COUNCIL OF ENGINEERS
FOR THE ENERGY TRANSITION

An independent advisory council to the
United Nations Secretary-General

Managed Phaseout of Fossil Fuels Power Generation Facilities by Repurposing and Retrofitting for a Low-Carbon Future

KEY MESSAGES

The Power sector contributes to over 42% of the global carbon dioxide emissions. A realistic, smooth, and affordable transition plan for the decarbonization of this sector is needed for a reliable and resilient low carbon energy future. However, phase-out of traditional fossil fuel resources requires due consideration and planning to avoid significant negative impact on the reliability and resilience of the power systems.

The large-scale renewable development and systems to provide dispatchability takes years and is reliant on robust transmission and distribution infrastructure. Thus, to manage the phaseout of fossil fuels including in existing fossil fuel power plants, the re-purposing and/or retrofitting of existing fossil fuel generation facilities can promote the smooth and managed energy transition and create benefits for all stakeholders.

There are several ways to reduce the carbon intensity of fossil fuel generation facilities such as (a) using natural gas blended with hydrogen and/or biomethane in gas turbines; (b) ammonia co-firing in diesel engines; and (c) addition of carbon capture usage and storage (CCUS) particularly for peak generation for resource adequacy, operation flexibility, network stability, and system reliability/resilience during the transition period.

Repurposing and retrofitting of fossil fuel energy generation facilities can help address the challenges with large-scale renewable energy projects, for example their weather dependent intermittent and variable generation. Without other infrastructure support, the power supply is considered non-dispatchable with inadequate load following capability and lends to worse power quality. Other issues related to large-scale renewable energy projects include higher Rate of Change of Frequency (RoCoF) of the system due to low inertia; insufficient frequency and voltage support due to fewer dispatchable units; and protection coordination due to variation on the direction of the power flows and short circuit contribution from renewable resources or inverter-based resources (IBR).

There are significant efforts underway to better integrate renewables, for example improved mid- and long-term accuracy of wind and solar generation forecasting; installation of energy storage and synchronous condensers; and decarbonizing existing base-load fossil sites to mitigate these challenges and promote smooth energy transition.

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Introduction

According to the March 2023 IEA Flagship Report on CO_2 Emissions in 2022, the power and heat sector contributed to over 42% of the global CO_2 emissions.[1] To decarbonize this sector, developers must evaluate their options to repurpose, retrofit, and/or phase out their fossil fuel generation while working on the development of large-scale renewable energy projects. While planning for large-scale renewable energy projects and the phaseout of traditional fossil fuel generation, repurposing and/or retrofitting existing fossil fuel generation facilities to emit less CO_2 can be achieved more quickly and economically while maintaining stability and resilience of the power systems, which is not feasible in a timely manner with phase out and replacement alone.

Large scale renewable development can take years. Developers must acquire land, establish access to transmission lines which are often reliant on the development of grid infrastructure, secure project finance, procure equipment, and build out the projects. As electricity demand increases in response to electrifying transportation, heating of buildings, cooking and other sectors, renewable energy generation facilities will be developed at further distances away from demand centers and gradually move to sites in areas with lower available renewable energy resources as better sites will be taken first, and thus potentially impacting the cost and volume of electricity delivered. Further, phaseout of traditional fossil fuel infrastructure without thorough consideration and planning may have significant negative impact on the reliability and resilience of the power systems. Repurposing and/or retrofitting of existing fossil fuel power generation infrastructure until the end of its technical lifetime with sizeable reduction in CO_2 emissions e.g. above 40% reduction and as high as 90%reduction, creates a smooth and managed transition to low-carbon energy generation future.

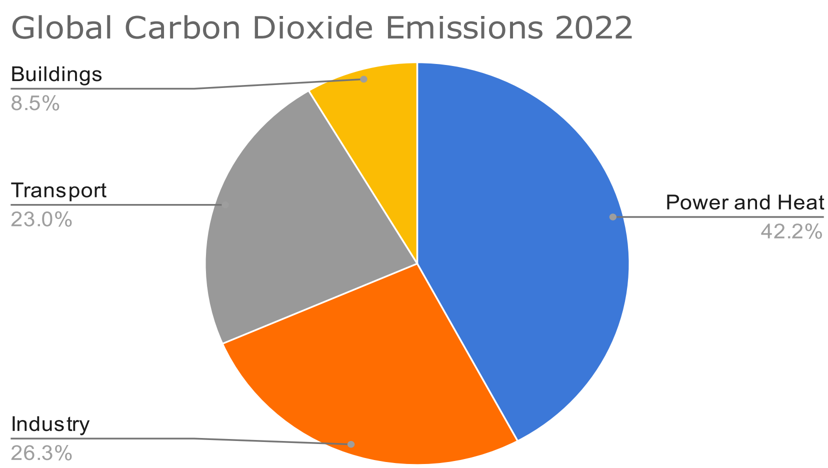
In the context of this document:

