



Cost-optimized design of hybrid power plants

White paper

Hybrid power plants are becoming an indispensable part of our energy landscape. When integrated, these elements can be flexibly optimized for energy efficiency and adapted to the specific conditions of a site. They can produce electricity at a lower cost than stand-alone thermal power plants co-firing or solely burning clean fuels.



The relevance of hybrid power plants

We're building a new decarbonized energy system. It's necessary to counter climate change and become independent of fossil fuels and countries exporting them. A key building block of this energy system will be renewables, mainly solar and wind. As these sources are intermittent, we also need solutions bridging times when the sun doesn't shine, and the wind doesn't blow.

Energy storage and thermal power plants burning low-carbon or ideally clean fuels can fill that gap. And if you put at least two of these three elements together in one power plant (renewables, storage, and thermal power generation), what you get is a hybrid power plant. These plants will become an indispensable part of our energy landscape, not only because they enable continuous carbon-free energy generation. When integrated, these elements can be flexibly optimized for energy efficiency as well as adjusted to a site's specific

conditions. That's particularly true for remote locations.

In remote locations, especially, environmentally sensitive areas, low-carbon or fully decarbonized hybrid power plants can generate electricity at a lower price than stand-alone thermal power plants co-firing or solely firing clean fuels. The key to achieving this result is applying a cost-optimized energy design. And while this allows building power plants that generate carbon-free electricity at a competitive price in island mode, it's also relevant for future power plants connected to the regular power grid.

The main economic drivers include decreasing cost for renewables, increasing carbon and fuel prices, governmental incentives as well as regulations for decarbonizing energy generation. In this short White paper, we take a close look at power plants with the help of Energy System Design (ESD).

What are hybrid power plants?

While hybrid power plants may combine two elements, either renewables, thermal power generation or energy storage, they're most powerful when they integrate all three elements. This way, the drawbacks of one element are being compensated by the other elements:

- Though renewables, such as wind and solar, are essential to the decarbonization solution, one can't fully rely on them due to their fluctuating output. For this purpose, energy storage and thermal power plants (firing low-carbon or preferably clean fuels) can remedy such short-term fluctuations.
- Energy storage solutions, while delivering instant green energy (if charged with renewables), eventually run out. Such is the case for batteries, which are still the top choice for storing energy to balance load differences in the grid. Thermal power generation can assure continued power supply.
- While thermal power plants continuously generate energy, in the long run, this is

only sustainable if fired with a clean fuel, such as green hydrogen. Renewables can ensure that there's enough supply of clean fuels. For example, they can produce green hydrogen with the help of electrolyzers and storage tanks.

All elements form a complementary and altogether more powerful solution. Indeed, this integration wouldn't work without a fourth element: a smart control system, including a dispatch optimizer that can manage such a dynamic system. In some cases, it can do so remotely or even enable autonomous operation, thereby lowering OPEX overall.

Since all these components can be individually configured, they can be adjusted to a site's specific needs, thus ultimately optimizing their use. As a result, these tailored configurations can ensure steady energy flow, grid stability, and 24/7 power availability in a wide range of different settings.

Energy System Design (ESD)

How can we figure out what makes hybrid power plants in remote locations a viable business case? With the help of Energy System Design (ESD). ESD is a model-based, optimized selection and sizing of energy conversion and storage technologies that meet a specific customer's energy needs.

