

Paper-1 — Formula & Concept Guide

General Aspects of Energy Management & Energy Audit — all 11 chapters.

For every formula: what each symbol means and its unit, what the formula actually tells you, a worked example in the guidebook's style, and the exam trap. Plus 23 pictures of the graphs and diagrams the exam refers to, 73 short definitions, and 42 verified online videos (each link checked against the video's real title). 67 formulas in all. Values are the 2014 BEE Book-1's.

► **Download the whole guide as one PDF · Paper-3 numericals drill**

Ch 1 · Energy Scenario (5 formulas)

Ch 2 · Energy Conservation Act 2001 (4 formulas)

Ch 3 · Basics of Energy and its Forms (14 formulas)

Ch 4 · Energy Management and Audit (6 formulas)

Ch 5 · Material and Energy Balance (8 formulas)

Ch 6 · Energy Action Planning (1 formulas)

Ch 7 · Financial Management (8 formulas)

Ch 8 · Project Management (6 formulas)

Ch 9 · Energy Monitoring and Targeting (4 formulas)

Ch 10 · Energy Efficiency and Climate Change (3 formulas)

Ch 11 · New and Renewable Energy Sources (8 formulas)

Chapter 1 • Energy Scenario

7–10 % of the paper. Mostly theory, but the two formulas below (toe conversion, energy intensity) come every year as objectives or a 5-marker.

Tonne of oil equivalent (toe)

$$1 \text{ toe} = 10^7 \text{ kcal} = 11,630 \text{ kWh} = 41,868 \text{ MJ} \quad \cdot \quad 1 \text{ MTOE} = 10^6 \text{ toe}$$

WHAT EACH SYMBOL MEANS • UNIT

toe	the heat released by burning one tonne of crude oil — the common yardstick for comparing coal, gas, electricity and oil	10^7 kcal
kWh	one unit of electricity	$1 \text{ kWh} = 860 \text{ kcal}$

WHAT IT MEANS

Different fuels are measured in different units (tonnes of coal, m^3 of gas, kWh). To add them up or compare countries, every one is converted to the heat it contains, expressed as tonnes of oil. Divide any energy in kcal by 10^7 to get toe.

Worked example. A plant uses 4,000 MWh of electricity a year. Energy = $4,000,000 \text{ kWh} \times 860 \text{ kcal/kWh} = 3.44 \times 10^9 \text{ kcal} \div 10^7 = 344 \text{ toe}$.

Exam trap. Use 860 kcal per kWh (the electricity delivered), not the 2,500–3,000 kcal it took to generate it, unless the question says 'primary energy'.

Reserves-to-production ratio (R/P)

$R/P \text{ (years)} = \text{Reserves remaining at end of year} \div \text{Production in that year}$

WHAT EACH SYMBOL MEANS · UNIT

Reserves	proven reserves still in the ground	tonnes (or m ³)
Production	amount produced in that one year	tonnes/year

WHAT IT MEANS

How many years the known reserves would last if production stayed at this year's rate. Book values: coal $\approx$ 130 years (world), oil $\approx$ 45, gas $\approx$ 65; India coal $\approx$ 100+ years, oil $\approx$ 20.

Worked example. Reserves 892,000 million tonnes; production 7,800 million tonnes/year $\rightarrow R/P = 892,000 \div 7,800 \approx 114$ years.

Exam trap. It is a ratio of the same units, so the answer is in years — it is not a percentage.

Energy intensity

$\text{Energy intensity} = \text{Energy consumed} \div \text{GDP}$

WHAT EACH SYMBOL MEANS · UNIT

Energy consumed	total (final or primary) energy used by the country in the year	toe
GDP	gross domestic product, at constant prices, or at purchasing-power parity (PPP)	million US\$

WHAT IT MEANS

Energy needed to produce one unit of economic output. A LOWER intensity means the economy gets more output from each toe. Comparing at PPP removes exchange-rate distortion, which is why India looks far better on the PPP basis than on the exchange-rate basis.

Worked example. Country A: 2,000 toe, GDP US\$ 100 million $\rightarrow$ 20 toe per million US\$. Country B: 2,500 toe, GDP 140 $\rightarrow$ 17.9. B uses energy more efficiently (2025 Paper-1, S-2).

Exam trap. Lower energy intensity does NOT automatically mean higher energy efficiency — it can come from a shift to services or a strong currency. This is the exact 2024 short question.

Per-capita energy consumption

$$\text{Per-capita consumption} = \text{Total energy consumption} \div \text{Population}$$

WHAT EACH SYMBOL MEANS · UNIT

Total consumption	country's yearly energy use	toe or kgoe
Population	people	—

WHAT IT MEANS

The book's indicator of living standard: India $\approx$ 0.5 toe per person against a world average $\approx$ 1.8 and USA $\approx$ 8 (2014 book figures).

Exam trap. India's figure is LOW because population is large, not because the country uses little energy in total.

Gross inland (primary) consumption

$$\text{Gross inland consumption} = \text{Production} + \text{Imports} - \text{Exports} \pm \text{Stock changes}$$

WHAT EACH SYMBOL MEANS · UNIT

Production	domestic production of primary energy	toe
Imports / Exports	energy traded across the border	toe
Stock change	withdrawal (+) or build-up (-) of stocks	toe

WHAT IT MEANS

The energy actually available to the economy in the year. Import dependence = Imports $\div$ Gross inland consumption (India's oil import dependence $\approx$ 80 %).

Worked example. Production 500, imports 300, exports 50, stock drawn 10 $\rightarrow$ 760 MTOE.

Exam trap. Subtract exports; do not add them.

Energy intensity — why PPP changes the picture

Same country, same energy (2,000 toe)

GDP at exchange rate  US\$ 100 M → 20 toe/M\$

GDP at PPP  US\$ 250 M -

Lower number = economy gets more output per toe

PPP revalues India's output at what it buys locally, so the intensity falls — but it says nothing about equipm

Same energy, same physical output: valued at market exchange rate India's GDP looks small, so intensity looks high; at PPP the GDP is revalued upward and the intensity falls. The exam asks 'why is intensity expressed at PPP?' — this is the answer.

DEFINITIONS THE EXAM ASKS

Primary vs secondary energy

Primary energy is found in nature (coal, crude oil, gas, sunlight, uranium); secondary energy is made from it (electricity, petrol, coke). Electricity is always secondary.

Commercial vs non-commercial

Commercial energy is bought and sold (coal, oil, gas, electricity); non-commercial is gathered free (firewood, dung, agricultural waste).

Renewable vs non-renewable

Renewable replenishes naturally in human time (solar, wind, hydro, biomass); non-renewable is finite (coal, oil, gas, nuclear fuel).

Energy security

Assured supply of energy at affordable prices, achieved by diversifying fuels and sources, strategic reserves, efficiency and domestic renewables.

Energy pricing in India

Coal, oil products and electricity are cross-subsidised: households and agriculture pay below cost, industry and commerce pay above it. Long-term marginal cost (LTMC) pricing is the book's recommendation.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

Primary/Secondary & Energy Mix — Energy Conservation & Audit | Energy Scenario | Primary & Secondary Energy | Energy demand & Supply · CRAZY POLYTECHNIC

Reserves & R/P Ratio — Fundamentals of Energy Statistics · IEA Webinars

Energy Intensity & PPP — Power Tech Webinar - 1 for Energy Auditor Exam of BEE -Energy Scenario-1 · Power Tech

TOE & MTOE Conversions — CONVERT ANNUAL ENERGY CONSUMED INTO TOE (TONS OF OIL EQUIVALENT) · Nishant Bajpai's FinTech Education

Chapter 2 · Energy Conservation Act 2001

6–8 % of the paper, pure theory and fast marks: designated consumers, BEE's functions, S&L, ECBC, PAT and the 2010 amendment. Learn the numbers.

Designated-consumer thresholds (energy-intensive industries)

Annual energy consumption $\geq$ threshold $\rightarrow$ notified as a Designated Consumer (DC)

WHAT EACH SYMBOL MEANS · UNIT

30,000 MTOE	thermal power plants, fertiliser, cement, iron & steel, railways, pulp & paper	per year
12,000 MTOE	chlor-alkali	per year
7,500 MTOE	aluminium	per year
3,000 MTOE	textiles	per year

WHAT IT MEANS

A DC must appoint a certified energy manager, get a mandatory audit by an accredited auditor, report energy data, and meet PAT targets.

Worked example. A textile mill using 4,200 MTOE/year is a DC (above 3,000).

Exam trap. MTOE here means metric tonne of oil equivalent (the Act's spelling), i.e. toe — not million toe.

PAT — Perform, Achieve and Trade

Target SEC for each DC → shortfall or excess (toe) → 1 ESCert = 1 toe of saving

WHAT EACH SYMBOL MEANS · UNIT

SEC	specific energy consumption, energy per unit product	toe per tonne
ESCert	Energy Saving Certificate, issued for saving beyond target, tradable at power exchanges	1 toe each

WHAT IT MEANS

A market mechanism under the 2010 amendment: over-achievers earn ESCerts, under-achievers buy them or pay a penalty. ESCerts can be bought, sold and banked for the next cycle, but not traded directly between DCs outside the exchange.

Worked example. Target 0.90 toe/t, achieved 0.85 toe/t on 100,000 t → 5,000 toe saved → 5,000 ESCerts.

Exam trap. 'ESCerts cannot be traded directly between DCs' — exchange-traded only (2015 and 2023 exams).

ECBC applicability

Commercial building with connected load ≥ 100 kW or contract demand ≥ 120 kVA

WHAT EACH SYMBOL MEANS · UNIT

Connected load	sum of rated loads installed	kW
Contract demand	demand contracted with the utility	kVA

WHAT IT MEANS

Energy Conservation Building Code sets minimum efficiency for envelope, HVAC, lighting, hot water and power in new large commercial buildings; states may adopt it and lower the thresholds.

Exam trap. It is 100 kW OR 120 kVA — either one makes the code applicable.

Standards & Labelling (S&L)

Star rating 1★ (least efficient) → 5★ (most efficient), against the BEE test standard

WHAT EACH SYMBOL MEANS · UNIT

Comparative label star label — lets buyers compare models (ACs, refrigerators, TVs, fans, pumps, motors...) 1–5 stars

Endorsement label pass/fail mark that the product meets a minimum standard —

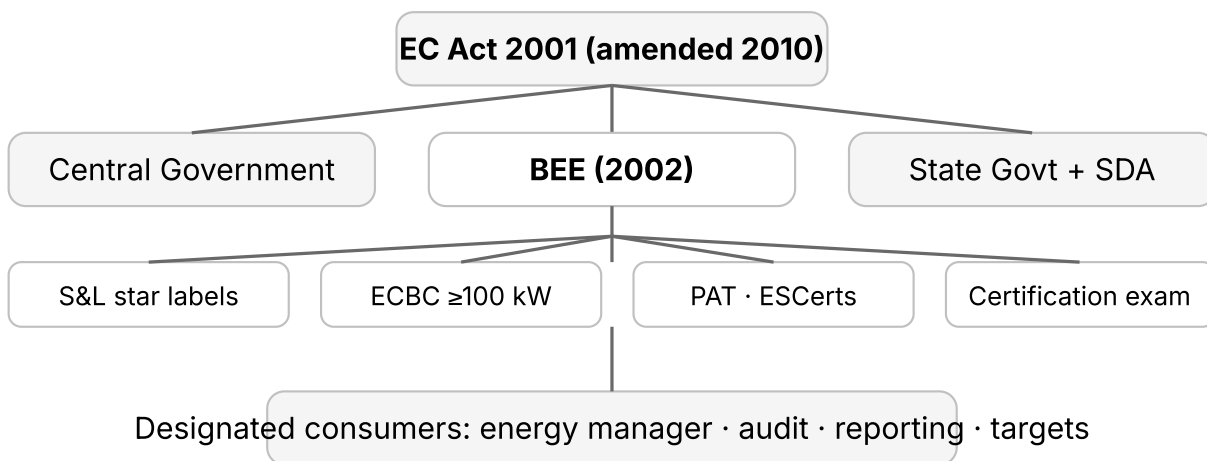
MEPS minimum energy performance standard below which sale is not allowed —

WHAT IT MEANS

Mandatory for some appliances (frost-free refrigerators, room ACs, TFLs, distribution transformers...), voluntary for others. Manufacturer declares, BEE verifies by sample testing.

Exam trap. More stars = LESS energy; the star bands are revised upward every few years.

The EC Act at one glance



Who does what: the Act empowers the Centre and States, BEE implements, designated consumers comply through energy managers, audits, PAT and reporting.

DEFINITIONS THE EXAM ASKS

BEE

Bureau of Energy Efficiency, set up 1 March 2002 under the Act, under the Ministry of Power; it recommends norms, certifies energy managers/auditors, runs S&L, PAT, ECBC and awareness

programmes.

Powers of Central Government

Notify designated consumers, norms of energy consumption, energy managers, mandatory audits, S&L for appliances, ECBC, and set up the Central Energy Conservation Fund.

Powers of State Government

Adopt/amend ECBC, enforce audits and reporting in the state, set up the State Energy Conservation Fund, appoint the State Designated Agency (SDA).

Penalty (2010 amendment)

Up to ₹10 lakh for each failure, plus up to ₹10,000 per day of continuing failure; PAT non-compliance is charged at the price of the shortfall in energy.

