Caiazza Comment Renewable Energy Systems and the Second Law of Thermodynamics

Summary
The Integration Analysis and the Draft Scoping Plan zero-emissions electric grid transition plan depend on a long-duration, dispatchable, and emission-free resource that does not exist. This comment explains why there are reasons to believe that a commercially viable and affordable resource like this may never be developed. I conclude that the Final Scoping Plan must include a conditional implementation schedule based on the availability of this resource.

Reliability Concerns
My primary concern with the Draft Scoping Plan is the lack of emphasis on reliability issues related to the integration of large amounts of intermittent energy from wind and solar. It is disconcerting that some members of the Council stated that concerns about reliability with a 100% renewable grid were mis-information at the May 26, 2022 Climate Action Council meeting. This directly contradicts the experts who authored the New York Independent System Operator (NYISO) Power Trends 2022 report that notes: "Long-duration, dispatchable, and emission-free resources will be necessary to maintain reliability and meet the objectives of the CLCPA. Resources with this combination of attributes are not commercially available at this time but will be critical to future grid reliability."

The presumption in the Draft Scoping Plan is that this long-duration, dispatchable, and emissions-free resource will be available in the time-frame needed to meet the Climate Act targets. This comment raises the concern that this kind of resource may not ever be a viable resource for ensuring reliability.

Second Law of Thermodynamics and Renewable Technology
Although I wanted to make a comment about this concern for some time, I would have had to do a lot of research to develop the comment. Fortunately, I found a reference article (Addendum 1) by Kevin Kilty that makes the points better than I could. He has taught engineering thermodynamics for twenty years and his article about energy storage raises some fundamental issues vis-à-vis the feasibility of the energy storage necessary for a reliable zero-emissions electric grid:

> Whenever I read about some new or improved scheme to store energy, I ponder two things about it. These are two ubiquitous Achilles heels: 1) What limitations does the second law of thermodynamics place on it, and 2) what are the other constraints that would limit its usefulness in a system? I focus on the second law because the first law just refers to conservation of energy itself, and this is not where most limitations on the use of energy, or in fact limitations on any human activity, come from.

He explains that any energy storage system must lose energy as it is stored and then again as it comes out of storage. This limits the viability of every storage system. He goes on to explain that there are system issues that further limit specific technological availability. For example, pumped storage hydro is a proven technology but it requires specific terrain characteristics.

One of the points I wanted to include in my comments on the electric system is the importance of storage to cover intermittency on different time scales. Kilty explains this issue well:

> One of the most serious systems problems for renewable energy to solve is the various time-scales of response required to make a reliable grid. There is first the very short time scale of fractions of a second needed for automatic control systems to keep frequency and voltage within prescribed limits. Next there is a daily time scale of response needed to handle the daily variations in load. Following this is an unknown amount of storage to handle outages resulting from weather that may last for 10 days or more. Finally, there is the issue of seasonal shifting of energy supply which requires either a large overbuilding of generation or massive long-term storage, or some hybrid in between.

The present grid has evolved over time to address these problems:

> The present grid handles the very short time scale problem by relying on the rotational KE of its turbomachinery which stores several seconds worth of demand in spinning mass. All other time-scales are covered by using stored fossil fuels on site right up to 95% capacity factor of the plant. It is not overly complex and we have nearly a century of systems engineering experience making this system 99.9% or more reliable.

In theory and as presumed in the Draft Scoping Plan there are potential solutions. However, Kilty explains that technical and logistical concerns with those solutions:

> Wind plants have very little rotational energy to aid in the very short time scale stability issue and solar has none. One remedy is to add "synchronous condensers" into a renewables grid to act as an analog to the rotating turbomachinery of thermal plants. These solutions are parasitic which only consume energy in exchange for short term stability. Solutions to the longer-term system problems rely on cascading elements of diverse energy storage and conversion schemes that require lots of mass, lots of ground space, exotic materials, transmission utilities, embodied energy, excess generating capacity, and so forth. Not only are such elements unproven themselves, but we have zero systems engineering experience with them. Could they be made to work? Who knows? Have a look at their heels.

