Chapter 4

Study on Financial Framework for Deployment of CCUS in the Asian Region, including ASEAN

Eric Williams, Selim Cevikel, Bernardene Smith, Alex Zapantis, Matthew Loughrey, Joey Minervini, Ian Havercroft, Errol Pinto

4.1. Introduction

CCS and other climate mitigating technologies deliver a public good; a stable climate. The value they create for society is far greater than the value that can be captured by a private sector investor in an individual project. Thus any consideration of the financing of CCS, or any climate mitigation technology, necessarily requires a consideration of public policy to ensure that investment is sufficient to meet the needs of society. Public policy must create additional incentives for private sector investment beyond those that naturally exist in the market to secure the investment necessary to meet broader societal objectives (stable climate) that would otherwise not be made. These policies will generally require the allocation of public and private resources by governments on behalf of the communities they represent. However governments have many competing priorities to which they could allocate scarce resources including but not limited to health, education, infrastructure, defence etc.. The United Nations Sustainable Development Goals generally describe the objectives of governments.

The most fundamental question that must first be answered with respect to financial frameworks for the deployment of CCS is how much capital is required and when must the investments be made. Sound policy requires that governments optimise their use of resources to deliver on their priorities (eg, achievement of the UN Sustainable Development Goals). Put simply, governments should provide the most benefit for the least cost. Having set the achievement of net-zero emissions as one of many priorities or commitments, governments need to find the lowest cost solution. This can only be defined through the use of an appropriate model, such as the Global CCS Institute's Global Economic Net Zero Optimization (GENZO) model.

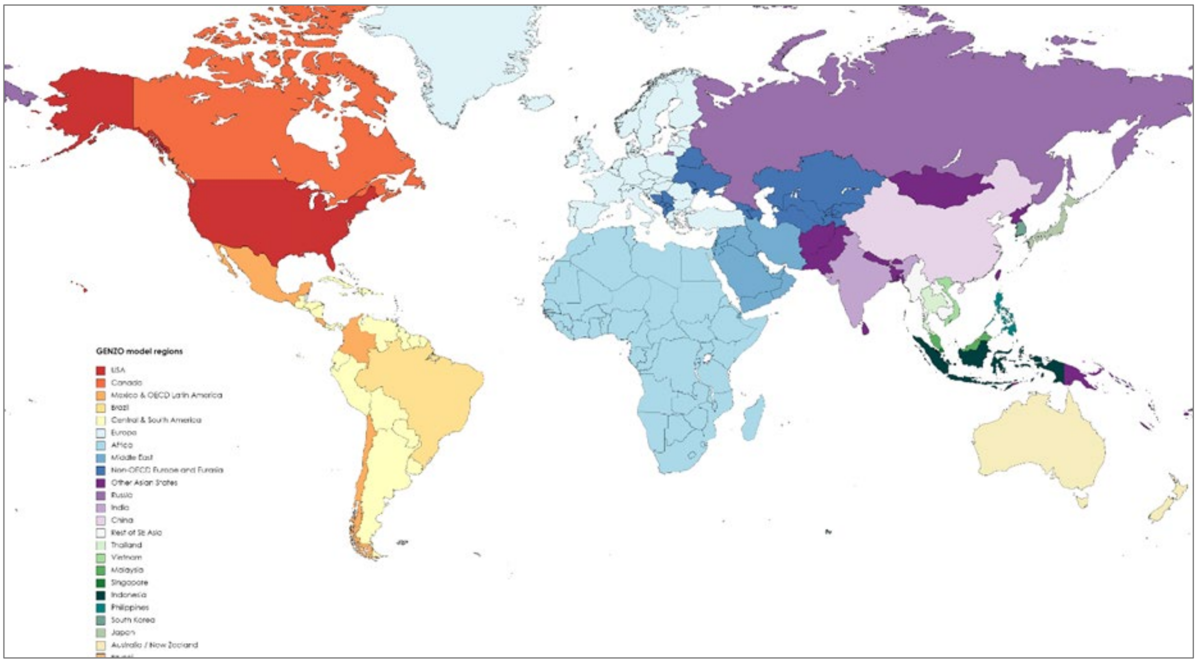
4.2. Global Economic Net Zero Optimization (GENZO) Model

The GENZO model is a bottom-up technology-focused model based on the Open Source Energy Modelling System (OSeMOSYS) framework. OSeMOSYS is similar to MARKAL and TIMES and is used widely in academia and in government for policy analysis and energy system planning (Gardumi et al. 2018; Howells et al. 2011; Löffler et al. 2017; Niet et al. 2021; Welsch et al. 2014).

GENZO consists of 24 regions as shown in Figure 4.1. Although we run GENZO with all 24 regions simultaneously to ensure that results reflect trade in energy and commodities across regions, we present results in this study for ASEAN countries based on the following model regions:

BRN: Brunei Darussalam
IDN: Indonesia
MYS: Malaysia
PHL: Philippines
RoSEA: Rest of South-East Asia
    Cambodia, Laos, Myanmar
SGP: Singapore
THA: Thailand
VNM: Viet Nam

Figure 4.1. GENZO Regions



Source: GCCSI.

GENZO solves for the lowest total cost whilst meeting emission trajectories and other constraints. GENZO is technologically rich and has good sectoral representation: 5 heavy industries + other industry, 4 modes of passenger travel, 7 modes of freight transport, Buildings, and agriculture. GENZO models trade in oil, LNG, coal, ammonia, Bio-LNG, synfuel, steel, aluminum, physical CO_2 for storage, and, optionally, CO_2 emission credits.

GENZO invests in and operates technologies over the entire energy system from energy resources to energy transformations to end-use technologies to satisfy final demands and to fall within constraints like net zero pathways.

In GENZO, future final energy service and commodity demands are exogenous, and everything else is endogenous. For example, we do not set oil prices or have an oil price forecast. GENZO models the supply of oil in each region, and the demand for oil that results from investment in technologies that require oil and the decision to operate those technologies. Oil prices result from the balance of supply and demand, along with trade of oil between regions. The same is true for all energy and commodity prices in GENZO.

Further information about the GENZO model, its structure and key assumptions can be found in the Global Economic Net Zero Optimization (GENZO) model documentation.[9]

4.3. Scenarios

We run GENZO without net zero targets to establish a reference case by which to compare results of net zero scenarios. Unless specifically highlighted as a reference case result, the results shown and discussed in this report are all based on the net zero assumptions shown in Figure 4.2, which are linear reductions to a 2030 target if a particular country has one and to a 2050 net zero target for all of ASEAN except Indonesia, which has a 2060 net zero target.

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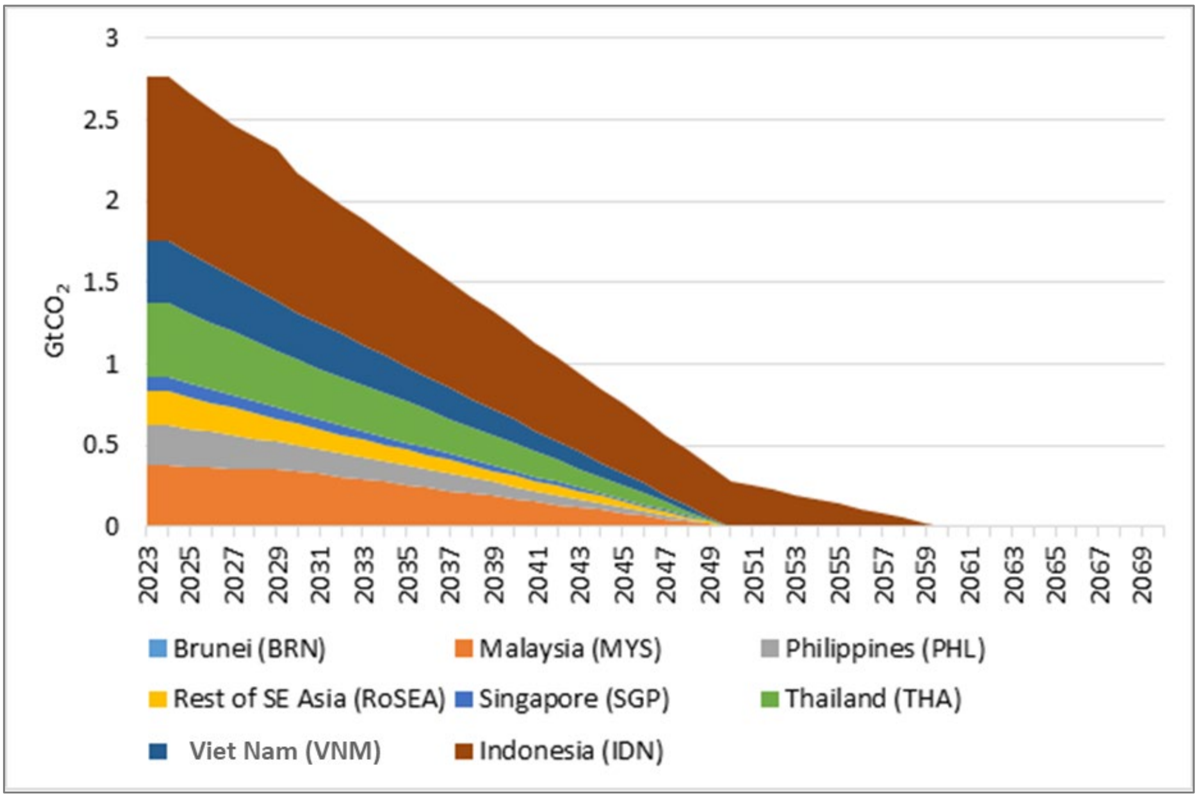
[9] genzo1123.pdf; globalccsinstitute.com.

Figure 4.2. Net Zero Pathways for South-East Asia

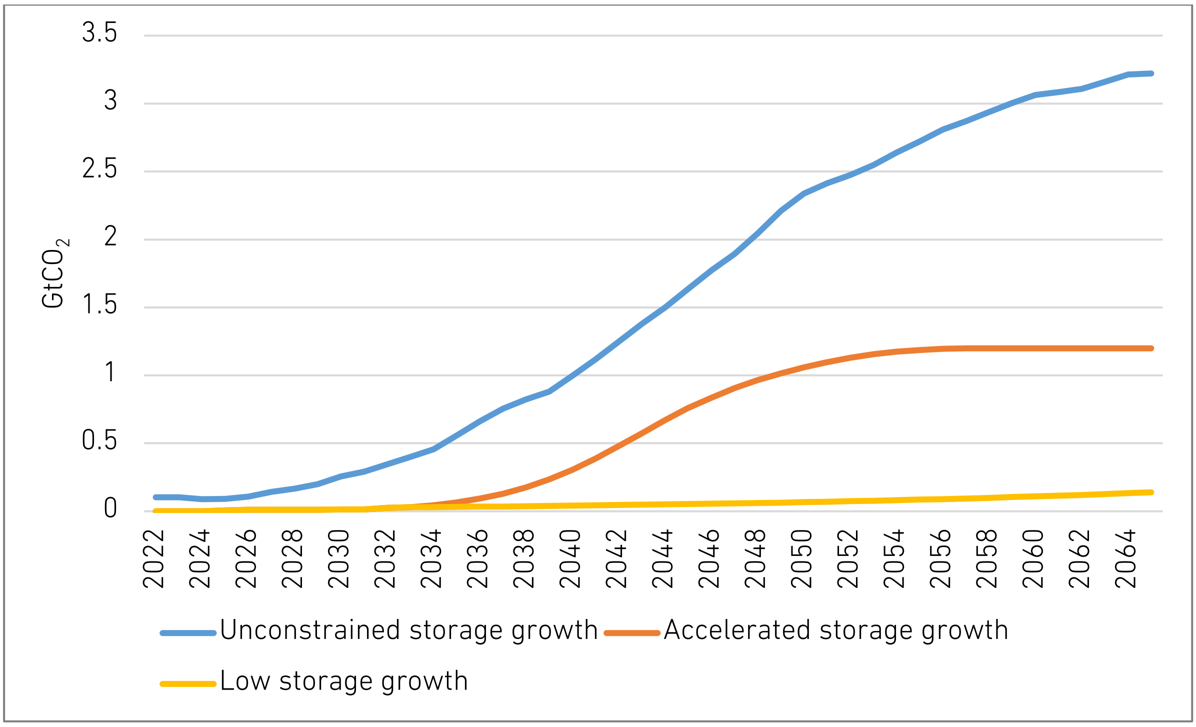


Source: GCCSI

What distinguishes the scenarios discussed and evaluated in this report is the assumption around the growth in storage capacity development. We distinguish the growth in development in storage capacity from the total evaluated storage resource available. Just like any resource, it must be developed to be used, and development of storage takes time and investment. Government policy can accelerate storage development. Based on what we know about the current project pipeline for storage development expected by 2032, we created storage development scenarios that apply to all regions in GENZO. Figure 4.3 shows the aggregation of each of the ASEAN countries/regions in GENZO for the three scenarios considered: a low storage growth scenario that grows at 5% per year beginning in 2032, an accelerated storage growth scenario that begins at 50% growth in 2032 with a declining growth rate through 2060 when the growth rate reaches 0%, and an unconstrained storage growth scenario.

The low storage growth and accelerated storage growth scenarios do not require that GENZO stores that level of CO_2, but places a limit on how much can be stored by when; GENZO can opt to store less if it is economic to do so. The Unconstrained scenario is a little different. The total storage capacities for each region are still in place – no region can store more than it has the capacity to store[10]. Unconstrained in this case is that we allow GENZO to store as much is it finds economic to store when it decides to store it while not exceeding the evaluated storage capacity in a region. The Unconstrained line in Figure 4.3 is the resulting storage GENZO opted for in the Unconstrained scenario model run. This scenario can be thought of as an optimal least-cost outcome; the average annual growth in storage development in the unconstrained scenario is about 15%. Sustained growth at this rate over 30+ years is not impossible but would depend on clear policy to drive the required investment.

Figure 4.3. South-East Asia Annual Potential Storage Development Scenarios



Source: GCCSI.

4.4. High-Level Results

Figure 4.4 shows at a high level how South-East Asia achieves net zero in each scenario. The black line in each figure shows the reference case emissions that would occur absent the net zero commitment. The red dotted line shows the aggregate net zero commitment for ASEAN. The blue area shows how much CO_2 is reduced from the

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[10] GENZO can transport physical CO_2 by ship or by pipeline from one region to another, so if an opportunity to store in a neighboring or even more distant region is available in any scenario, and doing so lowers the total system cost, then GENZO will opt to transport CO_2 to other regions. Singapore, which has no storage capacity of its own, and the Philippines, which has very little storage capacity, can both still take advantage of carbon capture opportunities by transporting their captured CO_2 elsewhere.

reference case by direct carbon capture and storage applied to applications using fossil fuels. The green area shows the contribution of renewables, hydrogen, fuel switching, electrification, energy efficiency, and so on, toward meeting net zero targets. The dark green line shows the direct emissions in the scenario. The orange area shows bioenergy with CCS or BECCS as well as direct air carbon capture and storage (DACCS) – these technologies are carbon removals and are what enable a scenario to offset direct emissions to reach net zero.

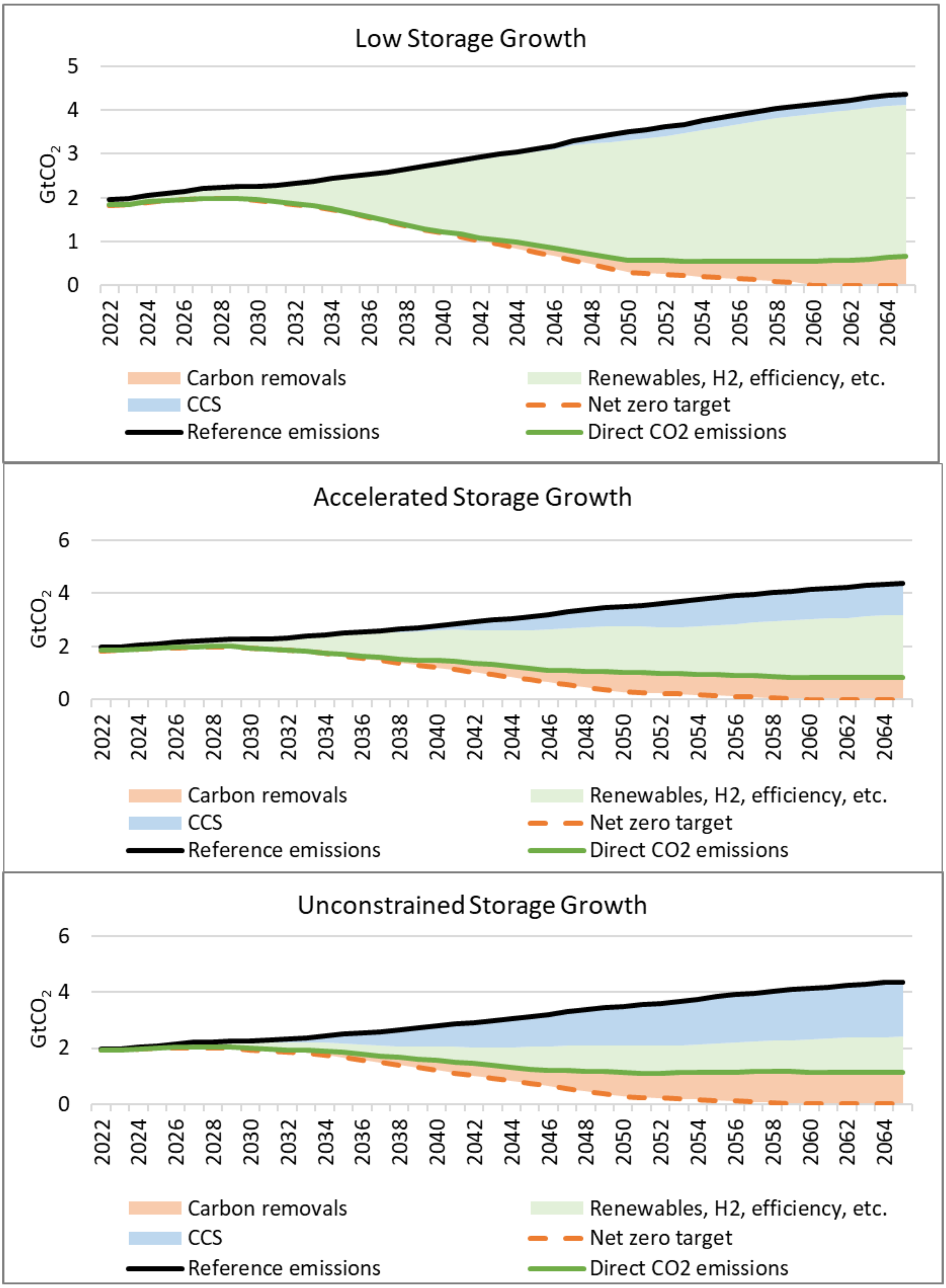
All three scenarios result in the same net zero emissions pathway.

The low storage growth scenario limits the development of CO_2 storage capacity, and with that limited available CO_2 storage GENZO finds that the optimal storage allocation is primarily to carbon removals and, in this case, almost all BECCS. BECCS serves two roles. BECCS provides useful energy while removing CO_2 from the atmosphere. A small amount of CCS is deployed with applications using fossil fuels. As discussed in more detail later, this CCS is primarily for natural gas combined cycles in the electricity sector. The low storage growth scenario relies overwhelmingly on renewable energy and hydrogen pathways to reduce CO_2 emissions.

The accelerated storage growth scenario enables a modest increase in BECCS, along with a very small amount of DACCS, but also enables a considerable increase in direct CCS. This scenario is less dependent on renewable energy and hydrogen pathways.

The unconstrained storage growth scenario allows for a significant increase in direct CCS while relying even less on renewable energy and hydrogen pathways. Although carbon removals go up compared to the accelerated scenario, what is not apparent here is that the increase is almost all from DACCS. The potential for BECCS is more or less maxed out in the accelerated scenario.

Figure 4.4. How Net Zero is Achieved

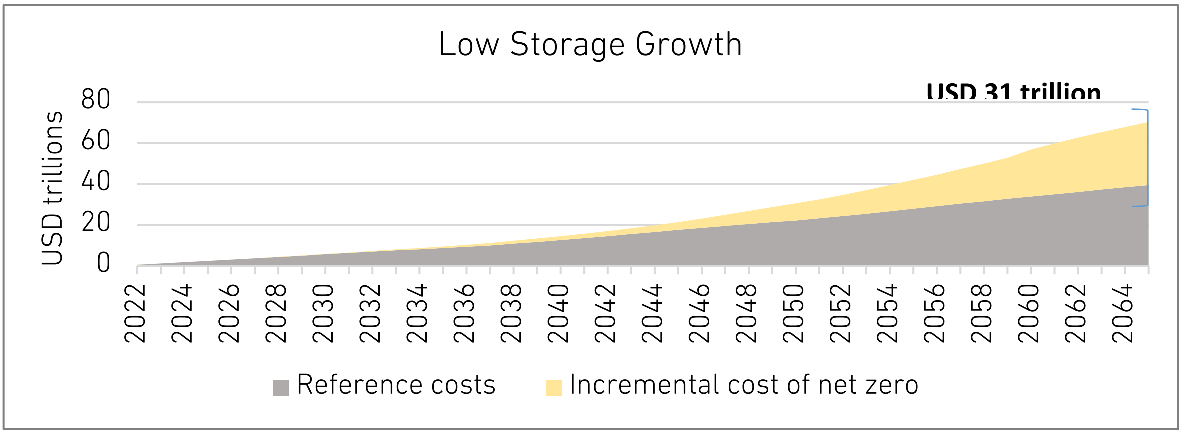


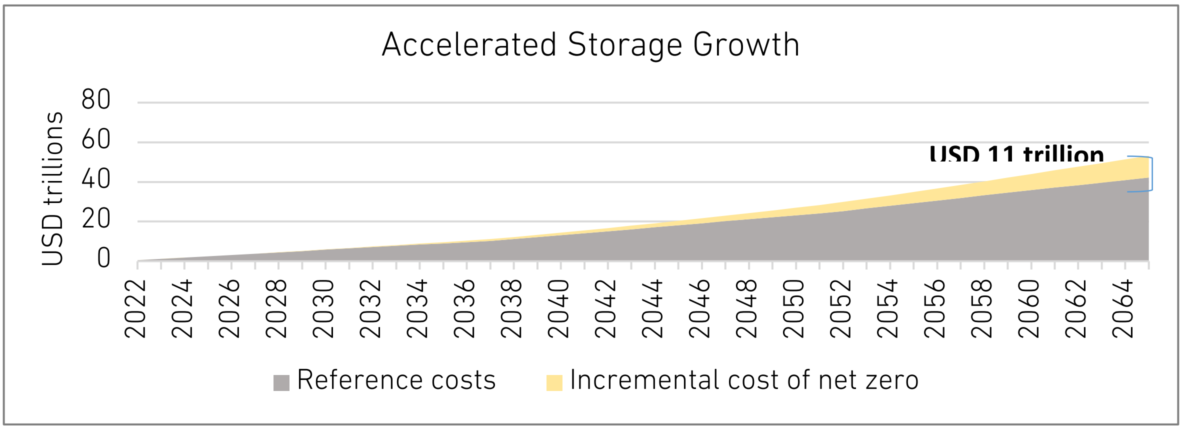
Source: GENZO result.