Energy Manager vs Energy Auditor

Both certified by BEE exam; a DC must appoint or designate an energy manager; the mandatory audit must be by an accredited energy auditor (Paper-4 qualified).

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

EC Act 2001 & 2010 Amendment — Energy Conservation Act 2001 (in hindi) | EC Act 2001 | Features of EC Act | Energy Conservation · Paradise Educator

Designated Consumers & Mandatory Audits — BEE Mandatory Energy Audit Explained | PAT Scheme, Compliance & Penalties (India) · SARK Engineers & Consultants

Standards & Labeling (S&L) Program — Energy Conservation Act 2001, Bureau of Energy Efficiency, Star energy label, ECBC, DSM, PAT, HV · ShreeDevi Classes

PAT Scheme & ESCerts — Perform, Achieve and Trade (PAT) Scheme · Bureau of Energy Efficiency

Chapter 3 · Basics of Energy and its Forms

The biggest chapter: 18–22 % of the paper. Units, electricity, heat, steam and fuels. Almost every objective numerical comes from here.

Ohm's law and electrical power

$$V = I \times R \quad \cdot \quad P = V \times I = I^2 \times R = V^2 \div R$$

WHAT EACH SYMBOL MEANS · UNIT

V	voltage (electrical pressure)	volt, V
I	current (flow of charge)	ampere, A
R	resistance	ohm, Ω
P	power	watt, W

WHAT IT MEANS

Power is how fast energy is used. Doubling voltage across the same resistance quadruples power (V^2/R) — this is why a 250 V heater at 230 V gives less heat.

Worked example. Kettle of 25Ω on 250 V: $I = 250/25 = 10 \text{ A}$; $P = 250 \times 10 = 2,500 \text{ W}$ (2023 long, part 1).

Exam trap. I^2R loss: halving current cuts loss to one quarter — this is the whole reason for high-voltage transmission and PF correction.

AC power — single and three phase

$$P_{1ph} = V \times I \times \cos \phi \quad \cdot \quad P_{3ph} = \sqrt{3} \times V_L \times I_L \times \cos \phi$$

WHAT EACH SYMBOL MEANS · UNIT

V_L	line-to-line voltage (415 V in India LT)	V
I_L	line current	A
cos φ	power factor	0–1
√3	1.732	—

WHAT IT MEANS

Only the part of current in phase with the voltage does work; cos φ is that fraction. Divide by 1000 for kW.

Worked example. 415 V, 12 A, PF 0.9: $P = 1.732 \times 415 \times 12 \times 0.9 \div 1000 = 7.76 \text{ kW}$.

Exam trap. Use the LINE voltage with √3; never assume PF = 1 unless told.

Power triangle and power factor

$$\text{kVA}^2 = \text{kW}^2 + \text{kVAr}^2 \quad \cdot \quad \text{PF} = \cos \phi = \text{kW} \div \text{kVA} \quad \cdot \quad \text{kVAr} = \text{kVA} \times \sin \phi$$

WHAT EACH SYMBOL MEANS · UNIT

kW	real (active) power — does the work	kW
kVAr	reactive power — builds the magnetic field, does no work	kVAr
kVA	apparent power — what the cables and transformer must carry	kVA
φ	angle between kW and kVA	degrees

WHAT IT MEANS

Think of a right-angled triangle: kW along the bottom, kVAr up the side, kVA the diagonal. Adding capacitors shortens the kVAr side, so kVA falls and PF (= kW/kVA) rises. Utilities bill and penalise on kVA and PF.

Worked example. kW 812, PF 0.70 → $\text{kVA} = 812/0.70 = 1,160$; $\text{kVAr} = \sqrt{(1160^2 - 812^2)} = 828$.

Exam trap. Improving PF does not reduce kW; it reduces kVA, current and I²R losses.

Motor kVA from HP

$$\text{kVA} = (\text{HP} \times 0.746) \div (\eta \times \text{PF})$$

WHAT EACH SYMBOL MEANS · UNIT

HP	motor rating in horsepower	hp
0.746	kW per HP	kW/hp
η	motor efficiency	0–1
PF	power factor	0–1

WHAT IT MEANS

Converts a nameplate HP into the apparent power the supply must provide, allowing for the motor's own losses and its lagging PF.

Worked example. 50 HP, η 0.9, PF 0.8: $\text{kVA} = 50 \times 0.746 \div (0.9 \times 0.8) = 51.8 \text{ kVA}$.

Exam trap. Divide by both η and PF, not just one.

Motor loading

$$\% \text{ loading} = \text{Input kW} \div (\text{Rated kW} \div \text{Rated } \eta) \times 100$$

WHAT EACH SYMBOL MEANS · UNIT

Input kW	measured $\sqrt{3} \cdot V \cdot I \cdot \cos \phi$	kW
Rated kW	nameplate output	kW
Rated η	nameplate full-load efficiency	0–1

WHAT IT MEANS

Compares what the motor is drawing now with what it would draw at full load. Motors below ~40 % load run at poor efficiency and PF.

Worked example. 10 HP (7.46 kW) motor, η 0.9, drawing 4.5 kW → rated input 8.29 kW → loading 54 % (2021/2024 short).

Exam trap. Never estimate loading from the current ratio alone — current does not fall in proportion at low loads.

Synchronous speed and slip

$$N_s = 120 f \div P \quad \cdot \quad \text{Slip \%} = (N_s - N) \div N_s \times 100$$

WHAT EACH SYMBOL MEANS · UNIT

f	supply frequency (50 Hz)	Hz
P	number of poles	—
N	actual rotor speed	rpm

WHAT IT MEANS

A 4-pole motor on 50 Hz has a synchronous speed of 1,500 rpm; it runs slightly slower (e.g. 1,470 rpm = 2 % slip). Speed can only be varied by changing frequency (VFD) or poles.

Worked example. 6 poles: $120 \times 50 \div 6 = 1,000$ rpm.

Exam trap. More poles = slower motor.

Electrical energy and its cost

$$\begin{aligned} \text{Energy (kWh)} &= \text{Power (kW)} \times \text{Hours} & \cdot & \quad \text{Cost} = \text{kWh} \times \text{Tariff} \\ (\text{₹/kWh}) & & \cdot & \quad 1 \text{ kWh} = 860 \text{ kcal} = 3.6 \text{ MJ} \end{aligned}$$

WHAT EACH SYMBOL MEANS · UNIT

kW	power	kW
h	running hours	h
Tariff	energy charge	₹/kWh

WHAT IT MEANS

A unit of electricity is one kilowatt for one hour. 860 kcal is the heat you get from a unit in a resistance heater (100 % conversion).

Worked example. 5 kW heater for 8 h = 40 kWh = 34,400 kcal; at ₹7/kWh = ₹280.

Exam trap. Cooling 2,000 kg of water by 10 °C removes $2,000 \times 1 \times 10 = 20,000$ kcal — the 2025 objective; do not divide by 860 unless kWh is asked.

Sensible heat

$$Q = m \times C_p \times \Delta T$$

WHAT EACH SYMBOL MEANS · UNIT

Q	heat added or removed	kcal
m	mass	kg
C_p	specific heat (water = 1 kcal/kg °C; air ≈ 0.24)	kcal/kg °C
ΔT	temperature change	°C

WHAT IT MEANS

Heat that changes temperature without changing state. Water has the highest common specific heat, so it stores the most heat per °C — the reason it is the universal coolant.

Worked example. Heat 25,000 kg/h water from 28 to 80 °C: $25,000 \times 1 \times 52 = 1,300,000$ kcal/h.

Exam trap. Equal heat to equal masses: the metal with the LOWER specific heat gets hotter (iron 0.11 vs copper 0.09 → copper rises more).

Latent heat and heat of fusion

$$Q = m \times L \quad (\text{no temperature change})$$

WHAT EACH SYMBOL MEANS · UNIT

L	latent heat: ice→water 80 kcal/kg (335 kJ/kg); water→steam 540 kcal/kg at 1 atm	kcal/kg
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WHAT IT MEANS

Heat absorbed while a substance changes state at constant temperature. Melting ice or boiling water takes far more heat than warming it: raising water 1 °C costs 1 kcal/kg, boiling it costs 540.

Worked example. 2,000 kJ to 500 kg ice at 0 °C melts $2,000 \div 335 = 5.97$ kg (2013/2017/2022 objective).

Exam trap. Latent heat is per kg of the substance CHANGING state, not the total mass present.

Steam: enthalpy and dryness fraction

$$h_{\text{wet}} = h_f + x \times h_{\text{fg}} \quad \cdot \quad x = \text{mass of dry steam} \div \text{total mass}$$

WHAT EACH SYMBOL MEANS · UNIT

h_f	enthalpy of saturated water (sensible heat)	kcal/kg
h_{fg}	latent heat of evaporation at that pressure	kcal/kg
x	dryness fraction, 1.0 = dry saturated	0–1

WHAT IT MEANS

Wet steam carries less heat than dry steam because part of it is still water.

Superheated steam has extra sensible heat above saturation. Latent heat FALLS as pressure rises (540 kcal/kg at 1 atm, ~460 at 10 kg/cm²).

Worked example. At 3 bar: $h_f \approx 133$, $h_{\text{fg}} \approx 517$ kcal/kg; $x = 0.9 \rightarrow h = 133 + 0.9 \times 517 = 598$ kcal/kg.

Exam trap. Higher pressure steam has LESS latent heat per kg — good for temperature, bad for heat delivered per kg.

Fuel calorific value — GCV and NCV

$$\text{NCV} = \text{GCV} - \text{latent heat of the water vapour formed} \approx \text{GCV} - 9 \times \text{H} \times 587 \div 100 \text{ (kcal/kg)}$$

WHAT EACH SYMBOL MEANS · UNIT

GCV	gross (higher) calorific value: all heat, with the water vapour condensed	kcal/kg
NCV	net (lower) value: vapour leaves as vapour, its latent heat is lost	kcal/kg
H	hydrogen in the fuel	% by mass

WHAT IT MEANS

Burning hydrogen makes water vapour; if it goes up the stack you never get its latent heat back. Efficiency on GCV basis is always LOWER than on NCV basis for the same boiler.

Worked example. GCV 10,000, H 12 %: $\text{NCV} \approx 10,000 - 9 \times 12 \times 587/100 \approx 9,366 \text{ kcal/kg}$.

Exam trap. India reports boiler efficiency on GCV; Europe on NCV — the same boiler shows a higher number on NCV.

Fuel energy and TOE from fuel

$$\text{Heat} = \text{mass} \times \text{GCV} \quad \cdot \quad \text{toe} = \text{Heat (kcal)} \div 10^7$$

WHAT EACH SYMBOL MEANS · UNIT

mass	fuel burnt	kg or tonnes
GCV	calorific value	kcal/kg

WHAT IT MEANS

Turns a fuel quantity into energy so it can be added to electricity and other fuels (in toe or MTOE).

Worked example. $125 \text{ t coal} \times 4,000 \text{ kcal/kg} = 5 \times 10^8 \text{ kcal} = 50 \text{ toe}$.

Exam trap. Watch units: 125 tonnes = 125,000 kg.

Common conversions

$1 \text{ kcal} = 4.187 \text{ kJ} \cdot 1 \text{ kWh} = 3,600 \text{ kJ} = 860 \text{ kcal} \cdot 1 \text{ HP} = 746 \text{ W} \cdot 1 \text{ BTU} = 252 \text{ cal} = 1.055 \text{ kJ} \cdot 1 \text{ atm} = 1.013 \text{ bar} = 760 \text{ mm Hg} = 10.33 \text{ m water} = 1.033 \text{ kg/cm}^2 \cdot \text{K} = ^\circ\text{C} + 273$

WHAT EACH SYMBOL MEANS · UNIT

1 kg/cm² $\approx 10 \text{ m of water head} \approx 0.98 \text{ bar}$ —

Specific gravity density $\div$ density of water (no unit) —

WHAT IT MEANS

Exam numericals live or die on these. Watt = joule per second; kW is power, kWh is energy.

Worked example. $1 \text{ MJ} = 278 \text{ Wh}$; $1 \text{ kcal/h} = 1.163 \text{ W}$.

Exam trap. 'Rate of energy transfer' is power (watt), not kcal.

