The Sultanate of Oman's National Strategy for an Orderly Transition to Net Zero

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Foreword by His Excellency the Minister of Energy and Minerals

As the world increasingly experiences the effects of global climate change, the imperative to decarbonize and transition the world's economies to cleaner energy has never been greater. The momentum of the global energy transition continues to gather pace and nations must decide how they will position for the future. To this end, the Sultanate of Oman has taken the bold step to define a pathway toward a more sustainable and prosperous future for all Omanis.

Under the leadership of His Majesty Sultan Haitham bin Tarik, Oman has announced its commitment to achieve net zero emissions by 2050, in line with the Paris Climate Agreement's objective of limiting global climate change to below 1.5C compared to pre-industrial levels. With this commitment, the Sultanate has staked a position amongst the leading nations on the world stage in defining a sustainable pathway to the future.

This document introduces Oman's vision of its journey to net zero emissions by 2050. Oman's will be an orderly energy transition, underpinned by a set of fundamental objectives: ensure environmental sustainability, minimize economic costs to Omani citizens and industries, optimize the economic impact arising from the transition, encourage job creation, and ensure a secure energy supply.

The vision is as compelling as it is challenging – the transition will involve many changes to the economy and will involve trade-offs along the way. But thanks to Almighty Allah, Oman is blessed with a bountiful endowment of natural resources to support the transition: plentiful sunlight, ideal windspeeds and a favorable geographic location to grow a new hydrogen economy.

While the net zero 2050 pathway is a critical step in the journey, it is only the beginning. With the announcement of the creation of the Oman Sustainability Center, the Sultanate has laid the foundation to ensure the necessary supervision, implementation, and support for the net zero 2050 plan.

With the guidance of Almighty Allah, we are starting on the journey toward a more sustainable and prosperous future for all Omanis.

Preface

Under the leadership of His Majesty Sultan Haitham bin Tarik, in October of 2022 Oman announced its commitment to achieve net zero emissions by 2050. With this commitment, Oman joins a group of over 70 countries[1] that have pledged to achieve net zero emissions by 2050[2]. It aligns with the Sultanate's 2040 vision to be "the gateway to overcome challenges, keep pace with regional and global changes, generate and seize opportunities to foster economic competitiveness and social well-being, stimulate growth, and build confidence in all economic, social, and developmental relations nationwide"[3].

To this end, the Sultanate of Oman commissioned a project to revalidate its baseline emissions and understand its options to attain net zero by 2050.

This report presents the findings of that work. It establishes a new current emissions baseline and explores the potential pathways that Oman could follow to achieve its net zero aspiration focusing in detail on one – an orderly transition. It does not constitute a forecast, estimate or projection of the future, nor is it intended as a recommendation of the pathway Oman should follow.

1 *For a liveable climate: Net-zero commitments must be backed by credible action,* United Nations Climate Action, https://www.un.org/en/climatechange/net-zero-coalition

2 *Oman sets 2050 goal to achieve net-zero carbon emissions,* Mina Aldroubi, 17 October 2022, The National News, https://www.thenationalnews.com/gulf-news/oman/2022/10/11/oman-sets-2050-goal-to-achieve-net-zero-carbon-emissions/

3 *Vision Document,* Oman 2040 vision, https://isfu.gov.om/2040/Vision_Documents_En.pdf

Executive summary

As of 2021, Oman's net emissions totaled approximately 90Mt CO_2e, with five sectors contributing ~95% of net emissions—industry, oil and gas, power, transport, and buildings. Unless it acts now, Oman is set to increase emissions by 16% to 104 Mt CO_2e by 2050.

Oman could adopt several different paths to net zero by 2050. To make the transition smooth and sustainable, Oman has set five objectives for its path: environmental sustainability, energy system costs, economic impact, social impact and security of supply.

Three main archetypes exist for Oman's transition: delayed, accelerated and orderly pathways.

A delayed transition would sustain existing export industries for as long as possible and activate the lowest-cost emissions abatement initiatives as late as possible. This pathway would optimize for two of the five objectives – minimizing energy system costs and adverse economic impact. However, in the long run a delayed transition pathway could result in stranded assets and missed opportunities in future green value pools.

At the other end of the spectrum, an accelerated transition would focus on early and fast decarbonization across all sectors and would achieve the environmental sustainability objective. However, it could increase energy system costs in the long term as technologies may be adopted earlier than economically viable and assets may be forced to retire.

An orderly transition offers an attractive middle option that would allow Oman to achieve its net zero goal by 2050. This path would implement the lowest-cost decarbonization levers first as they become economically viable, then activate levers to address harder-to-abate emissions. Individual sectors would decarbonize at different paces, but the national pathway would consider all five objectives.

An orderly transition path could help Oman abate 97 Mt CO_2e by 2050, with decarbonization through 2030 and 2040 accounting for 6% and 54% of the total pathway respectively relative to 2021 emissions. Industry, oil and gas and transport would drive these efforts. This pathway would result in a remaining "last mile" gap of ~8% (7Mt) that could be addressed through breakthrough decarbonization technologies and natural negative emissions (e.g., direct-air capture (DAC) of carbon with storage in depleted reservoirs or planting mangrove trees to absorb atmospheric carbon), and critical behavioral changes (e.g., substituting carbon-intense products or materials).

Six main decarbonization technologies would support an orderly transition: energy and resource efficiency, electrification and renewables, battery electric technology, sustainable hydrogen, carbon capture and storage and negative-emission solutions. Together, these technologies would cover ~90% of abatement to 2050. However, the decarbonization targets would require technology to mature (e.g., long-duration energy storage), building new infrastructure (e.g., electric vehicle charging networks), increasing adoption levels (e.g., uptake of electric vehicles) and introducing policies and legislation (e.g., policies to incentivize behavioral changes) and market mechanisms (e.g., carbon pricing).

The net zero pathway would cost ~USD 190 billion additional capital investment relative to Oman's "business-as-usual" scenario (~15% net of opex savings). This spending would cover power and hydrogen infrastructure (e.g., upgrading and extension of Oman's electricity grid, hydrogen pipelines and storage, electric vehicle charging infrastructure and at-scale deployment of long-duration energy storage). If we include investment required to unlock a hydrogen export economy, the capital investment required would increase by an additional ~USD 230 billion. These expenditures are not expected to be financed fully by the Government; public estimates suggest that the private sector could finance 70-80% of the global energy transition to 2050[4].

This investment would also help Oman to achieve its broader energy transition objectives:

- **Energy system costs.** The pathway would affect sectors differently (Exhibit 9). For example, in transport it could reduce the total cost of vehicle ownership by ~20-25% by 2050 (even with the required charging infrastructure). In power, the transition to solar and onshore wind could halve generation cost per kWh (upfront infrastructure costs are expected to be recovered by approximately two-thirds of the aggregate cost savings through 2050). However, in industry it could increase the levelized cost of steel production by 10-15% (which may be offset by a green steel premium in the short term).
- **Economic impact.** An orderly transition could contribute an additional 50% to GDP by 2050 (vs 2021), two-thirds of which would come from domestic investment in hydrogen (including export infrastructure) and the rest from expanded green power capacity. Electrifying the economy could free up a large amount of gas, creating a compelling opportunity for Oman to capture a fuel "double play", i.e., ramp up export of LNG and hydrogen.
- **Social impact.** Together with new green business growth opportunities, an orderly transition could increase total employment in Oman by 20-30%, mainly in the power sector (~43% of total new direct jobs) and the emerging hydrogen economy (~55% of total new direct jobs in domestic and export markets). Omani citizens could be upskilled and reskilled, e.g., in clean technologies like hydrogen, electric vehicles and carbon capture and storage, to supply trained workers to fill these jobs.
- **Security of supply.** By 2050, Oman could become self-sufficient in power and hydrogen, using hydrocarbons during the transition. However, an orderly transition also implies greater dependency on several imported clean technologies and materials, e.g., batteries, electric vehicles and rare earth metals.

To follow this path, Oman should continue to build momentum. This would involve balancing longer-term planning with near-term delivery by deciding which priority levers to implement first to unlock their full potential, capture immediate value and remove future bottlenecks. It would require an integrated approach underpinned by clear ownership and accountability. The recently announced Oman Sustainability Center would play an important role in establishing governance and cadence to track progress, communicate with stakeholders and develop investment plans. To change behavior on the ground, policies, legislation, and regulation should align across sub- and cross-sectoral policies.

