2. Global Net Zero by 2050

Key Points

- 2050 Net Zero requires all GHG-emitting sectors to achieve Net Zero by 2050.
- A full transition away from today's fossil fuels based economic systems and infrastructure is required by 2050.
- Full decarbonization of the global power generation sector and a full transition away from fossil fuels are both critical for achieving 2050 Net Zero across all sectors.
- Nuclear energy is a critical component within any global 2050 Net Zero pathway scenario.

As already established in Section 1 - *Introduction* of this IRAP, achieving net zero by 2050 is quickly becoming the guiding policy target for the nations of the world in effort to collectively limit anthropogenic global average temperature increases to no more than 1.5°C relative to pre-industrial levels. It is also well-understood that the actual achievement of global net zero by 2050 will require unprecedented levels of societal and economic transformation and international co-operation in the span of only 30 years. It is clear that the risks of inaction (or insufficient action) are extremely high and any "business as usual" approach by the nations of the world will certainly not resolve the climate crisis, resulting in predictable dire consequences for humanity and the environment.

Each nation of the world is now faced with the enormous task of developing 30-year actionable and achievable plans, strategies and policies that will provide the economically sustainable means to achieve maximum possible decarbonization of their respective energy, industry and transport sectors, and built environments. Nations will need to otherwise mitigate or provide carbon sinks to offset all other residual GHG emissions across their AFLU and industrial sectors that may otherwise prove difficult or impossible to fully decarbonize through application of affordable, proven and emerging technological solutions. It should be borne in mind that the current 171 NDCs (80 of which have been updated and also considering the 44 plus EU net zero pledges) currently in place under the Paris Agreement and UNFCCC frameworks do not provide for the collective achievement of even +2°C average global temperature increase, let alone <1.5°C. The vast majority of the NDC's of most nations are currently "toothless" and have no associated binding commitments even with respect to the insufficiently ambitious GHG emissions targets initially offered. As of August 23, 2020 only 10 UNFCCC signatory nations have put in place any legally binding net zero obligations.

What is abundantly clear is that the key issue facing most countries, and the vast majority of those nations responsible for the vast majority of GHG emissions and fossil fuels consumption, will be *how* they go about adopting and enacting acceptable and sustainable policies, plans and strategies aimed to achieve their 2050 net zero commitments. Achieving the necessary enactment of such policies required achieve 2050 net zero will be undoubtedly transformational and overcoming the political and economic resistance and pressures for inaction, delay and "business as usual" from well-established market forces (such as those from the entrenched and well-funded fossil fuels interests) will be tremendous. Such required transformational changes to the economic foundations in any nation are fraught with economic and political risks. Such transformations may result in economic winners (industries that are able and willing to adapt to new realities) and losers (those industries that are unable and unwilling to adapt to new realities). Policymakers will need to be extraordinarily adept in navigating these political and economic waters, both in term of overcoming market inaction forces as well as avoiding any unintended detrimental market consequences, such as capital markets shocks and investor panic which could result from abrupt policy changes impacting some of the world's largest industries (such as fossil fuels).

Irrespective of the very significant challenges as they are, achieving 2050 net zero will require a complete decarbonization of each nation's energy sector (as discussed below) as well as a complete transition away from fossil fuels. As stated above, there will be no "one size fits all" solution to achieve 2050 net zero. Each nation will need to develop its own solution and policies which will enable it to achieve 2050 net zero considering the specific economic and political limitations and circumstances relevant to that country. It is predictable, however; that many countries will develop plans and policies that involve some combination of the following common technological, efficiency/conservation and behavioral elements:

- Rapid replacement of carbon-intensive energy sources (fossil fuels) with clean and sustainable low-carbon sources such as renewable technologies (various combinations of hydro, wind, solar, geothermal, biomass, wave and tidal) and nuclear generation;
- Complete decarbonization of the energy generation, industrial and transportation sectors as well as the built environment (applying CCUS to industries – for example cement and steel production – in cases where certain industries prove to be otherwise difficult to economically decarbonize);
- Intensive electrification (including hydrogen and electrofuels) of industrial and transport sectors and the built environment;
- Evolution of flexible, dynamic and decentralized intelligent electricity grids which have the capabilities to accommodate increased sources of geographically dispersed intermittent renewable generation, storage, interconnections, and evolving dynamic demand profiles resulting from increased electrification and energy storage;
- Energy efficiency and conservation measures; and,
- Policies and incentives to affect systemic and individual consumer behaviors with respect to energy consumption (including carbon pricing/carbon emissions trading, dynamic time-of-day pricing and incentives).

