Waste heat recovery

– Optimizing your energy system

Alfa Laval

Volcanoes are extraordinary sources of energy. For example, the Laki eruption of 1783 in southern Iceland produced 15 km^3 of lava. The heat released from the lava measured 80 exajoules; enough energy to keep all the world's industries running for six months …

Contents

1. Profit on waste heat

Rising energy prices are a major challenge for many industrial plants. The days of cheap energy are over, and energy efficiency is becoming a crucial success factor.

Great potential ...

The good news is that most sites have a considerable unexploited potential for energy savings. A report from the International Energy Agency states the industrial plants throughout the world are using about 50% more energy than necessary. By switching to the most energy-efficient technology available, companies can make huge savings and significantly reduce environmental impact.

... for higher profitability

Recovering waste heat using compact heat exchangers is a straightforward and easy way to boost the energy efficiency of a plant. The investments are often very profitable and payback periods often less than one year.

Many process industries are already recovering heat, but use shell-and-tube technology. Switching to compact heat exchangers boosts the energy efficiency and is a very good investment in most cases.

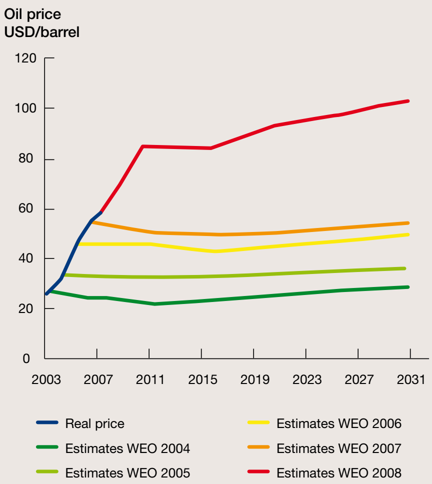
<1 year

Payback periods for waste heat recovery investments are often shorter than one year thanks to the high thermal efficiency of Alfa Laval's compact heat exchangers.

1.1 The challenge …

Figure 1.1

Oil price predictions have increased every year.
Source: International Energy Agency, World Energy Outlook 2008



Increased demand

In the “World Energy Outlook 2008” report*, the International Energy Agency (IEA) predicts world energy demand to increase by 45% over the next 20 years. They also predict the supply of fossil fuels will not be able to meet this demand, even when taking new, undiscovered fields into account.

More and more governments around the world will probably start charging industries for emitting CO_2, with emission credits becoming more and more expensive.

Higher energy prices

The result of all this will undoubtedly be increasing energy prices; just how much is hard to predict. In 2007, the IEA predicted oil prices to stay at 50-55 dollars per barrel until 2030. A year later, in June 2008, it peaked at 147 dollars per barrel and at the time of writing (2011) it is above 100 dollars per barrel.

*** International Energy Agency, World Energy Outlook 2008, www.worldenergyoutlook.org/2008.asp**

… and its common-sense solution

There are many alternative ways to battle the energy challenge. Internationally renowned consulting firm McKinsey made a thorough investigation into future energy needs and supply, comparing the benefits of different alternatives. They came to the following conclusion:

“McKinsey has looked long and hard to obtain an affordable, secure energy supply while controlling climate change. Energy efficiency stands out as the single most attractive and affordable component of the necessary shift in energy consumption”

McKinsey Quarterly January 2010

The natural starting point

As common sense predicts, the first step towards lower energy costs is to start using less energy. Increasing energy efficiency is the least costly and most easily implemented solution to energy challenges for the average process plant.

Energy-saving investments often have short payback periods, even at much lower energy price levels than today’s. In the future, energy efficiency will most likely be a prerequisite for staying in business.

x3

The total energy-saving potential from the world’s industries is estimated to be about three times the world’s total nuclear power generation.

1.2 Waste heat recovery

An effective way to increase energy efficiency is to recover waste heat.

The process industry mainly consumes two types of energy:

- Fossil fuel to generate process heat
- Electric energy to drive motors and for use in specific process steps, e.g. electrolysis

The energy and cost saving potential is closely linked to the flow of heat in the plant in most cases. The basic idea behind waste heat recovery is to try to recover maximum amounts of heat in the plant and to reuse it as much as possible, instead of just releasing it into the air or a nearby river.

Figure 1.2
Energy flow without waste heat recovery

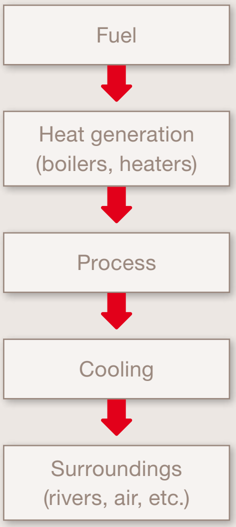
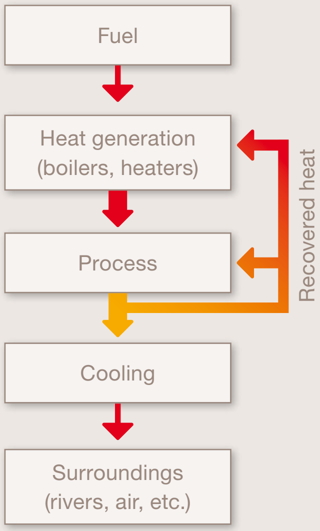


Figure 1.3
Energy flow with waste heat recovery



1.3 Heat exchangers

A key component in waste heat recovery is the heat exchanger. The profitability of an investment in waste heat recovery depends heavily on the efficiency of heat exchangers and their associated life cycle costs (purchase, maintenance, etc).

Different designs

All these factors vary considerably between different heat exchanger technologies. Although compact heat exchangers are very common in the process industry today, shell-and-tube heat exchangers are still dominating.

Compact heat exchangers have many benefits over shell-and-tubes:

- Up to five times higher heat transfer efficiency
- Lower costs for both initial investment and maintenance
- Much smaller in size

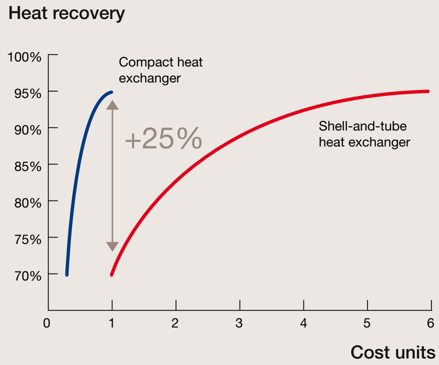
These arguments are especially true for heat recovery services where the differences are maximal.

An important choice

The choice of heat exchanger is very important and has a direct impact on the bottom-line result. In fact, replacing old shell-and-tubes with new compact heat exchangers in existing heat recovery systems is often a very good investment, thanks to the strong benefits.

Figure 1.4

The diagram shows the heat recovery level as a function of initial cost. The yield from compact heat exchangers is up to 25% higher than for shell-and-tubes at a comparable cost. To reach the same levels of heat recovery, shell-and-tube solutions often become several times more expensive. The basis of comparison is a BEM shell-and-tube system with stainless steel tubes and fusion bonded AlfaNova compact heat exchangers. For more details, please visit www.alfalaval.com/waste-heat-recovery.



Compact heat exchangers are up to five times more efficient than shell-and-tubes, making heat recovery profitable even where the energy sources traditionally have been deemed worthless.

1.4 Heat integration analysis

Boliden Harjavalta, Finland

Boliden Harjavalta recovers 20 MW (68.2 MMBtu/h) of heat in its sulphuric acid plant. Half of this energy is used in Boliden's copper and nickel plants in the area, and the other half is sold to the local district heating network.

Photo: Liisa Valonen

Recovering heat is only valuable if the heat can be reused. The recovered heat must add to the bottom-line result in some way for an investment to be justifiable.

Finding the best opportunities

To find all the potential ways to create value from recovered heat, the whole energy system of the plant must be analyzed, as well as the processes, the cooling system and surrounding factors.

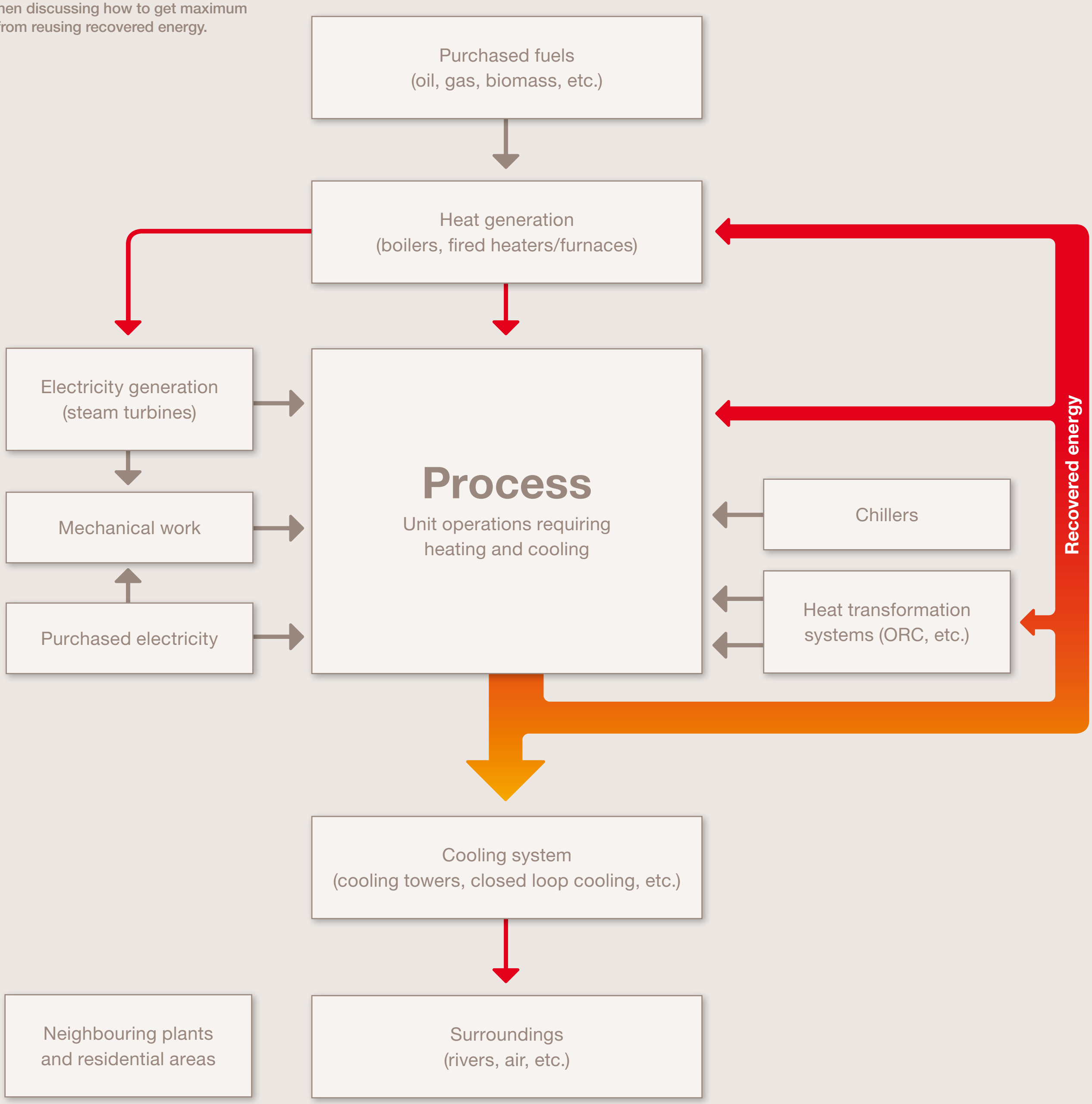
Often the best way to profit on recovered heat is less obvious than just saving fuel. There are many parameters to take into account, some being:

- How is process heat generated?
- What is the optimum load on the boilers/burners?
- How is electricity generated? Is there any spare capacity in the co-generation systems?
- Are there constraints in the cooling systems?
- Are there bottlenecks related to heating or cooling?
- Are there neighbouring plants or residential areas?

The flowchart on the next page shows the basic energy-related units found in most plants, and will be the starting point for the discussion in the next chapter on how to make money from waste heat.

Figure 1.5

The flow chart below shows the basic systems found in most plants and is a good starting point when discussing how to get maximum results from reusing recovered energy.



2. Eight ways to profit from waste heat

Before investing in waste heat recovery it is important to analyse all potential gains, and assess the profitability of the investment.

