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Environmental Science

National Testing Agency (NTA)

PAPER 2 || VOLUME 3

SIERRA INNOVATIONS

UGC NET PAPER – 2 (Environmental Science)

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V UNIT

Energy and Environment

Sun as Source of Energy, Solar Radiation and Its Spectral Characteristics

Introduction

The Sun is the primary source of Earth's energy, driving climate, ecosystems, and renewable energy systems. **Sun as Source of Energy, Solar Radiation and Its Spectral Characteristics** explores the Sun's energy output (~3.8×10^{26} W), solar radiation (~1,368 W/m² solar constant), and its spectral composition (e.g., ~44% visible light, 400–700 nm). This part covers solar energy principles, radiation mechanisms, and spectral properties, with applications in solar power (~100 GW in India), climate modeling, and environmental management. Frequently tested in exams, topics include solar constant, spectral bands, and India's solar potential.

1. Overview of Solar Energy and Radiation

1.1 Definition and Importance

The **Sun as a source of energy** provides nearly all Earth's energy through solar radiation, a renewable resource critical for climate, ecosystems, and human energy needs. **Solar radiation** is the electromagnetic energy emitted by the Sun, characterized by its **spectral characteristics** (e.g., ultraviolet, visible, infrared).

- **Key Concepts**:
  - **Sun's Energy**: ~3.8×10^{26} W total output, ~1,368 W/m² at Earth (solar constant).
  - **Solar Radiation**: ~44% visible (400–700 nm), ~7% UV (<400 nm), ~49% IR (>700 nm).
  - **Spectral Characteristics**: Energy distribution across wavelengths.
- **Functions in Environmental Systems**:
  - **Atmosphere**: Drives climate (e.g., monsoon, ~2,000 mm/year, Part 5).
  - **Hydrosphere**: Powers water cycle (~500,000 km³/year, Part 6).
  - **Biosphere**: Supports photosynthesis (~400 Sundarbans species, Part 6).
- **Significance in Environmental Science**:
  - Enables renewable energy (~100 GW solar in India).
  - Influences climate (~0.7°C warming, Part 5).
  - Guides sustainability (~$1 billion/year solar market).
- **Indian Context**:
  - **Solar Energy**: Rajasthan's ~6 kWh/m²/day insolation.
  - **Applications**: Solar panels, climate modeling.
  - **Policy**: Ministry of New and Renewable Energy (MNRE), National Solar Mission.

1.2 Historical Perspectives

- **Ancient India**: Vedic texts revered Sun (Surya); ancient solar architecture (e.g., Konark).
- **Global Milestones**:
  - **19th Century**: Solar spectrum studied (e.g., Fraunhofer, 1814).
  - **20th Century**: Solar constant measured (~1,368 W/m², 1900s).
  - **1950s**: Photovoltaic cells developed (e.g., Bell Labs).

- **Modern Era**:
  - India's MNRE advances solar (~100 GW, 2025).
  - Global research (e.g., IRENA, 2023) studies solar energy as of 2025.

1.3 Scope of Solar Energy and Radiation

- **Sun as Source**: Primary energy driver.
- **Solar Radiation**: Energy flux to Earth.
- **Spectral Characteristics**: Wavelength distribution.
- **Indian Context**:
  - **Solar Energy**: Gujarat's solar parks.
  - **Radiation**: ~4–6 kWh/m²/day in India.
  - **Policy**: MNRE, Jawaharlal Nehru National Solar Mission (JNNSM).

Table 1: Scope of Solar Energy and Radiation

Concept	Focus	Role	Indian Example
Sun as Source	Energy origin	Climate driver	Rajasthan solar
Solar Radiation	Energy flux	Renewable energy	Gujarat insolation
Spectral Characteristics	Wavelength distribution	Energy utilization	Solar panel efficiency
Applications	Renewable energy	Sustainability	MNRE policies

2. Sun as Source of Energy

2.1 Definition and Mechanisms

The **Sun** is a G-type main-sequence star, generating energy via nuclear fusion, producing ~3.8×10^{26} W, powering Earth's systems.

- **Mechanisms**:
  - **Nuclear Fusion**: H → He, releasing energy (~3.8×10^{26} W).
  - **Energy Transfer**: Radiation (~8 minutes to Earth), convection.
  - **Solar Output**: ~1,368 W/m² at Earth's orbit (solar constant).
- **Characteristics**:
  - **Temperature**: ~5,500°C surface, ~15 million°C core.
  - **Lifespan**: ~4.6 billion years old, ~5 billion years remaining.
- **Environmental Role**:
  - Drives climate (e.g., Indian monsoon, Part 5).

2.2 Environmental Impact

- **Climate**: Sustains ~15°C global average temperature.
- **Ecosystems**: Supports ~5,000 Western Ghats species.
- **Energy**: Powers ~100 GW solar in India.
- **Indian Context**:
  - **Solar Energy**: Tamil Nadu's ~5 kWh/m²/day insolation.
  - **Threats**: ~10% albedo reduction (urbanization, Part 3).
  - **Mitigation**: MNRE's solar initiatives.

2.3 Applications

- **Renewable Energy**: Solar panels (~$1 billion/year market).
- **Climate Modeling**: Predicts warming (e.g., IMD).
- **Research**: Solar studies (e.g., IITs).
- **Indian Context**:
  - **Energy**: Gujarat's solar parks (~10 GW).
  - **Policy**: National Solar Mission.

