Overview of Steam Turbines

Shwe Myat Myo Oo

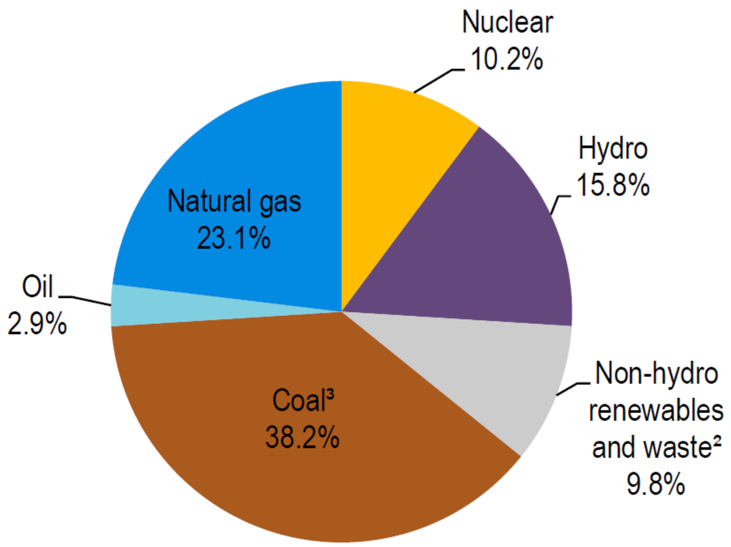
Introduction

12.9 trillion kWh generated from steam turbine plants (2012)

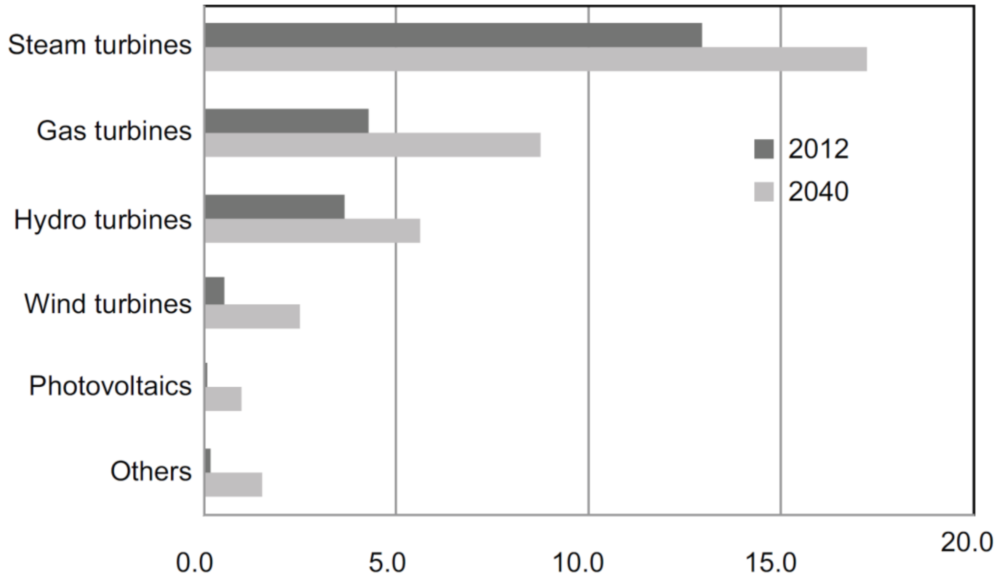
74% of generation was from gas and/or steam turbines (2018)

60% of prime mover power generation is from steam turbines (2012)

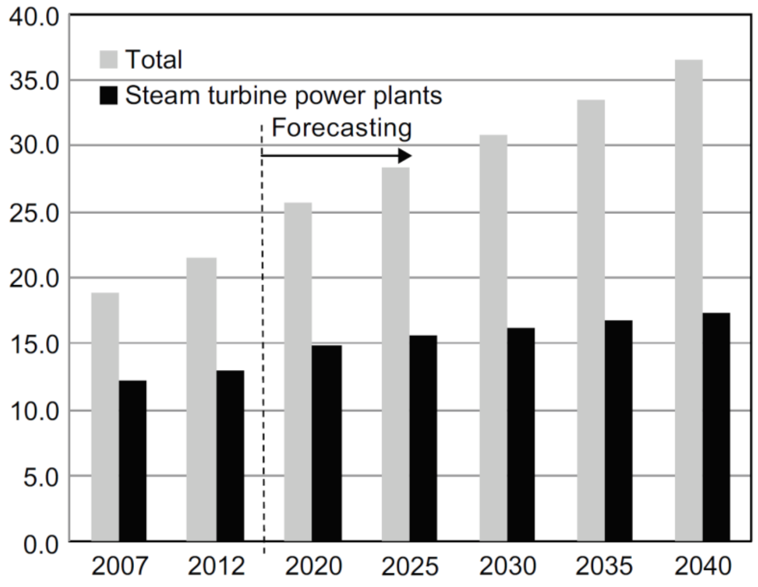
17.3 trillion kWh projected generation from steam turbine plants (2040)



Distribution of electricity generation worldwide in 2018, by energy source



World electricity generation by prime movers in 2012 and projected energy generation in 2040 (trillion kWh)

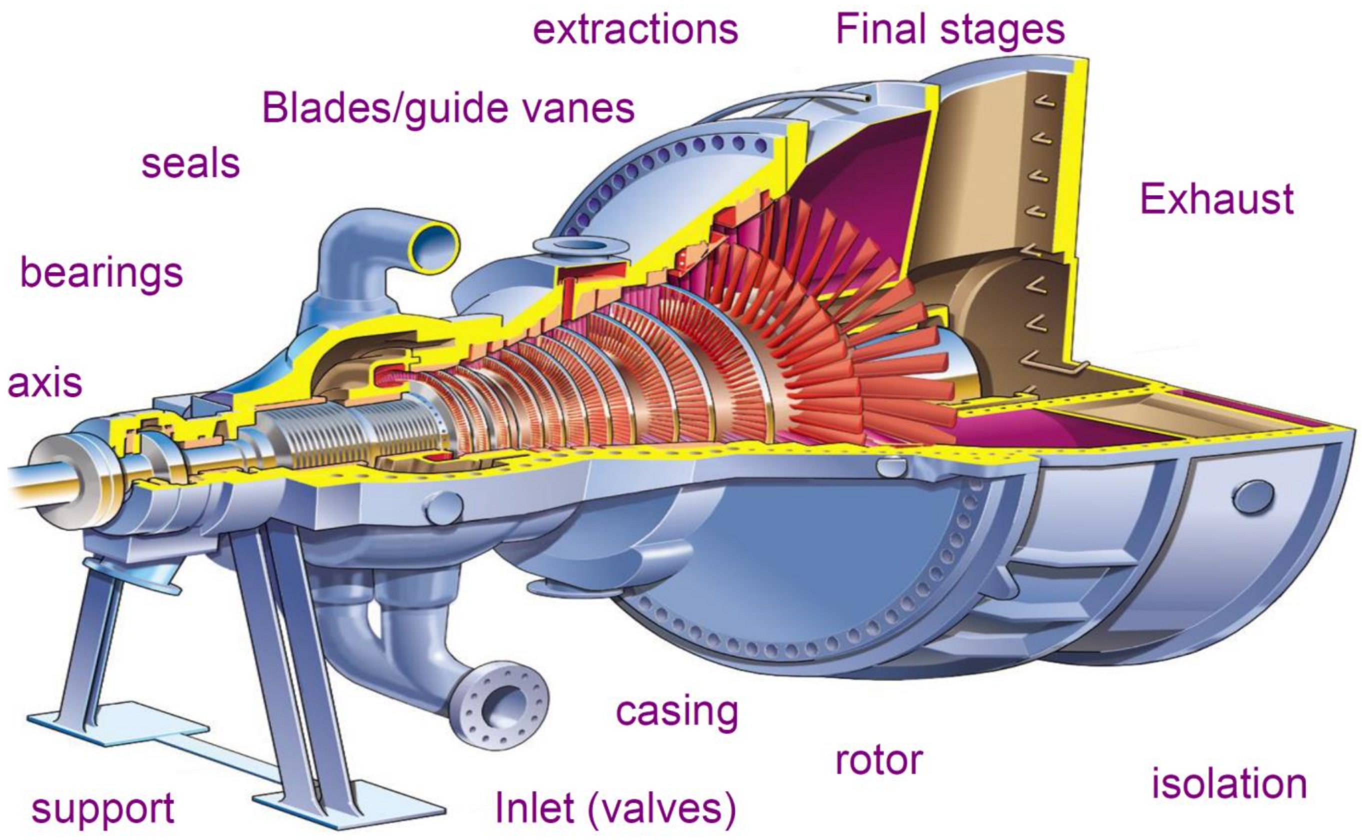


Worldwide power generation of steam turbine power plants (trillion kWh).

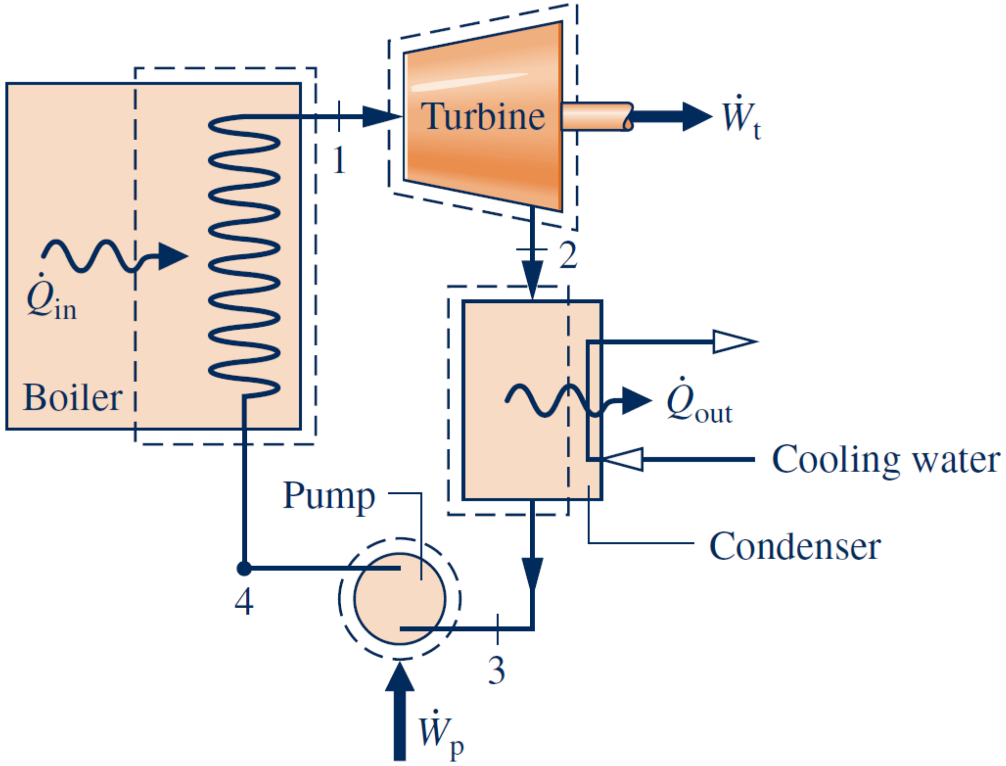
1. Excludes electricity generation from pumped storage.
2. Includes geothermal, solar, wind, tide/wave/ocean, biofuels, waste, heat and other.
3. In these graphs, peat and oil shale are aggregated with coal.

