

**NIST Advanced Manufacturing Series 200-9**

# **The Manufacturing Cost Guide: A Primer Version 1.0**



*A Tool for Estimating Average Costs in the U.S. Manufacturing Industry and its Supply Chain*

Douglas S. Thomas

This publication is available free of charge from:  
<https://doi.org/10.6028/NIST.AMS.200-9>

**NIST**  
**National Institute of  
Standards and Technology**  
U.S. Department of Commerce

**NIST Advanced Manufacturing Series 200-9**

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June 2020



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**National Institute of Standards and Technology Advanced Manufacturing Series 200-9  
Natl. Inst. Stand. Technol. Adv. Man. Ser. 200-9, 37 pages (June 2020)**

**This publication is available free of charge from:  
<https://doi.org/10.6028/NIST.AMS.200-9>**

## Abstract

This primer provides an overview in using the Manufacturing Cost Guide: <https://www.nist.gov/services-resources/software/manufacturing-cost-guide>. It explains how to use the tool and provides documentation on how the estimates are calculated in the tool. Specifically, this tool estimates the costs in U.S. manufacturing, which can be used to help gauge the potential returns on manufacturing industry research projects. These costs are grouped into various standardized categories such as the North American Industry Classification System (NAICS) and the Standard Occupational Classification (SOC) system along with other non-standardized costs. Version 1.0 of the tool is providing this information based upon data from 2012 onward from the U.S. Census Bureau, Bureau of Labor Statistics, Bureau of Economic Analysis, and other sources. The tool outputs its results based upon static data that is embedded within the tool.

## Key words

Manufacturing, primer, manufacturing cost guide, supply chain, input-output, maintenance

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## 1. Introduction

Many public research organizations and other change agents seek to improve efficiency in the manufacturing industry. The Manufacturing Cost Guide is a tool that estimates the costs that U.S. manufacturers face and can be used to help gauge the potential returns on manufacturing industry research projects through cost reductions. These costs are grouped into various standardized categories such as the North American Industry Classification System (NAICS) and the Standard Occupational Classification (SOC) system along with other non-standardized costs. The tool also scales industry data to examine average costs at the establishment level. The tool can be used to answer questions such as:

- An organization is conducting research to reduce redundant engineering labor. *How much do manufacturers spend on engineering?*
- A researcher is proposing a project to reduce the use of steel by advancing material standards, thereby, reducing scrap caused from material deficiencies. *How much do manufacturers spend on steel?*
- A research organization is proposing to reduce energy consumption from machinery. *How much is spent on energy for machine operation?*
- A manufacturer is considering investing in energy efficient lighting in manufacturing facilities. *What is the average spending on lighting for an establishment of their size?*
- A manufacturer is considering investing in predictive machinery maintenance. *On average, how much does a manufacturer of their size lose to unplanned downtime and defects that result from reactive maintenance?*

### 1.1. Scope

This primer provides an overview in using the Manufacturing Cost Guide. It explains how to use the tool and provides documentation on how the estimates are calculated in the tool.

### 1.2. Approach

Section 2 describes the overall design of the tool and the first steps in using the tool. Section 3 provides guidance on the data and applications. Section 4 through Section 6 describe selecting details and the results. Appendix A and Appendix B provide documentation for how the values provided by the Manufacturing Cost Guide are calculated.

## 2. First Steps

The tool is embedded in a Microsoft Excel file that can be downloaded from the National Institute of Standards and Technology website: <https://www.nist.gov/services-resources/software/manufacturing-cost-guide>. The tool requires Microsoft Excel to be installed with the optimal version being Microsoft Excel version 1908 (Build 11929.20708), as this is the version that was used during the tool’s creation. Some familiarity with Microsoft Excel is recommended but not required to use this tool.

The opening screen is shown in Figure 2.1. To get started with examining manufacturing costs, click the “Let’s Get Started” button (if shown, you will have to click the ‘Enable Content’ button at the top of the Excel screen to enable macros). This takes the user to the next tab, which is the “Start” tab. Note that tabs are the worksheet tabs used in Microsoft Excel and are located near the bottom of the Excel window. The tool guides the user through a series of tabs to narrow the scope of the analysis. A map of these tabs is provided in Figure 2.2.

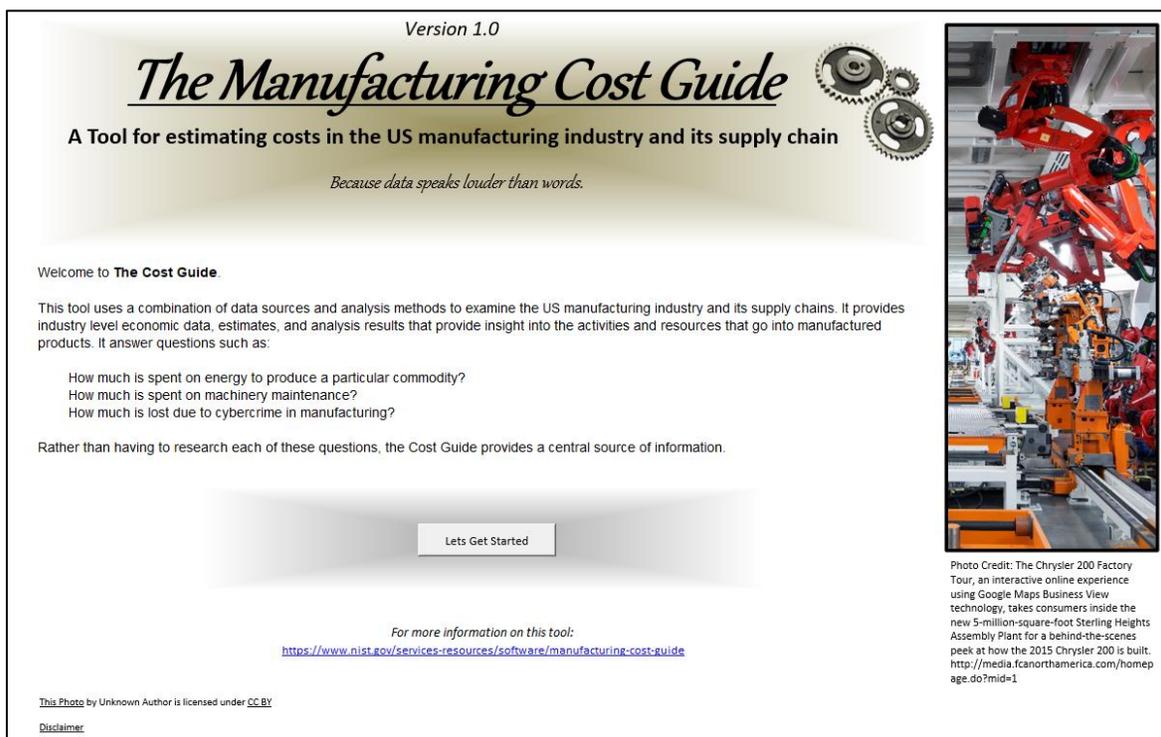


Figure 2.1: Opening Screen of The Manufacturing Cost Guide

Within the “Start” tab there are three alternatives to choose from using a radial button and one option to select using a checkbox, as shown in Figure 2.2 and Figure 2.3. Figure 2.2 will be referenced throughout this document to explain the workflow. The first option is the “Industry Analysis.” This option presents data collected on the activities occurring at establishments categorized as being in the manufacturing industry. It does not provide

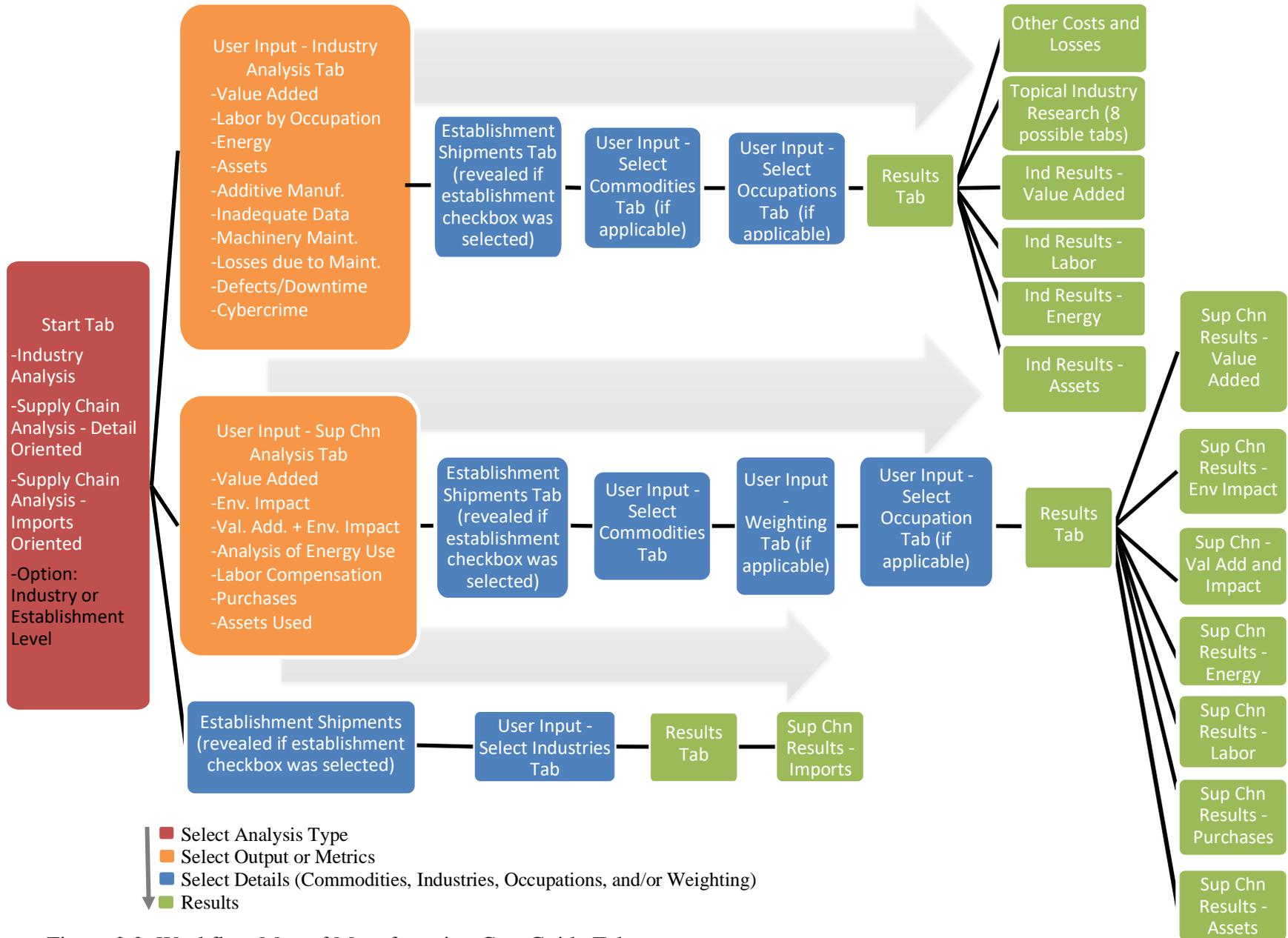


Figure 2.2: Workflow Map of Manufacturing Cost Guide Tabs

### What do you want to Examine?

The first step is to choose what you want to analyze. Below are a series of options:

	Option Summary
<input checked="" type="radio"/> <b>Industry Analysis:</b> The industry analysis presents data collected from establishments categorized as being in the manufacturing industry. An establishment is a physical location where business or operations are performed. They are categorized by industry using the North American Industry Classification System (NAICS).	Activity at the factory/industry
<input type="radio"/> <b>Supply Chain Analysis - Detail Oriented:</b> The detailed supply chain analysis uses economic input-output analysis to estimate the contribution that each industry makes to produce a selection of manufactured commodities. It uses data collected from US establishments categorized using the North American Industry Classification System (NAICS). This analysis is referred to as "detailed" because it provides a detailed breakdown of cost categories. The method is further used to estimate a number of other cost categories for producing goods, including: <ul style="list-style-type: none"> <li>Environmental Impact</li> <li>Energy Consumption by End Use</li> <li>Labor Cost by Occupation</li> <li>Purchases from Other Industries</li> <li>Assets or Capital (e.g., machinery and buildings)</li> </ul>	Activity at the factory/industry and its supply chain
<input type="radio"/> <b>Supply Chain Analysis - Imports Oriented:</b> The imports oriented supply chain analysis uses economic input-output analysis to examine the imports needed for producing commodities in the US. It provides an estimate of imports by industry by country brought into the US manufacturing supply chain. Industries in this analysis are categorized by the Standard Industrial Classification (SIC) system.	Activity at the factory/industry and its supply chain
<input type="checkbox"/> <b>Estimate Establishment Level Costs/Losses:</b> The establishment level analysis provides costs and losses based on user inputs, including the number of employees, value of shipments, and industry. Costs and losses are then estimated based on industry trends.	Checked indicates factory while unchecked indicates industry

Figure 2.3: “Start” Tab within the Manufacturing Cost Guide

any supply chain information. For instance, one could look at the value added from the automobile manufacturing industry (i.e., assembly factories), but it will not provide information on the value added from the steel or the electronic components used in automobiles. The second option is the “Supply Chain Analysis – Detail Oriented” button. This analysis examines the activities occurring in user-selected industries along with the associated supply chains. So, in this option, one could examine the value added in the aerospace industry along with estimating the steel and other supplies that were used by the industry. This option focuses on supplies that originate domestically; however, it also provides an estimated value of imported goods/services used. It is important to note that imports often have U.S. goods/services embedded in them, which is not revealed in this option of the tool. The benefit of using the “Supply Chain Analysis – Detail Oriented” option is that it has the greatest detail in cost categories, including approximately 400 industry codes and 800 labor codes along with examinations of energy use and environmental impact.

The last option is the “Supply Chain Analysis – Imports Oriented” button. This analysis focuses on imported goods/services used by the U.S. manufacturing industry. The advantage of this option is that it distinguishes between imported parts and components originating in the U.S. and those that do not originate in the U.S. It further details the country of origin for the imported goods/services not originating in the U.S. The drawback of this option is that the industry detail is relatively coarse. The following sections discuss the details of each of the three options and their sub-options. At the bottom of the “Start” tab is a checkbox that allows one to choose between an

establishment level analysis or industry level. The establishment level scales the data to represent the costs for a single establishment while the industry level analysis is the aggregated costs for all establishments. The establishment level analysis requires the user to indicate the value of shipments at the establishment of interest, as shown in Figure 2.4.

After submitting all the sub options within each of the categories in Figure 2.3 (i.e., after moving through multiple screens), the tool eventually displays a “Results” tab with a notification that the results are in a series of revealed tabs, as seen in Figure 2.5. The results are in the highlighted tabs shown at the bottom of the window. The user must navigate to each of the tabs.

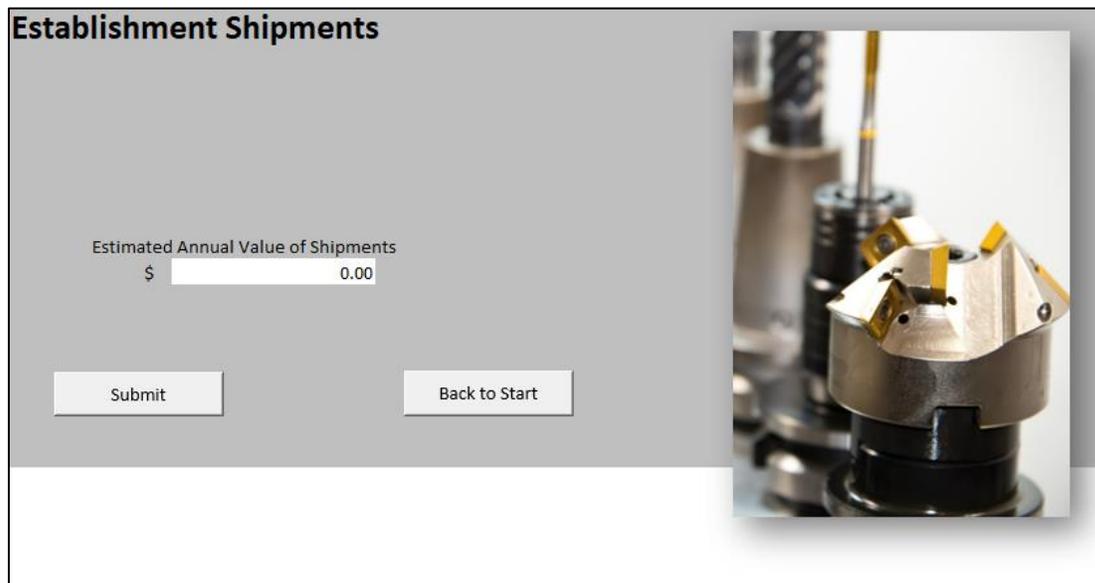


Figure 2.4: “Establishment Data” Tab within the Manufacturing Cost Guide

There are some functions that appear in multiple locations throughout the tool. In a number of locations, there are buttons for additional information. In the tabs that contain the results, there are buttons for clarifying definitions and classifications. On a number of tabs, there is a button that takes the user “Back to Start.” This takes the user back to the “Start” tab; however, it does not change any selections. In order to clear all selections, the user must click the “Reset” button on the “Start” tab. The column header in each of the tabs with results has a button with an arrow. If the user clicks this button the tool opens a drop-down menu that allows the user to sort and filter the results, as shown in Figure 2.6. The user can select to filter, where only certain results are shown, or to sort it to view the largest/smallest results. To use or export the data, the user can copy and paste the cells to a new Excel workbook.

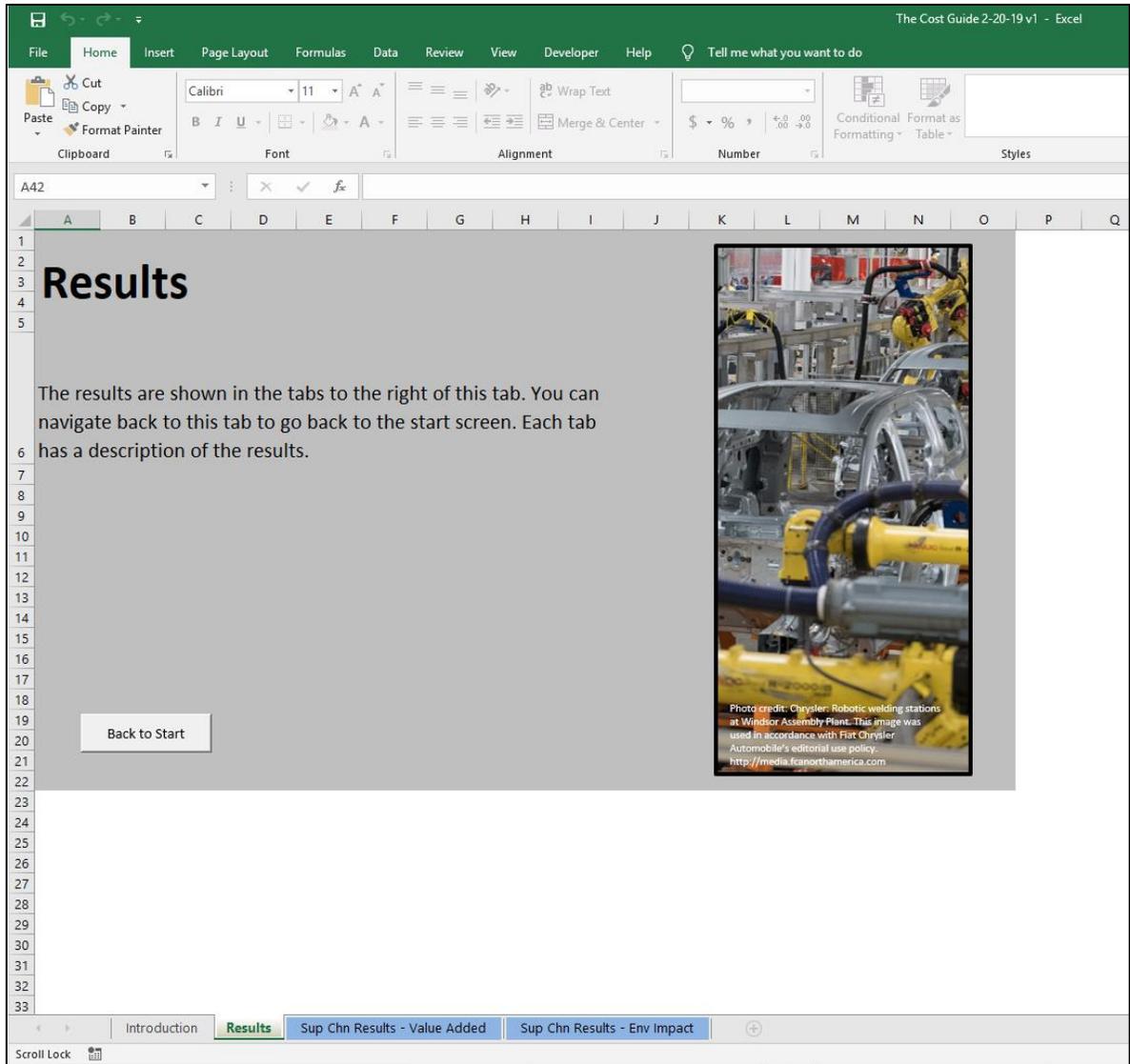


Figure 2.5: “Results” Tab within the Manufacturing Cost Guide



Figure 2.6: Example of Results

### 3. Data Guidance

This section provides background on the data and its organization. Section 3.1 discusses the metrics for measuring economic activity while Section 3.2 discusses classification categories.

