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Fast Automated Demand Response to Enable the Integration of Renewable Resources

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Publication Date
2012-06-21

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KEMA

June 2012

Disclaimer

ACKNOWLEDGEMENTS

The work described in this report was coordinated by the Demand Response Research Center and funded by the California Energy Commission (CEC), Public Interest Energy Research (PIER) Program, under Work for Others Contract No. 500-03-026 and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

The authors would like to thank Mike Gravely and Pedro Gomez of the California Energy Commission for their interest and support of this timely research. The CEC's Demand Analysis Office provided invaluable data and interpretive assistance in the evaluation of the base load data and load profiles. The CAISO and the UC Berkeley DR-renewable-ISO group have made significant contributions to this research and will continue to be an active part of this research subject. Roger Levy and Ron Hofmann have provided significant support through their participant in research approach and related policy discussions. We'd also like to thank Phillip N. Price and Alma Rubalcava for clarifications to the report content and the reviewers Johanna L. Mathieu, Joseph H. Eto, Roger Levy and Duncan S. Callaway for their substantial input and guidance.

ABSTRACT

This study examines how fast automated demand response (AutoDR) can help mitigate grid balancing challenges introduced by upcoming increases in intermittent renewable generation resources such as solar and wind in an environmentally friendly and cost effective manner. This study gathers data from multiple sources to determine the total electric end-use loads in the commercial and industrial sectors of California. The shed capacity available from AutoDR in these sectors varies based on many factors including weather, time of year and time of day. This study estimates that the lowest shed capacity could occur on cold winter mornings and the highest on hot summer afternoons. Based on this analysis, a large-scale deployment of fast AutoDR could provide between 0.18 and 0.90 GW of DR-based ancillary services from the existing stock of commercial and industrial facilities throughout California. With modest investments to upgrade and expand use of automated control systems in commercial and industrial facilities the estimated shed potential could approximately double to between 0.42 and 2.07 GW. Deployed costs for fast AutoDR (installation, materials, labor and program management) are about 10% of the deployed costs of grid scale battery storage. However, AutoDR in California has less capacity than what is required to meet the grid balancing challenges introduced by the 2020 renewable portfolio standard goals. There are many different types of ancillary services necessary to keep the electric grid in balance. Though AutoDR may not be suitable for all forms of ancillary services, the lower installed cost of AutoDR indicates that it should be considered for use in the time domains and capacities for which it is applicable. By combining AutoDR with traditional gas fired thermal generation and battery storage technologies, an optimal mix of generation, AutoDR and storage should be considered to meet upcoming challenges introduced by the increased use of renewable generation.

Keywords: California Energy Commission, demand response, automated demand response, AutoDR, ancillary services, renewable generation, integration, energy storage, commercial, industrial, controls, peak demand, demand, regulation, spinning reserves, non-spinning reserves

Please use the following citation for this report:

David S. Watson, Nance Matson, Janie Page, Sila Kiliccote, Mary Ann Piette (Lawrence Berkeley National Laboratory); Karin Corfee, Betty Seto, Ralph Masiello, John Masiello, Lorin Molander, Samuel Golding, Kevin Sullivan, Walt Johnson, David Hawkins (KEMA). ***Fast Austomated Demand Response to Enable the Integration of Renewable Resources.*** California Energy Commission. Publication number: CEC-XXX-2012-XXX.

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EXECUTIVE SUMMARY

California's ambitious Renewables Portfolio Standard (RPS) requires utilities to increase procurement from eligible renewable energy resources to 33% of the total by 2020. (CEC 2002). Because renewables such as wind and solar power are intermittent and non-dispatchable, research shows that substantial increases in grid balancing resources known as ancillary services will be required. A 2010 study used known intermittent behavior of wind and solar resources in California in computer simulations of the electric grid to show that "…between 3 and 5 Gigawatts (GW) of regulation and energy for balancing and ramping services from fast resources …would be required to meet California's 2020 RPS goals " (Masiello et al., 2010). Traditionally, combustion turbines are used to provide these types of grid balancing ancillary services. A more environmentally friendly alternative to combustion turbines is grid scale battery storage. However, storage is comparatively more costly than traditional generation. (Masiello et al., 2010).

This scoping study explores the hypothesis that fast acting automated demand response (DR) used in the commercial and industrial sectors is more environmentally friendly than fossil fuel based generation and may be more cost effective than grid scale battery storage. Commercial and industrial (C&I) demand response is considered in this report; residential DR is not included.

Demand response has traditionally been defined as a set of time dependant activities that reduce, shed or shift electricity use to improve electric grid reliability and manage costs. DR event sheds have traditionally been initiated through programs that are initiated the day ahead or many hours in advance and last for two to six hours in duration, usually during periods of peak usage or when there are constraints or contingencies in generation or transmission systems. The term "automated demand response" (AutoDR) is used to describe systems in which electric loads respond to remotely generated control or pricing signals without the need for human operators to actively adjust equipment. Recent research shows that DR can be used for some types of ancillary services such as non-spinning reserves and regulation.

This study gathers data from multiple sources to determine total electric end-use load data in the commercial and industrial sectors in California. The percentage of loads that could be shed using fast automated demand response is calculated based on previous DR research in these types of facilities.

A large-scale deployment of AutoDR could provide between 0.18 and 0.90 GW of DR-based ancillary services from the existing stock of commercial and industrial facilities throughout California (Table E-1). Energy management and control systems (EMCS) are typically required to implement AutoDR at the facilities. The aforementioned GW values are based on the existing penetration of EMCSs in commercial and industrial facilities. By upgrading and expanding automated control systems in facilities that are currently "unreachable" by AutoDR, the estimated shed potential could approximately double to between 0.42 and 2.07 GW. The shed capacity available from AutoDR can vary by weather, time of year, time of day and other factors. DR resources are particularly prone to such variation, but to date, there has been little research regarding DR capacities in off-peak and shoulder periods. Due to the limitations of available data sets, there is relatively high uncertainty in the aforementioned results. A sensitivity analysis calculates that the AutoDR shed potentials identified in this report are expected to be between 0.5 and 1.8 times its predicted value in 90% of the cases.

Table E-1. Estimated shed of electric loads by automated demand response in California commercial and industrial sectors

	Shed during Minimum hour of the year* (GW)	Shed during Maximum hour of the year* (GW)
Current Controllability	0.18	0.90
Increased Controllability	0.42	2.07

*Average of 2 hour and 20 minute demand response products. Base year 2007 used for analysis. Minimum and maximum hours identified are based on CEUS statewide minimum and maximum hourly demand.

This study suggests that fast automated demand response may help mitigate grid balancing challenges introduced by upcoming increases in intermittent renewable generation resources in an environmentally friendly and cost effective manner. Deployed costs for fast automated demand response including installation, materials, labor and program management are about 10% of the deployed costs of grid scale battery storage (Table E-2). However, though data are preliminary, AutoDR in California appears to have capacity that is substantially less than that required to meet the grid balancing challenges introduced by the 2020 RPS goals. There are many different types of ancillary services necessary to keep the electric grid in balance. This report focuses on two types; a 20 minute product and a two hour product, both of which match or are similar to the requirements for existing non-spinning reserves products available on the wholesale market. While these products are useful for the integration of renewables, regulation and load following are even more important (Eto 2012). To date, only pilot scale field tests have been conducted using AutoDR for non-spinning reserves and regulation. While the results from these pilots are promising, further research is required to determine the degree to which AutoDR is useful in integrating higher penetrations of renewable generation onto the electric grid.

There is hope that, in the future, AutoDR can serve as a useful tool in addressing grid operational challenges associated with increasing penetration of variable and intermittent generation resources. Though AutoDR may not be suitable for all forms of ancillary services, the lower installed cost of AutoDR indicates that it should be considered for use in the time domains and capacities for which it is applicable. By combining AutoDR with traditional gas fired thermal generation and battery storage technologies, an optimal mix of generation, DR and storage should be considered.

Table E-2. Demand response costs (average) compared to various grid scale battery costs (average)

Grid Scale Battery Technology	Demand Response Costs Compared to Various Grid Scale Battery Costs		
	DR Cost* ($/kW)	Battery Cost** ($/kW)	DR / Battery (% cost)
Lithium-ion - High Power	$230	$2,050	**11%**
Advanced Lead Acid	$230	$2,100	**11%**
Lithium Ion - High Energy	$230	$2,750	**8%**
Vanadium Redox Battery	$230	$2,375	**10%**
Zinc Bromine	$230	$1,625	**14%**
Sodium Sulfur (NaS)	$230	$3,500	**7%**
Zinc- Air Battery	$230	$2,625	**9%**

* DR Cost = Deployed cost, average. (Wikler et al., 2009)
** Battery Costs = Deployed cost, average. (Seto 2010)

CHAPTER 1:
Background and Introduction

California's Renewables Portfolio Standard (RPS) is one of the most ambitious renewable energy standards in the country. The RPS program requires investor-owned utilities, electric service providers, and community choice aggregators to increase procurement from eligible renewable energy resources to 33% of total procurement by 2020 (CEC 2002).

Renewables integration with the grid has been intensively studied for impacts on production cost, markets, electrical interconnection and grid stability. A 2010 study using known intermittent behavior of wind and solar resources in California with computer simulations of the electric grid showed that "…between 3,000 and 5,000 MW of regulation and energy for balancing and ramping services from fast resources (hydroelectric generators and combustion turbines) would be required for 33 percent renewable penetration scenario in 2020. This will require significant increases in ancillary services (regulation) and real-time dispatch energy, with attendant changes in the day-ahead schedules of generation production by hour to ensure that such services are available—that is, that enough generators will be on-line with excess capacity available during each hour. Such a change…will incur additional economic costs. The use of storage in conjunction with new control and generation ramping strategies offers innovative solutions… to comply with current North American Electric Reliability Corporation system performance standards. Electricity storage promises to be a useful tool to provide environmentally benign additional ancillary service and ramping capability to make renewable integration easier. However, …storage is not performed at a comparative cost (*to traditional generation*)" (Masiello et al., 2010).

In 1995, the Federal Energy Regulatory Commission defined ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system. FERC identified six ancillary services: reactive power and voltage control, loss compensation, scheduling and dispatch, load following, system protection, and energy imbalance. Researchers have since identified at least thirteen additional ancillary services (Kirby et al., 1995).

Demand Response (DR) has traditionally been defined as a set of time dependant activities that reduce, shed or shift electricity use to improve electric grid reliability and manage costs. DR event sheds have traditionally been initiated through programs that are called many hours in advance and last for two to six hours in duration, usually during periods of peak usage or when there are constraints or contingencies in generation or transmission systems. The term automatic demand response (AutoDR) is used to describe systems in which electric loads respond to remotely generated control or pricing signals without the need for human operators to actively adjust equipment. AutoDR is used generically to describe the functionality of automated demand response and includes both proprietary systems and open-standards based technologies such as OpenADR.

The requirements for ancillary services differ from peak load management in that much less advanced notice is given and events last for shorter time durations. Some types of ancillary services are used to balance the grid by ramping electric generation either up or down depending on grid conditions. Similarly, DR can be used to shed electric loads, as done intraditional DR, or to increase electric loads. Ideally, increases in electric loads could be used to store energy for future use such as through precooling, but not all DR strategies lend themselves to storage. While fast automated demand response is capable of both shedding and increasing demand, this report focuses on fast automated DR shedding of electric loads.

Ancillary services are used for a variety of grid balancing activities including those necessary to integrate more renewable generation on the California electric grid. Recent research shows that DR can be used for some types of ancillary services such as non-spinning reserves, regulation (Kiliccote et al., 2010 and Starke et al., 2009). In the Kiliccote study, AutoDR at a commercial facility produced demand response or "pseudo generation" that ramped from zero to maximum in less than one minute. In the Starke study, an aluminum smeltering plant in Indiana used AutoDR to provide (+/–) 15 MW of regulation services over several 5-6 hour test periods. During each test, reg-up and reg-down services were provided with near instantaneous response to an Midwest ISO generated setpoint signal that varied up to 10 times per minute.

This scoping study explores the potential for fast automated DR to provide ancillary services in California. As shown in Table 1-1, certain ancillary services are of the "*most interest*" for the integration of wind: Regulation, Load Following, Reactive Supply and voltage control, Frequency Responding (spinning) Reserve and Supplemental (non-spinning) Reserves (Ernst et al., ISET 1999). In addition, "Regulation and load following are most important for renewables integration. Contingency reserves (spin and non-spin) are not as important for renewables integration. For regulation in particular, the ramping rate of demand response (in both directions) is the most important issue, not the duration of an interruption." (Eto 2011). Table 1-1 also includes a column showing evidence of successful AutoDR field pilots for these types of ancillary services, based on an evaluation of Eto 2011, Kiliccote 2012 and Starke 2009 as well as typical AutoDR response times for the end uses evaluated in this report. Though research data about the use of fast automated demand response is limited, the authors provide engineering judgments about the estimated portion of AutoDR that may be suitable for each type of ancillary service. Because the integration of renewable generation can require grid balancing services at any time, this report uses methodologies that estimate AutoDR shed capacities that vary during each hour of the year (see Chapter 2, Approach).

The California Energy Commission requested LBNL to conduct a scoping study to estimate the potential capacity of demand response resources that could provide ancillary services to help stabilize the electric grid and enable California to reach its 33% RPS goals. The study is based on the hypothesis that fast acting automated demand response is more environmentally friendly than fossil fuel based generators and more cost effective than grid scale battery storage. Table 1-2 shows cost estimates of grid scale battery technologies that are currently available for deployment.

