ECE 333 – GREEN ELECTRIC ENERGY

11. Basic Concepts in Power System Economics

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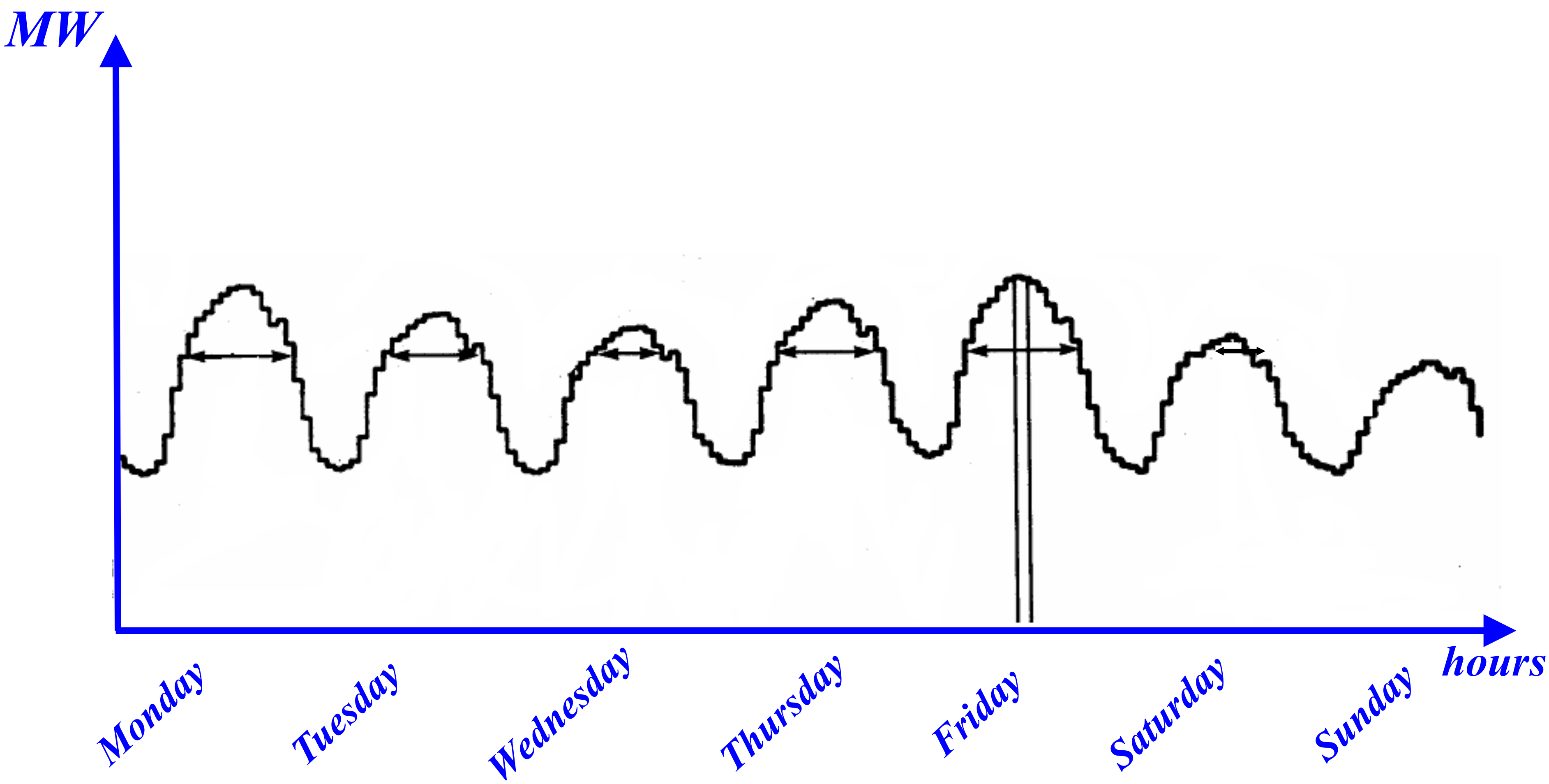
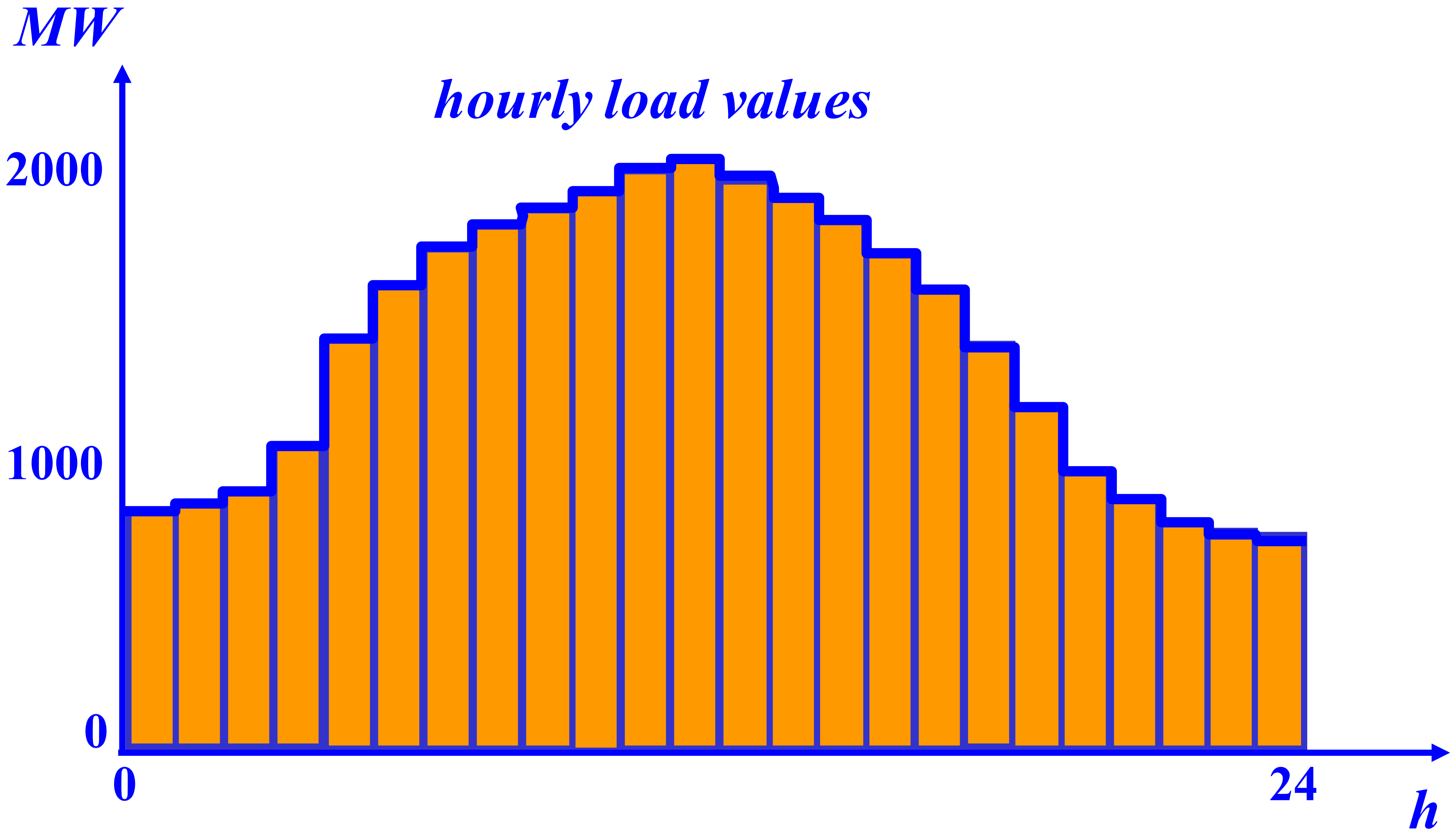
CHRONOLOGICAL LOAD FOR A SUMMER WEEK



