SALT E

energy storage

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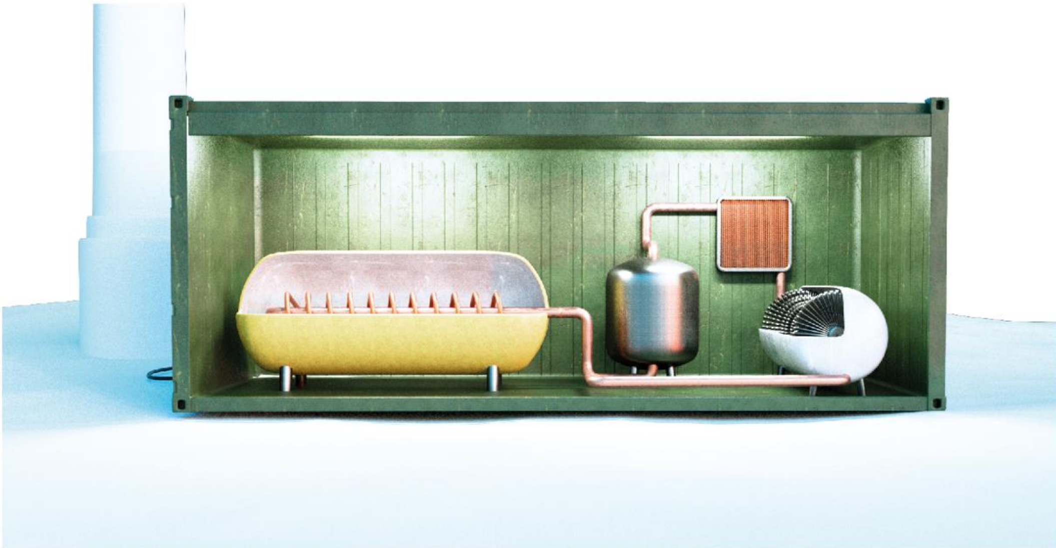

SALT-E is a system that uses conventional thermodynamics techniques to store the excess energy produced by renewable energy sources. The whole mechanism is manufactured with sustainable materials, closed in the transport container which makes it easily deployable. It can be installed at the production facilities, at different points of the stressed electrical grids, or become the center of new energy community developments. Moreover, SALT-E has quick and unlimited charging cycles and requires low maintenance.

RESEARCH

THE PROBLEM

In recent years, the energy produced from renewable energy sources is becoming a trend. We are seeing more and more users who install their solar panels to generate their energy and, in this way, isolate themselves, as far as possible, from the main network managed by large companies.

It is also true that more and more enormous energy production plants are being seen, such as photovoltaic solar plants, thermal solar plants, wind power plants, biomass plants...

And in addition, we see headlines in the news such as the following from the official website of the REE: "Renewables reach 43.6% of electricity generation in 2020, their largest share since records exist" (1). From what we can deduce that the system tends to be increasingly supplied by green energy. Or graphs like the following one that shows the percentage occupied by clean energies in Spain.

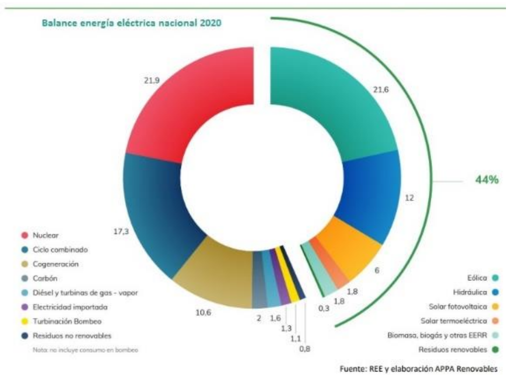

Figure 1: Graph www.energias-renovables.com

The supply from renewable energies stands out for being highly volatile and unpredictable. In contrast, the energy consumption by users and companies is usually quite predictable and constant.

Obviously, unlike with fossil fuels, adapting the production of green energy to demand is impossible, therefore, the current system should be rethought to be able to supply ourselves only with clean energy and create a sustainable impact.

https://www.ree.es/es/sala-de-prensa/actualidad/nota-de-prensa/2020/12/las-renovables-alcanzan-el-43-6-por-ciento-de-la-generacion-de-2020-su-mayor-cuota-desde-existen-registros (1)

Another of the main problems in the renewable energy sector is the difficulty of its storage. Storing energy is very complex because there are many losses and storage periods are relatively short.

Figure 2: Lithium batteries https://www.bbc.com/

In any case, there are several methods to store energy, for example, batteries, water pumps, heat... Currently, the most used batteries are lithium batteries, due to their high efficiency (80-90%) but due to their low durability, their prices, the limited number of loads, and the pollution it causes, it is necessary to look for storage alternatives. On the other hand, the rest of the options studied so far have too low efficiencies. It is for this reason that storing the excess green energy produced is a complicated process. Although the rise of renewable energies has caused many studies to be carried out in this regard.

Figure 3: Energy Transport https://www.techtitute.com/

On the other hand, there is a high cost in infrastructure for the transport and distribution of energy.

In the case of Germany, they have the problem that a lot of renewable energy is produced in the north of the country, while the entire area of factories is in the south, which is where more energy is consumed. This causes the prices at which the energy is sold to be very high, due to the extra cost caused by transport and distribution.

Finally, there is the problem of consumption. Society is used to consuming large amounts of energy, which are often not necessary and are not adapted to production. In addition, the sector is controlled by large companies that control prices and foresee the demand that is going to be always there, and which are not interested in losing their power.

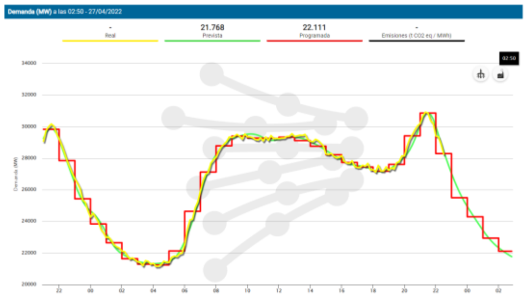

Figure 4: Graph of demand in Spain

In summary, the current system is impossible to adapt to be supplied solely by renewable energies, therefore the solution is to take advantage of all the technology that we have at our disposal and invest in research to redefine the system.

TYPES OF RENEWABLE ENERGY

If we compare the main ways of obtaining renewable energy:

- **Solar:** cheap but has a structural problem. Even if we installed solar panels everywhere in Catalonia, we would not have enough. Another stochastic problem, although you can make statistical promises, you can't predict exactly. There are two types: solar photovoltaic and solar thermal.

- **Wind:** We still can be able to generate all the consumption we need with wind energy. Also intermittent.

- **Geothermal:** More predictable but slightly variable subsoil temperature. But it has an economic problem for the infrastructure (basement holes, pipes ...). Expensive installation and maximum thermodynamic performance of 40%.

- **Biomass:** The use of biomass in energy production creates carbon dioxide that is put into the air, but the regeneration of plants consumes the same amount of carbon dioxide, which is said to create a balanced atmosphere. Although new plants need carbon dioxide to grow, plants take time to grow. We also don't yet have widespread technology that can use biomass instead of fossil fuels.

- **Renewable gas (synthetic):** Can be used for excess energy storage and transportation.

- **Hydrogen:** Its benefits are being studied, it can be used both in production and in transportation, but the processes it needs are complex. It's getting cheaper and cheaper.

- **Nuclear power:** Can be produced at a low price. Power plants cannot be distributed. It can be used to give the base price.

Figure 5: Renewable energy **https://regenpower.com/**

FUTURE SOLUTION

Today, we have very advanced technology that is constantly growing. We also have a large amount

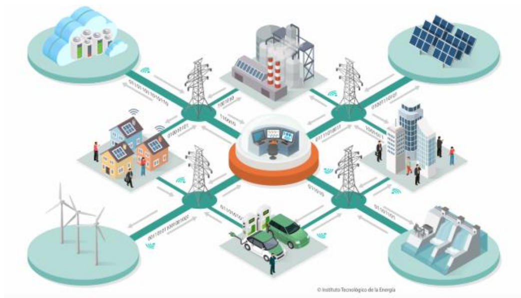

Figure 6: Energy communities

of data that, with a correct analysis, can provide us with a lot of information and can help us optimize processes for saving infrastructure and costs.

From all the information described in the previous section, we can conclude that the centralized system is not the future due to its lack of capacity to adapt to renewable energies.

A proposal for a future solution to this global challenge is based on the decentralization of the system.

The redefinition of the system based on decentralization would consist of the design of the electrical network from micro-networks generated in energy communities. These energy communities would be producers of energy from renewable sources and would also be capable of storing the excess energy produced to be used in situations of greater demand than production. In addition, they would have the benefit of being partially manageable and would be able to share energy between communities as needed.

In the hypothetical case of achieving a system like the one just defined, it would be possible to avoid the great problem of renewable energy and its instability. Because with this system, it would be guaranteed to always have energy available and always supply clean energy, which would greatly help combat climate change.

