Evidence Book

The role of natural soda ash in building a sustainable future

Edition 1 | December 2025

Executive Summary

About this Document

The Evidence Book brings together the latest analysis of scientific literature, industry data, and WE Soda's own operational data to stress test and validate the two core principles that guide WE Soda's long-term approach:

Principle 1: Soda ash makes an important contribution to sustainable development.

The evidence outlined in this report demonstrates that soda ash plays a critical role across multiple sectors. By lowering melting points in virgin glass production, serving as a key ingredient in renewable energy technologies such as solar photovoltaics, batteries, and enhancing water and waste treatment, soda ash is integral to products that drive environmental, economic and social progress. In this way, it makes a clear and important contribution to sustainable development. At the same time, we recognise that the downstream use of soda ash can generate significant process emissions which, in turn, contribute to climate change (for example, CO_2 released from carbonate decomposition in glass furnaces). The nature of these use-phase emissions means that they require collective solutions and, therefore, can only be effectively addressed through industry-wide collaboration.

Principle 2: Primary solution mined natural soda ash has better sustainability credentials than synthetic soda ash.

The evidence presented in this report shows that soda ash derived from primary solution mined natural trona offers a significantly lower environmental footprint than synthetic alternatives. With reduced greenhouse gas emissions, lower energy and water consumption, primary solution mining provides WE Soda with a compelling sustainability advantage and a clear source of competitive differentiation.

Our analysis draws on scientific and industry references and was conducted with rigour by in-house experts and our partners at Robertsbridge. Key takeaways include:

- **The need for continuous learning:** Science evolves, and new evidence will challenge previous concepts and mindsets. The evidence we present in this book will need challenging. We are strengthening our sustainability team to have dedicated resource to do this, and we work with external parties to supply us with the latest thinking and challenge our mindset.
- **Maintaining our advantage:** The current environmental and sustainability benefits of natural soda ash are not immutable. Synthetic producers are investing heavily in decarbonisation and resource-efficiency measures. To safeguard our position at the forefront of low-impact soda ash production, we will need to invest in improvements in operational performance, transparency and stakeholder engagement.
- **Next steps:** Building on this evidence, our Sustainability Plan sets out clear targets, milestones and actions that define how we will achieve low-carbon, water-neutral and nature positive outcomes, while positioning sustainability as a service for our customers.

This first edition of the Evidence Book marks the beginning of an ambitious and transparent journey. As WE Soda deepens its evidence base, we commit to regular updates, open dialogue with stakeholders and rigorous alignment with the latest scientific and regulatory developments.

This document is one part of a trilogy of documents that shapes WE Soda's approach to sustainability.

Alongside our Evidence Book, we have published the 'Case for Change', outlining the global trends that shape our understanding of the sustainability landscape. The third document in the trilogy is our Sustainability Plan, explaining how we will achieve those improvements with concrete targets, milestones, and actions.

Commercial feedback is essential and welcome. Please, if you have any comment, good or bad, contact me directly at: alan.knight@wesoda.com

Principle 1

Soda ash makes an important contribution to sustainable development
= Evidence Book

See page 04

Principle 2

Primary solution mined natural soda ash has better sustainability credentials than synthetic soda ash
= Evidence Book

See page 12

Principle 3

Global trends require a proactive response – business as usual is no longer viable, creating both opportunities and risks for WE Soda
= Case for Change

Principle 1 + Principle 2 + Principle 3 = WE Soda's Sustainability Plan

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A Word from our CSO – Alan Knight

At WE Soda, we believe that soda ash – a little-known yet ubiquitous agent in many industrial processes – is an essential ingredient in the sustainable future envisioned by the global community. This Evidence Book is the first step in substantiating this belief, collecting the evidence that supports our position.

So, how does soda ash contribute to sustainability? And, how sustainable is the process to produce it? This document aims to answer these questions. Soda ash is a primary ingredient in the manufacture of virgin container and flat glass, solar glass, washing powders, water treatment, and increasingly in the manufacture of electric vehicle (EV) batteries, pollution control, and other industries. These industries, which require soda ash as a raw material, will also be considering their own contribution to sustainability, looking to their value chain for opportunities to reduce their environmental impacts. At WE Soda, we have the opportunity to be proactive, rather than reactive, supporting us to become the supplier of choice.

Without evidence, claims about sustainability are just that – claims. We read all too often about greenwashing, misleading claims of environmental benefit, and product labelling that implies sustainability credentials with no substance. Our opinion is that too few businesses take a deep dive into the real, validated evidence behind any claim they make. WE Soda intends to be one of the few exceptions, taking a step towards transparency and accountability. In that spirit, we are publishing the first version of our Evidence Book – a document that lays out the evidence as it is now, while committing us to improving over time. This book is expected to evolve as WE Soda delves deeper into the metrics and facts underpinning our claims, which will ultimately inform our targets and actions.

To do so, WE Soda needs to demonstrate that our soda ash (and related products) are among the lowest-carbon and environmental impact choices soda ash buyers can make today. Our organisation makes what is legitimately described as 'natural' soda ash, a term we have tested against the EU Green Claims Directive. It is natural because we only make it from mined trona, a naturally occurring 'non-marine evaporate mineral' or, in other words, a mineral made of sodium bicarbonate, sodium carbonate and water.

However, simply claiming that WE Soda's product is natural is not enough. Our objective is to analyse the environmental impact of every aspect of our business and to minimise or eliminate those impacts until we have robust, irrefutable evidence for the claims we want and need to make the sustainability credentials of our product and business.

Our Sustainability Plan will outline the steps WE Soda will take to improve — working towards low carbon, water neutrality, nature positivity, and making our business a safe and progressive place to work. These goals reflect our commitment to making WE Soda a strategic partner that helps customers meet their own sustainability objectives. Sustainability, therefore, becomes a service for our customers, and their customers, to help them achieve their sustainability goals.

In that way, we will be able to offer our customers and their customers – often consumer-facing brands – an advantage beyond quality, price or volume: the advantage of making a major contribution to their own environmental footprint reduction efforts. WE Soda will consequently represent a significant value proposition.

For us, it is about singling out the operational changes, innovations and standard-setting WE Soda can do to ensure we help our customers support their brands. Our aim is to operate responsibly and to provide products that enable better environmental outcomes.

Our Sustainability Plan lays out the detail behind the future of those operations. This is how we become a service provider to our customers, and turn what for many businesses would be a necessary but challenging journey into an opportunity.

Our aim is to update this annually. As mentioned earlier, we welcome all feedback, so please feel free to contact me if you have any comments or suggestions.

Alan Knight OBE, PhD. HonFSE
Chief Sustainability Officer, WE Soda

Principle 1: Soda ash makes an important contribution to sustainable development, particularly through the products it helps make.

This section explores soda ash's contributions to sustainable development from environmental, economic, and social dimensions.

Principle 1: Soda ash makes an important contribution to sustainable development, particularly through the products it helps make.

1.1 How Does Soda Ash Contribute to Sustainable Development?

Despite not being a household name, soda ash serves as an essential enabler of everyday modern life (Figure 1).

Beyond its importance in daily consumer products, soda ash is a fundamental input into a wide range of industries that directly and indirectly support sustainable development. It underpins cleaner technologies, supports resource efficiency, and, in doing so, contributes to environmental, economic, and social progress.

This section outlines, for each sector below, the specific role soda ash plays in production and how the resulting products contribute to sustainable development:

- Container glass
- Flat glass
- Solar panels
- Batteries and electric vehicles
- Powdered detergents
- Pollution control

Note: WE Soda does not seek to assert that soda ash is directly responsible for the contribution of these products to sustainable development. Rather, this section aims to illustrate how soda ash is indirectly linked to sustainable development through its role in the production of these products.

Figure 1 The role of soda ash in our daily lives[1].

Principle 1 continued

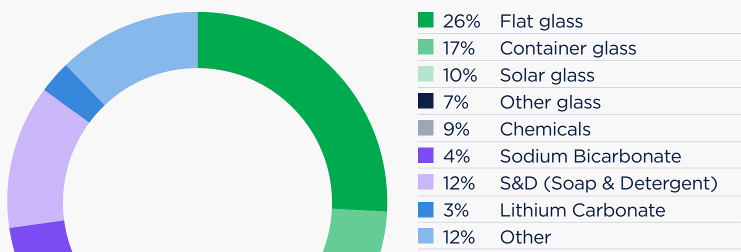
Glass

1.1.1 Container Glass

Container glass is the rigid, chemically inert, mechanically robust and transparent glass used in bottles, jars and similar packaging to preserve and hold beverages, foodstuffs and pharmaceuticals[2]. Glass in general accounts for approximately 60% of world soda ash consumption, with container glass accounting for 17% (Figure 2)[3]. Annual shipments of container glass are projected to rise from approximately 0.83 trillion units in 2024 to over 1.03 trillion units by 2029, reflecting a Compound Annual Growth Rate (CAGR) of about 4.3%, as consumers and manufacturers favour more sustainable packaging[4].

How does soda ash contribute to container glass production?

Soda ash is a fundamental raw material in the manufacture of virgin container glass, where it acts as a fluxing agent. By lowering the melting point of silica (SiO_2), it reduces the temperature required in the furnace, which in turn decreases fuel consumption (and, depending on fuel mix, CO_2 emissions) and refractory wear[5]. In a typical glass batch, soda ash accounts for approximately 12 to 15% of the total batch composition by weight, alongside silica and lime[6].