A WEEKDAY CHRONOLOGICAL LOAD CURVE

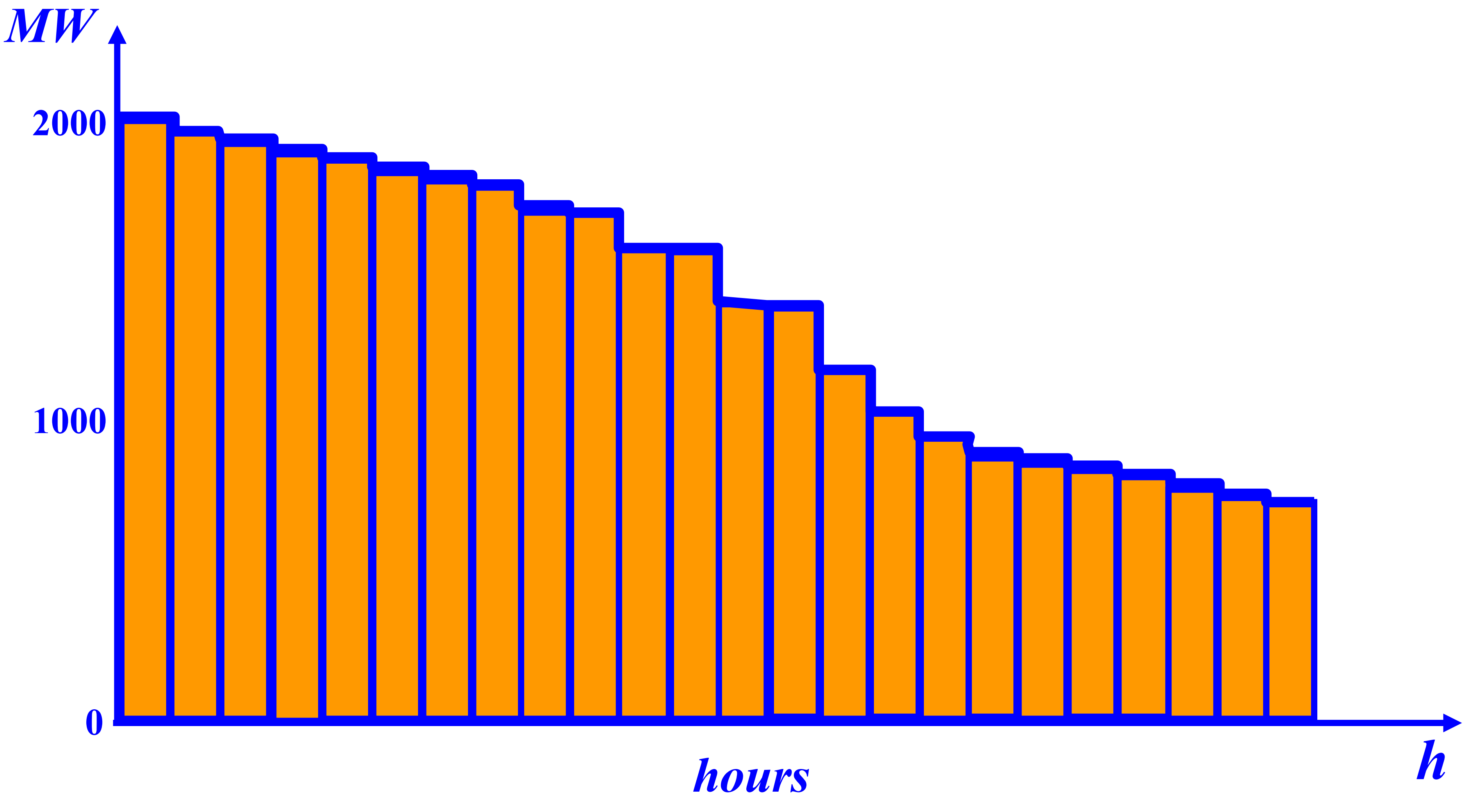


FRIDAY HOURLY LOAD VALUES

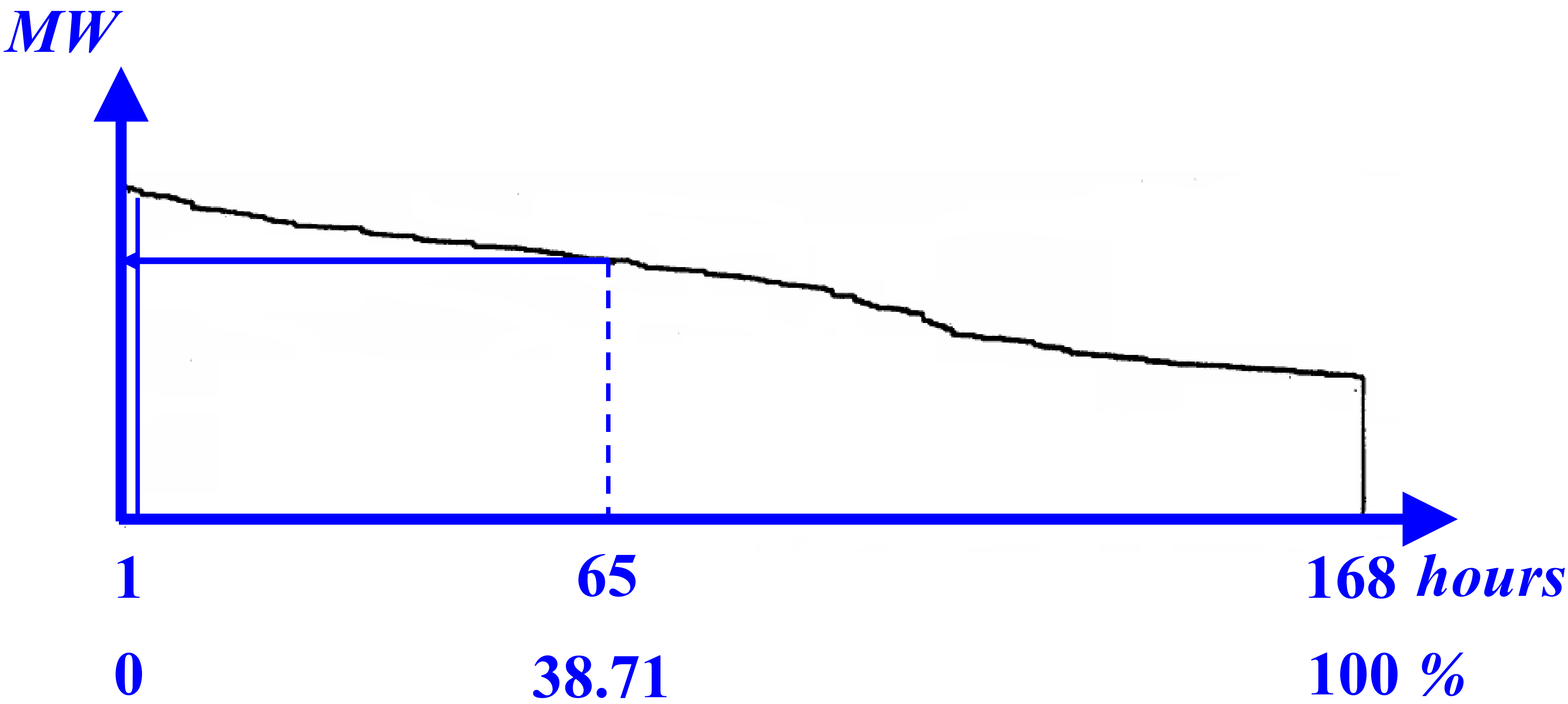
h	*load (MW)*
0100	820
0200	840
0300	885
0400	1010
0500	1375
0600	1560
0700	1690
0800	1775
0900	1810
1000	1875
1100	1975
1200	2000

h	*load (MW)*
1300	1900
1400	1850
1500	1780
1600	1680
1700	1550
1800	1370
1900	1130
2000	975
2100	875
2200	780
2300	775
2400	750

