Assessing Measurement Error in an Energy Use Survey of Manufacturing Businesses

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Abstract:
The Manufacturing Energy Consumption Survey (MECS) is a national sample survey that collects energy-related building characteristics, energy consumption, and energy expenditures of manufacturing businesses in the United States every four years. The U.S. Energy Information Administration (EIA) sponsors the MECS and the U.S. Census Bureau collects the data. For the 2014 MECS, EIA proposed implementing a modified estimation model of energy use in the United States. In order to provide the data necessary to make the modifications to the estimation model, EIA developed seven questions specific to the flow of energy through asphalt plants and seven questions specific to the flow of energy through petrochemical plants. Cognitive testing with petrochemical plants and asphalt plants revealed not only potential measurement errors related to these seven questions, but also the existing paper questionnaire. This paper highlights the findings from cognitive testing and discusses their implications not only to the 2014 MECS, but also to questionnaire design best practices for business surveys. Specifically, we focus on lessons learned on using the correct terminology, appropriate questionnaire formatting, and being cognizant of question order effects. Additionally, the paper outlines the steps EIA and the U.S. Census Bureau are taking to reduce measurement error in the 2014 MECS and future data collection cycles.

1. Introduction

The Manufacturing Energy Consumption Survey (MECS) is a mixed-mode (paper and web) national sample survey of approximately 15,000 businesses that collects energy-related building characteristics, energy consumption, and energy expenditures in the United States on a quadrennial basis. The U.S. Energy Information Administration (EIA) sponsors the MECS and the U.S. Census Bureau (Census Bureau) collects and processes the data. The 2014 MECS is the ninth data collection cycle since the survey's inauguration in 1985.

The MECS data collection utilizes two forms: the longer EIA-846(A) form that is sent to the majority of manufacturing businesses and the shorter EIA-846(B) form that is sent to petroleum refineries. Petroleum refineries receive the shorter EIA-846(B) form because

[1] This report is released to inform interested parties of research and to encourage discussion. The views expressed on methodological, technical, or operational issues are those of the authors and not necessarily those of the U.S. Census Bureau or the U.S. Energy Information Administration (EIA).

EIA uses existing data from other EIA surveys to estimate feedstock and offsite-produced fuel usage, such as petrochemical feedstocks and asphalt.

Historically, EIA has estimated feedstock and offsite-produced fuel usage for petroleum refineries from the EIA-810, "Monthly Refinery Report", to account for energy used in manufacturing that would otherwise not be seen as energy sources downstream in any end-use sector. Thus, the MECS has accounted for the production (i.e., transformation of crude oil) of asphalt, petrochemical feedstocks (naphtha and gas oil type), lubricants, waxes, solvents, and miscellaneous non-fuels using estimation from upstream versus collecting the data on the MECS. By using the EIA-810 data to estimate petroleum refinery outputs, versus having respondents directly report it, EIA and the Census Bureau have reduced the reporting burden on these respondents.

For the 2014 MECS, EIA made the decision to collect all petrochemical feedstocks and asphalt data from the petrochemical and asphalt plants directly using the EIA-846(A), rather than continue to include them as part of the non-energy source shipment estimate from the petroleum refineries. The benefit of explicitly gathering these data using questions versus estimating the data is that EIA now has a more complete picture of consumption flows at petrochemical and asphalt plants; and thus, a more accurate estimation model of energy use in the United States. Conceptually, these non-energy products will now be treated as energy sources versus non-energy source estimates.

To collect these petrochemical feedstocks and asphalt data, EIA developed seven questions specific to the flow of energy through petrochemical plants and seven questions specific to the flow of energy through asphalt plants. The decision was made to develop these seven questions late during the survey-cycle planning process, and as such, financial resources and time were limited. Because of this, the decision was made to use existing MECS terminology (e.g., referring to different fuels as an "energy source"), existing formatting, and the existing double column layout (see Figure 1).

During an expert review of these draft questions, we noted that they adhered to some best practices of questionnaire design and in other areas could use improvement. We came to this conclusion while reviewing the questionnaire design literature during the expert review. We first reviewed the questionnaire design strategies presented by Fowler (Fowler 1995), then Dillman and his colleagues (Dillman et al., 2009). This research directed us to the questionnaire guidelines developed by Morrison and her colleagues' specific to business surveys (Morrison et al., 2008; Morrison et al., 2010). In their research, they outline 18 guidelines that survey methodologists should be cognizant of when developing questionnaires specifically for businesses. These 18 guidelines are:

1. Phrase data requests as questions or imperative statements, not sentence fragments or keywords.
2. Break down complex questions into a series of simple questions.
3. Use a consistent page of screen layout.
4. Align questions and answer spaces or response options.
5. Clearly identify the start of each section and question.
6. Use strong visual features to interrupt the navigational flow.
7. Use blank space to separate questions and make it easier to navigate questionnaires.
8. Avoid unnecessary lines that break up or separate questions that need to appear as groups.

