Tool Documentation

INDUSTRIAL DECARBONIZATION TOOLKIT

USER GUIDE FOR LEVELIZED COST OF AVOIDED CO_2e TOOL

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Introduction to the Tool

Simple payback period has been the standard metric to communicate techno-economics of energy efficiency measures for years. This has resulted in the familiarity of industrial executives and operators with the term to assess the economic viability of the recommended measures. Unfortunately, due to the nuances with decarbonization measures, it is not appropriate to use simple payback period for comparing the assessment recommendations. Not all decarbonization measures yield net savings, resulting in a negative payback period confusing the decision makers at a facility. Therefore, a more appropriate and intuitive metric for comparing the decarbonization measures is needed. Levelized cost of avoided carbon (LCAC) is the cost of abating a metric ton 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 each of the 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 90s 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.

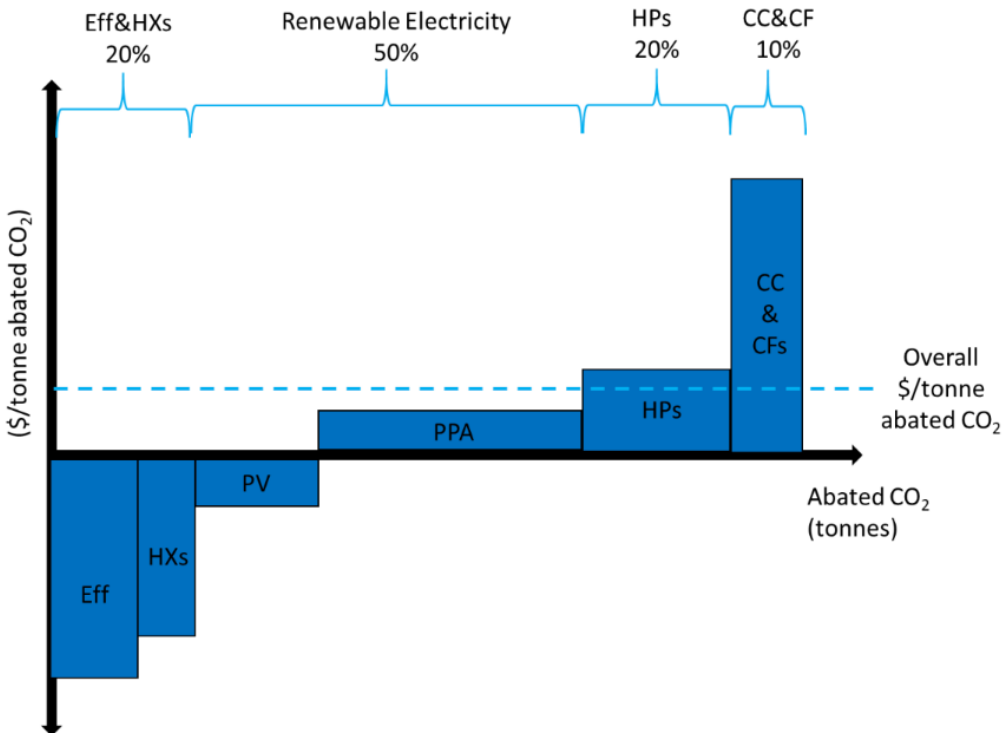


Figure 1 - Representative levelized cost of avoided carbon curve (Not generated by the tool)

For industries, this levelized cost of avoided carbon curve communicates the cost of carbon abatement in $/tonne for each of the decarbonization measure to get to 100% decarbonization. This curve is demonstrated as an example in figure 1 where 20% abatement

can be seen coming from efficiency and heat exchange recommendation and these measures offer negative costs (savings). Similarly, onsite photovoltaic system also offers savings. Other renewable measures combined with onsite solar can result in further 50% decarbonization where renewable power purchase agreements are cost positive. The final 30% of the facility emissions can be abated using heat pumps (20%) and carbon capture & clean fuels (10%). The dashed line indicates the 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. Unlike the simple payback period, understanding the negative and positive levelized cost of avoided carbon is much more intuitive. There are two components to this tool; one is an Excel-based calculator that lets users calculate the levelized cost of avoided carbon 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 carbon 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

Similar in concept to the levelized cost of electricity, LCAC gives a levelized estimate of per unit cost of carbon abatement based on the lifetime costs and savings associated with a carbon 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:

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

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. Assuming that this operational cost is entirely the cost of electricity for running the boiler, and assuming that the electricity cost is going to annually increase at 5% (e). Let's calculate the present value of this operational cost over 10 years (n) with a discount rate (i) of 10%.

