SECTION 5

ALTERNATIVE ENERGY & DISTRIBUTED GENERATION SYSTEMS – POTENTIAL CONCEPTS

This University of California Santa Cruz (UCSC) Campus Electrical Infrastructure Master Plan for 2005-2020 must look forward to the greatest extent possible into the realm of Alternative Energy and Distribution Concepts. The technology of today is already obsolete by industry standards, having grown largely from the advances in materials science, means of manufacturing, and methodologies of installation and maintenance during the 1960-1975 timeframe. While advances continue to come to the industry forefront since then and into the first decade of the 21st century, they are not particularly foundational, rather more discovering how to utilize the newfound knowledge base of the latter part of the 20th century.

Sustainability of any power generation source has become a top priority as indicated in the University of California *Policy on Sustainable Practices* statement dated March 22, 2007. The viable Alternative Energy sources investigated for this Master Plan are currently available technologies, albeit some are impractical, some are as yet unaffordable for commercial consumption in their present form, and some have not been developed beyond the Proof-of-Concept stages. The following list indicates the technologies investigated. Each one will be addressed further below.

- Wave Motion Power Generators
- Wind Power Generators
- Superconducting Magnetic Energy Storage
- Fuel Cell Power Generators
- Solar Power Generators

Wave Motion Power Generation Systems

Wave motion electrical power generation is a futuristic technology that is just now beginning to be investigated within the research and development communities. The most daunting aspect of the technology is the enormous amounts of real estate required for any meaningful output, and that real estate is mostly offshore and underwater. This real estate requirement would be along vast portions of the coastline of both the East Coast and the West Coast of the continent. The immense deployment challenges notwithstanding, such vast areas would undoubtedly be the cause of more lawsuits than there are lawyers and would tie the process up in the courts for decades, if not permanently.

Wave Motion Power Generation technology is presently not viable and will not be investigated further as part of the Scope of Work of this Master Plan.

Wind Power Generation Systems

Wind power generation is a well-developed technology that is increasing in its installed base throughout the West Coast and the continental United States. The West Coast of North America in particular is well-suited to wind power generation as the prevailing winds are primarily from the west as a direct onshore flow. The preponderance of wind power generators deployed today are in the 1 MW range for large scale, utility-class “wind farm” deployments, with units as small as 50 KW for individual, standalone, generally grid-connected units. The types of blade configurations are the traditional blade propeller, parabolic “egg-beater”, and single or double helix units, all of which are a form of airfoil not unlike the wings of an aircraft or rotorcraft.

The advantage to wind energy “harvesting” is that, of all the different renewable energy sources available on a 24-hour basis, wind energy is the only one completely decoupled from the rest of its environment during the off-hours, with the exception of periods wherein the wind is stagnant for whatever reason. This is a rare occurrence on the coast and should not be a detractor to the concept, nor should it be a deterrent to the deployment of wind power machines.

Wind generators typically require a minimum steady airspeed over the blades in order to generate a consumable amount of power, typically 8 mph. The UCSC campus is directly in the path of the onshore flow coming from Monterey Bay, and has measured a sustained 8.5-9 mph along the coastline at the Marine Research Center. It stands to reason that the UCSC should therefore explore in earnest the possibility of installing an on-campus Wind Energy Farm to harvest the available renewable energy it can from the wind energy present. However, it has not been absolutely determined that the wind is steady enough to support a small to medium wind energy farm on campus in the most likely locations for consideration.

The most likely location and the area where the most consistent airspeed and presence of “working wind” would be found are near the northernmost perimeter of the UCSC property along the ridgeline. Of direct advantage to such a location is the proposal to site and install the new North Campus Main 21KV Service Entrance Substation just down the hill from such a ridgeline site. The integration of this completely sustainable and renewable energy site into the campus overall MV distribution system would be much easier and cost-effective once the new North Campus Main Substation is in place.

Wind Power Generation appears to be a technically viable implementation technology. However, much more detailed project study and scope developments are necessary to develop the foundation for such a project.

> **Recommendation:** Commission a Feasibility Study to research the Wind Energy and Wind Power Generation Concept for UCSC. Include a study of the typical “wind days” at the viable sites as part of the foundation of the study. The timeframe for such a project is quite long, so the earlier the project is put into the Feasibility Phase, the earlier can be determined the ultimate project feasibility.