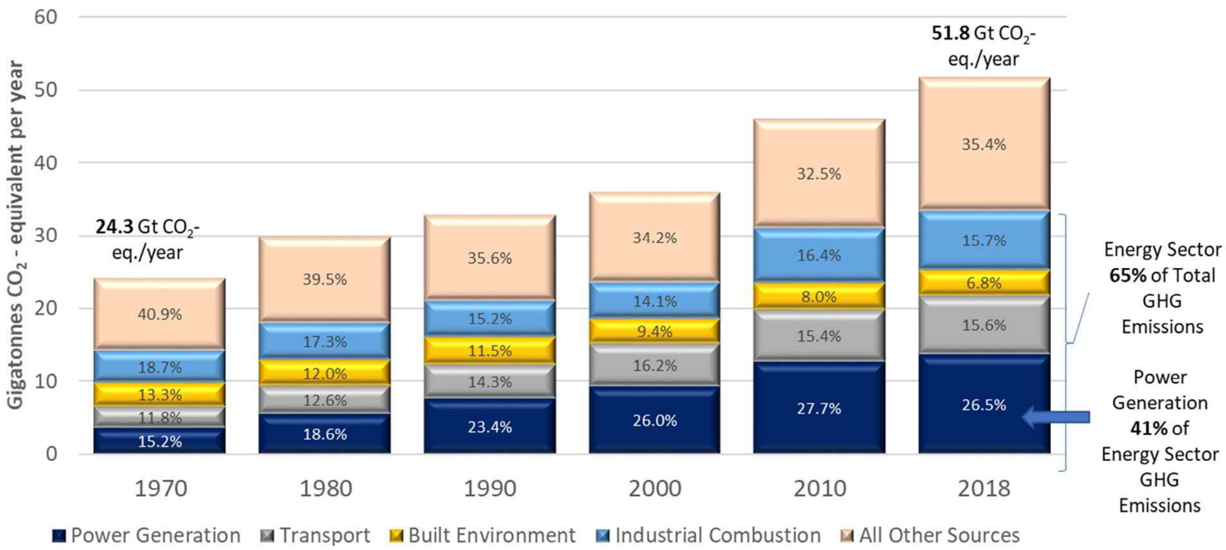
2.1 Full Decarbonization of the Global Power Generation Sector is Necessary

The achievement of net zero in the power generation sector no later than 2050 is amongst the most important and readily achievable components of climate change mitigation plans designed to limit the rise in global average temperature to no more than 1.5°C above pre-industrial levels. The worldwide effort to rapidly decarbonize the electricity generation sector, in a rapid and economically viable manner, is also inextricably linked to the decarbonization of all other energy-intensive sectors, such as industry and transportation as well as the built environment. Therefore, decarbonization of the power generation sectors should be the quintessential aim and priority of all nations in their pursuit of 2050 net zero policies. For example, under the IEA's NZE scenario, emissions from power generation are projected to fall to net-zero in aggregate in advanced economies by 2035 and globally by 2040[12]. The Intergovernmental Panel on Climate Change (IPCC) states that "[T]he electricity sector is completely decarbonized by mid-century in 1.5°C pathways…"[13].

Why is decarbonization of the power generation sector such a critical target in the pursuit of net zero GHG emissions by 2050? The energy sector (including energy utilization in the power generation, industry, and transportation sectors and the built environment) is currently responsible for almost two thirds (65%) of the total GHG emissions globally[14] Power generation remains the single largest source of energy-related CO_2 emissions today, accounting for approximately 41% of total energy-related emissions and 27% of all GHG emissions (compared to 15.2% in 1970). CO_2 emissions from electricity generation totaled 13.6Gt in 2019, of which 9.8Gt was from coal-fired generation and 3.1Gt was from gas-fired plants[15]. It is also worthy to note that while global GHG emissions for the electricity generation sector have more than tripled since 1970, even despite the recent rapid growth in renewables, the percentage of low carbon generation has steadily decreased since 1970. This has been due in large part to the retirements of and failure to extend, renew or and replace as well as expand world nuclear generation capacities over the previous decades[16], while at the same time there has been further reliance on coal and gas to meet the world's generation needs.