Josep Bordonau

Researcher at the UPC

One of the key points in the transition to a world that produces all energy from renewable sources is decentralization. To have the production distributed and in smaller areas but closer to its consumption. This redefinition of the system makes it possible to avoid blocking the network in the event of a failure in any zone. Also, the closer you are to the production of a product, the more control you can have over it. Therefore, having a distributed system allows for flexibility and a more robust system. Although the main objective is always generation proportional to consumption.

Therefore, it is important to make the most of energy efficiency, everything that we should not consume we can save and save and maximize distributed generation, creating energy communities with energy production, storage, and distribution.

Roberto Villafafila

Researcher at the UPC

One of the main problems with renewable energies is the investment required and all the bureaucracy that it entails. To adapt our system to a distributed system, commitment is needed from society and education on consumption to the end-user, as well as regulation and administration issues. The transition should be promoted by both public and private entities.

For example, in large cities photovoltaic energy is not enough because they are dense and there is much more consumption than production. That is why a distributed and flexible generation is needed.

Another of the biggest challenges is the storage of energy, being able to store excess production to supply the network in times of scarcity, would also provide great flexibility and adaptability, always having energy produced in renewable sources available to the consumer.

Microgrids or energy communities are a solution to isolate yourself from the system. They are self-sufficient in the generation and storage. All of this can be achieved with increased digitization, societal engagement, communication, and education, and by involving the end-user as well as architects and engineers.

Francisco Diaz

Researcher at the UPC

If we compare the production of energy from renewable sources with the production of energy from fossil fuels, we can see that while fossil fuels are very manageable and predictable, renewable energies are very intermittent and difficult to manage and predict. Furthermore, the problem is that bidirectional flow injection stresses the network since it can cause overcurrent. In addition, there is a large impact on the cost of energy due to taxes and transportation.

The main players in the energy market: generation, transport, distribution, and consumers.

That is why one of the great challenges is to share energy in energy communities. Because the energy has to be consumed as close as possible to the generation, to make transport cheaper and avoid losses.

We have enough hardware to do it, but there is a shortage of software and algorithms to get better prices. A possible option to control this decentralization would be to use blockchain technology.

Hydrogen is attracting a lot of interest due to its versatility. However, it is only interesting for large-scale use cases and the technology is still very expensive. In addition, the efficiency is very low (40%). Hydrogen solutions must be centralized.

Therefore, the greatest opportunities currently lie in decentralization to energy communities, data management for the benefit of the user, the study of alternatives for energy storage, and the development of consumption optimization software.

Jose Luis Muñoz

Researcher at the UPC

The main problem of energy is based on its excessive regulation; therefore, it is a difficult sector to innovate. However, the future of energy generation from renewable sources is based on the decentralization of the system, designing energy communities that self-produce energy and are capable of storing it. For the management of production and consumption data in the field of decentralization, blockchain technology will be used. Smart contracts will be created to manage the consumption data and expenses of each user. In this way, the regulation and control of the large companies in the sector will be avoided.

Oriol Batiste

Researcher at the UPC

To evolve in the field of energy production, research in power electronics is needed. It is also important to calculate the costs between the energy produced and the prices at which it is purchased. Another big problem is that if too much electricity is injected into the grid, it can cause excess power and grid collapse.

For this reason, it is important to anticipate the amount of energy that is going to be produced at any given moment and look for alternatives for storing the excess energy produced. For example, storing excess energy by heating water, with flywheel systems, hydrogen, melting silicon... There are many studies in this regard, but there is a lack of development and research.

Antonio Ruiz

Project Manager in Svea Solar

The biggest problem in the energy sector is storage, battery technology is very poorly developed and does not allow the excess energy that could be produced to be stored.

In addition, the prices to make your photovoltaic installation are very high and create a lot of uncertainty. Customers show a lot of interest but are afraid to spend what they can't. In Spain, the architecture is not prepared for photovoltaic installations and the city councils are very strict about permits for the installations.

In small installations, injecting power into the network is very easy. But, on the other hand, for very large powers it is complicated because special delivery points are needed. This is a great cost to energy companies.

This implies that the compensation systems are not fair, therefore, it would be more effective to store the energy. But if the legislation changed, batteries would not be needed.

Andre Broessel

Founder of Rawlemon

Society lacks interest in thermodynamics of the energy. Many systems and technologies are already on the market. However, they haven't been properly developed and implemented. The effectiveness of this process is high, and all mechanism is easy.

Moreover, the market is monopolized by big players that deeply influence the direction that which the industry is developing in. The main companies are not always accommodating to the innovations. Also, we are lacking society's awareness of how energy works and its issues. The public should be more involved and empowered in the process of energy development. By achieving that the big players that monopolize the energy market would be more limited.

SUMMARY

From the different points of view that we have been able to acquire thanks to the interviews carried out, summarized above, we have reached the following conclusions.

First, we can see that there is a problem in the current network and that it is difficult to deal with and innovate on it. The network is managed by large companies with economic interests that control prices and resources. Therefore, making any changes at that level is very complicated.

On the other hand, we see that the problem of the renewable energy industry is low production, excess energy is not managed correctly and much of it is lost or not produced. The main cause is its volatility and it is difficult to predict, in addition, the network is not prepared to absorb very high energy peaks, because they would cause its saturation.

In the case of production, we have sufficient technologies to produce large amounts of energy from renewable sources, but its transport is very expensive. Which entails another of the main problems. Generating renewable energy in large plants implies that production is carried out far from the consumer, therefore transport plays an important role.

In addition, energy storage is not sufficiently developed, batteries must evolve, and new storage methods should be sought, to supply the network when necessary and store energy when it is produced in excess. With efficient energy storage, stability would be achieved in a system powered by renewable energy.

Everything mentioned above leads us to the fact that one of the main solutions found and named by the interviewees is decentralization.

The decentralization of the system based on the design of energy communities is one of the main trends in the sector. If the system were distributed, in communities that generated their

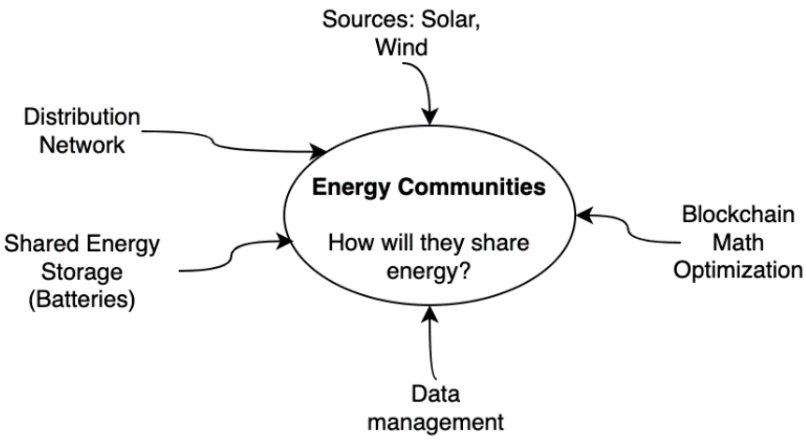

Figure 7: Summary diagram

energy from renewable sources and in case of excess had the capacity t and in case of excess could store it to be able to self-supply it in situations of scarcity, it would cause the decentralization of a system that is currently quite centralized.

It would allow the microgrids to be disconnected from the main network, the large companies in the sector would lose their monopoly and a much more flexible system would be achieved, even adaptive based on the analysis of all the data that is generated.

In addition, all the technologies used for power generation would be much more efficient and energy transport much shorter, which would greatly reduce costs.

But to achieve this goal, the consumer needs to be much more aware of the situation and the impact it has. For this, it would be necessary to involve the end-user in the change, educate and raise awareness in society, and promote it from both private and public entities.