Superconducting Magnetic Energy Storage (SMES) Systems

The Superconducting Magnetic Energy Storage (SMES) system is an energy storage medium that stores electrical energy in a magnetic field without conversion to a chemical or mechanical form. However, to remain in the superconductive state necessary to sustain the magnetic, and hence, the electric field which "holds the current" for use by the load, the magnetic coil must operate at cryogenic temperatures. Therefore, the SMES system requires cryogenic refrigerators and several related support subsystems such as solid-state power conditioning devices, monitoring and control systems, climate and environmental controls, utility company and user interface equipment as necessary, required personnel and facility safety maintenance systems, and power transportation features.

Most SMES systems deployed to date have been integrated into utility systems to provide very limited, short duration power quality improvements, particularly in areas where the utility grid is slightly unstable and erratic. The SMES systems have been used to correct voltage sags and dips in heavy industrial systems in the USA and Africa, with some experimental research units finding their way into similar uses in Eurasia. Further experimental installations, up to a six-parallel, 2MW each system, have been deployed in the utility space to determine the feasibility of using SMES to stabilize oscillations on the transmission grid network in the USA.

SMES systems possess several advantages in power quality applications. The SMES coil has the inherent ability to discharge relatively large quantities of power in a fraction of a cycle and completely recharge in just a few minutes. Unlike a battery where repeated discharge, deep or short, is deleterious, the SMES system does not suffer any known adverse effects to discharges of any percentage magnitude. Such rapid, efficient and economical response promotes the most desired system controllability, reliability and safety. Because of its very high current density and compact, self-contained design, the typical SMES system is highly mobile and can be kept at remote locations (such as unmanned area substations). The cryogenic medium is typically liquid helium held at 4 deg K (-269 deg C), and is an inert, non-toxic, non-flammable gas, and therefore non-hazardous in any way, precluding any special materials handling or containment issues. All of these advantages promote a typical performance and equipment life cycle of at least 20 years of clean, reliable, renewable, environmentally very friendly power quality conditioning source.

The list of challenges to the deployment of a SMES system is relatively short. A SMES device produces very strong and pervasive magnetic fields. Such fields require strictly controlled "stay out" zones and, in some cases, additional shielding to minimize the magnetic field effects outside of the controlled zones. In addition to the magnetic effects, the components supporting the SMES system, particularly the cryostats, must be designed carefully so as not to promote self-destruction if the coil happens to "go normal", or, becomes "non-superconducting." Small SMES systems have the unfortunate side effect of a larger percentage of the total system energy input dedicated to feeding the parasitic losses from the air conditioning and cryogenic refrigeration systems. Physical footprint is also an important aspect of SMES system design --- as the SMES coils are improved, the physical characteristics and shielding requirements change, promoting an evolutionary process that benefits both parts of the spectrum.

Clearly, the SMES technology has an important place in any larger commercial or industrial system such as the UCSC campus. The SMES system can be an important power conditioning medium at the system MV level for mitigating overvoltage transients, swells and sags that can cause voltage, and as a result, current, perturbations to propagate throughout the distribution system, showing up at the most inopportune times in the most sensitive of locations. However, just as evident, the SMES technology is purely asymmetric in that it can provide only momentary power conditioning and not a sustained power delivery methodology.

The SMES technology will not be investigated any further within the Scope of Work of this Master Plan.

Fuel Cell Power Generation Systems

The fuel cell power generating unit operates on the principles of electrochemical conversion of chemical energy directly into electrical energy. This process bypasses completely the typical chemical energy-to-mechanical energy-to-electrical energy conversion process by removing the mechanical energy (prime mover engine) piece in the chain. Direct conversion by electrochemical means is very environmentally friendly because of the inherently low emissions, minor carbon footprint, and minimal noise and vibration.

Fuel cell technology has been around since the 1800's, but the practical application and the subsequent development of the technology did not really take off until the US space program needs of the 1960's and since. Fuel cells provide a very high density current footprint for a relatively small physical footprint. For example, a typically available fuel cell rated at 215 KW DC, 155 volts DC, requires a physical space of 36" square and 9.5 feet high, clearances around required for maintenance and NEC safety notwithstanding. The byproducts of the process are heat (used in the infrastructure for environmental conditioning) and water (perfect for drinking purposes since it is essentially pure and highly distilled).