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

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

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. This net costs and savings estimate can then be annualized using SPWF and the resulting number can be divided by the annual carbon abatement from the electric boiler to get the levelized cost of avoided carbon (LCAC). It is expressed in the following equation:

$$LCAC = \left(\frac{1}{Carbon\ Abatement/yr}\right)\left(\frac{IC + FO\&M \cdot SPWF + EBOC \cdot ESPWF_1 - NGCS \cdot ESPWF_2 - CCS \cdot ESPWF_3}{SPWF}\right)$$

IC:	*Investment cost.*
FO&M:	*Fixed operation and maintenance cost excluding the energy costs.*
SPWF and ESPWF:	*Series and escalated series present worth factors.*
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 carbon by entering some facility and measure specific inputs. The calculator has notes added next to every input cell to help users throughout the input process. The user starts with specifying the grid emissions for the facility being studied. 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 saves the filled input sheet and uploads it to the web tool to generate the levelized cost of avoided carbon curve. The input sheet has two sets of inputs, first one is for the electricity emissions factor & carbon cost and the second one is for entering the energy and cost information for the recommended measures. Users must navigate to the 'Assessment Recommendations' tab in the worksheet to get started. This is the tab where users will enter all the inputs and save changes to upload it to the web component of the tool. There is a color-coding legend on top of this sheet to guide the users through the nature of cells. The input cells are shaded light yellow and output cells are shaded light blue. Overwriting the output cells will overwrite the formulas therein, thus rendering the sheet not suitable for a new set of inputs. If users must overwrite output cells for analysis, they must download a new copy of the input sheet for further analyses.

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

Specifying Emissions and Carbon Cost

Option A – Specifying Custom Grid Emissions

If facility-specific emissions factor is available for the calculations, users can enter that emissions factor for more accurate calculations. **The calculator overwrites the State dropdown emissions factor in option B with this input cell if it is populated**. **Users MUST ensure that the entered value is converted into tonnes (metric tons) of CO_2e per kWh** for the calculations to be accurate. The users can also enter the clean energy offset for this grid emissions factor to represent the rate at which the custom emissions are expected to decline. **This factor is a percentage value input and must be entered as a negative number to represents de-escalation**. Annualized electricity emissions calculated with this set of inputs is calculated as follows as follows:

$$Annualized\ Emissions_{De-escalated} = CEF \cdot \left(\frac{ESPWF_{Emissions}}{n}\right)$$

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

Where:

CEF = Custom emissions factor
$ESPWF_{Emissions}$ = Escalated series present worth factor for emissions factor
n = Project lifetime in years
e = Custom electricity emissions factor de-escalation factor
i = Discount rate (zero for this case as emissions are not subject to discounting)

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

Option B – Grid Emissions from Local Databases

The second option for the users to specify grid emissions is from a dropdown of states with locally stored emissions databases. Users can choose the grid emissions for their state from either EPA's 2022 eGrid data (most recent data as of the date of this publication) or from the mid-case scenario from the Cambium forecast by NREL. There are two input cells with

drop-down to allow users to select their state and year for forecast data. The drop-down for state selection only

Select State and Grid Emissions Factor	
STATE (select from dropdown)	**BASELINE YEAR (select from dropdown)**
CA	2022 (eGRID)

Once the users have made their choice of State and baseline year for the analysis, they must specify the grid emissions forecast to be used for accounting grid emissions beyond the baseline year. This is important as accurate carbon accounting is vital to the accuracy of the LCAC calculation. This input is titled 'Select Temporal Variation in Grid Emissions Factor' and has three dropdown options. First one is 'Static (grid emissions do not change over time)' which corresponds to keeping the grid emissions constant at the baseline year level for the LCAC calculation. The second and third options are titled 'Dynamic NREL's Cambium mid-case forecast (average emission factor)' and 'Dynamic NREL's Cambium mid-case forecast (long-run marginal emission factor)' respectively. The former assigns a proportionate share of grid emissions to all users of grid electricity and finds use in emissions footprint analysis. The latter estimates grid emissions based on the change in demand, by taking the grid composition and operational changes into consideration based on the added demand. It finds its application in policy and academic emission analyses. You can read more about it at the Cambium forecast by NREL website.

