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Pollman, Anthony G.; Gannon, Anthony J.

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MULTI-PHYSICS ENERGY APPROACH & DEMONSTRATION FACILITY

Anthony G. Pollman & Anthony J. Gannon
Naval Postgraduate School, 700 Dyer Rd, MAE Dept
Monterey, California, United States of America

ABSTRACT

A methodology to investigate the generation, transport and storage of energy based on a multi-physics approach, tied to the end use application, is presented. Often little or no consideration is given to the end use or desired product of the energy used. Current energy generation, transport and storage are dominated heavily by a few large sectors, notably electricity and hydrocarbons. These are very effective and practical systems that facilitate the delivery of vast amounts of energy. It is then not surprising that most strategies for renewable energy generation and storage revolve around this centralized model in some way. In larger scale generation, power is usually fed onto the electrical grid with a current challenge being grid stabilization with increasing penetration of intermittent renewable resources. In small grid-independent system a mix of battery and hydrocarbon storage are often used to keep a micro-grid available for various end use applications.

A paradigm shift in the thinking and design of energy systems based on the required end use or product is needed. The philosophy and motivation that lead to the consideration of this new approach are outlined in this article. Following this a summary of a methodical approach to developing the most energy and cost-effective solution to general processes by considering their end-use physics is presented. Examples of innovative energy generation, storage, and transport solutions based on the multi-physics approach are then outlined. Finally, a brief description of the Multi-physics Renewable Energy Lab (MPREL), a demonstration facility based on the approach and currently under construction at the Naval Postgraduate School, is given.

INTRODUCTION

Energy, its availability and cost are arguably some of the most important drivers of our modern economy. Persistent high oil prices and increasing concern about the effects of the use of non-renewable energy on the environment have focused attention on increasing energy availability and security, lowering its cost and reducing its environmental impact during generation and use. Researchers are focused on many areas of this challenging problem but it is suggested here that consideration of the end service or product should be given more attention.

The current approach

Renewable resources have the potential to generate large amounts of energy but the intermittency of these resources is a well-known shortfall of these technologies. Depending on the scale of the renewable resource various strategies to overcome this intermittency are used. Energy efficiency and improving residential and industrial processes is also receiving much attention as this directly affects the costs and profits of consumers and companies respectively. In each of these examples the research is often done is isolation from other areas of the energy sector. There is merit to this approach as it allows for focused and optimized solution to specific problems.

The disadvantage of this approach to these problems is that the solutions are steered by the current approaches to energy that have been developed over many decades.

The proposed approach

The approach that this study proposes is based on the following assumption:

In order to effectively start to tackle the problem of energy generation, storage and transport, the end application of the energy should be used as the starting point in designing systems and making best use of the vast array of new technologies becoming available.

This study begins with a very simply overview of the current organization of the energy infrastructure will be used as a starting point as to look at how it influences the current approach to energy technology development. Following this a breakdown of energy usage within the United States of America which is used a justification for the proposed approach. A method to develop energy systems based on the desired end use is then proposed with some examples of how is it sometimes used in practice. Finally the core of the experimental facility that will be used to investigate the performance of individual systems based on this approach will be presented. The laboratory architecture is being developed to be flexible and tackle real world large users of energy starting with cooling and heating.

Motivation

The question must be asked; why is a shift in approach to energy required? As mentioned it is the authors' opinion that may decades of dominance of hydrocarbons and electricity for the distribution of electricity has led to a narrow view of energy and thus a narrow view of how we should move forward in lowering our energy costs and improving our energy security. Some examples are used to illustrate the point.

In the area of electricity many renewable projects are concerned with how they will connect to the grid. This leads to concerns as to how the grid will deal with these supplies and what technologies can be attached to the grid to store and resupply electricity to make intermittent renewable supplies useable. In certain processes such as heating or electrolysis, power from photovoltaic panels could be used directly. This would require a simple DC-to-DC (direct current) inverter without any connection or phasing to the grid. Searches for inverters that have maximum power point tracking (MPPT) input and a simple constant current constant voltage (CCCV) output are only available as demonstration units of typically 50 W or less [REF]. Larger power types are common but only supply power above a certain voltage as this is typically what a battery requires for charging or what a DC-to-AC (alternating current) inverter require [REF]. Generally reducing the number of energy conversions is preferable as this increases efficiency but it is felt that a focus on the end use could lead to even greater improvements in energy generation, storage and transport.

Historically the end-use of energy approach has been used. Early wind-turbines used direct shaft power to do work to grind grain or pump water [REF]. The authors are in no way advocating a return to such technologies but perhaps a combination of such thinking combined with modern technology could be of use in reducing the cost and impact of energy generation and use.