The commercially available fuel cells marketed today can be lumped roughly into five distinct technologies. Each technology has its proponents and each is being developed by several companies. They are as follows:

- Polymer Electrolyte Membrane Fuel Cell (PEMFC)
- Alkaline Fuel Cell (AFC)
- Molten Carbonate Fuel Cell (MCFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Solid Oxide Fuel Cell (SOFC)

Each of the technologies listed above uses natural gas (CH_4) as its input fuel stream to derive the hydrogen to generate the electricity. The methodologies differ in the methods of extraction of the hydrogen, but the end result is a pure hydrogen stream that recombines with the oxygen from a different part of the process to form the byproduct of potable/distilled grade water, exhaust heat, and excess electrons that are forced through the system to do work as electrical current. This Direct Current (DC) may then be inverted into a very high quality Alternating Current (AC) for customer use. Of course, there are the requisite controls, monitoring, and safety interlocks to make the system viable for smooth, reliable functioning during most modes of operation so that the fuel cell will integrate seamlessly into the customer's electrical network. Fuel cells can operate on other hydrogen sources such as industrial waste hydrogen, hydrogen from propane, or hydrogen from methane gas generated from several different kinds of waste treatment and/or biomass organic sources. The following diagram illustrates the concepts of hydrogen extraction and usage methodologies.

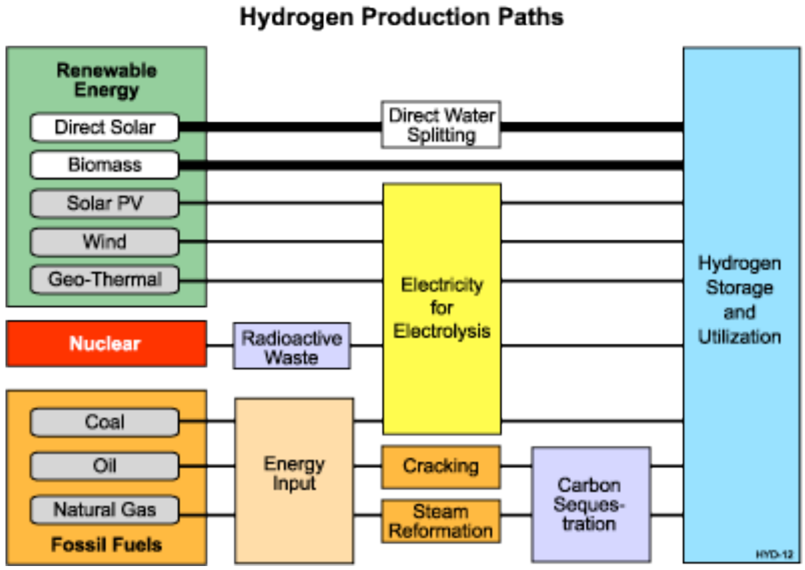

Figure 5.1: Hydrogen Fuel generation Technologies

The fuel cell technologies listed, although not completely sustainable by the strictest definition, will generally convert between 30 and 50 percent of the input fuel's energy into electricity. And, between 30 and 40 percent of the fuel's input energy can be recovered as useful thermal energy for commercial uses such as space heating, water heating and air conditioning.

The fuel cell is a self-contained power generation unit, capable of completely safe and reliable automatic startup and running operations. The fuel cell is capable of maintaining the required utility grid to customer interrelationship under all typical integrated conditions.

Fuel cell technology is a much more environmentally viable and reliable alternative energy source than fossil fuel powered electricity generation such as the diesel and natural gas fueled emergency (10 second response) and standby (60 second response) generator sets that populate the UCSC campus at each building or load necessary for compliance with the NEC/CEC (NFPA 70) and Life Safety (NFPA 101) Codes. The key to any deployment of fuel cells will be the ready and adequate availability of natural gas or some other economically feasible hydrogen fuel source. The rest of the technical equation is electrical interconnection and physical siting.

