Renewables - Solar and Wind Energy Require Energy Storage and Throttle-able Energy Sources

By

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Introduction

Renewable energy sources include bio-mass, geothermal, small hydro, wind, solar, and ocean tide and wave. Table 1. shows an estimate of the breakdown of the percentage of types of renewables making up the total. The breakdown is critical because of the capacity factor of the various types of renewables. The capacity factor for each type is Biomass, 100%, Geothermal, 90%, Small Hydro 90%, Solar 20%, Wind 20% and Ocean tide-wave 60%. The capacity factor is the percentage of the hours of the day that the system is working

Table 1. Estimated Percentage Breakdown of Renewable Electrical Energy Sources

Renewable Sources	Years 2010	2020	2030	2040	2050
Renewables	**12.0%**	**20.0%**	**33.0%**	**33.0%**	**33.0%**
Biomass	**2.1%**	**2.0%**	**2.2%**	**2.5%**	**2.5%**
Geothermal	**4.5%**	**4.0%**	**4.5%**	**4.5%**	**4.5%**
Small Hydro	**2.8%**	**2.0%**	**1.0%**	**0.3%**	**0.0%**
Solar	**0.3%**	**2.0%**	**12.9%**	**12.5%**	**12.5%**
Wind	**2.8%**	**10.0%**	**13.3%**	**13.0%**	**13.0%**
Ocean Tide-Wave				**0.2%**	**0.5%**

Solar and wind are green, but limited by low capacity factor of 20% average This has a very restrictive limit on how much can be used by the grid. Economical, safe, environmental and reliable energy storage must be used for the grid to have more than about 5% of the energy supplied by wind and solar. One must realize that to get 15% of the electrical power from wind and solar with their 20% capacity factor when the sun is shining and the wind is blowing all but 25% of the other sources must be turned off unless 80% of the wind and solar production is stored so it can be efficiently put onto the grid when wind and solar are not producing. Table 2 indicates the percentage of energy storage needed per the percentage of total grid electricity produced by solar and wind.

As shown in Table 2.the amount of throttle-able power must be 5 times the amount of wind & solar if there is no storage. As shown, if we have more than 20% of our energy requirements by renewables when they are producing and we are not storing any of the energy then we have more energy on the grid than can be used by California. So, if we are to meet the requirements of 33% by 2030 established by our legislature we must have storage for the extra 65% being produced when renewables are working or get out of state customers to procure it. If we do not have the required storage we need the 100% output (except for stable nuclear) level from throttle-able sources.
Note: Data on future electrical energy planning is provided by California Energy Commission

Table 2. Storage and Throttle-able Energy Needed with Percentage of Wind & Solar
The percentages are based on 30% of energy provided by nuclear and 10% by large hydro

Percentage of Grid Energy Provided by Renewables	Percentage of Grid Energy Provided by Wind & Solar	Percentage of Grid energy Provided by Wind & Solar To be Stored	Percentage of Total Energy Level That Must be Provided by Wind & Solar When Operating	Percentage of Grid Energy That Must be Provided by Throttle-able Energy with no Storage	Percent Provided by Throttle-able with Storage
5%	2.5%	80%	18.75%	55.5%	55%
10	5	80	37.5	49	50
15	7.5	80	56.2	46.3	45
20	10	80	75.0	42.0	40
25	12.5	80	93.75	40.0	35
30	15	80	112.5	36.1	30
33	16.5	80	123.75	30.3	27

The best source of this throttle-able power is gas powered turbo-generators. The gas industry is pushing renewables because they feel the only cooperative source is gas fired energy production. The gas industry has influenced the California legislature and the California Energy Commission to outlaw any new nuclear power and insist on the high use of renewables. If we do not have storage, then 4 times the amount of energy produced by wind and solar must be supplied by throttle-able sources, mainly gas turbines. We may need more than the 4 times the wind and solar by throttle-able sources in order to stabilize the grid power with the daily variables of renewables.

As shown in Table 3. If we get 20% of our energy from wind and solar and we store 80% of that generated by wind and solar we still would need several GigaWatt hours of power per year from throttle-able sources. What ever amount is not stored that amount will need to be produced by throttle-able sources. By 2050 it can vary from 0 to 148 thousand GigaWatt hours per year. If the throttle-able sources are efficient, safe and economical they can be some of the etc. sources in the last column.

Table 3. Renewable Energy Storage and Throttle-able Energy Levels

Energy in thousands of GigaWatt hours

Year	Percent Renewables	Percent Wind & Solar	Total Energy	Amount by Renewables	Amount by Wind & Solar	Amount to be Stored	Amount Must* be Throttle-able	Amount from Nuclear, etc.
2020	20%	12%	445	89	53	42	42	356
2030	33%	26.2	765	252	66	53	53	513
2040	33%	25.5	1377	454	115	93	93	923
2050	33%	25.5	2185	727	185	148	148	1458

*Must be throttle-able to fill in that wind and solar that is not stored

Information on California energy use and sources is shown in the appendix. Item number 1. is a geometric curve showing the rate of change from fossil fuel to electrical power for transportation. This is used for the basis for the growth of electrical power use with time.