- Repurposing means that the part or whole of the asset/generation facility is modified and adapted to work for a purpose different from its original intent e.g. a power generation facility repurposed to provide ancillary services for network stability to the grid.
- Retrofitting is making changes to the asset/generation facility to lower its carbon emissions
- e.g. installation of post combustion Carbon Capture Usage and Storage (CCUS) in both coal and gas power powerplants, change combustors to burn gas blended with hydrogen in gas turbines, co-firing of ammonia or biomass in coal powerplants etc.
- Phaseout is the shutdown and decommissioning of the asset/generation facility.

Repurposing and/or retrofitting existing fossil fuel energy generation facilities benefits all stakeholders. Developers can continue to extract value from their investments in existing facilities, which avoids stress on state, commercial, and financing institutions, or where states have built these assets under bi-lateral agreements and aid programs. It is also a mechanism to supply reliable lower carbon and affordable electricity to consumers that is at least 40% lower in CO_2 emissions and could be as high as 90% with CCUS or alternate green fuels. Such orderly migration provides for a smooth energy transition and feasible path forward to system operators, asset owners (often state-owned utilities), fuel and mining industry, and governments entering a low carbon future.

Global decarbonization will depend on each country's existing dependency on fossil fuel generation, the age and extent of its existing facilities, local fuel resources, economic status, electrification status and demand growth, regulations, policies, and current priorities. Although unable to address all concerns and aspects, this document offers a high-level roadmap to re-purpose and retrofit fossil fuel power generation. It discusses the potential challenges, solutions, and examples to support an orderly and affordable energy transition and promote the development of a trained and qualified workforce.

FIGURE 1: Global carbon dioxide emissions for transport, power, heat, and buildings in 2022. Source: IEA, "IEA Flagship Report on CO_2 Emissions in 2022." March, 2023.



Solutions to retrofit fossil fuel generation facilities:

MIX CARBON-BASED FUELS WITH GREEN FUELS: A possible carbon reduction solution to energy generation is to blend natural gas (methane) with green, blue hydrogen, or biomethane. This practice is also known as "Hydrogen combustion" and "hydrogen-enriched natural gas" or "hydrogen-blended natural gas." Major gas turbine manufacturers have already successfully combusted hydrogen blends of 30% to 75% without significant modifications to existing facilities. Over the long term, they plan to deploy 100% hydrogen in gas turbines. Some smaller turbines have millions of hours of operational experience with hydrogen-enriched fuel.

Though most of the current hydrogen-blended natural gas generation projects are either pilots or demonstrator facilities, a few trials already use 100% hydrogen. To reach commercial level operation, however, manufacturers must overcome economic and regulatory challenges for hydrogen-blended natural gas power generation.

Moreover, some coal fired units can be converted to combined cycle gas turbine plants which in turn can operate on hydrogen or biomethane blended gas and subsequently 100% hydrogen as stated above. As examples, two units at the Big Bend Power Station in Tampa, Florida have been converted in 2021 and Capital Power is converting two units of the Genesee Power Station in Alberta Canada. These lead to significant reductions in CO_2 emissions while also increasing the capacity. Several units have already been similarly converted.

Ammonia co-firing, particularly in Diesel or Fuel Oil operated engines, also offers a sustainable alternative to fossil fuels. Ammonia fuel blends can also power boilers. Likewise, Biomass co-firing or full conversion of coal fired units are feasible options. Such generation is a low-carbon solution to meet peak generation requirements and improve grid stability.

CARBON CAPTURE USAGE AND STORAGE (CCUS): CCUS can serve as a transitional technology to phase out fossil fuel generation by capturing the CO_2 byproduct of fossil fuels. CCUS operators can supply captured CO_2 to industries that require CO_2 in their process. Alternatively, operators can store CO_2 in underground caverns, depleted oil/gas wells and other storage facilities.

Although CCUS is a not a new concept, it requires further research and development to improve its performance and commercial readiness. CCUS consumes high levels of energy, which may diminish the technology's benefits. Furthermore, scalable CCUS must work for various industries with different emission sources. Cost and locational specificities could reduce the net emissions reduction benefits and commercial attractiveness of CCUS. Facilities that are in close proximity to depleted oil and gas wells or underground caverns can benefit from these natural features for storage of CO_2 more cost and performance effectively as opposed to those which require the CO_2 to be compressed and piped over long distances. Likewise, locational vicinity to industries such as food and beverage, greenhouses and synthetic fuels that can utilize the captured CO_2 also helps to valorize the gas cost effectively. Government, industries, and academia should work together to deploy CCUS. Financial incentives, subsidies, tax credits, and regulations can encourage the development and implementation of CCUS technologies on a large scale.

