Brownfield Transformation: Building a bridge to a new energy future

White paper

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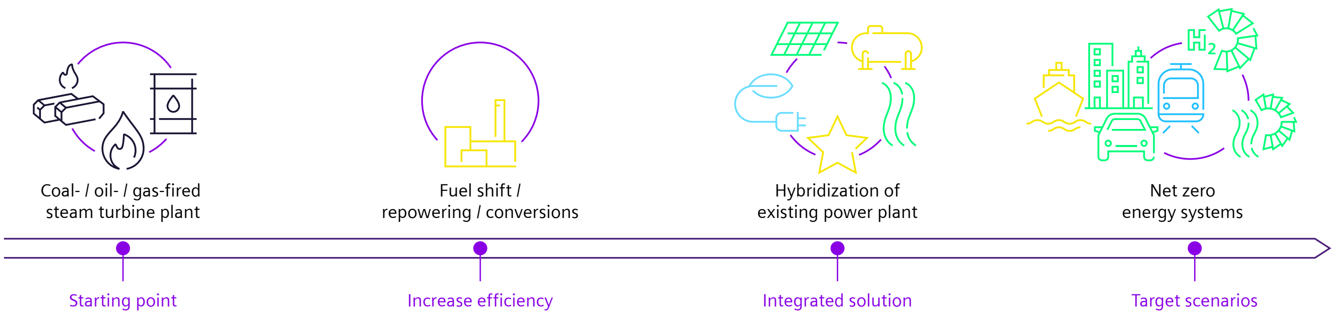
We're heading towards a carbon-free future, but we won't get there overnight. The journey will require a complete technological toolkit. Apart from intelligent energy management and improved energy efficiency, we need to decarbonize power generation, for both utilities and industries. And since we can't build new energy generation from scratch, assets considered burdensome today, such as coal-fired power plants, shouldn't simply become stranded assets. With "Brownfield Transformation", we can repurpose them as bridges to a new energy future. With this approach, existing plants are converted to help us reach the decarbonized economy we all aim for.

Moving towards a net-zero energy world

Brownfield Transformation is a holistic approach for decarbonizing legacy coal, oil, and natural gas-fired power plants. A first step would be, e. g., repowering steam power plants with highly efficient and flexible gas turbines. Going further, one could – and should – turn legacy assets into future-proof power plants, which may include power generation from renewable energy sources, various storage technologies, and grid stability services; today such conversion is already feasible at many sites.

Carrying out these primary steps lays down the groundwork for future net-zero energy systems. Such systems could facilitate sector coupling by, for example, integrating renewables, industry, or mobility sectors with the help of green hydrogen.



Sustainability

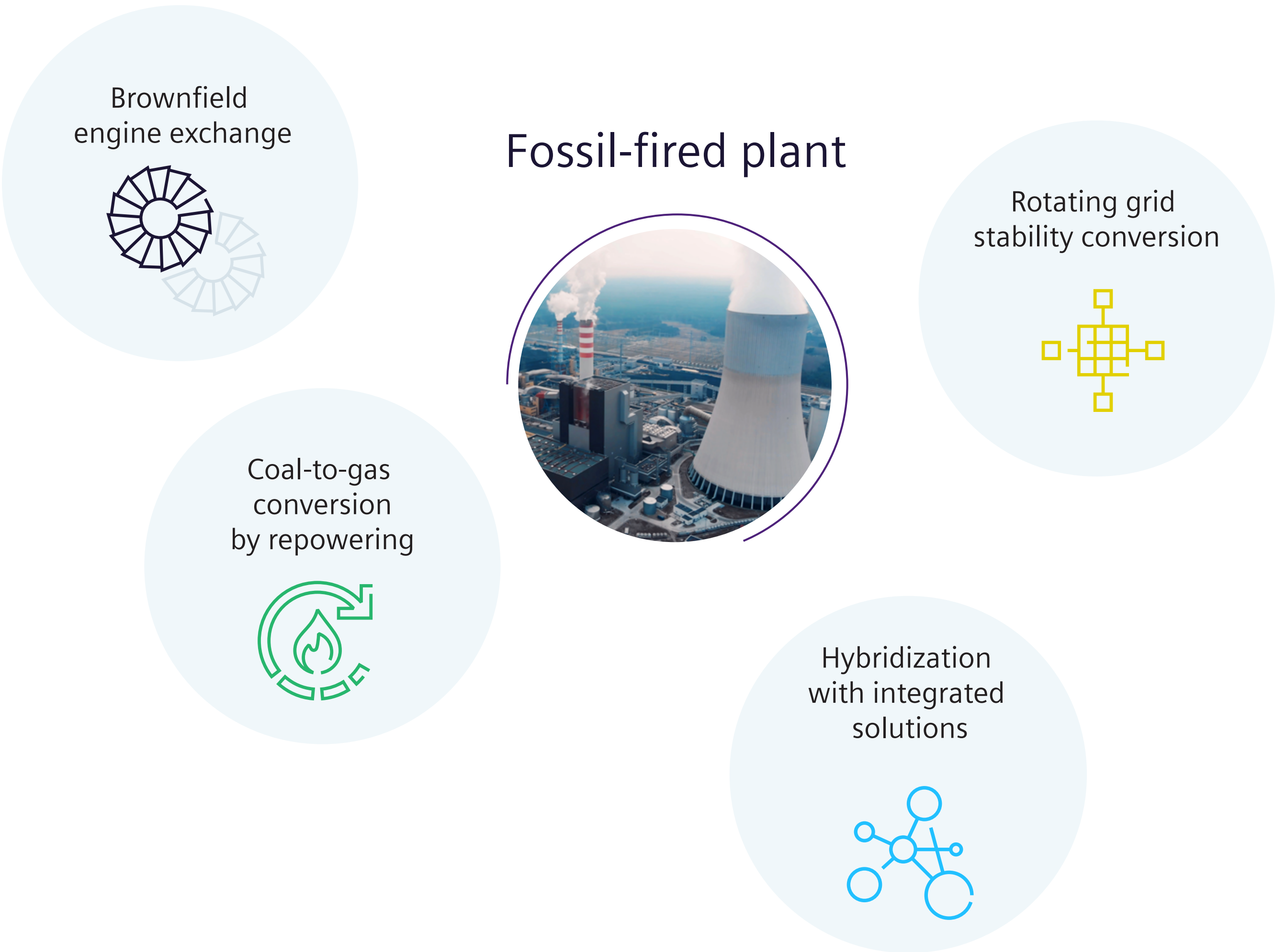
Essentially, Brownfield Transformation projects are more sustainable, in terms of reducing CO_2 emissions by reusing existing buildings, machines, and infrastructure, such as grid connections. Furthermore, due to climate change and extreme weather events, it's essential for limiting further impervious areas.