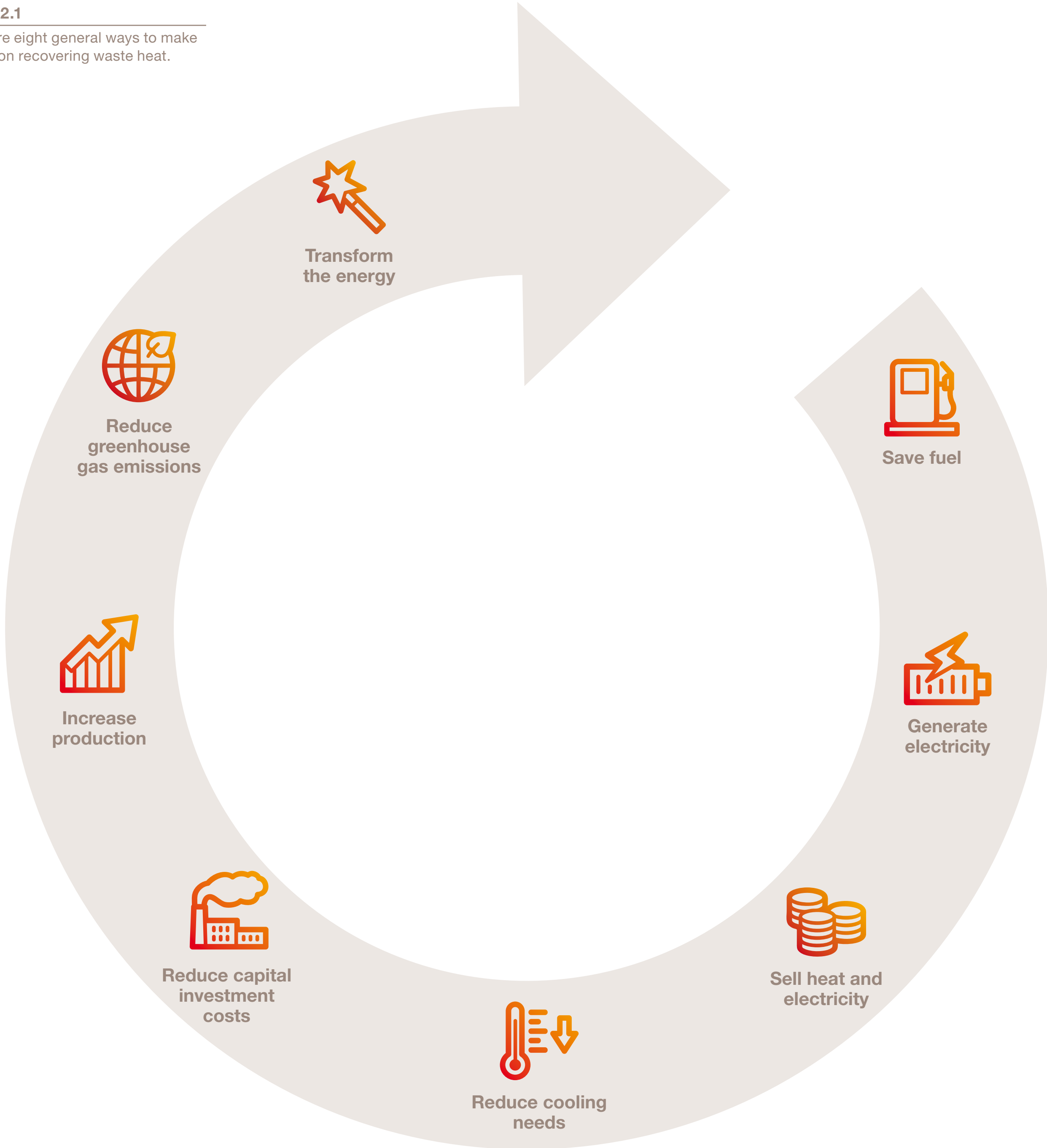
There are eight ways to profit from waste heat:

- Saving fuel
- Generating electricity and mechanical work
- Selling heat and electricity
- Reducing cooling needs
- Reducing capital investment costs
- Increasing production
- Reducing greenhouse gas emissions
- Transforming the heat to useful forms of energy

Most plants have the opportunity to make use of recovered energy in several ways. The optimum mix depends on the specific characteristics of the plant, its location, and energy prices.

Figure 2.1

There are eight general ways to make a profit on recovering waste heat.



2.1 Saving fuel

Avdeevka Coke, Ukraine

Replacing two shell-and-tube heat exchangers in the light oil recovery section of the plant with a single Alfa Laval Compabloc saved more than 100 m^3 of coke oven gas per hour in a burner.

Process heat is usually generated in steam boilers and/or in fired heaters/furnaces. In both cases, waste heat recovery can lead to substantial fuel savings.

Process heat from steam boilers

Recovering waste heat often reduces the need for steam in a plant. Consequently the boiler's fuel consumption is reduced, as are greenhouse gas emissions and the load on the cooling system.

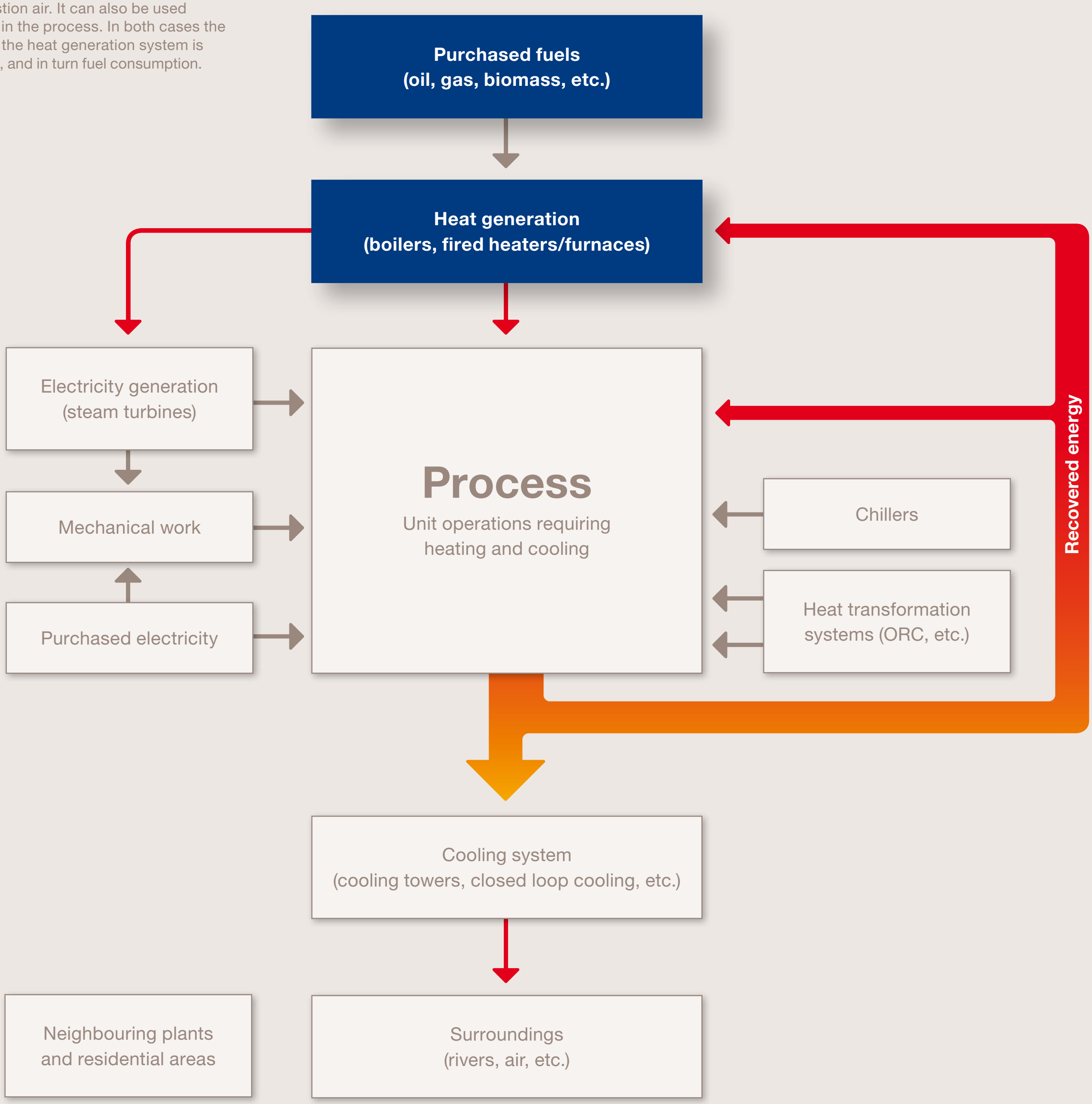
Recovered heat can also be used for preheating the boiler feed, lowering fuel consumption.

Process heat from fired heaters/furnaces

The fuel consumption of a fired heater/furnace can be reduced by using waste heat from the plant for preheating the heater feed. Again, this reduces fuel bills, cooling system load, and greenhouse gas emissions.

Figure 2.2

Heat can be reused in the heat generation system to preheat the feed or the combustion air. It can also be used directly in the process. In both cases the load on the heat generation system is lowered, and in turn fuel consumption.



2.2 Generating electricity and mechanical work

Electricity

Many plants generate their own electricity by directing part of the steam from a process-heat boiler to a turbine.

Recovering waste heat reduces steam consumption in the plant, making it possible to use a greater portion of the steam for generating electricity (provided there is more capacity in the turbines).

This can provide a very attractive way of reducing energy costs for plants with a high consumption of electricity.

Mechanical work

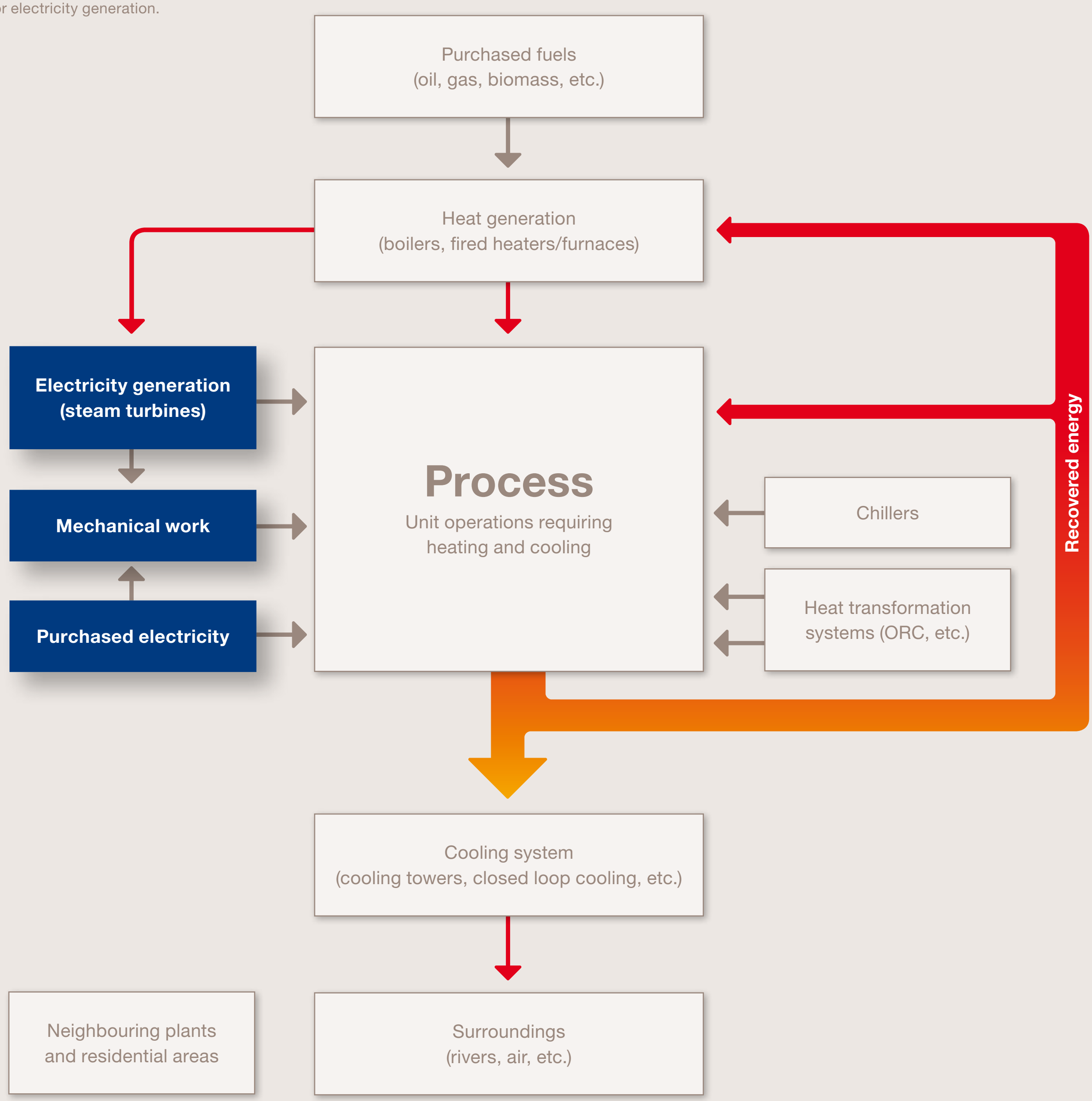
Some plants use turbines to drive compressors or pumps directly. Waste heat recovery will make it possible to generate more mechanical work as described above.

Santelisa Vale, Brazil

Steam consumption was reduced by 40% to 50% in this sugar and ethanol plant by replacing existing shell-and-tubes with Alfa Laval WideGap heat exchangers. The excess steam is used for generating electricity, which is sold to the national grid.

Figure 2.3

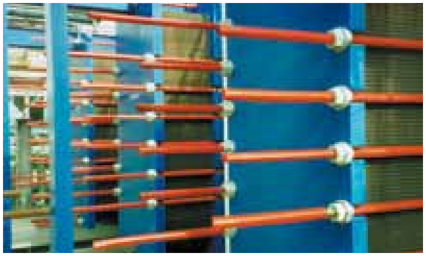
Reducing the need for steam in the process means more steam can be used for electricity generation.