Solutions to repurpose fossil fuel generation facilities:

CONVERSION TO SYNCHRONOUS CONDENSERS FOR GRID SUPPORT: Depending on location on the network and system specific requirements, some of the existing fossil fuel generating units can be converted to synchronous condensers which provide rotating inertia lending to grid stability particularly as inverter-based resources (IBR) such as Solar PV, wind power, and battery energy storage systems form a substantial share of generation. Such installations are relevant and important as the share of renewable generation particularly wind and solar PV, rises in the networks thereby lending to supporting the decarbonization of generation. The 24th April 2024 article, "Analysis: Fossil fuels fall to record 2.4% of UK electricity", mentions the use of synchronous condensers from large turbines also lending support to grid stability.

THERMAL ENERGY STORAGE (CARNOT BATTERIES): Some thermal power plants can be repurposed such that the required thermal energy to operate the plant is derived from longer duration thermal energy storage charged with renewable energy rather than from combustion of fossil fuel i.e. steam turbine receives steam produced with thermal energy from energy storage and this the plant operates like a Carnot battery. This is one of the readily deployable energy storage technologies that is based on storing and discharging renewable energy but one that enables the conversion of an existing thermal power generation facility with remnant technical lifetime into a renewable energy dispatchable asset.

The Challenges and drivers for repurposing and retrofitting fossil fuel power generation facilities

INVESTMENT AND COMMITMENTS IN EXISTING GENERATION: Many fossil fuel generation facilities have entered commitments to provide transmission operators, planners, and customers stable, controllable, and reliable power supply. Both sides must continue to deliver/accept power under these commitments. Premature terminating or altering the agreement may create uncertainty and impact the financials of the asset owners and lenders, and stability and reliability of the power systems. For example: utility companies and governments have invested large sums of money into fossil fuel power generation sites. They are protective over the remaining useful life of fossil fuel infrastructure, their return on investment, avoiding write-offs, contractual arrangements including those in existing power offtake agreements, and avoiding bad debts. In response, government/quasi- government agencies attempt to protect their investments and commitments of power supply to operate the fossil fuel generation until the end of their expected lifetime, sometimes create barriers to the necessary pace for the energy transformation with actions/inactions such as delaying or limiting grid connections, putting unreasonable requirements to connect to the network etc.

Even with lower capital investment and smaller changes to the current infrastructure, repurposing fossil fuel generation facilities may still require some asset retirements and asset book value write-offs, particularly for low efficiency old assets or those on locations that have a low impact on networks if removed from service. Re-purposing will sometimes demand additional capital investment, which will vary depending on respective project requirements. Without proper planning and security of revenue streams, financing these projects can be challenging. This is especially true in regions where fossil fuels have dominated the energy landscape, and political and local stakeholders resist low-carbon energy.

However, significant reductions in emissions from fossil fuel generation by instituting green fuels, and even full abatement of emissions with Carbon Capture Usage and Storage (CCUS), can help to reduce resistance and barriers to energy transition, if such emission reductions can be monetized at a fair carbon price. Since these retrofits will incur additional costs, it will also provide a monetary incentive for a more rapid development and implementation of affordable renewables and energy storage to achieve an orderly and cost-effective transition.

INSUFFICIENT GRID INFRASTRUCTURE: Utility scale renewable developments are stymied by insufficient access to the electric grid due to the existing infrastructure's capacity constraints, not only impacting new developments but also leading to curtailments in generation. To meet the growing demand on electricity grids due to electrification, utilities must build new transmission and distribution infrastructure and upgrade existing infrastructure wherever possible. However, transmission and distribution infrastructure improvement are very expensive and time consuming. In fact, estimates for the investment required to sufficiently upgrade and expand transmission capacity equals or exceeds that for new renewable generation capacity addition[2] governments can have an active role to address the challenges of grid access and expansion through progressive and targeted policies including regional interconnections.

Governments can also institute policies that accelerate the permitting processes and incentivize transmission companies to invest in infrastructure. Examples include Regulated Asset Base (RAB) models and long-term availability-based agreements to invest in transmission lines. The energy companies can also work with communities and landowners to devise mutually beneficial arrangements, such as revenue sharing, to secure the necessary rights-of-way to accelerate this development.

