Singapore Looks To Develop and Deploy
Low-Carbon Technological Solutions

Seeks collaborations with local and global partners following feasibility studies

1. The Singapore Government is following up on the findings from two feasibility studies on low-carbon hydrogen and on carbon capture, utilisation, and storage (CCUS) technologies respectively. As an alternative energy disadvantaged country, we expect these technologies to play important roles in our transition to a low-carbon future. They will help us in our effort to meet our commitments and ambitions in climate action, as set out in our enhanced 2030 Nationally Determined Contribution and Long-Term Low-Emissions Development Strategy[1], and the Singapore Green Plan 2030[2].

2. **The "Study of Hydrogen Imports and Downstream Applications for Singapore"** was jointly commissioned by the National Climate Change Secretariat (NCCS), Singapore Economic Development Board (EDB) and Energy Market Authority (EMA); while **the study on "Carbon Capture, Storage, and Utilisation: Decarbonisation Pathways for Singapore's Energy and Chemicals Sectors"** was jointly commissioned by NCCS and EDB. They highlighted the pathways for low-carbon hydrogen and CCUS that could be relevant for Singapore, and the barriers to deployment that would need to be overcome. Both studies were able to garner valuable stakeholder feedback from the industry and research community.

3. The key findings of the two studies were as follows:

a. **"Study of Hydrogen Imports and Downstream Applications for Singapore"**

Hydrogen has the potential to diversify Singapore's fuel mix towards low-carbon options for electricity generation, heavy transportation and some industrial processes. Given Singapore's limited renewable energy resources, it is challenging for Singapore to produce green hydrogen at scale using domestic green electricity. As such, Singapore would need to explore various supply pathways for price-competitive low-carbon hydrogen. More details can be found in Annex A.

[1] More information on Singapore's Long-Term Low-Emissions Development Strategy can be found in Annex D.
[2] More information on the Singapore Green Plan 2030 can be found in Annex E.

b. **Study on "Carbon Capture, Storage, and Utilisation: Decarbonisation Pathways for Singapore's Energy and Chemicals Sectors"**

The study identified carbon dioxide emissions, mainly from power plants and industrial facilities, that could be captured and stored in suitable sub-surface geological formations (i.e. CCS) or converted into useful products (i.e. CCU). For CCU, some of the more promising pathways include (i) mineralisation, to use waste-based feedstock or natural minerals to produce aggregates for reclamation or structural and non-structural building use, and (ii) conversion to chemicals and synthetic fuels, such as kerosene and methanol, which have the potential to be used as fuel for aircraft and marine vessels. More details can be found in Annex B.

4. The findings will be used to inform existing Research, Development and Demonstration (RD&D) efforts, such as the S$49 million Low Carbon Energy Research (LCER) Funding Initiative (FI)[3], a multi-agency effort involving the Agency for Science, Technology and Research (A*STAR), EDB, EMA, NCCS and the National Research Foundation (NRF); and to guide private sector consortiums such as those led by Keppel DC[4], Chiyoda[5], and Itochu[6] on the deployment of low-carbon solutions, and the development of the hydrogen supply chain. The Singapore Government welcomes more of such partnerships, and opportunities to pilot new technologies in sectors including maritime, aviation, mobility, industry and power sectors.

5. Following the release of the both reports, Singapore will also seek to partner other countries to advance emerging low-carbon technological solutions. Such collaborations could include joint contributions to international regulations, standards and certification on these emerging technologies, and participation in joint RD&D and test-beds. To date, Singapore has signed a Memorandum of Understanding (MOU) with Australia on low-emissions technologies and an MOU with Chile on low-carbon hydrogen, and is actively in discussions with other like-minded countries.