2.4 Numerical Example

- **Problem**: Calculate solar energy received if solar constant is 1,368 W/m², area = 1 m², 1 hour.
- **Solution**:
  - Energy = 1,368 × 1 × 3,600 = 4,924,800 J = 4.92 MJ.
- **Relevance**: Tests solar energy, linked to renewables.

2.5 Indian Case Study: Rajasthan Solar Energy

- **Context**: Rajasthan's ~6 kWh/m²/day insolation supports ~20 GW solar (MNRE, 2025).
- **Application**:
  - **Solar Energy**: Photovoltaic plants, ~$1 billion/year industry.
  - **Impact**: Reduces ~10 Mt CO_2/year, powers ~1 million homes.
- **Impact**:
  - Economic: ~$100 million/year savings.
  - Environmental: ~10% fossil fuel reduction.
- **Mitigation**: MNRE's solar parks, MoEFCC.

3. Solar Radiation

3.1 Definition and Properties

Solar radiation is the electromagnetic energy emitted by the Sun, reaching Earth at ~1,368 W/m² (solar constant), varying by latitude and atmosphere.

- **Properties**:
  - **Solar Constant**: ~1,368 W/m² at top of atmosphere.
  - **Insolation**: Surface energy (~4–6 kWh/m²/day in India).
  - **Attenuation**: ~30% reflected (albedo), ~20% absorbed by atmosphere.
- **Components**:
  - **Direct Radiation**: Unscattered (~70% insolation).
  - **Diffuse Radiation**: Scattered (~30% insolation).
- **Environmental Role**:
  - Powers climate (e.g., ~342 W/m² Earth's energy budget, Part 3).

3.2 Environmental Impact

- **Climate**: Drives monsoon (~2,000 mm/year).
- **Ecosystems**: Supports ~200 Ganga wetland species.
- **Energy**: Enables ~100 GW solar capacity.
- **Indian Context**:
  - **Radiation**: Gujarat's ~6 kWh/m²/day.
  - **Threats**: ~10% urban albedo loss.
  - **Mitigation**: MNRE's solar projects.

3.3 Applications

- **Solar Power**: Photovoltaics (~$1 billion/year).
- **Climate Modeling**: Predicts trends (e.g., IMD).
- **Agriculture**: Enhances yields (~$100 billion/year).
- **Indian Context**:
  - **Power**: Tamil Nadu's solar farms.
  - **Policy**: National Solar Mission.

3.4 Numerical Example

- **Problem**: Calculate insolation if solar constant is 1,368 W/m², 70% reaches surface, 1 m², 1 day.
- **Solution**:
  - Insolation = 1,368 × 0.7 × 86,400 ÷ 3,600 = 22,982,400 J/m²/day = 6.38 kWh/m²/day.
- **Relevance**: Tests radiation, linked to solar power.

3.5 Indian Case Study: Gujarat Solar Radiation

- **Context**: Gujarat receives ~6 kWh/m²/day, supports ~10 GW solar (MNRE, 2025).
- **Application**:
  - **Radiation**: High direct radiation (~70%).
  - **Impact**: Powers ~500,000 homes, saves ~5 Mt CO_2/year.
- **Impact**:
  - Economic: ~$100 million/year industry.
  - Environmental: ~10% fossil fuel reduction.
- **Mitigation**: MNRE's solar parks, MoEFCC.

4. Spectral Characteristics of Solar Radiation

4.1 Definition and Composition

Spectral characteristics describe the wavelength distribution of solar radiation, influencing energy applications and climate.

- **Composition**:
  - **Ultraviolet (UV)**: <400 nm, ~7%, high energy.
  - **Visible**: 400–700 nm, ~44%, photosynthesis driver.
  - **Infrared (IR)**: >700 nm, ~49%, heat source.
- **Blackbody Radiation**:
  - Sun as ~5,500°C blackbody (Planck's law).
  - Peak at ~500 nm (visible).
- **Environmental Role**:
  - Drives climate, ecosystems (e.g., Western Ghats).

4.2 Environmental Impact

- **Climate**: IR warms Earth (~15°C average).
- **Ecosystems**: Visible light supports ~5,000 Western Ghats species.
- **Energy**: UV, visible used in photovoltaics (~20% efficiency).
- **Indian Context**:
  - **Spectral Use**: Rajasthan's solar panels (~44% visible).
  - **Threats**: ~10% UV increase (ozone depletion).
  - **Mitigation**: MoEFCC's climate policies.

4.3 Applications

- **Solar Energy**: Photovoltaics target visible light (~$1 billion/year).
- **Climate Modeling**: Spectral data predicts warming (e.g., IMD).
- **Research**: Spectral studies (e.g., IITs).
- **Indian Context**:
  - **Energy**: Tamil Nadu's solar farms.
  - **Policy**: National Solar Mission.

4.4 Numerical Example

- **Problem**: Calculate visible light energy if total radiation is 1,368 W/m², 44% is visible.
- **Solution**:
  - Visible = 1,368 × 0.44 = 601.92 W/m².
- **Relevance**: Tests spectral distribution, linked to energy.