[12] Source: [5] - p. 99.
[13] Source: [5] – p. 137.
[14] Source: [3] - p. 13
[15] Note: Related to gas fired generation, does not include methane emissions related to gas extraction, which is an additional and significant source of total world GHG emissions. Source*:* [1]
[16] Source: [3] - pgs. 13 and 26.

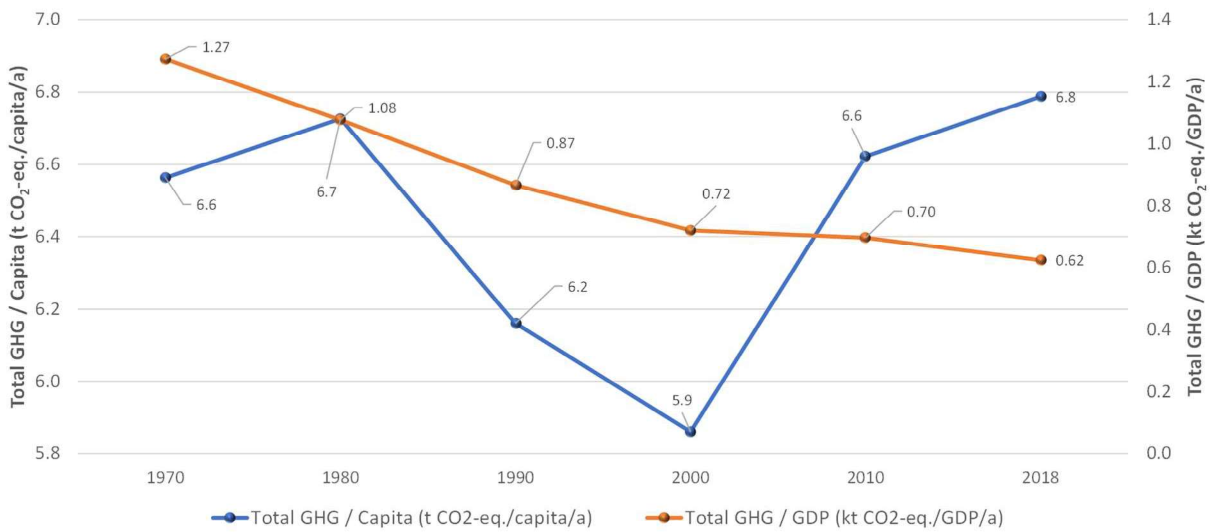
FIGURE 1 - WORLD GREENHOUSE GAS EMISSIONS BY SECTOR (1970 - 2018)



Data Sources: [7] and [8].

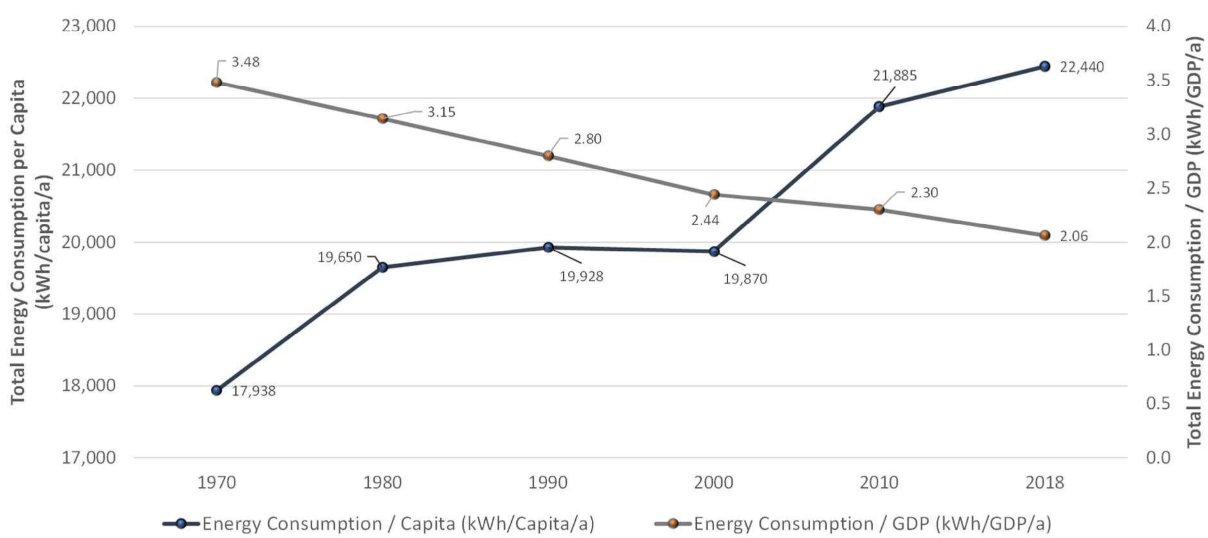
Over the past five (5) decades, the world has been increasingly successful in de-coupling economic growth with both energy consumption and GHG emissions (as shown in Figures 2 and 3, below). Both energy consumption and GHG emissions have decreased per unit of GDP. However, these gains have not been sufficient to offset overall increases in total worldwide energy demand and GHG emissions. Total energy consumption and energy consumption per capital, as well as total GHG emissions and GHG emissions per capita have each increased since 1970. The trends of increasing total world energy consumption, energy consumption per capita (and particular, total electricity consumption and electricity consumption per capita) are likely to continue and significantly accelerate, to the extent that population growth, robust economic development, improvements in living standards and electrification rapidly accelerate. Given these trends, significantly increased volumes of energy (and in particular, electrical energy) will need to be provided on both an affordable and low carbon basis. This is inherently the global challenge over the next three decades.

