Tool Documentation

INDUSTRIAL DECARBONIZATION TOOLKIT

USER GUIDE FOR LEVELIZED COST OF AVOIDED CO_2 TOOL

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Background and Introduction

Simple payback period is a well-established standard metric for communicating techno-economic tradeoffs of energy efficiency measures. Due to the nature of decarbonization measures where carbon reductions may not yield net economic savings, there would be no payback on investment. Therefore, other metrics complementing simple payback are needed to compare and prioritize the implementation of decarbonization assessment recommendations. One such complementary metric is the Levelized cost of avoided CO_2 (LCAC). The LCAC is the cost of abating a metric ton (or tonne) of carbon dioxide by accounting for the lifetime costs and savings associated with a decarbonization measure. An intuitive bar chart that plots this cost for all decarbonization measures on the vertical axis and adjusts the bar width for each measure to represent the metric tons of carbon it abates is referred to as the Marginal Abatement Cost Curve (MACC). This curve communicates the marginal cost of abating the next bit of carbon at every level of progress towards decarbonization. It gained popularity in late 1990s among environmental researchers, policymakers, and management consultancy firms for sector-level decarbonization. Bringing this level of detail to small industries for decarbonizing their facility not only helps them better understand their decarbonization options but also makes decarbonization more accessible.

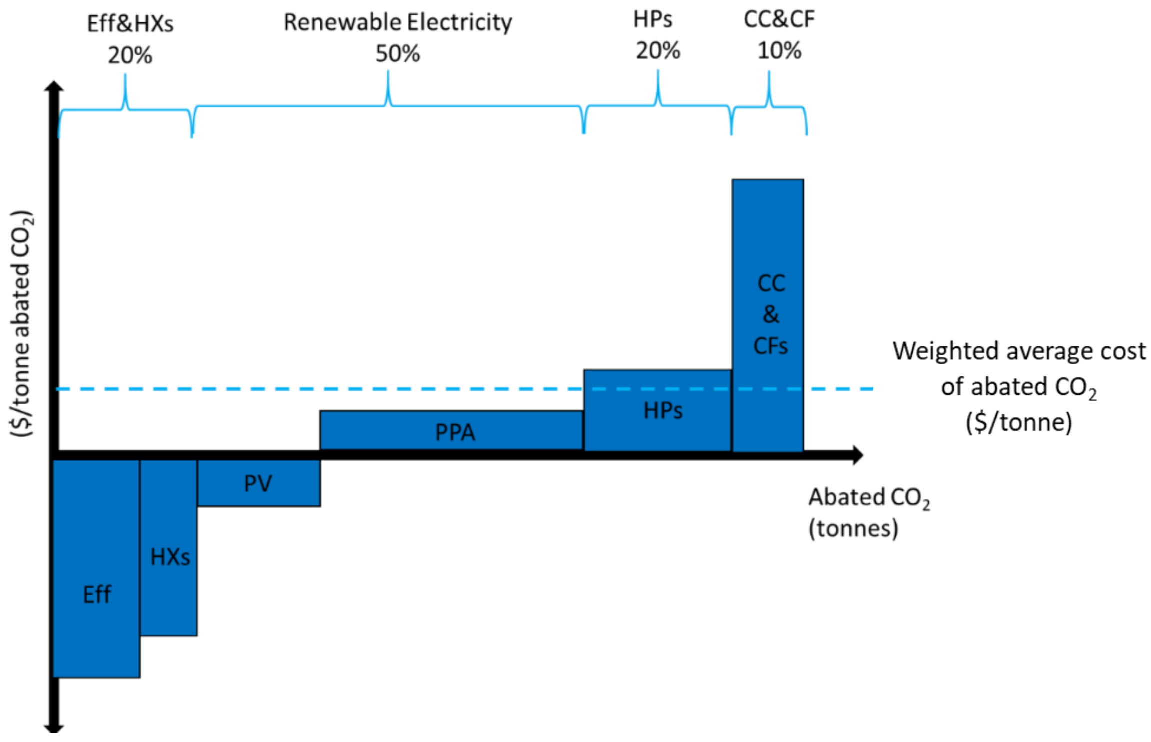


Figure 1 - Representative LCAC curve (Not generated by the tool)

For industries, the LCAC curve communicates the cost of carbon abatement, in \$/tonne, for each of the decarbonization measures needed to achieve 100% decarbonization. This curve is demonstrated as an example in Figure 1 where 20% abatement is obtained from the implementation of energy efficiency and heat exchangers (Eff and HXs in the figure) recommendations. These measures offer negative costs in terms of the LCAC indicating that they deliver cost savings. Similarly, the implementation of an onsite photovoltaic system (PV in the figure), a renewable energy measure, also offers cost savings. Unlike onsite PVs though, renewable power purchase agreements (PPA in figure) are cost positive meaning they deliver CO_2 reductions but at an increased cost. Similarly heat pumps (HPs in the figure) and carbon capture and clean fuels (CC & CF in the figure) are also cost positive. The dashed line indicates the weighted-average cost of carbon abatement for this facility which is overall cost positive. The intuitiveness and information density of this figure is well suited to an industrial decarbonization assessment.