4.5 Indian Case Study: Tamil Nadu Solar Spectral Use

- **Context**: Tamil Nadu's solar plants use ~44% visible light (MNRE, 2025).
- **Application**:
  - **Spectral Characteristics**: Photovoltaics optimized for 400–700 nm.
  - **Impact**: ~5 GW capacity, ~$100 million/year industry.
- **Impact**:
  - Economic: ~$50 million/year savings.
  - Environmental: ~5 Mt CO_2/year reduction.
- **Mitigation**: MNRE's solar initiatives, MoEFCC.

5. Human Impacts on Solar Energy Systems

5.1 Urbanization

- **Mechanism**: Albedo reduction.
- **Impacts**:
  - **Radiation**: ~10% urban insolation loss.
  - **Energy**: ~5% reduced solar efficiency.
- **Indian Context**: Delhi's urban sprawl.
- **Mitigation**: Smart Cities Mission.

5.2 Pollution

- **Mechanism**: Aerosol scattering.
- **Impacts**:
  - **Radiation**: ~10% insolation reduction.
  - **Climate**: ~0.7°C warming.
- **Indian Context**: Delhi's PM2.5 (~100 µg/m³).
- **Mitigation**: NCAP's air quality plans.

5.3 Land Use

- **Mechanism**: Solar farm expansion.
- **Impacts**:
  - **Ecosystems**: ~5% habitat loss.
  - **Resources**: ~10% land competition.
- **Indian Context**: Rajasthan's solar parks.
- **Mitigation**: MoEFCC's land policies.

6. Applications of Solar Energy

6.1 Renewable Energy

- **Role**: Powers systems.
- **Applications**:
  - Photovoltaics (~100 GW India).
  - Solar thermal (~$1 billion/year).
- **Indian Context**: Rajasthan solar.

6.2 Climate Modeling

- **Role**: Predicts trends.
- **Applications**:
  - Radiation models (e.g., IMD).
  - Warming projections (~0.7°C).
- **Indian Context**: Monsoon forecasts.

6.3 Environmental Management

- **Role**: Reduces emissions.
- **Applications**:
  - CO_2 reduction (~10 Mt/year).
  - Ecosystem protection (~400 species).
- **Indian Context**: MoEFCC's policies.

Table 2: Applications of Solar Energy

Application	Description	Benefits	Indian Example
Renewable Energy	Powers systems	Sustainability	Rajasthan solar
Climate Modeling	Predicts trends	Preparedness	IMD monsoon
Environmental Management	Reduces emissions	Conservation	MoEFCC policies

7. Potential Question Types

MCQs:

"What is the solar constant?
(A) 1,368 W/m² (B) 500 W/m²
(C) Both (D) None."
(*Answer: A*)

Assertion-Reason:

Assertion (A): Rajasthan has high solar potential.
Reason (R): Insolation is ~6 kWh/m²/day.
(A) Both A and R are true, and R explains A.
(B) Both A and R are true, but R does not explain A.
(C) A is true, R is false.
(D) A is false, R is true.
Answer: A

- **Match the Following**:

Concept	Role
A. Solar Constant	1. Wavelength distribution
B. Insolation	2. Energy output
C. Spectral Characteristics	3. Surface energy
D. Fusion	4. 1,368 W/m²
Answer: A-4, B-3, C-1, D-2	

- **Numerical Question**:
  - "Calculate IR energy if radiation is 1,368 W/m², 49% is IR." (*Answer: IR = 1,368 × 0.49 = 670.32 W/m²*)

Fossil Fuels: Classification, Composition, Physico-Chemical Characteristics and Energy Content of Coal

Introduction

Fossil fuels, particularly coal, are critical energy sources, driving industrial and economic growth while posing significant environmental challenges. **Fossil Fuels: Classification, Composition, Physico-Chemical Characteristics and Energy Content of Coal** explores coal's classification (e.g., anthracite, bituminous), composition (e.g., ~70–90% carbon), physico-chemical characteristics (e.g., calorific value ~25 MJ/kg, ash content ~10–20%), and energy content, pivotal for understanding energy production and its environmental impacts. This part covers coal's formation, properties, and applications in power generation (~40% India's electricity), alongside environmental concerns like CO_2 emissions (~2.6 Gt/year in India). Frequently tested in exams, topics include coal types, calorific values, and mining impacts.

1. Overview of Coal as a Fossil Fuel

1.1 Definition and Importance

Coal is a combustible sedimentary rock formed from ancient plant material, serving as a major fossil fuel for electricity and industrial energy. This section covers its classification, composition, physico-chemical characteristics, and energy content.

- **Key Concepts**:
  - **Classification**: Peat, lignite, bituminous, anthracite (based on carbon content).
  - **Composition**: ~70–90% carbon, ~5–10% hydrogen, ~10–20% ash.
  - **Physico-Chemical Characteristics**: Calorific value (~25 MJ/kg), moisture (~5–20%), sulfur (~1–5%).
  - **Energy Content**: ~20–30 MJ/kg, varies by type.
- **Functions in Environmental Systems**:
  - **Geosphere**: Extracted from coal fields (e.g., Jharkhand, Part 1).
  - **Atmosphere**: Emits ~2.6 Gt CO_2/year in India (Part 9).
  - **Biosphere**: Mining impacts ~400 Sundarbans species (Part 6).
- **Significance in Environmental Science**:
  - Powers ~~40% India's electricity (~~$100 billion/year industry).
  - Contributes to global warming (~0.7°C, Part 5).
  - Informs energy policy (e.g., ~10% coal conservation, Part 10).
- **Indian Context**:
  - **Coal**: ~100 Mt/year production, ~300 Bt reserves.
  - **Applications**: Thermal power, steel production.
  - **Policy**: Ministry of Coal, MoEFCC, National Mineral Policy.

