ES-Select™ Documentation and User's Manual

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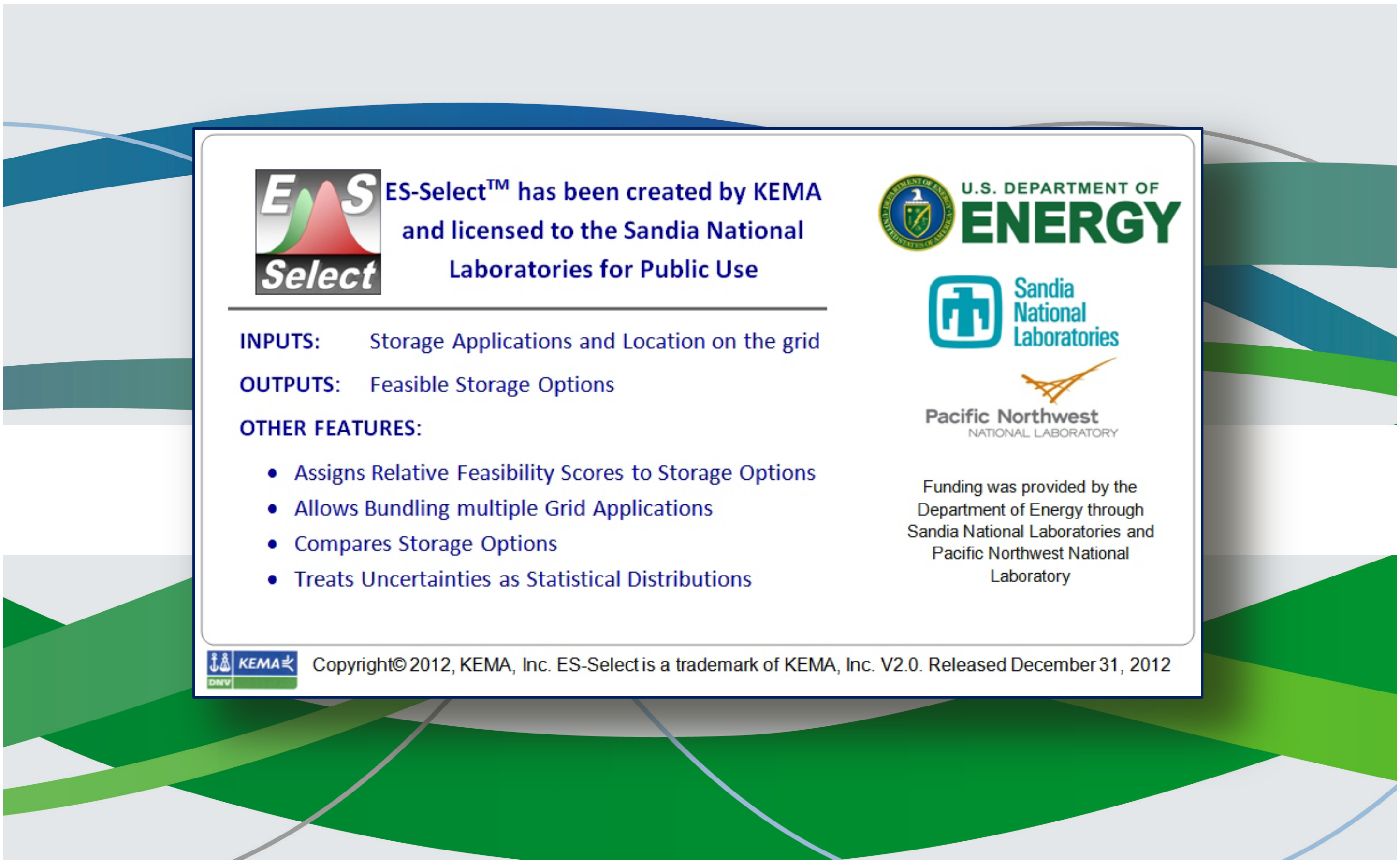

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ES-Select™ was originally developed and used by KEMA, Inc. (KEMA) for its consulting services. However, due to its high educational value, Dr. Imre Gyuk offered to purchase a license of this tool for the free and unlimited use of the public. Dr. Ross Guttromson, manager of the storage program at Sandia National Laboratories (Sandia) supported the modification of ES-Select™ for the public use and it is now available for download from the Sandia website (http://www.sandia.gov/ess/). Mr. Dhruv Bhatnagar of Sandia has been the project manager for this project.

Dr. Imre Gyuk further supported ES-Select™ by funding a study using actual data to substantiate some of the estimated parameters for bundling multiple grid applications. This effort was undertaken with the help of Dr. Michael Kintner-Meyer and his team in the Pacific Northwest National laboratory (PNNL).

The support and collaboration of Dr. Imre Gyuk, Dr. Russ Guttromson, Mr. Dhruv Bhatnagar and Dr. Michael Kintner-Meyer are acknowledged and appreciated.

Last, but not least, the tireless help of Dr. Khoi Vu who collaborated in the design and development of ES-Select™ is appreciated.

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1 Introduction

Unlike other equipment connected to electric grids, energy storage devices come in a very wide range of types (technologies) and capabilities. The fact that they can act as both a controllable load and a dynamic generator gives them the capability to offer many different grid benefits, depending on where they are located on the grid and how they are controlled. Additionally, different vendors offer the same storage technology in very different packages and functionalities. What adds to the challenge in selecting feasible energy storage solutions to serve a given need is that storage types and capabilities are highly "interdependent."

When an end user asks about a good energy storage solution or a vendor asks for the best markets for the storage technology that the company is offering, the correct but often frustrating answer is "it depends." Managers cannot make a sound decision on their storage applications, technologies or markets with a set of "it depends" statements and thus, demand a better answer, at least for the initial screening.

ES-Select™ was developed to address the above need. Consequently, instead of requiring accurate input to provide accurate answers, it is designed to work with the uncertainties of storage and applications characteristics, costs, and benefits and provides answers in some reasonable "ranges." ES-Select™ applies the Monte Carlo analysis to randomly choose hundreds of possible values within the provided ranges of input parameters, assuming a normal distribution. Consequently, the provided answers also have a range but the probability of occurrence of the answer within the provided range does not necessarily have a normal distribution.

To further educate and help decision makers on their options for energy storage or their applications and markets, ES-Select™ offers a wide variety of charts to compare the "ranges" of answers over a wide set of criteria, such as price and cost components, cycle life, size, efficiency, cash flow, payback, benefit range, and market potential.

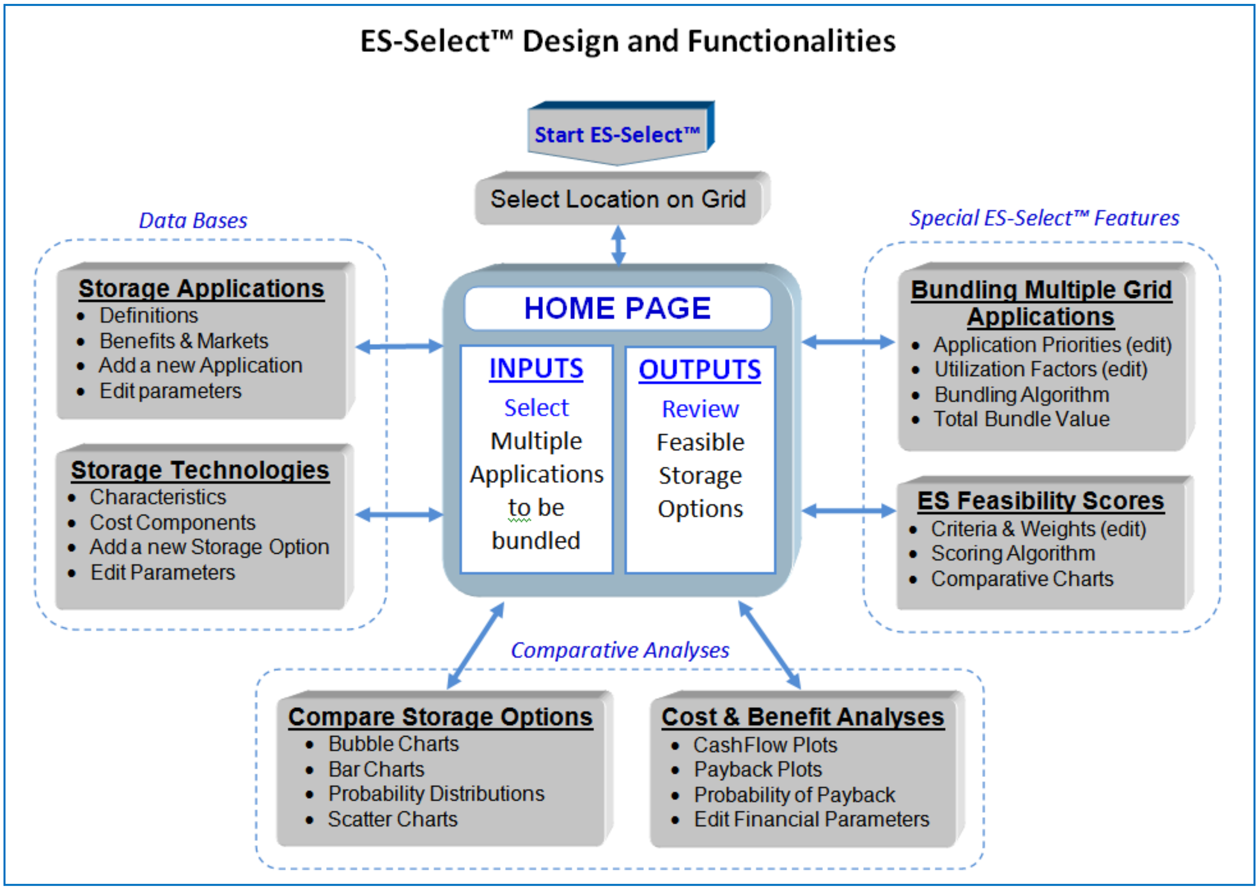
The key characteristic that needs to be kept in mind when using ES-Select™ is that in developing this educational/consulting/screening tool, "simplicity" had far more priority than "accuracy." This decision support tool is made for the initial screening purpose when most facts are still unknown to the user, but some decisions still need to be made based on what is already known.

Another design principle in ES-Select™ is not to confuse the user by asking hard to answer questions upfront, but rather assume the most likely answers and allow the user to overwrite them if s/he has different answers. In other words, every question has a default answer that is often in the form of a range that would cover most, if not all, cases. The objective behind this design principle is to make the tool useful to both a beginner who needs to be educated on "reasonable" values as well as an experienced user who knows exactly what the problem is and has all of his or her numbers ready to enter.

2 An Overview of ES-Select™ Design and Functionality

At the center of ES-Select™ user interface is the home page where a user enters one or more grid applications and receives the list of prioritized feasible energy storage options to serve those applications. Exhibit 2-1 shows a diagram of the ES-Select™ design with the home page as the central hub of all its capabilities and functionalities.

Exhibit 2-1: Overview of ES-Select™ Design and Functionalities



The only question the user will be asked before accessing the home page is the location where energy storage is (to be) connected to an electric grid. Once on the home page, the user can access the many features and capabilities of ES-Select™ :

1. Database of energy storage technologies (physical, operational, and economic parameters)
2. Database of storage applications (benefits, market potentials, and storage requirements)
3. Bundling multiple applications (priorities, operational compatibilities, business compatibilities)
4. Scoring feasibility of energy storage options (criteria and their relative weights)
5. Cost and benefit analyses (cash flow, payback range, and probability of having a payback)
6. Graphic comparison of energy storage options (economics, cycle life, efficiency, markets)

The details of each feature are explained in the following sections.

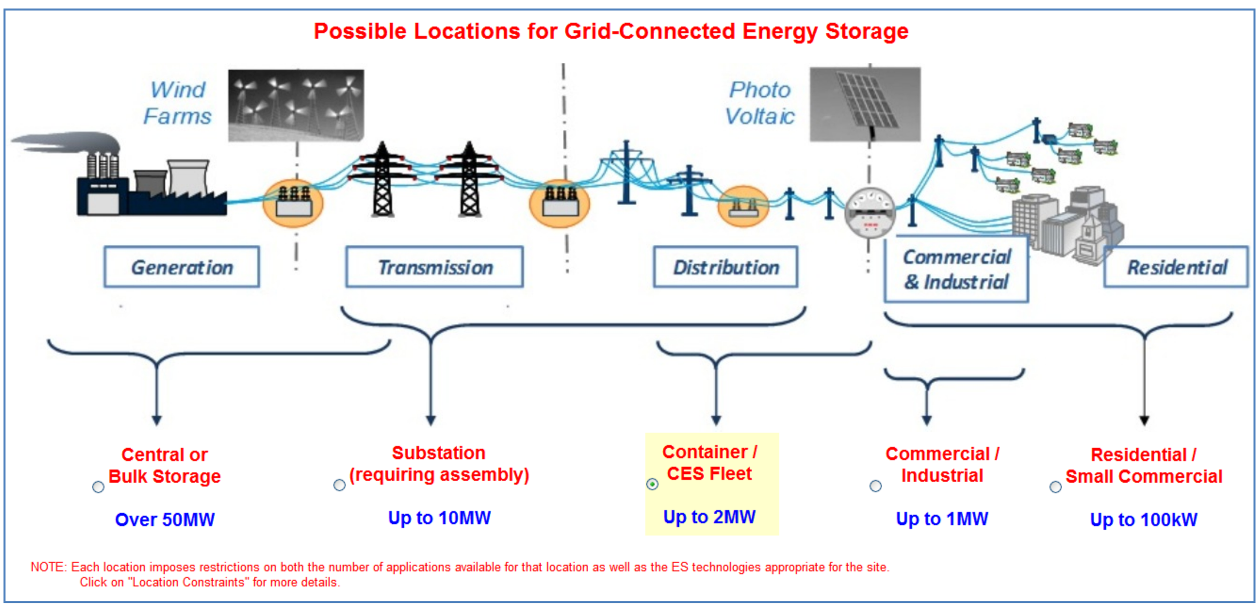
3 Selecting the Location of Energy Storage on an Electric Grid

The first question that is asked of the ES-Select™ user before starting with the home page is the “location” of the storage application on the electric grid. Knowing the asset location (or ownership) is important, because it impacts three critical factors:

- Installation cost
- Available grid applications
- Available energy storage options

One example of a limited grid application due to location is the inability to provide black start service where the storage unit is located behind the meter and controlled by commercial owners. Another example is that large pumped hydro or compressed air energy storage (CAES) systems are not feasible for residential or distribution location. Exhibit 3-1 shows the simplified sketch of an electric grid with five options for locating the storage asset. If the user still does not know the location of the storage asset, ES-Select™ assumes the option of a storage unit up to 2 MW on the distribution circuit, using shipping containers or a fleet of community energy storage (CES) units.

Exhibit 3-1: Five approximate locations for connecting energy storage to an electric grid



As indicated earlier, many default assumptions are made for providing the answers that could be satisfactory for a high level educational or screening objective. However, an experienced user needs to review the assumptions and replace the assumed default values with more accurate or factual values that may be known for his or her project.

Exhibit 3-2 shows the limitations that any of the five grid locations would put on the available grid applications for the user to work with. The check marks in the green squares identify the default application for each location on the grid. The informed user, of course, has the option to change that based on his/her specific grid and its requirements. Exhibit 3-3 shows the limitations that any of the five grid locations would put on the available energy storage technologies or types for the user to choose from.

Exhibit 3-2: Restriction on the grid applications of energy storage based on the storage location

	Grid Applications	Central or Bulk	Substation (requiring assembly)	Container / CES Fleet	Comm-ercial / Industrial	Res-idential / Small Comm-ercial
1	Energy Time Shift (Arbitrage)	✔	✔	✔	✔	✔
2	Supply Capacity	✔	✔	✔		
3	Load Following	✔	✔	✔	✔	✔
4	Area Regulation	✔	✔	✔	✔	✔
5	Fast Regulation	✔	✔	✔	✔	✔
6	Supply Spinning Reserve	✔	✔	✔		
7	Voltage Support		✔	✔		
8	Transmission Support	✔	✔	✔		
9	Transmission Congestion Relief	✔	✔	✔		
10	Dist. Upgrade Deferral (top 10%)		✔	**✔**		
11	Trans. Upgrade Deferral (top 10%)	✔	**✔**	✔		
12	Retail TOU Energy Charges				**✔**	✔
13	Retail Demand Charges				✔	✔
14	Service Reliability (Utility Backup)	✔	✔	✔		
15	Service Reliability (Customer Backup)				✔	**✔**
16	Power Quality (Utility)			✔		
17	Power Quality (Customer)				✔	✔
18	Wind Energy Time Shift (Arbitrage)	**✔**	✔	✔	✔	✔
19	Solar Energy Time Shift (Arbitrage)	✔	✔	✔	✔	✔
20	Renewable Capacity Firming	✔	✔	✔	✔	✔
21	Wind Energy Smoothing	✔	✔	✔	✔	✔
22	Solar Energy Smoothing	✔	✔	✔	✔	✔
23	Black Start	✔	✔			

"**✔**" means default application at given location

Exhibit 3-3: Restriction on energy storage options based on the storage location

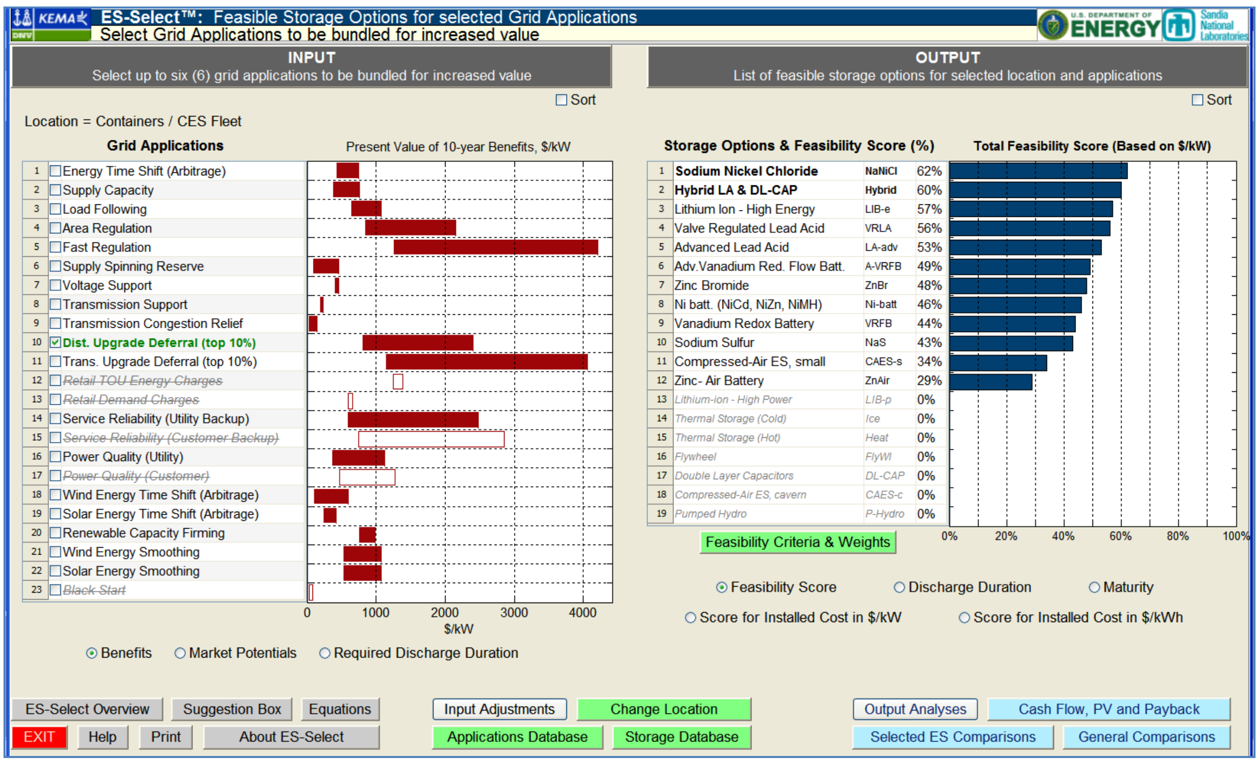
Storage Technologies	Central or Bulk	Sub-station (requiring assembly)	Container / CES Fleet	Comm-ercial / Industrial	Res-idential / Small Comm-ercial
Lithium-ion - High Power	✔	✔	✔	✔	✔
Lithium Ion - High Energy	✔	✔	✔	✔	✔
Ni batt. (NiCd, NiZn, NiMH)		✔	✔	✔	✔
Advanced Lead Acid	✔	✔	✔	✔	✔
Valve Regulated Lead Acid	✔	✔	✔	✔	✔
Vanadium Redox Battery	✔	✔	✔	✔	
Adv.Vanadium Red. Flow Batt.	✔	✔	✔	✔	
Zinc Bromide	✔	✔	✔	✔	✔
Sodium Sulfur	✔	✔	✔	✔	
Sodium Nickel Chloride	✔	✔	✔	✔	✔
Thermal Storage (Cold)		✔		✔	✔
Thermal Storage (Hot)				✔	✔
Zinc- Air Battery		✔	✔	✔	✔
Flywheel	✔	✔	✔	✔	✔
Double Layer Capacitors	✔	✔	✔	✔	
Hybrid LA & DL-CAP	✔	✔	✔	✔	✔
Compressed-Air ES, cavern	✔	✔			
Compressed-Air ES, small	✔	✔	✔	✔	
Pumped Hydro	✔				

A user can access the above two restriction tables by clicking on the “location restrictions” button at the bottom of the location page.

