Futuristic Marine and Space Biotechnology

Mains: *GS III – Science and Technology*

Why in News?

Recently, the sustainable marine and space technology is gaining importance due to depleting and uneven distribution of resources.

What is futuristic marine and space biotechnology?

- **Futuristic marine and space biotechnology** – It refers to advanced biological research and manufacturing that draws on two extreme, underexplored environments—the deep oceans and outer space—to create new materials, products, and life-support solutions for the future economy and exploration.
- **Marine biotechnology –** Marine biotechnology studies ocean life—microorganisms, algae, invertebrates, and fish—to develop:
  - **Bioactive compounds** (for drugs, nutraceuticals, cosmetics)
  - **Industrial enzymes** (stable under high pressure, salinity, or temperature)
  - **Biomaterials** (bioplastics, wound dressings, hydrogels)
  - **Food and feed ingredients** (seaweed proteins, omega-3s)
  - **Biostimulants** for climate-resilient agriculture
- Marine organisms are valuable because they have evolved to survive extreme conditions (high pressure, low light, low nutrients), making their biology useful for sustainable and resilient industrial applications.
- **Space biotechnology –** Space biotechnology examines how biology behaves in microgravity and high radiation on:
  - **Microbial and algal biomanufacturing** for food, oxygen, fuel, and materials.
  - **Closed-loop life-support systems** (waste recycling, air and water regeneration).
  - **Human health in space**, including astronaut microbiomes, immunity, bone loss, and muscle atrophy.
  - **Drug discovery and regenerative medicine**, where microgravity enables unique cell and protein behavior.
- This research is essential for long-duration human spaceflight, space stations, and planetary missions.

Why does India need them?

- **Strategic and economic reasons –** India has an 11,000+ km coastline and a 2 million sq. km Exclusive Economic Zone, yet underutilises its marine bioresources.

- Marine biotechnology can:
  - Reduce pressure on land, freshwater, and agriculture.
  - Create new sources of food, chemicals, energy, and materials.
  - Strengthen the blue economy and climate resilience.
- **Space ambitions –** India's human spaceflight goals require self-reliant biological systems for food, health, and life support.
- Space biotechnology helps India avoid dependence on foreign biological solutions that may not suit Indian genetic, nutritional, and health profiles.
- Together, these fields support bioeconomic growth, technological leadership, and strategic autonomy.

Where does India stand today?

- **Marine biotechnology**
  - Seaweed cultivation is still modest (~70,000 tonnes annually).
  - India imports key marine products like agar, carrageenan, and alginates.
- **Government initiatives**:
  - Blue Economy agenda
  - Deep Ocean Mission
  - BioE3 policy
- **Emerging players and institutions:**
  - Private firms: Sea6 Energy, ClimaCrew
  - Research bodies: ICAR–CMFRI
  - State-led innovation platforms
- **Space biotechnology**
- ISRO runs a microgravity biology programme studying microbes, algae, and biological systems.
  - Focus areas include:
  - Food production
  - Life-support regeneration
  - Astronaut health and microbiomes
- Private participation is currently limited due to the early stage of the sector.

What are other countries doing?

- **European Union** – Large collaborative programmes on marine bioprospecting, algae biomaterials, and bioactive compounds.
- **China** – Massive seaweed aquaculture and integration of deep-sea research with industrial bioprocessing.
- **USA & Australia** – Strong support for marine biotech innovation.
- **Space biotechnology leaders:**
  - NASA (ISS) – Microbes, stem cells, protein crystallisation, closed-loop systems
  - ESA, China (Tiangong), JAXA – Plant growth, microbiomes, and biomaterial research in space

What lies ahead?

- These are first-mover domains where early leadership brings long-term advantages.

- India needs:
  - A dedicated national roadmap for marine and space biotechnology
  - Clear timelines, milestones, and funding pathways
  - Better coordination between research institutions, startups, and industry
- The biggest risk is slow, fragmented R&D, which could cause India to miss the opportunity despite strong natural and strategic advantages.

Reference

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