Source: Chemical Market Analytics by OPIS

Figure 2 Soda ash demand by sector in 2024[3].

Container glass' contribution to sustainable development.

Environmental

- **Glass offers strong environmental benefits:** Glass is infinitely recyclable, inert, contains no microplastics, and is reusable. However, its drawbacks such as high melting temperatures, transport weight, and limited recycling routes in some regions make its environmental benefits nuanced and dependent on several factors, including location, recycling rates, and waste content.
- **Closed-loop recycling and reuse:** The leading alternative to container glass is plastic (alongside paper, paperboard, and aluminium), with rigid plastics accounting for almost a 30% market share[7]. However, unlike plastic, container glass can be endlessly recycled without quality loss[8] and can be reused, unlike many forms of aluminium packaging. In a policy landscape where progress on a binding Global Plastics Treaty has stalled, this closed-loop potential gives container glass an even more significant sustainability advantage. By enabling the production of virgin glass, soda ash underpins a packaging material that can be continually recycled, reducing reliance on single-use plastics, curtailing landfill waste and conserving both energy and virgin raw materials.

  While soda ash is essential for producing virgin glass, greater energy efficiency and lower environmental impacts are achieved through the incorporation of cullet – recycled, broken, or waste glass. Incorporating cullet into glass manufacturing[8]:
  - Saves 1.2 tonnes of raw materials for every tonne of cullet used.
  - Reduces energy demand by 3% for every 10% of cullet used.
  - Avoids 250 – 300 kg of CO_2 emissions per tonne of cullet used.
  - Reduces the process emissions from carbonate decomposition.

However, in certain regions globally, the availability of high-quality cullet is limited, preventing it from playing a leading role in glass production. The significant variation in, and largely limited, global recycling rates is one of the core reasons for this, with the average recycling rate in the EU being 75%, but only 33% in the US and 21% globally[9], well below the levels required for a fully circular, cullet-based glass production system. As such, virgin glass production – and consequently the use of soda ash – will remain essential for the foreseeable future.

Economic

Thanks to its impermeability and chemically inert nature, virgin container glass plays a vital role in packaging – and therefore storage and transportation – across the food, beverage and pharmaceutical industries[10]. For example, its pharmaceutical applications include the storage and transport of medications in vials, syringes, and infusion bottles[11]. By enabling these sectors, container glass underpins vast areas of economic activity.

Principle 1 continued

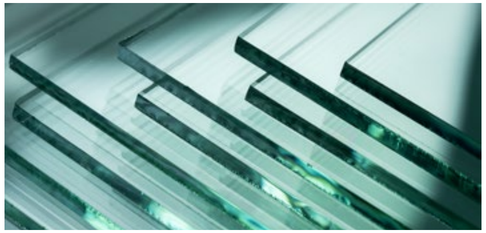
Social

- **Contribution to human health:** As briefly highlighted above, virgin container glass contributes directly to public health. For example, its:
  - Chemical inertness and barrier property preserve the potency and safety of pharmaceuticals in glass bottles, vials and ampoules[11].
  - Robustness and compatibility with cold-chain logistics enable the storage and transportation of temperature-sensitive biologics (e.g., vaccines, monoclonal antibodies), preventing thermal and chemical degradation and, ultimately, ensuring the stability and efficacy of the drug[12].
  - Impermeability to gases and moisture protects hygroscopic or oxygen-sensitive drugs (e.g., insulin) from degradation[13].
  - Collectively, these properties enable virgin container glass (and, indirectly, soda ash) to contribute to the preservation of medicine integrity, to extend shelf life and maintain safety during storage and transit – thereby enabling wider distribution of pharmaceuticals and enhancing health and wellbeing.

1.1.2 Flat Glass

Flat glass (often referred to as float glass) is manufactured by spreading molten soda-lime glass onto a bed of molten tin, resulting in a smooth and uniform surface[14]. It is a highly versatile material, with applications across windows, glass doors, mirrors, car windshields and backlights, as well as electronic screens. Flat glass is the largest end-use sector of soda ash, accounting for approximately 26% of total consumption (Figure 2), and demand is projected to increase further, with the global flat glass market expected to grow at a CAGR of 4.6% through to 2030[15].

How does soda ash contribute to flat glass production?



Similar to virgin container glass, soda ash is used as a fluxing agent to lower the melting point of silica in the production of virgin flat glass.

Flat glass' contribution to sustainable development

Environmental

- **Energy efficiency in buildings:** Flat glass, especially in windows of double and triple glazing, can be used to increase the energy efficiency of buildings through insulation and the use of natural light. Some studies have quantified this, for instance the transmissivity of one glass sheet is >90%, meaning proper daylighting designs for buildings can lead to a 30 to 50% savings in total energy bills compared with buildings relying primarily on artificial lighting[16]. This upgrading/retrofitting of infrastructure with flat glass, therefore, helps to reduce reliance on fossil fuels, which continue to dominate electricity production[17].
- **Energy efficiency in transport:** Flat glass plays a crucial role in the design of windscreens for cars, trains, and aircraft. Modern flat glass used in the automotive and aerospace sectors incorporates areodynamics, advanced coatings and lamination technologies that improve thermal insulation, reduce glare, and enhance UV protection. These features contribute to greater fuel efficiency by reducing the need for air conditioning and heating, thereby lowering energy consumption and related emissions[18].

Economic

- **Flat glass as a core component of industry:** Flat glass's unique physical and chemical properties (e.g., transparency, electric insulation, chemical inertness) make it one of the preferred construction materials. In fact, more than 80% of the global production of flat glass is used in the construction industry[16], which in turn contributes to around 13% of global Gross Domestic Product (GDP) and employs more than 100 million people[19]. About 15% of the remaining flat glass is processed into glazing for the automotive and transport industries, while 5% is shared between a variety of applications[20].

Social

- **Natural lighting and human wellbeing:** Buildings that maximise natural lighting (e.g., by installing more flat glass windows) can improve mood, reduce stress, and facilitate productivity among the people that use them, thus promoting better health outcomes[21].

Fibreglass for building insulation

Together with container and flat glass, other glass products also depend on soda ash for their manufacture. One of the most significant is fibreglass (i.e., glass wool), which is typically used as insulation in walls and roofs. Fibreglass insulation is made up of a combination of recycled glass cullet, sand, soda ash (11% of composition), limestone, borax and binding coatings[22]. In the same way as container glass and flat glass, soda ash reduces energy consumption by lowering the batch melting temperature, after which the molten glass is processed into fibres using rapidly rotating spinners[23]. Fibreglass is a cost-effective insulator – its low thermal conductivity of approximately 0.043 W/m·K significantly reduces the heat loss from buildings – helping to lower energy demand for heating and cooling[23,24,25].

Principle 1 continued

1.1.3 Solar Panels

Solar panels are systems made of photovoltaic (PV) cells that convert solar energy into electrical energy. They are made of semiconductor materials – covered by a layer of glass – that absorb sunlight and release electrons, generating an electric current in the process[26,27]. As demand for solar technology increases, forecasts project that glass consumption for photovoltaic manufacturing could rise to 259 million tonnes by 2100[28]. According to the International Energy Agency (IEA), global solar PV generation increased by a record 320 TWh (up 25%) in 2023, reaching over 1600 TWh. It demonstrated the largest absolute generation growth of all renewable technologies in 2023. This generation growth rate is close to the level envisaged from 2023 to 2030 in the IEA's Net Zero Emissions by 2050 Scenario[29].

How does soda ash contribute to solar panel production?

Soda-lime-silica glass is highly transparent, with only around 4% of visual light reflected per surface[16], making it well suited for use in PV applications. PV glass is produced from specifically processed soda-lime glass – typically low-iron, coated, laminated, and often tempered – to maximise light transmission, durability, and efficiency as the protective top layer of solar panels[30]. This application currently accounts for about 10% of global soda ash demand (Figure 2), but it is also the fastest-growing demand sector[3].

Solar panels' contribution to sustainable development.

Environmental

- **Renewable energy through solar panels:** PV glass acts as a protective layer for solar cells, both guarding against water and dirt, and improving the panel's overall productivity e.g., by providing low reflection. Solar panels can be stand-alone, feeding the electricity grid with renewable energy, or incorporated into buildings and windows to supply energy directly to the relevant recipients[30]. Both approaches support the upgrading of infrastructure and greater energy resilience and security. By enabling the large-scale and economically viable deployment of solar technology, PV glass directly advances the transition to low-carbon energy systems and long-term climate goals.

Economic

- **Cheap renewable energy growth:** Policy incentives and regulatory measures that lower financing costs have reduced the levelised cost of electricity (LCOE) for utility-scale solar PV, making it one of the lowest-cost sources of power generation globally. While recent oversupply has pushed module prices to record lows, potentially slowing short-term investment, the IEA still projects an increase in renewable energy capacity by more than 5500 GW of new renewable capacity between 2024 and 2030, with solar PV contributing nearly 80% of that expansion[31]. Cheaper renewable electricity generated through PV glass-enabled solar panels also lowers operating costs for households and businesses, increases industrial competitiveness, and reduces energy poverty. In these ways, PV glass contributes directly to the economic dimensions of sustainable development, acting as both a driver of industrial growth and an enabler of more affordable, stable and resilient energy systems.