Deployment of fuel cells on the UCSC Campus should be viewed as a direct replacement of the fossil fueled generator sets in an area. The interconnection of the various legacy units within an area "block" would be implemented as an underground networking of the existing load service points into the area consolidation switchboard. Coupled with the deployment of the fuel cells would be the replacement of the individual distribution panelboards and equipment local to each generator set and the centralizing of their functions in appropriately sized distribution switchboards that would be configured as "Distributed Generation Blocks". With today's "smart circuit breakers" and "intelligent control systems", it would be relatively simple to integrate the power transfer functions into the circuit breakers and eliminate the legacy transfer switches in many of the locations. Such consolidation is much more efficient than the legacy localized deployment approach.

On earth, even though hydrogen is the most plentiful element in nature, it is typically not found in its elemental state, rather it is usually found combined with other elements. For example, in water, hydrogen is combined with oxygen. In fossil fuels, it is combined with carbon as in petroleum, natural gas or coal. The challenge is to separate the hydrogen from other naturally occurring compounds in an efficient and economic manner. Please refer to the listings below for some representative examples of the ultimate costs of production of hydrogen from various fuel sources.

Table 5-1: A brief listing of the cost and performance characteristics of various hydrogen production processes is as follows:

	Energy Required (kWh/Nm3)				
Process	**Ideal**	**Practical**	**Status of Tech.**	**Efficiency [%]**	**Costs Relative to SMR**
Steam methane reforming (SMR)	0.78	2-2.5	mature	70-80	1
Methane/ NG pyrolysis			R&D to mature	72-54	0.9
H2S methane reforming	1.5	-	R&D	50	<1
Landfill gas dry reformation			R&D	47-58	~1
Partial oxidation of heavy oil	0.94	4.9	mature	70	1.8
Naphtha reforming			mature		
Steam reforming of waste oil			R&D	75	<1
Coal gasification (TEXACO)	1.01	8.6	mature	60	1.4-2.6
Partial oxidation of coal			mature	55	
Steam-iron process			R&D	46	1.9
Chloralkali electrolysis			mature		by-product
Grid electrolysis of water	3.54	4.9	R&D	27	3-10

Solar & PV-electrolysis of water	R&D to mature	10	>3
High-temp. electrolysis of water	R&D	48	2.2
Thermochemical water splitting	early R&D	35-45	6
Biomass gasification	R&D	45-50	2.0-2.4
Photobiological	early R&D	<1	
Photolysis of water	early R&D	<10	
Photoelectrochemical decomp. of water	early R&D		
Photocatalytic decomp. of water	early R&D		

This table was originally published in **IEEE Power & Energy, Vol. 2, No. 6, Nov-Dec, 2004,** page 43, "Hydrogen: Automotive Fuel of the Future," by Florida Solar Energy Center's Ali T-Raissi and David Block.

The cost of hydrogen production is an important issue. Hydrogen produced by steam reformation costs approximately three times the cost of natural gas per unit of energy produced. This means that if natural gas costs $6/million BTU, then hydrogen will be $18/million BTU. Also, producing hydrogen from grid-powered electrolysis with electricity at 5 cents/kWh will cost $28/million BTU — slightly less than two times the cost of hydrogen from natural gas. Note that the cost of hydrogen production from electricity is a linear function of electricity costs, so electricity at 10 cents/kWh means that hydrogen will cost $56/million BTU.

Worth investigating in today's technologically advancing scientific community would be the large scale feasibility of water electrolysis using solar photovoltaic electricity for hydrogen production. If the system could be truly scaled up to meet the demand, not only would this be a definite financial incentive but it would also be both renewable and sustainable, thus fulfilling the University of California *Policy on Sustainable Practices* statement referenced earlier.

There are still available certain "Grant Programs" that could be used to at least partially offset the cost of a Fuel Cell System. The serving utility, PG&E, offers grant monies for such projects, but to a limited degree. The maximum projected opportunity for Fuel Cell Replacement for the UCSC Campus is 5,400 KW. Since the UCSC Campus is currently provided power under one meter (primary metered at 21KV), and under the current rules set up for the Grant Programs, the contribution from such Grants would tier as follows:

- The maximum allowed installed base is 3,000 KW (3 MW)
    - The first 1,000 KW (1 MW) would be at $2,500/KW, or, $2.5M
    - The second 1,000 KW (1 MW) would be at $1,250/KW, or, $1.25M
    - The third 1,000 KW (1 MW) would be at $625/KW, or, $625K

Thus, the current Grant monies available would be no more than $4,375,000. Although not insignificant, the proposed installed base would cost much more than this, the final costing which would be determined once a design has been developed and the bidding process executed.