Table 1-1. Key ancillary services for the integration of renewable generation

Ancillary Services Type	Description	Successful AutoDR Field Pilots and/or meets ISO system requirements?	Portion of total AutoDR Shed Capacity *
Regulation	Maintenance of the minute to minute generation/load balance	Yes	Small
Load Following	Maintenance of the hour to hour generation/load balance	Yes	Medium
Reactive Supply and voltage control	Immediate response to contingencies and frequency	Unlikely **	Unlikely
Frequency Responding (spinning) Reserve	Immediate response to contingencies and frequency deviation	Yes	Small
Supplemental (non-spinning) Reserves	Response to restore generation/load balance within 10 minutes of a generation or transmission contingency	Yes	Large
Future Ancillary Service products designed for AutoDR	AutoDR end-uses with similar characteristics can be aggregated into cost effective portfolios that meet specific grid balancing requirements	NA	Large

"Ancillary Services Types" and associated descriptions by Ernst et al., 2009.
***** The term "total AutoDR shed capacity" and portions thereof are based on the definitions in this report. Relative values shown (unlikely, small, medium, large) are engineering judgments based on ancillary product-specific response times and durations (discussed further in Chapter 2 and illustrated in Figure 2-2 and Table 2-2).
****** The requirements for Reactive Supply and Voltage Control are unlikely to be met using remote command and control AutoDR architecture described in this report. Local autonomous control or other methods may be possible for this purpose.

Table 1-2. Estimated deployed costs of various grid scale batteries

Grid Scale Battery Technology	Grid Scale Battery Deployed Cost ($/kW)		
	Low	High	Average
Lithium-ion - High Power	$1,600	$2,500	**$2,050**
Advanced Lead Acid	$1,700	$2,500	**$2,100**
Lithium Ion - High Energy	$2,500	$3,000	**$2,750**
Vanadium Redox Battery	$1,750	$3,000	**$2,375**
Zinc Bromine	$1,250	$2,000	**$1,625**
Sodium Sulfur (NaS)	$3,000	$4,000	**$3,500**
Zinc- Air Battery	$2,250	$3,000	**$2,625**

Source: Seto 2010

In a comprehensive study of costs to implement AutoDR at 82 commercial and industrial sites in California, "The cost of the Auto-DR equipment enablement (including parts, labor and programming… yielded an enablement cost of $66/kW. The full technical incentive (TI) cost for the 2007 AutoDR efforts, when including the costs associated with recruitment, technical coordination, equipment and participation was $230/kW". (Wikler et al., 2009).

Deployment and operational costs for grid scale batteries and demand response are both coming down over time due primarily to improvements in technology and increased production volumes. AutoDR costs referenced by Wikler et al. were based on traditional slower acting day-ahead DR programs offered in 2007. Some commercial facilities outfitted with traditional AutoDR technology used in day-ahead DR programs can be switched to faster, ancillary services pilots without changing the core AutoDR technology (Kiliccote et al., 2009). However, in order to participate in financially binding ancillary services programs such as non-spinning reserves, additional telemetry equipment would need to be installed to provide grid operators visualization of dispatched shed performance. Telemetry equipment adds to the cost of AutoDR above and beyond what is shown in Table 1-3. Additional research is required to determine the most cost effective means to provide visualization and verification of dispatched shed performance.

Table 1-3. Demand response costs (average) compared to various grid scale battery costs (average)

Grid Scale Battery Technology	Demand Response Costs Compared to Various Grid Scale Battery Costs		
	DR Cost* ($/kW)	Battery Cost** ($/kW)	DR / Battery (% cost)
Lithium-ion - High Power	$230	$2,050	**11%**
Advanced Lead Acid	$230	$2,100	**11%**
Lithium Ion - High Energy	$230	$2,750	**8%**
Vanadium Redox Battery	$230	$2,375	**10%**
Zinc Bromine	$230	$1,625	**14%**
Sodium Sulfur (NaS)	$230	$3,500	**7%**
Zinc- Air Battery	$230	$2,625	**9%**

* DR Cost = Deployed cost, average. (Wikler et al. 2009)
** Battery Costs = Deployed cost, average. (Seto 2010)

This feasibility study developed a set of scenarios to estimate the technical potential for mass-deployed demand-side resources in the commercial and industrial (C&I) sectors using automated demand response (AutoDR) technology to help manage the grid and provide some types of existing and future ancillary services.

Key resources or end-uses evaluated in this study include HVAC, lighting, refrigerated warehouses, agricultural pumping, data centers and wastewater treatment facilities.

The results are developed to inform the degree to which California may be able to rely on demand resources employing AutoDR to support its environmental policy goals and the integration of greater levels of variable energy resources on the electric grid:

- Reducing statewide greenhouse gas (GHG) emissions to 1990 levels by 2020 and to 20 percent of 1990 levels by 2050;
- Providing 33 percent of our electricity demand in 2020 from renewable resources;
- Addressing limitations on regional air emissions credits; and
- Adhering to California's Loading Order (CEC 2008), with energy efficiency and demand response as the highest-ranking resources.

Phase 1 of this project is reported herein and includes the following tasks:

- Task 1: Literature Review
- Task 2: Framework Development
- Task 3: Identification of Key Sectors and End-uses by Season and Time of Day
- Task 4: Estimation of DR Resources by Sector, Season, and Time of Day

Phase 1 addresses economic and incentive issues at a very high level. Quantitative economic analysis of the scale up of AutoDR for use as an ancillary service for grid reliability and integration with renewables and storage is planned for future phases of research.

The project provided inputs and contributions to presentation materials to the CEC as it developed the 2011 Integrated Energy Policy Report (IEPR). Key milestone dates were:

- IEPR-2011 Integrated Energy Policy Report Planning Meeting - November 16, 2010
- IEPR-2011 Integrated Energy Policy Report Adoption Meeting – April 2011

This report consists of five chapters and two appendices: Chapter 1 (Introduction and Background) describes the context and purpose of the research, Chapter 2 (Approach) describes the analysis framework, Chapter 3 (Analysis Methodology) describes the methodology in depth, Chapter 4 (Results) provides the analysis results and Chapter 5 (Conclusions) provides a discussion of the results, including next steps.

CHAPTER 2: Approach

The analysis approach is summarized below. Additional details regarding the analysis methodology and assumptions made can be found in Chapter 3, Analysis and Methodology.

Commercial and Industrial (C&I) sector electricity use data in California are gathered from the Commercial End-Use Survey (CEUS 2006) and data from the CEC Demand Analysis Office (2010) literature. The load data, including detailed end-uses, are adjusted to represent the best estimates of current hourly electric loads for the entire state.

From the end-use load data, a framework and methodology are created to estimate the potential of automated demand response (AutoDR) to meet the aforementioned goals of the project. For the purposes of this scoping study, the shed potential of all C&I loads are considered to be accessible solely for fast acting ancillary services, as if traditional slower, longer duration DR programs did not operate simultaneously and reduce the availability of shedable loads for ancillary services. In practice it is likely that a blend of AutoDR products (fast and slow) could best balance the needs of grid operators and ratepayers. However, due to its higher value, it is likely that fast acting AutoDR services could be placed higher in the loading order than slower ones. In this study, the data analysis and visualizations are built on the following algorithm which also shown graphically in figure 2-1:

AutoDR Shed Potential = (Total Load) x (% Controllable) x (% Shed),

where:

AutoDR Shed Potential is the estimated total AutoDR capacity that could be shed (in W). As used in this report, this term may apply to end-use, facility, or statewide estimates.

Total Load is the total electrical load for a given end use, building type, industrial sector, or statewide. This value is determined based on the aforementioned data sources. The term, "Total Load," used in Figure 2-1 below, represents the maximum load that could be considered for DR. The Total Load does not include loads that should never be shed, such as emergency egress lighting and other critical loads.

% **Controllable** is the percentage of the installed base of a given C&I category that is technically feasible to do automated DR. Previous DR research (Piette et al., 2005) indicates that buildings and industrial facilities with existing energy management and control systems are technically feasible to retrofit with AutoDR at a modest cost. This study uses known and estimated values for the percentage of sites that have energy management and control systems. These percentages, which vary by site type and end use, are used as a proxy for technical feasibility of controllability. Controllable sites include building types or industrial segments that could be outfitted with automated DR without extensive retrofits. The presence of modern functional energy management and control systems (EMCS) or system control and data acquisition (SCADA) systems are key enablers of controllability for DR purposes. The multiplier, "%Controllable" specifies the percentage of the Total Load that is able to receive and execute AutoDR signals at the targeted end-use level.

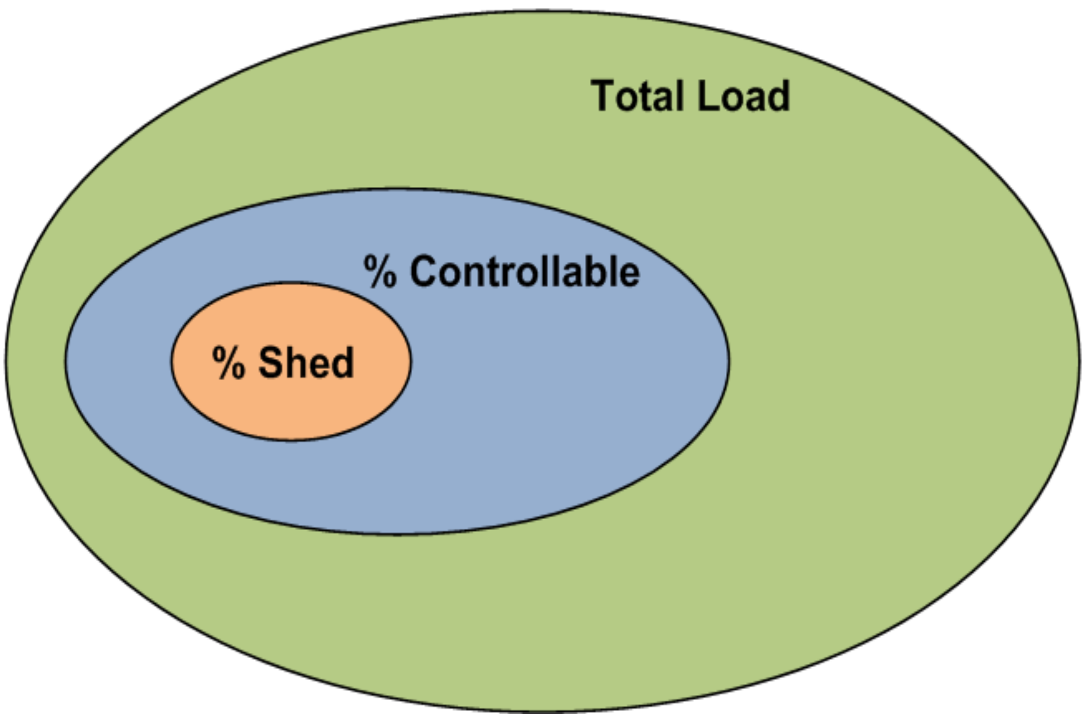
Two controllability cases are modeled:

- "current controllability" assumes penetrations of controls systems capable of receiving and executing DR signals as currently found in the existing stock of commercial buildings
- "increased controllability" assumes increased controllability in the future, typically through modest capital investment to improve EMCS or SCADA systems beyond their current state.

The values used for the controllability multiplier are detailed in Chapter 3, Analysis Methodology.

Of the sites that are controllable, % Shed is the percentage of load shed by a given end use, building type, or industrial sector. In this study, % Shed refers to the average power shed over the duration of the DR event or period of DR activity.

Figure 2-1. AutoDR Shed Potential equals the percentage shed of the percentage controllable of the Total Load (not to scale)



Sensitivity Analysis

Each of the three factors that determine the AutoDR Shed Potential have a level of uncertainty. Total Load is the most precisely known: according to the CEUS documentation, it is known to within 5% with 90% confidence. The other factors, "% Controllable" and "% Shed", have much higher uncertainties: based on engineering judgment, the authors believe that each of these parameters can be estimated to within 50%, meaning that in 90% of cases the true value will be within 50% of the prediction. The errors in the factors are assumed to be independent.

Combining the error estimates for the individual factors to get an estimated error for the AutoDR Shed Potential requires making assumptions about the statistical distributions of the errors, beyond what is summarized in the 90% confidence intervals. The uncertainty in the AutoDR shed potential is calculated using two approaches: (1) assuming the error in each term follows a normal (Gaussian) distribution that has the correct 90% confidence interval and using Monte Carlo simulation to generate the resulting distribution for the product of the terms; and (2) assuming each distribution is lognormal with parameters that give the right 90% confidence intervals, in which case the statistical distribution of the product is also lognormal and the parameters can be directly calculated. Both methods give a similar result: the AutoDR Shed Potential is expected to be between 0.5 and 1.8 times its predicted value in 90% of cases. This distribution is slightly asymmetrical about 1, which is a statistical consequence of multiplying uncertain numbers together. (Price 2012).

Shed Durations

From a grid operator's perspective, it is important to have many different tools or "products" available to balance the supply and demand of electricity. Various types of generators have unique attributes and limitations that lend themselves to various product categories (for example: base load, load following, and ancillary services). From a grid operator's perspective, the term "pseudo generation" is used to describe the effect of dispatchable AutoDR on the grid and allows the ISO to model the … resources like a *(traditional)* market Generating Unit" (Traweek, CAISO, August 2011). Each type of generation; traditional and pseudo generation from AutoDR have their own unique attributes and limitations.

In the commercial and industrial sectors in California, major deployments have used AutoDR in non-dispatchable day-ahead DR programs such as critical peak pricing and demand bidding programs (Wikler et al., 2008). Recent pilot studies show that DR can be used for some types of ancillary services such as non-spinning reserves, regulation-up and regulation-down (Kiliccote et al., LBNL, Nov. 2010 and Starke et al., ORNL, Jan. 2009). Figure 2-2 shows the range in response times and durations for various ancillary services.

In a statewide scale-up of AutoDR, it is expected that multiple DR products could be managed as a portfolio to provide grid operators the greatest flexibility to manage all generation and storage resources. For this phase of research, two hypothetical AutoDR "products" are evaluated, each with unique ramp rates and shed durations. These products match or nearly match the requirements of various non-spinning reserve programs offered by CAISO over the last several years.