4 ES-Select™ Home Page

The home page is the main interface for the ES-Select™ user. As shown in Exhibit 4-1, this page is divided in two halves. The left half is INPUT, where the user enters his or her one or more desired applications. The right half is OUTPUT, where the user can see all storage options listed in the order of their feasibility to serve the desired application(s). A horizontal bar chart on each side helps the user visualize, sort, and compare different options to support a better decision.

Exhibit 4-1: ES-Select™ Home Page for reviewing storage options for selected grid applications



On the INPUT side, three radio buttons below the left display area allow the user to review the benefits, market potential, and required discharge duration for all applications before choosing one. The grayed-out applications are not available or recommended for the selected location on the grid. A checkbox on the top of the bar chart area allows the user to sort the applications based on their selected characteristic. If more than one application is used, the default priority of the application is the order in which they have been selected by the user. However, clicking on the green button below the bar chart takes the user to the bundling page, where the priority of the grid applications can be changed to increase the total bundle value. Additional information on the bundling algorithm and its implementation is also provided on this page.

On the OUTPUT side, all energy storage technologies (options) considered in ES-Select are listed. The grayed-out ones with a feasibility score of zero mean that those storage options are not available due to failing to meet one or more of the feasibility criteria. Those that at least partially meet all of the feasibility criteria are listed in decreasing order of their total feasibility score. In order to help the user have a better insight into the listed storage options, five radio buttons below the right display area let the user review total feasibility scores, cost scores (based on $/kW or $/kWh), maturity, or discharge duration. A checkbox on the top of the bar chart area allows the user to sort the storage options based on their selected characteristic (total feasibility score is always sorted). Selecting the green button under the energy storage list takes the user to the feasibility page, where more details on the feasibility scoring algorithm, criteria, and their relative weights are provided. A user may adjust the weights to obtain a scoring scheme that better matches the intended application(s).

In addition to the two green buttons that offer unique functions for bundling grid applications and scoring feasible storage options to serve them, there are two rows of buttons at the bottom of the page. The upper blue buttons are for more detailed comparisons of the storage options including cash flow and payback analyses and the lower gray buttons provide more information about ES-Select™ and its operations. Following is a list of these two rows of buttons on the home page:

Blue buttons for further analyses:

1. Change Location
2. Applications and Markets (includes comparison charts and applications database)
3. Storage database
4. Selected Energy Storage Comparisons (for pre-defined pairs of parameters)
5. General Energy Storage Comparison (plotting any parameter vs. any other parameter)
6. Costs / Benefits (cash flow and payback charts)

Gray buttons for more general information:

1. Exit
2. Help Page - additional information on the page contents (most pages have a help button)
3. Print - ability to copy and paste the whole page in a document or send it to a printer
4. About ES-Select™ (displays version number and its copyright information)
5. ES-Select™ overview
6. Suggestion Box (send your comments to the ES-Select™ development team)
7. Equations - a list of equations used in ES-Select™

5 Database for Energy Storage Options

This database is accessible by selecting the Storage Database button at the bottom of the home page. The ES-Select™ version 2.0 energy storage database includes detailed information for 19 different energy storage technology classes or types. This data has been obtained from several surveys of the vendors for MW-scale applications and adjusted based on the actual quotations observed in different project proposals. It should be noted that ES-Select uses a range for most parameters that vary between a low (LO) and high (HI) value assumed to represent the 5% and 95% points on a normal distribution. Each energy storage technology type, such as lithium ion, is described by 47 different pieces of information and ranges of numbers that are expected to cover the majority of the variations within a technology class and manufacturing differences. For convenience, a user may look at all of the 47 columns of data collectively or in four different pages that are accessible from the dropdown box in the top left corner of the page. Exhibit 5-1 through Exhibit 5-4 list the energy storage database in four different groups.

The data items in the characteristics group (Exhibit 5-1) are:

- Identification of the storage type (name and abbreviation)
- Discharge at rated power (low and high values)
- Energy density and specific energy (low and high values for each)
- Round trip AC energy efficiency (low and high values)
- Response time from standby to full charge to discharge
- AC storage equipment footprint for MW scale applications (low and high values)

Exhibit 5-1: Data on Energy Storage Characteristics

Characteristics

	Storage Technology	Abbreviations	Discharge Duration (hours) LO	Discharge Duration (hours) HI	Specific Energy (kWh/ton-metric) LO	Specific Energy (kWh/ton-metric) HI	Energy Density (kWh/m³) LO	Energy Density (kWh/m³) HI	Round Trip AC Energy Efficiency at Rated Power and 80% DoD LO	Round Trip AC Energy Efficiency at Rated Power and 80% DoD HI	Response time to full power	Footprint (m²/MWh) LO	Footprint (m²/MWh) HI
1	Lithium-ion - High Power	LIB-p	0.2500	1	60	90	60	90	0.8400	0.9100	ms	40	60
2	Lithium Ion - High Energy	LIB-e	1	4	80	120	90	130	0.8500	0.9200	ms	18	26
3	Ni batt. (NiCd, NiZn, NiMH)	Ni-batt	0.3000	3	50	90	40	210	0.7000	0.8000	ms	26	93
4	Advanced Lead Acid	LA-adv	2	5	18	30	30	70	0.8000	0.9000	ms	33	45
5	Valve Regulated Lead Acid	VRLA	2	4	18	25	30	60	0.6800	0.7800	ms	25	35
6	Vanadium Redox Battery	VRFB	3	5	8	11	15	21	0.5800	0.6800	ms	37	55
7	Adv.Vanadium Red. Flow Batt.	A-VRFB	3	6	17	21	25	30	0.6500	0.7000	ms	17	33
8	Zinc Bromide	ZnBr	2	4	30	50	30	45	0.6200	0.7000	ms	9	19
9	Sodium Sulfur	NaS	6	7	80	140	100	170	0.7300	0.8000	ms	4	5
10	Sodium Nickel Chloride	NaNiCl	2	4	100	150	170	190	0.8200	0.8700	ms	8	11
11	Thermal Storage (Cold)	Ice	4	7	10	20	10	20	0.9000	1	sec	108	135
12	Thermal Storage (Hot)	Heat	4	9	150	160	110	130	0.9100	0.9800	sec	11	13
13	Zinc- Air Battery	ZnAir	5	6	130	170	300	500	0.6500	0.7700	ms	5	6
14	Flywheel	FlyWl	0.0300	1	5	12	5	15	0.8400	0.8600	ms	530	670
15	Double Layer Capacitors	DL-CAP	0.0800	1.2000	2.3000	16	2.1000	15	0.9200	0.9700	ms	100	400
16	Hybrid LA & DL-CAP	Hybrid	0.5000	5	16	28	32	65	0.8200	0.8700	ms	65	150
17	Compressed-Air ES, cavern	CAES-c	8	10	NaN	NaN	NaN	NaN	0.6000	0.7000	min	NaN	NaN
18	Compressed-Air ES, small	CAES-s	3	5	NaN	NaN	NaN	NaN	0.6000	0.7000	sec	NaN	NaN
19	Pumped Hydro	P-Hydro	8	10	NaN	NaN	NaN	NaN	0.7000	0.8000	min	NaN	NaN

The “NaN” code in the data table means that “no applicable number” is available.

The data items in the Cycles and Costs group (Exhibit 5-2), are:

- Identification of the storage type (name and abbreviation)
- Cycle life at 80% and 10% depth of discharge (low and high values)
- Estimated annual operational losses for the intended applications (low and high values)
- Estimated annual maintenance cost (low and high values)
- AC storage equipment cost, including power electronics, if applicable (low and high values)

Exhibit 5-2: Data on Energy Storage Cycle Life and Cost Components (excluding installation cost)

Cycles & Costs

	Storage Technology	Abbreviations	Cycle Life at 80% DoD (1,000 cycles) LO ALL CELLS EDITABLE min=0.5 MAX=500	Cycle Life at 80% DoD (1,000 cycles) HI ALL CELLS EDITABLE min=0.5 MAX=500	Cycle Life at 10% DoD (1,000 cycles) LO ALL CELLS EDITABLE min=0.5 MAX=500	Cycle Life at 10% DoD (1,000 cycles) HI ALL CELLS EDITABLE min=0.5 MAX=500	Annual Operational Losses over Equipment Rating (kWh/yr/kW) LO ALL CELLS EDITABLE min=0 MAX=5000	Annual Operational Losses over Equipment Rating (kWh/yr/kW) HI ALL CELLS EDITABLE min=0 MAX=5000	Annual maintenance or Warranty cost per kW rating (often 0.5% - 1.5% of cost) ($/yr/kW) LO ALL CELLS EDITABLE min=0.5 MAX=200	Annual maintenance or Warranty cost per kW rating (often 0.5% - 1.5% of cost) ($/yr/kW) HI ALL CELLS EDITABLE min=0.5 MAX=200	AC Storage Unit Price at Factory (Equipment Cost) ($/kW) LO ALL CELLS EDITABLE min=200 MAX=5000	AC Storage Unit Price at Factory (Equipment Cost) ($/kW) HI ALL CELLS EDITABLE min=200 MAX=5000
1	Lithium-ion - High Power	LIB-p	5	7	60	110	110	250	8	35	800	1200
2	Lithium Ion - High Energy	LIB-e	3.5000	6	50	100	120	250	7	25	2500	3500
3	Ni batt. (NiCd, NiZn, NiMH)	Ni-batt	1	3	1	3	150	500	2.2500	40.5000	1100	1900
4	Advanced Lead Acid	LA-adv	1.2000	2.4000	20	30	250	900	10	30	2200	3900
5	Valve Regulated Lead Acid	VRLA	0.6000	1	2	4	300	900	10	40	1600	2500
6	Vanadium Redox Battery	VRFB	6	8	160	200	300	875	9	15	2200	3100
7	Adv.Vanadium Red. Flow Batt.	A-VRFB	6	8	160	200	100	300	10	14	2000	2500
8	Zinc Bromide	ZnBr	1.5000	2.5000	15	25	570	670	10	30	1200	3000
9	Sodium Sulfur	NaS	5	6	40	50	200	625	15	60	2600	3100
10	Sodium Nickel Chloride	NaNiCl	3	5	50	100	85	145	10	22	2000	3000
11	Thermal Storage (Cold)	Ice	5.5000	11	5.5000	11	0	15	3	15	500	1300
12	Thermal Storage (Hot)	Heat	3.6000	3.8000	7.2000	7.5000	30	90	2	12	110	300
13	Zinc- Air Battery	ZnAir	5	10	10	20	540	750	15	40	1200	1400
14	Flywheel	FlyWl	100	200	170	200	750	850	35	50	1200	1600
15	Double Layer Capacitors	DL-CAP	100	200	100	200	80	250	8	10	600	1000
16	Hybrid LA & DL-CAP	Hybrid	5	17.5000	20	70	100	700	5	15	1000	1200
17	Compressed-Air ES, cavern	CAES-c	6	12	6	12	300	1000	3	12	700	1300
18	Compressed-Air ES, small	CAES-s	10	20	100	200	300	1000	1	4	1800	2100
19	Pumped Hydro	P-Hydro	10	12	10	12	200	750	10	60	1800	2200

The data items in the Installation Costs group (Exhibit 5-3), are:

- Identification of the storage type (name and abbreviation)
- Estimated installation cost at five different grid locations (low and high values for each location)
- Calendar life for full or partial replacement
- Estimated cost of replacement/refurbishment as a percentage of the initial cost

In addition to the estimated time to replacement that is specified for each storage technology, there are three other factors that impact the full or partial replacement cost:

- Percentage of the full "installed storage system" cost that needs to be replaced since some components such as building, racks, enclosures, etc. may not need to be replaced
- Inflation rate
- Expected price/cost reduction over the years necessary to remain competitive in the market

Since most storage technologies are relatively new, the above information is not known accurately. Therefore, the current version of ES-Select™ assumes that inflation rate and price reduction are going to be comparable and uses estimates for the percentage of an installed cost that needs to be replaced after the calendar life. Since users may have a more accurate estimate of this cost for a specific technology or project, this number is editable.

Exhibit 5-3: Data on Energy Storage Installation Cost at different Grid Locations

Installation Cost

	Storage Technology	Abbreviations	Installation Cost at Residential / Small Commercial up to 100 kW ($/kW) LO ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Residential / Small Commercial up to 100 kW ($/kW) HI ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Commercial / Industrial up to 1 MW ($/kW) LO ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Commercial / Industrial up to 1 MW ($/kW) HI ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Containers / CES Fleet up to 2 MW ($/kW) LO ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Containers / CES Fleet up to 2 MW ($/kW) HI ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Substation (requiring installation) up to 10 MW ($/kW) LO ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Substation (requiring installation) up to 10 MW ($/kW) HI ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Central / Bulk Over 50 MW ($/kW) LO ALL CELLS EDITABLE min=1 MAX=2000	Installation Cost at Central / Bulk Over 50 MW ($/kW) HI ALL CELLS EDITABLE min=1 MAX=2000	Replacement time in Years ALL CELLS EDITABLE min=1 MAX=30	Replacement cost as % of Cap Cost ALL CELLS EDITABLE min=1 MAX=200
1	Lithium-ion - High Power	LIB-p	300	450	300	500	250	600	400	800	250	600	8	50
2	Lithium Ion - High Energy	LIB-e	400	600	500	650	300	600	500	900	250	600	8	30
3	Ni batt. (NiCd, NiZn, NiMH)	Ni-batt	300	450	300	700	300	700	500	900	NaN	NaN	8	30
4	Advanced Lead Acid	LA-adv	500	700	400	700	600	1200	600	1100	300	700	8	50
5	Valve Regulated Lead Acid	VRLA	450	650	400	650	550	1100	550	1000	300	650	6	35
6	Vanadium Redox Battery	VRFB	NaN	NaN	600	1200	600	800	600	1000	NaN	NaN	10	20
7	Adv.Vanadium Red. Flow Batt.	A-VRFB	NaN	NaN	100	200	90	140	100	150	NaN	NaN	10	20
8	Zinc Bromide	ZnBr	800	1000	300	900	500	600	400	700	NaN	NaN	8	20
9	Sodium Sulfur	NaS	NaN	NaN	600	800	1000	1100	800	1000	700	800	16	30
10	Sodium Nickel Chloride	NaNiCl	300	400	400	600	300	500	300	500	300	500	10	30
11	Thermal Storage (Cold)	Ice	NaN	NaN	500	1500	NaN	NaN	500	1200	NaN	NaN	10	30
12	Thermal Storage (Hot)	Heat	100	200	100	150	NaN	NaN	NaN	NaN	NaN	NaN	12	50
13	Zinc- Air Battery	ZnAir	300	700	500	1000	300	700	NaN	NaN	NaN	NaN	6	50
14	Flywheel	FlyWl	300	600	400	800	400	800	500	800	400	800	10	20
15	Double Layer Capacitors	DL-CAP	100	250	400	700	300	450	300	600	200	400	8	30
16	Hybrid LA & DL-CAP	Hybrid	400	600	300	650	500	1000	500	1000	250	650	8	30
17	Compressed-Air ES, cavern	CAES-c	NaN	NaN	NaN	NaN	NaN	NaN	0	0	0	0	16	10
18	Compressed-Air ES, small	CAES-s	NaN	NaN	400	900	250	750	600	900	NaN	NaN	16	15
19	Pumped Hydro	P-Hydro	NaN	NaN	NaN	NaN	NaN	NaN	0	0	0	0	16	5

The data items in the storage Feasibility Score group (Exhibit 5-4), are all estimates between 0.0 and 1.0, where 0.0 means not feasible (such as CAES in residential location) and 1.0 means very feasible:

- Identification of the storage type (name and abbreviation)
- Estimated relative feasibility score for each of the five locations on an electric grid
- Estimated relative feasibility score for commercial readiness or maturity
- Feasibility score for meeting the application requirements (all applications are divided in four groups - see the section on Database for Grid Applications of Energy Storage for more details)
- Identification of whether the storage option has an electric output or not. This parameter can impact the feasibility if a storage option does not have an electric output while the selected application, such as backup power, would require one.

Exhibit 5-4: Data on the Feasibility of Storage Options for different Requirements

Feasibility

	Storage Technology	Abbreviations	Residential / Small Commercial up to 100 kW (0 to 1) Feas. Score for Installation cost	Commercial / Industrial up to 1 MW (0 to 1) Feas. Score for Installation cost	Containers / CES Fleet up to 2 MW (0 to 1) Feas. Score for Installation cost	Installation Cost at Substation (requiring installation) up to 10 MW (0 to 1) Feas. Score for Installation cost	Central / Bulk Over 50 MW (0 to 1) Feas. Score for Installation cost	Feasibility Score based on Maturity for Grid Applications	Feasibility Score Based on ability to meet application requirements in App Grp 01	Feasibility Score Based on ability to meet application requirements in App Grp 02	Feasibility Score Based on ability to meet application requirements in App Grp 03	Feasibility Score Based on ability to meet application requirements in App Grp 04	Output NOT in electric form 'x': NOT electric; Otherwise, use blank
1	Lithium-ion - High Power	LIB-p	0.3000	0.6000	1	0.8000	0.5000	0.7000	0	0.8000	0	0.8000	
2	Lithium Ion - High Energy	LIB-e	1	1	1	0.8000	0.3000	0.6000	0.7000	0.5000	0.6000	0.4000	
3	Ni batt. (NiCd, NiZn, NiMH)	Ni-batt	0.3000	0.3000	0.3000	0.3000	0	0.7000	0.5000	0.4000	0.5000	0.4000	
4	Advanced Lead Acid	LA-adv	0.8000	0.8000	0.5000	0.5000	0.1000	0.8000	0.6000	0.5000	0.7000	1	
5	Valve Regulated Lead Acid	VRLA	0.8000	0.8000	0.5000	0.5000	0.1000	0.8000	0.6000	0.2000	0.7000	1	
6	Vanadium Redox Battery	VRFB	0	0.5000	0.4000	0.6000	0.3000	0.5000	0.6000	0.3000	0.6000	0.2000	
7	Adv.Vanadium Red. Flow Batt.	A-VRFB	0	0.5000	0.5000	0.6000	0.3000	0.5000	0.6000	0.3000	0.6000	0.2000	
8	Zinc Bromide	ZnBr	0.2000	0.5000	0.4000	0.6000	0.1000	0.6000	0.6000	0.3000	0.6000	0.2000	
9	Sodium Sulfur	NaS	0	1	0.2000	1	0.9000	0.9000	0.9000	0.6000	0.7000	0.6000	
10	Sodium Nickel Chloride	NaNiCl	0.3000	1	1	0.8000	0.2000	0.7000	0.7000	0.6000	0.6000	0.6000	
11	Thermal Storage (Cold)	Ice	0.1000	0.9000	0	0.5000	0	0.6000	0.7000	0	0.4000	0	x
12	Thermal Storage (Hot)	Heat	1	0.7000	0	0	0	0.6000	0.7000	1	0.4000	0	x
13	Zinc- Air Battery	ZnAir	0.3000	0.3000	0.2000	0.3000	0	0.2000	0.3000	0	0.4000	0.1000	
14	Flywheel	FlyWl	0.2000	0.4000	0.2000	0.9000	0.8000	0.8000	0	1	0	0.7000	
15	Double Layer Capacitors	DL-CAP	0	0.5000	0.2000	0.3000	0.1000	0.3000	0	0.7000	0	0.6000	
16	Hybrid LA & DL-CAP	Hybrid	0.4000	0.7000	0.7000	0.6000	0.1000	0.6000	0.6000	0.6000	0.7000	0.6000	
17	Compressed-Air ES, cavern	CAES-c	0	0	0	0.3000	1	0.8000	0.8000	0.1000	0.5000	0	
18	Compressed-Air ES, small	CAES-s	0	0.5000	0.2000	0.8000	0.1000	0.3000	0.7000	0.2000	0.6000	0.2000	
19	Pumped Hydro	P-Hydro	0	0	0	0	1	1	0.9000	0.2000	0.5000	0	

Some data, such as prices and costs or cycle life that are either debatable or subject to change with time, can be edited or adjusted by ES-Select™ users.

