Innovation action plan to transform industrial waste gases to chemicals

Circular Economy Innovation Network

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Contents

Introduction

The Circular Economy

In the UK most of what we use and consume flows through a take, make, waste linear economy. By contrast in a Circular Economy, products or their component parts are recovered or processed in a way that they can be repaired for reuse, resold, refurbished or remanufactured, or reduced to composite elements for recycling.

A Circular Economy supply chain can help mitigate the upfront investments in carbon, energy, water, chemicals, labour, money etc. resulting from current manufacturing and production processes. Circular economy principles are based on a holistic systems-thinking approach that seeks to eliminate pollution and waste being emitted from the outset. By adopting a Circular Economy framework and building collaborative communities aligned to three key principles: Circular Design, Circular Business Models, and Circular Recovery; we aim to inspire industry members to come together to reduce environmental impact and achieve Net Zero goals through circular innovation.

Research shows specialist collaborations produce results that wouldn't be possible when people think and work in isolation, so we are focused on convening Challenge Communities: which will collaborate and consult across the value chain to co-create a Circular Innovation Action Plan for each of our target challenges identified by industry stakeholders. Each of these Action Plans will identify the key barriers preventing progress towards Net Zero and highlight how Innovation for a Circular Economy can help overcome these barriers.

Transforming Industrial Waste Gases to Chemicals

In this 'Transforming Industrial Waste Gases (CO/CO_2) to Chemicals' challenge we set out a vision for using CO/CO_2 in the manufacture of higher-value chemicals to support a circular carbon future.

It aims to create a chemical sector and associated supply chains that can thrive in a circular, net zero world and promote the existing and emerging technologies to benefit the chemicals supply chain in the UK.

Circular Economy Opportunities

Why Transform Industrial Waste Gases (CO/CO_2) to Chemicals?

As we look towards building UK global resilience and competitiveness, we must find ways of establishing UK manufacturing supply chains that produce products without having a negative impact on our environment yet meet the demands of an increasing and ageing population. In 2018 it was estimated that 66MtCO2eq (12%) of direct UK greenhouse gas (GHG) emissions were from manufacturing and construction of which 65.4MtCO2e (98.6%) was CO_2. While direct GHG emissions from the chemical sector were 9.42CO_2eq (14%) or 12.6MtCO_2eq if emissions from electricity and bioenergy use are included.[(1)]

For most of the chemical and chemical intermediates manufactured, about a third of the carbon footprint is from the manufacturing process while the other two-thirds is from the embedded carbon in the molecules.[(2)] In 2020 the global demand for carbon embedded in organic chemicals and their derived materials was estimated to be 450 Mt/year with 85% of this carbon being fossil based, and it was predicted that the global demand for embedded carbon in chemicals will increase to 1000 Mt/yr by 2050.[(3)]

In 2020 the manufacture of chemicals and chemical products for the UK generated a turnover of approximately £32 bn and a GVA of approximately £11bn.[(4)] Given the size and its direct contribution to emissions the UK chemicals sector must invest in the development of more sustainable chemical processes that reduce in-sector emissions, in order to deliver chemical products that enable the net zero and circular future in other sectors.

Our challenge is to meet the demand for carbon using alternative sources[(5)] and to increase product longevity while ensuring we also focus on other social responsibilities, impact factors and other sustainable metrics[(6)]. Through Carbon Capture and Utilisation (CCU) of industrial waste gases the chemical sector can produce higher-value, lower carbon footprint chemicals and reduce its reliance on fossil fuel feedstocks. This has the potential to reduce scope 1 and 2 emissions for the sector, while enabling lower scope 3 emissions along the supply chain by embedding carbon into new products and materials which can be maintained, re-used, recycled, or recaptured at the end of life, reducing the total amount of carbon needed from other sources.

