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UNBOUND

FRESHERS' PERSPECTIVES

Pre-Academic Term Magazine of the
Faculty of Engineering, University of Moratuwa



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The Cover Story - *The Future is Built on the Past*

Long before the word “engineering” reached our shores, Sri Lankans were building with remarkable wisdom. Sigiriya still stands as proof of ancient skill in planning, building and managing water, and the Nine Arch Bridge carries that tradition into the age of rail.

Our cover follows this story from past to present. That heritage is still alive today, and modern engineering and design helps to preserve it, keeping our traditions alive and opening a new era of cultural tourism. Rising from this proud foundation are the innovations of today, from smart cities to robotics, prosthetics and an electric race car, many of them shaped by the hands and minds at the University of Moratuwa.

For young engineers and designers, progress does not mean leaving the past behind. It means carrying the legacy with its curiosity, ingenuity and resilience into the future we build next.

On the cover: Sigiriya Rock Fortress, Sigiriya; King Vimaladharmasuriya I, Ehelepola Wax Museum, Kandy; Lotus Tower, Colombo; Humanoid robot head; Prosthetic arm; Nine Arch Bridge, Demodara; Formula Student E2 EV, Falcon Racing, University of Moratuwa.

Editorial Note

Every journey into research begins with curiosity, a question, and the willingness to look beyond what one already knows.

UNBOUND Freshers' Perspectives brings together selected work produced by students of Batch 25 through the Library and Information Skills Programme conducted during the Pre-Academic Term of the Faculty of Engineering, University of Moratuwa. The contributions in this inaugural volume emerged from the Information Literacy assignment, My First Research Project, which introduced students to some of the essential practices of academic inquiry.

The assignment required students to engage with an engineering or design-related topic through systematic information searching, the use of library resources and academic databases, source evaluation, academic writing, referencing, reflection, and collaborative work. Students were also expected to explain their chosen topics in their own words, draw upon relevant sources, organise their ideas in a coherent manner, and demonstrate responsible academic practice.

The pieces presented in this magazine emerged from an evaluation process involving 110 submissions, of which 32 were selected for final evaluation. The final evaluation considered the relevance and clarity of the selected topic, the students' understanding of the problem, use of research sources, authenticity of writing, organisation and coherence, and the depth of discussion and synthesis. And 14 were selected for publication

These writings should be read as the early work of students at the beginning of their undergraduate journey. Their value lies not only in the topics they explore, but also in the process they represent. Through this experience, students began to encounter research as a practice of questioning, searching, evaluating, interpreting, connecting ideas, and communicating evidence with care.

The title *Unbound* reflects this stage of intellectual growth. Entering university opens new possibilities for thinking beyond familiar boundaries, questioning assumptions, and approaching problems from different perspectives. For future engineers, such habits are closely connected to their ability to investigate problems responsibly, communicate ideas clearly, and make informed decisions.

This publication is also the outcome of a collective effort. We gratefully acknowledge the Library, the Faculty of Engineering, the coordinators, academic staff, mentors, reviewers, and all those who contributed to the Pre-Academic Term and supported the students throughout this process. Above all, we acknowledge the students whose work, curiosity, and emerging perspectives have made this first volume possible.

We hope that *UNBOUND Freshers' Perspectives* will serve not merely as a record of an assignment, but as a record of a beginning. May it encourage students to continue asking worthwhile questions, seeking reliable knowledge, communicating responsibly, and developing the intellectual independence that will shape their future as engineers and designers.

Message from the Vice-Chancellor



Senior Prof. K.T.M.U. Hemapala

Vice-Chancellor,
University of Moratuwa

It gives me great pleasure to congratulate the students of Batch 25, whose efforts have led to the publication of *UNBOUND Freshers' Perspectives*, the first volume of its kind at our university.

University education is not only about acquiring knowledge but also about learning how knowledge is created and renewed. I am pleased that our freshers were allowed to experience research at the very start of their undergraduate journey. Through My First Research Project, they learned to find reliable information, evaluate sources and write with integrity and authenticity. As the futurist Alvin Toffler observed, the illiterate of the future will not be those who cannot read and write, but those who cannot learn, unlearn and relearn. Research is this very process. We learn when we gather knowledge and explore what others have discovered. We unlearn when evidence challenges our assumptions, and we let go of ideas that no longer hold. We relearn when we build a clearer, better-informed understanding from what we have found. This is exactly the journey our students began in My First Research Project. Engineers and designers of the twenty-first century will face problems that do not yet have names, and the habit of learning, unlearning and relearning will matter more than any single body of facts.

A maxim attributed to St Isidore of Seville puts it: "Study as if you were to live forever; live as if you were to die tomorrow." I hope our students carry this spirit with them: a lifelong commitment to learning, together with the urgency to use that learning for the good of society today.

I commend the Library, the Faculty of Engineering, and the UNBOUND Team for making this initiative possible. Above all, I congratulate the student authors. Their work shows what curiosity can achieve when it is guided well. May this be the first of many contributions to knowledge from each of them.

Message from the Dean



Prof. J.M.A. Manatunga

Dean, Faculty of Engineering
University of Moratuwa

An engineer's most important decisions often come before the first calculation: What problem are we really solving, and whose lives will our solution change?

The inaugural volume of *UNBOUND Freshers' Perspectives* celebrates students taking their first steps towards that thoughtful engagement. These contributions show the beginnings of independent inquiry, a habit that will shape their education and, eventually, the decisions they make as professionals.

When a convincing answer is only a few keystrokes away, knowing what makes it trustworthy becomes essential. Students must learn to examine the evidence behind a claim and recognise when a question remains unresolved. The willingness to revise a conclusion is a mark of intellectual strength. Such honesty is fundamental to engineering and to the public trust our profession carries.

My ambition for our Faculty is to educate engineers whose technical confidence is matched by an understanding of the people and environments affected by their work. That responsibility begins with experiences such as this: giving students room to explore ideas while expecting them to support those ideas with care.

I congratulate our student contributors and thank the Library, coordinators, mentors and editorial team for making this publication possible.

To our new undergraduates: you have entered a community in which your questions matter. Use that opportunity well. A question you begin exploring today may one day lead to a solution that others depend upon.

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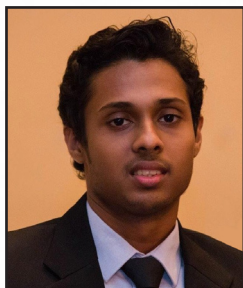
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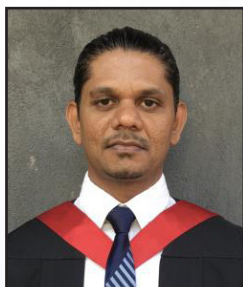
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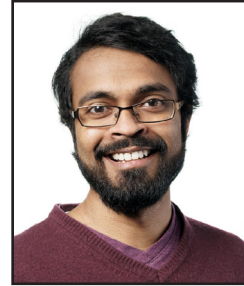
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Artificial Intelligence in Healthcare

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Introduction

Artificial intelligence is the intelligence created by humans. It is a part of computer science. Artificial intelligence is used to create smart machines that can think like humans and learn new things (Fig. 1).



Fig. 1. Human and robotic hands meeting at a DNA strand [1]. AI-generated image, Vecteezy Free License.

The most immediate threat to healthcare is the growing shortage of human resources. This is not a temporary problem but a structural issue caused by multiple factors. The World Health Organization has projected a global shortfall of 10 million health workers by 2030. This shortage means that fewer staff are available to manage an increasing patient load, leading to longer waiting periods and crowded hospitals. Developed countries are increasingly recruiting healthcare workers from developing nations to fill their own staffing gaps. This causes shortages in the regions that can least afford to lose their skilled workers, further widening global health workforce gaps. Therefore, many hospitals find it hard to recruit skilled surgeons and consultants. Hospitals also face rising operating costs for labour, resources, and pharmaceuticals. Governments often fail to keep pace with these increasing expenses, leaving many providers with very narrow operating margins and threatening their financial viability [2], [3].

By using this new technology in the healthcare sector, artificial intelligence can automatically manage tasks, reduce congestion in the healthcare sector, and achieve many other benefits. Through this technology, patients can get health advice from their homes. A significant advantage is that AI can accurately store and recall the patient's medical history. The main areas in which AI is changing healthcare are shown in Fig. 2 and discussed in this article.

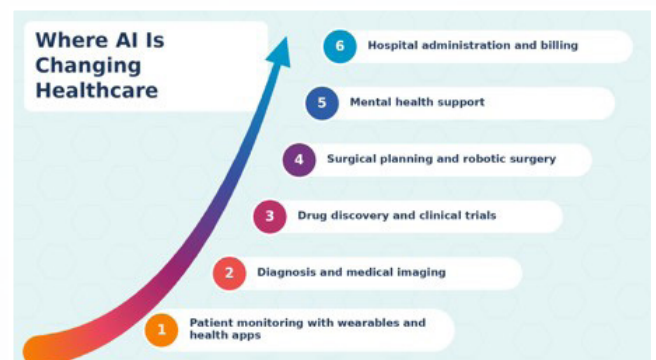


Fig. 2. Where AI is changing healthcare.

A Brief History of AI in Medicine

In its early decades, from the 1950s to the 1970s, AI received little attention or acceptance from the medical community. Most effort at that time went into converting medical information into digital form, through clinical informatics databases and electronic medical records, work that laid the groundwork for biomedical search tools such as today's PubMed [4]. By the mid-1970s, computer networks linking researchers had spread to universities such as Rutgers and Stanford. This closer collaboration led to the first National Institutes of Health (NIH) workshop on AI in medicine, which began a series of joint research meetings [4].

Since then, AI and machine learning have influenced almost every industry. Much of the discussion about their future has centred on automation, and healthcare is expected to be one of the sectors most transformed by it. In the long term, AI could make parts of the diagnostic process largely paperless and reduce the need for routine face-to-face visits [5].

AI as a Personal Health Assistant

Artificial intelligence as a health assistant plays an important role in the modern healthcare system. These systems can analyse large amounts of medical data quickly and support better health decisions.

Wearable devices use AI to track heart rate, blood pressure, physical activity, oxygen level, and sleep patterns. AI-based apps can also remind patients to

take medicines at the right time. If problems appear in the daily routine, AI can alert doctors and nurses before they become serious (Fig. 3).

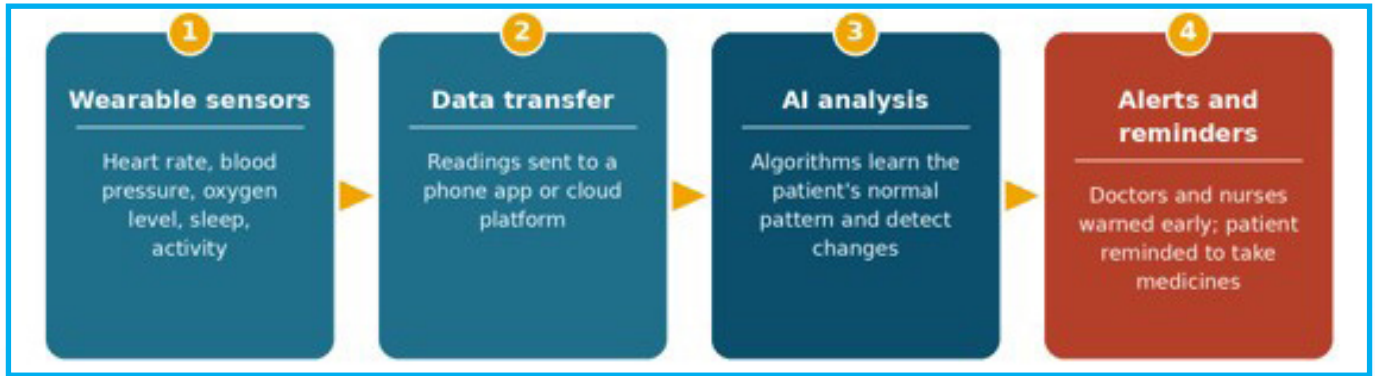


Fig. 3. How AI-based patient monitoring works.

AI chatbots and apps can ask patients about their symptoms. A healthcare chatbot is designed to provide immediate medical information and help patients manage their own health. Health chatbots can answer common medical questions, give medication reminders, and advise patients to seek professional medical help. Furthermore, AI can predict diseases and suggest a list of therapies, and it can explain what drugs are made of and what they are used for. Health chatbots also communicate in a simple and user-friendly way that makes healthcare information more accessible to everyone. In particular, they reduce the workload of healthcare staff by handling routine inquiries and administrative tasks. Although health chatbots cannot replace doctors, they act as a supportive tool [6].

Personalised care with AI focuses on providing treatment plans tailored to each patient's individual needs. AI analyses data such as medical history, lifestyle, and genetics, and then recommends customised therapies and suitable treatments [7].

In hospitals, AI assists doctors by analysing X-rays, scans (Fig. 4), medical reports, and patient records that may be difficult for humans to analyse. This improves the accuracy of diagnosis and treatment and supports early disease detection [6], [8].



Fig. 4. A CT scanner with spiral scanning capability [9]. Public domain.

AI in Diagnosis and Treatment

AI is also being rapidly integrated into medical imaging, surgery, and drug development. AI has revolutionised cancer detection by accurately finding abnormalities at early stages, before they can be identified by the human eye. Deep learning algorithms such as convolutional neural networks (CNNs) are now used to analyse mammograms and lung CT scans [10].

Modern AI algorithms can measure heart chamber volumes and calculate the “ejection fraction” with precision that matches expert cardiologists. AI-driven coronary calcium scoring on CT scans helps predict a patient's risk of a future heart attack [11].

AI and machine learning (ML) are now used at several stages of modern surgery. Before the patient enters the operating room, AI models analyse complex data and provide a more accurate understanding of the case [12]. Traditional risk assessment relies on the personal judgement of the physician, which carries risk; in contrast, ML models provide a more accurate summary by studying the complex relationships between a large number of variables. For emergency surgery, the Predictive OpTimal Trees in Emergency Surgery Risk (POTTER) tool supports accurate assessment of morbidity and mortality. AI models also evaluate factors such as glucose levels, age, and platelet counts, which can help predict the recovery of the nervous system in patients with severe brain injuries [12].

During surgery, robotic systems can analyse data within milliseconds, allowing fine control of the speed and action of the robotic arm [13]. A robotic drilling system can also detect changes in the drilling force, so it can sense the exact moment when the drill is about to break through the bone and stop automatically before damaging the delicate internal membranes [14].

Artificial intelligence plays a crucial role in the pharmaceutical industry by greatly improving the “drug life cycle,” which includes discovering, clinically testing, manufacturing, and supplying medicines. AI improves the efficiency of the pharmaceutical industry by transforming each of these steps.

Developing a new drug in traditional ways takes over a decade, costs billions of dollars, and always carries major safety concerns. AI, however, can analyse large amounts of biological and chemical data to identify potential drug candidates much faster and more cheaply. These machine learning algorithms (in silico screening) [15] help researchers predict how different chemical compounds will interact with the human body, reducing the costs and safety issues of traditional methods.

AI can also aid clinical trials by selecting suitable patients and monitoring side effects more accurately. This not only makes trials more efficient but also helps ensure that the right drug reaches the right patient.

Furthermore, AI streamlines drug production and distribution. AI-powered systems can monitor production lines to ensure quality control, predict demand for different drugs to optimise inventory, and enhance supply chain efficiency. This helps ensure that medicines are available to the people who need them at the right time [16].

AI in Mental Health

One in every eight people in the world lives with a mental disorder, a statistic that underscores the deep and growing impact of mental illness on global health [17].

The use of AI in the mental health field has grown significantly in recent years. These advances allow AI to offer timely, tailored support, helping people manage their mental health in ways that were once unimaginable [18].

AI is also making mental health care more accessible, especially where traditional resources are limited. Apps such as Woebot and Wysa offer conversational support to large numbers of users, and many tools for detecting mental health disorders are based on the analysis of facial expressions and speech [18], [19].

AI in Hospital Administration

Beyond patient care, artificial intelligence is being used to improve efficiency in healthcare delivery. This is crucial to reducing the heavy workload in the hospital system. AI can predict staffing needs and support supply chain decisions. This can ensure that patients receive the resources they need and minimise waste. The main benefit is that the hospital system runs smoothly [20].

Some surgeries for insured patients require authorisation from insurance companies, which can take days, but AI can do this quickly. Also, some bills that hospitals submit to insurance companies are rejected. AI can predict which ones will be rejected in advance and suggest changes. This reduces errors and ensures that money is received quickly [21].

When doctors see patients, they must record the patient's condition. However, writing records takes time and can reduce the attention given to the patient. When AI handles the writing using large language models such as GPT-4, the doctor's full attention can be given to the patient [22].

Limitations of AI

AI also has clear limitations. AI tools approved by the US Food and Drug Administration (FDA) perform well on specific, well-defined tasks such as pattern recognition, and deep learning algorithms can work quickly and continuously without fatigue [23]. However, AI cannot yet reason like a human. It struggles to apply what it has learned to situations it has not seen before, and it cannot combine several imaging findings with a patient's clinical history in the way a radiologist does [23]. AI can also be misled by problems in the image itself, such as artefacts, poor patient positioning or badly timed contrast injections in CT angiography. For example, it may mistake calcium deposits in an unusual location on a head CT scan for bleeding [23].

Conclusion

Artificial intelligence has become an unavoidable force within the healthcare sector, evolving from a simple tool into a crucial component of modern medical science. AI is capable of learning and automating tasks, and it helps address urgent structural issues such as the global shortage of human resources and the rising costs of healthcare delivery. AI acts as a personal health assistant through wearable monitoring devices and chatbots that provide immediate medical information. Administratively, AI improves hospital efficiency by managing staff, supply chains, and insurance billing, which allows physicians to focus on patient care rather than documentation. However, the integration of AI is not without challenges. AI systems struggle with analytical tasks involving multifactorial contributions and can interpret a test image incorrectly, leading to potential diagnostic errors. Therefore, while AI is a powerful supportive tool, it is not yet capable of replacing the critical thinking of human medical professionals.

Acknowledgment

Fig. 1 is an AI-generated image created by a third party and obtained from Vecteezy under its Free License. The authors did not use generative AI tools to create or modify this image.

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Global Warming and Natural Disasters

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Introduction

Global warming is the gradual increase in Earth's average surface temperature over time [1]. Although the climate changes naturally, current warming is occurring much more rapidly because of human activities such as industrialisation and the burning of fossil fuels [2]. The greenhouse effect is a natural process that keeps the Earth warm. Sunlight enters the atmosphere and heats the surface, while greenhouse gases trap some of this heat [3]. Human activities have increased the concentration of these gases, causing extra heat to remain in the atmosphere and leading to global warming [4]. Carbon dioxide is the main greenhouse gas released by burning coal, oil, and gas. Methane, produced by animal husbandry, landfills, and gas leaks, traps much more heat than carbon dioxide despite its shorter lifetime in the atmosphere [5]. Water vapour also contributes: its concentration increases as temperatures rise, which strengthens the warming effect [6]. Human activities such as fossil fuel use and deforestation are the primary causes of global warming [7]. Natural factors such as volcanic eruptions also affect the climate, but they cannot explain the rapid temperature rise seen today [8]. Global warming leads to melting polar ice, rising sea levels, damaged ecosystems, and disrupted weather patterns, threatening both wildlife and human life [9].

Rising Global Temperatures

Global warming is now exceeding earlier scientific estimates, and 2024 was the warmest year in the instrumental record [10]. The Paris Agreement aims to limit global warming to 1.5 °C above preindustrial levels. Nearly 200 countries adopted the agreement, but many are not meeting its targets, and in January 2025 the United States government ordered its withdrawal [11]. Land and oceans do not warm at the same rate. Land has a lower heat capacity than the ocean, so it responds to warming more quickly; land surface temperatures are now more than 2.2 °C above preindustrial levels. The ocean warms more slowly, but it absorbs about 90 percent of the excess heat trapped by greenhouse gases [12].

Several independent lines of evidence show that the planet is warming:

- **Temperature records:** 2024 was the warmest year on record, about 1.55 °C above preindustrial levels [10], and scientists expect 2026 to be the fourth consecutive year more than 1.4 °C above that baseline.

- **Glaciers and ice sheets:** Greenland is losing ice about four to five times faster than it did in the 1980s.
- **Arctic sea ice:** the Arctic has lost sea ice at an average rate of about 31,100 square miles (80,500 km²) per year since 1979 [13].

The surplus energy trapped in the climate system is already having severe global impacts:

- **Extreme weather:** heat waves are becoming longer and more intense, and extra ocean heat makes hurricanes and typhoons stronger [14]. Warmer air also increases heavy rainfall.
- **Ecosystem stress:** higher temperatures shift climate zones, reduce biodiversity, and drive species toward the poles [9].
- **Health and the economy:** heat stress and extreme events harm human health and livelihoods, as discussed later in this article.

Warming varies by location and time of year. The Arctic is warming three to four times faster than the global average. In the Northern Hemisphere, snow is melting earlier and spring is arriving sooner, so seasonal events no longer occur at their usual times.

Scientists usually compare modern data with the 1850–1900 average, which represents preindustrial conditions. Table 1 summarises how the climate has changed since then.

Table 1. Preindustrial and modern climate indicators.

Feature	Preindustrial (1850–1900)	Modern (2024–2026)
Global average temperature	Baseline (0 °C)	About 1.46 °C above baseline (2026 central estimate)
Warmest year	N/A	2024 (1.55 °C above baseline)
Atmospheric CO ₂	About 280 ppm	About 50% higher than preindustrial levels
Sea level	Stable baseline	8–9 inches (20–23 cm) higher than in 1880

Water Vapour in the Atmosphere

Evaporation and Transpiration

Evaporation is one of the primary processes that add water vapour to the atmosphere. Oceans, rivers, lakes, and soil surfaces absorb incoming solar radiation, warming the surface water until it changes into vapour. The amount of water vapour added by evaporation depends strongly on temperature: as temperature increases, evaporation rates also increase. Globally, evaporation supplies about 85–90 percent of atmospheric water vapour [15]. On average, about 425,000 km³ of water evaporates each year, of which 361,000 km³ comes from the oceans and about 64,000 km³ from land surfaces, including soil, lakes, and rivers.