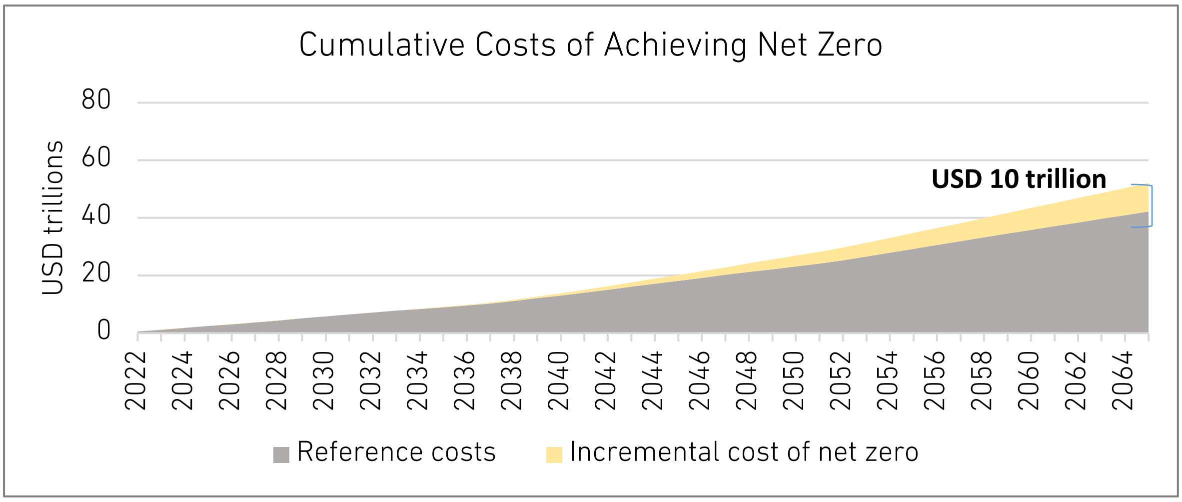
The scenarios have remarkably different incremental costs for meeting net zero (Figure 4.5). We define the incremental cost of meeting net zero as the total cost of the scenario minus the cost of the reference case scenario. The low storage growth scenario that relies so heavily on renewable energy and hydrogen pathways costs South-East Asia US$31 trillion through 2065 to reach net zero, an increase of 73% compared to the reference case. By contrast, the accelerated storage growth scenario costs only US$11 trillion (26% more than the reference case) – almost 1/3 the cost of the low storage scenario – to achieve the same net zero goal. The accelerated storage scenario shaves an additional US$1 trillion for a total cost of US$10 trillion. With many competing development priorities, a pathway to the same climate outcome that can save in excess of US$20 trillion is one that deserves consideration.

Another way to view it is that investing in CCS infrastructure, while costly, is far less costly than the alternative. The alternative may not simply be 3 times the cost but could be that we pay more while losing our political resolve due to the cost and, consequently, veer off the path, missing the net zero targets and facing potentially higher climate costs down the track.

Figure 4.5. Cumulative Costs of Achieving Net Zero



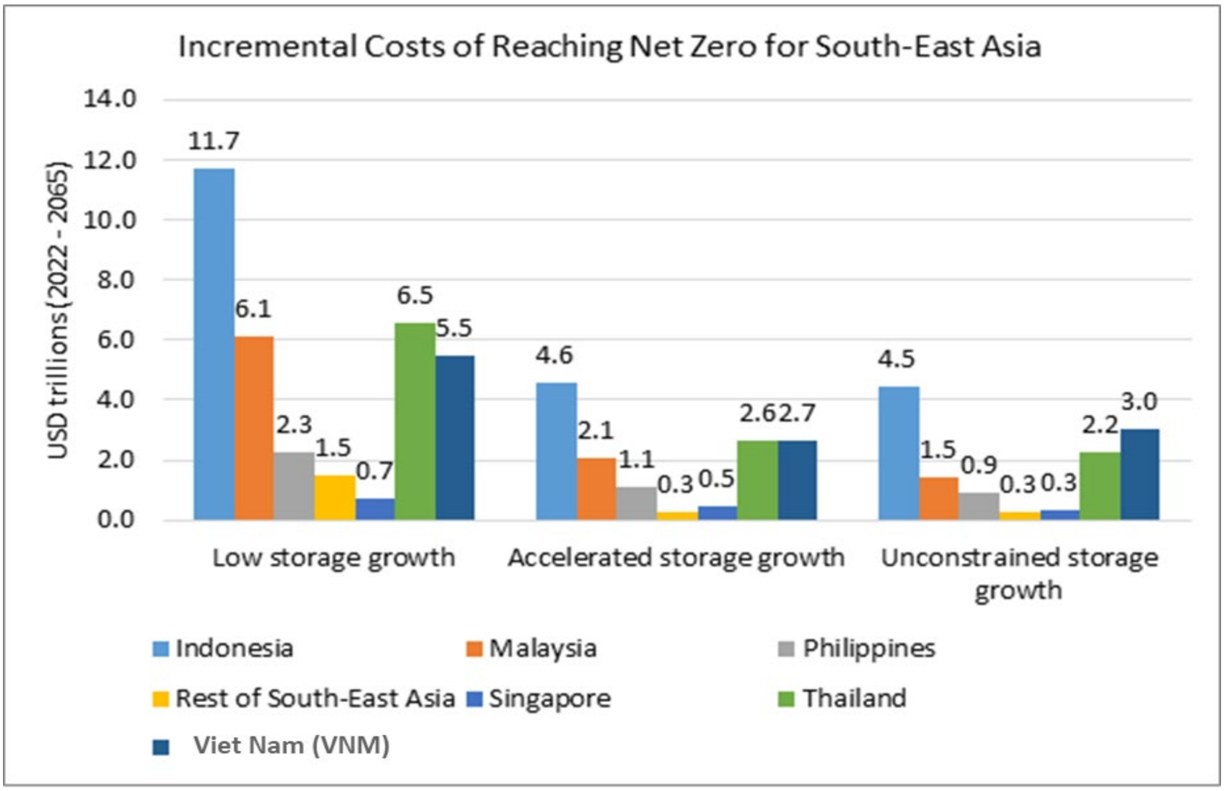




Source: GENZO result.

The cost of reaching net zero varies by country, with Indonesia facing the highest absolute cost in the region regardless of scenario, and Brunei, not shown, facing the lowest absolute cost.[11] Indonesia alone faces a higher cost in the low storage growth scenario than all of South-East Asia in the unconstrained storage growth scenario, and almost as much as the accelerated scenario for the whole region.

Figure 4.6. Incremental Costs of Reaching Net Zero by Country



Source: GENZO result.

While all countries face lower costs with the accelerated and unconstrained scenarios, some countries gain more than others (Figure 4.7). The 'Rest of South-East Asia' region (Cambodia, Laos and Myanmar) faces costs in the low storage development scenario that are just over 5 times higher than its costs in the unconstrained scenario. Myanmar has low storage scenario costs that are 4 times its costs in the unconstrained scenario. Viet Nam, with the lowest cost multiple, still faces 1.8 times the cost in the low storage development scenario compared to the unconstrained scenario. Viet Nam has limited storage capacity, so its costs are high regardless of scenario and sees smaller, though still substantial, cost benefits from an unconstrained or accelerated scenario.

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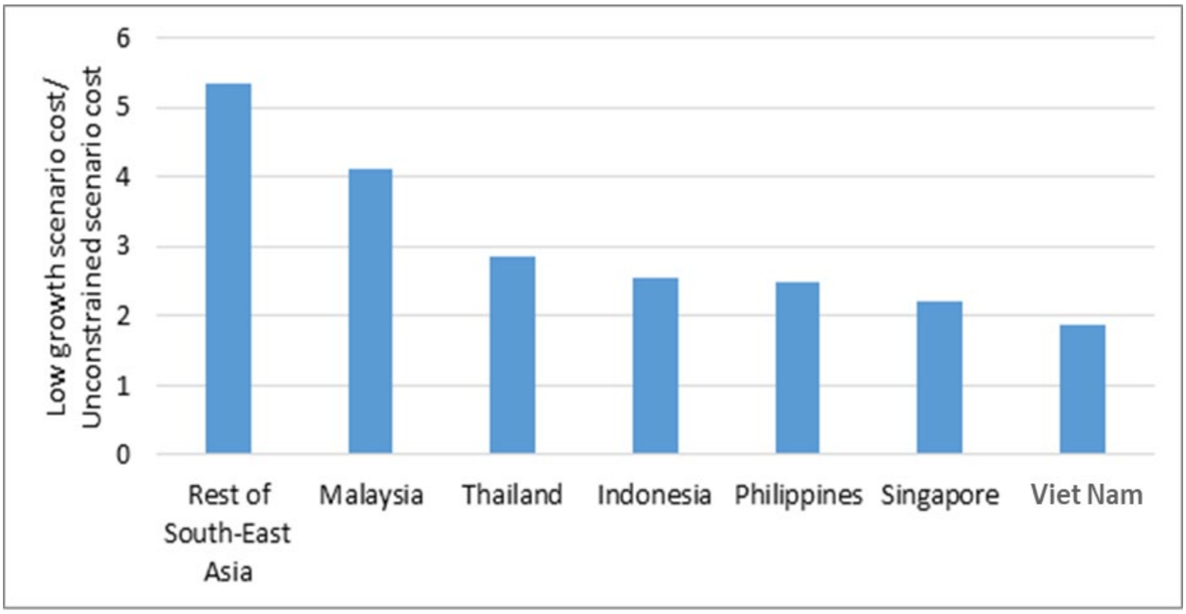
[11] Because the cost reflects net trade, Brunei's oil revenue more than compensates for the cost of the Brunei energy system. Therefore the cost is negative, but also so small compared to the scale of the other countries that it is not visible in a figure, so we have left it out.

Figure 4.7. Net Zero Cost Ratio: Low Storage Growth Scenario Cost to Unconstrained Storage Growth Cost



Source: GENZO result.

Breaking out the full cost of each scenario by key components reveals where the major cost differences are amongst the scenarios. shows the cost, through 2065, of CAPEX and OPEX in end-use and energy transformation sectors for South-East Asia plus the cost of energy production within the region, and the net cost of fuel imports. We can see that the non-energy costs in the buildings sector are almost identical across scenarios. The Accelerated storage scenario sees moderately lower non-energy costs in industry compared to the low growth scenario. The unconstrained storage scenario sees an additional US$1 trillion compared to the low growth scenario and 1.2 trillion compared to the accelerated scenario. The additional investment in CCS accounts for this added cost in the unconstrained scenario. The reliance on hydrogen infrastructure in the low growth scenario leads to moderately higher costs than the accelerated scenario, despite its having substantially more CCS. The low storage growth scenario has slightly more non-energy transportation costs than the other two scenarios.

Cross-sector CCS costs reflect the level of CCS deployment across the scenarios.[12]

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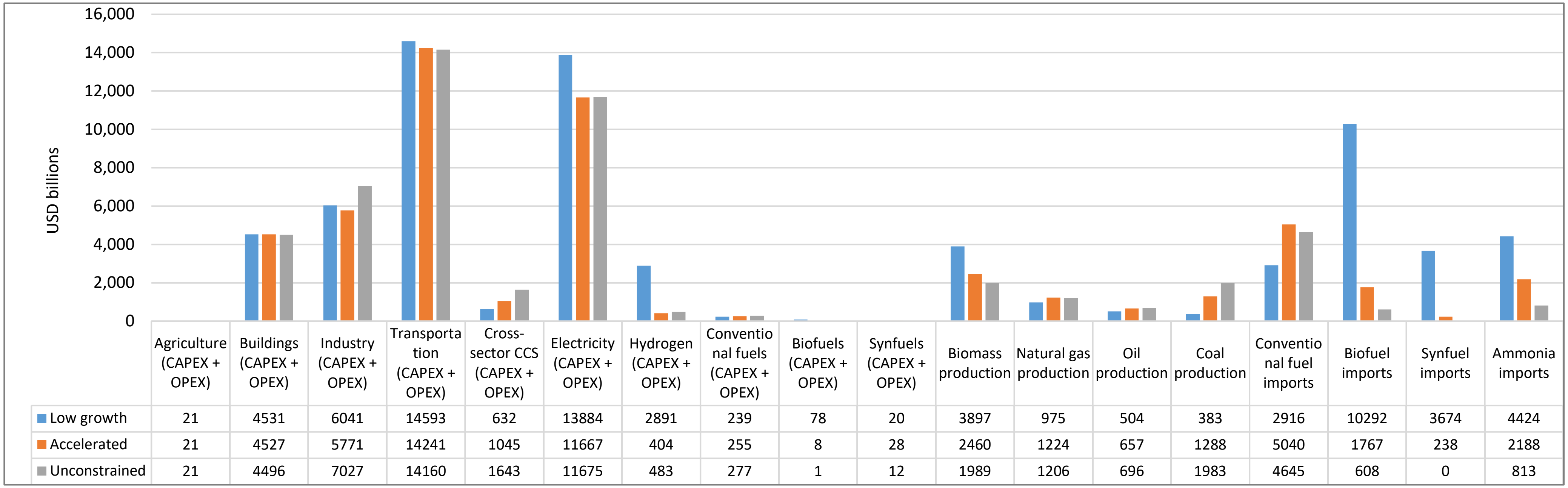
[12] GENZO assumes that, once captured, CO_2 goes along a pipeline with a distance scaled based on the relative size of the country and the type of source (DACCS is assumed to be near CO_2 storage, for example) and either arrives at a storage location if capacity is available or a shipping terminal or inter-region pipeline or, if the source is bioenergy or direct air capture, to synfuel production if synfuel is needed. Once the CO_2 leaves the initial pipeline, its costs are no longer trackable directly to the source and are allocated in post-processing to cross-sector CCS. DACCS itself, since it is not within aparticular end-use sector, is also allocated to cross-sector CCS costs. Finally, for some industrial applications, particularly for 'other industry' that typically has smaller facilities, we assume that the thermal load for CCS would be met by a separate thermal supply akin to industrial hub district heating. For the purposes of the calculations in this figure, we have included the non-energy costs of the thermal supply for these CCS applications in cross-sector CCS costs.

Figure 4.8. Total Energy System Cost through 2065 Broken Out by End-Use and Transformation CAPEX and OPEX, Fuel Production Costs, and Net Cost of Fuel Imports

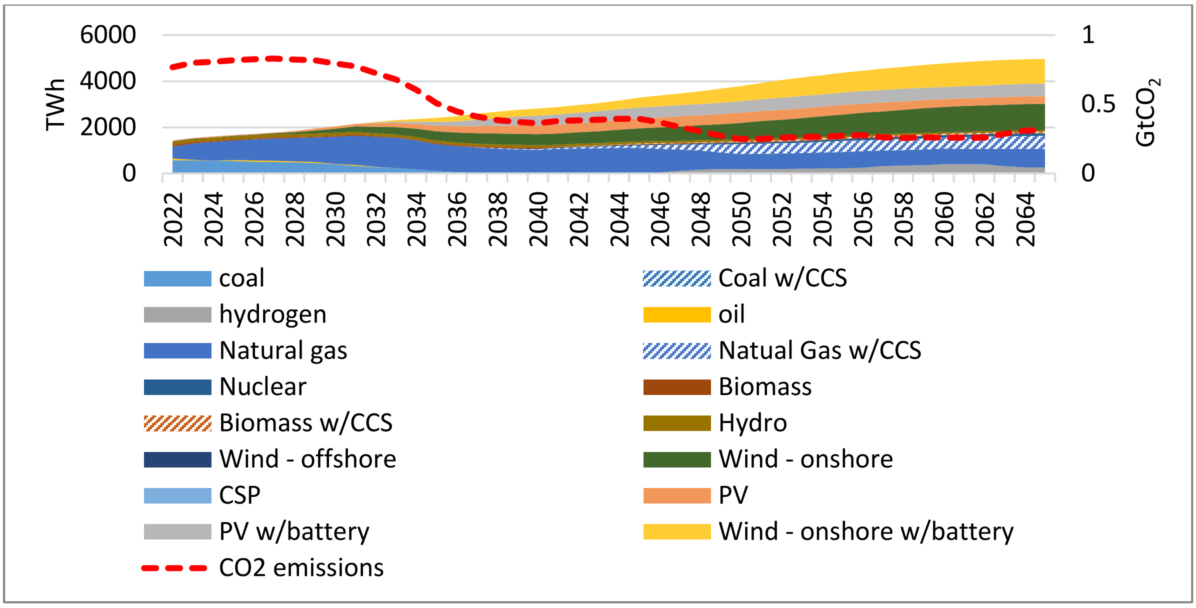


	Agriculture (CAPEX + OPEX)	Buildings (CAPEX + OPEX)	Industry (CAPEX + OPEX)	Transportation (CAPEX + OPEX)	Cross-sector CCS (CAPEX + OPEX)	Electricity (CAPEX + OPEX)	Hydrogen (CAPEX + OPEX)	Conventional fuels (CAPEX + OPEX)	Biofuels (CAPEX + OPEX)	Synfuels (CAPEX + OPEX)	Biomass production	Natural gas production	Oil production	Coal production	Conventional fuel imports	Biofuel imports	Synfuel imports	Ammonia imports
🟦 Low growth	21	4531	6041	14593	632	13884	2891	239	78	20	3897	975	504	383	2916	10292	3674	4424
🟧 Accelerated	21	4527	5771	14241	1045	11667	404	255	8	28	2460	1224	657	1288	5040	1767	238	2188
◼ Unconstrained	21	4496	7027	14160	1643	11675	483	277	1	12	1989	1206	696	1983	4645	608	0	813

Source: GENZO result.

The low storage scenario sees a significant increase in CAPEX and OPEX in the electricity sector compared to the other two scenarios, owing in part to the necessity to use relatively poor wind resources in the region, but primarily for biomass and hydrogen-based generation for firm power – these lead to an additional US$2.3 trillion just in non-energy expenditures in the electricity sector.

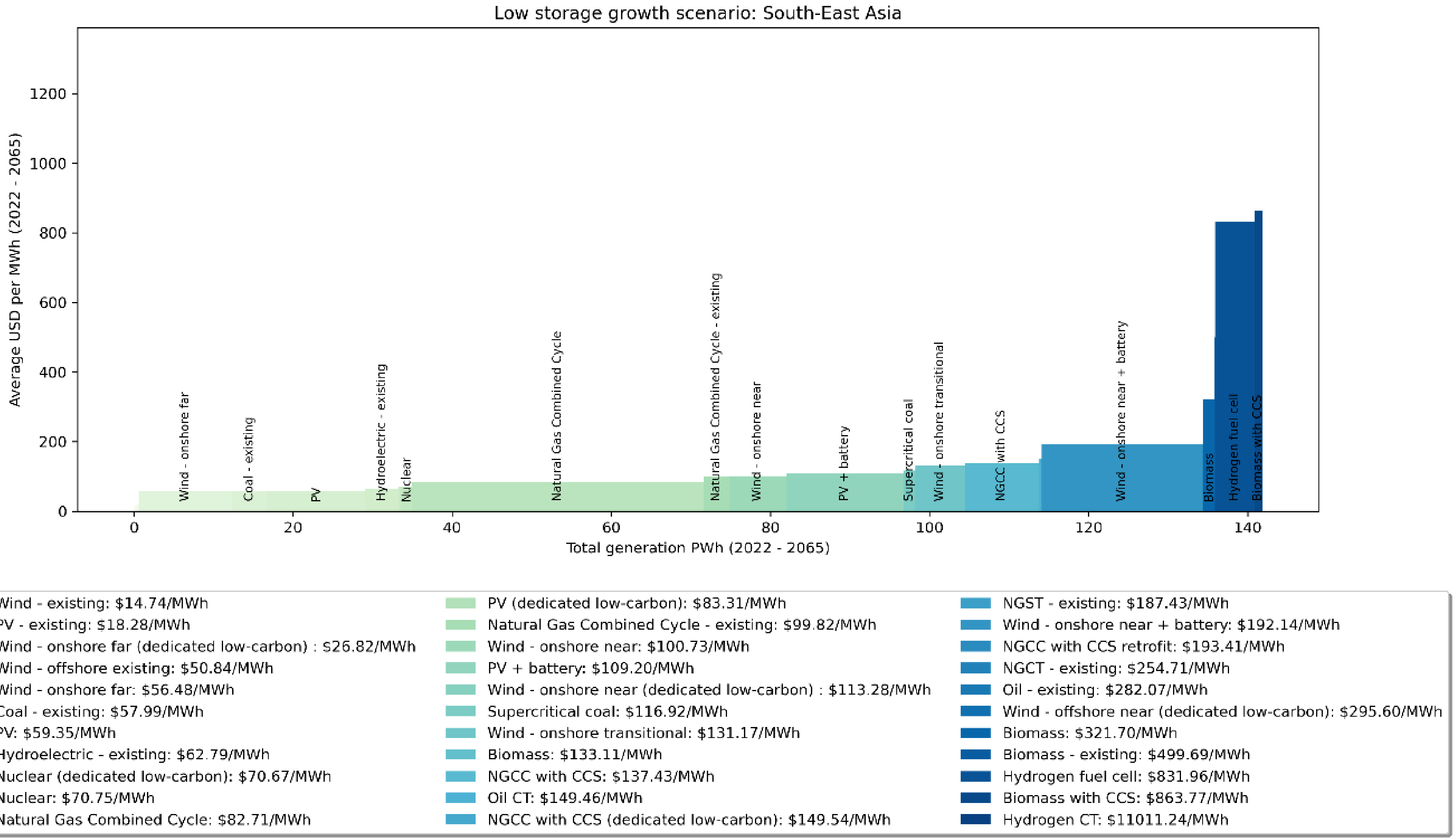
Figure 4.9. Electricity Generation and CO_2 Emissions through 2065: Low Storage Growth Scenario



Source: GENZO result.

Even though total hydrogen and biomass-based generation is not a large portion of the overall generation mix in the low storage growth scenario, the cost of that generation is quite high (Figure 4.10).

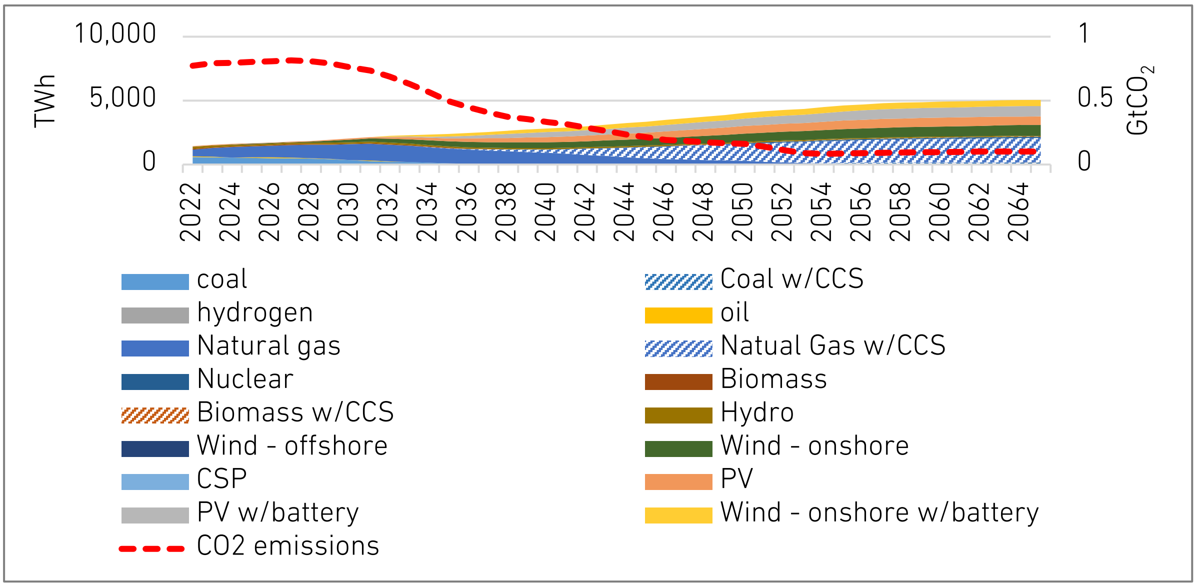
Figure 4.10. Cost of Electricity Generation: Low Storage Growth Scenario



Source: GENZO result.

