Layout, Auxiliary Components, Development & State-of-Art of Thermal Power Plants

Lecture for the course

Sustainable Power Generation (SPG) MJ2405

Miro Petrov

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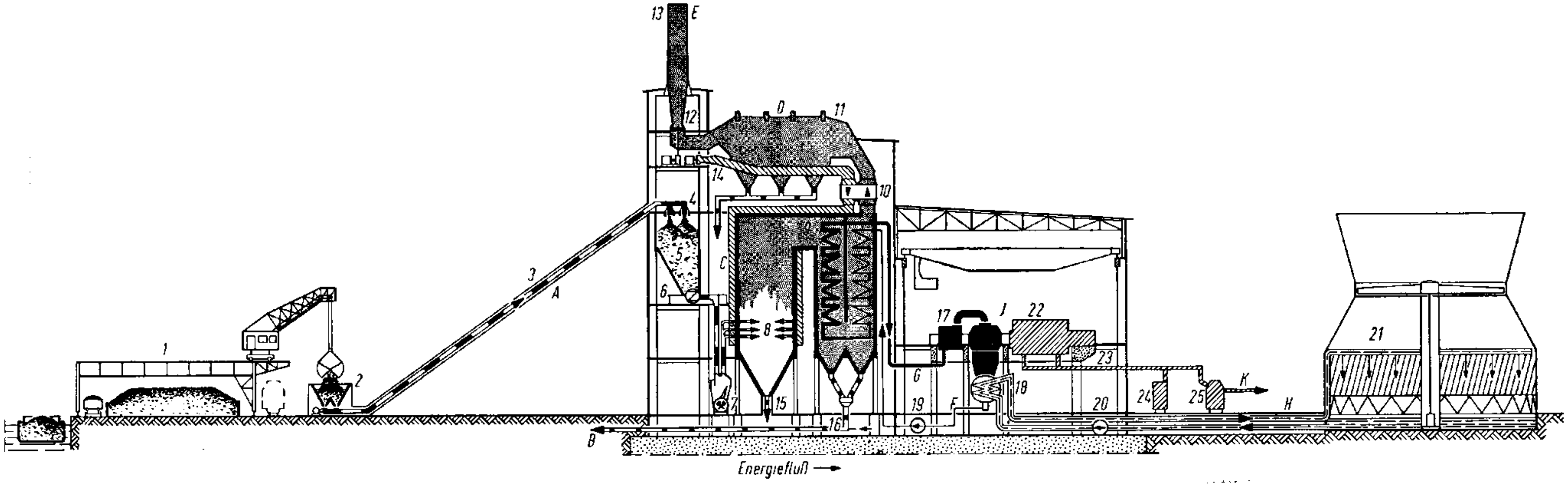

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Types of thermal plants

- Large-scale Steam power (fossil or nuclear)
- Medium- or small-scale utility power or CHP
- Combined Cycles
- Waste incinerators
- Medium-scale gas turbines or piston engines
- Small-scale back-up power (UPS)
- Geothermal power plants (steam)
- Utilizing low-temperature heat (ORC)

Choice of Type and Size

- Base-load or Peak-load;
- Demand for district heating or process steam;
- Upgrading older plants with new technology;
- Fuel availability – regionally produced or imported;
- Fuel blends or shifting to alternative fuels;
- Specific rules for operation (pollution prevention, local or national taxes, ban on certain fuels, etc...)

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Major parts of the power plant

- **Process equipment**
- **Buildings**
- **Other**

Process Equipment:

- *Main Components* – Boiler house and Turbine hall.
- *Auxiliaries* – Heat Exchangers, Pumps, Fans, Pipes, Valves, Fuel preparation; Electrical Equipment and Switchyard, Measurement and Control Equipment; Flue Gas Cleaning…

Buildings and premises:

- Foundations and Structural support for large equipment,
- Boiler and Turbine housing (main building), el. switchyard,
- Special structures like stacks and cooling towers,
- Office and staff quarters. Architectural & design issues.

Types of Fuels for thermal power

- High-quality Coal (anthracite, bituminous coal)
- Medium- or low-quality Coal (brown coal, lignite)
- Natural gas
- High-quality liquid petroleum fuels (diesel, LFO, jet fuel)
- Low-quality liquid petroleum fuels (HFO, bunker oil)
- Biomass and biofuels
- Waste materials (Municipal Solid Waste, demolition wood, plastics, chemical wastes)
- Geothermal heat, Ocean Thermal, other renewable heat
- Waste heat from industrial processes
- Nuclear Reactors – they also need a thermal cycle for el. generation

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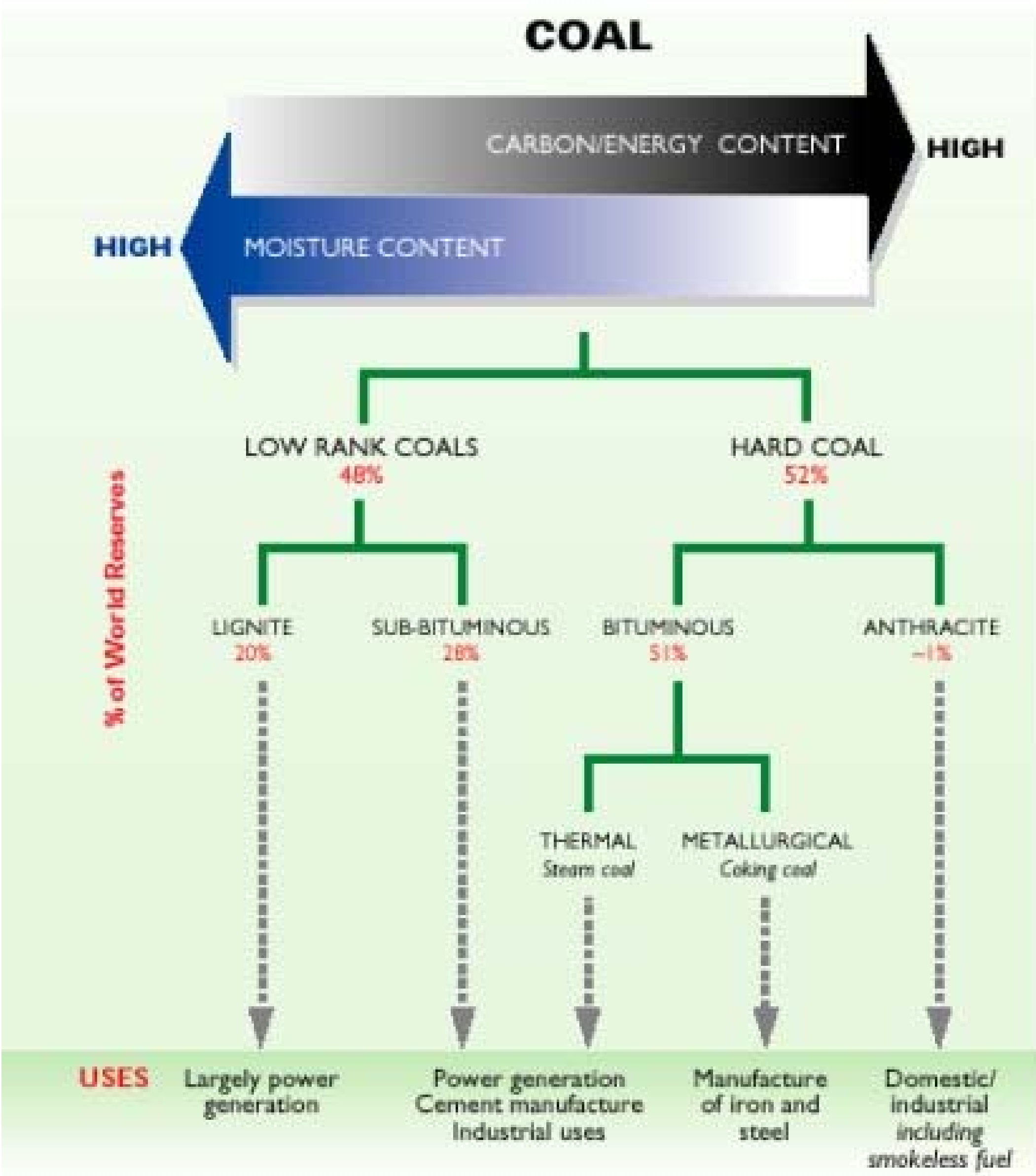

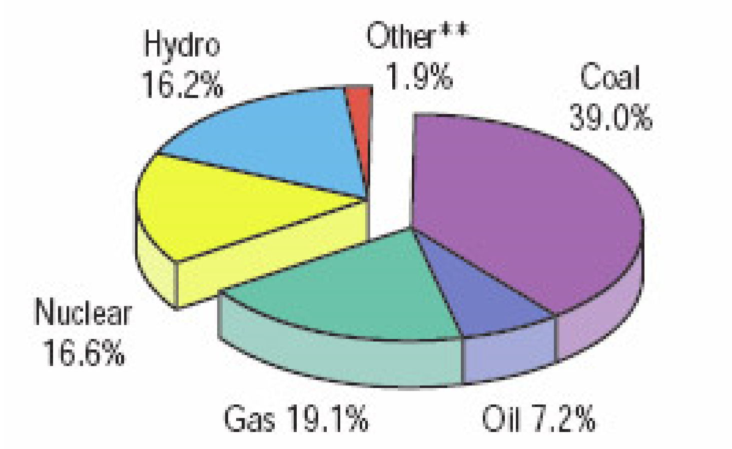

16 054 TWh

Worldwide electricity generation in 2002

(figures from CompEdu)

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Bituminous Coal (black / stone / hard coal)

Old age, high-quality coal, low ash content, rich in energy.
A product of biomass petrified for millions of years under the ground.
Looks shiny and feels hard like a stone, crushes into pieces if hammered.

Source: www.mii.org/Minerals/

Bituminous Coal (black / stone / hard coal)

Coal mining has been and still is the livelihood of millions of people around the world. Bituminous coal is usually mined in deep underground gallery mines.

Source: www.royalforestofdean.info/heritage/

Source: www.designer-iii.com

Lignite (brown coal)

Low-quality, ”young” coal type. High ash and moisture content, low energy content. Usually found shallow underground, excavated in open-pit mines, cheap and in large volumes. Feels soft and difficult to crush due to remaining biomass fibre structure.

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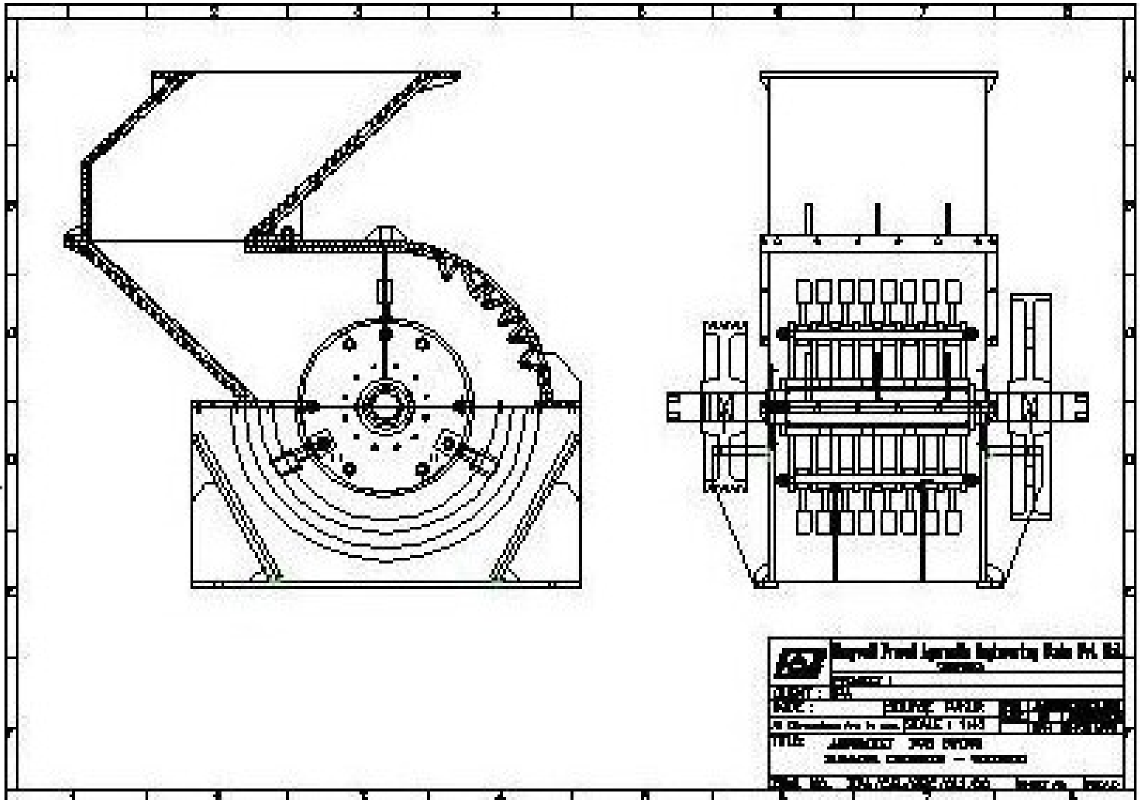
Pictures from CompEdu

Coal Crushers

Preparing the raw coal feed by grinding it to small pieces, usually by a hammer mill (left) or by a cog crusher (right).



Source: www.agarwalla.com

Source: www.penncrusher.com

Coal Powder Mill (Roller type)

Final milling for preparing fine coal powder to be injected in highly loaded furnaces.