Select Temporal Variation in Grid Emissions Factor	Dynamic NREL's Cambium mid-case forecast (average emission factor)

Users can also enter clean electricity share to offset the grid emissions factor selected from the local databases. This clean electricity can come from a virtual power purchase agreement, a carbon offset 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 100-kW facility with an annual consumption of 876,000 kWh, the presence of a 10-kW onsite solar plant with 29,200 kWh of annual would give a 29,200/876,000 = 3.33% clean electricity share. It is important to note that unlike the de-escalation factor in Option A, the clean energy share does not need to be negative as it represents the share of electricity use at the facility coming from carbon-free sources. **For facilities with no share of clean electricity, leave this input cell blank or enter zero.**

For Facilities with Clean Electricity Procurement	
Clean Electricity Share (%)	50%

Carbon Cost

The final input for the first stage of inputs is the carbon cost. The carbon costs for a facility may either be internal or external, 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 enter '0' and proceed with other inputs.**

Additional Cost of CO_2 ($/MT CO_2)	$ -

Emissions from Other Fuels

The emission factors for energy sources other than electricity are listed in a table in the 'Emission Factors' tab. They have been referenced from the Energy Information Administration. **Users can modify any emissions factor if needed but it must be converted to metric tons of CO_2e per MMBtu** for accurate calculation of LCAC. **A common case of changing one of these values for example, 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 in the 'Assessment Recommendations' tab and the users do not need to change that. For most cases, these emission factors should be applicable without modification since unlike grid emissions, carbon emissions from fossil fuels do not vary spatially or temporally. Users can also add custom fuel emissions factors in the three slots for custom fuels or blends.

Energy Source	Emissions	Units (ensure consistency of manual entries with these units)
Electricity	0.000206473	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)		

Inputs for Decarbonization Assessment Recommendations

There is a total of 14 measure-specific inputs required 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 you with some 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 is a large number of 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	Primary Energy Source
	If switching fuels, select the fuel to switch FROM
Air Compressor Efficiency	Electricity
Process Heating Efficiency	Natural Gas
HVAC Energy Efficiency	Electricity
Industrial Heat Pump	Natural Gas
Electric Boiler	Natural Gas
Onsite Solar	Natural Gas

Energy Sources for Assessment Recommendations

Next three inputs ask users to specify the energy source corresponding to the assessment recommendation. All of 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.

You can see in the figure below that there can either be one or two 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, we know that **process integration pertains to heat exchange within the facility so we'd choose only 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 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 how '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 the case with recommendations involving fuel switching, 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
Air Compressor Efficiency	Electricity		
Process Heating Efficiency	Natural Gas		
HVAC Energy Efficiency	Electricity	Natural Gas	
Industrial Heat Pump	Natural Gas		Electricity
Electric Boiler	Natural Gas		Electricity
Onsite Solar	Natural Gas		

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. These units for electricity are kWh/year and MMBtu/yr for non-electricity energy sources. Not doing so would 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 (tonnes CO_2e/year) are tonnes of CO_2e per kWh for electricity and tonnes of CO_2e 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
Air Compressor Efficiency	44,000	-	-
Process Heating Efficiency	-	1,100	-
HVAC Energy Efficiency	37,000	-	250
Industrial Heat Pump	-	2,600	-
Electric Boiler	-	2,000	-
Onsite Solar	52,000	2,400	-

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 carbon 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
	Fuel switched TO	
	MMBtu/yr or kWh/yr	$/yr
Air Compressor Efficiency	-	
Process Heating Efficiency	-	
HVAC Energy Efficiency	-	
Industrial Heat Pump	171,000	$ 19,000
Electric Boiler	187,000	$ 21,000
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 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 Fuel Cost Savings (Avoided Cost)
	$/yr	$/yr
Air Compressor Efficiency	$ 4,500	$ -
Process Heating Efficiency	$ -	$ 16,000
HVAC Energy Efficiency	$ 11,000	$ 3,000
Industrial Heat Pump	$ -	$ 16,800
Electric Boiler	$ -	$ 14,500
Onsite Solar	$ 9,000	$ -

Financial Inputs

Next four input columns ask users to enter some important financial inputs for calculating the levelized cost of avoided carbon 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 not be 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.