Another solution to improve grid access is to manage energy deployment so as not to overwhelm the grid and increase network utilization. Technologies such as energy storage; dynamic line loading management; upgrading conductors; and digitalizing existing infrastructure to increase load flows manage congestion while increasing the capacity of existing infrastructure. Smart grid technologies use artificial intelligence to manage intermittent power flow and help manage demand on the grid. Intelligent Electronic Devices (IED) and flexible AC transmission systems (FACTS) are helpful to manage the power flow, increase the observability and controllability of the system, and optimize the operation efficiency through peak shaving and load shifting by using energy storage systems. These also reduce production curtailment, and both create and protect the value of the investments in renewable energy generation.

When repurposing or retrofitting existing fossil fuel generation sites, the resultant low- carbon energy can make use of preexisting connections to the grid. For younger facilities that are essential energy providers, transitioning to 100% green fuels and CCUS can reliably bridge the transition until renewable energy facilities are up and running.

RESOURCE ADEQUACY AND FLEXIBILITY: Fossil fuel generation, hydropower, nuclear power and, more recently, batteries offer consistent, “baseload,” or demand profile following energy. Baseload energy is important to meet consumers’ energy demand at all times, regardless of the weather. Renewables such as wind, solar, and run of river hydropower, however, are subject to weather and seasonality. Without adequate balancing support and smart grid technologies, they can generate intermittent energy that is insufficient to meet the demands of modern society.

To meet baseload energy requirements, renewable sources require help from other technologies. For example, batteries, pumped hydro storage, hydrogen, and Carnot batteries can help to store energy at peak production to distribute during periods of low generation. Other decarbonized generation sources, namely nuclear power, biomass generation, reservoir-based hydropower, and generation with green fuels, can help to achieve a fully decarbonized scenario.

Retrofitted fossil fuel generation facilities that utilize 100% hydrogen, biomethane or biomass could provide adequate baseload and peak power generation. Likewise, existing thermal units can be repurposed as Carnot batteries to provide adequacy and flexibility. By filling in resource gaps left by other forms of renewable energy, retrofitted fossil fuel generation sites can offer huge potential to effectuate global decarbonization.

RELIABILITY, RESILIENCE, SECURITY, AND STABILITY OF THE SYSTEMS: Fossil fuels provide a reliable and dispatchable source of energy. Fossil generation, nuclear power and hydropower with large rotating masses of the turbine generators provide inertia on the energetic system. On the other hand, renewable energy or inverter-based resources (IBR) such as wind and solar do not have the same rotating masses and are unable to provide the same level of system inertia as these power plants. This lack of inertia may impact on the Rate of Change of Frequency (RoCoF) of the system. Protection coordination and power quality are other challenges.

One of the major challenges with large-scale renewable energy projects is their intermittency and variability. Wind and solar power generation are dependent on weather conditions, the forecasting of which is unreliable after short periods of time. Unpredictable weather makes it difficult for grid operators to maintain a stable and reliable power supply. The subsequent power supply can be unreliable and lends to worse power quality; inadequate load following; instability due to low inertia; lack of frequency regulation; and protection coordination due to variation on the direction of the power flow; and short circuit contribution from renewable resources or inverter-based resources (IBR).

There is significant effort being made to improve energy reliability through better mid- and long-term accuracy of wind and solar generation forecasting. Also, these developments would reduce capital expenditure on storage systems and overbuild of capacity to achieve the targeted dispatchability.

Additionally, with the digital transformation of energy systems, ensuring the necessary digital system reliability, cyber and control system security, and stability in an interconnected environment are new challenges to the whole sector. In this regard, more efforts are put in the core technology breakthrough and testing/verification work.

Energy storage systems such as batteries and pumped hydro storage are crucial technologies to improve energy reliability. Re-purposing fossil generation to Carnot batteries and synchronous compensators is an efficient way to protect against intermittency-including provision of frequency regulation and load following. Demand side management can also help mitigate the impact of intermittency. Governments can incentivize energy storage system, energy efficiency, and demand side management with tax holidays, import duty exemptions, and robust contractual frameworks. Government can also support energy companies and research institutions to invest in research and development and scaling to reduce the cost of these systems.

IMPACT ON ECONOMICS AND JOB MARKET: Fossil fuel industries are significant to some national economies and job markets. The oil and gas industry in the USA contributes to over 10 million jobs and 8% of the GDP[3] while in South Africa the coal industry employed over 475,000 people and contributed nearly 494 billion rand out of the total GDP of 4.6 trillion rand in 2022.[4] The transition away from these industries could lead to job loss and economic disruption. At the same time, as the world transitions to a more sustainable and low-carbon energy future, there is a deficit of talent in such areas while demand for talent continues to rise. There must be a dedicated effort to re-skill workers and develop local renewable industry, thus creating alternative sustainable employment.

