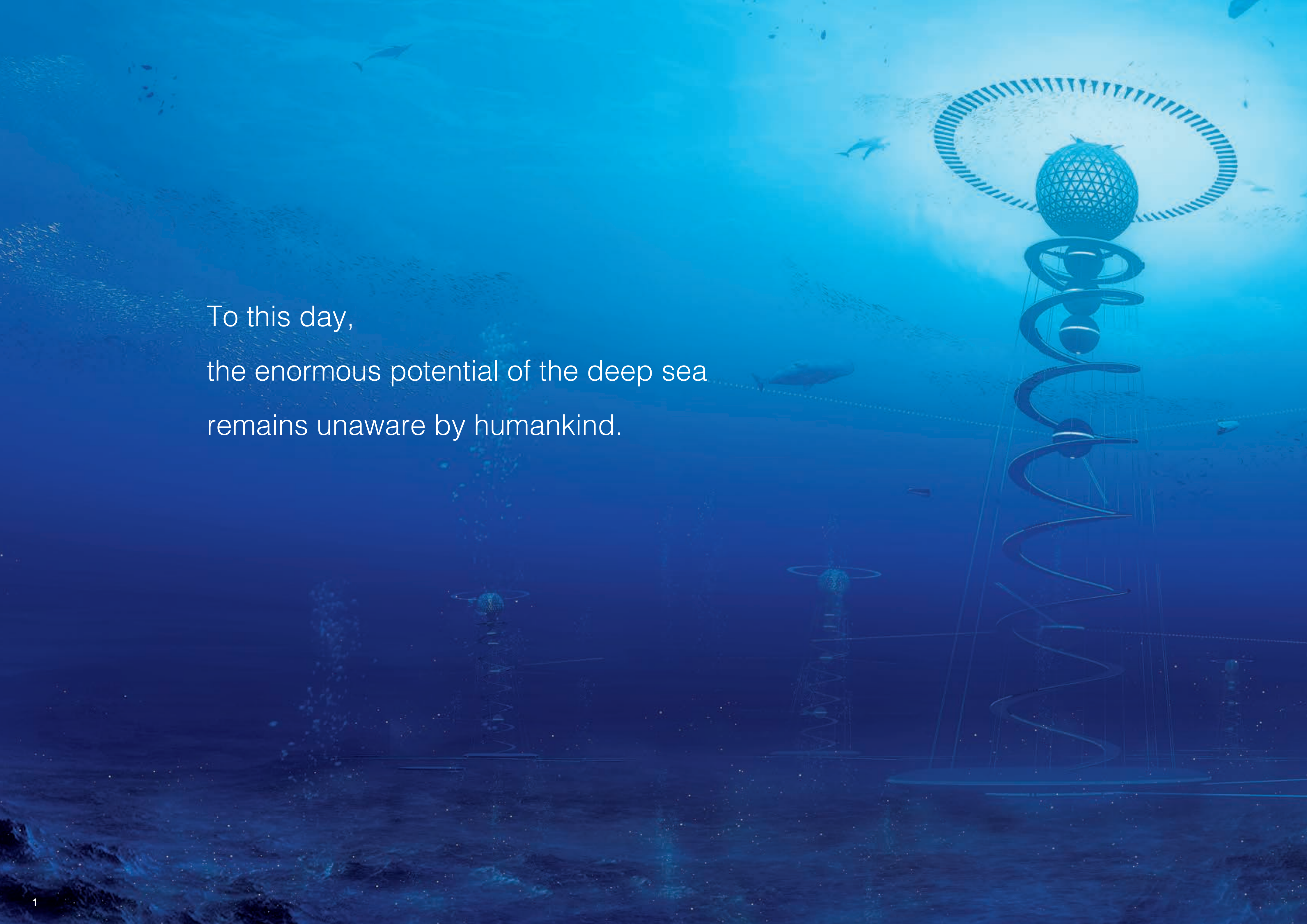
A New Interface
between Humankind and the Deep Sea

— A Deep Sea Future City Concept —

OCEAN SPIRAL

SHIMIZU CORPORATION
SHIMZ



To this day,

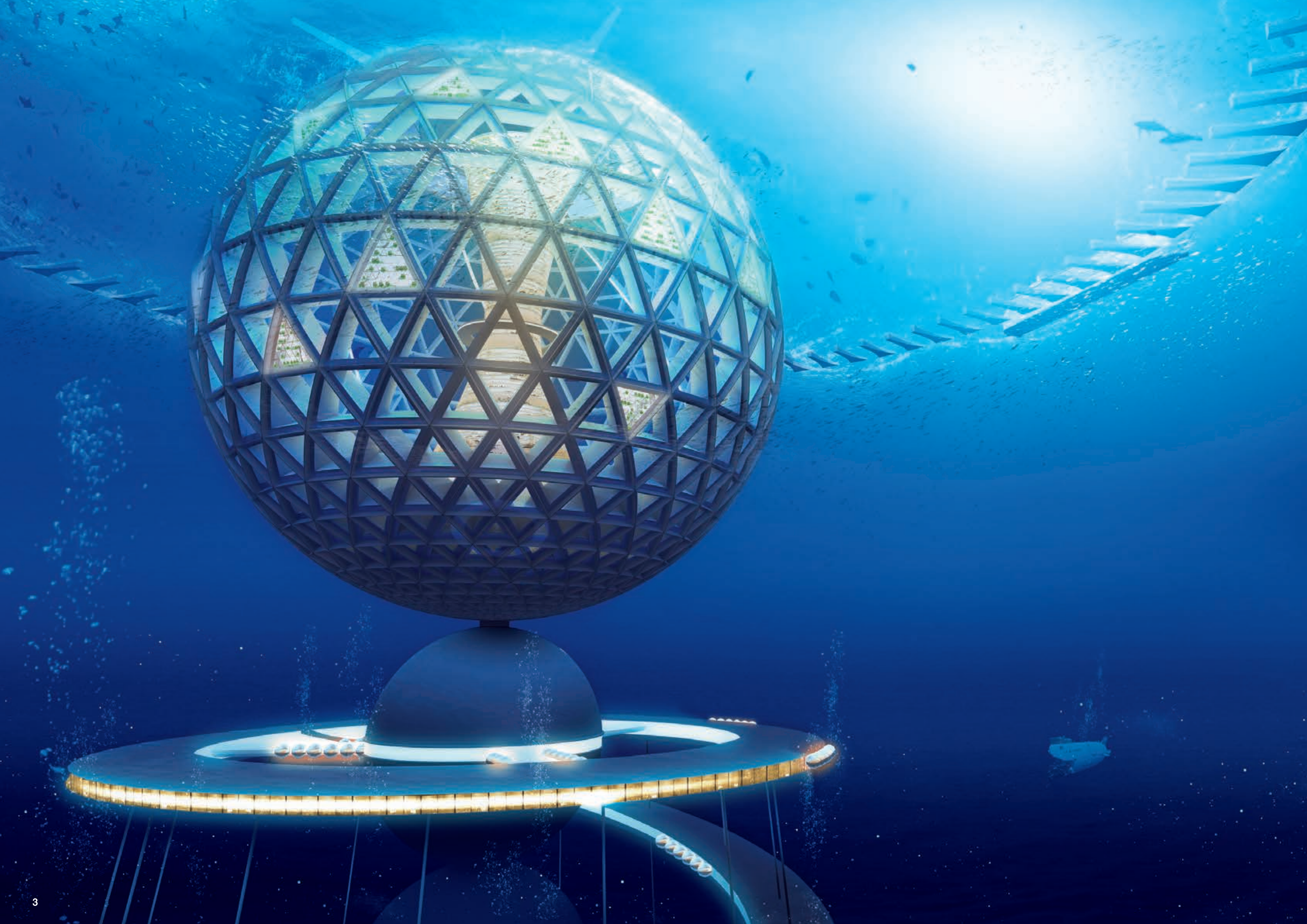
the enormous potential of the deep sea

remains unaware by humankind.

An Idea to Connect Vertically with the Deep Sea

OCEAN SPIRAL

Approximately 70% of the earth's surface is covered by the ocean,
and the ocean itself consists of approximately 80% deep sea.
The deep sea offers enormous potential for ensuring effective
and appropriate cycles and processes in the earth's biosphere.
Unfortunately, we have yet to make the most of this potential.
This large-scale concept seeks to take advantage of the limitless possibilities
of the deep sea by linking together vertically the air, sea surface, deep sea, and sea floor.
Now is the time for us to create a new interface with the deep sea, the earth's final frontier.
Breaking free from past patterns of land development, which have focused mainly on efficiency,
this plan is intended to promote true sustainability while maximizing use of the deep sea's resources.



Five Reasons for Developing this Project in the Deep Sea

The deep sea offers the potential to resolve five current crises revolving around food, energy, water, carbon dioxide, and natural resources.

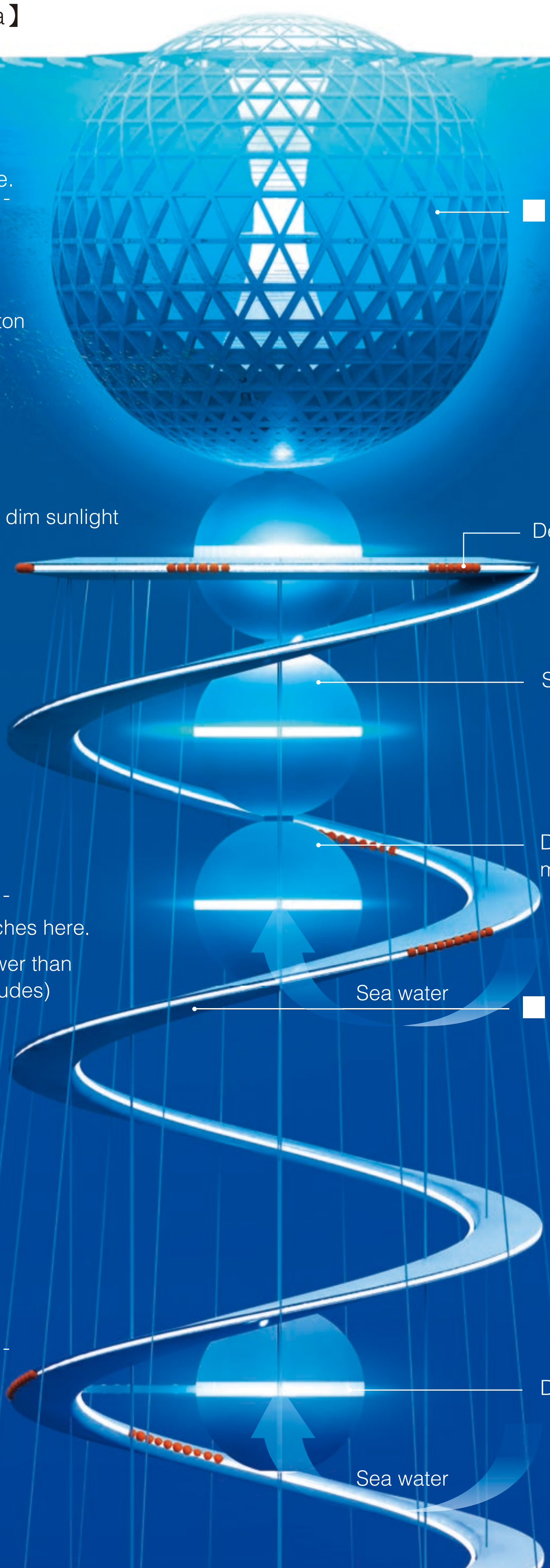
FOOD	The deep sea offers unlimited potential for fisheries, both in terms of quality and quantity.
ENERGY	The deep sea offers unlimited potential for untapped energy.
WATER	The deep sea offers unlimited potential for creating fresh water.
CO_2	The deep sea offers unlimited potential for treating CO_2 emissions.
NATURAL RESOURCES	The volume of resources available on the sea floor and in the sea itself is limitless.

