SELECTED SUSTAINABLE ENERGY LESSONS FROM FUTURE

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ABSTRACT

The examples given in this paper stand in opposition to the common addiction to fossil fuels. Unfortunately, maintaining the status quo is always simpler than making drastic changes or U turns. Numerous decision-makers do not perceive a clear and immediate threat from these daily rising PPMs of CO_2 in the atmosphere. As a result of these failed policies, world is rapidly approaching tipping points, which mark the point at which climate change becomes exponential and irreversible.

These lessons are the result of: unconventional thinking, fighting for the independence from fossil fuels, the ideal fusion of creativity and engineering, moonshots, ground-breaking solutions, game changers, the "walk the talk approach," saturation with empty promises, locating and implementing the missing puzzles, decarbonization at the right time, not waiting for disasters to strike, for some next Uri-like winter storm, for some next stronger than Katrina hurricane, for some billion dollar in damages flooding, or any other disaster.

This paper's constrained page count unavoidably leaves out several solutions, companies, or countries; as a result, it highlights a few distinguished members of the hall of fame of energy sustainability. This paper thus is virtual travel to Esbjerg (DK), Dronninglund (DK), Heerlen (NL), Helsinki (FI), takes us to the desert (AU), mentions some cutting-edge machines like HOFIM (DE), some cutting-edge concepts like Virtual power plants (US), highlights the strategy and outcomes of one company

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Vattenfall (SE), and one country Chile, discusses how air that is all around us is being used as energy storage (UK), and even is being used as a motive fluid (UK).
Key words: sustainable energy, decarbonization, electrification

INTRODUCTION

During the 20th century, coal was king almost everywhere. In Serbia was in the second half of the 20th century. It served as the foundation for the stability and growth of the nation. Especially in the 90s it has demonstrated its significance. Today, transitioning to a low-carbon economy is vital on the one hand while supply stability is also crucial. Coal and hydropower, where coal predominates, are the main sources of energy in Serbian power system. CO_2 emissions are generated when coal is used as a fossil fuel, making it unlikely to be a future energy source. Because of the occurrence of droughts, the effects of global warming can have a significant impact on hydropower. Rankine steam cycle-based power plants can experience cooling issues due to drought as well. Given that problems are getting worse as a result of global warming, more severe droughts can be anticipated. Floods, the opposite of droughts, are also to be anticipated and for which one should be ready. 2014 floods caused severe damage to Serbia and the surrounding area. The economic cost of the Balkan Tsunami was in the billions.

Serbia joined the European Energy (EE) community in 2005. With the signing of the contract with EE Community, additional regulations for combustion plants were accepted in exchange for supply security and the chance to export power at higher price points. The grace period for implementing these new regulations is now over. Since 2005, the EU has implemented carbon pricing for all power plants. Prior to the start of the conflict in Ukraine, the price of carbon was practically continuously rising. At 7.2.2022, the record price was 97 euros. Serbia is not yet actively taking part. However, it has been announced that there will be new CO_2 border charges for our exported goods. Stowaway tactics won't likely be accepted for very long. As if the effects of global warming on energy supplies weren't bad enough, the war in Ukraine makes matters worse. The world is on the verge of extinction due to looming other conflicts. There is a profit-driven agenda that takes precedence rather than devoting all of our resources and efforts to halting climate change.

The typical criticism of the green transition was that it was only affordable for wealthier countries since it was so expensive. Recent auctions in the developing world deny it.

The common defense offered against global warming induced by humans is that it is cyclical and natural. However, the severity and frequency of fires, droughts, floods, and glacier melt are sufficient to provide a counterargument. If that isn't enough, one can always wait till the following year to discover what the nature has in store for people. Maybe a disaster that hasn't happened in 1000 years. Other than decarbonization, there is no weapon that can defend us or superpowers. Even a late decarbonization effort won't be able to save us if we have passed the climatic tipping points.

The goal of this paper is to highlight good practices that should be copied and pasted as quickly as possible when appropriate. It is unknown how long this game of civilization will last. We are unable to find an answer to this question, not even with the help of supercomputers and artificial intelligence.