Energy Storage Development – Types of Energy Storage Systems

Pumped Water Storage

This system consists of a reservoir behind a dam on a high part of a sloping contour with another reservoir down the slope. Just above the bottom reservoir is a pump system and a water turbo-generator system. There must be adequate water in the total system to take care of the needs. When there is excess energy produced by solar and wind it is used to pump water up to the upper reservoir. When wind and solar facilities are not producing energy the water from the upper reservoir is flowing through the water turbo-generators into the lower reservoir to produce the percent of energy needed. This is the most reliable, economical, safe and environmental system that has been operating for several years.

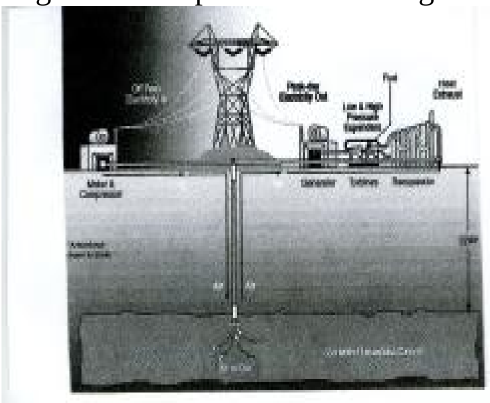
The problem with pumped storage is the possible location especially in the state of California. If we get 20% of our electrical energy in 2020 from wind and solar we need 4 pumped storage sites, each with two dams with reservoirs and a pumping and turbo-generation facility the size of Hoover Dam. If we have the California Legislature's target energy level of 33% by wind and solar in the year 2030 we will need 10 of these huge sites.

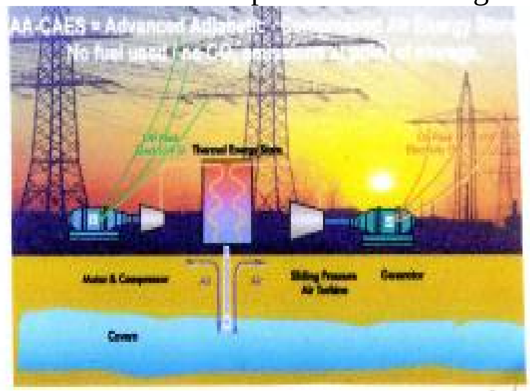
One 2000 megawatt pumped storage facility will require an upper reservoir about 3 square miles in area and 10 to 30 feet in depth. The drop must be at least 600 feet to the power plant. The lower reservoir can be half the size of the upper one. Where can we put these in California?

High Pressure Air Storage

Some energy storage has been developed by compressing air to the level of about 1000 psi and storing it in underground caverns. The air is then blown from the storage and heated with gas and used to power a gas turbo-generator. This concept is shown in figure 1. A system similar to this is operating in McIntosh, AL. With the use of gas to reheat the air the efficiency is about 50% of the regular gas turbine generation. The major problem with compressed air storage is that the air is heated when it is compressed to a very high pressure (1000 PSI) and the heat energy is lost when the air cools in storage. There is a program under way to develop a system for removing the heat from the air and using it for more energy storage. to improve the efficiency This concept is shown in figure 2. While compressed air storage is environmentally clean and safe the main problem is its low efficiency

Figure1. Compressed Air Storage Figure 2. Adiabatic Compressed Air Storage



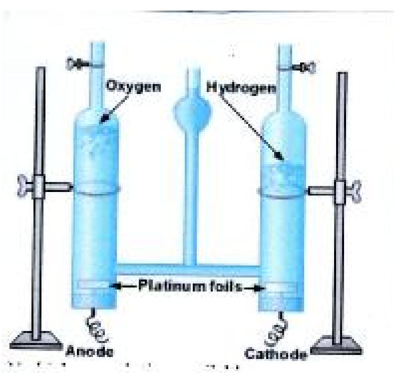


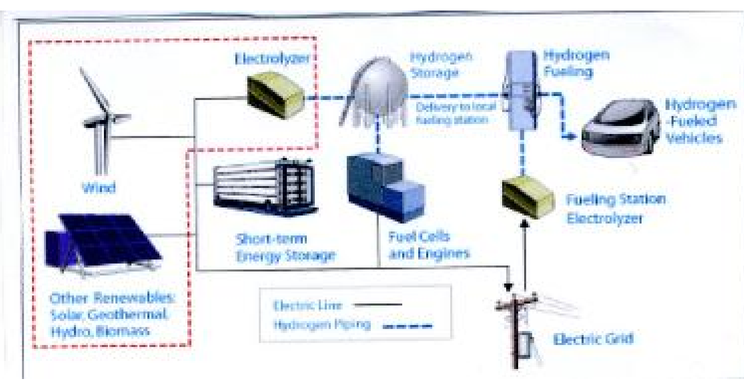
Other storage systems under development

Chemical

Hydrogen: Hydrogen can be produced from water by electricity produced by wind and solar. The hydrogen can then be used to produce electricity by burning it to power gas turbines. It can also be used to power transportation vehicles. The typical process for electrolysis separation of hydrogen and oxygen from water is shown in Figure 3. A schematic of a hydrogen generating and storage facility is shown in figure 4.

Figure 3. Basic Electrolysis Figure 4. Hydrogen electrolysis and storage facility





Biofuels: Biofuels are not environmentally clean if the energy used for fertilizer, cultivating, watering, harvesting, transportation and processing into biofuels is provided by fossil fuel. Biofuels are clean and green if the required energy to produce them is provided by wind and solar thus they are a possible storage and transport system for renewables.