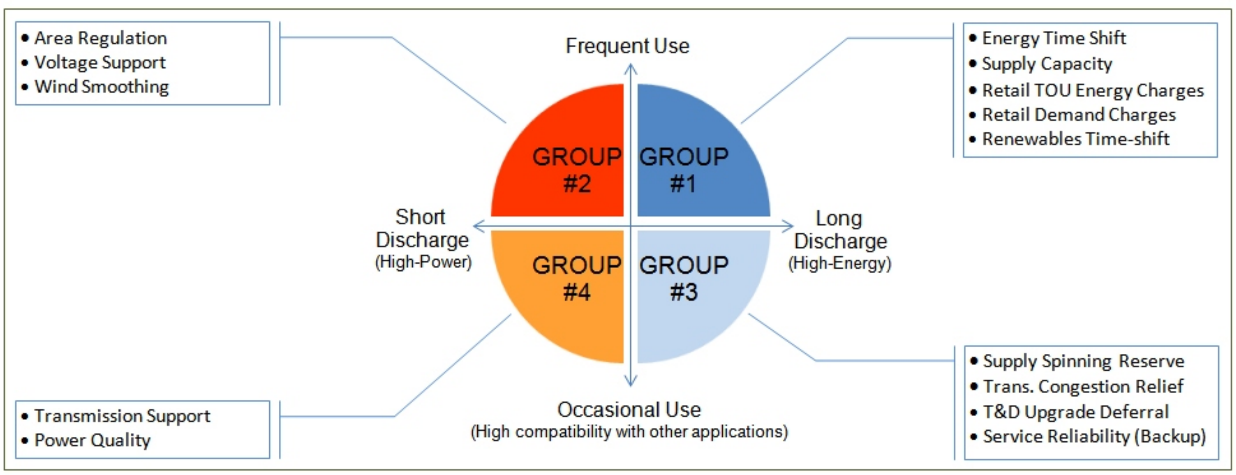
The user may also add a new storage technology to be included in the feasibility ranking, cash flow analysis, payback estimates, and other comparative studies. Selecting the Add a New Technology button at the bottom of the page adds a new line of data to the database for a new or different storage technology option. An automatic pop-up screen asks the user to copy a similar technology to save time for entering all data.

6 Database for Grid Applications of Energy Storage

This database is accessible by selecting the Applications Database button at the bottom of the Applications and Markets page (accessible from the home page). The database for grid applications released with version 2.0 of ES-Select™ includes information for 23 different applications. There is an ongoing effort by the Department of Energy (DoE), Sandia, and EPRI to reach a consensus on the naming and definitions of grid applications. By the time this version of ES-Select™ was released, there was no consensus in these definitions. Appendix A provides a definition for each of the 23 grid applications used in ES-Select™. Sandia and EPRI titles for each application are also provided for comparison.

ES-Select™ also divides all grid applications into four groups that have distinctly different requirements to be met by energy storage devices. Exhibit 6-1shows the four application groups with a few examples of applications in each group. These four groups can be defined as the four quadrants of two axes, discharge duration and frequency of use.

Exhibit 6-1: Four Groups of Grid Applications for Energy Storage



Each grid application is described by 25 different pieces of information and ranges of numbers that are expected to cover the majority of the variations in the application benefits and market size. The current version of ES-Select™ covers the benefits and markets in the US, but the database will be expanded to other major global markets in future versions of the tool. For convenience, a user may look at all of the 25 columns of data collectively or in two different pages that are accessible from the dropdown box in the top left corner of the page.

Some data, such as the benefits and market potentials that are either debatable or subject to change from one market location to another can be edited or adjusted by the ES-Select™ user. A user may also add a new grid application to be included in the application bundles and comparative studies. Exhibit 6-2 and Exhibit 6-3 show the application database in two different groups

The data items in the Benefits and Requirements group (Exhibit 6-2) are:

- Application name
- Required discharge time (low and high values)
- Estimated annual Benefits (low and high values)
- Estimated ten-year market potential (low and high values)
- Minimum required response time
- Minimum required deep (80% depth of discharge) cycles
- Minimum required shallow (10% depth of discharge) cycles
- Requirement for electric output on the storage. This parameter is used to assess the feasibility of storage options for a given application.

Exhibit 6-2: Data on Benefits and Requirements of Grid Applications

Benefits & Requirements

	Application Name	Application Group	Min. Required Discharge Duration @ rated power (hours) LO ALL CELLS EDITABLE min=0.25 MAX=12	Min. Required Discharge Duration @ rated power (hours) HI ALL CELLS EDITABLE min=0.25 MAX=12	Annual Benefit ($/kW) LO ALL CELLS EDITABLE min=1 MAX=1000	Annual Benefit ($/kW) HI ALL CELLS EDITABLE min=1 MAX=1000	Total 10-Year Market Potential (Billion USD) LO ALL CELLS EDITABLE min=1 MAX=10000	Total 10-Year Market Potential (Billion USD) HI ALL CELLS EDITABLE min=1 MAX=10000	Minimum Required response time ALL CELLS EDITABLE	Minimum Required Deep Cycles (80% dod) (cycles/year) ALL CELLS EDITABLE min=10 MAX=10000	Minimum Required Shallow Cycles (10% dod) (cycles/year) ALL CELLS EDITABLE min=10 MAX=10000	Requires Electric output? ("x" = yes) ALL CELLS EDITABLE
1	Energy Time Shift (Arbitrage)	1	3	7	57	100	8.5000	11	hrs	190		
2	Supply Capacity	1	4	6	51	101	7.6100	12.1000	hrs	100		
3	Load Following	1	2	4	86	143	22	28.2000	min		1900	
4	Area Regulation	2	0.3000	0.5000	112	287	2.7000	3.9200	sec	NaN	4000	
5	Fast Regulation	2	0.3000	0.5000	168	560	0.6800	1.9600	sec	NaN	4000	
6	Supply Spinning Reserve	3	0.3000	1	12	61	0.5200	2.1000	sec	100		
7	Voltage Support	2	0.3000	1	55	60	3	4.6800	sec			x
8	Transmission Support	4	6.0000e...	0.0014	26	29	2.4000	2.5000	sec		1000	
9	Transmission Congestion Relief	3	3	5	5	20	2.1400	4.1900	min	100		
10	Dist. Upgrade Deferral (top 10%)	3	3	6	108	320	6.1800	9.4300	min	100		
11	Trans. Upgrade Deferral (top 10%)	3	3	6	153	540	15.5000	20.3000	min	100		
12	Retail TOU Energy Charges	1	4	6	166	184	38	54	min	190		
13	Retail Demand Charges	1	5	8	79	87	10.6000	29	min	190		
14	Service Reliability (Utility Backup)	3	0.5000	2	80	330	7.3100	9.0100	sec	100		x
15	Service Reliability (Customer Backup)	3	0.5000	2	100	380	7	8.2000	sec	100		x
16	Power Quality (Utility)	4	0.0030	0.0200	50	150	4	8.3000	ms		500	x
17	Power Quality (Customer)	4	0.0030	0.0200	63	170	6	9	ms		500	x
18	Wind Energy Time Shift (Arbitrage)	1	3	6	14	80	7.8000	13.4000	hrs	190		
19	Solar Energy Time Shift (Arbitrage)	1	3	5	33	56	8.9000	13.1000	hrs	190		
20	Renewable Capacity Firming	1	2	3	101	131	24.8000	26.8000	sec	190		x
21	Wind Energy Smoothing	2	0.3000	0.5000	71	143	1.1500	2.3000	sec		20000	x
22	Solar Energy Smoothing	2	0.3000	0.5000	71	143	0.1000	0.2000	sec		20000	x
23	Black Start	3	1.5000	2	4.6000	8.9000	0.0100	0.0120	min	2		x

The data items in the Bundling and Compatibility group (Exhibit 6-3), are:

- Application name
- Application group (see Exhibit 6-1)
- Application Type (see section on "bundling multiple grid applications")
- Peak time compatibility (low and high values - see section on "bundling multiple grid applications")

- Availability for other applications (low and high values - see section on “bundling multiple grid applications”)
- Compatibility with each of the five locations on an electric grid (check mark means compatible and letter “D” means it will be recommended as a default application for that location unless user changes that)

Exhibit 6-3: Data on Bundling and Compatibility of Grid Applications

Bundling & Compatibility

	Application Name	Application Group	Application Type, or Use Pattern	Peak-Time Compatibility ("P") in % LO	Peak-Time Compatibility ("P") in % HI	Availability for other Applications ("A") in % LO	Availability for other Applications ("A") in % HI	Compatible with Residential/ Small Commercial ("x" = NO) ("D" = default)	Compatible with Commercial/ Industrial ("x" = NO) ("D" = default)	Compatible with Containers/ CES Fleet ("x" = NO) ("D" = default)	Compatible with Substation ("x" = NO) ("D" = default)	Compatible with Central or Bulk ("x" = NO) ("D" = default)
1	Energy Time Shift (Arbitrage)	1	1	95	100	75	83					
2	Supply Capacity	1	1	95	100	75	83	x	x			
3	Load Following	1	1	95	100	75	83					
4	Area Regulation	2	2	0	0	0	0					
5	Fast Regulation	2	2	0	0	0	0					
6	Supply Spinning Reserve	3	3	0	0	90	95	x	x			
7	Voltage Support	2	2	0	0	5	10	x	x			x
8	Transmission Support	4	3	0	0	90	95	x	x			
9	Transmission Congestion Relief	3	3	0	0	75	80	x	x			
10	Dist. Upgrade Deferral (top 10%)	3	1	95	100	85	98	x	x	D		x
11	Trans. Upgrade Deferral (top 10%)	3	1	95	100	85	95	x	x		D	
12	Retail TOU Energy Charges	1	1	95	100	70	72		D	x	x	x
13	Retail Demand Charges	1	1	95	100	75	83			x	x	x
14	Service Reliability (Utility Backup)	3	3	0	0	85	90	x	x			
15	Service Reliability (Customer Backup)	3	3	0	0	85	90	D		x	x	x
16	Power Quality (Utility)	4	3	0	0	90	95	x	x		x	x
17	Power Quality (Customer)	4	3	0	0	90	95			x	x	x
18	Wind Energy Time Shift (Arbitrage)	1	1	80	90	10	30					D
19	Solar Energy Time Shift (Arbitrage)	1	1	90	95	35	55					
20	Renewable Capacity Firming	1	2	0	0	50	60					
21	Wind Energy Smoothing	2	2	0	0	10	30					
22	Solar Energy Smoothing	2	2	0	0	40	70					
23	Black Start	3	3	0	0	95	99	x	x	x		

Some data, such as benefits or market potentials, which are either debatable or subject to change with time, can be edited or adjusted by the ES-Select™ user.

Selecting the Add a New Application button at the bottom of the page adds a new line of data to the database for a new application. An automatic pop-up screen asks the user to copy a similar application to save time for entering all data.

7 Bundling multiple grid applications for increased value

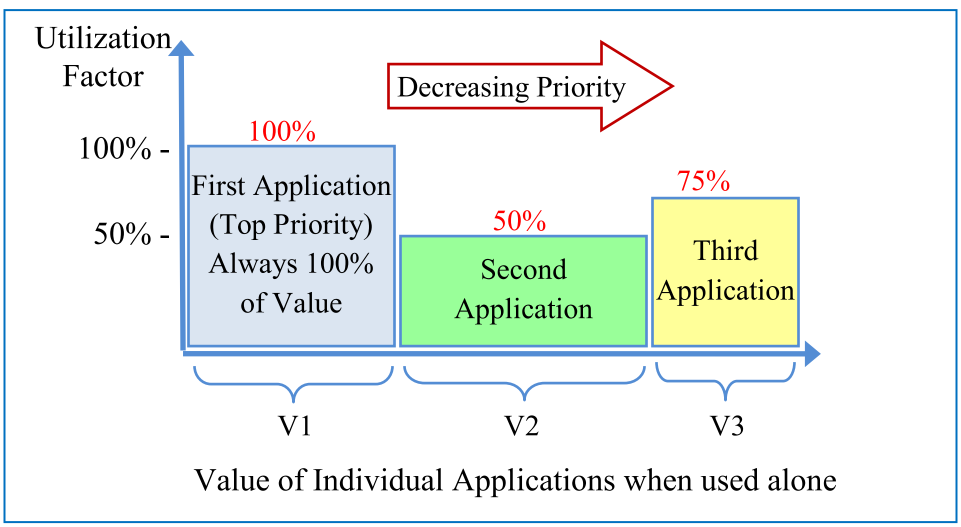
One effective way to increase the value of an energy storage asset is to use it in multiple applications such that its capacity, power, or time could be "shared" among them in a coordinated, overlapping manner. If the shared capacities are not overlapping, such as dedicating certain percentages of the capacity to different functions (for example, 20% for back up and 80% for peak shaving), the total value is not necessarily increased and almost the same result can be obtained by buying two smaller storage units. Overlapping shared capacity, power, or time, is what can help stack up different benefits, but proper controls are required to assure the priority of access.

The type and assigned priority of each application in a bundle can limit the access of the lower priority applications to the shared storage asset and, therefore, limit their contribution to the total bundle value. The total value of the bundle is the weighted sum of the individual application values where the weight or utilization factor (UF) of each application corresponds to the availability of the storage to serve that application. For example, the total bundle value for the three sample applications shown in Exhibit 7-1may be calculated as:

Total Bundle Value = 100% V1 + 50% V2 + 75% V3

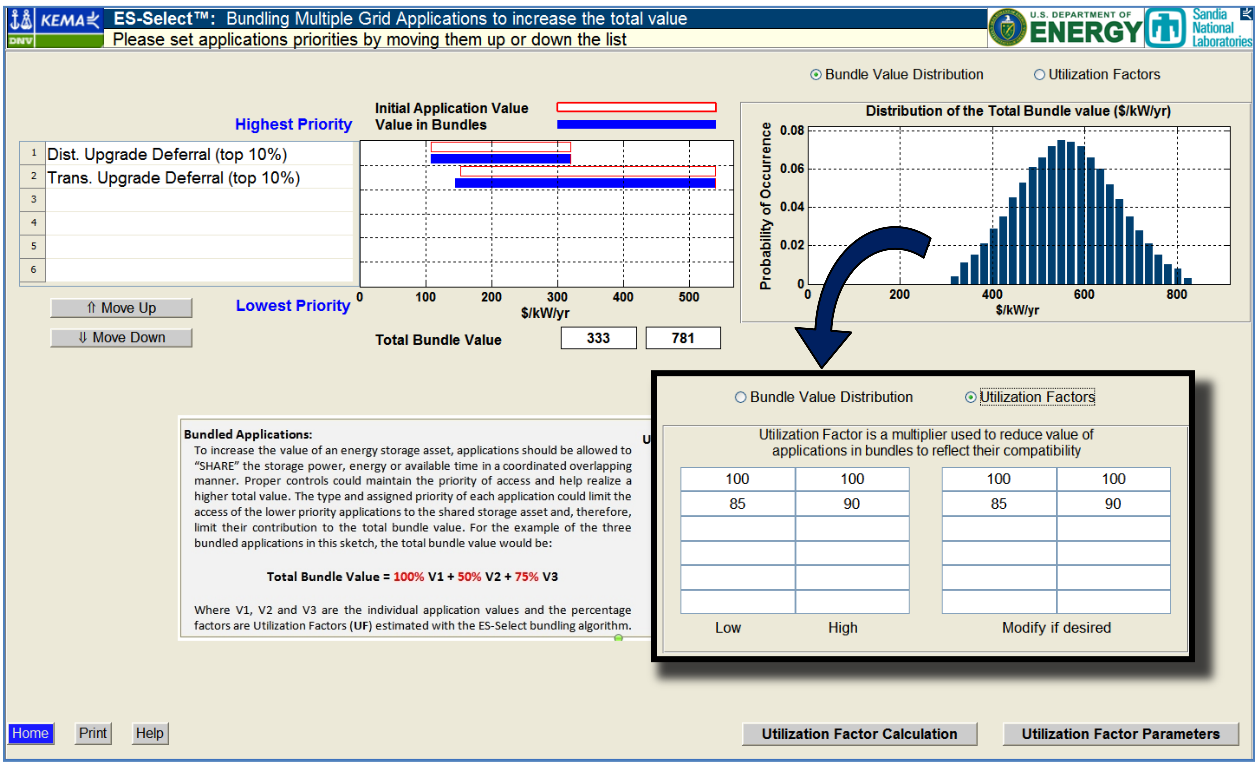
Where V1, V2 and V3 are the individual application values and the percentage factors are UFs. Note that the utilization factor of a lower priority application (like the third one in this exhibit) could be larger than the utilization factor of a higher priority application (second application), if it has a better compatibility with other applications in the bundle. For analyzing business cases, utilization factors need to be calculated and averaged over a long period, such as a year.

Exhibit 7-1: Individual Application Values and their Contribution to the total Bundle Value



When a user selects more than one grid application, a green button appears below the applications list that would take the user to the bundling page (Exhibit 7-2) where the user may change the default priority of selected applications in an effort to increase the total bundle value. As the user moves each application up or down the list of applications, the range of each application value (individual and in the bundle) can be reviewed in the bar chart at the middle. The distribution chart on the right side of the page shows the range of the total bundle value. Selecting the radio button for Utilization Factors above the right side chart displays a table of the estimated range of utilization factors for each application. A user can adjust the utilization factors on this table.

Exhibit 7-2: Application Bundling Page for adjusting the priority of different applications



The following are definitions of the factors used in calculating the utilization factor for each application.

Utilization Factor – This factor expresses how effectively a shared energy storage device can be "utilized" for a specific application. It is a multiplier, less than or equal to 1.00 (100%), that is multiplied by the nominal value of a storage application when it is offered or bundled with other applications that share a common storage asset. For example, when a storage device is used to provide a diurnal energy shift at its full power, it just would not be available to be utilized for area regulation during that time. Therefore, doing area regulation during a limited number of hours each day will decrease the realizable value for area regulation. Utilization factor is influenced by four other factors:

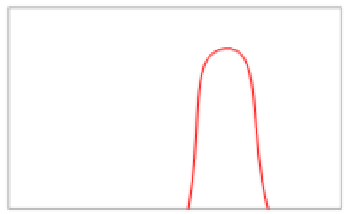
1. Application priority
2. Application type (use pattern)
3. Peak time alignment
4. Asset availability (from prior applications)

Application Priority - In the current version of ES-Select™, the default priority order is the order in which applications are selected by the user. However, a user may change the priority by changing the order of applications in the list on the bundling page.

Application Type (or Use Pattern) – An application usage pattern for storage can be divided into three main types. While each storage application is somewhat unique in when and how it offers its "value," the current version of ES-Select™, for simplicity, categorizes all grid applications into one of the three types shown in Exhibit 7-3. Application type impacts the peak time alignment and availability factors that determine the utilization factor of an application.

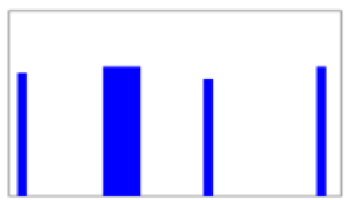
Exhibit 7-3: Three main types of grid applications for energy storage

Type 1 – Grid applications with their discharge pattern highly aligned with the load peak time (like retail Time of Use charge management)



Type 2 - Grid applications with frequent random demand on storage (like area regulation or smoothing renewable generation)

Type 3 - Grid applications with infrequent random demand on storage (like backup power or power quality applications)



Peak Time Alignment - Many diurnal energy shifting applications (type 1), such as peak shaving, supply capacity and transmission and distribution upgrade deferral, offer their "value" when the load or demand is highest, and that is often a few hours during a day. This does not mean that they will have no value during other times, but rather their charging time is not as critical to the grid operation as their discharge time is. The applications that have the same or overlapping value times will be highly compatible with each other and, therefore, their utilization factors are close to unity when they are bundled together (see Exhibit 7-4).