- **Two-hour DR shed duration.** A two-hour shed is a useful duration for grid operators, especially during transition periods created by variable generation sources such as wind and solar. Although a longer shed duration could also be useful, many C&I loads, such as temperature control in commercial buildings, can start to "decay" if sustained beyond two hours or so. For this product, a ramp time of 15 minutes is envisioned. Up to four hours of advanced notice may be required in order for some loads to prepare (for example, frozen warehouses). Other load types, such as commercial buildings, may not require advanced notice. It is unlikely that multiple two-hour sheds could be appropriate for a given site within one 24-hour period. Though not studied in detail here, many end-use loads in this category could shed or increase loads on similar time scales.
- **Twenty-minute shed duration.** A twenty-minute shed is also a useful resource for grid operators. While such a short duration could not in itself fill in most transition periods created by variable generation sources such as wind and solar, some interruptions are very short in duration. In addition, the 20-minute product could allow operators time to dispatch other resources, including two-hour shed events. For this product, a ramp time

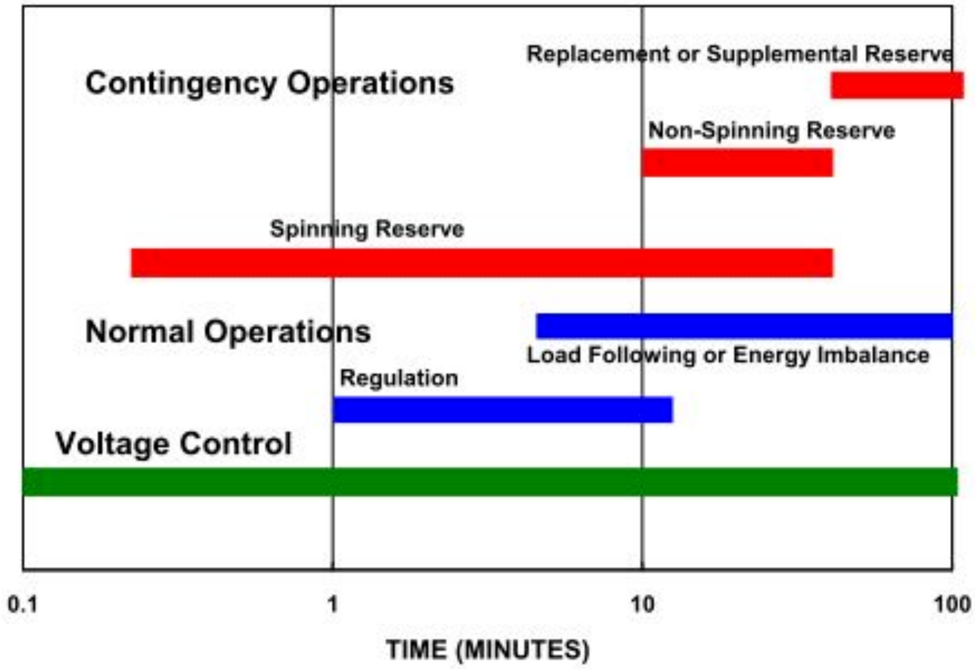
of 5 minutes is envisioned. Most loads that could be good candidates to participate for the 20 minute shed product would not require advanced notice. It is likely that, if required, multiple 20 minute sheds could be called at a given site within a 24-hour period. For a given AutoDR resource, such as a commercial building, the % Shed value for a 20 minute event could tend to be higher than that of a two-hour event. This is because shorter duration sheds have less shed decay than longer ones when averaged over the entire duration of the shed. Though not studied in detail here, many end-use loads in this category could shed or increase loads on similar time scales.

Alignment of DR Durations with CAISO Programs

AutoDR enabled loads have the potential to assist CAISO operators in several areas that may be impacted by a higher penetration of variable resources. These include shifting some load from peak to off-peak or nighttime, managing (reducing) daily peaks, and smoothing ramps associated with rapid swings in renewables production.

The CAISO currently purchases four different types of ancillary services: regulation up, regulation down, non-spinning reserves, and spinning reserves. Regulation-down functionality is achieved using AutoDR technology by temporarily increasing end-use loads. Ideally, this should be done in a manner that stores the energy for later use, such as sub-cooling frozen storage warehouses. The characteristics of the CAISO products are summarized in Table 2-1. At the present time, demand resources such as those enabled with AutoDR are allowed to provide all of these services except spinning reserves which as currently defined must be supplied by generation assets operating in synch with the grid.

Figure 2-2. Response time and duration of various ancillary services



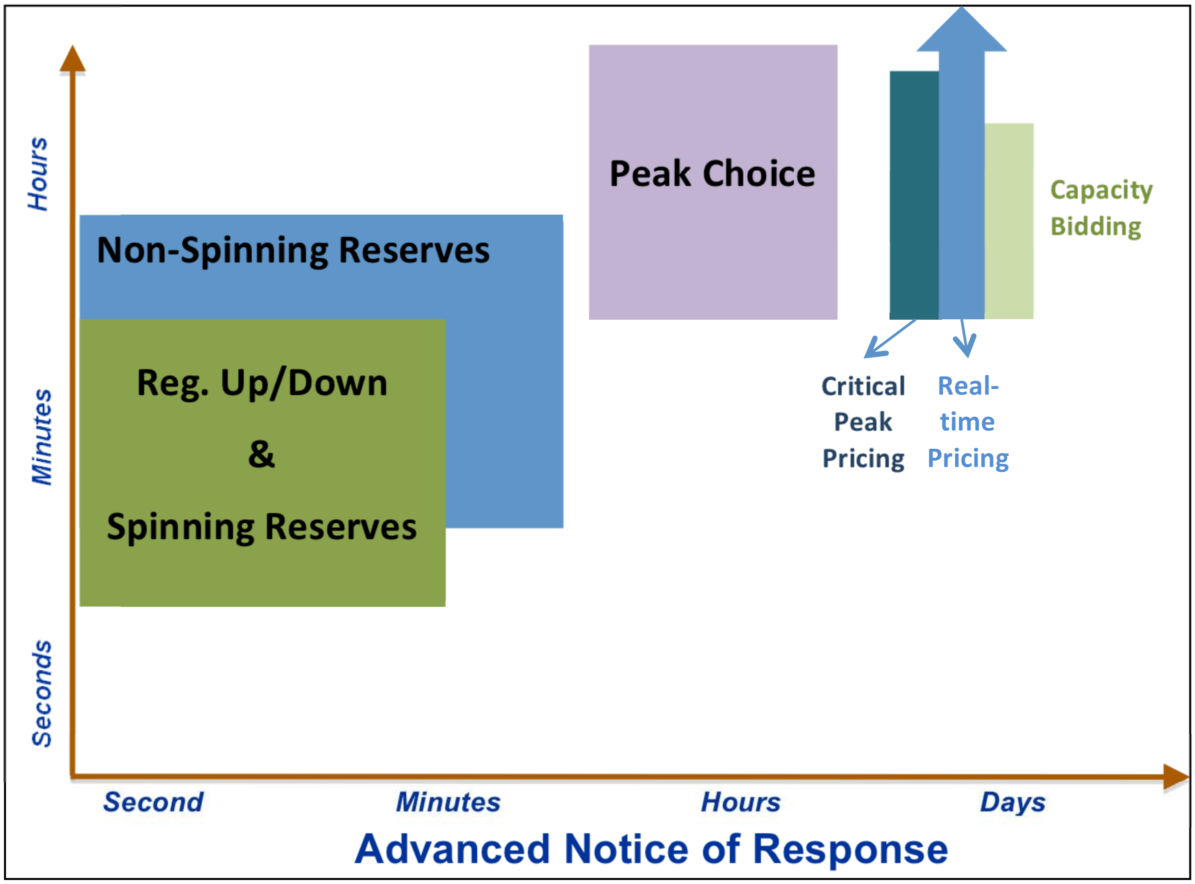
Source: Starke et al., Jan. 2009

Table 2-1. CAISO Programs suitable for AutoDR (circa 2009).

AutoDR Approved for CAISO use	Existing CAISO products	Response Time	Duration
AutoDR	Regulation Up	Start <1 min. Reach bid <10 min.	15 - 60 min.
AutoDR	Regulation Down	Start <1 min. Reach bid <10 min.	15 - 60 min.
AutoDR	Non-Spinning Reserve	< 10 minutes	30 min.
Future (?)	Spinning Reserves	~ Instant Start Full Output <10 min.	30 min.

Another way of comparing these ancillary service products with the programs historically associated with AutoDR is shown in Figure 2-3, where the width of each shape represents the range of amounts of advanced notice that the DR opportunity provides to customers, ranging from seconds to months, and the height represents the range of amounts of time for which customers are expected to sustain their response, ranging from seconds to hours. The details of the shapes in the figure are illustrative and not to scale. The programs that AutoDR have historically supported have larger advance notification (hours to day ahead) and expect sheds ranging from two to six hours. Ancillary services programs will require very short advanced notifications (5 seconds to 30 minutes) and expect a change in consumption to last from less than 10 minutes to up to 2 hours.

Figure 2-3. Response time and duration of various ancillary services



The types of resources that are typically controlled by AutoDR vary in the amount of time they require to initiate a response. Table 2-2 summarizes these resources along with some of their characteristics. While many resources contain components can simply be switched off, Table 2-2 shows that some kinds of end-uses are capable of finer-grained control, such as reducing dimmable lighting levels or adjusting setpoints on thermostats. The judicious selection of the types of responses requested, potentially combined with cycling of individual resources to maintain a specific response level, could allow AutoDR to provide grid operators with a range of flexible resources.

Table 2-2. Typical AutoDR end-uses and minimum response times

End Use	Type	Ramp Down	Switching Off	Response Time
HVAC	Chiller Systems	Setpoint Adjustment		15 min.
	Package Unit	Setpoint Adjustment	Disable Compressors	5 sec.-5 min.
Lighting	Dimmable	Reduce Lighting Levels		5 sec.-5 min.
	On/Off		Bi-Level/Off	5 sec.-5 min.
Refrig/Frozen Warehouse		Setpoint Adjustment		15 min.
Data Centers		Setpoint Adjustment, Reduce CPU Processing		15 min.
Ag. Pumping			Turn Off selected pumps	5 sec.-5 min.
Wastewater			Turn Off selected pumps	5 sec.-5 min.

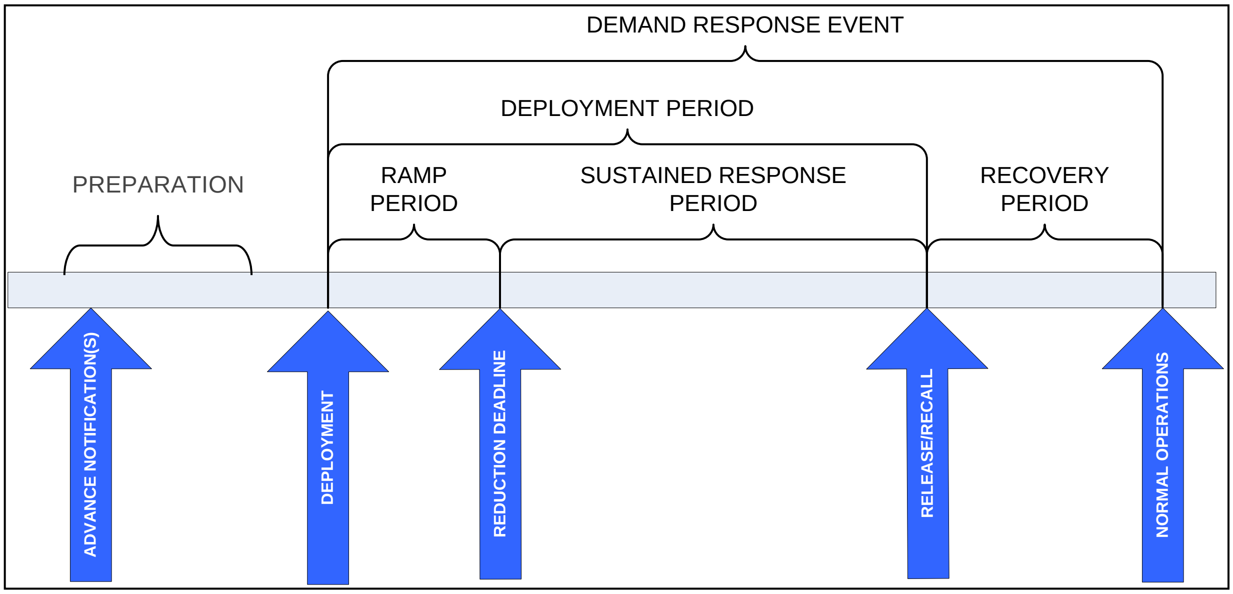
Comparison of DR and Traditional Energy Storage for Grid Services

Energy storage technologies do not store electric energy directly; rather, they convert electrical energy into a more easily stored form, such as chemical energy (batteries), or thermal energy (chilled water). Although they are not often thought of as such, office buildings and refrigerated warehouses are also energy storage devices. The thermal mass of the structure and its contents can be exploited through DR to provide many of the same functions that more recognizable energy storage devices provide. The only real difference between what is usually thought of as "energy storage" and DR is that some types of storage devices can return their stored energy to the grid, whereas DR resources do not. Examples of these energy storage options include:

- *Potential Energy* - Pumped storage, Compressed Air Energy Storage
- *Kinetic Energy* - Flywheels (rotating mass)
- *Thermal Energy* - Chilled water, building heat capacity (thermal mass)
- *Latent Energy* – Ice making/melting (phase changes)
- *Electrostatic Energy* - Supercapacitors
- *Magnetic Energy* - Superconducting magnetic energy storage)
- *Chemical Energy* - Batteries