THE MODERN ENERGY INFRASTRUCTURE

In the United States, centrally-generated electricity is more or less synonymous with energy – the two are almost inseparable. This close association is a relic of the industrial age, when electricity first came into widespread use. Naturally, generation required a great deal of technical know-how. Also, there was a need for a high degree of standardization and economies of scale to make electricity safe, profitable, and reliable, and to pave the way for its acceptance and eventual widespread use. The industrial base, with their large factories and enormous energy requirements, adopted electricity to satisfy their energy needs. In addition, certain key scientific and technical breakthroughs, that would make decentralized generation practical, had not yet occurred. These forces (and undoubtedly many more) forever fused electricity and energy in the collective public psyche, and made large-scale, centrally-generated electricity the default approach. Today, with so much inertia and capital investment, the approach and mindset persist.

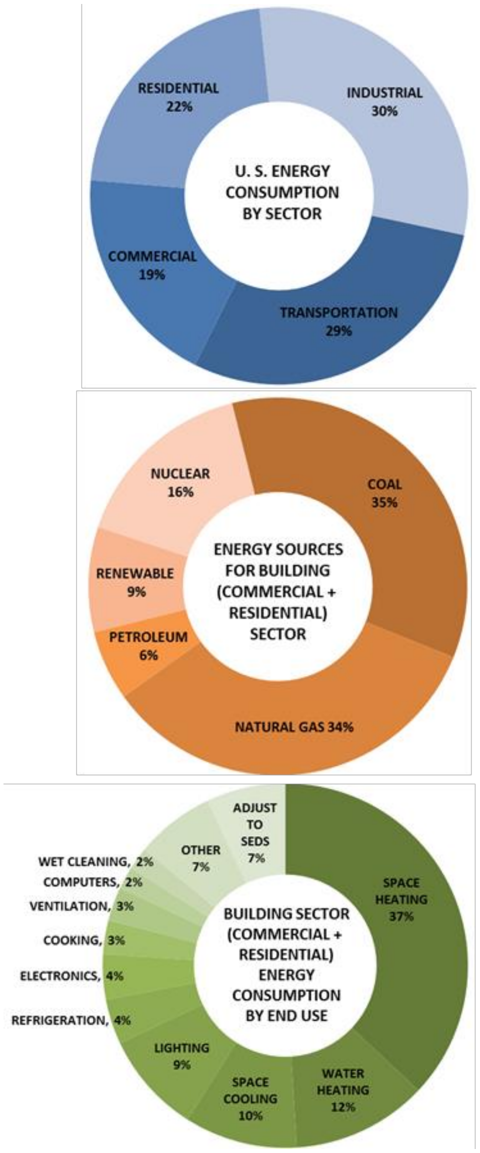

Figure 1. Department of Energy Consumption, Sources and End-Use Data [1].

Figure 1 summarizes Department of Energy [1] consumption, source, and end-use data for the United States in 2011. This figure is intended to provide motivation for the end-use approach being outlined. The building sector (the combination of the commercial and residential sectors) accounts for 41% of all energy used. Space heating, space cooling and water heating account for a full 59% of total energy demand for this sector. These applications are generally satisfied using electricity (from centralized coal, natural gas, petroleum, or nuclear power plants) or natural gas (for heating applications). Renewables account for about 9% of the total energy consumed by the building sector, and include centralized hydro-electric power generation as well as multi-scale wind and solar.

ENERGY EFFICIENCY AT THE MARGINS

Renewables (solar and wind, excluding hydro-electric for this paper) lack sufficient energy density to serve as a practical primary energy source for the industrial sector in its current clustered form. Unless factories were built adjoining custom renewable energy farms the current energy generation density is not sufficient. And, without substantial investment in infrastructure (as well as cultural changes), renewables arguably have little hope of altering fossil fuel dominance of the transportation sector. However, it is reasonable to believe that renewables can make marginal gains in the residential and commercial building sector, particularly in space/water heating/cooling applications with current technologies. Yet, in order to help renewables realize their full potential for these (and other) applications in the areas of heavy energy use, we must modify the way we think about energy and power generation.

In business circles, "distributed power generation" is recognized as a potential disruptive technology to the established central power generation approach [2]. In addition, the Institute for Electrical and Electronic Engineers (IEEE) has established standards for micro-grids, which it terms "distributed resources" [3], a key step to the disciplined advancement of renewable energy and other technologies associated with micro-grids. Barring a technological revolution, a promising way to realize future efficiency is to decouple energy from electricity and hydrocarbon fuels through a multi-physics approach to design, and then look for evolutionary efficiency gains at the margins. In doing so, it is likely that novel solutions to renewable intermittency will also emerge.