Exhibit 7-4: Example of two applications with high Peak Time Alignment

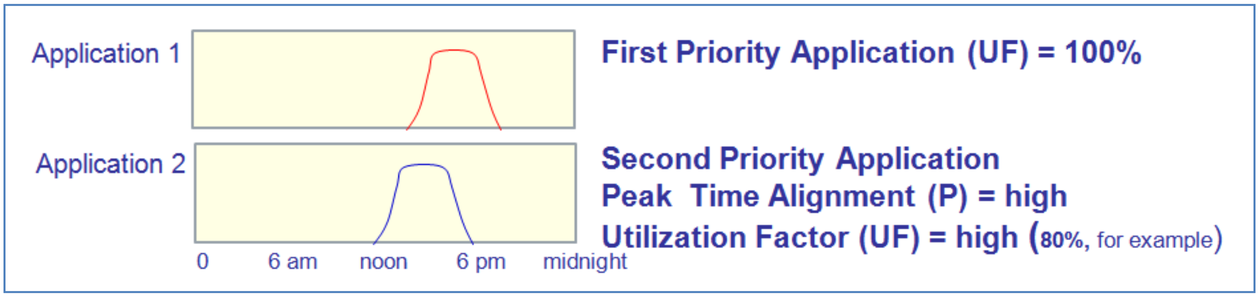
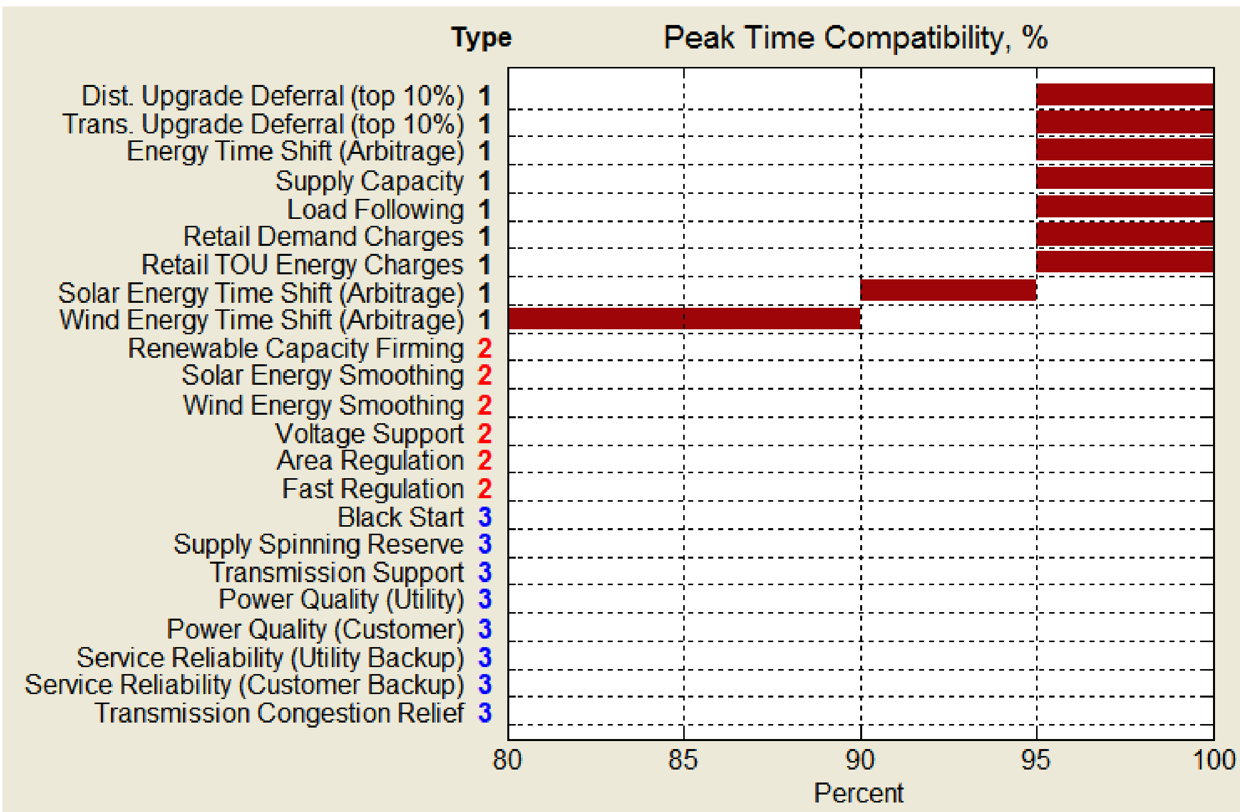


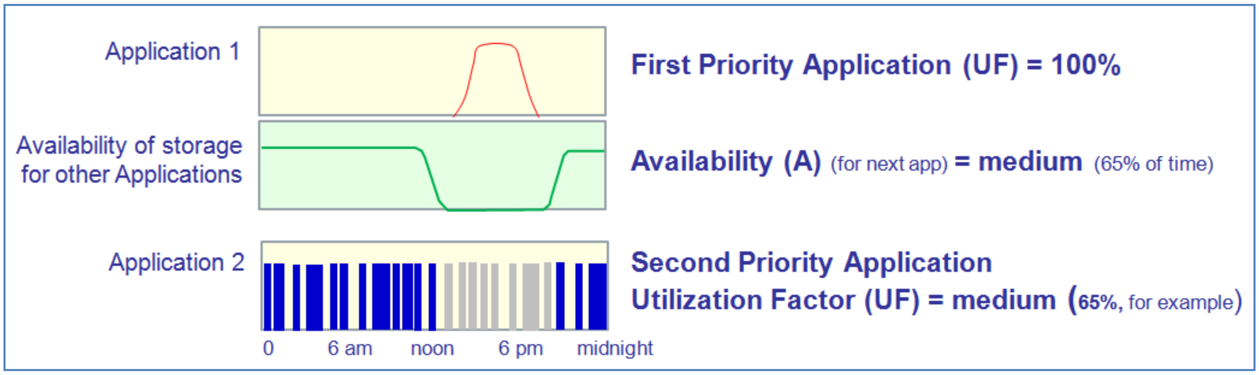
Exhibit 7-5shows the estimated ranges of peak time alignment for different grid applications as used in the current database of ES-Select™.

Exhibit 7-5: Range of Peak Time Compatibility for different Grid Applications



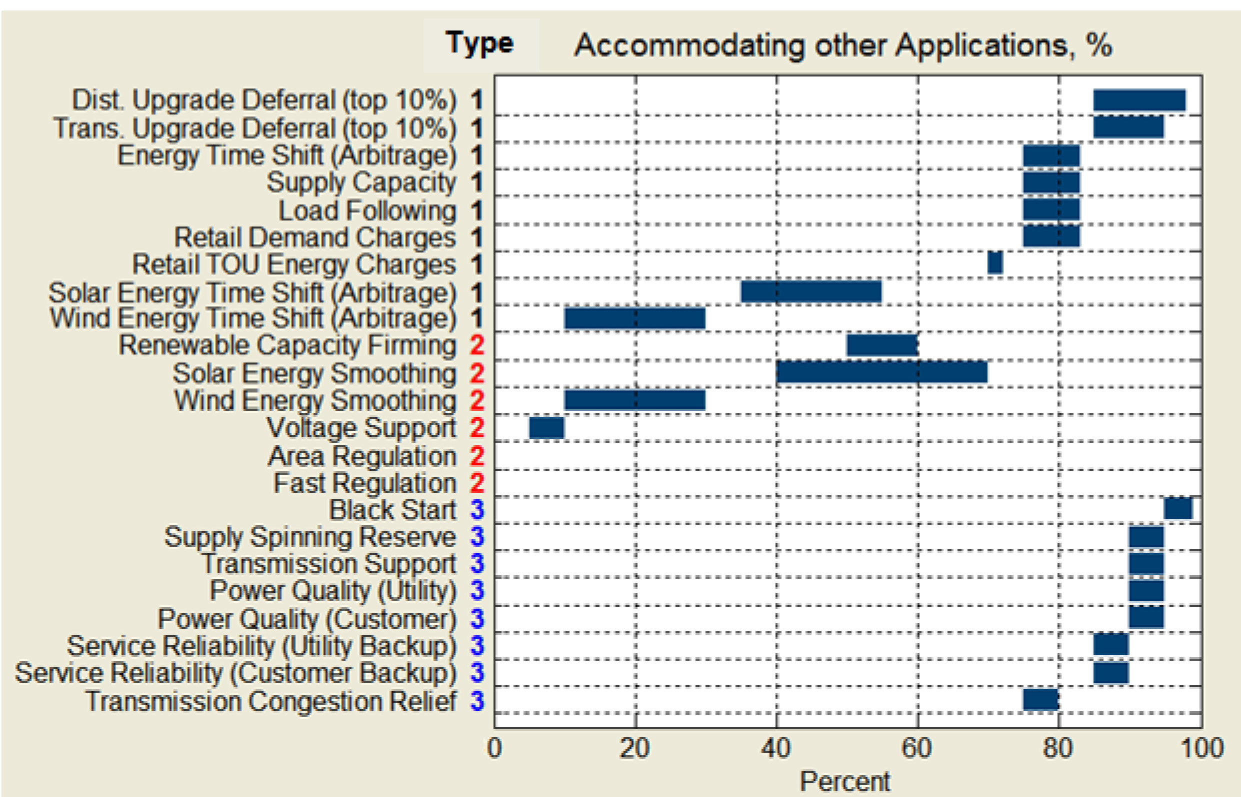
Asset Availability - When there is no direct correlation between the "value times" of multiple applications, lower priority applications can only offer their value during the left over time made available to them by the higher priority applications. The utilization factor for such lower priority applications, in most cases, is basically equal to the availability factor. For example, if a higher priority application calls upon a storage device 35% of the time in a day, the next application can have access to storage and offer its value in, at most, 65% of the time in a day (see Exhibit 7-6).

Exhibit 7-6: Example of UF being dictated by the Availability of storage



Another example is the area regulation that is almost constantly calling upon the storage device. This application will leave very low asset availability for the next application. In other words, if area regulation is the high priority application for a storage asset, it can barely be used for any other application. There are some complicated schemes to share the "power" of storage between area regulation and other applications, but they have not been tried yet due to the regulatory limitations and, therefore, are not considered in this version of ES-Select™. Exhibit 7-7 shows the estimated ranges of availability factor for different grid applications as used in the current database of ES-Select™.

Exhibit 7-7: Ranges of Availability Factors for different Grid Applications



Asset availability could be statistical for applications that offer their value at random times or for random durations, such as smoothing of renewable generation, backup power, or power quality applications.

Peak time alignment and asset availability need to be studied and formulated for each grid application. These factors were originally estimated and then, with the support of the Pacific Northwest National Laboratory (PNNL), the estimated availability and utilization of the following bundle combinations were substantiated through analysis of actual 2011 load and regulation data in the PJM area:

- T&D Deferral + Area Regulation (two different feeder load profiles)
- Retail Time of Use + Area Regulation (Office and store load patterns)
- Solar Power Firming + Area Regulation (Pittsburg and Phoenix PV data)
- Solar Power Shifting + Area Regulation (Pittsburg and Phoenix PV data)

The substantiation of the remaining estimated values is underway and the results will be provided in the future versions of ES-Select.

7.1 Calculating Utilization Factors - Methodology

The utilization factor for each application in a bundle depends on its order in the priority list, as well as the type of the application as its type determines the peak alignment and asset availability factors. So, each grid application has three parameters (PAT) that are needed to calculate its utilization factor, namely:

P = Peak-time alignment factor
A = Availability of storage time or capacity for the next application to be added
T = Type of the application as defined above

When a grid application is added to one or more grid applications of higher priority, the new bundle will have its own cumulative PAT parameters, identified by using the subscript "c" for cumulative:

.

$\mathbf{P_C}$ = Peak-time alignment factor for the bundled applications
$\mathbf{A_C}$ = Availability of storage time or capacity for the next application to be added
$\mathbf{T_C}$ = Type of the bundled applications, as a group

The initial values, before any bundle is made yet, would be $\mathbf{P_C = 1}$, $\mathbf{A_C = 1}$ and $\mathbf{T_C = 1}$. Also, for the first application (n=1), $\mathbf{P_C = 1}$ and $\mathbf{U_1 = 1}$.

The Utilization Factor (U) for the $\mathbf{n^{th}}$ application added to the bundle of **n-1** other applications, in general, is a function of six parameters:

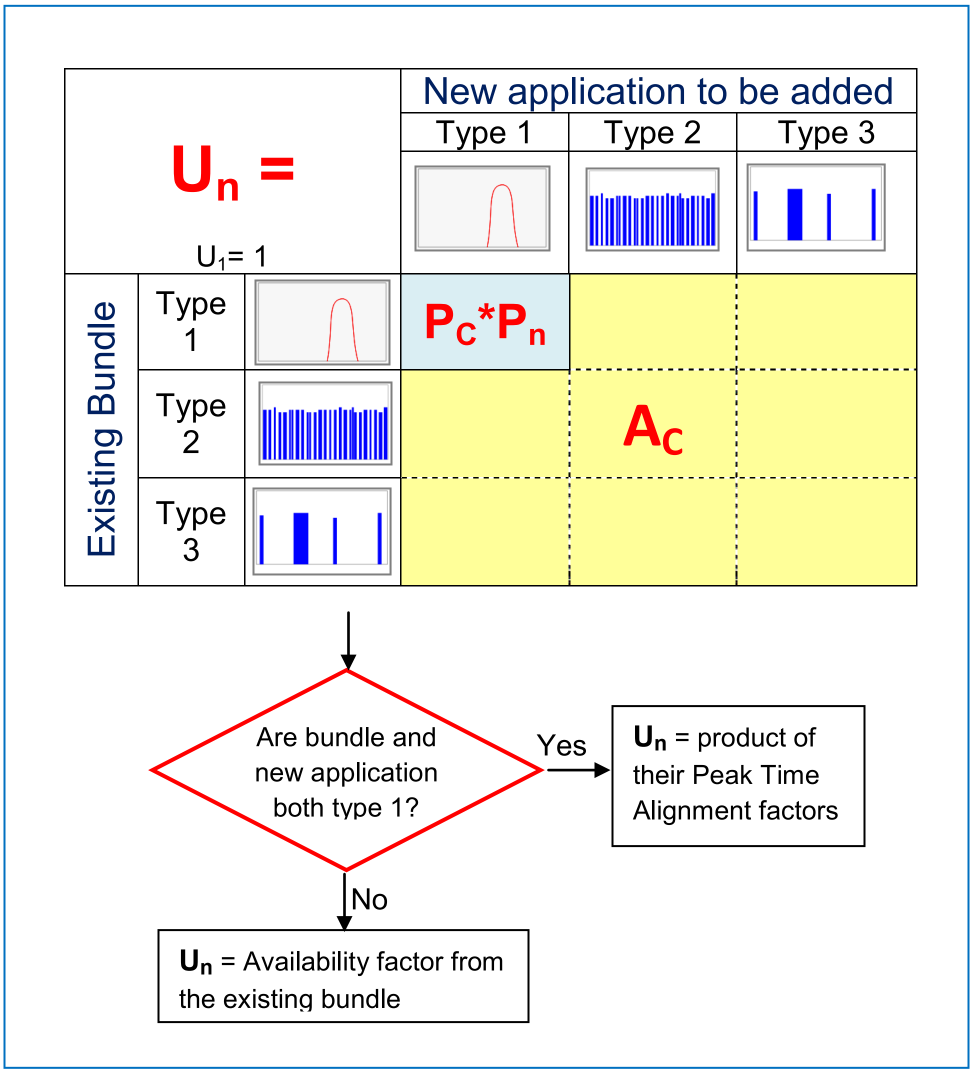
$$\mathbf{U_n} = \text{fn}\, \mathbf{(P_C, A_C, T_C, P_n, A_n, T_n)}$$

After calculation of the utilization factor for the **n**th added applications, the new bundle (cumulative) parameters $\mathbf{P_C}$, $\mathbf{A_C}$ and $\mathbf{T_C}$, need to be updated. So, at each step for adding a new application, four parameters need to be calculated.

The simplified form of $\mathbf{U_n}$ and **PAT** calculations, based on logic and interaction between parameters rather than a mathematical derivation, is summarized in the following four exhibits. Each exhibit is a 3x3 matrix showing the nine possible combinations of two applications, each could be one of the three possible types.

As noted from this matrix (Exhibit 7-8), utilization factor equals the asset availability offered by the accumulated applications in the bundle ($\mathbf{A_C}$) in almost all cases, except when the existing and new applications are both type 1 (high peak time alignment). In this case, utilization factor equals the product of the two peak time alignment factors.

Exhibit 7-8: Equation and Flowchart of utilization factor for nine possible cases



Once the new utilization factor is calculated and the application is added to the bundle, the bundle **PAT** parameters need to be updated as shown in Exhibit 7-9, 7-10 and 7-11.

Exhibit 7-9: Equation and Flowchart of bundle's peak time alignment for nine possible cases

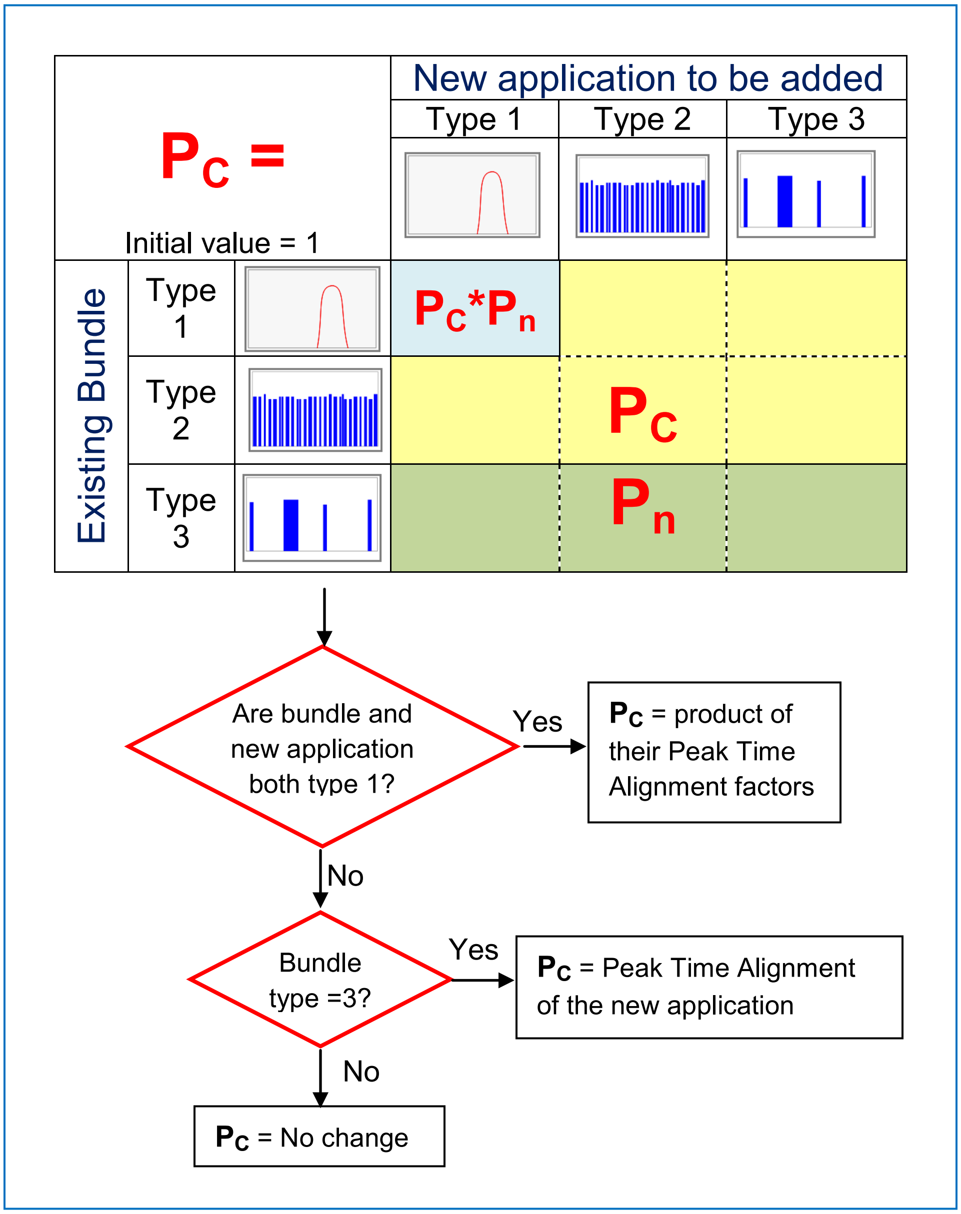


Exhibit 7-10: Equation and Flowchart of bundle's availability factor for nine possible cases