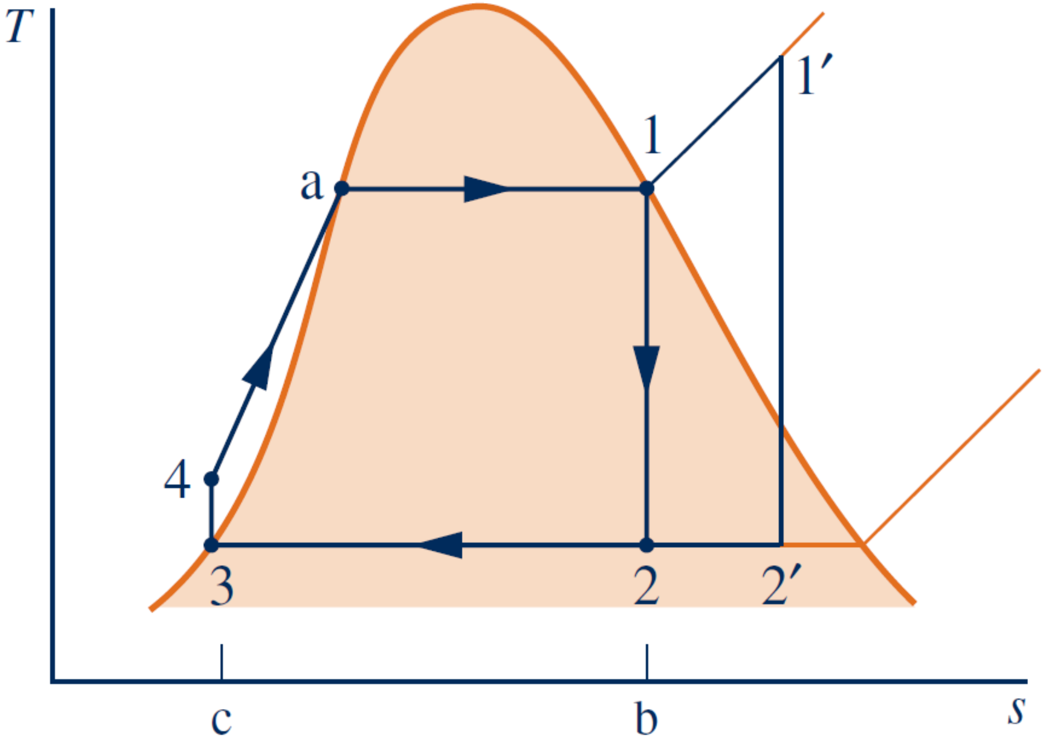
What is a Steam Turbine?

- Extracts energy from pressurized steam
- Uses energy to perform mechanical work
- T ↓, P↓, v ↑
- Key equations:
  - $\frac{\dot{W}}{m} = h_1 - h_2$
  - $\eta = \frac{h_1 - h_2}{h_1 - h_2'}$



The Rankine Cycle

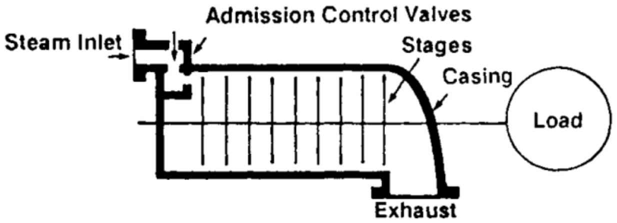




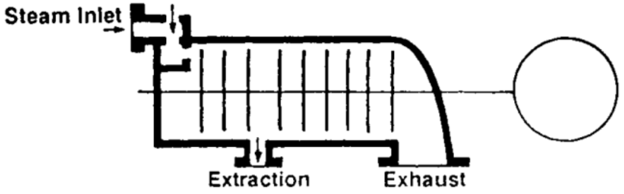
1-2: Isentropic expansion
2-3: Heat rejection
3-4: Isentropic compression
4-1: Heat addition

Types of Steam Turbine

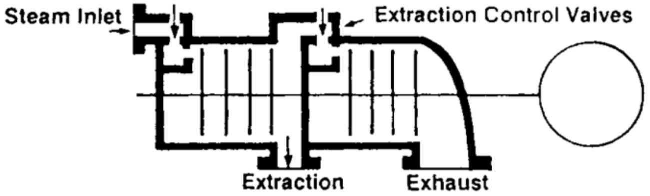
Noncondensing



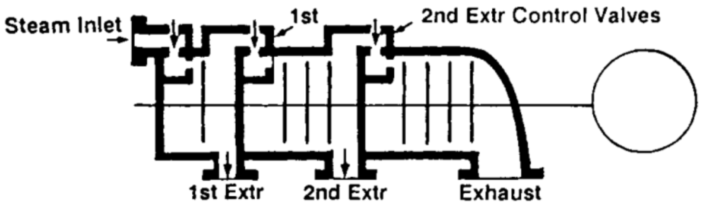
a – STRAIGHT NONCONDENSING (SNC)



b – SINGLE NONAUTOMATIC EXTRACTION NONCONDENSING (SNAXNC)

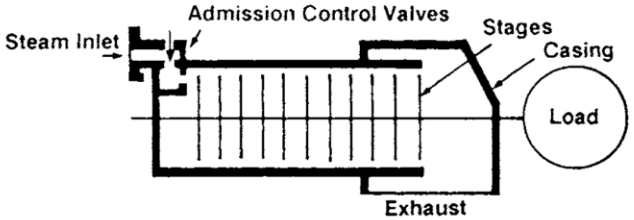


c – SINGLE AUTOMATIC EXTRACTION NONCONDENSING (SAXNC)

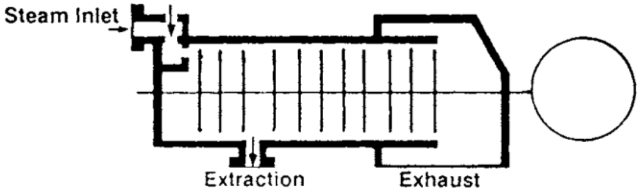


d – DOUBLE AUTOMATIC EXTRACTION NONCONDENSING (DAXNC)

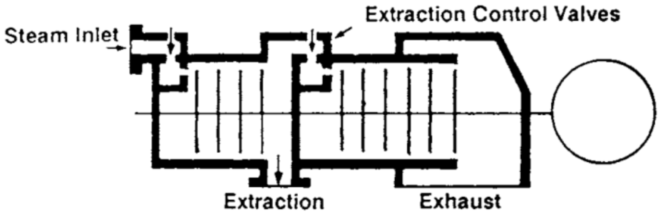
Condensing



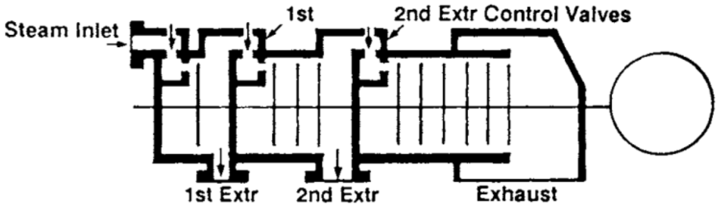
e – STRAIGHT CONDENSING (SC)



f – SINGLE NONAUTOMATIC EXTRACTION CONDENSING (SNAXC)



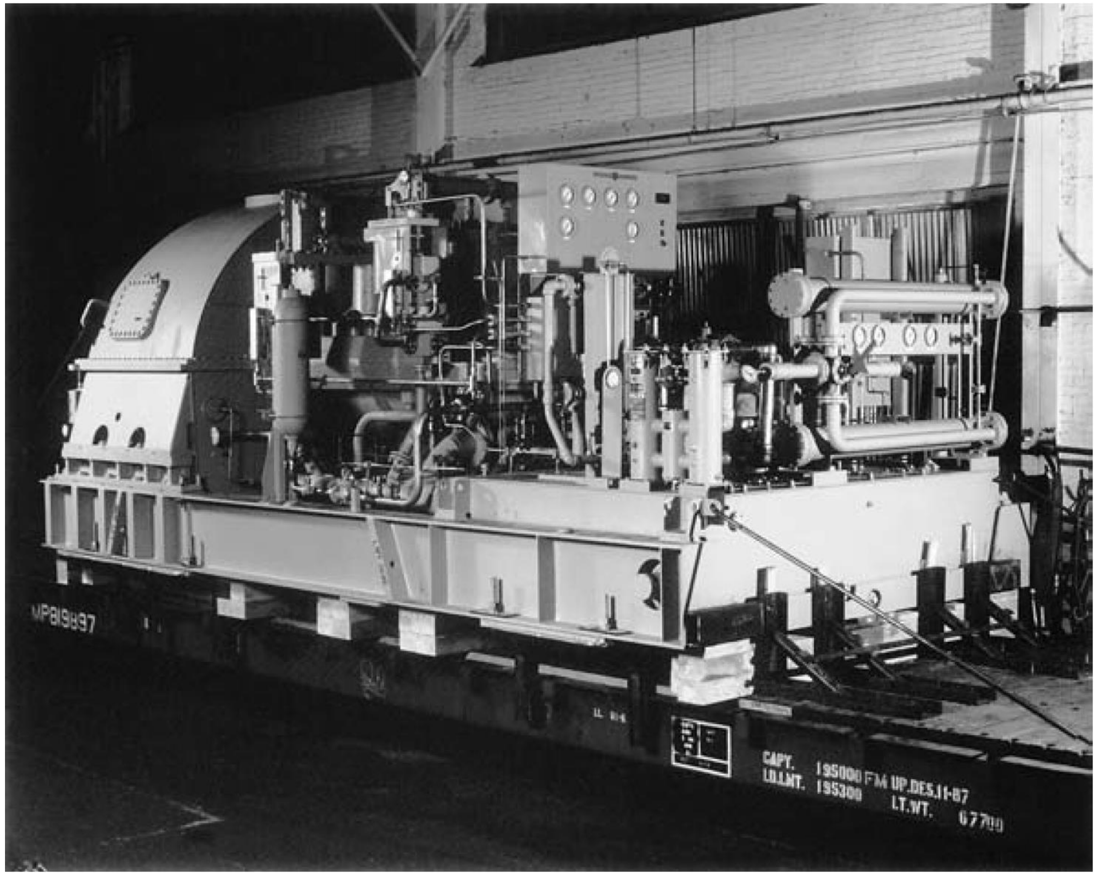
g – SINGLE AUTOMATIC EXTRACTION CONDENSING (SAXC)



h – DOUBLE AUTOMATIC EXTRACTION CONDENSING (DAXC)