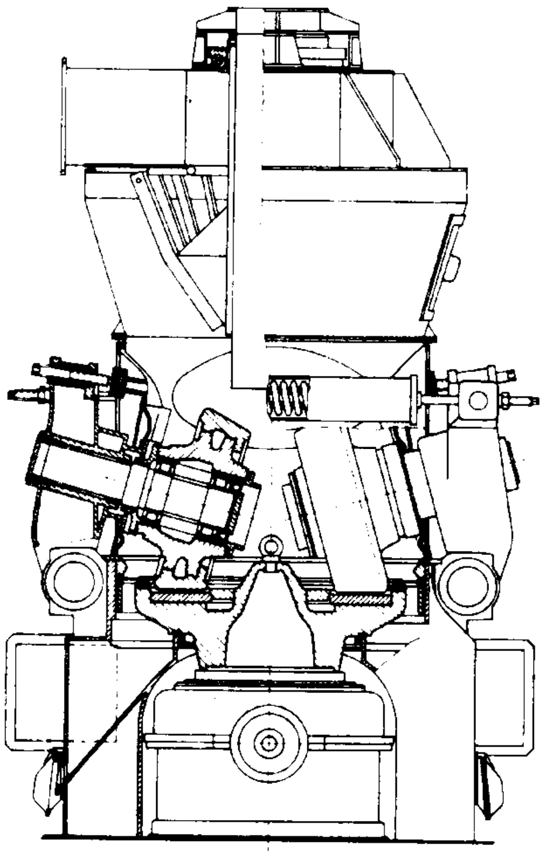
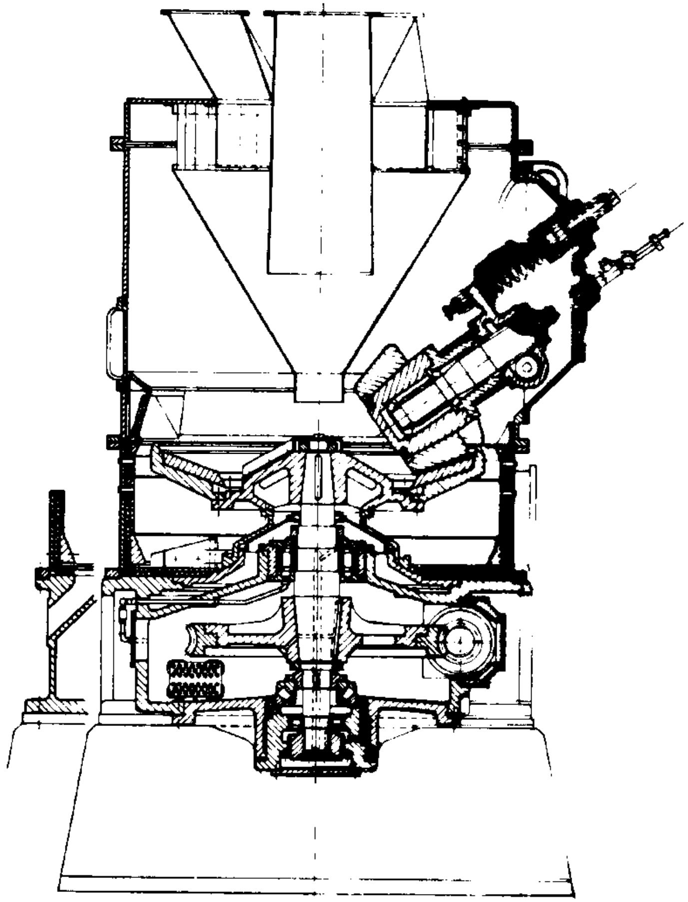
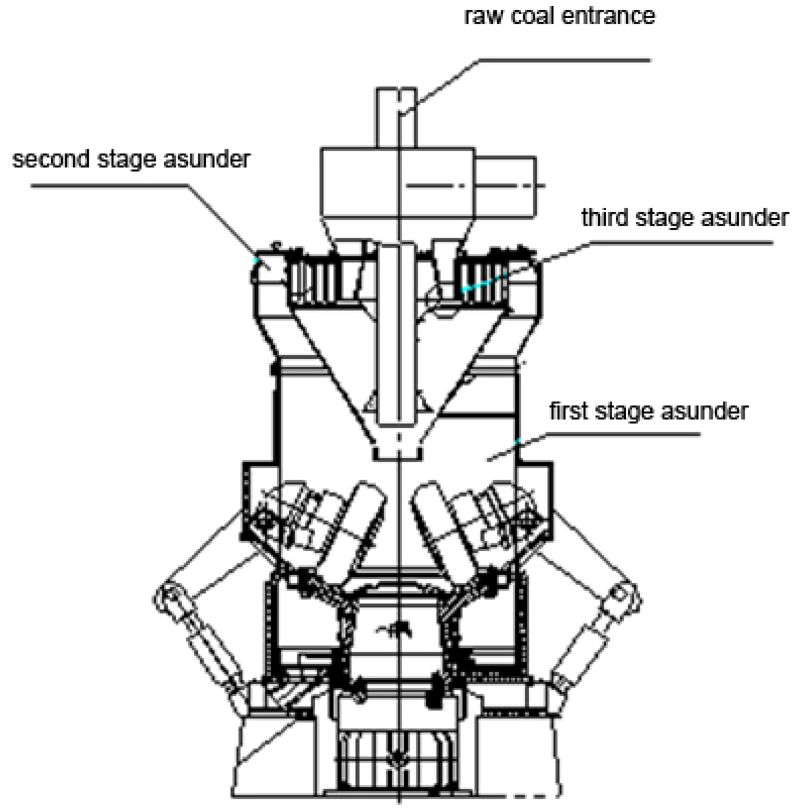


Abb. 13. Schüsselmühle, Bauart Lösche



Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966



Source: www.hytaihe.com

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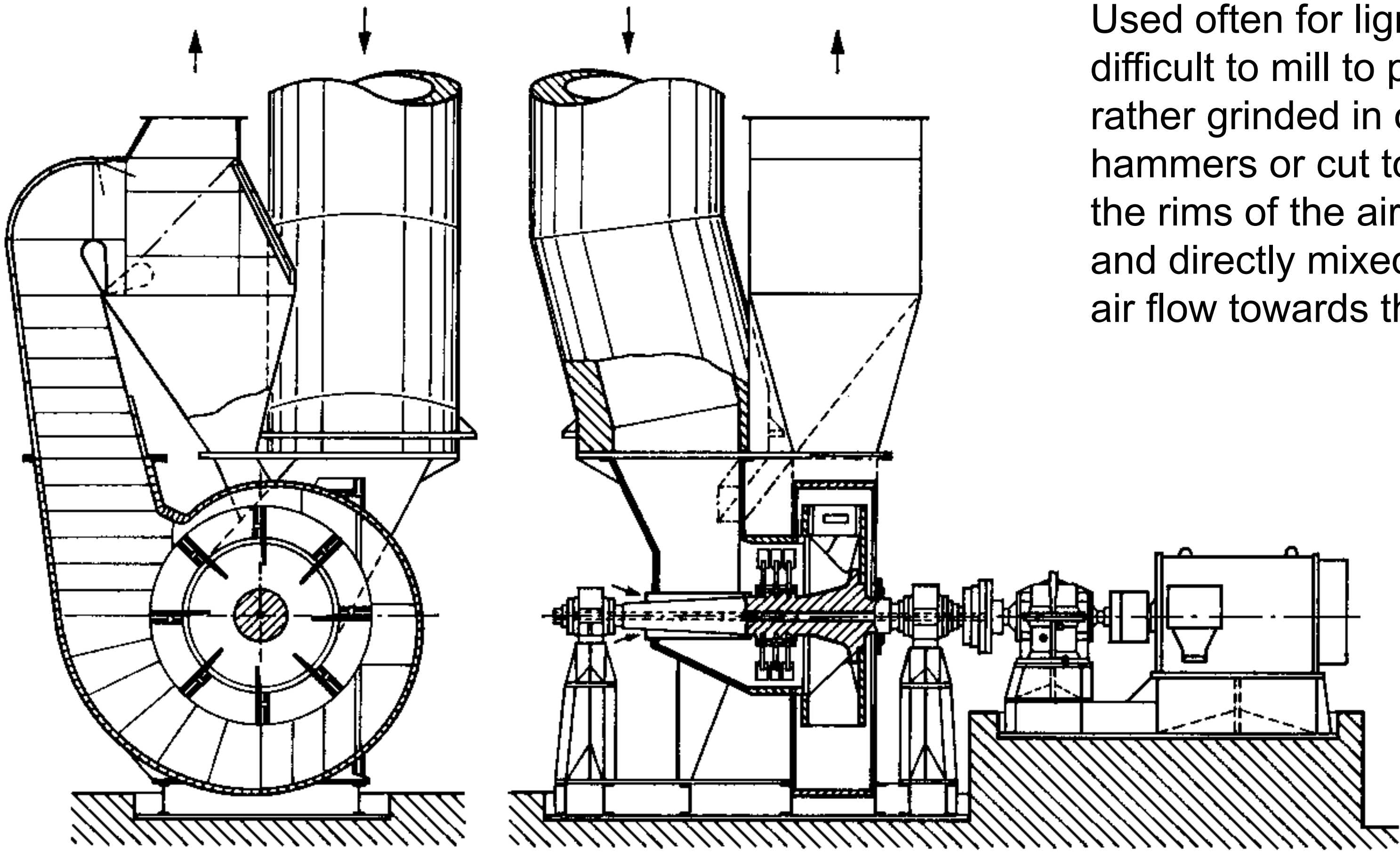
Combined Hammer Coal Crusher + Air Fan



Used often for lignite that is difficult to mill to powder, it is rather grinded in one step by hammers or cut to pieces by the rims of the air fan blades and directly mixed with the air flow towards the furnace

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Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

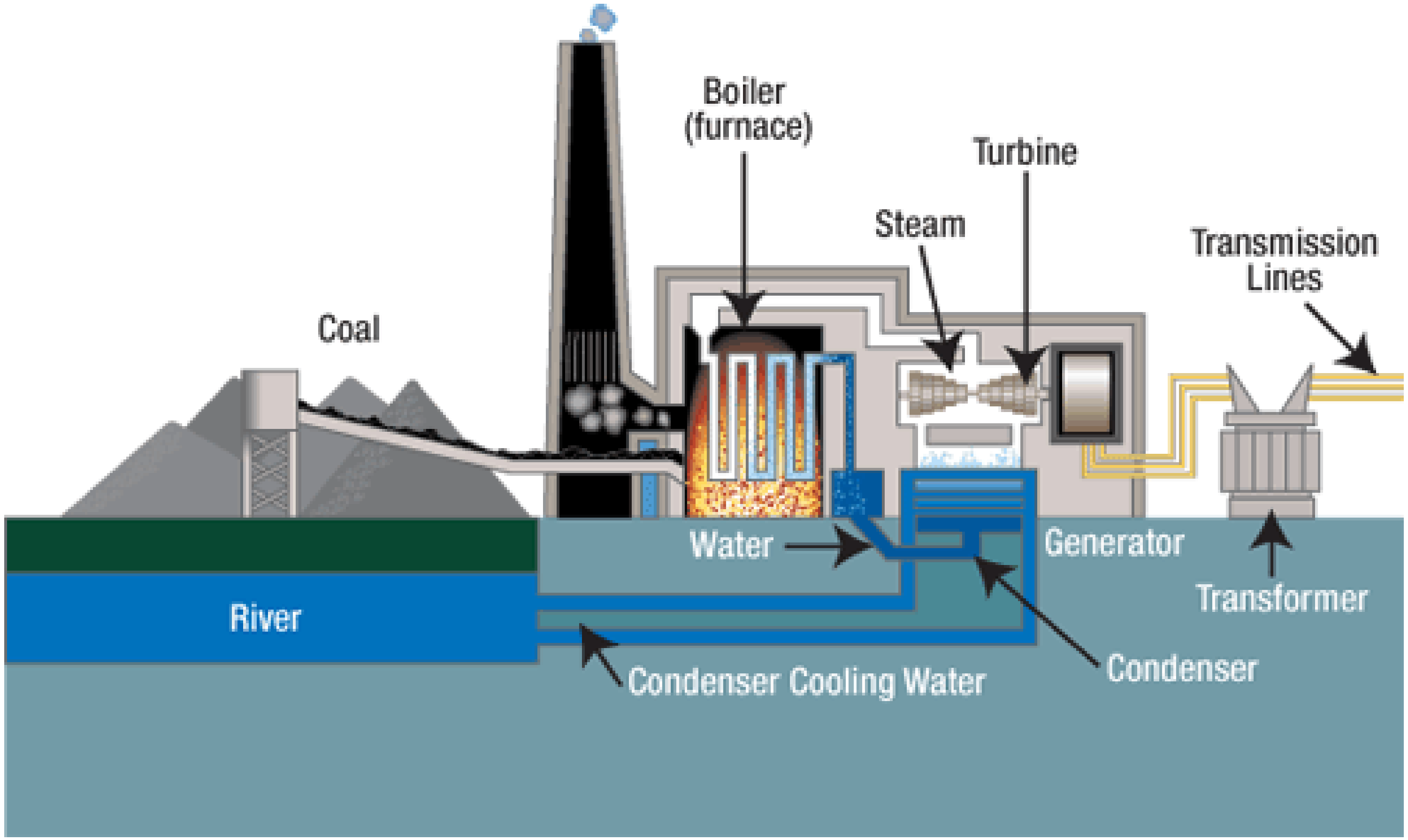
Biomass Chipping and Transportation

Biomass (wood or straw/grass) has fibrous structure and can't be crushed or milled, only sawed/cut/chipped to small pieces for transportation and feeding to furnace

Source: www.upwoodybiomass.org

Source: VGB PowerTech, Vol.84/2004

Typical power plant layout



Source: www.tva.gov/power/coalart.htm

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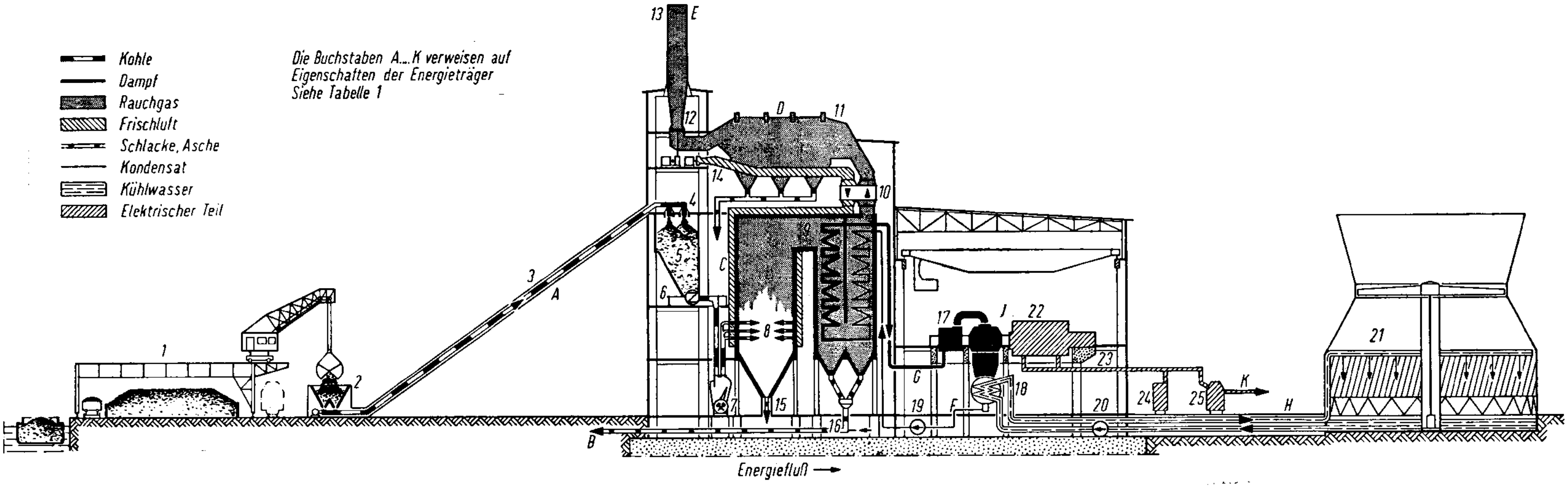
Typical power plant layout (2)

Energy flows from left to right – from fuel via combustion into hot steam to turbine, into produced el. power and waste heat sunk in the cooling tower...



Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

Large Coal Plant Example

The "R.W.Scherer" generating station in the town of Juliette, GA (USA), with a total output of 4 x 880 MWel, fired with high-quality coal transported all the way from Wyoming (~3000 km away)

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Source: www.wikipedia.org

Combined Cycle layout

More compact and cheaper to build, but requiring expensive fuels

Source: www.products.endress.com

Source: www.powergeneration.siemens.com

Combined Cycle development

Recent examples of large-scale NG-fired CCs:

Right: The 1346 MWel Front Royal CC in Virginia, with 3 GTs from MHPS, 3 HRSGs and one single steam turbine from Alstom at 573 MW.

Left: A new 1050 MWel CC in Pennsylvania with 2 GTs from GE and 1 ST.

Source: www.powerengineeringint.com

Choice of Location

- Distance to consumer and to fuel source;
- Distance to grid connection or grid extension;
- Easy transportation of fuel for the plant, or of construction material for the erection of plant;
- Availability of cooling water;
- Good ground with possibilities to expand;
- Surroundings not very sensitive to disturbances;
- Good accommodation for operational staff.