Also importantly, the continued employment of qualified personnel and continued use of existing infrastructure can lead to higher public acceptance, particularly when thousands of jobs in a certain region may be tied to a coal power plant, associated mines, etc.

What to do with a fossil-fired power plant?

From the outset, the path ahead might not be completely clear to a utility or industrial plant owner or operator. How to proceed can depend a lot on national decarbonization goals, which in most countries appear rather ambitious. And while some national decarbonization goals may be legally enforced, others may be demanded and shaped by the public. In addition, market mechanisms that are put in place, such as CO_2 pricing as well as public financial incentives, could potentially make a brownfield conversion an economically sensible undertaking and valuable investment. Nevertheless, the question arises as to whether converting an existing power plant in a cost-efficient manner can actually help achieve these targeted goals. Site conversion options may include: brownfield engine exchange, which entails replacing existing gas turbines with new ones; coal-to-gas conversion; installing synchronous condensers with flywheels for grid stability; and the hybridization of power plants with energy storage and gas turbines fired by up to 100% hydrogen.

Given the above options, when compared to greenfield projects, the potential lower investment costs for a Brownfield Transformation project that allows for possible shorter implementation times, less paperwork, and easier permits, should all be factors worth considering.



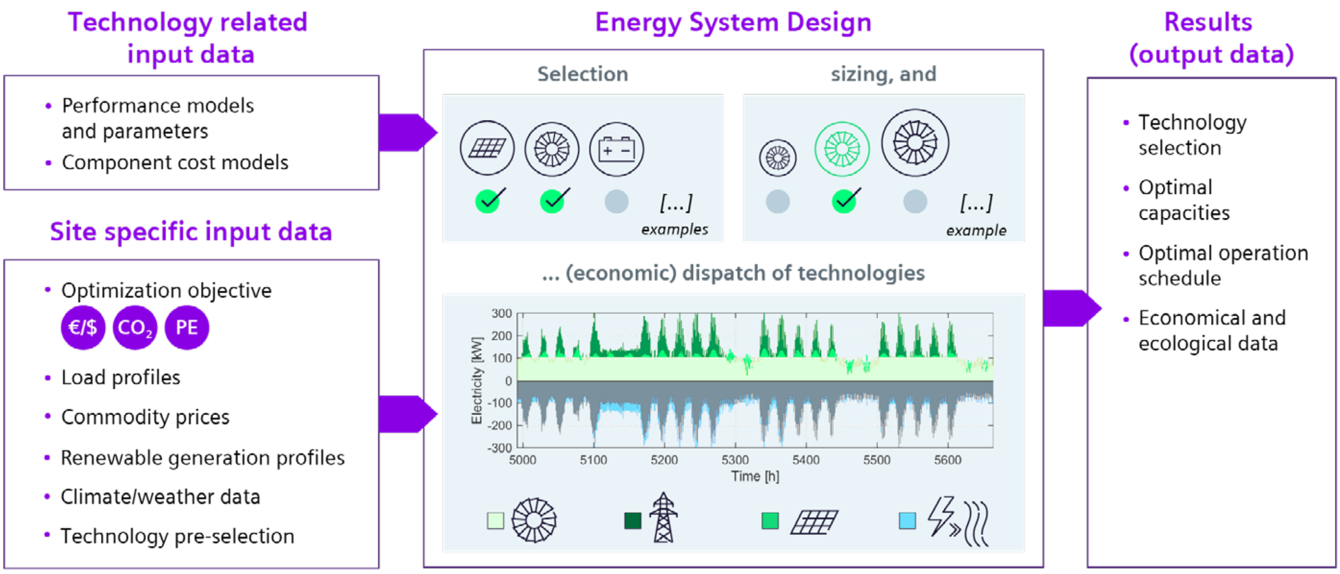
Making the right decision: Energy System Design

As there's no one-size-fits-all solution, one step is essential: Energy System Design. It is usually offered by either energy consulting companies or OEMs such as Siemens Energy that also offer turnkey solutions. The existing setup allows Siemens Energy to form a common understanding of your site development plan, considering political, regulatory, and economic factors as well as short-term vs. long-term goals for the site.