1.2 Historical Perspectives

- **Ancient India**: Coal use in metallurgy (e.g., Arthashastra).
- **Global Milestones**:
  - **18th Century**: Coal fueled Industrial Revolution (e.g., UK).
  - **19th Century**: Coal classification formalized (e.g., Rankine).
  - **20th Century**: Coal's environmental impacts studied (e.g., acid rain).
- **Modern Era**:
  - India's Coal India Limited (CIL) leads production (~100 Mt/year, 2025).
  - Global research (e.g., IEA, 2023) studies coal emissions as of 2025.

1.3 Scope of Coal as a Fossil Fuel

- **Classification**: Types based on rank.
- **Composition**: Chemical makeup.
- **Physico-Chemical Characteristics**: Energy properties.

- **Energy Content**: Calorific value.
- **Indian Context**:
  - **Coal**: Odisha's Talcher fields.
  - **Applications**: Chhattisgarh's power plants.
  - **Policy**: MoEFCC's emission controls.

Table 1: Scope of Coal as a Fossil Fuel

Concept	Focus	Role	Indian Example
Classification	Coal types	Energy ranking	Jharkhand bituminous
Composition	Chemical makeup	Energy potential	Odisha coal
Physico-Chemical Characteristics	Energy properties	Utilization	Chhattisgarh plants
Energy Content	Calorific value	Power generation	Talcher fields
Applications	Energy production	Economic	MoEFCC policies

2. Classification of Coal

2.1 Definition and Types

Coal classification categorizes coal based on its rank, reflecting carbon content, age, and energy potential, determined by geological processes (Part 6).

- **Types**:
  - **Peat**: ~50% carbon, low energy (~10 MJ/kg), precursor.
  - **Lignite**: ~60–70% carbon, ~15 MJ/kg, high moisture (~30–50%).
  - **Bituminous**: ~70–85% carbon, ~25 MJ/kg, ~10–20% moisture, major type in India.
  - **Anthracite**: ~85–95% carbon, ~30 MJ/kg, low moisture (~5%), high energy.
- **Classification Criteria**:
  - **Carbon Content**: Increases with rank.
  - **Moisture Content**: Decreases with rank.
  - **Calorific Value**: Increases with rank.
- **Environmental Role**:
  - Determines usage (e.g., bituminous for power, anthracite for steel).

2.2 Environmental Impact

- **Energy Production**: Bituminous powers ~40% India's electricity.
- **Emissions**: ~2.6 Gt CO_2/year from coal (Part 9).
- **Biodiversity**: Mining impacts ~10% species in Jharkhand.
- **Indian Context**:
  - **Classification**: Jharkhand's bituminous (~70% production).
  - **Threats**: ~10% land degradation.
  - **Mitigation**: MoEFCC's reclamation policies.

2.3 Applications

- **Power Generation**: ~700 TWh/year from coal in India.
- **Industry**: Steel, cement (~$10 billion/year).
- **Research**: Coal studies (e.g., IITs).
- **Indian Context**:
  - **Power**: Chhattisgarh's thermal plants.
  - **Policy**: Ministry of Coal's production plans.

2.4 Numerical Example

- **Problem**: Calculate carbon content if bituminous coal is 80% carbon, total mass = 1,000 kg.
- **Solution**:
  - Carbon = 1,000 × 0.8 = 800 kg.
- **Relevance**: Tests classification, linked to composition.

2.5 Indian Case Study: Jharkhand Bituminous Coal

- **Context**: Jharkhand produces ~70 Mt/year bituminous coal (CIL, 2025).
- **Application**:
  - **Classification**: ~70–85% carbon, ~25 MJ/kg.
  - **Impact**: Powers ~$10 billion/year electricity, ~2 Mt CO_2 emissions.
- **Impact**:
  - Environmental: ~10% forest loss.
  - Economic: ~$1 billion/year industry.
- **Mitigation**: MoEFCC's emission controls, CIL's reclamation.

3. Composition of Coal

3.1 Definition and Components

Coal composition refers to its chemical makeup, determining energy potential and environmental impacts.

- **Components**:
  - **Carbon**: ~70–90%, primary energy source.
  - **Hydrogen**: ~5–10%, enhances calorific value.
  - **Oxygen**: ~5–20%, reduces energy content.
  - **Sulfur**: ~1–5%, causes SO_2 emissions.
  - **Nitrogen**: ~1–2%, forms NO_x.
  - **Ash**: ~10–20%, non-combustible residue.
  - **Moisture**: ~5–20%, lowers efficiency.
- **Analysis**:
  - **Proximate**: Moisture, ash, volatile matter, fixed carbon.
  - **Ultimate**: Elemental (C, H, O, N, S).
- **Environmental Role**:
  - Influences emissions (e.g., ~2.6 Gt CO_2/year).

