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Coupling Renewables via Hydrogen into Utilities:
Temporal and Spatial Issues, and Technology
Opportunities

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COUPLING RENEWABLES VIA HYDROGEN INTO UTILITIES: TEMPORAL AND SPATIAL ISSUES, AND TECHNOLOGY OPPORTUNITIES

EXECUTIVE SUMMARY

The primary goal of this project has been to estimate the technical potential for systems comprised of renewable electricity generation and energy storage using hydrogen production, storage, and electricity conversion to meet some or all of a region's demand for electricity. Objectives were to evaluate regional capacity requirements for: renewable electricity generation and hydrogen storage reservoirs required to store renewable energy for use during low resource periods. As an extreme case the combinations of renewable capacity and hydrogen storage necessary to serve each region's entire load was calculated. Backing down from that maximum penetration, the same sizing algorithms were used to serve 80%, 60%, 40%, and 20% of the annual energy requirement.

The basic assumption in this approach is that renewables provide the "primary" energy and hydrogen storage is employed to compensate for time-related mismatches between renewables production and electric loads.

For intermittent renewables, hour-by-hour simulations were used to model the time dependence of three leading technologies—wind, photovoltaics, and solar thermal—in various regions of the U. S. Renewables' regional electricity production patterns were compared to local annual electric load demand shapes.

Figure S-1 shows the schematic model which simulates the flow of energy from the renewables plant to the regional load. The model determines how much renewable resource (e.g. peak megawatts and hence, the land area) is required to meet the specified load pattern, taking into account the temporal mismatch between the source and the load, placing the excess energy into storage as hydrogen.

Analysis for intermittent renewables yields:

- installed capacity of renewables generation
- hydrogen production capacity (via electrolysis)
- hydrogen storage capacity
- fuel cell generation capacity required in each region to meet the demand

For baseload renewables such as hydroelectric power, a simple annual energy production analysis was undertaken.

Figure S-1 Modeling Elements

The amount of renewable capacity required to meet the load depends on several variables:

- 1) the peak load requirements in the region and the annual energy consumed
- 2) the pattern of energy consumption as compared to the renewable supply pattern, in that poor temporal matching forces more energy to pass through the hydrogen storage unit and suffering its efficiency losses

The number of hours of hydrogen storage required depends primarily on the temporal match between the load and the renewable supply pattern.

The requirement to supply 100% of a region's load is fairly unrealistic, therefore a sensitivity was performed to supplying fractions of that load. To do so, hour-by-hour simulations are undertaken for regional peak loads whose magnitudes have been reduced such that the renewables/hydrogen storage system meets only a portion of annual energy needs (i.e., 20%, 40%, 60%, and 80% of full annual electric energy use).

For each renewable technology, regional estimates have been developed for maximum hydrogen production per year and alternative ranges of hydrogen storage

capacity needed in each year (for intermittent renewables). An energy flowchart for the model is shown in Figure S-2.

Electric peak load in each region is projected for the year 2010, and that year is used as a basis for all analysis. No economic analyses were performed in this study, since the scope of work only includes the technical feasibility and sizing of the components required to supply the loads with electricity.

Figure S-2 Energy Flowchart

The analysis results indicate a potentially large market for hydrogen technologies in this application.

There is a very important family of storage and renewables combinations which are all perfectly feasible. It would take an economic analysis to select which of these pairs is optimal, but because the storage requirements decrease so quickly with small increments of renewables capacity beyond the critical size, the optimal economic solution is almost certainly not the critical renewables and critical hydrogen storage plant combination.

To allow the reader to appreciate the tradeoff between storage sizes and renewable plant over-sizing, in all cases the full set of storage and renewables combinations beyond the "critical" sizes is calculated and presented.

The results for the critical case (minimum renewable resource and maximum storage) are shown in Figure S-3.

Figure S-3 Results

Each of the renewable/region combinations has its own requirements for hydrogen storage due to a unique matching between load and resource patterns. Wind requires the least storage capacity primarily due to its higher capacity factor.

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ABSTRACT

In this project, we show the technical potential for hydrogen used as an energy storage medium to couple time-dependent renewable energy into time-dependent electric utility loads. This technical analysis provides estimates of regional and national opportunities for hydrogen production, storage and conversion, based on current and near-term leading renewable energy and hydrogen production and storage technologies. Appropriate renewable technologies have been matched to their most viable (high quality and quantity) regional resources (e.g., examining wind electricity production in high wind resource areas only). The renewables are assumed to produce electricity which is instantaneously used by the local utility to meet its loads; any excess electricity is used to produce hydrogen electrolytically and stored for use later in the day, week or year. The hydrogen production from renewables and hydrogen storage use are derived based on a range of assumptions of renewable power plant capacity and fraction of regional electric load to be met (e.g., the amount of hydrogen storage required to meet the Northwest region's top 20% of electric load). Renewable production/utility load/hydrogen storage coupling models have been developed for wind, photovoltaics, and solar thermal. Hydro power (which normally has its own inherent storage capability) has been analyzed separately.

1

INTRODUCTION

The primary goal of this project has been to estimate the technical potential for systems comprised of renewable electricity generation and energy storage using hydrogen production, storage, and electricity conversion to meet some or all of a region's demand for electricity. Objectives were to evaluate regional capacity requirements for: renewable electricity generation and hydrogen storage reservoirs required to store renewable energy for use during low resource periods. As an extreme case the combinations of renewable capacity and hydrogen storage necessary to serve each region's entire load was calculated. Backing down from that maximum penetration, the same sizing algorithms were used to serve 80%, 60%, 40%, and 20% of the annual energy requirement.

The basic assumption in this approach is that renewables provide the "primary" energy and hydrogen storage is employed to compensate for time-related mismatches between renewables production and electric loads.

For intermittent renewables, hour-by-hour simulations were used to model the time dependence of three leading technologies—wind, photovoltaics, and solar thermal—in various regions of the U. S. Renewables' regional electricity production patterns were compared to local annual electric load demand shapes.

Figure 1-1 shows the schematic model which simulates the flow of energy from the renewables plant to the regional load. The model determines how much renewable resource (e.g. peak megawatts and hence, the land area) is required to meet the specified load pattern, taking into account the temporal mismatch between the source and the load, placing the excess energy into storage as hydrogen.

Analysis for intermittent renewables yields:

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The amount of renewable capacity required to meet the load depends on several variables:

- 1) the peak load requirements in the region and the annual energy consumed
- 2) the pattern of energy consumption as compared to the renewable supply pattern, in that poor temporal matching forces more energy to pass through the hydrogen storage unit and suffering its efficiency losses

The number of hours of hydrogen storage required depends primarily on the temporal match between the load and the renewable supply pattern.

The requirement to supply 100% of a region's load is fairly unrealistic, therefore a sensitivity was performed to supplying fractions of that load. To do so, hour-by-hour simulations are undertaken for regional peak loads whose magnitudes have been reduced such that the renewables/hydrogen storage system meets only a portion of annual energy needs (i.e., 20%, 40%, 60%, and 80% of full annual electric energy use).

For each renewable technology, regional estimates have been developed for maximum hydrogen production per year and alternative ranges of hydrogen storage capacity needed in each year (for intermittent renewables). Electric peak load in each

region is projected for the year 2010, and that year is used as a basis for all analysis. No economic analyses were performed in this study, since the scope of work only includes the technical feasibility and sizing of the components required to supply the loads with electricity. However, a very interesting quasi-economic effect needed to be explored to show a full range of reasonable storage sizes and renewables sizes:

Consider trying to serve all of a given temporal load with a very small renewables plant, clearly there will not be enough energy collected over the year to meet the full load, no matter how much storage is included. Now add renewable capacity until just enough energy is collected to meet the annual load (of course including inefficiencies of going through hydrogen storage as needed); this marginally acceptable ("critical") renewables capacity requires the most storage that could ever be useful for that load and renewable combination, thus it is the extreme ("critical") case of storage capacity. But there are many other combinations of storage and renewables capacities which will also meet the annual load, but require discarding energy at some points during the year. As renewables capacity is increased beyond the absolute minimal requirement, the amount of storage required drops dramatically. Now consider the theoretical case of an enormous renewables plant which requires a minimal storage capacity; that capacity is the length of the longest period in the year without renewable resources available.

Thus there is a very important family of storage and renewables combinations which are all perfectly feasible, but collect slightly more renewable energy than the minimum required. It would take an economic analysis to select which of these pairs is optimal, but because the storage requirements decrease so quickly with small increments of renewables capacity beyond the critical size, the optimal economic solution is almost certainly not the critical renewables and critical hydrogen storage plant combination.

To allow the reader to appreciate the tradeoff between storage sizes and renewable plant over-sizing, in all cases the full set of storage and renewables combinations beyond the "critical" sizes is calculated and presented.

2

MODELING APPROACH

2.1 General modeling assumptions

The energy flow paths for the analysis model are shown in Figure 2-1. The renewable energy converted to electricity eventually finds its way to the load either (a) directly through the transmission and distribution system or (b) by going through the electrolyzer and hydrogen storage to be delivered later in the year. The decision as to which of these paths is correct for any energy collected by the renewables plant cannot be predicted in advance. The model has as its first priority serving the regional load, placing any excess energy into storage for later dispatch. If there is sufficient energy in storage to meet the regional load, storage is decreased by the amount required.

*(if needed)

Figure 2-1 Energy Flowchart

In the case that insufficient energy is available from the renewable and/or storage, the choice of renewable plant size is deemed insufficient and the annual simulation is abandoned and the renewable plant size is increased for another simulation attempt.

There are three types of evaluations made by DUA's GenStorCalc model, the MS Excel spreadsheet used to perform the analysis.

First the spreadsheet undertakes a base case sizing for a given generation resource hourly production profile, electric hourly demand profile, and annual maximum demand for electricity (e.g. for the region under investigation).

Note that at this scale, the shape is dominated by annual storage needs and that daily variations appear small. Note also that daily filling and emptying of storage determines the electrolyzer size and that most hydrogen is created and used daily.

Figure 2-2 Daily State-of-charge for the Energy Storage Reservoir, in MWh/MW_{load}

Second, as shown by the chart and numeric values in Figure 2-3, the spreadsheet calculates storage reservoir size needed to satisfy all of a region's electricity demand given various degrees of "oversizing" of the generation resource (nameplate generating capacity). Oversizing is relative to the generation resource capacity calculated during the base case sizing, described just above.

The Resource Oversizing table in Figure 2-3 shows: 1) generation resource oversizing *factor*, 2) the resulting resource nameplate generation *capacity* (base case capacity times oversizing factor), 3) the smallest energy storage *reservoir size* needed to meet all energy demand given the oversized generation resource, and 4) the amount of *energy* that is stored throughout the year.

Figure 2-3 Results for Resource Oversizing and Levels of Energy Demand Served

Third, GenStorCalc calculates the generation and storage capacity needed to meet only a *portion* of the total use of electric energy within a given region. For this study, sizing is undertaken for resource/reservoir capacity needed to supply 100% of energy used throughout the year, for 80%, for 60%, for 40% and for 20%. Typical results are shown in the Resource and Reservoir Capacity for Various Levels of Energy chart in Figure 2-3.

The Levels of Annual Energy Served table in Figure 2-3 shows: 1) portion (%) of all annual demand for electric energy met by the generation/storage plant, 2) the smallest generation resource nameplate generation capacity needed to meet the specified portion of annual energy use, and 3) the smallest energy storage reservoir size needed to meet the specified portion of annual energy use.

2.2 Modeling Assumptions

All calculations are made with the following expressed or implicit assumptions:

1. specified efficiency of converting the generation's electric energy to hydrogen
2. specified efficiency of placing hydrogen into and taking it out of the storage reservoir
3. specified energy losses associated with transmitting and distributing electricity using a grid
4. specified efficiency of converting hydrogen into electricity, via fuel cells, for times when the (hydrogen storage) reservoir must supply some or all of the energy needed by customers
5. all renewable generation resources: a) are available in sufficient quantities to satisfy all demand and b) have characteristics consistent across the entire resource base
6. time zone effects are ignored
7. effects associated with generation and/or T&D outages are ignored
8. the hydrogen taken from the storage reservoir is assumed to be converted to electricity using nearby fuel cells
9. regional *peak load* is determined for the year 2010 although load *profiles* used are for 1994. It is assumed that that profile still applies in the year 2010. The maximum load associated with the profile for 2010 is based on load projections from the North American Electric Reliability Council (NERC)

2.3 GenStorCalc Model Description

2.3.1 Inputs and Outputs

Figure 2-4 shows key numeric inputs to and outputs from GenStorCalc. On the left side of the data table, the top item is the name of the region being evaluated. Hourly electric demand and hourly generation output profiles for an entire year (not shown) are used to determine the hour-by-hour match between load and renewable generation output for the region specified. In other words, for each hour in the year (8760) GenStorCalc contains an hourly value for electric *demand* and for the same hour, a value for *production* from a renewable energy generator in the same region.

WSSCs			Reservoir Size:	511.56	MWh
			0th Hour Energy	195.11	MWh
Resource Tech:	Solar Thermal		Annual Max:	511.6	MWh
Year:	2010		Annual Min:	0.00	MWh
Region Peak Load	70,000	MW	Present State, Last Hr:	195.13	MWh
Block Size (MW):	100	MW	Reservoir "Ceiling Size"	511.6	MWh
Resource to Load Eff.	0.96		Last Hour minus		
Resource into			0th Hour (Stored)":	0.02	MWh
Storage Eff.	0.89		Max. Hourly Charge:	2.029	MWh
Storage to Load Eff.	0.64		Annual Energy Stored:	3.73	GWh
Resource Capacity	2,840	MW	Annual Load Factor:	.58 (5,084 MWh / MW)	
(All values per MW of Load)			Annual Capacity Factor:	.3 (2,623 MWh / MW)	

Figure 2-4 GenStorCalc Key Inputs and Results

Year

The year data item indicates the year for which the analysis is being undertaken.

Region Peak Load

Region peak load is the maximum projected demand for *power* (i.e., for generation *capacity*) in the region.

Block Size

Block size is used to specify size increments of renewable nameplate generation capacity that can be installed. For example, for this study, it is assumed that renewable generation is added in 100 MW "blocks."

Note that the spreadsheet performs most calculations per unit of electric power requirements (load), in units of MW. For example, a generation resource of 2.8 MW and a reservoir capacity of 512 MWh indicates that 2.8 MW of generation capacity and 512 MWh of reservoir capacity respectively are required to produce and to store all electric energy needed to serve 1 MW of peak load within a region. Also calculated are generation and reservoir capacity needed to meet all energy needs within a region for an entire year.

Totals	
<i>Per MW_{Load}</i>	
Resource	2.84 MW
Reservoir	.5116 GWh
H ₂ Stored	3.73 GWh
<i>Gross</i>	
Resource	198,790.8 MW
Reservoir	35,809 GWh
H ₂ Stored	261,106 GWh
<i>Blocks (100MW)</i>	
Resource Blocks	1,987.9
Reservoir/Blk	358.1 GWh
H ₂ Stored	2,611.1 GWh

Figure 2-5 Example Results Calculated Three Ways

Resource-to-load Efficiency

Resource-to-load efficiency is the annual average efficiency of the T&D system (when transmitting electric energy from the theoretical electrical “center” of the T&D system to an average node in the T&D system.) An efficiency of 96% means that 4% of energy generated is lost during transmission and distribution to customers.

Resource-into-storage Efficiency

Resource-into-storage efficiency is the annual average efficiency of the process of converting electric energy into hydrogen and then storing the hydrogen. This is a function of: 1) the electrolyzer used to convert water into hydrogen (and oxygen) using electricity from the renewable resource, and 2) frictional and pumping related losses associated with transporting and storing the hydrogen. An efficiency of 89% means that 11% of all energy from the renewable resource used to produce hydrogen is lost when converting electricity into hydrogen and then storing the hydrogen in the reservoir.

Storage-to-load Efficiency

Storage-to-load efficiency is the annual average efficiency of the portion of the system involving discharge and transmission of hydrogen (from the reservoir) and conversion of hydrogen to electricity to meet electric demand. This is a function of: 1) frictional and pumping related losses associated with discharging and transporting (in a pipeline) hydrogen to the conversion device (fuel cell) and 2) conversion efficiency of the fuel cell used to transform hydrogen into electricity. An efficiency of 64% means that 36% of all energy taken from the reservoir is lost when removing hydrogen and then converting that hydrogen into electricity.

Resource Capacity

The data item named Resource Capacity is the nameplate output rating of the generation resource. A value of 2.84 indicates that for each MW of peak electric load the renewable/hydrogen storage system would have to have 2.84 MW of generation capacity to meet all energy requirements. This is the amount of renewable energy resource generation capacity (nameplate rating) that is needed to serve 1 MW of peak load. In other words, 284 MW of renewable resources (nameplate generation capacity) is needed to serve each 100 MW segment of a region's peak load.

Reservoir Size

The Resource Capacity data item shown in Figure 2-3 is the size of the energy storage reservoir in terms of energy (MWh) which, when coupled with the resource capacity described just above meets all annual energy needs associated with 1 MW of peak electric load. A value of 512 indicates that to serve each MW of peak electric load within the region being investigated the renewable/hydrogen storage system would have to have 512 MWh of reservoir storage capacity to provide all energy needed. (This can also be stated as 512 hours during which peak load can be served by the reservoir.)

Annual Max

This value indicates the largest amount of energy that is in the reservoir during any hour of the year. After a two pass sizing this number is equal to the Reservoir Size.

After a two pass sizing this should be equal to the size of the reservoir, indicating the size of the reservoir needed to store enough energy from the generation resource throughout the year serve all regional energy needs throughout the year.

Annual Min

This value indicates the smallest amount of energy that is in the reservoir during any hour of the year.

After a one pass sizing this value may be negative. The negative value means that that amount of energy *would* have been used to meet demand if it were available. For the next pass (of a two pass sizing) this "negative energy" specified must be offset by the same amount of real energy—it is provided as 0th hour energy placed into the reservoir before the year starts. (In practice it is common to charge a storage plant before it is placed into commercial operation.)

After a two pass sizing Annual Min should be zero. (Actually GenStorCalc allows this value to be within +/-1% of the reservoir size.) A zero value indicates that: 1) the reservoir was just large enough to serve all energy needs, and 2) just enough energy was stored throughout the year (including 0th hour energy *and* energy

produced by the generation resource) to serve all regional energy needs throughout the year.

Present State, Last Hour

Present State, Last Hour is the amount of energy that is left in the storage plant at the end of the last hour of the year. The sizing logic compares this value to the 0th hour energy amount to determine whether the sizing is complete. Please see a more detailed discussion of this topic in the *Resource and Reservoir Sizing Logic* section below.

Reservoir Ceiling Size

When calculating the storage reservoir capacity needed for a pre-specified generation capacity (e.g. for an oversized resource) GenStorCalc must determine the smallest possible reservoir size that satisfies demand for electricity. This is done by testing increasingly larger reservoir sizes to find the first (i.e., lowest) acceptable value. To do this the spreadsheet increases the reservoir ceiling size until all electricity demand is met (again, given the specified resource generation capacity). This calculation is different from a two pass sizing which determines both generation capacity *and* reservoir capacity; in this case generation capacity is fixed.

Last Hour minus 0th Hour (Stored)

Last Hour minus 0th Hour (Stored) is the difference between the amount of energy stored as the year begins (hour 0) and the last hour of operation in the year (hour 8760). The sizing logic compares the 0th hour energy value to the amount of energy that is left in the storage reservoir at the end of the last hour of the year. Please see a more detailed discussion of this topic in the *Resource and Reservoir Sizing Logic* section below.

Max Hourly Charge

The largest amount of energy placed into the reservoir during any one hour of the year is the Max Hourly Charge. That value indicates the size of the electrolyzer which produces hydrogen from water and electricity. For the example shown in Figure 2-4 the value 2.029 MWh indicates the largest amount of energy that is placed into the reservoir during one hour of the year. That also indicates that the electrolyzer must be rated at 2.029 MW (of hydrogen production) to be able to produce that much hydrogen (during a one hour period) to be stored.

Annual Energy Stored

Annual Energy Stored is the amount of hydrogen that was placed into the reservoir throughout the year. In the example shown in Figure 2-3 there was 3.73 GWh of (hydrogen) energy stored during the year.

Annual Load Factor

This number specifies the ratio of the average load (MW) to the peak load (MW_p) in the region. For the example shown the load factor is .58.

Annual Capacity Factor

This value specifies the ratio of the average power production (MW) from renewable generation to maximum power production (MW_p) in the region. For the solar thermal example shown, the load factor is .3.

2.3.3 Reservoir Fill Logic

Figure 2-6 below shows a portion of the calculation engine in the spreadsheet. There are 24 columns (one for each hour of the day, only six are shown in the figure below) and 365 rows (one for each day of the year, only six are shown in the figure below), for a total of 8760 cells, one for each hour of the year.