An Energy System Design study may start out with an assessment of a utility or industrial power plant operator's basic operational parameters. First, the optimization objectives are determined, such as economic concerns and carbon footprint reduction. In addition, the load profiles for heat and electricity have to be assessed. Moreover, existing, and future revenue streams should be identified, such as connections to the industrial environment, e. g., process heat and future hydrogen options. Likewise, whether industrial byproducts, e. g., hydrogen, could be used as fuels at the power plant should be considered.

Furthermore, an assessment should evaluate whether providing grid stability services, integration of renewables, such as wind or solar based on local weather conditions, and additional hybridization, may be options for a given location. All these assessments and considerations help provide a basic understanding of the makeup and potential of a given site.

If decarbonization requirements turn out to be complex, an even more detailed study may need to be conducted, in the form of a data-based integrated technology and business case study that assesses future revenue streams and site surroundings using the currently available decarbonization portfolio. If technology preselection is a given, e. g., fuel switch, energy storage, heat pumps, etc., a project can be directly developed. Either way, a solution will likely comprise a combination of technology components tailored to a company's business case, market demands as well as efficiency and decarbonization goals.



Energy System Design allows to find the optimal technology mix that accounts for both technological and economic boundary conditions. It involves all available levers for decarbonization, enabling future-proof solutions.

Coal-to-gas shift: a bridge to a sustainable energy mix

Coal-fired power plants emit around 10 Gt of CO_2 per year[1] and are considered one of the largest emitters of greenhouse gases in the power generation industry. Today, while there are substantial economic reasons for converting legacy coal fleets to gas, the pressure to decarbonize is largely driven by climate change, policies and regulations, and public opinion. For power generation, it's expected that decarbonization will be pursued in three phases. In the first phase, coal generation will be converted to natural gas, supporting the continued growth of renewables. In the second phase, renewables will become more prevalent, while natural gas infrastructure will start co-firing hydrogen and other clean fuels. In the third phase, which would be around mid-century, one may begin to augment the predominance of natural gas, and then potentially replace it with clean fuels, which would be an essential part of hybrid power plants – power plants that could integrate renewables, electrolyzers, energy storage, and other elements for carbon-free energy generation.

1 IEA (2021), World Energy Outlook 2021, IEA, Paris www.iea.org/reports/world-energy-outlook-2021, p. 130.

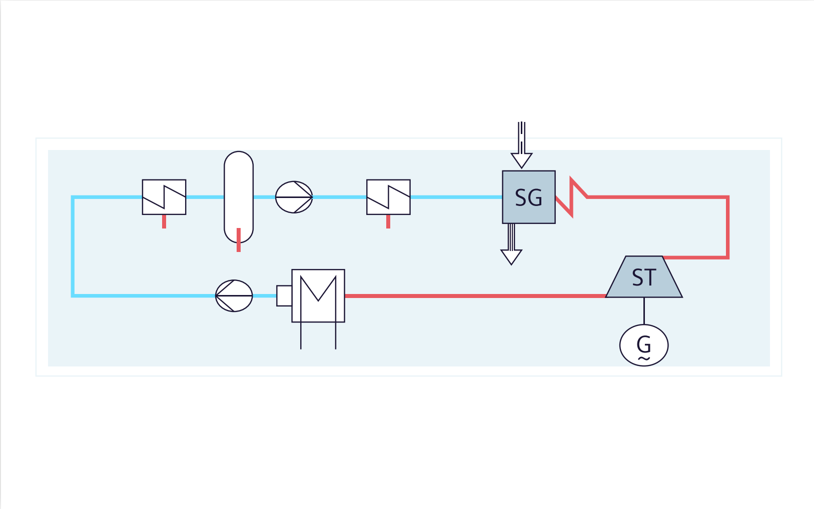
Repurposing legacy power plants

The most obvious and common solution for decarbonizing power generation is replacing old assets with more efficient technology that enables less emission of greenhouse gases. While it's certainly possible to shut down and recycle parts of a coal-fired power plant, one can also transform the existing asset into an advanced power generation facility. Of course, this isn't a new idea. Over the past 20 years, several large-scale projects around the globe have proven to be technically and commercially sound.

With the effects of climate change becoming increasingly apparent, and new legislation, decarbonization targets, and specific coal exit plans being set in motion, repowering legacy coal-fired power plants is expected to experience a strong renaissance in terms of embodying optimized economics and performance. Moreover, compared to greenfield projects, they represent a logical business case. The potential business case could include lower investment cost, reduced permits, shorter implementation time, and reusing existing grid connections and other physical and social infrastructure already in place. Moreover, these repowering transformations are designed to incorporate technologies, such as energy storage, energy conversion or carbon capture, all of which are intended to help achieve zero carbon emissions at the end of the transformation journey.

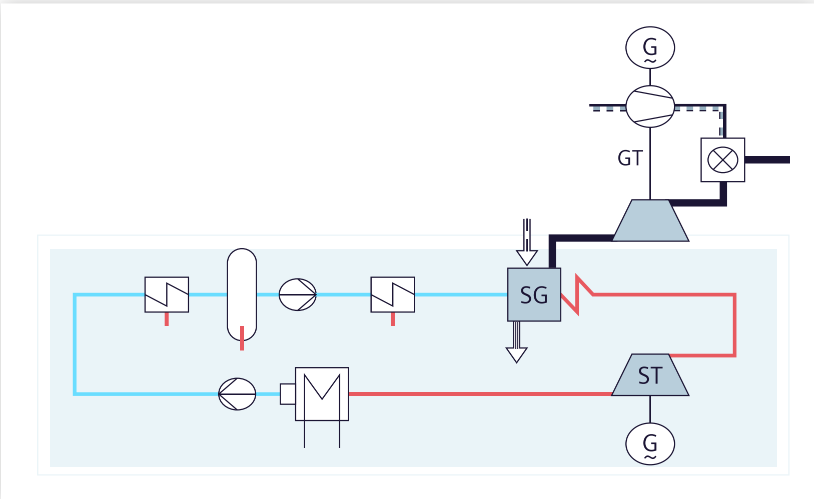
Repowering existing plants ranges from a simple boiler conversion from coal-to-natural gas firing to so-called "topping", "booster", "parallel repowering" and finally "full repowering", whereby not only fuel is changed from coal to gas, but a power plant is converted into a highly efficient combined cycle power plant. Here's a short description of these options:

A **boiler / steam generator (SG) conversion** involves a modification of the burner technology and a change of coal or oil to gas. While switching to gas as a fuel does not increase the efficiency of the steam plant, it may reduce CO_2 emissions by up to 50%.



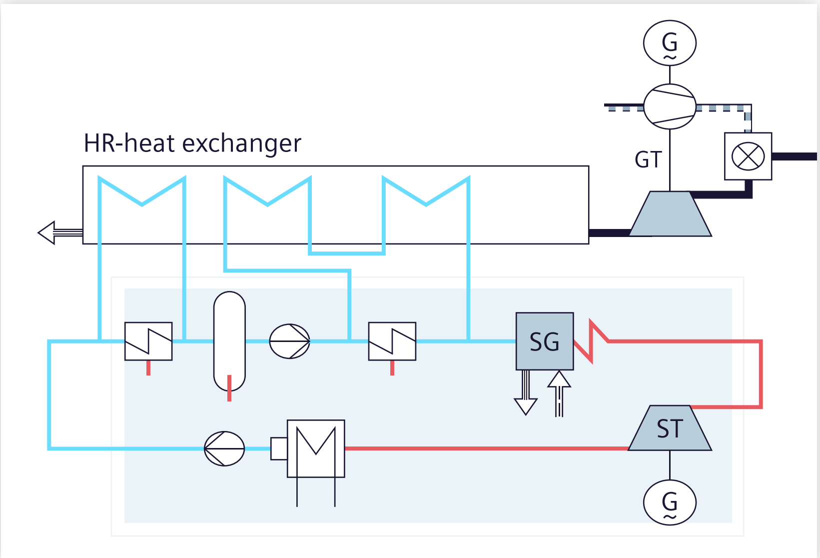
Boiler / steam generator conversion

Topping requires the installation of a small gas turbine, regardless of whether the fuel is switched from coal to gas or not. The thermal energy contained in the flue gas of the topping gas turbine is fed directly to the steam generator of the existing plant. This typically results in a slight improvement in overall plant efficiency.



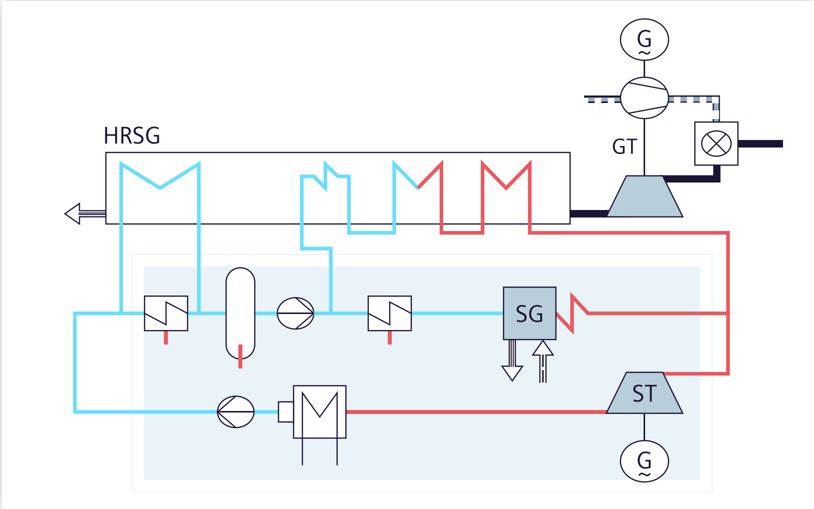
Topping

Boosting requires the installation of an additional – usually medium – gas turbine and a waste heat boiler. In contrast to topping, the heat energy contained in the flue gas of the gas turbine is used with the aid of a heat exchanger to generate high-pressure steam and preheat the feed water of the existing process. Boosting essentially aims to make the steam power plant marginally more flexible, while at the same time slightly increasing efficiency and reducing CO_2 emissions



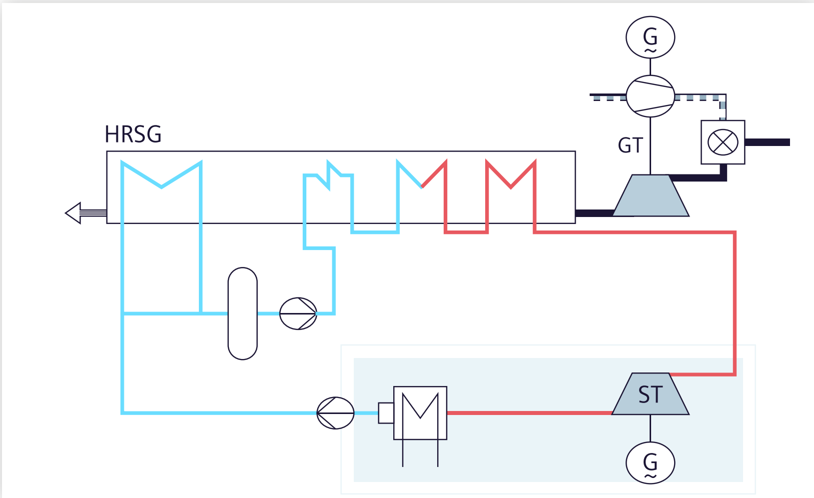
Boosting

Parallel repowering goes one step further by utilizing the steam contained in the flue gas of a newly installed large gas turbine with the aid of a heat recovery steam generator for additional feedwater preheating and steam generation in the existing steam power plant process. This conversion is also designed to increase the flexibility and efficiency of steam power plants, but to a greater degree than boosting.