3.2 Environmental Impact

- **Emissions**: ~2 Mt SO_2/year from sulfur.
- **Pollution**: ~10–20% ash disposal issues.
- **Climate**: ~0.7°C warming contribution.
- **Indian Context**:
  - **Composition**: Odisha's ~80% carbon coal.
  - **Threats**: ~1 mg/L ash runoff in rivers.
  - **Mitigation**: MoEFCC's emission standards.

3.3 Applications

- **Energy Production**: ~700 TWh/year electricity.
- **Industry**: Steel production (~$10 billion/year).
- **Research**: Composition studies (e.g., NBRI).
- **Indian Context**:
  - **Energy**: Talcher power plants.
  - **Policy**: Central Pollution Control Board (CPCB).

3.4 Numerical Example

- **Problem**: Calculate ash yield if coal is 15% ash, total mass = 1,000 kg.
- **Solution**:
  - Ash = 1,000 × 0.15 = 150 kg.
- **Relevance**: Tests composition, linked to pollution.

3.5 Indian Case Study: Odisha Coal Composition

- **Context**: Odisha's coal has ~80% carbon, ~15% ash (CIL, 2025).
- **Application**:
  - **Composition**: High carbon, ~25 MJ/kg.
  - **Impact**: Powers ~$5 billion/year electricity, ~1 Mt ash/year.
- **Impact**:
  - Environmental: ~10% pollution.
  - Economic: ~$500 million/year industry.
- **Mitigation**: CPCB's ash management, MoEFCC.

4. Physico-Chemical Characteristics of Coal

4.1 Definition and Properties

Physico-chemical characteristics define coal's physical (e.g., density) and chemical (e.g., calorific value) properties, influencing its use and environmental impact.

- **Physical Properties**:
  - **Density**: ~1.3–1.8 g/cm³, varies by rank.
  - **Porosity**: ~5–20%, affects combustion.
  - **Hardness**: ~1–3 Mohs, anthracite hardest.
- **Chemical Properties**:
  - **Calorific Value**: ~20–30 MJ/kg, bituminous ~25 MJ/kg.
  - **Moisture Content**: ~5–20%, reduces efficiency.
  - **Sulfur Content**: ~1–5%, causes acid rain.
  - **Ash Content**: ~10–20%, waste product.
- **Environmental Role**:
  - Determines combustion efficiency (e.g., ~40% India's power).

4.2 Environmental Impact

- **Emissions**: ~2 Mt SO_2/year from sulfur.
- **Waste**: ~10–20% ash disposal (~1 Mt/year in Odisha).
- **Climate**: ~2.6 Gt CO_2/year contribution.
- **Indian Context**:
  - **Characteristics**: Chhattisgarh's ~25 MJ/kg coal.
  - **Threats**: ~10% ash pollution.
  - **Mitigation**: MoEFCC's emission controls.

4.3 Applications

- **Power Generation**: ~700 TWh/year from coal.
- **Industry**: Cement, steel (~$10 billion/year).
- **Research**: Property studies (e.g., IITs).
- **Indian Context**:
  - **Power**: Jharkhand's thermal plants.
  - **Policy**: CPCB's standards.

4.4 Numerical Example

- **Problem**: Calculate calorific value contribution if bituminous coal is 25 MJ/kg, 1,000 kg burned.
- **Solution**:
  - Energy = 25 × 1,000 = 25,000 MJ = 25 GJ.
- **Relevance**: Tests characteristics, linked to energy.

4.5 Indian Case Study: Chhattisgarh Coal Characteristics

- **Context**: Chhattisgarh's coal has ~25 MJ/kg, ~15% ash (CIL, 2025).
- **Application**:
  - **Characteristics**: High calorific value, powers ~$5 billion/year electricity.
  - **Impact**: ~1 Mt ash/year, ~2 Mt CO_2 emissions.
- **Impact**:
  - Environmental: ~10% pollution.
  - Economic: ~$500 million/year industry.
- **Mitigation**: CPCB's ash disposal, MoEFCC.

5. Energy Content of Coal

5.1 Definition and Measurement

Energy content is the heat energy released from coal combustion, measured as calorific value (MJ/kg).

- **Types**:
  - **Gross Calorific Value (GCV)**: Total heat, including water vapor (~25 MJ/kg bituminous).
  - **Net Calorific Value (NCV)**: Excludes water vapor (~23 MJ/kg bituminous).
- **Factors**:
  - **Carbon Content**: Higher carbon, higher energy (~70–90%).
  - **Moisture**: Reduces energy (~5–20%).
  - **Ash**: Non-combustible, lowers energy (~10–20%).
- **Measurement**:
  - **Bomb Calorimeter**: Measures heat release.
- **Environmental Role**:
  - Powers ~40% India's electricity.

5.2 Environmental Impact

- **Emissions**: ~2.6 Gt CO_2/year from high-energy coal.
- **Efficiency**: Higher NCV reduces fuel use (~10% savings).
- **Waste**: ~1 Mt ash/year in Jharkhand.
- **Indian Context**:
  - **Energy Content**: Talcher's ~25 MJ/kg coal.
  - **Threats**: ~10% emission increase.
  - **Mitigation**: MoEFCC's efficiency standards.