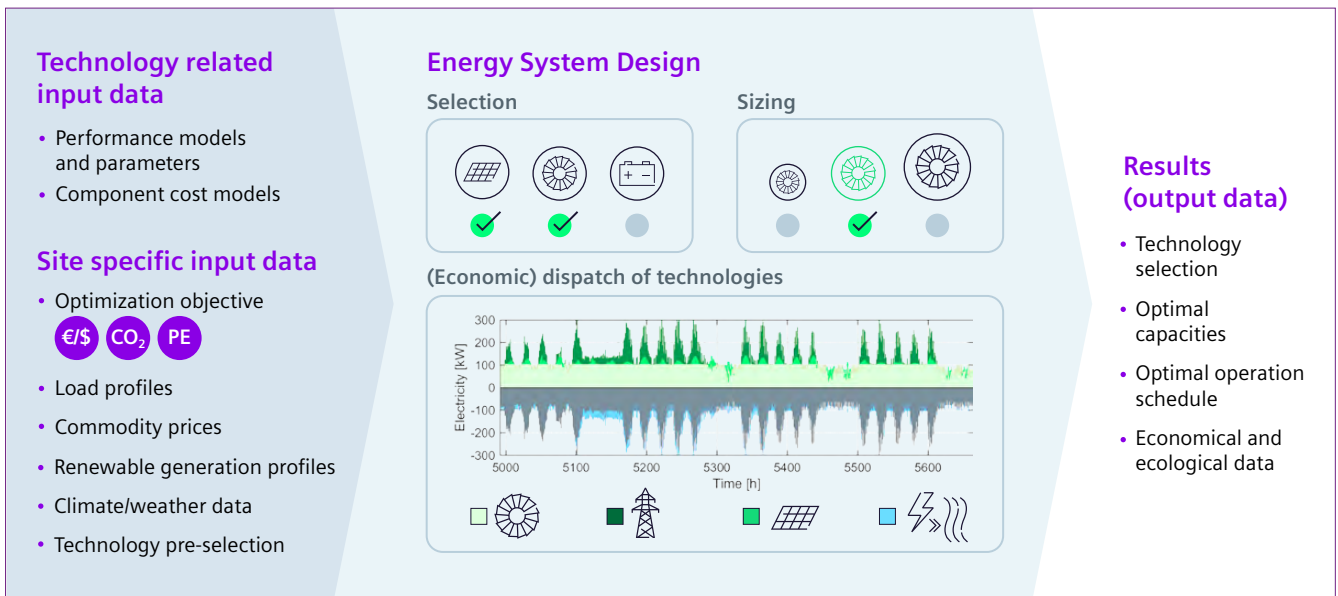
The optimization accounts for:

- the energy system's loads, for instance the electricity and heat demand of a factory;
- all relevant options for purchasing and/or selling energy commodities and the corresponding prices for, e.g., electricity and green hydrogen;
- the local renewable potential, for instance the PV generation profile;
- the local climate or weather conditions to account for, e.g. the impact of ambient temperature on chiller efficiency; and

- customer-specific technological preferences, for instance the inclusion of storage prototype or the exclusion of wind turbines for an airport's energy system.

Based on a solid understanding of the customer's energy needs, targets and site-specific boundary conditions, a set of energy conversion and storage technologies is defined and included as an option in a so-called model super-structure. The technologies are described by performance models on the one hand, and cost models on the other.

This data is then run through a state-of-the-art modelling and optimization tool that selects and sizes energy conversion and storage technologies. In addition, an optimal dispatch is calculated for all storage and conversion units that are selected and sized.



Graph 1: Energy System Design (ESD) is a model-based, optimized selection and sizing of energy conversion and storage technologies to meet a specific customer's energy needs.

As a result, one obtains:

- optimal technologies,
- optimal capacities,
- an optimal dispatch for the time frame under consideration (typically one year); and
- model data facilitating economic and ecological evaluation.

Since each piece of input data is subject to uncertainties, scenarios and parameters for sensitivity analyses are defined to evaluate their impact on the design of the energy system. Essentially, one gets a tailor-made design for developing a plant with superior economic and ecological performance across different scenarios.

Example: Hybrid power plant design for a mine

Let's take as an actual example: a hybrid power plant design for a customer's mine with an electricity demand between 180 and 220 MW and no grid connection in north-western Mexico. It's no small feat: Energy supply is often a roadblock for developing off-grid sites. Also energy costs are critical for a mine's profitability. And like with any fossil power plant, there's immense pressure to improve environmental performance.

Starting point

The goal is to develop a power plant that delivers reliable, cost-efficient, and low carbon electricity supply. To achieve this goal, PV or wind turbines are installed on available land. Additionally, LNG or H2 can be shipped.