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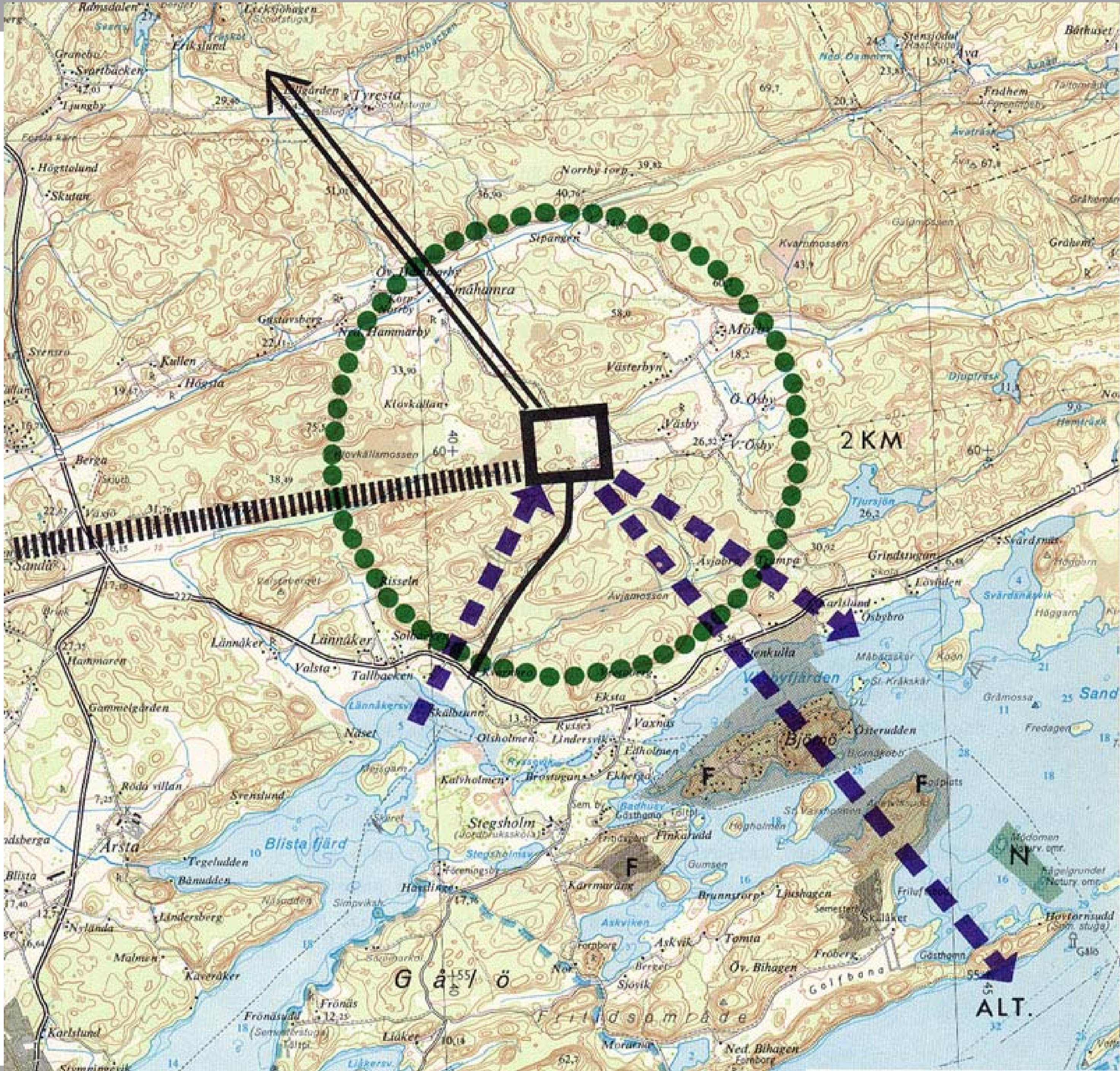

Location ?

- Cooling water
- District Heating
- Power line

Layout issues to consider

Utilizing the available space in an optimum way = small footprint

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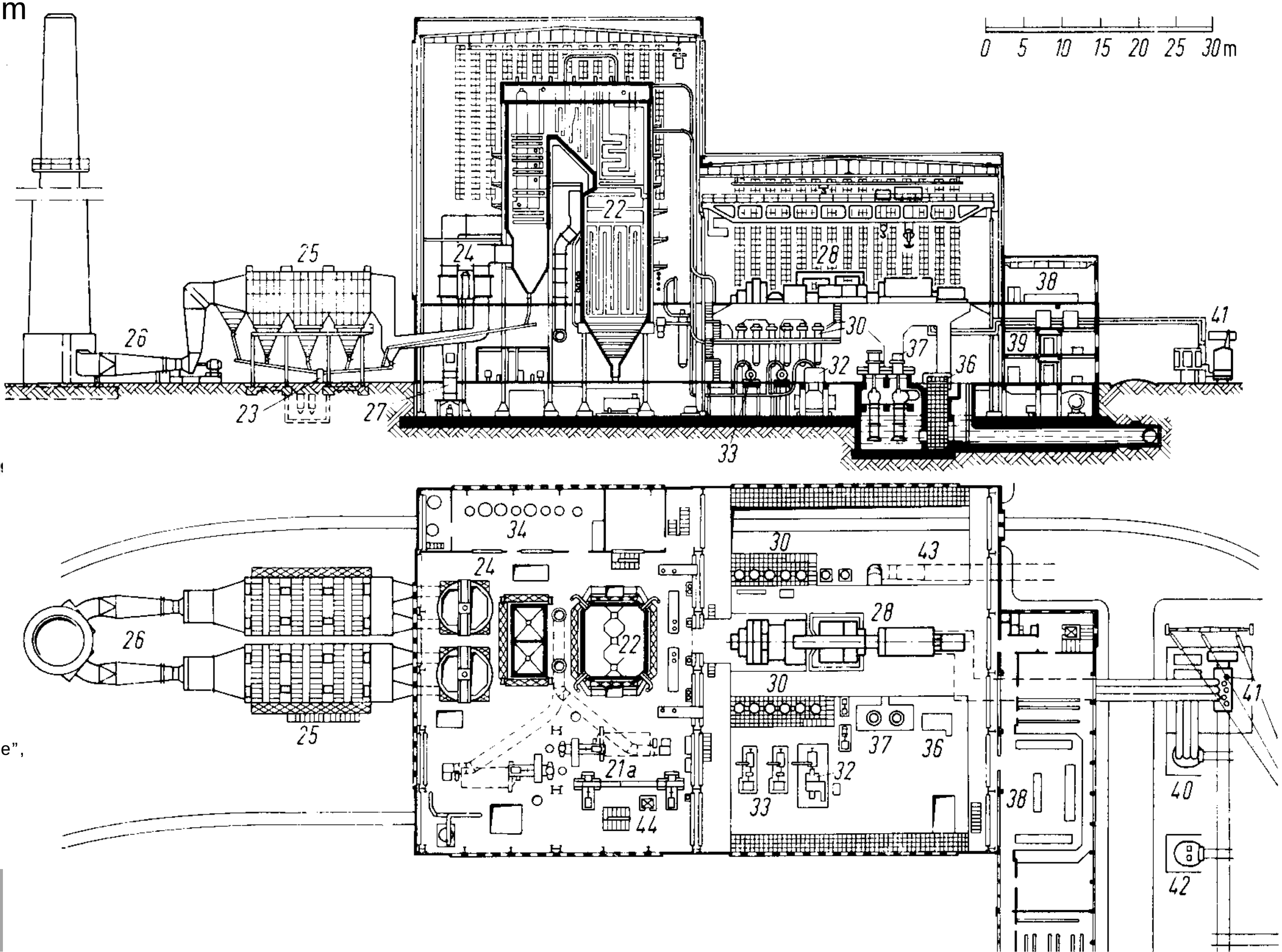

Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

Layout issues

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Assuring proximity to fuel delivery routs (boat, rail), fuel storage space, and high-voltage lines

Lagepläne

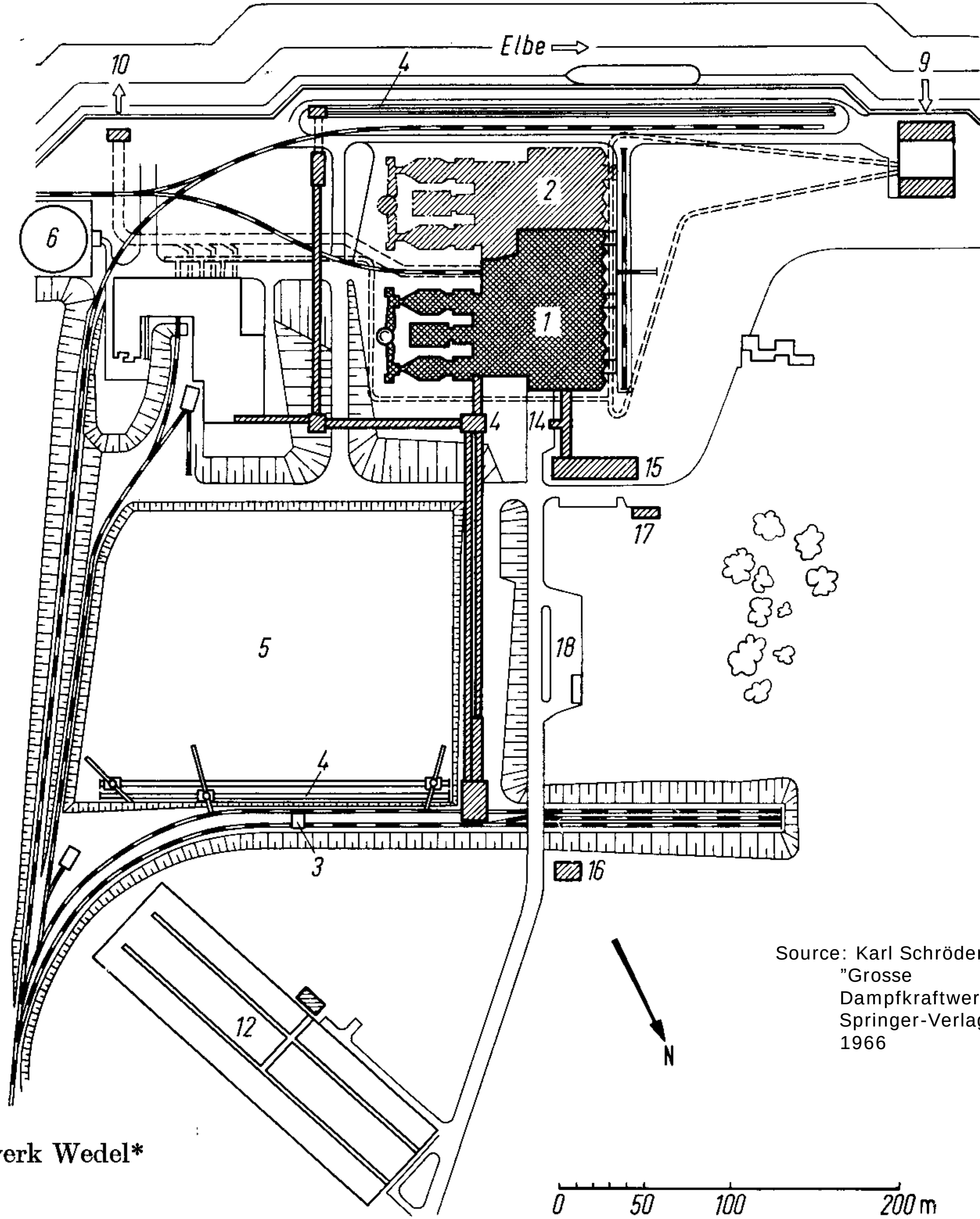

Abb. 318. Kraftwerk Wedel*

Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

Centrifugal Fans

Very necessary for delivering air to the furnace (called Forced Draft Fan) and pushing out the gases to the stack (called Induced Draft Fan). Processing high volumes of air or gas but with low pressure ratios.

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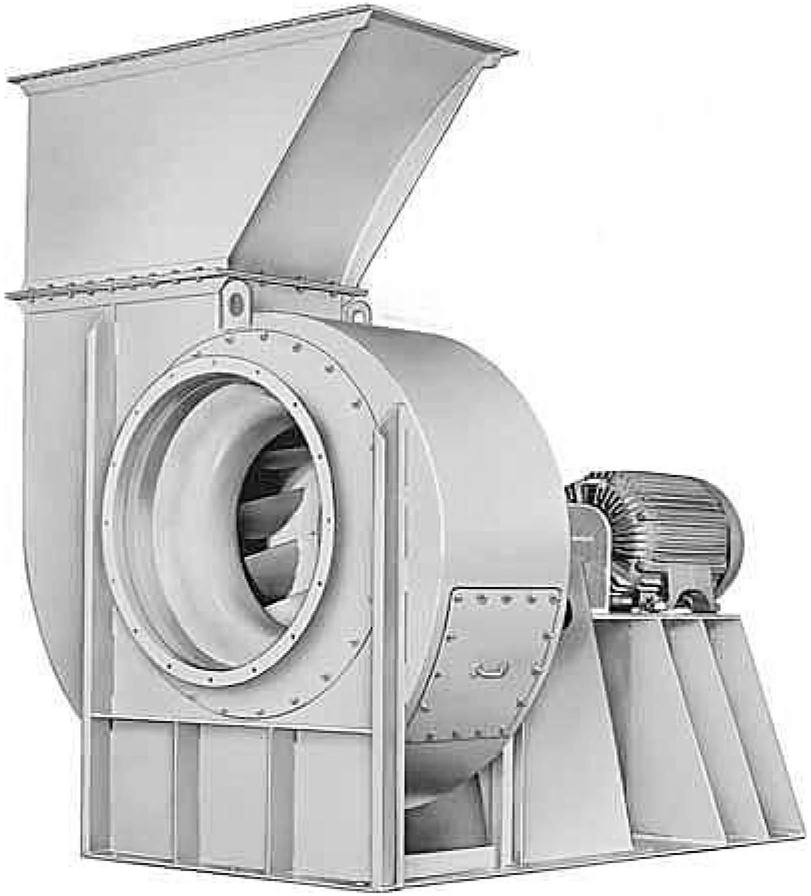
Source: www.fantek.co.in