▼

This concept seeks to harness the power of the deep sea to renew the earth, with a deep sea city of the future serving as a base camp.

The OCEAN SPIRAL Concept for a Deep Sea City of the Future

Harnessing the power of the deep sea in order to renew the earth



【Features of the Deep Sea】

−200m The deep sea starts here.

- Euphotic zone:
  Sunlight readily penetrates to this depth.
- Photosynthesis by phytoplankton occurs up to this depth.
- Disphotic zone: Penetrated by dim sunlight

−1,000m Start of the upper bathypelagic zone

- Aphotic zone: No sunlight reaches here.
- Temperatures around 20°C lower than on the sea surface (at low latitudes)
- Sound travels farthest here.
- The lowest part of the layer at which the characteristics of sea water (e.g., temperature, density, and salt content) vary significantly.

−1,500m Start of the lower bathypelagic zone

- Temperature of sea water roughly 2° to 3°C

【Features of this Plan】

■ BLUE GARDEN

- A comfortable, healthy, and safe deep sea city base camp (sphere measuring 500m in diameter)

Deep sea gondola lobby

Super ballast ball

- Uses sand and air to control buoyancy

Deep sea sound wave monitoring facility

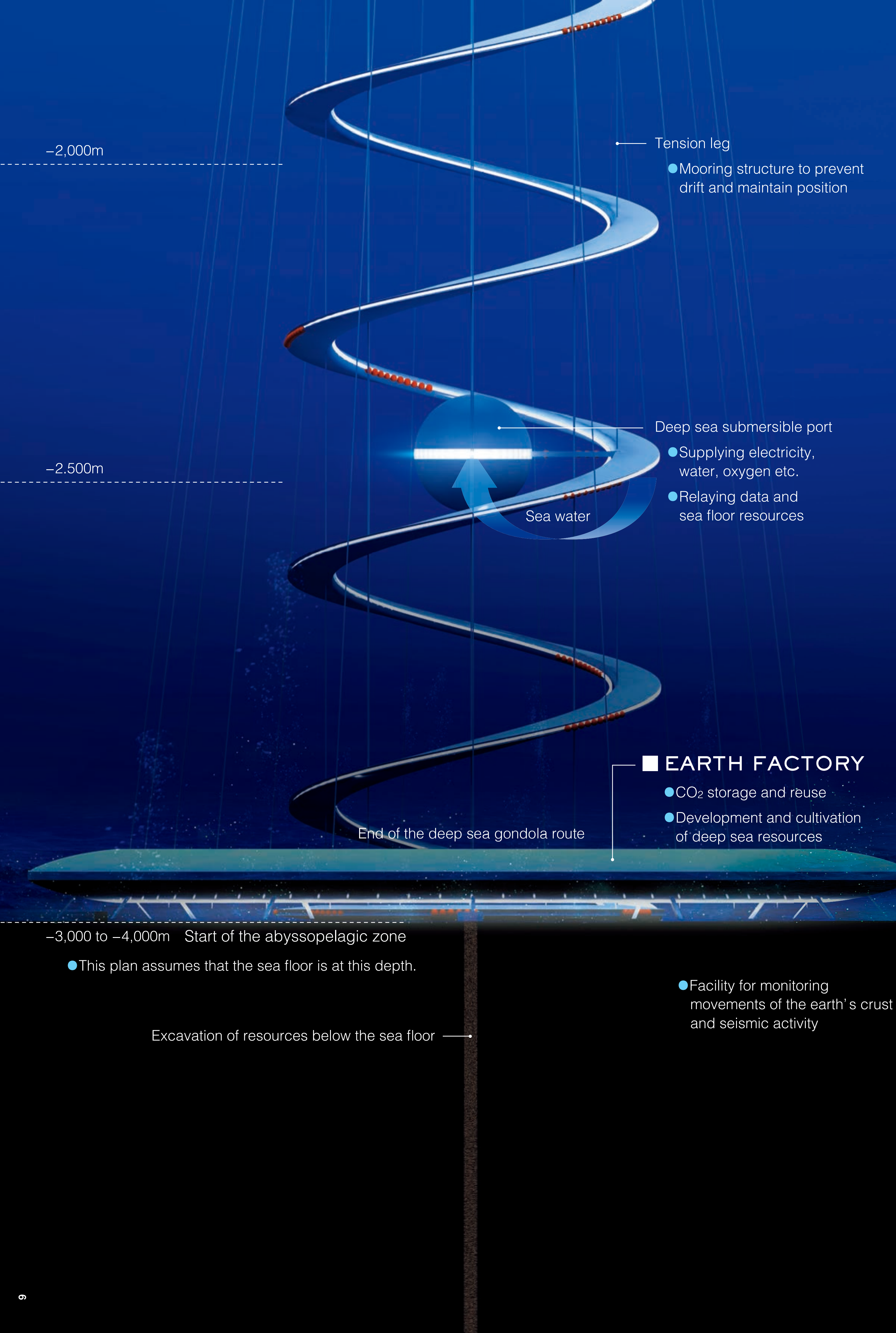
- Uses the depth at which sound waves travel best to monitor the marine environment

■ INFRA SPIRAL

- Transportation functions
  Outbound:
  people, electricity, water, oxygen etc.
  Inbound:
  people, sea floor resources, bioresources etc.
- Water intake functions
  −1,000m: For power generation
  −1,500m: For cold water needed for aquaculture
  −2,500m: For desalination of sea water

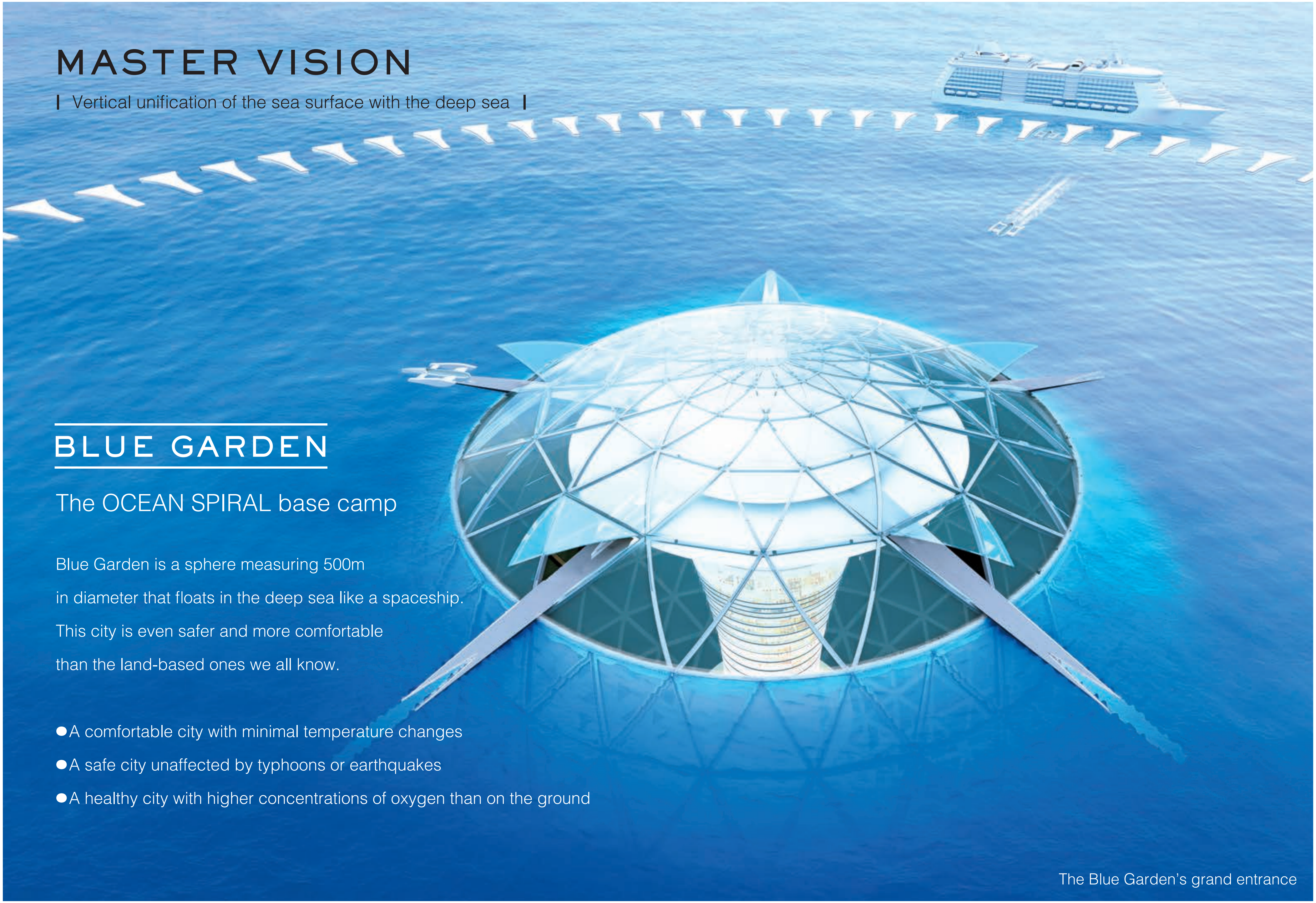
Deep sea biological monitoring facility

- Constantly monitors creatures living in sea water at temperatures of 2° to 3°C.


−2,000m
Tension leg
Mooring structure to prevent drift and maintain position
−2,500m
Deep sea submersible port
Supplying electricity, water, oxygen etc.
Relaying data and sea floor resources
Sea water
EARTH FACTORY
CO_2 storage and reuse
Development and cultivation of deep sea resources
End of the deep sea gondola route
−3,000 to −4,000m Start of the abyssopelagic zone
This plan assumes that the sea floor is at this depth.
Facility for monitoring movements of the earth' s crust and seismic activity
Excavation of resources below the sea floor

MASTER VISION

| Vertical unification of the sea surface with the deep sea |



BLUE GARDEN

The OCEAN SPIRAL base camp

Blue Garden is a sphere measuring 500m in diameter that floats in the deep sea like a spaceship. This city is even safer and more comfortable than the land-based ones we all know.