A MULTI-PHYSICS APPROACH TO ENERGY GENERATION, TRANSPORT, AND STORAGE

The multi-physics approach to energy storage is a methodology that suggests design alternatives based on first principles and consideration of what the end-use of the energy will be. Rather than associating energy with electricity or hydrocarbons by default, the approach simply requires consideration of different energy generation, storage or transfer methods, based on all available physical phenomena. Employing such an approach frees an engineer from the electricity and hydrocarbon-centric, default attitude toward energy in order to find efficiency gains in the margins. By thinking about each problem or system design in terms the final desired service or product, the approach suggests potential new ways to mitigate intermittency, decrease battery size, or address other shortfalls/trade-offs/detractors associated with renewable energy or just reducing energy use. It also suggests novel alternative concepts like matching peak generation capacity, rather than demand load matching or stabilization (this topic is being addressed for specific applications separately).

There is nothing necessarily novel about a multi-physics approach; it is simply a way of thinking or approaching energy problems. The approach is based in the fundamentals. As such, it is appropriate to summarize the fundamentals before introducing the approach and implementation strategy formally.

In broad classic physical terms, the energy associated with the state of an object or system can be categorized into 3 major categories: kinetic, potential, or radiant energy. Kinetic energy is energy associated with the state of motion of an object. Potential energy is energy associated with the arrangement of a system of objects that exert forces on one another. Radiant energy is energy associated with light and other forms of electromagnetic radiation. All other forms of energy are subsets of these. For example, gravitation, electric/magnetic, chemical, nuclear, and elastic energy are all subsets of potential energy. Thermal or internal energy is the combination of both potential and kinetic energies.

Naturally, all available energy generation, transport, and storage mechanisms are linked to these fundamental energy types as well. The following paragraphs briefly outline energy generation, transport, storage and systems examples that apply to renewable or alternative systems. These examples are meant to highlight the broad range of novel approaches that a general, multi-physics approach enables and build an appreciation for the approach. Specific examples will also serve to substantiate the validity of the multi-physics approach and implementation strategy outlined follow later.

IMPLEMENTATION STRATEGY

Utilizing multi-physics energy storage methods requires a modified approach to the design of an energy system for a particular application. A house, office, factory or manufacturing plant will have vastly differing energy needs and thus different systems would be suited to each. A structured approach to tackling this problem is summarized as follows;

1. **Energy demands:** Starting with the largest, list the major energy demands of the system.
2. **Reduce demand:** First research if any technologies are available to reduce the demand for each and modify step 1 if required.
3. **Classification:** Attempt to classify the physical mechanism used for each process e.g. heating, cooling, gas compression etc.
4. **Power and Energy:** Quantify the energy demands (Joules) and power demands (Watts) of each. This affects sizing.
5. **Generation:** Identify suitable energy sources, including renewables for each energy demand.
6. **Transport:** Identify suitable energy transport methods.
7. **Storage:** Identify suitable energy storage methods.
8. **Safety and Practicality:** Consider the safe and practical implementation of each supply, transport or storage method.
9. **Lifecycle Costs:** Calculate cost taking into account cycle life.

The steps outlined above are ordered in such a way that all known method of energy generation, transport and storage should be considered for each demand. It is assumed that the largest energy demands will be the most costly but there may be exceptions to this and it is expected that the above steps be implemented in coordination with a person knowledgeable in a particular process. Steps 5-7, generation, storage and transport will often have to be considered together. Each step of the strategy, its motivation and examples are given to better illustrate the implementation.

1. Energy demands: A useful first step is to identify the energy demands of a building or process. Figure 1 is a good example of this as applied to a representative commercial or residential building. In a factory or manufacturing process setting this chart would vary greatly depending on the process.

2. Reduce demands: Once the high energy use processes have been identified the first task should be to identify technologies that will reduce the energy demand. In industrial processes this approach is common but not rigorous; a well-placed heat exchanger may allow waste heat to be recovered to reduce the overall heat demand. This often obvious but mundane step is often omitted, for example, rather than choosing to increase cooling or heating capacity it may be cheaper to improve insulation.

3. Classification: Without consideration to the traditional way of achieving an end-use goal the physics of the process must be identified. While gas or electricity are common methods of space heating and an evaporation refrigeration cycle is a common method for cooling, heat addition or removal is the physical process desired. This classification is important for all the following steps and can lead to consideration of integrated systems for generation and storage.

4. Power and Energy: The total amount of energy required and the power level required is crucial. This affects the methods of transport and storage as well as the sizing of the system. Depending on the space available this may be a deciding factor. Phase change ice thermal-storage is an example where large amounts of thermal storage are possible but the rate of heat transfer can be low when using plastic freezing tubes compared to metal [4].