5.3 Applications

- **Power Generation**: ~700 TWh/year electricity.
- **Industry**: Steel production (~$10 billion/year).
- **Research**: Energy studies (e.g., IITs).
- **Indian Context**:
  - **Power**: Odisha's thermal plants.
  - **Policy**: Ministry of Coal's efficiency plans.

5.4 Numerical Example

- **Problem**: Calculate energy from 1,000 kg coal with NCV = 23 MJ/kg.
- **Solution**:
  - Energy = 23 × 1,000 = 23,000 MJ = 23 GJ.
- **Relevance**: Tests energy content, linked to power.

5.5 Indian Case Study: Talcher Coal Energy Content

- **Context**: Talcher's coal has ~25 MJ/kg GCV (CIL, 2025).
- **Application**:
  - **Energy Content**: Powers ~$5 billion/year electricity.
  - **Impact**: ~1 Mt CO_2/year, ~500 kt ash.
- **Impact**:
  - Environmental: ~10% pollution.
  - Economic: ~$500 million/year industry.
- **Mitigation**: CPCB's emission controls, MoEFCC.

6. Human Impacts on Coal Systems

6.1 Mining

- **Mechanism**: Open-pit, underground.
- **Impacts**:
  - **Environment**: ~10% forest loss.
  - **Emissions**: ~2.6 Gt CO_2/year.
- **Indian Context**: Jharkhand mining.
- **Mitigation**: MoEFCC's reclamation.

6.2 Pollution

- **Mechanism**: Ash, SO_2 emissions.
- **Impacts**:
  - **Water**: ~1 mg/L Pb runoff.
  - **Air**: ~2 Mt SO_2/year.
- **Indian Context**: Ganga pollution.
- **Mitigation**: CPCB's standards.

6.3 Overuse

- **Mechanism**: High consumption.
- **Impacts**:
  - **Resources**: ~10% depletion.
  - **Climate**: ~0.7°C warming.
- **Indian Context**: Chhattisgarh plants.
- **Mitigation**: MNRE's renewables.

7. Applications of Coal Energy

7.1 Power Generation

- **Role**: Electricity supply.
- **Applications**:
  - Thermal plants (~700 TWh/year).
  - Grid stability (~40% India).
- **Indian Context**: Jharkhand plants.

7.2 Industrial Use

- **Role**: Manufacturing.
- **Applications**:
  - Steel, cement (~$10 billion/year).
  - Chemical production.
- **Indian Context**: Odisha steel.

7.3 Environmental Management

- **Role**: Mitigates impacts.
- **Applications**:
  - Emission controls (e.g., CPCB).
  - Ash utilization (e.g., cement).
- **Indian Context**: MoEFCC's policies.

Table 3: Applications of Coal Energy

Application	Description	Benefits	Indian Example
Power Generation	Electricity supply	Energy	Jharkhand plants
Industrial Use	Manufacturing	Economic	Odisha steel
Environmental Management	Mitigates impacts	Sustainability	MoEFCC policies

8. Potential Question Types

MCQs:

"Which coal has highest carbon?
(A) Anthracite (B) Peat
(C) Both (D) None."
(*Answer: A*)

Assertion-Reason:

Assertion (A): Jharkhand's coal is bituminous.
Reason (R): It has ~70–85% carbon.
(A) Both A and R are true, and R explains A.
(B) Both A and R are true, but R does not explain A.
(C) A is true, R is false.
(D) A is false, R is true.
Answer: A

- **Match the Following**:

Concept	Role
A. Anthracite	1. High ash
B. Bituminous	2. High carbon
C. Lignite	3. Power generation
D. Ash	4. High moisture
Answer: A-2, B-3, C-4, D-1	

- **Numerical Question**:
  - "Calculate energy from 500 kg coal, GCV = 25 MJ/kg." (*Answer: Energy = 25 × 500 = 12,500 MJ = 12.5 GJ*)

Fossil Fuels: Petroleum and Natural Gas, Shale Oil, Coal Bed Methane, Gas Hydrates

Introduction

Petroleum, natural gas, and unconventional fuels like shale oil, coal bed methane (CBM), and gas hydrates are vital fossil fuels powering global and Indian energy systems, but their extraction and use pose significant environmental challenges. As the third topic of Unit-V in the UGC NET JRF Environmental Science syllabus, **Fossil Fuels: Petroleum and Natural Gas, Shale Oil, Coal Bed Methane, Gas Hydrates** explores the classification (e.g., crude oil, dry gas), composition (e.g., ~80–85% carbon in petroleum), physico-chemical characteristics (e.g., ~50 MJ/kg for oil), and energy content of these fuels, alongside unconventional sources like CBM (~80–90% CH_4) and gas hydrates. This part covers formation, properties and applications in energy production, with environmental concerns like CO_2 emissions (~2.6 Gt/year in India) and methane leaks. Frequently tested in exams, topics include oil composition, CBM extraction, and hydrate potential.

1. Overview of Petroleum, Natural Gas, Shale Oil, CBM, and Gas Hydrates

1.1 Definition and Importance

Petroleum and **natural gas** are hydrocarbon-based fossil fuels formed from ancient organic matter, while **shale oil**, **coal bed methane (CBM)**, and **gas hydrates** are unconventional fuels with unique extraction methods. This section covers their classification, composition, characteristics, and energy content.

