CRYOGENIC ENERGY STORAGE

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"Be the change you seek to make in the world."
Mahatma Gandhi

"When you come to a fork in the road, take it."
Yogi Berra, USA baseball legend

INTRODUCTION

The demand for electricity drawn from the national grid varies significantly at different times of day.

The demand usually peaks in the early evening for a couple of hours after people head back home from school and work. Short lived spikes are also common after major televised sporting events, during commercial breaks and in the morning hours.

Matching the highs and lows in demand with a steady supply is a major challenge for the electric utility suppliers.

The energy companies typically top up a base supply of energy with electricity from power plants that are just switched on to cope with the peaks. The natural gas fired generators often used to feed these peaks are notoriously inefficient, expensive to run and sit idle for long periods of time which is a waste of both energy and capital resources.

A solution is a system that would store the excess energy produced by an electrical plant supplying the base demand, and use it to supply the peaks in demand as and when they happen.

Because the excess energy is stored for later use, there is less need to ramp up the output of gas fired plants whenever a peak in demand is expected, generating electricity that may never be used.

Figure 1. Cryogenic liquid nitrogen tank. Source: Wikipedia.

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The key idea in cryogenic energy storage is to use the excess electricity to run a unit producing and storing liquid nitrogen and oxygen or “cryogen.”

At times of peak demand, such as the end of the work day, the stored liquid nitrogen would be boiled off using heat from the environment and waste heat from the power plant. The hot nitrogen gas would then be used to drive a turbine or engine, generating “top up” electricity.

Meanwhile, the gasified oxygen could be fed into the power plant's combustor, where it would be mixed with natural gas before it is burned.

Mixing natural gas with pure oxygen rather than air makes the combustion process more efficient and would cut down on nitrogen oxides (NO_x) production.

This “oxy-fuel” combustion method produces a concentrated stream of carbon dioxide that can be removed easily in solid form as dry ice.

ENERGETICS

For cryogenic liquid hydrogen storage, the theoretical cooling energy expenditure is:

2.94 MJ/kg, for gas from 25 °C to 20 K
0.45 MJ/kg, for gas to liquid at 20 K
Total: 3.39 MJ/kg

However, liquefaction involves a reverse Carnot Cycle efficiency of:

$$\eta_{\text{Reverse Carnot}} = \frac{Q_{extraction}}{Q_{rejection} - Q_{extraction}} = \frac{T_2 \Delta S}{T_1 \Delta S - T_2 \Delta S} = \frac{T_2}{T_1 - T_2} \tag{1}$$

One can calculate the reverse Carnot cycle efficiency for liquefaction from T_1 = 25 °C = 25 +273 K= 298 K to T_2 = 20 K:

$$\eta_{\text{Reverse Carnot}} = \frac{20}{(25+273)-20} = \frac{20}{298-20} = \frac{20}{278} = 0.072$$

This lead to actual liquefaction energies for refrigeration of:

Refrigeration energy = $\dfrac{3.39}{\eta_{\text{Reverse Carnot}}} = \dfrac{3.39}{0.072} = 47.08\, MJ/kg$ for gas to liquid at 20 K

The vaporization and warmup energy is 3.39 MJ/kg.

Thus the total energy expenditure is: 47.08+3.39 = 50.47 MJ/kg

DISCUSSION

Using such an integrated system, the amount of fuel needed to supply peak demand is estimated to be cut by 50 percent.

Greenhouse gas emissions would be lower due to the greatly reduced nitrogen oxide emissions and the capture of carbon dioxide gas in solid form for storage.

Research on such a system is being conducted at the University of Leeds and the Chinese Academy of Science.

Theoretically, the efficiency gains are substantial, and the system needs to be tested in practice.