Conclusion

I conclude that the Final Scoping Plan has to address this issue. I believe that the Climate Action Council should develop criteria for schedule implementation that includes a technology viability component. The New York Independent System Operator and New York State Reliability Council should work with the Council to develop this metric for long-duration, dispatchable, and emission-free resource implementation. The first component of the metric should be a criterion for when the electric grid distribution of intermittent resources will require this resource to be available for use. I imagine that would be some fraction of wind and solar generating capacity or energy of the total resources available. The second component would be an acceptability criterion that ensures that the solution will work as advertised.

This is necessary because there is a reliability condition in New York Public Service Law § 66-p. "Establishment of a renewable energy program": "(4) The commission may temporarily suspend or modify the obligations under such program provided that the commission, after conducting a hearing as provided in section twenty of this chapter, makes a finding that the program impedes the provision of safe and adequate electric service; the program is likely to impair existing obligations and agreements; and/or that there is a significant increase in arrears or service disconnections that the commission determines is related to the program". If this necessary resource is not available then the implementation schedule has to be put on hold until the resource is ready to be deployed. Failure to do so will risk blackouts.

The bottom line is that a collective crossing of fingers that a new technology will maintain existing standards of reliability and affordability is inappropriate. The Climate Action Council must ensure that the Final Scoping Plan recommends deployment of this untested technology only if pre-established milestones and conditions are met.

I prepared this comment because I believe that the presumption that a dispatchable, emissions-free resource will be available for the transition to a zero-emissions grid may not be accurate. I have written extensively on implementation of the Climate Act because I believe the ambitions for a zero-emissions economy outstrip available renewable technology such that it will adversely affect reliability and affordability, risk safety, affect lifestyles, will have worse impacts on the environment than the purported effects of climate change in New York, and cannot measurably affect global warming when implemented. The opinions expressed in this document do not reflect the position of any of my previous employers or any other company I have been associated with, these comments are mine alone.

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Systems and the Second Law

Kevin Kilty

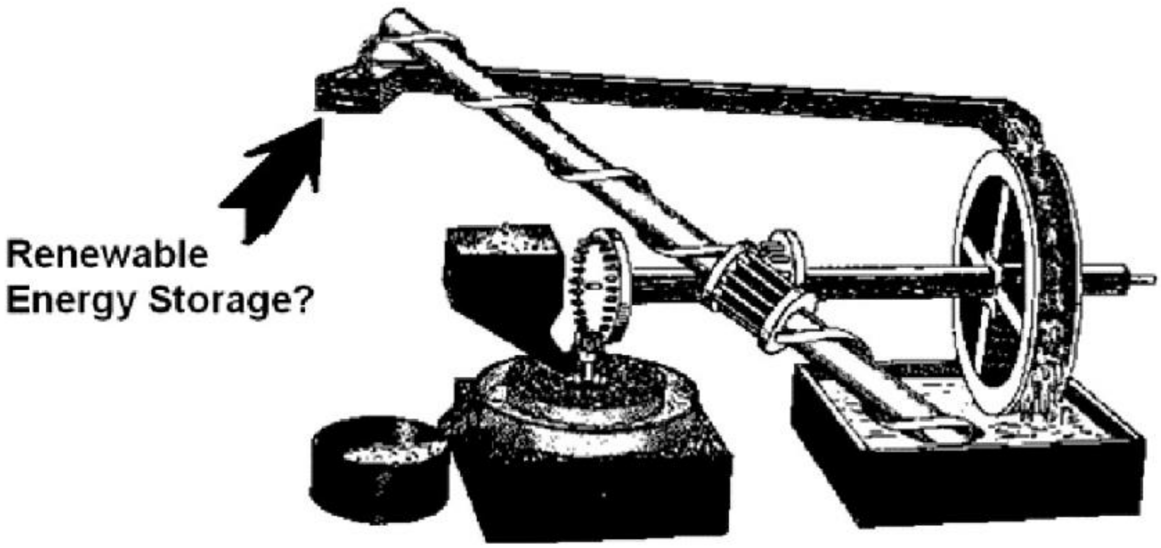

Figure 1. Robert Fludd's perpetual motion machine has no energy source and far too little storage.