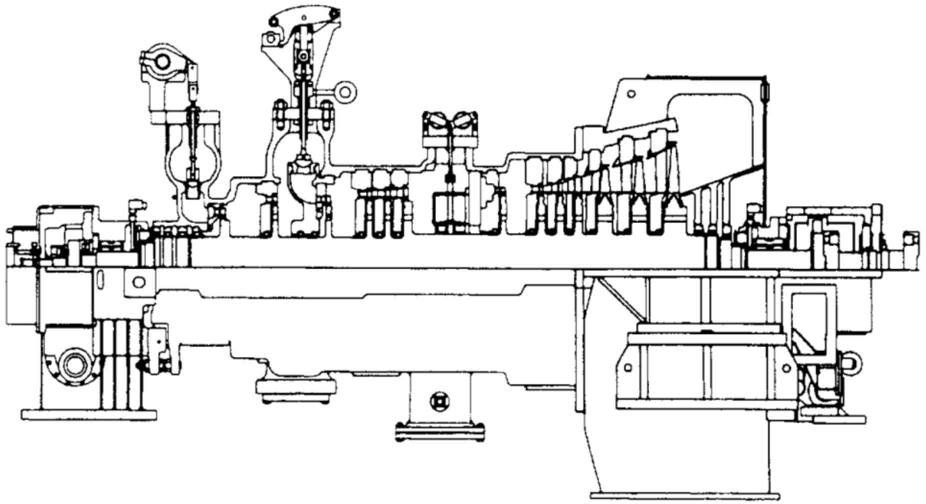
Extraction Condensing Turbine

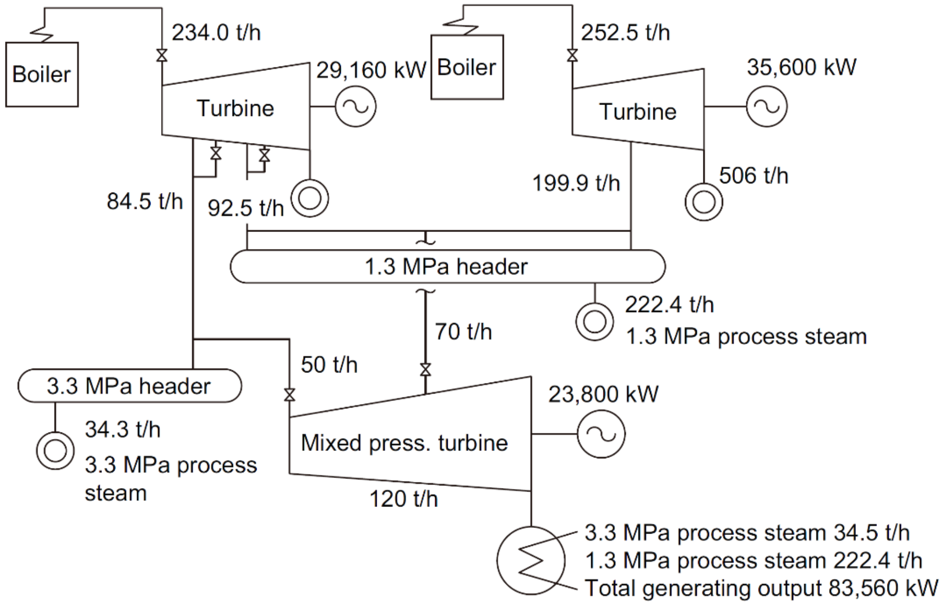
- Can handle variations in process steam requirements while maintaining electric power delivery to utility
- Can be sized for electrical generation considerably in excess of that associated with the extraction steam flows.
- Uses extraction control valve and main control valve for inlet



Mixed-Pressure Condensing Turbine

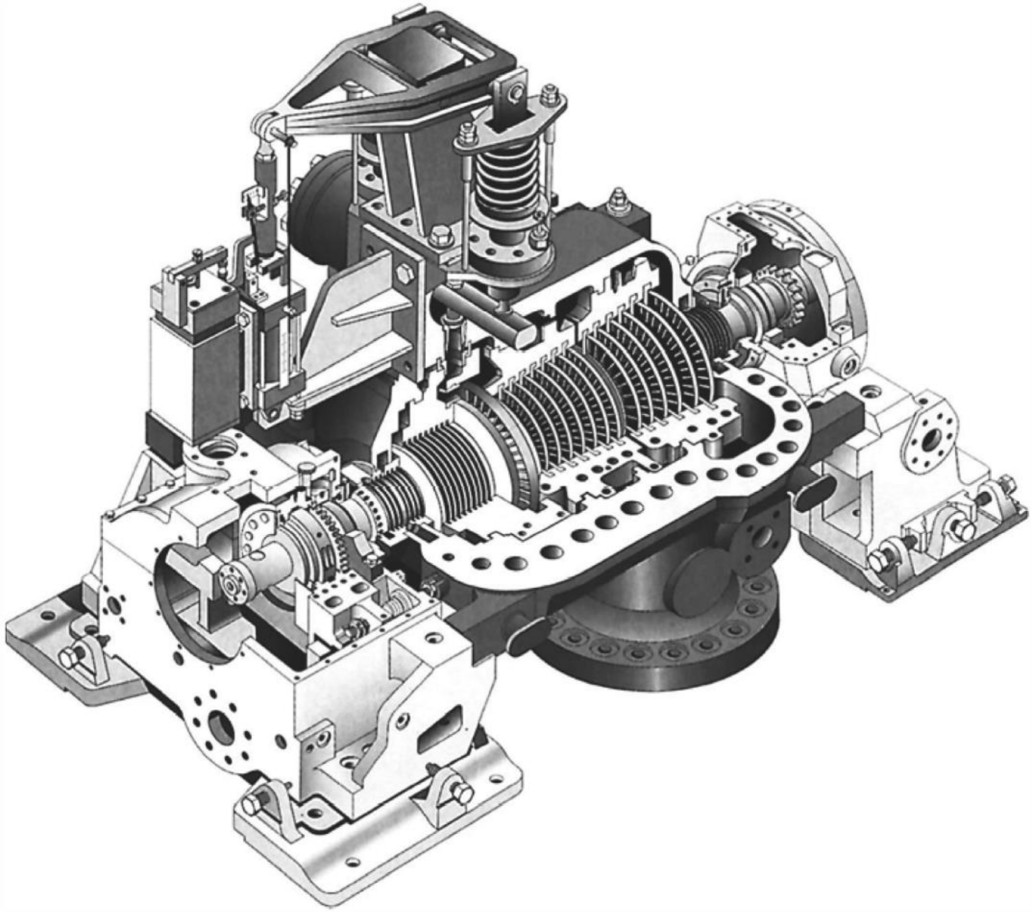
- Double automatic extraction condensing units
- Can effectively utilize surplus medium/low-pressure steam from facilities into the intermediate stage
- Throttle or nozzle-controlled





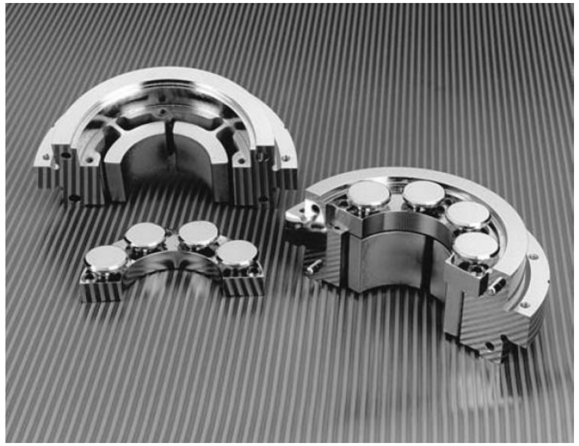
Back-Pressure (Noncondensing) Turbine

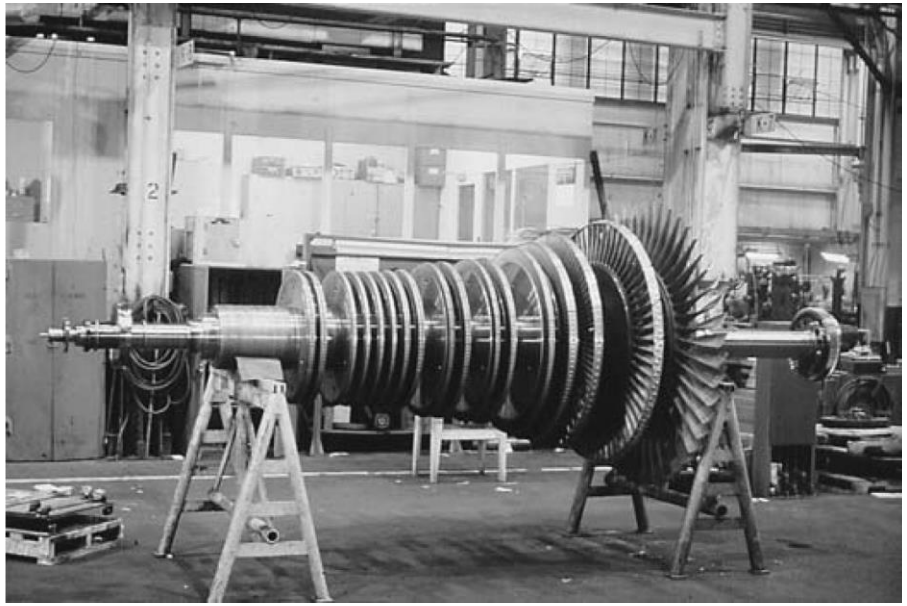
- Supplies process steam to facilities in addition to generation
- Small effective heat drop: relatively small generation output
- Relatively few stages, simple structure and small exhaust parts

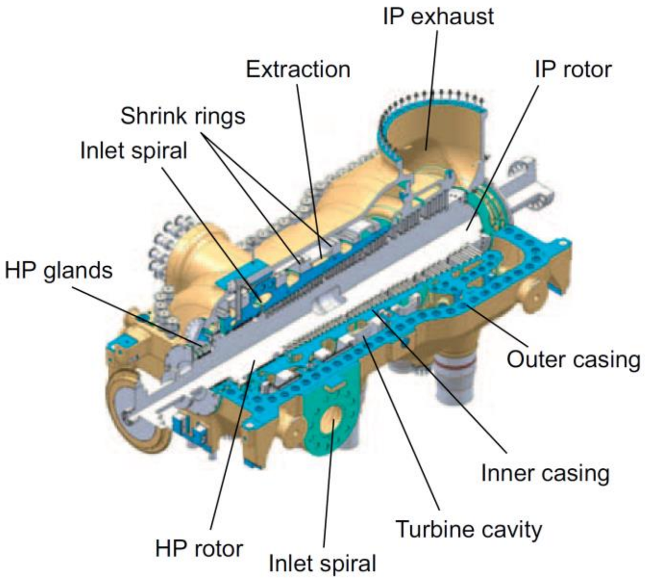


Turbine Design Considerations

- **Major design objectives:**
  - Performance, reliability, flexibility, cost
- Major load-bearing components:





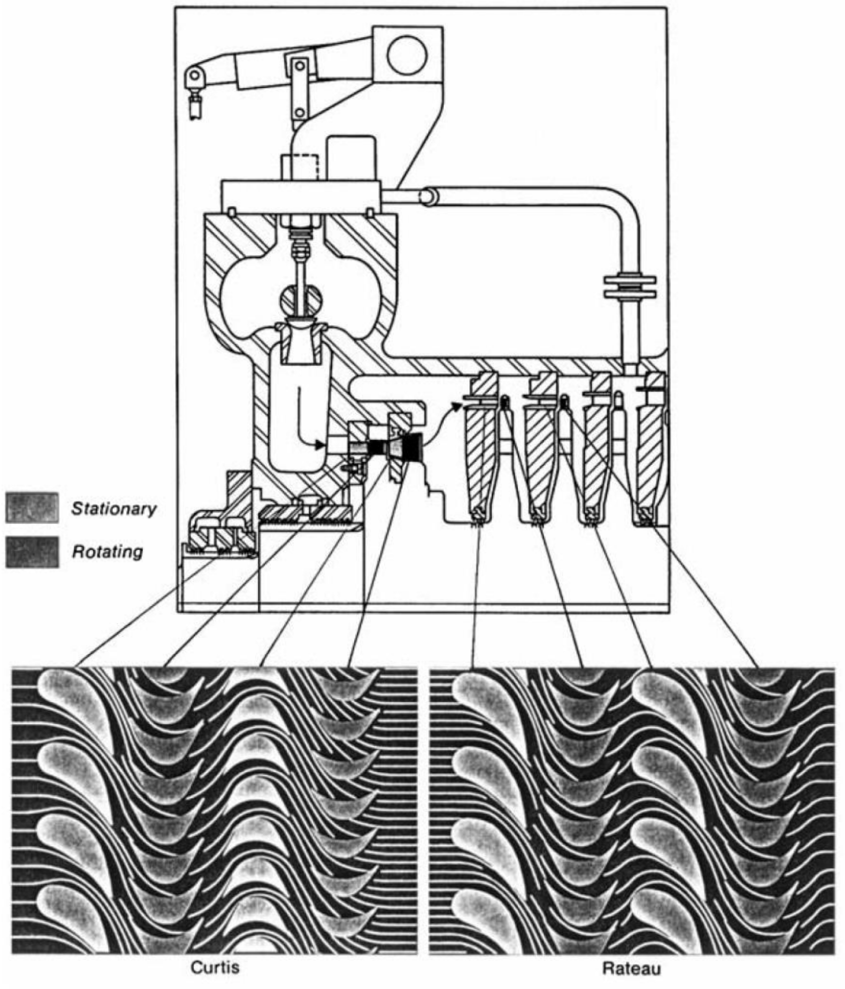


Blade Staging

- Modern turbines use a combination of impulse and reaction features
- Velocity-compounded (Curtis), pressure-compounded (Rateau) staging
- Euler's turbine equation:

  $$w = \Delta h = U \times (V_{u2} - V_{u3})$$

  - U = blade speed
  - w = work per unit mass
  - v_{u2} = entering tangential velocity
  - v_{u3} = exiting tangential velocity

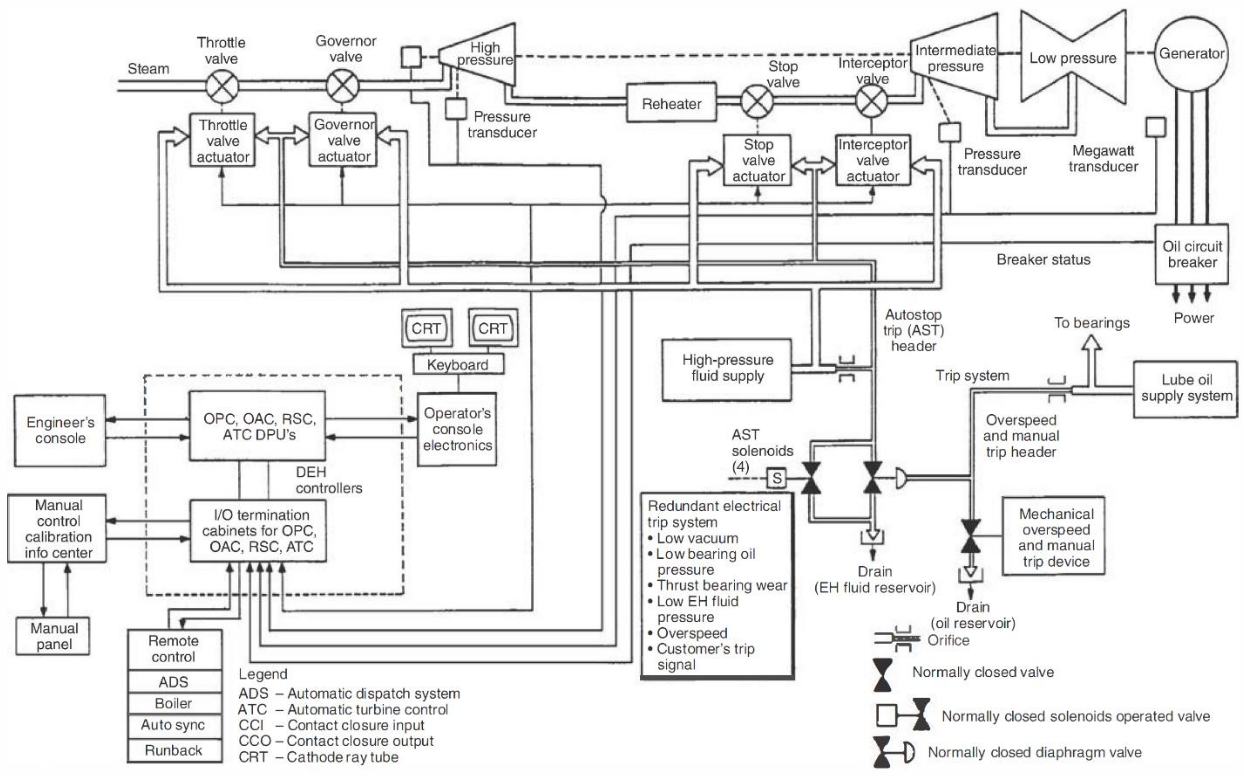


Blade Design

- Main function: extract steam energy
- Determines turbine performance and efficiency
- Consider aerodynamics, integrity, roots, materials (e.g. 403 stainless steel), manufacturability

Control System

- Main function: control turbine speed and load
- Diagnostically monitor turbine and other plant components



Steam Turbine Selection Example

- Applicable procedure for simple, single-stage machines
- Use Mollier diagram, charts and manufacturer data

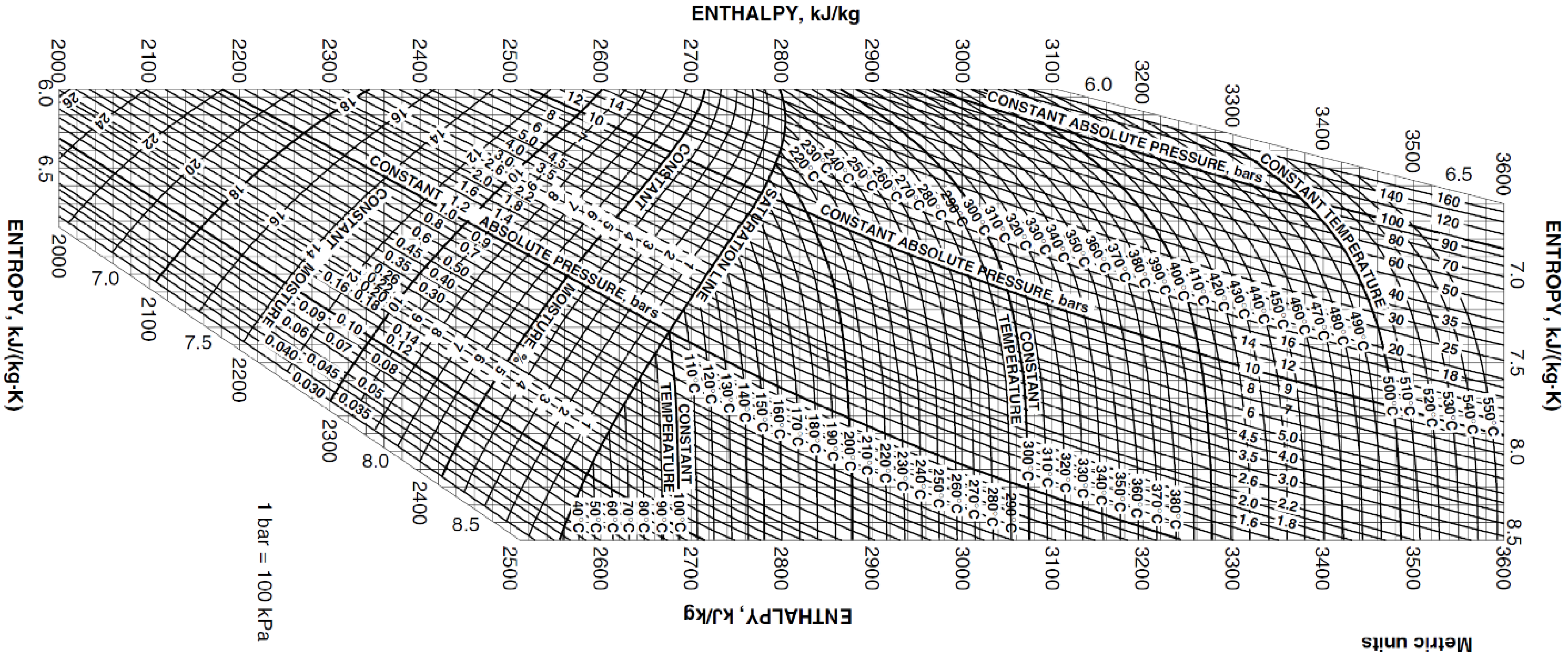


TABLE 14.1 General Specifications for Simple Single-Stage Steam Turbines

Frame	AYR	BYR (& BYRIH)	CYR	DYR (& DYRM)	BYRH (& BYRHH)
Maximum initial gauge pressure (psi/bar)	700/48	700/48	700/48	700/48	700/48
Maximum initial temperature (°F/°C)	750/399	750/399	750/399	750/399	750/399
Maximum exhaust pressures (gauge, psi/bar)	vac-100/6.9	vac-100/6.9*	vac-90/6.2	vac-100/6.9	250/17†
Speed range (r/min)	1000–7064	1000–6675	1000–6950	1000–5770	1000–7090
Wheel pitch diameter (in/mm)	14/360	18/460	22/560	28/710	18/460
Number of stages (impulse type)	1	1	1	1	1
Number of rows of rotating blades	2	2	2	2	2
Inlet sizes (ANSI, in)	3	2, 3, 4	2, 3, 4, 6	2, 3, 4, 6	2, 3, 4, 6
Inlet location (facing governor)	right	right	right	right	right
Exhaust size (ANSI, in)	6	8	10	12‡	8
Exhaust location (L.H. Standard)	R.H. optional	R.H. optional	R.H. optional	R.H. optional§	R.H. optional
Approximate range of capacities (hp/kW)	750/560	to 1400/1050	to 2500/1850	to 3500/2600	to 3000/2250
Approximate shipping weight (lb/kg)	870/400	1275/580	2050/930	2600/1180	2300/1050

* BYRIH: 160 psi/11 bar.
† BYRHH: 375 psi/25 bar.
‡ DYRM: 14 in, max. exhaust pressure 75 psig.
§ DYRM: Optional R.H. not available.
SOURCE: Elliott Company, Jeannette, Pa.