To support the calculation and use of the LCAC when analyzing potential assessment recommendations identified during an IAC audit, LCAC Tool has been developed. There are two components to this tool; one is an Excel-based calculator that lets users calculate the Levelized cost of avoided CO_2 and the other is a web-based tool that lets users upload the output Excel file from this calculator to create the Levelized cost of avoided CO_2 curve. Let's discuss levelized cost of avoided carbon, the core metric of this tool, before individually exploring both the components of this tool.

Levelized Cost of Avoided Carbon

LCAC gives a levelized estimate of per unit cost of CO_2 abatement based on the lifetime costs and savings associated with a CO_2 abatement measure. The levelized estimate comes from the series present worth calculations where the series present worth factor (SPWF) can be calculated from the following equation:

$$SPWF = \left(\frac{1-(1+i)^{-n}}{i}\right)$$

Where *i* is the discount rate and *n* is the project lifetime. Multiplying future costs with this factor gives a levelized estimate of the present value of those future costs. This is appropriate for costs that do not escalate over time like upfront capital cost or fixed operation and maintenance cost.

For escalating series costs, like the cost of electricity or natural gas, escalated series present worth (ESPWF) can be used.

$$ESPWF = \frac{1-\left(\frac{1+e}{1+i}\right)^{n}}{i-e}$$

To understand how this factor enables us to estimate the present value of future costs, let's take the example of operational cost of an electric boiler. Let's assume that we have an electric boiler that costs $5,000 to operate in the current year. Simplifying the operational cost to consist entirely of the cost of electricity for running the boiler, and assuming that the electricity cost is going to annually increase at 5% (*e*), the present value of this operational cost over 10 years (*n*) with a discount rate (*i*) of 10% is 7.44, as shown below.

$$ESPWF = \frac{1 - \left(\frac{1+0.05}{1+0.1}\right)^{10}}{0.1 - 0.05} = 7.44$$

$$Present\ Value\ of\ 10\ year\ Electric\ Boiler\ Operational\ Cost = 7.44 * 5{,}000 = \$\mathbf{37,199}$$

By using these two series present worth factors, we can account for both fixed and escalating costs associated with the electric boiler to estimate its net costs and savings over its lifetime. These net costs and savings estimate can then be annualized using SPWF and the resulting number can be divided by the annualized avoided CO_2 from the electric boiler to get LCAC. It is expressed in the following equation:

$$LCAC = \left(\frac{1}{Annualized\ Avoided\ CO_2}\right)\left(\frac{IC + FO\&M \cdot SPWF + EBOC \cdot ESPWF_1 - NGCS \cdot ESPWF_2 - CCS \cdot ESPWF_3}{SPWF}\right)$$

IC:	*Investment cost.*
FO&M:	*Fixed operation and maintenance cost excluding the energy costs.*
SPWF and ESPWF$_i$:	*Series and escalated series present worth factors where i is a subscript to denote the ESPWF for electricity, natural gas or carbon cost.*
EBOC:	*Electric boiler energy usage cost.*
NGCS:	*Natural gas cost savings.*
CCS:	*Carbon cost savings.*

Using the Excel Based LCAC Calculator

The Excel based calculator allows the user to calculate the Levelized cost of avoided CO_2 by entering some facility and measure specific inputs. The calculator has notes added (top-right of the relevant cells) to help the user throughout the input process at every step of the calculation. The user starts with specifying the emissions factor for electricity at the facility. After that, the user has the option to enter an external or internal carbon cost borne by the facility. Entering the decarbonization assessment recommendations follows where the user enters energy use and energy savings alongside the financial inputs to allow the expression presented above to calculate the LCAC. Finally, the user clicks on the 'generate file for upload' to the web tool to locally save a file. This file is then uploaded to the web-based tool to generate the Levelized cost of avoided CO_2 curve. The user **must enable macros** to get started when they open the Excel workbook for the LCAC calculator. Navigate to the 'Assessment Recommendations' tab to get started. This is the tab where the users will enter all the inputs and then export the filled spreadsheet to the web component of the tool. There is a color-coded legend on top of this sheet to guide the users through the nature of cells. For example, input cells are shaded light yellow and output cells are shaded light blue.