The UCSC campus could definitely benefit from strategic deployment of "distributed generation fuel cell blocks" throughout the developed campus. Subject to final design and engineering approvals as well as adequate funding, the following locations are proposed as an initial deployment concept. The sizing after each block indicates the amount of current generator KW that can be replaced. Refer to the "Proposed Fuel Cell Replacement Block Map" for details.

- KZSC Tower Hill – 100KW + TBD
- Engineering – 180 KW
- Communications/Fackler Co-Generation Plant/Natural Sciences Woodshop – 425 KW
- Interdisciplinary Science Bldgs/Earth & Marine Sciences/Science Labs/Natural Sciences – 330 KW
- Physical Sciences/Sinsheimer Labs/Thimann Labs/Kerr hall – 690 KW
- College 9/10 – 715 KW
- Crown College/Merrill College/Fire Station – 195 KW
- Cowell Health Center/Student Center/Classrooms/Humanities – 87.5 KW
- Cowell College/Stevenson College & Apartments – 570 KW
- McHenry Library/Hahn Student Services – 31.5 KW + Hahn Student Services
- The Arts Complex – 60 KW + Digital Arts
- Kresge College/Porter College & Porter/Kresge Apartments – 245 KW
- Kresge Housing East/Graduate Student Housing/Core West Parking Structure – 285 KW
- College Eight and Oakes College – 488 KW
- Family Student Housing - TBD
- East Field House/Fitness Center/<F> Events Center Complex – TBD
- Quarry/Village/Farm/Agroecology – TBD
- Arboretum – TBD
- Barn G/Barn H/Central Stores/Garage/Carriage House/Cardiff House/Faculty Housing – 20 KW + TBD
- Emergency Response Center – TBD

Recommendation: Commission a detailed study of the potential interconnection points for fuel cells in individual standalone or multiple-parallel configurations at strategic locations on campus. Include in the study the collocation of hydrogen fuel generating and storage stations at strategic locations on campus, close enough to provide piped distribution to the fuel cells and remote enough to be safe, secure and inconspicuous. Once the study is complete and the locations finalized, place the results into a Design Project to implement the Plan. The timeframe for this project should be immediate upon approval of this Master Plan, particularly in light of the rapidly escalating prices of fossil fuels for the generators that are much less environmentally friendly than fuel cells. As there are nominally 20 potential fuel cell distributed generation blocks, each block would be a potential standalone project from both the technical engineering and funding perspectives. The more of such projects in the pipeline, the sooner the reciprocating engine generators can be replaced by the fuel cell technology.

Solar Photovoltaic Power Generation Systems

The sun we experience on a daily basis is an enormous source of energy that is only now being explored for use on Earth. The electromagnetic radiation that bathes the earth after being filtered by space travel and our own protective atmosphere amounts to about an average of 93 Watts per square foot (1000 Watts per square meter) over the total irradiated surface of the sphere exposed at any one moment. That figure is modulated constantly due to the position of the earth in its travel around the sun (the season), the azimuth of the sun in its apparent travel across the sky, and the current cloud conditions at the point of interest. All in all, the amount of energy available is still far more than the amount of energy harvested and put to use.

The solar photovoltaic power generation method is definitely coming of age. The advances in technology over the last couple of decades have seen a cell output go from less than 3 Watts per square foot to an average today of 8-10 watts per square foot, with some semi-commercial technologies clearly in the 15-17 watts per square foot range. This means that the economic feasibility of large scale deployment of solar power generation systems has arrived.

The following block diagrams illustrate the fundamental concepts involved in the operation of Solar Photovoltaic Power Systems.

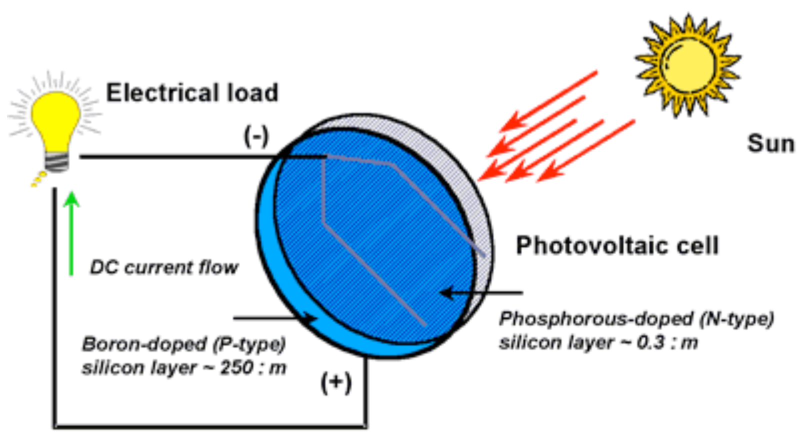

Figure 5.1: How Does a Photovoltaic Cell Work?

