CENTER FOR GLOBAL COMMONS

SYSTEMIQ

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Planet Positive Chemicals

Pathways for the chemical industry to enable a sustainable global economy

Executive summary

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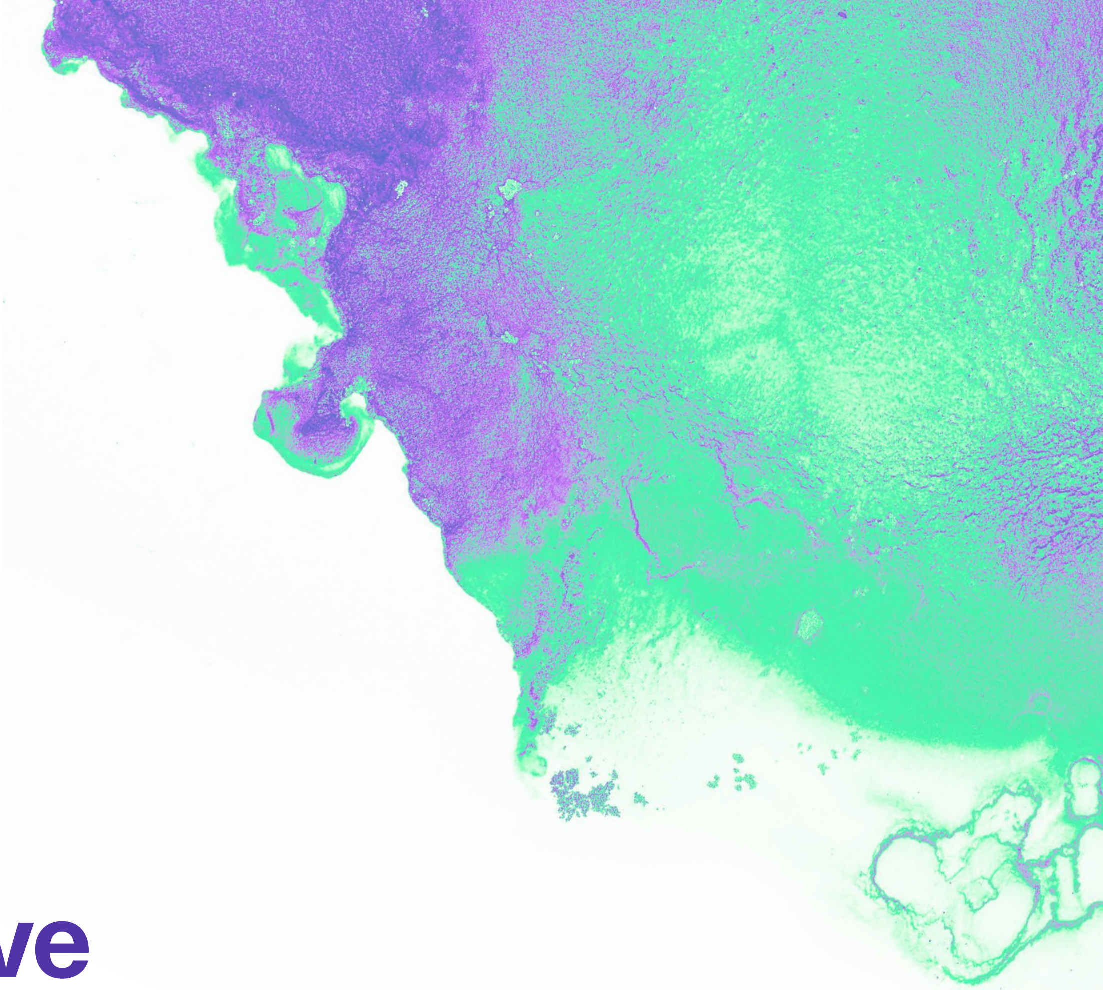


Executive summary

The chemical industry is a major building block of our global economy, providing 15 million jobs worldwide and 4% of global GDP.

