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- Relevance to the Prelims and Mains syllabus under the following topics:

What is the news?

Climate Change: Can White Hydrogen Be Considered the New Solution?

- A substantial deposit of “white hydrogen,” found in northeastern France by two scientists, is regarded as one of the highest concentrations of this environmentally friendly energy source ever discovered.
- The energy and climate change landscape has been significantly impacted by the recent discovery of extensive reserves of natural or “white” hydrogen.
- The aforementioned development has ignited a sense of enthusiasm among individuals, as it is

perceived by many as a prospective catalyst in the ongoing battle against climate change.

- In the midst of our enthusiasm, it is imperative that we carefully analyze and examine the true nature and implications of this recently discovered energy source.

White hydrogen is an exceptional natural and clean energy source:

- Hydrogen, a highly regarded fuel, is frequently hailed as the energy source of the future due to its ability to offer clean and sustainable energy for a wide range of sectors and applications. However, it is important to note that the majority

of hydrogen that is currently produced is derived from fossil fuels or through energy-intensive methods. These practices unfortunately undermine the potential environmental advantages of hydrogen. **Is there a more optimal method for acquiring hydrogen that aligns with principles of sustainability and environmental consciousness?**

- **One possible solution could potentially be found in white hydrogen,** which is a naturally occurring form of hydrogen present in both the Earth's crust and mantle. In contrast to various other forms of hydrogen, such as gray, brown, blue, or green, it is important to note that white hydrogen can be generated without the need for any human intervention or input. The resource is readily available, patiently awaiting activation and utilization.

What is white hydrogen and how is it formed?

- White hydrogen, also known as natural hydrogen or geologic hydrogen, is hydrogen that occurs naturally in underground deposits. It is formed through a variety of geological processes, including:

    - **Serpentinization:** This is a process in which ultramafic rocks, such as peridotite and dunite, react with water to form hydrogen and other minerals.
    - **Volcanic activity:** Volcanic eruptions can release

hydrogen gas into the atmosphere and surrounding rocks.

Hydrothermal vents: These are openings in the Earth’s crust where hot, mineral-rich water flows out. Hydrogen gas can be a component of this hydrothermal fluid.

- **Crystallization of magma:** As magma cools and crystallizes, it can release hydrogen gas.

Degassing of primordial hydrogen: This is a process in which hydrogen gas that was trapped in the Earth’s mantle is released into the atmosphere and surrounding rocks.

- White hydrogen is typically found in underground reservoirs that are capped by impermeable rock layers. This prevents the hydrogen from escaping into the atmosphere. White hydrogen reservoirs can be found in a variety of geological settings, including sedimentary basins, volcanic areas, and fault zones.
- White hydrogen is a promising source of clean energy. It can be extracted from underground reservoirs and used to generate electricity, power vehicles, and produce other fuels. White hydrogen is also considered to be a carbon-neutral energy source, as its production does not release greenhouse gases.

How White hydrogen is extracted?

- White hydrogen is a naturally occurring, geological hydrogen found in underground deposits. It’s a renewable resource that can be captured by simply drilling a well.
- White hydrogen is extracted by fracking. The process involves drilling through geological layers and injecting a mixture of water, sand, and chemicals under high pressure to release the gas from the rocks.
- White hydrogen is also gained by SMR (Steam Machine Reforming), which currently is the most common method for producing hydrogen.

However, the extraction of white hydrogen is still in its early stages of development. More research is needed to develop efficient and cost-effective ways to extract white hydrogen from underground reservoirs.

White hydrogen can be formed by several natural processes, such as:

- **Degassing of deep hydrogen** from the Earth's crust and mantle is thought to be the most significant source of white hydrogen. The Earth's mantle contains a large reservoir of hydrogen, which is released into the crust and mantle through volcanic activity and tectonic processes.
- **Water reaction with ultrabasic rocks (serpentinisation)** is another important process for the formation of white hydrogen. Serpentinisation is a chemical reaction between water and ultramafic rocks, such as peridotite and dunite. This reaction produces hydrogen gas, as well as other minerals, such as serpentine and magnetite.
- **Contact of water with reducing agents in the Earth's mantle** can also produce white hydrogen. Reducing agents are substances that remove oxygen from other compounds. When water comes into contact with reducing agents in the mantle, it can be converted to hydrogen gas.
- **Interaction of water with freshly exposed rock surfaces (weathering**) can also produce white hydrogen. Weathering is the process of rocks breaking down into smaller pieces due to exposure to the elements. When water comes into contact with freshly exposed rock surfaces, it can react with minerals in the rocks to produce hydrogen gas.
- **Decomposition of hydroxyl ions in the structure of minerals can also produce white hydrogen.** Hydroxyl ions are compounds that contain hydrogen and oxygen. When minerals containing hydroxyl ions are

heated or exposed to pressure, they can decompose to release hydrogen gas.

