Reliable Renewable Hybrid Energy Solutions

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ABSTRACT

Worldwide studies, including the Paris agreement, show that it is necessary to reduce dependency on the non-renewable energy sources and fossil fuels such as oil and coal. Transition to renewable energy is evident, and different reliable renewable energy systems are needed. The energy production with renewable energy sources is typically non-continuous when using only a single technique. This can be avoided by using a hybrid system and/or seasonal storage. This study introduces several hybrid systems and examples of storages operating mainly in Finland most of them in co-operation with University of Vaasa. Hybrid renewable energy systems (HRES) can be implemented in multiple different ways, scope varies from larger energy villages and other residential areas to single buildings. The amount of renewable energy generated by any HRES depends on both the technology and the meteorology. Some energy sources like different forms of geoenergy (geothermal energy) are available around the year. Instead, some renewable energy sources like solar and wind are often season dependent energy. To ensure constant production in HRES for the electric grid or the heating network, the energy storage or backup energy systems are in almost all cases needed. Advantages of the hybrid techniques are reliable, constant energy production and scalable energy production. When designing a hybrid system it also needs to be solved, what to do with the excess energy; whether to deliver it to the grid, use the dump loads or the storage systems.

KEYWORDS

Hybrid techniques, Local Energy, Renewable Energy, Energy production, Energy Storage

INTRODUCTION

Worldwide studies show that it is necessary to reduce dependency on the non-renewable energy sources and fossil fuels such as oil and coal. According to IEA 2013 review, Finland for example has been highly dependent on imported fossil fuels, which was predicted to remain also in the long run and pose a significant challenge in terms of energy security [1]. In recent years, this situation has been in change. Since the 2013 review, the share of fossil fuels has declined significantly, and the power sector in Finland is largely decarbonized. [2].
Also the energy infrastructure is in change. Traditionally energy production in Finland and in many other countries has been centralized and especially electricity is distributed long distances. Due to the transition from the fossil fuels to the renewable sources and the energy security, decentralized energy production has started to increase. The transition from a hierarchical centralized system to a semi-decentralized energy system is well known for

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example in Denmark, where the energy infrastructure has changed dramatically since 1985 [3].