2.3 Selling heat and electricity

Kemira, Sweden

Every year the Kemira sulphuric acid plant delivers a total of 240 GWh (819 GBtu) of recovered heat to the district heating network of the city of Helsingborg. The payback period was less than one year.



The most profitable options are sometimes found outside the site. If the plant is situated in the vicinity of other plants or a city, selling heat and electricity externally may be an excellent business opportunity.

Heat

If the plant is located in an industrial cluster, it may be possible to sell heat to neighbouring sites.

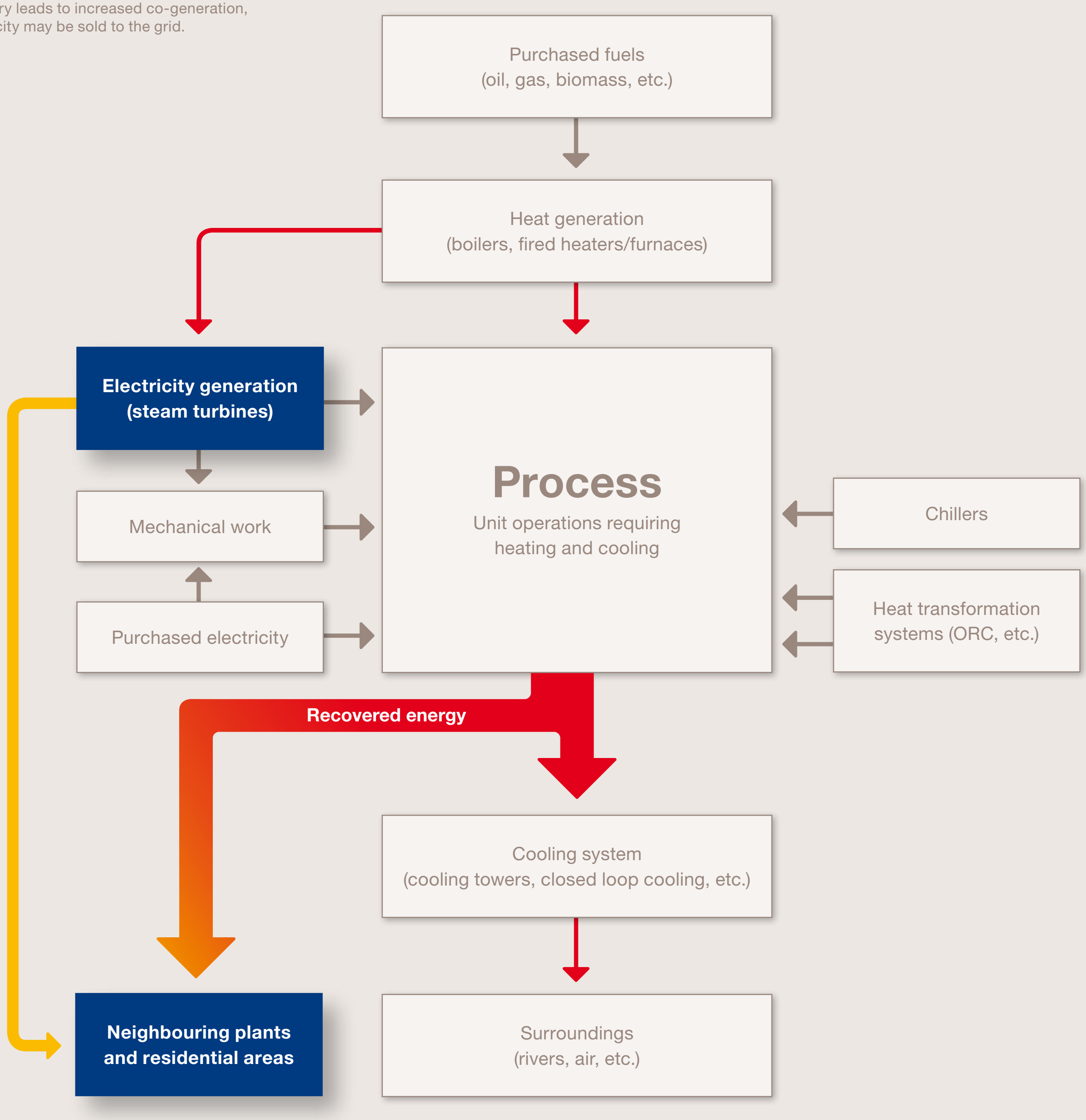
Recovered heat can also be sold for use in district heating, fish breeding, greenhouse heating, etc.

Electricity

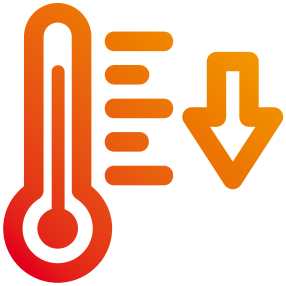
For plants where heat recovery offers the opportunity to increase electricity generation, the new possible power output may be greater than needed in the plant. In this is the case, it may be possible to sell the surplus to neighbouring plants or to the grid.

Figure 2.4

The recovered energy can be sold externally as district heating or to a neighbouring plant. If heat recovery leads to increased co-generation, electricity may be sold to the grid.



2.4 Reducing cooling needs



Unipar, Brazil

UNIPAR reduced steam consumption by 4.7 MW (16 MMBtu/h) when installing an Alfa Laval Compabloc heat exchanger in its cumene production plant. This also eliminated the need for cooling water in the cumene condenser. The payback period was less than one year.

Recovering heat often has positive effects on the cooling system. The more heat is recovered and reused, the less it needs to be cooled off after the process steps. This can be valuable in a number of cases.

Bottlenecks

If cooling is a limitation in the plant, recovering heat can free up capacity and resolve cooling-related bottlenecks in other parts of the plant.

Environmental constraints

Many plants have environmental constraints in terms of how much cooling water can be taken from a river and/or temperature limitations on the returned water.

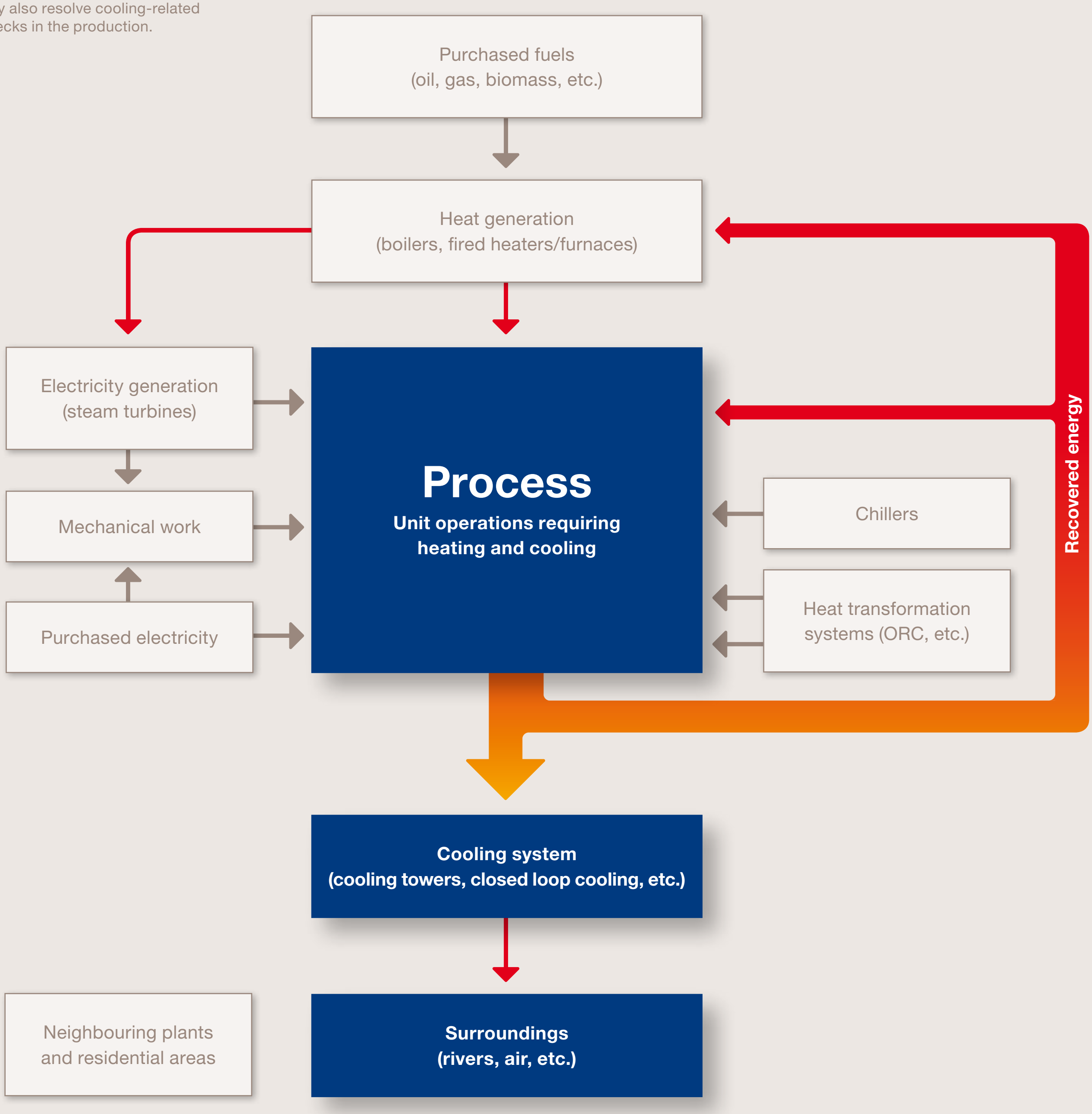
Waste heat recovery can be the solution to either one or both of these problems, allowing the plant to run at full capacity.

Operating costs

Solving cooling limitations through heat recovery has the added benefit of reducing operating costs. The load on circulation pumps and cooling tower fan systems is lowered, and in turn, the consumption of electricity. Reduced need for cooling water means reduced need for water treatment chemicals.

Figure 2.5

Waste heat recovery often leads to a reduced load on the cooling system, and may also resolve cooling-related bottlenecks in the production.



2.5 Reducing utility investments

Considering heat recovery can lead to substantial savings in both new and existing plants when planning new utility investments. It can cut both future operating costs, utility systems and capital investment costs.

Recovering process heat reduces investment costs in systems for heat generation and cooling, as well as costs for space.

Shell Sarnia, Canada

Installing Alfa Laval Compabloc heat exchangers led to a 13.5 MW (46 MMBtu/h) increase in heat recovery. Recovering this heat means the steam plant still has additional capacity to meet any further increase in demand.

Boilers and burners

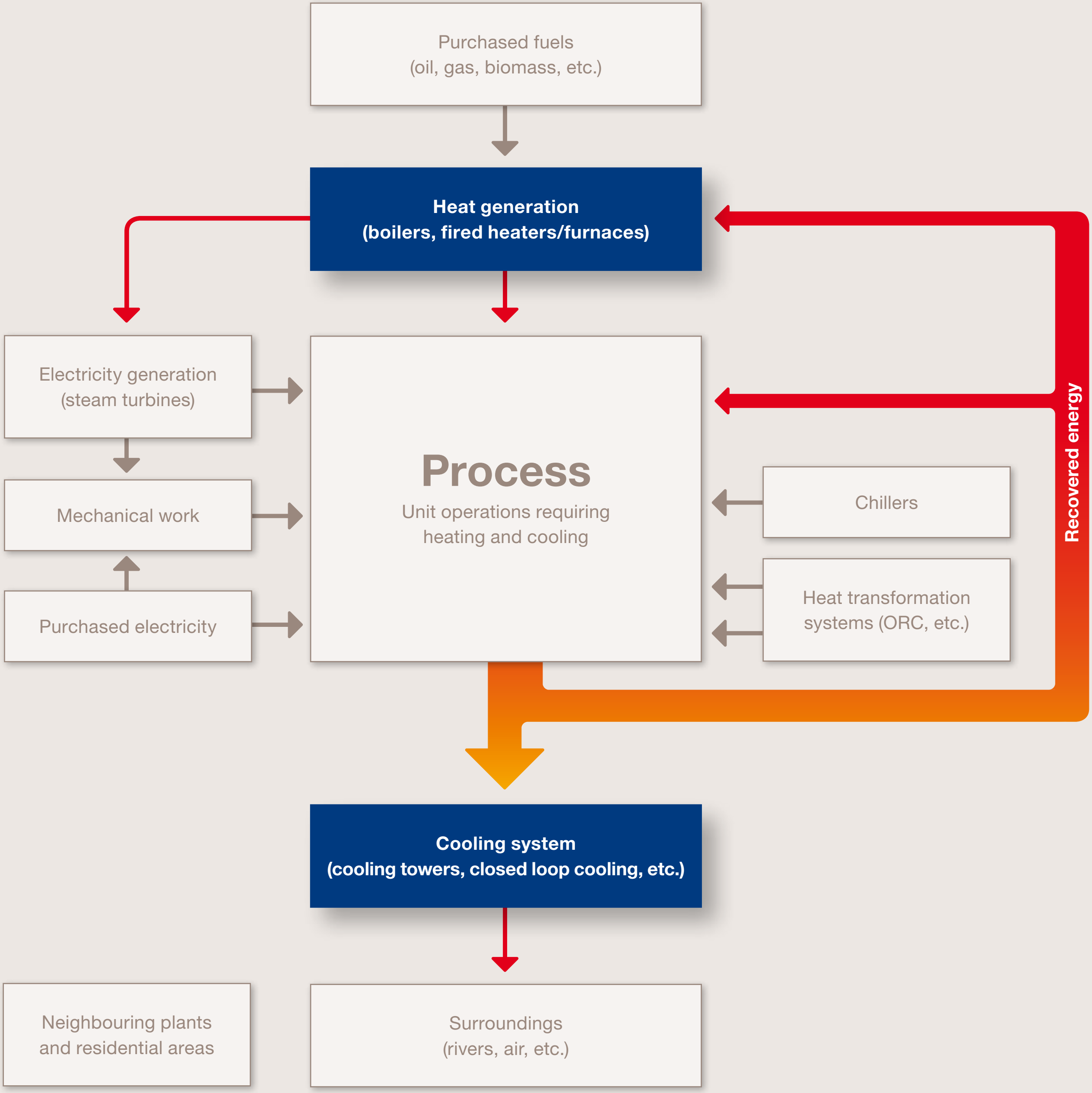
Recovering heat leads to a lower need for new heat, reducing the capacity need of boilers, direct fired heaters and furnaces.

