Note 10

Recommendations for cities that work with CO_2 capture, utilisation and storage

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Summary

Cities are the largest demand centres of any developed economy. They consume vast amounts of goods that emit CO2 at different stages of their existence, i.e. during their production, consumption and end-of-life treatment. At the same time, crucial industries like cement, steel, chemicals, and waste incinerators are commonly located within the borders or proximity of cities. As such, cities have a significant market power in directing consumer behaviour and demanding cleaner production processes. This can translate into direct control over acceptable emission levels in local industry and limit dirty products' entry to the market, thereby incentivising industrial decarbonisation far beyond their jurisdictions.

CCS will be required to enable carbon neutrality in energy-intensive industries and other major point source emissions. CCU can also contribute toward this goal by providing new resource-saving (yet energy intensive) process pathways. Municipalities can be at the forefront of driving investments into deploying these technologies and help create the necessary market and infrastructural frameworks. Levers to do so include public procurement mandates for low carbon products, waste tax on non-recyclable products, and other regulatory incentives. As cities are set to become the points of entry and exit of green energy carriers and CO2 respectively, creating an infrastructural hub around this can bring new business opportunities and help incite decarbonisation elsewhere. Cross-municipal cooperation on these matters is crucial.

Actions and investments taken today need to enable the reaching of net-zero emissions across the economy as soon as possible. By establishing themselves as drivers for clean products and infrastructural hubs for new climate technologies, cities can directly ensure that new innovations can enter the market, and increase their own attractiveness for inward, clean investment.

True technology openness and optionality is only created through the availability of infrastructures that enable industry to make investments and decisions required for deep decarbonisation. Many cities operate or oversee waste incinerators inside their border, making the related emissions a direct part of the city's emissions inventory and providing a natural starting point for such an infrastructure driven approach. However, luck with city borders or exporting waste for incineration cannot be a way to tackle emissions. It is crucial that related regulatory frameworks, incentives, and procurement mandates and standards drive true climate innovation and do not merely reinforce incremental changes to the current system or even displace CO2 emissions to other sectors or jurisdictions, e.g. just beyond the city limits. Within this necessary systems view, cities can play a crucial role in driving change and leading entire economies by example.

Drive innovation in industry and heat

Cities have direct CO_2 emissions within their borders

Within city boundaries CO2 emissions may be broken down into two main sources, distributed and centralised. Distributed emissions such a road transport is not applicable for CO2 capture, since these emissions sources generally benefit from direct electrification via renewable electricity and a modal shift from car to e.g. public transport and active modes. Centralised producers such as district heating, waste incineration and potentially local industrial sites such as cement production are characterised by large concentrated emissions. Attracting large scale, near-term hydrogen production would also benefit from CO2 transport and storage. These centralised emissions are potential candidates for CO2 capture, usage and/or permanent storage.

Below you will find a list of city actions that may support cities work with CCS and CCU varying from direct to indirect measures. Due to the financial costs and high complexity of working with both technologies, there is no "one size fits all" model that will lead to full implementation. The actions aren't listed in a step-by-step order.

Action 1: Mapping

Cities should begin by mapping of direct centralised emissions sources within their vicinity. The function of these emissions sources must also be understood. What service is being provided, and can it be replaced or avoided? What is the ownership structure? When is the planned upgrading or renovation of the facility? The aim of the mapping process is to identify the most persistent emitters that will require CO2 capture, use, transport and storage techniques to fulfil the city's climate target.

The most probable candidates to look for are energy-intensive industries such as steel, cement or chemicals, as well as municipal waste-to-energy and large district heating facilities.