Psychrometry basics

$\text{RH \%} = (\text{actual water vapour in air} \div \text{maximum it can hold at that temperature}) \times 100$

WHAT EACH SYMBOL MEANS · UNIT

DBT dry-bulb temperature — ordinary thermometer $^\circ\text{C}$

WBT wet-bulb temperature — wetted thermometer; lower because of evaporative cooling $^\circ\text{C}$

Dew point temperature at which air becomes saturated on cooling $^\circ\text{C}$

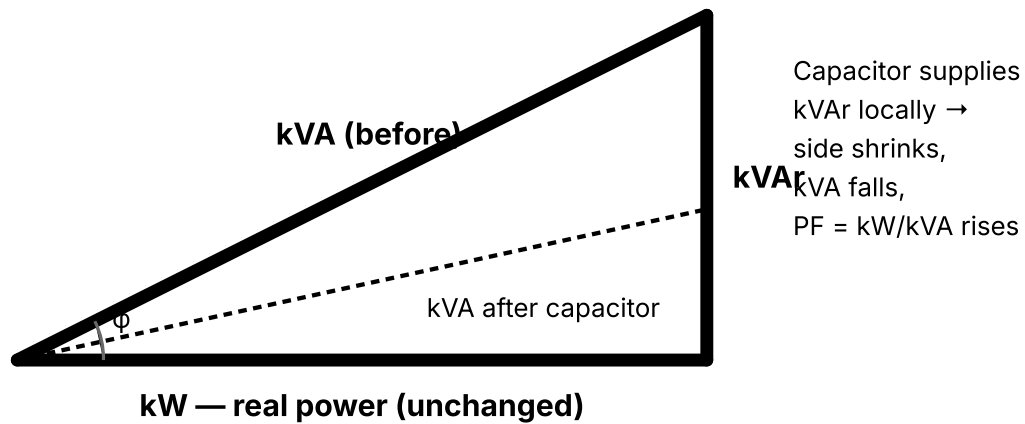
WHAT IT MEANS

To find RH you need DBT and WBT (a sling psychrometer). When DBT = WBT = dew point the air is saturated (RH 100 %) and no water evaporates from a wet surface. Heating air without adding moisture LOWERS its RH.

Worked example. If a wet substance stops losing water, the air's RH is 100 %.

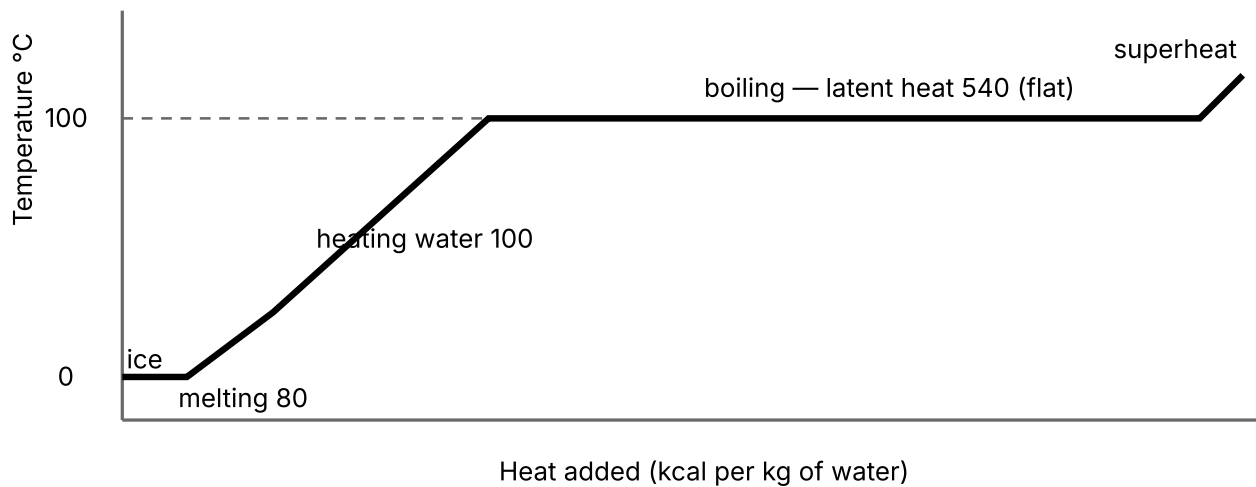
Exam trap. Sensible heat content of moist air is shown by the DRY-bulb temperature; total heat (enthalpy) by the wet-bulb.

Power triangle — what a capacitor does



kW stays fixed; the capacitor supplies the magnetising kVAR locally, the triangle gets shorter, kVA falls and $\cos \phi$ rises. Utilities charge on kVA, so the bill falls.

Heating curve of water — sensible and latent heat



Temperature rises with sensible heat (sloping lines) but stays flat during melting and boiling while latent heat is absorbed. The flat boiling step (540 kcal/kg) is 5× longer than heating from 0 to 100 °C.

GCV vs NCV — where the difference goes

GCV — all heat, water vapour condensed

NCV — usable heat when vapour leaves as vapour

latent
heat lost

$\text{NCV} = \text{GCV} - 9 \times \text{H\%} \times 587 \div 100 \text{ (kcal/kg)}$. Efficiency on GCV basis is always lower than on NCV basis

Both start from the same fuel; the latent heat carried away by water vapour in the flue gas is the gap between gross and net.

DEFINITIONS THE EXAM ASKS

Energy vs power

Energy is the capacity to do work (kWh, kcal, joule); power is the rate of using it (kW, W). A 100 W bulb for 10 h uses 1 kWh.

Sensible vs latent heat

Sensible heat changes temperature (you can sense it); latent heat changes state at constant temperature (hidden).

Heat capacity

Heat needed to raise the whole body by $1^\circ\text{C} = m \times C_p \text{ (kcal/}^\circ\text{C)}$.

Superheated steam

Steam heated above its saturation temperature at that pressure; used in turbines, not for heating (poor heat transfer).

Frequency

Cycles per second of AC, 50 Hz in India; the speed of AC motors depends on it.

Kilovolt-ampere hour (kVAh) billing

Some utilities bill on apparent energy (vector sum of kWh and kVAh) — so poor PF costs money directly.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

Power Triangle & Power Factor — what is power factor how to improve in Telugu · Venkat Kaviti Engineering

3-Phase Power & Motor Loading % — Motor Calculations Made Easy: Power, Current, Efficiency & Slip Explained! · [Edge of technology](#)

Sensible vs. Latent Heat — Energy Balance in Open and Closed Systems · [LearnChemE](#)

Steam Enthalpy & Dryness Fraction (\$x\$) — Example 2.2: Calculating dryness fraction, specific volume and internal energy of saturated steam. · [Dr. Arshad Ali Khan Official](#)

Fuel Calorific Value (GCV/NCV) — Boiler efficiency calculation by indirect method | Boiler Efficiency Calculation | Indirect method | · [Power Plant Discussion](#)

Chapter 4 · Energy Management and Audit

7–9 %: audit types and steps, instruments and their parameters, benchmarking, plant energy performance and payback. The PEP formula and the instrument table are asked almost every year.

Specific energy consumption (SEC)

$$\text{SEC} = \text{Energy used} \div \text{Units of production}$$

WHAT EACH SYMBOL MEANS · UNIT

Energy used	electricity, fuel or total in the period	kWh, kcal, toe
Units of production	output in the same period	tonnes, pieces, m ²

WHAT IT MEANS

The basic benchmark: energy per unit of product (kWh/tonne of cement, kcal/kg of steel). Compare with the previous year, with sister plants (internal benchmarking) or with the best in the industry (external benchmarking).

Worked example. 12,000 MWh for 40,000 t → 300 kWh/t.

Exam trap. SEC rises when production falls, because fixed energy (lighting, idling) is spread over fewer units — that is not a real efficiency loss.

Production factor

$$\text{Production factor} = \frac{\text{Current year production}}{\text{Reference year production}}$$

WHAT EACH SYMBOL MEANS · UNIT

Reference year	the base year against which improvement is judged	—
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WHAT IT MEANS

Adjusts for the plant making more or less product than in the base year, so energy can be compared fairly.

Worked example. 2010: 45,000 t; 2009: 50,000 t → 0.9.

Exam trap. It is a plain ratio, no percentage.

Reference-year equivalent (RYE)

$$\text{RYE} = \text{Reference year energy use} \times \text{Production factor}$$

WHAT EACH SYMBOL MEANS · UNIT

Reference year energy energy used in the base year kcal or kWh

WHAT IT MEANS

The energy the plant WOULD have used this year at base-year efficiency, given this year's production.

Worked example. 12 million kcal $\times$ 0.9 = 10.8 million kcal.

Exam trap. Multiply by the production factor, do not divide.

Plant energy performance (PEP)

$$\text{PEP \%} = (\text{RYE} - \text{Current year energy}) \div \text{RYE} \times 100$$

WHAT EACH SYMBOL MEANS · UNIT

Current year energy actual energy used this year same unit as RYE

WHAT IT MEANS

Percentage improvement (positive) or deterioration (negative) in efficiency after removing the effect of production change. Monthly PEP tracks progress; a rolling 12-month PEP smooths seasonality.

Worked example. RYE 10.8, current 11 million kcal $\rightarrow$ $\text{PEP} = (10.8 - 11)/10.8 \times 100 = -1.85 \%$ (worse).

Exam trap. Capacity utilisation is NOT needed for PEP — a recurring objective (2009, 2015, 2024).

Simple payback (audit report format)

$$\text{Payback (months)} = \text{Investment} \div \text{Net savings per year} \times 12$$
$$\text{Net savings} = \text{Annual savings} - \text{Annual operating cost}$$

WHAT EACH SYMBOL MEANS · UNIT

Investment	one-time cost	₹
Net savings	yearly benefit after running costs	₹/year

WHAT IT MEANS

Quick screening measure used in the audit report for each energy conservation opportunity; details are in Chapter 7.

Worked example. ₹12 lakh investment, ₹4 lakh/yr net savings → 36 months.

Exam trap. Use NET savings (benefits minus costs).

Heat rate and energy cost of output

$$\text{Heat rate} = \text{kcal of fuel} \div \text{kWh generated}$$
$$\text{Energy cost per unit product} = \Sigma(\text{fuel} \times \text{price}) \div \text{production}$$

WHAT EACH SYMBOL MEANS · UNIT

Heat rate	fuel heat needed per unit of electricity; a benchmark for power plants	kcal/kWh
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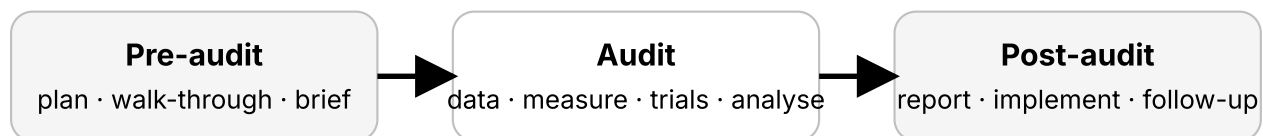
WHAT IT MEANS

A benchmark parameter must be energy per unit output (kcal/kWh, kWh/kg, kWh/m²). 'kg/°C' is not one — the 2017/2021 objective.

Worked example. 2,500 kcal/kWh means 34.4 % efficiency (860/2,500).

Exam trap. Lower heat rate = better plant.

Detailed energy audit — the three phases



Steps 1–3: plan, walk-through, primary data & process flow

Steps 4–8: survey & monitoring, trials, analysis, identify ENCONs, cost-benefit

Steps 9–10: report with recommendations, implementation & follow-up

Pre-audit (plan, walk-through, brief), audit (data, measurements, trials, analysis) and post-audit (report, implement, follow-up). Ten steps sit inside these three phases.

Plant energy performance — what the formula compares

Reference year energy (12 M kcal)



× production factor 0.9 = RYE (10.8)



Actual this year (11.0)



$$\text{PEP} = (\text{RYE} - \text{actual}) \div \text{RYE} \times 100 = (10.8 - 11.0) \div 10.8 \times 100 = -1.85 \%$$

Negative = used more than the base year would have at this production → performance worsened.

The bar for 'what we should have used' (RYE) is scaled from the reference year by the production factor; the gap to actual use is the PEP.

DEFINITIONS THE EXAM ASKS

Energy audit (EC Act definition)

Verification, monitoring and analysis of energy use, including a technical report with recommendations for improving efficiency with cost-benefit analysis and an action plan.

Preliminary vs detailed audit

Preliminary (walk-through): 1–3 days, readily available data, identifies major opportunities and the need for a detailed study. Detailed: full measurement, mass and energy balances, economics of every opportunity, 3 phases (pre-audit, audit, post-audit), 10 steps.

Ten-step methodology

1 Plan & organise · 2 Walk-through · 3 Primary data & process flow · 4 Conduct survey & monitoring · 5 Trials/experiments · 6 Analyse energy use · 7 Identify opportunities (ENCONs) · 8 Cost-benefit analysis · 9 Report & recommendations · 10 Implementation & follow-up.

Instruments and what they measure

Power analyser — kW, kVA, PF, harmonics · Ultrasonic flow meter — liquid flow (transit-time or Doppler) · Fyrite — O₂/CO₂ in flue gas · Flue gas analyser — O₂, CO, temperature, efficiency · Pitot tube + manometer — air/gas velocity · Anemometer — air velocity · Stroboscope — speed, non-contact · Tachometer — speed, contact · Sling psychrometer — DBT/WBT → RH · Infrared thermometer — surface temperature, non-contact · Lux meter — illuminance · Leak detector (ultrasonic) — compressed-air/steam leaks · Combustion analyser · Thermocouple/RTD — temperature.

Matching energy use to requirement

Avoid oversized equipment and 'just in case' running; supply energy at the lowest grade that does the job (e.g. do not use steam where hot water will do).

Fuel substitution

Switching to a cheaper or cleaner fuel for the same duty (e.g. LDO → LSHS, coal → natural gas) after checking availability, cost and equipment changes.

