ICE Calculator 2.0: Assisting Consumer Advocates, Utilities, and Regulators Estimate the Costs of Power Outages

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November 11, 2025

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Agenda

- ❑ Motivation for updating the ICE Calculator
- ❑ ICE Calculator is being updated in at least three phases
- ❑ Surveying approach and results
- ❑ Modeling approach and results
- ❑ ICE Calculator website and API
- ❑ Simple comparison of ICE 2.0 to 1.0
- ❑ Upcoming milestones

Motivation for updating the ICE Calculator

ICE Calculator estimates customer costs of shorter duration interruptions

- Berkeley Lab's Interruption Cost Estimate (ICE) Calculator is the leading and only publicly-available tool for estimating the customer cost impacts of power interruptions

- Development of the ICE Calculator was sponsored by the U.S. Department of Energy Office of Electricity

- ICE Calculator is being used to:
  - Support internal utility reliability planning activities
  - Provide a basis for discussing utility reliability investments with regulators
  - Assess the economic impact of past power outages

Motivation for updating the ICE Calculator

- The original ICE Calculator, ICE 1.0, is based on utility-sponsored customer surveys
- Reliance on ICE 1.0 has been challenged because the surveys are:
  - Dated—many of the surveys are 25+ years old
  - Not statistically representative of all regions of the U.S.
  - Limited survey data available for estimating the cost of interruptions over 12 hours

Summary of ICE 1.0 Surveys

Utility Company	Survey Year	Number of Observations			Min. Duration (Hours)	Max. Duration (hours)
		Medium and Large C&I	Small C&I	Residential		
Southeast-1	1997	90			0	1
Southeast-2	1993	3,926	1,559	3,107	0	4
	1997	3,055	2,787	3,608	0	12
Southeast-3	1990	2,095	765		0.5	4
	2011	7,941	2,480	3,969	1	8
Midwest-1	2002	3,171			0	8
Midwest-2	1996	1,956	206		0	4
West-1	2000	2,379	3,236	3,137	1	8
West-2	1989	2,025	5		0	4
	1993	1,790	825	2,005	0	4
	2005	3,052	3,223	4,257	0	8
	2012	5,342	4,632	4,106	0	24
Southwest	2000	3,991	2,247	3,598	0	4
Northwest-1	1989	2,210		2,126	0.25	8
Northwest-2	1999	7,091		4,299	0	12

Updating and upgrading the ICE Calculator

Berkeley Lab and Resource Innovations have:

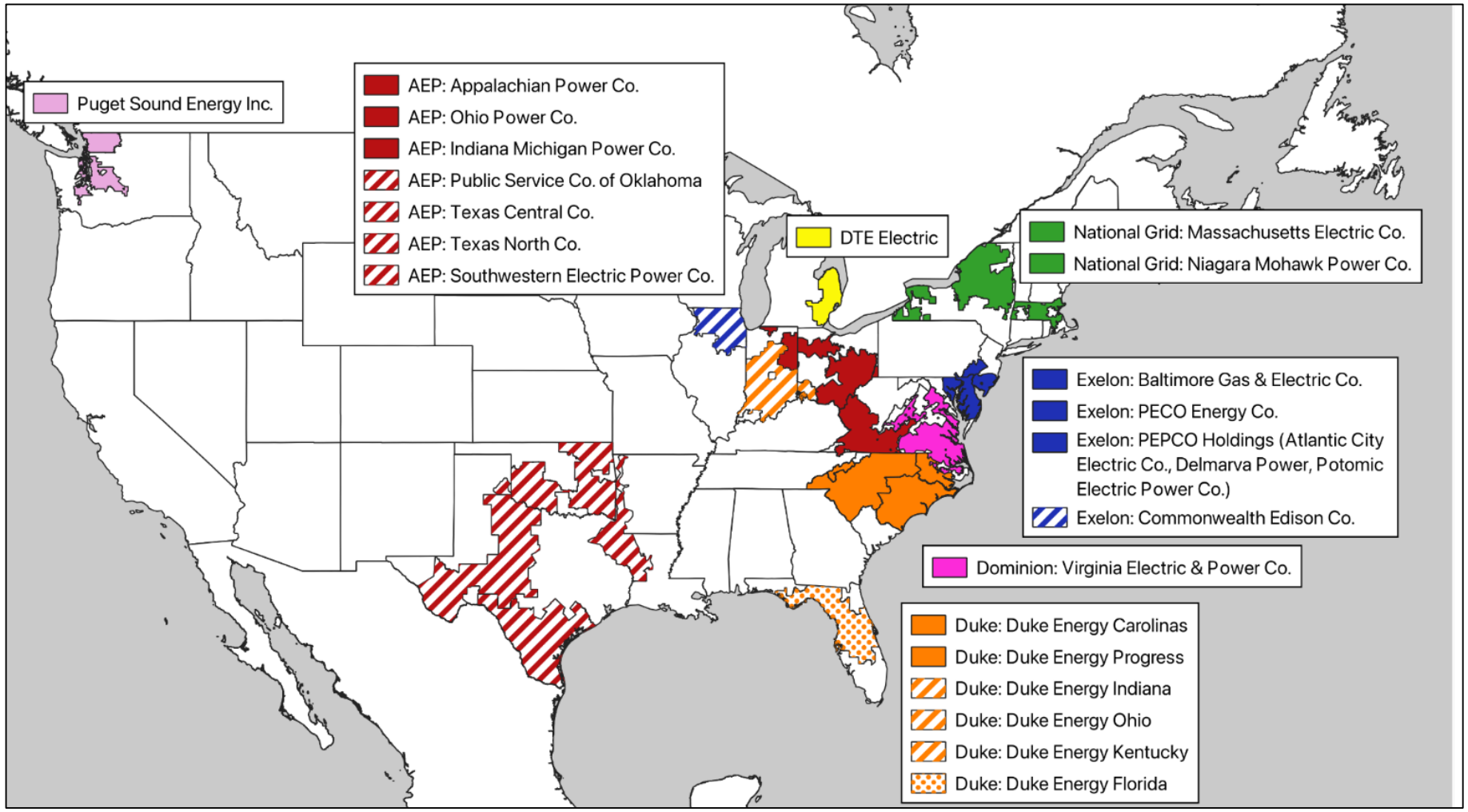
- ❑ Created a Project Executive Committee (PEC) made up of the sponsoring utilities
- ❑ Created a Project Advisory Committee (PAC) made up of well-known external stakeholders, including NASUCA
- ❑ Received key feedback and/or approvals from PEC and PAC throughout the Initiative
- ❑ Developed a consistent set of short duration (up to 24 hours) customer interruption cost surveys
- ❑ Coordinated consistent administration of surveys
- ❑ Developed new short duration customer damage function (CDF) equations with new survey information
- ❑ Updated the ICE Calculator website including new enhancements

ICE Calculator is being updated in phases

Update of ICE Calculator happening in phases

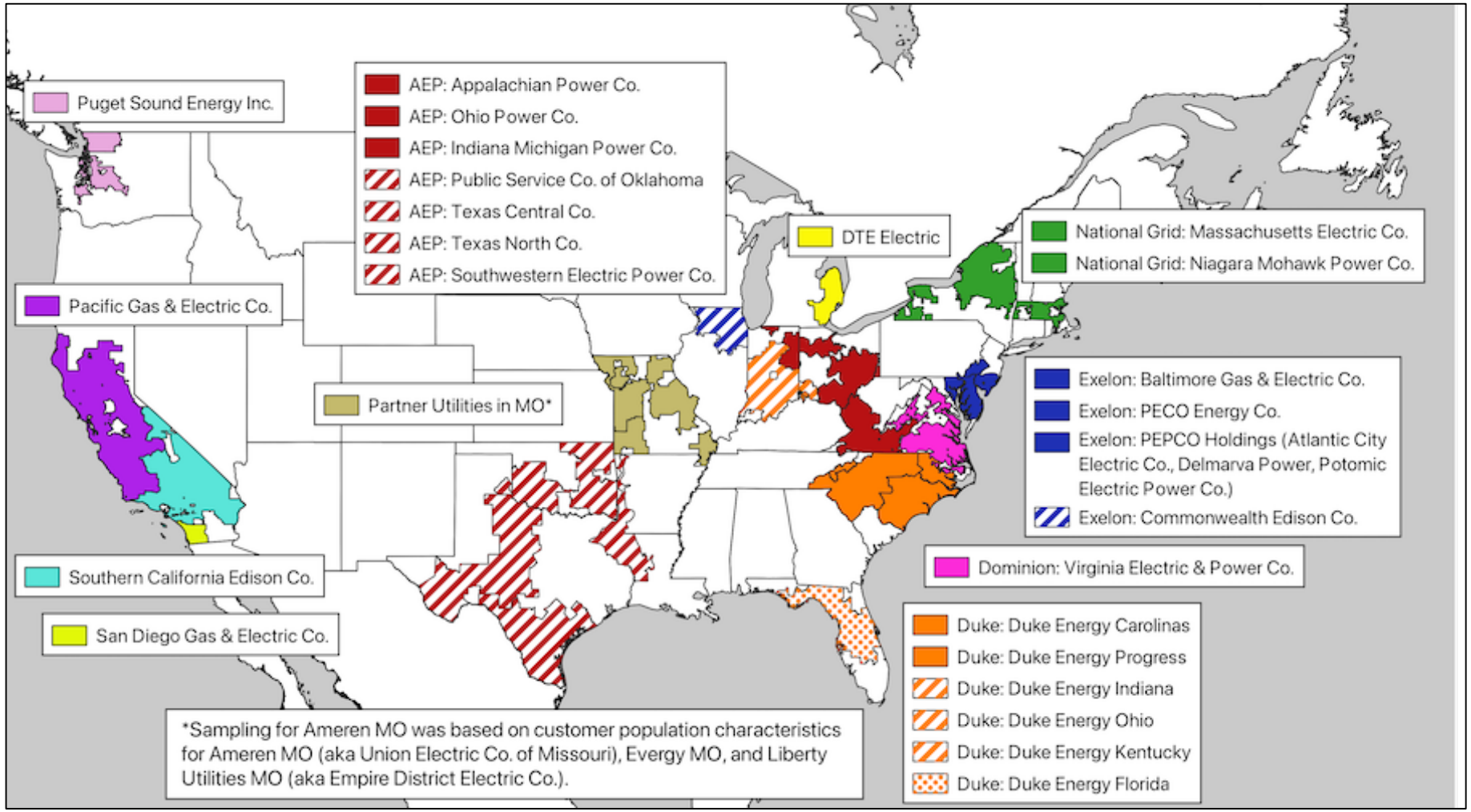
- Phase 1 (complete)
  - Based on 11 surveys conducted in Eastern and Midwestern U.S., with one utility in the Pacific Northwest
  - ICE 2.0 version of ICE Calculator released April 28, 2025
  - Updated customer damage functions
  - Upgraded web interface with enhanced capabilities
- Phase 2 (nearing completion)
  - Surveying recently completed for California investor-owned utilities and Missouri utilities
  - Another ICE Calculator update expected late 2025/early 2026
- Phase 3 (in process)
  - Surveying in process with select utility cooperatives in the U.S.
  - Surveying early next year with another Western utility
  - Continue to seek additional utility partners, especially in New England, Upper Great Plains, Rockies, and Desert Southwest

