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NY Prize

Assessing the Benefits and Costs of Developing a Microgrid: Model User's Guide

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INDUSTRIAL ECONOMICS, INCORPORATED

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NY PRIZE

ASSESSING THE BENEFITS AND COSTS OF DEVELOPING A MICROGRID: MODEL USER'S GUIDE

To assist the New York State Energy Research and Development Authority (NYSERDA) with the evaluation of the economic viability of microgrids, Industrial Economics, Incorporated, has developed a benefit-cost assessment (BCA) model designed for application to individual sites. The model estimates the costs and benefits of a microgrid from the perspective of society as a whole, taking into account the benefits of maintaining operations at the facilities served by the microgrid in the event of a prolonged emergency.

The BCA model considers the following aspects of a microgrid's costs:

- Initial design and planning costs.
- Capital costs.
- Operation and maintenance (O&M) costs.
- Environmental costs.

Similarly, the model quantifies the following potential benefits of developing and operating a microgrid:

- Energy benefits.
- Reliability benefits (during outages not caused by events beyond a utility's control).
- Power quality benefits.
- Environmental benefits.
- Benefits of avoiding major power outages (*i.e.*, outages caused by major storms or other events beyond a utility's control).

This user's guide provides an overview of the model's structure and the inputs it requires. The guide then describes in detail the calculations the model employs and provides instructions to the user on its application to the evaluation of potential projects. The discussion proceeds as follows:

1. MODEL OVERVIEW

The BCA model is a spreadsheet tool comprising 38 linked worksheets developed in Microsoft Excel. The tabs for these worksheets are color-coded according to the content and function of each worksheet. Exhibit 1 provides an overview of the worksheets.

EXHIBIT 1. OVERVIEW OF BCA MODEL WORKSHEETS

WORKSHEET KEY	NUMBER OF WORKSHEETS
Site Summary	1
Site Inputs	5
Intermediate Outputs	2
Underlying Standard Data	12
Cost Calculations	6
Benefit Calculations	4
Major Power Outage - Fire Station Benefits	1
Major Power Outage - Emergency Medical Services Benefits	1
Major Power Outage - Hospital Benefits	1
Major Power Outage - Police Station Benefits	1
Major Power Outage - Electric Power Benefits	1
Major Power Outage - Wastewater Benefits	1
Major Power Outage - Water Benefits	1
Major Power Outage - Other Benefits	1

The model evaluates the economic viability of a microgrid based on the user's specification of project costs, the project's design and operating characteristics, and the facilities and services the project is designed to support. The model analyzes discrete operating scenarios specified by the user; it does not identify an optimal project design or operating strategy.

The model is structured to analyze a project's costs and benefits over a 20-year operating period, assumed to begin in 2016 and continue through 2035.[1] The model applies conventional discounting techniques to calculate the present value of costs and benefits, employing an annual discount rate specified by the user. It also calculates an annualized estimate of costs and benefits based on the anticipated engineering life of the system's equipment. Once a project's cumulative benefits and costs have been adjusted to present values, the model calculates both the project's net benefits and the ratio of project benefits to costs. The model also calculates the project's internal rate of return, which indicates the discount rate at which the present value of the project's costs and benefits would be equal. All monetized results are adjusted for inflation and expressed in 2014 dollars.[2]

Exhibit 2 shows the model's Summary worksheet. The Summary worksheet begins with an overview of key aspects of the microgrid's design. It then asks the user to specify several key assumptions for the analysis, including the duration of the major power outage to be analyzed as part of the BCA, the probability of an outage of that duration in any year, and the discount rate to be employed in calculating present values and annualized values. Specification of these inputs in the Summary worksheet is designed to facilitate sensitivity analysis. The worksheet then provides estimates of present values and annualized costs and benefits, as well as the project's net benefits, benefit-cost ratio, and internal rate of return. Finally, the worksheet provides a table (see Exhibit 3) that allows the user to track results for different major power outage scenarios (defined by alternate assumptions about the probability and duration of major power outages), and to evaluate impacts across multiple scenarios. To use this table, the user must specify major power outage duration and probability assumptions in the "Key Assumptions" table, then press one of the "Copy Values" buttons to the right of the "Summary of Major Power Outages" table to paste scenario-specific assumptions and outputs into that row of the table. The user may repeat this process for up to eight scenarios, copying the results of one scenario into each row of the table. To clear the values in a given row, the user should press the "Reset Values" button to the right of the "Summary of Major Power Outages" table.

[1] This time period was selected to align with price forecasts in New York's Draft 2013 State Energy Plan (SEP).

[2] Values are adjusted for inflation using the Gross Domestic Product Implicit Price Deflator, as reported by the U.S. Department of Commerce, Bureau of Economic Analysis on January 30, 2015.

EXHIBIT 2. SUMMARY WORKSHEET

EXAMPLE SITE: EXAMPLE SCENARIO

Site Characteristics

Location of microgrid (State Energy Plan zone)	Long Island (Zone K)
System nameplate capacity	12.095 MW
Average annual generation	132.64 MWh
Number and type(s) of DER utilized:	
Natural Gas	0
Diesel	10
Wind	0
Solar	1
Hydro	0
Other	0

Key Assumptions

Parameter	Unit	Value
Total duration of outage	Days	3
Annual probability of outage	Percent	100%
Discount Rate	Percent	7%
Number of times microgrid fuel would be replenished during outage	n/a	Indefinite

Results Summary

Cost or Benefit Category	Present Value Over 20 Years (2014$)	Annualized Value (2014$)
Costs		
Initial Design and Planning	$3,021,888	$266,584
Capital Investments	$955,463	$71,960
Fixed O&M	$1,148,863	$101,350
Variable O&M (Grid-Connected Mode)	$27,395	$2,417
Fuel (Grid-Connected Mode)	$463,443	$40,884
Emission Control	$0	$0
Emissions Allowances	$0	$0
Emissions Damages (Grid-Connected Mode)	$70,682	$6,235
Total Costs	**$5,687,734**	**$489,430**
Benefits		
Reduction in Generating Costs	$166,870	$14,721
Fuel Savings from CHP	$0	$0
Generation Capacity Cost Savings	$11,894,738	$1,049,326
Transmission & Distribution Capacity Cost Savings	$0	$0
Reliability Improvements	$99,387	$8,768
Power Quality Improvements	$0	$0
Avoided Emissions Allowance Costs	$1,388	$122
Avoided Emissions Damages	$0	$0
Major Power Outage Benefits	$8,609,895	$759,545
Total Benefits	**$20,772,278**	**$1,832,482**
Net Benefits	**$15,084,544**	**$1,343,052**
Benefit/Cost Ratio	**3.65**	
Internal Rate of Return	**127.63%**	

EXHIBIT 3. MAJOR POWER OUTAGE SENSITIVITY ANALYSIS TABLE

Alternate Duration and Frequency: Summary of Major Power Outage Benefits

Total Duration of Outage (Days)	Annual Probability of Outage (Percent)	Present Value of Major Power Outage Benefits (2014$)	Present Value of Total Benefits (2014$)	Benefit/Cost Ratio
	Total	$0		

2. SITE INPUTS

Key Worksheets: *Microgrid Questionnaire, Facility Questionnaire, System Specifications and Costs, Reliability Inputs, Major Power Outage Inputs*

The BCA model uses information from three primary input worksheets in its calculations (System Specifications and Costs, Reliability Inputs, and Major Power Outage Inputs). In addition, the model includes two worksheets that facilitate data entry from two questionnaires (Microgrid Questionnaire and Facility Questionnaire) developed for NY Prize applicants. The user can populate the latter two worksheets by copying and pasting information directly from applicant questionnaires; conduct any necessary data manipulation (*e.g.*, unit conversions); then enter the required information into the primary input worksheets. The inclusion of the Microgrid Questionnaire and Facility Questionnaire worksheets also ensures that the user can easily reference applicant responses by storing all site information in a single file.

For questions that are unlikely to require manipulation or interpretation of responses, the model directly links the input fields in the Microgrid Questionnaire and Facility Questionnaire worksheets to corresponding fields in the primary input worksheets. For questions that may require manipulation, the model uses Excel's comment feature, denoted by a red triangle in the upper right corner of a cell, to provide the user with instructions or other guidance. Exhibit 4 illustrates the type of guidance provided for two instances in which data manipulation is likely to be required. Before running the model, the user should review all information in the primary input worksheets for accuracy and completeness.