#### 3.1. Shipments, Output, and Value Added

The Manufacturing Cost Guide examines activities within the U.S. manufacturing industry along with its supply chain. Goods and services are exchanged between establishments within an industry and between industries. Different metrics are useful for different applications. It is difficult for the user to identify appropriate results without some understanding of the data. Below is a discussion of some more prominent issues.

Shipments, which is sometimes referred to as output, is the net selling value of all products shipped. This value can result in double counting the costs of producing a product. For instance, in Figure 3.1, industry A contains 3 establishments<sup>1</sup> where establishment X ships items to Y who ships items to Z. Thus, the products of establishment Z contain products of establishment X and Y with the value of shipments reflecting the value of all three establishments. The products of establishment Y contain the products of establishment X. When data is collected to calculate shipments, the value from all three establishments are added together. This means that the value of shipments at X are counted 3 times: 1) when X reports shipments, 2) the value of X's shipments

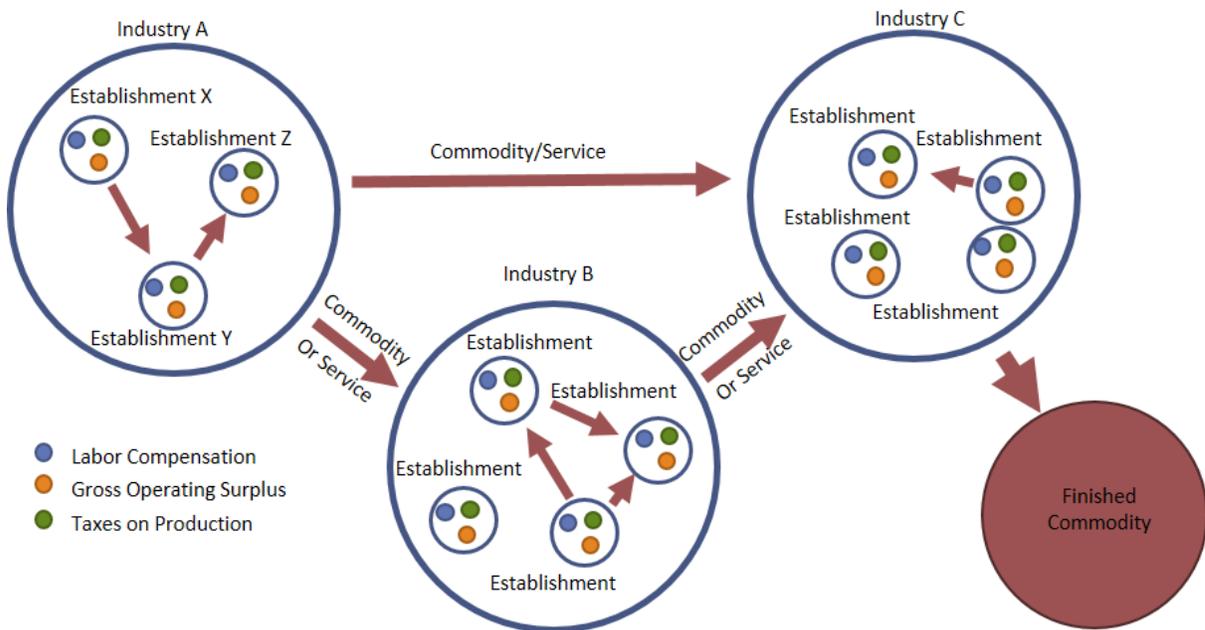


Figure 3.1: Supply Chain Illustration

<sup>1</sup> Note that an establishment is a physical location of economic activity such as a factory. It should not be confused with a company or enterprise. Each establishment (e.g., factory) is categorized by NAICS code. A company could have multiple establishments categorized into different NAICS codes.

embedded in Y's shipments, and 3) the value of X's shipments embedded in Z's shipments. Caution should be exercised when using "purchases by industry," as this is equivalent to shipments and double counting can occur when adding data together. Double counting is not present in value added, which can also be referred to as GDP, as this is calculated by taking the value of shipments and subtracting the purchases of goods/services from other establishments. The remaining value contains labor compensation, gross operating surplus (which includes profit), and taxes on production, as shown in Figure 3.2. The downside of using value added is that it breaks all products into their subcomponents and services. Thus, if one wants to know about the manufacturing industry's electricity costs using value added, they would have to sum the value added from the "Electric power generation" industry (NAICS 221100) along with all the value added that the "Electric power generation" industry used to produce electricity, such as coal, natural gas, and transportation.

Compensation and depreciation, which are presented in this tool, are part of value added. Since this tool focuses on presenting data for improving efficiency and productivity, items such as net operating surplus, which includes profit, and taxes are not examined. Establishments (physical locations of economic activity, such as a factory) are classified by NAICS. Occupations are classified by the Standard Occupational Classification system (SOC). The results for the analyses are shown at varying aggregation of NAICS codes (i.e., from 2 to 6 digit NAICS codes, as discussed below).

### 3.2. Standard Data Categorization

The following discussion on data categorization is, largely, taken from Thomas and Kandaswamy.<sup>2</sup> A number of datasets are used in developing an inventory and model of

		Value Added							
		Compensation				Taxes*	Gross Operating Surplus		
		SOC Code	SOC Code	SOC Code	...		Net Operating Surplus	Depreciation	
						Machinery		Buildings	Inventory
Establishments	NAICS Code								
	NAICS Code								
	NAICS Code								
	⋮								

\* Taxes on production

Figure 3.2: Illustration of Data Relationship

<sup>2</sup> Thomas, Douglas and Anand Kandaswamy. Tracking Industry Operations Activity: A Case Study of U.S. Automotive Manufacturing. NIST Special Publication 1601. December 2015. <https://doi.org/10.6028/NIST.SP.1601>

industry operations activities. Bringing these datasets together requires standard categories of classification. Although standard categorization seems mundane, it is critical to tracking resources. The standardized classification systems used in this report include

- North American Industry Classification System (NAICS): a standard used by Federal statistical agencies to classify business establishments in the US
- Standard Occupational Classification System (SOC): a standard used in the U.S. to classify workers into occupational categories for collecting and distributing data on employees

### **3.2.1. The North American Industry Classification System (NAICS)**

Domestic data tends to be classified using NAICS codes. It is the standard used by Federal statistical agencies classifying business establishments in the U.S. NAICS was jointly developed by the U.S. Economic Classification Policy Committee, Statistics Canada, and Mexico's Instituto Nacional de Estadística y Geografía and was adopted in 1997.<sup>3</sup> NAICS has several major categories each with subcategories. Historic data and some organizations continue to use the predecessor of NAICS, which is the Standard Industrial Classification system (SIC). NAICS codes are categorized at varying levels of detail. Table 3.1 presents the lowest level of detail, which is the two-digit NAICS. There are 20 categories. Additional detail is added by adding additional digits; thus, three digits provides more detail than the two digit and the four digit provides more detail than the three-digit. The maximum is six digits, as illustrated for automobile manufacturing (NAICS 336111) and light truck and utility manufacturing (NAICS 336112). Sometimes a two, three, four, or five-digit code is followed by zeros, which do not represent categories. They are null or place holders. For example, the code 336000 represents NAICS 336. The results presented in the Manufacturing Cost Guide have varying levels of NAICS due to data availability.

### **3.2.2. Standard Occupational Classification System (SOC)**

US federal statistical agencies classify workers into occupational categories for collecting and distributing data on employees. The 2010 version has 840 occupations, which are categorized into 23 major groups. Similar to the NAICS codes, additional digits represent additional detail up to a maximum of six digits, as illustrated for SOC 514011 and SOC 514012 in Table 3.2

Table 3.2, which presents the 23 major groups. The SOC classifies all occupations in which work is performed for pay or profit. It was first published in 1980. In 2000, it was revised and then again revised in 2010. The Bureau of Labor Statistics now publishes occupation data based on this system.

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<sup>3</sup> U.S. Census Bureau. North American Industry Classification System. <<http://www.census.gov/eos/www/naics/>>

Table 3.1: North American Industry Classification System, Two Digit Codes with Example Breakout for Automobile Manufacturing

Sector	Description
<b>11</b>	Agriculture, Forestry, Fishing and Hunting
<b>21</b>	Mining, Quarrying, and Oil and Gas Extraction
<b>22</b>	Utilities
<b>23</b>	Construction
<b>31-33</b>	Manufacturing
336	<i>Transportation Equipment Manufacturing</i>
3361	<i>Motor Vehicle Manufacturing</i>
33611	<i>Automobile and Light Duty Motor Vehicle Manufacturing</i>
336111	<i>Automobile Manufacturing</i>
336112	<i>Light Truck and Utility Manufacturing</i>
<b>42</b>	Wholesale Trade
<b>44-45</b>	Retail Trade
<b>48-49</b>	Transportation and Warehousing
<b>51</b>	Information
<b>52</b>	Finance and Insurance
<b>53</b>	Real Estate and Rental and Leasing
<b>54</b>	Professional, Scientific, and Technical Services
<b>55</b>	Management of Companies and Enterprises
<b>56</b>	Administrative and Support and Waste Management and Remediation Services
<b>61</b>	Educational Services
<b>62</b>	Health Care and Social Assistance
<b>71</b>	Arts, Entertainment, and Recreation
<b>72</b>	Accommodation and Food Services
<b>81</b>	Other Services (except Public Administration)
<b>92</b>	Public Administration

Table 3.2: Standard Occupational Classification System, Two Digit Codes with Example Breakout for Machine Tool Operators

<b>Occupation Code</b>	<b>Occupation Name</b>
<b>11</b>	Management Occupations
<b>13</b>	Business and Financial Operations Occupations
<b>15</b>	Computer and Mathematical Occupations
<b>17</b>	Architecture and Engineering Occupations
<b>19</b>	Life, Physical, and Social Science Occupations
<b>21</b>	Community and Social Service Occupations
<b>23</b>	Legal Occupations
<b>25</b>	Education, Training, and Library Occupations
<b>27</b>	Arts, Design, Entertainment, Sports, and Media Occupations
<b>29</b>	Healthcare Practitioners and Technical Occupations
<b>31</b>	Healthcare Support Occupations
<b>33</b>	Protective Service Occupations
<b>35</b>	Food Preparation and Serving Related Occupations
<b>37</b>	Building and Grounds Cleaning and Maintenance Occupations
<b>39</b>	Personal Care and Service Occupations
<b>41</b>	Sales and Related Occupations
<b>43</b>	Office and Administrative Support Occupations
<b>45</b>	Farming, Fishing, and Forestry Occupations
<b>47</b>	Construction and Extraction Occupations
<b>49</b>	Installation, Maintenance, and Repair Occupations
<b>51</b>	Production Occupations
514	<i>Metal Workers and Plastic Workers</i>
5140	<i>Metal Workers and Plastic Workers</i>
51401	<i>Computer Control Programmers and Operators</i>
514011	<i>Computer-Controlled Machine Tool Operators, Metal and Plastic</i>
514012	<i>Computer Numerically Controlled Machine Tool Programmers, Metal and Plastic</i>
<b>53</b>	Transportation and Material Moving Occupations
<b>55</b>	Military Specific Occupations

## 4. Industry Analysis

If the user selects the first option (Industry Analysis) on the “Start” tab and then clicks the “Submit” button, they are brought to the “User Input – Industry Analysis” tab, which can be seen in Figure 4.1. In this tab, the user selects up to 12 options for examining

**Select the output or metrics** Back to Start    Data Guidance    Submit

Select the output or metrics to be used for the examination.