Innovations in CCU, especially when coupled with renewable energy, low carbon hydrogen and Power-2-X technologies present a significant opportunity to manufacture chemicals with a lower carbon footprint[(7)]. Advances need to be developed with a systems approach considering real world process conditions, from individual unit operation design through to complete processes. It will require new collaborations to be formed along the value chain to develop and establish for the UK the technical and commercially viable routes from feedstock (quality and quantity) through to the final product.

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(2) Kähler, F. and Carus, M. et al. 2022: CO2 Reduction Potential of the Chemical Industry Through CCU. Editor: Renewable Carbon Initiative (RCI), April 2022. Available at:www.renewable-carbon-initiative.com
(3) vom Berg, C. and Carus, M. et al. 2022: Renewable Carbon as a Guiding Principle for Sustainable Carbon Cycles. Editor: Renewable Carbon Initiative (RCI), Febr. 2022. Available at: www.renewable-carbon-initiative.com
(4) Office for National Statistics. (2022, June 16). Non-financial business economy, UK: Sections A to S. Retrieved Jan 2023, from Office for National Statistics: https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/datasets/uknonfinancialbusinesseconomyannualbusinesssurveysectionsas
(5) Michael Carus, Christopher vom Berg (all nova-Institut GmbH and Renewable Carbon Initative (RCI)). (2022, July). Renewable Carbon Initative (RCI) Webinar slides - July 2022 (PDF). Retrieved Jan 2023, from Renewable Carbon Publications: https://renewable-carbon.eu/publications/product/renewable-carbon-initiative-rci-webinar-slides-july-2022-pdf/
(6) Lamb, K. (2022, June). The UKRI Interdiscplinary Centre for the Circular Economy and its approach to CCU.
(7) Innovate UK KTN. (2022, August). New Innovate UK KTN report: How can catalysis accelerate the path towards Net Zero? Retrieved from Innovate UK KTN: https://ktn-uk.org/news/new-innovate-uk-ktn-report-how-can-catalysis-accelerate-the-path-towards-net-zero/

Vision, aim and outcomes

Vision

Our vision is to capture industrial waste gases (CO/CO_2) to be used in the manufacture of higher-value chemicals, leading the UK towards a circular carbon future that reduces our reliance on virgin fossil-based carbon feedstocks.

Aim

We aim to create a chemical sector and associated supply chains that can thrive in a circular Net Zero world. This will benefit society through the employment of skilled scientists and engineers in high-value jobs, producing low carbon footprint products for local and global markets.

> In 2020 the global demand for carbon embedded in organic chemicals and their derived materials was estimated to be 450 Mt/year with 85% of this carbon being fossil based, and it was predicted that the global demand for embedded carbon in chemicals will increase to 1000 Mt/yr by 2050.

Source: Renewable Carbon Initiative (RCI), Feb. 2022

These are the outcomes we anticipate:

Development of a clear, consistent and concise narrative capable of conveying:

A. The value of the chemicals supply chain to the UK and its role in achieving net zero.
B. The rationale and urgent need to diversify away from virgin petrochemicals and create new supply chains for the production of chemicals from alternative feedstocks, including waste gases.
C. Why the UK is the right environmental and economic investment choice for manufacturing chemicals from industrial waste gases.
D. The key target opportunities for existing and emerging technologies to benefit the chemicals and associated supply chains in the UK.

Roadmaps and timelines for the various technologies and supply chains.

A policy and regulatory environment that recognises the opportunity for using carbon capture and utilisation for the manufacture of chemicals, with funding for developing innovative economic and environmental business models and technology solutions across the value chain, including the creation of pilot and demonstration facilities.

Key exemplars of precompetitive collaborative value chain projects using Innovate UK KTN Collaboration Exchange.

Designing for Circularity

Understanding the products we use, how they're made, what they're made from, and how the end of life can be facilitated

Action:

Industry, innovators and academia must work together to identify and develop a shared understanding of the key opportunities for industrial clusters and dispersed sites.

This will enable the creation of scalable circular supply chains for the manufacture of sustainable chemical products, using industrial waste gases as a feedstock.