Participating utilities: Phase 1



- ❑ 8 sponsors
- ❑ 11 distinct survey activities
- ❑ 24 investor-owned utility distribution service territories represented

Participating utilities: Phase 1 and 2



- ❑ 12 sponsors
- ❑ 15 distinct survey activities
- ❑ 30 investor-owned utility distribution service territories represented

Phase 3

- ❑ We received support from U.S. DOE to partner with NRECA to survey select rural cooperatives across the U.S.
- ❑ One utility in the West
- ❑ Recruiting ongoing

Surveying approach and results

Valuation approach

Residential Customers	Non-residential Customers
Willingness-to-pay for hypothetical backup service*	Direct cost = value of lost production + interruption related costs – interruption related savings
Residential costs are often related to inconvenience. However, potential tangible costs include: ● Relocation costs ● Buying supplies ● Going out to eat ● Inability to work	Interruption-related costs: ● Labor costs to make up any lost production (which can be made up) ● Labor costs to restart the production process ● Material costs to restart the production process ● Costs resulting from damage to input feed stocks ● Costs of re-processing materials (if any) ● Cost to operate backup generation equipment
	Interruption-related savings: ● Savings from unpaid wages during the interruption (if any) ● Savings from the cost of raw materials not used because of the interruption ● Savings from the cost of fuel not used ● Scrap value of any damaged materials

*One-and-one-half-bound dichotomous choice contingent valuation (Cooper, Hanemann, and Signorello 2002)

Survey overview

- ❑ Three different customer surveys: residential, small/medium non-residential (SMNR), and large non-residential (LNR)
- ❑ Four interruption durations: momentary (up to 5 min), 2 hours, 8 hours, and 24 hours
- ❑ Four interruption scenarios: season, day of week, time of day, and advanced warning
- ❑ One longer duration (3 days) scenario question (not used to update the ICE Calculator)
- ❑ Target responses per survey: 250 residential, 250 SMNR, and 67 LNR
- ❑ Stratified sample of customers in each class based on usage

Example set of interruption scenarios for a respondent

Scenario	Season	Time of Week	Onset Time	Advance Warning	Duration	Pivot
A	Summer	Weekday	2:00 PM	No	5 minutes or less	Weekend
B	Summer	Weekday	2:00 PM	No	2 hours	Weekend
C	Summer	Weekday	2:00 PM	No	24 hours	Weekend

Survey responses: All customers

Segment	Customer Sampling Population	Customers Sampled	Response Target	Total Responses	Overall Response Rate	Validated Responses	Validated Response Rate
Residential	22,276,695	35,743	2,750	3,316	9.3%	3,026	8.5%
Non-residential	2,141,558	90,464	3,487	4,579	5.1%	3,874	4.3%

*Initial responses were screened for invalid, illogical, or outlier responses

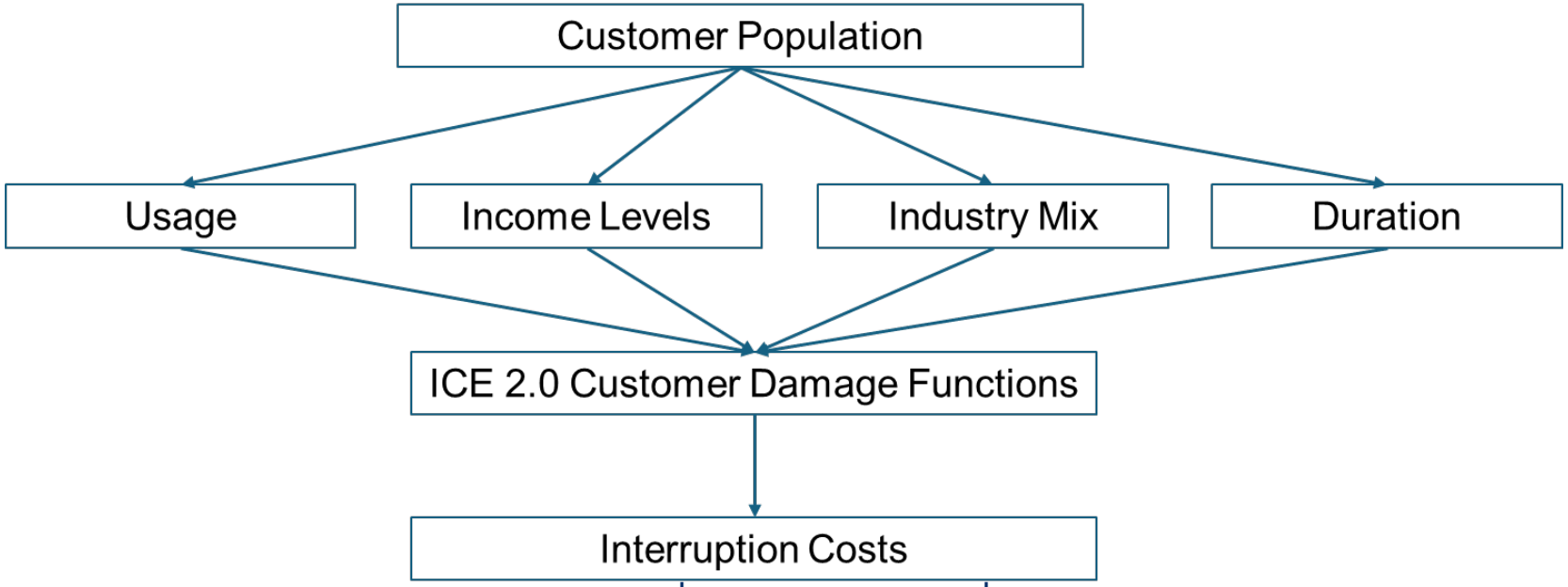
Validated survey responses

Utility	Validated Residential Responses	Validated Non-residential Responses
AEP East	314	342
AEP West	263	301
ComEd	259	369
Duke Energy Carolinas	270	404
Duke Energy Florida	267	367
Duke Energy Midwest	280	384
DTE Electric	271	351
Dominion Energy	281	288
Exelon	270	294
National Grid	275	350
PSE	276	424
Total	**3,026**	**3,874**

Modeling approach and results

Goal: Develop “customer damage functions” (CDF)

- LBNL/RI processed the survey responses and developed customer damage functions
- These equations correlate interruption costs to a range of explanatory variables
  - Duration, electricity consumption, income, industry types, and more
- The customer damage functions allow users to estimate interruption costs for specific customer populations
  - For example, costs could be estimated at the circuit level if the characteristics of the customers served on that specific circuit are known



Residential model selection: Potential and selected explanatory variables

Potential Model

Continuous Variables

- Interruption duration (in minutes)
- Annual electricity usage (in kWh)
- GDP per kWh (collected at the state level)

Categorical Variables

Interruption Onset Time
- Morning
- Midday
- Evening

Season
- Summer
- Winter

Day of Week
- Weekday
- Weekend

Advance Warning
- Yes
- No

Previous Interruption in Last 12 Months
- Yes
- No

Persons in Household
- 1-2 people
- 3+ people

Ownership of Backup Generation
- Yes
- No

Work from Home
- Yes
- No

Age of Respondent
- Under 40 years
- 40-70 years
- 70+ years

Total Household Income
- Under $50,000 per year
- $50,000-$100,000 per year
- $100,000-$150,000 per year
- Over $150,000 per year

Housing Type
- Apartment/Condominium
- Attached Single-Family
- Detached Single-Family
- Mobile Home
- Unknown/Other