Social

- **Poverty reduction in developing countries:** Solar energy, as a whole has created significant employment opportunities – around 12 million jobs worldwide – with a significant portion of these in the developing world (e.g., 70% in Asia). In particular, solar energy has enabled the growth of 'micro-enterprises' in developing countries[32], giving people not only the opportunity to improve their energy security (particularly important in regions where electricity grids are often unreliable or inaccessible[33]), but also to pursue new business opportunities that bolster income. As a key component in virgin solar glass manufacturing, soda ash plays a supporting role in expanding access to solar energy and, by extension, contributing to improved livelihoods.

1.1.4 The Challenge of Glass Production Process Emissions

More than 50% of the global demand for soda ash comes from glass production[3]. During the manufacturing process, soda ash is used in the melting of silica sand, where it decomposes, releasing CO_2 into the atmosphere[34]. Alongside fuel combustion at a high temperature and electricity generation, the emissions associated with the decomposition of carbonates are one of the primary sources of CO_2 emissions from glass manufacturing, making up a total of 18%[8]. For WE Soda specifically, this means over 30% of all our Scope 3 emissions, in 2024 came from glass production[1].

Solutions include increased use of cullet in glass production and Carbon Capture, Utilisation and or Storage (CCUS) technology[34,8]. But as well as innovation, the decarbonisation of glass production requires collaboration across different stakeholders and industries, for which there is a wealth of opportunities across the glass value chain[8]. Consequently, WE Soda is actively looking to collaborate with our customers and regulators to tackle these process emissions within the glass sector together.

Principle 1 continued

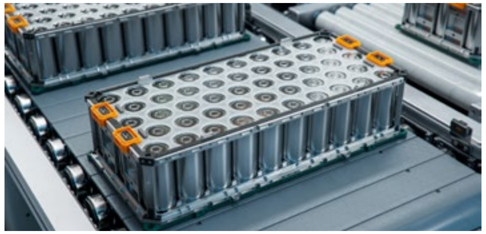
Batteries

1.1.5 Batteries and Electric Vehicles (EVs)

Batteries and EVs are central to the global energy transition[35]. Batteries store chemical energy and convert it into electric energy on demand[36]. They are indispensable for portable electronics, for balancing variable renewable energy generation on power grids, and for powering EVs[37]. Notably, EV market penetration has increased rapidly over the last decade: EVs accounted for 18% of global car sales in 2023[38]. This growth in uptake is reflected in battery demand, which exceeded 750 GWh for EV applications in 2023[39].

The majority of this growth in battery demand is being met by lithium-ion batteries. Global lithium-ion battery capacity reached 2.8 TWh in 2023 and is expected to more than double by 2030[40]. However, sodium-ion batteries are emerging as an alternative technology. The sodium-ion market, for example, was valued at $1.47 billion in 2024 and is projected to reach $6.25 billion by 2032[41]. This, when combined with recent industry announcements – such as BYD's $1.4 billion sodium-ion plant and CATL's second-generation sodium-ion platform – highlights the growing commercial interest and belief in the technology[42,43].

How does soda ash contribute to battery production?



Soda ash is a critical, if often overlooked, input across both lithium-ion and sodium-ion battery supply chains.

- **Lithium-ion:** Soda ash is used to convert lithium-bearing intermediates into lithium carbonate (Li_2CO_3)[44,45], a key precursor for cathode material across battery chemistries such as lithium iron phosphate (LFP), nickel manganese cobalt oxide (NMC), and nickel cobalt aluminium oxide (NCA), all of which rely on high-purity lithium compounds[39].
- **Sodium-ion:** Meanwhile, in some emerging sodium-based battery chemistries, soda ash provides the sodium required for cathodes and electrolytes (e.g., sodium iron phosphate). Given the abundance of soda ash, it supports scaling more geographically diversified and potentially lower-cost battery supply chains[46,47,38].

In this way, soda ash underpins both today's dominant lithium-ion technologies and tomorrow's sodium-ion alternatives.

Batteries' and EV's contribution to sustainable development.

Environmental

- **Decarbonising energy and transport:** Batteries are key enablers of renewable energy integration and the electrification of vehicles. When charged using renewable electricity, battery-powered systems significantly reduce fossil fuel consumption and associated greenhouse gas emissions, contributing to cleaner power grids and lower-emission mobility[48].
- **Resource efficiency and diversification:** While lithium-ion batteries remain dominant, sodium-based chemistries enabled by soda ash provide a pathway to reduce dependence on limited lithium reserves (estimated at ~9 million tonnes in Chile compared to ~23 billion tonnes of natural soda ash reserves in the US)[49,50]. This diversification improves long-term resource security, supports sustainable materials management, and reduces the environmental pressures associated with lithium extraction and processing[48].

Economic

- **Supporting high-value industries:** Batteries underpin a wide range of sectors, from portable electronics (supporting around 28 million jobs globally in 2022[51]) to the automotive and energy industries. Together, battery technologies and EVs are foundational to the growing digital and clean-energy economies, projected to represent around 17% of global GDP by 2028[52].
- **Lowering input costs and enhancing supply resilience:** Sodium carbonate is substantially cheaper than lithium carbonate – by approximately $12,850 per mt in 2019 data – and exhibits more stable price behaviour over time[50]. This cost advantage, combined with abundant supply, helps stabilise production costs for both lithium-ion and sodium-ion batteries, supporting affordable and resilient supply chains[48].

Social

- **Sustainable urban transport:** Unlike fossil fuel-powered vehicles, EVs emit zero air pollutants (e.g., particulate matter, NOx, hydrocarbons) at the tailpipe. Although EVs may still emit air pollutants at the point of resource extraction and electricity generation if not powered by renewables (and, like all motor vehicles, they emit some non-exhaust particulate matter locally), they produce lower street-level emissions of air pollutants. Alongside the environmental benefits mentioned above, this also reduces the risk of respiratory-related illness and premature death, and is especially important in more highly concentrated urban environments[53].

Principle 1 continued

Detergents

1.1.6 Powdered Detergents

Detergents are synthetic cleaning agents designed to remove dirt, stains, and impurities from clothing, dishes and other household items. The value of the global detergent chemicals market currently stands at around $60.3 billion, and is expected to achieve a CAGR of 4.8% from 2025 to 2032[54]. Alongside virgin glass and renewable energy applications, powdered detergents are a leading source of demand for soda ash[55].

How does soda ash contribute to powdered detergent production?

Soda ash and other similar compounds like sodium sesquicarbonate can be used as a detergent builder in powdered detergents, made desirable by both its absorptive and alkaline properties. Sodium carbonate sequesters calcium and magnesium ions – softening hard water and maintaining an elevated pH that boosts surfactant efficacy[56].

Detergents' contribution to sustainable development.

Environmental

- **Phosphate-free detergents:** Soda ash enables the formulation of phosphate-free powdered detergents by acting as a builder that softens water and maintains optimal alkalinity[57]. By replacing phosphates, it reduces the discharge of nutrient pollutants that contribute to eutrophication and algal blooms in aquatic systems[57]. Therefore, soda ash, as a powdered detergent ingredient, supports safer chemical management and lowers the ecological footprint of detergent use.

Economic

- **Cost efficiency:** Sodium carbonate is generally more cost-effective than other detergent builders. It will therefore be critical for ensuring access to powdered detergent, particularly as the growing middle class in developing economies on the Asian and Latin American continents drives demand for modern laundry technologies[56].

Social

- **Enhanced hygiene via detergent:** Soda ash improves powdered detergent performance by helping to maintain an elevated pH that boosts surfactant efficacy[56]. By increasing the effectiveness of powdered detergent, soda ash supports communal sanitation (e.g., laundering bedding, or cleaning shared facilities), which helps reduce pathogen loads. This, in turn, lowers the risk of infectious diseases, advancing access to adequate and equitable sanitation and hygiene for all.

Pollution Control

1.1.7 Pollution Control Devices

Pollution control regulation has become stricter over time – for example, the EU Industrial Emissions Directive[58], the US Clean Air[59] and Clean Water[60] Acts. A standard requirement under these regulations is the use of Best Available Technology/Techniques (BAT) to limit pollutants. Soda ash is a key ingredient in many of the techniques used to reduce pollution.

How does soda ash contribute to pollution control?

Soda ash can be used to help control polluting substances from industrial waste, both in water and air. The use of sodium carbonate as a precipitant and a sorbent is listed as part of the EU BATs for wastewater and waste gas treatment for substances including heavy metals (e.g., lead) and sulphur dioxide[61]. The market share of soda ash used for pollution control is more challenging to pinpoint; however, this could be because the sodium carbonate used for these processes can also come from waste streams of the soda ash production[62,63].

Pollution controls contribution to sustainable development.

Environmental

- **Wastewater heavy metal removal:** Sodium carbonate is widely used in wastewater treatment to raise alkalinity and shift pH into the optimal range for precipitating dissolved heavy metals as insoluble hydroxides or carbonates, meaning harmful substances can more easily settle out of water[64]. Industrial reports confirm that sodium carbonate can remove over 95% of lead from plating and battery effluents by shifting solution pH above 10, reducing dissolved heavy metal concentrations to below regulated limits[65]. By removing toxic metals from effluents, soda ash protects aquatic ecosystems, directly contributing to reductions in pollution and the release of hazardous chemicals.
- **Flue-gas desulphurisation:** Desulphurisation is critical in industries such as coal-fired power that emit sulphur dioxide as a by-product. Soda ash's alkalinity reacts with these acidic gases, a process that can achieve sulphur dioxide removal efficiencies of between 90 to 95%[66]. This consequently reduces pollution of the atmosphere, as well as rainwater acidification, which damages forests and freshwater bodies[67]. It must be noted that the process of desulphurisation using soda ash does also generate CO_2.

