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RISE3D

A NICE FUTURE INITIATIVE PROJECT

TOWARD A CLEAN AND JUST ENERGY TRANSITION

NICE FUTURE

THIS WORK WAS AUTHORED AS PART OF THE NICE FUTURE INITIATIVE IN COLLABORATION WITH TERRA PRAXIS.

To accelerate the repurposing of unabated coal plants with new advanced nuclear technologies, and to bring about breakthrough nuclear innovations, the NICE Future Initiative launched an expert group, RISE^3. This campaign has enabled the discussion about how nuclear innovations can lift economies and raise the quality of life for communities and nations. This report highlights environmental justice issues and key communication points in the transition toward a clean energy future, with a focus on the role of nuclear energy and emissions-free heat sources (such as fission) in the transition from coal. This report reflects existing research and RISE^3 activities (webinars and workshops) to date.

NET ZERO BY 2050 REQUIRES CLIMATE JUSTICE

On December 12, 2015, world leaders at the United Nations Climate Change Conference (COP21) signed the Paris Agreement, which includes commitments from all countries to reduce their emissions, work together to adapt to the impacts of climate change, and strengthen their commitments over time (2.1). The Paris Agreement is a legally binding treaty that went into effect on November 4, 2016, and today includes 193 states plus the European Union. It states that global temperatures should not increase more than 2°C above pre-industrial levels in this century and that efforts should be made worldwide to limit this increase to 1.5°C by 2050 to prevent permanent warming of the planet and catastrophic consequences. To limit warming to 1.5°C, global emissions from all sources need to be reduced by 45% by 2030 relative to 2010 and reach net zero by 2050 (2.2).

Surpassing 1.5°C global temperature rise means accepting severe climate impacts, which may include 10 million more people being displaced by sea level rise; 65 million more people exposed to exceptional heatwaves; a doubling of biodiversity-related impacts such as species loss; the elimination of Arctic Ocean sea ice; and the loss of virtually all coral reefs. Missing the 2°C target would expose half the world's population to summertime "deadly heat," Greenland and the West Antarctic ice sheets would collapse, droughts would increase by 500%, and the Sahara Desert would begin to expand into southern Europe. Furthermore, world food supplies would be imperiled, driving major refugee flows and a growing risk of civilizational collapse (2.3). Because annual emissions accumulate in the atmosphere, it also matters how much carbon dioxide (CO_2) is emitted on the way to 2050.

Intermediate targets are useful, because they help demonstrate progress; however, the data indicates that the world as a whole is not. The earth is already 1.1°C warmer than it was before fossil fuel combustion took off in the 19th century. At the current rate of warming, achieving the 2030 target is no longer a realistic possibility. Instead of decreasing, annual emissions have increased from 2010.

Current climate commitments are insufficient. Thus far, no country is even on track to meet their commitments. In February 2022, a new report published by the Intergovernmental Panel on Climate Change found that deep divisions between rich and poor nations and within societies will determine people's ability to withstand the worst effects of climate change—with huge implications for global politics (2.4). The divisions will worsen if countries fail to rein in greenhouse gas emissions, but there are already steep challenges. The Intergovernmental Panel on Climate Change report underscores that the countries facing the worst climate impacts are those that have historically contributed the least to global warming—and have the fewest resources to help themselves to adapt. Speaking about the report findings, Antònio Guterres, United Nations Secretary-General, said: "I have seen many scientific reports in my time, but nothing like this..." He called the findings "an atlas of human suffering and a damning indictment of failed climate leadership."

> "Climate justice is really the key dimension of the new report. The idea that clearly the most vulnerable people—just about half of humankind—are living in regions that are really highly exposed to climate impacts."
>
> — François Gemenne, Lead Author and Director of Belgium's Hugo Observatory

THE IMPERATIVE FOR A PROFOUND TRANSFORMATION

Climate change is, by and large, an energy problem. The energy sector (electricity, industry, and transportation) presently accounts for nearly three-quarters of global emissions. The world must reduce annual emissions to net zero in less than three decades. This means we must replace all emitting sources of energy we use with clean, non-emitting energy sources by 2050, while also introducing CO_2-removal technologies such as direct air capture, which extracts CO_2 directly from the atmosphere (2.5).

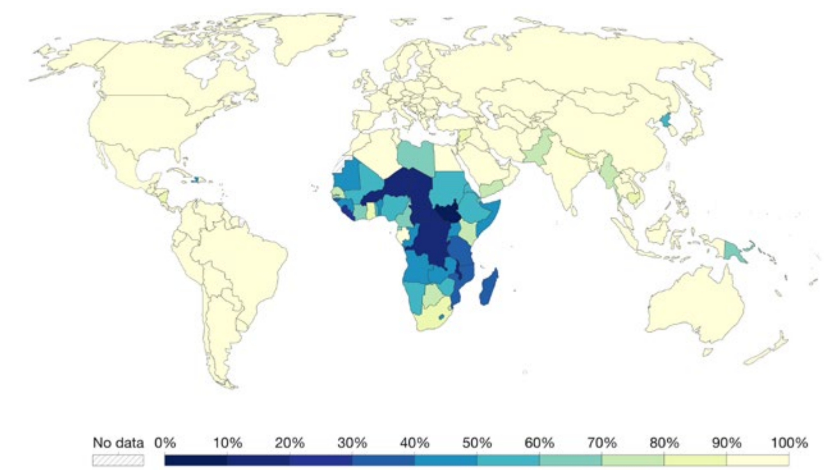

Figure 2- 1. Access to electricity in 2020 (2.12)

However, the imperative for a profound transformation requires not just a shift away from polluting energy sources toward sustainable alternatives, but also expanded access to clean energy for all of humanity and in support of socioeconomic development, especially in emerging economies. All this must happen while simultaneously limiting the impacts of climate change, pollution, and other unfolding global environmental crises. The sequencing and time-sensitivity for achieving net zero involves a massive, simultaneous infrastructure buildout in every country. An unprecedented logistical challenge, we must not only build enough clean electricity generation to power the world, but do so quickly, all while building the infrastructure required to decarbonize end-use sectors such as heat, industry, and transport.

In addition to decarbonizing heating for residential, commercial, and industrial purposes, we must produce hydrogen and synthetic fuels to support a transition in transport and address the difficult-to-decarbonize sectors of aviation and shipping. Furthermore, desalinating seawater in regions suffering from water scarcity and ensuring access to modern energy services in remote and developing communities are all essential components of a just energy transition. Rapid reductions in emissions cannot come at the cost of the future prosperity of developing nations. Access to modern energy is directly related to development, quality of life, opportunity for education, increased life expectancy, and reduced maternal and child mortality rates. Higher levels of development will also make people less vulnerable to the negative effects of climate change.

We are faced with an "energy trilemma": energy not only needs to become clean, but also affordable and reliable. These three elements are critical to averting global catastrophe and meeting fundamental needs like health care, welfare, education, and security, while enabling every country to share in global prosperity. The United Nations Sustainable Development Goals call for rapidly and cohesively addressing each of these societal needs (2.6). Today, most of the world's population lives in countries in which more than 90% of people live on less than $30 per day (adjusted for purchasing power parity). An analysis by Our World in Data suggests that the global economy would need to increase fivefold to substantially reduce poverty (2.7).

Africa currently contributes about 3% to global emissions but is one of the regions hit worst by climate change. If Africa were to use all its known reserves of natural gas, the cleanest transitional fossil fuel, its share of global emissions would rise from a mere 3% to 3.5% (2.8).

> "Don't tell Africa that the world cannot afford the climate cost of its hydrocarbons and then fire up coal stations whenever Europe feels an energy pinch."
>
> — Mr. Buhari, President of Nigeria

Global access to electricity has increased since 2010, but wide regional disparities remain (Figure 2- 1). Variations in regional and national per-capita emissions partly reflect different development stages, but emissions also vary widely at similar income levels. The 10% of households with the highest per-capita emissions contribute a disproportionately large share of global household greenhouse gas emissions (2.9). The 20 countries with the largest access deficits were home to 76% of the entire global population (mostly in sub-Saharan Africa) living without access to electricity in 2020 (Figure 2- 1). Closing the access gap by 2030 hinges on electrification efforts in these countries (2.10). Enhanced mitigation and broader action to shift development pathways toward sustainability are expected to have positive distributional consequences within and between countries (2.11).

ENABLING A JUST ENERGY TRANSITION

Enabling a just energy transition requires that key environmental justice and equity issues be addressed. These include:

1. Distributional impacts: It is crucial to ensure that the benefits and burdens of the clean energy transition are fairly distributed. Efforts should be made to avoid exacerbating existing disparities and ensure that clean energy benefits reach all communities. Historically marginalized regions and communities, such as those in rural or remote areas, should not be left behind and should have equal access to the benefits of clean energy, including improved air quality, job opportunities, and affordable energy solutions.
2. Access to clean energy: Affordability and accessibility can be a challenge for disadvantaged communities, including those in emerging economies, islanded nations, and remote areas. Efforts should be made to address energy poverty by implementing initiatives that provide affordable and reliable clean energy solutions to these communities.
3. Workforce and economic opportunities: The clean energy transition should prioritize inclusive economic growth and job creation in all communities. This includes supporting workforce development and providing training programs and job opportunities in clean energy sectors. It is particularly important to ensure that communities reliant on traditional industries, such as fossil fuels, are not left behind and have opportunities for a just transition.
4. Community engagement and decision-making: Meaningfully engaging communities in the decision-making processes related to clean energy projects is essential. This includes involving diverse perspectives, considering local knowledge and needs, and fostering transparent and inclusive discussions. Communities should have a say in shaping the clean energy transition to ensure their specific concerns and interests are considered.
5. Environmental health and pollution: The clean energy transition should prioritize improving environmental health and reducing pollution in all communities. Efforts should be made to avoid the unintended concentration of environmental hazards and ensure that all communities benefit from improved air and water quality as a result of the transition.

Addressing these environmental justice and equity issues in diverse communities, including rural, global, emerging economies, islanded nations, and remote areas, is crucial for a successful and inclusive clean energy transition that benefits all segments of society and leaves no community behind.