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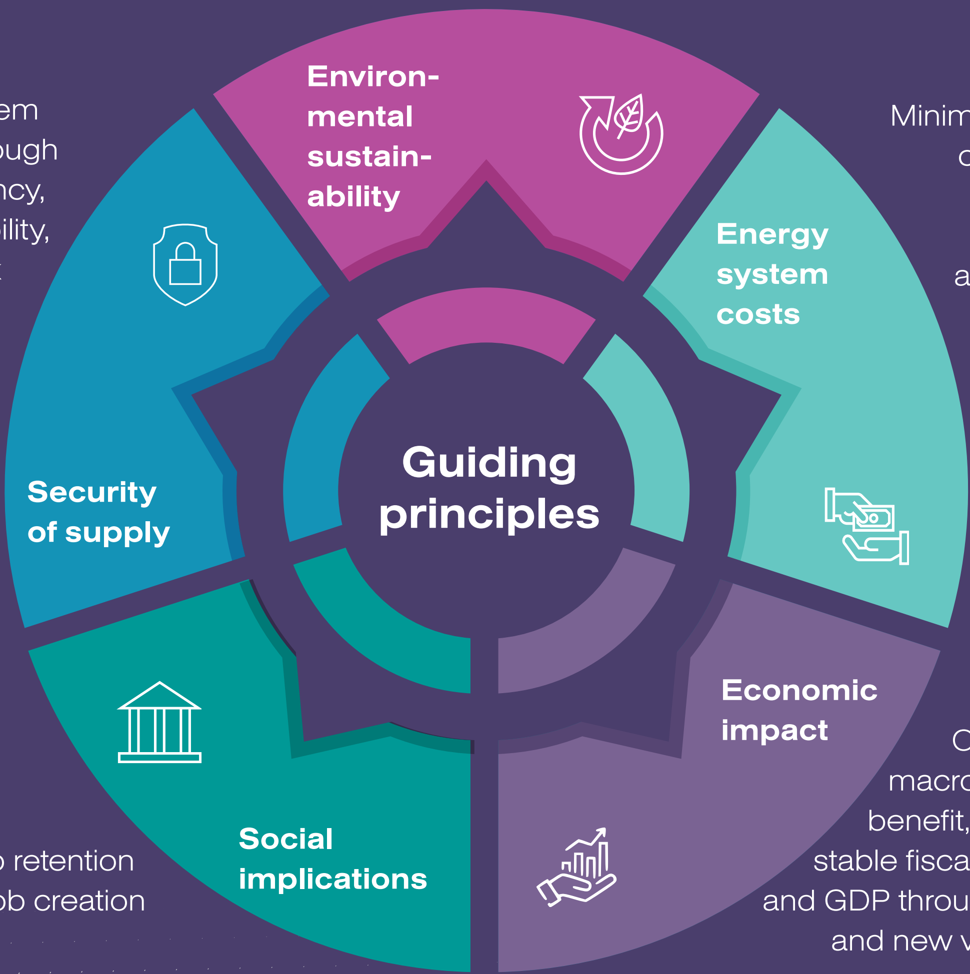
4 *Accelerating private finance for the Arab renewable energy transition*, EU Parliament, IEA, IRENA, Whitepaper CEBC and SDG, 2021

Objectives for Oman's Orderly Transition

Reduce carbon emissions to reach Net Zero by 2050 and minimize the overall carbon budget

Ensure system security through self-sufficiency, system stability, and low-risk access to supplies

Minimize energy costs to the domestic population and energy-dependent domestic sectors



Solve for job retention and future job creation potential

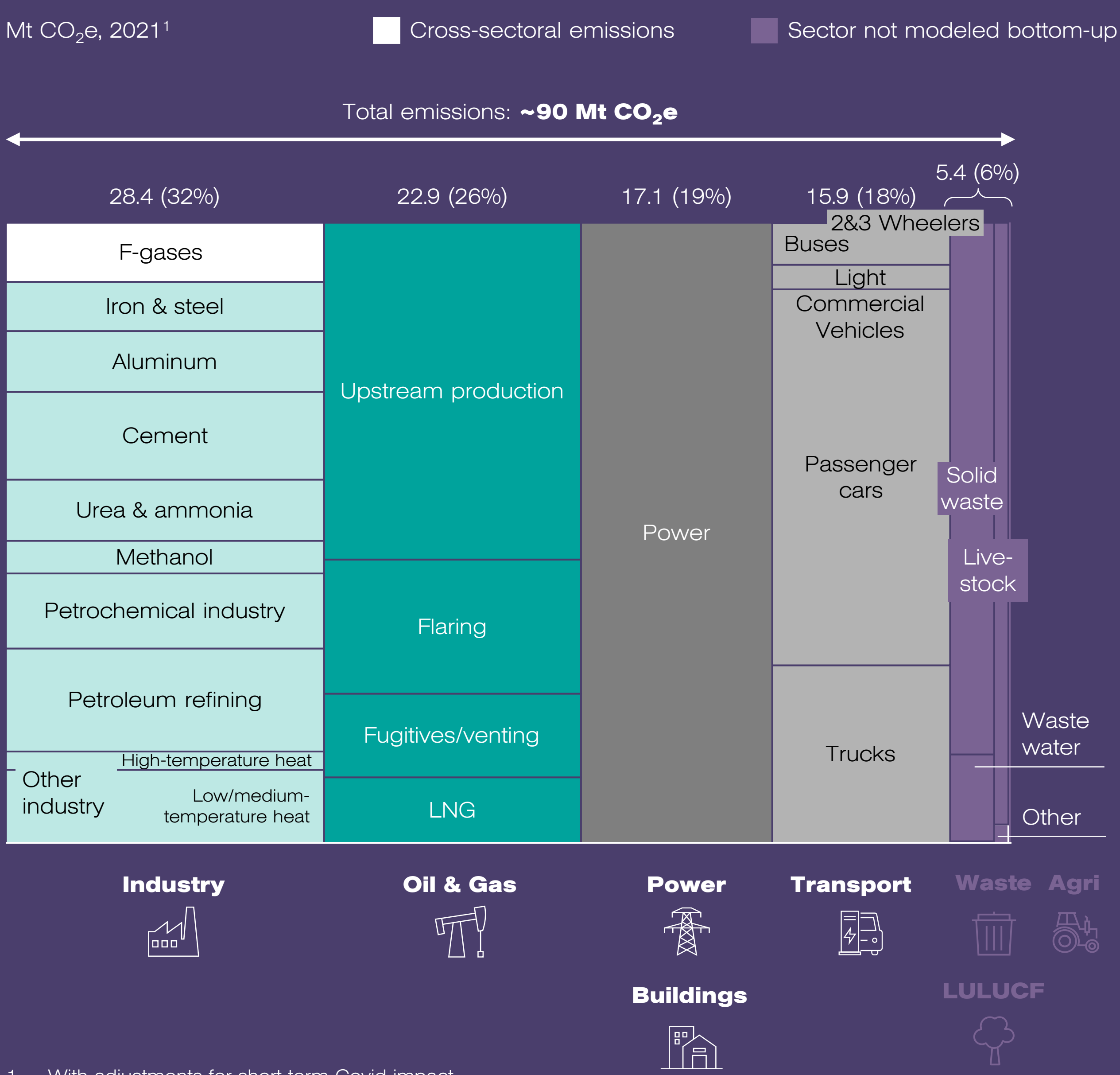
Optimize for macroeconomic benefit, solving for stable fiscal revenues, and GDP through existing and new value pools

1. Oman's emissions baseline

In 2020, the Sultanate of Oman released its second Nationally Determined Contributions (NDCs) to reduce greenhouse gas (GHG) emissions by 7% by 2030 against a baseline of ~125Mt CO2e (2030 business-as-usual emissions). As part of its recent net zero 2050 announcement, the Sultanate commissioned a team to collect and verify emissions data through Oman's Carbon Management Lab to validate the country's emissions baseline.

Oman's 2021 carbon emissions have been assessed at 90 Mt CO2e (Exhibit 1). Five sectors account for 95% of these emissions: industry, oil and gas, power, transport and buildings. Industry produces the lion's share at 32%, followed by oil and gas at 25%.

Exhibit 1: Oman's net carbon emissions



1. With adjustments for short-term Covid-impact

Source: Oman's Carbon Management Lab

By 2050, Oman's emissions are set to rise 16% to 104 Mt CO2e unless it takes action to reduce the amount of emissions it produces. The Sultanate is therefore evaluating energy transition pathways that could help it curb these numbers and reach its net zero goal.

Oman has identified five objectives for its transition pathway. First, it should help the country achieve **environmental sustainability** by reaching net zero and minimizing the cumulative carbon budget by 2050. It should minimize **energy system costs** for Omani citizens and businesses while optimizing **economic impact** impact including fiscal outlook and gross domestic product (GDP). It should factor in the **social impact** of the transition in terms of creating jobs. And it should maximize **security of supply** to ensure that demand centers are connected to the grid and that the system provides a stable supply of electricity.

Multiple pathways are open to Oman in its journey to reach net zero. They fall under three broad archetypes: delayed , orderly and accelerated transition (Exhibit 2).

A **delayed transition** transition would sustain Oman's existing export industries and introduce decarbonization levers as late as possible. This pathway would prioritize two of the five guiding principles: energy system costs and economic impact. However, it could have a negative effect on the economy in the long term as it risks creating 'stranded assets', e.g., legacy energy assets such as gas power generation plants that may become uncompetitive as the global energy system evolves. It could also mean that Oman loses out by failing to stake an early claim in new green businesses that offer valuable future revenue streams, e.g., hydrogen.

At the opposite end, an **accelerated transition** would decarbonize sectors early and fast to minimize the total carbon budget and match the commitments of other front-runner countries (55% carbon emission reduction by 2030[5]) – thus prioritizing environmental sustainability. This path could be more expensive in the near term, as it would likely require the uptake of technologies before they are economically viable and would incur forced abatement costs induced by pivoting away from existing assets before their natural replacement cycle.

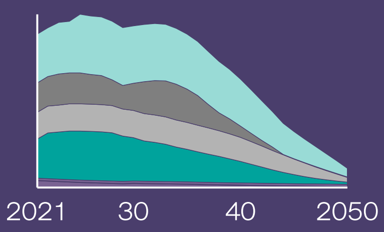
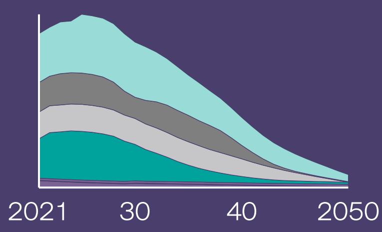
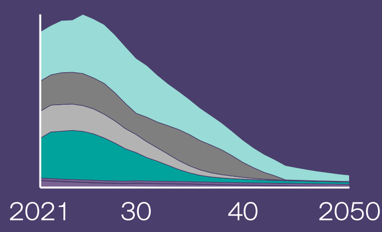
An **orderly transition** represents the middle ground. It would focus first on decarbonization levers with the lowest abatement costs, and then on segments that are harder to abate. This would be a more gradual transition that would pace adoption rates of green technologies (e.g., purchase of electric vehicles) to that of peer countries and would time major system changes to coincide with natural asset replacement cycles (e.g., replace low-and medium temperature furnaces with electric boilers at the end of their lives). Individual sectors would decarbonize at different paces, but this pathway would help Oman achieve all five of its transition objectives.