9. Use visual cues to achieve grouping between questions and answer categories.
10. Avoid including images or other graphs that are not necessary.
11. Incorporate instructions into the question where they are needed. Avoid placing instructions in a separate sheet or booklet.
12. Consider reformulating important instructions as questions.
13. Consider converting narrative paragraphs into a bulleted list.
14. Use white spaces against a colored background to emphasize answer spaces.
15. Use similar answer spaces for the same task.
16. Limit the use of matrices. Consider the potential respondent's level of familiarity with tables when deciding whether to use them.
17. If a matrix is necessary, help respondents' process information by reducing the number of data items collected and by establishing a clear navigational path.
18. Use font variations consistently and for a single purpose within a questionnaire.

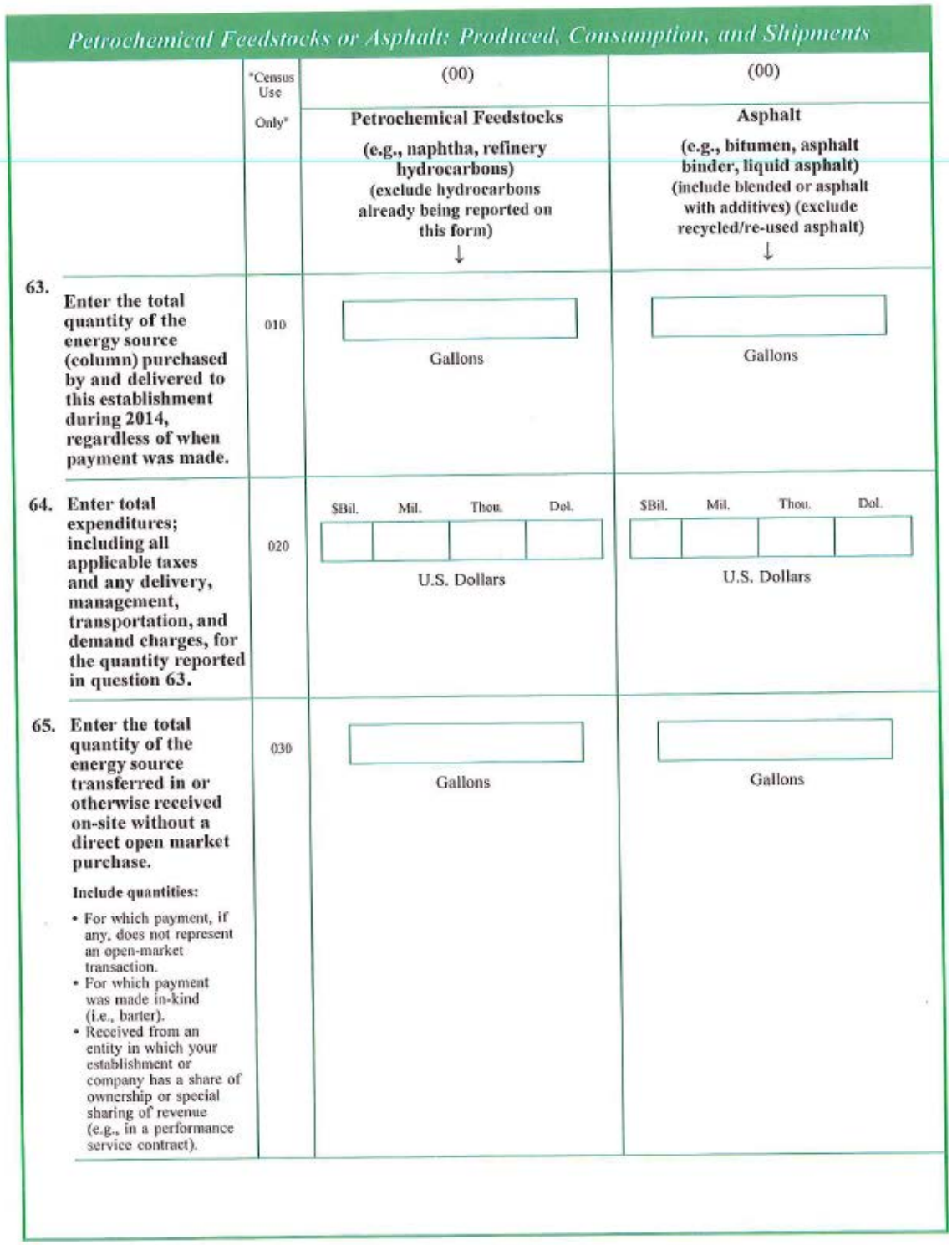
These seven draft questions adhered to 17 of these 18 guidelines; the exception being that questions did not have a clear navigational path.