Electrochemical – Battery Storage

Batteries Two major battery design systems are under development for electrical energy storage. They are sodium sulfur batteries and vanadium redox batteries

Vanadium Battery

Vanadium batteries are well suited for large power storage applications such as helping to store the output of wind and solar energy sources. They are not good for transportation because they have a low energy density of about 25 Wh/kg, with possible improvement to 35 Wh/kg. They are being developed by the University of South Wales and have been used in Japan, Australia and Canada for storage. A picture of one is shown in Figure 5 and a diagram is shown in Figure 6.

Figure 5. Vanadium Battery

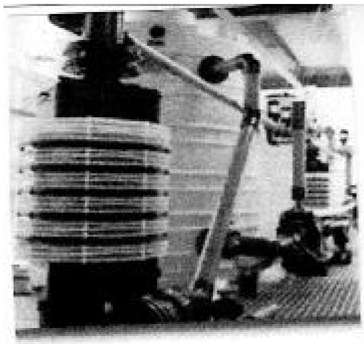
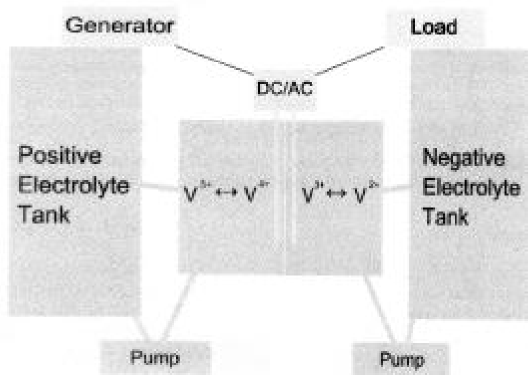


Figure 6. Vanadium Battery Diagram



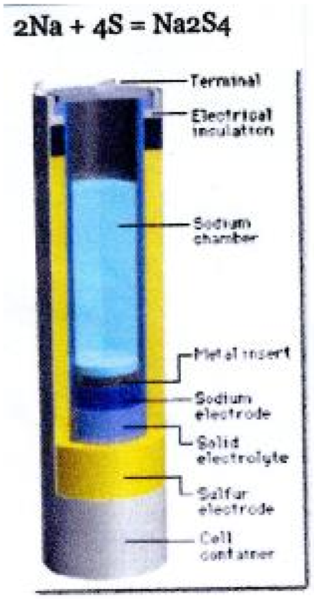
The vanadium Redox batteries are evolving to be ideal batteries for home storage where there are solar panels producing electrical power. A solar demonstration house is on the grounds of the Gypsum Factory in Thailand to store energy from the solar panels. The total energy is self sufficient providing power for air conditioning, lighting, appliances, etc. The storage has 1 battery stack with 36 cells. Each cell has 400 liters of electrolytes. The peak power is 4.9 kW and the capacity is 13.0 kWh**.**

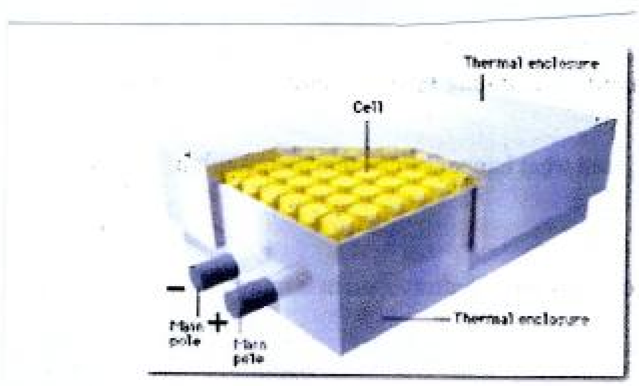
Sodium-Sulfur Batteries

Sodium sulfur batteries are high capacity battery systems developed for electric power applications. This battery has 89% efficiency. It has energy density of 66 Wh/kg and an energy density/volume of 367 Wh/l. The current batteries are 3.6 inch diameter and 21 inches tall. Each battery can store1.220 kWhr. A typical NAS cell is shown in figure 7. The batteries are placed in a metal container with insulation so that the temperature can be maintained about 300^0 C. The container shown in Figure 8 has 8 by 12 batteries totaling 96. This gives a storage of 117.12 kWhr per container. The plan is to put two containers side by side in the rows and make the rows of 100 each. There are 4 containers stacked in each row and the rows are 4 feet apart for maintenance. Each row then is 10 feet of width and 500 feet long. Each building housing the batteries has 10 rows making the building 500 feet long and 100 feet wide. Each row has four containers stacked. This gives us a total of 8,000 containers per building with a total output of 937 GigaWatt hours per building per day.

To meet the storage requirements of 271,000 gWhr of energy for the year 2020 it will take 742.5 gWhr per day. This will require only one building that size. However, it will be much better for the grid to have several smaller buildings in the proper locations.

Figure 7. NaS battery **Figure 8 Battery Container – 96 Batteries**





The capital cost can vary from $120 to $1000 per kWhr output depending on batteries capacity and efficiency, construction, maintenance and location. Most battery producers are estimating less than $200 per kWhr cost once high production is going.

