INDUSTRIAL APPLICATIONS OF STEAM

Harnessing Thermal Energy Across Engineering Sectors

Introduction — What Is Industrial Steam?

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STEAM

Water vapour above 100 °C at atmospheric pressure, carrying latent and sensible heat energy used to perform work across industrial processes.

2,260	kJ/kg Latent Heat
100°C+	Operating Temp
80%	Global Electricity

- Power Generation
- Manufacturing
- Food Processing
- Petrochemicals
- Healthcare
- District Heating

Global Importance of Steam in Industry

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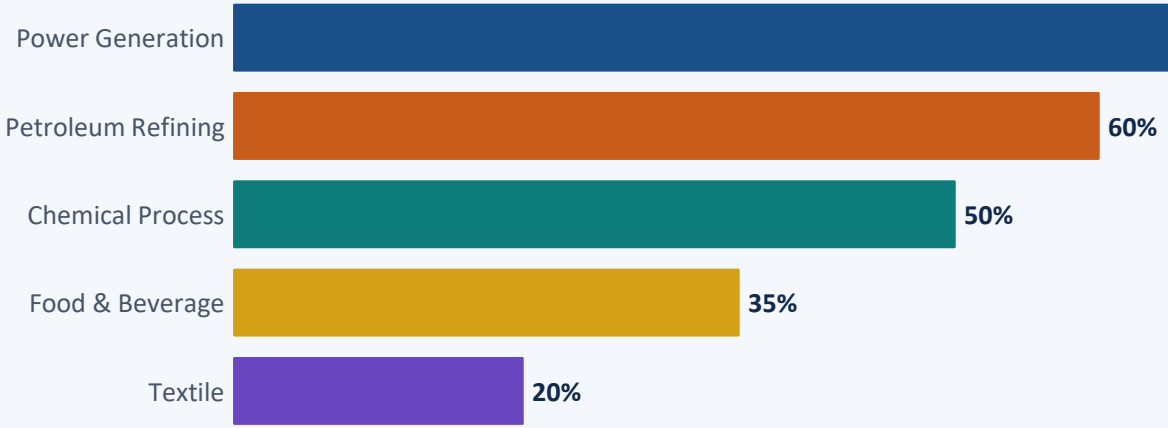
80%
of world electricity generated via steam

$500B
global steam equipment market value (2023)

140+
countries use steam in industrial processes

45%
of industrial energy consumption is steam

Steam Usage by Sector (% of energy input)