Economic

- **More cost-effective pollution control:** Soda ash can be a more economical option for pollution control. For example, using soda ash as the precipitating agent in wastewater treatment results in a lower volume and a larger particle size of sludge, which can make the subsequent drying process more cost-effective[68].

Social

- **Pollution control for human health:** At the same time as protecting the health of ecosystems, pollution control using soda ash mitigates human health risks. For example, metal mining and smelting can increase surface water contamination by heavy metals such as lead, zinc and cadmium, which are all toxic to humans[62]. By removing toxic metals from effluents, soda ash can help to reduce the number of illnesses from these hazardous substances.

Principle 1 continued

1.2 Conclusion

This section has outlined how soda ash supports sustainable development – both as a direct input in cleaner industrial processes and as a component of products that enable environmental progress. Soda ash can help minimise greenhouse gas emissions by reducing energy use in glass processes, remove chemical pollutants from other industrial processes, improve resource efficiency by creating highly recyclable products namely glass, and it underpins the global transition to renewable energy.

Beyond its environmental role, soda ash supports economic resilience by serving as an abundant and cost-effective raw material across multiple sectors. Its use also contributes to social sustainability by reducing health risks associated with toxic substances such as phosphates and heavy metals, and by enabling broader access to affordable, low-carbon technologies.

In this way, soda ash plays a vital role in advancing an environmentally responsible, economically viable, and socially equitable future.

Thus, the sustainability case for soda ash-enabled materials/products (or any materials made from raw materials) rests on a systems-level response across the value chain. Coordinated action and continued innovations aimed at maximising net benefit (designing for longevity, enabling recycling, improving manufacturing efficiency) will be critical for reducing both embodied and process-related emissions and realising genuine net-positive outcomes.

The evidence presented above supports the first principle in our approach to sustainability – that soda ash makes an important contribution to sustainable development, particularly through the products it helps make.

Principle 2: Primary solution mined natural soda ash has better sustainability credentials than synthetic soda ash.

This section lays out the different processes and systems behind soda ash production, showing how these impact the environment.

Principle 2: Primary solution mined natural soda ash has better sustainability credentials than synthetic.

What is Soda Ash?

Soda ash, or sodium carbonate (Na_2CO_3), is an alkali chemical that has been utilised for over 5,000 years for various purposes. It is an inorganic compound that, under standard conditions of temperature and pressure, forms as a white, odourless, water-soluble salt. Sodium carbonate was originally discovered by ancient Egyptian civilisations, who extracted it from dry desert lake beds or produced it by burning sodium-rich marine plants like kelp and seaweed. This resulted in the ash that led to its common name, 'soda ash'[69].

The Egyptians first used soda ash to lower the melting point of silica sand to manufacture glass vessels and ornaments, a technique that remains central to virgin glass production today, The Romans further utilised its related compound, sodium bicarbonate, for medicinal purposes and for baking bread. Successive generations continued to produce soda ash using these 'natural' methods until the mid-1800s Industrial Revolution, which saw the development of synthetic production techniques to increase supply[69].

Today's global soda ash industry relies on two principal routes of production: extraction from natural trona deposits, and synthetically via the ammonia-Solvay (ammonia-soda) or the modified ammonia-Solvay (Hou) process. While synthetic soda ash currently dominates the market, recent capacity expansions in China and the US have increased natural soda ash's share of global production to 33% in 2024 – a rise of 5% since 2018[49,70].

The next section of this Evidence Book outlines the operational context and presents the quantitative data supporting these observations, produced using WE Soda[1] and publicly available data analysed by FGE NexantECA[71]. It is important to note that the processes described are high-level overviews, and there may be variations in approach between different facilities and companies.

Principle 2 continued

2.1 What is Trona?

Trona is a naturally occurring evaporite mineral composed primarily of sodium sesquicarbonate dihydrate ($Na_3H(CO_3)_2 \cdot 2H_2O$)[72]. The formation of today's economically viable trona deposits occurred over millions of years through a series of natural geological and chemical processes. There are several theories as to how these deposits formed, including leaching of alkaline carbonatites, thermal spring evaporation, bacterial sulphate reduction, CO_2 absorption, and ion exchange. One of the leading depositional theories is:

Step 1: Evaporation of Alkaline Lakes: Millions of years ago, large, shallow lakes existed in regions with warm climates and low rainfall. These lakes, fed by surface streams and thermal springs and surrounded by sodium-rich volcanic and magmatic rocks, became enriched with sodium, carbonate, and bicarbonate ions. As the lake water evaporated, the concentration of these dissolved minerals increased over time.

Step 2: Precipitation of Trona: Once the concentration of carbonate and bicarbonate reached saturation point, trona began to crystallise out of the solution and accumulate on the lakebed. This process is similar to how sodium chloride (table salt) crystallises when seawater evaporates.

Step 3: Burial and Preservation: Over time, sediment from surrounding rock layers buried the trona deposits, protecting them from erosion and ensuring their long-term preservation[72,73]. Four main trona provinces are recognised globally, spanning Türkiye, the US, China and Botswana (Figure 3).

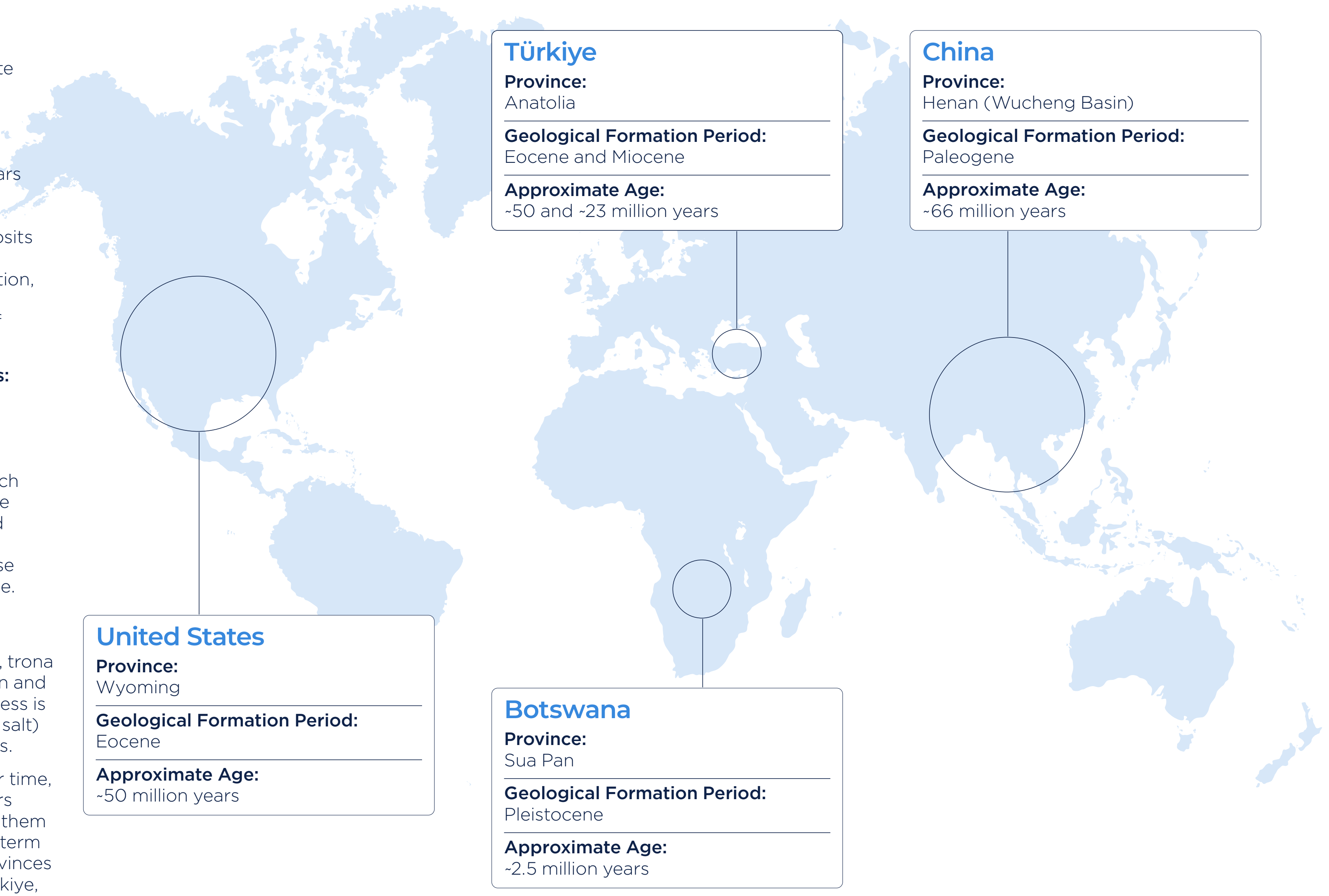


Figure 3 A graphic to show the distribution of the four main globally recognised trona deposits[73,74,75].