Model Selection →

Final Model

Continuous Variables

- Interruption duration (in minutes)
- Annual electricity usage (in kWh)

Categorical Variables

Season
- Summer
- Winter

Ownership of Backup Generation
- Yes
- No

Work from Home Status
- Yes
- No

Total Household Income
- Under $50,000 per year
- $50,000-$100,000 per year
- $100,000-$150,000 per year
- Over $150,000 per year

Non-Residential model selection: Potential and selected explanatory variables

Potential Model

Continuous Variables

- Interruption duration (in minutes)
- Annual electricity usage (in kWh)
- GDP per kWh (collected at the state level)

Categorical Variables

Interruption Onset Time
- Morning
- Midday
- Evening

Season
- Summer
- Winter

Day of Week
- Weekday
- Weekend

Advance Warning
- Yes
- No

Previous Interruption in Last 12 Months
- Yes
- No

Ownership of Backup Generation
- Yes
- No

Industry
- Accommodation and Food Services
- Administrative and Support and Waste Management and Remediation Service
- Agriculture, Forestry, Fishing and Hunting
- Arts, Entertainment, and Recreation
- Construction
- Educational Services
- Finance and Insurance
- Health Care and Social Assistance
- Information (e.g., Data Centers)
- Management of Companies and Enterprises
- Manufacturing
- Mining, Quarrying, and Oil and Gas Extraction
- Other Services
- Professional, Scientific, and Technical Services
- Public Administration
- Real Estate and Rental and Leasing
- Retail Trade
- Transportation and Warehousing
- Utilities
- Wholesale Trade

Model Selection →

Final Model

Continuous Variables

- Interruption duration (in minutes)
- Annual electricity usage (in kWh)

Categorical Variables

Advance Warning
- Yes
- No

Day of Week (Probit Only)
- Weekday
- Weekend

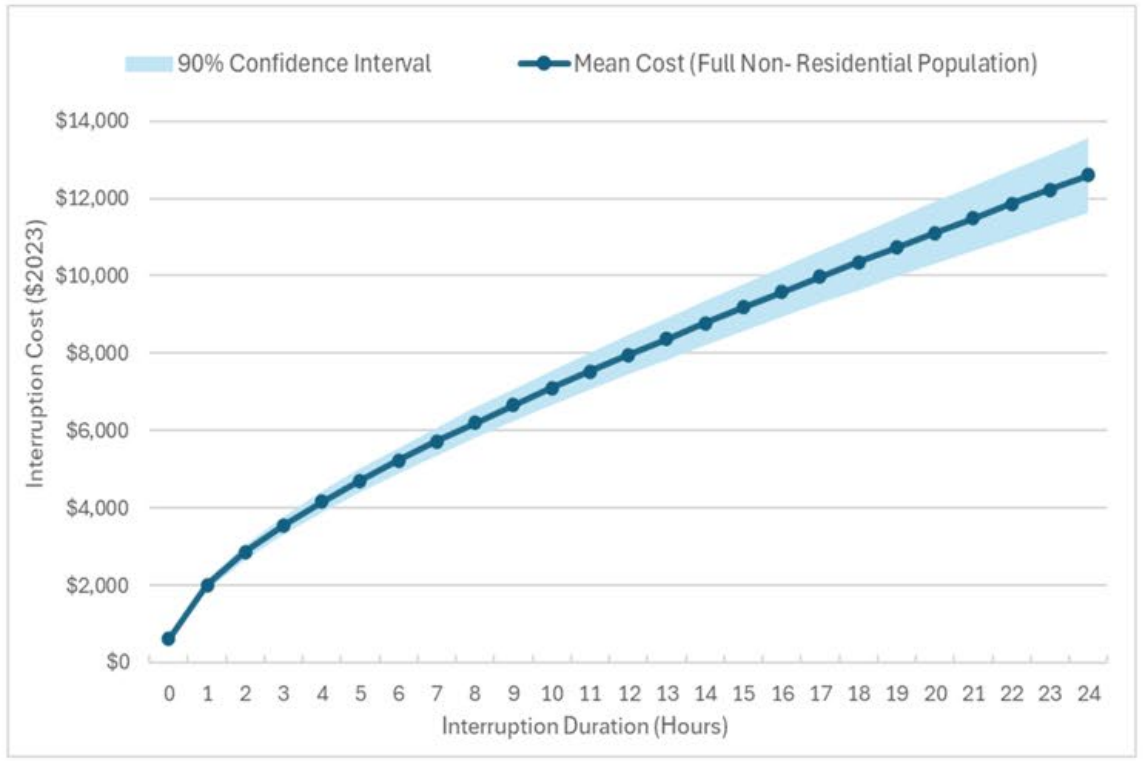
Industry (GLM Model Only)
- Health Care and Social Assistance
- Manufacturing
- All other industries

- ❑ For modeling purposes, the SMNR and LNR responses were combined into one non-res segment
- ❑ The single non-res model can estimate costs for all customer segmentations, regardless of size
- ❑ Users can input usage values into the tool that align with their jurisdictions definition of “small”, “medium”, or “large” customers

Predicted interruption costs by duration (default values; 90% confidence)

Residential

Non- Residential

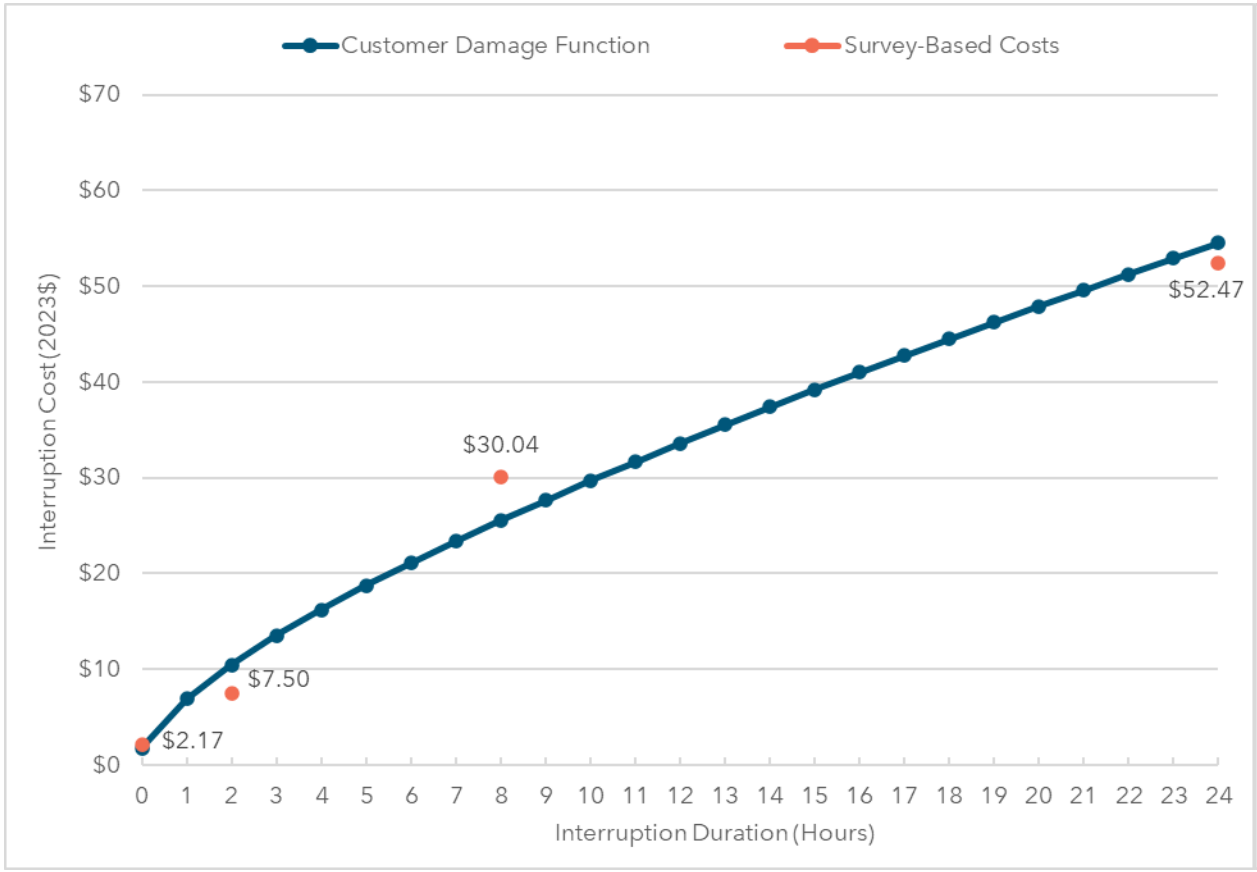


Modeled results (2023$)