Many of the jobs required for the energy transition, such as those in renewable energy, energy storage, repurposed fossil fuel generation, and digital solutions, require specialized skills that are not widely available in the workforce. Bridging the skills gap will require the government and private sector to invest in targeted training programs, apprenticeships, and upskilling opportunities for workers and professionals. Certified development programs for the workforce are important to ensure a smooth transition to a low-carbon economy These programs should create workforce diversity; alleviate regional disparities; enable innovation; and accelerate digitalization while also retaining key competencies in traditional generation until they phase out.

In conclusion, there are technical, commercial, and capacity challenges that make the case for retrofitting and repurposing of part of the fossil fuel generation to accelerate and support the large-scale deployment of renewables and energy storage and deliver a low carbon, reliable and managed transition to net zero.

Examples of retrofits and repurposing of fossil fuel generations and mechanisms for development of carbon removal and large-scale renewable energy projects

CCUS FACILITIES: According to the IEA report, CCUS facilities around the world have the capacity to capture more than 40 $MtCO_2$ each year. Some of these facilities have been operating since the 1970s. The first large-scale CO_2 capture and injection project was commissioned at the Sleipner offshore gas facility in Norway in 1996. The project has now stored more than 20 $MtCO_2$ in a deep saline formation located around 1 km under the North Sea.[5] Since then, CCUS deployment has expanded to many regions and different applications. With seven million metric tons per year, the Shute Creek Gas Processing Plant in the United States is the largest carbon capture and storage CCUS facilities in 2022.[6] The China Energy Taizhou Power plant CCUS project processes 500,000 tons of CO_2 per year. This project could achieve 100% consumption of carbon captured, as well as reach CO_2 purity of 99.99%. This is the largest demonstration project for coal power CCUS in the Asia pacific region.[7]

CONVERSION OF RETIRED COAL FIRED UNITS INTO GRID SUPPORTING SYNCHRONOUS CONDENSERS: 3 (three) retired coal fired unit turbine generators in Midwest USA owned by an investor- owned utility have been converted to synchronous condensers.[8][9]

The Australian Renewable Energy Agency (ARENA) has published a report on the repurposing of existing generators as synchronous condensers.[10]

DIRECT AIR CAPTURE (DAC) OPERATION: To date, twenty-seven DAC plants have been commissioned worldwide. The facilities capture almost 0.01 Mt CO_2/year. Plans for at least 130 DAC facilities are now at various stages of development. The United States is leading the race on policy support for DAC. New funding under the Inflation Reduction Act (IRA) was announced in 2022 to increase the 45Q tax credit to USD 180/t CO_2 captured for storage via DAC. The IRA also instituted a capture threshold of as little as 1 kt CO_2/year.[11] On August 11, 2023, the US Department of Energy (DOE) announced up to $1.2 billion in funding for two direct air capture (DAC) hubs in Louisiana and Texas. The two regional DAC hub projects, Project Cypress and South Texas DAC Hub, will capture, process and permanently store carbon dioxide underground. Once running, the hubs are expected to collectively remove over two million metric tons of carbon dioxide from the atmosphere every year and to create over 5,000 jobs.

HYDROGEN-BLENDED NATURAL GAS: The HyBlend™ initiative[12] from the US Department of Energy will produce a report to address technical barriers to blending hydrogen in natural gas pipelines. National Renewable Energy Laboratory (NREL) leads a collaborative research and development project within HyBlend that includes three other national laboratories (Sandia National Laboratories, Pacific Northwest National Laboratory, and Argonne National Laboratory) and more than 30 partners from industry and academia. The report is to inform the development of models and analytic tools to evaluate the technical requirements of blending hydrogen.[13][14]

INFRASTRUCTURE IMPROVEMENT: In California and Texas, the state government has launched plans to build a high-voltage transmission line to connect the renewable energy resources with load centers. It includes the construction of new transmission lines and the expansion of existing infrastructure. They are aiming to integrate large-scale RE projects into the grid and ensure a reliable supply of renewable energy to urban centers.

MITIGATING INTERMITTENCY: In South Australia, the government has launched a plan to build the world's largest virtual power plant (VPP), which will use rooftop solar panels and battery storage systems to provide reliable and affordable electricity to households. The virtual power plant will store excess energy during periods of high solar power production and release it when the demand for electricity is high. This initiative aims to address the intermittency of solar power and reducing regional reliance on fossil fuels.[15] Such virtual power plants provide partial dispatchability and therefore, during the transition, the retrofitting and repurposing of existing fossil generation is a low carbon solution to support the necessary dispatchability and contingency requirements of the networks.