- **Natural radiolysis** of water can also produce white hydrogen. Radiolysis is the process of breaking down molecules using radiation. When water is exposed to radiation from natural sources, such as uranium and thorium, it can be broken down to produce hydrogen gas.
- **Decomposition of organic matter** can also produce white hydrogen. When organic matter, such as plant and animal remains, is buried and heated, it can decompose to produce hydrogen gas.
- **Biological activity** can also produce white hydrogen. Some bacteria and other microorganisms can produce hydrogen gas as a byproduct of their metabolism.

The factors that influence the formation and migration of white hydrogen include:

- **The availability and mobility of water:** Water is essential for the formation of white hydrogen. The availability of water in the subsurface is influenced by factors such as rainfall, infiltration, and groundwater flow.
- **The presence and type of catalysts:** Catalysts are substances that speed up chemical reactions. Some catalysts, such as iron and nickel, can promote the formation of white hydrogen.
- **The porosity and permeability of the rocks:** The porosity and permeability of the rocks in the subsurface influence the movement of water and hydrogen gas.
- **The tectonic and volcanic activity:** Tectonic and volcanic activity can create fractures and other pathways in the subsurface that allow water and

hydrogen gas to migrate.

- **The geological history and evolution of the area:** The geological history and evolution of an area can influence the presence of the necessary ingredients for white hydrogen formation, as well as the pathways for migration.

Where is white hydrogen found and how much is there?

- White hydrogen is naturally occurring hydrogen gas that is found in the Earth’s crust. It is formed through a variety of geological processes, including the decomposition of organic matter, the reaction of water with iron-rich minerals, and the interaction of magma with water.White hydrogen deposits have been found in a variety of locations around the world, including:
- Mali
- France
- Australia
- Russia
- Oman
- United States
- Canada
- China
- India

The estimated global reserves of white hydrogen are in the tens of billions of tons, far exceeding the current and predicted annual production rates. This suggests that white hydrogen could potentially be a major source of clean energy

in the future.

However, it is important to note that white hydrogen is still a relatively new and underexplored resource. More research is needed to develop efficient and cost-effective ways to extract and produce white hydrogen.

Here are some additional details about the white hydrogen deposits that have been discovered so far:

- In 2018, a well in Mali was found to be producing 98% hydrogen gas. This discovery is considered to be one of the largest deposits of white hydrogen ever found.
- In 2023, a large reservoir of white hydrogen was discovered in northeastern France. The estimated size of the deposit is between 6 million and 250 million metric tons of hydrogen.
- In 2023, a white hydrogen deposit was discovered in the Lorraine mining basin in France. This deposit is estimated to contain approximately 20 million metric tons of hydrogen.
- In 2023, a startup company called Natural Hydrogen Energy began exploration work for white hydrogen in Kansas, United States.
- The discovery of these white hydrogen deposits has generated a lot of excitement among scientists and investors. White hydrogen is seen as a potential clean energy source that could help to reduce greenhouse gas emissions and combat climate change.

Nevertheless, determining the precise quantity and dispersion of white hydrogen poses a challenge, as it is contingent upon numerous variables and necessitates further investigation and scholarly inquiry. According to certain estimates, it has been

suggested that white hydrogen has the potential to make up approximately 10% of the overall global hydrogen allocation. However, alternative viewpoints propose that white hydrogen may actually be more abundant than initially believed.

Why is white hydrogen important and how can it be used?

- White hydrogen is important for several reasons. **Firstly,** it is a versatile and clean source of energy. It can be used as a fuel in various applications, such as transportation and power generation. **Additionally,** white hydrogen plays a crucial role in the production of ammonia, which is used in the manufacturing of fertilizers and other chemical products. In terms of its usage, white hydrogen can be employed in fuel cells to generate electricity. This can be particularly beneficial in the transportation sector, as it offers a sustainable alternative

White hydrogen is of utmost significance due to the multitude of advantages it presents in comparison to alternative forms of hydrogen. These advantages encompass:

- It causes no CO2 emissions when used as a fuel.
- It is compatible with existing infrastructure and technologies for hydrogen production and utilization.
- It is cheaper and more efficient than steam

reforming or electrolysis.
- It is renewable and non-polluting, as it is continuously generated by natural processes.