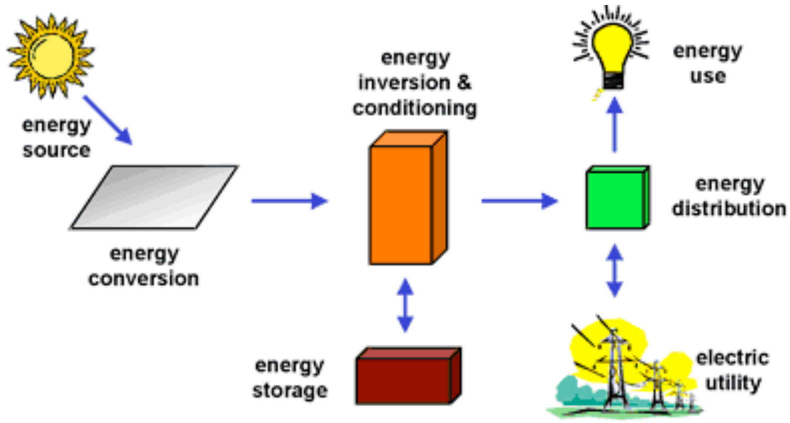

Figure 5.2: How Does a Photovoltaic Electrical Power Generation System Work?

The advantages (pros) of solar energy electricity production as a sustaining medium over the conventional legacy methods of electricity production and usage are many. The following is a brief, not inclusive, list of some of the major benefits.

- The sun is a free source of energy to be harvested and used, once the initial capital cost of the harvesting and conversion systems is recovered.
- The Return on Investment (ROI) can be quick and attractive (paybacks short) depending on the ultimate utilization of the electricity produced.
- Financial incentives are still available from government entities that can be used to help “buy down” the initial capital investment.
- Solar electricity production is a standalone system, “Green Clean” renewable, and wholly self-sustainable, requiring no connection to any of the conventional electrical power or natural gas systems that other electricity generation means require.
- For all practical purposes, the sun is a virtually limitless supply of solar energy for conversion to electricity. Solar energy will never run out in our lifetime or the lifetimes of countless generations hence.
- The use of solar energy as the conversion methodology to electricity is a replacement medium for our conventional electricity production methods, thereby promoting a proportional decrease in environmentally destructive greenhouse emissions and ozone layer depletion byproducts.
- Solar energy generation is a zero carbon footprint electrical power delivery method.
- Solar energy production is silent, has no moving parts, and is good for organic health.
- If the installed system produces more usable electricity than is necessary to support the system to which it is connected, energy “credits” can be “put in the bank” for the time when energy cost offsets are necessary.
- The U.S. Government offers tax credits, as do most states.
- On a global scale, solar energy is not tied to any other form of energy-producing fuels or systems, and therefore is not dependent on any world market conditions or government whims.

The list of disadvantages (cons) is much shorter.

- The initial capital outlay is still quite substantial at close to $13 per watt installed.
- When factoring in the initial capital cost of solar electric systems, they still are not as inexpensive as most non-renewable utility-provided electricity producers. However, as the cost of fossil fuels continues to escalate, the solar systems are becoming much more price competitive.
- Solar panels and tiles require a relatively large physical area in order to be cost-effective. Some people do not appreciate the aesthetics that the solar panels present.
- The production output is affected by environmental conditions such as rain, clouds, smoke and pollutants in the air, thus obscuring the direct sunlight to a greater or lesser degree.
- Solar electricity is purely a daytime operation. Batteries can be used to store the energy for use during the dark hours if the use dictates, which incurs greater initial and ongoing system costs.