The remainder of this report explores the opportunities and impact for Oman presented by an orderly transition.

5 The European Union has committed to reduce its greenhouse gas emissions by 55% by 2030 through the Fit for 55 package

Exhibit 2: Three archetypes for Oman's energy transition

In comparison to the Business-as-Usual scenario

	Delayed transition	Orderly transition	Accelerated transition
Pathway description	Focus on sustaining the existing export industries, implementing the most cost-attractive initiatives only when latest required to reach Net Zero	Focus on decarbonization levers with the lowest abatement costs (priority levers), followed by segments that are hard-to-abate (optimizing for economic gain, and staying within sustainable fiscal and cost limits)	Early and fast decarbonization across sectors aligned with the European targets, minimizing the required carbon budget and matching the commitment of other front-runners (i.e., 55% reduction by 2030)
Abatement Pathway, CO_2e			
Carbon budget, Mt CO_2	~2,100	~1,760	~1,500
Leading objectives			
Considerations	Delayed transition is often disruptive and can in the long-term result in asset stranding, whilst leading to higher cumulative emissions Unsustainable price flare-ups for consumers as legacy products become scarce or uncompetitive, whilst focus on existing revenue streams can limit the uptake of future green value pools	Optimizing for (long-term) economic gain and environmental impact Enabling gradual transition and adoption rates to allow for matching natural switching points and repurposing of gas consumption from power and industries DETAILED PATHWAY	Uptake of technologies before these are economically viable, adopting larger technology and security of supply risks, as well as forced retirement costs Economically suboptimal because of asset stranding and forced retirement costs to reach short-term abatement targets

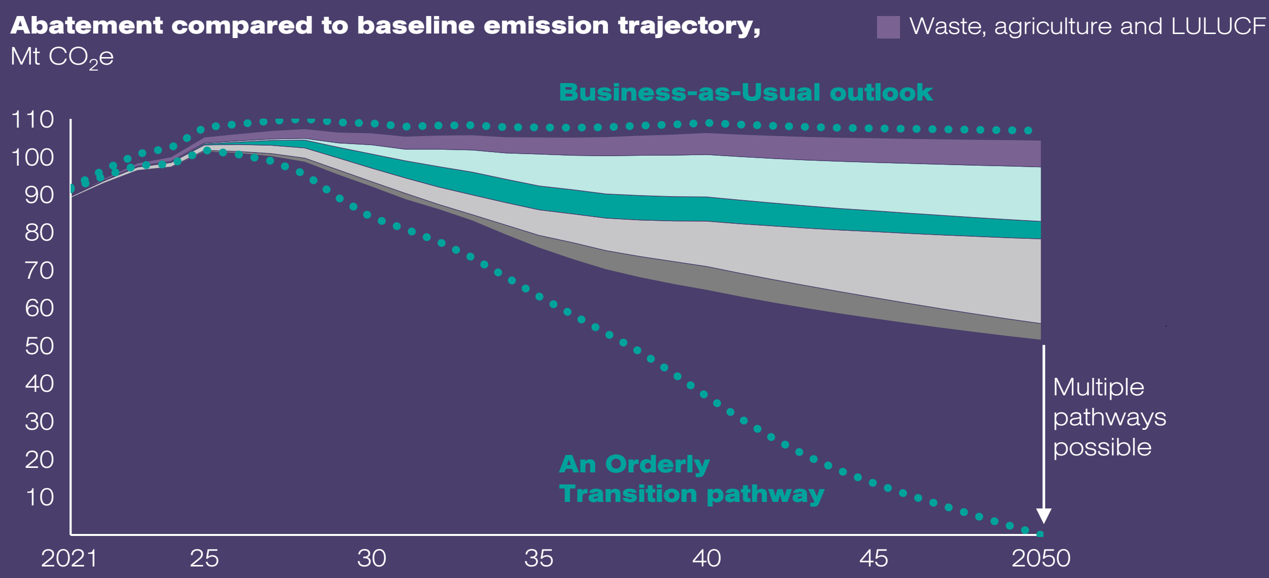
Source: Oman's Carbon Management Lab

2. An orderly transition

In considering a pathway to net zero emissions, two categories of lever were identified: priority decarbonization levers (those with the lowest cost of abatement) and system choices (levers that entail trade-offs to address hard-to-abate emissions).

Under an orderly transition, priority decarbonization options levers would optimize for all five of Oman's transition objectives. They are expected to drive half (52 Mt) of the abatement Oman seeks to achieve by 2050 across all sectors, driven largely by the industry, power and transport sectors (Exhibit 3).

Exhibit 3: Priority levers across the five key sectors



Key priority levers (not exhaustive)

Industry	Electrify low/medium-temperature heat across industries, feedstock changes in steel, cement, PetChem, and selective grid connections
Oil & Gas	Electrify low/medium-temperature heat and implement efficiency improvements, LDAR[1] for fugitives, and repurpose/export flared gas
Transport	Wide transition to EVs[2] and H_2-fuel cells for long-distance trucks and buses, behavioral changes reducing car usage, biofuels blending for lower emissions from ICE[3] vehicles
Buildings (incl. in power)	Improve insulation standards for new builds, improve energy efficiency of air conditioning units, and other electrical equipment
Power	Deploy renewable power generation at large scale, mainly driven by solar PV and onshore wind

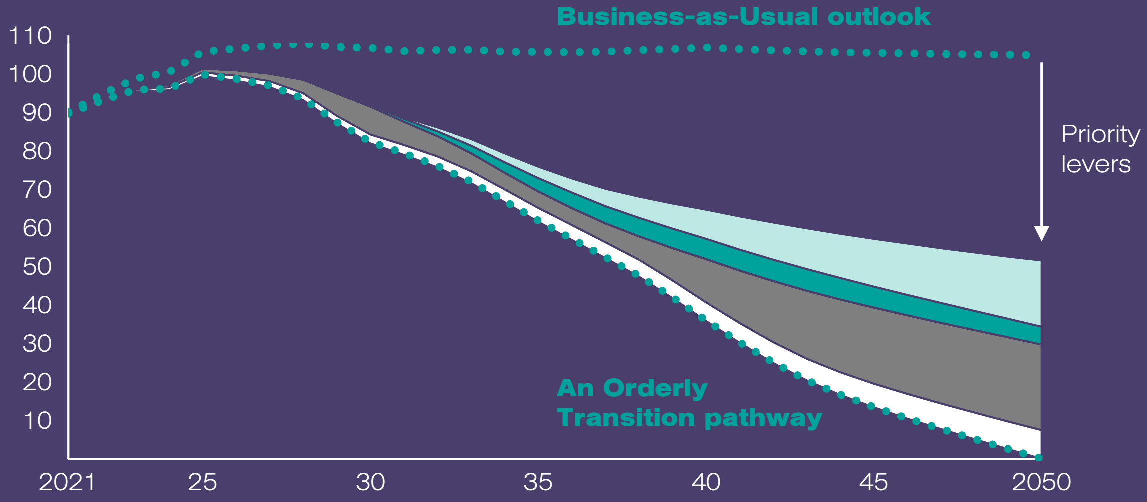
1. Leak Detection and Repair 2. Electric Vehicles 3. Internal Combustion Engine

Source: Oman's Carbon Management Lab

For example, priority levers for the industry sector could include electrification of low-to-medium temperature heat processes, changing the feedstock in cement production (e.g., substituting clinker) and making selective grid connections. The power sector could deploy solar and wind power generation at scale. The transport sector could transition to electric light vehicles and hydrogen fuel cells for long-distance trucks and buses, whilst supporting behavioral changes to reduce (individual) car usage.

Exhibit 4: Systems choices for harder-to-abate emissions

Abatement compared to baseline emission trajectory,
Mt CO_2e



5 key areas with system choices — Positioning in Orderly Transition scenario

Industry	How to decarbonize the hard-to-abate sectors?	Further electrification / CC(U)S / Hydrogen
Oil & Gas	How to decarbonize the sector?	Further electrification / CC(U)S
Buildings	How to optimally cool existing buildings?	District Cooling / Rapid demand response management / Active retrofits and insulation
Power	How to deliver baseload?	RES + gas + CC(U)S / RES + Nuclear / RES[1] + LDES[2]
"Last mile" to Net Zero	How to close the final gap?	Technology-based solutions / Nature-based solutions

1. Renewables (mainly solar PV and onshore wind)
2. Including pumped hydro

Source: Oman's Carbon Management Lab

Harder-to-abate emissions would require more difficult system choices with trade-offs (Exhibit 4). For example, oil and gas players would have to choose between addressing remaining emissions through electrification (e.g., of combined heat processes and LNG plants) or via carbon capture and storage.

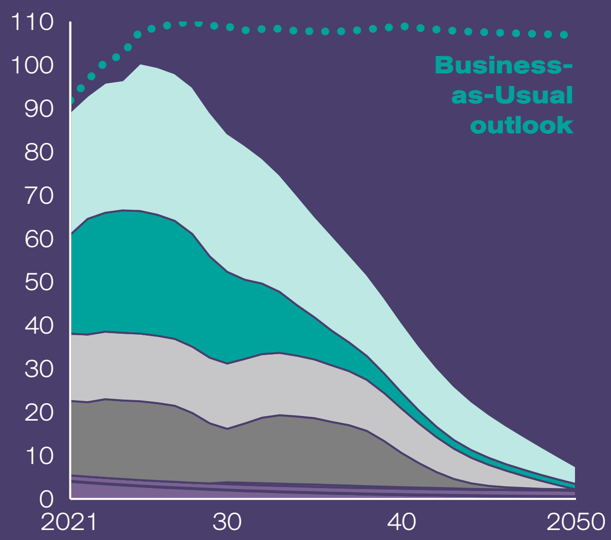
An orderly transition would activate both priority levers and system choices to lower emissions 6% by 2030, 54% by 2040 and 92% by 2050 compared to the 2021 baseline (Exhibit 5). This would leave a “last mile” gap of ~8% (7Mt) to achieve net zero by 2050. Oman could cover this gap through breakthrough decarbonization technologies and engineered or natural negative emissions (e.g., DAC of carbon with storage in depleted reservoirs or by planting mangrove trees to absorb atmospheric carbon), and changing behaviors, e.g., substituting carbon-intense products or materials).