FRIDAY LOAD DURATION CURVE



LOAD DURATION CURVE FOR A SUMMER WEEK



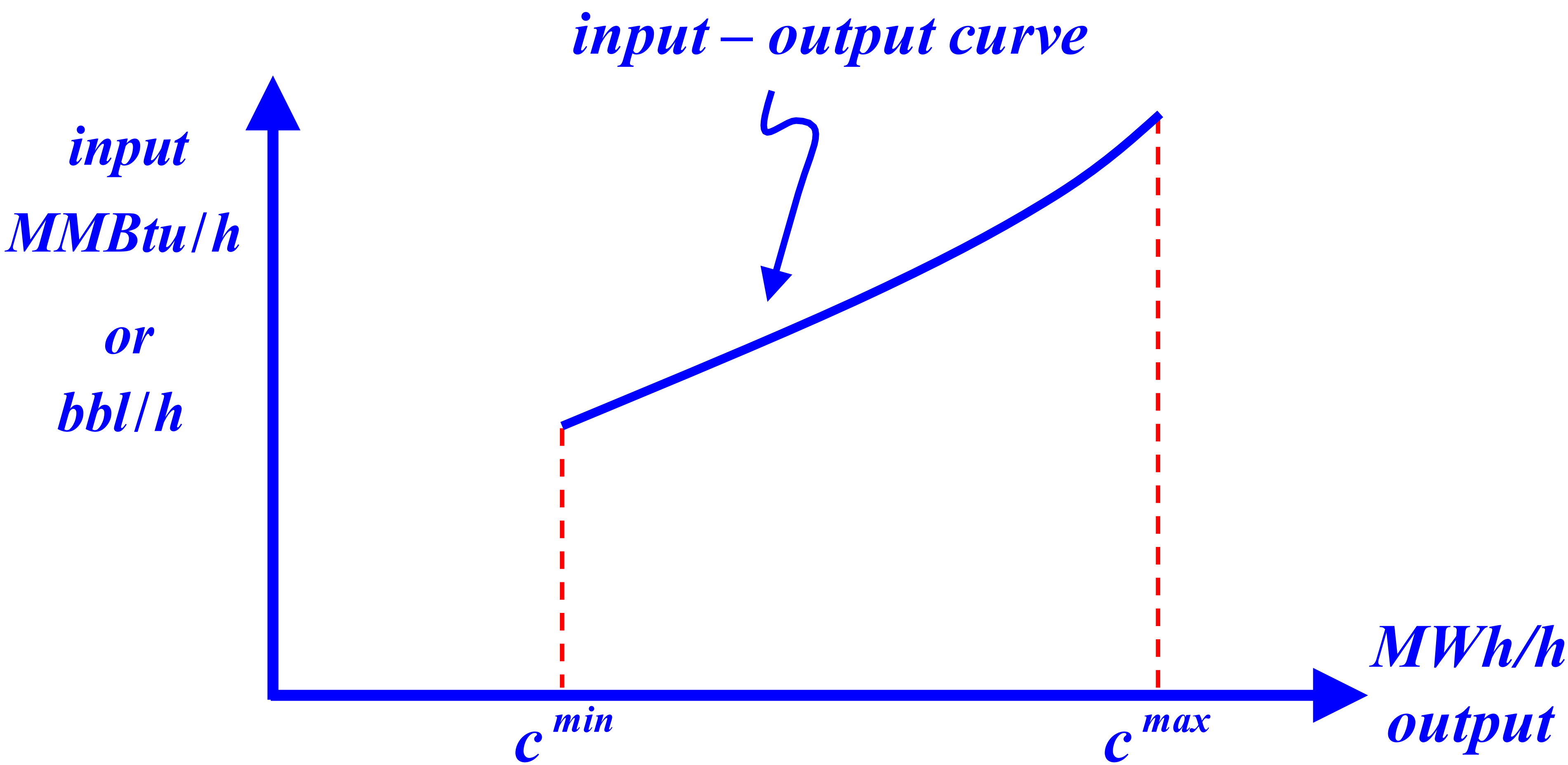
LOAD DURATION CURVE CHARACTERISTICS

- Inability to
  - specify the load at any specific hour
  - distinguish between weekday and weekend loads
- Ability to
  - specify the number of hours at which the load exceeds any given value
  - quantify the total energy requirement for the given period in terms of the area under the *LDC*

CONVENTIONAL GENERATION UNIT ECONOMICS

- The costs of generation by a conventional unit are described by an *input-output curve*, which specifies the level of input required to obtain a required level of output
- Typically, such curves are obtained from actual measurements and are characterized by their monotonically non–decreasing shapes

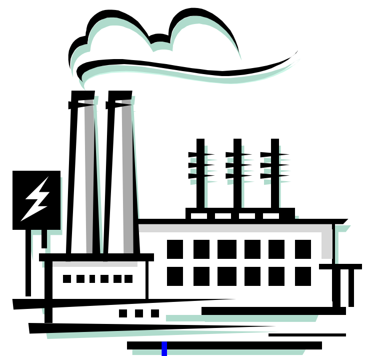
GENERATION UNIT ECONOMICS

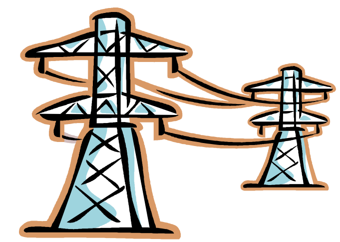


INPUT – OUTPUT MEASUREMENTS

heat input
(MMBtu/h)

output
(MWh/h)