Solar energy is not only the most viable form of renewable energy, it is ultimately sustainable in even the most conservative of applications. Solar energy is clean, sustainable, "Green" in the purest sense of the definition, and, on the West Coast of the North American continent and at the UCSC latitude and southward, insolation of the earth is present well into the 300+ sun-days per year on average. Even on days that seem unfit for electricity production due to overcast clouds or even rain, the solar cells produce electricity during daylight hours, although at a reduced rate. Such a prevalence of the sun's energy must be taken advantage of by every possible means to maximize the substitution of "free" energy for "costly, fossil fuel, high carbon footprint" energy sources. American energy independence depends on each and every electricity consumer to convert the "easy way out" fossil fuel legacy into an ultimately completely renewable and sustainable energy future that can be passed down to our successive generations.

The UCSC campus has many thousands of square feet of southerly-oriented sloping rooftops and building faces that are positioned nearly perfectly to harvest most of the day's sunshine. These locations are ideal for the unobtrusive placement of solar panels and/or tiles on rooftops as well as the integration of vertical building window walls made from photovoltaic materials that generate electricity, yet still let light through and provide shading and temperature control inside the buildings.

The UCSC-owned facility located at 2300 Delaware Avenue has a building footprint that is over 80,000 square feet and the roof is essentially flat. If the available clear area for solar panels is set conservatively at 40,000 square feet, at an average output of 10 watts per square foot, the available solar produced electricity should be around 400 KW during the most productive parts of the day. This 400 KW represents fully 1/3 of the target 1200 KW of renewable and sustainable power assigned to UCSC by the University of California as a goal to be achieved by 2020. If the usage profile of 2300 Delaware is such that 400 KW is more than needed, the University should be able to negotiate a surplus power buyback program with PG&E for the excess, essentially "spinning the meter backwards."

Should the need arise, there are many acres of available south-facing open ground that can be utilized as ground-mounted "solar array farms" that would be environmentally friendly and would put the fallow ground to excellent use as an integrated piece of the energy independence model. Combining these technologies is now relatively simple and can be fed directly back into the campus wide electrical power delivery grid for fossil fuel energy replacement without any known electrical system side effects. Since the UCSC campus is on its own internal grid, the replacement takes effect immediately as soon as generation starts and directly offsets the need to take electricity from the PG&E utility source.

Recommendation: Commission a detailed study of the potential installation points for solar electricity production arrays. Once the study is complete, the locations are finalized, and the stakeholders all agree to the placement, initiate a series of Design Projects to implement the Plan. As the Design Projects are being accomplished, an appointed committee should begin the delicate but essential negotiations with PG&E to secure the energy sharing policies that are the most advantageous to the University. The timeframe for these projects should be immediate upon approval of this Master Plan, particularly in light of the rapidly escalating prices of fossil fuels that are driving up the price of electricity on almost a daily basis.

The Plan for Deployment of solar electricity production throughout the UCSC campus will need to be twofold. The first part of the Plan will be to retrofit all viable existing buildings and structures with solar panels, roof tiles and/or semi-transparent window wall shades. The second part will be to develop an integrated architectural standard that applies to all new buildings and structures that will include solar electrical production from Concept to Occupancy.

The following block diagrams illustrate the typical system configurations for solar power delivery systems. The ultimate decision for deployment will come from the Design and Engineering phases.

