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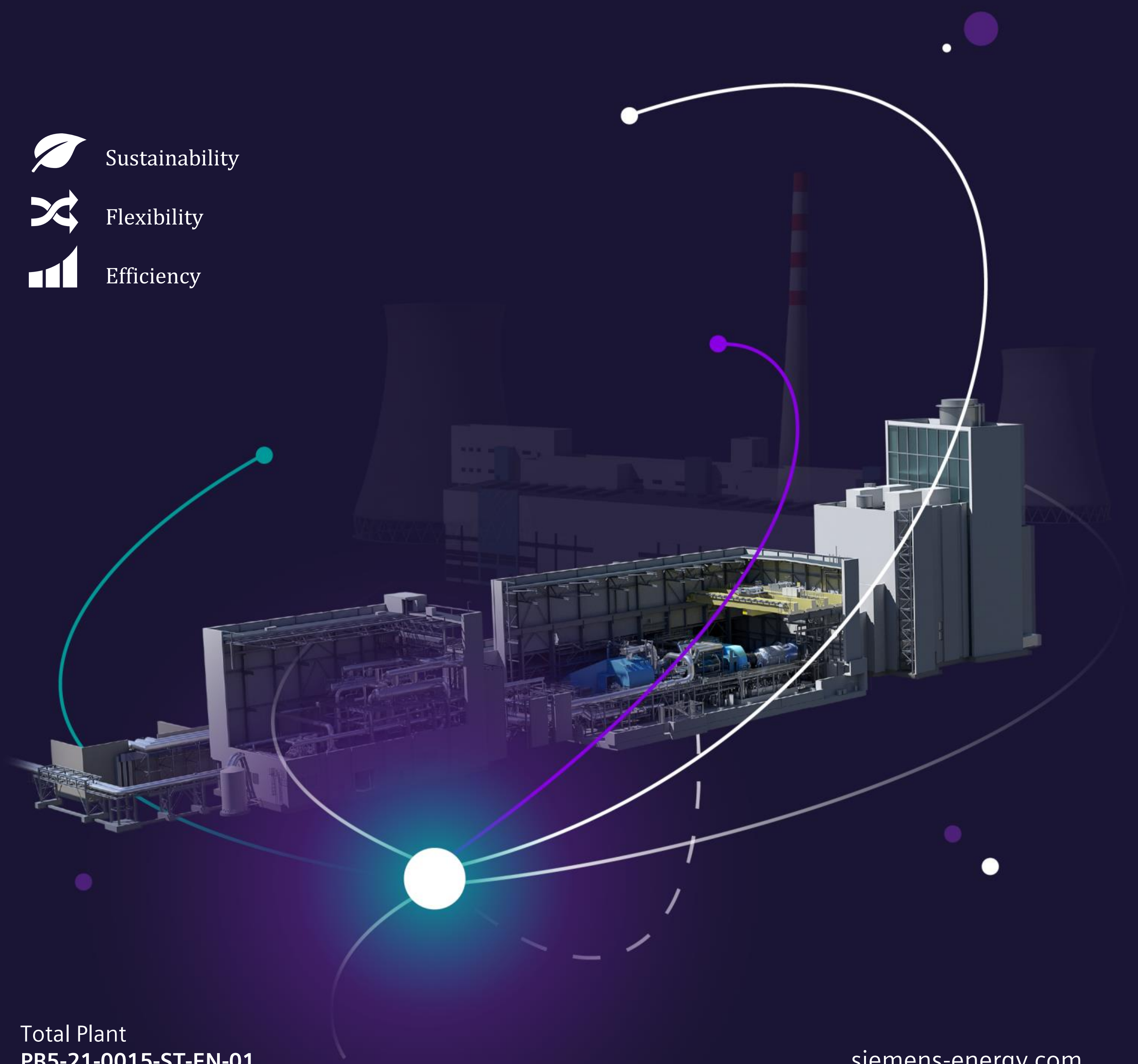
Product Bulletin

Coal to Gas Repowering

Sustainability

Flexibility

Efficiency



Total Plant

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Coal to Gas Repowering

Reducing CO2 emissions up to 70% by reusing existing infrastructure as a major milestone towards complete decarbonization.