Hour-> Day #	1	2	3	4	5	6
Min	3.98	3.31	2.87	2.03	1.38	0.80
Max	504.23	505.52	504.82	504.11	503.34	502.62
1	194.448	193.82	193.22	192.63	192.04	191.42
2	195.14	194.56	193.98	193.39	192.79	192.13
3	192.23	191.61	191.01	190.41	189.81	189.20
4	193.94	193.22	192.61	192.01	191.41	190.78
5	178.52	177.91	177.29	176.68	176.03	175.28
6	157.50	156.87	156.24	155.62	154.94	154.18

Figure 2-6 Portion of 8760 Reservoir State Cells in the Spreadsheet

The value in a given cell indicates the state-of-charge of the reservoir at the end of a specific hour during the year (there are 8760 cells, one for each hour of the year). What happens in a given hour (either energy is stored in the reservoir or is taken out of the reservoir) is determined based on the logic shown in Figure 2-6.

Note that in parts of the spreadsheet (not shown here) there are hourly load and hourly generation production values. These indicate the energy production from the generator and the energy used by customers, respectively, within a given hour of the year. Those hourly values are used as indicated in the Figure 2-7 below to determine the storage reservoir's state of charge in a given hour.

Resource and Reservoir Sizing Logic

The spreadsheet performs a two pass sizing. During the first pass it determines the resource size and reservoir size as well as the amount of energy which must be

stored before the first hour of operation (known to the spreadsheet as 0th hour energy). The second pass accommodates the need for the as 0th hour energy by adding energy needed (to meet demand) as determined during the first pass.

Figure 2-7 Reservoir Fill Logic

The amount of generation resource capacity needed (to meet a given level of demand for electricity in a given region) is determined by seeking the generation resource capacity size which, when coupled with an energy storage reservoir provides all energy needed throughout the entire year. To do this, the sizing routine increases the nameplate capacity of the generation resource until the end state (energy stored at the end of the last hour in the year) and the beginning state (hour 0) in the reservoir are equal, indicating that all energy required was supplied. (Note: Mathematically there may be more than one storage reservoir capacity/size that will meet electricity demand given a specific generation resource capacity/size—GenStorCalc calculates the *lowest* value (i.e., the smallest reservoir size possible).)

After the first of two passes (for a two pass sizing) two key results are: 1) the amount of generation capacity needed to satisfy regional electricity demand throughout the year, and 2) the amount of energy that must be placed into the reservoir before it begins operation to serve load (hour 0 energy).

The amount of 0th hour energy that must be placed into the reservoir is indicated by a negative value in the Annual Min field. This negative energy indicates the result of chronological discontinuities between energy production, storage, and use. Specifically, although the generation plant (as sized) provides all energy needed *within* the year, the generator may not have provided enough energy during the beginning of the year when needed. For example, if most energy is used in the Spring but most energy is produced in the Fall then the storage plant needs enough

“pre-stored” energy to serve load during Spring months before the generator plant has an opportunity to produce needed energy.

For the next pass this “negative energy” is offset by the same amount of actual 0th hour energy which is put into the reservoir before the first hour of the year begins. (Storage plants are often charged before being placed into operation.)

After the second pass, GenStorCalc has calculated the energy storage reservoir size needed, given the resource capacity and 0th hour energy needs calculated during the first pass. Also calculated during the second pass are: Max Hourly Charge and Annual Energy Stored.

2.3.4 Resource Oversizing

To determine the energy storage (reservoir) capacity requirements needed to satisfy all of a region’s electricity demand given various degrees of “oversizing” of the generation resource (nameplate generating capacity) GenStorCalc begins with a storage capacity of 1 MWh (per MW of peak load). It increases that storage (reservoir) capacity until all energy required to meet demand is provided (by the oversized generation resource and the “corresponding” storage reservoir size). Resource size (capacity, MW per MW of peak electric load) and reservoir size (capacity, MWh per MW of peak electric load) are plotted as shown in Figure 2-2.

As discussed in the description of the Reservoir Ceiling Size data item above, when calculating the storage reservoir capacity needed for a specific generation capacity, in this case an oversized resource, the spreadsheet calculates the smallest possible reservoir size. To do that, GenStorCalc tests increasingly larger reservoir sizes (by increasing the value in the Reservoir Ceiling Sizes data item) until it finds the first (i.e., lowest) reservoir size that will meet demand. This type of sizing is different from a two pass sizing yields both generation capacity and reservoir capacity; resource oversizing requires that the generation capacity be fixed/specified.

2.3.5 Serving a Portion of Annual Energy Demand

To determine the hourly energy requirements associated with a portion of annual energy requirement GenStorCalc begins by scaling (down) the load profile (i.e., hourly demand values) for the region such that the energy required throughout the entire year is equal to the target amount. This is done on a day-by-day basis. That is, the spreadsheet determines the electric load for each day of the year that cannot be exceeded (during that day) such that only the target amount of energy is used within that day.

After scaling the energy demand profile, the spreadsheet sizes the resource generation capacity and storage reservoir capacity so they can provide that *portion* of the region’s annual electric energy use. As shown in Figure 2-3, GenStorCalc charts

results for: 1) MW of resource capacity and 2) MWh of storage capacity needed to provide the specified portion electric energy used in the region being considered.

Note that for this study, as shown in Figure 2-8, the energy not served was energy that would have been used during "peak load" periods. That is, energy not served was "shaved" from the top of the load profile. (The other likely alternative is to not serve same amount of energy from each hour during the day—that would comprise reduction of "base load" energy.) Also note that the resource capacity and reservoir capacity calculated would be different depending upon which energy is not served.

Figure 2-8 Peak Load and Base Load Energy Use Reduction

For this study, for each region, resource/reservoir capacity sizing is undertaken for 100% of energy used throughout the year (base case, no scaling), for 80%, for 60%, for 40% and for 20%. Typical results are shown in the Resource and Reservoir Capacity for Various Levels of Energy chart in Figure 2-3, on the right hand side. For the example shown there, as the portion of annual energy served decreases to 20%, lower renewable resource requirements and by hydrogen storage capacities are needed.

3

HYDROGEN SYSTEM TECHNOLOGIES

3.1 Hydrogen Technology Descriptions

Coupling time-varying renewable resources to a time-varying electric load using hydrogen to manage the time variation requires a multitude of technologies. For the analysis presented in this report, assumptions were made regarding technology choices and performance parameters. Assumptions regarding the renewable technologies, i.e. photovoltaics, wind, and solar thermal, are described in section 4. Converter technologies were not considered in detail; rather, a 2% inefficiency was assumed for ac-dc conversion and for dc-ac conversion.

The hydrogen system components are the electrolyzer, which uses dc electricity to convert water to hydrogen and oxygen; the storage system; and the fuel cell unit, which produces electricity from hydrogen and air. These components and the selection of baseline assumptions for the project analysis are described in the following sections.

3.1.1 Electrolysis Technologies

In this study, we assume that all hydrogen production is accomplished by water electrolysis using electricity generated by the renewable resource. Other methods of hydrogen production, such as direct solar electrolysis or other innovative approaches, are not considered because of the large-scale need and the near-term time frame. Also, reforming of methane or other hydrocarbons was not considered, as in this study we intended to consider only a completely renewable system with no other fuels included.

In electrolysis, water molecules are split into gaseous hydrogen and oxygen molecules by passing dc electricity through an electrolyte. The most commonly available commercial systems use an aqueous alkaline electrolyte containing potassium hydroxide. Asbestos diaphragms separate the anode and cathode and prevent the remixing of hydrogen and oxygen.

Commercially available electrolyzers generate hydrogen at 30 to 130 psig [1]. These systems are used primarily to produce high purity hydrogen for chemical processes.

A number of companies sell alkaline electrolysis systems worldwide. A few have expressed interest in meeting the needs of a hydrogen energy economy through large manufacturing systems.

Another type of electrolyzer, the proton exchange membrane (PEM) electrolyzer has been developed for closed cycle applications, primarily naval and space craft power [2], in which regenerative combinations of electrolyzer and fuel cells are useful. PEM electrolyzers use solid polymer electrolytes made of special materials called perfluorocarbon ion exchange membranes. The possible advantage of a PEM electrolyzer in the future is reduced cost (although today's systems require platinum catalysts), and reversible operation. The Solid Polymer Electrolyzer (SPE®) developed by United Technologies Corporation is specifically intended for reversible use. PEM electrolyzers are currently only available in relatively small sizes, however. Characteristics of available electrolysis technologies are listed in Table 3-1.

Table 3-1. Electrolysis Technologies

Technology	Maximum Unit Size (MW)	Efficiency (kW _{out} / kW _{in})	Footprint (ft ² /kW)
Alkaline	5 - 10 [1]	80 - 90 [2]	1.5 [3]
Solid Polymer Electrolyzer	0.1 [4]	87 - 94 [2]	1.5 [5]

3.1.2 Storage Technologies

Hydrogen can be stored in many different ways. These include:

- In underground reservoirs, similar to natural gas
- As compressed gas in pressurized containers such as steel or carbon-wound cylinders
- As liquefied hydrogen in cryogenic tanks
- As a metal-complex in hydride compounds
- Within a matrix of carbon filaments
- In glass microspheres which serve as tiny pressure vessels.

Underground storage is suitable for large quantities of hydrogen gas at relatively low pressure. Compressed gas cylinders are typically employed for fleet storage or process plants. Liquid storage is the most compact form commercially available and is used for transportation applications. Hydride and carbon storage have good potential for efficient, compact storage, but are currently in the development stage. Heat is required to release the hydrogen from storage. In microsphere storage, tiny glass beads are filled by diffusion at modest temperature and pressure. The greatest advantage is one of safety in that only tiny amounts of hydrogen are stored in each sphere. Others are high efficiency and high volumetric density. Some heat is required to release the hydrogen if the spheres are to be reused.

Different forms of hydrogen storage are often compared on the basis of volumetric density, as shown in Figure 3-1. For bulk storage this is important, but not as critical as it is for transportation applications. Manufacturing of these in large quantities is currently being developed. The characteristics of various forms of hydrogen storage are given in Table 3-2.

Figure 3-1 Hydrogen storage comparison

Table 3-2. Storage Technologies

Technology	Maximum Unit Size (MWh)	Efficiency , % (kWh _{out} / kWh _{in})	Volumetric Density (kg H ₂ /m ³)
Underground Storage	20x10 ⁶ [6]	97 - 99 [2]	5 - 10 [2]
Pressurized Gas Vessels	30 [4]	97 [2]	2.2 [2]
Liquid Storage	~100 [4]	30 - 45 [2]	67 [2]
Hydride Storage	2800 [7,8]	70 - 85% w/o reject heat [2]	55 - 60 [2]
Microspheres	~40x10 ⁶ [9]	90 - 95 [10]	20 [9]

3.1.3 Fuel Cell Technologies

Fuel cells generate electricity from the reaction of hydrogen and oxygen in an electrochemical cell.

Often the oxygen is contained in air and the hydrogen in a hydrocarbon fuel. In this study, air and pure hydrogen were assumed. A number of types of fuel cells are commercially available, including

- phosphoric acid
- molten carbonate
- solid oxide
- polymer electrode membrane (PEM)

The first three can use hydrogen-containing fuels, such as natural gas or methane, as well as pure hydrogen. All can use suitably treated air as the oxidizer. In spacecraft applications, pure hydrogen and pure oxygen are used. Some PEM fuel cells are specially designed to run on pure hydrogen.

Phosphoric acid fuel cells (PAFCs) use a KOH electrolyte separating carbon electrodes. The performance of the fuel cells is almost entirely determined by the catalyst loading of the cathode and the system pressure. PAFCs are fabricated by a number of companies.

Molten carbonate fuel cells (MCFCs) use an electrolyte system comprising of a mixture of lithium-potassium carbonate and inert powder. The system operates at relatively high temperature (~650°C) and has high conversion efficiency. Large-scale MCFCs are in testing in a number of facilities.

Solid-oxide fuel cells (SOFCs) use a tubular rather than filter press stack configuration. This approach avoids the problem of sealing the edges of the individual cells, which would be impractical since SOFCs operate at 1000°C. The solid electrolyte is typically stabilized zirconia. SOFCs work well in combined cycle systems which can take advantage of the high exhaust temperature.

The proton exchange membrane (PEM) or solid polymer electrolyte (SPE) fuel cells use an ion exchange membrane as the electrolyte (as in the SPE electrolyzer). The advantages are 1) the electrolyte, being solid, cannot move, change, or vaporize; 2) the only liquid in the fuel cell is water. The system is limited in temperature range and best suited to pure hydrogen fuel. All of these fuel cell types are commercially available, some in larger sizes than others. Some of their characteristics are given in Table 3-3.

Table 3-3. Fuel Cell Technologies

Technology	Maximum Unit Size (MW)	Pressure, MPa	Temp., °C	Efficiency, % (kW _{out} /kW _{in})	Footprint (ft ² /kW)
Phosphoric Acid	10 - 20 [11]	0.1	190-210	43 - 50 [2]	1.1 [11]
Molten Carbonate	2 - 3 [12]	.1-1	500-700	54 - 70 [2]	0.9 - 1.0 [12]
Solid Oxide	2 - 3 [13]	.6	800-900	60% w/ combustion turbine [13]	.25 - 3.0 [13]
Proton Exchange Membrane	.25 [14]	.1-.6	80-100	40 - 60 [2]	~.5 [14]

3.2 Baseline Hydrogen System

For the very large power systems being considered in this study, only hydrogen technologies that scale to large sizes are practical. Even though SPE electrolyzers are promising, for the near future, commercial alkaline electrolysis is the most logical for bulk production of hydrogen.

For the huge masses of hydrogen needing to be stored for utility-scale, seasonal load-leveling, underground storage makes sense because it is extremely efficient compared to other methods of storage. Only a maximum 3% loss rate must be made up. Even though the pressure is relatively low, the space required is still moderately small compared with the other subsystems and the relatively low pressure is compatible with the electrolyzer and fuel cell.

In the region where underground storage is not available, the next near-term choice would be pressurized vessels, and the long-term choice would be microspheres.

Several fuel cells were considered. Molten carbonate was ultimately selected because of high efficiency and large unit size. Phosphoric acid would be a second choice for a large number of large units.

The selected technologies are listed in Table 3-4.

Table 3-4. Baseline System Assumptions

Technology/ Selection	Efficiency, %	Footprint	Operating Temp. (°C)	Operating Pressure (atm)
Hydrogen Production/ Alkaline Electrolysis	.9	1.5 ft ² /kW	70 - 90	1 - 30
Hydrogen Storage/ Underground	.97	1.3 ft ² /MWh	55	15 - 200
Electricity Production/ Molten Carbonate Fuel Cell	.68	1.0 ft ² /kW	500 - 700	1 - 6
Inverter	.98	N/A	N/A	N/A
Converter	.98	N/A	N/A	N/A

3.3 Hydrogen System Sizing

The footprint for the hydrogen portion of the renewable resource generation plant is calculated as follows:

For the fuel cell, the footprint area is:

$$A_{fc} = 1.1 \text{ ft}_2/\text{kW} * P_{fc}$$

where the generated power $P_{fc} = 1.10 * L$,

where L is the peak load to be served and the 1.10 multiplier results from the combined inefficiencies of the dc-to-ac convertor (2%), T&D losses (4%), and storage losses (3%).

For the electrolyzer, the footprint area is:

$$A_{el} = 1.5 \text{ ft}^2/\text{kW} * P_{el}$$

where the electrolyzer rating, P_{el} depends on the need for each region, as described in Section 5.

Sizing the resource capacity must take into account the conversion efficiency of the renewable resource and the convertor, either ac-to-dc or dc-to-dc., as well as the usage rate for directly supplying the load and charging storage.

Calculating the footprint of the electrolyzer and fuel cell is neatly the same for all regions and resources, with small variability in the conversion losses and T&D losses.

Calculating the energy storage reservoir footprint depends on the resource and load patterns for the region. The kilowatt-hours (E_{st}) of storage come from the resource/load model described in Section 5. In all cases, assuming underground bulk storage at modest pressure (~ 6 atm):

$$V_{st} = E_{st} / (39.4 \text{ kWh/kg})(5 \text{ kg/m}^3), \text{ where}$$

Assuming a spherical volume of gas, the cross sectional area of the reservoir,

$$A_{st} = \pi (3V/4\pi)^{2/3}$$

As will be shown later, in the northern WSCC region, for a wind source, the calculated storage requirement is 628 MWh/MW load or 628 hours of storage. This is the equivalent of 26 days at full power. The electrolyzer is rated at 1.4 MW, per MW load.

As an example, we calculate the footprint for a 100 MW load in this region:

$$\begin{aligned} A_{fc} &= (1.1 \text{ ft}^2/\text{kW}) * (1.10) * (100 \times 10^3 \text{ kW}) \\ &= 1.21 \times 10^5 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} A_{el} &= (1.5 \text{ ft}^2/\text{kW}) * 1.4 * (100 \times 10^3 \text{ kW}) \\ &= 2.10 \times 10^5 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} E_{st} &= 628 \text{ kWh/kW} * (100 \times 10^3 \text{ kW}) \\ &= 6.28 \times 10^7 \text{ kWh} \end{aligned}$$

$$V_{st} = 3.19 \times 10^5 \text{ m}^3$$

$$A_{st} = 5.67 \times 10^3 \text{ m}^2 = 6.09 \times 10^4 \text{ ft}^2$$

Total area $\approx 3.92 \times 10^5 \text{ ft}^2$.

A possible site layout for this case is shown in Figure 3-2. Note that the underground storage can extend under the facility hovering the electrolyzer and fuel cell units.

Figure 3-2 Possible Site Layout for Hydrogen System Serving 100 MW load

The electrolyzer footprint dominates the site, and the storage reservoir, even for nearly a month of storage, is relatively small. Other storage types, such as liquid hydrogen could be even smaller, but the inefficient storage (i.e. high parasitic requirements) would result in even larger electrolyzer requirements.

Two directions are suggested to minimize site size:

- 1) making the downstream system, i.e. the fuel cell and storage unit, as efficient as possible
- 2) efforts to shrink the footprint of the electrolyzer units themselves.

The footprint of the renewable resources are so much larger, however, that these efforts may not be important, except for economic reason.

Site areas for 100 MW blocks for the other regions are compared in the Results Section 6.

4

RENEWABLES GENERATION TECHNOLOGIES AND RESOURCES

4.1 Solar Power Systems

4.1.1 Solar Technology Descriptions [15]

4.1.1.1 Photovoltaics

Photovoltaic energy systems are currently used wherever relatively small electrical loads cannot be conveniently powered by an existing utility grid. As prices for this technology decline through technology improvements and increased manufacturing automation, photovoltaics (PV) will become the preferred source for an increasing diversity of loads requiring more power. Throughout this evolution, the unique advantage of photovoltaics—its modularity—is expected to remain the cornerstone for cost-effective applications. Unlike other technologies for production of electricity, photovoltaic systems can be installed in sizes ranging from 100 W to 100 MW with relatively little variation in the cost per unit energy produced. This flexibility permits PV systems to be installed wherever the demand is greatest, allowing the technology to fill smaller, higher value applications as it matures toward ever-larger markets.

PV systems convert sunlight into DC electricity using large-area, solid-state devices called PV modules. The amount of incident sunlight depends on the latitude and local climate. For simplicity, this study uses fixed (nontracking) systems. The output of a PV system is nearly proportional to the incident sunlight, and that proportionality is called the 'efficiency' of the system. Efficiency is defined for both energy and power. Power is the instantaneous amount of sunlight on an array (units of watts/m²; energy is the amount over a period of time (units of kWh/MW-yr). Efficiency is a critical figure of merit for PV, since both output and cost are strongly coupled to efficiency. Different PV options have the potential for greatly different costs. These costs are a combination of PV device costs (or PV module costs) and the rest of the PV system costs (support structures, power conditioning inverters if AC is desired, a tracker if needed, land, installation, and other items).

A non-concentrating photovoltaic system efficiency could range up to 20% conversion of insolation into AC power, although current systems are much closer to 10% efficiency. Using fairly dense (20% ground cover ratio) packing of 20%

efficiency modules, a PV system can produce up to 100 MW (peak) per square mile of land.

4.1.1.2 Solar Thermal Dishes

Solar thermal electric technologies concentrate sunlight onto a small area to build up high-temperature heat, which can then be converted into electricity in a conventional heat engine. Three major solar thermal technologies have been developed, each characterized by the shape of the mirrored surface on which sunlight is collected and concentrated:

1. Parabolic dish systems use a dual-axis tracking dish reflector to concentrate sunlight onto either a receiver/engine or a receiver/heat exchanger mounted at the focal point of the dish.
2. Central receiver systems use two-axis sun-tracking mirrors call heliostats to reflect solar energy onto a receiver/heat exchanger located on top of a tower.
3. Parabolic trough systems concentrate solar energy onto a receiver pipe located along the focal line of a curved trough collector. The trough tracks the sun with a one-axis tracker.