- A comfortable city with minimal temperature changes
- A safe city unaffected by typhoons or earthquakes
- A healthy city with higher concentrations of oxygen than on the ground

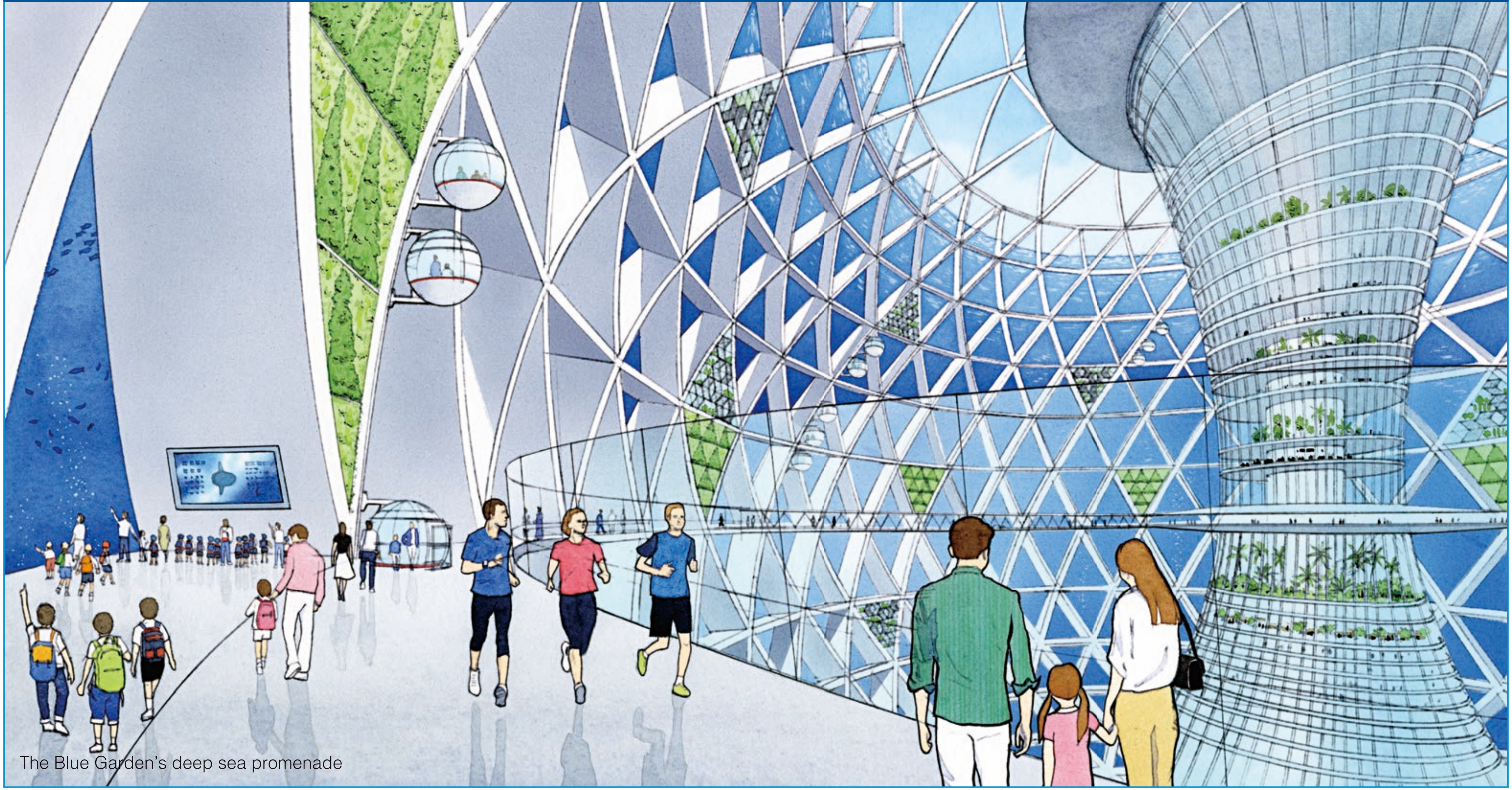
The Blue Garden’s grand entrance


The Blue Garden's atrium

A New Lifestyle

In the Casual Zone facing the deep sea, people can experience and enjoy the deep sea, while learning about and discussing its unique qualities.

Examples: Deep sea sightseeing tours
Hands-on education on the deep sea
Deep sea high-concentration oxygen therapy
Comfortable and safe places to live and work



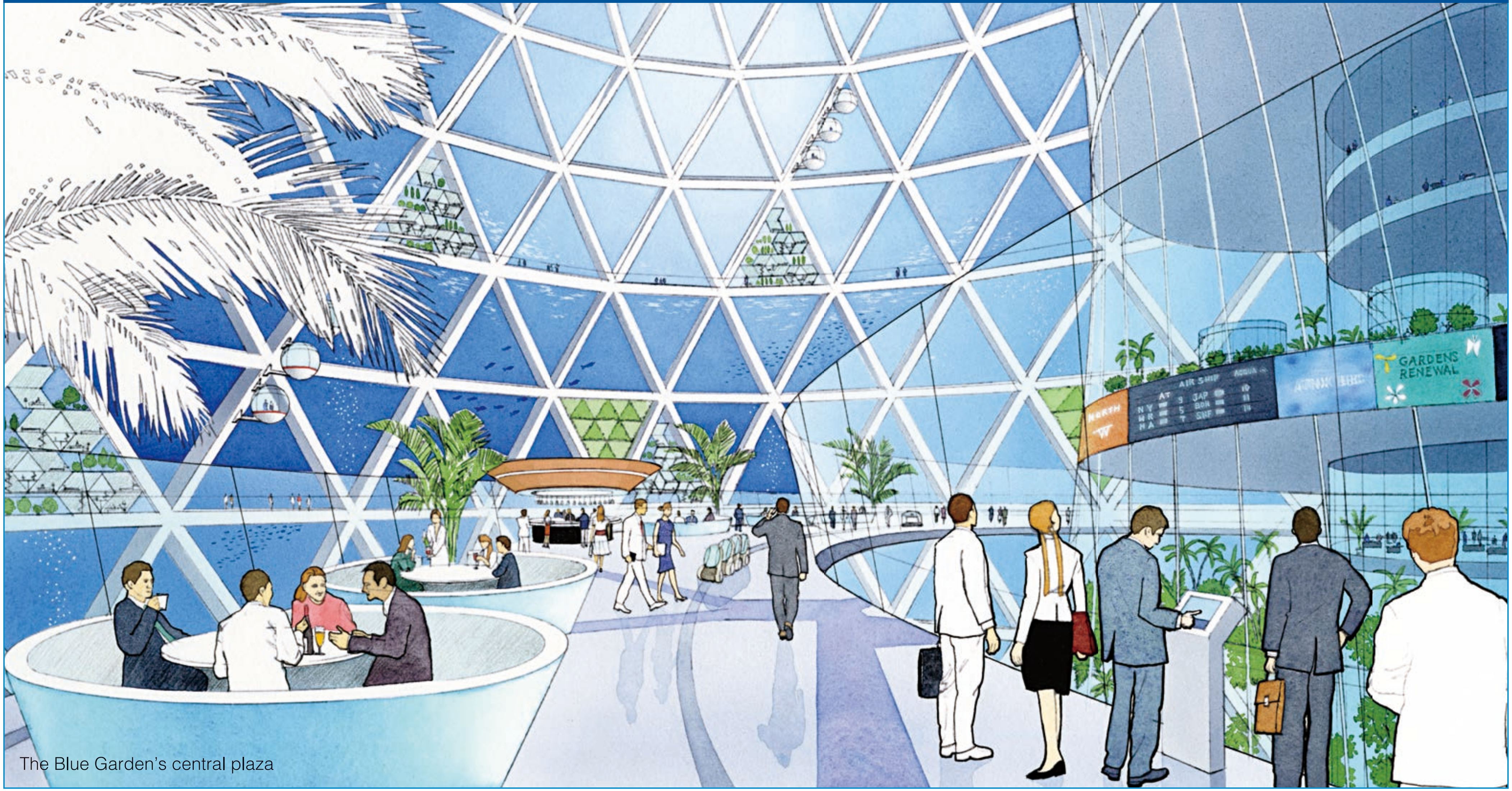
The Blue Garden's deep sea promenade

New Business Models

The Business Zone of the central tower

incubates business models for new deep sea industries.

Examples: Deep sea resource industries
Deep sea energy industries
Deep sea tourism industries
Advanced deep sea research facilities