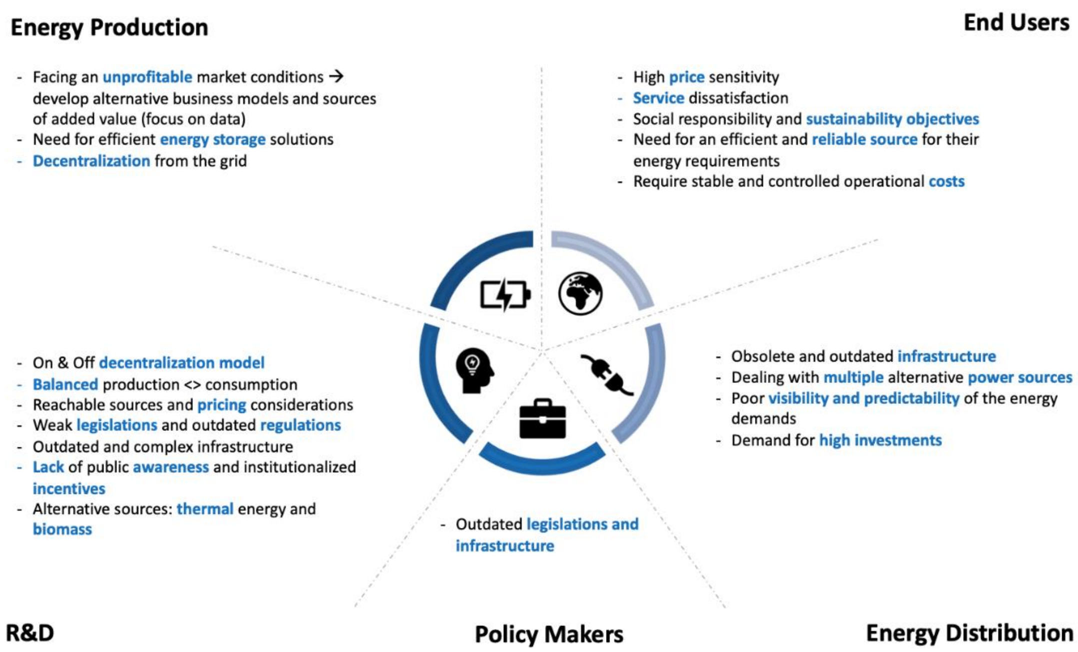

Figure 8: Most relevant insights

IDEA DEVELOPMENT

FIRST STEPS

When starting this project, with the knowledge that we were acquiring about renewable and affordable energy, our proposals were based on methods of producing energy. We tried to find solutions or alternatives to generate energy from new sources or through other methods.

SOLAR PANEL UMBRELLA

Figure 9: Solar panel umbrella

One of the initial proposals to take advantage of the solar energy that was wasted daily was to design an umbrella with solar panels to generate energy from the sun. In this way, all the solar energy accumulated in terraces and streets would be used.

But due to the low efficiency of the solution, its high cost, and other viability problems, that first option was discarded.

BIDIRECTIONAL GRID

Our second proposal was based on creating a system that could calculate how much energy a domestic solar panel installation produces, calculating what the household consumption is and the excess of energy produced was supplied to the general network, this method was more effective if we scaled it to the community level. In addition, users who contribute energy to the network would obtain rewards in the form of a rate reduction.

We also wanted to develop optimization software, so that in the event of a power shortage in a home, our system would be able to draw more power from the main grid and store it for short-term use.

The problem is that the network is not prepared for many users to supply energy, because it would cause energy peaks that would saturate it. Finally, we also observed that there were many legal restrictions in this regard and a large part of the network cannot be accessed because it is public, a fact that prevented the project from continuing.

BLOCKCHAIN NETWORK

The third idea was more set in the decentralization of the system. After interviewing some experts, we realized that one of the key points when decentralization becomes feasible is the blockchain.

When energy communities are created, a large amount of data will have to be managed in a decentralized and secure manner. This means that the most likely way to manage and analyze them is through blockchain technology.

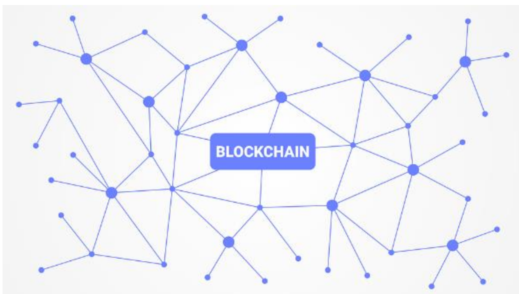

Figure 10: Blockchain Network https://www.rankia.cl/

We proposed to design an intelligent contract where we could establish certain consumption rules for the user and thus control the system in a decentralized manner.

DECENTRALIZED CONCENTRATED THERMAL SOLAR POWER

Our fourth proposal also focused on the decentralization of the system intending to create energy communities supplied by a distributed system of electricity generation from solar thermal energy.

The idea was to divide the city into zones, which would be called "energy communities". Each community would have an energy concentration tower, where all the solar thermal energy would be stored in the form of heat by melting some material, chosen according to its specific heat.

For the concentration of energy, the roofs of the cities would be used, where heliostats would be installed that would focus all the solar energy towards the concentration tower.

Figure 11: Draft of the system

In the concentration tower, all the energy would be stored, and when it wanted to be used, water would be passed through a circuit to create high-pressure steam that would turn a turbine and electricity would be obtained through an alternator.

The problem with this project is visual pollution, aerial problems, the irregularity of the heights of the buildings in the city, the variety of objects that can interfere and the low efficiency of the system, as well as a very high cost in infrastructures.

FINAL IDEA

SALT-E ENERGY BUFFERS

After the entire process of research and the planning of ideas carried out in the previous section, we arrived at our final idea.

We conclude that one of the key points in the renewable energy system is storage. We believe that it is an area where there are many possibilities for improvement and innovation. Currently, we are capable of producing much more energy than we generate, but the great drawback is storing it to have it available when it is needed.

We have also discovered many studies in this regard and many alternatives that are being carried out, which allow us to validate our idea. Every time we have at our disposal more materials with very different properties.

This is how Salt-E was born, a system of renewable energy buffers. Our proposal consists of an energy buffer, which is capable of storing the green energy produced for more than 24 hours.

The idea is to design a product that can be transportable, to be able to load it with energy in renewable energy generation plants and that can later be transported to cities for consumption. Its maximum utility is acquired during peak hours of consumption, to avoid using non-renewable energy, in addition to being able to obtain energy at more reasonable prices.

Our product can store energy in the form of heat in molten salt inside a tank. Through a water circuit, when you want to obtain energy, water is circulated through the circuit and evaporates under a high-pressure process with which when turning the turbine and the alternator electricity is generated to be consumed by the end-user.

We consider that our project collaborates with the trend of decentralization of the system, generating energy in a distributed manner, participating in the improvement of storage, avoiding excessively long transports of energy, stabilizing the supply of energy and its prices, and finally having an impact on the environment. Reasons that motivate us to carry out Salt-E.

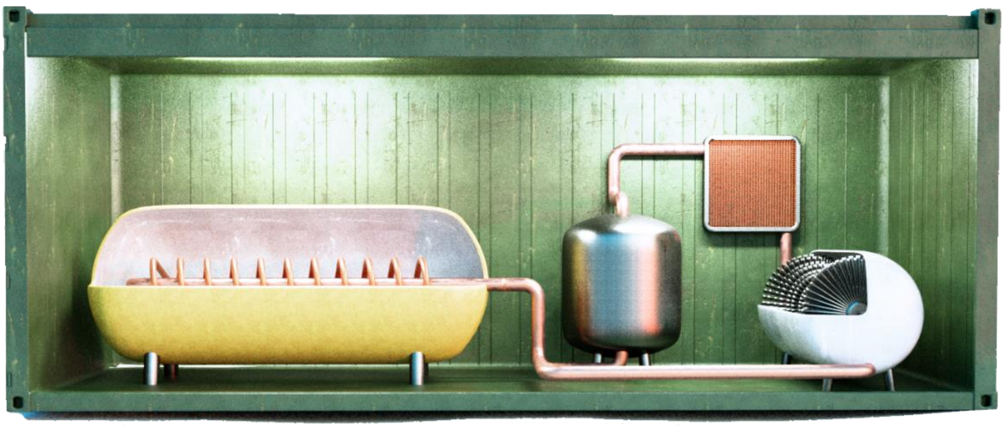

Figure 12: SALT-E model.

DESIGN ELEMENTS OF SALT-E

Naturally, the strongest side of our proposal is the mechanism, but it doesn't lack the advantages related to the product design. SALT-E energy storage has four main characteristics: sustainable materials, universal shipping container size and movability, as well as customizability, and attractiveness of the machinery design. All that combined brings a lot of benefits to the business model of this energy buffer.

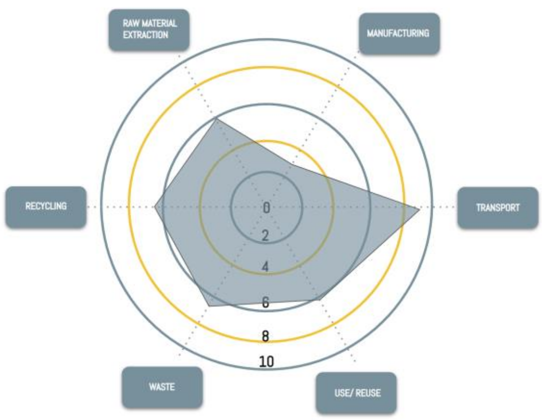

Figure 13: Spider diagram of SALT-E.

SUSTAINABLE MATERIALS

All the material used in our system can be recycled. Most of the hard parts of the system would be created from steel or copper. Both materials have a relatively low environmental impact. Especially while used from the secondary source the carbon footprints represent.

Figure 14: Carbon footprint data from the IDEMAP app.

Besides the turbine, all elements have a relatively affordable cost but even in the turbine, we found the space for some quality improvement. By applying a ceramic coat on it we would reduce the amount of energy needed for cooling as this material has lower heat transfer.