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 default values of 5% for the discount rate and 10-years for the project lifetime are entered in the calculator that must 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 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		
Air Compressor Efficiency	$ 17,000	$ 1,300	5%	10
Process Heating Efficiency	$ 8,000	$ 700	5%	20
HVAC Energy Efficiency	$ 95,000	$ 3,200	5%	20
Industrial Heat Pump	$ 39,000	$ 4,500	5%	20
Electric Boiler	$ 120,000	$ 8,567	5%	10
Onsite Solar	$ 32,000	$ 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
Air Compressor Efficiency	3.5%	3.5%	7.5%
Process Heating Efficiency	3.5%	3.5%	7.5%
HVAC Energy Efficiency	3.5%	3.5%	7.5%
Industrial Heat Pump	3.5%	3.5%	7.5%
Electric Boiler	3.5%	3.5%	7.5%
Onsite Solar	3.5%	3.5%	7.5%

Manual Input of LCAC Values

In case the users want to bypass the calculator and just create an LCAC curve with their own calculation, they can do so by manually inputting the LCAC values. **The users should only populate two input columns in this instance as the code to generate LCAC curve only looks at the 'Assessment Recommendation' and 'Levelized Cost of Avoided CO_2e' columns**. The users should enter the names of the assessment recommendations in the respective column as they would like for them to be shown in the final LCAC curve. In the 'Levelized Cost of Avoided CO_2e' column, the users should enter LCAC values from their calculation. No other values need to be changed or adjusted for the manual input of LCAC values. Uploading the saved version of these inputs is going to generate the LCAC curve as per the entered values. **It is important to note that if the users overwrite the default input sheet with manual input of LCAC values, it nullifies the formulas written to calculate LCAC in the calculator. Therefore, the worksheet can not be reused for non-manual LCAC values**. The users must re-download the default input sheet with preserved formulas if they overwrite the downloaded file with the manual LCAC input.

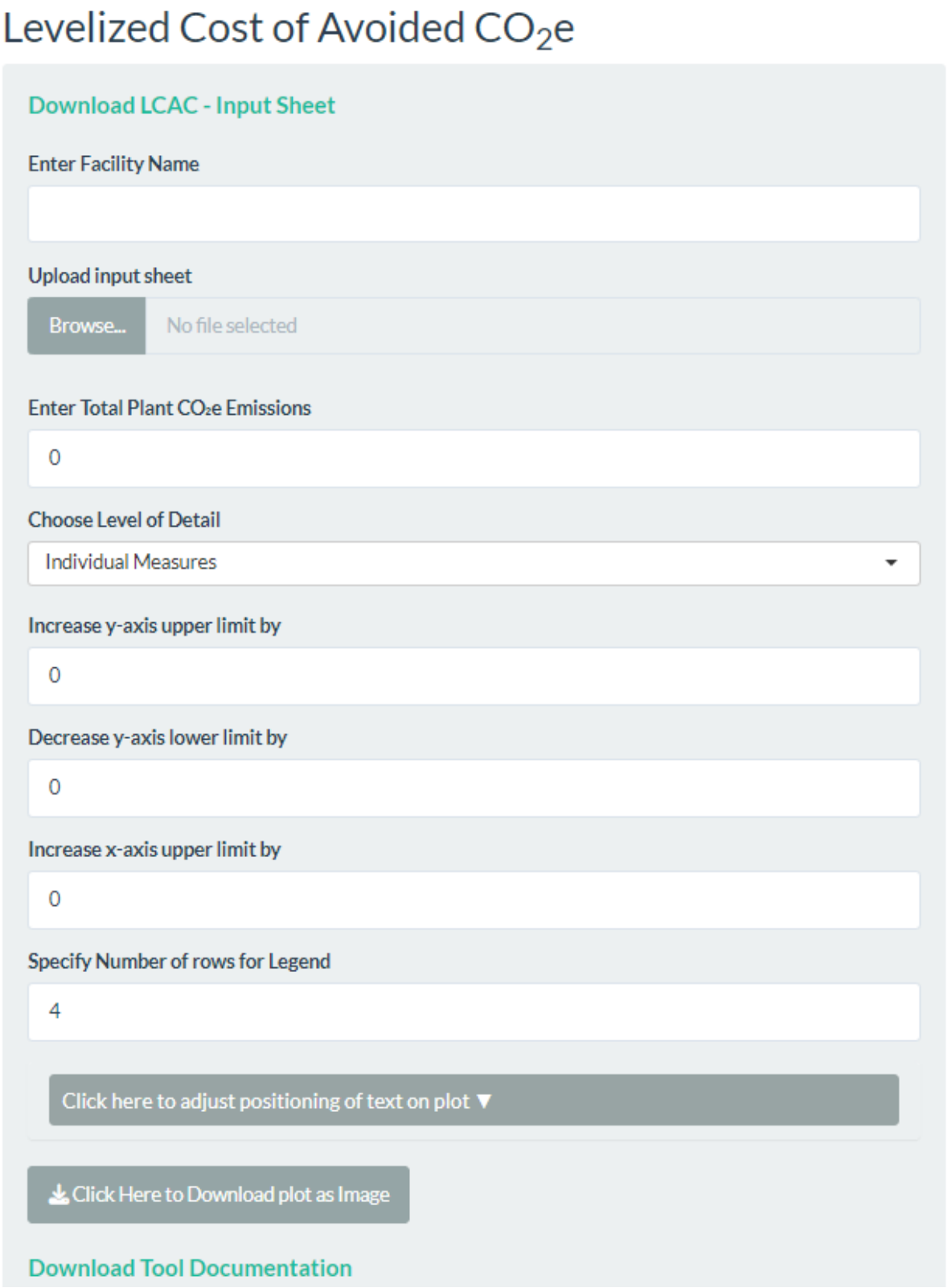
Assessment Recommendation	Annualized Total Costs	Annualized Avoided CO_2e	Levelized Cost of Avoided CO_2e
	ATC	ACO_2e	LCAC = ATC/ACO_2e
	ATC = PV_{costs}/SPV	MT CO_2e/yr	\$/MT CO_2e
Air Compressor Efficiency	$ (1,705.1)	7	**$ (246.4)**
Process Heating Efficiency	$ (20,062.0)	58	**$ (344.8)**
HVAC Energy Efficiency	$ (7,905.4)	17	**$ (462.8)**
Industrial Heat Pump	$ 10,572.5	120	**$ 88.3**
Electric Boiler	$ 31,628.3	76	**$ 414.0**
Onsite Solar	$ (3,269.2)	135	**$ (24.2)**