White hydrogen, also known as pure hydrogen, possesses numerous applications across various domains. Some of these purposes include:

- Power generation can be achieved through the process of burning fuel in combustion engines or fuel cells.
- Transportation involves the utilization of fuel to power various modes of travel, such as vehicles, ships, or planes.
- One way in which industry can utilize it is by employing it as a feedstock for chemical synthesis or metallurgy.
- In the field of agriculture, one can utilize various methods such as employing substances as fertilizers or biocides.
- Domestic energy can be utilized for various purposes such as heating, cooking, or lighting.

What are the challenges and opportunities of white hydrogen?

One must acknowledge that white hydrogen does present certain challenges and limitations, which we shall now discuss.

- The challenge lies in the search and acquisition of white hydrogen sources, as they are frequently situated in distant or hard-to-reach regions.
- The uncertainty and variability of white hydrogen availability and quality are influenced by numerous factors and have the potential to fluctuate over time.
- The potential environmental and social impacts of white hydrogen exploitation, including but not limited to land use, water consumption, and effects on local communities, should be carefully considered and analyzed.
- The absence of proper regulation and standardization in the production and utilization of white hydrogen is a significant concern due to its status as a nascent and developing field.

Nevertheless, it is important to note that white hydrogen also offers numerous opportunities and potential benefits.

- The contribution to the global energy transition and climate mitigation is significant as it offers a clean and renewable alternative to fossil fuels.
- The creation of new markets and industries is achieved by effectively stimulating innovation and entrepreneurship within the hydrogen sector.
- One of the objectives is to enhance energy security and diversity. This can be achieved by reducing our reliance on imported or scarce resources.
- The promotion of regional and international cooperation is achieved through the fostering of

collaboration and exchange among various stakeholders and countries.

White hydrogen, also known as pure or pristine hydrogen, is being hailed as a promising clean energy source for the future.

- White hydrogen, which is also referred to as natural hydrogen or geologic hydrogen, is a variant of hydrogen that occurs naturally and can be found in subterranean reservoirs. The creation of this energy source occurs via a natural geochemical process that takes place deep within the Earth's crust. As a result, it can be considered a sustainable and inexhaustible source of energy. One advantage of white hydrogen, as compared to green hydrogen that derived from the electrolysis of water using renewable energy sources, is that it possesses several distinct benefits. White hydrogen, as it is commonly known, is indeed a more cost-effective option for production and is also found in greater abundance. Furthermore, it is important to note that this particular solution is also fully compatible with the current infrastructure and technologies that are already in place for the production and utilization of hydrogen.
- White hydrogen, also known as pure hydrogen, possesses the remarkable capability to generate electricity, propel vehicles, and generate heat. Additionally, synthetic fuels, such as methane and ammonia, can be generated using this method. These

fuels offer the advantage of being more convenient to store and transport compared to hydrogen.

- White hydrogen, a technology that is still in its early stages of development, possesses the potential to significantly contribute to the shift towards a sustainable and environmentally friendly energy landscape. Renewable energy is an excellent and plentiful source of power that has the potential to decrease our dependence on non-renewable resources such as fossil fuels.

In recent times, there have been notable advancements or changes that have taken place:

- In 2012, an unintentional finding was made in Mali. A borehole built for a well decades ago was discovered to exude practically pure natural hydrogen.
- Since then, geologists have been increasingly experimenting with obtaining supplies of this natural gas from beneath the earth's surface, which is theorized to develop through water-mineral reactions.
- Natural or 'white' hydrogen is constantly replenished, unlike fossil fuel stocks, which take millions of years to create.

- In recent years, there has been an increasing fascination with white hydrogen as a prospective form of sustainable energy. Several companies are currently in the process of developing various technologies for the extraction and production of white hydrogen. In the year 2022, GenCell Energy, a company, made an announcement regarding the development of a novel technology. This technology