5. Generation: By considering the desired end-use, consider any methods of generation and suitable sources of power for these. For cooling this could be a classical chiller but all options should be considered; waste heat from a gas turbine or concentrated solar can drive an absorption chiller. A Brayton type cooling cycle with a high pressure tank after the heat exchanger may allow for cooling with storage.

6. Transport: Electricity is an extremely effective energy transport medium; however for many applications other methods may have advantages. Consider forced-air heating in more modern houses, a single natural gas burner is required to heat many different spaces through using piped hot air to transport the heat. This lowers capital costs as only one heating unit is required. Other methods of energy transport may be more cost effective than incumbent methods and should always be investigated.

7. Storage: A major shortcoming of renewable energy is its intermittency. At present this is limiting its penetration into the grid and making batteries and generators the backup of choice in off-grid systems that are renewably powered. By considering other types of energy storage the size of battery and generator backup can be reduced for off-grid system. In grid tied system, on-site renewable power can either be stored locally or power can be purchased when rates are low. Heating and cooling are two large energy users that have commercially available thermal storage methods available. Their cycle life tends to be much greater than batteries on the order of 10+ years.

8. Safety and Practicality: Considerations of the safety and ease of practical implementation of a new generation, transport or storage method must be considered. This must be balanced against institutional resistance to incumbent methods. Aside from batteries many energy storage methods require little maintenance for long periods but something like a high-pressure air storage system requires routine inspections for safe operation.

9. Lifecycle Costs: The overall cost of the system must be considered including the maintenance and life of the system. Energy storage systems vary widely in their cycle lives. Water phase change systems typically last for decades [5] and are not damaged when completely melted. This contrasts to batteries which must be monitored to not be completely drained to avoid damaging them. In this study cost considerations has purposely been left until the last step. This is to ensure that as many possibilities as possible are considered and that these approached should first be considered or discarded for technical reasons.

The above steps are meant to be a generalized, rigorous approach to reducing the cost and increasing the energy security of a building or industrial process. Once it has been applied once to a particular application or process, then a more targeted and efficient method can be developed for that particular situation.

Generation examples

The following examples highlight the benefits of applying the multi-physics approach to generate energy for various end uses. In particular, sometimes it is possible to find generation sources in things that are frequently considered waste. Although in many of these cases the solution is obvious (particularly in hindsight), in other cases solutions may not be forthcoming. The challenge is to change the way we think about energy and waste, apply a multi-physics approach, and thereby identify possible solutions and efficiencies in more difficult problems.

Bagasse: Bagasse is a by-product of sugar production. It is the fibrous residue remaining after the sugarcane stalk has been crushed and the juice removed. Bagasse is commonly used as a fuel, as pulp for paper production, as structural material, and for agricultural purposes. Some research has also been performed to investigate its suitability as a protein replacement source for humans [6]. Other researchers have used it for treatment of groundwater [7].

Of particular note, bagasse is used as the only fuel source in the sugar-alcohol industry in Brazil. At one time, electricity was required to process the raw cane into sugar. Now, almost without exception, bagasse is burned to generate heat to dry the sugar and produce electricity to run the mill. In addition, surplus power is sold to the grid [9] thereby boosting profitability. Much work has been done to optimize (to include making burning more environmentally friendly) and fully utilize what was once considered waste [10]-[11]. By thinking about the entire process and taking a multi-physics approach, this particular sector has changed from an electrical energy user to provider.

Direct/indirect solar thermal heating: Socrates is credited with saying, "Now, supposing a house to have a southern aspect, sunshine during the winter will steal in under the verandah, but in the summer, when the sun traverses a path right over our heads, the roof will afford agreeable shade, will it not?"[14]. Direct solar thermal heating occurs when water, an enclosed space, or a thermal mass such as brick wall is heated by incident solar radiation. Indirect solar thermal heating occurs when a closed loop heat exchanger is used as an intermediary. A greenhouse is an excellent example of direct solar thermal heating in practice. The end use or desired state is a heated room. Instead of using electricity to warm the greenhouse, the building is constructed with the end state in mind and solar radiance provides the majority of the heat needed. A thermal mass, such as a brick wall, is another interesting example. During the day, the brick wall is heated by the sun. At night, the wall releases the energy into the surrounding room, reducing the need for other heating sources. If properly designed and integrated into a well-insulated passive solar building, this type of design feature can virtually eliminate the need for further comfort heat generation in many parts of the world [12]. Direct solar heating is also a viable option for heating water for home or other uses [12]. High-entropy energy, such as solar radiation, is an acceptable source for comfort heating in general, where lower-entropy energy is really not required and better suited to the task. Yet in spite of being high-entropy energy, solar radiation can be concentrated, with mirrors or lens, to perform energy intensive tasks such as desalination or perform other thermodynamic cycles to do useful work [12]-[13].