The energy transition presents challenges as well as opportunities. For example, in the labor market, the International Energy Agency (IEA) has indicated that the transition toward net-zero emissions will lead to an overall increase in energy sector jobs (Figure 2- 2). The IEA has set out the Net-Zero Emissions by 2050 scenario, which shows a pathway to achieving net zero by 2050. In this scenario, it is estimated that 30 million new jobs could be created in clean energy, efficiency, and low-emissions technologies by 2030, while 5 million jobs would be lost in fossil fuel production over the same period (2.13).

Managing the clean energy transition is about much more than simply replacing one kind of energy generation for another. A massive program of reskilling, training, and professional development will be required to ensure the future workforce is ready to build, maintain, and operate the new energy infrastructure required for production, storage, transport, distribution, and end uses. Existing fossil fuel-based global energy infrastructure has been developed within complex social, political, and economic ecosystems, upon which communities, and whole economies, depend. Disrupting these complex systems to achieve large-scale change is likely to be met by intense resistance. A holistic view will be required to understand and work with the multiple dynamics at play. With just 27 years to 2050, it is essential to mobilize our collective technological, financial, governmental, and industrial capabilities to meet the task of bringing the climate crisis under control.

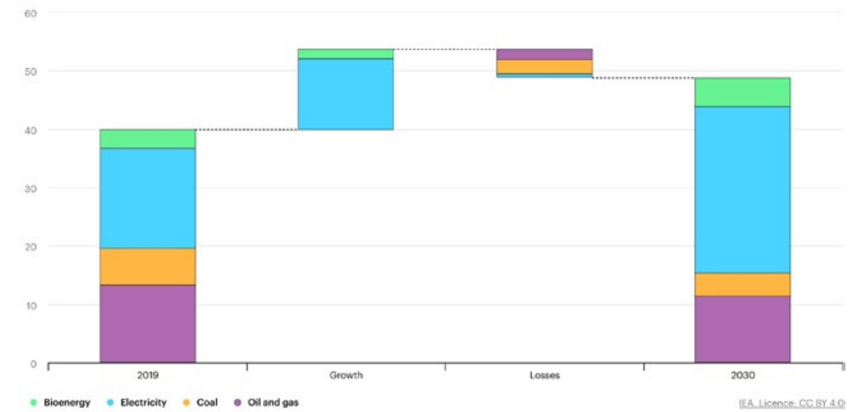

Figure 2- 2. Global employment in energy supply in the Net-Zero Emissions scenario, 2019–2030 (2.14)

TRANSITIONING COAL IS ESSENTIAL TO A JUST ENERGY TRANSITION

Coal energy is the largest component of the existing fossil fuel-based global energy infrastructure that must be reimagined as part of a just energy transition. Coal plants are the single-largest source of carbon emissions on the planet. As of 2022, the world has more than 2 terawatts (TWe) of coal-fired electric power plants, adding roughly 12 gigatons of CO2 emissions per year. In Europe alone (excluding countries that oppose nuclear or are phasing it out), 34 GWe of installed coal capacity, or 32% of the total, is made up of plants with 50 MW to 700 MW of capacity (2.15). Countries in Africa are also heavily dependent on coal to power their economies.

It is also worth noting that coal plants are, on average, relatively young assets (14 years old) that provide reliable energy and wealth generation to local communities. Closing down these assets that have decades of usable life is challenging from an economic perspective, especially considering growing energy demand and supply shortages—even more so during the current global energy crisis resulting from Russia's war against Ukraine. There is currently $1 trillion of unrecovered capital in the global coal fleet.

In South Africa, for instance, coal-fired power plants are the primary source of energy. In summer 2022, the urgent energy crisis in South Africa, which resulted in rolling blackouts, sparked new public discourse around advanced heat sources as a potential clean energy solution. At the same time, the debate to decommission coal plants in South Africa is becoming more heated as European countries delay their decommissioning plans due to growing energy needs.

COAL TO CLEAN ENERGY WITH NUCLEAR POWER

Nuclear energy's attributes, notably its low emissions, dispatchability, and flexibility, will boost its value to electricity systems as they are progressively decarbonized. In particular, dispatchability will become increasingly valuable in grids with high penetrations of variable renewables. Nuclear energy can also provide much-needed emissions-free heat as well as potentially low-cost, large-scale, emissions-free hydrogen production (2.15).

An established body of knowledge exists surrounding flexible operation of nuclear plants, which the NICE Future Initiative has gathered within its Flexible Nuclear Campaign (2.16). Off-grid applications, such as providing heat and power to remote communities and industries (e.g., mining), are examples of additional high-value applications for nuclear energy. SMRs, for example, could be coupled to thermal energy storage systems or hydrogen production to further increase value and flexibility (2.17). SMRs are being designed for factory fabrication and use of modular construction techniques, which should also lead to lower costs and reduced construction schedules (2.15).

Another attribute of both traditional and advanced nuclear is the potential to repurpose coal plant sites. Coal-fired power plants can be repowered with advanced nuclear heat sources to ensure the equivalent production of electricity for the grid, with a similar footprint as the existing plant (see Figure 2- 3 and 2- 4) (2.19).

The opportunity to repurpose coal plants facing closure can contribute to a just transition. These sites offer enormous value due to (2.20; 2.21):

- Established power markets
- Existing grid connections, which reduce the need to build new transmission (access to the grid is set to become increasingly important as more distributed power generation grows with the increased penetration of solar photovoltaic and wind power).
- Cooling water access
- Real estate holdings
- Experienced site personnel (i.e., leverage the established skills and workforce available). Plus, these repurposed power plants and their surrounding communities would benefit from:
    - Continued use of existing energy storage distribution and end-use infrastructure to produce drop-in substitute fuels, leveraging the enormous skills and capability within the global oil and gas sector to de-risk our approaches
    - Expansion of the energy services around that plant, attracting other industries
    - Retaining jobs with the opportunity for skills transfer
    - New job opportunities (e.g., a

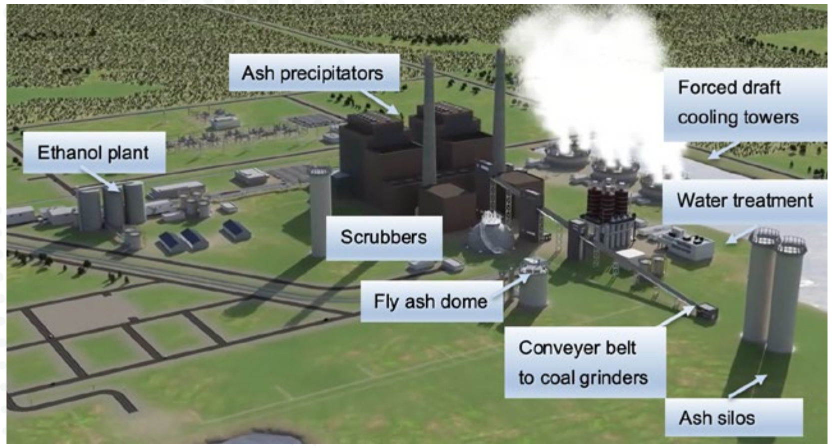

Figure 2- 3. Rendering of an existing coal plant. Graphic from Terra Praxis, 2022.

repurposed coal plant will require 250 workers for its day-to-day activities). (2.22)

- Opportunities for skilled and higher-paying jobs, such as reactor operators or radiation protection technicians that do not have a coal-fired power plant equivalent (e.g., the median hourly wages for on-site SMR jobs would pay a premium of approximately 17% relative to the equivalent position at a coal plant.) (2.23).

Several countries have started to analyze the potential to repurpose coal-fired power plants with clean heat sources to avoid the consequences of phasing them out. Poland, for example, is considering the use of nuclear power to repurpose its coal assets as they begin planning their nuclear program. To determine whether Polish coal plants could be repurposed, a detailed study (2.25) was undertaken to characterize Polish coal units in terms of age, steam conditions, sites, site sizes, and the kind of retrofit that would be suitable. The study concluded that about half of the coal fleet in Poland could be suitable for repurposing and that the most effective way would be to replace the coal burner itself with a zero-carbon heat source. The most appropriate technical fit would be a high-temperature nuclear reactor or a high-temperature geothermal heat source.

The study also shows the feasibility of retaining much of the equipment on-site, which would save about one-third of the cost of a new nuclear plant, a 30%–35% reduction in total plant capital expenditure, and reduce construction time substantially. Furthermore, 60%–70% of the local workforce could be retained.

Figure 2- 3 shows an existing coal-fired power plant, while Figure 2- 4 shows the proposed repurposed plant with nuclear energy—retaining large parts of the existing infrastructure (Figure 2- 3 identifies the components of the existing coal power plant).

BRIDGING THE GAPS

One challenge of the clean energy transition is the scale of infrastructure that must be built, with respect to supply chain, materials, land use, and public acceptability.

Reducing emissions while ensuring a just transition, providing energy security, and increasing access to electricity requires (2.15):

- A market framework that adequately values both low emissions generation and the full range of electricity system services
- Electricity markets designed to ensure that the economic value of nuclear power, alongside other low-emissions technologies, is fully reflected in price signals
- Systems modeled with the whole suite of potential pathways, including repurposing coal-fired power plants
- A change from the usual nuclear development and deployment models—moving from bespoke design engineering and a traditional construction project each time to a standardized manufacturing-based product
- The repurposing of as much of the existing infrastructure as possible, such as transmission lines
- Consultation groups with all relevant stakeholders included from the start, such as the government, regulators, industry, nongovernmental organizations, and the local and indigenous communities
- Consideration of the community's concerns and suggestions, encouraging their participation in the decision-making process and allowing them take part in the potential economic opportunities provided by a new clean energy project
- Training and education programs for new job opportunities.