Electrical

Capacitor

Superconducting Magnetic Energy

Neither of these storage sources is practical for long time storage and use for integration with renewables.

Mechanical

Flywheel

Flywheels are efficient storage for fast sources for filling needs for slight power gaps in the UPS. They can only supply the stored power for about 15 seconds. They are not a possible storage source for renewable energy.

Hydraulic

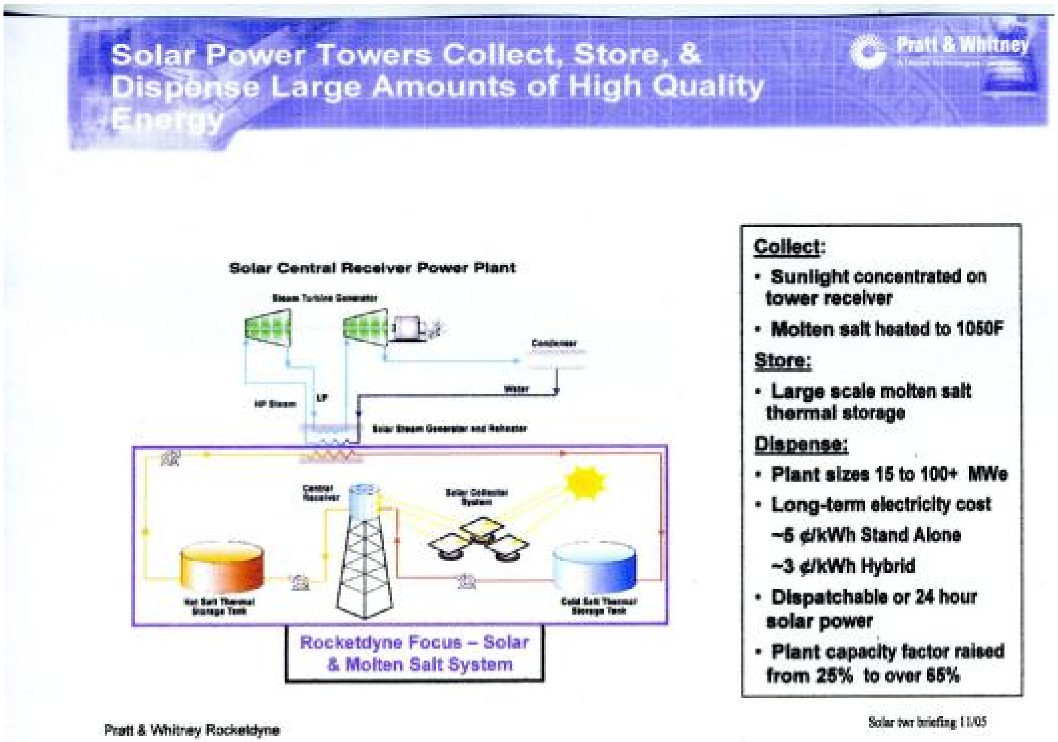
Hydraulic is not a practical storage source for renewables because of low efficiency.

Thermal

Molten Salt

Molten salt is not a good storage source for electrical energy because the energy is used for heating the liquid salt and pumping the carrier into it and out of it to the turbo generator. This makes the efficiency very small. The best use for molten salt and liquid metal storage is to store the heat collected from the sun reflected solar power tower in the solar energy plants as shown in figure 9. These solar storage plants do not solve the energy storage problem since their capacity factor is about 45 to65%. These plants could maximise the capacity factor by storing more energy than they ordinarily use to make electrical energy during the day and use it over a longer time. This will lower the efficiency because of the heat loss over the length of the day.

Figure 9. Solar Power Tower Energy collection, Storage and Electrical Production



Liquid metal

Steam Accumulator

Neither liquid metal nor steam accumulation has been demonstrated as good electrical energy storage systems. Steam storage can be used as a few second energy storage for steam plants.

Hybrid Solar-Gas powered plants

This new concept combines solar power and throttle-able gas turbine power to provide a constant power level as needed on the grid. New plants of this design are being built in Morocco and Israel.