Joules calorimetric heating: Fluids can be heated by direct agitation such as in a Joules calorimeter. Such a device could be directly coupled to a wind turbine using air as the working fluid, resulting in a very simple heating system. Figure 2 shows such a device.

Direct ambient heat rejection: While heat from ambient rejection is often considered little more than high-entropy waste, if your goal is to heat the passenger compartment of a vehicle, ambient rejection may be considered a source. Although in this example the solution is obvious, in other cases it may not be.

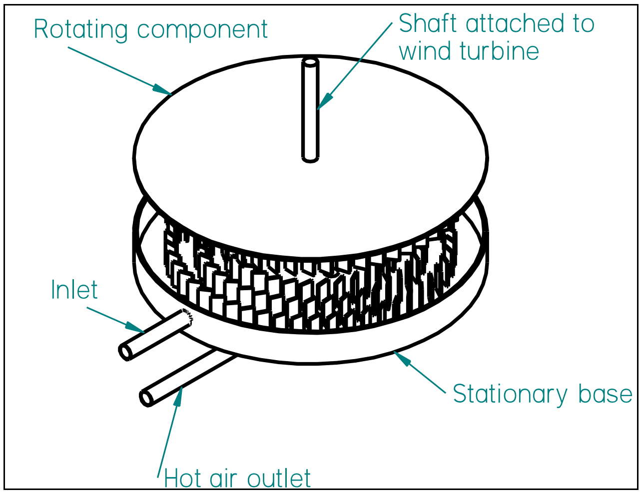

Figure 2. Direct heating using shaft power.

On-site electric generation: On-site electric generation is a rather common approach to alternative energy generation due to relatively simple implementation and integration with existing, commercially-available equipment and systems. On-site electric generation can be accomplished in a number of different ways, depending on available resources. Photovoltaic, wind turbines, wave generators, & water wheels are all examples of common on-site generation equipment. On-site electric generation systems can be either grid-tied or stand alone. Grid-tied systems are commonly called distributed resources [3]. Stand-alone systems are generally called micro-grids.

Transport examples

A multi-physics approach may also be applied to energy transport problems, and can identify potential solutions or novel efficiency gains.

Forced air heating: This example was mentioned previously but bears expansion. It greatly simplifies heating systems by isolating the hazardous part of the system to one place, often outside of the structure. The transport of the energy uses air as a working fluid. Thus even small leaks, while lowering efficiency do not stop the system working or make it dangerous. Contrast this with domestic electrical systems where damaged insulation can be extremely hazardous.

Fluid heat transport: The transport of heat using liquids is common in the field of chemical engineering and through the use of industrial heat exchangers. In the food preparation industry, waste heat from the cooking process is often used to pre-heat the ingredients through the use of heat-exchangers.

Direct Current: In the case of a remote outpost or hybrid solar/generator backup electrical system it may be prudent to switch to a high voltage direct current (DC) microgrid. There is less complexity within the system and for applications where high-quality alternating current (AC) is needed a local DC-to-AC inverter can be used.

Storage examples

While remaining ever cognizant of the end-use, a multi-physics approach may also be applied to energy storage problems, in order to identify innovative solutions, appreciate the problem, or gain efficiency. Multi-physics energy storage boasts many mature technologies, some of them mentioned briefly here. It is the opinion of this study that they hold great potential to be integrated into energy systems to make more use of renewables or dramatically improve the energy efficiency of existing systems.

Batteries: These are the most commonly thought of electrical energy storage systems. Where high energy density without the use an engine to convert hydrocarbons to electricity is required these are most effective. Due to their ease of use they are often used in situations where other technologies may be better suited.

Super-capacitors: Recent advances in capacitor technology have led to devices that while only having 1/10 of the energy density of a lithium-ion battery they have about 10 times the power density [15] and cycle lives or over 1 million. Where short bursts of power are required these are often a better solution to batteries. A successful test of converting a hybrid car from using a battery to super-capacitor has been completed by the National Renewable Energy Laboratory [16]. Hybrid generator/renewable backup systems may be better operated using these than batteries.

Phase change: For heating and cooling application these technologies are already used. Ice thermal storage systems are used to storage energy thermally for cooling application. During periods of low cooling demand, ice is created; this is then melted during periods of peak cooling demand. There seems to be little use of them in integrated renewable systems although mention is made of their potential use in grid demand smoothing. Waxes can be used for higher temperature thermal storage where heat is required or the control of temperature. The change from a solid to a liquid dramatically changes the insulation properties of a material and could be more effective than an active cooling system.