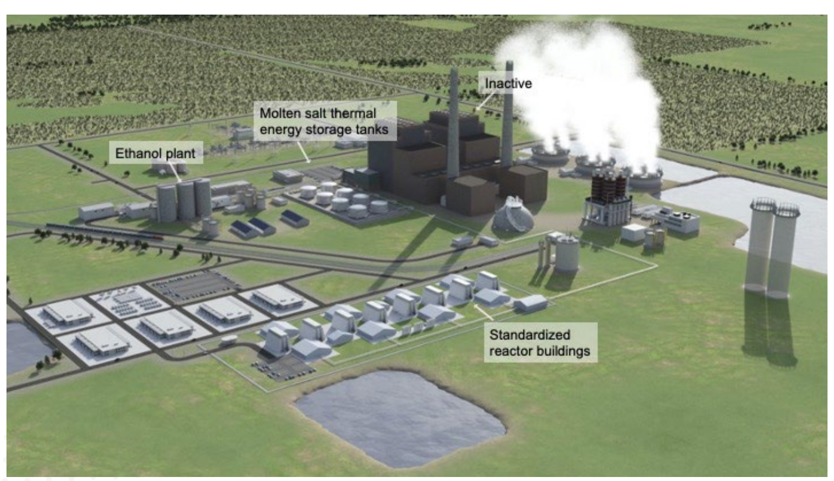

Figure 2- 4. Rendering of a repowered 1,200-MWe two-steam-unit plant (2.24). Graphic from Terra Praxis, 2022.

Finally, we must be asking the right questions, like:

- How can we reach net zero at the required scale and speed while considering constraints in terms of existing infrastructure, land availability, weather conditions, technology availability, financing mechanisms, and workforce readiness?
- What zero-carbon emission solutions are available or under development, including all technologies, rather than focusing only on renewable energy?
- What are the risks to the deployment for each technology option?
- How can we make the most of the existing infrastructure, rather than building from scratch and decommissioning young assets?
- How can we leverage the huge investments and enormous infrastructure, skills, human resources, capabilities, and capital we already have in our system to transform it, rather than focusing on demand-side changes?

MOVING IN THE RIGHT DIRECTION

Several steps are being taken in the right direction. For example, when Canada started drafting its SMR road map in 2019, it involved all the stakeholders from the start. Together, they developed several targets, goals, and objectives that would enhance the engagement and amplify potential economic opportunities. This created a safe ethical space, based upon traditional values and knowledge and where indigenous viewpoints and worldviews were not only accepted but valued and integrated into the decision-making process and follow-on development processes. Canada offers many collaboration opportunities concerning funding for indigenous participation in SMR projects.

The U.S. government launched the Justice40 Initiative to ensure that disadvantaged communities receive the benefits of new and existing federal investments to advance environmental justice. Specifically, 40% of investment benefits and 40% of jobs must go to local communities, and community stakeholders must be meaningfully involved in determining program benefits (2.26; 2.27).

The U.S. Department of Energy has also issued several announcements regarding funding for the energy transition. In November 2021, the Loan Program Office indicated that $11 billion is available in loan financing to repower existing coal infrastructure with advanced nuclear reactors to accelerate the transition (2.28). At the same time, the Department of State launched the Nuclear Futures package, which provides $25 million to support expanding access to clean nuclear energy for capacity building, equipment, feasibility and siting studies, demonstration projects, study tours, site visits, and technical collaboration. This package includes support for partnerships with Poland, Kenya, Ukraine, Brazil, Romania, Indonesia, and others to help countries make progress toward meeting their nuclear energy goals (2.29).

Similarly, the governments of South Africa, France, Germany, the United Kingdom, and the United States, along with the European Union, announced the launch of the Just Energy Transition Partnership to support South Africa's decarbonization efforts (2.30). The program includes an initial commitment of $8.5 billion for the first phase. It is expected to prevent as much as 1 to 1.5 gigatons of emissions over the next 20 years as it supports South Africa's move away from coal and accelerates its transition to a low-emission, climate-resilient economy.

Much like countries came together to address the COVID-19 pandemic by getting vaccines ready in months instead of years, these examples demonstrate that when matters are addressed with the urgency they require, we are able to organize and find solutions by working together.

It is high time we address climate change with the global-scale urgency it requires by bringing together new voices with different perspectives and the same sense of urgency and motivation.

REFERENCES

2.1. United Nations. "The Paris Agreement." Accessed July 2022. https://unfccc.int/process-and-meetings/the-paris-agreement.

2.2. United Nations. "For a livable climate: Net-zero commitments must be backed by credible action." Accessed September 2022. https://www.un.org/en/climatechange/net-zero-coalition.

2.3. Lucid Catalyst. 2020. Missing Link to a Livable Climate. https://www.lucidcatalyst.com/hydrogen-report.

2.4. IPCC (Intergovernmental Panel on Climate Change). 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi:10.1017/9781009325844. https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf.

2.5. IEA. 2022. "Direct Air Capture." https://www.iea.org/reports/direct-air-capture.

2.6. United Nations. "Sustainable Development Goals." Accessed July 2022. https://sdgs.un.org/goals.

2.7. Roser, Max. 2021. "How much economic growth is necessary to reduce global poverty substantially?" Our World in Data. March 15, 2021. https://ourworldindata.org/poverty-minimum-growth-needed.

2.8. Okafor, Chiamaka. 2022. "Climate Change: Western countries are hypocrites, can't dictate to Africa." Premium Times. November 11, 2022. https://www.premiumtimesng.com/news/headlines/564715-climate-change-western-countries-are-hypocrites-cant-dictate-to-africa-buhari.html.

2.9. IPCC. 2022. "Summary for Policymakers." In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg3/chapter/summary-for-policymakers/.

2.10. ESMAP. 2022. TRACKING SDG 7: The Energy Progress Report 2022. https://trackingsdg7.esmap.org/data/files/download-documents/sdg7-report2022-executive_summary.pdf.

2.11. Intergovernmental Panel on Climate Change, 2022

2.12. Our World in Data. "Electricity access, 2020." Accessed 2022. https://ourworldindata.org/grapher/share-of-the-population-with-access-to-electricity.

2.13. Cozzi, Laura, and Brian Motherway. 2021. "The importance of focusing on jobs and fairness in clean energy transitions." IEA. July 6, 2021. https://www.iea.org/commentaries/the-importance-of-focusing-on-jobs-and-fairness-in-clean-energy-transitions.

2.14. IEA. 2021. "Global employment in energy supply in the NZE Scenario, 2019-2030." https://www.iea.org/data-and-statistics/charts/global-employment-in-energy-supply-in-the-net-zero-scenario-2019-2030.

2.15. IEA. 2022. Nuclear Power and Secure Energy Transitions. Paris, France: IEA. https://iea.blob.core.windows.net/assets/0498c8b8-e17f-4346-9bde-dad2ad4458c4/NuclearPowerandSecureEnergyTransitions.pdf.

2.16. NICE Future Initiative Flexible Nuclear Campaign (September 2020) — https://www.nrel.gov/docs/fy20osti/77088.pdf.

2.17. Clean Energy Ministerial. 2020. Flexible Nuclear Energy for Clean Energy Systems. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A50-77088. https://www.cleanenergyministerial.org/content/uploads/2022/06/flexiblenuclear-energy-for-clean-energy-systems-2020.pdf.

2.18. IEA, 2022, Nuclear Power and Secure Energy Transitions — https://iea.blob.core.windows.net/assets/0498c8b8-e17f-4346-9bde-dad2ad4458c4/NuclearPowerandSecureEnergyTransitions.pdf.

2.19. IEA, 2022

2.20. IEA, 2022

2.21. RISE^2 Webinar. "Nuclear Energy Innovations — Supporting Global Communities." March 22, 2022. https://youtu.be/fSk4BGlkm34?si=AuGIDN8i7lRCeYrw.

2.22. TerraPower. 2021. "TerraPower selects Kemmerer, Wyoming, as the preferred site for advanced reactor demonstration plant." November 16, 2021. https://www.terrapower.com/natrium-demo-kemmerer-wyoming/.

2.23. Downer, Will, and Chris Vahoplus. 2021. Gone with the Steam White Paper. Scott Madden Management Consultants. https://www.scottmadden.com/insight/gone-with-the-steam/.

2.24. Terra Praxis. 2022. www.terrapraxis.org.

2.25. Qvist et al. 2021. "Retrofit Decarbonization of Coal Power Plants—A Case Study for Poland." Energies 14(1): 120. https://www.mdpi.com/1996-1073/14/1/120/s1.

2.26. The White House. "Justice 40." Accessed July 2022. https://www.whitehouse.gov/environmentaljustice/justice40/.

2.27. Jerome Foster II at Terra Praxis Energy Day. 2021. https://youtu.be/Lq1ow-nF0t0.

2.28. Jigar Shah at Terra Praxis Energy Day. 2021. https://www.terrapraxis.org/events/de-risking-the-terawatt-transition.

2.29. IEA. 2022. "From today's challenges to tomorrow's clean energy systems." https://www.state.gov/the-united-states-announces-25-million-to-support-access-to-clean-nuclear-energy/.

2.30. European Commission. 2021. "France, Germany, UK, US and EU launch ground-breaking International Just Energy Transition Partnership with South Africa." November 2, 2021. https://ec.europa.eu/commission/presscorner/detail/en/IP_21_5768.

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REPOWERING 2 TW OF PHASED-OUT COAL BY 2050 WITH CLEAN NUCLEAR ENERGY

THIS WORK WAS AUTHORED AS PART OF THE NICE FUTURE INITIATIVE IN COLLABORATION WITH TERRA PRAXIS.

THE CHALLENGE

In 2015, the world came together to sign the Paris Agreement (12.1), which states that, to limit global warming to 1.5°–2°C above pre-industrial levels and maintain Earth as a livable planet, we must reach net-zero emissions by 2050 at the latest.

More than 2,000 GW worth of coal-fired plants are operating in the world today, generating roughly 15 billion tons of CO_2 emissions per year. Should the coal fleet keep operating unabated, its emissions alone would exceed the 2°C commitment in the Paris Agreement. Mainstream climate thinking risks making an unrealistic assumption that countries will simply shut down their unabated coal plants (12.2). Most coal plants are young assets, and more than half are less than 15 years old (12.3). These plants deliver around 37% of global electricity supply and provide jobs, tax revenue, reliability to the electric power grid, and an enormous amount of electricity and industrial heat to drive economic growth. It is unclear whether these same benefits can be supplied by renewables, energy storage, or clean hydrogen. Land availability, transmission, and investment requirements also represent serious constraints to the clean energy transition being achieved at the necessary scale, cost, and speed.