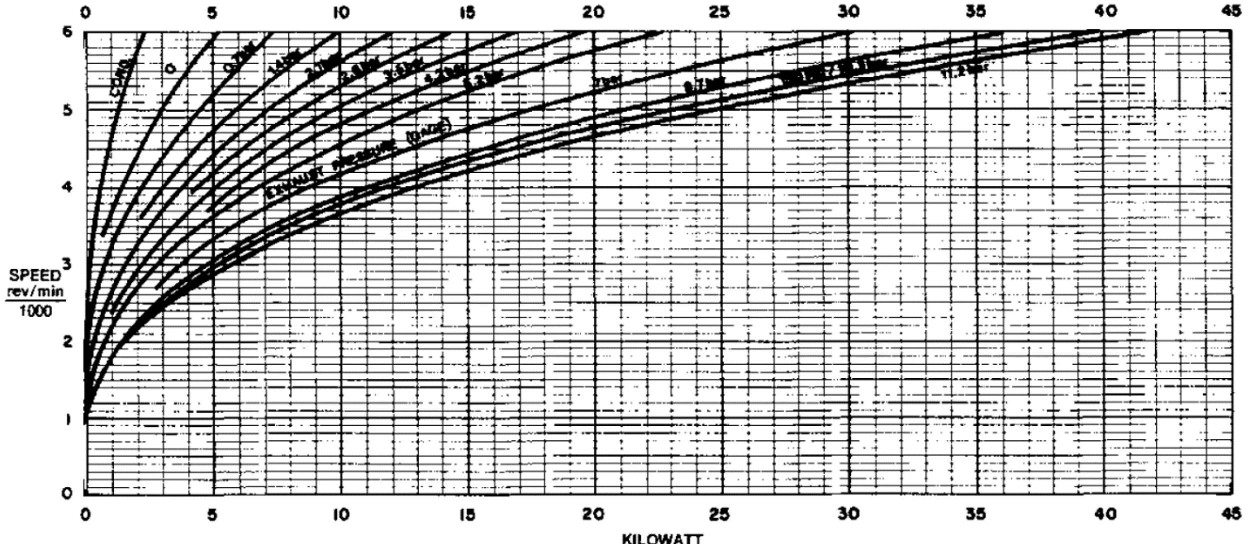
Step 1: Determine the TSR using a Mollier Chart or relevant steam tables and the TSR equation. The TSR equation in metric units is $TSR = \frac{3600}{h_1 - h_2}$ kg/(kWh).

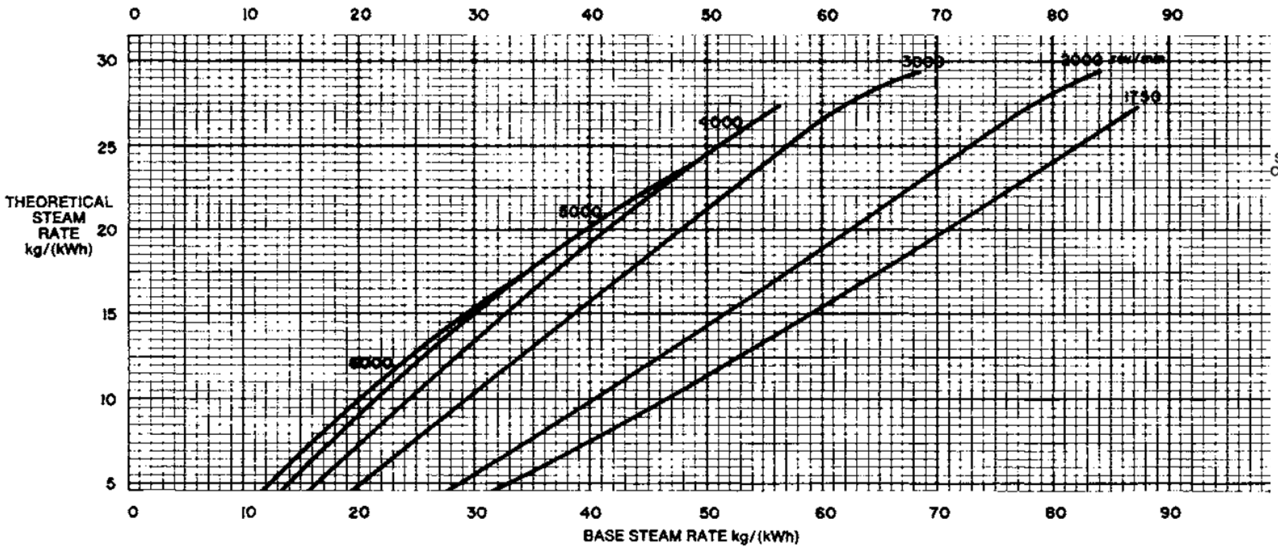
Step 2: Determine base steam rate (BSR) using relevant BSR graphs, selecting the BSR value from TSR, turbine speed, and turbine frame.

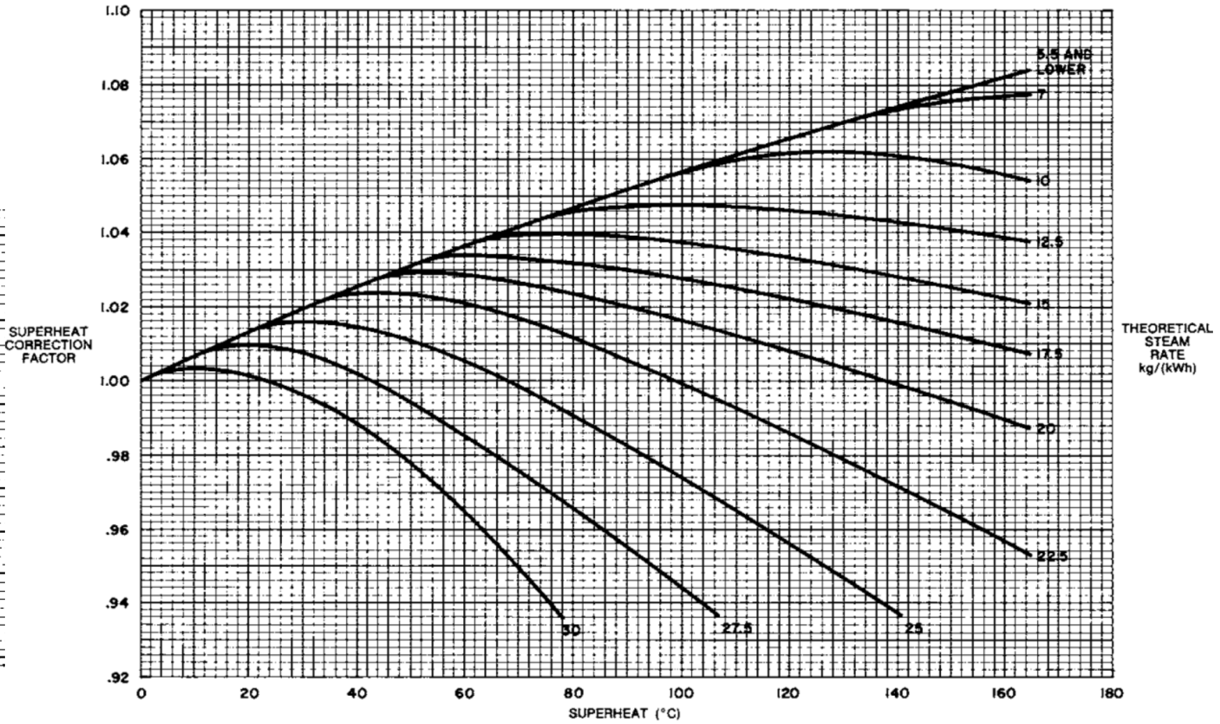
Step 3: Determine the mechanical loss using relevant loss graphs, selecting based on turbine speed, exhaust pressure, and turbine frame.

Step 4: Determine superheat based on steam tables for dry and saturated steam.

Step 5: With superheat and TSR, determine the superheat correction factor (SCF) from the relevant SCF graph.







Step 6: Determine the corrected steam rate via the formula

$$\text{Corrected steam rate} = \frac{\text{base steam rate}}{\text{superheat correction factor}} \times \frac{\text{kW+kW loss}}{\text{kW}} \text{ (SI units)}$$

Step 7: Determine steam flow via the formula

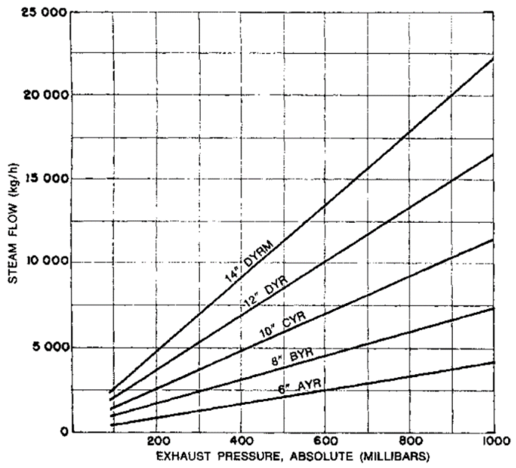
$$\text{Steam flow} = \text{corrected steam rate} \times \text{kW}$$

Step 8: Determine the required inlet size using the relevant graph such as shown in Figure 16, using steam flow and turbine inlet pressure and temperature.

Step 9: Determine the required exhaust size using the relevant sizing graph as shown in Figure 17 using steam flow and exhaust pressure.