Energy Management System (EnMS) / ISO 50001

A systematic Plan-Do-Check-Act framework for continually improving energy performance; adopted to manage energy systematically, not only to cut cost.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

10-Step Audit Methodology — Preliminary Energy Audit & Detailed Energy Audit · Abhi Electrical Lectures

Audit Field Instrumentation — ENERGY AUDIT INSTRUMENTS | Part-1 | Rahul Roy · Yours Auditor

Plant Energy Performance (PEP) — Detailed Energy Audit Steps. · Azhar Inamdar

Energy Benchmarking — ENERGY AUDIT /WITH SIMPLE EXPLANATION /IN HINDI #EnergyAudit #Audit · Cent Percent

Chapter 5 • Material and Energy Balance

15–18 %, almost all numerical: drying, evaporation, mixing, dust collection, humidity, boiler blowdown. Every question is the same two equations applied carefully.

The mass-balance law

Mass in = Mass out + Mass stored (steady state: Mass in = Mass out)

WHAT EACH SYMBOL MEANS • UNIT

Mass in	every stream entering the box	kg/h
Mass out	products, wastes, losses leaving	kg/h
Stored	accumulation inside (zero at steady state)	kg

WHAT IT MEANS

Draw a box around the process; whatever enters must leave or stay. Apply it to the TOTAL mass and separately to each component (solids, water, fat, ash). Two unknowns need two balances.

Worked example. Milk 5,833 kg/h = cream Y + skim Z (total balance) and $0.04 \times 5,833 = 0.45$ Y + 0.0045 Z (fat balance) → solve Y and Z.

Exam trap. Pick the component that does NOT change (solids in drying, salt in evaporation) — its balance gives the answer in one line.

Solids balance for drying and evaporation

$$\begin{aligned} \text{Dry solids in} &= \text{Dry solids out} \rightarrow W_1 \times (1 - m_1) = W_2 \times (1 - m_2) \\ \cdot \quad \text{Water removed} &= W_1 - W_2 \end{aligned}$$

WHAT EACH SYMBOL MEANS · UNIT

W_1, W_2	wet mass before and after	kg
m_1, m_2	moisture fraction (wet basis) before and after	0–1

WHAT IT MEANS

The dry solid passes through unchanged; only water leaves. This single line solves every 'moisture reduced from x % to y %' question.

Worked example. 200 kg at 60 % moisture $\rightarrow$ dry solid 80 kg; at 30 % moisture final mass = $80 \div 0.7 = 114.3$ kg; water evaporated 85.7 kg (2015/2016 objective).

Exam trap. Moisture % is on WET basis unless stated: 60 % moisture means 40 kg solid per 100 kg wet material.

Wet-basis and dry-basis moisture

$$\begin{aligned} m_{\text{wet}} &= \text{water} \div (\text{water} + \text{solid}) & \cdot & \quad m_{\text{dry}} = \text{water} \div \text{solid} & \cdot \\ m_{\text{dry}} &= m_{\text{wet}} \div (1 - m_{\text{wet}}) \end{aligned}$$

WHAT EACH SYMBOL MEANS · UNIT

m_{wet}	moisture as fraction of total wet mass	0–1
m_{dry}	moisture as fraction of bone-dry solid	can exceed 1

WHAT IT MEANS

Dry basis can exceed 100 %; wet basis cannot. Convert before using in a balance.

Worked example. 60 % wet basis = $0.6/0.4 = 150$ % dry basis.

Exam trap. Mixing the two bases is the commonest mark-losing error in this chapter.

Concentration by weight and mole fraction

$$\begin{aligned} \text{w/w \%} &= \frac{\text{solute}}{\text{total solution}} \times 100 & \cdot & \quad \text{Moles} = \frac{\text{mass}}{\text{molar mass}} \\ & & \cdot & \quad \text{Mole fraction} = \frac{\text{moles of A}}{\text{total moles}} \end{aligned}$$

WHAT EACH SYMBOL MEANS · UNIT

Molar mass	H ₂ = 2, O ₂ = 32, N ₂ = 28, H ₂ O = 18, CO ₂ = 44, C = 12	g/mol
1 mole of gas	22.4 litres at STP	—

WHAT IT MEANS

Gas mixtures are handled in moles because equal volumes hold equal moles.

Combustion balances (C + O₂ → CO₂) work in moles too.

Worked example. 25 kg salt in 100 kg water: 25/125 = 20 % w/w. 90 kg water = 5,000 moles (90,000/18). 7.5 g H₂ (3.75 mol), 3.25 g O₂ (0.10), 5.55 g N₂ (0.20) → mole fraction O₂ = 0.10/4.05 = 0.025.

Exam trap. Salt in water: divide by the TOTAL (salt + water), not by the water alone.

Energy balance

Energy in = Energy out + Energy stored · Heat duty $Q = m \times C_p \times \Delta T$ · Steam heat = $m_{\text{steam}} \times \text{latent heat}$ · Electrical heat = kWh $\times 860$

WHAT EACH SYMBOL MEANS · UNIT

Q	heat gained or lost by a stream	kcal/h
Cp of water	1 kcal/kg °C	—
Latent heat	of the steam at its pressure (≈ 540 kcal/kg at 1 atm)	kcal/kg

WHAT IT MEANS

Heat given up by the hot stream equals heat taken by the cold stream plus losses.
Used for heat exchangers, evaporators, dryers and boilers.

Worked example. Evaporator: feed 10,000 kg/h at 1 % solids to 2 % solids $\rightarrow$ product 5,000 kg/h, vapour 5,000 kg/h; steam needed $\approx (\text{vapour} \times \text{latent} + \text{heating feed}) \div \text{steam latent}$ (2011/2024 long).

Exam trap. Include the sensible heat to bring the feed up to boiling before the latent heat of evaporation.

Energy conversion efficiency and losses

$$\text{Efficiency \%} = \frac{\text{Useful energy out}}{\text{Energy in}} \times 100 \quad \cdot \quad \text{Losses} = \frac{\text{Energy in} - \text{Useful out}}{\text{Energy in}} \times 100$$

WHAT EACH SYMBOL MEANS · UNIT

Energy in	fuel (kg × GCV) or electricity (kWh × 860)	kcal
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WHAT IT MEANS

A Sankey diagram draws the energy balance: one wide input arrow splitting into useful output and each loss, arrow width proportional to energy. The book's DG-set Sankey: fuel 100 % → electricity ≈ 35 %, exhaust ≈ 30 %, cooling water ≈ 25 %, radiation ≈ 10 %.

Worked example. DG set: 3.5 kWh per litre; diesel 10,200 kcal/kg, SG 0.85 → input 8,670 kcal/L; output $3.5 \times 860 = 3,010$ → 34.7 % (2013 short).

Exam trap. Convert litres to kg with specific gravity before multiplying by GCV.

Humidity and humidification

$$\text{Absolute humidity } w = \frac{\text{kg water vapour}}{\text{kg dry air}} \quad \cdot \quad \text{Water added} = \text{Air flow} \times \rho_{\text{air}} \times (w_2 - w_1)$$

WHAT EACH SYMBOL MEANS · UNIT

w	specific (absolute) humidity	kg/kg dry air
ρ_{air}	air density ≈ 1.2 kg/m ³	kg/m ³
RH	relative humidity — see Ch3	%

WHAT IT MEANS

Humidifying by spraying water without heat follows a constant-enthalpy line: DBT falls, RH rises. Textile humidification problems use this.

Worked example. $3,000 \text{ m}^3/\text{h} \times 1.2 \times (0.0062 - 0.002) = 15.1 \text{ kg/h water}$.

Exam trap. w is per kg of DRY air, so multiply by the dry-air mass flow.

Dust / particulate balance

$$\text{Dust in} = \text{Dust collected} + \text{Dust in clean gas} \quad \cdot \quad \text{Collection efficiency \%} = \frac{\text{collected}}{\text{inlet}} \times 100$$

WHAT EACH SYMBOL MEANS · UNIT

Dust loading	concentration in gas	g/Nm ³ or mg/Nm ³
Gas flow	volume at normal conditions	Nm ³ /h

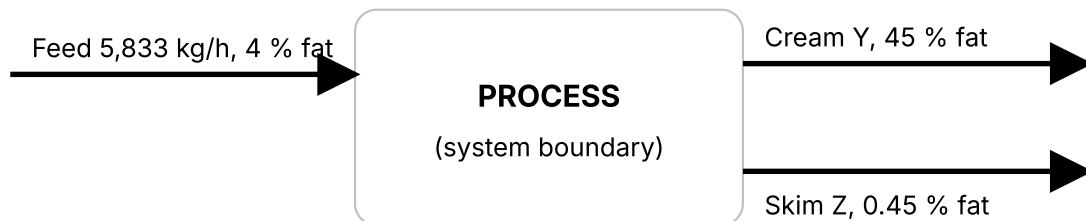
WHAT IT MEANS

Bag-house, cyclone and ESP questions: mass of dust per hour = flow × concentration; the balance across the collector gives what escapes.

Worked example. 50,000 Nm³/h at 10 g/Nm³ in, 0.1 g/Nm³ out → 500 kg/h in, 5 kg/h out, 495 collected, 99 %.

Exam trap. Keep concentration and flow in the same normal-condition basis.

The balance box

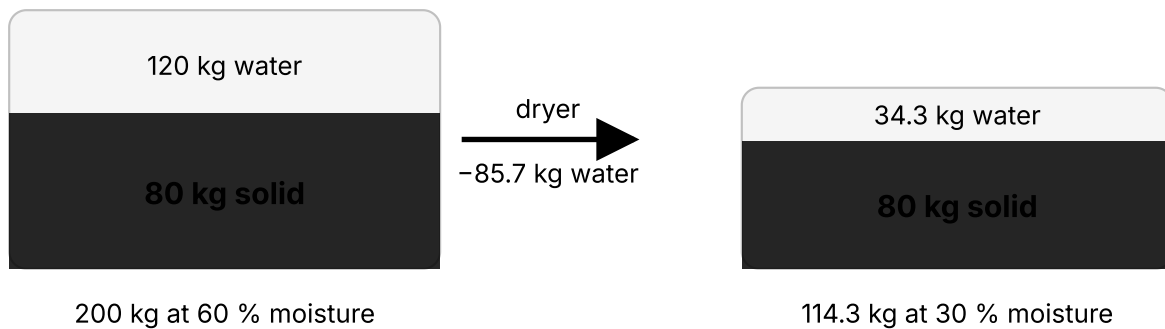


$$\text{Total: } 5,833 = Y + Z \quad \cdot \quad \text{Fat: } 0.04 \times 5,833 = 0.45 Y + 0.0045 Z$$

two equations, two unknowns → solve for Y and Z

Everything crossing the boundary is listed; at steady state the arrows in equal the arrows out for total mass AND for each component.

Drying — the solid is the tie component



The 80 kg of solid is the same on both sides; only the water leaves, so the final wet mass is $\text{solid} \div (1 - \text{final moisture})$.

Sankey diagram of a diesel generator



Fuel enters at 100 %; the arrow splits into $\approx 35\%$ electricity and three loss streams — exhaust gas is the biggest, which is why waste-heat recovery targets it.

DEFINITIONS THE EXAM ASKS

System boundary

The imaginary box you draw; choose it so the unknown crosses it and the fewest streams do. A whole plant, one unit, or one heat exchanger can each be a system.

Basis of calculation

Fix a basis first (100 kg feed, 1 hour, 1 kmol) and carry it through; results scale linearly.

Tie component

A component that passes through unchanged (dry solid in drying, ash in combustion, salt in evaporation) — balance on it first.

Recycle, by-pass and purge

Recycle returns part of the output to the inlet (raises conversion); by-pass sends part of the feed around the unit; purge bleeds off inerts that would build up in a recycle loop.

Process flow diagram (PFD)

Boxes for units, arrows for streams with flow, composition and temperature; the starting point of every balance.

Sankey diagram

Energy-flow picture with arrow widths proportional to energy; shows at a glance where the losses go.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

System Boundaries & PFD — Performing a Material Balance on a Single Unit · LearnChemE

Solids Balance & Drying — How to Perform Material Balances · Dr. Ray

Enthalpy Balance & Heat Exchangers — Energy Balance on a Condenser · LearnChemE

Boiler Blowdown & Ash Balances — Steam Boiler Performance Evaluation | Indirect Method | Model 7 | Boiler Efficiency · Therm Science

Chapter 6 · Energy Action Planning

Only 2–3 %, pure theory: energy policy, the action-plan steps, force-field analysis, duties of the energy manager. Learn the lists; there are no numericals.

Energy conservation target (as a formula)

$$\text{Saving \%} = (\text{Baseline energy} - \text{Target energy}) \div \text{Baseline energy} \times 100$$

WHAT EACH SYMBOL MEANS · UNIT

Baseline	energy use in the base year, normalised for production	kWh or toe
Target	the level management commits to	same unit

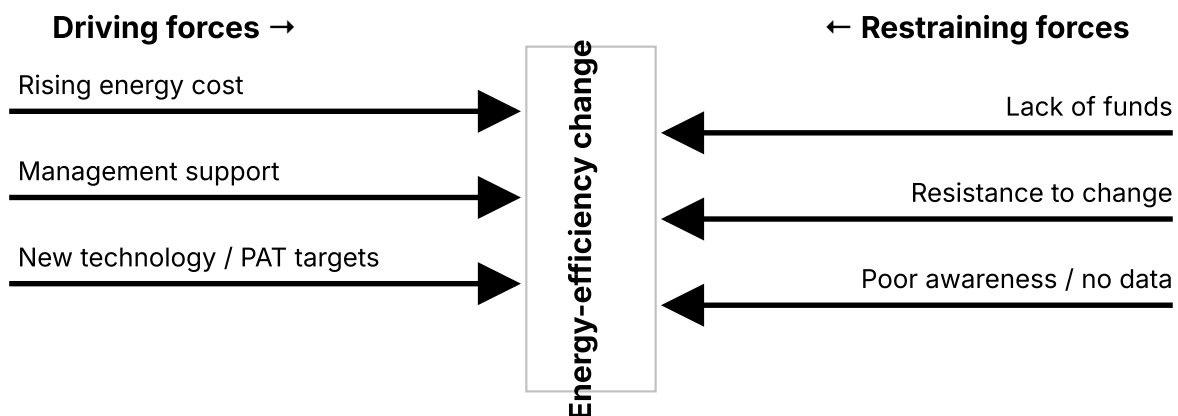
WHAT IT MEANS

Targets in an energy policy must be specific, measurable and time-bound (e.g. 'reduce SEC by 5 % in 2 years'). Progress is tracked by M&T (Chapter 9).

