Subject Name & Code:

ENVIRONMENTAL SCIENCE, SUSTAINABILITY AND RENEWABLE ENERGY- BE04000101

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Assignment 4: Renewable Energy (CO5)

A. Renewable Energy (CO5)

1. What is renewable energy? *(Short)*

- **Renewable Energy:** Energy derived from natural sources that are **replenished at a rate equal to or faster than the rate of consumption**. Sources are virtually inexhaustible on a human timescale. Examples: Solar, wind, hydro, geothermal, biomass, tidal.

2. How many different types of renewable energy are there? *(Short)*

Six main types:

1. **Solar Energy** (PV panels, solar thermal)
2. **Wind Energy** (turbines)
3. **Hydropower** (dams, run-of-river)
4. **Biomass Energy** (wood, biogas, ethanol, biodiesel)
5. **Geothermal Energy** (heat from Earth's interior)
6. **Tidal/Wave Energy** (ocean movement)

3. Differentiate between Conventional and Renewable Energy with examples. *(Medium)*

Feature	Conventional (Non-renewable) Energy	Renewable Energy
Definition	Energy from sources that are **finite** and will eventually deplete.	Energy from sources that are **naturally replenished** quickly.
Examples	Coal, Oil, Natural Gas, Nuclear (Uranium).	Solar, Wind, Hydro, Biomass, Geothermal, Tidal.
Replenishment rate	Millions of years (effectively zero on human scale).	Hours to years (solar daily, wind seasonally).

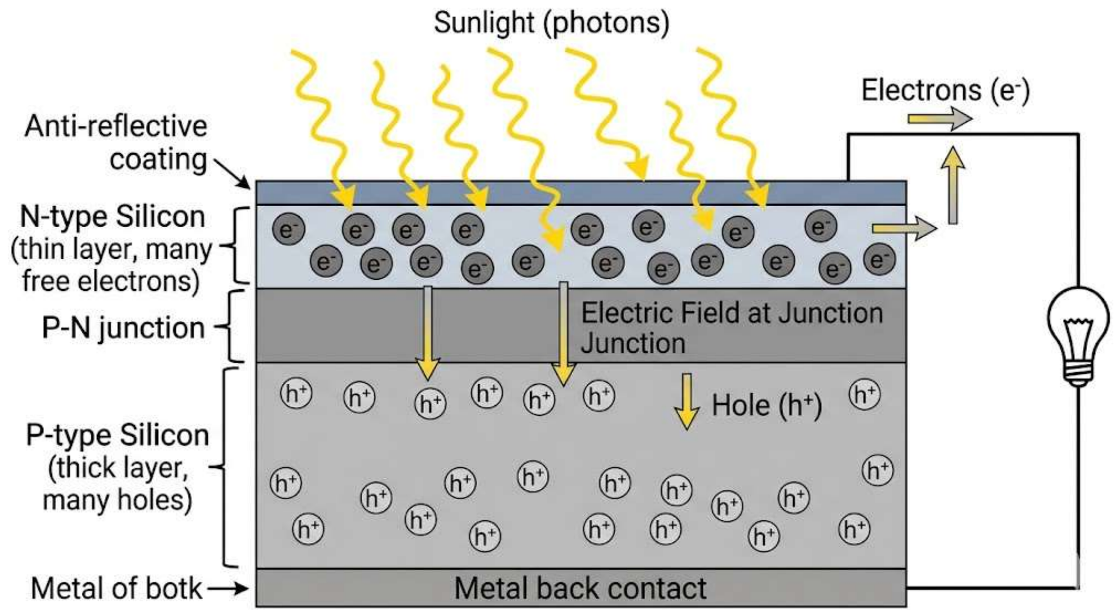
Feature	Conventional (Non-renewable) Energy	Renewable Energy
Environmental impact	High: CO_2 emissions (climate change), air pollution, mining destruction.	Low: Zero or low emissions during operation; land use impact.
Cost	Low upfront (but high external cost of pollution).	Higher upfront cost, but near-zero fuel cost (low operational cost).
Sustainability	Not sustainable; will run out.	Sustainable indefinitely.

