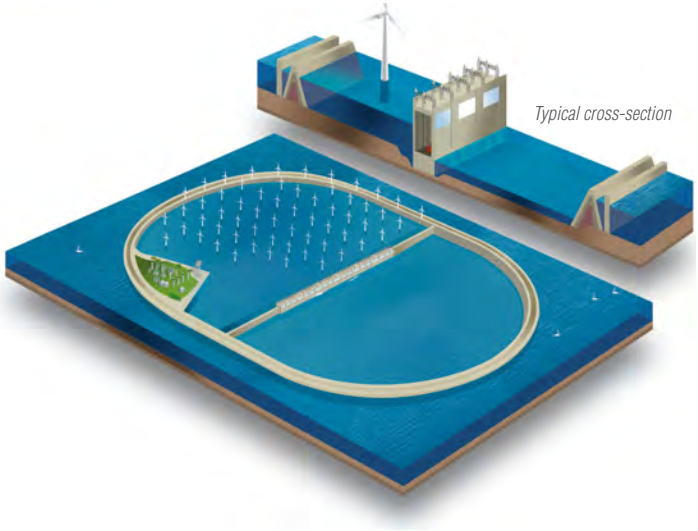
Like the Swansea Bay project (UK)



## OFFSHORE LAGOON

An isolated basin at sea

*No scheme of this type built to date*

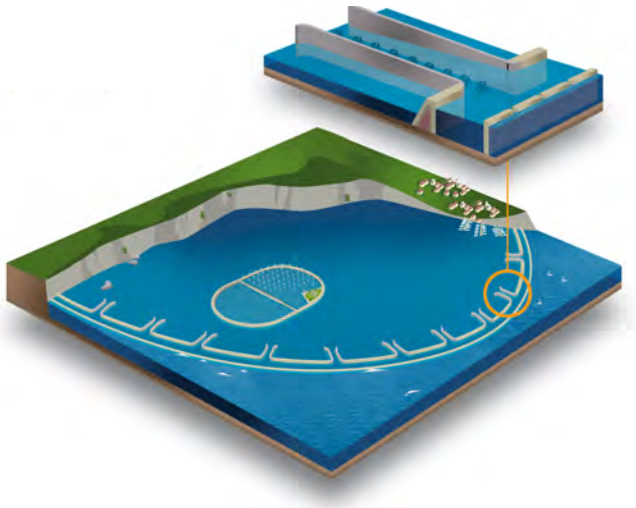


*Typical cross-section*

## TIDAL GARDEN* ON THE COAST

An innovative project combining the principle of tidal energy and marine turbine technology