POLICY AND REGULATION: The German government implemented policies and regulations to support large-scale RE projects, including feed-in tariffs and renewable energy targets. The country also plans to phase out nuclear and coal power by 2022. These policies have created a favorable environment for the development of large-scale RE projects. Germany is now a world leader in renewable energy.[16] The German research institute DLR has been investigating and developing solutions around Carnot batteries and thermal storage. Development of these solutions via policy and regulation, is to provide network support with existing fossil assets that have been repurposed and will not use fossil fuels.

INVESTMENT AND FINANCING: The Indian government states that it will achieve 500GW of renewable power generation capacity by 2030.[17] This is being facilitated by large capacity auctions for procurement of renewable energy via long term bankable power purchase agreements. Additionally manufacturing of PV equipment in India is being incentivized including via auctions based on domestic content for new generation capacity plans. Already, domestic and international developers invested significantly into renewable energy projects and India is one of the fastest-growing markets for renewable energy.[18]

The US has a system of Investment and Production tax credits which has led to rapid growth of renewables and competitively priced renewable energy to consumers.[19]

THE COMPETITIVE RENEWABLE ENERGY ZONES (CREZ): The Texan government created CREZ to develop new transmission lines and expand existing infrastructure to integrate renewable energy into the Electric Reliability Council of Texas (ERCOT) grid. The program was launched in response to growing demand for renewable energy and increased transmission capacity to support such renewable energy projects.[20]

- Under the CREZ program, the Texas Public Utility Commission (PUC) identified zones where new transmission lines were needed to connect wind and solar power projects to the grid. The PUC then approved the construction of transmission lines within these zones, which were developed and financed by transmission companies.
- The CREZ program facilitated wind and solar power deployment in Texas. Since the program was launched in 2008, the state installed more than 18,000 MW of wind power capacity, making Texas the largest wind power producer in the United States. CREZ has created thousands of jobs and has had a positive economic impact on the state.

Examples of workforce development

RESOURCE AND ENERGY ENGINEERING IN UNIVERSITIES: Resource and Energy Engineering is vital for a successful energy transition. The University of Texas at Arlington (UTA) launched a Resource and Energy Engineering program in fall 2023. The program has received a 12- million-dollar gift from Mr. Kelcy Warren to elevate UTA to the forefront of the growing resource and energy engineering (REE) field for comprehensive workforce development.[21]

India has been emphasizing on a Skills Development Program which has been ongoing for several years and has established Solar PV training institutes such as the National Institute of Solar Energy.[22] In fact, Germany is trying to secure trained manpower from India to achieve its renewable energy ambitions.[23]

SOLAR WORKS DC: Through Solar Works DC, the US Department of Energy and Environment and the Department of Employment Services in Washington, D.C provide training and job opportunities in the solar energy sector to low-income residents of the city. Participants receive classroom and hands-on training in solar panel installation and maintenance. The program also connects with local employers who are hiring for these types of jobs.[24]

ENERGY TRANSITION INITIATIVE IN GERMANY: Germany has implemented a comprehensive energy transition program, known as the Energiewende, to transition the country to a low- carbon economy. As part of this program, the government invested in workforce development initiatives, including a national training program for energy auditors and a certification program for energy efficiency experts.[25]

ELECTRIC VEHICLE INFRASTRUCTURE TRAINING PROGRAM: The Electric Vehicle Infrastructure Training Program, run by the National Renewable Energy Laboratory in the United States, trains participants to install and maintain electric vehicle charging stations. The program is designed for electricians, construction workers, and other professionals who are interested in transitioning to the clean energy sector.[26]

RENEWABLES ACADEMY AG (RENAC): RENAC is an international training provider based in Germany that offers courses on renewable energy and energy efficiency. The organization has trained over 7,000 professionals from more than 140 countries in areas such as solar PV, wind energy, and energy efficiency.[27]

SOLAR READY VETS: Solar Ready Vets is a partnership between the U.S. Department of Energy and the Department of Defense that trains military veterans on solar installation and maintenance. The program is designed to help veterans transition to civilian careers in the solar industry. It includes hands-on training, job placement assistance, and support for veterans with disabilities.[28]

NYSERDA CLEAN ENERGY WORKFORCE DEVELOPMENT AND TRAINING: The New York State Energy Research and Development Authority (NYSERDA) offers several workforce development programs to prepare workers for careers in the clean energy sector in New York State. The programs offered by NYSERDA include:[29]

