CONTROL STRATEGY TOOL (CoST)

DEVELOPMENT DOCUMENTATION

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Preface

The Control Strategy Tool (CoST) is a software system for estimating the emission reductions and costs associated with future-year control scenarios, and then to generate emission inventories with the control scenarios applied. CoST has been developed under a multi-year contract between the U.S. EPA and the University of North Carolina Institute for the Environment (UNC-IE). Initiated in 2005 to replace the AirControlNET software system, CoST development has been funded incrementally under annual work assignments (WA) under two consecutive contracts. The documentation for CoST, including this document to describe the design and functionality of the system, was first funded under WA 2-01 in project fiscal year 2009. This version of the CoST Development Document includes information on updates made during WA 4-01 in project fiscal year 2016.

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Acronyms

CE ....Control Efficiency
CMAQ........................Community Multiscale Air Quality model
CMAS ....Community Modeling and Analysis System
CoST ....Control Strategy Tool
CRF ....Capital Recovery Factor
CSV ....Comma-separated values
DBF............................D-base Format
EC ....Elemental Carbon
EMF ....Emissions Modeling Framework
EPA ....Environmental Protection Agency
ESRI...........................Environmental Systems Research Institute
FGD............................Flue Gas Desulfurizer
FIPS............................Federal Information Processing Standards
GDP............................Gross Domestic Product
GIS ....Geographic information system
HEID ....Health and Environmental Impacts Division
IE................................Institute for the Environment (UNC)
IPD ....Implicit Price Deflator
LNB............................Low NOx Burner
NAICS........................North American Industry Classification System
NEI ....National Emissions Inventory
NSCR ....Non-Selective Catalytic Reduction
OC ....Organic Carbon
O&M ....Operating and Maintenance
ORL............................One record per line
PR...............................Percent Reduction
RE ....Rule Effectiveness
RP...............................Rule Penetration
SCC ....Source Classification Code
SIC ....Standard Industrial Classification
SNCR ....Selective Non-Catalytic Reduction
SQL ....Structured Query Language
SMOKE......................Sparse Matrix Operator Kernel Emissions modeling system
tpy ....Tons per year
UNC ....University of North Carolina

1 Introduction

EPA's Health and Environmental Impacts Division (HEID) is developing the Control Strategy Tool (CoST) to allow users to estimate the emission reductions and costs associated with future-year control scenarios, and then to generate emission inventories with the control scenarios applied [Misenheimer, 2007; Eyth, 2008]. CoST tracks information about control measures, their costs, and the types of emissions sources to which they apply. The purpose of CoST is to support national- and regional-scale multipollutant analyses. CoST is being developed to provide an extensible software system for developing control strategies that match control measures to emission sources using algorithms such as "Maximum Emissions Reduction", "Least Cost", and "Apply Measures in Series".

The result of a control strategy contains information that specifies the estimated cost and emissions reduction achieved for each control measure-source combination. CoST is an engineering cost estimation tool for creating controlled inventories and is not currently intended to model emissions trading strategies, nor is it an economic impact tool. Control strategy results can be exported to comma-separated-values (CSV) files, Google Earth-compatible (.kmz) files, or Shapefiles. The results can also be viewed in a graphical table that supports sorting, filtering, and plotting. The Strategy Detailed Result tables that are output from a strategy can also be merged with the original inventory to create controlled emissions inventories that can be exported to files that can be input to the Sparse Matrix Operator Kernel Emissions modeling system (SMOKE), which is used by EPA to prepare emissions inputs for air quality modeling.

CoST is a component of the Emissions Modeling Framework (EMF), which is currently being used by EPA to solve many of the long-standing complexities of emissions modeling [Houyoux, 2008]. Emissions modeling is the process by which emissions inventories and other related information are converted to hourly, gridded, chemically speciated emissions estimates suitable for input to an air quality model such as the Community Multiscale Air Quality (CMAQ) model. The EMF supports the management and quality assurance of emissions inventories and emissions modeling-related data, and also the running of SMOKE to develop CMAQ inputs. Providing CoST as a tool integrated within the EMF facilitates a level of collaboration between control strategy development and emissions inventory modeling that was not previously possible. CoST supports multipollutant analyses and data transparency, and provides a wide array of options for developing control strategies. CoST has been developed to replace the older AirControlNET software. Recent applications of CoST include the computation of detailed onroad and nonroad mobile-source strategies, a point- and area-source least-cost comparison study with AirControlNET, and a pilot study for greenhouse gases emitted from the cement sector.

CoST uses a Control Measures Database to develop control strategies, and provides a user interface to that database. The system provides several types of algorithms for developing control strategies:

- "Maximum Emissions Reduction"
- "Multi-Pollutant Max Emissions Reduction"
- "Least Cost"
- "Least Cost Curve"
- "Apply Measures in Series"

The first four algorithms are typically used for point and area sources; the last one is usually used for mobile sources, for which most control techniques are independent of one another. Because CoST is an extensible system that is implemented as modules within the EMF, it was possible to develop additional algorithms that can be used to create altered emissions inventories, although these may not be considered "control strategies" in the traditional sense. These algorithms are also discussed in this document and are called "Annotate Inventory" and "Project Future Year Inventory". A brief summary of the available algorithms is provided in Section 2.1, and the details of how each of the algorithms functions are provided in Sections 3 through 8.

This document describes how CoST computes control strategies. Information is given on the input parameters to the strategies, on how the computations of the strategies are performed, and on the outputs from the strategies. Each type of strategy algorithm that has been implemented to date is discussed. The document is intended to provide technical descriptions to readers with some familiarity with emissions modeling and control strategy development, and it is not intended to be a user's guide. For additional information on other aspects of CoST, please see the following independent documents:

- CoST User's Guide
- CoST Control Measures Database Document

These documents, and additional information about CoST, can be found at: http://www.epa.gov/ttn/ecas/cost.htm. A glossary of terms is included as an appendix to this document.

2 Concepts General to All Control Strategies

2.1 Introduction to Control Strategies

A control strategy is a set of control measures applied to emissions inventory sources in a specified geographic region (in addition to any controls that are already in place) to accomplish an emissions reduction goal. Such goals are usually set to improve air quality and/or to reduce risks to human health. CoST automates the key steps for preparing control strategies.

The inputs to a control strategy consist of:

- a set of parameters that control how the strategy is run,
- one or more emissions inventory datasets,
- filters that determine which sources are to be included from those datasets;
- filters that determine which control measures are to be included in the analysis; and
- constraints that limit the application of measures to specific sources based on the resulting costs or emissions reduction achieved.

A diagram of the basic steps for running a control strategy is shown in Figure 1.

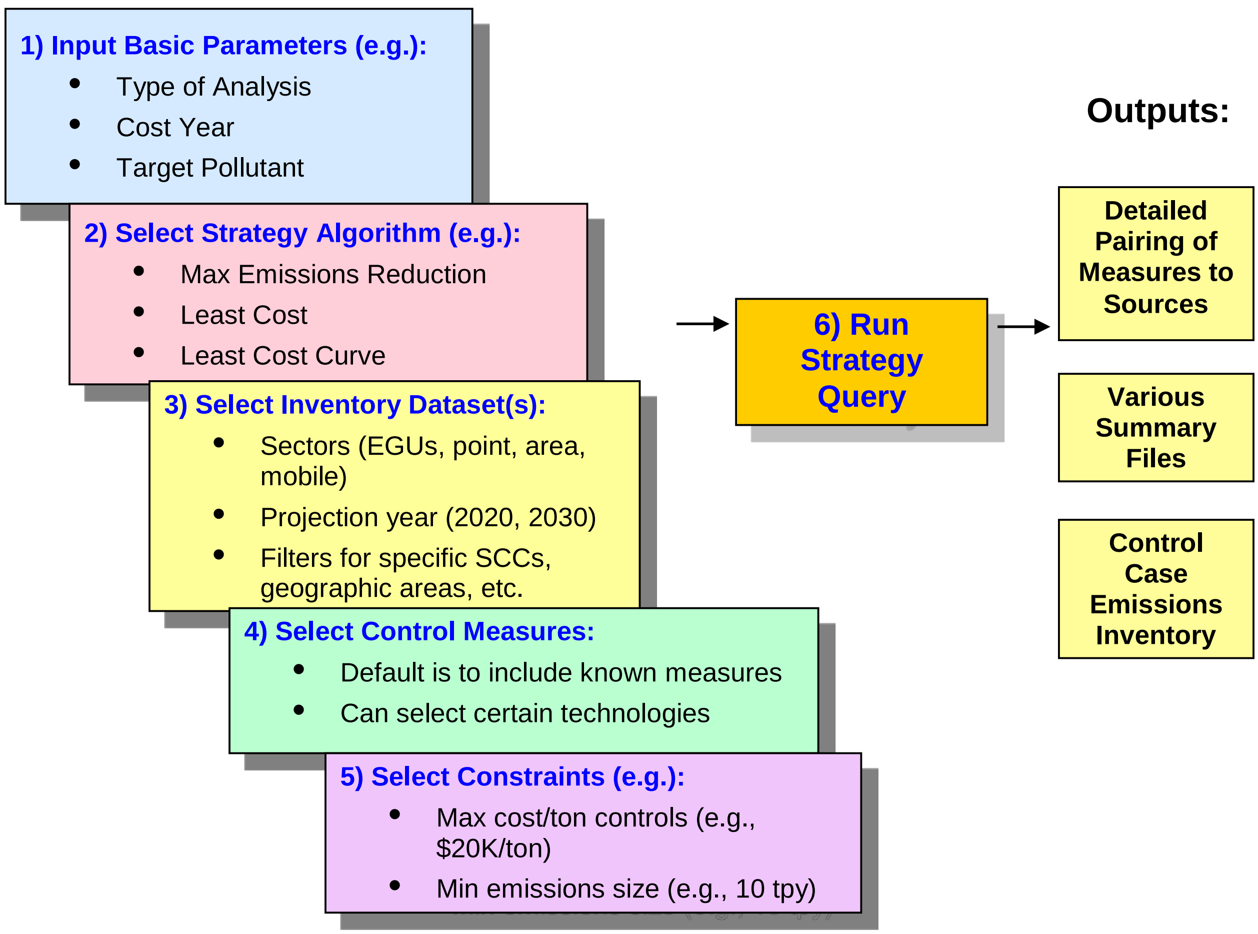

Figure 1. Basic Steps for Running a Maximum Reduction Control Strategy

At this time, seven algorithms are available to determine how measures are assigned to sources:

1. **Annotate Inventory**: assigns control measures to the inventory based on its control efficiency, and can be used to fill in control measure information for inventory sources that are missing these details but have a control efficiency assigned (this strategy could be applied to either a base- or a future-year inventory).
2. **Apply Measures in Series:** assigns all control measures that can be used for a source to the source in the specified order; this is often used for mobile sources, for which the control measures are typically independent of one another.
3. **Least Cost:** each source may be assigned only a single measure to achieve a specified percent or absolute reduction in a region with the minimum possible annualized cost.
4. **Least Cost Curve:** performs least-cost runs iteratively at multiple percent reductions so that a cost curve can be developed that shows how the annualized cost increases as the level of desired reduction increases.

5. **Maximum Emissions Reduction:** assigns to each source the single measure that provides the maximum reduction to the target pollutant, regardless of cost.
6. **Project Future Year Inventory:** applies control programs and growth factors to sources, as would be needed to project a base-year inventory to a future-year inventory.
7. **Multi-Pollutant Maximum Emissions Reduction:** assigns all control measures that can be used for a source based on a specific target pollutant order (e.g., NOx first, PM10 second, VOC third, and SO2 last); each source target pollutant may be assigned only a single measure that provides the maximum reduction regardless of cost; if a measure already controlled a source's target pollutant via a co-impact from a previous target pollutant iteration, then no additional control will be chosen for that specific source's target pollutant (e.g., if a NOx measure also controlled VOC as a co-impact, during the VOC iteration no measure would be attempted for this source, since VOC was already controlled via the NOx co-impact).

The main CoST output for each control strategy is a table called the "Strategy Detailed Result". This table consists of emission source-control measure pairings, each of which contains information about the cost and emission reduction that would be achieved if the measure were to be applied to the source. The Strategy Detailed Result table can be used with the original input inventory to produce, in an automated manner, a controlled emissions inventory that reflects implementation of the strategy; this inventory includes information about the measures that have been applied to the controlled sources. The controlled inventory can then be directly input to the SMOKE modeling system to prepare air quality model-ready emissions data. In addition, comments are placed at the top of the inventory file to indicate the strategy that produced it and the settings of the high-level parameters that were used to run the strategy.

More detailed information on the inputs to and outputs from control strategies is given in Sections 2.2 (inputs) and 2.6 (outputs), while the strategy algorithms themselves are discussed in detail in Sections 3 through 8. Section 2 also addresses inventories and inventory filtering (Section 2.3), control measure filtering and custom overrides (Section 2.4), constraints (Section 2.5), and summaries of strategy inputs and outputs (Section 2.7).

2.2 Inputs to Control Strategies

All types of control strategies have fields that can be specified by the user prior to running the strategy. This section describes these fields.

2.2.1 Summary Information

The following input fields provide summary information to the control strategy:

- Name: Unique name for the control strategy.
- Project: The name of the project for which this strategy run was performed (e.g., Initial Ozone NAAQS).
- Type of Analysis: The type of algorithm used to match the control measures with sources (e.g., Maximum Emissions Reduction, Least Cost).
- Cost Year: The cost year to use for the results of the strategy. All cost data specified for the control measures will be converted to this year using the Gross Domestic Product

(GDP): Implicit Price Deflator, issued by the U.S. Department of Commerce, Bureau of Economic Analysis. An example of this computation is provided in Section 2.6.

- Target Year: This is the target year for the strategy run. Typically, this is the year represented by the input inventory or inventories. For the "Project Future Year Inventory" analysis type, the target year represents the future year to which you are projecting the inventory. For control measure efficiency records to be considered for a strategy, the specified effective date for the record must be equal to or earlier than the target year.
- Region: The name of the geographic region to which the strategy is to be applied. This is for user information only and does not impact the strategy results. This is different from the concept of 'Locale', used in the control measure efficiency records to indicate the state or county code to which the record applies. See the CoST Control Measures Database Document for more information on the use of Locale.
- Target Pollutant: The pollutant that is targeted as the primary interest for reduction in this control strategy. The Least Cost and Maximum Emissions Reduction algorithms will consider reductions of this pollutant when performing their computations. Note that reductions of pollutants other than the selected target pollutant (e.g., PM_{10}, $PM_{2.5}$, elemental carbon [EC], organic carbon [OC]) will be included in strategy results if they appear in the inventories input to the strategy and they are reduced by measures applied as part of the strategy. These pollutants are sometimes referred to as "coimpact pollutants", because the impact on the emissions could either be a reduction (i.e., a benefit) or an increase (i.e., a disbenefit).
- Discount Rate: The discount (i.e., interest) rate used to compute the annualized capital cost for control measures when appropriate data are available.
- Use Cost Equations: A Boolean (i.e., true/false) flag indicating whether cost equations should be used for a strategy run. If not selected, only the default cost per ton values will be used.
- Include Measure With No Cost Data: A Boolean (i.e., true/false) flag indicating whether control measures with no cost information should be included in the strategy run. If not selected, only measures with known costs will be used during the strategy run.

2.2.2 Inventories

The following input fields for the control strategy are related to inventories:

- Inventories: The emissions inventories for which the control strategy will be run. The inventories must already have been loaded into the EMF and have one of the following EMF dataset types: ORL point, ORL nonpoint, ORL nonroad, and ORL onroad, where ORL stands for 'one record per line', meaning that each line of the file has information for a single source-pollutant combination. Multiple inventories can be processed for a strategy. Note that multiple versions of the inventories may be available, and the appropriate version of each inventory must be selected prior to running a control strategy.
- Merge inventories: A Boolean check box that specifies whether all inventory data should be merged together prior to applying the strategy algorithm (such as might be desirable

for a least-cost strategy running across multiple sectors), versus processing each inventory independently to create separate, independent results.

- Inventory Filter: A general filter that can be entered using the same syntax as a Structured Query Language (SQL) "where clause". Any of the columns in the inventory can be used in the expression. Examples include (1) "SCC like '212%' " to limit the analysis to apply to only inventory records for which the SCC code starts with 212, and (2) "FIPS like '06%' or FIPS like '07%' " to limit the strategy analysis to apply only to inventory records with Federal Information Processing Standards (FIPS) numeric state-county codes starting with 06 or 07.
- County Dataset: An EMF dataset containing a specific list of counties within which to apply control measures during the strategy run. If the user chooses a county dataset when creating a control strategy, control measures will be applied only to counties that are included in this list. The system will show as options the names of the available datasets in the EMF that have the dataset type 'List of Counties (CSV)'. When importing one of these datasets into the EMF, ensure that the CSV file has at least two columns, the first row of which is the column names. One of the columns must have a name that starts with "FIPS". CoST will assume this column has the list of FIPS codes that should be controlled. Make sure that leading zeros are present for FIPS codes less than 10000.
- County Dataset Version: If a county dataset is specified, a version of the dataset to use must be selected. This input is required because the EMF can store multiple versions of each dataset.

2.2.3 Control Measures and Control Programs

For all strategy types except "Project Future Year Inventory", the control strategy takes inputs related to control measures with the following fields:

- Measure Classes to Include: A list of measure classes from which to include control measures to be used as part of a control strategy. Currently available classes are Emerging (feasible, but not currently in wide use), Hypothetical (a truly made-up control used for sensitivity runs), Known (known to be currently deployed in the field), Obsolete (used in older installations, but should not be used when performing new runs), and Temporary (controls that are used during the analysis only if the user was the creator of the control measure; CoST Super Users will be able to use all Temporary measures, whereas a non-Super User will be able to use only their specific Temporary controls, not other users' Temporary controls). Other types of measure classes may be included in the future, such as measures that have reduction information but no costs specified.
- Measures to Include: A list of specific measures to consider using for the strategy run may be specified. Measures with similar names may be selected as a group. When measures to include are chosen this way, it is possible to specify a County Dataset that lists the counties in which each measure may be applied, along with a County Dataset Version. The relative order of measure application may be specified (i.e., for the 'Apply Measures in Series' strategy type). In addition, override values for the rule penetration and rule effectiveness measure may be specified.

For the "Project Future Year Inventory" strategy type, the control strategy takes only one type of input related to control programs:

- Programs to Include: A list of specific control programs to use for the run.

2.2.4 Input Constraints

The following settings for the strategy are known as 'constraints'. If the constraint values are not satisfied for a particular combination of control measure and source, the measure under consideration will not be applied to the source, and CoST will look for another measure that satisfies all of the constraints.

- Minimum Emissions Reduction (tons): If specified, requires each control measure to reduce the target pollutant by the specified minimum tonnage for a particular source (down to the plant+point+stack+segment level of specification); if the minimum tonnage reduction is not attainable, the measure will not be applied.
- Minimum Control Efficiency (%): If specified, requires each control measure used in the strategy to have a control efficiency greater than the specified control efficiency for a particular source and target pollutant.
- Maximum Cost per Ton ($/ton): If specified, each control measure must have an annualized cost per ton less than the specified maximum annualized cost per ton for the target pollutant for each source. This cost is based on 2013 dollars.
- Maximum Annualized Cost ($/yr): If specified, each control measure must have an annualized cost less than the specified annualized cost for each source and target pollutant. This cost is based on 2013 dollars.
- Minimum Percent Reduction Difference for Replacement Control (%): If specified, this constraint determines when a replacement control measure achieves an additional suitable percent reduction with respect to the preexisting control percent reduction for the inventory source target pollutant emission. This constraint is used only in the "Maximum Emission Reduction" and "Least Cost" strategy types. This constraint is not applicable to add-on controls or to sources with no existing control. The following formula defines the calculation used during the constraint validation:

  [(inventory emission - remaining emission) / inventory emission] x 100
  ≥ Minimum Percent Reduction Difference for Replacement Control (%)

  where

  remaining emission

  = uncontrolled inventory emission
  x [1 – (replacement control percent reduction / 100)]

  = inventory emission / [1 – (existing control percent reduction / 100)]
  x [1 – (replacement control percent reduction / 100)]

  replacement control percent reduction

  = control efficiency (%) x (rule penetration (%) / 100) x (rule effectiveness (%) / 100)

2.2.5 Fields Automatically Set by CoST

The following fields of a control strategy are set automatically by the software and are not specified by the user. (Note that some of these summarize the results of the strategy analysis and are therefore not available until after the strategy has been run.)

- Creator: The name of the person who created the strategy.
- Last Modified Date: The date and time when the strategy was last modified.
- Start Date: The date and time on which the strategy run was most recently started.
- Completion Date: The date and time on which the strategy run was most recently completed.
- Total Annualized Cost: The total annualized cost of applying the strategy.
- Target Pollutant Reduction: The absolute emissions reduction achieved for the target pollutant (tons).
- Run Status: The status of the strategy run, which will be either “Not started”, “Running”, “Waiting”, “Completed”, or “Failed”.

2.3 Inventories and Inventory Filtering

A control strategy can have one or more emissions inventories as input. The inventories must first be imported into the EMF as datasets before they can be used by CoST. As noted in Section 2.2.2, only EMF datasets of types ORL point, ORL nonpoint, ORL nonroad, and ORL onroad can be used for the strategies. The point inventories have information about emissions sources with specific locations, which are specified using latitude and longitude. Nonpoint, nonroad, and onroad inventories contain data aggregated to the county level. The EMF database stores the data for the emissions inventories along with metadata about the inventories in its PostgreSQL (http://www.postgresql.org) database.

The EMF user interface provides users with access to the inventory data and metadata via the Dataset Manager. Some control strategy algorithms process the inventories iteratively and produce results for each inventory that is specified as an input for the strategy. The “Least Cost” and “Least Cost Curve” strategy types, on the other hand, can merge the input inventories from multiple sectors together prior to processing them, thereby facilitating cross-sector analyses.

Inventory filters can be specified to limit the inventory records that are processed during the strategy analysis. The inventory can be filtered by specifying a SQL “where clause” and by assigning a county dataset to the strategy. A SQL “where clause” provides a powerful filtering capability. Any column in the inventory can be used in the “where clause”. Some inventory filter examples are given in Table 1.

Table 1. Examples of Inventory Filters

Filter Purpose	SQL Where Clause
Filter on a particular set of SCCs	scc like '231%' or scc like ‘232%’
Filters on a particular set of pollutants	poll in ('PM10', 'PM2_5') *or* POLL = 'PM10' or POLL = 'PM2_5'
Filter sources only in NC (State FIPS = 37), SC (45), and VA (51); Note that FIPS column format is State + County FIPS code (e.g., 37001)	substring(FIPS,1,2) in ('37', '45', '51')
Filter sources only in CA and include only NO_x and VOC pollutants	substring(fips,1,2) = '06' and poll in ('NOX', 'VOC') *or* fips like '06%' and (poll = 'NOX' or poll = 'VOC')

Within the inventory filter, you may use upper or lower case to refer to the column names and for the SQL keywords, but note that the specified values within single quotes are case sensitive (e.g., ‘NOx’ is different from ‘NOX’).

Specifying a county dataset is another way to filter the inventory. If you select a “List of Counties (CSV)” dataset type, then only the sources within the specified list of counties would be considered for controls. The list of FIPS codes to include is obtained from the column in the dataset with the name ‘FIPS’.

Note that only the records of the input inventories that pass both the inventory and county filters will be considered for control measure application. Thus, if you use a filter to include only specific pollutants, then pollutants that are not specified by the filter will not be considered for the computation of co-impacts. In addition, pollutants like elemental carbon (EC) and organic carbon (OC) that are not traditionally included in input inventories will not be included in the results unless the inventory has been preprocessed to include EC and OC.

2.4 Control Measures, Control Measure Filtering, and Custom Overrides

Control Measures. The emissions reductions achieved by control strategies are due to the application of control measures to emissions sources. Control measures are devices or techniques that reduce emissions for at least one pollutant of interest for a particular group of emissions sources. CoST tracks information about control measures, their costs, and the types of emissions sources to which they apply. See the **Control Strategy Tool (CoST) Control Measures Database (CMDB) Document** for more detailed information about control measures and how they are defined in the CoST system.

Control Measure Add-on vs. Replacement Application. A control measure can be defined as either a replacement control or an add-on control. A replacement control is used to replace an existing source control or is used as a new control on uncontrolled sources. An add-on control is used as an additive/incremental control to an existing source control and will be applied only to sources with existing controls. This definition occurs via two columns in the “control measure efficiency record” table: the existing measure abbreviation and the existing National Emissions Inventory (NEI) device code. If either of these fields is populated, then the control is an incremental/add-on control. If both fields are blank (note that an NEI device code of zero is equivalent to blank), then the control is a replacement control. See **Control Strategy Tool (CoST) Control Measures Database (CMDB) Document** for more detailed information on a how add-on vs replacement controls are defined. A source with an existing control can be indicated in the emission inventory by populating the following inventory record fields: CEFF (existing control efficiency), control_measures, Primary Control Equipment Code (CPRI) (relevant only for ORL Point dataset type), or primary_device_type_code (relevant only for ORL Nonpoint dataset type). In order for an add-on control to be applied to a source, the emission inventory source record must indicate an existing control via one of the following columns: control_measures, CPRI, or primary_device_type_code.

Table 2 shows four sample sources in a point emissions inventory. The data on the first three sources indicate that they already have an existing control. The first source has the control_measures column populated. The second source has the CPRI column populated. The third source has the existing control efficiency (CEFF) column populated. The data on the last source indicate that there is no existing control, because the CEFF, control_measures, and CPRI columns are blank.

Table 2. Example Inventory Sources

Inventory No.	Source [PlantId, PointId, StackId, Segment]	FIPS	SCC	Pollutant	Annual Emissions (tons)	CEFF (%)	control_measures	CPRI or primary_device_type_code	Add-On Control Eligible
1	ABC Industrial Plant [0001,01,01,01]	37001	10100201	PM2_5	10	95	PDESPWPUBO		Y
2	XYZ Industrial Plant [0101,01,01,01]	37001	10100201	PM2_5	20	95		10	Y
3	DEF Industrial Plant [0201,01,01,01]	37001	10100201	PM2_5	20	95			N
4	MNO Industrial Plant [0201,01,01,01]	37001	10100201	PM2_5	120				N

Only the first two sources are eligible to use an add-on control, since they are the only two that have the control_measures or CPRI (or primary_device_type_code) columns populated. The third source does indicate it has an existing control, since the CEFF is populated, but because there is no information in the control_measures or CPRI (or primary_device_type_code) columns, an add-on control would not be considered during a CoST analysis.

If the inventory source record control_measures column contains a matching abbreviation to a suitable measure efficiency record existing measure abbreviation, this match will indicate that a valid add-on control can be used on the source. Likewise, if either the CPRI or primary_device_type_code columns can be used to match against a suitable measure efficiency record existing NEI device code field, this will also indicate a possible add-on control scenario.

The overall choice of a replacement control versus an add-on control depends on which scenario gives the best reduction at the lowest cost. In some cases, the replacement control might provide a better overall control efficiency than if just an add-on control were placed on the source; in other cases, it might be more effective to put a replacement control on the source. The specifics regarding how this works with the various strategy types will be discussed in later sections for the "Maximum Emission Reduction" strategy type.

Currently, the only algorithms that support the concept of using add-on and replacement controls are the "Maximum Emission Reduction" and "Least Cost" strategy types. The "Apply Measures In Series" strategy type does not follow the same logic as described above; regardless of how a measure in defined in the CMDB, this strategy will always try to incrementally use the controls. See the "Apply Measures In Series" section for more information on how control measures are applied during this analysis.

Control Measure Filtering. For all strategy types except "Project Future Year Inventory", the measures used during an analysis can be filtered either by measure class (discussed in Section 2.2.3) or by specifying specific measures to consider for the strategy run. By default, only measures with the class set to "Known" are included in a strategy run. Measures with other classes — Emerging, Hypothetical, Obsolete, or Temporary — may be selected for inclusion in a strategy. Note that only the measures with the classes selected by the user will be included in the strategy run. Also note that if someone who is not a CoST Super User includes Temporary measures, only the Temporary controls created by that person will be included in the analysis.

Custom Overrides. As an alternative to selecting the classes of measures to include, users can select specific measures to include in the strategy. Values for rule penetration and rule effectiveness can be overridden for the specified measures. Note that in the Control Measures Database, the geographic extent for individual measures can be limited to certain sets of counties by specifying a region dataset for the measure from one of the available datasets with the "List of Counties (CSV)" dataset type. For algorithms that support the application of multiple measures to sources, such as "Apply Measures in Series", an order of application can be specified for the selected measures and they will then be applied in ascending order. For example, a mobile-source strategy may have the following specified for each measure: an order of application, a geographic region, and a rule penetration override.

Control measure filtering and custom overrides are not available for the "Project Future Year Inventory" strategy type. Instead, control program selection is available, which is discussed in Section 8.1.

2.5 Constraints

Constraints can be specified to limit the control measures assigned during the strategy run. For example, the strategy could be set up to not use any measures that cost more than $5,000 per ton for the target pollutant. Alternatively, the user could specify that measures not be assigned to sources if the measures do not reduce at least 1 ton of the target pollutant for the source. CoST evaluates the constraints while the source is being matched with the control measures. For example, the emission reduction achieved by applying a measure to a source is not known until the measure and its control efficiency have been selected. Thus, constraint calculations are dependent on both the inventory source and the measure being considered for application to the source. Note that the term "source" here refers to a single row of the emissions inventory, which for point sources is uniquely determined by FIPS, plant, point, stack, segment, and SCC, and for nonpoint sources is uniquely determined by FIPS and SCC. Sources should not be confused with "plants", each of which can contain many sources.

As discussed in Section 2.2.4, the constraints available for all strategy types are the following:

- Minimum Emissions Reduction (tons): The control measure must be able to reduce the target pollutant by this minimum tonnage for the source.
- Minimum Control Efficiency (%): The control measure must have a control efficiency greater than the specified control efficiency for the source and target pollutant.
- Maximum Cost per Ton ($/ton): The control measure must have an annualized cost per ton less than specified maximum cost per ton for the source and target pollutant. This cost is based on 2013 dollars.
- Maximum Annualized Cost ($/yr): The control measure must have an annualized cost less than the specified annualized cost for a particular source and target pollutant. This cost is based on 2013 dollars.