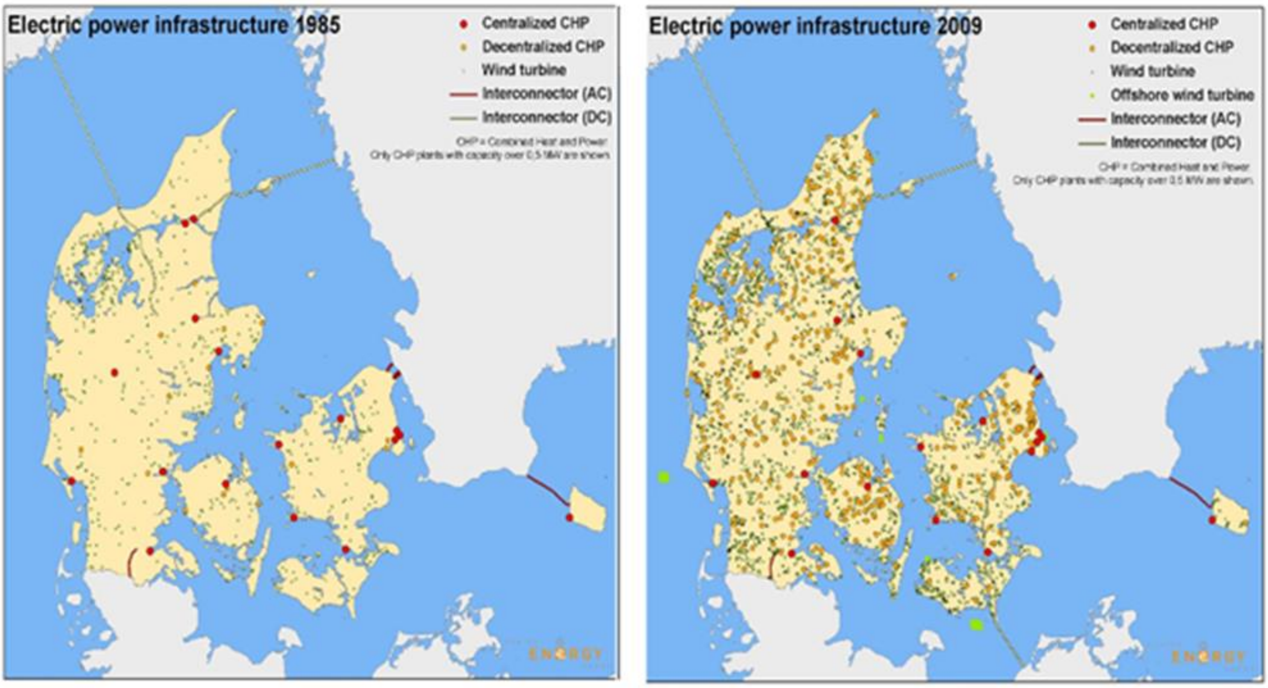

Figure 1. Transition from a hierarchical centralized system to a semi-decentralized energy system between 1985 and 2009 [3].

The weather and the amount of sunlight may vary greatly between the four seasons. Renewable energy production, especially solar and wind energy, are unpredictable and cannot alone provide continuous energy production. Therefore, as a part of the transformation to decentralized energy production and the increasing use of RES, the hybrid renewable energy solutions are now increasing.

Hybrid renewable energy systems (HRES) consist of two or more renewable energy sources together. They provide greater balance in energy production as a single RES would do and are therefore seen as efficient solutions for decentralized energy production. Essential part of the hybrid system are also energy storages, for both heat and electricity. Heat is mainly stored to water or bedrock and electricity to the batteries. There are multiple examples in the world how the hybrid energy system can be carried out. A few of them are presented in the next chapter.

The amount of excess energy generated by any HRES depends on both the technology and the meteorology. The types of the energy sources used in the hybrid systems, component sizes, the availability and the profiles of the meteorological quantities all have their effects. Also the load profile variations with respect to variations in the meteorological quantities are important to evaluate. When designing a hybrid system it also needs to be solved what to do with the excess energy; whether to deliver it to the grid, use the dump loads or the storage systems as examples. [4].

Different renewable energy sources can be used for hybrid systems. Solar energy systems with photovoltaic cells are used for electricity production and solar collectors enable heat generation. Wind energy turbines can be integrated to HRE system if wind conditions of the area are suitable and the turbine is not disturbing the neighborhood and landscape. Wind energy turbines are used to generate electricity. Wind power is a non-polluting, renewable energy source.

Geothermal energy can also be utilized in HRE system. In non-volcanic area geothermal energy is suitable only for generating heat. The heat collection pipes are assembled to the bedrock vertically or to the ground or even seabed sediment horizontally. The heat pump must be integrated to this low energy network. Bedrock heat wells can be used as energy storages for excess heat too.

Combined heat and power production (CHP) is one solution in the decentralized energy production. CHP plants can be large, small or micro scale plants. CHP plants can be driven by the different biomass derived fuels. It depends on the technology what kind of fuel is used. One common way to convert biomass to energy is to combust solid biomass like wood chips directly. Direct combustion units vary between the small stoves for domestic heating and the large boilers which produce heat and electricity or heat only. [5]

CHP plant can also be internal combustion engine which uses bioethanol, biodiesel or biogas as a fuel. The used fuel can be a blend of bioethanol and gasoline or a blend of biodiesel and petroleum diesel. There are internal combustion engine based CHP systems which can use both liquid biofuel and biogas. [5]

INTERNATIONAL EXAMPLES OF HRES IMPLEMENTATIONS

Hybrid renewable energy systems can be implemented in multiple different ways. In this chapter the different existing HRE systems in the world are presented. Focus in presentation is in larger communities and residential areas that can operate completely self-sufficient.

