

Energy stores, Sankey diagrams and efficiency

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: Efficiency is the fraction of the total input energy that becomes useful output: $\text{efficiency} = \text{useful output} \div \text{total input}$, often shown as a percentage. Energy is never destroyed, but some is always wasted, mainly as thermal energy. A Sankey diagram shows these transfers with arrows whose widths match the energy.

Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** GCSE P1, HS-PS3-4

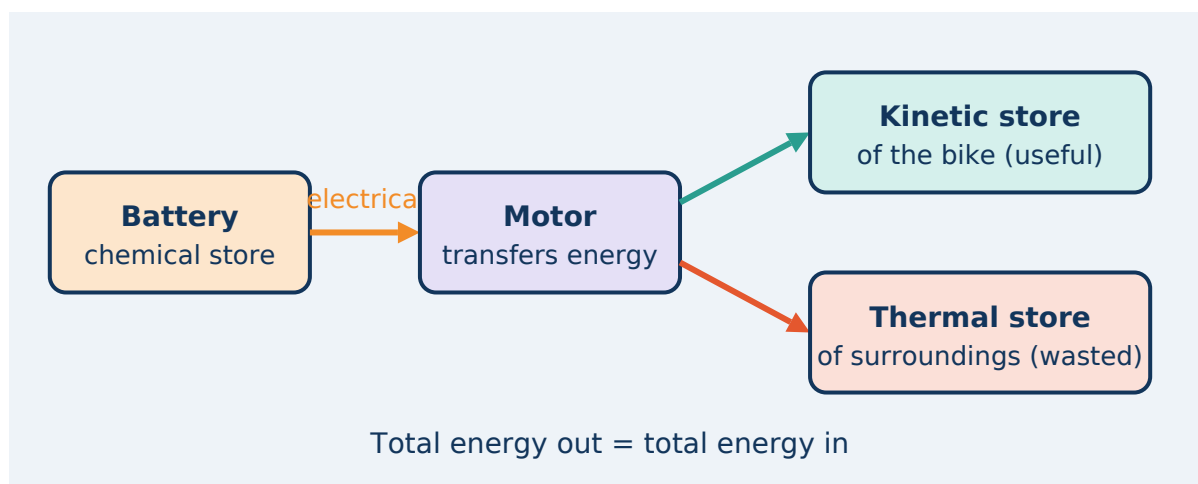
What are energy stores and energy transfers?

Energy is stored in different ways and moves from one store to another. Engineers follow it with a simple idea: **energy is never made or destroyed**. It is only transferred, and some of it spreads into the surroundings where nobody can use it.

Energy store	Example
Chemical	Fuel, food, a battery
Kinetic	A moving bus
Gravitational potential	Water behind a dam
Elastic potential	A stretched catapult band
Thermal	A cup of hot tea
Nuclear	Uranium in a reactor

Definition

Conservation of energy: the total energy in a closed system stays the same. Energy can be transferred mechanically (by a force), electrically, by heating or by radiation (light and sound), but it is never created or destroyed.



Energy chain for an electric bike showing useful and wasted energy.

In an electric bike, energy goes from the chemical store of the battery through the motor to the kinetic store of the bike. Some energy always goes to the thermal store of the surroundings. This is **wasted energy**: it is not destroyed, but it is not useful.

How do you calculate efficiency?

Efficiency tells you what fraction of the input energy becomes useful output. A high efficiency means little waste.

Formula

efficiency = useful output energy ÷ total input energy, and as a percentage:

efficiency (%) = (useful output ÷ total input) × 100

The same works with power: useful output power ÷ total input power. Efficiency has no unit. It can never be more than 100 %.

Worked example 1

An electric motor in a workshop in Nairobi takes in 800 J of electrical energy and lifts a load, which gains 560 J of gravitational potential energy.

Wasted energy = $800 - 560 = 240$ J.

Efficiency = $560 \div 800 = 0.70$, so **70 %**.