SUSTAINABLE ENERGY SYSTEMS

Vattenfall, a Swedish public utility with the motto "Fossil free life within one generation", is the first destination on this energy sustainability quest. They started in the coal industry around the turn of the century when it was possible to purchase large coal mines and plants in East Germany. They have grown to become one of Germany's top four utilities. After making a purchase, their logical first move was to address the primary issue: capture CO_2. Other coal utilities did not commonly take this route. Prior to the pilot at Schwarze Pumpe Power Plant and the demonstration plant plans, there was laboratory research. Because Carbon Capture and Storage (CCS) was viewed as a lifeline for coal-based energy there was popular opposition to it. Potentially unprofitable CCS economics led to the cancellation of CCS development and to the sale of the lignite coal fleet to a Czech business in 2016.

A coal power plant Moorburg was being built concurrently with the CCS project. Resistance to this construction was encountered, and it was effective in delaying the launch. In terms of efficiency and emissions, this power plant is cutting edge. The emission is less than the limits established by federal and Hamburg regulations. The plant was conceptualized in 2004. Construction started in 2007. The first firing was in 2013. By the end of 2015, it was operational. The project's opponents were successful in preventing Hamburg's district heating from being supplied by the power plant. However, it was a pyrrhic victory. A CO_2 tax was introduced in the interim; it was minimal at first but quickly increased. However, it was still lower than it is now. Then there was a priority for solar and wind energy in terms of network access. Underutilization and losses were the outcomes. The first auction that saw owners of coal-fired power facilities bid to allow their closure followed. 4,000 GW of coal power was shut down in exchange for €300 million in compensation. One of them was Moorburg, a 5-year-old who was most efficient one. As a result, the 2.7 billion euro investment made by Vattenfall in Moorburg ended up being a stranded asset. Not every company will remain standing after such a blow. Vattenfall did, though. They chose to invest extensively in wind power as their strategy. Started working on hydrogen as a type of energy storage. First CO_2 free steel and plastic were jointly developed, and Volvo is collaborating on the development of an electric vehicle. The first offshore park with an integrated electrolyser is being built. They are installing electric boilers, heat accumulators, and high temperature heat pumps for heating. Last but not least, a 100 MW electrolyzer is planned for the site of the Moorburg power station.

Was the closure of the Moorburg power plant a canary in a coal mine for things to come for coal-fired power plants?

The questionnaire for the utilities sustainability check is presented in the table below. Vattenfal's answers that can be used as a benchmark, are listed in the third column, which are evaluated in the last column.

Table 1 The questionnaire for the utilities sustainability check

Does your business do CCS research?	**Yes–1 pt; No– 0 pts**	**Yes**	**1**
How much money has been invested in CCS?	€0M – 0pts; up to €1M – 1 pt; up to €10M –2 pts; up to €51M–3 pts	€50M [1]	3
Does your company have a decarbonization division?	Yes–1 pt; No–0 pts	Yes [2]	1
What green energy source do you use most often?	if Wind–1 pt if Solar–1 pt if Wind and Solar–2 pts	Wind [3]	1
Where have you installed your wind turbines?	If onshore–1 pt If offshore–1 pt If on- and off-shore –2 pts	Onshore and offshore [4]	2
Do you have wind farms abroad?	If one foreign country –1 pt, if two f.c. –2 pts,…	Yes, [5], Denmark, UK..	2
Do you develop your own methods for storing energy?	Yes–1 pt; No– 0 pts	Yes, hydrogen [6]	1
Do you currently have any projects relating to decarbonization under way?		Steel [7], plastic [8], cars [9]	3
Do you intend to construct a hydrogen storage facility at the site of the offshore wind park?	Yes–1 pt; No– 0 pts	Yes, in Aberdeen, look at [10]	1
Are you using heat pumps as part of your heat generation systems?	Yes–1 pt; No– 0 pts	Yes, in UK, look at [11]	1
To increase efficiency, are you installing heat accumulators in heating plants?	Yes–1pt; No–0 pts	Yes, in Berlin, look at [12]	1
Are there electric boilers at your heating plants?	Yes–1 pt; No–0 pts	Yes, of course, in Amsterdam, largest, look at [13]	1
SUM			**19**

Of course, it would be nearly impossible to surpass this fantastic score of 19, but let's get started. Small steps taken in the right direction are preferable to the big ones in the wrong direction.