> Example: CO2 emissions from municipal waste
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> A municipal waste incinerator is generally multifunctional, providing a waste management role along with energy and heat provision to the city. This deep integration makes such CO2 emissions sources difficult to reduce. In the foreseeable future, avoiding emissions from waste incineration through closures would require the export or transport (out of the city) of unrecyclable waste (and related emissions) and alternative large-scale heat sources to meet demand from district heating systems.
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> The city of Oslo aims to reduce CO2 emissions by 95% by 2030.[1] Within Oslo's city limits the Klemetsrud waste-to-energy plant is a large source of emissions with annual emissions of more than 400,000 tonnes of CO2. By capturing and storing the emitted greenhouse gas, the city of Oslo aims to cut city-wide fossil CO2 emissions by 12 percent with a single project.[2] The application of CCS to this facility will prevent CO2 emissions from waste incineration and provide low carbon heat to the city's district heating system.

Many cities are host to emissions intensive large industrial clusters. Cities such as Rotterdam, Antwerp and Duisburg depend on industrial production as the core of economic activity. Such cities have emissions intensities far beyond the national average due to large chemicals, steel and cement production. Those cities will be challenged on mitigating the climate impact, but it also creates an opportunity for developing a hub for CO2 capture and lead to cost reductions in the establishment of a shared infrastructure.

> Example: Strategic planning for industrial emissions
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> The Netherlands has a national emissions reduction goal of 49% by 2030. Industry based in Rotterdam accounts for 17% of total Netherlands CO2 emissions, these emissions must reduce rapidly for the national goal to be reached.[3] The Netherlands climate action plan aims to store seven million tonnes of captured CO2 per annum by 2030. The port of Rotterdam has begun preparing to do its part in reaching the targets, focusing on the development of strategic CO2 and H2 (hydrogen) infrastructure to serve the port. This includes a backbone CO2 pipeline to provide access to offshore CO2 storage, and extra

[1] https://www.oslo.kommune.no/politics-and-administration/green-oslo/best-practices/oslo-s-climate-strategy-and-climate-budget/

[2] https://www.oslo.kommune.no/politics-and-administration/green-oslo/best-practices/carbon-capture/

[3] https://www.portofrotterdam.com/sites/default/files/port-of-rotterdam-co2-neutral.pdf

capacity to expand over time. Rotterdam effectively seeks to become the CO_2 transport and storage hub of the region.

Action 2: Cities as facilitators of collaboration

An ambitious climate strategy within a city will be attractive for innovative businesses, knowledge institutions, as well as waste and energy utilities, since the strategy potentially will provide an opportunity for these stakeholders to become solution providers. Cities shouldn't neglect this and acknowledge their position of being facilitators of collaboration related to climate issues within their municipal borders. Numerous examples of public private partnerships have developed new solutions and created results beyond expectations.

Formerly, there has been a tendency to have a negative image of the technology and perceive it as something that will prolong the existence and acceptance of fossil fuels, in particular coal and gas fired power plants. Also, many have seen carbon capture as a solution for the future, and mostly something the world of academia has been working with. However, the winds are changing. More and more political and industry conversations mention carbon capture to mitigate the climate impact, in particular when it comes to industries with few or no other near-term mitigation alternatives. Therefore, it is important that local authorities take advantage of this momentum and engage their key stakeholders to generate local commitment and start a carbon capture project in their city.

This of course requires the engagement of an organization with an actual emission point source (according to Action #1) that will provide a physical location. In this engagement it is important to emphasize carbon capture in connection to the city climate target. If any organizations with large emissions shows interest in continuing this work, other stakeholders can be invited to sit at the table. In the start, it shouldn't be about making too many commitments. Instead it will be about learning more about the technology, possibilities and each other. Inviting all relevant stakeholders for a workshop with the attendance of city politicians may be a good starting point.

Through time this collaboration should lead to a formal commitment with shared statements of working with the technology as one of the solutions to reach the city climate target. Having different partners announcing this statement will potentially reach the broader media, and open new possible collaboration, funding opportunities and political focus from the national government and their agencies.

Action 3.1: Assessing CO_2 capture, transport and storage viability

After initial mapping concludes that one or more emissions sources requires CO_2 capture and storage to meet decarbonisation goals a high-level assessment of access to CO_2 storage and CO_2 transport routes will need to be undertaken.