MOVABILITY

As the whole system is placed in a shipping container, it is easy to transport it and adjust to the existing conditions. It creates the possibility to use it for many purposes -as the center of the energy community or to de-stress the grid. Moreover, it significantly reduces the cost of transportation because of the universal size and a widely developed communication mechanism.

CUSTOMIZABILITY

The system allows the consumer to decide what amount of energy they need to store. By doing that we can adjust all the elements to the needed values. This treatment creates the possibility for this product to find its place in many use locations. It is suitable not only for the industry but also for users with lower demand.

Figure 15: Models represent SALT-E movability.

MACHINERY DESIGN

To attract and get the attention of the audience the option of one transparent glass wall would be introduced. The explanation graph would be added to shortly explain the system. It would have an educational and marketing function. Additionally, there would be an option to choose the color of the container. As a future development SALT-E would collaborate with the local artist to create some decoration design on the outside walls, this option is specially planned for energy communities. By doing it with the local representatives and the citizens the sense of belonging and inclusion would increase.

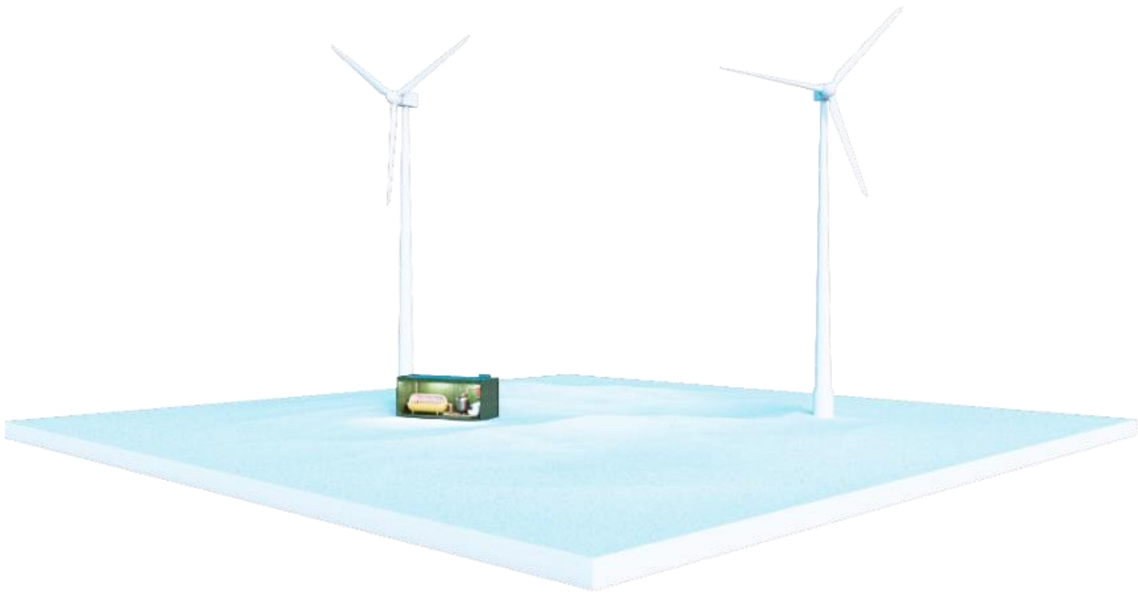

Figure 16: Models represent SALT-E movability.

IMPACT MODEL CANVAS

Salt-E's depends on the synergy of different elements that, combined, will create the core of the business model. Initially, we will be targeting to create alliances with local governments, NGOs, and strategic customers that could help Salt-E scale. Our ultimate goal is to provide our cities, communities, and companies all over the world with the necessary technology to make the most out of the available energy renewable sources. Making it more affordable, reliable, and available to everyone. The business model canvas below detail the partners' activities and revenue streams we are projecting to develop to achieve our business goals.

VALUE PROPOSITION

Currently, there is a sizeable gap between the supply of energy from renewable sources and demand. To bridge this gap, we are still using fossil fuels. We propose to use SALT-E to bridge this gap without using fossil fuels. Usually, there are certain times of day, when solar & wind farms need to be turned down due to oversupply. Instead of turning down the farms, the excess

energy can be stored in form of heat in SALT-E. When demand exceeds the supply, for example, at nighttime for a solar farm, the stored heat can be converted back to electricity.

In addition to the production end, it can be used at several chokepoints in Grids, to gain stability. By using SALT-E in these two places, we can further reduce the usage of fossil fuel as a backup source of power.

REVENUE STREAMS

Salt-E is looking to generate revenue from three main pillars: Hardware sales, maintenance, and use-base. The hardware sales will consist of the operations related to supplying the final customers with all the equipment and technology needed to set up and operate Salt-E buffers. Meanwhile, an additional source of income will

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
• Energy Producers • Local Govts • Energy distributors • Communities • Strategic customers (Heavy Industry)	Production: • Maintain high production • Install Salt-E at the production sites Distribution: • Install Salt-E at strategic chokepoints in the Grid Industry 4.0: • Connect all the devices to central server. • AL-ML based system to operate and control.	Producers: • Store energy in form heat when supply is greater than demand. • Meet high demand by using the stored heat to generate electricity. • Take advantage of economy of scale Distributors/Grid: • Bridge the gap between supply and demand. • Stabilize Grid Governments: • Meet Climate action goals by reducing fossil fuel based electricity • Decentralize the system Consumers: • Cheaper electricity • Overall, better standard of living	• Heavy industries/Industri parks: they can utilize this solution to take advantage of low energy price during peak supply hours. • Energy communities can use this for energy storage and exchange.	Industries: • Power producers • Grid operators • Hreavy industry Others: • Local Govts • Communities
	Key Resources		**Channels**	
	• Stringent emission control regulation • Tax on non-RES energy • Deregulation of energy, with regards to energy communities		Primariliy B2B – Direct sales to power plants & Grids As a service model for communities & heavy industries	

Cost Structure	Revenue Streams
• Initial development cost • Production and maintenance cost. • Sourcing turbine and radiators from third party • Investment would be required to digitize and integrate into Smart-Grid. • High shippping cost, due to the size and weight of the system.	• Direct sales to the Power plants and Grids • Usage based revenue from the heavy industry & communities • Maintenance contracts Other sources of funding: • Philanthropic. Ex. Gates foundation • Govt subsidies

come from the maintenance of the equipment sold, proving preventive and corrective actions to extend the life and guarantee the correct performance of the buffers to the existing customers. Moreover, our business model will also depend on the operational fee from the on-demand usage of the equipment.

OVERVIEW OF DIFFERENT TECHNOLOGIES FOR ENERGY STORAGE/STRESS RELIEF.

Due to their unpredictable nature, renewable energy sources are usually only available during certain times of day, as can be seen in the following figure.

Because of this intermittence, unprepared electrical grids become unstable and difficult to manage.[1]

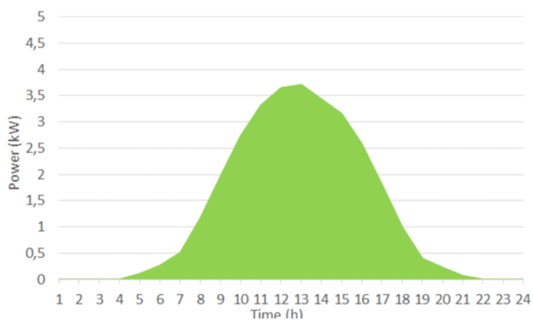

Figure 17: Modelled solar power production curve (National Renewable Energy Laboratory, 2015).

Furthermore, it is difficult to change consumption patterns and habits to match them with renewable energy availability.

One possible solution to these problems is to integrate an energy storage system with the power network to manage unpredictable loads.

A lot of research is being done into creating energy-efficient, long-term energy storage systems. The main energy storage solutions right now present in the market are the following ones:

PUMPED HYDRO

Pumped Storage Hydroelectricity Storage or Pumped Hydro Storage techniques are mainly implemented in reversible Hydroelectric Centrals. These facilities take advantage of potential energy into electricity thanks to the use of water to spin turbines.

The key advantage of these systems is that the process can be also done in a reverse manner. This is perfect for shortcoming the renewable's energy intermittence as when there is an excess of energy it is used to pump water uphill and when there is no energy, the potential energy of that water is used to spin a turbine and generate electricity.

Disadvantages are related to CAPEX for building the facilities and sustainability regarding the destruction of existing ecosystems.

ELECTROCHEMICAL BATTERIES

An electrochemical cell is any device that converts chemical energy into electrical energy or electrical energy into chemical energy. These systems are the ones that are mainly used for the storage of low capacities.

Some disadvantages they present are their limited storage cycles and their cost.

THERMAL

Because of basic thermodynamic laws, a material gains energy when its temperature, increases and loses it when its temperature decreases.

Thermal Energy Storage techniques take advantage of this property and with the use of different materials with different thermal

[1] https://www.sciencedirect.com/science/article/abs/pii/S0196890420308347

properties, different thermal energy storage applications can be achieved.