*No scheme of this type built to date*



*(*) New concept – see p. 15*

**Project sizes can vary considerably:** from local basins measuring a few hectares to ones that cover tens of km². **Re-using existing coastal or port infrastructure constitutes a real opportunity for added value** on some sites.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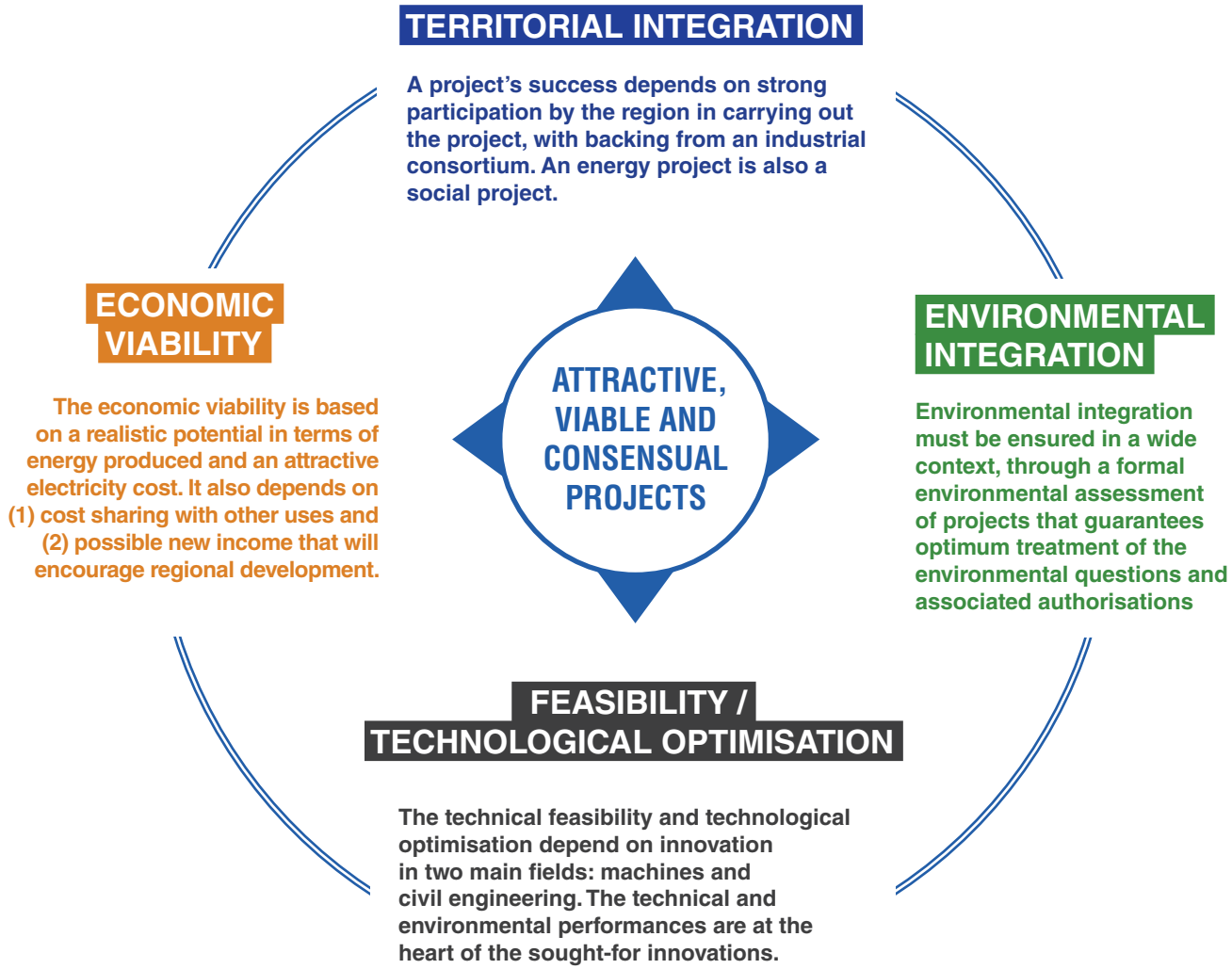
# NEW PROJECTS
## 4 CONDITIONS FOR SUCCESS

**The 4 pillars for success for a new tidal project are** its territorial integration, its economic viability, its environmental integration and its technical feasibility.




**Each of these pillars constitutes a corner stone without which no new project can be carried out.** Together, they guarantee that the goal of truly sustainable territorial development will be reached.