Process products: The resultant products of various products are a form of energy storage. An example is aluminum where plants are built where cheap power is available and the finished product transported. There are many products that consume vast amounts of energy to produce and locating factories close to renewable resources or in fact building customized complexes may be worth considering. Distilled water, fertilizer and almost any high energy use product could be considered a form of stored energy and highlights the need to look at the desired product of the process.

Systems

Systems could be put together using various energy generation, transport and storage systems. Some have been mentioned already such as forced air heating and sugar production using bagasse.

Many systems could be put together using existing technologies. Local renewable sources could be used to drive chillers and store any excess cooling in the form of ice. A similar approach could be used for heat storage, either in the form of hot water or thermal bricks.

EVALUATION OF MULTI-PHYSICS APPROACH

The best forum for testing systems and different approaches to new technologies is obviously in actual applications. This carries risks however and many users may not be willing to tolerate these even with significant potential savings in energy costs. It was decided to design a system that closely resembles a real world type of application with some added emphasis on energy security in being able to deliver services even when traditional energy delivery such as the grid fails. Some discussion as to the motivations for the current system design is warranted. First and foremost a practical and modern system that could be used by current users of energy was desired. This means balancing a mix of electrical energy delivery and control with an end-use based model. In addition commercial-off-the-shelf (COTS) components were used in the system. Certain custom units such as a small variable speed chiller was included in the system as this allowed a significant advantage to the investigation of concepts such as actively balancing the energy load to the available supply. Using the proposed steps outlined earlier the system design was influences as follows;

1. **Energy demands:** Heating and cooling in the residential sector were identified as two large energy users and the system designed to be able to drive these types of systems.
2. **Reduce demand:** Better insulation would be an obvious improvement for the building in question but this was not implemented.
3. **Classification:** Space heating and cooling.
4. **Power and Energy:** a) Heating: 100 kWh of thermal storage and 8 kW of power. b) Cooling: 82 kWh of thermal storage and a 9 kW chiller. Both systems have variable power control.
5. **Generation:** Wind, solar and the main grid are available.
6. **Transport:** Electrical for prime heating and cooling. Air for heating and glycol for cooling.
7. **Storage:** Thermal brick for heat storage and ice for cooling applications.
8. **Safety and Practicality:** Standard electrical components and breakers build to local codes were used. Air for heating is used in many building application. Propylene glycol was chosen for cooling as it has a low oral toxicity versus ethylene glycol.
9. **Lifecycle Costs:** Matching the load to the supply of the heater and chiller reduced the size and dependence on a battery system. The heating and cooling systems have no obvious cycle limits.

IMPREL: Integrated Multi-physics renewable energy lab

The Integrated Multi-Physics Renewable Energy Laboratory (IMPREL) is being commissioned at the Naval Postgraduate School in Monterey, CA. The purpose of the facility is to integrate, and demonstrate the feasibility of different schemes, of generating, storing and transporting energy from renewable (wind and solar) sources. The focus is on heating and cooling applications in the commercial and residential building sector. Ultimately, the facility would like to demonstrate the feasibility of heating/cooling facilities like data centers independent of the grid - solely with distributed, renewable energy sources. Figure 3 is a schematic drawing of the IMPREL. While it is possible to design individual systems for heating, cooling or other end uses, in real application there is usually some interaction between these systems.