Cooling

The first thing to consider when planning new cooling capacity is how to reduce the input of heat into the system. Recovering heat reduces the cooling need and a cooling tower of less capacity will suffice.

Figure 2.6

Waste heat recovery often reduces the load on the utility systems.



2.6 Increasing production

Mulgrave Central Mill, Australia

When Mulgrave Central Mill installed Alfa Laval M30 plate heat exchangers in its raw sugar plant, the capacity of the evaporation system increased by 2.5% to 5%.

Debottlenecking

It is not uncommon to find limitations in boiler or cooling capacity that hamper production rates. Waste heat recovery can be an easy way to resolve these bottlenecks. Recovering heat means the load on the cooling and heating systems is reduced and the free capacity can be used for increased production.

Space constraints

Alfa Laval's compact heat exchangers are a perfect match when space is the limiting factor for increased production. The high efficiency and small footprint means they offer much higher capacity per square meter than shell-and-tube heat exchangers.

Higher by-product production rates

In some processes, such as sugar production from sugar cane, coke oven gas refining, and sugar-based ethanol production, combustible by-products are burned to generate process steam and heat.

With the introduction of a heat recovery system, the need to burn by-products as fuel may be reduced and they can be sold instead. Some Alfa Laval customers have started profitable biomass pellet operations, or gasification-based chemicals production.

2.7 Reducing greenhouse gas emissions

Since waste heat recovery often leads to significant fuel savings, CO_2 emissions are often reduced. The primary benefit of lower emissions is of course the positive effects on our environment, but they can have monetary value as well.

Many parts of the world have, or are about to introduce, emissions trading systems (cap and trade), the European Union Emission Trading Scheme being the largest in use.

After implementing waste heat recovery systems, companies may find they have unused emission permits. These can then be sold if the company is operating under a cap and trade system.

In countries without cap and trade systems there may still be possibilities to sell emission permits to other parts of the world through the UN's flexible mechanisms.

Dow Wolff Cellulosics, Belgium

Installing an Alfa Laval Compabloc for energy recovery in a solvent recovery column has resulted in substantial energy savings and reduced CO_2 emissions.

2.8 Transforming energy

Recovered heat can also be used in combination with waste-heat transformation technologies for producing:

- Chilled water
- Hot water
- Distilled water
- Electricity

Chilled water – absorption chilling

Absorption chilling is a technology that converts low-temperature waste heat to chiller capacity. Absorption chillers can be attractive investments in plants with chilling need and large amounts of available low-grade heat. Especially so if electricity prices are high, since the power consumption of an absorption chiller is practically negligible compared to that of a conventional chiller.

Figure 2.7

Recovering 20 MW at 95°C for use in an absorption chiller can give 7 MW of chilling at 7°C.

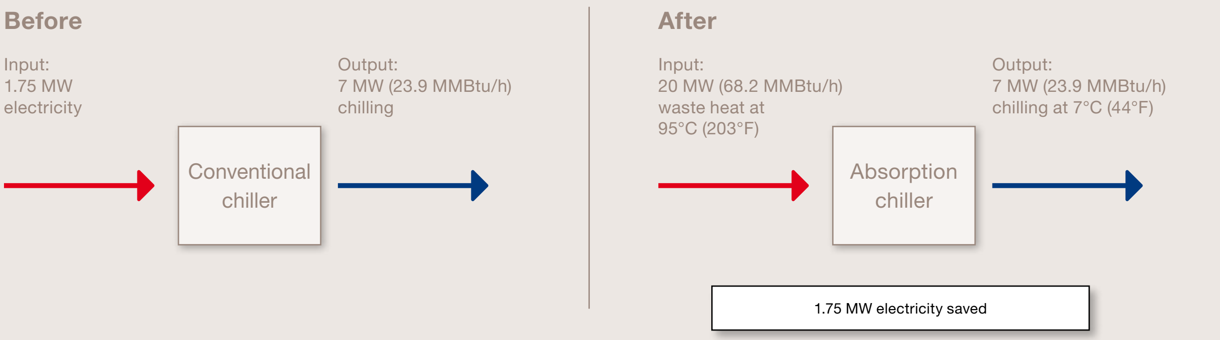


Figure 2.8

Valuable assets can be produced using recovered waste heat thanks to heat transformation technologies.

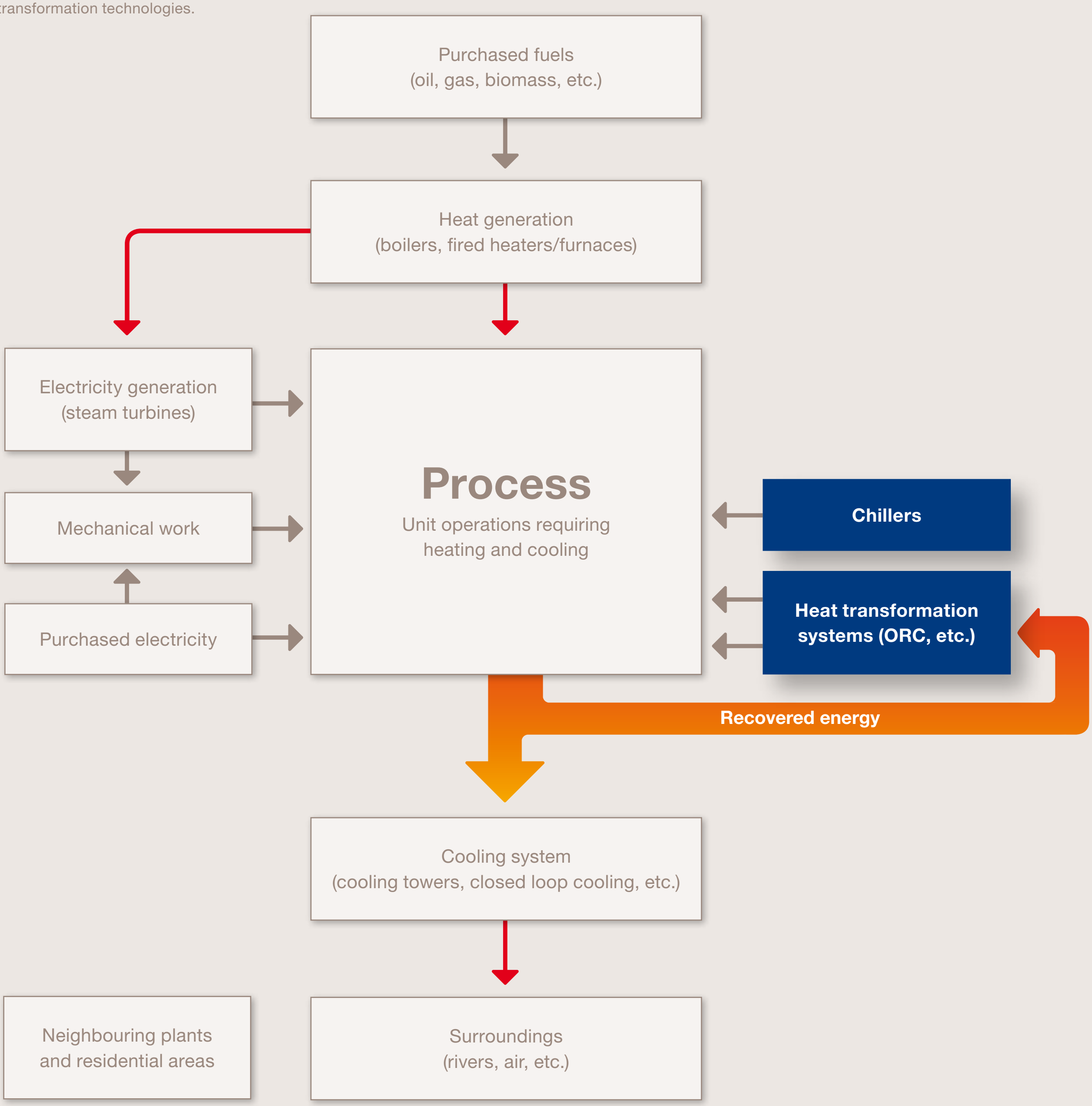
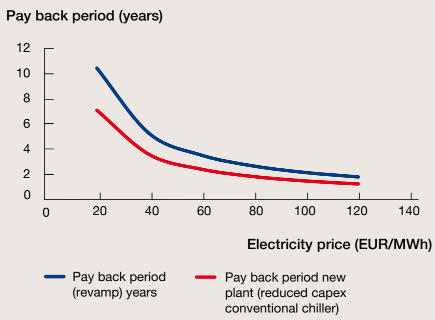


Figure 2.9

Absorption chilling

The payback period for a system with heat integration and absorption chilling as a function of electricity price. For assumptions, see www.alfalaval.com/waste-heat-recovery.



Coastal Aruba Refining Company, Aruba

The Coastal Aruba refinery uses an Alfa Laval desalination system to generate fresh water from seawater.

Example

In 2008 Alfa Laval supervised a thesis from Lund University where waste-heat powered absorption chilling was studied. Assuming there is a high need for chiller capacity and good supply of low-temperature waste heat, absorption chillers proved to be a profitable investment, both when replacing existing chillers and in new plants.

Heat pumps and mechanical vapour recompression (MVR)

Heat pumps and MVRs are used when the temperature of the waste heat stream is too low to be used for heat recovery. Both heat pumps and MVRs raise the temperature of the waste heat, but require an input of electricity or mechanical work (for driving a compressor). However, electrical energy is usually only a fraction, typically 25%, of the amount of heat energy that can be upgraded to higher temperatures.

Waste heat to pure water

In areas where pure water is a scarce resource, recovered waste heat can be used for producing demineralised water. This application is especially interesting if planning a new installation, since an evaporative desalination system will have minimal operating costs. It is often possible to cut life-cycle costs of water by 50% to 75% compared to a reverse osmosis system.

Electricity – organic Rankine cycle (ORC) systems

An ORC system works according to the same principles as a normal steam turbine. The main difference is that an organic fluid is used instead of water, and that waste heat is used to vapourize the fluid instead of a boiler. Commercially available systems can generate electricity from temperatures as low as 55°C (131°F).

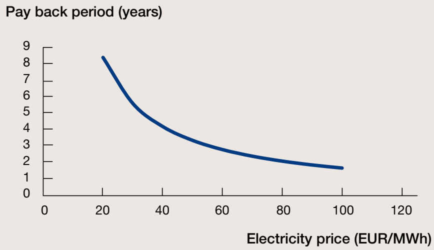
Example

The graph shows a profitability analysis based on information from a supplier of organic Rankine cycle systems. The cycle converts waste heat to electricity with an efficiency of approximately 10%. In this case the ORC system converts approximately 7 MW (23.9 MMBtu/h) of waste heat into 0.7 MW of electricity, i.e. an annual production of 5,880 MWh.

Figure 2.10

ORC system

Payback period for an ORC system. The annual saving amounts to 5,880 MWh. For assumptions, see www.alfalaval.com/waste-heat-recovery.



Opcon, Sweden

Opcon develops and markets cutting-edge products for waste heat recovery. Opcon Sweden uses Alfa Laval heat exchangers in its organic Rankine cycle systems. The systems are used for generating electricity from waste heat with temperatures as low as 55°C (131°F).