**For Industry Analysis**

- Value Added:** Value added is considered the primary measure of economics activity. This data provides the value added of each manufacturing industry. Value added by industry does not reveal information about the costs or purchases of items in other industries needed for production.
- Labor by Occupation:** This data provides an estimate of compensation of employees by occupation, giving insight into how labor is used in each industry.
- Energy:** This data provides an estimate of the cost of energy by end use (e.g., machine drive).
- Assets:** This data provides an estimate of the purchase cost of assets (i.e., capital) needed for production.

**Topical Industry Research**

- Additive Manufacturing:** This section provides estimates of the revenue received for parts and components produced using additive manufacturing technologies.
- Inadequate Design Data:** This section presents the costs that result from making or needing clarifications in design data.
- Inadequate Interoperability:** This section presents the costs that result from interoperability between software platforms (e.g., re-entering data) in discrete high-tech manufacturing (i.e., NAICS 333-336)

**Maintenance Costs/Losses**

- Machinery Maintenance Costs:** This section provides estimates of maintenance costs and losses due to inadequate maintenance for discrete manufacturing.
- Losses due to Inadequate Maintenance:** This section provides estimates of losses due to maintenance issues, including defects, downtime, lost sales, and injuries compares establishments that primarily use reactive maintenance to those that use preventive/predictive maintenance.
- Comparison of Maintenance Strategies:** This section compares establishments that rely more heavily on each of three different maintenance strategies: reactive, preventive, and predictive.
- Defects and Downtime:** This section provides estimates on the defect rate and unplanned downtime in manufacturing facilities
- Digital Economy and Cybercrime Losses:** This section presents the value of the digital economy and losses due to cybercrime



Figure 4.1: “User Input – Industry Analysis” Tab within the Manufacturing Cost Guide

industry data. The first four include: 1) Value added, 2) Labor by occupation, 3) Energy, and 4) Assets. An additional eight options for examining specific topics within manufacturing are also included: 1) additive manufacturing, 2) inadequate design data, 3) inadequate interoperability, 4) machinery maintenance costs, 5) losses due to inadequate maintenance, 6) comparison of maintenance strategies, 7) defects and downtime, and 8) the digital economy and cybercrime. The following sections discuss each of these options. Each option reveals information about activities occurring within establishments categorized as manufacturing. No supply chain information is provided in this section.

If the user selects any of the first four options (i.e., Value added, Labor by occupation, Energy, and/or Assets), the “User Input – Select Commodities” tab is shown next. In this tab the user selects the industry or industries (based on the commodities produced) to be examined. As discussed previously, they are categorized by NAICS codes. If the “Estimate Establishment Level Costs/Losses” check box was selected in the “Start” tab, then only one industry can be selected. Otherwise, multiple industries can be selected. After clicking submit, the “User Input – Select Occupations” tab appears if the “Labor by Occupation” check box was selected in the “User Input – Industry Analysis” tab (see Figure 4.1). Otherwise, the “Results” tab is shown. In the “User Input – Select Occupations” tab, the user selects the occupations that they want to examine. As discussed previously, they are categorized by SOC codes. When the user clicks “Submit,” the “Results” tab is shown.

The user can then navigate to the “Ind Results – Value Added” tab if it was selected, which provides the total value added for each U.S. manufacturing industry. If the user checked the “Energy” and/or “Assets” boxes, the “Ind Results – Energy” tab and/or “Ind Results – Assets” tabs will appear. The “Ind Results – Energy” tab provides the value of energy consumed by end use for each manufacturing industry. The end use categories include indirect uses – boiler fuel, facility lighting, facility HVAC, conventional electricity generation, facility support, other nonprocess use, electro-chemical processes, machine drive, onsite transportation, other process use, process cooling/refrigeration, process heating, and end use not reported.

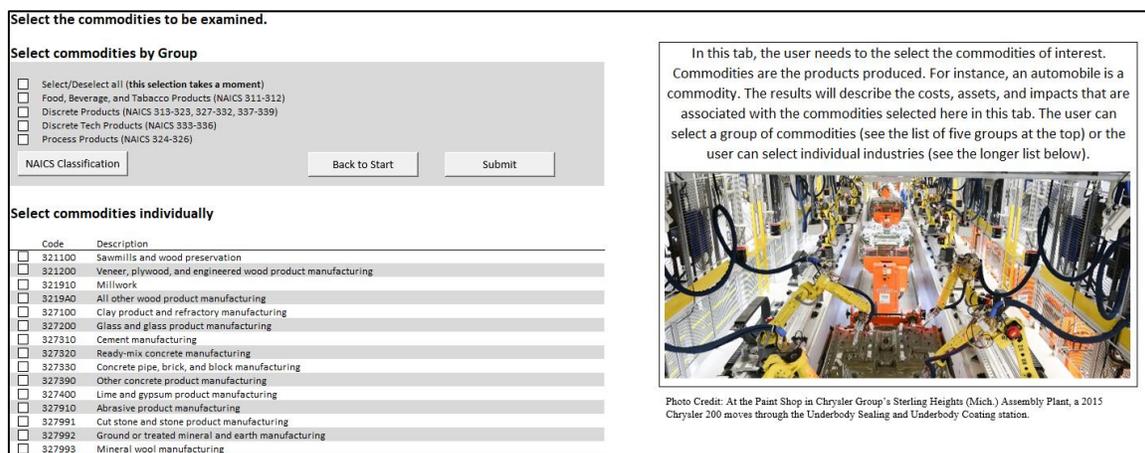


Figure 4.2: “User Input – Select Commodities” Tab within the Manufacturing Cost Guide

Value added is from the Bureau of Economic Analysis Input-Output tables. All dollar values are adjusted to 2019 using the Consumer Price Index from the Bureau of Labor Statistics.<sup>4</sup> The value for energy by end use is calculated by taking the cost of purchased fuels consumed and cost of purchased electricity from the annual survey of manufactures. These values are then portioned out using the Manufacturing Energy Consumption Survey (MECS).<sup>5</sup> The energy estimates are in the form of output or shipments; so, they include the supply chain items needed to produce energy, an issue discussed in Section 3. The MECS data has detail only to the 3-digit NAICS code. The estimates in the Manufacturing Cost Guide assume the proportions within each 3-digit NAICS code is constant. The value for assets is the “Gross value of depreciable assets (acquisition costs), beginning of year” and “Depreciation charges during year” from the Annual Survey of Manufactures.

If the user checked the box to examine “Labor by Occupation,” the “User Input – Select Occupations” tab will be revealed (see Figure 4.3) after clicking the submit button. The user then can select from 1071 categories from the Standard Occupational Classification System. After clicking the “Submit” button, the “Ind Results – Labor” tab provides the compensation for the occupations selected for each manufacturing industry.

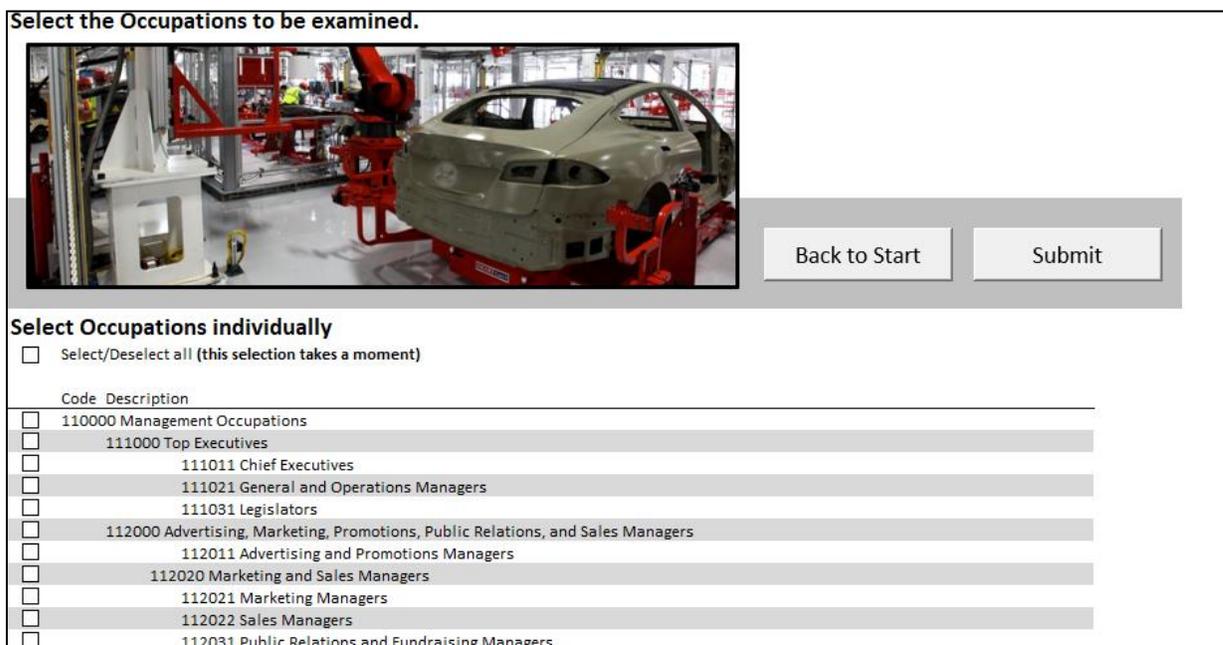


Figure 4.3: “User Input – Select Occupations” Tab within the Manufacturing Cost Guide

<sup>4</sup> Bureau of Economic Analysis. “Input-Output Accounts.” November 2018. <https://www.bea.gov/data/industries/input-output-accounts-data>

<sup>5</sup> Energy Information Administration. “Table 5.4 End Uses of Fuel Consumption, 2014.” Manufacturing Energy Consumption Survey. October 2017. <https://www.eia.gov/consumption/manufacturing/data/2014/>

If the user selected any of the check boxes under the “Topical Industry Research” category in the “User Input – Industry Analysis” tab, then additional tabs will be shown when the “Results” tab comes up. The “Topical Industry Research” selections do not require choosing industries or occupations.