Enabler:

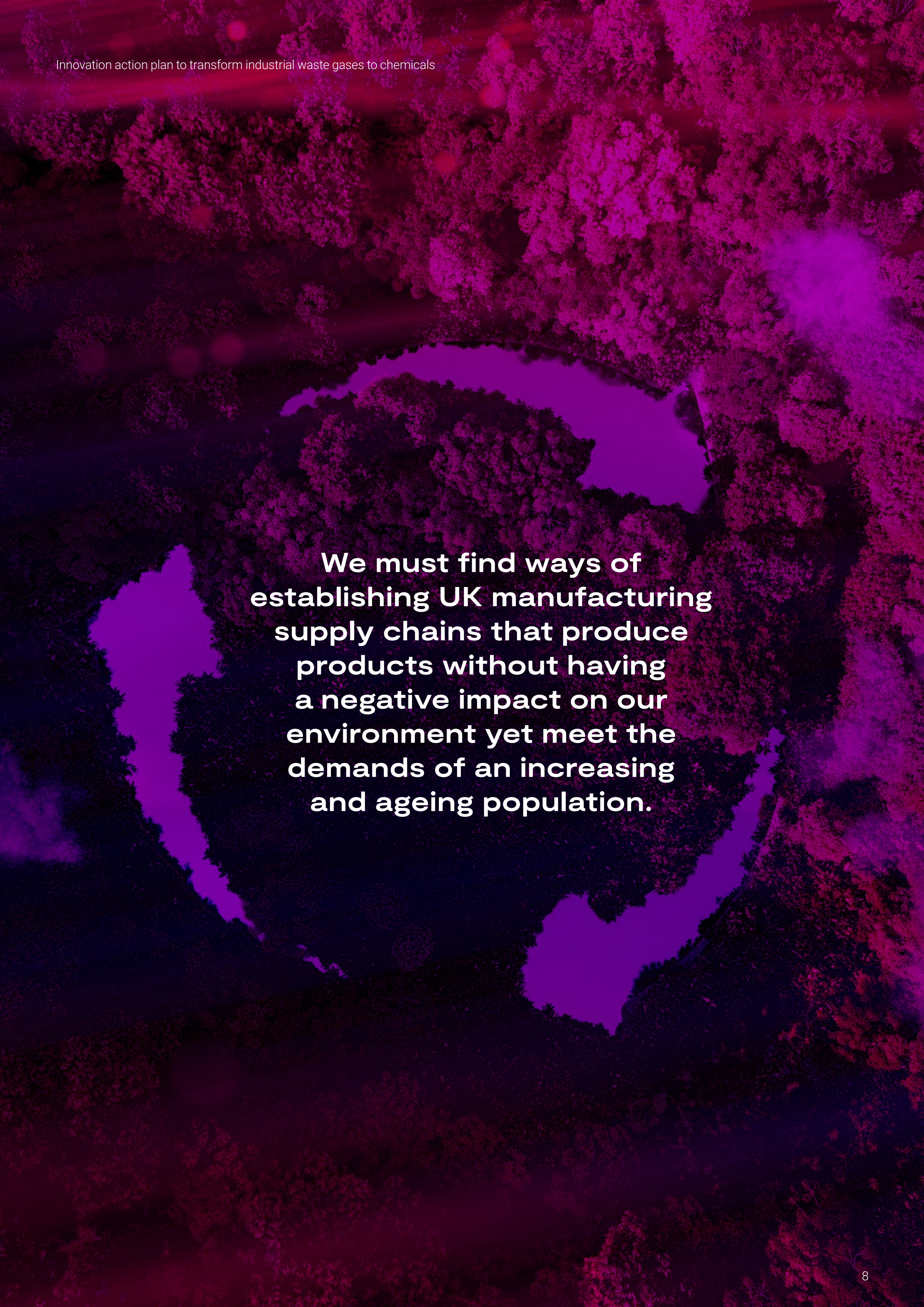
Data will be established at a site, regional and national level to be used by industry, academia, innovators, investors and Government bodies to identify the opportunities for the capture and utilisation of industrial waste gases for the manufacture of chemicals.