3. COST ANALYSIS

The principal cost categories estimated in the BCA model include initial design and planning costs, capital investments, operation and maintenance (O&M) costs, and environmental costs. The latter two cost categories are analyzed for two general operating scenarios: (1) operation of the microgrid in grid-connected mode, and (2) operation of the microgrid in islanded mode during an outage of a given duration.

EXHIBIT 4. EXAMPLE OF EXCEL COMMENT FEATURE

Rate Class	Number of Customers	Average Annual Usage	Economic Sector (Commercial/Industrial only)
Residential	0	0	
Small Commercial/Industrial (<50 annual MWh)	1	18.36	Public Administration
Large Commercial/Industrial (>50 annual MWh)	13	2125	Public Administration

IEc: Sum responses to Q1 in Microgrid Questionnaire

IEc: Input from Q1 in Microgrid Questionnaire

The cost analysis relies on information entered into the System Specifications and Costs primary input worksheet. This information is then used in six cost calculations worksheets (Nominal & PV Costs, Annualized Costs, Capital Costs Calculations, Fuel Costs Calculations, Emissions Costs Calcs, and Power Outage Costs). For all cost categories, the stream of costs ($/year) is reported in the Nominal & PV Costs worksheet, and the present value of these costs is calculated. The stream of payments is also reported in an intermediate outputs worksheet (Annual Costs & Benefits) to compare directly to the annual stream of benefits, the calculation of which is described later in this document. Annualized costs are calculated and reported in the Annualized Costs worksheet. The Summary worksheet draws on information from the Nominal & PV Costs, Annualized Costs, and Annual Costs & Benefits worksheets.

INITIAL DESIGN AND PLANNING COSTS

Key Worksheets: *System Specifications and Costs, Nominal & PV Costs, Annualized Costs*

The costs of developing a microgrid include an initial investment in the project's design, as well as costs associated with obtaining building and development permits, securing financing, marketing the project, and establishing contracts with the local utility and/or bulk energy suppliers.[3] The magnitude of these costs may be substantial, particularly if the project's design is complex or presents novel challenges. The microgrid's developers – including the owner/operator of the distributed energy resources within a proposed microgrid, the owner/operator of the distribution network within the microgrid, and any others engaged in the project's development – are likely to bear the majority of these costs. Costs may also be borne by local utilities and/or bulk energy suppliers to negotiate contracts or develop plans for connecting the microgrid to the macrogrid (NYSERDA, 2011).

As shown in Exhibit 5, the System Specifications and Costs worksheet asks the user to provide an aggregate estimate of a microgrid's design and planning costs. These costs are treated as an initial investment, assumed to occur in 2016, and thus are not discounted in

[3] Interest expenses associated with a project's financing are not included in evaluating project costs from a social welfare standpoint; the equivalent value of such expenses is already captured in the BCA through the application of the discount rate. The transaction costs (*e.g.*, management time) incurred in *securing* financing, however, represent a real resource cost. The model treats these costs as an element of project design and planning.

the model's calculation of present values. In calculating annualized values, planning and design costs are amortized over the life of the project.

EXHIBIT 5. PROJECT COST INFORMATION, EXCLUDING CAPITAL COSTS

Other Cost Information

Category	Parameter	Unit	Value
Planning	Initial Design and Planning Costs	$	3,021,888.00
O&M Costs	Fixed O&M Costs per Year	$/year	101,350.00
	Check: Fixed O&M Costs per MW	*$/MW*	*8,379.50*
	Variable O&M Costs per Unit of Energy Produced	$/MWh	18.22
Fuel Consumption	*Islanded Mode:* Max. period of time for operating without replenishing fuel supply	Days	Indefinite
	Islanded Mode : Fuel consumption if operating in islanded mode for full duration of design event	Gallons/Month	165,432
	Type of fuel offset by new CHP system		
	Fuel savings from new CHP system	MMBtu/year	
Environmental	Capital costs associated with emissions control equipment, if not included above	$	0.00
	Lifespan of emissions control equipment, if not included above	Years	0
	O&M costs associated with emissions control equipment, if not included above	$/MWh	0.00
	Other costs associated with emissions control equipment, if not included above	$/year	0.00
Emissions Rates	CO_2	Tons/MWh	0.79
	SO_2	Tons/MWh	0.0016
	NO_X	Tons/MWh	0.0119
	$PM_{2.5}$	Tons/MWh	0.0001
	$PM_{2.5\text{-}10}$	Tons/MWh	0.0000

Do environmental regulations mandate the purchase of emissions allowances for the microgrid (for example, due to system size thresholds)? No

CAPITAL INVESTMENTS

Key Worksheets: *System Specifications and Costs, Nominal & PV Costs, Annualized Costs, Capital Costs Calculations*

Capital investments must be made to purchase and install the equipment to be incorporated into the microgrid. These costs fall into two general categories: those associated with power generation and energy storage, and those associated with distribution services.

The capital costs for microgrid power generation and energy storage include the cost of the equipment itself and the costs associated with its installation (Herman, 2003). The magnitude of these costs depends primarily on the type and capacity of distributed energy resources and storage technologies employed.

The capital costs for microgrid distribution services include the costs associated with acquisition and installation of the infrastructure that (1) connects distributed energy resources to the microgrid, and (2) connects the microgrid to the macrogrid. The equipment that comprises this infrastructure may include controllers, communication devices, disconnect switches, transformers and substations, capacitor banks, distribution feeders, and other components (Morris et al., 2011; Morris, 2012). The capital costs of a microgrid project may also include "interconnection costs"; i.e., upgrades to the macrogrid necessary to accommodate connection of the microgrid.

As shown in Exhibit 6, the System Specifications and Costs worksheet asks the user to identify the elements of the microgrid's power generation, energy storage, and distribution infrastructure, and to specify the fully-installed cost and engineering life of each component. The user may enter information for up to 30 components.[4] Based on this information, the model projects the 20-year time-stream of capital expenditures the project requires, for each component and for the system as a whole, and calculates the present value of each stream of payments (Capital Costs worksheet). The Capital Costs worksheet also calculates an annualized cost figure for each component, based on its expected useful life. The annualized capital cost for the system as a whole is the sum of the annualized costs calculated for each component.

EXHIBIT 6. CAPITAL COST INPUTS

Capital Cost Information

Capital Component	Installed Cost ($)	Lifespan (round to nearest year)
MG Electrical Infrastructure	$153,000	30
MG Control & Communication	$802,463	30

[4] If the number of components exceeds 30, the user should group components with similar lifespans, and list the total installed costs for these components.

OPERATION AND MAINTENANCE COSTS

Key Worksheets: *System Specifications and Costs, Nominal & PV Costs, Annualized Costs, Fuel Costs Calculations, Fuel Price Forecasts*

Once microgrid equipment is purchased and installed, stakeholders must cover the costs of the system's operation and maintenance (O&M). This includes costs directly associated with power generation and distribution services, as well as costs associated with the provision of ancillary services to the macrogrid (*e.g.*, frequency support, voltage support, peak load support, and black start or system restoration support).

The principal O&M costs associated with a microgrid's power generation and distribution services include:

- The cost of labor to operate and monitor the system (including operator training costs).
- The cost of fuel consumed by the microgrid's power generating equipment.
- The cost of other materials consumed in operating the microgrid (*e.g.*, materials such as oil, fuel filters, coolant fluid, and emissions control catalysts).
- The cost of labor and materials for scheduled and unscheduled maintenance (Herman, 2003).

Many of these costs are likely to vary with utilization of the microgrid (i.e., the amount of electricity it produces); the model identifies these as "variable" O&M costs. Other O&M costs, such as the costs associated with software licenses, are unlikely to vary with utilization of the system; the model designates these as "fixed" O&M costs.

In addition to providing power to its own customers, a microgrid can provide ancillary services that support the operations of the larger macrogrid. Providing these services may impose additional operating costs on microgrid stakeholders. The nature of these costs is described below.