4. Explain the principles of generation for Solar and Wind energy. *(Medium)*

- **Solar Energy (Photovoltaic - PV):**
  - **Principle: Photoelectric effect** (discovered by Einstein).
  - **Process:**
    1. Solar panels contain **semiconductors** (usually Silicon - Si), doped with impurities (Phosphorus for N-type, Boron for P-type) to create a **P-N junction**.
    2. When **photons** (sunlight) strike the semiconductor, they transfer energy to **electrons** in the material.
    3. Electrons gain enough energy to break free from their atoms, creating **electron-hole pairs**.
    4. The built-in electric field at the P-N junction pushes free electrons toward the N-side and holes toward the P-side.
    5. Connecting an external circuit allows electrons to flow → **Direct Current (DC)** electricity.
    6. An **inverter** converts DC to AC for home/ grid use.
- **Wind Energy:**
  - **Principle:** Conversion of **kinetic energy** of moving air into **mechanical energy**, then into **electrical energy**.
  - **Process:**
    1. Wind flows over the **turbine blades** (airfoil shape, like airplane wings).
    2. **Aerodynamic lift** (lower pressure on the curved side) causes the rotor to spin (even at low wind speeds).
    3. The rotor (blades + hub) spins a **low-speed shaft**.
    4. A **gearbox** increases the rotational speed (low speed → high speed).

5. The high-speed shaft spins a **generator** (electromagnetic induction: rotating magnets inside coils of wire produce AC electricity).
6. Transformer steps up voltage for transmission to grid.

Diagram (Solar PV):



5. How can renewable energy benefit the environment? *(Medium)*

- **Climate Change Mitigation:** Most renewables (solar, wind, hydro, geothermal) produce **near-zero greenhouse gas emissions** during operation. Replacing coal/gas plants with renewables drastically reduces CO_2 and methane.
- **Air Quality Improvement:** No combustion means no emission of **SO_2** (acid rain), **NOx** (smog), **particulate matter** (respiratory disease), or **mercury** (neurotoxin). Reduces deaths from air pollution (millions annually).
- **Water Conservation:** Conventional power plants (coal, nuclear, gas) require huge amounts of water for cooling (thermal pollution). Solar PV and wind turbines use **very little to no water**.
- **Land & Habitat Protection:** While renewables require land, they avoid the environmental destruction of **coal mining** (mountaintop removal, acid mine drainage) and **oil drilling** (spills, habitat fragmentation).
- **Waste Reduction:** No production of **fly ash** (coal waste, toxic heavy metals) or radioactive waste (nuclear).
- **Biodiversity:** Reduced climate change and pollution help protect species from extinction.

B. Green Hydrogen (CO5)

1. Explain the term "Green Hydrogen." How does it differ from Grey and Blue hydrogen in terms of environmental impact? *(Medium)*

- **Green Hydrogen:** Hydrogen (H_2) produced by **electrolysis of water** (splitting H_2O into H_2 and O_2) using **renewable electricity** (solar, wind, hydro). *Carbon footprint: Zero.*
- **Difference from Grey and Blue:**

Type	Production Method	Carbon Footprint	Environmental Impact
Grey Hydrogen	**Steam Methane Reforming (SMR)** of natural gas ($CH_4 + H_2O \rightarrow CO_2 + H_2$).	**High** (~10 kg CO_2 per kg H_2)	Releases CO_2 directly into atmosphere. Currently 96% of H_2 is grey.
Blue Hydrogen	Same SMR as grey, but **CO_2 is captured** and stored underground (Carbon Capture & Storage - CCS).	**Low to Medium** (~2-5 kg CO_2 per kg H_2, depending on capture rate)	Less direct emissions, but CCS has energy penalty (20-25% efficiency loss) and risk of leakage.
Green Hydrogen	**Electrolysis** using renewable energy (solar, wind).	**Zero** (if renewable energy is truly zero-carbon)	No CO_2 emissions. Only byproduct is Oxygen (O_2), which is harmless.