2.6 Strategy Outputs

CoST automatically generates three main outputs after each successful strategy run:

- Strategy Detailed Result
- Strategy Measure Summary
- Strategy County Summary

Each of these outputs is created as an EMF Dataset. Also discussed in this section are the controlled emissions inventory output (Section 2.6.4), the strategy messages output (Section 2.6.5) and special strategy outputs (Section 2.6.6).

2.6.1 Strategy Detailed Result

The Strategy Detailed Result is the primary output from the control strategy. It is a table of emission source-control measure pairings, each of which contains information about the costs and emission reduction achieved for measures after they are applied to the sources. The contents of this table are described later in this section. When generating the Strategy Detailed Result table, some additional inputs are needed for CoST to calculate the values of some columns related to costs, such as:

- Stack Flow Rate (cfs) – from the emissions inventory
- Capital Annual Ratio – from the control measure efficiency record
- Discount Rate (%) – from the control measure efficiency record
- Equipment Life (yrs) – from the control measure efficiency record
- Boiler Capacity (MW) – from the design capacity column of the inventory; units are obtained from the design_capacity_unit_numerator and design_capacity_unit_denominator columns from the inventory. Note that boiler capacity is often blank in inventories, so special steps may need to be taken to fill in this information.

- Annual Average Hours per Year (hrs) – from the annual_avg_hours_per_year column of the inventory

The stack flow rate provides information on the volume of effluent that requires treatment by the control device. The capital annual ratio is used to calculate the capital cost of a control device from an available operating and maintenance cost estimate for that device. The capital costs are the one-time costs to purchase and install the device, and the operating and maintenance costs are those required to operate and maintain the device for each year. The discount rate and equipment life are used to compute the annualized capital costs for the device. The discount rate can be considered an annual interest rate used to calculate the cost of borrowing money to purchase and install the control device. The annualized capital cost is computed based on the discount rate, and the costs are spread over the life of the equipment. The algorithms to compute these cost breakdowns vary based on whether the input data required to utilize a cost equation are available. (This is described in further detail in Table 4.)

When cost data are provided for the control measures, the resulting costs are also specified in terms of a particular year. To compute the cost results for a control strategy, it is necessary to escalate or de-escalate the costs to the same year in order to adjust for inflation and to allow for consistency in comparing control strategy results. This is done with the following formula:

$$\text{Cost (\$) for a year of interest} = \frac{\text{Cost for original cost year} \times \text{GDP IPD for year of interest}}{\text{GDP IPD for original cost year}}$$

where the GDP IPD is the Gross Domestic Product: Implicit Price Deflator available from the United States Department of Commerce Bureau of Economic Analysis Table 1.1.9. Implicit Price Deflators for Gross Domestic Product (http://bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&904=2013&903=13&906=a&905=2015&910=x&911=1). The current version used in the CoST system is dated November 24, 2015. An excerpt of this version is shown in Table 3.

Table 3. Excerpt from the gdplev Table Used to Convert Data between Cost Years

Year	GDP IPD
1996	76.699
1997	78.012
1998	78.859
1999	80.065
2000	81.887
2001	83.754
2002	85.039
2003	86.735
2004	89.120

Year	GDP IPD
2005	91.988
2006	94.814
2007	97.337
2008	99.246
2009	100
2010	101.221
2011	103.311
2012	105.214
2013	106.929
2014	108.686

To facilitate comparing the costs of control measures with one another, a normalized version of the control measure cost per ton is stored within the control measures database. These costs have all been converted to a consistent 'Reference Year' using the above formula, so that the cost of any measure can be compared with any other even if their cost years differ. Currently, the reference year is 2013. In addition, during the course of the strategy run, the costs are converted (using the above formula) from the reference year to the cost year that was specified as an input to the strategy. The results of the strategy are therefore presented in terms of the specified cost year.

The columns in the Strategy Detailed Result table are shown in Table 4. Examples of the Strategy Detailed Result are given for each type of strategy as the strategies are discussed in detail in Sections 3 through 9.

Table 4. Columns in the Strategy Detailed Result

Column	Description
SECTOR	The source sector specified for the input inventory dataset.
CM_ABBREV	The abbreviation of the control measure that was applied to the source.
POLL	The pollutant for the source, found in the inventory
SCC	The SCC code for the source, found in the inventory
FIPS	The state and county FIPS code for the source, found in the inventory
PLANTID	For point sources, the plant ID for the source from the inventory.
POINTID	For point sources, the point ID for the source from the inventory.
STACKID	For point sources, the stack ID for the source from the inventory.
SEGMENT	For point sources, the segment for the source from the inventory.

Column	Description
ANNUAL_COST ($)	The total annual cost (including both capital and operating and maintenance) required to keep the measure on the source for a year. Default Approach (used when there is no cost equation, or inputs to cost equation are not available): Annual Cost = Emission Reduction (tons) x Reference Yr Cost Per Ton ($/tons in 2013 Dollars) x Cost Yr GDP IPD / Reference Yr GDP IPD Annual Cost = 11.88 tons x $159 x 94.814 / 106.929 = $1,674.90
ANN_COST_PER_ TON ($/ton)	The annual cost (both capital and operating and maintenance) to reduce one ton of the pollutant. Ann_Cost_Per_Ton = Annual Cost ($) / Emis Reduction (tons) Ann_Cost_Per_Ton = $1,674.90 / 11.88 tons = $140.98/ton
ANNUAL_OPER_ MAINT_COST ($)	The annual cost to operate and maintain the measure once it has been installed on the source. Default Approach (used when there is no cost equation, or inputs to cost equation are not available): = (Annual Cost – Annualized Capital Cost) = ($1,674.90 - $174) = $1,500.90 Note: if the capital recovery factor was not specified for the measure, it would not be possible to compute Annualized Capital Cost or Annual O&M Costs
ANNUAL_VARIABLE_ OPER_MAINT_COST ($)	The annual variable cost to operate and maintain the measure once it has been installed on the source. Default Approach (used when there is no cost equation, or inputs to cost equation are not available): = blank (not calculated, no default approach available)
ANNUAL_FIXED_ OPER_MAINT_COST ($)	The annual fixed cost to operate and maintain the measure once it has been installed on the source. Default Approach (used when there is no cost equation, or inputs to cost equation are not available): = blank (not calculated, no default approach available)

Column	Description
ANNUALIZED_ CAPITAL_COST ($)	The annualized cost of installing the measure on the source assuming a particular discount rate and equipment life. Annualized_Capital_Cost = Total Capital Cost x Capital Recovery Factor (CRF) Note: if the CRF is not available for the measure, it is not possible to compute the ACC or the breakdown of costs between capital and O&M costs. CRF = (Discount Rate x (1 + Discount Rate)^Equipment Life) / ((Discount Rate + 1) ^Equipment Life - 1) CRF = (0.07 x (1 + 0.07)^20) / ((0.07 + 1) ^20 - 1) = 0.0944 Annualized_Capital_Cost = $1,842.40 x 0.0944 = $174
TOTAL_CAPITAL_ COST ($)	The total cost to install a measure on a source. Default Approach (used when there is no cost equation or cost equation inputs are not available): TCC = Emission Reduction (tons) x Reference Yr Cost Per Ton ($/tons in 2013 Dollars) x Capital Annualized Ratio x Cost Yr GDP IPD / Reference Yr GDP IPD TCC = 11.88 tons x $159 x 1.1 x 94.814 / 106.929 = $1,842.40
CONTROL_EFF (%)	The control efficiency of the measure being applied, stored in the measure efficiency record
RULE_PEN (%)	The rule penetration of the measure being applied, stored in the measure efficiency record, but could be overridden as a strategy setting (see the Measure Filtering section)
RULE_EFF (%)	The rule effectiveness of the measure being applied, stored in the measure efficiency record, but could be overridden as a strategy setting (see the Measure Filtering section)
PERCENT_ REDUCTION (%)	The percent by which the emissions from the source are reduced after the control measure has been applied. Percent reduction = Control Efficiency (%) x Rule Penetration (%) / 100 x Rule Effectiveness (%) / 100 = 99% x 100% / 100 x 100% / 100 = 99%
ADJ_FACTOR	The factor that was applied by a control program to adjust the emissions to the target year.
INV_CTRL_EFF (%)	The control efficiency for the existing measure on the source, found in the inventory
INV_RULE_PEN (%)	The rule penetration for the existing measure on the source, found in the inventory
INV_RULE_EFF (%)	The rule effectiveness for the existing measure on the source, found in the inventory

Column	Description
FINAL_EMISSIONS (tons)	The final emission that results from the source being controlled. = Annual Emission (tons) - Emission Reduction (tons) = 12 - 11.88 = 0.12 tons
EMIS_REDUCTION (tons)	The emissions reduced (in tons) as a result of apply the control measure to the source. Emissions reduction = Annual Emission (tons) x Percent Reduction (%) / 100 = 12 x 99% / 100 = 11.88 tons
INV_EMISSIONS (tons)	The annual emissions, found in the inventory. Note that if the starting inventory had average day emissions, the average day value is annualized and the resulting value is shown here. This is necessary to properly compute the costs of the measure.
APPLY_ORDER	If multiple measures are applied to the same source, this is a numeric value noting the order of application for this specific control measure. The first control to be applied will have a value of 1 for this field, the second will have a value of 2, and so on.
INPUT_EMIS (tons)	The emissions that still exist for the source after previous control measures have been applied. Usually this is the same as inv_emissions, but for the “Apply Measures In Series” strategy type when multiple measures are applied to the same source, this is the emissions that are still available for the source after prior control measures have been applied.
OUTPUT_EMIS (tons)	The emissions that still exist for the source after the current and all prior control measure has been applied. Usually this is the same as Final Emission, but for the “Apply Measures In Series” strategy type when multiple measures are applied to the same source, this is the emissions that are still available for the source after the current and all prior control measures have been applied.
FIPSST	The 2 digit FIPS state code
FIPSCTY	The 3 digit FIPS county code
SIC	The SIC code for the source from the inventory
NAICS	The NAICS code for the source from the inventory
SOURCE_ID	The record number from the input inventory for this source.
INPUT_DS_ID	The numeric ID of the input inventory dataset (for bookkeeping purposes). If multiple inventories were merged to create the inventory (as can be done for Least Cost strategies), this ID is that of the merged inventory.
CS_ID	The numeric ID of the control strategy
CM_ID	The numeric ID of the control measure

Column	Description
EQUATION TYPE	The control measure equation that was used during the cost calculations. If a negative sign is in front of the equation type, this indicates that the equation type was missing inputs and the strategy instead used the default approach to estimating costs.
ORIGINAL_ DATASET_ID	The numeric ID of the original input inventory dataset, even if a merged inventory was used for the computation of the strategy, as can be done for Least Cost strategies.
SECTOR	The sector specified for the input inventory (text, not an ID – e.g., ptnonipm)
CONTROL_PROGRAM	The control program that was applied to produce this record
XLOC	The longitude for the source, found in the inventory for point sources, for nonpoint inventories the county centroid is used. This is useful for mapping purposes
YLOC	The latitude for the source, found in the inventory for point sources, for nonpoint inventories the county centroid is used. This is useful for mapping purposes.
PLANT	The plant name from the inventory (or county name for nonpoint sources)
REPLACEMENT_ADDON	Indicates if the measure was a replacement or add-on control. A = Add-On Control R = Replacement Control
EXISTING_MEASURE_ ABBREVIATION	This column is used when an Add-On Control was applied to a source, this indicates the existing control measure abbreviation that was on the source.
EXISTING_PRIMARY_ DEVICE_TYPE_CODE	This column is used when an Add-On Control was applied to a source, this indicates the existing control measure primary device type code that was on the source.
STRATEGY_NAME	The name of the control strategy that produced the detailed result.
CONTROL_TECHNOLOGY	Indicates the control technology of the control measure.
SOURCE_GROUP	Indicates the source group of the control measure.
COMMENT	Information about this record and how it was produced either created automatically by the system or entered by the user.

2.6.2 Strategy Measure Summary

The Strategy Measure Summary output dataset is a table of emission reduction and cost values aggregated by the inventory sector (i.e., an EMF Sector), state/county FIPS code, SCC, pollutant, and control measure. This table contains information only for sources that were controlled during the strategy run and is generated by running a SQL statement that aggregates the data from the Strategy Detailed Result according to the five categories just listed. The annual cost and emission reduction are calculated by summing all costs and emission reductions for the specified grouping (sector, FIPS, SCC, pollutant, and control measure). The average annual cost per ton is calculated by dividing the total annual costs by the total emission reduction for each measure. The percent reduction is calculated by dividing the total emission reduction by the total of the emissions entering the measure, then multiplying by 100. The columns in this summary and the formulas used to compute their values are shown in Table 5. For reference, the SQL code used to generate the Strategy Measure Summary from the Strategy Detailed Result is provided following Table 5. An example Strategy Measure Summary is shown in Table 9 (located at the end of Section 2.6).

Table 5. Columns in the Strategy Measure Summary

Column	Description
SECTOR	The sector for the source (i.e., ptnonipm for the point non-ipm sector)
FIPS	The state and county FIPS code for the source
SCC	The SCC for the source
POLL	The pollutant for the source
CONTROL_MEASURE_ ABBREV	The control measure abbreviation
CONTROL_MEASURE	The control measure name
CONTROL_TECHNOLOGY	The control technology that is used for the measure (e.g. Low NOx burner, Onroad Retrofit).
SOURCE_GROUP	The group of sources to which the measure applies (e.g. Fabricated Metal Products – Welding).
ANNUAL_COST	The total annual cost for the measure. This is calculated by summing the annual costs for the measure = sum(annual_cost)
INPUT_EMIS	The total of emissions entering the control measure. This is calculated by summing the input emissions for all sources that were controlled by this measure = sum(input_emis)
AVG_ANN_ COST_PER_TON	The average annual cost per ton ($/ton). This is calculated by dividing the total annual cost by the total emission reduction. = sum(annual_cost) / sum(emis_reduction)
EMIS_REDUCTION	The total reduction in emission in tons for the control measure
PCT_RED	The percent reduction (%) for all sources controlled by this measure. This is calculated by dividing the total emissions reduction by the total input emissions. = [sum(emis_reduction) / sum(input_emis)] x 100

The SQL code used to generate the Strategy Measure Summary is the following:

```
select summary.sector, summary.fips,
        summary.scc,  summary.poll,
        cm.abbreviation, cm.name,
        ct.name as Control_Technology, sg.name as source_group,
        case
                when sum(summary.Emis_Reduction) <> 0 then
                        sum(summary.Annual_Cost) / sum(summary.Emis_Reduction)
                else
                        null::double precision
        end as avg_cost_per_ton,
        sum(summary.Annual_Cost) as Annual_Cost,
        sum(summary.input_emis) as input_emis,
        sum(summary.Emis_Reduction) as Emis_Reduction,
        case
                when sum(summary.input_emis) <> 0 then
                        sum(summary. Emis_Reduction) / sum(summary. input_emis)  * 100.0
                else
                        null::double precision
        end as pct_red
from (
        select e.sector, e.fips,
                e.scc, e.poll,
                e.cm_id, sum(e.Annual_Cost) as Annual_Cost,
                sum(e.Emis_Reduction) as Emis_Reduction,
                sum(e.input_emis) as input_emis
        from STRATEGY_DETAILED_RESULT_TABLE e
        group by e.sector, e.fips,
                e.scc, e.poll,
                e.cm_id ) summary
        inner join emf.control_measures cm
        on cm.id = summary.cm_id
        left outer join emf.control_technologies ct
        on ct.id = cm.control_technology
        left outer join emf.source_groups sg
        on sg.id = cm.source_group
group by summary.sector, summary.fips,
        summary.scc, summary.poll,
        cm.abbreviation, cm.name,
        ct.name, sg.name
order by summary.sector, summary.fips,
        summary.scc, summary.poll,
        cm.abbreviation, cm.name,
        ct.name, sg.name
```

2.6.3 Strategy County Summary

The Strategy County Summary output dataset is a table of emission reduction and cost values aggregated by inventory sector, county, and pollutant. This dataset includes all of the inventory sources regardless of whether they were controlled. If there is more than one inventory included in the strategy inputs, then all inventories and their associated Strategy Detailed Results are merged and aggregated in this summary. The columns that compose this summary are shown in Table 6. For reference, the SQL code used to generate this summary from the Strategy Detailed

Result is provided following Table 6. An example Strategy County Summary is shown in Table 10 (located at the end of Section 2.6).

Table 6. Columns in the Strategy County Summary

Column	Description
SECTOR	The sector for the source (i.e., ptnonipm for the point non-ipm sector)
FIPS	The state and county FIPS code for the source
POLL	The pollutant for the source
INPUT_EMIS	The original inventory emission in tons for the county
EMIS_REDUCTION	The total emission reduction in tons for the county
REMAINING_EMIS	The remaining emissions after being controlled (in tons)
PCT_RED	The percent reduction for the pollutant
ANNUAL_COST	The total annual cost for the county. This is calculated by summing the annual costs for the county = sum(annual_cost)
ANNUAL_OPER_MAINT_COST	The total annual operating and maintenance costs for the county. This is calculated by summing the annual operating and maintenance costs for the county = sum(annual_oper_maint_cost)
ANNUALIZED_CAPITAL_COST	The total annualized capital costs for the county. This is calculated by summing the annualized capital costs for the county = sum(annualized_capital_cost)
TOTAL_CAPITAL_COST	The total capital costs for the county. This is calculated by summing the total capital costs for the county = sum(total_capital_cost)
AVG_ANN_COST_PER_TON	The average annual cost per ton ($/ton). This is calculated by dividing the total annual cost by the total emission reduction for the county. = sum(annual_cost) / sum(emis_reduction)

The SQL code used to generate the Strategy County Summary is the following:

```
select sector, fips,
	poll, Input_Emis,
	Emis_Reduction, Remaining_Emis,
	Pct_Red, Annual_Cost,
	Annual_Oper_Maint_Cost, Annualized_Capital_Cost,
	Total_Capital_Cost, Avg_Ann_Cost_per_Ton
from (
	select INVENTORY_SECTOR as sector, i.fips,
		i.poll,
		sum(i.ann_emis) as Uncontrolled_Emis,
		sum(i.ann_emis) - sum(e.final_emissions) as Emis_Reduction,
		coalesce(sum(e.final_emissions), sum(i.ann_emis)) as Remaining_Emis,
		sum(e.Emis_Reduction) / sum(i.ann_emis) * 100.0 as Pct_Red,
		sum(e.Annual_Cost) as Annual_Cost,
```

```
        sum(e.Annual_Oper_Maint_Cost) as Annual_Oper_Maint_Cost,
        sum(e.Annualized_Capital_Cost) as Annualized_Capital_Cost,
        sum(e.Total_Capital_Cost) as Total_Capital_Cost,
        case
            when sum(e.Emis_Reduction) <> 0 then sum(e.Annual_Cost) / sum(e.Emis_Reduction)
            else null::double precision
        end as Avg_Ann_Cost_per_Ton
    from INVENTORY_TABLE i
        left outer join STRATEGY_DETAILED_RESULT_TABLE e
        on e.source_id = i.record_id
    where VERSION_AND_DATASET_FILTER
    group by i.fips,
        i.poll ) summary
order by fips, sector, poll
```

2.6.4 Controlled Emissions Inventory

Another output that can be created is a controlled emissions inventory. This dataset is not automatically created during a strategy run; instead, a user can choose to create it after the strategy run has completed successfully. When CoST creates a controlled inventory, comments are placed at the top of the inventory file that indicate the strategy used to produce it and the high-level settings for that strategy. For the sources that were controlled, CoST fills in the CEFF (control efficiency), REFF (rule effectiveness), and RPEN (rule penetration) columns based on the control measures applied to the sources. The CEFF column is populated differently for a replacement control than for an add-on control. For a replacement control, the CEFF column is populated with the percent reduction of the replacement control. For an add-on control, the CEFF column is populated with the overall combined percent reduction of the add-on control plus the preexisting control, using the following formula: (1 – {[1 – (existing percent reduction / 100)] x [1 – (add-on percent reduction / 100)]}) x 100. For both types of measures, the REFF and RPEN are defaulted to 100 since the CEFF accounts for any variation in the REFF or RPEN by using the percent reduction instead of the CEFF. CoST also populates several additional columns toward the end of the ORL inventory rows that specify information about measures that it has applied. These columns are:

- CONTROL MEASURES: An ampersand (&)-separated list of control measure abbreviations that correspond to the control measures that have been applied to the given source.
- PCT REDUCTION: An ampersand-separated list of percent reductions that have been applied to the source, where percent reduction = CEFF × REFF × RPEN.
- CURRENT COST: The annualized cost for that source for the most recent control strategy that was applied to the source.
- TOTAL COST: The total cost for the source across all measures that have been applied to the source.

In this way, the controlled inventories created by CoST always specify the relevant information about the measures that have been applied as a result of a CoST control strategy.

2.6.5 Strategy Messages

The Strategy Messages output provides useful information that is gathered while the strategy is running. The Strategy Messages output is currently created by the following strategy types:

- Project Future Year Inventory
- Maximum Emission Reduction
- Least Cost (but not Least Cost Curve)

The columns of the Strategy Messages output are described in Table 7. An example of the contents of the Strategy Messages output is shown in Table 8.

Table 7. Columns in the Strategy Messages Result

Column	Description
Fips	The state and county FIPS code for the source, found in the inventory
Scc	The SCC code for the source, found in the inventory
PlantId	For point sources, the plant ID for the source from the inventory.
PointId	For point sources, the point ID for the source from the inventory.
StackId	For point sources, the stack ID for the source from the inventory.
Segment	For point sources, the segment for the source from the inventory.
Poll	The pollutant for the source, found in the inventory
Status	The status type. The possible values are listed below: Warning – description Error – description Informational – description
control_program	The control program for the strategy run, this is only populated when using the "Project Future Year Inventory" strategy type.
message	The message contains the text describing the strategy issue.
message_type	The message type contains a high level message type category. Currently this is populated only when using the "Project Future Year Inventory" strategy type. The possible values are listed below: Inventory Level (or blank) – message has to do specifically with an issue with the inventory Packet Level – message has to do specifically with an issue with the packet record being applied to the inventory
inventory	Identifies the inventory with the issue.

Table 8. Example of Strategy Messages

fips	scc	plantid	pointid	stackid	seg-ment	poll	status	control_program	message	message_type	Inventory
42049	30900201	420490009	942	S942	1	PM2_5	Warning		Emission reduction is negative, -1693.9.	Inventory Level	ptipm_2020cc

2.6.6 Special Strategy Outputs

Two additional specialized outputs can be created from the resulting Strategy County Summary: RSM (Response Surface Model) Percent Reduction Summary, and Strategy Impact Summary. The RSM Percent Reduction Summary is a report that provides summary input data for the Response Surface Model. The Strategy Impact Summary is an output that is useful for characterizing the emissions impact of the control strategy.

Table 9. Example of Strategy Measure Summary Data

Sector	FIPS	SCC	Poll	Control Measure Abbreviation	Control Measure	Control Technology	Source Group	Annual Cost	Avg Ann Cost Per Ton	Input Emis	Emis Reduction	Pct Red
ptnonipm	37001	10200906	PM10	PFFPJIBWD	Fabric Filter (Pulse Jet Type);(PM10) Industrial Boilers - Wood	Fabric Filter (Pulse Jet Type)	Industrial Boilers - Wood	$419,294	$12,862	32.93	32.6007	99.0
ptnonipm	37001	10200906	PM2_5	PFFPJIBWD	Fabric Filter (Pulse Jet Type);(PM10) Industrial Boilers - Wood	Fabric Filter (Pulse Jet Type)	Industrial Boilers - Wood			19.74	19.5426	99.0
ptnonipm	37001	30500311	PM10	PFFPJMIOR	Fabric Filter (Pulse Jet Type);(PM10) Mineral Products - Other	Fabric Filter (Pulse Jet Type)	Mineral Products - Other	$446,026	$83,379	5.4035	5.3494	99.0
ptnonipm	37001	30500311	PM2_5	PFFPJMIOR	Fabric Filter (Pulse Jet Type);(PM10) Mineral Products - Other	Fabric Filter (Pulse Jet Type)	Mineral Products - Other			2.115	2.0939	99.0
ptnonipm	37001	30501110	PM10	PFFPJMIOR	Fabric Filter (Pulse Jet Type);(PM10) Mineral Products - Other	Fabric Filter (Pulse Jet Type)	Mineral Products - Other	$110	$147	0.7573	0.7498	99.0
ptnonipm	37001	30501110	PM2_5	PFFPJMIOR	Fabric Filter (Pulse Jet Type);(PM10) Mineral Products - Other	Fabric Filter (Pulse Jet Type)	Mineral Products - Other			0.2631	0.2605	99.0

Table 10. Example of Strategy County Summary Data

Sector	FIPS	Poll	Input Emis	Emis Reduction	Remaining Emis	Pct Red	Annual Cost	Annual Oper Maint Cost	Annualized Capital Cost	Total Capital Cost	Avg Ann Cost Per Ton
ptnonipm	37001	VOC	313.8724		313.8724						
ptnonipm	37001	PM2_5	33.4717	21.897	12.3929	65.4194					
ptnonipm	37001	NH3	6.9128		6.9128						
ptnonipm	37001	CO	162.5032		162.5032						
ptnonipm	37001	NOX	146.2904		146.2904						
ptnonipm	37001	PM10	51.0928	38.6999	12.3929	75.7443	$865,430	$746,831	$83,300	$882,489	$22,363
ptnonipm	37001	SO2	54.3864		54.3864						

2.7 Dealing with Missing PM10 and PM2.5 Inventory Control Efficiencies

It has been found that point source inventories sometimes do not have the existing control measure efficiencies populated for both the PM10 and PM2.5 pollutants. For example, an inventory might show that PM10 has an existing control efficiency of 99% but the inventory does not have the PM2.5 control efficiency populated. Therefore, a process was set up to provide a way to override these values. If the control efficiency is known for one pollutant, this value can be assumed for the other pollutant. So in the previous example, PM2.5 would also be assumed to have a control efficiency of 99%.

During strategy runs for the Maximum Emission and Least Cost strategy types, but not for the Apply Measures In Series strategy type, a temporary override table is built in memory and populated with the missing control efficiencies. This is used during the strategy analyses to help fill in the unknown PM control efficiencies. This is a temporary process that occurs only during the strategy run; a process has not been set up to override/populate the base inventory dataset in the EMF system.

The Strategy Messages dataset that is created during the strategy run is also populated with the sources that have missing PM control efficiencies. This can help identify the sources that have this issue.

2.8 Estimating Stack Flow Rate

The Control Strategy Tool utilizes a point source's stack flow rate when calculating the engineering costs. The stack flow rate is also used when calculating the control efficiency for certain refinery gas-fired process heaters. The pseudo code below explains the formulas used when calculating the stack flow rate from point source inventories. Note that all of these fields are available in the ORL Point Inventories.

IF (stack velocity (in ft/s) <= 0.1 or stack diameter (in ft) <= 0.1) AND stack flow (in cfs) > 0.1 THEN

    = stack flow from inventory (in cfs)

ELSE IF stack velocity <> 0.0 AND stack diameter <> 0.0 THEN

    $= \pi \times (\text{stack diameter} / 2)^2 \times \text{stack velocity}$

ELSE

    = unkown stack flow rate (null is assumed)

END IF

2.9 Costing Control Measures

The Control Strategy Tool costs emission control measures in 2 ways: (1) cost equations are used to determine engineering costs that take into account several variables for the source when those variables are available; or (2) if those data are not available, a simple cost factor in terms of dollars per ton of pollutant reduced is used to calculate the cost of the control measure when applied to a specific source. The second approach can also utilize a simple incremental cost factor in terms of dollars per ton of pollutant when there is a preexisting control already on the source, as identified in the inventory CEFF field. If the inventory CEFF field is populated and the control measure has an incremental cost per ton factor specified, this cost factor will always be used instead of the normal cost per ton factor. If on the other hand the incremental cost factor is not specified on a control with a preexisting control, than the default cost factor will be used instead.

Currently, cost equations are used only for some EGU and nonEGU source measures. They are not used for area sources.

During a strategy run, if the engineering cost equation was not found to have the appropriate inputs (e.g., missing design capacity), this issue can be identified by looking for a negative sign in front of the equation type in the Strategy Detailed Result equation_type column (e.g., -Type 2 or -Type 8). The sources with this issue will be populated in the Strategy Messages dataset. The message will help identify which equation inputs are missing.

See the **Control Strategy Tool Cost Equations Document** for more detailed information on how cost equations are used in CoST.

2.10 Calculating Control Efficiency for Control Measures

The Control Strategy Tool calculates emission control measure control efficiencies (CEFF) in two ways: (1) CEFF equations are used that take into account several variables for the source when those variables are available; or (2) if the data are not available, a simple CEFF factor is used to calculate the CEFF of the control measure when applied to a specific source. The default CEFF factor is defined as part of the control measures efficiency record table.

Currently, the CoST software is utilizing control measure properties to help with calculating the control efficiency calculation approach. Designers of future versions of the software should consider taking an approach similar to the way in which cost equations are used in CoST. This approach uses several database tables to help store control measure cost equation definitions.

The software currently supports estimating control efficiencies only for several refinery gas-fired process heater control measures, listed in Table 11. The software currently handles at most two input variables via the CEFF_EQUATION_POLLUTANT_VAR1 and CEFF_EQUATION_ POLLUTANT_VAR2 control measure properties. The CEFF equation type (and the pollutant it is used for) is specified using the property CEFF_EQUATION_**POLLUTANT**_TYPE, where the POLLUTANT part of the property name specifies the pollutant of interest (e.g., POLLUTANT = NOX). Keeping the pollutant in the name of the properties will allow CoST to use different CEFF equations for different pollutants for the same or different measures.