European CO_2 storage development to date has focused on the North Sea. Norway, the United Kingdom and the Netherlands are all developing offshore CO_2 storage capacity with the possibility to store CO_2 from third countries. The potential to transport CO_2 to the North Sea region would be beneficial as it would allow cooperation with mature CO_2 storage sites.

CO2 can be transported via major transport waterways. Ships and river barges are an efficient and flexible way of transporting CO2 from the emissions source to offshore storage sites.[4] Cities and industrial sites that have access to port facilities are good candidates for ship and barge transport.

For very large volumes of CO2, pipelines become the most cost-effective link to storage sites. Existing offshore natural gas pipelines can be re-used to transport CO2.[5]

Example: CO2 transport and storage requires planning

CO2 transport and storage is a minority cost in a CCS project. At large volumes, costs for transport have been estimated at € 6-11 per tonne and storage at € 2-20.[6] Costs for CO2 networks are reduced through sharing of the transport and storage infrastructure.

Cities and their adjacent regions can play a role in aiding cost-effective shared CO2 transport infrastructure development. CO2 transport benefits from future planning and correct sizing allowing other emitters to join the network as national emissions targets are met.

Example: CO2 Capture cost is dependent on the source of CO2

Both CO2 storage and CO2 utilisation require the CO2 to be captured directly at the industrial site. The costs for capture will vary, depending on factors such as level of CO2 concentration in flue gas and availability of excess heat to power the capture process. Capture cost are lowest at high purity sources (e.g. gas treatment €12/tCO2) with increasing cost of capture from more dilute sources (e.g. cement manufacture €61/tCO2)[7].

Action 3.2: Assessing CO2 capture and use viability

The use of CO2 to make products can under specified criteria reduce overall emissions. CO2 use is distinct from CO2 storage, as when CO2 is converted to a temporary product such as a fuel. For this example, the captured CO2 is released to the atmosphere shortly after, limiting the overall climate benefit to at best being neutral. To prevent double counting, the CO2 accounting framework would either need to retain the CO2 emissions liability with the industrial installation capturing the CO2, else such fuels would still need to be accounted as full carbon (fossil origin, if fossil fuels are used in the industrial process) fuels[8].

CO2 uses are very diverse, from the synthesis of fuels to the mineralisation of building products. Hence it is not simple to characterise the requirements and inputs needed. A prominent proposed use of CO2 is the synthesis of aviation fuels to reduce the emissions of flights to and from major cities. The production of these fuels requires a CO2 source and a low carbon electricity source. Characterising

[4] IEAGHG, "CO2 Transport via Pipeline and Ship. CCOP-EPPM Workshop (Indonesia).," 2012.
[5] P. Brownsort, V. Scott and S. Haszeldine, "Reducing costs of carbon capture and storage by shared reuse of existing pipeline—Case study of a CO2 capture cluster for industry and power in Scotland," International Journal of Greenhouse Gas Control, vol. 52, pp. 130-138, 2016.
[6] Zero Emissions Platform (2011). The costs of CO2 transport and storage. http://www.zeroemissionsplatform.eu/library/publication/165-zep-cost-report-summary.html
[7] IEA, "Technology Roadmap: Energy and GHG Reductions in the Chemical Industry via Catalytic Processes," IEA, Paris, 2013
[8] http://www.co2value.eu/wp-content/uploads/2019/09/C.-JRC.pdf

the electricity requirement and expected availability should be undertaken to assess the feasibility of using CO2 at scale in the medium term.

Cities should engage with local stakeholders that have an interest in utilizing the CO2 and facilitate the development of potential collaboration between the two partners respectively capturing and utilizing the CO2.