For this study we have selected a parabolic dish system since they have the highest efficiency of the three leading solar thermal technologies. A parabolic dish concentrates incoming direct normal solar energy onto a receiver located at the focal point of the dish. The energy is absorbed by the receiver to provide heat to a free piston or kinematic Stirling engine. The Stirling engine produces electricity by expanding helium or hydrogen gas against a piston which actuates an alternator. Heat can also be supplied by a supplemental natural gas burner to allow hybrid operation during cloudy weather and at night.

A very efficient solar thermal dish system could produce power at 30% efficiency on peak, producing close to 150 MW per peak square mile of land assuming a 20% ground coverage ratio.

4.1.2 Photovoltaic Production Data

The chronological hour-by-hour "production profiles" from PV (fixed orientation) modeled using a conversion function along with measured hour-by-hour solar radiation (insolation) levels for 1987, for a representative city or cities within the NERC region [16].

4.1.3 Solar Thermal Production Data

Hour-by-hour production for solar thermal distributed resources are modeled using hour-by-hour solar radiation (insolation) levels for a "typical" year. Solar plant

output (electricity generation) is calculated for 8760 hours based on Typical Meteorological Year (TMY) datasets for a specific location or locations. TMY data consists of datasets with hourly values for insolation and several other meteorological parameters, for a one year period.

TMY data are intended for use with computer simulations addressing solar energy conversion systems and solar energy's affects on building systems. Data is intended to facilitate performance comparisons of different system types, configurations, and locations in the United States and its territories. Because TMY data represent typical rather than extreme conditions they are not suited for designing systems to meet worst-case conditions.

The most recent version of the TMY data, TMY2, was developed by the National Renewable Energy Laboratory's (NREL's) Analytic Studies Division under the Resource Assessment Program [17]. That program is funded and monitored by the U. S. Department of Energy's Office of Solar Energy Conversion. Of the 239 stations, there are 56 "primary" stations which have actual insolation measurements for some or all of the 30 years that the program has been underway. 183 other stations have estimated hourly insolation values based on cloud cover and other criteria.

4.2 Wind Power Systems

4.2.1 Wind Technology Descriptions [15]

A wind turbine system contains three basic subsystems: (1) a rotor, usually consisting of two or three blades; (2) a drive train, generally including a gearbox and generator; and (3) a tower and foundation that supports the rotor and drive train. A windfarm is comprised of turbines and various supporting systems including controls, electrical cables, and voltage step-up transformers, and "balance-of-station" subsystems which, depending on the application, might include roads, fences, ground support equipment, operation and maintenance buildings, supplies and equipment, or utility interconnection equipment. There are two basic technical approaches to wind turbine design: horizontal-axis machines, in which the axis of the rotor's rotation is parallel to the wind stream and the ground; and vertical-axis (Darrieus) machines, in which the axis of rotation is perpendicular to the wind stream and the ground. The majority of turbines in commercial use today are of the horizontal-axis type.

The efficiency of a wind system in converting air kinetic energy into electricity is highly dependent on wind speed and wind turbine design. A modern turbine can be expected (on average) to convert 25% of the wind energy in the swept area of the blades into AC power.

Wind plants can take up a large amount of land (although the turbines themselves take up very little space allowing multiple uses such as farming); a modern wind farm in a favorable wind resource area can produce up to 10 MW per square mile of land.

4.2.2 Wind Resource Data

The hourly wind data was from the National Renewable Energy Laboratories [18]. It was collected in the 1980's for aid in siting the first generation of government sponsored large wind turbines, the MOD-0 series. The data was from the anemometers at 50 meter height.

For the WSCC area the study used the data from Bridgers Butte in Southwestern Wyoming, for MAPP the analysis used the site at Finley, North Dakota. For SPP and ERCOT data from Meade, Kansas was used.

There was a large amount of missing data in the NREL data set. We choose the year with the highest data recovery rate for each site. In a few annual data sets entire months were missing, in which case we used the same month for another year. In the case of a missing week or so, we copied half of the previous and half of the following week. In the case of a missing day we took the average for each hour of the previous and following day. In the case of a missing hour we took the average of the previous and following hours. In the case of a few hours missing we "straight-lined" from the hour at the beginning of the gap to the hour at the end.

Although Altamont Pass output data were available it was not used for the WSCC area. Altamont Pass has a summer peaking pattern as do the other windy areas near the Pacific Coast including San Geronio, Tehachapi, and Solano County in California and the Columbia River Gorge between Washington and Oregon. Although this is a good seasonal fit with electric load, these areas would only be able to produce about five percent of the WSCC load. Under the assumptions of the Hydrogen study it would be better to use the wind patterns over most of the area, better represented by the Wyoming site.

4.3 Hydroelectric Systems

Another renewable resource which is available in many regions is hydroelectric power. Although the use and dispatch of this resource is already very efficiently integrated into most regional systems, it is possible that combining it with hydrogen storage may be beneficial under some circumstances. Table 4-1 shows the year 2010 projection of these resources for all NERC regions in capacity and some energy production [19]. Also listed are the GWh of hydrogen which could be produced from these resources, at an 80% capacity factor, and assuming an efficiency of 89% for electricity into stored hydrogen. No additional analysis was performed for this resource.

Table 4-1 NERC Region Hydro Resources-2010

	Resource (GW)		Annual Energy Generation (GWh)	
	Renewable Hydro Capacity	Pumped Storage	Energy Hydro	Potential for Stored H ₂
SPP	2.71	0.5	9,320	16,903
WSCC/NWP	34.95	0.31	162,440	217,987
WSCC/RA	4.68	0.72	20,390	29,190
WSCC/CNV	13.92	3.83	71,620	86,821
SERC	11.3	6.79	45,130	70,480
NPCC/NE	2.02	1.65	21,780	12,599
NPCC/NY	4.8	1.28	42,770	29,938
MAPP	3.49	0	13,290	21,768
MAIN	0.64	0.35	4010	3992
MAAC	1.13	1.34	13,650	7048
ERCOT	0.58	0	1690	3618
ECAR	1.36	3.27	12,150	8423

4.4 Electrical Systems

All hydrogen systems are assumed to be collocated with the renewables. This eliminates the need for any hydrogen transmission and does not require any extra electrical transmission and distribution investments. Transmission and distribution system efficiency is assumed to be 96%.

5

REGIONAL ELECTRIC DEMAND

5.1 Load Data

Actual hourly load data for eight U. S. regions is used to simulate hour-by-hour power requirements and energy use. For each region, systemwide electric load data are provided for all 8760 hours of the year 1987. Loads are measured as systemwide power requirements experienced by the region (one hour averages) including all customer classes and including exports of power to other regions. For a given region these actual hourly load values for 1987 are bases for hour-by-hour load profiles.

Forecasts for peak (maximum) electric demand (in units of megawatts) are applied to the profile to determine the hourly electric energy requirements, which in turn indicate the annual electric energy use in the region. All data are derived from North American Electric Reliability Council (NERC) data sets [16].

5.2 Selection of Regions and Renewables

Appropriate renewable technologies have been matched to their most viable (high quality and quantity) regional resources (e.g., considering solar thermal electricity production in high direct normal insolation areas only). The objective was to select regions which had at least one renewable per region, included the best region for each renewable, and used the best renewable in each region.

For the intermittent renewables wind, photovoltaics and solar thermal we selected a total of a dozen renewable patterns nationally. We selected the most viable renewables technologies in each geographic region based on known resource size and quality. The regions have been derived from the basic NERC boundaries adjusted and combined based on energy available from renewables to get the best coverage of the US with twelve cases. The analysis was limited to the contiguous 48 states and the large WSCC region was divided into WSCC North (WA, OR, ID, WY, most of MT and a small part of SD), and WSCC South (CA, NV, AZ, UT, CO, extreme West TX, and most of NM). MAIN and ECAR were combined into one renewable region as were MAAC and NPCC. These modified NERC regions are shown in Figure 5-1 and list of the regions and matching renewable technologies is shown in Table 5-1.

Figure 5-1 Modified NERC Regions used in this study

Table 5-1 Selected Renewable Region Definitions (NERC region designations)

PV	Wind	Solar Thermal
SERC	SPP	ERCOT
ECAR / MAIN	MAPP	WSCC South
NPCC / MAAC	ERCOT	
WSCC South	WSCC South	
WSCC North	WSCC North	

The amount of renewable resource in each region was a prime determinate of its selection. Wind resource is the most limited of the three renewables in question, followed by solar thermal and photovoltaics. Thus wind resource size was used to choose its target regions, then solar thermal was selected, and finally photovoltaics was used in all remaining regions and in its most favored locations.

Wind is an enormous resource; several sources have estimated the high quality wind potential to be greater than the US electricity consumption nationally, but have shown regional variations; the Southeast is especially poor in wind

resource. We have used regionally adjusted wind resource capacities to determine whether a region is resource or electric utility demand limited.

Flat plate photovoltaics can use any quality of insolation and thus are theoretically feasible throughout any of the regions, its penetration limited only by the annual energy consumption in every region for photovoltaics.

Solar thermal requires high levels of direct normal insolation, normally only available in the Southwest, California, and perhaps the South Central regions. We will assume that solar thermal could produce all of the load demand in those regions but none in the other regions.

6

RESULTS

6.1 Hydrogen storage analysis results

Each analysis case was a combination of an electrical region of the US and a reasonable renewable resource, the process for their selection was discussed in Section 5.2. When all twelve analysis cases were run, as might be expected, the amount of hydrogen storage, the rating of electrolyser and the quantity of renewable resource required varied dramatically from case to case.

The results should be expected to vary considerably from case to case due to variations in

1. hourly electric load patterns in each region
2. hourly renewables resource availability in each region
3. the interaction between these two patterns
4. the quality of the renewable resource in each region

The analysis results are discussed below in normalized terms to make the results more intuitive to discuss (e.g., the renewable capacity is stated in terms of the capacity required per 100 MW of peak regional load). The total potential market sizes for each of the components can be derived by scaling up by the full load in each region which are shown in Table 6-1.

Table 6-1 Results Summary

Resource Type / Region		Resource Capacity MW*	Reservoir Size MWh*	Max. Hourly Charge MWh*	Annual Energy Stored GWh*	Annual Regional Load Factor --	Annual Renewable Capacity Factor --
FFP PV	ECAR - MAIN	5.60	1371.9	4.31	5.66	0.7	0.17
	NPCC - MAAC	3.85	516.8	3.06	3.72	0.5	0.18
	SERC	3.80	416.5	2.91	4.22	0.57	0.21
	WSCCn	4.76	1161.5	3.77	5.15	0.65	0.2
	WSCCs	3.84	894.7	2.98	4.41	0.58	0.23
Solar Thermal	ERCOT	3.14	454.7	2.32	3.70	0.55	0.23
	WSCCs	2.84	511.6	2.03	3.73	0.58	0.3
Wind	ERCOT	1.84	637.1	1.33	2.37	0.55	0.33
	MAPP	1.45	406.5	1.00	2.53	0.55	0.48
	SPP	1.58	516.0	1.13	2.05	0.47	0.33
	WSCCn	1.99	628.2	1.40	3.54	0.65	0.43
	WSCCs	1.78	571.5	1.24	3.16	0.58	0.43

* Per MW of Regional Peak Load

Wind plants required the least amount of MW capacity to meet the annual loads in any of the regions in which it was studied, due to its having the highest annual capacity factor of the three technologies. Solar thermal dishes require the next most resource since they have the second highest capacity factor, and fixed flat plate photovoltaics needs the largest resource capacity in the regions studied due to its low capacity factor. No presumption should be made of the relative economic attractiveness of this result since no economic analysis is included in this study, only the technical sizing of the components was included.

In each analysis case, the minimum amount of MW to serve the annual load is determined simultaneously with the maximum amount of storage needed; this is called the "critical" renewables/storage combination. Further, we calculated the reduction in hydrogen storage capacity which is made possible by oversizing the renewables capacity beyond these critical sizes.

The results will be grouped and discussed by technology type since the greatest results similarities are found among regions using the same renewables technology.

6.1.1 Fixed flat plate photovoltaics

Fixed flat plate photovoltaics were analyzed for ECAR-MAIN, NPCC-MAAC, SERC, WSCCnorth and WSCCsouth. These region definitions can be seen in map in Figure 5-1.

The fixed flat plate photovoltaics hydrogen storage required for a 100 MW load in each of the five regions, as shown in Table 6-2, ranges from a low of 417 hours for SERC (most of the Southeast) up to 1372 hours in the combined ECAR-MAIN region (roughly the Central Midwest). A very large amount of fixed flat plate photovoltaics is required also, 380 MW (per 100 MW of regional load) for SERC up to 560 MW for ECAR-MAIN; WSCCsouth and NPCC-MAAC are nearly as favorable for fixed flat plate photovoltaics as SERC, requiring only a few more MW to serve the annual load.

**Table 6-2 Photovoltaic Results Summary, normalized to regional peak loads
(normalized to regional peak loads)**

Resource Type / Region		Resource Capacity MW*	Reservoir Size MWh*	Max. Hourly Charge MWh*	Annual Energy Stored GWh*	Annual Load Factor --	Annual Capacity Factor --
FFP PV	ECAR - MAIN	5.60	1371.9	4.31	5.66	0.7	0.17
	NPCC-MAAC	3.85	516.8	3.06	3.72	0.5	0.18
	SERC	3.80	416.5	2.91	4.22	0.57	0.21
	WSCCs	4.76	1161.5	3.77	5.15	0.65	0.2
	WSCCs	3.84	894.7	2.98	4.41	0.58	0.23

* Per MW of Regional Peak Load

The patterns of charging and discharging hydrogen storage are seen in Figures A-1 through A-5 in the Appendix. Since the fixed flat plate photovoltaics energy output is highest during the Summer in most regions the amount of hydrogen in storage grows during this period, levels off through the Fall, and declines during the Winter to an empty condition in the late Winter or early Spring, depending on the region in question. The patterns of photovoltaic output and energy consumption for SERC are quite different; in SERC the hydrogen storage system is most highly charged in late June, declining from that point until the next Spring when it is rapidly refilled.

The electrolyser sizes are similarly ranked. 291 MW are needed for SERC, while 431 MW would be needed for ECAR-MAIN. The amount of hydrogen which was created by the electrolyzers is as low as 3720 hours of output for NPCC-MAAC up to 5660 hours of output for ECAR-MAIN. The SERC region created 4220 hours of hydrogen output, this is more than the NPCC-MAAC result due to the appreciably higher electricity load factor in the SERC region (57% for SERC, versus 50% for NPCC-MAAC).

If we consider the possibility of oversizing the renewable plant sizes, a dramatic reduction occurs in the required hydrogen storage. As can be seen in Figure A-3, the effect of adding roughly 20 MW to the critical 380 MW fixed flat plate photovoltaics plant in SERC is that the hydrogen storage size can be cut in half. It is likely that the best economic combination of fixed flat plate photovoltaics plant and hydrogen storage capacity would be to oversize the fixed flat plate photovoltaics facility somewhat. Only a careful economic analysis could truly resolve this issue.

As a sensitivity, we have also reduced the load in these regions and examined the reductions in renewable plant size and storage requirements. These results are also shown in Figure A-1 through A-5. No interesting results were found, the load reduction and storage size simply tracked one another and declined as the load fraction was reduced.

6.1.2 Solar thermal dish

Solar thermal dishes were considered for ERCOT and WSCCsouth and the results are quite similar, as can be seen in Table 6-3.

Table 6-3 Solar Thermal Results Summary (normalized to regional peak loads)

Resource Type / Region		Resource Capacity MW*	Reservoir Size MWh*	Max. Hourly Charge MWh*	Annual Energy Stored GWh*	Annual Load Factor --	Annual Capacity Factor --
Solar Thermal	ERCOT	314	454.7	2.32	3.70	0.55	0.23
	WSCCs	2.84	511.6	2.03	3.73	0.58	0.3

* Per MW of Regional Peak Load

The hydrogen storage requirements are 454 hours for ERCOT and 512 hours for WSCCsouth, and the electrolyzers would be 232 MW and 203 MW respectively. Apparently the renewable plant size and the patterns of resource and load are such that more hydrogen storage is required for WSCCsouth while larger electrolyzers should be specified for ERCOT. 314 MW (per 100 MW of regional peak load) of solar thermal dishes are needed to serve the annual load in ERCOT, while only 284 MW are appropriate for WSCCsouth. Much of the reason for the difference between these two regions is the higher capacity factor of a dish system in WSCCsouth (30% versus 23%) for ERCOT.

The patterns of storage charge and discharge are seen in Figure A-6 and A-7. In both regions the hydrogen storage system is nearly empty in late Winter and rises to its maximum capacity by about mid-year. ERCOT then declines rapidly and levels off for the Fall, eventually emptying during the Winter. WSCCsouth maintains nearly a full charge through the Fall before emptying in the Winter months.

The amount of hydrogen which was created by the electrolyzers is as low as 3700 hours of output for ERCOT and 3730 hours of output for WSCCsouth.

When oversizing the dish field is considered, very small additions of collectors once again can lead to dramatic hydrogen storage size reductions. In both regions adding less than 10% more renewables capability decreases the hydrogen storage requirements by more than half. See Figures A-6 through A-7 in the Appendix.

As a sensitivity, we have also reduced the load in these regions and examined the reductions in renewable plant size and storage requirements. These results are shown in the Appendix. No interesting results were found, the load reduction and storage size simply tracked one another and declined as the load fraction was reduced.

6.1.3 Wind

Wind was analyzed for ERCOT, MAPP, SPP, WSCCnorth and WSCCsouth. These region definitions can be seen in map in Figure 5-1.

The hydrogen storage required for a 100 MW load in each of the five regions, as shown in Table 6-4, ranges from a low of 407 hours for MAPP (the northern Midwest) up to 637 hours in ERCOT region (roughly Texas). Small amounts of wind capacity is required compared to the two solar technologies due to the higher potential capacity factors, only 145 MW (per 100 MW of regional load) were needed in MAPP and in the worst case 199 MW for WSCCnorth to serve the annual load.

Table 6-4 Wind Results Summary (normalized to regional peak loads)

Resource Type / Region		Resource Capacity MW*	Reservoir Size MWh*	Max. Hourly Charge MWh*	Annual Energy Stored GWh*	Annual Load Factor %	Annual Capacity Factor %
Wind	ERCOT	1.84	637.1	1.33	2.37	0.55	0.33
	MAPP	1.45	406.5	1.00	2.53	0.55	0.48
	SPP	1.58	516.0	1.13	2.05	0.47	0.33
	WSCCn	1.99	628.2	1.40	3.54	0.65	0.43
	WSCCs	1.78	571.5	1.24	3.16	0.58	0.43

* Per MW of Regional Peak Load

The patterns of charging and discharging hydrogen storage with wind are seen in Figures A-8 through A-12. Since the wind energy output is different region-to-region the amount of hydrogen in storage varies depending on the region in question. The patterns of wind output and energy consumption for both SERC and WSCCsouth allow the storage capacity to empty in the Fall; while MAPP is empty in the Spring and its wind and load patterns cause the storage state of charge to oscillate broadly during most of the year.

The wind system electrolyser sizes are similarly modest compared to the solar technologies. 100 MW are needed for MAPP, while 124 MW would be needed for WSCCsouth up to a maximum of 140 MW of electrolyser output capacity for WSCCnorth. The amount of hydrogen which was created by the electrolyzers is as low as 2050 hours of output for SPP up to 3540 hours of output for WSCCnorth. The WSCCsouth region created 3160 hours of hydrogen output during the year.

Considering the possibility of oversizing the wind plant sizes allows a dramatic reduction in the required hydrogen storage for every wind region studied. For example as can be seen in Figure wwwww, the effect of adding roughly 20 MW to the critical 145 MW wind plant in MAPP is that the hydrogen storage size can be cut in half. It is likely that the best economic combination of wind plant and hydrogen storage capacity would be to oversize the wind facility somewhat.

As a sensitivity, we have also reduced the load in these regions and examined the reductions in wind plant size and storage requirements. These results are shown in the Appendix. No interesting results were found, the load reduction and storage size simply tracked one another and declined as the load fraction was reduced.

6.1.4 Cross-technology discussion of WSCCsouth

WSCCsouth has appreciable renewable resources for wind, fixed flat plate photovoltaics, and solar thermal dishes and therefore was studied for hydrogen storage applications for all three technologies.

WSCCsouth results are seen in Table 6-5.

Table 6-5 WSCCsouth Results Summary, all renewable technologies (normalized to regional peak loads)

Resource Type / Region		Resource Capacity MW*	Reservoir Size MWh*	Max. Hourly Charge MWh*	Annual Energy Stored GWh*	Annual Load Factor --	Annual Capacity Factor --
PV	WSCCs	3.84	894.7	2.98	4.41	0.58	0.23
Solar Thermal	WSCCs	2.84	511.6	2.03	3.73	0.58	0.3
Wind	WSCCs	1.78	571.5	1.24	3.16	0.58	0.43

* Per MW of Regional Peak Load

Wind requires the second largest amount of hydrogen storage capacity (572 hours) but the lowest MW capacity (145 MW per 100 MW of regional peak load) of the three technologies considered in the WSCCsouth. The high wind capacity factor in WSCCsouth allows a low wind MW capacity to meet the annual energy needs of the region with wind, but the seasonal and daily mismatch of the wind resource with the regional load pattern requires a lot of storage capacity to meet the year's need for hydrogen storage.