Source: www.directindustry.com

Axial Fans

Good for even larger volume flows but very low pressure ratio

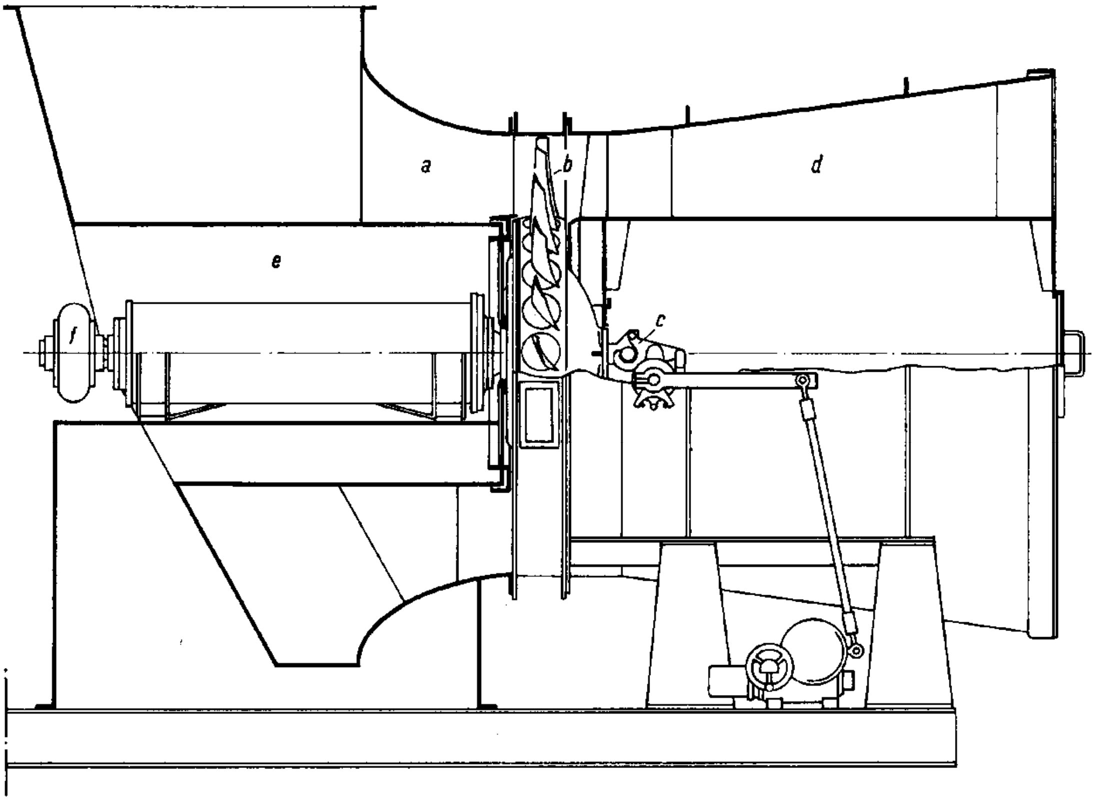


Abb. 182. Axiales Überdruckgebläse mit verstellbaren Laufschaufeln (Nordisk Ventilator)

a Ansaugdüse
b Laufrad
c Laufschaufelverstellung
d Diffusor
e Lager
f Kupplung

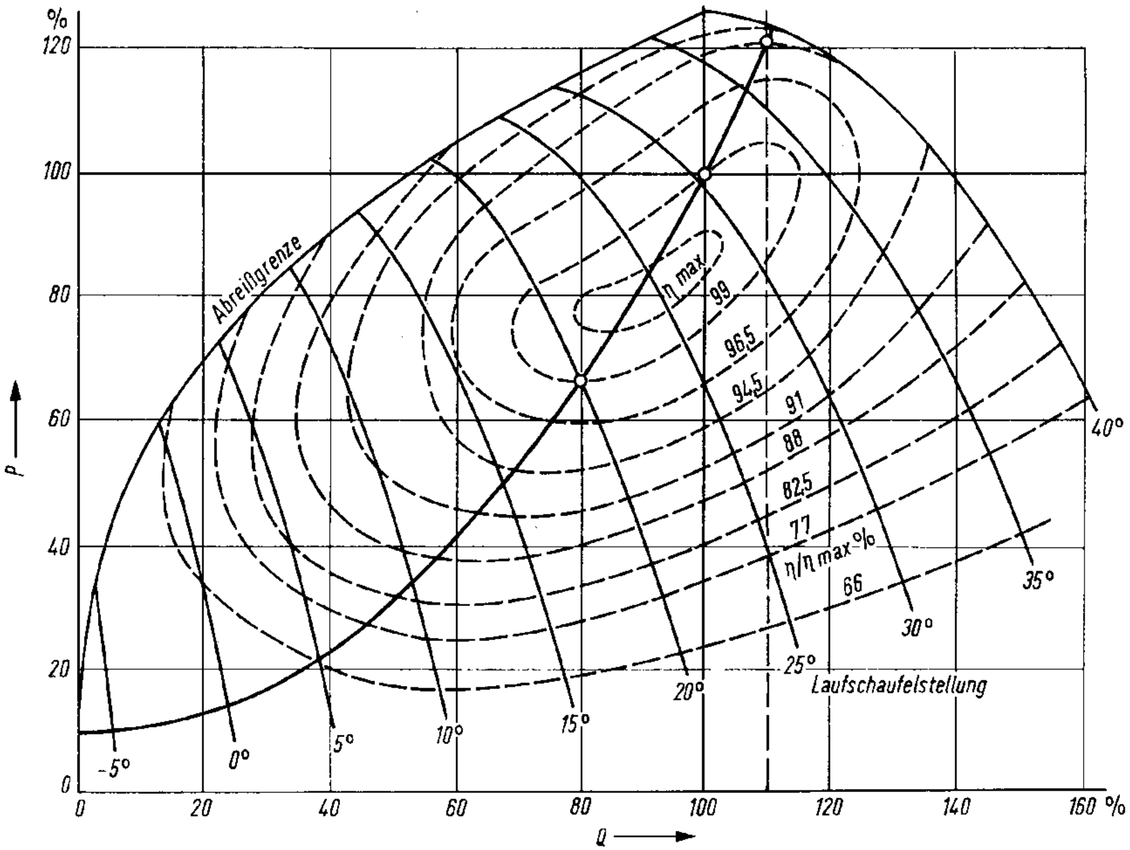


Abb. 183. Kennfeld eines axialen Überdruckgebläses (Nordisk Ventilator)

Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

Pipes and Valves

There are miles of pipework and hundreds of valves in a steam power plant, regardless of size.

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There are two main issues to consider:

1. Thermal expansion:
   - Pipes can bend or twist, therefore they are never set straight or sharply cornered but gently curved at each several meters of length;
   - Valves should be tight both at cold and hot conditions.
2. Redundancy (back-up):
   - Small equipment (pumps, valves, gauges, etc.) is applied in two or more units at each location, to ensure that at least one of those will remain fully operational if the other one fails.

Shut-off Valves

Either fully opened or fully closed.

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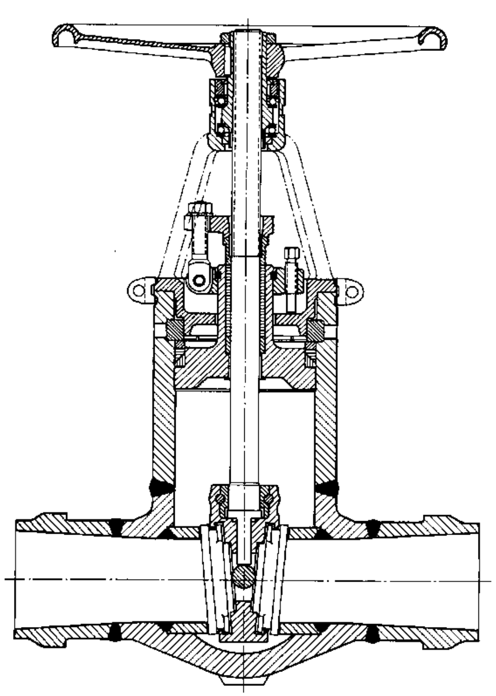

Abb. 472. Permador-Hochdruck-Absperrschieber (Babcock-Werke)

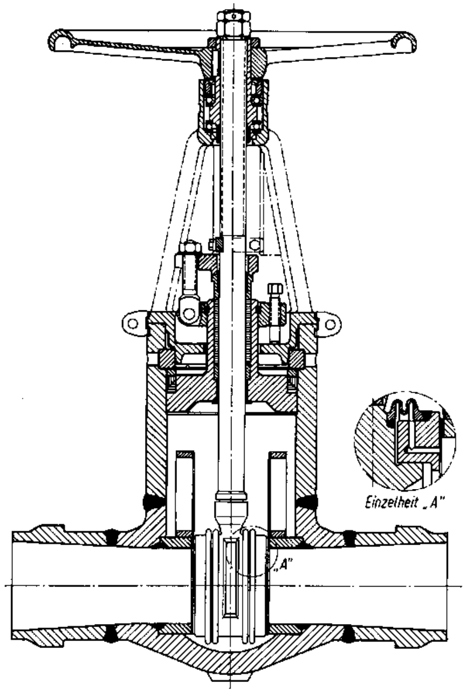

Abb. 473. Eldidor-Hochdruck-Absperrschieber (Babcock-Werke)

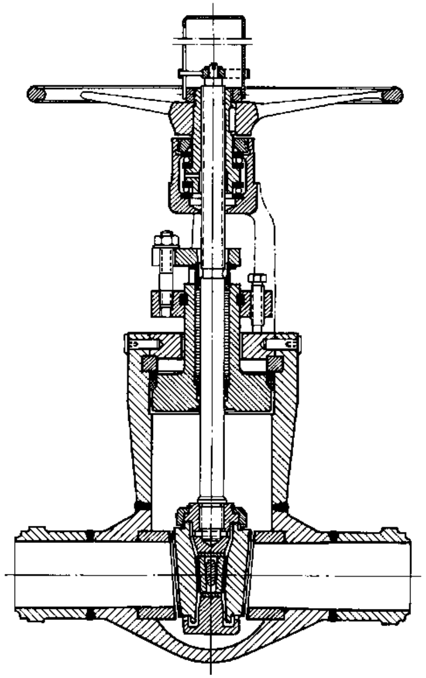

Abb. 474. EK-Hochdruck-Absperrschieber (Dingler-Werke)

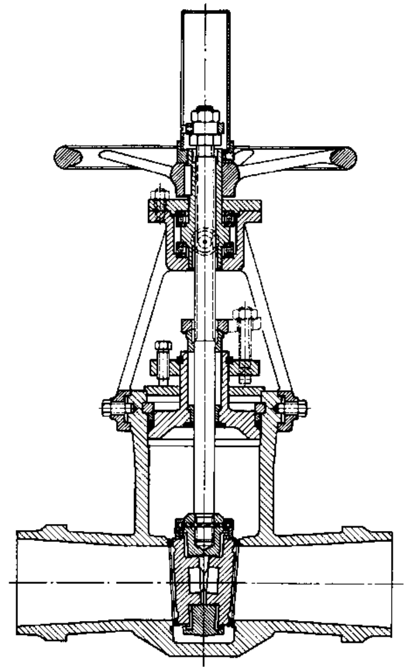

Abb. 475. Panzer-Hochdruck-Absperrschieber (KSB, Werk AMAG)

Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

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Shut-off Valves (2)

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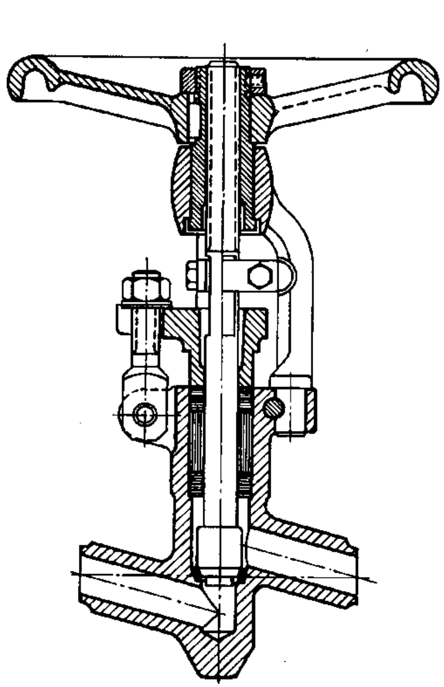

Abb. 492. Nico-Hochdruck-Absperrventil (Babcock-Werke)

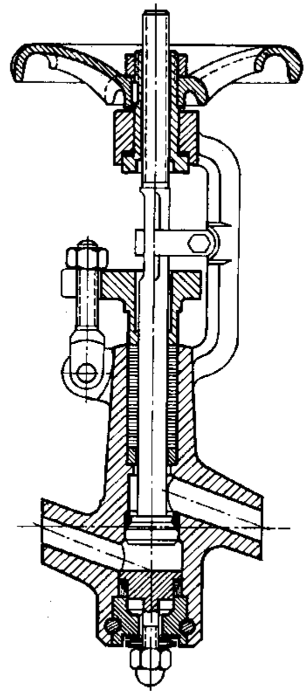

Abb. 493. Seba-Hochdruck-Absperrventil (Babcock-Werke)

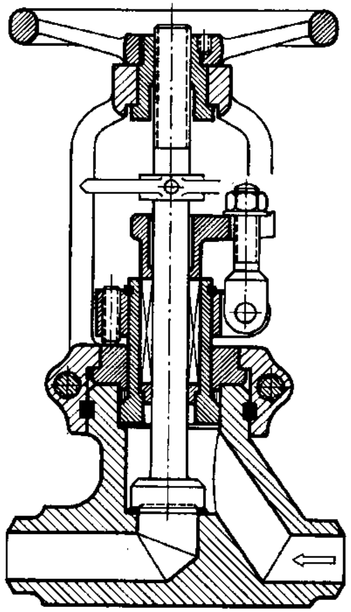

Abb. 494. Hochdruck-Absperrventil (Sempell)

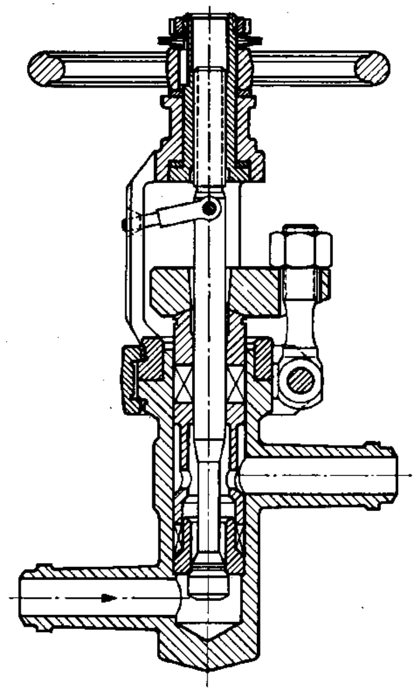

Abb. 495. Hochdruck-Eck-Absperrventil (C. H. Zikesch)

Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

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Regulation Valves

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Used to regulate or throttle a fluid flow, that is, can work partially open/closed.

Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

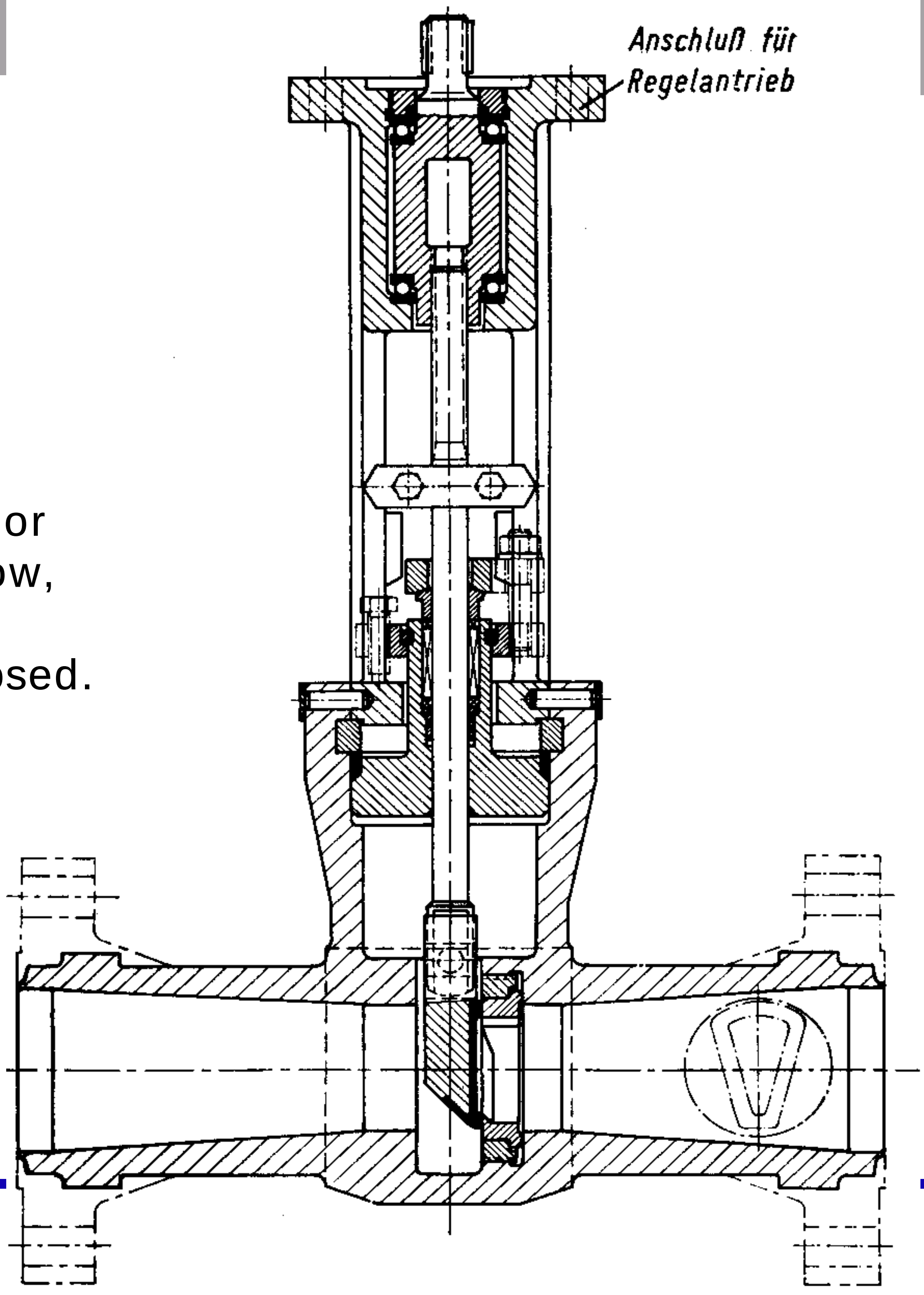

Abb. 515. Düsen-Regelschieber für Speisewasser-Mengenregelung (Dingler-Werke)