If the “Estimate Establishment Level Costs/Losses” checkbox was selected on the “Start” tab, then only the “Other Costs and Losses” tab is shown for the “Topical Industry Research.” Otherwise, there is a tab for each of the “Topical Industry Research” selections. The establishment level options scales the data to represent costs/losses at the establishment level rather than the aggregated national level. The data is scaled by the value of shipments for the establishment and represents the average costs/losses for the U.S.

## 5. Supply Chain Analysis: Detail Oriented

If the user selects the “Supply Chain Analysis – Detail Oriented” option on the “Start” tab, then the “User Input – Sup Chn Analysis” tab is revealed after clicking the “Submit” button (see Figure 5.1). However, if the “Estimate Establishment Level Costs/Losses” checkbox is selected the “Establishment Data” tab is revealed where the user inputs the estimated annual value of shipments for their establishment. Similar to the industry analysis, the establishment level options scales the data to represent costs/losses at the establishment level rather than the aggregated national level. The data is scaled by the value of shipments for the establishment and represents the average costs/losses for the U.S.

The “User Input – Sup Chn Analysis” tab is shown after clicking submit on the “Establishment Data” tab. There are seven options for analysis: Value Added, Environmental Impact, Identify Industries with High Value Added + Environmental Impact, Analysis of Energy Use, Analysis of Labor Compensation by Occupation, Purchases by Industries, and Assets Used. All seven options are based on an input-output model using the 2012 Benchmark input-output data from the Bureau of Economic Analysis. A number of additional data sources are needed for tracking costs, including energy use data from the Energy Information Administration (EIA), asset purchases from the Annual Survey of Manufactures (ASM), and employment/wage data from the Bureau of Labor Statistics. As illustrated in Figure 5.2, these datasets are mapped together based

**Select the output or metrics**  
Select the output or metrics to be used for the examination.

**For Supply Chain Analysis**

- Value Added:** Value added is considered the primary measure of economic activity. This data provides the value added required to produce commodities for intermediate use (i.e., supplies to other industries) and final demand
- Environmental Impact:** This analysis provides an estimate of the environmental impact associated with producing intermediate use (i.e., supplies to other industries) and final demand
- Identify Industries with High Value Added + Environmental Impact:** This analysis combines the value added analysis and the environmental impact analysis to identify those industries in the supply chain that have a disproportionately high level in both areas
- Analysis of Energy use:** This analysis estimates the value of energy used throughout the supply chain to produce intermediate use (i.e., supplies to other industries) and final demand. It further details how the energy was used.
- Analysis of Labor Compensation by Occupation:** This analysis provides the different types of labor needed from different industries to produce commodities for intermediate use (i.e., supplies to other industries) and final demand
- Purchases by Industries:** This table provides the use of commodities by industries. It is the Use table of an input-output model
- Assets (i.e., capital) Used:** This table estimates the value of capital needed to produce intermediate use (i.e., supplies to other industries) and final demand

Back to Start
Guidance and Help
Submit



Figure 5.1: “User Input – Sup Chn Analysis” Tab from the Manufacturing Cost Guide

on NAICS codes, which categorizes establishments based on their products and processes, and the SOC codes, which categorizes labor by occupation. The calculations made in the “Supply Chain Analysis: Detail Oriented” option is documented in the Appendix.

After selecting one or more outputs or metrics and clicking the “Submit” button on the “User Input – Sup Chn Analysis” tab, the “User Input – Select Commodities” tab is revealed (see Figure 5.3). In this tab, the user selects which commodities they would like to examine (more than one can be selected if the “Estimate Establishment Level Costs/Losses” check box in the “Start” tab is unchecked). The results that are provided describe both the final production and the supply chain activities needed for producing the commodities. For instance, if the user puts a checkmark in the box next to “NAICS

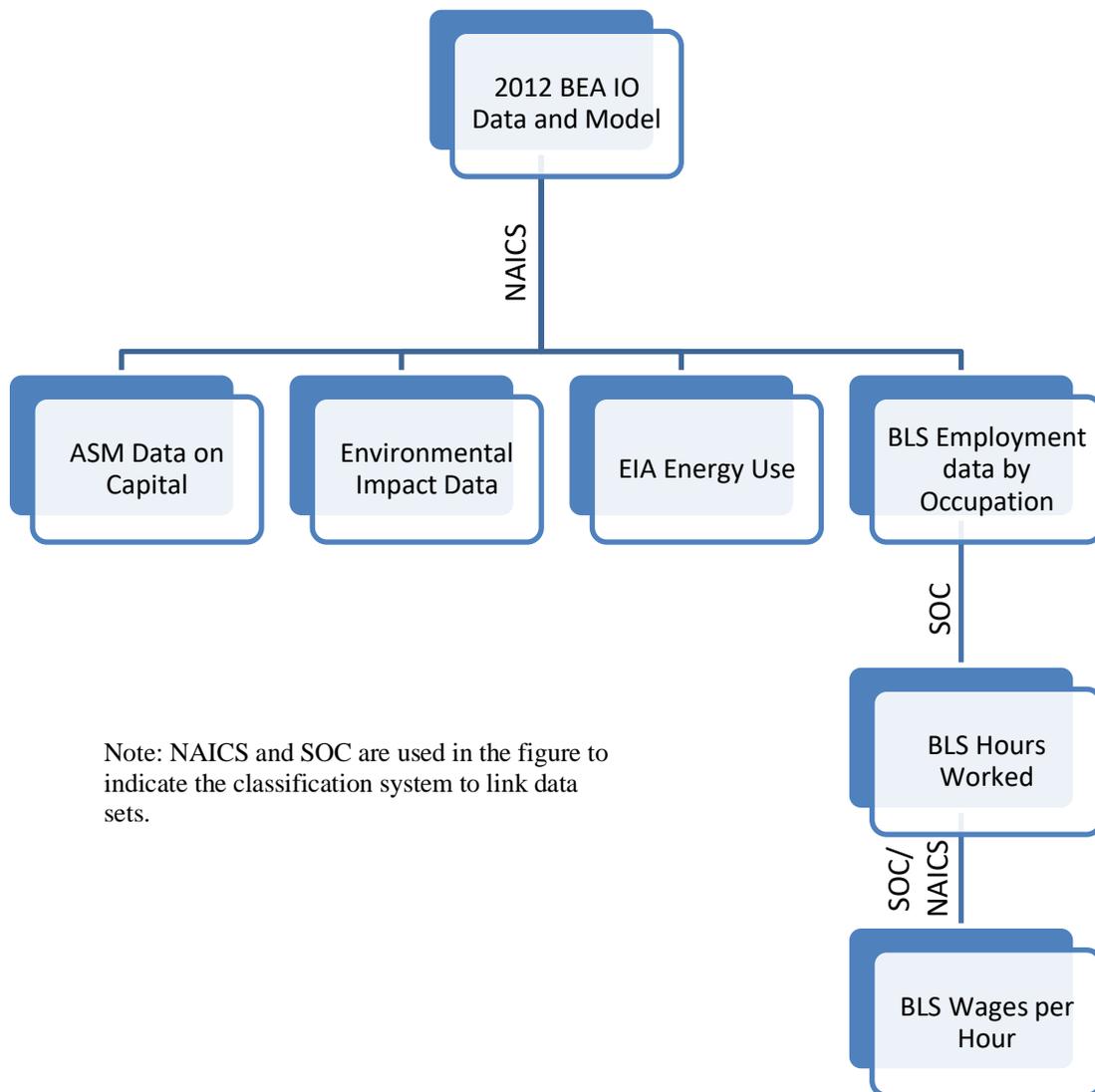


Figure 5.2: Map of Data Connections

336111 Automobile Manufacturing,” the results (e.g., value added, environmental impact, and the other items listed in the “User Input – Sup Chn Analysis” tab) are in regards to NAICS 336111 and its supply chain, including related services. If the user selects multiple commodities, the results are the aggregated industry activity and supply chains.

After the “User Input – Select Commodities” tab, there are potentially three additional tabs that require user input depending on the options selected by the user. All options require the user to select a commodity for analysis in the “User Input – Select Commodities” tab. If the user opted to analyze “Environmental Impact,” a tab related to weighting is revealed, as discussed below. If the user checked the “Analysis of Labor Compensation by Occupation,” a tab is revealed where the user can select occupations for analysis, also discussed below.

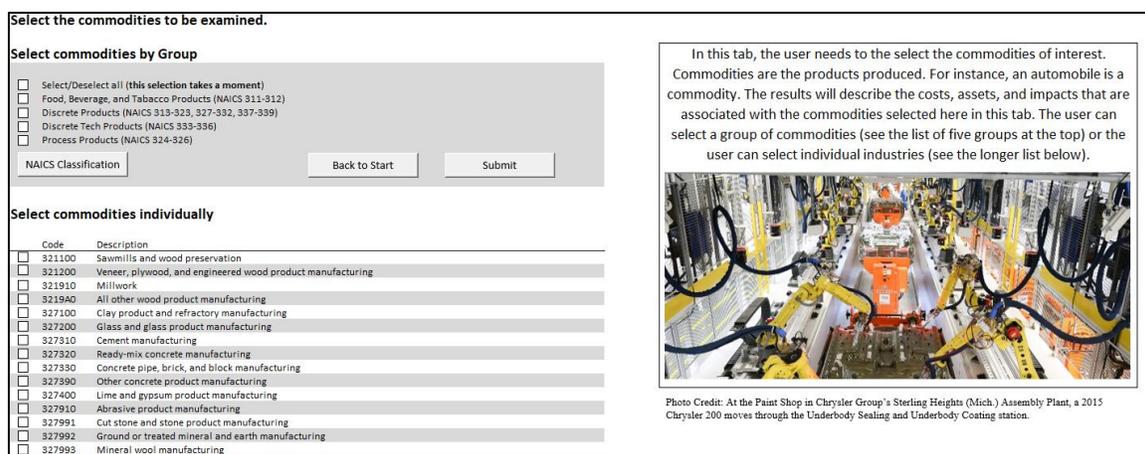


Figure 5.3: “User Input – Select Commodities” Tab within the Manufacturing Cost Guide

If the user checks the “Environmental Impact” box, after the “User Input – Select Commodities” tab, “User Input – Weighting” tab is revealed (see Figure 5.4). The calculation for environmental impact is made for 12 impact items with preselected weights, which are discussed in the appendix and are used to estimate the environmental impact of the user selected commodities. The user can change these weights; however, they must sum to 1. The results show the impacts required from each NAICS code to produce the selected commodities. Some items might be unexpected, such as food for automobile manufacturing. It is important to note that although food may not be part of the finished commodity being examined, it might be a purchase within the supply chain for other uses (e.g., cafeteria, advertising, and other purposes).