Higher MW capacity plants are required for the solar options: 284 MW (per 100 MW of peak regional load) for solar thermal dishes, and 384 MW for fixed flat plate photovoltaics. The fixed flat plate photovoltaics system must have 895 hours of output stored to make it through the year.

The wind plant can be coupled to a 124 MW electrolyser in WSCCsouth but a 203 MW electrolyser is needed for the solar thermal dish plant and a 298 MW unit for

the fixed flat plate photovoltaics. These results are driven primarily by the relative capacity factors of the technologies.

6.3 Hydrogen System Sizes and Market Opportunities

6.3.1 Site Areas

The breakdown of site areas for 100 MW-block in each region is shown in Figure 6-1. Total hydrogen site areas for all regions are compared in Figure 6-2 .

Figure 6-1 Hydrogen System Footprint for each 100 MW Resource Block, assuming minimum renewables and maximum storage

Figure 6-2 Total hydrogen site areas for all regions

6.3.2 Technology Opportunities

This study has also generated values of the technological need for hydrogen system components, to accompany renewable technologies. The market sizes for electrolyzer and fuel cell units, as well as storage capacity are enormous.

Table 6-6 shows the number of 10 MW electrolyzer units and 3 MW fuel cell units, and the mass of hydrogen, for the maximum (i.e., critical) hydrogen case for each region. Each billion kg requires 200 million m³ of underground storage. If other technologies were to be used for storage, the market would be huge: 450 million m³ of gas vessels or 50 million m³ of microspheres for each billion kg of H₂ stored. The renewable resource and hydrogen system technology requirements for the 100% load/minimum resource/maximum storage case are shown graphically in Figure 6-3.

Table 6-6 Hydrogen Technology Requirements by Region

Case Name	#10 MW Electrolyzer Units	#3 MW Fuel Cells	Stored Mass (kg)
WindWSCCn	9.29E+03	2.16E+04	9.39E+08
WindMAPP	4.19E+03	1.37E+04	4.88E+08
WindSPP	9.60E+03	2.77E+04	7.79E+08
WindERCOT	9.40E+03	2.30E+04	1.02E+09
WindWSCCs	9.78E+03	2.56E+04	1.02E+09
PV ECAR-Main	8.24E+04	6.22E+04	5.92E+09
PV NPCC-MAAC	3.83E+04	4.09E+04	1.46E+09
PV SERC	6.32E+04	7.08E+04	2.05E+09
PV WSCCn	2.50E+04	2.16E+04	1.74E+09
PV WSCCs	2.34E+04	2.56E+04	1.59E+09
ST ERCOT	1.46E+04	2.31E+04	7.26E+08
ST WSCCs	1.42E+04	2.57E+04	9.09E+08

Figure 6-3 Resource and Hydrogen Technology Requirements for the 100% Load/Minimum Resource/Maximum Storage Case for each Region

7

CONCLUSIONS AND RECOMMENDATIONS

If renewables are going to make the deep penetrations explored here, storage will be required and hydrogen would be a viable option for storage, especially to meet seasonal needs. As can be seen in the results, very large quantities of hydrogen and hydrogen technologies would be needed to carry over renewables during low resource times.

These analyses also serve as a starting point for projecting the market opportunity for hydrogen conversion, storage and transmission systems, including economic potential and economic equipment/system unit sizes.

8

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APPENDIX

Results Charts

A-1 PV ECAR-Main

ECAR - MAIN		Reservoir Size:	1371.90 MWh
Resource Tech:	FFP PV	0th Hour Energy:	988.25 MWh
Year:	2010	Annual Max:	1371.9 MWh
Region Peak Load:	170,100 MW	Annual Min:	0.00 MWh
Block Size (MW):	100 MW	Present State Last Hr:	987.71 MWh
Resource to Load Eff.:	0.95	Reservoir "Ceiling" Size:	1371.9 MWh
Resource Info		"Last Hour minus"	
Storage Eff.:	0.89	0th Hour (Stored):	0.54 MWh
Storage to Load Eff.:	0.84	Max. Hourly Charge:	4.314 MWh
Resource Capacity	5.601 MW	Annual Energy Stored:	5.66 GWh
ECAR (114.2 GW) & MAIN (55.9 GW)		Annual Load Factor:	7.7 (6,180 MWh / MW)
		Annual Capacity Factor:	17.1 (1,525 MWh / MW)

Totals	
Per MW Load	
Resource	5.601 MW
Reservoir	1,371.9 GWh
H ₂ Stored	5,659 GWh
Gross	
Resource	952,745.6 MW
Reservoir	233,360 GWh
H ₂ Stored	982,537 GWh
Blocks (100MW)	
Resource Blocks	9,527.5
Reservoir/Blk	2,333.6 GWh
H ₂ Stored	9,825.4 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)																								H ₂ Stored	9,625.4 GWh
Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Min	5.73	4.86	4.00	3.14	2.27	1.32	0.23	0.00	0.67	2.36	5.52	9.45	19.29	16.69	16.77	15.79	14.62	13.46	12.24	10.99	9.77	8.62	7.57	6.65	
Max	1367.33	1362.04	1359.17	1356.24	1357.30	1355.38	1353.41	1358.29	1368.31	1361.22	1364.52	1367.79	1369.20	1374.29	1371.15	1371.90	1370.80	1369.33	1367.97	1365.56	1363.37	1361.18	1359.09	1357.00	
1	967.414	966.63	965.87	965.14	964.39	963.62	962.82	961.98	961.14	960.32	959.82	959.81	960.02	959.30	958.44	957.54	956.59	955.61	954.44	953.42	952.44	951.49	950.62	949.80	
2	949.04	948.29	947.53	946.81	946.06	945.26	944.38	943.22	942.38	941.35	941.43	941.56	940.94	939.97	938.91	937.81	936.65	935.45	934.27	932.95	931.50	930.04	928.58	927.18	
3	928.58	927.82	926.88	926.15	925.41	924.64	923.81	922.92	921.88	921.01	920.15	919.59	918.74	917.91	916.94	915.98	914.87	913.72	912.60	911.51	910.48	909.52	908.61	907.77	
4	908.59	907.82	906.87	906.04	905.19	904.39	903.59	902.44	901.55	900.59	900.29	900.63	901.26	901.82	902.04	902.21	902.19	902.06	901.81	901.45	901.00	900.52	900.01	899.50	
5	912.26	911.44	910.64	909.83	909.01	908.10	906.98	907.26	906.84	912.71	918.78	919.72	923.48	928.78	929.57	930.89	929.89	928.22	926.81	925.66	924.56	923.19	922.06	921.08	
6	920.19	919.24	918.29	917.47	916.67	915.82	914.82	913.80	912.81	918.29	923.16	928.95	929.92	931.24	932.54	933.64	934.59	935.29	935.07	934.67	934.11	933.17	932.01	930.94	
7	924.06	923.18	922.39	921.47	920.69	919.86	918.88	917.29	916.02	914.80	913.73	912.81	911.84	910.76	909.57	908.39	907.14	905.88	904.59	903.33	902.10	900.84	899.66	898.88	
8	927.98	927.08	926.27	925.34	924.48	923.49	922.24	901.06	899.77	898.83	897.44	896.48	895.59	894.89	893.91	893.10	892.09	891.50	890.39	889.20	887.92	886.66	885.40	884.20	
9	871.47	870.56	869.68	868.80	867.90	866.92	865.78	864.47	863.17	861.88	860.87	859.94	859.17	858.07	856.87	855.88	854.48	853.22	852.01	850.84	849.70	848.61	847.58	846.64	
10	849.75	848.81	847.87	846.94	846.02	845.08	844.08	839.89	838.85	837.87	837.02	836.24	835.53	834.81	834.54	833.97	833.61	832.49	831.29	830.30	829.28	828.26	827.34	826.40	
11	824.86	824.12	823.40	822.67	821.94	821.18	820.37	819.51	818.60	818.06	817.92	816.68	816.19	816.17	815.47	814.87	813.59	812.48	811.39	810.30	809.27	808.30	807.38	806.65	
12	806.70	804.69	804.06	803.30	802.49	801.50	800.86	799.10	797.61	796.60	795.84	797.91	798.29	799.04	800.27	800.89	799.49	798.14	796.84	795.51	794.26	793.25	792.17	791.17	
13	790.24	789.39	788.44	787.55	786.55	785.67	784.52	783.24	781.86	780.56	779.88	787.81	789.83	792.29	794.18	796.30	794.01	792.67	791.35	790.07	788.80	787.62	786.51	785.81	
14	754.88	753.81	752.74	751.65	750.59	749.59	748.21	747.49	746.14	745.28	744.54	747.54	747.89	748.87	748.82	744.63	743.40	742.12	740.79	739.45	738.16	737.00	735.80	734.60	
15	768.77	767.87	766.96	766.10	765.20	764.28	763.11	761.82	760.52	759.54	758.87	767.79	768.57	768.87	768.82	764.63	763.40	762.12	760.79	759.45	758.16	757.00	755.80	754.60	
16	752.83	751.70	750.79	749.63	748.62	747.51	746.29	745.44	744.19	743.19	742.01	740.89	739.83	738.57	737.09	735.60	734.09	732.57	731.04	729.51	728.00	726.50	725.00	723.50	
17	710.19	709.29	708.40	707.52	706.64	705.71	704.71	703.69	702.87	702.03	701.58	700.84	700.41	700.79	700.57	700.51	700.57	700.51	700.55	700.55	700.49	700.49	700.49	700.49	
18	697.98	697.18	696.34	695.53	694.74	693.89	692.91	691.82	690.69	689.51	688.22	686.98	685.79	684.49	683.18	681.86	680.54	679.24	677.94	676.64	675.34	674.04	672.74	671.44	
19	682.84	681.98	681.07	680.18	679.28	678.30	677.14	675.94	674.61	673.30	672.48	671.79	670.84	670.57	670.51	670.57	670.51	670.55	670.55	670.49	670.49	670.49	670.49	670.49	
20	694.65	693.71	692.80	691.89	690.96	690.00	689.01	687.98	686.82	685.54	684.25	682.92	681.57	680.25	678.94	677.64	676.34	675.04	673.74	672.44	671.14	669.84	668.54	667.24	
21	634.89	633.93	632.97	632.02	631.08	630.04	628.84	627.51	626.19	625.01	624.22	623.86	623.14	622.92	621.12	619.85	618.55	617.19	615.85	614.56	613.26	612.05	610.81	609.88	
22	608.82	607.99	607.08	606.16	605.29	604.36	603.39	602.38	601.35	600.30	599.22	598.14	597.04	595.92	594.80	593.68	592.56	591.44	590.32	589.20	588.08	586.96	585.84	584.72	
23	602.88	601.62	600.68	600.71	600.72	600.59	600.42	600.29	600.18	600.30	600.35	600.38	600.38	600.38	600.38	600.38	600.38	600.38	600.38	600.38	600.38	600.38	600.38	600.38	
24	609.23	608.35	607.39	606.43	605.49	604.51	603.49	602.46	601.35	600.25	599.22	598.22	597.22	596.22	595.22	594.22	593.22	592.22	591.22	590.22	589.22	588.22	587.22	586.22	
25	598.74	598.86	598.98	599.08	599.21	599.35	599.51	599.64	599.81	599.94	600.04	600.14	600.24	600.34	600.44	600.54	600.64	600.74	600.84	600.94	601.04	601.14	601.24	601.34	
26	578.32	577.48	576.64	575.79	574.93	574.06	573.18	572.29	571.39	570.48	569.56	568.64	567.71	566.78	565.84	564.90	563.96	563.02	562.08	561.14	560.20	559.26	558.32	557.38	

PV ECAR-Main

Reservoir Size:	1371.90	MWh
0th Hour Energy:	968.25	MWh
Annual Max:	1371.9	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	887.71	MWh
Reservoir Ceiling Size:	1371.9	MWh
Last Hour minus 0th Hour (Stored):	-0.54	MWh
Max Hourly Charge:	4.314	MWh
Annual Energy Stored:	5.66	GWh
Annual Load Factor:	7	(5,160 MWh / MW)
Annual Capacity Factor:	17	(1,525 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	5.6	1371.9	5.659
1.1	6.16	1211.8	5.623
1.25	7.0	1049.5	5.581
1.5	8.4	887.1	5.529
1.75	9.8	718.3	5.490
2	11.2	570.5	5.459
2.5	14.0	428.0	5.410
2.75	15.4	387.2	5.389
3	16.8	307.3	5.372
4	22.4	140.4	5.320

Levels of Annual Energy Served (all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	5.60	1371.9
80%	4.46	1089.4
60%	3.33	823.0
40%	2.19	548.9
20%	1.06	274.9

Effect of Resource Capacity Oversizing on Reservoir Size

FFP PV, ECAR, 170,100 MW, 2010

Resource and Reservoir Capacity for Various Levels of Energy Served

FFP PV, ECAR, 170,100 MW, 2010

À-2 PV NPPC-MAAC

NPPC - MAAC		Reservoir Size: 516.75 MWh
Resource Tech: FFP PV		0th Hour Energy: 305.13 MWh
Year: 2010		Annual Max: 516.8 MWh
Region Peak Load: 111,800 MW		Annual Min: 0.00 MWh
Block Size (MW): 100 MW		Present State Last Hr: 303.70 MWh
Resource to Load Eff.: 0.95		Reservoir Ceiling Size: 516.4 MWh
Resource Info		*Last Hour minus 0th Hour (Stored): 1.44 MWh
Storage to Load Eff.: 0.89		Max Hourly Charge: 3.058 MWh
Storage to Load Eff.: 0.84		Annual Energy Stored: 3.72 GWh
Resource Capacity: 3.852 MW		Annual Load Factor: 5.4 (4,391 MWh / MW)
NPPC (55.5 GW) - MAAC (56.2 GW)		Annual Capacity Factor: 18 (1,592 MWh / MW)

Totals	
Per MW Load	
Resource	3.852 MW
Reservoir	.5168 GWh
H ₂ Stored	3.716 GWh
Gross	
Resource	430,881.8 MW
Reservoir	57,773 GWh
H ₂ Stored	415,443 GWh
Blocks (100MW)	
Resource Blocks	4,306.8
Reservoir/Blk	577.7 GWh
H ₂ Stored	4,154.4 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	4.02	8.48	2.88	2.33	1.78	1.20	0.83	0.00	0.57	1.78	3.47	5.42	7.50	9.40	10.88	11.72	10.77	8.78	6.82	7.88	6.98	6.13	5.35	4.65
Max	110.79	209.74	308.29	406.84	505.39	603.94	702.49	801.04	900.01	1000.00	1100.00	1200.00	1300.00	1400.00	1500.00	1600.00	1700.00	1800.00	1900.00	2000.00	2100.00	2200.00	2300.00	2400.00
1	904.555	903.98	903.41	902.84	902.27	901.70	901.13	900.56	900.00	899.43	898.86	898.29	897.72	897.15	896.58	896.01	895.44	894.87	894.30	893.73	893.16	892.59	892.02	891.45
2	283.78	283.27	282.76	282.25	281.74	281.23	280.72	280.21	279.70	279.19	278.68	278.17	277.66	277.15	276.64	276.13	275.62	275.11	274.60	274.09	273.58	273.07	272.56	272.05
3	279.08	278.55	278.02	277.49	276.96	276.43	275.90	275.37	274.84	274.31	273.78	273.25	272.72	272.19	271.66	271.13	270.60	270.07	269.54	269.01	268.48	267.95	267.42	266.89
4	270.49	269.94	269.39	268.84	268.29	267.74	267.19	266.64	266.09	265.54	264.99	264.44	263.89	263.34	262.79	262.24	261.69	261.14	260.59	260.04	259.49	258.94	258.39	257.84
5	268.04	267.48	266.92	266.36	265.80	265.24	264.68	264.12	263.56	263.00	262.44	261.88	261.32	260.76	260.20	259.64	259.08	258.52	257.96	257.40	256.84	256.28	255.72	255.16
6	264.59	263.92	263.25	262.58	261.91	261.24	260.57	259.90	259.23	258.56	257.89	257.22	256.55	255.88	255.21	254.54	253.87	253.20	252.53	251.86	251.19	250.52	249.85	249.18
7	262.01	261.33	260.65	259.97	259.29	258.61	257.93	257.25	256.57	255.89	255.21	254.53	253.85	253.17	252.49	251.81	251.13	250.45	249.77	249.09	248.41	247.73	247.05	246.37
8	248.54	247.85	247.16	246.47	245.78	245.09	244.40	243.71	243.02	242.33	241.64	240.95	240.26	239.57	238.88	238.19	237.50	236.81	236.12	235.43	234.74	234.05	233.36	232.67
9	244.58	243.88	243.18	242.48	241.78	241.08	240.38	239.68	238.98	238.28	237.58	236.88	236.18	235.48	234.78	234.08	233.38	232.68	231.98	231.28	230.58	229.88	229.18	228.48
10	230.58	229.87	229.16	228.45	227.74	227.03	226.32	225.61	224.90	224.19	223.48	222.77	222.06	221.35	220.64	219.93	219.22	218.51	217.80	217.09	216.38	215.67	214.96	214.25
11	217.24	216.52	215.80	215.08	214.36	213.64	212.92	212.20	211.48	210.76	210.04	209.32	208.60	207.88	207.16	206.44	205.72	205.00	204.28	203.56	202.84	202.12	201.40	200.68
12	207.43	206.70	205.97	205.24	204.51	203.78	203.05	202.32	201.59	200.86	200.13	199.40	198.67	197.94	197.21	196.48	195.75	195.02	194.29	193.56	192.83	192.10	191.37	190.64
13	194.58	193.84	193.10	192.36	191.62	190.88	190.14	189.40	188.66	187.92	187.18	186.44	185.70	184.96	184.22	183.48	182.74	182.00	181.26	180.52	179.78	179.04	178.30	177.56
14	183.07	182.32	181.57	180.82	180.07	179.32	178.57	177.82	177.07	176.32	175.57	174.82	174.07	173.32	172.57	171.82	171.07	170.32	169.57	168.82	168.07	167.32	166.57	165.82
15	192.82	192.07	191.32	190.57	189.82	189.07	188.32	187.57	186.82	186.07	185.32	184.57	183.82	183.07	182.32	181.57	180.82	180.07	179.32	178.57	177.82	177.07	176.32	175.57
16	182.20	181.45	180.70	179.95	179.20	178.45	177.70	176.95	176.20	175.45	174.70	173.95	173.20	172.45	171.70	170.95	170.20	169.45	168.70	167.95	167.20	166.45	165.70	164.95
17	179.40	178.65	177.90	177.15	176.40	175.65	174.90	174.15	173.40	172.65	171.90	171.15	170.40	169.65	168.90	168.15	167.40	166.65	165.90	165.15	164.40	163.65	162.90	162.15
18	181.00	180.25	179.50	178.75	178.00	177.25	176.50	175.75	175.00	174.25	173.50	172.75	172.00	171.25	170.50	169.75	169.00	168.25	167.50	166.75	166.00	165.25	164.50	163.75
19	167.90	167.15	166.40	165.65	164.90	164.15	163.40	162.65	161.90	161.15	160.40	159.65	158.90	158.15	157.40	156.65	155.90	155.15	154.40	153.65	152.90	152.15	151.40	150.65
20	151.78	151.03	150.28	149.53	148.78	148.03	147.28	146.53	145.78	145.03	144.28	143.53	142.78	142.03	141.28	140.53	139.78	139.03	138.28	137.53	136.78	136.03	135.28	134.53
21	197.81	197.06	196.31	195.56	194.81	194.06	193.31	192.56	191.81	191.06	190.31	189.56	188.81	188.06	187.31	186.56	185.81	185.06	184.31	183.56	182.81	182.06	181.31	180.56
22	193.35	192.60	191.85	191.10	190.35	189.60	188.85	188.10	187.35	186.60	185.85	185.10	184.35	183.60	182.85	182.10	181.35	180.60	179.85	179.10	178.35	177.60	176.85	176.10
23	118.04	117.29	116.54	115.79	115.04	114.29	113.54	112.79	112.04	111.29	110.54	109.79	109.04	108.29	107.54	106.79	106.04	105.29	104.54	103.79	103.04	102.29	101.54	100.79
24	108.08	107.33	106.58	105.83	105.08	104.33	103.58	102.83	102.08	101.33	100.58	99.83	99.08	98.33	97.58	96.83	96.08	95.33	94.58	93.83	93.08	92.33	91.58	90.83
25	105.04	104.29	103.54	102.79	102.04	101.29	100.54	99.79	99.04	98.29	97.54	96.79	96.04	95.29	94.54	93.79	93.04	92.29	91.54	90.79	90.04	89.29	88.54	87.79
26	100.31	99.56	98.81	98.06	97.31	96.56	95.81	95.06	94.31	93.56	92.81	92.06	91.31	90.56	89.81	89.06	88.31	87.56	86.81	86.06	85.31	84.56	83.81	83.06