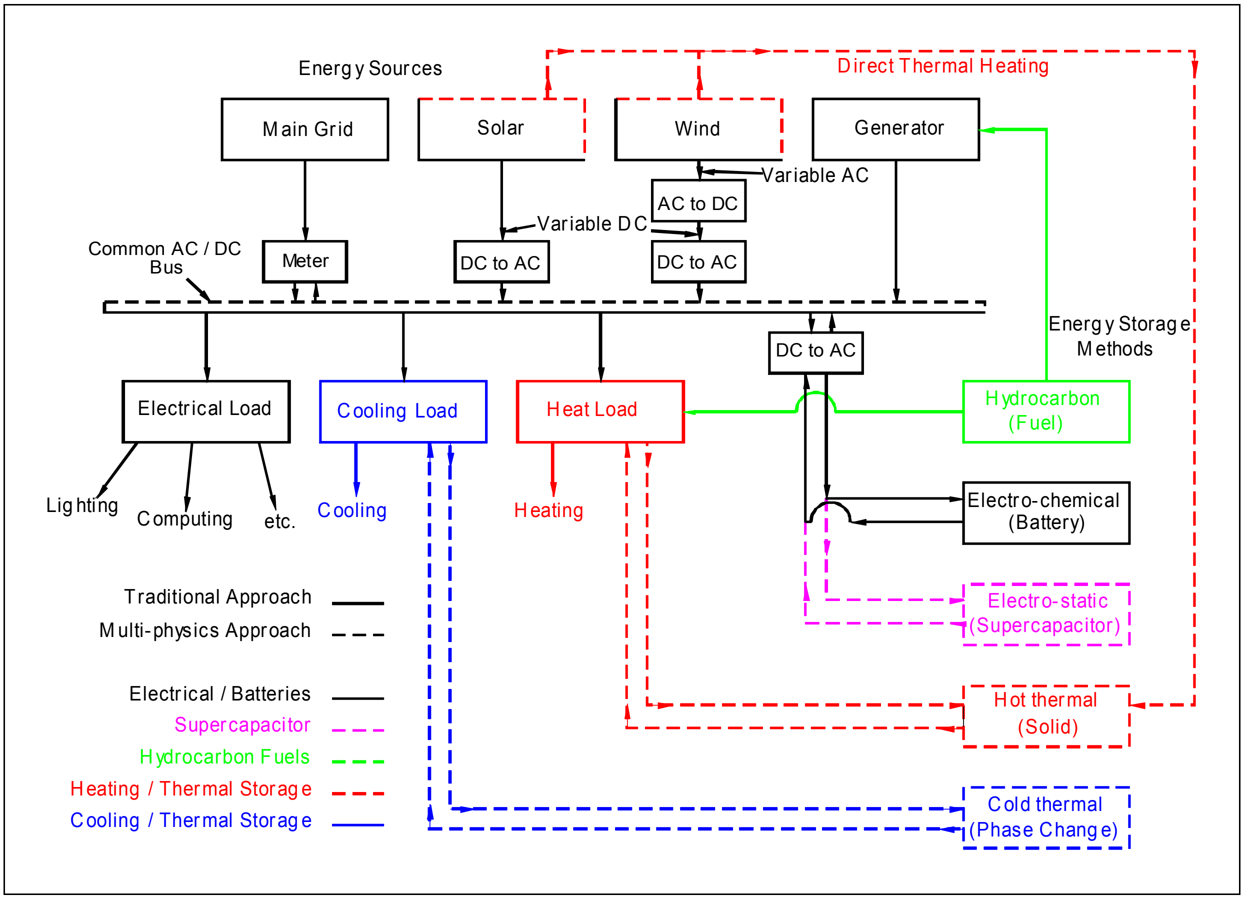

Figure 3. Multi-Physics Renewable Energy Lab (MPREL) Schematic.

The facility is designed to be able to operate grid-independently which is useful from a research perspective but also means that it investigates the energy security of such a system. The solid lines in the figure are meant to denote the traditional type of architecture that such systems were based on. Most of the energy flow was electrically with a suitable device being used to convert the electrical energy to the desired form at the end of the process. The dashed lines show modified ways to transport the energy through the system. At IMPREL, the loads will be matched to incoming power (rather than trying to generate sufficient power for the anticipated load). This is a subtle but important distinction - in essence, reversing the traditional approach to power generation with renewables. For cooling applications, the grid will be used to run a chiller to produce ice, storing all available energy in the phase change (rather than traditional approaches like batteries). For heating, the grid will be used to run an Ohmic heater to store energy as internal energy in thermal bricks. In addition, an array of solar thermal panels will be used as a heat source to subsequently store as internal energy. Thinking of renewables as a source for heating and cooling (in terms of end use), rather than as a source of electricity alone, is not a novel idea (as mentioned wind “mills” were used to grind grain and pump water). However, fully integrating renewables to solely cool/heat commercial buildings, like data centers, is novel. While all equipment is commercially available, the research challenge will be the integration and proper control of various multi-physics generation and storage techniques in order to reliably cool/heat on this scale.

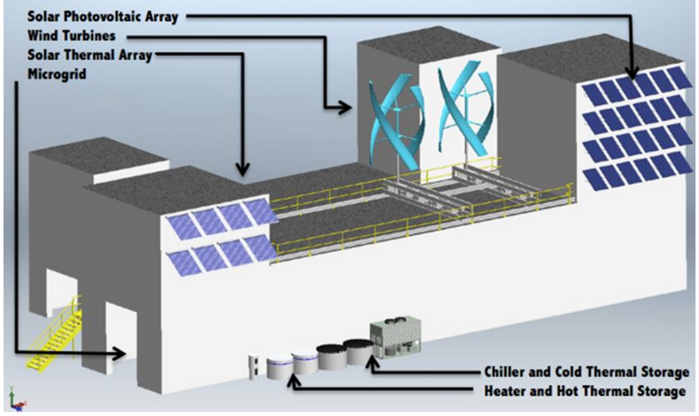

Figure 4. Multi-Physics Renewable Energy Lab (MPREL) Physical Model.