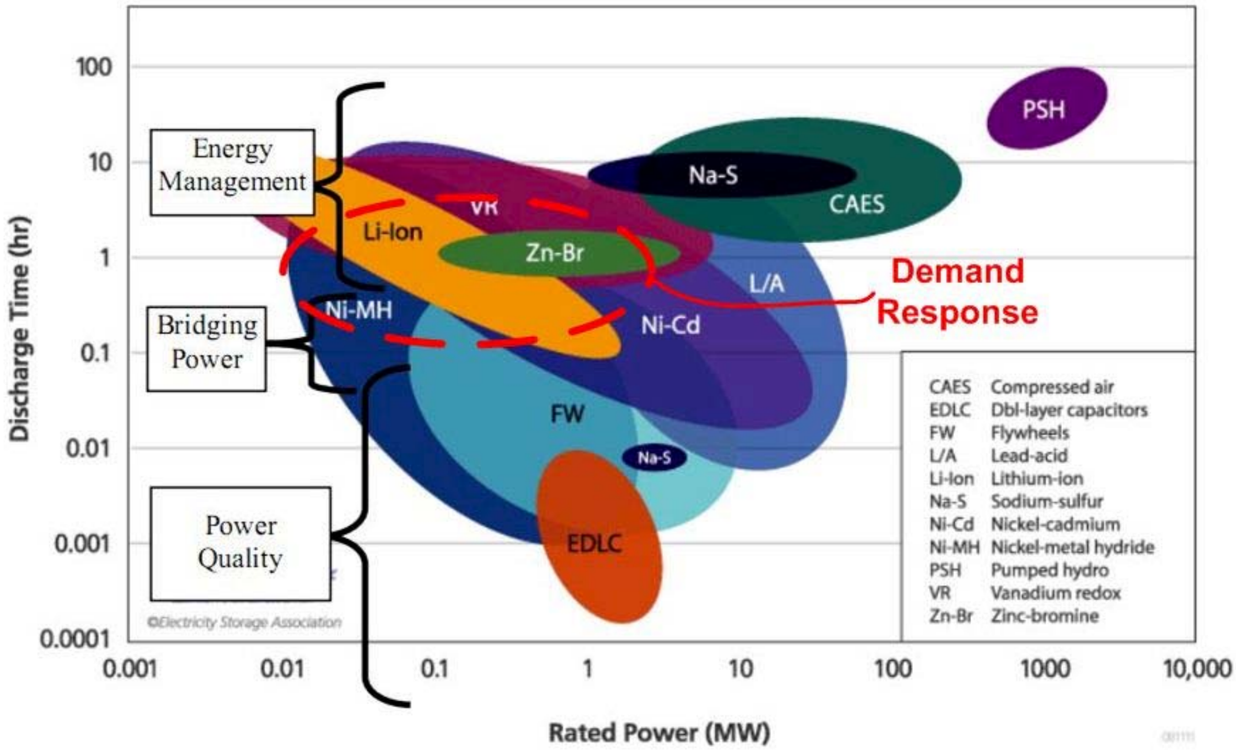
As is the case with traditional energy storage (ES) devices, DR resources need to be "charged" before they can be "discharged." "Charging" an ES resource consists of converting grid-supplied electricity into one of these storable forms. "Discharging" consists of drawing down the stored energy, either in its stored form with thermal mass or by converting it back to electricity for local consumption or for injection into the grid. This sequence of events is illustrated in Figure 2-4, which is based on the NAESB Phase I Measurement and Verification Standard timeline with an added "Preparation" period to account for the time during which the resource consumes above its normal demand level for charging of its energy storage capability. This can occur either synchronously with the DR event or outside of it. Definitions of all other labels are those adopted by NAESB.

Figure 2-4. DR event timeline



Once a storage resource has been charged, its ability to deliver power or energy to a load either directly or through the grid or to reduce its consumption varies depending on the characteristics of the resource. The discharge times and power ranges of several storage technologies are shown in Figure 2-5. This figure also includes an overlay indicating the range of these values for the resources typically accessible through AutoDR. In terms of power availability and discharge time, AutoDR resources align and overlap with those of battery storage technologies.

Figure 2-5. AutoDR and energy storage discharge time and power



Source: Electricity Storage Association (underlying figure only. Demand Response illustration by authors).

CHAPTER 3: Analysis Methodology

This analysis of around the clock demand response potential is based on a series of estimations of hourly statewide demand by facility type and end-use, shed availability (% of demand) for each facility/end use combination, and controllability (% of demand able to receive and execute DR signals down to targeted end use). The following section describes how each of these estimates is determined.

HVAC and Lighting Hourly Demand. The California End Use Survey 2004 (CEUS 2004) provides statewide hourly electricity and natural gas consumption estimates by building type for specific end-uses. CEUS Facility types include small and large offices, restaurants, retail, food stores, refrigerated warehouses, unrefrigerated warehouses, schools, colleges, health, lodging and miscellaneous buildings. Of interest to this study are HVAC and interior lighting-related electricity use. CEUS splits HVAC-related electricity use into three end-uses: heating, cooling and ventilation. CEUS heating and cooling end-uses represent the heat transfer portion of HVAC energy consumption. The CEUS ventilation end use includes all HVAC fan energy consumption required to deliver heating and cooling energy and provide ventilation to the building. As natural gas and other fossil fuels are the predominant heating fuels for California's commercial buildings, heating electricity demand is not included in this analysis. Thus, this analysis includes the hourly CEUS cooling, ventilation and interior lighting electricity consumption by building or facility type.

Refrigerated Warehouses – Refrigeration Hourly Demand. CEUS 2004 provides statewide hourly electricity consumption estimates for refrigeration. Of interest is the distribution of refrigeration electricity consumption between cold (32-55°F) and frozen (below 32°F) refrigerated warehouses as these two types of warehouses are operated differently and have different energy intensities and different demand response potentials. Absent data quantifying the relative energy intensities of cold and frozen refrigerated warehouses, the CEUS hourly demand values are disaggregated based on the split in volume (cubic feet) between cold (38%) and frozen (62%) refrigerated warehouses in California (USDA 2010).

Data Centers – Hourly Demand. The EPA report to Congress in 2007 (U.S. EPA 2007) stated that US data center electricity consumption was 3% of the total national energy consumption. While California's data center population density may be higher than the national average, the 3% value is used to estimate California's annual data center electricity consumption. As data center electricity consumption is relatively steady throughout the year, the hourly demand can be calculated as the annual data center electricity consumption divided by 8760 hours, resulting in a statewide data center hourly demand of 940 MW. About 39% of the data center-related electricity consumption is HVAC and lighting-related (Silicon Valley Leadership Group and Accenture 2008). As these loads are anticipated to be included in the corresponding CEUS end use data, the remaining 61% of data center-related electricity demand, or 573.4 MW, corresponds to data center process activities (servers, etc.). As HVAC and lighting loads have been treated separately in this analysis, it is this 573.4 MW that is identified as the base data center load against which potential demand response activities could act.

Agricultural Pumping – Hourly Demand. The agricultural pumping-related energy demand varies by season and time of day. The CEC Demand Analysis Office developed load curves (ratio to peak hour of electricity demand for an average weekday and weekend for each month) based on utility-provided data in order to provide model inputs to represent variations in related energy consumption throughout the year (CEC 2010). Electricity consumption for agricultural pumping is included in the crops (sic01) and agricultural irrigation (sic51) load curves. Of the sic01 whole farm electricity consumption, approximately 90% of the whole farm consumption is assumed to be related to irrigation and thus available for irrigation pump-based demand response activities. The sic51 irrigation electricity curves for the PG&E service territory include a significant amount of night-time electricity consumption during the weekday nights from November through March. It is assumed that irrigation districts move water into reservoirs and canals at night using the agricultural time-of-use (TOU) rate structure in order to reduce pumping costs. To parse out the farm-based agricultural pumping for use in this analysis, it is assumed that the night-time, non-TOU, agricultural pumping electricity consumption is the same as for the rest of the day. The curve data is used in this analysis to calculate the equivalent number of peak hours per year (the sum of the hourly ratios divided by 8760), estimate the corresponding statewide peak hour demand (statewide 2007 agricultural pumping annual consumption divided by the equivalent number of peak hours per year), and then multiply the individual hours' ratio by the peak hour demand to obtain the 8760 hours of demand values.

Extrapolation to 2007 Base Year. Through discussions with the CEC Demand Analysis Office and reviewing historical annual electricity consumption rates, 2007 electricity consumption levels are determined to best represent California's electricity consumption in the next five years. Taking into account the statewide commercial, industrial and total energy consumption data provided in the California Energy Commission's California Energy Consumption Database (http://ecdms.energy.ca.gov/) for the years relating to the source data, a factor of 1.3 is applied to the CEUS (2004) data to estimate the 2007 end use consumption values for commercial buildings and refrigerated warehouses. The energy demand values for the data centers and agricultural pumping sectors are derived based on the corresponding CEC 2007 statewide annual consumption values, and do not need further scaling.

Controllability, Shed Depth, and Length Estimation

As described in Chapter 2 (Approach), this analysis looks at two cases: 1) 20 minute sheds with five minute ramps and 2) 2 hour sheds with ten minute ramps. The shed depth (% of demand reduction) possible for each of these cases varies depending on three factors: the type of facility and related operational needs; the specific end use and how deep a shed is possible while still maintaining mission critical functions; and the percentage of the related stock that have the control capabilities to receive AutoDR signals and execute control strategies at the targeted end uses.

HVAC-related Sheds and Controllability

Table 3-1 summarizes the assumed HVAC (cooling and ventilation) shed depths and controllability factors for the commercial building types included in this analysis.

Shed Availability. HVAC-related shed activities for 2 hour and 20 minute DR include ramping down related electricity demand by adjusting temperature setpoints, switching off by disabling compressors in package units, and, in facilities with multiple package units serving the same space, using a shed pattern that turns off selected packaged units completely while running the remaining package units under normal control. The level of shed estimated for a given facility type is determined by reviewing previous peak day field tests (Piette et al., 2007) and evaluating the level of HVAC-related shed possible in each of the target facility types. It is assumed that the two hour shed availability is similar to that found in four hour peak day field tests. Where possible, shed availability can be a third higher for 20 minute shed events. The shed levels can be grouped together: 60% HVAC-related demand shed for two hour events and 80% for 20 minute events for those facilities with rooftop units which can turn off compressors (small offices, office areas within warehouse facilities, schools, lodging and miscellaneous facilities); 50% for two hour and 20 minute events for large office and college buildings that can do setpoint adjustments to reduce demand; and 30% for two hour and 40% for 20 minute events for restaurants who can turn off compressors on rooftop units or do setpoint adjustments, but may not be able to do so to the extent of other facilities as they need to maintain ventilation supply rates to balance kitchen exhaust rates. Hospitals and health facilities have not been included in pilot tests to date so are assumed to not be able to participate in HVAC-related demand sheds for the purpose of this analysis.

Controllability. The percent of HVAC demand able to receive and execute DR signals down to the targeted end use is estimated from data provided by EnergyIQ (Mathew, et al., 2008) (http://energyiq.lbl.gov/), taking into account the weighting of typical HVAC systems in a given building type. The technical potential controllability case assumes that this value can be doubled from that of the current controllability case.

Time of Day HVAC Shed Impacts. This analysis assumes that full HVAC-related shed capability, as calculated based on these shed availability and controllability assumptions, is obtainable during standard building operating hours (6 a.m. to 10 p.m.). The night-time (10 p.m. to 6 a.m.) HVAC-related demand may take place in a smaller percentage of facilities which may have a much lower controllability factor than for the statewide stock. As such, this analysis applies the shed availability and controllability assumptions to 10% of the HVAC-related demand in order to determine the HVAC-related shed capability at night.

Table 3-1. HVAC-related End-uses – Shed Availability and Controllability

	Shed Availability (% of Demand)		Controllability (% of Demand able to receive and execute DR signals at targeted end use)	
Facility Type	**Slow DR (2 Hour shed)**	**Fast DR (20 minute shed)**	**Current %**	**Technical Potential %***
Small Office**	60%	80%	15%	30%
Large Office	50%	50%	30%	60%
Restaurant**	30%	40%	1%	2%
Retail**	50%	50%	11%	21%
Food Store**	40%	60%	11%	22%
Refrigerated Warehouse – Frozen Storage***	60%	80%	4%	8%
Refrigerated Warehouse – Cold Storage**	60%	80%	4%	8%
Unrefrigerated Warehouse**	60%	80%	2%	3%
School**	60%	80%	20%	40%
College	50%	50%	2%	4%
Health	0%	0%	2%	4%
Lodging**	60%	80%	3%	7%
Miscellaneous**	60%	80%	1%	2%

Lighting-related Sheds and Controllability.

Table 3-2 summarizes the assumed lighting shed depths and controllability factors for the commercial building types included in this analysis.

Shed Availability. Previous peak day field tests in a variety of commercial buildings (Rubinstein and Kiliccote, 2007) have shown it is possible to dim or turn off lighting in order to reduce lighting electricity demand by 33% for the demand response period (up to four hours). Retail facilities, due to their display lighting requirements, have shown a shed of 25% of their lighting electricity demand. An assumption is made that restaurants and health facilities would not be able to dim or turn off lighting, thus a 0% shed assumption is made for these two facility types. This analysis assumes the shed level (% of demand) is the same whether it is a 20-minute or two hour shed event.

Controllability. The percent of lighting demand able to receive and execute DR signals down to the targeted end use is estimated from data provided by EnergyIQ, taking into account the weighting of typical lighting control systems in a given building type. For the purpose of this analysis, only those facilities with energy management systems are assumed to be able to receive and execute DR signals. The technical potential controllability case assumes that this value can be doubled from that of the current controllability case.

Time of Day Lighting Shed Impacts. This analysis assumes that full lighting-related shed capability, as calculated based on these shed availability and controllability assumptions, is obtainable during standard building operating hours (6 a.m. to 10 p.m.). The night-time (10 p.m. to 6 a.m.) lighting-related demand may take place in a smaller percentage of facilities which may have a much lower controllability factor than for the statewide stock. As such, this analysis applies the shed availability and controllability assumptions to 10% of the lighting-related demand in order to determine the lighting-related shed capability at night.

Table 3-2. Lighting-related End-uses – Shed Availability and Controllability

	Shed Availability (% of Demand)	Controllability (% of Demand able to receive and execute DR signals at targeted end use)	
Facility Type	**Slow or Fast DR (2 Hour or 20 minute shed)**	**Current Controllability%**	**Increased Controllability %**
Small Office	33%	5%	10%
Large Office	33%	10%	20%
Restaurant	0%	1%	1%
Retail	25%	17%	33%
Food Store	33%	23%	46%
Refrigerated Warehouse – Frozen Storage	33%	1%	3%
Refrigerated Warehouse – Cold Storage	33%	1%	3%
Unrefrigerated Warehouse	33%	2%	4%
School	33%	6%	13%
College	33%	0%	0%
Health	0%	2%	4%
Lodging	33%	3%	5%
Miscellaneous	33%	0%	0%

Industrial Sector Sheds and Controllability

Three industrial sector facility types are included in this analysis: refrigerated warehouses, data centers, and agricultural pumping. Table 3-3 summarizes the assumed shed depths and controllability factors for these facility types. For ease of comprehension, these facilities are discussed separately.