FIGURE 2 – WORLD GHG EMISSIONS PER CAPITA AND PER UNIT OF GDP (1970 - 2018)



Data Sources: [7], [8], [9] & [10].

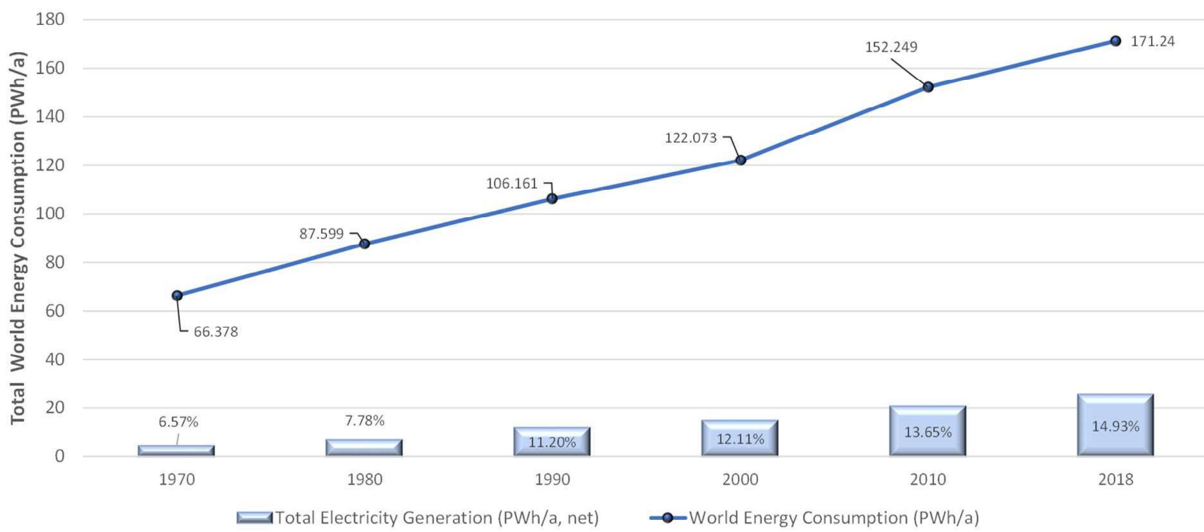
FIGURE 3 - WORLD ENERGY CONSUMPTION PER CAPITA AND PER UNIT OF GDP (1970 - 2018)



Data Sources: [9], [10], [11] & [12].

As total world energy consumption continues to escalate, and energy consumption continues to increase both on a per capita and per unit of GDP basis, also the share of electricity in final energy consumption continues to increase.