The global chemical industry generates $4.7 trillion in revenues annually, representing ~4% of global GDP, and directly employs over 15 million people.[1,2] The products from the chemical industry underpin our way of life, health and prosperity and our transition to a net-zero-emissions economy. They are present in the healthcare, packaging, agriculture, textiles, automotive, construction and many other systems, with 96% of manufactured goods depending on their use.[3] As a result, the production of basic chemical intermediates, such as those in scope for this study (ammonia, methanol, ethylene, propylene, butadiene, benzene, toluene, xylene), directly impacts almost every part of the global economy. Therefore, unless the chemical system transitions to a sustainable model of operation, it makes it challenging for other parts of the global economy using chemical products to be truly sustainable.

By embracing a "planet positive" circular and net-zero-emissions transition, the chemical system could grow 2.5x by 2050 and enable transitions to net-zero-emissions in other sectors, whilst keeping its own Scope 1-3 greenhouse gas emissions in line with the Paris Climate Agreement.

This report is grounded in a detailed economic model that outlines future pathways for the chemical system from 2020-2050, along with the environmental impacts of each of these pathways. The analysis highlights three key opportunities:

1. The global transition to a circular and net-zero-emissions economy is an opportunity for the chemical system to grow annual production volumes 2.5 times annual production volume by 2050, enable transitions to net-zero-emissions in other systems such as shipping and energy storage and create 29 million new jobs globally, of which 11 million would be direct new chemical industry jobs;

2. Even with this 2.5x growth trajectory by 2050, Scope 1-3 greenhouse gas emissions from the system could realistically align with the Paris Climate Agreement; and

3. With new manufacturing approaches based on bio-based feedstock and direct air captured carbon dioxide, there is a technically feasible pathway for the non-ammonia chemical system to become a "carbon sink" that absorbs 500 million tonnes (net) of CO_2 per year by 2050.

This growth opportunity is not evenly distributed across the chemical system – it is particularly significant for ammonia and methanol-based chemical pathways. The opportunity relies on urgent and ambitious transformations in chemical manufacturing alongside aggressive demand-side circular economy approaches in the downstream value chains using chemicals in materials and products. These transformations, action plans and investment needs are outlined in detail in this report.

The chemical industry today has a significant carbon footprint and is lagging other industries in the transition to net-zero-emissions. The current trajectory of the system is aligned with 4˚C of global warming.

The chemical industry is currently lagging in its commitments to science-based targets to transition to net-zero-emissions and is expected to be the last system to achieve the key tipping points needed to mainstream emission reduction technologies.[1]

The production of basic chemical intermediates in-scope for this report has a Scope 1, 2 & 3 emissions of 2.3 Gt CO_{2eq}, representing just under 4% of the 59 Gt global annual emissions and an estimated 72% of all chemical system emissions. Within the 2.3 Gt, Scope 3 represents the majority at 64% (1.5 Gt CO_{2eq}), while Scope 1&2 only represent 36% (0.8 Gt CO_{2eq}). The magnitude of Scope 3 in the chemical system is driven by its dependence on fossil, leading to high upstream scope 3 emissions from oil and gas extraction (0.5 Gt CO_{2eq}), as well as carbon-dense products such as plastics and urea resulting in high associated downstream Scope 3 emissions (1.0 Gt CO_{2eq}). It is for this reason that focusing on Scope 3 in the chemical system transition to net zero is so essential.