The Blue Garden's central plaza

Hotel, retail, convention facilities

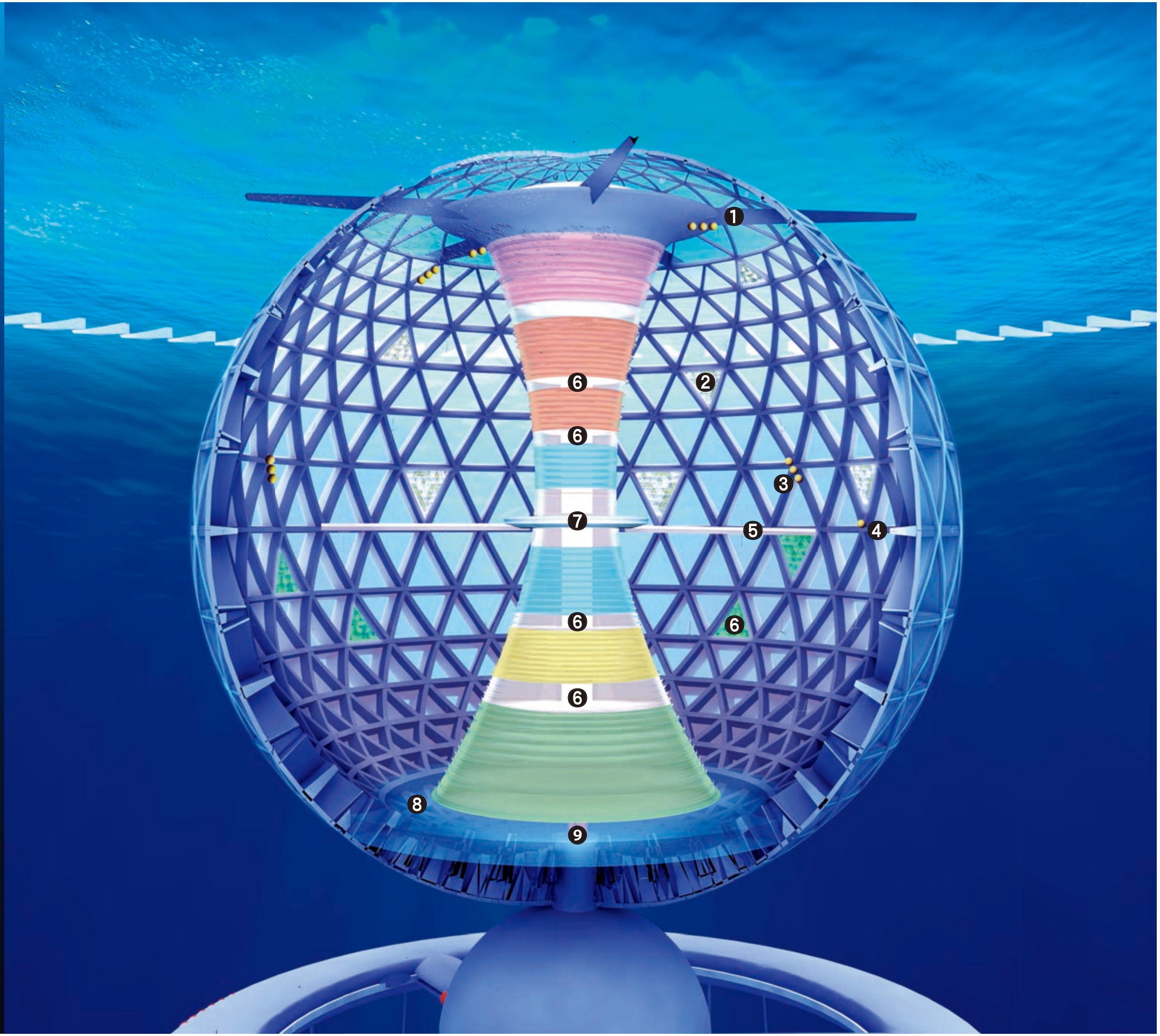
Residences

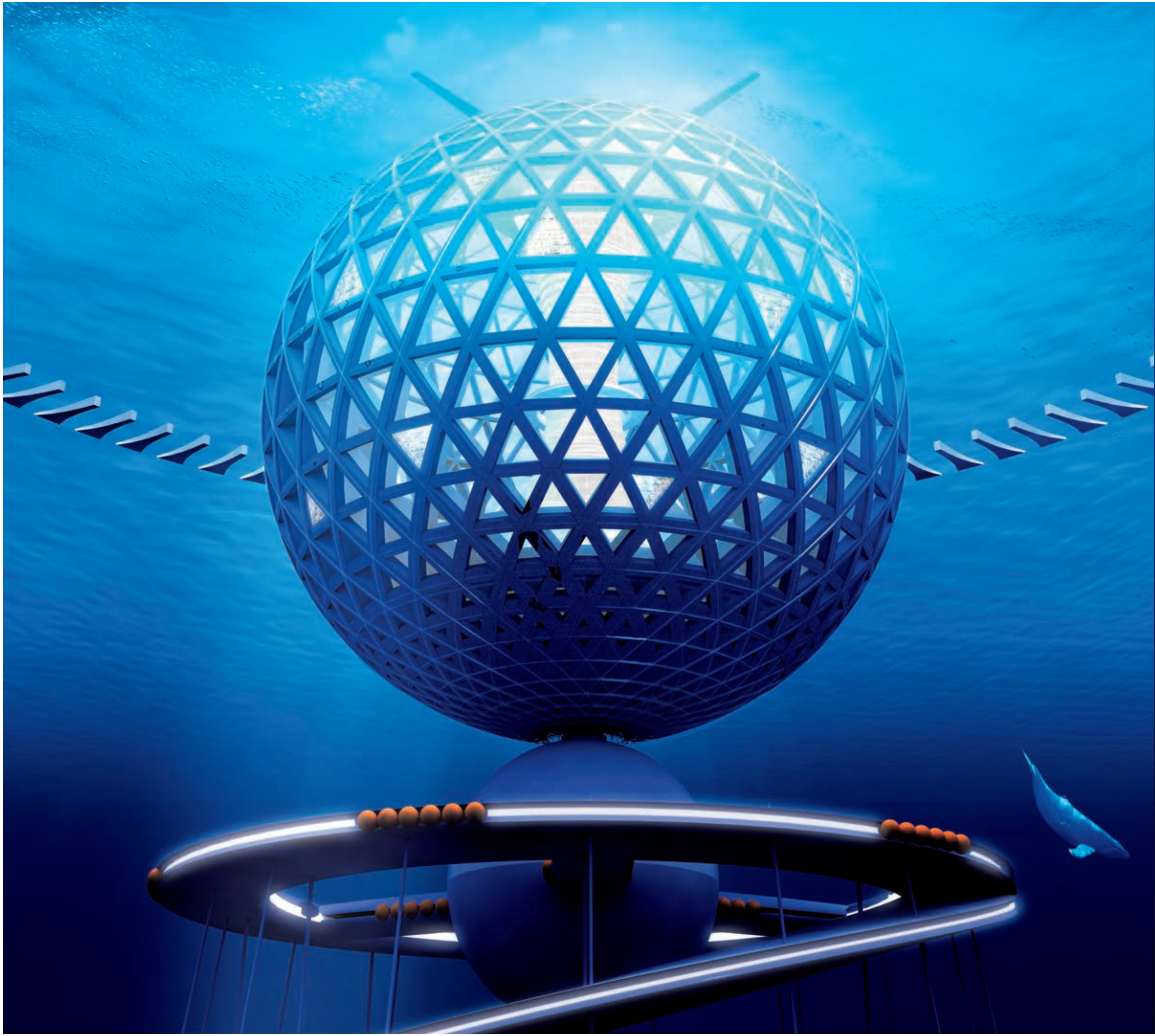
Offices

Apartments

Research facilities, laboratories

❶ Grand entrance
❷ Deep sea suites
❸ Observation gondola
❹ Deep sea promenade
❺ Deep sea walkway
❻ Deep sea park
❼ Central plaza
❽ Freshwater spring
❾ Deep sea gondola platform





◉Overview of the Blue Garden

Diameter of the sphere: 500m

Structure: concrete (resin concrete)

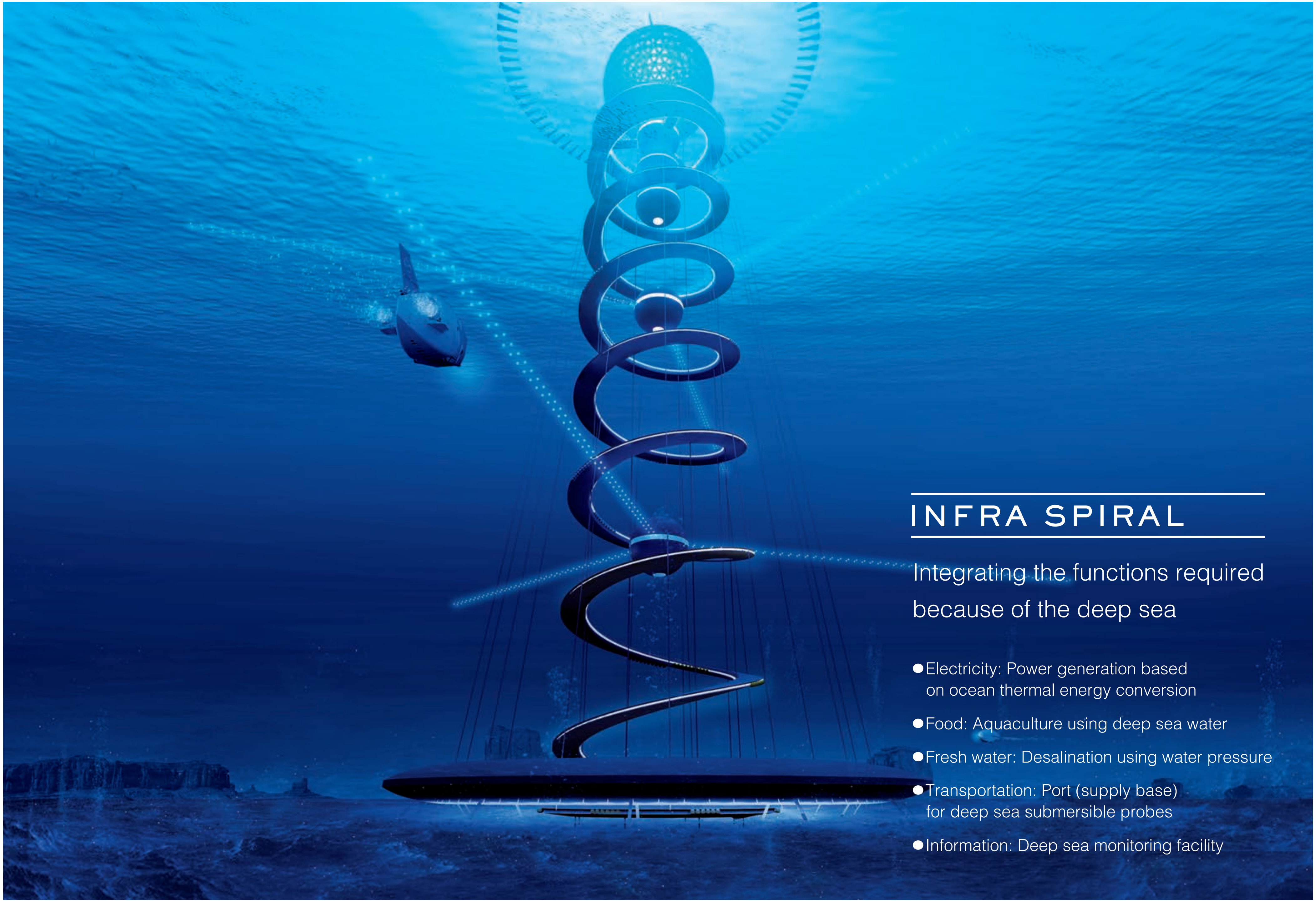
Exterior walls: acrylic plates
and fiber-reinforced plastic ribs

Number of floors: 75
(sea surface floor to deep sea floor 75)

Anticipated population: 5,000
(4,000 permanent residents, 1,000 visitors)

