

PRACTICE PAPER — NATIONAL CERTIFICATION EXAMINATION FOR ENERGY MANAGERS & ENERGY AUDITORS

PAPER – 1: GENERAL ASPECTS OF ENERGY MANAGEMENT & ENERGY AUDIT

Question code: 3P1CEM001 – 3P1CEM064 | SOLUTIONS & MODEL ANSWERS

Duration: 3 HRS Max. Marks: 150 Pass: 50% marks in the paper

General instructions:

- Please check that this question paper contains 64 questions
- The question paper is divided into three sections
- All questions in all three sections are compulsory
- All parts of a question should be answered at one place
- Use of a non-programmable scientific calculator is permitted; show formula, substitution with units and result for every numerical

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Section – I: OBJECTIVE TYPE

Marks: 50 × 1 = 50

- (i) Answer all 50 questions
- (ii) Each question carries one mark

1. A State's peak electricity demand is 24 GW in 2025-26 and is projected to grow at 6.5% a year, compounded. Using exact compound growth (not a rule of thumb), after how many years will the peak reach 48 GW?

[3P1CEM001 | Chapter 1: Energy Scenario | Compound growth - doubling time of peak demand]

- a) 11.01 years
- b) 6.44 years
- c) 10.77 years
- d) 15.38 years

Correct answer: (a) 11.01 years.

Given: $P_0 = 24$ GW; target = 48 GW; growth $g = 6.5\%$ per year, compounded annually.

Formula: $P = P_0(1 + g)^n$, so doubling needs $(1 + g)^n = 2$ and $n = \ln 2 \div \ln(1 + g)$.

Substitution: $n = 0.693147 \div \ln(1.065) = 0.693147 \div 0.062975 = 11.007$.

Result: **$n = 11.01$ years**, so the State must double its peak supply capability in about 11 years.

The guidebook notes that at the growth rates seen in India, generating capacity would have to be doubled roughly every decade; this arithmetic is behind that statement and behind the emphasis on demand-side efficiency as the cheapest 'new capacity'.

Why the other options are wrong: (b) 6.44 years – is the time for a 50% rise (to 36 GW), not for doubling. (c) 10.77 years – is the 'rule of 70' shortcut, which is only an approximation. (d) 15.38 years – treats growth as simple (non-compounded) interest, $100 \div 6.5$.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

2. A country's annual use of primary fuels is 980 Mt of coal (GCV 3,900 kcal/kg), 250 Mt of crude oil (GCV 10,000 kcal/kg) and 64 billion m³ of natural gas (GCV 9,000 kcal/m³). Taking 1 toe = 10⁷ kcal, what is the share of coal in the primary energy mix of these three fuels?

[3P1CEM002 | Chapter 1: Energy Scenario | Primary energy mix on a common oil-equivalent basis]

- a) 60.5%

- b) 76.1%
- c) 69.0%
- d) 55.4%

Correct answer: (d) 55.4%.

Given: coal 980 Mt $\times$ 3,900 kcal/kg ($\approx$ 16,329 kJ/kg); oil 250 Mt $\times$ 10,000 kcal/kg ($\approx$ 41,868 kJ/kg); gas $64 \times 10^9 \text{ m}^3 \times 9,000 \text{ kcal/m}^3$ ($\approx$ 37.7 MJ/m³); 1 toe = 10^7 kcal.

Formula: Mtoe = quantity $\times$ GCV $\div 10^7$ kcal per toe (Mt $\times$ kcal/kg $\div 10,000$ gives Mtoe); share = coal Mtoe $\div$ total Mtoe $\times$ 100.

Substitution: coal = $980 \times 3,900 \div 10,000 = 382.2$ Mtoe; oil = 250.0 Mtoe; gas = $64 \times 9,000 \div 10,000 = 57.6$ Mtoe; total = 689.8 Mtoe; share = $382.2 \div 689.8 \times 100$.

Result: **coal share = 55.4%** of 689.8 Mtoe ($\approx$ 28.9 EJ).

Why the other options are wrong: (a) 60.5% – leaves natural gas out of the total primary energy. (b) 76.1% – treats one tonne of coal as one toe, ignoring its low GCV. (c) 69.0% – converts coal at the 7,000 kcal/kg standard coal value, not its actual GCV.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

3. A rural energy survey lists the fuels used by households in a block. Which group would normally be LEFT OUT of the country's commercial energy statistics?

[3P1CEM003 | Chapter 1: Energy Scenario | Commercial and non-commercial energy]

- a) Natural gas from a city network, firewood and cattle dung
- b) Firewood gathered locally, cattle dung cakes and crop residues
- c) Grid electricity, LPG cylinders and coal bought from a depot
- d) Kerosene from the ration shop, firewood and crop residues

Correct answer: (b) Firewood gathered locally, cattle dung cakes and crop residues.

The guidebook defines commercial energy as energy available in the market for a definite price, such as electricity, coal, refined petroleum products and natural gas; these form the basis of industrial, commercial and transport energy use.

Non-commercial energy is energy not normally traded in the commercial market. It includes firewood, cattle dung and agricultural wastes, which are traditionally gathered rather than bought. Such fuels are often ignored in national energy statistics, which understates rural energy use.

The trap in the wrong options is that each mixes a traded fuel, such as kerosene, LPG or piped gas, with traditional fuels; one traded item makes the whole group commercial.

Why the other options are wrong: (a) Piped natural gas is a commercial fuel sold through a market. (c) All three are traded commercial forms of energy. (d) Kerosene is traded and counted as commercial even when it is subsidised.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

4. The guidebook groups strategies for meeting future energy needs into 'reducing energy requirements' and 'substituting imported oil and gas with domestic alternatives'. Which measure belongs to the SUBSTITUTION group?

[3P1CEM004 | Chapter 1: Energy Scenario | Energy security strategies - substitution of imported fuels]

- a) Supercritical pulverised-coal boilers in new thermal power plants
- b) Metro rail and other mass transit systems in large cities
- c) Biomass gasification for process heat in place of natural gas
- d) Better recovery efficiency when extracting oil, gas and coal

Correct answer: (c) Biomass gasification for process heat in place of natural gas.

As per the guidebook, energy security means continuous availability of energy in varied forms, in sufficient quantity, at reasonable prices. India imports most of its oil, so strategies fall into two groups.

Reducing energy requirements: efficient extraction of fossil fuels, supercritical coal-fired plants, energy efficiency and demand side management, mass transport, and solar and wind development.

Substituting imported oil and gas: ethanol and biodiesel for petrol and diesel, biomass gasification for heat or power instead of gas or coal, and coal-to-oil technology.

Biomass gasification replaces imported gas with a domestic fuel, so it is a substitution measure.

Why the other options are wrong: (a) Raises plant efficiency, so it reduces the energy requirement. (b) Cuts fuel use per passenger, so it reduces energy requirement. (d) Improves extraction efficiency, which the guidebook lists under reducing requirements.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

5. A PAT designated consumer's gate-to-gate data for its three baseline years are given in the table. Its baseline SEC is the production-weighted value over the three years, and the notified target is a 5% reduction on that baseline.

What is the target SEC?

[3P1CEM005 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | PAT scheme - baseline and target SEC from three baseline years]

Baseline year	Energy (toe)	Production (t)
Year 1	1,80,000	4,00,000
Year 2	1,71,000	4,50,000
Year 3	2,08,000	6,50,000

a) 0.3540 toe/t

b) 0.3642 toe/t

c) 0.3227 toe/t

d) 0.3040 toe/t

Correct answer: (a) 0.3540 toe/t.

Given: energy = 1,80,000, 1,71,000 and 2,08,000 toe ($\approx 8,709$ TJ); production = 4,00,000, 4,50,000 and 6,50,000 t; reduction = 5%.

Formula: Baseline SEC = $\Sigma \text{ energy} \div \Sigma \text{ production}$; target SEC = baseline $\times (1 - 0.05)$.

Substitution: $\Sigma \text{ energy} = 5,59,000$ toe; $\Sigma \text{ production} = 15,00,000$ t; baseline = $5,59,000 \div 15,00,000 = 0.3727$ toe/t; target = 0.3727×0.95 .

Result: **target SEC = 0.3540 toe/t (≈ 14.8 GJ/t).** The yearly SECs (0.4500, 0.3800, 0.3200) average 0.3833, which over-weights the low-output first year; weighting by production avoids that bias.

Why the other options are wrong: (b) 0.3642 toe/t – applies 5% to the simple average of the three yearly SECs, ignoring production weights. (c) 0.3227 toe/t – subtracts 0.05 toe/t instead of reducing the baseline by 5%. (d) 0.3040 toe/t – uses only the latest year's SEC as the baseline.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

6. Under BEE's regulations for accredited energy auditors, which combination makes an energy auditor eligible for accreditation?

[3P1CEM006 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Qualification of an accredited energy auditor]

a) Graduate engineer, passed Paper 4 only, with five years' experience in any plant operation

b) Certified energy auditor with ten years' experience, accredited by the State Designated Agency

c) Certified energy manager, passed Paper 4, five years' audit experience, three in energy-intensive industry

d) Certified energy manager with three years' audit experience, of which two in any industry

Correct answer: (c) Certified energy manager, passed Paper 4, five years' audit experience, three in energy-intensive industry.

As per the guidebook (BEE Qualifications for Accredited Energy Auditors and Maintenance of their List Regulations), an energy auditor qualifies as an accredited energy auditor if he or she:

(a) is a certified energy manager and has passed the examination in 'Energy Performance Assessment for Equipment and Utility Systems' (Paper 4) conducted by the Bureau;

(b) has five years' experience in energy audit, of which at least three years are in energy-intensive industries; and

(c) has been granted a certificate of accreditation by the Bureau of Energy Efficiency.

Why the other options are wrong: (a) The candidate must first be a certified energy manager, and the experience must be in energy audit. (b) Accreditation is granted by BEE, not by the State Designated Agency. (d) The regulation requires five years, with three in energy-intensive industries, plus Paper 4.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

7. To be empanelled by BEE for verification and check-verification under the PAT scheme, an accredited energy auditor's firm must meet several criteria. Which of the following is NOT one of them?

[3P1CEM007 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | PAT - empanelment of verification firms]

- a) At least five accredited energy auditors on the firm's own rolls
- b) At least three energy auditors as defined in the regulations
- c) At least one accredited energy auditor listed by the Bureau
- d) Turnover of ₹10 lakh a year in one of last three years

Correct answer: (a) At least five accredited energy auditors on the firm's own rolls.

The guidebook lists the empanelment criteria for an accredited energy auditor firm doing verification and check-verification under PAT. The firm (a) has at least one accredited energy auditor whose name is in the list maintained by BEE; (b) has at least three energy auditors; (c) has adequate expertise in field studies, data collection, probing skills and analysis; and (d) has a minimum turnover of ₹10 lakh a year in at least one of the previous three years, or a net worth of ₹10 lakh for a newly formed organisation.

Why the other options are wrong: (b) This option is a stated criterion for the firm's field team. (c) This option is a stated criterion; one listed accredited auditor is required. (d) This option is a stated criterion; a new firm may show ₹10 lakh net worth instead.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

8. Section 18 of the EC Act, 2001 empowers the Central or State Government to issue written directions to any person, officer, authority or designated consumer. The Act states that this power expressly includes the power to direct which of the following?

[3P1CEM008 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Section 18 - power to issue directions]

- a) Approval of carbon credit prices for registered CDM projects
- b) Regulation of energy consumption standards for equipment and appliances
- c) Grant of distribution licences to electricity supply companies
- d) Fixing of retail electricity tariffs payable by designated consumers

Correct answer: (b) Regulation of energy consumption standards for equipment and appliances.

Section 18 reads: the Central Government or the State Government may, for efficient use of energy and its conservation, issue such directions in writing as it deems fit to any person, officer, authority or designated consumer, who shall be bound to comply.

The explanation declares that the power includes the power to direct (a) regulation of norms for process and energy consumption standards in any industry, building or building complex; and (b) regulation of the energy consumption standards for equipment and appliances.

Tariff fixing and licensing are functions under the Electricity Act, 2003, and carbon prices are not regulated by the EC Act.

Why the other options are wrong: (a) Credit prices are set by markets and are outside the EC Act. (c) Licensing falls under the Electricity Act 2003, not Section 18. (d) Tariffs are set by electricity regulatory commissions under the Electricity Act.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

9. BEE's programme for small and medium enterprises (for example the Surat textile and Warangal rice-milling clusters) relies mainly on which approach to accelerate energy efficiency?

[3P1CEM009 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | BEE programme for SME clusters]

- a) Notifying each cluster as a group of designated consumers
- b) Capital subsidy on each machine linked to installed capacity

c) Cluster-level capacity building with collateral funding through lead banks

d) Mandatory energy audits of every unit by accredited auditors

Correct answer: (c) Cluster-level capacity building with collateral funding through lead banks.

The guidebook explains that energy efficiency in SMEs matters because of high energy costs and supply concerns. BEE's SME programme aims to accelerate the adoption of energy-efficient technologies and practices in chosen clusters through knowledge sharing, capacity building of local service and technology providers, diagnostic studies, pilot projects at cluster level and innovative financing.

The programme is described as entirely market driven: after local capacity is built, implementation of energy efficiency measures is facilitated through collateral funding by lead banks. Examples of clusters are Ahmedabad (chemicals), Surat (textiles) and Warangal (rice milling). It is not a regulatory or subsidy scheme.

Why the other options are wrong: (a) SME clusters are not notified as designated consumers under the Act. (b) The programme is market driven and not a capacity-linked capital subsidy. (d) Mandatory audits apply to notified designated consumers, not to SME units.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

10. The Integrated Energy Policy (Expert Committee report) recommended a change in the way renewable energy incentives are given. What was the recommended basis?

[3P1CEM010 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Integrated Energy Policy - incentives for renewable energy]

a) Incentives linked to energy actually generated, as tradable tax rebate certificates

b) One uniform national feed-in tariff paid for every renewable technology

c) Accelerated depreciation allowed on all the renewable capacity commissioned each year

d) Capital subsidy paid upfront in proportion to the installed capacity

Correct answer: (a) Incentives linked to energy actually generated, as tradable tax rebate certificates.

The guidebook's summary of the Integrated Energy Policy notes that renewable energy will play a key part in energy security because of its distributed and environment-friendly nature.

To promote renewables, incentives or capital subsidy should be linked to actual energy generated and not to capacity installed. A subsidy in the form of a Tradable Tax Rebate Certificate (TTRC), based on electricity actually supplied and certified, was proposed. It also suggested mandatory feed-in laws or differential tariffs so that utilities integrate wind, small hydro and cogeneration, and a Renewable Portfolio Standard.

Linking incentives to generation rewards well-run plants rather than plants that are merely installed.

Why the other options are wrong: (b) The policy proposed differential tariffs and feed-in laws, not one uniform tariff. (c) This option is also capacity-linked and does not reward actual generation. (d) This is the capacity-based approach that the policy wanted to move away from.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

11. A boiler generates steam at a pressure where the saturation temperature is 184 °C and the enthalpy of dry saturated steam is 665 kcal/kg. The steam is superheated to 260 °C (mean specific heat of superheated steam 0.52 kcal/kg °C). Feed water enters at 85 °C. How much heat is added per kg of steam?

[3P1CEM011 | Chapter 3: Basics of Energy and its Various Forms | Heat to generate superheated steam from feed water]

a) 704.5 kcal/kg

b) 619.5 kcal/kg

c) 580.0 kcal/kg

d) 656.0 kcal/kg

Correct answer: (b) 619.5 kcal/kg.

Given: $h_g = 665 \text{ kcal/kg}$ ($\approx 2,784 \text{ kJ/kg}$) at $t_{\text{sat}} = 184 \text{ °C}$; superheat to 260 °C ; $C_p(\text{steam}) = 0.52 \text{ kcal/kg °C}$ ($\approx 2.18 \text{ kJ/kg·K}$); feed water 85 °C (enthalpy $\approx 85 \text{ kcal/kg}$ ($\approx 356 \text{ kJ/kg}$)).

