POWER PLANT ENGINEERING

DIPLOMA WALLAH

MECHANICAL

Jharkhand University Of Technology (JUT)

5.1 – Captive Power Plant: Definition & Benefits

📚 Definition

- Under Electricity Act, 2003 (India), a **Captive Generating Plant (CGP)** or captive power plant is defined as *"a power plant set up by any person to generate electricity primarily for his own use and includes a power plant set up by any co-operative society or association of persons for generating electricity primarily for use of members of such co-operative society or association."* (Ijpiel)
- Further, according to Electricity Rules, 2005 (Rule 3), to qualify as a captive-plant in India:
    - The captive user(s) must hold at least **26% ownership** of the plant. (Sarthak Law)

  - At least **51% of the aggregate electricity generated (on annual basis)** must be consumed for captive use by the owner(s). (TNERC)

- Key point for students: It's **not just any industry plant** generating power—it must be primarily for **own consumption**, satisfy ownership and consumption tests, and be distinguishable from grid-based generation. (Mondaq)

🏭 Benefits of Captive Power Plants

For students studying power plant engineering, especially mechanical/plant aspects, it helps to view the benefits from both technical & economic angles:

1. **Reliable & uninterrupted power supply**
   - Industries with heavy loads (e.g., steel, cement, aluminium) suffer large losses during grid outages. A captive plant gives control over supply, improving continuity. (KPI Green Energy)
   - From engineering viewpoint: less reliance on external grid means more freedom in designing internal distribution, backup systems, plant layout.
2. **Cost control & competitive advantage**
   - Generation cost under own control → potential lower cost than buying from grid plus transmission/distribution charges & surcharges. (KPI Green Energy)
   - Engineers must design the captive plant for optimal fuel usage, high efficiency (heat-rate, utilisation), low auxiliary losses — all of which tie into cost reduction.
3. **Fuel-flexibility & optimisation**
   - Captive plants may choose fuel better suited to the site (coal, gas, biomass, renewables) rather than being tied to central plant fuel decisions. (KPI Green Energy)
   - For mechanical engineering, this means design of boilers/turbines or engines must accommodate the chosen fuel, fuel handling, emissions, and maintenance regimes.

4. **Reduced transmission/distribution losses & infrastructure dependency**
   - Generating power near or at the site of consumption avoids long transmission lines and associated losses. (KPI Green Energy)
   - This affects plant layout, cabling, switching, protection design in captive plants.
5. **Surplus power / flexible business model**
   - If plant capacity is slightly above own need or if generation is high, excess can be sold to grid (subject to regulations). This generates additional revenue. (Ijpiel)
   - Engineers/planners must then factor in grid-connection, export switchgear, metering, and regulatory compliance.

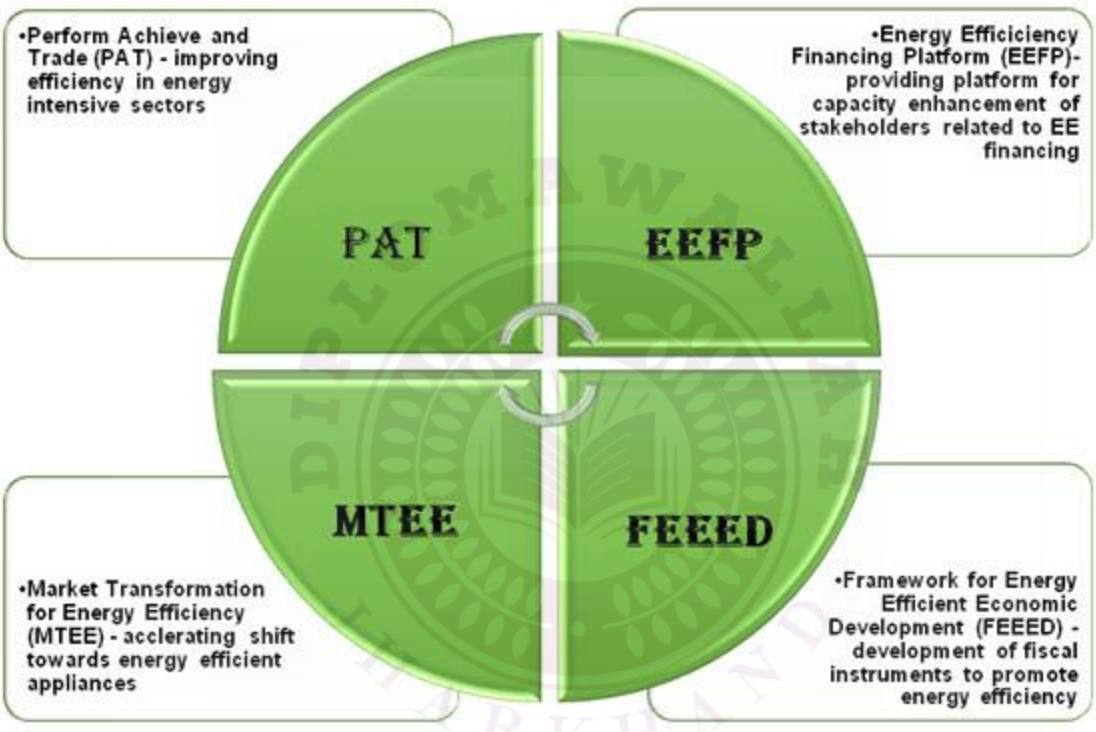
🛠 Engineering / Economic Considerations

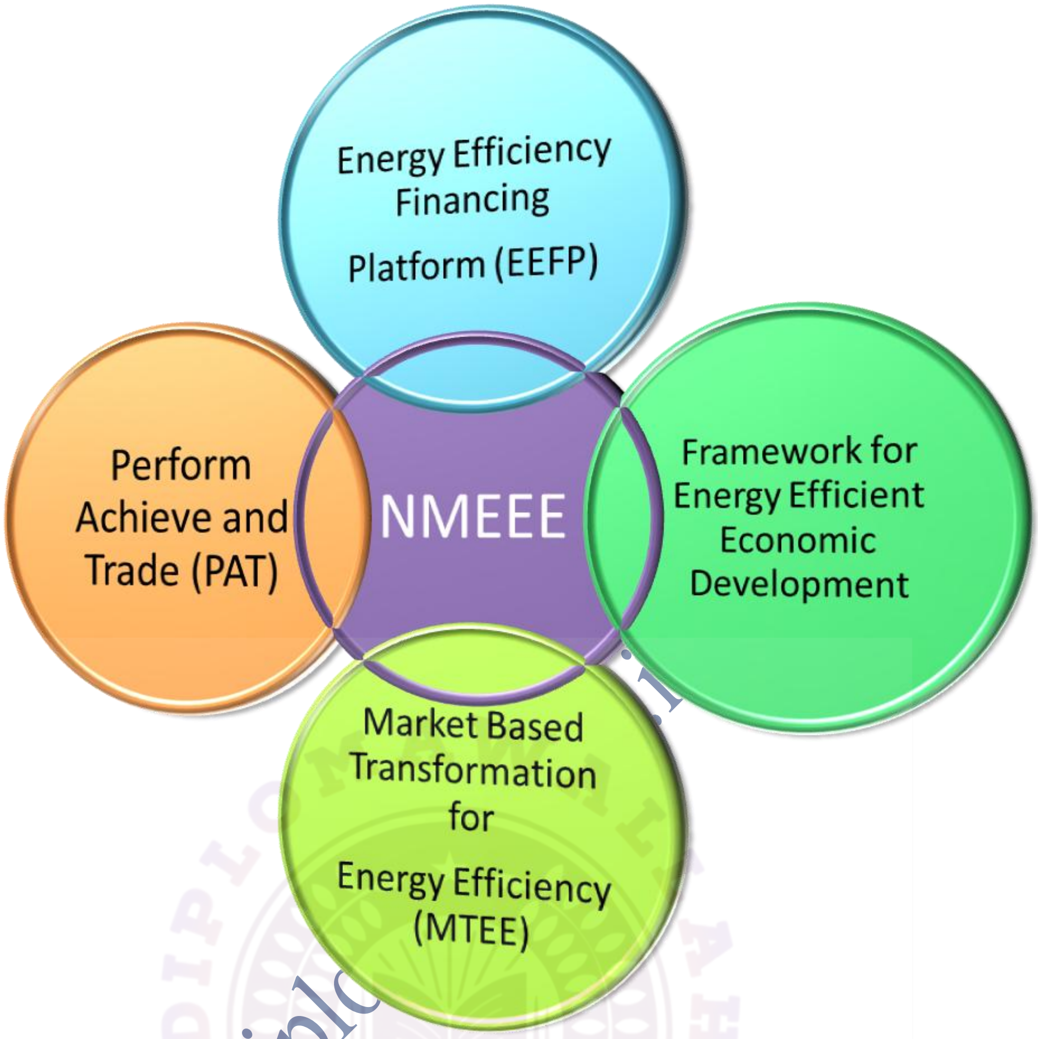
- **Capacity sizing**: The plant must be sized to suit the industry's load profile (base load + peak demands). Under-sizing causes deficits; over-sizing increases capital cost and under-utilisation.
- **Fuel supply & logistics**: Secure fuel (coal, gas, biomass) is critical. Engineers must plan fuel handling, storage, ash or residues processing, and ensure continuity of supply.
- **Compliance & captive status risks**: Failure to meet 26% ownership or 51% consumption criteria may result in loss of captive status → additional charges, surcharges. (TNERC)
- **Maintenance & O&M**: Since supply is critical for the host industry, maintenance planning, redundancy, reliability engineering are vital.
- **Cost of capital vs grid cost**: The captive plant must have favourable economics—initial investment, fuel costs, O&M, lifecycle cost must compare well with purchasing power from the grid.

🧠 Student

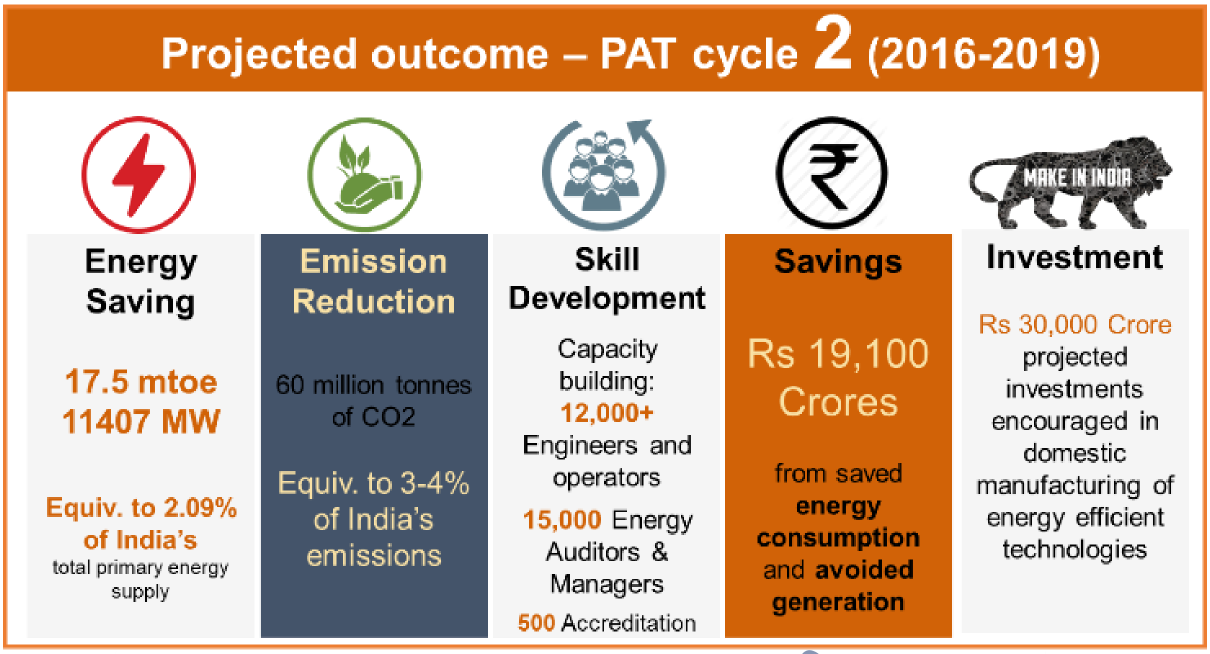
- **Definition**: Power plant set up for own use; meets ownership (≥ 26%) & consumption (≥ 51%) criteria.

