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REPOWER

Introduction to the global programme

The *Repower* Initiative

- Funded by Founders Pledge, we are in the middle of a global non-profit research & promotion programme dedicated to the *repowering* of fossil power plants by low carbon heat sources such as **nuclear** or geothermal energy, reconfiguration as thermal heat stores or as clean energy grid interconnection points
- The initiative was joined **this week** by a **new partner**, one of the world's top-10 financial institutions, with \$1 trillion USD earmarked for decarbonization project finance by 2050

Addressing a Key Decarbonization Challenge

“Decarbonisation is about two things:
Building stuff and closing stuff”

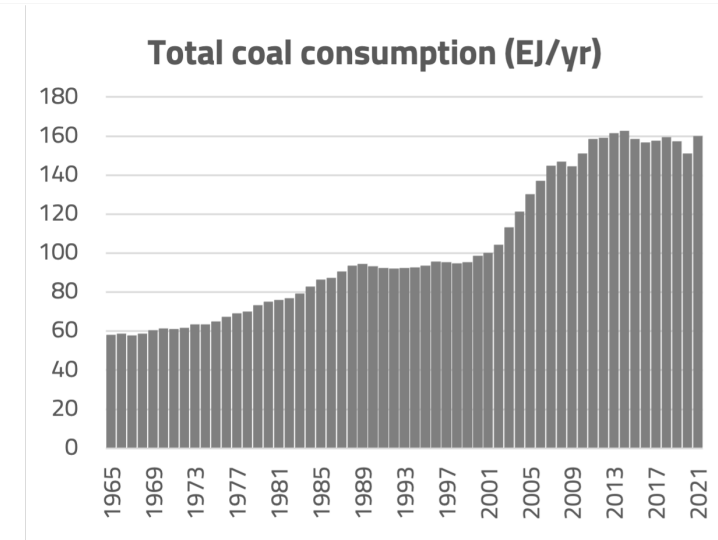
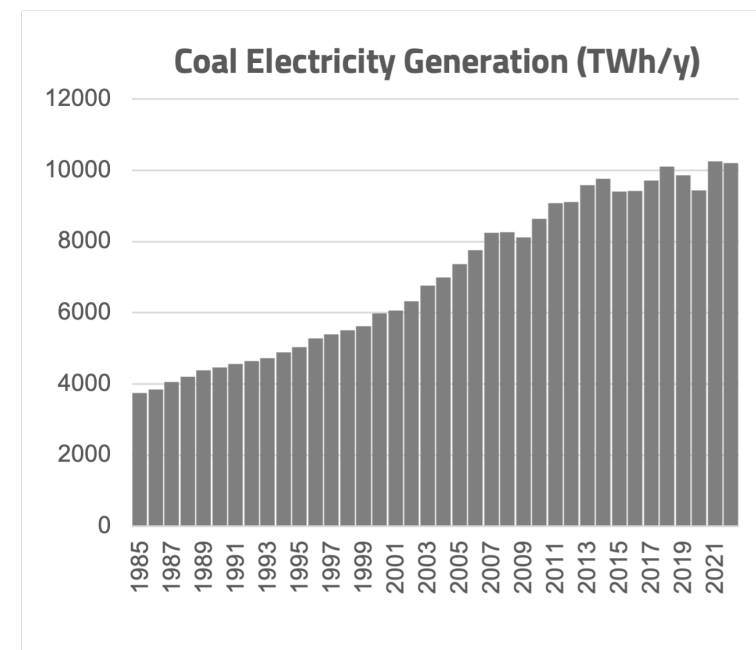
The Original Research Question(s)

1. Can we decarbonize and at the same time avoid stranding investments, avoid firing the local workforce & avoid abandoning the site and the equipment?
2. Can fossil power plant sites continue to fill *all their full current roles* in the system without the continued burning of fossil fuels?

A Vested Problem

1. Coal power is the largest form of electricity generation & largest source of emissions
2. The effective age of all coal plants is ~15 years, in critical places 7 years!
3. \$ Trillions of recent investments

All to be scrapped, trillions stranded and millions of workers fired?