Throttle-able Electrical Energy Sources

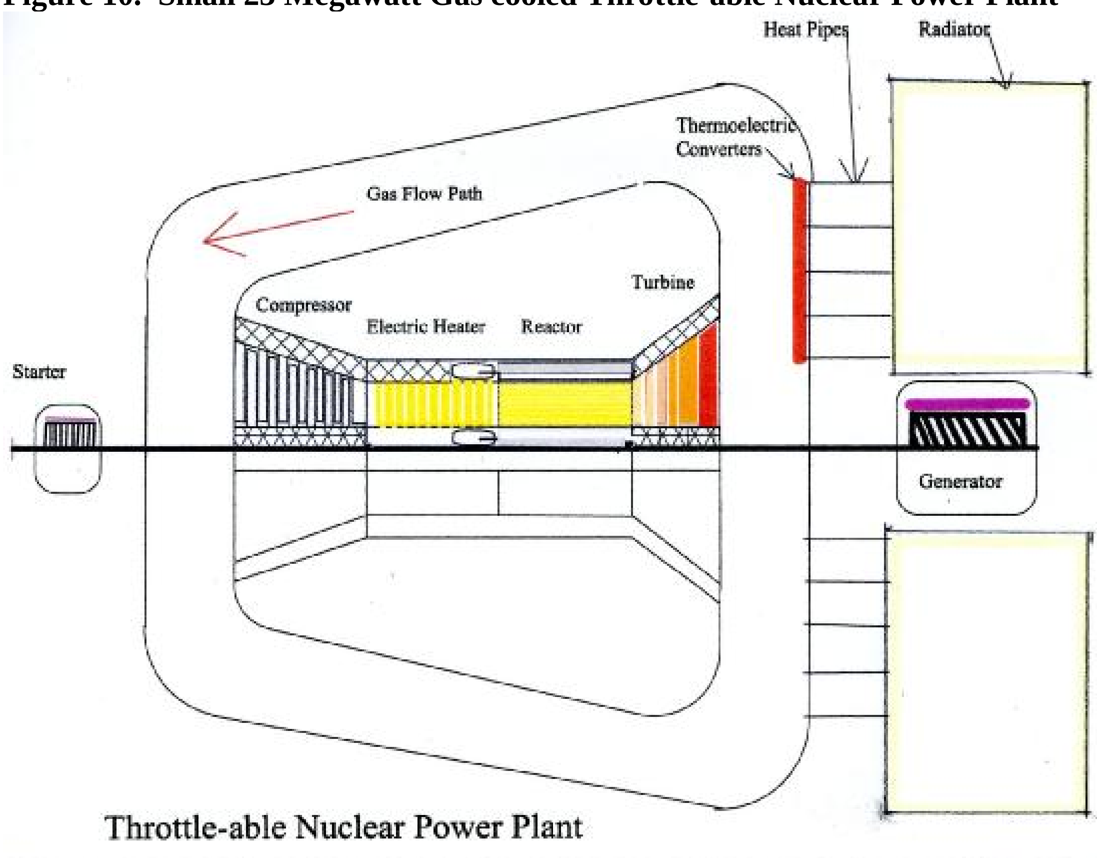
Throttle-able electrical energy sources are sources that can be turned on and off to fill in the energy gap when the sun gradually comes up from and goes toward the horizon and the wind stops and starts blowing. There are two power systems that provide the most throttle-able power today. They are small gas turbine plants and small hydroelectric plants. These can be efficiently used to keep a stable grid load with variable renewable sources Large gas turbine plants can also be used to balance the grid power since they comprise of several small gas turbines.

Small hydroelectric plants can be turned on and off to balance the power produced by wind and solar. It is more difficult to use large hydroelectric plants as throttle-able sources, but it can be done when they have a number of water turbo generators.

Smaller Throttle-able Nuclear Power Plants are More Friendly to the Environment
Some nuclear power plants are under development that may have the potential for being throttle-able and still maintain efficiency and be economical. The ideal design is from 30 to 100 megawatts capacity and be able to be turned on in minutes time, pick up the load onto the grid and be turned off when not needed with solar and wind power prevailing. Some of the small nuclear power plant designs can't be turned on in a few minutes but can be collected in groups and operated in varying percentages of output to the grid. This way they can be integrated with the renewables output variations during the day.

Small Gas Cooled Throttle-able Nuclear Power Plant
Aircraft nuclear plant programs during the 1950s had concepts that could probably fulfill these needs with the improved performance gained with advanced technology over the last 50 years. Figure 10 is a sketch of a small fast reactor nuclear power plant with closed cycle of noble gas going from compressor through electrical heater, fast reactor and through the turbine. The electrical heater is used to start the power in a few seconds. .This system has six 10 megawatt reactors and an electrical output of a little over 23 megawatts with the additional thermoelectric converters...

Figure 10. Small 23 Megawatt Gas cooled Throttle-able Nuclear Power Plant



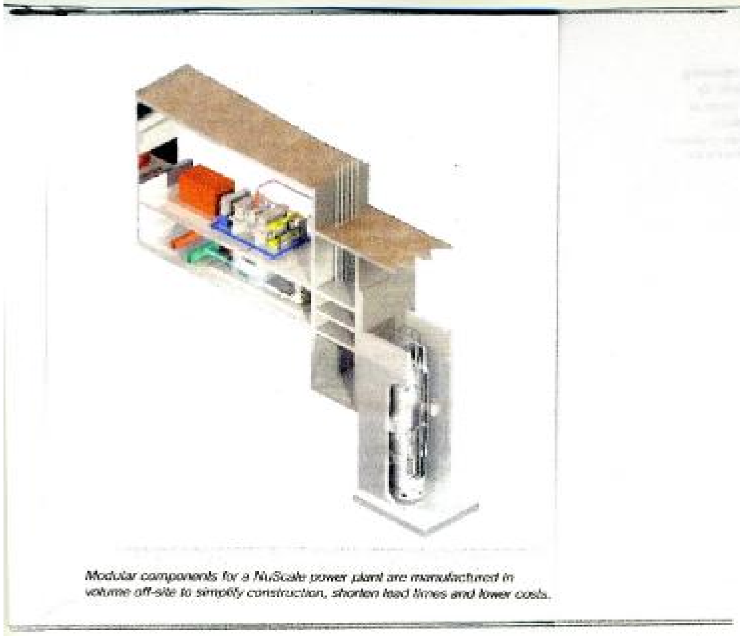
NuScale Nuclear Power Plant.
Another possible small nuclear power plant that can fill the variable needs is the NuScale Power 40 megawatt water cooled reactor. While it will not be efficient to turn on and off in a very few minutes a group of them can be put on the grid and operated on a percentage basis to regulate the input variations from the renewables. The total plant concept and the reactor concept are shown in Figure 11.