Annex A: Whole-of-Government's Assessment of the Hydrogen Feasibility Study
Annex B: Key Findings from the CCUS Study
Annex C: Factsheet on Singapore's Vision to be a Bright Green Spark
Annex D: Factsheet for Singapore's Long-Term Low-Emissions Development Strategy
Annex E: Singapore Green Plan

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[3] More information (including topics of interest) can be found at this link (https://www.a-star.edu.sg/Research/funding-opportunities/lcer-fi-grant).
[4] Keppel Data Centres announced an MoU with Kawasaki Heavy Industries, Mitsui O.S.K. Lines, Vopak LNG, and Linde to study the commercial viability of a liquefied hydrogen supply chain in May 2021.
[5] Chiyoda, Mitsubishi, PSA, Jurong Port, City Gas, Sembcorp, SLNG (with the support of MPA and NRF) signed an MoU to develop a business case for the technical and commercial feasibility of hydrogen import to Singapore.
[6] Itochu Corp signed an MoU with Itochu Enex, Vopak, Pavilion Energy, Mitsui OSK line, and Total on the joint development study of ammonia as a new marine fuel in Singapore.

ANNEX A

WHOLE-OF-GOVERNMENT'S ASSESSMENT OF THE HYDROGEN FEASIBILITY STUDY [7]

1. Hydrogen can serve as an energy carrier to store and transport renewable energy, and has the potential to diversify Singapore's fuel mix towards low-carbon options for electricity generation and heavy transportation (e.g. in goods vehicles, international shipping and aviation), for example. Hydrogen is also required as a raw material for some industrial processes.

2. While the hydrogen feasibility study has provided a useful analysis of the price points of the supply pathways for low-carbon hydrogen, there remains much global uncertainty over the trajectory of cost of deploying hydrogen technologies. NCCS, EDB and EMA are studying the recommended pathways, including importing hydrogen via shipping[8], piping hydrogen from neighbouring countries[9], and the domestic production of hydrogen (e.g. steam methane reforming (SMR) with CCUS, electrolysis of water using imported renewable electricity, biomass gasification, or through methane pyrolysis). For the import of low-carbon hydrogen via shipping, different carriers (i.e. Ammonia, Liquid Organic Hydride Carriers, Liquefied Hydrogen) can be adopted. There is currently no global consensus on the dominant carrier. The Government will continue to monitor developments in the market, and work towards the most competitive options for Singapore.

3. Low-carbon hydrogen has the potential to contribute greatly to our long-term decarbonisation efforts. However, technical and economic challenges, as well as the need for extensive infrastructural support (e.g. for hydrogen transportation, storage and utilisation) and new regulations to permit the use of hydrogen in new applications, currently limit large-scale deployment. NCCS, EDB and EMA will continue to collaborate closely with industry and academic partners to undertake further technical assessment to enable the feasible deployment of low-carbon hydrogen in Singapore.

4. This section outlines our preliminary assessment of the potential of hydrogen to be deployed in various sectors, and the steps being undertaken to further study these applications.

a. **Maritime Sector** – The decarbonisation of the maritime sector will require low- or zero-emission alternative fuels to meet the long-term goals outlined by the International Maritime Organization (IMO). Hydrogen, as well as hydrogen-carriers such as ammonia, holds significant promise in offering a pathway to

[7] For the full report on the hydrogen feasibility study, please refer to this link (https://www.nccs.gov.sg/docs/default-source/default-document-library/hydrogen-study-report.pdf).

[8] The hydrogen feasibility study has recommended a shortlist of 12 potential hydrogen import sources for Singapore to consider. However, developments in this area are rapid and many new producers are joining the market. We will continue to seek potential import sources beyond those shortlisted.

[9] Low-carbon hydrogen can also be imported in its gaseous form through pipelines from nearby countries which will likely to be more economical for shorter distance (e.g. less ~1,000 km when compared against liquefied hydrogen).

decarbonise the shipping industry. Collaboration among stakeholders will be key in accelerating the development of low-carbon fuels. The Maritime and Port Authority of Singapore (MPA) is actively encouraging the formation of ecosystems with key stakeholders across the maritime value chain, to come together in joint industry projects to trial and test-bed low-carbon fuels. MPA has also announced the establishment of a maritime decarbonisation centre to focus Singapore's efforts in maritime decarbonisation. The centre will bring together industry partners to coordinate, drive and catalyse maritime decarbonisation solutions, with a focus on translating technologies into commercially viable solutions for ocean-going vessels.

b. **Power Sector** – As one of the low-carbon options under the fourth switch of Singapore's Energy Story, hydrogen could play an important role in the deep decarbonisation of the power sector alongside CCUS, solar, and green electricity imports. In the future, hydrogen fuel could be blended with natural gas to fuel the Combined Cycle Gas Turbines (CCGTs) used to generate electricity today. EMA is further studying the infrastructure needed to support the deployment of low-carbon hydrogen technologies, and is working with other agencies to bring down the costs of hydrogen in Singapore.

c. **Industry Sector** – Currently, brown hydrogen is produced though steam-methane reforming and partial oxidation on Jurong Island and is a critical feedstock for industry processes (e.g. in the refineries). Low-carbon hydrogen can be used to directly replace existing brown hydrogen feedstock with minimal infrastructural impact to end users. Also, hydrogen can be used to replace natural gas for embedded heat and electricity generation. However, these applications are currently not cost-competitive. The Government is keen to partner with industry players to enable new streams of cost-competitive supply or explore possible pilots to couple existing production with CCUS for blue hydrogen.

d. **Aviation Sector** – Hydrogen has been identified as a potential solution to reduce the impact on climate change from the aviation sector. While near-term efforts to move towards carbon-neutral growth in aviation involve the extensive use of hydrogen to produce sustainable aviation fuels (SAF) for aircraft, in the longer term, the plan by the industry is to move towards hydrogen propulsion for future aircraft. Further research and development (R&D), as well as major infrastructural changes, is needed to ensure the safe and economic use of hydrogen. The Civil Aviation Authority of Singapore aims to work closely with various stakeholders to study the feasibility of, and conditions for hydrogen deployment within the aviation sector.

e. **Mobility Sector** – As hydrogen technology for transport remains nascent, the report does not foresee a global shift towards hydrogen fuel cell electric vehicles (FCEVs) in the near-term. Battery electric vehicles (BEVs) are projected to remain the more viable cleaner-energy vehicle technology. A possible

exception is the heavy vehicle segment, where FCEVs could be more economically viable than BEVs by 2050. However, this is also contingent on sufficiently widespread adoption of hydrogen in other areas in Singapore.

ANNEX B

KEY FINDINGS FROM THE CCUS STUDY[10]

1. CCUS can, like low-carbon hydrogen, reduce Singapore's emissions from the industry and power sector, and can complement the adoption of low-carbon hydrogen.

2. Some potential CCUS carbon dioxide (CO_2) utilisation pathways are currently already available or nearing technologically ready levels for deployment, but most are not yet commercially viable without further technological advancements and cost reductions:

a. For instance, CO_2 emissions from power plants and industrial facilities can be captured and stored in suitable sub-surface geological formations (i.e. CCS) or converted into usable products (i.e. CCU). For CCU, CO_2 can also be used to produce carbonate-based building materials, through mineralisation. Mineralisation processes can utilise waste-based feedstock, such as incineration ash, and in turn, reduce the waste generated in Singapore. Furthermore, captured CO_2 can be used as feedstock for chemicals and synthetic fuels, such as kerosene and methanol, which have the potential to be used as fuel for aircraft and marine vessels.

b. Agencies will further monitor the technological and market developments in these areas and explore opportunities for new CO_2 utilisation pathways in Singapore.

3. While the CCUS study has identified significant potential for CCUS to reduce Singapore's emissions in the long-term, near-term technical and economic challenges must be overcome for the large-scale deployment of CCUS solutions:

a. **Capture** – The majority of carbon dioxide emissions from industrial and power plant facilities are dilute (3-15%). As such, substantial energy and costs are needed today to separate and concentrate CO_2 from these dilute emissions sources. Further capture technology development and upscaling is needed to lower the energy and costs presently required.

b. **Utilisation** – Manufacturing fuel and chemicals from CO_2 often requires low-carbon hydrogen and is more energy-intensive than conventional processes, although this will improve over time as technology matures and new pathways develop. Agencies will study new catalysts and novel chemical pathways in utilising CO_2 for more cost-effective solutions for Singapore.

c. **Storage** – Singapore does not have any known suitable geological formations for the permanent storage of CO_2 underground. Singapore will explore

[10] For the full report on the CCUS feasibility study, please refer to this link (https://www.nccs.gov.sg/docs/default-source/default-document-library/ccus-study-report.pdf).

partnerships with companies and other countries with suitable geological formations to enable CO_2 storage opportunities.

4. To overcome these challenges, A*STAR evaluated technologies and research capabilities that need further development for CCUS based on key findings from the CCUS feasibility study. Singapore will continue to invest in RD&D to develop innovative solutions to overcome these barriers and reduce the costs of CCUS. Singapore will also seek partnerships on opportunities to pilot and testbed new CCUS solutions which have the potential to scale in the long run.

ANNEX C

FACTSHEET ON SINGAPORE'S VISION TO BE A BRIGHT GREEN SPARK

1. To tackle climate change concerns, Singapore has to change the way we produce and consume energy. Then-Minister for Trade and Industry Mr Chan Chun Sing shared Singapore's aspiration to be a "Bright Green Spark" at the Singapore International Energy Week (SIEW) in October 2020 to be an inspiration to other cities as we move towards a cleaner, more reliable and affordable energy future.

2. As part of this vision, we will harness four switches to transform and diversify our energy supply. The four switches are natural gas, solar energy, regional power grids, and emerging low-carbon alternatives. This will be supported by energy conservation efforts and improving energy efficiency across all sectors.

1st Switch: Natural Gas

Natural gas is the cleanest form of fossil fuel and will continue to be a dominant fuel for Singapore's electricity in the near future. EMA will continue to diversify our gas sources and work with our power generation companies to improve the efficiency of their power plants.

2nd Switch: Solar

Solar is the most promising renewable energy source for Singapore. Energy storage systems are also vital as it helps us manage the intermittency of renewable energy sources. Singapore is working towards a solar target of 1.5 gigawatt-peak by 2025, and at least 2 gigawatt-peak by 2030, with an energy storage deployment target of at least 200 megawatts beyond 2025.

3rd Switch: Regional Power Grids

We are studying ways to develop regional power grids for cost-competitive and low-carbon energy. This could be realised through bilateral cooperation and regional initiatives. For a start, we intend to embark on a two-year trial for 100 megawatts[11] of electricity imports from Peninsular Malaysia to Singapore. We are also initiating cross-border power trade under the 4-country Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP).

4th Switch: Emerging Low-Carbon Alternatives

We are exploring emerging low-carbon solutions (e.g. carbon capture, utilisation and storage technologies, low-carbon hydrogen) that can help reduce Singapore's carbon footprint.

We will continue to improve our energy efficiency in the various sectors. We will also empower our households with more information to help them better manage their electricity consumption.

3. Visit www.beyondthecurrent.gov.sg for more information.

[11] This will make up about 1.5% of Singapore's peak electricity demand (based on 2020's figures).

ANNEX D

FACTSHEET FOR SINGAPORE'S LONG-TERM LOW-EMISSIONS DEVELOPMENT STRATEGY

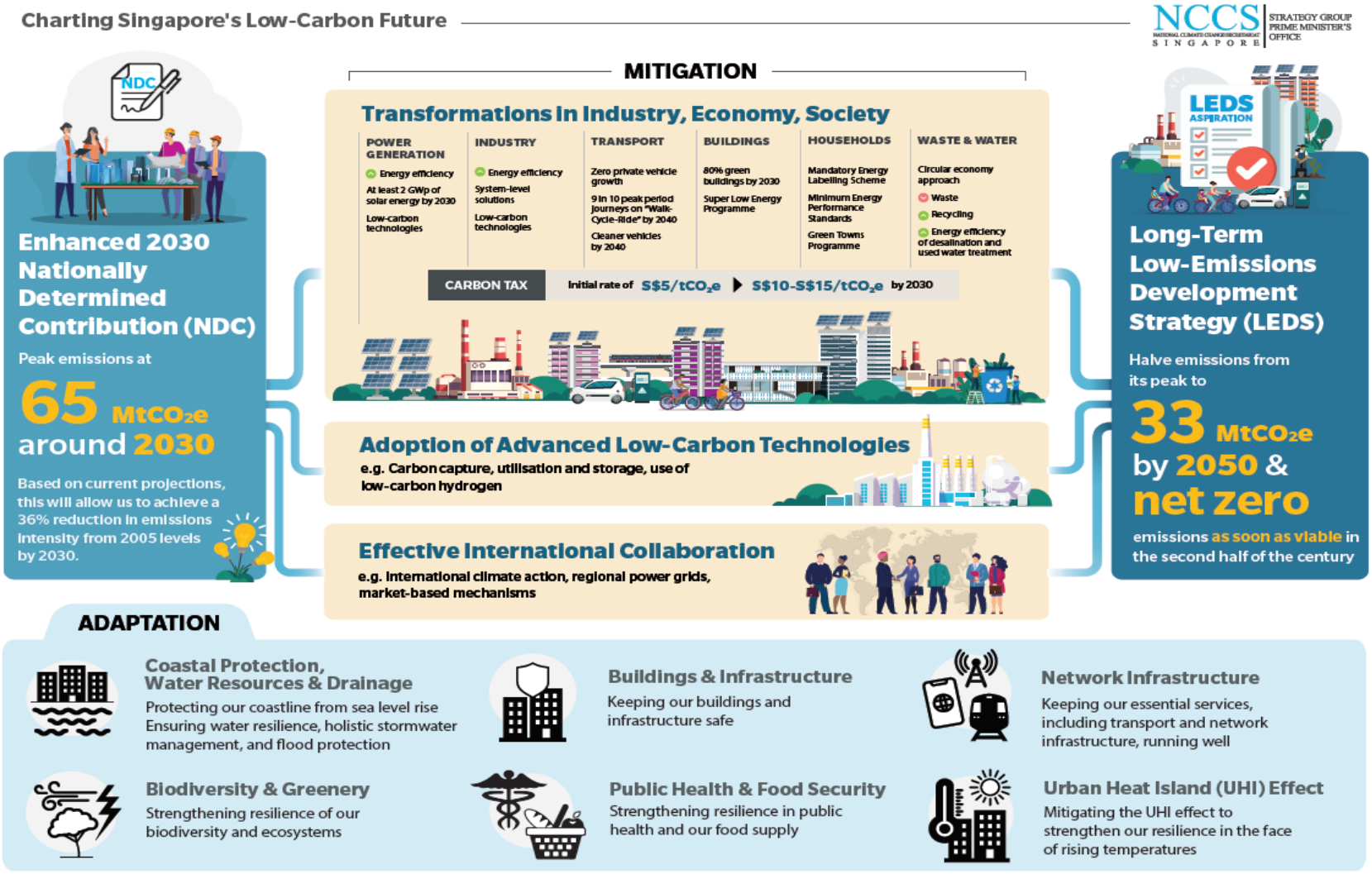
1. On 31 March 2020, Singapore submitted its Long-Term Low-Emissions Development Strategy (LEDS) to the United Nations Framework Convention on Climate Change (UNFCCC).

2. Singapore's LEDS sets out our aspiration to halve our emissions from its peak to 33MtCO_2e by 2050, with a view to achieving net zero emissions as soon as viable in the second half of the century.

3. Singapore will take concrete actions across all sectors to facilitate the low-carbon transition, building on our long-standing emphasis on sustainable development. The Government's strategy to achieve our LEDS aspiration will have three thrusts.

a. Transformations in industry, economy and society, e.g. more renewable energy, greater energy efficiency, reducing energy consumption;
b. Adoption of advanced low-carbon technologies, e.g. carbon capture, utilisation and storage (CCUS), use of low-carbon hydrogen; and
c. Effective international collaboration, e.g. international climate action, regional power grids, market-based mechanisms.

Infographic: Charting Singapore's Low-Carbon Future



For more details on Singapore's LEDS, please refer to this link (https://www.nccs.gov.sg/media/press-release/submission-of-singapores-enhanced-nationally-determined-contribution-and-long-term-low-emissions-development-strategy).

ANNEX E

SINGAPORE GREEN PLAN 2030

For more information on the Singapore Green Plan 2030, please refer to this link (http://www.greenplan.gov.sg/).