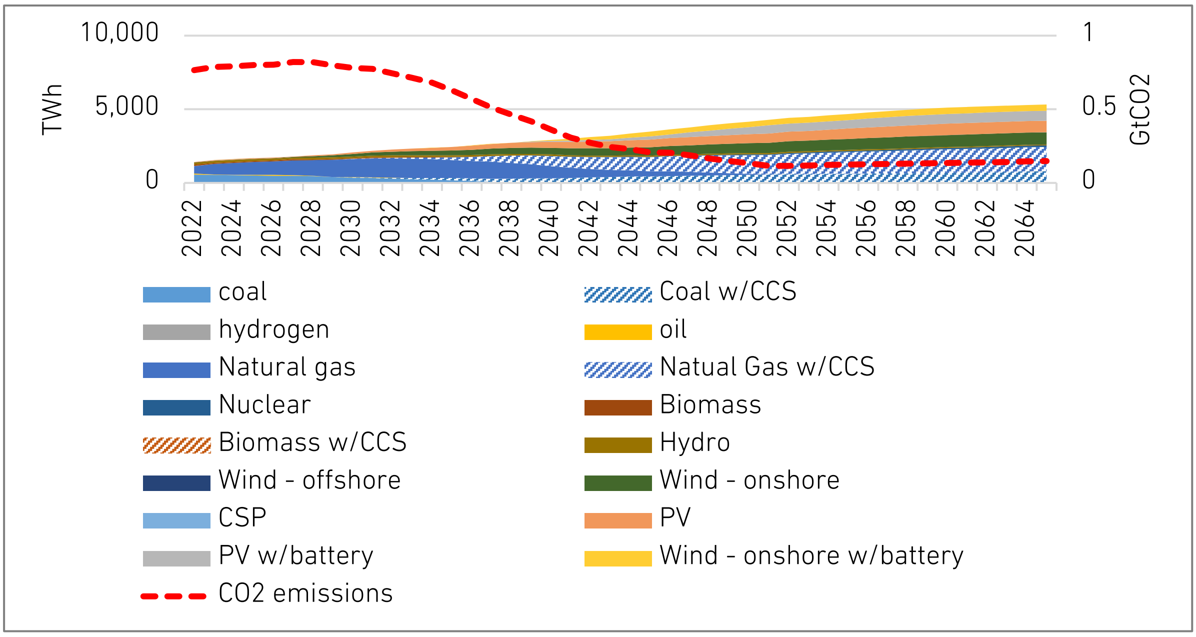
By comparison, the accelerated storage growth scenario has sufficient CO_2 storage to use natural gas combined cycle with carbon capture for firm power (Figure 4.11). The unconstrained storage growth scenario, with even more available CO_2 storage, also uses supercritical coal with post-combustion capture (Figure 4.12).

Figure 4.11. Electricity Generation and CO_2 Emissions through 2065: Accelerated Storage Growth Scenario



Source: GENZO result.

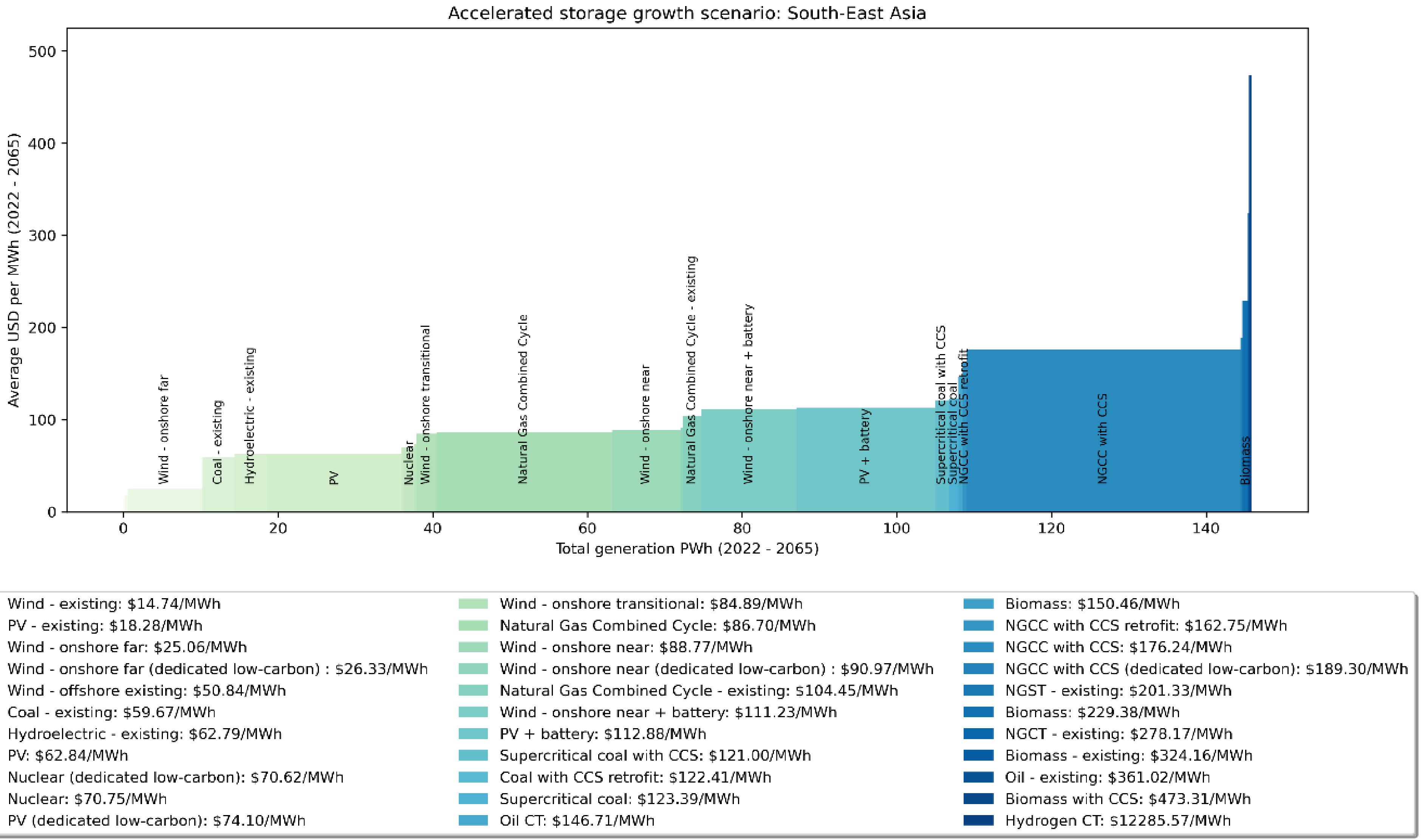
Figure 4.12. Electricity Generation and CO₂ Emissions: Unconstrained Storage Growth Scenario



Source: GENZO result.

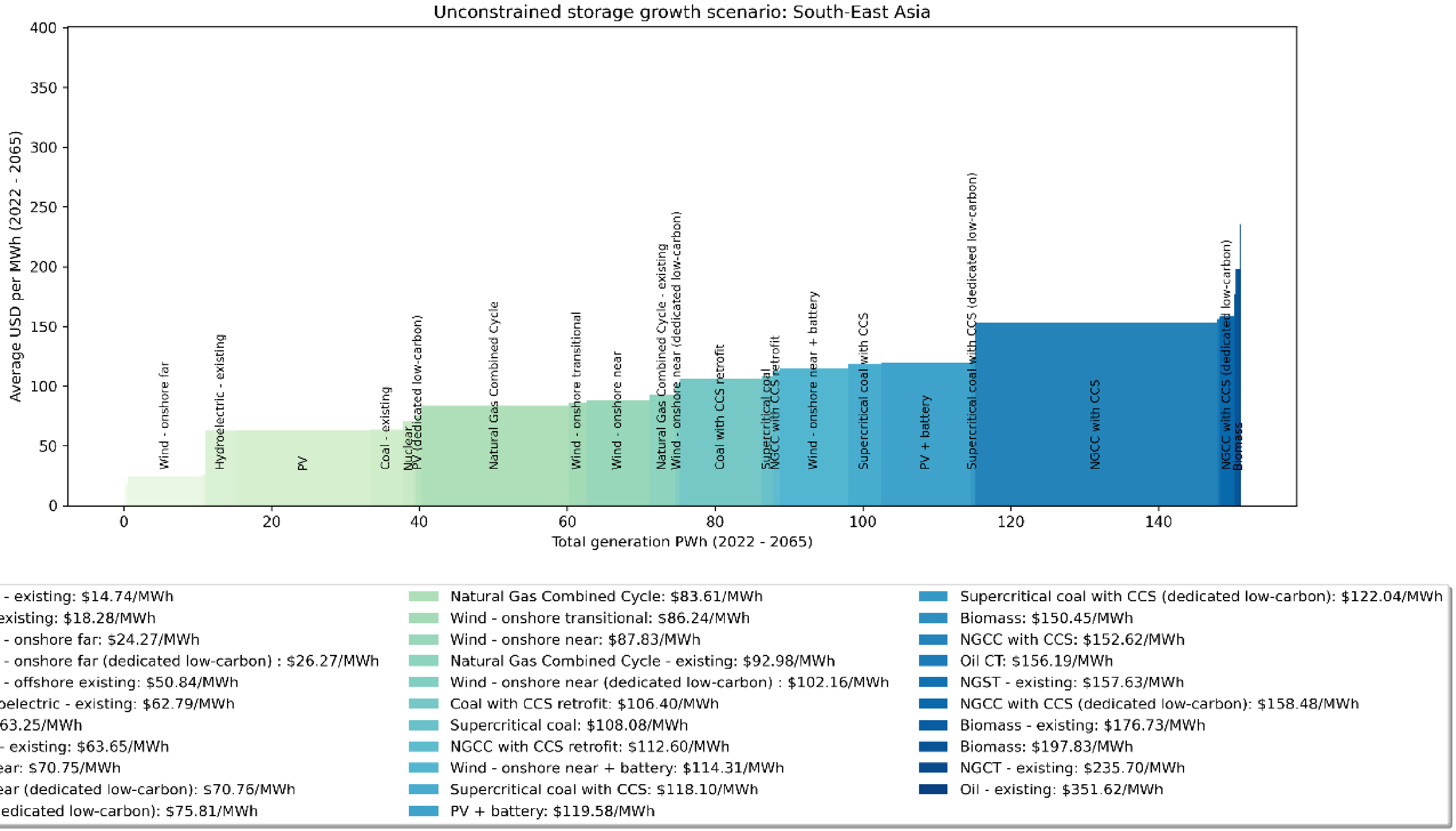
By avoiding the use of biomass and hydrogen-based generation, the cost of supplying electricity in the accelerated (Figure 4.13) and unconstrained (Figure 4.14) storage growth scenarios is significantly lower than in the low growth scenario, resulting in electricity prices that are also significantly lower. Many decarbonisation pathways, even if not directly achieved through electrification, depend in part on additional electricity consumption. For example, carbon capture requires both thermal energy and electricity. Electricity then drives the compression and pumps required to send CO_2 through pipelines and into geologic storage. Electricity also can provide a decarbonisation pathway itself. Electric heat pumps can offer low-carbon space heating and cooling in buildings. Electric vehicles, particularly for light-duty vehicles, offer a low-carbon alternative. Electrical heating for some industrial applications is also possible. Hydrogen, which offers its own decarbonisation options, especially in transportation, can be produced from electricity and must be produced from electricity if CO_2 storage availability is limited. The added cost of electricity generation and higher electricity prices in the low carbon storage scenario cascades throughout the energy system to contribute higher overall cost of net zero in the low carbon storage scenario than the other two scenarios.

Figure 4.13. Cost of Electricity Generation: Accelerated Storage Growth Scenario



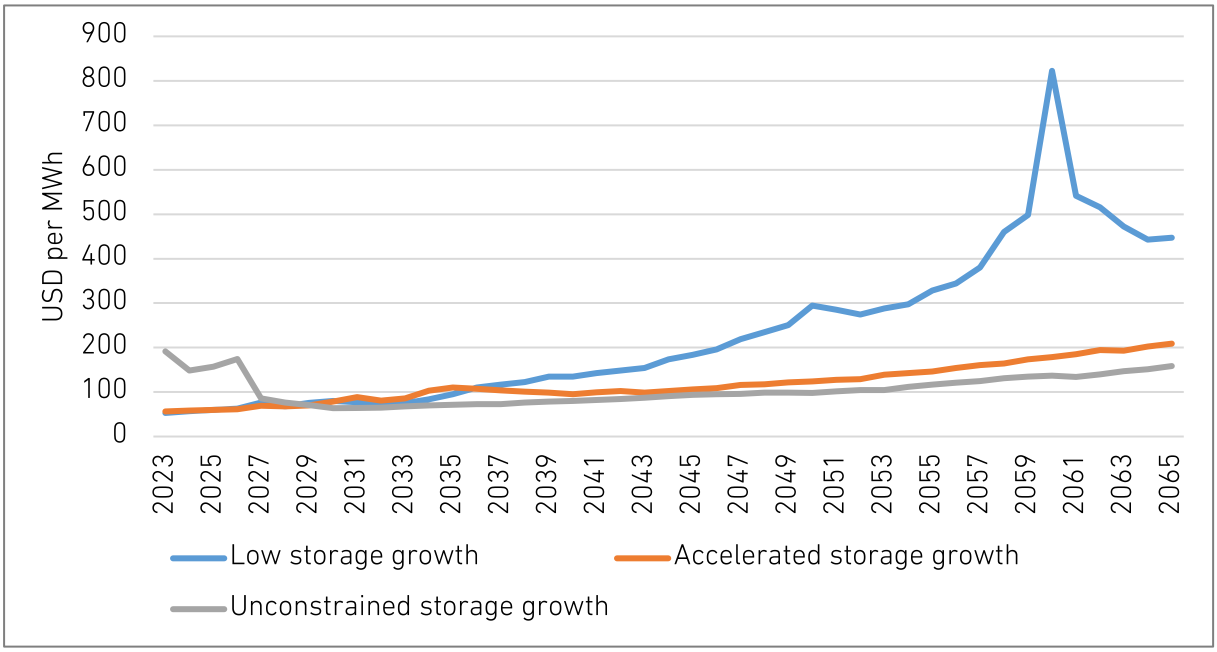
Source: GENZO result.

Figure 4.14. Cost of Electricity Generation: Unconstrained Storage Growth Scenario



Source: GENZO result.

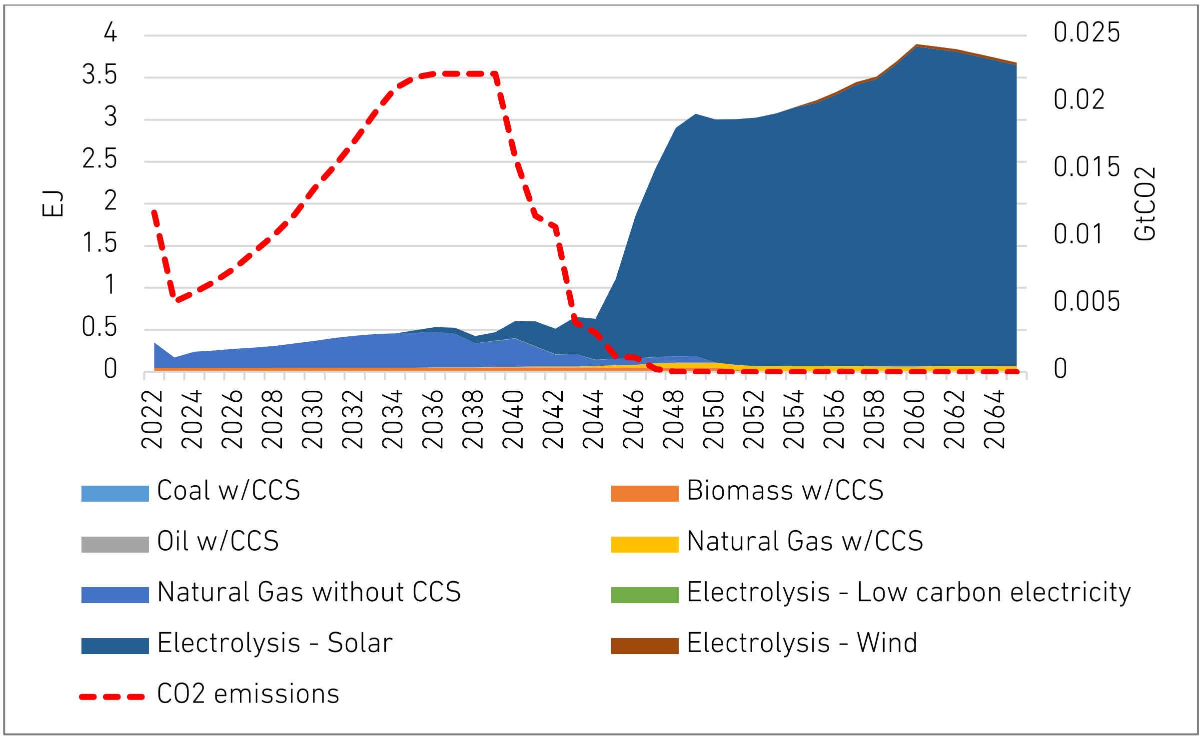
Figure 4.15. Electricity Prices Averaged Over All Countries in South-East Asia



Source: GENZO result.

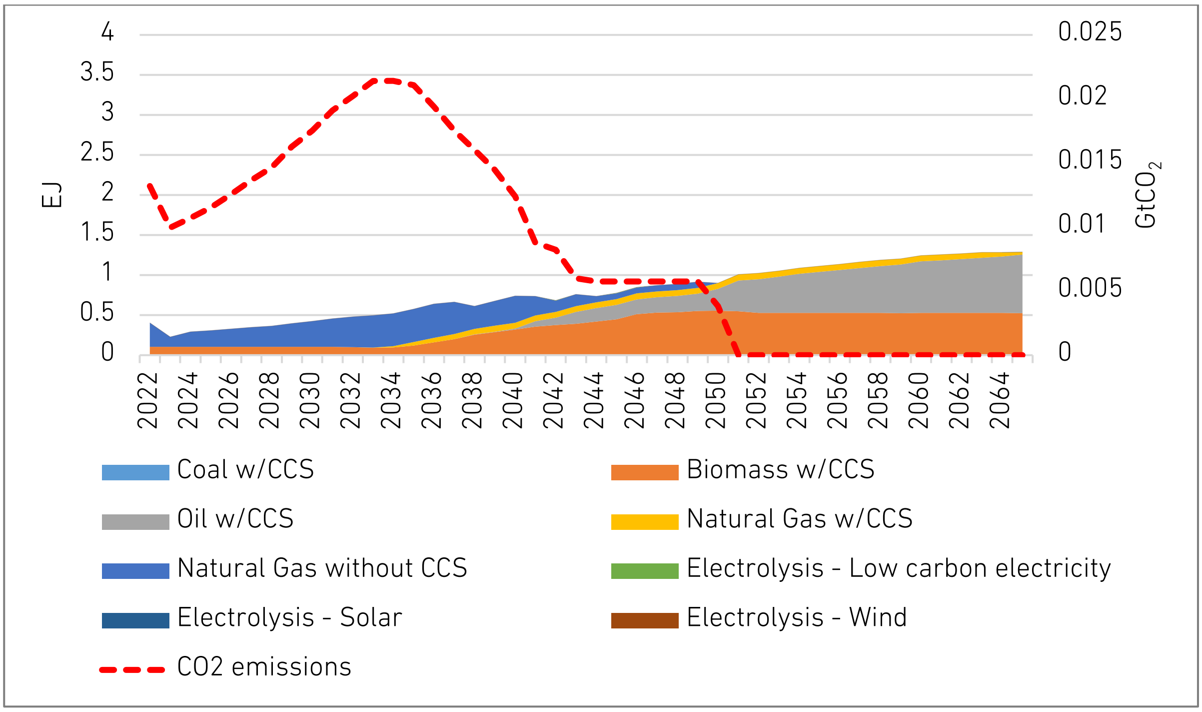
Because the low storage growth scenario has limited CO_2 storage availability, the hydrogen it generates is via electrolysis, primarily with dedicated solar (Figure 4.16). The low growth scenario also produces considerably more hydrogen than the accelerated (Figure 4.17) and unconstrained (Figure 4.18) scenarios because hydrogen is the primary method of decarbonisation in the low growth scenario. As a result, the CAPEX and OPEX needed for hydrogen in the low storage growth scenario is about US$2.5 trillion more than in the accelerated and unconstrained storage scenarios. The unconstrained storage scenario sees additional hydrogen production from coal gasification with CCS compared to the accelerated storage scenario because the greater availability of storage can accommodate coal gasification, which has a higher capture rate per kg of hydrogen production.

Figure 4.16. Hydrogen Production: Low Storage Growth Scenario



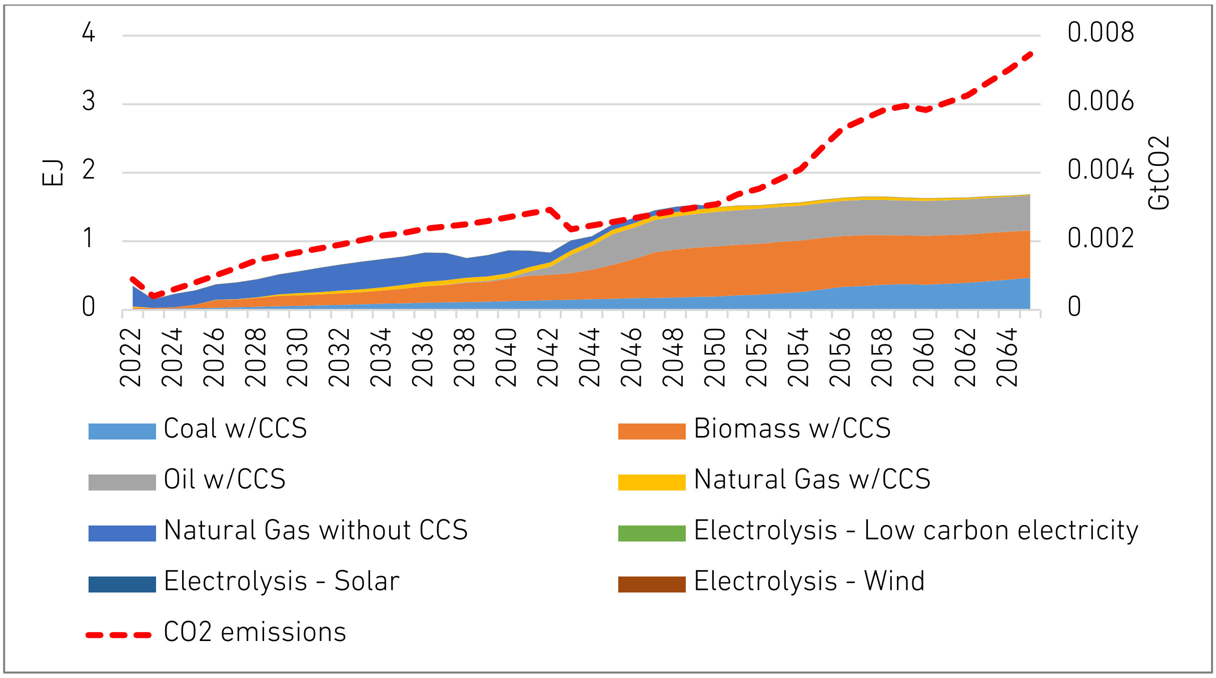
Source: GENZO result.