3. Energy efficiency – ten generic cases

Building blocks

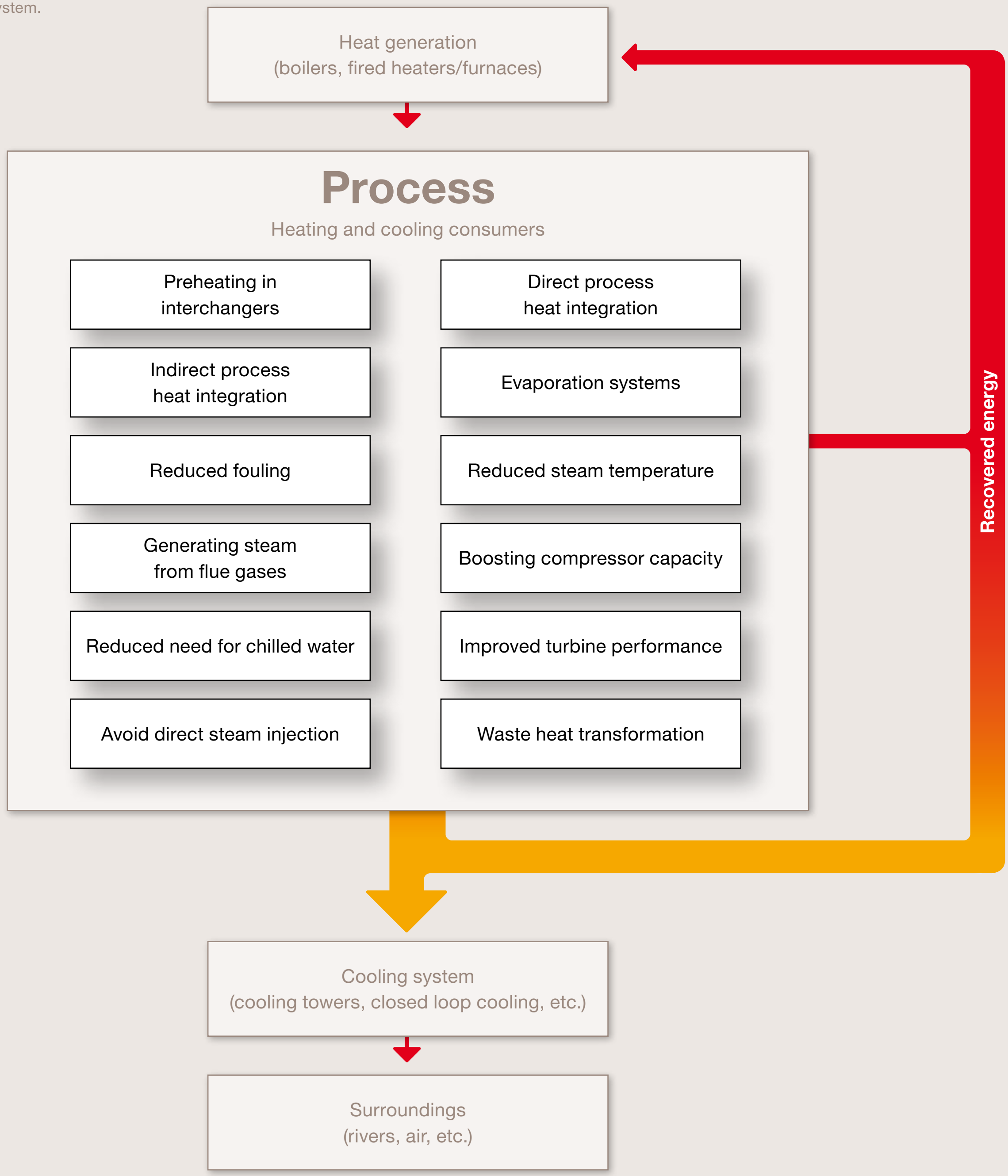
Unit operations are the basic building blocks of process industries. The conditions and media vary, but the operating principles and several typical heat transfer services within these process systems are the same.

This section presents the results of ten in-depth profitability analyses from different industries. One or more of the heat transfer services in the cases are found in most process plants and the results can be applied to many industries.

When calculating a cost-optimized heat recovery level, people often use data for inefficient shell-and-tube heat exchangers. Since cost is higher and output is lower for shell-and-tubes than for compact heat exchangers, the calculations are often misleading, resulting in unnecessary losses of energy and profitability. The following studies all examine the profitability when using compact heat exchangers – the most efficient technology.

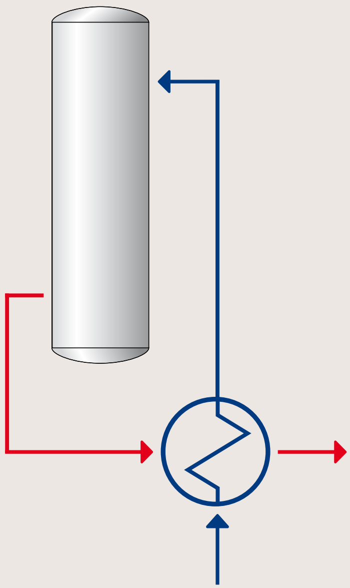
Figure 3.1

Overview of possibilities in a typical process plant energy system.



3.1 Preheating in interchangers

Figure 3.2
Preheating in interchangers.



Feed/effluent heat exchangers, lean/rich interchangers, in-and-out heat exchangers, and feed/bottoms heat exchangers are all different names for the same concept: preheating of an ingoing stream of a unit operation using heat from the outgoing stream.

This is commonly done in:

- Reactors
- Electrolytic cells
- Absorption stripping systems
- Leaching tanks
- Stripper- or distillation columns
- Evaporation systems

Changing to compact heat exchangers is a straightforward way to improve heat recovery levels. This reduces the heat/steam consumption, resulting in either fuel savings and reduced emissions, or increased electricity generation. Cooling needs are also often reduced, which is valuable in many situations.

Example: Feed/effluent heat exchanger – condensate stripper

The following example is based on a heat exchanger specification from a condensate treatment stripper. An existing shell-and-tube heat exchanger is replaced with a Compabloc welded plate heat exchanger, which increases heat recovery by 3.8 MW (13 MMBtu/h). It is assumed that 85% of the recovered heat translates into saved steam and, in turn, fuel savings or increased electricity generation. The two diagrams on the next page show the payback period for the investment.

Results

	SI	American
Increased heat recovery	3.8 MW	13 MMBtu/h
Reduced cooling water temperature, fixed flow of 1,000 m³/h (4,400 gpm)	3°C	5.4°F
Reduced cooling water flow, fixed ΔT = 10°C (18°F)	300 m³/h	1319 gpm
Reduced CO_2 emissions	5,600 metric tons/year	

Assumptions

- 8,400 operating hours per year
- Overall pressure drop increases by approximately 1 bar, but no new pump is needed (only operating costs increase)
- Physical properties on both sides are similar to water
- Installation factor = 3, i.e. the heat exchanger represents 33% of the total project cost
- Cold side flow rate 75 m³/h and hot side 90 m³/h
- Boiler efficiency 90% (boiler case)
- Turbine isentropic efficiency 80% (electricity case)

Figure 3.3

Condensate treatment stripper before and after revamp.

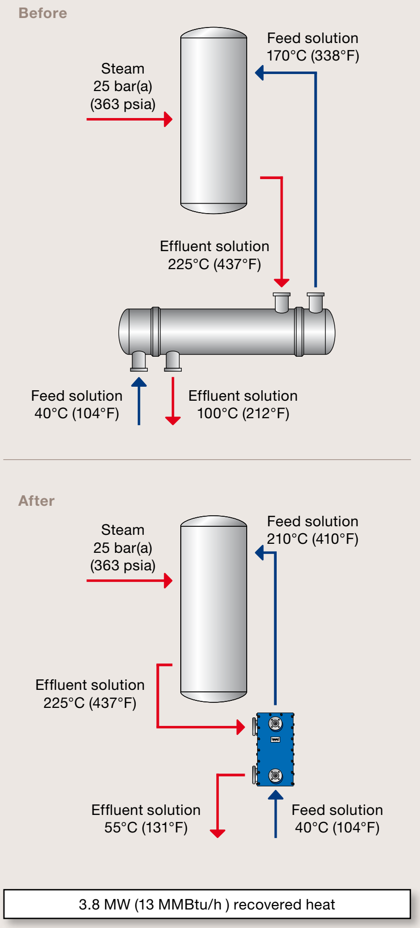


Figure 3.4

Fuel savings in boiler

Payback period as a function of energy price when using the recovered energy for saving fuel.

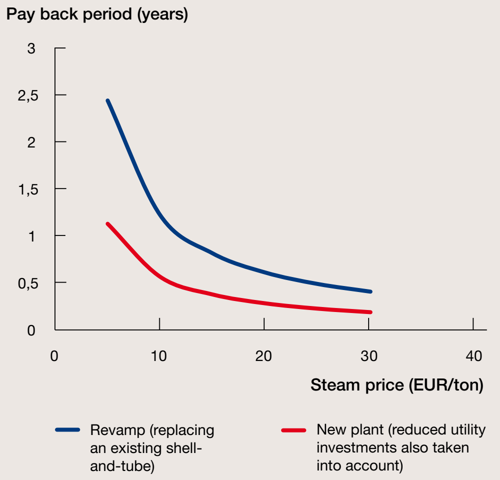
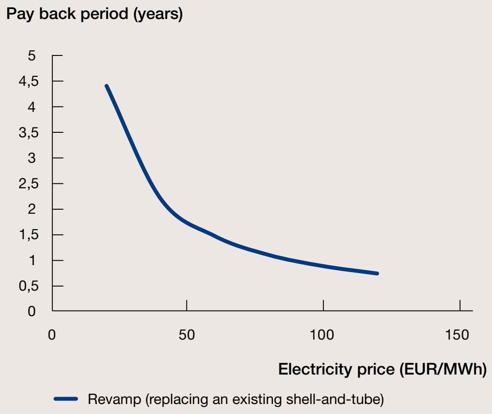


Figure 3.5

Increased electricity generation

Payback period as a function of energy price when using the recovered energy for electricity generation.



3.2 Direct process heat integration

Process heat integration means heat that was previously cooled off is recovered and reused in another unit operation. With direct process heat integration, heat is transferred directly from one process stream to the other in a single heat exchanger.

The two streams need to be fairly close to each other, and there should not be any dangers involved if the streams mix in case of a leak.

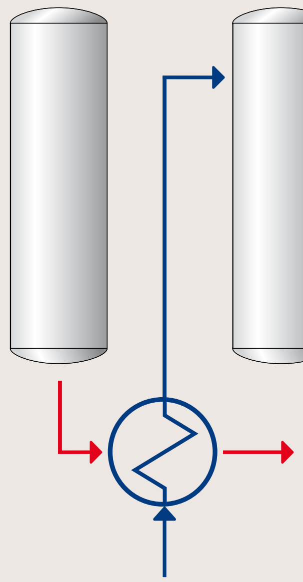
The result is a reduced load on both the heating and cooling utility systems, which transform into value in many ways, as described in chapter 2.

There are numerous examples in chemical plants where direct process heat integration can be utilized, for example:

- In refineries, the heat from several waste streams can be used to preheat crude oil upstream of a fired heater.
- Preheating of naphtha or feed gas in steam reformers.
- Preheating of the feed in fired heaters.
- Preheating of mill water and chlorine dioxide in chemical pulp mills.
- Column integration in multistage distillation.

Figure 3.6

Direct process heat integration.

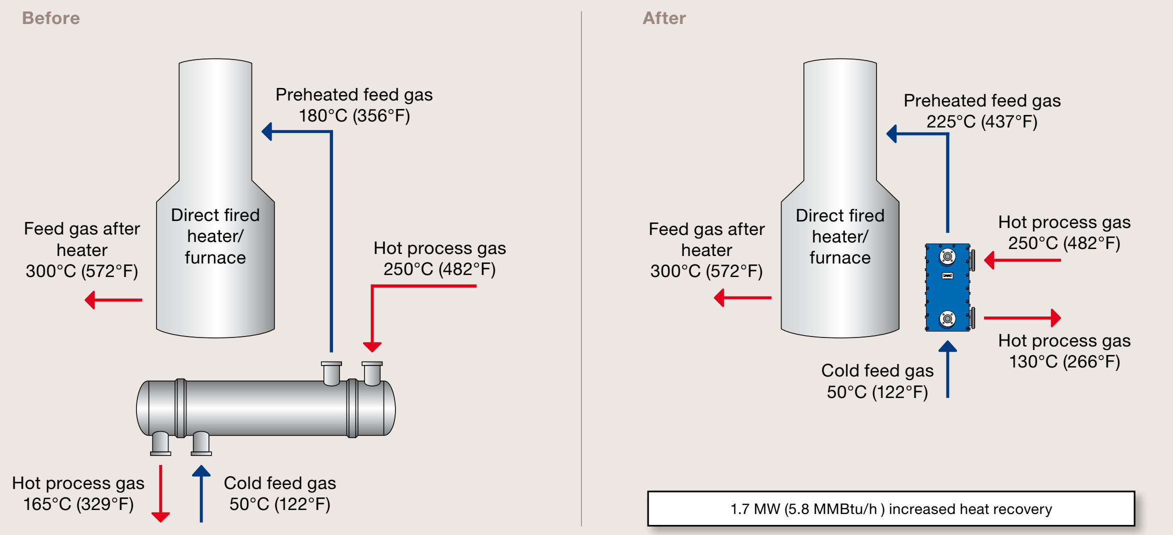


Example: Feed preheating in direct fired heater/furnace

In this example heat from a process gas stream is recovered and used for preheating the feed gas of a direct fired heater. A shell-and-tube is replaced by a compact heat exchanger, increasing heat recovery and reducing gas consumption. The result is an increase in heat recovery by 1.7 MW (5.814 MMBtu/h).