Input Cells	**Fill from Left to Right**
Output Cells	**Filled with Calculated Outputs**

Specifying Electricity Emissions Factor and Carbon Cost

The emissions specification dashboard of the calculator is located on top of the 'Assessment Recommendations' tab in the Excel workbook for the calculator. There are two options for the users to specify the electricity emissions factor in the first input panel on the dashboard. The first option or option A allows users to input custom/market-based grid emissions factor for the facility. This can be the electricity emissions factor reported by the utility or it can be the site-specific electricity emissions factor considering the purchase of offsite clean electricity by the facility. Since grid emissions can greatly vary over time, the users must specify the grid emissions de-escalation rate for option A themselves. The second option or option B lets users select grid emission factors from the eGRID database. This also lets users pick National Renewable Energy Laboratory's (NREL) Cambium forecast for prospective analysis. Option B also allows users to consider two different dynamic grid de-escalation scenarios to pick from for accurate LCAC analysis.

Option A: Specifying Custom/Market-Based Electricity Emissions Factor

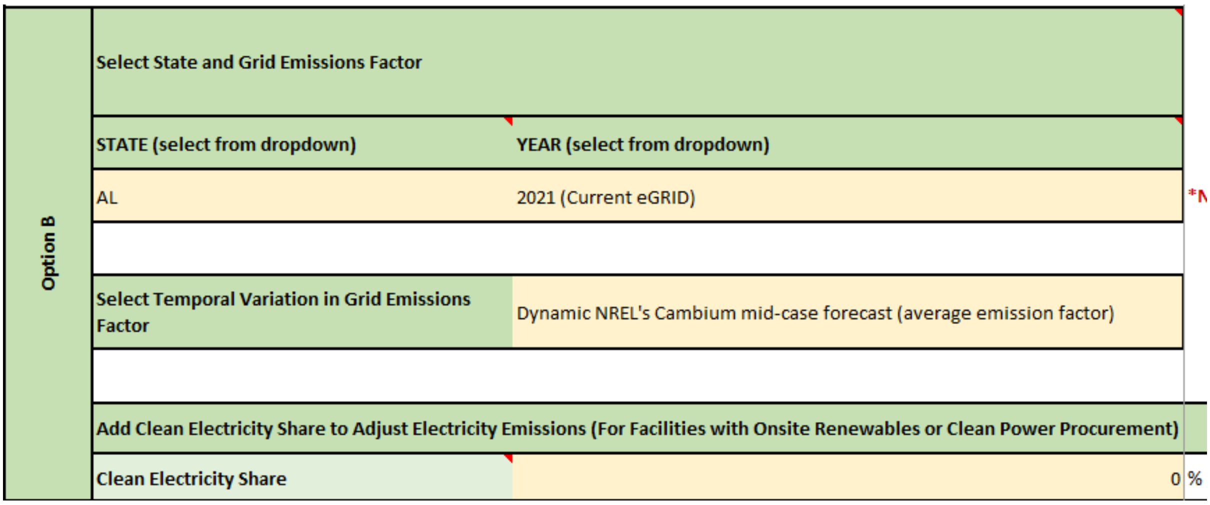
If there is a facility-specific emissions factor available for the calculations, users can enter it in option A. **The calculator overwrites the State emissions factor (option B) when BOTH the input cells in option A are populated**. The default de-escalation rate is set to 0% which allows users to just populate the custom emissions input and overwrite the state selection from option B. If there are any adjustments needed to the emissions factor based on clean electricity share at the facility, the users must do that themselves. For example, let's calculate the clean electricity share for the same facility with 8.76 MWh annual consumption if it buys 1 MWh of renewable energy certificates. The clean electricity share would be 1 MWh/8.76 MWh = 11.42%. Similarly, using the same method to calculate clean electricity share from onsite solar generation, we'd get 3.33%. The total weighted average clean electricity share for this facility will thus be 11.42 + 3.33 = 14.75%. **Users MUST ensure that the entered value is converted into MT (metric tons) of CO_2 per kWh** for the calculations to be accurate.