Example: Clean electricity is required to convert CO2 to a fuel

Danish airports sale of jet fuel is equivalent to 12TWh of energy and results in 3.1 million tonnes of CO2 emissions[9]. Replacing the current jet fuel demand with synthetic fuels from CO2 would require approximately 24 TWh of renewable electricity[10]. Total current wind electricity production in Denmark (14.78 TWh) would meet only 70% of this demand[11]. In a situation where one must prioritise the use of limited renewable electricity, one could argue that much greater efficiency and climate benefit would be achieved by e.g. electrifying road transport (via battery-power vehicles) rather than using the electricity to produce e-fuels. In a situation with abundant cheap renewable electricity, this becomes less of an issue.

Action 4: Developing a project – access to European funding

European funds are available for leading decarbonisation projects. Such finance can cover portions of the capture unit and thereby help mobilise industry investments together with national funds, but also the transport infrastructure and intermediate storage facilities. Ensuring fair access to CO2 infrastructure for emitters across Europe is critical to ensure competitiveness of its regions. Cities and regions can be a driving force in this development, by clarifying their needs to European and national authorities. It is therefore important for cities to be aware of these opportunities and take advantage of them by careful planning. Gaining an understanding of the requirements for access to available funds is a key prerequisite for successful bids.

In 2020, the European Union is commencing calls for proposals for its Innovation Fund, which targets mature and scalable projects with innovative funding and business models. Clear development stages need to be set, and overall project costs should be clearly identified. Cooperation between various cities and companies increases the benefits and learning of a project, as well as its likelihood to receive European funding.

The same goes, and in fact is required, for EU funding mechanisms under the Connecting Europe Facility (CEF). Transport infrastructures, including intermediate storage facilities and transnational shipping terminals can be eligible to financial support by gaining the status of Projects of Common Interest (PCI). Planning CO2 projects, therefore, with an international/inter-European dimension should be a priority. Overall project costs should be clearly identified.

Example: EU PCI funding is helping to finance cross-border carbon dioxide network

[9] https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics
[10] At an overall conversion efficiency of 50% https://www.transportenvironment.org/sites/te/files/publications/2017_11_Cerulogy_study_What_role_electrofuels_final_0.pdf
[11] https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/key-figures

The Connection Europe Facility is aiding the maturation of CO_2 transport and storage projects around the North Sea. Recipients include Rotterdam, Amsterdam, Ireland, Norway and Scotland[12]. Grants have been provided for project scoping and engineering and design. The PCI fund is aiding cities such as Rotterdam to mature designs for a shared CO_2 transport and storage network reaching beyond their own city and even national borders, in advance of national and European capital funding schemes.

Action 5: Strategic consideration, planning a project for future expansion

The initial European CO_2 capture, use and storage projects should, where possible, be strategically located, enabling such hub-based infrastructure to expand to other cities and industrial clusters.

When considering the development of an initial regional CCS project, focus should be placed on the potential for future expansion of CO_2 transport and storage. Dialogue with relevant cities, regions and mapping of infrastructure expansion to relevant emitters and industries should inform the right sizing of transport infrastructure capacity. Expanding CO_2 infrastructure capacity on an ad-hoc basis later can be significantly more expensive than adequately sizing the initial investment[13].

Cooperation and integration with nearby regional CO_2 transport and storage networks can add resilience and reduce complexity. The development of flexible ship CO_2 transport and open access CO_2 storage sites in the North Sea is reducing the barrier for entry of new CO_2 capture projects at scale.

Example: Joining existing infrastructure for transport and storage

Following and learning from a planned CO_2 capture plant at a waste incinerator in Oslo, an industry cluster in Fredrikstad, Norway, is currently mapping CO_2 sources in the area, with the purpose of setting up a joint infrastructure for CO_2 capture, transport, utilisation and storage. The new cluster aims to share CO_2 storage with the initial Oslo capture project.[14]

Carbon dioxide networks can benefit CO_2 storage, CO_2 utilisation and atmospheric carbon dioxide removal. CO_2 infrastructure established by an initial CCS project can also provide high purity CO_2 streams for CO_2 utilisation technology piloting, and expansion as sufficient resources become available. Carbon dioxide networks can provide CO_2 supply predictability for companies that want to buy and use CO_2 at scale. CO_2 transport and storage networks can also allow for CO_2 to be permanently removed from the atmosphere through geological sequestration. CO_2 captured from biomass use (Bio-CCS) or CO_2 captured directly from ambient air can be stored, thus removing CO_2 from the atmosphere and reducing its stock of global warming gasses. In addition to nature-based solutions (e.g. afforestation) these processes can aid countries to achieve net-zero emission.