<u>Juehnde, Germany:</u> This is a small energy village of 800 inhabitants. Its energy system is based on bioenergy. There is an anaerobic digestion plant where biogas is produced by digesting the animal manure and locally cultivated energy crops. The biogas is used as a fuel in the CHP plant to produce heat and electricity. The heat produced in the CHP plant is used partially in the digestion process and producing heat for households. This produced heat is sufficient to cover 75 % of the heat demand of the households. In summertime when the heat demand is low, the surplus heat is used to dry wood chips and cereals. During winter more heat is produced to cover the peak heat demand by burning wood chips in the heat power plant. Electricity produced in the CHP plant is fed into the national electricity grid. The village has its own heating net where the heat energy is fed. Juehnde is completely energy self-sufficient. Electricity is produced a double compared to the consumption of the village. The heat production covers the heating of the village. There is also an oil boiler to secure the energy production but the energy produced using oil is under 5 % of the total energy produced. [6]

<u>Utsira, Norway:</u> One way of implementing hybrid energy system is to produce electricity using the wind power and storing it as a hydrogen. This has been done in the municipality of Utsira in Norway. Utsira is a 6 km2 island and there live around 250 inhabitants. The hybrid system has been carried out by utilizing wind-hydrogen system. When there is excess production of wind power, the wind power is stored as a hydrogen via electrolysis. Hydrogen is used as fuel in the fuel cell or hydrogen combustion engine to produce electricity when weather is calm. The system consists of the wind turbine and the electrolyzer and the compressor to press the hydrogen to 200 bar pressure. The hydrogen storage can cover the consumption of three windless days. There are also fuel cell, combustion engine, flywheel and synchronous machine to stabilize the local energy grid. In the case of the emergency there is also a battery. [7]

Drake Landing, Canada: The community consists of 52-houses, where space and water heating are supplied by the solar energy. There is an 800-panel garage mounted array capturing solar energy year round. Seasonal and short-term thermal storage (STTS) is used for storing the solar heat in the summer to use it in the space heating of houses in cool weather. Borehole thermal energy storage (BTES) is used for the seasonal energy storing. Solar collectors transfer the heat to the STTS and then to the distribution network for heating houses. If there is warm enough in the distribution net the heat is transferred to the BTES for longer storage. The BTES consists of 144 boreholes which all are 37 meters deep. The storage covers an area 35 meters in iameter. Temperature around the BTES reaches 80 degrees Celsius by the end of each summer. To keep the heat in, the BTES is covered with sand, high-density R-40 insulation, a waterproof membrane, clay and other landscaping materials. The energy centre`s backup is a gas boiler. [8]
The above presented HRE systems are all energy self-sufficient, shown in Table 1.

Table 1. Comparison of used HRE systems in three countries.

Country	Germany	Norway	Canada
Inhabitants	800	250 (island)	52 houses
Energy System	Bioenergy CHP-plant Surplus heat in summertime is used to dry wood chips and cereals	Wind power Hydrogen storage Only electricity	Solar heat and solar panels BTES, STTS
Backup	Oil boiler	Battery	Gas boiler
Degree of energy self-sufficiency	Completely self-sufficient	Completely self-sufficient	Completely self-sufficient

OBSERVATIONS OF STUDIED HYBRID SYSTEMS

In this chapter the studied hybrid systems are introduced and the observations of the systems are entered. All the studied hybrid systems are located in the Western Finland, and most of them are single buildings. Compared to international HRES implementations, there are still few larger HRES residential areas in Finland.

<u>Museum building.</u> Meteoria - a museum building in Vaasa, Western Finland, opened year 2008. The Meteoria area itself is a protected area where a meteorite fell down over 600 million years ago. The building is an old drying barn, which has been rebuilt in the middle of the Meteoria area. In the museum there is an exhibition and multimedia show telling about the history of the area. There is also a tower build for the birdwatchers and an observatory. It is also a living lab research platform to study island use of energy and also to study a small scale grid.

Meteoria is a self-sufficient museum area. Power and heat to the museum building are produced in the “energy cellar” by using 1.5 kW solar cells and a wind turbine of 4 kW, (Fig. 2). “Energy cellar” is planned in co-operation with University of Vaasa. Energy from solar panel and wind turbine covers over 90 % of all activities in the museum area. The load following power is produced by an internal combustion engine (11 kW) fueled by biodiesel. The wind turbine consists of three blades, length 2.5 m. The produced energy is stored in the 12 batteries (12 V/200 Ah). The maximum energy is 30 kWh.

Figure 2. Meteoria is producing power by the 4 kW wind turbine, by solar cells and by solar air heating collectors. Meteoria is an energy self-sufficient museum area.

Museum building. On the Kvarken World heritage gate there will be an exhibition house, which is planned to be heated and cooled partly by using seawater and a heat pump. The heat is collected by a water heat exchanger (Fig. 3) which has been sunk to the sea. In the summer the heat would be stored into the seasonal storage in the boreholes.