Generating File for Online Visualization Tool

After all these inputs, the users can see the LCAC in the right most column of the main inputs table. This column is titled 'Levelized Cost of Avoided Carbon' and is shaded blue as it is the output cell. Once done entering inputs, the users can save the calculator file as a new file to preserve the default values in the downloaded calculator or overwrite the values by selecting 'Save'. In case the users overwrite the default values, they can download the default calculator worksheet from the online tool website at any time.

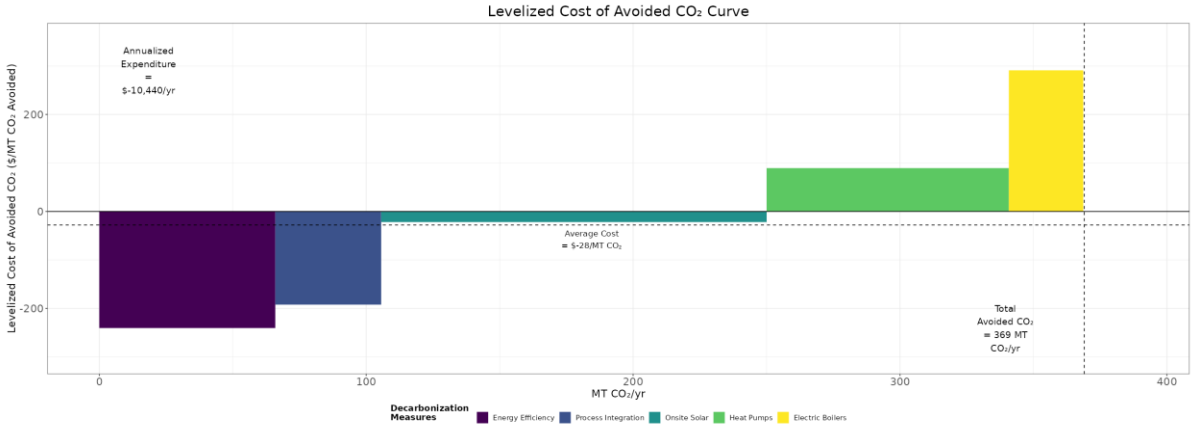
Visualization Component of the Tool

The visualization component of the tool is hosted online at the Lawrence Berkeley National Laboratory's server and can be publicly accessed. The screen that users will see on the web address for this tool is shown in figure below.



The users can download the excel based calculator using the hyperlink titled 'Download LCAC Curve – Excel Sheet' and **download this user guide using the 'Download Tool Documentation' hyperlink**. 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 input sheet has been saved to upload it to

generate the LCAC curve. **The final 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**. 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 LCAC curve developed with the default values in the calculator is shown in the figure below:



Feedback

For queries and feedback:

https://industrialdecarb.lbl.gov/