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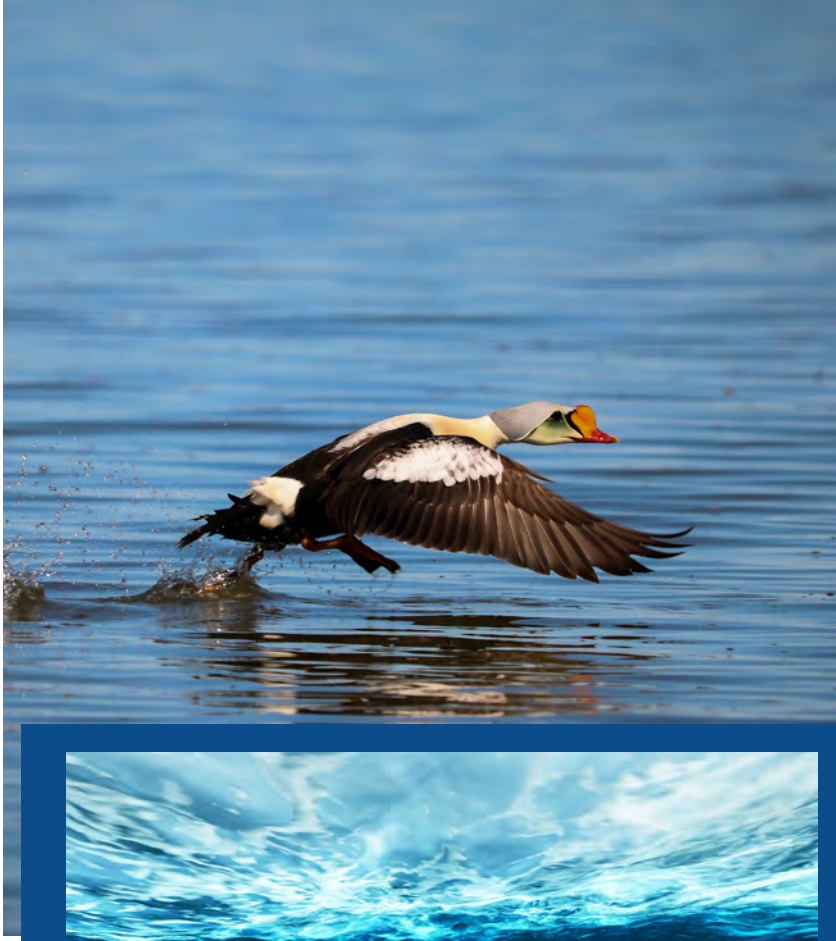
# TIDAL ENERGY & THE ENVIRONMENT

## SUSTAINABLE AND SHARED ENVIRONMENTAL PERFORMANCE



The environment is at the heart of territorial identity. As such, the environmental performance of a tidal project is a crucial requirement for encouraging its social integration. Whatever the project type, **it can profoundly alter the local environment and ecosystems.** A project's environmental performance is based on a detailed technical and strategic analysis, both on a local scale and on the strategic scale of the hydrosystem. The environmental assessment must ensure that the environmental risks are controlled during the construction and operation phases, based on the principle of "Prevention, Reduction, Compensation" (P.R.C).

The more-or-less significant effects of projects on the environmental conditions and the coast and in the basins and close to infrastructures, is expressed by:

- a modification of the amplitude of tides and tidal ranges, currents, surfaces of tidal flats, slack water periods, flows and volumes exchanged between the sea and the basin,
- a potential modification of the salinity,
- a modification of waves and swell in the basins and on the shore,
- a modification of sediment transport, the rate of silting, the sea bed or the bathymetry,
- the creation of maritime obstacles or new connections,
- the generation of noise (extraction of materials; construction phases; turbines in operation; possible dismantling).[6]

**Different types of projects will not have the same effects on environmental conditions.**
These effects can be appreciated using environmental indicators or descriptors, such as the biological diversity, the native species, the integrity of the seabed, the noise level.

**These same processes can also give rise to positive effects** on the environmental conditions.


**A few examples of positive effects:**

- The restoration or control of salinity conditions (as is the case at Sihwa in South Korea),
- the limitation of sediment transport,
- the creation of bird or aquatic wildlife sanctuaries,
- the limitation of swells and surges along the coastline.

The assessment must take the project's lifetime into account. The end-of-life dismantling conditions must be examined to decide on the pertinence and possibility of putting things back how they were, integrating the complexity of a long period under the influence of large-scale phenomena (climate change, natural evolution…).

Any project must therefore be initially envisaged in the context of a strategic *environmental assessment* and large-scale *planning*, which is necessary in any case for any energy plan being developed in France: this is the subject of the Policy Documents drawn up in response to European directive 2014/89/EU. The procedure must result in the identification of suitable sites, in consideration of the environmental challenges and the development of tidal energy projects, and taking into account the potential impacts as well as the environmental benefits linked to the projects.

[6] *See the indicators of the Marine Strategy Framework Directive: www.dcsmm-d4.fr*

# TIDAL ENERGY & TERRITORIAL INTEGRATION

## TERRITORIAL SYNERGIES AND INNOVATIVE MULTI-USE PROJECTS

Tidal energy is intended to be used for territorial development. In this context, a successful tidal project will be a project where the overall relationship with the territory has been considered very early on from all aspects of its "ecosystem". It structures the territory's geographic and socio-economic landscape: on the one hand, its presence necessarily alters this landscape, but, on the other, it opens it up to a number of developments.