Figure 3. The assembling of water heat exchanger in Kvarken World heritage gate building implemented by renewable energy research group (University of Vaasa) in the Autumn 2018.

Buildings on the sea islands. Islands Moikipää and Mikkelinsaaret are examples of island using the renewable energy and having the hybrid solutions too. The buildings on island

Moikipää were previously used by the coast guard. At that time there was a oil based central heating. Oil was delivered to the island by a boat. The kitchen is mainly using liquid gas for the heating and cooling. The solar panels and a wind turbine have been built on the island in order to provide electricity for the lighting and heating, too. The solar panels are working properly but with the wind turbine there has been problems because the circumstances on the sea can be quite challenging. The wind turbine mounted on the roof of the main building has been broken due to a strong wind.

On island Mikkelinsaaret has also been used hybrid solution of the solar panels and a wind turbine. The solar panels have been placed both on the ground and on the roof of the main building (Fig. 4). The solar panels are working properly. The wind turbine was erected on the ground close to the main building. Also in this solution problems existed with the endurance of the wind turbines. It seems that circumstances on these islands are very challenging for small wind turbines.

Figure 4. On island Mikkelinsaaret part of the solar panels are assembled on the ground and a part to the wall of the observation tower.

On the basis of these experiences, it seems that in those very demanding circumstances on the islands the small wind turbines are not very reliable alternatives in the hybrid solutions.

Small residential building. EcoHouse is a building sized like a private house in Western Finland (Fig. 5). In general in Finnish private houses different energy production solutions have been used. Most often nowadays in the new houses is used geothermal energy or air heat pumps, solar panels or collectors or even small wind turbines. Also heat collection from greywater and exhaust air have been used especially for the preheating of service water. EcoHouse uses the solar energy passively collecting heat in the summer time under the roof and storing it into the energy piles under the floor as geoenergy. Studies of the energy efficiency of chosen solutions are still going on.

Figure 5. Ecohouse is using solar energy, storing it as geoenergy into energy piles under the building and using it after seasonal storing.

<u>Block house.</u> There are 2 similar apartment houses with 8 floors in Suvilahti, Vaasa (Fig. 6). They are utilizing geothermal and solar energy for the heating. There are 14 boreholes with depth of 200 meters of each around one building and 10 boreholes around another. The geothermal energy was already used for heating at the building stage to accelerate the drying process of structures. There are 33.6 m² of solar collectors on the roof of each block house. The solar energy is stored to the boreholes to increase the temperature of heat carrier fluid. Later the aim is to produce the hot service water of the building by the solar energy too. The buildings are now self-sufficient in heating energy. The apartment houses have a common heat distribution room where are 2 heat pumps; a 60 kW main pump and a 40 kW relay pump. [9].

Figure 6. Block houses in Suvilahti Vaasa use geothermal and solar energy. [9]

<u>Office building.</u> Futura IV office building located in Runsor Vaasa was built 2014. The building (Fig. 7) is using geothermal energy for both heating and cooling. Are Sensus hybrid

technology integrates the geothermal energy and district heating. The geothermal energy is a primary heat source. The system has 8 boreholes each 280 metres deep. District heating is used as backup system.

Figure 7. Futura IV office building uses renewable hybrid technology in the heating and cooling system.

Office/laboratory building. EnergyLab, an energy laboratory building, was built in the campus area of University of Vaasa in 2017. The main heating system is 18 boreholes each 270 meters deep. A future plan is to utilize the industrial waste heat from internal combustion engine laboratory, the heat of the cooling water of the engines. This heat would be transferred to the seasonal storage into a bedrock heat battery (Fig. 8). The EnergyLab building is actually a CHP unit producing electricity too.

Figure 8. EnergyLab building is heated by geothermal energy from the boreholes. Thermal Response Test (TRT)-trailer is monitoring one research borehole in the yard. Research borehole will be joined to bedrock heat battery in future.

Residential area. The House Fair affair was arranged in Suvilahti, Vaasa, Ostrobothnia, Finland in 2008. The theme of the Fair was “homes for everyone and ecology”. The energy solutions of the area were full of ecology. It was decided to utilize the annually reloaded heat energy of the seabed sediment as the heating energy. This energy is mainly produced by the Sun. The unique low energy network was built to cover the heating and cooling demand of 42 detached houses.