Steam is the backbone of global energy infrastructure

Steam Generation — The Core Process

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01 — Feedwater Treatment

Deaeration, demineralisation

02 — Boiler Furnace

Fuel combustion, heat transfer

03 — Steam Drum

Phase separation sat. steam

04 — Super-heater

>300 °C, dry superheated steam

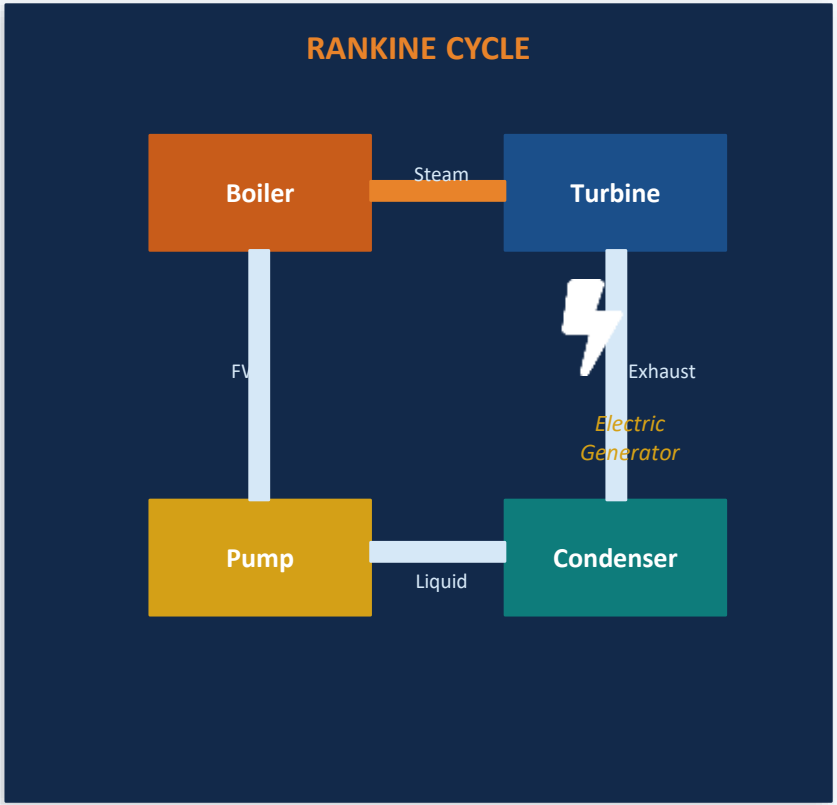
05 — Distribution Header

Pipework, valves, traps

HEAT SOURCES:

- Coal / Gas / Oil
- Nuclear Fission
- Biomass
- Solar Thermal
- Waste Heat Recovery

Application 1 — Power Generation



Coal Power Plants

Steam at ~570 °C, 250 bar. Efficiency 33–40%. Largest single source of electricity globally.

Nuclear Power

Steam at ~280 °C, 70 bar. No CO_2 emissions. Provides ~10% of world electricity.

Combined Cycle (CCGT)

Gas turbine exhaust heat used to generate steam. Efficiency up to 60%.

Cogeneration (CHP)

Simultaneous electricity and heat supply. Efficiency 80–90%, reducing fuel waste.

Application 2 — Petroleum Refining & Petrochemicals

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Crude Oil Preheat

Steam heat exchangers 250–350 °C

Atmospheric Distillation

Steam stripping of light fractions

Vacuum Distillation

Steam ejectors maintain vacuum

Steam Reforming

H2 production: CH4+H2O -> 3H2+CO

Hydroprocessing

Steam for H2S removal

60%

of a typical refinery's energy demand is supplied by steam

Steam Tracing

Keeps viscous crude and product pipelines warm to prevent solidification in transit.

Turbine Drives

High-pressure steam drives pumps and compressors — no electrical power needed.

Sour Gas Stripping

Steam strips H2S from amine solutions, enabling sulphur recovery.

Ejectors & Vacuum

Steam jets create vacuum in distillation columns without moving parts.

Application 3 — Food & Beverage Processing

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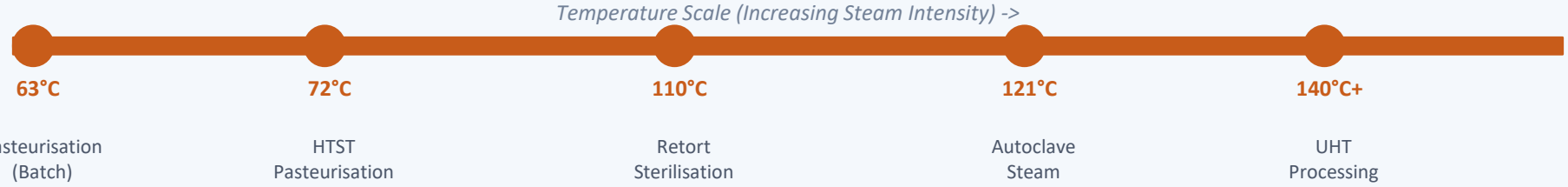


Sterilisation

Autoclave steam kills pathogens at 121 °C / 15 psi. Essential for canned goods and dairy.

Blanching

Brief steam exposure deactivates enzymes in vegetables, preserving colour and nutrients.