The Second NDC aspires to reduce GHG emissions 7% by 2030 against a baseline of ~125 Mt CO2e business-as-usual emissions. Under an orderly transition, emissions abatement by 2030 would be ~6% (relative to the 90 Mt CO2e 2021 baseline determined during Oman’s Carbon Management Lab), however, ~20% relative to Oman’s 2030 business-as-usual scenario.

The total carbon budget for the pathway would be 1,760Mt CO2e to 2050.

Exhibit 5: Projected decarbonization efforts to 2050

Pace of GHG emission reduction per sector, 2021-2050, Mt CO_2e[1]



	2021	30	40	2050
Vs 2021		-6%[1]	-54%	-92%
Vs BaU		-21%	-62%	-93%

	Decarbonization vs. 2021, percent		
Sector	**2030**	**2040**	**2050**
Industry	13[2]	-43	-86
Oil & Gas	-7	-84	-94
Transport	-3	-34	-100
Buildings	5[3]	14[3]	10[3]
Power	-3	-57	-99
Other[4]			

1. Emission reduction compared to 2021 level; resulting 2030 projection of ~85 MT CO_2e compared to the original target of ~116 MT CO_2e based on a 7% reduction and a baseline of 125 MT CO_2e
2. Emissions increase due to production capacity expansion in cement and iron & steel
3. Indirect emissions; emissions accounted for in the power sector
4. Out of scope (waste, LULUCF, agriculture)

Source: Oman’s Carbon Management Lab

Decarbonization levers in each sector would support the pathway as described below.

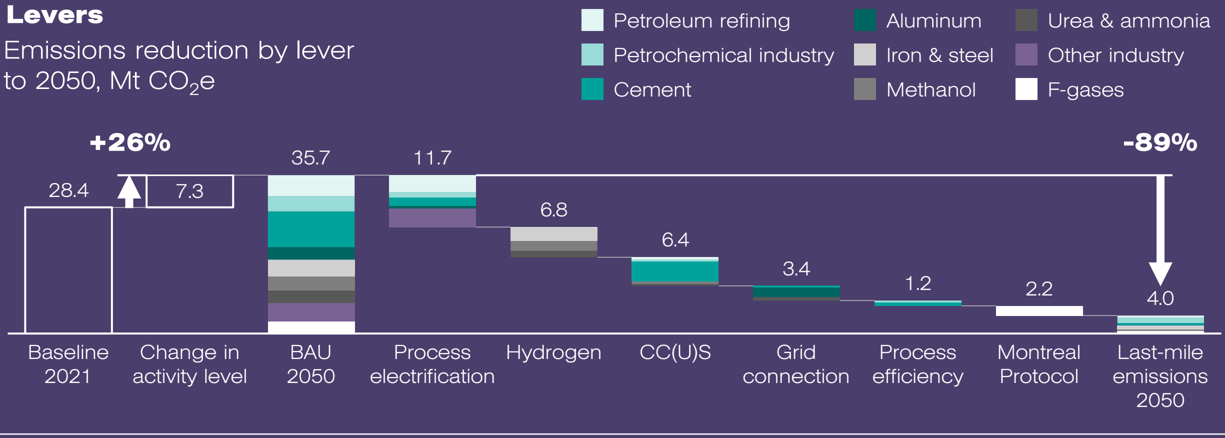
Baseline and growth

32% of Oman's CO_2e emissions in 2021

- Petroleum refining, petrochemical industry and cement account for ~50% of emissions in 2021
- ~8 BCM p.a. of natural gas available to be repurposed in 2050
- Growth in the business as usual case in 2050 (26%) is mainly driven by planned expansions in 2025

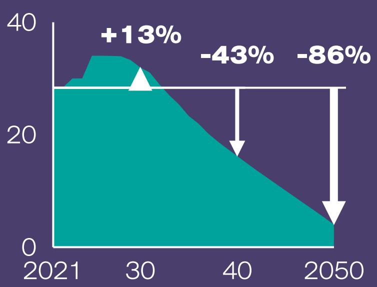
Levers

Emissions reduction by lever to 2050, Mt CO_2e



Pathway and technological enablers

Anticipated emission reduction, Mt CO_2e



~6-7 Mtpa
CO2e CC(U)S capacity required by 2050

~70 TWh
of renewable electricity required by 2050 for electrified assets

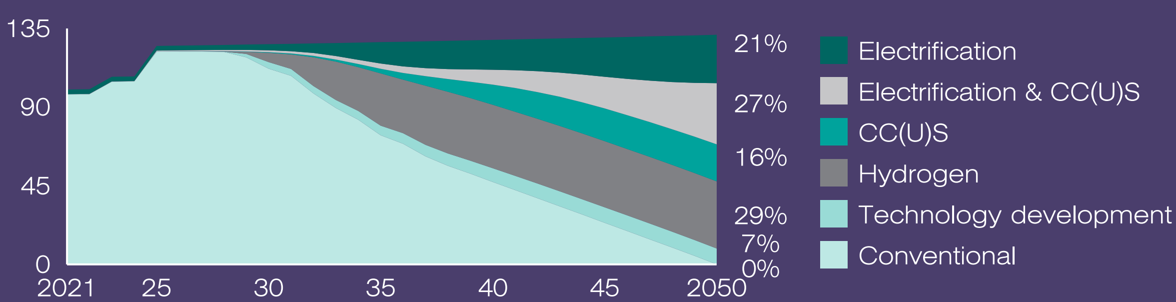
Broader implications

10-15%
increased cost for changing to hydrogen-based steel, could potentially be offset by a "green premium" in the short term

~8 BCM p.a.
of natural gas available to be repurposed in 2050

Activity level by segment

Change in technology route for production – scaled and indexed to 2021 emissions



Industry

Industry produces 28.4 Mt of CO2e – 32% of Oman's total emissions – and this number is projected to grow to 35.7 Mt by 2050 under a business-as-usual scenario driven largely by petroleum refining, petrochemicals, cement, aluminum, iron and steel. This sector is the biggest carbon emitter but low-cost levers have the potential to abate ~41%, mainly by electrifying refining and low-to-medium temperature heat processes (14%), connecting selected sectors to the grid (9%), and increasing hydrogen-based steel production (8%).

System choices entailing trade-offs would be required for the ~48% of emissions that are harder-to-abate. Three main technologies could be considered: electrify costly processes in the petrochemical, aluminum and cement industries as technology matures and assets need to be replaced; replace gas with green hydrogen when economically feasible; and deploy carbon capture, utilization and/or storage (CC(U)S) after 2030 in hard-to-abate sectors (cement, ammonia, methanol, petrochemicals). The remaining 11% (4.0Mt CO2e) would fall under last mile measures.

By 2050, alternative production methods would almost fully replace conventional production. The energy mix would change from hydrocarbon-dominant to a 50/50 split with renewable sources.

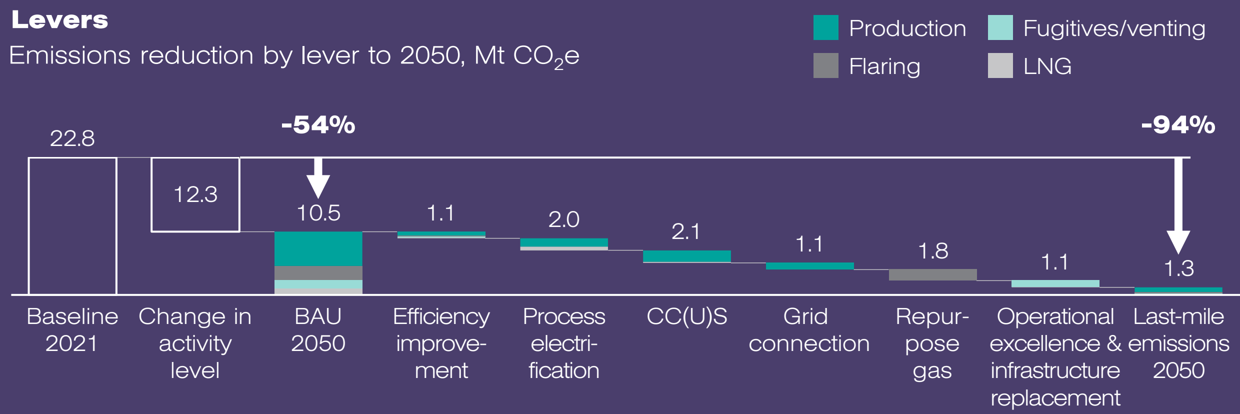
Baseline and growth

25%
of Oman's CO_2e emissions in 2021

- Fuel consumption from upstream production contributes more than half of the emissions in oil & gas in 2021
- ~3 BCM p.a. of natural gas available to be repurposed in 2050
- Current increasing emission trajectory in business as usual case is expected to peak in 2030, resulting in a 50+% reduction by 2050