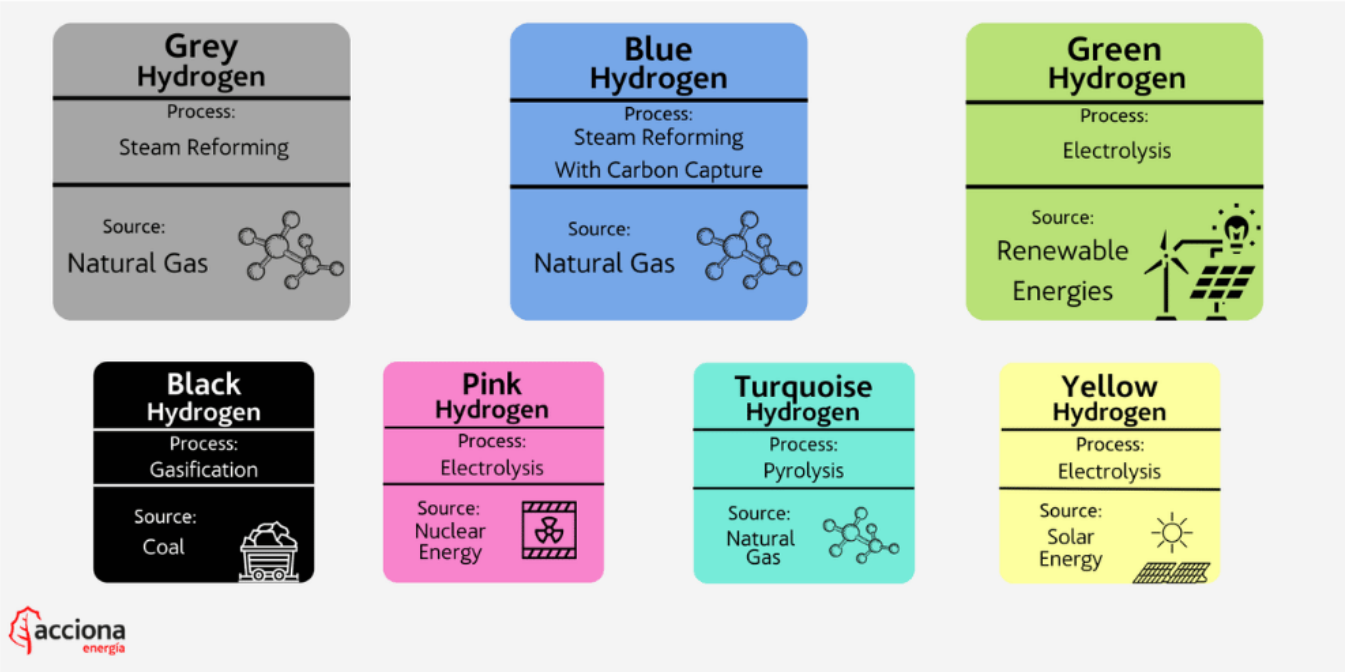
has the capability to generate white hydrogen by utilizing underground salt water deposits.

- White hydrogen, which is also known as pure or high-purity hydrogen, has been garnering significant interest from governments across the globe. In the year 2021, the European Union made an important announcement regarding their decision to allocate a significant amount of €10 billion towards the advancement and progress of white hydrogen technologies. The United States government is currently engaged in the investment and exploration of white hydrogen research and development.

Difference between WHite hydrogen, Green Hydrogen,Blue Hydrogen and Grey Hydrogen:

Type of hydrogen	Production method	Carbon emissions	Color
White hydrogen	Extracted from underground reservoirs	Carbon-neutral	White
Green hydrogen	Electrolysis of water using renewable energy	Zero carbon emissions	Green
Blue hydrogen	Steam methane reforming of natural gas with carbon capture and storage (CCS)	Low carbon emissions	Blue
Grey hydrogen	Steam methane reforming of natural gas without CCS	High carbon emissions	Grey

Other Forms:



The Importance of this Discovery:

- **A paradigm shift:** In the past, scientists held the belief that the production of hydrogen on a large scale necessitated laboratory-based procedures. Hydrogen was classified into distinct varieties according to its source, including gray, brown, blue, and green.
- **Unrealized Potential:** White hydrogen, being a ubiquitous and naturally occurring resource, presents a substantial opportunity as a source of clean-burning energy.
- **Natural and economical:** In contrast to energy-intensive manufacturing processes, white hydrogen is cost-effective and naturally occurring. The production of white hydrogen is estimated to cost around $1 per kilogram, whereas green hydrogen is priced at approximately $6 per kilogram.