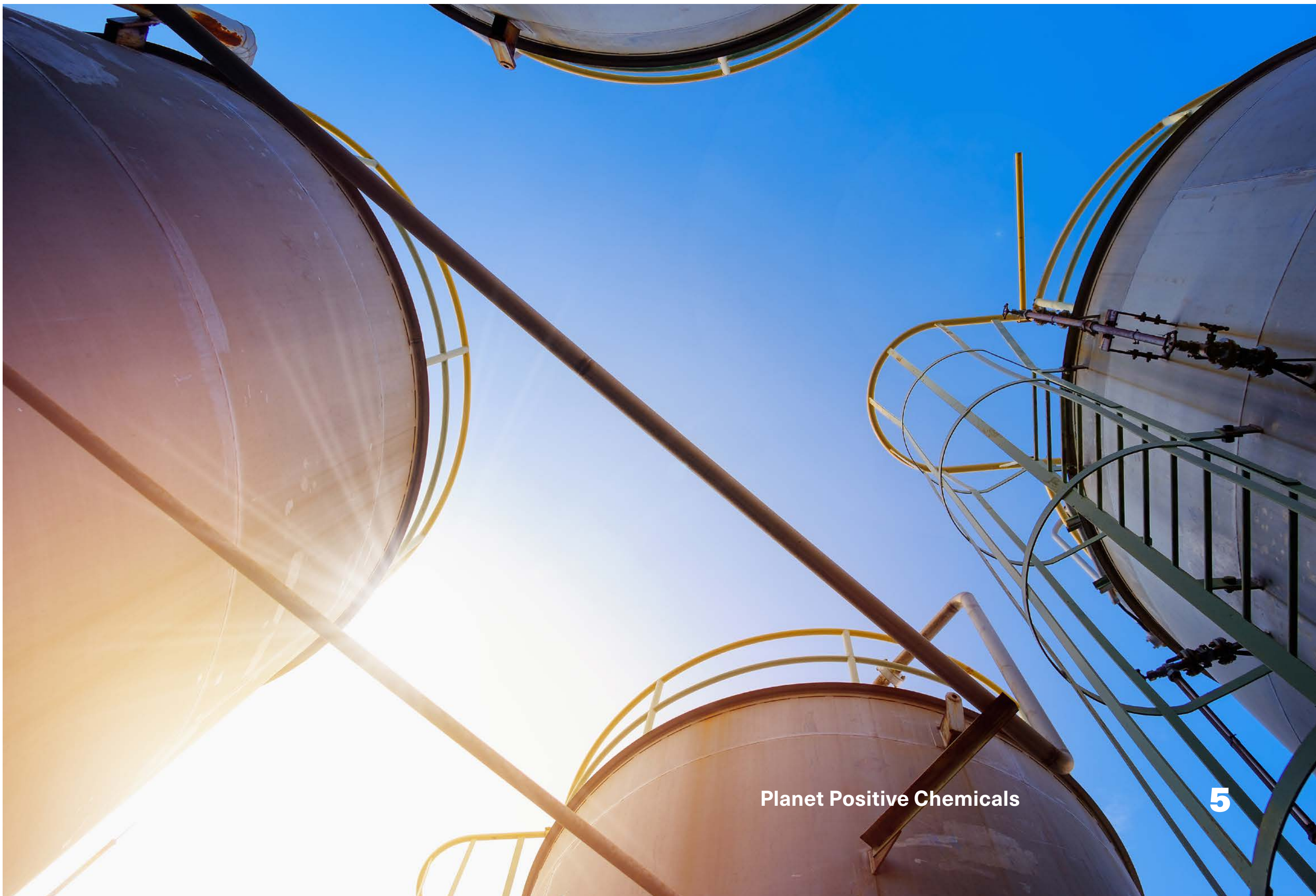
Based on the most recent IPCC carbon budgets and the analysis carried out for this report, the chemical system's combined production and Scope 3 emissions mean that if this one industry continues to scale up without reducing its emissions, it would be responsible for 24-38% of the total 2020-2050 global carbon emissions budget for a 1.5˚C future. This "business as usual" scenario would align the system with a 4˚C global warming scenario by 2050.[2]

The chemical system is already transgressing other planetary boundaries. Environmental pollution and potential unintended consequences from climate solutions (such as land use change) must be avoided.

Beyond climate impacts, the leakage of chemicals and downstream products (e.g. plastics and fertilisers) into the environment has a range of other adverse impacts on the nine essential planetary processes that regulate the stability and resilience of the Earth system. The tolerable limits of human impact on these systems are referred to as "planetary boundaries",[3] and there has been increasing awareness that the chemical system is breaching many of these boundaries.

The planetary boundaries for the release of novel entities, including chemical pollution and specifically plastics, as well as biogeochemical flows (e.g. nitrogen flows contained in ammonia-based fertilizer run off), into the biosphere have both already been exceeded.[4,5] Furthermore, care must be taken to avoid an uncontrolled net zero transition, which could have severe impacts on biodiversity and land use if the use of biomass as feedstock is not regulated and sustainable, particularly in light of competition for sustainably produced feedstocks. Therefore, the current operating model of the chemical system represents a multi-pronged threat to the planet and society. Mitigating these impacts requires that the industry take a broader approach than solely abating climate impacts.