Evaporation

Steam-heated evaporators concentrate fruit juices, syrups, and dairy products efficiently.

Cooking

Steam ovens maintain moisture. Retort cooking sterilises packaged ready-meals.

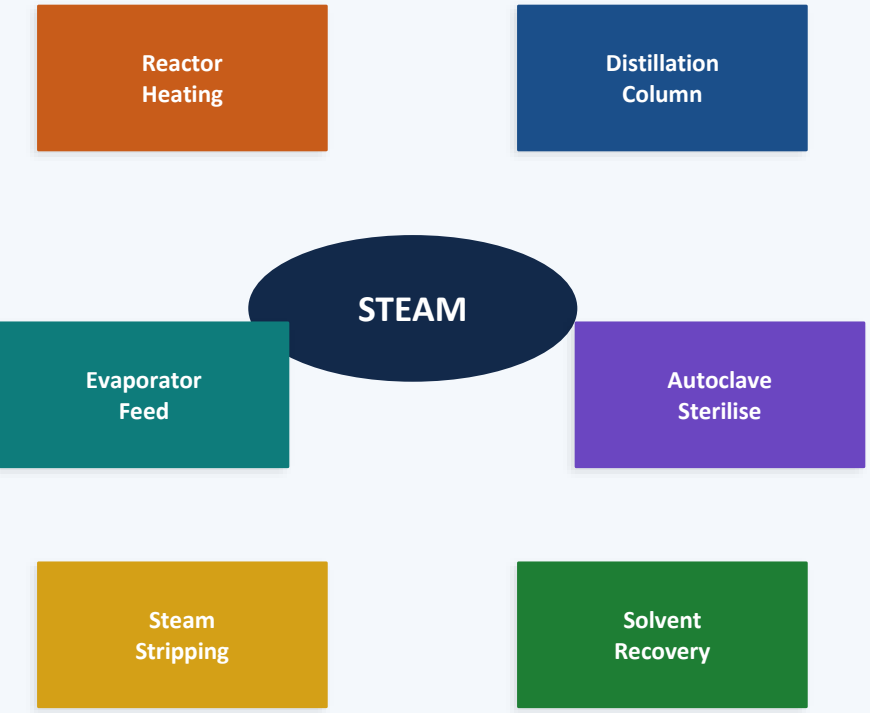
CIP Cleaning

Clean-in-place systems use steam to sanitise tanks, pipelines, and heat exchangers.

Drying

Steam-heated drum dryers produce milk powder, instant coffee, and cereal products.

Application 4 — Chemical & Pharmaceutical Industries



Pharmaceutical Applications

WFI Production

Water For Injection via multi-effect distillation using clean steam.

Vessel Sterilisation

SIP (Steam-in-Place) sterilises bioreactors at 121 °C / 15 min.

Clean Steam

Filtered, pharmaceutical-grade steam meeting EU GMP standards.

Lyophilisation

Steam-heated shelves in freeze-dryers for vaccine preservation.

Application 5 — Textile & Paper Industries

TEXTILE INDUSTRY

1. **Scouring**
   Steam + alkali removes natural oils and waxes from raw fibres.
2. **Dyeing**
   Steam fixing at 100–130 °C bonds reactive dyes to fabric permanently.
3. **Finishing**
   Steam calendering and pressing gives fabric final texture and shine.
4. **Steaming**
   High-temp steam sets print patterns without colour bleed.

PAPER INDUSTRY

1. **Pulping**
   Steam + chemicals break down wood into cellulose pulp (kraft process).
2. **Drying**
   Steam-heated cylinders (>120 °C) evaporate water from the paper web.
3. **Calendering**
   Steam softens fibres before pressing — improves sheet smoothness.
4. **Coating**
   Steam drying of clay coating improves print quality.