If the user checked the “Analysis of Labor Compensation by Occupation” on the “User Input – Sup Chn Analysis” tab (shown in Figure 5.1), the “User Input – Select Occupations” tab, which was shown in Figure 4.3, is revealed. The user then can select from 1071 categories from the Standard Occupational Classification System. After

submitting, the “Ind Results – Labor” tab provides the compensation for the occupations selected for each manufacturing industry.

After the user provides all the required input, a results tab is displayed for each analysis option selected in the “User Input – Sup Chn Analysis” tab (see Figure 5.1). All of the results are in regards to producing the selected commodities. If the “Estimate Establishment Level Costs/Losses” is selected, then the values are scaled down to represent a single establishment with the level of shipments entered by the user in the “Establishment Data” tab.

Items to be measured	Units	Weights
Global Warming	kg CO2 eq	0.03
Acidification	H+ moles eq	0.06
HH Criteria Air	kg PM10 eq	0.07
Eutrophication	kg N eq	0.30
Ozone Depletion Air	kg CFC-11 eq	0.05
Smog Air	kg O3 eq	0.09
ecotox	CTUe	0.08
HH_can	CTUHcan	0.02
HH_noncan	CTUHnoncan	0.04
Primary Energy Consumption	thousand BTU	0.10
Land Use	acre	0.06
Water Consumption	kg	0.08
		1.00

Back to Start

Submit

Figure 5.4: “User Input – Weighting” Tab within the Manufacturing Cost Guide

## 6. Supply Chain Analysis: Imports Oriented

If the user selects the “Supply Chain Analysis – Imports Oriented” option in the “Start” tab (see Figure 2.3), the “User Input – Select Industries” tab is revealed. The user can select from 18 manufacturing industries to examine. After clicking the “Submit” button, the “Sup Chn Results – Imports” tab is revealed, which provides the value added from each industry/country combination. This data uses the International Standard Industrial Classification (ISIC) rather than NAICS codes to classify industries. The methods used for these calculations are described in the Appendix. If the user selects the “Estimate Establishment Level Costs/Losses” checkbox in the “Start” tab, then the “Establishment Data” tab will be shown where the user inputs the annual value of shipments for the establishment. The values will be scaled to show the establishment level supply chain values. The scaled data does not represent any particular establishment, but rather it represents an average.

**Select the Industries to be examined.**



Select/Deselect all

Code	Description
<input type="checkbox"/> C10-C12	Manufacture of food products, beverages and tobacco products
<input type="checkbox"/> C13-C15	Manufacture of textiles, wearing apparel and leather products
<input type="checkbox"/> C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
<input type="checkbox"/> C17	Manufacture of paper and paper products
<input type="checkbox"/> C18	Printing and reproduction of recorded media
<input type="checkbox"/> C19	Manufacture of coke and refined petroleum products
<input type="checkbox"/> C20	Manufacture of chemicals and chemical products
<input type="checkbox"/> C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
<input type="checkbox"/> C22	Manufacture of rubber and plastic products
<input type="checkbox"/> C23	Manufacture of other non-metallic mineral products
<input type="checkbox"/> C24	Manufacture of basic metals
<input type="checkbox"/> C25	Manufacture of fabricated metal products, except machinery and equipment
<input type="checkbox"/> C26	Manufacture of computer, electronic and optical products
<input type="checkbox"/> C27	Manufacture of electrical equipment
<input type="checkbox"/> C28	Manufacture of machinery and equipment n.e.c.
<input type="checkbox"/> C29	Manufacture of motor vehicles, trailers and semi-trailers
<input type="checkbox"/> C30	Manufacture of other transport equipment
<input type="checkbox"/> C31_C32	Manufacture of furniture; other manufacturing

Figure 6.1: “User Input – Select Industries” within the Manufacturing Cost Guide

## Acknowledgments

The author wishes to thank all those who contributed so many excellent ideas and suggestions for this report. Special appreciation is extended to Brian A. Weiss of the National Institute of Standards and Technology's Intelligent Systems Division for his recommendations and insights. Special appreciation is also extended to David Butry and Juan Fung of the National Institute of Standards and Technology's Applied Economics Office for their thorough reviews and many insights. The author also wishes to thank Nicos Martys, of the Materials and Structural Systems Division at the National Institute of Standards and Technology.

## References

- Bare, Jane. "TRACI 2.0: The Tool for the Reduction and Assessment of Chemical and other Environmental Impacts 2.0." *Clean Technologies and Environmental Policy*. Vol 13 no. 5 (January 2011): 687-696.
- Bureau of Economic Analysis. "Input-Output Accounts." November 2018. <https://www.bea.gov/data/industries/input-output-accounts-data>
- Bureau of Labor Statistics. Consumer Price Index. <https://www.bls.gov/cpi/>
- Census Bureau. "Annual Survey of Manufactures." <https://www.census.gov/programs-surveys/asm.html>
- Census Bureau. "Economic Census." <https://www.census.gov/EconomicCensus>
- E. Dietzenbacher, B. Los, R. Stehrer, M.P. Timmer and G.J. de Vries (2013), "The Construction of World Input-Output Tables in the WIOD Project", *Economic Systems Research*, 25, 71-98.
- Energy Information Administration. "Table 5.4 End Uses of Fuel Consumption, 2014." *Manufacturing Energy Consumption Survey*. October 2017. <https://www.eia.gov/consumption/manufacturing/data/2014/>
- Horowitz, Karen J. and Mark A. Planting "Concepts and Methods of the U.S. Input-Output Accounts." (2009). [http://www.bea.gov/papers/pdf/IOmanual\\_092906.pdf](http://www.bea.gov/papers/pdf/IOmanual_092906.pdf)
- Lippiatt, Barbara, Anne Landfield Greig, and Priya Lavappa. *Building for Environmental and Economic Sustainability*. National Institute of Standards and Technology. (2010). <http://www.nist.gov/el/economics/BEESSoftware.cfm>
- Miller, Ronald E. and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. (New York, NY: Cambridge University Press, 2009): 16.
- Thomas, Douglas and Anand Kandaswamy. "Identifying High Resource Consumption Areas of Assembly-Centric Manufacturing in the United States." *Journal of Technology Transfer*. Vol 44, iss 1. 2019: 264-311.

Thomas, Douglas and Anand Kandaswamy. Tracking Industry Operations Activity: A Case Study of U.S. Automotive Manufacturing. NIST Special Publication 1601. December 2015. <https://doi.org/10.6028/NIST.SP.1601>

Thomas, Douglas and Brian Weiss. Economic of Manufacturing Machinery Maintenance: A Survey and Analysis of U.S. Costs and Benefits. NIST Advanced Manufacturing Series. Forthcoming 2020.

Thomas, Douglas and Stanley Gilbert. Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion. NIST SP 1176. 2014. <http://dx.doi.org/10.6028/NIST.SP.1176>

Thomas, Douglas. The Model Based Enterprise: A Literature Review of Costs and Benefits for Discrete Manufacturing. NIST Advanced Manufacturing Series 100-26. 2019. <https://doi.org/10.6028/NIST.AMS.100-26>

Thomas, Douglas S. “Reliability of using Periodic IO Data to Identify High Return Investments in Efficiency and Environmental Sustainability: An Examination of U.S. Manufactured Tech Products.” 27th International Input-Output Association Conference. July 2019.

Thomas, Douglas S. “The Costs and Benefits of Advanced Maintenance in Manufacturing.” NIST AMS 100-18. April 2018. <https://doi.org/10.6028/NIST.AMS.100-18>

US Environmental Protection Agency. USEEIO Elementary Flows and Life Cycle Impact Assessment Characterization Factors. (2018). <https://catalog.data.gov/dataset/useeio-elementary-flows-and-life-cycle-impact-assessment-lcia-characterization-factors>

US Environmental Protection Agency. USEEIO v1.1. (2018). <https://catalog.data.gov/dataset/useeio-v1-1-matrices>

Wohlers, Terry. “Wohlers Report 2019: Additive Manufacturing and 3D Printing State of the Industry.” Wohlers Associates, Inc. 2019.

World Input-Output Database. <http://www.wiod.org/database/wiots16>

Yang, Yi, Wesley W. Ingwersen, Troy R. Hawkins, Michael Srocka, David E. Meyer. “USEEIO: A New and Transparent United States Environmentally-Extended Input-Output Model.” Journal of Cleaner Production. Vol 158, no. 1 (2017): 308-318. <https://doi.org/10.1016/j.jclepro.2017.04.150>

## Appendix A: Data Used, Scaling, and Adjusting for Inflation

A discussion on manufacturing cost data is presented in NIST AMS 100-18, Thomas (2019), and Thomas and Kandaswamy (2017).<sup>6,7,8</sup> The following draws a great deal from these publications. This version of the Manufacturing Cost Guide (i.e., Version 1.0) estimates a number of values using 2012 economic input-output data. This data is released every 5 years and is delayed in its release due to the time required for assembly. The 2012 data, for instance, was released in the fall of 2018. The economy will have changed somewhat between 2012 and the present: however, these types of changes are relatively slow at the economy scale, as shown by Thomas.<sup>9</sup>

*Bureau of Economic Analysis Input-Output Data:* Annual input-output data is available from the BEA for the years 1998 through 2016. Prior to 1998, the data is available for every fifth year starting in 1967. There is also data available for the years 1947, 1958, and 1963. More detailed data is available for years ending in two or seven. The input-output accounts provide data to analyze inter-industry relationships. BEA input-output data is provided in the form of make and use tables. Make tables show the production of commodities (products) by industry. Use tables show the components required for producing the output of each industry. There are two types of make and use tables: “standard” and “supplementary.” Standard tables closely follow NAICS and are consistent with other economic accounts and industry statistics, which classify data based on establishment. Note that an “establishment” is a single physical location where business is conducted. This should not be confused with an “enterprise” such as a company, corporation, or institution. Establishments are classified into industries based on the primary activity within the NAICS code definitions. Establishments often have multiple activities. For example, a hotel with a restaurant has income from lodging (a primary activity) and from food sales (a secondary activity). An establishment is classified based on its primary activity. Data for an industry reflects all the products made by the establishments within that industry; therefore, secondary products are included. Supplementary make-use tables, which are used in the Manufacturing Cost Guide, reassign secondary products to the industry in which they are primary products.<sup>10,11</sup> The make-use tables are used for input-output analysis as developed by Leontief.<sup>12,13</sup>

<sup>6</sup> Thomas, Douglas S. “The Costs and Benefits of Advanced Maintenance in Manufacturing.” NIST AMS 100-18. April 2018. <https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.100-18.pdf>

<sup>7</sup> Thomas, Douglas S. “Reliability of using Periodic IO Data to Identify High Return Investments in Efficiency and Environmental Sustainability: An Examination of U.S. Manufactured Tech Products.” 27<sup>th</sup> International Input-Output Association Conference. July 2019.