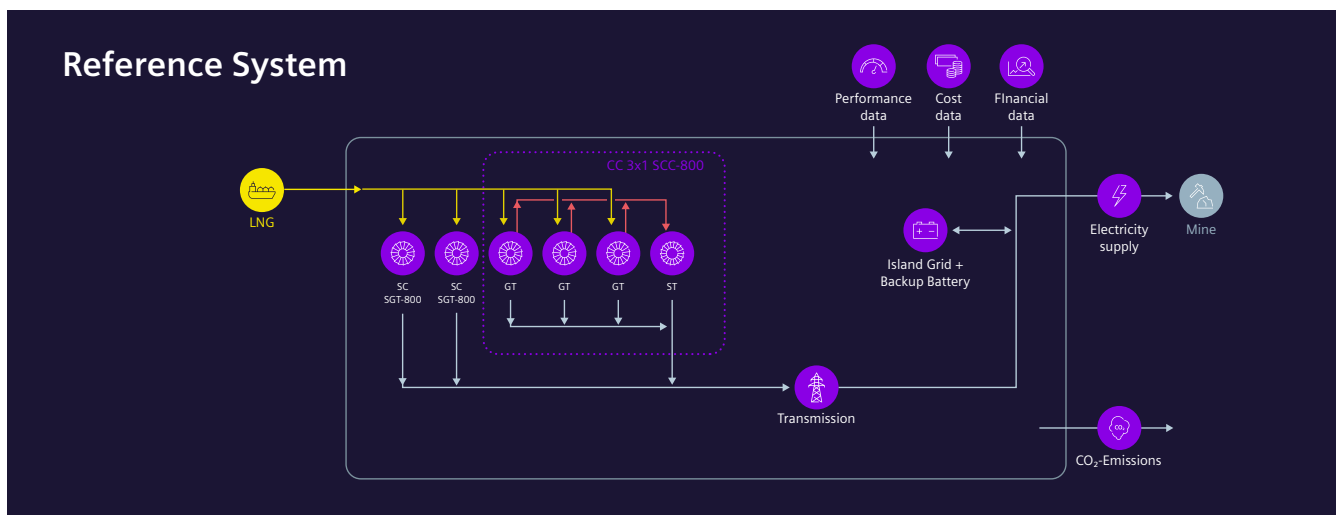
The approach taken in this case was to develop a power plant with PV, wind, and storage

that generates decarbonized energy. LNG-fired gas turbines were added for reliability and a thorough analysis with the Energy System Design methodology was applied.

As a reference, a highly efficient combined cycle LNG power plant was chosen (see graph 2). In addition to an efficient three-on-one combined cycle power plant configuration, two open cycle gas turbines are installed to ensure security of supply. Additionally, it has a battery energy storage system (BESS) in place to enable a black start. With this benchmark, costs and savings of hybridization can be measured.

There are different options for optimizing the aforementioned system (see graph 3). It includes PV, wind power, additional battery storage, and long duration storage, such as thermo-mechanical energy storage. In addition, LNG could be replaced by green hydrogen.