	Enter Inputs in Option A if Available, Otherwise Proceed to Option B (Option A overwrites Option B)		
Option A	Enter Custom/Market-Based Electricity Emissions Factor		
	Custom/Market-Based Electricity Emissions Factor (Enter value with facility's onsite or offsite clean power procurement)		MT CO_2/kWh
	Do not leave the de-escalation factor cell blank if choosing option A		
	Custom/Market-Based Electricity Emissions Factor De-escalation Factor (% per year)	0%	De-escalation rate is represented by a negative value
	If you want to assume static grid emissions over time, leave it at '0'		

Option B: Grid Emissions from Local Databases

For specifying grid emissions, the option B gives users the choice to either pick grid emissions for their state from either EPA's eGRID or from the mid-case scenario from the Cambium forecast by NREL. The mid-case scenario for this forecast predicts emissions balanced between the optimistic and slow-paced grid decarbonization scenarios. There are two input cells with drop-down to allow users to select their state and year for forecast data in the first input panel within option B. **The notes on the column headers for these inputs can**

help users get more information or the context about the input and the drop-down options. In terms of year, the users get the option to perform a prospective analysis by using a forecast year, for example 2026 or 2035. If the dropdown for state selection does not have your state or territory as an option, please go for option A and enter the most appropriate grid emissions rate. Next input asks users to specify their temporal variation preference. The choices are static, dynamic with Cambium mid-case average emissions factor, and dynamic with Cambium mid-case long-run marginal emissions factor. Selecting the static as your preference assumes the grid emissions to stay the same as they are as per the current eGRID database for your state. Dynamic choices give users to pick two different de-escalation forecasts within Cambium mid-case with incentives phase-out. The default is the dynamic average emissions forecast as it does not assume major infrastructural changes when forecasting hence being more conservative. The NREL's Cambium forecast is not available for Alaska, District of Columbia, Hawaii, and Puerto Rico. If users select any of these states and select any forecast or a prospective emissions year, the calculator defaults to static emissions with the 2021 (Current eGRID) emissions factor.



If the user chooses this option to specify grid emissions, there is a secondary adjustment option to offset emissions from clean electricity. This clean electricity can come from sources such as on-site solar PV, power purchase agreements or a renewable energy certificate opted for by the facility. This secondary input asks the user to enter the percentage share of the total electricity consumed by the facility coming from this clean source. For example, for a 1 MW facility with an annual consumption of 8.76 MWh, the presence of a 100-kW onsite solar plant with 292,000 kWh of annual electricity yield would give a 292,000 kWh/8,760,000 kWh = 3.33% clean electricity share. **For facilities with no share of clean electricity, leave this input cell blank or enter zero.**

Emissions from Other Fuels

For energy sources other than electricity, there is a tab in the workbook titled 'Emission Factors' which is prepopulated with emission factors for different fuels referenced from the Energy Information Administration. **Users can modify any emissions factor if needed but it must be converted to MT (metric tons) of CO_2 per MMBtu** for accurate calculation of the LCAC. **A common case of editing one of these values would be to change the emission**

factor for biofuels if the facility prefers lifecycle emissions associated with the biofuels. The electricity emissions factor in this table is auto populated based on the selections made by the users on the electricity emissions dashboard. For most cases, these emission factors should be applicable since, unlike grid emissions, CO_2 emissions from fossil fuels do not vary spatially or temporally. There are three slots for custom fuel/blend where users can rename the custom blend or fuel and specify the respective emissions factor for it. The users must ensure that the units for the custom emissions factor are consistent with other units as the calculator does not have a converter built-in.

Energy Source	Emissions	Units (ensure consistency of manual entries with these units)
Electricity	0.000342235	MT CO_2/kWh
Natural Gas	0.052902494	MT CO_2/MMBtu
Gasoline	0.07066	MT CO_2/MMBtu
Diesel	0.07414	MT CO_2/MMBtu
Biogas, RNG, Green Hydrogen or Other Clean Fuel	0	MT CO_2/MMBtu
Propane	0.062870748	MT CO_2/MMBtu
Petroleum Coke	0.102099773	MT CO_2/MMBtu
Distillate or Light Fuel Oil	0.074126984	MT CO_2/MMBtu
Coal	0.0961	MT CO_2/MMBtu
Custom Fuel/Blend 1	0	MT CO_2/MMBtu
Custom Fuel/Blend 2	0	MT CO_2/MMBtu
Custom Fuel/Blend 3	0	MT CO_2/MMBtu
Source for Fuels: EIA (https://www.eia.gov/environment/emissions/co2_vol_mass.php)		

Carbon Cost

The final input for the first stage of inputs is the carbon cost. The carbon costs for a facility may be internal, external, or both depending upon the regulation or commitment of the facility. If applicable, the users may enter the overall cost of carbon for the facility and the calculator will add this avoided cost to the savings from decarbonization measures. **If this cost is not applicable, the user may leave it blank or enter '0' and proceed with other inputs.**

Cost of CO_2 (External and Internal)		\$/MT CO_2

Inputs for Decarbonization Assessment Recommendations

There is a total of 14 possible measure-specific inputs for each of the assessment recommendations. They may be less than 14 for measures that do not have secondary energy sources or do not recommend fuel switching. This section goes over all these inputs and provides context with examples based on a demonstrative assessment entered into the tool.