- ***Frequency or Real Power Support:*** Microgrid operations can provide frequency support to the macrogrid network. To provide this support, microgrids set aside certain reserves that can be made available to the macrogrid when needed. Costs to the microgrid include the opportunity cost of maintaining these reserves as well as any additional fuel or other O&M costs associated with increased utilization of equipment, such as power generators, to provide frequency support (Morris, 2012).
- ***Voltage or Reactive Power Support:*** Similar to active power support, microgrids can provide voltage or reactive power support to the macrogrid. This support can enhance power quality and stability within the network. For the microgrid, the cost of voltage support stems primarily from reduced power output; this represents

an opportunity cost for the owner/operator of distributed energy resources within the microgrid (Morris, 2012).[5]

- ***Black Start or System Restoration Support:*** Microgrids can mitigate the effects of a power outage by providing black start support to critical loads and other system loads. This involves providing power to certain loads while the larger macrogrid is undergoing black start procedures to restore operations. In this manner, microgrids can improve reliability and reduce the effects of long outages. Given the low frequency of power outages, the variable O&M costs associated with black start support are likely to be relatively minor. Other costs, however, could prove to be more substantial. These costs include staff training, infrastructure maintenance, and fuel storage costs (Morris, 2012).
- ***Peak Load Support:*** By reducing system loading on the macrogrid, microgrids can support network infrastructure and reduce the possibility of power failures due to peak load congestion. Depending on the configuration of the microgrid, peak load support may or may not impose additional O&M costs. If a microgrid's distributed energy resources are ordinarily all in operation, providing peak load support to the macrogrid may not impose additional O&M costs; however, if a microgrid brings additional distributed energy resources into operation during times of peak load, perhaps exporting power to the macrogrid, additional O&M costs may be incurred for factors such as labor, fuel, and maintenance (Morris, 2012).

The BCA model estimates the O&M costs associated with a project's standard power generation and distribution services and any additional costs associated with the provision of ancillary services. These costs are categorized as follows:

- *Fixed O&M* – costs that are unlikely to vary with the amount of electricity generated.
- *Variable O&M* – costs (other than fuel costs) that are likely to vary with the amount of electricity generated.
- *Fuel Costs* – for distributed energy resources powered by natural gas, petroleum, or other fossil fuels.[6]

The NY Prize applicant questionnaires ask the user to provide a direct estimate of fixed O&M costs, either as an annual average ($/year) or separately for each year if costs are expected to vary over time (e.g., due to maintenance cycles). As directed in the System Specifications and Costs worksheet, shown in Exhibit 7 below, if costs are expected to vary by year, the user should enter the stream of fixed O&M costs directly into the

[5] The provision of reactive power support requires equipment with reactive power control, such as an induction machine. This type of equipment, however, is also necessary for a microgrid to be capable of operating in islanded mode. Thus, microgrids designed with the ability to island may be able to provide reactive power support without incurring additional equipment costs.

[6] The model captures any opportunity costs associated with the provision of ancillary services in its estimate of the energy cost savings the microgrid would provide; thus, separate estimation of such costs is not required.

Nominal & PV Costs worksheet. Otherwise, the user may enter the annual average estimate into the System Specifications and Costs worksheet. As a point of reference, the worksheet also calculates fixed O&M costs per MW of system capacity, although this value is not used in the model's calculations.

EXHIBIT 7. GUIDANCE FOR ENTERING FIXED O&M COST INFORMATION

Other Cost Information

Category	Parameter	Unit	Value
Planning	Initial Design and Planning Costs	$	3,021,888.00
O&M Costs	Fixed O&M Costs per Year	$/year	101,350.00
	Check: Fixed O&M Costs per MW	*$/MW*	*8,379.50*
	Variable O&M Costs per Unit of Energy Produced	$/MWh	18.22
Fuel Consumption	*Islanded Mode:* Max. period of time for operating without replenishing fuel supply	Days	[illegible]
	Islanded Mode: Fuel consumption if operating in islanded mode for full duration of design event	Gallons/M	[illegible]
	Type of fuel offset by new CHP system		[illegible]
	Fuel savings from new CHP system	MMBtu/ye	[illegible]
Environmental	Capital costs associated with emissions control equipment, if not included above	$	[illegible]
	Lifespan of emissions control equipment, if not included above	Years	[illegible]
	O&M costs associated with emissions control equipment, if not included above	$/MWh	[illegible]
	Other costs associated with emissions control equipment, if not included above	$/year	0.00

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Enter value from Q12 in Microgrid Questionnaire unless annual variation is expected. In that case, use values from Q13 directly in the calculations on "Nominal & PV Costs" and "Annualized Costs" tabs

The model estimates variable O&M costs on the basis of two user-specified values: a unit cost factor ($/MWh generated) and an estimate of the average amount of electricity to be generated annually (MWh/year). As noted in the System Specifications and Costs worksheet, the user may need to convert the unit cost factor provided in the applicant questionnaire to $/MWh before entering the value into the appropriate cell in the System Specifications and Costs worksheet.

Fuel costs are calculated in the Fuel Costs Calculations worksheet for each natural gas- or petroleum-fired source based on the average amount of electricity to be generated annually (MWh/year), the user's estimate of fuel consumption per unit of production (MMBtu/MWh), and forecasts of natural gas or petroleum prices ($/MMBtu) developed for New York's Draft 2013 State Energy Plan (SEP).[7] As noted in the System Specifications and Costs worksheet, the user may need to convert fuel consumption per unit of production to MMBtu/MWh before entering the value into the appropriate cell in the System Specifications and Costs worksheet. The System Specifications and Costs worksheet also incorporates scaling factors – one for the price of petroleum and one for the price of natural gas - that allow the user to adjust the forecast energy prices relative to the SEP forecast.

The Fuel Costs Calculations worksheet sums across all distributed energy resources to determine total fuel costs ($/year) for the system as a whole. As a point of reference, the worksheet also calculates a weighted average fuel cost ($/MWh) for the microgrid.

[7] See the Fuel Price Forecasts worksheet for fuel price projections.

ENVIRONMENTAL COSTS

Key Worksheets: *System Specifications and Costs, Nominal & PV Costs, Annualized Costs, Emissions Costs Calcs, Emissions Price Data, Emissions Damages Data*

In order to install and operate the distributed energy resources that will serve microgrid projects, the microgrid's developers may incur costs related to acquiring, installing, operating, and maintaining pollution control equipment. In particular, microgrids that rely upon the combustion of fuels to generate power may incur costs to control emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and/or particulate matter ($PM_{2.5}$ and/or $PM_{2.5\text{-}10}$). These costs will vary with the type of distributed generation technology the project employs, but could prove to be significant (Herman, 2003).

In most cases, the user is likely to include these costs in the capital investment and O&M cost categories described above. However, if this is not the case, the System Specifications and Costs worksheet asks the user to specify the fully-installed cost and engineering life of the emissions control equipment to ensure that these costs are considered. It also asks the user to specify the unit cost of operating and maintaining this equipment ($/MWh), as well as the annual cost of any other expenditures on emissions control ($/year). Based on this information and an estimate of the average amount of electricity the system will generate (MWh/year), the model calculates the total cost of emissions controls on both a present value (Nominal & PV Costs worksheet) and annualized (Annualized Costs worksheet) basis.

In addition to the cost of installing, operating, and maintaining pollution control equipment, microgrid developers may be required to purchase allowances for the emission of certain air pollutants: SO_2 and NO_x, which are subject to the requirements of the Federal Clean Air Act; and CO_2, which in New York is subject to the requirements of the Northeast states' Regional Greenhouse Gas Initiative. The applicability of these requirements depends upon the capacity of the distributed generation source and the technology it employs. The System Specifications and Costs worksheet asks the user to indicate if the microgrid is subject to these requirements. If it is, the model calculates the annual cost of obtaining emissions allowances based on (1) the user's estimate of the average amount of electricity the system will generate (MWh/year); (2) the user's estimate of unit emissions factors for CO_2, SO_2, and NO_x (tons/MWh); and (3) forecasts of allowance prices ($/ton) for each pollutant, as reported in the Draft 2013 SEP.[8] These calculations occur in the Emissions Costs Calcs worksheet.