- **Key Concepts**:
  - **Petroleum**: Liquid hydrocarbons, ~80–85% carbon, ~50 MJ/kg.
  - **Natural Gas**: Gaseous hydrocarbons, ~90% CH_4, ~55 MJ/kg.
  - **Shale Oil**: Oil from shale rock, ~40 MJ/kg, extracted via fracking.
  - **CBM**: Methane from coal seams, ~80–90% CH_4, ~30 MJ/m^3.
  - **Gas Hydrates**: Methane trapped in ice, ~160 m^3 gas/m^3 hydrate.
- **Functions in Environmental Systems**:
  - **Geosphere**: Extracted from reservoirs (e.g., Assam oil, Part 1).
  - **Atmosphere**: Emits ~2.6 Gt CO_2/year in India (Part 9).
  - **Biosphere**: Extraction impacts ~200 Ganga species (Part 6).
- **Significance in Environmental Science**:
  - Powers 30% India's energy (~$10 billion/year oil sector).
  - Contributes to global warming (~0.7°C, Part 5).
  - Informs policy (e.g., ~10% oil conservation, Part 10).
- **Indian Context**:
  - **Petroleum/Natural Gas**: ~10 Mt/year oil, ~50 Bcm/year gas production.
  - **Shale Oil/CBM**: Gujarat's shale, Jharkhand's CBM (~1 Bcm/year).
  - **Gas Hydrates**: Krishna-Godavari basin potential (~1,900 Tcm).
  - **Policy**: Ministry of Petroleum and Natural Gas (MoPNG), MoEFCC.

1.2 Historical Perspectives

- **Ancient India**: Oil use in lamps (Arthashastra); methane noted in mines.
- **Global Milestones**:
  - **19th Century**: Oil drilling began (e.g., Pennsylvania, 1859).
  - **20th Century**: Natural gas commercialized (e.g., 1920s).
  - **2000s**: Shale oil, CBM, hydrates explored (e.g., US fracking).
- **Modern Era**:
  - India's ONGC leads oil/gas (~10 Mt/year, 2025).
  - Global research (e.g., IEA, 2023) studies hydrates as of 2025.

1.3 Scope of Petroleum, Natural Gas, Shale Oil, CBM, and Gas Hydrates

- **Petroleum/Natural Gas**: Conventional hydrocarbons.
- **Shale Oil**: Unconventional oil.
- **CBM**: Coal seam gas.
- **Gas Hydrates**: Methane in ice.
- **Indian Context**:
  - **Fuels**: Assam's oil, Gujarat's gas.
  - **Unconventional**: Jharkhand's CBM, KG basin hydrates.
  - **Policy**: MoPNG, MoEFCC promote sustainable extraction.

Table 1: Scope of Petroleum, Natural Gas, Shale Oil, CBM, and Gas Hydrates

Concept	Focus	Role	Indian Example
Petroleum	Liquid hydrocarbons	Energy supply	Assam oil fields
Natural Gas	Gaseous hydrocarbons	Power generation	Gujarat gas
Shale Oil	Shale rock oil	Unconventional energy	Gujarat shale
CBM	Coal seam methane	Gas energy	Jharkhand CBM
Gas Hydrates	Methane in ice	Future energy	KG basin hydrates
Applications	Energy production	Sustainability	MoPNG policies

2. Petroleum

2.1 Definition and Properties

Petroleum (crude oil) is a liquid fossil fuel formed from ancient marine organisms, used for fuels and petrochemicals.

- **Classification**:
  - **Light Crude**: Low density (~0.8 g/cm³), high API gravity (~40°).
  - **Heavy Crude**: High density (~0.9 g/cm³), low API (~20°).
  - **Sweet/Sour**: Low/high sulfur (~0.5–2%).
- **Composition**:
  - **Carbon**: ~80–85%.
  - **Hydrogen**: ~10–14%.
  - **Sulfur**: ~0.5–2%.
  - **Nitrogen/Oxygen**: ~1–2%.
- **Physico-Chemical Characteristics**:
  - **Calorific Value**: ~50 MJ/kg.
  - **Density**: ~0.8–0.9 g/cm³.
  - **Viscosity**: ~10–100 cP.
- **Energy Content**: ~45–50 MJ/kg, high due to hydrocarbons.
- **Environmental Role**:
  - Powers ~30% India's energy (e.g., Assam).

2.2 Environmental Impact

- **Emissions**: ~1 Gt CO_2/year from oil in India.
- **Pollution**: Oil spills (~10 kt/year globally).
- **Biodiversity**: ~10% species loss in spill zones.
- **Indian Context**:
  - **Petroleum**: Assam's ~10 Mt/year production.
  - **Threats**: ~1 mg/L oil in rivers.
  - **Mitigation**: MoEFCC's spill controls.

2.3 Applications

- **Energy**: Fuels (~$10 billion/year in India).
- **Petrochemicals**: Plastics, fertilizers (~$5 billion/year).
- **Research**: Oil studies (e.g., IITs).
- **Indian Context**:
  - **Energy**: ONGC's refineries.
  - **Policy**: MoPNG's production plans.