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Safety Valves

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Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

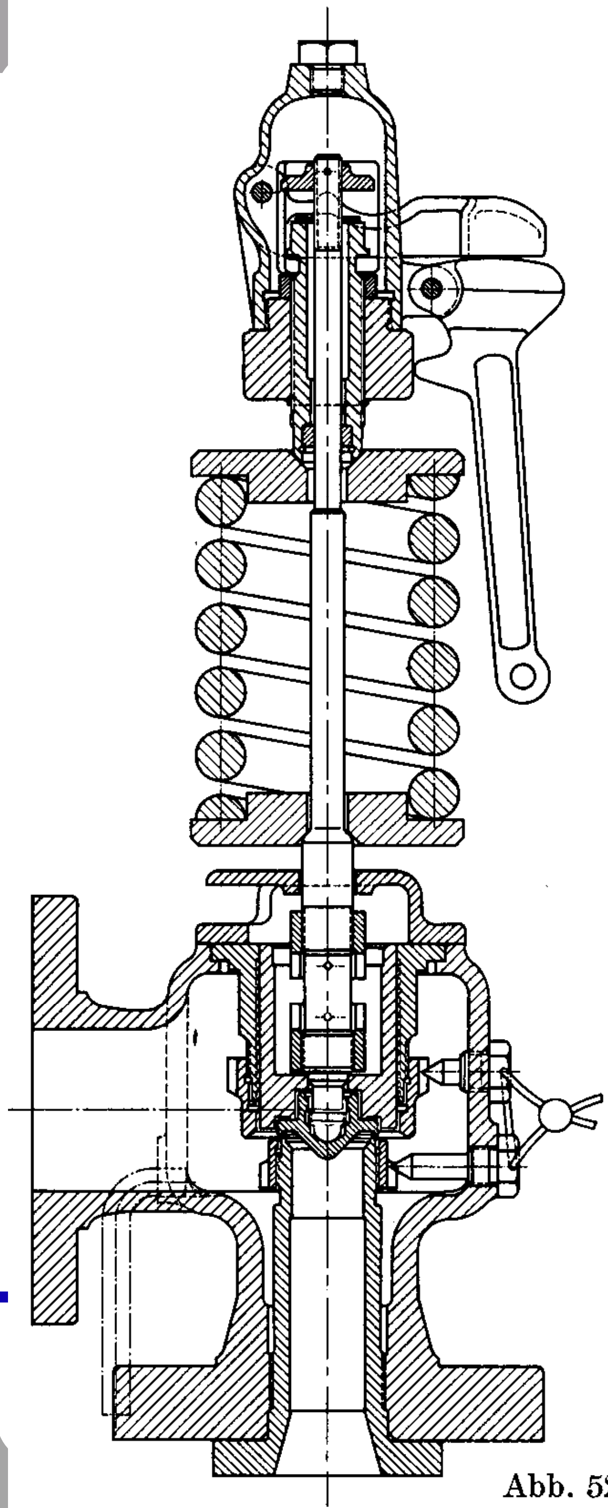

Abb. 520. Maxiflow-Hochdruck-Federsicherheitsventil (Babcock-Werke)

Releasing pressure or shutting off a flow quickly, if necessary

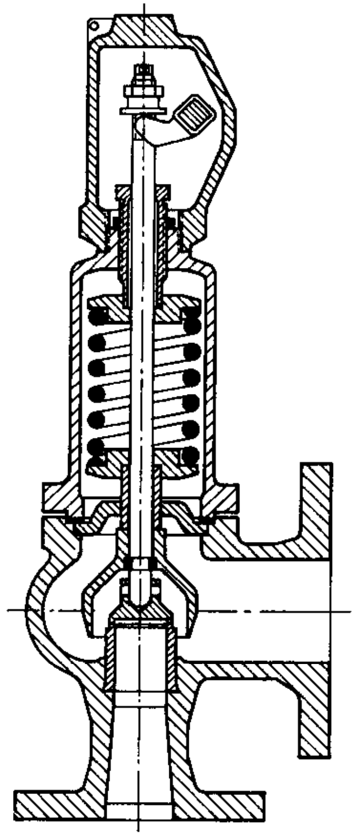

Abb. 521. Mitteldruck-Federsicherheitsventil (Bopp & Reuther)

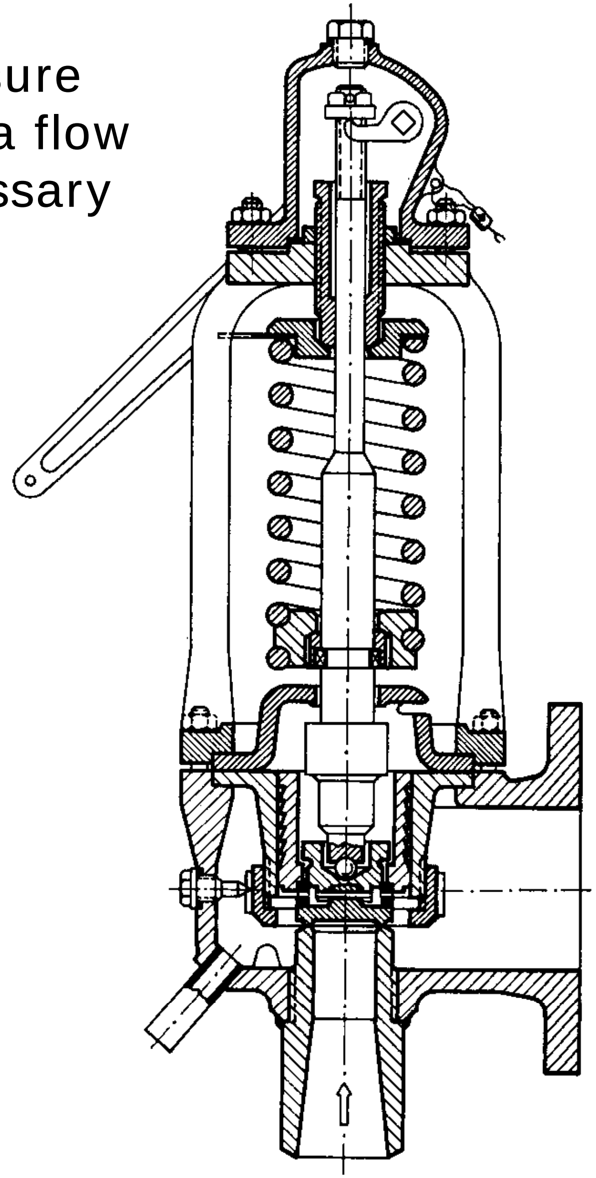

Abb. 522. Reaktor-Federsicherheitsventil (Sempell)

Combined shut-off & regulating valve

Typically used in front of a steam turbine to regulate the flow of steam with minimum throttling losses, or to shut it off entirely.

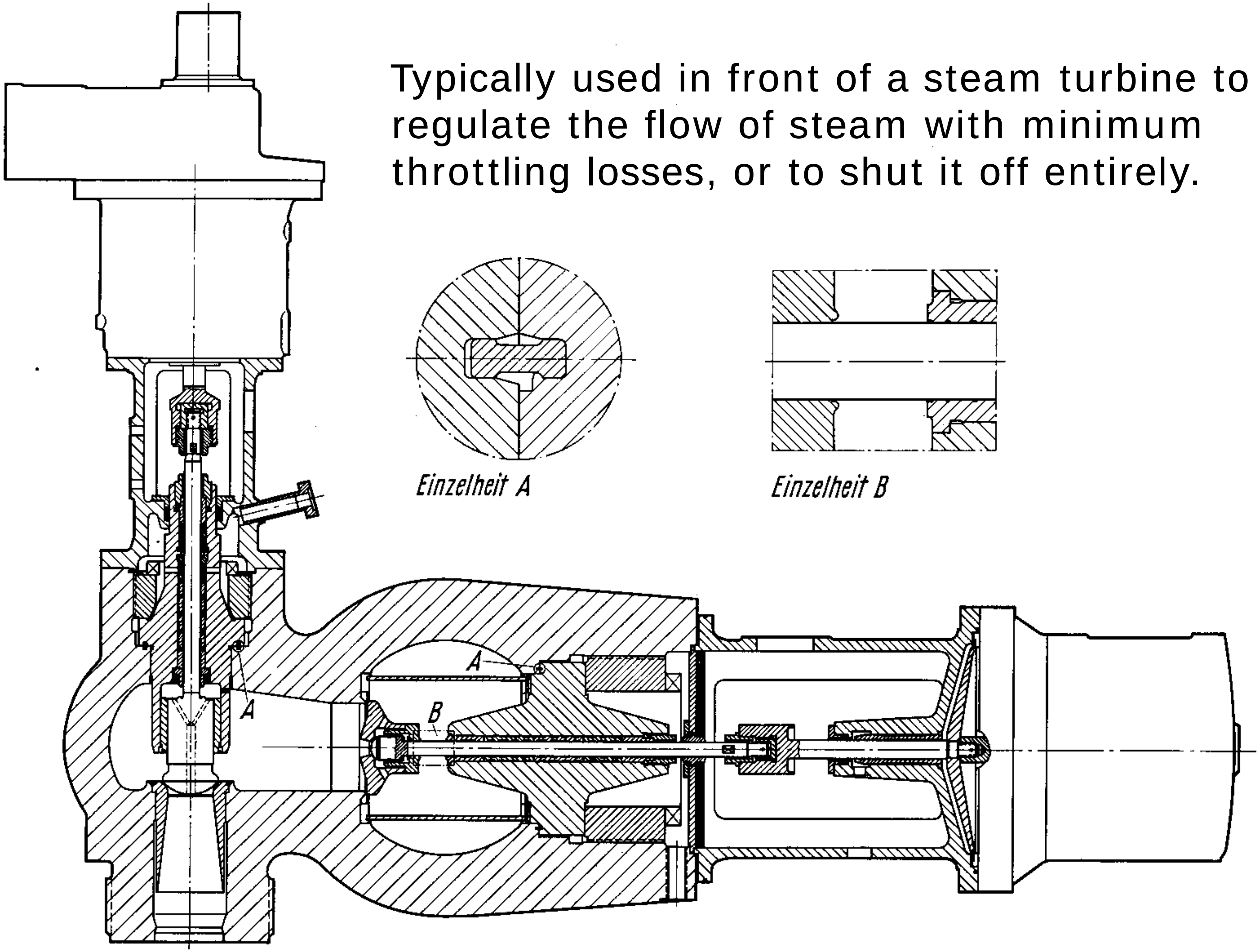

Abb. 69. Kombiniertes Schnellschluß-Stellventil

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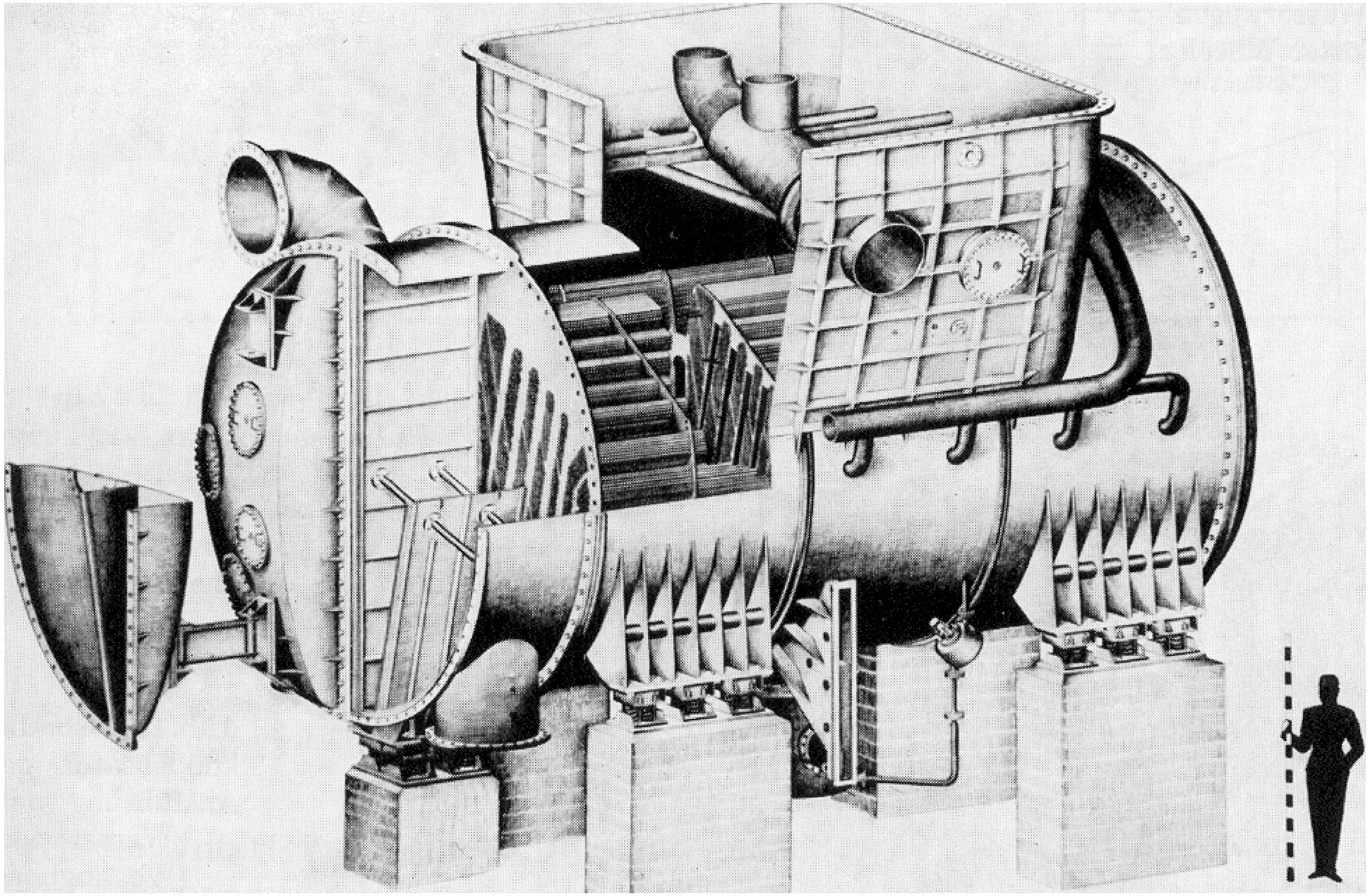
Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