### What new services will it bring to the territory?

**The synergies and opportunities to create value for the territory are tangible and linked to the type of project:**

- **Protection of the shoreline from coastal erosion and the risks of coastal submersion,**
- A multi-energy project, hybridation with other methods of production and energy storage and sharing of infrastructures (wind turbines, swell meters),
- Improved connections and land transport,
- Development of aquaculture,
- Attractivity and development of a sustainable local tourism, including industrial tourism,
- Sports, leisure and cultural activities,
- Improved landscape for impoverished sites, better sediment management…


**These synergies can largely counterbalance the impacts on existing activities.**
Successful territorial integration centres on a full and lucid evaluation of the project's interactions with the existing socio-economic activities:

- Government missions: territorial defence, surveillance, signalling, communication,
- Port and industrial activities (discharge and intake of sea water,...), energy production, cables and pipelines,
- Maritime transport, professional fishing, marine cultures, extraction of materials, maritime and coastal tourism, recreational boating and nautical activities.

# TIDAL ENERGY & TECHNOLOGICAL INNOVATIONS

## NATURALLY INNOVATIVE ENERGY, WITH PROMISING SOLUTIONS

Tidal energy is the strength of the tides in action. Technology can be used to tame this force and benefit from it. Engineers and manufacturers are working on the solution.

If most of the existing and available technologies for exploiting tidal energy are mature, there are still real opportunities for innovation. Whether it is about reducing costs, or improving the industrial and environmental performance of plants, innovation remains a crucial lever for developing tidal energy.

**As regards innovation, France has tried-and-tested skills and expertise.** France has a network of engineers and industrial skills that are recognized worldwide.

- Top-level operators with design and operation/maintenance experience that is unparalleled in the world,
- Engineering services and research centres at the forefront in maritime engineering and physical and environmental oceanography,
- World-renowned constructors of electromechanical equipment,
- The first industrial-sized demonstrator: La Rance.

**For the future of tidal energy, the civil engineering of dikes and machine and electrical equipment design** are the two areas where innovation will have added value.

*Design VLH - Tidetec © MJ2Tech*

**Depending on the project, civil engineering can represent a very large part of the investment, somewhere between 50 - 70%.**

New solutions can help to reduce this cost. For example, they may concern:

- the use of more modular components manufactured "on-shore" that reduce de facto the environmental impact of the construction: concrete boxes possibly combined with rockfill,
- Dike technologies using geotubes.

**Innovations in machine and electrical equipment design can cover a wide spectrum:**

- Variable speed bulb-type turbine-generator,
- Orthogonal turbines,
- Counter-rotating turbines,
- Marine turbines to equip gate sluices, using new types of turbines.

To prove their technical and economic viability, the developments of these technologies must result in the production of **demonstrators.**

### LA RANCE: A UNIQUE INDUSTRIAL-SIZED LABORATORY TO PROVIDE FEEDBACK

With the La Rance tidal energy plant, France has a unique industrial-sized "laboratory" to learn the crucial lessons for making the construction of future projects safe, as regards:

**- environmental integration:** the plant's operating mode and control of the tidal signal in the basin, transparency for wildlife, new construction methods to prevent impacts

**- plant optimisation:** layout of the electro-mechanical equipment, anti-corrosion and antifouling protection, equipment maintainability