1. Analysis conducted on SBTi commitments across the sector placed chemicals commitments at 17% vs a 35% cross-sectoral average. For "The Paris Effect: COP 26 Edition" SYSTEMIQ conducted a balanced scorecard survey of all sectors to evaluate readiness to mainstream abatement technologies, among which the chemicals system was the found to be the slowest.
2. IPCC AR6 III below 4 degree is 4,220 Gt and above 4 degrees is 5,600 Gt. Based on an allocation of chemicals (2.0%), of which only 72% is in scope, and shipping (1.6%) of global emission, total emissions budgets would be 128-170 Gt respectively in a below and above 4-degree scenario. BAU-BAU scenario is expected to generate 146 Gt of CO_{2eq} emissions during the period 2020-2050.
3. The planetary boundaries are: i) chemical pollution and novel entities, ii) climate change, iii) atmospheric aerosol loading, iv) ocean acidification, v) freshwater use, vi) land system change, vii) biosphere integrity, viii) biogeochemical flows, and ix) stratospheric ozone depletion.



Demand reduction through circular economy approaches would save over $1 trillion in transition costs from 2020-2050 (~30% of total) and reduce pressure on planetary boundaries.

Demand-side circular economy approaches (reduction, reuse, substitution and recycling) can reduce the absolute amount of future chemical production and therefore the transition investment needed over the next decades by over $1 trillion (almost 30% of total incremental investment required) between 2020 and 2050. This requires coordinated and ambitious action from the chemical system and the downstream value chains using chemicals in materials, fertilisers and products.

Today, the global chemical value chain is predominantly linear,[4] with low reuse and recycling rates and significant waste generation. For example, up to 70% of nitrogen input in fertilizer is not taken up by crops and only 9-14% of plastic ever created has been recycled.[6-8]

Ambitious demand-side circular economy approaches reduce the reliance on new technology developments that are still scaling up (e.g. new bio-based or waste-derived feedstocks or carbon capture storage and utilization (CCUS)). They also reduce the growth of production, waste and pollution from the system and its associated downstream products, directly reducing planetary boundary impacts.

Applying circular economy approaches to this linear value chain can reduce total demand in the system by 23-31% (372-526 Mt) versus business-as-usual and net zero growth without sacrificing any functional benefit or utility. This is particularly relevant for non-ammonia demand resulting in 33-51% reduction. Of total system reduction, elimination represents 41% of total circularity impact, reuse 19%, substitution 14%, and recycling[5] 26%. The chemical industry must embrace this demand reduction from downstream customers, while pursuing a broad range of direct and indirect benefits circularity brings about, including; social (e.g., net job creation, thriving communities), environmental (e.g., biodiversity, soil, and natural ecosystem preservation) and climate (reduced greenhouse gas emissions).[9-12]

4. The chemical value chain today converts fossil feedstocks to chemical products which are rarely returned into the value chain via reuse or material/chemical/carbon recycling.

5. Mechanical recycling, dissolution and depolymerisation only.

The chemical system transition requires a supply-side shift away from fossil-based inputs for feedstocks and energy, towards inputs that are based on alternative forms of carbon, green hydrogen, and renewable energy. There is no silver bullet technology solution for the transition.

Decoupling from fossil: Almost the entire carbon feedstock (713 Mt carbon) used in the system is from virgin fossil sources. Fossil faces multiple uncertainties in its future, including extraction abatement challenges, potential price volatility, and unacceptable environmental impacts. Continued unilateral dependence on fossil for fuel and feedstock is a risky strategy. Furthermore, incineration and landfill are not attractive end-of-life options for non-ammonia chemicals today and carbon capture and storage (CCS) has yet to scale. Therefore, the continued extraction of virgin carbon augments the challenge of abating emissions and achieving true net zero Scope 1-3 emissions.

Switching to renewable feedstocks: There is an imperative to switch to alternative feedstocks for basic chemical intermediates production. Key alternative carbon feedstocks are biogenic and direct air captured CO_2 (atmospheric carbon), as well as point source CO_2 and solid waste (carbon as an economic by-product). By 2050, as much as 82%[6] of carbon feedstock can come from alternative sources, leaving only 77 Mt of virgin fossil carbon in the system, an 89% reduction from today. In addition, up to 234 Mt p.a. of green hydrogen may also be required, predominantly (99%) as feedstock for ammonia and methanol to enable use of alternative carbon feedstocks for chemical production.

