Global electricity generation has grown rapidly over the last decade. This growth created many new fields for investments. Beyond any doubt, the ones that will result with most profitable outputs will be those which will bring a new perspective to contemporary problems of energy such as energy pricing, climate framework and grid stability with the growing use of renewable energy sources. According to the World Energy Issues Monitor 2015[1], these are the critical issues with high uncertainty and impact on social life. Having 5 million in my pocket, I would definitely invest my capital in a project that will take care all of the above issues while giving a new impulse to conventional energy generation methods. Electrical Energy Storage seems to be the most promising field for this purpose.

**What is Electrical Energy Storage?**

Electrical Energy Storage (EES) basically implies storing energy in a certain state to be converted back to electricity when needed. Its importance underlies in today’s world power network challenges in transmission and distribution to meet demand with unpredictable daily and seasonal variations. Technologies have been deployed to ensure that grid can meet the ever-changing energy needs—from batteries and magnetic flywheels, to pumped hydro-power and compressed air energy storage. According to market research firm IHS, the energy storage market is set to “explode” to an annual installation size 6 GW in 2017 and over 40 GW by 2022- from an initial base of only 0.34 GW installed in 2012 and 2013. [2]

**What is LAES and why did I choose LAES?**

Liquid Air Energy Storage (LAES) is one of the energy storage methods, which uses liquefied air to create a potential energy reserve. Storing air in liquid form at -196 °C, in insulated, unpressurized vessels and exposing them to ambient temperatures in case of energy needs to acquire a 700-fold expansion in volume (thanks to regasification of air) that will be used to drive a turbine and create electricity.

To liquefy air, user will use the off-peak electricity, which is much cheaper than the peak of supply electricity. Liquefied air will be stored in an insulated tank at low pressure. When the price of electricity becomes high (which we call peak-load period), liquid air will be drawn from the tank, pumped to high pressure. Exposure to ambient heat in addition to the waste heat (this one is not necessary, but lifesaving when it comes to efficiency) will result in a phase change from liquid air to a high pressure gas which will be used to drive a turbine and generator.

Examining in detail the reason why I will invest my capital in LAES is that, first of all it doesn’t have any geological constraints unlike pumped-hydro systems. If I become successful in integrating this storage technology in a certain power facility effectively, there won’t be any geographical borders
preventing this technology to broaden. Secondly, this technology uses off the shelf components with long lifetimes (since those components have proven life times and performances) which implies lower capital costs and technology risks. In addition to these advantages, there comes the most prominent feature of LAES, which is the ability to use waste heat from a co-located industrial plant or provision of cold from an existing LNG (Liquefied Natural Gas) plant. Last but not least, the fluid which will be stored and used to produce electricity is air, the fluid will be free and advantageous compared to chemical electrical storage systems such as batteries. To build up a general understanding of this technology and integration with thermal power and LNG plants, working principle is given below:

Figure 1: Liquid Air Energy Cycle

In the above figure, cold store denotes a LNG plant. Note that 1 ton of LNG approximately contains cold energy equivalent of 230 kWh [3] and unfortunately in most of the cases large amount of this energy is just thrown away. This system will take the advantage of waste cold energy while LNG is re-gasifying and will directly reduce our consumption of electricity during air liquefaction process. Waste heat coming from the co-located combined or any thermal power plant will increase the round trip efficiency (which is also called as AC/AC efficiency) of the LAES. Round trip efficiency in this case is defined as the electricity retrieved from the storage divided by the electricity consumed during the liquefaction process. Standalone LAES with no waste heat or cold gives a round trip efficiency around 60%, with the existing waste heat source, it increases up to 70%. If there is only waste cold (LNG facility) available, this efficiency can reach up to 90%. In the case of waste cold and industrial waste heat, this efficiency can reach up to 150% (efficiency larger than 100% can be misleading, but it should be noted that while calculating these values,
only electricity generated/consumed is taken into account, ie. waste heat addition is not taken as an energy input, since it's “waste”).

How the system will generate cash? Target is simple, refrigerating air when the price of electricity is low (night times, low demand) and releasing this stored energy when the price of electricity is high (peak times, highest demand). The sun side of the picture is that, its usage is not restricted to provide this main target, it has way more advantageous usage ways. I will explain those in the following party of my paper, in my case study.

-How and where LAES should be used?

Before getting into the details of the case study, remarks should be made regarding the possible locations that suits best for this LAES technology. Waste heat and cold plant complements the requirements of a LAES, maximum round-trip efficiency is achieved in the case of inclusion of waste heat and cold. Hence, the best suitable location for the LAES will be somewhere between a thermal power plant and a LNG plant, where especially feeding of liquefied natural gas into the gas distribution system takes place. Taking these into account, there is a great location in Turkey (it should not be hard to guess since there are only 2 LNG plants in Turkey), to integrate a LAES system, and this will be analyzed in a detailed manner in the case study part.

Another vital issue that needs to draw the attention of the investor at this point is the difference between electricity prices at on-demand (peak times) and off-demand (out of peak times) times. Investor should choose a region, country, where there is a bigger gap between these electricity prices to experience a shorter payback time. A good example representing this can be given by comparing Japan to Turkey. Difference between on-peak and off-peak prices of electricity is around 19.73$cents in Japan, meanwhile it is 9.03 $cents in Turkey [4, 5]. Taking this difference into account, LAES system integrated in Japan will profit two times more than the same LAES system integrated in Turkey. A table will be presented in the last part of this paper, assuming same LAES systems with same outputs and capital costs integrated in Turkey and Japan and their payback times will be compared.