measurement

heat content & flow-rate of fuel

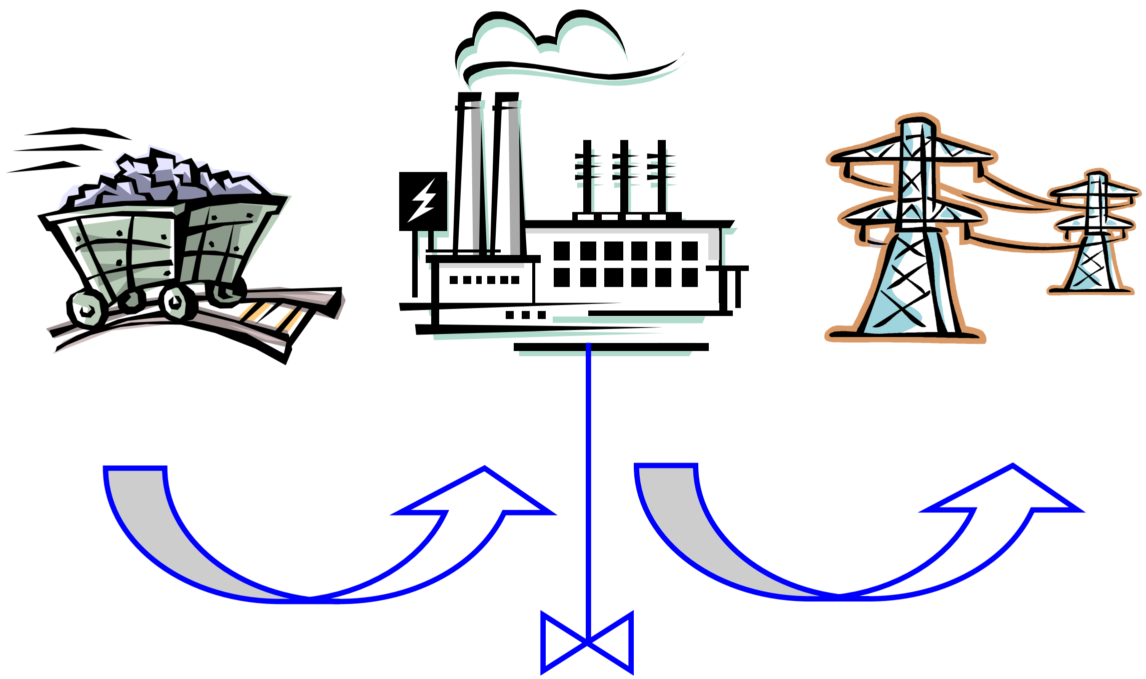
measurement

energy output

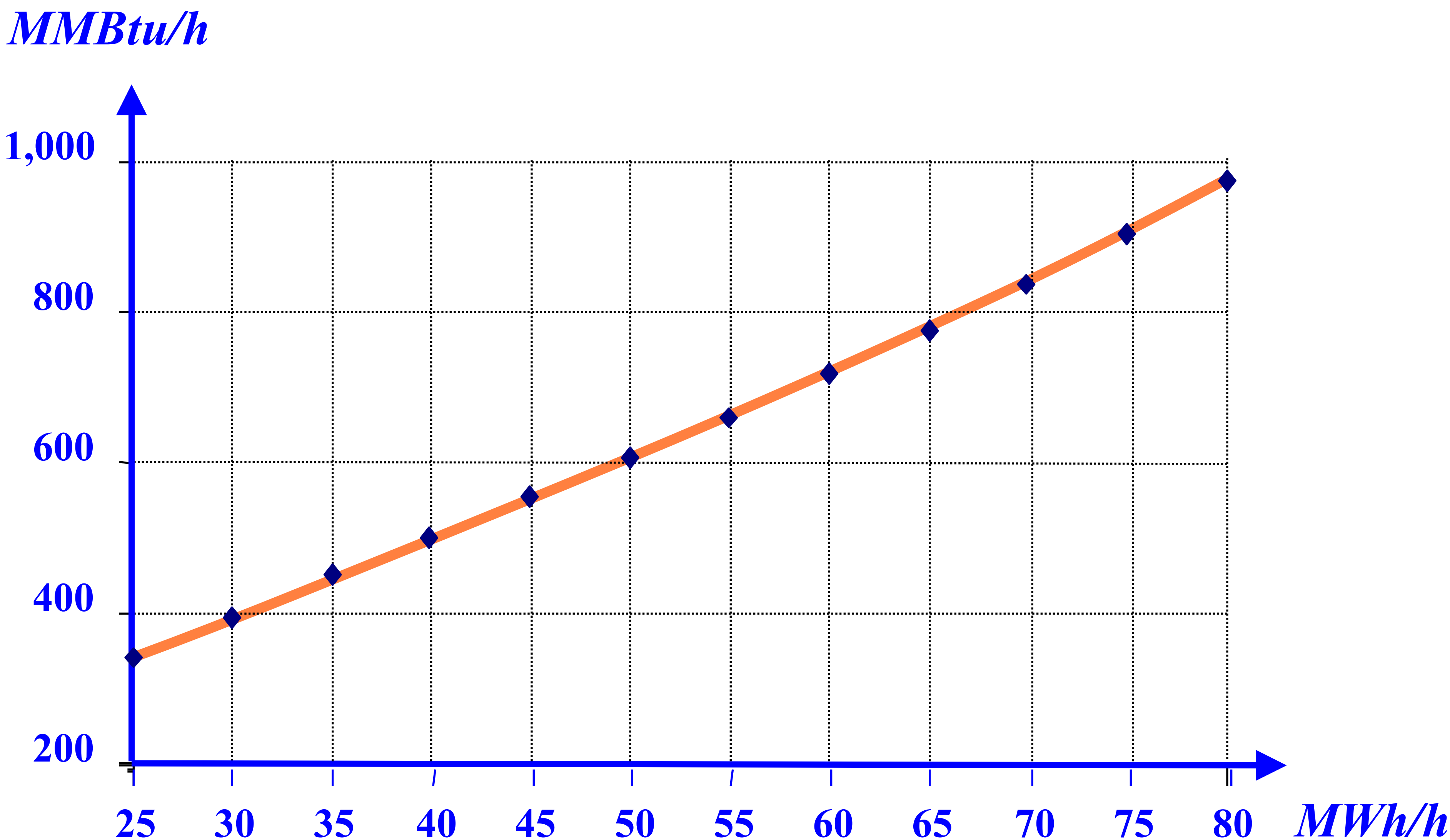
set control valve points

EXAMPLE : CWLP DALLMAN UNITS 1 AND 2

heat input (MMBtu/h)	*output (MWh/h)*
972	80
901	75
835	70
773	65
715	60
659	55
605	50
552	45
499	40
446	35
392	30
336	25