Figure 4.17. Hydrogen Production: Accelerated Storage Growth Scenario



Source: GENZO result.

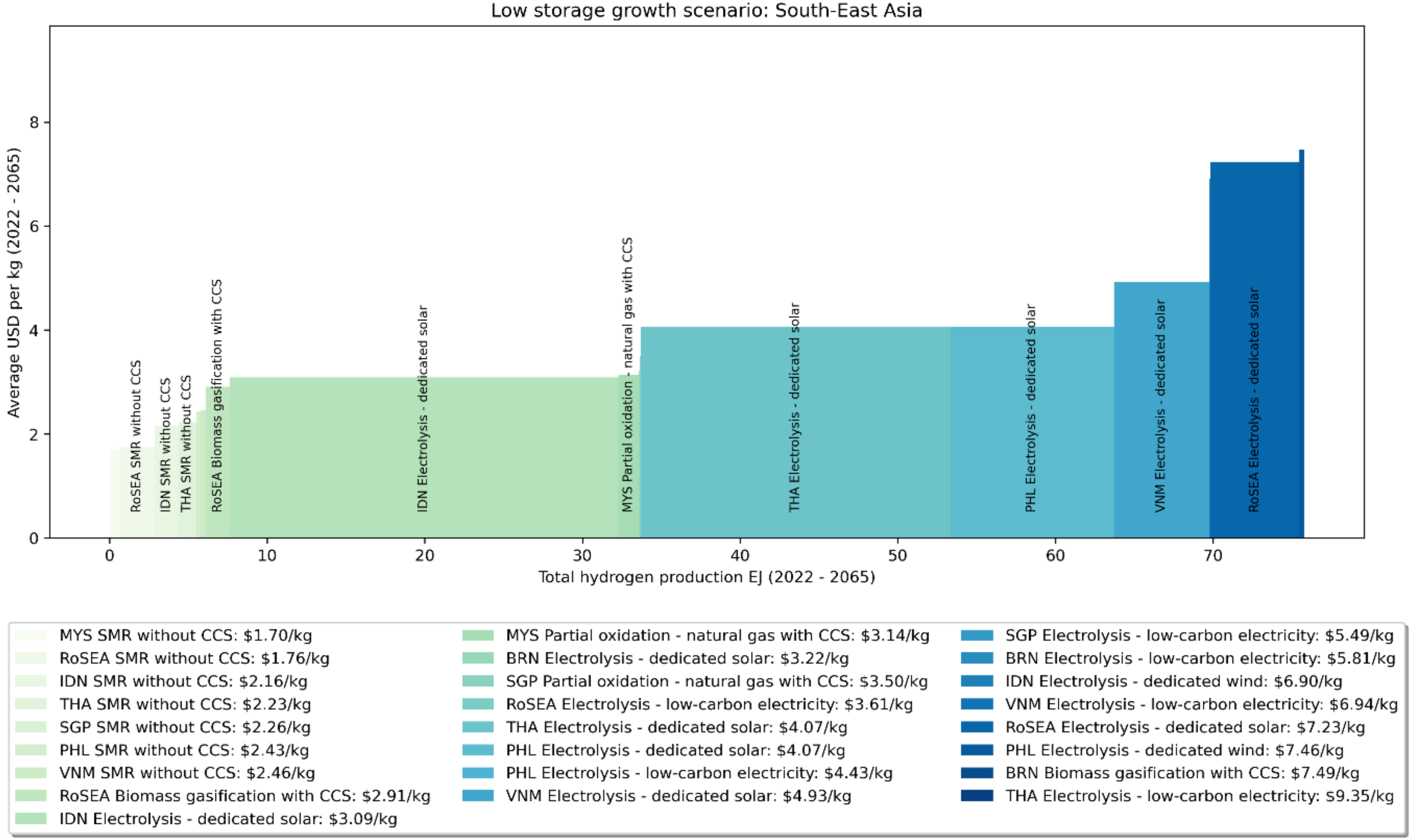
Figure 4.18. Hydrogen Production: Unconstrained Storage Growth Scenario



Source: GENZO result.

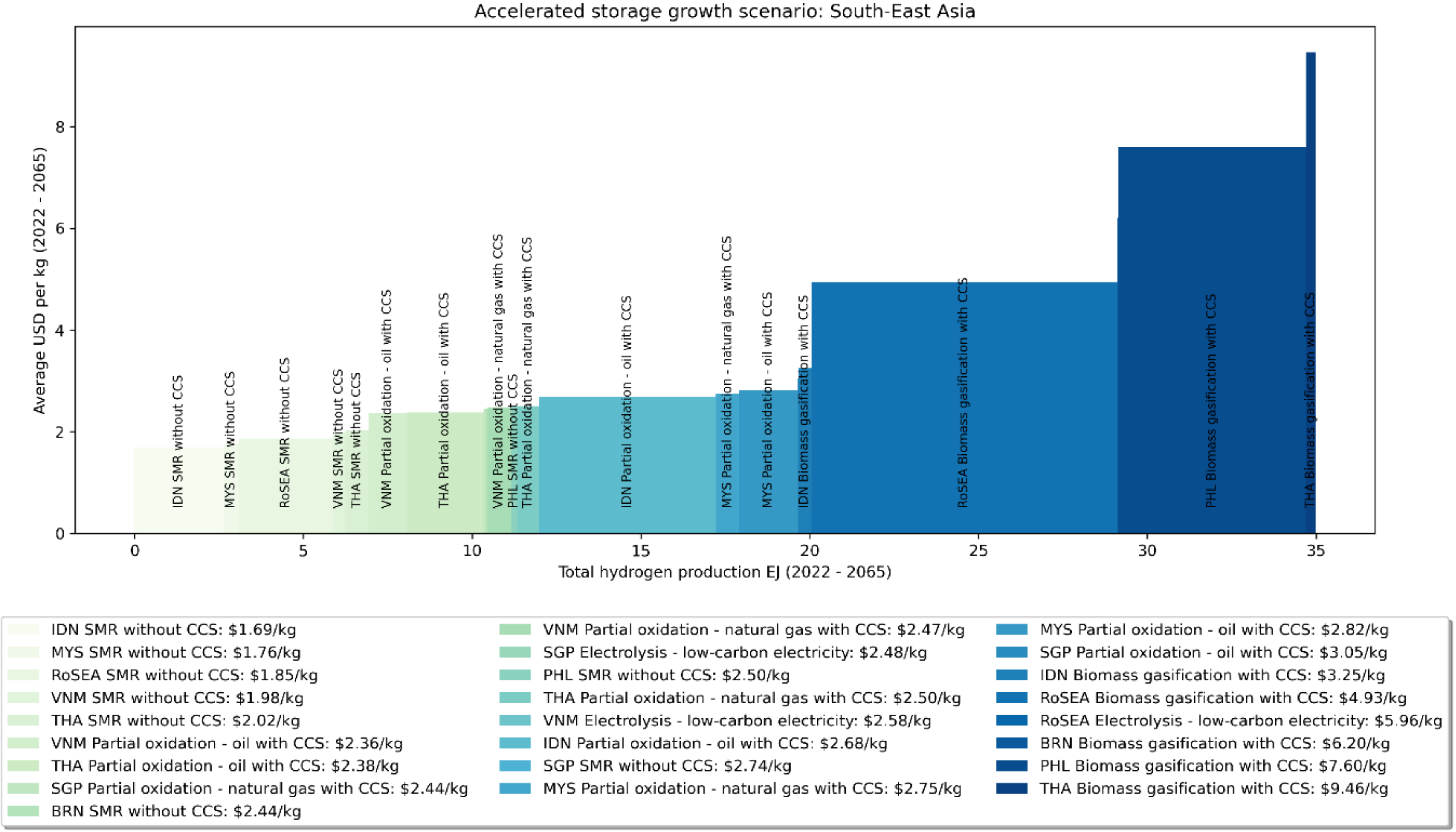
The total cost of producing hydrogen reveals some of the complexity of GENZO and the overall optimisation involved. The low storage growth scenario (Figure 4.19) has lower total cost of hydrogen production than the accelerated (Figure 4.20) and unconstrained (Figure 4.21) scenarios. Beyond around US$3 per kg, any meaningful level of production of hydrogen in the accelerated and unconstrained scenarios is from biogasification with CCS, which serves two purposes – providing low-carbon hydrogen for use in transportation and industry and carbon removals. The cost of producing hydrogen from biogasification with CCS is higher than most of the electrolysis based production costs in the low storage growth scenario, but the value in carbon removals more than compensates for the higher production costs for biogasification with CCS. If the low storage growth scenario had more available storage, it would opt for biogasification with CCS as well.

Figure 4.19. Hydrogen Production Cost: Low Storage Growth Scenario



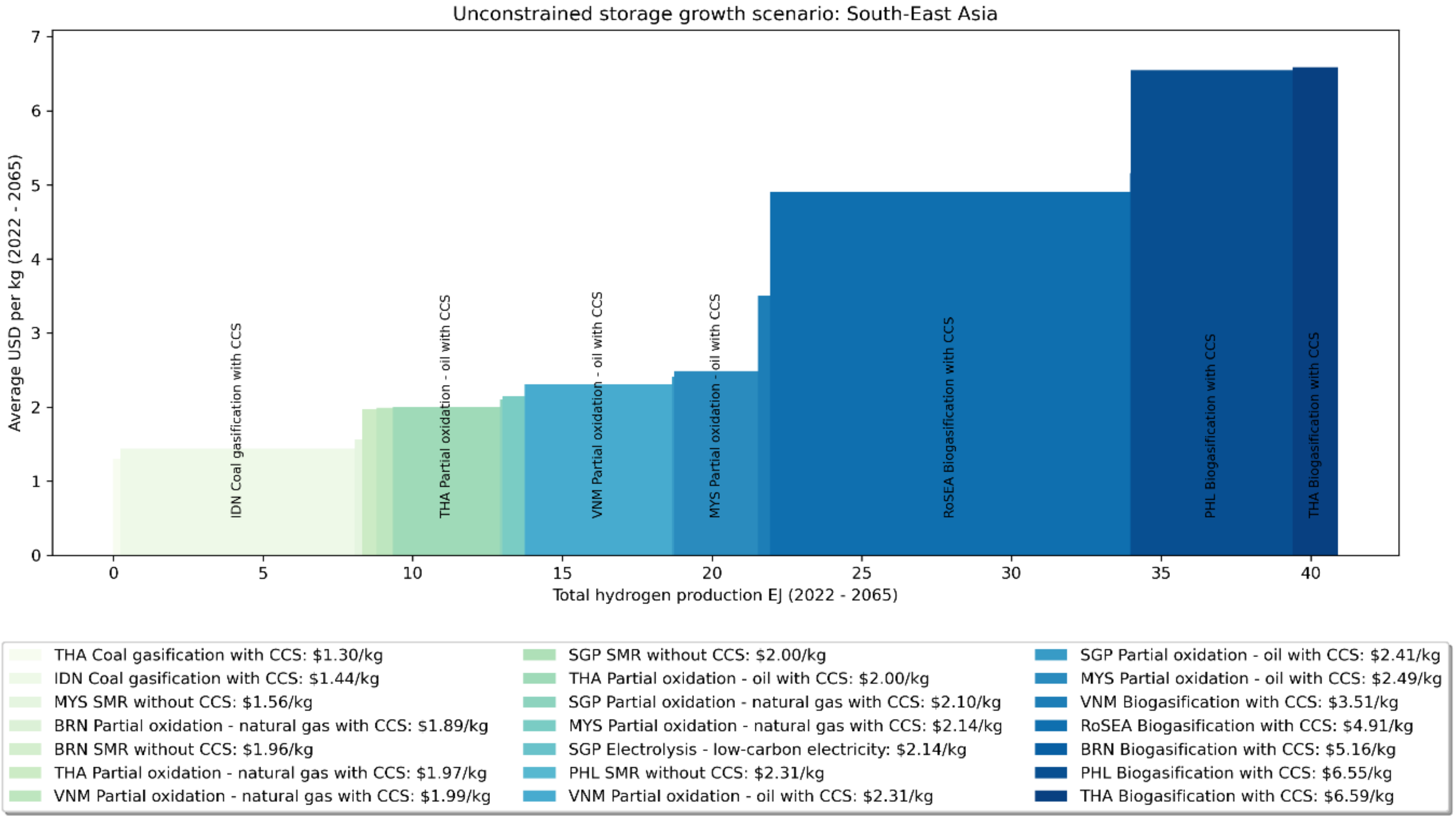
Source: GENZO result.

Figure 4.20. Hydrogen Production Cost: Accelerated Storage Growth Scenario



Source: GENZO result.

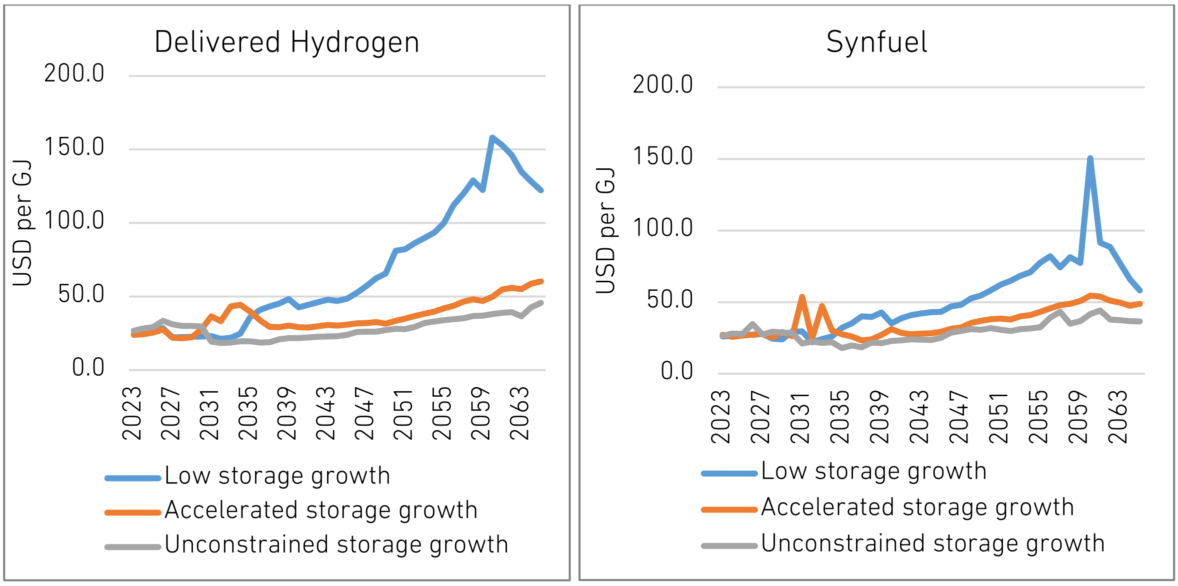
Figure 4.21. Hydrogen Production Cost: Unconstrained Storage Growth Scenario



Source: GENZO result.

The demand for hydrogen in the low storage growth scenario far outstrips the region's ability to produce it at a cost less than it can import ammonia – a hydrogen carrier – and synfuel, in which hydrogen can be a precursor. On the far right of Figure 4.8 we can see that the cost of synfuel dwarfs the import costs in the accelerated and unconstrained storage scenarios, costing more than an additional US$3 trillion. Ammonia imports also cost US$2.3 trillion more than the accelerated scenario and US$3.5 trillion more than the unconstrained scenario. Between the expensive ammonia and synfuel imports and the higher cost of domestic hydrogen production in the low carbon storage scenario, the prices of delivered hydrogen and synfuel are significantly higher than in the other two scenarios. Although hydrogen can be a precursor to synfuel, synfuel can also be produced via a process with biomass that does not require a separate production of hydrogen. Shipping and handling of synfuel, once created, is also far less costly than hydrogen or hydrogen-to-ammonia-to-hydrogen, which is why the delivered hydrogen prices in the region are generally higher than synfuel prices.

Figure 4.22. End-use Prices for Hydrogen and Synfuel Averaged Over the South-East Asia Region



Source: GENZO result.

Biofuel imports in the low storage growth scenario are even higher compared to the other scenarios than synfuel and ammonia imports. The cost of imported biofuels is US$8.5 trillion more in the low storage growth scenario compared to the accelerated scenario and a staggering US$9.3 trillion more than in the unconstrained scenario. Biomass production within the region is also significantly more costly in the low growth scenario – US$1.5 trillion more than accelerated and US$1.9 trillion more than unconstrained.

By contrast, the production of conventional fuels, especially coal, sees higher costs for the unconstrained scenario compared to the accelerated and low storage growth scenarios, but at a significantly smaller scale compared to the cost differences in imported advanced fuels. For example, the sum of conventional fuel production costs in the unconstrained scenario is only US$2 trillion more than in the low storage growth scenario. The cost of conventional fuel imports is also greater in the accelerated and unconstrained scenarios compared to the low storage scenario (accelerated is US$2.4 trillion more and unconstrained is US$1.7 trillion), but again far less than the additional cost for advanced fuel imports in the low storage growth scenario.

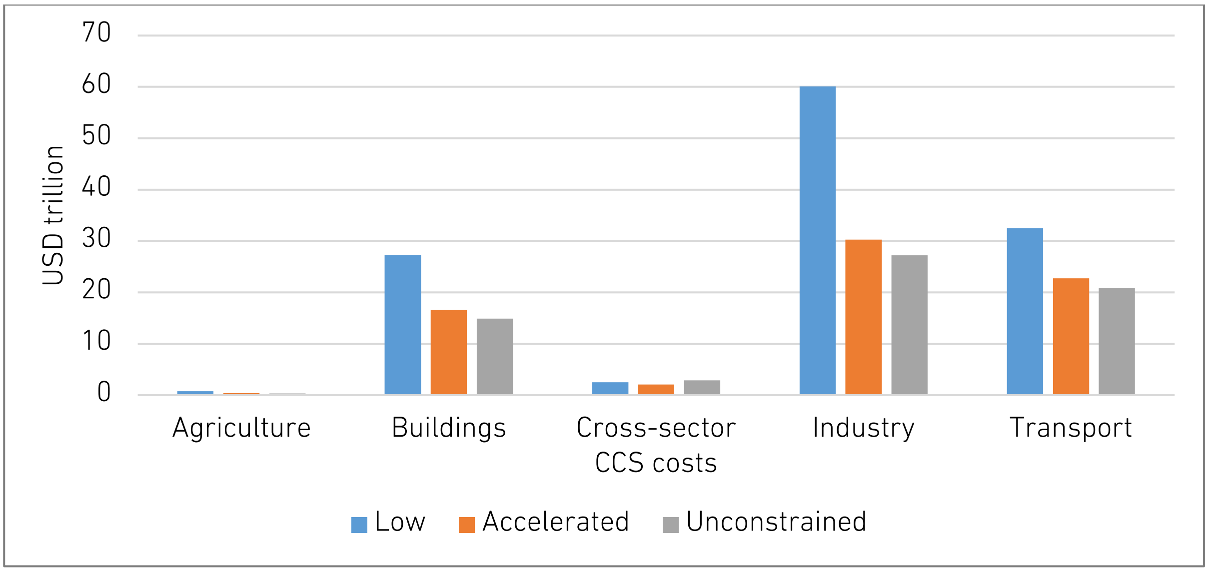
One implication for South-East Asia if it follows a low storage growth pathway is that a significant portion of its energy system costs will be dedicated to energy imports. If we add all of the CAPEX, OPEX and domestic energy production costs, the low storage growth scenario spends US$48.5 trillion, the accelerated storage growth scenario spends US$43.6 trillion, and the unconstrained scenario US$45.6 trillion. The net costs of all energy imports for the low storage growth scenario is US$20.7 trillion or 43% of its total energy system costs. Rather than spending those resources domestically in a way that supports the economy and contributes to additional jobs, 43% of the money entering the energy system will be transferred to other countries to use to develop their own advanced energy production for export. Producing the advanced fuels within the region would be even more costly, which is why GENZO opts to import. The accelerated scenario, on the other hand, spends US$9.1 trillion on imports or 21% of its total energy system spending. The unconstrained scenario spends US$6.2 trillion on energy imports for only 13.5% of total energy system spending. Both the accelerated and unconstrained scenarios allocate far greater shares of energy system spending to productive domestic resources than the low storage growth scenario. Because the total cost of the energy system is also substantially lower in these two scenarios, the additional resources that would have been used to buy imported energy in the low storage growth scenario could be used for other economic development needs like education and health care.

Up to this point in the report, we have considered costs for the entire energy system, but end-users do not face production costs for electricity and fuels. They face market-clearing prices. For example, oil production consists of some very low-cost wells followed by slightly higher cost wells and so on up to the point of demand for oil. All those buying oil are charged the marginal cost of the last well in that supply curve rather than some buyers being charged at the lowest cost production and some the next cost as so on. If we consider the consumption of energy and their marginal costs – or prices – faced by end-use sectors along with their end-use CAPEX and OPEX costs, we can see how the scenarios will fully impact end-use sectors (Figure 4.23).

The total cost to industry in the low carbon storage scenario is 2 times the cost of the accelerated scenario and 2.2 times the cost of the unconstrained scenario. Pursuing a net zero pathway within limited CO_2 storage development can double the total cost to industry – not the incremental cost over and above reference case, but the full cost to industry.

Although the quantitative assessment of the macroeconomic implications of the low carbon storage scenario are beyond the scope of this analysis, qualitatively, the result is clear. A low carbon storage scenario would significantly harm industry compared to either the accelerated or unconstrained scenario. If every other country in the world pursued the same strategy, then the export opportunities may remain unchanged, but if some countries rigorously pursue CO_2 storage, any country or region that does not will likely be at a competitive disadvantage.