Title and Category of Assessment Recommendation

First two inputs are the title of the assessment recommendation and the decarbonization pillar. **Input regarding the pillars is a drop-down selection** which helps users categorize the recommendations into decarbonization pillars put forward by the Department of Energy (DOE). For the final diagram, these categories would allow users to collapse the results into these broader thematic pathways for decarbonization. This can be particularly useful for assessments where there are many recommendations for decarbonization. The ability to collapse the 20 or so recommendations into four broader categories can make the LCAC curve much easier to read. These pillars are as follows:

- Energy Efficiency
- Industrial Electrification
- Low-Carbon Fuels, Feedstocks and Energy Sources
- Carbon Capture Utilization and Storage

They should cover most of the decarbonization measures within their respective domains with very few to no exceptions. **If the users are not able to find a relevant pillar, they can leave the cell empty. This would not affect the users' ability to make an LCAC curve for the expanded measures and only limit the prospect of collapsing them appropriately.**

Assessment Recommendation	Decarbonization Pillar/Category
	Corresponds to decarbonization pillars devised by DOE in its industrial decarbonization roadmap
Energy Efficiency	Energy Efficiency
Process Integration	Energy Efficiency
Heat Pumps	Industrial Electrification
Electric Boilers	Industrial Electrification
Onsite Solar	Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)

Energy Sources for Assessment Recommendations

Next three inputs ask users to specify the energy source corresponding to the assessment recommendation. All these inputs are to be **selected by the users from the drop down list of energy sources**. It only includes the fuels with their emissions specified in the emissions specification dashboard.

As seen in the figure below, there can either be one (primary) or two (secondary) energy sources per assessment recommendation. For example, for the demonstrative decarbonization assessment, the first recommendation is energy efficiency. If the team performing the assessment wanted to combine all the energy efficiency measures (thermal and electrical) at the facility as one recommendation, the energy sources would be both electricity and natural gas. Therefore, we populate the primary energy source input with electricity and secondary energy source input with natural gas. Moving to the second recommendation in this demonstrative assessment, assuming this **process integration recommendation only pertains to waste heat recovery within the facility's processes, we'd only select natural gas as the primary energy source and leave the secondary energy source blank**. You can look at other recommendations in the figure to see how their energy sources are entered.

The next input column is for the recommendations involving fuel switching. For example, switching from natural gas to biogas or electricity (electrification) is a fuel switching recommendation. For the demonstrative assessment, we have two such recommendations, Heat Pumps and Electric Boilers. **Users must specify the fuel being recommended or the fuel that will be used after fuel switching in this column**, which is electricity for both recommendations. **Notice that the 'Primary Energy Source' column has the fuel being switched from and the 'Switched Energy Source' column has the fuel being switched to**. This is only for recommendations involving fuel switching; for non-fuel switching recommendations, users may leave this cell blank for other recommendations as shown in figure.

Assessment Recommendation	Primary Energy Source	Secondary Energy Source	Switched Energy Source *(Only select if switching fuels)*
	If switching fuels, select the fuel to switch FROM	(Leave blank for single fuel systems)	If switching fuels, select the fuel to switch TO
Energy Efficiency	Electricity	Natural Gas	
Process Integration	Natural Gas		
Heat Pumps	Natural Gas		Electricity
Electric Boilers	Natural Gas		Electricity
Onsite Solar	Electricity		

Energy Savings

The next three inputs require users to specify the energy savings in MMBtu or kWh for the assessment recommendations. These savings come from the avoided consumption of energy resulting from a recommendation. In the demonstrative assessment for example, the energy efficiency recommendation results in the avoided consumption of both electricity and natural gas. **Notice that there is a dedicated input column for the avoided consumption of electricity titled 'Annual Electricity Saved' so the users must not enter electricity savings in the 'Annual Primary Non-Electricity Fuel Saved' column**. This is because the calculator is tuned to look up only the fossil emission factors for the numerical input in the Annual Primary Non-Electricity Fuel Saved' and 'Annual Secondary Non-Electricity Fuel Saved'.

When entering the energy savings (avoided consumption) in these columns, the users must ensure that the units are consistent with the given units in the column description. The units for electricity are kWh/year and MMBtu/yr for non-electricity energy sources. Not doing so will result in inaccurate estimates of levelized cost of avoided carbon. This is because the emissions factors to translate these energy savings (avoided consumption) into carbon savings (MT CO_2/year) are MT of CO_2 per kWh for electricity and MT of CO_2 per MMBtu for non-electricity energy sources.