FIGURE 4 - TOTAL WORLD ENERGY CONSUMPTION AND ELECTRICITY'S SHARE OF CONSUMPTION (1970 - 2018)

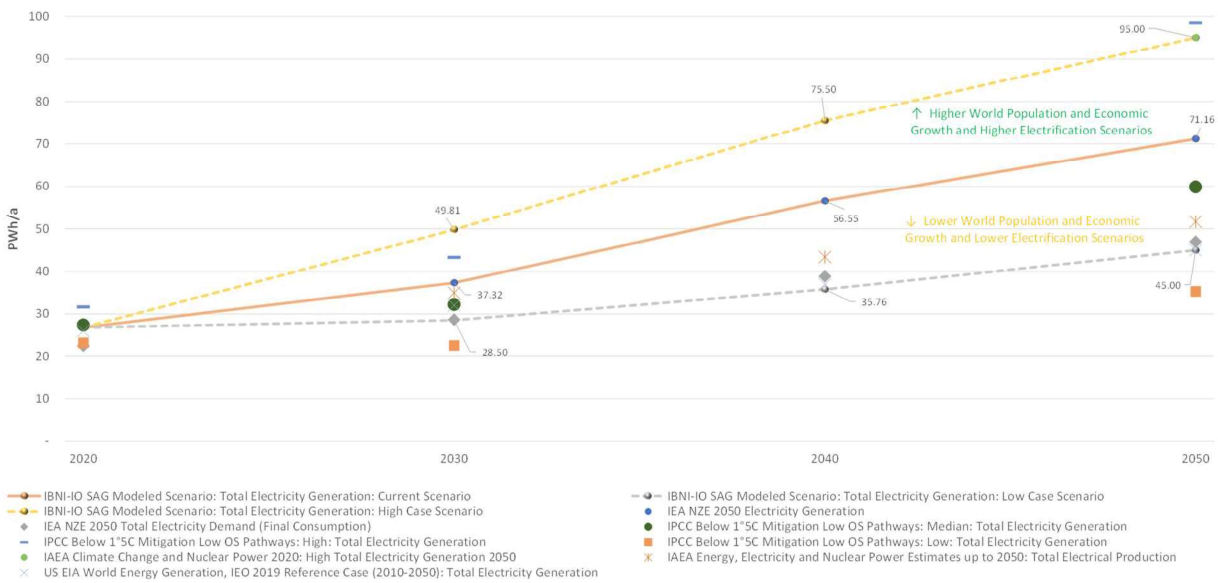


Data Sources: [11], [12] & [13].

Different 1.5°C pathways contemplate different trajectories for electricity demand. Despite significant gains in energy efficiencies and behavioral changes, global demand for electricity (and other related electricity-based carriers of energy such as hydrogen and electrofuels) is projected to increase significantly over the next three decades. This additional electricity demand is expected to result from a combination of global population growth, economic development, intensive electrification and transition away from fossil fuels in the industrial and transport sectors as well as in the built environment. Under the four pathway scenarios in the IPCC SR15 report, 2050 electricity consumption is projected to reach between 27 PWh/a and 95 PWh/a (which corresponds to a range of 6% to 272% increase over 2018 levels of approximately 25.6 PWh/a)[17]. The assumptions embodied for the high-range demand include both robust and sustained global population and economic growth, coupled with intensive electrification as well as build-out of hydrogen and electrofuels infrastructure. In-line with IBNI's core focus on promoting sustainable economic development, we have assumed the higher-end of the demand range will most likely materialize between now and 2050.

[17] Source: [3] - p. 16

FIGURE 5 - WORLD ELECTRICITY DEMAND FORECASTS AND IBNI-IO SAG MODELED CASES



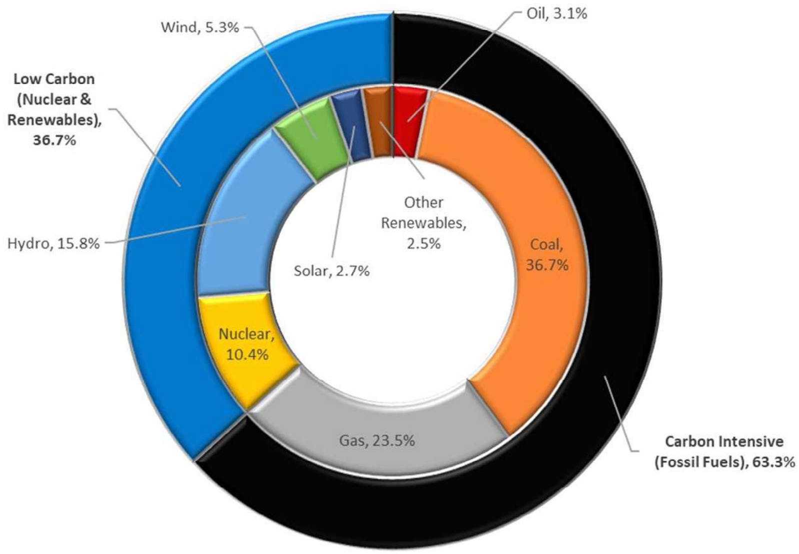
Data Sources: [3], [5] & [6].