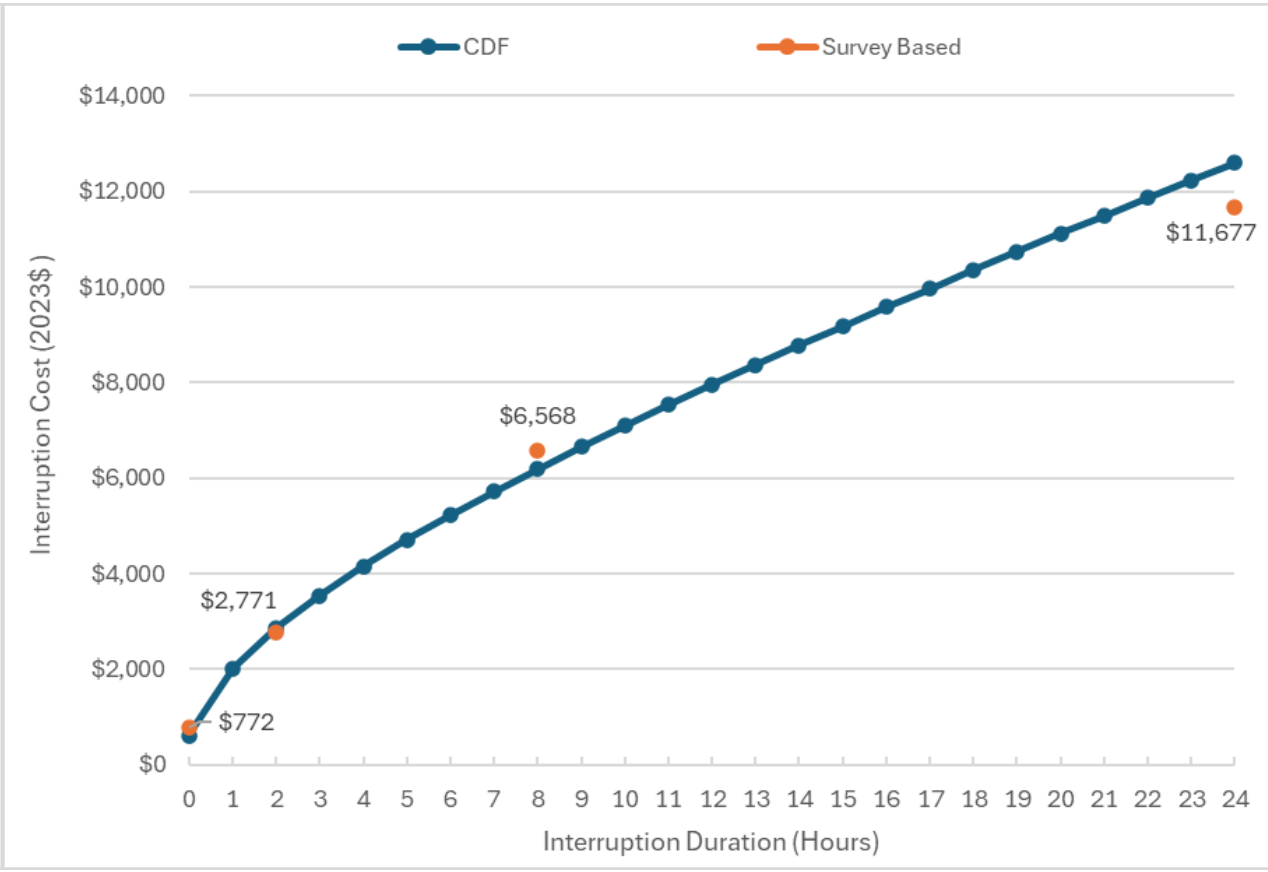
Duration of Power Interruption Event	Cost per Event	Cost per kW	Cost per Unserved kWh	Cost per CMI
Residential				
Momentary	$1.80	$1.50	$18.03	$0.36
2 Hours	$10.49	$8.62	$4.31	$0.09
8 Hours	$25.55	$21.21	$2.65	$0.05
24 Hours	$54.52	$44.76	$1.86	$0.04
Non-residential				
Momentary	$609	$43	$521	$122
2 Hours	$2,839	$202	$101	$24
8 Hours	$6,172	$440	$55	$13
24 Hours	$12,646	$902	$38	$9