Here, the emphasis moves to **Chile**an energy transition to show that Vattenfall's carbon U turn is not an isolated instance but rather just plain common sense. Chile is referred to as "Solar Saudi Arabia" and "El Dorado for Renewable Energy." It features extensive shorelines and mountain ranges that are ideal for the development of wind, hydroelectric, geothermal, and ocean energy. The Atacama Desert in the north of the country has ideal solar energy conditions. However, 2011's energy mix did not contain a considerable amount of solar and wind energy. Change resulted from the auctions. Wind and solar energy have grown from 0.36 TWh to 20.08 TWh between 2011 and 2022. There are installed capacities of 1424 MW for wind, 1840 MW for solar, 615 MW for small hydro, 481 MW for biofuel, 48 MW for geothermal, and 39 MW for solar thermal. 4447 MW in total, a significant change. The lowest solar PV price attained was 2.15 USD¢/kWh, with the average being 3.25 USD¢/kWh.

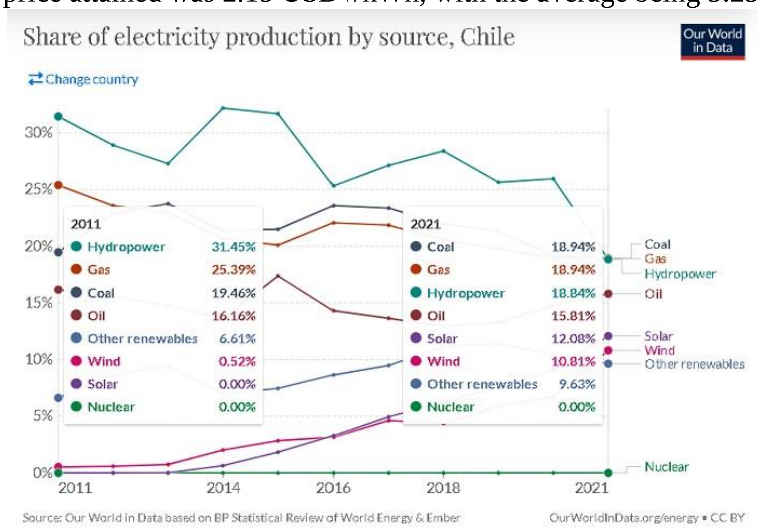

Figure 1 Chilean energy mix change from 2011 to 2021 [14]

This accomplishment did not come easily, though. At the turn of the century, natural gas, coal, and hydropower made up the majority of a country's energy mix. Chile had a gas shortage between 2004 and 2007 as a result of importing 90% of its gas needs from Argentina, where gas production could not keep up with rising domestic demand, leading to a halt in Argentina's gas exports to Chile. Despite having supply agreements with Argentina, Chile faced significant supply issues that drove it even more toward coal. Then, a devastating drought in 2008 forced Chile to reconsider its reliance on hydropower. These two occurrences caused the share of coal to rise from 10% in 2003 to 24% in 2009 to 41% in 2016. As the number of participants in auctions increased, power prices decreased. Without any direct subsidies, solar and wind power became competitive. The coal power stations remain as a part of the flexibility plan. The possibility of using them as storage is also examined. The Chilean energy market is served by a number of well-known foreign companies, including AES Gener (Chile), Cerro Dominador (Spain), Colbun (Chile), EDF (France), Enel Chile (Italy), Engie (France), Orazul Energy (Peru), Pacific Hydro (Australia), and Statkraft (Norway).

Following paragraphs try to find the Holy Grail in power production by giving answer to the eternal question: "What is the fastest way to generate clean electricity without installing CCS in existing coal plants or building wind parks or solar farms?"

Solution is easier than imagined: "By saving". However, there is one issue that must be addressed: "How to convince people to conserve energy." Simple solution: "Just pay them". The alternative is to buy electricity on the market at the SPOT price, which was 280.09 €/MWh on 16.9.2022. So, isn't it preferable to pay its own population to produce by conserving electricity? It will supplement the modest budgets of ordinary people. It's a win-win situation. Of course, this sounds fantastic, but is it just a theory? No, it has already been implemented, it is operating, and it is growing. Ohm Connect is the company that has put this tremendous concept into practice. Solving Immediate Challenges while Creating a Long-term Solution. During the summer months, California has long had issues with a lack of electricity and outages. Ohm Connect's system is known as **Virtual power plant**. Connected customers have smart devices and appliances that they may turn off when Ohm Connect notifies them that it is Ohm hour, a period when the network is constrained. Customers can transfer total control of smart devices to Ohm Connect. Both methods reward the user points, which may be converted into money. Additional points are awarded for

Figure 2 Redondo power plant to be substituted with virtual power plant

participation in numerous consecutive Ohm hours. Participation and savings level increase user advancement and incentives. There are also weekly and monthly sweepstakes. This network saved one GWh of energy during the week of 13.8.2020 to 20.8.2020, which is equivalent to taking 600,000 houses off the grid for one hour. To accomplish this, smart gadgets were turned on and off 739,000 times, and consumers won $1 million [15]!