Figure 3.7

Direct process heat integration before and after revamp.



Results

	SI	American
Increased heat recovery	1.7 MW	5.814 MMBtu/h
Reduced cooling water temperature, fixed flow of 1,000 m³/h (4,400 gpm)	1.5°C	2.7°F
Reduced cooling water flow, fixed ΔT = 10°C (18°F)	150 m³/h	660 gpm
Reduced CO_2 emissions	3,300 metric tons/year	

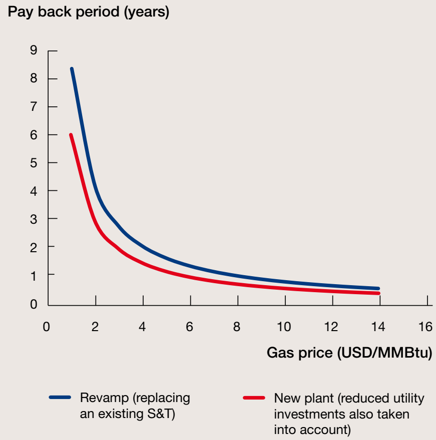
Assumptions

- Operating hours: 8,400 hours/year
- Installation factor: 3
- Heat recovered before/after: 4.3/6 MW
- Fired heater efficiency: 80%
- Gas pressures 20-30 barg – only centrifugal compressors used
- Physical properties similar to syngas on process side and natural gas on feed side
- ΔP: same before and after technology change

Figure 3.8

Fuel savings in direct fired heater/ furnace

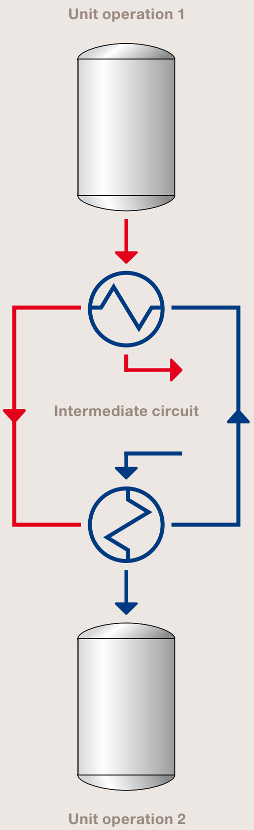
Payback period for heat recovery system as a function of fuel price.



3.3 Indirect process heat integration

Figure 3.9

Indirect process heat integration.



Indirect process heat integration differs from direct process heat integration in that an intermediate circuit is used for transferring heat between the two process streams. The transfer medium (water or thermal oil) absorbs heat in one part of the plant and releases it in another. This approach is used when:

- Direct contact between heat source and heat sink is not allowed. The intermediate circuit works as a safety barrier and leakages can be detected in the loop, before the process fluids mix.
- Long distances need to be covered.
- Flexibility and reduced interdependence is required. Equipping the intermediate circuit with standby coolers and heaters makes it easier to disconnect a unit operation for maintenance, avoiding interdependence between plants.
- One heat sink requires multiple heat sources.

Indirect process heat integration opens up a vast range of possibilities. Common application examples are:

- Sulphuric acid and mineral processing industries.
- Boiler feed-water heating where it is important to avoid interleakage and/or where there is a long distance between boiler and heat source.
- Ammonia still condenser systems with integrated mother liquor heating in the soda ash industry.
- Caustic soda pre-evaporation by recovery of electrolysis heat.

Example: Sulphuric acid plant

The following is a typical example from a metallurgical sulphuric acid plant. Here there are often opportunities to recover waste heat from the acid plant absorption towers and reuse it for heating in mineral processing steps. Examples where the heat can be reused are copper electrolyte heating, spent acid and zinc sulphate solution heating in zinc plants, boiler feed water heating, etc.

Before the technology change, the hot sulphuric acid from the absorption towers was cooled off in a shell-and-tube heat exchanger. Afterwards, the heat is transferred to a heat integration loop via a compact heat exchanger and released to an electrolyte heating bath. The result is 10 MW (34 MMBtu/h) of recovered energy.

Results

	SI	American
Increased heat recovery	10 MW	34 MMBtu/h
Reduced cooling water temperature, fixed flow of 1,000 m^3/h (4,400 gpm)	8.5°C	15.3°F
Reduced cooling water flow, fixed ΔT = 10°C (18°F)	860 m^3/h	3784 gpm
Reduced CO_2 emissions	18,000 metric tons/year	

Assumptions

- 60 W/m heat loss in pipeline
- Boiler efficiency 90% (fuel savings case)
- Turbine isentropic efficiency 80% (electricity generation case)
- Total system operating and capital cost estimation based on real quotations
- Demineralized water used in intermediate loop
- Installation factors 1.5-2 for heat exchangers
- Installation factor 3 for pipeline construction (insulated pipes)

Figure 3.10

Before and after indirect process heat integration.

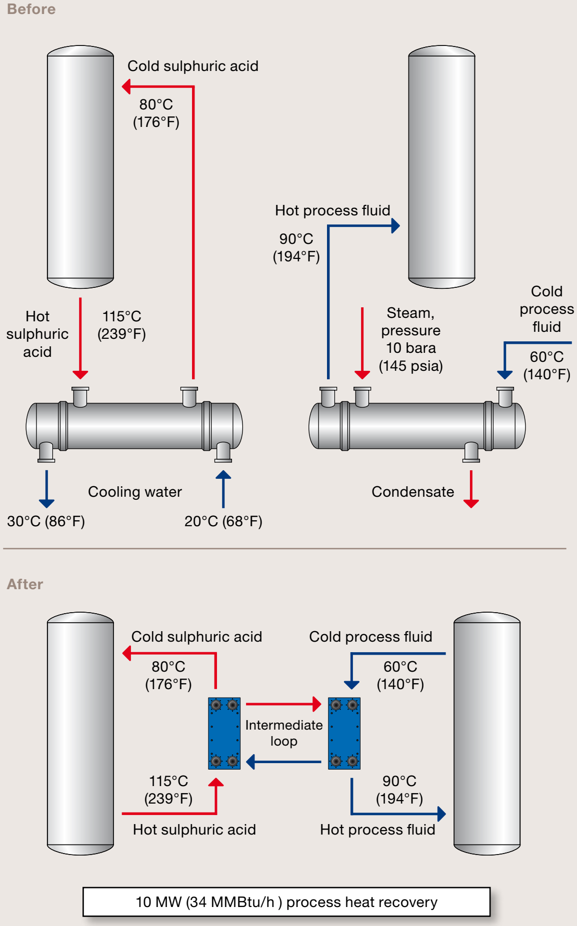


Figure 3.11

Fuel savings, revamp of existing plant

Payback period as a function of energy price when using the recovered energy for saving fuel.

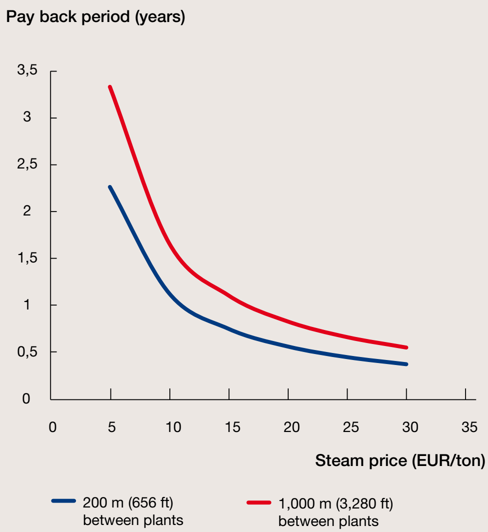


Figure 3.12

Electricity generation, revamp of existing plant

Payback period as a function of energy price when using the recovered energy for electricity generation.

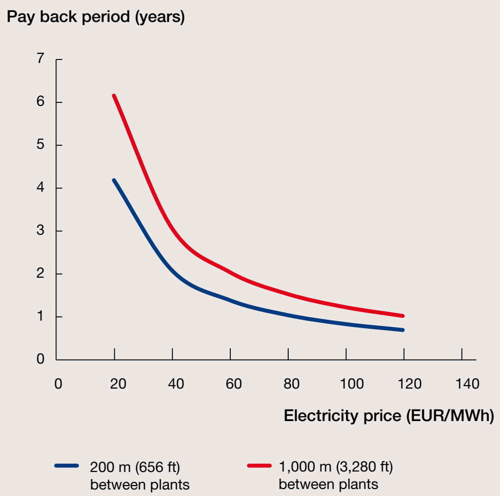
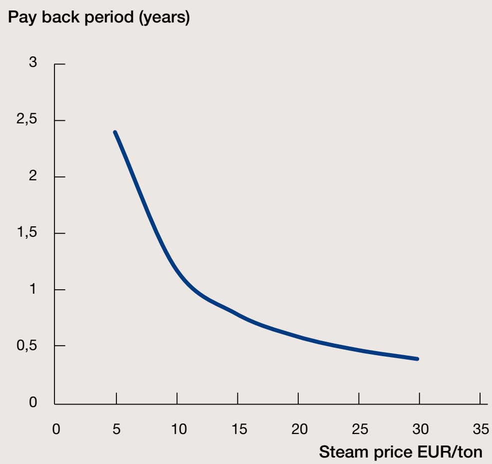


Figure 3.13

Fuel savings, new plant

Payback period for new plant (reduced utility investments). 1,000 m between unit operations.



3.4 Increased number of effects in evaporation systems

The most effective way to lower steam consumption in evaporation systems is to increase the number of effects. Steam is recovered one extra time, reducing the need for fresh steam.

Example: Caustic soda evaporation

This example is taken from a 600 tpd caustic soda plant. Increasing the number of effects from two to three means the steam consumption is reduced by 6.5 tph (14,330 lb/h).

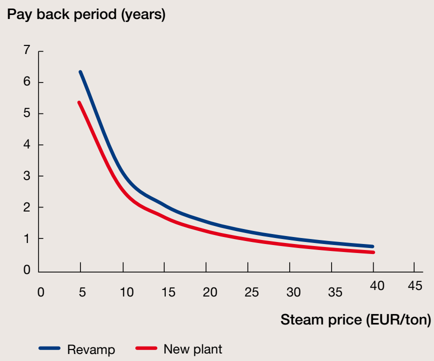
Rebuilding the preheaters reduces the steam consumption by another ton per hour. The total steam saving potential adds up to 7.5 tph (16,530 lb/h), equalling a 35%–40% reduction of fresh steam.

The total suggested investment amounts to approximately 2 million euro.

Figure 3.14

Going from two to three evaporation effects

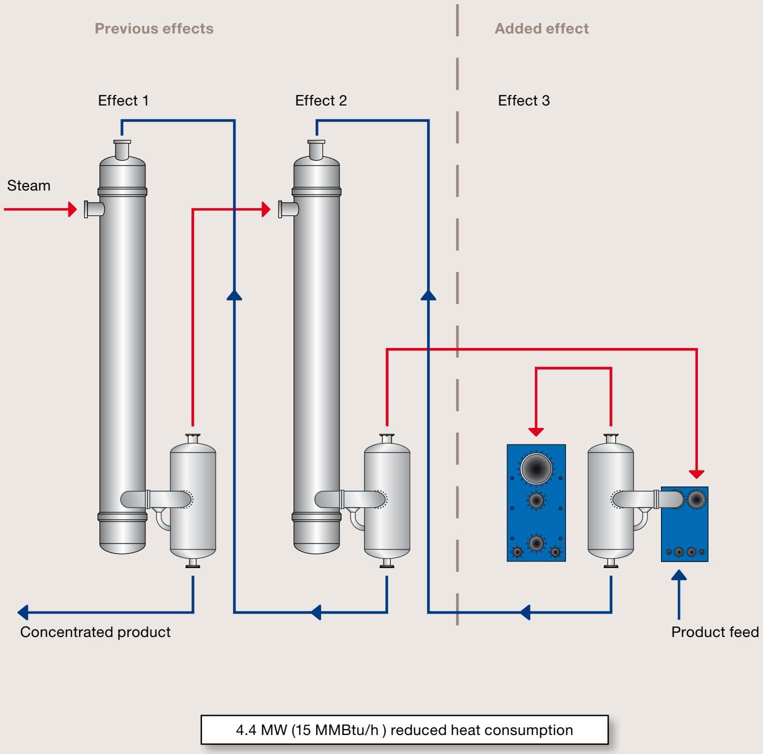
Payback period when improving preheating and increasing the number of effects from two to three in a caustic soda plant.



Results		
	SI	**American**
Saved heat	4.4 MW	15 MMBtu/h
Reduced cooling-water temperature, fixed flow of 1,000 m^3/h (4,400 gpm)	3.5°C	6.3°F
Reduced cooling-water flow, fixed ΔT = 10°C (18°F)	350 m^3/h	1540 gpm
Reduced CO_2 emissions	8,000 metric tons/year	

Figure 3.15

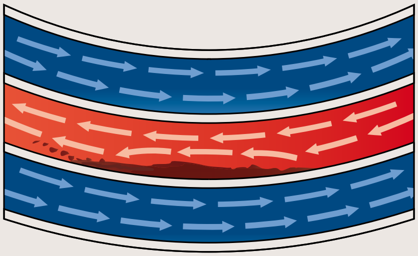
Increasing the number of effects in an evaporation system dramatically reduces the steam consumption.