This includes mass and energy balances around the requirements for electrons, carbon, hydrogen, and water; CO/CO_2 feedstock availability (volume, quality); raw materials, product demand (type, quality, volume) and other related environmental factors.

Designing for Circularity

	Specific Actions	Suggested Ownership	Timeline for actions*
1	Identify existing sources of regional and national data to share with industry, academia, innovators and Government around the carbon capture utilisation of industrial waste gases for chemicals, including carbon footprints and impact on environmental factors beyond carbon.	Innovate UK KTN, Government, Industry	Short Term
2	Research and studies to enable industrial clusters and dispersed sites to: A. Evaluate near to long term availability and demands for carbon, hydrogen and renewable electricity, with consideration of fuels, switching and electrification. B. Establish the near and long-term quality and quantity of CO/CO_2 sources; C. Evaluate the existing UK petrochemical manufacturing supply chains for the raw materials requirements, production volumes, products manufactured and the functional requirements (including end uses); D. Identify potential near and long-term strategic opportunities within clusters (impact generated through economies of scale e.g. methanol, ethylene, formate salts. Also, ability to leverage existing and new infrastructure e.g. CCUS pipelines, hydrogen development) and for dispersed sites in capturing and transforming waste gases to chemicals; E. Identify potential opportunities to combine CCU with other sources of alternative feedstock to generate impact through economies of scale with clusters and dispersed sites	Government Academia RTO's	Short to Medium Term
3	Identify existing opportunities where there is a demand for sustainable chemical products and circularity from the sector and its supply chain.	Innovate UK, Industry and Professional Bodies, Industry Interest Groups	Short to Medium Term

***Timeline for action (Short 0-2yrs, Medium 3-5yrs, Long 5yrs+)**



We must find ways of establishing UK manufacturing supply chains that produce products without having a negative impact on our environment yet meet the demands of an increasing and ageing population.

Circular Business Models

Defining and creating the business models that can deliver value

Action:

New circular and sustainable business models should establish the business and environmental case for the UK to manufacture chemicals from captured industrial gases within industrial clusters and at dispersed sites.

These can be used by industry, the Government and innovators to de-risk and support investment decisions.

Enablers:

(1) Business models that adequately share the burden of financial risk across the industry supply chain and enable the development and adoption of this new feedstock and pathway for industrial clusters and dispersed sites;

(2) Data from techno-economic analysis (TEA) and Life Cycle Analysis (LCA) that provides assurance to business and Government that this new pathway is sustainable.

Circular Business Models

	Specific Actions	Suggested Ownership	Timeline for actions*
1	Standardise Life Cycle Assessment (LCA) and Techno Economic Analysis (TEA) for the manufacturer of chemical	Innovate UK KTN, Industry Academia,Centres of Excellence (including NICER Circular Chemicals) RTO's,Regulatory / Standards Bodies	Short to Medium Term
2	Establish LCA & TEA data that can be used by industry to gain an understanding of the potential of manufacturing chemicals from captured industrial gases within the UK: A. Using LCA to determine the overall sustainability of manufacturing from industrial gases at this scale; B. Using LCA & TEA to compare existing manufacturing process against new CCU to chemicals supply chains to support the transition to new business models; C. Incorporating the use of renewable energy, low carbon hydrogen into the LCA & TEA; D. Incorporate social impacts into LCA.	Industry, RTO, Government Agencies, Regulatory / Standards Agency, Centres of Excellence (including NICER Circular Chems)	Short to Long Term
3	Creation of a business model(s) that incentivises the capture and transformation of waste gases for the production of chemicals, providing certainty for investment by industry in at-scale deployment within industrial clusters and at dispersed sites: A. Establishing a common definition of economic success for the capture and use of industrial waste gases for the manufacture of chemicals; B. Establishing the rationale and justification for the UK to manufacture chemicals from captured industrial gases utilising renewable energy, low carbon hydrogen; C. Evaluating if using industrial waste gases along with other regionally available sustainable or waste feedstocks generates a stronger economic and environmental business case; D. Demonstrating the impact generated through economies of scale and the ability to leverage existing and new infrastructure (capabilities and the associated manufactured products) across the supply chain within clusters and at dispersed sites; E. Evaluating the social impacts.	Innovate UK, Industry and Professional Bodies, Industry Interest Groups	Short to Long Term
4	Chemical sector to use the business models to identify a list of key target chemicals to produce from captured CO_2.	Industry, Industry Bodies, Industry Interest Groups	Short to Long Term