**- territorial integration** and cohabitation/synergy with local uses.

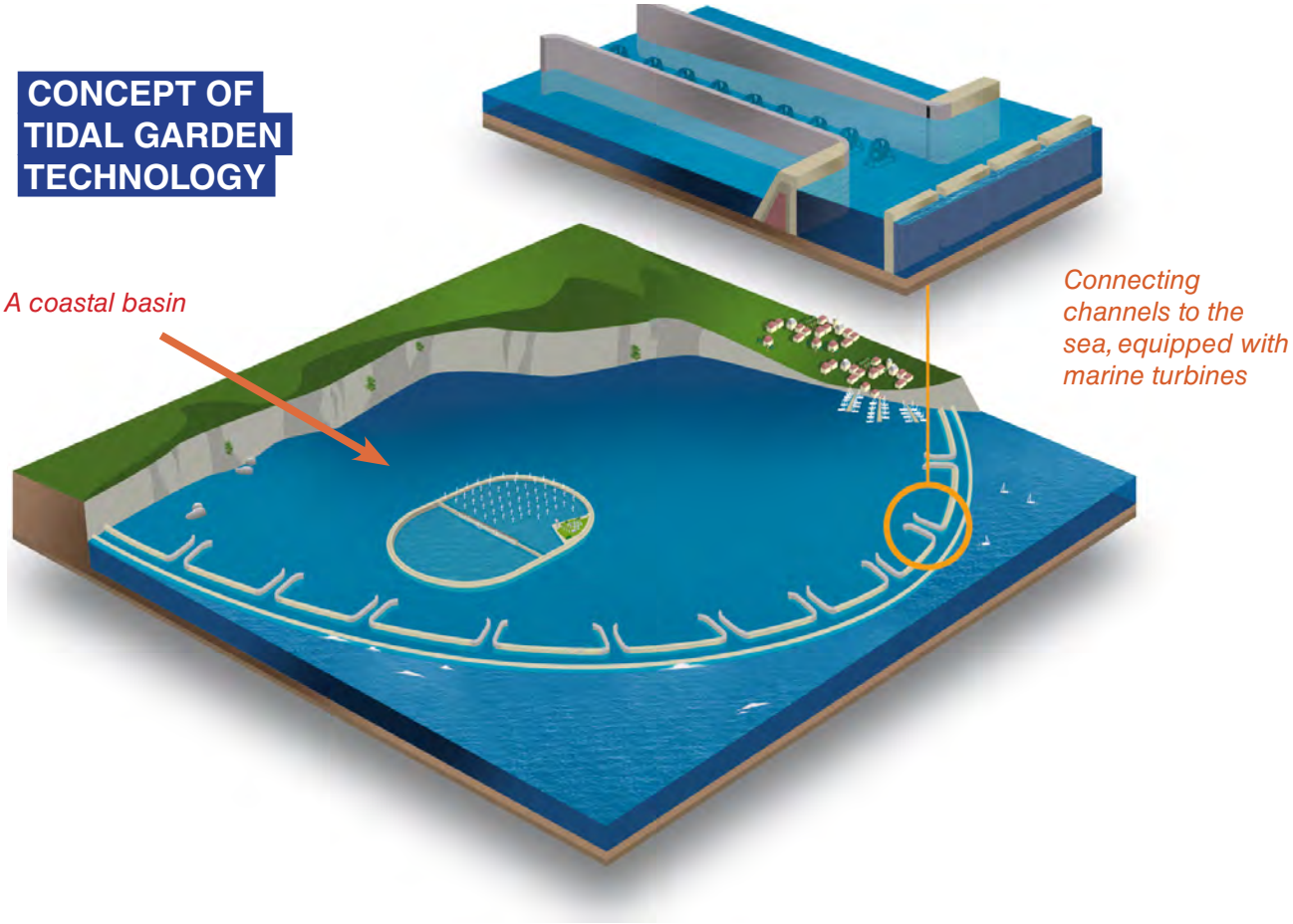
# TIDAL GARDEN *(MARÉLIENNE)*
## A NEW INNOVATION

The concept of ***Tidal Garden*** combines the best of marine turbine technology and tidal energy technology: a coastal basin is connected to the sea by open channels equipped with rows of marine turbines.

**The concept can be used on sites with moderate tidal range (3 to 5 metres), where the bulb-type turbine-generator technology used at La Rance or Sihwa cannot be used.**

**This attribute multiplies the potential number of sites and opens up the field of exploitation of tidal energy to new areas in France (e.g. Pays de la Loire) or elsewhere in the world (e.g. the Netherlands …).**

**CONCEPT OF TIDAL GARDEN TECHNOLOGY**




## Its potential assets are considerable.

**Technically,** the Tidal Garden allows:

- the installation of several dozen marine turbines to be envisaged, thereby reducing costs **through scale effect,**
- better **speed regularisation**, close to optimum operation for marine turbines, by concentrating currents in the channels; and an interesting load factor of around 40%