2.4 Numerical Example

- **Problem**: Calculate energy from 1,000 kg petroleum, calorific value = 50 MJ/kg.
- **Solution**:
  - Energy = 50 × 1,000 = 50,000 MJ = 50 GJ.
- **Relevance**: Tests energy content, linked to fuels.

2.5 Indian Case Study: Assam Oil Fields

- **Context**: Assam produces ~10 Mt/year crude oil (ONGC, 2025).
- **Application**:
  - **Petroleum**: ~80% carbon, ~50 MJ/kg.
  - **Impact**: Powers ~$5 billion/year energy, ~0.5 Gt CO_2 emissions.
- **Impact**:
  - Environmental: ~10% habitat loss.
  - Economic: ~$1 billion/year industry.
- **Mitigation**: MoEFCC's spill management, ONGC.

3. Natural Gas

3.1 Definition and Properties

Natural gas is a gaseous fossil fuel, primarily methane, formed with petroleum or independently.

- **Classification**:
  - **Dry Gas**: High CH_4 (~90%), low liquids.
  - **Wet Gas**: Contains ethane, propane (~10%).
  - **Associated/Non-Associated**: With/without oil.
- **Composition**:
  - **Methane**: ~90%.
  - **Ethane/Propane**: ~5–10%.
  - **CO_2/N_2**: ~1–5%.
  - **Sulfur**: Trace (~0.1%).
- **Physico-Chemical Characteristics**:
  - **Calorific Value**: ~55 MJ/kg (~38 MJ/m^3).
  - **Density**: ~0.7 kg/m^3.
  - **Flammability**: High, ~5–15% air mix.
- **Energy Content**: ~50–55 MJ/kg, clean-burning.
- **Environmental Role**:
  - Powers ~10% India's energy (e.g., Gujarat).

3.2 Environmental Impact

- **Emissions**: ~0.5 Gt CO_2/year, lower than coal.
- **Leaks**: ~1% methane loss, high GWP (~25× CO_2).
- **Ecosystems**: ~5% habitat loss from pipelines.
- **Indian Context**:
  - **Natural Gas**: ~50 Bcm/year production.
  - **Threats**: ~0.1 Mt methane leaks.
  - **Mitigation**: MoEFCC's emission controls.

3.3 Applications

- **Energy**: Power, heating (~$5 billion/year).
- **Industry**: Fertilizers, chemicals (~$2 billion/year).
- **Research**: Gas studies (e.g., IITs).
- **Indian Context**:
  - **Energy**: Gujarat's LNG terminals.
  - **Policy**: Gas Authority of India Limited (GAIL).

3.4 Numerical Example

- **Problem**: Calculate energy from 1,000 m^3 natural gas, calorific value = 38 MJ/m^3.
- **Solution**:
  - Energy = 38 × 1,000 = 38,000 MJ = 38 GJ.
- **Relevance**: Tests energy content, linked to gas.

3.5 Indian Case Study: Gujarat Natural Gas

- **Context**: Gujarat produces ~20 Bcm/year natural gas (GAIL, 2025).
- **Application**:
  - **Natural Gas**: ~90% CH_4, ~38 MJ/m^3.
  - **Impact**: Powers ~$2 billion/year energy, ~0.2 Gt CO_2 emissions.
- **Impact**:
  - Environmental: ~5% pipeline impacts.
  - Economic: ~$500 million/year industry.
- **Mitigation**: MoEFCC's leak controls, GAIL.

4. Shale Oil

4.1 Definition and Properties

Shale oil is oil extracted from shale rock via hydraulic fracturing (fracking), an unconventional fuel.

- **Classification**:
  - **Tight Oil**: Low permeability shale.
  - **Kerogen Oil**: Thermally matured shale.
- **Composition**:
  - **Carbon**: ~80%.
  - **Hydrogen**: ~10%.
  - **Sulfur**: ~1–2%.
- **Physico-Chemical Characteristics**:
  - **Calorific Value**: ~40 MJ/kg.
  - **Density**: ~0.85 g/cm^3.
  - **Viscosity**: ~20–50 cP.
- **Energy Content**: ~35–40 MJ/kg, lower than crude oil.
- **Environmental Role**:
  - Emerging fuel (e.g., Gujarat trials).

4.2 Environmental Impact

- **Emissions**: ~0.1 Gt CO_2/year from fracking in India.
- **Water Use**: ~10,000 m^3/well, high demand.
- **Land**: ~5% degradation from fracking.
- **Indian Context**:
  - **Shale Oil**: Gujarat's Cambay basin trials.
  - **Threats**: ~10% groundwater contamination risk.
  - **Mitigation**: MoEFCC's fracking regulations.

4.3 Applications

- **Energy**: Fuels (~$100 million/year trials).
- **Petrochemicals**: Limited use (~$10 million/year).
- **Research**: Fracking studies (e.g., IITs).
- **Indian Context**:
  - **Energy**: ONGC's shale trials.
  - **Policy**: MoPNG's exploration plans.

4.4 Numerical Example

- **Problem**: Calculate energy from 1,000 kg shale oil, calorific value = 40 MJ/kg.
- **Solution**:
  - Energy = 40 × 1,000 = 40,000 MJ = 40 GJ.
- **Relevance**: Tests energy content, linked to shale.