Sustainability

- CO_2 footprint
- Operational emissions

Flexibility

- Operational flexibility

Efficiency

- Base load efficiency
- Transient efficiency

Summary

Decarbonization is the primary goal in this century. More and more countries define targets to achieve net zero CO_2 emissions by mid-century. However global warming correlates to the absolute amount of CO_2 emitted into the atmosphere. Therefore, to achieve these goals, it is necessary to rapidly reduce emissions based on affordable and state of the art technologies. Renewable energy is expected to play a significant role. Nevertheless, today's power plants may very likely turn into important hubs for energy transformation, storage, and distribution. In the foreseeable future, natural gas fired power plants are expected to play a major role as bridging technology to maintain the security of power supply and to efficiently generate heat for district heating or the process industry. With a growing competitivity and availability, hydrogen (H_2) can be mixed with the natural gas. Over the years its share in the fuel may be stepwise increased. With Coal to Gas Repowering, CO_2 emissions can be reduced within a short time frame by up to 70% while maintaining most of the existing power plant infrastructure. By firing or co-firing with H_2 these emissions can be reduced even further. Further, these repowered plants can perfectly fit into energy systems with a growing share of renewable power production as time and costs for startups and shutdowns can be significantly lower than those of other fossil or nuclear power plants. Besides the advantage of significant CO_2 reduction, Coal to Gas Repowering can be an effective measure for improving the air quality in megacities and densely populated regions. Emissions of SO_2, CO, NO_2 and particles from a natural gas fired power plant have been reported to be between 68 and 99% lower than those of coal fired power plants. (Wikipedia, 2021)

Figure 1: Coal fired power plants may end up as stranded assets

Uncertain future for coal fired power generation

Coal has been the world's largest source of fuel for power generation. However, it is being looked at carefully as this fuel contributes to nearly 30% of global energy related CO_2 emissions and to nearly 75% of the power sector CO_2 emissions. (IEA, 2020) As a result of growing political attention, many projects for construction of new coal fired power plants were discontinued around the globe. (IEA I. E., 2020). For the installed fleet, future operation may depend on its geographic situation. Many nations either have already introduced carbon emissions trading schemes and/or defined targets for the phase out of coal fired plants. The competitiveness of coal fired power generation depends, besides other factors, mainly on the relative development of the coal price against the gas price and the cost for emitting CO_2. Further, in power systems with a high share of renewable energy, flexible gas fired power plants with low fixed costs can have a significant advantage against coal fired power plants.

At the beginning of 2021 gas prices were low around the world. (Trading Economics, www.tradingeconomics.com, 2021) Coal prices on the contrary remained relatively stable. (Trading Economics, www.tradingeconomics.com, 2021)

In the European market this price difference had a substantial impact on the competitiveness of coal fired power plants. (Dambeck, 2021) Gas prices were at about 18€/MWh in beginning of 2021, whereas the price for Emission Trading Scheme (ETS) certificates was at up to 40 EUR/t. (Energy Charts, 2021) In that situation the marginal generation cost of modern natural gas fired combined cycle plants was lower than that of most coal fired power plants. Thus, sooner or later even the newest and most efficient coal power plant may face a challenging future.

In Asia countries like Korea and Japan are setting ambitious decarbonization targets that are impacting the future of coal fired power generation. Also, China lately introduced a national Emission Trading Scheme and stated its intention to be carbon neutral by 2060. (International Carbon Action Partnership, 2021)

In the US, power production from coal decreased significantly due to a growing share of renewable power production and low gas prices. (IEA I. E., 2020) A more ambitions decarbonization agenda may accelerate this trend.

Our solution

The concept of Coal to Gas Repowering is to replace the boiler of a coal fired power plant with one or more highly efficient gas turbine power trains consisting of gas turbine, generator, and heat recovery steam generator (HRSG). The existing steam turbine is retained and retrofitted to adapt to combined cycle operation.