2.10.1 Refinery Gas-Fired Process Heater Control Measures CEFF Equation Type

This section details how the CEFF equation approach is set up for the refinery gas-fired process heater control measures. The CEFF equations are relevant only for the pollutant NOX. Table 11 gives a list of the control measures that utilize these equations.

Table 11. Refinery Gas-Fired Process Heater Control Measures

Name	Abbreviation	Pollutant	Outlet Concentration (ppmv NOx)	SCC
Petroleum Refinery Gas-Fired Process Heaters; Excess O2 Control	PRGFPREO2C	NOX	80	30600102 30600104 30600105 30600106 30600107 30600108
Petroleum Refinery Gas-Fired Process Heaters; SCR-95%	PRGFPRSC95	NOX	40	
Petroleum Refinery Gas-Fired Process Heaters; SCR	PRGFPRSCR	NOX	20	
Petroleum Refinery Gas-Fired Process Heaters; Ultra Low NOX Burners	PRGFPRULNB	NOX	10	

The control measure properties given in Table 12 are used to store variable inputs needed to calculate the control efficiency via engineering equations.

Table 12. Control Measure Properties used to Store CEFF Equation Input Variables

Property Name	Description	Units
CEFF_EQUATION_NOX_TYPE	CEFF Equation Type	
CEFF_EQUATION_NOX_VAR1	NOX Molecular Weight	lb/lb-mole
CEFF_EQUATION_NOX_VAR2	Outlet Concentration	ppmv

This equation type has been labeled as a Type 1 equation (CEFF_EQUATION_NOX_TYPE = Type 1). The various CoST SQL algorithms will look for the Type 1 equation type and, instead of using the basic efficiency record, they will calculate the CEFF using the engineering equations describe in this section. The outlet concentration is stored in the CEFF_EQUATION_NOX_VAR2 property, and the NOX molecular weight is stored in the CEFF_EQUATION_NOX_VAR1 property (see Table 12). The latter property is used when calculating the NOx outlet concentration as described below.

The following constraints must be met in order for the equation calculations to proceed, or a missing CEFF will be assumed and the measure will not be selected during the measure selection process (since a CEFF is required to produce an emission reduction):

- Annual Emissions of NOx (ann_value) is not missing and is > 1 ton
- Stack Temperature (stktmp) is not missing and is ≠ 0
- Hours per Year (annual_avg_hours_per_year) is not missing and is > 1 hr
- Stack flow rate is not missing (see Estimating Stack Flow Rate section on how stack flow rate is estimated)

The steps below show the CEFF calculations. The example uses the sample point source data supplied in Table 13.

Table 13. Example Point Source Inventory Data

ORL Inventory Field Name	Value
plant_name	Example Petroleum Corp
fips	22019
plantid	1111
pointid	111
stackid	11
segment	1
scc	30600104
poll	NOX
ann_emis (tons)	53.33
design capacity	413
design capacity units	E6BTU/HR
stkhgt	173.4 ft
stkdiam	13.8 ft
stktemp	650 °F
stkflow	708.4 ft^3/sec
stkvel	4.8 ft/sec
annual_avg_hours_per_year	8736

These steps detail the various calculations involved in estimating the current outlet concentration of NOx and ultimately comparing that to a measures's allowable outlet concentration, which in turn can be used to calculate the CEFF. The items highlighted in turquoise come from the point source example data listed in Table 13.

1. Convert actual volumetric flow rate (acfm) to standard volumetric flow rate (scfm):

$$\text{Vol. flow rate}_{\text{scfm}} = \text{Vol. flow rate}_{\text{acfm}} \times [\text{standard temp (520 Rankine)} / (\text{stack temp (stktmp in °F)} + 460)]$$

or

$$\text{Vol. flow rate}_{\text{scfm}} = \pi \times (\text{stack diameter} / 2)^2 \times \text{stack velocity} \times [\text{standard temp (520 Rankine)} / (\text{stack temp (stktmp in °F)} + 460)]$$

$$\text{Vol. flow rate}_{\text{scfm}} = \pi \times (13.8\text{ ft} / 2)^2 \times 4.8\text{ ft/sec} \times 60\text{ sec} / 1\text{ min} \times [520 / (650 + 460)] = 20{,}170\text{ ft}^3/\text{min}$$

2. Calculate NOx outlet concentration:

Calculate volume (ft^3/lb-mole) of NOx in gaseous form under standard conditions (60 °F, 1 atm) using Ideal Gas Law:

$$pV = nRT \text{ or } V/n = RT/p$$

where:

V = volume in ft^3

n = molecular weight of NOx (46 lb/lb-mole) (NOTE: This is stored as an equation input variable using the CEFF_EQUATION_NOX_VAR1 property)
R = gas constant (0.7302 atm-ft^3/lb-mole R)
T = absolute temperature in Rankine (°F + 460) = 60 + 460 = (520 R)
p = pressure in atmospheres (1 atm)

Ideal Gas Law approximates the volume of a gas under certain conditions:

$$V/n = (0.7302 \times 520) / (1) = 379.7 \text{ ft}^3\text{/lb-mole}$$

Calculate NOx emissions (in lb-mole/yr):

$$53.33 \text{ tons/yr NOx} \times 2000 \text{ lb/ton} \times 1 \text{ lb-mole} / 46 \text{ lb NOx} = 2{,}319 \text{ lb-mole/yr}$$

Convert NOx emissions (lb-mole/yr) to NOx volumetric flowrate (ft^3/min):

$$2{,}319 \text{ lb-mole/yr x 1 yr / 8736 hrs x 1 hr / 60 min x } 379.7 \text{ft}^3\text{/lb-mole} = 1.680 \text{ ft}^3\text{/min}$$

Calculate outlet concentration of NOx (ppmv):

$$\text{ppmv NOx} = (\text{ NOx emissions (ft}^3\text{/min) / Stack vol flow rate}_{\text{scfm}}) \text{ x } 10^6$$

$$= (1.680 \text{ ft}^3\text{/min / 20,170 ft3/min }) \text{ x } 10^6 = 83.28 \text{ ppmv}$$

3. Compare the outlet concentration to the concentrations that can be achieved by various control measures and calculate control efficiency:

   a) For this example, the outlet concentration is 83.28 ppmv, which is higher than the concentration achievable by each of the measures listed in Table 11. Therefore, any of these measures could be applied to this example source to reduce emissions from the process heater.

   b) Calculate the control efficiency, which for this example will use the control measure "Petroleum Refinery Gas-Fired Process Heaters; Excess O2 Control". The key factor in calculating the control efficiency is to use the amount of NOx (80 ppmv) that will be emitted (outlet concentration) from the control measure. The outlet concentration is stored as a measure property in the CEFF_EQUATION_NOX_VAR2 property.

NOx Control Efficiency (%) =

(NOx Flow Rate (ppmv) - Control Measure NOx Outlet Concentration (ppmv)) / NOx Flow Rate (ppmv)

NOx Control Efficiency (%) = (83.28 ppmv - 80 ppmv) / (83.28 ppmv) = 3.93%

2.11 Summaries of Strategy Inputs and Outputs

The EMF/CoST system can prepare summaries of the datasets that are loaded into the system, including both the emissions inventory datasets and the Strategy Detailed Result outputs. The ability to prepare summaries is helpful because in many cases, when the results of a strategy are analyzed or presented to others, it is useful to show the impact of the strategy in a summarized fashion because there could be thousands of records in a single Strategy Detailed Result. Frequently, it is helpful to summarize a strategy for each county, state, SCC, or control technology. The power of the PostgreSQL relational database that contains the system data is used to develop these summaries. Currently, they are prepared using the EMF subsystem that was designed to support quality assurance (QA) of emissions inventories and related datasets. Each summary is stored as the result of a "QA Step" that is created by running a SQL query. Summaries can be added to inventory or Strategy Detailed Result datasets by editing the dataset properties, going to the QA tab, and using the available buttons to add and edit QA steps. Examples of the types of summaries available for ORL Point Inventories are:

- "Summarize by Pollutant with Descriptions"
- "Summarize by Pollutant"
- "Summarize by SCC and Pollutant with Descriptions"
- "Summarize by SCC and Pollutant"
- "Summarize by U.S. State and Pollutant with Descriptions"
- "Summarize by U.S. State and Pollutant"
- "Summarize by U.S. County and Pollutant with Descriptions"
- "Summarize by MACT Code, U.S. State and Pollutant with Descriptions"
- "Summarize by Data Source Code, U.S. State and Pollutant with Descriptions"
- "Summarize by U.S. State, SCC and Pollutant with Descriptions"
- "Compare CoST to NEI measures"
- "Roll Up CoST and NEI measures"
- "Summarize by Plant and Pollutant"

Note that the summaries "with Descriptions" have more information than the ones without. For example, the "Summarize by SCC and Pollutant with Descriptions" summary includes the SCC description in addition to the pollutant description. The disadvantage to including the descriptions is that they are slower to generate, because information has to be brought in from tables other than the Strategy Detailed Result table.

Each of the summaries is created using a customized SQL syntax that is very similar to standard SQL, except that it includes some EMF-specific concepts that allow the queries to be defined generally and then applied to specific datasets as needed. An example of the customized syntax for the "Summarize by SCC and Pollutant" query is:

```
"select SCC, POLL, sum(ann_emis) as ann_emis from $TABLE[1] e group by SCC, POLL order by SCC, POLL"
```

Notice that the only difference between this and standard SQL is the use of the $TABLE[1] syntax. When this query is run, the $TABLE[1] portion of the query is replaced with the table name used to contain the data in the EMF. Note that most datasets have their own tables in the EMF schema, so you do not normally need to worry about selecting only the records for the specific dataset of interest. The customized syntax also has extensions to refer to another dataset and to refer to specific versions of other datasets using tokens other than $TABLE. For the purposes of this discussion, it is sufficient to note that these other extensions exist.

Some of the summaries are constructed using more complex queries that join information from other tables, such as the SCC descriptions, the pollutant descriptions (which are particularly useful for HAPs), and to account for any missing descriptions. For example, the syntax for the "Summarize by SCC and Pollutant with Descriptions" query is:

```
"select e.SCC, coalesce(s.scc_description,'AN UNSPECIFIED DESCRIPTION')::character
varying(248) as scc_description, e.POLL, coalesce(p.descrptn,'AN UNSPECIFIED
DESCRIPTION')::character varying(11) as pollutant_code_desc, coalesce(p.name,'AN
UNSPECIFIED SMOKE NAME')::character varying(11) as smoke_name,p.factor, p.voctog, p.species,
coalesce(sum(ann_emis), 0) as ann_emis, coalesce(sum(avd_emis), 0) as avd_emis from $TABLE[1]
e left outer join reference.invtable p on e.POLL=p.cas left outer join reference.scc s on e.SCC=s.scc
group by e.SCC,e.POLL,p.descrptn,s.scc_description, p.name, p.factor,p.voctog, p.species order by
e.SCC, p.name"
```

This query is quite a bit more complex, but is still supported by the EMF QA step processing system.

In addition to summaries of the inventories, there are many summaries available for control strategy Strategy Detailed Results and for some of the other CoST-related dataset types. Some of the summaries available for control strategy Strategy Detailed Results are as follows:

- "Summarize by Pollutant"
- "Summarize by County and Pollutant"
- "Summarize by SCC and Pollutant"
- "Summarize by Control Technology and Pollutant"
- "Summarize by Control Measure and Pollutant"
- "Summarize by Source Group and Pollutant"
- "Summarize by U.S. State and Pollutant"
- "Summarize by State, SCC, and Control Technology"
- "Summarize by Control Technology, FIPS, and SCC"
- "Summarize by Control Program, U.S. State and Pollutant"
- "Summarize by Plant and Pollutant"
- "Summarize all Control Measures"
- "Summarize by Sector and Pollutant with Descriptions"
- "Summarize by Sector, U.S. State, and Pollutant"
- "Summarize by U.S. State and SMOKE Pollutant Name"
- "Cost Curve"

When multiple datasets need to be considered in a summary (e.g., to compare two inventories), the EMF ‘QA Program’ mechanism is used. The QA programs each have customized user interfaces that allow users to select the datasets to be used in the query. Some of the following QA programs may prove useful to CoST users:

- "Multi-inventory sum": takes multiple inventories as input and reports the sum of emissions from all inventories
- "Multi-inventory column report": takes multiple inventories as input and shows the emissions from each inventory in separate columns
- "Multi-inventory difference report": takes two sets of inventories as input, sums each set of inventories, and computes the difference of the two sums
- "Compare Control Strategies": compares the data available in the Strategy Detailed Result datasets output from two control strategies

To facilitate mapping the summaries using geographic information systems (GIS), mapping tools, and Google Earth, many of the summaries that have ‘with Descriptions’ in their names have been updated to include latitude and longitude. For plant-level summaries, the latitude and longitude provided are the average of all the values given for the specific combination of FIPS and PLANT_ID. For county- and state-level summaries, the latitude and longitude are the centroid values specified in the “fips” table of the EMF reference schema. It is useful to note that after the summaries have been created, they can be exported to CSV files and also to shapefiles. The summary results can be viewed in a table called the Analysis Engine that does sorting, filtering, and plotting. From the File menu of the Analysis Engine window, a compressed Keyhole Markup Language (.kmz) file can be created and subsequently loaded into Google Earth. Note each KMZ file is currently provided with a single latitude and longitude coordinate representing its centroid, even for geographic shapes like counties. Shapefiles, on the other hand, may represent regions. The user selects the appropriate shapefile to use as a template (e.g., US States, US Counties) during the export process, and the attribute data are attached to the shapes in the selected shapefile.

3 Maximum Emissions Reduction Control Strategy

Note: The CoST algorithms for all of the control strategies have similarities among them. Because this is the first of the sections discussing the six algorithms, the most detailed information is provided for this algorithm. The descriptions of the remaining algorithms (Sections 4 through 9) are contrasted against the “Maximum Emissions Reduction” algorithm description. Each section includes discussion of algorithm inputs and outputs and of the algorithm itself, and some sections include examples of how the algorithms work.

3.1 Maximum Emissions Reduction Inputs and Outputs

The Maximum Emissions Reduction control strategy assigns to each source the single measure that provides the maximum reduction to the target pollutant, regardless of cost. This algorithm uses the inputs described in Section 2: summary parameters, input inventories, inventory filters, measures, and constraints. The strategy produces the three standard types of strategy outputs described in Section 2.6: Strategy Detailed Result ***for each input inventory***, Strategy Measure Summary, and Strategy County Summary.

3.2 Maximum Emissions Reduction Algorithm

This section provides an overview of the algorithm that matches sources with control measures for a Maximum Emissions Reduction control strategy. Figure 2 diagrams the process that is used when running this type of strategy. The steps in the source-measure matching algorithm for the Maximum Emissions Reduction strategy are given below. (Note that many of these steps also apply to all of the other strategy types).

1. Process/read the emissions inventory.

2. Use inventory filtering (discussed in Section 2.3) to filter the emissions inventory and compute monthly emissions, then compute uncontrolled emissions.
    a. Filter by SQL WHERE Clause (based on contents of the Inventory Filter field), if any
    b. Filter by the counties specified in the selected County Dataset, if any
    c. If average-day emissions are specified in the inventory and annual emissions are not specified, compute the monthly emissions by multiplying the average-day emissions by the number of days in the month that the inventory represents. Otherwise, use the annual emissions figures directly.
    d. Compute uncontrolled emissions for controlled sources using one of these formulas:
        unc. emis. = ann. emis. / (1 - CE / 100 × RE / 100 × RP / 100)
        unc. emis. = avg. day emis. × days_in_month / (1 - CE / 100 × RE / 100 × RP / 100)
        where CE = existing inventory control measure efficiency
        RE = existing inventory control measure rule effectiveness
        RP = existing inventory control measure rule penetration

3. Use control measure filtering (discussed in Section 2.4) to filter the Control Measures to consider for the strategy.
    a. By the selected Measure Classes, OR
    b. By the selected Specific Measures

4. Match the Inventory Sources for the Target Pollutant to Control Measure Efficiency Records.
    a. Of the remaining measures that passed the filter, find the ones that apply to the SCC of the source (as specified by the SCCs listed as applicable to each measure)
    b. Match efficiency records based on FIPS (control measure data could be available at the National, State, or County level)
    c. Match efficiency records based on Target Pollutant
    d. Match efficiency records based on month of the inventory (Note: If the inventory is month-specific and the measure is not specified to be applicable to the month, do not consider this record as an option.)
    e. Match efficiency records based on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
    f. Match efficiency records based on measure's Minimum and Maximum Emissions (inventory source must have greater than or equal to the minimum emissions and less than the maximum emissions)

5. Evaluate Constraints (discussed in Section 2.5) while the source is being matched with the control, if any constraints were specified. For example, the emission reduction of a source due to a certain control is not known until we apply the measure to the source with its specific percent reduction, where percent reduction = control efficiency × rule effectiveness/100 × rule

penetration/100. Constraint calculations are dependent on both the inventory source and the measure. Limit the source's measures using the following constraints, if any were specified:

a. Include measure for the source if it reduces the target pollutant by the minimum emissions reduction
b. Include measure for the source if it has at least the minimum control efficiency for the target pollutant
c. Include measure for the source if the cost per ton for the target pollutant is less than the maximum cost per ton
d. Include measure for the source if it does not cost more than the maximum annualized cost
e. Include measure for the source if it meets other strategy-specific constraints

6. Evaluate source for preexisting control:

a. If the source has an existing control, then evaluate whether replacement control measure fulfills the minimum percent reduction constraint (see Section 2.2.4 for more information on this constraint)
b. Do not double-control source with the same control measure

7. If multiple measures are available for a source, then the best measure is chosen according to the following criteria:

a. Closest Locale (matching both FIPS state and county is best, then FIPS-state, followed by national)
b. Highest Percent Reduction (PR)
c. Lowest Annualized Cost (Cost is considered for all pollutants, which includes both the target pollutant and coimpact pollutants. For example, cost might be based on coimpact pollutant PM2.5 instead of on target pollutant PM10.)

8. Apply target pollutant source measure to source's coimpact pollutants.

a. Match efficiency records based on FIPS (control measure data could be available at the National, State, or County level)
b. Match on any pollutants that are controlled by the measure and are also available in the inventory, and thereby produce co-impacts, which could be co-benefits or co-disbenefits
c. Match efficiency records based on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
d. Match efficiency records based on measure's Minimum and Maximum Emissions (inventory source must have greater than or equal to the minimum emissions and less than the maximum emissions)

9. Compute the Strategy Detailed Result to include the source-control pairs obtained from the algorithms shown in 4, 5, 6, 7, and 8.

10. After completing the computation of Strategy Detailed Results for all input inventories, prepare the summary outputs (described in Section 2.6) along with any controlled inventories upon user request.

Note: In the above text, the term "Locale" refers to the part of a control measure efficiency record that can limit the applicability of the record to a specific county by using a full five-digit FIPS state and county code, or to a state by using a two-digit FIPS state code. If no entry is given, it applies generally to any source. This allows control efficiency, rule effectiveness, rule penetration, and cost to vary by county or state

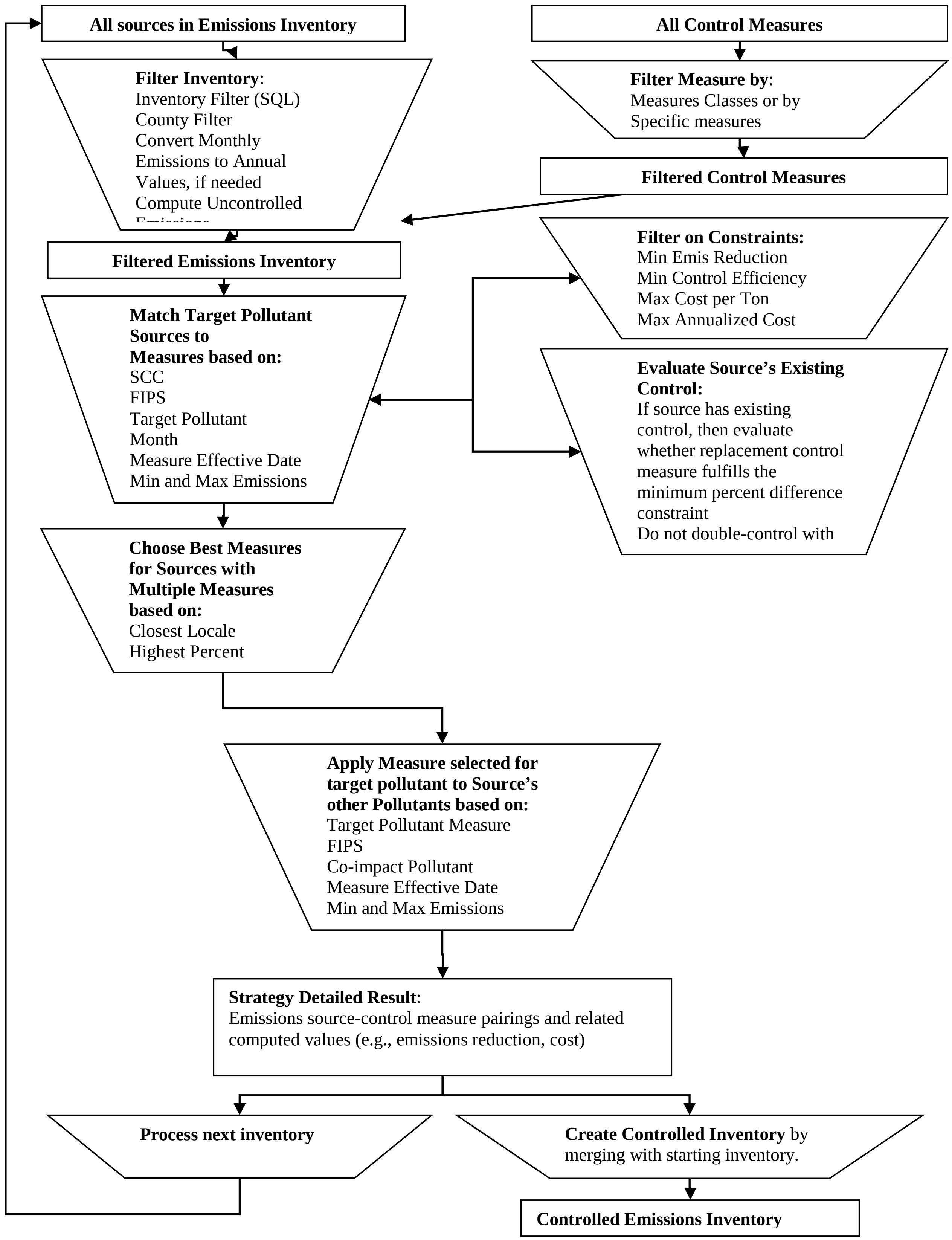

Figure 2. The Process for Running a Maximum Emissions Reduction Control Strategy

3.3 Maximum Emissions Reduction Strategy Example

In Section 2.1 there was a brief description of how the Maximum Emission Reduction strategy algorithm works. This section provides much more detail using a specific example, including what the inputs to the strategy are, what the source-measure pairings are, and what the outputs look like. Note that in this and the following sections describing the strategy algorithms, only the inputs that actually have an impact on the results are included; ones that are informational may be left out (e.g., Project, Region).

Strategy Inputs:
Name: Maximum Emissions Reduction Strategy Sample
Type of Analysis: Max Emissions Reduction
Cost Year: 2006
Target Year: 2008
Target Pollutant: PM10
Discount Rate: 7%
Use Cost Equations: Yes
Inventories: ORL Point Dataset, ptinv_ptnonipm_2008, version 1
Measures: Include all measure classes
Minimum Percent Reduction Difference for Replacement Control (%): 15%

Table 14 shows the inventory sources to be used in this example. It was created based on data in an ORL point EMF dataset. Note that in this example, two of the rows have existing control efficiency information, but the others do not. The information in the brackets for the Source column helps define the key structure for a source. As specified in the SMOKE documentation (http://www.smoke-model.org/version2.5/html/), a point source can be uniquely identified by the following fields: FIPS, SCC, PlantId, PointId, StackId, and Segment; a nonpoint source can be uniquely identified by just two fields: FIPS and SCC.

Table 14. Maximum Emissions Reduction Filtered Inventory Records

Inventory No.	**Source** [PlantId, PointId, StackId, Segment]	**FIPS**	**SCC**	**Pollutant**	**Annual Emissions (tons)**	**CEFF (%)**	**Existing_Measure_ Abbrevation**
1	ABC Industrial Plant [0001,01,01,01]	37001	10200906	PM10	12		
2	ABC Industrial Plant [0001,01,01,01]	37001	10200906	PM2.5	6		
3	XYZ Industrial Plant [0005,G-36,S-2,1]	37001	30405001	CO	20		
4	XYZ Industrial Plant [0005,G-36,S-2,1]	37001	30405001	PM10	14		
5	WTU Industrial Plant [0001,N-6,ST-1,1]	37003	30500311	PM10	5		
6	WTU Industrial Plant [0001,N-6,ST-1,1]	37003	30500311	PM2.5	2		
7	UTC Industrial Plant [0001,T-6,S-1,1]	37005	30500311	PM10	10	99	
8	UTC Industrial Plant [0001,T-6,S-1,1]	37005	30500311	PM2.5	4	98	
9	JKL Industrial Plant [0002,Y-1,K-1,1]	37071	10100202	PM10	50	98	PDESPWPUBC
10	JKL Industrial Plant [0002,Y-1,K-1,1]	37071	10100202	PM2.5	45	95	PDESPWPUBC
11	GMT Industrial Plant [0001,Z-6,ZT-1,1]	37003	10200905	PM10	10	75	
12	GMT Industrial Plant [0001,Z-6,ZT-1,1]	37003	10200905	PM2.5	4	70	

Table 15 contains a sample listing of point-source control measures (and associated efficiency records) from the CoST database that might apply to the sources in the example inventory. Note that the value in the percent reduction column can be computed from three fields specified for a measure's efficiency record (this example does not include a control efficiency calculated using equations), as follows:

$$\text{Percent Reduction} = (\text{Control Efficiency (\%)} / 100) \times (\text{Rule Penetration (\%)} / 100) \times (\text{Rule Effectiveness (\%)} / 100) \times 100$$

Table 15. Maximum Emissions Reduction Filtered Measures

Measure Name	CM Abbrev.	SCCs of Interest	Pollutant	Locale	Percent Reduction (%)	Cost Year	Cost Per Ton ($)	Increme n-tal Cost Per Ton ($)	Effectiv e Date	Min Emis (tons)	Max Emis (tons)	Existing Measure	Equation Type	Notes
Fabric Filter (Pulse Jet Type); Industrial Boilers – Wood	PFFPJIBWD	10200905 10200906	PM10		99	1998	117	100						
Fabric Filter (Pulse Jet Type); Industrial Boilers – Wood	PFFPJIBWD	10200905 10200906	PM2.5		99									
Fabric Filter (Pulse Jet Type); Mineral Products	PFFPJMIOR	30500310 30500311	PM10		99	1998	117						Type 8	No locale indicates this measure is good anywhere
Fabric Filter (Pulse Jet Type); Mineral Products	PFFPJMIOR	30500310 30500311	PM10	37	99.1	1998	117						Type 8	Measure is relevant only to NC State FIPS 37
Fabric Filter (Pulse Jet Type); Mineral Products	PFFPJMIOR	30500310 30500311	PM10	37003	99.3	1998	117						Type 8	Measure is relevant only to Alamance County FIPS 37001
Fabric Filter (Pulse Jet Type); Mineral Products	PFFPJMIOR	30500310 30500311	PM2.5		99								Type 8	
Fabric Filter (Mechanical Shaker Type)	PFFMSM	30500310 30500311	PM10		95	1998	150			10	365		Type 8	
Fabric Filter (Mechanical Shaker Type)	PFFMSM	30500310 30500311	PM2.5		95					10	365		Type 8	

Measure Name	CM Abbrev.	SCCs of Interest	Pollutant	Locale	Percent Reduction (%)	Cost Year	Cost Per Ton ($)	Incremen-tal Cost Per Ton ($)	Effective Date	Min Emis (tons)	Max Emis (tons)	Existing Measure	Equation Type	Notes
Dry ESP – Wire Plate Type	PDESP	10200905 10200906	PM10		90	1995	160		2010	10	365		Type 8	
Dry ESP – Wire Plate Type	PDESP	10200905 10200906	PM2.5		90				2010	10	365		Type 8	
Fabric Filter (Mech. Shaker Type); Utility Boilers - Coal	PFFMSUBC	10100201 10100202	PM10		99								Type 8	
Fabric Filter (Mech. Shaker Type); Utility Boilers - Coal	PFFMSUBC	10100201 10100202	PM2.5		99								Type 8	
Dry ESP – Wire Plate Type; Utility Boilers - Coal	PDESPWPUBC	10100201 10100202	PM10		98								Type 8	
Dry ESP – Wire Plate Type; Utility Boilers - Coal	PDESPWPUBC	10100201 10100202	PM2.5		95								Type 8	
Adding Surface Area of Two ESP Fields, an Agglomerator, and ID Fans	PDESPM2FAF	10100201 10100202	PM10		80							PDESPWPUBC PDESPWPUBO	Type 10	Measure can only be used in Add-On scenario since existing measure is populated
Adding Surface Area of Two ESP Fields, an Agglomerator, and ID Fans	PDESPM2FAF	10100201 10100202	PM2.5		80							PDESPWPUBC PDESPWPUBO	Type 10	Measure can only be used in Add-On scenario since existing

Measure Name	CM Abbrev.	SCCs of Interest	Pollutant	Locale	Percent Reduction (%)	Cost Year	Cost Per Ton ($)	Incremen-tal Cost Per Ton ($)	Effective Date	Min Emis (tons)	Max Emis (tons)	Existing Measure	Equation Type	Notes
														measure is populated

Table 16 contains the logic for pairing the sources and control measures. The Measure Selection column shows the logic used when determining the best measure to use for each source.