If the doubling, tripling or quadrupling of global power generation by 2050 is not to be accompanied by a corresponding doubling, tripling or quadrupling of GHG emissions from the sector then it is clearly essential that the power generation sector must be rapidly decarbonized to the fullest extent possible. As discussed above the IEA's NZE envisages emissions from power generation fall to net-zero in aggregate in advanced economies by 2035 and globally by 2040. The IPCC envisages the carbon intensity of electricity falling rapidly to -92 to 11 gCO_2/MJ by 2050[18] Under any scenario, the power generation sector will need to rapidly transform it current generation mix, which currently includes about 63% carbon intensive fossil fuels (dominated by coal and gas fired generation) to an energy mix comprised entirely of low carbon generation sources comprised of only nuclear and renewables. Carbon intensive fossil fuels currently provide about 84% of total energy mix (primary sources)[19]. The world's power generation industry will have less than three (3) decades to make this monumental transition away for fossil fuels and bring the low carbon generation mix (nuclear and renewables) up to 100% on global scale. Clearly, there is no time to waste.

[18] Any residual carbon emissions from low-carbon generation sources, are typically related to the life-cycle emissions related to the extraction of raw materials, transportation, manufacturing, assembly, construction, installation, operations, maintenance and decommissioning and the disposal/recycling of materials. To the extent that scaled-up generation from biomass energy with carbon capture (BECC) becomes technically and commercially viable, net GHG emissions from the power generation sector could actually become negative.

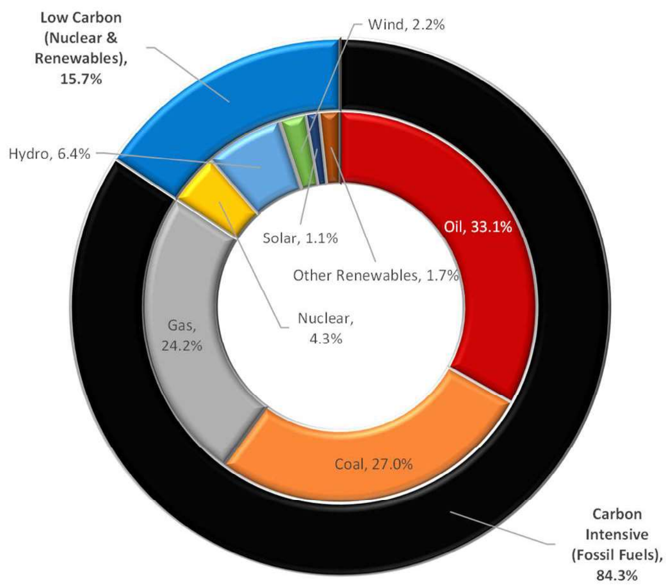
[19] Source: [12].

FIGURE 6 - 2019 WORLD ELECTRICITY GENERATION MIX



Data Source: [12].

FIGURE 7 - 2019 WORLD TOTAL ENERGY MIX (PRIMARY SOURCES)



Data Source: [12].

2.2 Why Nuclear Energy is Needed Under Any 2050 Net Zero Pathway

"*Nuclear is integral to the clean energy transition*"

- Dr. Fatih Birol, IEA DG, March 2021

Decarbonization as drastic as that discussed above in section **Error! Reference source not found.** will require first a dramatic reduction and then a rapid complete transitioning away from existing fossil fueled generation. As the IEA notes: "Net zero means a huge decline in the use of fossil fuels. They fall from almost four-fifths of total energy supply today to slightly over one-fifth by 2050. Fossil fuels that remain in 2050 are used in goods where the carbon is embodied in the product such as plastics, in facilities fitted with [Carbon Capture Utilization and Storage], and in sectors where low-[carbon]emissions technology options are scarce."[20]

Nuclear power has amongst the lowest carbon emissions of all generating technologies (see section **Error! Reference source not found.**) and many experts regard a significant acceleration of investment in increased nuclear capacity as a key component of pathways to achieve net zero by 2050. Nuclear power in combination with renewables offers the only proven, scalable and affordable strategy to replace carbon-intensive fossil fuels generation over the next three (3) decades.