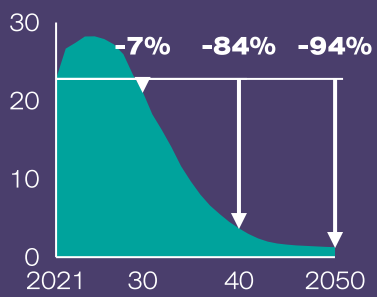
Levers

Emissions reduction by lever to 2050, Mt CO_2e



Pathway and technological enablers

Anticipated emission reduction, Mt CO_2e



~10-15 TWh
of renewable electricity required by 2050 for electrifying production

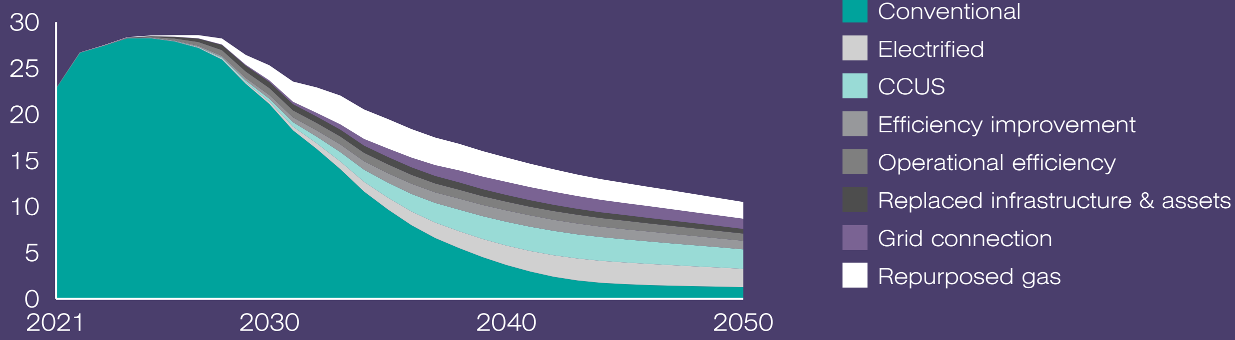
~1-3 Mtpa
CO_2e CC(U)S capacity required by 2050

Broader implications

60-70%
of abatement potential is economical with a carbon price of 100 USD/t

~3 BCM p.a.
of natural gas available to be repurposed in 2050

Emissions abated per lever, Mt CO_2e



Oil and Gas

The oil and gas sector accounts for 22.9Mt of CO_2e and ~26% of Oman's total emissions in 2021. The business-as-usual scenario forecasts a ~50% reduction in emissions from current production by 2050. It is assumed that new production from exploration above this projection would be fully decarbonized.

Combined, the lowest cost decarbonization levers could abate ~23% of the sector's total emissions. These levers would include continuing ongoing energy efficiency measures, capturing and repurposing natural gas (mainly from flaring), enhancing production and flaring efficiency and lower-cost electrification of upstream production processes.

Trade-offs would need to be considered around the remaining abatement required through more costly electrification (e.g., of LNG terminals) or CC(U)S .

Full electrification of the sector would require upgrades to the electricity grid, more extensive renewable energy generation and long-duration energy storage. The economic feasibility of CC(U)S would depend on the availability of concentrated point sources of carbon, enhanced oil recovery (EOR) opportunities, scale and/or carbon pricing. Upstream oil and gas is characterized by disperse low-concentration gas streams, making capture more complex. CC(U)S is more broadly applicable downstream where there are more concentrated point sources. Cross sectoral projects (CC(U)S + H_2) and scaling would help reduce the cost of CC(U)S . Replacing existing infrastructure (pipelines) and assets (compressor rod packaging, seals, connections) would eliminate remaining emissions directly addressable by the sector.

Together, these system choices could address ~18% (4.0Mt CO_2e) of emissions abatement, leaving 6% (1.3Mt of CO_2e) for last-mile measures.

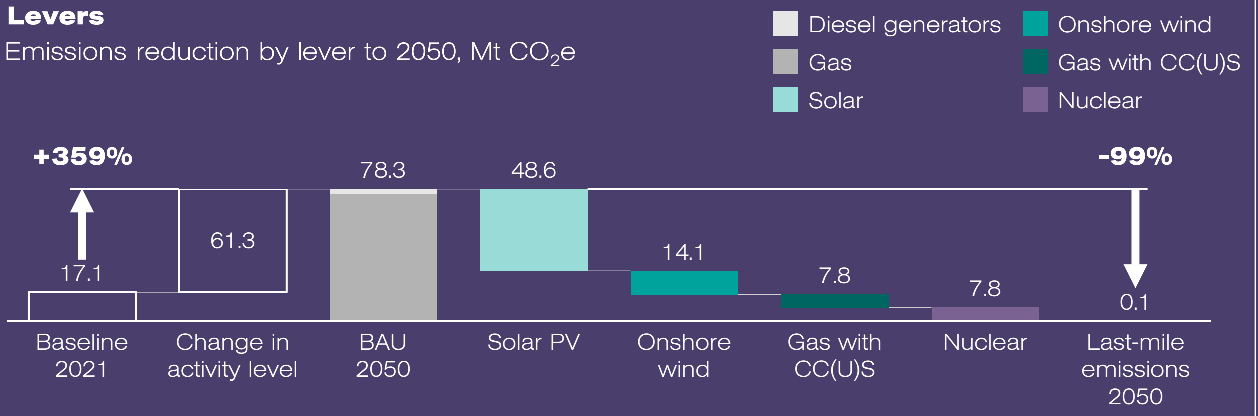
Baseline and growth

19%
of Oman's CO_2e emissions in 2021

- 97% of electricity in 2021 is generated by fossil fuels, mostly natural gas
- ~13 BCM p.a. of natural gas available to be repurposed in 2050
- Growth in the business as usual case (58%) is mainly driven by an increase in electricity demand in industry and buildings
- Growth would increase by 359% if accounting for the electricity demand increase driven by electrification in a net zero pathway

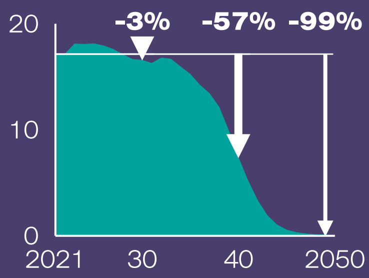
Levers

Emissions reduction by lever to 2050, Mt CO_2e



Pathway and technological enablers

Anticipated emission reduction, Mt CO_2e



65 Mtpa
of renewables with 15-30 GW of Long Duration Energy Storage

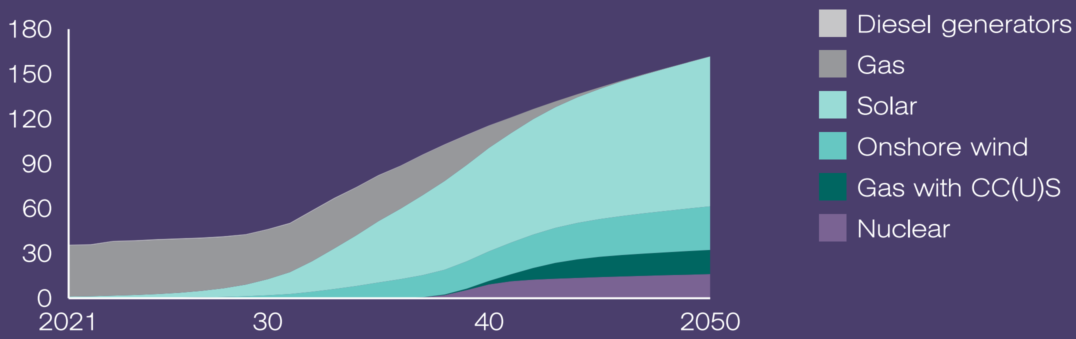
5 GW
capacity of a combination of gas + CC(U)S and nuclear

Broader implications

~50%
reduction in total system costs by 2050, likely to be able pay back additional Capex by ~2045

~13 BCM p.a.
of natural gas available to be repurposed in 2050

Activity level by segment, TWh



Power

The power sector accounts for 17.1Mt CO2e of emissions, which equates to 19% of Oman's overall emissions. Today, approximately 92% of electricity is generated by fossil fuels, mostly natural gas. Emissions are expected to rise 58% (9.8Mt CO2e) by 2050 under the business-as-usual scenario on the back of rising electricity demand in the industry and building sectors. An orderly transition pathway would see the electrification of the remaining sectors and total emissions for the power sector (if unabated) would rise 4.5 times to 78.3Mt CO2e.

The pathway to net zero involves building out renewables (mainly solar PV and onshore wind) to ~60% of the power supply mix, without significant (long-duration) storage requirements. Oman's strong wind and solar resources already make these renewable technologies 20-25% cheaper than new gas-fired power plants.

To decarbonize the remaining 40% of fossil-based power supply, Oman could select technology options that balance economic and strategic implications. These could include further renewables penetration with long-duration energy storage, supported by a combination of low-utilization gas with CC(U)S and/or nuclear. A decision on the final mix of technologies would not need to be immediate. In the short term, Oman would focus on building out its renewables to reach 60% penetration around 2034. Over the next five years, technology costs will decline and market mechanisms (e.g., carbon pricing) will become clearer.