Figure 4.23. Full Costs to End-Use Sectors in South-East Asia by Scenario



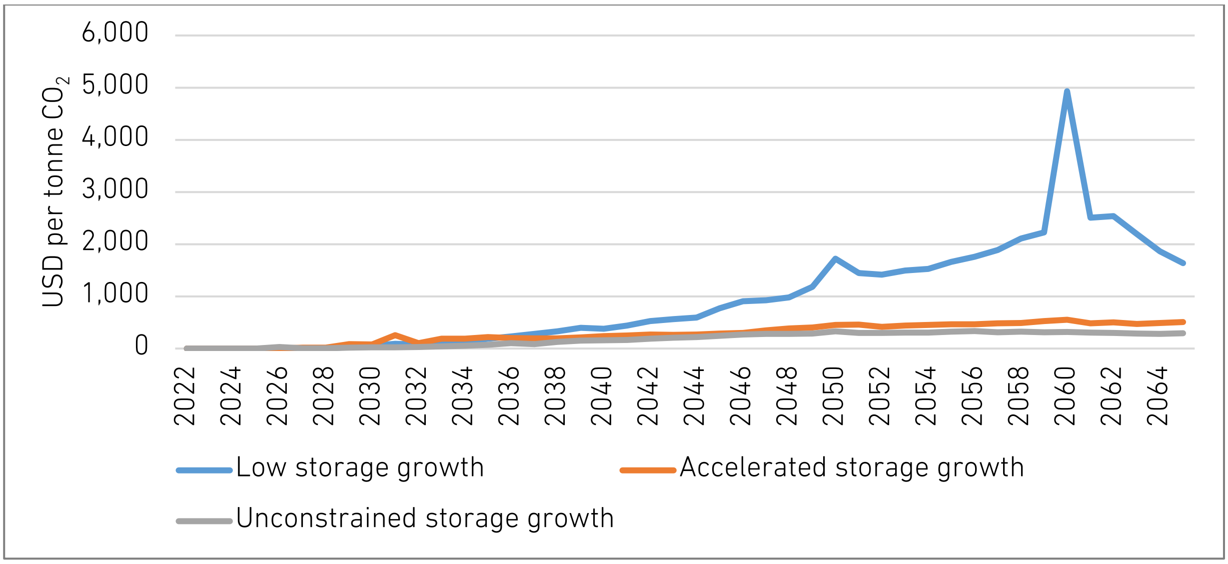
Source: GENZO result.

Buildings and transport do not face quite as stark cost increases in the low storage scenario as with industry, but nevertheless see substantially higher costs. The full energy costs of buildings, which disproportionately affects individuals and specifically low-income households, is 65% higher in the low storage scenario than the accelerated scenario and 83% higher than the unconstrained scenario. Similarly, transport costs – the majority of which is personal transport directly affecting households – are 43% higher in the low storage scenario than accelerated and 56% higher than the unconstrained scenario.

By applying a constraint on CO_2 emissions (net zero pathway) in GENZO, the model can generate the marginal cost of CO_2 emission reductions by country and scenario, which gives further insight into the relative costs across the scenarios. The marginal costs of CO_2 emission reductions mirror the total costs of the scenarios. The low storage growth scenario has significantly higher marginal CO_2 reduction costs compared to the accelerated and unconstrained storage growth scenarios (Figure 4.24). Setting aside the spike in 2060, the marginal costs in the low storage growth scenario are between

US$1500 and US$2500 per tCO_2 from 2050 onwards, after a steady rise from around US$200 per tCO_2 in the mid-2030s. The unconstrained storage growth scenario stays around US$300 per tCO_2, owing in large part to the availability to store additional CO_2 on the margin from DACCS, which acts as a backstop technology to keep CO_2 marginal costs contained. The accelerated scenario, while having significantly more development of CO_2 storage capacity than the low storage growth scenario, lacks the incremental capacity needed for sufficient DACCS to act as a backstop to keep marginal costs in line with the cost of DACCS. Nevertheless, the marginal CO_2 costs with the accelerated scenario are much lower than the low storage growth scenario and range between US$450 and US$500 per tCO_2 after 2050.

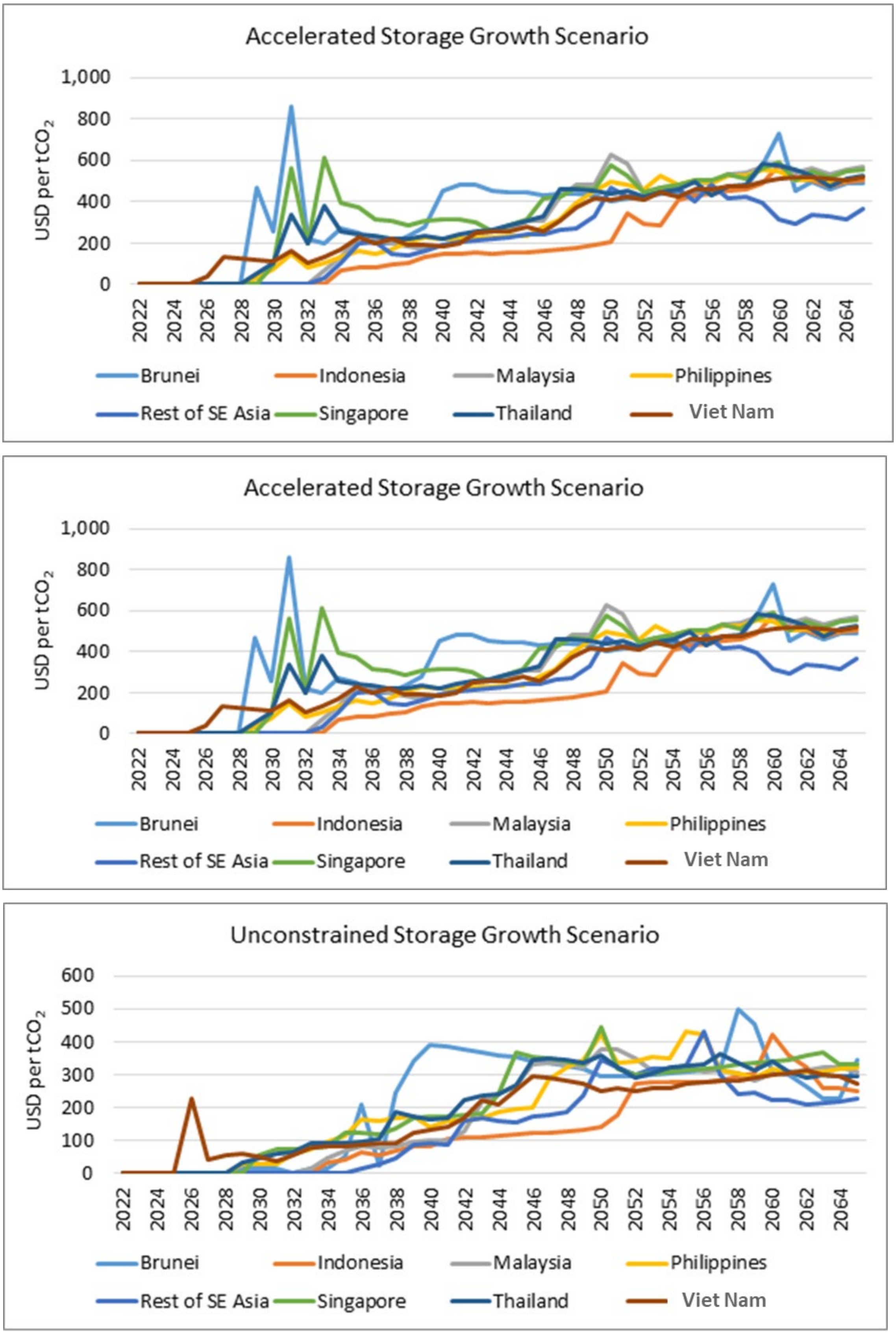
Figure 4.24. Marginal Cost of CO_2 Reductions, Averaged Across South-East Asia



Source: GENZO result.

Examining the marginal cost of CO_2 reductions by country (Figure 4.25) reveals the range of marginal costs in South-East Asia. Indonesia – with its later 2060 net zero target, relatively large CO_2 storage capacity for the region, and domestic energy resources – consistently has the lowest marginal CO_2 reduction cost in South-East Asia. At the other end of the range is Singapore, which consistently has one of the highest marginal costs of CO_2 reduction in the region. The low storage growth scenario sees the widest range between lowest and highest marginal cost in an absolute sense, with a spread of more than US$1000 per tCO_2 in some years.

Figure 4.25. Marginal Cost of CO_2 Reductions by Country



Source: GENZO result.

4.5. CCS

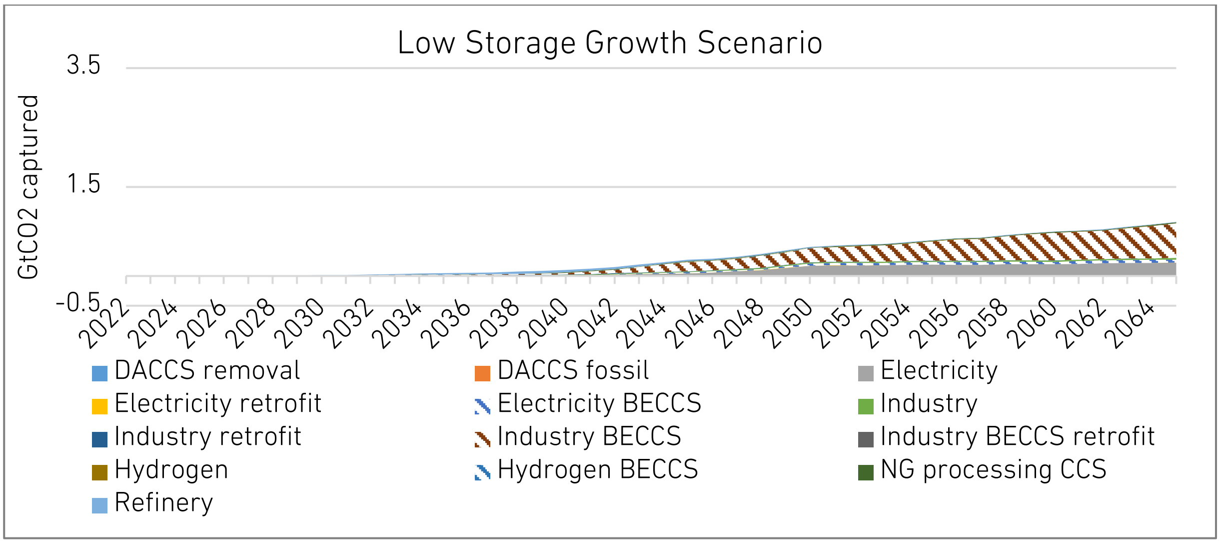
Delving into more details on the deployment of carbon capture in the scenarios (Figure 4.26), we can see that with limited storage availability in the low storage growth development scenario, most of the CCS is in the form of industrial BECCS, which provides carbon removals as well as direct decarbonisation within industry. Some BECCS in the electricity sector is also deployed, as well as some CCS in the electricity sector, specifically natural gas combined cycle with CCS. These CCS applications result in the lowest cost for the entire energy system given the availability of storage, energy prices and alternative decarbonisation options throughout the energy system.

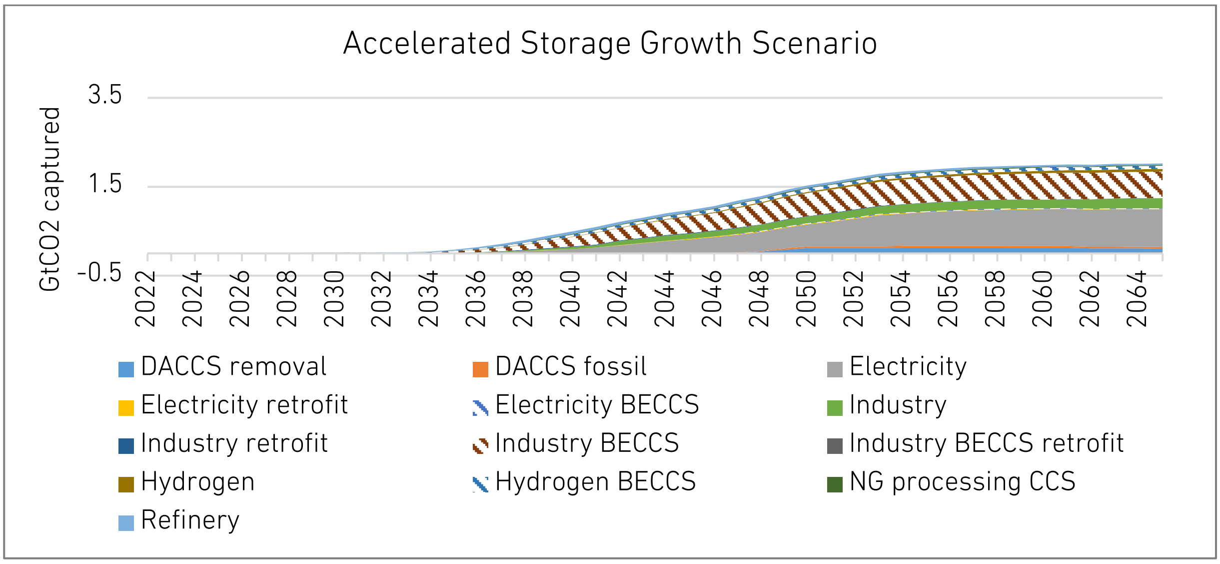
The accelerated storage growth scenario's greater availability of CO_2 storage allows for other applications of carbon capture, including in refineries, natural gas processing, hydrogen production, industry, and direct air capture, as well as a significant expansion of carbon capture in the electricity sector. Compared to the accelerated scenario, the unconstrained storage growth scenario primarily expands direct air capture and CCS retrofits in the electricity sector. The tail end of the carbon capture supplied has lower costs in the accelerated and unconstrained scenarios than the low storage growth scenario because the low storage growth scenario must use electricity-based BECCS because it needs firm power supply options and carbon removals. The cost of biomass generating capacity is high, and the price of biomass itself in the low growth scenario is much higher than in the accelerated and unconstrained scenarios.

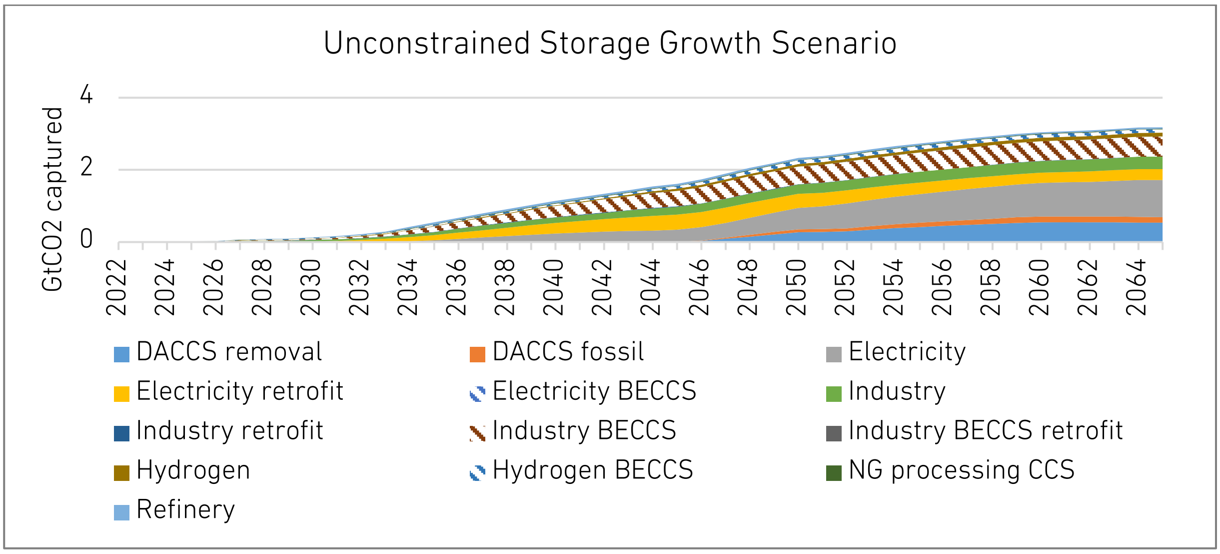
The supply curves presented are a modeling result and not a modeling input. What this means is that the cost and supply depend on many dynamic factors within the model, including energy prices, the cost of alternatives, which change as energy prices change, and the capacity factor or how much of a given capacity, once built, is used. The core inputs for technology costs and operating characteristics are identical, but if in one scenario the same amount of capacity is built, but that capacity operates 80% of the time, then the cost on a per tonne basis would be higher than an identical facility that operates at 90% of the time.

These costs also do not include the cost of transport and storage, which average over the period and the region to US$99 per tCO_2 in the low storage growth scenario. The average cost of transport and storage in the accelerated scenario is US$28 per tCO_2 and in the unconstrained scenario is US$8 per tCO_2. The widely diverging costs of transport and storage are directly related to the availability of storage in the scenarios. In all the scenarios, the same assumptions for storage development growth rates apply to all regions in the model, including those outside of South-East Asia. In the low growth scenario, CO_2 is shipped from South-East Asia to as far away as the USA and Canada because these regions have relatively greater storage availability – they are expected by 2032 to have already developed a significant storage capacity, and the low growth assumption is applied to that higher value in 2032. Shipping CO_2 that distance is costly, yet still cost-effective in the low growth scenario. In the accelerated scenario, Australia develops more capacity than it needs for its own use, so the CO_2 captured in South-East Asia that exceeds the locally developed storage capacity is primarily shipped to Australia. In the unconstrained scenario, all countries in South-East Asia that have sufficient storage capacity develop that capacity as needed so that the only countries shipping or piping CO_2 to another country are Singapore, the Philippines, and Viet Nam, which have from zero to limited CO_2 storage capacity.

Figure 4.26. CCS by Type and Sector

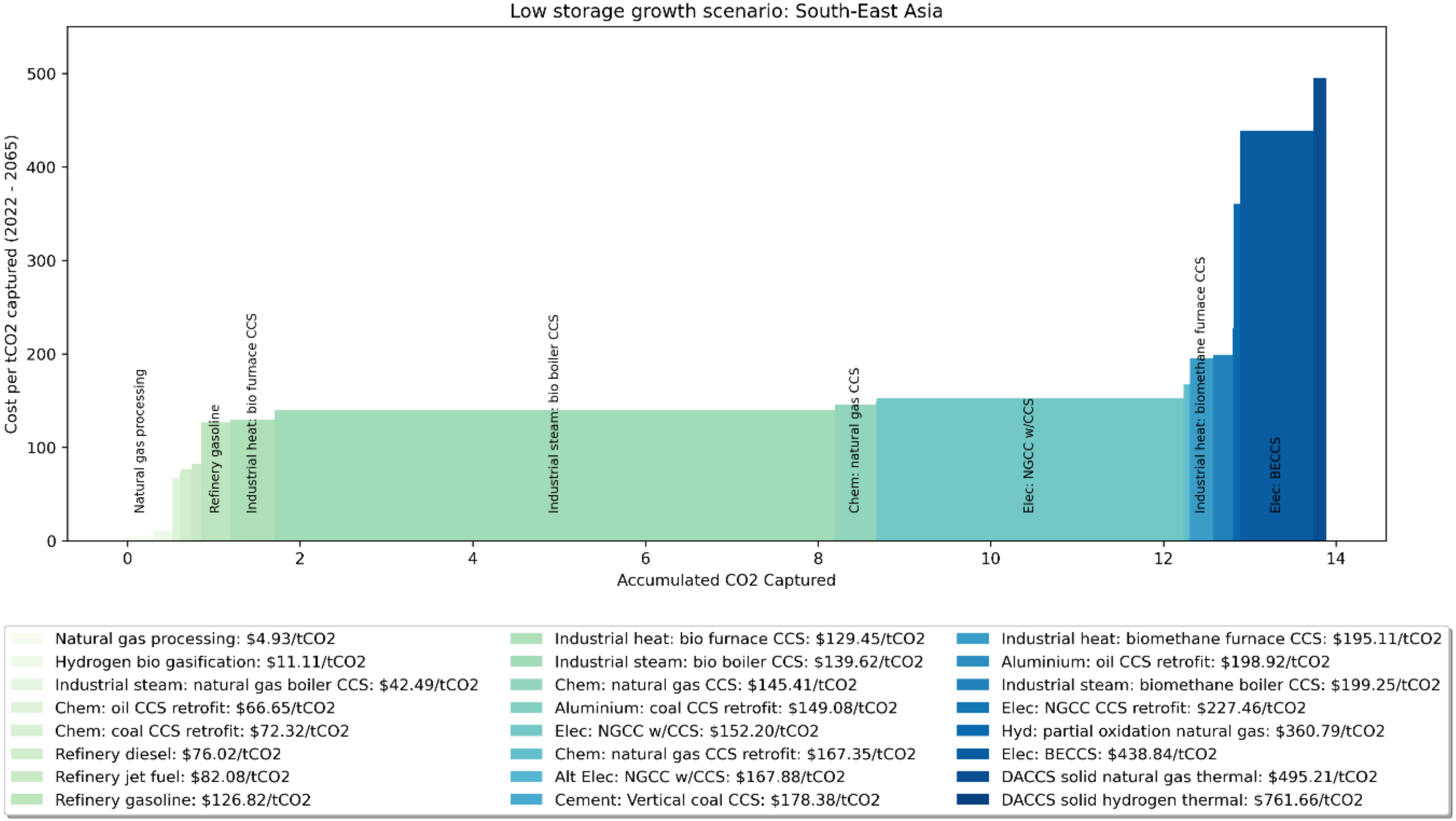

Low Storage Growth Scenario


Accelerated Storage Growth Scenario


Unconstrained Storage Growth Scenario

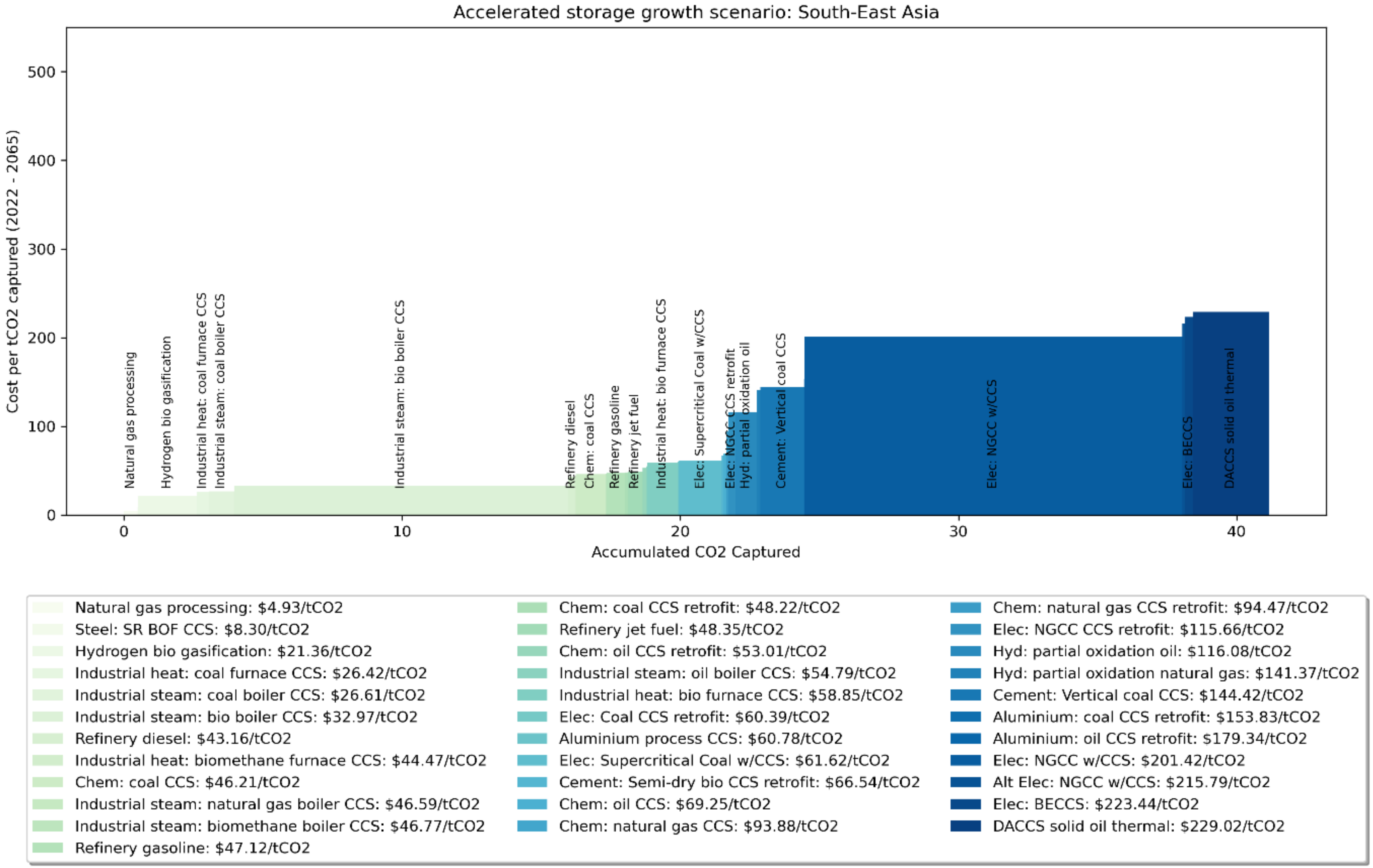
Source: GENZO result.