Worked example. Baseline 300 kWh/t, target 285 → 5 %.

Exam trap. A target with no baseline, date or responsibility is not a target.

Force-field analysis



Change happens when the drivers outweigh the restrainers

Driving forces push the change, restraining forces hold it back; the change happens when the drivers outweigh the restrainers.

DEFINITIONS THE EXAM ASKS

Energy policy

Top management's written commitment: a declaration of intent, objectives, targets, responsibilities, a review cycle and a link to the corporate objectives; short (one page), signed, communicated to all staff.

Action-plan steps (book order)

1 Top-management commitment → 2 Appoint energy manager & form the energy committee → 3 Energy policy → 4 Energy audit / baseline → 5 Set targets and priorities → 6 Action plan (who, what, when, cost) → 7 Implement → 8 Monitor & report → 9 Review and revise.

Force-field analysis

Lewin's tool: list the DRIVING forces for a change (rising costs, management support, new technology) against the RESTRAINING forces (lack of funds, resistance to change, poor awareness); strengthen drivers and weaken restrainers. It considers BOTH positive and negative forces.

Energy manager — duties (Act)

Prepare the annual activity plan, set up an energy-efficiency team, report to the SDA, implement audit recommendations, monitor consumption and submit data, create awareness, and be the link with BEE.

Responsibilities

Report to management, coordinate the audit, establish benchmarks, follow the action plan, prepare the budget and information system.

Motivation & training

Awareness campaigns, suggestion schemes, recognition and rewards, and training at every level are the book's soft measures for sustaining savings.

5S / Kaizen / TPM

Japanese workplace tools the book mentions: 5S (sort, set in order, shine, standardise, sustain), Kaizen (continuous small improvements), Total Productive Maintenance — all reduce hidden energy waste.

ISO 50001

Energy management system standard: Plan-Do-Check-Act; requires an energy baseline, energy performance indicators (EnPIs), objectives, targets and action plans, and management review.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

6 Steps of Action Planning — Lecture 30: Energy Management & Audit_Unit 4_Energy Action Planning_CUSUM charts · Bleed Electrical

Force Field Analysis — Force Field Analysis: Driving Forces vs Restraining Forces · AssistKD

Chapter 7 · Financial Management

13–16 %, numerical: payback, ROI, NPV, IRR appear EVERY year (NPV or IRR is a 10-marker). Master the discount-factor table and the interpolation for IRR.

Simple payback period

$$\text{Payback (years)} = \text{Investment} \div \text{Annual net savings} \quad \cdot \quad \text{Net savings} = \text{Annual savings} - \text{Annual operating cost}$$

WHAT EACH SYMBOL MEANS · UNIT

Investment	first cost (capital)	₹
Annual net savings	yearly cash benefit after running costs	₹/year

WHAT IT MEANS

How long until the project pays for itself. Simple, so widely used to screen, but it ignores the time value of money and everything after the payback point.

Worked example. ₹2 lakh VFD saving ₹45,000/yr with ₹5,000/yr maintenance → $2,00,000 \div 40,000 = 5$ years.

Exam trap. Payback 'does not consider cash flow after the payback period' and 'does not take into account time value of money' — both appear as exam statements.

Return on investment (ROI)

$$\text{ROI \%} = \text{Annual net savings} \div \text{Investment} \times 100 \quad (= 1 \div \text{payback} \times 100)$$

WHAT EACH SYMBOL MEANS · UNIT

Annual net savings ₹/year

—

Investment ₹

—

WHAT IT MEANS

The yearly return the project earns on its cost; compare it with the company's cost of capital or bank interest.

Worked example. Saves ₹45,000 on ₹2,00,000 → 22.5 % (2017/2024 objective).

Exam trap. The question may want the figure after operating costs — read carefully.

Time value of money — present and future value

$$\text{FV} = \text{PV} \times (1 + i)^n \quad \cdot \quad \text{PV} = \text{FV} \div (1 + i)^n \quad \cdot \quad \text{Discount factor} = 1 \div (1 + i)^n$$

WHAT EACH SYMBOL MEANS · UNIT

PV present value — money today

₹

FV future value — money n years ahead

₹

i interest or discount rate (cost of capital)

fraction per year

n number of years

—

WHAT IT MEANS

Money today is worth more than the same money later because it can earn interest. To compare cash flows in different years, discount each one back to today.

Worked example. ₹1,00,000 in 3 years at 10 %: $\text{PV} = 1,00,000 \div 1.331 = ₹75,131$. Discount factors at 10 %: yr1 0.909, yr2 0.826, yr3 0.751, yr4 0.683, yr5 0.621.

Exam trap. Investment at the START of year 1 is at year 0 — factor 1.0, not 0.909.

Net present value (NPV)

$$NPV = \sum [CF_t \div (1 + i)^t] - \text{Initial investment} \quad (t = 1 \dots n)$$

WHAT EACH SYMBOL MEANS · UNIT

CF_t	net cash flow in year t (savings – costs)	₹
i	discount rate	—
Salvage	include the resale value in the final year's cash flow	₹

WHAT IT MEANS

Sum of all discounted future cash flows minus what you pay now. $NPV > 0 \rightarrow$ the project earns more than the cost of capital $\rightarrow$ accept. Choosing between projects: the higher NPV wins.

Worked example. Invest ₹50,000; inflows ₹20,000, 30,000, 20,000 at 10 %: $NPV = 20,000 \times 0.909 + 30,000 \times 0.826 + 20,000 \times 0.751 - 50,000 = ₹8,000$ (2011/2022 short).

Exam trap. Depreciation is not a cash outflow, but the tax it saves is a cash INflow — 'if depreciation is considered net operating cash inflow is HIGHER' (2018/2024 objective).

Internal rate of return (IRR)

$$IRR = \text{the discount rate } i \text{ at which } NPV = 0 \quad \cdot \quad IRR \approx i_1 + NPV_1 \div (NPV_1 - NPV_2) \times (i_2 - i_1)$$

WHAT EACH SYMBOL MEANS · UNIT

i_1	a rate giving a positive NPV_1	%
i_2	a higher rate giving a negative NPV_2	%

WHAT IT MEANS

The project's own earning rate. Accept if $IRR >$ cost of capital. Found by trial: compute NPV at two rates that bracket zero, then interpolate.

Worked example. NPV at 15 % = +2,000, at 20 % = -1,500 $\rightarrow IRR \approx 15 + 2,000/3,500 \times 5 = 17.9$ %.

Exam trap. IRR is the rate where NPV is ZERO (not positive, not negative) — 2017/2024 objective. For a single equal annual saving A over n years, IRR solves $\text{Investment} \div A = \text{annuity factor}$.

Annuity (uniform series) present value

PV of A per year for n years = $A \times [(1 + i)^n - 1] \div [i (1 + i)^n]$
· Capital recovery factor = the inverse

WHAT EACH SYMBOL MEANS · UNIT

A	equal yearly cash flow	₹/year
n	years	—

WHAT IT MEANS

Shortcut when every year's saving is the same. The bracket is the annuity factor (at 10 %, 5 years = 3.791). Capital recovery factor turns a loan into equal yearly instalments.

Worked example. ESCO project: ₹10 lakh/yr for 7 years at 30 % → factor 2.802 → maximum investment ₹28.0 lakh (2018 short).

Exam trap. Use the annuity factor only when the yearly amounts are equal.

Depreciation — straight line

Annual depreciation = $(\text{Cost} - \text{Salvage value}) \div \text{Useful life}$

WHAT EACH SYMBOL MEANS · UNIT

Salvage	resale value at the end of life	₹
Useful life	years	—

WHAT IT MEANS

Spreads the capital cost over the years for accounting and tax. Reduces taxable profit, so it raises after-tax cash flow via the tax shield.

Worked example. ₹12 lakh, salvage ₹2 lakh, 5 years → ₹2 lakh/year.

Exam trap. Depreciation itself is not cash — do not subtract it from cash flow in NPV; add back the tax saving.

Sensitivity and risk analysis

Recompute NPV/IRR after changing one input (energy price, savings, tax rate, cost of capital) by $\pm x \%$

WHAT EACH SYMBOL MEANS · UNIT

Macro factors tax rates, interest rates, energy prices, inflation —

Micro factors savings estimate, capital cost, operating hours —

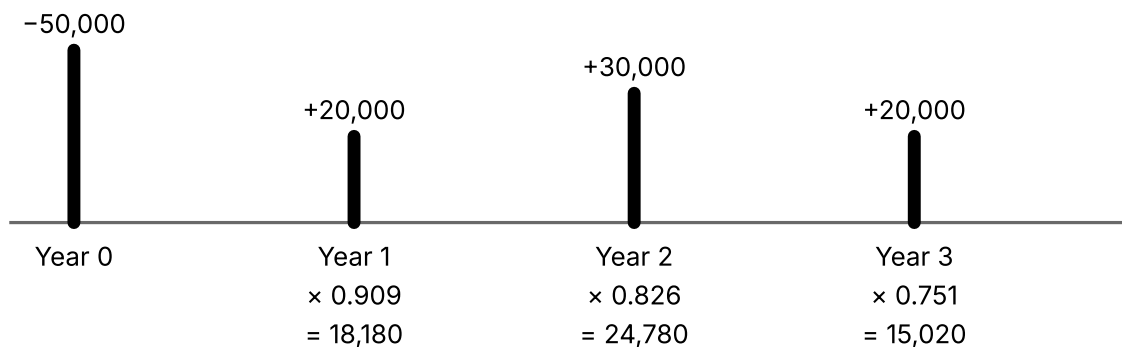
WHAT IT MEANS

Shows which assumption the decision is most sensitive to, because 'all the above situations' can occur — the result is uncertain. Change in TAX RATE is the book's example of a macro factor.

Worked example. If savings fall 20 % and NPV stays positive, the project is robust.

Exam trap. Sensitivity analysis is applied because of uncertainty in all the inputs — 'all of the above' (2017/2019 objective).

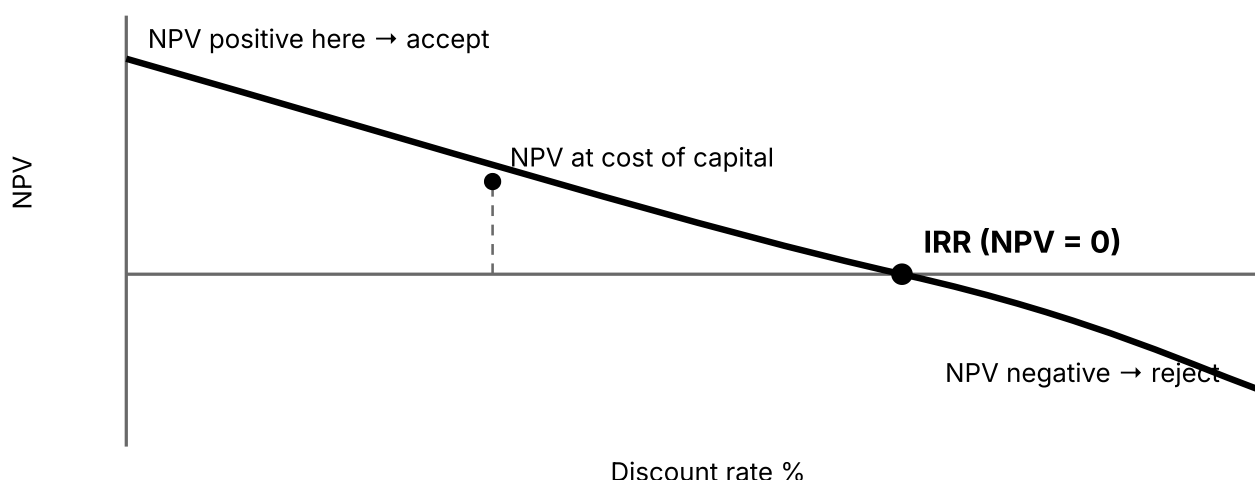
Cash-flow timeline and discounting



NPV at 10 % = 18,180 + 24,780 + 15,020 - 50,000 = +7,980 → accept

Each year's cash flow is shrunk by its discount factor before adding; the investment at year 0 is not discounted.

NPV falls as the discount rate rises — IRR is where it crosses zero



At low rates NPV is positive; at the cost of capital you read the project NPV; where the curve crosses zero is the IRR. Interpolate between two bracketing rates.