When emissions are subject to the allowance programs described above, the development of a microgrid should yield no net increase in air pollution. Since the supply of allowances is capped, the acquisition of allowances by the microgrid would be offset by a sale of allowances by other sources, which would need to reduce their emissions accordingly. Thus, the development of the microgrid should have no net impact on public

[8] See the Emissions Price Data worksheet for emissions allowance price projections.

health or environmental quality.[9] Conversely, when emissions are not capped, microgrid operations could result in a net increase in emissions, and thus a negative impact on health or the environment. This is the case for emissions of particulate matter (which may be measured as $PM_{2.5}$and/or $PM_{2.5-10}$) and for any emissions of CO_2, SO_2, and NO_x that are not subject to emission allowance requirements. The Emissions Costs Calcs worksheet estimates damage values ($/year) for such emissions based on (1) the user's estimate of the average amount of electricity the system will generate (MWh/year); (2) the user's estimate of unit emissions factors for CO_2, SO_2, NO_x, and PM, including both $PM_{2.5}$, and $PM_{2.5-10}$ (tons/MWh); and (3) the median estimated marginal damage value ($/ton) presented in a report by the Electric Power Research Institute (Wakefield, 2010). For purposes of sensitivity analysis, the Emissions Damages Data worksheet also reports 5th and 95th percentile marginal damage values for each pollutant; users can employ these values to determine their impact on estimated emissions damage costs.

Importantly, the NY Prize applicant questionnaires do not ask applicants to separately estimate $PM_{2.5}$ and $PM_{2.5-10}$ emissions. This decision reflects feedback from technical engineers that most energy modeling software does not differentiate between the two size classes of emissions. Nevertheless, because social damage values of $PM_{2.5}$ and $PM_{2.5-10}$ differ significantly, the BCA model is designed to allow the user to separately estimate damages associated with $PM_{2.5}$ and $PM_{2.5-10}$ emissions. To do so, the user must make assumptions about the relative proportion of PM emissions in each category. For example, emissions from diesel generators are typically less than one micrometer; thus, for diesel generators, it is reasonable to assume that all PM emissions are $PM_{2.5}$.

4. BENEFIT ANALYSIS

The principal benefit categories estimated in the BCA model include energy benefits, reliability benefits (during outages not caused by major storms), power quality benefits, environmental benefits, and benefits associated with avoiding major power outages (*i.e.*, outages caused by major storms or other events generally regarded as beyond a utility's control). The benefit analysis relies on information entered into each of the three primary inputs worksheets (System Specifications and Costs, Reliability Inputs, and Major Power Outage Inputs). These inputs are then used in 12 benefit calculations worksheets, including eight associated with the calculation of benefits of avoiding major power outages, and one intermediate outputs worksheet. The stream of benefits ($/year) is also reported in the Annual Costs & Benefits worksheet to compare directly to the annual stream of costs.

ENERGY BENEFITS

Key Worksheets: *System Specifications and Costs, Energy Benefits Calcs, Fuel Price Forecasts, Energy and Capacity Price Data, Peak to Avg Price Ratio, Distrib. Capacity Price Data*

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[9] This assumes that the damages attributable to the emissions of a particular pollutant are relatively insensitive to the location of the source. This is arguably the case with emissions of SO_2 and NO_x, the impacts of which manifest on a regional scale, and is clearly the case with emissions of greenhouse gases like CO_2, the impacts of which are global.

Microgrids may provide energy benefits both to their customers and to society as a whole (Morris *et al.*, 2011). The BCA model distinguishes between two types of energy benefits: energy cost savings and capacity cost savings.

Energy Cost Savings

A microgrid can provide energy cost savings if its operation reduces the variable costs (*e.g.*, the consumption of fuel) incurred in the production of electricity. A number of factors may contribute to such savings, including:

- Meeting demand for electricity with technologies that operate at a lower marginal cost than the technologies they displace.
- Incorporating CHP/CCHP systems into a microgrid, thus reducing demand for energy from bulk energy suppliers with little or no increase in the energy costs incurred by the operator of the microgrid.
- Reducing transmission and distribution losses as a result of reliance on distributed energy resources located at an end user's site or in close proximity to end users.
- Providing ancillary services (*e.g.*, reserve power, voltage and frequency regulation, black start support, or peak load support) more efficiently than conventional sources (Wakefield, 2010; Morris *et al.*, 2011).

The BCA model's analysis of energy cost savings estimates the impact of the microgrid on demand for electricity from the macrogrid (MWh/year) based on the amount of electricity (MWh/year) to be generated by the microgrid in grid-connected mode. This reduction in demand for electricity from the macrogrid is adjusted upward by a factor of 7.2 percent, based on NYSERDA's estimate of typical losses in the transmission and distribution of electricity in New York State; application of this factor accounts for the additional energy that would be required to supply electricity to microgrid customers via the conventional grid.[10] The Energy Benefits Calcs worksheet values the reduction in demand for electricity from the macrogrid based on forecasts of energy prices ($/MWh) developed for the Draft 2013 SEP; these forecasts are differentiated by region.[11] As a default, the user can rely on average energy prices for each region. Alternatively, if the microgrid is likely to generate electricity primarily during periods of peak demand, the user can adjust energy prices to reflect the higher value of this electricity. The adjustment is based on the ratio of peak energy prices to average energy prices in each region. The model allows the user to select one of five options to make this adjustment, based on the

[10] In light of the proximity of distributed energy resources to the loads they serve, the calculation assumes negligible losses in the distribution of electricity from these sources. See the Distrib. Capacity Price Data worksheet for the 7.2 percent adjustment factor.

[11] The model incorporates forecasts of energy prices for the Capital Region (Zone F); Hudson Valley (Zones G through I); Long Island (Zone K); New York City (Zone J); and Upstate (Zones A through E).

number of hours each year that are included in the definition of peak demand: the top one percent; top five percent; top 15 percent; top 40 percent; or top 65 percent.[12]

As noted above, microgrids that incorporate CHP or CCHP systems may generate energy cost savings through more efficient use of fuel. To quantify this impact, the System Specifications and Costs worksheet asks the user to specify the type (natural gas or diesel) and amount (MMBtu or gallons per year) of fuel saved. The Energy Benefits Calcs worksheet values the annual reduction in fuel consumption based on the forecasts of fuel prices ($/MMBtu) developed for the Draft 2013 SEP.[13]

Capacity Cost Savings

Society as a whole will benefit if the development of a microgrid defers the need to invest in expansion of the macrogrid's energy generation, transmission, or distribution systems (Morris et al., 2011). These benefits will be realized, however, only if the impact of the microgrid on demand for capacity can be estimated with reasonable certainty.

The BCA model evaluates potential impacts on generating capacity by asking the user to specify the estimated impact of the microgrid on demand for peaking capacity (MW/year), either due to the direct provision of peak load support or as a result of participation by the microgrid's customers in a demand response program. This estimate is adjusted upward by 16 percent to account for the reserve margin that regulated utilities must maintain above anticipated peak load.[14] For example, if the microgrid provides 10 MW of peak load support each year, then the total impact on peaking capacity demand estimated by the model would be 11.6 MW each year. The value of impacts on generating capacity is calculated in the Energy Benefits Calcs worksheet based on forecasts of prices for generating capacity ($/MW-year) developed for the Draft 2013 SEP; like the SEP's forecast of energy prices, its forecasts of capacity prices are differentiated by region.[15]

The evaluation of distribution capacity benefits is similar, relying on the user to specify the potential impact of the microgrid on the transmission and distribution capacity the local utility must maintain (MW/year). The value of impacts on transmission and distribution capacity is calculated based on prices for distribution capacity ($/MW-year) reported by the New York State Public Service Commission (PSC, 2009) and Con Edison (Con Edison Case 13-E-0573, 2013).[16] The model differentiates prices for New York City from other geographic locations in New York State. For New York City, the model incorporates separate price forecasts for capacity in network and non-network (radial or overhead) distribution areas.

[12] See the Energy and Capacity Price Data worksheet for energy price projections. The ratios of peak energy prices to average energy prices that are used to adjust these price projections are included in the Peak to Avg Price Ratio worksheet.

[13] See the Fuel Price Forecasts worksheet for fuel price projections.

[14] See the Energy and Capacity Price Data worksheet for the assumed reserve margin.

[15] See the Energy and Capacity Price Data worksheet for generating capacity price projections.

[16] See the Distrib. Capacity Price Data worksheet for distribution capacity price projections.