CDF vs. survey-based interruption costs

Residential

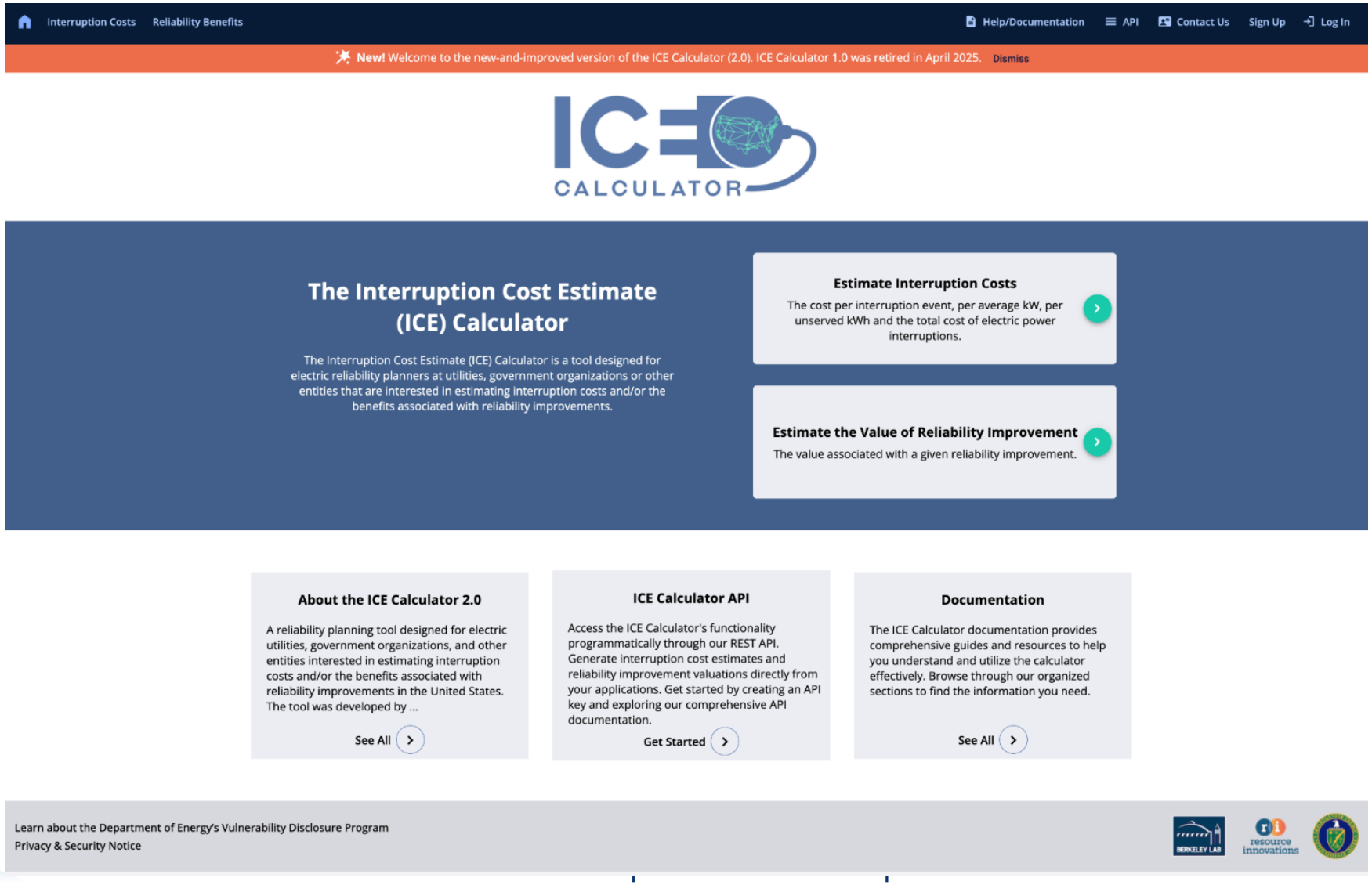


Non- Residential

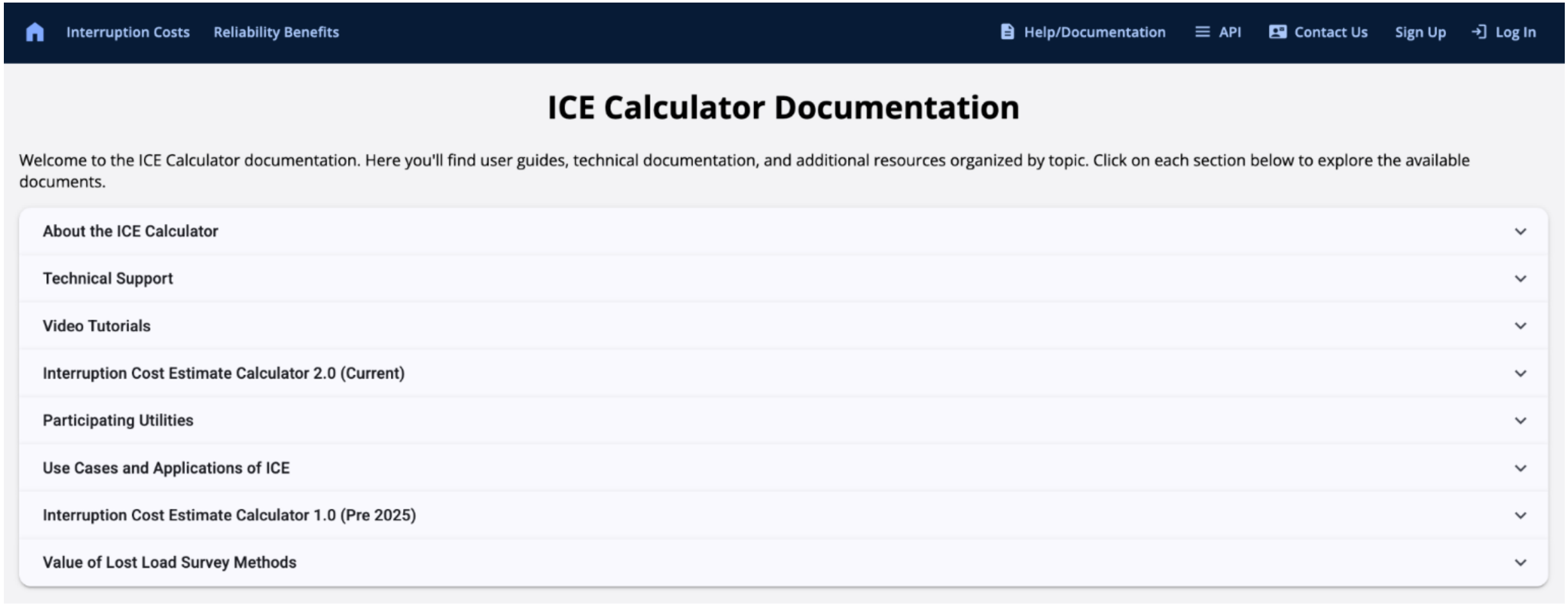


ICE Calculator website and API

ICE 2.0 website: https://icecalculator.com/

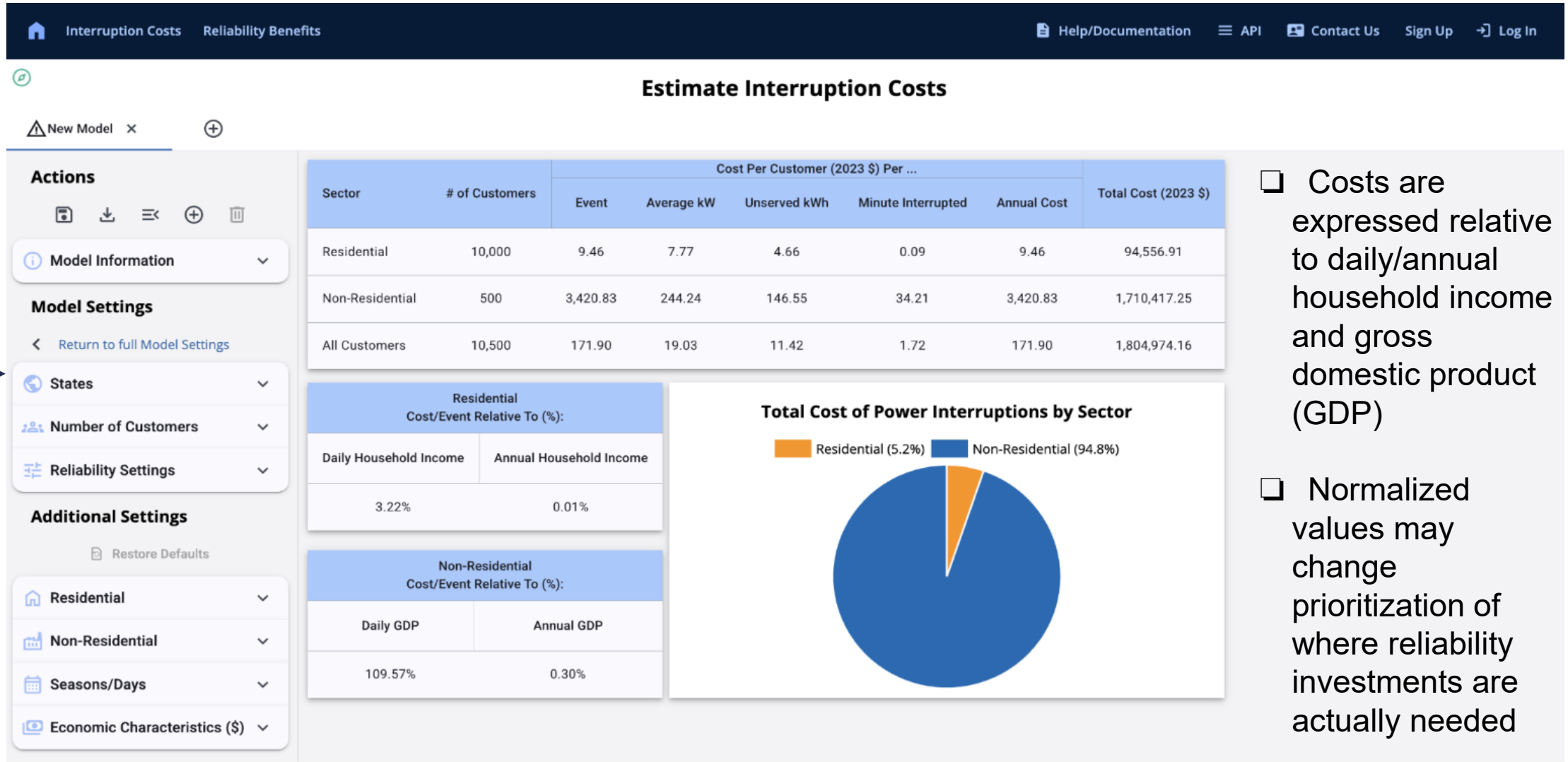


Help/Documentation page



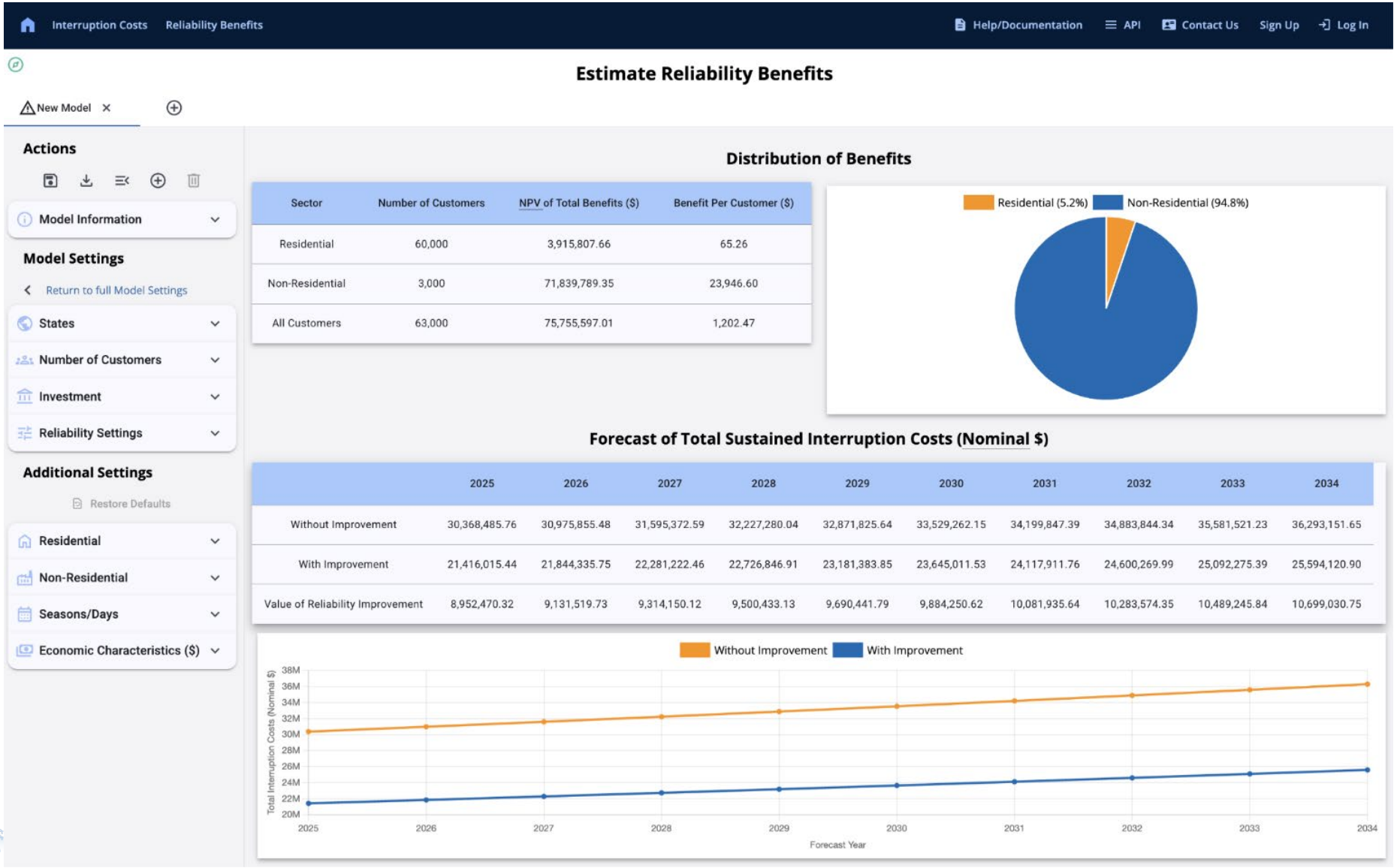
Estimate interruption costs

Customize model inputs →

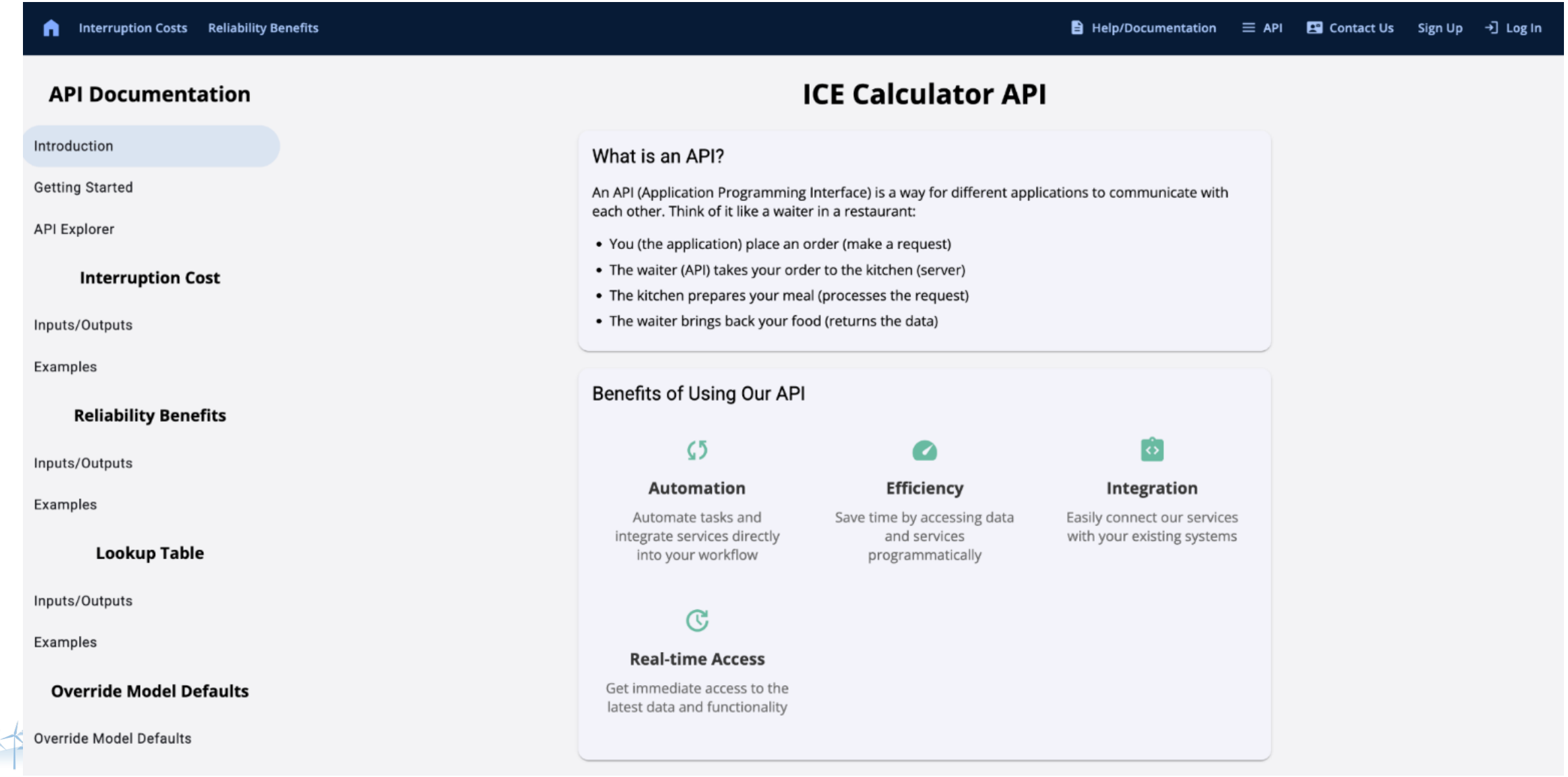


- ❑ Costs are expressed relative to daily/annual household income and gross domestic product (GDP)