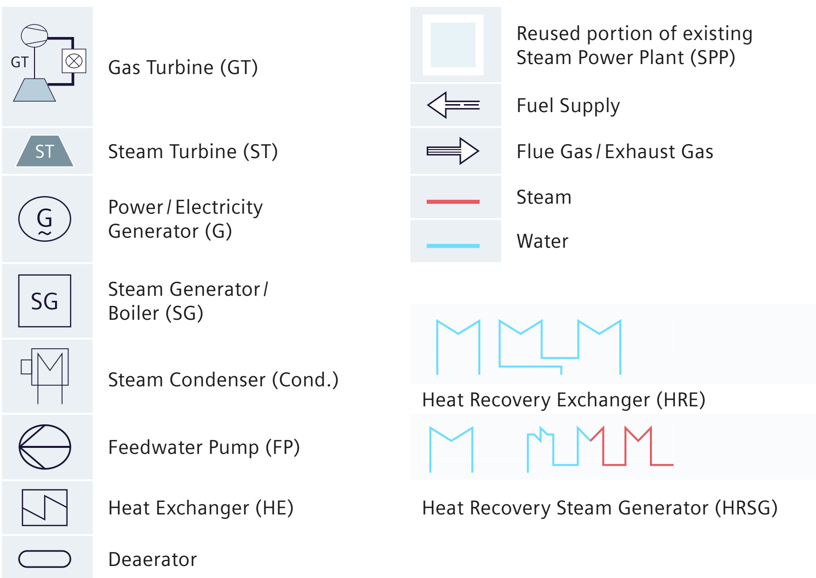
Parallel Repowering

Full repowering includes not only the fuel change from coal or oil to gas, but also the conversion of the existing steam power plant to a combined cycle power plant. However, the conversion of the existing steam power plant to a combined cycle power plant (CCPP) can also be implemented for direct steam power plants with gas-fired boiler. In a full repowering project, one or more gas turbines with downstream heat recovery steam generators replace the steam generator previously fired with coal, oil, or gas.

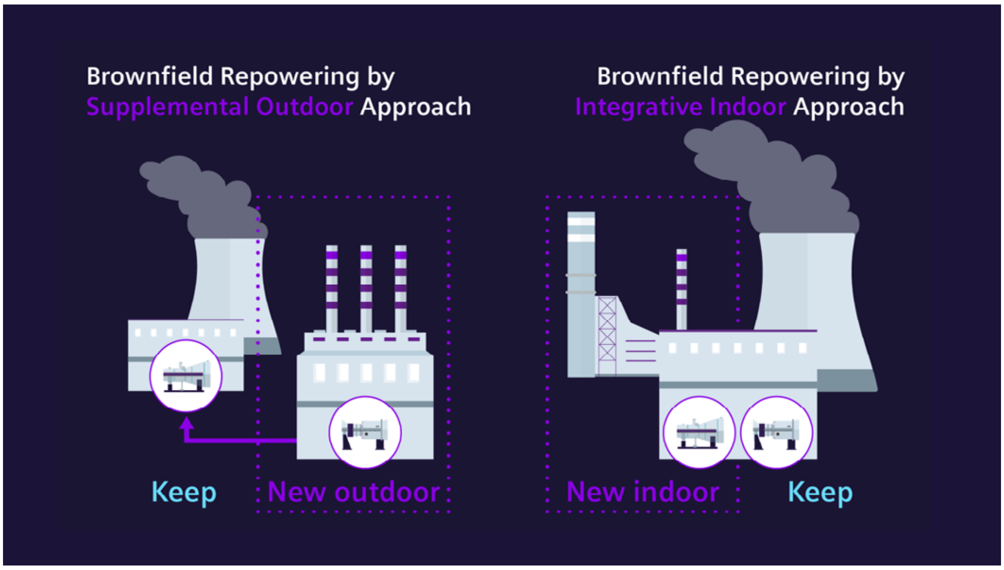


Full Repowering

Legend



Depending on the site specifics, such full repowering can be implemented as a supplemental solution, where the simple cycle gas turbine installation and the HRSG would be built outside of the existing turbine or boiler building, or as an integrative solution, where all new equipment would be installed within the boundaries of the existing plant buildings. Both approaches have their pros and cons.



The supplemental outdoor approach requires enough free space for constructing new equipment at the plant location, preferably close to the steam turbine hall. Connecting old and new equipment is less complex and the overall downtime of the unit during the reconstruction period should be shorter. However, it's expected to be more costly and less sustainable compared to an indoor integrative approach, as it requires significantly more new construction work and material.

Either way, the potential benefits of both approaches are impressive: CO_2 emissions may be reduced by up to 70%[2] thanks largely to the fuel switch in combination with a significant increase in efficiency from an average of 38% to up to 63%.[3] Based on various market analyses, such as those conducted by the IEA World Energy Outlook and HIS Markit, up to 25% of the world's installed coal-fired power plants alone have the potential for full repowering.