***Timeline for action (Short 0-2yrs, Medium 3-5yrs, Long 5yrs+)**

Circular Recovery

Retaining and recovering value from materials and products

Capturing industrial waste gas emissions

Action:

Industries located at industrial clusters and dispersed sites need to be able to determine the economic, technical and environmental capabilities of existing and new carbon capture technologies based on the location, volume and quality of industrial waste gases available, the chemical manufacturing location and end product quality specifications.

Enablers:

(1) Providing industry with knowledge of how the quality, quantity and source location of industrial gases along with the end chemical product requirements, impacts the selection of different carbon capture technology based on factors such as, capability, scalability, cost and environmental impact.

(2) The research, development and deployment of new emerging and existing carbon capture technologies for the at-scale capture in industrial clusters and dispersed sites.

Increasing innovation and investment in chemical manufacture from captured industrial gases

Action:

Investment in technologies and projects that embed captured carbon into higher value chemical products at industrial clusters and dispersed sites

Enablers:

(1) Providing industry with knowledge of the capability and scalability of existing and emerging chemical processing and the impact of waste gas quality has on transformation processes, cost and environmental impact.

(2) Investment in the research, development and deployment of new emerging and existing chemical transformation technologies for the at-scale conversion of industrial waste gases to chemicals in industrial clusters and dispersed sites.

Capturing industrial waste gas emissions

	Specific Actions	Suggested Leads	Timeline for actions*
1	A desktop study which collates all available data on the state of the art and emerging technologies for capturing carbon which can be shared with industry including: A. The economics and overall carbon footprint of capture technology (including energy) at-scale; B. The capability and scalability of current and emerging technology; C. Horizon scanning for new low TRL technologies.	Innovate UK KTN, RTO, Academia.	Short Term
2	Generate data which provides industry with confidence in the TEA and LCA, associated with adoption of the different capture technologies.	RTO, Academia	Short to Medium Term
3	Investment in: A. Novel carbon capture technologies, projects and start-ups that can further improve the cost effectiveness of the carbon capture process; B. Pilot and demonstration facilities to de-risk the scale-up of technology and establish the impact of industrial waste gas quality on the techno economics and environmental impact.	Government, UKRI, Investors	Short to Long Term

***Timeline for action (Short 0-2yrs, Medium 3-5yrs, Long 5yrs+)**

Increasing innovation and investment in chemical manufacture from captured industrial gases

	Specific Actions	Suggested Leads	Timeline for actions*
1	A desktop study which collates all available data on the state of the art and emerging technologies for transforming waste gases (chemo, electro, bio), which can be shared with industry to inform future opportunities: A. The economics and overall carbon footprint of at-scale and emerging technology (including energy); B. The capability and scalability of current and emerging technology; C. Horizon scanning for new low TRL technologies.	Innovate UK KTN, RTO, Academia.	Short Term
2	We need investment in innovation projects that help industry to: A. Determine the quality requirements of CO/CO_2 needed for different processes; B. Demonstrate technical and economic capability with the incumbent technologies and supply chains; C. Establish the capability and scalability of current and emerging technology; D. Evaluate technologies and innovations needed to enable assets to remain competitive in the future; E. Research novel carbon transformation technologies; E. Develop pilot and demonstration facilities to de-risk the scale-up of transformation technology and establish the techno economics and environmental impact.	Government, UKRI, Investors	Short to Long Term
3	A study which specifically looks at the feasibility of a cluster based approach tapping-off and transforming CO_2 from a CCUS network to transform into a new platform chemical feedstock (e.g. Methanol) or final products.	Government, UKRI, Centres of Excellence (including NICER Circular Chems), Investors	Short Term
4	Bring together industry, supply chain and innovators to learn from one another, share knowledge and showcase innovative projects	Innovate UK KTN	Short Term