Transpiration is the biological process by which plants release water vapour through their stomata during photosynthesis. It is controlled mainly by plant type, soil moisture, leaf area, and air temperature. Although transpiration supplies only about 5–10 percent of total atmospheric water vapour, it plays a crucial role over land, where it accounts for nearly 60 percent of total evapotranspiration [16]. Forests return about 70–80 percent of their evapotranspiration through transpiration, and croplands about 40–60 percent. During droughts, plants close their stomata, reducing transpiration.

As the global temperature rises, the atmosphere can hold significantly more moisture. The Clausius–Clapeyron relationship shows that for each 1°C of warming, the atmosphere can hold about 7 percent more water vapour [17]. By 2025, global temperature had risen by about 1.5°C compared with the preindustrial era, so the atmosphere can now hold about 10 percent more moisture than it could then. Fig. 1 shows how atmospheric water vapour has increased since the 1990s.

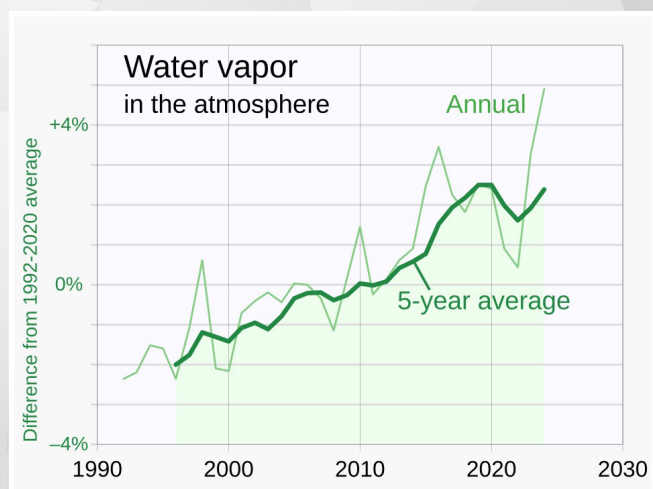


Fig. 1. Global atmospheric water vapour, shown as the difference from the 1992–2020 average (data: Copernicus C3S/ECMWF, ERA5) [18]. Image: RCraig09, CC BY-SA 4.0.

Atmospheric moisture is carried around the world mainly by large-scale wind circulation. One of the key mechanisms is the atmospheric river, a narrow band

of moist air that can transport about 250–275 million kilograms of water per second. An atmospheric river that persists for 24 hours can therefore deliver roughly 2.2×10^{13} kg (about 22 km³) of water. As a result, tropical regions tend to receive very heavy rainfall, while arid regions tend to become drier [15].

Water Vapour as a Greenhouse Gas

A water molecule is composed of one oxygen atom and two hydrogen atoms [19]. Because of its molecular geometry, the molecule is bent, or V-shaped (Fig. 2). This shape gives the oxygen atom a partial negative charge (δ^-) and each hydrogen atom a partial positive charge (δ^+), so water is a polar molecule. This polarity allows water to interact with electromagnetic radiation and absorb infrared radiation. After absorbing infrared radiation, the molecule becomes excited and re-emits the energy in all directions, which adds to global warming [6]. Warming, in turn, increases atmospheric moisture, and the cycle continues. Water vapour is one of the main greenhouse gases because it is present all over the world and is far more abundant than CO₂. Water vapour and clouds together are estimated to account for about 50–70 percent of the greenhouse effect [20].

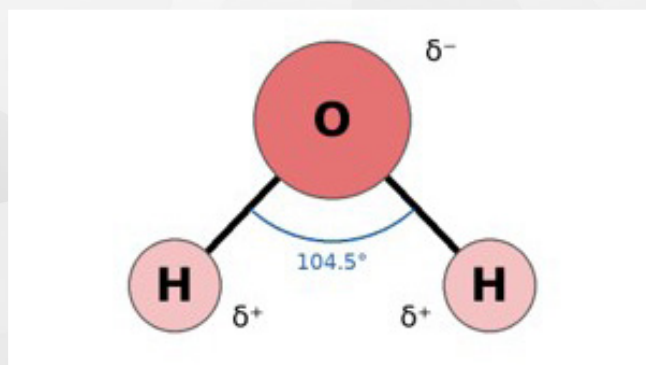


Fig. 2. The bent (V-shaped) water molecule, showing the partial charges that make it polar.

Warming is initiated by CO₂. As the amount of CO₂ increases, more infrared radiation is re-radiated back toward the surface, and the temperature rises. The warmer atmosphere then accumulates more water vapour, which re-radiates additional infrared energy and heats the planet further [21]. When moist air is lifted by convection, weather fronts, or mountains, its water vapour condenses. Clouds grow larger and rainfall intensifies in wet regions, while dry regions become drier because they receive less rain.

Water Vapour and Cyclones

Cyclones are fuelled by water vapour through latent heat. As seawater evaporates, it absorbs energy from the sun and stores it in the vapour. When this vapour rises and cools, it condenses into droplets and releases the stored heat back into the atmosphere [22]. Fig. 3 shows how this process drives cyclone formation. The cycle continues for as long as the storm remains over warm water.

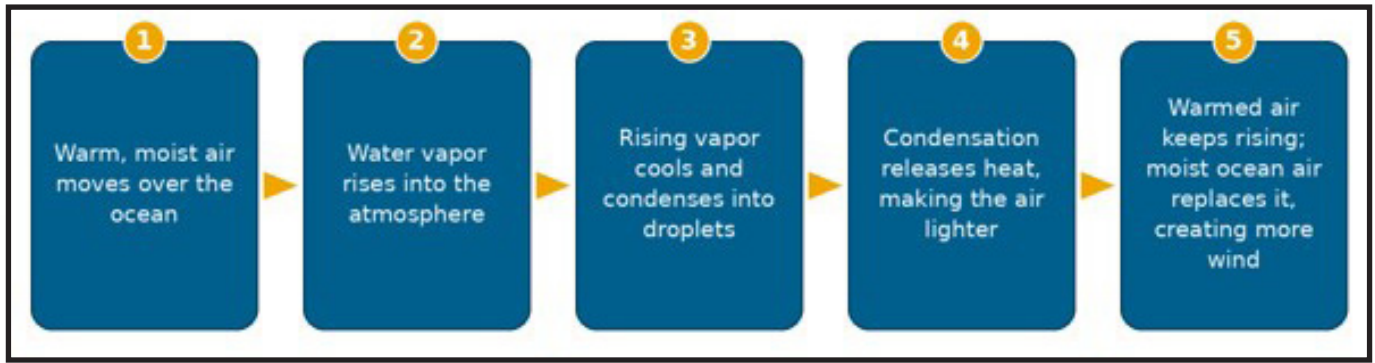


Fig. 3. How water vapour drives cyclone formation.

As global temperatures rise, the atmosphere can hold about 7 percent more water vapour for every 1 °C of warming [23], giving storms more fuel. Global warming makes cyclones more intense by heating both the atmosphere and the upper layers of the ocean [24]. A warmer atmosphere holds more moisture and increases the potential energy available to storms. Stronger cyclones have more powerful updrafts that lift larger quantities of moist air, producing extensive cloud formation and prolonged rainfall. The resulting flooding and landslides often make a cyclone deadly. Cyclones generally form over waters warmer than 26 °C, where evaporation is high. Warm ocean water continuously supplies heat and moisture, allowing a cyclone to maintain its strength. Most cyclones form in the tropical belt and move westward before curving toward the poles. They regularly affect the coastlines of the Atlantic, Pacific, and Indian Oceans [25]. Cyclones form regularly in seven ocean basins (Table 2).

Table 2. The seven cyclone basins and the regions they affect.

Basin	Main regions affected
North Atlantic	United States, Mexico, and the Caribbean islands
Northwest Pacific	China, Japan, the Philippines, Vietnam, and Taiwan
Southeast Indian	Northern and western coasts of Australia, and Indonesia
North Indian Ocean	India, Bangladesh, Myanmar, Sri Lanka, and Oman
Southwest Indian Ocean	Madagascar, Mozambique, and Mauritius
South Pacific	Fiji, Vanuatu, and the Solomon Islands
Northeast Pacific	Western Mexico and Hawaii

Effects on Weather Patterns Heavier and More Sudden Rainfall

Increased water vapour in the atmosphere causes heavier and more sudden rainfall because water vapour acts as both the fuel and the energy source for rain-producing systems. The Clausius–Clapeyron relation [26] describes how the saturation vapour pressure e_s changes with temperature T :

$$de_s/dT = L_v(T) e_s / (R_v T^2)$$

where $L_v(T)$ is the latent heat of vaporisation and R_v is the gas constant for water vapour. The solution of this equation shows that e_s grows exponentially with temperature: for every 1 °C increase, the atmosphere's moisture-holding capacity rises by roughly 7 percent. This creates a large reservoir of water available for heavy rainfall.

When water evaporates, it absorbs heat from the sun. This heat enables more water vapour to accumulate in clouds, making them taller and denser with moisture. Eventually, the weight of the water overcomes the updraft, which collapses and releases the water as a heavy downpour.

The heat from the sun is locked inside the water vapour. When the vapour condenses into raindrops, this heat is suddenly released into the surrounding air, making the air inside the cloud warmer and lighter than the air around it. The air then rises even faster, and the result is a sudden, intense downpour.

Droughts and Expanding Dry Zones

As the atmosphere warms, its capacity to hold water increases faster than the actual evaporation rate, so it takes longer for air to reach the saturation point needed to trigger rain. The atmosphere “hoards” water for longer periods, carrying it over great distances without releasing a drop [27].

Deserts form where hot air rises at the equator and sinks in the subtropics. This circulation pattern, known as the Hadley cell, is spreading toward the poles because of global warming [28]. The drying power of the air depends on the vapour pressure deficit (VPD),

which measures how strongly the atmosphere draws moisture from the soil [29]:

$$VPD = e_s(T) - e_a$$

where e_a is the actual vapour pressure. As global warming raises T , e_s increases exponentially, but e_a often increases much more slowly or stays constant over land. The gap between them therefore widens significantly, and a higher VPD means the atmosphere draws water from crops and soil much faster, causing rapid drying.

Stronger Storms and Cyclones

Because more water vapour gives storms and cyclones access to more fuel, they become more powerful and destructive. In a warming world, a cyclone (hurricane or typhoon) functions much like a massive heat engine. Because of the Clausius–Clapeyron relation, a warmer atmosphere allows a much larger mass of water vapour m_v to accumulate in a storm system [30]. The heat Q released when this vapour condenses is

$$Q = m_v L_v$$

Since L_v is a large constant, a small increase in m_v produces a large increase in Q . Part of this energy is converted into the kinetic energy of the storm winds, $E_k = \frac{1}{2}mv^2$, so more heat means faster winds.

Cyclones behave like heat engines. The efficiency of heat transfer between the warm ocean surface and the cold upper atmosphere determines their theoretical maximum intensity, known as the maximum potential intensity (MPI) [31]:

$$V_{max}^2 \approx (C_k/C_d) \cdot [(T_s - T_0)/T_0] \cdot (h_s - h_a)$$

where T_s is the sea surface temperature, T_0 is the outflow temperature at the top of the storm, C_k/C_d is the ratio of the exchange coefficients for enthalpy and momentum, and $(h_s - h_a)$ is the difference between the saturation enthalpy at the sea surface and the enthalpy of the air above it. Global warming increases T_s and, through extra moisture, the enthalpy difference. Even a small increase in the efficiency term or the moisture term therefore produces a larger increase in V_{max}^2 .

Link to Natural Disasters

Global warming is more than a rise in temperature; it also drives natural disasters. The excess heat makes Earth's weather more unpredictable and extreme. Warmer oceans supply extra energy that makes hurricanes stronger. Warmer air draws moisture out of the ground, contributing to droughts and wildfires. Because warm air holds more moisture, it can carry more water before cooling and releasing it as heavy rain. Landslides are generally caused by soil saturation:

during heavy rain, excess water fills the gaps between soil particles and acts as a lubricant, reducing the friction that holds the ground in place, until gravity pulls the entire mass downhill in a destructive slide.

Impact on Human Health and Livelihoods

Global warming and natural disasters create a dangerous feedback loop in which physical illness and financial loss reinforce each other. Rising temperatures cause health crises such as heat stroke, especially among elderly people and children. Indirect effects include the spread of diseases such as dengue and malaria into previously cooler regions, and the spread of diseases such as cholera through water pollution.

For people who depend on the land, global warming is also an economic disaster:

- **Agriculture:** unpredictable weather, alternating between extreme drought and heavy rainfall, can wipe out entire harvests and kill livestock, leading to food insecurity and sharply rising food prices.
- **Outdoor work:** extreme heat can make outdoor work such as construction and farming physically impossible for parts of the year, reducing workers' incomes.
- **Coastal communities:** rising sea levels and erosion destroy homes and businesses, turning people into climate refugees who must leave their homes and traditional occupations such as fishing.

Case Studies

Sri Lanka: Floods and Landslides, May 2017

In May 2017, heavy monsoon rains flooded large parts of Sri Lanka, with flooding worsened by a nearby cyclone. Although the storm did not make landfall, it pushed additional moisture inland. Rivers overflowed banks that were too low for such volumes, roads turned into rivers and cut off towns, and homes on hillsides cracked under the pressure of waterlogged soil. Water levels rose faster than warnings could spread, and even cities with drainage systems were flooded [32].

A warmer Indian Ocean fuelled the monsoon winds with extra moisture. Some areas received more than 500 mm of rain in a single day, close to a full month's rainfall in 24 hours. In Ratnapura and Kalutara, saturated hillsides gave way in landslides. After the floods, stagnant water created ideal breeding sites for mosquitoes, and more than 100,000 people contracted dengue in the largest outbreak recorded in the country. Some 77,000 homes were damaged, and soil erosion affected tea and rubber plantations, which provide much of Sri Lanka's export income.

The Philippines: Super Typhoon Haiyan, 2013

The Philippines shows what happens when island communities face repeated tropical storms. In 2013, four years before the Sri Lankan floods, exceptionally warm ocean water fuelled Super Typhoon Haiyan, one

of the most powerful tropical cyclones ever recorded. Its winds drove a storm surge far inland that behaved much like a tsunami. Many families lost their homes, and farming communities that depended on coconut crops lost their livelihoods when the crops were destroyed [33].

What this Means for Sri Lanka

Sri Lanka regularly ranks near the top of global climate-risk indexes. As an island, it faces threats both inland and along its coasts. In the hill country, sudden downpours saturate slopes until they fail, causing landslides with little warning. Along the coast, rising seas push salt water into wells, wetlands, and rice fields in areas such as Jaffna and Matara, contaminating drinking water and making soil unsuitable for crops.

Cyclone Ditwah, Sri Lanka, 2025

Cyclone Ditwah made landfall on Sri Lanka's eastern coast on 28 November 2025, triggering widespread flooding and deadly landslides across all 25 districts in one of the country's worst disasters in decades [34]. Because earlier rains had already saturated the soil, much of the rainfall became immediate runoff, causing intense flooding. The World Bank estimated the direct physical damage at about US\$4.1 billion, equivalent to around 4 percent of Sri Lanka's gross domestic product (GDP), with close to 2 million people severely affected. Infrastructure, including roads, bridges, railways, and water networks, accounted for the largest share of the damage, followed by housing and agriculture, including farming areas such as Nuwara Eliya [35]. For a developing country, this is a very large loss.

Global warming contributed to the disaster in several ways:

- **Increased energy:** warmer-than-usual sea surface temperatures gave the storm more energy.
- **Moisture loading:** the warmer atmosphere held significantly more water vapour, which fuelled catastrophic rainfall even though the cyclone's winds were relatively weak.
- **Secondary disasters:** the moisture-laden air triggered numerous landslides, mainly in the hilly interior.

Nearly 200,000 displaced people were housed in government shelters [36]. The armed forces and police led rescue operations, and the Sri Lanka Red Cross mobilised volunteers to provide food, water, and other essentials. India launched Operation Sagar Bandhu on 28 November to provide search-and-rescue and relief support [37], and other countries also sent relief supplies. Looking ahead, island-wide awareness programmes on climate responsibility for schools and government agencies, together with expanded rainwater harvesting and groundwater recharge in the Dry Zone, would help the country manage extreme rainfall variability.

Conclusion

Global warming and climate change have severely disrupted the global water cycle, leading to irregular rainfall, melting glaciers, droughts, and rising sea levels. As a result, natural disasters such as floods, cyclones, heat waves, and landslides are becoming stronger and more frequent, affecting all living beings. Addressing these challenges requires greater awareness of climate change. Using renewable energy is essential for reducing greenhouse gas emissions, and improved early warning systems can protect people from impacts that can no longer be avoided. Climate models show that the Earth is still warming, so science-based policies must be implemented and followed. Increasing public awareness and education is also important because informed people can make better decisions in an emergency. Together, these measures can help reduce global warming and the damage caused by natural disasters.

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Modern Dam and Reservoir Designs

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Introduction

Dams and storage reservoirs are key infrastructure elements enabling modern water resource management. These water storage structures are built across river courses to provide water storage capacity for a variety of essential applications, such as flood control, hydroelectric power generation, and irrigation [1]. The choice of a dam site is complex, determined by hydrological data and topographical analysis to guarantee the stability of the structure and prevent seepage [2]. In addition, the design of a reservoir involves precise calculations of capacity and safe yield, taking into account specific urban water supply and energy demands [3]. From a structural perspective, dams are classified based on the type of mechanical response expected under external forces, which are mainly hydrostatic pressure and self-weight. This subject combines fundamental knowledge of hydraulic engineering and mechanics.

Site Selection and Geological Investigation

Site selection and geological investigation are among the most important stages of the dam construction process. These stages directly affect the safety, stability, and overall budget of the dam. When choosing a site, factors such as orography, hydrology, accessibility, and availability of construction materials are normally considered.

“Divisive hierarchical clustering of existing and potential dam locations based on the area size, proportion of arable land, forestland and built-up area, degree of exposure to soil erosion and the volume of surface runoff allows to identify possible issues that might be relevant to area management using experience obtained from the environment of other sites” [4].

A comprehensive geological investigation helps to evaluate subsurface conditions and identify potential risks. Mosul Dam in Iraq shows what can go wrong when these conditions are not fully understood [5]:

- **Soluble foundations:** the dam sits on the Fars Formation, which contains thick layers of gypsum and anhydrite. These minerals dissolve rapidly when they come into contact with pressurised reservoir water.
- **The grouting “band-aid”:** because the rock is constantly dissolving, engineers must perform continuous grouting, pumping cement into the foundation 24 hours a day to fill new voids as they appear.

- **Seepage and sinkholes:** inadequate initial mapping of the karstification (the process of forming caves and sinkholes) meant that the dam’s cutoff depth was insufficient to stop water from undermining the structure [5].

“Effective grouting is an extension of site-specific geological investigation; it cannot be divorced from the unique structural and hydraulic characteristics of the rock foundation” [6].



Fig. 1. Hoover Dam from the air [7]. Public domain.

Types of Dams and Structural Behaviour

Dams can be categorised by their construction materials and structural design. There are gravity, arch, buttress, and embankment dams. Each type exhibits different structural behaviour to resist the enormous force of impounded water.

The structure of a gravity dam is simple: it is built from heavy concrete and resists water pressure through its own weight. “The usual procedures of verifying the overall stability of concrete dams are based on deterministic methods and use of safety factors” [8]. An arch dam is curved so that the water’s own pressure locks the dam into the canyon walls. Arch dams are designed using an elastic structural model [9]. An embankment dam is a large mound of compacted earth or rock, which makes it very strong. The last type is the buttress dam, which is similar to a gravity dam, but with material removed from the middle section [3].

Hydraulic Design of Dams and Spillways

A special civil engineering structure designed to store, control, divert, and measure water flow is called a hydraulic structure [10]. The three main hydraulic design categories are:

- **Water-retaining structures**, which store water (dams, tanks, and reservoirs);
- **Water-conveying structures**, which transport water to specific locations (canals, tunnels, and pipelines);
- **Intake structures**, which withdraw water.

Dams are barriers built across rivers to create artificial lakes, or reservoirs. They are built to block and store water for a specified period. “Dams are thus also effective structures for flood protection as they store water and release it with a temporal lag” [11]. The main hydraulic components, such as spillways, outlet works, intake structures, and control gates, help to store water in the reservoir and release it in a controlled manner. Spillways are built to pass excess floodwater. “In cases where safety of the inhabitants downstream is a key consideration during development of the project, the spillway should be designed to accommodate the probable maximum flood” [12]. Outlet works control water release for irrigation and other purposes. The intake structure guides water flow, and gates regulate the flow of water according to the hydraulic conditions (Fig. 2).



Fig. 2. Water released through the sluice gates of Hartbeespoort Dam, South Africa [13]. Image: Bluesnap, Pixabay Content License.

Reservoir Storage Analysis and Water Balance

Reservoir storage analysis and water balance are important aspects of dam design. They help engineers manage water storage while ensuring protection against floods. According to the U.S. Bureau of Reclamation, reservoir storage is divided into dead, active, and flood storage to ensure efficient water use and flood safety (Fig. 3). Reservoir storage analysis is performed using elevation–area and elevation–capacity curves, which allow engineers to determine water volume at different reservoir levels. The reservoir water balance

is governed by the relationship between inflow, outflow, evaporation, seepage, and change in storage. These principles form the basis of modern dam design and reservoir operation planning [3].

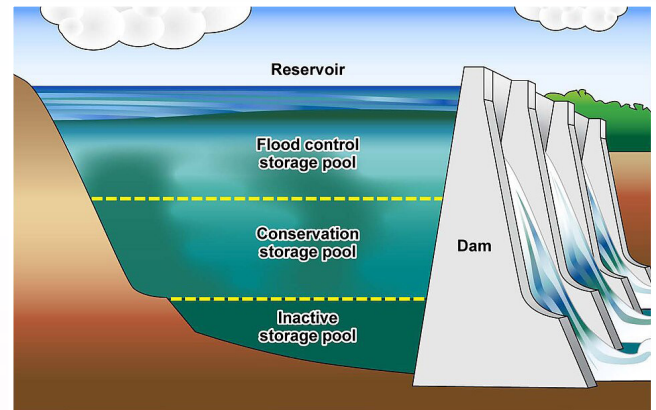


Fig. 3. Storage pools of a U.S. Army Corps of Engineers reservoir [14]. Public domain (U.S. Government Accountability Office).

