Haber-Bosch Process and Production of Fertilizers

For Prelims: **Haber-Bosch process**, **Nitrogen**, **Ammonia**, **Lightning**, **Azotobacter and Rhizobia**, **Volcanic eruptions**, **Acid rain**, **organic farming**, **biofertilizers**.

For Mains: Importance of the Haber-Bosch process, Implications of Using Fertilizers, Nitrogen cycle.

Source: TH

Why in News?

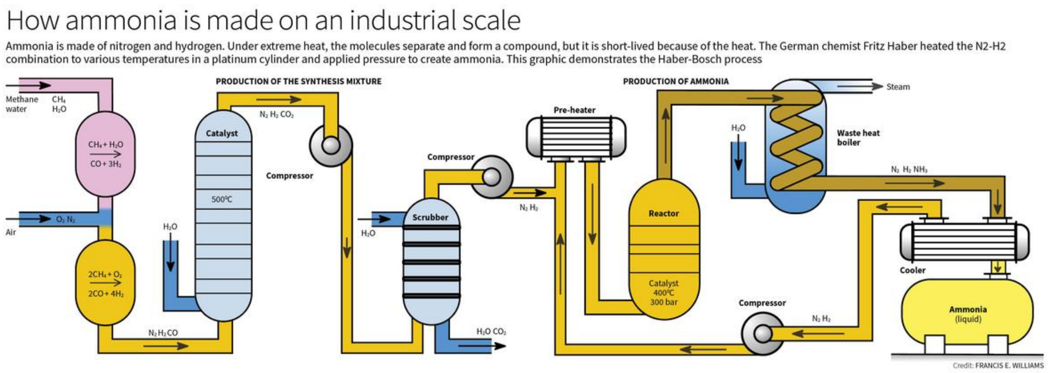
Through **the Haber-Bosch process**, a hundred million tonnes of **nitrogen** **are extracted from the atmosphere and transformed into fertiliser,** resulting in the addition of 165 million tonnes of reactive nitrogen to the soil.

- In comparison, **natural biological processes** generate an estimated **100-140 million** tonnes of reactive nitrogen annually.

What is the Haber-Bosch Process?

- **About:**
    - The **Haber-Bosch process** is an **industrial method for synthesizing ammonia** by combining nitrogen from the air with hydrogen, significantly contributing to fertiliser production.
- **Process:**
    - **Experimental Setup:**
        - The reaction occurs in a steel chamber at a pressure of 200 atm, allowing the **nitrogen-hydrogen mixture to circulate** effectively.
        - A specially designed valve withstands high pressure while allowing the N_2-H_2 mixture to flow through.
        - Haber implemented a system to transfer heat from the outgoing hot gases to the incoming cooler gases, optimizing energy efficiency.
    - **Catalyst Development:**
        - Haber **initially experimented with various materials** looking for suitable filament materials as Catalyst to speed up reaction.
        - Among the tested materials was **osmium, which, when placed in the pressure chamber with the N_2-H_2 mixture,** successfully cracked the nitrogen triple bond, **allowing for ammonia production.**
            - **Uranium** was another effective catalyst but both osmium and uranium were too expensive for large-scale applications.
            - The search for a **more cost-effective catalyst led to the identification of** specific iron oxides as viable options.
- **Applications:**
    - **Manufacturing:** As a refrigerant in industrial refrigeration systems and air conditioning.
    - **Household:** An ingredient in household **cleaning products, i**ncluding glass and surface

cleaners.
    - **Automotive fuel:** An internal combustion **engine powered by ammonia is being explored** as an alternative propulsion technology.
    - **Chemicals:** A precursor for various chemicals, including nitric acid and explosives.
- **Key Milestones:**
    - **In 1913,** the **German chemical company opened its first ammonia factory**, marking a significant milestone in the production of fertilizers.
    - **Fritz Haber**, a German chemist, won the **Nobel Prize in Chemistry in 1919** for his work on **ammonia synthesis.**



What is the Nitrogen Cycle?