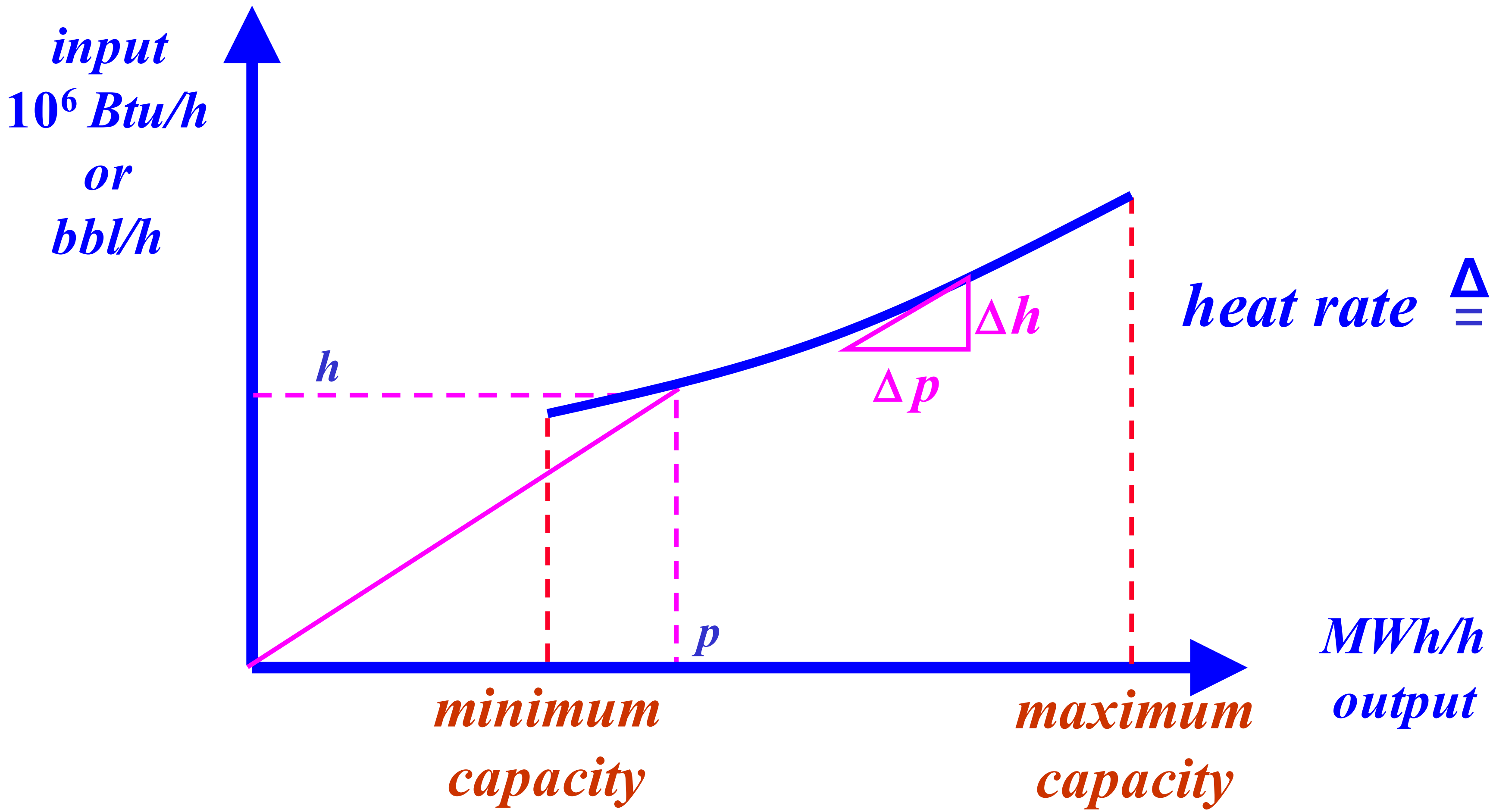
CWLP DALLMAN UNITS 1 AND 2 INPUT – OUTPUT CURVE FITTING



GENERATION UNIT ECONOMICS

- The output is in *MW* and the input is in *bbl/h* or *Btu/h* (volume or thermal heat contents of the input fuel)
- We may also think of the abscissa in units *$/h* since the costs of the input are obtained via a linear scaling the fuel input by the fuel unit price
- We use the input-output curve to obtain the *incremental input – output curve* which provides the costs to generate an additional *MWh* at a given level of output