PV NPPC-MAAC

Reservoir Size:	516.75	MWh
0th Hour Energy:	305.13	MWh
Annual Max:	516.8	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	303.70	MWh
Reservoir "Ceiling" Size:	516.8	MWh
"Last Hour minus 0th Hour (Stored)":	-1.43	MWh
Max. Hourly Charge:	3.058	MWh
Annual Energy Stored:	3.72	GWh
Annual Load Factor:	5 - (4,391 MWh / MW)	
Annual Capacity Factor:	38 - (1,592 MWh / MW)	

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	3.85	516.8	3.718
1.1	4.24	407.2	3.684
1.25	4.82	306.4	3.647
1.5	5.78	204.1	3.608
1.75	6.74	121.7	3.583
2	7.7	65.6	3.564
2.5	9.63	48.0	3.536
2.75	10.59	46.5	3.525
3	11.56	45.1	3.515
4	15.41	39.9	3.484

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	3.85	516.8
80%	3.08	415.0
60%	2.27	312.3
40%	1.48	209.3
20%	0.71	106.2

Effect of Resource Capacity Oversizing on Reservoir Size

FFP PV, NPPC, 111,800 MW, 2010

Resource and Reservoir Capacity for Various Levels of Energy Served

FFP PV, NPPC, 111,800 MW, 2010

A-3 PV SERC

SERC		Reservoir Size:	416.50	MWh
		0th Hour Energy:	161.88	MWh
Resource Tech:	FPP PV	Annual Max:	416.5	MWh
Year:	2010	Annual Min:	0.00	MWh
Region Peak Load:	193,500	Present State Last Hr:	160.40	MWh
Block Size (MW):	100	Reservoir "Ceiling Size":	416.5	MWh
Resource to Load Eff.:	0.98	"Last Hour minus 0th Hour (Stored)":	1.47	MWh
Resource Info		Max Hourly Charge:	2.908	MWh
Storage Eff.:	0.89	Annual Energy Stored:	4.22	GWh
Storage to Load Eff.:	0.64	Annual Load Factor:	57 (5,001	MWh / MW)
Resource Capacity	3,799	Annual Capacity Factor:	21 (1,873	MWh / MW)

Totals	
Per MW Load	
Resource	3,799 MW
Reservoir	.4165 GWh
H ₂ Stored	4.224 GWh
Gross	
Resource	735,145.5 MW
Reservoir	80,593 GWh
H ₂ Stored	817,294 GWh
Blocks (100MW)	
Resource Blocks	7,351.5
Reservoir/Blk	805.9 GWh
H ₂ Stored	8,172.9 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	9.98	9.44	2.93	2.44	1.92	1.34	0.82	0.00	0.87	1.98	9.98	6.31	8.68	9.70	10.01	10.17	10.25	9.39	8.44	7.51	6.64	5.84	5.12	4.50
Max	407.71	405.83	406.09	405.22	404.48	403.83	403.24	403.10	402.55	402.28	402.28	402.42	413.59	413.87	415.18	416.22	416.80	416.08	414.70	413.34	412.00	410.81	409.66	408.84
1	161.303	160.73	160.28	159.77	159.20	158.82	158.52	157.80	157.21	156.78	156.71	156.77	156.88	157.00	157.90	158.88	159.28	159.81	159.87	159.08	158.34	157.54	156.84	156.02
2	163.48	162.93	162.41	161.89	161.38	160.75	160.07	159.27	158.41	157.27	156.87	156.43	156.30	157.81	158.36	159.24	159.77	159.88	159.83	159.53	158.80	158.11	157.41	156.91
3	165.59	165.00	164.23	163.57	162.89	162.17	161.39	160.50	159.58	158.68	157.84	156.84	156.88	158.41	158.92	159.88	159.12	158.28	157.58	156.85	156.09	155.39	154.78	154.03
4	167.72	167.14	166.38	165.69	164.98	164.24	163.47	162.65	161.78	160.88	160.00	159.04	158.04	157.04	156.04	155.04	154.04	153.04	152.04	151.04	150.04	149.04	148.04	147.04
5	169.85	169.27	168.50	167.81	167.10	166.37	165.62	164.85	164.07	163.28	162.48	161.68	160.88	159.98	159.08	158.08	157.08	156.08	155.08	154.08	153.08	152.08	151.08	150.08
6	171.98	171.40	170.63	170.00	169.27	168.52	167.77	167.00	166.21	165.41	164.61	163.81	163.01	162.01	161.01	160.01	159.01	158.01	157.01	156.01	155.01	154.01	153.01	152.01
7	174.11	173.53	172.76	172.13	171.40	170.65	169.90	169.13	168.34	167.54	166.74	165.94	165.14	164.14	163.14	162.14	161.14	160.14	159.14	158.14	157.14	156.14	155.14	154.14
8	176.24	175.66	174.89	174.26	173.53	172.78	172.03	171.26	170.47	169.67	168.87	168.07	167.27	166.27	165.27	164.27	163.27	162.27	161.27	160.27	159.27	158.27	157.27	156.27
9	178.37	177.79	177.02	176.39	175.66	174.91	174.16	173.39	172.60	171.80	171.00	170.20	169.40	168.40	167.40	166.40	165.40	164.40	163.40	162.40	161.40	160.40	159.40	158.40
10	180.50	179.92	179.15	178.52	177.79	177.04	176.29	175.52	174.73	173.93	173.13	172.33	171.53	170.53	169.53	168.53	167.53	166.53	165.53	164.53	163.53	162.53	161.53	160.53
11	182.63	182.05	181.28	180.65	179.92	179.17	178.42	177.65	176.86	176.06	175.26	174.46	173.66	172.66	171.66	170.66	169.66	168.66	167.66	166.66	165.66	164.66	163.66	162.66
12	184.76	184.18	183.41	182.78	182.05	181.30	180.55	179.78	178.99	178.19	177.39	176.59	175.79	174.79	173.79	172.79	171.79	170.79	169.79	168.79	167.79	166.79	165.79	164.79
13	186.89	186.31	185.54	184.91	184.18	183.43	182.68	181.91	181.12	180.32	179.52	178.72	177.92	176.92	175.92	174.92	173.92	172.92	171.92	170.92	169.92	168.92	167.92	166.92
14	189.02	188.44	187.67	187.04	186.31	185.56	184.81	184.04	183.25	182.45	181.65	180.85	180.05	179.05	178.05	177.05	176.05	175.05	174.05	173.05	172.05	171.05	170.05	169.05
15	191.15	190.57	189.80	189.17	188.44	187.69	186.94	186.17	185.38	184.58	183.78	182.98	182.18	181.18	180.18	179.18	178.18	177.18	176.18	175.18	174.18	173.18	172.18	171.18
16	193.28	192.70	191.93	191.30	190.57	189.82	189.07	188.30	187.51	186.71	185.91	185.11	184.31	183.31	182.31	181.31	180.31	179.31	178.31	177.31	176.31	175.31	174.31	173.31
17	195.41	194.83	194.06	193.43	192.70	191.95	191.20	190.43	189.64	188.84	188.04	187.24	186.44	185.44	184.44	183.44	182.44	181.44	180.44	179.44	178.44	177.44	176.44	175.44
18	197.54	196.96	196.19	195.56	194.83	194.08	193.33	192.56	191.77	190.97	190.17	189.37	188.57	187.57	186.57	185.57	184.57	183.57	182.57	181.57	180.57	179.57	178.57	177.57
19	199.67	199.09	198.32	197.69	196.96	196.21	195.46	194.69	193.90	193.10	192.30	191.50	190.70	189.70	188.70	187.70	186.70	185.70	184.70	183.70	182.70	181.70	180.70	179.70
20	201.80	201.22	200.45	199.82	199.09	198.34	197.59	196.82	196.03	195.23	194.43	193.63	192.83	191.83	190.83	189.83	188.83	187.83	186.83	185.83	184.83	183.83	182.83	181.83
21	203.93	203.35	202.58	201.95	201.22	200.47	199.72	198.95	198.16	197.36	196.56	195.76	194.96	193.96	192.96	191.96	190.96	189.96	188.96	187.96	186.96	185.96	184.96	183.96
22	206.06	205.48	204.71	204.08	203.35	202.60	201.85	201.08	200.29	199.49	198.69	197.89	197.09	196.09	195.09	194.09	193.09	192.09	191.09	190.09	189.09	188.09	187.09	186.09
23	208.19	207.61	206.84	206.21	205.48	204.73	203.98	203.21	202.42	201.62	200.82	200.02	199.22	198.22	197.22	196.22	195.22	194.22	193.22	192.22	191.22	190.22	189.22	188.22
24	210.32	209.74	208.97	208.34	207.61	206.86	206.11	205.34	204.55	203.75	202.95	202.15	201.35	200.35	199.35	198.35	197.35	196.35	195.35	194.35	193.35	192.35	191.35	190.35
25	212.45	211.87	211.10	210.47	209.74	208.99	208.24	207.47	206.68	205.88	205.08	204.28	203.48	202.48	201.48	200.48	199.48	198.48	197.48	196.48	195.48	194.48	193.48	192.48
26	214.58	214.00	213.23	212.60	211.87	211.12	210.37	209.60	208.81	208.01	207.21	206.41	205.61	204.61	203.61	202.61	201.61	200.61	199.61	198.61	197.61	196.61	195.61	194.61

PV SERC

Reservoir Size:	416.50	MWh
0th Hour Energy:	161.88	MWh
Annual Max:	416.5	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	180.40	MWh
Reservoir "Ceiling" Size:	416.5	MWh
"Last Hour minus 0th Hour (Stored)":	-1.47	MWh
Max Hourly Charge:	2.908	MWh
Annual Energy Stored:	4.22	GWh
Annual Load Factor:	57	(5,001 MWh / MW)
Annual Capacity Factor:	21	(1,873 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	3.8	416.5	4.224
1.1	4.18	109.5	4.200
1.25	4.75	54.8	4.172
1.5	5.7	49.5	4.141
1.75	6.65	44.4	4.120
2	7.6	39.4	4.104
2.5	9.5	31.9	4.081
2.75	10.45	28.8	4.071
3	11.4	26.5	4.062
4	15.2	19.8	4.030

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	3.80	416.5
80%	3.02	333.0
60%	2.25	249.0
40%	1.47	165.1
20%	0.72	82.1

Effect of Resource Capacity Oversizing on Reservoir Size

FFP PV, SERC, 193,500 MW, 2010

Resource and Reservoir Capacity for Various Levels of Energy Served

FFP PV, SERC, 193,500 MW, 2010

WSCCn		Reservoir Size: 1161.48 MWh	
Resource Tech:	FFP PV	0th Hour Energy:	669.78 MWh
Year:	2010	Annual Max:	1161.6 MWh
Region Peak Load:	59,000 MW	Annual Min:	0.00 MWh
Block Size (MW):	100 MW	Present State Last Hr:	669.78 MWh
Resource to Load Eff.:	0.96	Reservoir Ceiling Size:	1161.6 MWh
Resource Into Storage Eff.:	0.89	Last Hour minus 0th Hour (Stored):	0.03 MWh
Storage to Load Eff.:	0.64	Max Hourly Charge:	3.775 MWh
Resource Capacity:	4.756 MW	Annual Energy Stored:	6.15 GWh
(All values per MW of Load)		Annual Load Factor:	.65 (6,695 MWh / MW)
		Annual Capacity Factor:	.2 (1,757 MWh / MW)

Totals	
Per MW Load	
Resource	4.756 MW
Reservoir	1.1615 GWh
H ₂ Stored	5.146 GWh
Gross	
Resource	280,578. MW
Reservoir	68,527 GWh
H ₂ Stored	303,629 GWh
Blocks (100MW)	
Resource Blocks	2,805.8
Reservoir/Blk	685.3 GWh
H ₂ Stored	3,036.3 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	4.74	4.00	3.27	2.52	1.76	0.93	0.00	0.14	1.00	2.43	4.69	7.77	11.06	12.38	12.54	12.35	11.61	10.75	9.88	8.94	8.02	7.11	6.26	5.48
Max	1164.08	1159.98	1152.70	1142.20	1128.30	1110.31	1100.60	1116.07	1149.75	1150.39	1152.33	1158.06	1167.37	1169.70	1161.48	1150.58	1139.81	1128.89	1118.01	1107.12	1096.30	1085.51	1074.79	1064.26
1	668.957	668.08	667.20	666.32	665.45	664.57	663.69	662.70	662.80	663.77	665.51	667.53	669.53	671.02	671.58	671.82	670.83	669.82	668.76	667.67	666.55	665.48	664.36	663.20
2	669.07	668.28	667.45	666.64	665.84	665.04	664.24	663.33	663.43	664.40	666.14	668.16	670.16	671.65	672.21	672.45	671.46	670.45	669.38	668.29	667.18	666.09	664.97	663.82
3	669.19	668.40	667.57	666.76	665.96	665.16	664.36	663.45	663.55	664.52	666.26	668.28	670.28	671.77	672.33	672.57	671.58	670.57	669.50	668.41	667.32	666.23	665.11	663.96
4	669.31	668.52	667.69	666.88	666.08	665.28	664.48	663.57	663.67	664.64	666.38	668.40	670.40	671.89	672.45	672.69	671.70	670.69	669.62	668.53	667.44	666.35	665.23	664.08
5	669.43	668.64	667.81	667.00	666.20	665.40	664.60	663.69	663.79	664.76	666.50	668.52	670.52	672.01	672.57	672.81	671.82	670.81	669.74	668.65	667.56	666.47	665.35	664.20
6	669.55	668.76	667.93	667.12	666.32	665.52	664.72	663.81	663.91	664.88	666.62	668.64	670.64	672.13	672.69	672.93	671.94	670.93	669.86	668.77	667.68	666.59	665.47	664.32
7	669.67	668.88	668.05	667.24	666.44	665.64	664.84	663.93	664.03	665.00	666.74	668.76	670.76	672.25	672.81	673.05	672.06	671.05	669.98	668.89	667.80	666.71	665.59	664.44
8	669.79	669.00	668.17	667.36	666.56	665.76	664.96	664.05	664.15	665.12	666.86	668.88	670.88	672.37	672.93	673.17	672.18	671.17	670.10	669.01	667.92	666.83	665.71	664.56
9	669.91	669.12	668.29	667.48	666.68	665.88	665.08	664.17	664.27	665.24	666.98	669.00	671.00	672.49	673.05	673.29	672.30	671.29	670.22	669.13	668.04	666.95	665.83	664.68
10	670.03	669.24	668.41	667.60	666.80	666.00	665.20	664.29	664.39	665.36	667.10	669.12	671.12	672.61	673.17	673.41	672.42	671.41	670.34	669.25	668.16	667.07	665.95	664.80
11	670.15	669.36	668.53	667.72	666.92	666.12	665.32	664.41	664.51	665.48	667.22	669.24	671.24	672.73	673.29	673.53	672.54	671.53	670.46	669.37	668.28	667.19	666.07	664.92
12	670.27	669.48	668.65	667.84	667.04	666.24	665.44	664.53	664.63	665.60	667.34	669.36	671.36	672.85	673.41	673.65	672.66	671.65	670.58	669.49	668.40	667.31	666.19	665.04
13	670.39	669.60	668.77	667.96	667.16	666.36	665.56	664.65	664.75	665.72	667.46	669.48	671.48	672.97	673.53	673.77	672.78	671.77	670.70	669.61	668.52	667.43	666.31	665.16
14	670.51	669.72	668.89	668.08	667.28	666.48	665.68	664.77	664.87	665.84	667.58	669.60	671.60	673.09	673.65	673.89	672.90	671.89	670.82	669.73	668.64	667.55	666.43	665.28
15	670.63	669.84	669.01	668.20	667.40	666.60	665.80	664.89	664.99	665.96	667.70	669.72	671.72	673.21	673.77	674.01	673.02	672.01	670.94	669.85	668.76	667.67	666.55	665.40
16	670.75	669.96	669.13	668.32	667.52	666.72	665.92	665.01	665.11	666.08	667.82	669.84	671.84	673.33	673.89	674.13	673.14	672.13	671.06	669.97	668.88	667.79	666.67	665.52
17	670.87	670.08	669.25	668.44	667.64	666.84	666.04	665.13	665.23	666.20	667.94	670.06	672.06	673.55	674.11	674.35	673.36	672.35	671.28	670.19	669.10	667.99	666.89	665.74
18	670.99	670.20	669.37	668.56	667.76	666.96	666.16	665.25	665.35	666.32	668.06	670.18	672.18	673.67	674.23	674.47	673.48	672.47	671.40	670.31	669.22	668.11	667.01	665.86
19	671.11	670.32	669.49	668.68	667.88	667.08	666.28	665.37	665.47	666.44	668.18	670.30	672.30	673.79	674.35	674.59	673.60	672.59	671.52	670.43	669.34	668.23	667.13	665.98
20	671.23	670.44	669.61	668.80	668.00	667.20	666.40	665.49	665.59	666.56	668.30	670.42	672.42	673.91	674.47	674.71	673.72	672.71	671.64	670.55	669.46	668.35	667.25	666.10
21	671.35	670.56	669.73	668.92	668.12	667.32	666.52	665.61	665.71	666.68	668.42	670.54	672.54	674.03	674.59	674.83	673.84	672.83	671.76	670.67	669.58	668.47	667.37	666.22
22	671.47	670.68	669.85	669.04	668.24	667.44	666.64	665.73	665.83	666.80	668.54	670.66	672.66	674.15	674.71	674.95	673.96	672.95	671.88	670.79	669.70	668.59	667.49	666.34
23	671.59	670.80	669.97	669.16	668.36	667.56	666.76	665.85	665.95	666.92	668.66	670.78	672.78	674.27	674.83	675.07	674.08	673.07	672.00	670.91	669.82	668.71	667.61	666.46
24	671.71	670.92	670.09	669.28	668.48	667.68	666.88	665.97	666.07	667.04	668.78	670.90	672.90	674.39	674.95	675.19	674.20	673.19	672.12	671.03	669.94	668.83	667.73	666.58
25	671.83	671.04	670.21	669.40	668.60	667.80	667.00	666.09	666.19	667.16	668.90	671.02	673.02	674.51	675.07	675.31	674.32	673.31	672.24	671.15	670.06	668.95	667.85	666.70
26	671.95	671.16	670.33	669.52	668.72	667.92	667.12	666.21	666.31	667.28	669.02	671.14	673.14	674.63	675.19	675.43	674.44	673.43	672.36	671.27	670.18	669.07	667.97	666.82

Reservoir Size:	1161.48	MWh
0th Hour Energy:	669.78	MWh
Annual Max:	1161.5	MWh
Annual Min:	0.00	MWh
Present State, Last Hr:	669.78	MWh
Reservoir "Ceiling" Size:	1161.5	MWh
*Last Hour minus 0th Hour (Stored):	-0.03	MWh
Max. Hourly Charge:	3.775	MWh
Annual Energy Stored:	5.15	GWh
Annual Load Factor:	.65	(5,695 MWh / MW)
Annual Capacity Factor:	.2	(1,757 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	4.76	1161.5	5.146
1.1	5.23	978.6	5.114
1.25	5.94	718.0	5.082
1.5	7.13	389.7	5.048
1.75	8.32	221.5	5.026
2	9.51	128.6	5.007
2.5	11.89	64.3	4.978
2.75	13.08	74.8	4.966
3	14.27	69.1	4.955
4	19.02	49.7	4.922

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	4.76	1161.5
80%	3.79	926.9
60%	2.83	697.6
40%	1.87	463.9
20%	0.91	234.1

Effect of Resource Capacity Oversizing on
Reservoir Size

FFPV PV, WSCCn, 59,000 MW, 2010

Resource and Reservoir Capacity for Various Levels
of Energy Served

FFPV PV, WSCCn, 59,000 MW, 2010

WSCCs		Reservoir Size:	894.70	MWh
Resource Tech:	FFPV	0th Hour Energy:	311.53	MWh
Year:	2010	Annual Max:	894.7	MWh
Region Peak Load:	70,000	Annual Min:	0.00	MWh
Block Size (MW):	100	Present State, Last Hr:	311.12	MWh
Resource to Load Eff.:	0.86	Reservoir Ceiling Size:	894.7	MWh
Resource Info		Last Hour minus		
Storage Eff.:	0.89	0th Hour (Stored):	0.42	MWh
Storage to Load Eff.:	0.64	Max Hourly Charge:	2.978	MWh
Resource Capacity	3,640	Annual Energy Stored:	4.41	GWh
		Annual Load Factor:	58	(6,084 MWh / MW)
		Annual Capacity Factor:	23	(2,055 MWh / MW)