Assessment Recommendation	Annual Electricity Saved (Avoided Consumption)	Annual Primary Fuel Saved (Avoided Consumption)	Annual Secondary Fuel Saved (Avoided Consumption)
		Do not enter electricity saved	Do not enter electricity saved
	kWh/yr	MMBtu/yr	MMBtu/yr
Energy Efficiency	512,336	-	4,033
Process Integration	-	364	-
Heat Pumps	-	2,240	-
Electric Boilers	-	1,685	-
Onsite Solar	51,958	-	-

Impact from Fuel Switching

Next two input columns incorporate the additional energy consumption and the associated energy cost with fuel switching into the Levelized cost of avoided CO_2 calculation. The first of these two columns ask the users to enter the additional energy consumption coming from fuel switching. For example, in case of heat pumps in the demonstrative assessment, we can see that an additional 170,460 kWh/year is consumed because of this fuel switching recommendation. For electric boilers, additional 287,163 kWh/year is consumed. The calculator assigns the unit MMBtu/yr or kWh/yr to the entered values in this column based on the drop-down list selection made by the user in the column titled ‘Switched Energy Source’. The next column asks the users to enter the additional cost associated with fuel switching. This is essentially the energy cost for the additional kilowatt-hours of electricity or million British thermal units of non-electricity fuel. For the demonstrative assessment, the additional 170,460 kWh/year from heat pumps and 287,163 kWh/year from electric boilers cost $20,455 and $34,460 respectively. These costs are obtained by multiplying the annual energy consumption values with the cost of electricity and adding the demand charges associated with this additional consumption. **The users may leave these cells blank for the assessment recommendations that do not involve fuel switching**.

Assessment Recommendation	Switched Fuel Enegy Consumption	Annual Switched Fuel Energy Cost
	MMBtu/yr or KWh/yr	$/yr
Energy Efficiency		
Process Integration		
Heat Pumps	170,460	20,455
Electric Boilers	287,163	34,460
Onsite Solar		

Energy Cost Savings

Next two input columns ask users to enter the cost savings resulting from the assessment recommendations. These inputs are split into two columns with the first one asking the annual electricity cost savings and the second one asking the annual non-electricity fuel cost savings. **The users must incorporate utility and facility-specific demand charges or time-of-use tariffs (if applicable to the measure) to calculate these savings for both electricity and non-electricity fuels.** For non-electricity fuel cost savings, users may have to add primary and secondary fuel cost savings for measures corresponding to unit operations with multiple fuels. **Users may enter 0 or leave the cell empty for recommendations that do not offer either the electricity or non-electricity fuel cost savings.** This is shown in the demonstrative assessment for Process Integration, Heat Pumps and Electric Boilers having zero electricity savings.

Assessment Recommendation	Annual Electricity Cost Savings (Avoided Cost)	Annual Non-Electricity Fuel Cost Savings (Avoided Cost)
	$/yr	$/yr
Energy Efficiency	$ 11,737	$ 3,421
Process Integration	$ -	$ 9,217
Heat Pumps	$ -	$ 17,696
Electric Boilers	$ -	$ 10,942
Onsite Solar	$ 8,907	

Financial Inputs

Next four input columns ask users to enter some important financial inputs for calculating the Levelized cost of avoided CO_2 from the assessment recommendations. First one titled **'Investment Cost' asks the users to enter the total capital cost, including all other upfront costs** like installation and retrofit costs (if any) for the recommended measures. For example, the $34,713 investment cost for energy efficiency in the demonstrative assessment is comprised of the costs of VFDs, boiler auxiliaries and sensors etc. along with their installation costs. Similarly for Heat Pumps, the investment cost of $38,918 includes the costs of heat pumps, hot water pipe infrastructure and the accompanying thermal storage tank etc. along with their installation costs. The next input column asks the users to enter the fixed operation and maintenance cost associated with the equipment (if any). These costs may include, but are not limited to, the scheduled maintenance or servicing of the equipment. In the demonstrative assessment for example, only heat pumps and electric boilers have the annual fixed operation and maintenance costs. Energy costs are not to be included as a fixed operation and maintenance cost.