Refrigerated Warehouses – Shed Availability and Controllability. Shed availability varies for cold storage (32-55°F) vs. frozen storage (below 32°F) refrigerated warehouses. While temperature setpoint adjustment strategies can be used to shed refrigeration demand in both types of facilities, frozen products in frozen storage facilities are better able to withstand a reasonable amount of temperature deviation over a two hour period than do products in cold storage. Goli (2010) reports a case where a cold storage warehouse was able to shed 90% of their demand by shutting down their process, though this could be considered an extreme case. For the purpose of this analysis, a more conservative 25% frozen storage refrigeration load shed is assumed for a two hour shed event. A much lower 5% shed is assumed for cold storage for a two hour event. For a twenty minute event, the analysis assumes that it is possible to have a 35% refrigeration load shed for either cold or frozen storage.

A large portion of refrigerated warehouses use SCADA or EMCS controls to regulate storage and product temperatures. For the purpose of this analysis, the current controllability case assumes that 40% of the frozen storage facilities and 25% of the cold storage facilities' refrigeration systems are able to receive and execute DR signals. The increased controllability case assumes this percentage is doubled to 80% and 50%, respectively.

Data Centers – Shed Availability and Controllability. Ghatikar et al. (2010) reports a number of demand response strategies that can be implemented in data centers, including data center thermal conditioning (HVAC), lighting, scheduling and virtualization (operating remotely mirrored or cloud servers). A potential 5-10% HVAC and lighting sheds, and 12-15% from virtualization is proposed. For the purpose of this analysis, a 15% shed availability is assumed for both two hour and 20 minute shed events. Data centers are highly controlled, thus a 75% controllability value is assumed for the current controllability case. The increased controllability case assumes 100% controllability.

Agricultural Pumping – Shed Availability and Controllability. Water pumping is a resource that has already been integrated into the CAISO demand response activities, particularly large scale water transport (peripheral canal, municipal, and large agricultural). House (2007) states that 25% of the water pumping load has already been shifted to off-peak hours. Smaller pumps such as deep-well turbine pumps (approximately 300-400 kW each) and booster pumps used in crop irrigation also make up a significant load in California. Companies such as M2M Communications (now EnerNOC) have successfully performed AutoDR events using these agricultural pumps by installing wireless control systems. While these pumps can respond quickly to AutoDR events, field managers indicate that cycling the pumps on and off too quickly can cause problems with the filtration systems[1]. As such, this analysis assumes a 100% shed availability for two hour events and 0% for 20 minute events. An estimate is made that 10% of the agricultural pumping demand is currently controllable. With implementation of additional wireless controls, an increase to 80% controllability could be technically feasible.

[1] Based in information gathered at a meeting with Nic Stover, M2M Communications Inc. and Sila Kiliccote and Sasank Goli of LBNL on November 9, 2010.

Table 3-3. Industrial end-uses – Shed Availability and Controllability

	Shed Availability (% of Demand)		Controllability (% of Demand able to receive and execute DR signals at targeted end use)	
Industrial Type	**Slow DR (2 Hour shed)**	**Fast DR (20 minute shed)**	**Current Controllability %**	**Increased Controllability %**
Refrigeration – Frozen Storage Refrigerated Warehouse**	25%	35%	40%	80%
Refrigeration – Cold Storage Refrigerated Warehouse**	5%	35%	25%	50%
Data Centers	15%	15%	75%	100%
Agricultural Pumping	100%	0%	10%	80%

Determination of Overall Shed Capability

Statewide shed capability (the sum of the shed capability for commercial buildings, refrigerated warehouses, data centers and agricultural pumping) is calculated for the minimum and maximum statewide demand hours as well as the 8760 hours of the year. The minimum and maximum demand hours are determined by identifying the hours corresponding to the CEUS statewide minimum and maximum demands. The minimum hour is identified to be 3 a.m. on November 28, 2004. The maximum hour is identified as 2 p.m. on September 23, 2004. For the purpose of this analysis, the statewide demand is assumed to be the sum of the demand for only the commercial and industrial sectors and facilities included in this study and thus is not equal to the full statewide demand.

$$Shed\ Capability\ \Sigma GW = \sum (End-use\ load\ [GW\}) * \left(\frac{shed\%}{100}\right) * \left(\frac{controllability\%}{100}\right) * (time\ flag)$$

Where:

End-use load	=	hourly demand GW for a given end use
Shed%	=	Shed availability (% of demand)
Controllability %	=	% of demand able to receive and execute DR signals at targeted end use
Time flag	=	1 (Refrigeration, Data Centers, Agricultural Pumping) 1 (6 a.m. to 9:59 p.m. – HVAC and Lighting) 0.10 (10 p.m. to 5:59 a.m. – HVAC and Lighting)

CHAPTER 4: Results

This chapter describes the results based on the aforementioned analysis methodology of data gathered from the referenced sources.

Shed Estimates

As described in Chapters 2 and 3, shed estimates are calculated based on total load, shed capability and controllability. The following section presents the estimated sheds graphically by controllability (current and increased cases). First, shed estimates are provided for the highest (2 p.m. on September 23) and lowest (3 a.m. on November 28) load hours statewide, with results presented in units of shed capability by end use. The highest and lowest load hours are selected to be the hours coinciding with the highest and lowest load hours for the CEUS (2006) statewide total commercial hourly load profile. Second, intra-hour shed variability estimates for the 20 minute and two hour products are provided for a typical winter and summer day for the products. The CEUS-determined typical days are used for this presentation.

Highest and Lowest Load Hours – Current Controllability

Figure 4-1 shows the statewide shed estimates by end-use for the highest and lowest electrical load use hours of the year, which correspond to the highest and lowest DR capacities calculated for the state of California. These estimates are based on the previously defined currently controllable stock of existing C & I facilities. Figure 4-1a shows the 2 hour and 20 minute DR capacity by end use, while Figure 4-1b's pie chart shows the relative shares of shed capacity by end-use, based on the average of the two hour and 20 minute product. Figures 4-1c and 4-1d provide the same view for the lowest hour of the year. As can be seen, the best case estimate is that 0.90 GW could be accessible over the peak (at 2 PM on September 23). This could drop by about eighty percent, to 0.18 GW, off peak (at 3 AM on November 28).

Looking at Figures 4-1b and 4-1d, HVAC (72%) and lighting (12%) provide the majority of the current controllability shed capability for the highest load hour, followed by industrial loads (data centers, 7%; agricultural pumping, 5%; refrigerated warehouses, 3%; and wastewater, 1%). For the lowest load hour, shed capability is distributed between the various industrial loads and building-based loads with data centers (35%), lighting (23%) and HVAC (20%) providing the largest portion of the shed capacity, followed by agricultural pumping, 10%; refrigerated warehouses, 8%; and wastewater, 4%.

These distributions reflect two facts found in the disaggregated raw data and two analysis assumptions impacting the outcome of the results. Assumptions are made that the data centers, refrigerated warehouse, and wastewater treatment loads are relatively flat year-round, resulting in the same level of shed contribution for the summer afternoon hour and the winter nighttime hour. The CEUS data showed that nighttime (10 p.m. – 6 a.m.) HVAC and lighting loads are much smaller than those on hot summer afternoons. An assumption is made that these loads are more geographically distributed and therefore an individual site may have a much smaller portion of the statewide load and may have a much lower effective controllability % than could be seen on a hot summer afternoon. To reflect this, it is assumed that the controllability % reduces to 1/10th of the assumed controllability % for the HVAC and lighting end-uses during the nighttime, resulting in an overall much lower shed contribution by these end-uses. The combination of these factors resulted in the industrial sites playing a larger part in providing shed capabilities for the winter nighttime (low hour) case.

Highest and Lowest Load Hours – Increased Controllability

An increased penetration of AutoDR could be achieved through the implementation of additional automated load controls. If this is done, the shed estimates could increase corresponding to the level to which each end-use's controllability percentage is able to be increased. Based on this analysis, the shed capacities for the increased controllability case double that found for the current controllability case. Figure 4-2a shows that the on-peak (highest hour) shed capability doubles to 2.07 GW while Figure 4-2c shows that the off-peak (lowest hour) shed capability more than doubles from 0.18 to 0.42 GW.

Figures 4-2b and 4-2d show the shed capability distribution by end-use for the increased controllability cases. HVAC sheds (63%) dominate for the highest hour, similar to that found in the current controllability case. The other loads play a smaller but significant part at the highest hour (agricultural pumping, 19%; lighting, 11%; data centers, 4%; refrigerated warehouses, 2%; and wastewater, 1%). Agricultural pumping sheds (35%) dominate for the lowest hour, followed by data centers (20%), HVAC (18%), lighting (13%), refrigerated warehouses (10%) and wastewater (4%). The primary driver behind this change is the controllability of agricultural pumping in California is increasing rapidly from the 10% controllability factor assumed for the current controllability case. The implementation cost for this increased wireless controllability capability is reasonable, thus driving the assumption that the increased controllability capability could be as high as 80% of the agricultural pumping load.

Figure 4-1a. Shed Estimates for the Highest Hour of the Year (2 p.m. September 23rd) – Current Controllability

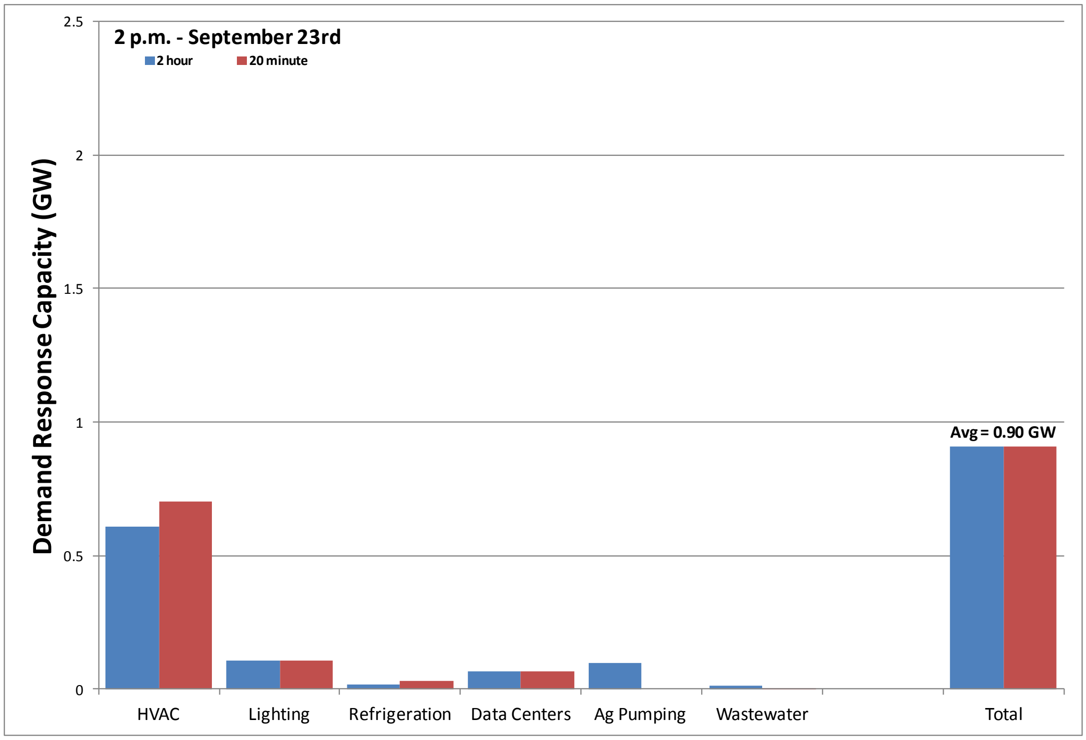


Figure 4-1b. Shed Estimates for the Highest Hour (2 p.m. September 23rd) (0.90 GW) – Average of 20 minute and 2 hour shed variability – Current Controllability

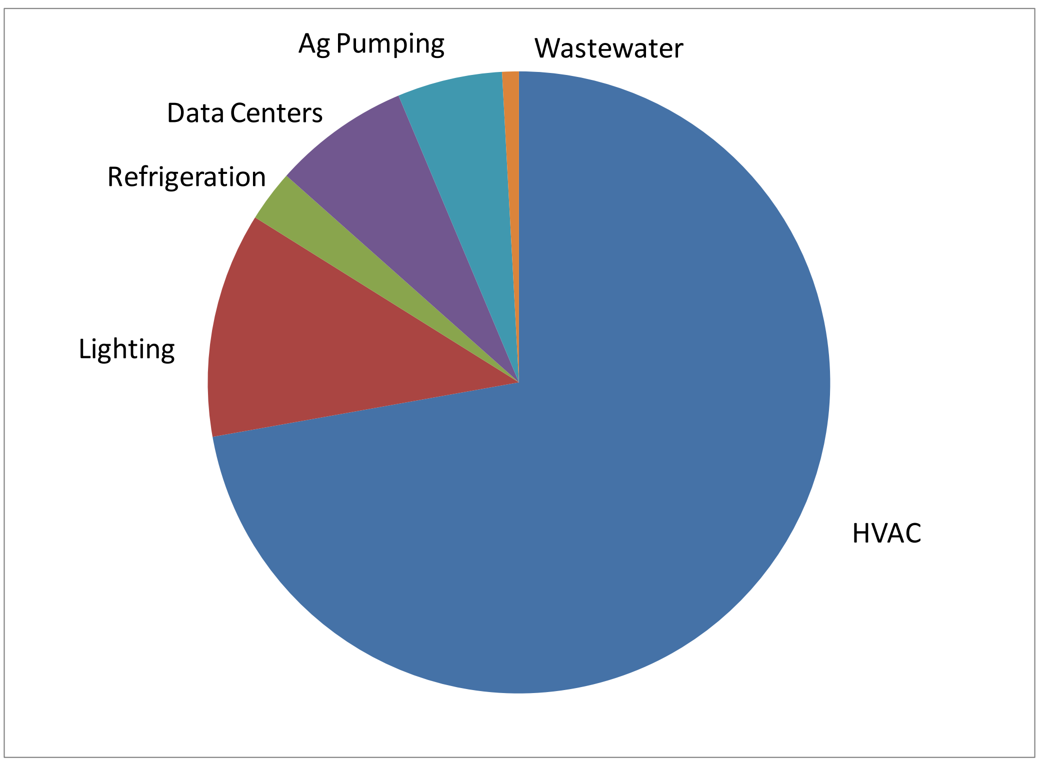


Figure 4-1c. Shed Estimates for the Lowest Hour of the Year (3 a.m. November 28th) - Current Controllability