Formula: $h_{\text{sup}} = h_g + C_p \times (t_{\text{sup}} - t_{\text{sat}})$; heat added = $h_{\text{sup}} - h_{\text{fw}}$.

Substitution: $h_{\text{sup}} = 665 + 0.52 \times (260 - 184) = 665 + 39.5 = 704.5 \text{ kcal/kg}$; heat added = $704.5 - 85$.

Result: **619.5 kcal/kg ($\approx 2,594$ kJ/kg)**. Superheated steam has a much lower specific heat than water, so a large temperature rise adds relatively little enthalpy.

Why the other options are wrong: (a) 704.5 kcal/kg – ignores the sensible heat already in the feed water at 85 °C. (c) 580.0 kcal/kg – omits the superheat added above the saturation temperature. (d) 656.0 kcal/kg – uses the specific heat of water (1 kcal/kg °C) for superheated steam.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

12. A steam header pressure gauge reads 10.5 kg/cm²(g) on a day when the barometer reads 1.033 kg/cm². What is the absolute header pressure in bar?

[3P1CEM012 | Chapter 3: Basics of Energy and its Various Forms | Gauge and absolute pressure in SI units]

- a) 9.28 bar(a)
- b) 11.31 bar(a)
- c) 11.53 bar(a)
- d) 10.30 bar(a)

Correct answer: (b) 11.31 bar(a).

Given: gauge = 10.5 kg/cm²(g) (≈ 10.3 bar(g)); atmospheric = 1.033 kg/cm² (≈ 1.01 bar); 1 kg/cm² = 0.980665 bar.

Formula: Absolute pressure = gauge pressure + atmospheric pressure; then convert to bar.

Substitution: 10.5 + 1.033 = 11.533 kg/cm²(a); 11.533 $\times$ 0.980665 = 11.310 bar.

Result: **11.31 bar(a)**. Steam tables are entered with absolute pressure, so using the gauge value directly would understate the saturation temperature and enthalpy. The 2% difference between kg/cm² and bar is small but matters in exam options and in instrument calibration.

Why the other options are wrong: (a) 9.28 bar(a) – subtracts atmospheric pressure instead of adding it. (c) 11.53 bar(a) – adds correctly but treats 1 kg/cm² as exactly 1 bar. (d) 10.30 bar(a) – converts the gauge reading but forgets to add atmospheric pressure.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

13. A plant preheats 12,000 kg/day of furnace oil from 35 °C to 105 °C with electric heaters of 90% efficiency. The specific heat of the oil is 0.5 kcal/kg °C. What is the daily electricity use of the heaters?

[3P1CEM013 | Chapter 3: Basics of Energy and its Various Forms | Sensible heat for preheating furnace oil]

- a) 1085.3 kWh/day
- b) 488.4 kWh/day
- c) 439.5 kWh/day
- d) 542.6 kWh/day

Correct answer: (d) 542.6 kWh/day.

Given: m = 12,000 kg/day; Cp = 0.5 kcal/kg °C (≈ 2.09 kJ/kg·K); $\Delta T = 105 - 35 = 70$ °C; $\eta = 0.9$; 1 kWh = 860 kcal ($\approx 3,601$ kJ).

Formula: $Q = m \times C_p \times \Delta T$; electricity = $Q \div (860 \times \eta)$.

Substitution: $Q = 12,000 \times 0.5 \times 70 = 4,20,000$ kcal/day; electricity = $4,20,000 \div (860 \times 0.9)$.

Result: **542.6 kWh/day**. Furnace oil is heated to reduce its viscosity for proper atomisation at the burner; overheating wastes energy and can cause carbon deposits, so the set temperature should match the viscosity required.

Why the other options are wrong: (a) 1085.3 kWh/day – uses the specific heat of water instead of 0.5 kcal/kg °C for oil. (b) 488.4 kWh/day – ignores the heater efficiency altogether. (c) 439.5 kWh/day – multiplies by the heater efficiency instead of dividing by it.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

14. An 11 kV incomer energy meter (rated 110 V, 5 A) is fed through a CT of 300/5 A and a PT of 11,000/110 V. Its kWh register reads 4,512.36 at the start of the month and 4,583.61 at the end. What is the energy consumed in the month?

[3P1CEM014 | Chapter 3: Basics of Energy and its Various Forms | Energy meter multiplying factor with CT and PT]

- a) 4,275 kWh
- b) 21,37,500 kWh
- c) 7,125 kWh
- d) 4,27,500 kWh

Correct answer: (d) 4,27,500 kWh.

Given: reading difference = $4,583.61 - 4,512.36 = 71.25$; CT ratio = $300/5 = 60$; PT ratio = $11,000/110 = 100$; meter rated at the CT and PT secondary values.

Formula: Multiplying factor (MF) = CT ratio $\times$ PT ratio; kWh = (final – initial reading) $\times$ MF.

Substitution: MF = $60 \times 100 = 6,000$; kWh = $71.25 \times 6,000$.

Result: **4,27,500 kWh** in the month. Auditors must always check the MF on the meter or panel; a wrong MF makes every specific energy figure in the audit wrong by the same factor.

Why the other options are wrong: (a) 4,275 kWh – applies the CT ratio but forgets the PT ratio. (b) 21,37,500 kWh – takes the CT ratio as 300 instead of $300/5 = 60$. (c) 7,125 kWh – applies the PT ratio but forgets the CT ratio.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

15. A torque transducer on a fan shaft reads 1,150 N·m at 1,480 rpm. What shaft power is being transmitted?

[3P1CEM015 | Chapter 3: Basics of Energy and its Various Forms | Shaft power from torque and speed]

- a) 178.2 kW
- b) 28.4 kW
- c) 89.1 kW
- d) 238.9 kW

Correct answer: (a) 178.2 kW.

Given: T = 1,150 N·m; N = 1,480 rpm.

Formula: $P = T \times \omega$, where $\omega = 2\pi N \div 60$ rad/s; P (kW) = $2\pi NT \div 60,000$.

Substitution: $\omega = 2\pi \times 1,480 \div 60 = 154.99$ rad/s; P = $1,150 \times 154.99 = 1,78,233$ W.

Result: **P = 178.2 kW**. Mechanical power is work per unit time; torque in N·m times angular speed in rad/s gives watts directly. Comparing shaft power with electrical input gives the motor efficiency during an audit.

Why the other options are wrong: (b) 28.4 kW – forgets to convert revolutions to radians. (c) 89.1 kW – uses π instead of 2π when converting rpm to rad/s. (d) 238.9 kW – is the power in horsepower but labelled as kW.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

16. Energy exists in two broad categories, potential (stored) and kinetic (working). Which classification is correct?

[3P1CEM016 | Chapter 3: Basics of Energy and its Various Forms | Forms of energy - potential and kinetic]

- a) Thermal energy is potential because it can be stored in hot water
- b) Electrical energy is potential because batteries store electricity
- c) Chemical, nuclear, gravitational and stored mechanical energy are potential forms
- d) Motion energy of water in a canal is potential because water flows

Correct answer: (c) Chemical, nuclear, gravitational and stored mechanical energy are potential forms.

The guidebook classifies energy as potential (stored) or kinetic (working).

Potential energy forms: chemical energy stored in the bonds of fuels and biomass; nuclear energy in the nucleus of atoms; stored mechanical energy, such as a compressed spring; and gravitational energy, such as water held behind a dam.

Kinetic energy forms: electrical energy (movement of electrons), radiant energy (electromagnetic waves, light), thermal energy (vibration and movement of molecules), motion energy (moving objects and substances) and sound.

A battery or a dam stores potential energy that becomes kinetic energy when it is used, which is why the trap options are wrong.

Why the other options are wrong: (a) Thermal energy is the motion of molecules, a kinetic form. (b) Electrical energy is the movement of charge; a battery stores chemical energy. (d) Moving water has kinetic energy; only water held at a height is potential.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

17. A clinker grinding unit of 1,00,000 t/month capacity draws a fixed 1,200 MWh a month (auxiliaries, lighting, compressors, idle running) plus 32 kWh per tonne ground. Last month it ran at 55% capacity utilisation and this month at 85%, with no change in equipment. By how much has its specific electricity consumption fallen?

[3P1CEM017 | Chapter 4: Energy Management and Audit | Benchmarking - effect of capacity utilisation on SEC]

- a) 14.3%
- b) 16.7%
- c) 35.3%
- d) 30.0%

Correct answer: (a) 14.3%.

Given: fixed energy $E_f = 12,00,000$ kWh/month; variable = 32 kWh/t; capacity = 1,00,000 t/month; utilisation 55% and 85%.

Formula: $SEC = (E_f + v \times P) \div P = E_f \div P + v$; fall = $(SEC_1 - SEC_2) \div SEC_1 \times 100$.

Substitution: $P_1 = 55,000$ t, $SEC_1 = 12,00,000 \div 55,000 + 32 = 53.82$ kWh/t; $P_2 = 85,000$ t, $SEC_2 = 46.12$ kWh/t.

Result: **SEC falls by 14.3%** with no efficiency improvement at all. The guidebook lists capacity utilisation among the factors to normalise before benchmarking, so this gain must not be claimed as an energy saving.

Why the other options are wrong: (b) 16.7% – divides the SEC drop by the new SEC instead of the old one. (c) 35.3% – applies the change to the fixed part only and ignores the 32 kWh/t. (d) 30.0% – takes the 30-point rise in utilisation as the fall in SEC.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

18. A pumping system delivers 55 kW of hydraulic power. The pump efficiency is 72%, the belt drive 96%, the motor 92% and the VFD 97%. What electrical input does the system draw?

[3P1CEM018 | Chapter 4: Energy Management and Audit | System efficiency of a drive chain]

- a) 83.0 kW
- b) 89.2 kW
- c) 61.6 kW
- d) 76.4 kW

Correct answer: (b) 89.2 kW.

Given: $P_{hyd} = 55$ kW; $\eta_{pump} = 0.72$; $\eta_{belt} = 0.96$; $\eta_{motor} = 0.92$; $\eta_{VFD} = 0.97$.

Formula: Overall $\eta = \eta_{pump} \times \eta_{belt} \times \eta_{motor} \times \eta_{VFD}$; $P_{in} = P_{hyd} \div \text{overall } \eta$.

Substitution: overall $\eta = 0.72 \times 0.96 \times 0.92 \times 0.97 = 0.6168$; $P_{in} = 55 \div 0.6168$.

Result: **$P_{in} = 89.2$ kW** (overall efficiency 61.7%). This illustrates the audit strategy of maximising system efficiency: every element in series multiplies its loss, so a small gain in the weakest element can save more than replacing an already efficient motor.

Why the other options are wrong: (a) 83.0 kW – ignores the belt drive and VFD losses in the chain. (c) 61.6 kW – averages the four efficiencies instead of multiplying them. (d) 76.4 kW – gives only the pump shaft input, not the electrical input.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

19. During a surface-loss survey an auditor's infrared thermometer, left at its default emissivity setting of 0.95, reads 150 °C on an oxidised steel duct whose actual emissivity is 0.8. Ignoring reflected background radiation, what is the true surface temperature?

[3P1CEM019 | Chapter 4: Energy Management and Audit | Audit instruments - emissivity setting of an infrared thermometer]

- a) 178.1 °C
- b) 168.6 °C
- c) 132.2 °C
- d) 156.6 °C

Correct answer: (b) 168.6 °C.

Given: indicated $T = 150\text{ °C} = 423.15\text{ K}$ at $\epsilon_{\text{set}} = 0.95$; actual $\epsilon = 0.8$.

Formula: the instrument sees the same radiant power, so $\epsilon_{\text{set}} \times T_{\text{ind}}^4 = \epsilon_{\text{act}} \times T_{\text{true}}^4$, i.e. $T_{\text{true}} = T_{\text{ind}} \times \text{fourth root of } (\epsilon_{\text{set}} \div \epsilon_{\text{act}})$, in kelvin.

Substitution: ratio = $0.95 \div 0.8 = 1.1875$; fourth root = 1.0439; $T_{\text{true}} = 423.15 \times 1.0439 = 441.73\text{ K}$.

Result: **true surface temperature = 168.6 °C**. Because a lower emissivity surface emits less, an instrument set too high reads low, and surface losses are then underestimated. Infrared thermometers are among the portable audit instruments listed in the guidebook.

Why the other options are wrong: (a) 178.1 °C – scales the reading linearly by the emissivity ratio. (c) 132.2 °C – inverts the emissivity ratio, so the correction goes the wrong way. (d) 156.6 °C – applies the fourth-root correction to degrees Celsius, not kelvin.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

20. An audit recommends three measures for a boiler house whose fuel bill is ₹360 lakh a year: an economiser cutting fuel use by 8%, insulation and condensate recovery cutting steam demand by 12%, and O₂ trim cutting fuel by 5%. Each figure was estimated on the existing plant. What is the realistic combined annual saving?

[3P1CEM020 | Chapter 4: Energy Management and Audit | Interaction of energy conservation measures]

- a) ₹ 43.2 lakh
- b) ₹ 68.5 lakh
- c) ₹ 83.1 lakh
- d) ₹ 90.0 lakh

Correct answer: (c) ₹ 83.1 lakh.

Given: savings of 8%, 12% and 5%, each on the existing fuel use; bill = ₹360 lakh/yr.

Formula: Each later measure acts on the energy left after the earlier ones: combined saving = $1 - (1 - s_1)(1 - s_2)(1 - s_3)$.

Substitution: $1 - (0.92 \times 0.88 \times 0.95) = 1 - 0.7691 = 0.2309$; saving = $0.2309 \times ₹360\text{ lakh}$.

Result: **₹ 83.1 lakh a year (23.09%)**. Simple addition gives 25% and overstates savings; audit reports must account for interaction so that the client's expectations and payback figures are realistic.

Why the other options are wrong: (a) ₹ 43.2 lakh – takes only the single largest measure as the total saving. (b) ₹ 68.5 lakh – combines only the two largest measures and leaves out O₂ trim. (d) ₹ 90.0 lakh – adds the percentages, double-counting the interaction between measures.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

21. The guidebook justifies energy audit by noting that, in any industry, energy is one of the top three operating expenses. Which are the three expenses named?

[3P1CEM021 | Chapter 4: Energy Management and Audit | Need for energy audit - top operating expenses]

- a) Energy, labour and materials
- b) Energy, depreciation and interest
- c) Energy, transport and marketing
- d) Energy, maintenance and taxes

Correct answer: (a) Energy, labour and materials.

The guidebook states that in any industry the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. Of these, energy is the one with the highest potential for cost reduction through management, which makes energy management a strategic area.

An energy audit helps to understand how energy is used, identify where waste occurs and where scope exists for improvement, and gives a positive orientation to energy cost reduction, preventive maintenance and quality control. It is therefore the key to a systematic approach to decision making in energy management.

Why the other options are wrong: (b) Energy, depreciation and interest – depreciation and interest are capital-related charges, not the three named. (c) Energy, transport and marketing – transport and marketing costs are not the expenses

the guidebook names. (d) Energy, maintenance and taxes – maintenance and taxes are not among the three expenses named.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

22. In BEE's suggested format for a detailed energy audit report, the table 'energy audit options at a glance', listing each measure with its saving, investment and payback, is placed in which part of the report?

[3P1CEM022 | Chapter 4: Energy Management and Audit | Energy audit reporting format]

- a) The description of the production process
- b) The annexures of measured field data
- c) The energy and utility system description
- d) The executive summary with recommendations

Correct answer: (d) The executive summary with recommendations.

The guidebook's energy audit reporting format runs: acknowledgement; executive summary (energy audit options at a glance and recommendations); introduction about the plant; production process description; energy and utility system description; detailed process flow diagram with energy and material balance; energy efficiency in utility and process systems; energy conservation options and recommendations; and annexures.

The 'options at a glance' table sits in the executive summary because top management reads that first and decides on investment from it. Measures are usually grouped as no or low cost, medium investment and high investment, with savings and payback for each.