◉Overview of facilities

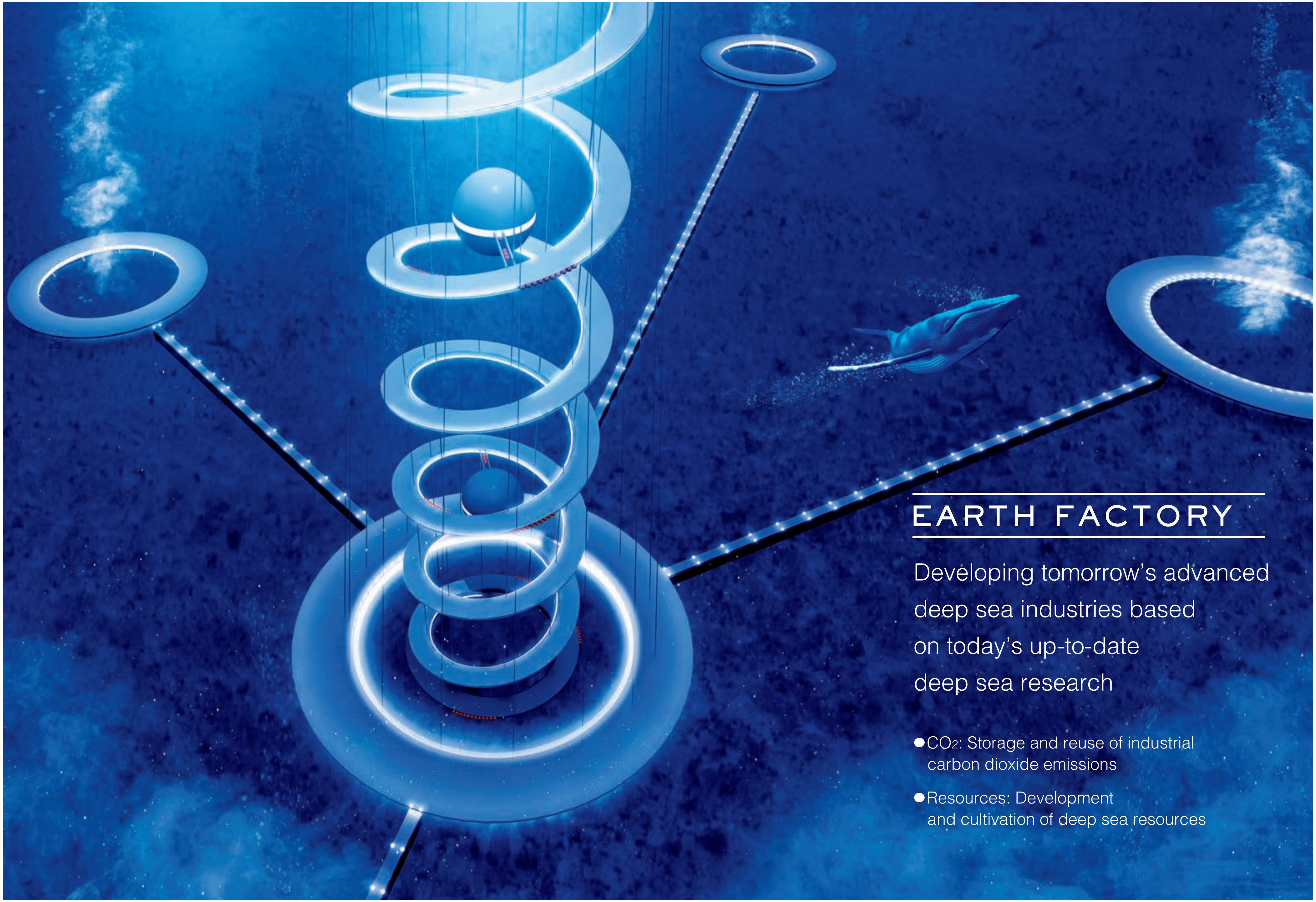
Hotel, tower guestrooms	350 rooms
Deep sea suites	50 suites
Retail, convention facilities	10,000m²
Residences	350 units
Offices	50,000m²
Apartments	800 units
Research facilities, laboratories	140,000m²



INFRA SPIRAL

Integrating the functions required because of the deep sea

- Electricity: Power generation based on ocean thermal energy conversion
- Food: Aquaculture using deep sea water
- Fresh water: Desalination using water pressure
- Transportation: Port (supply base) for deep sea submersible probes
- Information: Deep sea monitoring facility



EARTH FACTORY

Developing tomorrow's advanced deep sea industries based on today's up-to-date deep sea research

- CO_2: Storage and reuse of industrial carbon dioxide emissions
- Resources: Development and cultivation of deep sea resources

SOLUTION

| Earth regeneration by potentials of the deep sea |

Renewing Global Cycles in Five Areas

Harnessing the potential of the deep sea to renew the earth's cycles
and processes and to create a more sustainable human society in five critical areas

FOOD

Food shortages due to explosive population growth worldwide

▼

Environmental destruction due to the expansion of farmland worldwide

▼

The deep sea offers unlimited potential for fisheries, both in terms of quality and quantity.

Harnessing the temperature
and nutrients of the deep sea
(Example: Aquaculture of branded seafood)

▼

Expansion of offshore aquaculture
and fisheries

ENERGY

Tight supply of electric power due to globalization of economic development

▼

Need for base-load power supplies capable of stable and continuous power generation

▼

The deep sea is an limitless source of untapped energy.

Ocean thermal energy conversion utilizing
differences in temperature between
the deep sea and the sea surface.

▼

Energy self-sufficiency

WATER

Global water shortages caused by abnormal weather and increased consumption

Problem solved if sea water can be desalinated easily

Unlimited volume of fresh water could be generated from the deep sea.

Reverse osmosis membrane desalination using deep sea pressure differences

▼

Water self-sufficiency

CO_2

A pressing need to reduce CO_2 emissions in response to global warming

Difficulty in reaching a global consensus on CO_2 reductions

The deep sea offers unlimited potential for treating CO_2 emissions.

Harnessing the earth's natural CO_2 cycle
(Example: creating energy from CO_2)

▼

From simply reducing CO_2 to putting it to use

RESOURCES

Tight supplies of resources due to globalization of ecomonic development

Extraction can deplete resources on land and cause environmental problems

The resources available on the sea floor and the sea itself are limitless.

Harnessing the unused resources in sea water and on the sea floor
(Example: artificial hydrothermal deposits)

▼

Moving from resource extraction to resource breeding

FOOD: Cultivatiing Tasty and Hygienic Branded Fish

Offshore aquaculture of the future

Enclosed deep sea aquaculture system at depths of 300m

❶Cultivation in a clean offshore water environment

❷A wall enclosure system allows feed
and livestock waste to fertilize the deep sea.

❸Harnessing the cold temperatures of deep sea water

❹Healthy supply of nutrients from deep sea water

▼

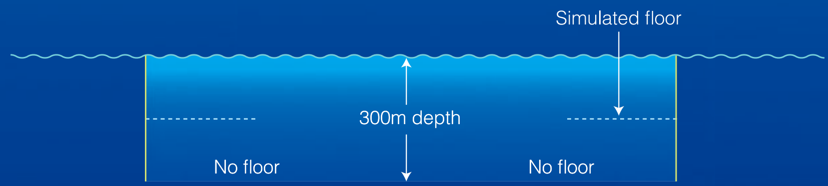
Sustainable hygienic, high-quality aquaculture and fisheries

●Growing stocks of tasty fish

●Highest safety of food

●Contributing to the health of surrounding ecosystems

●Details on offshore aquaculture of the future



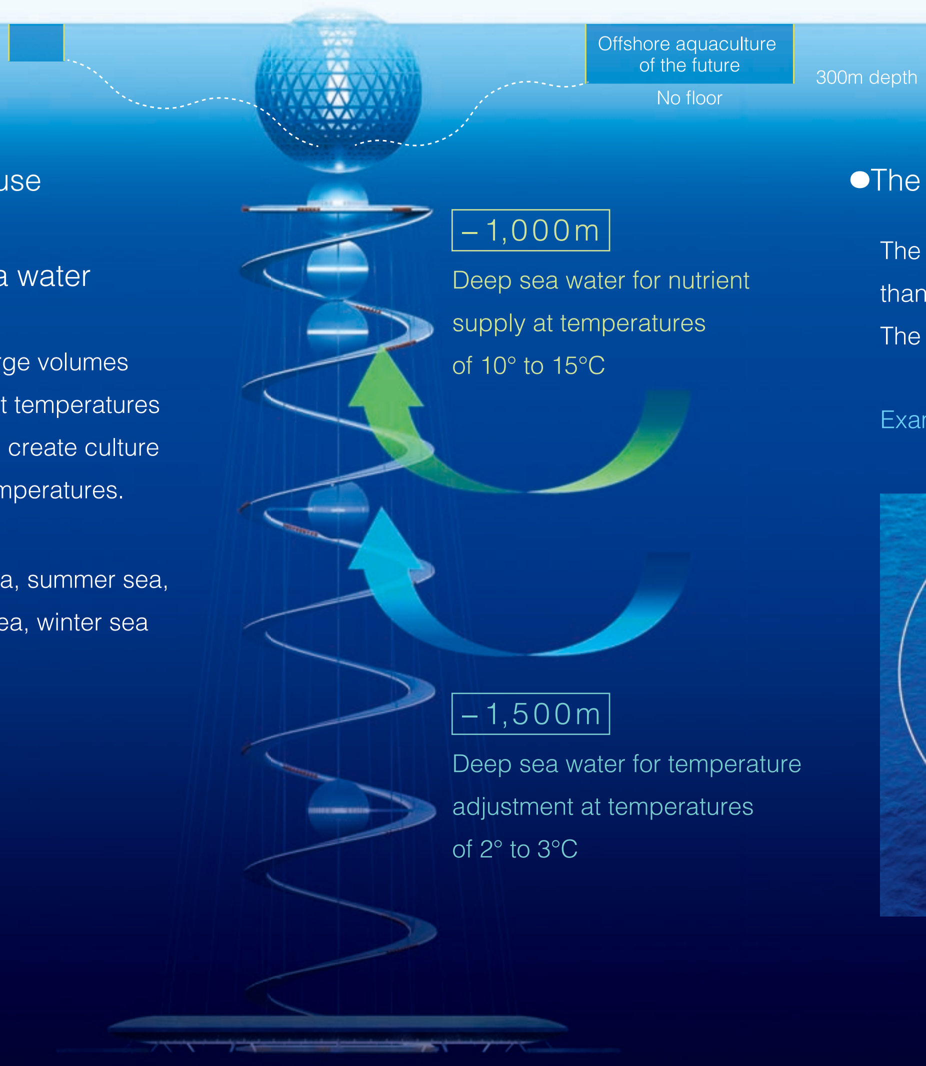
Why use deep sea water? Not only are the large volumes of cold deep sea water nutrient-rich, but they make it possible to adjust the temperature and nutrient content of culture ponds. Cold water makes it possible to create culture ponds with temperatures optimized for specific marine species.

Why depths of 300m? At this depth, it's difficult for migratory fish to escape from the bottom of the culture pond.

Why a wall enclosure system? Feed and livestock waste sink into the deep sea to serve as nutrients for the sea. This also helps maintain clean water in the culture pond.

Technical information provided by: Fisheries Research Agency

Capable of Mixed Aquaculture of Multiple Fish Species, from Migratory to Coastal Fish



●The capacity to use the temperature of cold deep sea water

With the inflow of large volumes of deep sea water at temperatures of 2° to 3°C, we can create culture ponds of various temperatures.

Example: Spring sea, summer sea, autumn sea, winter sea

●The size of the wall enclosure system can be adjusted.

The offshore location makes it possible to build culture ponds larger than those possible in coastal areas.
The size of the wall enclosure system can be freely adjusted.