A special case of repowering is coal-fired combined heat and power (CHP) plants. Keeping CHP plants in their current location is highly important for the continued supply of district heating networks and/or industrial plants. Given this, Brownfield Transformation is even more important for CHP plants than for power plants exclusively generating electric power. By integrating modern high-efficiency gas turbines, CHP plants may significantly increase both electrical efficiency and heat utilization; integration of modern high-efficiency gas turbines are also expected to improve operational flexibility. Going even further, as part of this repowering process, CHP plants can also undergo hybridization by installing heat storage systems (typically hot water storage), which are intended to improve the plant operation's economic efficiency.

2 Unit specific results may vary.

3 Kraftwerkstechnik 2021, Power Plant Technology, ed. Michael Beckmann, Antonio Hurtado; p. 40.

Brownfield Engine Exchange (BEX)

One of the easiest and obvious means for transforming an existing power plant with gas turbines is replacing these turbines with more efficient ones. Compared to regular standard maintenance or modifying and upgrading an existing turbine, an engine exchange might be economically favorable in the long run.

As energy efficiency is essential when reaching climate goals, BEX is one of the suitable options for existing gas-fired power generation. With the BEX approach, the existing water steam cycle can be maintained, while potentially achieving greater output with lower NOx, CO, and CO_2 emissions relative to power output. The BEX approach aims at providing better operational flexibility by allowing part load capability and fast ramp rates, improving responsiveness to electricity demand and market conditions. Moreover, new turbines are expected to require less maintenance than older models. Finally, Siemens Energy's advanced gas turbines are designed for hydrogen co-firing, thus making the power plant H_2-ready. For many turbines in operation, a brownfield engine exchange may therefore offer an economically sound solution in the long term, thereby building a bridge towards a decarbonized future.

An old gas turbine is being replaced at a power plant in Convington County, Alabama. It enables the power plant to produce 114 megawatts (MW) of cleaner energy, up from an average of 102 MW.

Rotating grid stability conversions

Inertia is the resistance of a physical object to any change in velocity – essentially, the kinetic energy that keeps something moving. In energy terms, inertia is energy stored in the physical rotating mass of a turbo set. It helps slow the rate at which the grid frequency changes, as rapid changes can create instability in the system. Yet its availability is shrinking. With fewer fossil power plants connected to the grid, there are also less large spinning turbines on the grid. In addition, the increasing amount of renewable power does not add inertia to the grid. As a result, the danger lies in having less inertia than necessary in the system, and with it, the risk of power outages increases.

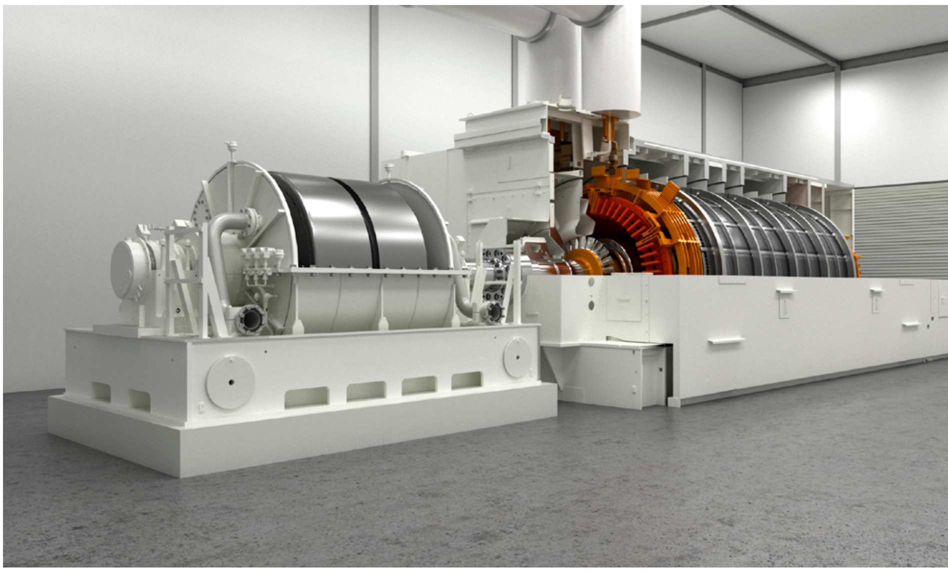
But with this challenge, a new opportunity arises in the form of rotating grid stabilizers. Designed to supply the inertia necessary to help stabilize the grid, these stabilizers can be installed in former power plants. A rotating grid stabilizer is a large piece of spinning machinery made up of a generator – also called a synchronous condenser – and usually a flywheel, which when connected to the grid, is designed to provide inertia by spinning continuously. By spinning in sync with the grid frequency, it contributes to the stability of the system by dampening fluctuations in the grid frequency, just as car shock absorbers dampen a bump in the road.

In addition, rotating grid stabilizers can help support voltage stability by providing reactive power while enhancing grid strength at connection points by providing short circuit power. Moreover, rotating grid stabilizers are designed to respond inherently without time delay. They also help integrate renewables into the electricity system, ultimately leading to further decarbonization. Therefore, it's not surprising that rotating grid stabilizers are experiencing a renaissance today. Essentially, they're designed to stabilize the grid while reducing the number of fossil power plants over time, thus making way for a decarbonized energy system.