Next two inputs are critical to the financial analysis that goes into the calculator. As we saw in the calculation of series and escalated series present worth factors in the introductory section about the levelized cost of avoided carbon, these two parameters greatly influence the results. Discount rate is the interest rate used to translate the future costs into present value. Project lifetime is the number of years for which we expect for the equipment to be functional or for it to keep giving us the costs and savings that we entered in the input columns before**. The calculator cannot take decimal inputs for project lifetime so the users must ensure that they enter whole number input. The default values of 5% for the discount rate and 10-years for the project lifetime are entered in the calculator that may be edited by the user based on the assessment recommendation**. For example, in the demonstrative assessment, number of years for heat pumps, electric boilers and onsite solar have been changed to 20 years because of their 20-year expected lifetime. Similarly, the discount rate for heat pumps and electric boilers has been changed to 10% because they are not commercially well established and thus are high-risk investments. **Users may consult the facility and/or experts for using an appropriate discount rate.**

Assessment Recommendation	Implementation Cost	Annual Fixed Operation and Maintenance Cost *(do not include energy costs)*	Discount Rate	Project Lifetime
	IC	O&M	i	n
	$	$/yr		
Energy Efficiency	$ 25,000	$ -	5%	10
Process Integration	$ 300	$ 3,000	5%	10
Heat Pumps	$ 38,918	$ 1,946	5%	20
Electric Boilers	$ 120,000	$ 3,400	5%	20
Onsite Solar	$ 31,934	$ 3,000	5%	10

Energy and Carbon Cost Escalation Rates

Finally, the users can enter the escalation rates for the different costs going into the calculation of levelized cost of avoided carbon. There are three input columns corresponding to the electricity, non-electricity fuel and carbon cost escalation rates. For convenience, default escalation rates of 3.5% are added for electricity and non-electricity fuel cost escalation. 3.5% is close to the average annual rate of inflation in the United States across commodities so it may not be best suited to energy costs. **Users may enter a more appropriate energy cost escalation rate or may consult with the facility to ask them about their preference regarding this.** The default carbon cost escalation rate is set to be 7.5% considering the ambitious decarbonization goals in the United States. This may also greatly vary for each facility or state as per their sustainability commitments or environmental laws respectively. **If carbon cost is applicable, users may consult the facility regarding an appropriate carbon cost escalation rate.**

Assessment Recommendation	Electricity Cost Escalation Rate	Fuel Cost Escalation Rate	Carbon Cost Escalation Rate
	e1	e2	e3
Energy Efficiency	3.5%	3.5%	7.5%
Process Integration	3.5%	3.5%	7.5%
Heat Pumps	3.5%	3.5%	7.5%
Electric Boilers	3.5%	3.5%	7.5%
Onsite Solar	3.5%	3.5%	7.5%

Workaround for Carbon Capture Recommendations

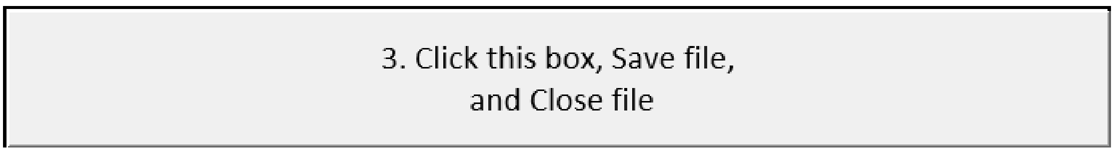
Carbon capture and sequestration (CCS) is a unique decarbonization measure in that it does not offer any energy savings or avoided energy consumption. Since the calculator in this tool is written to estimate carbon abatement based on the net energy savings, it becomes challenging to calculate LCAC for carbon capture assessment recommendations. The calculator does not give LCAC when the annual CO_2 abatement is less than zero. So in order to calculate carbon abatement cost using carbon capture, the users must make two adjustments. These adjustments are as follows:

1. After filling the input cells for CCS in 'Title and Category of Assessment Recommendation' tab, do not enter energy savings. Since there are no energy savings, these inputs are going to be negative and they'd result in negative carbon abatement. **Only fill the input cells in the 'Energy Cost Savings' tab with negative cost savings numbers and the 'Financial Inputs' tab with the investment and fixed operation and maintenance costs**.
2. **Manually enter the carbon abatement resulting from CCS in the 'Annual CO_2 Abatement' column**. This will plug a positive carbon abatement value into the LCAC calculation equation and will give users the LCAC for CCS. Make sure to enter net carbon abatement after subtracting the carbon capture process related emissions to get more accurate results.

This will allow the tool to calculate the Levelized cost of avoided CO_2 using the financial inputs and additional energy costs incurred based on the annual carbon abatement.