***Timeline for action (Short 0-2yrs, Medium 3-5yrs, Long 5yrs+)**

Government Framework for Circularity

Stimulating the transition to a UK circular carbon economy

Action:

Industry needs a policy, regulatory and standards environment that drives behavioural change and makes the utilisation of industrial waste gases to chemicals an attractive long-term investment.

Enablers:

(1) Policy and regulatory mechanisms that encourage the move towards a circular economy and the opportunity to utilise 'waste' carbon feedstocks to displace virgin petrochemicals.

(2) Developing new standards for LCA, TEA, waste carbon and the chemicals products manufactured.

Government Framework for Circularity

	Specific Actions	Suggested Leads	Timeline for actions*
1	A summary of the current policy and regulation landscape and the challenges / opportunities.	Innovate UK KTN, UKRI Centre of Excellence (NICER)	Short Term
2	Build a case for policy and regulation changes in key areas that are required to enable the chemical sector and its supply chain to invest.	Industry and Professional Bodies, Trade Associations	Short to Medium Term
3	Define and develop standards for A. Carbon emissions and carbon accounting throughout the value chain, including a framework for measurement and traceability; B. Development of a standards for chemical products made from waste gases; C. TEA & LCA	Regulatory / Standards Bodies	Short to Medium Term
4	Develop the strategic case for the Government investment in CAPEX intensive projects.	Industry Bodies, Industry, RTO's	Short to Medium Term
5	Establish a virtual circular economy policy centre that can provide fast responses to government requests for policy input and evidence.	Industry Bodies, Centres of Excellence (including NICER Circular Chems)	Short to Long Term

***Timeline for action (Short 0-2yrs, Medium 3-5yrs, Long 5yrs+)**

Looking ahead

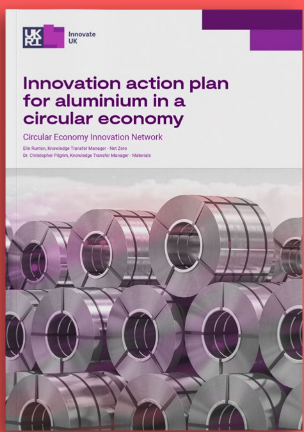
Transforming Industrial Waste Gases to Chemicals Action Plan: Next Steps

As our growing population increases its demands on energy systems, raw materials and supply chains, this action plan offers a pathway to reduce our reliance on fossil feedstocks through the recovery and transformation of industrial waste gases to chemicals. The Innovate UK KTN Circular Economy Network will continue to champion the move towards a circular carbon future and the delivery of this action plan by the community.

Join the Innovate UK KTN Circular Economy Innovation Network:

The Circular Economy Innovation Network is open to all organisations across the UK, from large companies, SMEs and start-ups, to academics and researchers. Be part of our collaborative communities working towards: Circular Design, Circular Business Models, and Circular Recovery. Together we can enable more resilient industries, inspire innovative businesses to create value through circular economy principles, andinvolve talented people to create vibrant and successful ecosystems, for a positive impact on the UK’s economy, environment, and society.

Find out more



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Connecting for
Positive Change.

Innovate UK

This is an independent paper reflecting the views of the Circular Economy Innovation Network team at Innovate UK KTN.
This programme aims to enable more resilient industries to work together, connect, collaborate, and share experiences to achieve Net Zero through circular innovation.

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