Example: diameters of 200, 400, 600, 800, or 1,000m

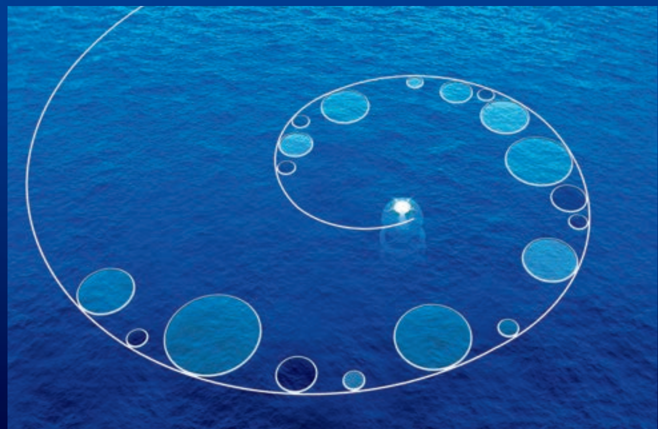


Illustration of variable culture pond sizes

ENERGY: Ocean Thermal Energy Conversion Harnessing the Temperature Differences in the Deep Sea

WATER: Reverse Osmosis Membrane Desalination Using Deep Sea Pressure Differences

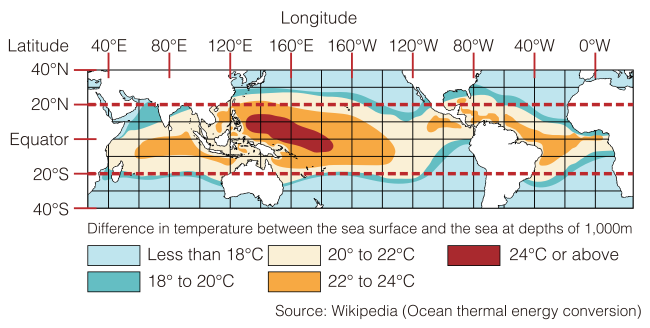
Ocean thermal energy conversion

The deep sea's untapped energy resources are unlimited.

Ocean thermal energy conversion generates electricity via a heat engine that takes advantage of differences in temperature between water on the ocean surface, which is heated by the sun, and cold deep sea water (at depths of approximately 1,000m). Sea water from the equator to the 20th parallel can differ in temperature by up to 20°C. The water between the Tropic of Capricorn and the Tropic of Cancer meets the conditions required for ocean thermal energy conversion.

Projected power generation: 100MW

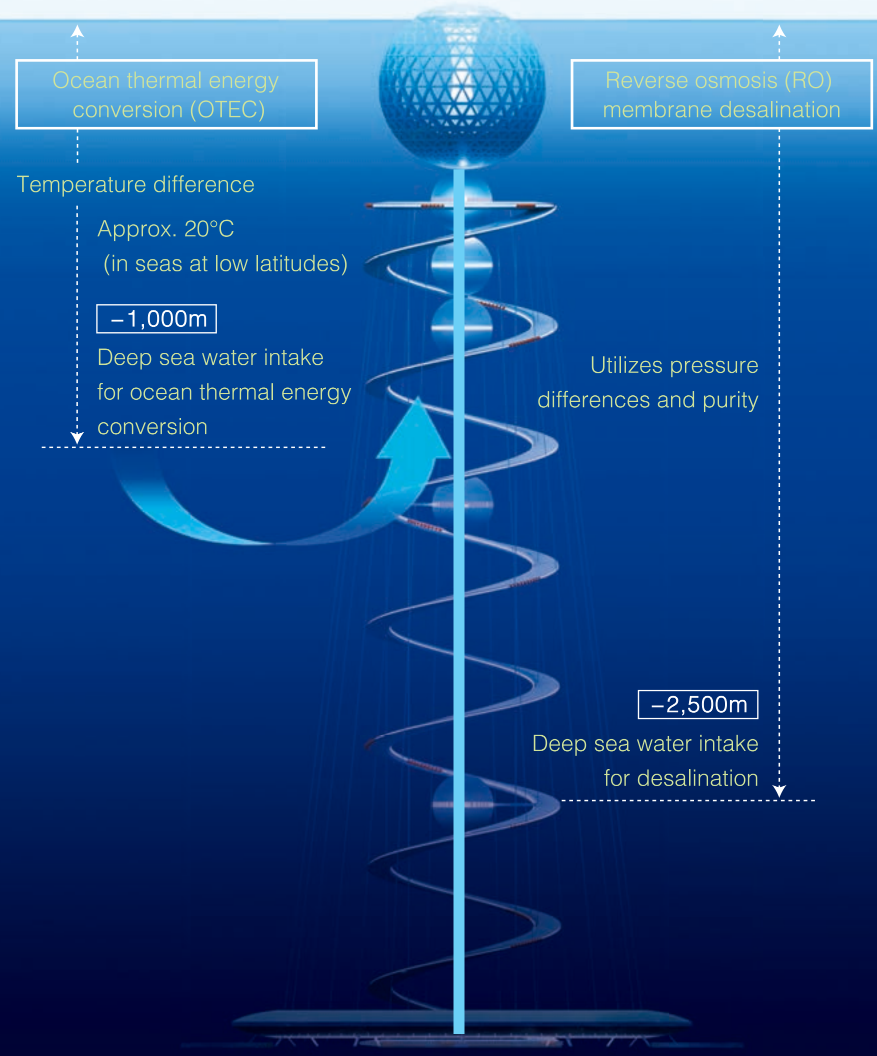
Byproducts include fresh water supply, fertilizer for culture ponds, and harvesting of resources from the sea etc,.



Reverse osmosis membrane desalination

The amount of fresh water that can be created from the deep sea is limitless.

This is a type of filter membrane used to desalinate water by blocking out all impurities. It uses differences in water pressure in the deep sea, which is higher than osmotic pressure, to generate the pressure needed to separate water from impurities.



CO_2: From Decreasing CO_2 to Putting it to Use

Developing tomorrow's advanced industries from today's up-to-date research (Ex.)

Producing methane gas from CO_2

The deep sea offers unlimited potential for treating CO_2 emissions.

Harnessing the earth's natural carbon cycle to produce methane gas from CO_2 by applying energy to water and microorganisms beneath the sea floor.

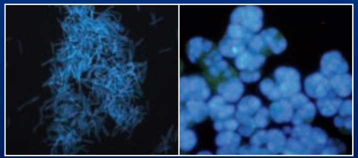
Sea floor methane gas production process

- Before: Takes about 50,000 years beneath the sea floor

↓

- In this concept: Only five hours are needed using a supply of highly concentrated CO_2
  CO_2 is a valuable material for methane gas production.

Today :
Currently studying the carbon cycle beneath the sea floor, which is driven by methane-producing microorganisms, and the actual conditions of their living environment.



Fluorescence microscopic photographs of methane-producing microorganisms
©JAMSTEC

Future :
There are high expectations for a sustained carbon cycle that harnesses the power of methane-producing microorganisms to convert industrial carbon dioxide emissions trapped in marine sediment into natural biogas.

(JAMSTEC research theme)

RESOURCES: Moving from Resource Extraction to Resource Generation

Developing the advanced industries of the future from the up-to-date research of today (Ex.)

Artificial hydrothermal deposits

The resources available on the sea floor and in the sea are limitless.

Hydrothermal vents are treasure troves of natural resources.
This is a technology for using artificial hydrothermal vents to develop sustainable mineral resources.

Sea floor resource-extraction process

- Before: Unsustainable resource extraction due to the depletion of excavated resources

↓

- This concept: Sustainable resource extraction from artificial hydrothermal deposits

Today :
Rare metals, rare earths, and precious metals are valuable resources. Yet the deep sea floor is an untapped source for all these resources. A current focus of study is the sea's hydrothermal vents, which release hot water from the sea floor like underwater hot springs.

Black ore from the chimney of an artificial hydrothermal vent
©JAMSTEC

Future:
It could be possible to grow resources from artificial versions of hydrothermal vents, which generate a treasure trove of natural resources.

(JAMSTEC research theme)

TECHNOLOGY

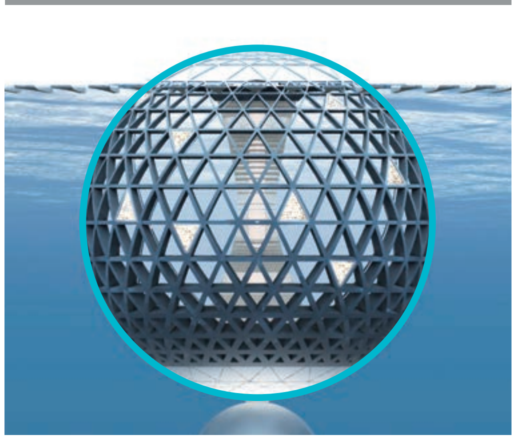
Technological challenges for the future

Note: Technologies shown are current as of the time of publication.
Efforts will be made to refine these technologies further through industry-academy partnerships.

Structural Design: Building a Submerged City of Concrete, 500m in Diameter

Major technological challenges for the future

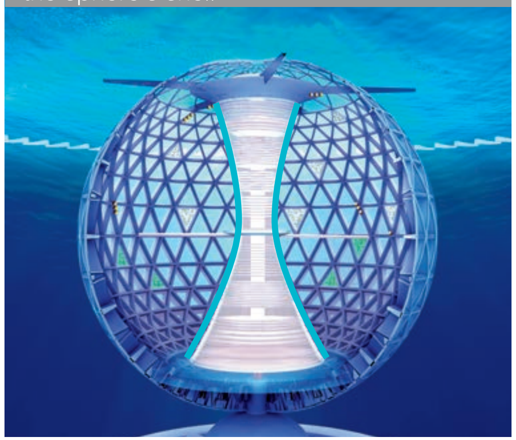
Spherical concrete lattice shell of 500m in diameter



❶ Strength
Using a spherical shape to withstand water pressure

❷ Concrete
High-strength resin concrete

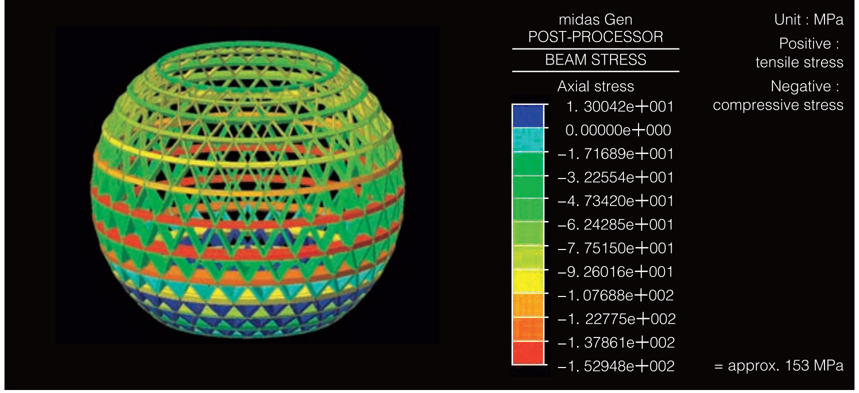
Using an internal tower to reinforce the sphere's shell



❸ Reinforcement bars
Rustproof resin bars

❹ Environmental considerations
Use of materials recycled from PET beverage containers in the resin concrete

Reference: Stress diagram of concrete truss under water pressure



Reference: Current performance of resin concrete

	Resin concrete	Concrete
Unit weight (kg/m³)	2200〜2400	2300〜2450
Compressive strength (MPa)	80〜160	20〜50
Tensile strength (MPa)	9〜14	2〜7
Bending strength (MPa)	14〜35	1〜4
Curing period (days)	1〜3	30
Linear shrinkage (%)	0〜0.4	0.1
Water absorption (wt%)	0.1〜1.0	4.6〜6.0

Reference: Use of materials recycled from PET beverage containers

Material	Percentage of weight (%)
Resin	15 ←Includes 4% to 5% materials recycled from PET beverage containers
Aggregate	20
Sand	45
Pebbles	20
Total	100

