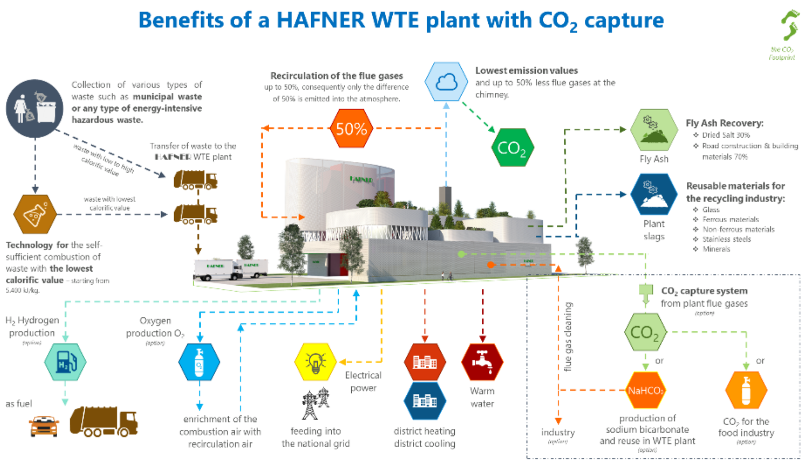
“WASTE TO ENERGY” FOR CLIMATE CHANGE & SUSTAINABLE SOLUTIONS FOR THE NEXT GENERATION



Heinrich Hafner - 2024

HAFNER® ENERGY FROM WASTE

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"WASTE TO ENERGY"

FOR CLIMATE CHANGE & SUSTAINABLE SOLUTIONS FOR THE NEXT GENERATION

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Foreword

In an era where the urgency of climate change can no longer be ignored, we face the collective challenge of developing innovative and efficient solutions to reduce greenhouse gas emissions. Waste management, particularly waste incineration, plays a central role in this context. Although Waste to Energy plants are essential for handling the growing volume of waste and recovering energy, they also produce significant amounts of CO_2 and other pollutants that contribute substantially to global warming and local air pollution.

This book introduces an advanced method that not only has the potential to significantly reduce CO_2 emissions but also to extract valuable resources from this waste product: Sodium bicarbonate. Our goal is to bridge current scientific knowledge with practical applications. We explore in depth the process of CO_2 capture using sodium carbonate and its conversion to sodium bicarbonate, a method that is both ecologically and economically sustainable. From the basic chemical reactions to the technical challenges and possibilities for industrial application, this publication provides a comprehensive understanding.

Moreover, readers will gain insights into the current technological, economic, and regulatory conditions that influence the implementation of this technology. Through detailed case studies and model simulations, we illustrate not only the theory but also the practical implementation of CO_2 capture and conversion in various global contexts.

This book includes two different visions (Scenario 1 and 2) for the year 2030, to forge new paths in waste management that contribute not only to emission reduction but also create economic and ecological value. The research and content of this work have been compiled in the hope of making a significant contribution to global emission reduction and indirectly improving health through new thinking in waste management.

It is a call to action, a call to explore and implement innovative solutions that protect our environment and enhance the quality of life for future generations. We warmly invite you to join us on this exciting and crucial journey toward a more sustainable planet.

CONTENT

1. Climate Change - A Global Challenge

Climate change encompasses significant and permanent changes in the statistical distributions of weather patterns that can extend over a long period of time - from decades to millions of years. In modern times, the term mainly refers to global warming – and is often used synonymously with the term – which has been observed since the industrial revolution. Natural phenomena such as volcanic eruptions can also influence the climate by emitting large amounts of volcanic ash and sulphur dioxide into the atmosphere, which reflects solar radiation and temporarily cools the earth.

The increased levels of greenhouse gases in the atmosphere are due to various human activities, such as burning fossil fuels – Including waste incineration –, deforestation, agricultural practices, and industrial processes. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs).

The conversion of forests to agricultural land, urban areas or other land uses affects the land's ability to absorb CO_2 and changes the Earth's reflectivity, affecting both local and global temperatures.

Since the industrial revolution, the average global surface temperature has risen by around 1.1°C, which has had a significant impact on the global climate and the increase in extreme weather events. The melting of the polar ice caps, glaciers and Arctic sea ice is causing sea levels to rise, threatening coastal areas and island nations with flooding and erosion.

Higher global temperatures are causing an increase in the frequency and intensity of extreme weather events such as hurricanes, heat waves, heavy rainfall and storms. These climatic changes have drastic effects on natural ecosystems; they influence migration patterns, mating seasons and interactions between species, which can lead to a decline in biodiversity and the functioning of ecosystems.

The agriculture, fresh water supply, health and economic structures of societies worldwide are also affected by climate change. Countries with fewer resources are often the hardest hit. At an international level, countries are striving to reduce their CO_2 emissions through policies such as the Paris Agreement, which aims to keep warming well below 2 °C.

The European Union (EU) has positioned itself as a leader in the global fight against climate change and has introduced a variety of policy measures and legal frameworks to reduce greenhouse gas emissions, increase energy efficiency and promote the use of renewable energy.

1.1 The EU Climate and Energy Package 2020

Introduced in 2008, this package set three key objectives for 2020 (known as the "20-20-20" targets):

- **A 20% reduction in CO_2 emissions compared to 1990 levels.**
- **An increase in the share of renewable energy sources to 20% of total energy consumption.**
- **A 20% improvement in energy efficiency.**

1.2 The EU Climate and Energy Package 2030

The EU has set even more ambitious targets for 2030, which were adopted in 2014:

- **At least a 40% reduction in greenhouse gas emissions compared to 1990.**

- **At least a 32% share of renewable energy sources in total energy consumption.**
- **At least a 32.5% improvement in energy efficiency.**

1.3 The European Green Deal (European Green Deal)

Introduced at the end of 2019, the European Green Deal is a comprehensive EU action package to combat climate change with the aim of making Europe the first climate-neutral continent by 2050. Key components of this agreement include:

- **<u>Biodiversity:</u> A new Biodiversity Strategy Plan for 2030.**
- **<u>Farm to fork:</u> Strategies to ensure more sustainable food systems.**
- **<u>Sustainable agriculture:</u> Promoting the use of sustainable energy sources in agriculture.**
- **<u>Circular economy:</u> Initiatives to promote the recycling economy and reduce overall waste production.**
- **<u>Zero pollution ambition:</u> For a toxic-free environment.**
- **<u>Sustainable mobility:</u> Promoting the switch to more sustainable modes of transportation.**

1.4 Fit for 55

The ‘Fit for 55’ package, presented in 2021, includes a series of measures to achieve the climate and energy targets for 2030. It aims to ensure that the EU reduces its emissions by at least 55% by 2030.
Important measures include:

- **Reform of the EU Emissions Trading System (ETS):** Expansion to new sectors and tightening of the cap-and-trade system.

- **Carbon Border Adjustment Mechanism (CBAM):** Introduction of costs for imports of products with high CO_2 emissions.
- **Revision of the Effort Sharing Regulation:** increasing the targets for reducing emissions from buildings, transport, and agriculture**.**
- **Renewable Energy Directive:** Increasing the target for the share of renewable energy.
- **Energy Efficiency Directive:** Raising the target for improving energy efficiency.

1.4.1 Achieving Net Zero Emissions

Total emissions: The EU aims to reduce net greenhouse gas (GHG) emissions to zero by 2050. This means that all remaining emissions must be offset by measures to absorb CO_2, such as reforestation or carbon capture and storage technologies.

Legally binding: This target was made legally binding in the European Climate Law, which was adopted in 2021.

1.4.2 Decarbonisation of the Economy

Energy sector: Switch to renewable energy sources and move away from fossil fuels. This includes the expansion of wind and solar energy, biomass and other renewable technologies.

Industry: Promotion of energy efficiency and clean technologies in production, including the introduction of carbon capture and utilisation technologies.

Buildings sector: Increasing energy efficiency in buildings and switching completely to sustainable energy sources for heating and cooling.

1.4.3 Sustainable Mobility

Transport: Significantly reduce emissions in the transport sector by promoting electric vehicles, improving public transport systems, expanding infrastructure for cyclists and pedestrians and introducing stricter emission standards for cars and lorries.

Aviation and shipping: Introduce sustainable fuels and practices to reduce CO_2 emissions in these international sectors.

1.4.4 Conservation and Expansion of Greenhouse Gas Sinks

Land use and forestry: Promote afforestation and reforestation, sustainable forestry practices that not only help absorb CO_2, but also protect biodiversity and improve soil quality.

Technological innovations: Development and deployment of Direct Air Capture (DAC) technologies and biological methods for CO_2 absorption.

1.4.5 Promotion of the Circular Economy

Waste management: Reducing waste generation, maximising recycling and minimising landfill, in particular by banning certain single-use plastic products and promoting the recycling of materials.

1.4.6 Adaptation to Climate Change

Increasing resilience: Developing strategies to adapt to the inevitable effects of climate change, such as rising sea levels, more frequent and intense weather extremes, and their impact on various economic sectors.

1.4.7 International Cooperation and Financing

Global Partnerships: Strengthening international cooperation on climate issues, supporting less developed countries in their climate protection efforts and promoting global agreements that contribute to climate protection.

Financing: Providing financial resources for climate change mitigation and adaptation measures, both within the EU and internationally, including the use of the EU budget and the involvement of private investment.

Through these and other measures, the EU aims to assert its leadership in the global fight against climate change and demonstrate that economic development does not have to come at the expense of the planet. These policies and initiatives are aimed not only at reducing emissions, but also at promoting a comprehensive environmental sustainability and circular economy that improves the quality of life of citizens and creates new economic opportunities.

2. CO_2 Emitters Worldwide

The ranking of countries according to their CO_2 emissions may vary depending on their economic activities, industrial structures, energy sources and policies. The data presented here is largely based on 2021 statistics and provides an overview of the world's largest CO_2 emitters.

China CO_2 Emissions: approx. 10,065 megatons (Mt),
Share of global emissions: approx. 28.8%,
Main sources: coal consumption, industrial production, increasing number of vehicles.

United States CO_2 Emissions: approx. 4,461 megatons (Mt),
Share of global emissions: approx. 14.5%,
Main sources: energy sector, transport, industrial processes.

India CO_2 Emissions: approx. 2,654 megatons (Mt),
Share of global emissions: Approx. 7.1%,
Main sources: coal combustion, cement production, agricultural activities.

Russia CO_2 Emissions: approx. 1,711 megatons (Mt),
Share of global emissions: approx. 4.6%,
Main sources: energy production, flaring of gases in oil and gas production, heavy industry.

Japan CO_2 Emissions: approx. 1,162 megatons (Mt),
Share of global emissions: approx. 3.3%,
Main sources: energy production, industrial activities, transport.

Iran CO_2 Emissions: approx. 720 megatons (Mt),

Share of global emissions: approx. 2.1%,

Main sources: oil and gas production, power generation.

Germany CO_2 Emissions: approx. 702 megatons (Mt),

Share of global emissions: approx. 2.0%,

Main sources: coal and gas-fired power plants, industrial processes, automotive sector.

South Korea CO_2 Emissions: approx. 659 megatons (Mt),

Share of global emissions: approx. 1.8%,

Main sources: industrial processes, energy production.

Saudi Arabia CO_2 Emissions: approx. 621 megatons (Mt),

share of global emissions: approx. 1.7%,

Main sources: oil and gas extraction, petrochemicals.

Indonesia CO_2 Emissions: approx. 615 megatons (Mt),

Share of global emissions: approx. 1.7%,

Main sources: deforestation, peat fires, fossil fuels.

China and the USA together are responsible for almost 43% of global CO_2 emissions, which emphasises their central role in international climate protection negotiations. India and Russia follow at a considerable distance, which illustrates the global distribution of emission sources. The EU as a whole would also be high on the list if considered as a single entity, with significant emissions from other countries such as Poland, Italy, and France. These figures highlight the need for a globally coordinated response to climate change, including international co-operation and agreements such as the Paris Agreement, to reduce emissions and limit the rise in global temperatures. These countries have a particular responsibility to take leadership roles, both in reducing their emissions and in supporting global climate resilience efforts.

2.1 Average CO_2 Emissions Per Capita Worldwide

CO_2 emissions per capita (tonnes per year, 2021) vary widely from country to country based on a variety of factors, including wealth levels, energy sources, industrial structure, and individual lifestyles. Here is an overview of the average CO_2 emissions per capita for selected countries based on 2021 data.

2.1.1 High Emitting Countries

Qatar: approx. 37.0 tonnes, extremely high emissions due to intensive use of fossil fuels in all sectors and a small population.

Kuwait: approx. 25.2 tonnes, similar to Qatar, high per capita emissions due to oil production and processing.

United Arab Emirates: approx. 21.8 tonnes; high energy consumption and an energy-intensive lifestyle contribute to high per capita emissions.

Saudi Arabia: approx. 18.1 tonnes; oil production and energy consumption are the main drivers of emissions.

Australia: approx. 16.8 tonnes; large coal and natural gas deposits that are used intensively; high standard of living.

United States: approx. 13.7 tonnes. One of the largest energy consumers worldwide, high automobile use, and energy-intensive industries.

2.1.2 Average Emissions - Countries

Canada: approx. 15.6 tonnes; for reasons similar to those in Australia and the USA, with the additional factor of intensive tar sands extraction.

South Korea: approx. 11.5 tonnes; high industrial activity, particularly in electronics and automotive production.

Japan: approx. 8.7 tonnes; dense population and strong industrial base.

Germany: approx. 8.7 tonnes, large industrial economy with a high share of coal energy.

Europe: approx. 6.3 tonnes.

China: approx. 7.2 tonnes.

Note: While China is the world's largest overall emitter, its per capita emissions are relatively moderate due to its huge population.

2.1.3 Lower Emissions Countries

Brazil: approx. 2.2 tonnes; extensive use of hydropower and ethanol reduces dependence on fossil fuels.

India: approx. 1.9 tonnes. Despite rapidly growing industry and energy demand, per capita emissions are low due to the large population and lower individual consumption.

Indonesia: approx. 2.3 tonnes: a lot of biomass combustion and growing energy demand but spread over a very large population.

2.1.4 Low Emissions Countries

African countries (e.g. Kenya, Ethiopia): less than 1.0 tonne; low industrial activity and low energy consumption per capita.

This per capita emissions data reflects the inequalities in the global emissions landscape. While industrialised nations such as the USA, Canada and Australia have high per capita emissions, many developing countries have significantly lower per capita emissions despite often rapid industrialisation and growth.

This discrepancy is a key challenge in international climate negotiations, as it highlights the different contributions to climate change and the different capacities for mitigation and adaptation.

For a sustainable reduction of global CO_2 emissions, it is crucial that high per capita emitters develop and implement innovative technologies to reduce emissions, while low emitters receive support to advance their development in sustainable ways.

3. What Political Targets have already been set Worldwide?

Many countries around the world have introduced legislation to reduce CO_2 emissions in recent decades in order to strengthen climate protection and curb global warming. These laws vary widely in their stringency and scope but reflect a growing international commitment to climate action. Here are some of the leading countries supporting climate action through comprehensive legislation:

3.1 European Union

The EU is leading the way in implementing strong climate change legislation - EU Emissions Trading Scheme (EU ETS): the world's largest emissions trading scheme, which sets a cap on total emissions and gradually reduces them.
European Green Deal: a package of measures aimed at making Europe climate neutral by 2050. It includes initiatives such as the Farm to Fork Strategy, the 2030 Biodiversity Plan and clean energy measures. Climate neutrality by 2050 - a legally binding target supported by the European Climate Law.

3.2 United States

Clean Air Act (updates): this foundational law has been used to enforce regulations limiting CO_2 emissions from power plants and industrial facilities. Paris Agreement Re-Entry, 2021 - After re-entering the Paris Agreement under President Biden, the U.S. has committed to reducing its emissions by 50-52% below 2005 levels by 2030.
American Clean Energy and Security Act: although never passed, this proposal reflects the extent of legislative efforts that have been made to

regulate CO_2 emissions.

3.3 China

Five-year plans: China has set specific targets to reduce the emissions intensity of its economy in its five-year plans. National Emissions Trading Scheme - in 2021, China launched a national emission trading scheme, starting with the energy sector.
Target of carbon neutrality by 2060: China has committed to achieving carbon neutrality by 2060, with a peak in CO_2 emissions before 2030.