The analysis of capacity cost savings (both for generation and distribution) assumes that the microgrid begins to operate in 2016, assigning projected capacity prices for that year to the system's first year of operation. The estimate of capacity cost savings in each subsequent year is based upon the corresponding year's price forecast. Since capacity impacts may vary over a 20-year operating period, the Energy Benefits Calcs worksheet also incorporates annual scaling factors – one for generation and one for distribution – that allow the user to specify the percentage of the maximum capacity benefit that would be realized in any given year.

RELIABILITY BENEFITS

Key Worksheets: *System Specifications and Costs, Reliability Inputs, Power Outage Costs, Reliability Benefits Calcs, Fuel Price Forecasts, DPS Reliability*

The reliability benefits of microgrids are those associated with reductions in the frequency or duration of power outages its customers may face. The ability of microgrids to improve system reliability is particularly important to microgrid customers who require uninterrupted power. For example, hospitals or public service offices may require uninterrupted computer and telecommunication abilities (Gumerman et al., 2003).

To evaluate reliability benefits, the BCA model relies on the web-based U.S. Department of Energy (DOE) Interruption Cost Estimate (ICE) Calculator, which Freeman, Sullivan & Company developed for DOE and Lawrence Berkeley National Laboratory. The ICE Calculator is designed to value interruption costs and reliability improvements in static or dynamic environments (DOE, 2011). Use of this calculator requires the following user-specified inputs:

- Baseline values for two measures of service reliability: the System Average Interruption Frequency Index (SAIFI) and the Customer Average Interruption Duration Index (CAIDI) for the facilities the microgrid would serve.[17, 18]
- The number of residential and non-residential customers served by the microgrid.
- The state where the project is located.

[17] As a means of monitoring service reliability, DPS requires utilities delivering electricity in New York State to collect and regularly submit information regarding electric service interruptions of more than five minutes in length (DPS, 2014). These reports provide a variety of information on each outage, including its duration and cause. This information provides a basis for calculating SAIFI and CAIDI. Reliability information for each utility operating in New York State, compiled from the DPS 2014 Electric Reliability Performance Report, is included in the DPS Reliability worksheet.

[18] The DPS service interruption reporting system specifies 10 cause categories: major storms; tree contacts; overloads; operating errors; equipment failures; accidents; prearranged interruptions; customers' equipment; lightning; and unknown (there are an additional seven cause codes used exclusively for Con Edison's underground network system). SAIFI and CAIDI can be calculated in two ways: including all outages, which indicates the actual experience of a utility's customers; and excluding outages caused by major storms, which is more indicative of the frequency and duration of outages within the utility's control (a major storm is defined as any storm which causes service interruptions of at least 10 percent of customers in an operating area, and/or interruptions with duration of 24 hours or more). The BCA model treats the benefits of averting lengthy outages caused by major storms or manmade events as a separate category; therefore, the analysis of reliability benefits focuses on the effect of a microgrid on SAIFI and CAIDI values that exclude outages caused by major storms.

Using this information, the ICE Calculator develops state-specific default inputs characterizing the customer base. For example, the calculator considers annual energy use by residential, commercial, and industrial customers; the distribution of commercial and industrial customers by economic sector; the prevalence of backup generation among customers; demographic characteristics, such as the median age and income of residential customers; the type of residential dwellings served (e.g., detached, attached, apartments, mobile homes); and the distribution of annual outages by time of day, time of year, and time of week. The calculator allows these inputs to be tailored, if desired, to incorporate site-specific data for the project area.

Once these inputs are specified, the ICE Calculator estimates the annual cost of service interruptions for each class of customer and for all customers combined. These values are generated using the results of an econometric model of customers' willingness-to-pay to avoid service unreliability or willingness to accept compensation for service interruptions (Sullivan et al., 2009).[19]

The BCA model calculates the benefits of improved service reliability based on this estimate of annual service interruption costs. Because the ICE Calculator is only available online, the Reliability Inputs worksheet provides a link to the ICE Calculator website, emulates the ICE Calculator's initial input table, and instructs the user on the values to enter for the analysis, drawing on values from the System Specifications and Costs worksheet. Exhibit 8 shows how the Reliability Inputs worksheet draws on information from the System Specifications and Costs worksheet to populate the input fields required by the ICE Calculator.

The Reliability Inputs worksheet also includes, for reference, the default values that the ICE Calculator will generate for projects located in New York State. The model uses Excel's comment feature to note the data sources relied upon by the ICE Calculator to generate the defaults, which are shaded in purple. The model instructs the user to replace the default values when site-specific information is available. Exhibit 9 provides an example in which the user modified certain default values based on information in the System Specifications and Costs worksheet. In contrast, Exhibit 10 shows that the user chose to use the ICE Calculator's default values for many parameters.

[19] The data underlying the econometric model were collected through 28 studies of electric utility customers across the U.S. between 1989 and 2005.

EXHIBIT 8. USING THE ICE CALCULATOR TO ESTIMATE RELIABILITY BENEFITS, STEPS 1-4: REQUIRED INPUTS

The analysis of the value of reliability improvements relies on the U.S. Department of Energy's Interruption Cost Estimate (ICE) Calculator, which is available online. As instructed below, you must copy input values from this spreadsheet into the ICE Calculator, then paste results back into the spreadsheet. Changing input values in the spreadsheet will NOT update results.

Step	Instructions
1	In your internet browser, navigate to: http://icecalculator.com/
2	Click on "Estimate Interruption Costs"
3	Enter these input values:

Reliability Inputs	
SAIFI; AND	0.67
SAIDI (minutes) OR	
CAIDI (minutes)	75.6
Number of Customers	
Non-Residential	14
Residential	0
Choose 1 or More States	
New York	

Step	Instructions
4	Click "Go"

EXHIBIT 9. USING THE ICE CALCULATOR TO ESTIMATE RELIABILITY BENEFITS, STEPS 5-6: REPLACING DEFAULTS

5 At the top of the screen, you will see a table similar to the table shown below. The ICE Calculator will populate the table with state-specific default values for the number of customers in each C&I size class, as well as for average use (shown to the right); these values are based on FERC data. Replace the default values with data provided for the site you are evaluating.

Customer Category	No. of Customers	Average Usage (Annual MWh)
Medium and Large C&I (Over 50,000 Annual kWh)	13	2,125
Small C&I (Under 50,000 Annual kWh)	1	18.4
Residential	0	7.3

Default Values:

Average Usage (Annual MWh)
892.2
30.2
7.3

6 Scroll down the screen until you reach a table similar to the table shown below. The ICE calculator will populate this table with state-specific default values (highlighted in purple in the tables below or to the right). When available information allows, replace these default values with data pertaining to the customers to be served by the microgrid you are evaluating. Cells that can be updated to reflect site-specific information from the Microgrid and Facility Questionnaires are shaded green in the tables below.

C&I Industry Percentages	Medium and Large C&I	Small C&I
Agriculture, Forestry and Fishing	0.0%	0.0%
Mining	0.0%	0.0%
Construction	0.0%	0.0%
Manufacturing	0.0%	0.0%
Transportation, Communication & Utilities	0.0%	0.0%
Wholesale and Retail Trade	0.0%	0.0%
Finance, Insurance & Real Estate	0.0%	0.0%
Services	0.0%	0.0%
Public Administration	100.0%	100.0%
Unknown Industry	0.0%	0.0%
Total (must add to 100%)	100.0%	100.0%

Default Values:

Medium and Large C&I	Small C&I
0.0%	0.1%
0.3%	0.1%
2.1%	9.9%
12.7%	3.5%
7.8%	4.3%
22.9%	20.7%
8.2%	11.2%
45.8%	50.1%
0.0%	0.0%
0.1%	0.1%

Percent of C&I Customers with:	Medium and Large C&I	Small C&I
No or Unknown Backup Equipment	15.4%	100.0%
Backup Generation or Power Conditioning	84.6%	0.0%
Backup Generation and Power Conditioning	0.0%	0.0%
Total (must add to 100%)	100.0%	100.0%