DEFINITIONS THE EXAM ASKS

Cash flow

Actual money in and out each year: savings, operating costs, taxes, salvage. Profit is not cash flow.

Cost of capital / discount rate

The rate the company must earn to satisfy lenders and shareholders; used as i in NPV and as the hurdle for IRR.

Debt vs equity financing

Debt: borrow (loan or bond) and repay with interest, company keeps ownership. Equity: sell shares (or use retained earnings), investors share ownership and profit.

Leasing

Lessee pays rent to use equipment owned by the lessor — no large capital outlay; operating lease vs finance lease.

ESCO / performance contracting

An Energy Service Company funds and implements the project and is paid from the savings: shared-savings (ESCO takes a % of savings) or guaranteed-savings (client borrows, ESCO guarantees the saving).

Life-cycle cost

All costs over the life — capital, energy, maintenance, disposal — discounted to present value; the right basis for comparing an efficient motor with a cheap one.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

Simple Payback & ROI — Internal Rate of Return Explained for Business Professionals · AssistKD

Time Value of Money & Discounting — Project Return Forecasting with FV, NPV and IRR | Project Management Key Concepts · David McLachlan

Net Present Value (NPV) — NPV vs. IRR · 365 Financial Analyst Tutorials

Internal Rate of Return (IRR) — NPV and IRR explained · The Finance Storyteller

ESCO Performance Contracts — How to Calculate NPV and IRR in Excel · Ryan O'Connell, CFA, FRM

Chapter 8 • Project Management

10–12 %: a CPM/PERT network is nearly always a 10-mark long question, plus objectives on float, expected time and Gantt charts.

CPM — forward pass

$$ES = \text{largest EF of all predecessors} \quad \cdot \quad EF = ES + t$$

WHAT EACH SYMBOL MEANS • UNIT

ES	earliest start	weeks/days
EF	earliest finish	—
t	activity duration	—

WHAT IT MEANS

Go left to right: an activity can start only when ALL activities before it have finished.
The largest EF at the end is the project duration.

Worked example. A (4 wk) starts at 0 → EF 4; B (5 wk) after A: ES 4, EF 9.

Exam trap. Where two arrows enter a node, take the LARGER EF.

CPM — backward pass

LF = smallest LS of all successors (last activity: LF = project duration) • $LS = LF - t$

WHAT EACH SYMBOL MEANS · UNIT

LF	latest finish without delaying the project	—
LS	latest start	—

WHAT IT MEANS

Go right to left from the project end: the latest an activity may finish is the earliest any following activity must start.

Worked example. Project 20 wk; last activity E (3 wk): LF 20, LS 17.

Exam trap. Where two arrows leave a node, take the SMALLER LS.

Float (slack) and the critical path

Total float = $LS - ES = LF - EF$ • Critical path = the longest path = activities with zero float

WHAT EACH SYMBOL MEANS · UNIT

Float	time an activity can slip without delaying the project	—
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WHAT IT MEANS

Critical activities have no slack: a one-day delay delays the whole project. Non-critical ones can be delayed by their float. The critical path is the LONGEST route through the network.

Worked example. LS 8, LF 12, duration 1 wk → ES could be as late as 8 and EF 9... float = $LF - EF = 12 - 9 = 3$ weeks (2018/2024 objective).

Exam trap. The critical path is the longest path, and 'minimum project duration' equals its length — never the shortest path.

PERT — expected time and variance

$$t_e = (a + 4m + b) \div 6 \quad \cdot \quad \sigma = (b - a) \div 6 \quad \cdot \quad \text{Variance} = \sigma^2$$

WHAT EACH SYMBOL MEANS · UNIT

a	optimistic time	—
m	most likely time	—
b	pessimistic time	—
σ	standard deviation of the activity	—

WHAT IT MEANS

PERT uses three estimates weighted 1-4-1 (a beta distribution). Project variance = sum of variances along the critical path; project $\sigma = \sqrt{(\text{sum})}$.

Worked example. a 15, m 18, b 60 days: $t_e = (15 + 72 + 60)/6 = 24.5$ days; $\sigma = 7.5$. (Real exam: 15/18/21 → 18 days.)

Exam trap. Add VARIANCES (σ^2), never standard deviations, along the critical path.

Probability of finishing by a date

$$Z = (T - T_e) \div \sigma_{\text{project}} \rightarrow \text{probability from the normal table}$$

WHAT EACH SYMBOL MEANS · UNIT

T	target completion time	—
T_e	expected project duration (critical path)	—
σ_{project}	$\sqrt{\Sigma}$ variances on the critical path	—

WHAT IT MEANS

$Z = 0 \rightarrow 50\%$ chance; $Z = +1 \rightarrow 84\%$; $Z = +2 \rightarrow 97.7\%$.

Worked example. T_e 40 wk, σ 2, target 44 → $Z = 2 \rightarrow 97.7\%$.

Exam trap. Use the project σ (from the critical path), not one activity's σ .

Crashing — cost slope

$$\text{Cost slope} = (\text{Crash cost} - \text{Normal cost}) \div (\text{Normal time} - \text{Crash time})$$

WHAT EACH SYMBOL MEANS · UNIT

Crash the shortest possible duration with extra resources —

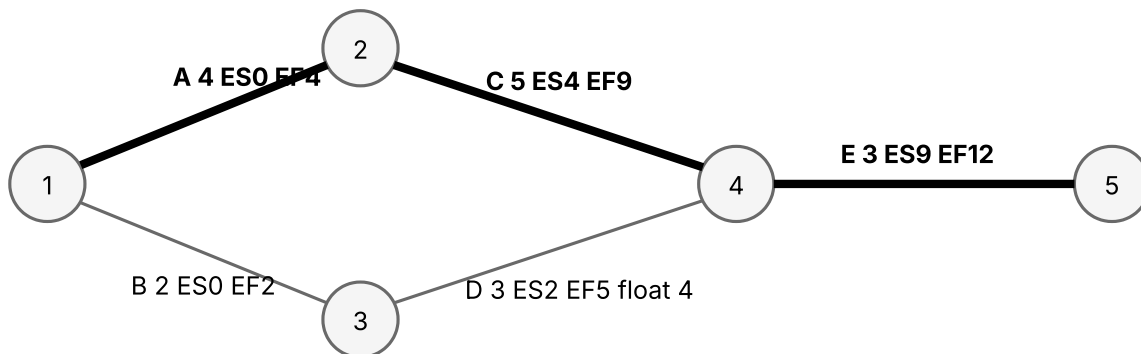
WHAT IT MEANS

Extra cost per unit of time saved; crash the critical activity with the lowest slope first, and re-check which path is critical after each step.

Worked example. Normal 10 days ₹1 lakh, crash 7 days ₹1.6 lakh → ₹20,000/day.

Exam trap. Crashing a non-critical activity saves nothing.

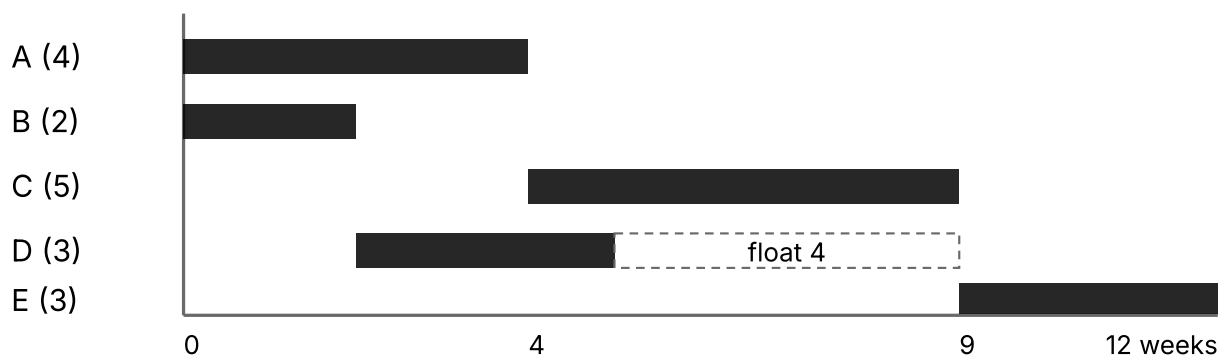
CPM network with forward and backward pass



Thick path 1-2-4-5 = A+C+E = 12 weeks = longest = critical (zero float). D has LS 6, ES 2 → float 4 weeks.

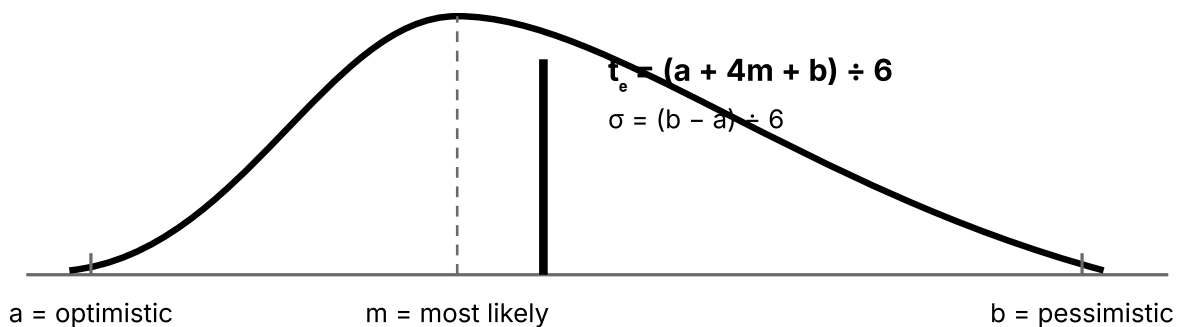
ES/EF above each activity, LS/LF below; the thick path has zero float and is the critical path (longest route).

Gantt chart of the same project



Bars show when each activity runs; the critical activities are shaded — the chart cannot show WHY they are critical, which is the Gantt limitation.

PERT three-time estimate



A beta curve: most likely time near the peak, optimistic and pessimistic at the tails; the mean is weighted 1-4-1.

DEFINITIONS THE EXAM ASKS

Project

A temporary, unique endeavour with a defined start and end, scope, budget and quality — e.g. installing a cogeneration plant.

Project cycle

Definition & scope → technical design → financing → contracting → implementation (procurement, construction, commissioning) → measurement & verification (M&V) → operation.

Work breakdown structure (WBS)

Hierarchical split of the project into work packages small enough to estimate, assign and track.

Gantt chart

Bar chart of activities against time — easy to read and to show progress, but it does not show dependencies or the critical path (its limitation).

Network diagram (AOA / AON)

Activity-on-arrow: arrows are activities, circles are events; dummy activities (dashed) show dependency only. Activity-on-node: boxes are activities.

Dummy activity

Zero-duration arrow used only to show a logical dependency or to keep activity identities unique.

M&V (measurement and verification)

Proving the savings after implementation by measured before/after data adjusted for production and weather — IPMVP options A–D.

Contracting

Turnkey (one contractor does all), BOOT (build-own-operate-transfer), performance contract (ESCO paid from savings).

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

WBS & Gantt Limitations — Project Scheduling in Excel -Critical Path- Complete Table -PERT/CPM · Joshua Emmanuel

Network Precedence & Dummies — Use forward and backward pass to determine project duration and critical path · Engineer4Free

CPM Forward/Backward Pass — Project Scheduling - PERT/CPM | Finding Critical Path · Joshua Emmanuel

PERT 3-Time Estimates & Variance — CPM (Critical Path Method) in Software Engineering | PERT/CPM Numerical · Gate Smashers

Crashing & M&V — Project Crashing Numerical in 15 Minutes | PERT & CPM | MBA, BSC Maths and GATE ME · KN Prasad Academy (NITian)

Chapter 9 • Energy Monitoring and Targeting

8–10 %: the energy-vs-production line (base load), CUSUM (a recurring 10-marker), specific energy consumption and target setting.

Energy–production relationship (regression line)

$$E = m \times P + c$$

WHAT EACH SYMBOL MEANS • UNIT

E	energy in the period	kWh, toe
P	production in the period	tonnes
m	slope — variable energy per unit product	kWh/t
c	intercept — fixed (base) energy used even at zero production	kWh

WHAT IT MEANS

Plot monthly energy against production and fit a straight line (linear regression). The intercept is the base load (lighting, idling, standby losses); the slope is the true variable SEC. The line is the 'standard' against which targets are set.

Worked example. $E = 0.4 P + 180$ toe/month: at 500 t → 380 toe; the 180 is fixed energy.

Exam trap. Linear regression is the statistical technique that quantifies the relationship (2013/2017 objective); CUSUM is not.

Specific energy consumption trend

$$\text{SEC} = E \div P = m + c \div P$$

WHAT EACH SYMBOL MEANS · UNIT

$c \div P$	the fixed energy spread over production	kWh/t
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WHAT IT MEANS

Because of the fixed term, SEC falls as production rises even with no efficiency change — so SEC alone can mislead; use the regression line or CUSUM.

Worked example. At 200 t: $0.4 + 180/200 = 1.3$ toe/t; at 500 t: 0.76.

Exam trap. A rise in SEC in a low-production month is not proof of waste.