Furthermore, this method can lessen the demand for peaker power plants such as the Redondo power station seen in the image. It is an old plant that pollutes when it is operational. There is a campaign on Twitter called #PowerDownForGood that aims to save energy and make these power plants obsolete. In California, there are 80 of these power plants.

The next step was expansion, which was also completed in the form of a Resi-station capable of saving 5 GWh. This equates to not burning 2 million kg of coal. California Energy Commission, California Public Utilities Commission, and CAISO all recommended the project. „Resi-Station is one of the few clean, sustainable resources that can come online at scale by 2021 and address the urgent need for capacity to prevent outages in the next peak season in California“. They are demand side champions.

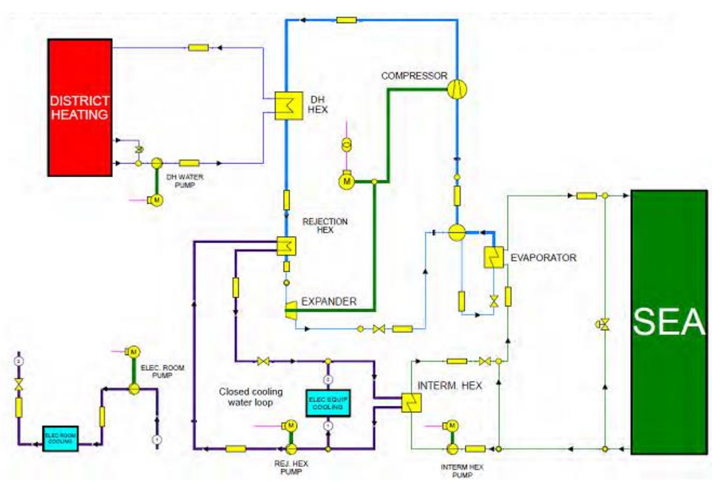

Figure 3 Esbjerg heating by heat pump

The following paragraphs focus on how heating can be modernized using **<u>Esbjerg</u>** as an example. Currently, district heating is provided by cogeneration from a coal power station, which will close in April 2023. Green electricity is already available from nearby offshore wind farms. It will run the compressor in the MAN ETES heat pump system, which uses seawater as a low-temperature heat source. This 50 MW system heating capacity will provide approximately 235,000 MWh of heat annually to 100,000 locals. This solution is emission-free. A backup 60 MW chip-fired boiler is planned for heat supply security (to be supplied by Finnish KPA Unicon Oy) [16].

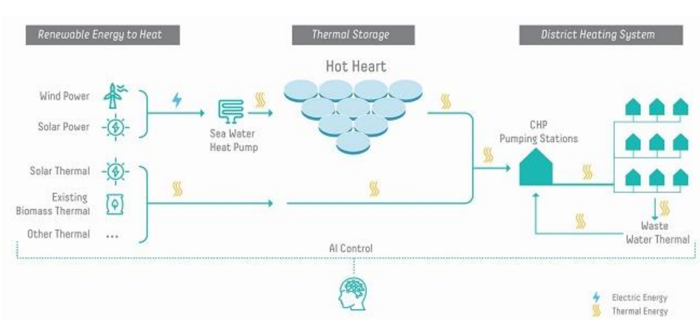

Figure 4 Helsinki hot hearts

Another possible step toward environmentally friendly district heating is the example from Finland that is given below. For them, the issue with the color of the electric energy source has been resolved. Green, yes; black, no; and all shades of grey, no. A global competition with a one million euro reward has been created to find the answer for the future of heating. There are also preconditions. Heating that does not just take coal out of the equation but also does not use biomass. It should be noted that Finland has a sizable biomass resource base, which stands in opposition to the preceding statement. It appears that cutting, chipping, and burning biomass for heating purposes is not acceptable to Finns. The cost of the new solution should be lower than that of the existing one. The concept "**Helsinki hot hearts**" was one of the winners. The project was developed by CRA-Carlo Ratti Associati in collaboration with Ramboll, Transsolar, Danfoss Leanheat®, Schneider Electric, OP Financial Group, Schlaich Bergermann partner and Squint/Opera [17].