Last thing to be mentioned about the integration of the LAES technology is the scalability of the system. According to the full report published by The Centre for Low Carbon Futures which is investigating the use of liquid air as an energy vector with applications in grid electricity and waste heat recovery, LAES technology is scalable up to 100 MW/400MWh [6]. Like in some of the large-scale energy businesses, increase in the capital cost makes huge impacts on the system power rating (MW) and energy capacity (MWh). Increasing investment cost by a slight amount increases energy fed into the system and storage
capacity drastically. A table showing the effect of large scale investments on payback times is presented in case study part.

**CASE STUDY:**

Figure 2: Location of the LAES plant

The aim of the investment will be to develop a pilot-project in shown region, since we have the opportunity to get waste heat from the Uni-Mar Combined Cycle Power Plant which has a generation of nominal 480 MW and the annual generation of approximately 3.6 billion kilowatt hours, and provision of cold waste of BOTAŞ LNG Terminal, which consists of 3 LNG storage tanks with a total capacity of 255,000 m³[8]. Critical parameter that makes LAES extremely advantageous is the provision of cold waste. It won’t be hard to convince BOTAŞ, since they initiated a tender in 2012, and in the scope of that tender, they wanted a project which will enable producing electricity from the cold waste of BOTAŞ [7]. Note that, in case of a disagreement with BOTAŞ, it won’t make LAES investment impossible, other technologies like solar refrigeration can come into play instead of using cold waste from a LNG facility. Uni-Mar can be convinced to provide waste heat and the pilot plant performance can be shared with them for a future collaboration.

The energy generated by using natural gas at Uni-Mar plant is sold to TETAŞ according to energy sale agreement between TETAŞ and Uni-Mar. Prices at different times of the day is given below for the period after October, 2015:
Our LAES system will charge itself between 22:00-06:00, where price of electricity is the lowest (8,37 Krş/kWh) and it will be able to discharge between 17:00-22:00, where price of electricity is maximum (34,10 Krş/kWh). With 5 million US dollar investment, this system will be able to have a power rating of 2 MW (discharge) and it will consume 0,82 MW during the charging phase [9]. Having this data, for each day we have the following profit:

Cost of Used Electricity (TL) = (0,82x1000 kW) x (8 Hours) x (8, 37 Krş/Hours) / 100 = 549 TL

Sold Electricity (TL) = (2x1000 kW) x (5 Hours) x (34, 10 Krş/Hours)/100= 3411 TL

Daily Income ($) = (3411 – 549) / 2, 85 = 1004 $

Payback Time (Years) = (5.000.000/1004)/365 = 13,6 years

Now let’s see what would happen if we have invested same amount of money for a similar LAES system in Japan to see the effect of the larger difference between electricity prices between peak and off-peak periods, following this, impact of a larger scale investment, with 60 million $ which will increase our power rating to 50 MW/250MWh (with same charge/discharge hours):

<table>
<thead>
<tr>
<th></th>
<th>Cost of Used Electricity($)</th>
<th>Sold Electricity($)</th>
<th>Daily Income($)</th>
<th>Payback Time(Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR(5M)</td>
<td>193</td>
<td>1197</td>
<td>1004</td>
<td>13,6</td>
</tr>
<tr>
<td>JAP(5M)</td>
<td>640</td>
<td>2948</td>
<td>2308</td>
<td>5,9</td>
</tr>
<tr>
<td>TR(60M)</td>
<td>4895</td>
<td>29920</td>
<td>25025</td>
<td>6,6</td>
</tr>
<tr>
<td>JAP(60M)</td>
<td>16251</td>
<td>73700</td>
<td>57449</td>
<td>2,9</td>
</tr>
</tbody>
</table>

Table 2: Comparison of investments in different regions and scales

The significant gap between payback times is resulting by the difference between on-demand and off-demand price of electricity as shown below for the investigated countries:
Electricity Prices

<table>
<thead>
<tr>
<th></th>
<th>On-Demand Price($)</th>
<th>Off-Demand Price($)</th>
<th>Difference($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR</td>
<td>0,12</td>
<td>0,03</td>
<td>0,09</td>
</tr>
<tr>
<td>JAP</td>
<td>0,29</td>
<td>0,10</td>
<td>0,20</td>
</tr>
</tbody>
</table>

Table 3: Comparison of electricity prices

As a result, LAES technology seems a promising way of energy storage and becomes much more profitable when the capital investment increases. With this 5 million $ investment between Uni-Mar plant and BOTAS LNG facility, I would be able to introduce this technology to my country and motivate power plant owners to make their plants operate more efficiently and money-winning. In my opinion, this kind of business will boost when the future deployment of LNG plants is also taken into consideration. One last note regarding the scalability, it will not just save money when you invest more; when the power rating of the LAES increased significantly, it will help power plants to meet the excess demand periods. Another advantage of employing a LAES plant with a combined power plant is to increase its power output capacity such as evaporative cooling does at hot air conditions. In addition, when demand decreases, power plants need to operate at a lower load instead of their base load, which decreases the plant efficiency. When the combined plant integrated with a LAES system, plant can work at higher load at a higher combined efficiency condition, and feed the LAES system with its excess electricity production, and LAES system will store this electricity and feed it back to the grid at the peak periods with a higher price of electricity. In this way, plant will operate efficiently for a longer period meanwhile earning more money.

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