Table 16. Maximum Emissions Reduction Measure-Source Assignments

Inventory Source No.	**Source Name** [PlantId, PointId, StackId, Segment]	**FIPS**	**SCC**	**Pollu-tant**	**Annual Emissions (tons)**	**CEFF (%)**	**Best Measure**	**Measure Selection**
1	ABC Industrial Plant [0001,01,01,01]	37001	10200906	PM10	12		PFFPJIBWD	Step 4a,b,c,e finds PFFPJIBWD and PDESP Step 4d eliminates PDESP (2010 is after target year of 2008)
2	ABC Industrial Plant [0001,01,01,01]	37001	10200906	PM2.5	6		PFFPJIBWD	Must use measure previously selected for this source (PFFPJIBWD) based on the target pollutant
3	XYZ Industrial Plant [0005,G-36,S-2,1]	37001	30405001	CO	20		None	Step 4c - finds source has no target pollutant, so no control will be applied
4	XYZ Industrial Plant [0005,G-36,S-2,1]	37001	30405001	PM10	14		None	Step 4a - finds no measures control this SCC, so no control will be applied
5	WTU Industrial Plant [0001,N-6,ST-1,1]	37003	30500311	PM10	5		PFFPJMIOR	Step 4a and c - finds PFFPJMIOR or PFFMSM Step 4b and 7 – finds PFFPJMIOR with a locale of 37003 will be chosen; this is a better FIPS match (closer), than the state or national level record Step 4e – eliminates PFFMSM (5 tons is not between 10 and 365 tons).
6	WTU Industrial Plant [0001,N-6,ST-1,1]	37003	30500311	PM2.5	2		PFFPJMIOR	Must use measure previously selected for this source (PFFPJMIOR) based on the target pollutant

Inventory Source No.	**Source Name** [PlantId, PointId, StackId, Segment]	**FIPS**	**SCC**	**Pollu-tant**	**Annual Emissions (tons)**	**CEFF (%)**	**Best Measure**	**Measure Selection**
7	UTC Industrial Plant [0001,T-6,S-1,1]	37005	30500311	PM10	10	99	None	Step 4a, c, e - finds PFFPJMIOR or PFFMSM Step 4b and 7 – finds PFFPJMIOR with a locale of 37 will be chosen; this is a better FIPS match (closer), than the national level record Step 6 – eliminates PFFMSM since the source already has a control with a 99% CE; the new measure CE is 95%, which would actually increase the emissions. Step 6 – eliminates PFFPJMIOR since the source already has a control with a 99% CE; the new measure CE is 99.1%. More than a 15% difference is needed for a new a measure to be applied. *Percent Difference Calculation:* [(inventory emission - remaining emission) / inventory emission] x 100 ≥ Minimum Percent Reduction Difference for Replacement Control (%) [(50 – 50 / (1– 0.99) × (1 – 0.991)] / 50 × 100 10% is not ≥ 15%
8	UTC Industrial Plant [0001,T-6,S-1,1]	37005	30500311	PM2.5	4	98	None	No measure was found for target pollutant, so no control will be applied.

Inventory Source No.	**Source Name** [PlantId, PointId, StackId, Segment]	**FIPS**	**SCC**	**Pollu-tant**	**Annual Emissions (tons)**	**CEFF (%)**	**Best Measure**	**Measure Selection**
9	JKL Industrial Plant [0002,Y-1,K-1,1]	37071	10100202	PM10	50	98	PDESPM2FAF	Step 4a,b,c – finds PFFMSUBC, PDESPWPUBC, or PDESPM2FAF Step 6d – eliminates PDESPWPUBC (same as source's existing measure; can not be double control with same measure) Step 7b – eliminates PFFMSUBC since the Add-On control, PDESPM2FAF, gives a higher emission reduction (see below for calculations) *Emission Reduction Calculations:* PFFMSUBC Replacement Control: = 50 / (1 – 0.98) × (0.99) = 25 tons PDESPM2FAF Add-On Control: = 50 × (0.80) = 40 tons
10	JKL Industrial Plant [0002,Y-1,K-1,1]	37071	10100202	PM2.5	45	95	PDESPM2FAF	Must use measure previously selected for this source (PDESPM2FAF) based on the target pollutant
11	GMT Industrial Plant [0001,Z-6,ZT-1,1]	37003	10200905	PM10	10	75	PFFPJMIOR	Step 4a, c, e - finds PFFPJMIOR or PFFMSM Step 4b and 7 – finds PFFPJMIOR with a locale of 37 will be chosen; this is a better FIPS match (closer) than the national level record Step 7b – eliminates PFFMSM since the control, PFFPJMIOR, gives a higher emission reduction (see below for calculations): *Emission Reduction Calculations:* PFFMSM Replacement Control Reduction = = 10 / (1 – 0.75) × (0.95) = 38 tons PFFPJMIOR Replacement Control Reduction = = 10 / (1 – 0.75) × (0.991) = 39.64 tons
12	GMT Industrial Plant [0001,Z-6,ZT-1,1]	37003	10200905	PM2.5	4	70	PFFPJMIOR	Must use measure previously selected for this source (PFFPJMIOR) based on the target pollutant

The Strategy Detailed Result in Table 17 shows the source-measure pairings and related computed values — emissions reduction, percent reduction, annual cost, etc. All costs reported in this Strategy Detailed Result are in 2006 dollars.

Table 17. Maximum Emissions Reduction Strategy Detailed Result

Inventory Source No.	Source Name	FIPS	SCC	Pollutant	Measure Abbrev	Annual Emis (tons)	Emis Red (tons)	Pct Red (%)	Annual Cost	Annual Cost Per Ton	Annual O&M Cost	Annualized Capital Cost	Total Capital Cost
1	ABC Industrial Plant [0001,01,01,01]	37001	10200906	PM10	PFFPJIBWD	12	12×0.99 = 11.88	99	$1,675	$141[1]	-[4]	-[4]	-[4]
2	ABC Industrial Plant [0001,01,01,01]	37001	10200906	PM2.5	PFFPJIBWD	6	5.94	99					
5	WTU Industrial Plant [0001,N-6,ST-1,1]	37003	30500311	PM10	PFFPJMIOR	5	4.965	99.3	$7,382	$1,487	$6,371	$711	$7,529
6	WTU Industrial Plant [0001,N-6,ST-1,1]	37003	30500311	PM2.5	PFFPJMIOR	2	1.98	99					
9	JKL Industrial Plant [0002,Y-1,K-1,1]	37071	10100202	PM10	PDESPM2FAF	50	40	80					
10	JKL Industrial Plant [0002,Y-1,K-1,1]	37071	10100202	PM2.5	PDESPM2FAF[2]	45	36	80	$638,700	$15,968	$101,041	$59,032	$537,658
11	GMT Industrial Plant [0001,Z-6,ZT-1,1]	37003	10200905	PM10	PFFPJIBWD	10	9.91	99.1	$1,192	$120[3]	-[4]	-[4]	-[4]
12	GMT Industrial Plant [0001,Z-6,ZT-1,1]	37003	10200905	PM2.5	PFFPJIBWD	4	3.96	99					

[1] This measure uses a default cost per ton factor for calculating the annual cost. The cost per ton factor is based on 1998 dollars and needs to be inflated to 2006 dollars using the following approach. The implicit price deflators are stored in the reference schema gdplev table in the CoST database and are also listed in Table 3:

= $117 × GPD IPD ($2006) / GDP IPD ($1998)
= $117 × 94.814 ($2006) / 78.859 ($1998)

[2] Note how the cost was determined for PM2.5 and not for the target pollutant, PM10. Not all costs will be determined from the target pollutant; control measure costs will sometimes be defined by pollutants other than target pollutant of interest. This measure uses Type 10 engineering cost equations.

[3] The incremental cost per ton factor is used in this situation, since the source already has a preexisting control. This incremental cost per ton is used only when there is a preexisting control already on the source, as identified in the inventory CEFF field. If the inventory CEFF field is populated and the control measure has an incremental cost per ton factor specified, this factor will always be used instead of the normal cost per ton factor; if an incremental cost per ton factor is not specified, then the normal cost per factor will be used. Measure cost engineering equations will also take precedence over the approach just mentioned.
[4] Control measure did not have a capital annualized ratio specified. Therefore, these other costs could not be calculated and are left blank.

For many of the control measures in CoST, a simple cost factor in terms of dollars per ton of pollutant reduced is used to calculate the annualized cost of the control measure when applied to a specific source. However, a few control measures use a more complex cost equation to determine engineering costs that take into account several variables for the source, when those variables are available. Please see the **CoST Control Measures Database Document** and **Control Strategy Tool Cost Equations Document** for a more detailed discussion on cost equations, their inputs, and their computation. The equations below show how the costs were calculated for inventory source no. 1. The measure for this source uses a Non-EGU PM control equation (Type 8).

Total Capital Cost	=	Typical Capital Cost × Min. Stack Flow Rate
O&M Cost	=	Typical O&M Cost × Min. Stack Flow Rate
Annual Cost	=	(Total Capital Cost × Capital Recovery Factor) + (0.04 × capital cost) + O&M Cost
Annualized Capital Cost	=	Total Capital Cost × Capital Recovery Factor
Annual Cost Per Ton	=	Annual Cost / Emission Reduction

The capital recovery factor (CRF) and other equation parameters (e.g., typical capital cost) are stored with the measure in the CoST database. This information can be found by viewing a Measure in CoST and looking at the Efficiencies and Equations Tabs. If the user specifies that the strategy should not use cost equations, then the specified default cost per ton is used to calculate the annual cost. This default cost per ton is also used to calculate the annual cost if any of the required cost equation inputs (e.g., stack flow rate) are unknown. **Note that if there is no default cost per ton specified for an efficiency record that uses a cost equation, and the information needed to compute the cost for that source is not available, the cost will currently be computed as zero dollars. Therefore, it is important to include a default cost per ton for a measure even if a cost equation is available.**

4 Apply Measures in Series Control Strategy

4.1 Apply Measures in Series Inputs and Outputs

The Apply Measures in Series control strategy applies all relevant controls to a source, as opposed to the Maximum Emission Reduction strategy, where only the most relevant measure (with the best possible reduction for lowest cost) is applied to the source. The Apply Measures in Series strategy is typically used for mobile sources, for which the input inventories are often average-day inventories specific to a given month, and for which there are often multiple independent controls available for each source. Therefore, the measures are applied to the source in series, one after the other. The order of application is based on the user-specified “apply order,” but the system also considers the greatest control efficiency and lowest cost. Thus, the cost factor in terms of dollars per ton of pollutant reduced is used to calculate the annualized cost of the control measure when applied to a specific source. If there happens to be a tie breaker between the measures’ apply order, then the lowest cost measure will be applied first, if there is also a tie on the cost then highest control efficiency will break the tie.

The summary parameters for an Apply Measures in Series control strategy (e.g., cost year, target year, inventory filter) work the same way as they do for the Maximum Emissions Reduction strategy type (see Section 2.2), except that this strategy type does not currently support cost equations. If multiple inventories are specified as inputs to an Apply Measures in Series strategy, they are processed independently and Strategy Detailed Results are generated for each input inventory. The details of the algorithm for matching measures to sources for this strategy type are described in Sections 4.2, and an example is given in Section 4.3.

The measures to consider applying in an Apply Measures in Series strategy are selected in the same way as for the Maximum Emissions Reduction strategy (see Section 3.2): either by measure class or by including a list of specific measures. Note that the option to specify a list of specific measures to include is typically invoked for this strategy type. This option makes it possible to specify the apply order, override the rule penetration and rule effectiveness, and specify the list of counties to which each measure can apply.

The constraints for the Apply Measures in Series strategy type are the same as those used for the Maximum Emissions Reduction strategy type (see Section 2.5), except that the minimum percent difference for replacement control does not apply for this strategy type because each control measure is assumed to be independent of the other measures and therefore measures are not 'replaced' for this type of strategy. Thus, any existing measures in the input inventory are appended to and carried through to the output inventory.

The three main types of outputs discussed in Section 2.6 are generated after a successful strategy run: a Strategy Detailed Result ***for each input inventory***, a single Strategy Measure Summary, and a single Strategy County Summary. Note that when input inventories contain average-day emissions data for a month, the corresponding Strategy Detailed Result datasets will specify total monthly emissions as opposed to average-day emissions for each source; otherwise, they will specify annual emissions. The total monthly emissions are calculated by multiplying the average-day emissions by the number of days in the month. Regarding the two types of summary outputs, if the input datasets have data for each of the 12 months, the summaries will provide annual emissions.

4.2 Apply Measures in Series Strategy Algorithm

The Apply Measures in Series algorithm uses several criteria to determine the order of application of controls for a given source. The apply order is considered first. For measures that have the same apply order, ties are broken by first applying measures with the least cost, and if there is still a tie, then the one with the largest control efficiency is applied first. The following pair of tables provides an example of the order in which the hypothetical measures would be applied to a source.

Measures for Source:

Measure	Apply Order	Annual Cost	Percent Reduction
1. Measure GHI	1	$30,000	85
2. Measure JKL	2	$60,000	75
3. Measure MNO	2	$50,000	90
4. Measure DEF	3	$20,000	65
5. Measure ABC	3	$20,000	75
2. Measure JKL	2	$60,000	90
3. Measure MNO	2	$50,000	75

Order of Measure Application based on Apply Measures in Series Algorithm:

Measure	Apply Order	Annual Cost	Percent Reduction
1. Measure GHI	1	$30,000	85
3. Measure MNO	2	$50,000	90
2. Measure JKL	2	$60,000	75
5. Measure ABC	3	$20,000	75
4. Measure DEF	3	$20,000	65

The remainder of this section gives an overview of the source-measure matching algorithm for the Apply Measures in Series strategy type. Figure 3 is a diagram of the process that is used when running this type of control strategy.

Apply Measures in Series Algorithm:

1. Process/read the emissions inventory.

2. Filter the emissions inventory and compute monthly emissions, if needed.
    a. Filter by SQL WHERE Clause (from Inventory Filter field), if any
    b. Filter by the selected County Dataset, if any
    c. If average-day emissions are specified in the inventory and annual emissions are not specified, compute the monthly emissions by multiplying the average-day emissions by the number of days in the month that the inventory represents. Otherwise, use the annual emissions figures directly. Note that uncontrolled emissions are *not* computed for this strategy type because any control measures are being added to existing control measures instead of replacing existing control measures. This means that it is possible to add more controls to an inventory output from an earlier "Apply Measures in Series" strategy.

3. Filter the Control Measures to consider for the strategy.
    a. By the selected Measure Classes, OR
    b. By the selected Specific Measures

4. Match the Inventory Sources (for all pollutants, not just target pollutants; this is different from the Maximum Emissions Reduction control strategy) to Control Measure Efficiency Records.
    a. Of the remaining measures that passed the filter, find the ones that apply to the SCC of the source (as specified by the SCCs listed as applicable to each measure)
    b. Match efficiency records based on FIPS (control measure data could be available at the National, State, or County level)
    c. Match efficiency records based on Pollutant
    d. Match efficiency records based on month of the inventory (if the inventory is month-specific and the measure is not specified to be applicable to the month, do not consider this record as an option)
    e. Match efficiency records based on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
    f. Match efficiency records based on measure's Minimum and Maximum Emissions (inventory source must have greater than or equal to the minimum emissions and less than the maximum emissions)

5. Evaluate Constraints while the source is being matched with the control, if any constraints were specified. If there are constraints, they are in terms of the target pollutant. It is therefore necessary to purge all Strategy Detailed Result measures that do not control the target pollutant because they will not satisfy the constraints, and the strategy is limited to including only measures that meet the constraints. Note that if a measure that controls the target pollutant also provides coimpacts for other pollutants, those will not be purged during this step. Limit the source's measures using the following constraints, if any were specified:
    a. Include measure for the source if it reduces the target pollutant by the minimum emissions reduction
    b. Include measure for the source if it has at least the minimum control efficiency for the target pollutant
    c. Include measure for the source if the cost per ton for the target pollutant is less than the maximum cost per ton

   d. Include measure for the source if it does not cost more than the maximum annualized cost
   e. Include measure for the source if it meets other strategy-specific constraints

6. Apply source's measures in the correct order, based on:
   a. Apply Order
   b. Lowest Annualized Cost
   c. Highest Percent Reduction

7. Compute the Strategy Detailed Result to include the source-control pairs obtained from the algorithms shown in 4, 5, and 6.

8. After completing the computation of Strategy Detailed Results for all input inventories, prepare the summary outputs (described in Section 2.6) along with any controlled inventories upon user request.

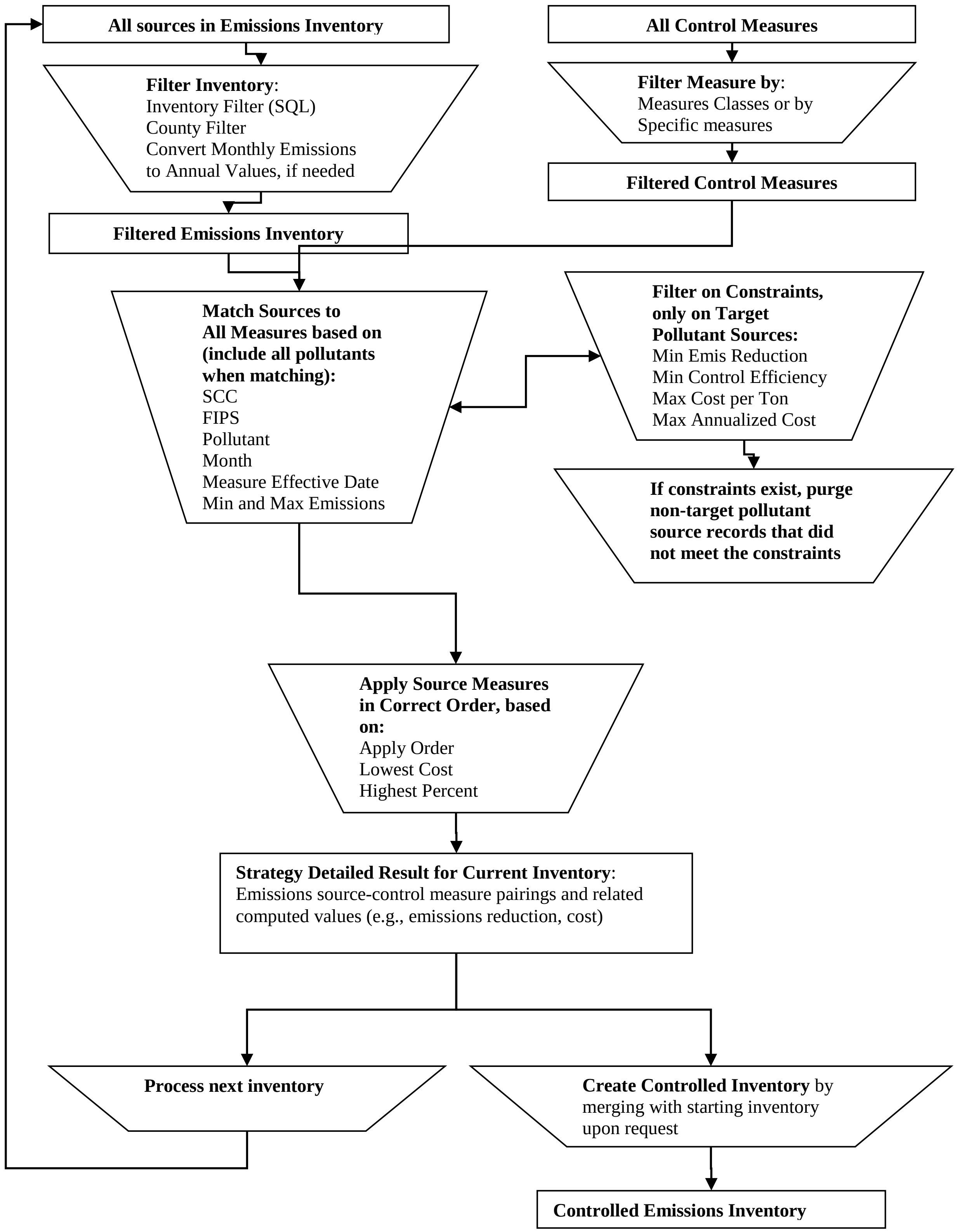

Figure 3. The Process for Running an "Apply Measures in Series" Control Strategy

4.3 Apply Measures in Series Control Strategy Example

This section provides an example of how the Apply Measures in Series algorithm works. It demonstrates how the measure order is determined and also how measure geographic region filters are used.

Strategy Inputs:
Name: Apply Measures In Series Strategy Sample
Type of Analysis: Apply Measures In Series
Cost Year: 2006
Target Year: 2008
Target Pollutant: EXH__VOC
Use Cost Equations: No
Inventories: ORL Onroad Dataset, onroad_2008, version 1

Table 18 shows the measures that should be included in the strategy run, the order of application, the geographic region of application, and the rule penetration override value for the specified measures. The region of application for these measures limits which counties the measures can be used in.

Table 18. Apply Measures in Series Strategy Measures

Sector	Control Measure Name	Measure Abbreviations Start With	Order of Application	Region of Application	Rule Penetration Override*
Onroad	Tier 3 Standards	T3S	1	National	
Onroad	Plug In Hybrids	PLH	2	National	100%
Onroad	Aftermarket Catalysts	AFC	3	National	100%
Onroad	Onroad Low RVP (Seasonal)	ORV	4	Statewide	100%
Onroad	ONRetrofit (Seasonal)	ONR	6	Statewide	75%
Onroad	Best Workplaces for Commuters	BWC	7	Local	100%

* Note that the "Tier 3 Standards" measures do not have a rule penetration override value specified. In this case the rule penetration specified in the efficiency records for the control measure will be used, and these values do not need to be uniform for each county.

For this example, we will consider a subset of the Statewide and Local geographic region data that might be used in an actual analysis. This will help clarify how the Strategy Detailed Result will be generated in the event that Regions of Application are specified for some measures. For our example, we are focused on counties in North Carolina. The "National" Geographic Region includes at least the following counties:

FIPS	County	State
37027	Caldwell County	NC
37029	Camden County	NC

The "Statewide" Geographic Region includes at least the following counties:

FIPS	County	State
37027	Caldwell County	NC
37029	Camden County	NC

The "Local" Geographic Region includes the following county:

FIPS	County	State
37027	Caldwell County	NC

Table 19 contains an example subset of data from an ORL onroad EMF dataset. Note how the emissions are reported as average-day emissions; these will be converted to monthly total emissions by multiplying the average-day emissions by the number of days in the month, and the monthly totals will be summed to get to the annual emissions. If the month for the inventory is not known, but it is specified as a monthly dataset, then 30 days is assumed for the number of days in the month. If this inventory specifies only annual emissions or is an annual dataset, the annual emissions values are used directly.

Table 19. Apply Measures in Series Filtered Inventory Records

Inventory No	Source	FIPS	SCC	Pollutant	Average Day Emissions (tons)	Total Emissions (tons)
1	Caldwell County	37027	2201001130	EVP__VOC	2.292E-02	0.687568 (= 30×0.02292)
2	Camden County	37029	2230073130	EXH__VOC	6.035E-04	0.018106

Table 20 shows the Strategy Detailed Result for this strategy type. The following columns in the result are used solely for this strategy type:

- Apply_Order: Indicates the order in which the control was applied to the source.
- Input_Emis: Contains the emissions input to the individual control measure.
- Output_Emis: Contains the emissions output from the individual control measure.
- Inv_Emis: Contains the starting emissions for the first control being applied.
- Final_Emis: Contains the final resulting emissions after all controls have been applied to the source.

When reviewing the Strategy Detailed Result, you can identify the type of control measure by examining the first few letters of the CM_ABBREV column and matching them with the letters provided in the 'Measure Abbreviations Start With' column in Table 18 above.

Table 20. Apply Measures in Series Strategy Detailed Result

Source #	FIPS	SCC	Poll	cm_abbrev	Ann. cost	Ann cost per ton	O&M cost	Control eff	Rule pen	Pct red	Final emis	Emis red	Inv emis	Apply order	Input emis	Out. emis
1	37027	2201001130	BRK__PM10	BWCOLGVPR				1.0	100	1.0	0.074	0.001	0.075	1	0.075	0.074
1	37027	2201001130	BRK__PM2_5	BWCOLGVPR				1.0	100	1.0	0.032	0.000	0.032	1	0.032	0.032
1	37027	2201001130	EVP__VOC	T3SDLGVPR	$254	$8,400	$254	4.4	100	4.4	0.504	0.030	0.688	1	0.688	0.657
1	37027	2201001130	EVP__VOC	PLHYLGVPR				3.6	100	3.6		0.024		2	0.657	0.634
1	37027	2201001130	EVP__VOC	AFCTLGVPR				3.2	100	3.2		0.020		3	0.634	0.613
1	37027	2201001130	EVP__VOC	ORVFLGVPR	$594	$5,700	$666	17.0	100	17.0		0.104		4	0.613	0.509
1	37027	2201001130	EVP__VOC	BWCOLGVPR				1.0	100	1.0		0.005		5	0.509	0.504
1	37027	2201001130	EXH__CO	ORVFLGVPR				4.4	100	4.4	65.647	3.023	69.333	1	69.33	66.31
1	37027	2201001130	EXH__CO	BWCOLGVPR				1.0	100	1.0		0.663		2	66.30	65.65
1	37027	2201001130	EXH__NOX	T3SDLGVPR	$305	$8,400	$305	2.1	100	2.1	1.546	0.036	1.754	1	1.754	1.718
1	37027	2201001130	EXH__NOX	PLHYLGVPR				2.2	100	2.2		0.037		2	1.718	1.681
1	37027	2201001130	EXH__NOX	AFCTLGVPR	$416	$3,700	$434	6.7	100	6.7		0.112		3	1.681	1.568
1	37027	2201001130	EXH__NOX	ORVFLGVPR				0.5	100	0.5		0.007		4	1.568	1.561
1	37027	2201001130	EXH__NOX	BWCOLGVPR	$300	$19,200	$337	1.0	100	1.0		0.016		5	1.561	1.546
1	37027	2201001130	EXH__PM10	BWCOLGVPR				1.0	100	1.0	0.025	0.000	0.025	1	0.025	0.025
1	37027	2201001130	EXH__PM2_5	BWCOLGVPR				1.0	100	1.0	0.023	0.000	0.023	1	0.023	0.023
1	37027	2201001130	EXH__SO2	BWCOLGVPR				1.0	100	1.0	0.040	0.000	0.041	1	0.041	0.040
1	37027	2201001130	EXH__VOC	T3SDLGVPR	$1,189	$8,400	$1,189	4.4	100	4.4	2.758	0.142	3.216	1	3.216	3.075
1	37027	2201001130	EXH__VOC	PLHYLGVPR				3.6	100	3.6		0.110		2	3.075	2.964
1	37027	2201001130	EXH__VOC	AFCTLGVPR				3.2	100	3.2		0.095		3	2.964	2.869
1	37027	2201001130	EXH__VOC	ORVFLGVPR	$476	$5,700	$533	2.9	100	2.9		0.083		4	2.869	2.786
1	37027	2201001130	EXH__VOC	BWCOLGVPR				1.0	100	1.0		0.028		5	2.786	2.758
1	37027	2201001130	TIR__PM10	BWCOLGVPR				1.0	100	1.0	0.047	0.000	0.048	1	0.048	0.047
1	37027	2201001130	TIR__PM2_5	BWCOLGVPR				1.0	100	1.0	0.012	0.000	0.012	1	0.012	0.012
2	37029	2230073130	EXH__CO	ONRFMHDVPR				50.5	75	37.9	0.014	0.008	0.022	1	0.022	0.014
2	37029	2230073130	EXH__NOX	ONRFMHDVPR	$310	$9,850	$310	46.7	75	35.0	0.058	0.032	0.090	1	0.090	0.058
2	37029	2230073130	EXH__PM10	ONRFMHDVPR				56.3	75	42.2	0.001	0.001	0.002	1	0.002	0.001
2	37029	2230073130	EXH__PM2_5	ONRFMHDVPR				56.2	75	42.2	0.001	0.001	0.002	1	0.002	0.001
2	37029	2230073130	EXH__VOC	ONRFMHDVPR				20.8	75	15.6	0.015	0.003	0.018	1	0.018	0.015

Here are descriptions of the specific measures used in the Strategy Detailed Result (from the cm_abbrev column):

AFCTLGVPR ....Aftermarket Catalysts, LD Gas Vehicles (LDGV); Rural Other Principal Arterial
BWCOLGVPR...........Best Workplaces for Commuters, LD Gas Vehicles (LDGV); Rural Other Principal Arterial
ONRFMHDVPR........ONRetrofit Fall, HD Diesel Vehicles 6 & 7; Rural Other Principal Arterial
ORVFLGVPR............Onroad Low RVP Fall, LD Gas Vehicles (LDGV); Rural Other Principal Arterial
PLHYLGVPR............Plug In Hybrids, LD Gas Vehicles (LDGV); Rural Other Principal Arterial
T3SDLGVPR.............Tier 3 Standards, LD Gas Vehicles (LDGV); Rural Other Principal Arterial

When examining the Strategy Detailed Result, first note that the Poll column contains pollutants with modes, as are typically used for mobile-source emissions. The 'EVP__' prefix stands for Evaporative, the 'BRK__' prefix stands for Brake Component Wear, the 'TIR__' prefix stands for Tire Wear, and the 'EXH__' prefix stands for Exhaust. Both the emissions inventories used for this analysis and the control measures had to specify the pollutants that included these modes as prefixes; otherwise, the sources would not have been controlled.

Let us review the order in which the measures were applied. The Strategy Detailed Result table shows (based on the first three characters of the measure abbreviations) that for source 1's (Caldwell County's) EVP_VOC (target pollutant) emissions, "Tier 3 Standards" were applied first, next the "Plug In Hybrids" measures were applied, then the "Aftermarket Catalysts" measures, and so on. If a situation arises where two or more measures end up tied for apply order (as discussed at the beginning of Section 4.2), CoST breaks the tie by first applying the measure with the lowest cost that gives the best reduction. If there happens to be a tie on the cost, then measures are applied in order of highest percent reduction to lowest percent reduction. Note that the Apply Order shown in the Strategy Detailed Result indicates the actual order in which the measures were applied to that source during the CoST run; this order may differ from the original apply order specified by the user before performing the run (in this case, the order shown in Table 18). For source 2 (Camden County), the "Best Workplaces for Commuters" (BWCOLGVPR) measure could potentially have been applied according to the source's SCC, but because the measure is defined to be applicable only to the Local geographic region (which, as indicated earlier, includes just Caldwell County, not Camden County), the BWCOLGVPR measure was not applied to this source because it is outside of the Local region.