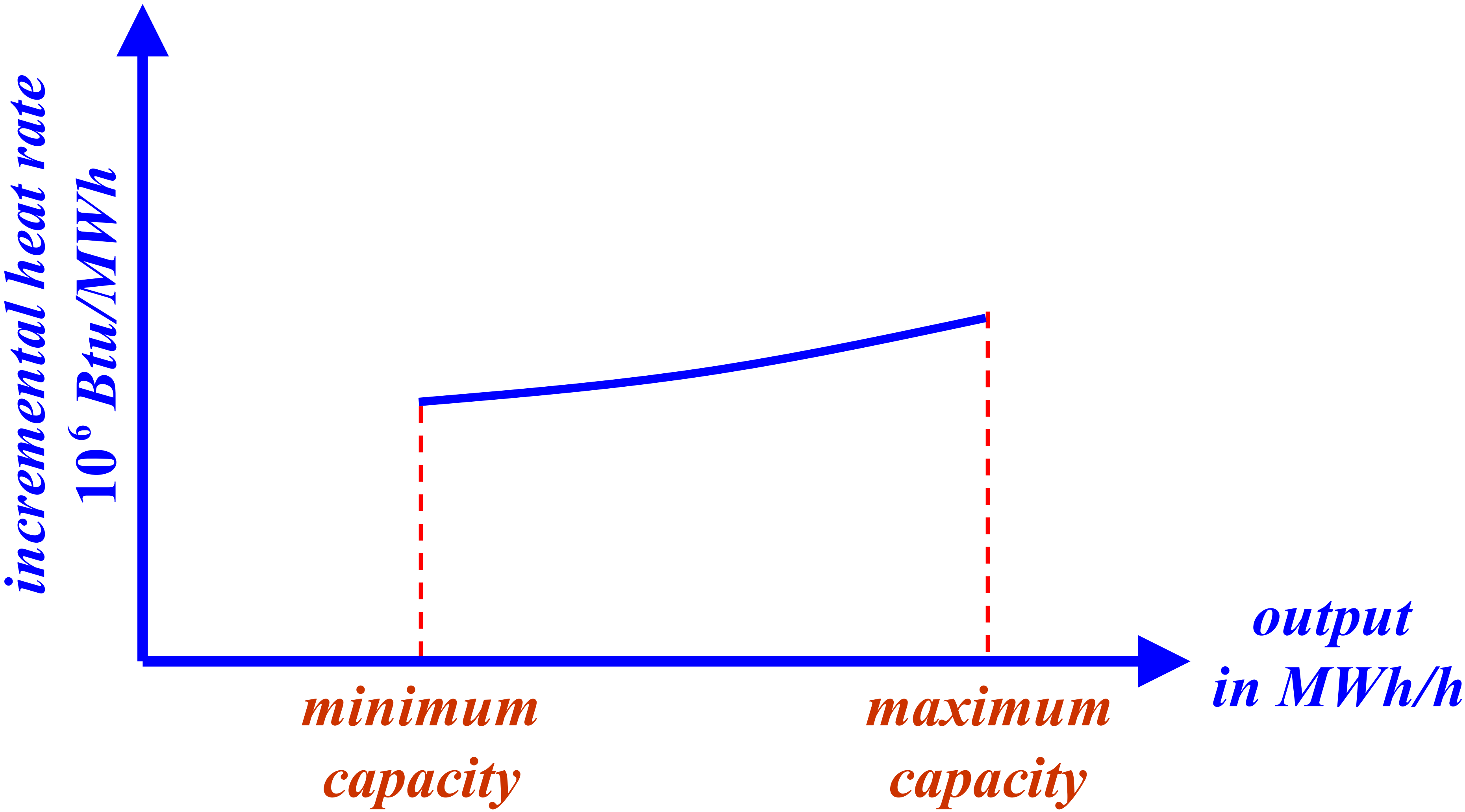
GENERATION UNIT ECONOMICS



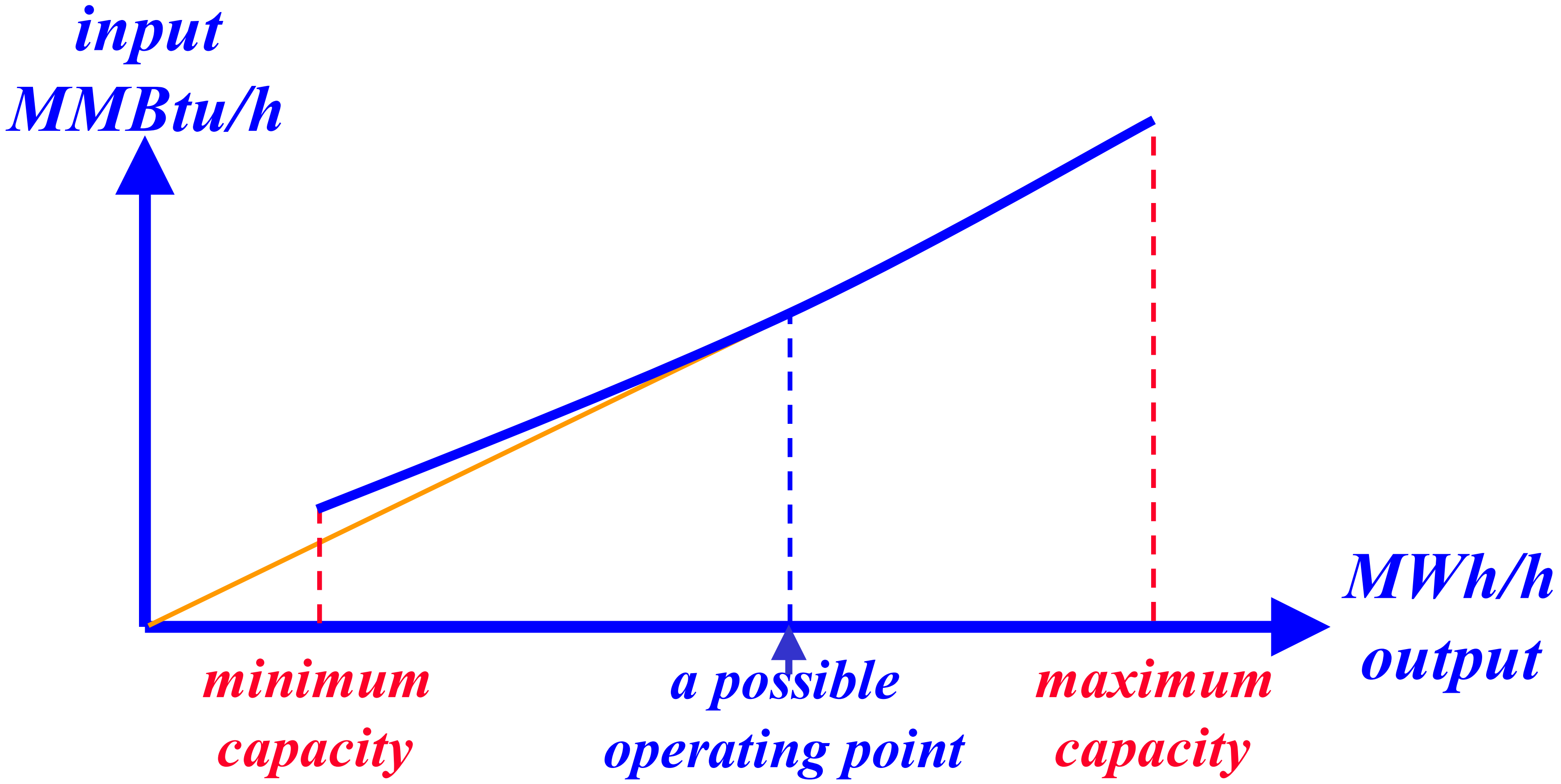
heat rate $\triangleq \dfrac{h}{p}$

$$\textit{incremental heat rate} = \frac{\Delta h}{\Delta p} = \textit{incremental input output}$$

INCREMENTAL CHARACTERISTICS



HEAT RATE



$$\textit{heat rate} = \frac{\textit{input}}{\textit{output}}$$

$$\textit{incremental heat rate} = \frac{\textit{incremental input}}{\textit{incremental output}}$$

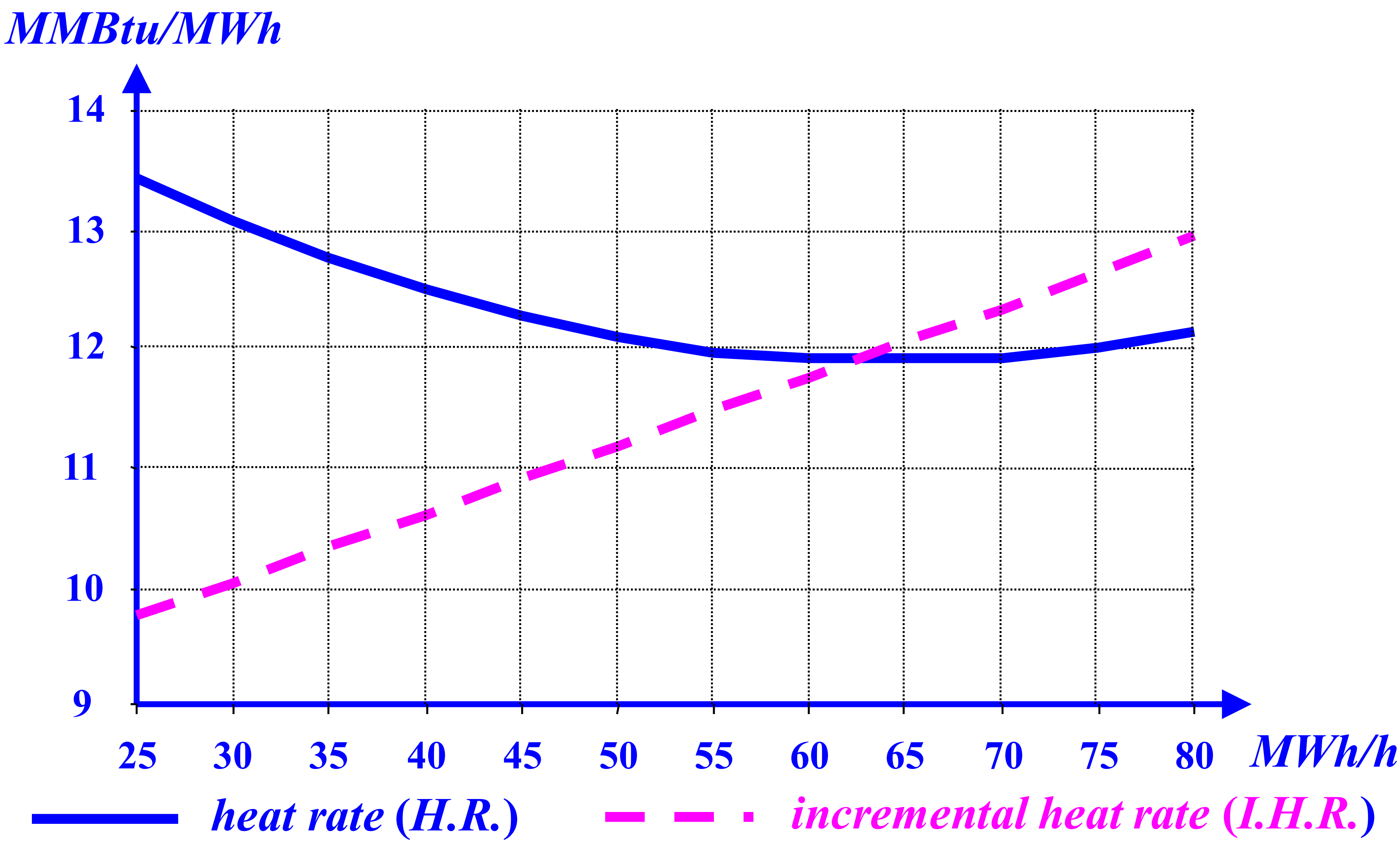
HEAT RATE

- The *heat rate* is a figure of merit widely used by the industry
- The *heat rate* gives the inverse of the efficiency measure of a generation unit since

$$H.R. = \frac{input}{output}$$

- The lower the *H.R.*, the higher is the efficiency of the resource

CWLP DALLMAN UNITS 1 AND 2 H. R. & INCREMENTAL H. R. CURVES



GENERATOR CAPACITY FACTOR

- The amount of generation a generating unit produces is a function of
  - the generator capacity
  - the generator availability
  - the generator loading order to meet the load
- A 100 % available base–loaded unit with c_{max} capacity runs around the clock and so in a *T–hour* period generates total *MWh* given by

$$\mathcal{E} = c_{max} T$$

GENERATOR CAPACITY FACTOR

- The maximum it can generate is

$$\mathcal{E}_{max} = c_{max} T$$

- The capacity factor κ of a base-loaded unit is

$$\kappa = \frac{\mathcal{E}}{\mathcal{E}_{max}} = 1$$

- A cycling unit exhibits on – off behavior since its loading depends on the system demand; its $\mathcal{E}_{max} = c_{max} T$ exceeds the actual generation since the unit generates only during certain periods

GENERATOR CAPACITY FACTOR

- Therefore, a cycling unit has a *c.f.*

$$\kappa = \frac{\mathcal{E}}{\mathcal{E}_{max}} < 1$$

- For example, a cycling unit of $150\,MW$ that operates typically $1{,}800$ *hours* per year with no outages and at full capacity has

$$\kappa = \frac{150 \cdot 1{,}800}{150 \cdot 8{,}760} = \frac{180}{876} = 0.21$$