Totals	
<i>Per MW Load</i>	
Resource	3.84 MW
Reservoir	.8947 GWh
H ₂ Stored	4.407 GWh
<i>Gross</i>	
Resource	288,817.5 MW
Reservoir	82,829 GWh
H ₂ Stored	308,521 GWh
<i>Blocks (100MW)</i>	
Resource Blocks	2,888.2
Reservoir/Blk	628.3 GWh
H ₂ Stored	3,065.2 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	3.88	3.08	2.48	1.88	1.28	0.68	0.08	0.32	1.48	3.38	5.82	8.81	11.11	11.33	11.38	10.98	10.18	9.28	8.38	7.44	6.58	5.77	5.02	4.39
Max	287.89	288.83	288.33	288.28	288.24	288.21	288.18	288.15	288.12	288.09	288.06	288.03	288.00	287.97	287.94	287.91	287.88	287.85	287.82	287.79	287.76	287.73	287.70	287.67
1	310.864	310.24	309.64	309.06	308.48	307.84	307.22	306.68	306.14	305.12	304.65	304.37	304.10	303.78	303.58	302.79	301.93	301.01	300.13	299.27	298.45	297.67	296.93	296.30
2	298.88	298.18	297.51	296.84	296.18	295.53	294.87	294.21	293.55	292.89	292.23	291.57	290.91	290.25	289.59	288.93	288.27	287.61	286.95	286.29	285.63	284.97	284.31	283.65
3	286.94	286.22	285.50	284.78	284.06	283.34	282.62	281.90	281.18	280.46	279.74	279.02	278.30	277.58	276.86	276.14	275.42	274.70	273.98	273.26	272.54	271.82	271.10	270.38
4	284.09	283.37	282.65	281.93	281.21	280.49	279.77	279.05	278.33	277.61	276.89	276.17	275.45	274.73	274.01	273.29	272.57	271.85	271.13	270.41	269.69	268.97	268.25	267.53
5	280.83	280.11	279.39	278.67	277.95	277.23	276.51	275.79	275.07	274.35	273.63	272.91	272.19	271.47	270.75	269.99	269.27	268.55	267.83	267.11	266.39	265.67	264.95	264.23
6	286.60	285.88	285.16	284.44	283.72	283.00	282.28	281.56	280.84	280.12	279.40	278.68	277.96	277.24	276.52	275.80	275.08	274.36	273.64	272.92	272.20	271.48	270.76	270.04
7	298.08	297.36	296.64	295.92	295.20	294.48	293.76	293.04	292.32	291.60	290.88	290.16	289.44	288.72	288.00	287.28	286.56	285.84	285.12	284.40	283.68	282.96	282.24	281.52
8	299.89	299.17	298.45	297.73	297.01	296.29	295.57	294.85	294.13	293.41	292.69	291.97	291.25	290.53	289.81	289.09	288.37	287.65	286.93	286.21	285.49	284.77	284.05	283.33
9	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
10	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
11	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
12	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
13	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
14	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
15	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
16	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
17	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
18	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
19	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
20	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
21	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
22	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
23	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
24	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
25	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32
26	298.88	298.16	297.44	296.72	296.00	295.28	294.56	293.84	293.12	292.40	291.68	290.96	290.24	289.52	288.80	288.08	287.36	286.64	285.92	285.20	284.48	283.76	283.04	282.32

PV WSCCs

Reservoir Size:	894.70	MWh
0th Hour Energy:	311.53	MWh
Annual Max:	894.7	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	311.12	MWh
Reservoir "Ceiling" Size:	894.7	MWh
*Last Hour minus		
0th Hour (Stored):	-0.42	MWh
Max. Hourly Charge:	2.978	MWh
Annual Energy Stored:	4.41	GWh
Annual Load Factor:	.58	(5,084 MWh / MW)
Annual Capacity Factor:	.23	(2,055 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	3.84	894.7	4.407
1.1	4.22	755.0	4.375
1.25	4.8	563.0	4.335
1.5	5.76	324.3	4.293
1.75	6.72	232.9	4.266
2	7.68	143.3	4.248
2.5	9.6	94.3	4.220
2.75	10.56	87.3	4.210
3	11.52	80.4	4.200
4	15.36	59.4	4.169

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	3.84	894.7
80%	3.05	717.5
60%	2.27	539.9
40%	1.48	360.8
20%	0.71	184.2

Effect of Resource Capacity Oversizing on Reservoir Size

FFP PV, WSCCs, 70,000 MW, 2010

Resource and Reservoir Capacity for Various Levels of Energy Served

FFP PV, WSCCs, 70,000 MW, 2010

A-6 Solar Thermal ERCOT

ERCOT		Reservoir Size:	454.70	MWh
Resource Tech:	Solar Thermal	0th Hour Energy:	131.02	MWh
Year:	2010	Annual Max:	454.7	MWh
Region Peak Load:	62,900 MW	Annual Min:	0.00	MWh
Block Size (MW):	100 MW	Present State Last Hr:	136.79	MWh
Resource to Load Eff.:	0.96	Reservoir Ceiling Size:	454.7	MWh
Resource Info		Last Hour minus 0th Hour (Stored):	0.23	MWh
Storage Eff.:	0.89	Max Hourly Charge:	2,324	MWh
Storage to Load Eff.:	0.64	Annual Energy Stored:	3,70	GWh
Resource Capacity	3,137 MW	Annual Load Factor:	55	(4,823 MWh / MW)
(All values per MW of Load)		Annual Capacity Factor:	23	(2,004 MWh / MW)

Totals	
<i>Per MW Load</i>	
Resource	3,137 MW
Reservoir	454.7 GWh
H ₂ Stored	3.7 GWh
<i>Gross</i>	
Resource	197,347.3 MW
Reservoir	26,801 GWh
H ₂ Stored	232,732 GWh
<i>Blocks (100MW)</i>	
Resource Blocks	1,973.5
Reservoir/Blk	268.0 GWh
H ₂ Stored	2,327.3 GWh

Reservoir Status—Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	9.96	9.32	2.68	1.89	1.31	0.61	0.00	0.63	1.72	2.92	4.58	6.37	8.20	9.92	9.34	9.41	8.52	9.19	8.43	7.64	6.86	6.10	5.36	4.66
Max	447.76	448.97	448.18	448.42	448.63	448.20	448.85	448.51	448.78	447.85	449.57	450.65	451.55	452.95	453.60	454.46	454.70	454.18	453.82	452.70	451.57	449.51	448.33	446.89
1	190.396	129.64	129.98	129.31	127.69	126.92	126.19	126.00	126.82	127.26	128.08	128.96	129.87	130.74	131.59	132.28	132.66	131.95	131.15	130.39	129.60	128.83	128.06	127.27
2	128.28	128.00	128.90	129.58	129.83	129.06	128.19	127.24	126.34	125.61	126.36	127.39	128.39	129.37	130.49	131.58	132.34	132.68	131.97	131.16	129.37	127.53	125.64	123.64
3	128.28	127.87	127.08	126.44	125.83	125.20	124.83	125.92	126.06	126.23	126.36	126.52	126.66	126.74	126.77	126.74	126.66	126.52	126.36	126.16	125.91	125.61	125.27	124.89
4	114.33	113.41	112.70	112.24	111.81	111.32	110.74	109.44	108.61	107.40	111.12	111.92	112.73	113.53	114.27	114.88	115.08	114.49	113.81	113.04	112.16	111.27	110.35	109.40
5	108.89	108.17	107.45	106.72	106.05	105.13	104.15	103.56	104.09	104.75	105.60	106.32	107.18	108.07	108.82	109.67	110.19	109.81	109.86	109.81	109.69	109.51	109.29	109.05
6	109.85	109.17	108.48	107.82	107.14	106.39	105.42	104.43	103.83	104.72	105.34	106.24	106.83	107.11	110.29	111.84	112.84	113.12	113.81	114.48	115.08	115.61	116.12	116.61
7	108.92	108.32	107.72	107.11	106.48	105.76	105.06	104.44	103.53	105.21	107.12	109.13	111.12	113.04	114.80	116.58	117.23	118.68	119.74	120.44	121.84	123.12	124.39	125.64
8	110.93	110.28	109.58	108.91	108.22	107.48	106.67	105.91	105.30	106.84	108.63	110.58	112.22	114.88	116.88	118.58	119.88	120.88	121.88	122.88	123.88	124.88	125.88	126.88
9	91.72	91.02	90.32	89.62	88.90	88.13	87.23	86.29	85.33	84.37	83.48	82.68	82.42	81.79	81.50	80.85	81.17	80.70	79.77	78.84	77.95	77.07	76.28	75.44
10	74.58	73.83	73.10	72.44	71.68	70.88	70.04	69.86	70.18	70.78	71.18	71.61	72.84	73.48	73.83	73.98	73.87	73.27	72.84	72.40	71.40	70.43	69.51	68.60
11	68.97	68.16	67.34	66.52	65.68	64.82	63.94	63.03	62.65	64.26	66.14	68.15	70.21	72.29	74.14	75.59	76.64	76.18	75.28	74.39	73.50	72.62	71.77	70.97
12	70.31	69.43	68.59	67.69	66.77	65.82	64.85	63.84	62.78	61.53	60.31	59.13	57.91	56.41	54.48	52.98	51.91	50.78	49.48	47.98	46.48	44.98	43.48	41.98
13	78.67	78.01	77.34	76.67	75.98	75.28	74.58	73.84	73.03	72.18	71.29	70.31	69.24	68.08	66.83	65.48	64.08	62.68	61.28	59.88	58.48	57.08	55.68	54.28
14	74.28	73.64	73.00	72.36	71.71	71.00	70.27	69.52	68.75	67.96	67.14	66.29	65.43	64.56	63.68	62.79	61.88	60.97	60.06	59.15	58.24	57.33	56.42	55.51
15	78.98	78.37	77.77	77.16	76.54	75.90	75.25	74.58	73.89	73.18	72.46	71.72	70.97	70.21	69.44	68.66	67.87	67.08	66.28	65.48	64.68	63.88	63.08	62.28
16	86.03	84.90	83.69	82.42	81.09	79.70	78.25	76.74	75.18	73.51	71.74	69.86	67.87	65.78	63.58	61.28	58.88	56.38	53.78	51.08	48.28	45.48	42.68	39.88
17	90.80	89.81	88.70	87.44	86.03	84.48	82.79	80.97	79.03	76.98	74.81	72.51	70.08	67.51	64.81	61.98	59.03	55.98	52.83	49.58	46.23	42.78	39.23	35.68
18	93.88	92.18	90.38	88.58	86.68	84.68	82.58	80.38	78.08	75.68	73.18	70.58	67.88	65.08	62.18	59.18	56.08	52.88	49.58	46.18	42.68	39.13	35.58	31.98
19	77.06	76.17	75.27	74.36	73.45	72.54	71.63	70.72	69.81	68.90	68.00	67.09	66.18	65.27	64.36	63.45	62.54	61.63	60.72	59.81	58.90	58.00	57.09	56.18
20	78.43	77.54	76.65	75.76	74.87	73.98	73.09	72.20	71.31	70.42	69.53	68.64	67.75	66.86	65.97	65.08	64.19	63.30	62.41	61.52	60.63	59.74	58.85	57.96
21	74.15	73.81	73.48	73.14	72.80	72.46	72.12	71.78	71.44	71.10	70.76	70.42	70.08	69.74	69.40	69.06	68.72	68.38	68.04	67.70	67.36	67.02	66.68	66.34
22	68.82	68.01	67.19	66.37	65.55	64.73	63.91	63.09	62.27	61.45	60.63	59.81	58.99	58.17	57.35	56.53	55.71	54.89	54.07	53.25	52.43	51.61	50.79	49.97
23	68.62	67.77	66.92	66.07	65.22	64.37	63.52	62.67	61.82	60.97	60.12	59.27	58.42	57.57	56.72	55.87	55.02	54.17	53.32	52.47	51.62	50.77	49.92	49.07
24	47.69	47.00	46.31	45.62	44.93	44.24	43.55	42.86	42.17	41.48	40.79	40.10	39.41	38.72	38.03	37.34	36.65	35.96	35.27	34.58	33.89	33.20	32.51	31.82
25	38.85	38.08	37.26	36.46	35.65	34.82	34.00	33.18	32.36	31.54	30.72	29.90	29.08	28.26	27.44	26.62	25.80	24.98	24.16	23.34	22.52	21.70	20.88	20.06
26	41.89	40.84	40.19	39.42	38.62	37.79	36.95	36.10	35.26	34.41	33.57	32.72	31.87	31.02	30.17	29.32	28.47	27.62	26.77	25.92	25.07	24.22	23.37	22.52

Solar Thermal ERCOT

Reservoir Size:	454.70	MWh
0th Hour Energy:	131.02	MWh
Annual Max:	454.7	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	130.79	MWh
Reservoir 'Ceiling Size':	454.7	MWh
Last Hour minus 0th Hour (Stored):	-0.23	MWh
Max. Hourly Charge:	2.324	MWh
Annual Energy Stored:	3.70	GWh
Annual Load Factor:	55	(4,623 MWh / MW)
Annual Capacity Factor:	23	(2,004 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	3.14	454.7	3.700
1.1	3.45	175.9	3.666
1.25	3.92	98.0	3.623
1.5	4.71	54.8	3.567
1.75	5.49	44.7	3.524
2	6.27	42.4	3.492
2.5	7.84	40.2	3.445
2.75	8.63	39.1	3.426
3	9.41	38.0	3.409
4	12.55	34.3	3.359

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	3.14	454.7
80%	2.50	363.8
60%	1.86	274.0
40%	1.22	182.9
20%	0.59	93.2

Effect of Resource Capacity Oversizing on
Reservoir Size

Solar Thermal, ERCOT, 62,900 MW, 2010

Resource and Reservoir Capacity for Various Levels of
Energy Served

Solar Thermal, ERCOT, 62,900 MW, 2010

A-7 Solar Thermal WSCCs

WSCCs		Reservoir Size:	511.56 MWh
Resource Tech:	Solar Thermal	0th Hour Energy:	195.11 MWh
Year:	2010	Annual Max:	511.6 MWh
Region Peak Load:	70,000 MW	Annual Min:	0.00 MWh
Block Size (MW):	100 MW	Present State, Last Hrs:	195.13 MWh
Resource to Load Eff.:	0.96	Reservoir "Ceiling Size":	511.6 MWh
Resource Info		"Last Hour minus	
Storage Eff.:	0.89	0th Hour (Stored):	0.02 MWh
Storage to Load Eff.:	0.64	Max. Hourly Charge:	2.028 MWh
Resource Capacity	2,840 MW	Annual Energy Stored:	3.73 GWh
(All values per MW of Load)		Annual Load Factor:	55 (5,094 MWh / MW)
		Annual Capacity Factor:	3 (2,823 MWh / MW)

Totals	
<i>Per MW Load</i>	
Resource	2.84 MW
Reservoir	.5116 GWh
H ₂ Stored	3.73 GWh
<i>Gross</i>	
Resource	198,790.8 MW
Reservoir	35,808 GWh
H ₂ Stored	261,106 GWh
<i>Blocks (100MW)</i>	
Resource Blocks	1,987.9
Reservoir Bk	358.1 GWh
H ₂ Stored	2,611.1 GWh

Reservoir Status—Hourly Deliverable Energy Stored (MWh)

Hour→ Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	3.96	9.31	2.67	2.03	1.55	0.60	0.00	0.76	2.16	9.74	5.15	6.51	8.02	9.36	9.86	10.35	10.76	9.89	8.89	7.90	6.95	6.08	5.32	4.62
Max	508.25	508.33	504.83	504.13	503.34	502.82	502.28	503.77	503.74	504.76	505.84	506.83	507.88	508.30	508.38	510.30	511.07	511.58	511.27	510.30	509.33	508.48	507.68	508.94
1	194.448	195.82	199.22	192.63	192.04	191.42	190.80	190.67	191.22	192.82	194.59	196.45	198.35	199.90	200.72	201.10	201.30	200.47	199.58	198.72	197.90	197.12	196.39	195.75
2	196.14	194.56	193.95	189.39	192.79	192.15	191.35	191.90	192.04	192.35	194.88	196.91	198.96	197.92	198.83	198.81	198.99	198.01	197.01	196.04	195.12	194.33	193.55	192.85
3	192.23	191.81	190.41	189.81	189.20	188.54	187.94	188.13	188.54	188.98	190.01	191.57	192.45	192.01	191.23	190.32	189.41	188.47	187.57	186.71	185.81	184.91	184.00	183.14
4	188.64	189.23	194.61	183.31	181.41	180.76	180.13	179.55	180.17	180.66	181.37	181.96	183.10	184.22	184.53	185.28	185.20	184.22	183.24	182.30	181.39	180.55	179.83	179.14
5	178.52	177.81	177.20	178.68	178.09	178.28	177.37	179.43	172.58	171.65	170.68	169.55	168.68	167.72	166.76	165.81	164.79	163.68	162.57	161.53	160.55	159.65	158.88	158.16
6	157.40	168.67	194.21	183.30	184.34	184.14	183.24	182.53	182.95	181.33	180.31	179.92	178.10	176.60	175.71	174.72	173.10	171.14	169.04	166.96	164.89	162.87	160.83	158.81
7	151.82	151.18	150.49	149.82	149.14	148.37	147.41	146.89	146.81	147.84	148.97	150.28	151.33	152.31	153.20	153.83	153.76	152.64	151.53	150.47	149.45	148.53	147.68	146.92
8	148.16	148.90	144.82	144.14	143.39	142.82	141.26	140.78	140.79	140.86	140.88	141.18	141.57	141.81	142.00	142.88	143.24	143.14	142.13	141.00	139.90	138.83	137.84	136.89
9	139.80	139.19	132.48	131.78	131.07	130.29	129.34	128.40	128.16	128.38	128.68	128.98	129.34	129.77	130.12	130.41	130.34	129.44	128.40	127.40	126.45	125.57	124.77	124.04
10	123.35	122.89	122.03	121.38	120.73	120.02	119.28	118.01	118.54	121.11	122.26	123.33	124.29	125.84	126.85	127.96	127.83	126.80	125.68	124.73	123.84	122.90	122.23	121.47
11	120.78	120.19	119.45	118.83	118.18	117.50	116.79	116.48	116.75	117.23	117.79	118.44	119.18	119.82	120.47	120.88	120.88	119.74	118.71	117.72	116.76	115.89	115.10	114.42
12	119.74	119.09	118.44	117.79	117.09	116.35	109.34	108.94	109.79	111.09	112.60	114.17	115.77	117.42	118.94	120.31	120.42	119.43	118.33	117.45	116.40	115.49	114.87	114.29
13	119.29	112.58	111.90	111.23	110.54	109.78	108.81	108.34	108.92	108.70	110.89	112.93	114.08	115.68	117.18	118.06	118.41	117.58	116.48	115.42	114.49	113.52	112.71	111.96
14	111.29	110.53	109.98	109.29	108.81	107.84	106.87	106.90	107.85	109.43	111.18	112.93	114.80	116.83	118.97	119.80	120.94	120.37	119.27	118.22	117.22	116.30	115.60	114.79
15	114.10	113.43	112.78	112.12	111.43	110.68	109.68	109.58	109.97	110.83	111.20	111.89	112.87	113.24	113.87	114.41	114.69	113.78	112.85	111.86	110.83	109.88	108.74	107.97
16	107.28	106.83	104.60	103.19	104.43	103.54	102.66	102.63	102.81	102.90	103.24	104.49	105.81	107.92	108.31	108.75	110.29	109.17	108.06	107.01	106.00	105.06	104.19	103.40
17	102.68	101.98	101.25	100.60	99.91	99.19	98.40	98.09	98.39	98.90	99.48	100.12	100.78	101.52	102.33	102.70	102.22	101.28	100.30	99.38	98.48	97.53	96.84	96.11
18	93.42	94.78	94.09	93.44	92.66	91.86	91.39	90.87	91.08	91.39	91.73	91.84	92.47	93.52	95.07	95.86	92.81	92.08	91.11	90.16	89.28	88.41	87.82	86.93
19	86.23	85.59	84.94	84.29	83.58	82.79	81.87	81.75	82.58	83.96	85.84	87.28	88.87	90.48	92.10	93.83	94.23	93.67	92.49	91.45	90.45	89.55	88.74	88.03
20	87.26	88.34	89.03	88.69	88.43	88.07	87.33	86.97	87.84	89.84	91.84	93.85	95.85	97.66	98.29	96.68	94.90	92.14	90.45	88.40	86.42	84.52	82.72	81.45
21	85.34	84.65	83.97	83.29	82.58	81.78	80.78	80.97	81.05	82.48	84.10	85.78	87.50	88.20	90.77	92.06	92.74	92.18	91.09	90.03	89.04	88.14	87.32	86.60
22	85.92	85.73	84.33	83.93	83.22	82.42	81.45	80.77	81.16	82.25	83.94	85.90	87.82	88.95	91.89	92.59	92.87	92.99	92.88	92.84	92.86	92.87	92.87	92.87
23	80.70	79.84	79.20	78.47	77.69	76.81	75.75	75.24	75.45	76.80	78.26	79.78	77.90	77.78	78.08	78.28	77.92	76.91	75.79	74.58	73.51	72.52	71.60	70.76
24	70.07	69.43	68.60	67.19	67.54	66.94	66.37	65.63	65.92	66.40	66.99	67.61	68.30	68.94	69.84	70.31	70.77	70.41	69.46	68.37	67.31	66.30	65.18	64.49
25	64.85	64.23	63.63	63.02	62.49	61.81	61.16	60.96	61.80	62.68	64.04	65.87	67.02	68.57	70.74	72.41	73.93	75.11	72.20	71.32	70.47	69.69	68.96	68.33
26	67.89	67.59	68.50	69.39	69.28	68.81	68.31	68.09	68.17	68.86	69.19	68.84	70.81	72.43	74.03	75.48	76.98	75.99	74.90	73.28	72.93	71.44	70.65	69.69