TES can help to balance energy demand and supply on a daily, weekly, and even seasonal basis, presented in thermal systems. TES can also reduce peak demand, energy consumption, CO2 emissions, and costs; while also increasing the overall efficiency of energy systems.[2]

COMPRESSED AIR

Compressed-air energy storage (CAES) is a way to store energy for later use using compressed air. At a utility-scale, energy generated during periods of low demand can be released during peak load periods.[3]

It is important to note, that for solving the intermittence and stress problems caused by renewable energy production, we don't need a long-term energy solution. What is needed is an energy storage system that can take high excess energy inputs, keep that energy and discharge it when there are peaks in demand. This behavior resembles more a capacitor than a battery.

And that is why we created the concept of buffer energy storage.

This buffer-like energy storage system will be small, and easily deployable so that it enables decentralization thanks to the possibility of being installed at different points of the stressed electrical grids or even next to the production facilities such as wind farms or solar power plants.

THERMAL ENERGY PRODUCTION & STORAGE

THERMAL ENERGY

In thermodynamics, thermal energy or heat is energy that is transferred to or from a thermodynamic system by mechanisms other than thermodynamic work or transfer of matter.[4]

Heat refers to a quantity transferred between systems, not to a property of any one system, or "contained" within it. On the other hand, internal energy and enthalpy are properties of a single system. Heat and work depend on how an energy transfer occurred, whereas internal energy is a property of the state of a system and can thus be understood without knowing how the energy got there.[5]

THERMAL ENERGY PRODUCTION IN SOLAR PLANTS

Concentrated solar power systems or CSP systems generate energy by concentrating solar power by using mirrors and lenses spread over large areas onto a central tower or receiver. A fluid is circulated through the collector tower and the concentrated energy is transferred to the fluid. This fluid will later generate steam in a heat exchanger. Finally, electricity is generated with the steam driving a heat engine (usually a steam turbine) that is connected to an electrical power generator.

[2] Dinçer, 2011

[3] https://en.wikipedia.org/wiki/Compressed-air_energy_storage

[4] Thomas W. Leland, Jr., G. A. Mansoori (ed.), Basic Principles of Classical and Statistical Thermodynamics (PDF)

[5] Robert F. Speyer (2012). Thermal Analysis of Materials. Materials Engineering. Marcel Dekker, Inc. p. 2. ISBN 978-0-8247-8963-3.

Figure 18: CSP Plant

According to NREL, the unique feature of CSP is the ability to store heated material in an inexpensive and efficient thermal energy storage system. The stored thermal energy can be tapped between sunset and sunrise or during cloudy weather to provide renewable electricity on demand.[6]

FROM ELECTRICAL TO THERMAL ENERGY

Electrical to thermal energy conversion can be achieved technically quite easily. With the use of simple resistors and great efficiency rates.

In metal conductors, electrical current flows due to the exchange of electrons between atoms. As electrons move through a metal conductor, some collide with atoms, other electrons, or impurities. These collisions cause resistance and generate heat.

We plan to use this well-known physical effect to generate the necessary heat inside a vessel to heat molten salt, up to the point to reach a liquifying point.

The important thing to note is that this will be done using excess energy, that otherwise would not be generated because the grid cannot receive it at times when there is not enough demand.

THERMAL ENERGY STORAGE

Thermal Energy storage methods, known as TES methods and techniques are a series of techniques and systems that allow storing energy in the form of heat during long periods. This can be achieved with different specific technologies but most of them take advantage of the specific or latent heat of different materials.

The great potential of this technology is that if good insulating materials are used, heat can be kept for a long time.

Usage examples are the balancing of energy demand between daytime and nighttime, storing summer heat for winter heating, or storing energy produced during excess availability in Concentrated Solar Power Plants for its use when there is back a peak in demand.

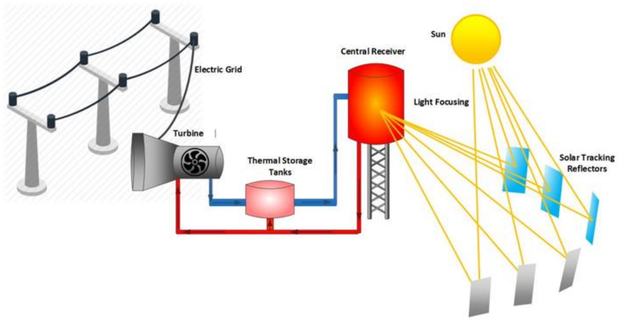

Figure 19: Concentrated Solar Power Production plant with TES system

TES systems are used mainly when there are processes that can generate enough heat, or there is an excess of heat to keep them functioning.

Storage media include water or ice-slush tanks, masses of native earth or bedrock accessed with heat exchangers using boreholes, deep aquifers contained between impermeable strata; shallow, lined pits filled with gravel and water and

[6] https://www.nrel.gov/csp/

insulated at the top, as well as eutectic solutions and phase-change materials.[7]

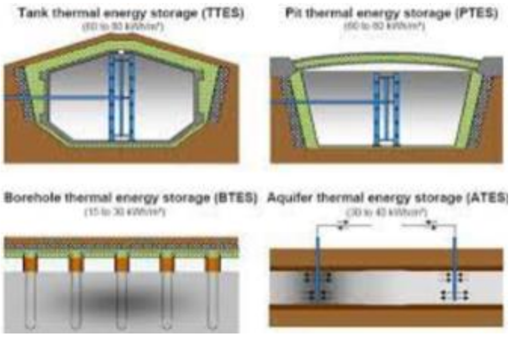

Figure 20: Different TES systems

According to the technologies and techniques used, TES systems can be classified into different categories:

SENSIBLE HEAT STORAGE

Sensible heat storage means shifting the temperature of a storage medium without phase change. It is the most common simple, low-cost, and longstanding method. This storage system exchanges the solar energy into sensible heat in a storage medium (usually solid or liquid) and releases it when necessary.[8]

LATENT HEAT STORAGE

Latent heat storage uses the phase transition of a material. Usually, the solid-liquid phase change is used, by melting and solidification of a material. Upon melting heat is transferred to the material, storing large amounts of heat at constant temperature; the heat is released when the material solidifies.[9]

THERMO-CHEMICAL HEAT STORAGE

Thermochemical storage uses chemical reactions to store energy. It is based on the reversible chemical energy which absorbs heat for storage and then releases it. The storage is "charged" by the endothermic reaction and is later discharged by an "exothermic" one.[10]

We understood the potential of this technology with our first project, and we took the main ideas of thermal storage systems to shrink them down into small-sized, easily deployable energy storage systems, creating the concept of Energy buffers.

The system we propose will use a eutectic mixture of salts for storing the energy in the form of heat, so it is important to understand the properties and advantages of the use of molten salts for Thermal Energy storage.

[7] https://en.wikipedia.org/wiki/Thermal_energy_storage

[8] https://www.sciencedirect.com/topics/engineering/sensible-heat-storage

[9] https://www.sciencedirect.com/topics/engineering/latent-heat-storage

[10] https://www.sciencedirect.com/topics/engineering/thermochemical-energy-storage

MOLTEN SALT FOR TES

Eutectic mixtures of molten salt can be employed as a thermal energy storage method to retain thermal energy.

Actually, this is a commercially used technology to store the heat collected by concentrated solar power The heat can later be converted into superheated steam to power conventional steam turbines and generate electricity in bad weather or at night.

Molten salt energy storage is an economical, highly flexible solution that provides long-duration storage for a wide range of power generation applications.

STATE OF THE ART THERMAL INSULATION

The most important part of a molten salt energy storage system is the vessel where the fluid will be contained at high temperatures. For being able of storing energy for long periods, great insulation is required. The lower the thermal conductivity the vessel has, the longer, energy will be stored. Considering the system losses due to thermodynamic mechanics, it is salient to develop a system that has high insulation to avoid energy losses due to conductivity, convection, or radiation.

Usually, the vessel has the form of a cylinder or a sphere, due to mechanical properties such as pressure resistance.

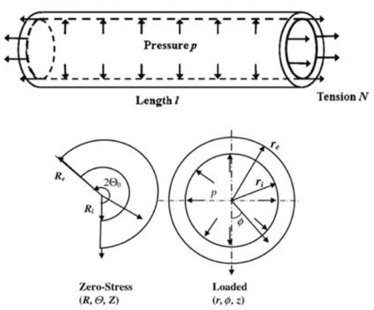

Figure 21: Cylindrical geometry of the vessel

In this kind of geometry, the thermal conductivity of insulators can be calculated easily using the following formulas:

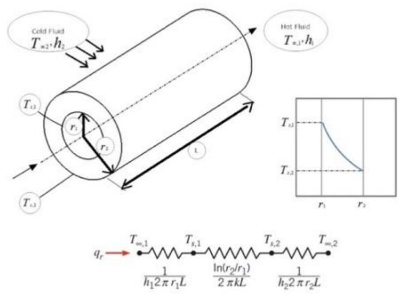

Figure 22: Thermal conductivity for insulators on cylindrical vessels

Once the desired total energy storage capacity has been calculated, using the density of the fluid, the amount of eutectic salt mixture can be defined, and with that, the size of the vessel can be designed. (Please have a look at our MATLAB script). Then it is just a matter of choosing the right insulation materials.