The facility is located at building 216 at the Naval Postgraduate School with the planned complete facility shown in Figure 4. Two 3.2 kW vertical axis wind turbines and 7 kW of photovoltaic solar cells provide energy to a 3-phase, 208 V micro-grid comprised of 2 DC-to-AC wind inverters, one DC-to-AC solar panel inverter and 3 inverter/controllers connected to provide each of the three phases. Turbine placement was based on modeling and simulation work [18] and dictated tied to the direction of prevailing winds. The non-renewable resources are electricity from the main-grid and eventually traditional backup generation to ensure an uninterrupted supply.

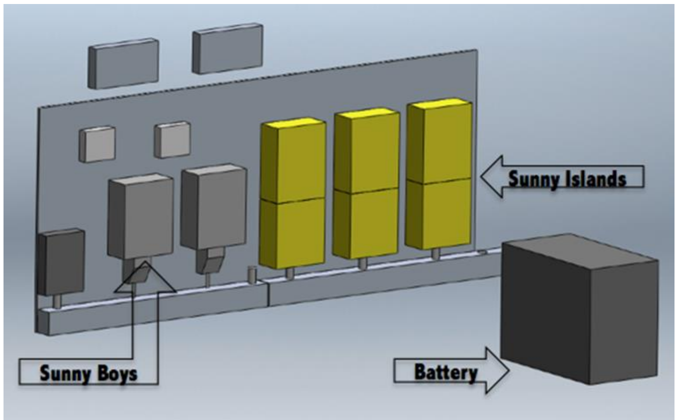

Figure 5. Microgrid schematic.

Figure 5 is a schematic drawing of the micro-grid control room located inside the building. Figure 6 shows the installed vertical axis wind turbines and solar panels which are connected to the microgrid and producing power. Figure 7 shows the installed microgrid with the three yellow boxes forming the three phase grid and the two white inverter boxes converting the wind turbine DC power to 60 Hz power. The DC-to-AC inverter for the solar panels is similar in appearance to the wind inverters.

Figure 6. Vertical axis wind turbines and solar panels.

Figure 7. Installed 3 phase 208V microgrid.

System Development Challenges

At present the microgrid has been commissioned and it operating, absorbing power from the wind turbines and solar panels. A cooling system with thermal storage is being powered using the renewable energy. The seemingly simple task of commissioning the system has already helped in the understanding of the challenges involved in developing such a system. A major issue is the communication of what is desired to the various suppliers of components and systems. Microgrid systems are designed on an assumed usage of a certain number of Joules or kilowatt hours per day. There was found to be a great resistance to developing a system where electrical demand is matched to the available supply and energy stored in other forms. In the field of cooling a similar concept of daily cooling load is assumed even in systems with thermal storage these are normally designed for daily cycles even though the manufacturers make claims about the ability of these thermal storage systems to remain cold for a number of days [5]. This issue was in part the motivation of this paper in that this concept of considering the end-use of energy while obvious is not widely considered.

Instrumentation and the requirement to measure the various component performances in the system are essential. Here not just electrical level would need to be measured but other methods of measuring alternative means of energy storage. In addition this information must be passed back to a central controlling unit and commands passed back out. It is essential to ensure that this communication is possible before embarking on the system design. Some retrofitting and customizing of components in the current system was required.

Finally and still in the stages of development are the control strategies and implementations of these in such a system. While challenging from an integration standpoint the actual control speeds required, on the order of 30 seconds between reading and making changes to systems setting are easily achievable. Matlab has been used to for this purpose as it is simple to program in compile executables from.

The first practical systems that will be powered from the microgrid are for cooling and heating. The cooling system will use ice-based thermal storage for cooling application where excess power will run the variable speed chiller at high speed to produce excess ice for use in cooling at a later time. The heating system will use thermal bricks with air passed over these to reject heat to the space where it is required.

Quantifiable performance data from each subsystem is not included here as the intention of this work is foremost to propose a new approach to energy based on the end use. The second part of the work is to propose a system to evaluate this approach.

CONCLUSION

A new approach to designing energy systems based on the physics of the desired product or service has been proposed. It is hoped that this approach will lead to more efficient systems that are able to make more use of renewable energy with targeted storage systems. To investigate this method a multi-physics energy laboratory has been planned with the core components in place. The design motivation for this experimental facility is to mimic a real world installation as closely as possible with some of the services to be eventually used within the building. Initially cooling and heating systems with building applications will be tested. The strategy of these systems will be to control the demand to match the renewable energy and store the excess cooling and hearing thermally.

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