- A peaking unit operates only for a few hours each year and consequently has a relatively small *c.f.*

GENERATOR CAPACITY FACTOR

- An expensive peaker may have, say, a *c.f.*

$$\kappa = 5\%$$

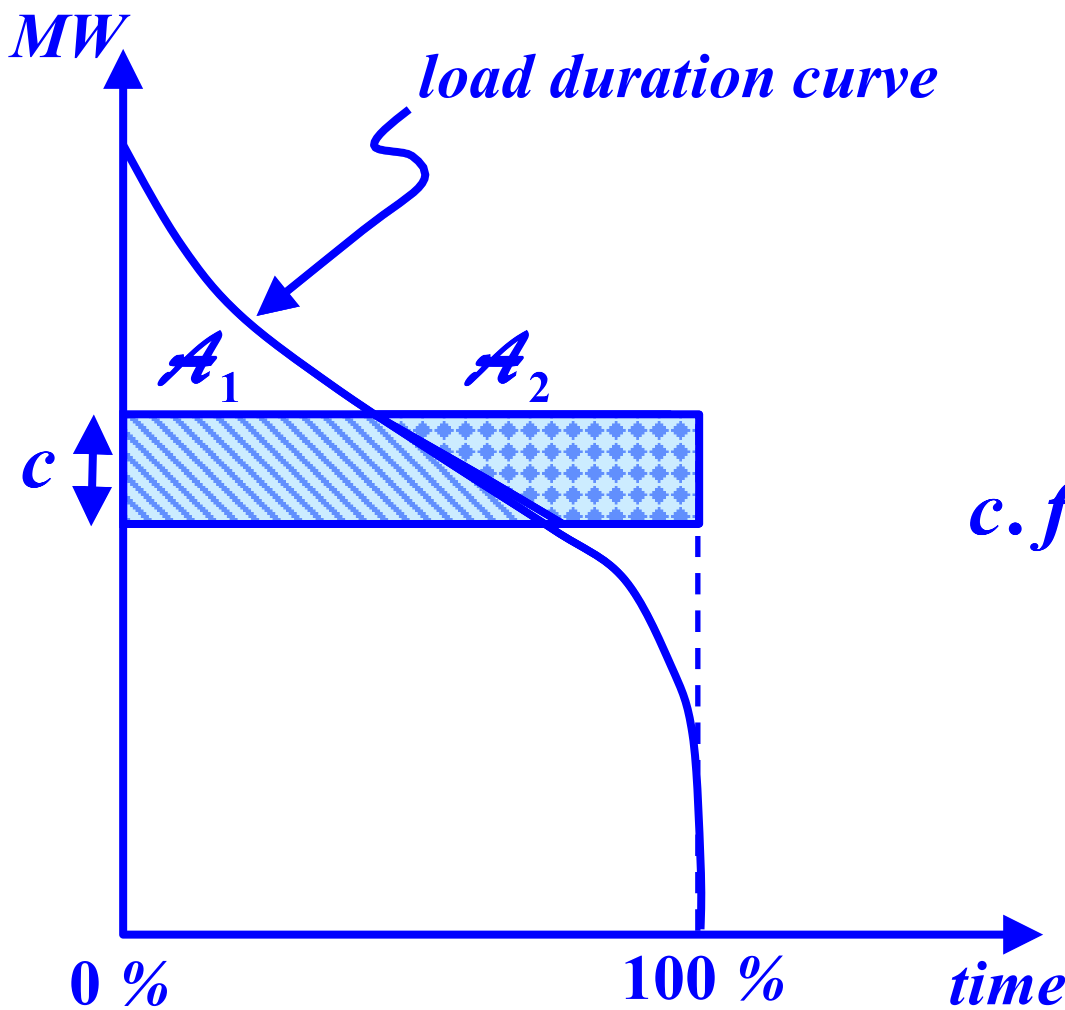
indicating that under perfect availability it operates about 438 hours a year

- Typically, κ is given a definition on a yearly basis

$$\kappa = \frac{annual\ energy\ generated}{maximum\ energy\ generated}$$

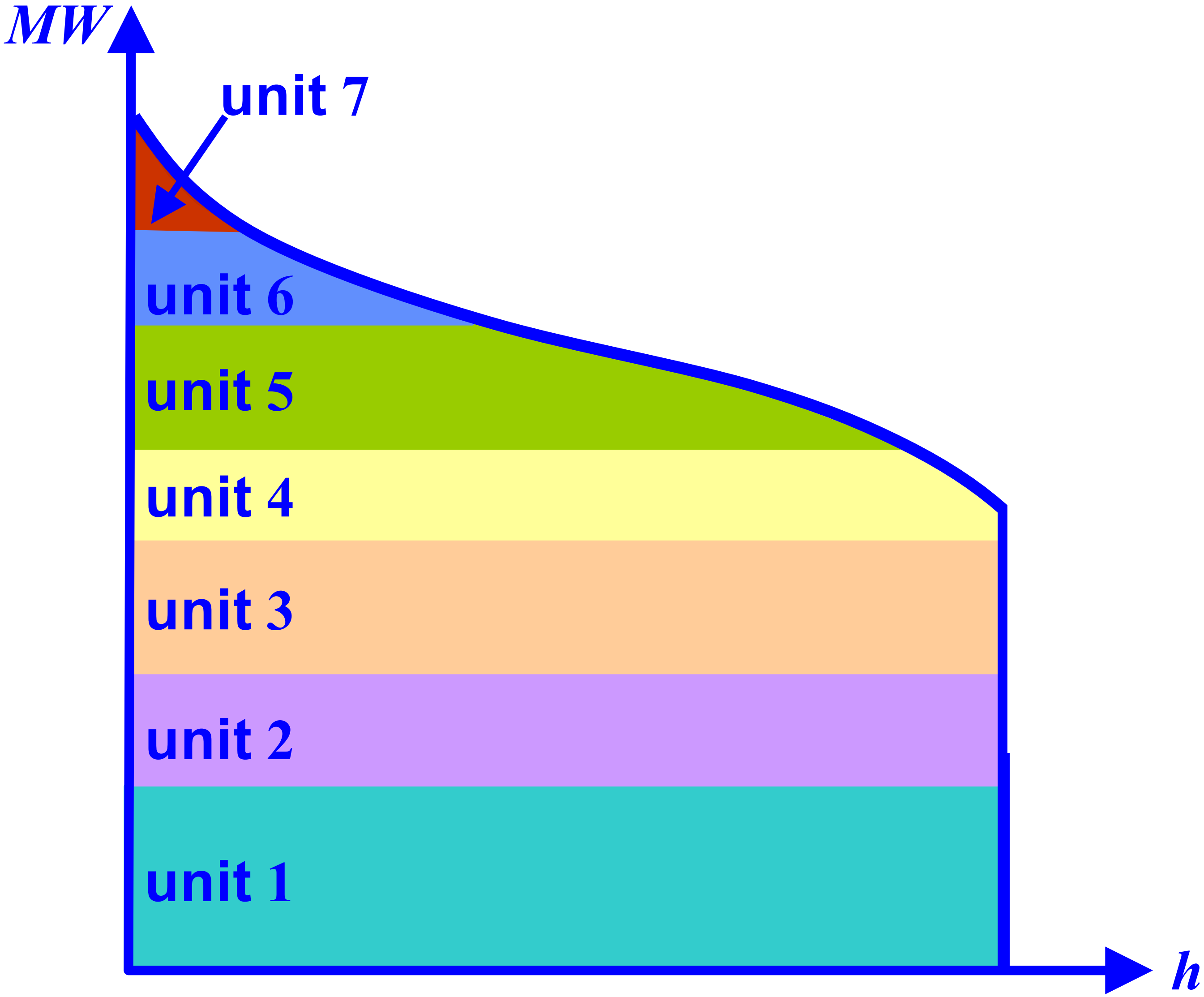
where, the denominator may account for annual maintenance and forced outages and so would imply less than 8,760 hours of operation