Medium and Large C&I	Small C&I
54.4%	70.4%
37.2%	26.2%
8.4%	3.4%

EXHIBIT 10. USING THE ICE CALCULATOR TO ESTIMATE RELIABILITY BENEFITS, STEPS 6-7: REVIEWING DEFAULTS

Step	Residential Customer Characteristics	Estimate		
6	Median Household Income	$50,372		
	Residents per Household 0-6 Years Old	0.24	NOTE: These values are not percentages. These are the average number of residents per household within each age range.	
	Residents per Household 7-18 Years Old	0.44		
	Residents per Household 19-24 Years Old	0.21		
	Residents per Household 25-49 Years Old	0.98		
	Residents per Household 50-64 Years Old	0.41		
	Residents per Household 65+ Years Old	0.34		
	Percent with Medical Equipment	5.1%		
	Percent with Backup Generation	6.5%		6.5%
	Percent with Recent Prolonged Outage	71.3%	NOTE: Percent that have experienced an outage of longer than 5 minutes within the past year.	
	Residential Housing Percentages	**Estimated Percentage**		
	Detached	41.8%		
	Attached	4.8%		
	Apartment/Condo	50.9%		
	Mobile Homes	2.5%		
	Manufactured Housing	0.0%		
	Other or Unknown	0.0%		
	Total (must add to 100%)	100.0%		
	Distribution of Outages by Time of Day	**Estimated Percentage**		
	Morning (6 am to 12 pm)	25.0%		
	Afternoon (12 pm to 5 pm)	20.8%		
	Evening (5 pm to 10 pm)	20.8%		
	Night (10 pm to 6 am)	33.3%		
	Total (must add to 100%)	99.9%		
	Distribution of Outages by Time of Year	**Estimated Percentage**		
	Summer (Jun thru Sep)	33.3%		
	Non-Summer (Oct thru May)	66.7%		
	Total (must add to 100%)	100.0%		
	Distribution of Outages by Time of Week	**Estimated Percentage**		
	Weekday (Mon thru Fri)	71.4%		
	Weekend (Sat/Sun/Holiday)	28.6%		
	Total (must add to 100%)	100.0%		
	Distribution of Outages by Advanced Warning	**Estimated Percentage**		
	Advanced Warning Provided	0.0%		
	Advanced Warning Not Provided	100.0%		
	Total (must add to 100%)	100.0%		
7	Click "Go"			

The Reliability Inputs worksheet then instructs the user to run the ICE Calculator and enter the results it generates into the green-shaded cells, as shown in Exhibit 11 below. The results generated by the ICE Calculator represent baseline service interruption costs for each class of customers the microgrid would serve.

EXHIBIT 11. USING THE ICE CALCULATOR TO ESTIMATE RELIABILITY BENEFITS, STEP 8: ENTERING RESULTS

8 Paste results from the table generated by the ICE Calculator into the green cells in the table below:

Sector	No. of Customers	Cost per Event (2011$)	Cost per Average kW (2011$)	Cost per Unserved kWh (2011$)	Total Cost of Sustained Interruptions (2011$)
Medium and Large C&I	13	$6,406.60	$26.40	$21.00	$55,801.70
Small C&I	1	$316.10	$150.50	$119.40	$211.80
Residential	0	$3.60	$4.40	$3.50	$0.00
All Customers	14	$5,971.60	$26.50	$21.00	$56,013.50

The annual benefits of improved service reliability are calculated in the Reliability Benefits Calcs worksheet. These benefits are based on the estimate of annual service interruption costs for all customers provided by the ICE Calculator (Reliability Inputs worksheet) and the user's estimate of the percentage of service interruptions the microgrid would prevent (System Specifications and Costs worksheet). These benefits are calculated net of any additional costs (*e.g.*, variable O&M, fuel, environmental) associated with operating the microgrid while service from the conventional grid is out. Costs associated with operating the microgrid are calculated on a per-hour basis in the Power Outage Costs worksheet and are scaled to the average duration of service interruptions in a given year (hours per year), estimated as the product of SAIFI (events per year) and CAIDI (hours per event). The calculation of operating costs also accounts for the expected failure rate of any existing backup generation.[20]

POWER QUALITY BENEFITS

Key Worksheets: *System Specifications and Costs, Power Quality Benefits Calcs, Power Quality Valuation Data*

The power quality benefits of a microgrid may include reductions in the frequency of voltage sags and swells or reductions in the frequency of momentary outages (*i.e.*, outages of less than five minutes). To estimate these benefits, the Power Quality Benefits Calcs worksheet first calculates the baseline cost of power quality events ($/year) for the customers served by the microgrid. These costs are calculated for three groups:

- Small commercial and industrial customers.
- Medium and large commercial and industrial customers.
- Residential customers.

The estimate of baseline power quality costs is based on the number of customers in each class the microgrid would serve; the baseline frequency of power quality events (events/year), as specified by the user; and the cost of a power quality event ($/event) for

[20] As a default value, the BCA model assumes that backup generators have a 15 percent likelihood of failing (Major Power Outage Std. Values worksheet). This assumption is based on an estimate by the Electric Power Research Institute (Kopytoff, 2012). Users can modify this assumption by specifying an alternative failure rate.

the average customer in each class, as reported in Sullivan *et al*. (2009).[21] The annual benefits of improved power quality are calculated based on the percentage of power quality events the microgrid would prevent, as estimated by the user in the System Specifications and Costs worksheet.

ENVIRONMENTAL BENEFITS

Key Worksheets: *System Specifications and Costs, Environmental Benefits Calcs, Emissions Price Data, Emissions Damages Data, Baseline Emissions Data*

By reducing the demand for electricity from the macrogrid, microgrids may reduce the emission of greenhouse gases and other pollutants from bulk energy suppliers (Morris *et al.*, 2011). The Environmental Benefits Calcs worksheet calculates emissions avoided (tons/year) based on the amount of electricity (MWh/year) to be generated by the microgrid; an adjustment factor of 7.2 percent to account for transmission and distribution losses; and unit emissions factors (tons/MWh) for SO_2, NO_x, CO_2, $PM_{2.5}$ and $PM_{2.5\text{-}10}$ for natural gas combined cycle units.[22] This approach assumes that the energy generated by the microgrid would otherwise have been generated by natural gas combined cycle units.

The Environmental Benefits Calcs worksheet values reductions in emissions of SO_2, NO_x, and CO_2 (tons/year) based on forecasts of allowance prices ($/ton) for each pollutant, as reported in the Draft 2013 SEP.[23] This approach assumes that the energy generated by the microgrid would otherwise have been generated by units subject to emissions allowance requirements for these pollutants. In contrast, the model values reductions in emissions of $PM_{2.5}$ and $PM_{2.5\text{-}10}$ based on the median estimated marginal damage value ($/ton) presented in a report by the Electric Power Research Institute (Wakefield, 2010). For purposes of sensitivity analysis, the Emissions Damages Data worksheet also reports 5th and 95th percentile marginal damage values for $PM_{2.5}$ and $PM_{2.5\text{-}10;}$ users can employ these values to determine their impact on estimated emissions reduction benefits.

In addition to reducing the demand for electricity from bulk energy suppliers, microgrids may reduce the emission of greenhouse gases and other pollutants from commercial boilers through the installation of CHP/CCHP systems (Morris *et al.*, 2011). The Environmental Benefits Calcs worksheet calculates emissions avoided (tons/year) based on information provided by the user on the type (natural gas or diesel) and amount (MMBtu or gallons per year) of fuel saved by the installation of the CHP/CCHP system, and unit emissions factors (tons/MMBtu) for SO_2, NO_x, CO_2, $PM_{2.5}$ and $PM_{2.5\text{-}10}$ for natural gas and distillate oil commercial boilers.[24] Because commercial boilers are not

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[21] See the Power Quality Valuation Data worksheet for the cost of a power quality event for the average customer in each rate class.

[22] See the Distrib. Capacity Price Data worksheet for the 7.2 percent adjustment factor, and the Baseline Emissions Data worksheet for unit emissions factors for natural gas combined cycle units.

[23] See the Emissions Price Data worksheet for emissions allowance price projections.

[24] See the Baseline Emissions Data worksheet for unit emissions factors for SO_2, NO_x, CO_2, $PM_{2.5}$ and $PM_{2.5\text{-}10}$ for natural gas and distillate oil commercial boilers.

currently subject to emissions allowance requirements, the BCA model values reductions in emissions of all pollutants based on the median estimated marginal damage values ($/ton) presented in a report by the Electric Power Research Institute (Wakefield, 2010). For purposes of sensitivity analysis, the Emissions Damages Data worksheet also reports 5th and 95th percentile marginal damage values for each pollutant; users can employ these values to determine their impact on estimated emissions reduction benefits.