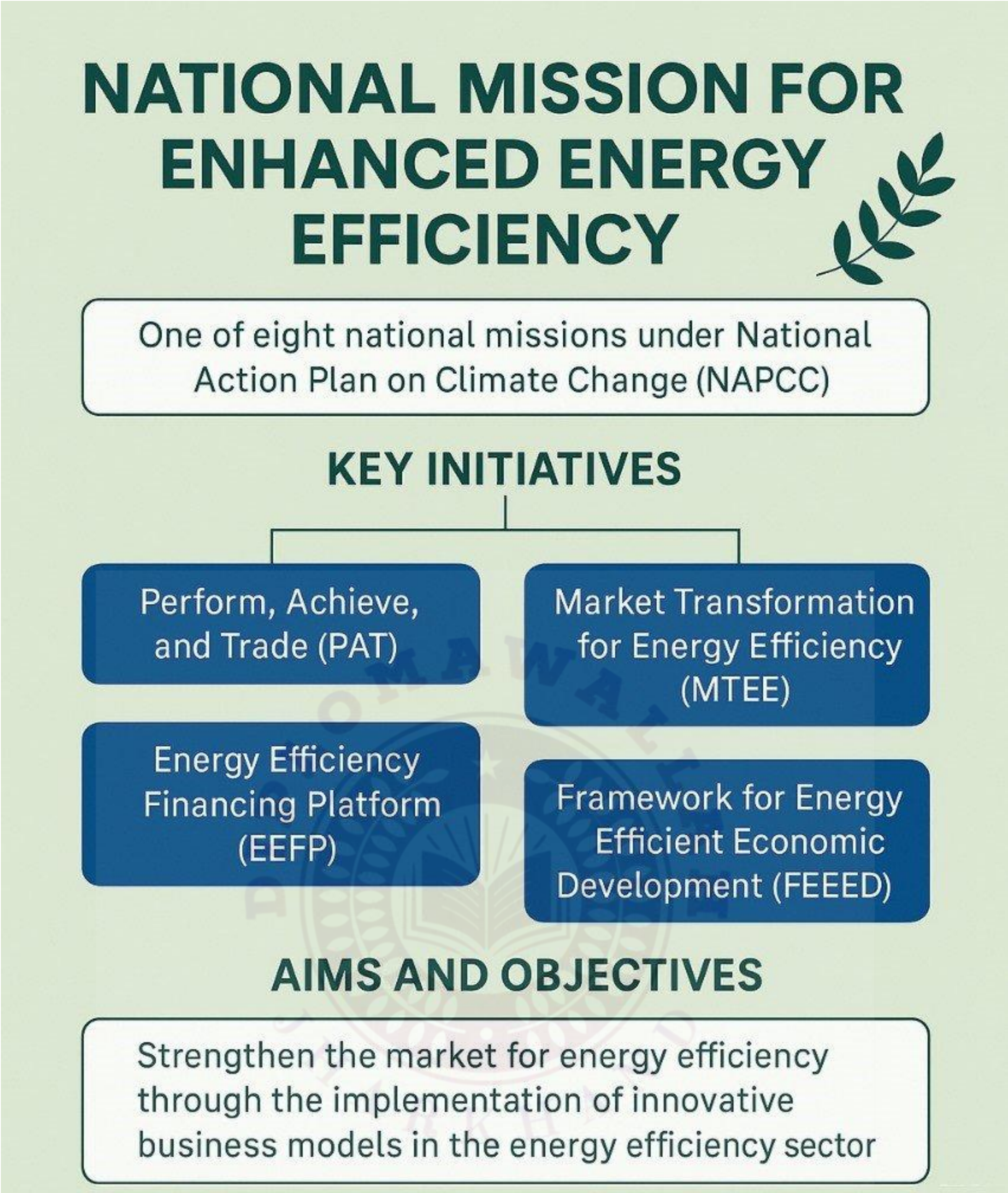
- **Benefits**: Reliable supply, cost savings, fuel flexibility, lower losses, potential surplus revenue.
- **Important tests/criteria**: Ownership – 26%, Consumption – 51%.
- **Engineering viewpoint**: Focus on design, fuel handling, layout, reliability, economics of captive plants.
- **Regulatory aspects**: Captive status has legal/regulatory implications (exemptions, surcharges) if criteria not met.

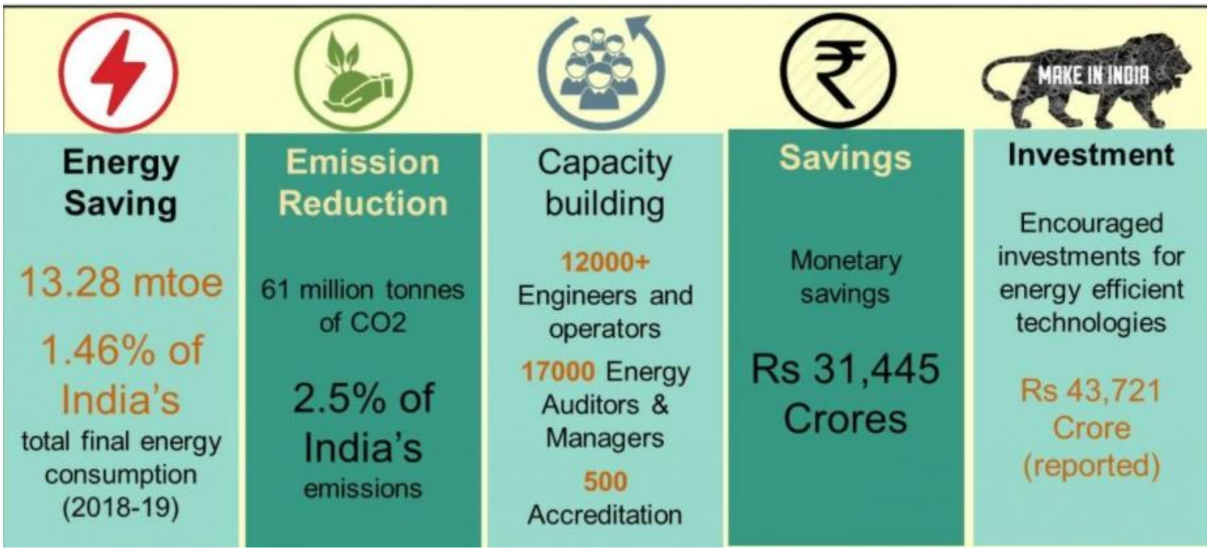



Energy Efficiency Financing Platform (EEFP)
Perform Achieve and Trade (PAT)
NMEEE
Framework for Energy Efficient Economic Development
Market Based Transformation for Energy Efficiency (MTEE)

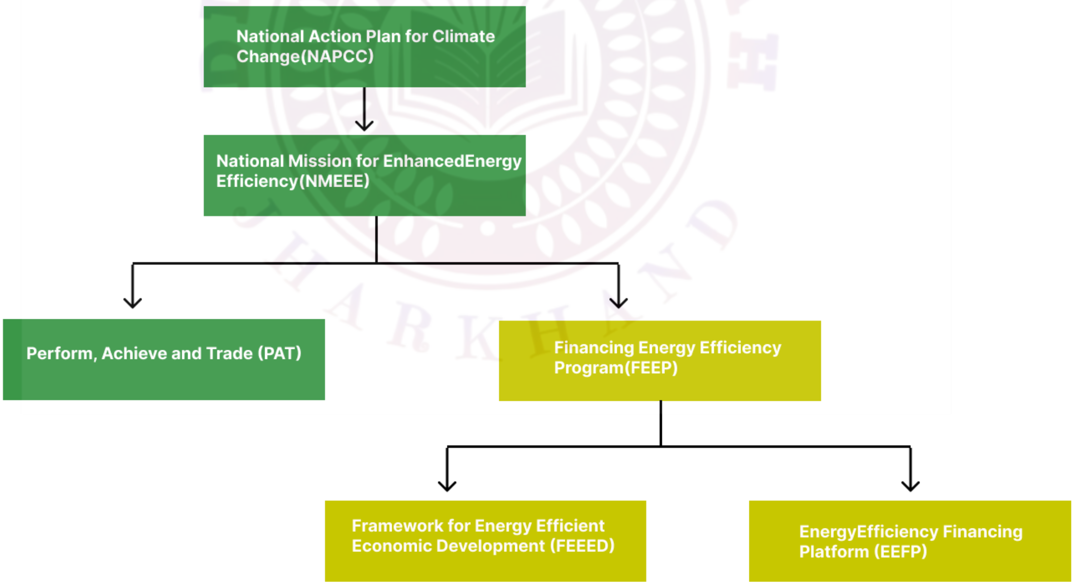

GOVERNMENT OF INDIA
MINISTRY OF POWER
PAT SCHEME
BUREAU OF ENERGY EFFICIENCY
The PAT Scheme currently covers 13 energy-intensive sectors
1,333 DCs achieved 27.07 MTOE* energy savings (2012-23), surpassing the 23.867 MTOE target!
*till PAT VI (2020-23) initial assessment
www.beeindia.gov.in


Projected outcome – PAT cycle 2 (2016-2019)
Energy Saving
17.5 mtoe
11407 MW
Equiv. to 2.09% of India's
total primary energy supply
Emission Reduction
60 million tonnes of CO2
Equiv. to 3-4% of India's emissions
Skill Development
Capacity building:
12,000+ Engineers and operators
15,000 Energy Auditors & Managers
500 Accreditation
Savings
Rs 19,100 Crores
from saved energy consumption and avoided generation
MAKE IN INDIA
Investment
Rs 30,000 Crore
projected investments encouraged in domestic manufacturing of energy efficient technologies


NATIONAL MISSION FOR ENHANCED ENERGY EFFICIENCY
One of eight national missions under National Action Plan on Climate Change (NAPCC)
KEY INITIATIVES
Perform, Achieve, and Trade (PAT)
Market Transformation for Energy Efficiency (MTEE)
Energy Efficiency Financing Platform (EEFP)
Framework for Energy Efficient Economic Development (FEEED)
AIMS AND OBJECTIVES
Strengthen the market for energy efficiency through the implementation of innovative business models in the energy efficiency sector


Energy Saving
13.28 mtoe
1.46% of India's
total final energy consumption (2018-19)
Emission Reduction
61 million tonnes of CO2
2.5% of India's
emissions
Capacity building
12000+ Engineers and operators
17000 Energy Auditors & Managers
500 Accreditation
Savings
Monetary savings
Rs 31,445 Crores
MAKE IN INDIA
Investment
Encouraged investments for energy efficient technologies
Rs 43,721 Crore (reported)


Framework for Energy Efficient Economic Development
FEEED


National Action Plan for Climate Change(NAPCC)
National Mission for EnhancedEnergy Efficiency(NMEEE)
Perform, Achieve and Trade (PAT)
Financing Energy Efficiency Program(FEEP)
Framework for Energy Efficient Economic Development (FEEED)
EnergyEfficiency Financing Platform (EEFP)

1. What is NMEEE & Why is it Important

- NMEEE is one of eight national missions under India's National Action Plan on Climate Change (NAPCC), launched to **promote large-scale energy efficiency** across sectors. (Hareda)
- Its goal is to **strengthen the market for energy efficiency**—not just through regulations, but through financial instruments, market-based trading, and transformation of equipment/technology. (Escerts)
- Some of the big targets: unlocking a market potential of ~ **₹ 74,000 crore**; annual fuel savings of ~23 million toe; avoiding ~19,000 MW capacity addition; GHG reduction of ~98.55 million tCO_2 per year at full implementation. (Prepp)
- For power-plant engineering students, this matters because: the efficiency of power plants (heat rate, fuel consumption, auxiliary power) is directly impacted by how these regulatory/market instruments shape industry behaviour. Efficiency improvement = cost saving + emissions reduction.