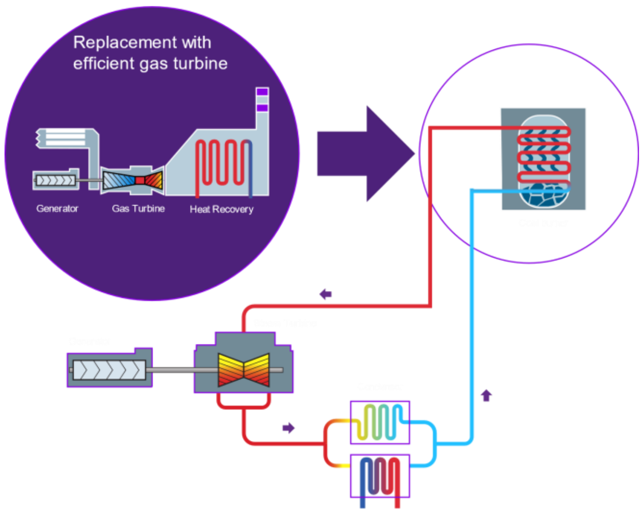

Figure 2: schematic sketch of Coal to Gas Repowering

Intended Benefits

Compared to conventional steam plants, combined cycle plants can provide several advantages.

a) Reduced CO_2 emissions by up to 70%

Of conventional fuels natural gas has with approximately 200 g/kWh$_{thermal}$ the lowest specific carbon dioxide emissions. In comparison the corresponding value for lignite is around 380 g/kWh$_{thermal}$. This means that even at the same efficiency a gas fired power plant would emit ~47% less CO_2 than a lignite plant. However, an average example lignite plant may have an efficiency of approximately 37%, whereas new constructed combined cycle plants achieve up to 64% efficiency. (Siemens Energy, 2021) As a result, due to a Coal to Gas Repowering CO_2 emissions may be reduced by up to 70%.

b) H_2 readiness

As of today, newly manufactured Siemens Energy gas turbines can burn gas containing up to 50 volume percent hydrogen. (Siemens Energy, 2021) Taking this into account the CO_2 emissions can be further reduced to by up to 76% compared to the example lignite plant referenced above.

Further, Siemens Energy is endeavoring to gradually increase the H_2 capability in its future manufactured gas turbines to 100 percent by 2030. (Siemens Energy, 2019)

c) Operational flexibility

As the share of renewable energy increases almost everywhere around the world expectations towards conventional power stations are likely to change from baseload to cycling operation and from a few plant startups per year to several startups per week. Modern combined cycle plants perfectly match to these requirements. Main flexibility features can include:

- More than 200 startups per year
- Minimum startup times of
  - 90 minutes for a cold start
  - 45 minutes and for a warm start
  - 30 minutes for a hot start
- The load gradient in load following mode up to 85 MW/min
- Operational range from 20% - 100% of maximum power output

Figure 3: Indented Benefits of Coal to Gas Repowering

d) Up to 30% less investment cost, compared to a typical Siemens Energy greenfield combined cycle power plant as well as fast track implementation.

A major objective of Coal to Gas Repowering is to reuse as much as possible of the existing site infrastructure including existing permits without compromising on plant performance. As a result, significant savings can be achieved on civil works including demolition costs, pipework, water, grid connection and others. Such reuse also allows fast track project implementation. Depending upon the customers' expressed need, the project can be planned and executed in a way that the interruption of power production is minimized.

Economic Value

A main value contributor of Coal to Gas Repowering is the reduction of CO_2 emissions. Depending on applicable regulations, the savings in emission certificates can potentially compensate for the additional costs resulting from the fuel switch from coal to gas. For an example coal fired power plant in Europe with an average efficiency of 38% a certificate cost of 40 €/t can result in CO_2 costs of 36 € per MWh of electricity produced. Whereas for an example natural gas fired combined cycle plant with an average efficiency of 60%, the respective CO_2 cost can be only 13 € per MWh of electricity produced. As this difference in CO_2 certificate cost can often not be outweighed by the cheaper fuel cost for coal, marginal generation costs of the gas plant in this example are lower than those of the coal plant. In a liberalized energy system, lower marginal costs can typically lead to an increase in annual production, as the plant is able to enter the market at lower prices than before. The below graph shows that a plant that operates at an average load of 1.100 MW might generate up to 85 Mio € additional value per year, if repowered to a combined cycle plant.