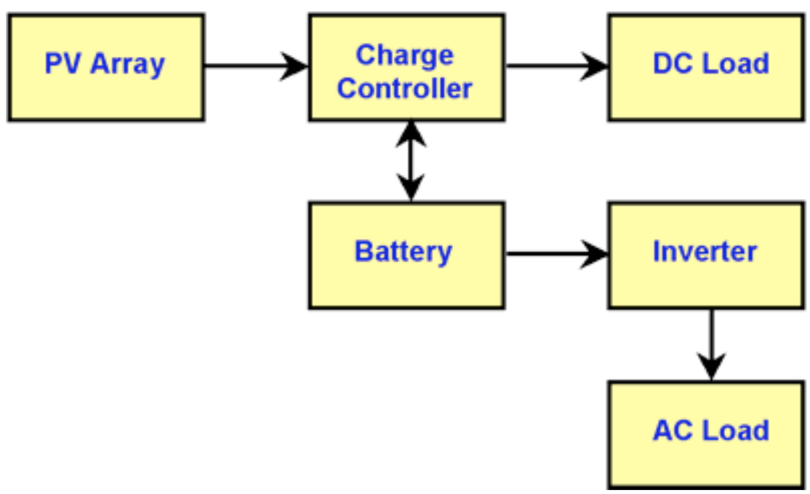

Figure 5.3: Standalone PV System with Batteries

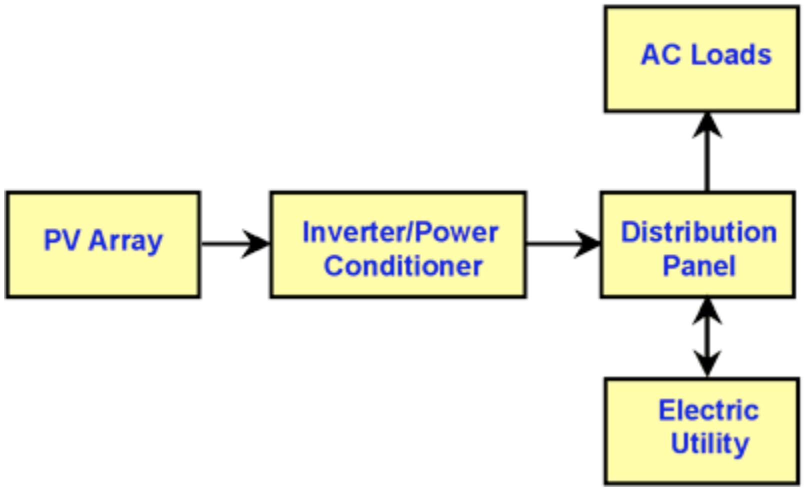

Figure 5.4: Grid Connected PV System

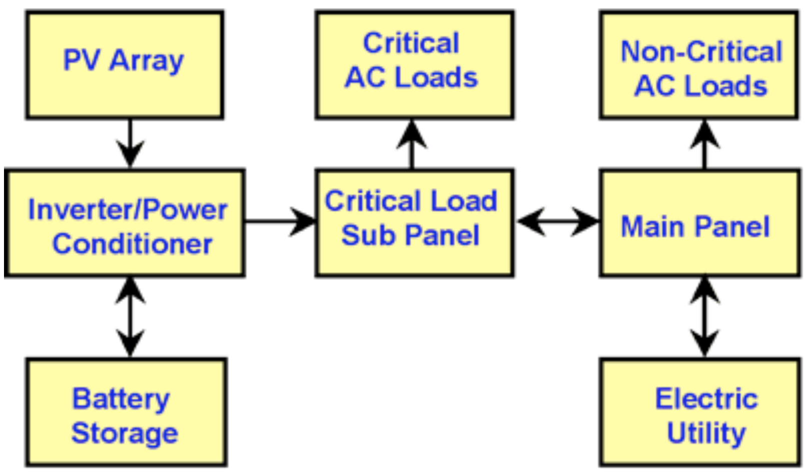

Figure 5.5: Grid Connected Critical PV System

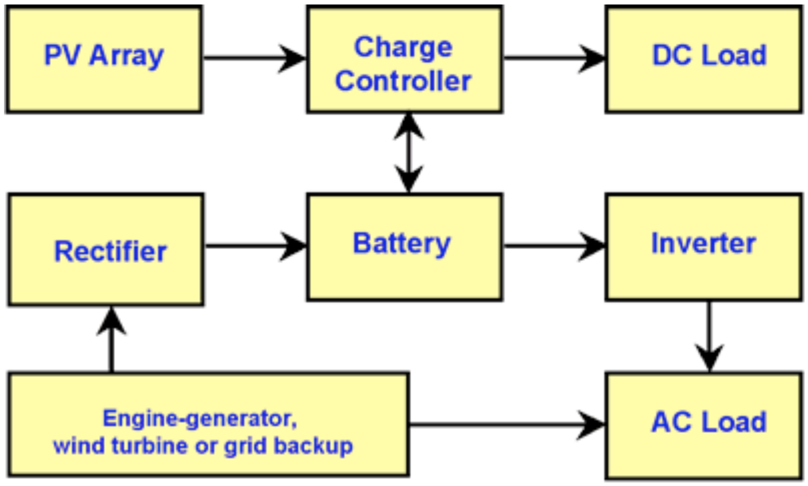

Figure 5.6: Hybrid Standalone PV System