Principle 2 continued

2.2 Soda Ash Production Methods

Although the basic geological process that forms trona is generally the same across the world, variations in geological conditions lead to significant differences in the final characteristics of each deposit. For example, in some areas, trona is found in thin layers, while in others it forms thick beds. The depth at which deposits are found also varies significantly, with some found close to the surface and others several hundred metres underground[75]. The variation in the morphology – the shape and structure – of these deposits directly influences both the economic feasibility and the safety of their extraction, consequently requiring different extraction methods. For example, a thin and deep-seated bed is unlikely to warrant the costs and risks of conventional mining.

These geological differences are reflected in the operational strategies of producers such as WE Soda. In Türkiye, where trona deposits are typically thin and located deep underground, we employ a method known as primary solution mining, as conventional mining is not feasible[75]. Following our acquisition of Genesis Energy's trona operations in Wyoming, we now oversee operations that cover all forms of natural soda ash extraction and production, including secondary solution mining as well as conventional longwall mining.

In order to compare the environmental and sustainability credentials of natural and synthetic soda ash production, it is important to first understand the underlying processes that sit behind them. Therefore, in the following section, a high-level overview of each production method is outlined.

2.2.1 Primary Solution Mining

Primary solution mining is a technique that involves dissolving subterranean soluble deposits (in this case, trona) using heated water and then pumping the brine to the surface for processing. This is the technique WE Soda uses in Türkiye.

Preparatory Step: Drilling Wells:
The process begins with the drilling of a series of wells into the trona deposit, typically comprising several vertical wells that intersect a horizontal well, as illustrated in Figure 4. This well design maximises contact with the mineral seam while minimising surface impact.

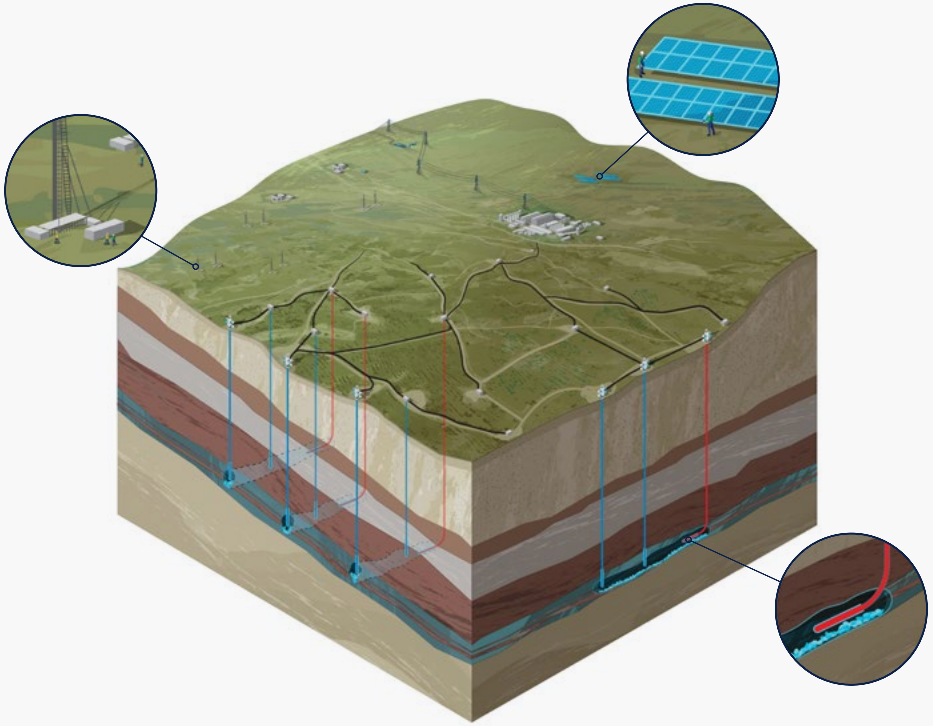


Figure 4 Model of the primary solution mining extraction process[1].

Principle 2 continued

Step 1: Injecting Hot Water:

Heated water is then injected into the trona deposit through the wells, causing the trona to dissolve and form a concentrated solution known as trona brine. Moreover, insoluble materials such as shale and clay remain underground, eliminating the need for extensive solid waste handling at the surface.

The water and energy used in this process are largely sourced from the recycling of water recovered during downstream crystallisation stages, introducing a significant element of circularity to the process, reducing overall inputs and minimising waste.

Step 2: Pumping the Brine to the Surface:

The trona-rich brine is then pumped to the surface, where the dissolved minerals can be processed (Figure 5).

Note: Once a well set or cavern is exhausted, WE Soda ensures safe closure. The caverns are kept pressurised with air or water to maintain their structural integrity and prevent subsidence. This pressure is carefully monitored and maintained to minimise environmental impact and ensure long-term stability.

Once above ground, the brine progresses through several carefully controlled stages to produce high-purity dense soda ash.

Step 3: Filtration:

The brine is first filtered to remove any trace suspended solids, ensuring only the brine proceeds through the remaining system.

Step 4: Evaporation and Wet Calcination (Stripping):

The filtered brine is then subjected to evaporation and steam stripping. In this step, water is removed, and sodium bicarbonate in the solution is thermally decomposed according to the following reaction:

$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$

This process, sometimes referred to as wet calcination[76], increases the concentration of sodium carbonate in the brine – an important step in the formation of dense soda ash. The water vapour generated, along with steam for evaporation, is condensed and reused in the process to improve water and energy efficiency. Furthermore, some of the CO_2 released is captured and reused in later stages for sodium bicarbonate production.

Step 5: Crystallisation:

The concentrated sodium carbonate solution is then cooled to promote the crystallisation of sodium carbonate decahydrate ($Na_2CO_3 \cdot 10H_2O$). The chemical structure of the crystals – one sodium carbonate formula unit with ten water molecules incorporated into the crystal lattice of the compound – means that the obtained decahydrate crystals are extremely pure, and a large percentage of any dissolved impurities are purged from the crystalliser.

To further improve the efficiency of the process and reduce excess waste, the purge liquor (liquid waste from the crystalliser) is mixed with slaked lime, as seen in the soda-lime process:

$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3$

This reaction yields sodium hydroxide (NaOH), which is fed back into the system before the deca-crystalliser to react with the remaining bicarbonate ions and eliminate excess bicarbonate concentration, thereby increasing the overall yield of sodium carbonate.

$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O$

Step 6: Re-dissolution and Monohydrate Crystallisation:

The purified decahydrate crystals are then re-dissolved and crystallised again to reduce the water content of the soda ash, forming a monohydrate ($Na_2CO_3 \cdot H_2O$). The evaporated water and energy is recovered as steam condensate for reuse in the process.

Step 7: Drying and Calcination:

The final step involves drying and calcination – a controlled heating process that converts the monohydrate crystals into pure, dense anhydrous soda ash (Na_2CO_3).

$Na_2CO_3 \cdot H_2O \rightarrow Na_2CO_3 + H_2O$

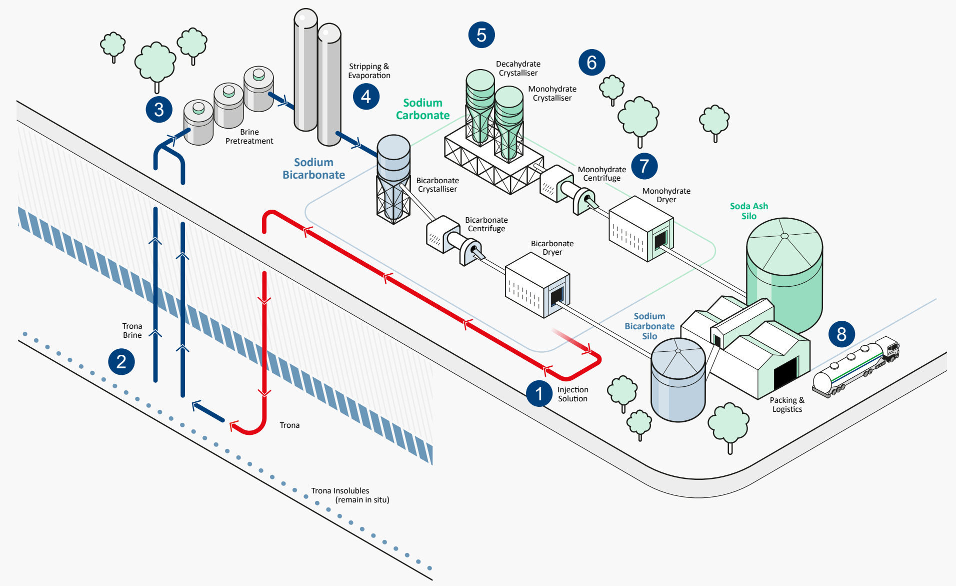


Figure 5 High-level overview of WE Soda primary solution mining operations.

Principle 2 continued

2.2.2 Conventional Mining

A high-level summary of the conventional mining method is outlined below.

Step 1: Trona Ore Extraction

In contrast to primary solution mining, conventional mining involves physically removing the solid trona ore from underground using mechanical means. Two common methods account for the vast majority of underground mining, which are:

- **Longwall Mining:** The longwall mining employed at Westvaco, is a highly mechanised underground method used in the extraction of trona ore. In this process, a long wall of trona, typically several hundred metres wide and extending for kilometres, is mined in a single continuous operation. Hydraulic roof supports protect the equipment and workers as a shearer cuts the ore, which is conveyed to the surface for processing. As mining advances, the roof behind the supports is allowed to collapse in a controlled manner.
- **Room and Pillar Mining:** Involves excavating a network of alternating open spaces and large pillars of ore.