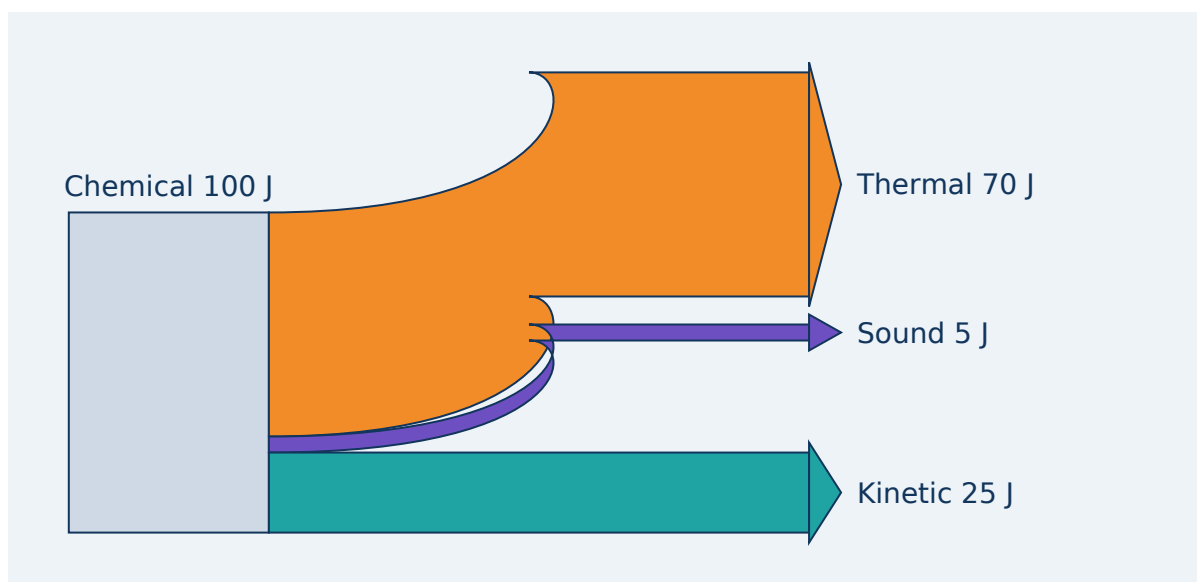
Worked example 2

A gas boiler is 85 % efficient and takes in 40 MJ of chemical energy from gas.

Useful energy = $0.85 \times 40 = \mathbf{34 \text{ MJ}}$. The wasted energy is 6 MJ.

What is a Sankey diagram?

A Sankey diagram shows where the energy goes. The width of each arrow is proportional to the amount of energy. The arrow for the input splits into a useful arrow and one or more wasted arrows. The widths of the outputs add up to the width of the input.

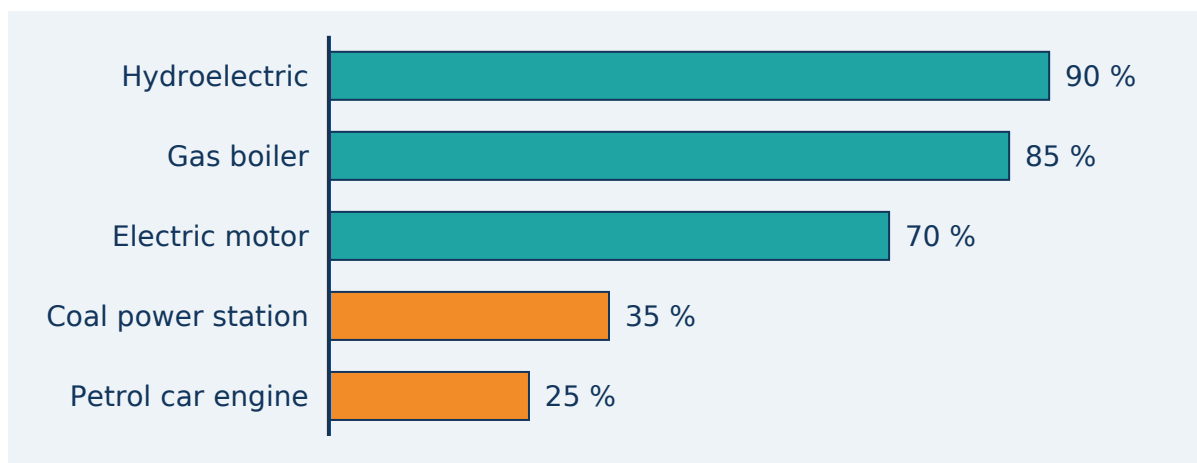


Sankey diagram of a petrol engine: the width of each arrow is proportional to the energy.