The combined heat and power plant, which utilize the biogas of the landfill, was also built to the area. The CHP station produces electricity to the heat pumps of the low energy network. There is used both the fuel cell technology and the micro turbine technology in the CHP plant. The decomposition of the organic material generates landfill gas from which 40-60 % is methane and the most of the rest is carbon dioxide. Methane is 21 times more harmful greenhouse gas than carbon dioxide, that is why its way to the atmosphere is worth to prevent. The energy content of methane (50 MJ/kg) is very high to make it a good fuel. As a comparison the heat value of coal is 28 MJ/kg on average [10].

The House Fair area in Suvilahti was planned to be self-sufficient in the energy production and annually there is a possibility to produce electricity even 20 % and heat 60 % over demand of the area. The annual carbon dioxide emissions of the CHP plant and low energy network are approximately 1800 tons lower than coal and oil based CHP plant [11, 12]. The seabed sediment heat based low energy network has worked now several years. Although the technology was excellent the fuel cell motor of CHP plant is taken out of use. Micro turbine is still in use.

42 single-family houses were connected to the low energy heat distribution network. A collector pipework totally about 8 km (12x300 m and 14x300 m) was installed into the sulfide clay mud layer horizontally into the seabed sediment (Fig. 9). The position of the pipes was in 3–4 meters depth from the sea bottom of the Gulf of Bothnia. Sediment heat is utilized with help of this heat collector pipe field and the heat pumps in low energy network. The heat collection fluid circulates in the heat collection pipes. The network is also used for cooling houses in the summertime. Mäkiranta et al. [13] have researched the correlation between air, sediment and heat carrier liquid temperatures. Especially, high correlation was observed when sediment data was compared to the previous month heat carrier liquid data. Also heat carrier liquid and sediment temperature of the same month were correlating strongly. Sediment temperatures were indicating the previous weather conditions. The sizing of installed network system was observed to be sufficient.

The main network of low energy system runs through the House Fair Area having 12 distribution wells to serve heating and cooling energy for houses in the area. The heat carrier fluid runs in the brackets of the pipe on the outer casing gathering the heat. After the heat release in the heat pump the fluid returns in the middle of pipe to the end of the pipeline to start the cycle again.