It suggests utilizing seawater heat pumps that are powered by carbon-free electrical energy, similar to the Esbjerg system. It consists of ten cylinder-shaped reservoirs filled with hot water that are each 225 meters in diameter and are placed in a harbor. Ten million m^3 of water are stored there. In addition, these tanks serve as energy storage. These reservoirs are connected to backup heat sources. When electricity is affordable, stores are heated. This stores are linked to Helsinki's district heating. In addition to decarbonizing heating, it can also help the national grid stay balanced. Helsinki is expected to receive 6,000 GWh of energy from it. The operation is to be managed by an AI system. The commissioning date is expected at the end of 2020s. However, that's not all. Out of 10, four of the cylinders will be used as a tourist attraction. They will house floating artificial islands with tropical trees, year-round hot pools, and LED lighting that mimics tropical sun under the transparent dome. The Finnish idea of "Jokamiehen Oikeudet," which means that everyone has a right to relax in nature, will be realized in this way. Not to mention Finland's harsh climate. Future heating costs are anticipated to be 10% lower. This is a „future-proof" solution.

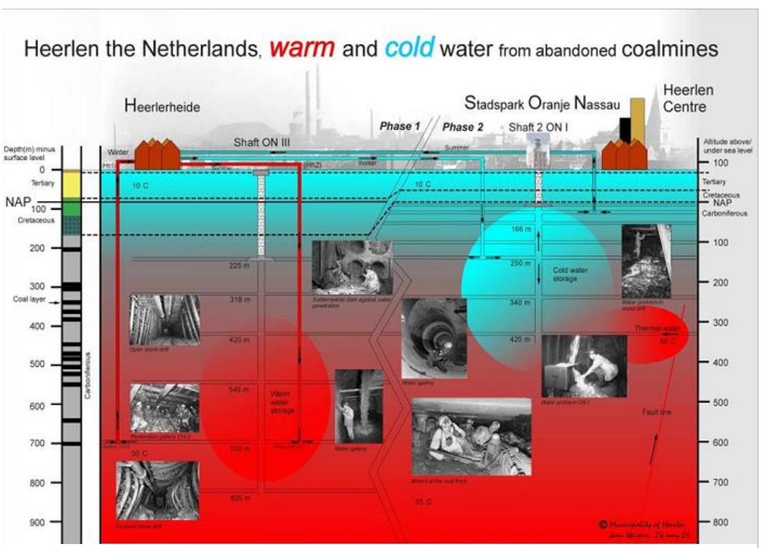

Figure 5 Heerlen geothermal heating system

The Dutch city of **Heerlen** is the next destination as an illustration of the shift from a coal mining hub to a location with a sustainable energy heating system that creatively utilizes coal mining infrastructure. This smart heating system also needs to be combined with smart and efficient energy consumption for it to be effective [18].

Tens of thousands of miners were engaged during the zenith of the mining sector, and there were three working mines in Heerlen. Groundwater accumulated in the mine corridors after the coal mines in the Heerlen area were shut down between 1965 and 1974. This groundwater was then heated by the soil. The town of Heerlen came up with a plan in 2003, years before the EU climate agreement, to conduct exploratory drillings to determine whether geothermal sources may be utilised as a heat source. Old shafts were cemented. The investigation revealed that mine water can be used for heating as well as cooling. Five wells were drilled and an 8-kilometer underground piping infrastructure was constructed in 2005 with help from the EU and Agentschap NL. In 2008, the first user of the system was connected. Since then, 500 houses and businesses were connected by the system. The installation of a wind and solar park, whose electricity is intended to power heat pumps, was the next step that was taken to further decarbonize the system. Additionally, the system transfers surplus heat from one location to another in order to provide heat there.

The Danish city of **Dronninglund** is the next stop for a textbook case of a sustainable heating system. Dronniglund Fjernvarme, a consumer-owned cooperative, is demonstrating to the world how heating should be done for the second time. They were the first Danish district heating system to