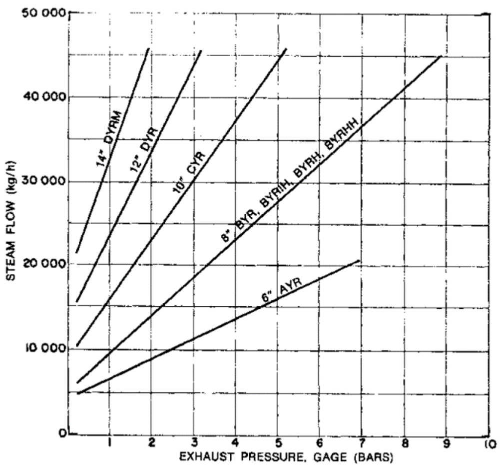
Exhaust Size—Condensing

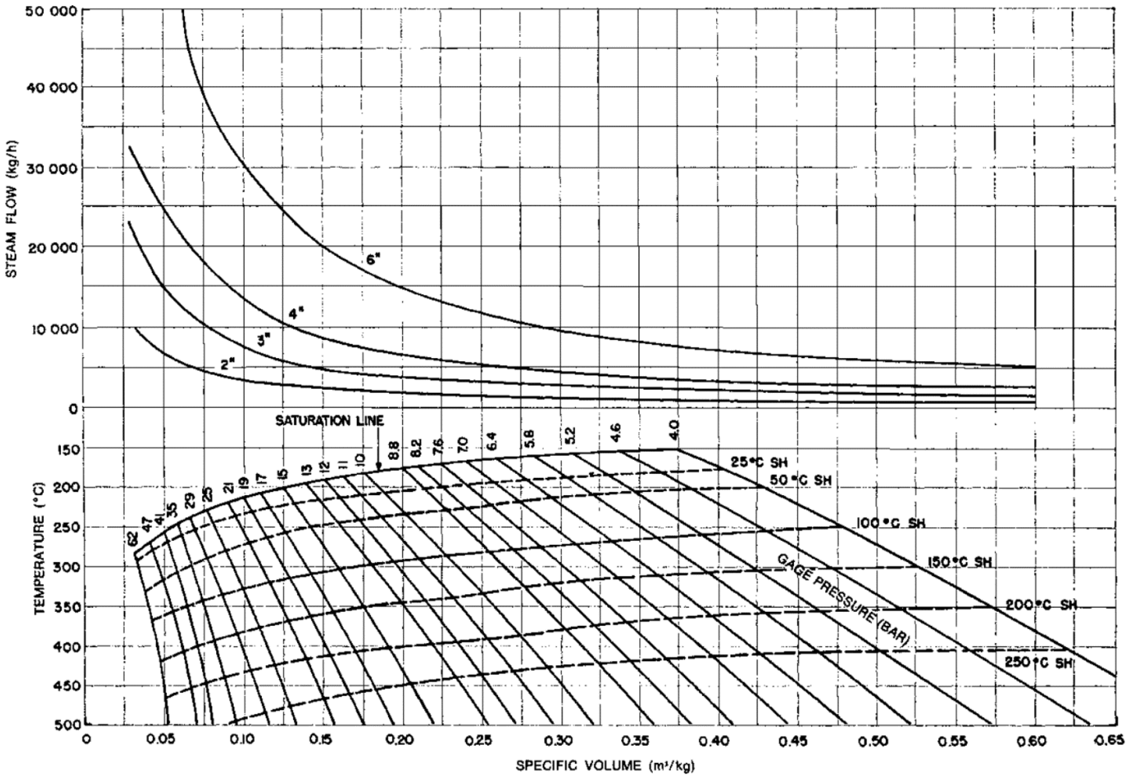
(Based on 107 m/s steam velocity)



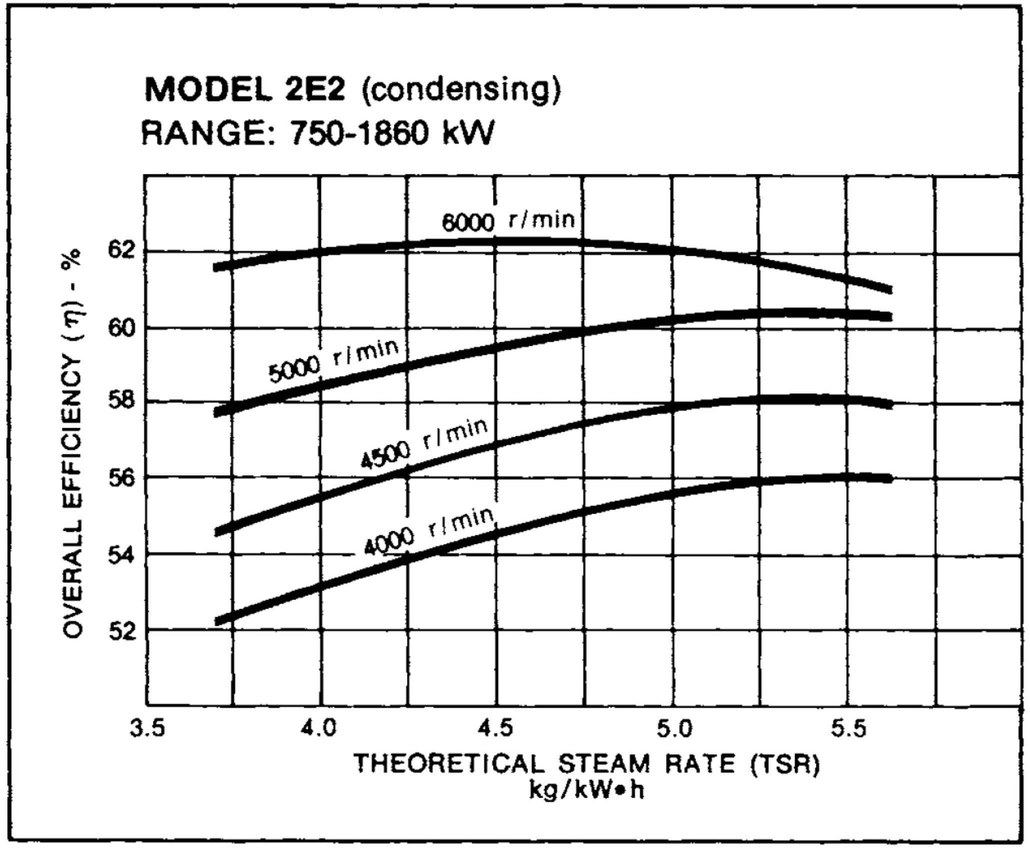
Exhaust Size—Non-Condensing

(Based on 76 m/s steam velocity)





Multi-Stage, Single-Valve Turbine Selection



(b)

Figure 14.22 Selection charts, three-stage, single-valve turbines (condensing). *(Elliott Company, Jeannette, Pa.)*

Elliott Shortcut Selection Method

- Applicable for multivalve, multistage steam turbines
- Useful for early stage selection
- Estimate:
  - Full and part load steam rates
  - Stage pressures and temperatures
  - Turbine performance
- Detailed selection done in collaboration with manufacturers

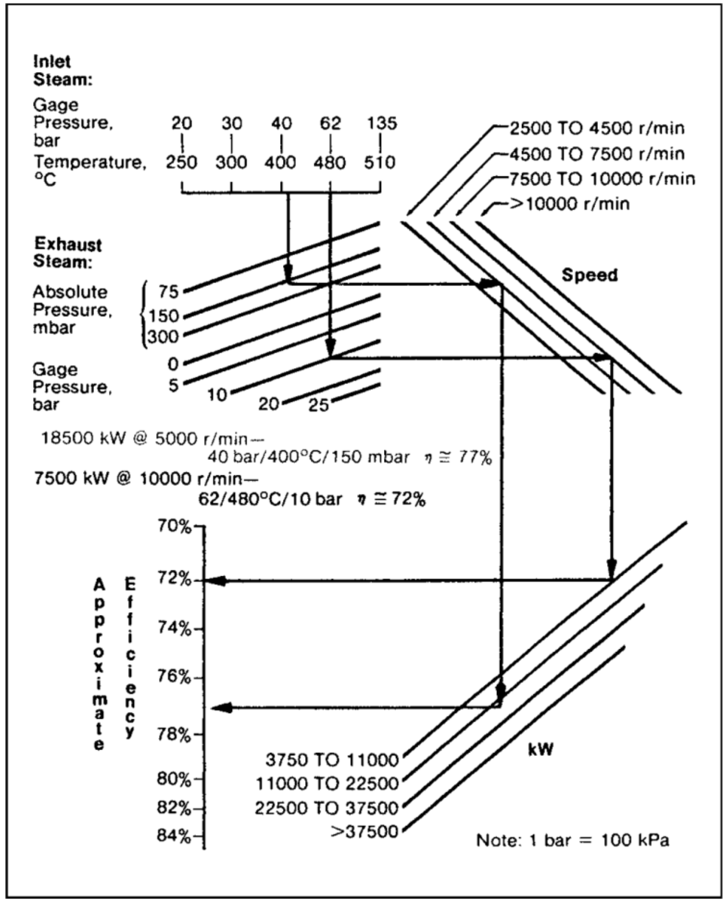
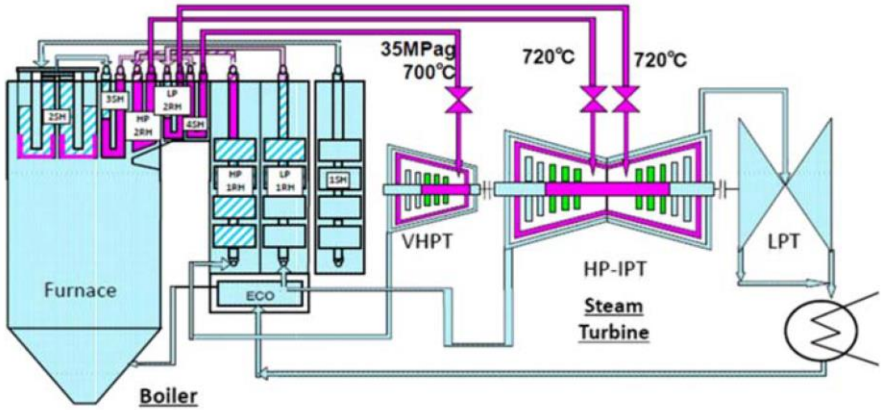
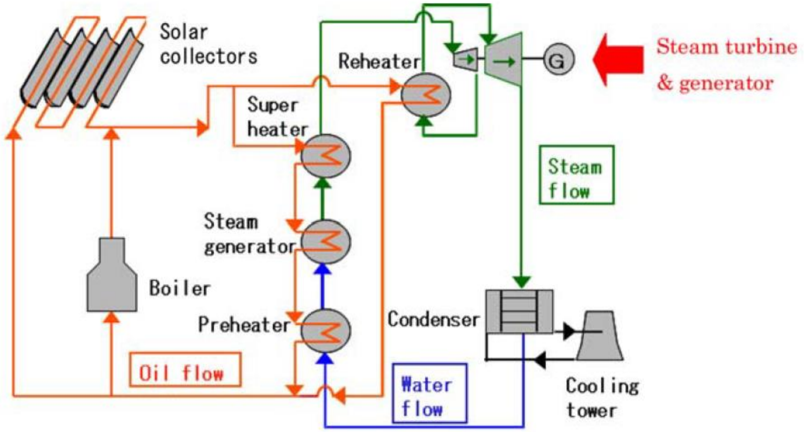
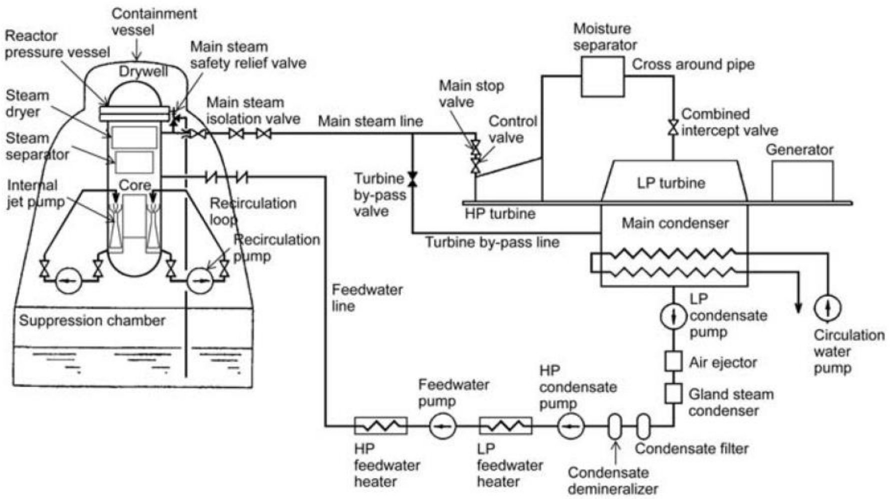


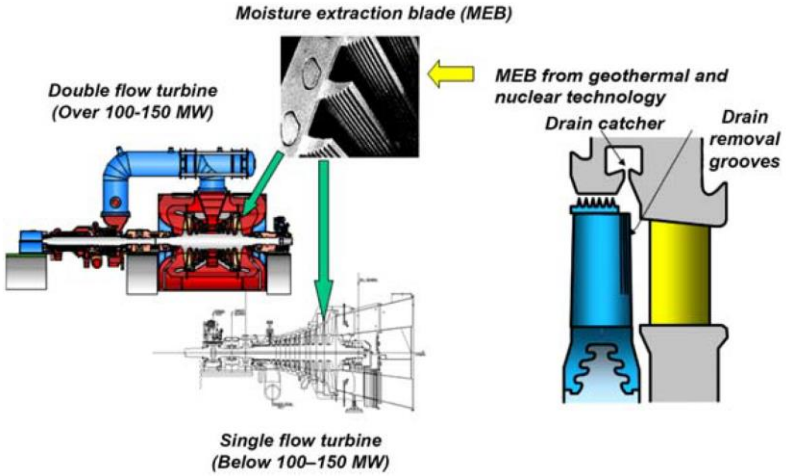
Figure 15.2 Determination of approximate efficiency for multivalve, multistage turbines, metric units. *(Elliott Company, Jeannette, Pa.)*