**Environmentally,** this technology

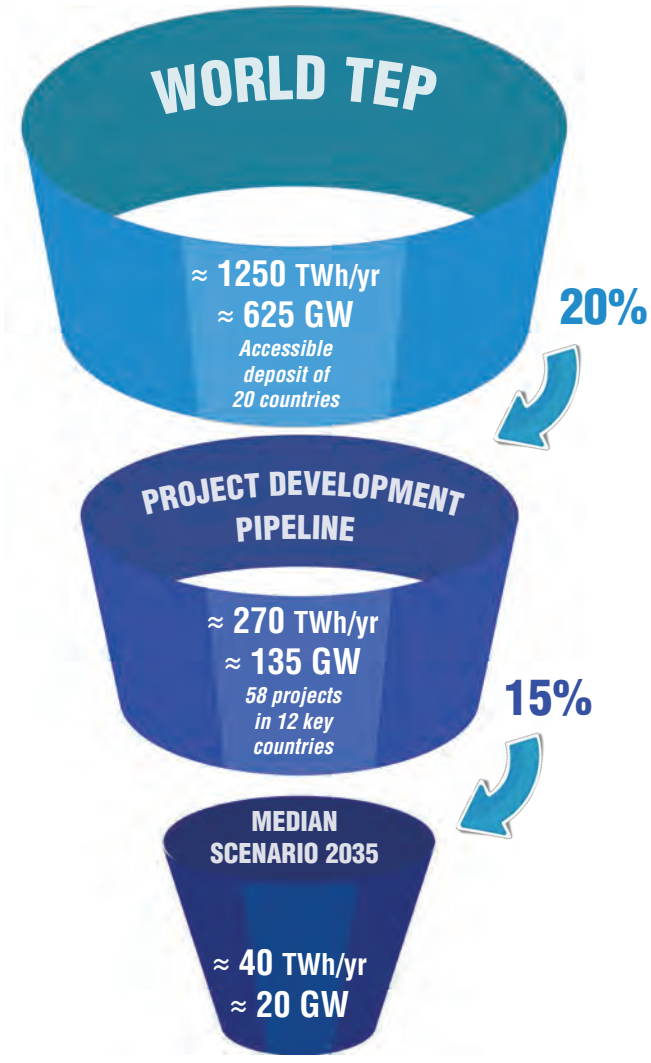
- offers virtual transparency for **marine wildlife**,
- gives a tidal signal in the basin that is very close to the natural one (apart from a little phase shift) and therefore does not greatly disturb the existing **ecosystems,**
- allows much better **maintenance and accessibility** compared to sites in the open sea (thanks to the installation of marine turbines in the channels) and therefore reduced maintenance costs.

# TIDAL ENERGY & ECONOMIC BENCHMARKS

## REALISTIC POTENTIAL FOR NEW PROJECTS

**An estimated 1 250 TWh/yr** of Technically Exploitable Potential (TEP) worldwide v. current effective annual industrial production of **1 TWh: two figures that give an idea of the possible realistic development of projects based on tidal energy.**

Based on the world TEP, the SHF proposes a target for a pragmatic development potential, i.e. that combines the 4 conditions for success (see p. 11), of around **40 TWh of annual production :**




**3% of the world TEP accessible within 15 to 20 years**

### What are investment costs for new projects?

The SHF identifies an initial cost benchmark on the more mature projects, with a **ratio of around 3.5 M€/MW** installed for structures with electrical capacity of several hundred MW, like the new projects currently being developed to revive the sector (UK projects).

The opportunity to lower the CAPEX is essentially in the dike's civil engineering cost. **The SHF considers it credible to define an objective cost of 2.5 M€/MW for structures that exceed the installed GW,** with the dike representing between 50 and 70% of this global CAPEX.

### What revenue will the new projects contribute?

**The sale of electricity represents the main source of income by far.** However, it is judged insufficient in the current conditions of evolving government aid (<100€/MWh).

This is why the externalities constitute one of the essential elements for any project. Considering the multi-use nature (aquaculture, tourism, etc.) and the creation of direct long-lasting and non-relocatable jobs, they represent top-level levers of attractiveness. They create a link between socio-economic policy and energy policy in a major territorial project.