- ❑ Normalized values may change prioritization of where reliability investments are actually needed

Estimate reliability benefits

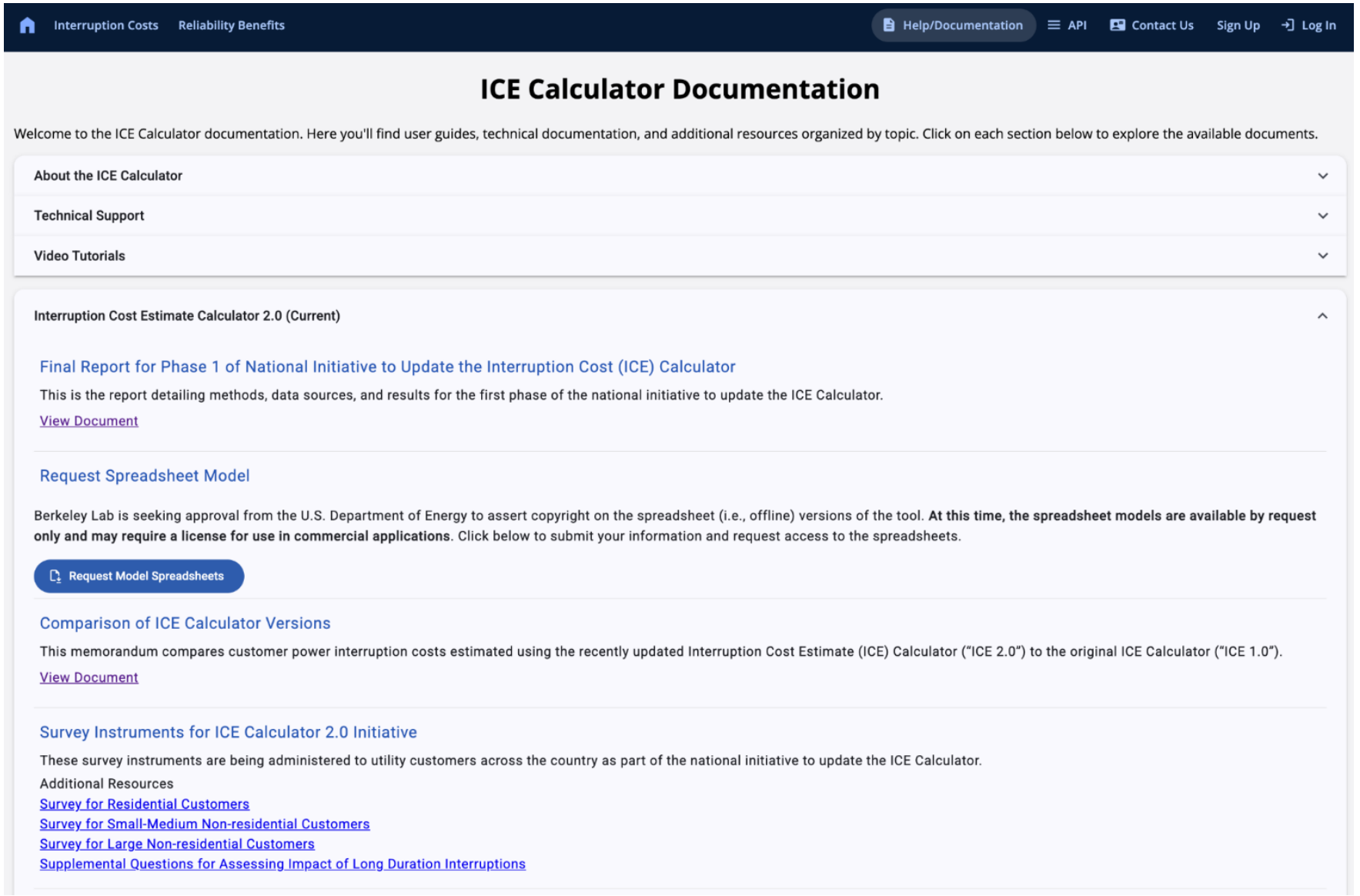


Application programming interface (API)



Request spreadsheet model (non-commercial use only)

- ❑ Users can request spreadsheet-based version of ICE 2.0
- ❑ We are sharing these on a case-by-case basis
- ❑ Spreadsheets will be made available if not shared outside of organization and not used for commercial purposes
- ❑ ICE 1.0 spreadsheet is available on website