CUSUM — cumulative sum of differences

$$\begin{aligned} \text{Difference} &= E_{\text{actual}} - E_{\text{predicted}} \text{ (from } E = mP + c) & \cdot & \text{CUSUM} \\ &= \text{running total of the differences} \end{aligned}$$

WHAT EACH SYMBOL MEANS · UNIT

$E_{\text{predicted}}$	energy the standard line says the month should have used	same unit
CUSUM	cumulative deviation from the standard	same unit

WHAT IT MEANS

Read the slope, not the value: horizontal = performing as the standard; sloping DOWN = saving energy (using less than predicted); sloping UP = waste. A change of slope marks the month something changed. Savings over a period = CUSUM at end – CUSUM at start.

Worked example. Months 1–6 differences –20, –25, –18, –30, –22, –15 toe → CUSUM after 6 months = –130 toe = saving of 130 toe.

Exam trap. A negative CUSUM is GOOD (less energy than predicted). The 2022 long question asks for savings from a CUSUM table.

Target setting

Target = best historical performance line (or standard line – agreed % improvement)

WHAT EACH SYMBOL MEANS · UNIT

Standard performance the regression line from past data —

Target a tighter line management commits to —

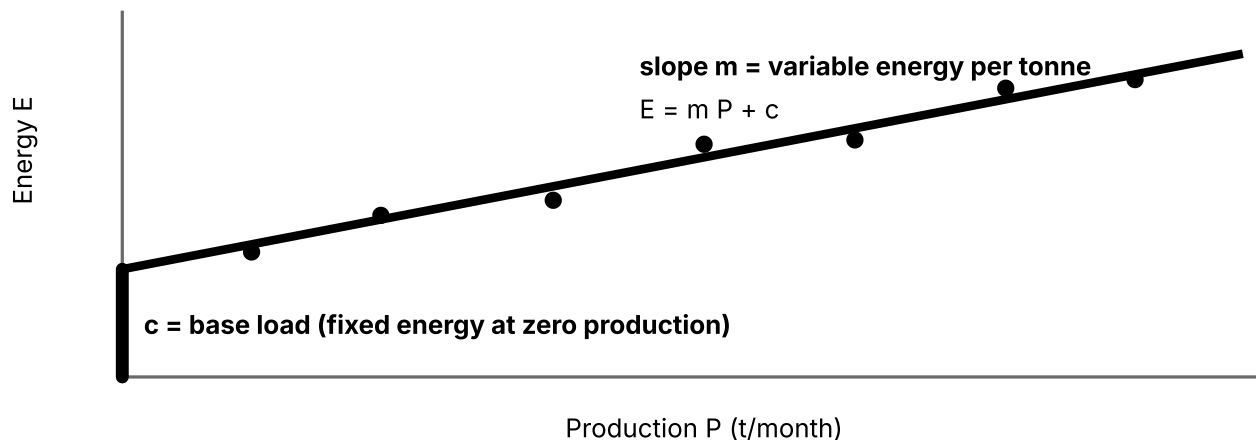
WHAT IT MEANS

M&T needs a target to compare against; targets are based on historical best, benchmarks, or engineering estimates, and are revised as improvements stick.

Worked example. Standard $0.4P + 180 \rightarrow$ target $0.38P + 160$.

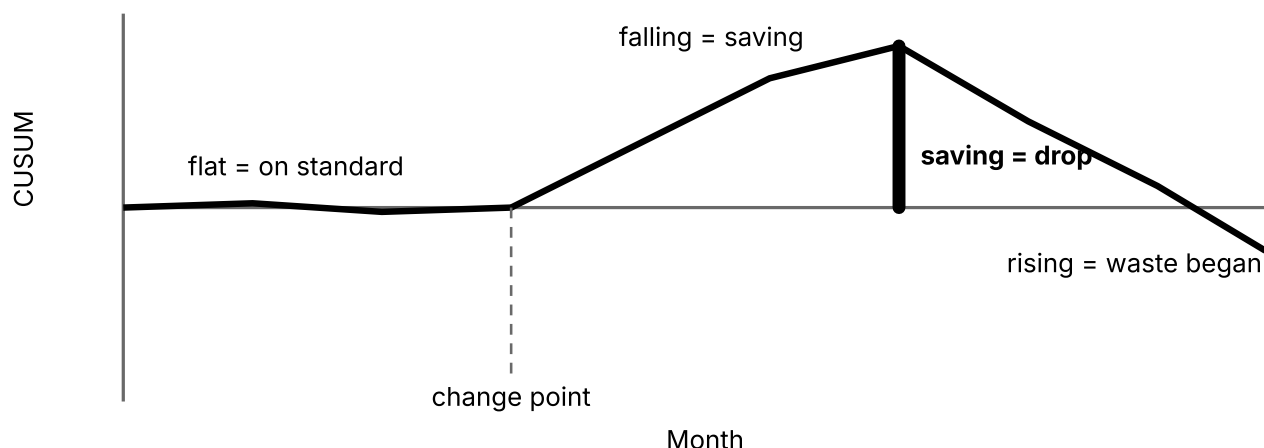
Exam trap. Monitoring without targeting shows nothing to act on.

Energy vs production — the standard line



Each dot is a month; the fitted line's intercept c is the fixed energy, the slope m the variable energy per tonne.

Reading a CUSUM chart



Flat = on standard; falling = saving; rising = waste; a kink shows when performance changed. Savings between two dates = the vertical drop.

DEFINITIONS THE EXAM ASKS

Monitoring & targeting (M&T)

A management technique using energy information to eliminate waste, reduce cost and improve performance: measure, compare with a standard/target, report, act. Typical savings 5–10 %.

Energy account centres (EACs)

Departments or processes to which energy use is allocated and for which a manager is accountable — the unit of M&T.

Elements of M&T

Recording (meters), analysing (relate energy to drivers), comparing (against targets), setting targets, monitoring, reporting, controlling.

Data and information

Raw meter readings become information when related to production, weather (degree-days) and time; an EMIS (energy management information system) automates this.

Degree-days

Driver for heating/cooling energy: sum of daily (base temperature – average temperature) over the period.

Standard vs target energy performance

Standard = what past behaviour predicts (regression); target = the improved level to aim for.

M&T System & EACs — Monitoring and Targeting for Industrials · Energent Incorporated

Regression & Base Load ($\$E = mP + c\$$) — Relating Energy consumption and production_CUSUM
Technique · Azhar Inamdar

CUSUM Calculation & Analysis — CUSUM - Energy Monitoring and Targeting - Design,
Management and Auditing of Electrical Systems · Ekeeda

Chapter 10 · Energy Efficiency and Climate Change

5–7 %, mostly theory: greenhouse effect, the six Kyoto gases, GWP, ozone/CFCs, UNFCCC, Kyoto mechanisms (CDM/JI/ET), plus one CO₂ calculation.

CO₂ from carbon burnt

$$\text{CO}_2 \text{ (kg)} = \text{Carbon (kg)} \times 44 \div 12 = \text{Carbon} \times 3.67$$

WHAT EACH SYMBOL MEANS · UNIT

44	molar mass of CO ₂	g/mol
12	molar mass of carbon	g/mol

WHAT IT MEANS

Every kg of carbon in a fuel becomes 3.67 kg of CO₂. Multiply fuel mass by its carbon fraction first.

Worked example. 1 tonne coal at 60 % carbon → 600 kg C → 2,200 kg CO₂.

Exam trap. 44/12, not 12/44.

CO₂ from fuel or electricity via emission factors

$$\text{CO}_2 = \text{Quantity} \times \text{Emission factor}$$

WHAT EACH SYMBOL MEANS · UNIT

Emission factor kg CO₂ per unit — e.g. per kWh of grid power, per litre of diesel, per kg of coal (given in the question) kg CO₂/unit

WHAT IT MEANS

Turns energy saved into CO₂ avoided. The factor for Indian grid electricity in exam questions is usually stated ($\approx$ 0.8–1 kg/kWh in the book's era).

Worked example. Save 100,000 kWh at 0.9 kg/kWh → 90 t CO₂/yr.

Exam trap. Use the factor the question gives; do not invent one.

CO₂e equivalent and global warming potential

$$\text{CO}_2\text{e} = \sum (\text{mass of gas} \times \text{GWP of gas})$$

WHAT EACH SYMBOL MEANS · UNIT

GWP (100-year, book table) CO₂ = 1 · CH₄ = 21 · N₂O = 310 · HFCs 140–11,700 · PFCs 6,500–9,200 —
· SF₆ = 23,900

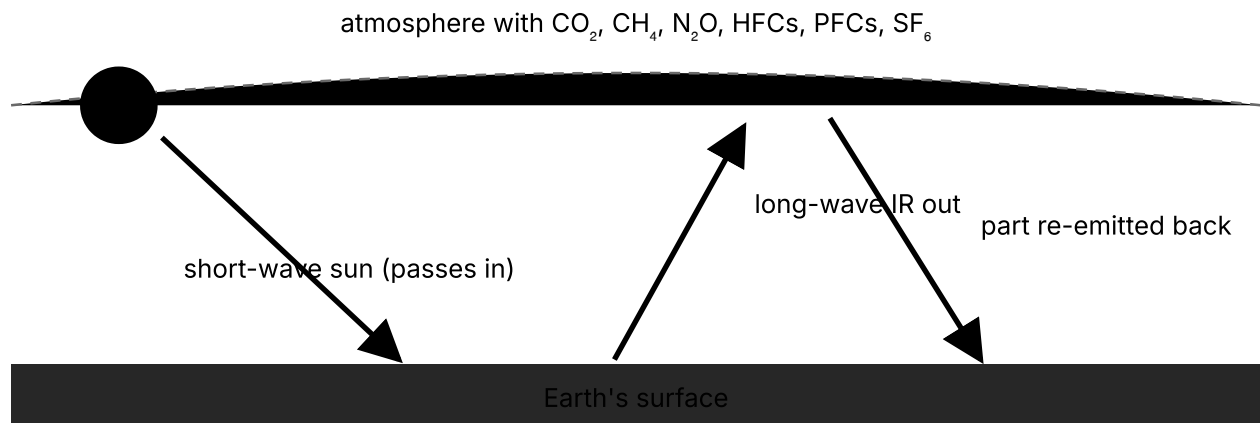
WHAT IT MEANS

Puts all greenhouse gases on one scale. SF₆ has the highest GWP; perfluorocarbons (PFC) have the LONGEST atmospheric lifetime (thousands of years).

Worked example. 10 t CH₄ = 210 t CO₂e.

Exam trap. Highest GWP = SF₆; longest lifetime = PFC — two different questions.

The greenhouse effect



Trapped IR keeps the surface $\approx 33^\circ\text{C}$ warmer; more gases $\rightarrow$ more trapping $\rightarrow$ global warming.

Incoming short-wave radiation passes in; outgoing long-wave radiation is partly trapped by greenhouse gases and re-emitted back to the surface.

Carbon to CO₂ — the 44/12 rule



1 kg of carbon $\rightarrow 44 \div 12 = 3.67$ kg of CO₂. 1 tonne coal at 60 % C $\rightarrow 2.2$ t CO₂.

12 units of carbon pick up 32 units of oxygen to make 44 units of CO₂ — the mass grows 3.67 times.

DEFINITIONS THE EXAM ASKS

Greenhouse effect

Short-wave sunlight passes through the atmosphere, warms the earth, which re-radiates long-wave infrared; greenhouse gases absorb and re-emit it downward, keeping the surface $\approx 33^\circ\text{C}$ warmer than it would be. Extra gases from human activity strengthen it — global warming.

Six Kyoto gases

CO₂, CH₄, N₂O, HFCs, PFCs, SF₆ (water vapour is a GHG but not counted; CFCs are covered by Montreal, not Kyoto).

Ozone depletion

CFCs (and HCFCs, halons) release chlorine in the stratosphere that destroys ozone; the Montreal Protocol (1987) phases them out. Ozone depletion and global warming are DIFFERENT problems — global warming does not enlarge the ozone hole.

UNFCCC and IPCC

UNFCCC (Rio 1992) — the treaty; IPCC (1988) — the scientific body assessing climate change; COP — the yearly conference of parties.

Kyoto Protocol (1997, in force 2005)

Annex-I (developed) countries took binding reduction targets ($\approx 5\%$ below 1990 by 2008–12); India is non-Annex-I with no binding target.

Flexible mechanisms

Emission Trading (between Annex-I), Joint Implementation (Annex-I project in another Annex-I country $\rightarrow$ ERUs), Clean Development Mechanism (Annex-I finances a project in a developing country $\rightarrow$ CERs; 1 CER = 1 t CO₂e). India's DNA = Ministry of Environment & Forests.

Carbon capture and sequestration (CCS)

Capturing CO₂ from point sources and storing it (geological, ocean, mineral) or enhancing natural sinks (forests). 'Carbon sequestration' = the storing step.

Impacts of warming

Melting ice caps, sea-level rise, unpredictable climate, crop and water stress — not 'a bigger ozone hole'.