These externalities could represent an annual value contributing to the project's economic assessment of **up to +40 or 50%**, broken down as follows:

- Annual revenue from multi-use activities (aquaculture, pleasure boats, catering, hotels, tourism, etc.): **+5%**
- Economic value of long-lasting and non-relocatable jobs: **+25%**
- Positive carbon footprint, confirming the interest of such investments for meeting the challenge of mitigating the effects of climate change (reduction of greenhouse gas emissions): **+7%**
- Protection of the coastline, confirming the interest of such investments for meeting the challenges of adapting to climate change (rise in water levels and extreme events): **+3% to +10%** *(and without highlighting the probably considerable indirect effects of altering the coastline).*

## How can projects' economic performance be guaranteed?

**The SHF identifies four levers:**

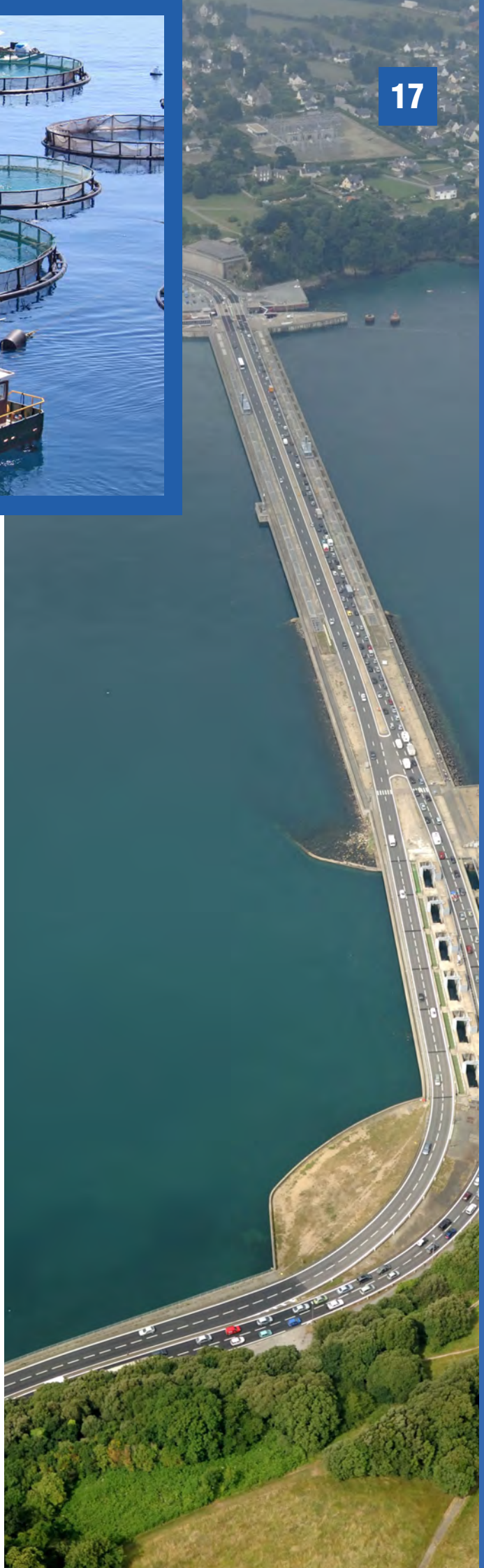
1. **Progressively favouring large-scale projects, when it is environmentally pertinent and once the solutions have been "de-risked" on small-scale demonstrators:** from several hundred MW to a few GW, projects gain significantly in economic attractiveness until they can count on the sale of electricity alone to reach the specific thresholds for this type of project (purchase price < 100€/MWh).

2. **Adapting the project's financing through two levers:**

- *Financial engineering:* Project IRR under 5% attainable thanks to financing innovations: public warranties and funds, crowdfunding, green bonds, etc.
- *Commercial setup:* preferential electricity purchase tariffs, investment subsidies, contracts for difference… between 80 and 100€/MWh.

3. **Resorting to multi-use making a special effort on aquaculture (fish farms or seaweed farms) with reflections for large-scale projects.** The different projection scenarios studied tend to validate almost systematically the economic, social and ecological pertinence of new large tidal energy projects.