3.5 Reduced fouling and maintenance

Figure 3.16

The self-cleaning design of spiral heat exchangers make them the ideal choice for fouling duties.



Shell-and-tube heat exchangers gradually lose efficiency in applications with heavy fouling. The result is lower energy transfer and high maintenance costs.

Spiral heat exchangers on the other hand have a self-cleaning design, making them much less prone to these problems and very suitable for handling highly fouling fluids. Examples of where spiral heat exchangers are used include oil refineries, pulp and paper mills, mineral processing plants, and petrochemical plants, typically in services most suffering from fouling.

Example – oil refinery visbreaker cooler/interchanger

This example is based on input from a European oil refinery, where spiral heat exchangers replaced shell-and-tubes in a visbreaker cooler service (interchanger) in an existing plant. There are usually multiple heat exchangers operating in parallel in this service, but this example shows a one-to-one comparison between the two technologies.

The increased heat recovery in this case originates from two factors; reduced downtime and better performance due to less fouling build up. Reduced fouling also means reduced cleaning frequency and lower cleaning costs.

The two alternatives in this example represent two different maintenance philosophies; making few or many stops for cleaning.

Improved performance and reduced cost when using spiral heat exchanger

	Compared to shell-and-tube cleaned twice per year	Compared to shell-and-tube cleaned 12 times per year
Increased performance	41%	11%
Reduced annual cleaning cost	€6,000	€66,000

Figure 3.17

Performance in heavy fouling services – shell-and-tubes versus spiral heat exchangers

Heat transfer efficiency for spiral heat exchangers and shell-and-tubes in oil refinery visbreaker cooler.

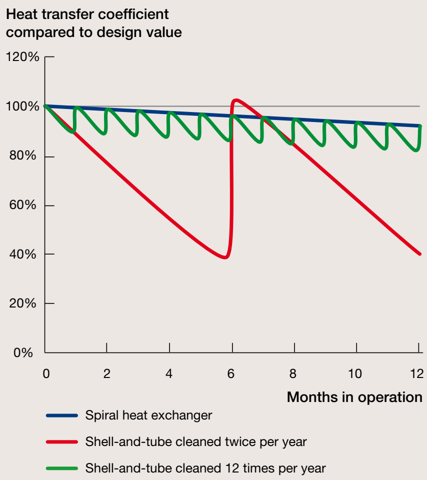
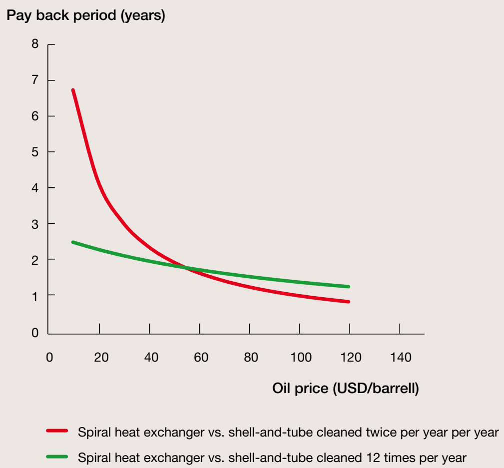


Figure 3.18

Replacing existing shell-and-tube with spiral heat exchanger

Payback period when changing from shell-and-tubes to spiral heat exchanger.



Assumptions

- Heat transfer at startup = 1 MW (3.4 MMBtu/h)
- Operating hours per year = 8,400
- Working days per cleaning = 1.5
- Cost per day for cleaning = €4,000
- Installed cost of spiral heat exchanger = €200,000

Shell-and-tube cleaned twice per year

- Annual cleaning cost = €12,000
- Average performance loss = 30%
- Annual heat recovery loss due to cleaning = 0.86%
- Total performance loss = 31% or 0.31 MW (1.1 MMBtu/h, 0.21 barrels of oil/hour)

Shell-and-tube cleaned 12 times per year

- Annual cleaning cost = €72,000
- Average performance loss = 7.5%
- Annual heat recovery loss due to cleaning = 5.14%
- Total performance loss = 12.5% or 0.125 MW (0.43 MMBtu/h, 0.1 barrels of oil/hour)

Spiral heat exchanger cleaned once per year

- Annual cleaning cost = €6,000
- Average performance loss = 2.9%
- Total performance loss = 2.9% or 0.029 MW (0.10 MMBtu/h, 0.02 barrels of oil/hour)

3.6 Reduced steam temperature

Many plants can cut energy costs considerably by replacing their shell-and-tube reboilers or steam heaters with compact heat exchangers. The higher thermal efficiency of compact heat exchangers often allows you to use a lower temperature heating medium compared to shell-and-tubes. Switching to lower grade steam will cut energy costs in most cases.

Example: Sour water stripper unit

A refinery asked Alfa Laval to evaluate the possibilities of using lower grade steam in their sour water stripper unit.

Exchanging the existing shell-and-tube for a Compabloc allowed the refinery to switch heating medium from medium-pressure steam at 180°C (356°F) to low-pressure steam at 138°C (280°F).

The stripper column operates at 127°C (261°F) and Compablocs are capable of handling temperature approaches as close as 3°C (5.4°F). This means the steam temperature in this example could have been as low as 130°C (266°F).

As well as cutting energy costs, the new Compabloc also had a much smaller installation footprint.

Assumptions

- Initial steam consumption = 14.15 metric tons/hour
- Operating hours per year = 8,400
- Low-pressure steam at 3.5 bar(a) available and possible to use as heating medium in the reboiler
- Cost for heat exchanger = €568,000
- Installation factor = 3
- Installed cost of heat exchanger = €1,704,000

Figure 3.19

Reduced utility temperature

Payback period when switching from medium-pressure steam at 180°C (356°F) to low-pressure steam at 138°C (280°F).

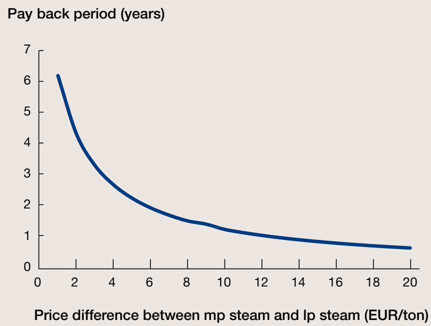
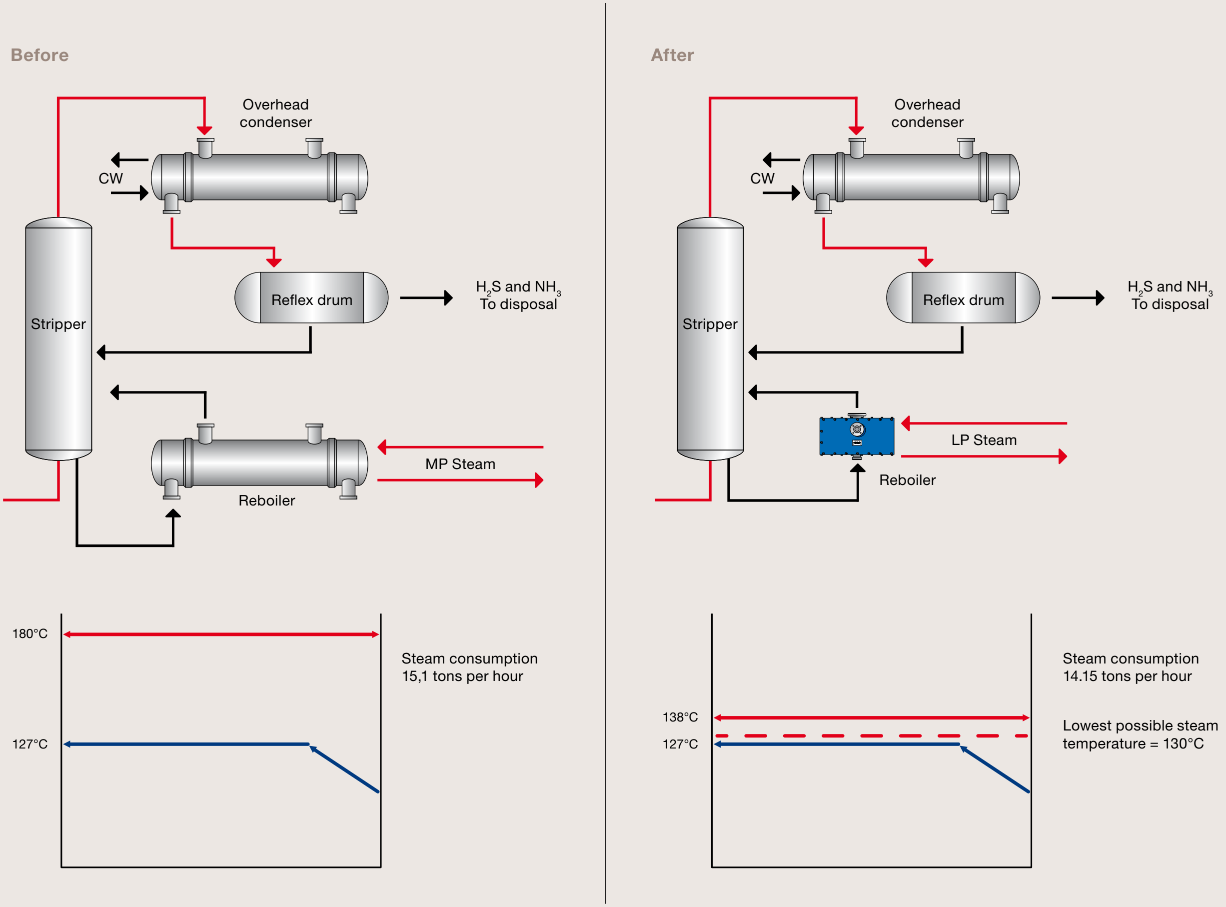


Figure 3.20

Using a more efficient heat exchanger as a reboiler allows you to use steam of a lower grade.



3.7 Generating steam from flue gases

Generating steam is a profitable way of reusing high-temperature waste heat. This can reduce the load on process steam boilers and allows you to save fuel or use the extra capacity for electricity generation.

Alfa Laval Aalborg offers a series of highly efficient waste heat recovery boilers that extract heat from hot flue gases and generate steam or hot water.

A boiler is easily added to your flue gas stream and recovers heat that would normally be released into the air through a chimney.

There are many possibilities to profit from recovered heat. It can be used for process heating, electricity generation or for district heating.

Example

In this example an Alfa Laval Aalborg waste steam boiler generates steam from flue gases.

The diagrams show the payback time for different amounts of recovered energy, from 2 to 15 MW.

Assumptions

- 8,400 operating hours per year
- Automatic cleaning system removes ash during operation
- Total installation cost estimate based on experience
- Exit temperature of the flue gas assumed to be well above the sulphur dew point

Figure 3.21

Adding an Alfa Laval Aalborg waste heat recovery boiler helps you make use of energy in your fuel gases.

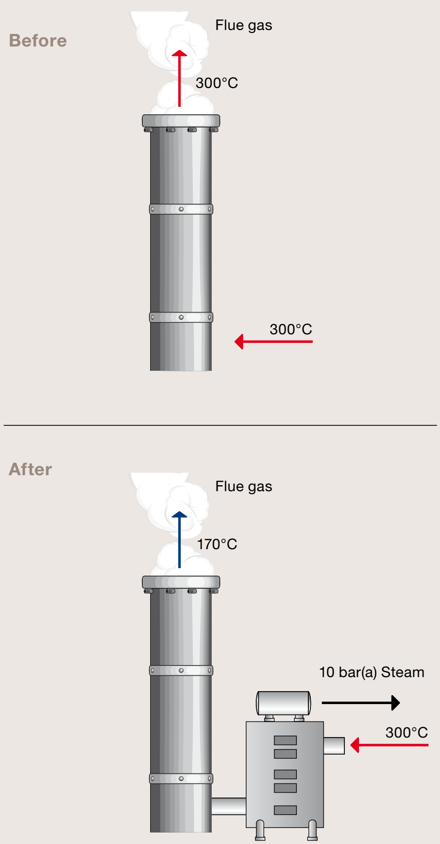
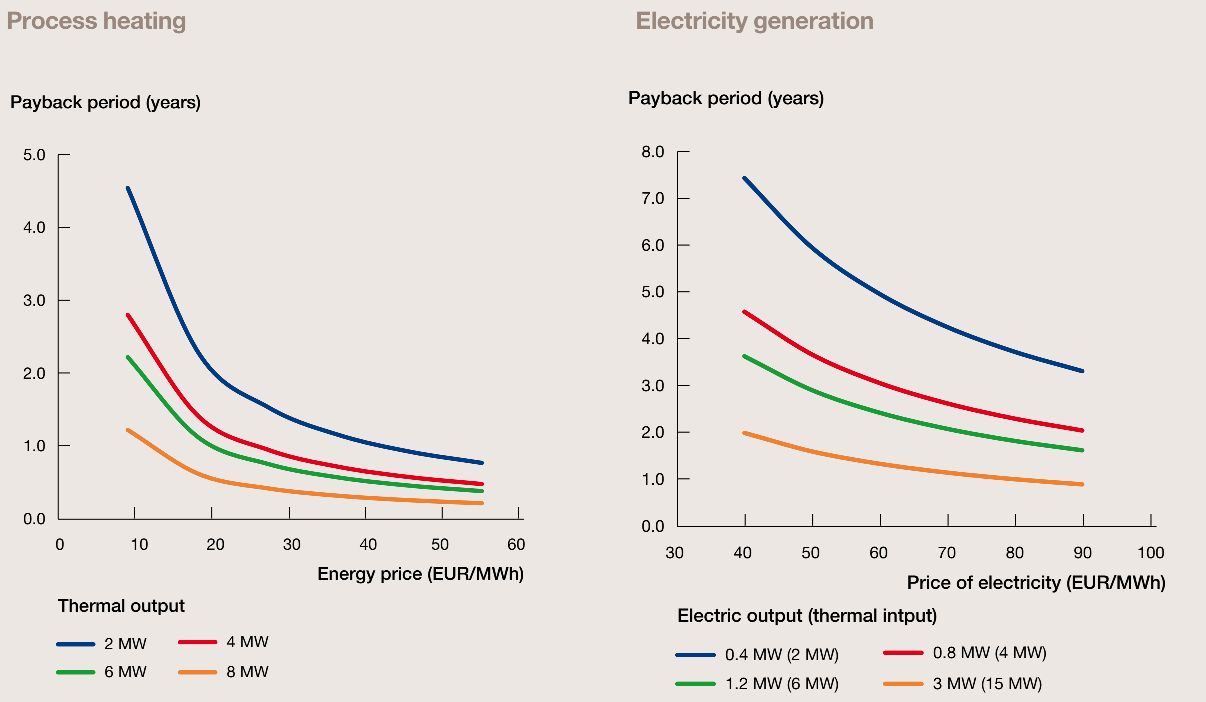


Figure 3.22

Recovering heat from flue gases

Payback period for flue gas heat recovery system for different steam prices



3.8 Boosting compressor capacity

The superior heat transfer in compact heat exchangers make them just as suitable for cooling services as for heat recovery.