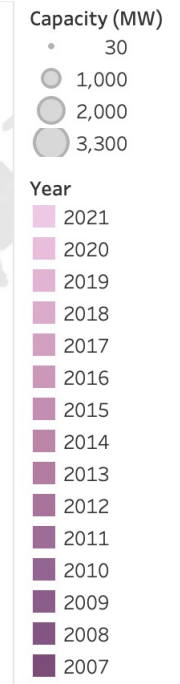


Last 15 years of new coal power

1350 GW capacity

3400 units

1300 large sites



A wide suite of great options with varying TRL & timeline!

1. Repower or repurpose site with new heat sources
2. Use as renewable resource grid interconnection point
 - Large utility-scale solar farms
 - Onshore wind farms
 - *Offshore wind farms (coastal plants)*
3. Repower as “thermal battery” energy storage plants
4. Partially repurpose (for example the district heat interconnect)
5. Combination of the above

A spectrum within the repowering options!

- **Full repowering**

Brand new (or under construction) coal plants are repowered by high-temp heat sources in 2030s, including re-use of the full steam cycle, condenser cooling system, grid connection and all auxiliary buildings

- **Partial repowering**

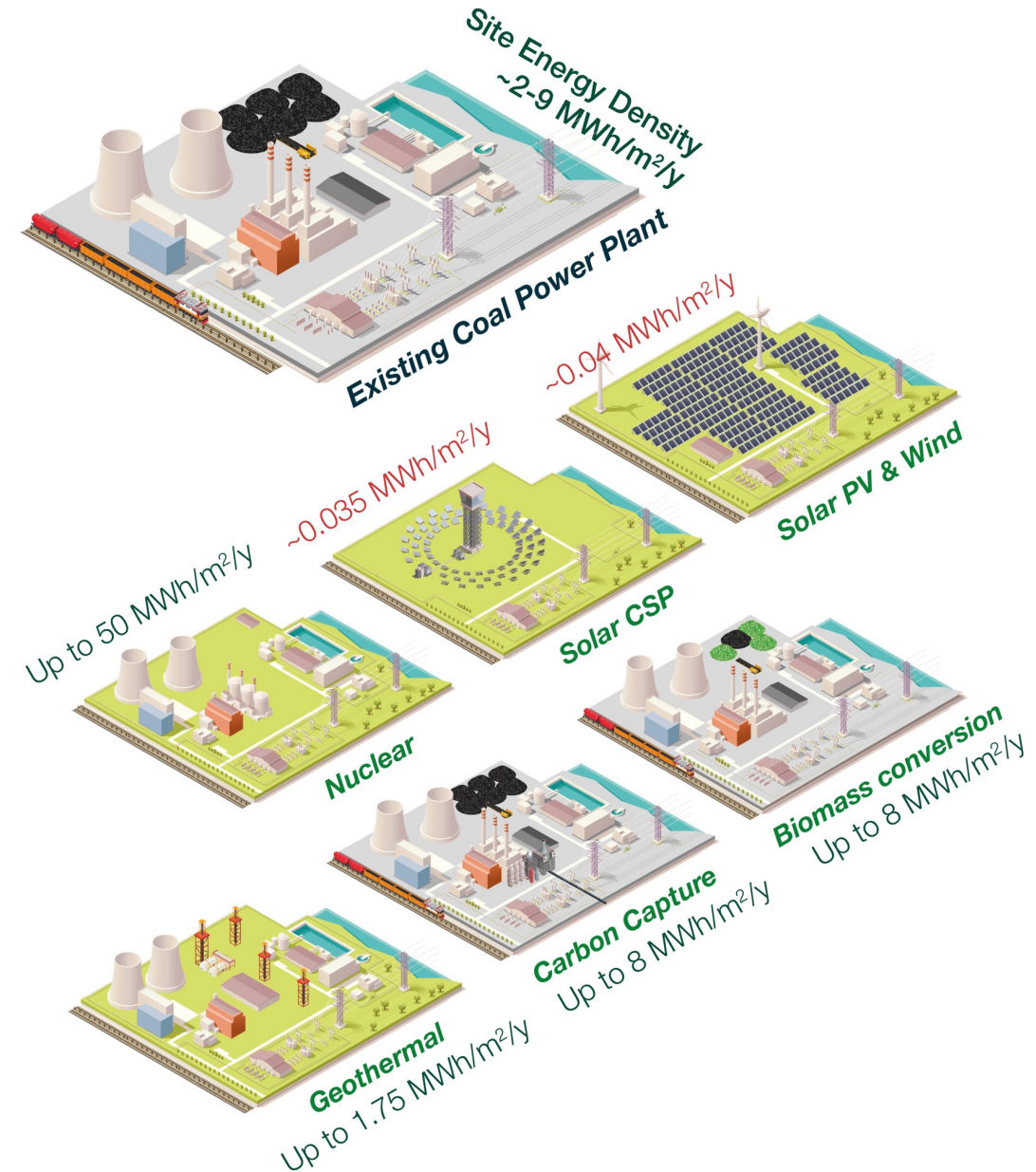
Modern coal plants (effectively less than 15 y/o) today are repowered re-using condenser cooling, grid connection and auxiliary buildings