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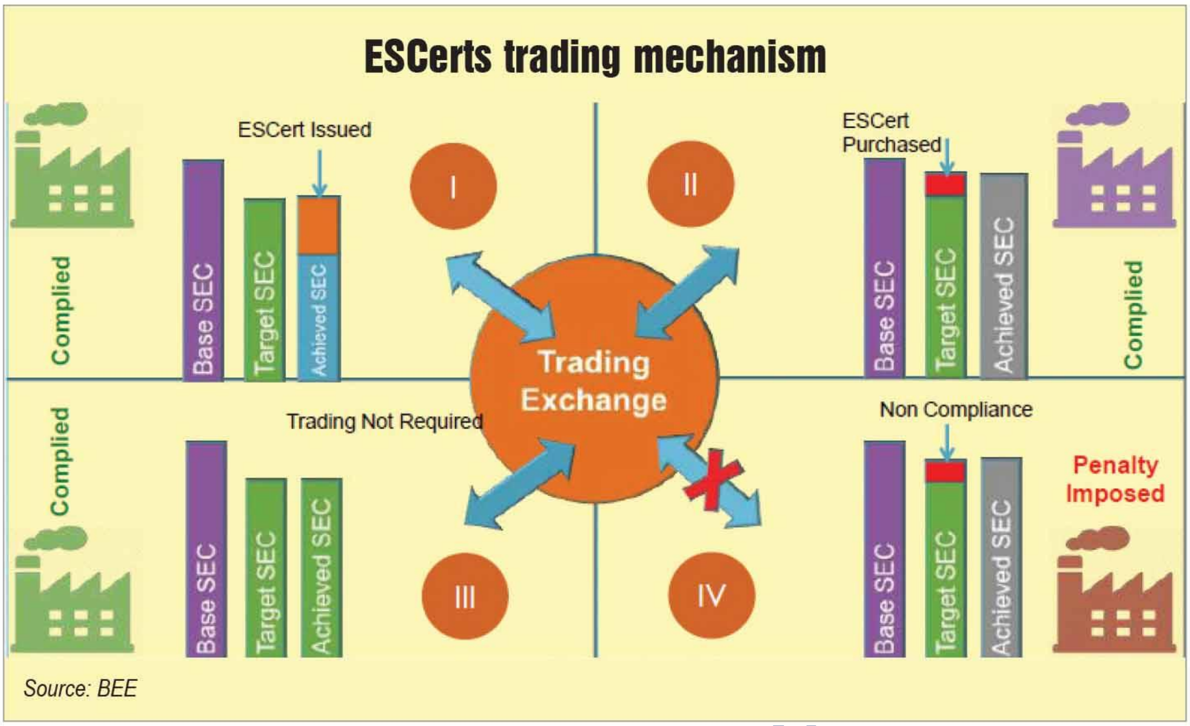
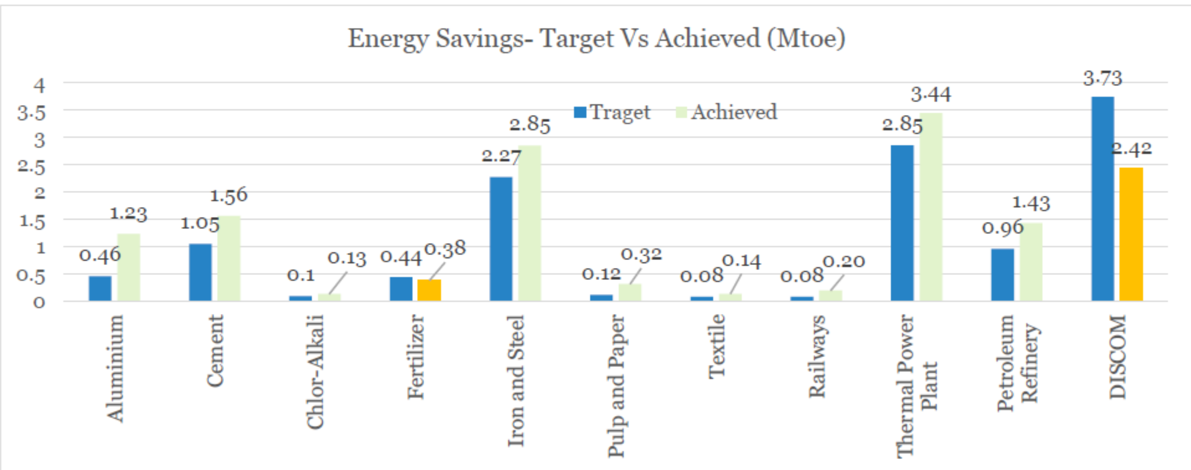
2. The Four Key Components of NMEEE

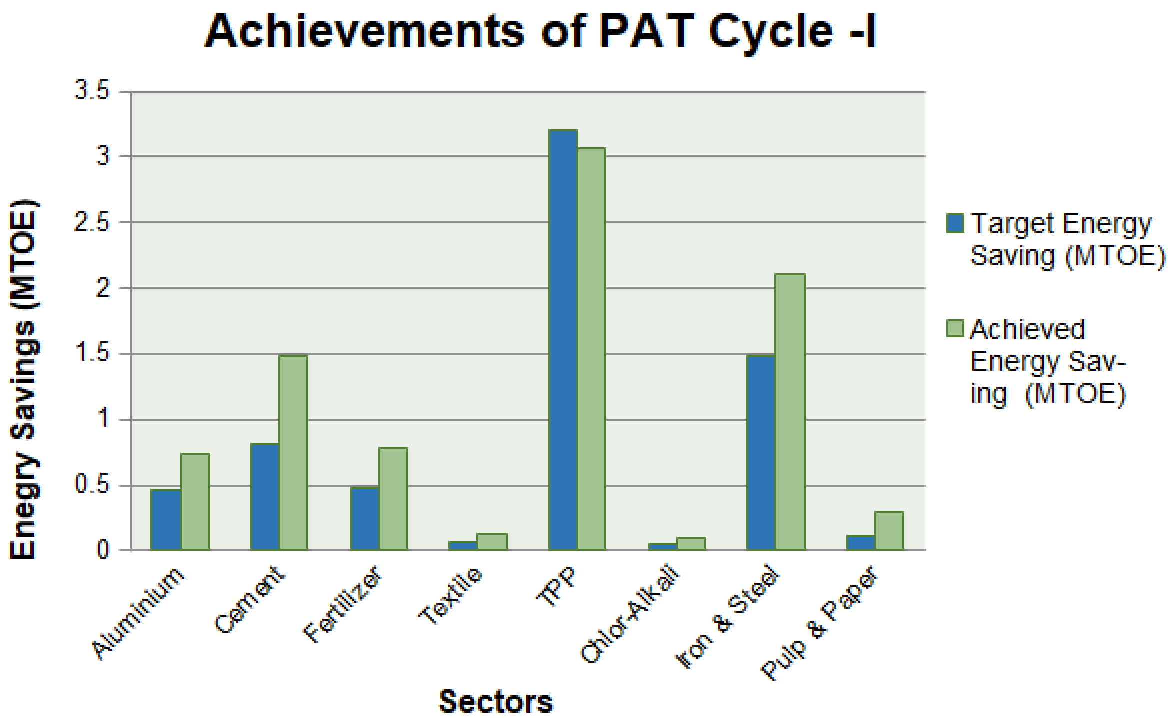
NMEEE is made up of four main initiatives. Let's explore each in more depth.

2.1 Perform, Achieve and Trade (PAT)

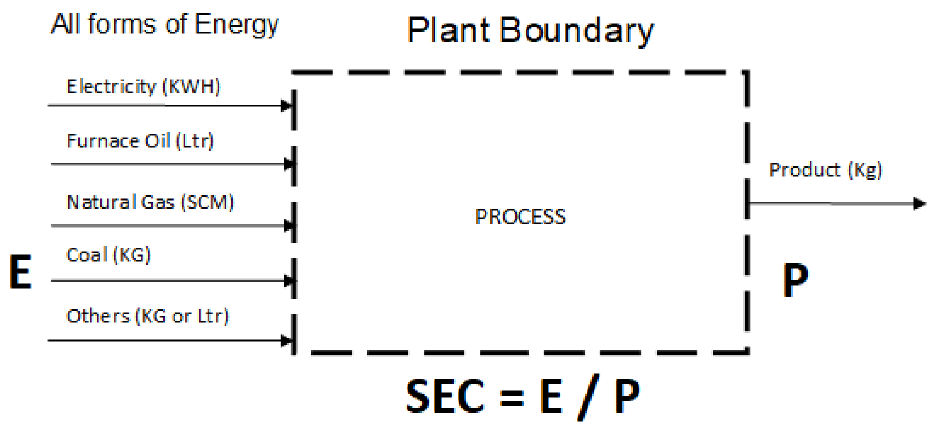

ESCerts trading mechanism
ESCert Issued
ESCert Purchased
Complied
Base SEC
Target SEC
Achieved SEC
I
II
III
IV
Trading Exchange
Trading Not Required
Non Compliance
Penalty Imposed
Source: BEE


Concept of Target, Compliance, ESCerts & Penalty
Baseline SEC
Issued Escerts
Penalty
Target
Achieved SEC
Compliance
Target SEC
Purchase Escerts
Scenario 1
Scenario 2


Energy Savings- Target Vs Achieved (Mtoe)
Traget
Achieved
4
3.5
3
2.5
2
1.5
1
0.5
0
0.46
1.23
1.05
1.56
0.1
0.13
0.44
0.38
2.27
2.85
0.12
0.32
0.08
0.14
0.08
0.20
2.85
3.44
0.96
1.43
3.73
2.42
Aluminium
Cement
Chlor-Alkali
Fertilizer
Iron and Steel
Pulp and Paper
Textile
Railways
Thermal Power Plant
Petroleum Refinery
DISCOM



$$SEC = \frac{Net\ Energy\ Input\ into\ the\ designated\ consumer\ (DC)}{Total\ quantity\ of\ output\ exported}$$



Pictorial representation for gate-to-gate concept

PAT Sector (Demand Side)	PAT Sector (Supply Side)	Number of PAT DCs analyzed for M&V	Energy Savings Achieved (Mtoe)	% Share of Savings (Sector-wise)	% Share of Savings (Demand & Supply wise)
Aluminium		11	1.226	8.7%	
Cement		99	1.559	11.1%	
Chlor-Alkali		24	0.133	0.9%	
Fertilizer		36	0.383	2.7%	
Iron and Steel		67	2.845	20.2%	48.24%
Pulp and Paper		24	0.315	2.2%	
Textile		85	0.135	1.0%	
Railways		22	0.196	1.4%	
	Thermal Power Plant	118	3.435	24.4%	
	Petroleum Refinery	17	1.430	10.2%	51.76%
	DISCOM	39	2.423	17.2%	
Grand Total		**544**	**14.08**	**100%**	**100%**

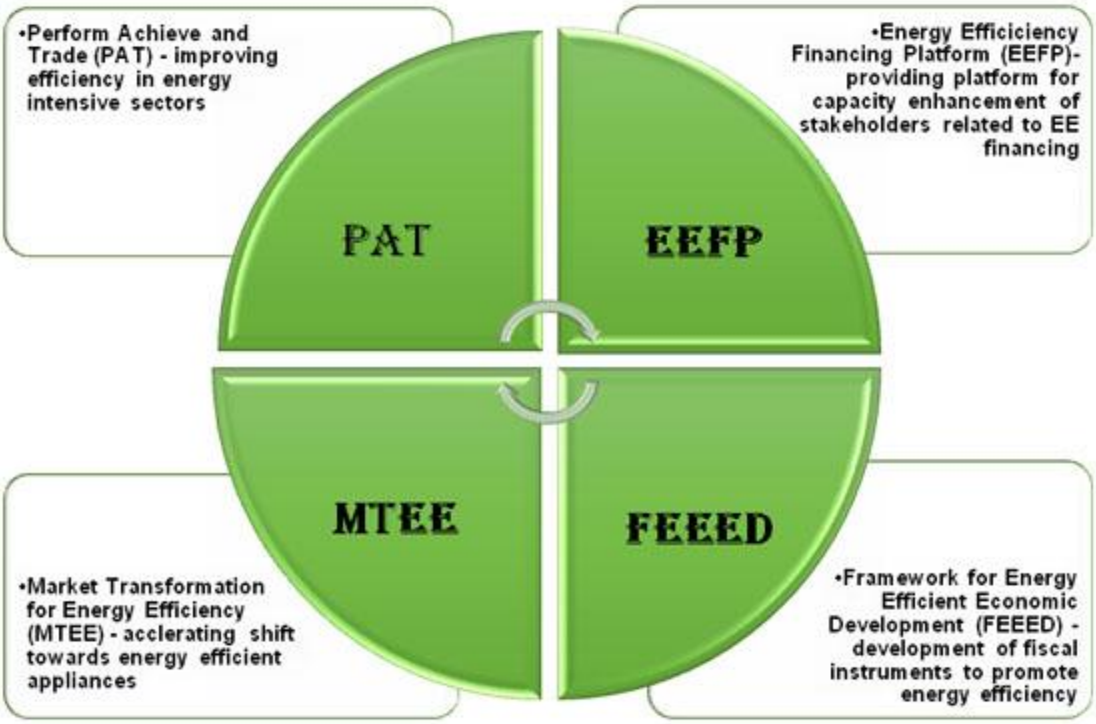
Deep Explanation / Points to note:

- **Definition & purpose**: PAT is a market-based regulatory instrument under National Mission for Enhanced Energy Efficiency (NMEEE) that sets targets for selected energy-intensive industrial units (called Designated Consumers, DCs) to reduce their Specific Energy Consumption (SEC) over a "cycle" (usually 3 years). (IEA)
- **Designated Consumers (DCs)**: Industries in predefined sectors (e.g., thermal power plants, cement, aluminium, iron & steel) that exceed a threshold energy consumption are notified as DCs under the scheme. (BYJU'S)
- **Baseline & target**: For each DC a baseline year is established. The SEC is calculated (energy per unit production) and normalised for factors such as capacity utilization, fuel change, product mix. A target reduction is set for the cycle end. (Bureau of Energy Efficiency)
- **Excess savings → tradable certificates**: If a DC reduces more than its target, it receives Energy Saving Certificates (ESCerts). These can be traded. If a DC falls short, it must purchase ESCerts or face penalties. (cCarbon)
- **Cycle mechanism**: PAT is implemented in cycles. For example, Cycle I (2012-15) covered 478 DCs across 8 sectors and achieved ~8.67 MTOE savings vs target ~6.686 MTOE. (Bureau of Energy Efficiency)

- **Relevance for power plants**: Thermal power plants are among DCs — reducing heat rate, auxiliary power, improving turbine/boiler efficiency directly helps meet PAT targets.
- **Engineering/Operational implications**:
  - Monitoring & measurement: Must track energy and production carefully.
  - Upgrades & retrofits: To reduce SEC, plants may need new turbines, better controls, improved condensers, efficient auxiliary equipment.
  - Cost/benefit analysis: The ability to gain from ESCerts or avoid buying them influences investment decisions.
- **Challenges**:
  - Setting fair baselines and targets considering technical variability.
  - Market liquidity for ESCerts may be low in some cases.
  - Implementation lag or insufficient retrofits reduce actual savings.
  - Data accuracy & verification is critical for credibility. (Bureau of Energy Efficiency)

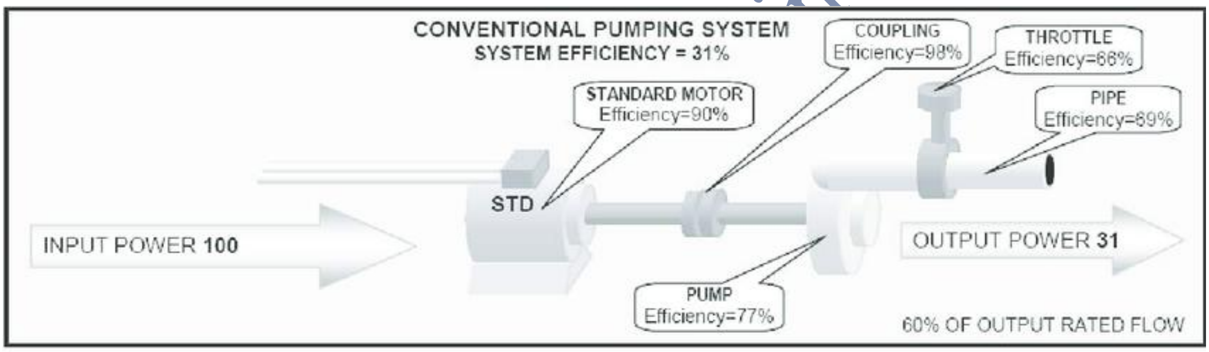
Key points for exam revision: Define PAT, mention DCs & sectors, explain baseline→target→certificate process, note achievements (Cycle I), note relevance to power plants, list challenges.

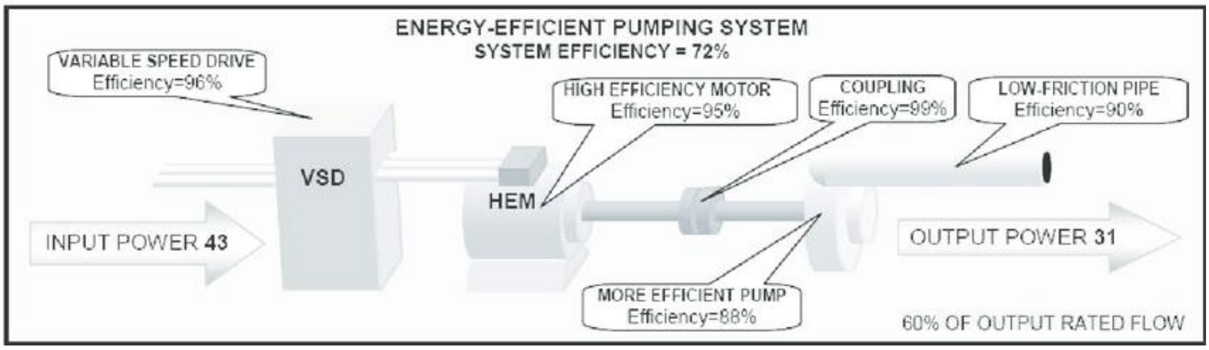
2.2 Market Transformation for Energy Efficiency (MTEE)

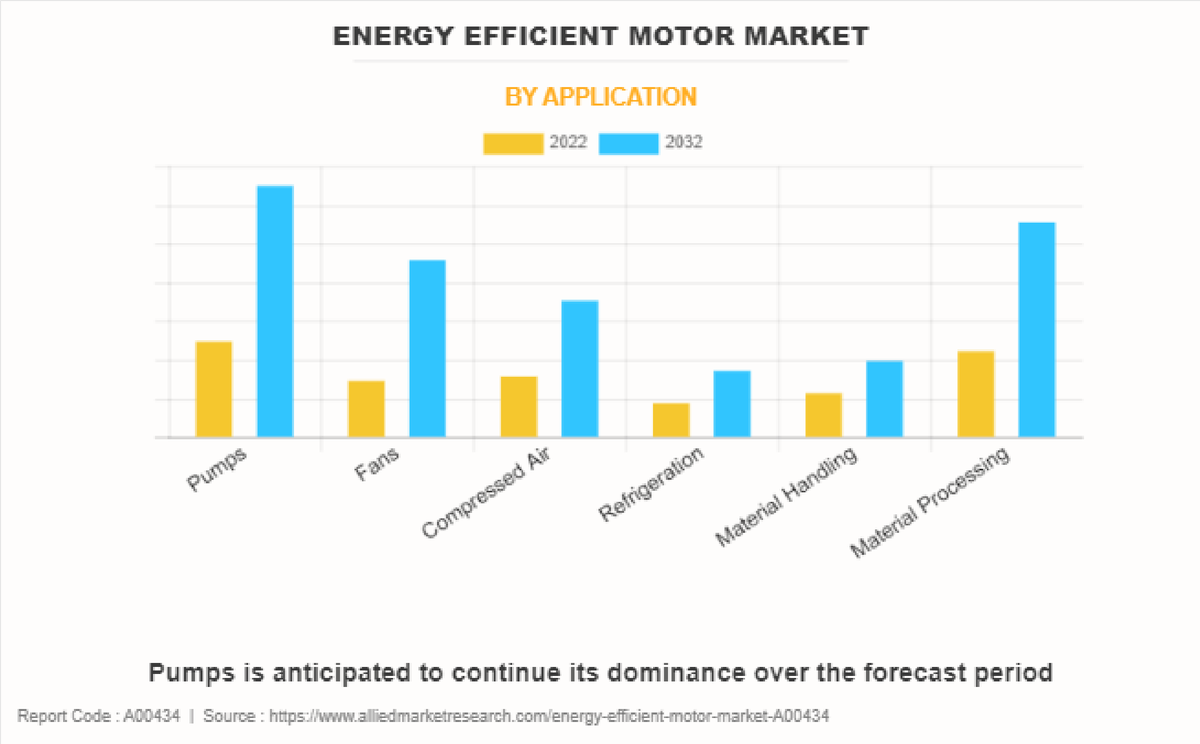

•Perform Achieve and Trade (PAT) - improving efficiency in energy intensive sectors
PAT
•Energy Efficiciency Financing Platform (EEFP)- providing platform for capacity enhancement of stakeholders related to EE financing
EEFP
MTEE
•Market Transformation for Energy Efficiency (MTEE) - acclerating shift towards energy efficient appliances
FEEED
•Framework for Energy Efficient Economic Development (FEEED) - development of fiscal instruments to promote energy efficiency


Regular Ceiling Fans
Energy Efficient Ceiling Fans
Super-Efficient Ceiling Fans
75-80 W
50-60 W
25-40 W


MORE STARS MORE SAVING
ENERGY SAVINGS GUIDE


CONVENTIONAL PUMPING SYSTEM
SYSTEM EFFICIENCY = 31%
COUPLING Efficiency=98%
THROTTLE Efficiency=66%
STANDARD MOTOR Efficiency=90%
PIPE Efficiency=69%
STD
INPUT POWER 100
OUTPUT POWER 31
PUMP Efficiency=77%
60% OF OUTPUT RATED FLOW


ENERGY-EFFICIENT PUMPING SYSTEM
SYSTEM EFFICIENCY = 72%
VARIABLE SPEED DRIVE Efficiency=96%
HIGH EFFICIENCY MOTOR Efficiency=95%
COUPLING Efficiency=99%
LOW-FRICTION PIPE Efficiency=90%
VSD
HEM
INPUT POWER 43
OUTPUT POWER 31
MORE EFFICIENT PUMP Efficiency=88%
60% OF OUTPUT RATED FLOW



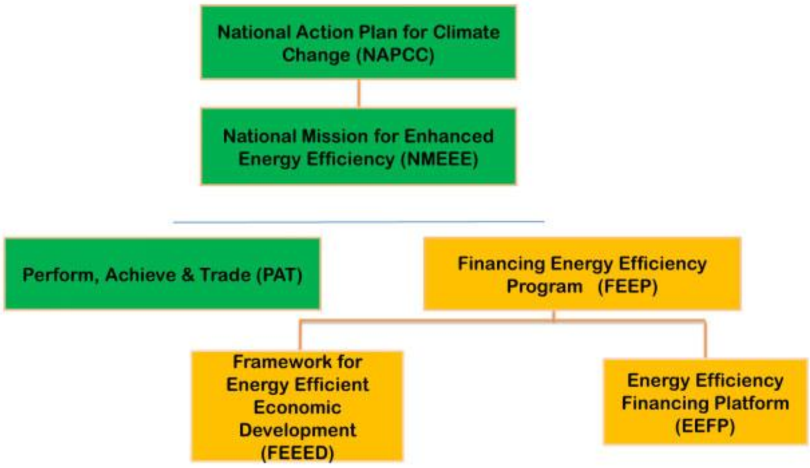
Deep Explanation / Points to note:

- **Definition & objective**: MTEE aims to shift the market towards energy-efficient appliances and equipment in designated sectors—so that efficient equipment becomes the norm, not the exception. (Hareda)
- **Key interventions**:
  - Setting Minimum Efficiency Performance Standards (MEPS) for appliances & equipment.
  - Labelling and certification of efficiency levels to inform buyers.
  - Incentives or bulk procurement for "super-efficient" equipment (e.g., in the Super-Efficient Equipment Programme (SEEP)). (IEA)
  - Awareness programmes, capacity building, technology demonstration.
- **Engineering relevance for power plants**:
  - Many losses in a power plant come from "auxiliary" systems (pumps, fans, compressors). Under MTEE, upgrading these to high-efficiency versions reduces auxiliary load, improves plant efficiency/heat rate.

  - Retrofitting older equipment under MTEE contributes to performance parameters which you study (Unit V topics 5.3/5.4).
- **Economic / market implications**:
  - Equipment cost may be higher for high efficiency but lifecycle cost is lower due to energy savings. The market push under MTEE aims to reduce first-cost premium via scale and policy incentives.
  - As efficient equipment becomes baseline, plants must upgrade to stay competitive.
- **Challenges**:
  - High first-cost and longer payback periods often delay adoption.
  - Supply chain issues: availability of high-efficiency equipment, reliable vendors.
  - Measuring actual efficiency gains: Just installing new equipment does not guarantee savings unless properly operated/maintained.
- **Examples**: SEEP for super-efficient fans: aim to produce fans with ~35 W vs market ~70 W, via incentives to manufacturers. (IEA)

Key revision points: Define MTEE, list interventions (MEPS, labelling, incentives), highlight engineering relevance, note market/finance issues, example (SEEP).