Solar Thermal WSCCs

Resource Capacity	2,840	MW
Reservoir Size	511.56	MWh
0th Hour Energy	195.11	MWh

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	2.84	511.6	3,730
1.1	3.12	315.9	3,697
1.25	3.55	186.3	3,658
1.5	4.26	58.0	3,603
1.75	4.97	39.7	3,563
2	5.68	37.6	3,530
2.5	7.1	34.0	3,482
2.75	7.81	32.2	3,464
3	8.52	31.3	3,448
4	11.36	30.9	3,398

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	2.84	511.6
80%	2.26	408.7
60%	1.67	306.3
40%	1.09	203.7
20%	0.52	102.0

Effect of Resource Capacity Oversizing on Reservoir Size

Solar Thermal, WSCCs, 70,000 MW, 2010

Resource and Reservoir Capacity for Various Levels of Energy Served

Solar Thermal, WSCCs, 70,000 MW, 2010

A-8 WindERCOT

ERCOT		Reservoir Size: 837.09 MWh
Resource Tech: Wind		0th Hour Energy: 114.79 MWh
Year: 2010		Annual Max: 837.1 MWh
Region Peak Load: 62,900 MW		Annual Min: 0.00 MWh
Block Size (MW): 100 MW		Present State Last Hr: 114.34 MWh
Resource to Load Eff.: 0.98		Reservoir Ceiling Size: 837.1 MWh
Resource Info		*Last Hour minus 0th Hour (Stored): 0.45 MWh
Storage Eff.: 0.89		Max Hourly Charge: 1.331 MWh
Storage to Load Eff.: 0.64		Annual Energy Stored: 2.37 GWh
Resource Capacity 1.837 MW		Annual Load Factor: 55 (4,823 MWh / MW)
		Annual Capacity Factor: 33 (2,864 MWh / MW)

Totals	
<i>Per MW Load</i>	
Resource	1.837 MW
Reservoir	.8371 GWh
H ₂ Stored	2,367 GWh
<i>Gross</i>	
Resource	115,526.1 MW
Reservoir	40,073 GWh
H ₂ Stored	148,911 GWh
<i>Blocks (100MW)</i>	
Resource Blocks	1,155.3
Reservoir/Blk	400.7 GWh
H ₂ Stored	1,489.1 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	1.08	0.41	0.00	0.66	1.90	1.87	1.87	1.90	2.28	2.69	2.97	3.41	3.68	2.88	2.11	1.48	1.68	1.88	1.82	1.19	0.68	0.70	1.11	1.72
Max	832.87	832.23	831.42	831.80	832.82	832.42	834.11	834.23	834.41	834.88	835.08	835.08	835.54	836.82	836.33	837.55	837.29	836.31	835.91	835.38	835.60	834.52	833.53	832.81
1	114.949	118.16	118.18	118.23	118.27	118.56	118.98	118.13	118.19	118.37	118.59	118.84	117.38	118.09	118.80	119.82	120.19	120.30	120.57	120.63	119.84	119.07	118.92	117.61
2	117.83	118.08	118.21	118.24	118.28	118.48	118.84	118.30	117.94	117.78	117.34	117.08	116.30	116.86	117.18	117.38	116.89	116.88	116.99	116.41	115.70	115.93	117.17	117.38
3	117.39	117.48	117.34	117.23	118.84	118.01	118.88	114.83	114.68	114.06	114.87	115.25	115.77	114.85	114.25	113.42	112.58	112.60	112.77	113.16	115.27	113.42	113.56	113.71
4	112.68	112.25	111.66	110.89	110.10	109.36	108.60	107.78	107.62	106.91	106.30	105.81	105.22	104.76	104.39	103.89	103.37	102.87	102.34	101.80	101.22	100.54	100.82	100.78
5	108.90	108.57	108.68	109.00	109.39	110.07	111.07	111.33	111.51	111.38	111.16	110.83	109.89	109.61	109.48	109.31	109.28	108.87	108.09	107.18	106.22	105.34	104.52	103.78
6	104.74	105.81	104.05	103.90	103.44	102.76	101.88	100.88	100.03	99.17	98.31	97.79	97.45	96.90	96.29	95.60	100.16	100.37	100.80	100.84	100.02	99.88	99.88	97.82
7	98.11	98.37	98.42	98.82	98.87	98.88	98.78	98.80	98.77	99.08	99.18	99.19	99.39	99.53	99.85	100.25	100.88	101.47	102.02	102.49	102.66	102.78	102.83	102.11
8	102.34	102.80	103.29	102.98	102.29	103.32	103.98	102.38	103.18	103.19	102.82	103.85	102.39	103.34	101.88	100.81	101.04	101.89	101.48	100.58	99.82	99.88	100.17	100.48
9	100.40	100.48	100.29	100.21	100.28	100.01	99.81	99.85	97.87	96.91	95.99	94.98	94.91	95.59	96.19	96.88	95.90	95.16	94.23	93.30	93.91	93.49	93.89	94.06
10	89.30	89.88	89.81	91.08	90.28	89.50	88.88	87.78	86.89	85.98	84.94	84.19	83.80	83.39	82.88	82.29	82.80	83.29	83.58	84.01	84.18	84.43	84.77	85.08
11	84.92	85.13	85.38	85.22	85.41	85.64	85.68	85.90	85.64	85.58	85.23	84.01	83.15	82.14	81.73	81.30	81.18	81.13	80.89	80.81	80.43	80.88	84.88	84.09
12	83.99	84.10	84.19	84.07	84.17	84.20	83.71	82.90	81.89	80.88	79.84	78.09	76.17	74.24	72.64	71.00	70.68	70.27	70.65	70.90	70.97	70.86	70.54	70.82
13	79.11	78.54	78.40	78.87	78.78	78.72	78.88	78.39	78.47	78.76	78.83	78.79	78.80	80.04	80.34	80.70	81.15	81.67	81.71	80.87	79.98	80.07	80.59	80.88
14	81.74	82.44	83.11	83.26	83.84	83.76	82.47	83.58	83.98	83.81	83.63	83.27	83.31	83.37	83.74	81.91	81.32	80.88	79.88	78.89	78.97	78.10	78.97	79.77
15	79.38	78.58	79.60	79.61	79.74	79.68	79.28	78.39	77.80	78.89	78.95	78.06	76.06	75.72	76.39	76.89	77.38	77.88	78.24	78.54	78.79	79.08	79.48	79.86
16	80.02	80.12	80.46	79.91	79.12	78.97	77.60	78.54	78.49	78.69	78.87	78.74	78.13	71.82	71.17	70.39	70.09	69.78	69.96	69.14	68.70	67.82	67.00	66.18
17	65.37	64.58	63.79	63.88	63.90	64.16	64.20	64.45	65.11	65.10	65.38	66.97	66.42	66.22	65.61	64.95	64.10	63.21	62.21	61.22	60.26	59.31	59.24	59.17
18	58.80	58.84	58.79	59.51	59.70	59.74	59.40	58.78	57.77	56.77	55.78	54.78	53.71	52.58	51.59	50.09	49.09	48.20	47.26	46.23	45.29	44.35	43.73	
19	52.02	51.89	51.79	51.85	51.93	51.72	51.62	51.50	51.67	51.83	51.83	51.78	51.69	51.45	51.78	52.42	53.95	55.86	54.46	54.84	55.95	55.87	55.19	54.49
20	58.73	59.43	59.19	58.64	58.41	58.91	57.39	57.78	58.39	58.88	58.28	56.89	55.92	55.05	54.11	53.47	51.79	51.68	52.12	52.19	52.84	53.31	53.05	51.20
21	51.31	51.38	51.57	50.84	50.99	50.74	50.98	50.80	51.81	52.78	53.95	55.07	54.14	53.29	52.39	51.55	50.70	49.81	48.85	48.08	48.18	48.44	48.74	48.82
22	48.94	48.89	48.83	48.98	48.98	49.18	49.23	49.37	49.21	49.29	49.89	49.88	47.92	47.51	46.18	45.33	44.49	43.78	42.89	41.94	40.78	39.78	38.83	37.88
23	37.55	37.55	37.53	36.67	36.78	34.84	33.76	32.61	31.54	30.49	29.48	28.53	27.62	26.78	25.85	25.10	24.77	25.41	25.13	24.77	24.23	24.54	24.81	25.39
24	34.61	34.60	34.06	25.49	25.80	26.87	26.96	28.88	24.11	24.44	23.97	23.17	22.59	21.94	20.41	20.19	20.37	20.92	20.16	20.51	20.67	20.49	20.12	19.92
25	30.86	31.74	32.48	31.88	31.82	31.80	30.94	30.03	29.21	28.26	27.49	26.56	25.72	25.01	24.26	23.82	22.99	23.03	23.22	23.40	23.62	23.90	24.00	24.05
26	24.28	24.54	24.79	24.19	23.84	23.81	23.29	22.84	22.89	22.12	21.02	20.00	21.80	21.80	21.79	23.02	22.97	22.87	23.90	24.31	25.04	25.95	26.82	28.90

WindERCOT

Reservoir Size:	637.09	MWh
0th Hour Energy:	114.79	MWh
Annual Max:	637.1	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	114.34	MWh
Reservoir "Ceiling" Size:	637.1	MWh
*Last Hour minus 0th Hour (Stored):	-0.45	MWh
Max Hourly Charge:	1.331	MWh
Annual Energy Stored:	2.37	GWh
Annual Load Factor:	.55 (4,823 MWh / MW)	
Annual Capacity Factor:	.33 (2,854 MWh / MW)	

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	1.84	637.1	2.367
1.1	2.02	417.3	2.264
1.25	2.3	269.4	2.140
1.5	2.75	125.2	1.992
1.75	3.21	93.0	1.890
2	3.67	77.4	1.816
2.5	4.59	57.0	1.712
2.75	5.05	54.8	1.676
3	5.51	52.7	1.645
4	7.35	45.2	1.563

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	1.84	637.1
80%	1.47	510.3
60%	1.10	382.4
40%	0.74	259.3
20%	0.38	135.5

Effect of Resource Capacity Oversizing on
Reservoir Size

Wind, ERCOT, 62,900 MW, 2010

Resource and Reservoir Capacity for Various Levels
of Energy Served

Wind, ERCOT, 62,900 MW, 2010

MAPP	
Resource Tech: Wind	Year: 2010
Region Peak Load: 37,240 MW	Block Size (MW): 100
Resource to Load Eff: 0.96	Resource Int: 0.99
Storage to Load Eff: 0.64	Resource Capacity 1,449 MW
Reservoir Status-Hourly Deliverable Energy Stored (MWh)	
Reservoir Size: 406.50 MWh	0th Hour Energy: 159.26 MWh
Annual Max: 406.5 MWh	Annual Min: 0.00 MWh
Present State, Last Hr: 159.18 MWh	Reservoir Ceiling Size: 406.5 MWh
Last Hour minus 0th Hour (Stored): 0.09 MWh	Max Hourly Charge: 0.888 MWh
Annual Energy Stored: 2.63 GWh	Annual Load Factor: 55 (4,655 MWh / MW)
Annual Capacity Factor: 49 (4,171 MWh / MW)

Totals	
Resource	1,449 MW
Reservoir	406.5 GWh
Gross	2,526 GWh
Resource	53,846.5 MWh
Reservoir	15,136 GWh
H ₂ Stored	84,079 GWh
Resource Blocks	539.5
Reservoir/Block	151.4 GWh
H ₂ Stored	840.8 GWh

Hour ->	Day #	MWh	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
2	2	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
3	3	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
4	4	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
5	5	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
6	6	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
7	7	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
8	8	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
9	9	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
10	10	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
11	11	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
12	12	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
13	13	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
14	14	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
15	15	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
16	16	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
17	17	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
18	18	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
19	19	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
20	20	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
21	21	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
22	22	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
23	23	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87
24	24	159.26	159.18	159.16	159.15	159.14	159.13	159.12	159.11	159.10	159.09	159.08	159.07	159.06	159.05	159.04	159.03	159.02	159.01	158.99	158.97	158.95	158.93	158.91	158.89	158.87

Reservoir Size:	406.50	MWh
0th Hour Energy:	159.26	MWh
Annual Max:	406.5	MWh
Annual Min:	0.00	MWh
Present State, Last Hrs:	159.18	MWh
Reservoir "Ceiling" Size:	406.5	MWh
"Last Hour minus 0th Hour (Stored)":	-0.06	MWh
Max. Hourly Charge:	0.999	MWh
Annual Energy Stored:	2.53	GWh
Annual Load Factor:	55%	(4,855 MWh / MW)
Annual Capacity Factor:	48%	(4,173 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	1.45	406.5	2.526
1.1	1.59	194.5	2.430
1.25	1.81	155.9	2.312
1.5	2.17	119.0	2.165
1.75	2.54	92.9	2.050
2	2.9	82.0	1.978
2.5	3.62	60.4	1.863
2.75	3.98	59.8	1.820
3	4.35	58.9	1.783
4	5.79	55.9	1.680

Effect of Resource Capacity Oversizing on Reservoir Size

Wind. MAPP, 37,240 MW, 2010

Levels of Annual Energy Served (all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	1.45	406.5
80%	1.16	324.8
60%	0.87	244.8
40%	0.58	165.2
20%	0.30	88.0

Resource and Reservoir Capacity for Various Levels of Energy Served

Wind. MAPP, 37,240 MW, 2010

SPP		Reservoir Size: 515.99 MWh
Resource Tech: Wind		0th Hour Energy: 79.28 MWh
Year: 2010		Annual Max: 516.0 MWh
Region Peak Load: 75,627 MW		Annual Min: 0.00 MWh
Block Size (MW): 100 MW		Present State Last Hr: 78.33 MWh
Resource to Load Eff.: 0.96		Reservoir Ceiling Size: 516.0 MWh
Resource Info		Last Hour minus 0th Hour (Stored): 0.92 MWh
Storage Eff.: 0.89		Max Hourly Charge: 1.13 MWh
Storage to Load Eff.: 0.64		Annual Energy Stored: 2.05 GWh
Resource Capacity 1,579 MW		Annual Load Factor: 47 (4,140 MWh / MW)
		Annual Capacity Factor: 33 (2,854 MWh / MW)

Totals	
Per MW Load	
Resource	1,579 MW
Reservoir	.516 GWh
H ₂ Stored	2.05 GWh
Gross	
Resource	119,390.4 MW
Reservoir	39,023 GWh
H ₂ Stored	155,004 GWh
Blocks (100MW)	
Resource Blocks	1,193.9
Reservoir/Blk	390.2 GWh
H ₂ Stored	1,550.0 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	0.88	0.94	0.00	0.57	1.15	1.41	1.45	1.75	2.09	2.48	2.74	3.14	3.87	4.28	4.78	5.98	5.20	2.39	1.57	0.94	0.92	0.54	0.91	1.43
Max	819.28	812.79	812.43	811.52	810.88	811.81	812.16	813.36	812.81	812.96	813.48	814.45	815.02	815.22	815.23	815.85	815.99	816.68	816.31	816.19	815.28	814.50	815.75	815.01
1	79.426	79.65	79.72	79.80	79.90	80.29	80.65	80.85	81.00	81.21	81.45	81.79	82.19	82.81	83.43	84.02	84.53	84.84	84.84	84.81	84.26	83.64	83.04	82.50
2	82.71	83.00	83.17	83.19	83.26	83.61	83.78	83.92	83.90	83.78	83.51	83.09	82.60	82.89	83.19	83.68	84.10	84.45	84.61	84.29	83.64	83.04	82.50	82.15
3	83.13	83.24	83.17	83.10	82.60	82.07	81.71	81.14	80.52	80.58	81.14	81.68	82.19	81.57	81.06	80.47	79.85	79.89	80.08	80.47	80.83	80.81	80.98	81.17
4	80.66	80.19	79.64	79.14	78.65	78.16	77.45	77.19	76.43	76.94	76.90	76.94	76.87	76.08	75.31	74.09	73.39	72.99	72.85	72.84	72.69	72.66	72.60	72.61
5	78.87	78.55	78.31	78.49	79.87	80.81	81.58	81.89	81.83	82.04	81.89	81.42	80.91	80.67	80.65	80.59	80.31	79.85	79.29	78.61	77.77	77.07	76.42	75.85
6	76.87	76.04	75.16	74.19	73.61	73.22	74.64	75.81	73.64	72.26	71.56	71.04	71.13	71.61	72.18	72.63	73.09	73.06	73.50	73.19	72.43	71.73	71.10	70.59
7	70.87	70.88	70.93	71.11	71.34	71.58	71.34	71.24	71.40	71.67	71.72	71.70	71.79	71.81	72.16	72.46	72.96	73.43	73.88	74.26	74.31	74.51	74.56	74.95
8	74.15	74.39	74.81	74.73	74.96	75.87	74.39	74.50	75.01	75.84	74.28	74.54	74.49	74.35	73.77	73.29	73.35	73.58	73.78	73.96	72.28	72.27	72.81	73.13
9	73.09	73.20	73.08	73.07	73.16	73.00	72.73	71.97	71.19	70.86	69.78	68.98	68.87	69.37	69.87	70.31	69.61	68.82	68.12	67.35	67.59	67.58	67.54	68.11
10	67.54	68.89	69.41	69.50	69.35	64.82	64.32	63.87	62.92	63.19	61.43	60.78	60.98	60.30	59.76	59.22	59.85	60.07	60.43	60.78	60.98	61.29	61.81	61.81
11	61.97	62.24	62.55	62.80	62.88	63.19	63.35	63.67	64.39	65.39	65.79	65.84	65.14	64.19	63.89	63.63	63.47	63.40	63.27	63.29	64.98	64.48	63.88	63.30
12	63.34	63.82	63.87	63.71	63.68	61.05	63.78	64.37	62.43	61.64	60.90	60.19	59.64	58.89	58.12	57.39	56.77	56.28	56.73	60.13	60.19	60.40	60.47	60.68
13	60.87	60.30	60.38	60.55	60.78	60.78	60.69	60.68	60.73	60.99	61.05	61.06	61.15	61.30	61.58	61.87	62.26	62.63	62.76	62.06	61.38	61.48	61.93	62.25
14	62.35	63.57	64.15	64.43	64.73	64.85	64.87	64.81	64.95	65.01	64.77	64.81	64.83	64.85	64.86	64.87	64.77	64.72	64.73	64.73	64.73	64.73	64.73	64.73
15	60.82	60.77	60.80	60.80	60.90	60.72	60.48	60.70	58.69	58.39	57.58	56.77	56.70	57.23	57.71	58.14	58.53	58.91	59.23	59.49	59.66	59.90	60.28	60.59
16	60.79	60.61	61.13	60.36	59.94	59.93	58.69	57.78	56.90	56.06	55.31	54.44	53.89	53.67	53.01	52.93	52.98	51.87	51.34	51.43	51.10	50.60	50.61	50.69
17	48.56	47.96	47.39	47.40	47.63	47.92	48.04	48.34	49.02	49.96	50.50	50.40	50.54	50.52	50.19	49.72	49.12	48.47	47.73	47.01	46.92	46.68	46.71	46.77
18	46.14	46.27	46.38	46.59	46.76	46.91	46.81	46.47	45.88	45.25	44.53	44.05	43.99	43.79	43.35	42.87	42.70	42.91	43.10	43.24	43.41	43.73	43.91	44.10
19	49.69	48.74	48.82	49.69	44.20	44.23	44.32	44.41	44.57	44.64	44.76	44.83	44.84	44.82	44.71	44.68	44.51	44.29	43.70	42.91	42.91	43.10	43.24	43.41
20	48.87	48.37	48.47	48.14	48.72	50.21	50.71	51.18	51.59	52.23	52.65	53.19	53.65	53.93	54.23	54.64	54.77	54.66	54.10	53.19	52.36	51.92	51.36	51.63
21	54.81	54.92	55.18	54.80	54.94	54.91	54.43	53.69	52.88	52.06	51.41	50.69	49.91	49.19	48.37	47.63	46.88	46.09	45.27	44.65	44.76	45.08	45.37	45.50
22	48.89	48.78	48.81	48.98	48.09	48.22	48.46	48.07	48.59	48.83	48.99	49.16	49.16	49.16	49.16	49.16	49.16	49.16	49.16	49.16	49.16	49.16	49.16	49.16
23	37.82	37.89	37.98	37.40	38.81	39.19	39.44	34.61	33.77	32.93	32.08	31.25	30.45	29.68	29.21	28.89	28.66	28.18	27.87	27.63	27.03	27.10	27.49	27.99
24	37.44	37.41	37.65	39.01	39.10	39.84	39.40	38.35	36.42	35.81	35.15	34.58	33.92	33.82	33.82	33.82	33.82	33.82	33.82	33.82	33.82	33.82	33.82	33.82
25	32.42	33.16	33.85	33.46	33.50	33.56	32.95	32.33	31.82	31.18	30.58	29.99	29.29	28.68	28.02	27.56	26.85	26.83	26.98	27.16	27.36	27.47	27.55	27.80
26	28.97	29.59	29.85	29.09	27.94	27.74	27.87	27.49	27.08	26.90	26.81	26.74	26.90	26.81	26.30	26.44	26.67	27.03	27.51	28.22	28.92	29.08	29.18	29.65