Graph 2: Reference system is a highly efficient combined cycle LNG power plant

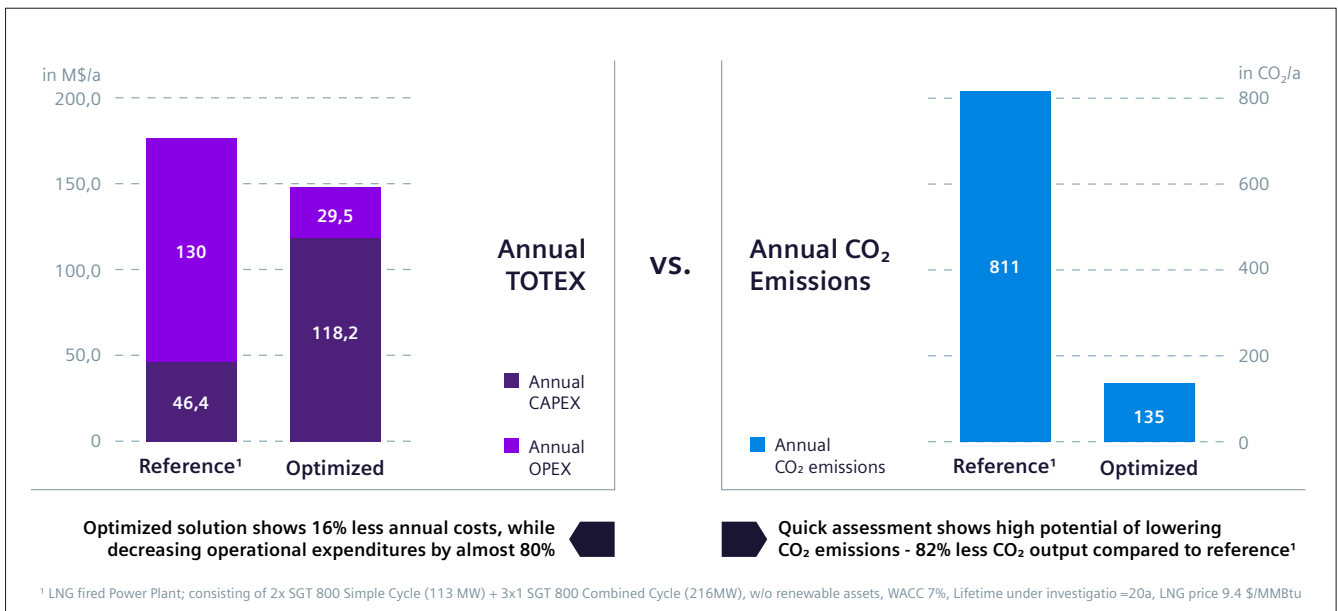
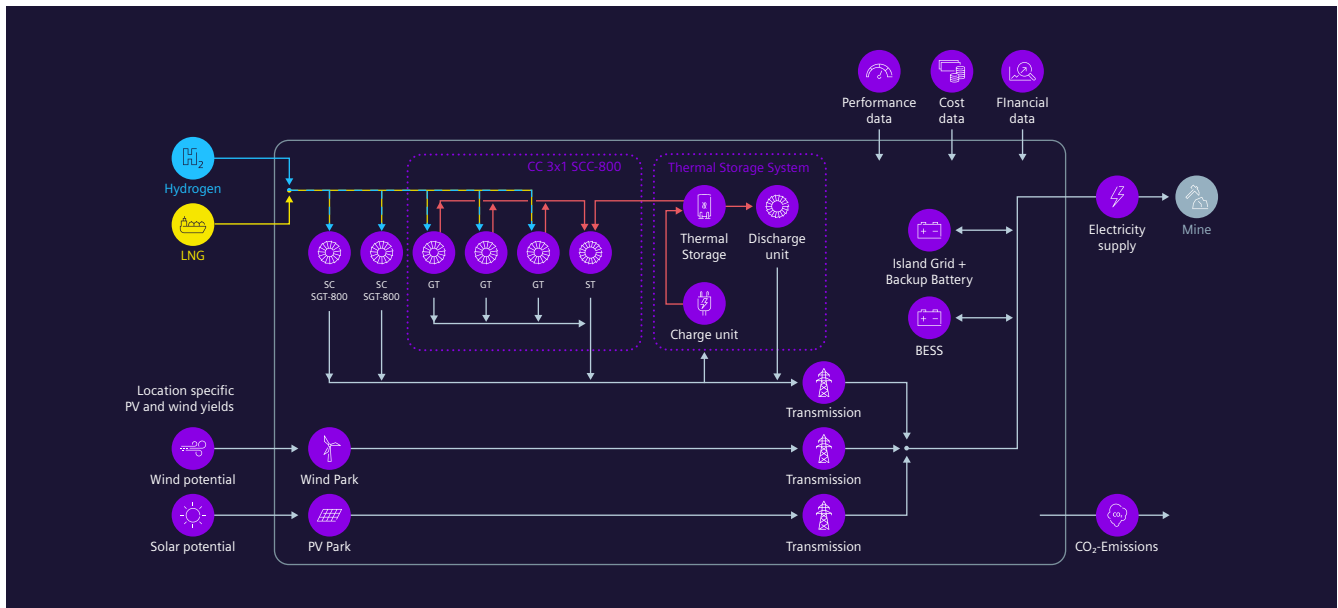


Results

Based on the Energy System Design analysis, we get different results for the annual TOTEX vs. annual CO₂ emissions and optimized capacities, from which we can compare electricity costs and CO₂ emissions on the path to zero CO₂ emissions. They all illustrate the advantage of hybrid power plants.

Annual TOTEX vs. annual CO₂ emissions: Compared to the reference plant, the hybrid power plant's CAPEX is increased and the annual OPEX reduced, resulting in a TOTEX reduction of 16%. As impressive as this is, CO₂ reductions are even more significant, in that the hybrid power plant generates 83% less CO₂ emissions than the reference plant (see graph 4).