THE OPPORTUNITY

Repowering coal fleets with clean generation offers a fast, low-risk, large-scale contribution to decarbonizing the world's power generation. Installing advanced heat sources, such as SMRs, to replace the coal-fired boilers at existing coal plants enables the continued use of existing infrastructure for emissions-free electricity generation. By sustaining permanent high-quality jobs for communities, repowered coal plants reduce the negative impacts on communities to help enable public and political support for a just transition. It also reduces the overall global investment required to transition to clean energy. As shown in a recent study by Scott Madden (12.3), aside from the difference in how steam is generated, a nuclear power plant is remarkably similar to a coal plant.

> "The actual transferability of skills is amazing between a coal plant and a nuclear plant. At the heart of it, what a nuclear plant does is boil water differently."
>
> – Maria Korsnick, President and CEO of the NEI4 (12.4)

The Clean Energy Ministerial's NICE Future Initiative, under its RISE^3 campaign, is convening governmental, industry, and nonprofit partners to examine practical solutions to decarbonization. The NICE Future partner organizations are looking into ways to accelerate coal plant repurposing.

For example, the nonprofit Terra Praxis is leading a REPOWER Consortium to repower coal plants with emissions-free heat sources at the speed and scale necessary to outcompete fossil fuels. REPOWER's radical innovation is a building system that consists of standardized, pre-licensed parts designed for manufacture which can be reconfigured to accommodate various regulatory requirements, heat sources, sites, and energy/heat demands. It uses

a standardized heat transfer system and is designed to 'plug in' to existing plant infrastructure, reducing design work and costs. A seismic isolation system allows for multiple sites of varying seismic risk. The target cost of the system is $2,000/kWe. Target schedule is 5 years. REPOWER also includes a partnership with Microsoft

to provide AI and digital tools to quickly evaluate the business case for repowering a plant (EVALUATE); or reduce cost/time for licensing and permitting applications. The Gateway for Accelerated Innovation in Nuclear (12.6) and INL are conducting extensive research and providing support in feasibility analysis to repurpose coal plants in the United States. For example, a case study for the Colstrip site in Montana concludes that it is a potential location to transition from coal to nuclear. Colstrip (12.7) presents several attractive factors—like the benefits to the local community in terms of jobs and tax base.

This transition would provide a clean, firm, dispatchable form of electricity that can make use of the existing infrastructure, such as the grid connection and the cooling system (depending on which type of reactor design chosen).

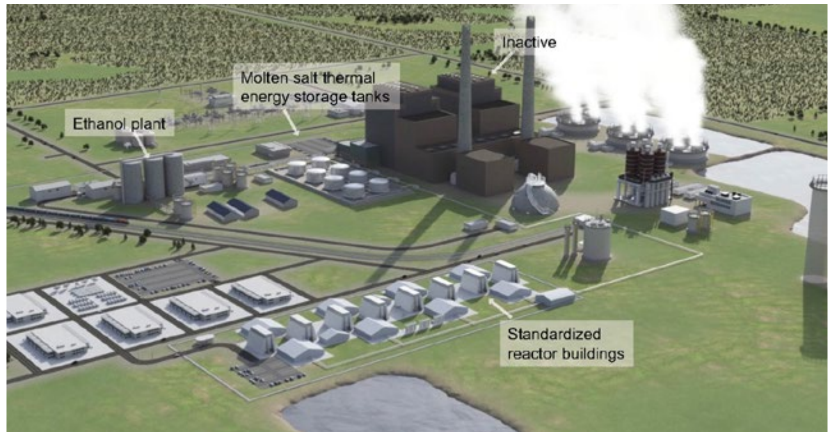


Figure 12- 1. Repowering coal case study of Coal Creek Station, conceptual repowering of a two-steam-unit, 1,200-MW electric plant with eight advanced reactors and thermal storage (turbine halls and storage units in the foreground). Image credit: Terra Praxis.

THE BENEFITS

- Opportunity to accelerate and de-risk the clean energy transition while reducing the overall scale of investment required.
- Large public health benefits associated with eliminating coal-fired boilers and the associated pollution from toxic coal ash.
- Continued affordable, reliable, grid-scale electricity generation to support regional and national economic well-being and prosperity, without emissions.
- Advanced nuclear plants are expected to hire more professionals at a higher wage than the coal plants and with the potential to be long-lasting jobs (12.8). A case study from the U.S. Department of Energy has found that replacing 1,200 MWe of coal capacity with 924 MWe of nuclear capacity would create 650 additional and permanent jobs to the region (12.9).
- The increase in job opportunities, in turn, fosters economic growth in the local community around the power plant maintaining or even enhancing tax revenues (12.8).
- Potential for new energy services such as clean hydrogen production, heat supply, and direct air capture of CO_2.

NEW DIGITAL PLATFORM

Coal-fired power stations could, depending on the case, be replaced by nuclear reactors (both large and SMRs), ensuring the equivalent production of electricity into the grid. Various initiatives can facilitate the fast, low-cost, and repeatable replacement of coal-fired plants with SMRs (12.11) such as standardized and prelicensed designs supported by automated project development and design tools with a set of purpose-driven digital applications and data exchange infrastructure for the building system to standardize and optimize:

- Site assessment and repowering feasibility
- Procurement, investment, and regulatory approval
- Construction and engineering systems
- Design, manufacture, assembly, and operation
- Increased collaborative interactions between supply chain organizations.

These applications are being developed to compress plant design and engineering from years to months or weeks and to leverage proven and demonstrated innovations in other sectors (12.12).

This large-scale solution to the world's largest single source of carbon emissions could repurpose trillions of dollars of existing infrastructure to continue supplying reliable energy without emissions and could advance ground-breaking progress toward net zero by 2050.

> "With these [advanced nuclear]

technologies now maturing, the next horizon is about their deployment, which is really a bridge to bankability for nuclear. And that's to me what we're really talking about here today, which is that we need a phased approach to the deployment of new nuclear that prioritizes speed to market."

– Jigar Shah, Director of the Loan Programs Office at the U.S. Department of Energy (12.10)

REFERENCES

12.1. Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement.

12.2. Drawing on public sources, Terra Praxis aggregated a global data set that allows you to explore information about coal plants across the globe. https://www.terrapraxisrepower.com/The-Platform/Global-Plant-Data/.

12.3. IEA. "Coal." https://www.iea.org/energy-system/fossil-fuels/coal.

12.4. Gone with the Steam. 2021. Scott Madden. https://www.scottmadden.com/insight/gone-with-the-steam/.

12.5. Maria Korsnick at Terra Praxis' Energy Day at COP26. 2021. https://www.terrapraxis.org/events/de-risking-the-terawatt-transition.

12.6. TerraPraxis. "Repowering Coal System." https://www.terrapraxis.org/projects/repower.

12.7. Gateway for Accelerated Innovation in Nuclear. https://gain.inl.gov/SitePages/Home.aspx.

12.8. Griffith, George. 2021. Transitioning Coal Power Plants to Nuclear Power. Idaho Falls, ID: Idaho National Laboratory. INL/EXT-21-65372. https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_54812.pdf.

12.9. SMR Start To a Clean Energy Future. 2021. The Economics of Small Modular Reactors. https://smrstart.org/wp-content/uploads/2021/03/SMR-Start-Economic-Analysis-2021-APPROVED-2021-03-22.pdf.

12.10. Hansen, J., W. Jenson, A. Wrobel, N. Stauff, K. Biegel, T. Kim, R. Belles, and F. Omitaomu. 2022. Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants. Idaho Falls, ID: Idaho National Laboratory. INL/RPT-22-67964. https://fuelcycleoptions.inl.gov/SiteAssets/SitePages/Home/C2N2022Report.pdf.

12.11. IEA, Nuclear Power and Secure Energy Transitions From today's challenges to tomorrow's clean energy systems, 2022. https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions.

12.12. IEA Nuclear Power and Secure Energy Transitions From today's challenges to tomorrow's clean energy systems, 2022. https://iea.blob.core.windows.net/assets/016228e1-42bd-4ca7-bad9-a227c4a40b04/NuclearPowerandSecureEnergyTransitions.pdf.