> **CLEAN ENERGY WORKFORCE DEVELOPMENT PROGRAM:** This program funds community colleges, workforce training centers, and other institutions to offer clean energy training programs. The program trains workers for jobs in energy efficiency, renewable energy, and clean transportation sectors.
>
> **SOLAR TRAINING NETWORK:** NYSERDA partners with the Department of Energy's Solar Training Network to provide training and certification programs for solar installers and other solar energy professionals.
>
> **CAREER DEVELOPMENT PROGRAM:** This program provides financial assistance to individuals looking to advance their careers in the clean energy sector. The program funds training, certification, and other career development opportunities.
>
> **OFFSHORE WIND TRAINING INSTITUTE:** NYSERDA is developing an Offshore Wind Training Institute to train and educate participants for careers in the offshore wind industry. The Institute will offer a range of training programs, including safety training, technical training, and job-specific training.

Notes

1 IEA World Energy Outlook, 2022.

2 IEA World Energy Outlook, 2022.

3 American Petroleum Institute, Oil & Natural Gas: supporting the economy, creating jobs and driving America forward, 2018.

4 Statista, South Africa's coal mining industry.

5 IEA, "Carbon Capture, Utilisation and Storage – Energy System."

6 Statista, " Largest Operational CCS Project Globally 2022."

7 Wang et. al., "The Compressor of Asia's Largest Coal Power CCUS Project is Shipped for the First Time."

8 US Department of Energy, "HyBlend: Opportunties for Hydrogen Blending in Natural Gas Pipelines."

9 Topolski et. al., "Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology."

10 Energy & Mining, "South Australia's Virtual Power Plant."

11 Wang et. al., "The Compressor of Asia's Largest Coal Power CCUS Project is Shipped for the First Time."

12 IEA, "Direct Air Capture – Energy System."

13 US Department of Energy, "HyBlend: Opportunties for Hydrogen Blending in Natural Gas Pipelines."

14 Topolski et. al., "Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology."

15 Energy & Mining, "South Australia's Virtual Power Plant."

16 REN21 - Renewables Now, "Renewables 2022 Global Status Report: Germany Factsheet."

17 Wind Exchange, "Production Tax Credit and Investment Tax Credit for Wind Energy."

18 Invest India, "Renewable Energy in India – Indian Power Industry Investment."

19 Ministry of New and Renewable Energy, India, "Skill Development Programme: Ministry of New and Renewable Energy: India."

20 Electric Transmission Texas, "Project Information."

21 UT Arlington, "Resource and Energy – Undergraduate Programs."

22 Roland, "Germany Trying to Attract Solar Workers from India."

23 Roland, "Germany Trying to Attract Solar Workers from India."

24 Solar Works DC, "DC Infrastructure Academy."

25 Agora Energiewende, "Agora Energiewende."

26 Federal Energy Mangement Program, "Electric Vehicle Training."

27 RENAC, "Welcome to Renewables Academy."

28 Office of Energy Efficiency and Renewable Energy, "Solar Ready Vets Network."

29 NYSERDA, "Clean Energy Workforce Development."

Bibliography

American Petroleum Institute. "Fact Sheet, Oil & Natural Gas: Supporting the economy, creating jobs and driving America forward." American Petroleum Institute , 2018. https://www.api.org/-/media/files/policy/taxes/dm2018-086_api_fair_share_onepager_fin3.pdf.

Carbon Brief, 24th April 2024, "Analysis: Fossil fuels fall to record 2.4% of UK electricity". https://www.carbonbrief.org/analysis-fossil-fuels-fall-to-record-low-2-4-of-british-electricity/

"Clean Energy Workforce Development." NYSERDA. Accessed February 20, 2024. https://www.nyserda.ny.gov/all-programs/clean-energy-workforce-development-and training.

"Electric Vehicle Training." Energy.gov. Accessed February 20, 2024. https://www.energy.gov/femp/electric-vehicle-training.

"Hyblend: Opportunities for Hydrogen Blending in Natural Gas Pipelines." Energy.gov. Accessed February 20, 2024. https://www.energy.gov/eere/fuelcells/hyblend-opportunities-hydrogen-blending-natural-gas-pipelines.

"Hydrogen-Fueled Gas Turbines: GE Gas Power." gepower-v2. Accessed February 20, 2024. https://www.gevernova.com/gas-power/future-of-energy/hydrogen-fueled-gas-turbines

"India to Achieve 500 GW Renewables Target before 2030 Deadline: RK Singh." *The Economic Times*, September 25, 2023. https://economictimes.indiatimes.com/industry/renewables/india-to-achieve-500- gwrenewables-target-before-2030-deadline-rk-singh/articleshow/103936965.cms.