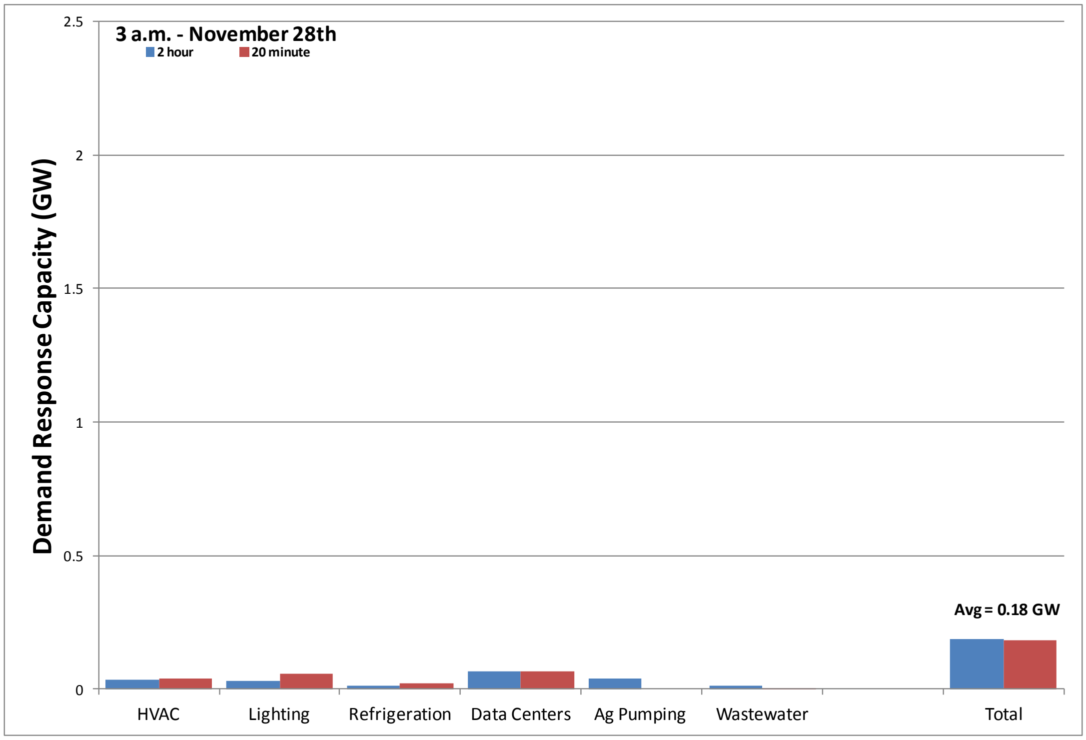


Figure 4-1d. Shed Estimates for the Lowest Hour of the Year (3 a.m. November 28th) (0.18 GW) – Average of 20 minute and 2 hour shed values – Current Controllability

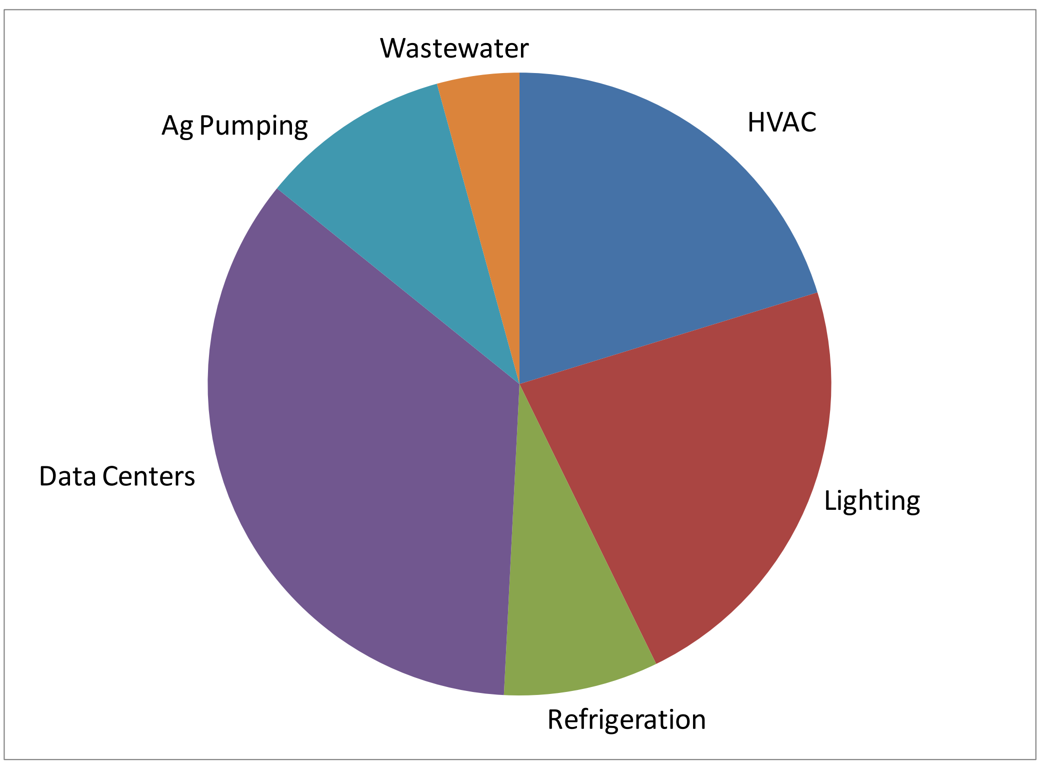


Figure 4-2a. Shed Estimates for the Highest Hour of the Year (2 p.m. September 23rd) - Increased Controllability

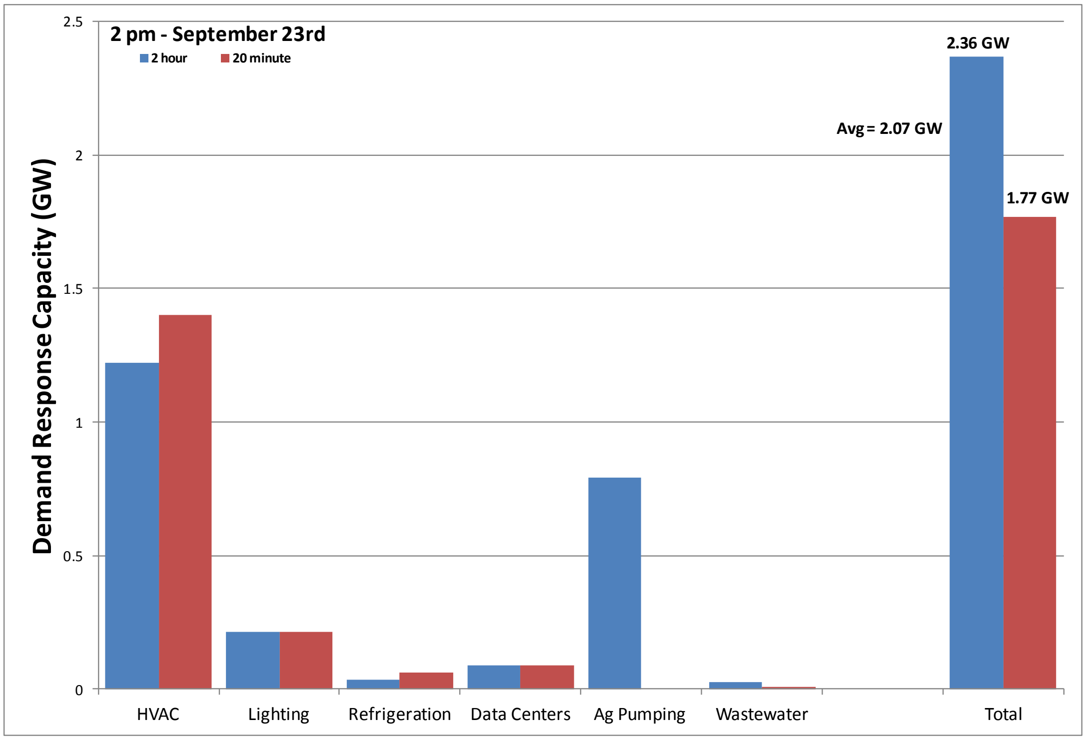


Figure 4-2b. Shed Estimates for the Highest Hour of the Year (2 p.m. September 23rd) (2.07 GW) – Average of 20 minute and 2 hour shed values – Increased Controllability

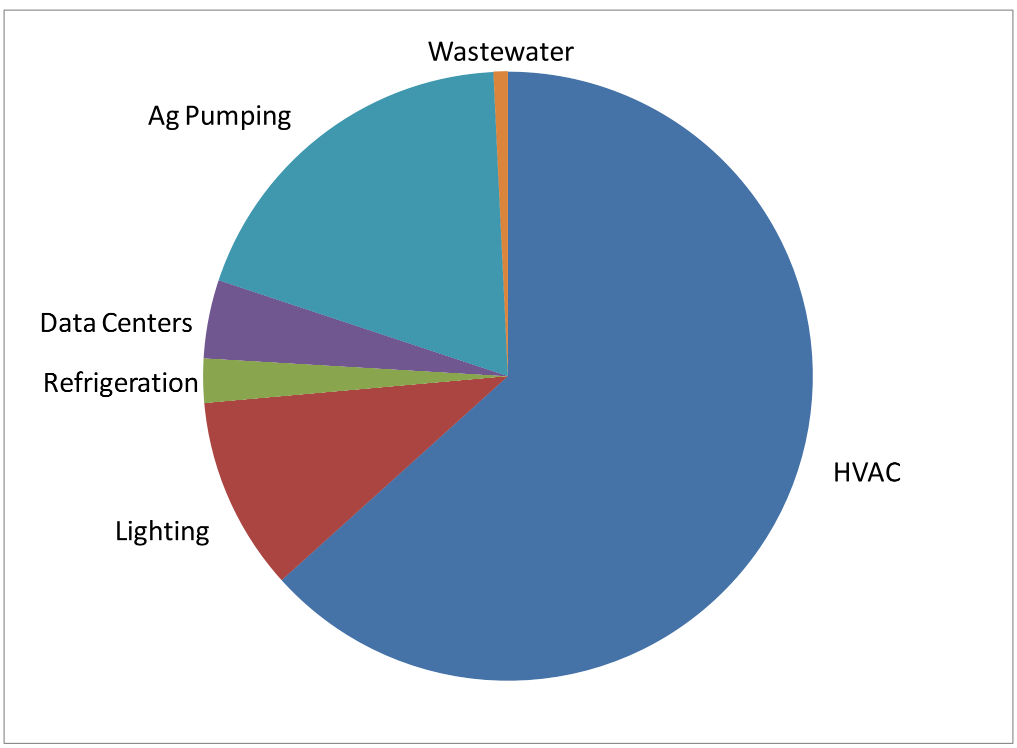


Figure 4-2c. Shed Estimates for the Lowest Hour of the Year (3 a.m. November 28th) - increased controllability

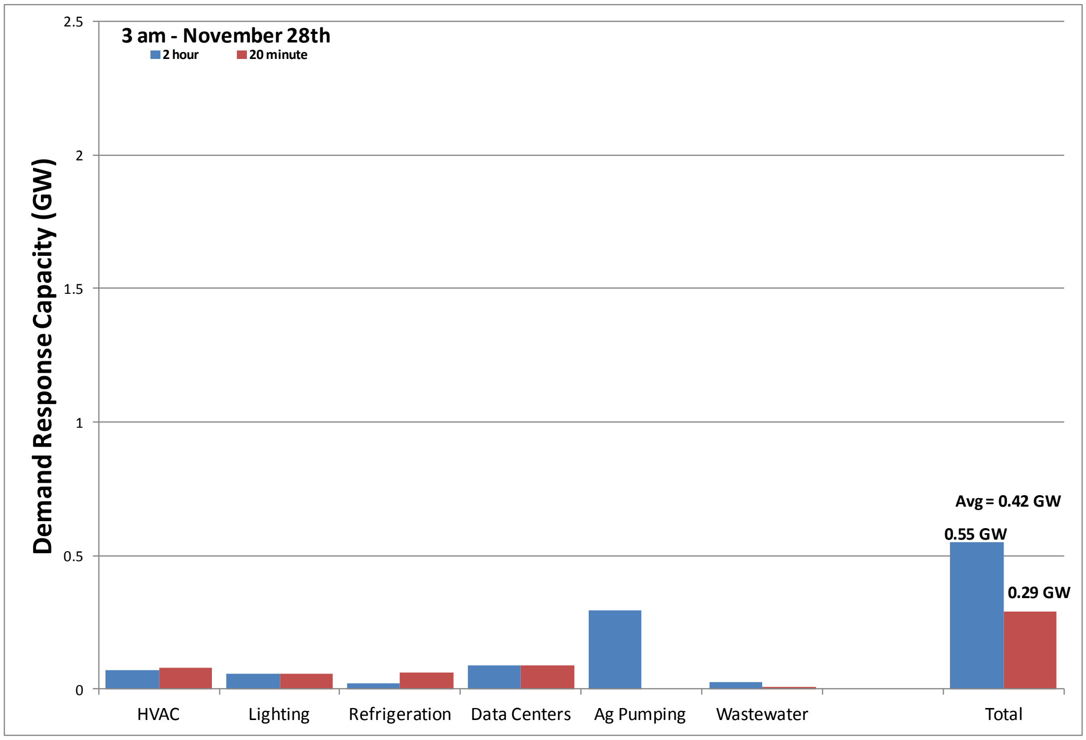
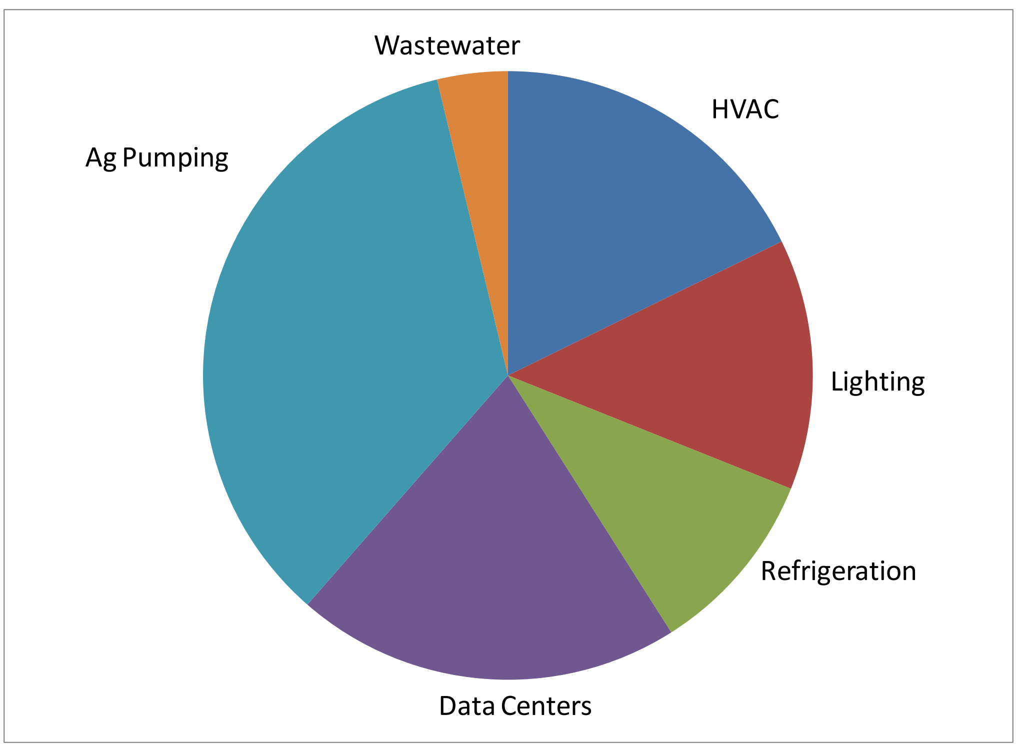