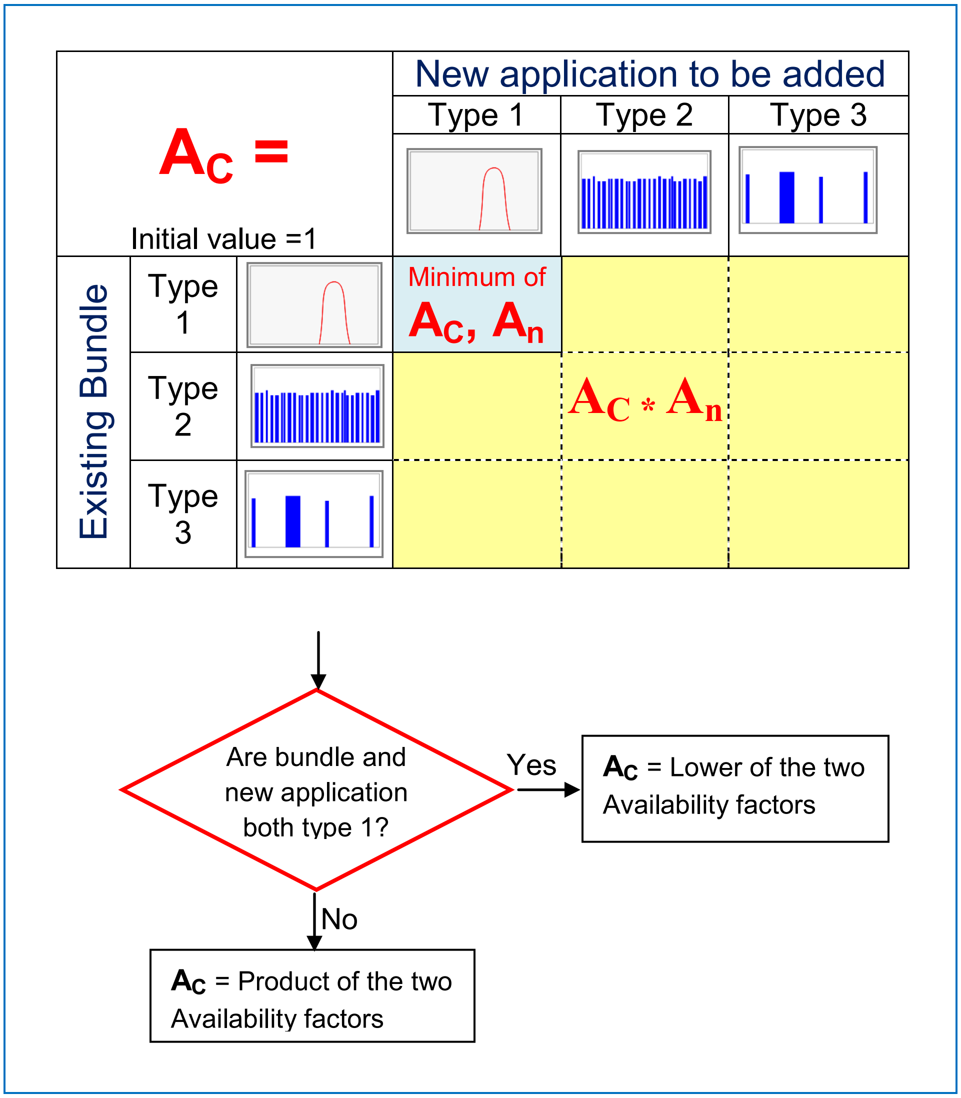
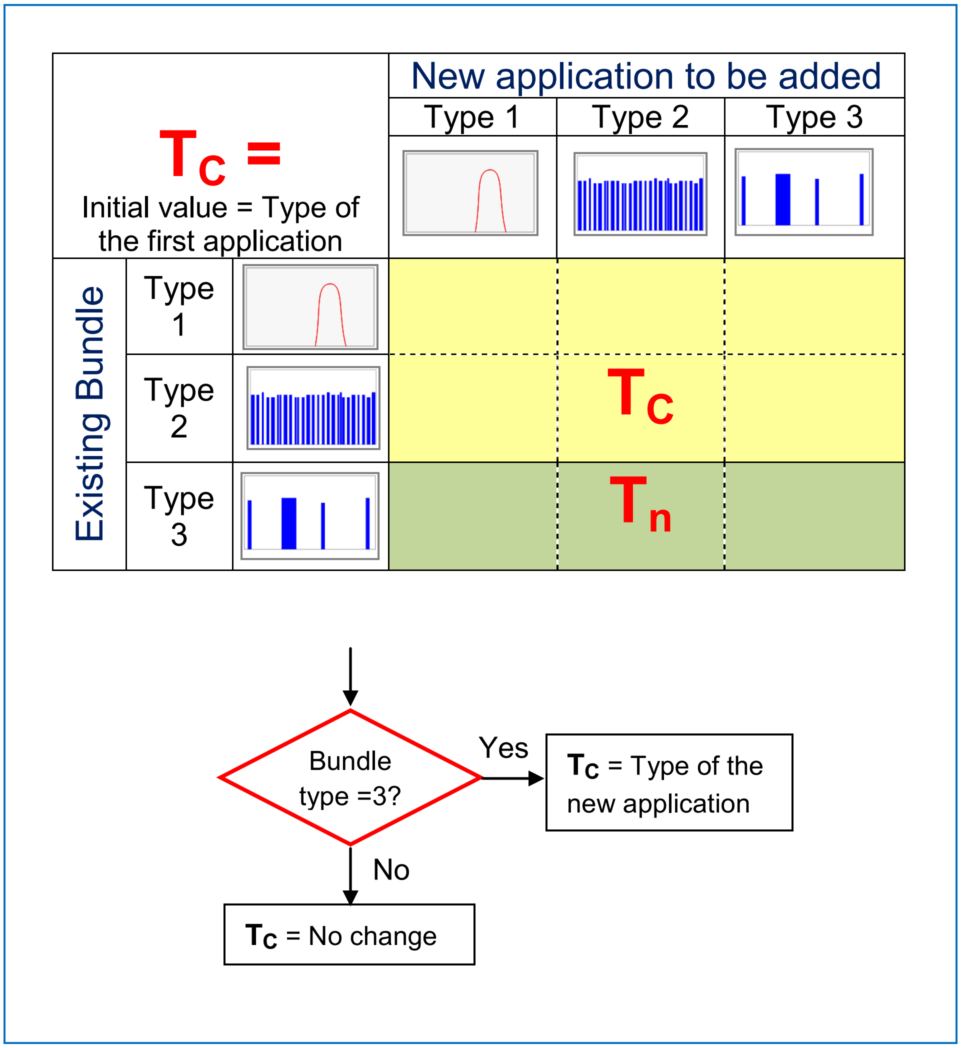


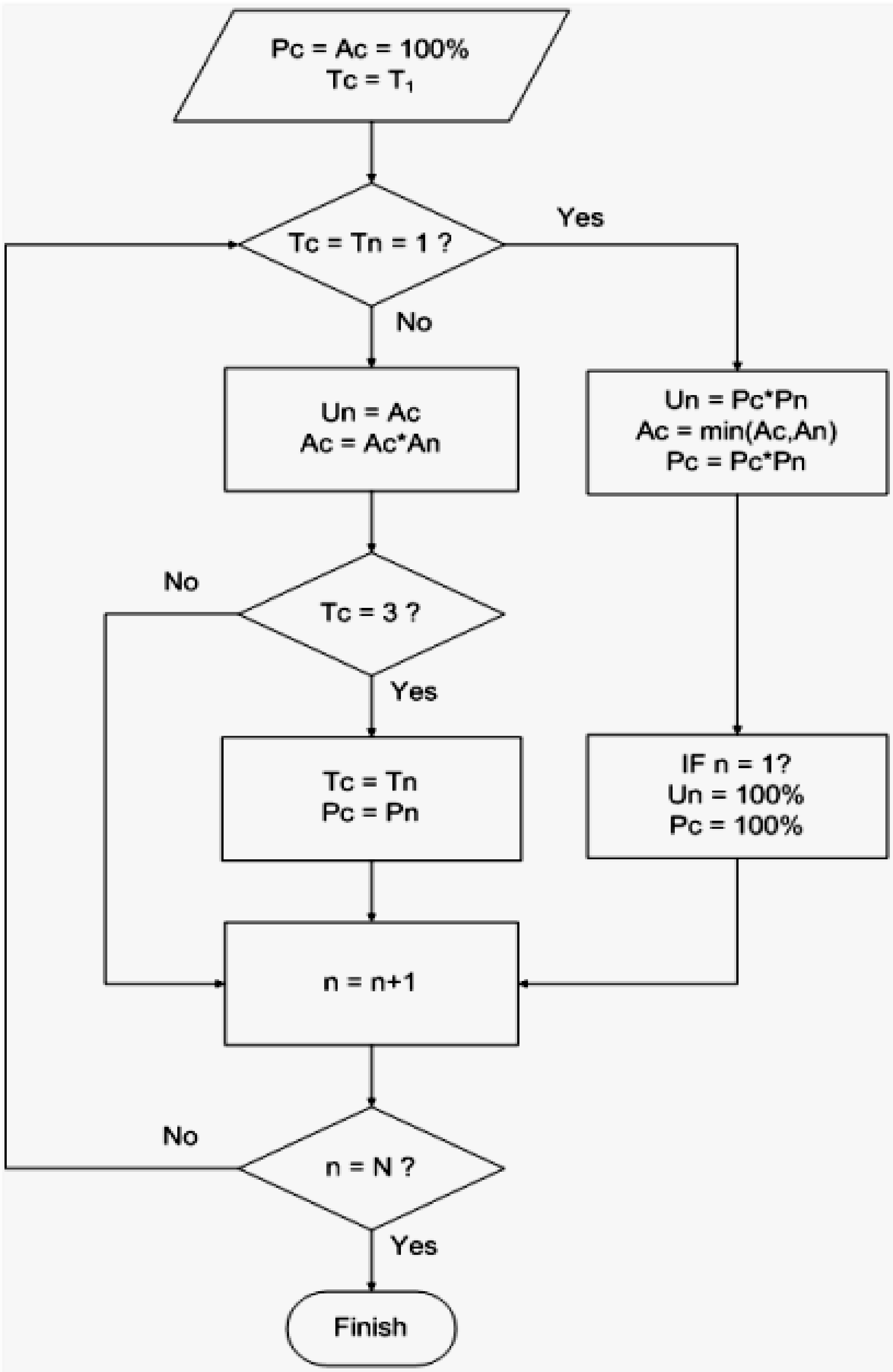
Exhibit 7-11: Equation and Flowchart of bundle's type for nine possible cases



When an application is added to an existing bundle, the bundle type may or may not change, depending on the nature of the applications.

The flowchart in Exhibit 7-12 summarizes all of the above logic tables and is used by ES-Select™ to calculate the bundling parameters based on the above 3x3 matrices.

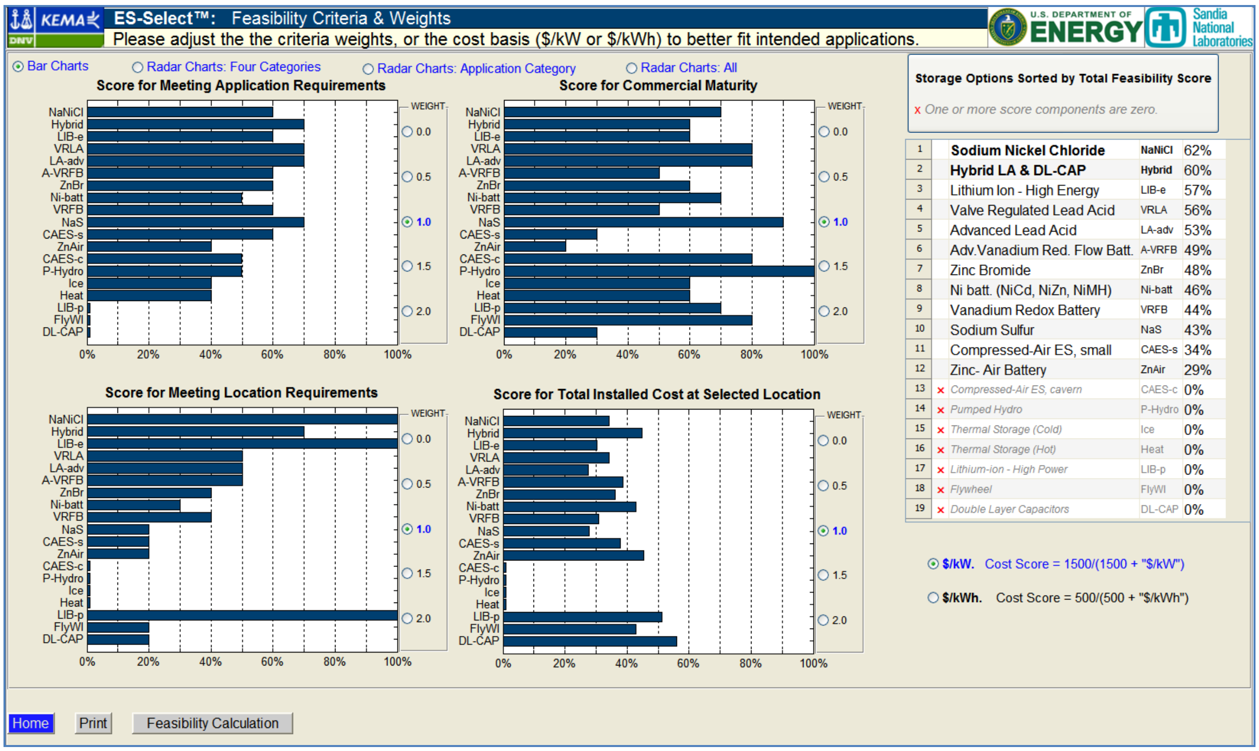
Exhibit 7-12: Flowchart for Calculating Utilization Factors



8 Scoring feasibility of energy storage options for grid applications

ES-Select™ displays what appears to be feasible storage options for user's selected applications at the right side or OUTPUT side of the home page. Selecting the green button, Feasibility Scores and Weights, below this list displays the feasibility page (Exhibit 8-1), where more details are available about how the feasibility of different storage options are calculated.

Exhibit 8-1: Feasibility Page listing storage option with their individual Feasibility Scores



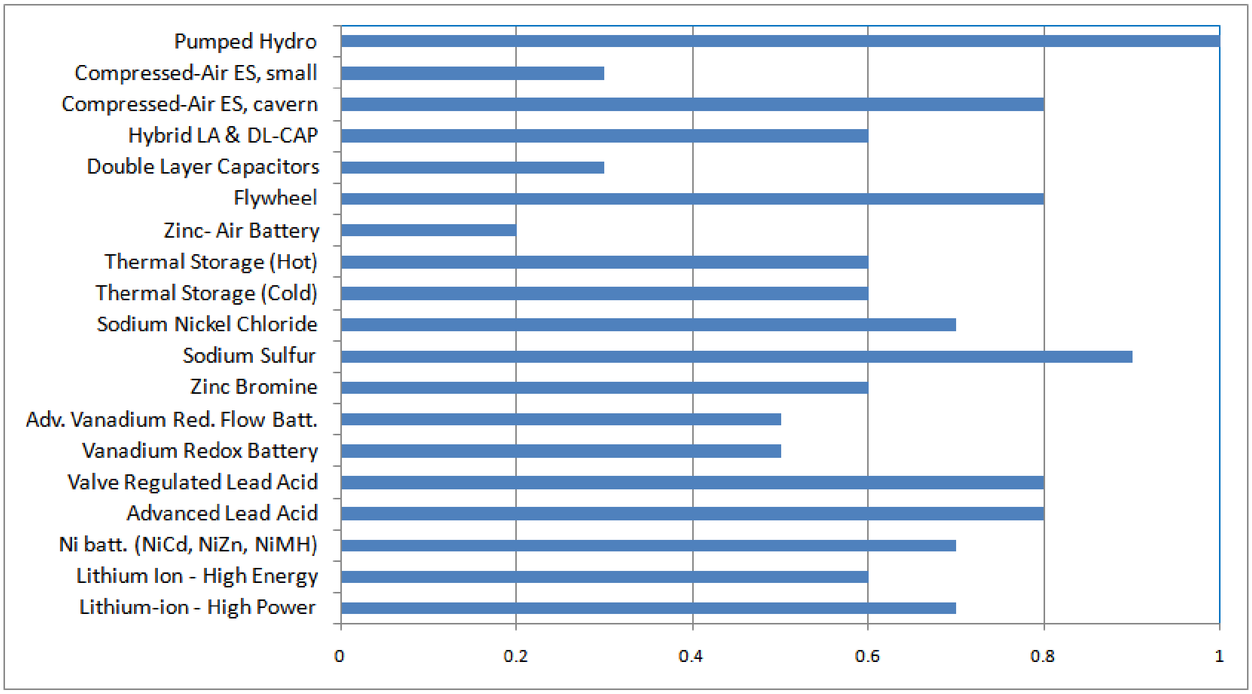
In order to select an energy storage option that would be appropriate for the intended grid application(s), ES-Select™ attempts to score the feasibility of each storage option based on the following four criteria:

- **Maturity** or readiness for commercial deployment
- Appropriateness for the selected grid **location** (considers availability, mobility, size, weight, scalability, etc.)
- Meeting application **requirements** (considers discharge duration, cycle life, efficiency, etc.)
- Installed **cost** in either $/kW or $/kWh basis (user's choice)

The four horizontal bar charts on the feasibility score page compare the feasibilities of different storage options for each of the above four criteria. To the right side of each bar chart is a 5-level weighting scale where, by default, all four criteria have the equal weight of 1.0. The weights may be adjusted to obtain a more balanced feasibility score for the intended application(s).

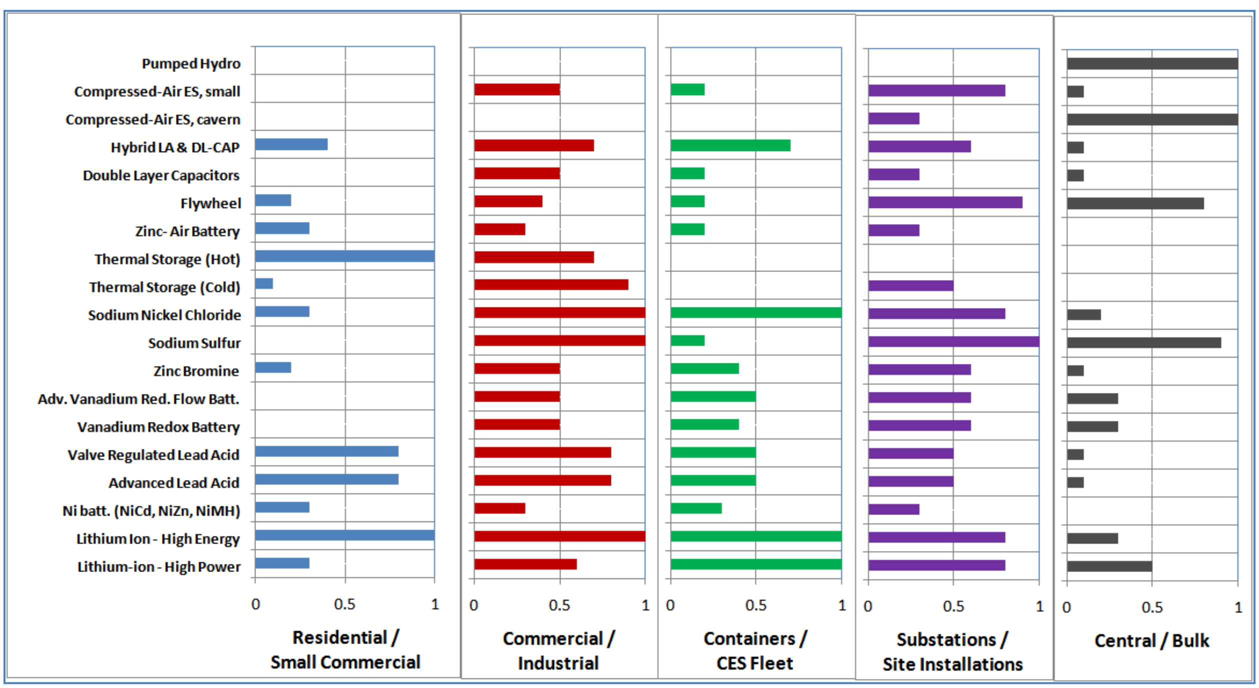
The estimated relative maturity of different storage technologies in terms of commercial readiness are shown in Exhibit 8-2.

Exhibit 8-2: Relative feasibility scores for commercial readiness of energy storage technologies for grid applications



The estimated and relative feasibility scores, reflecting the appropriateness for different grid locations, are shown in Exhibit 8-3.

Exhibit 8-3: Relative feasibility scores of energy storage options for different grid locations



The score for "meeting application requirements," by itself, could be divided into several sub-criteria for each application requirement, such as discharge duration, cycle life, and efficiency. In ES-Select™, this process has been simplified and all grid applications are divided into four main groups with similar requirements for efficiency, cycle life, discharge duration, and response time, as shown in Exhibit 8-4. Each storage option in the ES-Select™ database has been assigned an estimated feasibility score for each of the application groups as shown in Exhibit 8-5.