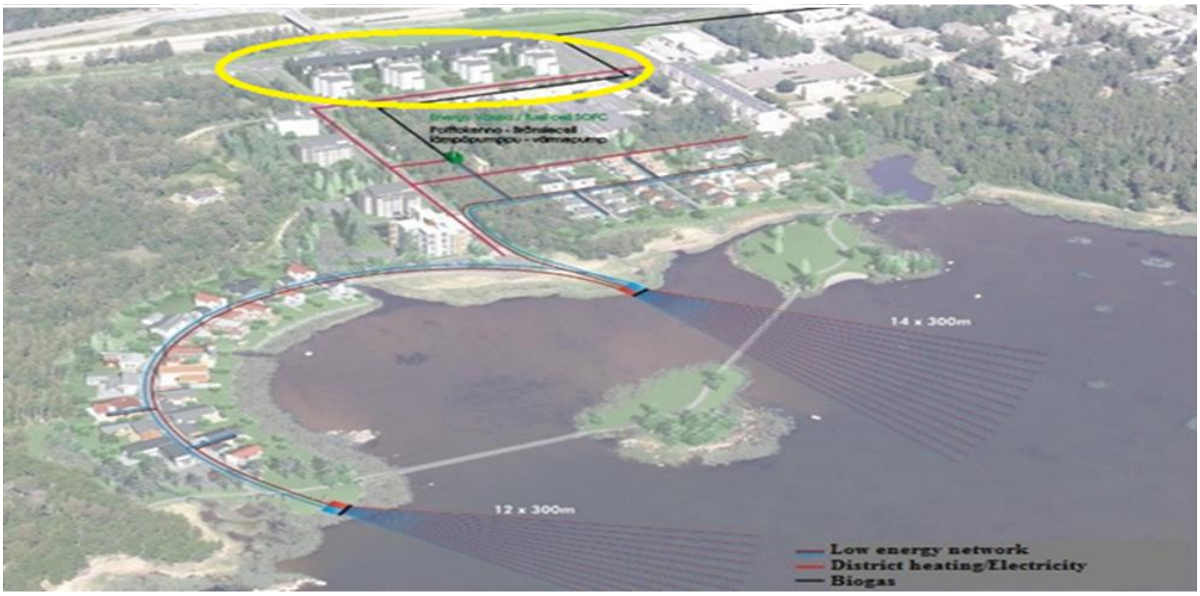

Figure 9. The sediment heat based low energy network for 42 houses in Suvilahti Vaasa. 4 block houses with boreholes (presented in fig. 6) are circulated with yellow line. (Vaasan Ekolämpö Oy)

Municipality. Jepua is a village situated in the Ostrobothnia region and is one the few energy villages in Finland. The municipality has a special area having a biodiesel plant, biogas plant and a filling station of compressed biogas. (Fig. 10) They also have their own micro grid. For energy production there are used biomaterials from they own region. Also the biodiesel and biogas are mainly used on their own area. This area is an excellent example of area producing and using near energy and an example of industrial symbiosis too.

Figure 10. Jeppo municipality has an area with biodiesel plant, biogas plant and filling station of compressed biogas. (Jeppo Biogas)

RESULTS AND DISCUSSION

In an old renovated building a hybrid solution can be partly based on the renewable energy and partly on the existing fossil energy, especially during a transition period. Burning of wood or oil and using of the electricity from the grid can also be used as a load following energy to guarantee continuous energy supply. (Buildings on the sea islands)

It is also good to remember that the using of some renewable energy sources means also using of other energy sources. Like geoenergy (energy from boreholes, sediment, water or asphalt) requires electricity for the heat pumps. The sediment heat is loaded by Sun every summer annually. Because of that the seabed sediment is an excellent seasonal heat storage. (look at Residential area).
One type of hybrid is using both solar and wind energy for producing electricity. This hybrid energy can then be stored as electricity or heat, used for own needs or sell to electricity company. Also in this case the grid is a good source for load following power (look at Meteoria).
For new buildings it is wise to plan the complementary energy sources, energy storage and the regulatory energy source (look at Meteoria or Buildings on the sea island).
According to the previous examples many combinations of renewable energy are available but they must be planned case by case. So far in Finland hybrid solutions are quite small compared to hybrid solutions in other countries even if also bigger regional solutions exit.

CONCLUSIONS

Some renewable energy sources like different forms of geoenergy (geothermal energy) are available around the year. Instead some renewable energy sources like solar, wind and bioenergy are often season dependent energy. To ensure constant production for the grid or the district heating network, the hybrid systems and the energy storing is in almost all cases needed. For storing electricity there are different kinds of batteries, but still there is a need to develop more efficient ways to store the electric energy. There are experiments to develop heat storing, water tanks for example, but to store heat in larger scale a lot of work must still be done. The hybrid systems can also help in the seasonal fluctuation. In some cases load following energy is also needed. To ensure the constant production of electricity or heat energy in a small scale, a hybrid system is needed and also an adjusting method or an energy store.
In a larger scale a solution could be a virtual power plant. With the help of virtual power plant small producers, using different production methods, start to market their energy together. Together they can guarantee a constant supply of the energy. For the consumer it is not essential where the renewable energy is produced. The single producers can work independently. Essential is only that they market their energy using the common virtual power plant. For marketing electricity and marketing heat, the idea of the virtual power plant is the same.
Part of the hybrid system can also be the plants producing fuels like biogas or biodiesel. This fuel can then be utilized for example in the CHP-plants or as a fuel for transportation.
When using renewable energy the production can vary daily i.e. short periods or there can be seasonal fluctuation. To compensate these variations the hybrid systems or/and energy storing can be used. By using these modifications the continuous self-sufficient energy production can be reached. In the same ways hybrids and storing can be used in the island solutions, or they can even be used to produce energy for sale.
Especially the regional economy of renewable energy can be profitable. Using hybrid solutions and energy storages, also continuous energy production is possible and depending on the subsidies for renewable energy and fossil energy also larger scale production can be profitable (look at previous observations Suvilahti, regional hybrid solution and Meteoria, energy self-sufficient museum building). Especially virtual power plants (heat and power) can be serviceable in the future.

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