Hyperion Nuclear Power Plant
The Hyperion nuclear reactor is a new unique design with uranium hydride fuel. With the hydride fuel and a hydrogen atmosphere inside a hot chamber the reaction is automatically controlled and a very safe system. The heat generated is sent to a heat exchanger to provide steam for a steam turbo generator system. The fuel in the reactor has a performance age of 8 to 10 years. This makes it possible for the reactor to be placed in a chamber underground for a very safe environment. Instead of refueling on site like most nuclear reactors this reactor is replaced after it runs low on energy and the old one is brought back to the supplier factory to be refueled and refreshed for 8 to 10 more years of service at another operation site.

This reactor may not be throttle-able, to the degree of shutting down and starting up in a matter of minutes like gas turbines with efficiency. It can be grouped to 5or 6 and the group output to the grid can be reduced and increased by required percentages to moderate the grid energy efficiently.

Figure 11. NuScale 40 Megawatt Water Cooled Nuclear Plant

Plant Illustration **Reactor Illustration**



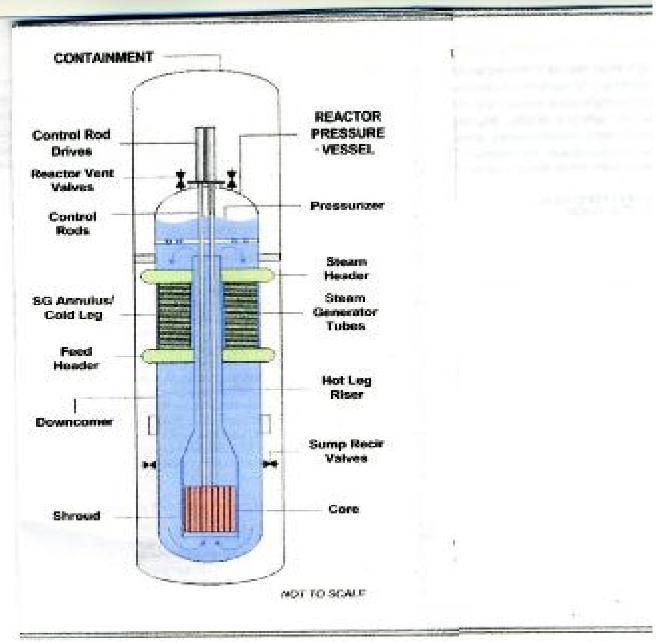
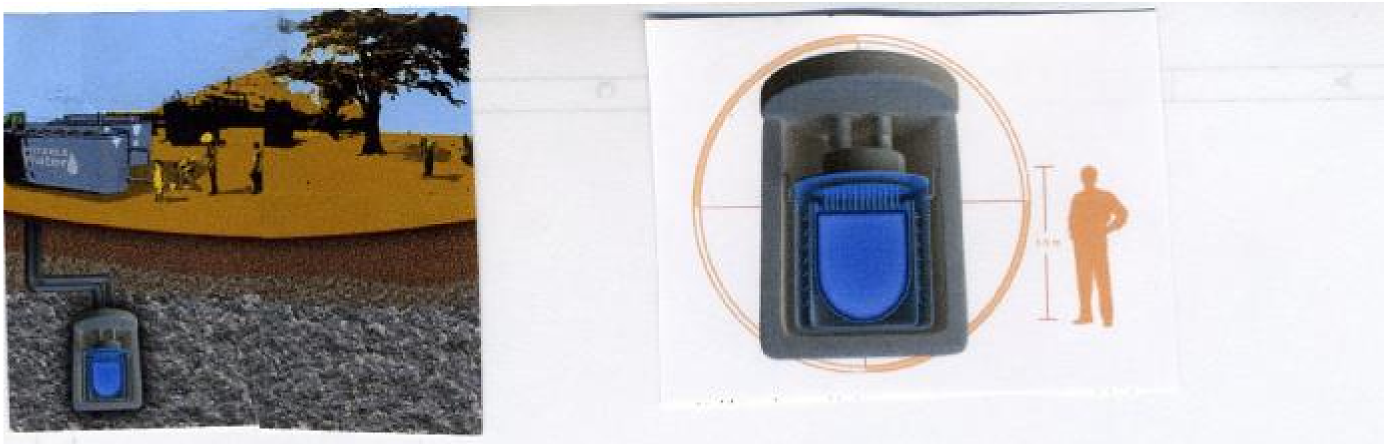
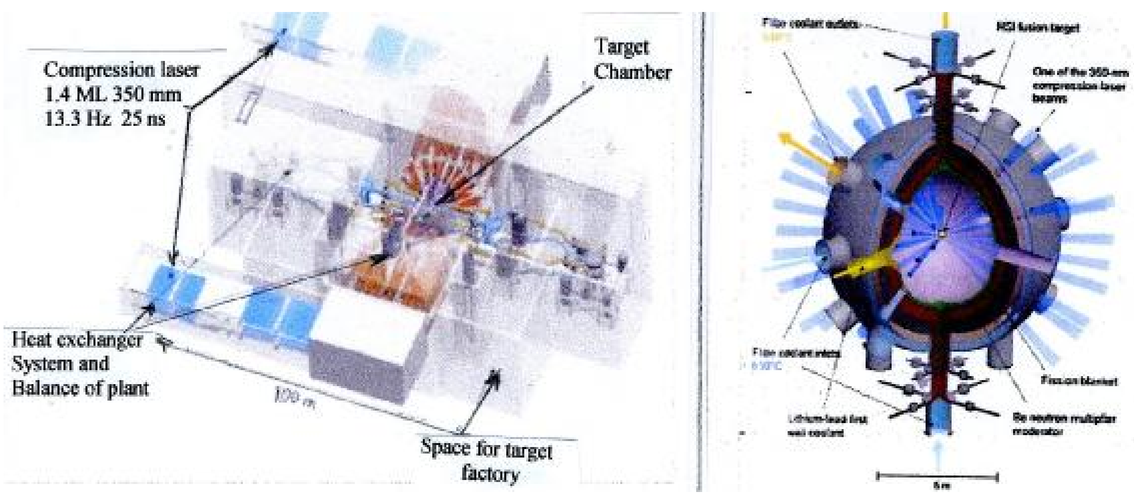