Paper industry uses up to 30 GJ of steam per tonne produced | Textile sector: ~45% of process energy is steam

Application 6 — Steel & Metallurgical Processes

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- Steam Power for Rolling Mills & Mechanical Drives
- Descaling — Steam Jets at 250 bar Remove Oxide Scale
- Quenching & Cooling Control
- Blast Furnace Humidification
- Sintering Process

WHR
Waste Heat Recovery

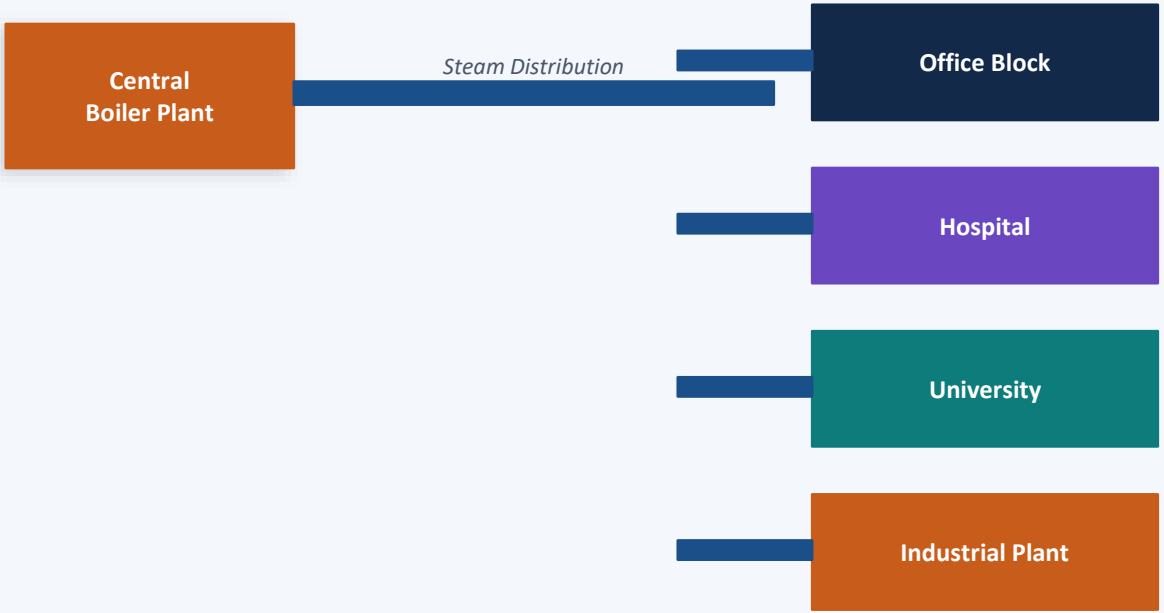
Steel mills recover exhaust gas heat to generate steam — reducing fuel use by up to 40% and cutting CO_2 significantly.

1,700°C
steel melting temperature

250 bar
descaling steam pressure

40%
energy savings with WHR steam

Application 7 — District Heating & Building Systems



City-Scale Networks

Cities like New York, Helsinki, and Paris use steam district heating for thousands of buildings.

Space Heating

Steam radiators heat buildings without combustion on-site — safer and cleaner.

HVAC Integration

Absorption chillers use steam to provide cooling — one network for heat and cool.

Efficiency Advantage

Centralised steam plant runs at 90%+ efficiency vs individual boilers at 70–80%.

New York City — 100+ km of steam pipes serving 1,800+ buildings since 1882

Application 8 — Healthcare & Medical Sterilisation

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AUTOCLAVE STEAM STERILISATION

1. Pre-Vacuum	Air removed — maximise steam penetration
2. Steam In	Saturated steam at 121 °C fills chamber
3. Hold Phase	Maintain 15 psi for 15–20 minutes
4. Exhaust	Steam released, pressure reduced
5. Dry Cycle	Vacuum drying removes moisture from load

Surgical Instrument Sterilisation

Steam at 134 °C / 3 min or 121 °C / 15 min eliminates all pathogens including prions.