- **Repurposing**

The plant sites of old, already decommissioned or fully depreciated units are repurposed with low-carbon energy, in many cases including grid connection

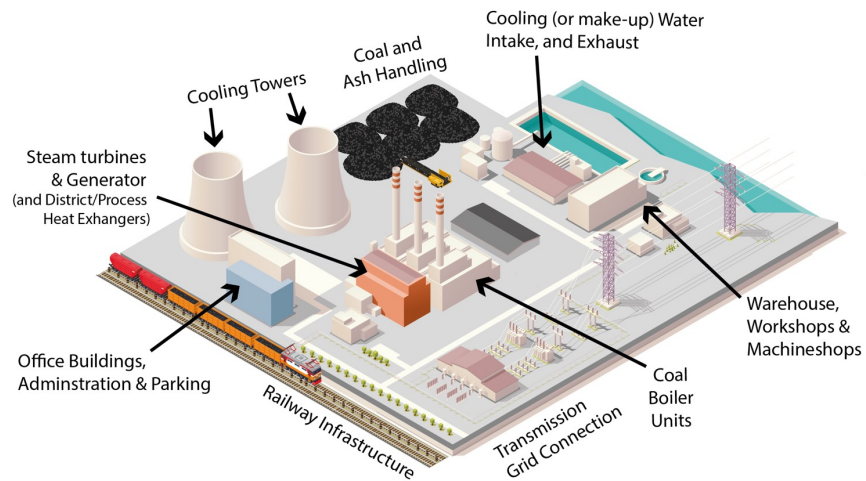
Options for “full” repowering

1. Energy density and ability to use existing equipment and workforce suggests advanced nuclear and advanced high-temp geothermal repowering as main pathways
2. Repowering a large steam turbine with smaller reactor(s) or geothermal wells via a thermal energy storage interface introduces flexibility!

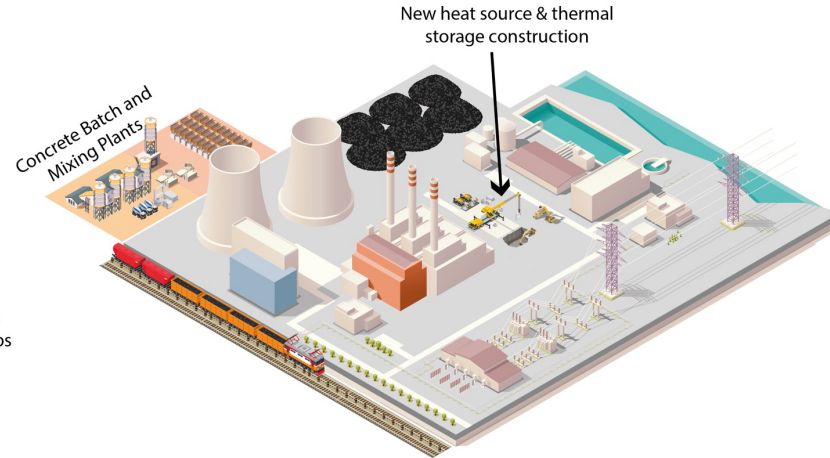


Summarized Example of a Parallel Process

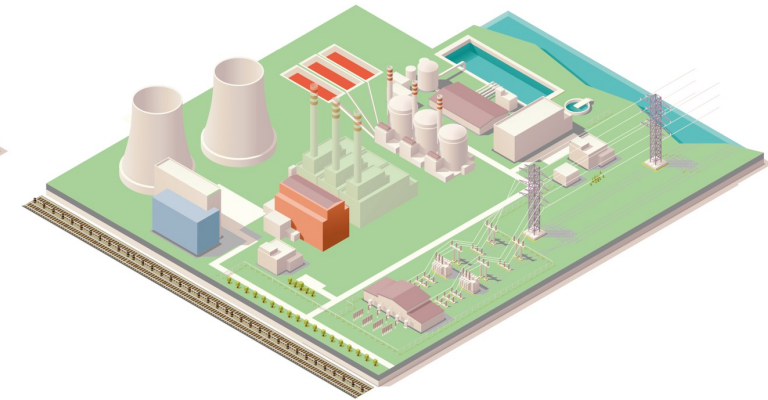
1. Coal power plant



2. Repowering



3. Decarbonized



Repowering highlights

- **Global emissions-avoidance:** potential of up to 200 billion tons of CO₂
- **Job retention:** potential of up to 2/3^{rds} of local plant work force
- **Just transition:** Long term investments and jobs in the communities that would otherwise suffer the worst local impacts from the energy transition
- **Cost savings:** Upfront cost savings of up to 35% compared to equivalent green-field projects (full repowering nuclear example)
- **Permitting:** No need for new sites, cooling water permits or power lines for new zero-carbon energy infrastructure – solving a main bottleneck

A solid and growing peer-reviewed research base

Article
Retrofit Decarbonization of Coal Power Plants—A Case Study for Poland
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Techno-Economic Assessment of Coal-Fired Power Unit Decarbonization Retrofit with KP-FHR Small Modular Reactors
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Abstract: The near and mid-term future of the existing Polish coal-fired power fleet is uncertain. The longer-term operation of unabated coal power is incompatible with climate policy and is economically challenging because of the increasing price of CO₂ emission allowances in the EU. The results of the techno-economic analysis presented in this paper indicate that the retrofit of existing coal-fired units, by means of replacing coal-fired boilers with small modular reactors, may be an interesting option for the Polish energy sector. It has been shown that the retrofit can reduce the costs in relation to greenfield investments by as much as 35%. This analysis focuses on the repowering of a 460 MW supercritical coal-fired unit based on the Lagiza power plant design with high temperature small modular nuclear reactors based on the 320 MW_{th} unit design by Kairos Power. The technical analyses did not show any major difficulties in integrating. The economic analyses show that the proposed retrofits can be economically justified, and, in this respect, they are more advantageous than greenfield investments. For the base economic scenario, the difference in NPV (Net Present Value) is more favorable for the retrofit by 556.9 M€ and the discounted payback period for this pathway is 10 years.

Keywords: supercritical steam cycles; retrofit decarbonization; small modular reactors; techno-economic assessment

1. Introduction
 Policymakers of many countries, even those that have taken a more passive approach toward decarbonization, have started to define the dates by which their countries will completely abandon coal as an energy source. In the specific case of Poland, there is no such target defined yet, but the government has started to take decisive steps towards decarbonization and to end the reliance on coal. On 25 September 2020, after consultations with miners' unions, it was decided that the last coal mine in Poland will close by 2049. Such developments raise many questions regarding the direction of the energy transformation of this large economy, where coal has been determining the dynamics of economic development for many decades. Exploring viable techno-economic solutions that meet the above policy objective is key to achieving its goals and mission. One family of possible decarbonization options is the "retrofit decarbonization" of existing coal power plants. Retrofit decarbonization is an umbrella term that includes adding carbon capture, fuel conversion, and the replacement of coal boilers with new low-carbon energy sources, in each case re-using as much of the existing equipment as economically practicable while eliminating emissions [1].

In this paper, we study the retrofit decarbonization of coal units using a low-carbon heat source to an existing brownfield coal site. It is proposed that an advanced small

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Techno-economic assessment of natural gas combined cycle power plant decarbonization: small modular reactors versus carbon capture and storage

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Repowering Coal Power in China by Nuclear Energy—Implementation Strategy and Potential
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Abstract: This article discusses a sustainable low-carbon development strategy that uses nuclear heat sources to replace coal boilers at existing coal power plants in China, to help support a resource and cost-effective low-carbon development. Based on the local situation in China, a three-stage strategy to explore the potential of repowering coal power by nuclear energy is proposed. The main focus of this study is to conduct a more detailed exploration of the 1st stage of this strategy, which includes coal plants located on the coast in regions that already have nuclear power installations. The study makes use of HTR-PM modular reactor for retrofit analysis for the types of coal units present in 1st stage of the strategy. The results show that 1. There is a technical and economic basis for exploring nuclear power retrofit decarbonization. This conclusion is backed up by on-site transformation analysis and demonstration of the conversion of representative plant units to ensure the validity and reliability of the data. 2. This research provides a new pathway for the problem of stranded assets in China's power sector decarbonization. The use of HTR-PM modules for retrofit can save up to 1200 billion \$ as well as retaining local jobs and economic activity in areas currently hosting coal plants, which brings to society great economic and social benefits.

Keywords: retrofit; three-stage strategy; HTR-PM; stranded assets; economic benefits

1. Introduction
1.1. Background and Challenges of Retrofit Decarbonization
 China's rapidly increasing power consumption, based primarily on coal, has brought severe challenges to national energy security, climate change, and environmental pollution control [1–3]. In the context of tightening of resource constraints, global warming, air pollution, and severe damage to the environment [3,4], achieving "carbon neutrality" and moving away from coal as a primary source of energy have become a core focus for China going forward.

The purpose of this study is to evaluate the role of existing coal power assets in China's future low-carbon power system. The leaders of the Chinese government proposed "Dual carbon" goals in 2020 [5], and started to introduce electricity market reform. These market-based reforms aim to improve the efficiency of both dispatch and investments in the power sector [6], and to help facilitate decarbonization. However, there are some challenges in this process [7], mainly in the planning, investment, and operation of low-carbon power systems. It is not only necessary to ensure the reliable operation of the power system, but also to consider the impact on the environment, health, biodiversity, and other factors during the transition. How to best coordinate the economics of the transformation of new and old technologies and the impact of new technologies on the old power system, including employment opportunities, has proven difficult for policymakers.

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Article
Repowering a Coal Power Unit with Small Modular Reactors and Thermal Energy Storage
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Repowering a Coal Power Plant Steam Cycle using Modular Light Water Reactor Technology
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Abstract: The article presents the results of technical analyses of the possibility of adapting a steam turbine to new operating conditions resulting from the replacement of a coal-fired boiler with a pressurized water reactor (PWR)-type small modular nuclear system. A 460 MW supercritical power unit with steam parameters of 28 MPa / 560 °C / 380 °C and operated in the Polish Lagiza Power Plant was selected for the analysis. After the modernization, the turbine of the power unit will be fed with saturated steam at a pressure of 7 MPa, which corresponds to a temperature of 285 °C. In total, four options for adjusting the turbine to the new steam parameters were analyzed. For the first three cases, it was assumed that the repowering project would make use of the medium and low-pressure section of the turbine previously operating as part of a coal-fired unit, while in the fourth case only the low-pressure section of the 460 MW turbine would remain in use. On the basis of the results of the conducted analyses, conclusions were presented regarding the adaptation of the existing turbine of the supercritical coal-fired unit to work with the steam generated in the steam generator of the Small Modular Pressurized Water Reactor. The article also presents the results of economic analyses. The analyses also included the greenfield investment variant, for which the results were obtained, constituting a reference point in the assessment of variants assuming nuclear retrofit of a coal-fired unit. The NPV and NPVR indicators were used to assess the validity of carrying out a retrofit, and as part of this investment also to modernize the turbine to supercritical parameters in order to adapt it to cooperation with the reactor. Based on these indicators, for each modernization variant, the break-point for the modernization cost was estimated, at which the potential modernization creates conditions for economic profitability in relation to the reference investment.