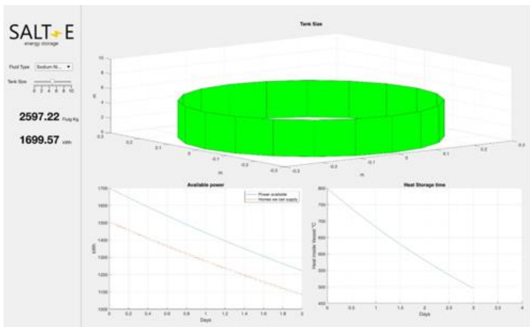

Figure 23: MATLAB Script for validating size and insulation

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https://en.wikipedia.org/wiki/Thermal_energy_storage

https://www.sciencedirect.com/topics/engineering/sensible-heat-storage

We propose these different alternatives for insulation materials:

MINERAL WOOL ROCK

Mineral wool is any fibrous material formed by spinning or drawing molten mineral or rock materials such as slag and ceramics.[11]

Applications of mineral wool include thermal insulation filtration, soundproofing, and hydroponic growth medium.

It is a great thermal insulator, but there is an even better version which is called High-temperature mineral wool.

High-temperature mineral wool is a type of mineral wool created for use as high-temperature insulation and is generally defined as being resistant to temperatures above 1,000 °C. This type of insulation is usually used in industrial furnaces and foundries.[12]

In the following graph, we can see the thermal conductivity of Mineral Wool. As it can be seen it is not very linear. And taking into consideration that we plan to use it for high-temperature insulation, it may not be the best alternative. That's why we also propose other materials.

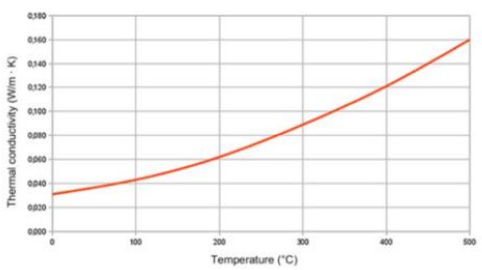

Figure 24: Mineral Wool Thermal Conductivity

INCONEL

Inconel is a brand name of Special Metals Corporation that refers to a family of nickel-chromium-based austenitic superalloys. Inconel alloys are typically used in high-temperature applications

Common trade names for Inconel include Inconel 625, Chronic 625, Altemp 625, Haynes 625, Nickelvac 625, and Nicrofer 6020.

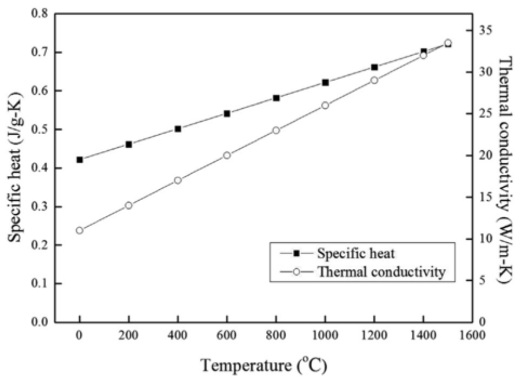

Figure 25: Inconel Thermal conductivity

AEROGELS

Aerogels have very little mass through which heat can conduct. Additionally, the solid part of aerogel is highly disordered and thus makes conduction of heat through the little solid that is there inefficient. This happens because they are extremely porous, and the pores are in the nanometer range. The existence of these pores makes the aerogel so adept at insulating.[13]

The thermal conductivity of the monolithic aerogel is around 0.018 W/mK at ambient

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[11] https://en.wikipedia.org/wiki/Mineral_wool

[12] https://en.wikipedia.org/wiki/Mineral_wool#HTMW

[13] https://www.nasa.gov/topics/technology/features/aerogels.html

pressure. [14] This makes them perfect for high heat insulation.

But with current technology, it would not be economically feasible to use them as insulators in our project. However, great advancements in material engineering are expected in the following years.

OVERALL SYSTEM FUNCTIONING

The system that we propose uses the well-known thermal storage capabilities of fluids with high specific heat.

We envision the use of a cylinder vessel that contains a eutectic mixture of salt (from different options presented in previous sections). This vessel will have a thick insulation layer that will have been calculated to prevent thermal losses.

According to the previous section (State of the art thermal insulation), right now, we propose Incanol or Mineral Rock Wool insulation. But in the close future, we expect to be able to have materials with much lower and more linear thermal conductivity such as aerogels.

The insulators that we have proposed have low thermal conductivity, and this makes them great to avoid thermal losses in our system. Thanks to this thick layer of insulation, the heat inside the vessel can be contained.

Once we have heated the salt to the liquifying point thanks to the excess energy in the grid and using a mesh of electrical resistors inside the tank which will be controlled using PID processes, we can hold power for almost a day as can be seen in our simulations.

Whenever there is a peak in demand, the vessel's internal heat can be used to transform pumped water from a water tank into steam. This will turn a micro-turbine such as the MAN MST010 or bigger models according to planned demand.

Thanks to the micro-turbine high efficiency, we expect overall system efficiencies superior to 55%, and improvements in this field are expected in the following decades.

The final step is generating electricity from the turbine's movement and injecting it into the grid when there is demand.

A high-level system working functioning/process diagram can be seen in the following diagram:

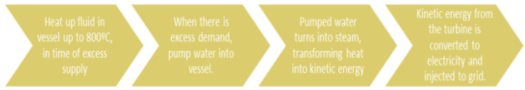
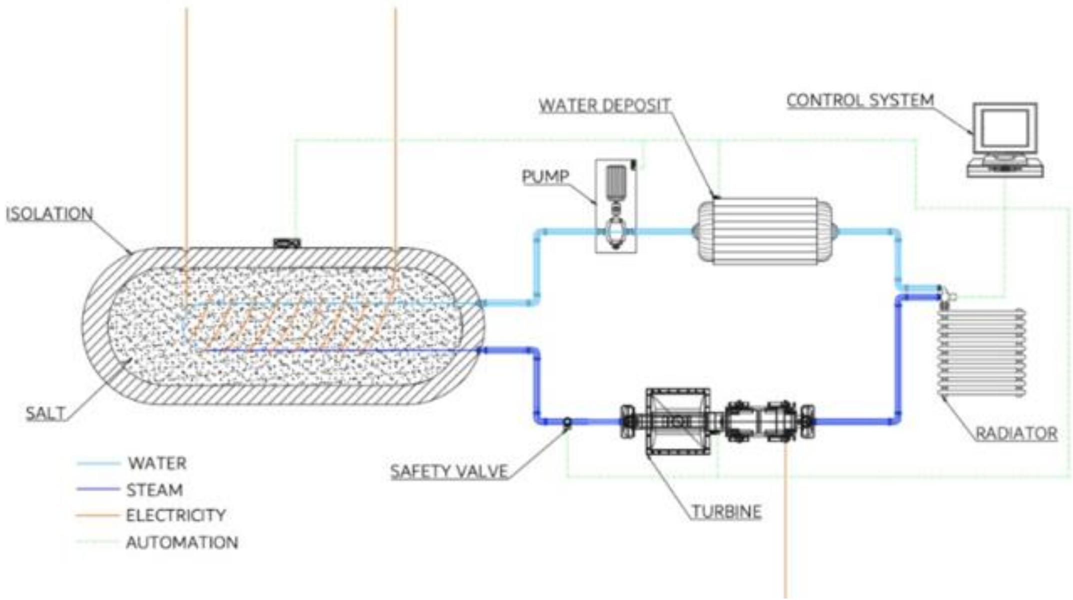


Figure 26: Overall system function

14 https://link.springer.com/chapter/10.1007/978-0-387-88953-5_46

SCHEMATICS / PLANS



SYSTEM COMPONENTS

As can be seen in the technical drawings, our system will be composed of the following components:

- Vessel & Insulation
- Piping
- Turbine
- Pump & Actuators
- Refrigeration System
- Recirculation System.
- Housing (Shipping Container)
- Control & Automation Modules

DECENTRALIZATION CAPABILITIES

Thanks to its containerized architecture, the system we propose can be easily deployed at different points of the grid.

The PLC and automation system that controls the electromechanical equipment of our solution such as pumps, valves, turbines, and fluid levels… will have embedded an IoT module that will make it easy for grid operators to manage the flow and storage of energy in a decentralized way.

SMALL PROTOTYPE

In addition to MATLAB code for calculating rough projections of system capacity, we have developed a small-scale 3D model which shows a simple layout of all the components inside a shipping container. This form-factor is ideal for decentralization and ease of deployment. STLs can be found attached in the communication dossier.

In the following model, a view of all the insulated components can be seen.