Technical information provided by: Showa Denko K.K. (resin)

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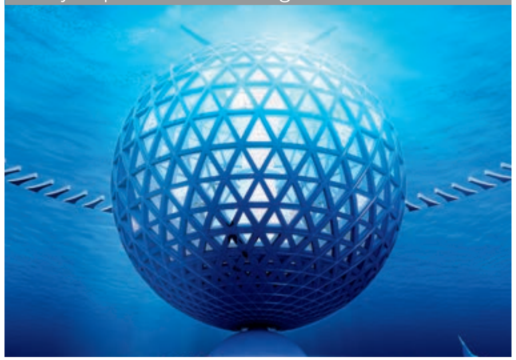
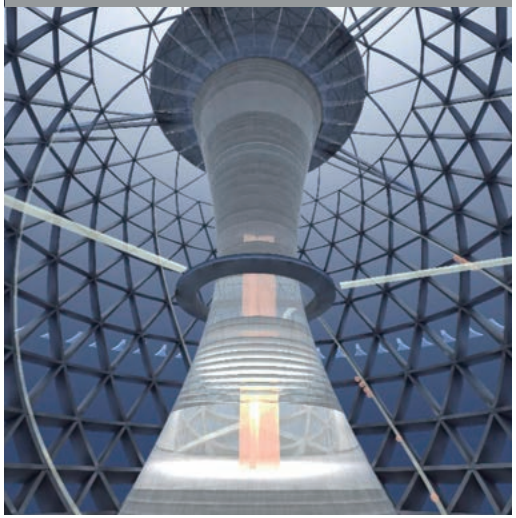
Exterior Wall Design: Tackling the Challenge of Building a Transparent Sphere with 360° Panoramic Views of the Deep Sea

Building a spherical shell with triangular acrylic plates measuring 50m on each side



360° panoramic views of the deep sea



Major technological challenges for the future

❶ Strength
Realized using triangular acrylic plates measuring 50m each a side

❷ Strength
Reinforced using semitransparent FRP ribs

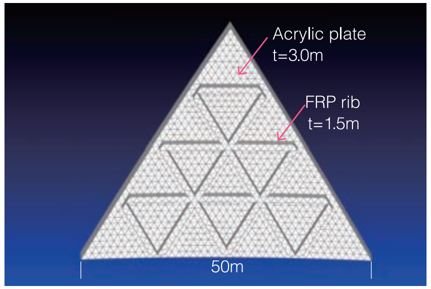
❸ Cleaning
Using microbubbles and other means to prevent the adhesion of marine life

❹ Joints
Sealing against water, absorbing displacement etc,

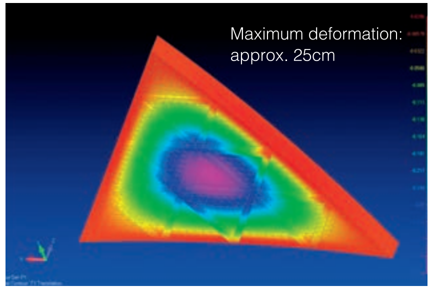
Using current materials technologies, deformation and stress allowances can be met utilizing t=3.0m for acrylic plates and t=1.5m for FRP ribs.

Note: FRP stands for “fiber-reinforced plastics.”

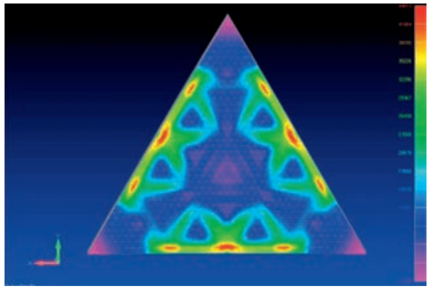
●Overview of a single unit
Acrylic plates and FRP ribs used to construct the spherical shell



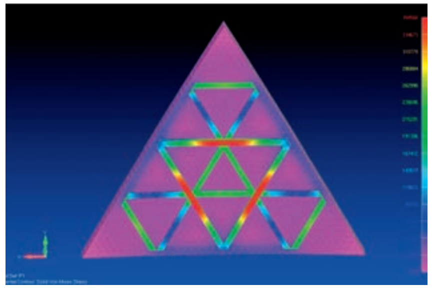
●Structural analysis of a single unit
Deformation distribution is within tolerances



●Stress distribution of an acrylic plates by structural analysis
Maximum stress from water pressure is within allowance



●Stress distribution of FRP ribs by structural analysis
Maximum stress from water pressure is within allowance

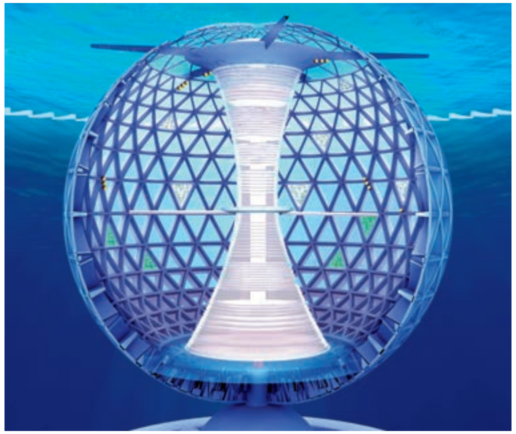


Technical information provided by: Showa Denko K.K. (FRP), NIPPURA CO., LTD. (acrylic)

Note: Technologies shown are current as of the time of publication.
These technologies will be refined further by industry-academy partnerships.

Indoor Environment Design: Challenge to Achieve the Comfortable Environment Making the Best Use of the Conditions of the Deep Sea.

Major technological challenges for the future

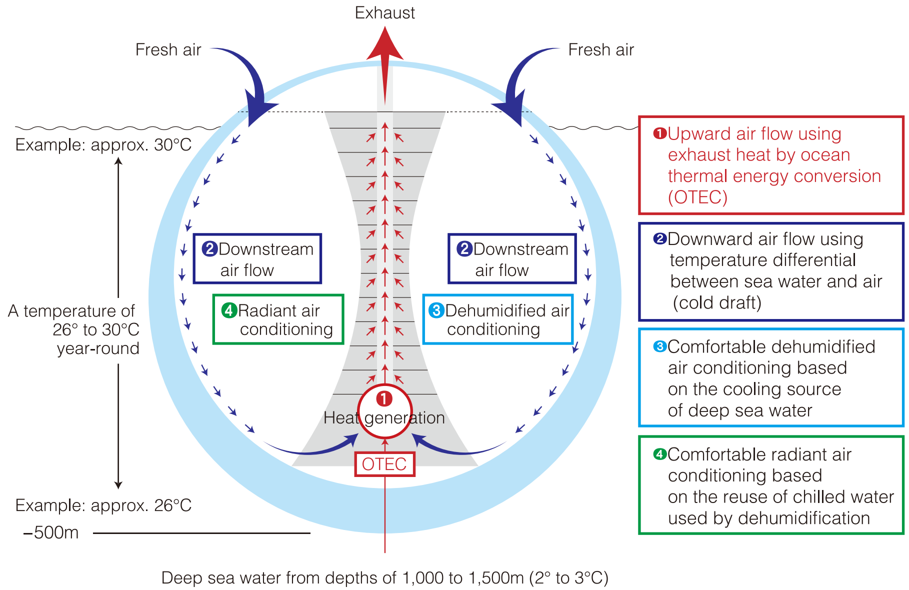


❶ Natural convection
Using temperature differential between the sea water and air to ensure the natural convection with comfortable and cool air

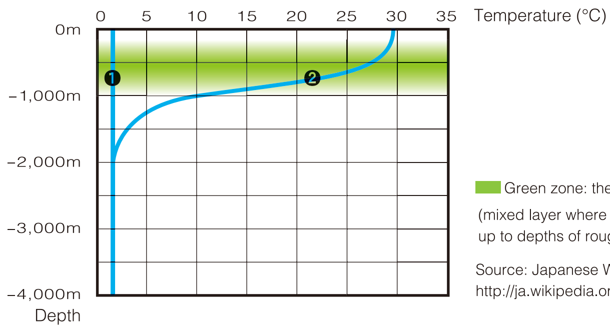
❷ Dehumidification
Using the cooling source of deep sea water to ensure comfortable dehumidified air conditioning

❸ Air conditioning
Reusing chilled water after dehumidification to ensure comfortable radiant air conditioning

❹ Thermal insulation
A comfortable environment due to the insulation effects of acrylic plates (3m thick)



●Deep sea water temperature (❶high latitudes, ❷low latitudes)



Green zone: thermocline
(mixed layer where sea water can move up and down, up to depths of roughly 1,000m)

Source: Japanese Wikipedia (deep sea)
http://ja.wikipedia.org/wiki/%E6%B7%B1%E6%B5%B7

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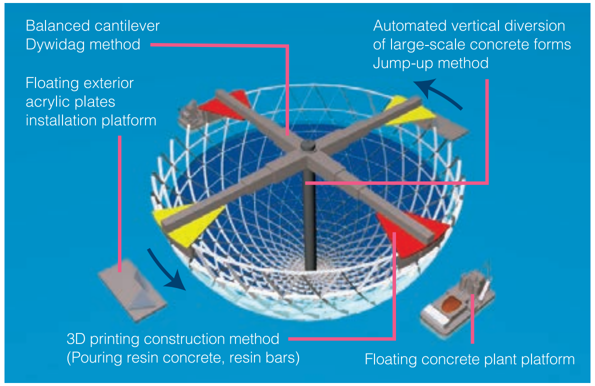
Construction Plans: Challenge to Achieve Fully Automated Maritime Construction of the Sphere

Major technological challenges for the future

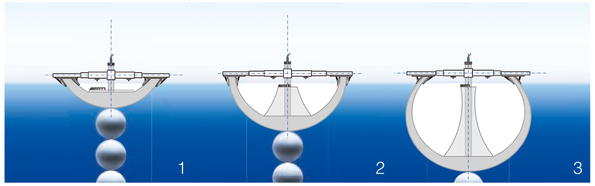
❶ Early adoption of future technologies
3D printing construction method
(Pouring resin concrete, resin bars)

❷ Integrating proven technologies
Automated vertical diversion of large-scale concrete forms
Jump-up method
Balanced cantilever
Dywidag method

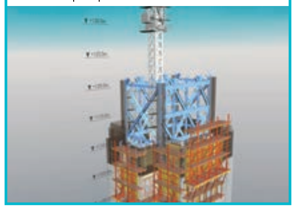
❸ Construction methods specific to maritime construction
All construction work undertaken at the sea surface
(Submersion of completed structure)



Construction steps



Core of central tower
② Integrating proven technologies
Automated vertical diversion of large-scale concrete forms:
Jump-up method

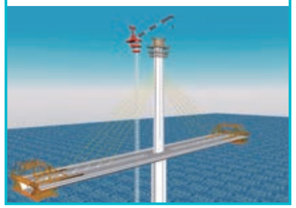


① Early adoption of future technologies
3D printing construction method
(Pouring resin concrete, resin bars)