Exhibit 8-4: Dividing requirements of grid applications in four basic groups

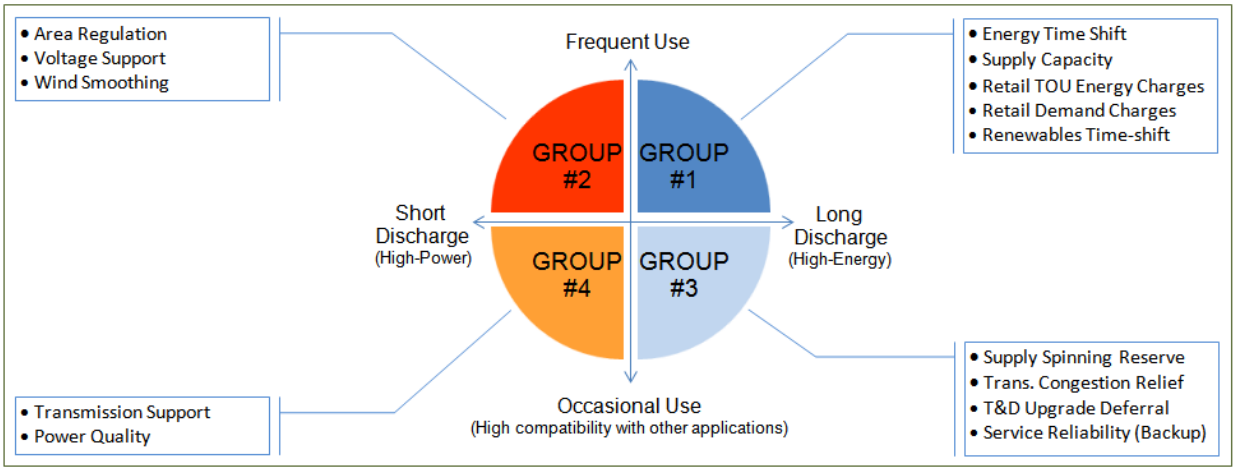
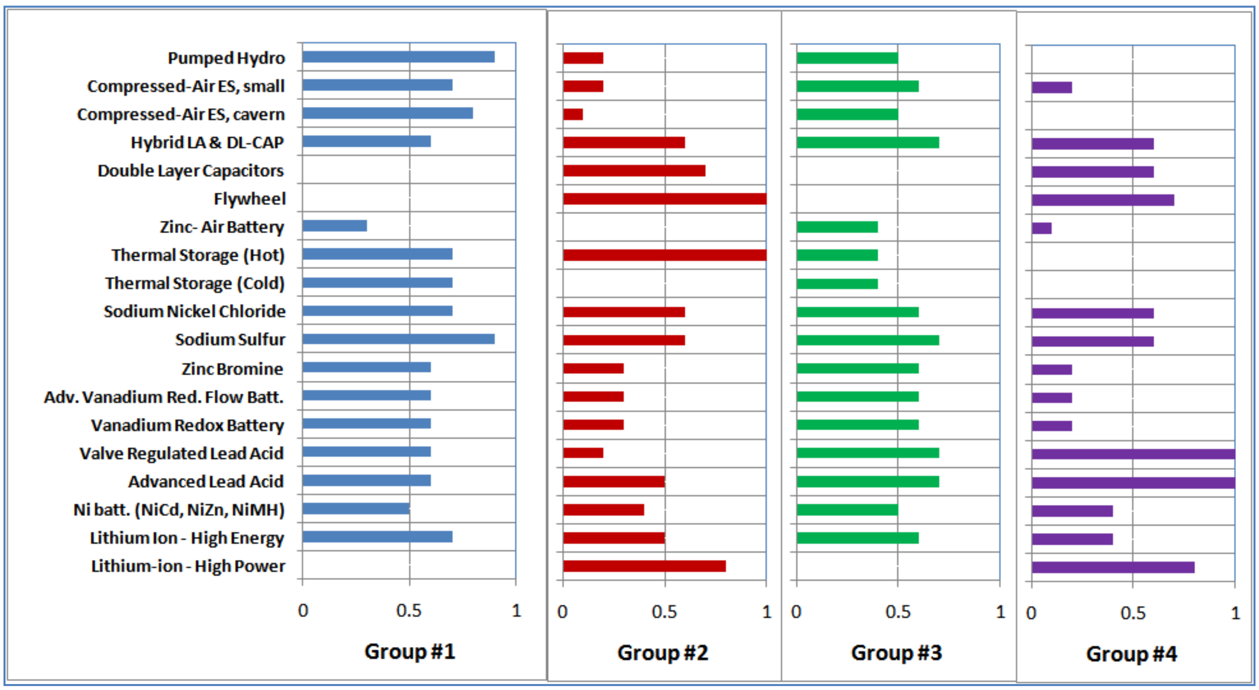


Exhibit 8-5: Relative feasibility scores of energy storage options for different application groups



Feasibility for requirements such as size, weight, and modularity are implicitly considered in the "location" score.

The cost score for each storage option is inversely proportional to the installed cost and is normalized with respect to the desirable target values of $1500/kW or $500/kWh, depending upon whichever applies to an application:

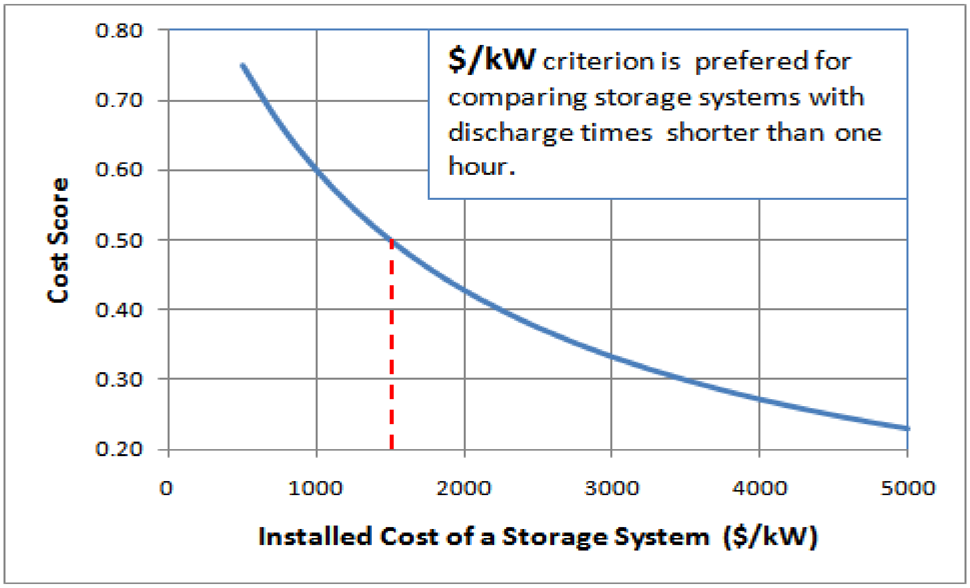
Cost Score = 1500 / (1500+ "Installed Cost in $/kW")

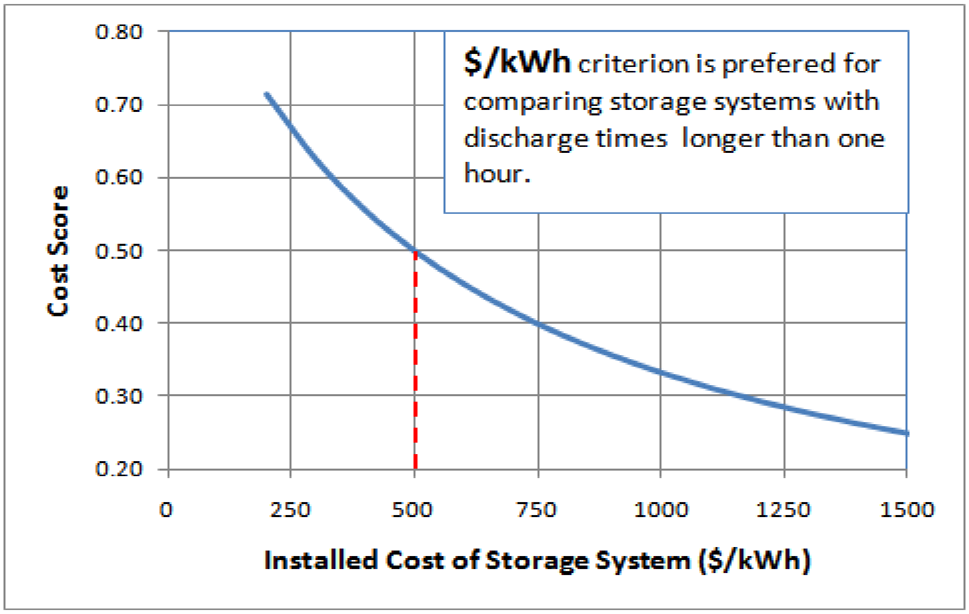
or

Cost Score = 500 / (500 + "Installed Cost in $/kWh")

Exhibit 8-6 shows the score to the cost in both $/kW and $/kWh. User selects the appropriate cost basis ($/kW or $/kWh) from either the home page or the feasibility page. The score for the targeted costs would be 0.5 that is the approximate average score of all storage options for each of the other three criteria.

Exhibit 8-6: Cost Scores for Feasibility Calculations

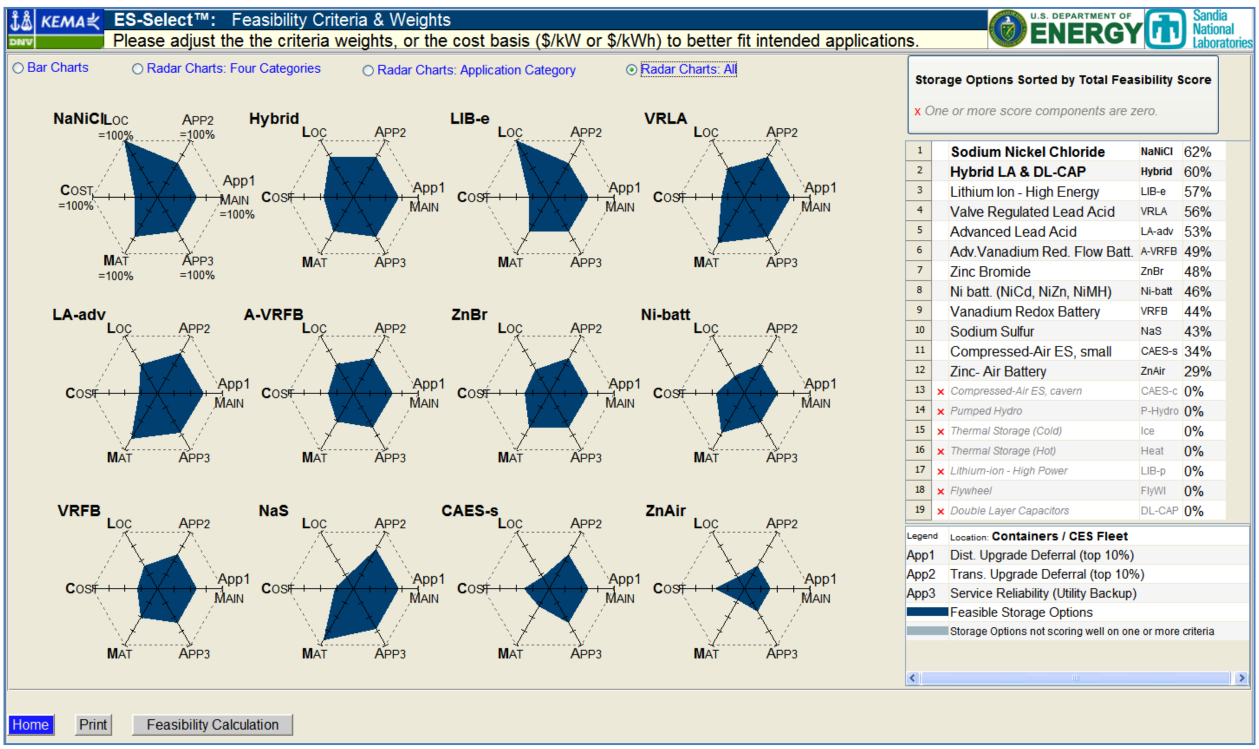




It should be noted that these scores are somewhat judgmental and are subject to change as the storage technologies evolve. Therefore, ES-Select™ scoring of storage options is only a suggestion and a user may choose any storage option desired, regardless of its feasibility score. Some storage options, however, are grayed out by ES-Select™ and are not made available for the user to select. These are the storage options that, at least at this time, are not available or not meaningful for the selected grid location, such as pumped hydro or cavern-based CAES for residential or containerized applications. The requirement for having an electric output is also considered to remove certain technologies from the list of the feasible options, such as thermal storage (without electric output) for use as backup power.

The radio buttons on top of the feasibility page allow user to compare the feasibility scores in different ways, including the radar charts one of which is shown in Exhibit 8-7 below.

Exhibit 8-7: Comparison of Feasibility scores of different Storage Options



8.1 Combining multiple Feasibility Scores

To combine multiple feasibility scores, ES-Select™ prefers geometric averaging to the more common arithmetic averaging:

$$\textbf{Arithmetic Average} = (S_1 + S_2 + S_3 + \ldots) / n$$

$$\textbf{Geometric Average} = (S_1 \times S_2 \times S_3 \times \ldots)^{(1/n)}$$

Where S_1, S_2, S_3 …are the individual feasibility scores to be averaged and "n" is their count. The main difference between the two averaging methods is that geometric average is more sensitive to lower numbers (scores) than arithmetic average. For example, a single "zero" score may lower the arithmetic average a little but would force the geometric average to zero. When a storage option scores zero for any one of the feasibility criteria, it means that it is not acceptable and this deficiency needs to be clearly reflected in the combined feasibility score. Hence, geometric averaging is preferred for combining multiple feasibility scores.

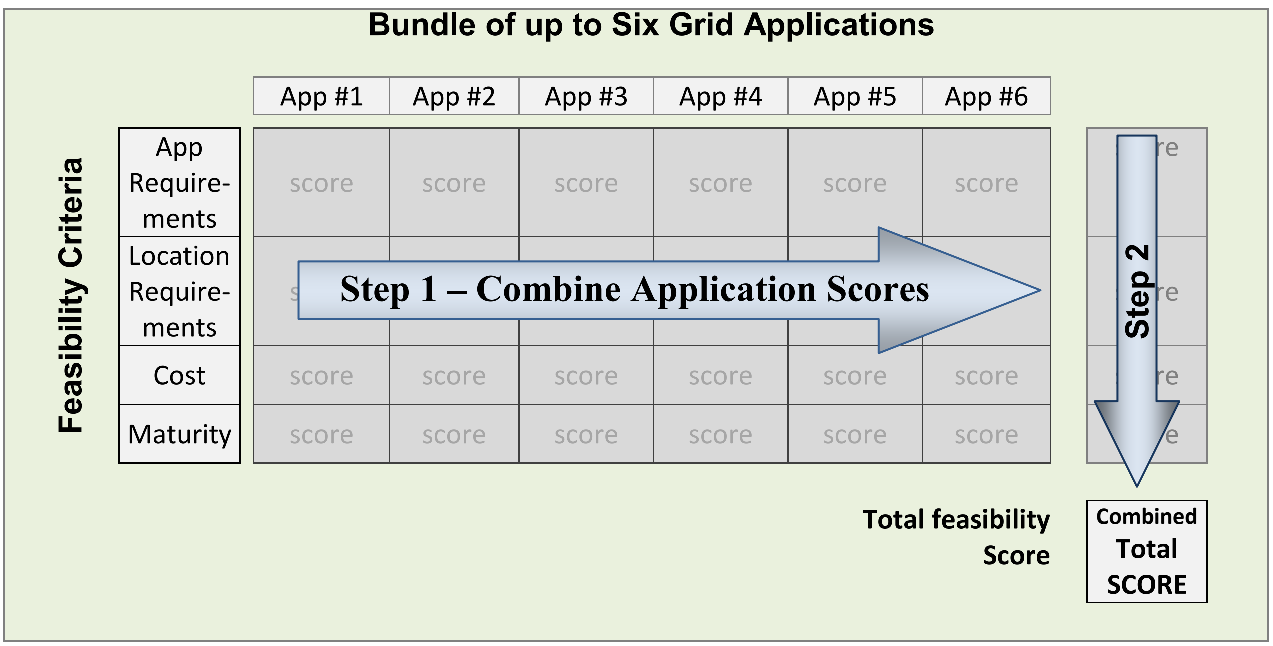
In order to be able to apply different weights to different criteria scores when combining them, ES-Select™ uses the following geometric averaging equation for weighed scores:

$$\textbf{Combined Feasibility Score} = (S_1^{a} \times S_2^{b} \times S_3^{c} \times \ldots)^{[1/(a+b+c+\ldots)]}$$

Where **a** is the weight of the $\mathbf{S_1}$ score**, b** is the weight of the $\mathbf{S_2}$ score, etc.

Exhibit 8-8 below shows the two-step process ES-Select™ uses first to score each storage option for multiple applications and then average them for different criteria to find the combined feasibility score for each storage option.

Exhibit 8-8: Calculation Process for the Total Feasibility Score of each Storage Option



In the first step, for one criterion at a time, the feasibility of a storge option for different applications are combined. The weights for each application feasibility score is its utilization factor (see section on bundling multiple applications). Once such a multi-application feasibility score is estimated for each criterion, they are then combined again using the user-modified weights for each criterion.

9 Comparison of Energy Storage Options

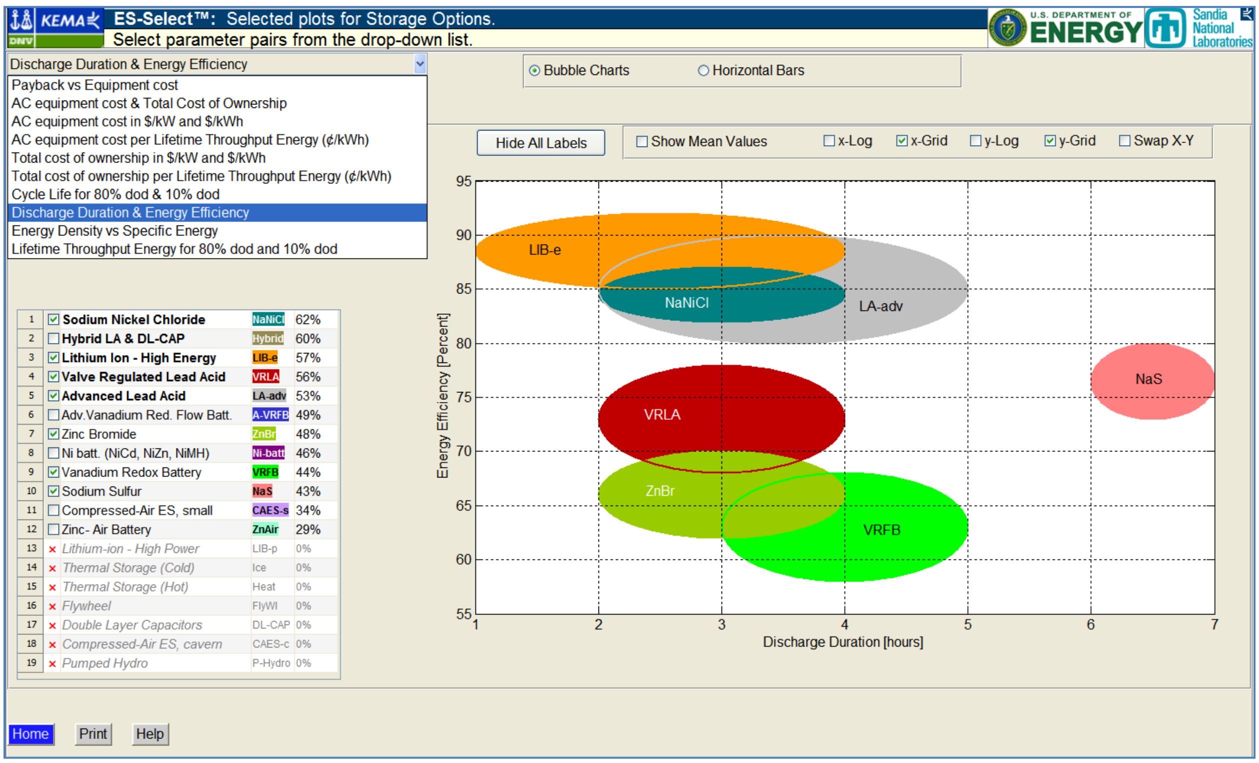
Once a list of feasible energy storage options is suggested for the selected application(s), a user may compare the storage options based on a variety of factors, such as size, cost, discharge duration, cycle life, payback time, etc. There are two buttons at the bottom of the home page for this purpose:

- Selected ES Comparisons
- General Comparisons

Exhibit 9-1shows the Selected ES Comparison page. The drop box list in the top left corner shows the most common type of X-Y parameter pairs that a user may select to see the storage comparisons based on those pairs of parameters. A user may also include or exclude different storage options from the chart by using the check list of the storage options at the left side. The grayed out options are those that are not acceptable for one or more criteria, such as using CAES at a residential site.