WindSPP

Reservoir Size:	515.99	MWh
0th Hour Energy:	79.26	MWh
Annual Max:	516.0	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	78.33	MWh
Reservoir "Ceiling Size":	516.0	MWh
"Last Hour minus 0th Hour (Stored)":	-0.92	MWh
Max Hourly Charge:	1.13	MWh
Annual Energy Stored:	2.05	GWh
Annual Load Factor:	47	(4,140 MWh / MW)
Annual Capacity Factor:	33	(2,854 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	1.58	516.0	2.050
1.1	1.74	349.2	1.958
1.25	1.97	208.8	1.849
1.5	2.37	77.0	1.722
1.75	2.76	61.7	1.632
2	3.16	58.9	1.565
2.5	3.95	51.2	1.475
2.75	4.34	49.4	1.443
3	4.74	47.6	1.415
4	6.31	41.0	1.343

Levels of Annual Energy Served
(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	1.58	516.0
80%	1.27	414.2
60%	0.95	312.3
40%	0.64	211.2
20%	0.33	110.4

Effect of Resource Capacity Oversizing on Reservoir Size

Wind, SPP, 75,627 MW, 2010

Resource and Reservoir Capacity for Various Levels of Energy Served

Wind, SPP, 75,627 MW, 2010

WSSCn		Reservoir Size:	628.18 MWh
Resource Tech:	Wind	0th Hour Energy:	410.73 MWh
Year:	2010	Annual Max:	628.2 MWh
Region Peak Load:	59,000 MW	Annual Min:	0.00 MWh
Block Size (MW):	100 MW	Present State, Last Hr:	410.47 MWh
Resource to Load Eff.:	0.96	Reservoir Ceiling Size:	628.2 MWh
Resource Info:		*Last Hour minus	
Storage Eff.:	0.89	0th Hour (Stored):	-0.26 MWh
Storage to Load Eff.:	0.64	Max Hourly Charge:	1.401 MWh
Resource Capacity:	1.991 MW	Annual Energy Stored:	3.54 GWh
(All values per MW of Load)		Annual Load Factor:	65.5 (5,605 MWh / MW)
		Annual Capacity Factor:	43.3 (3,788 MWh / MW)

Totals	
Per MW Load	
Resource	1.091 MW
Reservoir	.6282 GWh
H ₂ Stored	3.54 GWh
Gross	
Resource	117,462 MW
Reservoir	37,063 GWh
H ₂ Stored	208,850 GWh
Blocks (100MW)	
Resource Blocks	1,174.6
Reservoir/Blk	370.6 GWh
H ₂ Stored	2,088.5 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mn	0.44	0.70	2.04	3.37	4.31	4.99	5.27	5.82	6.21	6.92	7.93	8.95	9.95	9.01	8.32	7.37	6.41	5.44	4.44	3.44	2.48	1.59	0.77	0.00
Max	328.26	328.54	328.75	328.92	329.23	329.43	329.84	329.87	329.15	327.35	327.55	327.55	327.70	328.84	328.02	325.13	324.08	322.73	323.77	324.78	325.81	326.84	327.83	328.77
1	409.907	409.03	408.15	407.27	406.40	405.52	404.60	403.68	402.85	401.81	400.88	399.44	398.34	397.28	396.26	395.28	394.27	393.28	392.20	391.11	390.09	389.12	388.20	387.34
2	388.91	388.70	388.89	389.09	389.28	389.44	389.50	389.43	389.29	389.11	388.92	388.70	388.53	388.37	388.20	388.00	387.78	387.54	387.29	387.07	386.80	386.58	386.33	386.05
3	368.07	368.46	368.85	369.22	369.58	369.93	370.17	370.15	370.08	369.98	369.85	369.70	369.53	369.37	369.20	369.00	368.78	368.54	368.29	368.07	367.80	367.58	367.33	367.05
4	348.26	348.49	348.72	348.99	349.21	349.41	349.57	349.68	349.76	349.80	349.81	349.79	349.74	349.67	349.59	349.49	349.38	349.26	349.13	348.99	348.84	348.68	348.51	348.34
5	329.74	329.49	329.91	330.24	330.56	330.87	331.18	331.48	331.78	332.08	332.38	332.68	332.98	333.28	333.58	333.88	334.18	334.48	334.78	335.08	335.38	335.68	335.98	336.28
6	310.45	310.46	310.24	310.75	311.25	311.75	312.25	312.75	313.25	313.75	314.25	314.75	315.25	315.75	316.25	316.75	317.25	317.75	318.25	318.75	319.25	319.75	320.25	320.75
7	291.53	291.77	291.91	292.84	293.68	294.52	295.36	296.20	297.04	297.88	298.72	299.56	300.40	301.24	302.08	302.92	303.76	304.60	305.44	306.28	307.12	307.96	308.80	309.64
8	272.81	273.70	274.78	275.85	276.91	277.97	279.03	280.09	281.15	282.21	283.27	284.33	285.39	286.45	287.51	288.57	289.63	290.69	291.75	292.81	293.87	294.93	295.99	297.05
9	254.91	255.06	255.92	256.75	257.58	258.41	259.24	260.07	260.90	261.73	262.56	263.39	264.22	265.05	265.88	266.71	267.54	268.37	269.20	270.03	270.86	271.69	272.52	273.35
10	237.88	237.81	238.81	239.58	240.35	241.12	241.89	242.66	243.43	244.20	244.97	245.74	246.51	247.28	248.05	248.82	249.59	250.36	251.13	251.90	252.67	253.44	254.21	254.98
11	221.48	221.80	222.51	223.20	223.89	224.58	225.27	225.96	226.65	227.34	228.03	228.72	229.41	230.10	230.79	231.48	232.17	232.86	233.55	234.24	234.93	235.62	236.31	237.00
12	205.79	206.06	206.74	207.41	208.08	208.75	209.42	210.09	210.76	211.43	212.10	212.77	213.44	214.11	214.78	215.45	216.12	216.79	217.46	218.13	218.80	219.47	220.14	220.81
13	190.17	190.28	190.41	190.54	190.67	190.80	190.93	191.06	191.19	191.32	191.45	191.58	191.71	191.84	191.97	192.10	192.23	192.36	192.49	192.62	192.75	192.88	193.01	193.14
14	174.88	175.50	176.31	177.00	177.69	178.38	179.07	179.76	180.45	181.14	181.83	182.52	183.21	183.90	184.59	185.28	185.97	186.66	187.35	188.04	188.73	189.42	190.11	190.80
15	159.16	159.88	160.79	161.48	162.17	162.86	163.55	164.24	164.93	165.62	166.31	167.00	167.69	168.38	169.07	169.76	170.45	171.14	171.83	172.52	173.21	173.90	174.59	175.28
16	143.85	144.81	145.92	146.77	147.52	148.27	149.02	149.77	150.52	151.27	152.02	152.77	153.52	154.27	155.02	155.77	156.52	157.27	158.02	158.77	159.52	160.27	161.02	161.77
17	128.74	129.68	130.79	131.64	132.39	133.14	133.89	134.64	135.39	136.14	136.89	137.64	138.39	139.14	139.89	140.64	141.39	142.14	142.89	143.64	144.39	145.14	145.89	146.64
18	113.77	114.92	116.10	117.05	117.80	118.55	119.30	120.05	120.80	121.55	122.30	123.05	123.80	124.55	125.30	126.05	126.80	127.55	128.30	129.05	129.80	130.55	131.30	132.05
19	98.93	100.28	101.79	103.04	104.04	104.89	105.64	106.39	107.14	107.89	108.64	109.39	110.14	110.89	111.64	112.39	113.14	113.89	114.64	115.39	116.14	116.89	117.64	118.39
20	84.40	86.12	87.97	89.47	90.62	91.52	92.27	92.97	93.62	94.27	94.92	95.57	96.22	96.87	97.52	98.17	98.82	99.47	100.12	100.77	101.42	102.07	102.72	103.37
21	70.31	72.19	74.17	75.84	77.19	78.34	79.29	80.04	80.69	81.34	81.99	82.64	83.29	83.94	84.59	85.24	85.89	86.54	87.19	87.84	88.49	89.14	89.79	90.44
22	56.88	58.92	61.09	63.04	64.69	66.04	67.19	68.14	68.89	69.54	70.19	70.84	71.49	72.14	72.79	73.44	74.09	74.74	75.39	76.04	76.69	77.34	77.99	78.64
23	43.15	45.44	47.89	50.04	51.79	53.14	54.29	55.24	56.09	56.84	57.49	58.14	58.79	59.44	60.09	60.74	61.39	62.04	62.69	63.34	63.99	64.64	65.29	65.94
24	29.40	31.92	34.59	37.04	39.19	40.84	42.09	43.04	43.79	44.44	45.09	45.74	46.39	47.04	47.69	48.34	48.99	49.64	50.29	50.94	51.59	52.24	52.89	53.54
25	15.79	18.44	21.19	23.64	25.79	27.44	28.69	29.64	30.39	31.04	31.69	32.34	32.99	33.64	34.29	34.94	35.59	36.24	36.89	37.54	38.19	38.84	39.49	40.14
26	2.28	4.92	7.64	10.04	11.99	13.34	14.09	14.74	15.29	15.74	16.19	16.64	17.09	17.54	17.99	18.44	18.89	19.34	19.79	20.24	20.69	21.14	21.59	22.04

Reservoir Size:	628.18	MWh
0th Hour Energy:	410.73	MWh
Annual Max:	628.2	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	410.47	MWh
Reservoir Ceiling Size:	628.2	MWh
Last Hour minus 0th Hour (Stored):	-0.26	MWh
Max. Hourly Charge:	1.401	MWh
Annual Energy Stored:	3.54	GWh
Annual Load Factor:	65	(5,695 MWh / MW)
Annual Capacity Factor:	43	(3,788 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	1.99	628.2	3.540
1.1	2.19	443.7	3.465
1.25	2.49	304.9	3.376
1.5	2.99	269.1	3.268
1.75	3.48	246.1	3.193
2	3.98	226.7	3.136
2.5	4.98	189.2	3.057
2.75	5.47	178.4	3.028
3	5.97	168.8	3.003
4	7.98	156.9	2.935

Levels of Annual Energy Served

(all per MW_{load})

% of Ann Energy	MW Resource	MWh Reservoir
100%	1.99	628.2
80%	1.59	501.9
60%	1.19	376.5
40%	0.80	249.8
20%	0.40	124.8

Effect of Resource Capacity Oversizing on
Reservoir Size

Wind, WSCn, 50,000 MW, 2010

Resource and Reservoir Capacity for Various Levels of
Energy Served

Wind, WSCn, 50,000 MW, 2010

WSCCs		Reservoir Size: 571.47 MWh
Resource Tech:	Wind	0th Hour Energy: 340.23 MWh
Year:	2010	Annual Max: 571.5 MWh
Region Peak Load:	70,000 MW	Annual Min: 0.00 MWh
Block Size (MW):	100 MW	Present State, Last Hr: 336.78 MWh
Resource to Load Eff.: 0.96		Reservoir "Ceiling Size": 571.5 MWh
Resource Info		"Last Hour minus 0th Hour (Stored)": -4.47 MWh
Storage Eff.: 0.89		Max Hourly Charge: 1.244 MWh
Storage to Load Eff.: 0.64		Annual Energy Stored: 3.16 GWh
Resource Capacity: 1,776 MW		Annual Load Factor: 58 (5,094 MWh / MW)
(All values per MW of Load)		Annual Capacity Factor: 43 (3,788 MWh / MW)

Totals	
Per MW Load	
Resource	1,776 MW
Reservoir	.5715 GWh
H ₂ Stored	3,157 GWh
Gross	
Resource	124,310.1 MW
Reservoir	40,003 GWh
H ₂ Stored	220,970 GWh
Blocks (100MW)	
Resource Blocks	1,243.1
Reservoir/Blk	400.0 GWh
H ₂ Stored	2,209.7 GWh

Reservoir Status-Hourly Deliverable Energy Stored (MWh)

Reservoir Status - Hourly Deliverable Energy Stored (MWh)																								
Hour-> Day #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Min	0.98	0.60	1.74	2.90	3.70	4.26	4.81	4.96	5.23	5.76	6.46	7.29	8.29	9.06	9.28	7.21	6.20	5.14	4.10	3.12	2.22	1.43	0.71	0.00
Max	288.77	288.78	288.86	288.88	289.02	289.05	289.04	289.31	289.47	289.31	289.04	289.10	289.50	289.22	288.76	288.96	288.70	287.08	286.06	286.40	287.23	287.83	287.88	288.00
1	339.56	338.99	338.34	337.74	337.16	336.53	335.91	335.27	334.63	333.71	332.89	332.08	331.25	330.44	329.65	328.85	327.99	327.07	326.18	325.32	324.50	323.72	322.99	322.35
2	321.91	321.16	320.38	319.59	318.79	317.99	317.19	316.34	315.48	314.59	313.62	312.62	311.60	310.57	309.48	308.46	307.48	306.48	305.52	304.50	303.54	302.58	301.64	300.74
3	304.74	304.12	303.52	302.92	302.32	301.68	301.03	300.21	300.30	299.81	299.62	299.71	299.82	299.85	299.68	299.22	298.29	297.31	296.45	295.61	294.79	293.99	293.22	292.48
4	287.77	287.14	286.53	285.93	285.34	284.71	284.03	283.34	282.74	281.91	281.07	280.23	279.38	278.54	277.64	276.71	275.81	274.87	273.94	273.04	272.14	271.24	270.34	269.44
5	282.26	282.87	283.59	284.29	284.70	285.80	286.47	287.27	287.76	287.88	287.94	288.01	287.76	287.48	287.22	286.87	286.61	286.85	287.38	287.96	288.58	289.03	289.14	289.26
6	297.08	297.87	298.66	299.45	300.25	301.05	301.84	302.67	303.46	304.60	305.04	305.15	305.94	306.34	306.91	307.45	307.81	308.85	309.38	309.84	310.32	310.79	311.24	311.69
7	289.68	290.39	291.45	292.61	293.71	294.28	294.88	294.78	294.26	293.40	292.15	290.94	289.34	287.94	286.91	285.80	284.67	283.54	282.37	281.14	279.84	278.43	276.93	275.33
8	283.47	284.79	286.11	287.43	288.71	290.90	290.89	290.08	288.87	287.10	284.08	281.44	278.99	276.92	274.33	271.25	267.68	264.58	260.97	256.84	252.14	246.93	241.24	235.04
9	283.68	284.77	285.82	286.84	287.87	288.25	288.08	286.79	284.26	280.63	275.87	270.08	263.44	256.92	249.54	241.33	232.37	222.68	212.29	201.14	189.24	176.54	163.04	148.74
10	287.29	288.48	289.66	290.84	292.02	293.20	293.38	290.45	286.83	282.50	277.62	272.16	266.04	259.32	252.04	244.21	235.84	226.94	217.51	207.54	197.04	186.04	174.54	162.54
11	287.59	288.87	290.15	291.43	292.71	293.99	294.28	289.76	285.40	280.34	274.62	268.34	261.54	254.26	246.54	238.34	229.64	220.44	210.74	200.54	190.04	179.24	168.04	156.44
12	287.59	288.87	290.15	291.43	292.71	293.99	294.28	289.76	285.40	280.34	274.62	268.34	261.54	254.26	246.54	238.34	229.64	220.44	210.74	200.54	190.04	179.24	168.04	156.44
13	228.17	224.50	220.84	217.17	213.50	209.84	206.17	202.50	198.84	195.17	191.50	187.84	184.17	180.50	176.84	173.17	169.50	165.84	162.17	158.50	154.84	151.17	147.50	143.84
14	202.59	207.43	212.27	217.11	221.95	226.79	231.63	236.47	241.31	246.15	250.99	255.83	260.67	265.51	270.35	275.19	280.03	284.87	289.71	294.55	299.39	304.23	309.07	313.91
15	183.71	189.48	195.25	201.02	206.79	212.56	218.33	224.10	229.87	235.64	241.41	247.18	252.95	258.72	264.49	270.26	276.03	281.80	287.57	293.34	299.11	304.88	310.65	316.42
16	159.81	168.80	177.79	186.78	195.77	204.76	213.75	222.74	231.73	240.72	249.71	258.70	267.69	276.68	285.67	294.66	303.65	312.64	321.63	330.62	339.61	348.60	357.59	366.58
17	150.55	149.85	149.16	148.48	147.80	147.07	146.34	145.61	144.88	144.15	143.42	142.69	141.96	141.23	140.50	139.77	139.04	138.31	137.58	136.85	136.12	135.39	134.66	133.93
18	183.43	182.40	181.38	180.36	179.34	178.32	177.30	176.28	175.26	174.24	173.22	172.20	171.18	170.16	169.14	168.12	167.10	166.08	165.06	164.04	163.02	162.00	160.98	159.96
19	158.17	158.59	159.01	159.43	159.85	160.27	160.69	161.11	161.53	161.95	162.37	162.79	163.21	163.63	164.05	164.47	164.89	165.31	165.73	166.15	166.57	166.99	167.41	167.83
20	185.89	186.87	187.85	188.83	189.81	190.79	191.77	192.75	193.73	194.71	195.69	196.67	197.65	198.63	199.61	200.59	201.57	202.55	203.53	204.51	205.49	206.47	207.45	208.43
21	150.14	149.45	148.76	148.07	147.38	146.69	146.00	145.31	144.62	143.93	143.24	142.55	141.86	141.17	140.48	139.79	139.10	138.41	137.72	137.03	136.34	135.65	134.96	134.27
22	128.27	127.70	127.13	126.56	125.99	125.42	124.85	124.28	123.71	123.14	122.57	122.00	121.43	120.86	120.29	119.72	119.15	118.58	118.01	117.44	116.87	116.30	115.73	115.16
23	106.31	105.55	104.82	104.08	103.34	102.60	101.86	101.12	100.38	99.64	98.90	98.16	97.42	96.68	95.94	95.20	94.46	93.72	92.98	92.24	91.50	90.76	90.02	89.28
24	85.61	87.01	88.42	89.83	91.24	92.65	94.06	95.47	96.88	98.29	99.70	101.11	102.52	103.93	105.34	106.75	108.16	109.57	110.98	112.39	113.80	115.21	116.62	118.03
25	111.69	112.90	114.11	115.32	116.53	117.74	118.95	120.16	121.37	122.58	123.79	125.00	126.21	127.42	128.63	129.84	131.05	132.26	133.47	134.68	135.89	137.10	138.31	139.52
26	122.17	122.79	123.41	124.03	124.65	125.27	125.89	126.51	127.13	127.75	128.37	128.99	129.61	130.23	130.85	131.47	132.09	132.71	133.33	133.95	134.57	135.19	135.81	136.43

WindWSCCS

Reservoir Size:	571.47	MWh
0th Hour Energy:	340.23	MWh
Annual Max:	571.5	MWh
Annual Min:	0.00	MWh
Present State Last Hr:	335.76	MWh
Reservoir Ceiling Size:	571.5	MWh
Last Hour minus 0th Hour (Stored):	-4.47	MWh
Max. Hourly Charge:	1.244	MWh
Annual Energy Stored:	3.16	GWh
Annual Load Factor:	58	(5,064 MWh / MW)
Annual Capacity Factor:	43	(3,788 MWh / MW)

Resource Oversizing (all per MW_{load})

Factor	MW Resource	MWh Reservoir	GWh Storage
1	1.78	571.5	3.157
1.1	1.95	428.5	3.094
1.25	2.22	294.7	3.019
1.5	2.66	266.4	2.926
1.75	3.11	244.6	2.861
2	3.55	226.8	2.812
2.5	4.44	193.9	2.743
2.75	4.88	184.2	2.717
3	5.33	174.4	2.695
4	7.1	136.2	2.636

Levels of Annual Energy Served

(all per MW _{load})		
% of Ann Energy	MW Resource	MWh Reservoir
100%	1.78	571.5
80%	1.42	455.9
60%	1.07	341.5
40%	0.71	228.2
20%	0.36	115.6

Effect of Resource Capacity Oversizing on Reservoir Size

Wind, WSCCs, 70,000 MW, 2010

Resource and Reservoir Capacity for Various Levels of Energy Served

Wind, WSCCs, 70,000 MW, 2010