Reservoirs can also be operated together with pumped-storage power stations in combined power generation systems, helping to meet and regulate peak electricity demand [15]. Previous studies show that combining ensemble rainfall and inflow forecasts with optimisation, machine learning, and stochastic programming techniques greatly reduces flood damage while improving the performance of reservoir operations [16].

Construction Materials and Modern Construction Methods

Construction materials and modern construction methods are essential for dam and reservoir design.

Construction Materials

Concrete and large stones are commonly used for dams, but dams are also built using soil, wood, and steel, and the material is selected according to the site. According to Barco Herrera, “As far as knowledge and use of materials is concerned, it was the Roman engineers and architects who improved and generalised the use of lime mortars, and began the addition of pozzolanic matters” [17].

Modern Construction Methods

According to Adamo et al., modern construction methods include roller-compacted concrete, modular construction, advanced geotechnical investigation, risk-informed decision-making, advanced monitoring and inspection technologies, and environmental and sustainability considerations. These methods help to create high-quality dams [18]. However, designers’ mathematical calculations may not predict the actual stresses in the structure if designers do not consider how the dam is actually built, and unexpected construction methods can cause serious problems [2].

Hydropower Components Integrated within Dams

Dam construction involves storing and managing water as well as using water to generate electricity. Hydropower components integrated with dams are responsible for converting the energy of water into electrical energy [19]. The key components are the reservoir, intake, penstock, turbine, generator, powerhouse, draft tube, control gates, transformers, and transmission lines [20] (Fig. 4).

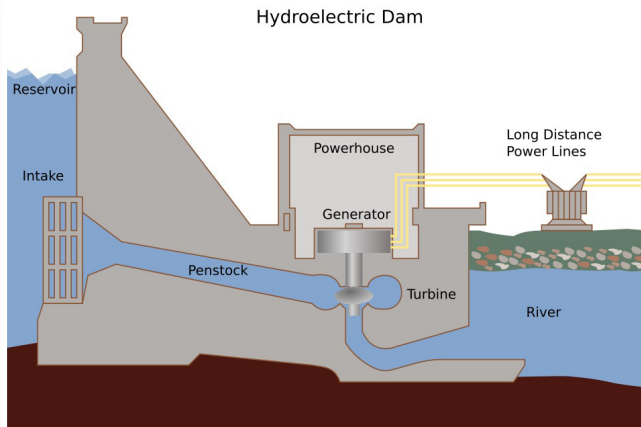


Fig. 4. Hydropower components integrated with a dam [21]. Image: Tennessee Valley Authority; SVG version by Tomia, CC BY 2.5.

The intake directs water into the penstock and ensures that debris does not enter the system. The turbine transforms the water's kinetic energy into mechanical rotation, which is transferred to the generator to produce electrical energy. The draft tube carries the water leaving the turbine to the tailrace, recovering part of its remaining energy, while control gates regulate how water is discharged [22].

Instrumentation, Monitoring, and Safety of Dams

Instrumentation and monitoring are critical to dam safety, allowing unusual behaviour to be detected at an early stage. According to the U.S. Bureau of Reclamation, the safety of dams is based on the "systematic measurement of seepage, deformation, uplift pressure, and pore water pressure to recognize possible failure mechanisms before they become critical" [23]. These instruments are placed in the dam structure and foundation to obtain performance information in addition to the inspection process [23], [24].

Continuous monitoring through instrumentation helps engineers detect long-term performance trends so that remedial action can be taken in a timely manner [25]. The literature shows that using instrumentation data in decision-making supports risk-informed decisions and improves safety in the operation of dams, especially older dams. Therefore, instrumentation in conjunction with inspection is a core component of modern dam safety programmes.

Social and Environmental Impact of Dams

Dams play a significant role in managing water resources that support daily human needs, agriculture, and power generation. However, research shows that dams also have social and environmental impacts. Large dam projects often result in the displacement of local communities, loss of farmland, and disruption of traditional livelihoods, including the "resettlement of people near the dam sites; changes in the rural economy and employment structure; effects on infrastructure and housing" [26]. Environmentally, dams alter the natural flow of rivers and negatively affect aquatic ecosystems [27]. Furthermore, reservoirs may also cause degradation of water quality [28]. Dams can generate electricity and provide a reliable water supply, but without careful planning, they can harm people and nature. Long-term success depends on balancing engineering with care for communities and the environment.

Modern Trends and Future Developments

In modern dam engineering, greater attention is given to safety through improved design methods, proper maintenance, and regular inspections. These practices ensure successful dam construction, enhance long-term safety, and improve the future performance of dams [29]. "Modern trends in dam engineering involve advancements in materials, construction techniques, and digital technologies to enhance safety, sustainability, and performance" [30]. Furthermore, engineers are undertaking significant work to advance dam engineering technology: "Therefore, for future intelligent dam construction, it is essential to establish and enhance innovative technologies for spatial information digitization and visualization to achieve four-dimensional management during project construction" [31].

Conclusion

Dams and reservoirs are essential for flood control, irrigation, water supply, and hydropower. Building them safely depends on careful site selection and geological investigation, the right choice of dam type and materials, and sound hydraulic design of spillways and outlet works. Once in service, continuous instrumentation and regular inspection help detect problems before they become dangerous. At the same time, dams affect communities and ecosystems, so these impacts must be considered from the planning stage. With advances in materials, construction methods, and digital technologies, future dams can become safer, more efficient, and more sustainable.

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The Electric Blueprint: Architecture, Power, and the Future of Mobility

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Introduction

Electric vehicle technology dates back to the 19th century, and the first electric vehicles were built in the late 1880s. According to Larminie and Lowry, electric vehicles were popular in the early 1900s because they were quieter and easier to handle than vehicles with internal combustion engines [1]. However, the development of petrol-powered vehicles and the availability of cheap fuel reduced their use. Interest in developing and manufacturing electric vehicles returned in the late 20th and 21st centuries, driven by environmental concerns and improvements in battery technology.

Types of Electric Vehicles

Electric vehicles (EVs) can be divided into categories based on their powertrain configuration [2]. The three main types are as follows:

- **Battery electric vehicles (BEVs):** BEVs are all-electric vehicles that use high-capacity batteries and electric motors as their only means of propulsion. Because they rely entirely on the battery pack and produce no tailpipe emissions, they are considered zero-emission vehicles.
- **Hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs):** HEVs combine

an internal combustion engine (ICE) with an electric motor. The vehicle can run on the engine, the motor, or both, and the battery is charged by the engine and by regenerative braking. A PHEV is an improved version of an HEV, with a larger battery that can also be charged from an external power supply.

- **Fuel cell electric vehicles (FCEVs):** an FCEV has an electric motor powered by an on-board fuel cell. It is also considered a zero-emission vehicle because water is its only exhaust product.

How an Electric Vehicle Works Energy Flow from Battery to Wheels

In EVs, the main energy source is a lithium-ion battery, which provides direct current (DC) power. A battery management system (BMS) protects the cells, and a DC-link capacitor smooths the battery current. An inverter converts DC into alternating current (AC), which drives the electric motor. Common motor types are permanent magnet synchronous motors (PMSMs) and induction motors, which produce torque and rotational speed. A mechanical transmission then delivers usable torque to the wheels efficiently. In this way, the electrical energy stored in the battery is converted into the kinetic energy of the vehicle (Fig. 1) [3].

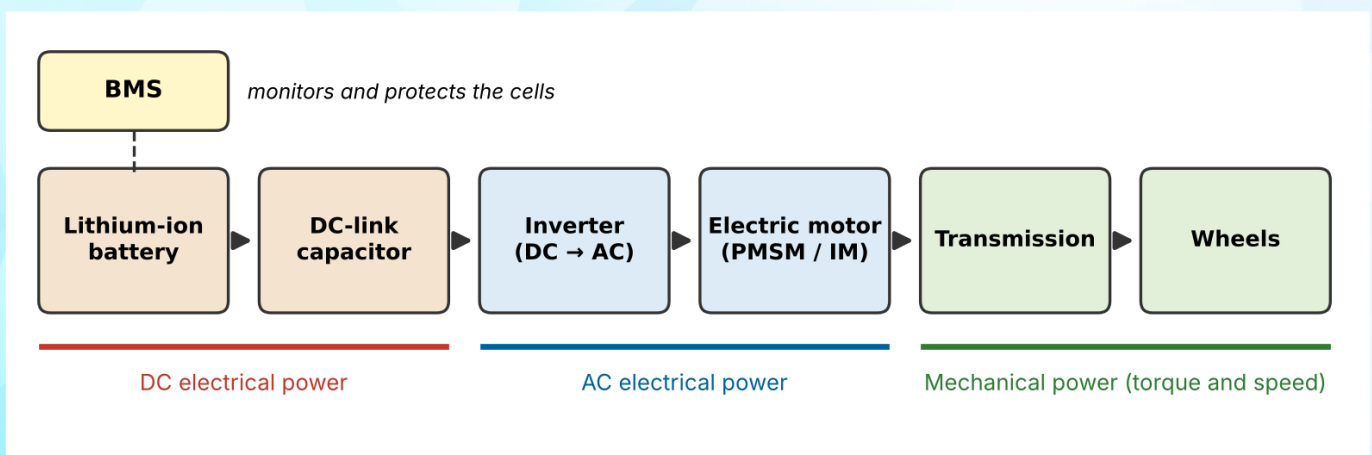


Fig. 1. Energy flow from battery to wheels in an electric vehicle.

Electric Motors

Electric motors play a significant role in EVs by converting electrical energy into mechanical energy to drive the vehicle. Several types of electric motors are used in EVs [1]:

- **Brushless DC motors (BLDCMs):** their high efficiency lowers energy costs and allows the vehicle to travel longer distances on a single charge.
- **Induction motors (IMs):** their high starting torque is beneficial for starting a motor under load.

- **Permanent magnet synchronous motors (PMSMs):** a popular choice for EVs because of their high-power density, high efficiency, and simple structure.
- **Switched reluctance motors (SRMs):** they do not rely on rare-earth minerals, which avoids the high cost and the environmental effects of mining and processing these minerals. Design optimisation has significantly improved their efficiency and performance [4].

Batteries and Charging

Battery Technology

Electrochemical energy storage systems, such as batteries and capacitors, are key components of electric and hybrid electric vehicles, and many models have been proposed to describe how they interact with the rest of the powertrain [5]. Modelling a battery accurately is difficult, because its main variables (state of charge, voltage, current and temperature) affect one another in a highly non-linear way [6].

The state of charge (SOC) is the amount of electrical charge stored in a battery, relative to its total charge capacity [7]. In principle, the SOC can be calculated by integrating the battery current over time:

$$SOC(t) = SOC(0) - (1/Q) \int_0^t i(\tau) d\tau$$

where Q is the battery capacity and i is the discharge current. In practice, this simple calculation drifts over time and is affected by measurement and modelling errors, so vehicles use more advanced SOC estimation methods that also use the measured terminal voltage and current [8].

Batteries in electric and hybrid vehicles also age, because they go through repeated and demanding charge and discharge cycles. Ageing appears as a loss of capacity and an increase in internal resistance, which can reduce vehicle performance, and researchers are developing models that predict the remaining life of a battery from the way it has been used [9]. Because these changes happen slowly, over months and years, they are usually not included in short-term vehicle simulations [10].

Battery Management System

The BMS is a key component of an EV, ensuring the safety, efficiency, and reliability of the battery [11], [12]. It continuously monitors cell voltage, current and, most importantly, temperature to prevent overcharging, deep discharging, and overheating. The BMS also performs cell balancing, which equalises the voltage differences between series-connected cells to improve performance and extend battery life [13]. In addition, it manages the thermal behaviour of the battery and controls its charging and discharging limits (Fig. 2) [14].

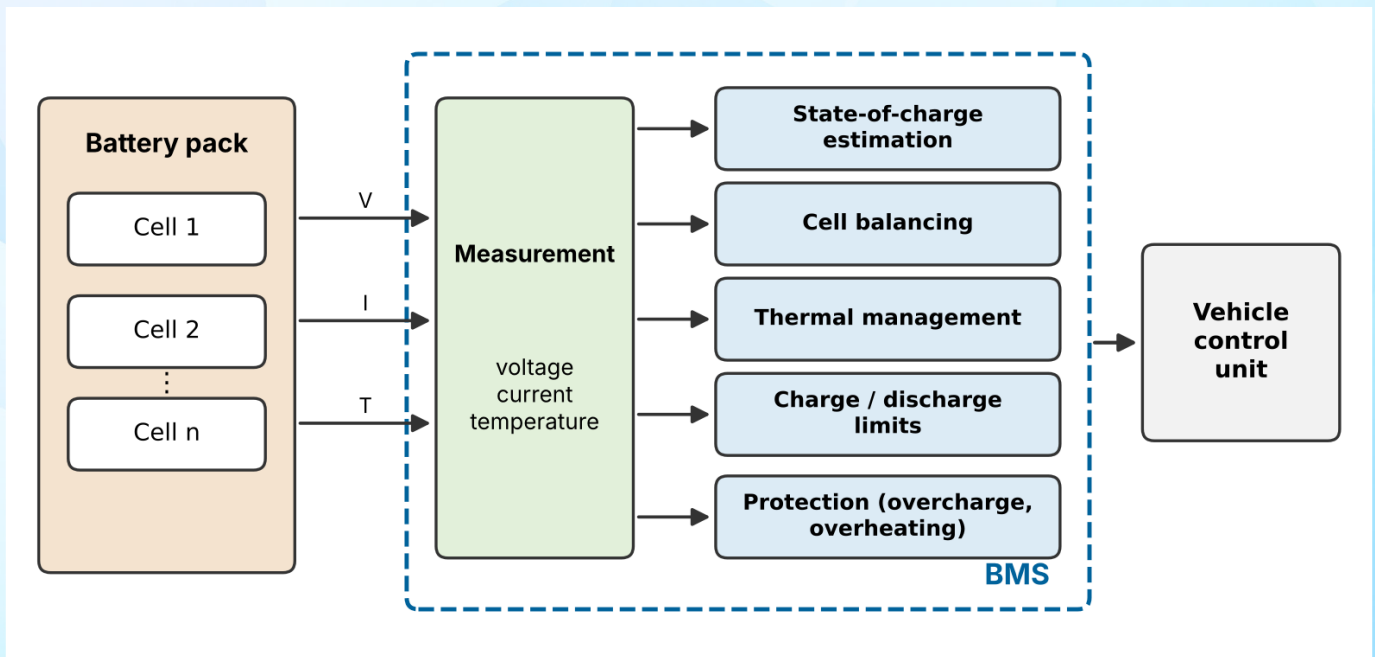


Fig. 2. Main functions of a battery management system.

Charging Methods and Infrastructure

Electric vehicles use different charging methods, depending on the power source and the charging speed. AC charging is the most common method; the AC power is converted to DC inside the vehicle. DC charging, which is commonly used at public charging stations, supplies direct current straight to the battery

and therefore allows much faster charging. Fast charging is a type of DC charging that can charge an EV battery to about 80% in a short time, which makes it ideal for long-distance travel. Wireless charging uses electromagnetic fields to charge vehicles without cables; it is highly convenient but less efficient [15].

Impacts of Electric Vehicles

The adoption of EVs supports the Sustainable Development Goals (SDGs), and research has found that, overall, it has a positive impact on the economy and society [16], [17].

Environmental Impact

Electric vehicles help to improve air quality, because they avoid the exhaust emissions of conventional vehicles [18], [19]. They do not burn petrol or diesel, so they produce no tailpipe carbon dioxide, which helps to slow climate change. When the electricity used to charge them comes from sources other than fossil fuels, their overall environmental impact is even smaller [18]. However, manufacturing EV batteries still has environmental costs, because extracting materials such as lithium and cobalt uses a lot of energy. Reusing and recycling batteries properly reduces waste and cost, and make EVs more environmentally friendly over their whole life cycle [20].

Economic Impact

EV adoption is expected to create many jobs in manufacturing and maintenance, and to support industrial growth, particularly in smart grid and battery technologies. EVs also reduce fuel costs, although their high initial purchase price remains a barrier [16].

Social Impact

As the EV sector expands, it can provide pathways for women to enter related fields, which supports SDG 5 (gender equality). On the negative side, charging and maintenance centres are often concentrated in urban areas, which can leave rural communities behind [16].

The Future of Electric Vehicles

Power electronic converters are the backbone of future EVs, which are moving towards a “wide-bandgap” revolution: a shift from traditional silicon (Si) to silicon carbide (SiC) and gallium nitride (GaN) semiconductors [21]. These materials allow converters to operate at significantly higher switching frequencies and temperatures. Charging downtime could also be reduced or eliminated by electric road systems, which allow EVs to recharge their batteries while in motion (dynamic charging). These systems mainly use dynamic wireless power transfer, in which inductive copper coils are embedded beneath the road surface [22].

Conclusion

Electric vehicles have returned from a niche of the early 1900s to a central place in modern transport. Their performance depends on how well the battery, power electronics, motor, and transmission work together, with the battery management system keeping

the battery safe and efficient. EVs reduce tailpipe emissions and bring economic and social benefits, but battery production, high purchase prices, and unequal access to charging remain challenges. Advances such as wide-bandgap semiconductors and dynamic wireless charging are likely to make future EVs more efficient and convenient.

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Kinetic Energy Harvested by Human Movements

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Introduction

Biomechanical energy harvesting offers a sustainable alternative to conventional power sources by converting the kinetic energy of routine human activities, such as walking, breathing, and the beating of the heart, into electricity. Biomechanical energy harvesters are commonly grouped by the type of motion they exploit: linear, deformation, vibrational, rotational, and swinging motion [1]. Despite continuous improvement, conventional batteries remain limited by their bulk, rigidity, risk of leakage, and the environmental problems of disposal. These limitations are especially serious for implantable electronics and widely distributed devices, where frequent battery replacement is hazardous or impractical.

To overcome these challenges, harvesting energy from the human body has emerged as a promising option. Biomechanical motion is a sustainable source of mechanical energy [2]. Human motion is abundant, continuous, and naturally compatible with wearable electronics, so it offers a practical route to self-powered devices [1].

Four main mechanisms are used to convert biomechanical energy into electricity: electromagnetic induction, the piezoelectric effect, electrostatic induction, and triboelectricity. Emerging directions for next-generation wearables include bio-conformal designs, intelligent energy management, and hybrid harvesting approaches, which aim to make devices efficient, autonomous, and adaptable to their environment [1].

A Brief History of Human Energy Harvesting

Human-powered energy generation began with basic mechanical tools, such as hand cranks and pedal-driven dynamos, used to produce power locally. These systems played an important role in powering radio units for communication, especially in remote areas and emergencies [3].

By the 1990s, research had moved toward electronics, introducing wearable computing [4] and “energy scavenging” for mobile devices [3].

More recently, advances in biomechanical engineering and microsystems have enabled sophisticated, body-integrated harvesters. Innovations such as piezoelectric shoe inserts and nanogenerators now capture kinetic energy from natural movements such as walking and

jogging and convert it into usable electricity [3]. This progression marks a significant shift from manual effort to seamless energy recovery from everyday human activity.

The Human Body as an Energy Source

The world faces many problems because of the ever-increasing demand for energy and declining energy resources. Energy from the human body has therefore been proposed as a potential clean energy source for sustainable use [5]. The body obtains energy from food and releases chemical, thermal, and mechanical energy during regular activities [6]. Mechanical energy is generated mainly during daily activities such as walking, running, and arm movements. To produce the maximum electricity from human motion, different types of motion should be analysed in terms of force, speed, frequency, and power output. If human energy could be harnessed properly, the benefits would be considerable given the size of the global population [5].

The power generated by the human body is limited, and this energy can be used only for low-power applications [5], [6]. Nevertheless, biomechanical energy harvesting is a promising approach for self-powered wearable systems, with further improvements possible through advances in materials and design.

Converting Human Motion into Electricity

Electromagnetic harvesting

Electromagnetic energy harvesting from human movement is an important innovation in green energy technology, using various mechanical principles to derive electricity from human activity. Research on swing electromagnetic energy harvesting exploits the kinetic energy generated by limb or body movement to develop a stable power supply for handheld devices [7].

Alongside limb-based solutions, a hydraulic energy harvesting system has been developed to capture energy from the motion of a backpack load during walking [8]. Such solutions aim to exploit the low-frequency, high-amplitude vibrations of human motion. This technology is of substantial interest for battery-free wearable devices and medical sensors, which use the body's natural energy instead of conventional energy storage with a limited lifetime [8].

Piezoelectric harvesting

Piezoelectric energy harvesting is another method of harvesting energy from human activities. The piezoelectric effect was discovered in 1880 by Pierre and Jacques Curie [9]. The piezoelectric effect links mechanical and electrical energy in piezoelectric materials: mechanical stress produces electric polarisation in the material [10] (Fig. 1). This effect can be used to convert the kinetic energy of human activity into electrical energy.

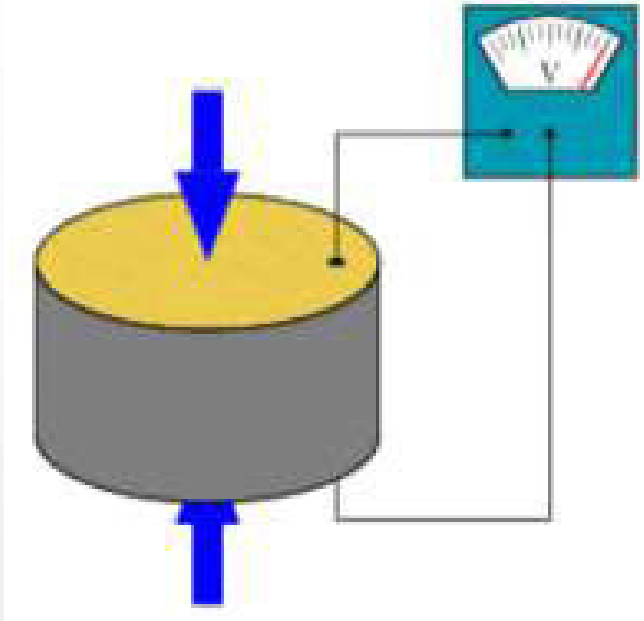


Fig. 1. A piezoelectric disk generates a voltage when deformed [11]. Licensed under CC BY-SA 3.0.