Keywords: retrofit decarbonization; steam turbine modernization; small modular reactors; techno-economic assessment

1. Introduction
 In many regions of the world, accelerated decarbonization pathways to limit greenhouse gas emissions mean existing coal and gas-fired power plants will need be phased out well ahead of their technical lifespans. As plants are phased out of operation, much of the value of the accompanying infrastructure may be stranded. At the same time, decommissioning of fossil power plant will lead to a loss in local job opportunities and taxable income, and as a result the attractiveness of the location will decrease over time.

Over the past decade, wind farms and solar power plants have dominated new energy investments in Europe. Alongside variable renewables such as wind and solar,

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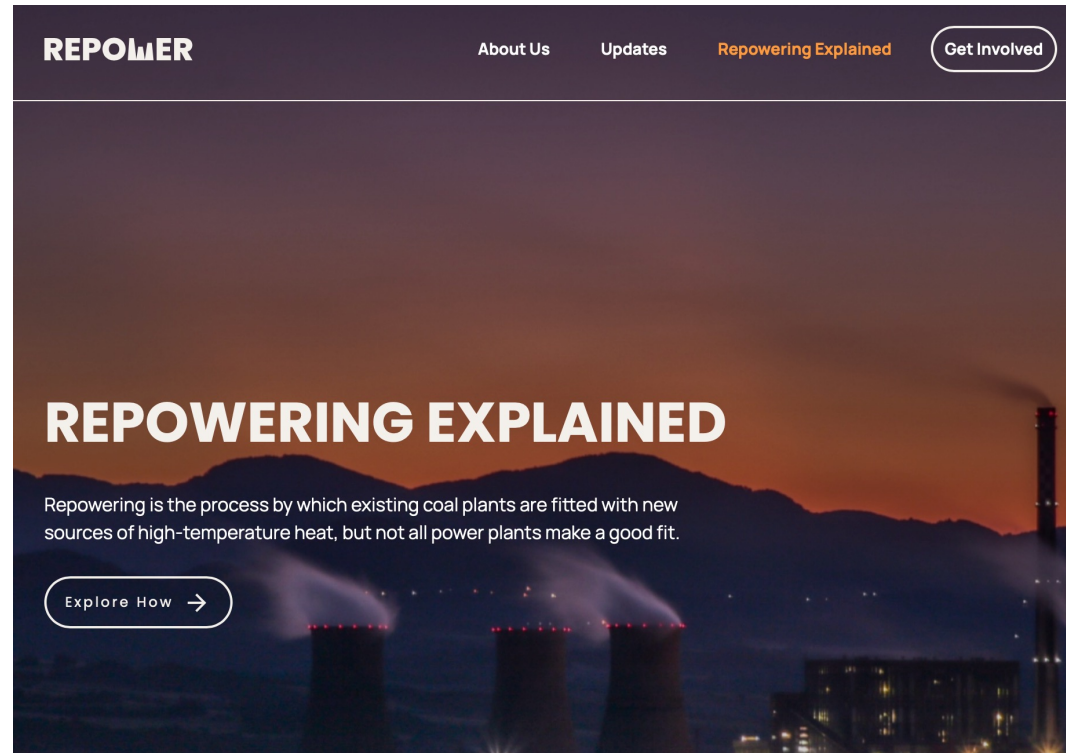
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