12.13. Terra Praxis. "Repowering Coal System." https://www.terrapraxis.org/projects/repower.

Photo from Getty Images 1186617948

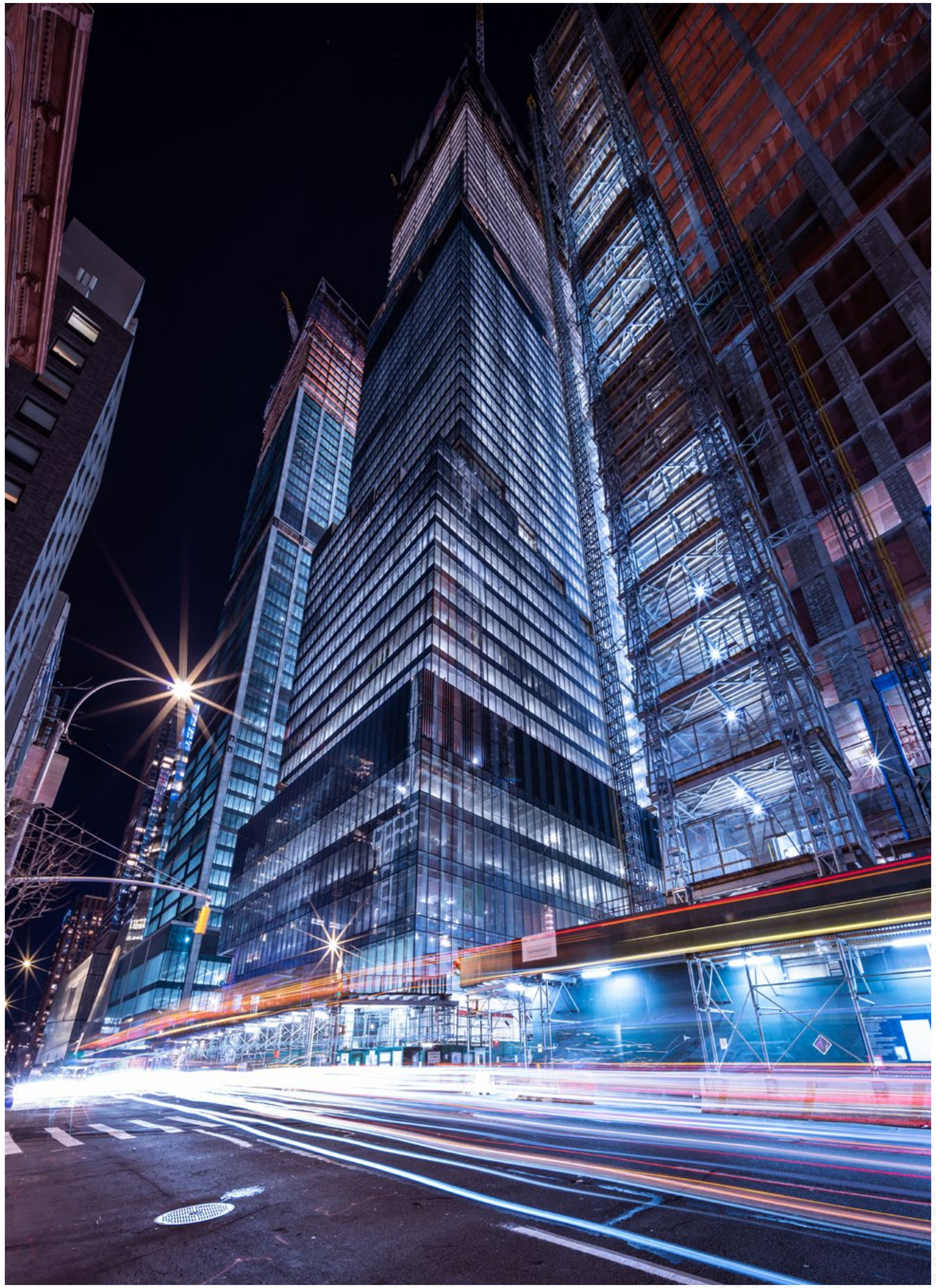


Photo from Getty Images 1356014049

REPURPOSING COAL PLANTS: AN INNOVATIVE WAY FOR LOCAL COMMUNITIES TO THRIVE

THIS WORK WAS AUTHORED AS PART OF THE NICE FUTURE INITIATIVE IN COLLABORATION WITH TERRA PRAXIS.

Climate change is, by and large, an energy problem. More than two-thirds of anthropogenic (human-caused) emissions come from burning fossil fuels for energy and transportation. In the 2015 Paris Agreement on climate change, most nations pledged to try to keep global warming under 2°C or even under 1.5°C (14.1).1 Left unchecked, climate change of 3°C or more will wreak havoc on the world's ecological systems, which would have enormous consequences for people and nature.

The world's energy sector is undergoing a profound transition to achieve these emissions reduction goals and expand access to clean energy in support of socioeconomic development, especially in emerging economies, while at the same time limiting the impacts of climate change, pollution, and other unfolding global environmental crises.

The urgency and scale of the needed emissions reductions cannot come at the cost of the future prosperity of developing nations. Access to energy is a fundamental requirement for socioeconomic development, improved quality of life, education, longer life expectancy, and lower maternal and child mortality rates. Increased levels of wealth and development also reduce people's vulnerability to the adverse effects of climate change.

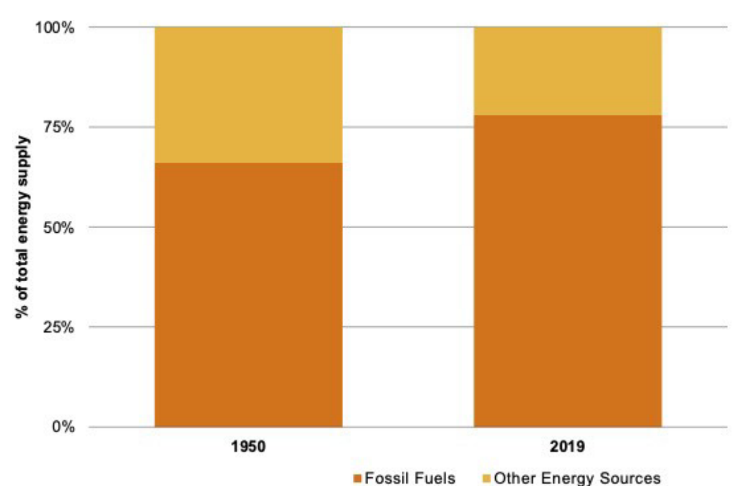


Figure 14- 1. Percentage of energy supply, fossil vs. other, 1950–2019 (14.2)

The challenge of transforming the energy sector can be described as an "energy trilemma."(14.3) It is crucial for energy to not only become clean but also affordable and reliable. These three elements are vital to preventing global catastrophe while meeting basic needs such as health care, welfare, education, and security, while enabling every country to share in global prosperity.

The United Nations Sustainable Development Goals call for a swift and unified approach to addressing societal needs (14.4). Currently, most of the world's population resides in impoverished countries, where over 85% of individuals survive on less than $30 per day (adjusted for purchasing power parity).

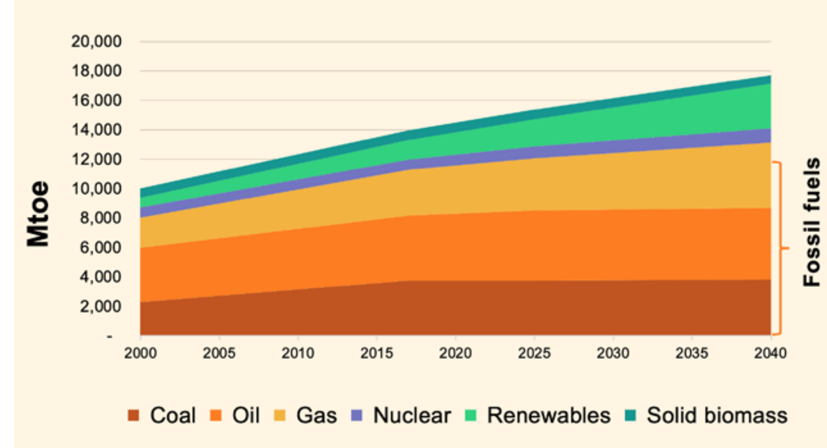


Figure 14- 2. IEA stated policies by scenario: world energy by source (14.2)

Analysis by Our World in Data suggests that the global economy would need to expand fivefold to achieve a significant reduction in poverty.

A transition from polluting energy sources to sustainable alternatives is necessary to ensure that these goals are met. According to most 1.5°C pathways, a 45% reduction in annual emissions from 2010 levels is needed by 2030.6 Annual emissions have instead increased from 2010 to 2019, making it impossible to reduce emissions rapidly enough to achieve the desired goal.

Coal-fired power plants are the primary source of global CO2 emissions, resulting in immense pressure to close them down.

However, many of these power plants are relatively new assets (less than 15 years old) and have the potential to operate for another 50 years. In addition to providing reliable energy access, these power plants also generate employment opportunities and contribute to socioeconomic development.

Furthermore, new coal power plants are under construction or in the planning stages in several developing countries, particularly in Southeast Asia and Africa. Halting the operation or canceling the construction of these coal plants would have a significant impact on the growth and development of regional economies. Many of these countries are already exposed to the impacts of climate change and urgently need new energy infrastructure to strengthen their resilience against increasing risks.

Currently, coal remains a crucial energy source and driver of economic growth in both developed and developing countries. Despite international climate agreements to "phase down" the use of coal (14.8). Global consumption of coal has reached unprecedented levels, contributing almost one-third of global net annual CO2 emissions.

The RISE^3 campaign within the NICE Future Initiative, under the Clean Energy Ministerial, together with its partner organizations and member countries, seeks to address these challenges.

RISE^3 is exploring the potential to repurpose retired coal plant sites with carbon-free, reliable, and resilient clean energy sources, such as nuclear energy. This would enable local communities that depend on coal plants for employment and tax revenue to continue to thrive. Closing these plants would result in job losses and economic stagnation for surrounding communities, losses of trillions of dollars of infrastructure investments, and reduce availability of reliable and resilient energy and transmission.

BENEFITS OF REPURPOSING COAL

Repurposing coal plants can enable a just transition in communities and provide many benefits, including: (14.10)

- Workforce retention due to high skills transferability
- Creation of new, well-paid jobs
- Potential developmental paths for current coal plant workers where there are no equivalent jobs nuclear power plant (e.g., reactor operators and radiation technicians)
- Higher salaries relative to coal plant job equivalents
- Establishment of long-term jobs (more than 40 years)
- Maintenance and growth of a vibrant local economy
- Growth of local tax revenue
- Encouragement of outside investment (e.g., govern-ments, corporations.

REPURPOSING COAL PLANTS FOR A JUST TRANSITION

Governments and utilities around the world are exploring the potential for emissions-free heat sources (such as SMRs) to replace coal boilers at retired coal plants. Replacing the coal boiler with a new source of heat can enable continued operation of the power plant with a new supply of clean steam, eliminating harmful air pollution and other environmental impacts from coal while maintaining employment and community benefits.

CLIMATE STRATEGIES WITH ENVIRONMENTAL JUSTICE AT THE HEART

A just transition should enhance human well-being, health, and capabilities; increase resilience; drive innovation toward a sustainable society at all levels; and spur economic growth and prosperity. Increasing access to clean, reliable, and affordable energy is fundamental for quality of life, health, and well-being and must be at the heart of global strategies to decarbonize global energy infrastructure.

Universal access to affordable clean energy is the focus of the United Nations Sustainable Development Goal 7. Despite some progress in increasing energy access, the Energy Progress Report for Goal 7 indicates that 733 million people still do not have access to energy in 2021, compared to 1.2 billion lacking access in 2010 (14.11). Ensuring a just transition with expanded access to clean energy is a key tenet of the RISE³ mission.