Figure 4-2d. Shed Estimates for the Lowest Hour of the Year (3 a.m. November 28th) (0.42 GW) – Average of 20 minute and 2 hour shed values – Increased Controllability



Intra-Day Variations

Besides the annual variation in DR capability, intra-day variations are also investigated. Figures 4-3a and 4-3b show the estimated resource capacity in each hour of a typical winter weekday. The blue bars in Figure 4-3a indicate the availability of resources for a twenty-minute shed, while the red bars are for a two-hour shed. More capacity is typically available for shorter period sheds in commercial buildings, while some loads (e.g., deep water agricultural pumps) are not suitable for sheds as short as 20 minutes due to design or operational constraints. In both figures, the graph on the left represents current controllability, while the graph on the right reflects increased controllability. Figures 4-4a and 4-4b provide the results for the typical summer day. For most end-uses, including commercial buildings, it is assumed that controllability could double in the future to provide more AutoDR. For some sectors, such as agricultural pumping, a larger percentage increase (from 10% to 80%) is used because the incremental cost to provide wireless controllability functions to distributed agricultural pumping systems is reasonable and within reach and the percentage of agricultural pump facilities going through straightforward and quickly implemented wireless controls retrofits is increasing quickly. If investments in this sector are similar to those that could double controllability in commercial buildings; controllability could increase eight-fold for agricultural pumping.

Figure 4-3a. Hourly Shed Estimates for a Typical Winter Weekday – Current and Increased Controllability

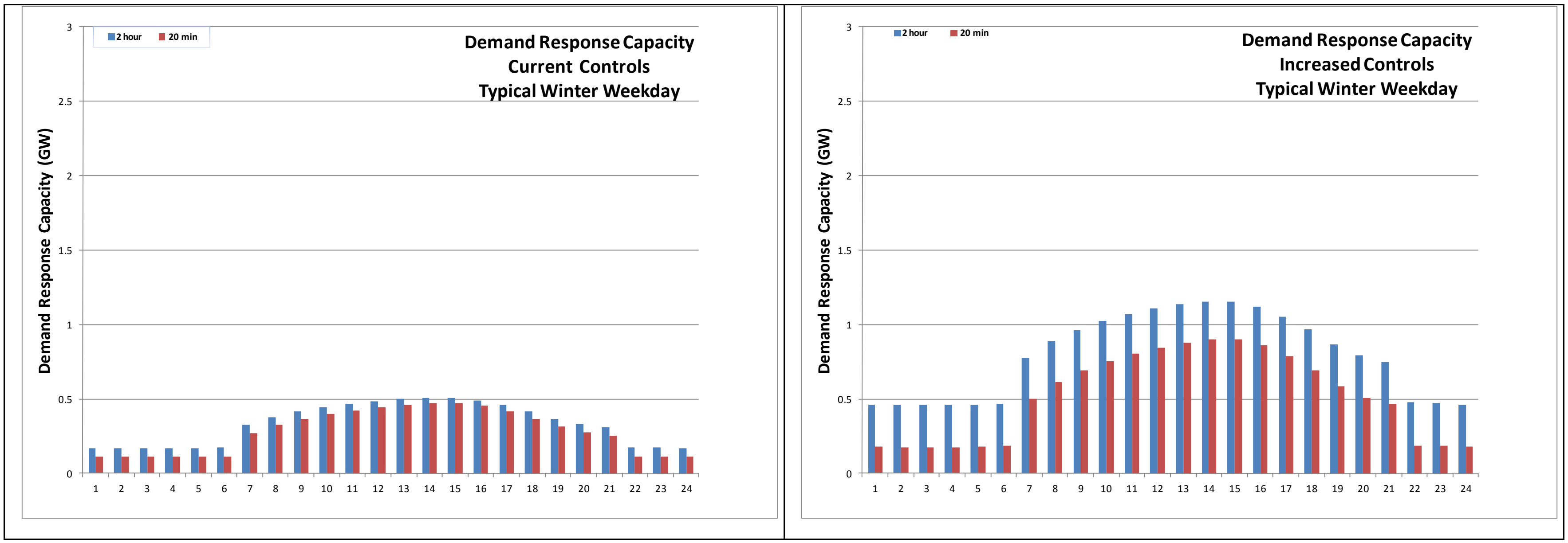


Figure 4-3b: Shed Estimates – Average of 2 hours and 20 minute sheds – Winter – Current and Increased Controllability

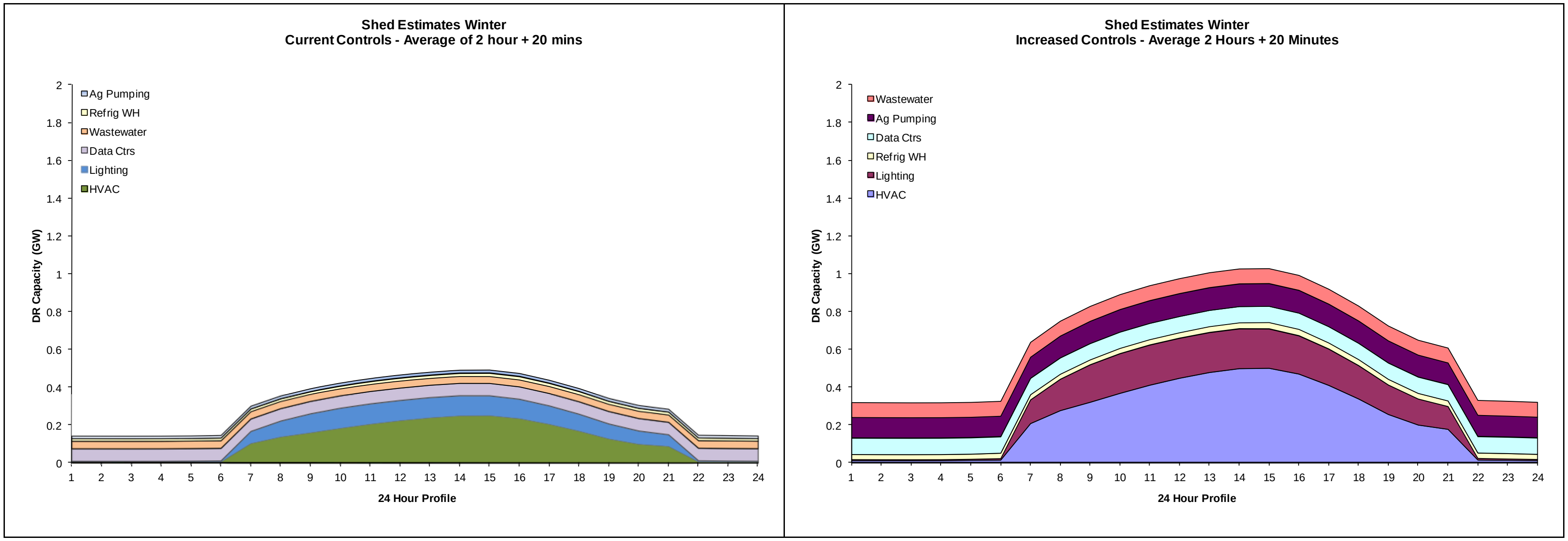
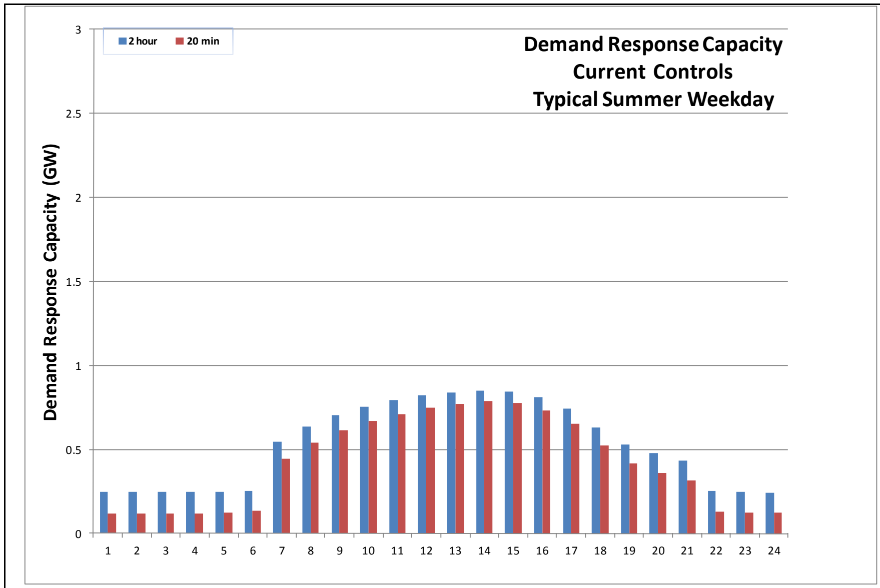


Figure 4-4a Hourly Shed Estimates for a Typical Summer Weekday – Current and Increased Controllability



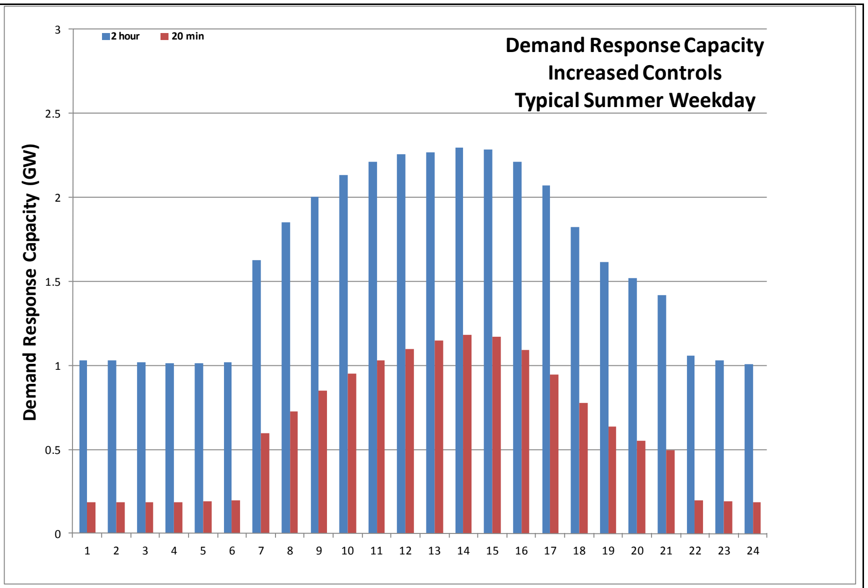
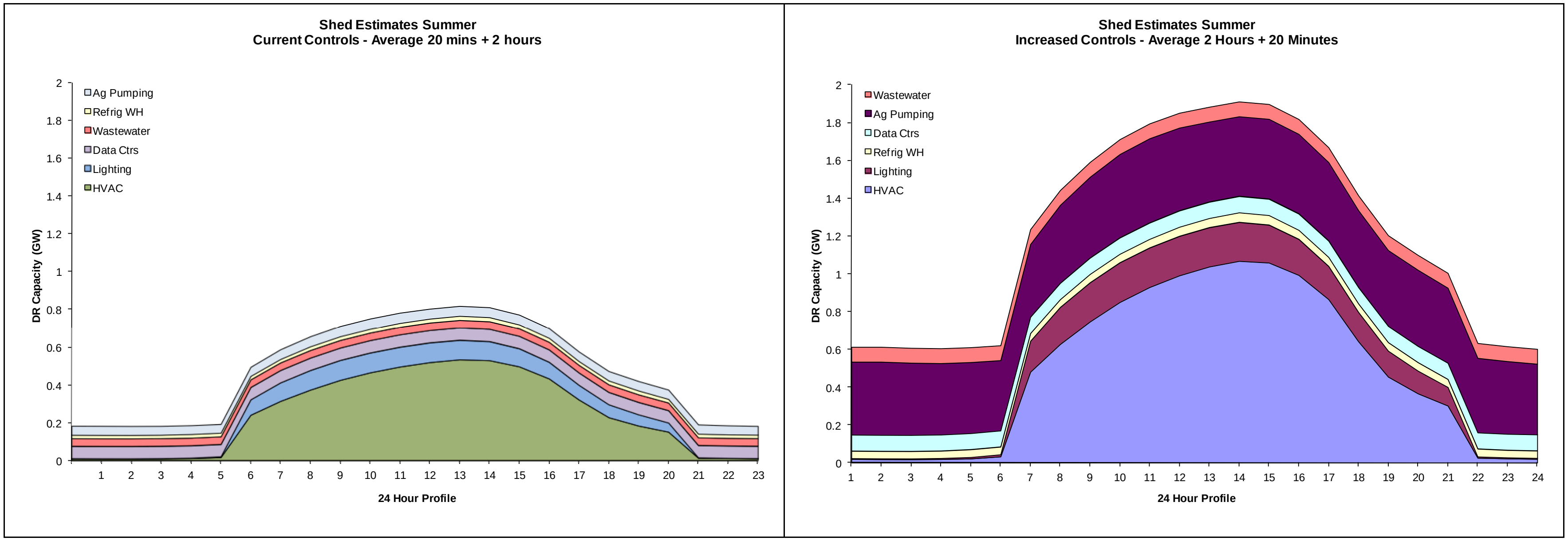


Figure 4-4b: Shed Estimates – Average of 2 hours and 20 minute sheds – Summer – Current and Increased Controllability



For grid reliability, it is useful to have an estimate as to what the annual hour-by-hour shed capabilities for ancillary services could be. This study calculates hour-by-hour shed capabilities for typical days in each of the four seasons but does not attempt to calculate the shed capabilities for each hour of the year. The following figures provide an overview of an entire year of calculated average shed capabilities. In these figures the 20 minute and 2 hour products are averaged and the four season's typical days are interpolated using a straight-line interpolation (See Figure 4-5 for current controllability case, Figure 4-6 for increased controllability case). While this approximation shows smooth increases and decreases in shed capabilities, it is anticipated that there could be significant variation from day to day and hour to hour over a typical year.