BENEFITS OF AVOIDING MAJOR POWER OUTAGES

Key Worksheets: *Summary, System Specifications and Costs, Major Power Outage Inputs, Power Outage Costs, MPO Annual Costs & Benefits, Fire Station Calculations, EMS Calculations, Hospital Calculations, Police Station Calculations, Electric Power Calculations, Wastewater Calculations, Water Calculations, Other Calculations, Major Power Outage Std. Values, Fuel Price Forecasts, Crime Data*

By maintaining commercial, industrial, and public services – including those critical to public health and safety – in the event of a prolonged outage, microgrids can reduce the losses that would otherwise occur during major power outages (i.e., outages caused by major storms or other events generally regarded as beyond a utility's control). The expected value of benefits associated with avoiding major power outages is dependent upon the anticipated frequency and severity of outages caused by major storms or other events that are difficult to predict. For this reason, the model treats the expected frequency and duration of major power outages as a key input to the analysis. Users can explore the implications of alternative assumptions about the frequency and duration of major outages on the cost-effectiveness of a particular project by using the table provided in the Summary worksheet, shown previously in Exhibit 3.

Community microgrids may help to support services at a wide variety of commercial and industrial facilities, as well as services that are critical to public health and safety, such as fire services, emergency medical services (EMS), hospital services, police services, wastewater services, and water services. The BCA model distinguishes between two categories of services in its calculation of the benefits of avoiding major power outages: (1) critical public health and safety services, and (2) other commercial and industrial services. The BCA model includes a series of worksheets, organized by the type of service affected, that allow the user to tailor the valuation of benefits to the characteristics of a particular site. These service-specific analyses draw on information provided in the Major Power Outage Inputs worksheet and default data included in the Major Power Outage Std. Values worksheet. The results of these analyses are reported in the MPO Annual Costs & Benefits worksheet.

For both categories of services, the model employs the same general approach. The model first estimates the value of lost service at each facility, taking into account any existing backup generation capabilities. This includes adjusting for two factors: (1) the expected failure rate of existing backup generation, and (2) the level of service maintained at the facility while operating on backup power. The model then considers the cost of emergency measures that may be necessary either while operating on backup power or in the event of a total loss of power. Finally, the model considers the incremental costs of providing service to the facility while operating both on backup power and with the microgrid in islanded mode. This approach is discussed in more detail in the following sections.

Benefits of Maintaining Critical Services

The maintenance of public health and safety services – including fire services, EMS, hospital services, police services, wastewater services, and water services – could help to avoid or reduce deaths, injuries, and property damage that might otherwise occur if these services were lost during a power outage. A microgrid capable of operating in islanded mode could continue to supply power to providers of these key public services, resulting in a substantial benefit to society as a whole.

To estimate the losses that would occur due to a power outage affecting the facilities providing these critical services, the BCA model incorporates a methodology developed by the Federal Emergency Management Agency (FEMA, 2011). FEMA developed this methodology for use in administering its Hazard Mitigation Grant Program, which employs benefit-cost analysis to determine how to allocate grant funds among competing mitigation projects. The methodology incorporates site-specific data – including the length of time that a service provider is unable to function and the size of the population served by the provider – as well as standard values and formulas to quantify and value the potential impacts of a loss of public services. Exhibit 12 lists both the service categories covered by the FEMA methodology and the impacts that the methodology estimates for each service category. For fire, emergency medical, and hospital services, the methodology assumes that the population normally served by the non-functioning service provider would rely on the next-closest provider able to serve this population. The increased time that would be required for the next-closest provider to respond to a fire or medical emergency is assumed to result in an increase in property damage and health impacts.[25] For police services, the methodology estimates the value of an increase in property and violent crime that would result from a marginal reduction in police presence.[26] For wastewater, water, and electric power services, the methodology assumes that the population served by each provider would be left without the service and estimates the impact of the lost service on economic activity (for commercial users) and on social welfare (for residential users).[27]

[25] For fire and emergency medical services, if the distance to the nearest service provider that could serve the affected population is not available, or if it is not reasonable to assume that the nearest service provider would be responsible for serving the affected population, users can enter the percent increase in average response time that would occur at each facility during a complete loss of power.

[26] If it is not reasonable to assume that police presence would be affected by a complete loss of power, users can enter the percent reduction in police effectiveness that would occur during a complete loss of power.

[27] In some instances the FEMA methodology risks underestimating the true costs of a loss of public services. In the case of EMS, for example, the methodology only calculates the value of lives lost from cardiac arrest; due to a lack of data, it does not attempt to quantify increases in fatalities attributable to other causes.

EXHIBIT 12. CRITICAL SERVICE CATEGORIES AND BENEFITS ESTIMATED BY THE FEMA METHODOLOGY

SERVICE CATEGORY	IMPACTS ESTIMATED
Fire Service	1. Value of property losses due to fires, due to increased response time 2. Value of lives lost and injuries suffered due to fires, due to increased response time
Emergency Medical Service	1. Value of lives lost from cardiac arrest, due to increased response time
Hospital Service	1. Value of extra time spent getting to emergency department (ED) or waiting to be seen 2. Value of extra distance traveled to get to ED 3. Value of lives lost from acute myocardial infarction or unintentional injuries, due to increased time before ED treatment
Police Service	1. Tangible and intangible cost of property crimes 2. Tangible and intangible cost of violent crimes
Wastewater Service	1. Lost economic productivity due to a loss of commercial wastewater service 2. Welfare loss from lost residential service
Water Service	1. Lost economic productivity due to a loss of commercial water service 2. Welfare loss from lost residential service
Electric Power Service	1. Lost economic productivity due to a loss of commercial electric service 2. Welfare loss from lost residential service

The BCA model estimates the public health and safety benefits of a microgrid project by calculating the value of all critical service losses prevented by the microgrid, using the FEMA methodology to estimate the value of the services provided by facilities supplied by the microgrid. For each critical service provider supplied by the microgrid, the Major Power Outage Inputs worksheet asks the user to specify the population served by the provider, whether the provider has backup generating capacity, and additional information required by the FEMA methodology, such as the distance to the nearest service provider able to serve this population (for fire, emergency medical, and hospital services). This information is shown in Exhibit 13 and Exhibit 14. The Major Power Outage Std. Values worksheet reports the standard values used in the FEMA formulas, which in many cases are national or regional averages; users can substitute site-specific information for these standard values if such information is available.[28] With this

[28] Examples of standard values used in the FEMA methodology include annual fire incidence per capita (national average), annual emergency department visits per capita (national average), and annual incidences of property or violent crimes (New York State data, listed separately for metropolitan statistical areas, cities outside of metropolitan areas, and nonmetropolitan counties).

information, the model estimates the expected value of the loss of service that would result from major power outages of different durations, accounting for the expected failure rate of any backup generation in place.[29] The public health and safety benefits of a microgrid are then estimated as the lost value from any outages that would occur in the absence of a microgrid, adjusted by the percent of each service provider's load that can be supported by backup generation. For example, if a facility experiences a 20 percent reduction in the level of service it can provide while operating on backup generation (*i.e.*, the facility is able to maintain 80 percent of its service), the public health and safety benefits of the microgrid project are estimated to equal 80 percent of the lost value that would result from a loss of power to the hospital in the absence of a microgrid.

Because the services listed in Exhibit 12 are of such crucial importance to society, most service providers have redundant backup generation capacity or contingency plans in place to deal with a major power outage. In cases where it is not reasonable to assume that a power outage would lead to a loss of service, the model asks users to enter the costs (both one-time costs and ongoing costs) of any emergency measures that would be implemented during an extended power outage if a microgrid were not in place. For all emergency costs, users can specify scaling factors to test the sensitivity of public health and safety benefits to estimates of costs.

The calculation of these benefits is specific to the service affected and occurs in the Fire Station Calculations, EMS Calculations, Hospital Calculations, Police Station Calculations, Electric Power Calculations, Wastewater Calculations, and Water Calculations worksheets. The benefits are summarized in the MPO Annual Costs & Benefits worksheet.

[29] As a default value, the BCA model assumes that backup generators have a 15 percent likelihood of failing (Major Power Outage Std. Values worksheet). This assumption is based on an estimate by the Electric Power Research Institute (Kopytoff, 2012). Users can modify this assumption by specifying an alternative failure rate.