5 Least Cost Control Strategy

5.1 Least Cost Strategy Inputs

The Least Cost strategy type assigns measures to emissions sources to achieve a specified percent reduction or absolute reduction of a target pollutant for sources in a specified geographic region while incurring the minimum possible annualized cost. This algorithm is similar to the maximum emission reduction strategy in that only a single measure is applied to each source. For example, one measure might be selected for a source when trying to reduce the target pollutant by 20%. However, if you were trying to obtain a 40% reduction of the target pollutant, another more expensive measure that achieves a higher level of control might be selected for the same source to meet the targeted level of reduction. If multiple inventories are specified as inputs to a Least Cost strategy, they are automatically merged into one EMF dataset as an ORL Merged dataset type. This allows the multiple inventory sectors to be considered simultaneously during a single Least Cost run. Note that the merged inventory dataset will be truncated and repopulated at the start of each strategy run, to ensure that the most up-to-date inventory data are included in the run.

Note that all of the strategy parameters for Least Cost strategies have the same meaning and act in the same way as they do for the Maximum Emissions Reduction strategy (see Sections 2.2 and 2.3), such as cost year, inventory filter, and county dataset. So, if a filter for the inventory is specified, only sources that pass the filter will be considered for control.

The measures to consider applying in a Least Cost strategy are selected in the same way as for the Maximum Emissions Reduction strategy (see Section 2.4): either by measure class or by including a list of specific measures. If you choose specific measures and specify overrides for rule penetration or rule effectiveness, the overrides will be included in the Least Cost computation; so will the specification of any geographic limitations for the particular measures.

In addition to the standard five constraints that are available for the Maximum Emissions Reduction strategy type (see Section 2.6), the Least Cost strategy type has two other constraints that can be used during the run:

- Domain Wide Absolute Emission Reduction (tons): If specified, this is the domain-wide emission reduction of the target pollutant across all of the input inventories that the strategy is trying to achieve. For example, the strategy could be trying to obtain a 10,000-ton reduction in the strategy target pollutant (e.g., PM10) in the region of interest, where the region of interest is either the area covered by the input inventories, or a subset of that area specified by the county dataset and/or the inventory filter.
- Domain Wide Percent Emission Reduction (%): If specified, this is the domain-wide percent reduction of the target pollutant across all of the input inventories that the strategy is trying to achieve. For example, the strategy could be trying to obtain a 50% percent reduction in the strategy target pollutant (e.g., PM10) in the area covered by the input inventories or a subset thereof as specified by the county dataset and/or the inventory filter. *Note:* This percent reduction is the percent of the emissions in the inventory to be reduced, not the percent of the 'controllable' emissions as was specified in AirControlNET.

If a domain-wide type of constraint is desired, only one of these two constraints needs to be specified for the strategy to run. If you choose to specify the *percent* reduction constraint, the domain-wide emission reduction is computed and stored with the strategy during the run; this reduction is computed by multiplying the emissions in the inventory of the target pollutant times the percent reduction. **If both the domain-wide percent reduction and domain-wide absolute**

reduction are specified, the percent reduction will be used and the specified absolute reduction will be overwritten with the value computed based on the percent reduction.

5.2 Least Cost Strategy Outputs

The Least Cost strategy automatically creates the same three basic output datasets as a Maximum Emissions Reduction strategy—Strategy Detailed Result, Strategy Measure Summary, and Strategy County Summary (see Section 2.6)—but it also creates an additional output dataset called the Least Cost Control Measure Worksheet. This output is a table of all possible emission source-control measure pairings (for sources and measures that meet the respective filters specified for the strategy), and for each pairing it provides information about the cost and emission reduction achieved if the measure were to be applied to the source. An example of this table is given in Section 5.4. This dataset is used to help generate ***a single*** Strategy Detailed Result once the optimization process has been performed to achieve the desired reduction. This dataset has the all of the same columns as the Strategy Detailed Result (described in Table 4), plus the following columns:

- marginal: This column stores the marginal cost (dollars are given based on the specified cost year) for the source-measure record. This is calculated according to the following equation:

  marginal cost = source annual cost (for specified cost year) / emission reduction (tons)

  Note that cost equations are used to compute the annual cost, when applicable and when all required input data are available. For target pollutant source-control pair records, the annual cost will be the *total of the annual costs for the target pollutant and any costs associated with coimpact pollutants*. For example, a source has a control that will treat both NOx (the target pollutant) and VOC, and both these pollutants have an associated cost. In this case the target pollutant (NOx) marginal costs will include both costs in the calculation. For example,

  marginal cost = (NOx annual cost + VOC annual cost) / NOx emission reduction (tons)

- status: This column contains a flag that helps determine which source-control records should be actively considered during the strategy run. Source-control pair records with a status = null will be included during the generation of the Strategy Detailed Result and will also be considered during the optimization process to get the least cost. Source-control pair records with a status that is not null (e.g., status = 1) will not be considered during the generation of the Strategy Detailed Result and will also not be considered during the optimization process. More information on the use of this column is included in the description of the optimization algorithm in Section 4.3.

- cum_annual_cost: This column contains the cumulative annual cost for the source and all preceding sources that have been included in the strategy (i.e., those for which status is null). This is calculated only for target pollutant sources, but it also includes costs associated with coimpact pollutants. The annual cost for the source is cumulated by following the apply_order in an ascending order.

- source_annual_cost: This column contains the cumulative annual cost for the source only (no costs for preceding sources are included), which includes both the target and coimpact pollutant costs. This column ensures that all costs are looked at for a particular source. This is populated only for the target pollutant source records.

- cum_emis_reduction: This column contains the cumulative emission reduction for the source and all preceding sources that have been included in the strategy (i.e., those for which status is null). This is calculated only for target pollutant sources. The emission reduction is cumulated by following the apply_order in an ascending order.

If multiple input inventories are used for the strategy run and the user has chosen to create controlled inventories, there will be one controlled inventory created for each of the input inventories.

5.3 Least Cost Strategy Algorithm

This section describes the source-measure matching algorithm for a Least Cost strategy. Figures 4 and 5 illustrate the process used when running a Least Cost control strategy.

1. Process/read the emissions inventory.

2. Use inventory filtering (discussed in Section 2.3) to filter the emissions inventory and compute monthly emissions, then compute uncontrolled emissions.
    a. Filter by SQL WHERE Clause (from Inventory Filter field), if any
    b. Filter by the selected County Dataset, if any
    c. If average-day emissions are specified in the inventory and annual emissions are not specified, compute the monthly emissions by multiplying the average-day emissions by the number of days in the month that the inventory represents. Otherwise, use the annual emissions figures directly.
    d. Compute uncontrolled emissions for controlled sources using one of these formulas:
        unc. emis. = ann. emis. / (1 - CE / 100 × RE / 100 × RP / 100)
        unc. emis. = avg. day emis. × days_in_month / (1 - CE / 100 × RE / 100 × RP / 100)

3. Use control measure filtering (discussed in Section 2.4) to filter the Control Measures to consider for the strategy.
    a. By the selected Measure Classes, OR
    b. By the selected Specific Measures

4. Match the Inventory Sources for the Target Pollutant to Control Measure Efficiency Records.
    a. Of the remaining measures that passed the filter, find the ones that apply to the SCC of the source (as specified by the SCCs listed as applicable to each measure)
    b. Match efficiency records based on FIPS (control measure data could be available at the National, State, or County level)
    c. Match efficiency records based on Target Pollutant
    d. Match efficiency records based on month of the inventory (if the inventory is month-specific and the measure is not specified to be applicable to the month, do not consider this record as an option)
    e. Match efficiency records based on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
    f. Match efficiency records based on measure's Minimum and Maximum Emission

5. Evaluate Constraints (discussed in Section 2.5) while the source is being matched with the control, if any constraints were specified. Limit the source's measures using the following constraints, if any were specified:
    a. Include measure if it reduces target pollutant by the minimum emissions reduction
    b. Include measure if it controls target pollutant by the minimum control efficiency
    c. Include measure if the cost per ton for target pollutant is less than the maximum cost per ton
    d. Include measure if it does not cost more than maximum annualized cost
    e. Include measure for the source if it meets other strategy-specific constraints

6. Evaluate source for preexisting control:
    a. If the source has an existing control, then evaluate whether replacement control measure fulfills the minimum percent reduction constraint (see Section 2.2.4 for more information on this constraint)
    b. Do not double-control source with the same control measure

7. Apply target pollutant source measure to source's coimpact pollutants.
    a. Match on FIPS
    b. Match on any coimpact pollutants
    c. Match efficiency records based on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
    d. Match on Minimum and Maximum Emissions for the efficiency record

8. Prepare the Least Cost Control Measure Worksheet dataset to include the source-control pairs obtained from the algorithms shown in 4, 5, 6, and 7. This dataset will be used to determine the least-cost way to achieve the desired reduction. When the worksheet is first developed, the marginal [cost] column is populated with the cost per ton to control the emissions of the target pollutant.

9. Convert target pollutant source-control pairs' costs—annual cost and marginal [cost]—to be in terms of the target pollutant. All costs for the source's pollutants need to summed and associated with the target pollutant.

11. Determine the desired emissions reduction (in tons). This is computed based on the desired percent reduction, the inventory emissions of the target pollutant, and the maximum emission reduction possible for the strategy. The other option is to directly specify the desired emissions reduction instead of specifying the desired percent reduction. **If the desired emissions reduction is more than the emissions in the inventory, then this Least Cost strategy run will produce the same results as a maximum emission reduction strategy.** When this happens, the source-measure record that provides the largest reduction in emission will be chosen for each source. This is done using a query that determines for each source the record with the highest emissions reduction and lowest cost (so that if there are two measures that result in the same percent reduction but that have different costs, the least-cost measure will still be selected for the source), and then sets the status for all records that do not meet these criteria to 1. Thus, at the end of the process, only a single record for each source will have a status of null and will therefore be included in the Strategy Detailed Result.

12. If the desired emissions reduction (in tons) is less than the emission in the inventory, the Least Cost Control Measure Worksheet needs to be scanned to determine the point in the

worksheet at which the desired emissions reduction has been satisfied. To accomplish this, the worksheet is sorted in the following way: marginal [cost], emis_reduction (descending), and record_id, where the contents of record_id is the number of the row in the worksheet. With the worksheet sorted in this order (essentially by increasing cost per ton), then by including only the records that encompass the 'largest' reduction per source up to a certain point in the worksheet, it is possible to compute a total emissions reduction that includes all source-measure combinations up to that point of the worksheet. With this in mind, the different points in the sorted worksheet are evaluated to determine what area of the worksheet provides a solution that is close to the desired emissions reduction (in tons).

The algorithm starts by evaluating the available reduction at the midpoint of the table (position = 0.5 × target pollutant source-control table record count). If this is more than the desired emission reduction, then the available reduction 25% of the way through table is evaluated (position = 0.25 × target pollutant source-control table record count). Conversely, if the achievable emission reduction at the midpoint is less than the desired emission reduction, then the available reduction at the position 75% of the way through the table is evaluated. The minimum and maximum record to be considered is tracked during the process, and the available reduction is recursively evaluated at the midpoint of the section of interest until there is only a single record left in the section of interest. At this point the optimal point in the worksheet that provides at least the desired level of reduction at the least cost has been identified. This process is reflected in Figure 4. Note that the desired level of reduction may not be achieved exactly to the ton due to the discrete nature of applying measures to specific inventory sources.

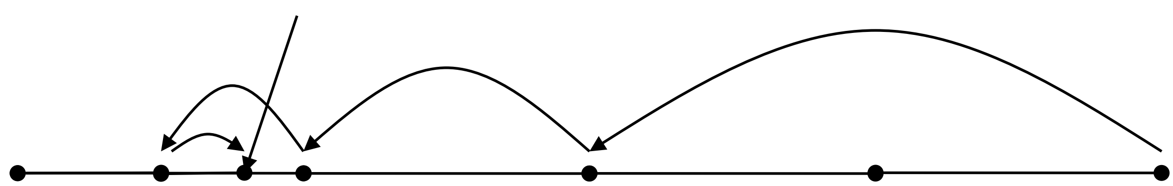

Figure 4. Recursively Identifying the Optimal Position

13. Once the position in the table that achieves the desired reduction with the minimum cost has been found, the worksheet is reevaluated. From the target position through the end of the table, these less cost-effective source-measure records are eliminated from the solution by setting the status field for those records to 1. In addition, the status field is set to 1 for any records prior to the target position that have lesser emissions reductions. Once this process is complete, the records that have status = null are the records that will be included in the final solution and therefore in the Strategy Detailed Result.

14. Next, the worksheet's apply_order, cum_emis_reduction, and cum_annual_cost cells are updated for the target pollutant source-measure records with status = null so that it is possible to see how the costs and emissions reductions accumulate to the final total numbers. Note that the apply_order for the strategy is calculated by sorting the worksheet in the same sort order (i.e.,

marginal [cost], emis_reduction (descending), record_id) as is used when determining the target position in the table.

15. Based on the worksheet, a single Strategy Detailed Result is computed that could include records from any of the input inventories. In addition, a Strategy Measure Summary and Strategy County Summary are prepared for the strategy as a whole. If the user requests that controlled inventories be created, those will be created separately for each of the input inventories. Thus, the output controlled inventories will contain the same sources as each of the input inventories.

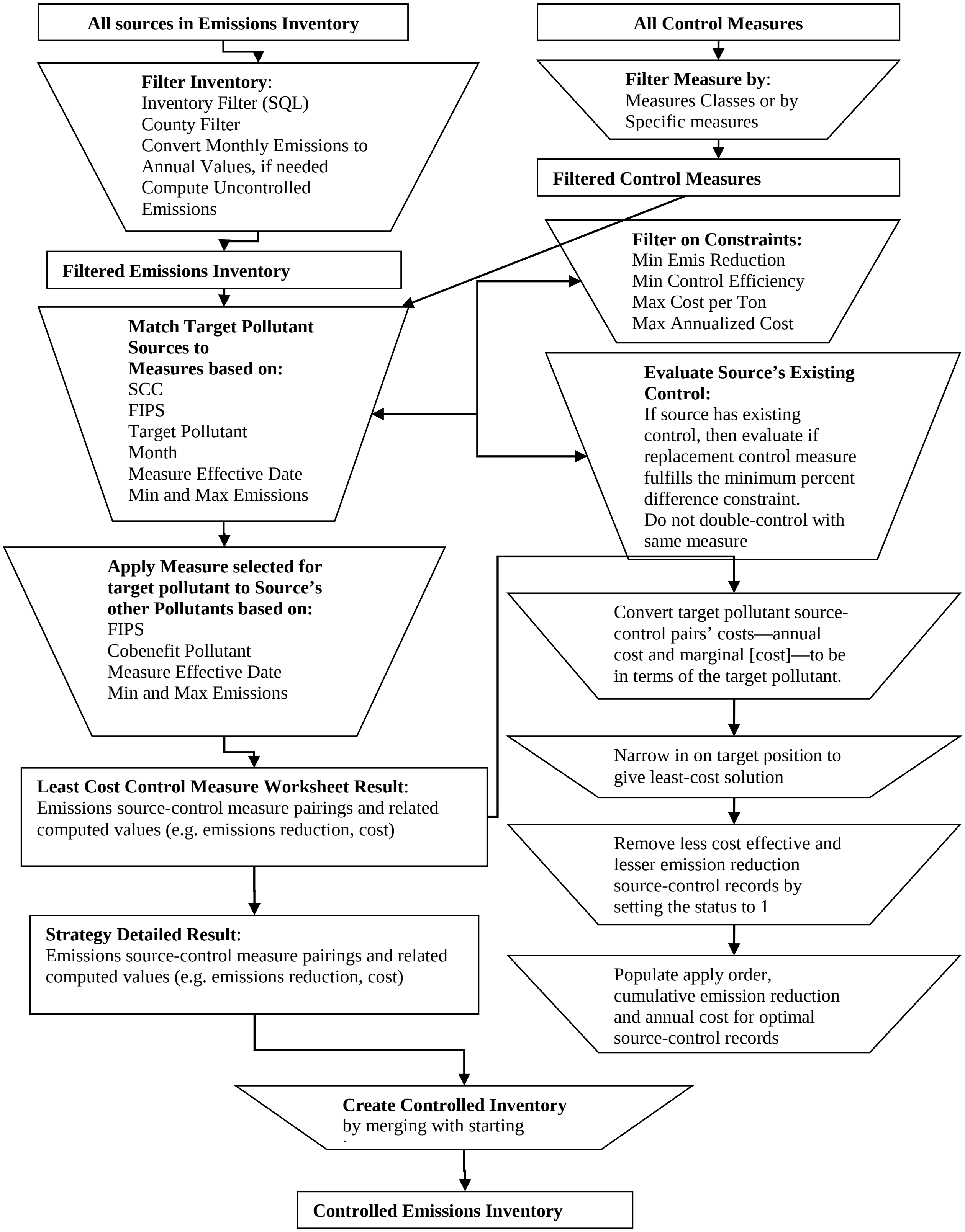

Figure 5. The Process for Running a "Least Cost" Control Strategy

5.4 Least Cost Control Strategy Example

This section provides two examples of using the algorithm to create domain-wide emissions reductions in PM10: one for 25%, the other for 75%. Table 21 shows the Least Cost Control Measure Worksheet for the 25% reduction, and Table 22 shows the corresponding Strategy Detailed Result, resulting in a total reduction of 1.55 tons. Table 23 shows the Least Cost Control Measure Worksheet for the 75% reduction, and Table 24 shows the corresponding Strategy Detailed Result, resulting in a total reduction of 2.45 tons.

Strategy Inputs:
Name: Least Cost Strategy Sample
Type of Analysis: Least Cost
Cost Year: 2006
Target Year: 2020
Target Pollutant: PM10
Use Cost Equations: Yes
Inventories: ORL Point Dataset, ptnonipm_2020, version 1
Inventory Filter: FIPS in ('42003','42005','42007','42009') and SCC in ('10200501')

Least Cost Targets (for two separate runs):

Domain Wide Percent Reduction (%)	Domain Wide Emissions Reduction (tons)
25	0.8
75	2.4

Measure names and abbreviations used in example

Abbreviation	Name
PDESPIBOL	Dry ESP-Wire Plate Type;(PM10) Industrial Boilers – Oil
PVESCIBOL	Venturi Scrubber;(PM10) Industrial Boilers – Oil

Table 21. 25% Target Least Cost Measure Worksheet

Source No.	Source Name	FIPS	SCC	Poll.	Measure Abbrev	Annual Emis (tons)	Emis Red (tons)	Pct Red (%)	Annual Cost	Annual Cost Per Ton ($/ton)	Marginal ($/ton)	Cumul.Annual Cost ($)	Cumul Emis Red (tons)	Stat.
1	[4200300008,033,34,1]	42003	10200501	PM10	PVESCIBOL	0.0658	0.0605	92.0	$89,615	$1,480,352	$1,481,240	–	–	1
1	[4200300008,033,34,1]	42003	10200501	PM10	PDESPIBOL	0.0658	0.0645	98.0	$39,972	$619,873	$619,721	–	–	1
2	[4200300008,035,35,1]	42003	10200501	PM10	PVESCIBOL	0.919	0.8455	92.0	$726,824	$859,658	$859,638	–	–	1
2	[4200300008,035,35,1]	42003	10200501	PM10	PDESPIBOL	0.919	0.9006	98.0	$324,194	$359,968	$359,976	–	–	1
3	[4200300008,037,36,1]	42003	10200501	PM10	PVESCIBOL	1.564	1.4389	92.0	$1,221,393	$848,850	$848,838	–	–	1
3	[4200300008,037,36,1]	42003	10200501	PM10	PDESPIBOL	1.564	1.5327	98.0	$544,793	$355,442	$355,447	$544,796	1.55	–
–	[4200300022,007,33,1]	42003	10200501	PM10	PVESCIBOL	0.0574	0.0528	92.0	$10,090,312	$191,202,032	$191,104,394	–	–	1
4	[4200300022,007,33,1]	42003	10200501	PM10	PDESPIBOL	0.0574	0.0562	98.0	$4,500,707	$80,062,727	$80,083,754	–	–	1
5	[4200300022,010,34,1]	42003	10200501	PM10	PDESPIBOL	0.011	0.0108	98.0	$4,772,643	$442,972,904	$441,911,389	–	–	1
–	[4200300102,018,9999,1]	42003	10200501	PM10	PVESCIBOL	0.0223	0.0205	92.0	$22	$1,067	$1,073	–	–	1
6	[4200300102,018,9999,1]	42003	10200501	PM10	PDESPIBOL	0.0223	0.0218	98.0	$3	$156	$138	$3	0.022	–
7	[4200300240,003,5,2]	42003	10200501	PM10	PDESPIBOL	8.0E-4	8.0E-4	98.0	$419,605	$507,651,538	$524,506,250	–	–	1
7	[4200300240,003,5,2]	42003	10200501	PM10	PVESCIBOL	8.0E-4	8.0E-4	92.0	$940,728	$1,212,349,480	$1,175,910,000	–	–	1
8	[4200300240,003,5,3]	42003	10200501	PM10	PVESCIBOL	0.5577	0.5131	92.0	$940,728	$1,833,314	$1,833,420	–	–	1
8	[4200300240,003,5,3]	42003	10200501	PM10	PDESPIBOL	0.5577	0.5466	98.0	$419,605	$767,670	$767,664	–	–	1
9	[4200300008,033,34,1]	42003	10200501	PM2_5	PVESCIBOL	0.0658	0.0586	89.0	–	–	0.0	–	–	1
9	[4200300008,033,34,1]	42003	10200501	PM2_5	PDESPIBOL	0.0658	0.0625	95.0	–	–	0.0	–	–	1
10	[4200300008,035,35,1]	42003	10200501	PM2_5	PVESCIBOL	0.919	0.8179	89.0	–	–	0.0	–	–	1
10	[4200300008,035,35,1]	42003	10200501	PM2_5	PDESPIBOL	0.919	0.873	95.0	–	–	0.0	–	–	1
11	[4200300008,037,36,1]	42003	10200501	PM2_5	PVESCIBOL	1.564	1.392	89.0	–	–	0.0	–	–	1
11	[4200300008,037,36,1]	42003	10200501	PM2_5	PDESPIBOL	1.564	1.4858	95.0	–	–	0.0	–	–	–
12	[4200300022,007,33,1]	42003	10200501	PM2_5	PVESCIBOL	0.0387	0.0344	89.0	–	–	0.0	–	–	1
12	[4200300022,007,33,1]	42003	10200501	PM2_5	PDESPIBOL	0.0387	0.0367	95.0	–	–	0.0	–	–	1
13	[4200300022,010,34,1]	42003	10200501	PM2_5	PVESCIBOL	0.0074	0.0066	89.0	–	–	0.0	–	–	1
13	[4200300022,010,34,1]	42003	10200501	PM2_5	PDESPIBOL	0.0074	0.0070	95.0	–	–	0.0	–	–	1
14	[4200300102,018,9999,1]	42003	10200501	PM2_5	PVESCIBOL	0.0122	0.0108	89.0	–	–	0.0	–	–	1

14	[4200300102,018,9999,1]	42003	10200501	PM2_5	PDESPIBOL	0.0122	0.0116	95.0	–	–	0.0	–	–	–
15	[4200300240,003,5,2]	42003	10200501	PM2_5	PVESCIBOL	8.0E-4	7.0E-4	89.0	–	–	0.0	–	–	1
15	[4200300240,003,5,2]	42003	10200501	PM2_5	PDESPIBOL	8.0E-4	7.0E-4	95.0	–	–	0.0	–	–	1
16	[4200300240,003,5,3]	42003	10200501	PM2_5	PVESCIBOL	0.3977	0.354	89.0	–	–	0.0	–	–	1
16	[4200300240,003,5,3]	42003	10200501	PM2_5	PDESPIBOL	0.3977	0.3779	95.0	–	–	0.0	–	–	1

Table 22. 25% Target Least Cost Strategy Detailed Result

Source No.	Source Name	FIPS	SCC	Pollutant	Measure Abbrev	Annual Emis (tons)	Emis Red (tons)	Pct Red (%)	Annual Cost	Annual Cost Per Ton ($/ton)
3	[4200300008,037,36,1]	42003	10200501	PM10	PDESPIBOL	1.564	1.5327	98.0	$544,793	$355,442
6	[4200300102,018,9999,1]	42003	10200501	PM10	PDESPIBOL	0.0223	0.0218	98.0	$3	$156
11	[4200300008,037,36,1]	42003	10200501	PM2_5	PDESPIBOL	1.564	1.4858	95.0	–	–
14	[4200300102,018,9999,1]	42003	10200501	PM2_5	PDESPIBOL	0.0122	0.0116	95.0	–	–

Table 23. 75% Target Least Cost Measure Worksheet

Source No.	Source Name	FIPS	SCC	Poll.	Measure Abbrev	Annual Emis (tons)	Emis Red (tons)	Pct Red (%)	Annual Cost	Annual Cost Per Ton ($/ton)	Marginal ($/ton)	Cumul. Annual Cost ($)	Cumul. Emis Red (tons)	Status
1	[4200300008,033,34,1]	42003	10200501	PM10	PVESCIBOL	0.0658	0.0605	92.0	$89,615	$1,480,352	$1,481,240	–	–	1
1	[4200300008,033,34,1]	42003	10200501	PM10	PDESPIBOL	0.0658	0.0645	98.0	$39,972	$619,873	$619,721	–	–	1
2	[4200300008,035,35,1]	42003	10200501	PM10	PVESCIBOL	0.919	0.8455	92.0	$726,824	$859,658	$859,638	–	–	1
2	[4200300008,035,35,1]	42003	10200501	PM10	PDESPIBOL	0.919	0.9006	98.0	$324,194	$359,968	$359,976	$868,990	2.4551	–
3	[4200300008,037,36,1]	42003	10200501	PM10	PVESCIBOL	1.564	1.4389	92.0	$1,221,393	$848,850	$848,838	–	–	1
3	[4200300008,037,36,1]	42003	10200501	PM10	PDESPIBOL	1.564	1.5327	98.0	$544,793	$355,442	$355,447	$544,796	1.5545	–
–	[4200300022,007,33,1]	42003	10200501	PM10	PVESCIBOL	0.0574	0.0528	92.0	$10,090,312	$191,202,032	$191,104,394	–	–	1
4	[4200300022,007,33,1]	42003	10200501	PM10	PDESPIBOL	0.0574	0.0562	98.0	$4,500,707	$80,062,727	$80,083,754	–	–	1
5	[4200300022,010,34,1]	42003	10200501	PM10	PVESCIBOL	0.011	0.0101	92.0	$10,699,977	$1,057,887,014	$1,059,403,663	–	–	1
5	[4200300022,010,34,1]	42003	10200501	PM10	PDESPIBOL	0.011	0.0108	98.0	$4,772,643	$442,972,904	$441,911,389	–	–	1
–	[4200300102,018,9999,1]	42003	10200501	PM10	PVESCIBOL	0.0223	0.0205	92.0	$22	$1,067	$1,073	–	–	1
6	[4200300102,018,9999,1]	42003	10200501	PM10	PDESPIBOL	0.0223	0.0218	98.0	$3	$156	$138	$3	0.0218	–
7	[4200300240,003,5,2]	42003	10200501	PM10	PDESPIBOL	8.0E-4	8.0E-4	98.0	$419,605	$507,651,538	$524,506,250	–	–	1
7	[4200300240,003,5,2]	42003	10200501	PM10	PVESCIBOL	8.0E-4	8.0E-4	92.0	$940,728	$1,212,349,480	$1,175,910,000	–	–	1
8	[4200300240,003,5,3]	42003	10200501	PM10	PVESCIBOL	0.5577	0.5131	92.0	$940,728	$1,833,314	$1,833,420	–	–	1
8	[4200300240,003,5,3]	42003	10200501	PM10	PDESPIBOL	0.5577	0.5466	98.0	$419,605	$767,670	$767,664	–	–	1
9	[4200300008,033,34,1]	42003	10200501	PM2_5	PVESCIBOL	0.0658	0.0586	89.0	–	–	0.0	–	–	1
9	[4200300008,033,34,1]	42003	10200501	PM2_5	PDESPIBOL	0.0658	0.0625	95.0	–	–	0.0	–	–	1
10	[4200300008,035,35,1]	42003	10200501	PM2_5	PVESCIBOL	0.919	0.8179	89.0	–	–	0.0	–	–	1
10	[4200300008,035,35,1]	42003	10200501	PM2_5	PDESPIBOL	0.919	0.873	95.0	–	–	0.0	–	–	–
11	[4200300008,037,36,1]	42003	10200501	PM2_5	PVESCIBOL	1.564	1.392	89.0	–	–	0.0	–	–	1
11	[4200300008,037,36,1]	42003	10200501	PM2_5	PDESPIBOL	1.564	1.4858	95.0	–	–	0.0	–	–	–
12	[4200300022,007,33,1]	42003	10200501	PM2_5	PVESCIBOL	0.0387	0.0344	89.0	–	–	0.0	–	–	1
12	[4200300022,007,33,1]	42003	10200501	PM2_5	PDESPIBOL	0.0387	0.0367	95.0	–	–	0.0	–	–	1
13	[4200300022,010,34,1]	42003	10200501	PM2_5	PVESCIBOL	0.0074	0.0066	89.0	–	–	0.0	–	–	1
13	[4200300022,010,34,1]	42003	10200501	PM2_5	PDESPIBOL	0.0074	0.0070	95.0	–	–	0.0	–	–	1
14	[4200300102,018,9999,1]	42003	10200501	PM2_5	PVESCIBOL	0.0122	0.0108	89.0	–	–	0.0	–	–	1

14	[4200300102,018,9999,1]	42003	10200501	PM2_5	PDESPIBOL	0.0122	0.0116	95.0	–	–	0.0	–	–	–
15	[4200300240,003,5,2]	42003	10200501	PM2_5	PVESCIBOL	8.0E-4	7.0E-4	89.0	–	–	0.0	–	–	1
15	[4200300240,003,5,2]	42003	10200501	PM2_5	PDESPIBOL	8.0E-4	7.0E-4	95.0	–	–	0.0	–	–	1
16	[4200300240,003,5,3]	42003	10200501	PM2_5	PVESCIBOL	0.3977	0.354	89.0	–	–	0.0	–	–	1
16	[4200300240,003,5,3]	42003	10200501	PM2_5	PDESPIBOL	0.3977	0.3779	95.0	–	–	0.0	–	–	1

Table 24. 75% Target Least Cost Strategy Detailed Result

Source No.	Source Name	FIPS	SCC	Pollutant	Measure Abbrev	Annual Emis (tons)	Emis Red (tons)	Pct Red (%)	Annual Cost	Annual Cost Per Ton ($/ton)
2	[4200300008,035,35,1]	42003	10200501	PM10	PDESPIBOL	0.919	0.9006	98.0	$324,194	$359,968
3	[4200300008,037,36,1]	42003	10200501	PM10	PDESPIBOL	1.564	1.5327	98.0	$544,793	$355,442
6	[4200300102,018,9999,1]	42003	10200501	PM10	PDESPIBOL	0.0223	0.0218	98.0	$3	$156
10	[4200300008,035,35,1]	42003	10200501	PM2_5	PDESPIBOL	0.919	0.873	95.0	–	–
11	[4200300008,037,36,1]	42003	10200501	PM2_5	PDESPIBOL	1.564	1.4858	95.0	–	–
14	[4200300102,018,9999,1]	42003	10200501	PM2_5	PDESPIBOL	0.0122	0.0116	95.0	–	–

6 Least Cost Curve Control Strategy

6.1 Least Cost Curve Inputs

The purpose of the Least Cost Curve strategy type is to iteratively run Least Cost strategies so that a cost curve can be generated. Typically, a cost curve will show the total cost of emissions reduction and the cost per ton of emissions reduction as the desired level of reduction increases. Examples of cost curves can be seen in Figure 6 (in terms of percentage reduction) and Figure 7 (in terms of tons of reduction). These are classic examples of the marginal costs increasing as the desired level of control increases. Note that Figures 6 and 7 were generated by plotting data output from CoST with spreadsheet software. The vertical line on Figure 7 shows the total emissions that were available in the inventory.