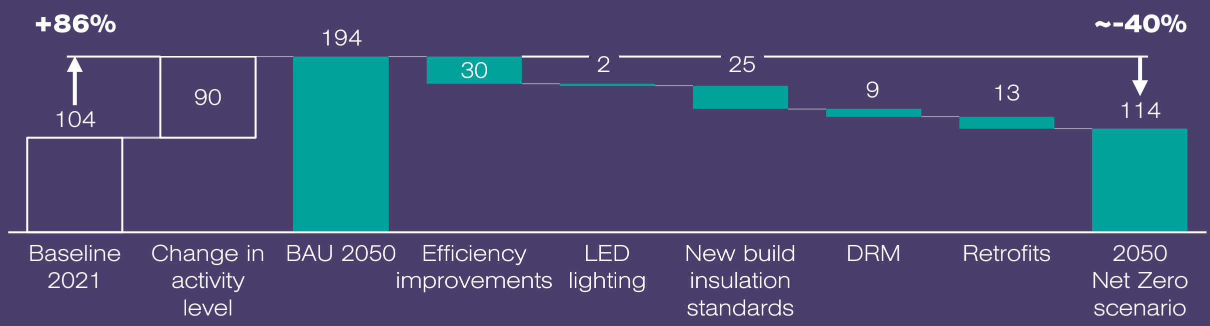
Baseline and growth

0%
of Oman's CO_2e emissions in 2021

- As the buildings sector is entirely electrified, there are no scope 1 emissions
- The buildings sector consumes ~80% of the electricity and thereby is indirectly contributing ~15% to Oman's total emission through the power sector, mostly driven by cooling demand in the residential sector
- Energy consumption Growth in the business as usual case by 2050 (~90%) is driven by an increase in dwellings to house expected population growth

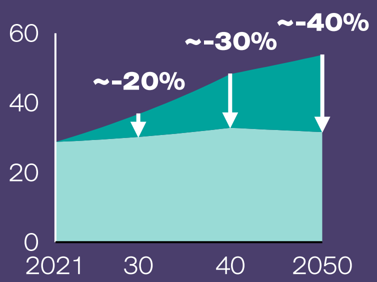
Levers

Electricity consumption reduction by lever to 2050, TWh



Pathway and technological enablers

Anticipated electricity consumption in pathway, TWh



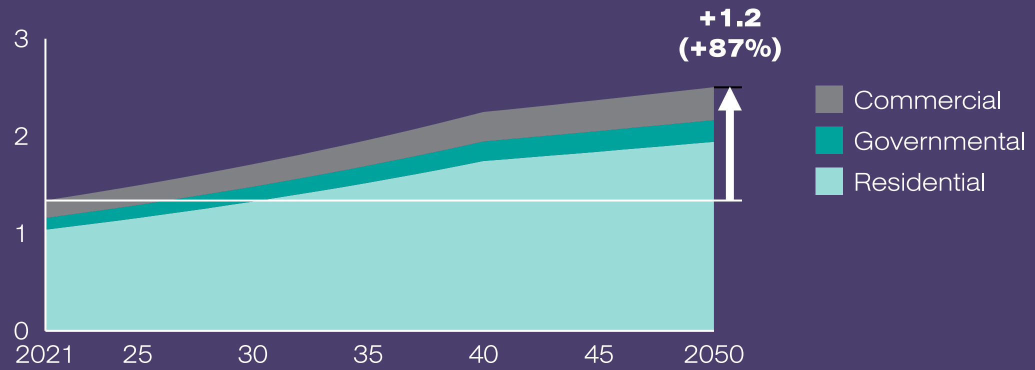
1.5% per annum
retrofitted dwellings between 2021-2050

7.5% reduction
in the energy demand by 2050 through rapid demand-side response management

Broader implications

<15-year
payback time of active retrofits of residential buildings, including improved insulation and solar panels

Activity level by segment, # of dwellings



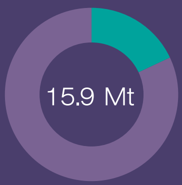
Buildings

The building sector has no direct emissions as it is fully electrified. However, the sector consumes 80% of power demand (2021) and therefore indirectly accounts for ~13.5 Mt CO2e in the power sector (or ~15% of Oman's overall emissions).

Low-cost priority levers could reduce total energy demand ~30% by 2050 versus business-as-usual by improving the energy efficiency of air conditioning units and appliances, switching to LED lighting, and setting building standards for all new builds (e.g., insulation, solar panels and smart design such as passive cooling). As the power sector moves toward full decarbonization by 2050, reducing energy consumption will lower system costs rather than further contributing to emissions savings.

The systems choices to be considered are retrofitting current buildings and rapid demand response management (DRM) to further reduce electricity consumption by ~10% by 2050.

Baseline and growth



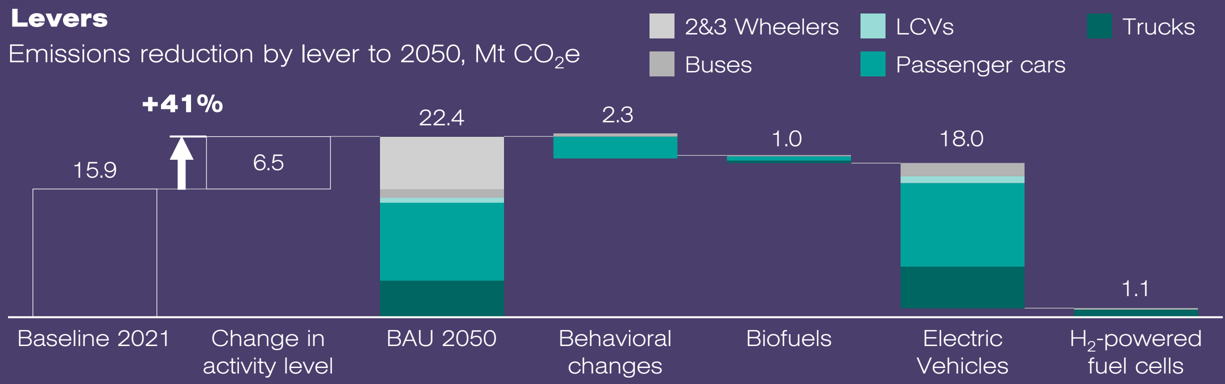
18%

of Oman's CO_2e emissions in 2021

- Emissions in 2021 are driven by passenger cars (~60%) and trucks (~29%)
- ~50mn BOE p.a. of oil available to be repurposed in 2050
- Growth in the business as usual case in 2050 (41%) is mainly driven by an increase in vehicles proportional to population increase

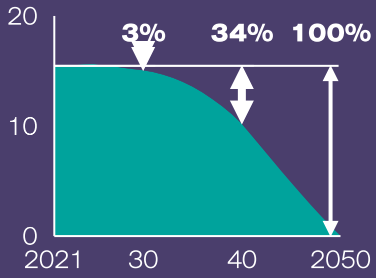
Levers

Emissions reduction by lever to 2050, Mt CO_2e



Pathway and technological enablers

Anticipated emission reduction, Mt CO_2e



16 TWh

of electricity required by full electrification of light vehicles

~0.1 Mtpa

of hydrogen required by transition to H_2-fuel cells for long-distance buses and trucks

Broader implications

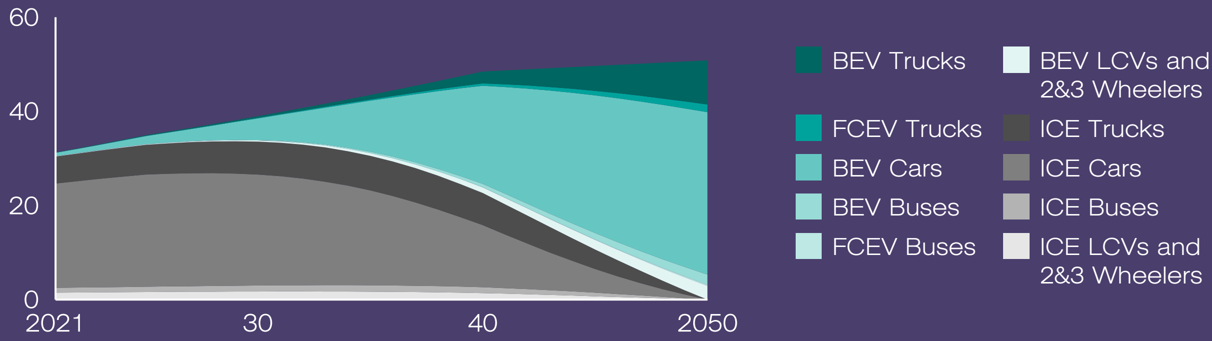
~20-25%

average reduction in cost of owning a car by 2050, including charging infrastructure investments

~50mn BOE p.a.

of oil available to be repurposed in 2050

Activity level by segment, bn vkm



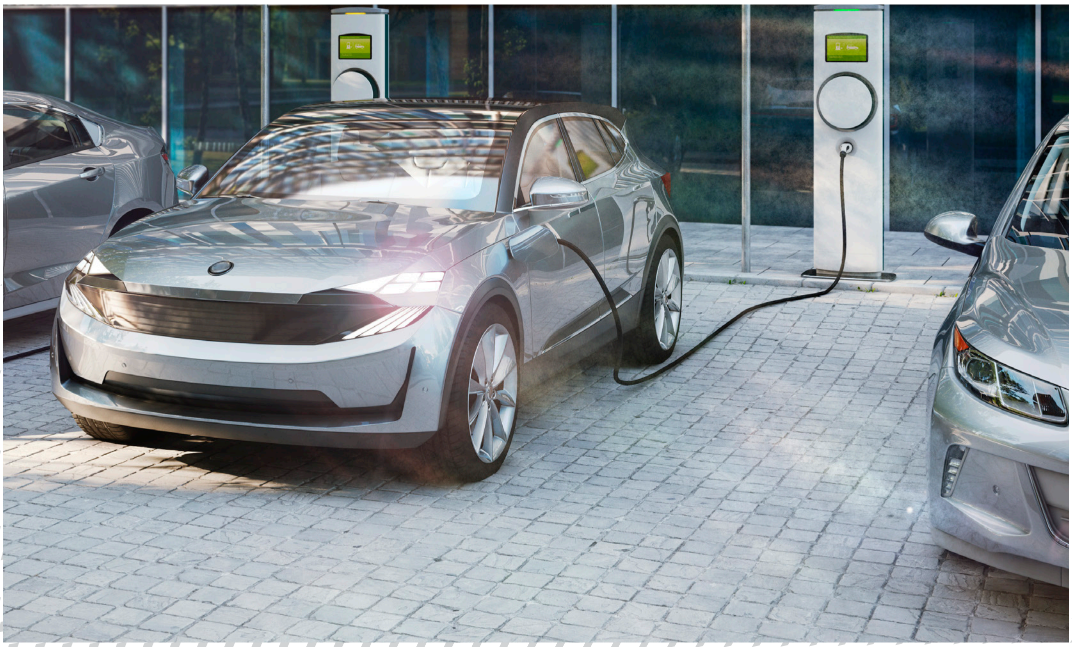
Transport

The transport sector emits 15.9Mt of carbon each year or 18% of Oman's emissions in 2021. Passenger cars make up ~60% of this total (1.3 million cars account for ~87% of the transport fleet). Emissions are expected to grow by 41% by 2050 under a business-as-usual scenario, driven by population growth.