Example: From preventing CO_2 emissions to removing CO_2 from the atmosphere

Stockholm's district heating system, which runs largely on local waste biomass, has also signalled interest in CCS and started testing CO_2 capture in December 2019. The utility Stockholm Exergi, supplies district heating, cooling, electricity and waste incineration to the city. Stockholm Exergi claims that incorporating CO_2 capture, transport and storage along with biochar production would result in a net removal of over one million tonnes of carbon

[12] https://ec.europa.eu/energy/sites/ener/files/c_2019_7772_1_annex.pdf
[13] http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/
[14] https://www.ostfoldenergi.no/nytt-prosjekt-kan-fa-betydning-for-klimautfordringene/

dioxide per year.[15] The proposed project intends to make use of ship CO2 transport and North Sea CO2 storage.

Action 6: use CO2 capture and storage to kick start a hydrogen economy

Hydrogen is widely anticipated to be required in the decarbonisation of industry, heating and shipping. CO2 transport and storage can aid a more rapid deployment by deploying low carbon hydrogen produced from natural gas. This can help to kick start hydrogen networks and hydrogen use in industry, while improved electrolysers and more renewable electricity will gradually make renewable hydrogen production scalable and more economically attractive.

> Example: Large scale hydrogen production for industrial decarbonisation
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> "HyNet will supply hydrogen to 10 energy intensive industrial gas users with up to 100% hydrogen via a dedicated hydrogen pipeline. This will achieve a material reduction in carbon dioxide emissions. Reducing industrial CO2 emissions helps to protect jobs by reducing exposure to carbon related costs from gas use."
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> https://hynet.co.uk/
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> https://hynet.co.uk/industry/

Action 7: Use public procurement to establish a first market for clean products

Through public procurement, ambitious governments and cities can take an exemplary role for the economy and create a parallel market of competition among contenders for public contracts.

> Example: Copenhagen aims to have all its municipal vehicles running on electricity, hydrogen or biofuels, and currently have succeeded in reaching 85 pct. More importantly, this led to the establishment of a shared electric vehicle procurement secretariat for the capital region, bringing 29 municipalities together and reducing the price by up to one-third.

The approach for a city-owned vehicle fleet can be extended. Cities are major consumers of construction materials like e.g. steel and cement. City leaders can thereby engage private investors through building permit approval requirements, but they can also introduce requirements for their own construction projects.

As with renewable energy, the extra costs of producing clean raw materials through CCS are expected to be transferred onto the final product. While such costs for concrete and steel can increase significantly, they translate into marginal increases of one-digit percentage range for constructing the final building.. The same applies to CCS on waste-to-energy plants, which would increase the cost for services for the final user by just € 0.27 a day (see note 9a).

Currently very few basic construction material industries have confidence in there being a market for low-carbon products, even at low premiums. Public procurement can therefore bridge the gap and provide a market for goods that otherwise would be uncompetitive.

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[15] GUSTAFSSON, K. 2018. Spearheading negative emissions in Stockholm's multi-energy system, in Bioenergy with carbon capture and storage: From global potentials to domestic realities. Y, 4

Example: In most cities it is the municipality that is the largest building owner and with the largest portfolio of construction projects in the pipeline. Therefore, several cities have developed more ambitious requirements to the building material and construction phase. In spring 2019, Copenhagen and Oslo developed a cross-national tender with requirements on non-road mobile machinery used in building and construction projects.