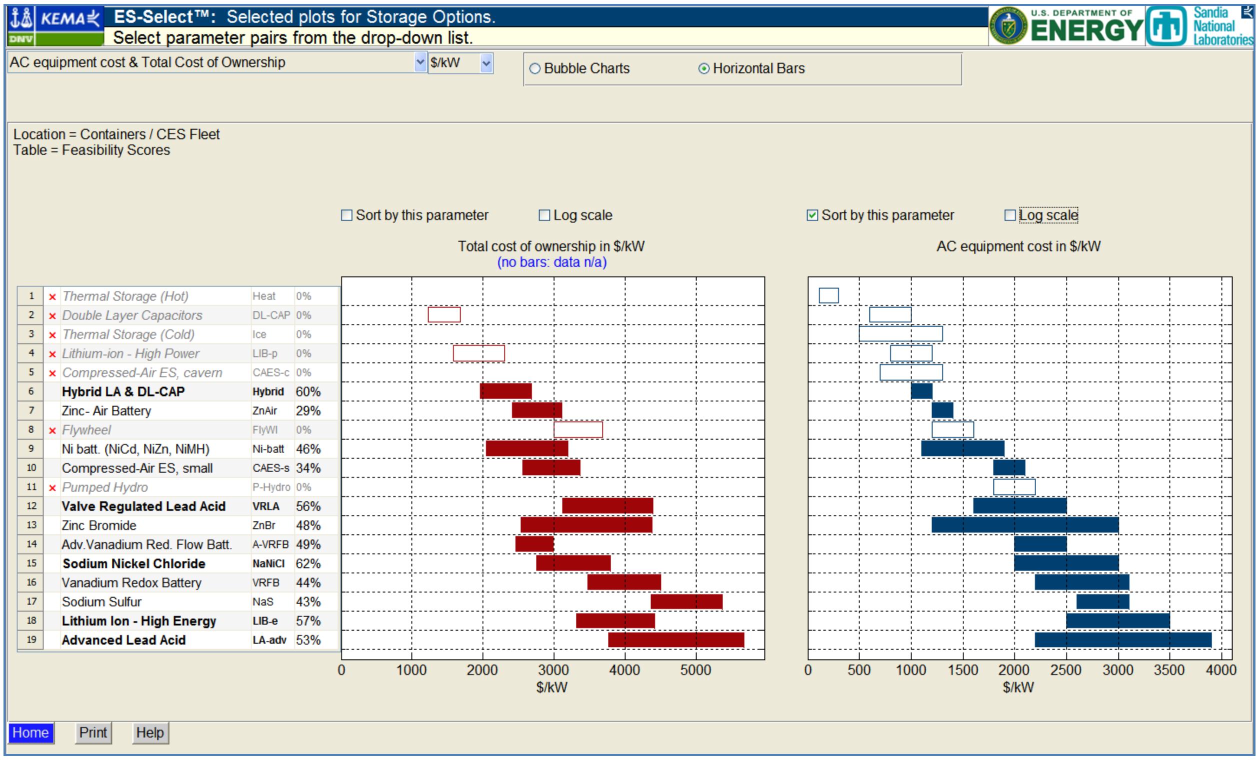
Above the chart area, there are a few options for enhancing the chart. The storage name labels may be moved to desirable locations by click and dragging them.

Exhibit 9-1: Page for displaying select ES Comparisons



Two chart types are available for better comparison of the storage options. The radio buttons near the top of the page will help a user choose one of these chart types. Exhibit 9-1 shows a sample of bubble chart and Exhibit 9-2 shows a sample of horizontal bars chart.

Exhibit 9-2: Sample of Horizontal Bars chart for comparing energy storage options



The General Comparison page is very similar to the Selected ES Comparison page. The only difference is that on this page more parameters are available for comparative plotting and an experienced user can choose to plot any parameter versus any other one from the two dropdown lists of parameters. The parameters that can be selected to be plotted on this page are shown in Exhibit 9-3below.

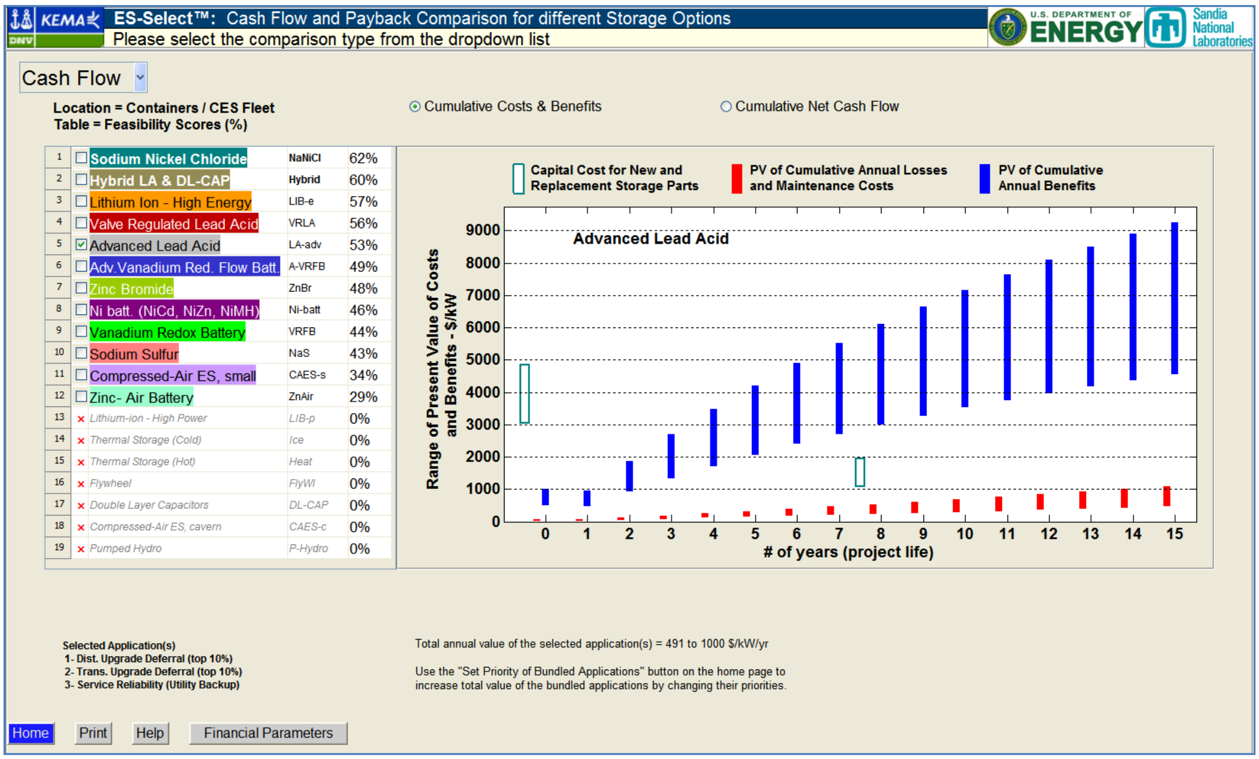
Exhibit 9-3: List of parameters that can be selected to be plotted

Payback
Total Installed Cost of AC Storage, $/kW
Total Installed Cost of AC Storage, $/kWh
Equipment Cost per cycle (10% dod)
Equipment Cost per cycle (80% dod)
Equipment cost per lifetime throughput energy (10% dod)
Equipment cost per lifetime throughput energy (80% dod)
Total cost of ownership in $/kW
Total cost of ownership in $/kWh
Annual Maintenance or Warranty cost, $/kW
Annual Maintenance or Warranty cost, $/kWh
Annual Operational Loss, $/kW
Annual Operational Loss, $/kWh
Installation Cost at Selected Location, $/kW
Installation Cost at Selected Location, $/kWh
AC equipment cost in $/kW
AC equipment cost in $/kWh
Energy Efficiency
Lifetime Throughput Energy at 10% dod
Lifetime Throughput Energy at 80% dod
Discharge Duration
Cycle Life (10% dod)
Cycle Life (80% dod)
Energy Density
Specific Energy
Footprint (AC equipment only)

10 Cash Flow and Payback Analyses

The current version of ES-Select™ provides some unique cash flow and payback analyses that take into account the uncertainty in both the cost of ownership of a storage device, as well as its benefits over the years. Selecting the Costs / Benefits button at the bottom of the home page opens the page for cash flow and payback analysis as shown in Exhibit 10-1 below.

Exhibit 10-1: Page for Cash Flow and Payback Analyses

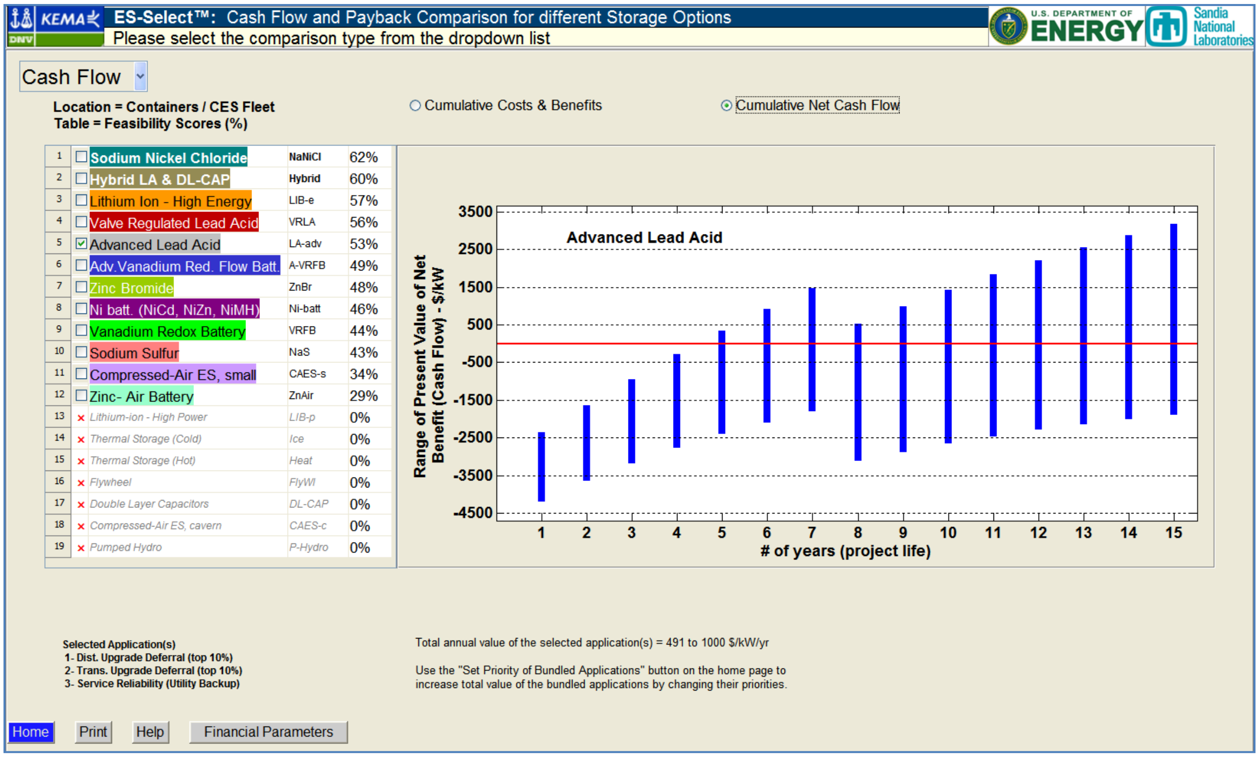


The dropdown box in the top left corner may be used to choose between the cash flow and payback analyses. On the cash flow page, one storage option can be selected at a time to display its cash flow. The vertical bars show the range or (or uncertainty in) the displayed parameters, including:

1. Range of capital cost (installed storage)
2. Range of present values (PV) of accumulated annual costs (sum of estimated maintenance and operational losses)
3. Range of replacement / refurbishment cost PVs
4. Range of PVs of accumulated annual benefits of the bundled applications

The radio button on top of the chart area provides the option to show the PV of the net cash flow as shown in Exhibit 10-2. Note that in the example shown below for certain bundles of applications, the range of the PV of net cash flow starts to include positive numbers after year five and increases each year despite a setback due to the partial replacement cost at year eight.

Exhibit 10-2: Range of Present Value of the Net Cash Flow



Selecting Payback from the dropdown box in the top left corner of the page displays the payback range in two different formats, bar charts, and statistical distribution as shown in Exhibit 10-3and 10-4 below:

Exhibit 10-3: Comparison of the Ranges of Payback years in bars

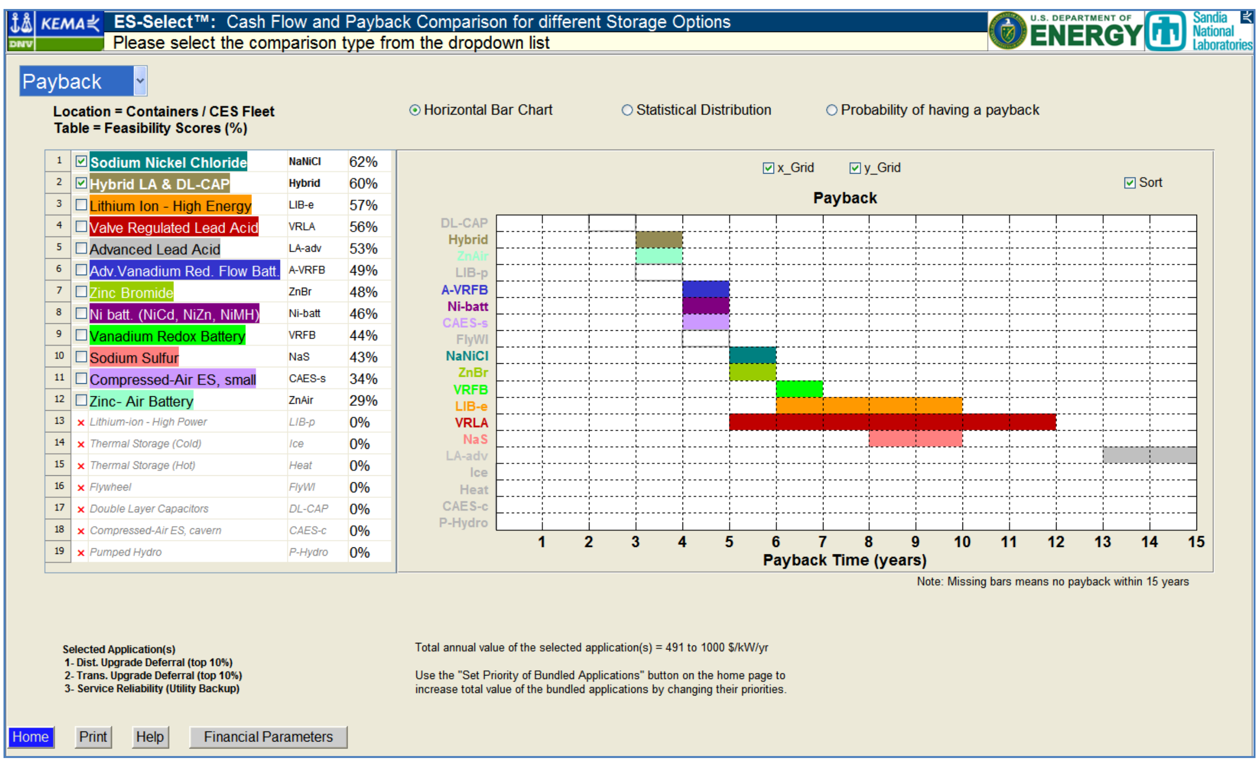
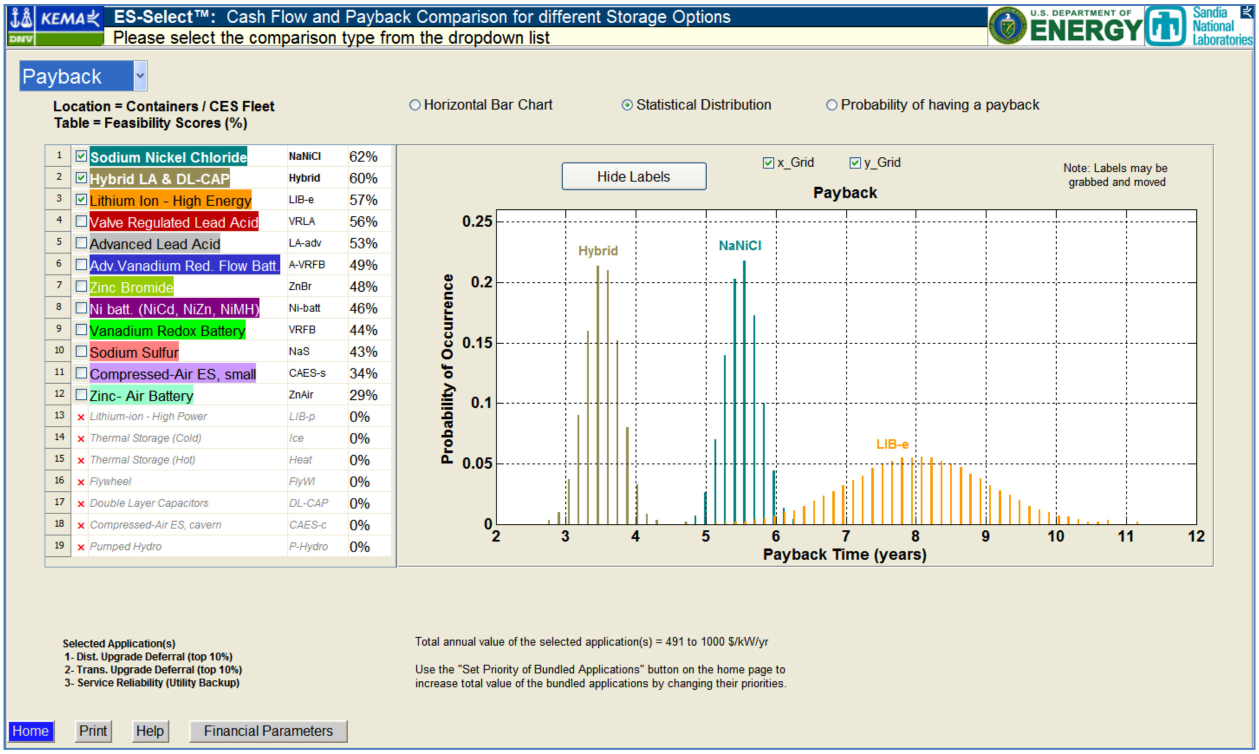
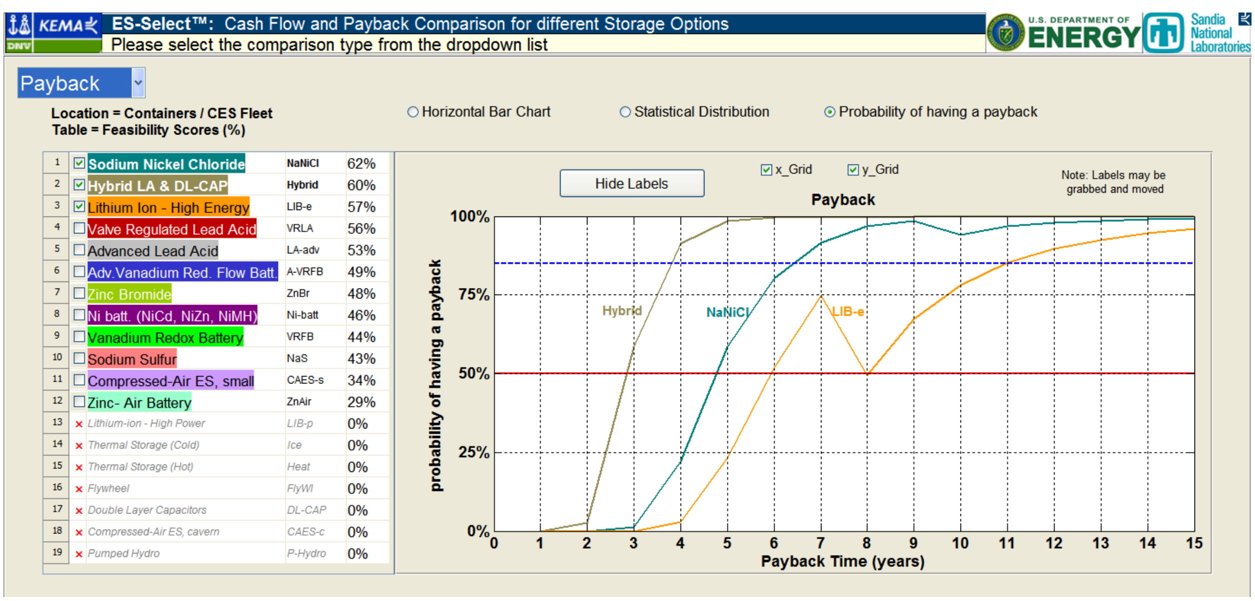