Over the past few days, I have been catching up on some reading in the scientific literature that shows up routinely in my mailbox or inbox. A surprising amount lately has been about energy storage. It appears that the storage problem is becoming almost universally recognized, but as is usual, not universally understood. When I read a paper filled with enthusiasm about some new breakthrough, the description is always limited to a very narrow technical discussion about how this particular idea works. It does not go into the details about how such a device would fit into a workable system. It is to little avail if a new technology comes with new burdens placed on the system in which it must work – this is one flaw of so-called renewables within the grid. They may add energy to a delivery network, but they can't be dispatched arbitrarily, and contribute little to voltage/frequency support. They place the burden of ancillary services on other parts of the system.

Two Achilles heels

Whenever I read about some new or improved scheme to store energy, I ponder two things about it. These are two ubiquitous Achilles heels: 1) What limitations does the second law of thermodynamics place on it, and 2) what are the other constraints that would limit its usefulness in a system? I focus on the second law because the first law just refers to conservation of energy itself, and this is not where most limitations on the use of energy, or in fact limitations on any human activity, come from.[1]

Some definitions

Losses on energy to work conversion imposed by the second law are called irreversibilities, or an even fancier term is "destruction of exergy". What this means is that some energy converted in a system doesn't contribute to useful work. Useful work is always and everywhere the goal. So, things that contribute to this problem include: 1) that heat can't be converted 100% into work; 2) chemical reactions cannot be made to go to completion and lead to some amount disordered materials; 3) that high temperatures contribute to heat flow into the dead state [2], or as Willis Eschenbach terms them, to parasitic losses; 4) high pressures contribute to loss of the mechanical energy used to produce high pressure in the first place. This work also heads to the dead state; 5) long chains of conversion with little losses at each step; and 6) fast rates of conversion. Be aware of these problems.

Systems issues include: 1) inadequate amounts of critical materials; 2) inadequate available terrain; 3) resources in the wrong places that require long distance transport; 4) demands for impossible slew rates (problems with time constants); 5) weight and volume constraints; 6) impossible demands of time span and huge demands for mass per unit of stored energy; and, 7) complexity.[3] Table 1 shows general examples.

Table 1.

General physical category of energy storage	Examples	Systems or second law constraints.
Kinetic energy (KE)	Rotating KE of the turbo-machinery in a thermal power plant	As mechanical energy it is 100% available, but is subject to varying amounts of friction. Severe systems constraints particularly duration.
Mechanical Potential energy (PE)	Pumped Hydro. Raising massive blocks.	As mechanical energy it is 100% available, but has frictional losses. Many systems constraints, mainly with regard to mass/terrain.
Thermal Energy	Molten salt reservoirs, hot rocks, glowing hot metals, etc.	Availability constraints following directly from the second law. Excessive materials demands. Parasitic losses.
Chemical Energy[4]	Batteries. Hydrogen or hydrogen carriers like ammonia.	Many second law constraints from chemical equilibrium and the production of disordered products. Many systems constraints, such as exotic material.

Recent Examples

Let's examine a couple of examples from my recent readings. How to power aircraft is a genuine problem to solve for advocates of renewable energy mainly because they like to fly places free of guilt. The December 2020 issue of Physics Today included an article on using hydrogen to power aircraft.[4] The systems problems with hydrogen as a fuel begin with means to produce the hydrogen in the first place, storing it, transporting it, and so on. Yet, just assuming an available hydrogen supply, aircraft are also weight and volume constrained. One reader of this Physics today article [5] wrote in to explain that through a constraint on available volume aircraft using hydrogen are limited to short hauls. So short in fact, that we would return to the air transport system of the 1930s.

The September 2021 issue of Physics Today included an article that began thusly,

> "Experts say lithium-ion batteries will be overtaken for grid-scale energy storage applications by other battery technologies and nonchemical storage."