Energy efficiency as mitigation

The cheapest CO₂ reduction is energy not used: every kWh saved avoids the grid's emission factor.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

Greenhouse Effect & 6 Kyoto Gases — Calculating greenhouse gas emissions according to the GHG Protocol · Holmen Board and Paper

Ozone Layer & Montreal Protocol — Converting Non-CO₂ Greenhouse Gases to CO₂ Equivalents (CO₂e using GWP) · Footprint Consulting

UNFCCC, IPCC, CDM & JI — How to Calculate Greenhouse Gas Emissions · e3solutionsincdotcom

Carbon to \$CO₂\$ Calculations — Calculating your Carbon Footprint - Carbon Dioxide Equivalents and Global Warming Potential · PECT

Chapter 11 • New and Renewable Energy Sources

10–12 %: solar (PV and thermal), wind ($P \propto v^3$), hydro, biomass and gasification, fuel cells, geothermal, tidal. Many objectives plus one long question with a calculation.

Solar constant and insolation

Solar constant $\approx 1,368 \text{ W/m}^2$ (top of atmosphere) • average
insolation at the surface $\approx \frac{1}{4}$ of it $\approx 342 \text{ W/m}^2$

WHAT EACH SYMBOL MEANS • UNIT

Insolation	solar energy received per unit area per day	kWh/m ² /day (India $\approx$ 4–7)
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WHAT IT MEANS

Only part of the top-of-atmosphere energy reaches the ground, after reflection and absorption; India gets about 300 sunny days a year.

Exam trap. The constant is at the TOP of the atmosphere, not at the ground.

Solar cell / panel efficiency

$$\eta = \text{Electrical output} \div (\text{Insolation} \times \text{Panel area}) \times 100$$

WHAT EACH SYMBOL MEANS • UNIT

Electrical output	rated (peak) power at standard test conditions, 1,000 W/m ²	W
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Panel area	m ²	—
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WHAT IT MEANS

Typical crystalline cells 12–15 %; the book's example: 175 W panel of $0.75 \times 1.5 \text{ m} \rightarrow 175 \div (1,000 \times 1.125) = 15.6 \%$. Efficiency depends on the cell material, area and peak power — NOT on the inverter.

Exam trap. 'The energy conversion efficiency of a solar cell does not depend on the inverter' (2017/2024 objective).

Solar PV sizing

Energy per day (kWh) = Panel kWp × Peak-sun hours × System efficiency
· Number of panels = Required kWp ÷ kWp per panel
· Roof area = panels × area each

WHAT EACH SYMBOL MEANS · UNIT

kWp	peak rating of the array at 1,000 W/m ²	kW
Peak-sun hours	daily insolation in kWh/m ² (e.g. 5)	h/day
System efficiency	inverter, wiring, temperature, dust losses (≈ 0.75–0.8)	—

WHAT IT MEANS

Net-metering questions (2021 short: 1,200 m² roof) ask how many kW fit, how many units per year, and the payback from the tariff.

Worked example. 10 kWp × 5 h × 0.8 = 40 kWh/day ≈ 14,600 kWh/yr.

Exam trap. 1 kWp of crystalline panels needs roughly 10 m² of roof (book-era panels).

Wind power

$$P = \frac{1}{2} \times \rho \times A \times v^3 \quad \cdot \quad A = \pi D^2 \div 4 \quad \cdot \quad \text{Power} \propto (\text{wind speed})^3$$

WHAT EACH SYMBOL MEANS · UNIT

ρ	air density $\approx 1.2 \text{ kg/m}^3$	kg/m^3
A	swept area of the rotor	m^2
v	wind speed	m/s
C_p	power coefficient — the fraction actually captured, max 0.59 (Betz), practical $\approx 0.35\text{--}0.45$	—

WHAT IT MEANS

Because of the cube law, doubling wind speed gives 8× the power and tripling gives 27×; siting for wind speed matters more than anything else. Doubling rotor diameter gives 4× (area).

Worked example. ρ 1.2, D 40 m ($A = 1,257 \text{ m}^2$), v 8 m/s $\rightarrow \frac{1}{2} \times 1.2 \times 1,257 \times 512 = 386 \text{ kW}$ available; $\times C_p$ 0.4 = 154 kW.

Exam trap. Wind speed TRIPLES $\rightarrow$ energy output $\times 27$, not $\times 3$ (this was a corrected answer in the bank).

Hydro power

$$P \text{ (kW)} = \rho \times g \times Q \times H \times \eta \div 1000 = 9.81 \times Q \times H \times \eta$$

WHAT EACH SYMBOL MEANS · UNIT

Q	water flow	m ³ /s
H	net head	m
η	turbine-generator efficiency (≈ 0.75–0.9)	—
ρ g	1000 × 9.81	—

WHAT IT MEANS

Power comes from mass flow × height. Classification by size (book): micro up to 100 kW, mini 101 kW – 2 MW, small 2 – 25 MW, large above 25 MW.

Worked example. 3 m³/s, 10 m head, η 0.77 → 9.81 × 3 × 10 × 0.77 = 226.6 kW (2013/2017 objective). 20 L/s, 12 m, 60 % → 9.81 × 0.02 × 12 × 0.6 = 1.41 kW.

Exam trap. Convert litres/second to m³/s (÷1000) before using the formula.

Biomass gasifier conversion efficiency

$$\eta = (\text{Gas produced} \times \text{CV of gas}) \div (\text{Biomass fed} \times \text{CV of biomass}) \times 100$$

WHAT EACH SYMBOL MEANS · UNIT

Gas produced	producer gas volume	m ³
CV of gas	≈ 1,000–1,200 kcal/m ³ (low)	kcal/m ³
CV of wood	≈ 3,200–4,000 kcal/kg	kcal/kg

WHAT IT MEANS

Gasification converts solid biomass into producer gas (mainly CO + H₂ + CH₄ with N₂) by partial combustion; cold-gas efficiency is typically 60–75 %.

Worked example. 20 kg wood × 3,200 = 64,000 kcal; 46 m³ gas × 1,000 = 46,000 → 71.9 % (2014 book / 2012 & 2018 exam).

Exam trap. Producer gas = CO, H₂ and CH₄ (2021/2025 objective) — it is NOT mainly methane.

Biogas

Biogas $\approx$ 55–65 % CH_4 + 35–45 % CO_2 (anaerobic digestion) ·
yield $\approx$ 0.04 m³ per kg fresh cattle dung

WHAT EACH SYMBOL MEANS · UNIT

Anaerobic digestion bacteria break down organic matter without oxygen —

WHAT IT MEANS

Methane is the fuel; CO_2 is the diluent. Biogas is different from producer gas (gasification, with oxygen-starved combustion).

(**Exam trap.** Biogas = methane + CO_2 (2017/2019/2022 objective).

Fuel cell

Input: hydrogen (fuel) + oxygen (air) $\rightarrow$ electricity + water + heat,
by electrochemical reaction – no combustion

WHAT EACH SYMBOL MEANS · UNIT

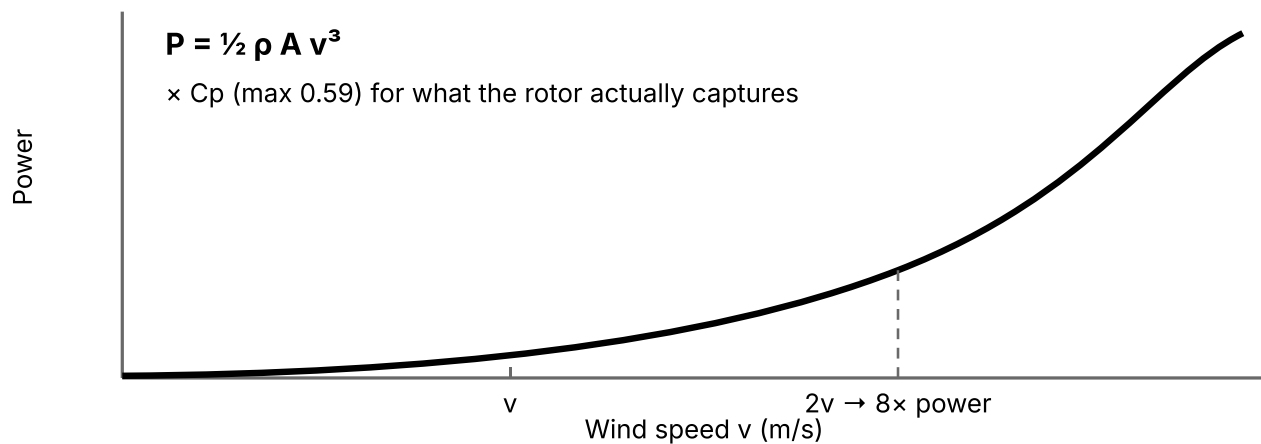
Efficiency 40–60 % electrical, higher with heat recovery —

WHAT IT MEANS

Like a battery that is refuelled instead of recharged; types PEM, PAFC, MCFC, SOFC by electrolyte. The INPUT is hydrogen (2015/2018 objective).

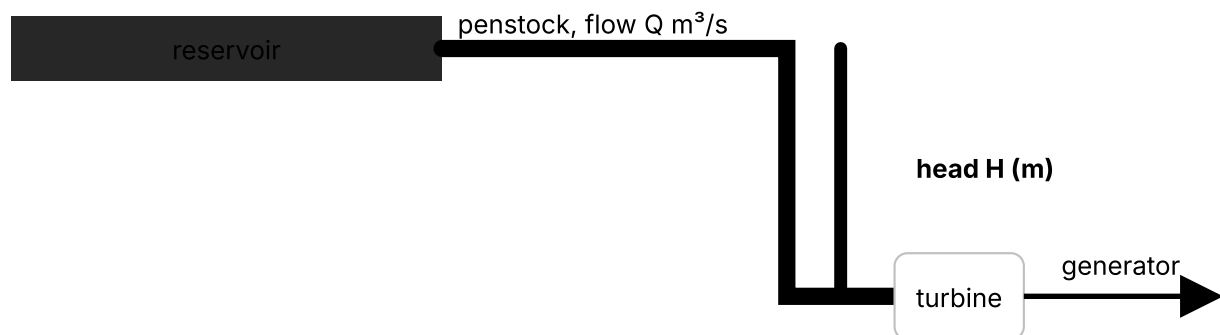
(**Exam trap.** It is not a combustion device and its input is not electricity.

Wind power rises with the cube of speed



Doubling the wind speed gives eight times the power — the curve bends upward steeply.

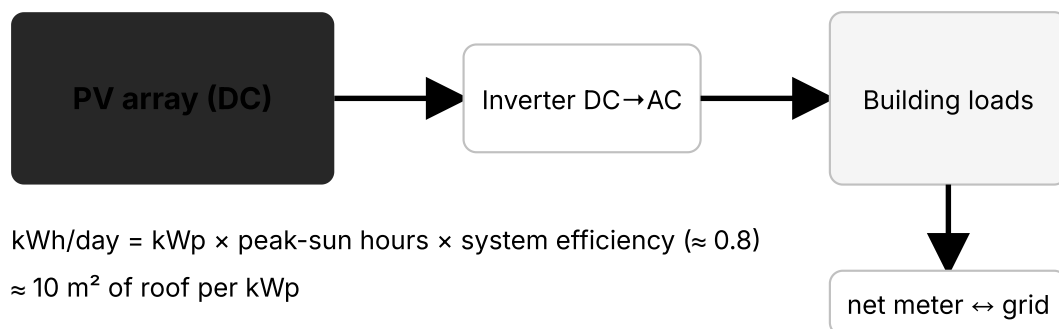
Hydro — head and flow



$$P \text{ (kW)} = 9.81 \times Q \times H \times \eta \rightarrow 3 \text{ m}^3/\text{s}, 10 \text{ m}, \eta 0.77 = 226.6 \text{ kW}$$

Power is set by how far the water falls (head) and how much falls per second (flow); the turbine converts most of it.

Solar PV system



Panels make DC; the inverter makes AC for the building; surplus goes to the grid through the net meter.

DEFINITIONS THE EXAM ASKS

Solar thermal

Flat-plate collectors (water heating, $\leq 100^\circ\text{C}$), evacuated tubes, concentrating collectors (parabolic trough/dish for process heat and power); solar cookers, dryers, ponds.

Solar PV

Photovoltaic cells (silicon: mono, poly, amorphous) convert light directly to DC; inverter makes AC; grid-tied (net metering) or off-grid with batteries.

Wind

Horizontal-axis turbines dominate; sites need annual mean speed $> 5\text{--}6 \text{ m/s}$; India's potential is concentrated in Tamil Nadu, Gujarat, Maharashtra, Karnataka, Rajasthan.

Biomass routes

Direct combustion, gasification (producer gas), anaerobic digestion (biogas), biofuels (ethanol from sugar/starch, biodiesel from oil seeds — jatropha).

Geothermal, tidal, wave, OTEC

Heat from the earth's crust; tidal range/stream; wave motion; ocean thermal energy conversion using the surface–deep temperature difference.

Availability-based tariff (ABT)

Grid tariff with fixed (capacity), variable (energy) and UI (unscheduled interchange) components to discipline frequency — appears in the 2023 long.

Net metering

Rooftop solar exports surplus to the grid; the meter runs backward, so the consumer pays only for net units.

VERIFIED VIDEOS FOR THIS CHAPTER (YOUTUBE)

Solar PV Sizing & Efficiency — 44-PV Modules 1 - Module Parameter, Orientation & Tilt · TAQA Academy - طاقة اكاديمي

Free open study guide for the BEE National Certification Examination. Formulas and values follow the 2014 BEE Book-1; videos are third-party and were verified by title only. **Home**