Recent analysis of four hundred (400) GHG mitigation climate mitigation scenarios showed a clear relation between the deployment of nuclear energy generation and the chances of limiting the average global temperature to less than 1.5°C above its pre-Industrial Revolution level[21]

Annual nuclear investment is projected to more than double by 2050 compared with current levels under the IEA's NZE[22]. At its peak in the early 2030s, global nuclear capacity additions are 30 GW per year – which is five times the rate of the past decade[23]. Even at these levels, the NZE pathway scenario reaches 70% VRE penetration, which SAG contends, while this may be technically feasible, it will most likely be unaffordable in most energy markets due to very high "system costs" related to high VRE penetration (see section 3.1) Therefore, SAG maintains that a much higher nuclear penetration will be required in order to achieve full decarbonization of the nuclear sector in an *affordable* manner.

SAG advises that targeted global 2050 VRE penetration should ideally be kept to 30% or less in order to avoid excessive VRE-related "system costs" and consequential heavy burdens on electricity consumers and the stifling of global economic development[24]. Given that the global resources for dispatchable forms of renewable generation (such as hydrological, geothermal and biomass) have limitations on their further

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[20] Source: [6] – pg. 18.
[21] Sources: [4], Fig. 10, and [5].
[22] Source: [6] – pg. 81.
[23] Source: [6] – pg. 115. *The World Nuclear Association (WNA) regards the NZE scenario as unduly conservative regarding the expansion of nuclear generation required to achieve power sector decarbonization, arguing that it relies too heavily on the deployment of technologies that are "uncertain, untested, or unreliable…"* Source: [17]. In this context it is important to note that fission-based nuclear generation is a proven technology.
[24] In the IEA report "*The Costs of Decarbonization – System Costs with High Shares of Nuclear and Renewables (2019)*", it is estimated that VRE with 75% penetration can add more than US $ 50/MWh in additional "system costs" to electricity generation costs (plant costs). Source: [14] – pg. 20.

exploitation, limiting VRE to less than 30% penetration will necessarily require a much more significant growth in global nuclear generation capacities by 2050. In contrast to the IEA's 2050 NZE scenario, SAG advises that global nuclear penetration should reach at least 50% of the world generation mix by 2050. IEA's 2050 NZE scenario shows nuclear falling to approximately 8% of the total global electricity generation mix in 2050[25]. Achieving this rate of growth in global nuclear capacities is significant, but not unprecedented on a historical basis. For example, under our SAG analysis, achieving a 60% nuclear share of the power generation mix in 2050 would require an estimated annual growth rate in worldwide nuclear capacity expansion 21.8% CAGR per year between 2030 and 2040 and a 4.6% CAGR per year between 2040 and 2050. This compares with IEA's nuclear growth rate of under the 2050 NZE of only 2.4% CAGR between 2020 and 2050. There is already strong evidence that the world's global nuclear industry can meet the challenge of scaling up nuclear generation to these levels. Why? Because this industry has already delivered higher capacity growth rates in the past. For example, between 1970 and 1980, global nuclear installed capacities demonstrated an average annual increase of 22.4% CAGR per year[26].

Viewed from the perspective of system requirements it is important to recognize that nuclear is a non-intermittent and dispatchable generation technology. Intermittent or variable renewables (VRE) technologies alone cannot fully replace dispatchable technologies; as back-up (low carbon) generation or grid-scale storage of various kinds (e.g. pumped-hydro storage, utility-scale battery arrays, thermal compressed gas energy storage; conversion to hydrogen and hydrogen-based fuels and other storage technologies and their related incremental infrastructure requirements) are needed. Various types of emerging and unproven utility-scale storage technologies are promising, but batteries also can pose both technical and economic challenges. The successful integration high shares of VRE into power systems – and the cost of compensating for the associated difficulties – remains an area of challenging research. Perhaps the IEA summarizes it best as it analyses the transition to a low emission global energy system: "Wind and solar energy need to play a much greater role in order for countries to meet sustainability goals, but it is extremely difficult to envisage them doing so without help from nuclear power."[27]

[25] Source: [6] – pg. 198, Table A.3 Electricity.
[26] Source [15] – pgs. 16 – 18, Table 7.
[27] Source: [6]