As a first step, it includes requirements for wheel loaders to be either low-emission or emission-free. Over the next years both cities will have to replace existing machinery, and with this new tender procedure it is hoped to lower the costs of greener wheel loaders to a maximum of 5 pct. total cost increase compared to standard diesel wheel loaders. It is a part of the project 'Scandinavian Green Public Procurement Alliance on Non-Road Mobile Machinery' and managed by GATE21. Stockholm is also a part of the project and is observing the tender.

With inspiration from Copenhagen and Oslo's collaboration, existing city networks such as Carbon Neutral City Alliance and C40 can play a key role in bringing together major city leaders, CO_2 infrastructure providers and construction material industries. If cities such as New York, Yokohama, Amsterdam and others issue statements of common, shared requirements to the building sector, it will create an incentive in the building industry of becoming the first manufacturers of low-carbon steel and cement.

Furthermore, it may be of interest to engage with regional and national municipalities on developing these tender requirements. Firstly, this will be less regulatory challenge related to international collaboration, and secondly there will probably be similar examples of shared tender material.

Action 8: Cities need support from the national government

In the last decade cities have taken a leading role with the development of ambitious climate targets and strategies and have often moved ahead of their national government. Most cities will have the mandate to achieve a significant CO2 reduction themselves, however implementing rapid solutions such as carbon capture will need support and an active role from the national government in implementing CCS and CCU technologies.

The difference in having support or not is significant, and it may be the difference between succeeding or failing. Learnings from Amsterdam, Copenhagen, Helsinki, Oslo and Stockholm gives an indication of the number of barriers that exist getting from idea to implementation of CCS or CCU, and the difference is shown in their pathways.

Example: Norway have set a path to become the main supplier of CO2 storage capacity for Europe, while the Danish government still awaits their future decision on the technology. In that regard, the Norwegian government is considering financing 1-2 carbon capture projects, potentially leading to the construction of a full-scale carbon capture facility at Klemetsrud in Oslo, and furthermore with the plans of establishing the Northern Lights Project as an offshore storage site.[16]

While, in Denmark and Copenhagen the work is driven without an overall strategic vision of CCS and CCU This means that regulatory barriers persist, and funding must be found somewhere else.

[16] https://northernlightsccs.com/en/about

It can be difficult for cities to coordinate and facilitate the process of making a strategy and vision for establishing the infrastructure for CCS and CCU. Therefore, cities should in an early stage engage with the national government and its climate department securing this support. Beforehand it may be beneficial to include different organizations and point sources with interest in carbon capture, to convince the government of the opportunities in the technology.

Action 9: **Drive consumption change through campaigns and levying**

As the major demand centres of the economy with growing waste management and air pollution challenges, cities' campaigns for responsible consumption and green products can have a far-reaching impact on shifting consumer behaviour and encouraging cleaner production to gain access to a growing market. Such a campaign should go hand-in-hand with aforementioned public procurement ambitions and industry-scale demonstration projects to lead by example.

Waste management is commonly the prerogative of the city municipality – from its collection to separation, recycling, incineration and energy recovery. Lacking the power to set standards on products and their production, waste management can be a useful lever in which a city government can 'tax' unsustainable and dirty products to use the new revenue stream to encourage low-carbon alternatives. Following the waste hierarchy of preventing, reusing, recycling, charging a levy for e.g. non-recyclable plastic waste that needs to be incinerated can directly be reinvested in the CO2 capture technology necessary at the waste incinerator. A municipal levy on non-recyclable waste can thereby promote clean and recyclable alternatives and simultaneously aid financing the correct disposal for non-recyclable waste.

Conclusions: Cities at the core of the Green Economy

Pulling green products onto the market means investments into infrastructures and projects that ensure a low-carbon production pay-off. Cities combine market power for decisive pull with regulatory push for zero carbon projects. Using both levers means cities can act faster and more targeted at developing and implementing industrial climate action around infrastructure-intensive technologies than the central government. Cooperating with adjacent municipalities and across other major cities means scalability is possible.