Conclusion:

The conclusion is a vital component of any piece of writing. It serves as the final opportunity to summarize:

- White hydrogen, which is a naturally occurring and environmentally friendly energy source, has the potential to bring about a significant transformation in our world. The substance in question is derived from a multitude of natural phenomena and can be observed in numerous geographical regions across the planet. One advantage of this particular type of hydrogen is its emission-free nature.
- Additionally, it is compatible with various systems and processes. Furthermore, it is relatively inexpensive and exhibits high efficiency compared to other types of hydrogen.
- There are several purposes for which it can be utilized, including power generation, transportation, industry, agriculture, and domestic applications.
- However, it is important to note that this particular subject also encounters a multitude of challenges and limitations. These include the task of locating and obtaining relevant sources of information, guaranteeing their accessibility and quality, effectively addressing environmental and social impacts, and establishing appropriate regulation and standardization measures. White hydrogen presents numerous opportunities and potential advantages. These include its

contribution to the energy transition and climate mitigation efforts, the creation of new markets and industries, the enhancement of energy security and diversity, and the promotion of regional and international cooperation. White hydrogen is indeed a field that shows great promise and generates excitement among various communities, including the scientific, political, and economic sectors. It is a topic that warrants further attention and support.

MCQs:

Q1. What is the main difference between white hydrogen and other types of hydrogen?

A) White hydrogen is produced by human intervention or input
B) White hydrogen is found in various geological environments on or in Earth
C) White hydrogen causes CO2 emissions when used as a fuel
D) White hydrogen is incompatible with existing infrastructure and technologies

- Answer: B) White hydrogen is found in various

geological environments on or in Earth

- Explanation: White hydrogen, also known as natural, gold, or geologic hydrogen, is molecular hydrogen (H2) that is found in various geological environments on or in Earth. It is different from hydrogen that is produced in the laboratory or in industry, which is usually derived from methane gas, coal, water electrolysis, or biomass. Therefore, option B is the correct answer.

Q2. Which of the following is not a natural process that can form white hydrogen?

A) Degassing of deep hydrogen from the Earth's crust and mantle
B) Reaction of water with ultrabasic rocks (serpentinisation)
C) Interaction of water with freshly exposed rock surfaces (weathering)
D) Decomposition of water by electric current (electrolysis)

- Answer: D) Decomposition of water by electric current (electrolysis)
- Explanation: White hydrogen can be formed by several natural processes, such as degassing of deep hydrogen from the Earth's crust and mantle, reaction of water with ultrabasic rocks (serpentinisation), interaction of water with freshly exposed rock surfaces (weathering), and others. However, electrolysis is not a natural process, but a human-made one, that uses electricity to split water into hydrogen and oxygen. Therefore, option D is the correct answer.

Q3. Where was one of the largest reservoirs of white hydrogen ever found?

A) The Lorraine mining basin in northeastern France
B) The Mali region in West Africa
C) The mid-ocean ridges
D) The oceanic crust

- Answer: A) The Lorraine mining basin in northeastern France
- Explanation: White hydrogen has been detected in many locations around the world, both on land and under the sea. However, one of the largest reservoirs of white hydrogen ever found was discovered in the Lorraine mining basin in northeastern France, where two scientists estimated that there could be up to 100 billion cubic meters of white hydrogen . Therefore, option A is the correct answer.

Q4. What are some of the advantages of white hydrogen over other types of hydrogen?

A) It causes no CO2 emissions when used as a fuel
B) It is compatible with existing infrastructure and technologies for hydrogen production and utilization
C) It is cheaper and more efficient than steam reforming or electrolysis
D) All of the above

- Answer: D) All of the above
- Explanation: White hydrogen offers several advantages over other types of hydrogen, such as being emission-free, compatible, cheap, and efficient. It causes no CO2 emissions when used as a fuel, unlike gray, brown, or blue hydrogen, which are derived from fossil fuels or require carbon capture and storage. It is compatible with existing infrastructure and technologies for

hydrogen production and utilization, unlike green hydrogen, which requires dedicated and costly facilities for water electrolysis and hydrogen storage. It is cheaper and more efficient than steam reforming or electrolysis, as it does not require any human intervention or input to be generated. Therefore, option D is the correct answer.

Q5. What are some of the potential applications of white hydrogen?

A) Power generation, by burning it in combustion engines or fuel cells
B) Transportation, by using it as a fuel for vehicles, ships, or planes
C) Industry, by using it as a feedstock for chemical synthesis or metallurgy
D) All of the above

- Answer: D) All of the above
- Explanation: White hydrogen can be used for various purposes, such as power generation, transportation, industry, agriculture, and domestic. It can be burned in combustion engines or fuel cells to generate electricity or heat, or used as a fuel for vehicles, ships, or planes to reduce emissions and noise. It can also be used as a feedstock for chemical synthesis or metallurgy, such as producing ammonia, methanol, or steel, or as a fertilizer or a biocide for agriculture. Therefore, option D is the correct answer.