Graph 3: Options for optimizing the reference system

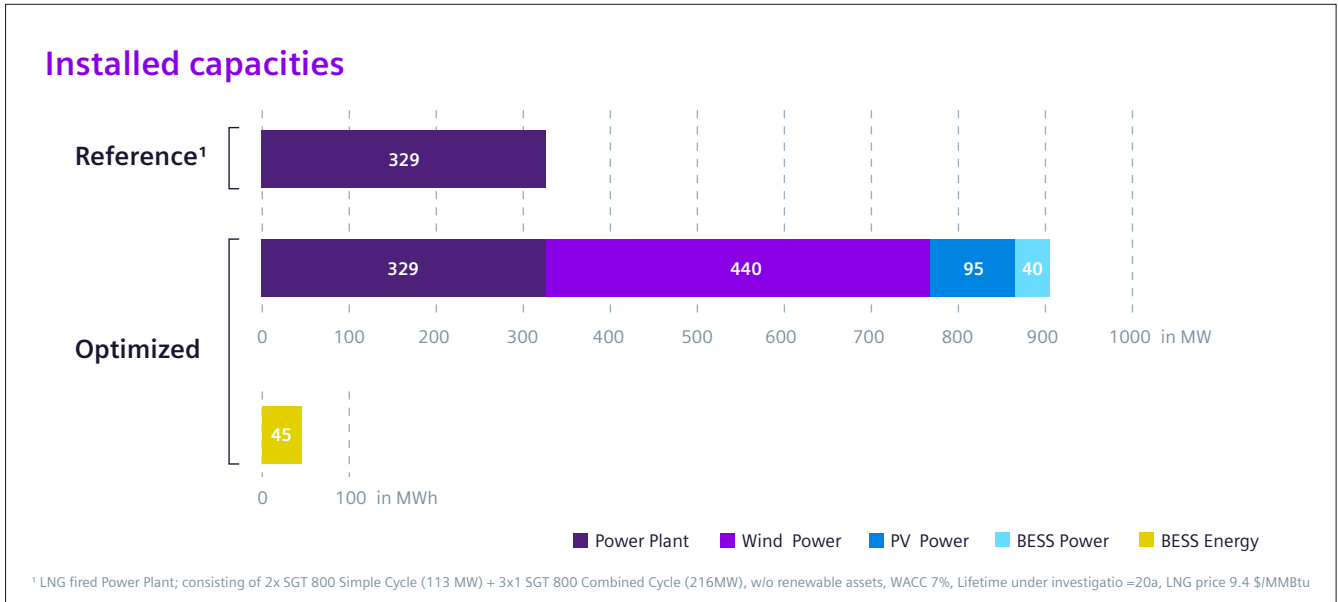


Graph 4: The hybrid power plant produces 83% less CO₂ emissions than the reference plant, at an annual cost that is 16% lower

Installed capacity: To ensure very high availability, the CCPP contains two extra gas turbines. In case one gas turbine breaks down during a maintenance outage of another gas turbine, a spare one is ready to use. This brings the installed capacity of the

reference plant to 329 MW. In addition to the reference plant's components, the optimized solution also includes a wind farm, a PV installation and an additional battery storage system.

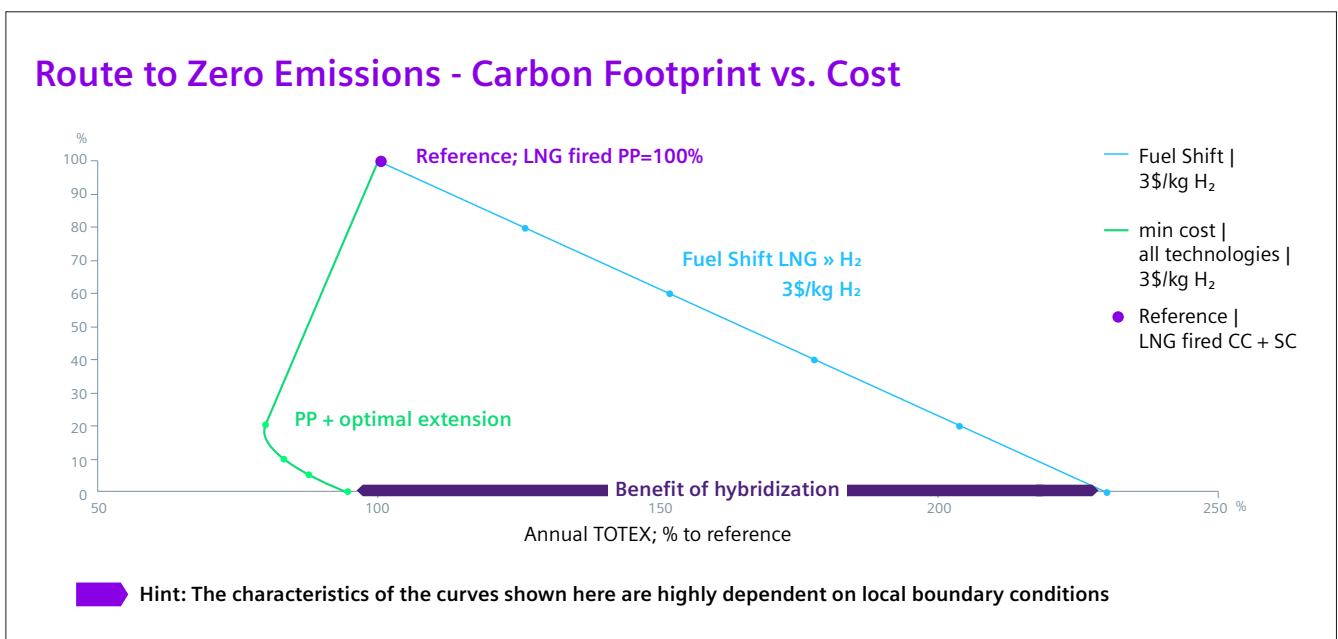
Graph 5: The optimized solution has a higher installed capacity because it includes a wind farm, a PV system, and an additional battery storage system



Electricity cost and CO₂ emissions: The tradeoff between CO₂ emissions and TOTEX is laid out in the graph 6 below. With an LNG-fired power plant being the baseline with 100% emissions and a 100% cost, we

see that a pure fuel shift significantly increases cost. On the other hand, if the plant is converted to a hybrid power plant, CO₂ emissions are reduced at a lower cost compared to a pure fuel shift.

Graph 6: Tradeoff between CO₂ emissions and TOTEX for the hybrid power plant



However, it's important to keep in mind that site-specific boundary conditions are crucial. To illustrate this, let's "move" the application from the aforementioned site in northwestern Mexico to a site in windy northern Germany with everything but the renewable energy potential remaining the same.

Based on an ESD analysis, the renewable energy potential in each location has a significant impact on annual TOTEX for achieving the same CO₂ emissions. Decarbonizing a site in northern Germany would clearly be more costly than decarbonizing the site in Mexico, because wind and solar together provide less renewable energy. However, in both cases the benefits of hybridization are far greater than simply relying on a mere fuel shift.

Overall, when calculating the price of electricity for an off-grid hybrid power plant, several additional factors are in its favor. For one, rising carbon pricing just like higher fossil fuel prices make fossil-fired thermal power plants a pricy proposition compared to low-carbon or carbon-free ones. Also the prices for installing renewables are dropping due to improved technology and the economy of scale. And depending on the region, where a hybrid power plant is to be built, other financial incentives, such as government subsidies can come into play.

Reference: Haru Oni

Now let's look at an actual reference for a hybrid power plant that demonstrates the advantage of hybrid power plants especially in remote locations. In Punta Arenas, Chile, the world's first large-scale integrated plant for climate-neutral e-fuel production is being developed by several international companies. The e-fuel is produced from water and CO₂ captured from air by using renewable energy from wind for the chemical processes. For production, the plant takes advantage of the strong and steady winds in the Magallanes, the southernmost region of Chile. The e-fuel is a liquid energy carrier that emits about 90% less CO₂ than its fossil fuel counterpart, and is simultaneously compatible with existing liquid fuel infrastructure. It's currently planned to produce 550 million liters of e-fuel per year until 2026.

Going forward

No matter the solution, a hybrid power plant will always represent a site-specific tailored mix and match of technologies. There'll clearly be no one-size-fits-all solution. Rather, different configurations will fit different needs. Ultimately, this flexibility also means that hybrid power plants will make the most of the resources in any situation. Energy System Design can tremendously help plant owners to achieve the best configuration.

Haru Oni, the world's first large-scale integrated carbon-neutral e-fuel production facility, demonstrates the benefits of hybrid power plants



Site-specific conditions are of crucial importance: A hybrid power plant will always be a site-specific, customized mix of technologies. Different configurations meet different needs. Hybrid power plants will make the best use of resources in each situation. Energy system design can help tremendously in achieving the best configuration.



The Isabela Island Hybrid Power Plant on the Galapagos Island integrates solar and biofuel sources, an electrical energy storage system, and a smart hybrid control system

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