Brownfield conversions to rotating grid stabilizers can happen in three ways:

1. A basic conversion consists in converting existing generators into synchronous condensers at comparably low cost. It's an attractive way to repurpose generators in coal plants faced with exit decisions.
2. Adding a flywheel to the train maximizes system inertia.
3. Finally, a hybrid train conversion adds an additional synchro-self-shifting (SSS) clutch between a gas or steam turbine and the generator, which is intended to enable both generation and grid stabilizing mode for maximum flexibility. This can be applied to existing gas turbine or steam turbine trains. The flexibility between power generation and grid stabilizer mode may also enable additional revenue streams by providing grid stability when no active power is needed.

All of these different solutions are being implemented worldwide. At the Killingholme Power Plant in the UK, for instance, two steam turbines are being converted to synchronous condensers with added flywheels. This way, the old assets can continue to operate as rotating grid stabilizers, and help with the more decentralized, renewable power generation.

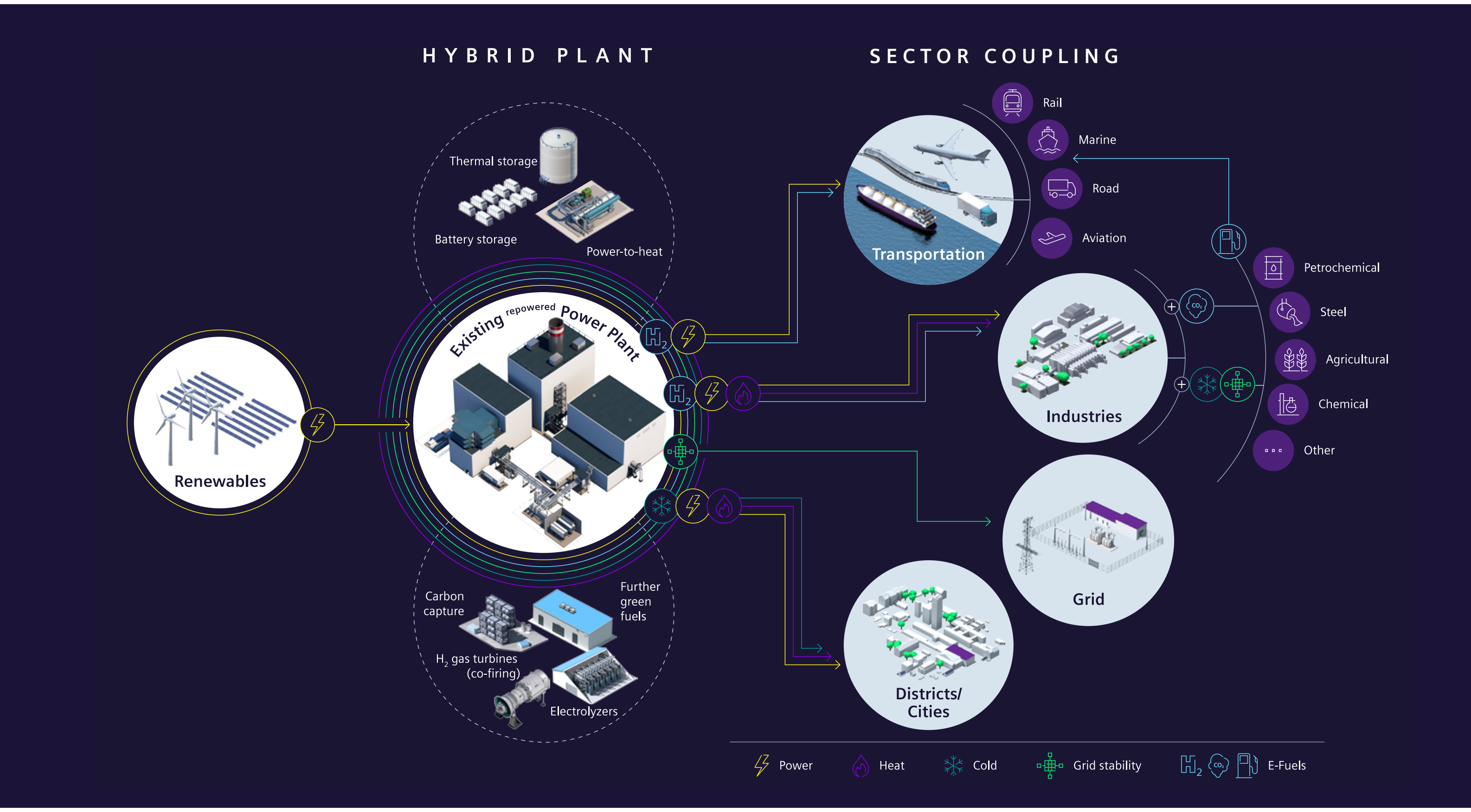


A synchronous condenser such as this one at the Killingolme Power Plant in the UK can supply short circuit power, reactive power, inertia, as well as revenue from grid ancillary services.

Hybrid power plants

In the long run, many power plant sites will likely become hybrid power plants, laying the foundation for a new energy system. They'll connect and integrate various functional elements, such as different means of generating power. For example, renewable power sources, such as solar and wind, or gas turbines, capable of burning 100% green hydrogen produced by electrolyzers with clean energy, would be integrated. Hybrid power plants would also include energy storage systems – such as hydrogen, batteries, or thermal storage – and applications for grid stability services, such as the aforementioned RGS. And running all of these different elements efficiently would require digital management systems that are designed to flexibly and automatically manage fluctuating and distributed power supply and demand. One main advantage of building these hybrid power plants on existing infrastructure is that they bring significant cost savings and reduced life cycle CO_2 emissions, thereby promoting synergies between existing and new assets.