3.4 Canada

Greenhouse Gas Pollution Pricing Act: this law ensures that carbon pricing is applied nationwide to reduce emissions. Carbon neutrality by 2050 - a legally binding target, supported by Canada's Net-Zero Emissions Accountability Act.

3.5 United Kingdom

Climate Change Act: first passed in 2008, the Act sets legally binding targets to reduce CO_2 emissions by at least 80% by 2050 (compared to 1990 levels). This target was later updated to net zero emissions.
Carbon Budgets: Regularly updated budgets that set maximum emissions limits over five-year periods.

3.6 Germany

Federal Climate Protection Act: setting specific emissions reduction targets for sectors such as transport, buildings and agriculture and the requirement to be climate-neutral by 2050.

Energy Transition: Far-reaching measures in the energy sector that include the phasing out of nuclear energy and coal as well as the expansion of renewable energies.

3.7 France

Energy Transition for Green Growth Act: This law sets targets for reducing the use of fossil fuels and increasing energy efficiency. Ban on Fracking and Oil Extraction: France has banned fracking and announced plans to end oil extraction on its territory by 2040.

3.8 Scandinavian countries (Norway, Sweden, Denmark)

Comprehensive environmental legislation: These countries rely heavily on policies that drastically reduce emissions, including taxes on CO_2, investments in renewable energy and strict environmental standards.

These countries and their legislative measures demonstrate the broad range of strategies being pursued globally to mitigate climate change and reduce CO_2 emissions. The international framework, in particular the Paris Agreement, serves as an important basis for the alignment of national targets and measures. Each country has its own specific goals and methods, depending on its economic context, natural resources, and political will.

4. Can the World's Population 'Afford' Climate Protection in Terms of Reducing CO_2 Emissions?

This concern touches on economic, social, political and environmental aspects of global societies. The short answer is that the world cannot afford not to prioritise climate action, as the long-term costs of not addressing climate change - both financially and in terms of human health and safety - are likely to be far higher than the costs of proactive action now.

Here are some detailed considerations:

- **Costs of climate change:**

  The direct and indirect costs of climate change are already being felt and are expected to increase exponentially in the absence of adequate action:

  Natural disasters - increase in frequency and intensity of extreme weather events such as hurricanes, droughts and floods lead to billions of dollars in direct damage.

  Health costs - rising temperatures and changing climatic conditions favour the spread of diseases (e.g. mosquito-borne diseases such as malaria).

- **Economic influences:**

  Agriculture, fishing, and tourism, especially in climate-sensitive regions, suffer from the effects of climate change.

  While investments in climate change mitigation measures are significant, studies and modelling show that the economic benefits (by avoiding the most severe impacts of climate change and by creating new 'green' industries) can outweigh the costs.

- **Energy efficiency:**

  Improvements in energy efficiency reduce energy demand and therefore costs for consumers and businesses.

- **Renewable energy:**

  The cost of renewable energy technologies, such as solar and wind power, has fallen rapidly and in many cases are competitive with or cheaper than fossil fuels.

- **Job creation:**

  The transition to a greener economy has the potential to create jobs on a large scale in sectors such as renewable energy, energy efficiency and environmental protection.

- **A critical aspect of global climate change mitigation is social justice:**

  Developing countries:

  Rich countries have historically contributed more to the climate crisis and have more resources for climate action. It is argued that they therefore have a greater responsibility and should support developing countries, both financially and technologically.

  Domestic inequality:

  Measures such as carbon taxes must be carefully designed so as not to have regressive effects, i.e. so as not to disproportionately burden the poor.

- **International cooperation and financing:**

  The international community is increasingly recognising that comprehensive financial and technical support is needed to enable all countries to make the transition to more sustainable systems.

- **Green Climate Fund (GCF):**

  Established under the UNFCCC, aims to finance projects, programmes, policies, and other activities in developing countries related to mitigation and adaptation.

  Technology transfer - advanced technologies must be made globally accessible in order to enable a worldwide reduction in emissions.

Although the costs of climate action are significant, the costs of inaction are potentially catastrophic, both in financial and human terms. Investing in sustainable technologies and practices is not only necessary to avoid ecological disasters, but also offers significant economic and social benefits. The challenge will be to make these transitions fair and effective in order to share the burden equitably and make opportunities globally accessible.

5. Waste Management and the Climate

The utilisation of waste to generate energy also plays an important role in the context of climate protection. This approach can make a significant contribution to reducing greenhouse gas emissions, protecting biodiversity and reducing the environmental impact of traditional waste disposal methods and fossil fuels.

The benefits for climate protection are the reduction of greenhouse gas emissions. Utilising waste to generate energy helps to reduce greenhouse gas emissions. Landfills are a significant source of methane, a greenhouse gas up to 25 times more potent than CO_2. Anaerobic digestion captures and utilises this methane instead of allowing it to escape into the atmosphere. In future, landfill sites will only be suitable for mineral waste. CO_2 produced during the combustion of biomass or waste is often considered carbon neutral, as the materials that make up the biomass (e.g. plant material) have absorbed CO_2 during their growth. Although this is not completely neutral, as emissions are still produced during processing and combustion, it is more favourable compared to burning fossil fuels. Each unit of energy produced by waste replaces a unit that would otherwise have been produced by fossil fuels, thus reducing the use of fossil resources and the associated emissions. In the future, Waste to Energy with CO_2 capture and 100% circular economy (slag and filter dust as product utilisation) will change the market.

Converting waste into energy reduces the total amount of waste that ends up in landfill. This not only minimises the risk of methane formation, but also the contamination of groundwater and soil by leachate from landfills.

Waste recovery technologies promote the separation and recycling of waste, as reusable materials are separated, and the remaining waste is utilised for energy recovery. This supports the concept of the circular economy, which aims to use resources efficiently and minimise environmental impact.

The incineration of waste can lead to air pollution if the process is not state of the art. These emissions must be effectively controlled to minimise environmental and health risks. Advanced filter technologies and strict regulations are needed to minimise emissions. BAT and BREF are key instruments in European environmental policy that help waste management and other industrial sectors to minimise their environmental impact. By setting standards for best available techniques and documenting them in BREFs, a high level of environmental protection is promoted, while at the same time supporting industrial efficiency and innovation.

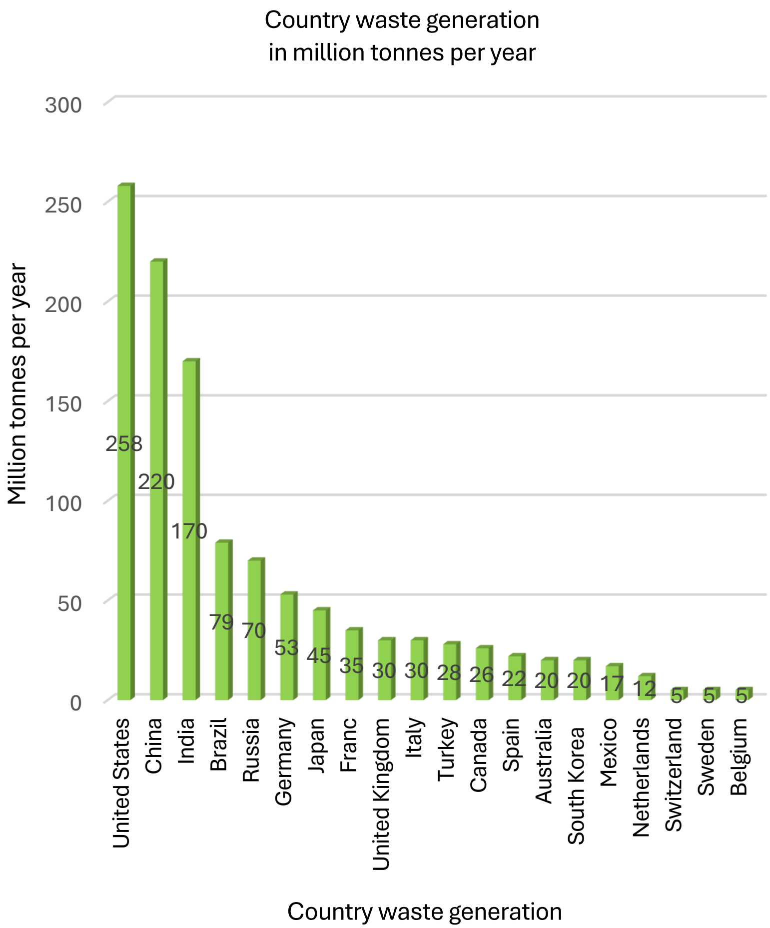
Waste-to-energy technologies are often capital intensive and require significant investment in technology and infrastructure. The economic viability of these projects depends on energy prices, technology costs and available subsidies.

It must be ensured that waste-to-energy does not undermine waste prevention and recycling. Priority should always be given to waste prevention and recycling before energy recovery is considered.

Overall, the use of waste to energy offers significant climate benefits by reducing greenhouse gas emissions, reducing dependence on fossil fuels and helping to promote the circular economy. The challenges lie in technological development, financing and the need to control emissions. However, with the right policies and technologies, this approach can provide a sustainable and environmentally friendly alternative to traditional energy sources.

Global waste generation varies greatly from country to country, depending on factors such as population size, consumer behaviour, industrial production, and the efficiency of waste management systems.

Here is a table showing the estimated annual waste generation per country in tonnes, based on available data and estimates for 2021:



United States:

The USA produces over 250 million tonnes of household waste annually, making it the world's largest producer of waste.

China and India:

Both countries are experiencing a rapid increase in waste generation due to their large populations and rapidly growing economies.

European countries:

Countries such as Germany, France, and the United Kingdom have relatively lower waste production rates per capita due to efficient recycling and waste management programmes, but still have significant overall volumes.

Countries such as Brazil, Russia and Mexico are facing challenges in dealing with rising waste volumes due to increasing urbanisation and consumption.

6. How much does all global Waste Contribute to Climate Pollution?

Worldwide, waste management contributes approximately 11% to anthropogenic methane emissions, equating to roughly 60-80 million tons of methane annually (Source: Global Methane Initiative Report, 2020). The primary sources of CO_2 in the waste sector are the combustion of fossil plastics and the energy used in waste treatment processes. Emission data fluctuates - the exact amount of CO_2 emissions varies significantly depending on waste composition and the combustion technologies employed.

Other greenhouse gases include nitrous oxide (N_2O), which is approximately 298 times more potent than CO_2 in terms of global warming, and fluorinated gases (HFCs, PFCs), emissions of which result from improper disposal of refrigerants and other electronic waste.

6.1 Impact and Strategies for Emission Reduction

International Efforts: Various international agreements aim to reduce methane emissions through improved landfill practices, such as capturing and utilizing landfill gas, and by promoting recycling and composting.

Potential for Emission Reduction: By optimizing waste treatment methods, including advanced Waste-to-Energy (WtE) technologies, the waste management sector can significantly lower its emissions. Utilizing landfill gas not only reduces methane emissions but also generates renewable energy.

This overview provides a structured and detailed representation of emission issues in waste management, emphasizing the importance of advanced technologies and international cooperation in reducing greenhouse gas emissions.

The worldwide waste management significantly contributes to global climate stress, primarily through emissions of greenhouse gases (GHGs) such as methane (CH_4) and carbon dioxide (CO_2). These gases originate from the decomposition of organic waste under anaerobic conditions, waste incineration, and inefficient recycling and disposal practices.
Capturing and utilizing landfill gas (mainly methane) for energy generation can help reduce methane emissions. These processes decrease the amount of waste ending up in landfills and prevent the generation of methane.

Modern WtE plants can efficiently utilize the energy content of waste while reducing emissions compared to landfills or traditional incineration. Waste avoidance and minimization. Reduction of waste production at the source through sustainable design, consumption reduction, and product lifespan extension.
The contributions of the waste sector to global climate stress are significant but also offer significant opportunities for emission reductions through improved waste management and technology deployment. Implementing these strategies can significantly reduce climate impacts and enhance the sustainability of waste management worldwide. Efficient, environmentally friendly waste management practices are crucial for achieving global goals to reduce greenhouse gas emissions.

6.2 Landfilling of Waste

Methane emissions from landfills. Methane is a major contributor, primarily generated in landfills through the anaerobic decomposition of organic waste. Methane has a Global Warming Potential (GWP) about 25 times higher than that of CO_2 over a 100-year period. Landfills are the third-largest source of anthropogenic methane emissions globally. Landfills contribute to global methane emissions, accounting for approximately 1.6% of total global GHG emissions.

The landfilling of waste, the long-term storage of waste materials in designated facilities, is one of the oldest methods of waste disposal. Despite its widespread use and economic benefits in certain contexts, landfilling poses significant disadvantages that can affect both the environment and human health.

Here are the key disadvantages of landfilling waste summarized:

- **Environmental pollution -** Groundwater contamination by chemicals from waste can seep into the soil and groundwater, affecting water quality and leading to long-term health risks.
- **Soil contamination** by heavy metals and other toxic substances can pollute the soil, affecting agricultural use and harming local flora and fauna.
- **Greenhouse gas emissions** such as organic waste in landfills decompose anaerobically (without oxygen), leading to the release of methane, a potent greenhouse gas that contributes significantly to global warming. CO_2 emissions: In addition to methane, carbon dioxide and other greenhouse gases are also released through the decomposition process.
- **Large land area requirements:** Landfills require extensive land areas that often cannot be used for other purposes for a long time. This leads to inefficient land use and can exacerbate local land scarcity.
- **Air pollution and the Release of Pollutants:** In addition to greenhouse

gases, landfills can also release volatile organic compounds (VOCs), sulphur dioxide, ammonia, and other harmful gases that contribute to air pollution and are harmful to health.

- **Significant health risks -** People living or working near landfills may be exposed to health risks from outgassing chemicals and microorganisms, including respiratory diseases and other chronic health problems. The accumulation of gases in landfills can lead to explosions, which are not only dangerous but can also cause significant damage. The construction and expansion of landfills can destroy natural habitats and reduce biodiversity in affected areas. Leachate from landfills can enter local water bodies and affect water quality, having negative impacts on aquatic flora and fauna, as well as the population. Proximity to landfills can significantly impact the quality of life for residents, often associated with property devaluation.

Monitoring and aftercare of landfills require long-term financial and administrative commitments that can last for generations.
Inefficiency and resource waste due to loss of valuable materials. Many materials in landfills could be reused or recycled, instead they are irretrievably lost.

Resource wastage: Manufacturing new products from raw materials instead of recycled materials consumes more energy and resources and results in increased emissions.

Although landfilling is considered a necessary measure for waste management in some situations, its negative impacts are considerable. Alternative methods such as recycling, composting, and waste-to-energy processes offer opportunities to avoid these disadvantages and should be preferred where possible to minimize environmental impact and use resources more efficiently.

6.3 Recycling of Waste

Recycling involves reusing materials such as paper, plastic, glass, and metal, thereby reducing the need for raw material extraction and processing. This leads to a significant reduction in CO_2 emissions, as the production of products from recycled materials is typically less energy-intensive than manufacturing from new materials. Recycling often also saves energy compared to the processes required to manufacture new products from raw materials, further contributing to the reduction of CO_2 emissions.
Waste recycling plays a central role in waste management and environmental protection. It offers numerous benefits but also presents some challenges.

Here are the key advantages and disadvantages of recycling:

- **Recycling reuses existing materials,** reducing the demand for resources such as wood, ores, and petroleum. This helps conserve natural resources and reduces the environmental impact associated with extracting and processing these raw materials.
- **Manufacturing products from recycled materials generally consumes less energy** than production from new materials. For example, producing aluminium from recycled material requires only about 5% of the energy needed for production from bauxite.
- **Since recycling typically consumes less energy, it also leads to a**

reduction in greenhouse gas emissions associated with energy production, contributing to climate protection.

- **Recycling helps reduce the amount of waste ending up in landfills** or incineration facilities, resulting in lower environmental impacts and costs in waste disposal.
- **Recycling creates jobs in the collection, sorting, and processing of recyclable materials, contributing to the creation of a sustainable economy.**
- **Recycling plants require significant investments in technology and infrastructure.** The high initial costs can be a barrier to establishing new recycling programs.
- **A challenge in recycling is the contamination of materials,** which often affects the quality of the recycled product. Contaminated or improperly sorted materials can render entire batches unusable.
- **Not all recycled materials easily find buyers, which can affect the profitability of recycling.** Demand for recycled materials, especially plastics, is often lower than the supply.

Although recycling is generally more energy-efficient than manufacturing from new materials, it still consumes energy and can be associated with environmental impacts, especially when transportation distances are long.