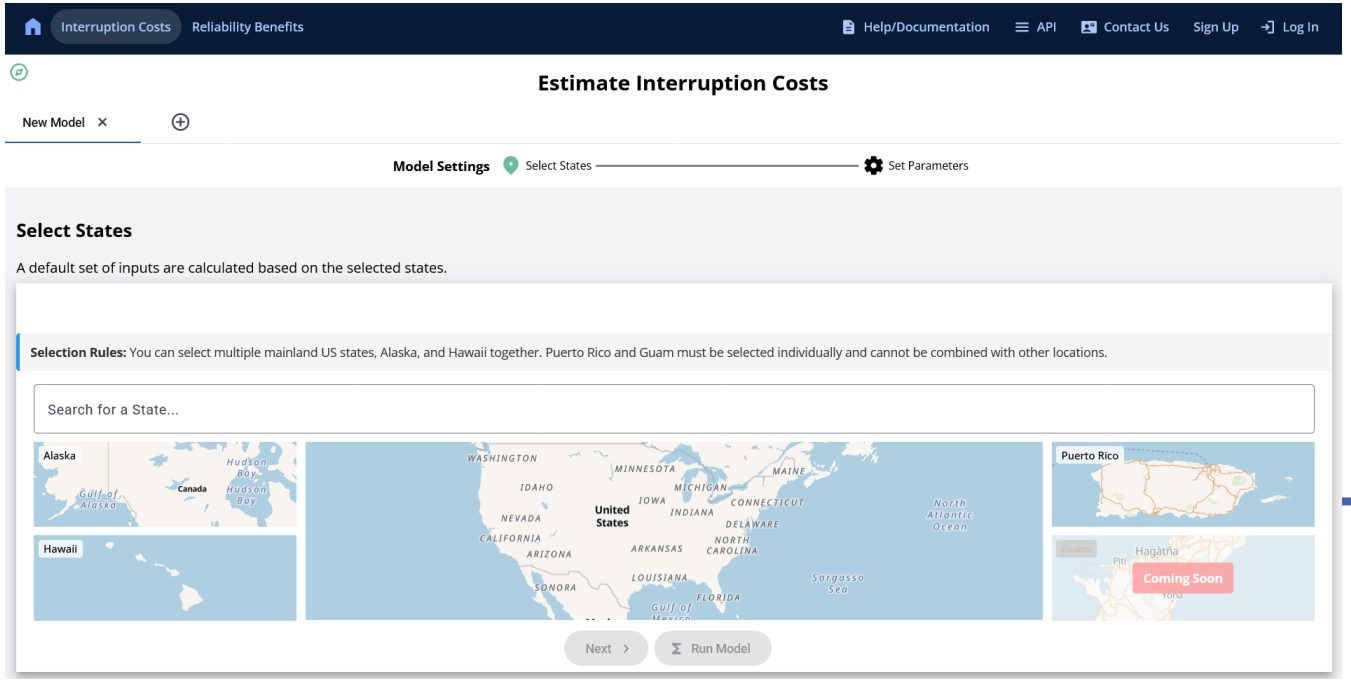
Comparison of ICE 2.0 to 1.0

Summary of differences between ICE 1.0 and 2.0

	ICE 1.0	ICE 2.0
Surveys Conducted (Years)	● 1989-2012	● 2022-2024 (Phase 1)
Survey Approach	● Administered independently ● Information on sample designs and recruitment procedures not available ● Different surveys with different questions	● LBNL/Resource Innovations (RI) administered in a fully coordinated manner ● Consistent sample designs and recruitment procedures ● Identical set of survey questions ● One-and-one-half-bound dichotomous choice contingent valuation (residential)
Geographic Coverage	● 15 distinct surveying efforts conducted across 10 utility service territories ● Mostly conducted in western and southeastern U.S.	● 11 distinct survey activities conducted across 24 utility service territories ● Eastern and midwestern U.S. as well as the pacific northwest (future phases will include additional regional representation)
Interruption Durations Considered	● Varied and generally limited to 12 hrs or less	● Momentary (lasting up to 5 min), 2 hrs, 8 hrs, and 24 hrs
Customer Damage Functions	● Residential ● Small non-residential ● Medium/large non-residential	● Residential ● Non-residential

Upcoming milestones

Upcoming milestones



Feature	Comments
Mobile-friendly version	• Just released
Inclusion of Guam and Puerto Rico	• Release expected later this year • Data collected via separate projects • ICE Calculator can estimate costs for up to 30 day power outage (Guam and Puerto Rico)
Confidence intervals around cost estimates	• Release expected later this year
Phase II update of ICE Calculator customer damage functions	• Release expected later this year or early next year

Interested in Joining Initiative?

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ICE CALCULATOR

ICE 2.0: Technical Support (link)

ICE 2.0: National Report Documenting Phase 1 (link)

Comparison of ICE 2.0 to 1.0 (link)

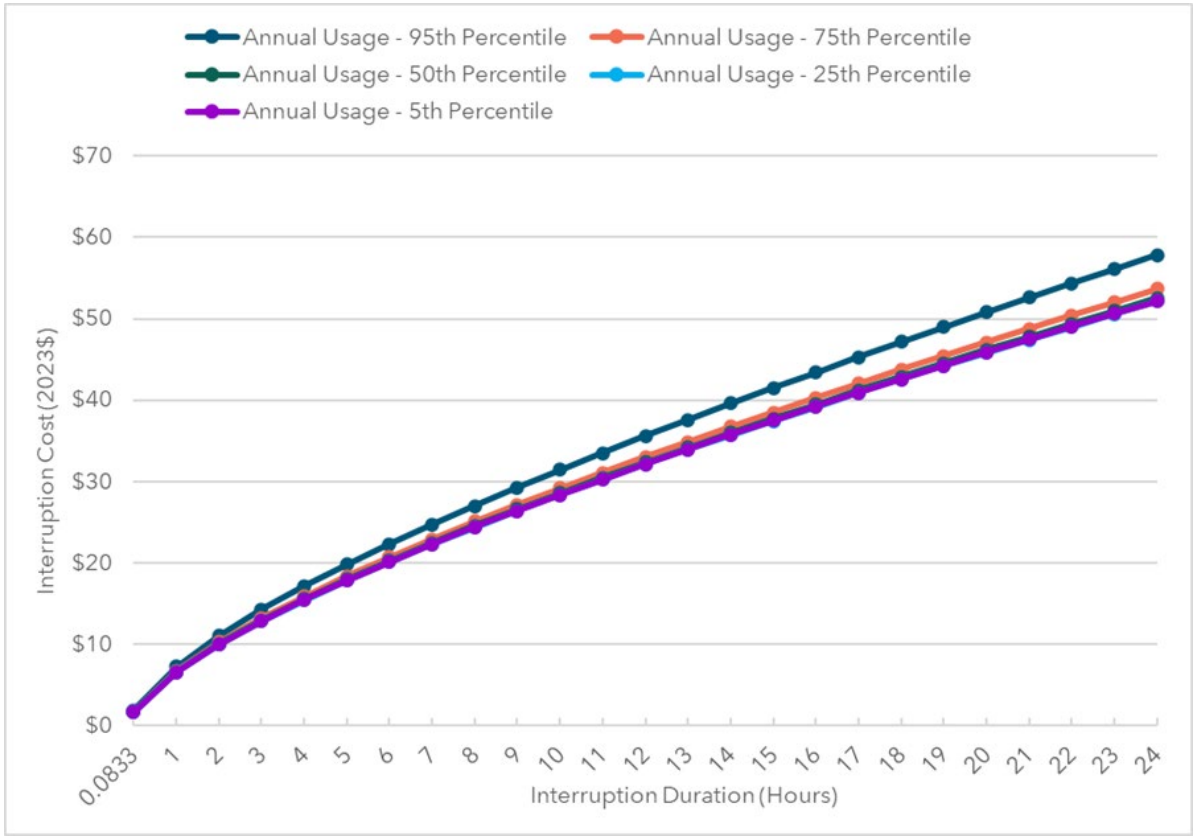
Explanatory variables included in the CDFs

Residential	Non-residential	
	Probit	GLM
Duration of Interruption**	Duration of Interruption**	Duration of Interruption**
Annual kWh Usage**	Annual kWh Usage**	Annual kWh Usage**
Season**	Day of Week**	Percentage of Customers Given Advance Warning**
Percentage of Customers with Backup Generators**	Percentage of Customers Given Advance Warning**	Percentage of Customers in the Manufacturing Industry**
Percentage of Customers Working From Home*	-	Percentage of Customers in the Health Care Industry**
Annual Household Income**	-	-

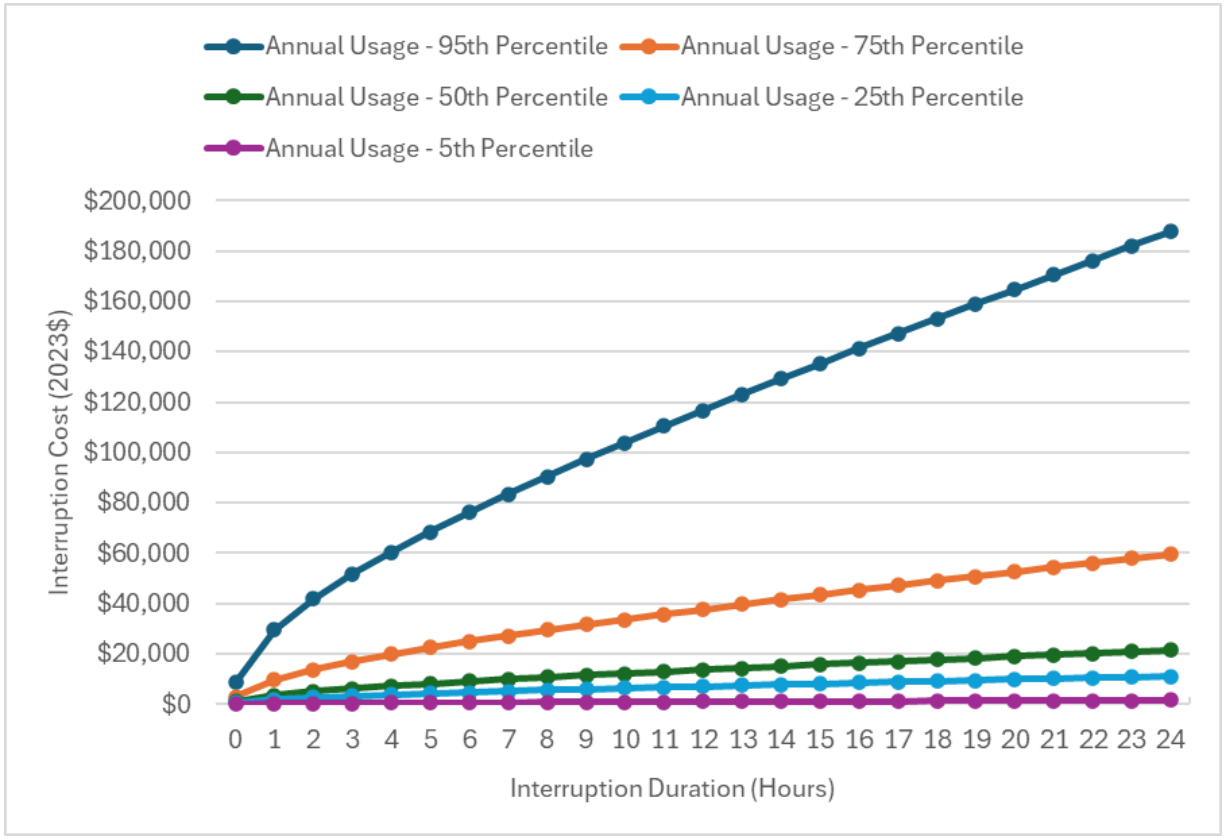
* significant at $p < 0.05$
** significant at $p < 0.01$