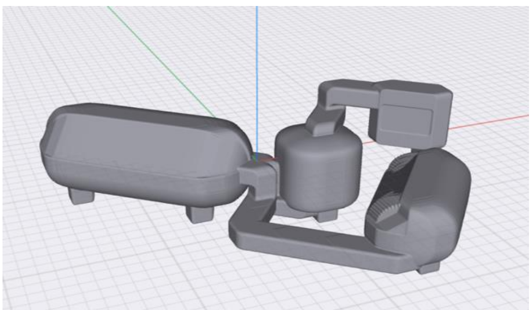


Figure 27: 3D model

A detailed view of the components, showing the turbine, the resistor that would melt the salt, and the water pumping equipment including piping can be seen in the following model:

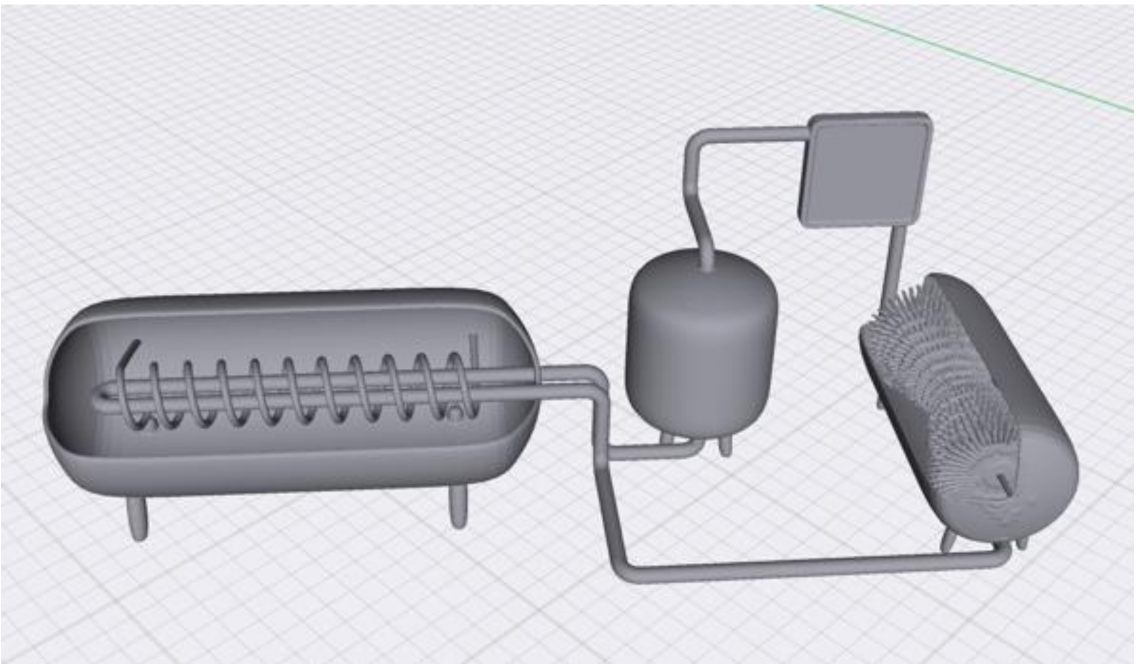


Figure 28: Detailed 3D model

OUR TEAM

Figure 29: Our team

- Katarzyna Wsol - IED
- Raquel Abad - UPC
- Marc nueno - UPC
- Mario Rosas - ESADE
- Prasenjit Barman - ESADE

OTHER INTERESTING PROJECTS & LINKS

NEWS:

Molten-Salt Battery Freezes Energy Over a Whole Season Researchers demonstrate a low-cost, freeze-thaw battery that stores electricity for months

https://spectrum.ieee.org/long-term-energy-storage-molten-salt

The most powerful renewable energy

https://www.bbc.com/future/article/20200713-the-most-powerful-renewable-energy

Hydrogen: The Energy Storage Technology Everyone is Talking About

https://ease-storage.eu/news/hydrogen-the-energy-storage-technology-everyone-is-talking-about/

PROJECTS:

MAN MOSAS - shaping the future of renewable energy

Molten salt energy storage (MAN MOSAS) is an economical, highly flexible storage solution for a wide range of applications throughout the energy industry.