"Production Tax Credit and Investment Tax Credit for Wind Energy." WINDExchange. Accessed February 20, 2024. https://windexchange.energy.gov/projects/tax-credits.

"Renewable Energy in India - Indian Power Industry Investment." Accessed February 20,2024. https://www.investindia.gov.in/sector/renewable-energy.

"Renewables 2022 Global Status Report: Germany Factsheet." n.d. REN21 - Renewables Now. REN21 - Renewables Now. Accessed October 2, 2024. https://www.ren21.net/wp-content/uploads/2019/05/GSR2022_Fact_Sheet_Germany.pdf.

"Resource and Energy – Undergraduate Programs." UT Arlington. https://catalog.uta.edu/engineering/electrical/undergraduate-resource-and-energy/#text.

"Skill Development Programme: Ministry of New and Renewable Energy: India." Ministry of New and Renewable Energy | India. Accessed February 20, 2024. https://mnre.gov.in/skill- development-programme/.

"Solar Ready Vets Network." Energy.gov. Accessed February 20, 2024. https://www.energy.gov/eere/solar/solar-ready-vets-network.

"Solar Works DC." DC Infrastructure Academy. Accessed February 20, 2024. https://dcia.dc.gov/page/solar-works-dc.

"Sources of Greenhouse Gas Emissions." EPA, November 16, 2023. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

"Zero Emission Hydrogen Turbine Center (ZEHTC)." (ZEHTC). Accessed February 20, 2024. https://www.siemens-energy.com/us/en/home/products-services/solutions-usecase/hydrogen/zehtc.html.

2raumwelten.de. "Welcome to Renewables Academy." RENAC - The Renewables Academy AG, January 1, 9180. https://www.renac.de/.

Agora Energiewende. Accessed February 20, 2024. https://www.agora-energiewende.org/.

Electric Transmission Texas - project information. Accessed February 20, 2024. http://www.ettexas.com/Projects.

Energy & Mining. "South Australia's Virtual Power Plant." Energy & Mining, February 20, 2024. https://www.energymining.sa.gov.au/consumers/solar-and-batteries/south-australias-virtual-power-plant.

Ernst, Roland. “Germany Trying to Attract ‘Solar Workers’ from India.” *PV Magazine*, February 28, 2023. https://www.pv-magazine.com/2023/02/28/germany-trying-to-attract-solar- workers-from-india/.

IEA. “Carbon Capture, Utilization and Storage - Energy System.” IEA. Accessed February 20, 2024. https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage.

IEA. “Direct Air Capture - Energy System.” IEA, 2023. https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/direct-air-capture.

IEA. “World Energy Outlook 2022.” IEA, 2022. https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf.

Mitsubishi Power, “Hydrogen Power Generation Handbook.” Mitsubishi Heavy Industries, Ltd. Energy Systems. June 2019. https://solutions.mhi.com/sites/default/files/assets/pdf/et-en/hydrogen_power-handbook.pdf

Our 100% renewable energy vision - the solutions project. Accessed February 20, 2024. https://thesolutionsproject.org/what-we-do/inspiring-action/why-clean-energy/.

Statista. “Largest Operational CCS Projects Globally 2022.” Statista, April 27, 2023. https://www.statista.com/statistics/1108355/largest-carbon-capture-and-storage-projects-worldwide-capacity/.

Statista. “South Africa’s Coal Mining Industry.” Statista April 27, 2023. https://www.statista.com/statistics/1311307/south-africa-coal-mining-employment/#:~:text=South%20Africa’s%20coal%20mining%20employment%202011-2022&text=As%20of%202022%2C%20the%20industry,a%20total%20of%20475%2C561%20people

Topolski, Kevin, Evan P. Reznicek, Burcin Cakir Erdener, Chris W. San Marchi, Joseph A. Ronevich, Lisa Fring, Kevin Simmons, Omar Jose Guerra Fernandez, Bri-Mathias Hodge, and Mark Chung. 2022. Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology. Golden, CO: National Renewable Energy Laboratory. NREL/TP5400- 81704. https://www.nrel.gov/docs/fy23osti/81704.pdf.

Vecchi, Andrea, Kai Knobloch, Ting Liang, Harriet Kildahl, Adriano Sciacovelli, Kurt Engelbrecht, Yongliang Li, and Yulong Ding. “Carnot Battery development: A review on system performance, applications and commercial state-of-the-art.” *Journal of Energy Storage* 55 (2022): 105782.

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