Piezoelectric tiles can be designed as normal floor tiles containing piezoelectric materials, which harvest electrical energy from people walking over them [10]. Used on a large scale, these systems can produce significantly larger amounts of electrical energy.

Triboelectric harvesting

Triboelectric energy harvesting is a relatively new mechanical energy harvesting technology, proposed in 2012 by Z. L. Wang's team [12]. A triboelectric nanogenerator (TENG) usually consists of two triboelectrically charged electrodes that generate electricity by electrostatic induction when they move relative to each other. TENGs are cost-effective for small-scale electricity generation compared with other energy harvesting methods [12]. Humans generate considerable energy during daily activities, and wearable TENGs can readily convert it into electricity [13]. TENGs still lack some properties essential for wearable use, such as air permeability, stretchability, and flexibility, because of limitations in fabrication techniques and materials. Research is therefore being conducted on improving the wearability of TENGs by using textile materials and manufacturing technologies [12].

Energy Storage and Power Management

Human-powered energy generation (HPEG) produces intermittent, low-power output, so it requires storage solutions that are efficient, cost-effective, and adaptable to various inputs. This section evaluates storage technologies in terms of their suitability for HPEG.

Traditional batteries include lead–acid batteries, with a voltage of 2 V per cell, and nickel–metal hydride (NiMH) batteries, with a voltage of 1.2 V. Lithium-ion batteries have a nominal voltage of 3.6–3.7 V.

Emerging energy storage technologies, such as supercapacitors (Fig. 2), redox-flow batteries, and phase-change materials (PCM), also offer sustainable and scalable storage. These technologies are more environmentally friendly and more flexible than batteries.

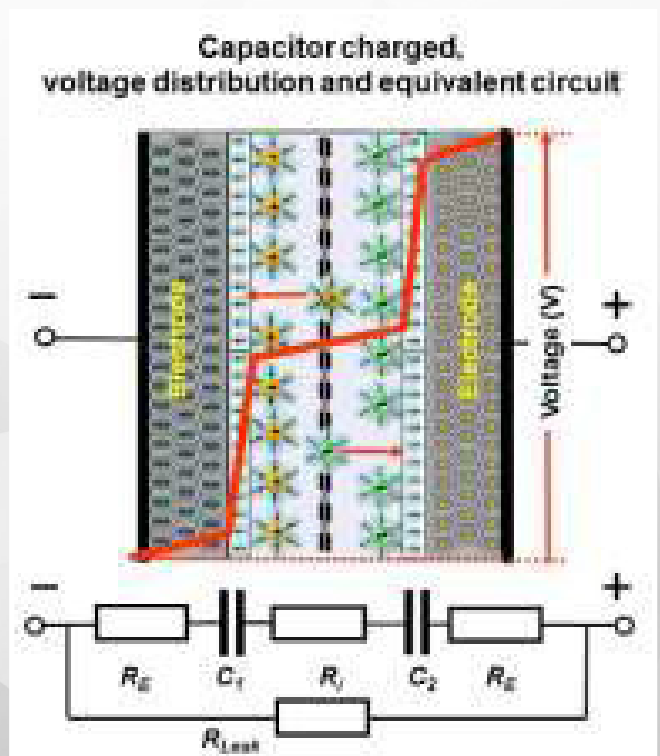


Fig. 2. Voltage distribution inside a charged supercapacitor and its simplified equivalent DC circuit [14]. Public domain (CC0 1.0).

Current Applications

Human kinetic energy harvesting has moved from experimental concepts to functional urban solutions. A key example is Pavegen, whose floor tiles use electromagnetic induction to convert footsteps into electricity for street lighting and data collection in high-traffic areas.

“Eco-gyms” integrate DC generators into elliptical trainers and stationary bicycles, enabling users to power the facility’s LED displays and charging stations through their workouts.

Challenges and Limitations

Despite the appeal of sustainable personal power, human-powered electricity generation faces severe physiological constraints. The human body is a thermodynamically inefficient engine, dissipating most of the metabolic energy it generates as heat rather than mechanical work [15]. Consequently, the food energy required to sustain power generation often makes the net energy balance negative, so it is practical mostly for micro-scale applications. Technically, harvesting this energy is hindered by the mismatch between low-frequency human motion and the high-frequency operation that generators require, resulting in small yields that struggle to meet device demands [15].

Furthermore, economic analyses show that retrofitting facilities for human power is only superficially sustainable: in one study, 40 gym users could supply only 3–5% of a gym's daily electricity, and converting the equipment would take 33 years to pay back [16]. Most critically, turning human physical effort into a commodity raises ethical concerns that large-scale use could encourage exploitative labour practices in the name of green energy [15].

Future Trends

Despite recent advances in energy harvesting devices, limitations and challenges remain, and these create opportunities for further development. The main constraints of these devices are size and weight [17]. When integrated into fabrics and textiles, wearable electronics must not restrict motion and must allow the user to move freely and comfortably. This opens research into lightweight, durable, and stretchable fabrics, electronics, and related materials [18] (Fig. 3).



Fig. 3. A stretchable electronic circuit wrapped around a cardiac balloon catheter [19]. Licensed under CC BY 2.0.

Human-based energy harvesting does not yield large amounts of energy; it can meet only the micro-energy requirements of small circuits [17]. Further research is therefore needed to improve the efficiency of electronics so that they perform well at low power.

Conclusion

Harvesting kinetic energy from human movement offers a sustainable way to power wearable and implantable electronics without frequent battery replacement. Electromagnetic, piezoelectric, and triboelectric harvesters each convert different kinds of body motion into electricity, and suitable storage devices such as batteries and supercapacitors are needed to smooth their intermittent output. Real-world applications, from energy-harvesting floor tiles to eco-gyms, show that the technology is moving beyond the laboratory. However, the power available from the human body is small, and physiological, technical, economic, and ethical limits mean that human energy harvesting is best suited to low-power devices. Advances in flexible materials and low-power electronics will determine how widely it can be used in the future.

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Nanomaterials: Small Scale, Big Impact

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Introduction

Nanotechnology is the manipulation of matter at the atomic and molecular scale. It involves the design, study, and application of materials and devices with at least one dimension between 1 and 100 nanometres [1]. Nanomaterials have attracted intense research interest because of their applications in electronics, medicine, energy, food technology, telecommunications, space exploration, and many other fields. As a result of many years of work by scientists and technologists, nanomaterials are fulfilling the potential of nanotechnology to benefit society in both expected and unexpected ways. As these materials move into industrial production, it is important to focus on the knowledge gaps that exist regarding their effects on the environment and their toxicity [2].

Properties of Nanomaterials

Mechanical properties

Nanomaterials display numerous physical properties that differ from those of conventional macroscopic materials. Unlike conventional metals and brittle ceramics, nanocrystalline materials have been found to be extremely strong, hard, and wear-resistant [3]. They show improved mechanical properties, such as higher fracture toughness, bending strength and hardness [4] (Table 1). For example, cement mortar containing nano-SiO₂ or nano-Fe₂O₃ has higher compressive and flexural strength than plain mortar [5]. These superior mechanical attributes are due to the volume, surface, and quantum effects of nanoparticles [5]. Nanocrystalline materials can also offer high erosion and corrosion resistance and good ductility at high temperatures [3]. Ultimately, these properties allow engineered nanomaterials to outperform their traditional counterparts.

Table 1. Mechanical properties of nano-modified cermet and ordinary cermet. Adapted from Q. Wu et al. [4] (fracture toughness unit corrected), licensed under CC BY 4.0.

Mechanical properties	Fracture toughness (MPa·m ^{1/2})	Bending strength (MPa)	Hardness (HRA)
Nano-modified cermet	12.7	1310	92.9
Ordinary cermet	11.9	1050	89.3

Electronic, electromagnetic and magnetic properties

The electronic and electromagnetic properties of nanomaterials are largely concerned with the transition from classical physics to quantum mechanics [6]. At the nanoscale, where “bulk” electronic band structures no longer apply because of confinement effects, electrons experience discrete energy levels instead of bands [6]. This affects conductivity: when the mean free path of electrons approaches the size of the particles, ballistic transport and Coulomb blockade effects become apparent [6].

Electromagnetically, nanoparticles show distinctive properties when exposed to light [7]. In noble metals, this can be described by surface plasmon resonance (SPR), in which the collective oscillation of conduction-band electrons produces strong localised electromagnetic fields [6], [7] (Fig. 1).

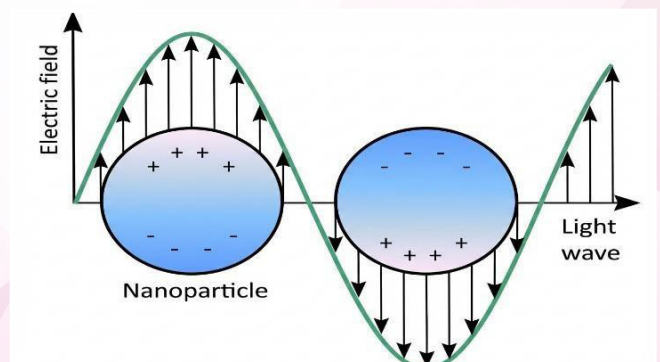


Fig. 1. Schematic of localised surface plasmon resonance in metal nanoparticles. Reproduced from E. A. Hussein et al. [7], Fig. 1(A), licensed under CC BY-NC 3.0.

Magnetic behaviour also changes at the nanoscale. When ferromagnetic particles become small enough, they become superparamagnetic: they are strongly magnetised in an external magnetic field but keep no magnetisation when the field is removed. This makes superparamagnetic nanoparticles useful as carriers in drug delivery and as contrast agents in magnetic resonance imaging (MRI) [8].

Applications of Nanomaterials

Nanomaterials are used across a wide range of sectors, from energy and electronics to medicine, textiles, and food as shown in Fig. 2.

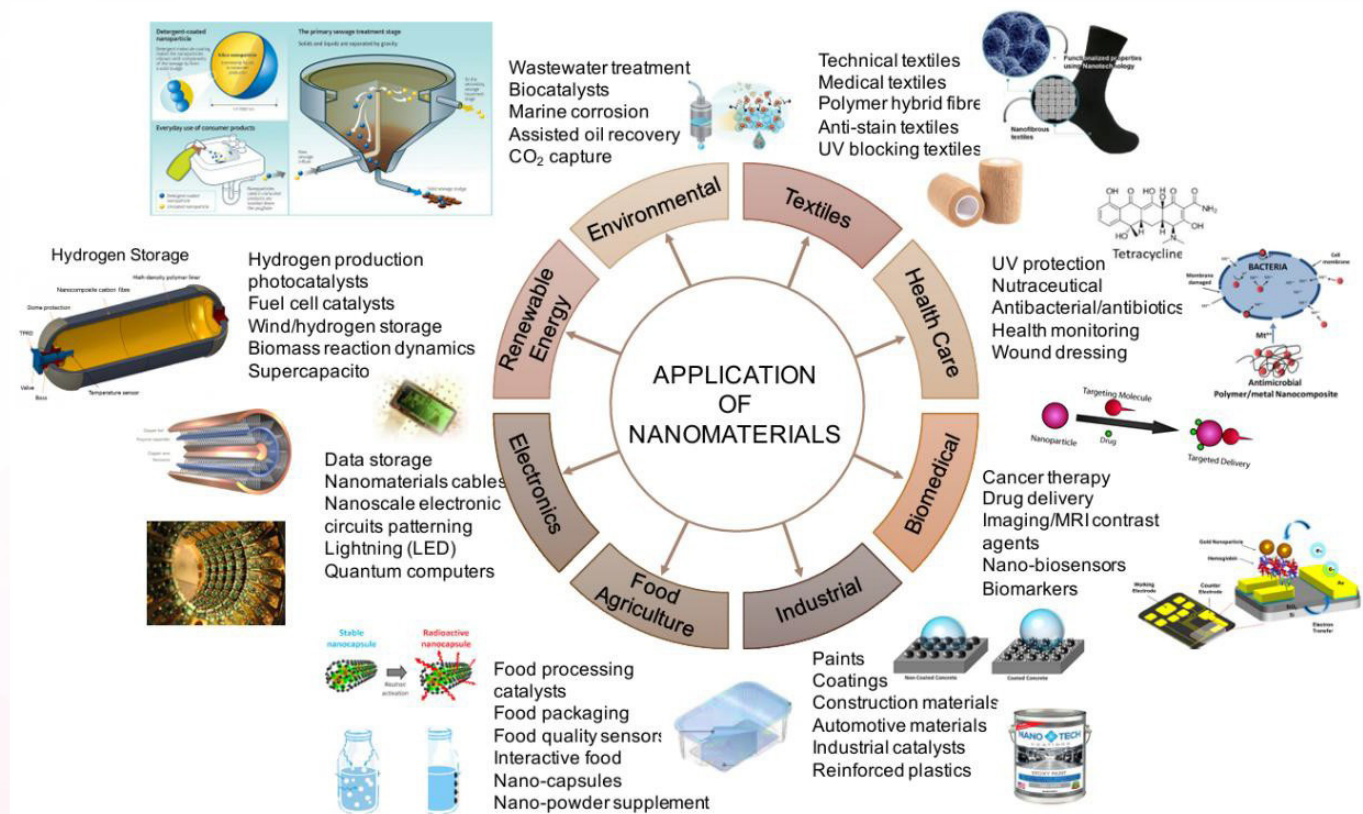


Fig. 2. Applications of nanomaterials in various sectors. Reproduced from N. U. M. Nizam et al. [9], Fig. 1, licensed under CC BY 4.0.

Electronics and energy

Carbon nanotubes exhibit metallic, semiconducting, and dielectric properties [10]. The elastic moduli of nanotubes are almost insensitive to the tube diameter and the chiral angle, and carbon nanotubes can sustain up to 15% tensile strain before fracture [10]. It has also been demonstrated that nanotube networks can become conductive, behaving as metallic conductors, as the nanotube density increases [11]. Nanotube formation is common among materials with anisotropic two-dimensional layered structures, such as WS_2 , MoS_2 , and V_2O_2 [10]. Some organic molecules, including a variety of hydrocarbons, show relatively high conductivity and distinct energy states [10]. Quantum dots are zero-dimensional nanomaterials [12]. The wavelength of light emitted by a quantum dot depends on its size, and quantum dots are being developed for use in next-generation solar cells [12] (Fig. 3).

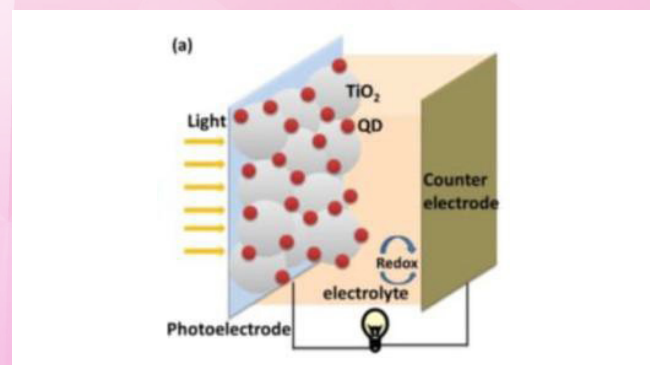


Fig. 3. Schematic illustration of a quantum dot-sensitized solar cell. Reproduced from J. Tian and G. Cao [13], Fig. 1(a), licensed under CC BY-NC 3.0.

Carbon nanotubes, quantum dots and conductive organic molecules are used in organic LEDs, flexible electronic circuits, liquid-crystal displays, carbon-nanotube-based data processing devices, and bioelectronic devices.

Biology and medicine

Nanomaterials are transforming biomedical applications by providing high-precision tools for targeted cancer therapy and diagnostics [14]. Nanomaterials such as nano-shells and carbon nanotubes use near-infrared radiation to generate localised heat, killing tumour cells through hyperthermia while sparing healthy tissue [15]. Magnetic nanoparticles can be guided by external magnetic fields to deliver drugs directly to diseased sites, a process known as magnetic targeted carrier (MTC) delivery [8]. For drug delivery, liposomes and micelles enclose chemotherapy agents and use specialised coatings such as PEG to evade the immune system [15]. Furthermore, nanoparticle drugs such as Abraxane use the protein albumin to carry medication through the bloodstream [15]. These nanodevices not only improve the efficacy of treatments but also serve as biosensors, using biomarkers to provide real-time information on the progress of therapy [14].

Future Trends and Challenges

Nanomaterials have many potential uses in future technologies. One trend is the use of nanoelectronics to succeed today's microelectronics, making devices faster and smaller, with applications such as quantum

computing. Self-healing nanomaterials represent another advance: researchers are developing materials that can repair small cracks or damage on their own. Another important use of nanomaterials is in medicine, to diagnose and treat diseases; for example, nanoparticles can deliver a drug directly to cancer cells [14]. Nanomaterials therefore have great potential for the future. Along with these benefits, there are challenges that prevent nanomaterials from being used everywhere. The most critical problem is the

difficulty of producing nanomaterials in large quantities, because it is hard to maintain good quality at low cost during manufacturing [16]. Another important concern is environmental safety, because it is not yet known how harmful nanomaterials are when they enter water and soil [9] (Fig. 4). These safety problems and manufacturing limitations are the main challenges that must be addressed before nanomaterials can be used widely in everyday products.

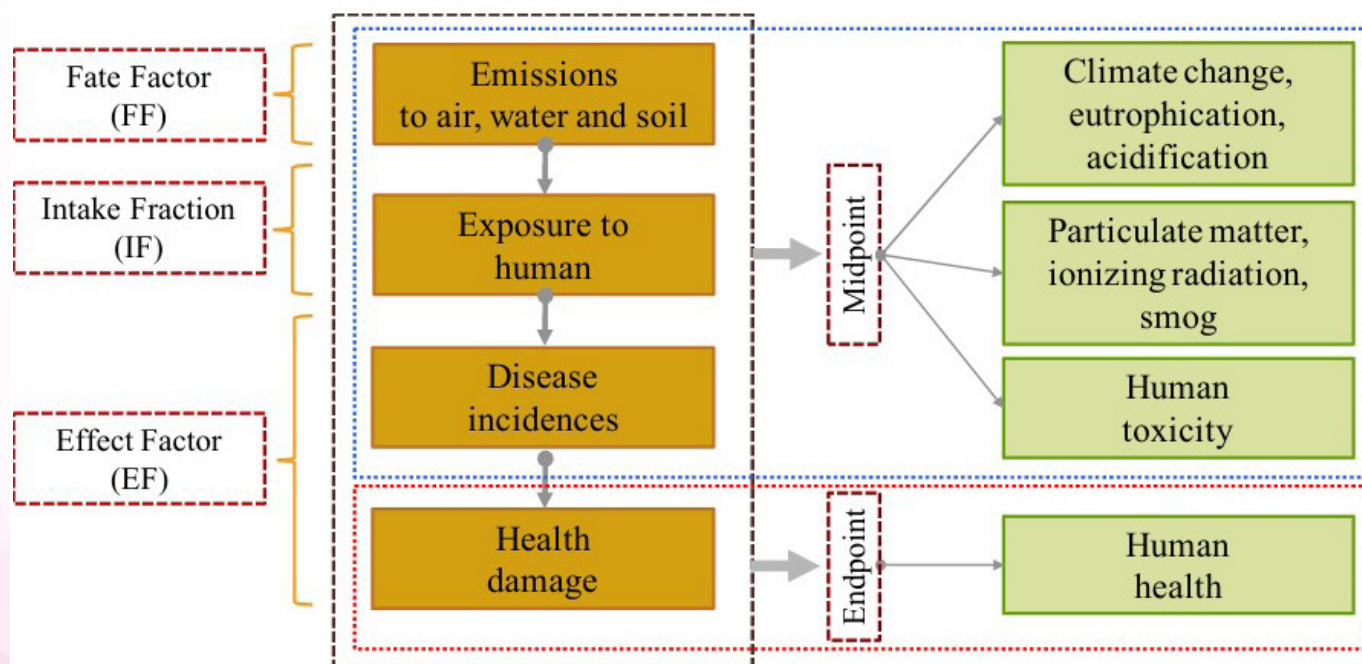


Fig. 4. Toxicity flow of nanomaterials. Reproduced from N. U. M. Nizam et al. [9], Fig. 6, licensed under CC BY 4.0.

Conclusion

Nanomaterials have properties that differ greatly from those of bulk materials, from higher strength and hardness to quantum effects in their electronic, optical and magnetic behaviour. These properties are already being used in construction, electronics, energy and medicine. At the same time, large-scale production remains difficult, and the long-term effects of nanomaterials on health and the environment are not yet fully understood. The future of nanotechnology therefore depends not only on the ability to create new materials but also on a commitment to responsible and ethical development, so that these powerful tools benefit society safely and fairly.

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Microprocessors: The Core Engine of the Computing World

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Introduction

The microprocessor can be labelled as the core engine of the computing world, acting as an extremely integrated circuit whose primary function is to combine the logic and control mechanisms of the central processing unit in a computer into one single piece, commonly referred to as the microprocessor chip. From its invention in the early 1970s to the current state, the technology has grown from a simple logic controller to a powerful engine that can process billions of instructions per second.

For this robust processing, there are four basic building components inside the architecture design.

- The Arithmetic Logic Unit (ALU) performs all mathematical and logical tasks.
- The Control Unit (CU) controls the synchronisation of the flow of information.
- The registers offer the quickest local storage for immediate access to information.
- Cache memory functions as an intermediary with very fast access between the processor and the system of memory.

