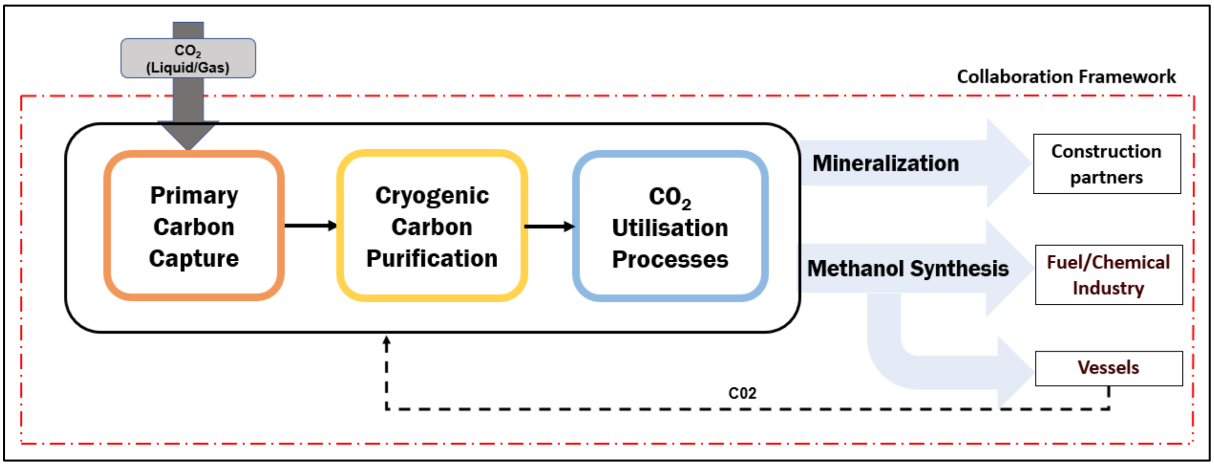
Annex A: Carbon Capture Utilisation and Sequestration (CCUS) system and value chain



In the first stage of the CCUS system – Primary Carbon Capture. Membrane separation technology is currently limited by the selectivity of currently available membrane materials as well as the high cost of materials. One of the most promising gas separation method is using polymeric membrane that acts as the filter for the separation CO2/N2 mixtures and generates a specific gas rich permeate.

In the second stage of the CCUS system – Cryogenic Carbon Purification. Cryogenic Carbon Capture is a post-combustion technology method that that cools CO2-laden flue gas to desublimation temperatures (-100 to -135 °C), separates solid CO2 that forms from the flue gas from the light gases, uses the cold products to cool incoming gases in a recuperative heat exchanger, compresses the solid/liquid CO2 to final pressures (100-200 atm), and delivers a compressed CO2 stream separated from an atmospheric pressure light-gas stream. Overall resulting in significantly reduced fixed capital and operational capital, especially with the availability of waste cold from LNG regasification.

In the third stage of the CCUS system - CO2 Sequestration Processes. Sequestration projects today are limited at oil/gas fields for subsequent EOR utilisation. The cost for storage, transport and sequestration of CO2, particularly in land scarce Singapore is expected to be high. However, aggregation of the captured CO2 and storing in liquid phase in pipelines networks (used as cold energy transfer medium etc.) or in solid phase in unused storage tanks or caverns could potentially provide alternative commercially viable options.

In the last stage of the CCUS system, Carbon utilisation. There are 3 tracks that will be explored:

- Low-Carbon Concrete: This concrete with a much-reduced carbon footprint is achieved by maximising the use of ground granulated blast furnace slag or GGBFS (a cementitious by-product of steel production) to replace ordinary Portland cement, which has high carbon emissions. In addition, natural aggregates are replaced by recycled concrete aggregates and washed copper slag. Carbon dioxide is injected into the concrete mix, converting the carbon dioxide into a mineral that increases the concrete strength, enabling less cement to be used. The final product is a very low carbon concrete that has a carbon footprint approximately 46% lower than normal concrete.

- Mineralisation: Carbon sequestration in construction materials (cement, sand, aggregates etc.) can be achieved through the introduction of carbonates. One of the primary objectives of concrete sustainability innovation is to increase the carbon dioxide (CO2) sequestration in such materials and consequently enable it to still meet construction industry standards.

- Methanol: Green methanol production, i.e. methanol synthesised via direct CO2 hydrogenation or via syngas hydrogenation after the reverse water-gas-shift reaction, rather than from methane reforming, can be a highly attractive CCU pathway for a future low-carbon economy