Hospital Laundry

High-pressure steam laundering at 71 °C kills MRSA, C. difficile, and viruses.

HVAC Humidification

Clean steam maintains 45–55% RH in operating theatres to prevent electrostatic discharge.

Pharmaceutical GMP

Clean steam sterilises bioreactors, filling lines, and WFI stills to GMP standard.

Application 9 — Marine, Transport & Defence

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1807	1825	1884	1906	1955	2024
Steam Boat (Fulton)	Steam Railway (Stephenson)	Steam Turbine (Parsons)	HMS Dreadnought Naval turbine	USS Nautilus Nuclear steam	LNG Carrier Steam turbine

LNG Tankers

Steam turbines power LNG carriers because boil-off gas feeds directly into boilers — elegant energy reuse.

Naval Vessels

Aircraft carriers and nuclear submarines use steam turbines to generate electricity and propel the vessel.

Steam Catapults

US Navy carriers use steam catapults to launch aircraft. Each launch uses ~3 tonnes of steam in 2 seconds.

Cargo Heating

Steam heating coils in tankers keep heavy fuel oil and crude at flow temperature during transport.

Advantages of Steam as an Industrial Energy Carrier

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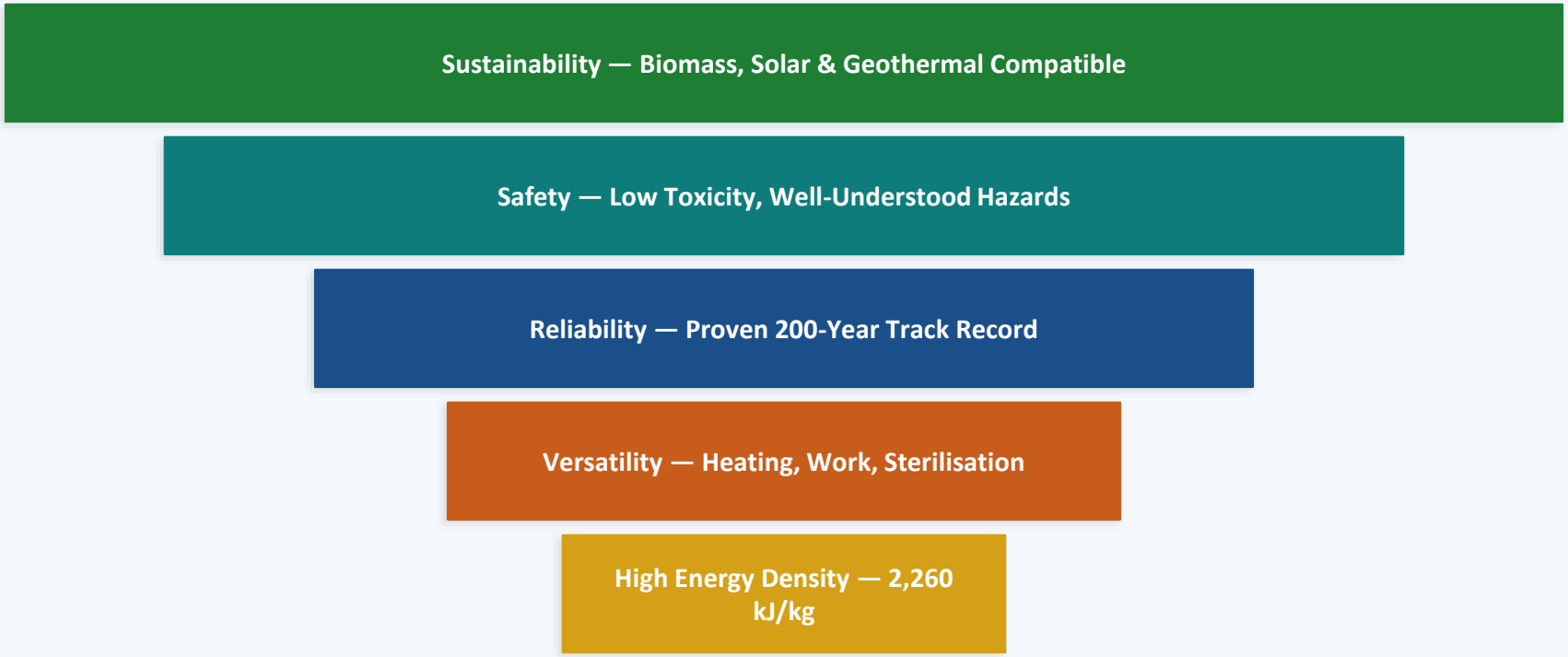