Exhibit 10-4: Comparison of the Statistical Distribution of Payback Years



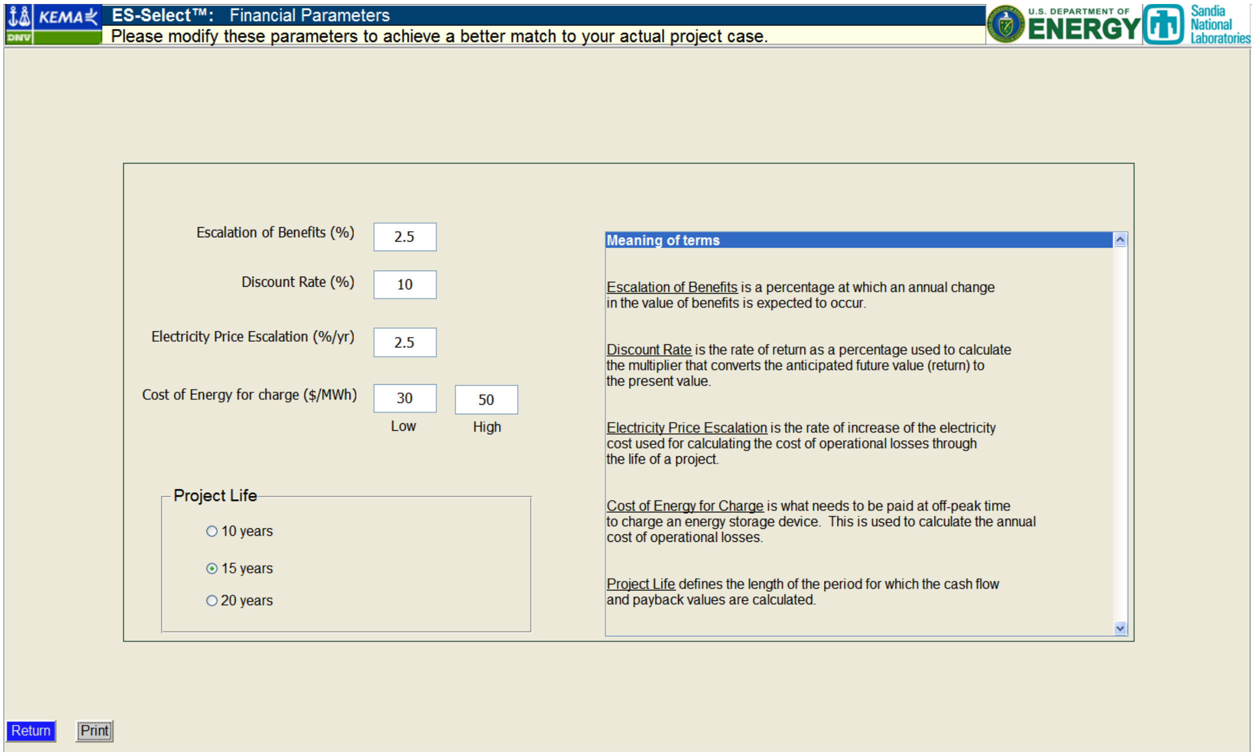
ES-Select™ also offers the option to display the probability of having a payback in any given year within the user-specified storage lifetime time (10, 15, or 20 years). Exhibit 10-5 compares the probability of having a payback for a few storage options. The drops in the charts are due to the replacement costs.

Exhibit 10-5: Probability of having a payback within the project lifetime



The financial parameters used in calculating cash flows and paybacks may be viewed by selecting the Financial Parameters button on the bottom of the page. These parameters are adjustable to better fit a particular project (see Exhibit 10-6).

Exhibit 10-6: ES-Select™ Financial Parameters



11 Further Enhancements / Feedback

ES-Select™ has been developed over the last few years based on the need to inform, educate, and provide an initial screening analysis for many decision makers who often may not have adequate information on all grid applications of energy storage or the storage options available to serve them. ES-Select™ was developed to help them explore different options in an effort to help them reach a conclusion, or at least a direction for considering energy storage for a variety of applications. While the ES-Select™ development includes many features and functionalities, there are many more features that are still in the "waiting list" to be implemented in the future versions of ES-Select™. These missing features or enhancement opportunities may be stated in three categories:

1) Expanding Existing Capabilities:
   a. Expanding the databases to include more storage options and a more accurate application data (benefits and market potentials) for different parts of the US, as well as globally to cover countries that are very active in the deployment of energy storage.
   b. Expanding ES-Select's analytical capabilities, especially for doing market penetration, cash flow, payback and other business analyses.
   c. Substantiating the remaining estimated bundling parameters through analysis of actual data.
   d. Including alternatives to energy storage or "conventional" options in cash flow and payback analyses.
2) Improving Accessibility
   a. Make ES-Select™ available to run directly from a server without needing to download its large library.
   b. Make ES-Select™ as an application that can run on popular touch-based "tablet PCs."
   c. Make ES-Select™ available to run on the Mac (Apple) platform.
3) Develop **App-Select** (a mirror image of ES-Select™) to help in repurposing used EV batteries
   a. While ES-Select™ can rank the feasibility of different storage technologies for one or more grid applications, it cannot do the reverse. Many energy storage manufacturers, system integrators or solution providers, as well as electric vehicle manufactures, are interested in a tool that can rank the feasibility of different applications for a given storage technology or EV battery.
   b. A special EV battery module with extended battery database for App-Select that would simplify the use of a battery's historical data and attempt to score the appropriateness of different grid application for the specific EV battery. This could be the first step leading to application risk assessment and provision of a right warranty coverage for used EV batteries.

The ES-Select™ development team is looking forward to comments and improvement suggestions from its users. For the user's convenience, a **Suggestion Box** button is provided at the bottom of the home page to facilitate feedback to the development team.

Appendix A: Installing ES-Select™

Presently, ES-Select™ is only supported on Windows (XP or newer). Mac (Apple) support is currently not available. The ES-Select™ tool and its accompanying library of functions as well as a copy of this users' manual are available from the website of the Sandia National laboratories: www.sandia.gov/ess.

The compiled version of ES-Select™ is under 4Mb but the standard Matlab library of functions that it needs for its data analysis and graphics is about 170Mb. This library, however, needs to be downloaded only once and does not need to be to be downloaded again with each update of ES-Select™. Therefore, depending on whether you are the first time user or have already installed it before, you may need to click on different links on the Sandia website:

1. First-time users need to download the tool including its supporting library; click **here** *[linked to ESSelectFullInstall_20120504.exe]*
2. For updated versions, you only need to download the tool; click **here** *[linked to ESSelectUpdates_20120504.exe]*

Once fully installed, the ES-Select™ installer will create the following directory on your computer:

[C:] (or root directory)

[ESselect]

[ESselet_mcr] – *ES-Select files*

[MCR] - *Matlab library*

Recommendations for computer screen settings:

ES-Select™ graphics work best for screens with 800 pixels or more in the vertical dimension. If an "extended" or multiple screens are used, ES-Select™ will run on the primary window (i.e., the one labeled "1"). Once ES-Select™ is launched; you may close the program by using the "Exit" button on the Home Page. If the "Exit" button is not visible due improper installation or using a screen that is too small, hit <ESC> key to close the program.

More details on installation are available from the Sandia website.

Appendix B: Definitions of Energy Storage Applications

The following definitions of different grid application of energy storage were originally adopted from the Sandia 2010-085 report “Energy Storage for the Electricity Grid: Benefits and Markets” published in Feb 2010 .The application names and their definitions were later expanded or slightly modified to make them closer to what EPRI used in their white paper that was published in December of the same year, “Electricity Storage Technology Options, - A White Paper Primer on Applications, Costs and Benefits-1020676” .

Application 1 —Energy Time-shift (Arbitrage)
Sandia Title: Electric Energy Time-shift
EPRI Title: Price Arbitrage
Electric energy time-shift means that storage can take advantage of the electricity price difference between on-peak and off-peak hour by purchasing and store energy at times when electricity price is low and selling it back to the grid when the price is higher.

Application 2 — Supply Capacity
Sandia Title: Electric Supply Capacity
EPRI Title: System Capacity
Energy storage could be used to defer the cost of installation of new power plant or to “rent” generation capacity in the wholesale electricity marketplace.

Application 3 — Load Following
Sandia Title: Same
EPRI Title: Not modeled in the EPRI White Paper
Energy storage could serve as load following capacity that adjusts its output to balance the generation and the load within a specific region or area.

Application 4 — Area Regulation
Sandia Title: Same
EPRI Title: Regulation (1 hr)
Area regulation is the use of on-line generation or storage which can change output quickly (MW/min) to track minute-to-minute fluctuations in loads and to correct for the unintended fluctuations in generation. It helps to maintain the grid frequency and to comply with Control Performance Standards (CPSs) 1 and 2 of the North American Reliability Council (NERC).

Application 5 — Fast Regulation
Sandia Title: N/A
EPRI Title: N/A
Similar to "Area Regulation", with specific reference to FERC 755 for area regulation compensation.

Application 6 — Supply Spinning Reserve
Sandia Title: Electric Supply Reserve Capacity
EPRI Title: Spinning Reserve
Reserve capacity is the generation capacity that can be called upon in the event of a contingency such as the sudden, unexpected loss of a generator. Three types of reserve capacities are: Spinning Reserve, Supplemental Reserve and Backup Supply.

Application 7 — Voltage Support
Sandia Title: Same
EPRI Title: Same
The purpose of voltage support is to maintain the grid voltage. Common method is to use resources like energy storage to inject or absorb reactive power (VAR) that offsets reactance in the grid.

Application 8 — Transmission VAR Support
Sandia Title: Transmission Support
EPRI Title: VAR Support
Energy storage could be used to enhance the transmission and distribution system performance by providing support during the event of electrical anomalies and disturbances such as voltage sag, unstable voltage, and sub-synchronous resonance.

Application 9 — Transmission Congestion Relief
Sandia Title: Same
EPRI Title: Transmission Congestion
Transmission congestion happens when shortage of transmission capacity to transmit power during periods of peak demand. When the transmission systems are becoming congested, congestion charges are usually applied and increased. Energy storage system would be installed to avoid the congestion related charges and cost. Energy could be stored during the off-peak hours, and be released during on-peak hours, when the transmission systems are congested.

Application 10 — Distribution Upgrade Deferral
Sandia Title: T&D Upgrade Deferral (90th percentile)
EPRI Title: Defer Distribution Investment
Energy storage could be installed to defer the installation/upgrade of distribution lines and substations. The market is believed to be necessary due to the difficulty in siting power lines/substation, and then once sited, the cost of building the power lines/substation. Storage can be utilized to defer the need for the additional lines/substation.

Application 11 — Transmission Upgrade Deferral
Sandia Title: T&D Upgrade Deferral (90th percentile)
EPRI Title: Defer Transmission Investment
Energy storage could be installed to defer the installation/upgrade of transmission lines and substations. The market is believed to be necessary due to the difficulty in siting transmission lines/substation, and then once sited, the cost of building the transmission lines/substation. Storage can be utilized to defer the need for the additional lines/substation.

Application 12 — Retail TOU Energy Charges
Sandia Title: Time-of-use Energy Cost Management
EPRI Title: Retail TOU Energy Charges
Energy storage could be used by end users (utility customers) to shift or reduce energy consumption at peak hours to reduce their overall cost for electricity. Energy is purchased at off-peak hours when electricity price is low, and then released at the on-peak hours when electricity price is high.

Application 13 — Retail Demand Charges
Sandia Title: Demand Charge Management
EPRI Title: Retail Demand Charges
Energy storage could be used by end users (utility customers) to reduce power consumption when demand charge is high to reduce their overall cost for electricity. Energy is purchased when demand charge do not apply or low, and then discharged when the demand charge do apply or high.

Application 14 — Service Reliability (Utility Backup)
Sandia Title: Electric Service Reliability
EPRI Title: Power Reliability
This electric service reliability application focuses on the need for back-up power systems at the utility side of the electric meter. Usually, the facilities use a combination of batteries for ride-through of momentary outages and then have a diesel generator for longer duration outages.

Application 15 — Service Reliability (Consumer Backup)
Sandia Title: Electric Service Reliability
EPRI Title: Power Reliability
This electric service reliability application focuses on the need for back-up power systems at Commercial and Industrial facilities. Usually, the facilities use a combination of batteries for ride-through of momentary outages and then have a diesel generator for longer duration outages.

Application 16 — Power Quality (Utility)
Sandia Title: Electric Service Power Quality
EPRI Title: Power Quality
Power quality problem may cause a misoperation or failure of sensitive industrial equipments and critical commercial operations. Energy storage could be used at the utility side of the meter to improve power quality on the feeder for all customers against short-duration events such as harmonics, variation in voltage magnitude, and frequency and interruptions in service, et al.

Application 17 — Power Quality (Consumer)
Sandia Title: Electric Service Power Quality
EPRI Title: Power Quality
Power quality problem may cause a misoperation or failure of sensitive industrial equipments and critical commercial operations. Energy storage could be used to improve power quality at end user side against short-duration events such as harmonics, variation in voltage magnitude, and frequency and interruptions in service et al.

Application 18 — Wind Energy Time Shift (Arbitrage)
Sandia Title: Renewables Energy Time-shift
EPRI Title: Price Arbitrage
This is a subset of Energy Time Shift (arbitrage). Renewable resources are unpredictable and do not align with typical peak load patterns. Wind production tends to peak during the evening and morning hours when load is at a low and ebbs during daytime hours when load is at a maximum. Having a storage device with durations of 4-6 hours can provide a tremendous advantage to renewable efficiencies, easing of grid impacts, and renewable production. The device will be able to (a) store and discharge renewable generation from low cost periods to high cost periods, (b) provide transmission relief for wind farms – wind farms infrastructure is typically not sized to maximum output of the farm, storage can capture energy that would be typically dumped in these cases and increase wind farm capacity factor.

Application 19 — Solar Energy Time Shift (Arbitrage)
Sandia Title: Renewables Energy Time-shift
EPRI Title: Price Arbitrage
This is a subset of Energy Time Shift (arbitrage). Renewable resources are unpredictable and don’t align with typical peak load patterns. Solar production tends to peak at or before noon when load is at a low and ebbs during the afternoon hours when load is at a maximum. Having a storage device with durations of 3-4 hours can provide a tremendous advantage to renewable efficiencies, easing of grid impacts, and

renewable production. The device will be able to (a) store and discharge renewable generation from low cost periods to high cost periods, (b) provide transmission relief for solar farms.

Application 20 — Renewables Capacity Firming
Sandia Title: Renewables Capacity Firming
EPRI Title: System Capacity
The objective of renewable capacity firming is to make the generation output somewhat constant. Storage could be used to store wind and solar power during hours of peak production regardless of demand, and discharge to supplement traditional generation when renewable output reduces during expected generation time.

Application 21 — Wind Energy Smoothing
Sandia Title: Wind Generation Grid Integration (short duration)
EPRI Title: Renewable Energy Integration
Short duration intermittency from wind generation is caused by variation of wind speed that occur throughout the day. Storage could be used to manage or mitigate the less desirable effects from high wind generation penetration. For example, wind farms are beginning to be faced with specific requirements in order to interconnect their devices to the grid. This requirement comes from utility interconnections and well as the power purchase requirements, which can apply penalties to the developers if certain ramping (2%) requirements are not met. Storage can be applied to smooth wind output and offset these requirements.

Application 22 — Solar Energy Smoothing
Sandia Title: Discussed but benefits not calculated
EPRI Title: Renewable Energy Integration
Shading caused by terrestrial obstructions such as clouds and trees. As a cloud passes over solar collectors, power output from the affected solar generation system drops. This rate of change could be quite rapid. Solar farms, in some cases, are beginning to be faced with specific requirements in order to interconnect their devices to the grid. This requirement comes from utility interconnections and well as the power purchase requirements, which can apply penalties to the developers if certain ramping (2%) requirements are not met. Storage can be applied to smooth solar output and offset these requirements. Electric energy time-shift means that storage can take advantage of the electricity price difference between on-peak and off-peak hour by purchasing and store energy at times when electricity price is low and selling it back to the grid when the price is higher.

Application 23 — Black Start
Sandia Title: Not covered
EPRI Title: Black Start
A black start is the process of powering up a generating (power) plant when the grid power is not available such as in blackouts. Black start uses the power from the generators inside the plant that are often started by small diesel generators. These small diesel generators can be replaced with energy storage devices.

Appendix C: ES-Select™ Parameters and Equations

	Abb.	Parameters	Display Unit	Calculation	Comments
1	ACM	Annual Cost of Maintenance	$/yr/kW	Input from Database	Normalized to the storage rated power
2	ACOL	Annual Cost of Operational Losses	$/yr/kW	= AOL x CE/1000	
3	ADD	Required Application Discharge Duration	cycles	Input from Database	
4	AMP	Application Market Potential in 10 years	GW	=1000 x Ec10 / PV10	
5	AnB	Annual Benefit	$/kW	Input from Database	
6	AnE	Annual Expenses	$/yr/kW	= ACM + ACOL	Estimated operating expenses in $/yr normalized to the storage rated power
7	AOL	Annual Operational Losses (of storage)	kWh/yr/kW		Normalized to the storage rated power
8	CE	Cost of Energy for charge	$/MWh	User input or default value	
9	CL10	Cycle Life at 10% depth of discharge	Cycles	Input from Database	
10	CL80	Cycle Life at 80% depth of discharge	Cycles	Input from Database	
11	CLC10	Storage Equipment cost per cycle at 10% dod.	Cents/kW	= SCw / CL10	See note for CLC80
12	CLC80	Storage Equipment cost per cycle at 80% dod.	cents/kW	= SCw / CL80	This is the capital cost per cycle the storage is used, regardless of the discharge duration
13	dod	Depth of Discharge	%	10% or 80% (from database)	
14	DR	Discount Rate	%/yr	User input or default value	
15	EB	Escalation of Benefits	%/yr	User input or default value	
16	Ec10	10-year Economy (total benefits)	$ billions	Input from Database	
17	EFF	AC roundtrip Energy efficiency	%	Input from Database	
18	FA	Storage Feasibility Score for meeting Application requirements	%	Input from Database	Different scores based on power, energy and frequency of use.
19	FC	Fixed Charge Rate	%/yr	User input or default value	

20	FCh	Storage Feasibility Score for Cost in $/kWh	%	= 500 /(500 + SCh)	Based on the AC equipment cost in $/kWh
21	FCw	Storage Feasibility Score for Cost in $/kW	%	= 1500 /(1500+SCw)	Based on the AC equipment cost in $/kW
22	FL	Storage Feasibility Score for selected Location	%	Input from Database	Different scores for different location on the grid
23	FM	Storage Feasibility Score for Maturity	%	Input from Database	Commercial maturity based on whether it is experimental, prototype, pre commercial or fully commercial
24	InCw	Installation Cost	$/kW	Input from Database	Installation cost varies at different locations on the grid
25	InCh	Installation Cost	$/kWh	= InCw / SDD	
26	ISCh	Installed Storage Cost	$/kWh	= ISCw/ SDD	
27	ISCw	Installed Storage Cost	$/kW	= SCw + InCw	
28	LTC10	Storage Equipment cost per lifetime throughput energy at 10% dod.	cents/kWh	= SCw / LTE10	See note for LTC80
29	LTC80	Storage Equipment cost per lifetime throughput energy at 80% dod.	cents/kWh	= SCw / LTE80	This is a levelized cost of storage for total expected output energy to be delivered over its lifetime. This is based on storage ability to cycle energy whether it is actually used or not.
30	LTE80	Lifetime throughput energy at 80% dod	MWh/kW	= CL80 x SDD x 0.8	Unit is MWh normalized to the equipment rated power (kW)
31	LTE10	Lifetime throughput energy at 10% dods	MWH/kW	= CL10 x SDD x 0.1	Unit is MWh normalized to the equipment rated power (kW)
32	PBK	Payback	years	Range of payback is defined as follows: LOW number = the year where probability of cumulative net cash flow is 50%. HIGH number = the year where probability of cumulative net cash flow is 85%.	
33	PE	Electricity Price Escalation	%/yr	User input or default value	
34	PV( )	Present Value of …		PV calculation based on the financial parameters	
35	PV10	Present Value of 10-year benefits	$/kW	= PV(AnB)	
36	SCw	AC Storage cost	$/kW	Input from	

				Database	
37	SCh	AC Storage cost	$/kWh	= SCw / SDD	
38	SDD	Storage Discharge Duration	cycles	Input from Database	
39	TCO	Total Cost of Ownership	$/kW	= ISCw + PV (AnE) + PV(Replacement Cost)	

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