OCEAN SPIRAL (OS) construction method

③ Construction methods specific to maritime construction
All construction work undertaken at the sea surface.
(Submersion of completed structure)

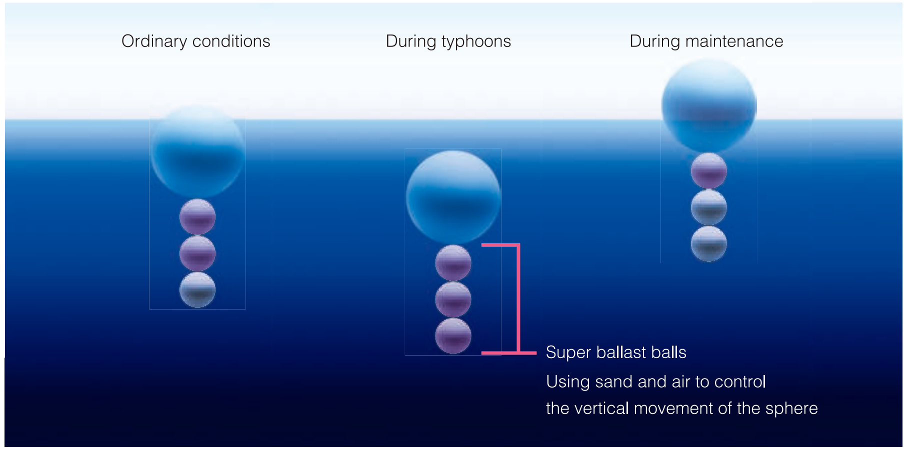
(Perimeter frame)
② Integrating proven technologies
Balanced cantilever:
Dywidag method



Operation and Maintenance Plans: Fail-safe Features and Maintenance

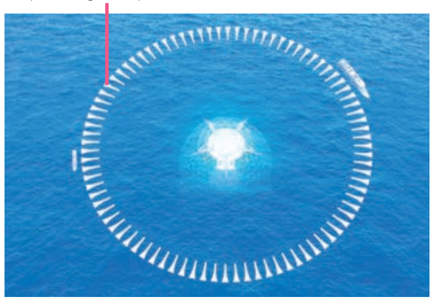
Major technological challenges for the future

❶ Control of vertical movement: Super ballast balls filled with sand



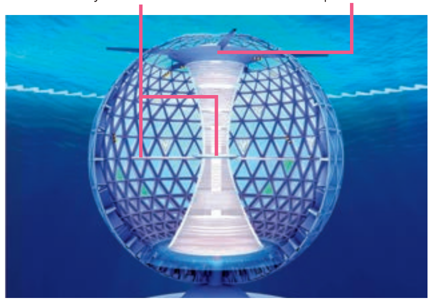
❷ Wave control: Floating seawall

Floating seawall that also serves as a terminal for passenger ships



❸ Control of everyday vibrations: Vibration-damping equipment

Damping system incorporated into walkways and the core
Damping system at the top of the tower



VARIATION

| Compatible with various sites and scales |

Site Variations: The OCEAN SPIRAL Network, Connecting the World's Seas

Candidate sites based on regional characteristics

❶ Coastal seas:

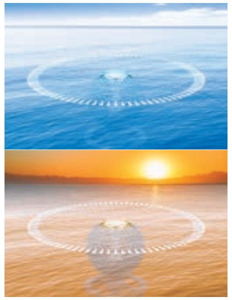
Stimulating economy on remote islands in exclusive economic zones

❷ Seas of island nations:

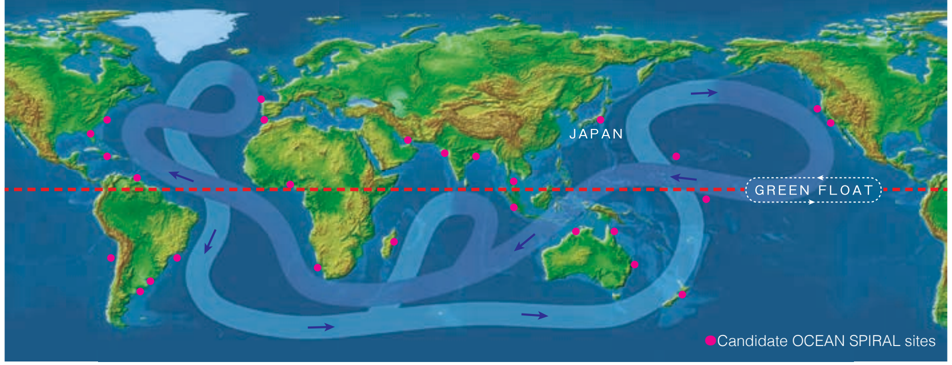
Countering rising sea levels in Pacific island nations

❸ Seas in desert regions:

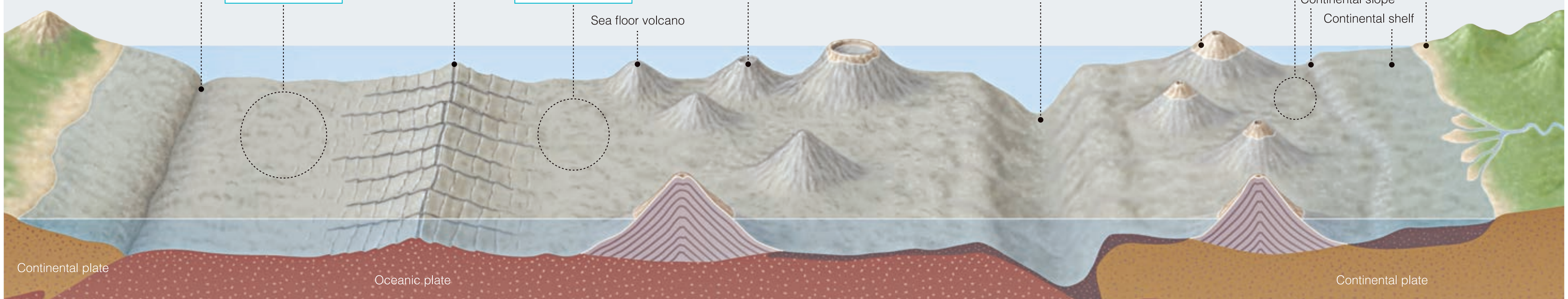
Comfortable deep sea living in the seas of the Middle East and Africa



The OCEAN SPIRAL network, connecting the world's seas



Candidate sites based on sea floor topography



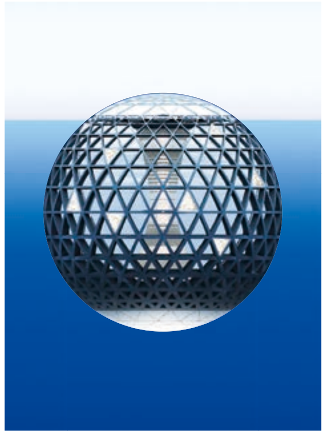
Candidate sites ❶ Deep sea plain: depths of 3,000–5,000m; flat; width of up to 1,000km ❷ Continental rise: depths of 3,000–4,000m; flat; width of up to 500km

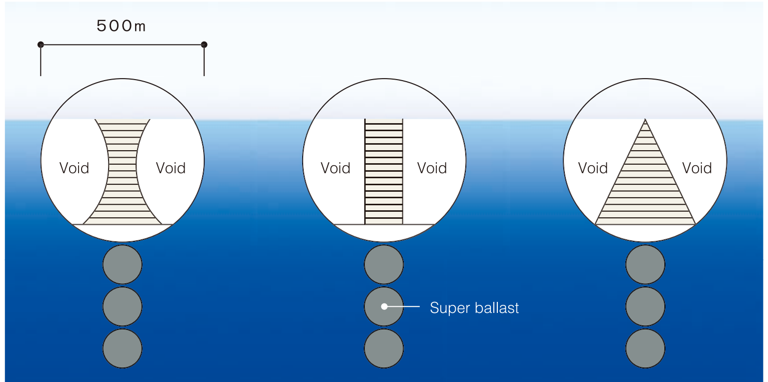
Source: The Deep Sea and its Denizens–A World of Beautiful Mysteries (Full-color illustrated)(Natsumesha CO., LTD.), Japan Agency for Marine-Earth Science and Technology (JAMSTEC),supervision.; illustrations by saimitu.com

Scale Variations:

In addition to the city-scaled 500-m diameter model, a more practical architectural-scale 200-m diameter model is prepared.

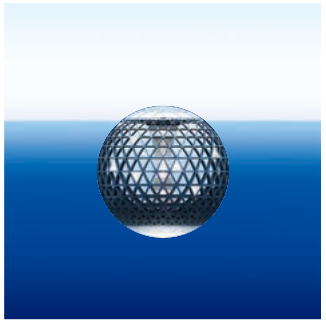
500-m diameter (city model)

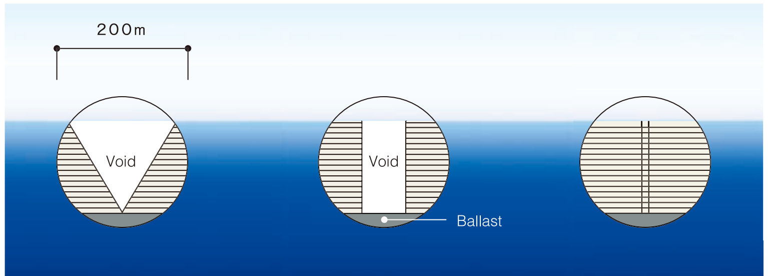




A super ballast filled with sand is needed to balance buoyancy.

200-m diameter (architectural model)





Buoyancy can be balanced using a sand-filled ballast inside the sphere.

The following parties provided technological information for the OCEAN SPIRAL concept for a deep sea city of the future:

- **Academic advisors**
  - Marine ecosystems, deep sea water
    - Masayuki Takahashi, Professor Emeritus, University of Tokyo, Kochi University
  - Ocean thermal energy conversion
    - Professor Yasuyuki Ikegami, Saga University
- **The deep sea**
  - Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
- **Specialized fields**
  - Fisheries resources, aquaculture
    - Fisheries Research Agency
  - Resin concrete, resin building materials
    - Showa Denko K.K
  - Large-scale acrylic plates
    - NIPPURA CO., LTD.

Comments from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

The Japanese Islands is located in one of the earth's most geologically active regions. JAMSTEC has long sensed its responsibility to transmit from Japan to the world an integrated understanding of the sea, the earth, life, and human activity. Current social trends and issues point to the urgent need to promote maritime innovations in areas ranging from the use of marine resources to the deployment of marine biotechnology, not to mention the need to advance our understanding of the sea and earth. When we heard of Shimizu Corporation's concept for a deep sea city of the future, one designed to serve as a new interface between humanity and the deep sea, we felt confident Shimizu would find our research findings useful. JAMSTEC's mission is to help establish Japan as a leading maritime power through new science and technology and to contribute to and maintain sustained progress for the Japanese public, human society, and the earth. Beyond providing information based on JAMSTEC's achievements for use in preparing this brochure, we are fully committed to joint efforts to improve the technological efficacy and feasibility of the OCEAN SPIRAL project.

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