Why the other options are wrong: (a) This section describes the process flow, not the savings summary. (b) Annexures carry instrument data and calculations, not the summary table. (c) This section describes existing systems, not the recommended measures.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

23. A column separates 2,000 kg/h of a methanol-water feed with 40% methanol (by mass) into a distillate with 95% methanol and a bottoms stream with 3% methanol. What is the distillate flow at steady state?

[3P1CEM023 | Chapter 5: Material and Energy Balance | Component balance on a distillation column]

- a) 842.1 kg/h
- b) 778.9 kg/h
- c) 1195.7 kg/h
- d) 804.3 kg/h

Correct answer: (d) 804.3 kg/h.

Given: $F = 2,000 \text{ kg/h}$; $x_F = 0.4$; $x_D = 0.95$; $x_B = 0.03$.

Formula: Total balance $F = D + B$; methanol balance $F \cdot x_F = D \cdot x_D + B \cdot x_B$; solving, $D = F(x_F - x_B) \div (x_D - x_B)$.

Substitution: $D = 2,000 \times (0.4 - 0.03) \div (0.95 - 0.03) = 2,000 \times 0.37 \div 0.92$.

Result: **$D = 804.3 \text{ kg/h}$** and $B = 1195.7 \text{ kg/h}$. Check: methanol in = 800 kg/h; out = $764.1 + 35.9 = 800.0 \text{ kg/h}$. Two independent balances are needed for two unknown streams.

Why the other options are wrong: (a) 842.1 kg/h – assumes no methanol leaves in the bottoms stream. (b) 778.9 kg/h – drops the bottoms composition from the denominator of the balance. (c) 1195.7 kg/h – is the bottoms flow, not the distillate flow.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

24. An induction furnace melts cast iron charged at 30 °C and taps it at 1,450 °C. The mean specific heat over the range is 0.17 kcal/kg °C and the latent heat of fusion 65 kcal/kg. The furnace uses 620 kWh per tonne of liquid metal. What is its thermal efficiency?

[3P1CEM024 | Chapter 5: Material and Energy Balance | Energy balance of an induction melting furnace]

- a) 42.5%
- b) 45.3%

c) 57.5%

d) 49.4%

Correct answer: (c) 57.5%.

Given: $\Delta T = 1,450 - 30 = 1420\text{ }^{\circ}\text{C}$; $C_p = 0.17\text{ kcal/kg }^{\circ}\text{C}$ ($\approx 0.712\text{ kJ/kg}\cdot\text{K}$); latent heat = 65 kcal/kg ($\approx 272\text{ kJ/kg}$); input = 620 kWh/t .

Formula: Theoretical heat per tonne = $1,000 \times (C_p \times \Delta T + L)$; $\eta = \text{theoretical kWh} \div \text{actual kWh} \times 100$.

Substitution: $1,000 \times (0.17 \times 1420 + 65) = 3,06,400\text{ kcal/t}$; $\div 860 = 356.3\text{ kWh/t}$; $\eta = 356.3 \div 620 \times 100$.

Result: **$\eta = 57.5\%$** . The other 42.5% is lost to coil cooling water, refractory, radiation from the open bath and idle holding, which a heat balance would apportion to target savings.

Why the other options are wrong: (a) 42.5% – is the share of losses, not the useful heat share. (b) 45.3% – leaves out the latent heat of fusion. (d) 49.4% – takes 1 kWh as 1,000 kcal instead of 860 kcal.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

25. A 250 kW (output) motor runs at 95% efficiency in a closed room. All its losses appear as heat that must be removed by ventilation air allowed to rise $15\text{ }^{\circ}\text{C}$ ($C_p\ 1.005\text{ kJ/kg}\cdot\text{K}$, density 1.15 kg/m^3). What air flow is needed?

[3P1CEM025 | Chapter 5: Material and Energy Balance | Energy balance - cooling air for motor losses]

a) $2,596\text{ m}^3/\text{h}$

b) $2,732\text{ m}^3/\text{h}$

c) $3,142\text{ m}^3/\text{h}$

d) $656\text{ m}^3/\text{h}$

Correct answer: (b) $2,732\text{ m}^3/\text{h}$.

Given: output = 250 kW ; $\eta = 0.95$; $\Delta T = 15\text{ K}$; $C_p = 1.005\text{ kJ/kg}\cdot\text{K}$; $\rho = 1.15\text{ kg/m}^3$.

Formula: Losses = output $\div \eta$ – output; mass of air = losses $\div (C_p \times \Delta T)$; volume = mass $\div \rho$.

Substitution: losses = $250 \div 0.95 - 250 = 13.16\text{ kW}$; $\dot{m} = 13.16 \div (1.005 \times 15) = 0.8728\text{ kg/s}$; $V = 0.8728 \div 1.15 \times 3,600$.

Result: **$\approx 2,732\text{ m}^3/\text{h}$** of air. Energy balance says input = output + losses; the loss is 5% of input, which is more than 5% of output.

Why the other options are wrong: (a) $2,596\text{ m}^3/\text{h}$ – takes losses as 5% of output instead of input minus output. (c) $3,142\text{ m}^3/\text{h}$ – treats the mass flow in kg as volume in m^3 , ignoring density. (d) $656\text{ m}^3/\text{h}$ – uses the specific heat of water instead of air.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

26. A dryer recirculates part of its exhaust air back to the inlet to save heat. When an overall material balance is drawn around the whole dryer system at steady state, which statement is correct?

[3P1CEM026 | Chapter 5: Material and Energy Balance | Recycle and bypass streams in a material balance]

a) The recycle stream is internal and does not appear in the overall balance

b) The recycle stream must be added as an extra input in the overall balance

c) A bypass is a stream returned from the outlet back to the unit's inlet

d) Recycling changes fresh feed and product rates needed for the same output

Correct answer: (a) The recycle stream is internal and does not appear in the overall balance.

In material and energy balance, the system boundary decides what is counted. Inputs = outputs + accumulation, and at steady state accumulation is zero.

A recycle stream takes part of the outlet back to an earlier point; when the boundary is drawn around the whole system, the recycle loop lies inside it and cancels out, so only fresh feed, fresh air, product and exhaust appear. Recycle balances are written around the mixing point or the unit itself to find the internal flows.

A bypass stream goes around a unit and rejoins the outlet without being processed.

Why the other options are wrong: (b) An internal stream crosses no boundary of the overall system. (c) That describes recycle; a bypass skips the unit and joins the outlet. (d) At steady state overall inputs and outputs are fixed by the product needed.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

27. A plant installs sub-meters on each production department and starts charging each department for the energy it uses. In energy action planning terms, what is the main purpose of this step?

[3P1CEM027 | Chapter 6: Energy Action Planning | Accountability through departmental cost centres]

- a) It allows the utility to bill each department at its own tariff
- b) It is a statutory duty of the energy manager under the Act
- c) It replaces the need for an energy audit by an accredited auditor
- d) It makes each department head accountable for the energy used

Correct answer: (d) It makes each department head accountable for the energy used.

Energy action planning stresses that energy must be managed like any other cost. Accountability is established by treating departments or major energy users as cost centres, metering their consumption and assigning responsibility for it to the line manager who controls the equipment.

Once each manager sees and pays for his own energy, energy becomes part of normal performance review rather than a remote overhead absorbed by the plant. The energy manager provides the data, analysis and support, but the people who run the equipment remain responsible for using it efficiently. This is why metering and an information system are basic elements of an energy management programme.

Why the other options are wrong: (a) The utility bills only the plant's main meter at one tariff. (b) The Act does not require departmental cost centres. (c) Sub-metering supports, but does not replace, the mandatory audit.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 6 – Energy Action Planning.

28. A cement company is drafting its corporate energy policy. Which item is LEAST appropriate to include in the policy statement itself?

[3P1CEM028 | Chapter 6: Energy Action Planning | Content of an energy policy statement]

- a) The assignment of overall accountability for energy management to a director
- b) A commitment to continual improvement in the plant's energy performance
- c) A commitment to report energy performance to the board regularly
- d) The make and model of economiser to be purchased this year

Correct answer: (d) The make and model of economiser to be purchased this year.

An energy policy is a short, formal statement of top management's commitment. It provides the foundation for setting performance goals and integrating energy management into the organisation's culture.

Typical contents are: a declaration of commitment to efficient use of energy and continual improvement; the objectives and broad targets; who is accountable and how the energy management function is organised; the resources to be provided; and how progress will be monitored, reported and reviewed.

Equipment selection, such as the make and model of an economiser, is a project-level decision taken in the action plan. Putting such detail in the policy would make it obsolete as soon as the project ends.

Why the other options are wrong: (a) Stating who is accountable is a standard policy element. (b) This option is a core commitment that belongs in an energy policy. (c) Regular reporting to top management is a typical policy commitment.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 6 – Energy Action Planning.

29. In an energy management information system, reports should match the needs of each level of the organisation. Which report best suits shift supervisors?

[3P1CEM029 | Chapter 6: Energy Action Planning | Energy information system - reporting levels]

- a) Daily or shift exception reports on their own process area
- b) Annual sustainability report with the plant's carbon footprint
- c) Monthly corporate summary of energy cost against the budget
- d) Quarterly board review of the energy policy and its targets

Correct answer: (a) Daily or shift exception reports on their own process area.

The guidebook's treatment of information systems in energy management stresses that data are useful only if they reach the right people in the right form and at the right time.

Operators and supervisors need frequent, detailed and quickly available information on the plant they control, preferably exception reports that flag deviations from targets in each shift or day, so they can act at once.

Middle managers need weekly or monthly departmental performance against targets, while senior management needs summarised monthly or quarterly cost and trend information. Sending everyone the same thick report is a common barrier to an effective information system.

Why the other options are wrong: (b) This option is for external stakeholders and top management, not shift control. (c) Suits senior management, who need trends and cost totals. (d) This option is a top-management review, too infrequent for operational control.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 6 – Energy Action Planning.

30. A heat pump saves ₹10 lakh in year 1, and the saving grows 6% every year with tariff escalation over an 8-year life. At a discount rate of 12%, what is the present value of the savings (end-of-year cash flows)?

[3P1CEM030 | Chapter 7: Financial Management | Present value of escalating energy savings]

a) ₹ 98.97 lakh

b) ₹ 62.10 lakh

c) ₹ 49.68 lakh

d) ₹ 59.38 lakh

Correct answer: (d) ₹ 59.38 lakh.

Given: $A_1 = ₹10$ lakh; $g = 0.06$; $r = 0.12$; $n = 8$ years.

Formula: $PV \text{ of a growing annuity} = A_1 \div (r - g) \times [1 - ((1 + g) \div (1 + r))^n]$.

Substitution: $(1.06 \div 1.12)^8 = 0.6437$; $PV = 10 \div 0.06 \times (1 - 0.6437) = 166.67 \times 0.3563$.

Result: **PV = ₹ 59.38 lakh.** Leaving out escalation would understate the value by ₹9.70 lakh, so energy price assumptions strongly affect appraisal.

Why the other options are wrong: (a) ₹ 98.97 lakh – adds the escalating savings without discounting them. (b) ₹ 62.10 lakh – discounts a flat saving at $r - g = 6\%$, an approximation that overstates the value. (c) ₹ 49.68 lakh – ignores the tariff escalation and discounts a flat ₹10 lakh a year.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

31. Pump A costs ₹4.5 lakh, lasts 6 years and uses energy worth ₹2.8 lakh a year. Pump B costs ₹7.2 lakh, lasts 10 years and uses ₹2.3 lakh of energy a year. At 10% discount rate and no salvage, which pump is cheaper and what is its equivalent annual cost?

[3P1CEM031 | Chapter 7: Financial Management | Equivalent annual cost of options with unequal lives]

a) Pump B, ₹ 3.47 lakh a year

b) Pump B, ₹ 3.02 lakh a year

c) Pump A, ₹ 3.83 lakh a year

d) Pump A, ₹ 3.55 lakh a year

Correct answer: (a) Pump B, ₹ 3.47 lakh a year.

Given: A: ₹4.5 lakh, 6 yr, ₹2.8 lakh/yr; B: ₹7.2 lakh, 10 yr, ₹2.3 lakh/yr; $i = 0.1$.

Formula: $CRF = i(1 + i)^n \div [(1 + i)^n - 1]$; $EAC = \text{capital} \times CRF + \text{annual energy cost}$.

Substitution: $CRF(10\%, 6) = 0.22961$; $EAC_A = 4.5 \times 0.22961 + 2.8 = ₹3.833$ lakh; $CRF(10\%, 10) = 0.16275$; $EAC_B = 7.2 \times 0.16275 + 2.3 = ₹3.472$ lakh.

Result: **Pump B, EAC ₹ 3.47 lakh/yr**, ₹0.36 lakh/yr less than A. EAC compares options with unequal lives fairly.

Why the other options are wrong: (b) Spreads capital straight-line and ignores interest on capital. (c) Picks the cheaper first cost, though its annual cost is higher. (d) This option uses straight-line capital and still selects the wrong pump.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

32. A bank offers an energy-efficiency loan at 11.4% a year, compounded monthly. What is the effective annual interest rate that should be compared with other offers?

[3P1CEM032 | Chapter 7: Financial Management | Effective annual interest rate]

- a) 11.40%
- b) 11.90%
- c) 10.84%
- d) 12.01%

Correct answer: (d) 12.01%.

Given: nominal rate $j = 11.4\%$ a year; $m = 12$ compounding periods.

Formula: Effective rate $= (1 + j/m)^m - 1$.

Substitution: monthly rate $= 0.114 \div 12 = 0.0095$; $(1 + 0.0095)^{12} = 1.12015$; minus 1 = 0.12015.

Result: **effective rate = 12.01%** a year. Discounted cash flow analysis needs the rate per period consistent with the cash flow timing; comparing loans on nominal rates with different compounding frequencies gives a false ranking.

Why the other options are wrong: (a) 11.40% – quotes the nominal rate, ignoring monthly compounding. (b) 11.90% – compounds quarterly instead of monthly. (c) 10.84% – converts in the reverse direction, treating 11.4% as the effective rate.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

33. A financed WHR project gives energy savings of ₹26 lakh a year, has O&M costs of ₹2 lakh a year and an annual loan instalment (principal plus interest) of ₹18.5 lakh. What is its debt service coverage ratio (DSCR)?

[3P1CEM033 | Chapter 7: Financial Management | Debt service coverage of a financed project]

- a) 1.30
- b) 0.30
- c) 1.41
- d) 0.77

Correct answer: (a) 1.30.

Given: savings = ₹26 lakh/yr; O&M = ₹2 lakh/yr; debt service = ₹18.5 lakh/yr.

Formula: $DSCR = \text{cash available for debt service} \div \text{debt service} = (\text{savings} - \text{O\&M}) \div (\text{principal} + \text{interest})$.

Substitution: $(26 - 2) \div 18.5 = 24 \div 18.5$.

Result: **DSCR = 1.30**. Lenders usually want a DSCR well above 1 (often 1.2 to 1.5) so that a shortfall in savings does not stop repayment. In debt-financed energy projects the savings stream is the security, so DSCR links the energy audit's saving estimate to the financing decision.

Why the other options are wrong: (b) 0.30 – divides the surplus after debt service by the instalment. (c) 1.41 – uses gross savings and ignores the O&M cost. (d) 0.77 – inverts the ratio, dividing debt service by net cash flow.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

34. A company funds energy projects 70% by debt at 10.5% interest (interest is tax-deductible; tax rate 25%) and 30% by equity on which shareholders expect 16%. What after-tax weighted average cost of capital should be used as the discount rate?

[3P1CEM034 | Chapter 7: Financial Management | Weighted average cost of capital as discount rate]

- a) 13.56%
- b) 10.31%
- c) 12.15%
- d) 13.25%

Correct answer: (b) 10.31%.

Given: debt weight 0.7, cost 10.5%; tax 25%; equity weight 0.3, cost 16%.

Formula: $WACC = w_d \times k_d \times (1 - t) + w_e \times k_e$.

Substitution: $0.7 \times 10.5 \times (1 - 0.25) + 0.3 \times 16 = 5.5125 + 4.80$.

Result: **WACC = 10.31%**. The discount rate in NPV reflects the cost of capital or the return the firm could earn elsewhere. Using too high a rate rejects good long-life energy projects; using too low a rate accepts weak ones.

Why the other options are wrong: (a) 13.56% – swaps the weights of debt and equity. (c) 12.15% – ignores the tax shield on interest payments. (d) 13.25% – takes a simple average of the two rates without weights.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

35. When two energy projects of different size and timing are ranked, IRR can give a different order from NPV. What is the underlying reason usually cited?

[3P1CEM035 | Chapter 7: Financial Management | Limitation of IRR when ranking projects]

- a) IRR always favours the project with the larger capital investment
- b) IRR cannot be calculated when savings change from year to year
- c) IRR assumes interim cash flows are reinvested at the IRR itself
- d) IRR ignores the time value of money just as simple payback does

Correct answer: (c) IRR assumes interim cash flows are reinvested at the IRR itself.

IRR is the discount rate at which NPV is zero. Both IRR and NPV are discounted cash flow methods and agree on accept or reject decisions for a single conventional project.

When ranking mutually exclusive projects of different scale or timing, IRR implicitly assumes that each interim cash flow is reinvested at that project's own IRR, while NPV assumes reinvestment at the firm's discount rate, which is more realistic. A small project with a high IRR may add less value than a larger project with a lower IRR.

IRR can also give multiple answers when cash flows change sign more than once. NPV is therefore preferred for ranking.

Why the other options are wrong: (a) IRR tends to favour smaller projects with high percentage returns. (b) IRR can be found for any conventional cash flow series. (d) IRR is a discounted cash flow method, so it accounts for timing.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

36. Last year a plant spent ₹12 lakh on a feasibility study for a waste heat recovery boiler. The project is now being appraised for investment. How should the ₹12 lakh be treated in the cash flows?

[3P1CEM036 | Chapter 7: Financial Management | Sunk cost in project appraisal]

- a) Added to the capital cost as part of the project investment
- b) Excluded, because it is sunk and unaffected by the decision
- c) Spread over the project life as an annual fixed cost item
- d) Deducted from the first year's savings as a project expense

Correct answer: (b) Excluded, because it is sunk and unaffected by the decision.

Project appraisal counts only incremental future cash flows that change with the decision: capital cost, energy savings, O&M, taxes and salvage. A sunk cost is money already spent that will not change whether the project goes ahead or not.

Including the ₹12 lakh study cost would make the project look worse and could lead to rejecting a profitable investment; the same logic means an earlier failed investment should not be used to justify throwing good money after bad.

The guidebook's financial analysis uses the investment still to be made and the savings expected after it. Opportunity costs, by contrast, must be included.

Why the other options are wrong: (a) The money is already spent and cannot be recovered by rejecting the project. (c)

Spreading a past cost still counts money that the decision cannot change. (d) Only future incremental cash flows caused by the decision should be counted.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

37. A chiller vendor is paid in full by the client at commissioning, and in addition guarantees the equipment's performance and provides service for a specified period. Under the guidebook's classification, which type of contract is this?

[3P1CEM037 | Chapter 8: Project Management | Types of energy project contracts]

- a) Extended financing terms by contractor

- b) Shared savings performance contract
- c) Guaranteed savings performance contract
- d) Extended technical guarantee or service

Correct answer: (d) Extended technical guarantee or service.

The guidebook lists types of contracts for energy efficiency projects:

Traditional contract: the client pays the contractor for equipment and services.

Extended technical guarantee or service: the contractor provides extended guarantees and/or service for the equipment for a specified period, while the client pays for the project.

Extended financing terms: the contractor extends the payment schedule to the client.

Guaranteed savings performance contract: the contractor guarantees the savings, and any shortfall is made good by the contractor.

Shared savings performance contract: the contractor finances the project and recovers its investment from an agreed share of the savings.

Why the other options are wrong: (a) Here the contractor spreads the payment; in the case the client paid in full. (b)

Shared savings performance contract – the contractor finances the project and is paid a share of savings. (c) Guaranteed savings performance contract – guarantees the energy savings in money, not just equipment service.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

38. For the energy retrofit activities in the table, when is the earliest start of commissioning activity E?

[3P1CEM038 | Chapter 8: Project Management | Forward pass - earliest start at a merge point]

Activity	Description	Duration (weeks)	Preceded by
A	Detailed survey	4	–
B	Procure VFDs	6	A
C	Design cabling	3	A
D	Lay cables	5	C
F	Install VFDs	3	B
E	Commissioning	2	D, F

- a) End of week 12
- b) End of week 15
- c) End of week 13
- d) End of week 21

Correct answer: (c) End of week 13.

Given: A 4 wk (start); B 6 wk after A; C 3 wk after A; D 5 wk after C; F 3 wk after B; E 2 wk after both D and F.

Formula: Forward pass: $EF = ES + \text{duration}$; at a merge, $ES = \text{the LARGEST EF of all preceding activities}$.

Substitution: $EF(A) = 4$; $EF(B) = 4 + 6 = 10$; $EF(F) = 10 + 3 = 13$; $EF(C) = 4 + 3 = 7$; $EF(D) = 7 + 5 = 12$; $ES(E) = \max(12, 13)$.

Result: **E can start at the end of week 13**, finishing at week 15.

Why the other options are wrong: (a) End of week 12 – takes the shorter of the two merging paths into E. (b) End of week 15 – is the earliest finish of E, not its earliest start. (d) End of week 21 – adds all the predecessor durations as if done one after another.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

39. Which of the following is an ERROR when drawing an activity-on-arrow network for an energy project?

[3P1CEM039 | Chapter 8: Project Management | Network construction rules]

- a) Several activity arrows merging into one common event
- b) An activity path that loops back to an earlier event
- c) Event numbers rising from the tail to the head of each arrow
- d) A dummy arrow used to keep two parallel activities distinct

Correct answer: (b) An activity path that loops back to an earlier event.

Network diagrams in CPM and PERT follow a few rules. Each activity is represented by one arrow between a unique pair of events. An event is reached only when all activities leading into it are complete. Time flows from left to right, and events are numbered so that the tail number is less than the head number (Fulkerson's rule).

Looping, where a chain of activities returns to an earlier event, is not allowed because an activity would then depend on its own completion and the forward pass would never end. Merging arrows and dummy activities are legitimate features. Why the other options are wrong: (a) Merging at an event is normal; the event waits for all of them. (c) Numbering tail lower than head is the recommended convention. (d) Dummies are a correct way to give each activity a unique pair of events.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

40. In the guidebook's sequence of project management steps for an energy project, in which step are detailed engineering, equipment specifications and tender documents prepared?

[3P1CEM040 | Chapter 8: Project Management | Steps in project management - technical design]

- a) The technical design step
- b) The project definition step
- c) The contracting step
- d) The performance monitoring step

Correct answer: (a) The technical design step.

The guidebook lists the steps in managing an energy project: project definition and scope; technical design; financing; contracting; implementation; and performance monitoring.

Technical design converts the approved idea into an engineering solution: detailed engineering, sizing, specifications, drawings, refined cost estimates and the tender documents. These outputs feed the financing decision and the contracting step, where bids are invited and contractors are selected.

Planning tools such as Gantt charts, CPM and PERT are then used to schedule implementation, and performance monitoring checks that the savings promised in the design are achieved.

Why the other options are wrong: (b) The project definition step – defines objectives, scope and team; detailed engineering comes later. (c) The contracting step – uses the tender documents already prepared to select contractors. (d) The performance monitoring step – compares actual with expected performance after implementation.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

41. A project monitoring report for a cogeneration retrofit gives the budget and completion of each work package (table). What is the overall weighted progress of the project?

[3P1CEM041 | Chapter 8: Project Management | Physical progress weighted by budget]

Work package	Budget (₹ lakh)	Completed
Civil works	18	100%
Equipment supply	52	60%
Erection	22	25%
Commissioning	8	0%

- a) 46.2%
- b) 25.0%
- c) 92.0%
- d) 54.7%

Correct answer: (d) 54.7%.

Given: civil ₹18 lakh at 100%; equipment ₹52 lakh at 60%; erection ₹22 lakh at 25%; commissioning ₹8 lakh at 0%; total ₹100 lakh.

Formula: Weighted progress = $\Sigma(\text{budget} \times \% \text{ complete}) \div \Sigma \text{ budget} \times 100$.

Substitution: $(18 \times 1.0 + 52 \times 0.60 + 22 \times 0.25 + 8 \times 0) \div 100 = (18 + 31.2 + 5.5 + 0) \div 100$.

Result: **54.7% complete**. A Gantt chart with weighted progress shows managers whether the project is on schedule; unweighted averages make a small finished task look as important as the main equipment package.

Why the other options are wrong: (a) 46.2% – takes a simple average of percentages, ignoring the budget weights. (b) 25.0% – counts only fully completed packages as a share of the four. (c) 92.0% – counts every package that has started as fully complete.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

42. A plant's moving annual total (MAT) of electricity use at the end of August 2026 is 52,40,000 kWh. September 2026 consumption is 4,62,000 kWh, against 4,18,000 kWh in September 2025. What is the MAT at the end of September 2026?

[3P1CEM042 | Chapter 9: Energy Monitoring and Targeting | Moving annual total of energy use]

- a) 52,84,000 kWh
- b) 55,44,000 kWh
- c) 51,96,000 kWh
- d) 57,02,000 kWh

Correct answer: (a) 52,84,000 kWh.

Given: MAT (Aug 2026) = 52,40,000 kWh; Sep 2026 = 4,62,000 kWh; Sep 2025 = 4,18,000 kWh.

Formula: $\text{MAT}(\text{new}) = \text{MAT}(\text{previous}) + \text{latest month} - \text{same month one year earlier}$.

Substitution: $52,40,000 + 4,62,000 - 4,18,000$.

Result: **MAT = 52,84,000 kWh**, a rise of 44,000 kWh. Because each MAT point always covers twelve months, seasonal effects cancel out and the trend becomes visible; a rising MAT is an early warning that a target is slipping, which a single month's figure could hide.

Why the other options are wrong: (b) 55,44,000 kWh – multiplies one month by twelve instead of rolling the total. (c) 51,96,000 kWh – reverses the signs, dropping the new month and adding the old one. (d) 57,02,000 kWh – adds the new month without dropping the same month of last year.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 9 – Energy Monitoring and Targeting.

43. A plant has three years of monthly energy-production data plotted as a scatter. Which basis for a target line is most defensible in monitoring and targeting practice?

[3P1CEM043 | Chapter 9: Energy Monitoring and Targeting | Basis for setting energy targets]

- a) The worst month's consumption, so that the target is always met
- b) The average fit through all points, kept unchanged as the target
- c) A line through the best performance the plant has actually achieved
- d) The sum of nameplate ratings of every installed piece of equipment

Correct answer: (c) A line through the best performance the plant has actually achieved.

Monitoring and targeting compares actual consumption with an expected value, and targets push that expected value down. A credible target must be both challenging and achievable.

A good basis is the best performance the plant has already demonstrated: a line drawn through the lower edge of the scatter, or the best-fit line lowered by the improvement that specific measures can deliver. Because these points were actually achieved with existing equipment, operators accept that the target is possible.

The average line is the standard for detecting deviations, not a target. Targets should then be reviewed as performance improves, so the cycle of monitoring, targeting and reporting continues.

Why the other options are wrong: (a) A target that is always met drives no improvement at all. (b) The average line describes past performance and builds in no improvement. (d) Nameplate ratings overstate actual demand and are not a performance target.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 9 – Energy Monitoring and Targeting.

44. A plant's monthly energy bill rose from ₹48.0 lakh to ₹56.4 lakh over a year. In the same period the all-in tariff per kWh rose 10% and production rose 4%. By how much did specific energy consumption (kWh per tonne) change?

[3P1CEM044 | Chapter 9: Energy Monitoring and Targeting | Separating price, volume and efficiency effects]

- a) +6.82%
- b) +2.71%
- c) +3.50%
- d) +17.50%

Correct answer: (b) +2.71%.

Given: bill ratio = $56.4 \div 48.0$; tariff ratio = 1.10; production ratio = 1.04.

Formula: kWh ratio = bill ratio $\div$ tariff ratio; SEC ratio = kWh ratio $\div$ production ratio.

Substitution: bill ratio = 1.1750; kWh ratio = $1.1750 \div 1.10 = 1.0682$; SEC ratio = $1.0682 \div 1.04 = 1.0271$.

Result: **SEC rose by 2.71%**, so efficiency really did worsen even after price and output are accounted for. Ratios must be divided, not percentages subtracted.

Why the other options are wrong: (a) +6.82% – is the change in kWh, not adjusted for higher production. (c) +3.50% – subtracts percentages instead of dividing the ratios. (d) +17.50% – is the change in the bill, which mixes price, output and efficiency.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 9 – Energy Monitoring and Targeting.

45. A coal-fired station burns 0.72 kg of coal per kWh sent out. The coal contains 38% carbon (as fired) and 98% of the carbon is oxidised. What is the CO₂ emission factor of the station?

[3P1CEM045 | Chapter 10: Energy Efficiency and Climate Change | CO₂ emission factor of a coal-fired station]

- a) 1.003 kg CO₂/kWh
- b) 0.983 kg CO₂/kWh
- c) 0.626 kg CO₂/kWh
- d) 0.268 kg CO₂/kWh

Correct answer: (b) 0.983 kg CO₂/kWh.

Given: coal = 0.72 kg/kWh; carbon = 0.38; oxidation = 0.98; C + O₂ → CO₂ (12 kg C gives 44 kg CO₂).

Formula: EF = coal per kWh $\times$ carbon fraction $\times$ oxidation fraction $\times$ 44/12.

Substitution: $0.72 \times 0.38 \times 0.98 = 0.2681$ kg C/kWh; $\times 44 \div 12 = 0.9831$.

Result: **EF = 0.983 kg CO₂/kWh** (≈ 0.983 t CO₂/MWh). Every kWh saved at the consumer end avoids more than this at the station, because of T&D losses. Such factors are used to work out baseline emissions for CDM-type energy efficiency projects.

Why the other options are wrong: (a) 1.003 kg CO₂/kWh – assumes all carbon is oxidised, ignoring unburnt carbon. (c) 0.626 kg CO₂/kWh – uses 28/12, the ratio for CO, instead of 44/12 for CO₂. (d) 0.268 kg CO₂/kWh – gives the carbon burnt and omits the 44/12 conversion.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 10 – Energy Efficiency and Climate Change.

46. Under the Kyoto Protocol, industrialised (Annex I) countries took binding emission targets while developing countries such as India did not. Which UNFCCC principle underlies this difference?

[3P1CEM046 | Chapter 10: Energy Efficiency and Climate Change | UNFCCC principle of differentiated responsibility]

- a) The polluter-pays principle applied equally
- b) The precautionary principle on uncertainty
- c) Common but differentiated responsibilities
- d) Additionality of project-based reductions

Correct answer: (c) Common but differentiated responsibilities.

The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992, asks parties to protect the climate system on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities.

Because industrialised countries are responsible for most historical greenhouse gas emissions and have greater capacity, the Kyoto Protocol (1997) set binding targets only for Annex I countries, an average cut of about 5% below 1990 levels in 2008-12. Developing countries took part through the Clean Development Mechanism, hosting projects that earn certified emission reductions. India's National Action Plan on Climate Change follows the same principle.

Why the other options are wrong: (a) Applied equally would give every country the same obligation. (b) Justifies acting despite scientific uncertainty, not differing obligations. (d) Additionality of project-based reductions – is a CDM project test, not the basis of country obligations.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 10 – Energy Efficiency and Climate Change.

47. An Indian company develops a CDM project. Which sequence of the CDM project cycle is correct?

[3P1CEM047 | Chapter 10: Energy Efficiency and Climate Change | CDM project cycle - sequence of steps]

- a) PDD, validation by DOE, verification, registration, monitoring, CER issuance
- b) PDD, registration, validation by DOE, monitoring, CER issuance, verification
- c) PDD, validation by DOE, registration, monitoring, verification, CER issuance
- d) Validation by DOE, PDD, registration, verification, monitoring, CER issuance

Correct answer: (c) PDD, validation by DOE, registration, monitoring, verification, CER issuance.

The CDM project cycle runs as follows. The project participant prepares the Project Design Document (PDD), with the baseline, additionality and monitoring plan. Host country approval is obtained from the Designated National Authority (in India, the National CDM Authority). A Designated Operational Entity (DOE) validates the PDD. The CDM Executive Board registers the project.

The participant then monitors emission reductions as per the plan. A DOE verifies the monitored reductions and certifies them, and the Executive Board issues Certified Emission Reductions (CERs). Verification and certification are normally done by a different DOE from the one that validated large projects.

Why the other options are wrong: (a) Verification checks monitored reductions, so it follows monitoring. (b) Validation must come before registration, and verification before issuance. (d) A project design document must exist before it can be validated.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 10 – Energy Efficiency and Climate Change.

48. An OTEC plant works between warm surface water at 28 °C and deep cold water at 6 °C. What is the maximum (Carnot) efficiency it could achieve?

[3P1CEM048 | Chapter 11: New and Renewable Energy Sources | Ocean thermal energy conversion - Carnot limit]

- a) 78.57%
- b) 21.43%
- c) 7.88%
- d) 7.31%

Correct answer: (d) 7.31%.

Given: $T_{\text{hot}} = 28 + 273.15 = 301.15 \text{ K}$; $T_{\text{cold}} = 6 + 273.15 = 279.15 \text{ K}$.

Formula: $\eta_{\text{Carnot}} = (T_{\text{hot}} - T_{\text{cold}}) \div T_{\text{hot}}$, with absolute temperatures.

Substitution: $(301.15 - 279.15) \div 301.15 = 22 \div 301.15$.

Result: $\eta = 7.31\%$. Real OTEC plants achieve only about 3%, because of pumping power and heat exchanger temperature differences. This is why OTEC needs a temperature difference of about 20 °C and huge water flows, and is suited only to tropical seas.

Why the other options are wrong: (a) 78.57% – uses temperatures in °C instead of kelvin. (b) 21.43% – divides the two Celsius temperatures, which has no physical meaning. (c) 7.88% – divides by the cold temperature instead of the hot one.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 11 – New and Renewable Energy Sources.

49. A 2.0 m² flat-plate collector receives 850 W/m² of solar radiation. Water flows through it at 40 kg/h and is heated from 32 °C to 46 °C; the ambient air is at 30 °C. Taking Cp of water as 4.187 kJ/kg·K, what is the collector efficiency?

[3P1CEM049 | Chapter 11: New and Renewable Energy Sources | Flat-plate solar collector efficiency]

- a) 76.6%
- b) 38.3%
- c) 9.2%
- d) 43.8%

Correct answer: (b) 38.3%.

Given: $A = 2.0 \text{ m}^2$; $G = 850 \text{ W/m}^2$; $\dot{m} = 40 \text{ kg/h} = 0.011111 \text{ kg/s}$; $\Delta T = 46 - 32 = 14 \text{ K}$; $C_p = 4.187 \text{ kJ/kg}\cdot\text{K}$.

Formula: Useful heat $Q = \dot{m} \times C_p \times \Delta T$; $\eta = Q \div (G \times A) \times 100$.

Substitution: $Q = 0.011111 \times 4.187 \times 14 = 0.6513 \text{ kW}$; $G \times A = 850 \times 2.0 = 1700 \text{ W} = 1.70 \text{ kW}$; $\eta = 0.6513 \div 1.70 \times 100$.

Result: **$\eta = 38.3\%$** . Efficiency falls as the mean plate temperature rises above ambient, because heat losses from the plate rise.

Why the other options are wrong: (a) 76.6% – divides by the radiation on 1 m^2 instead of the full 2 m^2 area. (c) 9.2% – takes C_p as $1 \text{ kJ/kg}\cdot\text{K}$ instead of $4.187 \text{ kJ/kg}\cdot\text{K}$. (d) 43.8% – uses the rise above ambient instead of the water temperature rise.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 11 – New and Renewable Energy Sources.

50. Which statement about tidal power, as described for new and renewable sources, is correct?

[3P1CEM050 | Chapter 11: New and Renewable Energy Sources | Tidal energy - basic features]

- a) It works on the temperature difference between warm and cold ocean layers
- b) Its output depends mainly on wind speed blowing over the sea
- c) Energy from a tidal basin rises with the square of tidal range
- d) Its output is steady and continuous at the same rate all day

Correct answer: (c) Energy from a tidal basin rises with the square of tidal range.

Tidal power uses the rise and fall of sea level caused by the gravitational pull of the moon and the sun. A barrage across an estuary or bay traps water at high tide, and the water is released through low-head turbines as the tide falls (or in both directions).

The potential energy available in a basin is proportional to its area and to the square of the tidal range, so only sites with a large range are economic; in India the Gulf of Kutch, the Gulf of Khambhat and the Sundarbans have been identified.

Output is predictable but intermittent, peaking twice a day, and capital costs are high.

Why the other options are wrong: (a) That is ocean thermal energy conversion (OTEC), not tidal power. (b) That describes wave energy, which is driven by wind. (d) Tides rise and fall twice a day, so output is intermittent.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 11 – New and Renewable Energy Sources.

..... End of Section I

Section – II: SHORT DESCRIPTIVE QUESTIONS

Marks: $8 \times 5 = 40$

- (i) Answer all Eight questions
- (ii) Each question carries Five marks

S-1 A country's primary commercial energy consumption and GDP (at constant prices) are given below. Domestic primary energy production in 2024-25 is 540 Mtoe and is expected to grow at 3% a year.

[3P1CEM051 | Chapter 1: Energy Scenario | Energy-GDP elasticity and primary energy demand projection]

Item	2015-16	2024-25
Primary commercial energy (Mtoe)	720	1,010
GDP at constant prices (₹ lakh crore)	113	187

(a) Calculate the compound annual growth rate (CAGR) of energy consumption and of GDP between 2015-16 and 2024-25. [2 Marks]

(b) Calculate the energy-GDP elasticity and interpret it. [1 Mark]

(c) If GDP grows at 7% a year from 2024-25 to 2031-32 and the elasticity stays the same, project the energy demand in 2031-32 and the share that must be imported, compared with 2024-25. [2 Marks]

S-1 Ans

(a) [2 marks]

Given: $E(2015-16) = 720$ Mtoe (≈ 30.1 EJ); $E(2024-25) = 1,010$ Mtoe (≈ 42.3 EJ); GDP = ₹113 lakh crore and ₹187 lakh crore; $n = 9$ years.

Formula: $CAGR = (final \div initial)^{1/n} - 1$.

Substitution: energy = $(1,010 \div 720)^{1/9} - 1 = (1.4028)^{0.1111} - 1 = 0.0383$; GDP = $(187 \div 113)^{1/9} - 1 = (1.6549)^{0.1111} - 1 = 0.0576$.

Result: **energy CAGR = 3.83% a year; GDP CAGR = 5.76% a year.** (2 marks)

(b) [1 mark]

Formula: Energy-GDP elasticity = growth rate of energy consumption $\div$ growth rate of GDP.

Substitution: $3.83 \div 5.76 = 0.666$.

Result: **elasticity = 0.67**. A value below 1 means energy use grows more slowly than the economy, i.e. energy intensity is falling through efficiency gains and a shift to less energy-intensive services; developing economies in early industrialisation often show values above 1. (1 mark)

(c) [2 marks]

Formula: energy growth = elasticity $\times$ GDP growth; $E(2031-32) = E(2024-25) \times (1 + e)^7$; production = 540×1.03^7 ; import share = $(demand - production) \div demand \times 100$.

Substitution: $e = 0.666 \times 7\% = 4.66\%$; $E = 1,010 \times (1.0466)^7 = 1,010 \times 1.3755 = 1389$ Mtoe; production = $540 \times 1.2299 = 664.1$ Mtoe; import share = $(1389 - 664.1) \div 1389 \times 100 = 52.2\%$; in 2024-25 it was $(1,010 - 540) \div 1,010 \times 100 = 46.5\%$.

Result: **demand ≈ 1389 Mtoe (≈ 58.2 EJ) in 2031-32 (≈ 58.2 EJ); import dependence rises from 46.5% to 52.2%.** This shows why energy security strategies stress both demand-side efficiency (lowering the elasticity) and domestic substitution. (2 marks)

Marking scheme (5 marks): a) Energy CAGR 1, GDP CAGR 1. b) Elasticity $\frac{1}{2}$, interpretation $\frac{1}{2}$. c) Projected demand 1, import shares and comment 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 1 – Energy Scenario.

S-2 A new office building covered by the Energy Conservation Building Code (ECBC) has a lit floor area of 8,400 m². The installed interior lighting load, including control gear, is 112 kW, operating 3,000 h a year. Take the allowable lighting power density (LPD) for offices under the building area method as 10.8 W/m². A retrofit with LED luminaires and occupancy controls would bring the LPD down to 7.5 W/m² for an investment of ₹28 lakh. Electricity costs ₹9.20/kWh.

[3P1CEM052 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | ECBC lighting power density compliance of an office building]

(a) Calculate the installed LPD and state whether the design complies with the ECBC limit. By what percentage does it differ? [2 Marks]

(b) Calculate the annual energy and cost saving of the retrofit and its simple payback. [2 Marks]

(c) Name the two compliance routes available under ECBC and any three building systems it covers. [1 Mark]

S-2 Ans

(a) [2 marks]

Given: lighting load = 112 kW = 1,12,000 W; area = 8,400 m²; allowable LPD = 10.8 W/m².

Formula: LPD = installed lighting power $\div$ lit floor area; excess = $(LPD - allowed) \div allowed \times 100$.

Substitution: LPD = $1,12,000 \div 8,400 = 13.33$ W/m²; excess = $(13.33 - 10.8) \div 10.8 \times 100$.

Result: **LPD = 13.33 W/m², which exceeds the 10.8 W/m² limit by 23.5%; the design does NOT comply.** (2 marks)

(b) [2 marks]

Formula: new load = new LPD $\times$ area; kWh saved = (old kW – new kW) $\times$ hours; ₹ saved = kWh $\times$ tariff; payback = investment $\div$ ₹ saved.

Substitution: new load = $7.5 \times 8,400 \div 1,000 = 63.0$ kW; kWh saved = $(112 - 63.0) \times 3,000 = 1,47,000$ kWh; ₹ saved = $1,47,000 \times 9.20 = ₹13,52,400$; payback = $₹28,00,000 \div ₹13,52,400$.

Result: **saving = 1,47,000 kWh/yr ($\approx$ 529 GJ) and ₹ 13.52 lakh/yr; simple payback = 2.07 years.** Lower lighting load also reduces the air-conditioning cooling load, an extra saving not counted here. (2 marks)

(c) [1 mark]

Compliance routes ($\frac{1}{2}$ mark): (i) meeting the mandatory requirements plus the prescriptive requirements (component-by-component, e.g. LPD, U-values, SHGC, equipment efficiency); or (ii) meeting the mandatory requirements plus the whole building performance method, in which the proposed design's simulated annual energy use must not exceed that of a standard design.

Systems covered ($\frac{1}{2}$ mark, any three): building envelope; heating, ventilation and air conditioning; service hot water and pumping; interior and exterior lighting; electrical power systems and motors. (1 mark)

Marking scheme (5 marks): a) LPD 1, compliance verdict with % 1. b) kWh and ₹ saving 1, payback 1. c) Two routes $\frac{1}{2}$, three systems $\frac{1}{2}$.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

S-3 An electric oven has three identical heating elements of 24.2Ω each, supplied from a 415 V, three-phase, 50 Hz supply. The elements can be connected either in star or in delta. Each batch needs 15,300 kcal of useful heat, and the oven's thermal efficiency is 85%. Electricity costs ₹9.00/kWh.

[3P1CEM053 | Chapter 3: Basics of Energy and its Various Forms | Three-phase resistive heater bank - star versus delta connection]

(a) Calculate the line current and total power when the elements are connected in star. [2 Marks]

(b) Calculate the line current and total power in delta, and the ratio of delta to star power. [1 Mark]

(c) Calculate the electricity needed per batch and the heating time per batch in each connection. [1 Mark]

(d) Calculate the energy cost per batch and explain whether the connection changes it. [1 Mark]

S-3 Ans

(a) [2 marks]

Given: $R = 24.2 \Omega$ per element; $V_L = 415$ V; star connection: $V_{ph} = V_L \div \sqrt{3}$, $I_L = I_{ph}$.

Formula: $V_{ph} = V_L \div \sqrt{3}$; $I_{ph} = V_{ph} \div R$; $P = 3 \times V_{ph}^2 \div R$ (unity power factor for resistive load).

Substitution: $V_{ph} = 415 \div 1.732 = 239.6$ V; $I = 239.6 \div 24.2 = 9.90$ A; $P = 3 \times 239.6^2 \div 24.2 = 7,117$ W.

Result: **star: line current = 9.90 A; power = 7.12 kW.** (2 marks)

(b) [1 mark]

Formula: delta: $V_{ph} = V_L$; $I_{ph} = V_L \div R$; $I_L = \sqrt{3} \times I_{ph}$; $P = 3 \times V_L^2 \div R$.

Substitution: $I_{ph} = 415 \div 24.2 = 17.15$ A; $I_L = 1.732 \times 17.15 = 29.70$ A; $P = 3 \times 415^2 \div 24.2 = 21,350$ W; ratio = $21.35 \div 7.12$.

Result: **delta: line current = 29.70 A; power = 21.35 kW; delta power = 3 $\times$ star power.** (1 mark)

(c) [1 mark]

Given: useful heat per batch = 15,300 kcal ($\approx$ 64.1 MJ); heater efficiency = 0.85; tariff ₹9.0/kWh; 1 kWh = 860 kcal ($\approx$ 3,601 kJ).

Formula: kWh per batch = useful heat $\div$ (860 $\times$ η); time = kWh $\div$ kW.

Substitution: $15,300 \div (860 \times 0.85) = 20.93$ kWh; delta time = $20.93 \div 21.35 = 0.980$ h; star time = $20.93 \div 7.12 = 2.941$ h.

Result: **20.93 kWh per batch; heating time $\approx$ 59 min in delta and $\approx$ 176 min in star.** (1 mark)

(d) [1 mark]

Substitution: cost = $20.93 \times ₹9.00 = ₹188.37$.

Result: **₹ 188.37 per batch in either connection.** The energy (kWh) depends only on the heat needed and the efficiency; the connection only changes the rate of heating. Delta gives three times the power and faster batches, but raises the

maximum demand (kVA) three-fold, so star (or star-delta switching: delta for heat-up, star for holding) may be cheaper on a kVA-based tariff and kinder to the elements. (1 mark)

Marking scheme (5 marks): a) Phase voltage and current 1, power 1. b) Delta current and power with ratio 1. c) kWh and times 1. d) Cost and reasoning 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 3 – Basics of Energy and its Various Forms.

S-4 A sugar mill has five independent energy-saving projects but only ₹60 lakh of capital this year. The investment and the present value (PV) of each project's net savings at the company's 12% discount rate are given below.

Projects cannot be split.

[3P1CEM054 | Chapter 7: Financial Management | Capital rationing - ranking energy projects by profitability index]

Project	Description	Investment (₹ lakh)	PV of net savings at 12% (₹ lakh)
P1	VFDs on ID and FD fans	18	31.5
P2	Condensate recovery system	24	36.0
P3	Waste heat recovery boiler	36	50.4
P4	LED lighting with controls	12	22.8
P5	Compressor replacement	20	27.0

(a) Calculate the NPV and the profitability index (PI) of each project. [2 Marks]

(b) Select the projects to be funded by ranking on PI within the budget, and find the total NPV obtained. [2 Marks]

(c) Compare this with selection by ranking on NPV and state why PI is the right ranking tool here. [1 Mark]

S-4 Ans

(a) [2 marks]

Given: investments and PVs of net savings as in the table; discount rate 12%.

Formula: NPV = PV of net savings – investment; PI = PV of net savings ÷ investment.

Substitution: P1: NPV = 31.5 – 18 = ₹13.5 lakh, PI = 31.5 ÷ 18 = 1.75; P2: NPV = 36.0 – 24 = ₹12.0 lakh, PI = 36.0 ÷ 24 = 1.50;

P3: NPV = 50.4 – 36 = ₹14.4 lakh, PI = 50.4 ÷ 36 = 1.40; P4: NPV = 22.8 – 12 = ₹10.8 lakh, PI = 22.8 ÷ 12 = 1.90; P5: NPV = 27.0 – 20 = ₹7.0 lakh, PI = 27.0 ÷ 20 = 1.35.

Project	NPV (₹ lakh)	PI	Rank by PI
P1	13.5	1.75	2
P2	12.0	1.50	3
P3	14.4	1.40	4
P4	10.8	1.90	1
P5	7.0	1.35	5

Result: **NPVs: P1 ₹13.5 lakh, P2 ₹12.0 lakh, P3 ₹14.4 lakh, P4 ₹10.8 lakh, P5 ₹7.0 lakh; PIs: P1 1.75, P2 1.50, P3 1.40, P4 1.90, P5 1.35.** All have PI > 1, so all are acceptable without rationing. (2 marks)

(b) [2 marks]

Formula: rank by PI (highest first) and accept projects while the cumulative investment stays within ₹60 lakh.

Substitution: PI order = P4 (1.90) > P1 (1.75) > P2 (1.50) > P3 (1.40) > P5 (1.35); cumulative investment: P4 → P1 → P2 → P3 → P5; P4, P1, P2 use ₹54 lakh; the next project would exceed ₹60 lakh.

Result: **fund P4, P1, P2; investment ₹54 lakh; total NPV = ₹36.3 lakh;** ₹6 lakh remains unused (can go to low-cost measures). (2 marks)

(c) [1 mark]

Substitution: ranking by NPV picks P3, P1 (₹54 lakh), total NPV = ₹27.9 lakh.

Result: **PI ranking gives ₹36.3 lakh against ₹27.9 lakh by NPV ranking, i.e. ₹8.4 lakh more value.** When capital, not projects, is the scarce resource, the aim is the most NPV per rupee invested, which is exactly what PI measures; a single large project with the highest NPV can crowd out several smaller ones that together add more value. (1 mark)

Marking scheme (5 marks): a) NPVs 1, Pls 1. b) Correct ranking 1, selection and total NPV 1. c) Comparison and reason 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 7 – Financial Management.

S-5 A vertical shaft kiln produces 100 t/day of quicklime by calcining limestone containing 92% CaCO_3 , the rest being inert matter that passes unchanged into the product. Calcination is complete: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$ (molecular weights 100, 56 and 44). The kiln burns 18.5 t/day of coal (GCV 5,400 kcal/kg, carbon 52%). Take the theoretical heat of calcination as 760 kcal per kg of CaO formed and ignore sensible heat in the products.

[3P1CEM055 | Chapter 5: Material and Energy Balance | Material and energy balance of a lime kiln]

(a) Calculate the limestone required per day and the process CO_2 released. [2 Marks]

(b) Calculate the kiln's thermal efficiency and its specific heat consumption per kg of quicklime. [2 Marks]

(c) Calculate the total CO_2 released per day (process + fuel) and per tonne of quicklime. [1 Mark]

S-5 Ans

(a) [2 marks]

Given: product = 100 t/day; limestone = 92% CaCO_3 + 8% inerts; 100 kg $\text{CaCO}_3 \rightarrow 56$ kg CaO + 44 kg CO_2 .

Formula: Mass balance on product: $L \times (0.92 \times 0.56 + 0.08) = \text{product}$; $\text{CO}_2 = 0.92 \times L \times 0.44$.

Substitution: $L \times (0.5152 + 0.08) = 100 \rightarrow L = 100 \div 0.5952 = 168.01$ t; CaO = $0.92 \times 168.01 \times 0.56 = 86.56$ t; inerts = 13.44 t; $\text{CO}_2 = 0.92 \times 168.01 \times 0.44$.

Result: **limestone = 168.0 t/day; process CO_2 = 68.0 t/day** (check: $168.01 = 86.56 + 13.44 + 68.01$ t). (2 marks)

(b) [2 marks]

Given: heat of calcination = 760 kcal/kg ($\approx 3,182$ kJ/kg) CaO; coal = 18.5 t/day at GCV 5,400 kcal/kg ($\approx 22,609$ kJ/kg); product = 100 t/day.

Formula: $\eta = \text{theoretical heat of calcination} \div \text{fuel heat input} \times 100$; specific heat consumption = fuel heat $\div$ product.

Substitution: theoretical heat = $86,559 \text{ kg} \times 760 = 6,57,84,946$ kcal/day; fuel heat = $18,500 \text{ kg} \times 5,400 = 9,99,00,000$ kcal/day; $\eta = 6,57,84,946 \div 9,99,00,000 \times 100$; SHC = $9,99,00,000 \div 1,00,000$ kg.

Result: **$\eta = 65.9\%$; specific heat consumption = 999 kcal/kg ($\approx 4,183$ kJ/kg) quicklime.** (2 marks)

(c) [1 mark]

Formula: fuel CO_2 = coal $\times$ carbon fraction $\times 44/12$; total = process + fuel CO_2 .

Substitution: fuel CO_2 = $18.5 \times 0.52 \times 44 \div 12 = 35.27$ t; total = $68.01 + 35.27 = 103.28$ t/day; per tonne = $103.28 \div 100$.

Result: **total CO_2 = 103.3 t/day, i.e. 1.033 t CO_2 per t of quicklime;** about 66% is process CO_2 that no fuel efficiency measure can remove. (1 mark)

Marking scheme (5 marks): a) Mass balance equation 1, limestone and CO_2 1. b) Theoretical and fuel heat 1, efficiency and SHC 1. c) Total CO_2 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 5 – Material and Energy Balance.

S-6 A coal-fired power station burns 9,600 t/day of coal containing 0.6% sulphur. 95% of the sulphur leaves as SO_2 in the flue gas; the rest is retained in the ash. A wet limestone flue gas desulphurisation (FGD) unit removing 90% of the SO_2 is being installed. Reactions: $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$ (32 $\rightarrow$ 64); $\text{CaCO}_3 + \text{SO}_2 \rightarrow \text{CaSO}_3 + \text{CO}_2$ (100 + 64 $\rightarrow$ 120 + 44). The limestone is 92% CaCO_3 and is fed at 1.05 times the stoichiometric quantity.

[3P1CEM056 | Chapter 10: Energy Efficiency and Climate Change | SO_2 emission from a coal-fired station and flue gas desulphurisation]

(a) Calculate the SO_2 generated per day before the FGD. [2 Marks]

(b) Calculate the SO_2 emitted and the SO_2 removed per day after the FGD. [1 Mark]

(c) Calculate the limestone required per day and the CO₂ released by the FGD reaction. [1 Mark]

(d) Explain how SO₂ emissions lead to acid rain and give one effect. [1 Mark]

S-6 Ans

(a) [2 marks]

Given: coal = 9,600 t/day; S = 0.6%; conversion to SO₂ = 95%; 32 kg S → 64 kg SO₂.

Formula: SO₂ = coal × S fraction × conversion × 64/32.

Substitution: 9,600 × 0.006 × 0.95 = 54.72 t S; × 2 = 109.44.

Result: **SO₂ generated = 109.44 t/day.** (2 marks)

(b) [1 mark]

Formula: emitted = generated × (1 – removal); removed = generated × removal.

Substitution: 109.44 × 0.10 = 10.94 t; 109.44 × 0.90 = 98.50 t.

Result: **SO₂ emitted = 10.94 t/day; removed = 98.50 t/day.** (1 mark)

(c) [1 mark]

Formula: CaCO₃ = SO₂ removed × 100/64 × feed ratio ÷ purity; CO₂ = SO₂ removed × 44/64.

Substitution: 98.50 × 100 ÷ 64 × 1.05 ÷ 0.92 = 175.6 t; CO₂ = 98.50 × 44 ÷ 64 = 67.72 t.

Result: **limestone = 175.6 t/day; CO₂ released by FGD = 67.7 t/day,** a small greenhouse penalty for a large cut in acid gas. (1 mark)

(d) [1 mark]

Acid rain (1 mark): SO₂ (and NO_x) emitted from fuel combustion are oxidised in the atmosphere and dissolve in cloud water to form sulphuric (and nitric) acid, which falls as rain, snow or dry deposition with pH below about 5.6. Effects (any one): acidification of lakes and soils harming fish and forests; corrosion of buildings, monuments and metal structures; leaching of nutrients from soil; respiratory effects of sulphate particles.

Marking scheme (5 marks): a) Formula 1, SO₂ generated 1. b) Emitted and removed 1. c) Limestone and CO₂ 1. d)

Mechanism ½, one effect ½.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 10 – Energy Efficiency and Climate Change.

S-7 A rice mill runs a diesel generator at an average load of 150 kW for 4,000 h a year. On diesel alone the specific consumption is 0.28 litre/kWh. A wood gasifier is proposed to run the engine in dual-fuel mode, replacing 65% of the diesel; it needs 1.1 kg of wood per kWh. Diesel costs ₹92/litre and wood ₹4.5/kg. Extra O&M of the gasifier is ₹1.10/kWh. The gasifier system costs ₹95 lakh.

[3P1CEM057 | Chapter 11: New and Renewable Energy Sources | Biomass gasifier in dual-fuel mode on a diesel generator]

(a) Calculate the annual diesel saved in litres and rupees. [2 Marks]

(b) Calculate the annual cost of wood and extra O&M, the net annual saving and the simple payback. [2 Marks]

(c) Why can a diesel engine not run on producer gas alone, and what are the two common options? [1 Mark]

S-7 Ans

(a) [2 marks]

Given: load = 150 kW; hours = 4,000; SFC = 0.28 L/kWh; diesel replacement = 65%; diesel ₹92/L.

Formula: annual kWh = kW × hours; diesel saved = SFC × replacement × kWh; ₹ saved = litres × price.

Substitution: kWh = 150 × 4,000 = 6,00,000 kWh; diesel saved = 0.28 × 0.65 × 6,00,000 = 1,09,200 L; ₹ = 1,09,200 × 92.

Result: **diesel saved = 1,09,200 litres/yr worth ₹1,00,46,400 (₹ 100.46 lakh).** (2 marks)

(b) [2 marks]

Formula: wood cost = wood per kWh × kWh × price; O&M = ₹/kWh × kWh; net saving = diesel saving – wood – O&M; payback = capital ÷ net saving.

Substitution: wood = 1.1 × 6,00,000 × 4.5 = ₹29,70,000; O&M = 1.10 × 6,00,000 = ₹6,60,000; net = 1,00,46,400 – 29,70,000 – 6,60,000 = ₹64,16,400; payback = ₹95,00,000 ÷ ₹64,16,400.

Result: **wood ₹ 29.70 lakh and O&M ₹ 6.60 lakh a year; net saving = ₹ 64.16 lakh/yr; payback ≈ 1.48 years** (660 t of wood a year must be sourced sustainably). (2 marks)

(c) [1 mark]

Reason (½ mark): a diesel engine is a compression-ignition engine; producer gas (mainly CO, H₂ and about 50% N₂, low calorific value) has a high self-ignition temperature, so it does not ignite by compression alone and a pilot injection of diesel is needed to start combustion.

Options (½ mark): (i) dual-fuel operation with 20 to 35% pilot diesel in an unmodified diesel engine; (ii) 100% producer gas in a spark-ignition gas engine or a converted engine with lower compression ratio and spark ignition. (1 mark)

Marking scheme (5 marks): a) kWh and litres 1, rupee saving 1. b) Wood and O&M cost 1, net saving and payback 1. c)

Reason ½, options ½.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 11 – New and Renewable Energy Sources.

S-8 A multi-plant engineering company has appointed a corporate energy manager. Top management wants a training plan and a way to 'market' energy management inside the company so that savings are sustained after the first round of projects.

[3P1CEM058 | Chapter 6: Energy Action Planning | Training, awareness and marketing of energy management]

(a) Outline a training plan suited to different groups of employees. [2 Marks]

(b) Describe four ways of marketing and communicating energy management results within the organisation. [2 Marks]

(c) Give one common barrier to sustaining energy savings and how you would overcome it. [1 Mark]

S-8 Ans

(a) [2 marks]

Training plan (½ mark for each group, any four):

Top management: short briefings on energy cost trends, the energy policy, targets, statutory obligations and the financial returns of energy projects, so that they commit resources.

Energy manager and energy team: technical training in auditing, measurement, utilities (boilers, motors, compressed air, HVAC), M&T and project appraisal; certification where required.

Supervisors and operators: hands-on training on efficient operation of the equipment they run, reading meters, daily logs, exception reporting and simple checklists (e.g. switching off idle equipment, leak tagging).

Maintenance staff: steam trap testing, insulation repair, compressed air leak detection, motor and drive alignment and other preventive maintenance with energy impact.

All employees: awareness campaigns, induction modules and suggestion schemes. Training needs should be reviewed yearly and linked to the action plan. (2 marks)

(b) [2 marks]

Marketing and communication (½ mark each, any four):

Publish monthly energy performance (energy cost, SEC against target) on notice boards, intranet dashboards and in management meetings.

Report achieved savings in rupees and as equivalent production or profit, so that energy is seen as a business result.

Recognise and reward departments and individuals who achieve targets or give implemented suggestions (awards, certificates, energy conservation day events).

Use case studies and before-and-after results of completed projects to win support for the next round of investment.

Involve employees through energy committees, competitions and campaigns (e.g. 'switch-off' drives) and share results with them. (2 marks)

(c) [1 mark]

Barrier and remedy (1 mark): savings decay as attention shifts to production and people revert to old habits (or the trained staff leave). Remedy: build energy into routine management - targets in each manager's key performance indicators,

regular M&T reports with exception follow-up, refresher training and continued recognition, so that energy performance is reviewed like quality and output. Other acceptable answers: lack of data (install sub-metering and an information system), or lack of funds (use savings from low-cost measures or ESCO financing). (1 mark)

Marking scheme (5 marks): a) ½ mark per group with relevant content, any four. b) ½ mark per method, any four. c) Barrier ½, remedy ½.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 6 – Energy Action Planning.

..... End of Section II

Section – III: LONG DESCRIPTIVE QUESTIONS

Marks: 6 × 10 = 60

(i) Answer all Six questions

(ii) Each question carries Ten marks

L-1 An auto-component forge signed a guaranteed savings performance contract with an ESCO for compressed air, VFD and furnace-control retrofits. The ESCO guarantees 8,00,000 kWh/yr of electricity savings, valued at ₹8.40/kWh; any shortfall is paid by the ESCO. The agreed M&V plan uses whole-facility metering with a baseline model developed from 24 months of pre-retrofit data: $E = 28,80,000 + 14.0 \times P$ (E in kWh/yr, P in tonnes of forgings/yr). In the base year the plant produced 1,90,000 t and used 55,60,000 kWh. In the first reporting year it produced 2,10,000 t and used 52,10,000 kWh. During the reporting year the plant also added a new heat-treatment line, separately metered at 1,20,000 kWh/yr, which was not part of the baseline.

[3P1CEM059 | Chapter 8: Project Management | Performance monitoring - M&V and settlement of a guaranteed savings contract]

(a) Calculate the adjusted baseline energy for the reporting-year production (routine adjustment). [2 Marks]

(b) Apply the non-routine adjustment for the new heat-treatment line and calculate the verified savings. [2 Marks]

(c) Determine whether the guarantee was met and the amount payable by the ESCO, if any. [2 Marks]

(d) Calculate the "savings" a simple comparison of base-year and reporting-year bills would show, and explain why it is wrong. [2 Marks]

(e) List four items that the M&V plan in such a contract must specify. [2 Marks]

L-1 Ans

(a) [2 marks]

Given: baseline model $E = 28,80,000 + 14.0 \times P$; reporting-year $P = 2,10,000$ t.

Formula: Adjusted baseline = energy the old (pre-retrofit) plant would have used at the reporting-year production = $a + b \times P_{\text{reporting}}$.

Substitution: $28,80,000 + 14.0 \times 2,10,000 = 28,80,000 + 29,40,000$.

Result: **adjusted baseline = 58,20,000 kWh** (≈ 20.95 TJ). (2 marks)

(b) [2 marks]

Formula: Non-routine adjustment adds the energy of loads added after the baseline period (static factor change); verified savings = adjusted baseline (incl. non-routine adjustment) – reporting-period energy.

Substitution: adjusted baseline = $58,20,000 + 1,20,000 = 59,40,000$ kWh; savings = $59,40,000 - 52,10,000$.

Result: **verified savings = 7,30,000 kWh/yr**. Without the non-routine adjustment the ESCO would be credited with only 6,10,000 kWh, unfairly charging it for the client's new load. (2 marks)

(c) [2 marks]

Formula: shortfall = guaranteed savings – verified savings; payment = shortfall × agreed value per kWh.

Substitution: $8,00,000 - 7,30,000 = 70,000$ kWh; $70,000 \times ₹8.40$.

Result: **guarantee not met by 70,000 kWh (8.75%); ESCO pays the client ₹5,88,000** for the year. The client still gains the verified 7,30,000 kWh ($\approx$ ₹ 61.32 lakh). (2 marks)

(d) [2 marks]

Substitution: base-year bill energy – reporting-year energy = 55,60,000 – 52,10,000 = 3,50,000 kWh.

Result: **a naive comparison shows only 3,50,000 kWh of 'savings'**, because it ignores the 20,000 t increase in production (worth 2,80,000 kWh at 14.0 kWh/t) and the new heat-treatment load of 1,20,000 kWh. Energy use must be compared under the same conditions; that is why the baseline is adjusted for production (routine) and for changes in facility (non-routine). Note also that the model predicts 55,40,000 kWh for the base year against 55,60,000 kWh actual, a 0.4% difference, which is acceptable model error. (2 marks)

(e) [2 marks]

Any four ($\frac{1}{2}$ mark each): (1) the baseline period, data and the baseline model with its independent variables (production, weather); (2) the measurement boundary (whole facility or retrofit isolation) and the meters to be used, with calibration requirements; (3) the method of routine and non-routine adjustments and who approves them; (4) the reporting period, frequency and format of savings reports; (5) the energy prices or values used to convert kWh to rupees; (6) responsibilities for data collection and the dispute resolution procedure. (2 marks)

Marking scheme (10 marks): a) Model use 1, adjusted baseline 1. b) Non-routine adjustment 1, verified savings 1. c)

Shortfall 1, payment 1. d) Naive figure 1, explanation 1. e) $\frac{1}{2}$ per item, any four.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 8 – Project Management.

L-2 A specialty paper mill makes three grades. An audit established energy weighting factors per tonne relative to grade A: A = 1.0, B = 1.6, C = 0.7. Base-year production was A 24,000 t, B 9,000 t and C 15,000 t, with total energy use of 2,07,825 GJ (steam and electricity on a primary-energy basis). Management has set a target of 6% reduction in specific energy consumption (SEC) per equivalent tonne, and wants corrective action in any quarter whose SEC is more than 3% above target. Energy is valued at ₹650/GJ. Current-year quarterly data are given in the table.

[3P1CEM060 | Chapter 9: Energy Monitoring and Targeting | Monitoring and targeting in a multi-product plant - equivalent production]

Quarter	Grade A (t)	Grade B (t)	Grade C (t)	Energy (GJ)
Q1	6,200	2,500	3,600	52,300
Q2	6,500	2,200	4,000	51,100
Q3	5,800	2,700	3,300	51,800
Q4	6,600	2,400	4,200	52,900

(a) Calculate the base-year equivalent production, base SEC (GJ per equivalent tonne) and the target SEC. [2 Marks]

(b) Calculate the equivalent production, SEC and % deviation from target for each quarter, and identify the quarters needing corrective action. [3 Marks]

(c) Calculate the annual SEC, the energy saved against the base-year SEC (GJ, toe and ₹), and the shortfall against target in GJ. [3 Marks]

(d) Show what SEC per actual tonne would indicate for the year, and explain why equivalent production is used. Give one limitation of the method. [2 Marks]

L-2 Ans

(a) [2 marks]

Given: weights A 1.0, B 1.6, C 0.7; base production A 24,000 t, B 9,000 t, C 15,000 t; base energy 2,07,825 GJ; target reduction 6%.

Formula: equivalent production = Σ (tonnes $\times$ weight); SEC = energy $\div$ equivalent production; target SEC = base SEC $\times$ (1 – 0.06).

Substitution: equivalent = $24,000 \times 1.0 + 9,000 \times 1.6 + 15,000 \times 0.7 = 24,000 + 14,400 + 10,500 = 48,900$ t-eq; SEC = $2,07,825 \div 48,900 = 4.250$ GJ/t-eq; target = 4.250×0.94 .

Result: **base equivalent production = 48,900 t-eq; base SEC = 4.250 GJ/t-eq; target SEC = 3.9950 GJ/t-eq.** (2 marks)

(b) [3 marks]

Formula: quarterly SEC = energy $\div$ equivalent production; deviation = $(\text{SEC} \div \text{target} - 1) \times 100$; act if deviation $> +3\%$.

Substitution: Q1: eq = $6,200 + 2,500 \times 1.6 + 3,600 \times 0.7 = 12,720$ t-eq, SEC = $52,300 \div 12,720 = 4.112$; Q2: eq = $6,500 + 2,200 \times 1.6 + 4,000 \times 0.7 = 12,820$ t-eq, SEC = $51,100 \div 12,820 = 3.986$; Q3: eq = $5,800 + 2,700 \times 1.6 + 3,300 \times 0.7 = 12,430$ t-eq, SEC = $51,800 \div 12,430 = 4.167$; Q4: eq = $6,600 + 2,400 \times 1.6 + 4,200 \times 0.7 = 13,380$ t-eq, SEC = $52,900 \div 13,380 = 3.954$.

Quarter	Equivalent production (t-eq)	Energy (GJ)	SEC (GJ/t-eq)	Deviation from target	Action?
Q1	12,720	52,300	4.112	+2.92%	No
Q2	12,820	51,100	3.986	-0.23%	No
Q3	12,430	51,800	4.167	+4.31%	Yes
Q4	13,380	52,900	3.954	-1.03%	No

Result: **corrective action is needed in Q3** (SEC more than 3% above the target of 3.995 GJ/t-eq); the other quarters are within the band (Q1 only just, at +2.92%, so it should be watched), with Q2 and Q4 below target. An exception report to the department heads should ask for the causes (e.g. grade changes, breaks, steam leaks, low dryer-section efficiency). (3 marks)

(c) [3 marks]

Formula: annual SEC = Σ energy $\div$ Σ equivalent production; saving vs base = $(\text{base SEC} - \text{annual SEC}) \times \text{annual equivalent production}$; shortfall = $(\text{annual SEC} - \text{target SEC}) \times \text{annual equivalent production}$; 1 toe = 41.868 GJ.

Substitution: Σ energy = 2,08,100 GJ; Σ eq = 51,350 t-eq; SEC = $2,08,100 \div 51,350 = 4.0526$ GJ/t-eq; saving = $(4.2500 - 4.0526) \times 51,350 = 10,138$ GJ = $10,138 \div 41.868 = 242.1$ toe; ₹ = $10,138 \times 650$; shortfall = $(4.0526 - 3.9950) \times 51,350$.

Result: **annual SEC = 4.053 GJ/t-eq (4.65% below base); saving = 10,138 GJ $\approx$ 242 toe, worth ₹ 65.89 lakh; but the target is missed by 2,957 GJ.** (3 marks)

(d) [2 marks]

Substitution: base SEC per actual tonne = $2,07,825 \div 48,000 = 4.330$ GJ/t; current year = $2,08,100 \div 50,000 = 4.162$ GJ/t.

Result: **SEC per actual tonne would show -3.87% change against -4.65% on the equivalent basis.** Product mix changed (more of the energy-intensive grade B relative to C), so plain tonnes give a misleading picture: equivalent production weights each grade by its energy intensity, so the SEC reflects efficiency, not product mix. Limitation (any one): the weighting factors are fixed averages that drift as processes change and must be re-validated by audit; they ignore other variables such as weather, machine speed, capacity utilisation and the fixed (production-independent) energy component. (2 marks)

Marking scheme (10 marks): a) Equivalent production 1, base and target SEC 1. b) Quarterly equivalent production and SEC 1½, deviations 1, flagged quarters ½. c) Annual SEC 1, saving in GJ/toe/₹ 1, shortfall 1. d) Comparison 1, reasoning and limitation 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 9 – Energy Monitoring and Targeting.

L-3 A dairy plans a heat pump system for pasteuriser heating and chilled-water recovery. Capital cost is ₹48 lakh, of which 20% is met by a State capital subsidy received at commissioning (year 0). First-year net energy savings are ₹11.5 lakh, rising 5% a year with tariff escalation. O&M costs are ₹1.2 lakh a year. A compressor overhaul costing ₹6 lakh is needed in year 5. Life is 8 years with a salvage value of ₹3 lakh at the end of year 8. The discount rate is 11%. All cash flows occur at year-ends; ignore taxes.

[3P1CEM061 | Chapter 7: Financial Management | Project appraisal with escalating savings, capital subsidy and mid-life overhaul]

(a) Prepare the cash flow table for years 0 to 8 with discount factors and present values. [3 Marks]

(b) Calculate the NPV at 11%. [2 Marks]

- (c) Find the IRR by trial and linear interpolation. [2 Marks]
 (d) Calculate the discounted payback period. [1 Mark]
 (e) By what percentage could the energy savings in every year fall before the project NPV becomes zero? [2 Marks]

L-3 Ans**(a) [3 marks]**

Given: net investment = ₹48 lakh $\times$ (1 – 0.2) = ₹38.4 lakh; savings_t = $11.5 \times 1.05^{(t-1)}$; O&M ₹1.2 lakh/yr; overhaul ₹6 lakh in year 5; salvage ₹3 lakh in year 8; r = 11%.

Formula: net cash flow_t = savings_t – O&M – overhaul (yr 5) + salvage (yr 8); discount factor = $1 \div (1.11)^t$; PV = cash flow $\times$ discount factor.

Substitution: see table.

Year	Savings (₹ lakh)	O&M, overhaul, salvage (₹ lakh)	Net cash flow (₹ lakh)	DF at 11%	PV (₹ lakh)	Cumulative PV (₹ lakh)
0	–	capital net of subsidy -38.4	-38.400	1.0000	-38.400	-38.400
1	11.500	-1.2	10.300	0.9009	9.279	-29.121
2	12.075	-1.2	10.875	0.8116	8.826	-20.294
3	12.679	-1.2	11.479	0.7312	8.393	-11.901
4	13.313	-1.2	12.113	0.6587	7.979	-3.922
5	13.978	-1.2 – 6	6.778	0.5935	4.023	0.100
6	14.677	-1.2	13.477	0.5346	7.205	7.306
7	15.411	-1.2	14.211	0.4817	6.845	14.151
8	16.182	-1.2 + 3	17.982	0.4339	7.803	21.954

Result: **net cash flows rise from ₹10.300 lakh (yr 1) to ₹17.982 lakh (yr 8, incl. salvage), with a dip to ₹6.778 lakh in year 5 for the overhaul.** (3 marks)

(b) [2 marks]

Formula: NPV = $\sum PV_t$ (t = 0 to 8).

Substitution: NPV = $-38.4 + 9.279 + 8.826 + 8.393 + 7.979 + 4.023 + 7.205 + 6.845 + 7.803$.

Result: **NPV at 11% = ₹ 21.95 lakh** (positive, so the project is acceptable). (2 marks)

(c) [2 marks]

Formula: $IRR = r_1 + (r_2 - r_1) \times NPV_1 \div (NPV_1 - NPV_2)$, with r_1 and r_2 bracketing NPV = 0.

Substitution: at 24%, NPV = ₹0.512 lakh; at 25%, NPV = ₹-0.610 lakh; $IRR = 24 + 1 \times 0.512 \div (0.512 + 0.610) = 24.46\%$.

Result: **IRR $\approx$ 24.46%** (exact solution 24.45%), well above the 11% cost of capital. (2 marks)

(d) [1 mark]

Formula: discounted payback = year before cumulative PV turns positive + (unrecovered PV at start of year $\div$ PV in that year).

Substitution: cumulative PV at end of year 4 = ₹-3.922 lakh; PV in year 5 = ₹4.023 lakh; DPB = $4 + 3.922 \div 4.023$.

Result: **discounted payback $\approx$ 4.98 years.** (1 mark)

(e) [2 marks]

Formula: NPV falls one-for-one with the PV of savings, so break-even fall in savings (%) = $NPV \div \text{PV of all savings} \times 100$.

Substitution: PV of savings = $\sum \text{savings}_t \times DF_t = ₹68.788$ lakh; break-even fall = $21.954 \div 68.788 \times 100$.

Result: **savings can fall by about 31.9% in every year before NPV becomes zero.** This sensitivity margin is what the energy manager should present to management along with NPV and IRR, since savings estimates and tariff escalation are the most uncertain inputs. (2 marks)

Marking scheme (10 marks): a) Savings and net cash flows 1½, discount factors and PVs 1½. b) NPV 2. c) Two trial NPVs 1, interpolated IRR 1. d) Discounted payback 1. e) PV of savings 1, break-even % 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 7 – Financial Management.

L-4 A dairy concentrates 24,000 kg/h of skimmed milk from 12% to 45% total solids before spray drying. The existing single-effect evaporator has a steam economy of 0.92 kg water evaporated per kg steam. A triple-effect falling-film evaporator with an economy of 2.6 is proposed. Steam is raised in a coal-fired boiler (efficiency 76% on GCV, coal GCV 4,000 kcal/kg at ₹7,200/t); the net heat added per kg of steam, allowing for condensate return, is 560 kcal/kg. The plant runs 6,000 h a year. As a further option, a mechanical vapour recompression (MVR) evaporator would need 18 kWh of electricity per tonne of water evaporated (and negligible live steam) at ₹8.5/kWh.

[3P1CEM062 | Chapter 5: Material and Energy Balance | Material and energy balance of a multiple-effect evaporator and MVR option]

- Using a solids balance, calculate the concentrate output and the water evaporated per hour. [2 Marks]
- Calculate the steam consumption of the single-effect and triple-effect evaporators and the steam saved. [2 Marks]
- Calculate the annual coal saving and its value for the triple-effect evaporator. [3 Marks]
- Compare the annual energy cost of the triple-effect and MVR evaporators and comment on the choice. [3 Marks]

L-4 Ans

(a) [2 marks]

Given: $F = 24,000 \text{ kg/h}$; $x_F = 0.12$; $x_P = 0.45$.

Formula: solids in = solids out: $F \times x_F = P \times x_P$; water evaporated $W = F - P$.

Substitution: $P = 24,000 \times 0.12 \div 0.45 = 6,400 \text{ kg/h}$; $W = 24,000 - 6,400 = 17,600 \text{ kg/h}$.

Result: **concentrate = 6,400 kg/h; water evaporated = 17,600 kg/h**. Check: solids 2,880 kg/h in = 2,880 kg/h out. (2 marks)

(b) [2 marks]

Formula: steam = water evaporated $\div$ steam economy.

Substitution: single effect = $17,600 \div 0.92 = 19,130 \text{ kg/h}$; triple effect = $17,600 \div 2.6 = 6,769 \text{ kg/h}$; saving = $19,130 - 6,769$.

Result: **steam saved = 12,361 kg/h (64.6% less steam)**. The vapour from each effect becomes the heating medium of the next, so one kg of live steam evaporates about 2.6 kg of water. (2 marks)

(c) [3 marks]

Given: $\Delta h = 560 \text{ kcal/kg}$ ($\approx 2,345 \text{ kJ/kg}$); $\eta = 0.76$; GCV = $4,000 \text{ kcal/kg}$ ($\approx 16,747 \text{ kJ/kg}$); $6,000 \text{ h/yr}$; ₹7,200/t.

Formula: coal per kg steam = $\Delta h \div (\eta \times \text{GCV})$; annual coal saving = steam saved $\times$ coal per kg steam $\times$ hours.

Substitution: coal per kg steam = $560 \div (0.76 \times 4,000) = 0.1842 \text{ kg}$; saving = $12,361 \times 0.1842 \times 6,000 \div 1,000 = 13,662 \text{ t/yr}$; value = $13,662 \times ₹7,200$.

Result: **coal saving $\approx$ 13,662 t/yr, worth ₹ 9.84 crore a year**. (3 marks)

(d) [3 marks]

Substitution: triple-effect coal cost = $6,769 \times 0.1842 \times 6,000 \div 1,000 \times ₹7,200 = ₹ 5.39 \text{ crore/yr}$; MVR power = $17,600 \times 18 \div 1,000 = 317 \text{ kW}$; energy = $317 \times 6,000 = 1,900,800 \text{ kWh}$; cost = $1,900,800 \times ₹8.5 = ₹ 1.62 \text{ crore/yr}$.

Result: **MVR would cost ₹ 1.62 crore a year against ₹ 5.39 crore for the triple effect, a further saving of ₹ 377.1 lakh a year**. Comment: MVR recompresses the vapour with an electric fan or compressor, so its running cost is low where electricity is reasonably priced, but the capital cost is higher, it needs reliable power, and the comparison must use the plant's actual tariff and the boiler's part-load efficiency; a TVR (thermo-compressor) on the triple effect is an intermediate option. (3 marks)

Marking scheme (10 marks): a) Solids balance 1, water evaporated 1. b) Two steam figures 1, saving 1. c) Coal per kg steam 1, annual coal 1, value 1. d) Triple-effect cost 1, MVR cost 1, comment 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 5 – Material and Energy Balance.

L-5 The annual energy data of a textile process house that processed 9,000 t of fabric are: electricity 1,26,00,000 kWh at an average cost of ₹8.20/kWh; coal for the steam boiler 9,800 t (GCV 4,100 kcal/kg) at ₹7,200/t; furnace oil for the thermic fluid heater 1,450 t (GCV 10,200 kcal/kg) at ₹46,000/t. Use 860 kcal/kWh for electricity, 1 toe = 10^7 kcal = 41.868 GJ. The best-practice benchmark for comparable process houses is 22 GJ/t. The audit team has identified the measures in the table.

[3P1CEM063 | Chapter 4: Energy Management and Audit | Detailed energy audit of a textile process house - cost analysis, benchmarking and ECM ranking]

Measure	Description	Investment (₹ lakh)	Annual saving (₹ lakh)
E1	Condensate recovery from stenters and jiggers	18	21
E2	VFDs on stenter supply-air fans	32	19
E3	Air preheater on thermic fluid heater	45	24
E4	Solar preheating of process water	120	28
E5	Compressed air leak arrest and pressure reset	4	9
E6	New FBC boiler replacing old coal boiler	380	95

- Calculate the annual cost of each energy source and its share of the energy bill, the total energy use in toe, and the SEC in GJ/t. [3 Marks]
- Compare the SEC with the benchmark and estimate the annual saving potential (GJ and ₹) if half the gap is closed, using the average cost per GJ. [2 Marks]
- Rank the measures by simple payback, select those with payback under 2 years, and give their total investment, annual saving, combined payback and saving as % of the energy bill. [3 Marks]
- Give two reasons why the SEC comparison with the benchmark may mislead, and what the auditor should do about them. [2 Marks]

L-5 Ans

(a) [3 marks]

Given: electricity 1,26,00,000 kWh at ₹8.20; coal 9,800 t at ₹7,200/t, GCV 4,100 kcal/kg ($\approx 17,166$ kJ/kg); furnace oil 1,450 t at ₹46,000/t, GCV 10,200 kcal/kg ($\approx 42,705$ kJ/kg); production 9,000 t.

Formula: cost = quantity $\times$ price; toe = quantity (kg) $\times$ GCV $\div 10^7$ (electricity: kWh $\times 860 \div 10^7$); SEC = total GJ $\div$ production.

Substitution: electricity ₹10,33,20,000 (42.9%); coal ₹7,05,60,000 (29.3%); oil ₹6,67,00,000 (27.7%); total ₹24,05,80,000.

Energy: electricity $1,26,00,000 \times 860 \div 10^7 = 1083.6$ toe; coal $98,00,000 \times 4,100 \div 10^7 = 4018.0$ toe; oil $14,50,000 \times 10,200 \div 10^7 = 1479.0$ toe; total = 6580.6 toe $\times 41.868 = 2,75,517$ GJ; SEC = $2,75,517 \div 9,000$.

Result: **energy bill = ₹ 24.06 crore (electricity 42.9%, coal 29.3%, oil 27.7%); total = 6,581 toe (≈ 275.5 TJ); SEC = 30.61**

GJ/t. Electricity is only 16.5% of the energy but 42.9% of the cost, so both energy and cost views are needed when setting priorities. (3 marks)

(b) [2 marks]

Formula: gap = SEC – benchmark; potential = $50\% \times \text{gap} \times \text{production}$; ₹ = potential GJ $\times$ average ₹/GJ (total cost $\div$ total GJ).

Substitution: gap = $30.61 - 22 = 8.61$ GJ/t; potential = $0.5 \times 8.61 \times 9,000 = 38,758$ GJ; average cost = $\text{₹}24,05,80,000 \div 2,75,517 = \text{₹}873/\text{GJ}$; ₹ = $38,758 \times 873$.

Result: **SEC is 39% above best practice; closing half the gap saves $\approx 38,758$ GJ/yr (≈ 926 toe), worth about ₹ 3.38 crore a year.** The average ₹/GJ is only indicative, since thermal savings are worth less per GJ than electrical savings. (2 marks)

(c) [3 marks]

Formula: simple payback = investment $\div$ annual saving; combined payback = Σ investment $\div \Sigma$ saving.

Substitution: E1 $18 \div 21 = 0.86$ yr; E2 $32 \div 19 = 1.68$ yr; E3 $45 \div 24 = 1.88$ yr; E4 $120 \div 28 = 4.29$ yr; E5 $4 \div 9 = 0.44$ yr; E6 $380 \div 95 = 4.00$ yr.

Rank	Measure	Investment (₹ lakh)	Saving (₹ lakh/yr)	Payback (yr)	Selected?
1	E5	4	9	0.44	Yes
2	E1	18	21	0.86	Yes
3	E2	32	19	1.68	Yes
4	E3	45	24	1.88	Yes
5	E6	380	95	4.00	No
6	E4	120	28	4.29	No

Result: **select E5, E1, E2, E3: investment ₹99 lakh, saving ₹73 lakh/yr, combined payback 1.36 years, i.e. 3.03% of the energy bill.** E4 and E6 are longer-payback, high-investment items to be appraised by NPV/IRR; their savings must be recalculated after the quick-payback measures, because E1 (condensate recovery) reduces the boiler steam and coal on which the savings of E4 and E6 were estimated. (3 marks)

(d) [2 marks]

Any two (1 mark each): (1) product mix and processes differ: fabric weight (GSM), fibre (cotton, polyester, blends), shade depth and the share of dyeing, printing and finishing change energy per tonne, so compare like with like or normalise; (2) boundary differences: some plants buy steam or outsource processes, or include captive power, so the same boundary and the same conversion factors (e.g. 860 kcal/kWh ($\approx 3,601$ kJ/kWh) vs primary-energy basis) must be used; (3) capacity utilisation: low output raises SEC because of fixed loads, so compare at similar loading or use an E-P relationship; (4) data quality: uncalibrated meters and GCV assumed instead of tested. The auditor should state the basis of the benchmark and adjust for these factors before drawing conclusions. (2 marks)

Marking scheme (10 marks): a) Costs and shares 1, toe 1, SEC 1. b) Gap and GJ potential 1, ₹ potential 1. c) Paybacks and ranking 1, selection 1, totals 1. d) Two valid reasons with action, 1 each.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 4 – Energy Management and Audit.

L-6 The side walls of a continuous reheating furnace (total area 120 m²) are made of 230 mm firebrick ($k = 1.3$ W/m·K), 115 mm insulating brick ($k = 0.2$ W/m·K, maximum service temperature 1,000 °C) and a 6 mm steel casing ($k = 45$ W/m·K). The inner hot-face temperature is 1,150 °C and the measured casing surface temperature is 95 °C. It is proposed to add a 75 mm ceramic fibre board ($k = 0.08$ W/m·K) between the insulating brick and the casing, after which the casing temperature is expected to fall to 65 °C. The furnace works 8,000 h a year on furnace oil (GCV 10,200 kcal/kg, ₹46/kg); take the available heat (fraction of fuel heat usable in the furnace at its flue gas exit temperature) as 0.55.

[3P1CEM064 | Chapter 3: Basics of Energy and its Various Forms | Heat loss through a composite furnace wall and the effect of extra insulation]

(a) Calculate the thermal resistance of each layer per m², the heat flux and the total heat loss through the walls.

[3 Marks]

(b) Calculate the temperatures at the firebrick/insulating brick and insulating brick/casing interfaces, and comment on the insulating brick. [2 Marks]

(c) Calculate the new heat flux and total loss with the ceramic fibre board, and the annual fuel and cost saving.

[3 Marks]

(d) Check the new interface temperatures against the material limits, recommend the maximum board thickness if needed, and state two practical points for the retrofit. [2 Marks]

L-6 Ans

(a) [3 marks]

Given: $L_1 = 0.23$ m, $k_1 = 1.3$; $L_2 = 0.115$ m, $k_2 = 0.2$; $L_3 = 0.006$ m, $k_3 = 45$ W/m·K; $T_{\text{hot}} = 1,150$ °C; $T_{\text{casing}} = 95$ °C; $A = 120$ m².

Formula: Fourier's law for layers in series: $R = L \div k$ per m^2 ; $q = (T_{\text{hot}} - T_{\text{casing}}) \div \Sigma R$; $Q = q \times A$.

Substitution: $R_1 = 0.23 \div 1.3 = 0.17692$; $R_2 = 0.115 \div 0.2 = 0.57500$; $R_3 = 0.006 \div 45 = 0.000133 \text{ m}^2 \cdot \text{K/W}$; $\Sigma R = 0.75206$; $q = (1,150 - 95) \div 0.75206 = 1402.8 \text{ W/m}^2$; $Q = 1402.8 \times 120 = 168,338 \text{ W}$.

Result: **$q = 1402.8 \text{ W/m}^2$; total wall loss = 168.3 kW** ($\approx 1,44,771 \text{ kcal/h}$). The steel casing's resistance is negligible; the insulating brick provides 76% of the total. (3 marks)

(b) [2 marks]

Formula: the same q flows through each layer: $T_{12} = T_{\text{hot}} - q \times R_1$; $T_{23} = T_{12} - q \times R_2$.

Substitution: $T_{12} = 1,150 - 1402.8 \times 0.17692 = 901.8 \text{ }^\circ\text{C}$; $T_{23} = 901.8 - 1402.8 \times 0.57500 = 95.2 \text{ }^\circ\text{C}$.

Result: **firebrick/insulating brick interface = 902 °C; insulating brick/casing interface = 95 °C** (check: casing hot side $\approx$ outer surface, since R_3 is tiny). The insulating brick's hot face at 902 °C is below its 1,000 °C limit, so the design is safe. (2 marks)

(c) [3 marks]

Given: board 75 mm, $k = 0.08 \text{ W/m}\cdot\text{K}$; new casing temperature 65 °C; 8,000 h/yr; furnace oil GCV 10,200 kcal/kg ($\approx 42,705 \text{ kJ/kg}$) at ₹46/kg; available heat 0.55; 1 kWh = 860 kcal ($\approx 3,601 \text{ kJ}$).

Formula: $R_{\text{new}} = L \div k$ of the board; $q_{\text{new}} = (T_{\text{hot}} - T_{\text{casing,new}}) \div (\Sigma R + R_{\text{new}})$; saving = $(Q - Q_{\text{new}}) \times \text{hours}$; fuel = heat saved $\div$ (available heat $\times$ GCV).

Substitution: $R_{\text{new}} = 0.075 \div 0.08 = 0.9375$; $\Sigma R = 1.68956$; $q_{\text{new}} = (1,150 - 65) \div 1.68956 = 642.2 \text{ W/m}^2$; $Q_{\text{new}} = 642.2 \times 120 = 77.1 \text{ kW}$; saving = $168.3 - 77.1 = 91.3 \text{ kW}$; annual = $91.3 \times 8,000 = 7,30,214 \text{ kWh} = 62,79,84,308 \text{ kcal}$; fuel = $62,79,84,308 \div (0.55 \times 10,200) = 1,11,940 \text{ kg}$; ₹ = $1,11,940 \times 46$.

Result: **new flux = 642.2 W/m²; wall loss falls from 168.3 kW to 77.1 kW (54% less); fuel saving $\approx$ 111.9 t/yr of furnace oil, worth ₹ 51.49 lakh a year.** The available-heat factor matters: each kW of wall loss costs about $1 \div 0.55 = 1.82 \text{ kW}$ of fuel because part of every unit of fuel heat leaves with the flue gas. (3 marks)

(d) [2 marks]

Substitution: $T_{12} = 1,150 - 642.2 \times 0.17692 = 1036.4 \text{ }^\circ\text{C}$; insulating brick cold face = $1036.4 - 642.2 \times 0.57500 = 667.1 \text{ }^\circ\text{C}$ (this is now the hot face of the fibre board).

Result: **the insulating brick's hot face rises to 1036 °C, ABOVE its 1,000 °C service limit, so the retrofit is not acceptable as proposed** (the fibre board's hot face at 667 °C is within its own rating). To keep the brick at or below 1,000 °C, q must be at least $(1,150 - 1,000) \div 0.17692 = 848 \text{ W/m}^2$, i.e. $\Sigma R \leq (1,150 - 65) \div 848 = 1.2797 \text{ m}^2 \cdot \text{K/W}$, so the board may be at most about 42 mm thick; alternatively upgrade the insulating brick to a higher-temperature grade and keep the 75 mm board.

Practical points (any two): adding insulation raises the temperature of every inner layer, so each material must be checked against its service limit, as shown here; avoid air gaps and seal joints so hot gases do not bypass the insulation; allow for casing expansion; and repair openings, doors and peep-holes, since radiation and gas leakage through openings often exceed wall losses. (2 marks)

Marking scheme (10 marks): a) Resistances 1, flux 1, total loss 1. b) Interface temperatures 1, comment 1. c) New flux and loss 1, heat saved 1, fuel and cost 1. d) New interface temperatures 1, two practical points 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 3 – Basics of Energy and its Various Forms.

..... End of Section III

Answer key — Section I

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	a	11	b	21	a	31	a	41	d
2	d	12	b	22	d	32	d	42	a
3	b	13	d	23	d	33	a	43	c
4	c	14	d	24	c	34	b	44	b
5	a	15	a	25	b	35	c	45	b
6	c	16	c	26	a	36	b	46	c
7	a	17	a	27	d	37	d	47	c
8	b	18	b	28	d	38	c	48	d

9	c	19	b	29	a	39	b	49	b
10	a	20	c	30	d	40	a	50	c