Experts say otherwise. One odd assertion in this article is that hydrogen is a non-chemical form of storage. As there are no sources of hydrogen, chemistry is central to its production and use.[6] More revealing still is the artist's rendering of a solar farm coupled to a gravity storage system like that proposed by Energy Vault(™). The storage facility is a tiny building four stories high that looks more appropriate to administrative offices. It wouldn't store but a few moments worth of energy. There seems to be little recognition of the materials handling problems to make raised mass storage feasible as I outlined here some time ago. There are constraints on slew rate of schemes that raise massive blocks into a pile of stored energy, or pull rail cars upslope. Pumped hydro is a better method of storing potential energy, but in this case the systems limitation is the lack of available terrain and issues over water use.[7]

Recently the "Science Magazine Table of Contents" came into my email inbox which allowed me access to a brief summary about thermal energy storage.[8] Thermal systems of energy storage suffer ubiquitously from second law limitations about converting heat into work. They all involve taking valuable work and turning it into heat, which then is turned back into useful work at the typical 35-40% efficiency of a thermal power plant. There are long chains of conversion involved.

This article was broadcasting a recent improvement in thermophotovoltaic (TPV) devices which could absorb the broad thermal spectrum of radiation from a hot mass of material at nearly 2,700K, heated so by renewable energy, and turn this back into electrical energy. Yet, the efficiency indicated here is only about 40%, which is the same efficiency that a conventional thermal plant operating at far lower temperature can provide. As high temperatures lead to increasingly larger parasitic losses, high temperature storage of energy as heat has a problem with not only the second law, but also with any system requiring long duration storage. Unavoidable parasitic loss accumulates into a huge total energy loss which has to be made up with generating facilities. Secondary storage batteries have this same problem.

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The present grid handles the very short time scale problem by relying on the rotational KE of its turbomachinery which stores several seconds worth of demand in spinning mass.[9] All other time-scales are covered by using stored fossil fuels on site right up to 95% capacity factor of the plant. It is not overly complex and we have nearly a century of systems engineering experience making this system 99.9% or more reliable.

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References:

1. I have taught engineering thermodynamics for twenty years. I find the first law of thermodynamics is relatively easy to understand even if people have some difficulty applying it. However, the second law is far more difficult for people, even chemists, physicists and engineers, to fully fathom. I am still learning about applying parts of it after five decades of use. It is entirely in control of all processes of energy use. It runs the universe. Since energy costs money to convert and deliver, the second law even controls the expense of activities that people wouldn't think of as related to thermodynamics. I think it even covers the zeroth and third laws of thermodynamics. Thus, while the best textbook on Thermodynamics, Zemansky's Heat and Thermodynamics calls friction a third-law issue, I think it more correctly belongs to the second law.
2. Dead state is an engineering concept. It is a physical state where despite being full of apparent energy, has none that can be used to do work. We usually consider the dead state to be a temperature of 288K, a pressure of one atmosphere, an electrical potential of Earth ground, chemical species in equilibrium at minimum Gibbs free energy, and a relative humidity of 100% saturation.
3. Owning two VW Beetles, I am familiar with the characteristics of German engineers, which is to make complicated designs work. The rest of us aim for simplicity.
4. David Kramer, Hydrogen-powered aircraft may be getting a lift, Physics Today, 73, 12, 27 (2020); doi: 10.1063/PT.3.4632
5. Peter Rez, Hydrogen as an aviation fuel, Physics Today, Readers Forum, September 2021, p. 11. While Mr. Rez contemplates hydrogen used in fuel cells to run a turbofan or turboprop sort of aircraft, hydrogen could be used as a combustion fuel. Yet this would involve the second-law constraints of turning heat into work, along with all the other mass, volume, and complexity constraints of hydrogen. In particular hydrogen possesses a lot of energy per unit mass, but a unit mass takes a lot of volume. It makes little sense to go this route.
6. David Kramer, Better ways to store energy are needed to attain Biden's carbon-free grid, Physics Today, September 2021, p. 20. Biden's?
7. Not only are the best places for pumped hydro already being put to use, but legal battles over water ownership and usage limit it even more.
8. Robert F. Service, Thermal Batteries could efficiently store wind and solar energy in a renewable grid, Science, Vol 376, Issue 6590, online version 13 April 2022. doi: 10.1126/science.abq5215