Interruption costs by annual usage (consumption)

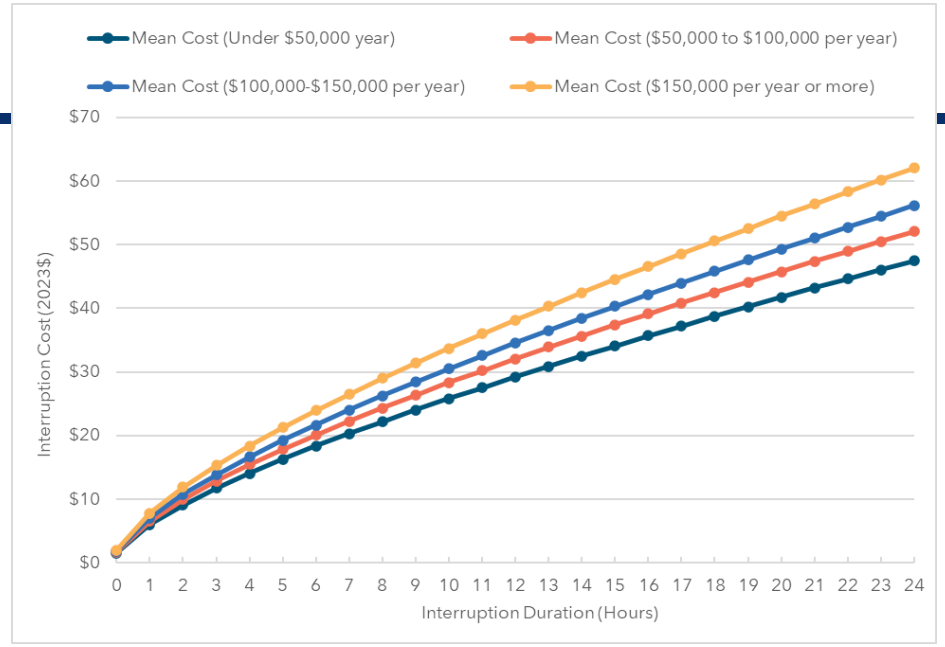
Residential

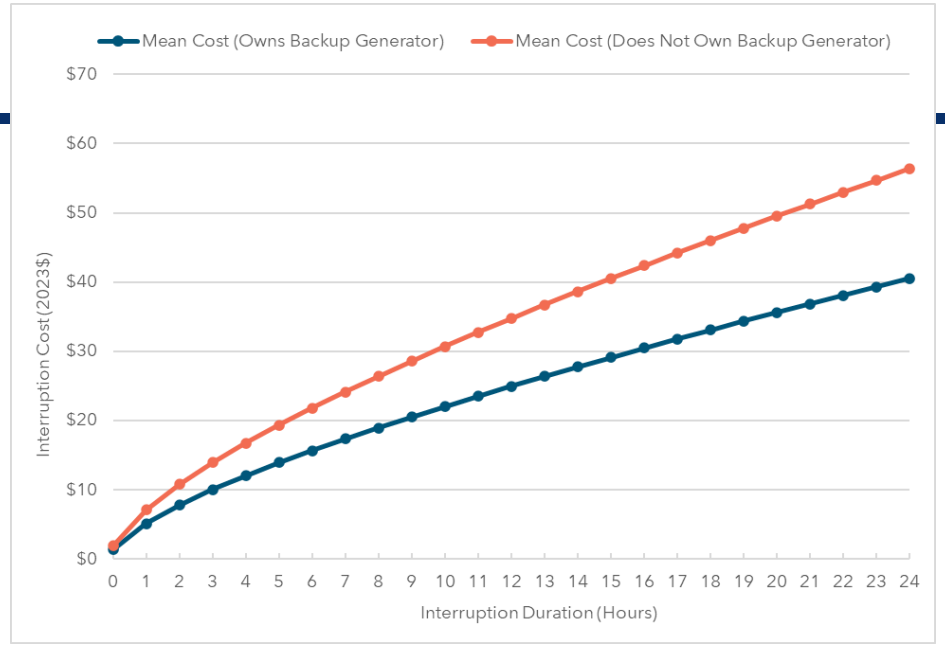


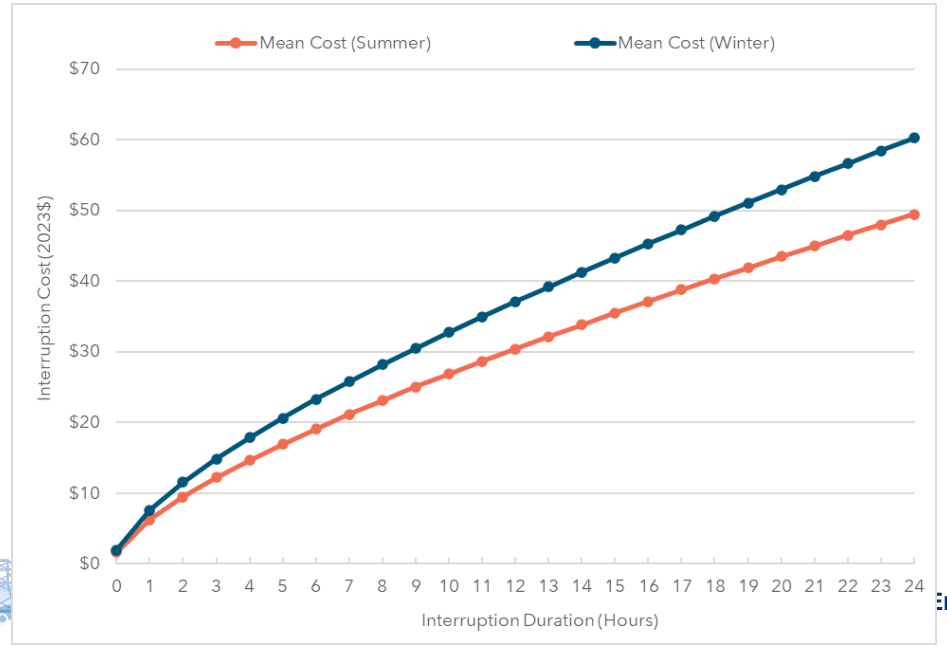
Non- Residential

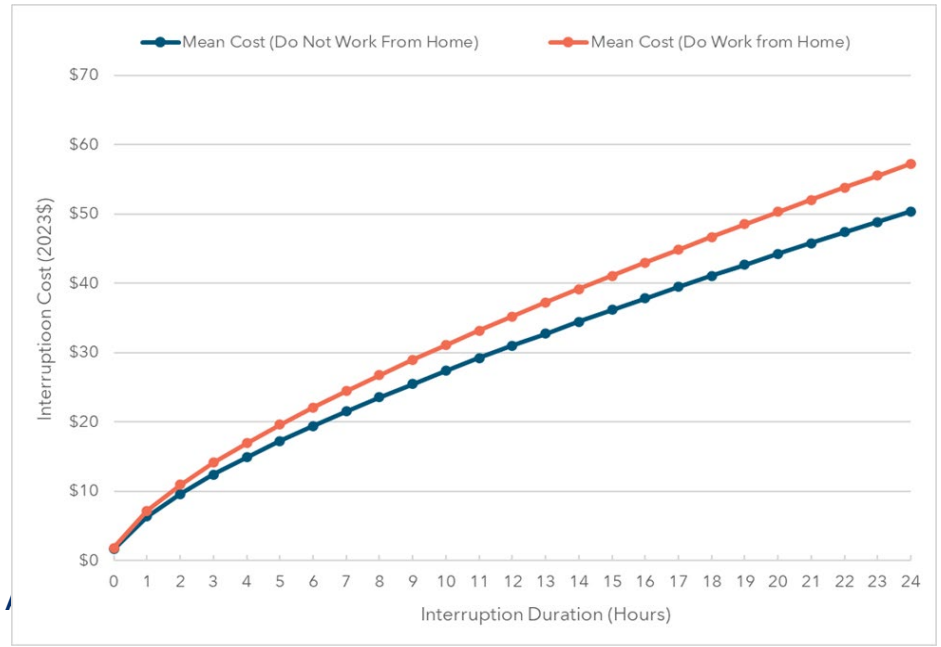


Residential cost by income, backup generator, season, and work from home









Non-residential costs by day of week, industry, and advanced warning