Repowering existing coal plant infrastructure by replacing coal-fired boilers with advanced nuclear energy offers a fast, low-risk path to decarbonizing global power generation.

Repurposing the global coal fleet could enable a just and efficient transition by offering communities that currently depend on coal-fired plants energy, jobs, and tax revenues retention or even improvement upon these critical benefits—providing them with the opportunity to prosper and become indispensable to the emerging clean energy economy.

REFERENCES

14.1. UN Paris Agreement, accessed 2022. unfccc.int/process-and-meetings/the-paris-agreement.

14.2. Our World in Data, 2017 and BP Statistical Review of World Energy, 2022 bp.com/en/- global/corporate/energy-economics/statistical-review-of-world-energy.html.

14.3. World Energy Trilemma Index 2022 (accessed 2022). worldenergy.org/transition-tool- kit/world-energy-trilemma-index.

14.4. UN Sustainable Development Goals. (accessed July 2022) sdgs.un.org/goals.

14.5. Max Roser, "How much economic growth is necessary to reduce global poverty substan- tially?" Our World in Data, 2021. ourworldindata.org/poverty-minimum-growth-needed.

14.6. Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science related to climate change. ipcc.ch/2022/04/04/ipcc-ar6-wgiii-pressrelease/.

14.7. World Energy Outlook 2021, IEA, Paris iea.org/reports/world-energy-out- look-2021, License: CC BY 4.0 iea.org/reports/world-energy-outlook-2021.

14.8. At the 2021 UN Climate Change Conference of the Parties, COP26, world leaders agreed to phase down coal. businessinsider.com/cop26-concludes-with-agree- ment-to-phase-down-coal-2021-11.

14.9. Terra Praxis Inc. render, 2022.

14.10. Scott Madden Gone with The Steam White Paper, October 2021. scottmadden.com/con- tent/uploads/2021/10/ScottMadden_Gone_With_The_Steam_WhitePaper_final4.pdf.

14.11. 2022 Tracking SDG 7 Executive Summary. https://trackingsdg7.esmap.org/.

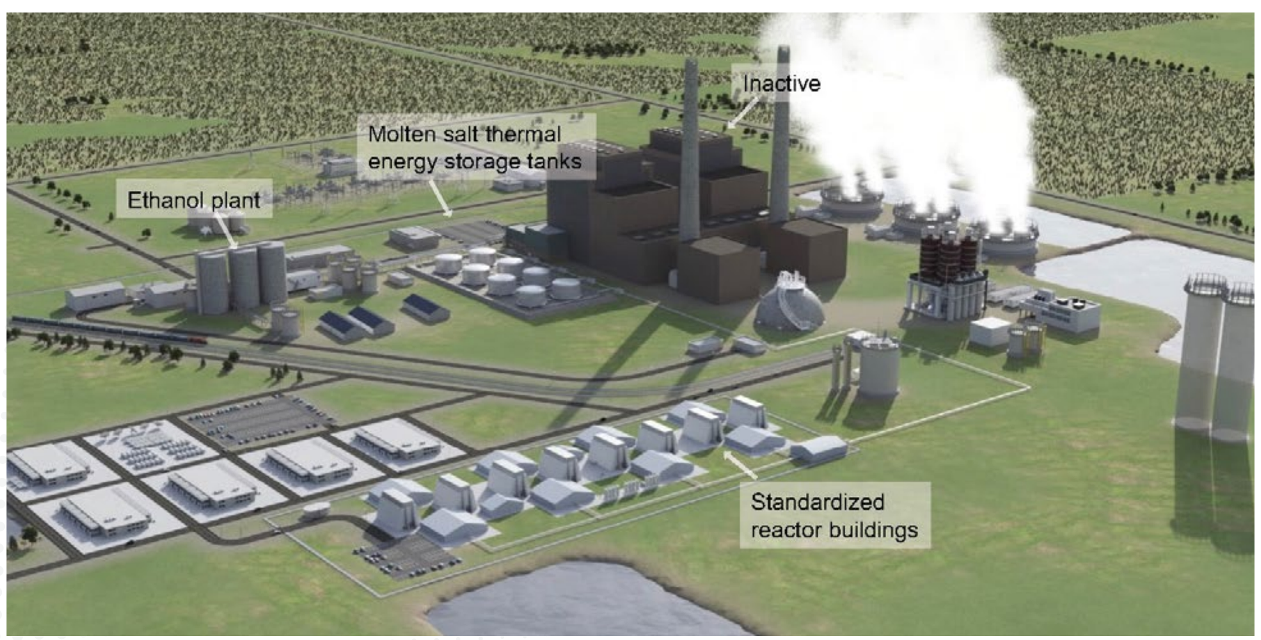
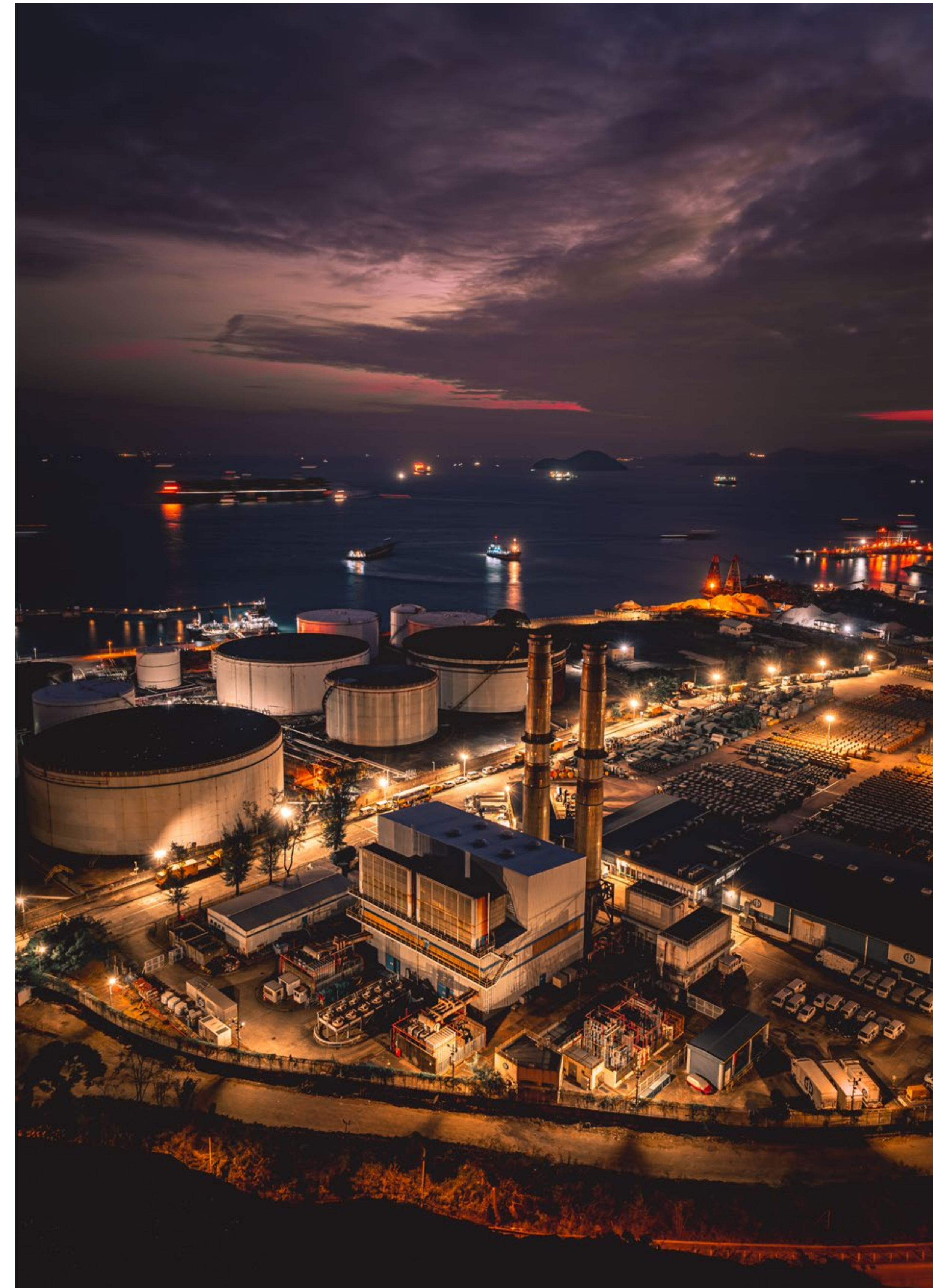


Figure 14- 3. Rendering of a repowered 1,200-MWe, two-steam-unit plant (14.9).



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CLIMATE SOLUTION FACTSHEET: FOUR SOLUTIONS FOR ACHIEVING NET ZERO BY 2050

THIS WORK WAS AUTHORED AS PART OF THE NICE FUTURE INITIATIVE IN COLLABORATION WITH TERRA PRAXIS.

Achieving Net Zero will be difficult, even if we use all zero-carbon energy technologies currently available. The challenge is not only to build enough clean electricity generation to power the world without associated environmental emissions, but to do so quickly while also building the infrastructure required to decarbonize end-use sectors such as heat, industry, and transport.

This NICE Future Initiative RISE³ campaign (15.1) factsheet describes four potential solutions that can help de-risk and accelerate the path to Net Zero (15.2).