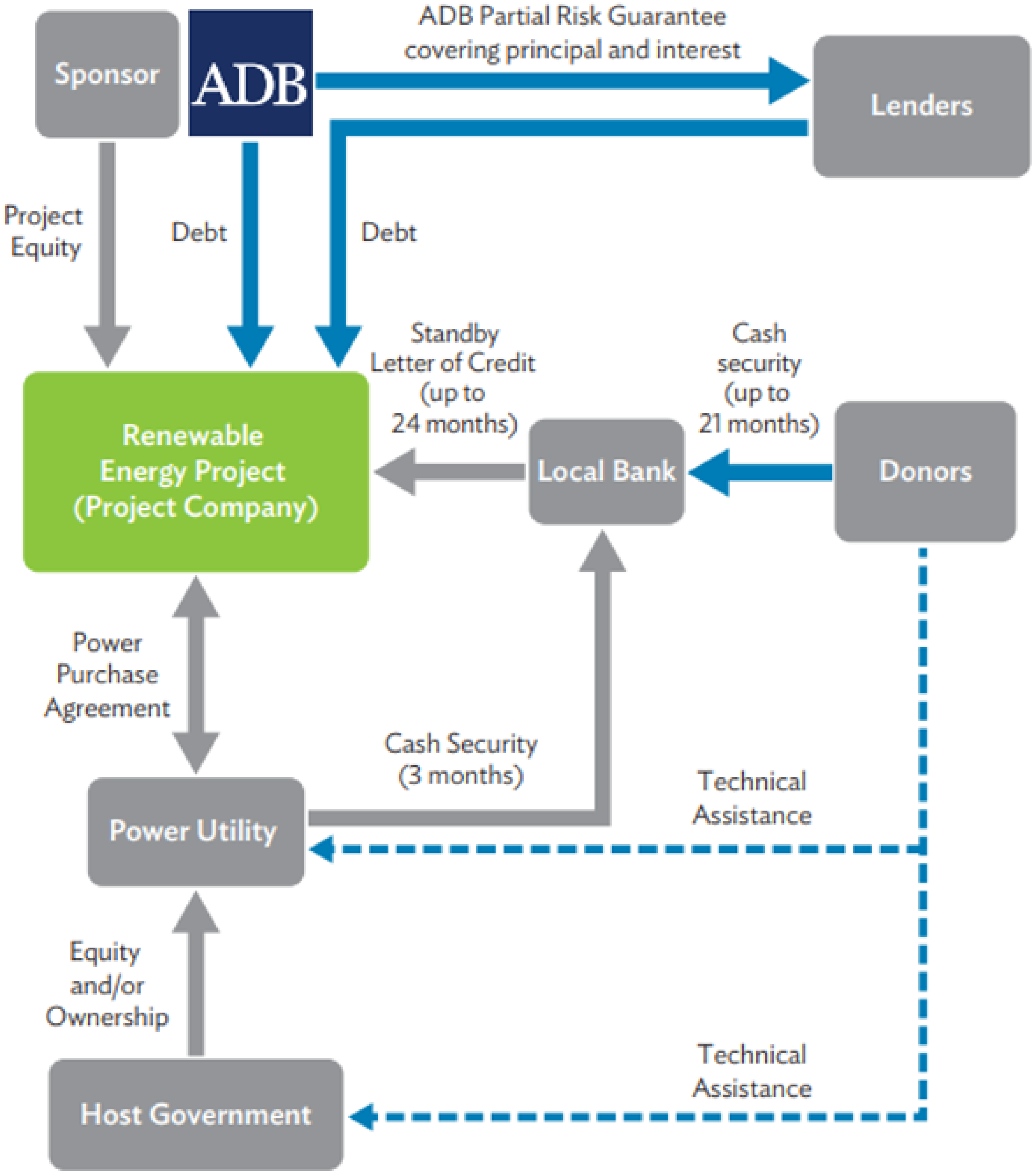
2.3 Framework for Energy Efficient Economic Development (FEEED)

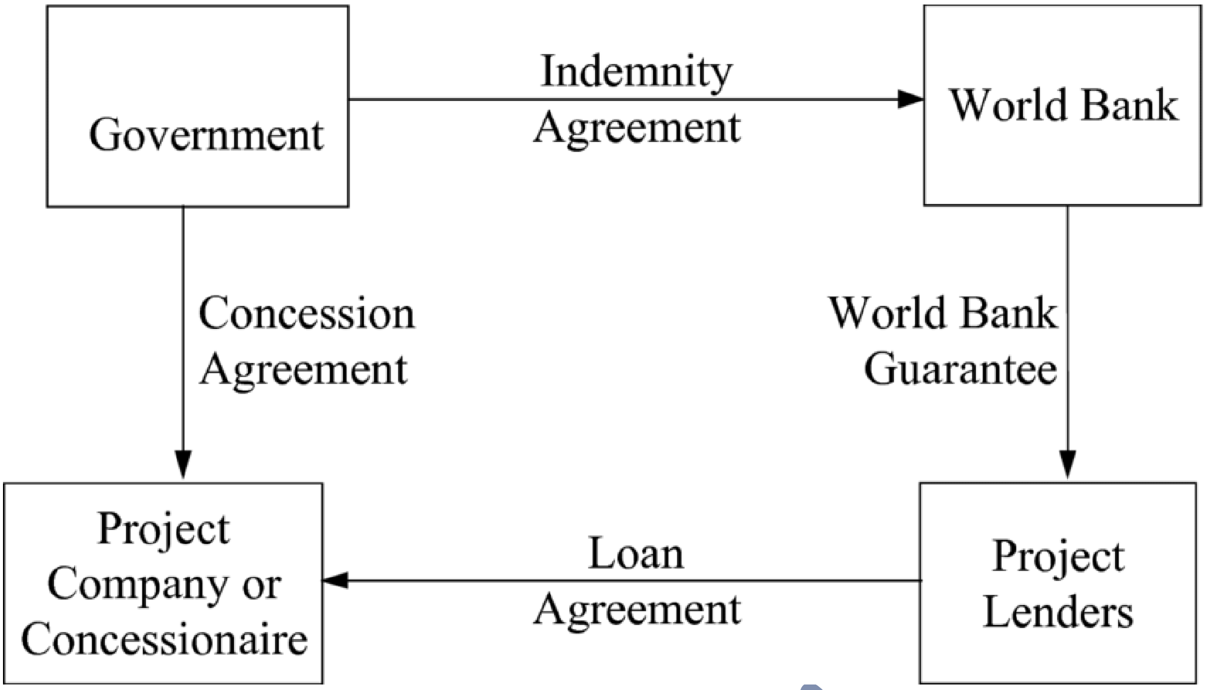


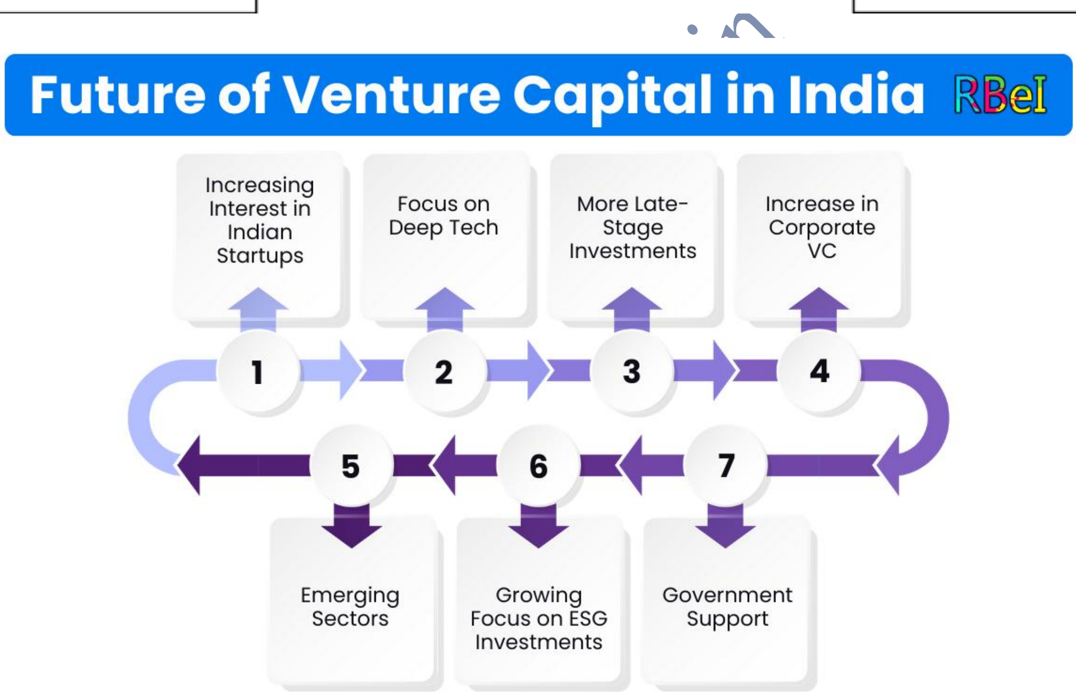
Energy Efficiency Financing Platform (EEFP)

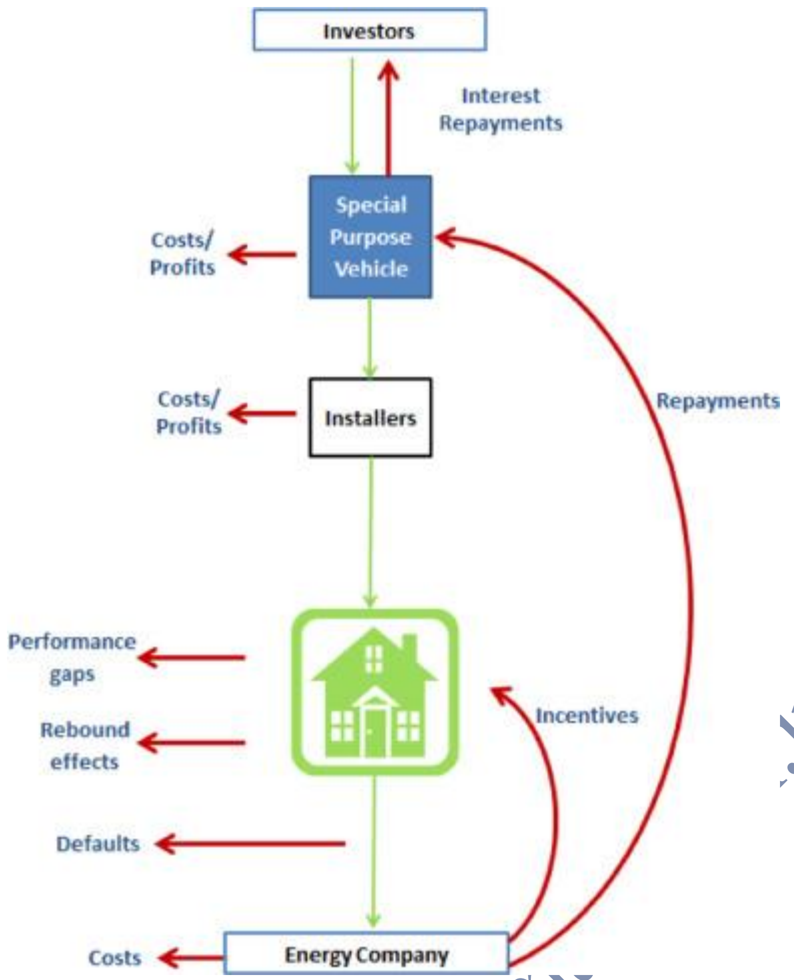
Framework for Energy Efficient Economic Development (FEEED)

Program Overview for a Potential Renewable Energy Project




Government
Indemnity Agreement
World Bank
Concession Agreement
World Bank Guarantee
Project Company or Concessionaire
Loan Agreement
Project Lenders


Future of Venture Capital in India
RBeI
1
Increasing Interest in Indian Startups
2
Focus on Deep Tech
3
More Late-Stage Investments
4
Increase in Corporate VC
5
Emerging Sectors
6
Growing Focus on ESG Investments
7
Government Support



Deep Explanation / Points to note:

- **Definition & purpose**: FEEED is the financing and economic-instrument component of NMEEE, designed to create the right fiscal, financial and institutional conditions so energy-efficiency projects are viable. (simplifiedupsc.in)
- **Key instruments under FEEED**:
    - *Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE)*: A guarantee fund that reduces risk for banks lending to energy-efficiency projects by covering a portion of default risk.
    - *Venture Capital Fund for Energy Efficiency (VCFEE)*: Equity or early-stage capital support for highly efficient technologies or business models.
    - Energy Service Company (ESCO) models and market financing for retrofit projects.
- **Relevance to power plants**:

- Upgrading major systems in a power plant (e.g., turbine retrofits, advanced instrumentation, heat-recovery systems) is expensive; FEEED helps enable such upgrades by making financing accessible.
- From a mechanical/plant engineering student's view: it is not enough to identify technical improvement—you must also justify the economics, prepare business case, and align with finance mechanisms like FEEED.