Switching energy source: using renewable energy rather than fossil fuel to produce heat can avoid process emissions. Up to 12,000 TWh of renewable energy capacity will be required in a net zero system, although this is predominantly needed to produce green hydrogen feedstock. Of the remainder, 4% is used for electric steam crackers and other production processes, 3% is used for carbon capture, and less than 1% is used to make green hydrogen for steam cracker heat.

Carbon capture and storage: some process emissions and end-of-life disposal emissions are unavoidable and thus CCS is likely to be required as a means of abating residual emissions that cannot be addressed via switching feedstocks or energy sources. Up to 640 Mt p.a. of CCS will need by 2050 to abate the system.

6. Multiple scenarios have been modelled. The most pertinent values have been selected to illuminate the executive summary to avoid complexity. For detail around values per scenario, the main report should be consulted.

Ammonia (5x growth by 2050) and methanol (4x growth by 2050) will be central to the chemical system transition

Ammonia production is the largest contributor to Scope 1&2 emissions (0.36 Gt of CO_{2eq} – 44%) by the basic chemical intermediates industry today. Continued growth in fertilizer demand due to population growth and ammonia's use in new applications, such as power storage and fuel for net-zero shipping, mean it would experience a surge in demand from 185 Mt in 2020 to more than 1,000 Mt by 2050 (of which three-quarters is new net zero applications). This would be the largest demand growth of any basic chemical intermediate by 2050, representing as much as 32% of the 500 Mt p.a. of projected global green hydrogen demand in a net-zero economy by 2050.[13,7] This is why transforming both existing and new production capacity to renewable (non-fossil) energy and feedstocks is critical to enable a sustainable future.

Methanol also has a bright future because it can be produced from non-fossil carbon and green hydrogen feedstocks, and it can be manufactured into a wide range of downstream chemicals, including olefins and aromatics. Green methanol can therefore be used to displace fossil feedstocks (i.e., naphtha), thus avoiding upstream production Scope 3 emissions. It can also enable more efficient recycling of waste carbon within the chemical system (e.g. via capture of CO_2 from industrial point-source emissions or waste gasification). As a result, methanol is expected to experience 330% growth from 102 Mt in 2020 to ~440 Mt in 2050.

The system transformation requires capital investments of around $100 billion per year over the next three decades, but will only have an estimated ~1% impact on costs of typical products that are made from chemicals.

Achieving net zero Scope 1-3 emissions will require ~$100 billion per year in capex deployment between 2020-2050, 2.7X larger than capital requirements for business as usual growth of the system. Firstly, adequate large-scale capital must be allocated for deployment into the system transition. Secondly, a network of financial intermediaries, infrastructure, products and expertise to deploy the capital must be developed. Thirdly, a pipeline of high-quality joint venture transformation projects are needed to create a clear track record for mainstreaming circular and low-emissions technologies. Achieving this will require government policy support as well as shifting perceptions of value, business models, technology risk, rates of return, and capex profiles across the chemical value chain.

Despite the scale and holistic nature of the infrastructure transformation, the impact of the increased manufacturing cost to end user products is limited to low single digit percentages, for example soft drinks 0.7-3.2%, cars 1.0-1.1% and food items 0.6-0.9%.

7. Projections vary considerably. In this instance 500Mt global production by 2050 has been taken.

The system transformation requires coordinated action from the chemical industry and companies in its upstream and downstream value chains, the energy system, innovators and governments.

Implications for the chemical industry: Operationally delivering the transition will require the chemical industry to drive major shifts in the technologies and locations of production. Existing brownfield production capacity such as steam crackers and steam methane reformers will need to undergo retrofitting with low-emissions technologies such as green hydrogen firing, electrification or CCS. The shift will also result in the retirement of some refinery assets such as catalytic reformers for the production of aromatics.