Mains Questions:

Q1. What are the challenges and potential of utilizing white hydrogen in India? Discuss using appropriate instances.

- White hydrogen is a natural and clean energy source found in a variety of geological conditions on or within Earth. It offers numerous advantages over other types of hydrogen, including the fact that it is emission-free, compatible, inexpensive, and efficient. It can be utilized for a variety of applications, including power generation, transportation, industrial, agriculture, and residential use. It does, however, face numerous obstacles and restrictions, such as locating and accessing supplies, assuring availability and quality, controlling environmental and social repercussions, and implementing regulation and standardization. White hydrogen provides numerous prospects and possible benefits, including aiding in the energy transition and climate mitigation, establishing new markets and businesses, increasing energy security and diversity, and

fostering regional and international collaboration.

The following are some of the problems and opportunities associated with white hydrogen exploitation in India:

- **Locating and gaining access to sources:** India has a wide and diversified geology that may include white hydrogen sources in various regions and depths. However, determining the exact amount and distribution of white hydrogen is challenging because it is dependent on numerous circumstances and requires additional inquiry and research. Furthermore, some white hydrogen sources, such as the Himalayas, the Thar Desert, or the Andaman and Nicobar Islands, may be located in distant or inaccessible places, posing logistical and technical hurdles for extraction. As a result, India must invest more in mapping and surveying its white hydrogen potential, as well as developing and implementing appropriate extraction and transportation technologies and infrastructure.
- **Ensuring availability and quality:** Because it is continuously generated by natural processes, white hydrogen is a renewable and non-polluting energy source. The availability and quality of white hydrogen, on the other hand, may fluctuate based on geological circumstances and natural variations in the Earth's system. White hydrogen, for example, may be impacted by tectonic and volcanic activity, which may change the pressure, temperature, and composition of hydrogen-bearing rocks and fluids. Furthermore, white hydrogen can

be contaminated by other gases or chemicals such as methane, carbon dioxide, sulfur, or metals, reducing its purity and effectiveness. As a result, India must monitor and manage its white hydrogen supplies while also ensuring quality and safety standards for production and use.

- **Managing environmental and social impacts:** White hydrogen is a clean and environmentally beneficial energy source because it emits no CO2 when used as a fuel. However, the usage of white hydrogen may have some environmental and social consequences, such as land use, water use, or local communities. For example, white hydrogen extraction may necessitate drilling, pumping, or fracturing of rocks and fluids, which may have an impact on the landscape, groundwater, or wildlife in the vicinity. Furthermore, white hydrogen extraction may result in the displacement, resettlement, or consultation of local people, particularly indigenous or tribal tribes with cultural, religious, or economic ties to the land and resources. As a result, India must examine and mitigate the environmental and social implications of white hydrogen extraction, as well as secure stakeholder and public participation and consent.
- **Creating regulations and standards:** White hydrogen is a novel and growing energy source that needs national and international regulation and standardization. There are no clear and uniform regulations, laws, or standards for the production and use of white hydrogen, which may lead to confusion, uncertainty, or conflict among the various people and interests involved. Furthermore, there are no universally accepted definitions, classifications, or measurements for white hydrogen, which could make it difficult to recognize, compare, or integrate with other energy

sources and systems. As a result, India must develop and unify its white hydrogen regulation and standardization, as well as coordinate and collaborate with other countries and organizations to establish a worldwide framework and governance for white hydrogen.

The following are some of the opportunities and possible benefits of white hydrogen exploitation in India:

- **Contributing to the energy transition and climate mitigation:** India has one of the world's largest and fastest-growing economies, with a massive and growing demand for energy. However, India must also reduce its greenhouse gas emissions and meet its pledges under the Paris Agreement and the Sustainable Development Goals. White hydrogen can assist India in meeting both its energy and climate goals by providing a clean and renewable alternative to fossil fuels, particularly coal, which accounts for more than half of India's electricity output and more than 70% of CO2 emissions. White hydrogen can also assist India in diversifying its energy mix and decreasing its reliance on imported or rare resources such as oil, gas, or uranium.
- **Developing new markets and industries:** India has a robust and vibrant industrial sector that accounts for more than 25% of the country's GDP and employs more than 100 million people. However, India confronts the challenge of increasing its global market competitiveness and innovation, as well as creating more jobs and opportunities for its young and skilled people. By fostering innovation and entrepreneurship in the hydrogen sector, which is predicted to grow enormously in

the coming years, white hydrogen can help India create new markets and businesses. White hydrogen can also assist India develop and export its white hydrogen production and utilization technology, as well as attract foreign investment and collaboration in the hydrogen sector.