- **Importance of Fiscal & Institutional Support**:
  - Without support, many technically feasible projects remain un-executed because payback periods are long or risk perception is high.
  - FEEED smartly links technical savings (energy/fuel) to financial flows (loan repayments, guarantees).
- **Challenges**:
  - Banks may still be hesitant to lend to EE projects due to monitoring/verification issues.
  - Ensuring that financed savings materialise is crucial—project performance risk remains.
  - Institutional capacity (ESCOs, financiers) may be limited.
- **Engineering/economic intersection**:
  - For a power plant upgrade case, you would need: cost estimate of upgrade, expected savings (fuel, maintenance, downtime), financing cost & instruments (from FEEED), payback/ROI, risk assessment.
  - Your engineering design must be aligned with economic viability which FEEED supports.

Key revision points: Define FEEED, list financing instruments (PRGFEE, VCFEE), explain relevance for power plants, engineering/finance intersection, key challenges.

5.3 Estimation of the Production Cost of Electrical Energy

Equation 1

$$COE = \underbrace{\frac{\beta \cdot C}{P \cdot H}}_{\text{Capital}} + \underbrace{\frac{f}{\eta}}_{\text{Fuel}} + \underbrace{\left\{ \frac{OM_f}{P \cdot H} + \mu \cdot OM_{v,b} \right\}}_{\text{O\&M}}$$

where

β = Levelized carrying charge factor or cost of money

C = Total plant cost ($)

H = Annual operating hours

P = Net rated output (kW)

f = Levelized fuel cost ($/kWh [LHV])

η = Net rated efficiency of the combined-cycle plant (LHV)

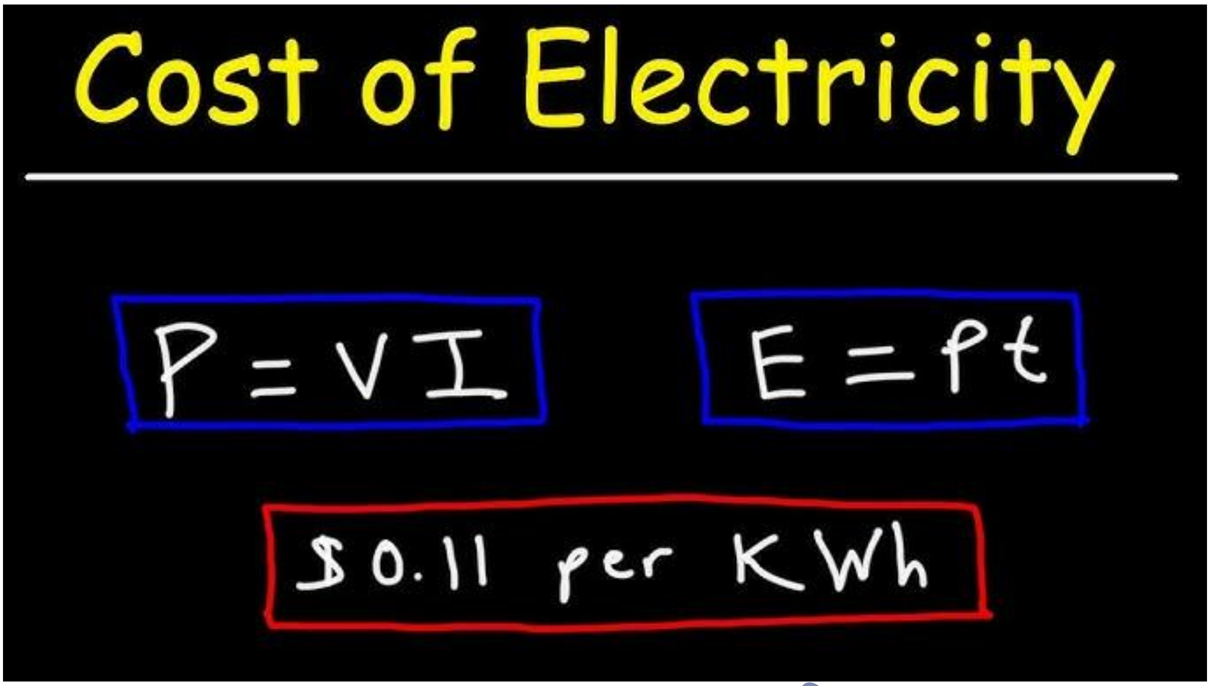
OM_f = Fixed O&M costs ($ or $/kW-yr)

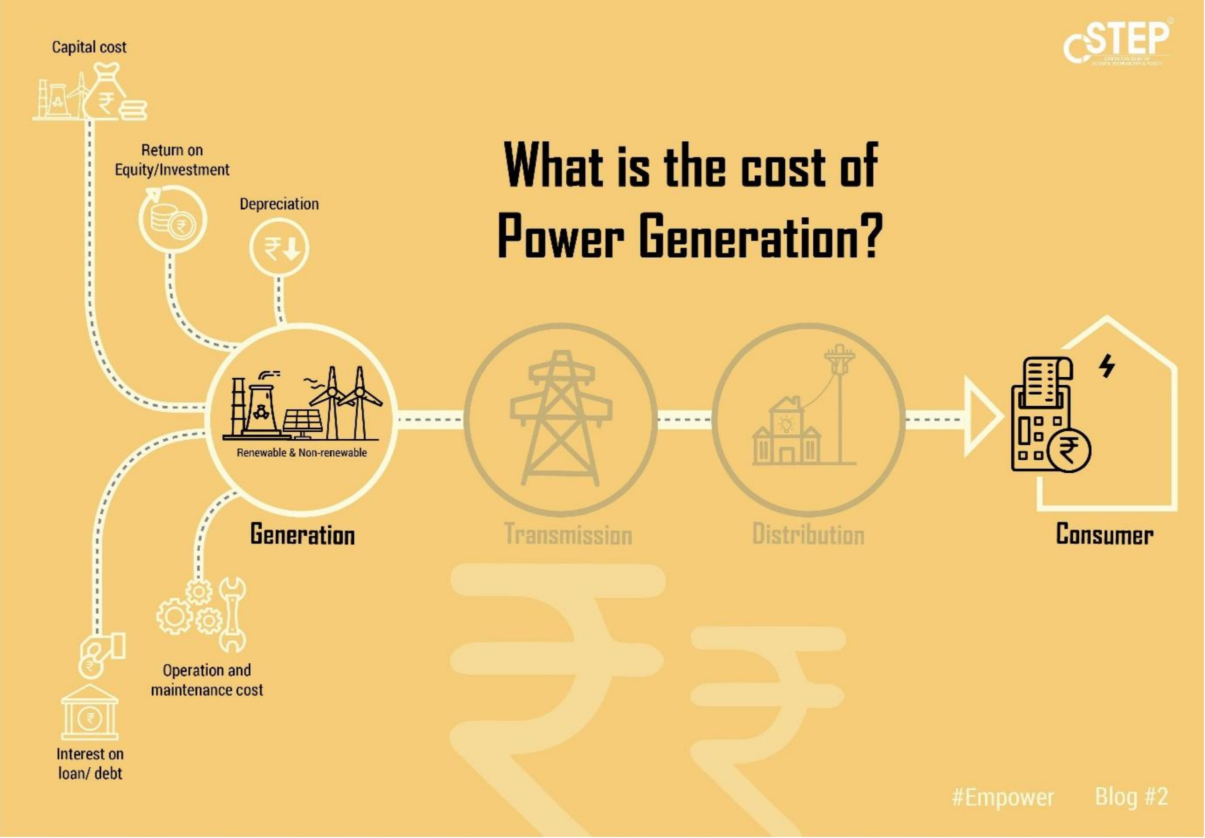
$OM_{v,b}$ = Variable O&M costs for baseload operation ($/kWh)

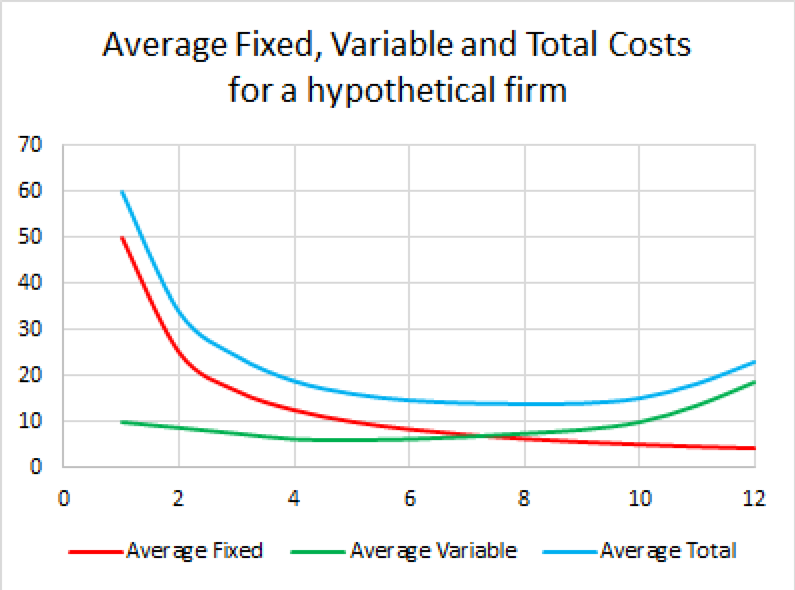
μ = Maintenance cost escalation factor (1.0 for baseload operation)

Equation 2

$$COE = \underbrace{\left\{ \frac{\beta \cdot C + OM_f}{P_{eff} \cdot H_{eff}} + \frac{f}{\eta_{eff}} + \mu \cdot OM_{v,b} \right\}}_{\text{Modified COE}} + \underbrace{\sum_i c_i \cdot m_{p,i}}_{\text{Emissions}} + \underbrace{\frac{S_c \cdot \Delta P + S_e \cdot \Delta E}{P_{eff} \cdot H_{eff}}}_{\text{System impact}}$$


Cost of Electricity
P = VI
E = Pt
$0.11 per KWh


Capital cost
Return on Equity/Investment
Depreciation
What is the cost of Power Generation?
Renewable & Non-renewable
Generation
Transmission
Distribution
Consumer
Operation and maintenance cost
Interest on loan/ debt
#Empower
Blog #2



$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

LCOE Levelized Cost of Electricity in EUR/kWh

I_0 Investment expenditure in EUR

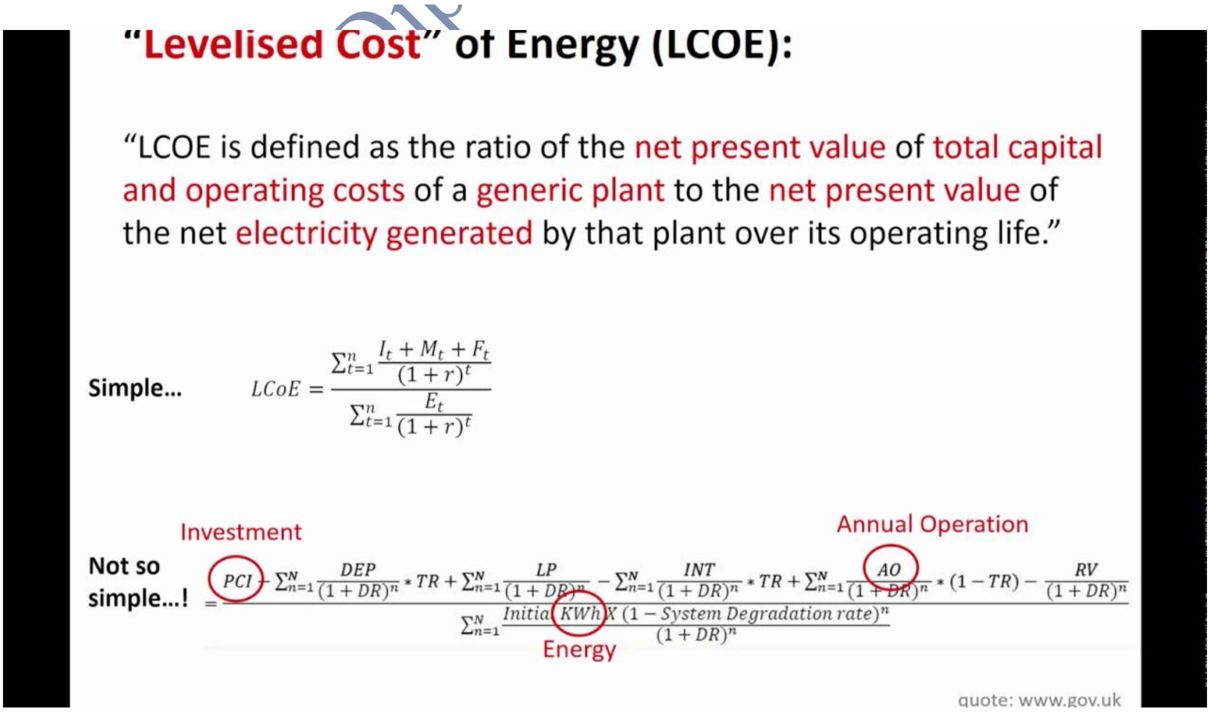
A_t Annual total cost in EUR per year t

$M_{t,el}$ Produced amount of electricity in kWh per year

i Real interest rate in %

n Economic lifetime in years

t Year of lifetime (1, 2, ...n)