Such building components make all the automation processes present in modern applications, ranging from health diagnostics to telecommunications, robotics, and self-driving cars.

Architecture and Operation

The microprocessor has four main internal registers. They are:

1. Program Counter (PC)
2. Instruction Register (IR)
3. Addressing Register (R)
4. Accumulator (AC)

Each of them has different tasks. PC guides the next instruction while IR holds the current command. Moreover, R buffers memory locations while AC is a main hub for data manipulation and I/O exchange. In terms of operations, the microprocessor is controlled by three different machine cycles known as M1, M2, and M3. During M1, the operation retrieves an instruction from memory into the IR, while during M2, it retrieves any necessary addresses. Other than that, M3 operates and may link AC with other external peripherals. Since the CPU works faster than most hardware, synchronisation is managed through WaitGo logic.

Ultimately, address decoders and I/O interfaces operate in concert in this architecture to execute program logic with mathematical precision on what would otherwise be a system of static semiconductor memory [1].

System Design

The utilitarian value of technology lies in the effectiveness of tools and techniques in accomplishing desired goals. The most effective and widely applicable technology today is that of micro-electronics, in which the ability to fabricate integrated circuits on a dielectric base has culminated in the monolithic microprocessor, or “computer on a chip” [2]. These are some designs of microprocessors that are being used and that were used before 1995 (Table 1, Fig. 1).

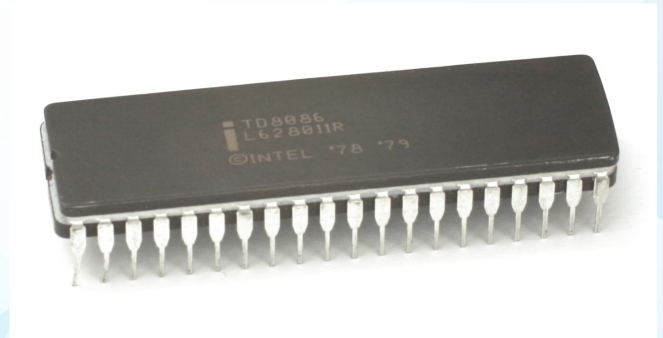


Fig. 1. Intel 8086 microprocessor (TD8086, 1978) [3]. Photo: K. Lanzet, CC BY-SA 3.0.

Table 1. Generations of microprocessors.

Generation	Names of the microprocessors
1st generation	4004, 8008, M6800
2nd generation	8080, 8085, IM6100
3rd generation	8086, 80186, 80286, 68000, 68010
4th generation	80386, HP32, 68020, 68030
5th generation	Pentium

The essential function of a processor in any application is to improve the efficiency of a process. The range of applications is limitless and is determined, in most cases, solely by economic factors. The design of the systems is based on digital integrated circuits. There are two main types of designs in microprocessor designing. They are general-purpose designs and embedded designs.

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There are two main types of designs in microprocessor designing. They are general-purpose designs and embedded designs.

General-Purpose Designs

General-purpose microprocessor designs focus on extensibility for multivariate tasks, built around device core components like CPU, ALU and control units. The general-purpose designs of microprocessors emphasise programmability, allowing software to rely on software-defined functionality to remain platform-independent [4].

Embedded Designs

These embedded microprocessors have been designed to increase efficiency and reduce workload. They are known for low power consumption, low cost, and high operating speed [5]. Here are some design approaches and components of microprocessors:

- Multi-processor systems
- Neural processing units
- Digital signal processors
- System on chip

These are the design considerations of microprocessors [2]:

- **Power efficiency:** should not get more power from battery-operated devices including mobile phones, tablets and laptops.
- **Time performance:** perform rapidly when analysing data.
- **Hardware/software co-design:** design hardware and software together.
- **Cost and area:** minimise the surface of the unit.

Subsystems

Interrupts

An interrupt is an input function that acts on the CPU to improve its processing efficiency. When an operational bit is busy, a task is repeated in a loop until the bit is free. This decreases the processing speed of the CPU. An interrupt stops a task from repeating in a loop when an operational bit is busy and the task resumes only when the operational bit is free. This ensures that the bits are working at optimal efficiency while maintaining the workflow in an orderly manner [5].

Polling is the process in which the CPU checks all devices one by one. This stalls the memory due to continuously checking devices, slowing down the overall operations. Interrupts solve the situation by allowing

the devices to send a signal to the CPU and check in. This allows the CPU to function smoothly without extra work [5], [6]. In a situation where multiple interrupts act simultaneously, a priority encoder is used to decide the order in which the signals should act. This ensures the most important interrupt gets priority, ensuring that the interrupts flow along smoothly, assisting the functions while improving efficiency [6].

Direct Memory Access (DMA) Controller

In input and output devices (I/O devices), if the whole process of data transfer is managed by the CPU, the memory is used heavily, and the process is slowed down. The DMA controller allows the I/O devices to directly access the memory without much involvement of the CPU (Fig. 2). This increases the overall speed of operation and allows for smooth operation [5].

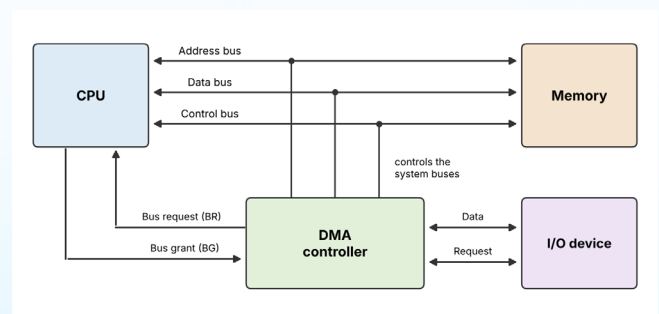


Fig. 2. Direct memory access (DMA) controller connected to the system buses.

Microprocessor Arithmetic

A computer with a microprocessor has the ability to execute basic operations like addition, subtraction, multiplication and division. Although these operations are done using a binary system, the computer has to convert the output to a decimal system every time. There are four major number systems used in computers.

- Decimal (base 10): uses ten digits, 0 to 9
- Binary (base 2): uses 0 and 1
- Octal (base 8): uses digits 0 to 7
- Hexadecimal (base 16): uses digits 0 to 9 and the first six letters of the alphabet

“Numerical data in digital machines is represented in binary form by a string of binary digits. This string is divided into groups, and each group is referred to as a word” [7]. Considering these word lengths, 4, 8, 16 and 32 bits are the most common.

Unsigned Binary Arithmetic

Unsigned (positive) binary arithmetic addition and subtraction have rules similar to the decimal system. However, they use “carries” and “borrows” based on powers of 2.

Table 2. Rules for binary addition, subtraction, multiplication, and division.

A	B	A + B (sum, carry)	A – B (differ- ence, borrow)	A × B	A ÷ B
0	0	0, 0	0, 0	0	Not defined
0	1	1, 0	1, 1	0	0
1	0	1, 0	1, 0	0	Not defined
1	1	0, 1	0, 0	1	1

Table 2 depicts the rules that have to be considered when executing addition and subtraction. When considering multiplication, a process named “shift and add” is used. During this process, partial products are generated for each bit of the multiplier. In a similar manner, binary division follows a “shift and subtract” process which is somewhat similar to decimal long division.

Signed Binary Arithmetic

A signed digit is a digit that has a positive or negative sign in front of it. Since a computer doesn't recognise the minus sign, a “sign and magnitude representation” is used, where the most significant bit (MSB) is used to represent these signs. 0 is used to indicate the positive sign, while 1 indicates the negative sign in the binary form.

$$\text{e.g., } -23 = 1,0010111 \quad +23 = 0,0010111$$

The 2's complement system is an efficient method which is used by computers to perform signed binary arithmetic. It is used to represent negative signed binary. The 2's complement of a binary number is defined as follows [7]:

$$[x]_2 = 2^n - x$$

where n represents the number of binary digits contained in the number and x is the binary representation of the number [7].

$$\text{e.g., } +19 = 0,0010011 \quad -19 = 1,1101101$$

Using this method, signed binary subtraction is also performed through addition. For example, $8 + (-5)$ is calculated as $00001000 + 11111011 = 1\ 00000011$; the final carry is discarded, giving $00000011 = 3$. Similarly, $8 + 5 = 00001000 + 00000101 = 00001101 = 13$. In both cases the sign bit is zero, so the result is a positive number.

A specially designed “Booth's Algorithm” is used for the multiplication of 2's complement numbers. The “Restoring Division” method is used to execute 2's complement divisions. If the result of these operations exceeds the number of bits available in the register, this should be detected immediately; otherwise, incorrect results will be provided as outputs. However, these methods are regarded as quite complex and have to be researched within a longer period of time.

Memory of Microprocessor Systems

The memories of microprocessor systems are essential components for storing information temporarily or permanently. This ensures efficiency and the higher speed of the overall system.

There are various types of memories as their uses vary. Mainly, this categorisation can be done by dividing them into two main types: primary memory and secondary memory. The detailed categorization is illustrated in Fig. 3.

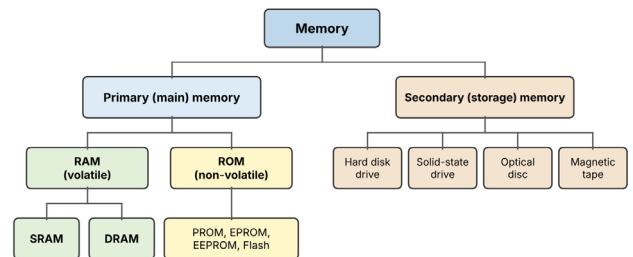


Fig. 3. Types of memories.

Between those two memory types, the primary memory is the section where faster operations are being done. As Fig. 3 shows, RAM and ROM are two types of primary memory. Table 3 compares these two types.

Table 3. Comparison of RAM and ROM.

RAM	ROM
Temporary data workspace	Stores firmware and BIOS
Reads and writes data	Only reads data
Volatile (loses data when power supply turned off)	Non-volatile (does not lose data when power supply turned off)
Used in calculators and computers	Used in computers and embedded systems
Fast operation	Slow operation (faster than HDD)
Large capacity	Small capacity

When it comes to microprocessors, the most commonly considered memory category is volatile memory, particularly RAM, as it is directly connected to the microprocessor's processing function. Also, one type of RAM can be found inside most microprocessors.

Static Random-Access Memory (SRAM)

As the name suggests, this memory type does not need to be refreshed to keep the data. At the same time, it is much faster in reading and writing operations than DRAM. Therefore, SRAM is used as cache memory (L1 cache and L2 cache) in computer systems as it can work as a bridge between the DRAM and the CPU. An SRAM chip is designed using a cell structure. A single cell of this structure consists of six transistors, two cross-coupled inverters, and two access transistors. By using these components, an SRAM cell is designed

to work as a flip-flop which can store a binary digit [8]. Although this type can operate at higher speeds when compared to DRAMs, this type is higher in cost and lower in capacity. This means the value of 1 MB in an SRAM is higher than the same capacity of DRAM. For the same reason, SRAMs are rarely used as separate ICs unless the design focuses only on operation time [8].

Dynamic Random-Access Memory (DRAM)

This RAM type needs to be refreshed frequently. Although DRAMs are slower than SRAMs, they are lower in cost and higher in capacity. This memory type is commonly used as a separate component to the microprocessor in computer systems.

This DRAM is also designed using a cell structure. A single cell consists of a MOSFET and a capacitor. As a single cell has only two components, this type has low power consumption [8].

Fig. 4 shows how the data and instruction transfer process occurs between those components when an input signal is given.

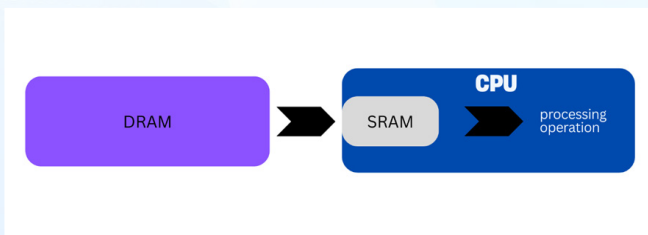


Fig. 4. Data transfer between DRAM, SRAM, and the CPU.

Data Transfer Instructions

Data transfer instructions are an essential group of instructions in a microprocessor that facilitate the movement of data between various components of the system. These instructions enable the transfer of data between registers, memory locations, and input/output devices without altering the data itself. Because they primarily focus on moving and managing data, data transfer instructions are also referred to as data handling instructions. Depending on the parts of microprocessors that are involved in data transfer, these instructions are referred to as Load instructions, Move instructions, or Store instructions. The data transfer instructions probably should be called “copy” instructions, because they just move a copy of data [9]. Efficient use of these instructions ensures proper data flow, faster execution, and effective utilisation of hardware resources, making them vital for smooth and reliable program execution.

Applications of Microprocessors

A microprocessor is typically a silicon chip that contains millions of transistors and other components, enabling it to process millions of instructions per second. With the evolution of technology, microprocessors

have undergone profound changes since the first microprocessor, built in 1971. There are mainly two types of microprocessors, namely General-Purpose Processors (GPP) and Application-Specific Processors (ASP). Microprocessors commonly used for general computing tasks, which are responsible for core processes such as calculation and data transfer, are known as GPPs, while those specialised to perform a specific function are known as ASPs.

Microprocessors have evolved to be used in a wide range of fields in the modern world. The most common types of equipment in which microprocessors play a vital role are smartphones, personal computers and laptops. They act as the central processing unit to perform arithmetic, logic, control and input/output operations. Household equipment such as washing machines, microwave ovens and air conditioners also have microprocessors integrated into them, paving the way for automated controls. Microprocessors have also enhanced the automobile industry since automotive systems like engine control units (ECUs), anti-lock braking systems (ABS), airbag control, and infotainment systems are mainly controlled by them. Medical equipment, such as ECG machines, patient monitoring systems, imaging systems, infusion pumps, and consumer electronics like televisions, digital cameras, music players, and gaming consoles, also consist of microprocessors [5].

Thus, microprocessors underpin modern technology, driving efficiency, automation, accuracy, and innovation across computing, industry, healthcare, transportation, and consumer applications worldwide.

Conclusion

Microprocessors have grown from simple logic controllers in the early 1970s into powerful engines at the heart of modern technology. Their performance depends on the close cooperation of the ALU, control unit, registers, and memory, supported by subsystems such as interrupts and DMA that keep data moving efficiently. Binary arithmetic and a hierarchy of memories, from fast SRAM caches to larger DRAM, allow them to process information quickly and reliably. As a result, microprocessors now drive applications ranging from smartphones and household appliances to vehicles and medical equipment.

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Sequential Analysis of Internal Combustion Engines and Related Physicochemistry

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Introduction

The internal combustion engine, essentially a machine harnessing a “simple controlled explosion,” revolutionised human transport [1]. In 1680, Christiaan Huygens designed a theoretical gunpowder engine, and by 1807 François Isaac de Rivaz had created an early hydrogen-powered version [2]. The true breakthrough arrived in 1876, when Nicolaus Otto invented the successful four-stroke “Otto cycle” engine, establishing the universal standard for fuel-burning motors [2]. This innovation paved the way for Karl Benz and Gottlieb Daimler to build the first practical gasoline-powered automobiles in 1885 [2] (Fig. 1).

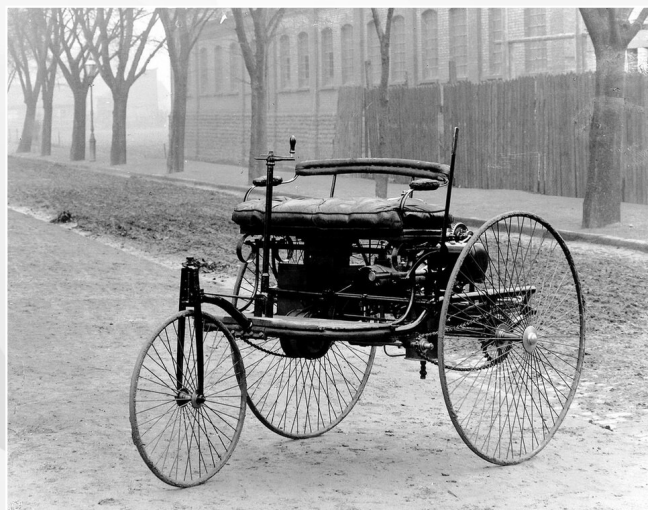


Fig. 1. The first automobile made by Karl Benz, the Benz Patent-Motorwagen of 1885 [3]. Public domain.

For a broader understanding of how this engine fits into the overall history of human engineering, from simple levers to computers, Sigvard Strandh's work offers a detailed visual history [4].

Types and Classification of Engines

Number of Strokes per Cycle

- **Two-stroke engine:** the intake and compression strokes, and the power and exhaust strokes, are combined [5].
- **Four-stroke engine:** a complete cycle has four stages (intake, compression, power, and exhaust), with an individual piston stroke for each [5] (Fig. 2).
- **Wankel engine:** intake, compression, power, and exhaust occur simultaneously, each in a different chamber around the rotor [6].

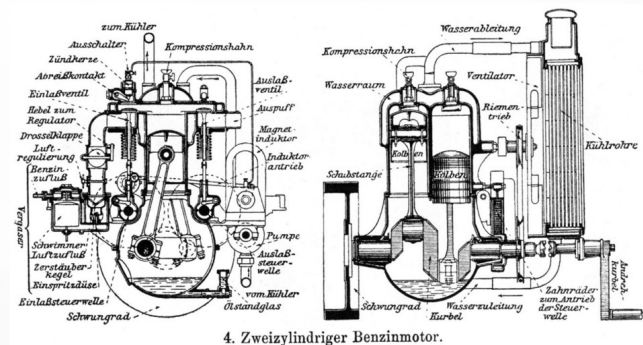


Fig. 2. A two-cylinder petrol engine [7]. Public domain.

Type of Fuel

Two main types of fuel are burned in engines. Spark-ignition engines use gasoline or gasohol, while compression-ignition engines use compression to ignite diesel fuel [5]. There is a growing body of literature on engines that burn hydrogen as fuel; however, hydrogen internal combustion engines still require numerous modifications to become mainstream [8].

Number of Cylinders and Their Arrangement

Engine cylinders can be arranged as follows [5]:

In-line (in a row);

- V-type (two rows set at an angle) (Fig. 3);
- Flat (two opposing rows);
- Radial, aircraft type (arranged in a circle).

More complex arrangements combine these basic layouts, as in the W16 engine.



Fig. 3. A MAN TGX V8 truck engine (2008), Deutsches Museum, Munich [9]. Image: High Contrast, CC BY 3.0 DE.

Supplementary Systems

Fuel System

The fuel system combines petrol or a comparable fuel with air to create a mixture that burns in the engine cylinders. In the past, the carburettor mixed air and fuel in the proper ratio; today, fuel injection is primarily used. There are two main types of electronic fuel injection: throttle-body injection and port injection. Throttle-body injection uses only one or two injectors, whereas port injection uses a fuel injector in each cylinder's intake port [5].

Gear System

In engine gear systems, spur gears with straight teeth are most commonly used for parallel shafts. However, if quieter operation is needed, helical gears are preferred because of their inclined teeth, while herringbone gears are used to balance axial thrust [10]. When shafts intersect at an angle, bevel gears are the standard solution. For shafts that are non-parallel and do not intersect, designers use spiral or skew gears. Specialised arrangements include internal gearing and rack-and-pinion systems that convert rotation into linear movement [10] (Fig. 4). Furthermore, advanced hypocycloid gears with a 1:2 ratio are used in high-efficiency Stirling engines to achieve perfectly linear motion and eliminate lateral friction [11].



Fig. 4. Gear train of the clockwork in the Heilig-Kreuz-Kirche, Dülmen, Germany [12]. Image: Dietmar Rabich, CC BY-SA 4.0.

Cooling System

When fuel burns inside the engine, temperatures can exceed 4000 °F. The cooling system removes about one-third of this heat to protect the engine and prevent the oil from breaking down [5]. Most cars use liquid cooling, in which a coolant flows through passages in the engine block and cylinder head called water jackets [5]. A centrifugal pump pushes the coolant through the system. The hot coolant travels to the radiator at the front of the car, where it is cooled, and the cooled liquid is then recirculated through the engine [5] (Fig. 5). Components such as the thermostat, radiator pressure cap, engine fan, expansion tank, and transmission

oil cooler ensure the smooth functioning of the entire system [5].

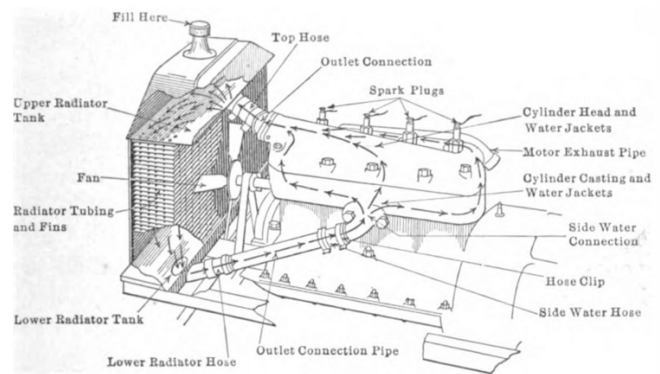
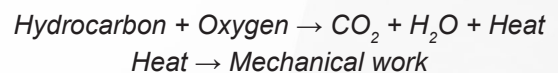


Fig. 5. The thermo-siphon water cooling system of the Ford Model T [13]. Public domain.

Combustion Chemistry

Combustion in an engine converts the chemical energy of the fuel into heat and then into mechanical work [14]:



Three types of reactions take place in engines [15]:

- **Complete combustion:** with excess oxygen, only CO_2 and H_2O are released.
- **Incomplete combustion:** with limited oxygen, dangerous products such as CO and soot are released.
- **Pollutant formation:** when the temperature and pressure in the engine are very high, NO_x is produced.

Combustion requires the three elements of the fire triangle [14]:

- **Fuel**, which stores chemical potential energy for combustion;
- **Oxidiser**, usually atmospheric oxygen;
- **Heat**, an ignition source such as a spark or the high temperature of compressed air.

Efficiency and Fuel Consumption

Internal combustion engines are widely used because of their efficiency, low initial cost, and high power density [16].

Thermal Efficiency

Thermal efficiency is the ratio of the useful work obtained from the engine to the heat supplied by the

fuel. When fuel energy is converted into useful work, a considerable amount of energy is lost to friction [17], [18]. Indicated thermal efficiency is the fraction of heat converted into indicated power, while brake thermal efficiency is the fraction of heat converted into useful shaft power [18].

Fuel Consumption

Specific fuel consumption (SFC) is the fuel used per hour per horsepower. A lower SFC indicates better engine efficiency [18].

Engine Maintenance

Diagnosing Engine Management System Faults

Modern engine management fault diagnosis uses a six-stage process: confirming the fault, gathering information, evaluating evidence, testing logically, correcting the fault, and finally verifying system operation [19]. Fault codes are retrieved from the electronic control unit (ECU) using diagnostic tools or, on older systems, by interpreting warning-light flash sequences [19].

Modern diagnostic research enhances traditional methods through model-based and intelligent systems [20], [21], [19]. Observer-based fault detection and artificial neural networks allow earlier and more accurate identification of complex faults, improving efficiency and vehicle reliability [20], [21], [19].

Diesel Engine Management

Diesel engine management is vital for achieving low exhaust emissions and good fuel control in modern diesel engines. Electronic Diesel Control (EDC) continuously monitors and adjusts the engine's operating conditions: the ECU collects data from several sensors on parameters such as engine speed, temperature, and air intake [22], and drives actuators to maximise combustion efficiency and enhance engine performance while minimising exhaust emissions. Diesel engine control systems enable engines to comply with strict emission standards while meeting their targets for fuel economy and dependability.

Laws and Regulations

To control emissions of nitrogen oxides (NO_x) and particulate matter (PM), governments have imposed strict legal limits such as the Euro V and Euro VI emission standards [23]. These regulations have prompted engine redesign and the use of emission control equipment, such as diesel particulate filters (DPFs) and selective catalytic reduction (SCR) systems [23].

Furthermore, alternative fuels such as biodiesel may increase NO_x emissions [24]. Therefore, compliance with emission standards, together with the introduction of less polluting fuels, can reduce pollution from diesel engines and engines in general.

Conclusion

The internal combustion engine is a complex system that relies on several supplementary systems, such as the fuel, gear, and cooling systems. Each of these systems has a specific function that ensures the smooth operation of the engine. Furthermore, engine maintenance is an integral part of maintaining engine efficiency and compliance with regulations. Future developments in internal combustion engines should aim to maximise efficiency, meet environmental regulations, and move toward sustainable and economical fuel sources.

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Sustainable Fashion: Environmental and Ethical Challenges and the Way Forward

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Introduction

Sustainable fashion is an approach in which brands create clothing that reduces its impact on the environment while remaining mindful of the people who produce the garments. In simple terms, it is fashion that is ethically made and environmentally friendly [1]. Achieving this is not simple: sustainable production carries higher overheads, which reduce profit margins. For the industry as a whole to become sustainable, consumers must be willing to pay more, or at the very least stop buying from brands that disregard the environment. This shift appears to be under way as younger, more eco-conscious consumers gain influence in marketing demographics [1] (Fig. 1).

The need is urgent. The fashion industry is a major polluter and is responsible for 20% of industrial water pollution, while labour exploitation in low-wage countries has damaged its reputation [2]. Sustainable fashion responds to these problems in four main ways [2].

Environmental impact mitigation: The conventional industry is associated with water pollution, deforestation, and excessive waste. Sustainable fashion adopts eco-friendly practices to reduce these impacts and foster a healthier planet.

Ethical practices: Sustainable fashion champions fair wages, safe working conditions, and the ethical treatment of workers, fostering a more humane and socially responsible sector.

Waste reduction: Fast fashion has created a culture of disposable clothing. Sustainable fashion disrupts this cycle by advocating a circular economy in which products are designed for reuse, recycling, or repurposing, reducing the burden on landfills.

Consumer empowerment: A shift in consumer behaviour toward sustainability has increased demand for eco-conscious fashion, enabling consumers to choose brands aligned with their values and encouraging the wider industry to adopt responsible practices.

Fig. 1. Concept illustration depicting sustainable clothing, generated via text-to-image AI [3].



Environmental Challenges Resource Use

The textile and fashion industry is one of the major consumers of water. Large volumes are used in pretreatment, dyeing, printing, and finishing. The total amount consumed depends on the fabric or fibre type, the finishing effect required, and the machinery used [4].

The industry consumes large amounts of energy. Thermal energy (steam) is used extensively for heating in dyeing and finishing, and producing synthetic fibres such as polyester from oil is extremely energy intensive. In key Asian producing countries such as China, Bangladesh, and India, manufacturing is powered mainly by coal, which worsens emissions. The fashion industry contributes about 10% of global carbon emissions, exacerbating global warming and posing a significant challenge to sustainable energy goals. Transportation adds further emissions because globalised, multicountry supply chains require extensive shipping; for example, cotton from India may be woven in China and then sewn in Bangladesh [5].

The overuse of natural resources is a global problem because some of them are nonrenewable. The fashion

industry uses many natural resources, including cotton, fossil fuels, metals, and leather. Fast fashion in particular overuses them through the massive water demand of cotton, the depletion of fossil fuels to make synthetics, biodiversity loss, and excessive carbon emissions [6].

Pollution and Waste

The global fashion industry creates major environmental challenges through pollution and waste [7]. Large quantities of chemicals used in the dyeing and finishing stages are released into water bodies, causing water pollution, damage to aquatic ecosystems, and health risks for nearby communities [8].

Fast fashion, the rapid production and discarding of clothing, has sharply increased textile waste. Because many of these garments are made from synthetic materials, they remain on land for many years without degrading, polluting the environment and releasing more greenhouse gases (Fig. 2).

When synthetic clothes such as polyester and nylon are washed, microplastic fibres are released into the environment. Once these fibres enter the ocean, marine organisms consume them, and they can ultimately enter the human body, posing long-term environmental and health risks [6].

According to Blackburn [9], textile finishing and dyeing processes contribute significantly to water pollution through chemical discharge, with negative effects on the environment and on human health. The clothing and textile industry also discharges toxic chemicals into the environment and uses huge amounts of energy [10].



Fig. 2. Concept image of a roadside pile of discarded clothing representing textile waste, generated via text-to-image AI [11].

Ethical Challenges

Ethical fashion emphasises healthy work practices and fair labour while also caring for the environment. It is an emerging trend that promotes sustainability in the fashion industry by aiming to minimise negative impacts on people, animals, and the environment throughout the entire garment manufacturing process [12]. Achieving these goals requires solutions to poor

labour conditions in garment factories, violations of workers' rights, unfair wages, child labour, and worker safety issues.

Labour Exploitation

The challenges in the industry range from labour conditions in garment factories to workers' rights, fair wages, health and safety, and child labour. Ethical manufacturing prioritises fair wages, safe working environments, and workers' rights throughout the supply chain [2].

Brown's Eco Fashion gives examples of ethical issues common in the apparel industry, including the public outcry against sweatshop and under-age labour in the 1990s [7]. Brown also points to overconsumption and inequality in wealthy Western countries as further drivers of the problem [7].

Animal Welfare and Environmental Responsibility

Unregulated factories and the sourcing of materials in inhumane and illegal ways harm not only workers but also the environment. The fashion industry is responsible for the deaths of millions of animals for fur, skin, wool, and similar materials, which also causes environmental pollution [13]. Preventive steps can be taken on both the industry side and the consumer side. At a larger scale, regulations can encourage cruelty-free fashion products and less harmful chemicals and materials, and can make the requirements for operating an eco-friendly factory stricter. The garment industry in Sri Lanka uses advanced technologies and includes the world's first "Green Garment Factory," which reduces water use by 70% and energy use by half [14]. Sustainable approaches also include clothing made from materials such as organic cotton, hemp, bamboo, and recycled fabrics [2].

Fast Fashion

Fast fashion is the design, manufacture, and marketing of high volumes of inexpensive clothing produced quickly to meet consumer demand for the latest styles, often imitating runway looks within weeks. Fletcher describes it as a modern system in which clothes are produced and sold very quickly and cheaply to meet constantly changing consumer demand [15]. Gwilt characterises it as a system based on rapid production, low prices, and quick trend turnover that prioritises speed and profit over environmental sustainability, ethical labour, and long-term value [16].

Environmental Impacts

High water and energy consumption, pollution from dyes and microplastics, high carbon emissions, textile waste filling landfills and oceans, and resource wastage from constant overproduction are among the forms of environmental damage caused by fast fashion. Damage occurs at every stage, from fibre to fabric, garment, and disposal [6]:

- **Excessive waste:** fast fashion encourages overconsumption; clothes are worn only a few times before being landfilled or burned.
- **Pollution from production:** toxic dyes and finishes pollute rivers and soil, especially in developing countries, affecting ecosystems and human health.
- **High water consumption:** growing cotton and processing fabrics require large amounts of freshwater, leading to water scarcity in manufacturing regions.
- **Carbon emissions:** global supply chains, factories, and transport release large amounts of greenhouse gases.
- **Microplastic pollution:** synthetic fabrics such as polyester and nylon shed microplastics during washing, harming marine life.
- **Resource depletion:** nonrenewable resources such as petroleum for synthetic fibres are used faster than they can be replaced.
- **Unsustainable fashion cycles:** ever-faster cycles increase production pressure.

Social and Ethical Impacts

Low-cost business models lead to worker exploitation, including poverty wages, forced labour, unsafe conditions, and long working hours [17]. The main issues are as follows:

- **Poor working conditions:** factories often lack ventilation, safety equipment, and emergency systems, and cost cutting leads to accidents and factory disasters.
- **Low wages:** wages often do not meet basic living needs because brands pressure suppliers to keep costs low.
- **Long working hours:** workers are forced into excessive overtime, which is often unpaid or underpaid.
- **Child labour:** in some countries children work in textile and garment production, violating basic human rights and preventing access to education.
- **Exploitation of developing countries:** production shifts to countries with weak labour laws and minimal regulation.
- **Lack of workers' rights:** workers are often not allowed to form unions and have little power to demand fair treatment or safer conditions.

Ethical responsibility is shared with consumers, who support fast fashion through constant buying and disposal. Brown argues that the consumer culture fuelled by fast fashion, with its quick trend turnover, cheap prices, and disposability, must change [7].

The consequences are visible far from the point of sale. Greenpeace has documented textile waste, much of it exported from Europe and North America, washing into the sea at Jamestown, a fishing community in Accra, Ghana [17].

Sustainable Practices Environmental Solutions

Environmental solutions in sustainable fashion focus mainly on eco-friendly materials, waste reduction through circular fashion, and sustainable production methods such as zero-waste garment construction and 3D printing. Eco-friendly textile materials should be prioritised. Fletcher and Grose state that renewable fibres such as cotton, wool, silk, hemp, and viscose, and biodegradable fibres such as PLA, have a lower environmental impact [8]. Aakko and Koskennurmi-Sivonen argue that fibres should be made from renewable resources and should be fully biodegradable, recyclable, or reusable [18].

Excessive energy, chemical, and water consumption is a major problem in the fashion industry. Fletcher and Grose discuss in depth how to reduce chemical load, energy use, and water consumption [8], and Aakko and Koskennurmi-Sivonen also stress minimising water, energy, and chemical use during dyeing, finishing, and processing [18]. Fletcher and Grose further discuss circular fashion methods that support waste reduction, such as reuse, reconditioning, recycling, and minimum waste in cut and sew, and suggest the following concepts [8]:

- Recycling fabric waste into new yarn;
- Low- to no-waste design methods;
- Integrating the design and pattern-making processes;
- Negative space-driven pattern cutting.

Aakko and Koskennurmi-Sivonen identify further practical measures [18]:

- Zero-waste pattern cutting and design;
- Slow fashion practices that promote fewer, high-quality garments;
- Encouraging repair and maintenance instead of overconsumption.

They also note that information transparency and eco-labelling are important in helping consumers make responsible choices [18].

Ethical Practices and Shared Responsibility

Ethical labour practices and fair-trade initiatives are important elements of sustainable fashion. Many workers in the fashion industry face low wages, long working hours, and unsafe working conditions. Ethical practices help solve these problems by ensuring safe workplaces and fair wages, and fair-trade initiatives promote responsible supply chains and help prevent worker exploitation.

Responsibility for sustainable fashion is shared among brands, consumers, and governments. Fashion brands are responsible for adopting ethical sourcing practices, using sustainable materials, and maintaining transparency in production. Consumers contribute by

supporting ethical brands and reducing consumption. Governments play an important part by enforcing labour laws and implementing environmental regulations that support sustainable practices.

Conclusion

Adopting sustainable fashion is essential for the future of the fashion industry. Sustainable practices help reduce environmental pollution, protect natural resources, and improve social conditions for people. As awareness of environmental and ethical issues increases, sustainable fashion can also support long-term industry growth. Adopting sustainable fashion is therefore necessary to create a more responsible and ethical global fashion industry [15], [16].

Acknowledgement

AI disclosure: Figs. 1 and 2 are images generated by third parties using text-to-image generative AI tools. Both were obtained from the Dreamstime stock platform under a royalty-free licence: Fig. 1 (Stock ID 267490487) [3] is used as a visual metaphor for eco-conscious textile design in the Introduction, and Fig. 2 (Stock ID 355521967) [11] illustrates textile waste in the Environmental Challenges section. Neither image depicts a real location or event. The authors did not modify the images or use generative AI to create them.

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Spanning the Gap: The Engineering Behind Bridges

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Introduction

A bridge is an engineered structure that enables movement across physical obstacles and plays a crucial role in the development of civilisation. As described by David Blockley, bridges are systems that safely manage forces while serving human needs [1]. The earliest bridges were natural crossings, such as fallen trees and stone arches, later replaced by simple timber and stone structures. Roman engineers advanced bridge construction using stone arch bridges and aqueducts, applying principles of compression and durability. This article examines the historical development of bridges, their materials, and the fundamental engineering principles behind their design.

The Evolution of Bridge Materials

The transition from masonry and timber to industrial metals fundamentally changed how engineers approach long-span crossings. During the Industrial Revolution, the shift to cast iron and high-tensile steel provided the necessary strength to manage heavy dynamic loads. These material advancements ensure that modern structures remain durable and structurally efficient while addressing diverse topographical challenges. Ultimately, this evolution allows bridges to be seamlessly integrated into global transportation networks while maintaining high safety standards. The materials used in bridge construction and their advantages are presented in Table 1 [2].

Table 1. Materials used in bridge construction and their advantages.

Material	Advantages	Examples
High-strength steel	Excellent tensile strength and flexibility	Suspension wires, cables
Reinforced concrete	High compressive strength and durability	Towers, support pillars
Prestressed concrete	Resists cracking	Beams
Weathering steel	Creates a protective rust layer	Highway bridges

Types of Bridges

Modern bridges use advanced materials and optimised structural designs to ensure efficiency and longevity. Bridges are mainly classified by their primary structural behaviour and their efficiency over different distances.

The fundamental classification includes truss, beam, and arch bridges, which generally support short to medium spans (Table 2), and cable-stayed and suspension bridges, which are designed for long-span applications.

Table 2. Main types of short- and medium-span bridges.

Bridge type	Description
Truss bridge	The design uses interconnected triangular trusses, which are ideal for heavy-load applications such as railways (Fig. 1).
Beam bridge	The superstructure contains connected beam sections over piers and is economical for short-span bridges, such as highway overpasses [2] (Fig. 2).
Arch bridge	Arches transfer the forces to the supports; this is the most favourable method for crossing deep valleys and bodies of water [3].

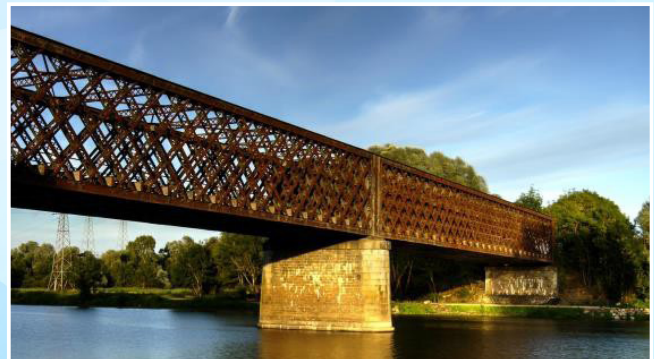


Fig. 1. A steel truss bridge (Pont de Segré) [4]. Image: Glabb, CC BY-SA 3.0.



Fig. 2. A beam bridge carried on piers (overpass, Yunyan District) [5]. Image: lin2015, Pixabay, CC0.

For long spans, suspension bridges support the deck using main cables suspended between towers and anchored at each end (Fig. 3), while cable-stayed bridges support the deck with cables connected directly to the towers (Fig. 4).

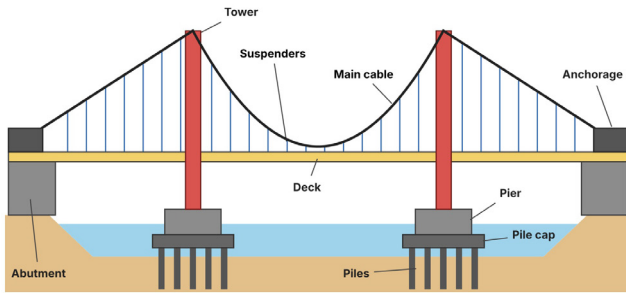


Fig. 3. Main parts of a suspension bridge.

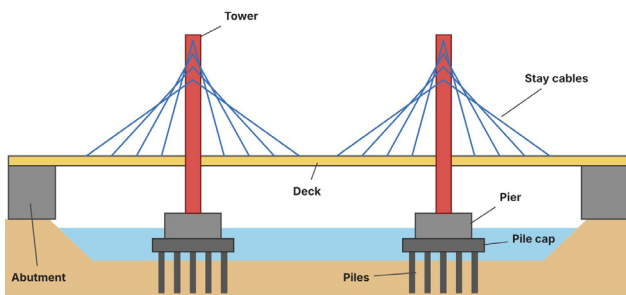


Fig. 4. Main parts of a cable-stayed bridge.

Structural Mechanics

A key aspect of bridge engineering is the physics behind structural stability. Bridge safety largely depends on controlling tensile and compressive forces. In this context, the bridge itself must transfer both its own weight and the loads acting on the deck by applying the principles of physics. Different types of bridges use different methods to control tension and compression. For example, arch bridges transfer the weight mainly through compression along the arch, while cable-stayed bridges use tension in the cables to span long distances. The ultimate purpose of applying these physical principles is to transfer the weight safely into the soil or rock beneath the foundation [2].

Geotechnical and Environmental Aspects

Geology is defined as “the science which treats the history of the earth, the rocks of which it is composed, and the changes which it has undergone or is undergoing” [6]. When designing bridges, several factors must be considered, including the structural efficiency of the design and the bridge’s environmental effects. In some locations, the ground is too weak to support a bridge directly. In these cases, pile foundations are driven through the unstable layers of the riverbed to reach the bedrock.

Maintenance, Safety, and Load Analysis

Ensuring bridge safety requires integrating routine maintenance with load analysis. As highlighted in *Safety and Reliability of Bridge Structures*, structural integrity degrades over time due to environmental stressors and traffic, necessitating regular assessments [7]. Consequently, maintenance is not merely reactive repair but a proactive strategy that uses reliability-based models to manage bridge networks efficiently [8]. Furthermore, modern frameworks use updated load-rating data to inform intervention priorities directly [9]. This directs limited resources toward critical components, preventing failure while managing costs.

Case Study: The London Millennium Bridge

The London Millennium Bridge incident provided a pivotal case study for failure analysis in bridge engineering. This three-span, 300-metre shallow suspension bridge opened in June 2000 [10] and recorded an estimated 80,000–100,000 crossings on its opening day, with up to 2,000 people on the deck at once [11]. This triggered excessive lateral swaying, and the bridge was closed after two days.

The cause was synchronous lateral excitation [12], in which pedestrian-induced lateral forces matched the bridge’s natural frequency, amplifying sideways movement. The problem was resolved by retrofitting viscous and tuned mass dampers to absorb kinetic energy. This incident prompted greater consideration of dynamic human–structure interaction in bridge design.

Future Trends

As the world develops, bridge technology advances. New materials such as ultra-high-performance concrete (UHPC) [13] and fibre-reinforced polymers (FRP) [14] provide extreme durability and water resistance, and some concretes can even heal their own cracks using bacteria [15]. Robotic 3D printing can now construct entire bridge sections [16]. Furthermore, modern designs turn bridges into power plants by harvesting traffic vibrations [17] and using solar pavements [18].

Conclusion

A bridge is a critical structure that brings resources and people closer together. The development of bridges from simple wooden structures to sophisticated designs represents progress in materials science and engineering. Understanding the mechanics and foundations of bridges improves standards of safety and design. Future advances will enable the design of even stronger and greener bridges.

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Integrated Vehicle Systems: How a Modern Car Works

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Introduction

A modern vehicle is not a single machine but a collection of integrated systems that must work together. The engine or electric motor produces power, the gearbox delivers it to the wheels, and supporting systems supply fuel, lubricate moving parts, and control temperature. Braking and security systems keep the vehicle and its occupants safe, while hybrid technology and sustainable design are reshaping how vehicles are built and used. This article gives an overview of these systems and how they contribute to a safe, efficient, and sustainable vehicle.

Power Sources

The Engine

The engine is the heart of a vehicle. A typical vehicle engine, the internal combustion engine, operates in four steps known as the four-stroke cycle: intake, compression, power, and exhaust. The power produced is converted into the mechanical energy needed to rotate the wheels through the pistons and crankshaft [1]. A modern trend in engine technology is to increase efficiency by using variable valve timing (VVT). Turbocharging is also popular: it increases the amount of air entering the engine, so that a small engine can produce more power. This improves fuel economy and reduces the environmental impact of the engine [1], [2], [3]. In a turbocharger, hot exhaust gases drive a turbine that powers a compressor, which forces more air into the engine cylinders after it passes through a charge air cooler (Fig. 1).

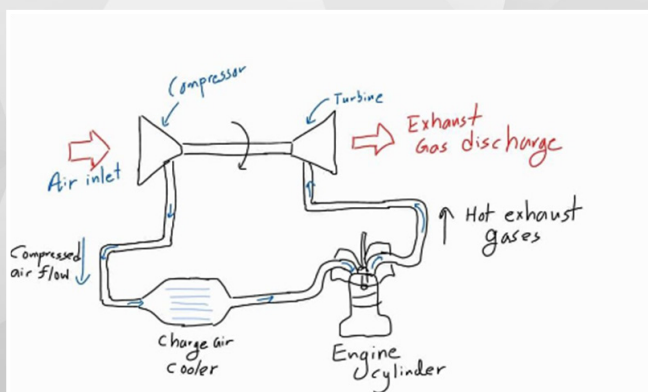


Fig. 1. Schematic of a turbocharger system.

Electric Motors

Electric motors convert electricity into motion using electromagnetic fields. When electric current flows through a coil in the motor, a magnetic field is created that causes the rotor to spin. The rotor and stator

form the core of the motor: the rotor spins inside the stator, which is equipped with windings that generate the electromagnetic fields. Power electronics manage the flow of electricity and control the motor's speed by adjusting the power frequency. Many DC motors use permanent magnets to generate the magnetic field, while most modern electric vehicles (EVs) use AC motors. The power output of an EV motor is directly proportional to the input current and voltage. Permanent magnet synchronous motors (PMSMs) are widely used in EVs because of their high efficiency and power density [4], [5].

Hybrid Technology

Hybrid technology is now common in vehicles. A hybrid system combines an internal combustion engine with an electric motor and battery, and the vehicle can run on fuel, electricity, or both [6] (Fig. 2). Because it allows electricity to be used instead of petrol, hybrid technology encourages eco-friendly transport and reduces carbon dioxide emissions. Combining the two power sources also allows the vehicle to optimise its energy efficiency. Although hybrid systems have a high initial cost, they reduce fuel and maintenance expenses. The main types are full hybrids, mild hybrids, and plug-in hybrids, with the Toyota Prius, Honda Insight, and Chevrolet Volt as respective examples [6].

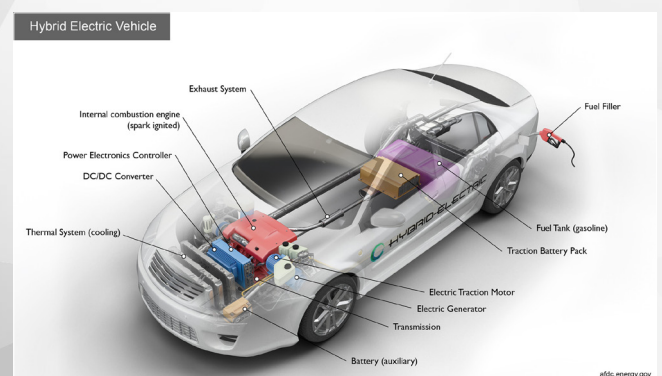


Fig. 2. Key components of a hybrid electric vehicle [7]. Public domain (U.S. Department of Energy).

Power Transmission: The Gearbox

Vehicles require high torque at the driving wheels when starting, accelerating, and climbing hills. Since road conditions and loads change, engine power must be delivered effectively over a wide range of vehicle speeds. This is achieved using a transmission system, or gearbox, which allows the engine to run at a suitable speed while the wheels rotate at different speeds. The gearbox is installed between the clutch and the driving

axle and transmits engine power to the road wheels in different ratios. Passenger cars usually need three or four gear ratios. Gears of different sizes are engaged or disengaged to transmit motion and power: a large gear meshed with a small gear drives the small gear at increased speed, and vice versa [8], [9]. The gear ratio is given by

$$\text{Gear ratio} = \frac{\text{number of teeth on the driven gear}}{\text{number of teeth on the driving gear}}$$

Three types of gearbox are commonly used [8]:

- **Sliding mesh gearbox:** the oldest and simplest type, in which gears are engaged by physically sliding them into mesh. It requires skilled operation, because improper shifting can cause gear noise and wear (Fig. 3).
- **Constant mesh gearbox:** all gears remain in constant engagement, and power is transmitted using dog clutches. It operates more smoothly and quietly than the sliding mesh gearbox.
- **Synchromesh gearbox:** synchronising devices match gear speeds before engagement, allowing smooth, silent, and clash-free gear shifting. This makes it ideal for modern vehicles.

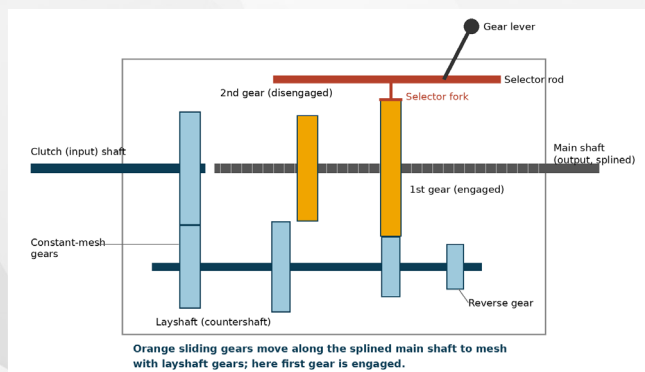


Fig. 3. Schematic of a sliding mesh gearbox, with first gear engaged.

Supporting Systems

The Fuel System

The main function of a vehicle's fuel system is to supply clean fuel to the engine continuously and efficiently. Its main components are the fuel tank, fuel pump, fuel filter, fuel lines, and injectors [10]. The fuel tank stores fuel and releases it for engine operation; it is made of steel or a rigid plastic such as high-density polyethylene and is usually installed under the rear seats. The fuel pump, which in most modern vehicles is located in the fuel tank and powered by the electrical system, draws fuel from the tank and delivers it to the engine under pressure. Fuel lines, made of steel, aluminium, or reinforced rubber, carry fuel through the system. The fuel filter prevents dirt and rust from reaching the engine, and the injectors, controlled by computer signals in modern vehicles, spray fuel into the combustion chambers, where it mixes with air and ignites to power the engine [11], [12].

The Oil System

The oil system is essential for the smooth running of a vehicle. The oil acts as a lubricant, cooling agent, and sealing agent [13]. The oil pump delivers pressurised oil through a filter that removes carbon, dirt, and metal particles, and the oil is then distributed to all the components that require lubrication. Excess oil drains back to the sump, from which the pump draws it again. Challenges include oil degradation, valve leakage, and faults in oil flow. In summary, the oil system is the circulatory system of a vehicle, and it extends the vehicle's lifetime [14].

Thermal Management

Effective thermal management is vital to remove the excess heat that is not converted into power, which would otherwise threaten the integrity of the engine. There are two main methods: air cooling and liquid cooling [15]. In liquid cooling, a coolant circulates through water jackets in the engine to absorb combustion heat and is pumped to the radiator, where the heat is released into the atmosphere; a thermostat regulates the flow so that the engine stays within its optimal temperature range. In air cooling, metal fins attached to the engine cylinders increase the surface area, and a continuous stream of air, produced by a fan or the vehicle's motion, carries the heat away [15]. Both methods prevent component seizure and keep the engine at its optimal operating temperature.

Safety and Security

The Braking System

Brakes slow or stop a vehicle by converting its kinetic energy into heat through friction. They ensure safety through controlled deceleration and stability. There are two main types of brakes. In disc brakes, calipers squeeze pads against a rotor attached to the wheel; they dissipate heat well, resist brake fade, and provide superior stopping power, which makes them ideal for high-performance use. In drum brakes, brake shoes expand outward inside a rotating drum; they are durable and cheaper but prone to overheating, and they are used mainly on rear wheels [16]. Hydraulic systems are commonly used to operate brakes: pressure on the pedal activates a master cylinder, which pressurises the brake fluid and transmits the force to the wheel calipers, providing consistent stopping power at all wheels. Regular maintenance of the braking system is essential for reliable performance and safety.

Security Systems

Vehicle security systems are designed to prevent theft, unauthorised entry, and damage. Modern vehicles have advanced features such as central locking, alarms, and GPS tracking. Sensors detect unusual activity, such as unauthorised entry or movement of the vehicle, and send alert notifications. Biometric systems, wireless keys, and smartphone control are also used in modern

vehicles. Effective security systems prevent theft, protect passengers, build user trust, and contribute to safe transport.

Sustainability

Automotive sustainability goes beyond the use of electric motors and covers the vehicle's full life cycle, from design and manufacture to the scrap yard. At the manufacturing stage, eco-friendly materials are increasingly used to reduce the carbon footprint.

In the operational stage, the emphasis moves to energy efficiency and emissions. Although electric vehicles produce no tailpipe emissions, their full environmental benefit is realised only when they are charged from renewable energy sources rather than coal-fired power. The industry is also moving toward a circular economy to address the end of a vehicle's life: designing vehicles for easy dismantling, reusing high-voltage batteries for energy storage, and recovering valuable materials efficiently.

Conclusion

A modern vehicle depends on many integrated systems working together. The engine, electric motor, or hybrid powertrain produces power; the gearbox delivers it to the wheels; and the fuel, oil, and thermal management systems keep the vehicle running efficiently and reliably. Braking and security systems protect the vehicle and its occupants. As technologies such as electric drives, hybrid systems, and circular design advance, these systems are becoming more efficient and sustainable, shaping the future of transport.

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Renewable Energy: A Sustainable Solution for Modern Energy Needs

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Introduction

This article discusses the importance of switching to renewable energy from traditional fossil fuel in response to the exponential growth of global energy demand. As global energy consumption reaching 186,383 TWh in 2024 and earth's average surface temperature increasing roughly by 1.3°C, the article states that transition to renewable is essential to prevent climatic changes and to ensure economic stability. This article provides detailed information on solar energy, hydro power and wind energy. Furthermore, the article evaluates the government's role in promoting renewable energy and how correct decisions taken within the government can cut pollution down, keep energy safe and build a sustainable future. Finally, the article analyses the future trends related to renewable energy identifying AI integrated forecasting, green hydrogen and hybrid systems as the technological backbone that will power the global electricity by 2030.

What Is Renewable Energy?

Energy that comes from natural processes and is renewed at a pace that is equal to or greater than the rate at which it is consumed is referred to as renewable energy [1].

Core components of renewable systems:

- **Solar energy:** direct use of sunlight by solar thermal collectors or photovoltaics (PV) [1].
- **Wind power:** the process of transforming air currents' kinetic energy into mechanical or electrical energy [1].
- **Biomass:** using organic materials as a carbon-neutral fuel source [1].
- **Hydropower and geothermal:** tapping into the energy of moving water and the internal heat of the earth [1].

Why Renewable Energy?

Over the last 75 years, the world population has exploded; in fact, it has tripled from 2.5B to 8B causing an exponential increase of global energy usage. In 1950, the global energy consumption was 28,564 TWh while in 2024, it was 186,383 TWh [2]. Due to increase in the usage of non-renewable energy sources during this period, earth's average surface temperature has increased by approximately 1.3°C [3] causing global warming. Therefore, the transition to renewable energy is critical to avoid the catastrophic impacts of global

warming, specifically intensification of extreme weather conditions and rising of sea levels.

Beyond environmental necessity, transition to renewable energy ensures profound economic stability. Due to the extreme weather conditions we encounter because of global warming, governments must spend billions of dollars to provide disaster relief which affects the GDP of the country. At present with technological advancement, generating power with renewable energy sources like solar power and wind power has become cheaper as well.

Fossil fuel burning, the traditional method of generating power is becoming more difficult as they deplete faster than they form as well as it releases CO₂, the main gas responsible for global warming.

In conclusion, due to the escalating risk of climate change and fiscal issues, switching to renewable energy is not an alternative, it's the best solution for powering the future world.

Global Energy Demand and Supply

Until the advent of industrial revolution, the demand for energy was modest, preserving seamless harmony with mother nature [4]. The boom of industrialization in the mid-1700s increased the quality of life while exorbitantly increasing the global demand for energy.

Amongst the ever most diversified sources of energy, the most end-utilized form of energy is electricity which is primarily being exploited by the chemical energy stored within fossil fuels, coal and natural gas [5].

The present-day global energy demand deals with EJ (exajoules), i.e. 10^{18} joules [5]. Though one would blindly go to the conclusion that demand for energy is proportional to the population, it is not so. The distribution and utilization of energy both qualitatively and quantitatively differ depending on the socio-economic surroundings of the people. Supply relates directly to demand, and it is evident that industrialization directly connects to the energy supply.

Renewable Energy Sources Solar Energy

The electromagnetic energy emitted by the sun is called solar radiation or solar energy. Tremendous amount of

energy is created within the sun, and only a fraction of this energy impacts the earth. This preserves the earth at a temperature suitable for the existence of life. The amount of solar energy reaching earth's surface can undoubtedly exceed energy needs of the planet. However, this remains impractical due to the low efficiency in extracting solar energy and its relatively high cost [6].

Few applications of solar energy:

1. **Flat-plate solar collector:** the objective of the solar collector is to produce useful heat energy from solar energy. Examples: solar water heater configuration; solar air collectors.
2. **Evacuated tube collector:** an effective method of improving collector performance which is based on reducing heat losses from the collector.
3. **Concentrating solar collection:** the concentration of solar energy is often obstructed by clouds, and as a result, the temperature of hot water obtainable through a flat-plate collector cannot be kept constant. The most common remedy for concentrating solar radiation to the collector is a parabolic collector.
4. **Solar pond:** a promising method of power generation which involves collection and storage of solar energy in large artificial lakes often few meters in depth, called solar ponds (Fig. 1).
5. **Solar power tower plant:** a solar power tower plant uses a large array of mirrors called heliostats that track the sun and reflect solar radiation into a receiver mounted on top of a tower. Water is heated, boiled and superheated by absorbing heat from the receiver system.

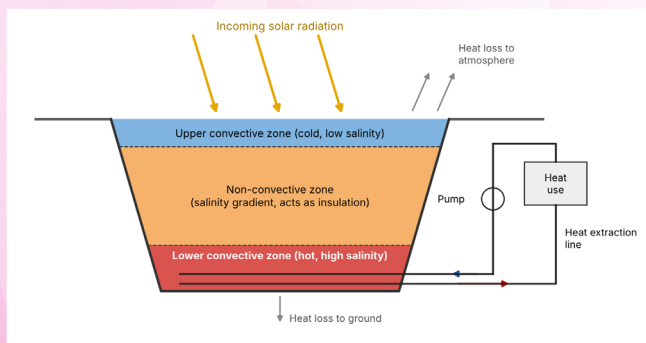


Fig. 1. Solar pond.

Solar photovoltaic systems:

Solar cells or photovoltaic (PV) cells are devices that convert solar radiation into electricity directly. Solar cells have no mobile parts or components and composes a relatively lightweight structure. A PV cell operates on the principle of photovoltaic effect. When photons from solar light are incident on a suitable material, electrons are released which in turn generates voltage difference or electric current [6].

Wind Power

The global wind power is an exceedingly vast, yet a relatively onerous source of energy to extract. The inception of wind power for the production of electricity is a rather recent methodology which dates back to the late nineteenth century. The average wind velocity considerably varies from place to place and in most cases it is seasonal. The world's wind resource is of course greatest at sea [4] which is mostly due to the uncluttered environment provided upon the sea.

Wind turbines are used in the conversion of wind power to electricity. There are mainly two types of wind turbines (Fig. 2). Namely, horizontal axis turbines and vertical axis turbines. The majority of the commercially available wind turbines rotate about a horizontal axis, yet vertical axis wind turbines remain indispensable due to some advantages offered by them.

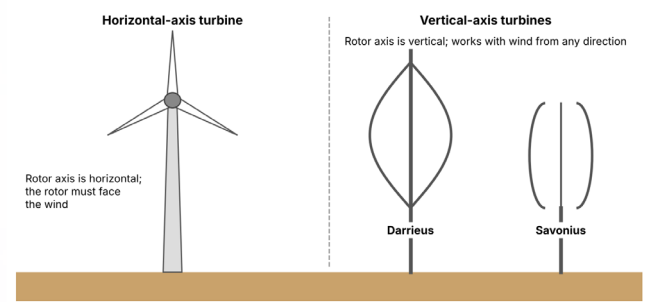


Fig. 2. Types of wind turbines.

Among turbines with one, two or three blades, the three bladed turbine abides to be the most common because of the high efficiency provided upon energy extraction. Furthermore, the blade diameter remains a crucial factor on the efficiency of electricity generation [7].

Wind energy remains paramount because the process of wind power extraction, results almost in no CO₂ or other harmful emissions. Yet one of the most consequential problems for the people living in the proximity of wind turbines is the screeching caused upon its operation [4].

Hydropower

Hydro power also known as hydroelectric power is a form of a renewable energy that uses the potential energy and kinetic energy of moving water for the process of electricity generation. Hydro power is recognized as a time-honored source of energy employed to generate electricity and is the most widely used renewable energy source in the present world. Hydro power generates electricity by converting the kinetic energy of water to mechanical energy in a turbine, which is then transformed into electrical energy using a generator.

Basic process:

- Water stored in a reservoir of relatively greater altitude (Fig. 3) with reference to the turbine is

discharged to the penstock under control to flow through the turbine resulting in rotation of the turbine.

- Thus, the generated spin rotates the shaft connected to turbine, which in turn lets the generators produce electricity. Then produced electricity is transmitted through the power lines.

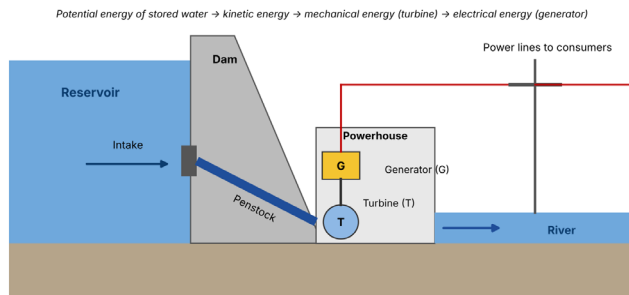


Fig. 3. Schematic diagram of a hydroelectric dam.

Hydro power will remain persistent in the global transition towards clean energy. It facilitates producing a stable electricity supply while supporting other renewable energy generation processes like solar and wind by balancing the energy supply in cases when other renewable forms are unavailable as well as when they are extreme.

Data shows that hydropower generates about 4,578 TWh (terawatt-hours) of electricity globally and this amount corresponds to about 14.3% of the global electricity generation, making it the largest single source of renewable energy [8].

Renewable Energy Policies

Good renewable energy policies are essential for making national energy systems sustainable and strong for the long haul. These policies give governments a way to push for clean energy and slowly cut back on fossil fuels. The best green policies look at factors like a stable economy, making investors feel satisfied, and getting people on board, not just hitting targets for cutting pollution.

Tools like renewable energy goals, special pricing, and regulations work better when they're used consistently. Mallon says that steady politics and a long-term policy promise a lot more than just big incentives [9]. If policies keep changing or aren't explained well, it makes investing riskier and slows down new green tech. Smart incentives, like feed-in tariffs, renewable portfolio standards, and rules for grid access, help the market grow and make investors more confident. Plus, flexible policies let governments roll with the punches as tech and the economy change.

Emerging Technologies and Future Trends

Hydrogen energy systems:

More attention will drive towards this section as Hydrogen is high in energy content, clean and efficient in the conversion to electricity. It is a good fuel and

can be used for aircrafts and automobiles that could encourage its large-scale commercial production, storage and distribution.

Solar power:

New technical innovations such as Tandem cells, floating PV, agrivoltaics, AI forecasting, recycling of PV waste will establish an auspicious future. Perovskite-silicon tandem cells hit an efficiency of 34.85% [10].

Wind:

When considering about wind, Vertical-axis turbines, predictive maintenance with AI, hybrid wind-solar systems, recyclable blades will be seen significant in the future.

Not only them but also Fish-safe turbines, hybrid hydro-solar plants and digital turbine controls in Hydro power section, Enhanced Geothermal Systems (EGS), closed-loop drilling and hybrid solar-geothermal plants in geothermal section will also play a major role in the renewable energy sector in future.

With these new innovations, the next five years will be defined by rapid development of solar and wind, integration of enabling technologies like AI and hydrogen, policy-driven investment flows and will position renewables as the backbone of global electricity by 2030.

Conclusion

This article presents information and infographics extracted through a diverse network of resources encouraging the readers to gain insights and inspiration on leaning towards Renewable energy. This addresses the core title, "A sustainable solution for modern energy" contrasting with the deficits and weaknesses in the present system while highlighting the importances and diversification provided in using green energy. More importantly, this enlightens readers to broaden their scope of knowledge in the field of renewables encouraging to innovate, invent and implement better solutions and methodologies for a clean future ahead.

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Bridges Touch All Our Lives

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Introduction

Bridges are a part of our daily lives. Every day, we drive over a bridge or walk under one. How often do we think about what a bridge really is? What is a bridge anyway? Bridges are interesting because they do a lot more than just get us over water or roads. A bridge is something that people build to help us.

Bridges are also a reminder of how far technology has come. The bridge is an amazing thing when you think about it. Bridges show us what people can do when they work together to design and build something. The people who designed and built the bridge are very smart and talented. A bridge is the result of centuries of efforts to find better ways of doing things.

From logs that have fallen across creeks to the huge steel and concrete suspension bridges we have today, the way we build bridges has changed a lot over time. This shows how good people are at building things and how much we want to connect places. This essay is about the changes that have happened in bridge building. We will look at how bridges have changed over time and how they are built. We will also look at the materials that have been used to build bridges, like stone, wood and strong metals that allow us to build longer bridges. We will study what is needed to make sure bridges are safe and reliable, which is very important when designing bridges. By analyzing historical failures, we gain insight into how engineering disasters have unexpectedly paved the way for safer, more resilient structures, ensuring that these vital links continue to stand against the forces of nature and time.

History and Evolution of Bridges

When studying the bridge-building industry, it is necessary to have an overview of its history and evolution. The history of bridge building dates back to the Late Palaeolithic era, and the earliest bridges humans used were largely natural creations. By the time of the early Neolithic Age, humans started to imitate natural structures to fulfill their physical needs when traveling, and this resulted in the first stage of bridge building. Prehistoric bridges were primarily made according to the materials that were available in the surrounding area; therefore, different types of bridges were more prominent in different areas. These can be classified under three main categories: stone bridges, beam bridges and suspension bridges [1].

- **Beam bridges:** European forested regions
- **Stone bridges:** European glacier regions
- **Suspension bridges:** regions with warm climates

This initial stage of bridge building lasted over a thousand years, but with the rise of the first civilizations, these techniques changed significantly. The discovery of the arch and vault concept by the Mesopotamians, the discovery of pontoon bridges by the Persians and the discovery of pozzolana by the Romans, which led to the creation of cement, are some monumental milestones in the history of bridge building that paved the way for modern bridge-building techniques [1].

The Industrial Revolution in the 1700s to 1800s had a major impact on the bridge-building industry. The introduction of iron and steel bridges created a revolution in bridge building, as these materials overcame many limitations of stone, timber, and early masonry, enabling longer spans and stronger structures. When considering the monumental bridges throughout history, the oldest datable bridge, the Caravan Bridge across the Meles River in Turkey [1], and the oldest datable wooden bridge, the Kapellbrücke (Chapel Bridge) in Switzerland [2], are widely praised for their structural brilliance and remarkable durability. However, as the creation of iron and steel bridges began relatively recently, the oldest datable iron and steel bridges are the Iron Bridge in England [3] and the Eads Bridge in the USA, respectively [1], [4].

Accordingly, bridge building began in prehistoric times and evolved through major human discoveries throughout history.

Materials Used in Bridges Concrete Bridges

There are two main categories of concrete bridges: reinforced and prestressed concrete bridges. Today, concrete is the dominant structural material because it can resist flexural, shear, torsional and serviceability demands arising from dead loads, temperature variations, creep and shrinkage. Reinforced concrete is used where tensile stress exceeds the tensile capacity of concrete [5]. Prestressing gives concrete a compressive force that counteracts tensile stresses and limits cracking. Concrete is suitable for bridge decks, girders, piers and abutments as it has qualities such as high compressive strength, stiffness, durability and fire resistance. However, these structures should be designed to ensure that movement due to loading, ground deformation, creep, shrinkage and thermal expansion or contraction does not induce stress levels in excess of permissible values; if neglected, this may lead to excessive local damage [5].

Stone Bridges

Stone is one of the main materials used for bridges. Stones have high compressive strength and durability, making them especially suitable for masonry arches. Granite, sandstone, dolomite and limestone are some of the commonly used materials for stone bridges. They have qualities such as durability, structural integrity and compressive strength. However, there are some disadvantages of using stone as a bridge material, such as limited span length and maintenance challenges [6], [7].

Steel Bridges

Steel is one of the most widely used engineering materials in the construction field. It is a well-known alloy that mainly contains iron. Steel used for building bridges contains iron along with small percentages of carbon, manganese and other metals.

In the second half of the 19th century, steel was developed and started replacing cast iron as a structural material for building bridges [8]. There are five basic types of steel bridges: girder bridges, rigid frame bridges, arches, cable-stayed bridges and suspension bridges. The properties of structural steel relevant for use in bridge construction are strength, ductility, weldability, notch toughness and weather resistance [8]. At present, weathering steels are used for building bridges to minimize rust and reduce maintenance costs.

Timber Bridges

Timber was the first type of material that humans used to construct a bridge. As a construction material, it has many advantages. Timber bridge structures present a natural and pleasing appearance, and unlike concrete, timber is not damaged by repeated freezing and thawing. They can be constructed in any weather conditions. Timber bridges are eco-friendly because they release relatively little carbon into the environment. Because these bridges are lightweight, they save money and time for builders [9].

Wood degradation is the main problem that affects timber bridges. In engineering science, this problem is solved by chemical preservation of wood [10]. There are many ways of applying chemicals to wood, such as brushing, spraying and dipping. However, timber is a material used in bridge construction that keeps bridges durable and eco-friendly.

Future Materials for Bridges

Fiber-reinforced polymers (FRP) and high-performance concrete (HPC) are some modern materials that are used for bridges. Fiber-reinforced polymer composites are two-phase materials consisting of a base material and a filler material. The base material is referred to as a matrix or binder material, which is a polymer (plastic), either thermoset or thermoplastic. A polymer

matrix needs to be reinforced by filler material due to its specific mechanical properties. Fatigue resistance, low weight, freedom from corrosion, minimal maintenance, freedom of form, competitive life-cycle cost, and electrical and thermal insulation are some benefits of FRP in bridges. Different parts of bridges can be built using this material, such as FRP deck panels and FRP beams and girders [11].

Bridge Structures

There is no perfect bridge structure because every location presents a different kind of problem to solve. Engineers choose a bridge structure according to the balance of span length, geography, cost, physics and aesthetics. There are six main types of bridge structures, and each has its own strengths and limitations [12], [13].

Beam Bridge

The beam bridge is the most common bridge. It carries vertical load by bending, with compression along the top of the beam and tension along the bottom. Beam bridges are best for short spans [14] (Fig. 1).

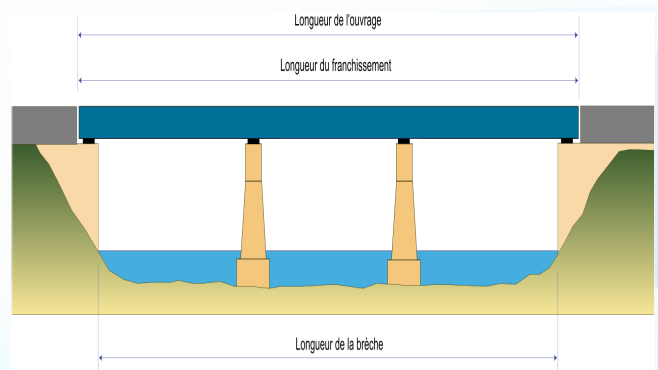


Fig. 1. Beam bridge, showing overall length (longueur de l'ouvrage), crossing length (longueur du franchissement), and gap length (longueur de la brèche) [15]. Image: Roulex45, CC BY-SA 3.0.

Truss Bridge

A truss is like a simply supported beam (a beam spanning between two supports is called a simply supported beam) because it carries vertical loads by bending. Truss bridges are used for medium spans [14].

Arch Bridge

The arch bridge carries loads mainly by compression, which applies horizontal and vertical forces on the foundations. Therefore, the arch foundations must prevent horizontal sliding and vertical settling. Arch bridges are generally used for medium to long spans [14] (Fig. 2).

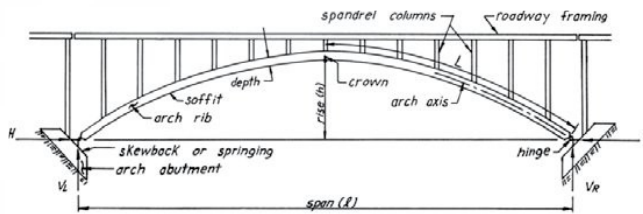


Fig. 2. Arch bridge nomenclature [16]. Public domain (U.S. Federal Highway Administration).

Suspension Bridge

A suspension bridge carries loads through curved cables in tension. Suspension bridges are designed for long spans [14] (Fig. 3).

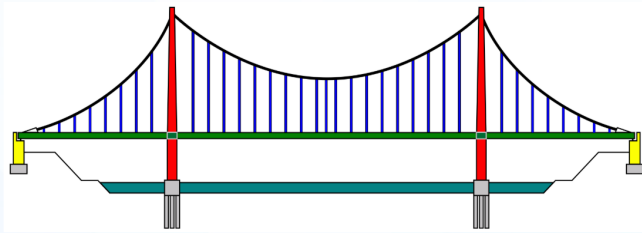


Fig. 3. Suspension bridge [17]. Image: Matthias079, modified by Svgalbertian, CC BY-SA 3.0.

Cable-Stayed Bridge

The deck is supported by cables connected directly to towers, providing a strong and efficient structure for long spans [14], [18] (Fig. 4).

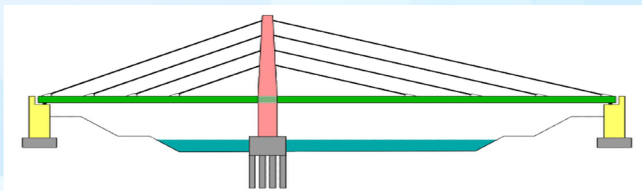


Fig. 4. Cable-stayed bridge (harp form) [19]. Image: Matthias079, vectorised by Mrmw, CC0 1.0.

Cantilever Bridge

Cantilever bridges are designed with horizontal beams supported only at one end to span large distances without intermediate support [14] (Fig. 5).

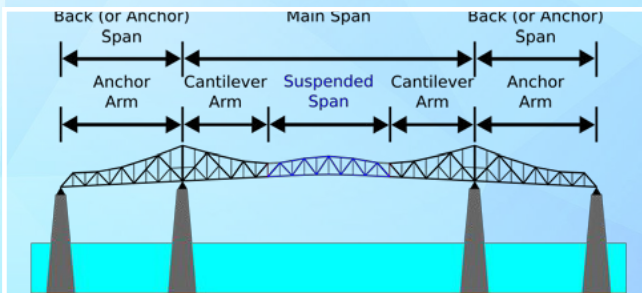


Fig. 5. Parts of a cantilever truss bridge [20]. Public domain (PennySpender1983).

Safety and Reliability of Bridges

In civil and structural engineering, engineers must prioritize bridge safety because these structures carry people. Although bridge collapses are rare, they are not voluntary risks. Therefore, engineers must minimize risk. When making calculations, engineers take careful account of dead loads and live loads from traffic, wind, and seismic forces [21].

Mathematical simulations, predictive modeling, and finite element analysis help ensure safety and reliability. Several systems and measures are used to detect problems and improve protection, including video management systems (VMS) [21], cable assembly monitoring [21], stability checks, optical sensors, among others. Such technologies enable the constant monitoring of structural behaviour, the identification of any irregular movements, cracks, or stress changes [22], and warnings of possible structural failure. With the use of real-time information, structural engineers can engage in preventive work and maintain the reliability of the bridge structure [21].

In addition, comparing the physical condition of bridges with models under development is an appropriate structural engineering method [21]. This creates a structural health monitoring (SHM) system that can detect unusual circumstances at an early stage [21], [22]. These systems may help to address structural failures that are not visible. Safety and reliability are important to ensure public safety and long-lasting structures.

Failure Analysis

When we look at bridge engineering, some of our greatest leaps in safety actually come from studying tragic mistakes. For example, the 1940 collapse of the Tacoma Narrows Bridge taught the industry that it is not enough simply to build a strong bridge [23]; you have to understand how it moves [24]. The bridge failed because of aerodynamic instability, specifically stall-induced torsional oscillations that turned the road deck into a giant ribbon fluttering in the wind [24]. The collapse is often explained as simple resonance, but it was caused by this self-excited aerodynamic flutter [23]. This disaster forced engineers to start testing bridge designs in wind tunnels to ensure they could handle dynamic forces.

Another case that changed everything was the Silver Bridge disaster in 1967 [24]. This collapse started with a microscopic crack in a single steel eyebar [24]. The bridge did not have “redundancy,” meaning there were no backup parts to share the load, so that one small fracture caused the entire structure to fall into the river [24]. Similarly, the failure of King’s Bridge in 1962 showed us that even the way we weld steel matters [24]. The steel used there became brittle in the cold, causing it to snap under pressure [24].

Conclusion

From fallen logs across streams to modern steel, concrete and cable-supported structures, bridges reflect the steady growth of human knowledge and skill. Each advance in materials, from stone and timber to iron, steel, concrete and fiber-reinforced polymers, has allowed engineers to build longer, stronger and more durable bridges. Choosing the right structural form depends on span length, site conditions, cost and appearance. Safety remains the highest priority: modern monitoring systems help detect problems early, and the lessons learned from failures such as the Tacoma Narrows, Silver Bridge and King's Bridge collapses have made today's bridges safer. As new materials and technologies develop, bridges will continue to connect communities safely and reliably for generations to come.

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Sri Lanka's Economic Crisis in 2022

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Introduction

In early 2022, the Democratic Socialist Republic of Sri Lanka's economy imploded, and this paved the path to many severe crises within the island. This occurred not because of a single chain of events. The factors that led to this crisis include years of tax cuts, being burdened with a huge debt and a rising fiscal deficit, poor political decision-making, and the collapse of the import and export processes and the industries that had been contributing to the growth of the economy for years. Apart from these years of dysfunction within the governmental administration, the crisis began to affect the lives of the people when Sri Lanka was severely affected by the COVID-19 pandemic. The effects became most severe in April 2022, when the government announced that it would suspend payments on its foreign debt.

Sri Lanka, as a country, went through an enormously difficult time compounded by the pandemic. Fuel and gas shortages, several kinds of food shortages and severe inflation affected people in the most terrible manner. The government being unable to pay for imports because of a shortage of foreign exchange, as well as the rupee being depreciated, made the situation much worse. All of these continuous events sparked a popular uprising against the government, which caused the then president, Gotabaya Rajapaksa, to resign from his post in July 2022, creating political instability within the country. The first half of this article discusses the different kinds of fields and industries which were affected by the crisis and the impact the crisis

had on them. The latter part discusses the recovery from the severe economic crisis and the remedies the government considered to stabilise the country's economy.

The Impact of the Crisis Healthcare

As the World Health Organization (WHO) declared the COVID-19 outbreak a pandemic, many countries faced numerous challenges. The pandemic presented deep uncertainty and a colossal challenge for the country's healthcare system. The public healthcare system played a key role in providing free universal healthcare with guidelines for patient care. With a vaccination programme, Sri Lanka successfully achieved high coverage of adult people. However, due to the broader national economic crisis, the existing healthcare system faced shortages of fuel, drugs and medical supplies in 2022 [1].

Transportation

The impact of the COVID-19 pandemic on the transport and supply chain sectors is another significant effect which affected Sri Lanka. Most of the people who make up the Sri Lankan workforce use public transportation as their mode of transport from home to their workplace. However, the COVID-19 pandemic resulted in a significant drop in the use of public transportation services.

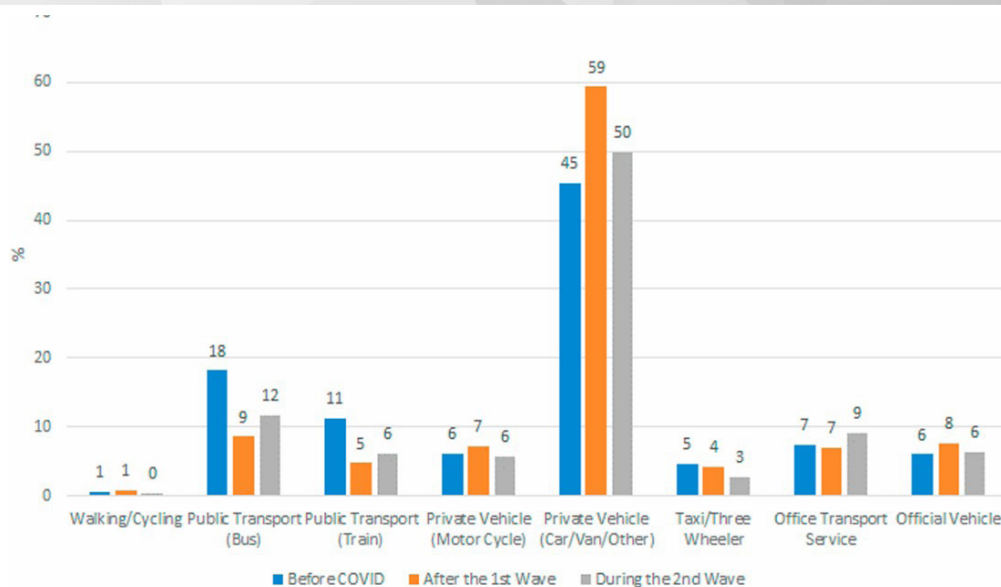


Fig. 1. Transport modes used by commuters in the Western Province of Sri Lanka before COVID-19, after the first wave, and during the second wave (percentage of respondents). Source: K. D. P. Damsara, D. De Silva, H. R. Pasindu, and T. Munasinghe, Transportation Research Procedia, vol. 82, 2025 [2]; reproduced under a Creative Commons license (CC BY-NC-ND 4.0).

As Fig. 1 shows, a study of the transport modes used by people found that the use of public transport decreased by about 15 percentage points during the pandemic, while the use of private vehicles increased by a similar amount [2]. The drop in public transport use affects the people who make up the workforce, which indirectly affects the supply chain sector in Sri Lanka [2].

Education

The economic crisis in 2022 had a severe impact on the education system, teaching and learning activities, development programmes and management across 10,155 government schools serving approximately 4.5 million students and over 235,000 teachers in Sri Lanka. From physical materials like paper and stationery to infrastructure needs like electricity and fuel, the lack of essential resources hindered regular school proceedings. Rising fuel costs made travel too expensive, which forced schools to close for some days and led to reduced attendance. Severe shortages of stationery, lab chemicals, and paper led to cancelled term tests in the Western Province. Beyond physical resources, frequent electricity shortages and ICT issues hindered distance learning. Furthermore, educational development programmes, including school meal schemes, were suspended or reduced because of financial constraints, negatively affecting students' nutrition, participation, and overall educational performance. All of these problems together slowed down the country's progress toward achieving quality education goals [3].

Tourism

Sri Lanka's tourism industry was almost lost due to the COVID-19 virus. Due to this pandemic situation, Sri Lanka had "zero income and zero tourists" for the first time in history. International arrivals collapsed from 1,913,702 to 507,704 within the years 2019–2020 (Table 1). Furthermore, tourism receipts dropped from USD 3,606 million to USD 682 million during this period, and tourism employment fell from about 403,000 to about 348,000. As a result, many hotels and restaurants began retrenching employees and also terminating the services of casual and temporary workers due to the complete loss of revenue, and Sri Lanka lost foreign currency inflows [4]. Thereby, the tourism downfall had a huge impact on the 2022 economic crisis.

Table 1. Key tourism indicators for Sri Lanka, 2019 and 2020. Source: Sri Lanka Tourism Development Authority [5] and Central Bank of Sri Lanka [6].

Indicator	2019	2020
International tourist arrivals	1,913,702	507,704
Tourism receipts (US\$ million)	3,606	682
Tourism employment	402,607	347,757

Economic Management and Politics

COVID-19 affected all sectors both in Sri Lanka and internationally. As a result, Sri Lanka faced a severe economic downturn, and the government was unable to manage the situation effectively. The Colombo Stock Exchange fell to an eight-year low and was temporarily closed [7], while poverty increased in 2020, with more than 500,000 people falling below the poverty line [8]. Poor economic decisions during the pandemic led to rising unemployment, inflation, and increased financial pressure on the public. The pandemic also exposed weaknesses in existing claims management systems, further increasing financial pressure on industries [9]. Due to these failures, public trust in the government gradually declined. Many Sri Lankans became dissatisfied with political leadership and demanded change. This loss of confidence and growing public frustration contributed to political instability in the country.

Recovery from the Crisis

In 2022, Sri Lanka defaulted on its debt, triggering an economic collapse. With a lack of foreign currency, it faced extreme shortages and a massive protest against the government of former president Gotabaya Rajapaksa. Recovery began when the government took emergency steps to stabilise the economy [10]. In late 2024, Sri Lanka's economy showed signs of recovery. The World Bank reported that the country's growth was expected to reach 4.4% in 2024, supported by the industrial and tourism sectors [10]. The main recovery methods were the IMF loan, India's help, tourism revival, and healthcare and transportation recovery.

The International Monetary Fund (IMF)'s programme of about USD 3 billion, approved in March 2023, helped Sri Lanka's recovery by stabilising inflation, rebuilding the country, and creating a foundation for growth. According to the IMF, "the economy grew 1.6 percent from a year earlier in the third quarter of 2023" [11].

As Sri Lanka faced a serious financial crisis, India stepped up and pledged about USD 2.4 billion to the nation to help overcome the crisis. Under the SAARC currency swap arrangement, India extended USD 400 million to Sri Lanka and deferred an Asian Clearing Union (ACU) settlement of USD 512.2 million by two months [12].

After the crisis in 2022, tourism became one of the fastest recovering sectors, and it plays a major role in foreign income. The Sri Lankan government prioritised tourism to earn foreign currency and launched tourism promotion in Europe, India, and the Middle East. According to the Central Bank of Sri Lanka, tourism earnings helped the country to boost foreign exchange inflows [13].

The 2022 economic crisis in Sri Lanka affected health care through shortages of medical equipment and

medicines. The World Health Organization provided support for these needs at that crucial time, with supplies worth USD 7.1 million, including insulin, HIV test kits, and life-saving drugs [14]. As for transportation, India delivered 40,000 metric tonnes of fuel to ease the country's suffering [15]. This assistance played a major role in maintaining important services and in Sri Lanka's recovery.

Conclusion

During the period from the first half of 2022 to the second half of 2023, our country had to face a very difficult situation. This was caused by government policies and global factors, as discussed above. Excessive foreign loans, the sudden implementation of a fully organic agriculture policy and the COVID-19 virus were the main causes. Everyone in our country, both the rich and the poor, had to go through this difficult period. Regardless of class differences within society, the whole country was affected by the situation.

Mr. Ranil Wickremesinghe was sworn in as the new president on 21 July 2022 and led the government through the IMF programme and debt restructuring, and the economy returned to growth in 2023 and 2024. Mr. Anura Kumara Disanayake, elected president in September 2024, committed his government to continuing the reform programme. The recovery is still fragile, and continued reform is needed to turn stability into lasting growth. The whole country has contributed to this far more comfortable economic situation than the one Sri Lanka had in 2022, united with one ambition: to raise the motherland higher and create a peaceful and bright future for the next generation.

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