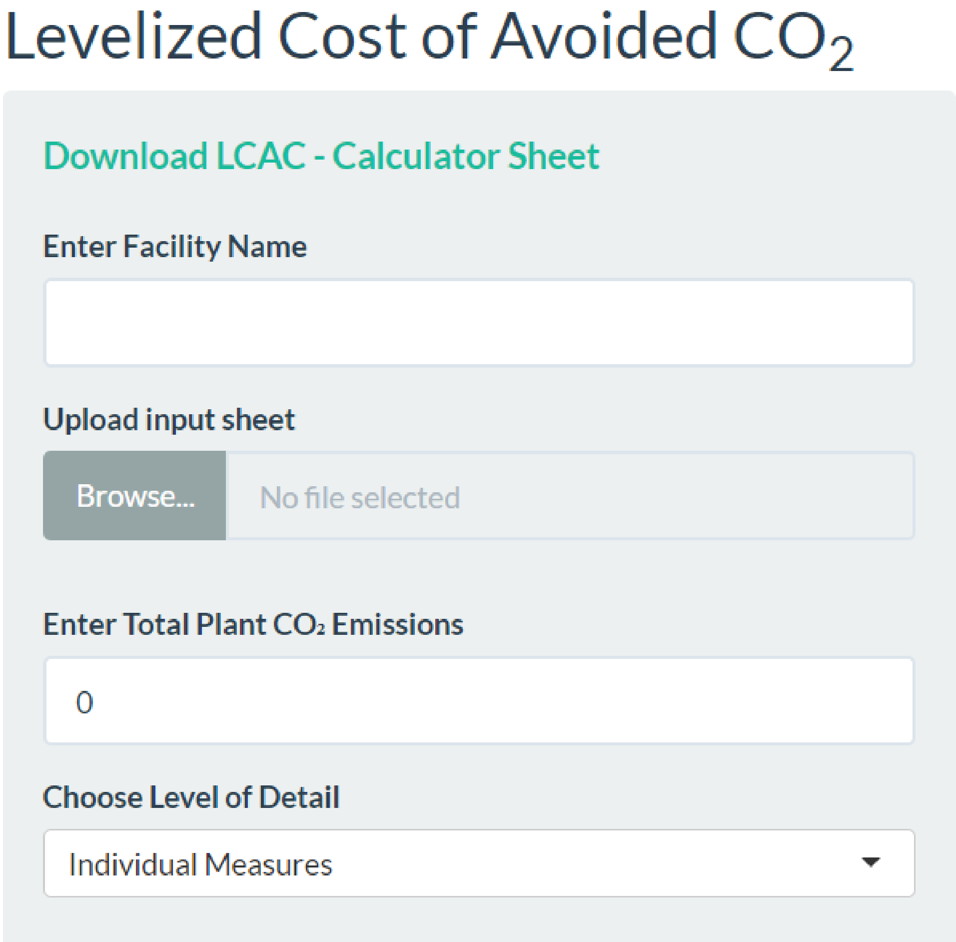
Generating File for Online Visualization Tool

After all these inputs are entered, the users can see the calculated LCAC for the recommendations in the right most column of the main inputs table. This column is titled 'Levelized Cost of Avoided Carbon' and is shaded green like the column titles. Users can click on the 'Click Here to prepare file for upload' button (see figure below) to generate an .xlsm version of this calculator to be uploaded to the online component of this tool. **The users can save changes made to the calculator Excel workbook as an .xlsm file or they can use the 'save as' option in Excel to save a copy for a specific assessment to a directory of their choice. This file is then navigated to and uploaded to the online tool to generate the LCAC curve** based on the inputs entered by the users in this calculator.



Visualization Component of the Tool

The visualization component of the tool is hosted online at the Lawrence Berkeley National Laboratory's server and can be publicly accessed. The users have the following key inputs for the visualization online tool:



The users can download the excel based calculator using the hyperlink titled 'Download LCAC – Calculator Sheet' and **download this user guide using the 'Download Tool Documentation' hyperlink at the very bottom**. Users can enter the facility name in the field titled 'Enter Facility Name' to be shown on the LCAC curve generated by the tool. The 'Upload input sheet' field lets users browse and navigate to where the .xlsm file has been saved to upload it to generate the LCAC curve. The 'Enter Total Plant CO_2 Emissions' button allows users to enter the total carbon to abate at the facility which will then show up in the final LCAC curve. **The field titled 'Choose Level of Detail' asks users to specify whether they want each individual assessment recommendation to show as a bar in the LCAC curve or if they want to collapse them into categories based on DOE pillars**. Although the tool is designed to display the axes and texts on the graph in an organized manner, some minor adjustment to their positioning may be required. The users can enter numeric values in the inputs to alter the positioning of axes labels, data labels, and text in the final image. Designed to be intuitive, a positive value in these inputs would either move the component upwards or rightwards and a negative value would do the opposite. Finally, the users can click on the 'Click Here to Download as Image' button to download a portable network graphics image of the LCAC curve for use. The final figure looks like this: