

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

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

Question code: 4P1CEM001 – 4P1CEM064 | 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 DISCOM's DSM programme cuts coincident peak demand by 120 MW at consumer meters. At peak, T&D losses are 18% of the energy sent out and station auxiliary consumption is 8% of gross generation. How much gross generating capacity does the programme avoid?

[4P1CEM001 | Chapter 1: Energy Scenario | Demand side management - saving expressed as avoided generating capacity]

- a) 146.3 MW
- b) 162.2 MW
- c) 159.1 MW
- d) 152.9 MW

Correct answer: (c) 159.1 MW.

Given: saving at meters = 120 MW; T&D loss = 18% of energy sent out; auxiliary = 8% of gross generation.

Formula: gross capacity = saving ÷ [(1 – T&D loss) × (1 – auxiliary fraction)].

Substitution: $120 \div (0.82 \times 0.92) = 120 \div 0.7544$.

Result: **159.1 MW** of gross capacity is avoided.

This is why the guidebook says DSM savings are treated as equivalent to new supply-side additions in MW. Each MW saved at the meter relieves more than one MW at the generator, along with its capital cost and fuel.

Why the other options are wrong: (a) 146.3 MW – allows for T&D losses but forgets station auxiliary consumption. (b) 162.2 MW – adds the two percentages and divides once, which is not how losses in series combine. (d) 152.9 MW – multiplies by (1 + loss) instead of dividing by (1 – loss).

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

2. Which statement about the power sector reforms brought by the Electricity Act, 2003 is NOT correct?

[4P1CEM002 | Chapter 1: Energy Scenario | Energy sector reforms - Electricity Act, 2003]

- a) It provided open access to transmission and, in phases, distribution
- b) It removed licensing for thermal generation projects in most cases
- c) It made metering of all electricity supplied to consumers compulsory

d) It made a licence compulsory for every new captive power plant

Correct answer: (d) It made a licence compulsory for every new captive power plant.

The guidebook's section on energy sector reforms lists the main features of the Electricity Act, 2003. Generation was delicensed, except that hydro projects need clearance. Captive generation was freely permitted, with no licence needed for a captive plant or its dedicated transmission lines.

The Act also provided for open access in transmission, and in distribution in phases. It made the State Commissions responsible for tariffs, made metering of all supply compulsory and recognised power trading as a distinct activity.

The option that says a licence is compulsory for captive plants reverses the Act's intent of encouraging industry to generate its own power, so it is the incorrect statement.

Why the other options are wrong: (a) This is correct; open access is a central feature of the Act. (b) This is correct; thermal generation was delicensed. (c) This is correct; the Act requires metering of all supply.

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

3. A coal-fired station has a gross heat rate of 2,450 kcal/kWh ($\approx 10,258$ kJ/kWh), auxiliary consumption of 7% and supplies a network with 17% T&D losses. Coal GCV is 3,600 kcal/kg ($\approx 15,072$ kJ/kg). How much coal is saved at the station for every kWh saved at the consumer's end?

[4P1CEM003 | Chapter 1: Energy Scenario | Primary fuel saved per kWh saved at the consumer end]

- a) 0.88 kg
- b) 0.85 kg
- c) 0.82 kg
- d) 0.68 kg

Correct answer: (a) 0.88 kg.

Given: gross heat rate = 2,450 kcal/kWh ($\approx 10,258$ kJ/kWh); auxiliary = 7%; T&D loss = 17%; coal GCV = 3,600 kcal/kg ($\approx 15,072$ kJ/kg).

Formula: coal per kWh delivered = heat rate $\div [(1 - \text{aux})(1 - \text{T\&D}) \times \text{GCV}]$.

Substitution: $2,450 \div (0.93 \times 0.83 \times 3,600) = 2,450 \div 2,778.8$.

Result: **0.88 kg of coal per kWh** saved at the consumer.

One kWh at the meter is only 860 kcal of useful energy, but it needs about 3,170 kcal of coal at the station. End-use savings therefore save three to four times as much primary energy.

Why the other options are wrong: (b) 0.85 kg – adds 7% and 17% to the heat rate instead of dividing by $(1 - \text{loss})$. (c) 0.82 kg – allows for T&D losses but forgets the station auxiliary consumption. (d) 0.68 kg – uses the heat rate alone and ignores auxiliary and T&D losses.

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

4. Pick the inaccurate description of how prices of electricity, gas and coal are set in India.

[4P1CEM004 | Chapter 1: Energy Scenario | Energy pricing in India]

- a) Electricity tariffs for all consumer categories are fixed by the Central Government
- b) Farm and household supply is often cross-subsidised through industrial tariffs
- c) Natural gas from different sources has been sold at different prices
- d) Coal is priced according to the grade, or calorific value, of the coal

Correct answer: (a) Electricity tariffs for all consumer categories are fixed by the Central Government.

The guidebook's section on energy pricing explains that retail electricity tariffs are set by the State Electricity Regulatory Commissions for the DISCOMs in their state. The Central Commission regulates only inter-state generation and transmission tariffs.

Tariffs for agriculture and households are commonly kept below cost and cross-subsidised by industrial and commercial consumers. This weakens the price signal for efficiency in the subsidised categories. Gas has had administered and market prices side by side, and coal prices depend on grade.

The statement giving the Central Government the power to fix every consumer tariff is therefore wrong.

Why the other options are wrong: (b) This is correct; cross-subsidy from industry is common. (c) This is correct; administered and market-priced gas have coexisted. (d) This is correct; coal prices depend on grade.

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

5. Section 13 of the EC Act lists what BEE does, while Section 14 lists what the Centre may do. Which item falls under Section 14?

[4P1CEM005 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | EC Act - powers of the Central Government (Section 14) versus functions of BEE (Section 13)]

- a) Arranging and organising training of personnel and specialists in energy conservation
- b) Specifying the qualifications and the accreditation procedure for energy auditors
- c) Specifying energy consumption norms and standards for the designated consumers
- d) Developing testing and certification procedures and promoting testing facilities

Correct answer: (c) Specifying energy consumption norms and standards for the designated consumers.

The Act separates roles. Section 13 lists BEE's functions, which are mostly technical and promotional. They include recommending norms, training personnel, specifying qualifications for accredited energy auditors, developing testing and certification procedures, running awareness programmes and supporting pilot projects.

Section 14 gives the Central Government, in consultation with BEE, the power to act. It notifies energy-intensive industries as designated consumers, specifies their energy consumption norms and standards, directs them to appoint energy managers and get audits done, and notifies labelling and standards for equipment.

Fixing norms for designated consumers is therefore a Section 14 power.

Why the other options are wrong: (a) This option is a BEE function listed under Section 13. (b) This option is a BEE function listed under Section 13. (d) This option is a BEE function listed under Section 13.

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

6. Which statement about the State Energy Conservation Fund under Section 16 of the EC Act is correct?

[4P1CEM006 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | State Energy Conservation Fund (Section 16)]

- a) It is financed only from the penalties collected under Section 26
- b) It is constituted by the State Government and can receive Central grants
- c) It must be set up only by states that have designated consumers
- d) It is managed by BEE and can be used only by designated consumers

Correct answer: (b) It is constituted by the State Government and can receive Central grants.

Section 16 of the EC Act requires every State Government to constitute a State Energy Conservation Fund to promote the efficient use of energy and its conservation within the state.

The fund is credited with grants and loans from the State Government, the Central Government or any other organisation or individual. It is applied as the State Government decides, for example for demonstration projects, audits in the public sector or awareness programmes. The State designated agency usually helps administer it.

The fund is a state-level mechanism and works alongside the Central Energy Conservation Fund that BEE administers.

Why the other options are wrong: (a) This option is wrong because the fund receives grants and loans from governments and other bodies. (c) This option is wrong because Section 16 applies to every State Government. (d) This option is wrong because the State, not BEE, constitutes and administers the fund.

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

7. A designated consumer is penalised for not complying with its notified energy consumption norms. Under the EC Act, who holds the inquiry and imposes the penalty, and where does the first appeal lie?

[4P1CEM007 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Adjudication of penalties and appeals under the EC Act]

- a) The designated agency of the State; appeal lies directly to the High Court
- b) The Director General of BEE himself; appeal lies to the Union Ministry of Power
- c) An adjudicating officer of the State Commission; appeal to the Appellate Tribunal for Electricity

d) The Central Electricity Authority; appeal lies to the Central Electricity Regulatory Commission

Correct answer: (c) An adjudicating officer of the State Commission; appeal to the Appellate Tribunal for Electricity.

Section 27 of the EC Act states that penalties are adjudicated by a member of the State Electricity Regulatory Commission appointed as the adjudicating officer. The officer holds an inquiry after a hearing.

Under Sections 30 and 31, the Appellate Tribunal for Electricity set up under the Electricity Act, 2003 hears appeals against the adjudicating officer's orders. A further appeal lies to the Supreme Court.

This keeps adjudication with the quasi-judicial electricity regulators rather than with BEE or the designated agencies, whose roles are promotional and administrative.

Why the other options are wrong: (a) This option is wrong because the designated agency enforces the Act but does not adjudicate penalties. (b) This option is wrong because BEE has no power to adjudicate penalties under the Act. (d) This option is wrong because neither body has an adjudication role under the EC Act.

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

8. Which statement on the Bureau of Energy Efficiency (BEE) is WRONG?

[4P1CEM008 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Bureau of Energy Efficiency - constitution and mission]

- a) Its mission is to reduce the energy intensity of the economy
- b) It works with State designated agencies to enforce the Act
- c) It was set up on 1 March 2002 under the EC Act, 2001
- d) Its Governing Council is chaired by the Director General of BEE

Correct answer: (d) Its Governing Council is chaired by the Director General of BEE.

BEE was set up on 1 March 2002 under the Energy Conservation Act, 2001 as a statutory body under the Ministry of Power. Its mission is to help develop policies and strategies, with a thrust on self-regulation and market principles, that reduce the energy intensity of the Indian economy.

BEE's Governing Council is chaired by the Union Minister of Power. Members include secretaries of the energy ministries, representatives of the Central Electricity Authority and industry, and others. The Director General is the Council's Member-Secretary, not its chairperson.

At state level, the Act is enforced through the designated agencies, which work with BEE.

Why the other options are wrong: (a) This is correct; it is BEE's stated mission. (b) This is correct; the designated agencies enforce it within each state. (c) This is correct.

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

9. A 14.2 kg LPG cylinder holds a 50:50 mixture of propane (C_3H_8) and butane (C_4H_{10}) by mass. Taking 22.4 Nm^3 per kmol, what volume of vapour at NTP does the full charge correspond to?

[4P1CEM009 | Chapter 3: Basics of Energy and its Various Forms | Moles and gas volume at NTP - LPG vapour]

- a) 3.12 Nm^3
- b) 5.48 Nm^3
- c) 6.36 Nm^3
- d) 7.23 Nm^3

Correct answer: (c) 6.36 Nm^3 .

Given: 7.1 kg propane ($M = 44$) and 7.1 kg butane ($M = 58$); $1 \text{ kmol} = 22.4 \text{ Nm}^3$.

Formula: moles = mass ÷ molecular weight; volume at NTP = total kmol × 22.4.

Substitution: $7.1 \div 44 = 0.1614 \text{ kmol}$; $7.1 \div 58 = 0.1224 \text{ kmol}$; total = 0.2838 kmol ; × 22.4.

Result: **6.36 Nm^3** of vapour.

When a mixture is given by mass, find the moles of each component separately. Averaging molecular weights wrongly is a common slip.

Why the other options are wrong: (a) 3.12 Nm^3 – divides by the sum of the two molecular weights instead of finding moles of each. (b) 5.48 Nm^3 – treats the whole charge as butane. (d) 7.23 Nm^3 – treats the whole charge as propane.

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

10. An EOT crane in a steel stockyard lowers a 20 t load through 15 m about 40 times per shift, on three shifts a day for 300 days a year. A regenerative drive returns the lowering energy to the plant bus with an overall gearbox, motor and inverter efficiency of 80%. About how much electricity does it return in a year?

[4P1CEM010 | Chapter 3: Basics of Energy and its Various Forms | Energy conversion - potential energy recovered by a regenerative crane drive]

- a) 7,848 kWh/year
- b) 23,544 kWh/year
- c) 36,787 kWh/year
- d) 29,430 kWh/year

Correct answer: (b) 23,544 kWh/year.

Given: $m = 20,000 \text{ kg}$; $h = 15 \text{ m}$; $g = 9.81 \text{ m/s}^2$; cycles = $40 \times 3 \times 300 = 36,000 \text{ a year}$; $\eta = 0.80$.

Formula: potential energy per lowering = $m \times g \times h \text{ (J)}$; kWh = $J \div 36,00,000$; energy returned = $PE \times \eta \times \text{cycles}$.

Substitution: $20,000 \times 9.81 \times 15 = 29,43,000 \text{ J} = 0.8175 \text{ kWh}$; $0.8175 \times 0.80 \times 36,000$.

Result: $\approx \mathbf{23,544 \text{ kWh/year}}$ returned to the bus.

With a conventional drive, the same energy is burnt as heat in braking resistors. Energy conversion from potential to electrical form is never complete, so the efficiency chain must be applied in the direction of energy flow.

Why the other options are wrong: (a) 7,848 kWh/year – counts only one shift a day instead of three. (c) 36,787 kWh/year – divides by the efficiency as if the drive were consuming power. (d) 29,430 kWh/year – ignores the 80% conversion efficiency.

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

11. A 230 V, 50 Hz single-phase load behaves as a resistance of 12Ω in series with an inductive reactance of 9Ω . What are its power factor and active power?

[4P1CEM011 | Chapter 3: Basics of Energy and its Various Forms | Series R-L circuit - current, power factor and active power]

- a) 0.80 lagging and 3.53 kW
- b) 0.60 lagging and 2.12 kW
- c) 0.80 lagging and 2.82 kW
- d) 0.80 leading and 2.82 kW

Correct answer: (c) 0.80 lagging and 2.82 kW.

Given: $R = 12 \Omega$; $X_L = 9 \Omega$; $V = 230 \text{ V}$.

Formula: $Z = \sqrt{R^2 + X_L^2}$; $I = V \div Z$; $PF = R \div Z$; $P = I^2 R = V I \cos \phi$.

Substitution: $Z = \sqrt{144 + 81} = 15 \Omega$; $I = 230 \div 15 = 15.33 \text{ A}$; $PF = 12 \div 15 = 0.80$; $P = 15.33^2 \times 12 = 2,821 \text{ W}$.

Result: **PF = 0.80 lagging; P = 2.82 kW** (apparent power 3.53 kVA).

A circuit combining resistance and inductance always has a power factor below unity and lagging.

Why the other options are wrong: (a) Gives the apparent power $V \times I$ in kVA, not the active power. (b) This option takes $X \div Z$, which is $\sin \phi$, as the power factor. (d) Calls an inductive load leading; current lags voltage in an inductive circuit.

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

12. A 48 V, 200 Ah battery bank feeds a 600 W load through an inverter with 90% efficiency. If the battery is limited to 80% depth of discharge, for how long can it supply the load?

[4P1CEM012 | Chapter 3: Basics of Energy and its Various Forms | Electrical energy stored in a battery bank and backup time]

- a) 11.5 hours
- b) 14.4 hours
- c) 12.8 hours
- d) 16.0 hours

Correct answer: (a) 11.5 hours.

Given: $V = 48 \text{ V}$; capacity = 200 Ah; DoD = 0.80; inverter $\eta = 0.90$; load = 0.6 kW.

Formula: stored energy = $V \times \text{Ah} \div 1,000$; usable AC energy = stored $\times \text{DoD} \times \eta$; time = usable $\div$ load.

Substitution: $48 \times 200 \div 1,000 = 9.6 \text{ kWh}$; $\times 0.8 \times 0.9 = 6.912 \text{ kWh}$; $\div 0.6 \text{ kW}$.

Result: **11.5 hours** of backup (24.9 MJ usable).

Energy (kWh) is the product of voltage and charge (Ah). Every conversion stage reduces what reaches the load.

Why the other options are wrong: (b) 14.4 hours – applies the inverter efficiency but ignores the 80% depth-of-discharge limit. (c) 12.8 hours – applies the depth-of-discharge limit but forgets the inverter loss. (d) 16.0 hours – uses the full nameplate energy with no depth-of-discharge or inverter loss.

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

13. During a walk-through audit, the LED on a whole-current energy meter (meter constant 1,600 impulses/kWh) flashes 45 times in 75 seconds. What is the average load on the meter?

[4P1CEM013 | Chapter 3: Basics of Energy and its Various Forms | Load measurement from energy meter pulses]

a) 2.16 kW

b) 1.08 kW

c) 1.69 kW

d) 1.35 kW

Correct answer: (d) 1.35 kW.

Given: meter constant = 1,600 imp/kWh; pulses = 45; time = 75 s.

Formula: energy = pulses $\div$ meter constant; average power = energy $\div$ time (h).

Substitution: $45 \div 1,600 = 0.028125 \text{ kWh}$; $75 \text{ s} = 0.02083 \text{ h}$; $0.028125 \div 0.02083$.

Result: **average load = 1.35 kW.**

This quick check lets an auditor confirm a load without breaking into the circuit. On a CT-operated meter, the result must also be multiplied by the meter's multiplying factor.

Why the other options are wrong: (a) 2.16 kW – takes the constant as 1,000 impulses per kWh, i.e. one Wh per flash. (b) 1.08 kW – multiplies by an assumed PF of 0.8, but a kWh meter already registers active energy. (c) 1.69 kW – times the flashes over 60 seconds instead of the measured 75 seconds.

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

14. An uninsulated hot-water tank has an outer surface area of 24 m² at 75 °C, standing in still air at 30 °C. The combined convective and radiative surface heat transfer coefficient is 11 W/m²K and the tank is in service 8,000 h a year. What is the annual heat lost from its surface?

[4P1CEM014 | Chapter 3: Basics of Energy and its Various Forms | Convective and radiative surface heat loss from an uninsulated tank]

a) 95,040 kWh

b) 1,58,400 kWh

c) 1,04,069 kWh

d) 1,18,800 kWh

Correct answer: (a) 95,040 kWh.

Given: $A = 24 \text{ m}^2$; $h = 11 \text{ W/m}^2\text{K}$; surface 75 °C, air 30 °C, so $\Delta T = 45 \text{ K}$; 8,000 h/yr.

Formula: $Q = h \times A \times \Delta T$ (watts); annual loss = Q (kW) $\times$ hours.

Substitution: $Q = 11 \times 24 \times 45 = 11,880 \text{ W} = 11.88 \text{ kW}$; $11.88 \times 8,000$.

Result: **annual surface heat loss = 95,040 kWh** ($\approx 342 \text{ GJ}$).

Heat flow by convection depends on the temperature difference between surface and surroundings. Insulating the tank cuts this loss by about 80–90%.

Why the other options are wrong: (b) 1,58,400 kWh – uses the surface temperature itself instead of the temperature difference to the air. (c) 1,04,069 kWh – uses 8,760 hours instead of the 8,000 service hours given. (d) 1,18,800 kWh – divides by an assumed 80% boiler efficiency, which gives fuel input, not surface heat loss.

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

15. An aluminium vessel weighing 5 kg (specific heat 0.215 kcal/kg°C (≈ 0.900 kJ/kg·K)) holds 2 kg of water. Both are heated together from 25 °C to 95 °C. What share of the heat supplied (ignoring losses) goes into the vessel itself?

[4P1CEM015 | Chapter 3: Basics of Energy and its Various Forms | Specific heat - heat absorbed by a vessel and its contents]

- a) 17.7%
- b) 71.4%
- c) 65.0%
- d) 35.0%

Correct answer: (d) 35.0%.

Given: vessel 5 kg, $C_p = 0.215$ kcal/kg°C (≈ 0.900 kJ/kg·K); water 2 kg, $C_p = 1$ kcal/kg°C (≈ 4.19 kJ/kg·K); $\Delta T = 70$ °C.

Formula: $Q = m \times C_p \times \Delta T$ for each body; share = $Q(\text{vessel}) \div Q(\text{total}) \times 100$.

Substitution: $Q(\text{vessel}) = 5 \times 0.215 \times 70 = 75.25$ kcal; $Q(\text{water}) = 2 \times 1 \times 70 = 140$ kcal; share = $75.25 \div 215.25 \times 100$.

Result: **35.0%** of the heat goes into the vessel (75.25 kcal (≈ 315 kJ) of 215.25 kcal (≈ 901 kJ)).

Even beside water's high specific heat, a heavy vessel absorbs a large share, so batch heating loses much energy to equipment mass.

Why the other options are wrong: (a) 17.7% – splits by specific heat only and ignores the masses. (b) 71.4% – splits the heat by mass only and ignores the specific heats. (c) 65.0% – gives the water's share instead of the vessel's.

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

16. A process heater needs 4,50,000 kcal/h (≈ 523 kW). It can be served by saturated steam at 4 kg/cm²(g) (saturation 151 °C, latent heat 504 kcal/kg ($\approx 2,110$ kJ/kg), total enthalpy 656 kcal/kg ($\approx 2,747$ kJ/kg)) with the condensate leaving at saturation, or by pressurised hot water cooled from 130 °C to 100 °C (specific heat 1.0 kcal/kg °C (≈ 4.19 kJ/kg·K)). About how many kg of hot water must circulate for every kg of steam it replaces?

[4P1CEM016 | Chapter 3: Basics of Energy and its Various Forms | Heat carriers - hot water circulation needed to replace condensing steam]

- a) 18.5 kg
- b) 21.9 kg
- c) 24.0 kg
- d) 16.8 kg

Correct answer: (d) 16.8 kg.

Given: duty = 4,50,000 kcal/h (≈ 523 kW); latent heat = 504 kcal/kg ($\approx 2,110$ kJ/kg); water 130 → 100 °C.

Formula: steam = duty ÷ latent heat; water = duty ÷ ($C_p \times \Delta T$); ratio = water ÷ steam = latent heat ÷ ΔT .

Substitution: steam = $4,50,000 \div 504 = 892.9$ kg/h; water = $4,50,000 \div 30 = 15,000$ kg/h; ratio = $504 \div 30$.

Result: **≈ 16.8 kg of hot water per kg of steam.**

Hot-water systems therefore need much larger pumps and pipes for the same duty.

Why the other options are wrong: (a) 18.5 kg – credits the steam with condensate cooling to 100 °C, but the condensate leaves at saturation. (b) 21.9 kg – uses the total enthalpy of steam instead of the latent heat it gives up. (c) 24.0 kg – uses the steam-to-water temperature gap instead of the water temperature drop.

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

17. Which statement on conduction, convection and radiation is WRONG?

[4P1CEM017 | Chapter 3: Basics of Energy and its Various Forms | Modes of heat transfer]

- a) Convection can carry heat across a vacuum with no material medium present
- b) Radiation needs no medium and can carry heat across a vacuum
- c) Natural convection is driven by density differences arising from temperature differences
- d) Conduction transfers heat through a solid by molecular contact without bulk motion

Correct answer: (a) Convection can carry heat across a vacuum with no material medium present.

The guidebook describes three modes of heat transfer.

Conduction is heat flow through a substance, mainly solids, by molecular interaction with no bulk movement of the material, as in a furnace wall.

Convection is heat transfer by the bulk movement of a fluid, liquid or gas. In natural convection the movement comes from density differences caused by heating. In forced convection a fan or pump drives it. Without a fluid there can be no convection.

Radiation is transfer by electromagnetic waves. It needs no medium and is the only mode that works across a vacuum. It dominates at high temperatures, as in furnaces.

The statement that convection works across a vacuum is therefore wrong.

Why the other options are wrong: (b) This is correct; this is how solar energy reaches the earth. (c) This is correct. (d) This is correct.

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

18. A plant's monthly bill has a demand charge of ₹400/kVA on 1,000 kVA, an energy charge of ₹7.00/kWh on 3,00,000 kWh, and electricity duty of 5% on the energy charge only. An energy conservation measure will save 20,000 kWh a month without changing the maximum demand. What is the monthly bill saving?

[4P1CEM018 | Chapter 4: Energy Management and Audit | Understanding energy costs - valuing kWh savings at the marginal, not the average, tariff]

a) ₹1,73,667

b) ₹1,58,111

c) ₹1,47,000

d) ₹1,40,000

Correct answer: (c) ₹1,47,000.

Given: demand charge ₹400/kVA on 1,000 kVA; energy ₹7.00/kWh plus 5% duty; saving 20,000 kWh with no change in maximum demand.

Formula: bill saving = kWh saved × marginal rate; marginal rate = energy charge × (1 + duty).

Substitution: marginal rate = $7.00 \times 1.05 = ₹7.35/\text{kWh}$; $20,000 \times 7.35$.

Result: **saving = ₹1,47,000 a month.**

Understanding the tariff structure is part of every audit. Savings must be priced at the charges they actually avoid.

Why the other options are wrong: (a) ₹1,73,667 – values the kWh at the average bill rate, which wrongly includes the unchanged demand charge. (b) ₹1,58,111 – also credits a demand reduction equal to the average load saved, though the maximum demand does not change. (d) ₹1,40,000 – uses the energy charge but leaves out the 5% duty levied on it.

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

19. Logging shows a 60 kW electric curing oven runs at full load for a 2-hour heat-up each day. Its heaters are then ON for 40% of the time during the remaining 16-hour holding period. For 300 working days a year, what is the oven's annual energy use?

[4P1CEM019 | Chapter 4: Energy Management and Audit | Estimating annual energy from a measured duty cycle]

a) 2,08,800 kWh

b) 1,29,600 kWh

c) 1,51,200 kWh

d) 3,24,000 kWh

Correct answer: (c) 1,51,200 kWh.

Given: rating = 60 kW; heat-up = 2 h at 100%; holding = 16 h at 40% duty; 300 days/yr.

Formula: daily kWh = kW × (heat-up h + duty × holding h); annual = daily × days.

Substitution: $60 \times 2 = 120 \text{ kWh}$; $60 \times 0.4 \times 16 = 384 \text{ kWh}$; $(120 + 384) \times 300$.

Result: **1,51,200 kWh/yr (544 GJ).**

Annual energy estimates from nameplate ratings overstate use badly. A detailed audit therefore logs actual duty cycles before working out savings from insulation or controls.

Why the other options are wrong: (a) 2,08,800 kWh – uses the 60% OFF time as if it were the ON time. (b) 1,29,600 kWh – applies the 40% duty cycle to the heat-up period as well. (d) 3,24,000 kWh – applies the full rated load to all 18 operating hours.

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

20. A company's production cost is 92% of its sales revenue, so its profit is 8% of sales. Energy makes up 22% of the production cost. If an energy audit cuts energy cost by 10% with output and prices unchanged, by what percentage does profit rise?

[4P1CEM020 | Chapter 4: Energy Management and Audit | Leverage of energy saving on profit - why energy audits pay]

- a) 25.3%
- b) 20.2%
- c) 10.0%
- d) 27.5%

Correct answer: (a) 25.3%.

Given: production cost = 0.92 S; profit = 0.08 S; energy = 22% of production cost; saving = 10% of energy cost.

Formula: rise in profit (%) = saving ÷ original profit × 100.

Substitution: energy cost = $0.22 \times 0.92 \text{ S} = 0.2024 \text{ S}$; saving = $0.1 \times 0.2024 \text{ S} = 0.02024 \text{ S}$; rise = $0.02024 \div 0.08 \times 100$.

Result: **profit rises by 25.3%.**

The guidebook makes this point about the need for energy audits. Energy is one of the top three operating costs, and savings flow straight to profit, so a modest cut in energy cost raises profit several times over.

Why the other options are wrong: (b) 20.2% – divides the saving by the new, higher profit instead of the original profit. (c) 10.0% – assumes profit rises by the same percentage as the energy saving. (d) 27.5% – applies the 22% energy share to sales instead of to production cost.

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

21. A plant's trivector meter records maximum demand as the average kVA over each 30-minute block. In one block the base load is a steady 800 kVA, and a 600 kVA induction furnace runs for only the first 10 minutes of that block. What maximum demand does the meter record for the block?

[4P1CEM021 | Chapter 4: Energy Management and Audit | Understanding energy costs - how a short peak sets the recorded maximum demand]

- a) 1,400 kVA
- b) 1,000 kVA
- c) 1,100 kVA
- d) 1,200 kVA

Correct answer: (b) 1,000 kVA.

Given: block = 30 min; base = 800 kVA for the whole block; furnace 600 kVA for 10 min.

Formula: recorded MD = $\Sigma (\text{kVA} \times \text{minutes}) \div \text{block length}$.

Substitution: $(800 \times 30 + 600 \times 10) \div 30 = 800 + 600 \times 10 \div 30$.

Result: **recorded MD = 1,000 kVA.**

At ₹450/kVA a month, this single short run adds ₹90,000 to the demand charge. Staggering large loads across blocks controls it.

Why the other options are wrong: (a) 1,400 kVA – takes the instantaneous peak; the meter records the block average, not the momentary maximum. (c) 1,100 kVA – averages the base and peak loads, ignoring how long the furnace actually ran. (d) 1,200 kVA – assumes a 15-minute integration period instead of the 30-minute block stated.

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

22. An oil expeller crushes 10 t/h of oilseed containing 40% oil by mass. The press cake leaving the expeller still contains 8% oil by mass. Assuming the expelled oil carries no solids, how much oil is recovered?

[4P1CEM022 | Chapter 5: Material and Energy Balance | Material balance - oil recovery in an expeller]

- a) 3.68 t/h
- b) 3.48 t/h
- c) 3.20 t/h

d) 3.52 t/h

Correct answer: (b) 3.48 t/h.

Given: feed = 10 t/h with 40% oil, so oil = 4 t/h and oil-free solids = 6 t/h; cake = 8% oil.

Formula: tie element = oil-free solids (all go to the cake): cake = solids ÷ (1 – 0.08); oil recovered = oil in feed – oil in cake.

Substitution: cake = 6 ÷ 0.92 = 6.522 t/h; oil in cake = 6.522 × 0.08 = 0.522 t/h; recovered = 4 – 0.522.

Result: **3.48 t/h of oil** (recovery 87.0%).

Choosing the component that passes unchanged into one stream as the tie element makes the balance a one-step calculation.

Why the other options are wrong: (a) 3.68 t/h – assumes 8% of the oil is lost, misreading the cake composition. (c) 3.20 t/h – takes 8% of the seed feed, not of the cake, as the oil lost. (d) 3.52 t/h – takes 8% of the oil-free solids as the oil lost, ignoring the cake basis.

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

23. Dry flue gas from a boiler contains 12% CO₂, 6% O₂ and 82% N₂ by volume. What are its mean molecular weight and its density at NTP (22.4 Nm³ per kmol)?

[4P1CEM023 | Chapter 5: Material and Energy Balance | Mean molecular weight and density of a gas mixture]

a) 30.16 kg/kmol and 1.35 kg/Nm³

b) 29.51 kg/kmol and 1.32 kg/Nm³

c) 30.16 kg/kmol and 0.74 kg/Nm³

d) 34.67 kg/kmol and 1.55 kg/Nm³

Correct answer: (a) 30.16 kg/kmol and 1.35 kg/Nm³.

Given: volume (mole) fractions CO₂ 0.12 (M = 44), O₂ 0.06 (M = 32), N₂ 0.82 (M = 28).

Formula: mean M = Σ (mole fraction × M); density at NTP = M ÷ 22.4.

Substitution: 0.12 × 44 + 0.06 × 32 + 0.82 × 28 = 5.28 + 1.92 + 22.96; density = 30.16 ÷ 22.4.

Result: **M = 30.16 kg/kmol; ρ = 1.346 kg/Nm³.**

For gases, volume fraction equals mole fraction, so a volume analysis is weighted directly. Mass fractions would need a harmonic average.

Why the other options are wrong: (b) This option treats the volume percentages as mass percentages. (c) This option inverts the density formula, giving specific volume in Nm³/kg. (d) This option takes a simple average of the three molecular weights.

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

24. A rolling mill must deliver 50 t of finished bars. Scale loss in the reheating furnace is 1.5% of the billet weight charged, and crop ends and cobbles in the mill are 4% of the hot billet weight entering the mill. What weight of billets must be charged to the furnace?

[4P1CEM024 | Chapter 5: Material and Energy Balance | Material balance across process stages in series - billet requirement with scale and crop losses]

a) 47.28 t

b) 52.88 t

c) 50.76 t

d) 52.75 t

Correct answer: (b) 52.88 t.

Given: product = 50 t; furnace yield = 1 – 0.015 = 0.985; mill yield = 1 – 0.04 = 0.96.

Formula: input = output ÷ (yield of stage 1 × yield of stage 2), working backwards stage by stage.

Substitution: hot billets into mill = 50 ÷ 0.96 = 52.083 t; billets charged = 52.083 ÷ 0.985.

Result: **billets charged ≈ 52.88 t.**

Each loss is a share of the stream entering its stage, so work backwards from the product. Scale lost was also heated, so yield loss is energy loss.

Why the other options are wrong: (a) 47.28 t – multiplies by the yields instead of dividing, which gives the output from 50 t of billets. (c) 50.76 t – allows for the furnace scale loss but forgets the crop and cobble loss in the mill. (d) 52.75 t – adds the two percentages to the output, but each loss is a share of what enters its own stage.

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

25. Select the **WRONG** statement about good practice in preparing material and energy balances.

[4P1CEM025 | Chapter 5: Material and Energy Balance | Good practice in drawing up material and energy balances]

- a) Fix the system boundary and a basis, such as one hour, before starting
- b) Put every stream into consistent units before adding inputs and outputs
- c) Heats of reaction can be ignored, since a balance counts sensible heat only
- d) Show recycle streams and losses so that inputs equal outputs plus accumulation

Correct answer: (c) Heats of reaction can be ignored, since a balance counts sensible heat only.

The guidebook's method for material and energy balances starts with a process flow chart. You then fix the system boundary and choose a basis, such as one hour, one batch or one tonne of product.

All quantities must be in consistent units before they are added. The general balance is input = output + accumulation, where any loss counts as an output. Recycle and bypass streams must be shown so that no stream is counted twice or left out.

An energy balance must include all forms of energy: sensible and latent heat, heats of reaction (exothermic or endothermic), electrical and mechanical inputs, and losses. Leaving out heat of reaction would distort the balance for kilns, reactors and furnaces.

Why the other options are wrong: (a) This is correct practice. (b) This is correct practice. (d) This is correct practice.

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

26. In an ISO 50001 energy management system, which of the following is **NOT** an output of the energy review?

[4P1CEM026 | Chapter 6: Energy Action Planning | ISO 50001 energy review - outputs]

- a) A list of significant energy uses and their relevant variables
- b) A certificate of conformity issued by the certification body
- c) An estimate of future energy use and energy consumption
- d) Prioritised opportunities for improving the energy performance

Correct answer: (b) A certificate of conformity issued by the certification body.

The energy review is the analytical core of planning in ISO 50001. Based on measurement and other data, the organisation analyses its past and present energy use and consumption.

From this it identifies significant energy uses (SEUs), the relevant variables that affect them and the people whose work affects them. It also judges current energy performance, estimates future use and lists improvement opportunities in priority order.

These outputs feed the energy baseline, the energy performance indicators (EnPIs) and the objectives, targets and action plans.

A certificate of conformity comes much later, from an external audit by a certification body. It is not part of the energy review.

Why the other options are wrong: (a) This option is an output; identifying SEUs is central to the energy review. (c) This option is an output of the energy review. (d) This option is an output of the energy review.

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

27. A plant certified to ISO 50001 is buying a new 250 kW air compressor, which will be one of its significant energy uses. What does the standard require of the organisation when it procures such equipment?

[4P1CEM027 | Chapter 6: Energy Action Planning | ISO 50001 - procurement of energy-using equipment with a significant impact on energy performance]

- a) Buy only BEE star-labelled models, whatever their energy cost over the expected life
- b) Have the certification body approve the chosen model before the order is placed

- c) Choose the lowest-priced offer and check its energy use at the next internal audit
- d) Tell suppliers that energy performance is one of the criteria used to evaluate their offers

Correct answer: (d) Tell suppliers that energy performance is one of the criteria used to evaluate their offers.

ISO 50001 has a procurement requirement for energy services, products and equipment that have, or can have, a significant impact on energy performance.

The organisation must establish and apply criteria for evaluating energy performance over the planned or expected operating life. It must also inform suppliers that procurement is partly evaluated on energy performance.

For a compressor whose lifetime electricity cost is many times its purchase price, this pushes buyers to compare specific power (kW per m³/min) and life-cycle cost, not price alone.

Why the other options are wrong: (a) A label can be useful evidence, but the standard requires evaluation criteria, not any particular label. (b) The certification body audits the system; it does not approve individual purchases. (c) Price-only buying is exactly what the procurement clause is meant to stop; checking afterwards is too late.

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

28. An internal EnMS audit finds compressed-air leakage at 32% of generation against a 15% target, because the monthly leak survey was skipped for four months. Which response is a CORRECTIVE ACTION in ISO 50001 terms, rather than just a correction?

[4P1CEM028 | Chapter 6: Energy Action Planning | ISO 50001 - nonconformity: correction versus corrective action]

- a) Record the finding in the audit report and close it when the leakage figure improves
- b) Carry out a leak survey at once and repair every leak found in the network this week
- c) Raise the leakage target to 30% so that the plant's present performance becomes fully compliant
- d) Find out why the surveys lapsed and change the schedule or responsibility so it cannot recur

Correct answer: (d) Find out why the surveys lapsed and change the schedule or responsibility so it cannot recur.

ISO 50001 separates two responses to a nonconformity. A correction is action to eliminate the detected nonconformity itself, such as repairing the leaks found.

A corrective action eliminates the cause, so that the nonconformity does not recur. The organisation must review the nonconformity, find its root cause, decide and implement action, check whether similar problems exist elsewhere, review the effectiveness of the action and update the system if needed.

Here the root cause is a lapsed survey routine. Fixing the routine through schedule, ownership or reminders is the corrective action; repairing today's leaks is still needed, but only as the correction.

Why the other options are wrong: (a) Only documents the nonconformity; nothing is done about its cause. (b) This option is a correction: it fixes the present leaks but not the reason the surveys stopped. (c) Hides the nonconformity by moving the target, which defeats continual improvement.

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

29. An energy-efficiency retrofit will give net savings of ₹4.2 lakh at the end of each year for 6 years, with no salvage value. Management requires an IRR of at least 14%. What is the maximum investment that meets this hurdle?

[4P1CEM029 | Chapter 7: Financial Management | Maximum justified investment for a hurdle rate (present value of an annuity)]

- a) ₹30.00 lakh
- b) ₹16.33 lakh
- c) ₹25.20 lakh
- d) ₹14.42 lakh

Correct answer: (b) ₹16.33 lakh.

Given: A = ₹4.2 lakh/yr; n = 6 years; hurdle rate i = 14%.

Formula: at IRR = hurdle rate, NPV = 0, so maximum investment = $A \times [1 - (1 + i)^{-n}] \div i$.

Substitution: $[1 - 1.14^{-6}] \div 0.14 = (1 - 0.4556) \div 0.14 = 3.8887$; 4.2×3.8887 .

Result: **maximum investment = ₹16.33 lakh.**

Any cost above this gives a negative NPV at 14%, meaning an IRR below the hurdle.

Why the other options are wrong: (a) ₹30.00 lakh – treats the savings as a perpetuity, saving ÷ rate. (c) ₹25.20 lakh – adds the savings without discounting them. (d) ₹14.42 lakh – discounts only five years of savings instead of six.

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

30. A dairy plans to replace its ammonia chiller in 6 years at an estimated ₹12 lakh. It will put an equal sum into a deposit earning 8% a year at the END of each year, the last deposit falling on the replacement date. How much must be set aside each year?

[4P1CEM030 | Chapter 7: Financial Management | Sinking fund for planned equipment replacement (future value of an annuity)]

- a) ₹1.64 lakh
- b) ₹2.60 lakh
- c) ₹1.26 lakh
- d) ₹2.00 lakh

Correct answer: (a) ₹1.64 lakh.

Given: future sum $F = ₹12$ lakh; $n = 6$ end-of-year deposits; $i = 8\%$.

Formula: $F = A \times [(1 + i)^n - 1] \div i$, so $A = F \times i \div [(1 + i)^n - 1]$ (sinking fund factor).

Substitution: $1.08^6 = 1.5869$; $[(1.08)^6 - 1] \div 0.08 = 7.3359$; $A = 12 \div 7.3359$.

Result: **annual deposit = ₹1.64 lakh.**

The six deposits total ₹9.81 lakh; interest supplies the rest.

Why the other options are wrong: (b) ₹2.60 lakh – applies the capital recovery factor, which converts a present sum (a loan taken today) into instalments, not a future target. (c) ₹1.26 lakh – discounts the ₹12 lakh to today and then divides by 6, mixing a present value with a future-value problem. (d) ₹2.00 lakh – simply divides ₹12 lakh by 6 years and ignores the interest the deposits earn.

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

31. A captive waste-heat power project takes two years to build. Its net savings of ₹40 lakh a year begin at the end of year 3 and continue to the end of year 10. At a 12% discount rate, what is the present value today of these savings?

[4P1CEM031 | Chapter 7: Financial Management | Present value of savings that start only after a construction period (deferred annuity)]

- a) ₹141.43 lakh
- b) ₹198.71 lakh
- c) ₹158.41 lakh
- d) ₹226.01 lakh

Correct answer: (c) ₹158.41 lakh.

Given: $A = ₹40$ lakh/yr for 8 years (end of years 3 to 10); $i = 12\%$; deferral = 2 years.

Formula: $PV = A \times PVAF(i, 8) \div (1 + i)^2$, since the annuity formula gives the value one year before the first saving, at the end of year 2.

Substitution: $PVAF(12\%, 8) = 4.9676$; $40 \times 4.9676 = 198.71$; $\div 1.12^2 = \div 1.2544$.

Result: **PV ≈ ₹158.41 lakh.**

The delay alone cuts the value of the savings by about a fifth, which is why long gestation hurts energy projects.

Why the other options are wrong: (a) ₹141.43 lakh – discounts back three years, treating year 3 itself as part of the delay.

(b) ₹198.71 lakh – values the eight savings as if they began at the end of year 1, ignoring the two-year construction delay.

(d) ₹226.01 lakh – counts ten years of savings, including the two construction years when there are none.

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

32. For the sensitivity analysis of an energy project, the guidebook groups the variables into macro factors and micro factors. Which group lists ONLY macro factors?

[4P1CEM032 | Chapter 7: Financial Management | Sensitivity analysis - macro and micro factors]

- a) Changes in debt-equity ratio, O&M cost and capital cost
- b) Changes in interest rates, tax rates and accounting standards

c) Changes in tax rates, operating expenses and form of financing

d) Changes in interest rates, capital cost and debt-equity ratio

Correct answer: (b) Changes in interest rates, tax rates and accounting standards.

Sensitivity analysis tests how a project's NPV or IRR responds when key inputs change. The guidebook groups these variables into two types.

Macro factors are economy-wide conditions outside the project's control: changes in interest rates, tax rates, accounting standards and depreciation rules, and the rate of inflation.

Micro factors are specific to the project: operating expenses such as O&M, the cost of the project, the capital structure (debt-equity ratio), the form of financing and the timing of savings.

Separating the two helps management see which risks it can manage through project decisions and which it can only hedge or accept.

Why the other options are wrong: (a) Lists project-specific micro factors. (c) This option mixes one macro factor with two micro factors. (d) This option mixes one macro factor with two micro factors.

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

33. Converting a boiler to biomass requires a fuel stock worth ₹15 lakh to be built up at the start and held throughout the project's 6-year life. The stock is run down and recovered as cash at the end of year 6. At a 10% discount rate, by how much does this working capital reduce the project's NPV?

[4P1CEM033 | Chapter 7: Financial Management | Working capital in project appraisal - cost of a fuel stock recovered at the end of the life]

a) ₹8.47 lakh

b) ₹6.53 lakh

c) ₹15.00 lakh

d) ₹9.00 lakh

Correct answer: (b) ₹6.53 lakh.

Given: working capital $W = ₹15$ lakh at year 0, recovered at year 6; $i = 10\%$.

Formula: NPV effect = $-W + W \div (1 + i)^n$.

Substitution: $1.1^6 = 1.7716$; $15 \div 1.7716 = 8.47$; $15 - 8.47$.

Result: **NPV falls by $\approx ₹6.53$ lakh.**

Working capital is not depreciated or used up, but holding it has a time cost. Fuel stocks, spares and receivables must be included in the year-0 cash flow and released at the end.

Why the other options are wrong: (a) ₹8.47 lakh – gives the present value of the cash recovered, not the net cost of tying up the money. (c) ₹15.00 lakh – treats the stock as a cost that is never recovered, like spending on equipment. (d) ₹9.00 lakh – charges simple interest of 10% for six years instead of discounting the recovery.

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

34. A shared-savings contract pays a client a fixed ₹5 lakh at the START of each year for 5 years, the first payment on signing. At a 10% discount rate, what is the present value of these savings to the client?

[4P1CEM034 | Chapter 7: Financial Management | Present value of savings received at the start of each year (annuity due)]

a) ₹25.00 lakh

b) ₹18.95 lakh

c) ₹20.85 lakh

d) ₹21.78 lakh

Correct answer: (c) ₹20.85 lakh.

Given: $A = ₹5$ lakh at the start of years 1 to 5; $i = 10\%$.

Formula: PV (annuity due) = $A \times PVAF(i, n) \times (1 + i)$, or $A + A \times PVAF(i, n - 1)$.

Substitution: $PVAF(10\%, 5) = 3.7908$; $5 \times 3.7908 \times 1.10$; check: $5 + 5 \times 3.1699 = 20.85$.

Result: **PV = ₹20.85 lakh.**

Each payment is received one period earlier than in an ordinary annuity, so it is discounted one period less.

Why the other options are wrong: (a) ₹25.00 lakh – adds the five payments without discounting them. (b) ₹18.95 lakh – treats the payments as received at the end of each year (ordinary annuity). (d) ₹21.78 lakh – discounts six end-of-year payments instead of five starting now.

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

35. In the work breakdown structure (WBS) for a waste-heat recovery project, what is the lowest level of the hierarchy, at which cost and time are estimated and responsibility is assigned?

[4P1CEM035 | Chapter 8: Project Management | Work breakdown structure - the work package]

- a) The critical path
- b) The milestone event
- c) The project charter
- d) The work package

Correct answer: (d) The work package.

A work breakdown structure divides a complex project into smaller, manageable parts in a hierarchy. It runs from the whole project to major deliverables, such as civil works, the heat exchanger, ducting and controls, and on to sub-deliverables.

The lowest level is the work package. It is small enough to estimate cost and duration reliably, to assign to one person or contractor, and to monitor. Work packages are then broken into the activities used in the CPM or PERT network.

A WBS decomposes the project so that no scope or cost is missed.

Why the other options are wrong: (a) The critical path – is a chain of activities found from the network, not a WBS level. (b) The milestone event – marks a point in time and has no work content or cost. (c) The project charter – is the document that authorises the project, not a level of the WBS.

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

36. In a precedence (activity-on-node) schedule, trench excavation A takes 8 days and cable laying B takes 5 days. B may start 4 days after A starts (start-to-start lag 4) but must finish at least 2 days after A finishes (finish-to-finish lag 2). If A starts on day 0, on which day can B finish at the earliest?

[4P1CEM036 | Chapter 8: Project Management | Precedence relationships with lags - start-to-start and finish-to-finish]

- a) Day 9
- b) Day 13
- c) Day 10
- d) Day 11

Correct answer: (c) Day 10.

Given: A = 8 d (ES 0, EF 8); B = 5 d; SS lag = 4 d; FF lag = 2 d.

Formula: $EF(B) = \max[ES(A) + SS \text{ lag} + d(B), EF(A) + FF \text{ lag}]$.

Substitution: SS route = $0 + 4 + 5 = 9$; FF route = $8 + 2 = 10$; $\max(9, 10)$.

Result: **B finishes on day 10 at the earliest**, so it starts on day 5.

Lags let overlapping work, such as laying cable behind an advancing trench, be modelled without splitting activities.

Why the other options are wrong: (a) Day 9 – applies only the start-to-start lag and ignores the finish-to-finish constraint, which governs here. (b) Day 13 – treats the link as finish-to-start, so B waits for A to finish completely. (d) Day 11 – adds both lags in sequence, although they are separate constraints on start and finish.

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

37. Midway through an energy retrofit with a total budget of ₹80 lakh, the work actually completed is worth ₹30 lakh at budgeted rates. The work scheduled by this date was worth ₹36 lakh, and ₹37.5 lakh has actually been spent. If the present cost efficiency continues, what is the forecast final cost of the project?

[4P1CEM037 | Chapter 8: Project Management | Project monitoring with earned value - cost performance index and estimate at completion]

- a) ₹100.0 lakh

- b) ₹96.0 lakh
- c) ₹87.5 lakh
- d) ₹83.3 lakh

Correct answer: (a) ₹100.0 lakh.

Given: budget at completion = ₹80 lakh; earned value = ₹30 lakh; planned value = ₹36 lakh; actual cost = ₹37.5 lakh.

Formula: $CPI = \text{earned value} \div \text{actual cost}$; forecast at completion = budget $\div$ CPI.

Substitution: $CPI = 30 \div 37.5 = 0.80$; forecast = $80 \div 0.80$.

Result: **forecast final cost = ₹100.0 lakh**, an overrun of ₹20.0 lakh.

The schedule index $30 \div 36 = 0.83$ also shows the work is behind plan.

Why the other options are wrong: (b) ₹96.0 lakh – divides the budget by the schedule index (work done $\div$ work planned), which measures time, not cost. (c) ₹87.5 lakh – assumes the rest of the work will be done exactly at budget, contrary to the stated trend. (d) ₹83.3 lakh – compares the money spent with the work planned instead of the work actually done.

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

38. A boiler retrofit must finish three weeks earlier to fit a plant shutdown, with no extra spending on labour or equipment. The project manager lets civil foundation work start before the detailed design is fully frozen. What is this technique, and what is its main risk?

[4P1CEM038 | Chapter 8: Project Management | Shortening a schedule without extra resources - fast-tracking and its risk]

- a) Crashing; the critical activities need extra resources at a higher direct cost
- b) Resource levelling; the peak demand for labour on site rises sharply
- c) Using float; every non-critical activity loses all of its spare time
- d) Fast-tracking; the overlapped work may need rework if the design later changes

Correct answer: (d) Fast-tracking; the overlapped work may need rework if the design later changes.

There are two standard ways to compress a schedule. Crashing adds resources, such as overtime or extra crews, to critical activities in order of lowest cost slope, so direct cost rises.

Fast-tracking does not add resources. It runs activities that were planned in sequence partly in parallel, such as starting foundations on preliminary design data.

Its price is risk. If the design changes after the overlap begins, completed work may have to be redone, which can wipe out the time saved. Fast-tracking therefore suits activities whose outputs are unlikely to change.

Why the other options are wrong: (a) Crashing buys time with added resources and cost, which the stem rules out. (b) Levelling smooths resource peaks and usually lengthens, not shortens, a project. (c) The foundations follow design on the critical path, so there is no float being used.

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

39. An energy project has three activities, with costs spread evenly over each. A runs from month 0 to month 2 (₹12 lakh). B follows A and lasts 3 months (₹18 lakh). C can run alongside A and B, lasts 2 months (₹8 lakh) and has 3 months of total float. If every activity starts as early as possible, how much will have been spent by the end of month 3?

[4P1CEM039 | Chapter 8: Project Management | Project cash-flow plan from the schedule - early-start versus late-start spending]

- a) ₹26.0 lakh
- b) ₹18.0 lakh
- c) ₹38.0 lakh
- d) ₹22.8 lakh

Correct answer: (a) ₹26.0 lakh.

Given: A months 0–2, ₹12 lakh; B months 2–5, ₹18 lakh; C early start month 0, 2 months, ₹8 lakh.

Formula: spend to date = $\Sigma (\text{activity cost} \times \text{fraction of its duration completed by the date})$.

Substitution: $A \ 12 \times 2/2 = 12$; $B \ 18 \times 1/3 = 6.0$; $C \ 8 \times 2/2 = 8$; total = $12 + 6.0 + 8$.

Result: **₹26.0 lakh by the end of month 3.**

At late start it would be ₹18.0 lakh. The gap between the two cumulative cost curves shows how much the timing of funds can be adjusted.

Why the other options are wrong: (b) ₹18.0 lakh – schedules C at its latest start (month 3), so none of its cost has fallen by then. (c) ₹38.0 lakh – books the whole cost of every activity at the moment it starts. (d) ₹22.8 lakh – spreads the total cost evenly over the five-month project, ignoring the schedule.

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

40. A plant's baseline electricity model is $E = 0.62P + 48$ (E in MWh, P in tonnes). The target for this year is to cut fixed (non-production) energy by 15% and variable energy per tonne by 4%. What is this month's energy target if production is 850 t?

[4P1CEM040 | Chapter 9: Energy Monitoring and Targeting | Setting a monthly energy target from the energy-production model]

- a) 546.7 MWh
- b) 575.0 MWh
- c) 553.9 MWh
- d) 494.0 MWh

Correct answer: (a) 546.7 MWh.

Given: $E = 0.62P + 48$; fixed –15%; variable –4%; $P = 850$ t.

Formula: target $E = 0.62 \times (1 - 0.04) \times P + 48 \times (1 - 0.15)$.

Substitution: $0.5952 \times 850 + 40.8 = 505.92 + 40.8$.

Result: **target = 546.7 MWh** (baseline 575.0 MWh, 4.9% lower).

Setting separate targets for fixed and variable energy turns a general aim into a monthly figure that tracks production.

Why the other options are wrong: (b) 575.0 MWh – is the baseline value with no improvement applied. (c) 553.9 MWh – applies the 4% cut to variable energy but forgets the 15% cut in fixed energy. (d) 494.0 MWh – swaps the two cuts, applying 15% to variable and 4% to fixed energy.

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

41. A plant's regression baseline was built on 2023-24 data. In 2025 it adds a new product line with its own electric furnace. What should the energy manager do to keep monitoring and targeting valid?

[4P1CEM041 | Chapter 9: Energy Monitoring and Targeting | Energy baseline - non-routine adjustment]

- a) Keep the baseline unchanged so that savings stay comparable with history
- b) Divide total energy by total output and track one plant-wide SEC
- c) Stop monitoring until a complete new year of data becomes available
- d) Make a documented, non-routine adjustment to the baseline for the new load

Correct answer: (d) Make a documented, non-routine adjustment to the baseline for the new load.

The baseline is the reference point against which energy performance improvements are measured. It assumes the plant's static factors, such as equipment, product mix and operating hours, stay the same.

Routine adjustments are built into the model, for example production volume or degree-days. A permanent change in static factors, such as a new product line with its own furnace, needs a non-routine adjustment. You estimate the new load's energy, by sub-metering or engineering calculation, and add it to the baseline or model it separately. The adjustment and its method must be documented.

Otherwise the CUSUM would show false overspending.

Why the other options are wrong: (a) Would show the new furnace's energy as a loss of efficiency. (b) This option mixes products with different energy intensities and hides real changes. (c) Would lose a year of control and accountability.

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

42. An office's monthly electricity use follows $E = 42,000 + 85 \times \text{CDD}$ (kWh). This month had 310 cooling degree-days and used 66,500 kWh. The same month last year had 235 CDD and used 61,200 kWh. What is this month's weather-normalised performance?

[4P1CEM042 | Chapter 9: Energy Monitoring and Targeting | Weather-normalised performance using cooling degree-days]

- a) 4,525 kWh excess (7.3%)
- b) 1,850 kWh saved (2.7%)
- c) 5,300 kWh excess (8.7%)
- d) 1,850 kWh excess (2.8%)

Correct answer: (b) 1,850 kWh saved (2.7%).

Given: $E = 42,000 + 85 \times \text{CDD}$; $\text{CDD} = 310$; actual = 66,500 kWh.

Formula: expected = $42,000 + 85 \times \text{CDD}(\text{this month})$; performance = expected – actual.

Substitution: expected = $42,000 + 85 \times 310 = 68,350$ kWh; $68,350 - 66,500$.

Result: **1,850 kWh saved (2.7% below expected)**, although the bill rose.

Normalising for the relevant variable, here weather, is what makes monitoring and targeting meaningful.

Why the other options are wrong: (a) 4,525 kWh excess (7.3%) – uses last year's degree-days in the model instead of this month's. (c) 5,300 kWh excess (8.7%) – compares raw bills year on year and ignores the hotter weather. (d) 1,850 kWh excess (2.8%) – gets the sign of actual minus expected backwards.

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

43. A coastal coal-fired power station is reviewing its climate-change plan. Which measure is ADAPTATION to climate change rather than MITIGATION of it?

[4P1CEM043 | Chapter 10: Energy Efficiency and Climate Change | Climate change response - adaptation measures versus mitigation measures]

- a) Replacing worn turbine blading to bring down the station's net heat rate
- b) Co-firing biomass pellets with coal to cut the station's fossil CO₂ emissions
- c) Fitting variable-speed drives on the cooling-water and boiler feed pumps
- d) Raising the switchyard and coal yard above the projected storm-surge flood level

Correct answer: (d) Raising the switchyard and coal yard above the projected storm-surge flood level.

Responses to climate change fall into two groups. Mitigation reduces the cause by cutting greenhouse gas emissions or increasing sinks. Fuel switching, efficiency improvement and renewable energy are all mitigation.

Adaptation reduces the harm from climate change that is already happening or expected, such as higher sea levels, heat waves and floods. Protecting assets against flooding, planning for higher cooling-water temperatures and drought-proofing water supply are adaptation.

The UNFCCC asks countries to pursue both. Energy managers mostly deliver mitigation, but plants in exposed locations also need adaptation plans.

Why the other options are wrong: (a) This option is mitigation, because less coal and CO₂ are needed per kWh. (b) This option is mitigation, because it reduces greenhouse gas emissions. (c) This option is mitigation, because it lowers auxiliary power and hence emissions.

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

44. Which statement on carbon sinks and sequestration is CORRECT?

[4P1CEM044 | Chapter 10: Energy Efficiency and Climate Change | Carbon sinks and carbon capture and storage]

- a) Forests are a natural sink, while CCS stores captured CO₂ in geological formations
- b) Sequestration means converting CO₂ into carbon monoxide for reuse as fuel
- c) Oceans cannot absorb CO₂, so they are never treated as carbon sinks
- d) A carbon sink is any process that releases more CO₂ than it absorbs

Correct answer: (a) Forests are a natural sink, while CCS stores captured CO₂ in geological formations.

A carbon sink is a reservoir that absorbs more carbon than it releases. Forests, soils and oceans are the main natural sinks.

A carbon source, such as fossil fuel combustion or deforestation, releases more than it absorbs.

Carbon sequestration is the long-term capture and storage of carbon. It may be natural, through afforestation and soil carbon, or engineered. Carbon capture and storage (CCS) separates CO₂ at large point sources such as power or cement plants. The CO₂ is compressed, transported and injected into deep geological formations such as depleted oil and gas fields or saline aquifers.

Both are key mitigation options.

Why the other options are wrong: (b) This option is wrong because sequestration stores carbon; it does not convert it to CO. (c) This option is wrong because oceans are among the largest natural sinks. (d) This option describes a carbon source, the opposite of a sink.

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

45. Which pairing of an international body or agreement with its role is CORRECT?

[4P1CEM045 | Chapter 10: Energy Efficiency and Climate Change | International climate bodies and agreements - roles]

- a) UNFCCC – sets legally binding emission caps for each developing country
- b) IPCC – assesses the climate science and publishes its periodic assessment reports
- c) Kyoto Protocol – created the IPCC to review the science of climate change
- d) Montreal Protocol – set binding CO₂ reduction targets for industrialised countries

Correct answer: (b) IPCC – assesses the climate science and publishes its periodic assessment reports.

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 by the World Meteorological Organization and UNEP. It assesses the scientific, technical and socio-economic information on climate change and publishes assessment reports. It does not make policy.

The UN Framework Convention on Climate Change (1992) set the overall goal of stabilising greenhouse gas concentrations, under the principle of common but differentiated responsibilities.

The Kyoto Protocol (1997) gave Annex I countries binding targets and created the flexible mechanisms, including CDM.

The Montreal Protocol (1987) phases out ozone-depleting substances such as CFCs.

Why the other options are wrong: (a) This option is wrong because the Convention set no binding caps, and developing countries had none. (c) This option is wrong because the IPCC was set up by WMO and UNEP in 1988. (d) This option is wrong because it controls ozone-depleting substances, not CO₂.

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

46. Which statement on acid rain is WRONG?

[4P1CEM046 | Chapter 10: Energy Efficiency and Climate Change | Acid rain - causes and control]

- a) SO₂ and NO_x from combustion form sulphuric and nitric acids in air
- b) Acid rain is caused mainly by carbon dioxide dissolving in rainwater
- c) Unpolluted rain is slightly acidic, with a pH of about 5.6
- d) Low-sulphur fuels and flue gas desulphurisation help reduce acid rain

Correct answer: (b) Acid rain is caused mainly by carbon dioxide dissolving in rainwater.

Acid rain is precipitation with a pH well below that of natural rain. Natural rain is already slightly acidic, at about pH 5.6, because atmospheric CO₂ dissolves to form weak carbonic acid.

The main causes are sulphur dioxide and nitrogen oxides released by burning coal and oil in power stations, industry and vehicles. In the atmosphere they oxidise and dissolve to form sulphuric and nitric acids, which may fall far from the source. Acid rain damages forests, lakes, soils, buildings and metal structures.

It is controlled by low-sulphur fuels, coal washing, flue gas desulphurisation, low-NO_x burners and energy efficiency, which cuts all emissions.

Why the other options are wrong: (a) This is correct. (c) This is correct; it comes from natural CO₂ dissolving in rain. (d) This is correct.

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

47. In a horizontal-axis wind turbine, which control turns the nacelle and rotor to face the wind, and which limits rotor power in high winds?

[4P1CEM047 | Chapter 11: New and Renewable Energy Sources | Wind turbines - yaw and pitch control]

- a) Yaw control faces the wind; blade pitch control limits power at high speeds
- b) Stall control faces the wind; the yaw drive limits power at high speeds
- c) Pitch control faces the wind; the yaw drive limits power at high speeds
- d) Yaw control faces the wind; the disc brake limits power during normal running

Correct answer: (a) Yaw control faces the wind; blade pitch control limits power at high speeds.

A horizontal-axis wind turbine must face into the wind to capture the most power. The yaw system, with a wind vane, controller and yaw motors, turns the nacelle and rotor about the tower axis to keep the rotor aligned as the wind direction changes.

Power in the wind rises with the cube of wind speed, so the rotor must be protected above rated speed. In pitch-regulated machines, the blades are turned about their own axes to reduce the angle of attack, which spills excess power. Older fixed-blade machines rely on stall regulation instead.

The disc brake stops the rotor for maintenance or emergencies.

Why the other options are wrong: (b) This option is wrong because stall regulation limits power and does not orient the rotor. (c) This option reverses the two functions. (d) This option is wrong because the brake is for parking and emergencies, not power regulation.

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

48. A wood gasifier with a cold-gas efficiency of 72% feeds a producer-gas engine generator delivering 100 kWe. The engine converts gas energy to electricity at 25% efficiency. If the wood has a GCV of 3,800 kcal/kg ($\approx 15,910$ kJ/kg), how much wood is needed per hour?

[4P1CEM048 | Chapter 11: New and Renewable Energy Sources | Biomass gasifier - wood requirement for a gas engine generator]

- a) 90.5 kg/h
- b) 125.7 kg/h
- c) 65.2 kg/h
- d) 46.7 kg/h

Correct answer: (b) 125.7 kg/h.

Given: output = 100 kWe; engine $\eta = 0.25$; cold-gas $\eta = 0.72$; wood GCV = 3,800 kcal/kg ($\approx 15,910$ kJ/kg); 1 kWh = 860 kcal ($\approx 3,601$ kJ).

Formula: wood = output $\times 860 \div (\eta(\text{engine}) \times \eta(\text{cold gas}) \times \text{GCV})$.

Substitution: $100 \times 860 = 86,000$ kcal/h; $0.25 \times 0.72 \times 3,800 = 684$; $86,000 \div 684$.

Result: $\approx$ **125.7 kg of wood per hour**, about 1.26 kg/kWh.

Cold-gas efficiency is the producer gas energy as a share of the fuel energy fed in.

Why the other options are wrong: (a) 90.5 kg/h – ignores the gasifier's cold-gas efficiency. (c) 65.2 kg/h – multiplies by the cold-gas efficiency instead of dividing by it. (d) 46.7 kg/h – averages the two efficiencies instead of multiplying them.

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

49. A solar PV module is rated at 545 Wp and measures 2.278 m $\times$ 1.134 m. What is its efficiency at standard test conditions (irradiance 1,000 W/m², cell temperature 25 °C)?

[4P1CEM049 | Chapter 11: New and Renewable Energy Sources | Solar PV module efficiency at standard test conditions]

- a) 26.4%
- b) 19.0%
- c) 15.4%
- d) 21.1%

Correct answer: (d) 21.1%.

Given: $P_{\text{max}} = 545$ W; area = $2.278 \times 1.134 = 2.5833$ m²; $G(\text{STC}) = 1,000$ W/m².

Formula: $\eta = P_{\max} \div (G \times A) \times 100$.

Substitution: $545 \div (1,000 \times 2.5833) \times 100 = 545 \div 2,583.3 \times 100$.

Result: $\eta \approx 21.1\%$.

Module efficiency depends on the irradiance used, the area and the peak output. The inverter does not enter into it.

Why the other options are wrong: (a) 26.4% – uses 800 W/m², the NOCT test irradiance, instead of the STC value. (b) 19.0% – applies a 0.9 derating, which belongs in yield estimates, not STC efficiency. (c) 15.4% – uses the extraterrestrial solar constant of 1,367 W/m².

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

50. Of the solar radiation reaching the earth's surface, which band carries nearly half the energy, and which band does stratospheric ozone absorb most strongly?

[4P1CEM050 | Chapter 11: New and Renewable Energy Sources | Solar radiation - spectral composition]

- a) Microwaves carry nearly half; ozone absorbs most of the infrared
- b) Ultraviolet carries nearly half; ozone absorbs most of the infrared
- c) Visible light carries nearly half; ozone absorbs most of the ultraviolet
- d) Infrared carries over 90%; ozone absorbs most of the visible light

Correct answer: (c) Visible light carries nearly half; ozone absorbs most of the ultraviolet.

Solar radiation is mainly ultraviolet, visible and infrared. At the earth's surface, visible light (about 0.4–0.7 μm) carries roughly 45–50% of the energy, infrared roughly 45–50%, and ultraviolet only a few per cent.

Stratospheric ozone absorbs nearly all UV-C and most UV-B, protecting living organisms. This is why ozone depletion by CFCs matters.

PV cells convert mainly the visible and near-infrared parts. Solar thermal collectors absorb across the whole spectrum, using selective coatings to limit their own infrared losses.

Why the other options are wrong: (a) This option is wrong because microwaves are a negligible part of sunlight. (b) Swaps the shares; UV is a small fraction. (d) This option is wrong because infrared is roughly half and visible light passes ozone.

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 × 5 = 40

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

S-1 A large HT consumer plans to buy 2 crore kWh a year (measured at its own meter) from a solar developer under open access, as permitted by the Electricity Act, 2003. The developer sells at ₹3.60/kWh at the injection point. Transmission losses are 3.5% and distribution (wheeling) losses 6%. Charges per kWh delivered are: transmission ₹0.35, wheeling ₹0.60, cross-subsidy surcharge ₹1.40, additional surcharge ₹0.90 and scheduling ₹0.05. The DISCOM's energy charge for the consumer is ₹8.10/kWh; demand charges are unaffected.

[4P1CEM051 | Chapter 1: Energy Scenario | Open-access power purchase - loss-adjusted landed cost compared with the DISCOM tariff]

- (a) Calculate the energy that must be injected per kWh delivered and the loss-adjusted energy cost per kWh delivered. [2 Marks]
- (b) Calculate the landed cost per kWh and the annual saving against the DISCOM energy charge. [2 Marks]
- (c) Find the highest developer price at which open access still breaks even, and explain why the cross-subsidy surcharge is levied. [1 Mark]

S-1 Ans

(a) [2 marks]

Given: generator price ₹3.60/kWh; losses 3.5% and 6% in series.

Formula: kWh injected per kWh delivered = $1 \div [(1 - \text{transmission loss}) \times (1 - \text{wheeling loss})]$; loss-adjusted cost = price $\times$ kWh injected.

Substitution: $(1 - 0.035) \times (1 - 0.06) = 0.90710$; $1 \div 0.90710 = 1.1024$; 3.60×1.1024 .

Result: **1.1024 kWh must be injected per kWh delivered; loss-adjusted energy cost = ₹3.97/kWh.** (2 marks)

(b) [2 marks]

Formula: landed cost = loss-adjusted energy cost + all per-kWh charges; saving = (DISCOM rate – landed cost) $\times$ kWh.

Substitution: charges = $0.35 + 0.60 + 1.40 + 0.90 + 0.05 = ₹3.30$; landed = $3.97 + 3.30$; saving = $(8.10 - 7.27) \times 2$ crore kWh.

Result: **landed cost $\approx$ ₹7.27/kWh; saving $\approx$ ₹0.83/kWh, about ₹1.66 crore a year.** Surcharges and network charges (45% of the landed cost) matter as much as the generator's price. (2 marks)

(c) [1 mark]

Substitution: break-even price = $(8.10 - 3.30) \times 0.90710$.

Result: **break-even developer price $\approx$ ₹4.35/kWh.** The cross-subsidy surcharge compensates the DISCOM for the cross-subsidy it loses when high-tariff industrial consumers leave, since their tariffs help to keep agricultural and domestic tariffs low. (1 mark)

Marking scheme (5 marks): a) Loss factor 1, loss-adjusted cost 1. b) Landed cost 1, saving 1. c) Break-even $\frac{1}{2}$, reason $\frac{1}{2}$.

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

S-2 India's National Action Plan on Climate Change (NAPCC), released in 2008, set out eight national missions. One of them, the National Mission for Enhanced Energy Efficiency (NMEEE), is implemented by the Bureau of Energy Efficiency through four initiatives.

[4P1CEM052 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | NAPCC and the National Mission for Enhanced Energy Efficiency - four initiatives and the financing instruments]

(a) Name the four initiatives of NMEEE and state the objective of each. [2 Marks]

(b) Explain how the Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE) and the Venture Capital Fund for Energy Efficiency (VCFEE) help energy-efficiency projects obtain finance. [2 Marks]

(c) Name any four of the other seven missions of the NAPCC. [1 Mark]

S-2 Ans

(a) [2 marks]

Result: **(i) Perform, Achieve and Trade (PAT)** – a market-based mechanism to make energy-efficiency improvements in energy-intensive large industries and facilities more cost-effective, through certification of energy savings that can be traded. **(ii) Market Transformation for Energy Efficiency (MTEE)** – accelerating the shift to energy-efficient appliances in designated sectors through innovative measures that make the products more affordable. **(iii) Energy Efficiency Financing Platform (EEFP)** – creating mechanisms to finance demand-side management programmes in all sectors by capturing future energy savings. **(iv) Framework for Energy Efficient Economic Development (FEEED)** – developing fiscal instruments to promote energy efficiency, such as the Partial Risk Guarantee Fund and the Venture Capital Fund for Energy Efficiency. ($\frac{1}{2}$ mark each, 2 marks)

(b) [2 marks]

Result: **PRGFEE** – a government-backed fund that guarantees a part of the loan (typically up to half of the loan, subject to a ceiling per project) that a bank or financial institution gives to an energy-efficiency project, for example an ESCO project in a building, municipality or SME. **If the borrower defaults, the fund covers the guaranteed share of the loss, so the lender's risk falls and it is willing to lend for projects whose security is mainly the future energy savings.** (1 mark)

VCFEE – provides last-mile equity to energy-efficiency projects, mainly in government buildings and municipalities, so that projects short of promoter equity can reach financial closure. Together the two funds address the main barrier that savings-based projects face: banks' reluctance to lend against savings rather than physical assets. (1 mark)

(c) [1 mark]

Result: **any four of: National Solar Mission; National Mission on Sustainable Habitat; National Water Mission; National Mission for Sustaining the Himalayan Ecosystem; National Mission for a Green India; National Mission for Sustainable Agriculture; National Mission on Strategic Knowledge for Climate Change.** (¼ mark each, 1 mark)

Marking scheme (5 marks): a) ½ mark per initiative with its objective. b) PRGFEE mechanism 1, VCFFEE role 1. c) ¼ per mission.

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 A power analyser shows that the motor of a limestone grinding mill draws 22 kW. The motor efficiency is 93%. The mill grinds 1,800 kg/h of limestone (specific heat 0.21 kcal/kg°C (≈ 0.879 kJ/kg·K)), which leaves 18 °C hotter than it enters. The mill's cooling jacket takes 1.2 m³/h of water, which warms by 6 °C. The mill runs 6,000 h a year and electricity costs ₹8.50/kWh.

[4P1CEM053 | Chapter 3: Basics of Energy and its Various Forms | Mechanical energy converted to heat - energy accounting of a grinding mill]

- Calculate the shaft power delivered to the mill. [1 Mark]
- Calculate the heat carried away by the product and by the cooling water, in kW. [2 Marks]
- Calculate the balance of the shaft power that is not accounted for by these two streams and express all three as a percentage of shaft power. Where does this balance go? [1 Mark]
- Calculate the specific energy consumption (kWh per tonne) and the annual electricity cost of the mill. [1 Mark]

S-3 Ans

(a) [1 mark]

Given: motor input = 22 kW; motor efficiency = 0.93.

Formula: shaft power = electrical input $\times$ motor efficiency.

Substitution: 22×0.93 .

Result: **shaft power = 20.46 kW.** (1 mark)

(b) [2 marks]

Given: product 1,800 kg/h, $C_p = 0.21$ kcal/kg°C (≈ 0.879 kJ/kg·K), $\Delta T = 18$ °C; water 1.2 m³/h = 1,200 kg/h, $\Delta T = 6$ °C.

Formula: $Q = m \times C_p \times \Delta T$; kW = (kcal/h) $\div$ 860.

Substitution: product: $1,800 \times 0.21 \times 18 = 6,804$ kcal/h $\div$ 860; water: $1,200 \times 1 \times 6 = 7,200$ kcal/h $\div$ 860.

Result: **heat to product = 7.91 kW; heat to cooling water = 8.37 kW.** (2 marks)

(c) [1 mark]

Formula: balance = shaft power – heat to product – heat to water; share = item $\div$ shaft power $\times$ 100.

Substitution: $20.46 - 7.91 - 8.37 = 4.18$ kW; shares = 38.7%, 40.9%, 20.4%.

Result: **unaccounted balance = 4.18 kW; product 38.7%, cooling water 40.9%, balance 20.4%** of shaft power. Almost all the mechanical energy put into grinding ends up as heat. The balance is lost from the mill shell and bearings to the surrounding air, as noise and vibration, and a very small part is stored as new surface energy of the fine particles. (1 mark)

(d) [1 mark]

Formula: SEC = input kW $\div$ throughput (t/h); annual cost = kW $\times$ hours $\times$ tariff.

Substitution: $22 \div 1.8 = 12.22$ kWh/t; $22 \times 6,000 = 1,32,000$ kWh; $\times$ ₹8.50.

Result: **SEC = 12.22 kWh/t; annual cost = ₹11,22,000 ($\approx$ ₹11.22 lakh).** (1 mark)

Marking scheme (5 marks): a) 1. b) Each stream 1. c) Balance and shares ½, explanation ½. d) SEC ½, annual cost ½.

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 Exhaust gas from a kiln, 60,000 Nm³/h at 350 °C, must be cooled to 180 °C before it enters a bag filter. Cooling is done in a conditioning tower by spraying water at 30 °C, which evaporates completely. Take the gas density as 1.3 kg/Nm³ and its specific heat as 0.25 kcal/kg°C ($\approx$ 1.05 kJ/kg·K). For water take specific heat 1 kcal/kg°C ($\approx$ 4.19 kJ/kg·K), latent heat of vaporisation 540 kcal/kg ($\approx$ 2,261 kJ/kg) at 100 °C, and specific heat of steam 0.47 kcal/kg°C ($\approx$ 1.97 kJ/kg·K). Ignore heat losses.

[4P1CEM054 | Chapter 3: Basics of Energy and its Various Forms | Evaporative cooling of kiln exhaust by water spray - sensible and latent heat]

- Calculate the heat to be removed from the gas. [2 Marks]
- Calculate the heat absorbed per kg of spray water and the water spray rate. [2 Marks]
- If ambient air at 30 °C (specific heat 0.24 kcal/kg°C ($\approx$ 1.00 kJ/kg·K), 1.293 kg/Nm³) were bled in instead to cool the gas, estimate the air volume needed and comment on the effect on the bag filter. [1 Mark]

S-4 Ans

(a) [2 marks]

Given: 60,000 Nm³/h $\times$ 1.3 kg/Nm³ = 78,000 kg/h; C_p = 0.25 kcal/kg°C ($\approx$ 1.05 kJ/kg·K); ΔT = 350 – 180 = 170 °C.

Formula: $Q = m \times C_p \times \Delta T$.

Substitution: 78,000 $\times$ 0.25 $\times$ 170.

Result: **heat to be removed = 33,15,000 kcal/h ($\approx$ 3,855 kW).** (2 marks)

(b) [2 marks]

Formula: heat per kg of water = sensible heat to 100 °C + latent heat + superheat of the vapour to the gas exit temperature; spray rate = $Q \div$ heat per kg.

Substitution: $(100 - 30) \times 1 + 540 + 0.47 \times (180 - 100) = 70 + 540 + 37.6 = 647.6$ kcal/kg; 33,15,000 $\div$ 647.6.

Result: **each kg of water absorbs 647.6 kcal ($\approx$ 2,711 kJ); spray rate $\approx$ 5,119 kg/h (about 5.12 m³/h).** About 83% of the cooling comes from the latent heat, which is why a small water flow cools a large gas flow. (2 marks)

(c) [1 mark]

Formula: air needed = $Q \div (C_{p,air} \times (\text{exit temperature} - 30))$; volume = mass $\div$ 1.293.

Substitution: 33,15,000 $\div$ $(0.24 \times 150) = 92,083$ kg/h; $\div$ 1.293 = 71,217 Nm³/h; water vapour from spraying = 5,119 $\times$ 22.4 $\div$ 18 = 6,370 Nm³/h.

Result: **air bleeding needs $\approx$ 71,217 Nm³/h, so the bag filter and ID fan would handle about 2.2 times the original gas volume, against only 1.11 times with water spray.** Water spray keeps the filter and fan smaller and saves fan power; recovering the heat in a waste heat boiler before conditioning would be better still. (1 mark)

Marking scheme (5 marks): a) Gas mass 1, heat 1. b) Heat per kg 1, spray rate 1. c) Air volume and comparison 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-5 A reverse osmosis (RO) plant treats 60 m³/h of borewell water containing 1,800 mg/litre of total dissolved solids (TDS). It runs at 75% recovery (permeate as a share of feed) and 97% salt rejection, based on feed concentration. The high-pressure pump raises the feed by 15 bar, and the pump-motor set is 72% efficient. Take the density of all streams as 1,000 kg/m³.

[4P1CEM055 | Chapter 5: Material and Energy Balance | Material balance of a reverse osmosis plant - flows, concentrations and specific energy]

- Calculate the permeate and reject flow rates. [1 Mark]
- Calculate the permeate TDS, and the reject TDS from a salt balance. Check the balance in kg/h of salt. [2 Marks]
- Calculate the power drawn by the high-pressure pump and the specific energy consumption in kWh per m³ of permeate. [2 Marks]

S-5 Ans

(a) [1 mark]

Given: feed = 60 m³/h; recovery = 0.75.

Formula: permeate = feed $\times$ recovery; reject = feed – permeate (overall balance).

Substitution: $60 \times 0.75 = 45 \text{ m}^3/\text{h}$; $60 - 45 = 15 \text{ m}^3/\text{h}$.

Result: **permeate = $45 \text{ m}^3/\text{h}$; reject = $15 \text{ m}^3/\text{h}$.** (1 mark)

(b) [2 marks]

Given: feed TDS = 1,800 mg/litre; rejection = 0.97.

Formula: permeate TDS = feed TDS $\times$ (1 – rejection); salt balance $F \times C_f = P \times C_p + R \times C_r$; mg/litre $\times \text{m}^3/\text{h} = \text{g/h}$.

Substitution: $C_p = 1,800 \times 0.03 = 54 \text{ mg/litre}$; $60 \times 1,800 = 45 \times 54 + 15 \times C_r$, so $C_r = (1,08,000 - 2,430) \div 15$.

Result: **permeate TDS = 54 mg/litre ; reject TDS = $7,038 \text{ mg/litre}$.** Check: salt in = 108.0 kg/h ; salt out = $2.43 + 105.57 = 108.0 \text{ kg/h}$, so the balance closes. (2 marks)

(c) [2 marks]

Formula: hydraulic power (kW) = $Q (\text{m}^3/\text{s}) \times \Delta p (\text{Pa}) \div 1,000$; input = hydraulic $\div \eta$; SEC = input $\div$ permeate flow.

Substitution: $60 \div 3,600 \times 15 \times 10^5 \div 1,000 = 25.00 \text{ kW}$; $25.00 \div 0.72 = 34.72 \text{ kW}$; $34.72 \div 45$.

Result: **pump input = 34.7 kW ; SEC = 0.772 kWh/m^3 of permeate.** Pressurising the whole feed but recovering only 75% wastes the pressure energy in the reject. An energy recovery device on the reject, or higher recovery where scaling allows, lowers the SEC. (2 marks)

Marking scheme (5 marks): a) Both flows 1. b) Permeate TDS $\frac{1}{2}$, reject TDS from salt balance 1, check $\frac{1}{2}$. c) Pump power 1, SEC and comment 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 frozen-foods plant is preparing for ISO 50001 certification. Its energy review gives the annual energy use of each end use on a common primary-energy basis (total 72,500 GJ). The company has decided that significant energy uses (SEUs) are the largest uses that together account for at least 80% of consumption.

[4P1CEM056 | Chapter 6: Energy Action Planning | ISO 50001 energy review - significant energy uses by Pareto analysis, EnPIs and baseline]

End use	Annual energy (GJ)
Steam boilers (coal)	38,400
Refrigeration compressors	15,800
Air compressors	7,600
Process pumps	5,200
Lighting	2,300
Office HVAC	1,900
Workshop and miscellaneous	1,300

(a) Carry out a Pareto analysis (share and cumulative share of each use) and identify the SEUs. [2 Marks]

(b) Propose a suitable energy performance indicator (EnPI) and one relevant variable for each SEU. [2 Marks]

(c) Define the energy baseline in ISO 50001 and state two situations in which it must be adjusted. [1 Mark]

S-6 Ans

(a) [2 marks]

Given: annual use of seven end uses, total 72,500 GJ; SEU rule = largest uses reaching $\geq 80\%$ of the total.

Formula: share = use $\div$ total $\times 100$; cumulative share = running total $\div$ total $\times 100$ (uses in descending order).

Substitution: Steam boilers (coal) $38,400 \div 72,500 = 53.0\%$ (cumulative 53.0%); Refrigeration compressors $15,800 \div 72,500 = 21.8\%$ (cumulative 74.8%); Air compressors $7,600 \div 72,500 = 10.5\%$ (cumulative 85.2%); Process pumps $5,200 \div 72,500 = 7.2\%$ (cumulative 92.4%); the remaining three add up to the last 7.6%.

End use	GJ	Share (%)	Cumulative (%)	SEU?
Steam boilers (coal)	38,400	53.0	53.0	Yes
Refrigeration compressors	15,800	21.8	74.8	Yes
Air compressors	7,600	10.5	85.2	Yes

Process pumps	5,200	7.2	92.4	No
Lighting	2,300	3.2	95.6	No
Office HVAC	1,900	2.6	98.2	No
Workshop and miscellaneous	1,300	1.8	100.0	No

Result: **SEUs = Steam boilers (coal), Refrigeration compressors, Air compressors, which together account for 85.2% of energy use** (the first two together reach only 74.8%). (2 marks)

(b) [2 marks]

Result (½ mark per EnPI with its variable, plus ½ for justification):

Steam boilers: GJ of coal per tonne of steam (or boiler efficiency); relevant variable: steam demand, which depends on tonnes of product blanched and cooked.

Refrigeration compressors: kWh per tonne of product frozen, or kW/TR; relevant variables: production rate and ambient wet-bulb (condensing) temperature.

Air compressors: specific power in kW per m³/min of free air delivered, or kWh per tonne of product; relevant variable: compressed air demand and generation pressure.

A simple ratio EnPI is misleading where a large share of energy is fixed, so a regression-model EnPI (energy against production and weather) is better for refrigeration. (2 marks)

(c) [1 mark]

Result: the **energy baseline (EnB) is a quantitative reference, based on a specified period of data, against which energy performance improvements are compared**. It must be adjusted when (any two) the EnPIs no longer reflect the organisation's energy performance; there are major changes to the process, operating patterns or energy systems (for example a new freezing tunnel or a change of fuel); or static factors change, such as product mix or plant boundary. (1 mark)

Marking scheme (5 marks): a) Shares and cumulative shares 1, SEUs at the 80% cut-off 1. b) ½ per SEU EnPI with variable, ½ justification. c) Definition ½, two adjustment triggers ½.

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

S-7 An energy auditor measured the input power of a process air blower with a portable power analyser before and after fitting a high-efficiency impeller, at the same duty point: 74.0 kW before and 61.0 kW after. The analyser's accuracy is ±2% of reading (with its clamp-on CTs). The blower runs 6,000 h a year, an estimate uncertain by ±5%. Electricity costs ₹8.00/kWh. Treat the uncertainties as independent unless stated, and combine them by the root-sum-square method.

[4P1CEM057 | Chapter 9: Energy Monitoring and Targeting | Uncertainty of measured savings - instrument accuracy and propagation of errors]

(a) Calculate the power saving and its absolute and percentage uncertainty. [2 Marks]

(b) Calculate the annual energy and cost saving, each with its uncertainty. [2 Marks]

(c) If the error of the analyser is systematic (the same percentage and sign at both readings, as when the same instrument and CTs are used), what is the uncertainty of the power saving? What does this teach about audit measurements? [1 Mark]

S-7 Ans

(a) [2 marks]

Given: $P_{\text{before}} = 74.0 \text{ kW} \pm 2\%$; $P_{\text{after}} = 61.0 \text{ kW} \pm 2\%$.

Formula: $\text{saving} = P_{\text{before}} - P_{\text{after}}$; for a difference of independent quantities, $u(\text{saving}) = \sqrt{u_{\text{before}}^2 + u_{\text{after}}^2}$.

Substitution: $\text{saving} = 74.0 - 61.0 = 13.0 \text{ kW}$; $u_{\text{before}} = 0.02 \times 74.0 = 1.48 \text{ kW}$; $u_{\text{after}} = 0.02 \times 61.0 = 1.22 \text{ kW}$; $u = \sqrt{(1.48^2 + 1.22^2)} = 1.92 \text{ kW}$.

Result: **saving = 13.0 ± 1.92 kW, i.e. ±14.8%**. A ±2% instrument gives a ±15% uncertainty on the saving, because the saving is a small difference between two large readings. (2 marks)

(b) [2 marks]

Formula: $E = \text{saving} \times \text{hours}$; for a product, relative uncertainties combine as $\sqrt{r_1^2 + r_2^2}$.

Substitution: $E = 13.0 \times 6,000 = 78,000 \text{ kWh}$; $r = \sqrt{(0.1475^2 + 0.05^2)} = 0.1558$; $u(E) = 0.1558 \times 78,000$; $\text{cost} = 78,000 \times ₹8.00$.

Result: **annual saving = 78,000 ± 12,151 kWh (±15.6%); cost saving = ₹6,24,000 ± ₹97,208.** (2 marks)

(c) [1 mark]

Substitution: with fully correlated errors, $u = 0.02 \times (74.0 - 61.0)$.

Result: **$u(\text{saving}) \approx 0.26 \text{ kW}$ (±2% of the saving) instead of ±1.92 kW.** Measure before and after with the same calibrated instrument and CTs, at the same operating point, and log over a representative period; a claimed saving smaller than its uncertainty cannot be demonstrated. (1 mark)

Marking scheme (5 marks): a) Saving ½, individual uncertainties ½, root-sum-square 1. b) kWh and its uncertainty 1, rupees 1. c) Correlated case ½, lesson ½.

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

S-8 A company must cut its CO₂ emissions by 3,500 t a year. Four options are shortlisted. The annualised cost of each option (capital recovery plus O&M and any fuel premium) is given; electricity saved or generated is worth ₹8.00/kWh and the grid emission factor is 0.82 tCO₂/MWh.

[4P1CEM058 | Chapter 10: Energy Efficiency and Climate Change | Marginal abatement cost - ranking CO₂ reduction options and meeting a target at least cost]

Option	Description	Annualised cost (₹ lakh/yr)	Electricity saved or generated (kWh/yr)	CO ₂ abated (t/yr, if not from electricity)
A	VFDs on cooling-tower fans and pumps	6.0	3,20,000	–
B	Rooftop solar PV, 1 MWp	52.0	14,00,000	–
C	Biomass briquettes replacing 1,000 t/yr of boiler coal (2.0 tCO ₂ per t coal)	40.0	–	2,000
D	Afforestation of 50 ha (8 tCO ₂ per ha per year)	9.0	–	400

(a) Calculate the annual CO₂ abated, the net annual cost and the marginal abatement cost (₹ per tCO₂) of each option. [3 Marks]

(b) Rank the options and select the least-cost combination that meets the 3,500 t target (part of an option may be used). What is the net annual cost of the plan? [1 Mark]

(c) Why are options with a negative abatement cost often not taken up without a policy push? [1 Mark]

S-8 Ans**(a) [3 marks]**

Given: target 3,500 tCO₂/yr; energy value ₹8.00/kWh; grid factor 0.82 tCO₂/MWh; annualised cost of each option as tabulated.

Formula: CO₂ abated = MWh × emission factor (or as given); net annual cost = annualised cost – value of energy saved; MAC = net annual cost ÷ tCO₂ abated.

Substitution: A: CO₂ = 262.4 t, net = –₹19.6 lakh, MAC = $-19.6 \times 10^5 \div 262.4$; B: CO₂ = 1,148.0 t, net = –₹60.0 lakh, MAC = $-60.0 \times 10^5 \div 1,148.0$; C: CO₂ = 2,000.0 t, net = ₹40.0 lakh, MAC = $+40.0 \times 10^5 \div 2,000.0$; D: CO₂ = 400.0 t, net = ₹9.0 lakh, MAC = $+9.0 \times 10^5 \div 400.0$.

Option	CO ₂ abated (t/yr)	Net annual cost (₹ lakh)	MAC (₹/tCO ₂)
A	262.4	–19.6	–7,470

B	1,148.0	-60.0	-5,226
C	2,000.0	+40.0	+2,000
D	400.0	+9.0	+2,250

Result: **MAC: A –₹7,470/t, B –₹5,226/t, C ₹2,000/t, D ₹2,250/t.** A and B pay for themselves; C and D cost money per tonne abated. (3 marks)

(b) [1 mark]

Substitution: in MAC order $A \rightarrow B \rightarrow C \rightarrow D$: $A + B + C = 3,410.4$ t; still needed = $3,500 - 3,410.4 = 89.6$ t from D at ₹2,250/t = ₹2.02 lakh; net = $(-19.6) + (-60.0) + 40.0 + 2.02$.

Result: **adopt A, B and C in full and about 22% of D (≈ 11 ha); the plan gives a net annual saving of $\approx$ ₹37.58 lakh while meeting the target.** (1 mark)

(c) [1 mark]

Result: **barriers include: limited capital and short payback expectations; split incentives (the party paying does not get the saving); lack of information, skills and measured data; perceived technical and production risk; and transaction costs.** Standards, PAT targets, financing schemes and awareness programmes address these barriers. (1 mark)

Marking scheme (5 marks): a) CO₂ abated 1, net cost 1, MAC 1. b) Ranking and combination $\frac{1}{2}$, net cost $\frac{1}{2}$. c) Any three barriers 1.

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

..... 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 The simplified annual energy balance of a country is given in the table (all figures in Mtoe; hydro, nuclear and renewable electricity are counted at the electricity generated). Coal-fired stations convert primary energy to gross electricity at 33% efficiency and gas-fired stations at 45%. Station auxiliary consumption is 7% of gross generation and T&D losses are 20% of the electricity sent out. Refineries lose 4% of crude oil input; all other fuels go to final consumers without loss. Take 1 Mtoe = 11.63 TWh.

[4P1CEM059 | Chapter 1: Energy Scenario | Simplified national energy balance - from primary supply to final consumption and the leverage of T&D losses]

Primary source	Total supply (Mtoe)	To power stations (Mtoe)	To final consumers or refineries (Mtoe)
Coal	420	300	120 (industry)
Crude oil	240	–	240 (refineries)
Natural gas	55	15	40 (industry and fertiliser)
Hydro, nuclear and renewable electricity	30	30	–

(a) Calculate the gross electricity generated, the electricity sent out and the electricity delivered to consumers (Mtoe and TWh). [3 Marks]

(b) Calculate the total primary energy supply, the total final energy consumption and the overall efficiency of the energy supply chain. How much of the loss occurs in the power sector? [3 Marks]

(c) Calculate the share of electricity in final consumption and the share of primary energy used to produce it. Comment. [2 Marks]

(d) If T&D losses fall from 20% to 15%, how much coal (Mtoe) is saved while delivering the same electricity, assuming coal-fired generation is reduced? [2 Marks]

L-1 Ans**(a) [3 marks]**

Given: coal to power 300 Mtoe (≈ 12.6 EJ) at 33%; gas to power 15 Mtoe (≈ 628 PJ) at 45%; hydro, nuclear and renewables 30 Mtoe ($\approx 1,256$ PJ); auxiliary 7%; T&D loss 20%.

Formula: gross = Σ (fuel to power $\times$ efficiency) + hydro, nuclear and renewables; sent out = gross $\times$ (1 – auxiliary); delivered = sent out $\times$ (1 – T&D loss).

Substitution: gross = $300 \times 0.33 + 15 \times 0.45 + 30 = 99.00 + 6.75 + 30 = 135.75$; sent out = $135.75 \times 0.93 = 126.25$; delivered = $126.25 \times 0.80 = 101.00$ Mtoe; $\times 11.63$.

Result: **gross = 135.75 Mtoe ($\approx 5,684$ PJ), i.e. 1,579 TWh; sent out = 126.25 Mtoe ($\approx 5,286$ PJ), i.e. 1,468 TWh; delivered = 101.00 Mtoe ($\approx 4,229$ PJ), i.e. 1,175 TWh.** (3 marks)

(b) [3 marks]

Formula: TPES = sum of all primary inputs; TFC = coal and gas used directly + oil products + electricity delivered; overall efficiency = $TFC \div TPES$.

Substitution: TPES = $300 + 120 + 240 + 15 + 40 + 30 = 745$; TFC = $120 + 240 \times 0.96 + 40 + 101.00 = 120 + 230.4 + 40 + 101.00$; power-sector loss = $(300 + 15 + 30) - 101.00$; refinery loss = 240×0.04 .

Result: **TPES = 745 Mtoe (≈ 31.2 EJ); TFC = 491.40 Mtoe (≈ 20.6 EJ); supply-chain efficiency = 66.0%; of the 253.60 Mtoe (≈ 10.6 EJ) lost, 244.00 Mtoe (≈ 10.2 EJ) (96%) is lost in power generation, auxiliaries and T&D, and only 9.6 Mtoe (≈ 402 PJ) in refining.** (3 marks)

(c) [2 marks]

Substitution: $101.00 \div 491.40 \times 100$; $(300 + 15 + 30) \div 745 \times 100$.

Result: **electricity is 20.6% of final consumption but takes 46.3% of primary energy.** Each unit of electricity saved at the consumer saves about 3.4 units of primary energy, so electrical efficiency and T&D loss reduction have the biggest national leverage. (2 marks)

(d) [2 marks]

Formula: sent out needed = delivered $\div$ (1 – new loss); reduction in gross = reduction in sent out $\div$ (1 – auxiliary); coal saved = reduction in gross $\div$ coal station efficiency.

Substitution: $101.00 \div 0.85 = 118.82$; reduction in sent out = $126.25 - 118.82 = 7.43$; gross = $7.43 \div 0.93 = 7.99$; coal = $7.99 \div 0.33$.

Result: **coal saved ≈ 24.2 Mtoe ($\approx 1,013$ PJ) a year ($\approx 3.2\%$ of TPES).** A 5-point cut in T&D loss saves about three times its electricity value in primary coal. (2 marks)

Marking scheme (10 marks): a) Gross 1, sent out 1, delivered in Mtoe and TWh 1. b) TPES $\frac{1}{2}$, TFC 1, efficiency $\frac{1}{2}$, power-sector share 1. c) Two shares 1, comment 1. d) Required sent-out 1, coal saved 1.

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

L-2 During a detailed audit of an engineering plant, the auditor built the load inventory in the table from nameplate data, spot measurements of loading and interviews on operating hours. The electricity bill for the same 30-day month was 2,40,000 kWh at an average cost of ₹8.20/kWh. On a Sunday with no production, the main meter recorded 920 kWh over 24 hours; essential loads on such a day (security lighting, server and fire-system controls) total about 5 kW.

[4P1CEM060 | Chapter 4: Energy Management and Audit | Load inventory reconciled with the electricity bill, ranking of end uses and base-load analysis]

End use	Rated kW (each)	Number	Measured loading (fraction of rated)	Hours/day	Days/month
Air compressors	90	2	0.85	20	30
Machine tools	7.5	60	0.4	16	26
Induction heater	150	1	0.7	8	26
Lighting (LED fittings of 72 W)	0.072	400	1.0	12	30
Cooling tower fans and pumps	30	1	0.8	24	30

Office air conditioning	40	1	0.6	10	26
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- (a) Estimate the monthly energy of each end use and the total, and reconcile it with the bill. State the likely causes of the difference. [4 Marks]
- (b) Rank the end uses by share of energy and cost, and say where the detailed audit effort should go. [2 Marks]
- (c) Analyse the Sunday base load. If it could be brought down to 15 kW on all 52 Sundays, what would be the annual saving in kWh and rupees? Suggest how. [3 Marks]
- (d) Why is reconciling a load inventory with metered energy an essential step in an energy audit? [1 Mark]

L-2 Ans**(a) [4 marks]**

Formula: kWh = rated kW × number × measured loading × hours/day × days.

Substitution: Air compressors: $90 \times 2 \times 0.85 \times 20 \times 30 = 91,800$; Machine tools: $7.5 \times 60 \times 0.4 \times 16 \times 26 = 74,880$; Induction heater: $150 \times 1 \times 0.7 \times 8 \times 26 = 21,840$; Lighting (LED fittings of 72 W): $0.072 \times 400 \times 1.0 \times 12 \times 30 = 10,368$; Cooling tower fans and pumps: $30 \times 1 \times 0.8 \times 24 \times 30 = 17,280$; Office air conditioning: $40 \times 1 \times 0.6 \times 10 \times 26 = 6,240$.

End use	kWh/month	Share of estimate (%)
Air compressors	91,800	41.3
Machine tools	74,880	33.7
Induction heater	21,840	9.8
Lighting (LED fittings of 72 W)	10,368	4.7
Cooling tower fans and pumps	17,280	7.8
Office air conditioning	6,240	2.8
Total estimated	2,22,408	100.0
Billed	2,40,000	
Unaccounted	17,592	7.3 of bill

Result: **estimated total = 2,22,408 kWh against 2,40,000 kWh billed; unaccounted = 17,592 kWh (7.3%)**. Likely causes: transformer and cable losses on the plant side of the meter, small loads missed in the survey (hand tools, welding sets, water coolers), idling of machines and compressors outside the logged hours, and errors in assumed loading and hours. A gap under about 10% is acceptable; a larger gap means the survey must be revisited. (4 marks)

(b) [2 marks]

Result: **ranking: Air compressors 41.3%; Machine tools 33.7%; Induction heater 9.8%; Cooling tower fans and pumps 7.8%; Lighting (LED fittings of 72 W) 4.7%; Office air conditioning 2.8%**. At a uniform average rate the cost shares equal the energy shares; compressors and machine tools together take 75% ($\approx$ ₹13.67 lakh a month), so the detailed study should concentrate on compressed air generation and use and on machine-tool idling. (2 marks)

(c) [3 marks]

Given: Sunday energy 920 kWh in 24 h; target base load 15 kW.

Formula: average base load = kWh ÷ 24; avoidable = average – target; annual saving = avoidable kW × 24 × 52 × tariff.

Substitution: $920 \div 24 = 38.33$ kW (against $\approx$ 5 kW essential); avoidable = $38.33 - 15 = 23.33$ kW; $23.33 \times 24 \times 52 = 29,120$ kWh; $\times$ ₹8.20.

Result: **Sunday base load $\approx$ 38.3 kW, about 8 times the essential load; saving $\approx$ 29,120 kWh and ₹2,38,784 a year**. Typical culprits are compressors left running to feed leaks, cooling-tower pumps, air-conditioners and machine controls left on. A shutdown checklist, interlocks or timers on non-essential feeders, and a small dedicated compressor for weekend needs bring the base load down. (3 marks)

(d) [1 mark]

Result: **reconciliation checks that the inventory accounts for the energy actually purchased; it exposes missed loads, wrong assumptions on loading and hours, and hidden losses, and so prevents ECMs being sized on false data and savings being over-claimed**. (1 mark)

Marking scheme (10 marks): a) End-use kWh 2, total and reconciliation 1, causes 1. b) Ranking 1, focus 1. c) Base load ½, avoidable kW ½, kWh and rupees 1, measures 1. d) 1.

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

L-3 A jacketed batch reactor is charged with 8,000 kg of reactants (specific heat 0.55 kcal/kg°C (≈ 2.30 kJ/kg·K)) at 30 °C. The steel reactor vessel (3,500 kg, specific heat 0.12 kcal/kg°C (≈ 0.502 kJ/kg·K)) is heated with the charge to 85 °C using steam that gives up 520 kcal/kg ($\approx 2,177$ kJ/kg) in the jacket; losses during heat-up are 8% of the heat taken up by the charge and vessel. The reaction then forms 7,600 kg of product, releasing 95 kcal (≈ 398 kJ) per kg of product over 4 hours, while the batch is held at 85 °C by cooling water; heat loss to the surroundings during this period is 15,000 kcal/h (≈ 17.4 kW). Finally the batch (still 8,000 kg, specific heat now 0.52 kcal/kg°C (≈ 2.18 kJ/kg·K)) and vessel are cooled to 40 °C before discharge. Cooling water warms by 10 °C in every phase.

[4P1CEM061 | Chapter 5: Material and Energy Balance | Energy balance of a batch reactor with an exothermic reaction - steam, cooling water and heat recovery]

- (a) Calculate the steam consumed per batch during heat-up. [3 Marks]
- (b) Calculate the cooling water needed during the reaction phase, per batch and in m³/h. [3 Marks]
- (c) Calculate the cooling water needed per batch for the final cool-down. [2 Marks]
- (d) It is proposed to preheat each new charge to 55 °C with heat recovered from the previous batch during cool-down, through a tempered-water loop. Check that enough heat is available and calculate the steam saved per batch. [2 Marks]

L-3 Ans

(a) [3 marks]

Given: charge 8,000 kg, Cp 0.55; vessel 3,500 kg, Cp 0.12; $\Delta T = 85 - 30 = 55$ °C; losses 8%; steam gives 520 kcal/kg ($\approx 2,177$ kJ/kg).

Formula: $Q = \Sigma m \times C_p \times \Delta T$; steam heat = $Q \times (1 + \text{loss fraction})$; steam = steam heat $\div$ heat given up per kg.

Substitution: $8,000 \times 0.55 \times 55 = 2,42,000$; $3,500 \times 0.12 \times 55 = 23,100$; $Q = 2,65,100$ kcal; $\times 1.08 = 2,86,308$ kcal; $\div 520$.

Result: **steam = 550.6 kg per batch** (heat 2,86,308 kcal ($\approx 1,199$ MJ) per batch). (3 marks)

(b) [3 marks]

Formula: heat to cooling water = heat of reaction – losses to surroundings during the hold; water = heat $\div (1 \times \Delta T)$.

Substitution: reaction heat = $7,600 \times 95 = 7,22,000$ kcal; losses = $15,000 \times 4 = 60,000$ kcal; to water = $6,62,000$ kcal; $\div 10 = 66,200$ kg; $\div 4$ h $\div 1,000$.

Result: **cooling water = 66,200 kg per batch ≈ 16.55 m³/h during the reaction.** The reaction releases about 2.5 times the heat supplied by steam, so the reactor is a net heat source. (3 marks)

(c) [2 marks]

Substitution: batch $8,000 \times 0.52 \times 45 = 1,87,200$; vessel $3,500 \times 0.12 \times 45 = 18,900$; total = $2,06,100$ kcal; $\div 10$.

Result: **cool-down water = 20,610 kg per batch** (heat rejected 2,06,100 kcal (≈ 863 MJ)). (2 marks)

(d) [2 marks]

Substitution: heat to preheat the charge = $8,000 \times 0.55 \times (55 - 30) = 1,10,000$ kcal, less than the 2,06,100 kcal rejected at cool-down; steam saved = $1,10,000 \times 1.08 \div 520$.

Result: **enough heat is available (53% of the cool-down heat is needed); steam saved ≈ 228.5 kg per batch, about 41% of heat-up steam,** and cool-down cooling water falls by the same heat quantity. The tempered-water loop must run warmer than 55 °C at the start of cool-down, so in practice only the hotter part of the cool-down heat can be used. (2 marks)

Marking scheme (10 marks): a) Sensible heat of charge and vessel 1, losses 1, steam 1. b) Reaction heat 1, net of losses 1, water and m³/h 1. c) Heat 1, water 1. d) Availability check 1, steam saved 1.

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

L-4 A factory buys 12 GWh a year from the grid at an average cost of ₹8.20/kWh. It is evaluating two captive options. Option 1: a 5 MWp ground-mounted solar PV plant at ₹4.0 crore per MWp, O&M 1.5% of capital cost a year, capacity utilisation factor (CUF) 19%, life 25 years. Option 2: a 1.5 MW natural gas engine generator costing ₹9 crore, life 15 years, plant load factor 85%, heat rate 2,250 kcal/kWh ($\approx 9,420$ kJ/kWh), gas GCV 8,600 kcal/Sm³ (≈ 36.0 MJ/Sm³) at ₹45/Sm³, and O&M ₹0.60/kWh. The discount rate is 10%. Ignore taxes and degradation.

[4P1CEM062 | Chapter 7: Financial Management | Levelised cost of electricity - captive solar PV and a gas engine compared with grid supply]

- Calculate the capital recovery factor and the levelised cost of electricity (LCOE) of the solar plant. [3 Marks]
- Calculate the LCOE of the gas engine, showing the fuel, O&M and capital components. [3 Marks]
- Calculate the annual cost of electricity with the solar plant plus grid supply for the balance, and the saving against grid-only supply. [2 Marks]
- Recalculate the solar LCOE if the CUF is only 16% and the discount rate rises to 12%. Comment on the decision. [2 Marks]

L-4 Ans

(a) [3 marks]

Given: capital = $5 \times ₹4.0$ crore = ₹20 crore; $n = 25$; $i = 0.1$; CUF = 0.19.

Formula: $CRF = i(1+i)^n \div [(1+i)^n - 1]$; annual kWh = kWp $\times 8,760 \times$ CUF; $LCOE = (\text{capital} \times CRF + \text{annual O\&M}) \div \text{annual kWh}$.

Substitution: $CRF = 0.11017$; kWh = $5,000 \times 8,760 \times 0.19 = 83,22,000$; capital charge = $20 \times 0.11017 = ₹2.2034$ crore; O&M = ₹0.30 crore; $LCOE = (2.2034 + 0.30) \times 10^7 \div 83,22,000$.

Result: **CRF = 0.1102; solar LCOE $\approx$ ₹3.01/kWh.** (3 marks)

(b) [3 marks]

Formula: fuel cost per kWh = heat rate $\div$ GCV $\times$ gas price; capital per kWh = capital $\times$ CRF $\div$ annual kWh; $LCOE = \text{fuel} + \text{O\&M} + \text{capital}$.

Substitution: kWh = $1,500 \times 8,760 \times 0.85 = 1,11,69,000$; fuel = $2,250 \div 8,600 \times 45 = ₹11.77$; $CRF(10\%, 15) = 0.13147$; capital = $9 \times 0.13147 \times 10^7 \div 1,11,69,000 = ₹1.06$.

Result: **gas engine LCOE $\approx$ ₹13.43/kWh (fuel ₹11.77, O&M ₹0.60, capital ₹1.06)**, well above the grid cost of ₹8.20; power-only generation on gas is uneconomic unless the engine's waste heat is used. (3 marks)

(c) [2 marks]

Substitution: grid only = $12 \times 10^6 \times 8.20 = ₹9.84$ crore; with solar = $(2.2034 + 0.30) + (12 \times 10^6 - 83,22,000) \times 8.20 \div 10^7 = ₹5.52$ crore.

Result: **annual cost falls from ₹9.84 crore to ₹5.52 crore, a saving of $\approx$ ₹4.32 crore a year**; solar meets 69% of the demand. (2 marks)

(d) [2 marks]

Substitution: $CRF(12\%, 25) = 0.12750$; kWh = $5,000 \times 8,760 \times 0.16 = 70,08,000$; $LCOE = (20 \times 0.12750 + 0.30) \times 10^7 \div 70,08,000$.

Result: **solar LCOE rises to $\approx$ ₹4.07/kWh, still below the grid cost.** The solar choice is robust, but the saving should be valued at the avoidable energy charge only: solar does not reliably cut the maximum demand, so demand charges remain. (2 marks)

Marking scheme (10 marks): a) CRF 1, generation 1, LCOE 1. b) Fuel cost 1, capital component 1, LCOE and comment 1. c) Two annual costs 1, saving 1. d) Revised LCOE 1, comment 1.

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

L-5 A 6 MW waste-heat recovery power project is scheduled over four quarters: engineering and orders in Q1, civil works and boiler supply in Q2, turbine supply and erection in Q3, and erection completion, testing and commissioning in Q4. Capital spending by quarter is ₹6 crore, ₹10 crore, ₹14 crore and ₹8 crore. 70% of each

quarter's spending is drawn from a term loan at 11% a year (charged quarterly, i.e. 2.75% a quarter); interest during construction (IDC) is capitalised. Assume each quarter's drawal is made mid-quarter, so it carries half a quarter's interest in that quarter. Once commissioned, the plant saves ₹9.5 crore a year in purchased power.

[4P1CEM063 | Chapter 8: Project Management | Implementation phase of an energy project - disbursement schedule, interest during construction and cost of delay]

- Prepare a quarter-wise table of loan drawals and IDC, and find the total IDC. [4 Marks]
- Find the completed project cost and the simple payback with and without IDC. [1 Mark]
- Turbine delivery slips and commissioning is delayed by one quarter. Estimate the cost of the delay (extra IDC plus savings forgone) and express it as a percentage of the project cost. [3 Marks]
- List four project-management measures that would protect the schedule. [2 Marks]

L-5 Ans

(a) [4 marks]

Given: quarterly spend ₹6, 10, 14 and 8 crore; loan share 70%; interest 2.75% per quarter; drawals mid-quarter.

Formula: drawal = spending × loan share; IDC in a quarter = quarterly rate × (opening balance + $\frac{1}{2}$ × drawal); closing balance = opening + drawal + IDC.

Substitution: Q1: drawal = $6 \times 0.7 = 4.20$; IDC = $0.0275 \times (0.0000 + 2.10) = 0.0577$; closing = 4.2577; Q2: drawal = $10 \times 0.7 = 7.00$; IDC = $0.0275 \times (4.2577 + 3.50) = 0.2133$; closing = 11.4711; Q3: drawal = $14 \times 0.7 = 9.80$; IDC = $0.0275 \times (11.4711 + 4.90) = 0.4502$; closing = 21.7213; Q4: drawal = $8 \times 0.7 = 5.60$; IDC = $0.0275 \times (21.7213 + 2.80) = 0.6743$; closing = 27.9956.

Quarter	Spending (₹ crore)	Loan drawal (₹ crore)	Opening balance (₹ crore)	IDC (₹ crore)	Closing balance (₹ crore)
Q1	6.0	4.20	0.0000	0.0577	4.2577
Q2	10.0	7.00	4.2577	0.2133	11.4711
Q3	14.0	9.80	11.4711	0.4502	21.7213
Q4	8.0	5.60	21.7213	0.6743	27.9956

Result: **total IDC ≈ ₹1.40 crore; loan outstanding at commissioning ≈ ₹28.00 crore.** (4 marks)

(b) [1 mark]

Substitution: completed cost = $38 + 1.40$; payback = $38 \div 9.5$ and $39.40 \div 9.5$.

Result: **completed cost ≈ ₹39.40 crore; payback 4.00 years without IDC and 4.15 years with IDC.** (1 mark)

(c) [3 marks]

Formula: extra IDC = quarterly rate × loan outstanding at the planned commissioning date; savings forgone = annual saving ÷ 4.

Substitution: extra IDC = $0.0275 \times 27.9956 = 0.770$; savings forgone = $9.5 \div 4 = 2.375$; total = $0.770 + 2.375$.

Result: **a one-quarter delay costs ≈ ₹3.14 crore (8.0% of the completed cost)**, three-quarters of it as lost savings. On energy projects the saving forgone, not the interest, is usually the main cost of delay, so schedule control matters as much as capital cost. (3 marks)

(d) [2 marks]

Result: **any four (½ mark each): a time-bound schedule with critical activities identified and monitored weekly; liquidated-damages clauses in supply and erection contracts; expediting and inspection of critical equipment at the vendor's works; advance clearances and permits; a single-point project manager with authority; progress-linked payments; and contingency plans for long-lead items.** (2 marks)

Marking scheme (10 marks): a) Drawals 1, IDC per quarter 2, total 1. b) Cost and paybacks 1. c) Extra IDC 1, savings forgone 1, total and comment 1. d) ½ per measure.

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

L-6 A binary-cycle geothermal plant draws 120 kg/s of hot brine at 165 °C from production wells and reinjects it at 75 °C after passing it through the vaporiser of an organic Rankine cycle (ORC). Take the specific heat of brine as

4.2 kJ/kg·K. The net cycle efficiency is 10.5% and the condenser works at 35 °C. The plant runs at a 92% capacity factor and its power is sold at ₹6.50/kWh, displacing grid power with an emission factor of 0.82 tCO₂/MWh. The plant costs ₹125 crore and O&M costs ₹4.0 crore a year.

[4P1CEM064 | Chapter 11: New and Renewable Energy Sources | Geothermal binary-cycle power plant - heat extracted, Carnot limit, well field, annual output and economics]

- Calculate the heat extracted from the brine and the net electrical output. [2 Marks]
- Calculate the Carnot efficiency between the brine supply and condenser temperatures and the ratio of actual to Carnot efficiency. Why is the efficiency low, and why is an organic working fluid used instead of water? [2 Marks]
- A second unit of 10 MW net is planned on the same resource conditions. Calculate the brine flow needed and the number of production wells if each well yields 40 kg/s. [2 Marks]
- Calculate the annual generation of the existing plant and the CO₂ emission avoided. [2 Marks]
- Calculate the simple payback period of the existing plant and state one advantage of geothermal power over solar and wind. [2 Marks]

L-6 Ans

(a) [2 marks]

Given: $\dot{m} = 120 \text{ kg/s}$; $C_p = 4.2 \text{ kJ/kg}\cdot\text{K}$; $\Delta T = 165 - 75 = 90 \text{ K}$; $\eta = 0.105$.

Formula: $Q = \dot{m} \times C_p \times \Delta T \text{ (kW)}$; $P = \eta \times Q$.

Substitution: $120 \times 4.2 \times 90 = 45,360 \text{ kW}$; $0.105 \times 45,360$.

Result: **heat extracted = 45,360 kW ($\approx 45.36 \text{ MW thermal}$); net output $\approx 4,763 \text{ kW}$ ($\approx 4.76 \text{ MW}$).** (2 marks)

(b) [2 marks]

Formula: $\eta_{\text{Carnot}} = 1 - T_{\text{cold}} \div T_{\text{hot}} \text{ (kelvin)}$.

Substitution: $1 - (35 + 273.15) \div (165 + 273.15) = 1 - 308.15 \div 438.15$; ratio = $0.105 \div 0.2967$.

Result: **Carnot efficiency = 29.7%; actual $\div$ Carnot = 35%.** The source temperature is low and the brine cools as it gives up heat, so the mean temperature of heat input is well below 165 °C. An organic fluid (for example isopentane) boils at a much lower temperature and higher pressure than water, so it can be vaporised by moderate-temperature brine and expands in a compact turbine without condensing in the last stages. (2 marks)

(c) [2 marks]

Formula: $\text{brine flow} = \text{net power} \div (\eta \times C_p \times \Delta T)$; $\text{wells} = \text{flow} \div \text{yield per well, rounded up}$.

Substitution: $10,000 \div (0.105 \times 4.2 \times 90) = 252.0 \text{ kg/s}$; $252.0 \div 40 = 6.30$.

Result: **brine flow $\approx 252 \text{ kg/s}$; 7 production wells** (plus reinjection wells and a standby). (2 marks)

(d) [2 marks]

Formula: $\text{MWh} = \text{MW} \times 8,760 \times \text{capacity factor}$; $\text{CO}_2 = \text{MWh} \times \text{emission factor}$.

Substitution: $4.763 \times 8,760 \times 0.92 = 38,384 \text{ MWh}$; $\times 0.82$.

Result: **annual generation $\approx 38,384 \text{ MWh}$; CO₂ avoided $\approx 31,475 \text{ t a year}$.** (2 marks)

(e) [2 marks]

Formula: $\text{revenue} = \text{kWh} \times \text{tariff}$; $\text{payback} = \text{capital} \div (\text{revenue} - \text{O\&M})$.

Substitution: $3,83,84,358 \times ₹6.50 = ₹24.95 \text{ crore}$; $125 \div (24.95 - 4.0)$.

Result: **payback $\approx 6.0 \text{ years}$.** Geothermal heat is available round the clock regardless of weather, so the plant supplies base load at a high capacity factor without storage. (2 marks)

Marking scheme (10 marks): a) Heat 1, power 1. b) Carnot and ratio 1, reasons 1. c) Brine flow 1, wells 1. d) Generation 1, CO₂ 1. e) Payback 1, advantage 1.

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

..... End of Section III

Answer key — Section I

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	c	11	c	21	b	31	c	41	d
2	d	12	a	22	b	32	b	42	b
3	a	13	d	23	a	33	b	43	d
4	a	14	a	24	b	34	c	44	a
5	c	15	d	25	c	35	d	45	b
6	b	16	d	26	b	36	c	46	b
7	c	17	a	27	d	37	a	47	a
8	d	18	c	28	d	38	d	48	b
9	c	19	c	29	b	39	a	49	d
10	b	20	a	30	a	40	a	50	c