Step 2: Surface Crushing and Screening

Once brought to the surface, the raw trona ore is mechanically crushed and screened to reduce particle size and remove any oversized materials.

Step 3: Calcination

Unlike primary solution mining, where trona is first dissolved, conventional mining typically involves dry calcination of the solid ore. The trona undergoes thermal decomposition in rotary kilns or fluidised bed reactors, which is relatively energy intensive due to the high thermal input required for calcination.

$$2(Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O) \rightarrow 3Na_2CO_3 + 5H_2O + CO_2$$

This produces anhydrous soda ash (Na_2CO_3), with water vapour and carbon dioxide as by-products.

Step 4: Impurity Removal and Refinement

Post-calcination, the crude soda ash may still contain insoluble impurities that must be separated. Depending on the final product's purity requirements, this can involve one or more of:

- Dry air classification
- Water washing or re-dissolution followed by filtration and crystallisation

Post-mine Extraction (Secondary Solution Mining)

Following the completion of conventional mining processes, the mine can be flooded, dissolving any remaining trona, which can then be extracted and processed similarly to the primary solution mining process. This production method is employed at WE Soda's Granger operation and within the ELDM plant at Westvaco.

Principle 2 continued

2.2.3 Synthetic Production

There are two typical methods of synthetically producing soda ash – the ammonia-Solvay process and the modified-Solvay process, also commonly known as the Hou process. The Hou process is predominantly utilised within China, contributing to approximately 49% of the country's soda ash production[77]. Outside of China, however, the ammonia-Solvay process is significantly more dominant, and the Hou process is rarely used due to its higher production costs. Given this distribution, it can be estimated that the Hou process accounts for roughly 25% of global synthetic soda ash production, with the ammonia-Solvay process responsible for the remaining 75%. For this reason, the following section will focus on the ammonia-Solvay process.

Step 1: Ammoniation and Carbonation

The synthetic production of soda ash begins with the preparation of ammoniated brine. This involves dissolving ammonia gas (NH_3) into a concentrated sodium chloride solution (NaCl), forming an ammoniated brine solution. Under controlled temperature and pH conditions, CO_2 is generated through the calcination of limestone, typically using coal coke or anthracite, and this CO_2 is then bubbled up through the ammoniated brine, as per the following reaction:

$$NaCl+NH_3+CO_2+H_2O \leftrightarrow NaHCO_3+NH_4Cl$$

Sodium bicarbonate ($NaHCO_3$) precipitates out of the solution due to its relatively low solubility at these conditions. The solid is then separated from the liquid via filtration, leaving behind an ammonium chloride-rich liquor.

Step 2: Calcination of Sodium Bicarbonate

The filtered sodium bicarbonate is then heated. This thermal decomposition converts sodium bicarbonate into the final product – soda ash (Na_2CO_3) – while releasing water vapour and carbon dioxide.

$$2NaHCO_3 \rightarrow Na_2CO_3+H_2O+CO_2$$

Step 3: Ammonia Recovery

Currently, almost all ammonia on the market is produced via steam methane reforming of natural gas[78]. Consequently, the CO_2 footprint of this process is relatively high (about 2–3 $mtCO_2e/mt$)[78]. The recycling of ammonia is therefore critical in synthetic soda ash production and producers typically attempt to regenerate the ammonia used in the initial brine treatment. To do this, the ammonium chloride by-product from the carbonation stage is reacted with lime, which in practice is often slacked ($Ca(OH)_2$) in a dedicated recovery unit.

$$2NH_4Cl+CaO \rightarrow 2NH_3+CaCl_2+H_2O$$

This reaction releases ammonia gas, which is recycled back into the brine tower in stage one. However, it also produces calcium chloride ($CaCl_2$), a waste by-product that has limited reuse potential in most markets and is typically disposed of via waterways, which can damage the local environment.

Note: In the Hou process, ammonium chloride (NH_4Cl) is crystallised and sold as a fertiliser. However, the overall CO_2 footprint of this process is even higher due to the need to replace the reacted ammonia feedstock each time.

Step 4: Lime Production

The lime required for ammonia recovery is produced onsite by calcining limestone ($CaCO_3$).

$$CaCO_3 \rightarrow CaO+CO_2$$

This is a major source of CO_2 emissions in the ammonia-Solvay process and contributes significantly to its overall carbon footprint. And, while the CO_2 generated in this step can be captured and reused in the carbonation stage, the high energy requirements and a reliance on coal coke or anthracite mean that indirect emissions from energy generation can be significant.

Step 5: Production of Dense Soda Ash

The initial obtained soda ash from the calcination of bicarbonate is called Light Soda Ash (LSA), on account of its relatively low bulk density (0.55 – 0.7 t/m^3). If a high-density soda ash product is required, the anhydrous LSA undergoes additional processing. First, the LSA is hydrated to form sodium carbonate monohydrate ($Na_2CO_3 \cdot H_2O$). This intermediate is then re-calcinated at 170°C to remove the bound water and obtain a high-density soda ash product. Mechanical compaction can also be used to densify the final product.

Principle 2 continued

2.3 Primary Solution Mined Natural Soda Ash's Environmental Advantage

The following section outlines the evidence supporting our position that some methods of natural soda ash production have a lower environmental impact than others. For our first Evidence Book, we have focused mostly on primary solution mining, given our long-term base in Türkiye. Future Evidence Books will contain more information on how we are developing other processes at our sites in Wyoming.

Environmental impact can, in its simplest form, be grouped under four core metrics:

1. Carbon
2. Energy
3. Water
4. Waste

We acknowledge impact on nature as another key metric which will be incorporated into future Evidence Books.

For each metric, the following section breaks down the evidence comparing the natural and synthetic production methods. This is done in two parts:

- A qualitative assessment, drawing on process comparisons and published literature.
- A quantitative analysis of carbon, energy, water and waste intensities, based on analysis from the recently commissioned FGE NexantECA report[71].

2.3.1 Carbon

Raw material sourcing and associated emissions

One of the principal advantages of using trona ($Na_3H(CO_3)_2{\cdot}2H_2O$) as a feedstock for soda ash (Na_2CO_3) manufacture is that it is already chemically similar to the desired product. In effect, geological processes over millions of years have done much of the pre-processing.

By contrast, the ammonia-Solvay process involves several energy-intensive stages and additional reagents – namely ammonia (NH_3), limestone (calcium carbonate, $CaCO_3$), coal coke or anthracite for calcining limestone, and brine (sodium chloride, NaCl). Ammonia, for example, is predominantly synthesised via the Haber–Bosch process, in which nitrogen (N_2) and hydrogen (H_2) are reacted at high temperatures (400–500 °C) and high pressures (150–300 bar). Furthermore, the hydrogen is typically produced by steam methane reforming of natural gas, itself a significant source of CO_2 emissions, highlighting the significant carbon emissions that can be associated with sourcing the raw materials for synthetic soda ash production.

Estimated emission factors for key soda ash raw materials are outlined below in Table 1 – these do not include transport emissions:

Raw material	Emission factor ($mtCO_2e$/mt)
Brine	0.002
Coke – US & Europe	0.713
Coke – China	1.395
Natural gas	0.423
Limestone	0.039
Ammonia: Natural gas, Europe	2.351
Ammonia: Coal, China	4.368
Caustic (100% wt%)	0.530
Lime	1.193
Carbon dioxide	(1.000)

Table 1 Soda ash raw material emissions factors[71]

Legacy plants and process chemistry

Many soda ash plants are over 50 years old and continue to use their original legacy technologies[71]. As a result, fossil fuels (particularly coal) remain a large part of the fuel mix used to generate the high temperatures needed to break the inorganic chemical bonds in synthetic processes such as limestone calcination – a process which is not required in natural soda ash production.

However, it is important to note that operators across all production methods – including synthetic, conventional, and solution mining – are actively working to modernise facilities, optimise energy use, and reduce environmental impacts. Upgrades to plant infrastructure and fuel switching, especially to biomass and waste, are examples of efforts being implemented sector-wide (see Section 2.5). While the baseline challenges differ between production routes, there is a broad commitment across the industry to improving sustainability performance.

Principle 2 continued

Natural vs. synthetic soda ash carbon intensity benchmarking and key insights

Carbon intensity benchmarking carried out by FGE NexantECA finds that:

Best-in-class Natural Outperforms Best-in-class Synthetic

- On an ex-works and product basis, meaning Scope 1, 2 and upstream Scope 3, soda ash produced at WE Soda's Eti facility (0.40 mt CO_2e/mt) has a 30% lower CO_2 intensity than the best synthetic performer (ammonia-Solvay Process – 100% biomass: 0.58 mt CO_2e/mt).
- Biomass offers decarbonisation opportunities for steam and energy production of both natural and synthetic production and is being utilised at varying scales at a handful of sites, although analysis of external factors such as fugitive emissions and life-cycle impacts of fuel sourcing will be essential to fully assess the net decarbonisation potential.

How carbon intensity varies across different soda ash producers

Figure 6 A graph to show how carbon intensity (Scope 1, 2 and Scope 3 (upstream)) varies across different soda ash producers[71].