Advances in Steam Turbine Technology

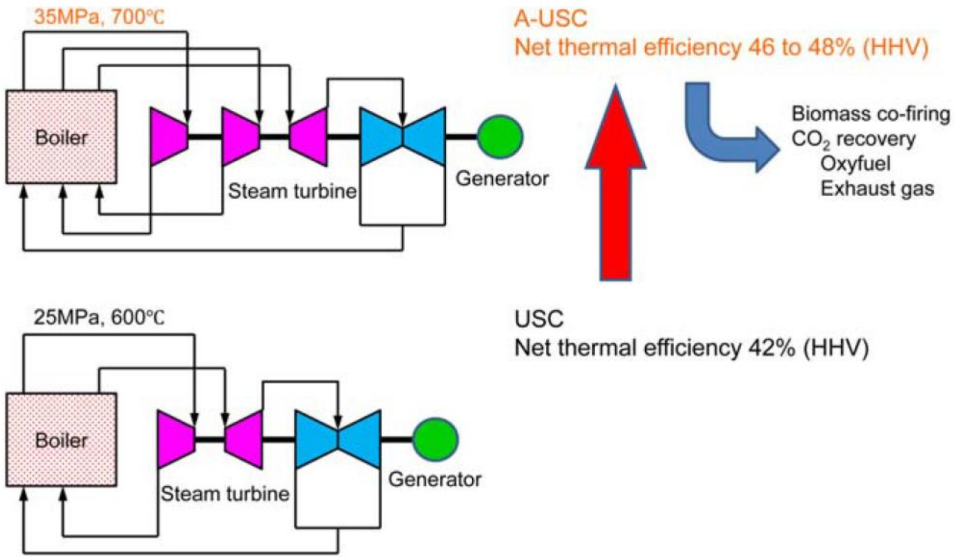


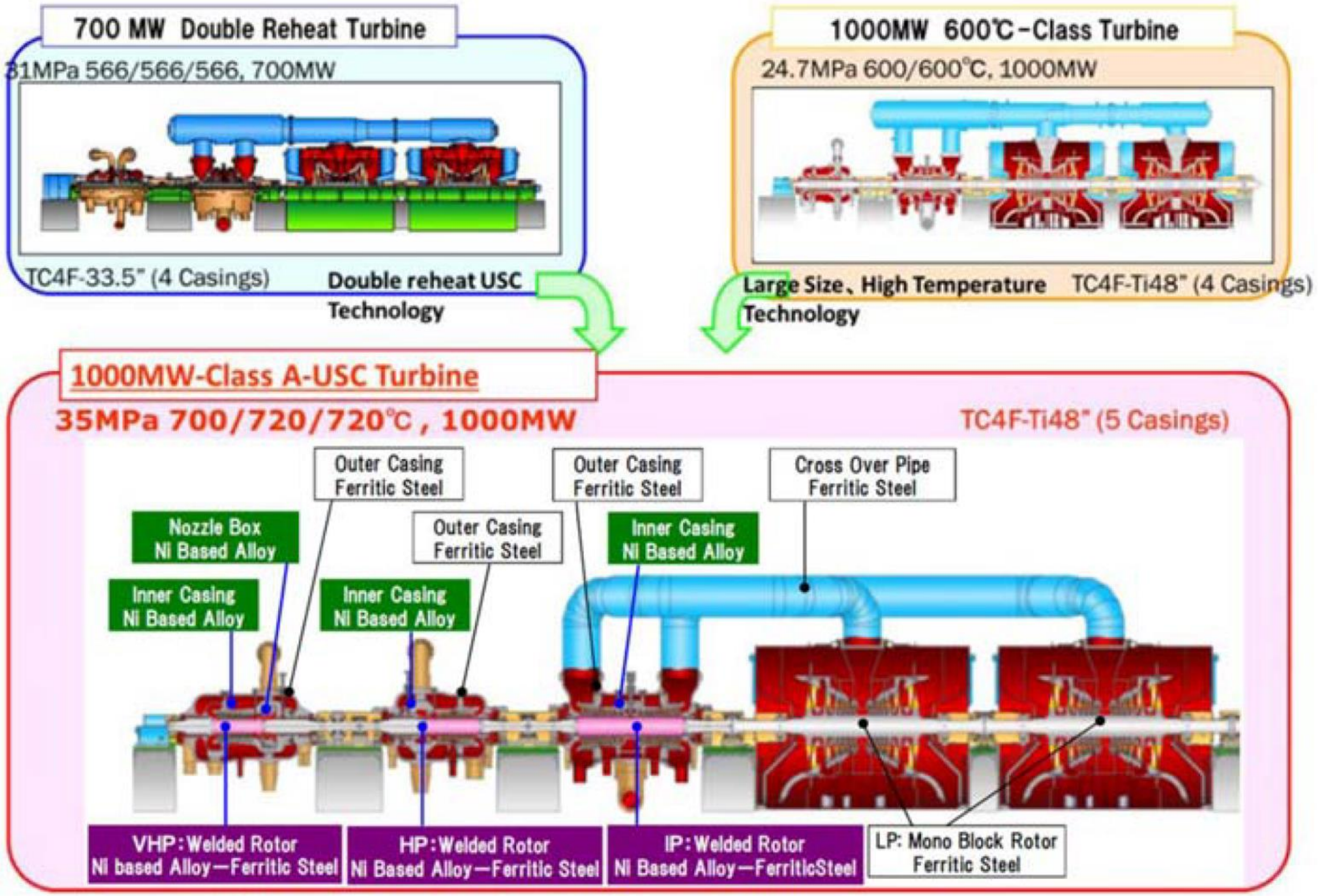




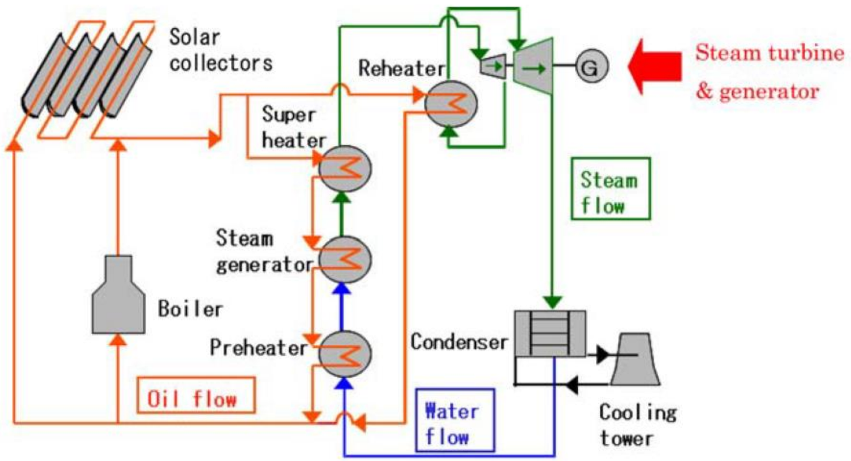


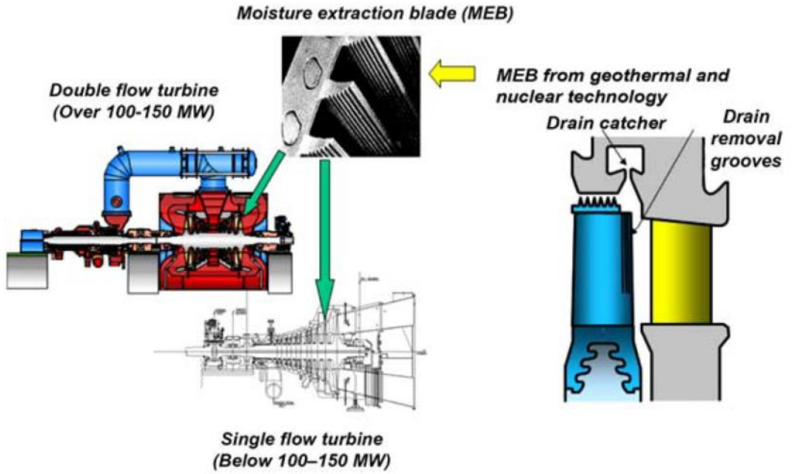
A-USC

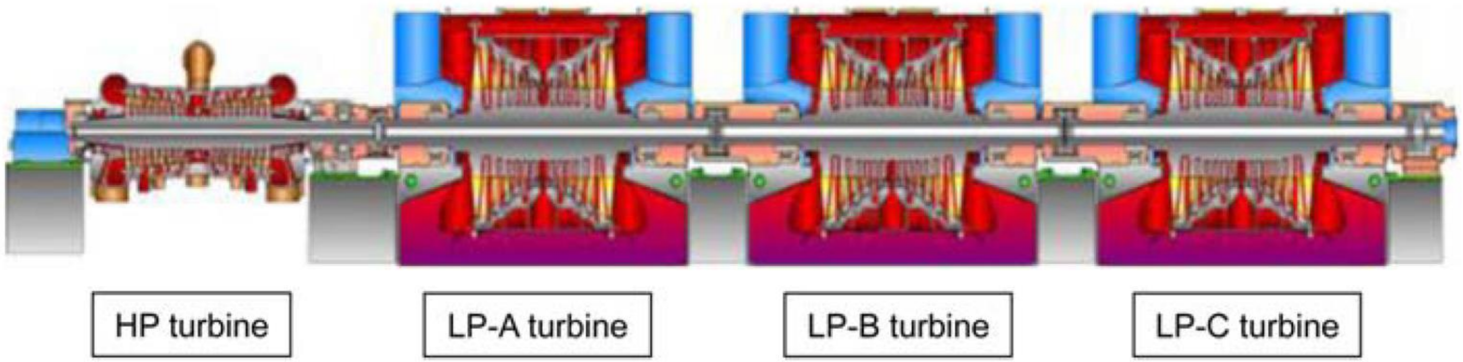

35MPa, 700℃
Boiler
Steam turbine
Generator
A-USC
Net thermal efficiency 46 to 48% (HHV)
Biomass co-firing
CO_2 recovery
Oxyfuel
Exhaust gas
USC
Net thermal efficiency 42% (HHV)
25MPa, 600℃
Boiler
Steam turbine
Generator


700 MW Double Reheat Turbine
31MPa 566/566/566, 700MW
TC4F-33.5" (4 Casings)
Double reheat USC
Technology
1000MW 600℃-Class Turbine
24.7MPa 600/600℃, 1000MW
Large Size、High Temperature
Technology
TC4F-Ti48" (4 Casings)
1000MW-Class A-USC Turbine
35MPa 700/720/720℃, 1000MW
TC4F-Ti48" (5 Casings)
Outer Casing
Ferritic Steel
Outer Casing
Ferritic Steel
Cross Over Pipe
Ferritic Steel
Nozzle Box
Ni Based Alloy
Outer Casing
Ferritic Steel
Inner Casing
Ni Based Alloy
Inner Casing
Ni Based Alloy
Inner Casing
Ni Based Alloy
VHP:Welded Rotor
Ni based Alloy—Ferritic Steel
HP:Welded Rotor
Ni Based Alloy—Ferritic Steel
IP:Welded Rotor
Ni Based Alloy—FerriticSteel
LP: Mono Block Rotor
Ferritic Steel

Nuclear, Solar, Geothermal







Simulation Technology (FEA, CFD)

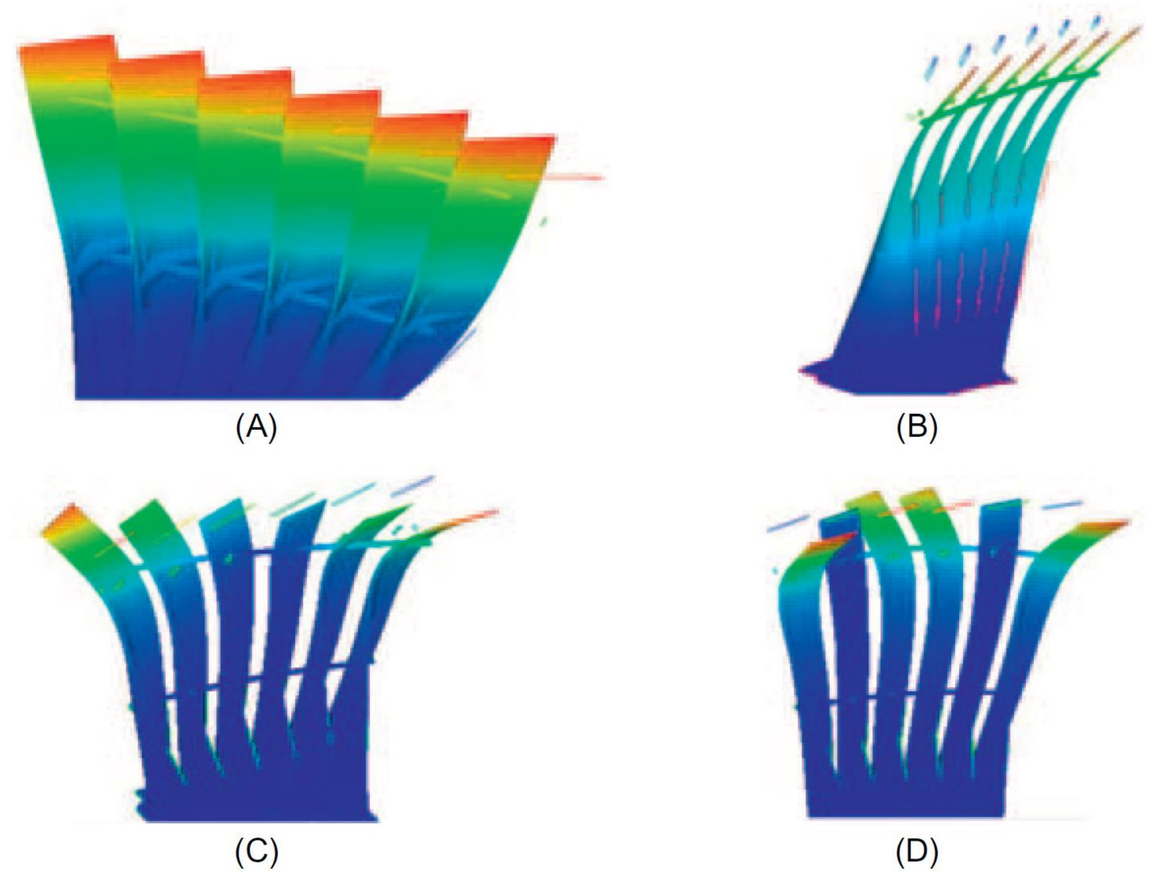


Figure 13.17 Modal analysis result: relative frequency normalized by measured frequency. (A) First mode frequency 1.06, (B) second mode frequency 1.02, (C) third mode frequency 0.93, (D) forth mode frequency 0.96.

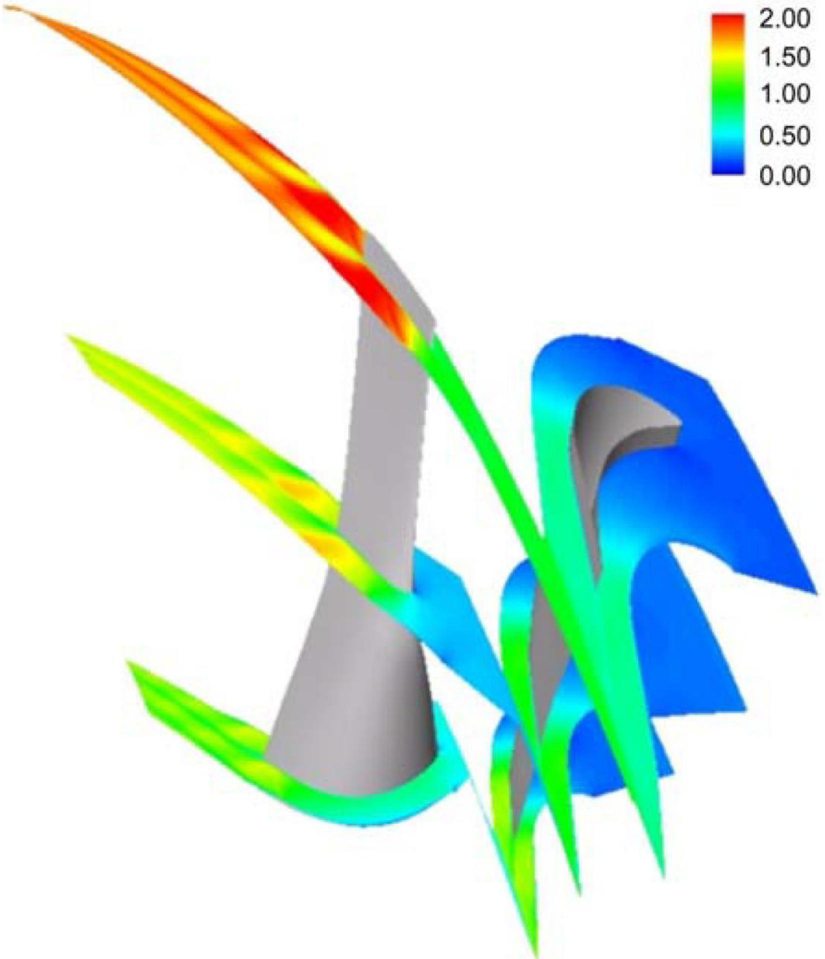


Figure 13.9 Three-dimensional Mach number contours of a developed last stage.

Conclusions

- Steam turbine technology is stable and resilient
- Steam turbines currently play a dominant role in energy generation
- This trend is expected to continue for the foreseeable future
- Many literature deep dives possible

Additional Picture Sources

- Slide 1 Picture: Contributors, T. S. (2020, February 16, 2020). "Doosan Škoda Power to supply steam turbine to Japan." from https://www.turbomachinerymag.com/doosan-skoda-power-to-supply-steam-turbine-to-japan/.
- Slide 3 Picture: Topel, M. (2017). Steam Turbine Technology: Design Aspects of Major Components. KTH Royal Institute of Technology. From https://kth.instructure.com/files/549701/download?download_frd=1