The input inventories are treated in the same way as the least cost run in that if there are multiple inventories they will be combined into an ORL Merged inventory prior to performing any of the runs. The inventory filters, measure filters, and constraints work in the same way as they do for the other strategy types. The main difference between the Least Cost and Least Cost Curve strategy types is in the specification of constraints. Instead of specifying a single percent reduction or absolute emissions reduction, three new constraints are used to control the run:

- Domain-wide Percent Reduction Start (%): Specifies a percent reduction to be used for the first Least Cost strategy to be run.
- Domain-wide Percent Reduction End (%): Specifies a percent reduction to be used for the last Least Cost strategy to be run.
- Domain-wide Percent Reduction Increment (%): Specifies an increment on percentages to use between the first and last runs (e.g., if 25% is specified, and if your start and end percentages are 25% and 100%, respectively, then runs will be performed for 25, 50, 75, and 100% reduction).

Figure 8 shows the Constraints tab of the Control Strategy Editor for a Least Cost Curve control strategy. Note that it is possible to run the strategy multiple times with different levels of reduction. Suppose that you generate a coarse cost curve (increment is 25%) and find an area of interest that bears further examination. You can then go back and specify different start, end, and increment to obtain more information (e.g., start=80%, end=90%, increment=2%) on that portion of the curve. The different types of points shown in Figure 7 illustrate data obtained from a 25% increment run followed by a run with the increment set to 5%.

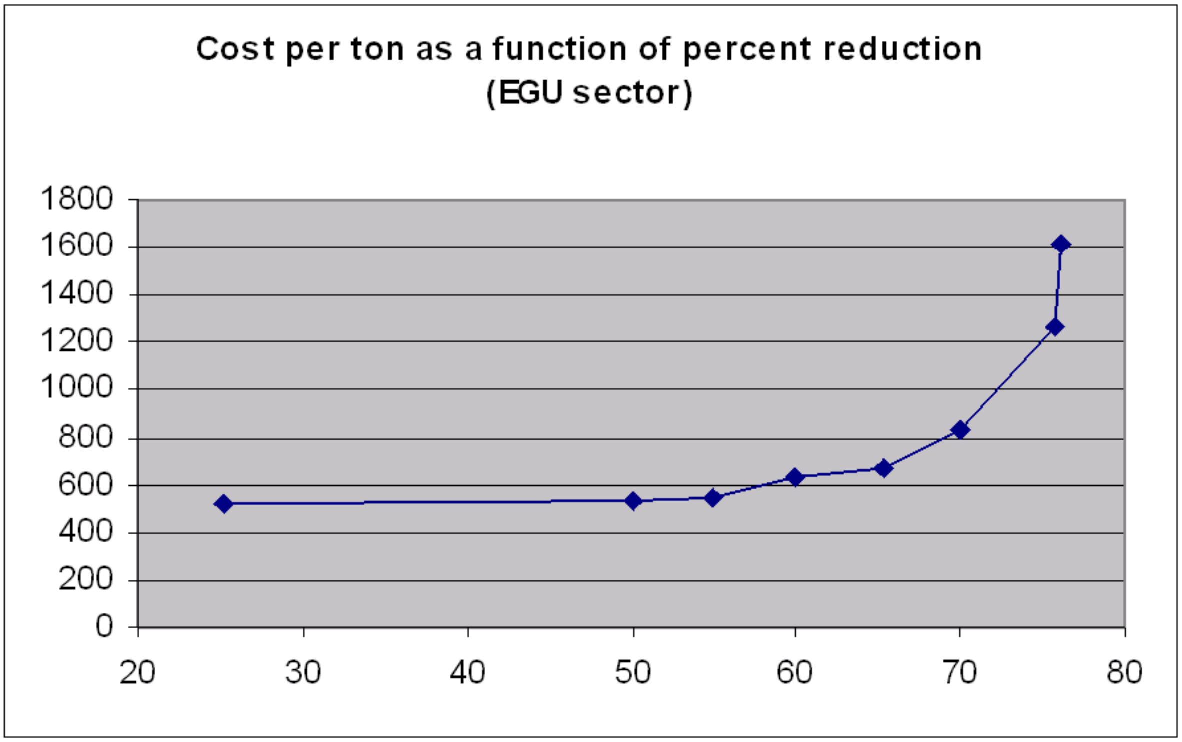

Figure 6. Cost Curve Showing Cost per Ton as a Function of Percent Reduction

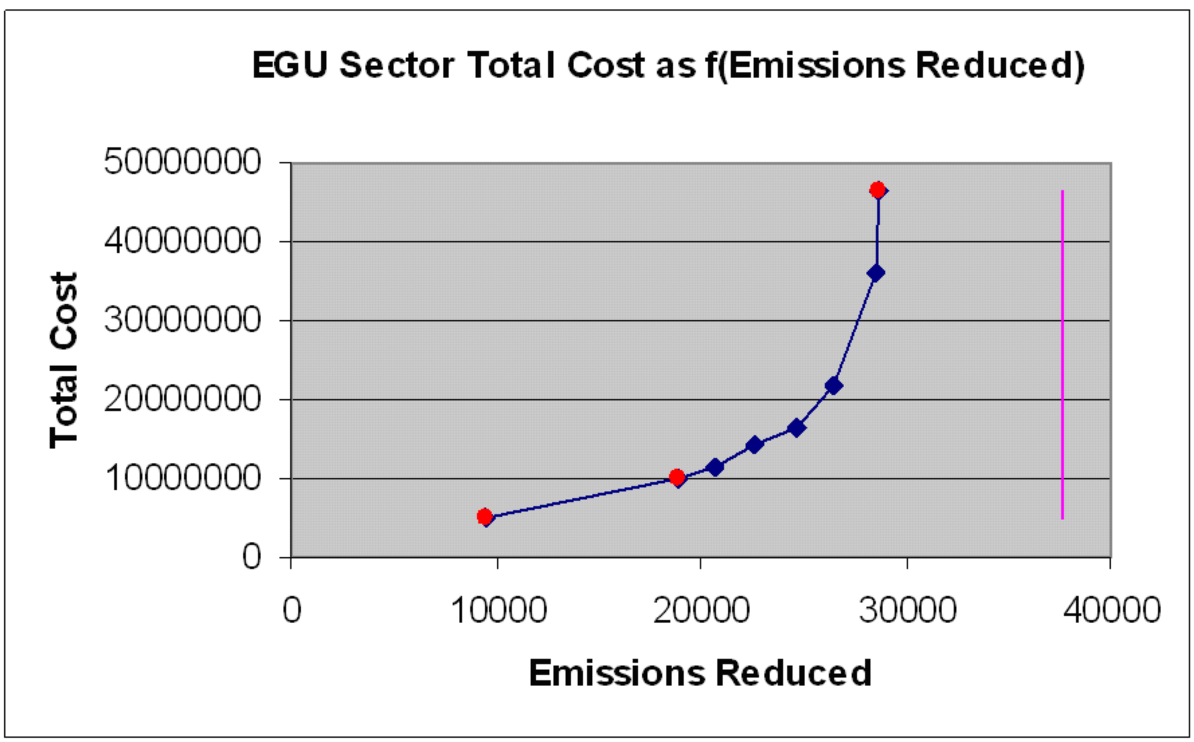

Figure 7. Cost Curve Showing Total Cost as a Function of Emissions Reduced

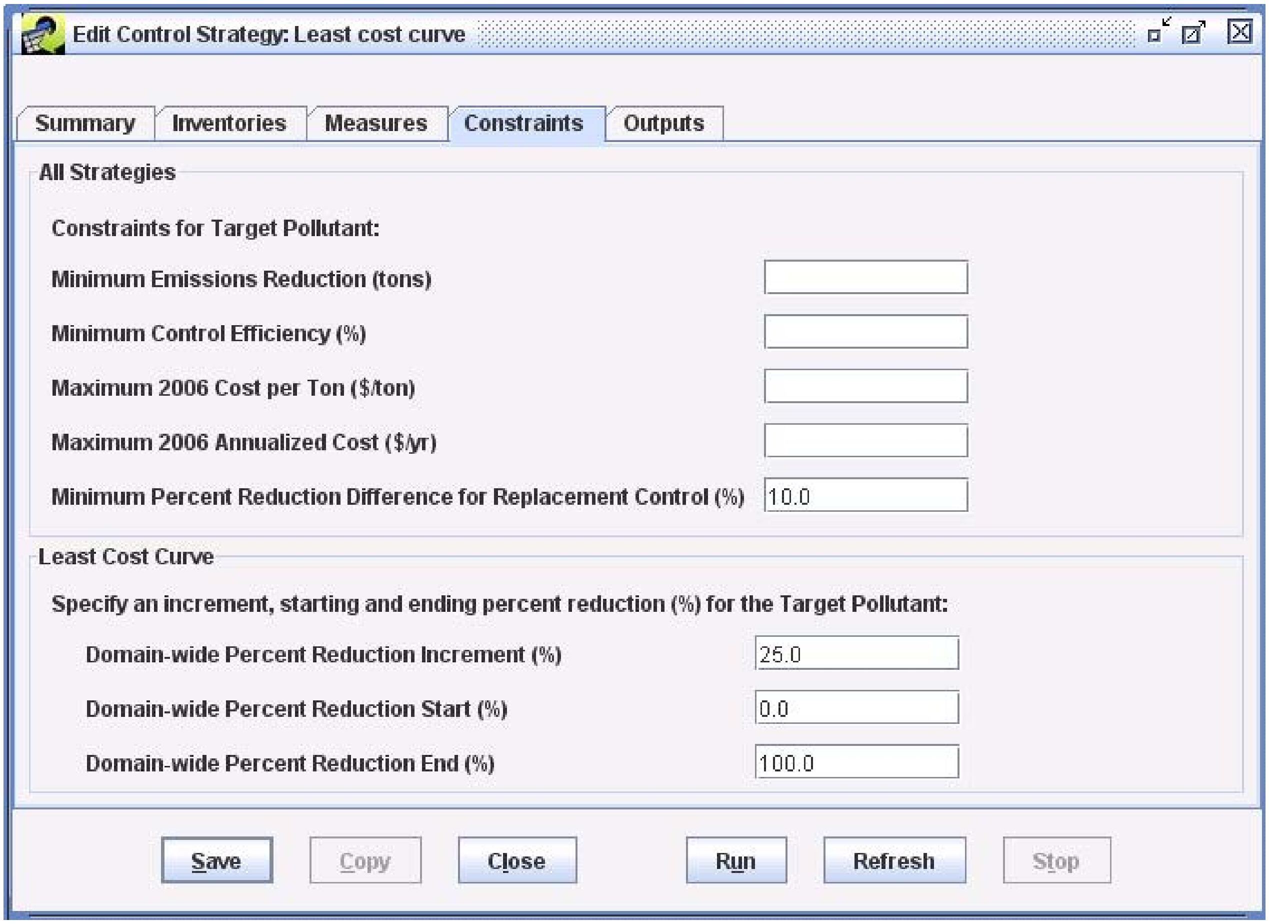

Figure 8. Constraints Tab for a Least Cost Curve Strategy

6.2 Least Cost Curve Outputs

A screenshot of the outputs tab for a Least Cost Curve strategy is shown in Figure 9. This tab was created using two sets of runs: the first from 0% to 100% with a 25% increment, and the second from 90% to 95% with a 1% increment. The types of outputs for a Least Cost Curve strategy are the following:

1. Detailed Result datasets for each targeted percent reduction. Note that several results could have the same actual percent reduction if the targeted reduction exceeds the maximum available reduction. As with a Least Cost strategy, the actual percent reduction may not exactly match the targeted reduction due to the discrete nature of applying specific controls to specific sources. CoST will ensure that each actual reduction is equal to or greater than the corresponding targeted reduction.
2. Least Cost Control Measure Worksheet: this output is the same as the worksheet produced for a regular Least Cost strategy run. Note that the same worksheet is used for all targeted percent reductions and only the status column is updated to specify which measure-source combinations are included in the current strategy.
3. Least Cost Curve Summary: this output dataset contains a row with cost and emissions reduction information for each of the runs that was performed for the strategy. Rows are

added to this output if additional strategy runs are performed (e.g., to examine different sections of the curve). The columns of this summary are: Poll, Uncontroll_Emis (tons), Total_Emis_Reduction (tons), Target_Percent_Reduction, Actual_Percent_Reduction, Total_Annual_Cost, Average_Ann_Cost_per_Ton, Total_Annual_Oper_Maint_Cost, Total_Annualized_Capital_Cost, Total_Capital_Cost. Here, the Uncontroll_Emis column contains the emissions in the inventory to be reduced, not the 'controllable' emissions as was specified in AirControlNET. The columns starting with Total are computed by summing all of the values of the corresponding column in the Strategy Detailed Result for the pollutant specified in the Poll column. Examples of Least Cost Curve Summaries are given in Figure 10 and Table 25.

4. Controlled Inventories: these output datasets may optionally be created based on any of the Strategy Detailed Results that are available for the strategy. Thus, results corresponding to any of the targeted reductions may be processed by SMOKE and the resulting data used as input to an air quality model. Note that for each targeted reduction, individual controlled inventories will be created for each of the input inventories.

Recall that in addition to the datasets output for control strategies, many types of summaries of these datasets can be created in CoST (see Section 2.7). Figure 11 shows a plot that can be created by summarizing a Least Cost Strategy Detailed Result using the "Summarize by Control Technology and Pollutant" query. Some of the technologies used in this run were Low NOx burners (LNB), Low NOx burners with Flue Gas Recovery (LNB + FGR), Non-Selective Catalytic Reduction (NSCR), and Selective Non-catalytic Reduction (SNCR). Note that Figure 11 was generated by plotting data output from CoST with spreadsheet software, and not by CoST itself. CoST does have some plotting capabilities, but they are not discussed in this document.

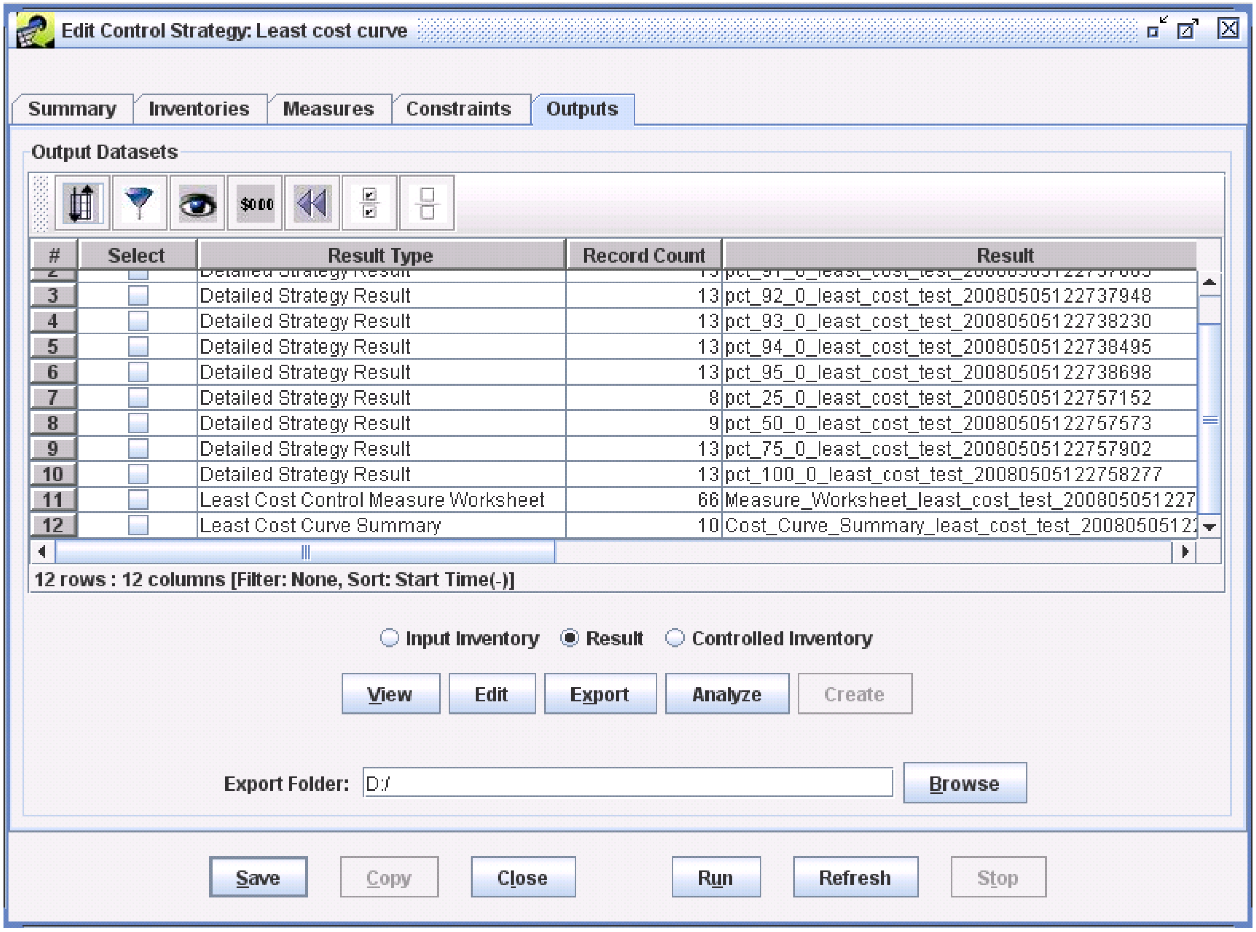

Figure 9. Outputs Tab for a Least Cost Curve Strategy

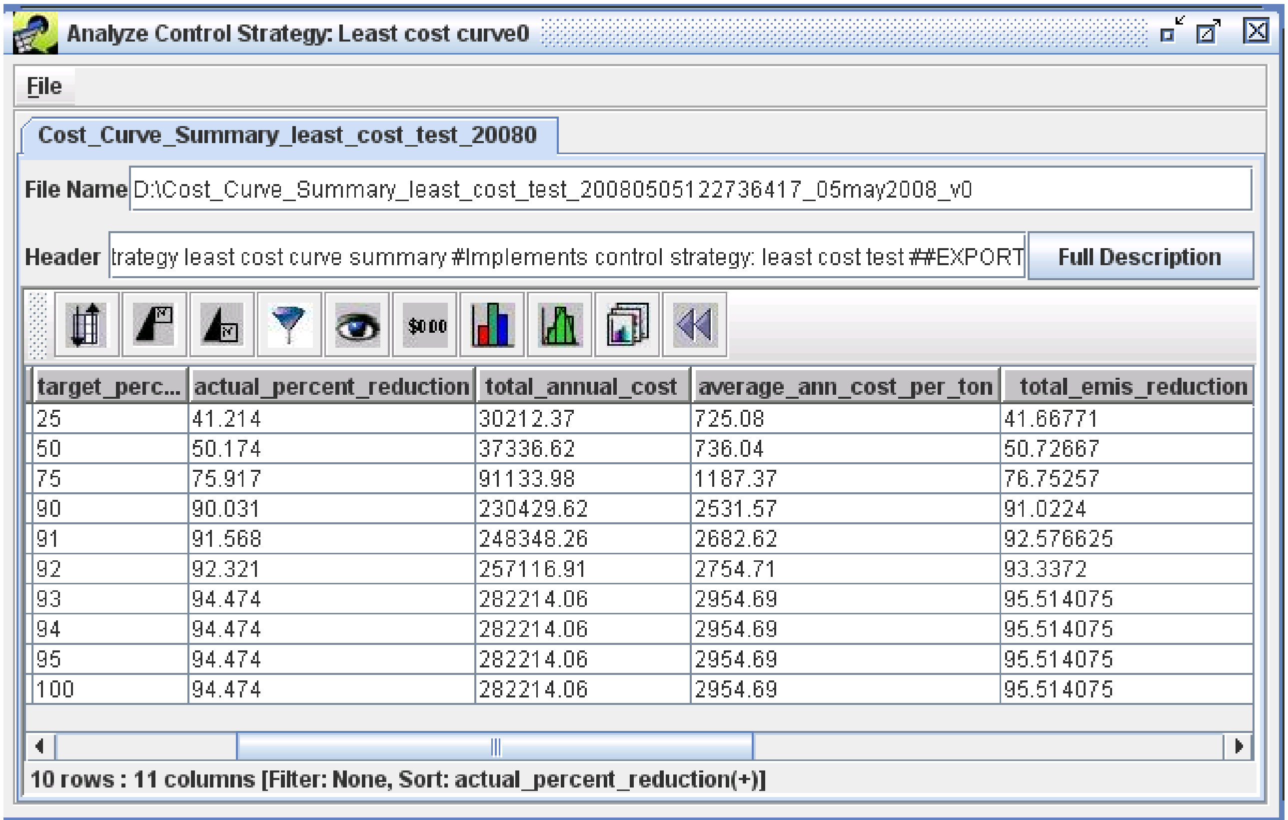

Figure 10. Example Values for Least Cost Curve Strategy

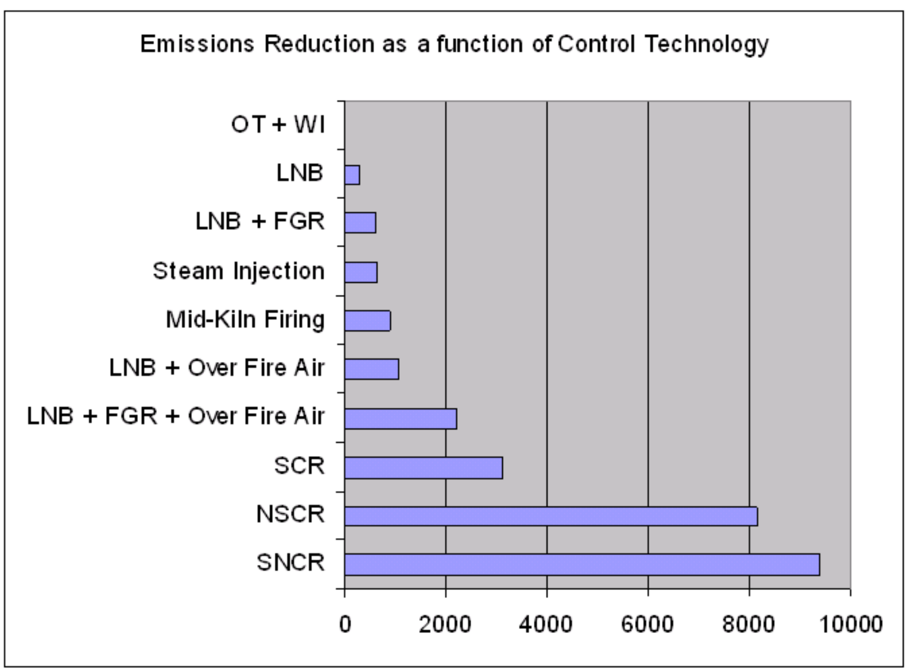

Figure 11. Control Technologies used within a Least Cost Analysis

Table 25. Example of Least Cost Curve Summary

poll	uncontrolled emis (tpy)	total emis reduction (tpy)	target percent reduction	actual percent reduction	total annual cost	average ann cost per ton	total annual oper maint cost	total annualized capital cost	total capital cost
PM10	3.198	1.5545	5	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	10	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	15	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	20	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	25	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	30	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	35	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	40	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	1.5545	45	48.608	$544,796	$350,464	$444,084	$70,737	$749,386
PM10	3.198	2.4551	50	76.769	$868,990	$353,953	$708,347	$112,831	$1,195,329
PM10	3.198	2.4551	55	76.769	$868,990	$353,953	$708,347	$112,831	$1,195,329
PM10	3.198	2.4551	60	76.769	$868,990	$353,953	$708,347	$112,831	$1,195,329
PM10	3.198	2.4551	65	76.769	$868,990	$353,953	$708,347	$112,831	$1,195,329
PM10	3.198	2.4551	70	76.769	$868,990	$353,953	$708,347	$112,831	$1,195,329
PM10	3.198	2.4551	75	76.769	$868,990	$353,953	$708,347	$112,831	$1,195,329
PM10	3.198	3.0662	80	95.877	$1,328,567	$433,294	$1,082,965	$172,503	$1,827,496
PM10	3.198	3.0662	85	95.877	$1,328,567	$433,294	$1,082,965	$172,503	$1,827,496
PM10	3.198	3.0662	90	95.877	$1,328,567	$433,294	$1,082,965	$172,503	$1,827,496
PM10	3.198	3.0662	95	95.877	$1,328,567	$433,294	$1,082,965	$172,503	$1,827,496
PM10	3.198	3.1340	100	97.997	$11,021,522	$3,516,759	$8,984,049	$1,431,051	$15,160,574

6.3 Least Cost Curve Algorithm

This section describes the source-measure matching algorithm for a Least Cost Curve strategy.

1. For the Domain-wide Percent Reduction Start, apply the standard Least Cost algorithm described in Section 5.3. This includes creating a Least Cost control measure worksheet and a Strategy Detailed Result corresponding to the strategy. The algorithm also assesses whether the reduction is actually achievable. If the targeted reduction is not achievable, the result provided will be the same result as the Maximum Emissions Reduction strategy would give.

2. Create or update the Least Cost Curve summary for the strategy with the summary information from the created Strategy Detailed Result and the targeted and actual percent reductions.

3. Add the Domain-wide Percent Reduction Increment to the targeted percent reduction that was just processed. If the resulting value is less than or equal to the Domain-wide Percent Reduction End *and* the targeted reduction is less than or equal to the maximum possible reduction, then apply the standard Least Cost algorithm described in Section 5.3. This includes creating a Least Cost control measure worksheet and a Strategy Detailed Result corresponding to the strategy.

4. Repeat steps 2 and 3 until all desired increments have been processed.

7 Annotate Inventory Control Strategy

As noted earlier, CoST can make use of add-on controls—control measures that can be applied in addition to other controls. It is therefore important that CoST first determine whether there are any existing control measures on the emissions source, and if so, what types of control devices are used by the existing measures. Currently, a data gap exists in this area for both the base-year emissions inventories and the future-year emissions inventories that may be used as inputs to a control strategy run. The NEI does contain data fields for storing this information, and there is a limited amount of existing control efficiency and control device code data in the base-year NEI. However, these fields are not very well populated in the base-year inventory for sectors other than the electricity generating unit (EGU) point sources, and the fields are even less well populated in the future-year modeling inventories. Generally, the control efficiency fields are much better populated than the control device fields. Another issue is that the control device codes stored in the NEI are a lot less specific than the control measure abbreviations that CoST uses. Therefore, even if the control device codes were well populated, these codes would need to be translated into the CoST control measure abbreviations for CoST to really have the information it needs to properly apply add-on controls.

To address the issue of unspecified control measures in inventories that can be input to CoST, several steps have been taken. First, when CoST creates a controlled inventory, in addition to filling in the information in the CEFF, REFF, and RPEN columns, CoST populates the Control Measures, Pct Reduction, Current Cost, and Total Cost columns in the ORL inventory (see Section 2.6) to specify information about measures that it has applied. In this way, the controlled inventories created by CoST always specify the relevant information about the measures that have been applied as a result of a CoST control strategy. A second step that has been taken to provide more information about existing control measures is creation of the Annotate Inventory strategy type. The eventual goal of the Annotate Inventory strategy is to develop a base-year inventory with more complete existing control measure information.