Let´s consider hydrogen power plants as an example. Hydrogen power plants integrate various components into one plant solution. Ideally, it means that renewables are used to produce green hydrogen with the help of electrolyzers when excess electricity is available. The power plant re-electrifies the energy stored in green hydrogen when renewables can't meet current demand. Likewise, the waste heat produced by the



Hybrid power plants integrate renewables, energy storage and thermal energy generation. And they enable sector coupling, the electrification of energy-intensive sectors of the economy.

turbine may also be utilized by, e. g., feeding it into district heating systems that only require input heat in the range of 150°C. The end result is an intricate integration of power production elements that requires an intelligent control system designed to optimize the different elements.

But this complex scenario won't be realized overnight. That's why, in most cases, it's expected that moving towards a hydrogen power plant will happen by upgrading a gas-fired power plant. Thus, the combustion system of the gas turbine will require an upgrade. The upgrade will be designed to allow for a higher percentage of hydrogen burn. And this upgrade should occur before incorporating a natural gas and hydrogen fuel blending station and ensuring all other relevant systems of the plant are hydrogen capable as well. As a next step, hydrogen could be produced on-site using an electrolyzer. And with this, one would also add hydrogen storage, and possibly even a hydrogen pipeline supplying, e. g, industries nearby.

One current example of a power plant taking the first steps towards becoming a hybrid power plant is located in Leipzig. With two new gas turbines for the Leipzig Süd district heating power plant in Germany, this modernized plant is expected to contribute to the decarbonization of the city's power supply in two ways. First, the investment is intended to make Stadtwerke Leipzig operate independent of district heat from a lignite-fired power plant; and second, within a few years, the plant is expected to operate with up to 30 to 50% green hydrogen. The long-term goal is to operate the facility with up to 100% hydrogen. Furthermore, the modernization package includes a battery solution that's designed to enable the plant's black-start capability, so that the power plant could be started up without an external power supply, even in the unlikely event of a widespread blackout.[4]

4 https://press.siemens-energy.com/global/en/pressrelease/gas-turbines-siemens-energy-are-providing-leipzig-climate-neutral-power-supply

The thermal power plant in Theiss, Austria, is the first to install a hydrogen-capable gas turbine.

Industry plants

Industry plants can also support the path towards decarbonization. They also work with assets that make a good case for Brownfield Transformation. Unlike the energy industry, wherein power is the final product, industrial power plants primarily support the manufacturing of a product. So, in the end, it's the carbon footprint of such a product that matters. But certainly energy-intensive industries, such as mining, chemicals, pulp and paper, steel, or cement, should seriously consider modernizing their power plants in order to reduce their carbon emissions. Like stand-alone power plants, industry plants can also switch fuels from coal or oil to gas, modernize gas turbines to co-fire more H_2, or increase the share of H_2 further with BEX.

Another option is transforming a gas turbine plant to a CCPP with the help of steam tailing – this involves adding a complete water-steam-cycle including a Heat Recovery Steam Generator (HRSG) and a steam turbine, thereby addressing increased power or heat demand as well as improving efficiency. To maintain the flexibility of an open-cycle gas turbine, the existing exhaust stack will be modified to operate as an exhaust bypass stack. An extant CCPP, which requires a bypass stack for increased flexibility, can be retrofitted.

Today, there are various projects worldwide aiming to reduce the carbon-footprint of industrial processes and their end products. As one example, Siemens Energy is modernizing an industrial power plant for a BASF-factory producing mainly polyurethane in Schwarzheide, Germany. The Brownfield Engine Exchange involves replacing a gas turbine with a new, highly efficient industrial gas turbine as well as servicing this machine for a period of 15 years. It also includes a battery storage solution that's designed to enable the entire power plant to start up without requiring external power supply.

In another case, the E.U. – with its ambitious climate goals in sight – supports HYFLEXPOWER, the world's first Power-to-X-to-Power demonstrator project at a paper factory in Saillat-sur-Vienne in France. For this an existing Siemens SGT-400 industrial gas turbine will be upgraded to convert stored hydrogen into electricity and thermal energy. Driven by a consortium that includes Siemens Energy, the German Aerospace Center (DLR), and other companies and universities, its first firing is planned for 2023. The goal is to completely decarbonize the plant's energy production. It's projected that energy production based solely on green hydrogen would save up to 65,000 tons of CO_2 per year.

5 https://press.siemens-energy.com/global/en/pressrelease/siemens-modernize-industrial-power-plant-basf-germany-key-components

6 https://press.siemens-energy.com/global/en/pressrelease/hyflexpower-worlds-first-integrated-power-x-power-hydrogen-gas-turbine-demonstrator

7 Unit specific results may vary.

Modernizing an industrial power plant: At the BASF Schwarzheide industrial plant a new efficient gas turbine was installed, as well as a battery storage system for black-start capability.

Our energy future – beyond technical solutions

As much as we'd like to have a decarbonized energy system based on renewables, with energy storage solutions, rotating grid stabilizers, green hydrogen, and sector coupling to be a beautiful reality tomorrow, it will take some time. And as we embark on this path, we have to work with what we have – and that includes power plants that can't and shouldn't simply be shut down for economic, social, and sustainability reasons. Despite the obvious need, transforming these assets over time won't happen magically. It takes the right political and financial measures that could lead to new market mechanisms as incentives for investments in decarbonization technologies to drive this potential, future development forward. For this reason, we also need close cooperation between policy makers and the private sector, and among companies competing for efficient as well as affordable energy solutions.

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