Production infrastructure will need to shift towards low-emissions orientated technologies of electrolysis, methanol-to-olefin and aromatics, bioethanol dehydration, gasification and carbon capture and utilization. While legacy production assets are likely to remain in situ in industrial clusters to benefit from downstream integrations and synergies, greenfield capacity installation will gravitate towards regions with abundant, affordable renewable energy (for green hydrogen production) and also renewable carbon sources (for methanol production). This will result in the restructuring of global chemical value chains and trade patterns. End-of-life emissions must be abated, thus a network of carbon capture, utilization and storage (CCUS) capabilities must be applied across the global incinerator portfolio.

Looking outwards, the new operating model of a net zero chemical industry will require far deeper engagement with adjacent segments of the economy such as renewable energy providers, biogenic feedstock producers, waste managers and end-of-life disposal i.e. incinerator owners. As a result, players will require lateral and vertical integration through a framework of "build, buy or partner" with these systems, offering new synergies and revenue opportunities. Equally, looking inwards to the value chain, engagement in circular economy models (e.g., through Chemicals-as-a-Service models), may present an opportunity to decouple from the volume-based model today and derive revenue from more efficient, value-adding, service-focused applications of chemicals.

Implications for the chemical value chain: Driving rapid change will require a coordination of industries moving in parallel and new models of system governance to accelerate the transition. This may include establishing a first movers demand coalition comprising converters, brands, retailers, shipping companies and fertilizer companies to guarantee a market for low-emissions chemicals through offtake agreements. Such a coalition can also demand mandatory recycled content regulations and call for more stringent end-of-life recycling and CO_2 emission reductions as part of extended producer responsibility obligations. Brands and retailers will be instrumental in driving the implementation of circular economy approaches for plastics such as elimination and reuse models. Downstream collection and sorting of plastics must be optimized, mechanical and chemical recycling infrastructure must be expanded, and end-of-life incineration facilities must be upgraded to include carbon dioxide capture. Finally, a global charter of transition principles would help the broad range of stakeholders involved in the transition align pre-competitive approaches to shifting the system to operate within planetary boundaries.

Implications for the energy system: The energy system will need to build out renewable energy sources to produce up to 12,000 TWh for the chemical system by 2050, representing as much as 13% of global generation. This will require establishing additional generation capacity in locations with affordable, abundant renewable energy potentially presenting a major economic development opportunity in the Global South. The majority of energy will be for green hydrogen feedstock production and represent almost 50% of total global green hydrogen demand in 2050. Therefore, the chemical (and particularly the ammonia) industry will be pivotal in driving the scale-up of electrolyser production for the green hydrogen industry.

Implications for innovators: Ensuring this transformation is possible at an affordable rate and with feasible economics will require the innovation community to fast-track critical technology innovations to commercial scale, specifically methanol-to-aromatics technologies, carbon capture technologies, and electrolysers. The innovation and innovation finance community should seek to overcome the key energy intensity, material efficiency, and technical challenges in these spaces to reduce cost and scale of the infrastructure buildout needed. Breakthrough technologies capable of disrupting the industry (e.g., biotechnology, electrochemistry) should be supported generously via R&D funding and scale-up programs.

Implications for government policy makers: Policy changes are required to enable the shift to a circular and net-zero-emissions chemical system. An enabling policy framework could help to cushion economic shocks, incentivize preferred actions and disincentivize harmful actions. This could be in the form of a carbon tax[8] or incentives to put the businesses cases for low-emissions technologies on-par or better than the traditional technologies. Ultimately, either the public and/or value chain shareholders must pay the additional costs of low-emissions chemicals. National governments are the ultimate arbiter of where these costs must be borne most heavily, and each government must determine its policy based on its perspective of how society should pay the dividend back to nature and eliminate market externalities over time. Lastly, scaling adoption of circularity models upstream and downstream is essential and will likely benefit from integration with industrial decarbonization policy to ensure circularity receives due precedence.

8. Preferred over emissions trading approaches.

Urgent and coordinated action is required to change the trajectory of the industry and reduce risks for corporations, investors and society at large.

There is no time to lose. Long lifetimes for chemical industry facilities mean that investment decisions in the next few years will determine the trajectory of the industry during the critical decades out to 2050. Recent extreme weather events caused by climate change are highlighting the risks to corporations, investors and society at large, meaning that investments in fossil-fuel dependent facilities now carry well-documented stranded asset risks. “Wait and see” is no longer a viable strategy for corporations and investors in this industry.