- **About:**
    - Plants obtain reactive nitrogen from the soil by **absorbing nitrogen-based minerals like ammonium (NH4+) and nitrate (NO3–),** dissolved in water.
    - Humans and animals rely on plants for **nine essential nitrogen-rich amino acids,** as nitrogen makes up about 2.6% of the human body.
    - After being ingested, nitrogen **returns to the soil through excreta and decomposition of dead organisms,** but some nitrogen escapes back into the atmosphere as molecular nitrogen, leaving the cycle incomplete.
- **Natural Availability of Nitrogen:**
    - **Lightning: Lightning** bolts **possess enough energy to break the N2 bond,** combining nitrogen with oxygen to form nitrogen oxides (NO and NO2).
        - These **oxides mix with water vapour**, forming **nitric and nitrous acids**, which fall as **acid rain**, providing reactive nitrogen to the soil.
    - **Biological Fixation:** Some bacteria, like **Azotobacter and Rhizobia**, can **convert atmospheric nitrogen into reactive nitrogen**.
        - These bacteria often have **symbiotic relationships with plants such as legumes or aquatic ferns** like Azolla, which enhance nitrogen availability in the soil, making them valuable for agriculture.
    - **Process of Nitrogen Replenishment:**
        - While **legumes can fix nitrogen naturally**, most **staple crops like rice,** wheat, corn, potatoes, cassava, bananas, and other fruits and vegetables **depend on soil nitrogen for growth.**
        - As **human populations grow,** the **depletion of nitrogen in agricultural soils accelerates**, requiring the use of fertilizers to restore soil fertility.
    - **Historical Fertilization Methods:**
        - Farmers historically cultivated legumes to naturally replenish nitrogen in the soil or applied ammonia-based fertilizers to increase crop yields.
        - They also **utilized ammonium-rich minerals from volcanic eruptions** and naturally occurring nitrates found in caves and rocks to enhance soil fertility.

What is the Impact of Industrial Production of Fertilizers?

- **Pros:**

    - The Haber-Bosch process enabled the **mass production of synthetic fertilizers,** significantly **boosting global food supply** during the 20th century, contributing to increased life expectancy.
    - An **estimated one-third of the world's population relies on food produced** using **nitrogen fertilizers.**
        - **Without the industrial production of ammonia** from nitrogen and hydrogen, it would have been **impossible to meet the growing global demand for food.**
- **Cons:**
    - Synthetic nitrogen fertilizers, although critical for food production, **have adverse environmental impacts.**
    - Excess nitrogen application leads to **plant over-nourishment, boosting bacterial activity and accelerating nitrogen release** into the atmosphere.
    - This **contributes to environmental degradation,** including **acid rain**, land corrosion, and surface water deoxygenation through runoff, causing excessive weed growth in water bodies.

Way Forward

- **Promote Sustainable Fertilizer Use:** Encourage the **adoption of precision agriculture and controlled-release fertilizers** to reduce nitrogen waste, minimize environmental damage, and enhance the efficiency of fertilizer usage in farming.
- **Invest in Alternative Technologies:** Develop and **promote eco-friendly alternatives to synthetic fertilizers**, such as **organic farming practices, nitrogen-fixing crops, and biofertilizers,** to mitigate the environmental impacts of chemical fertilizers.
- **Strengthen Policy Frameworks:** Governments should implement **regulations to control fertilizer overuse** and incentivize sustainable farming practices, ensuring food security while protecting ecosystems and public health.
- **Enhance Global Cooperation:** Foster international collaboration to **address food distribution disparities, improve access to agricultural innovations,** and support capacity-building initiatives for regions facing food insecurity, ensuring equitable solutions to global food challenges.

Drishti Mains Question:

Critically examine the impact of synthetic fertilizers on agriculture and the environment. Discuss sustainable alternatives to mitigate these challenges.

UPSC Civil Services Examination, Previous Year Question (PYQ)

Prelims:

Q. With reference to chemical fertilizers in India, consider the following statements: (2020)

1. At present, the retail price of chemical fertilizers is market-driven and not administered by the Government.
2. Ammonia, which is an input of urea, is produced from natural gas.
3. Sulphur, which is a raw material for phosphoric acid fertilizer, is a by-product of oil refineries.

Which of the statements given above is/are correct?

(a) 1 only

(b) 2 and 3 only

(c) 2 only

(d) 1, 2 and 3

Ans: (b)

Mains:

Q. Sikkim is the first 'Organic State' in India. What are the ecological and economical benefits of Organic State? **(2018)**