2. Why is storage a major hurdle for the Hydrogen Economy? Compare Compressed Gas storage with Liquid Hydrogen storage. *(Medium)*

- **Why storage is a hurdle:**
  - Hydrogen has **extremely low density** (at room temperature and pressure, it is the lightest gas).
  - To store a usable amount of energy, you must either **compress it** to very high pressure or **liquefy it** at cryogenic temperatures.
  - Hydrogen molecules are very small and **embrittle metals** (causing cracks and leaks in pipes/tanks).
- **Comparison:**

Feature	Compressed Gas (CGH_2)	Liquid Hydrogen (LH_2)
Storage condition	350-700 bar pressure (up to 10,000 psi)	**Cryogenic:** -253°C (20 Kelvin)

Feature	Compressed Gas (CGH_2)	Liquid Hydrogen (LH_2)
Energy density (volumetric)	~1.3 kWh/L (at 700 bar)	~2.4 kWh/L (better than compressed)
Energy cost	High (compressor energy ~10-15% of H_2 energy content)	**Very high** (liquefaction uses ~30-40% of H_2 energy content)
Boil-off loss	Negligible (no evaporation)	Significant (~1-3% per day evaporation, even with superinsulation)
Container	Thick-walled composite (carbon fiber) cylinders	Double-walled vacuum-insulated cryogenic tanks (heavy)
Application	Cars (Toyota Mirai), buses, stationary storage	Rockets (SpaceX, NASA), large ships, aircraft (future)

3. Discuss the "Ammonia as a Carrier" concept. Why is it preferred for international maritime transport of hydrogen? *(Medium)*

- **Concept:** Instead of shipping pure hydrogen (which is difficult), we convert hydrogen into **Ammonia (NH_3)** , transport the ammonia, and then "crack" it back into hydrogen at the destination.
- **Process:**
  1. **Synthesis:** Green H_2 + Nitrogen (from air) → **Haber-Bosch process** (high pressure, 400°C) → Liquid Ammonia (NH_3).
  2. **Transport:** Ammonia is shipped in standard liquid tankers (like LPG). It is stored at -33°C or moderate pressure (10 bar).
  3. **Cracking:** At destination, ammonia is heated with a catalyst to crack it back: $2NH_3 \rightarrow N_2 + 3H_2$.
- **Why preferred for maritime transport (ships):**
  - **Easier to liquefy:** Ammonia liquefies at -33°C (vs H_2 at -253°C). Much less energy for cooling.
  - **Higher energy density:** Volumetric energy density of liquid ammonia is ~3.5 kWh/L (better than compressed H_2, similar to liquid H_2).
  - **Existing infrastructure:** Global ports already handle ammonia (for fertilizer). Ships can burn ammonia directly in modified engines (no cracking needed for combustion).
  - **Safety (relative):** Ammonia is toxic and corrosive, but it does not have the wide flammability range or embrittlement issues of hydrogen.

- **Carbon-free carrier:** Cracking produces only N_2 (harmless) and H_2.

4. If 55 kWh of renewable electricity is used to produce 1 kg of Hydrogen (which contains 33.3 kWh of energy), what is the efficiency of the electrolysis process? *(Short - Numerical)*

- **Given:**
  - Input Energy = 55 kWh
  - Output Energy (in produced H_2) = 33.3 kWh
- **Formula:**

$$\text{Efficiency (\%)} = \left(\frac{\text{Output Energy}}{\text{Input Energy}}\right) \times 100$$

- **Calculation:**

$$\text{Efficiency} = \left(\frac{33.3}{55}\right) \times 100$$
$$\text{Efficiency} = 0.6054 \times 100 = 60.54\%$$

- **Answer:** The electrolysis process is **60.54% efficient**. (Note: 33.3 kWh/kg is the **Lower Heating Value** of Hydrogen; current commercial electrolyzers are ~60-80% efficient).

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