<sup>8</sup> Thomas, Douglas and Anand Kandaswamy. “Identifying High Resource Consumption Areas of Assembly-Centric Manufacturing in the United States.” *Journal of Technology Transfer*. Vol 44, iss 1. 2019: 264-311.

<sup>9</sup> Thomas, Douglas S. “Reliability of using Periodic IO Data to Identify High Return Investments in Efficiency and Environmental Sustainability: An Examination of U.S. Manufactured Tech Products.” 27<sup>th</sup> International Input-Output Association Conference. Glasgow, Scotland. July 2019.

<sup>10</sup> Over the years BEA has made improvements to its methods. This includes redefining secondary products. The data discussed in this section utilizes the data BEA refers to as “after redefinitions.”

<sup>11</sup> Horowitz, Karen J. and Mark A. Planting “Concepts and Methods of the U.S. Input-Output Accounts.” (2009): 1.5. [http://www.bea.gov/papers/pdf/IOmanual\\_092906.pdf](http://www.bea.gov/papers/pdf/IOmanual_092906.pdf)

<sup>12</sup> 4.1-4.10.

<sup>13</sup> Miller, Ronald E. and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. (New York, NY: Cambridge University Press, 2009): 16.

*Annual Survey of Manufactures and Economic Census:* The Annual Survey of Manufactures (ASM) is conducted every year except for years ending in 2 or 7 when the Economic Census is conducted. The ASM provides statistics on employment, payroll, supplemental labor costs, cost of materials consumed, operating expenses, value of shipments, value added, fuels and energy used, and inventories. It uses a sample survey of approximately 50 000 establishments with new samples selected at 5-year intervals. The ASM data allows the examination of multiple factors (value added, payroll, energy use, and more) of manufacturing at a detailed subsector level. The Economic Census, used for years ending in 2 or 7, is a survey of all employer establishments in the U.S. that has been taken as an integrated program at 5-year intervals since 1967. Both the ASM and the Economic Census use the NAICS codes; however, prior to NAICS the SIC system was used.<sup>14,15</sup> NAICS and SIC are classifications of industries, which are based primarily on the product produced (e.g., automobiles, steel, or toys). The categories include both intermediate and finished goods.

Together, the Annual Survey of Manufactures and the Economic Census provide annual data on manufacturing, including value added and capital. Value added is equal to the value of shipments less the cost of materials, supplies, containers, fuel, purchased electricity, and contract work. It is adjusted by the addition of value added by merchandising operations plus the net change in finished goods and work-in-process goods. Value added avoids the duplication caused from the use of products of some establishments as materials. It is important to note that the Bureau of Economic Analysis (BEA), which is a prominent source of data on value added, and the ASM calculate value added differently. The BEA calculates value added as “gross output (sales or receipts and other operating income, plus inventory change) less intermediate inputs (consumption of goods and services purchased from other industries or imported).”<sup>16</sup> Moreover, the difference is that ASM’s calculation of value added includes purchases from other industries such as mining and construction while BEA’s does not include it. Note that the BEA definition is followed for the Manufacturing Cost Guide, as the ASM’s definition can result in double counting when adding data together.

*Occupational Employment Statistics:* The Occupational Employment Statistics program at the Bureau of Labor Statistics provides data on employment and wages for over 800 occupations categorized by the Standard Occupation Classification (SOC) system and by NAICS code.

*Manufacturing Energy Consumption Survey:* The Energy Information Administration collects energy data on a quadrennial basis and samples approximately 15 500 establishments drawn from a nationally representative sample frame that includes 97 % to 98 % of the manufacturing payroll (Energy Information Administration 2010). Energy data is categorized by the NAICS codes and end use.

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<sup>14</sup> Census Bureau. “Annual Survey of Manufactures.” <<https://www.census.gov/programs-surveys/asm.html> />

<sup>15</sup> Census Bureau. “Economic Census.” <<https://www.census.gov/EconomicCensus>>

<sup>16</sup> Horowitz, Karen J. and Mark A. Planting “Concepts and Methods of the U.S. Input-Output Accounts.” (2009): Glossary-32. [http://www.bea.gov/papers/pdf/IOmanual\\_092906.pdf](http://www.bea.gov/papers/pdf/IOmanual_092906.pdf)

*Environmentally Extended Input-Output Data:* The environmental data used in this tool is the U.S. environmentally-extended input-output (USEEIO) data assembled by Yang et al.<sup>17, 18, 19</sup> This dataset provides the environmental impacts associated with the production of goods and services. A selection of the measures of impact were used in this analysis (see Figure 5.4), which are consistent with metrics used by the U.S. Environmental Protection Agency’s TRACI tool.<sup>20</sup>

*World Input-Output Data:* The World Input-Output Database (WIOD) covers 43 countries and the rest of the world. Unlike the BEA input-output data, the WIOD does not have make and use tables. Rather, it uses the more traditional input-output dataset format. This format includes a single table that shows the inter-industry relationships within the global economy. This data uses the ISIC system of industry classification rather than NAICS.<sup>21, 22</sup>

*Reports and Findings:* The “Topical Industry Research” within the “Industry Analysis” option relies on topical reports and datasets. The following includes a list of the tabs from the Manufacturing Cost Guide and their corresponding sources:

- “Additive Manufacturing”
  - Thomas, Douglas and Stanley Gilbert. Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion. NIST SP 1176
  - Wohlers, Terry. “Wohlers Report 2019: Additive Manufacturing and 3D Printing State of the Industry.” Wohlers Associates, Inc. 2019.
- “Inadequate Design Data” and “Interoperability”
  - Thomas, Douglas and Stanley Gilbert. Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion. NIST SP 1176. 2014. <http://dx.doi.org/10.6028/NIST.SP.1176>
- “Maintenance Costs,” “Reactive and Other Maintenance,” “Preventive and Predictive Maintenance,” “Defects and Downtime”, and the “Digital Economy and Cybercrime”
  - Thomas, Douglas and Brian Weiss. Economic of Manufacturing Machinery Maintenance: A Survey and Analysis of U.S. Costs and Benefits. NIST Advanced Manufacturing Series. Forthcoming 2020.

*Bureau of Labor Statistics:* Industry values are adjusted to 2019 using the Consumer Price Index for all cities for all items from the Bureau of Labor Statistics.<sup>23</sup>

<sup>17</sup> Yang, Yi, Wesley W. Ingwersen, Troy R. Hawkins, Michael Srocka, David E. Meyer. “USEEIO: A New and Transparent United States Environmentally-Extended Input-Output Model.” *Journal of Cleaner Production*. Vol 158, no. 1 (2017): 308-318. <https://doi.org/10.1016/j.jclepro.2017.04.150>

<sup>18</sup> U.S. Environmental Protection Agency. USEEIO Elementary Flows and Life Cycle Impact Assessment Characterization Factors. (2018). <https://catalog.data.gov/dataset/useeio-elementary-flows-and-life-cycle-impact-assessment-lcia-characterization-factors>

<sup>19</sup> U.S. Environmental Protection Agency. USEEIO v1.1. (2018). <https://catalog.data.gov/dataset/useeio-v1-1-matrices>

<sup>20</sup> Bare, Jane. “TRACI 2.0: The Tool for the Reduction and Assessment of Chemical and other Environmental Impacts 2.0.” *Clean Technologies and Environmental Policy*. Vol 13 no. 5 (January 2011): 687-696.

<sup>21</sup> E. Dietzenbacher, B. Los, R. Stehrer, M.P. Timmer and G.J. de Vries (2013), “The Construction of World Input-Output Tables in the WIOD Project”, *Economic Systems Research*, 25, 71-98.

<sup>22</sup> World Input-Output Database. <http://www.wiod.org/database/wiots16>

<sup>23</sup> Bureau of Labor Statistics. Consumer Price Index. <https://www.bls.gov/cpi/>

*Scaling:* If the “Estimate Establishment Level Costs/Losses” checkbox is selected, then the data is scaled by the value of shipments entered by the user. This scaling is done by taking the shipments entered by the user and dividing it by the total shipments for the industry that they select and multiplying it by the total for the metric selected (e.g., maintenance or energy).

## Appendix B: Methods for “Supply Chain Analysis”

A discussion on the methods for examining manufacturing costs is presented in NIST AMS 100-18, Thomas (2019), and Thomas and Kandaswamy (2017).<sup>24, 25, 26</sup> The following draws a great deal from these publications.

*Input-Output Analysis for BEA Data:* The Manufacturing Cost Guide utilizes input-output analysis, which develops a total requirements matrix that when multiplied by a vector of final demands equals the output needed for production. The total requirements matrix is developed using the methods outlined in Horowitz and Planting.<sup>27</sup>

Equation 1

$$X = W(I - BW)^{-1} * Y$$

Where:

$X$  = Vector of output required to produce final demand

$Y$  = Vector of final demand, as defined in the BEA Input-Output data

$W = (I - \hat{p})D$

$B = U\hat{g}^{-1}$

$I$  = Identity matrix

$D = V\hat{q}^{-1}$

$p$  = “A column vector in which each entry shows the ratio of the value of scrap produced in each industry to the industry's total output.”

$U$  = “Intermediate portion of the use matrix in which the column shows for a given industry the amount of each commodity it uses—including noncomparable imports, scrap, and used and secondhand goods. This is a commodity-by-industry matrix.”

$V$  = “Make matrix, in which the column shows for a given commodity the amount produced in each industry. This is an industry-by-commodity matrix.  $V$  has columns showing only zero entries for noncomparable imports and for scrap.”

$g$  = “A column vector in which each entry shows the total amount of each industry's output, including its production of scrap. It is an industry-by-one vector.”

$q$  = “A column vector in which each entry shows the total amount of the output of a commodity. It is a commodity-by-one vector.”

$\hat{\phantom{x}}$  = “A symbol that when placed over a vector indicates a square matrix in which the elements of the vector appear on the main diagonal and zeros elsewhere.”

<sup>24</sup> Thomas, Douglas S. “The Costs and Benefits of Advanced Maintenance in Manufacturing.” NIST AMS 100-18. April 2018. <https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.100-18.pdf>

<sup>25</sup> Thomas, Douglas S. “Reliability of using Periodic IO Data to Identify High Return Investments in Efficiency and Environmental Sustainability: An Examination of U.S. Manufactured Tech Products.” 27<sup>th</sup> International Input-Output Association Conference. July 2019.