Figure 12. Hyperion Small 40 Megawatt Power Plant with Reactor Under Ground
Power Plant with Reactor Under Ground Reactor & Containment



The LIFE, Laser Initiated Fusion-Fission Energy Nuclear Power Plant
This kind of power plant is under development by The Lawrence Livermore Laboratory and the University of Texas at Austin. The power plant concept and the fission and fusion chambers are shown in Figure 13.

Figure 13. The LIFE Laser Initiated Fusion-Fission Energy Nuclear Power Plant
Power Plant Conceptual Design Target Chamber



This power plant will be a long time in development but it will have many advantages in the future over the regular nuclear plants that use fission only. It does have a major disadvantage in that it may use a significant percentage of its electrical output for powering the laser system to produce fusion energy. A question is whether the plant can be throttle-able. The laser generated fusion can be turned on and off quickly in a matter of seconds. The question is, can an electrical system keep the fission fuel warm enough that the energy extraction can start immediately after the fusion-fission starts.

The current plan for this plant is for it to produce 2000 to 3000 MegaWatts of fission thermal energy from 300 MegaWatts of fusion energy. A plant with 2000 Megawatts of fission thermal energy can produce about 35% of that in electrical energy which is about 700 MegaWatts. There is no complete knowledge of how much electrical energy is needed to power the lasers and provide the pellets for the fusion.. Current plant design concepts cover plants with 200 MegaWatts electrical output to 1000 MegaWatts of output.

One very significant advantage of this kind pf nuclear plant is that it can use many varieties of fuel and it produces a minor amount of actinides that it does not fission away. It can use weapon grade uranium and plutonium, depleted uranium, used nuclear fuel, military radioactive actinide waste and thorium for fuel.

Future Possibilities
It is not known now just what the capability of small nuclear plants is in stabilizing the wind and solar power input to the grid. As the development of these small nuclear plants proceeds and as the increase in renewable energy takes place the advantage of the nuclear power for the environment and the economy will push it forward.

Conclusion

Energy Storage
It should be understood that there are certain complexities in the increase of renewables in our energy production with solar and wind sources. Because of their low capacity factor there is a need to develop energy systems that integrate with their energy into our grids. These required systems are storage and throttle-able energy systems. The only electrical energy storage system that has a lot of use in the world is the pumped storage. Pumped high air pressure has been used, but it proves to be very inefficient. There has been some experience with mechanical flywheel storage for short time requirements. The only storage system for a whole day's requirement in addition to pumped storage is the battery. The two types that are the most forward in development are the sodium sulfur battery and the vanadium redox battery.

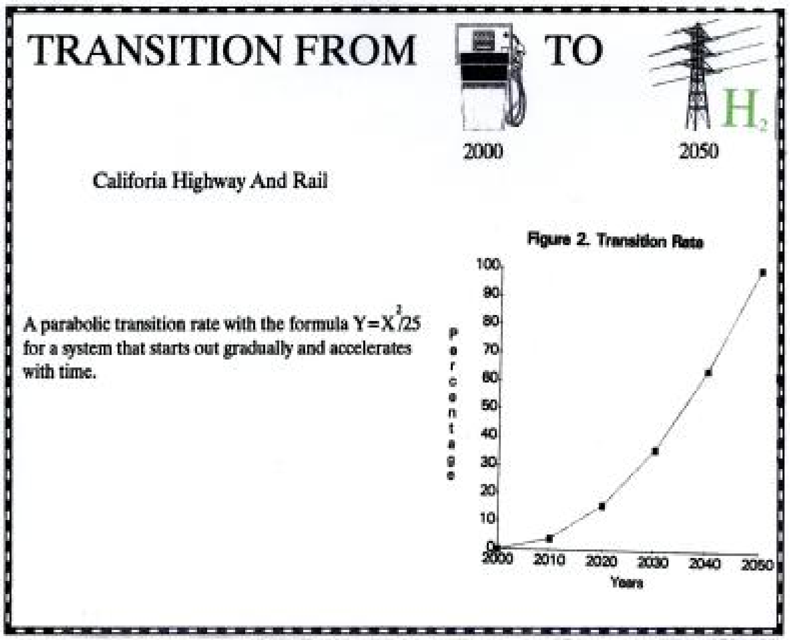
Throttle-able Sources
The definition of throttle-able sources are energy systems that can be turned on and off in a matter of seconds or one or two minutes and or can have their output changed by a significant amount in a short time. This gives them the ability to be used to maintain the required power level on the grid on a timely manner. There are two major sources of throttle-able electric power. They are gas turbines and small hydro plants. Some small coal powered plants are also used. Gas turbines and coal plants put carbon dioxide into the atmosphere.