Figure 4-5. Estimated Demand Sheds based on typical seasonal averages (with current controls).

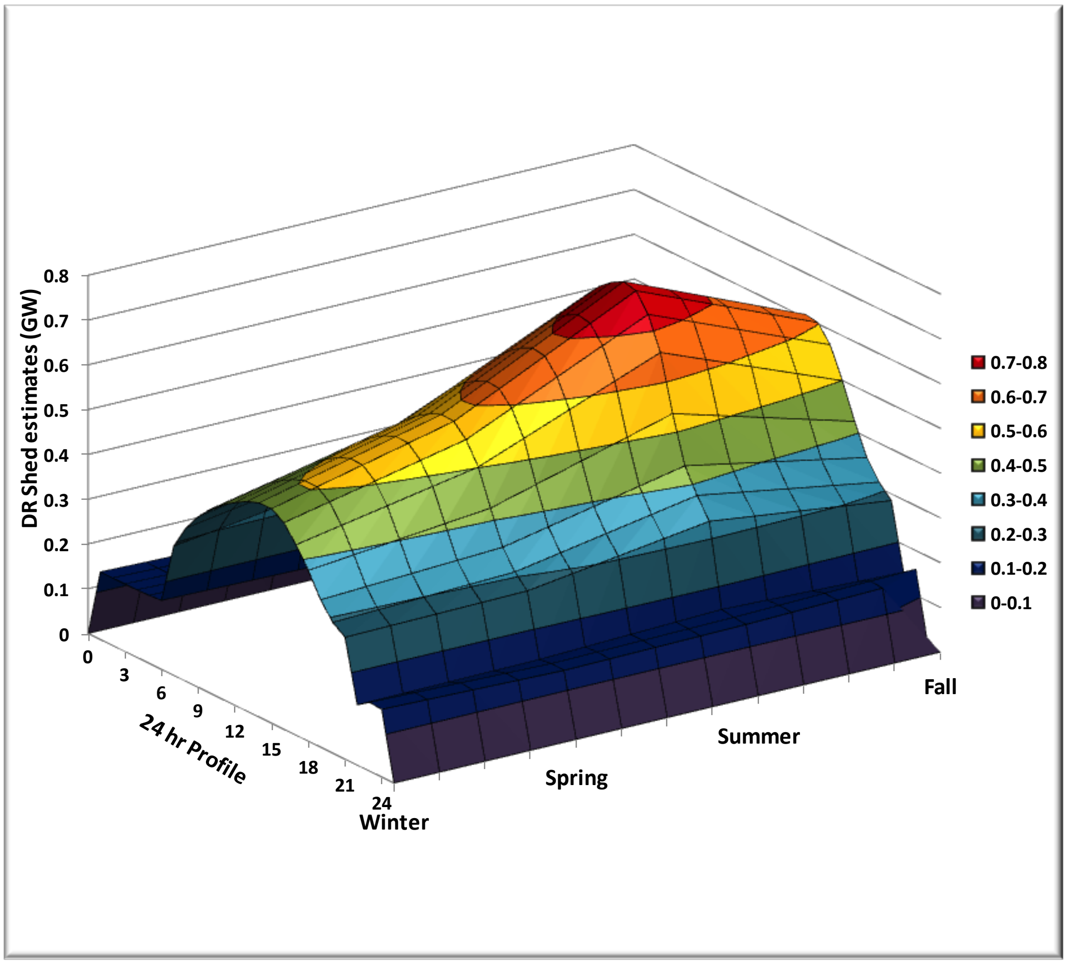
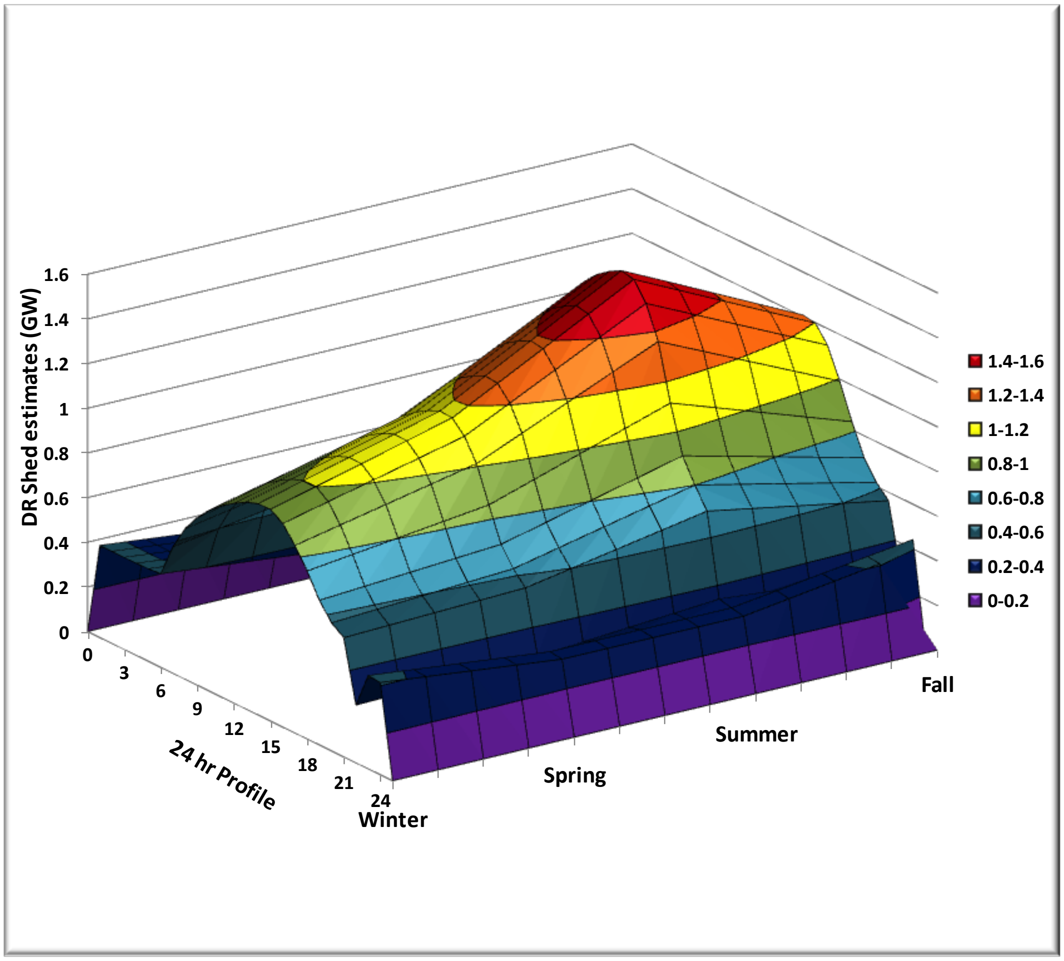


Figure 4-6. Estimated Demand Sheds based on typical seasonal averages (with increased controls).



CHAPTER 5: Conclusions

Traditionally most DR and AutoDR utility deployments have focused on the use of demand response as a resource for hourly energy in the day-ahead market or for emergencies. Ancillary services such as regulation and energy for balancing and ramping services from fast resources are required to meet the scenario of 33 percent renewables penetration. (Masiello et al., 2010). To date, only pilot scale field tests have been conducted using AutoDR for non-spinning reserves and regulation. While the results from these pilots are promising, further research is required to determine the degree to which AutoDR is useful in integrating higher penetrations renewable generation onto the electric grid.

This study estimates total statewide AutoDR capacities under during various seasons and times of day. AutoDR estimates are also characterized in terms of shed durations and ramp times similar to the requirements for some existing ancillary services programs, such as non-spinning reserves. The study does not attempt to breakdown the percentage of AutoDR capacities that may be technically suitable for other types of ancillary services.

The capacity available from AutoDR varies by time of year, time of day and length of the desired shed. DR resources are particularly prone to such variation, but to date there has been little research regarding DR capacities in off-peak or shoulder periods. By using the methodologies described in Chapter 3, preliminary estimates of the amount of shed potentially available via AutoDR have been developed and are presented here.

This analysis combines stock analysis, field observations and field research studies with input from subject area experts to determine a first estimate of the statewide AutoDR capability for use as a fast acting grid resource. Current hourly statewide end-use load data (HVAC, lighting and agricultural pumping) are combined with estimates for hourly load profiles for data centers, refrigerated warehouses and wastewater treatment facilities based on engineering assumptions, reported energy characteristics and related field studies to come up with hourly statewide load distributions. Demand response estimates for 20 minute and two hour sheds for these end-uses are developed based on published field studies and research reports as well as engineering estimates based on field experience. Current controllability, the percentage of a given end use load currently able to be controlled via automated demand response (AutoDR), is determined based on published stock analyses, field observations and discussions with subject area experts. Projections are made as to what a reasonable increased controllability percentage could be by end use, taking into account projected expansion of control penetration by end use. These data are combined to come up with a high level estimate of statewide AutoDR capacity throughout the year. With current controllability, this study estimates 0.90 GW of grid resource AutoDR potential on a hot summer day and 0.18 GW on a cold winter night. With the increased use of automated control systems in commercial and industrial facilities the estimated shed potential could approximately double to between 2.07 GW and 0.421 GW, respectively (see Table 5-1). While all of the end-uses considered contribute to the overall shed potential, HVAC and lighting predominate on hot summer days, while agricultural pumping dominates on cold winter nights.

Table 5-1. Summary of results of estimates of electric load sheds during the minimum and maximum usage hours of the year.

	Shed during Minimum hour of the year*			Shed during Maximum hour of the year*		
	2 hr. event (GW)	20 min. event (GW)	Average (20 min. & 2 hr) (GW)	2 hr. event (GW)	20 min. event (GW)	Average (20 min. & 2 hr) (GW)
Current Controllability	0.19	0.18	0.18	0.90	0.90	0.90
Increased Controllability	0.55	0.29	0.42	2.37	1.77	2.07

* Base year 2007 used for analysis. Minimum and maximum hours identified are based on CEUS statewide minimum and maximum hourly demand.

Based on this and other studies referenced throughout this study, AutoDR could provide some grid balancing capabilities similar to those provided by some ancillary services currently available in CAISO markets, such as non-spinning reserves and regulation. As such, AutoDR could serve as a useful tool in addressing the system operations challenges associated with increasing penetration of variable and intermittent resources.

In the future, AutoDR can serve as a useful tool in addressing grid operational challenges associated with increasing penetration of variable and intermittent generation resources. Though AutoDR may not be suitable for all forms of ancillary services, the lower installed cost of AutoDR indicates that it should be considered for use in the time domains and capacities for which it is applicable. By combining AutoDR with traditional gas fired thermal generation and battery storage technologies, an optimal mix of generation DR and storage should be considered.

Future Directions

Future efforts related to this research will focus on fine-tuning the assumptions behind this analysis and evaluating the economics and financial incentives. Additional research should be conducted to determine the percentage of AutoDR capacities that are technically suitable for specific types of ancillary services such as regulation, energy for balancing and ramping services and load following services. In addition, a quantitative economic analysis of the scale up of AutoDR as a grid resource integrated with renewable and energy storage should be planned for future research.

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Glossary

Ancillary Services	Services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system. Types of Ancillary services include scheduling and dispatch, reactive power and voltage control, loss compensation, load following, system protection and energy imbalance.
AutoDR	Automated Demand Response. Used generically in this study to represent both standards based and proprietary systems.
CAISO	California Independent System Operator
CEC	California Energy Commission
CEUS	Commercial End Use Survey
DR	Demand Response
EIS	Energy Information Systems
EMCS	Energy Management Control System
GHG	Greenhouse Gas
HVAC	Heating, Ventilation and Air Conditioning
Non-spin	Generating capacity available to the system operator within a short interval of time to meet demand in case a generator goes down or there is another disruption to the supply.
OpenADR	Open standards based data model used to transmit information to facilitate automated demand response
Reg-down	Regulation down (Ancillary Services)
Reg-up	Regulation up (Ancillary Services)
Spin	Extra generating capacity that is available by increasing the power output of generators that are already connected to the power system
SCADA	System Control and Data Acquisition System