4. **Enhancing the project's externalities in terms of environmental benefits** (protection of the coastline, flood risks, natural protected zones, carbon footprint), **jobs** (direct long-lasting and non-relocatable jobs) and the **creation of local value** (development of activities that will benefit from the project).



# VISION & AMBITION

## OUR ROADMAP GUIDELINES

**Despite France has one of the best resource in the world, the exploitation of tidal energy is almost inexistent in its energy roadmap. Energy from tidal stream turbines is only very marginally present[7] in recent MEPs, and tidal range is totally absent.**

**Convinced that France can be highly ambitious regarding the exploitation of tidal energy, in view of its assets (its sites, its industrial network, its engineering and research skills) and the challenges it faces, the SHF recommends starting a national action plan structured around the following 5 action areas:**

## 1 DEVELOP A STRATEGIC ENVIRONMENTAL ANALYSIS OF POTENTIAL SITES

This strategic analysis must allow **a detailed understanding of the interactions with the environment according to project type:**

- by applying the PRC principle mentioned earlier and by expressing the impacts on the environment in terms of ecological functionalities that the projects must include in their specifications from the design stage: tidal range in the basin, slack water levels, flows, fish continuity, sedimentation, etc.
- by adressing the issue of decomisionning.

## 2 DEVELOP A TERRITORIAL STRATEGIC ANALYSIS WITH THE LOCAL AUTHORITIES, PARTICULARLY THE REGIONAL AUTHORITIES

This crucial step must define a **site inventory that is coherent with the ambitions and policies of regional energy development** and presents the best conditions for territorial integration: synergy with the existing users and, above all, opportunities for new territorial services (in terms of multi-use) and economic development.

## 3 REALISE SUCCESSFUL TECHNICAL DEVELOPMENTS AND INNOVATIONS

Innovations concern both machine technology and dike construction. The objective is to ensure that the French professionals in this sector **have the best standard of solutions and the best fitted:**

- to the variety of sites and scheme configurations,
- and to the range of functionalities that the regions will define for this type of project.

Technological and construction method innovations must also allow environmental impacts to be reduced at sea and on land. These technological advances will put the French network in the best competitive position for exportation.

## 4 USE DEMONSTRATORS TO TEST THE INNOVATIONS ON A SMALL SCALE BEFORE THEIR GENERALISATION

Demonstrators constitute **essential "de-risk" steps** for imagining truly industrial-sized solutions. They also allow the acquisition of data, particularly environmental, **needed for definitive solutions**.

## 5 PREPARE A TENDER POLICY, TAKING A FRESH LOOK AT THE ADMINISTRATIVE AND LEGAL CONTEXT OF PROJECT DEVELOPMENT AND SIMPLIFYING IT

The administrative risks, like the technological and financial risks, are important for projects.
The current experience of developers working on renewable marine energy projects (offshore wind turbines, marine turbines) reveals the complexity of the institutional system and the current regulations. Not well adapted to the development constraints of this type of project, it causes real drift from the schedule that cannot be paid for.
These obstacles add to developers' reticence in committing to these projects. The simplification needed here must, within the confines of our laws, offer a coherent framework in the strategic decision stages, that allows all the stakeholders to carry out their role at the right time to define project's structural functions and give industrialists sufficient visibility to invest serenely and responsibly.

[7] *The marine turbine network must be allowed to develop to offer very localised pertinent solutions, like on certain sites close to islands, or ones where there is no connection to a network, but of a modest size (in power and energy).*

# NEW MULTI-SERVICE AND INNOVATIVE PROJECTS FOR THE FUTURE OF COASTAL TERRITORIES

“ **Réflechissez au mouvement des vagues,**
*Think of the movement of waves, the ebb*
**au flux et reflux, au va-et-vient des marées.**
*and flow, the coming and going of the tides.*
**Qu’est-ce que l’océan ?**
*What is the ocean?*
**Une énorme force perdue.**
*A huge force that is lost.*
**Comme la terre est bête !**
*How stupid the earth is!*
**Ne pas employer l’océan !**
*Not to use the ocean!* ”

*Victor Hugo, «93»*

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