The pathway to net zero involves full electrification of light vehicles and short-distance heavy vehicles and a transition to hydrogen fuel cells for long-distance heavy vehicles. Behavioral changes such as increased use of public transit and car-pooling are expected to reduce car usage resulting in 10% lower emissions.

Uptake of battery electric vehicles (2023-30) and fuel-cell electric vehicles (2035) is expected to rise when their cost matches that of internal combustion engine (ICE) vehicles from a total cost of ownership perspective. Government fleets are expected to lead the transition by adopting these technologies early.

Policy changes and investment in infrastructure would be needed to see full penetration of electric vehicles and fuel-cell electric vehicles by 2050.



The last mile

Several options could help reduce the remaining 7Mt CO2e of hard-to-abate emissions.

Oman could lead in negative emission technologies that will likely be required to reduce most emissions (e.g., DAC that removes atmospheric CO2 directly from the air and carbon utilization or storage), as it has a large number of aquifers and a vast amount of peridotite rock, a rare material that has unique carbon absorption and storage properties. Together with behavioral changes, this could abate most of the last mile. Nature-based solutions, such as mangrove tree planting or grassland management could help to abate the remainder.

Decarbonization technologies

Six main decarbonization technologies would account for more than ~90% of 2050 abatement (Exhibit 6): improving the **energy and resource efficiency** of equipment and processes to reduce fuel needs and process emissions; replacing fossil fuels through **electrification and renewables** (solar and wind energy); replacing internal combustion engines with **battery electric technologies** (passenger cars, buses, trucks); replacing fossil fuels with **sustainable** (green) **hydrogen** and its derivatives in industry and transport; decarbonizing industrial and/ or power processes by **capturing and storing carbon;** and adopting **negative-emission solutions** through breakthrough decarbonization technologies and natural negative emissions (e.g., DAC of carbon with storage in depleted reservoirs or planting mangrove trees to absorb atmospheric carbon).

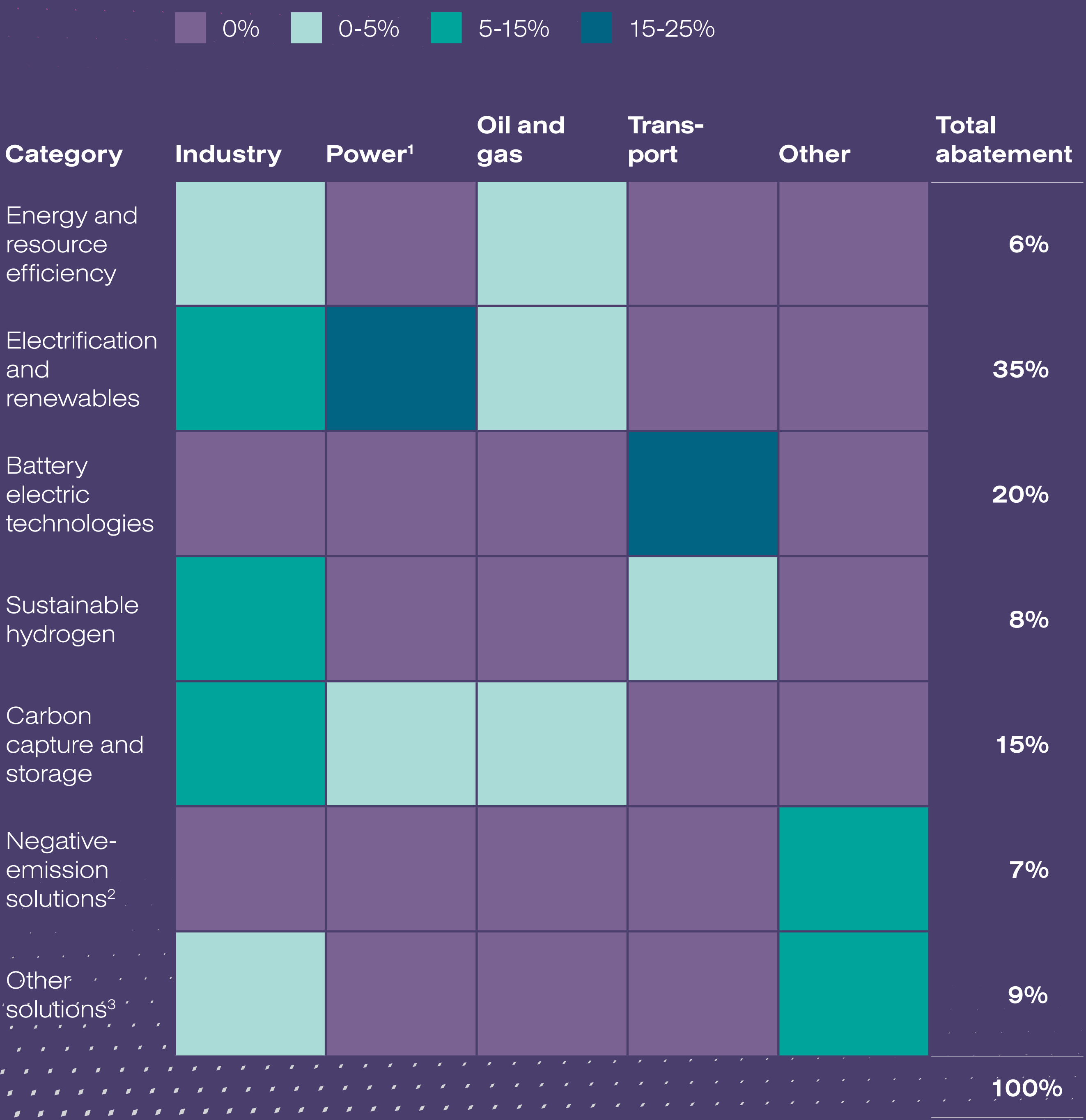
"Green electrification", based on electrification, renewables and battery electric technologies, would account for 50-60% of decarbonization and would therefore drive the 2030-40 abatement. Carbon capture and storage is needed for 5-25% and can be a viable option within the decade for select industrial point sources. Domestic hydrogen would account for 5-10% of decarbonization and could provide a sizeable export opportunity.

To enable these decarbonization technologies, four conditions would need to be in place.

Exhibit 6: Decarbonization technologies

Most of the abatement is driven by electrification & renewables, and battery electric technologies

Abatement percentage vs. BAU in an Orderly Transition pathway, 2050



1. Incl. all electricity consumption in buildings
2. Incl. forestation, advanced carbon capture and storage or utilization
3. Incl. f-gases decarbonization and waste reduction

First, technology would have to mature. The levelized cost of electricity for solar and wind would have to fall by 30% and 20% respectively, and electric and hydrogen fuel cell vehicles would have to compete in price with ICE options. If sustainable hydrogen is to scale, costs would need to fall to ~USD 2-3/kg.

Second, the new technologies would require major infrastructure. For example, grid extension to 50% of downstream oil and gas facilities, a charging network for electric vehicles and carbon capture and storage infrastructure for industrial (energy) players.

Third, legislation and policies would need to incentivize behavior changes (e.g., switch from ICE to electric vehicles), enable green products or production routes (e.g., grid regulation to facilitate new grid connections) and encourage private investors and developers to invest.

Finally, market mechanisms such as domestic and international carbon-pricing may be needed to incentivize the scale-up of more costly decarbonization technologies, notably carbon capture and storage.

Oman's pathway aspiration is bold. The Carbon Management Lab has already identified ongoing and planned projects that are estimated to contribute ~50% of Oman's expected abatement by 2030, largely through energy efficiency measures and green electrification (Exhibit 7).

Exhibit 7: Oman 2040 Vision Lab project pipeline

~50% of total projected abatement in pathway by 2030 (~13 Mt CO2e abatement[1])

Approved projects | Expected projects

Enablers in place: Few | Multiple | Most | All

	Key abatement initiatives	Enabling initiatives	Abatement	Approved projects	Enablers in place
Energy and resource efficiency	Reduce routine gas flaring, energy efficiency in O&G and ISO5001, efficiency measures and feedstock change in industry	Energy efficiency law in industry and building regulation & requirements	3,5 Mt CO_2e	73%	Most
Electrification & renewables	Clean energy projects in Oil & Gas, electrification, biogas and waste-to-energy in industry and solar and wind capacity in power sector	Reducing high-cost green energy generation initiative	8.8 Mt CO_2e	94%	Multiple
Battery electric technologies	Not applicable as lever is more about adoption, not projects	Regulations and incentives to support the usage of BEVs	0 Mt CO_2e	N/A[2]	Multiple
Sustainable hydrogen	Blue hydrogen project, incl. ammonia for export and FCEV buses	Educational center for alternative fuel, incl. hydrogen and study use of green H_2 in industry	0.2 Mt CO_2e	14%	Multiple
Carbon capture and storage	*N/A*, Potential CC(U)S projects (blue hydrogen, decarbonization aluminum) are captured under other levers to avoid double counting	CC(U)S structure set up potentially included in GHG emission reduction scope 1 & 2 project	0 Mt CO_2e	0%	Few
Negative-emission solutions	Afforestation and cultivation initiatives across industry, Oil & Gas, building and biofuels in transport	Sustainable city initiative supports carbon deductive activities, excl. DAC, BECCS projects	0.4 Mt CO_2e	19%	Few

1. Excl. other initiatives ~0.3 Mt CO_2e of out-of-scope industries, like glass recycling
2. Initiatives centered around enablers, with abatement expected to be naturally driven by uptake

Source: Oman's Carbon Management Lab

3. Broader impact of an orderly transition for Oman

The net zero pathway to 2050 would entail ~USD 190 billion in additional capital investment relative to Oman's business-as-usual scenario (~15% net of opex savings). The big-ticket items would mainly be in power and hydrogen infrastructure, e.g., to upgrade and extend the electricity grid, build out hydrogen pipelines and storage, build an electric vehicle charging infrastructure and deploy long duration energy storage at scale.