Cost-Effective

Water is the cheapest heat transfer fluid. Infrastructure is amortised over decades.

Controllable

Pressure and temperature can be precisely regulated via valves and controllers.

Long-Distance

Steam can be transported kilometres with less than 5% heat loss in insulated pipes.

Challenges & Limitations of Steam Systems

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STEAM SYSTEM CHALLENGES

- Corrosion & Scale Buildup
- High Capital Cost
- Steam Trap Failures
- Thermal Losses in Pipes
- Water Treatment Cost
- GHG if Fossil Fuel Fired

Mitigations: Water treatment | Insulation upgrades | Steam trap surveys | Green hydrogen boilers | Waste heat recovery

Steam vs Alternative Energy Carriers — Comparison

Property	Steam	Hot Water	Hot Oil	Electric
Temp Range	**100–600 °C**	70–200 °C	100–400 °C	Any
Energy Density	**Very High**	High	Medium	High
Controllability	**Excellent**	Good	Good	Excellent
Infrastructure	**Complex**	Moderate	Moderate	Simple
Safety	**Burns risk**	Moderate	Fire risk	Electrocution
Operating Cost	**Low**	Low	Medium	High
Carbon (green)	**Zero possible**	Zero poss.	Depends	Zero poss.

Steam's combination of high energy density, wide temperature range, and low operating cost makes it preferred for high-throughput industrial processes

Future Trends — Sustainable Steam & Industry 4.0

Solar Steam Generation

Concentrated Solar Power uses mirrors to generate steam at 500 °C+ with zero emissions.

Geothermal Steam

Iceland and Kenya generate over 90% of electricity from naturally occurring geothermal steam.

Electrolytic Steam

Electrode boilers run on surplus renewable electricity — turning excess wind and solar into steam.

Supercritical Steam

Steam beyond 374 °C / 221 bar unlocks 45–50% cycle efficiency in new power plants.

Smart Steam Traps

IoT-connected traps detect failure instantly, reducing annual steam leakage losses exceeding 15%.

Hydrogen Combustion

Hydrogen-fired boilers emit only water vapour — enabling fully decarbonised steam by 2040.

Summary — Industrial Applications of Steam at a Glance

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- Power Generation
- Petroleum Refining
- Food & Beverage
- Steel & Metal
- **STEAM APPLICATIONS**
- District Heating
- Chemical & Pharma
- Marine & Defence
- Textile & Paper

80% of global electricity | 60% of refinery energy | 30 GJ/tonne in paper | NYC steam network: 1882 to present

KEY TAKEAWAYS

01 Steam drives 80% of global electricity generation and remains central to energy infrastructure worldwide.

02 Industrial steam applications span power, refining, food, chemicals, textiles, steel, healthcare, and marine sectors.

03 Steam's high latent heat (2,260 kJ/kg), precise controllability, and low cost make it the preferred industrial heat carrier.

04 Challenges — corrosion, thermal losses, and CO2 — are addressed by green boilers, IoT monitoring, and renewable heat sources.

05 The future of steam is decarbonised: solar CSP, geothermal, hydrogen combustion, and supercritical cycles lead the way.

Steam was the master of the Industrial Revolution — and will be a cornerstone of the sustainable revolution.

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