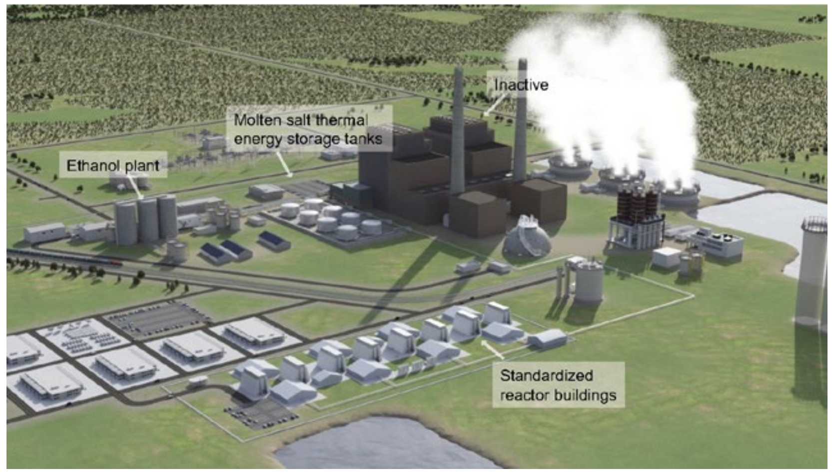

Figure 15- 1. Repowering coal case study: two-steam-unit, 1,200-MWe plant (15.5)

1. REPOWERING COAL

Repowering coal could offer a fast, large-scale, low-risk, and equitable contribution to decarbonizing the world's power generation.

Coal plants currently produce almost one-third of total global carbon emissions (15.3). Repowering the existing coal plant infrastructure is therefore the largest single carbon abatement opportunity on the planet. Repowering coal plants could also enable a just transition to clean energy by sustaining the jobs and local tax revenues associated with existing coal plants and providing larger social, economic, and environmental benefits associated with continued reliable and flexible electricity generation, as well as the continued use of existing infrastructure, including transmission lines—without emissions.

Replacing coal-fired boilers at existing coal plants with carbon-free advanced heat sources (SMRs, including small modular and advanced fission and fusion reactors) means that these power plants can generate carbon-free electricity rather than carbon-intensive electricity. This would quickly transform coal-fired power plants from polluting liabilities facing an uncertain future into jewels of the new clean energy transition—an important part of the massive and pressing infrastructure buildout needed to address climate change.

Converting 5,000–7,000 coal plant units globally between 2030 and 2050 (250–350 per year) will require a redesigned delivery model to meet this rate of deployment. To be successful, the deployment model has to de-risk the construction process, which can be the riskiest part of a project. Purpose-built automated tools can enable rapid, repeatable, and reliable project assessments to de-risk and facilitate initiation and completion of repowering projects.

Repurposing the majority of existing coal plant sites and infrastructure, including transmission, and maintaining the workforce employed today, would dramatically reduce the investments and effort required to site, plan, build, and connect new infrastructure (Figure 15- 1 shows a rendering of a repowered 1,200-MWe plant [15.5]).

Rather than closing these carbon-intensive and polluting power plants, repowering them with advanced heat sources would retain many permanent high-quality local jobs. Overall, repowered coal plants could reduce many of the negative impacts on communities to help enable public and political support for a just energy transition.

2. FLEXIBLE GENERATION

New advanced heat sources can do more than just provide reliable, clean electricity. They can offer added flexibility for power grids, decarbonize heating and industrial processes, and produce low-cost hydrogen and synthetic fuels. A helpful feature of some advanced designs is the separation of the heat source (reactor) from the turbine-generator that produces the electricity (called the power island) via a thermal energy storage and transfer system.

Thermal energy storage systems allow the heat sources to operate continuously at full capacity, while charging the thermal battery energy storage system. This enables the plant to operate flexibly, much like hydro or natural gas plants, enabling higher penetrations of variable renewable energy in support of lower overall system costs and emissions.

Decoupling the heat (nuclear) island from the power island creates other benefits, such as a smaller, more-focused scope for nuclear regulatory oversight, lower relative costs (and construction risks) for the turbine island and balance of plant, a shorter project schedule by leveraging opportunities for parallel construction, and greater overall certainty of cost and schedule.

Flexible advanced reactors—in combination with wind, solar, and hydro—can therefore make a substantial contribution to building reliable, responsive, affordable, and clean energy systems supplying clean dispatchable power-generating capacity.

3. HYDROGEN COGENERATION: ELECTRICITY, HEAT, AND HYDROGEN

Currently, 65% of the energy that nuclear power plants produce ends up in the cooling water (15.8). Cogeneration, or the production of both electricity and heat, can enable the more-efficient and flexible use of power plants.

While a normal power plant can usually turn 35% of the heat it produces into useful energy (electricity), a cogeneration plant can utilize well over 80% of the heat it produces—supplying a combination of electricity, high-quality process steam, and low-quality heat for district heating or desalination. For heat-only plants and applications, the total efficiency is almost 100%. Cogeneration increases flexibility, as it can allow a plant to switch seamlessly between electricity and other applications.

Cogeneration of power and heat, or power and hydrogen, for example, where hydrogen is an intermediate product, can increase the overall efficiency and economics of nuclear plants while decarbonizing heat that can be provided to industry and other heat users.

Heat production, in turn, can be used for other products.

Low-Temperature District Heating

Low-temperature district heating (80–120°C) is a form of cogeneration with only a relatively small effect on electricity generation. A lot of valuable heat that is otherwise rejected to the cooling system can instead be delivered to homes and businesses. Space heating and hot water represent a surprisingly large share of energy use (up to one-third in Europe). District heating offers one solution for reducing carbon emissions by providing space and water heating (and potentially cooling) for a city, town, or district from a large central heating source through a network of pipelines.

Hydrogen and Synfuels

Hydrogen-based synthetic fuels (synfuels) are economically promising "drop-in" alternatives for decarbonizing hard-to-abate sectors such as industry and heavy transport. Hydrogen-based fuels are made by combining hydrogen separated from water with carbon extracted from the atmosphere using carbon capture technology. Hydrogen derived from water electrolysis is emissions-free and entirely renewable, as it is returned to water upon combustion. Today, hydrogen is used in oil refining and ammonia manufacturing, but it is primarily produced using fossil fuels in a process called steam methane reforming, resulting in significant emissions. If clean hydrogen were used to produce synthetic fuels (hydrocarbons or ammonia) on a large scale, these could replace fossil fuels in many sectors that are difficult to electrify, such as aviation and shipping (15.6).

However, getting to costs below $1/kg hydrogen (15.7) within this decade will be a major challenge. The next section describes how new delivery models for advanced heat sources could help achieve these very low hydrogen production costs.

4. DEDICATED HYDROGEN/SYNFUELS PRODUCTION (15.7)

Two strategies are presented here for large-scale low-cost hydrogen and synfuels production with nuclear energy. The first "brings the factory to the project." The second "brings the project to the factory."

The Hydrogen Gigafactory

The refinery-scale hydrogen gigafactory is an "energy park" combined with an integrated manufacturing facility. The strategy is to bring the factory to the project to supply the needed heat and power, equipment, and facilities that can streamline manufacturing, operations, and maintenance. One gigafactory can house dozens of heat sources, which can be manufactured on-site. Each reactor could produce hundreds of megawatts of capacity used for hydrogen production.

For countries developing such refinery-scale facilities, the hydrogen gigafactory represents an opportunity to establish a world-class domestic supply chain capability, the potential to export synthetic fuels, and the potential to achieve affordable decarbonization. Simplified heat source designs and factory setting minimize installation labor costs and enable the application of fast, high-quality manufacturing techniques; streamlined licensing is enabled by reusable designs and repeatable processes in a standardized factory, managed by fixed teams, operating continuously enabling the hydrogen gigafactory to deliver large quantities of very low-cost hydrogen, eventually enabling a path to ultra-low-cost hydrogen at the target price of less than $1/kg (Figure 15- 2).

Figure 15- 2. Rendering of a hydrogen gigafactory. Image by Terra Praxis.

Shipyard-Manufactured Production Platforms

The second strategy for producing cost-competitive hydrogen is the shipyard-manufactured production platform, which brings the project to the factory. This route builds hydrogen production facilities in the form of a ship—at a shipyard. Such ships would be called floating production, storage, and offloading facilities. The proposed form uses onboard high-temperature nuclear reactors to generate heat and electricity, which are integrated with onboard hydrogen production equipment.

The hydrogen produced on the ship can be used to make synthetic hydrocarbons or ammonia, which can be used to fuel marine vessels or transported for other uses. The key innovation is transforming the currently unproductive, risky, and expensive construction-at-place method of delivering facilities to a highly productive shipyard environment.

Floating production ships come with the benefit of offshore siting (Figure 15- 3), adding flexibility. This bring-the-project-to-the-factory approach dramatically improves productivity; adds innovation, modularity, and state-of-the-art manufacturing methods; lowers costs; and makes quality control easier due to the streamlined factory production process, creating easy-to-manage quality checkpoints at different stages while maintaining strict regulation of nuclear power components. Currently, idle shipyard capacity is high around the world. These idle shipyards could provide critical economic development by serving as the basis of a new industry that attracts investment, boosts employment, generates clean energy, and contributes to decarbonization. Floating production, storage, and offloading facilities close to shore could also be configured to produce electricity and desalinated water—enabling low-cost and low-carbon energy services for countries that still lack the necessary institutions and expertise to have domestic nuclear programs.

Decarbonizing Oil and Gas

The rapid achievement of low-cost hydrogen via these innovative delivery models could accelerate deep decarbonization across sectors currently using oil and gas. By 2050, low-cost clean hydrogen could help avoid cumulative emissions on a scale measured in the hundreds of gigatons, equal to years, if not a decade's, worth of current global emissions.

The floating production, storage, and offloading facility model could also be used to produce other liquid fuels, including jet fuel, gasoline, and diesel. These scenarios utilize existing and proven chemical technologies and production processes; no further discovery or innovation is needed, although some technologies, such as high-temperature steam electrolysis, would need to be brought to commercial scale. The resulting commodities would be drop-in substitutes—not requiring major changes to existing supply chain infrastructure, regulations, or behavior.

CONCLUSION

Current and emerging advanced nuclear reactors can do more than just provide reliable, clean electricity. They can offer added flexibility for power grids, decarbonize heating and industrial processes, and produce low-cost hydrogen and synthetic fuels. The next decade will be critical for dramatically increasing clean energy generating capacity by applying innovative deployment models such as the ones described in this section.

REFERENCES

15.1. NICE Future Initiative RISE³ campaign. https://www.nice-future.org/nice-future-initiative-campaigns/rise3.

15.2. Lucid Catalyst (2022). Beautiful Nuclear. https://www.lucidcatalyst.com/beautifulnucleardrivingdeepdecarbonisation.