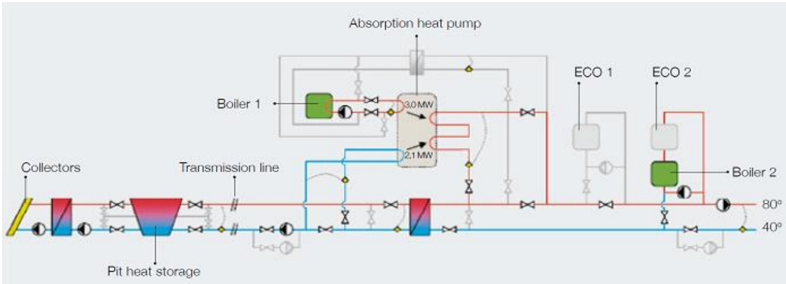

Figure 6 Dronninglund's solar heating scheme

install natural gas-powered engines for combined heat and power production in 1989. In Denmark, being first usually means being among the first in the world. As time passed and CO_2 concentrations in the atmosphere increased, they were looking for a new solution to provide 50% of the heating. The novel system obtains energy from the sun, an intermittent energy source, via solar collectors. After that, hot water flows into seasonal thermal energy storage, which stores thermal energy in a pit mostly during the summer for use in the winter. There are 3000 solar collectors with a total area of 37,573 m^2 and a 62,000 m^3 water filled pit. During the heating season, the flow water temperature is 80° and the return water temperature is 40°. The maximum power from the collector fields is 26 MW, which is comparable to the maximum consumption, which is 12 MW during the coldest winter months. Return water is also cooled from 40° to 10° by serving as a heat source in a 2 MW absorption heat pump. This cooling reduces heat losses and enhances pit storage capacity. The solar system is complemented with bio-fuel boilers and natural gas cogeneration engines. Niras, an engineering firm, developed new storage technology [19].

Figure 7 Aalborg CSP system in desert

Another example of Danish creativity in the field of renewable energy can be found in the Australian desert, a location not normally associated with tomato production. This system was conceived and deployed by Danish **Aalborg CSP**. The sun is a source of energy here as well, but the technique used is different - concentrated solar power. The sun is followed by 23,712 heliostats, which reflect the rays to the top of the 127-meter-high solar tower. Concentrated heat is transferred to water in the solar tower and then to the greenhouses via heat exchangers in the winter and on cool summer evenings. The tomato growing process necessitates a large amount of water, and because the ocean is close, the generated heat is also used in the ocean water desalination process. Last but not least, heat is used to power a steam turbine, which generates electricity. Every year, 17,000 tonnes of tomatoes are grown in greenhouses covering 200,000 m^2. The facility officially opened in October of 2016 [20].

Inventor Peter **Dearman** and the UK-based **Highview power** firm have tackled three problems: motion, cooling, and energy storage. Peter Dearman's work on a reciprocating engine powered by liquid nitrogen evolved into an energy storage system. Highview power was created in 2005, with the engine division becoming Dearman Engine Company.

The phase-change expansion of liquid air or liquid nitrogen is used by the

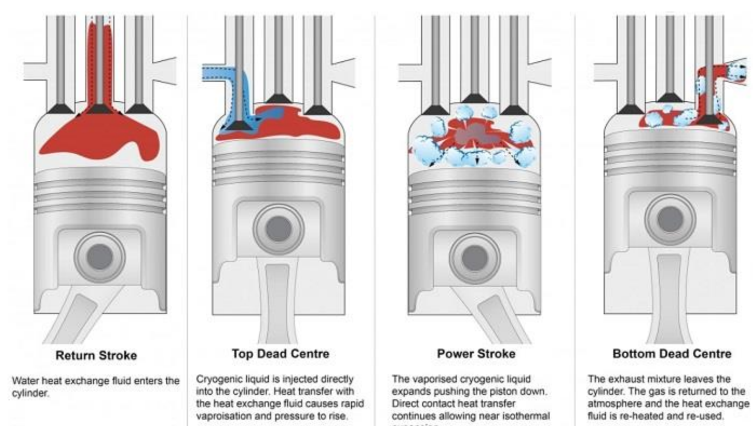

Figure 8 Dearman engine

Dearman engine. The boiling point of liquid air is -194 °C (-196 °C for nitrogen). So, first, ambient or warm heat exchange fluid (water) enters the cylinder, then liquid air is injected when the crankshaft is in top dead center. During the power stroke, liquid air vaporizes and expands. The exhaust mixture exits the cylinder during the return stroke. The air is expelled into the atmosphere, while the water is recirculated. As a result, there is no combustion, no CO_2, no NO_x, and no pollution. The operation is similar to that of a steam engine, but at temperatures 300° lower. It is great for refrigerated vehicles since it produces cold and power. It was already in commercial field trials in 2015. One interesting application under consideration is powering rickshaws in India, which may also function as mobile outside air conditioners. Normally, good ideas just sound wonderful, but this solution is an exception [21].