Steam Condenser



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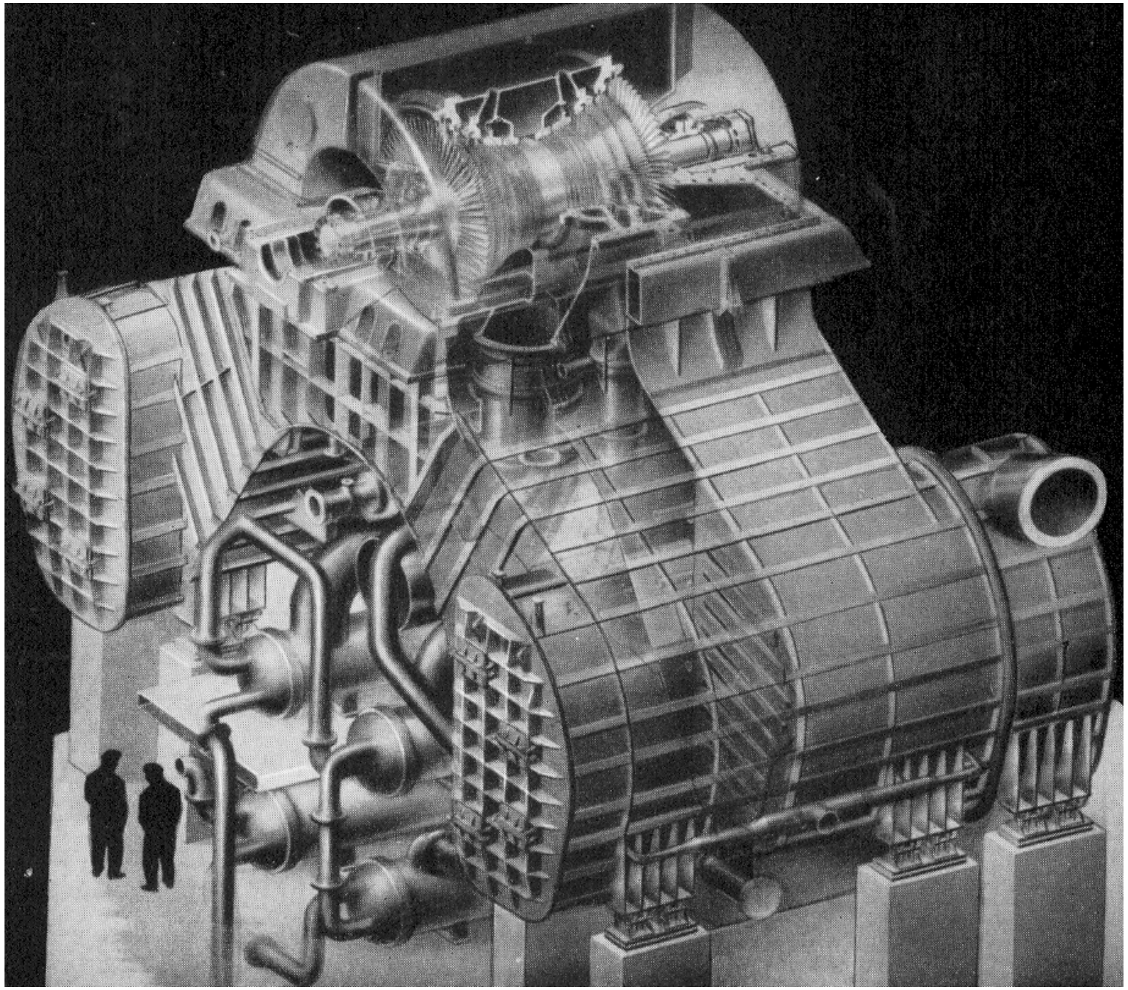
Source: Karl Schröder
"Grosse Dampfkraftwerke",
Springer-Verlag
1966

Steam Condenser



A very bulky heat exchanger, due to small temperature difference between condensing steam and cooling water.

Compare the turbine size (top of the figure) and the condenser size (with two sections, under the turbine)

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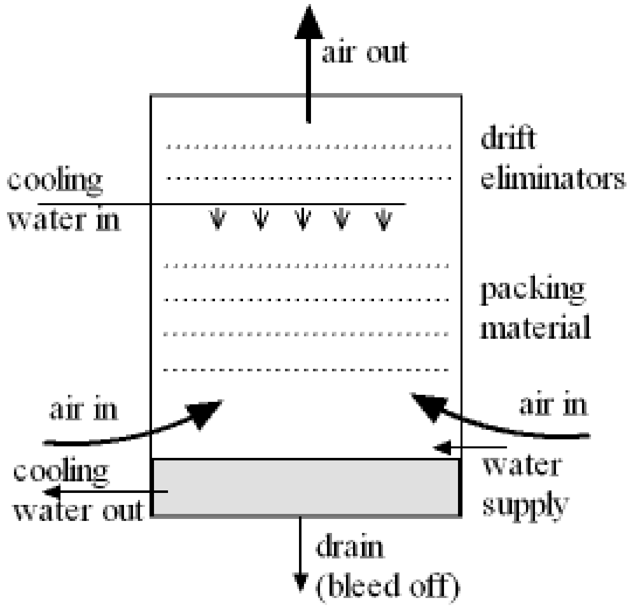
Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

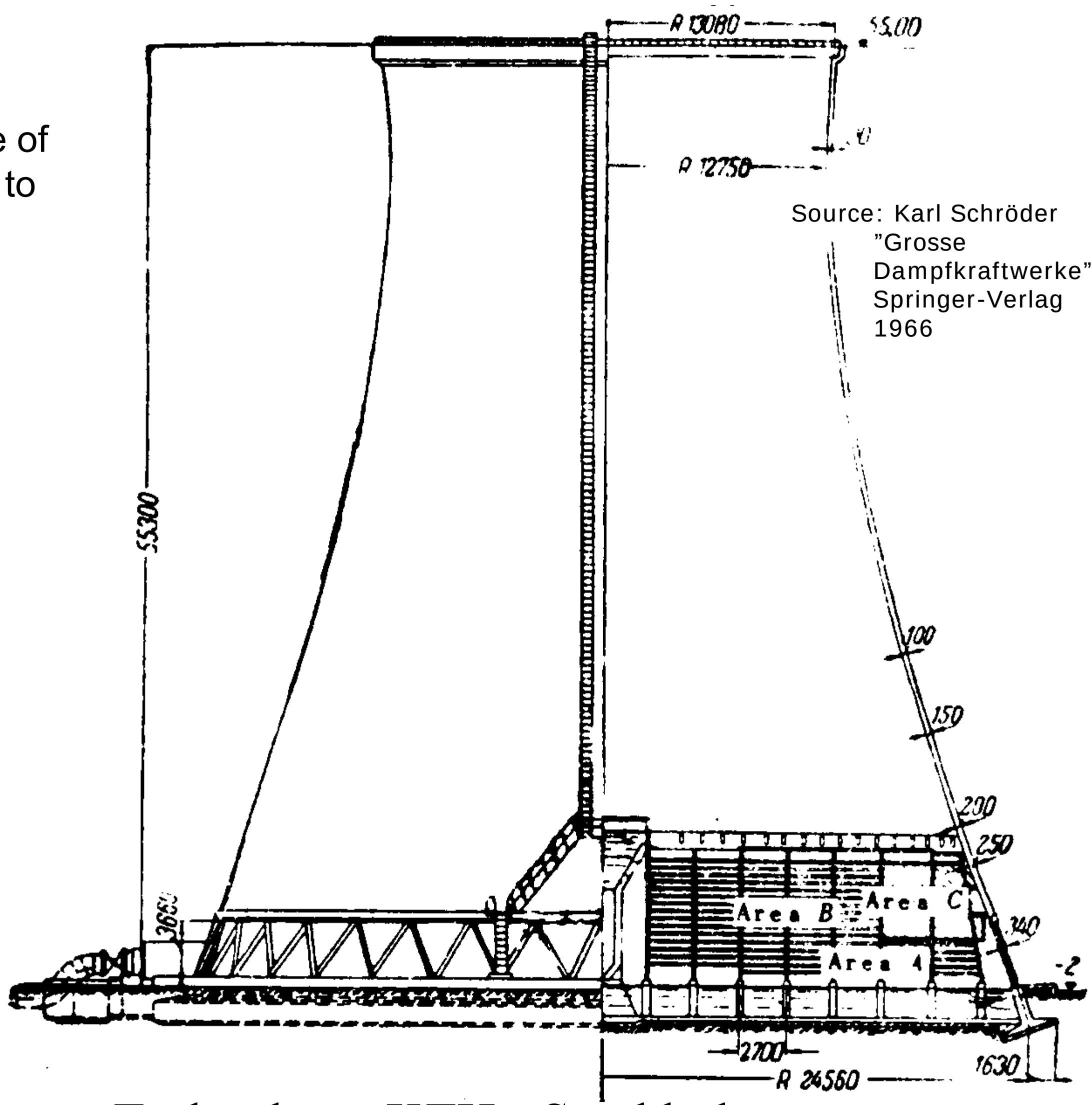
Cooling Towers (natural draft)

Used when cooling water supply (river/lake/sea) is not readily available in the vicinity.

The cooling water releases heat to the ambient air, while some of it evaporates in the process and thus the cooling tower is able to achieve temperatures lower than the ambient air temperature!



Source: www.engineeringtoolbox.com



Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

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Cooling Tower location

The cooling towers are situated close to the condenser hall.

They often are the largest structures in the plant, visible from far away. Can be integrated with the stack so that the gases are released inside the tower to help with the natural air draft.

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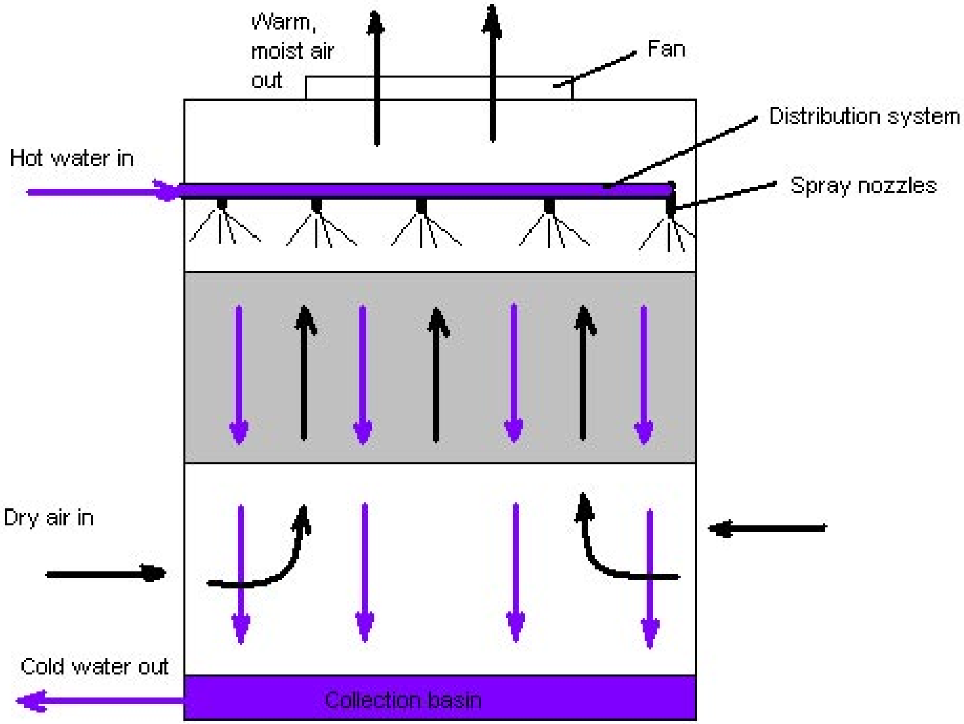
Source: www.lightandmatter.com

Cooling Towers (forced draft)

Cooling towers can use natural draft (thus the hyperbolic structure on the slides above), or forced draft where air flow is assisted by fans to decrease the tower size (shown here).



Counterflow type design

Source: www.bionwater.com.au

Source: www.bigvalleynews.net/BigValleyPower/TourOfBigValleyPowerLLC.html

Air-Cooled Condenser

Sometimes air-cooled condensers can be used, replacing both the condenser and the cooling tower. They save water, but are enormous in size due to poor heat exchange. Below is shown a steam power station in South Africa with an air-cooled condenser.

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Figure 1: The Matimba power station. To the left (the eastern side of the plant) is the air-cooled condenser (ACC) plant – by far the largest such system in the world

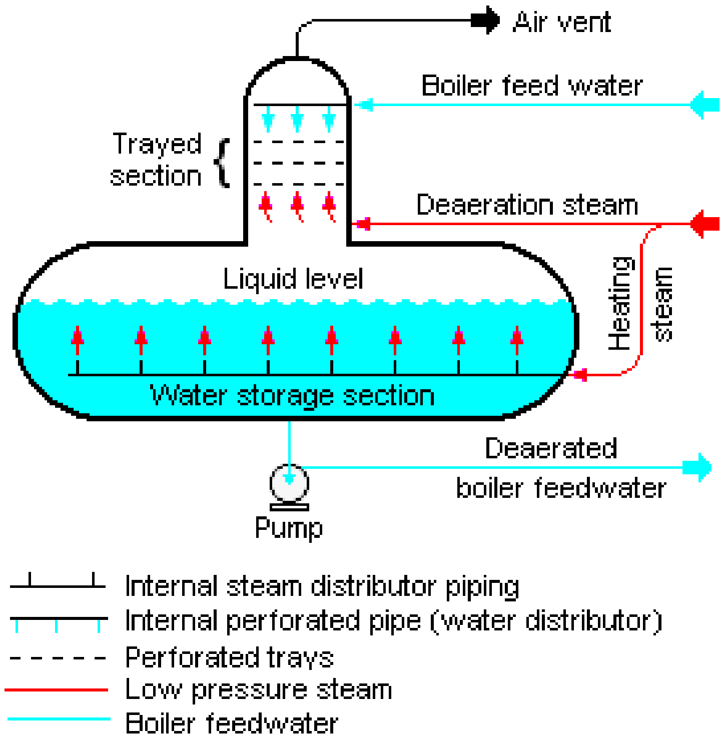
Source:
Modern Power Systems
Magazine, 2007

Water use in power plants

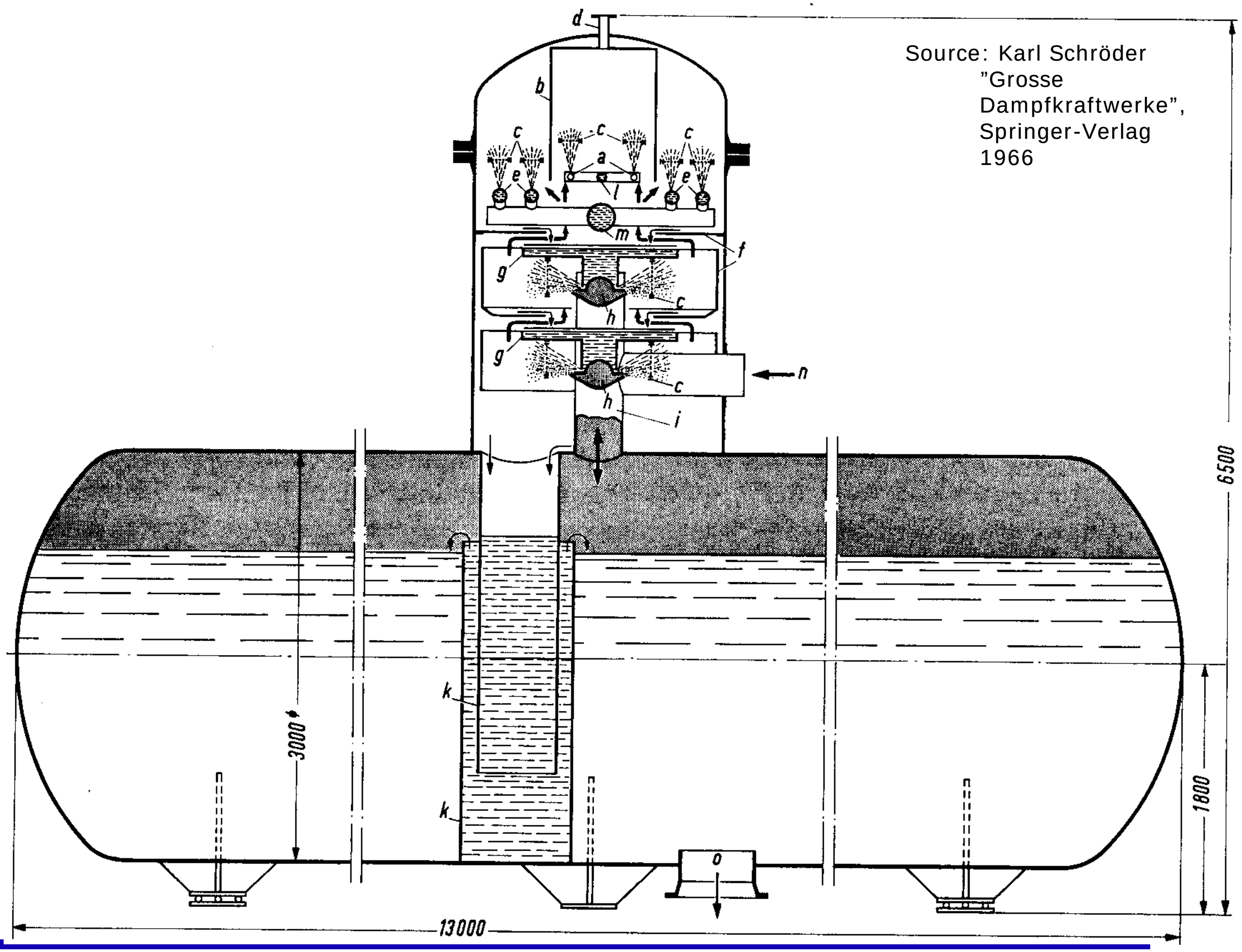
Eskom's new construction in South Africa (Medupi coal plant) will have 6 units of 794 MWel each, relying entirely on a huge air-cooled condenser. Special attention is given to achieve minimum water requirements, including effluent water treatment for maximum water reuse within the plant.

Source: www.powerengineeringint.com

Feedwater Tank - Deaerator

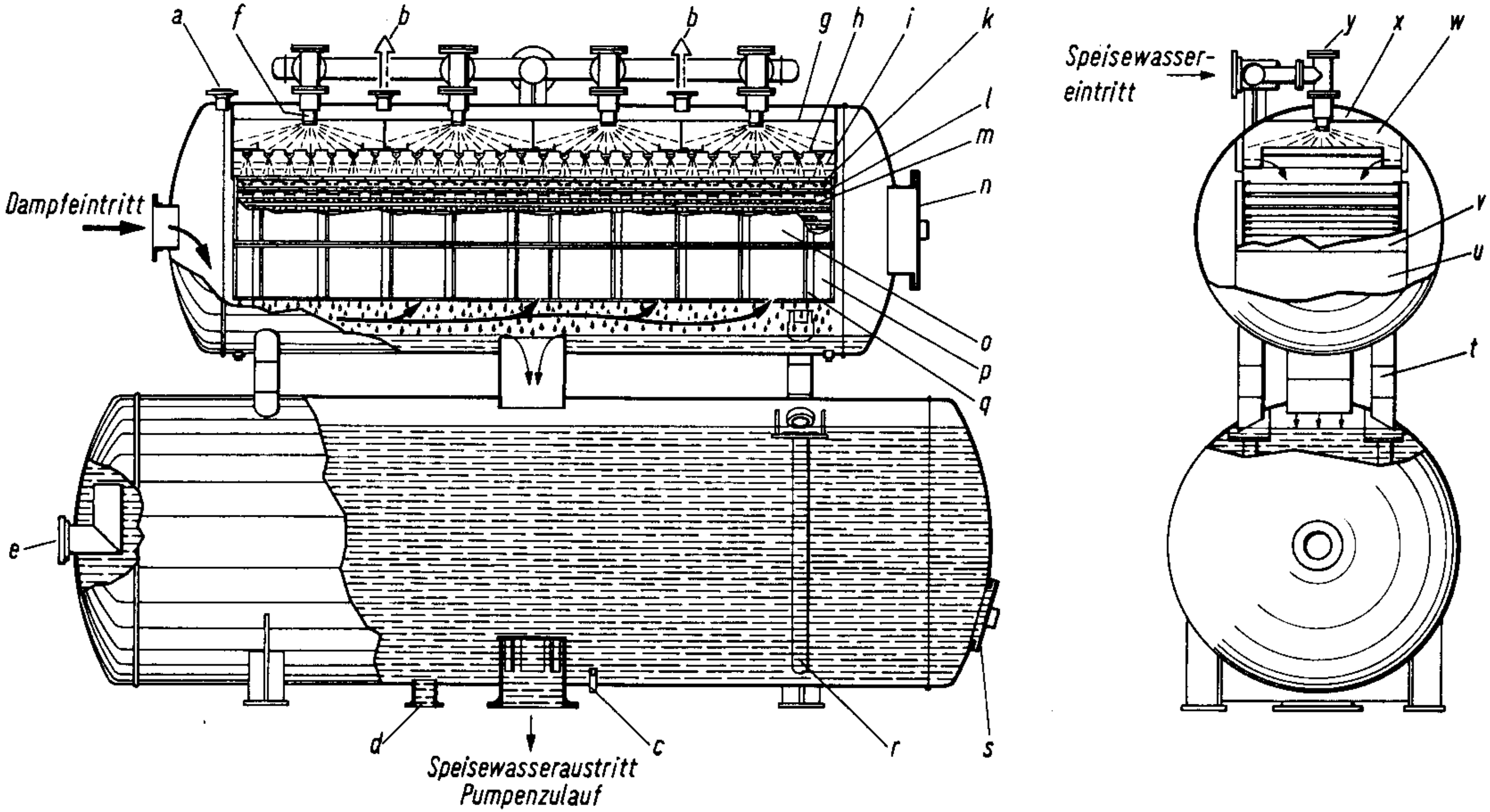


Source: Wikipedia



Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

Feedwater Tank (alternative design)



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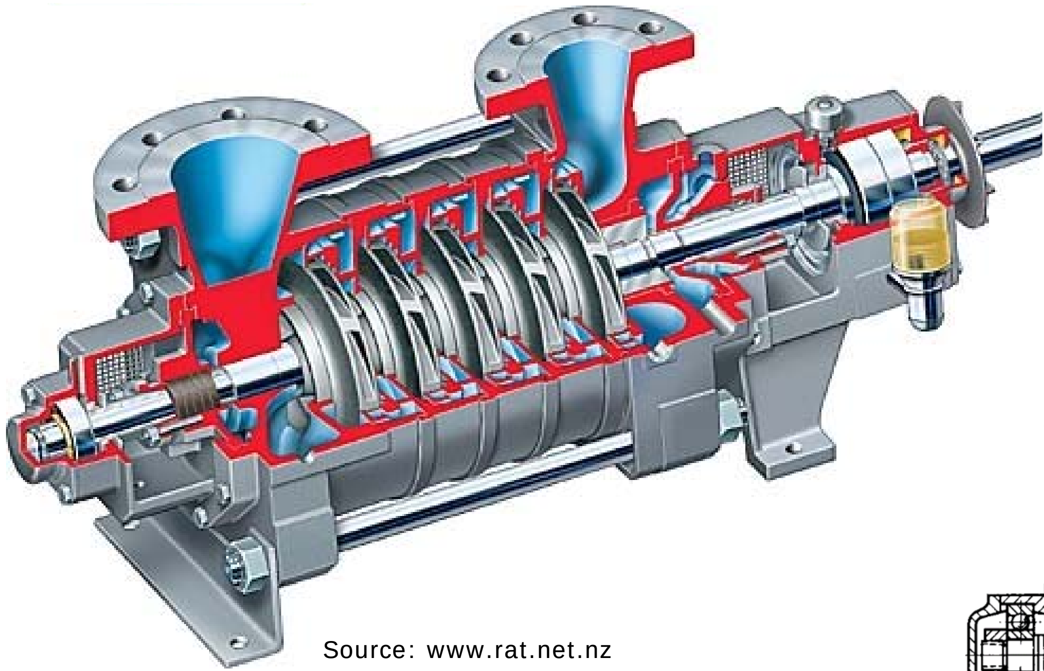
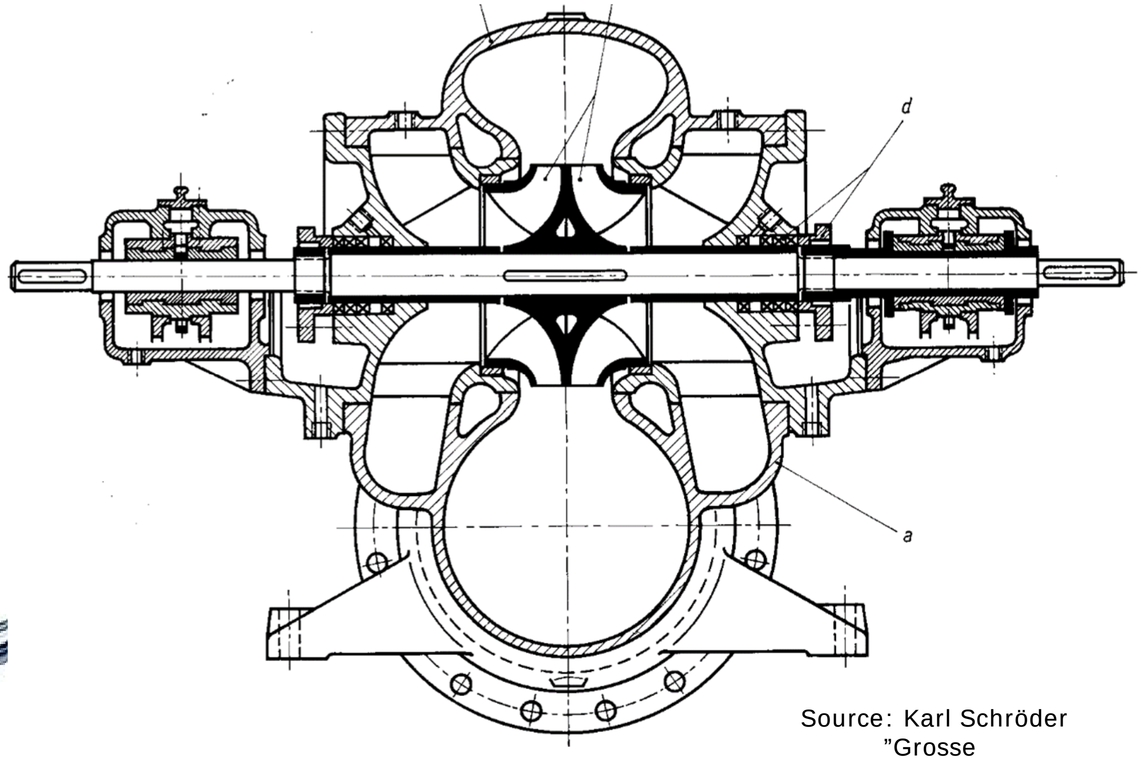
Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

Feedwater Pump

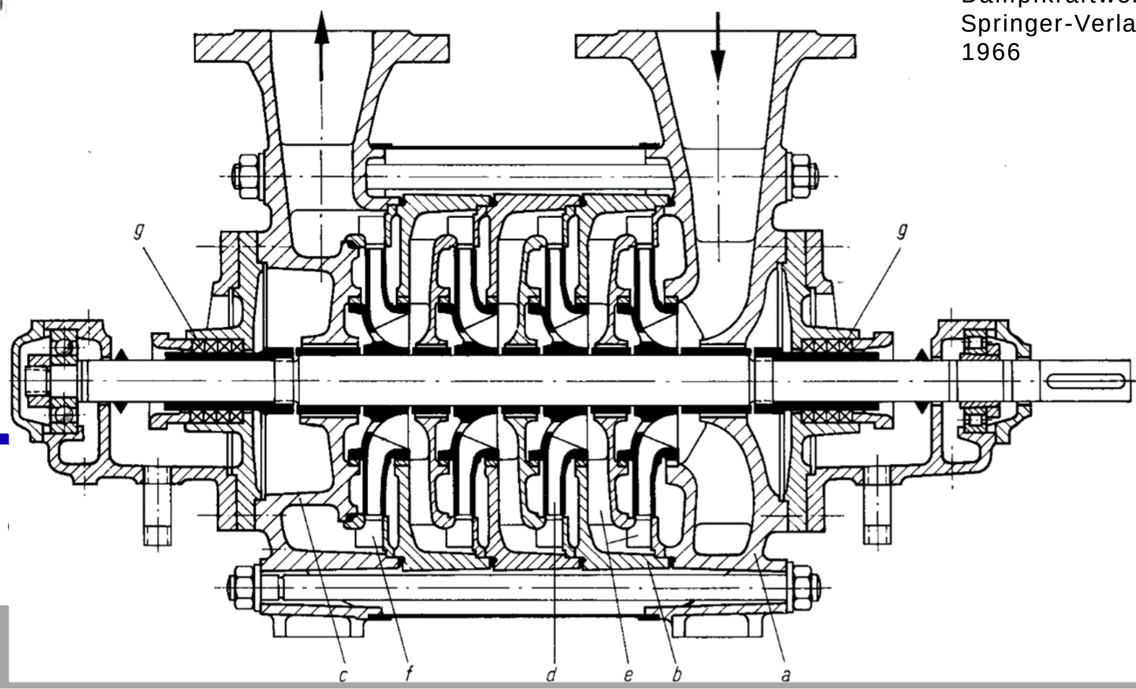
Double-inlet high-flow low-pressure pump (top right) after the condenser, or a multistage high-pressure feedwater pump (below) after the feedwater tank.



Source: www.rat.net.nz

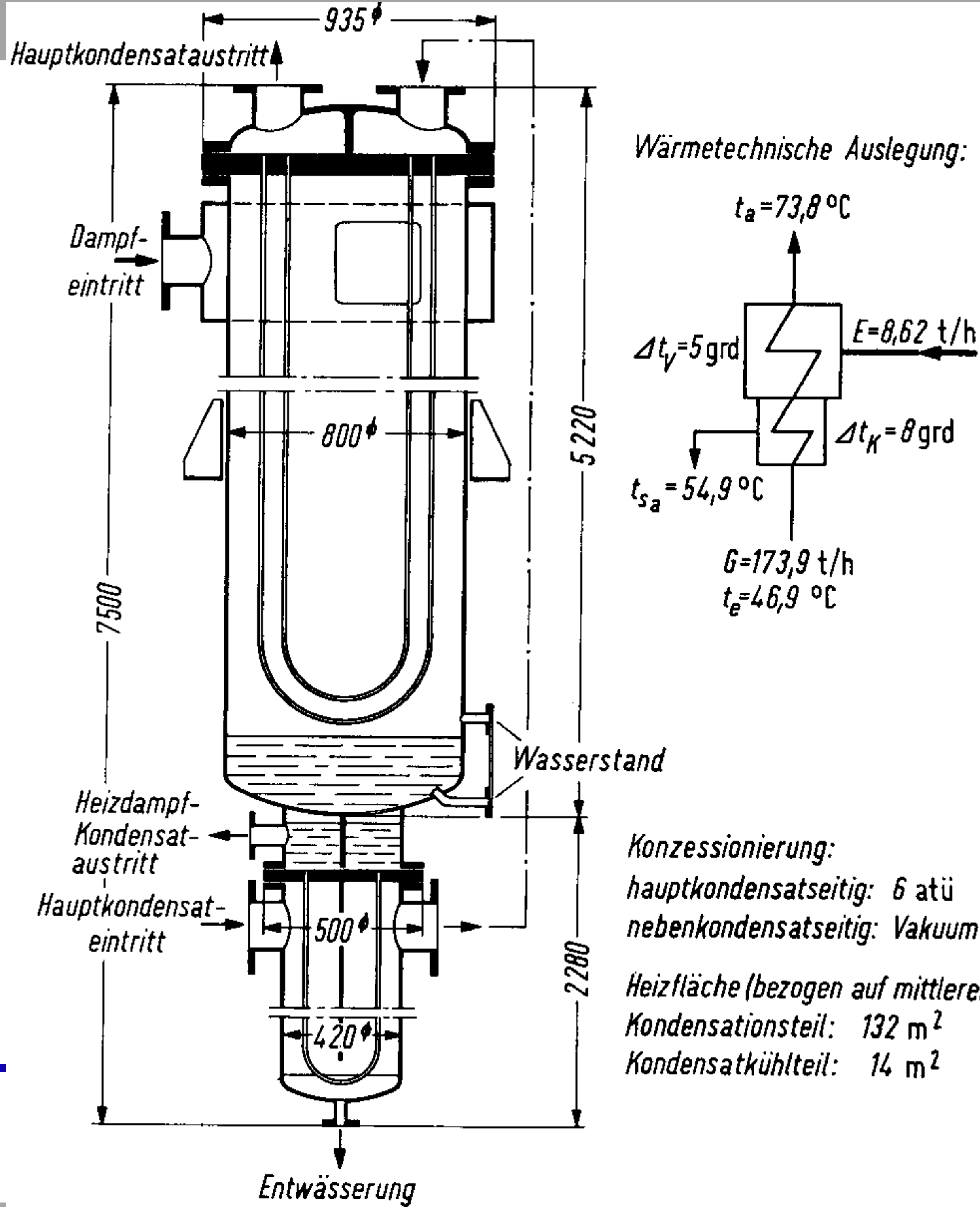


Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966



Feedwater Preheater

A typical low-pressure preheater design:



Source: Karl Schröder "Grosse Dampfkraftwerke", Springer-Verlag 1966

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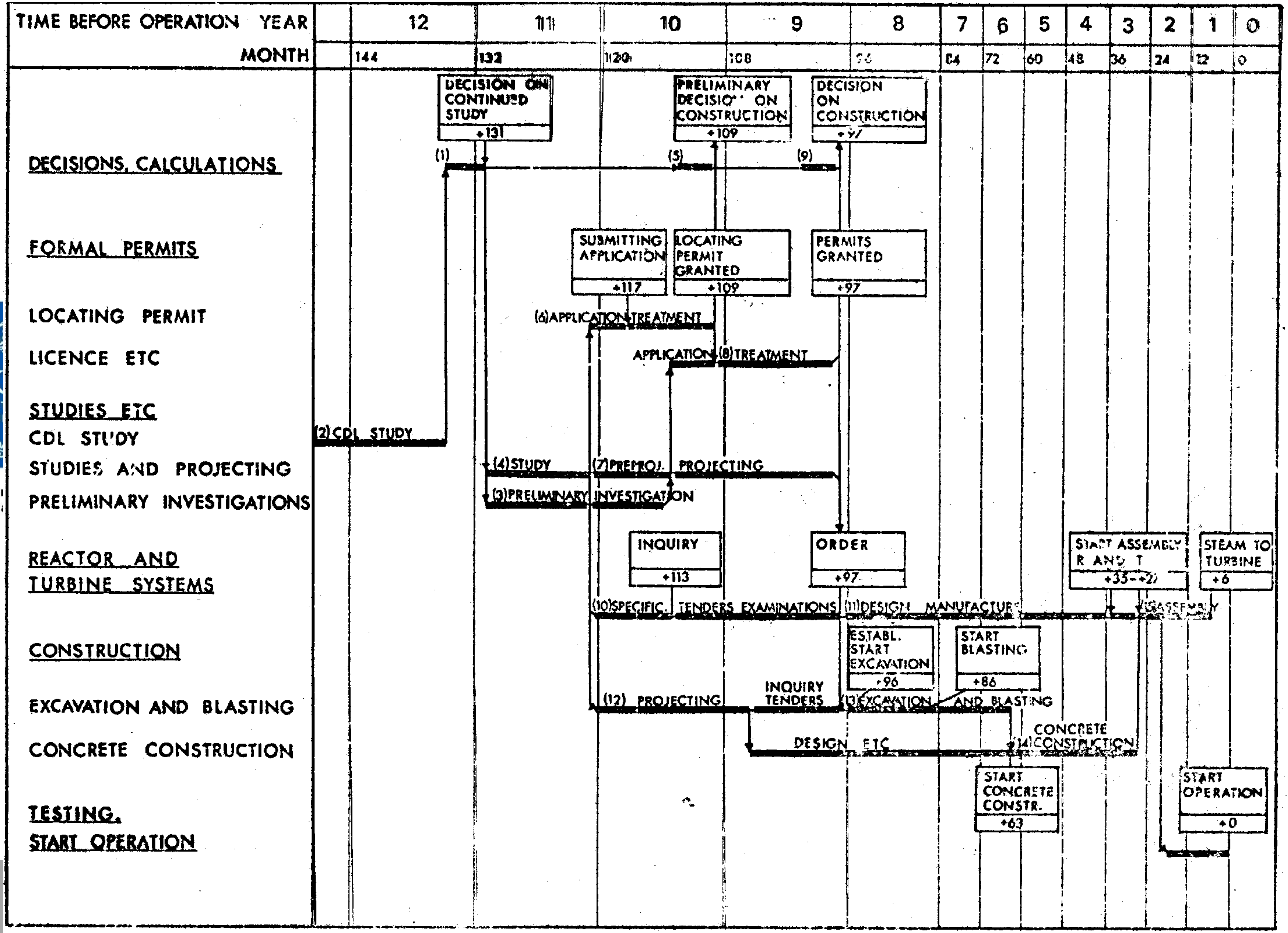
Project Time Scheme

- Principal decision on power plant investment
- Requests for permits, environmental screening
- Deciding the general layout and location
- Invitation of bids
- Evaluation of bids
- Final decision on “go” or “no-go”
- Contracts with suppliers and builders
- Construction and erection of hardware
- Tests and first grid-synchronization
- Evaluation of performance, repairs or alterations if necessary
- Official acceptance of delivery & start of operation
- Warranty period, insurances

Construction Time Scale



Options for Equipment Purchase

- Many separate suppliers (high own competence necessary)
- A few separate suppliers (good coordination necessary)
- One general supplier + several small sub-suppliers
- "Turnkey" delivery (everything supplied and built by one commissioner, including education of operating staff)

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Maintenance issues

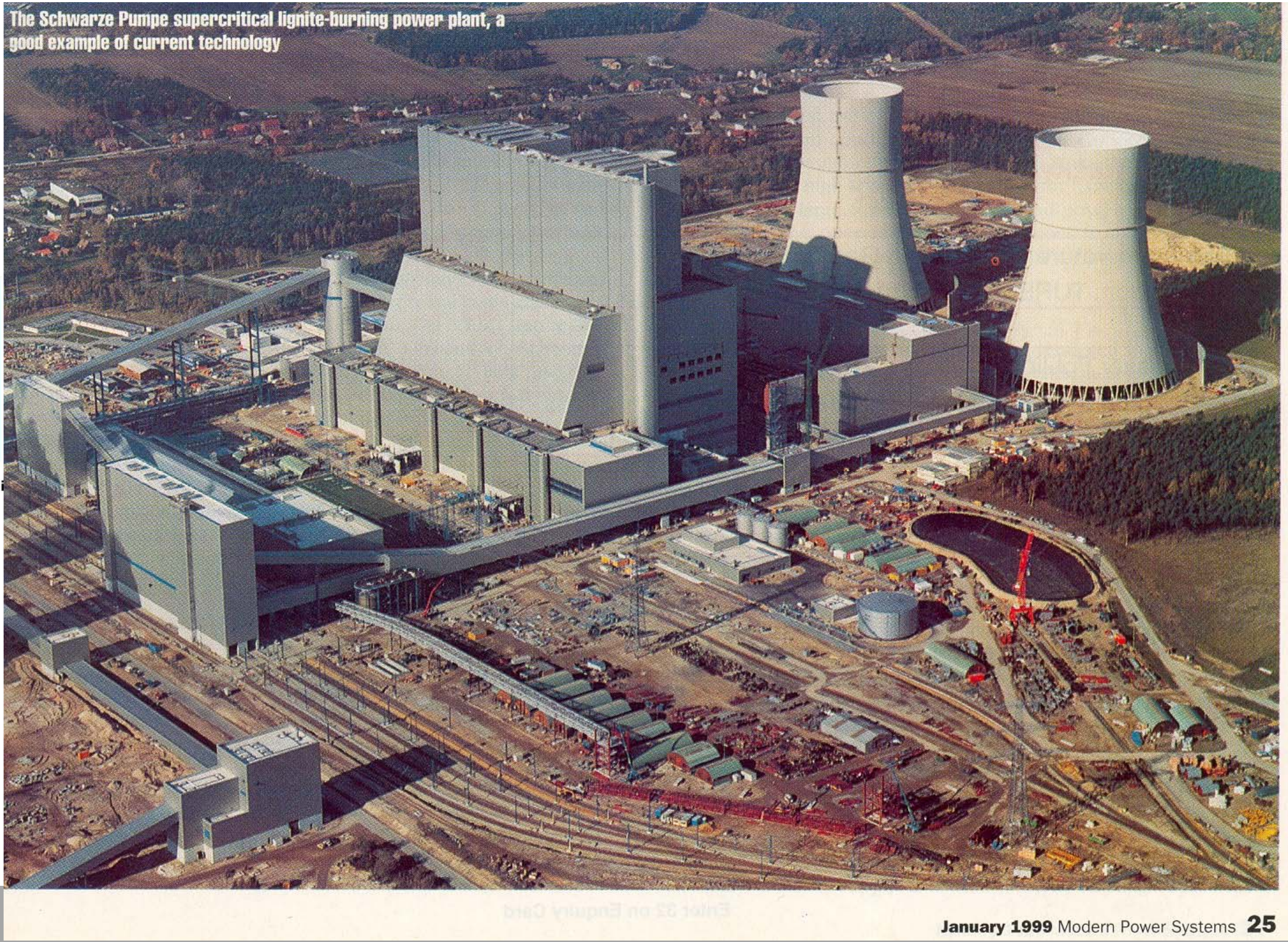
Maintenance of power plant components (or any mechanical device) involves two main types of activities:

•*Preventive maintenance* **- necessary regular activities without a real failure, control of parameters, regular checks.**
Preventive maintenance is often done while the facility is shut-down for other reasons.
***At least two service checks per major component per year*!**

•*Corrective maintenance* **- actual repair after a failure has occurred and a unit or component is out of order.**

The goal should be to maintain availability levels above 95%
Modern large power plants usually reach availability around 90%

Innovative Steam Power Plants



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Source:
Modern Power Systems,
January 1999

New Coal Power in Europe

A new coal-fired plant near the city of Hamm in Germany (2013), designed to operate flexibly for balancing the large intermittent renewable energy production. The cooling towers are also used as smoke stacks.

There is now about 65 GW installed capacity of wind turbines and solar PV in Germany, and the need for balancing power is becoming crucial. Fossil-based power generators will be getting subsidies to ensure the stability of the grid !!

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Source: Power Engineering International Magazine, (www.powerengineeringint.com)

Architectural and Safety Issues

Underground power plant near Stenungsund in Sweden, used only for back-up –
4 oil-fired steam units, inbuilt in the bedrock. Only the stacks are visible from outside.

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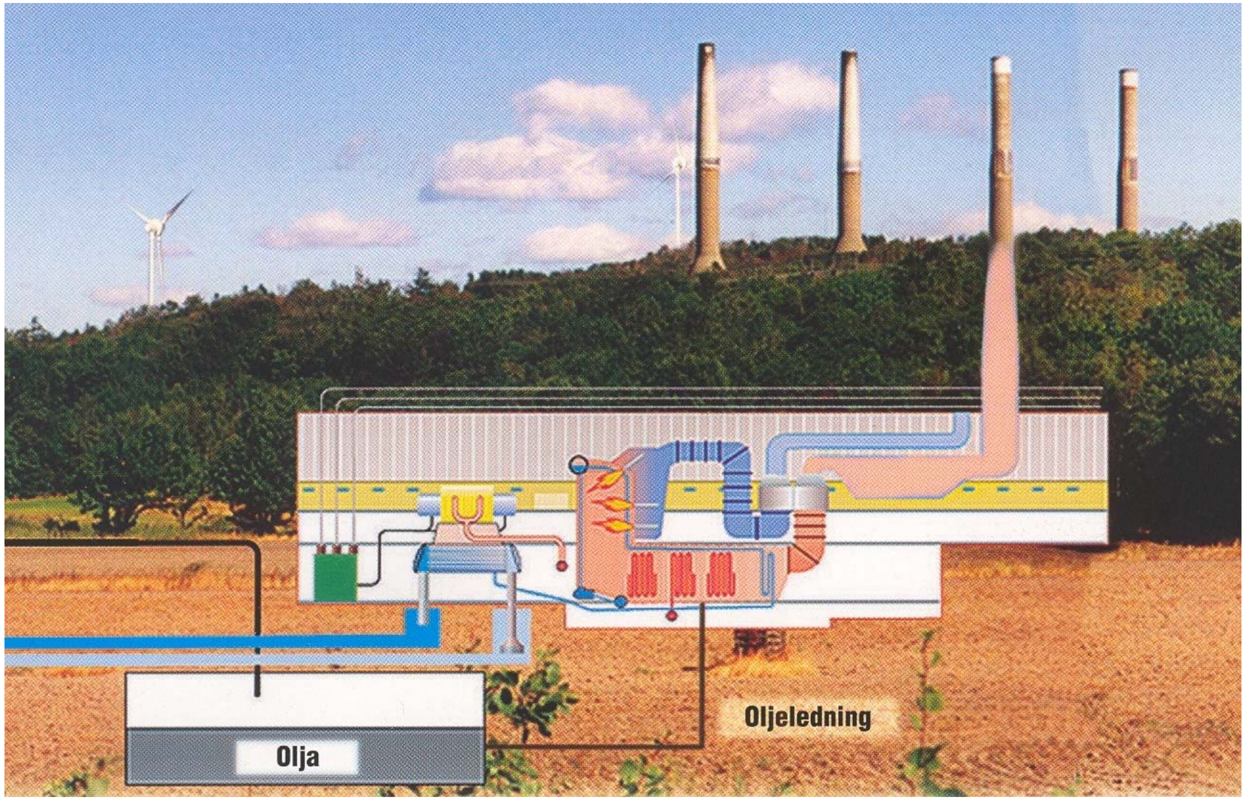

Architectural Issues

Examples of stylish CHP plants in Denmark: a Piston Engine plant in Helsingør (left), and the new large-scale gas-fired steam unit at Avedøre, Copenhagen (right)

Source: www.bwsc.dk

Source:www.greenpeace.org.uk

Efficiency Improvements

- Higher temperatures (and pressures) in steam plants
- Higher temperatures in gas turbines
- Decreasing the losses in boilers, turbines, pipes, etc.
- Less auxiliary (self-used) power
- Better control methods and planning, higher flexibility
- More complex cycles (combined or hybrid cycles)
- More extensive CHP operation or integration with industrial processes that consume heat or deliver waste heat…

¿ Sustainability ?

How to make a power plant more sustainable?

Problem: *Do we define sustainability as climate change, or as job opportunities, or as local/regional pollution?*

In your professional career, you will hopefully work with:

- *Refurbishing old power plants or designing new ones with improved technology and better (innovative) components;*
- *Shifting from fossil to renewable fuels or blends;*
- *Increased efficiency, decreased pollution, novel cycles;*
- *Carbon capture and sequestration from fossil fuels;*
- *Safer and more efficient nuclear plants and nuclear fuels...*

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