Figure 4.27. Average Cost of Carbon Capture in South-East Asia: Low Storage Growth Scenario



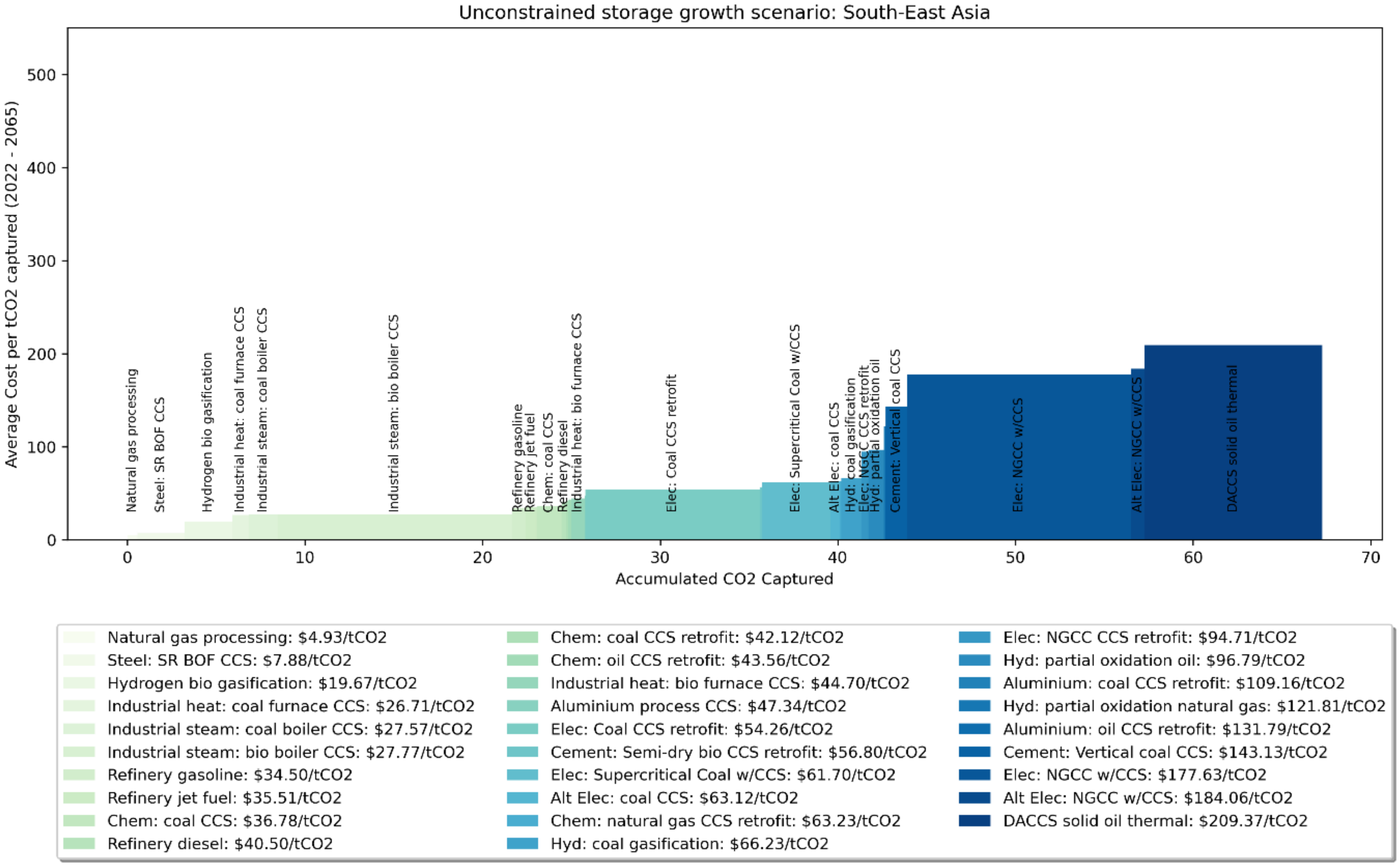
Source: GENZO result.

Figure 4.28. Average Cost of Carbon Capture in South-East Asia: Accelerated Storage Growth Scenario



Source: GENZO result

Figure 4.29. Average Cost of Carbon Capture in South-East Asia: Unconstrained Storage Growth Scenario



Source: GENZO result.

The benefits of pursuing a net zero pathway with an ample development of CCS infrastructure are clear. A savings in excess of US$20 trillion through 2065 is possible compared to a pathway with limited CCS infrastructure. Whatever technological pathway is chosen, countries in the region will need to make considerable investment and will likely need assistance from countries with developed economies. The potential for finance of CCS infrastructure is discussed in the next section. To get a sense for the scale of investment and finance needed, Table 4.1 shows the investment in CCS for the region by decade for the low storage growth scenario. Table 4.2 details the investment for the accelerated scenario, and table 4.3 the investment for the unconstrained scenario. While the accelerated and unconstrained scenarios obviously require greater investment in CCS, they avoid the high total cost of the low growth scenario and are thus remarkably cost-effective investments in the context of achieving net zero. However, the majority of investment in the low carbon storage scenario is in shipping rather than capture, underscoring just how cost-effective carbon capture is relative to other decarbonisation options that it is still pursued in the face of such high transport costs. The difference in total investment for CCS infrastructure between the low carbon and accelerated scenarios is surprisingly small. For an additional US$164 billion investment in CCS compared to the low storage scenario, in which resources are shifted toward capture rather than transport and storage is developed locally, the accelerated scenario saves US$20 trillion overall. What is not shown, but discussed more generally above, is that a greater level of investment is needed in the low storage growth scenario in other areas of the energy system while also resulting in significant outflows for purchasing low-carbon fuel imports.

Table 4.1. Investment (in US$ billions) for Each Decade by Type of CCS: Low Storage Growth Scenario

South-East Asia						
	2023 - 29	2030 - 39	2040 - 49	2050 - 59	2060 - 65	2023 - 65
DACCS	0.00	0.00	4.30	2.93	0.00	*7.23*
Electricity	0.00	3.33	27.44	3.40	0.13	*34.31*
Electricity BECCS	0.00	0.00	6.91	3.59	1.49	*11.99*
Electricity retrofit	0.00	0.00	1.29	0.00	0.00	*1.29*
Hydrogen	0.01	0.17	1.02	0.18	0.06	*1.43*
Hydrogen BECCS	0.17	0.01	0.00	0.00	0.00	*0.18*
Industry - aluminum	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - aluminum retrofit	0.08	0.10	0.01	0.01	0.00	*0.20*
Industry - cement	0.00	0.00	0.00	0.00	0.06	*0.06*
Industry - cement BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement BECCS retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement retrofit	0.00	0.00	0.01	0.02	0.02	*0.05*
Industry - chemicals	0.00	2.12	1.94	1.71	0.93	*6.71*
Industry - chemicals retrofit	0.73	1.57	0.45	0.17	0.03	*2.95*
Industry - heat	0.00	0.00	0.00	0.00	0.02	*0.02*
Industry - heat BECCS	0.00	3.17	2.16	7.46	3.44	*16.24*
Industry - steam	0.00	0.00	0.00	0.00	0.96	*0.96*
Industry - steam BECCS	0.00	0.74	26.75	49.96	29.34	*106.79*
Industry - steel	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - steel retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
NG processing	0.00	0.02	0.09	0.04	0.00	*0.16*
Refinery	0.57	13.31	1.34	0.22	0.16	*15.59*
CO2 pipeline	0.00	0.94	0.45	0.65	0.57	*2.61*
CO2 shipping	1.13	20.10	114.33	228.90	125.91	*490.36*
CO2 domestic storage	0.08	1.37	0.58	0.83	1.07	*3.93*
CO2 international storage	0.54	0.92	1.74	1.26	6.37	*10.83*
Total	*3.30*	*47.89*	*190.82*	*301.32*	*170.57*	*713.90*

Source: GENZO result.

Table 4.2. Investment (US$ Billions) for Each Decade by Type of CCS: Accelerated Storage Growth Scenario

South-East Asia						
	2023 - 29	2030 - 39	2040 - 49	2050 - 59	2060 - 65	2023 - 65
DACCS	0.00	0.00	77.88	25.53	0.00	*103.41*
Electricity	0.00	25.60	78.56	78.16	9.24	*191.55*
Electricity BECCS	0.00	0.00	3.22	0.00	0.87	*4.09*
Electricity retrofit	0.00	0.89	4.26	0.00	0.00	*5.16*
Hydrogen	0.00	1.25	3.55	7.11	2.22	*14.13*
Hydrogen BECCS	0.35	0.49	0.67	0.20	0.07	*1.79*
Industry - aluminum	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - aluminum retrofit	0.07	0.15	0.07	0.04	0.01	*0.34*
Industry - cement	0.00	1.52	6.13	4.17	1.63	*13.46*
Industry - cement BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement BECCS retrofit	0.00	0.08	0.14	0.15	0.09	*0.46*
Industry - cement retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - chemicals	0.00	1.60	4.96	3.58	0.97	*11.11*
Industry - chemicals retrofit	0.96	2.40	1.07	0.44	0.07	*4.95*
Industry - heat	0.00	0.00	4.32	0.27	0.00	*4.60*
Industry - heat BECCS	0.02	7.06	2.13	2.67	5.00	*16.88*
Industry - steam	0.00	0.30	7.00	0.80	0.57	*8.68*
Industry - steam BECCS	0.00	22.06	67.09	16.67	32.45	*138.27*
Industry - steel	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - steel retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
NG processing	0.00	0.16	0.00	0.00	0.00	*0.17*
Refinery	0.55	19.06	4.21	0.93	0.76	*25.51*
CO2 pipeline	0.00	1.63	7.46	0.82	0.04	*9.94*
CO2 shipping	0.37	60.29	101.50	95.82	8.52	*266.50*
CO2 domestic storage	0.07	8.24	24.18	6.47	0.45	*39.41*
CO2 international storage	0.56	2.99	9.60	2.43	2.18	*17.75*
Total	*2.95*	*155.79*	*408.00*	*246.27*	*65.14*	*878.15*

Source: GENZO result.

Table 4.3. Investment (US$ Billions) for Each Decade by Type of CCS: Unconstrained Storage Growth Scenario

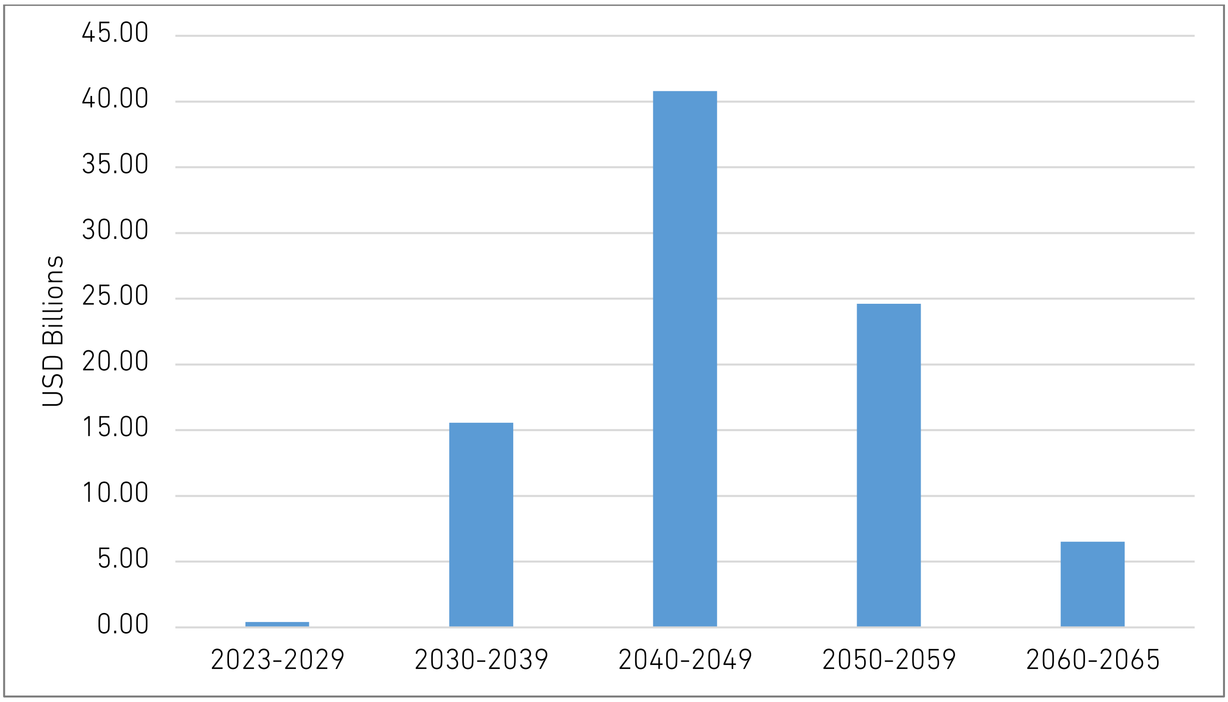
South-East Asia						
	2023 - 29	2030 - 39	2040 - 49	2050 - 59	2060 - 65	2023 - 65
DACCS	0.00	0.00	143.48	218.10	11.38	*372.96*
Electricity	0.11	57.34	73.58	70.12	23.90	*225.05*
Electricity BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Electricity retrofit	0.00	28.19	25.73	18.83	13.07	*85.83*
Hydrogen	4.86	5.57	10.04	15.37	9.07	*44.91*
Hydrogen BECCS	0.43	0.38	1.10	0.34	0.11	*2.36*
Industry - aluminum	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - aluminum retrofit	0.07	0.15	0.07	0.04	0.01	*0.34*
Industry - cement	0.00	2.13	6.16	2.97	0.91	*12.16*
Industry - cement BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement BECCS retrofit	0.08	0.17	0.15	0.15	0.09	*0.63*
Industry - cement retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - chemicals	0.00	3.74	3.72	3.00	1.13	*11.58*
Industry - chemicals retrofit	1.03	2.20	0.90	0.44	0.08	*4.65*
Industry - heat	0.05	5.06	1.21	2.30	3.28	*11.91*
Industry - heat BECCS	0.02	4.89	1.48	4.05	1.12	*11.56*
Industry - steam	5.57	3.20	1.45	6.98	2.04	*19.25*
Industry - steam BECCS	0.00	42.47	47.48	25.30	36.65	*151.90*
Industry - steel	0.36	0.00	1.04	0.52	0.39	*2.31*
Industry - steel retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
NG processing	0.01	0.15	0.00	0.00	0.00	*0.17*
Refinery	2.12	19.10	2.74	1.84	5.30	*31.10*
CO2 pipeline	0.00	2.64	2.47	0.84	0.12	*6.06*
CO2 shipping	0.23	10.21	11.10	5.28	0.42	*27.25*
CO2 domestic storage	3.12	31.54	44.85	35.78	7.72	*123.01*
CO2 international storage	0.09	5.34	5.72	2.40	0.24	*13.78*
Total	*18.18*	*224.44*	*384.48*	*414.63*	*117.04*	*1,158.77*

Source: GENZO result.

4.6. The CCS Financing Challenge

Assuming the central scenario modelled in this report (Accelerated Storage Scenario), almost US$880 billion must be invested in CCS between now and 2065 across southeast Asia, peaking at over USD40 billion per year, on average, in the 2040s.

Figure 4.30. Average Annual Investment (US$ Billions) for Each Decade: Accelerated Storage Growth Scenario



Source: GENZO result.

Mobilising this quantum of capital for CCS will require both public and private finance. The private sector has enormous financial resources, human capital and capabilities necessary for the development and operation of CCS projects. However, the private sector can only invest where there is an appropriate risk weighted return on that investment. Private investment is incentivised by the expectation of future profits. Applied to CCS, this condition will only be met if the unit cost of CCS (per tonne of CO_2 emissions avoided) is less than the cost of emitting CO_2 plus the value of any revenue generated (e.g. in enhanced oil recovery) through CCS.

The unit cost of CCS (full value chain) varies considerably depending on the capture source and scale, CO_2 transport distance and storage resource quality. The lowest cost applications may have a full value chain cost of less than USD25/tonne CO_2 including the cost of compression transport and storage. However, in most industrial applications, full value chain CCS will cost in the range of USD40-USD100 per tonne CO_2, application in power generation between USD60 and USD200 per tonne CO_2 and over USD200 per tonne

CO_2 for direct air capture. As shown previously using GENZO, CCS is required to be applied across all of these applications to deliver net zero emissions at lowest overall cost. However private sector investment incentives are currently insufficient to mobilise the necessary capital except in the lowest cost applications.

This presents a fundamental problem for governments that are charged with achieving net-zero emissions to stabilise the global climate – a significant public good. The cost of GHG emissions – climate change, surging insurance and disaster relief costs, loss of life and property – are increasing rapidly, becoming visible and felt by every society. Yet the emissions costs are dispersed, unevenly distributed, and back-ended, while abatement costs are front-ended. Governments face the classic economic problem of internalising negative externalities to incentivise removing emissions. Policies are required that align private investment incentives with public good investment incentives. This can be done through any combination of:

- Increasing the cost of emitting CO_2 (e.g. carbon taxes or emissions trading)
- Command and control mechanisms (e.g or prohibition or mandates through regulation)
- Reducing the cost to private sector investors of CCS (e.g. through capital grants or concessional finance)
- Increasing the revenue created through CCS (e.g. through payments per tonne of CO_2 stored or operational subsidies)

CCS has little economic value compared with freely emitting CO_2 into the atmosphere, and that calculus can only change with policy and regulation.

In simple terms, the challenge is how to reflect the cost of GHG emissions in prices so a low-carbon product is cheaper than its high-carbon substitute. This would drive the demand for abatement technologies and enable its applications to earn a profit – a powerful incentive.

Current experience from around the world demonstrates that significant public finance is necessary to leverage the private finance required to accelerate CCS investment. Whilst the private sector is investing to receive a financial return, governments are investing to deliver public goods – a stable climate. It is appropriate for governments to fail to achieve a financial return on investments as long as they are efficiently contributing towards the delivery of public goods. It is in this context that government support of CCS and other climate mitigating technologies is justified.

Governments, policymakers, and regulators have accelerated the design and implementation of these policy tools in the past two years, especially in developed economies. In the US, the policy choice is skewed towards direct and indirect subsidies for CCS and producing clean energy; in European countries, it can be a combination of carbon pricing and production subsidies; and in Japan, it is a mix of demand subsidies for clean energy and early phases of carbon pricing.

Financial institutions, whether commercial banks, pension funds, or infrastructure funds, consider the potential risks and returns of a project. The elimination or reduction of a risk factor is converted to a higher value for the project, or vice versa.

Hence, a policy designed to incentivise investment should consider not only rates of return but also the associated risks. This is especially true for capital-intensive long-term infrastructure projects. Some risks include the viability and durability of a long-term demand driver, cost and time overruns, execution, permitting, political, and liability risks.

The US, European Union, and Japan have devoted significant financial resources to support the development of a low carbon economy and to make CCS applications commercially viable, which in turn can be leveraged with private sources of capital. According to the Congressional Budget Office, the Inflation Reduction Act (IRA) in the USA will inject a total of $394 billion into clean energy and climate funding to leverage private capital. To finance this, the government proposed a 15% minimum corporate tax and a 1% excise tax on share buybacks.

The European Union is leveraging the Emissions Trading System and carbon taxes to raise an annual $40 billion to finance its public funding available for climate finance and CCS. Japan and South Korea have prioritised demand subsidies for clean energy and devoted significant financial resources.

4.7. Policies to Incentivise Investment in CCS

The following sections present a brief description of key policies in leading jurisdictions that have been successful in incentivising significant private sector investment in CCS.

4.7.1. USA

Infrastructure Investment & Jobs Act and the Inflation Reduction Act

In 2021, the Infrastructure Investment and Jobs Act (IIJA) authorised $12 billion in grants, loans, and loan guarantees for industrial emissions reduction, carbon capture, transport, and storage permitting, Direct Air Capture (DAC) and $8 billion for hydrogen hub development.

These developments were dwarfed by the Inflation Reduction Act of 2022 (IRA), ambitious legislation that aims to decrease GHG emissions by 50% to 52% below 2005 levels by 2030, in line with the country's nationally determined contribution (NDC). The IRA relies heavily on investment and production tax credits and low-cost government loans. Tax credits can be subtracted from corporate income taxes and are effectively a subsidy. The tax credits relevant to CCS are known as 45Q, 45Z, and 45V, after the section of the US tax code under which they are established.

The 45Q Tax Credit

The IRA boosted the 45Q tax credit for the capture, geological storage, and utilisation of CO_2. Companies capturing and geologically storing CO_2 are eligible for USD85/tCO_2 captured from a power or industrial source and USD180/tCO_2 captured from the atmosphere.

Table 4.4. Increases to the 45Q tax credit from the Inflation Reduction Act of 2022

Activity		Before IRA (in US$ per tonne of CO_2)	After IRA (in US$ per tonne of CO_2)
Geological storage of CO_2	From power generation and industrial facilities	50	85
	From direct air capture (DAC) facilities	50	180
Utilisation of CO_2	From power generation and industrial facilities	35	60
	From DAC facilities	35	130

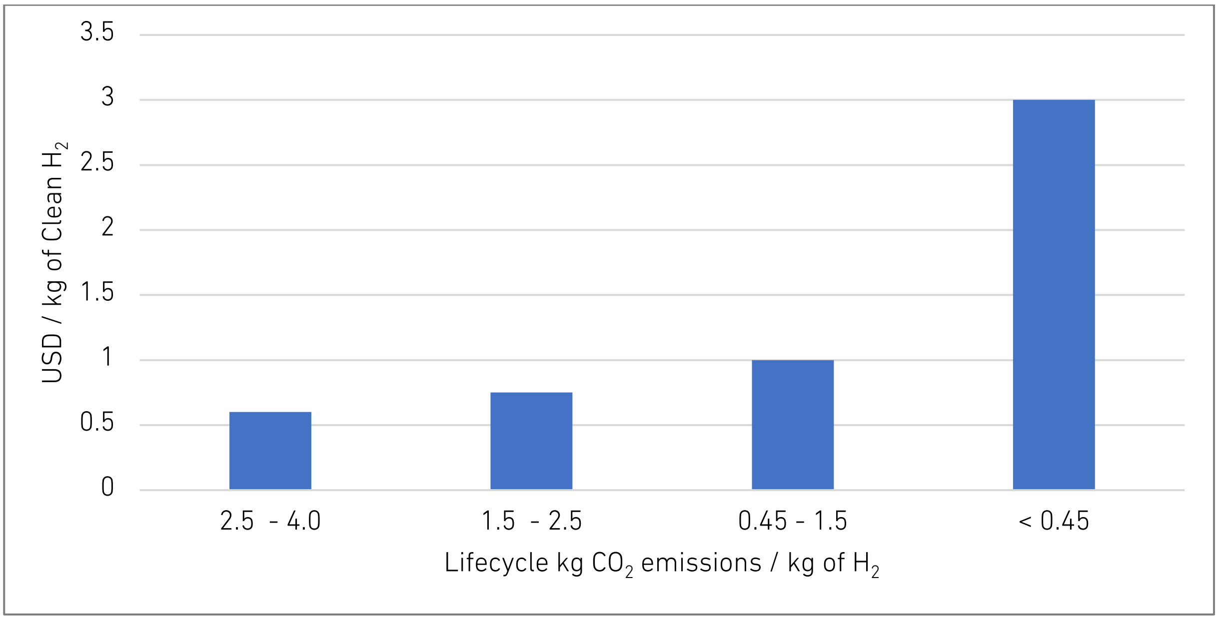
Source: GCCSI.

The tax credit for CO_2 which is utilised (as opposed to geologically stored) is lower at USD60/tCO_2 captured from a power or industrial source and USD130/tCO_2 captured from the atmosphere.

The 45V Tax Credit

The IRA introduced the 45V tax credit, paid per kg of clean hydrogen production. The value depends on its lifecycle production emissions intensity, with the highest value being $3 per kg of hydrogen for emissions intensities of less than 0.45 kgCO_2e/kg H_2 over 10 years. The maximum emissions intensity is 4 kgCO_2e/kg H_2 for eligibility. A project can claim 45Q or 45V but not both.

Figure 4.31. The Value of 45V Tax Credit Depending on The Carbon Intensity of Clean Hydrogen



Source: GCCSI.

The 45Z Tax Credit

The IRA expanded the scope of the 45Z tax credit for clean transportation fuels, mainly ethanol. 45Z is $0.02 per gallon of clean transportation fuel for each reduction point in the carbon intensity score below 50, as measured by CO_2kg per gallon. The carbon intensity of ethanol production can be reduced through the application of CCS at ethanol production plants. 45Z has strict time limits and is available for three years, from 2025 to 2027. Unlike 45Q and 45X, 45Z does not have direct pay optionality.

Title 17 Clean Energy Financing

The IRA has increased the financing capacity of the Title 17 Clean Energy Financing Program to $300 billion in loan guarantees and up to 80% of project costs. The cost of the loan guarantee is a 10-year treasury interest rate plus 0.375%.

The programme is managed by the Department of Energy's (DOE) Loan Programs Office (LPO). It has two sections: Section 1703, with some $40 billion capacity, includes projects under the Innovative Energy, Innovative Supply Chain, and State Energy Financing Institution categories, and Section 1706, which covers Energy Infrastructure Reinvestment projects and can provide loan guarantees of up to $250 billion. CCS, as a versatile technology with many applications, is eligible for loan guarantees under either section.

Low Carbon Fuel Standards and State-based Cap and Trade Programs

The Low Carbon Fuel Standard (LCFS) is a compliance baseline carbon market in California. Oregon, Washington State, and British Columbia (Canada) have similar legislation, and other states are expected to launch their LCFS programs. The LCFS encourages the use of transportation fuels with a lower carbon intensity based on the fuel's lifecycle emissions intensity. This includes fuel production, transportation, and combustion. The emissions intensity of each fuel is compared to an annually declining benchmark. Fuels with an emissions intensity below the benchmark generate credits, while those with emission intensities above the benchmark generate deficits. Credits created under the scheme are tradeable. Fuel wholesalers with deficits are required purchase and surrender an equivalent number of credits. California has a CCS Protocol under its LCFS, which allows for emission reductions through CCS that can be outside the state if the fuel is used in California.

California also has a compliance cap and trade programme, a vital element of the state's strategy to reduce emissions. The programme establishes a declining limit (cap) on GHG emissions, covering approximately 80% of the state's GHG emissions. The California Air Resources Board (CARB) creates allowances (a tonne of CO_2 emission) equal to the cap and auctions at an increasing floor price: the declining cap and the floor price aim to create a stable price to incentivise emissions reduction.

4.7.2. European Union and the United Kingdom

The EU's decarbonisation effort has several pillars: The Emission Trading Scheme (EU ETS), a compliance cap and trade carbon market, newly developed mechanisms like Carbon Contracts for Differences (CCfD), the EU Innovation Fund -- mainly funded by the auctioning of EU ETS allowances -- and the Carbon Border Adjustment Mechanism, effectively a carbon duty for imports from countries that lack a carbon pricing or tax mechanism.

Individual countries also have separate and additional mechanisms to support emission reductions and CCS investments.

EU Emissions Trading System

Dating back to 2005, Europe's climate policy cornerstone is the EU ETS, the world's first and largest carbon market covering the EU and Norway, Iceland and Liechtenstein. It is based on a cap-and-trade principle, which sets a cap for the covered GHG emissions and lets operators trade the allowances. The cap is reduced over time to reduce emissions, and participation is mandatory for covered sectors. The EU ETS covers about 40% of total emissions. CCS is included in the EU ETS; captured and permanently sequestered CO_2 in line with the European Commission's CCS Directive is considered not emitted.

The allowances are either auctioned or allocated for free. The free allocation is meant to protect the competitiveness of regulated sectors and to safeguard against carbon leakage -- the migration of production to other countries with no or less stringent emissions reduction requirements.

Until the recent reform of the EU ETS, there were too many free allowances resulting in a low EU ETS carbon price, and thus, the impact on emission reductions has been limited.

The presentation of the European Green Deal in December 2019, a package of policy initiatives aimed at reaching carbon neutrality by 2050 framed as a new economic growth policy, signaled the EU's more robust policy response. The proposal and then passage of the European Climate Law and Fit for 55 package (13 legislative proposals except for REDII, Revision of Gas Directive and Regulation) significantly reduced free allowances, leading to a fourfold increase in the carbon price and stabilisation despite major geopolitical shocks like the Russia-Ukraine war and Covid-19 pandemic. As a consequence of these reforms, the price of EU Carbon Permits increased from around 25 Euro/t to peak at over 100 Euro per tonne in March 2023 (*Trading Economics*, 2023).

Fit for 55

Released in July 2021, the Fit for 55 package aimed at updating European climate and energy policies to align them with the EU's new target of reducing GHG emissions by at least 55% by 2030, as defined under the European Climate Law. Amongst the 13 legislative proposals submitted were a revision of the EU ETS Directive and establishing a carbon border adjustment mechanism.

In April 2023, the EU adopted a reform of the package. The most important features include:

- Tightening of the EU ETS by increasing the emissions reduction target to 62% of 2005 levels from 43%
- Increasing the annual reduction of allowances from 2.2% to 4.3% for 2024-2027 and 4.4% for 2028-2030 in addition to one-off absolute cap reductions of 90 million and 27 million allowances in 2024 and 2027, respectively
- Coverage of maritime shipping in EU ETS starting 2024 and complete phase-out of free allowances in 2026
- Phase-out of free allowances for aviation by 2027
- A new ETS for buildings, road transport, and small industries and allocation of revenues to fund Social Climate Fund to support affected parties
- Implementing the carbon border adjustment mechanism (CBAM)

Whilst these measures do not specifically target CCS, they serve to increase the value of EU Carbon Permits, which strengthens the business case for investing in CCS to avoid the carbon liability.

The EU Innovation Fund

The EU ETS funds the EU Innovation Fund and provides financial support through grants for deploying innovative technologies, including CCS facilities, to meet net-zero commitments and the energy transition. The EU Innovation Fund supports various EU commitments like the Hydrogen Bank, the REPowerEU Plan, the Net-Zero Industry Act, and the Green Deal Industrial Plan.

In 2023, the EU increased the size of the ETS allowances from Eur450 million to Eur530 million. At current EU ETS prices, the total size of the EU Innovation Fund for the 2020-2030 period could be Eur40 billion.

Carbon Border Adjustment Mechanism (CBAM)

The EU parliament in April 2023 passed the CBAM to reduce the impact of European climate policy on the international competitiveness of European industry. It is effectively a carbon duty on imports from countries without an equivalent carbon tax or price. As free allowances under the EUETS phase out, CBAM will kick in to protect domestic industry from import competition.

The transitional phase, i.e. the reporting requirement, for importers commenced in October 2023 and ends in January 2024. It will initially apply to carbon-intensive goods like steel and cement and expand to 50% of the ETS-covered sectors. The permanent phase, i.e. the surrender of CBAM certificates based on the EU ETS price, will start in 2026.

CBAM creates a policy question for the EU's main trading partners: Whether to pay the carbon tax on products exported to Europe to the European Commission or to introduce their own carbon tax or carbon price generating domestic revenue.

European Country Initiatives

In addition to the EU-level policy and regulation, member states have developed policies and regulations to reach emission reduction targets. For instance, Denmark and the Netherlands pledged EUR 3.6 billion (over 15 years) and EUR 2.1 billion in state aid for CCS projects, respectively.

Germany announced the launch of Carbon Contracts for Difference (CCfD), a 15-year subsidy programme to increase carbon price visibility. The German government plans to support the programme with a budget in line with estimates of around EUR50 billion.

Norway has a carbon tax equivalent of NOK 761 ($71) per tonne of CO_2 for 2023, and the country introduced a plan to increase the tax to EUR200 ($220) by 2030. Norway is a leader in the CCS with the Longship CCS project to which it has committed USD2.3 billion in support.

United Kingdom

In March 2023 the UK Government committed 20 billion pounds to support CCS. The UK government has also allocated 1 billion pounds to support the establishment of 4 CCS networks by 2030, with the objective of capturing 20-30Mtpa CO_2.

4.7.3. Japan

The Japanese Ministry of Economy Trade and Industry (METI), announced its CCS Long Term Roadmap in January 2023, setting a target for the commencement of operations of Japan's first commercial CCS facility by 2030. METI has since announced capital support for feasibility studies for seven CCS networks.

4.7.4. Effective Policies – Observations

Of the 376 commercial CCS facilities in development, construction or operation in the Global CCS Institute's database, 254 are in the USA, Europe, the United Kingdom or Japan(Global CCS Institute, 2023b). Most CCS projects are being developed in advanced economies, especially North America and Europe where strong policy and existing CCS regulation supports a business case for investment. These jurisdictions have demonstrated how strong supportive policy can rapidly attract private investment in CCS.

A common factor across these leading jurisdictions is that public finance, whether through capital grants or operational subsidies or tax credits, is a critical enabler of the rapid growth in the CCS project pipeline. Nations mentioned in the previous section are all providing significant financial resources to CCS project developers, even in Europe which has the world's highest carbon price. Whilst the avoidance of a carbon liability certainly supports the business case for investment, it is the bankability or certainty of robust future revenues and/or the provision of free capital to reduce private sector capital-at-risk, that has proven most effective.

Whilst CCS technologies are mature and commercially available, the business models, norms and commercial experience that build confidence in investments in well established industries are still developing. Even where clear regulation for CCS exists, this results in uncertainties or risks that are significant barriers to investment. These risks relate to uncertainties in future revenues and costs and therefore return on investment, the risk that expenditure on exploration for storage resources will not yield a suitable resource as well as the normal project development and operational risks that apply to any large industrial facility.

CCS projects require the coordination of multiple investment decisions, each with long lead times, leading to cross chain risk. This arises as the decisions to develop each element of the CCS chain may be required before there is full certainty about the entire value chain. For example, capture plant developers may not have secured access to transport and storage infrastructure. Transport and storage infrastructure developers may not have secured contracts from capture sources to provide transport and storage services creating uncertainty regarding whether their assets will be sufficiently utilised. These uncertainties delay or may even prevent FID and put expenditure on studies at risk. Once projects are operational the interdependency remains, as the failure of one of the components to deliver on their obligations may affect the costs and revenues of others and prevent the value chain performing as a whole.

Put simply, businesses prefer not to be the first investor in a new CCS hub and cluster; they prefer to invest in a mature network. This is a significant barrier to initial investments, unless guarantees are provided for revenue during the early stages of development. This is where governments can play a significant role.

In summary, the role of public finance in this phase of CCS deployment, where there is a requirement to accelerate investment well beyond what the market would deliver without intervention, is to de-risk private investment in CCS.

4.8. Public Finance for CCS in ASEAN

There are significant differences between the developed economies of the USA, Europe and Japan and the developing economies of Southeast Asia. There are important differences in the CO_2 emission levels, income levels, state capacity, and existing infrastructure of the ASEAN Member States. For instance, Indonesia ranks first in CO_2 emissions (on a production basis) with 625 million tonnes in 2019 (IRENA, 2022) with a 2022 GDP per capita of $4,788 (at Purchasing Power Parity of $14,652) versus Singapore with 53 million tonnes in 2019 (IRENA, 2022) but with a GDP per capita of $82,807 (at Purchasing Power parity $108,036). The following table presents the CO_2 emissions of the ASEAN countries and their economic output as a proxy of state capacity to mobilise resources to decarbonise their economies.

Table 4.5. Economic and Emissions Metrics for ASEAN Member States

	CO_2 Emissions Mtpa	Per capita CO_2 Emissions Mtpa/Capita	GDP per capita Thousand USD/Capita	GDP per capita PPP Thousand USD/Capita
Laos	20.8	2.8	2.1	2.5
Viet Nam	326.0	3.3	4.1	13.2
Philippines	144.0	1.3	3.6	10.5
Singapore *	32.5	5.5	82.8	127.6
Malaysia	256.1	7.6	12.5	34.8
Indonesia	619.3	2.3	4.8	14.6
Thailand	278.5	3.9	7.1	21.2
Myanmar	36.3	0.7	1.2	4.9
Brunei *	10.5	23.5	37.9	70.8
Cambodia	19.0	1.1	2.8	5.6

Source: the IMF, Global Carbon Budget. Emissions data is 2021, GDP data is 2022.

By comparison, the United States' GHG emissions per capita in 2021 was 17.6 tonnes, and GDP per capita in 2022 was US$77,469 (*United States GDP*, n.d.). With the exception of Singapore, the GDP per capita of ASEAN Member States are very significantly less than developed economies. The governments of developing economies have far fewer resources making public financing for CCS at the scale available in the USA or Europe extremely difficult.

However, this is not to say that public finance for CCS is completely ruled out for ASEAN Member States. Considering that CCS reduces the total cost of achieving net zero commitments, carefully targeted public finance and policy that leverages private sector capacity and investment will ultimately reduce the total cost of climate action to these governments and to their economies. A key strategy for developing economies in ASEAN is to identify international sources of public and private finance or aid to support CCS deployment, in addition to public finance they can provide themselves. The provision of aid by developed economies to support the deployment of CCS in southeast Asia serves the interests of all nations. To meet global climate objectives, net zero emissions must be achieved everywhere and without CCS that will be impossible especially in the rapidly growing economies of southeast Asia.

As noted above, the ASEAN countries' economic and political structure differs significantly from the US and the EU. Infrastructure investments are generally financed by public funds through taxation and borrowing. The ASEAN country's debt-to-GDP and revenue-to-GDP ratios are favorable to finance infrastructure investments for years to come; in some cases, they fare better than the developed countries. The following table presents the data for 2022.

Table 4.6. Fiscal Capacity Indicators for ASEAN Member States

	Public Debt /GDP %	Revenue/GDP %	Current Account/GDP %	Exports /GDP %
Laos	68.0	14.9	(2.6)	33.2
Viet Nam	36.1	19.0	0.2	93.3
Philippines	60.9	20.4	(3.0)	28.4
Singapore *	135.9	17.3	16.6	186.6
Malaysia	60.4	19.5	2.7	73.8
Indonesia	39.5	15.2	(0.3)	24.5
Thailand	53.6	20.1	(0.2)	65.8
Myanmar	63.9	13.3	(1.6)	37.0
Brunei	2.1	28.9	10.6	86.4
Cambodia	37.0	24.0	(11.0)	77.6

*Note: Singapore's high debt-to-GDP ratio is misleading as it is gross. On a net basis, the country is a creditor.
Source: the IMF.

A high-level analysis shows that the wealthy ASEAN nations of Singapore and Brunei have ample fiscal capacity to finance energy and climate policies. Their economies also have the ability to raise funds through borrowing or taxation. Such public funding can then be leveraged with private sources of capital. For instance, just like its transition from coal to natural gas, Singapore can make the shift from natural gas to hydrogen. Malaysia, too, has the fiscal capacity to gradually phase out its unabated carbonisation through financing its government-controlled emitters like Petronas. These countries' high export and current account surplus ratios provide necessary incentives for decarbonisation.

Even though the ASEAN countries show very significant differences in the levels of development, fiscal capacity, and resources, the majority have low debt and revenue ratios. The pressing question is prioritisation: the developing countries need to balance their development needs to meet the demand of their populace with the need to decarbonise.

4.9. Potential Sources of External Finance

4.9.1. Multilateral Development Banks

Financing transformative climate action is vital for the development and support of the poorest people who are most affected by climate change. However, the fiscal constraints countries face today make it more challenging to find the necessary resources. Multilateral Development Banks (MDBs) provide grants and loans to support economic development in developing economies.

A multilateral development bank (MDB) is an international financial institution chartered by two or more countries to encourage economic development in poorer nations. Multilateral development banks consist of member nations from developed and developing countries. Five major MDBs are the World Bank and four regional development banks: the African Development Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, and the Inter-American Development Bank (IDB).

For ASEAN countries, the sources of Finance would be the World Bank Group and Asian Development Bank. The World Bank provided $31.7 billion, and Asian Development Bank $6.7 billion in 2022 to address climate change. These figures include adaptation, resilience, renewables, the grid, EVs, and batteries. Both the World Bank and the Asian Development Bank have active programs to support CCS in ASEAN. Grants may be provided to support feasibility studies or capacity building activities and low-cost loans may be available to support projects. These are unlikely to be sufficiently large to finance a commercial CCS project on their own, but can make a material contribution together with other sources of finance.

The World Bank Group

Established in 1946 in the post-World War II global order, The World Bank Group is the oldest and the largest MDB. The World Bank Group has three lending facilities. The first, the International Bank for Reconstruction and Development (IBRD), provides primarily market-based loans to the governments of middle-income countries. The IBRD, with a membership of 144 countries, focuses on financing large infrastructure projects and broadened efforts to include social projects and policy-based loans. A second lending facility, the International Finance Corporation (IFC), was established in 1955 to extend loans and equity investments to private firms in developing countries. The International Development Association (IDA) was created to make concessional loans (with low-interest rates and long repayment periods) to the poorest countries. IDA also now provides grants to these countries. (*Multilateral Development Banks: Overview and Issues for Congress*, n.d.)

The World Bank Group is the most significant multilateral financier of climate action in developing countries. The Group, as part of the Climate Change Action Plan, targets deploying an average of 35% of the institution's financing for climate action in the 2021-2025 period. In 2022, this target was exceeded to reach 36%. As a result, the World Bank Group provided a record of $31.7 billion in fiscal year 2022 to help countries address climate change. The Bank Group's climate finance is calculated based on the agreed joint Multilateral Development Bank methodology (*Climate Finance 2020*, n.d.). It counts the share of financing directly tied to climate action across all Bank Group projects. The breakdown of this financing is provided below: (*10 Things You Should Know about the World Bank's Climate Finance*, n.d.)

- IBRD and IDA delivered $26.2 billion in FY22 in climate finance.
- Building resilience to climate shocks is a priority. Nearly half of the Bank's finance—$12.9 billion—supported investments in adaptation and resilience.
- IFC, the private sector arm of the World Bank Group, delivered $4.4 billion in climate finance and mobilised an additional $3.3 billion from other sources.
- MIGA, the World Bank Group's political risk insurance and credit enhancement arm, delivered $1.1 billion in climate finance in FY22.

As can be observed from the breakdown, nearly half of the funding provided by the World Bank Group was destined towards adaptation and resilience instead of mitigation, of which CCS is a part. Of the total funding, very little, if any, was provided directly or indirectly for the funding of the CCS projects globally.

The World Bank has a CCS trust fund under the Energy Sector Management Assistance Program (ESMAP), which provided a few million dollars in projects in Mexico, Botswana, and Nigeria. This facility will shut down in December 2023. Even though the bank says it will support it through other means, it is unlikely to reach even $1bn globally.

For the World Bank Group to increase financing for CCS-related projects, there needs to be support from the member countries. The Carbon Challenge initiative led by the US plans to form a global consensus that includes CCS as an integral part of the mitigation plan to address climate change. If the US succeeds in gathering support for CCS investments, the financial resources allocated for CCS investments by the World Bank Group can be expected to increase significantly.

Even then, the CCS investment needs of the ASEAN countries dwarf the funds that can be provided using the World Bank Group's balance sheet. In a best-case scenario, such funds would help to finance activities such as studies to help write legislation, pay for consultancy reports, techno-economic optimisation modeling, feasibility studies, and a small number of small-scale demonstration or pilot projects.

The Asian Development Bank

The Asian Development Bank (ADB) is a regional multilateral development bank established to promote economic and social progress in Asia and the Pacific. It was founded in 1966 and is headquartered in Manila, Philippines. ADB is an essential institution in the region, and its primary mission is to reduce poverty, foster economic growth, and improve the quality of life for people in its member countries.

ADB's membership consists of 68 member countries, of which 49 are from Asia and the Pacific, and 19 are from outside the region, including the United States and several European countries. ADB's membership is open to countries within and outside Asia and the Pacific. ADB is governed by its Board of Governors, which comprises representatives from each member country. ADB provides financial resources, technical assistance, and policy advice to its member countries. It supports various development initiatives, including infrastructure development, poverty reduction, education, healthcare, environmental protection, and regional cooperation.

ADB raises funds from international capital markets and its member countries. It provides loans, grants, and technical assistance to its member countries for development projects and programs. ADB's financing helps member countries implement projects and policies that promote sustainable economic growth and social development. It places a particular emphasis on addressing poverty, inequality, and climate change in the Asia-Pacific region. ADB collaborates with various partners, including other international organisations, governments, private sector entities, and civil society organisations, to maximise its impact and leverage resources for development projects and initiatives.

ADB is committed to promoting environmentally sustainable development practices and integrating climate change mitigation and adaptation into its projects and policies. Overall, the Asian Development Bank is crucial in facilitating economic development and poverty reduction across the Asia-Pacific region.

An operational priority of ADB's Strategy 2030 is tackling climate change, building climate and disaster resilience, and enhancing environmental sustainability. ADB committed to ensuring that 75% of operations on a 3-year rolling average will support climate change mitigation and adaptation by 2030. In October 2021, ADB announced that it would be increasing its climate finance ambition by 25% to $100 billion in the 2019-2030 period from $80 billion. (Asian Development Bank, n.d.-a)

In 2022, ADB committed $7.1 billion in climate finance, 60% of which was towards mitigation and 40% for climate change adaptation. The amount committed for adaptation is the highest adaptation finance committed since 2011, showing the complex nature of climate finance. (Asian Development Bank, n.d.-b)

Like the World Bank Group, the ADB's commitment to finance CCS-related projects depends on the demand from its member states. So far, such demand has not been sufficient to prioritise CCS amongst its financing activities allocated to address climate change, although discussions with ADB indicate that CCS is rising in priority. Even in the most positive scenario, due to resource limitations, such funding would be limited to funding research studies, feasibility reports, mapping storage capacity, and small-scale demonstration and pilot projects. Large-scale deployment will depend on ASEAN countries fiscal support and ability to create business models to mobilise private capital.

4.9.2. Voluntary Carbon Markets

A Voluntary Carbon Market, in its broadest definition, is a marketplace that allows its participants to buy and sell carbon credits or carbon offsets voluntarily. A carbon offset is the removal of GHGs from the atmosphere, and a carbon credit is reducing GHGs released into the atmosphere. The conventional unit is a tonne of CO_2 in both. Its origins date back to the 1990s.

The global voluntary market is a noncentralised, fragmented, and emergent global industry ecosystem. The carbon credits in these markets are usually unregulated and non-standardised and generated by various types of projects such as forestry, biomass, etc., and certified by various independent organisations. Buyers purchase credits to offset emissions and meet internally set voluntary goals. A second kind is organised voluntary carbon market initiatives. These markets try to differentiate themselves with attempts to create regulated and centralised marketplaces with standards. (Center for Strategic & International Studies, 2023) The most prominent standards include Verra (The Verified Carbon Standard), Plan Viv, The Gold Standard, The American Carbon Registry, and the Climate Action Reserve

Paris Article 6 confirmed their role in achieving global emissions reduction targets of countries' NDCs, focusing on country-to-country transfers of carbon credits. These credits can then be used to meet NDCs. Implementation of Article 6 requires establishing standards, a registry, and a market for transfers. Such consolidation could streamline the fractured global market that exists today. Advocates argue that such a development would accelerate the growth of carbon markets, helping commercial returns and financing and deploying technologies like CCS.

However since then, the enthusiasm has been curbed with inconclusive negotiations over implementation. The uncertainty over Article 6 accounting and interaction with voluntary markets remains.

With the question marks increasing over the quality of carbon offsets, the credibility of the voluntary carbon markets has taken a hit. The industry continues to expect exponential growth in the voluntary markets, but so far, voluntary markets failed to live up to the expectations.

The total size of the voluntary carbon markets can vary from year to year and is influenced by various factors, including global demand for carbon offsets, regulatory changes, and the overall state of the global economy. Estimates of the size of the voluntary carbon market ranges from several hundred million to a couple of billion dollars.

Apart from the issues surrounding quality, standardisation, and lack of transparency, the fundamental problem with the voluntary carbon markets is the fact that they are voluntary. There is no obligation for the corporates or state actors to adhere to the aspirational targets. The mechanism is, to a large extent, limited in quantity. The price, quantity, conditionality, and maturity of the transactions are not transparent.

Furthermore, in the current legal system, the purchase of carbon offsets at scale can be in direct conflict with the fiduciary duty of the corporations to provide a return to their shareholders.

At the scale needed, the VCMs are unlikely to provide a reliable and durable source of revenue that against which the banks can provide credit. Indeed, the institute's engagement with the financial sector confirms this assessment.

The potential positive contributions of VCMs:

1) When executed and administered correctly, they help provide the know-how of carbon accounting and resources for the certifiers and evaluators of projects with the necessary experience and a platform to learn from mistakes. As such, they can be seen as a dress rehearsal for the compliance markets.
2) They potentially provide additional revenue streams for CCS even if such revenue streams are not yet at scale and the durability remains a concern.

The one major downside of VCMs is that due to a lack of standards, transparency, and issues related to measurability, they may create a false sense of a solution.

In summary, while VCMs can provide a marginal return for decarbonisation in general and CCS in particular, they cannot be relied upon as a base for a bankable business model.

4.9.3.Sustainable Finance – Green and Climate Bonds

Sustainable finance refers to financing available for investments that aim to increase clean energy and processes. Sustainable finance aims to increase funding and decrease the cost of capital for sustainable investments.

However, green and climate bond certification is not a transparent and standardised process. There are several certifiers to evaluate the marginal impact of a project. The certifiers typically rely on the GHG emission profile of a company or issuer rather than emissions reductions. The lower the emissions, the greener or the more sustainable the issuer. In that sense, sustainable finance can potentially divert funds from high emitters to already low emitters, for instance, from energy producers to information technology companies.

Second, even when sustainable finance pays attention to emission reductions, the focus is generally on percentage emission reductions, not absolute reductions. Such a bias also potentially diverts funds away from high-emitting firms, which could deliver a much higher absolute impact on the emissions with a slight percentage decrease compared with an already low-emitting issuer, which can deliver a higher percentage decrease but an immaterial absolute emission reduction. (Hartzmark et al., 2023)

CCS is an emissions abatement technology mainly utilised by high-emitting sectors and, therefore, potentially could suffer from the selection bias that is discussed above. Green and climate bond standards and certificates have historically omitted CCS technologies.

There are signs of more resources being allocated to examining the eligibility of CCS; however, those efforts are attempting to limit the eligibility of CCS to hard-to-abate sectors like cement and steel. Such limitations decrease the potential significant emission reductions that CCS can deliver in power and heating.

Even if CCS is increasingly admitted as eligible for sustainable finance, it does not ensure that it will be instrumental in filling the funding gap at the scale needed. The lower cost of debt that green bonds offer is found to be a meager 8 basis points (0.08%) (Board of Governors of the Federal Reserve System, 2022). Considering a selection bias given that, on average, companies with high investment grades qualify for green bonds, the difference is due to the quality of the borrower. One advantage of sustainable finance would be access to funds that would not be available but with the caveats detailed above.

4.9.4. The Loss and Damage Fund

The ‘loss and damage’ fund refers to a financial mechanism designed to assist developing countries that are disproportionately affected by the impacts of climate change and are unable to cope with the associated losses and damages. This fund is part of international climate negotiations and agreements, particularly under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement. Developing countries argue they bear a disproportionate burden of these impacts despite contributing less to global greenhouse gas emissions. The loss and damage fund intends to provide financial support for developing countries to address these losses and damages, as well as to enhance their capacity to adapt to future climate-related risks.

There are significant disagreements between the developed countries and developing countries' positions. The most important disagreement is over how to finance the loss and damage fund. Developing countries demand contributions from developed countries, given their wealth and historical responsibility for emissions. Developed countries, on the other hand, resist financial commitments due to the cost and their economic priorities.

The second most important disagreement is governance and accountability: There are concerns about how the fund would be governed, how funds would be allocated, and how accountability and transparency would be ensured. The developed nations prefer the funds to be governed by the World Bank, where they have a higher influence, and the developing countries prefer oversight by the UN.

There is also concern as to whether loss and damage should imply legal liability or compensation. Developed countries resist acknowledging legal responsibility.

Finally, defining what constitutes ‘loss and damage’ is another contentious issue. Some argue for a narrow definition to limit the financial burden, while others advocate for a broader one.

The first and second points continue to be contentious ahead of the COP28. The loss and damage fund at a size of $100 billion per year commitment was affirmed and agreed upon in the Paris Agreement at COP 21 in 2015. This commitment would start in 2020 and continue through 2025. It was a crucial element of the Paris Agreement to help address the needs of developing countries in their climate action and adaptation efforts.

Despite these concerns, the Loss and Damage Fund was formally established at COP 28 in December 2023. In total, USD700 million has been pledged, less than 1% of the annual commitment first agreed in Paris in 2015.

How much of these funds will be available to ASEAN countries, which are relatively wealthy compared with poorer African nations is yet to be determined. Further, of that amount, how much will be available for CCS technologies looms as a question.

In summary, like the MDB funding, Voluntary carbon markets, or Sustainable Funds, the Loss and Damage Fund in its current form, while providing marginal support for feasibility studies and pilot studies, is very unlikely to be material for large-scale deployment of CCS for the ASEAN region.

4.10.The Role of Carbon Pricing

There is no doubt that carbon pricing is an efficient mechanism for aligning private investment incentives with the need to reduce emissions. But to be effective, the price of carbon must be high enough to drive changes in behaviour and capital flows, must be broadly applied across all sectors, and there must be confidence in the long-term resilience of the carbon market and the carbon price. This is particularly important with respect to investments in capital intensive, long lived assets such as CCS facilities.

To achieve net-zero targets, modelling from Genzo illustrates that the marginal cost of abatement across ASEAN nations will be around USD100/tonne in the mid 2030s, rising to around 400-500 per tonne in the mid 2050s (see figure 4.24) if CCS is deployed (higher if it is not). To achieve the emissions reduction trajectory assumed in the model, which is derived from ASEAN member state net zero commitments, without any supportive policies, a comprehensive carbon price at least equal to this marginal cost of abatement would be required. Further, the market would need perfect foresight and must act rationally, investing without hesitation when it is economic to do so. If that were the case, then the private sector would invest in CCS, and all other necessary climate mitigation technologies at the appropriate time. Whilst this applies within a model, it does not apply in reality. Carbon pricing schemes are not comprehensive. The market does not have perfect foresight, nor does it invest without hesitation. Other non-economic factors (e.g. geopolitical) also disrupt or distort markets and the investment behaviour of market actors.

As noted previously, even in Europe where carbon prices have approached and even exceeded Euro100 per tonne, CCS has required significant policy support including public financing to attract private sector investment. Given time, experience and the confidence in business models etc that will develop over time, the effectiveness of carbon pricing alone in driving investments in CCS in Europe is expected to increase and at some point, the need for additional supportive policies or public finance will diminish. If there were no time constraint on achieving net zero emissions, then simply pricing carbon and letting the market respond would be an appropriate strategy. However there is a very significant time constraint – net zero emissions within the next 30 years. Supportive policies including public finance are essential to deploy CCS at an accelerated rate, faster than the market would otherwise achieve.

Considering ASEAN specifically, whilst carbon pricing is the most efficient mechanism for driving emissions reduction, a material carbon price also introduces additional costs across the economy, which may be opposed by some sectors, especially those that are energy or emissions intense. Perhaps with the exception of Singapore, a comprehensive and material carbon price, exceeding USD100/tonne, is unlikely to be in place in ASEAN nations for some time.

However, some ASEAN industries that export into Europe will be exposed to European carbon pricing through the European Carbon Border Adjustment Mechanism from 2026. It is possible that other nations may follow Europe's example and introduce their own carbon border taxes on imports to protect their import-exposed industries whilst they decarbonise. This may bring forward ASEAN firms' exposure to material carbon prices for exports into these markets. This future risk to the competitiveness of ASEAN exports supports a case for the introduction of carbon pricing sooner to collect revenue domestically (rather than pay the carbon tariff imposed by the importer), and to accelerate reductions in emissions intensity of production (to reduce the impact of any carbon tariff). It also supports the implementation of other policies to drive deployment of lower emission production processes, including CCS, to protect the competitiveness of exports into these markets.

Carbon pricing should be pursued as quickly as possible, in line with other priorities of government, but it is very unlikely to be sufficient to drive the rapid ramp-up in investment in CCS in ASEAN necessary to support the achievement of net zero targets. Other policies, including public finance will need to do the heavy lifting, at least in the short term.

4.11. Policy Recommendations

Achieving net zero emission commitments made by ASEAN Member States by the middle of this century requires the deployment of a comprehensive range of low emission and energy efficiency technologies. Carbon capture and storage is essential to reduce emissions in the power sector, across hard to abate industries, to support the production of clean hydrogen, and to deliver carbon dioxide removals through bioenergy with CCS and direct air capture with CCS.

If deployed at optimal or near optimal levels, CCS can reduce the overall cost of achieving net zero targets in ASEAN by more than USD20 trillion between 2023 and 2065. At these levels, at least 2Gtpa of CO_2 will be captured in southeast Asia by 2060. The capital investment required to establish CCS at this scale sums to almost US$880 billion to 2065 starting at USD420 million per year in the 2020s, rising rapidly to USD15.6 billion per year in the 2030s and peaking at over USD40 billion per year in the 2040s before declining to almost USD25 billion per year in the 2050s and USD6.5 billion per year in the 2060s (GENZO Accelerated Storage Scenario).

A phased approach to driving investment in CCS is recommended.

4.11.1. Phase 1 – First Projects; 2020s

ASEAN members benefit from the considerable resources, experience and expertise of national and international oil companies that are active in the region. This industry has some of the lowest cost opportunities for very significant emissions reductions in their production value chain. For example, reservoir CO_2 which is currently vented to atmosphere, may instead be compressed ready for transport and geological storage after minimal clean up (eg dehydration).

The oil and gas industry also holds subsurface data from oil or gas exploration and production necessary to identify, appraise and develop pore space for the geological storage of CO_2 and has the technical expertise and knowledge necessary to establish and operate CO_2 transport and injection infrastructure. In some cases, existing infrastructure such as pipelines or offshore platforms may be utilised or re-tasked to support CCS operations, very significantly reducing the necessary capital investment.

The oil and gas industry is studying several CCS projects in the ASEAN region that share a common strategy; establish CCS infrastructure to enable the reinjection of their own reservoir CO_2, and explore opportunities to receive third party CO_2 for storage for a fee.

These first projects are likely to be the lowest cost opportunities for CCS projects and may also be the anchor projects for the establishment of CCS networks that will serve the broader needs of industry in the region seeking a carbon management solution. Establishing these first projects and their infrastructure to kickstart CCS deployment in the region this decade and lay the foundations for broader CCS deployment should be a priority for government climate policy in the region.

In the absence of a material carbon price, these first CCS projects in the region will likely require capital investment support to reach FID. Where the developer is a National Oil Company, government should consider supporting the financing of the CCS project off the company's balance sheet. This will necessarily require government to accept a reduced return from the NOC for a period. This represents, in effect, government investment in the establishment of CCS infrastructure that will deliver a return in the future.

Government should put in place a proactive strategy to identify and obtain sources of external finance that could support these first CCS projects. This could be provided in the form of grants or concessional loans or loan guarantees. Sources to consider include the World Bank Group, the Asian Development Bank, the Green Climate Fund and developed countries with climate aid programmes or climate -related investments in the ASEAN region such as Japan, Australia, and the USA. Multilateral initiatives focused on CCS such as the Carbon Management Challenge which has an explicit objective of supporting carbon management efforts in the Global South (Clean Air Taskforce, 2023) should also be actively engaged.

If necessary, Government should consider the provision of targeted low-cost loans, capital grants or operational subsidies to CCS projects to bridge any remaining finance gap and allow developers to reach FID. Public finance could be awarded on a competitive basis to ensure funds are allocated and utilised efficiently.

Governments should commence the development and implementation of carbon pricing schemes, starting at low prices for the least developed ASEAN economies, but with announced plans to increase the price in the future. Even at low prices of a few dollars per tonne of CO_2, carbon pricing, if applied broadly across the economy, could generate hundreds of millions of dollars of revenue for each government which could then be used to support climate mitigation initiatives, including CCS. These schemes will also set a clear expectation in the market of more stringent future climate policies and higher carbon prices that will incentivise increased analysis of CCS opportunities, entrepreneurial activity and CCS project development.

4.11.2. Phase 2 – CCS Network Establishment and Deployment Ramp-up; 2030s

Investment in CCS in the 2030s must ramp up significantly to stay on track to achieve net-zero emissions targets, reaching an average of USD15.6 billion per year (Accelerated Storage Scenario) during this decade in southeast Asia. By this time, the global CCS industry will have accrued another decade of operational and commercial experience. Business models, risk mitigation strategies, and commercial confidence will have matured. More providers of CCS technologies and services will have entered the market and the policy and regulatory environments in developed economies will probably have strengthened the business case for CCS. The European Carbon Border Adjustment Mechanism will be in force, effectively exposing exports to Europe to the ETS carbon price. Private sector finance will likely be more accessible and attract a much lower risk premium (if any) as the finance sector becomes familiar with CCS. The first CCS projects in southeast Asia will have commenced operations.

In this decade, Governments should aim to facilitate investment in the next wave of CCS projects especially where they leverage the infrastructure developed by the first wave of CCS projects. Governments should prioritise investment in additional CO_2 transport and storage infrastructure, including shipping necessary to establish CCS networks that will reduce the overall cost of CCS, and emissions mitigation, in the region. This will require continued development of carbon pricing programs (carbon price should continue to rise), continued engagement with multilateral development banks and other potential sources of external finance, and continued provision of targeted capital support.

The top three sectors which must host capture projects in the 2030s include, in decreasing order of investment, bioenergy with CCS in industry, electricity generation, and refining. These capture projects will require access to CO_2 transport and storage infrastructure which will likely be provided, in the majority of cases through networks. The importance of investment in networks this decade is clear from the GENZO model (Accelerated Storage Scenario). From GENZO, of the USD155 billion required to be invested in CCS in the region in the 2030s, over USD73 billion is required for CO_2 transport and storage including shipping, pipelines and geological storage development. This infrastructure is essential to enable the region to reach its net zero targets.

Governments should increase international collaboration and regional cooperation and proactively seek to facilitate investment in geological storage resource development and CCS networks. In addition to leveraging CO_2 transport and storage infrastructure that has been constructed in the 2020s to service the first CCS projects, Governments should deliberately target specific opportunities to create CO_2 collection hubs to service regions with significant emissions intense industry, to support the next wave of investment in CO_2 capture projects.

To illustrate this opportunity, consider the port of Singapore. The port of Singapore hosts a large petrochemical industry including refineries with a capacity of 1.5 million barrels per day and accounts for a significant portion of Singapore's total emissions. The port, together with the port of Rotterdam, is aiming to decrease emissions from shipping between them by 20-30% by 2030 through the use of low emission fuels. (Bovenizer, 2023). Singapore has also announced plans to capture 2Mtpa CO_2 by 2030, and to produce biofuels and other low emission products to deliver total emissions abatement of 6Mtpa by 2050. (Nair, 2021). The government of Singapore is actively seeking to access geological storage resources in other countries, which will require the establishment of CCS networks. Singapore also has the highest GDP/capita in the region and so would be expected to have greater capacity to provide public finance to support CCS and network development. In addition, Singapore has the region's highest carbon tax. The carbon tax will rise from S$5/t CO_2 in 2023 to S$25/t CO_2 in 2024, S$45/t CO_2 in 2026 and between S$50 and S$80/t CO_2 by 2030. The government of Singapore plans to use revenue generated by the carbon tax to support decarbonisation efforts (National Climate Change Secretariat Singapore, 2023). These conditions make Singapore highly prospective with respect to both public and private finance of CCS.

Further, there are similarities between the Port of Singapore and the Port of Rotterdam which is already hosting a major CCS network development; the Porthos project. The Porthos project, which includes 4 refinery and petrochemical customers capturing CO_2 and then shipping it to the LongShip project in Norway has taken a final investment decision.

Porthos provides a good example of international cooperation to enable CCS network development. For the Porthos Project to be realised, it took two governments, the

Netherlands and Norway, to provide subsidies for the transportation of CO_2 and guarantees for the clients. The Dutch government set aside EUR 2.1 billion for the four clients (capture projects) at the Port of Rotterdam (Air Liquide, Air Products, ExxonMobil, and Shell), and the government of Norway also indirectly provided in excess of Eur 3 billion support for the project.

A similar partnership between Singapore and other nations in the region with geological storage resources and available infrastructure should be amongst the first to be vigorously explored and developed as a priority. Governments should also collaborate to proactively identify other potential hubs and CCS networks for development in the region.

4.11.3. Phase 3 - CCS Industry Maturity: 2040s and beyond

First-mover projects are the riskiest for the private sector to finance, so the first CCS projects in the region in the 2020s and 2030s will need public finance to bridge the funding gap. By the 2040s, if the region has been successful in maintaining its emissions reduction trajectory consistent with net zero targets, it is likely that a mature CCS Industry in the region will require significantly less public finance as private investors enter the market. As operational experience accumulates and networks are established in the region, government can shift from a capital subsidy policy model toward supplemental loan guarantees to lower the cost of private finance as the private sector takes a more active role. Government can gradually remove loan guarantees as the private sector gains confidence in lending for CCS projects and as the CO_2 price signal goes higher, making CCS projects more and more cost-effective.

During this decade, governments should achieve material carbon prices that are sufficient to drive investment in CCS, and all other climate mitigating technologies, with little or in some cases no public finance or policy support. The capital investment required for CCS in the region peaks in the 2040s at an average on over USD40 billion per year. Investment at this scale will only be possible with full private sector engagement.

In the 2040s Governments should look for opportunities to facilitate private sector investment in CCS investments that are commercially viable without significant public finance. One potential opportunity will likely be the production of low carbon hydrogen and its derivatives.

Hydrogen and its derivatives, the most prominent of which is ammonia, is gaining traction as an energy carrier. The research on applications is wide-ranging, including power generation with hydrogen and ammonia turbines, fuel cells, and the use of ammonia as a maritime fuel. Global CCS Institute's Investment Case for CCS details how blue hydrogen and ammonia production with Autothermal Reforming of methane with CCS is developing as one of the main investment themes in the US, enabled by strong policy support (production subsidy for clean hydrogen). Japan and Korea are actively looking for off-take agreements for coal cofiring and other applications using a hypothetical CO_2 price of \$130-150. The total amount to be produced, according to recent announcements amount to close to 40 million tonnes of low carbon ammonia in the US Gulf Coast alone – with a potential to sequester 60 million tonnes of CO_2 per annum. (Cevikel & Thomas, 2023). Southeast Asia has the opportunity to also develop a clean hydrogen production industry.

By the 2040s the production of clean hydrogen or ammonia with CCS may require very little if any subsidy, especially if carbon prices have reached material levels and global demand for clean hydrogen, particularly in developed economies, grows to hundreds of millions of tonnes per year, as projected by the IEA and others.

Malaysia and Indonesian both have significant natural gas resources, and natural gas prices are similar to US prices (around $3 per MMBtu) (Indexmundi, 2023). Southeast Asian nations are well positioned to take advantage of the shorter distance to the centers of demand for hydrogen like Japan, South Korea, Taiwan and potentially Singapore's refining petrochemical and maritime industries. Using LNG shipping as a proxy, Southeast Asia would have a freight advantage of USD70 per tonne of ammonia compared with the US Gulf Coast. Lower labor costs and lower capital expenses in ASEAN countries, if maintained through to the 2040s as expected, would add to the region's competitiveness as a supplier of clean hydrogen or ammonia.

Furthermore, Malaysia and Indonesia have existing natural gas pipelines connecting them to Singapore. These pipelines can be complemented by hydrogen pipelines to Singapore, creating a virtual loop of carbon sequestration in Malaysia and Indonesia while utilising natural gas resources in these countries and using clean hydrogen in Singapore's refining and petrochemical sectors.

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