The efficiency of recycling depends heavily on the quality of the collected waste. Poorly separated or contaminated materials can make the recycling process inefficient and costly.

Despite the challenges, recycling offers significant environmental and economic benefits by minimizing the use of natural resources, saving energy, and reducing emissions.

Overcoming the disadvantages requires ongoing innovation in recycling technology, improved waste collection and sorting systems, and the creation of markets for recycled products.
Overall, recycling is an indispensable part of a sustainable waste management strategy.

6.4 Composting and Anaerobic Digestion

These are two important methods for biological waste treatment. Both processes utilize microbial activity to break down organic waste and produce useful products such as compost or biogas. They play a crucial role in sustainable waste management strategies, especially in treating organic waste from households, agriculture, and industry.
Composting is an aerobic (oxygen-utilizing) process in which organic waste is decomposed by the natural activity of microorganisms. This process leads to the formation of compost, a nutrient-rich soil conditioner. Oxygen is essential for decomposition, and adequate aeration is required to allow microorganisms to respire. An optimal carbon-to-nitrogen ratio (approximately 30:1) promotes microbial breakdown. Moisture is ideally maintained at around 50-60%, and temperatures can rise to 40-60°C in hot compost piles, accelerating decomposition and killing pathogenic organisms. Compost is commonly used in agriculture and horticulture as a soil conditioner, improving soil fertility and structure, and promoting plant growth.
On the other hand, anaerobic digestion is a biological process in which organic waste is broken down by microorganisms in the absence of oxygen. The main product of this process is biogas, which contains methane. Decomposition occurs in closed vessels (digesters) where no oxygen is

present. Microorganisms produce biogas, consisting mainly of methane and carbon dioxide. A by-product of anaerobic digestion is digestate, a nutrient-rich material that can be used as fertilizer. Biogas can be used as a fuel for heat and power generation and is a renewable energy source.

Both processes reduce the amount of organic waste going to landfills, where it would otherwise release methane, a potent greenhouse gas. Biogas obtained from anaerobic digestion can replace fossil fuels. Both compost and digestate improve soil structure and promote biological activity in the soil. Anaerobic digestion plants are technically complex and costly to set up and maintain. In composting, emissions such as ammonia and nitrous oxide must be controlled. The quality of compost and digestate must be strictly monitored to avoid contaminants in the soil.

In summary, both composting and anaerobic digestion offer effective ways to recycle organic waste and protect the environment, but they require different technical approaches and have specific advantages and disadvantages.

6.5 Waste to Energy

Utilizing waste as a resource for energy generation is becoming an increasingly popular concept, offering the potential to partially replace fossil fuels and thereby reduce environmental impact. Here is a detailed overview of how waste can be utilized for energy generation and to what extent it could replace fossil fuels:

The most widespread method of generating energy from waste is the incineration of garbage in specialized Waste to Energy plants (grate furnaces for household waste or rotary kilns for special waste). In this process, the waste is burned, generating heat. This heat is used to heat water and produce steam, which then drives turbines that, in turn, produce electricity. The exhaust gases are cleaned to meet legally guaranteed emissions standards.

In gasification, waste is converted into synthetic gas (syngas) at high temperatures and under oxygen deficiency. This gas consists mainly of carbon monoxide and hydrogen.

The syngas can then be burned for electricity generation or further processed as a raw material for use in the chemical industry. Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen. Organic material is converted into oil, gas, and coal. The resulting pyrolysis oil can be used as fuel or further processed, while the gas can be used for energy generation.

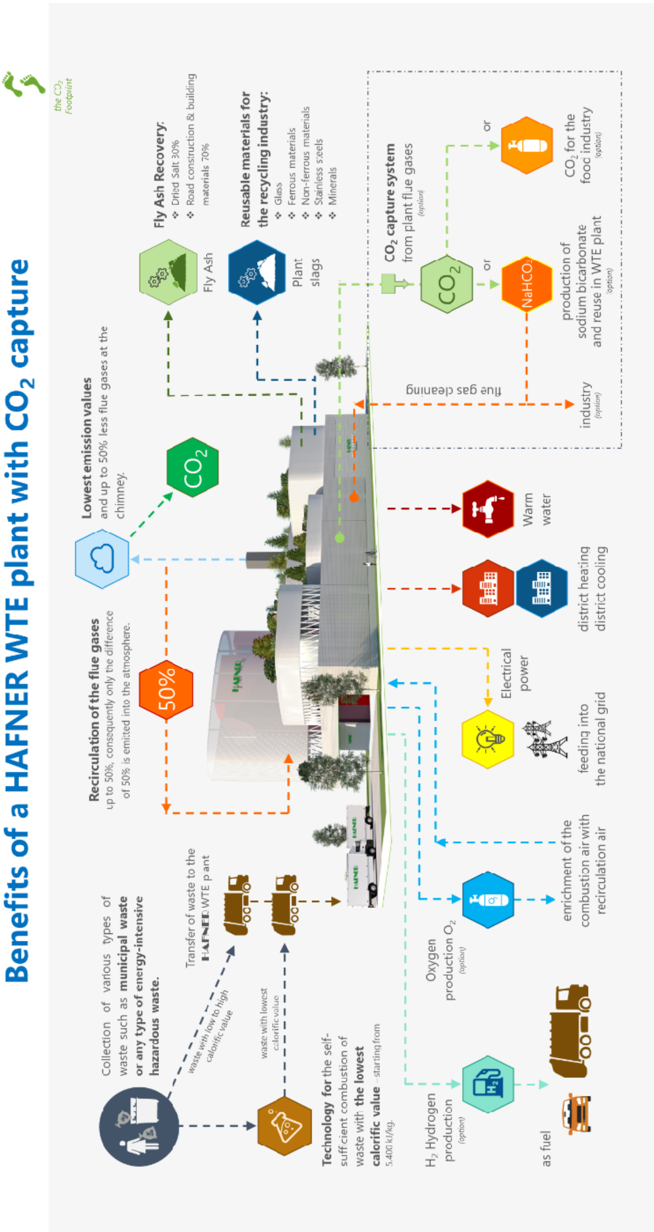
Waste as an energy source can be obtained locally, reducing dependence on imported fossil fuels. This promotes energy independence and security.

The conversion of waste into energy can also offer economic benefits by helping to reduce waste disposal costs while providing a continuous source of energy.

In the long run, utilizing waste for energy generation provides a more sustainable alternative to fossil fuels, maximizing resource utilization and contributing to the circular economy.

Technologies for converting waste into energy are often capital-intensive and require advanced techniques that need further development and optimization.

Public acceptance plays a critical role in the implementation of waste-to-energy projects. Political support and clear legal regulations are also crucial.



WTE with 100% circular economy

7. Could Waste to Energy be a partial Solution for Global Waste Management?

Waste incineration, also known as thermal waste treatment, plays a significant role in global waste management, particularly as a method to reduce the amount of waste ending up in landfills and for energy generation. By significantly reducing the volume and weight of waste, less landfill space is required, which is especially beneficial in densely populated or geographically constrained areas. Waste incineration enables the conversion of waste into energy. This energy can be utilized in the form of electricity or district heating, contributing to a reduction in dependency on fossil fuels. Burning waste avoids potential methane emissions that would occur from the decomposition of organic material in landfills. Methane is a much stronger greenhouse gas than CO_2. Modern Waste to Energy plants can recover metals and other materials from the combustion ash, which can then be recycled and reused.

To establish Waste to Energy as a sustainable solution in global waste management, it is necessary to continuously develop the technologies and further minimize emissions. At the same time, education and awareness about the benefits and safety measures of Waste to Energy plants should be improved to enhance public acceptance. An integrated waste management approach, incorporating recycling, waste prevention, and waste incineration, can contribute to a more sustainable and environmentally friendly future in the long term.

7.1 Waste Incineration - Greenhouse Effect and Global Warming

Carbon dioxide (CO_2) is a greenhouse gas naturally present in the atmosphere, contributing significantly to the greenhouse effect necessary to maintain a suitable temperature for life on Earth.

However, the massive increase in CO_2 concentrations in the atmosphere, mainly due to human activities such as fossil fuel combustion, deforestation, and industrial processes, has led to an intensification of the greenhouse effect. This results in global warming, causing extreme weather events, rising sea levels, and various ecological and social problems.

The combustion of fossil fuels for energy and industry is the largest single emitter of CO_2. In 2019, about 89% of global CO_2 emissions came from fossil fuel combustion and industrial processes. Waste to Energy plants also contribute to these emissions, especially through the combustion of carbon-containing materials in waste.

Waste to Energy plants produce significant amounts of CO_2, especially when the incinerated waste is rich in organic, carbon-containing materials. The specific CO_2 emission depends on the composition of the waste and the efficiency of the incineration plant. Organic waste produces more CO_2, while inert or mineral components such as glass and metal reduce the calorific value of the waste and can affect the efficiency of energy recovery.

The amount of CO_2 produced when burning 1 kg of waste depends on various factors, including the waste composition and the efficiency of the incineration plant. Calculating CO_2 emissions from Waste to Energy plants is complex but can provide a general estimate based on common average values.

The chemical combustion reaction for carbon-containing materials can be simplified as $C + O_2 \rightarrow CO_2$, where each mole of carbon reacts with one mole of oxygen to produce one mole of carbon dioxide. The calorific value of the waste indicates how much energy is released when burning a certain amount of waste (typically per kg).

Assuming the waste consists of a mixture of different materials, it is estimated that burning 1 kg of mixed municipal waste produces approximately 1 kg of CO_2. This estimate considers the calorific value and typical composition of the waste.

For a more accurate calculation, we use the calorific value and carbon content:

- **calorific value: 10 MJ/kg (average for mixed waste),**
- **carbon content: assuming 27 % carbon in the waste,**
- **molecular weight of carbon (C) to carbon dioxide (CO_2): the molecular weight of C is 12 g/mol and of CO_2 is 44 g/mol. The conversion from C to CO_2 corresponds to a mass increase by a factor of 44:12 = 3.67.**

  So, 0.27 kg of carbon x 3.67 = 0.9919 kg of CO_2.

  Therefore, burning 1 kg of mixed municipal waste produces approximately 1 kg of CO_2. This calculation serves as a simplified estimate. Actual emissions may vary depending on the specific composition of the waste and the incineration technology.

How much household waste will be produced worldwide by 2030?

According to the World Bank report "What a Waste 2.0" from 2018, global waste production is expected to increase from **2.01 billion tons in 2016 to**

about 3.40 billion tons by 2050.

For 2030, we can estimate an interim figure based on the growth rates mentioned in this report and other studies.

- **2016: 2.01 billion tons**
- **2030 (estimated): approximately 2.59 billion ton**

These numbers illustrate a rapid increase in waste production, primarily driven by population growth, increasing urbanization, and rising consumption in developing countries.

The world's population is expected to increase from about 8.0 billion in 2024 **to over 8.5 billion people by 2030**. An increase in population leads to more consumers, which in turn results in more waste. The increasing shift of the population to urban areas leads to a densification of consumption and waste production in cities. **Cities are estimated to produce about 65% of global waste by 2030**. With economic development, consumption of goods and packaging also increases, directly leading to higher waste volumes. The amount of household waste produced varies significantly between different regions and stages of development. Countries like the USA, Canada, and members of the European Union tend to have higher per capita waste production rates due to higher consumption and more intensive use of disposable products. While the absolute amount of waste in developing countries is increasing, per capita production often remains lower than in developed countries. However, this is where the largest growth is expected, especially in rapidly growing urban centres in Asia and Africa. Given the increasing amounts of waste, countries worldwide face the challenge of developing effective waste management and recycling systems. Reducing waste production and promoting recycling are not only important for minimizing environmental impacts but also for ensuring the sustainability of urban infrastructures and global ecosystems.

Estimates suggest that worldwide by 2030, approximately 2.59 billion tons of household waste could be allocated to the following waste streams:

- **15% of it goes to Waste to Energy (388,500,000.00 tons per year),**
- **30% of it is recycled (777,000,000.00 tons per year),**
- **55% of it is disposed of or illegally dumped (1,424,500,000.00 tons per year);**

7.2 CO_2 capture Technologies and their Application in Waste to Energy plants.

Given the urgent need to reduce global CO_2 emissions to achieve the goals of the Paris Agreement and limit global warming, the development and implementation of CO_2 capture technologies are critical.
Waste to Energy plants offer significant potential for the application of these technologies due to their high CO_2 emissions and continuous waste input.

CO_2 capture in Waste to Energy plants is a crucial approach to reducing greenhouse gas emissions. The various technologies used for CO_2 capture in these plants will be examined hereafter, along with examples of where these technologies have been implemented.

7.2.1 Overview of CO_2 Capture Systems on the Market

7.2.1.1 Amine Scrubbing

Amine scrubbing is the most widely used technology for CO_2 capture, employing aqueous solutions of amines (typically monoethanolamine - MEA) to chemically bind CO_2 from post-combustion flue gases. Flue gases are passed through an absorber where an amine solvent is sprayed. CO_2 reacts with the amine and is removed from the gas stream.

The CO_2-laden amine is heated in a desorber, releasing the CO_2 and regenerating the amine.

The captured CO_2 is then compressed and either stored or utilized.

Advantages: High CO_2 capture efficiency, established mature technology.

Disadvantages: High energy requirement for desorption; corrosiveness and toxicity of amines can pose material and environmental issues.

Example Applications: Klemetsrud plant in Oslo, Norway, implemented the technology to capture up to 400,000 tons of CO_2 annually.

7.2.1.2 Calcium Looping

In calcium looping, CaO serves as a sorbent to bind CO_2 in a carbonator, forming $CaCO_3$. The $CaCO_3$ is then heated in a calcinator to regenerate CO_2 and recycle CaO.

Carbonation from CaO reacts with CO_2 at approximately 650°C to form $CaCO_3$.

Calcination at around 900°C, $CaCO_3$ decomposes into CaO and CO_2.

Recycling the regenerated CaO is returned to the carbonator.

Advantages: There is a potentially lower energy costs compared to amine scrubbing, utilization of inexpensive raw materials.

Disadvantages: High energy requirement for calcination, material wear and tear over time.

Example Applications: la Pereda power plant in Spain conducted a pilot project to demonstrate the feasibility of the calcium looping process.

7.2.1.3 Membrane Processes

Membrane technologies use semipermeable membranes to separate CO_2 from flue gases. These membranes can be selectively permeable to CO_2, enabling direct capture from the gas stream.

Advantages: lower energy requirement compared to chemical absorption processes, modularity and scalability.

Disadvantages: Challenges with membrane lifespan and efficiency, high initial investments.

Example Applications: Hitachi Zosen Corporation in Japan has been developing and testing membrane technologies for CO_2 capture in Waste to Energy plants.

7.2.1.4 Oxy-Fuel Combustion

Oxy-fuel combustion involves burning waste in pure oxygen, resulting in a flue gas rich in CO_2. Condensation of water vapor leaves behind a highly concentrated CO_2 stream.

Advantages: Produces a pure CO_2 stream that is easier to handle, reduces volume and complexity of post-treatment.

Disadvantages: High costs for oxygen production, increased requirements for combustion technology.

Example Applications: Vattenfall AB's pilot plant in Sweden demonstrated oxy-fuel combustion for efficient CO_2 capture.

7.2.1.5 Bicarbonate production

The process of capturing CO_2 from flue gases using sodium carbonate (Na_2CO_3) and converting it into sodium bicarbonate ($NaHCO_3$) in a Waste to Energy plant is designed as follows:

After dry flue gas cleaning using bag filters and the addition of additives (sodium bicarbonate), the cleaned flue gas is cooled from 200 degrees to 50 degrees using a heat exchanger, which increases the efficiency of subsequent reaction processes. These steps are important to minimize corrosion in the subsequent processes and ensure the purity of the end product.

The cleaned flue gas enters the absorber, where an aqueous solution of sodium hydroxide (NaOH) circulates. CO_2 reacts with NaOH to form sodium carbonate ($Na2CO_3$). This reaction occurs at relatively low temperatures (typically below 50°C) to maximize energy efficiency and increase the solubility of CO_2 in water.

The sodium carbonate solution is pumped from the absorber into a second reactor. Additional CO_2 is introduced into this reactor, where it reacts with the sodium carbonate to form sodium bicarbonate.

The solution, now containing sodium bicarbonate, is cooled to promote the crystallization of sodium bicarbonate. The crystals are collected in a centrifuge or filtration process and then dried.

Example Applications: Hafner Energy from Waste Ltd. – Pilot Research WTE-Plant, South Tyrol - Italy.

Research of bicarbonate production for CO_2 Capture in Waste to Energy plants:

These examples illustrate how different technologies for CO_2 capture can be applied in Waste to Energy plants. We demonstrate the variety of approaches and the specific challenges and solutions associated with each technology. The choice of technology often depends on the specific conditions of the plant and regional environmental regulations. While some countries and companies rely directly on proven technologies like amine washing, others are experimenting with newer approaches such as calcium looping or membrane processes to further improve efficiency and reduce costs.

Reactivity and Physical Properties of CO_2:

Fundamentals of CO_2 Capture:

Understanding the binding behaviour, reactivity, and physical properties of carbon dioxide (CO_2) is crucial for its capture and handling in Waste to Energy plants. CO_2 is produced by the combustion of carbon-containing materials (such as household waste) and possesses specific chemical and physical properties that influence its treatment and the choice of capture technology.

Here is a detailed overview of these aspects:

Molecular Structure CO_2 is a linear molecule with the molecular formula O=C=O. The two carbon-oxygen bonds are double bonds, formed through the overlap of sp-hybrid orbitals of carbon with p-orbitals of oxygen.

Bonding each C=O bond consists of a sigma (σ) and a pi (π) bond. The σ-bond is formed by the overlap of sp-hybrid orbitals of carbon with p-orbitals of oxygen, while the π-bond results from the lateral overlap of p-orbitals.

Polarity - Although the C=O bonds are polar (oxygen is more electronegative than carbon), the CO_2 molecule is overall non-polar because it is linear, and the dipole moments cancel each other out.

Reactivity - CO_2 is a relatively inert molecule that does not easily react with other substances.

However, its reactivity can be increased under certain conditions or in the presence of catalysts.

Solubility in Water - CO_2 partially dissolves in water, forming carbonic acid (H2CO_3), which can further dissociate into bicarbonate (HCO_3-) and Catalytic Conversion under the influence of catalysts, CO_2 can be converted into useful chemicals, as demonstrated by the Sabatier reaction, where CO_2 is reduced to methane.

Physical Properties - At standard conditions, CO_2 is a colourless, odourless gas. It is heavier than air with a density of about 1.98 kg/m^3 at 0°C and 1 atm. CO_2 is soluble in water, although its solubility decreases with increasing temperature. CO_2 sublimates at normal pressure at -78.5°C, meaning it transitions directly from a solid to a gaseous state.

Understanding the chemical and physical properties of CO_2 is essential for selecting and optimizing CO_2 capture technologies in Waste to Energy plants. Effective capture methods can not only reduce environmental pollution from greenhouse gases but also pave the way for the utilization of CO_2 as a resource in various industrial processes.

7.3 Economic Aspects of CO_2 Capture

7.3.1 Amine Scrubbing

Capital expenditures (Capex) for a CO_2 capture process using amine scrubbing can vary, depending on several factors such as plant size, location, specific technology, and environmental conditions. The size of the facility and the amount of CO_2 to be treated play a crucial role in determining costs. Larger facilities require higher initial investments but can be more cost-effective due to economies of scale. The specific amine scrubbing technology and the quality of materials used also impact costs. High-quality materials can enhance the longevity and efficiency of the facility but also increase initial investments.

Local conditions such as climate, availability of infrastructure and labour, as well as regulatory requirements, can also influence costs. Locations requiring special adaptations or additional environmental protection measures can be more expensive. While not directly part of capital expenditures, operating expenses (Opex) are a significant aspect of budgeting for a CO_2 capture facility. These include energy consumption, maintenance, and the cost of the amine solvent itself.

In general, capital expenditures for smaller CO_2 capture facilities can be in the order of a few million euros, while larger facilities that handle industrial amounts of CO_2 can range from several tens of millions to over a hundred million euros.

7.3.2 Calcium Looping Process

The calcium looping process for CO_2 capture is an advanced technology that uses calcium oxide (CaO) to bind CO_2 from process gases, such as those from power plants or industrial facilities. This process typically involves two main reactors: a carbonator, where CO_2 is bound to CaO to form calcium carbonate ($CaCO_3$), and a calcinator, where the formed $CaCO_3$ is decomposed back into CaO and CO_2. The released CO_2 can then be collected and either stored or utilized.

Capital Expenditures (Capex) for a calcium looping process depend on several factors. Similar to other CO_2 capture technologies, the capacity of the facility plays a crucial role in determining costs. Larger facilities are more expensive to construct but can be more efficient in operation.

Calcium looping is technologically more demanding than some conventional capture methods. The costs for advanced materials, reactors, and the need to handle high temperatures increase capital expenditures. Local factors such as infrastructure, availability of labour and materials, local construction regulations, and environmental regulations also affect costs.

Integrating calcium looping into existing power plants or industrial facilities can pose additional challenges and costs, as existing systems may need extensive modifications.

Since calcium looping is not as widely implemented as other technologies, the costs can be higher due to less available data and potentially higher risks in initial projects.

Overall, the estimated capital expenditures for calcium looping facilities range from mid to high tens of millions of euros and can exceed one hundred million euros for very large facilities. Specific costs vary greatly depending on the aforementioned factors and the current state of the technology.

7.3.3 Oxy-Fuel Combustion

One of the major challenges and cost factors in Oxy-Fuel technologies is the need to produce large quantities of oxygen, typically done using air separation units. These facilities are energy-intensive and expensive to acquire and operate.

Existing combustion facilities often require extensive modifications to be suitable for Oxy-Fuel combustion. This includes changes in the combustion chamber, adjustments to the flue gas paths, and installations of specialized cooling systems.

CO_2 Handling and Storage after capture, the CO_2 must be compressed, transported, and stored or utilized. The costs for these processes also need to be considered. The capital costs for Oxy-Fuel combustion systems can range from tens of millions of euros for smaller plants to several hundred million euros for large power plants. The exact costs depend on the plant's capacity and the specific requirements of the project.

Smaller facilities might cost in the range of 50 to 100 million euros, especially if used for research purposes or in smaller industrial settings. Larger power plants or industrial facilities that require full integration of Oxy-Fuel combustion can range from 200 million euros to over 500 million euros, depending on the size of the facility and local conditions.

7.3.4 Bicarbonate CO_2 Capture

Capital expenditures (Capex) for CO_2 capture processes aimed at producing sodium bicarbonate ($NaHCO_3$) depend on the size and technological approach of the facility. This process typically converts captured CO_2 by reacting it with sodium hydroxide (NaOH) to form sodium bicarbonate, a process also known as mineralization. The need for sodium hydroxide and the costs of its procurement are significant cost drivers. Sodium hydroxide must be available in sufficient quantity and purity to efficiently react with CO_2.

In terms of technological infrastructure, facilities for CO_2 capture and bicarbonate production need to be specifically designed and constructed. This includes reactors, control systems, and filtration units to separate the sodium bicarbonate from other by-products.

Capital expenditures increase with the scaling of the facility. Larger plants capable of processing large amounts of CO_2 require bigger initial investments. The capital costs for facilities producing sodium bicarbonate from CO_2 vary widely but can range from tens of millions of euros to over a hundred million euros for medium to large-scale plants. Specific costs depend on the plant size, the technology used, and the geographical location. Pilot plants might require investments of 10 to 30 million euros, depending on the technology and scale. Commercial plants could cost from 50 million euros to over 200 million euros, depending on the capacity and complexity of the required infrastructure.

Additionally, captured CO_2 from the flue gas of a Waste to Energy plant can indeed be converted into e-Fuel, a synthetic fuel. This process is part of a technology known as "Power-to-X," where CO_2 is combined with hydrogen, produced through the electrolysis of water using renewable energy, to be transformed into liquid or gaseous fuels.

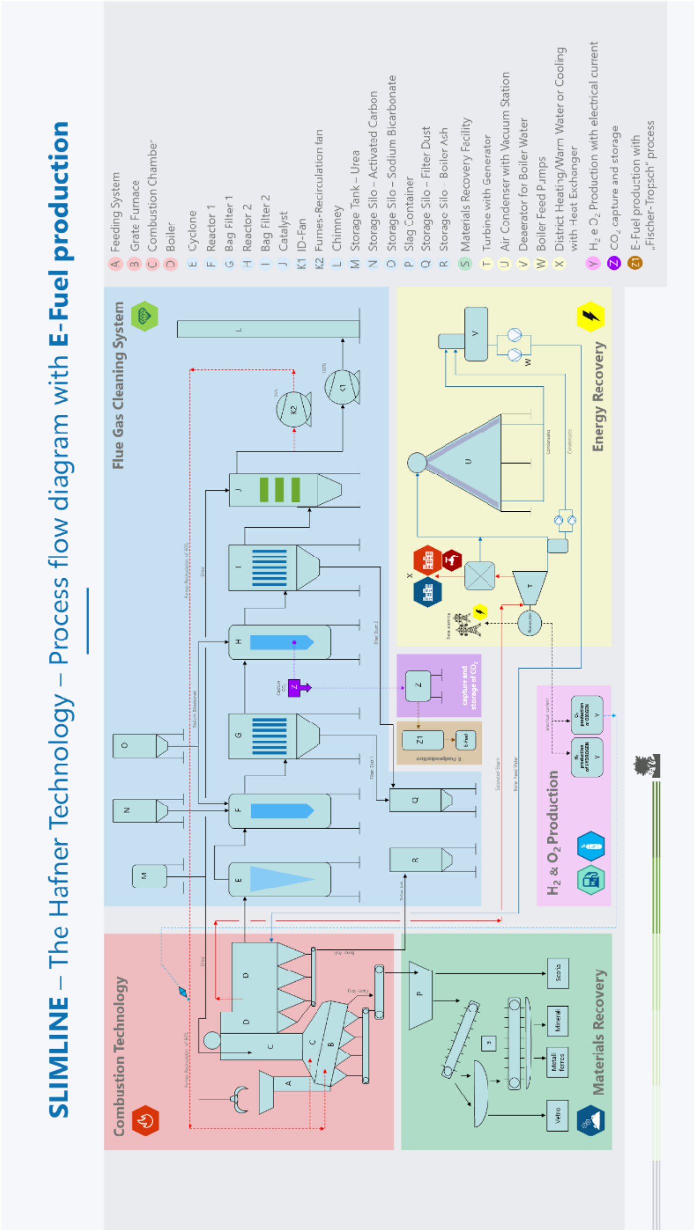
7.3.5 E-Fuel Production from CO_2

CO_2 can be efficiently captured from the flue gases of Waste to Energy plants using various technologies such as amine scrubbing, membrane filtration, or adsorption. In parallel, hydrogen is produced through electrolysis using the electricity generated by the Waste to Energy plant. The captured CO_2 is then combined with the produced hydrogen in a synthesis process, typically through Fischer-Tropsch synthesis or methanol synthesis, depending on the desired end product. The Fischer-Tropsch synthesis produces liquid hydrocarbons that can be further processed into gasoline, diesel, or kerosene. Methanol synthesis results in methanol, which can be used as a fuel or as a raw material for other chemical products.

The energy required to produce e-Fuel is intensive, especially the hydrogen production step through electrolysis. The costs for e-Fuels are currently higher than for conventional fossil fuels, primarily due to high operating costs and the need for scaling up the technology.

The overall efficiency of the process from energy input to finished fuel is comparatively low, which can affect the environmental balance. Although the production of e-Fuel from CO_2 is technically feasible and has the potential to reduce greenhouse gas emissions, further developments in efficiency improvement and cost reduction are necessary to make this technology economically and environmentally viable.

However, in the coming years, this could play an increasingly important role in the circular economy and in the decarbonization of the transport sector.



Flow chart with e-fuel production

Waste treatment with CO_2 capture and E-Fuel production

7.4 Environmental Technical Assessment - Analysis of the Ecological Impacts of CO_2 Capture

The analysis of the ecological impacts of CO_2 capture, especially in Waste to Energy facilities, involves a variety of factors, from direct emissions and energy consumption to indirect effects such as material usage and long-term environmental impacts. This section provides a comprehensive overview of the environmental impacts of various CO_2 capture technologies, including amine scrubbing, calcium looping, membrane processes, oxy-fuel combustion, and sodium bicarbonate conversion.

7.4.1 Environmental Impact of Amine Scrubbing

Amine scrubbing requires significant amounts of energy, particularly for the desorption in the solvent regeneration process, which constitutes the majority of the energy consumption. Volatile organic compounds, including the amines themselves, can be emitted into the atmosphere, leading to environmental and health issues. The high energy consumption results in indirect CO_2 emissions at locations where fossil fuels are used for energy production. There is a high-water demand for the solvents and their regeneration. Pollution from amine degradation products, which can be potentially toxic, requires specialized wastewater treatment.

7.4.2 Environmental Impact of Calcium Looping

The calcination process requires high temperatures (around 900°C), which are typically achieved by burning fossil fuels, although the use of waste heat is also possible. CO_2 emissions result from fuels used for the calcination process if not operated renewably. Dust and particulate emissions arise from handling solid raw materials (limestone, CaO, $CaCO_3$). There is a high consumption of limestone, which must be regularly replaced. Wear and tear on reactor materials limit the lifespan of plant components and lead to construction waste.

7.4.3 Environmental Impact of Membrane Processes

The energy consumption of membrane processes is relatively low compared to chemical absorption processes, as no thermal regeneration processes are required. The direct emissions are minimal, depending on the energy source used to operate the facility. Spent membranes may constitute hazardous waste, particularly if they have been treated with toxic substances. The material consumption depends on specialized polymers or inorganic materials for the membranes, whose production can be environmentally damaging.

7.4.4 Environmental Impact of Oxy-Fuel Combustion

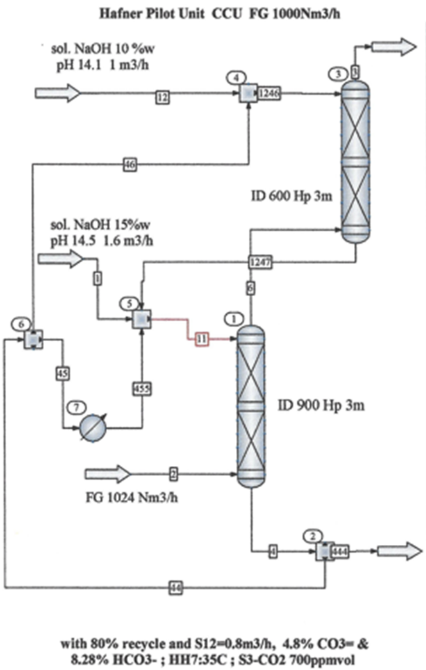
The energy consumption is very high since pure oxygen must be produced, typically through energy-intensive air separation plants. High CO_2 concentrations in the exhaust gases can be more easily captured; however, initially, this leads to an increase in overall emissions if the energy for oxygen production comes from fossil sources. Each CO_2 capture technology has specific environmental impacts that need to be considered. While technologies like membrane processes and oxy-fuel combustion offer advantages regarding certain types of emissions, they can be problematic in other areas, such as energy consumption. A comprehensive assessment that considers local conditions and the availability of renewable energy sources is crucial. In the long term, technological advancements and improved infrastructure for renewable energies could help minimize the environmental impacts of these technologies.

7.4.5 Environmental Impact of the Sodium Bicarbonate Process

Sodium bicarbonate is a versatile product used in the food industry, medicine, and as a cleaning agent. Converting CO_2 into sodium bicarbonate can not only contribute to emission reduction but also generate economic benefits by producing a marketable product.

The efficiency of the process heavily depends on the energy required. Transforming CO_2 into sodium bicarbonate demands energy, particularly for reaction heat and possibly for maintaining the process temperature. The energy balance of the entire procedure must be calculated to ensure that the process leads to a net reduction in environmental impacts overall.

Using sodium carbonate for CO_2 capture and conversion into sodium bicarbonate is a promising approach to reducing CO_2 emissions. However, a careful analysis of the entire ecological impact is necessary to ensure that the process maintains a positive environmental balance. The economic costs and energy requirements are also crucial factors that must be considered to assess the sustainability and feasibility of this method.



Stream No.	1	2	3	4	6	11	12	44
Name								
- - Overall - -								
Temp C	40.0000	50.0000	54.8798	46.0410	43.0570	41.2004	40.0000	46.0410
Pres bar	1.1000	1.0600	1.0100	1.0230	1.0130	1.1000	1.1000	1.0230
Enth kcal/h	-6.7786E+006	-9.6882E+005	-3.2370E+005	-5.7964E+007	-3.4324E+005	-5.7339E+007	-4.0460E+006	-4.6371E+007
Vapor mole fractio	0.0000	1.000	1.000	0.0000	1.000	0.0000	0.0000	0.0000
Molar flow kmol/h	102.1242	45.6795	38.9504	811.0756	38.0678	808.6467	60.4546	648.8605
Mass flow kg/h	1867.5543	1344.0000	1037.9724	16368.0439	1070.4270	16094.4404	1100.0000	13094.4355
Std liq m3/h	1.6000	3.4490	3.0725	14.0464	3.1234	13.7192	0.9871	11.2371
Std vap 0 C m3/h	2288.9756	1023.8437	873.0198	18179.1621	853.2386	18124.7207	1355.0072	14543.3311
- - Liquid only - -								
Actual vol m3/h	1.6107			14.1701		13.8144	0.9938	11.3361
pH value	14.5347			8.1277		8.6197	14.1350	8.1277
Flow rates in kg/h								
Carbon Dioxide	0.0000	314.0689	1.2143	3.1969	83.0719	0.3557	0.0000	2.5575
Nitrogen	0.0000	906.6133	906.5828	0.1523	906.5931	0.1321	0.0000	0.1218
Water	1587.4187	95.9056	102.7648	13092.5029	53.3511	13143.2979	990.0000	10474.0000
Oxygen	0.0000	27.4122	27.4104	0.0090	27.4110	0.0078	0.0000	0.0072
Sodium Hydroxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sodium Carbonate	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H+	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
OH-	119.1172	0.0000	0.0000	0.0045	0.0000	0.0209	46.7739	0.0036
CO3--	0.0000	0.0000	0.0000	798.0568	0.0000	1109.1010	0.0000	638.4454
HCO3-	0.0000	0.0000	0.0000	1352.8950	0.0000	720.2984	0.0000	1082.3160
Na+	161.0183	0.0000	0.0000	1121.2279	0.0000	1121.2279	63.2272	896.9823
Component mole f								
Carbon Dioxide	0.000000	0.156226	0.000708	0.000090	0.049584	0.000010	0.000000	0.000090
Nitrogen	0.000000	0.708477	0.830846	0.000007	0.850118	0.000006	0.000000	0.000007
Water	0.862837	0.116544	0.146453	0.896039	0.077795	0.902218	0.909016	0.896039
Oxygen	0.000000	0.018754	0.021992	0.000000	0.022502	0.000000	0.000000	0.000000
Sodium Hydroxide	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sodium Carbonate	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
H+	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
OH-	0.068582	0.000000	0.000000	0.000000	0.000000	0.000002	0.045492	0.000000
CO3--	0.000000	0.000000	0.000000	0.016397	0.000000	0.022856	0.000000	0.016397
HCO3-	0.000000	0.000000	0.000000	0.027337	0.000000	0.014598	0.000000	0.027337
Na+	0.068582	0.000000	0.000000	0.060130	0.000000	0.060311	0.045492	0.060130
Component mass f								
Carbon Dioxide	0.000000	0.233682	0.001170	0.000195	0.077606	0.000022	0.000000	0.000195
Nitrogen	0.000000	0.674563	0.873417	0.000009	0.846945	0.000008	0.000000	0.000009
Water	0.849999	0.071358	0.099005	0.799882	0.049841	0.816636	0.899999	0.799882
Oxygen	0.000000	0.020396	0.026408	0.000001	0.025608	0.000000	0.000000	0.000001
Sodium Hydroxide	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sodium Carbonate	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
H+	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
OH-	0.063782	0.000000	0.000000	0.000000	0.000000	0.000001	0.042522	0.000000
CO3--	0.000000	0.000000	0.000000	0.048757	0.000000	0.068912	0.000000	0.048757
HCO3-	0.000000	0.000000	0.000000	0.082655	0.000000	0.044754	0.000000	0.082655
Na+	0.086219	0.000000	0.000000	0.068501	0.000000	0.069666	0.057479	0.068501

Scheme of a Hafner Pilot Bicarbonate Calculation

7.5 How is CO_2 actually generated in a Waste to Energy Plant?

The combustion process of waste, especially when burning organic materials such as wood, paper, food scraps, and other biogenic substances, can be simplified as a chemical reaction where carbon (C) in the materials reacts with oxygen (O_2) from the air to form carbon dioxide (CO_2).

The exact composition of the waste determines the specific reaction equations, as waste typically comprises a complex mixture of various materials with different chemical compositions. Initially, the moisture in the waste is evaporated by the heat, drying the waste. This usually occurs in the first combustion grate area. Here, the combustion air can also be preheated to 200 degrees Celsius.

As heating continues, the dry materials begin to decompose, and volatile gases are released.

This process occurs in the absence of oxygen and produces carbon monoxide (CO), hydrogen (H_2), and other hydrocarbons.

The released gases react with oxygen in an exothermic reaction that generates heat, mainly producing carbon dioxide (CO_2) and water (H_2O).

Part of the solid material is converted to ash, while the remainder continues to gasify, releasing further gases that can also burn.

The basic reaction equation for the combustion of pure carbon (as found in coal or charcoal) to carbon dioxide is:

$$C + O_2 = CO_2$$

In practice, however, waste contains a mixture of many different chemical compounds, including carbohydrates, fats, proteins, and other organic and inorganic materials. **A simplified equation for the combustion of**

carbohydrates (for example, cellulose commonly found in paper and wood) might look like this:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

This equation demonstrates the oxidation of glucose, a simple carbohydrate, used as a model for more complex biomass.

Insufficient oxygen supply can lead to incomplete combustion, where carbon monoxide (CO) and other incompletely oxidized products are produced alongside CO_2. The carbon content and type of organic materials in the waste influence the amount of CO_2 produced. Higher temperatures promote more complete combustion and more efficient energy generation.

The entire combustion process must be carefully controlled to minimize pollutant emissions and maximize energy efficiency while complying with environmental regulations. Today, AI-driven fire performance controls are used.

Capturing CO_2 from flue gases and converting it into sodium bicarbonate ($NaHCO_3$) is an innovative approach that reduces greenhouse gas emissions and generates a valuable product. This process offers an environmentally friendly way to effectively utilize CO_2 from flue gases while producing a valuable product.

The technical implementation (currently in the trial phase) requires careful planning, appropriate technological infrastructure, and efficient chemical processes to be economically viable and ecologically sustainable.

While the initial investment and ongoing operating costs are significant, the production of sodium bicarbonate offers not only financial benefits but also environmental advantages by reducing greenhouse gas emissions.

The conversion of CO_2 from flue gases into sodium bicarbonate offers several ecological benefits that affect both the direct impact on the local environment and global efforts for climate protection.

Here are the key ecological benefits of this process:

7.5.1 Reduction of Greenhouse Gas Emissions

CO_2 capture involves chemically converting CO_2 into sodium bicarbonate, thereby removing this greenhouse gas from flue gases before it can escape into the atmosphere. This directly contributes to reducing CO_2 emissions, which are responsible for global warming.

Long-term Sequestration of CO_2 Sodium bicarbonate is a stable carbon product, meaning that the bound CO_2 does not easily return to the atmosphere. The use of sodium bicarbonate in products such as baking soda or in industrial applications keeps the CO_2 sequestered over long periods.

7.5.2 Promoting the Circular Economy

Transforming a waste product (CO_2) into a useful product (sodium bicarbonate) exemplifies a circular economy practice aimed at maximizing material use and minimizing waste. Waste to Energy plants produce not only CO_2 but also heat and ash. Integrating CO_2 conversion can be part of a broader approach where all by-products of combustion are utilized (e.g., using incineration ash in the construction industry).

7.5.3 Protecting Human Health and the Environment

Cleaning flue gases and reducing air pollutants improve air quality, which has direct benefits for human health, such as reducing respiratory diseases and other health issues.

7.5.4 Positive Climate Impacts

Each ton of CO_2 that is captured and converted through such technological processes contributes to achieving international climate protection goals, as outlined in the Paris Agreement. The capture and conversion of CO_2 from Waste to Energy plants into sodium bicarbonate offers significant ecological benefits by not only helping to reduce greenhouse gas emissions but also improving air quality and promoting the principles of the circular economy. These technologies represent a crucial step forward in the effort to make industrial processes more sustainable and minimize the environmental impacts of human activities. However, these approaches require initial investments and commitment from the industry to be technologically implemented and economically operated.

7.6 Economic Viability of CO_2 to Sodium Bicarbonate Conversion

The economic viability of converting CO_2 to sodium bicarbonate, especially in the context of CO_2 taxes and the Emissions Trading System (ETS), is a crucial factor in determining whether this technology will be widely adopted. The EU Emissions Trading System (ETS) is the European Union's primary tool for regulating greenhouse gas emissions by setting caps on total emissions and facilitating the trade of emission certificates. The economic feasibility of this technology depends on various factors, including the costs of implementation and operation, market prices for CO_2 certificates and sodium bicarbonate, and specific regulatory requirements.

7.6.1 Revenue from Product Sales

Market Price of Sodium Bicarbonate can vary, but sodium bicarbonate is a widely used product that is subject to stable and potentially lucrative market conditions. Sodium bicarbonate is utilized across numerous industries, including food processing, pharmaceuticals, cleaning products, and more, providing multiple sources of revenue.

7.6.2 Costs for Technology and Operation

Setting up absorption and processing facilities can incur significant capital expenses. These include energy costs, costs for raw materials (such as NaOH), maintenance of the facilities, and expenses related to the handling and disposal of by-products.

7.6.3 CO_2 Tax and Emission Certificates

Savings from Avoided CO_2 Emissions: Companies subject to the ETS (Emissions Trading System) must present emission certificates for each ton of CO_2 they emit.
By reducing CO_2 emissions through this technology, companies can save or sell emission certificates.

Current Price for CO_2 Certificates: The prices for emission rights have risen in recent years, enhancing the economic viability of CO_2 capture. In 2021, the price per ton of CO_2 occasionally exceeded 50 euros. Many governments offer financial incentives for technologies that reduce emissions, including grants, tax relief, or improved depreciation conditions. Stricter emission regulations can intensify the need for this technology and increase its economic appeal.

7.6.4 Economic Feasibility Calculation for Bicarbonate Production

Suppose a Waste to Energy plant emits 100,000 tons of CO_2 annually and implements a CO_2 capture and conversion system:

<u>Economic feasibility overview</u>

- **initial investments (CAPEX): € 30 million,**
- **annual operating costs (OPEX): € 3 million,**
- **lifespan of the facility: 20 years,**
- **revenue from reduction of CO_2 emissions: 90,000 tons per year,**
- **assumed price for emission certificates: € 50 per ton,**
- **savings from emission certificates per year: € 4.5 million (90,000 x 50),**
- **revenue from sale of sodium bicarbonate (ass.): € 2 million per year,**
- **total annual revenue: € 6.5 million.**

This example calculation demonstrates that the technology could potentially be profitable, especially under conditions of high CO_2 prices and favourable market conditions for sodium bicarbonate. However, the exact economic viability depends on local conditions, specific plant characteristics, and fluctuating market prices for emission rights. CO_2 capture and conversion to sodium bicarbonate can be economically sensible under the right circumstances, particularly in a regulatory framework that imposes high costs for emission certificates and financial incentives for emission-reducing technologies. Designing such systems to be not only ecologically desirable but also financially viable requires careful planning, efficient technology, and a clear strategic focus.

7.6.4.1 Sodium Carbonate Market Price Risk

The market price for sodium carbonate, also known as soda ash (chemical formula: $Na2CO_3$), can vary depending on market conditions, product purity, and purchase volume. Sodium carbonate is used in large quantities across various industries, including glass manufacturing, chemical production, detergents, and papermaking. Market Price (as of 2021/2022):

The price of sodium carbonate typically ranges between 150 and 300 euros per ton, depending on the quality and location of purchase. In some cases, and markets, the price may also fall outside this range. Technical grades are less expensive, while higher purity grades (e.g., for food or pharmaceutical applications) are more expensive. Transport Costs and Local Taxes: These can affect the price in different regions. Bulk buyers often receive discounts that can lower the unit price. Supply and demand heavily influence prices.

For instance, price fluctuations can occur due to production changes in major exporting countries like China or the USA.

7.7 Integration of CO_2 Capture Processes into Existing Waste to Energy plants and WTE Plants

For new and existing Waste to Energy plants that invest in CO_2 capture and conversion into sodium bicarbonate, securing long-term supply contracts for sodium carbonate is crucial to minimize price volatility and maximize cost efficiency. Additionally, local production of sodium carbonate, if technically and economically feasible, should be considered to shorten supply chains and reduce costs. It is important to note that if such investments are not made, waste delivery prices will need to be increased by 2028 to afford the necessary certificates (ETS). The cost of sodium carbonate is a significant factor in the economic analysis for projects that capture CO_2 from Waste to Energy plants and convert it into valuable products. Careful market analysis and strategic planning are required to ensure and optimize the financial feasibility of such initiatives. The current market price provides a starting point for these considerations, but individual factors such as contract terms, local taxes, and transportation costs must also be considered. To date, commercial processes for the direct capture of CO_2 from flue gases and its conversion into sodium bicarbonate ($NaHCO_3$) using sodium carbonate ($Na2CO_3$) are not widespread. However, there are related technologies and approaches either on the market or in advanced development stages that focus on the capture of CO_2 and conversion into various useful products.

8. Is it Possible to Achieve a 100% Circular Economy in Waste incineration?

A 100% circular economy in Waste to Energy aims to keep all waste materials in a closed loop in order to optimise the use of resources and minimise waste.

Here is a brief description of how this could be realised in practice:

In a fully circular waste management system, all waste is seen as a potential resource. The aim is to process waste materials in such a way that they can either be reused directly, recycled, or converted into energy. Waste incineration plays an important role here by enabling the thermal treatment of non-recyclable waste and utilising the energy generated in the process.

Non-recyclable residual waste is thermally treated in special Waste to Energy plants. The incineration process generates energy in the form of heat and electricity. This energy is then used to generate electricity or to heat buildings.

The ash and slag produced during incineration are processed and can be used as secondary raw materials in various industrial sectors such as construction.

The gases produced during incineration are purified using advanced filter technologies to minimise the emission of pollutants. The purified gases fulfil strict environmental standards.

A key aspect of the circular economy is the constant search for improvements to increase efficiency and reduce environmental impact. This includes technological innovation and the optimisation of logistics and waste treatment processes.

By maximising reuse, recycling and energy recovery, the amount of waste sent to landfill is drastically reduced.

Maximising the use of materials and energy contained in waste.

Reducing emissions and other negative environmental impacts through advanced technologies and processes.

A 100% circular economy in Waste to Energy thus creates a sustainable system in which waste is effectively used as a resource and its environmental impact is minimised.

This contributes significantly to sustainable development and environmental protection.

Slags from waste incineration, which is produced as incineration residue in Waste to Energy plants, can be recycled in various ways and reintroduced into the economic cycle.

This helps to reduce the volume of waste and conserve natural resources.

Here are some possible uses for slag:

- **Building materials:**

  Slags can be used as aggregates in the construction industry after appropriate processing and environmental compatibility checks.

  For example, **they are suitable for road construction** as a sub-base or filling material in road construction projects.

  Concrete production as an aggregate in concrete production, often as a substitute for natural aggregates.

  Production of bricks and other building materials - processing into building bricks or paving stones.

- **Landscaping:**

  Slag can also be used in landscaping, for example:

  Erosion control: Used as a material to reinforce embankments and banks.

  Soil preparation: In certain cases, slag can help to improve soil quality, for example by being used as a drainage layer.

- **Landfill cover:**

  Landfill reclamation: Slag can be used to cover and stabilise landfills, which reduces the generation of landfill gas and promotes landscape integration.

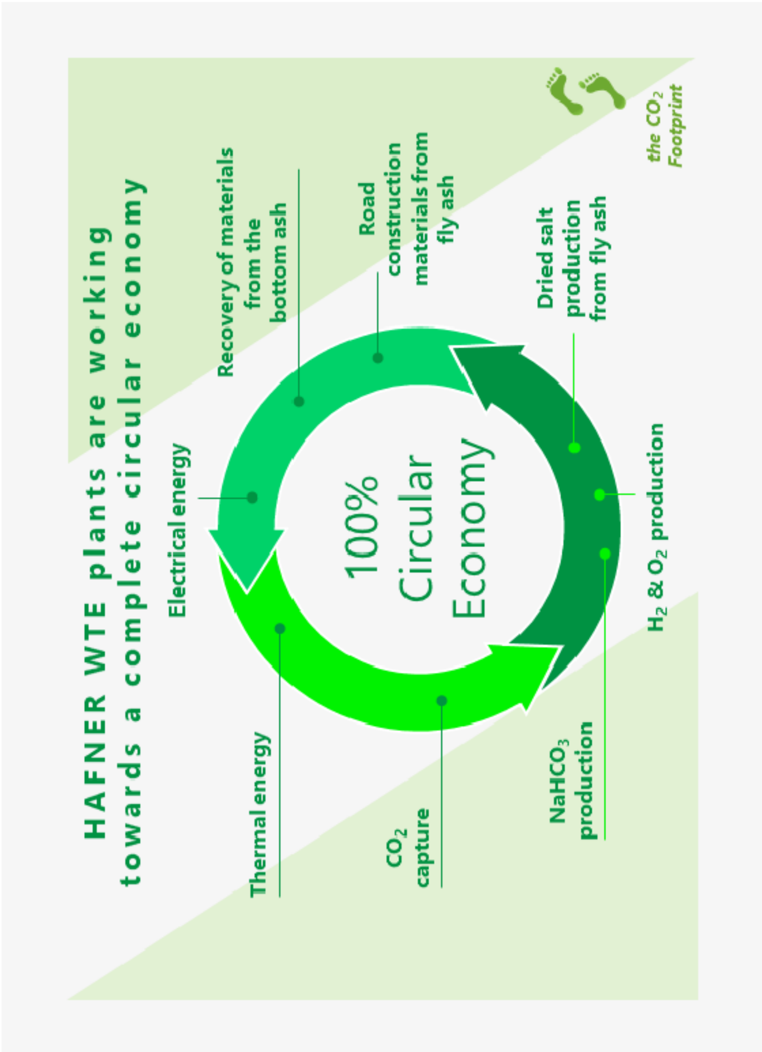
- **Recovery of metals:** metals that can still be used, such as iron, copper and aluminium, can be extracted from bottom ash and recycled.

Environmental aspects and precautionary measures - there are some important environmental aspects to consider when utilising slag as a secondary raw material:

- **Pollutant control:** Slags may contain heavy metals and other pollutants. Comprehensive analysis and treatment is required to ensure that the slag fulfils legal environmental standards.
- **Permanent stabilisation:** Environmental engineering measures to stabilise the pollutants in the slag are crucial to ensure long-term environmental compatibility.
- **Certification and quality control:** Products made from recycled bottom ash must be certified and regularly checked for their quality and environmental compatibility.

By effectively and responsibly reusing slag from waste incineration, valuable resources can be recovered, and the environmental impact of construction and landscaping projects can be reduced.

This contributes to the promotion of a sustainable circular economy.



9. National and International Funding Programs

Support and subsidization of CO_2 capture technologies and CO_2 reduction strategies in Waste to Energy plants are critical elements in improving the economic and technical feasibility of these projects. Both national governments and international organizations offer a range of funding programs aimed at supporting the research, development, and implementation of these technologies.

9.1.1 European Union

Horizon 2020 and Horizon Europe: These are funding programs that promote research and innovation across the EU, supporting projects in various fields, including clean energy and climate change. Specifically, they facilitate projects focused on developing CO_2 capture technologies and integrating them into existing industrial processes. Research institutes, companies, and sometimes public entities within the EU can benefit from these programs. They encourage the advancement of innovative low-carbon technologies. The funds support both large and small projects that reduce greenhouse gas emissions in industrial processes, including CCS projects. Companies of any size, particularly those with scalable and innovative technology solutions, are encouraged to apply.

9.1.2 United States

45Q Tax Credit: This tax credit incentivizes CCS (Carbon Capture and Storage) projects by offering a fixed amount per ton of CO_2 that is permanently stored or used for enhanced oil recovery. It is available to operators of CCS facilities that meet specific safety and permanence requirements for storage.

This support aids the development and demonstration of CCS technologies and their applications, providing funding, research resources, and technical support for CCS projects. Entities such as companies, research institutions, and sometimes states or municipalities can benefit.

9.1.3 United Kingdom

Support for CCS Infrastructure Development in the UK: With a budget of £1 billion, this fund aims to support several CCS projects and the associated infrastructure. It targets companies involved in the development or expansion of CCS projects in the UK.

9.1.4 International Funding Programs

Support for the implementation of low-emission technologies in developing and emerging countries is part of the Climate Investment Funds managed by several international development banks. The Clean Technology Fund (CTF) provides grants, loans, and other financial resources for projects that significantly reduce greenhouse gas emissions, often in partnership with private companies or international organizations. This accelerates the global application of CCS (Carbon Capture and Storage).

The Institute offers expertise, research resources, and financial support for CCS projects worldwide, involving states, companies, and non-governmental organizations that develop CCS projects.

The available funding and subsidies cover a wide range and are crucial for the development and implementation of CO_2 capture technologies. The exact eligibility and conditions may vary by program, and it is advisable for interested parties to carefully review the specific requirements and guidelines of each funding program. These financial supports play a significant role in overcoming the economic challenges of these environmentally friendly technologies and accelerating their adoption.

9.2 Political and Legal Frameworks

The regulations regarding when Waste to Energy plants must trade CO_2 certificates heavily depend on the legal requirements of the respective countries or regions that have implemented Emissions Trading Systems (ETS). Here, we primarily consider the European Union (EU), as it operates one of the most mature and comprehensive ETS globally, the EU ETS (European Union Emissions Trading System).

EU Emissions Trading System and Waste to Energy Plants:

Phase 1 (2005-2007) **and Phase 2** (2008-2012):

In the first two phases of the EU ETS, Waste to Energy plants were not fundamentally required to participate in the ETS. However, some facilities could voluntarily participate, especially if they exceeded certain thresholds for thermal capacity.

Phase 3 (2013-2020):

Starting from the third phase of the EU ETS in 2013, Waste to Energy plants were mandatorily included in the system if they met certain criteria.

<u>Thermal Capacity:</u> Waste to Energy plants with a thermal capacity of more than 20 megawatts (MWth) are required to participate in the EU ETS. This regulation aims to cover all larger facilities that emit significant amounts of CO_2.

The facilities must have certificates for all greenhouse gas emissions, not just CO_2, including those fully or partially powered by biomass, though emissions from biomass are usually exempt from certificates as they are considered carbon-neutral.

Phase 4 (2021-2030):

The fourth and current phase of the EU ETS, which began in 2021, continues the mandatory participation of Waste to Energy plants and tightens some of the rules.

Tightening of Caps: The caps on emissions are further lowered, increasing the pressure on all participating facilities to reduce their emissions.

Adjustment of Allocations: Free allocations are gradually reduced to set a stronger incentive for emission reduction.

Market Stability Reserve (MSR): Introduced in 2019, the MSR helps to regulate the supply of certificates in the market and ensure price stability, which directly impacts the costs of emission rights for Waste to Energy plants.

10. Research and Development at the Hafner Energy Tower (South Tyrol) - SLIMLINE

This innovative CO_2 utilization process, focuses on directly converting captured CO_2 into sodium bicarbonate ($NaHCO_3$) using sodium carbonate ($Na2CO_3$). A pivotal element of this method involves increasing the CO_2 concentration in the flue gases from the waste-to-energy plant to at least 15%.

This enhancement is achieved through flue gas recirculation coupled with O_2 enrichment.

The market adoption of such specialized processes could be expedited by advancements in reaction chemistry, improved absorbents, and supportive regulatory and market-based incentives.

Years ago, thorough research on a transportable hazardous waste incineration facility using a rotary kiln led to the development of the **"Slimline"** concept.

This innovative modular system, **capable of processing up to 25,000 tons per year**, sets a new standard in the industry, thanks to its design that allows a significantly higher degree of pre-assembly in workshops compared to traditional incineration plants.

The "SLIMLINE" facility from Hafner, designed to handle 25,000 tons per year, offers numerous advantages and innovations:

- Viable waste solution for smaller capacities (up to 25,000 tons annually).
- Features rapid on-site assembly due to its intelligently designed modular

block system.

- Occupies less space than conventional incineration or Waste-to-Energy (WTE) plants.
- Converts residential or hazardous waste into valuable energy – electricity, cooling or district heating.
- Achieving the lowest flue gas emissions in Europe.
- Comes with a fixed price guarantee, providing certainty right from the start.
- Ensures clearly defined construction timelines with a predetermined commissioning date.
- Designed for quick deployment, this transportable concept allows the small Waste to Energy plant to be operational within a year.

11. The Future of Global Waste Management and Climate Protection

The future of global waste management and climate protection is marked by an increasing urgency to develop and implement innovative solutions to minimize the ecological footprint of human activity.

This includes reducing greenhouse gas emissions, using resources efficiently, and minimizing waste.

- **Reduction of Greenhouse Gas Emissions:**

  Methane, primarily generated at landfills, is a potent greenhouse gas. Reducing these emissions through improved landfill management, such as capturing and utilizing landfill gas, is a crucial objective.

  Increasing Energy Efficiency in Waste Management with Optimizing waste collection and transport and promoting waste-to-energy technologies can reduce energy consumption.
- **Increasing Recycling Rates:**

  Efforts are underway worldwide to increase recycling rates to reduce the consumption of natural resources and promote the circular economy.

  Uniform standards can help improve the quality of recycling and stabilize international markets for recycled materials.
- **Waste Reduction and Avoidance:**

  Reduction of Food Waste and Initiatives and educational programs aimed at reducing food waste are crucial, as a significant portion of globally produced food is wasted.

- **Waste to Energy:**

  Promotion of Waste-to-Energy Technologies and Converting non-recyclable waste into energy is a strategy to reduce landfill waste while simultaneously generating energy. However, these technologies must be sustainable and efficiently designed to minimize negative environmental impacts.

- **Global Cooperation and Legislation:**

  International Agreements and Cooperation in the global nature of environmental problems requires international solutions. Collaboration at the international level, such as through the Paris Agreement, is essential for achieving climate goals.

  Local governments play a crucial role in implementing global goals through tailored regulations and guidelines.

- **Technological Innovation:**

  The development and application of new technologies that improve the collection, sorting, and processing of waste are crucial. This includes digital solutions such as the use of IoT for intelligent waste management.

11.1 Waste Management in the Gulf States

The waste management systems in the Gulf states, including Saudi Arabia, Qatar, Oman, Bahrain, Kuwait, and the United Arab Emirates, are characterized by rapid economic growth, urbanization, and an increasing population.

These factors lead to rising waste volumes and pose challenges for the respective governments.

Here is an overview of the situation in the mentioned countries:

11.1.1 Saudi Arabia

Saudi Arabia generates over 15 million tons of waste annually, most of which is urban. The country has begun to modernize its waste management systems by introducing recycling and waste separation programs.

There are also initiatives to develop waste-to-energy facilities to meet growing energy needs while reducing waste burden.

11.1.2 Qatar

Qatar has one of the highest per capita waste productions in the world. The country has set ambitious goals to implement innovative sustainability and climate protection solutions by 2030.

Major investments in infrastructure are planned, including facilities for generating energy from waste.

11.1.3 Oman

Oman faces challenges due to inadequate waste separation and recycling infrastructure. The country is working on a national waste reduction strategy that includes better waste collection and processing, as well as public education campaigns to raise recycling awareness.

11.1.4 Bahrain

Bahrain produces about 1 million tons of waste annually. The country has recently started introducing recycling initiatives and plans to develop a more sustainable waste management system, including the use of waste-to-energy technologies.

11.1.5 Kuwait

In Kuwait, most waste is disposed of in landfills, leading to significant environmental problems. There are efforts to develop advanced waste processing facilities and promote recycling.
The government has introduced measures to improve waste separation at home and raise public awareness.

11.1.6 United Arab Emirates (UAE)

The UAE is a leader in the region in terms of waste management. They have introduced advanced waste processing facilities and several large recycling and waste-to-energy projects.
For example, Dubai aims to reduce landfilling by 75% by 2030.
Abu Dhabi has also made significant investments in its waste management infrastructure, including setting up recycling plants and developing policies for waste reduction.

Overall, the Gulf states have made significant efforts to improve their waste management systems but still face challenges regarding recycling, waste reduction, and public awareness.

The governments of these countries are increasingly investing in technologies and infrastructures to make their waste management more efficient and sustainable.

11.2 Could Qatar become a Pioneer in Climate Protection?

In February 2024, a forum on sustainability in waste management was held in Doha.

It was seen that Qatar has taken significant steps in recent years to strengthen its sustainability efforts in the areas of environmental protection, climate change mitigation, waste management, health and empowering the next generation. As one of the richest countries in the world and a major oil and gas producer, Qatar faces particular challenges and opportunities in terms of environmental and climate protection.

Heinrich Hafner as spokesperson at EXPO Doha

11.2.1 Environmental and Climate Protection

Qatar has set for itself the goal of reducing its CO_2 emissions.

This includes increasing energy efficiency and expanding renewable energy sources.

Qatar plans to cover a significant proportion of its energy requirements with renewable energy sources by 2030.

Sustainable urban development: projects such as the planning and development of the city of Lusail, which is intended to serve as a model for sustainable living and working, are part of this strategy.

11.2.2 Waste Management

<u>Recycling and Waste Minimisation:</u> Qatar has introduced initiatives to improve its waste management systems, including recycling programmes and waste recovery technologies.

<u>Sustainable Waste Management:</u> The country is working to implement advanced waste treatment and prevention technologies to minimise its environmental impact.

11.2.3 Health

Qatar is investing heavily in the healthcare sector to provide modern medical facilities and services. This includes capacity building for public health and prevention.

Promoting public health awareness and awareness campaigns on topics such as nutrition, physical activity and preventive measures are part of the country's health strategy.

11.2.4 Next Generation

Qatar is investing in its education infrastructure and has made education a priority in its National Vision 2030. **Promoting technology and innovation through education is a key priority.**

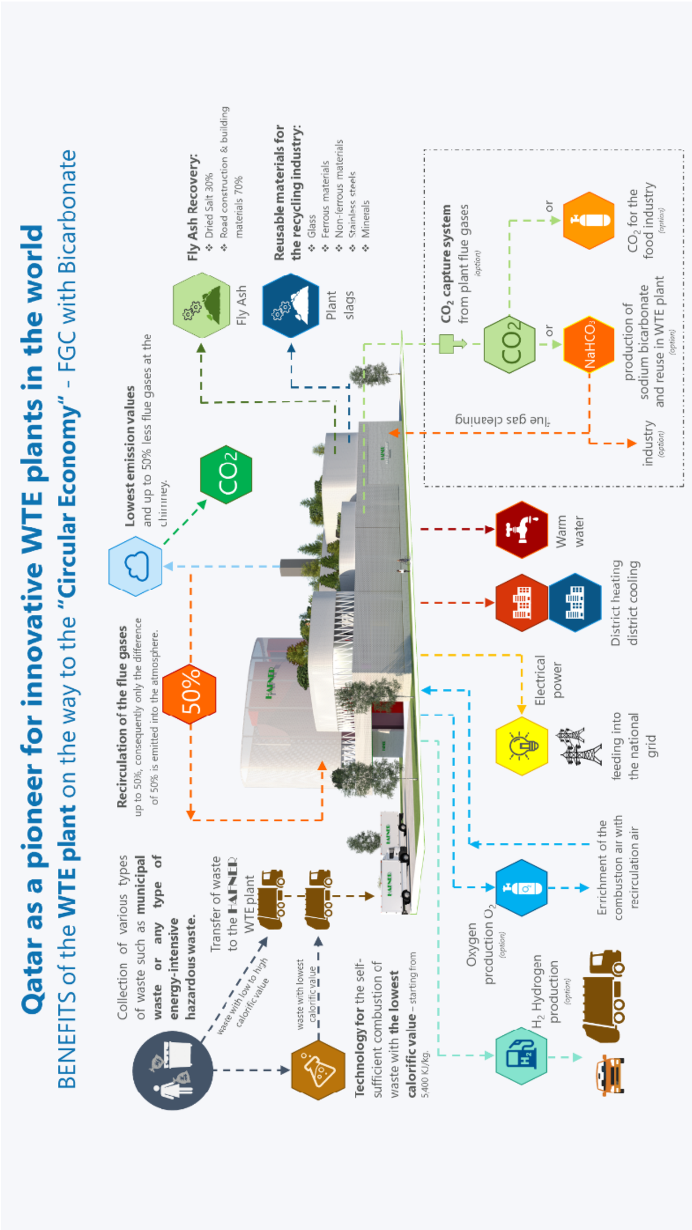
Youth Development: Programmes and initiatives that support young people in science, technology, engineering, and mathematics (STEM) are of strategic importance for the country's future.

11.2.5 International Co-operation

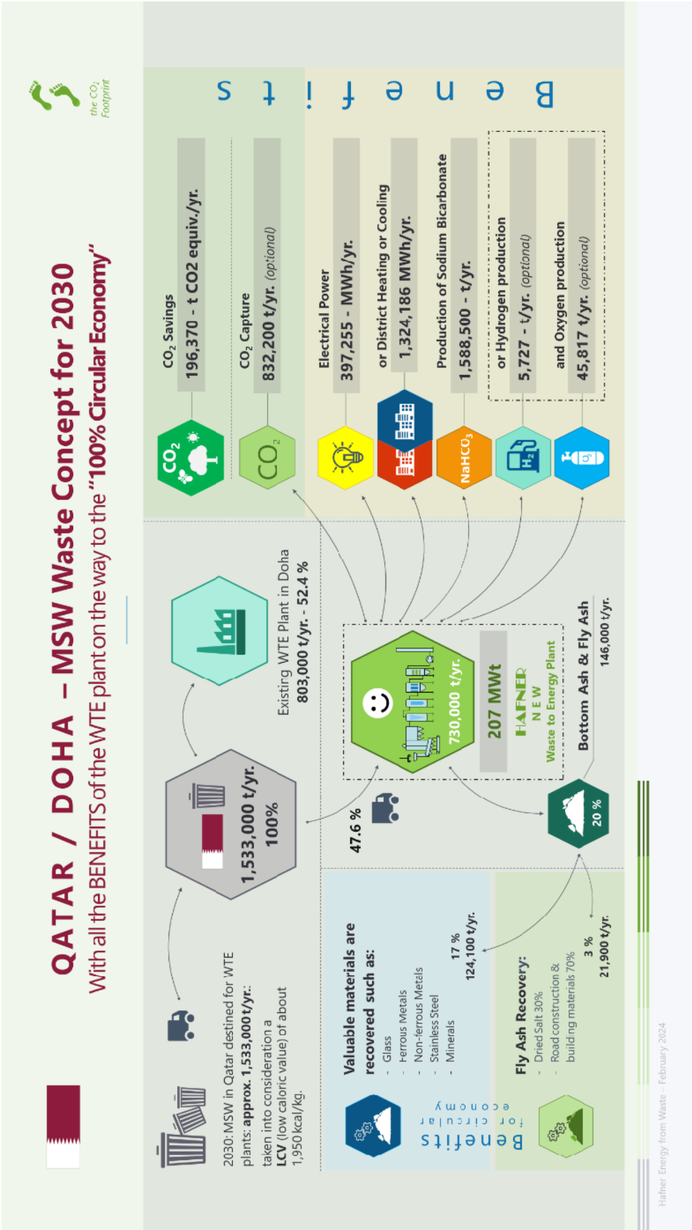
The country cooperates with international organisations to implement best practices in environmental protection and sustainable development. Dr. Jeremias Kettner and Hartwig Koenigsrainer are working closely with local authorities to realise the vision of a 100% circular economy in Qatar and other Gulf countries.

This vision includes waste incineration, CO_2 capture with conversion to sodium bicarbonate and hydrogen and oxygen production through electrolysis.

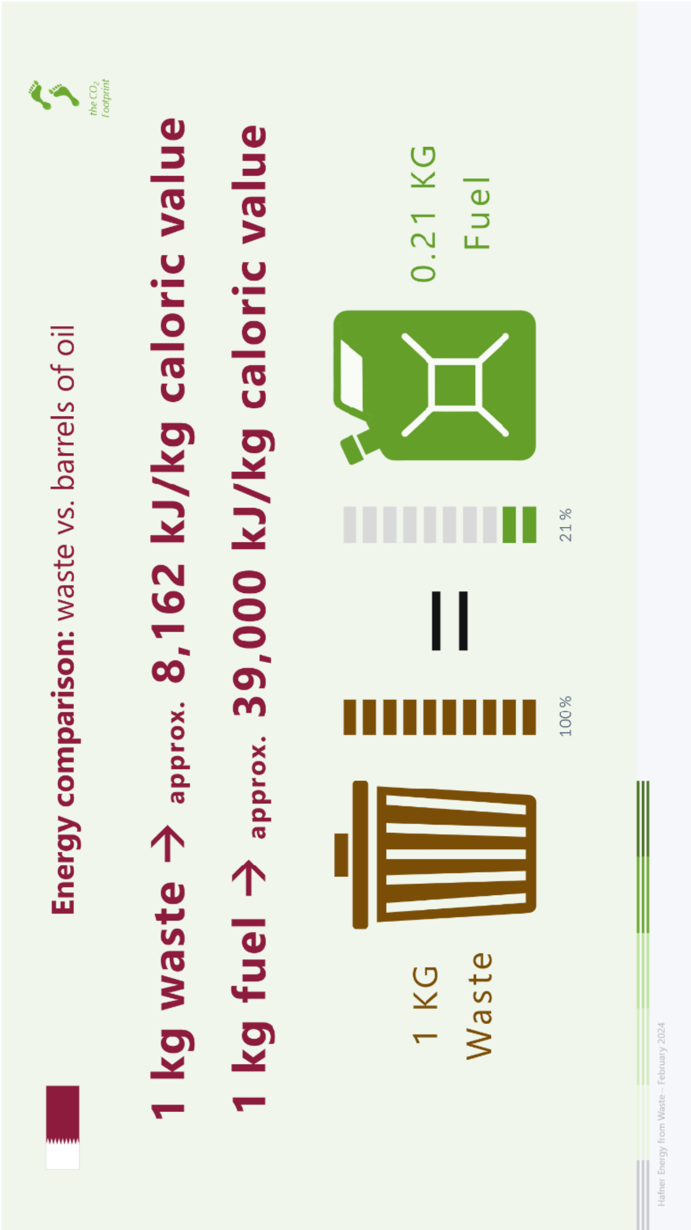
This comprehensive and forward-looking model for sustainable resource management and climate protection could make Qatar a leader in environmental technology by 2030.



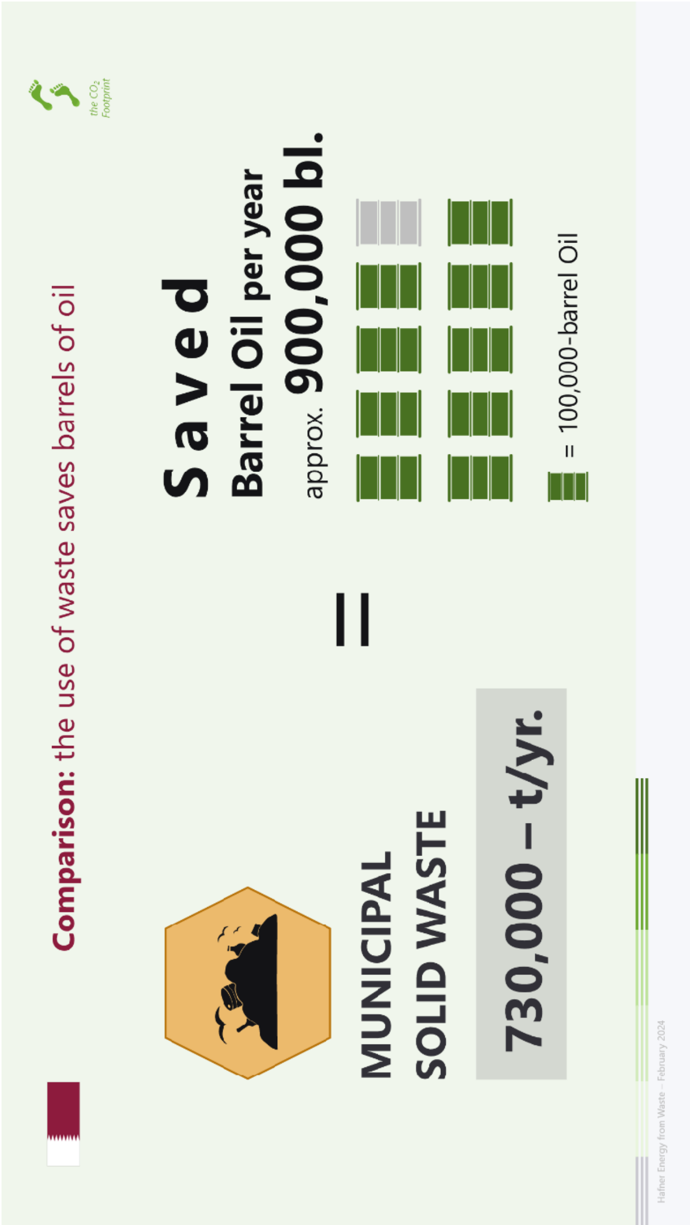
Qatar as a pioneer for innovative WTE plants in the world



Qatar / Doha – MSW Waste Concept for 2030



Qatar – Energy comparison: waste vs. barrels of oil



Qatar – Energy comparison: the use of waste saves barrels of oil

12. Hafner's Vision for a fast Solution to Waste Management in Harmony with Climate Protection

12.1 Hafner – Vision Description Scenario 1

The starting point here is the well-known waste hierarchy of the EU. This waste hierarchy prioritizes waste management and prevention strategies and is a crucial concept in European environmental policy, aiming to promote the most sustainable way of handling waste.

At the top of the pyramid is waste prevention, which means taking measures to prevent the generation of waste altogether. Examples include conscious consumption, the use of durable products, and the reduction of packaging materials.

The next step is preparation for reuse, which aims to reuse products or materials in their original condition. Repair, cleaning, and refurbishment are typical measures in this category.

Recycling follows on the hierarchy and involves processing waste materials into new products or raw materials. This conserves resources and reduces environmental impact by reducing the need for extracting new raw materials. (In scenario 1, we increase recycling from the current 30% to 50%.)

This category includes methods like energy recovery (waste incineration, increasing from 15% to 35%) where waste materials are used for energy generation, including processes where waste generates heat, electricity, or other forms of energy.

At the base of the pyramid is disposal, including landfilling (in this scenario, reduced from 55% to 15%). This is the least preferred option and is considered when other methods are not applicable. Landfilling often has the greatest negative environmental impact and is therefore seen as a last resort. The waste hierarchy is enshrined in EU law, particularly in the Waste Framework Directive, and serves as a guide for waste policy and practices in member states. It promotes a circular economy where the value of products and materials is kept in the economy for as long as possible, minimizing environmental impact.

We assume that globally, in 194 countries, 2,590,000,000 tons of household waste will be **generated by 2030**. The current situation is that **approximately 55% is landfilled, 30% is recycled, and 15% is treated in incineration plants**.

We want to envision a scenario where we drastically reduce global CO_2 emissions and solve the disorderly waste disposal so that people can live healthier lives while also protecting the climate to reduce global warming. Specifically, this means rethinking waste management.

Is the waste hierarchy, as handled in Europe, the right way?
The answer is straightforward: it is not the right approach. A careful analysis of current global waste streams clearly shows where plastic ends up or how waste is transported to poorer countries and illegally dumped.
We must reconsider the waste hierarchy to align it with ecological and economic principles.

This translates to 15% landfilling, 35% incineration, and 50% recycling.

Hafner – Worldwide – MSW Waste scenario 1 for 2030

12.2 Hafner - Vision Description Scenario 2

The starting point here is an economically and ecologically sound waste hierarchy.

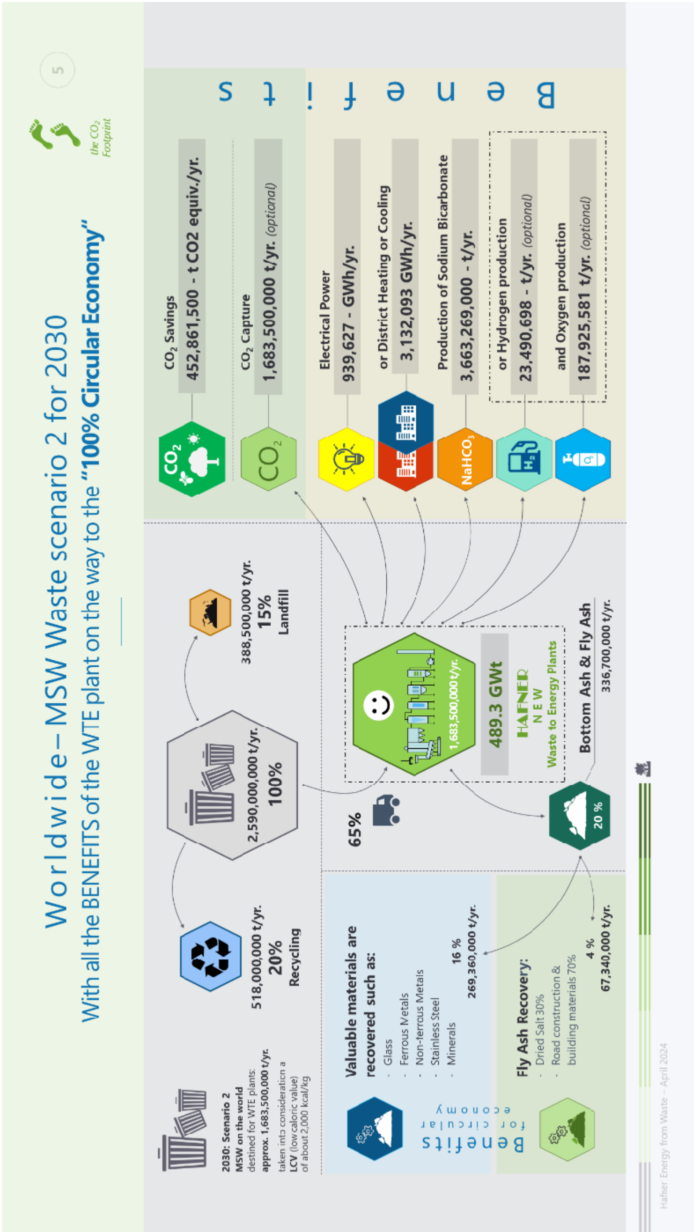
Here, the 65% material recovery is being replaced by 65% energy recovery.

Here, too, waste prevention is at the beginning of the pyramid, where measures are shown to prevent the generation of waste altogether. Changing consumption behaviour by using durable products and reducing packaging materials. Reuse is also important here, to reuse products in their original condition. Repair, cleaning, and refurbishment are indications. Material recycling is exclusively carried out here from the slag and filter dust of the incineration plant. Products like metals, glass, sand, etc., are returned to the cycle. Here, recycling is not done pre-consumer but post-consumer. Processing waste materials into new products or raw materials. This conserves resources and reduces environmental impact by reducing the need for extracting new raw materials. (In scenario 2, 20% of slag and filter dust is recycled.). Energy recycling mainly concerns Waste-to-Energy plants (scenario 2, 65% energy recovery). Here, apart from electricity and thermal heat, the possibility is also offered to produce hydrogen and oxygen through electrolysis.

Furthermore, the capture of CO_2 from the flue gas with the production of sodium bicarbonate is beneficial for climate protection.

In the end, only landfilling remains (in our scenario 2, 15%). This option should be avoided in the future. This residual waste should also be subjected to energy recovery in the future.

This translates to 15% landfilling, 65% incineration, and 20% recycling.



Hafner – Worldwide – MSW Waste scenario 2 for 2030

12.2.1 The Hafner Scenario 2: Global Waste to Energy Recovery and Recycling of Slag and Filter Dust

Modern Waste to Energy plants offer numerous advantages for both waste management and environmental protection.

A significant benefit is the reduction of waste volume. From **100%** input of waste, **approximately 15%-20%** remains as slag, and **3%-5%** as filter ash. This substantially reduces the need for landfill space, helping to alleviate the problem of waste overflow. Waste to Energy plants utilize the energetic value of waste by generating electricity and/or heat. This energy can be used for power generation or district heating, reducing dependency on fossil fuels and contributing to energy self-sufficiency. **Additionally, the electricity can be used for the electrolysis process to produce hydrogen and oxygen**.

The emissions from modern Waste to Energy plants, **according to Best Available Techniques (BAT) (see the explanation in chapter 13.1), are significantly below the limits set by BREF documents (see the explanation in chapter 13.2)**.

Emissions at the chimney can be greatly reduced (refer to the picture see page 47) by reintroducing **<u>50%</u>** of the flue gases as primary or secondary air into the combustion process. Oxygen is added to enrich the combustion air.

<u>Flue gas recirculation</u> combined with oxygen enrichment is an advanced method used in Waste to Energy plants to improve combustion efficiency and reduce emissions. This process combines two techniques: the recirculation of part of the flue gases into the combustion process and the enrichment of combustion air with additional oxygen.

Flue gas recirculation is a process where part of the flue gases, normally emitted from the chimney, is redirected back into the combustion chamber. Introducing already cooled flue gases into the combustion zones helps control and stabilize temperatures, crucial for minimizing slag formation and the release of nitrogen oxides (NOx). Nitrogen oxides primarily form at high combustion temperatures. Flue gas recirculation helps lower combustion temperatures, thereby reducing NOx formation. **Recirculating flue gases** results in a more homogeneous temperature distribution and supports a more stable combustion, thus enhancing efficiency and reducing unburned residues. Alongside flue gas recirculation, the enrichment of combustion air with additional oxygen further boosts combustion efficiency. Despite the temperature reduction due to flue gas recirculation, the additional oxygen enables higher combustion temperatures, promoting a more complete combustion of waste and reducing the formation of CO and other incomplete combustion products. More available oxygen means that more waste material can be oxidized more efficiently and quickly, increasing the overall efficiency of the facility. Since more oxygen supports a more complete combustion, the volume of flue gases is reduced, leading to lower emission levels. Even with a low calorific value, the additional preheating of combustion air can be reduced. **Specifically, waste with a low calorific value of about 1400 Kcal/kg can be burned in combination with AI-controlled fire performance regulation.**

In the CO_2 capture process with sodium bicarbonate production, the recirculation can increase the CO_2 proportion, thus enhancing the efficiency of the reaction from sodium carbonate to sodium bicarbonate. The combination of flue gas recirculation and oxygen enrichment leads to optimized combustion, where high efficiency and low emissions go hand in hand. Controlling process parameters such as oxygen content, temperature, and flue gas recirculation rate is crucial to achieve the best results while minimizing environmental impacts.

AI-controlled fire performance regulation is primarily used here. **AI-guided fire** performance regulation in Waste to Energy plants **is an innovative approach that aims to optimize the combustion process using artificial intelligence.**

This **approach uses algorithms and machine learning to recognize patterns**, make predictions, and automatically make adjustments that improve combustion efficiency, reduce emissions, and lower maintenance costs. Sensors and measuring instruments in the incineration plant continuously collect data in real-time. This data includes temperatures, pressure, air and fuel flows, flue gas composition, and other relevant parameters.

AI systems analyse these data streams to identify patterns and relationships. Machine learning is used to learn from the collected data and continuously improve system performance. Based on the analysis results, the AI uses algorithms to determine optimal operating conditions. This involves adjusting the air supply for combustion, modulating the fuel supply, and optimizing flue gas recirculation. The AI makes automatic adjustments to maximize combustion efficiency and minimize emissions. This occurs in real-time and without human intervention, with the AI responding to changes in waste input and other operating conditions. By optimizing combustion parameters, it is ensured that the waste is completely and efficiently burned, maximizing energy yield. The AI can help minimize the formation of pollutants such as

nitrogen oxides, carbon monoxide, and unburned hydrocarbons by precisely controlling combustion conditions. Continuous monitoring and adjustment can identify potential problems early and initiate preventive maintenance measures, leading to longer operating times and lower maintenance costs.
AI systems are capable of adapting to varying waste properties and changing operating conditions, making them particularly suitable for use in Waste to Energy plants where waste composition can vary significantly.

By waste energy recovery, methane emissions generated by the decomposition of organic material in landfills are significantly reduced.

Methane (Landfill) is a potent greenhouse gas, much more potent than CO_2.

Another important point is the risk of leachate from the landfill contaminating the groundwater. After incineration, metals and other recyclable materials can be recovered from the slag. This helps conserve resources and promotes recycling.

Here, the entire slag is processed using existing technologies to manufacture new products. Similarly, the filter ash can be processed using existing techniques and procedures and reused as products. To date, these two so-called waste products from incineration have been stored externally. The concept envisions processing these materials within the Waste to Energy plant so that the residual material does not have to be declared as a waste product. These modern Waste to Energy plants are equipped with advanced emission control technologies, which are continuously and transparently made available to the public via the web. By incinerating waste, harmful bacteria and pollutants that may be present in the trash are effectively eliminated.

The COVID pandemic has shown how important orderly waste disposal is in conjunction with hygiene. Incinerating waste is an **effective method to eliminate bacteria, viruses, and other pathogens, including the coronavirus.** This is particularly true for infectious medical waste from hospitals and other health facilities where COVID-19 patients were treated.

In this concept, **the capture of CO_2 from flue gas and the production of sodium bicarbonate are of high economic and ecological importance.** *Refer to the flow diagram of the Hafner Scenario 2.*

Waste incineration plants can process a wide range of wastes that would otherwise be difficult to dispose of. They are particularly useful for treating non-recyclable and problematic waste. In this case (Hafner Scenario 2), **all residual waste is subjected to energy recovery.**

Only purely sorted waste is recycled materially. Wastes where material recycling does not make ecological and economic sense are used energetically. Integrating Waste to Energy plants into a comprehensive waste management system supports the principle of a circular economy by helping to maximize the use of raw materials and transform waste into useful resources.

In Hafner Scenario 2, approximately 20% is recycled materially (slag and filter dust).

12.2.2 Fact Check for Hafner Scenario 2

How much electrical power is consumed worldwide by households?

The total estimated global power **consumption in 2020 was about 22,000 terawatt hours (TWh**). The proportion of power consumption by households varies greatly from country to country. **In many industrialized nations, households can account for about 25% to 40% of total power consumption**. In developing countries, this proportion may be lower, as industrial and commercial activities often make up a larger share or access to electricity is more restricted.

We assume an average percentage of 32.5%, which corresponds to 7,150 terawatt hours (TWh).

How much electrical power is produced from Waste to Energy according to Hafner Scenario 2 by 2030?

- **940 terawatt hours (TWh)** - worldwide consumption of 1,600,000,000 households
- **this corresponds to around 13.1 % of the electrical energy of all households worldwide.**

- **How much CO_2 is released into the atmosphere worldwide?**

  In 2021, approximately **36 gigatonnes of CO_2** were released into the atmosphere globally

  How much CO_2 is captured by incineration and not released into the atmosphere?

  1,683,500,000 tons of CO_2 = 1.6835 gigatonnes = 4.7% CO_2 capture for sodium bicarbonate and E-Fuel production.

  Substitution of fossil fuels. If the energy generated by Waste to Energy replaces fossil fuels such as coal, oil, or natural gas, this leads to a net reduction in CO_2 emissions, as these fuels typically have higher CO_2 emissions per unit of energy produced.

452,861,500 tons of CO_2 = 0.452 gigatonnes = 1.3%

In total, by energy recovery 1,683,500,000 tons of household waste per year worldwide, CO_2 emissions into the atmosphere are reduced by 6%.

- **The sodium bicarbonate produced from the CO_2 capture from the flue gas of the Waste to Energy plants worldwide**

  amounts tons: 3,663,296,000 t/year

  The globally produced sodium bicarbonate per year: 7,200,000 t/year.

  This means that the total production of sodium bicarbonate far exceeds the total consumption.

  The alternative here is to produce e-fuel with the remaining captured CO_2.

- **The E-Fuel produced from the remaining CO_2 capture from the flue gas of the Waste to Energy plants worldwide**

  amounts tons: 420,047,794 t/year

  The globally produced E-fuel per year: 250,000 t/year.

- **The following products are recycled from the resulting bottom ashes from waste to energy plants worldwide and integrated into the circular economy.**
  - **Bottom ashes: 16% to new products (269,360,000 t/year)**

    Glass, Ferrous Metals, Non-ferrous Metals, Stainless Steel and Minerals.

- **Fly ashes: 4% to new products (67,340,000 t/year)**

  When captured with lime additive:

  - Additives for the cement industry
  - Salt

  When captured with sodium bicarbonate:

  - Road construction
  - Salt

13. Descriptions

13.1 BAT - Best Available Techniques

The acronym "BAT" stands for "Best Available Techniques." These represent the highest standard of processes or methods that can be applied in industrial and agricultural processes to minimize environmental impacts.

In Europe, BAT is primarily employed within the framework of European environmental policy, specifically through the Industrial Emissions Directive (IED, Directive 2010/75/EU). The main goal of BAT is to achieve a high level of environmental protection overall by reducing emissions of pollutants into the air, water, and soil, and by reducing resource consumption.

The use of the best available techniques ensures that operations effectively control their environmental impacts. The determination of what is considered BAT is carried out through a systematic and transparent process known as the "Seville Process," coordinated by the European IPPC Bureau (Integrated Pollution Prevention and Control) in Seville, Spain.

This process involves the creation and regular revision of BAT reference documents (BREFs), which cover specific industry sectors.

Each BREF document provides detailed information about:

- **Techniques used in a specific industrial or agricultural sector.**
- **Emission levels associated with these techniques.**
- **Measures to prevent or reduce environmental impacts.**
- **Monitoring and management practices.**

Enterprises subject to the IED are legally required to apply BAT. Compliance is monitored through the issuance of operating permits by national authorities of EU member states. These permits include specific emission limits and other environmental conditions based on the BAT described in the BREFs.

Benefits of BAT

The implementation of the best available techniques leads to numerous benefits, including:

- **Reduction of environmental pollution and conservation of natural resources.**
- **Promotion of technical innovations and improvements in the industry.**
- **Harmonization of environmental standards and practices within the EU, contributing to fair competition.**

In summary, BAT is a central element of the European environmental strategy, serving to minimize the environmental impacts of industrial and agricultural processes while simultaneously promoting innovation and technical improvements.

13.2 BREF - Best Available Techniques (BAT) Reference Document

BREF documents are crucial within the framework of European environmental policy and serve as references for determining the Best Available Techniques (BAT) in various industrial sectors. These documents are used under the European Industrial Emissions Directive (IED, Directive 2010/75/EU) to ensure that industrial facilities efficiently manage their environmental impacts. This process involves stakeholders from various groups, including government agencies, industry representatives, environmental organizations, and independent experts.

A typical BREF document contains:

- **Description of the processes and technologies used in the respective industrial or agricultural sector.**
- **Detailed analysis of the technologies and methods used in the industry, including information about their environmental impacts.**
- **Identification and description of the best available techniques for reducing or avoiding environmental impacts.**
- **This section summarizes the techniques identified as BAT and sets the associated emission values and other performance standards.**
- **Recommendations for monitoring environmental impacts and managing the techniques.**

The BAT conclusions defined in the BREFs are legally binding for EU member states. Industrial facilities under the IED must apply BAT to obtain and maintain an operating permit. National authorities use the BAT conclusions to set specific emission limits and other conditions in the permits for industrial facilities.

BREF documents are regularly reviewed and updated to account for technological advances and changes in industrial practices. This ensures that the BAT truly represent the "best" available techniques according to the current state of science and technology.

Through BREF documents and the associated BAT conclusions, a high level of environmental protection is promoted in European industry, ensuring a uniform approach to minimizing environmental impacts across all member states.

14. The author Heinrich Hafner

Eng. Heinrich Hafner, born in 1955, founded Hafner GmbH in Bolzano at the age of 23. Over nearly five decades, he has proven himself as a successful entrepreneur characterized by foresight, courage, and a big heart.

"I see myself as a visionary thinker, always striving for excellence with strong convictions," says Hafner. As a staunch advocate for the "Waste to Energy" movement, he has initiated numerous projects that harmonize consumer needs with environmental protection and advance climate protection measures. In the 1980s, he made a significant contribution to the implementation of a waste incineration plant in South Tyrol, which has since gained international recognition and collaborates with other high-profile projects like the Mobile Special Waste Incineration Plant. His company, Hafner Holding Worldwide, operates in over 107 countries, helping businesses, municipalities, and nations to establish cost-effective and clean alternative energy sources. Hafner is also the author of three books addressing the pressing climate and energy crises and demonstrating solutions through sustainable practices such as energy generation from waste incineration: With Renewable Energy – Waste Is Moving The World (2010), The Energy Revolution In The Third Millennium (2011), and Climate Change with 'Waste to Energy' (2017).

"It is imperative to utilize low-carbon and resource-efficient strategies to protect our climate and ensure the health of our ecosystems," Hafner emphasizes, pointing out the urgent need for widespread adoption of these technologies. Projects like the one in South Tyrol serve as shining examples of the need to secure energy supply and consider sustainable energy as the gold of the third millennium. Following the Paris Climate Agreement, Hafner recognized the opportunity to expand "Waste to Energy" solutions. Subsequently, he developed the compact and efficient WTE plant "SLIMLINE," which is particularly advantageous for smaller communities. After the 2008 financial crisis, Hafner focused his efforts more on research and development, particularly on CO_2 capture, flue gas recirculation, and advancing the circular economy in waste incineration.

Today, Hafner continues his pioneering work in designing "Waste to Energy" facilities with a team of about 30 experts, marking this endeavour as one of his main focuses.

15. Conclusion

In a world increasingly impacted by climate change, innovative waste-to-energy technologies have the potential to revolutionize waste management and play a pivotal role in reducing greenhouse gas emissions. The conversion of CO_2 emissions from waste-to-energy plants into sodium bicarbonate demonstrates how municipal solid waste can be transformed into valuable resources. This process not only cuts CO_2 emissions but also offers a sustainable approach to advancing the circular economy.

The ongoing development and implementation of such technologies (as highlighted in the "Rethinking Waste Management" scenarios) are crucial for achieving the Paris Agreement's goals and reducing humanity's ecological footprint. The "Fact Check for Hafner Scenario 2" clearly shows that climate protection can be both ecologically and economically advantageous. It is the responsibility of scientists, engineers, policymakers, and society as a whole to advance and support the research and application of these technologies.

By working together, we can create a sustainable future where technology and the environment work in harmony. We are on the cusp of an era of technological innovation that could fundamentally change our relationship with planetary resources. Let’s embrace this challenge with optimism and determination to ensure a liveable world for future generations.

16. Disclaimer

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17. References, Methodology, and Data Sources

The methodology used in this book includes a combination of theoretical research from Hafner Waste to Energy, empirical studies, and model simulations.

It involves a systematic analysis of scientific articles, books, and reports. Databases such as Magic, JSTOR, PubMed, Scopus, ChatCPT, and Google Scholar were utilized to identify relevant literature and research specific examples of CO_2 capture technology worldwide.

Surveys and direct communication with experts and operators of Waste to Energy plants were conducted. Official data from environmental authorities and international organizations like the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC) were used. Industry data was provided through collaborations with companies and industry associations. Software like KED for process simulations was employed.

The data for the analyses and discussions in this book come from various, rigorously vetted sources: International and national environmental authorities: Data on emissions and energy consumption from sources such as the U.S. Environmental Protection Agency (EPA) and the European Environment Agency (EEA).

Reports and guidelines on environmental protection and waste management.

Scientific publications and specialist literature: Journal articles from peer-reviewed journals like "Environmental Science & Technology" and "Journal of Cleaner Production".

Specialist books and monographs on environmental engineering and chemical process engineering.

Ecoinvent and other Life Cycle Assessment (LCA) databases for environmental impact data. Reports from the World Bank, United Nations, and NGOs such as the World Resources Institute (WRI), which address climate change and CO_2 management.

”CREATING A SUSTAINABLE FUTURE WASTE MANAGEMENT FOR CLIMATE PROTECTION AND PROSPERITY”

Discover how innovative waste management can transform our world by 2030. With a visionary global strategy, where 65% of household waste is used for energy production (Waste to Energy), **20%** is recycled, and only **15% is landfilled**, we could **cut global CO_2 emissions by 6%.**
With CO_2 capture technology, we can produce valuable products like sodium bicarbonate and e-fuel to meet global demand. Moreover, electricity from waste could account for up to **23.5% of global hydrogen production and 100% of global oxygen production, while supplying electricity to 13.1% of households worldwide.**
Join us in building a more sustainable and healthier future for the next generation.

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