This report illustrates viable pathways to a “planet positive” chemical system that will allow the chemical industry to thrive and grow. A number of companies are already showing the way. If industry can mainstream and accelerate this transition, it has the prospect of being every bit as central to the progressive story of the 21st century as it has been to that of the 20th century.

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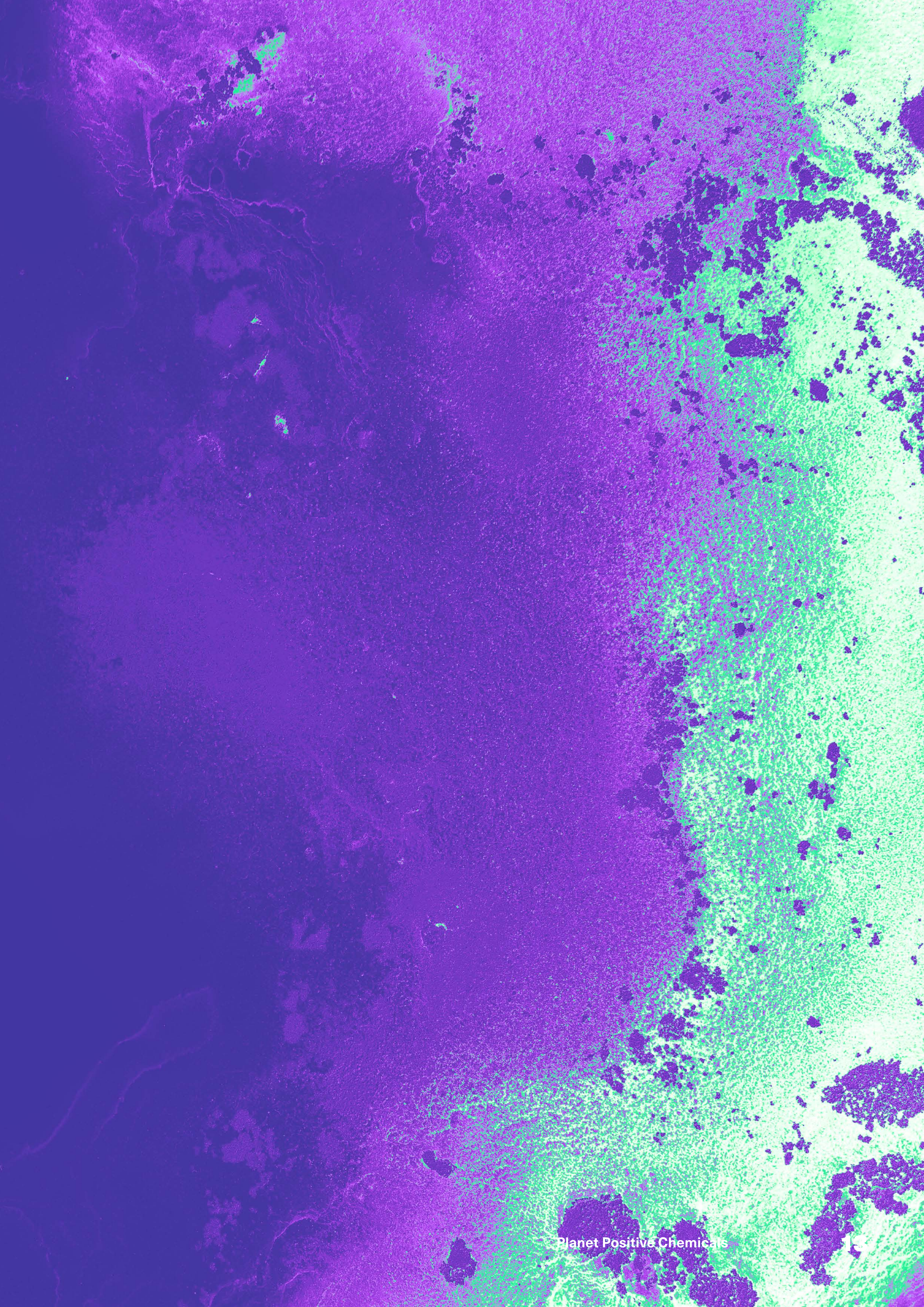

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