CAPACITY FACTOR

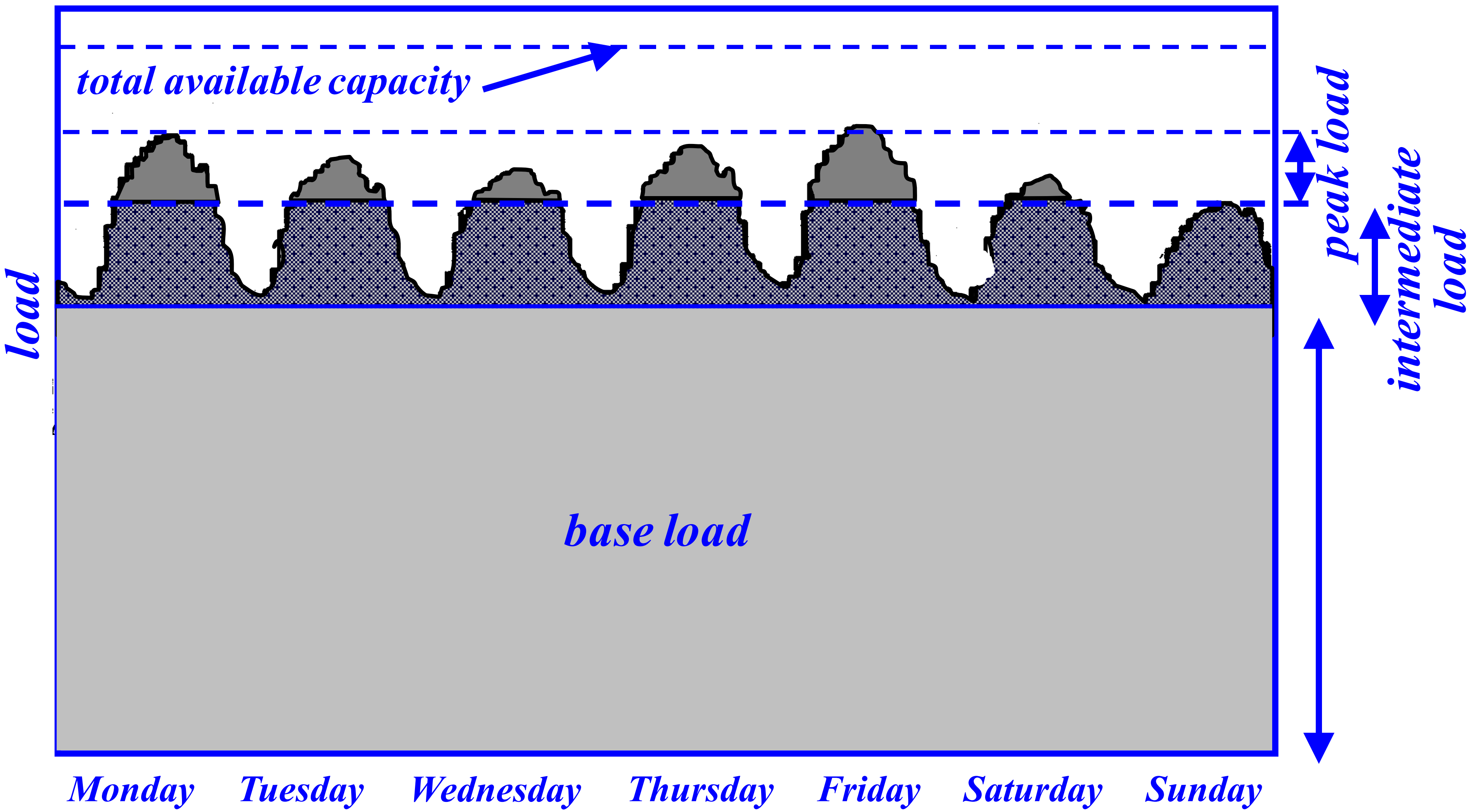


$$c.f. = \frac{\mathcal{A}_1}{\left(\mathcal{A}_1 + \mathcal{A}_2\right)}$$

LOADING OF RESOURCES



LOADING OF RESOURCES



RESOURCE FIXED AND VARIABLE COSTS

- Fixed costs are those costs incurred that are independent of the operation of a resource and are incurred even if the resource is not operating
- Typical components of fixed costs are:
  - investment or capital costs
  - insurance
  - fixed *O&M*
  - taxes

RESOURCE FIXED AND VARIABLE COSTS

- Variable costs are associated with the actual operation of a resource
- Key components of variable costs are
  - fuel costs
  - variable *O&M*
  - emission costs

ANNUALIZED INVESTMENT OR CAPITAL COSTS

- The *fixed charge rate* annualizes the capital costs to produce a yearly uniform cash–flow set over the life of a resource

- The annual fixed costs are

$$yearly\ costs\ =\ \left(fixed\ costs \right) \cdot \left(fixed\ charged\ rate \right)$$

- Typically, the yearly charge is given on a per unit – kW or MW – basis

ANNUALIZED INVESTMENT OR CAPITAL COSTS

- The fixed charge rate takes into account the interest on loans, acceptable returns for investors and other fixed cost components: however, each component is independent of the generated *MWh*
- The rate strongly depends on the costs of capital

ANNUALIZED VARIABLE COSTS

- The variable costs are a function of the number of hours of operation of the unit or equivalently of the capacity factor κ
- The annualized variable costs may vary from year to year

$$\begin{pmatrix} variable \\ costs \end{pmatrix} = \begin{pmatrix} fuel \\ costs \end{pmatrix} \begin{pmatrix} heat \\ rate \end{pmatrix} + \begin{pmatrix} variable \\ O \,\&\, M \; costs \end{pmatrix} \begin{pmatrix} number \; of \\ hours \end{pmatrix}$$

ANNUALIZED VARIABLE COSTS

- The yearly variable costs explicitly account for fuel cost escalation
- Often, the yearly costs are given on a *per unit* – *kW* or *MW* – basis
- We illustrate these concepts with a pulverized – coal steam plant

EXAMPLE: COAL – FIRED STEAM PLANT

characteristic	*value*	*units*
capital costs	1,400	*$/kW*
heat rate	9,700	*Btu/ kWh*
fuel costs	1.5	*$/MBtu*
variable costs	0.0043	*$/kWh*
annual fixed charge rate	0.16	
full output period	8,000	*h*

EXAMPLE: COAL–FIRED STEAM PLANT

- The annualized fixed costs per kW are

$$\left(1,400\ \$ / kW\right)\left(0.16\right) = 224\ \$ / kW$$

- The initial year annual variable costs per kW are

$$\left[\begin{array}{c}\left(1.5\times10^{-6}\ \$ / Btu\right)\left(9,700\ Btu / kWh\right) + \\ 0.0043\ \$ / kWh\end{array}\right]\left(8,000\ h\right)$$

$$= 150.8\ \$ / kW$$

EXAMPLE: COAL–FIRED STEAM PLANT

- Total annual costs for $8{,}000\ h$ are

$$\frac{\left(224+150.8\right)\$/kW}{8,000\,h}=0.0469\,\$/kWh$$

- Note, we do the example under the assumption of full output for $8{,}000\ h$ and 0 output for the remaining $760\ h$ of the year
- We also neglect any possible outages of the unit and so explicitly ignore any uncertainty in the unit performance