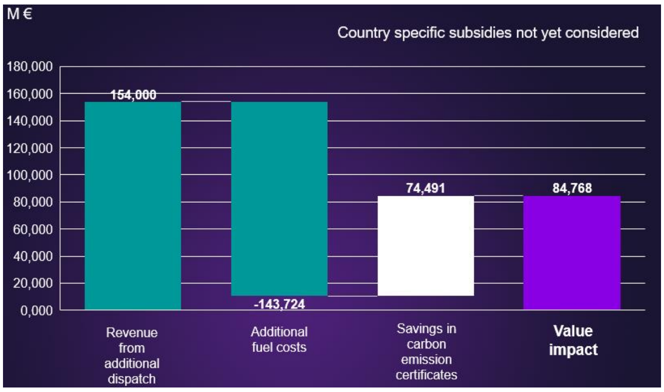

Figure 4 Possible net change in annual value resulting from an example Coal to Gas Repowering. Assumptions for the scenario: At a gas price of 18€/MWh, a coal price of 60€/t and an emission certificate cost of 40€/t the gas fired plant is expected to operate approximately 2500hrs/year more than the coal plant. At an average electricity price of 56€/MWh and an average load of 1.100 MW the gas plant would generate in one year ~85 Mio€ more revenue than a coal plant. (average efficiency coal plant 37% and gas > 60%). (assumptions may not reflect actual conditions and results may vary accordingly).

Market forecast suggests that CO_2 emission cost will continue to increase. The cost of coal is expected to remain stable and prices for natural gas may slightly increase over the years. (IHS Markit, 2021) As a result, if these assessments are accurate, the long-term prospects of a Coal to Gas Repowering are promising.

Figure 5 compares the annually generated value of a hypothetical coal plant with a Coal to Gas repowered plant for a period of ten years. For the given example the combined cycle plant has in each single year a clear value advantage against the coal fired plant.

Figure 5: Value forecast for Coal to Gas Repowering versus coal fired power plant

Data sources and assumptions: Increase of generation hours due to lower generation cost: 2500 hrs/yr; Price forecast electricity, gas, CO_2 certificate: IHS Markit (Poland); average load: 1.100 MW; ø efficiency coal plant 38%; ø efficiency gas plant >60% (assumptions may not reflect actual conditions and results may vary accordingly)

Technical Background

The Coal to Gas Repowering approach can be split into three phases:

1. Concept Design
2. Front-End Engineering Design (FEED) Study
3. Execution

1. Concept Design Phase

Purpose of the concept design phase is to first assess the power plants market environment and regional energy system including but not limited to the following factors:

- Existing and possible future revenue streams
- Situation of the plant with regards to fuel supply and offtake for power and heat
- Future plant size and operation
- Plant layout
- Plant performance
- Assessment of existing technology and infrastructure

Then the customer and Siemens Energy jointly develop, evaluate, and agree upon the optimal concept for the future plant. This is done in a sequential approach, starting with the geometrical fit.

Geometrical fit

The main consideration of the geometrical fit is to assess what equipment would fit into the existing site infrastructure dimensionally. Siemens Energy distinguishes between three possible solution types, depending on the extent of reuse of the existing site infrastructure agreed upon:

a) Greenfield repowering

The first one is to demolish an existent power block and to replace it with a new combined cycle plant. In this document we will refer to this approach as “greenfield repowering”.

b) Brownfield repowering with supplemental approach

If the existing power block is used at least partially and additional equipment is added outdoor, we will refer to the expression “brownfield repowering with supplemental approach”.

c) Brownfield repowering with integrative approach

Ideally the new equipment can be completely integrated into the existing building structure. This will be referred to as “brownfield repowering with integrative approach”.

Comparison criteria	Greenfield	Supplemental	Integrated
Capital expenditures	+	++	+++
Maintenance requirements	+++	++	++
Emissions during construction	+	++	+++
Project lead time	+	++	++

Table 1: Specific advantages of different coal to gas repowering approaches (+++ highest ranked approach for respective criteria)

The choice between the different approaches strongly depends on specific requirements for the future energy system and the local site conditions.

Each of the concepts has its individual advantages.

- The higher the share of the existing infrastructure that will be further used, the lower the capital expenditures. Therefore, from an investment point of view, the integrated approach might be the preferred solution.
- The integrated approach also has the lowest CO_2 emissions during the construction phase as it uses the lowest amount of new steel and concrete. Further, compared to the complete demolition and reconstruction of a plant also the emissions of noise and dust are significantly lower for the integrative approach.
- If the power production shall be interrupted as short as possible the supplemental approach might be the solution of choice. The existing steam power plant can be further operated during the construction phase of a GT power train situated outside to the existing steam plant. If the GT power train is equipped with a bypass stack the GT can already generate power when the steam section of the plant is repowered.