<sup>26</sup> Thomas, Douglas and Anand Kandaswamy. “Identifying High Resource Consumption Areas of Assembly-Centric Manufacturing in the United States.” *Journal of Technology Transfer*. Vol 44, iss 1. 2019: 264-311.

<sup>27</sup> Horowitz, Karen J. and Mark A. Planting. *Concepts and Methods of the U.S. Input-Output Accounts*. Bureau of Economic Analysis. (September 2006). <[http://www.bea.gov/papers/pdf/IOmanual\\_092906.pdf](http://www.bea.gov/papers/pdf/IOmanual_092906.pdf)>

In Equation 1, a total requirements matrix  $W(I - BW)^{-1}$  is multiplied by a vector of final demand for commodities  $Y$  to estimate the total output  $X$ . The total requirements matrix provided by the BEA was used in this analysis. All variables in Equation 1 have known values in the input-output data. The output  $X$  required to produce an alternate level of final demand can be calculated by altering the final demand vector from the actual final demand  $Y$  in the input output data to  $Y'$ . For the Manufacturing Cost Guide,  $Y'$  has the sum of the final demand and intermediate use for the commodities selected by the user. If the user selects multiple industries, the overlapping intermediate uses are subtracted from  $Y'$ .

*Environmental Impact Categories:* The TRACI 2 impact categories are each an aggregation of multiple emissions converted to a common physical unit. For example, the global warming impact category includes impacts of many pollutants, such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), Nitrous Oxide (NO<sub>x</sub>), and fluorinated gases, which are converted to their carbon dioxide equivalent (CO<sub>2</sub>e) impact and aggregated to estimate the total impact for that impact category. The environmental impacts are measured in terms of the common physical unit per dollar of output. The impact can be calculated by multiplying the output in the Input-Output analysis by the impact categories.

*Impact Category Weights:* Having 12 impact categories makes it difficult to rank industry environmental activity; therefore, the 12 impact categories have been combined into one using the Analytical Hierarchy Process (AHP). AHP is a mathematical method for developing weights using normalized eigenvalues. It involves making pairwise comparisons of competing items. The weights used in this paper were developed for the BEES software and can be seen in Figure 5.4.<sup>28</sup> This paper uses 12 of the 13 impact categories for which weights were developed. Indoor Air Quality (IAQ) is excluded because it is more applicable to the design of buildings and ventilation systems rather than to manufacturing activities. The weight of IAQ is proportionally allocated to the other 12 categories. The final metric for each industry or industry/commodity combination is the proportion of the total impact from assembly-centric products. The percent of environmental impacts, based on the weights, are calculated using the following equation:

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<sup>28</sup> Lippiatt, Barbara, Anne Landfield Greig, and Priya Lavappa. Building for Environmental and Economic Sustainability. National Institute of Standards and Technology. (2010). <<http://www.nist.gov/el/economics/BEESSoftware.cfm>>

Equation 2

$$\begin{aligned}
 Env_{z,Y'} = & \frac{x_{z,Y'} * GWP_z}{\sum_{i=1}^n x_{i,Y'} * GWP_i} * 0.30 + \frac{x_{z,Y'} * Acid_z}{\sum_{i=1}^n x_{i,Y'} * Acid_i} * 0.03 + \frac{x_{z,Y'} * HHA_z}{\sum_{i=1}^n x_{i,Y'} * HHA_i} \\
 & * 0.09 + \frac{x_{z,Y'} * Eut_z}{\sum_{i=1}^n x_{i,Y'} * Eut_i} * 0.06 + \frac{x_{z,Y'} * OD_z}{\sum_{i=1}^n x_{i,Y'} * OD_i} * 0.02 \\
 & + \frac{x_{z,Y'} * Sm_z}{\sum_{i=1}^n x_{i,Y'} * Sm_i} * 0.04 + \frac{x_{z,Y'} * Eco_z}{\sum_{i=1}^n x_{i,Y'} * Eco_i} * 0.07 + \frac{x_{z,Y'} * HHC_z}{\sum_{i=1}^n x_{i,Y'} * HHC_i} \\
 & * 0.08 + \frac{x_{z,Y'} * HHNC_z}{\sum_{i=1}^n x_{i,Y'} * HHNC_i} * 0.05 + \frac{x_{z,Y'} * PE_z}{\sum_{i=1}^n x_{i,Y'} * PE_i} * 0.10 \\
 & + \frac{x_{z,Y'} * LU_z}{\sum_{i=1}^n x_{i,Y'} * LU_i} * 0.06 + \frac{x_{z,Y'} * WC_z}{\sum_{i=1}^n x_{i,Y'} * WC_i} * 0.08
 \end{aligned}$$

Where

$Env_{z,Y'}$  = Environmental impact from industry  $z$  for final demand  $Y'$

$GWP_z$  = Global warming potential per dollar of output for industry  $z$

$Acid_z$  = Acidification per dollar of output for industry  $z$

$HHA_z$  = Human health –criteria air pollutants – per dollar of output for industry  $z$

$Eut_z$  = Eutrophication per dollar of output for industry  $z$

$OD_z$  = Ozone depletion per dollar of output for industry  $z$

$Sm_z$  = Smog per dollar of output for industry  $z$

$Eco_z$  = Ecotoxicity per dollar of output for industry  $z$

$HHC_z$  = Human health – carcinogens – per dollar of output for industry  $z$

$HHNC_z$  = Human health – non-carcinogen – per dollar of output for industry  $z$

$PE_z$  = Primary energy consumption per dollar of output for industry  $z$

$LU_z$  = Land use per dollar of output for industry  $z$

$WC_z$  = Water consumption per dollar of output for industry  $z$

$x_{z,Y'}$  = Output for industry  $z$  with final demand  $Y'$

*Value Added:* The total requirements matrix  $W(I - BW)^{-1}$  from Equation 1, which shows the total output required to meet a given level of final demand, is multiplied by final demand in the input-output data to estimate the total output. As mentioned previously, the output required to produce a particular level of final demand can be calculated by altering final demand to  $Y'$ . For the Manufacturing Cost Guide,  $Y'$  equals the sum of final demand and intermediate uses for those NAICS codes (or ISIC codes) selected by the user. If the user selects multiple industries, the overlapping intermediate uses are subtracted from  $Y'$ .

Value added is calculated by assuming the proportion of output needed to produce a commodity is the same proportion of value added, which is consistent with methods proposed by Miller (2009). The proportions calculated using the input-output analysis are then multiplied by the value added:

Equation 3

$$VA_{z,Y',2012} = \frac{x_{z,Y',2012}}{x_{z,2012}} * VA_{z,2012}$$

Where

$VA_{z,Y',2012}$  = Value added from industry  $z$  with final demand  $Y'$  in 2012

$x_{z,2012}$  = Total output for industry  $z$  in 2012

$x_{z,Y',2012}$  = Output for industry  $z$  with final demand  $Y'$  in 2012

$VA_{z,2012}$  = Total value added from industry  $z$  in 2012

Imports in the “Supply Chain Analysis – Imports Oriented” option are calculated in a similar fashion, where the proportion of total output used from a particular industry is the same for imports. The ratio is multiplied by the intermediate imports from the BEA import matrix.

*Energy Analysis:* The value for energy by end use is calculated by taking the cost of purchased fuels consumed and cost of purchased electricity from the annual survey of manufactures. These values are then portioned out using the Manufacturing Energy Consumption Survey (MECS).<sup>29</sup> Similar to Equation 3, the portioned-out values are multiplied by the ratio of  $x_{z,Y',2012}$  to  $x_{z,2012}$ .

*Labor:* Due to data limitations, the labor data is aggregated to the 3-digit NAICS codes. Employment estimates by industry NAICS code by SOC occupation code are multiplied by the estimated hours worked per week in each industry. Note that this assumes that all occupations are working the average hours. The product of this is multiplied by the estimate of wages by industry NAICS code by SOC occupation code. The values are then scaled to match the BEA input-output data estimate of compensation. The result is then multiplied by the proportion of the ratio of  $x_{z,Y',2012}$  to  $x_{z,2012}$ , which is consistent with methods proposed in Miller (2009). The result is a matrix of the compensation of labor, categorized by NAICS by SOC, to produce the selected commodities:

Equation 4

$$C_{z,s,Y'} = \frac{x_{z,Y'}}{x_z} * C_{z,s} * \left( \frac{E_{z,s} * LH_s * W_{z,s}}{\sum_{i=1}^n E_{z,i} * LH_s * W_{z,i}} \right)$$

Where

$C_{z,s,Y'}$  = Compensation for occupation  $s$  in industry  $z$  with final demand  $Y'$

$C_{z,s}$  = Total compensation for occupation  $s$  in industry  $z$

$x_z$  = Total output for industry  $z$

$x_{z,Y'}$  = Output for industry  $z$  with final demand  $Y'$

$E_{z,s}$  = Employment for industry  $z$  and occupation  $s$

$LH_s$  = Labor hours per employee for occupation  $s$

$W_{z,s}$  = Hourly wages per employee for industry  $z$  and occupation  $s$

*Gross Value of Depreciable Assets:* Depreciable assets are measured in a similar fashion to labor, energy, and value added. The proportion of output estimated from the input-

<sup>29</sup> Energy Information Administration. “Table 5.4 End Uses of Fuel Consumption, 2014.” Manufacturing Energy Consumption Survey. October 2017. <https://www.eia.gov/consumption/manufacturing/data/2014/>

output calculations is multiplied by the total depreciable assets for that industry from the Economic Census, resulting in an estimate of depreciable assets utilized for the production of the commodity being examined.

*Input-Output Analysis for WIOD Data:* The WIOD analysis for the “Supply Chain Analysis – Imports Oriented” option is slightly different than that for the “Supply Chain Analysis – Detail Oriented,” which uses BEA data. This follows the more traditional input-output model proposed by Leontief:<sup>30</sup>

$$X = (I - A)^{-1} * Y$$

Where

$X$  = Vector of output required to produce final demand

$Y$  = Vector of final demand, as defined in the BEA Input-Output data

$I$  = Identity matrix

$A$  = Matrix of coefficients

Similar to the BEA input-output data, the final demand  $Y$  can be altered to  $Y'$  to examine the output needed for production. For the Manufacturing Cost Guide,  $Y'$  has the sum of the final demand and intermediate use for the commodities selected by the user. If the user selects multiple industries, the overlapping intermediate uses are subtracted from  $Y'$ .

*Adjusting for Inflation:* Values are adjusted to 2019 using the Consumer Price Index for all cities for all items from the Bureau of Labor Statistics.<sup>31</sup>

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<sup>30</sup> Miller, Ronald E. and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. (New York, NY: Cambridge University Press, 2009).

<sup>31</sup> Bureau of Labor Statistics. Consumer Price Index. <https://www.bls.gov/cpi/>