https://www.man-es.com/energy-storage/solutions/energy-storage/mosas

Tesla Powerwall

https://www.tesla.com/es_es/powerwall

Hydrogen Storage

https://seam.no/solution/hydrogen/

MATLAB CODE

```
classdef app1 < matlab.apps.AppBase

    % Properties that correspond to app components
    properties (Access = public)
        UIFigure                matlab.ui.Figure
        GridLayout              matlab.ui.container.GridLayout
        LeftPanel               matlab.ui.container.Panel
        Image                   matlab.ui.control.Image
        kwh                     matlab.ui.control.Label
        kg                      matlab.ui.control.Label
        kWhLabel                matlab.ui.control.Label
        FluigKgLabel            matlab.ui.control.Label
        FluidTypeDropDown       matlab.ui.control.DropDown
        FluidTypeDropDownLabel  matlab.ui.control.Label
        TankSizeSlider          matlab.ui.control.Slider
        TankSizeSliderLabel     matlab.ui.control.Label
        RightPanel              matlab.ui.container.Panel
        heat_graph              matlab.ui.control.UIAxes
        power_graph             matlab.ui.control.UIAxes
        UIAxes                  matlab.ui.control.UIAxes
    end

    % Properties that correspond to apps with auto-reflow
    properties (Access = private)
        onePanelWidth = 576;
    end


    properties (Access = private)
        C_esp_fl=879; %J/kg·K
        masa_fl= 1000; %kg
        radio_int=0.28; %m
        e_lanaderoca=0.40;
        e_acero=0.02;
        cond_pol = 0.16; %W/m·K
        cond_acero = 58;
        radio_tub_agua=0.05; %m
        radio_ext_tub;
        radio_ext_ais;
        longitud=3; %m
        vol_salt=0.7; %m^3
        V_tub_agua;
        V_tubos_agua;
        V_total_1;
        C_fl;
        R_term_acero;
        R_term_ais;
        R_term_total;
        thau;
        time=0:1:3600*24*3;
        densidad;
        temp_init=800;
        T;

    end


    % Callbacks that handle component events
    methods (Access = private)

        % Value changed function: TankSizeSlider
        function TankSizeSliderValueChanged(app, event)
            % Inicializar valores:
            app.radio_ext_tub = 0.28 + app.e_acero;
            app.radio_ext_ais = 0.28 + app.e_lanaderoca + app.e_acero;
            app.longitud= app.TankSizeSlider.Value;; %m
            app.vol_salt=0.7; %m^3
            app.V_tub_agua=pi*app.radio_tub_agua^2*app.longitud; %m^3

            app.V_tubos_agua=2*pi*app.radio_tub_agua^2*app.longitud; %m^3

            app.V_total_1= pi*app.radio_int*app.radio_int*app.longitud;
            app.vol_salt = app.V_total_1 - app.V_tubos_agua;
            app.masa_fl = app.vol_salt * app.densidad;

            app.C_fl=app.masa_fl*app.C_esp_fl;
            app.R_term_acero=(log(app.radio_ext_tub/app.radio_int)/(2*pi*app.cond_acero*app.longitud));
            app.R_term_ais=(log(app.radio_ext_ais/app.radio_ext_tub)/(2*pi*app.cond_pol*app.longitud));
            app.R_term_total= app.R_term_acero +app.R_term_ais;
            app.thau=app.C_fl*app.R_term_total;
            app.time=0:1:3600*24*3;
            app.T=app.temp_init*exp(-app.time/app.thau);



            r = app.radio_int;
            [X,Y,Z] = cylinder(r);
```

```
    Z = Z*app.longitud;
    surf(app.UIAxes, X,Y,Z, 'FaceColor', 'green')
    temp_ambiente=20; %ºC
    temp_inicial=800; %ºC
    temp_init=800;
    temp_final=540;
    T=temp_init*exp(-app.time/app.thau);
    Q=zeros(length(app.time),1);
    Q_ini=app.masa_fl*app.C_esp_fl*(temp_inicial-temp_ambiente); %cal
    Average_hour_consumption = 9922 /(365*24);
    for t=1:length(app.time)
        if T(t) > 540
            Q(t) = app.masa_fl*app.C_esp_fl*(T(t)-temp_init);
        else
            Q(t) = -Q_ini;
        end
    end
    ef_1=1-temp_ambiente/temp_inicial;
    ef_2=0.6; %turbina
    Q_tot=(Q+Q_ini)*0.000001163*ef_1*ef_2; %kWh
    homes = ceil((Q_tot/Average_hour_consumption)/10)*10;

    %Actualizar
    app.kg.Text = sprintf('%.2f', app.masa_fl);
    app.kwh.Text = sprintf('%.2f', Q_tot(1));
    plot(app.heat_graph, app.time/(3600*24), T)

    plot(app.power_graph,app.time/(3600*24), Q_tot);
    hold( app.power_graph, 'on' )
    plot(app.power_graph, app.time/(3600*24),homes);
    hold( app.power_graph, 'off' )
    legend(app.power_graph,{'Power available', 'Homes we can supply'});

end

% Value changed function: FluidTypeDropDown
function FluidTypeDropDownValueChanged(app, event)
    value = app.FluidTypeDropDown.Value;
    if strcmp(value, 'potassium')
        app.densidad = 2.109*1000;
        app.C_esp_fl = 757;
    elseif strcmp(value, 'sodium')
        app.densidad = 2.257*1000;
        app.C_esp_fl = 1233.10;
    elseif strcmp(value, 'calcium')
        app.densidad = 2.504*1000;
        app.C_esp_fl = 1000;
    end

    app.radio_ext_tub = 0.28 + app.e_acero;
    app.radio_ext_ais = 0.28 + app.e_lanaderoca + app.e_acero;
    app.longitud= app.TankSizeSlider.Value;; %m
    app.vol_salt=0.7; %m^3
    app.V_tub_agua=pi*app.radio_tub_agua^2*app.longitud; %m^3

    app.V_tubos_agua=2*pi*app.radio_tub_agua^2*app.longitud; %m^3

    app.V_total_1= pi*app.radio_int*app.radio_int*app.longitud;
    app.vol_salt = app.V_total_1 - app.V_tubos_agua;
    app.masa_fl = app.vol_salt * app.densidad;

    app.C_fl=app.masa_fl*app.C_esp_fl;
    app.R_term_acero=(log(app.radio_ext_tub/app.radio_int)/(2*pi*app.cond_acero*app.longitud));
    app.R_term_ais=(log(app.radio_ext_ais/app.radio_ext_tub)/(2*pi*app.cond_pol*app.longitud));
    app.R_term_total= app.R_term_acero +app.R_term_ais;
    app.thau=app.C_fl*app.R_term_total;
    app.time=0:1:3600*24*3;

    r = app.radio_int;
    [X,Y,Z] = cylinder(r);
    Z = Z*app.longitud;
    surf(app.UIAxes, X,Y,Z)
    app.kg.Text = sprintf('%.1f', app.masa_fl)


end

% Changes arrangement of the app based on UIFigure width
function updateAppLayout(app, event)
    currentFigureWidth = app.UIFigure.Position(3);
    if(currentFigureWidth <= app.onePanelWidth)
        % Change to a 2x1 grid
        app.GridLayout.RowHeight = {480, 480};
        app.GridLayout.ColumnWidth = {'1x'};
        app.RightPanel.Layout.Row = 2;
        app.RightPanel.Layout.Column = 1;
    else
        % Change to a 1x2 grid
        app.GridLayout.RowHeight = {'1x'};
```

```
                app.GridLayout.ColumnWidth = {220, '1x'};
                app.RightPanel.Layout.Row = 1;
                app.RightPanel.Layout.Column = 2;
            end
        end
    end

    % Component initialization
    methods (Access = private)

        % Create UIFigure and components
        function createComponents(app)

            % Create UIFigure and hide until all components are created
            app.UIFigure = uifigure('Visible', 'off');
            app.UIFigure.AutoResizeChildren = 'off';
            app.UIFigure.Position = [100 100 640 480];
            app.UIFigure.Name = 'MATLAB App';
            app.UIFigure.SizeChangedFcn = createCallbackFcn(app, @updateAppLayout, true);

            % Create GridLayout
            app.GridLayout = uigridlayout(app.UIFigure);
            app.GridLayout.ColumnWidth = {220, '1x'};
            app.GridLayout.RowHeight = {'1x'};
            app.GridLayout.ColumnSpacing = 0;
            app.GridLayout.RowSpacing = 0;
            app.GridLayout.Padding = [0 0 0 0];
            app.GridLayout.Scrollable = 'on';

            % Create LeftPanel
            app.LeftPanel = uipanel(app.GridLayout);
            app.LeftPanel.Layout.Row = 1;
            app.LeftPanel.Layout.Column = 1;

            % Create TankSizeSliderLabel
            app.TankSizeSliderLabel = uilabel(app.LeftPanel);
            app.TankSizeSliderLabel.HorizontalAlignment = 'right';
            app.TankSizeSliderLabel.Position = [16 256 56 22];
            app.TankSizeSliderLabel.Text = 'Tank Size';

            % Create TankSizeSlider
            app.TankSizeSlider = uislider(app.LeftPanel);
            app.TankSizeSlider.Limits = [0 10];
            app.TankSizeSlider.ValueChangedFcn = createCallbackFcn(app, @TankSizeSliderValueChanged, true);
            app.TankSizeSlider.Position = [93 265 100 3];

            % Create FluidTypeDropDownLabel
            app.FluidTypeDropDownLabel = uilabel(app.LeftPanel);
            app.FluidTypeDropDownLabel.HorizontalAlignment = 'right';
            app.FluidTypeDropDownLabel.Position = [20 296 60 22];
            app.FluidTypeDropDownLabel.Text = {'Fluid Type'; ''};

            % Create FluidTypeDropDown
            app.FluidTypeDropDown = uidropdown(app.LeftPanel);
            app.FluidTypeDropDown.Items = {'Potassium Nitrate', 'Sodium Nitrate', 'Calcium Nitrate', ''};
            app.FluidTypeDropDown.ItemsData = {'potassium', 'sodium', 'calcium', ''};
            app.FluidTypeDropDown.ValueChangedFcn = createCallbackFcn(app, @FluidTypeDropDownValueChanged, true);
            app.FluidTypeDropDown.Position = [95 296 103 22];
            app.FluidTypeDropDown.Value = 'potassium';

            % Create FluigKgLabel
            app.FluigKgLabel = uilabel(app.LeftPanel);
            app.FluigKgLabel.Position = [169 154 50 22];
            app.FluigKgLabel.Text = 'Fluig Kg';

            % Create kWhLabel
            app.kWhLabel = uilabel(app.LeftPanel);
            app.kWhLabel.Position = [170 91 30 22];
            app.kWhLabel.Text = 'kWh';

            % Create kg
            app.kg = uilabel(app.LeftPanel);
            app.kg.HorizontalAlignment = 'right';
            app.kg.FontSize = 30;
            app.kg.FontWeight = 'bold';
            app.kg.Position = [21 154 140 40];
            app.kg.Text = '1000';

            % Create kwh
            app.kwh = uilabel(app.LeftPanel);
            app.kwh.HorizontalAlignment = 'right';
            app.kwh.FontSize = 30;
            app.kwh.FontWeight = 'bold';
            app.kwh.Position = [21 91 140 40];
            app.kwh.Text = '400';

            % Create Image
            app.Image = uiimage(app.LeftPanel);
            app.Image.Position = [21 327 188 135];
```

```
            app.Image.ImageSource = 'logo.png';

            % Create RightPanel
            app.RightPanel = uipanel(app.GridLayout);
            app.RightPanel.Layout.Row = 1;
            app.RightPanel.Layout.Column = 2;

            % Create UIAxes
            app.UIAxes = uiaxes(app.RightPanel);
            title(app.UIAxes, {'Tank Size'; ''})
            xlabel(app.UIAxes, 'm')
            ylabel(app.UIAxes, 'm')
            zlabel(app.UIAxes, 'm')
            app.UIAxes.ZLim = [0 10];
            app.UIAxes.XGrid = 'on';
            app.UIAxes.YGrid = 'on';
            app.UIAxes.ZGrid = 'on';
            app.UIAxes.Position = [26 229 377 205];

            % Create power_graph
            app.power_graph = uiaxes(app.RightPanel);
            title(app.power_graph, 'Available power')
            xlabel(app.power_graph, 'Days')
            ylabel(app.power_graph, 'kWh')
            zlabel(app.power_graph, 'Z')
            app.power_graph.XLim = [0 2];
            app.power_graph.XGrid = 'on';
            app.power_graph.YGrid = 'on';
            app.power_graph.Position = [26 33 181 185];

            % Create heat_graph
            app.heat_graph = uiaxes(app.RightPanel);
            title(app.heat_graph, 'Heat Storage time')
            xlabel(app.heat_graph, {'Days'; ''})
            ylabel(app.heat_graph, 'Heat inside Vessel '
            zlabel(app.heat_graph, 'Z')
            app.heat_graph.XLim = [0 4];
            app.heat_graph.XGrid = 'on';
            app.heat_graph.YGrid = 'on';
            app.heat_graph.Position = [222 33 181 185];

            % Show the figure after all components are c
            app.UIFigure.Visible = 'on';
        end
    end

    % App creation and deletion
    methods (Access = public)

        % Construct app
        function app = app1

            % Create UIFigure and components
            createComponents(app)

            % Register the app with App Designer
            registerApp(app, app.UIFigure)

            if nargout == 0
                clear app
            end
        end

        % Code that executes before app deletion
        function delete(app)

            % Delete UIFigure when app is deleted
            delete(app.UIFigure)
        end
    end
end
```

SALT E

energy storage