✅ What the Topic Covers

- What "production cost of electrical energy" means (cost per unit of electricity generated)
- The main cost components of a power plant (fixed cost + variable cost)
- The formulae and method to calculate cost per unit (Rs/kWh)
- How factors like load factor, heat rate, fuel cost, auxiliary consumption influence cost
- Advanced metric: Levelised Cost of Electricity (LCOE)
- Typical numerical problems you should be able to solve for the exam

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🧮 Key Concepts & Theory

1. Definition

- Production cost of electrical energy = **total cost** to generate electricity divided by **total energy generated**, typically expressed in Rs/kWh.
- It includes capital cost converted to annualised cost, operation & maintenance costs, fuel cost, auxiliary power consumption, etc.
- According to one source: "The cost of generating electricity… is the largest component of the price of electricity." (U.S. Energy Information Administration)
- Also: When comparing different power sources, the LCOE (levelised cost) is commonly used: "the total average cost of building and operating an electrical power station over its service life divided by total energy produced." (IDB Invest)

2. Cost Components

- **Fixed (or investment) costs**: These are incurred whether you generate little or full capacity. Examples: land, plant equipment, construction, interest, depreciation, fixed O&M. (open-electricity-economics.org)

- **Variable costs**: These vary with the amount of electricity produced. Examples: fuel, variable O&M, consumables, auxiliary power, maintenance linked to output. (powerplantandcalculations.com)
- Sometimes there are **semi-variable (quasi-fixed) costs**: costs that increase step-wise when output crosses a threshold (e.g., extra shift labour). (open-electricity-economics.org)

3. Basic Calculation (Simple)

- Annual Energy Generated = Installed capacity (kW or MW) × Load factor × Hours per year (8760) × (1 – auxiliary/internal consumption)
- Total Annual Cost = Annualised capital cost + Annual fixed O&M + Annual variable cost (fuel + variable O&M + others)
- Cost per unit (Rs/kWh) = Total Annual Cost ÷ Annual Energy Generated

Example: On a website, there is a formula where Power Generation Cost per unit = A1/E (where A1 = total cost, E = total energy) (powerplantandcalculations.com)

4. Levelised Cost of Electricity (LCOE) – More Advanced

- When you want to compare different technologies or lifetime costs, you use LCOE:
  $$\mathrm{LCOE} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1 + r)^t}}{\sum_{t=1}^n \frac{E_t}{(1 + r)^t}}$$
  where I_t = investment cost at year t, M_t = O&M cost, F_t = fuel cost, E_t = energy generated, r = discount rate, n = life years. (Wikipedia)
- Useful for comparing e.g., a coal plant vs solar plant vs nuclear.
- Factors impacting LCOE: discount rate, plant life, capacity factor, fuel cost, efficiency.

5. Important Influencing Variables – From Student Perspective

- **Heat rate / Efficiency**: Lower heat rate (i.e., less fuel per kWh) → lower fuel cost → lower cost per unit.

- **Load factor / Capacity utilisation**: Higher load factor → fixed cost spread over more units → lower cost per unit.
- **Fuel cost / Fuel availability**: For fossil fuel plants, fuel cost is major part of variable cost. If fuel price goes up, cost per unit increases. (arXiv)
- **Auxiliary power consumption and losses**: If a plant uses more internal power or has higher losses, the net exportable energy is less → cost per unit goes up.
- **Capital cost, interest / discount rate**: Higher capital cost or higher interest rate means fixed cost's annualised portion is higher.
- **Operation & Maintenance**: Poor maintenance or frequent outages reduce actual generation → cost per unit increases due to lower denominator (units generated).
- **Technology / Age of plant**: Older plants often have poorer efficiency, more downtime, higher maintenance → higher cost per unit.

📝 Typical Numerical Problems (Student-Ready)

Here are two maybe three sample problems with simplified data you might see in exams. **Work them out step by step**.

Problem A (Basic):
A 200 MW thermal power plant operates at 70% load factor. Annualised capital cost = ₹25 crores/year, fixed O&M = ₹10 crores/year, fuel cost = ₹120 crores/year, variable O&M = ₹5 crores/year. Calculate the cost per unit (Rs/kWh). Assume full year (8760 hours).
Solution Steps:

1. Annual energy = 200×0.7×8760 = 200×6132 = 1,226,400 MWh = 1.2264×10^9 kWh.
2. Total annual cost = 25 +10 +120 +5 = ₹160 crores = ₹1.60×10^10.
3. Cost per unit = ₹1.60×10^10 ÷ 1.2264×10^9 = ~₹13.05/kWh.
4. Interpret: This is the break-even cost for the plant.

Problem B (Includes Auxiliary Internal Use):
A 150 MW coal plant runs at 80% load factor but aux/internal

consumption is 10%. Heat rate = 10,000 kCal/kWh, coal cost = ₹2.50/kg, calorific value = 3500 kCal/kg, annualised fixed cost = ₹20 crores/year, other O&M = ₹8 crores/year. Calculate cost per unit sold.
Solution Guide:

1. Gross energy = 150×0.8×8760 = 150×7008 = 1,051,200 MWh = 1.0512×10^9 kWh.
2. Net exportable = 90% of that = 0.90×1.0512×10^9 = ~9.4608×10^8 kWh.
3. Fuel energy required = heat rate × gross kWh = 10,000 kCal/kWh × 1.0512×10^9 = 1.0512×10^13 kCal.
4. Coal needed = 1.0512×10^13 ÷ 3500 = ~3.0034×10^9 kg.
5. Fuel cost = 3.0034×10^9 × ₹2.50 = ₹7.5085×10^9 = ₹750.85 crores.
6. Total annual cost = fixed cost + O&M + fuel cost = 20 +8 +750.85 = ~₹778.85 crores = ₹7.7885×10^10.
7. Cost per unit = ₹7.7885×10^10 ÷ 9.4608×10^8 kWh ≈ ₹82.35/kWh.
8. Interpretation: High cost because of high fuel cost and relatively lower net export.

Exam tip: Always show steps and units conversions clearly.

NUMERICAL

Problem 1

Statement:
A thermal power plant has an installed capacity of **400 MW**. The plant load factor (PLF) is **70%** (i.e., it operates at 70% of full capacity on average). The annualised capital cost (including depreciation, interest) is ₹30 crores/year, fixed O&M cost is ₹12 crores/year, fuel cost is ₹140 crores/year, variable O&M cost is ₹6 crores/year. Assume the plant runs for 8760 hours/year. Calculate the **cost of production** in ₹/kWh for the plant.

Guidance / Solution Steps:

1. Annual energy generated = 400 MW × 0.70 × 8760 h = (400 × 0.70 = 280) MW average → 280 MW × 8760 h = 2,452,800 MWh = 2.4528×10^9 kWh.
2. Total annual cost = capital cost ₹30 cr + fixed O&M ₹12 cr + fuel ₹140 cr + variable O&M ₹6 cr = **₹188 crores/year**.
   Convert to ₹: ₹188 crores = ₹188 × 10^7 = ₹1.88×10^9.
3. Cost per unit = Total cost ÷ Annual energy = (₹1.88×10^9) ÷ (2.4528×10^9 kWh) ≈ **₹0.767 / kWh** (≈ 77 paise per kWh).
4. Interpretation: The plant must generate at a tariff higher than ~₹0.77/kWh to recover costs (ignoring profit).

Problem 2

Statement:
A coal-fired plant of capacity 250 MW runs at 75% load factor. Heat rate = 9,500 kCal/kWh. The coal calorific value = 3,800 kCal/kg. Coal cost = ₹2.30/kg. Auxiliary (internal) consumption of the plant is 7% (i.e., only 93% of generated energy is exportable). Annual fixed cost (capital + fixed O&M) = ₹18 crores. Variable O&M = ₹4 crores/year. Compute the cost per unit of **exported electricity** in ₹/kWh.

Guidance / Solution Steps:

1. Annual gross generation = 250 MW × 0.75 × 8760 h = 250×0.75=187.5 MW average → × 8760 = 1,643,250 MWh = 1.64325×10^9 kWh.
2. Net exportable energy after auxiliary consumption = 93% of gross = 0.93 × 1.64325×10^9 = 1.529823×10^9 kWh.
3. Fuel energy required = heat rate × gross generation = 9,500 kCal/kWh × 1.64325×10^9 kWh = 1.5600875×10^{13} kCal.
4. Coal needed = (Fuel energy) ÷ calorific value = 1.5600875×10^{13} ÷ 3,800 = ≈ 4.1055×10^9 kg.
5. Fuel cost = coal kg × ₹2.30 = 4.1055×10^9 × 2.30 = ₹9.44265×10^9 = ₹944.265 crores.
6. Total annual cost = fuel cost ₹944.265 crores + fixed cost ₹18 crores + variable O&M ₹4 crores = ₹966.265 crores = ₹9.66265×10^9.

7. Cost per unit = (₹9.66265×10^9) ÷ (1.529823×10^9 kWh) ≈ **₹6.32 / kWh**.
8. Interpretation: Because fuel cost and auxiliary consumption are large, cost per unit is high (~₹6.32/kWh).

Problem 3

Statement:
A gas-fired plant capacity 100 MW, load factor 80%. Annualised capital cost = ₹40 crores, fixed O&M = ₹10 crores. Fuel cost is ₹60 crores/year, variable O&M = ₹3 crores/year. Compute cost per unit in ₹/kWh assuming full year operation (8760 h).

Guidance / Solution Steps:

1. Annual energy = 100 × 0.80 × 8760 = 100 × 7008 = 700,800 MWh = 7.008×10^8 kWh.
2. Total cost = ₹40 +10 +60 +3 = ₹113 crores/year = ₹1.13×10^9.
3. Cost per unit = ₹1.13×10^9 ÷ 7.008×10^8 kWh ≈ **₹1.61 / kWh**.
4. Interpretation: Because fuel cost lower (relatively) and capacity factor high, cost is moderate (~₹1.61/kWh).

Problem 4

Statement:
A 50 MW renewable (solar) power plant has total investment cost ₹300 crores, expected life 25 years, discount rate 10%. Annual O&M cost ₹5 crores. Expected capacity factor = 20% (i.e., average generation at 20% of full). Estimate a simplified life-cycle cost per kWh (ignore escalation, residual value, fuel cost = zero since it's solar).

Guidance / Solution Steps:

1. Annual energy = 50 MW × 0.20 × 8760 = 50 × 1752 = 87,600 MWh = 8.76×10^7 kWh.
2. Present value of capital cost ~ ₹300 crores (at year 0) = ₹3.00×10^9.
3. Present value of annual O&M cost (₹5 crores/year for 25 years, discount rate 10%) = Use annuity PV:

(PV = C × \frac{1 - (1+r)^{-n}}{r} = 5 × \frac{1 - (1.10)^{-25}}{0.10} ≈ 5 × 9.077 = ₹45.385 crores = ₹4.5385×10^8).

4. Total present cost ≈ ₹3.00×10^9 + ₹0.45385×10^9 = ₹3.45385×10^9.
5. Total lifetime energy = annual energy × 25 years = 8.76×10^7 ×25 = 2.19×10^9 kWh.
6. Simplified cost per unit ≈ ₹3.45385×10^9 ÷ 2.19×10^9 kWh ≈ **₹1.58 / kWh**.
7. Interpretation: This gives a ball-park life-cycle cost of ~₹1.58/kWh for the solar plant.