In the figure the engine takes in 100 J. Useful output = 25 J, so the efficiency is $25 \div 100 = 25\%$. The wasted 75 J is 70 J of thermal energy plus 5 J of sound.

Common mistake

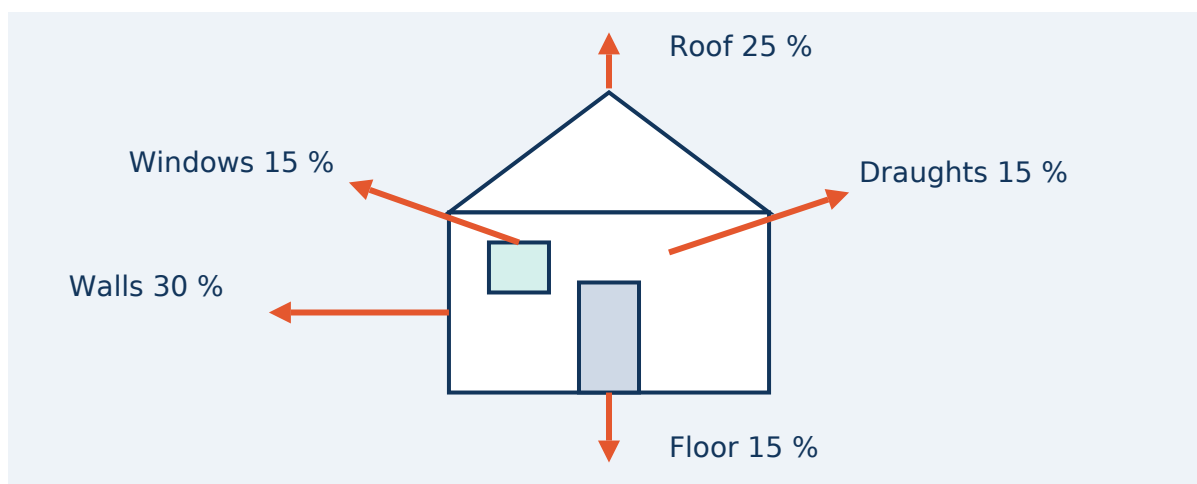
Do not say that wasted energy is "used up" or "lost". It is transferred to the surroundings, mainly as thermal energy. Also check that efficiency is never above 100 %: if your answer is 120 %, you divided the wrong way round.



Typical efficiencies of some energy converters, in per cent.

How can we reduce wasted energy?

To raise efficiency, reduce the unwanted transfers. Lubrication cuts friction in moving parts. Insulation slows thermal transfer. Streamlined shapes reduce air resistance. Better designs, such as LED lamps, give more light for the same electrical energy.



Typical shares of heat lost from an uninsulated house.

Method	How it reduces waste
Lubricating a bicycle chain	Less friction, so less energy to thermal and sound
Loft insulation	Slows thermal transfer from the house to the air
Double glazing	A trapped layer of air reduces conduction through the window
Streamlining a train	Less air resistance, so less drag work

Lina's tip

Write the energy balance first: total input = useful output + wasted output. If two of the three are known, the third follows, and the efficiency is the useful part divided by the input.

Key points to remember

- Efficiency (%) = useful output ÷ total input × 100.
- Energy is conserved: input = useful output + wasted output.
- Wasted energy spreads into the surroundings, mainly as thermal energy.
- In a Sankey diagram the arrow width is proportional to the energy.
- Lubrication, insulation and streamlining reduce wasted energy.

Energy stores, Sankey diagrams and efficiency: frequently asked questions

What is the formula for efficiency?

Efficiency = useful output energy ÷ total input energy. Multiply by 100 to give a percentage. The same formula works with power values.

Why can efficiency never be 100 % or more in real machines?

Some energy is always transferred to the surroundings as thermal energy by friction or electrical resistance. So the useful output is always less than the input.

Where does wasted energy go?

It spreads into the surroundings, mostly as thermal energy and sometimes as sound. The total energy is conserved, but the wasted energy is too spread out to be useful.

How do you read a Sankey diagram?

The width of every arrow is drawn in proportion to the energy it carries. The input arrow is the widest, and the useful and wasted arrows add up to the same width.

How does insulation improve efficiency?

Insulation slows the transfer of thermal energy out of a building. The heater then has to supply less energy to keep the rooms warm, so less is wasted.