Efficient cooling is essential for compressor performance. The capacity of the compressor can be increased by cooling the incoming gas.

The high thermal efficiency of compact heat exchangers makes them very suitable for this service. The gas flowing into the compressor will be cooler compared to a shell-and-tube under the same conditions, and you get higher output.

Besides higher compressor capacity, improved cooling can also lead to lower energy consumption and less wear on the compressor.

Example

Alfa Laval performed a study on a syngas compressor in an ammonia plant. The plant experienced capacity limitations during 20% of the year due to high cooling-water temperatures in the summer. The existing shell-and-tube syngas cooler was not able to cool the gas sufficiently and compressor capacity dropped.

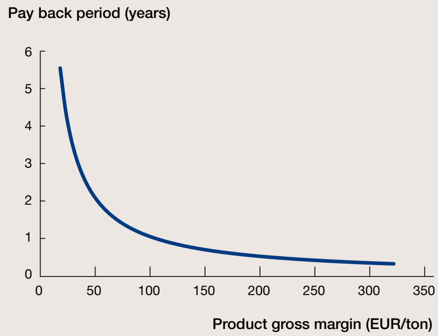
The study showed 3.2% more syngas could pass through the compressor during summer by exchanging the shell-and-tube syngas cooler for a compact heat exchanger just upstream of the compressor.

When the cooling water had a temperature of 30°C (86°F), the shell-and-tube cooled the gas to 46°C (115°F). The new compact heat exchanger lowered the temperature an additional 11°C (20°F) to 35°C (95°F).

Figure 3.23

Compressor debottlenecking

Payback period for compressor-cooler revamp for different product gross margins.



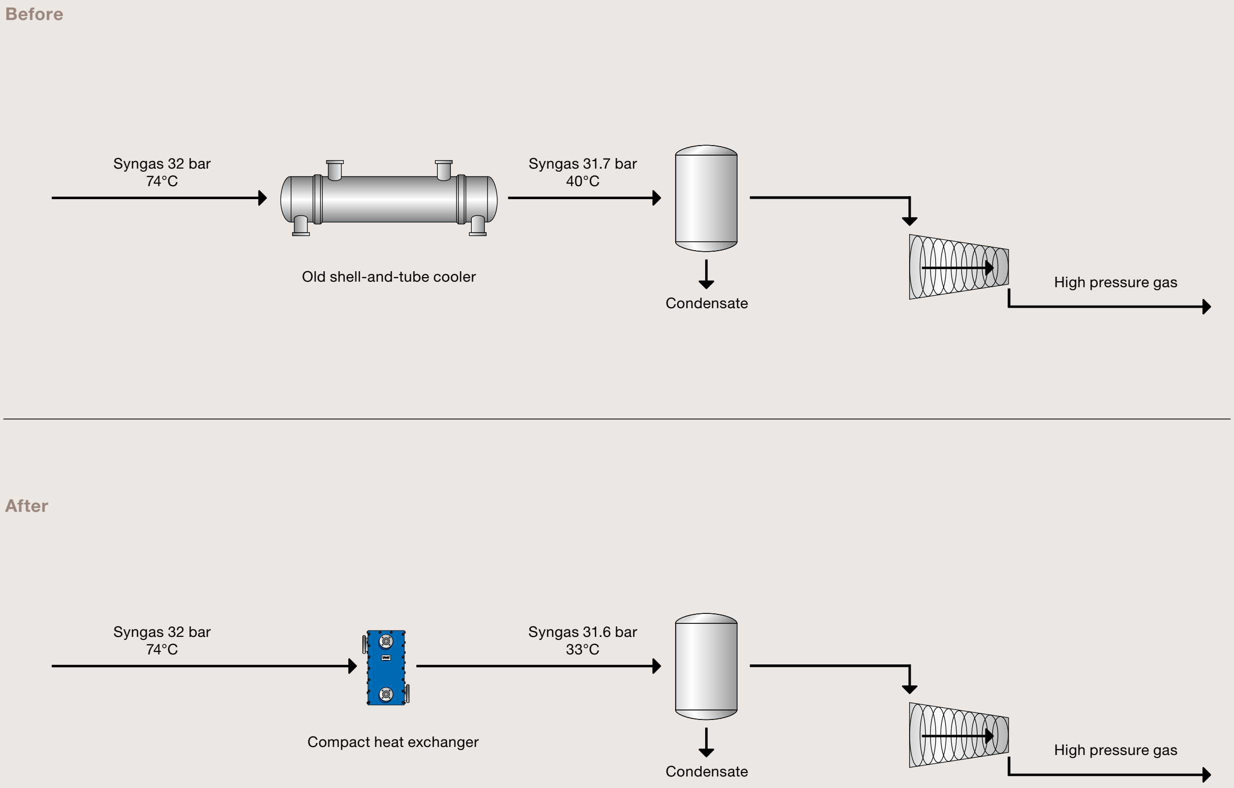
Results	
Increased production during summertime	3.2%

Assumptions

- 8,400 operating hours per year
- Capacity limitation 20% of the year (2.4 months), when cooling water is at its hottest.
- Syngas behaves as an ideal gas
- Compressor capacity is directly proportional to inlet gas volume, and hence inversely related to gas temperature
- Heat exchanger: Compabloc in Titanium
- Installation factor: 3
- Production capacity: 365,000 tons/year

Figure 3.24

Boost compressor capacity by using a more efficient heat exchanger for cooling inlet gas.



3.9 Reduced need for chilled water

Chilled water is often used as a cooling medium instead of regular cooling water in difficult condensation services. This can often be avoided by using compact heat exchangers instead of shell-and-tubes as condensers.

Compact heat exchangers offer an economical way of working with crossing temperatures and a very close temperature approach. This means a compact heat exchanger can perform required cooling with cooling water of a much higher temperature than a shell-and-tube condenser.

Eliminating the use of chilled water leads to lower operating costs, and cuts investment costs if you are building a new plant.

Example

In this example an acetone condenser cools the incoming gas from 38°C (100°F) to 22°C (72°F). An AlfaCond compact heat exchanger can accomplish this with 20°C (68°F) cooling water, whereas a shell-and-tube requires chilled water at 12°C (54°F). Figure 3.24 shows the temperature programmes when using chilled water and regular cooling water.

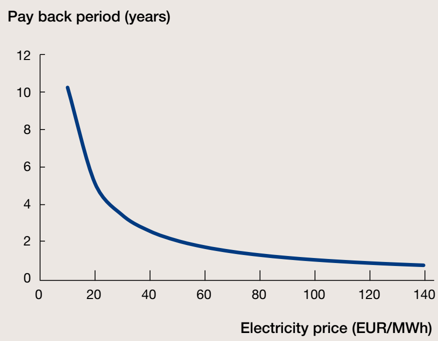
Switching to regular cooling water saves 200 kW of electricity. In addition, investment costs would drop by roughly €170,0000 if this was a new plant being built, since no chillers need to be installed. This compares to the estimated total investment cost for the plate heat exchanger of €172,000. For a new plant, the whole heat exchanger investment is more or less offset by avoiding chiller investment.

The diagram in figure 3.23 shows the payback period for different electricity prices. It shows a revamp scenario, i.e. reduced installation costs are not included in the calculations.

Figure 3.25

Eliminating the need for chilled water

Payback period for investment in more efficient cooler.



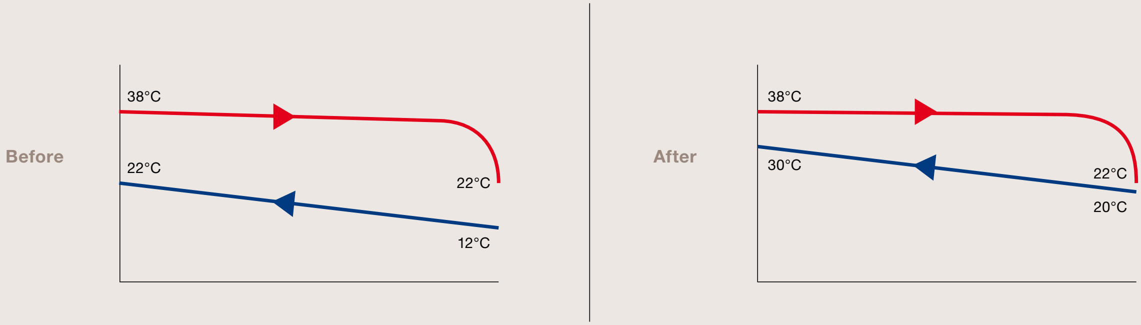
Results	
Saved electric energy	200 kW
Reduced chiller investment cost in case of new plant	€170,0000

Assumptions

- AlfaCond heat exchanger
- 8,400 operating hours per year
- Chilled water completely replaced by regular cooling water
- Negligible difference in required pumping power for chilled water and regular cooling water
- Revamp scenario
- Cost for heat exchanger: €43,000
- installation factor: 3
- Total installed cost: €172,000
- Chiller COP = 4
- Condenser capacity: 800 kW (thermal)

Figure 3.26

Thanks to the possibility of working with crossing temperatures and a close temperature approach, a compact heat exchanger can often use regular water for cooling whereas a shell-and-tube would require chilled water.



3.10 Improved turbine performance

The performance of turbine condensers has a high impact on electricity output. Exchanging condensers for more efficient units can work miracles on your electricity costs.

Example

The Avdeeka coke processing plant in Donetsk, Ukraine, experienced problems with their shell-and-tube turbine condensers. Efficiency was dropping year on year and rising energy prices made correcting the problem a top priority.

After installing an AlfaCond heat exchanger as condenser for one of the turbines, the electrical output from that turbine jumped from 8 to 12 MW, a 50% increase.

The payback time for the investment was approximately three months.

Results	
Increased electrical output	4 MW (+50%)
Payback time	3 months

Figure 3.27

Turbine performance

The diagram shows the general relationship between generated electricity and turbine exhaust pressure.

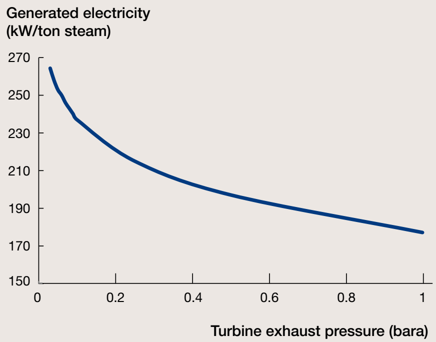
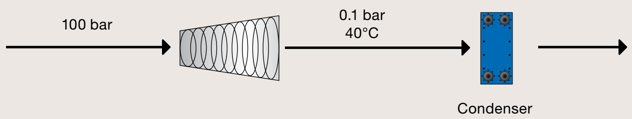


Figure 3.28

Replacing a shell-and-tube turbine condenser with a AlfaCond resulted in a 50% increase in electricity output in a turbine in the Avdeeka coke processing plant in Donetsk, Ukraine.



Alfa Laval in brief

Alfa Laval is a leading global provider of specialized products and engineering solutions.

Our equipment, systems and services are dedicated to helping customers to optimize the performance of their processes. Time and time again.

We help our customers to heat, cool, separate and transport products such as oil, water, chemicals, beverages, foodstuffs, starch and pharmaceuticals.

Our worldwide organization works closely with customers in almost 100 countries to help them stay ahead.

How to contact Alfa Laval

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