EXHIBIT 13. MAJOR POWER OUTAGE INPUTS

These inputs can be filled in using the information provided in the Facility Questionnaire.

	Name of Service Provided	Total Value of Service Provided	Population Served by the Facility Experiencing Outage	Number of Residents Left Without Power during Complete Loss of Power	Backup Generation Present in Baseline Scenario	Level of Service Maintained while Using Backup Generation	Hours per day of Microgrid Demand during Outage	One-Time Cost of Operating Backup Generation	Ongoing Cost of Operating Backup Generation	One-Time Cost of Emergency Measures Required while on Backup Power	Ongoing Cost of Emergency Measures Required while on Backup Power
		2014 Dollars/Day	People	People	Yes/No	Percent	Hours	2014 Dollars	2014 Dollars per Day	2014 Dollars per Day	2014 Dollars per Day
Fire Services	N/A	N/A	0	N/A	Yes	100%	24	$0	$0	$0	$0
Emergency Medical Services	N/A	N/A	0	N/A	Yes	100%	24	$0	$0	$0	$0
Hospital Services	N/A	N/A	0	N/A	Yes	100%	24	$0	$0	$0	$0
Police Services	N/A	N/A	0	N/A	Yes	100%	24	$0	$0	$0	$0
Electric Services	N/A	N/A	0	N/A	Yes	100%	24	$0	$0	$0	$0
Wastewater Services	N/A	N/A	2,850	N/A	Yes	100%	24	$0	$0	$0	$0
Water Services	N/A	N/A	0	N/A	Yes	100%	24	$0	$0	$0	$0
Other Service 1:	Sheriff & Jail	$0	N/A	0	Yes	100%	24	$0	$0	$0	$0
Other Service 2:	Other Facilities with Backup Power (Public Works, Board of Election, DPW Garage, Probation/FRES, Skilled Nursing, Quartermaster)	$602,252	N/A	0	Yes	80%	24	$0	$0	$0	$0
Other Service 3:	Other Facilities without Backup Power (Home & Infirmary, Slaughter House, Doctor's Cottage)	$145,814	N/A	0	No	50%	24	$0	$0	$0	$0
Other Service 4:			N/A								
Other Service 5:			N/A								

EXHIBIT 13. MAJOR POWER OUTAGE INPUTS (CONTINUED)

These inputs can be filled in using the information provided in the Facility Questionnaire.

	One-Time Cost of Emergency Measures Required during Complete Loss of Power	Ongoing Cost of Emergency Measures Required during Complete Loss of Power	Distance to Nearest Facility that Can Serve this Population	Alternate Estimate: Percent Increase in Average Response Time	Type of Area Where Population Is Located	% Adjustment Factor for Value of Service Loss	% Adjustment Factor for Cost of Operating Backup Generation	% Adjustment Factor for One-Time Cost of Emergency Measures Required while on Backup Power	% Adjustment Factor for Ongoing Cost of Emergency Measures Required while on Backup Power	% Adjustment Factor for One-Time Cost of Emergency Measures Required during Complete Loss of Power	% Adjustment Factor for Ongoing Cost of Emergency Measures Required during Complete Loss of Power
	2014 Dollars	2014 Dollars per Day	Miles	Percent	N/A	Percent	%	%	%	%	%
Fire Services	$0	$0	0	0%	N/A	100%	100%	100%	100%	100%	100%
Emergency Medical Services	$0	$0	0	0%	Suburban	100%	100%	100%	100%	100%	100%
Hospital Services	$0	$0	0	N/A	N/A	100%	100%	100%	100%	100%	100%
Police Services	$4,000	$0	N/A	N/A	Metropolitan Statistical Area	100%	100%	100%	100%	100%	100%
Electric Services	$0	$0	N/A	N/A	N/A	100%	100%	100%	100%	100%	100%
Wastewater Services	$0	$0	N/A	N/A	N/A	100%	100%	100%	100%	100%	100%
Water Services	$0	$0	N/A	N/A	N/A	100%	100%	100%	100%	100%	100%
Other Service 1:	$35,000	$40,680	N/A	N/A	N/A	100%	100%	100%	100%	100%	100%
Other Service 2:	$0	$0	N/A	N/A	N/A	80%	100%	100%	100%	100%	100%
Other Service 3:	$0	$0	N/A	N/A	N/A	50%	100%	100%	100%	100%	100%
Other Service 4:			N/A	N/A	N/A						
Other Service 5:			N/A	N/A	N/A						

Benefits of Maintaining Other Commercial and Industrial Services

The development of a microgrid may also support operations at a wide range of commercial and industrial facilities. The FEMA methodology does not estimate values for these types of services. As an alternative, the BCA model relies on the ICE Calculator to assess the value of the service that would be lost in the event of a major power outage.

To estimate the value of service for a given facility, the user can run the ICE Calculator using the link provided on the Reliability Inputs worksheet. The user should consider the following when running the ICE Calculator:

- SAIFI and CAIDI values should be calculated to reflect the expected duration of the prolonged outage. The ICE Calculator will not accept CAIDI values greater than 480 minutes (eight hours). Therefore, to evaluate the effects of a longer outage, the user must increase SAIFI. For example, to evaluate the effects of a 16-hour outage, the user may enter a value of two for SAIFI and a value of 480 for CAIDI.
- The user should always adjust the ICE Calculator default values for customer rate class, economic sector, average annual usage, and the presence of backup generation to reflect the characteristics of that facility.

After running the ICE Calculator, the user should inflate the resulting value of service from 2011 dollars to 2014 dollars using the 1.05 adjustment factor shown in the GDP Def worksheet. The user can enter the inflated value into the Major Power Outage Inputs worksheet as the total value of service provided by that facility. In addition, the user should enter information on the facility's existing backup generation capabilities, if any, in the Major Power Outage Inputs worksheet. The model will incorporate both the total value of the service provided and backup generation capabilities in its calculation of benefits. The calculation of these benefits occurs in the Other Calculations worksheet, and the results are summarized in the MPO Annual Costs & Benefits worksheet.

The MPO Annual Costs & Benefits worksheet, shown in Exhibit 14, summarizes all benefits of avoiding major power outages, including those associated with both critical services and other commercial and industrial services. This worksheet then calculates the total benefit net of any additional costs (*e.g.*, variable O&M, fuel, environmental) associated with operating the microgrid while service from the conventional grid is out. Costs associated with operating the microgrid during the outage are calculated on a per-hour basis in the Power Outage Costs worksheet and are scaled to the duration of the outage being analyzed in the model, as specified by the user in the Summary worksheet.

EXHIBIT 14. MPO ANNUAL COSTS & BENEFITS WORKSHEET

Annual Benefit Summary	
Benefit Type	**Annual Value**
Fire Station Benefits	$0
EMS Benefits	$0
Hospital Benefits	$0
Police Station Benefits	$600
Electric Power Benefits	$0
Wastewater Benefits	$57,365
Water Benefits	$0
Other Benefits	$704,806

Year	Benefit Type									Costs				Net Benefits
	Fire Station	EMS	Hospital	Police Station	Electric Power	Wastewater	Water	Other	Total	O&M Costs	Fuel Costs	Emissions Damages	Total	
2016	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,502	$393	$3,051	**$759,719**
2017	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,552	$393	$3,102	**$759,668**
2018	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,566	$393	$3,116	**$759,655**
2019	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,583	$393	$3,132	**$759,638**
2020	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,602	$393	$3,151	**$759,619**
2021	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,628	$393	$3,178	**$759,593**
2022	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,649	$393	$3,198	**$759,572**
2023	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,669	$393	$3,219	**$759,552**
2024	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,691	$393	$3,241	**$759,530**
2025	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,722	$393	$3,271	**$759,499**
2026	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,736	$393	$3,286	**$759,485**
2027	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,759	$393	$3,309	**$759,462**
2028	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,782	$393	$3,331	**$759,439**
2029	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,798	$393	$3,348	**$759,423**
2030	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,826	$393	$3,376	**$759,395**
2031	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,845	$393	$3,394	**$759,376**
2032	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,863	$393	$3,412	**$759,358**
2033	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,878	$393	$3,428	**$759,343**
2034	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,891	$393	$3,440	**$759,330**
2035	$0	$0	$0	$600	$0	$57,365	$0	$704,806	**$762,771**	$157	$2,900	$393	$3,450	**$759,321**

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