Problem 5

Statement:
A hydro power plant of 120 MW capacity has the following data: Load factor 50%. Annual fixed cost (capital + fixed O&M) = ₹25 crores. Fuel cost = negligible. Variable O&M = ₹2 crores. Compute cost per unit, assuming 8760 hours/year and that auxiliary consumption 5%.

Guidance / Solution Steps:

1. Annual gross generation = 120 MW × 0.50 × 8760 = 120 × 4380 = 525,600 MWh = 5.256×10^8 kWh.
2. Net exportable energy = 95% of gross = 0.95 × 5.256×10^8 = 4.9932×10^8 kWh.
3. Total cost = fixed cost ₹25 crores + variable O&M ₹2 crores = ₹27 crores = ₹2.7×10^9.
4. Cost per unit = ₹2.7×10^9 ÷ 4.9932×10^8 = **₹5.41 / kWh**.
5. Interpretation: Hydropower avoids fuel cost, but lower load factor and other costs mean cost per unit still moderate (~₹5.41/kWh) in this simplified example.

Fuel Flow = 3,430,000 scf/hr

HHV = 1,035 BTU/scf

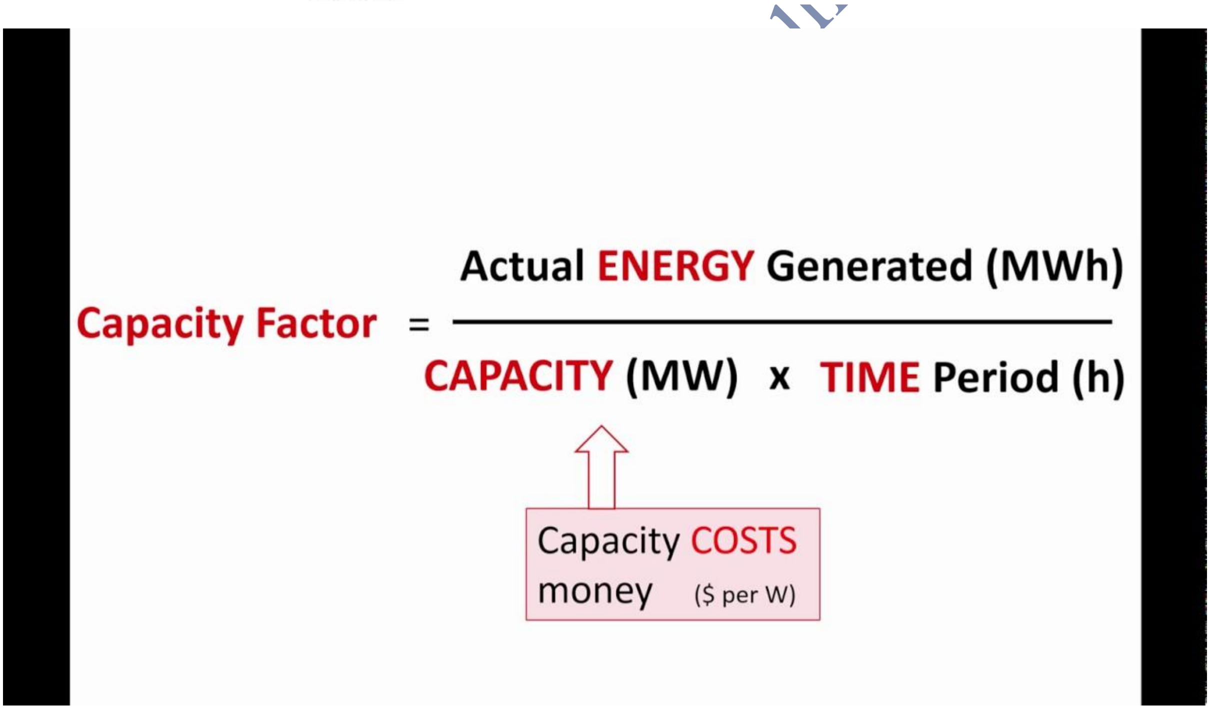
Total Plant Output = 480 MW (Net) and 500 MW (Gross)

$$\text{Net Unit Heat Rate}\left(\frac{BTU}{kWh}\right) = \frac{3{,}430{,}000 \text{ scf/hr} \times 1{,}035 \text{ BTU/scf}}{480{,}000 \text{ kW}}$$

$$\text{Net Unit Heat Rate}\left(\frac{BTU}{kWh}\right) = 7{,}395.94 \text{ BTU/kWh}$$

$$\text{Gross Unit Heat Rate}\left(\frac{BTU}{kWh}\right) = \frac{3{,}430{,}000 \text{ scf/hr} \times 1{,}035 \text{ BTU/scf}}{500{,}000 \text{ kW}}$$

$$\text{Gross Unit Heat Rate}\left(\frac{BTU}{kWh}\right) = 7{,}100.10 \text{ BTU/kWh}$$



$$\text{Availability} = \frac{MTBF}{MTBF + MTTR}$$

Equation 1

$$COE = \underbrace{\frac{\beta \cdot C}{P \cdot H}}_{\text{Capital}} + \underbrace{\frac{f}{\eta}}_{\text{Fuel}} + \underbrace{\left\{\frac{OM_f}{P \cdot H} + \mu \cdot OM_{v,b}\right\}}_{\text{O\&M}}$$

where

β = Levelized carrying charge factor or cost of money

C = Total plant cost ($)

H = Annual operating hours

P = Net rated output (kW)

f = Levelized fuel cost ($/kWh [LHV])

η = Net rated efficiency of the combined-cycle plant (LHV)

OM_f = Fixed O&M costs ($ or $/kW-yr)

$OM_{v,b}$ = Variable O&M costs for baseload operation ($/kWh)

μ = Maintenance cost escalation factor (1.0 for baseload operation)

Equation 2

$$COE = \underbrace{\left\{\frac{\beta \cdot C + OM_f}{P_{eff} \cdot H_{eff}} + \frac{f}{\eta_{eff}} + \mu \cdot OM_{v,b}\right\}}_{\text{Modified COE}} + \underbrace{\sum_i c_i \cdot m_{p,i}}_{\text{Emissions}} + \underbrace{\frac{S_c \cdot \Delta P + S_e \cdot \Delta E}{P_{eff} \cdot H_{eff}}}_{\text{System impact}}$$

$$LCOE = \frac{\sum \frac{(I_t + M_t + F_t)}{(1 + r)^t}}{\sum \frac{E_t}{(1 + r)^t}}$$

🔧 Important Formulas & Theory

Use these in your exams to cover theory + calculations.

1. Heat Rate & Thermal Efficiency

Theory & Key Points:

- Lower heat rate → better performance (less fuel per unit output). (powerplantandcalculations.com)
- Many losses in the plant (boiler, turbine, condenser, aux systems) add to heat rate.
- For your exam: define heat rate, show formula, mention relation to efficiency (inverse relation).
- Typical conversions: 1 kWh = 3,412 Btu (approx) when using Btu units. (U.S. Energy Information Administration)

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2. Capacity Factor (or Plant Load Factor)

Theory & Key Points:

- This parameter tells how well the plant's capacity is utilised. Higher CF/LF → better utilisation → lower cost per unit.
- For exam: mention that CF = (Generated energy) ÷ (Max possible energy) ×100%. (Makayda Energy)
- Also mention that low CF means idle capacity or poor scheduling/maintenance/fuel issues.

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3. Availability Factor

Theory & Key Points:

- Availability is the fraction of time the plant is **capable** of generating electricity (not necessarily generating).
- It influences reliability and maintenance of plant. If availability low → less opportunity to generate → cost per unit goes up.
- For exam: mention definition + formula + typical values (e.g., thermal plants 70-90%) (Wikipedia)

4. Auxiliary Power Consumption (Internal Power)

Theory & Key Points:

- Auxiliary consumption reduces the net electricity available for sale. So even if gross generation is high, net is lower → cost per unit rises.
- In your notes: show this formula, define auxiliary power, explain its impact on cost & efficiency.

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5. Cost per Unit of Electricity (Production Cost)

Where Total Annual Cost = Annualised capital cost + Fixed O&M + Variable costs (fuel + variable O&M + etc).

Theory & Key Points:

- Cost per unit is the key economic metric for power plants (ties into CO5 in your syllabus).
- Show formula, components of cost, mention that to reduce cost: increase generation (denominator) or reduce cost (numerator).
- LCOE helps compare across technologies/lifetimes.
- For exam: define cost per unit, show formula, mention components, optionally mention LCOE.

📋 Quick Reference Table for Exam

Parameter	Formula	Units	Why Important
Heat Rate	Fuel input ÷ Electrical output	kCal/kWh or Btu/kWh	Shows efficiency of converting fuel → electricity
Efficiency	(Electrical output ÷ Fuel input) ×100%	%	Higher means less fuel used per unit
Capacity Factor	Actual energy ÷ (Installed capacity × Hours) ×100%	%	Reflects utilisation of plant

Load Factor	Average load ÷ Peak load ×100%	%	Helps understand load profile usage
Availability Factor	Time ready ÷ Total time ×100%	%	Reflects plant readiness and reliability
Auxiliary Power %	Internal plant use ÷ Gross output ×100%	%	Lower is better (more exportable energy)
Cost per unit	Total annual cost ÷ Annual energy	₹/kWh	Key economic metric
LCOE	(Discounted costs ÷ Discounted energy)	₹/kWh or $/kWh	Compares technologies over lifetime

Here are **10 numerical-question prompts** covering the performance parameters from Unit 5.4 for your practise. You can solve these, and I can also provide solutions later if you like.

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1. A 200 MW steam power plant ran at a load factor of 72% in a year (8,760 h). If auxiliary power consumption is 6% of gross output and the fuel energy input was 18,000 million kCal, calculate:
   a) Gross generation in MWh
   b) Net exportable generation in MWh
   c) Heat rate in kCal/kWh (use net exportable output)
2. A 150 MW plant was available for service 8,200 hours in a year of 8,760 hours. It actually generated 1,120,000 MWh in that year. Determine:
   a) Availability factor (%)
   b) Capacity factor (PLF) (%)
   c) If auxiliary power consumption is 5% of gross generation, find net exported energy in MWh
3. A power plant has an installed capacity of 300 MW, and in a year it generated 2,016,000 MWh. If the average heat rate was calculated to be 10,500 kCal/kWh and fuel calorific value is 3,800 kCal/kg,

calculate:
a) Fuel consumption (in tonnes) for that year
b) If auxiliary consumption was 7% of gross output, what was the net exported energy in MWh?

4. A hydro power plant rated at 100 MW has a capacity factor of 45% for the year. If auxiliary power internal consumption is 4%, calculate:
   a) Annual gross generation in MWh
   b) Annual net exportable energy in MWh
   c) If annual fixed cost is ₹12 crores and variable O&M cost is ₹2 crores, what is the cost per unit (₹/kWh) ignoring any fuel cost?

5. A 250 MW coal-fired plant runs at 80% load factor. The plant recorded an auxiliary power consumption of 8% of gross output. The fuel cost is ₹2.10 per kg, calorific value of coal = 4,200 kCal/kg, and the heat rate of the plant is 11,000 kCal/kWh. Calculate:
   a) Gross generation in kWh for the year
   b) Fuel quantity required in kg and cost for the year
   c) Net exportable energy in kWh
   d) Fuel cost per kWh of exported energy (₹/kWh)

6. A 120 MW combined-cycle plant operates with availability factor of 90% and capacity factor of 75%. Its auxiliary consumption is 6%. If the plant generated 790,000 MWh during the year, verify whether the given capacity factor is correct, and compute net exportable energy.

7. A 500 MW plant runs at 70% load factor. It consumed 28,000 million kCal of fuel in the year. If auxiliary consumption is 9% of gross and 1 kWh = 860 kCal, calculate the heat rate in kCal/kWh and thermal efficiency (%) of the plant (based on gross generation).

8. A 90 MW solar PV plant has a capacity factor of 20%. If fixed annual cost is ₹15 crores and the plant generates no fuel cost, find the cost per unit (₹/kWh) assuming the year has 8,760 hours and auxiliary consumption is negligible.

9. A 180 MW thermal plant generated 1,200,000 MWh in a year. The fuel energy input was 13,500 million kCal. Auxiliary power consumption was 5% of gross output. Calculate:

a) Heat rate in kCal/kWh (based on net exportable)
b) Thermal efficiency (%)

10. A 220 MW plant operated for 8,000 hours in a year and generated 1,650,000 MWh. The plant had availability factor of 92%. Auxiliary power use was 7% of gross output. Determine:
a) Installed-capacity implied generation (if full load for available hours)
b) Capacity factor (%) based on actual generation
c) Net exportable energy in MWh

Diploma Wallah

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