If we include the investment needed to unlock the hydrogen export economy, the investment required would increase by a further ~USD 230 billion (60-65% additional capex vs business as usual). These incremental expenditures are not expected to be financed fully by the Government; public estimates suggest that the private sector could finance 70- 80% of the global energy transition by 2050[6].

This investment would also support Oman on its broader objectives

Energy system costs. The pathway would affect sectors differently (Exhibit 8). For example, in transport it could reduce the total cost of vehicle ownership by ~20-25% by 2050 (even with the required charging infrastructure). In power, the transition to solar and onshore wind could halve generation costs per kWh (upfront infrastructure costs are expected to be recovered by approximately two-thirds of the aggregate cost savings through 2050). However, in industry it could increase the levelized cost of steel production by 10-15% (which could be offset by a green steel premium in the short term).

Economic impact. An orderly transition could contribute an additional 50% to GDP by 2050 (vs 2021), two-thirds of which would come from domestic investment in hydrogen (including export infrastructure) and the rest from expanded green power capacity.

Electrifying the economy could free up a large amount of gas, creating a compelling opportunity for Oman to capture a "fuel double play". An estimated 1.5 MTPA (rising to 4.0 MPTA by 2050) of excess gas could be directed to a mix of additional LNG and blue hydrogen exports. Developing the blue hydrogen infrastructure could pave the way for up to 8 MPTA of green hydrogen exports by 2050.

Social impact. Together with new green business growth opportunities, an orderly transition could increase total employment in Oman by 20-30%, mainly in the power sector (~43% of total new direct jobs) and the emerging hydrogen economy (~57% of total new direct jobs, in domestic and export markets). Omani citizens could be upskilled and reskilled – e.g., in the technical expertise needed for clean technologies like hydrogen, electric vehicles and carbon capture and storage – to supply trained workers to fill these jobs.

6 IEA, IRENA

Oman's economy will benefit from new GDP contributors, reduced household costs and job gains in certain sectors

Additional required investments

~15%
addional Capex

is required at a system-level for a Net-Zero transition (net of Opex savings)

~20%
recovered Opex by 2050

20% of 2021-50 Capex could be recuperated through Opex savings

New employment opportunities

~40%+
in power by 2050

~55%+
in H_2 by 2050

Share of newly created direct jobs

Jobs to redeploy with up- and reskilling needs (i.e., technical expertise for clean techs like CC(U)S, hydrogen, and EVs)

New GDP contributors

60%+
from the hydrogen economy

30%+
from green power capacity expansion

Driven primarily by a new hydrogen export sector and an increased power sector, incl. electricity grid, and renewable energy generation

Energy system costs to end-users

Adoption of decarbonization technologies leads to:

~2%
in 2030

20-25%
in 2050

Decrease in total costs of ownership of cars[1]

~15%
in 2030

~50%
in 2050

Costs reduction of power generation[2]

Future security of supply

Self-sufficiency in supplying domestic demand for power and hydrogen in 2050 and hydrocarbons in the transition phase. Increased dependency on several imported clean technologies and materials (e.g., batteries, EVs, rare-earth metals)

1. Weighted average of the total costs of ownership of the total vehicles fleet vs. BAU, including additional Capex (e.g., EV charging infrastructure) only in 2050 when the total system costs allows for a decrease >5% thus able to absorb the increase in capex
2. Weighted average of the LCOE of the energy mix in 2030 and 2050 vs. BAU. Excluding additional Capex required for energy storage (e.g., LDES) and system balancing

Security of supply. By 2050, Oman could become self-sufficient in power and hydrogen, using hydrocarbons during the transition. The execution risk is low as most decarbonization technologies are already proven and Oman has high solar radiation, adequate wind speed densities and aquifers for carbon storage. However, other risks would need to be managed. An orderly transition implies greater dependency on some imported clean technologies and materials, e.g., the supply of batteries and electrolyzers must be secured and the grid will need to be built out to support large-scale electrification of the economy.

Exhibit 8: Energy system cost implications

Selected examples across the priority sectors

Transport	Buildings	Industry	Power	Oil & Gas
~20-25% average reduction in cost of owning a car by 2050 Infrastructure needs for electric vehicles[1] likely covered by this reduced cost of car ownership	**<15-year payback time** of active retrofits of residential buildings, including improved insulation and solar panels	**10-15%** levelized cost increase in transition to green hydrogen in 2030[2] **Breaking even** requires margin reduction in the long-run or capturing (short-lived) green steel premium of 50-100 USD/t	**~50%** lower generation costs per kWh by 2050 due to transition to solar PV and onshore wind Projected upfront infrastructure investments recovered by 2/3rd of expected savings in generation through 2050[3]	**~15%** of abatement driven by levers "in the money" Next ~45% requires carbon price of up to 50 USD/t CO_2e, and the last 20-40% up to 100-220 USD/t CO_2e

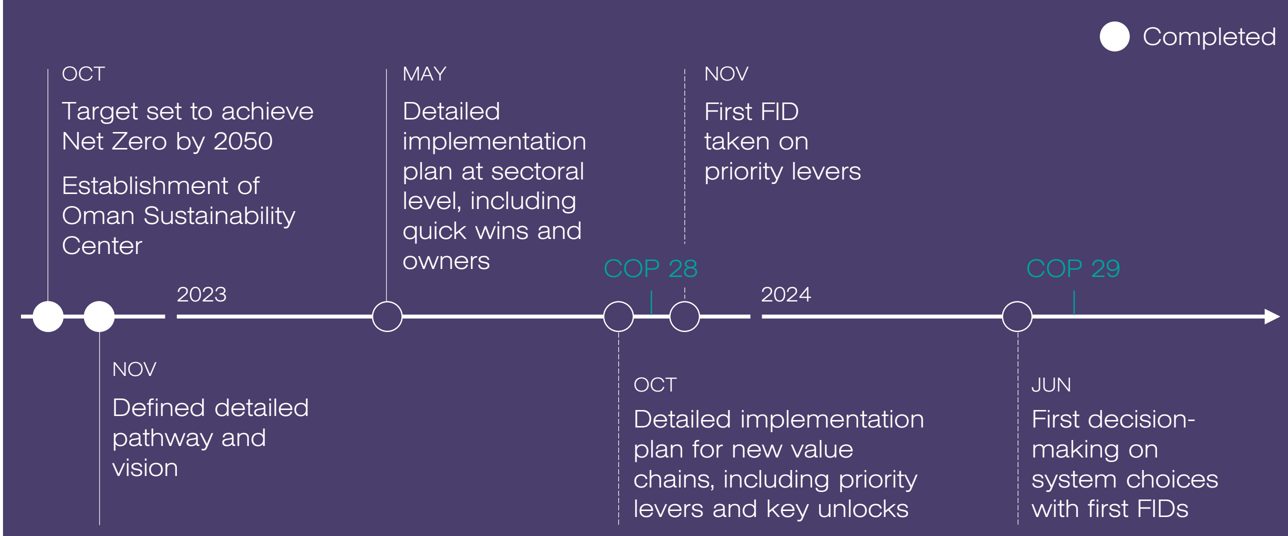
1. Assuming cumulative EV charging infrastructure investments of 10.8 bn USD by 2050, spread over 30 years and 2.4 mn EVs; implying a 0.007 USD/km cost increase, which translates to a 3.7% increase in total cost of ownership for EVs
2. Assuming: Steel-price of 800 USD/t, NG DRI EAF opex of 431 USD/t and capex of 650 USD/t, H_2 DRI EAF opex of 472 USD/t and capex of 850 USD/t, NG price: 4.76 USD/mmbtu, H_2 price: 2.11 USD/kg H_2, lifetime: 30 years
3. Infrastructure investments including Long-Duration Energy Storage and grid capacity expansion

4. The way forward

Oman is at the beginning of a longer journey to net zero emissions by 2050. Laying the right groundwork over the next 24 months is critical to its success (Exhibit 9). This would include:

- **Continuing to build credible momentum.** Balance longer-term planning with near-term delivery by deciding which priority levers to implement first to unlock their full potential, capture immediate value and remove future bottlenecks.
- **Organizing for success.** Develop an integrated approach with clear ownership supported by the Oman Sustainability Center whose role would be to set up (and execute on) governance, track progress, ensure alignment across initiatives and develop a financing plan with the Ministry of Finance.
- **Establishing regular and structured communication.** Ensure all stakeholders know and understand the actions to be taken, where decisions need to be made, and how decarbonization initiatives are interdependent across sectors.
- **Aligning policies, legislation and regulation.** Translate national targets into sub- and cross-sectoral policies to change behavior on the ground and develop end-to-end climate law to close legislative and regulatory gaps.

Exhibit 9: Next steps and the way forward



Source: Oman's Carbon Management Lab

Oman's vision for a cleaner, greener future is as compelling as it is challenging. But the opportunities presented by the energy transition are transformative and hold the promise for a bright and sustainable future for all Omanis. With the guidance of Almighty Allah, Oman will move forward boldly to stake its position as a leader in the energy landscape of the future.