Principle 2 continued

Synthetic Production

- Soda ash produced using coal as an energy source, either through the Hou process at 2.24 mt CO_2e/mt where no allocation to co-products occurs, or the ammonia-Solvay process where between 1.40 and 1.68 mtCO_2e/mt is 70 to 80% more emissions intensive than primary solution mining.
- Synthetic soda ash produced through the ammonia-Solvay process when powered by natural gas has a carbon intensity ranging from 0.97 to 1.04 mtCO_2e/mt, 60% higher than primary solution mining.

Synthetic Production vs. Conventional Mining

- Soda ash produced through conventional mining at Westvaco has a carbon intensity of 0.91 mtCO_2e/mt. This is 5 to 10% lower than the ammonia-Solvay process using natural gas and over 30% lower than the ammonia-Solvay process using coal. When using 100% biomass the ammonia-Solvay process can have 40% lower CO_2e intensity.

Transportation Emissions

One area where synthetic soda ash may appear to have an advantage over natural soda ash is in downstream freight emissions. Since natural soda ash production is tied to the location of trona deposits, transport distances to end markets are often longer than for synthetic producers, who can site plants closer to demand centres. This typically results in lower downstream freight (i.e., Scope 3 downstream transportation) emissions for synthetic soda ash, although this does not change primary solution mined soda ash's carbon intensity advantage.

While downstream freight emissions may be higher for natural soda ash, soda ash delivered from Eti, as shown by FGE NexantECA analysis (best-in-class primary solution mining) to Northern Europe (Terneuzen, Netherlands) is still around 20% lower footprint than the best-in-class synthetic. For example, product transportation from Eti, via inland truck transport to Derince Port and onward bulk carrier to Terneuzen, accounts for ~0.07 mt CO_2e/mt of the total product carbon intensity. This gives a delivered emissions intensity at the port of Terneuzen of 0.46 mt CO_2e/mt, which is approximately 20% lower than the best-in-class synthetic route at the factory gate, which stands at 0.58 mt CO_2e/mt (biomass-based), without accounting for its downstream transportation[71].

2.3.2 Energy

The ammonia-Solvay process and the Hou process have an energy intensity of approximately 2.2-2.7 MWh/mt. This high energy usage is primarily due to the calcination of 1.0-1.8 mt limestone per mt soda ash, which requires sustained temperatures of approximately 950-1100°C, and the regeneration of ammonia, both of which are thermally demanding. Beyond thermal energy, the process also relies heavily on electricity for auxiliary operations such as pumping large volumes of cooling water, carbon capture and recovery systems, and saline water refining[83]. In contrast, all forms of natural soda ash production operate at much lower temperatures, resulting in substantially lower energy demands.

Natural vs. Synthetic Energy Soda Ash Intensity Benchmarking and Key Insights

Energy intensity benchmarking carried out by FGE NexantECA finds that:

- Synthetic production has a higher energy demand than natural production methods.
- The ammonia-Solvay process has an energy intensity of around 2.2 MWh/mt.
- The Hou process is slightly less efficient at 2.7 MWh/mt.

Synthetic methods are more energy intensive

- The energy intensity of the ammonia-Solvay process is over 60% higher than the best-in-class primary solution mining at 0.8 MWh/mt (Eti).
- While all forms of natural production exhibit lower energy intensities than all synthetic, the differences are less pronounced.

How Scope 1 & 2 energy intensity varies across different soda ash producers

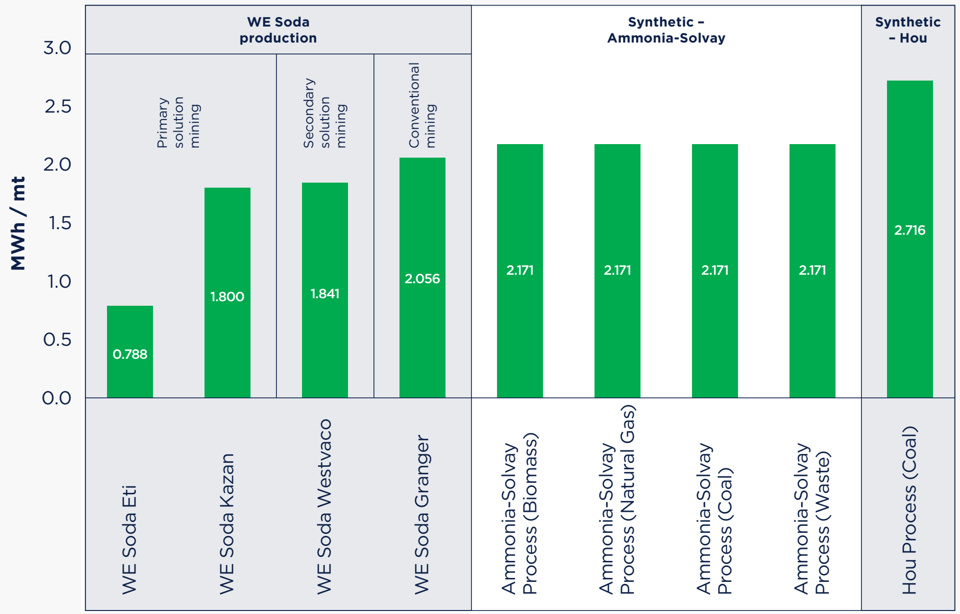


Figure 7 A graph to show how energy intensity varies across different soda ash producers[71].

Principle 2 continued

2.3.3 Waste

Natural soda ash production via solution mining dissolves trona underground, leaving insoluble materials (e.g., clay, shale) in situ. This approach limits the generation of surface solid waste and, subsequently, the need for extensive solid waste handling.

The process can produce similar quantities of co-products to synthetic production (deca-purge, calcium carbonate and salt), which can be either reused in the process in the production of other products in the case of deca-purge or sold. WE Soda's approach to these co-products can be found in our Sustainability Plan.

By-products from Synthetic Production

In natural soda ash production, the mother liquor – the liquid left over after crystallisation – is rich in residual sodium carbonate. This is causticised with lime, the products of which are reused to improve the efficiency of the process and minimise the volume of purge stream requiring treatment and disposal.

In contrast, synthetic production produces large volumes of calcium chloride as a by-product, a chemical for which demand is far lower than supply. As a result, much of it is disposed of, often into waterways, where it contributes to local degradation[79]. Furthermore, depending on the effectiveness of post-production wastewater treatment, other suspended solids can also be discharged into the environment, such as calcium carbonate ($CaCO_3$), calcium sulphate ($CaSO_4$) and calcium hydroxide ($Ca(OH)_2$). These often form slurry-like solids and accumulate on the bottom of the waters into which they are discharged[79].

To mitigate this, some ammonia-Solvay plants direct their effluent to sedimentation ponds, allowing solid particles to settle before discharging the liquid into the environment. However, this process is not 100% effective. The raw effluent from the ammonia-Solvay process often has a pH greater than 11.5, making it highly alkaline. If not neutralised beforehand, this can significantly impact the pH of the natural water that the waste is disposed into[79].

Additionally, the ammonia-Solvay process introduces trace heavy metals into effluents and solid wastes via raw material inputs. Approximately 64% of heavy metals in the waste stream originate from limestone, 21% from fuel (typically coke), and around 5% from the salt brine[83]. The most frequently detected elements include zinc, lead, cadmium, and chromium. EU data indicate that the total load of analysed heavy metal entering the EU soda ash plants represents a quantity of approximately 73 g/tonne of soda ash[83]. These metals pose a risk of bioaccumulation and persistent contamination in aquatic and sedimentary environments if not effectively controlled[80]. It should be noted that data on heavy metal concentrations in waste streams from natural soda ash production remain limited.

Raw Material Sourcing and Associated Impacts

As outlined in Section 2.2, the ammonia-Solvay process relies heavily on the sourcing of various raw materials such as:

Limestone: Limestone is a sedimentary rock that is typically mined from open quarries, although several underground mines also exist. Benchmarked synthetic producers used an estimated 1.0-1.8 mt of limestone per mt of product[83]. A smaller amount of limestone is used in natural production routes as a raw material in the production of lime. Notably, waste from limestone mining has broad and often long-lasting effects on ecosystems, air and water quality, and the physical landscape[81], for example:

- In some cases, limestone deposits also serve as aquifers. Where this occurs, there is a risk that oil, fuel and waste from limestone mining operations can pollute nearby surface water and groundwater bodies.
- Mining/quarrying can expose limestone to rainwater or shallow groundwater. This exposure can subsequently dissolve the limestone, creating caves and sinkholes, which can eventually collapse[81].
- Quarrying requires the clearance of vegetation and removal of fertile topsoil, which disrupts biodiversity. Waste material is also often dumped, causing soil degradation and affecting soil quality[81].

Principle 2 continued

Sodium Chloride/Brine (NaCl): Another raw material required for the production of soda ash using the ammonia-Solvay process is sodium chloride. This can be sourced from saltwater (typically from desalination plants) or extracted from the seabed or salt mines[80], and typically contains impurities such as magnesium, calcium and sulphate. Benchmarked synthetic producers used an estimated 1.60 mt of brine per mt of product produced.

- The discharge of concentrated saltwater can increase the salinity of nearby water bodies, harming freshwater ecosystems and benthic fauna and flora[83].
- In salt mining operations, dust can be generated from the mining process. This dust can contain harmful particulate matter that can impact air quality.
- Desalination surface water intake poses a threat to marine life, impinging and entraining fish, larvae and fish eggs[83].