Large hydropower plants with several small turbines can also be used. Hydropower is getting to be under pressure to be eliminated on many rivers because of their bad effect on fish. Probably the number of small hydropower plants will gradually be eliminated.

More safe, economical, and clean throttle-able sources need to be developed. Small nuclear plants are under development that can probably fill those needs in the future. The four different types of nuclear plants, fission heated gas turbine, fission heated small water cooled, hydride fuel reactors and fusion fission heated systems are the sources that have the potential for filling the needs. Their development should be expedited by the governments, product sources and the electric power companies.

Appendix

Item 1. Transition from Fossil Fuel to Electrical



Item number 1. is a geometric curve showing the rate of change from fossil fuel to electrical power for transportation. This curve is used for the basis for the estimated growth of electrical power use in the future.

Item 2. Energy Sources in the Past

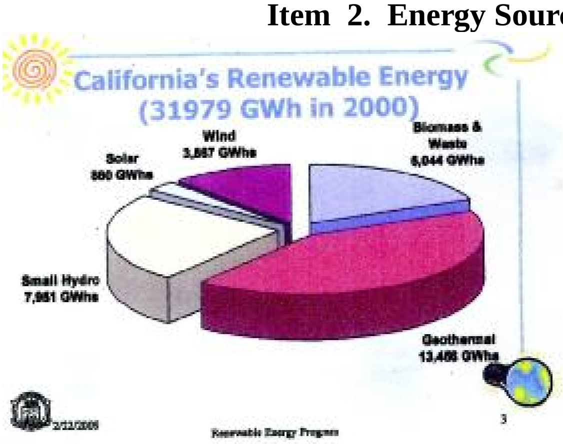


Table 2: 2007 Total System Power in Gigawatt Hours

Fuel Type	In-State	NW	SW	TSP	TSP %
Coal*	4,190	6,546	39,275	50,012	16.6%
Large Hydro	23,283	9,263	2,686	35,232	11.7%
Natural Gas	118,228	1,838	16,363	136,063	45.2%
Nuclear	35,692	629	8,535	44,856	14.8%
Renewables	28,463	6,393	688	35,545	11.8%
Biomass	5,398	837	1	6,236	2.1%
Geothermal	12,999	0	440	13,439	4.5%
Small Hydro	3,675	4,700	18	8,393	2.8%
Solar	668	0	7	675	0.2%
Wind	5,723	857	222	6,802	2.3%
Total	209,856	24,669	67,547	302,072	100.0%

Source: EIA, QFER and SB 105 Reporting Requirements

*Note: In earlier years the in-state coal number included coal fired power plants owned by California utilities.

Item 3. Estimated Energy Mix for 2020 and beyond with 33% renewables

Based on a scenario released by the California Independent System Operator on July 21st of this year, CEERT devised its own scenario of what California's mix of renewable energy resources might be with a 33 percent RPS by 2020. The result of this CEERT scenario is depicted in Figure 3.

Because renewable energy fosters greater economic development benefits than traditional fossil fuels, California has been missing out on an opportunity to bolster its economy through a renewable energy renaissance.

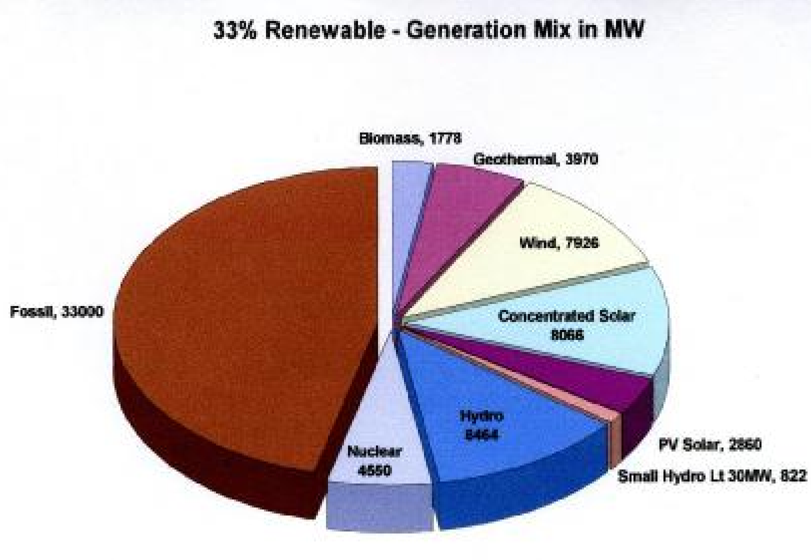


Figure 3 - 33% Renewables Resource Scenario (Source: CEERT)