- **Improving energy security and diversity:** India's vast and diversified topography provides a variety of natural and renewable energy sources, including solar, wind, hydro, biomass, and geothermal. However, India confronts the issue of assuring its energy security and variety, as it is exposed to energy market volatility and uncertainties, as well as climate change. White hydrogen can assist India in improving its energy security and diversification by providing a versatile and adaptable energy source that can be stored, transported, and used in a variety of industries and applications. White hydrogen can also assist India integrate and balance its energy sources and systems by complementing and supplementing its intermittent and variable renewable energy sources, such as solar and wind.
- **Promoting regional and international cooperation:** India enjoys a strategic and influential position in the region and around the world, which presents both opportunities and problems for its foreign policy and diplomacy. India must also preserve peace and stability while settling disagreements and conflicts with its neighbors and rivals, particularly Pakistan and China. White hydrogen can assist India boost regional and worldwide cooperation by encouraging collaboration and interaction among various stakeholders and countries in the hydrogen industry, which is of mutual interest and profit to all. White hydrogen may also help India strengthen its soft power and

leadership by highlighting its accomplishments and contributions in the hydrogen sector, as well as helping and assisting other countries and areas in their hydrogen development and transition.

Q2. What factors affect the creation and migration of white hydrogen? Explain with appropriate instances.

White hydrogen is molecular hydrogen (H2) found in a variety of geological conditions on or in Earth. It is created by a variety of natural processes, including deep hydrogen degassing from the Earth's crust and mantle, water reaction with ultrabasic rocks (serpentinisation), water interaction with freshly exposed rock surfaces (weathering), and others. These reactions can take place at a variety of depths, temperatures, and pressures, resulting in varying amounts and compositions of white hydrogen. The following are some of the factors that govern the generation and migration of white hydrogen:

- **Water availability and mobility:** Water is a necessary and abundant component of the Earth's system, and it plays an important role in the creation and migration of white hydrogen. Water can react with ultrabasic rocks like peridotites and serpentinites to form white hydrogen and other minerals including olivine, pyroxene, and magnetite. This is known as serpentinisation, and it can happen beneath the seafloor, in the oceanic crust, or on land, in the continental crust. Water can also mix with freshly exposed rock surfaces to form white hydrogen and other substances such as carbonates, silicates, or sulfides during weathering, erosion, or tectonic activity. Water

can dissolve, transport, and precipitate white hydrogen in a variety of forms and locations, therefore it can also operate as a carrier and a solvent for it. Water, for example, can transport white hydrogen from deep reservoirs to shallow reservoirs, or from interior sources to coastal or offshore outlets.

- **Catalysts' presence and type:** Catalysts are chemicals that can accelerate or promote the creation and migration of white hydrogen by lowering the activation energy or raising the pace of the reactions involved. Catalysts can be natural or manmade, and their actions and implications on white hydrogen vary. Metals such as iron, nickel, or platinum can act as electron donors or acceptors for hydrogen atoms or molecules, making them natural catalysts for white hydrogen. Metals can also combine with hydrogen to form alloys or nanoparticles, which improves their stability and mobility. Some manufactured white hydrogen catalysts are additions such as acids, bases, or salts that can change the pH or salinity of the water or rocks, affecting their reactivity and solubility with hydrogen. Additives can also change the surface characteristics or porosity of rocks, influencing their permeability and hydrogen conductivity.
- **The rock porosity and permeability:** The primary source and storage of white hydrogen is rocks, which can have a variety of features and attributes such as porosity and permeability. Porosity refers to the number of cavities or spaces within rocks that can contain fluids or gases such as water or hydrogen. The ease or difficulty with which fluids or gasses can flow through rocks is determined by the size, shape, and connectedness of the pores or gaps.

Relevance to the Prelims and Mains syllabus under the following topics:

White hydrogen is covered in the UPSC syllabus for prelims and mains under the following topics:

For prelims, white hydrogen is covered under the topic of Science and Technology, which includes the following sub-topics:

- Awareness in the fields of IT, Space, Computers, robotics, nanotechnology, biotechnology and issues relating to intellectual property rights.
- Conservation, environmental pollution and degradation, environmental impact assessment.
- Achievements of Indians in science & technology; indigenization of technology and developing new technology.