Thermodynamic fit

Purpose of the thermodynamic fit is to select the best plant size and configuration. Thanks to our broad gas turbine portfolio it is possible to find the equipment that suits best to the future energy system and operation regime. Depending on the future revenue streams requirements like load spread, minimum emission compliant load, redundancy and ancillary services may influence the decision between a multi-GT or a single GT configuration.

Steam turbine retrofit

After selection of the gas turbines, it is possible to quantify the exhaust mass flow and temperature which determine the main requirements for the water steam cycle. Typically, a retrofit of the steam turbine(s) is required since the heat flow distribution between the high-, intermediate- and the low pressure of conventional steam turbines plants deviates substantially from those of combined cycle plants. If the coal fired power plant consists of multiple steam units several combinations between the HP-, IP- and LP-sections of turbines are possible. Again, the customer can select the best combination for the future operating regime.

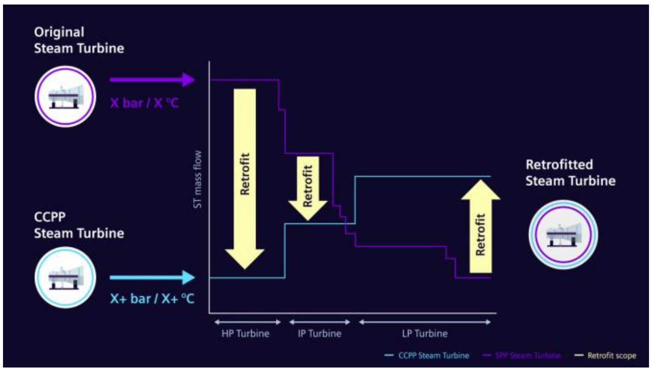

Figure 6: Example for site specific comparison of heat flows between steam turbines for classical steam plants versus combined cycle plants

2. Front-End Engineering Design (FEED) Study

Knowing type, number, and combination of units as well as the geometrical situation of the equipment the basic design parameters are set. As a next step a detailed front-end engineering design study will be executed with the objective to quantify performance values, detailed scope including the integration of all respective terminal points and cost of the specific Coal to Gas Repowering concept. With the completion of the front-end engineering design study Siemens Energy will be able to provide a proposal for the repowering concept chosen.

3. Implementation

Collaborating with Siemens Energy as the technology partner in a repowering project offers unique advantages:

a) Technological competency

Like no other company, Siemens Energy can directly provide a significant part of what is needed to plan and execute a complete Coal to Gas Repowering. Products and services that can be provided out of our portfolio are:

- A broad product spectrum of new gas turbines up to the nearly 600-Megawatt highest efficient HL class.
- Siemens Energy successfully performed more than 300 Steam Turbine retrofits across the globe. A significant amount of these retrofits was performed on steam turbines not originally designed and supplied by Siemens.
- For all gas turbines and steam turbines we can provide the perfect fitting generator.
- Inhouse heat recovery steam generators
- All types of electrical equipment including but not limited to transformers and switchgears.
- Our proven T3000 DCS system that is also used in many non-Siemens power plants around the world.
- In our portfolio for New Energy Business and Decarbonized Energy Systems we can provide all technology needed for transforming your plant into a modern hub for energy transformation, storage, and distribution. It comprises heat storage equipment that can decouple electricity and heat production, battery storage, electrolysers, H_2 storage and transportation facilities.

b) Worldwide project experience

Siemens Energy has a long track record of successful repowering and brownfield exchange projects all around the world. Having a lot of in-house competence results in reduced external interfaces. By involving our experts, we can decide quickly and move forward. We are known for high quality project management and for keeping up to our promises.

Notes

Our experienced service team is ready to assist you in deciding which solution is the right one for you. With our experts in engineering, manufacturing and/or field service in close collaboration, we can offer the optimum solutions for your power plant to match your specific demands.

Please do not hesitate to contact your local Siemens Energy representative for further information.

Visit our Customer Energy Portal siemens.force.com/cep or our webpage siemens-energy.com

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