7.1 Annotate Inventory Inputs

The purpose of the Annotate Inventory strategy type is to specify what measures are likely to have been used to achieve specified percent reductions in input inventories. The input inventories are treated the same way as in the Maximum Emissions Reduction runs in that each inventory is processed separately and separate results are created for each one. The inventory filters and measure filters work in the same way as they do for the other strategy types. Note that the selected target pollutant is important because only records for that pollutant will be annotated. Constraints are also applicable in that if the controlled source does not satisfy the specified constraints, it will not be included in the result and another measure that does satisfy the constraints will be sought.

7.2 Annotate Inventory Outputs

The outputs from the Annotate Inventory strategy type are an annotated inventory for each of the input inventories. The annotated inventories have the same dataset types as the input inventories. All of the source records for the specified target pollutant with nonzero control efficiencies in the input inventory will appear in the annotated inventory, and the control measures column will be filled in for sources for which a matching measure has been found. Note that the originally specified control efficiency fields and the emissions in the inventory are not changed, even if the inventory efficiency differed from the efficiency specified for the control measure. Once an annotated inventory has been created, a controlled inventory can be created from the annotated inventory. Unlike the annotated inventory, the controlled inventory will have all records found in the input inventory and can therefore be used as an input to SMOKE.

Table 26 shows an example of an annotated point inventory. Table 27 shows a report that can be generated for an annotated inventory that compares the inventory control efficiency to the control efficiency that was identified based on the available control measures.

Table 26. Example of Annotated Point Inventory

FIPS	PLANTID	POINTID	STACKID	SEGMENT	SCC	POLL	ANN_ EMIS	CEFF	REFF	CPRI	CM_ABBREV	PERCENT_ REDUCTION
37001	3700100226	GR10	S-2	4	30501110	PM10	0.07	99	–	100	PFFPJMIOR	99
37001	3700100226	GR9	S-2	3	30501108	PM10	0.09	99	–	100	PFFRAMIOR	99
37001	3700100237	G-7	S-3	3	10200906	PM10	14.91	42.7	–	76	PCUIMIBWD	7.7
37001	3700100237	G-7	S-3	3	10200906	PM2_5	13.07	71.6	–	76	–	–
37001	3700100237	G-8	S-1	1	10200906	PM10	7.39	24.3	–	76	PCUIMIBWD	7.7
37001	3700100237	G-8	S-1	1	10200906	PM2_5	6.45	46.7	–	76	–	–
37001	3700100237	G-9	S-2	2	10200906	PM10	20.58	42.7	–	76	PCUIMIBWD	7.7
37001	3700100237	G-9	S-2	2	10200906	PM2_5	17.99	76.1	–	76	–	–
37001	3700100256	G-3	S-1	2	40201619	PM10	0.04	97.7	–	79	–	–
37001	3700100256	G-3	S-1	2	40201619	PM2_5	0.01	99.5	–	79	–	–
37001	3700100276	G-45	S-16	14	30203399	PM10	0.04	97	–	100	–	–
37001	3700100276	G-45	S-16	14	30203399	PM2_5	0.03	95	–	100	–	–
37001	3700100276	G-52	S-8	16	30203399	PM10	0.7	97	–	127	–	–
37001	3700100276	G-52	S-8	16	30203399	PM2_5	0.59	95	–	127	–	–
37001	3700100283	G-1	S-1	1	10200906	PM10	3.81	85	–	78	PVESCIBWD	93
37001	3700100283	G-1	S-1	1	10200906	PM2_5	2.4	85	–	78	–	–
37001	3700100284	G-1	S-4	1	30500205	PM10	2.7	99	–	64	PFFRAASMN	99

Table 27. Example of Comparison Report between NEI Measures and Inventory Measures

measure_abbr	inv_ceff	measure_ceff	ceff_abs_diff	pri_control_device	measure_name
NSTINGTNG	79.99	80	0.01	STEAM OR WATER INJECTION	Steam Injection; Gas Turbines - Natural Gas
NLNC3UBCT2	69.99	58.3	11.69	MISCELLANEOUS CONTROL DEVICES	LNC3; Utility Boiler - Subbit Coal/Tangential
NLNC3UBCT2	69.99	58.3	11.69	MISCELLANEOUS CONTROL DEVICES	LNC3; Utility Boiler - Subbit Coal/Tangential
NLNBUGTNG	54.99	68	13.01	STEAM OR WATER INJECTION	LNB; Gas Turbines - Natural Gas
NLNC3UBCT2	89.99	58.3	31.69	STAGED COMBUSTION	LNC3; Utility Boiler - Subbit Coal/Tangential
NNGRECBNG	84.99	50	34.99	CONTROL OF % O2 IN COMBUSTION AIR (OFF STOICHIOMETRIC FIRING)	NGR; External Combustion Boilers, Elec Gen, Nat Gas (2)
NNGRECBNG	84.99	50	34.99	CONTROL OF % O2 IN COMBUSTION AIR (OFF STOICHIOMETRIC FIRING)	NGR; External Combustion Boilers, Elec Gen, Nat Gas (2)
	97.99			WET SCRUBBER - HIGH EFFICIENCY	
	94.6			DRY LIMESTONE INJECTION	

7.3 Annotate Inventory Algorithm

When an Annotate Inventory strategy is run, CoST looks at the percent reduction specified by the CEFF, REFF, and RPEN columns and uses the available control measures in the database to try to determine what control measure has the closest percent reduction to the one specified in the inventory. It then fills in the control measures column with the measure that was found. Note that the originally specified control efficiency fields and the emissions in the inventory are not changed, even if the inventory efficiency differed from the efficiency specified for the control measure. If no measure was found, it leaves the control measure field blank. Once the strategy has been run, a summary report can be generated using the "Compare CoST to NEI measures" query that shows the sources with nonzero CEFF values and the difference between the inventory-specified percent reduction and the percent reduction of the control measure that CoST "guessed" had been applied to the source. **It is important for the user to then examine the results of this report to find cases where the specified control efficiency matches were not even close and those for which no match was found.** Both of these situations can indicate that there are missing or incorrect data in the control measures database, or that the information in the inventory was erroneous. This kind of information can be used to help accomplish the eventual goal of the Annotate Inventory strategy, stated in Section 7.3: to develop a base-year inventory with more complete existing control measure information. The specific algorithm is described below, and an illustration of the algorithm is shown in Figure 12.

1. Process/read the emissions inventory.
2. Filter the emissions inventory and compute uncontrolled emissions.
   a. Filter by SQL WHERE Clause (based on contents of the Inventory Filter field), if any
   b. Filter by the counties specified in the selected County Dataset, if any
   c. Compute uncontrolled emissions for controlled sources using one of these formulas:
      unc. emis. = ann. emis. / (1 - CE / 100 × RE / 100 × RP / 100)
      unc. emis. = avg. day emis. × days_in_month / (1 - CE / 100 × RE / 100 × RP / 100)
3. Filter the Control Measures to consider for the strategy.
   a. By the selected Measure Classes, OR
   b. By the selected Specific Measures
4. Match the Inventory Sources for the Target Pollutant to Control Measure Efficiency Records.
   a. Of the remaining measures, find the ones that apply to the SCC of the source (as specified by the SCCs listed as applicable to each measure)
   b. Match on FIPS (data could be available at the National, State, or County level)
   c. Match on Target Pollutant
   d. Match on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
   e. Match on measure's Minimum and Maximum Emissions (inventory source must have greater than or equal to the minimum emissions and less than the maximum emissions)

5. Evaluate Constraints while the source is being matched with the control. For example, the emission reduction of a source from a certain control is not known until we apply the measure to the source with its specific percent reduction, where percent reduction = control efficiency × rule effectiveness/100 × rule penetration/100. Constraint calculations are dependent on both the

inventory source and the measure. Limit the sources' measures using the following constraints, if any were specified:

a. Include measure for the source if it reduces the target pollutant by the minimum emissions reduction
b. Include measure for the source if it has at least the minimum control efficiency for the target pollutant
c. Include measure for the source if the cost per ton for the target pollutant is less than the maximum cost per ton
d. Include measure for the source if it does not cost more than the maximum annualized cost
e. Include measure for the source if it meets other strategy specific constraints

6. If multiple measures are available for a source, then the best measure is chosen according to the following criteria:

a. Closest Locale (matching both FIPS state and county is best, then FIPS-state, followed by national)
b. Matching Primary NEI Device code (if the source's primary device code, from the inventory, is the same as the potential CoST measure, then more priority is given to these measures than to measures with a different device code than in the inventory)
c. Closest Control Efficiency (choose the measure that has the smallest absolute difference between the inventory control efficiency and the measure's efficiency record control efficiency). For example, a source has a preexisting control with a 50% control efficiency, and CoST has two measures that could be used with this source, one with a 75% and one with a 40% control efficiency. In this case the 40% measure would be chosen because it has a 10% difference from the specified efficiency as compared to a 25% difference.

9. Compute the annotated inventory result to include the sources with preexisting controls (i.e., sources that have control efficiencies [ceff] specified). Also, the result will contain each source's predicted control measure, if one was found, from the algorithms shown in 4, 5, 6, 7, and 8.

10. After completing the computation of annotated inventory results for all input inventories as required by the specific strategy algorithm, controlled inventories can be generated from the annotated inventories upon user request.

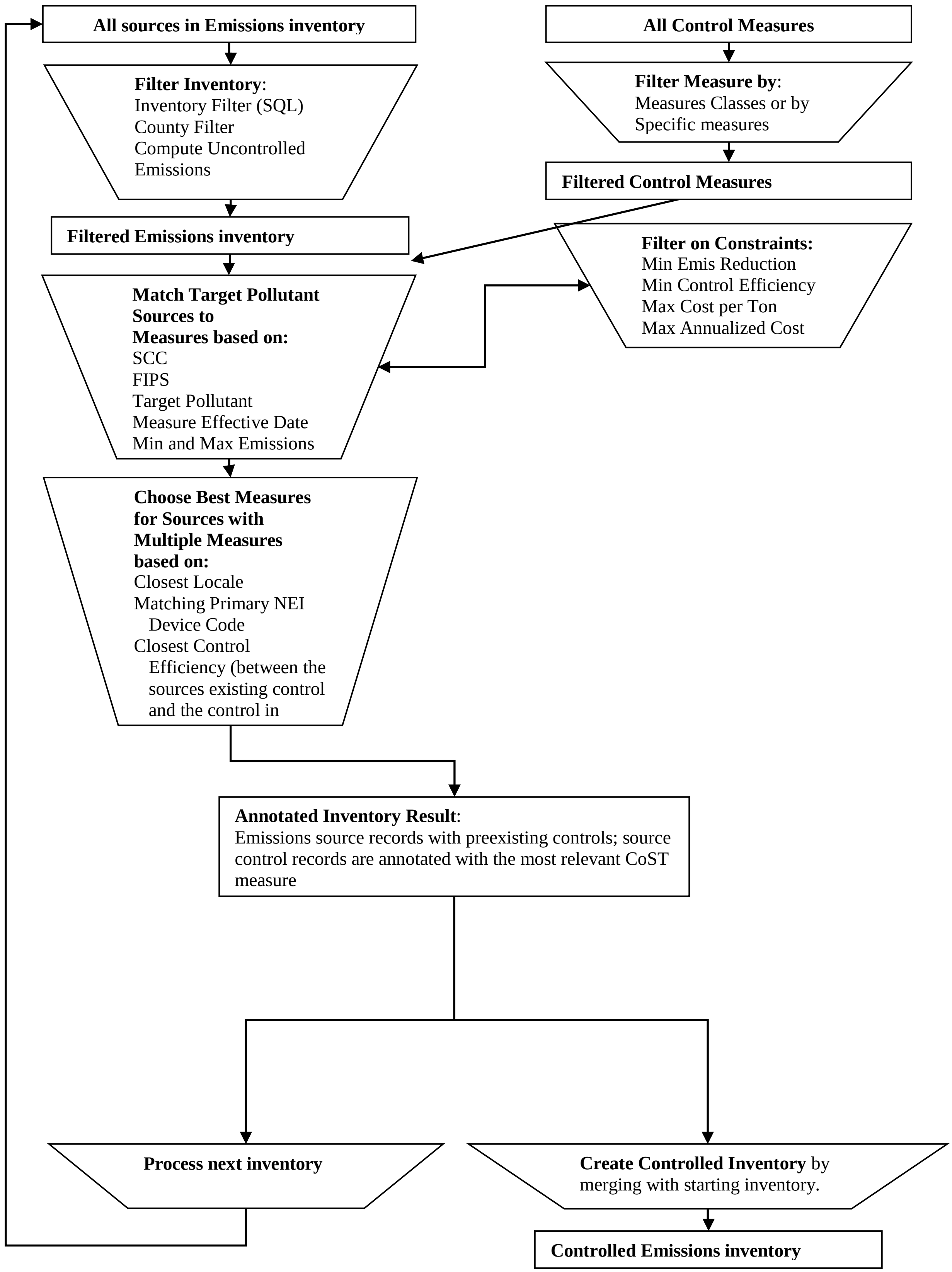

Figure 12. The Process for Running Annotate Inventory Control Strategy

8 Project Future Year Inventory Control Strategy

8.1 Project Future Year Inventory Background

The inventory projection process involves taking a base-year inventory and projecting it to a future-year base inventory). For the future-year base inventories to have information on existing control measures, it is helpful for the inventory projection process to specify what control measures have been applied to the sources. This can be accomplished in a way that is similar to how the Annotate Inventory strategy analysis works. It can also be accomplished by incorporating the concept of control programs (explained in Section 8.2) into CoST and the EMF. The process of projecting inventories is currently done using a series of SAS programs that take as input data tables collected from various sources. For several years, EPA has wanted to make the process of applying the control programs more explicit and documentable. By incorporating the control programs into CoST and having CoST apply the projection and control factors to create the projected inventory, it will be possible to annotate the inventories as the projection takes place.

To accomplish the application of control programs and projection factors to an inventory, the control programs concept is being incorporated into CoST. For each control program, it will be possible to specify the type of program, the start and end date, and one accompanying dataset that will identify the sources that will be affected by the program (e.g., a list of plants that will close). The types of control programs are expected to include, but not be limited to, the following:

- Planned closures at specific plants
- Planned reductions at specific plants
- Planned growth at specific plants
- Planned replacement control technology at existing plants
- Planned add-on control technology at existing plants
- Caps on emissions at existing plants
- Replacement of emissions at existing plants
- SCC-based reduction programs
- Commuter programs
- Estimated growth for specific sectors

In situations where the desired control measures or technologies for the control program are known, these can be specified as part of the control program. If the control measures are not known, CoST can search for a measure with the desired control efficiency and provide that as the best guess for the applied measure. If a probable measure is found for a source, a cost estimate will also be included as part of the analysis. To implement the process of inventory projection, a new strategy analysis algorithm is being added to COsT, called “Project Future Year Inventory”. The Strategy Detailed Result for this strategy will show the control efficiency (and probable control measure, including costs), growth factor, and cap value or replacement value that was applied to a source. This strategy will also be able to generate a complete inventory for use as input to SMOKE. It is important to note that there is another important data need: to collect planned control program data (e.g., from SIPs) from states so that future EPA control strategy modeling can incorporate these programs and thereby produce more realistic results than if the planned state-specific programs are ignored.

8.2 Introduction to Control Programs

A control program is used as an input to a "Project Future Year Inventory" control strategy. A control program contains a control packet type of dataset that will identify the sources that will be affected by the program, a start date and end date, and a list of probable control measure or control technologies to include during the analysis. There are four major types of control programs:

- *Plant Closure* – can identify specific plants to close; can vary the level of closure by targeting specific stacks or by closing whole plants (i.e., all stacks at the plant will be closed)
- *Control* – can apply replacement or add-on controls to inventory emission sources
- *Projection* – can apply projections to inventory emission sources
- *Allowable* – can apply a replacement cap on inventory emission sources or replace inventory emission sources

The Control Program Packet Dataset is used in conjunction with an emission inventory to create a control/projection matrix by matching the control packet to the emission inventory using a hierarchical weighted matching approach. This matching process creates source-control packet pairings. The matrix is stored in the Strategy Detailed Result. See Table 28 for a complete listing of the matching hierarchy combinations, the inventory types the matching criteria can be used for, and the Control Program Packet Types that can use these criteria.

Table 28. Control Packet Matching Hierarchy

Ranking	Matching Hierarchy	Inventory Types	Control Program Types
1	Country/State/County code, plant ID, point ID, stack ID, segment, 8-digit SCC code, pollutant	point	allowable, control, projection, plant closure
2	Country/State/County code, plant ID, point ID, stack ID, segment, pollutant	point	allowable, control, projection, plant closure
3	Country/State/County code, plant ID, point ID, stack ID, pollutant	point	allowable, control, projection, plant closure
4	Country/State/County code, plant ID, point ID, pollutant	point	allowable, control, projection, plant closure
5	Country/State/County code, plant ID, 8-digit SCC code, pollutant	point	allowable, control, projection, plant closure
6	Country/State/County code, plant ID, MACT code, pollutant	point	control, projection,
7	Country/State/County code, plant ID, pollutant	point	allowable, control, projection, plant closure
8	Country/State/County code, plant ID, point ID, stack ID, segment, 8-digit SCC code	point	allowable, control, projection, plant closure
9	Country/State/County code, plant ID, point ID, stack ID, segment	point	allowable, control, projection, plant closure
10	Country/State/County code, plant ID, point ID, stack ID	point	allowable, control, projection, plant closure
11	Country/State/County code, plant ID, point id	point	allowable, control, projection, plant closure
12	Country/State/County code, plant ID, 8-digit SCC code	point	allowable, control, projection, plant closure
13	Country/State/County code, plant ID, MACT code	point	control, projection,

Ranking	Matching Hierarchy	Inventory Types	Control Program Types
14	Country/State/County code, plant ID	point	allowable, control, projection, plant closure
15	Country/State/County code, MACT code, 8-digit SCC code, pollutant	point, nonpoint	control, projection
16	Country/State/County code, MACT code, pollutant	point, nonpoint	control, projection
17	Country/State code, MACT code, 8-digit SCC code, pollutant	point, nonpoint	control, projection
18	Country/State code, MACT code, pollutant	point, nonpoint	control, projection
19	MACT code, 8-digit SCC code, pollutant	point, nonpoint	control, projection
20	MACT code, pollutant	point, nonpoint	control, projection
21	Country/State/County code, 8-digit SCC code, MACT code	point, nonpoint	control, projection
22	Country/State/County code, MACT code	point, nonpoint	control, projection
23	Country/State code, 8-digit SCC code, MACT code	point, nonpoint	control, projection
24	Country/State code, MACT code	point, nonpoint	control, projection
25	MACT code, 8-digit SCC code	point, nonpoint	control, projection
26	MACT code	point, nonpoint	control, projection
27	Country/State/County code, NAICS code, 8-digit SCC code, pollutant	point, nonpoint	control, projection
28	Country/State/County code, NAICS code, pollutant	point, nonpoint	control, projection
29	Country/State code, NAICS code, 8-digit SCC code, pollutant	point, nonpoint	control, projection
30	Country/State code, NAICS code, pollutant	point, nonpoint	control, projection
31	NAICS code, 8-digit SCC code, pollutant	point, nonpoint	control, projection
32	NAICS code, pollutant	point, nonpoint	control, projection
33	Country/State/County code, NAICS code, 8-digit SCC code	point, nonpoint	control, projection
34	Country/State/County code, NAICS code	point, nonpoint	control, projection
35	Country/State code, NAICS code, 8-digit SCC code	point, nonpoint	control, projection
36	Country/State code, NAICS code	point, nonpoint	control, projection
37	NAICS code, 8-digit SCC code	point, nonpoint	control, projection
38	NAICS code	point, nonpoint	control, projection
39	Country/State/County code, 8-digit SCC code, 4-digit SIC code, pollutant	point, nonpoint	allowable, control, projection
40	Country/State/County code, 4-digit SIC code, pollutant	point, nonpoint	allowable, control, projection
41	Country/State code, 8-digit SCC code, 4-digit SIC code, pollutant	point, nonpoint	allowable, control, projection
42	Country/State code, 4-digit SIC code, pollutant	point, nonpoint	allowable, control, projection
43	4-digit SIC code, SCC code, pollutant	point, nonpoint	allowable, control, projection
44	4-digit SIC code, pollutant	point, nonpoint	allowable, control, projection
45	Country/State/County code, 4-digit SIC code, SCC code	point, nonpoint	allowable, control, projection
46	Country/State/County code, 4-digit SIC code	point, nonpoint	allowable, control, projection
47	Country/State code, 4-digit SIC code, SCC code	point, nonpoint	allowable, control, projection
48	Country/State code, 4-digit SIC code	point, nonpoint	allowable, control, projection
49	4-digit SIC code, SCC code	point, nonpoint	allowable, control, projection
50	4-digit SIC code	point, nonpoint	allowable, control, projection
51	Country/State/County code, 8-digit SCC code, pollutant	point, nonpoint, onroad, nonroad	allowable, control, projection

Ranking	Matching Hierarchy	Inventory Types	Control Program Types
52	Country/State code, 8-digit SCC code, pollutant	point, nonpoint, onroad, nonroad	allowable, control, projection
53	8-digit SCC code, pollutant	point, nonpoint, onroad, nonroad	allowable, control, projection
54	Country/State/County code, 8-digit SCC code	point, nonpoint, onroad, nonroad	allowable, control, projection
55	Country/State code, 8-digit SCC code	point, nonpoint, onroad, nonroad	allowable, control, projection
56	8-digit SCC code	point, nonpoint, onroad, nonroad	allowable, control, projection
57	Country/State/County code, pollutant	point, nonpoint, onroad, nonroad	allowable, control, projection
58	Country/State/County code	point, nonpoint, onroad, nonroad	allowable, control, projection, plant closure
59	Country/State code, pollutant	point, nonpoint, onroad, nonroad	allowable, control, projection
60	Country/State code	point, nonpoint, onroad, nonroad	allowable, control, projection, plant closure
61	Pollutant	point, nonpoint, onroad, nonroad	allowable, control, projection

More than one of the same type of control programs can be added to a strategy. For example, a client could add three Plant Closure Control Programs: Cement Plant Closures, Power Plant Closures, and Boiler Closures. All three of these control programs would be evaluated and a record of the evaluation would be stored in the Strategy Detailed Result. If there happen to be multiple Projection, Control, or Allowable Type Control Programs added to a strategy, packets of the same type are merged into one packet during the matching analysis so that no duplicate source-control packet pairings are created.

The Project Future Year Inventory strategy processes Control Programs in the following order:

1. Plant Closure Type Control Programs
2. Projection Type Control Programs
3. Control Type Control Programs
4. Allowable Type Control Programs

The Control analysis is dependent on the Projection analysis; likewise, the Allowable analysis is dependent on the Projection and Control analyses. The adjusted source emission values need to be carried along from each analysis step to make sure each portion of the analysis applies the correct adjustment factor. For example, a source could be projected, and also controlled, in addition to having a cap placed on the source. Or, a source could have a projection or control requirement, or perhaps just a cap or replacement requirement.

As much as possible, the Control Program Packet datasets are designed to be compatible with SMOKE. The Projection, Control, and Allowable Packets are fully compatible with SMOKE. The Plant Closure Packet, however, is not compatible with SMOKE; this dataset type is a CSV-based file that must contain the certain columns. Tables 29 through 32 show the formats of the four types of control program packets. CoST makes use of some of the SMOKE unused optional columns to further extend the matching hierarchy, as compared to the SMOKE matching hierarchy in cntlmat. These new columns are explained in the four tables below.

The format of the Control Program Plant Closure Packet (Table 29) is based on the CSV format. The first row of this dataset file must contain the column header definition as defined in Line 1 of Table 29. All the columns specified here must be included in the dataset import file.

Table 29. Table Format for Control Program Plant Closure Packet

Line	Position	Description
1	A..H	Column header definition – must contain the following columns: fips,plantid,pointid,stackid,segment,plant,effective_date,reference
2+	A	Country/State/County code, required
	B	Plant Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	C	Point Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	D	Stack Id for point sources, , optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	E	Segment for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	F	Plant name or description, for point sources, optional, leave blank for nonpoint inventories
	G	Effective Date, the effective date for the plant closure to take place, prior to this date the plant will not be closed. A blank value is assumed to mean that the control is within the compliance date and is available for analysis. The strategy target year is used to calculate the date to use in the compliance date check. For example, For a strategy with a target year of 2020 equates to an effective date of 1/1/2020 closure date >= 1/1/'strategy target year' >= 1/1/2020 A blank closure date assumes the source should be closed
	H	Reference, contains for the reference information for closing the plant

The format of the Control Program Projection Packet (Table 30) is based on the SMOKE format as defined in the SMOKE user's manual. One modification was made to enhance this packet's use in CoST: the unused SMOKE column at position K is used to store the NAICS code.

Table 30. Table Format for Control Program Projection Packet

Line	Position	Description
1	A	/PROJECTION <4-digit from year> <4-digit to year>/
2+	A	# Header entry. Header is defined by the # as the first character on the line
3+	A	Country/State/County code, or Country/state code with blank for county, or zero (or blank or -9) for all Country/State/County or Country/state codes
	B	8 or 10-digit SCC, optional, blank, zero, or -9 if not a SCC-specific projection

Line	Position	Description
	C	Projection factor [enter number on fractional basis; e.g., enter 1.2 to increase emissions by 20%]
	D	Pollutant , blank, zero, or -9 if not a pollutant-specific projection
	E	Standard Industrial Category (SIC), optional, blank, zero, or -9 if not a SIC-specific projection
	F	Maximum Achievable Control Technology (MACT) code, optional, blank, zero, or -9 if not a MACT-specific projection
	G	Plant Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	H	Point Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	I	Stack Id for point sources, , optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	J	Segment for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	K	North American Industry Classification (NAICS) Code, optional, blank, zero, or -9 if not a NAICS-specific projection
	L	Characteristic 5 (blank for ORL inventory input format), optional
3	A	/END/

The format of the Control Program Control Packet (Table 31) is based on the SMOKE format as defined in the SMOKE user's manual. Several modifications were made to enhance the packet's use in CoST. (1) The unused SMOKE column at position D is now used to store the primary control measure abbreviation; if one is specified, this measure is used on any source that was matched with those control packet entries. (2) The unused SMOKE column at position P is now used to store the compliance date the control can be applied to sources. (3) The unused SMOKE column at position Q is used to store the NAICS code.

Table 31. Table Format for Control Program Control Packet

Line	Position	Description
1	A	/CONTROL/
2+	A	# Header entry. Header is defined by the # as the first character on the line
3+	A	Country/State/County code, or Country/state code with blank for county, or zero (or blank or -9) for all Country/State/County or Country/state codes
	B	8 or 10-digit SCC, optional, blank, zero, or -9 if not a SCC-specific control
	C	Pollutant , blank, zero, or -9 if not a pollutant-specific control
	D	Primary control measure abbreviation; blank, zero, or -9 applies to all measure in the Control Measure Database
	E	Control efficiency (value should be a percent; e.g., enter 90 for a 90% control efficiency)
	F	Rule effectiveness (value should be a percent; e.g., enter 50 for a 50% rule effectiveness)

Line	Position	Description
	G	Rule penetration rate (value should be a percent; e.g., enter 80 for a 80% rule penetration)
	H	Standard Industrial Category (SIC), optional, blank, zero, or -9 if not a SIC-specific control
	I	Maximum Achievable Control Technology (MACT) code, optional, blank, zero, or -9 if not a MACT-specific control
	J	Application control flag • Y = control should be applied to inventory • N = control will not be used
	K	Replacement flag • A = control is applied in addition to controls from /MACT/ packet • R = control replaces controls from /MACT/ packet
	L	Plant Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	M	Point Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	N	Stack Id for point sources, , optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	O	Segment for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	P	Compliance Date, the compliance date a control can be applied to sources, prior to this date the control will not be applied. A blank value is assumed to mean that the control is within the compliance date and is available for analysis. The strategy target year is used to calculate the date to use in the compliance date check. For example, For a strategy with a target year of 2020 equates to an effective date of 1/1/2020 compliance date >= 1/1/'strategy target year' >= 1/1/2020 A blank compliance date assumes the entry is in compliance and is not subject to the conditional check listed above
	Q	North American Industry Classification (NAICS) Code, optional, blank, zero, or -9 if not a NAICS-specific control
4	A	/END/

The format of the Control Program Allowable Packet (Table 32) is based on the SMOKE format as defined in the SMOKE user's manual. Two modifications were made to enhance the packet's use in CoST. (1) The unused SMOKE column at position L is now used to store the compliance date the cap or replacement emission value can be applied to a source. (2) The unused SMOKE column at position M is used to store the NAICS code.

Table 32. Table Format for Control Program Allowable Packet

Line	Position	Description
1	A	/ALLOWABLE/
2+	A	# Header entry. Header is defined by the # as the first character on the line
3+	A	Country/State/County code, or Country/state code with blank for county, or zero (or blank or -9) for all Country/State/County or Country/state codes
	B	8 or 10-digit SCC, optional, blank, zero, or -9 if not a SCC-specific cap or replacement
	C	Pollutant , blank, zero, or -9 if not a pollutant-specific control; in most cases, the cap or replacement value will be a pollutant-specific value, and that pollutant name needs to be placed in this column
	D	Control factor (no longer used by SMOKE or CoST, enter -9 as placeholder)
	E	Allowable emissions cap value [tons/day] (required if no “replace” emissions are given)
	F	Allowable emissions replacement value [tons/day] (required if no “cap” emissions are given)
	G	Standard Industrial Category (SIC), optional, blank, zero, or -9 if not a SIC-specific cap or replacement
	H	Plant Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	I	Point Id for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	J	Stack Id for point sources, , optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	K	Segment for point sources, optional, blank, zero, or -9 if not specified, leave blank for nonpoint inventories
	L	Compliance Date, the compliance date a cap or replacement entry can be applied to sources, prior to this date the cap or replacement will not be applied. A blank value is assumed to mean that the cap or replacement is within the compliance date and is available for analysis. The strategy target year is used to calculate the date to use in the compliance date check. For example, For a strategy with a target year of 2020 equates to an effective date of 1/1/2020 compliance date >= 1/1/’strategy target year’ >= 1/1/2020 A blank compliance date assumes the entry is in compliance and is not subject to the conditional check listed above

Line	Position	Description
	M	North American Industry Classification (NAICS) Code, optional, blank, zero, or -9 if not a NAICS-specific projection
4	A	/END/

8.3 Project Future Year Inventory Inputs and Outputs

The Project Future Year Inventory strategy type assigns projection and control adjustment factors, applies add-on or replacement control measures, and applies a cap or replacement to emissions sources in a specified geographic region. If multiple inventories are specified as inputs to a Project Future Year Inventory strategy, each inventory is processed separately and one Strategy Detailed Result is generated per inventory. Control Programs are assigned to the strategy to drive the Project Future Year Inventory strategy, as described in Section 8.2.