1. Liquid air storage 2. Cryo pumps 3. Power turbine and generator (5 MW) 4. Heat exchanger containers 5. High grade cold stores © Highview Power

Figure 9 Liquid air energy storage

The cryogenic energy storage system is made up of three parts: a charging unit that uses off-peak or excess electricity to produce liquid air; a storage unit; and an expander that produces electricity when needed. The liquefaction process has been around for almost a century, and it is a mature, fully developed process. The process cost is also competitive with alternative energy storage technologies. In 2011, a 350 kW charge pilot facility for energy storage was developed in Slough. Scale-up to 5 MW/ 15 MWh occurred in June 2018 in Bury, Manchester, UK. The next step is already underway in Carrington, Manchester, UK, at a 50 MW/ 300 MWh facility. Concurrent to this work, the University of Birmingham established the world's first cryogenic storage research center [22].

The final example in this paper is a development of **MAN Energy solutions** that addresses heating, cooling, and energy storage. The basic type of MAN ETES system, MAN ETES Light is previously mentioned in the Esbjerg heating case. ETES is an acronym that stands for Electro Thermal Energy Storage system. The HOFIM compressor, or High-speed Oil Free Integrated Motor compressor, is at the core of the system. During the charging, electrical energy is converted into hot and cold thermal energy in the form of hot water and ice. The stored thermal energy can then be distributed for heating or cooling or used to generate electricity. It is a closed CO_2 R744 cycle. During the charging process, CO_2 is compressed to around 140 bar and 120 °C or higher. The heat is then transferred to the heat tanks by CO_2. The CO_2 is then expanded in the expander, where it liquefies and cools. Finally, CO_2 is heated at a low temperature by chilling the intermediate medium used for ice storage. Heating and cooling can be used independently, or

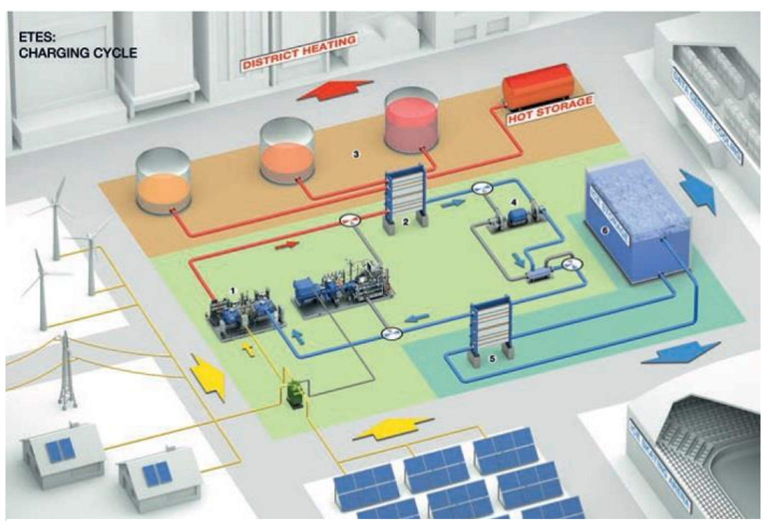

Figure 10 The ETES system’s charging cycle

power can be generated in a clockwise cycle. The HOFIM compressor was originally designed to transport offshore gas in subsea applications. It was also intended for use in the hydrocarbon business, where abrasive gases are abundant. In contrast to the previously described, today's planned area of activity is pharmacy-clean [23].

CONCLUSION

This paper's examples illustrate the tendency that future power will be generated by the sun and the wind. Energy storage is still the missing component. However, because thermal energy storage is the least expensive method for storing electrical energy, this strategy appears to have great potential, particularly if heat pumps are added to the system to further boost the system's efficiency.

A top priority is the decarbonization of the economy, whether this is accomplished through the adoption of cutting-edge technology or the creation of export-ready Serbian products.

Efficiency is always welcome, regardless of how advanced the system.

Other energy sources, such as biomass, biogas, geothermal, etc., are available for the backup and off-grid solution.

Just coal transition is necessary. Coal will be used as a transitional fuel to help Serbia move toward a new, sustainable system.

Sheik Ahmed Zaki Yamani, a former Saudi oil minister, is famous for having said, "**The Stone Age didn't end because we ran out of stones**."

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