For mains, white hydrogen is covered under the topic of General Studies Paper III, which includes the following sub-topics:

- Science and Technology- developments and their applications and effects in everyday life.
- Conservation, environmental pollution and degradation, climate change, environmental impact assessment.
- Disaster and disaster management.
- Infrastructure: Energy, Ports, Roads, Airports, Railways etc.

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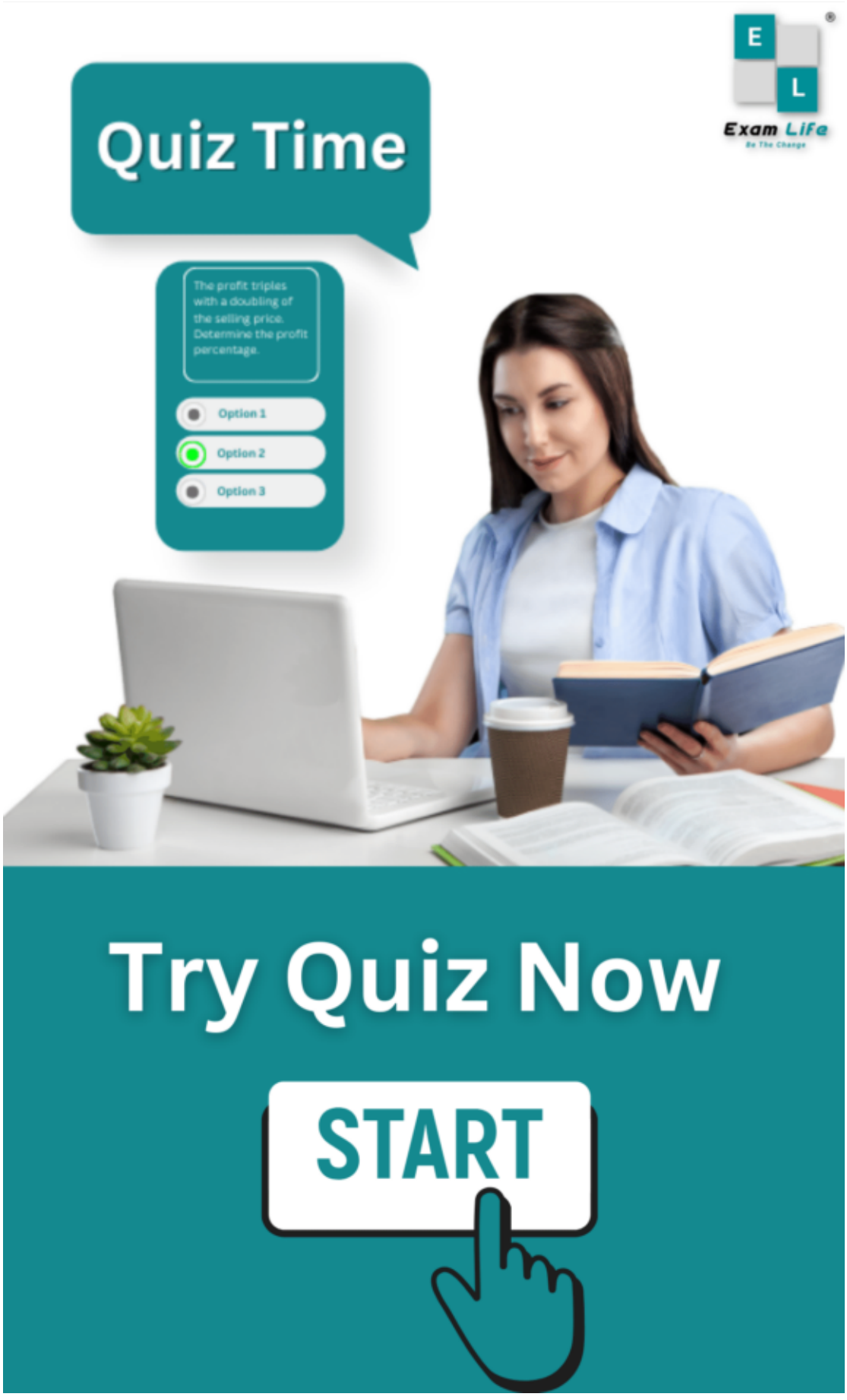
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