15.3. Global Energy Monitor. "Global Coal Plant Tracker." Accessed February 2022. https://globalenergymonitor.org/projects/global-coal-plant-tracker/.

15.4. Terra Praxis. 2022. "Climate Solution Profile: Repowering the Global Coal Fleet by 2050." https://uploads-ssl.webflow.

15.5. Rendering by Virtual Experience Company and features designs by Bryden Wood for Terra Praxis' Repowering Coal Project.

15.6. Kirsty Gogan and Eric Ingersoll, "Missing Link to a Livable Climate: How Hydrogen-Enabled Synthetic Fuels Can Help Deliver the Paris Goals," September 2020.

15.7. Energy.gov. "Hydrogen Shot." https://www.energy.gov/eere/fuelcells/hydrogen-shot.

15.8. The Royal Society. October 2022. "Nuclear Cogeneration: Civil Nuclear Energy in a Low-Carbon Future". https://royalsociety.org/-/media/policy/projects/nuclear-cogeneration/2020-10-7-nuclear-cogeneration-policy-briefing.pdf.

Figure 15- 3. Conceptual ammonia bunker offloading ammonia from a production platform. Lucid Catalyst Graphic.

CLIMATE SOLUTION FACTSHEET: ENERGY SYSTEMS MODELING 2.0

THIS WORK WAS AUTHORED AS PART OF THE NICE FUTURE INITIATIVE IN COLLABORATION WITH TERRA PRAXIS.

The NICE Future Initiative launched its RISE³ campaign in 2022, building a partnership amongst governments and the nuclear energy, renewables, nonprofit, and academic communities to accelerate the adoption of environmentally just clean energy solutions. This report section proposes a way of modeling the clean energy transition that includes all carbon-free alternatives—renewables and nuclear energy.

In 2021, Aurora Energy Research published a report (16.1) summarizing a modeling effort that showed how renewables and nuclear cost effectively produced the hydrogen needed to achieve a U.K. Net Zero economy. The results highlighted the remarkable cost-effectiveness of using nuclear energy to produce hydrogen, which led to a dramatic reduction in the amount of land and infrastructure needed. At the same time, it eliminated dependence on fossil fuels, lowered emissions, and reduced the overall system cost of achieving U.K. net zero. Using the same nuclear-plus-renewables modeling approach, this study can be extended to other regions.

This Aurora Energy Research model is one of the first energy system modeling efforts to fully represent the potential for nuclear energy (also referred to as "advanced heat sources") to supply clean, flexible generation, cogeneration of heat, and hydrogen production using high-temperature steam electrolysis. The findings show the transformative potential of using advanced heat sources to de-risk and lower the cost of achieving net zero. Importantly, the Aurora Energy Research model also highlights a path to full decarbonization that does not require full electrification of end uses by 2050.

The results of Aurora Energy Research's modeling exercise reveals three ways in which nuclear energy can complement the mainstream strategy of using renewables to decarbonize the electricity sector and end-use electrification:

1. Advanced heat source generators provide flexible, load-following dispatch, which complements variable output from renewables. This enables higher penetrations of wind and solar while reducing (or eliminating) the need for energy storage or natural gas-fired generation.
2. Electrolytic hydrogen is often considered a use of electricity that competes with electrification of various end uses. The Aurora Energy Research study highlighted the benefit of using advanced heat sources to flexibly produce electricity when needed by the grid and produce hydrogen when grid electricity is not needed.
3. Using advanced heat sources exclusively to produce large quantities of hydrogen and synthetic fuels can decarbonize existing end uses that are currently difficult to electrify and parts of the system lagging in the electrification process.

Together, these pathways can enable a cost-effective, timely transition to a net-zero economy and substantially reduce the existential risks to the energy transition that most mainstream modeling efforts are failing to capture.

INNOVATIONS FOR MODELING 2.0

Most mainstream energy models are optimized based on cost and do not include concepts related to deployment feasibility or the performance of innovative technologies across the whole energy system (e.g., large dedicated hydrogen production facilities powered by advanced heat sources).

Four major innovations in energy modeling could help improve the utility of the results and highlight alternative pathways to achieving net zero that are smaller in scope, less risky, and lower-cost. We have dubbed this evolution in modeling "Modeling 2.0." Incorporating these innovations could lead to a profound shift in the discourse on how we think about the risk, cost, and probability of decarbonizing by midcentury. The following list presents five shortcomings in current modeling approaches and offers related recommendations or possible innovations.

> Innovation 1: "Feasibility Guardrails" To De-Risk the Transition

Current energy models offer critical guidance about the quantities of generation capacity and related infrastructure by certain dates. However, these models are only optimized on cost and ignore real-world risks and challenges related to project development (e.g., public acceptance, raw materials availability). The magnitude of infrastructure needed in a relatively short time demands that energy models expand beyond cost optimization to include factors that can substantiate achievable deployment rates and scenarios that can be prioritized by risk.

Recommendation 1: Modeling net-zero scenarios should include feasibility measures to anticipate and mitigate risks to achieving deployment at the required speed and scale. All proposed deployment assumptions should be subject to feasibility guardrails related to cost, speed, scale, space, and supplies.

> Innovation 2: "Flexgen" Power, Heat, Hydrogen

We must decarbonize every sector of the economy, not just the electricity sector. The next generation of advanced reactors are being designed for flexible cogeneration (flexgen), to enable the highly economical production of multiple energy services (16.2). Flexible cogeneration—resources capable of producing hydrogen, heat, and power—enables low-cost hydrogen production and load-following/grid-balancing services, which improves plant economics and lowers the cost of energy to the system. Flexible advanced heat sources—in combination with wind, solar, and hydro—can make a substantial contribution toward reliable, responsive, affordable, and clean energy systems.

Figure 16- 1. Rendering of a hydrogen gigafactory. Image by Terra Praxis.

Recommendation 2: Modeling should represent the potential for flexible and cost-effective cogeneration of power, heat, and hydrogen in support of full decarbonization across the whole energy system.

> Innovation 3: High-Temperature Steam Electrolysis

Hydrogen production via high-temperature steam electrolysis can produce as much as 30% more hydrogen for the same electrical input as low-temperature water electrolysis—even when using "low-temperature" nuclear (e.g., light water) reactors. Furthermore, it can be produced at approximately half the cost of low-temperature water electrolysis systems. Larger plant sizes also enable dramatic cost reductions for electrolyzer plants. Nuclear energy's high-capacity factor results in higher utilization of the electrolyzer facility, which is a major contributor toward lowering costs. Keeping the system hot when not in use is easy for a nuclear plant and enables operational flexibility and efficiency. Several companies are now demonstrating and commercializing high-temperature steam electrolysis technology (16.3; 16.4).

Recommendation 3: Modeling should represent the transformative role of large, low-cost, high-capacity factor, high-temperature electrolysis to eliminate risks to the clean energy transition related to needed cost and scale of hydrogen supply.

> Innovation 4: Dedicated Large-Scale Hydrogen Production

Large-scale hydrogen production is needed to reduce the cost to the clean energy transition and lower emissions and dependence on fossil fuels. An example: large-scale hydrogen production is possible with the potential emergence of gigafactories. These factories are designed to be replicated quickly in new locations and are a useful high-volume, low-cost manufacturing model that can be applied to hydrogen production. A hydrogen gigafactory, powered by advanced heat sources, could be built, and integrated with a large, liquid fuels production facility.

The gigafactory model enables a highly integrated manufacturing, assembly, installation, and production process on one site—enabling high-quality, repeatable processes with quality assurance designed into every step of the process. Capital and operating costs are radically reduced by streamlining manufacturing, operations, and maintenance. At full production rate, a factory could be designed to produce twelve 600-MWth reactors per year, equivalent to approximately 3 GW of electricity to power hydrogen production. The hydrogen produced by the gigafactory could be either supplied directly to the gas networks or to a synthetic fuels plant on an adjacent site. The hydrogen gigafactory technology is proposed as a next-generation refinery located on brownfield sites, such as large coastal oil and gas refineries.

Recommendation 4: Modeling should represent the transformative role of refinery-scale, low-cost giga-scale hydrogen and synthetic fuels production utilizing advanced heat sources manufactured at scale.

CONCLUSIONS

Modeling often focuses on narrow issues that reflect the modeler's expertise or on-hand data. Modeling 2.0 seeks to emphasize modeling's goal of informing policymakers. Policymakers must contend with all interrelated matters, upstream and downstream, of the energy transition. A particularly salient and challenging aspect that NICE and RISE[3] asks modelers to consider and research is assessing and including the relative feasibility of paths forward.

REFERENCES

16.1. Aurora Energy Research, "Decarbonizing Hydrogen in a Net Zero Economy," 27 September 2021. https://auroraer.com/insight/decarbonising-hydrogen-in-a-net-zero-economy/#:~:text=The%20key%20findings%20include%3A,for%20net%20zero%20in%202050.

16.2. Ingersoll, E., K. Gogan, J. Herter, and A. Foss. 2020. Cost and Performance Requirements for Flexible Advanced Nuclear Plants in Future U.S. Power Markets. Lucid Catalyst. https://www.osti.gov/servlets/purl/1861031.

16.3. 2021. "Haldor Topsoe to build large-scale SOEC electrolyzer manufacturing facility to meet customer needs for green hydrogen production." March 4, 2021. https://hydrogen-central.com/haldor-topsoe-electrolyzer-manufacturing-plant-green-hydrogen-production/.

16.4. Frick, Konor, Paul Talbot, Daniel Wendt, Richard Boardman, Cristian Rabiti, Shannon Bragg-Sitton, Daniel Levie, Bethany Frew, Mark Ruth, Amgad Elgowainy, and Troy Hawkins. 2019. Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest. Idaho Falls, ID: Idaho National Laboratory. INL/EXT-19-55395. https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_18785.pdf.

16.5. Risks to the Energy Transition, Terra Praxis, September 2023. https://assets-global.website-files.com/6115b8dddcfc8904acfa3478/64c9594ee534975797f91414_Energy%20Transition%20Risks%20Decarbonization%20Brief.pdf.

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