Note that almost all of the strategy parameters for the Project Future Year Inventory strategy have the same meaning and act in the same way as they do for the Maximum Emissions Reduction strategy (see Sections 2.2 and 2.3), such as cost year, inventory filter, and county dataset. The user does not need to specify a target pollutant for this strategy type. So, if a filter for the inventory is specified, only sources that meet the filter will be considered for control.

Control Program Packet datasets are applied during the Project Future Year Inventory strategy by the Control Programs that are assigned to the strategy. The Control Program contains a packet dataset the will perform various actions on the sources in the emission inventory. The packet dataset contains several key fields that can be used for matching to key source identifiers in the emission inventory. Various combinations can be used when matching between the packet entry and the source. The control packet source matching criteria are defined in Table 28. For example, a control packet could be very specific, identifying a specific plant stack (i.e., fips, plantid, pointid, stackid, and segment are filled in), or the packet could be as broad as specifying all sources that are classified under a certain MACT code. The more specific the match, the higher the ranking is; so, in the example just given, the plant-specific control packet entry would outweigh the MACT-specific packet entry.

The Project Future Year Inventory strategy type uses only one constraint during the strategy run:

- <u>Minimum Percent Reduction Difference for Predicting Controls (%):</u> This required constraint is the minimum percent reduction for predicting the probable control measure that could be applied to the source. The percent difference calculation is based on the probable control measure percent reduction compared to the control percent reduction specified in the control packet.
    - <u>= [(Control Measure Percent Reduction – Control Packet Percent Reduction) / Control Measure Percent Reduction] x 100 ≤ Minimum Percent Reduction Difference for Predicting Controls (%)</u>
    - <u>= {[(CM CEFF x CM RPEN x CM REFF) – (CP CEFF x CP RPEN x CP REFF)] / (CM CEFF x CM RPEN x CM REFF)} x 100 ≤ Minimum Percent Reduction Difference for Predicting Controls (%)</u>

The control measure with the smallest Percent Reduction Difference will be assigned as the most probable measure by assigning the control measure abbreviation to the cm_abbrev column in the Strategy Detailed Result.

If the pri_cm_abbrev is populated in the Control Packet, the Minimum Percent Reduction Difference for Predicting Controls constraint is ignored, and the pri_cm_abbrev value is used to fill in the cm_abbrev column in the Strategy Detailed Result.

The Project Future Year Inventory control strategy can assign to each source many Control Program Packet records (e.g., plant closure, future-year projection, or applying an add-on control measure). As noted earlier, this algorithm uses similar inputs to those described in Section 2: summary parameters, input inventories, inventory filters, and a constraint, but not measures. The algorithm also expects control programs as input. The strategy produces the two standard types of strategy outputs described in Section 2.6: Strategy Detailed Result ***for each input inventory*** and Strategy Messages ***for each input inventory***.

The apply_order column of the Strategy Detailed Result defines what type of action the control packet takes on the inventory source pollutant record. Table 33 contains a list of valid action codes that will be stored in the apply_order column.

Table 33. Control Program Action Codes

Control Program Action Code	Control Program Action	Control Program Type	Control Program Packet Dataset Type
0	Close plants, plants will be removed from strategy controlled inventory	Plant Closure	Plant Closure (CSV)
1	Project inventory source emissions	Projection	Projection Packet
2	Apply add-on or replacement control to inventory source emissions	Control	Control Packet
3	Cap inventory source emissions	Allowable	Allowable Packet
4	Replace inventory source emissions	Allowable	Allowable Packet

The control_program column of the Strategy Detailed Result will contain the control program name that created the source-control packet pair. The cm_abbrev column will contain either the type of Control Program Packet that was applied or, for Control Packets, it could contain the predicted or specified control measure applied to the source.

- For the Control Program Projection Packet source-control packet pairs, the cm_abbrev column will be set to PROJECTION
- For the Control Program Plant Closure Packet source-control packet pairs, the cm_abbrev column will be set to PLTCLOSURE.
- For Control Program Control Packet source-control packet pairs, the cm_abbrev column will contain either the measure abbreviation specified via the control packet pri_cm_abbrev column, or the probable measure abbreviation (if the constraint discussed

above was met), or it will be set to UNKNOWNMSR if no measure was found in the CMDB (or if the constraint was not met).

8.4 Project Future Year Inventory Algorithm

This section provides an overview of the algorithm that matches sources with control measures for a Project Future Year Inventory control strategy. Figure 13 diagrams the process that is used when running this type of strategy. The steps in the source-measure matching algorithm for the Project Future Year Inventory strategy are given below.

1. Process/read the emissions inventory
2. Use inventory filtering (discussed in Section 2.3) to filter the emissions inventory, then compute uncontrolled emissions
    a. Filter by SQL WHERE Clause (based on contents of the Inventory Filter field), if any
    b. Filter by the counties specified in the selected County Dataset, if any
    c. Compute uncontrolled emissions for controlled sources using one of these formulas:
        unc. emis. = ann. emis. / (1 - CE / 100 × RE / 100 × RP / 100)
        unc. emis. = avg. day emis. × days_in_month / (1 - CE / 100 × RE / 100 × RP / 100)

3. Preprocess control program packets by cleaning all packet types; change -9, 0 (zero), and blank (empty string) values to null. The following is a list of the columns that are changed for each control packet:

    a. Control Packet: plantid, pointid, stackid, segment, fips, scc, poll, mact, sic, naics, pri_cm_abbrev
    b. Projection Packet: plantid, pointid, stackid, segment, fips, scc, poll, mact, sic, naics
    c. Allowable Packet: plantid, pointid, stackid, segment, fips, scc, poll, sic, naics
    d. Plant Closure Packet: plantid, pointid, stackid, segment, fips, effective_date

4. Match the Inventory Sources to Control Program Packets using the Control Packet Matching Hierarchy (see Table 28). Merge like Control Program Types (i.e., all Control Program Control Packets) to ensure that no duplicate source-control packet records are handled during the analysis. Ensure Control Program start and end dates lie within the strategy Target Year; if so, include in analysis. Process the Control Programs in the following order:
    a. Plant Closure Type Control Program
    b. Projection Type Control Program
    c. Control Type Control Program; uses the results from Projection Control Program Packet analysis to ensure the sources are projected before the sources are controlled
    d. Allowable Type Control Program; uses the results from Control and Projection Control Program Packet analyseis to ensure the sources are projected and/or controlled before the sources have a cap or replacement applied

5. *For Control Program Control Packet analysis only:* Filter the Control Measures to consider during the Control Program Control Packet analysis
    a. By the selected Specific Control Measures as specified in the Control Program, AND/OR
    b. By the selected Specific Control Technologies as specified in the Control Program

6. *For Control Program Control Packet analysis only:* Match the Inventory Sources to Control Measure Efficiency Records

a. Of the remaining measures, find the ones that apply to the SCC of the source (as specified by the SCCs listed as applicable to each measure)
b. Match on FIPS (data could be available at the National, State, or County level)
c. Match on Inventory Pollutant
d. Match on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
e. Match on measure's Minimum and Maximum Emissions (inventory source must have greater than or equal to the minimum emissions and less than the maximum emissions)

7. *For Control Program Control Packet analysis only:* Evaluate Minimum Percent Reduction Difference for Predicting Controls Constraint while the source is being matched with Control Program Control Packet. This Constraint calculation is dependent on both the inventory source and measure. The Minimum Percent Reduction Difference constraint is used to help predict when a measure is the most likely to match the control specified in the Control Packet. This constraint ***is applicable only during Control Program Packet analysis, not during the other packet analyses***.

8. *For Control Program Control Packet analysis only:* If multiple measures are available for a source, then the best measure is chosen according to the following criteria:

a. Closest Locale (matching both FIPS state and county is best, then FIPS-state, followed by national)
b. Closest Percent Reduction (choose the measure that has the minimum percent reduction difference between the Control Packet specified percent reduction and the measures efficiency record percent reduction).

9. Compute the Strategy Detailed Result to include the source-control packet pairs obtained from the algorithms shown in 4, 5, 6, 7, and 8.

10. After completing the computation of Strategy Detailed Results for all input inventories, prepare the summary outputs (described in Section 2.6) along with any controlled inventories upon user request.

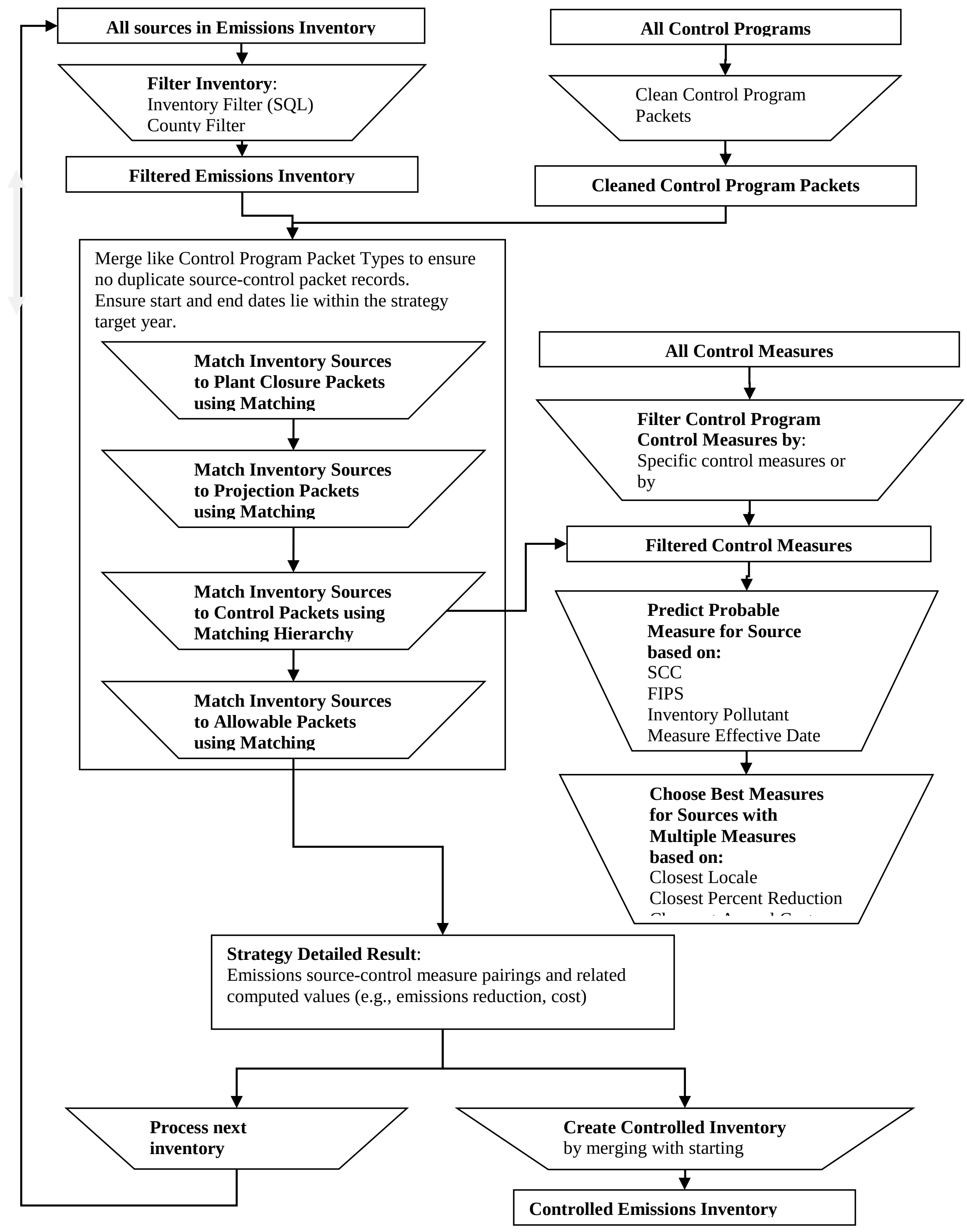

Figure 13. The Process for Running Project Future Year Inventory Control Strategy

8.5 Project Future Year Inventory Strategy Example

Placeholder for future example.

9 Multi-Pollutant Maximum Emissions Reduction Control Strategy

9.1 Multi-Pollutant Maximum Emissions Reduction Inputs and Outputs

The Multi-Pollutant Maximum Emissions Reduction control strategy assigns to each source the single measure for each target pollutant that provides the maximum reduction, regardless of cost. This process is performed for each target pollutant in an order specified by the user order (e.g., NOX first, VOC second, SO2 last). If a measure controls an already controlled pollutant from a previous target pollutant analysis iteration, that measure will be excluded from consideration during the source-measure matching process. For example, if measure ABC controlled NOX (the first analyzed target pollutant) and VOC, and during the next pollutant iteration (for VOC) measure DEF also controls NOX and VOC, this measure will not be considered because VOC control was a coimpact from applying the ABC measure.

This algorithm uses the inputs described in Section 2: summary parameters, input inventories, and measures. The inventory filter and county filter work differently for this control strategy than they do for the other strategy types. The inventory filter and county filter can be specified separately for each target pollutant, whereas for the other strategy types they are defined at the strategy level. The constraints are the same as defined in Section 2 except that the constraint can specified at the target pollutant level, not at the overall strategy level as is done in most of the other typical control strategy types.

This strategy type produces the three standard types of strategy outputs described in Section 2.6: Strategy Detailed Result ***for each input inventory***, Strategy Measure Summary, and Strategy County Summary.

9.2 Multi-Pollutant Maximum Emissions Reduction Algorithm

This section provides an overview of the algorithm that matches sources with control measures for a Multi-Pollutant Maximum Emissions Reduction control strategy. Figure 14 diagrams the process that is used when running this type of strategy. The steps in the source-measure matching algorithm for the Multi-Pollutant Maximum Emissions Reduction strategy are given below.

1. Process/read the emissions inventory.
2. Use control measure filtering (discussed in Section 2.4) to filter the Control Measures to consider for the strategy.
    a. By the selected Measure Classes, OR
    b. By the selected Specific Measures

3. Use inventory filtering (discussed in Section 2.3) and the county dataset filter to filter the emissions inventory and compute monthly emissions, then compute uncontrolled emissions. The inventory and county dataset filters can be specified differently for each target pollutant.
    a. Filter by SQL WHERE Clause (based on contents of the inventory filter field), if any
    b. Filter by the counties specified in the selected County Dataset, if any
    c. If average-day emissions are specified in the inventory and annual emissions are not specified, compute the monthly emissions by multiplying the average-day emissions by the number of days in the month that the inventory represents. Otherwise, use the annual emissions figures directly.
    d. Compute uncontrolled emissions for controlled sources using one of these formulas:
       unc. emis. = ann. emis. / (1 - CE / 100 × RE / 100 × RP / 100)
       unc. emis. = avg. day emis. × days_in_month / (1 - CE / 100 × RE / 100 × RP / 100)

4. Match the Inventory Sources for the Target Pollutant to Control Measure Efficiency Records.
    a. Of the remaining measures that passed the filter, find the ones that apply to the SCC of the source (as specified by the SCCs listed as applicable to each measure)
    b. Match efficiency records based on FIPS (control measure data could be available at the national, state, or county level)
    c. Match efficiency records based on Target Pollutant
    d. Match efficiency records based on month of the inventory (if the inventory is month-specific and the measure is not specified to be applicable to the month, do not consider this record as an option)
    e. Match efficiency records based on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
    f. Match efficiency records based on measure's Minimum and Maximum Emissions (inventory source must have greater than or equal to the minimum emissions and less than the maximum emissions)

5. Evaluate Constraints (discussed in Section 2.5) while the source is being matched with the control, if any constraints were specified. For example, the emission reduction of a source due to a certain control is not known until we apply the measure to the source with its specific percent reduction, where percent reduction = control efficiency × rule effectiveness/100 × rule penetration/100. Constraint calculations are dependent on both the inventory source and the measure. These constraints can be specified differently for each target pollutant. Limit the source's measures using the following constraints, if any were specified:
    a. Include measure for the source if it reduces the target pollutant by the minimum emissions reduction
    b. Include measure for the source if it has at least the minimum control efficiency for the target pollutant
    c. Include measure for the source if the cost per ton for the target pollutant is less than the maximum cost per ton
    d. Include measure for the source if it does not cost more than the maximum annualized cost
    e. Include measure for the source if it meets other strategy-specific constraints

6. Evaluate source for preexisting control:
   a. If the source has an existing control, then evaluate whether replacement or add-on control measure fulfills the minimum percent reduction constraint (see Section 2.2.4 for more information on this constraint)
   b. Do not double-control source with the same control measure

7. Exclude measures, if applicable. If the measure will control an already controlled pollutant from a previous target pollutant iteration, then exclude these measure from consideration.

8. If multiple measures are available for a source, then the best measure is chosen according to the following criteria:
   a. Closest Locale (matching both FIPS state and county is best, then FIPS state, followed by national)
   b. Highest Percent Reduction (PR)
   c. Lowest Annualized Cost (Cost is considered for all pollutants, which includes both the target pollutant and coimpact pollutants. For example, cost might be based on PM2.5 and not on the target pollutant PM10)

9. Apply target pollutant source measure to source's coimpact pollutants.
   a. Match efficiency records based on FIPS (control measure data could be available at the national, state, or county level)
   b. Match on any pollutants that are controlled by the measure and are also available in the inventory, and thereby produce coimpacts, which could be cobenefits or codisbenefits
   c. Match efficiency records based on Measure Effective Date (the target year must be equal to or later than the effective date for the measure to be included)
   d. Match efficiency records based on measure's Minimum and Maximum Emissions (inventory source must have greater than or equal to the minimum emissions and less than the maximum emissions)

10. Compute the Strategy Detailed Result to include the source-control pairs obtained from the algorithms shown in 3, 4, 5, 6, 7, 8, and 9.

11. Process next target pollutant in specified order (e.g., NOX first, VOC next, and PM2.5 last). Return to step 3 and proceed with the next target pollutant. Once all target pollutants have been iterated through, proceed to step 12.

12. After completing the computation of Strategy Detailed Results for all input inventories, prepare the summary outputs (described in Section 2.6), along with any controlled inventories upon user request.

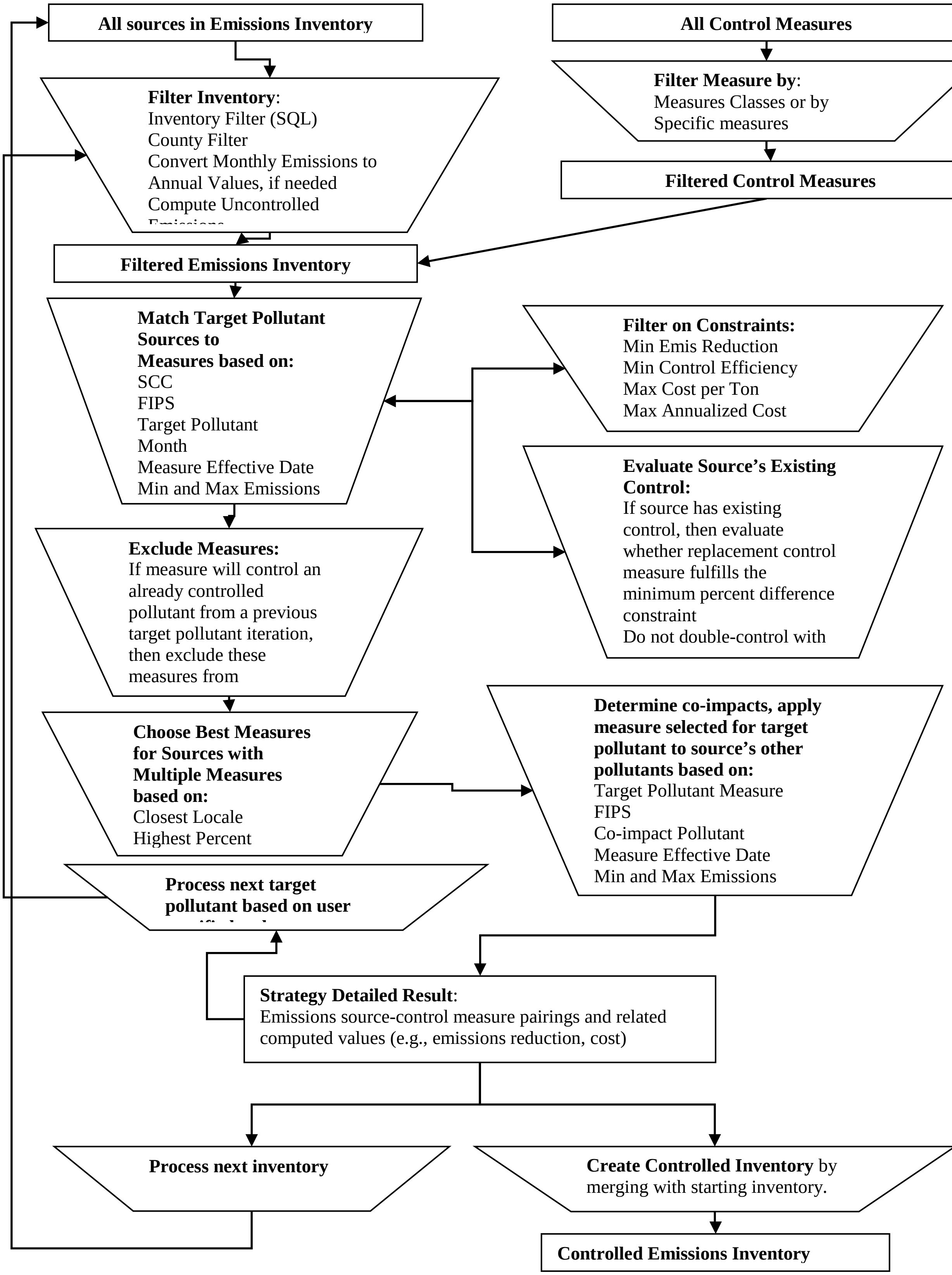

Figure 14. The Process for Running a Multi-Pollutant Maximum Emissions Reduction Control Strategy

9.3 Multi-Pollutant Maximum Emissions Reduction Strategy Example

In Section 9.1 there was a brief description of how the Multi-Pollutant Maximum Emission Reduction strategy algorithm works. This section provides much more detail using a specific example, including what the inputs to the strategy are, what the source-measure pairings are, and what the outputs look like. Note that in this and the following sections describing the strategy algorithms, only the inputs that actually have an impact on the results are included; ones that are informational may be left out (e.g., Project, Region).

Strategy Inputs:
Name: Maximum Emissions Reduction Strategy Sample
Type of Analysis: Max Emissions Reduction
Cost Year: 2006
Target Year: 2008
Discount Rate: 7%
Use Cost Equations: Yes
Inventories: ORL Point Dataset, ptinv_ptnonipm_2008, version 1
Measures: Include all measure classes
Target Pollutants and Constraints:

Target Pollutant	Iteration Order	Minimum Emissions Reduction (tons)	Minimum Control Efficiency (%)	Maximum Cost Per Ton ($/ton)	Maximum Annual Cost ($)	Minimum Percent Reduction Difference for Replacement or Add-On Control (%)	SQL Inventory Filter	County Dataset and Version
NOX	1	–	50	–	–	10	–	–
SO2	2	–	60	–	–	10	–	–
VOC	3	–	50	–	–	10	–	–
CO	4	–	–	–	–	10	–	–

Table 34 shows the inventory sources to be used in this example. It was created based on data in an ORL point EMF dataset. The information in the brackets for the Source column helps define the key structure for a source.

Table 34. Multi-Pollutant Maximum Emissions Reduction Filtered Inventory Records

Inventory No.	**Source** [PlantId, PointId, StackId, Segment]	FIPS	SCC	Pollutant	Annual Emissions (tons)
1	ABC Industrial Plant [0001,01,01,01]	37119	20200102	CO	0.2143
2	ABC Industrial Plant [0001,01,01,01]	37119	20200102	NOX	0.8067
3	ABC Industrial Plant [0001,01,01,01]	37119	20200102	VOC	0.0206
4	XYZ Industrial Plant [0005,G-36,S-2,1]	37119	10200401	NOX	29.65
5	XYZ Industrial Plant [0005,G-36,S-2,1]	37119	10200401	SO2	146.44
6	WTU Industrial Plant [0001,N-6,ST-1,1]	37159	40202599	VOC	176.886

Table 35 contains a sample listing of point-source control measures from the CoST database that might apply to the sources in the example inventory. Note that the value in the percent reduction column can be computed from three fields specified for a measure's efficiency record, as follows:

$$\text{Percent Reduction} = (\text{Control Efficiency (\%)} / 100) \times (\text{Rule Penetration (\%)} / 100) \times (\text{Rule Effectiveness (\%)} / 100) \times 100$$

Table 35. Multi-Pollutant Maximum Emissions Reduction Filtered Measures

Measure Name	CM Abbrev	SCCs of Interest	Pollu-tant	Locale	Percent Reduc-tion (%)	Cost Year	Cost Per Ton ($)	Incremen-tal Cost Per Ton ($)	Effec-tive Date	Min Emis (tons)	Max Emis (tons)	Equa-tion Type	Notes
Permanent Total Enclosure (PTE; Metal Furniture Surface Coating)	VPTENMFSC	40202599	VOC	–	95	1998	19,320	–	–	–	–	–	–
Non-Selective Catalytic Reduction; Rich Burn Internal Combustion Engines - Diesel	NNSCRRBIC	20200102	CO	–	90	–	–	–	–	–	–	–	–
Non-Selective Catalytic Reduction; Rich Burn Internal Combustion Engines - Diesel	NNSCRRBIC	20200102	NOX	–	90	1990	342	–	–	–	–	–	–
Non-Selective Catalytic Reduction; Rich Burn Internal Combustion Engines - Diesel	NNSCRRBIC	20200102	VOC	–	50	–	–	–	–	–	–	–	–
Wet Flue Gas Desulfurization; Residual Oil (Industrial Boilers)	SWFGDIBRO	10200401	SO2	–	90	–	–	–	–	–	–	Type 11	–
SCR; ICI Boilers - Residual Oil	NSCRIBRO	10200401	NOX	–	90	1990	1,568	1,568	–	0	365	Type 2	For small sources
SCR; ICI Boilers - Residual Oil	NSCRIBRO	10200401	NOX	–	80	1990	1,300	940	–	365	–	Type 2	For large sources

The Strategy Detailed Result in Table 36 shows the source-measure pairings and related computed values — emissions reduction, percent reduction, annual cost, etc. All costs reported in this Strategy Detailed Result are in 2006 dollars.

Table 36. Maximum Emissions Reduction Measure-Source Assignments

Inventory No.	**Source** [PlantId, PointId, StackId, Segment]	FIPS	SCC	Pollutant	Annual Emissions (tons)	Measure Abbrev	Emis Red (tons)	Pct Red (%)	Annual Cost ($)	Annual Cost Per Ton ($/ton)	Notes
1	ABC Industrial Plant [0001,01,01,01]	37119	20200102	CO	0.2143	NNSCRRBIC	0.1929	90	–	–	Only one measure used for this source since it was effective at controlling CO, NOX, and VOC
2	ABC Industrial Plant [0001,01,01,01]	37119	20200102	NOX	0.8067	NNSCRRBIC	0.7260	90	399	549	
3	ABC Industrial Plant [0001,01,01,01]	37119	20200102	VOC	0.0206	NNSCRRBIC	0.0103	50	–	–	
4	XYZ Industrial Plant [0005,G-36,S-2,1]	37119	10200401	NOX	29.65	NSCRIBRO	26.685	90	50,435	1,890	–
5	XYZ Industrial Plant [0005,G-36,S-2,1]	37119	10200401	SO2	146.44	SWFGDIBRO	139.118	95	–	–	No relevant measures where found for VOC or CO
6	WTU Industrial Plant [0001,N-6,ST-1,1]	37159	40202599	VOC	176.886	VPTEMFSC	168.0417	95	4,087,664	24,325	No relevant measures where found for SO2, VOC or CO

10 Potential Future Updates

This section describes updates that may be made to the CoST algorithms in the future. Reviewing these may also make the reader more aware of some of the nuances involved with applying the current version of CoST.

Analyses for criteria pollutants have been performed to compare the results of CoST to results of independently developed strategies. It was determined that CoST could reproduce these strategies if the inputs to the independently developed strategies were consistent with those given to CoST. CoST has not yet been used for hazardous air pollutants (HAPs), but it has been used in some limited analyses for greenhouse gases such as black carbon. The main limiting factor in using CoST greenhouse gas analyses is the availability of (1) greenhouse gas emissions inventories at an appropriate level of detail, and (2) control measures for greenhouse gases.

In addition to refining the capabilities in CoST for performing multi-pollutant analyses, the following updates could be supported in future versions of the software:

1) Consider defining new control measure classes based either on the state of the control efficiency of a measure or on the costs, but not both. For example, a point-source control measure may have a well-defined control efficiency but not a cost (either not enough data to run a cost equation, or no cost per ton data, or both).
2) Continue review of cost equations to ensure their accuracy and their applicability to particular SCCs.
3) Review cost per ton estimates currently used as defaults within CoST.
4) Review and adjust estimate for uncontrolled or base-case emissions within the tool.
5) Review how replacement controls are implemented within a control strategy.
6) Develop a capability to optimize control strategies on more than one target pollutant or objective.
7) Estimate cost defaults for control measures that currently do not have them (e.g., when stack flow or temperature data is not available to include in a cost equation).

11 References

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