Natural vs. Synthetic Waste Intensity Benchmarking

- Both the ammonia-Solvay process (coke kiln) and ammonia-Solvay process (natural gas kiln) produce an estimated 1.04 mt of waste calcium chloride per mt of product[71].
- In that same year, WE Soda published a total waste disposal intensity of 0.02 mt per mt of product. However, the total amount of co-products produced that are either sold, reused or stored for further processing are comparable.

2.3.4 Water

Water Recycling in Primary Solution Mining Natural Production

Primary solution mining operations, condense and reuse water from evaporation and calcination stages in the brine-processing loop. This significantly reduces freshwater withdrawals and promotes a circular use of water within the plant.

High Water Demand and Pollution in Synthetic Production

Many unit operations of the ammonia-Solvay soda ash process are exothermic, meaning that they release significant amounts of heat. Additionally, as outlined in Section 2.2.3 the operating temperatures required in the ammonia-Solvay process are high. As a consequence, many of the process units require extensive cooling, which is typically achieved through open-loop water systems where large volumes of river or lake water (up to 100m³ per tonne of soda ash) are withdrawn and later discharged. However, the temperature of the discharged water is typically greater than the ambient water it is being discharged into, which can cause thermal pollution[83]. Elevated water temperatures can lower dissolved oxygen saturation levels[84] and increase the proliferation of algae (which can decrease oxygen levels even further), ultimately impacting local habitat and ecosystem function[85]. In some cases, cooling water is blended with more withdrawn water to reduce the temperature before discharge. This further increases overall water usage and disruption to the local environment. While natural soda ash production also involves heating, it is significantly lower and the amount of cooling water required is therefore greatly reduced.

Natural vs. Synthetic Water Intensity Benchmarking and Key Insights

Water intensity benchmarking carried out by FGE NexantECA finds that:

Synthetic Production Demands Vastly More Water

- The ammonia-Solvay process regardless of fuel type has a water intensity of 11.26 m³/mt.
- The Hou process (100% coal) at 9.42 mt/mt is marginally more water-efficient than the ammonia-Solvay route.
- Primary solution mining has a water intensity of 1.68 at Eti and 2.25 at Kazan, around 80% lower than the ammonia-Solvay process.

How water intensity varies across different soda ash producers

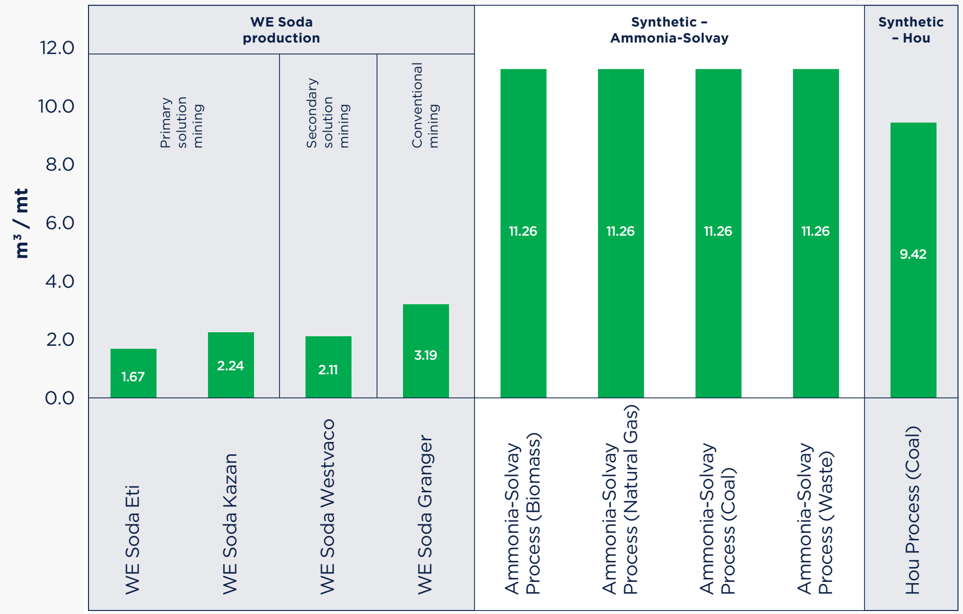


Figure 8 A graph to show how water intensity varies cross different soda ash producers[71].

Principle 2 continued

2.4 Conclusion

In conclusion:

- **Carbon:** Primary solution mining benefits from trona's inherent geological processing, resulting in emissions intensity from Scope 1, 2 and upstream Scope 3 of between 0.40 and 0.44 $mtCO_2$/mt, 30% lower than the best-in-class synthetic using biomass at 0.58 $mtCO_2$/mt and 60% lower than those using natural gas at 0.97 $mtCO_2$/mt.
- **Energy:** Primary solution mining uses between 0.8 MWh/mt and 1.8 MWh/mt compared to 2.2 MWh/mt for synthetic production.
- **Waste:** Primary solution mining produces a comparable quantity of co-products to synthetic production, however these co-products (deca-purge, calcium carbonate and salt) can be more readily valorised than those produced in synthetic production (calcium chloride).
- **Water:** Primary solution mining uses between 1.7 m^3/mt and 2.3 m^3/mt of water, 60 to 80% lower when compared to 11.3 m^3/mt for synthetic production.

Principle 2 continued

2.5 Looking Forward

2.5.1 Competitor Outlook

This section of the Evidence Book has demonstrated that naturally derived soda ash currently exhibits lower greenhouse gas emissions, energy consumption, water usage and waste generation compared with synthetic production. However, the sector remains dynamic. Significant investments by major synthetic producers indicate the potential for convergence in environmental performance and, therefore, the snapshot-like nature of the evidence outlined in this book. For example:

Solvay – a leading producer of synthetic soda ash – has committed to achieving carbon neutrality by 2050, with a 30% reduction in CO_2 emissions from its sites by 2030. Key initiatives include[86]:

- Replacing coal-fired boilers with waste-wood-chip units as its Rheinberg (Germany) site, cutting CO_2 emissions there by up to 65%.
- Switching to local, non-recyclable waste for onsite energy at Dombasle (France), thereby preventing 400,000 mt of waste going to landfill and eliminating the need for 200,000 mt of imported coal.
- Conversion to natural gas from coal in early 2024 at its Green River operations, reducing emissions by 20% despite a 25% capacity increase.
- Investing €48 million to modernise the gas-cogeneration system at Bernburg (Germany).
- Piloting a new, patented e.Solvay process at Dombasle, which, if operational, is projected to lower CO_2 emissions by 50%, reduce energy and resource usage (water, salt, limestone etc.) by 20%, and eliminate limestone residue altogether.

Tata Chemicals is also implementing multiple enhancements, including:

- Waste-heat recovery systems, deployment of high-efficiency motors and equipment, and digital IoT-based energy management across its manufacturing sites.
- Biomass trials to replace coal and a 2028 offtake agreement with Vertex Hydrogen for over 200 MW of low-carbon hydrogen.
- Recovery of calcium chloride from process effluent for use as a cement feedback, thereby closing material loops and reducing waste.

This demonstrates two things. Firstly, that natural soda ash's sustainability advantage outlined above is not a given and therefore, in order for the natural soda industry to maintain its advantage over synthetic production, continued technological and operational improvements are required. And, secondly, that alongside pursuing continuous operational sustainability improvement, WE Soda must consistently review and strengthen the credibility of the evidence underpinning our sustainability claims, to ensure we can continue to convey our advantage effectively and accurately to key stakeholders.

2.5.2 Circular Soda Ash

As outlined in Section 2.2, currently, there are two sources of soda ash: natural and synthetic. However, WE Soda is exploring a third source: circular carbonates produced from the emissions captured on ships and from plastic waste.

Plastic to a raw material for glass

There are now over 170 trillion pieces of plastic in the ocean[87], and the problem is not just confined to the sea; microplastics have been found in human brain tissue and reproductive organs, with the true impact not yet clearly understood[88]. As a result, industrial, societal, and policy stakeholders have, to varying degrees, taken steps to reduce the use of virgin plastic[89]. Glass is a practical alternative because it is infinitely recyclable, chemically inert, and not dependent on fossil-fuel-based materials. Although efforts are being made to reduce the use of virgin plastics, large volumes of plastic waste still require solutions. Emerging technologies can break this waste into basic components, producing hydrogen and carbonates that may serve as inputs for new glass production. This offers a potential circular pathway for turning plastic waste into valuable industrial materials.

Shipping emissions to soda ash

The shipping industry is responsible for 3% of global emissions, releasing over 1 billion tonnes of greenhouse gases (including CO_2, CH_4 and N_2O) a year[90]. These emissions are particularly hard to abate due to the long lifespan of these vessels and the current lack of maturity of low or zero-carbon fuels[91]. However, emerging carbon capture technology addresses both issues; it is able to be retrofitted to existing ships, capturing emissions directly from flue gases. Carbon dioxide in these gases dissolves into the liquid phase through a sodium hydroxide (NaOH) solution[92], forming sodium carbonate – soda ash – as per the following reaction:

$$CO_2 + 2NaOH\,(aq) \rightarrow Na_2CO_3 + H_2O$$

While the soda ash production capacity for these methods is currently limited, they represent a promising avenue for further development into a third, circular source of soda ash.

Thank you

We are committed to continuous improvement. Please contact us if you have any new information, comments, challenges or suggestions.

Please help us keep this accurate and up to date.

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