Post expert review, it was clear that the navigational path issues could be improved by clearly identifying the start of these new questions (i.e., a new section), using blank space to separate questions versus lines, grouping similar items together, and aligning questions and their response spaces together in a single-column (Morrison et al., 2008). Of particular concern was the fact that the draft questions were designed in such a way that two energy types, or energy sources, were aligned close together but were technically unrelated and would have different respondents; petrochemical processing plants would respond to the first column and asphalt plants would respond to the second column (see Figure 1). This was further complicated by the fact that the questions were aligned horizontally, not vertically in a single-column. However, despite these concerns, the decision was made to cognitively test the questions without further modifications due to resource and time constraints. Any problems found with the draft questions would be addressed after cognitive testing.

2. Methods

To assess the efficacy of these seven draft questions specific to the flow of energy through petrochemical plants and asphalt plants, we conducted 11 cognitive interviews during June of 2014. Five of the interviews were conducted onsite with petrochemical plants in the Houston, Texas metropolitan area and six of the interviews were conducted onsite with asphalt plants in the Philadelphia, Pennsylvania metropolitan area. Due to time constraints, we did not recruit existing MECS respondents; instead, we recruited potential respondents listed on association websites (Association of Chemical Industry of Texas, Pennsylvania Association of Asphalt Material Applicators, and the New Jersey Asphalt Pavement Association). Respondents varied in terms of business characteristics (e.g., size, types of product output) and were not paid a monetary incentive to participate. In general, our interviews lasted about 45 minutes and included observers that are subject-matter experts.

Cognitive interviews are used in survey methodology to assess potential measurement errors. They attempt to "understand the thought processes used to answer survey items, and to use this knowledge to find better ways of constructing, formulating, and asking



Petrochemical Feedstocks or Asphalt: Produced, Consumption, and Shipments

	Census Use Only	(00) Petrochemical Feedstocks (e.g., naphtha, refinery hydrocarbons) (exclude hydrocarbons already being reported on this form) ↓	(00) Asphalt (e.g., bitumen, asphalt binder, liquid asphalt) (include blended or asphalt with additives) (exclude recycled/re-used asphalt) ↓
63. Enter the total quantity of the energy source (column) purchased by and delivered to this establishment during 2014, regardless of when payment was made.	010	Gallons	Gallons
64. Enter total expenditures; including all applicable taxes and any delivery, management, transportation, and demand charges, for the quantity reported in question 63.	020	$Bil. Mil. Thou. Dol. U.S. Dollars	$Bil. Mil. Thou. Dol. U.S. Dollars
65. Enter the total quantity of the energy source transferred in or otherwise received on-site without a direct open market purchase. **Include quantities:** • For which payment, if any, does not represent an open-market transaction. • For which payment was made in-kind (i.e., barter). • Received from an entity in which your establishment or company has a share of ownership or special sharing of revenue (e.g., in a performance service contract).	030	Gallons	Gallons

Figure 1: Draft petrochemical feedstocks and asphalt questions for the 2014 MECS.

survey questions" (Forsyth and Lessler, 1991). Cognitive interviews traditionally focus on the four steps of Tourangeau's (1984) cognitive response model: comprehension, retrieval, judgment, and communication/reporting. Comprehension refers to the respondent's interpretation and understanding of the question's language, structure, and grammar. In order to answer the question, a respondent must understand what information is being requested on the survey. Retrieval is the step where relevant information is obtained, either from records or from memory. The next step, judgment, describes the respondent's evaluation of the completeness or relevance of the data obtained. It is here that estimates can be made based on partial or incomplete data. The last step, communication or reporting, deals with mapping the response to the answer space provided and possibly altering the answer.

While Tourangeau's model is suitable for many household and social surveys, the business survey setting presents additional factors that must be considered. First, instead of or in addition to a reliance on memory, business surveys rely heavily on records and the information contained within them. Second, businesses tend to have distributed knowledge. Some people are experts in one type of information, while others maintain information about other aspects of the business. Third, competing priorities, both for the business and for the individual(s) completing the questionnaire, mean that the survey sometimes does not always receive the amount of attention that researchers and data collectors would like. Finally, businesses regularly authorize only a few individuals to release data. If the data provider is not authorized to release the data, an additional review step must be added to the response process. Tourangeau's model was expanded by Sudman et al (2000) to account for these factors.

In terms of interviewing technique for these seven questions, a hybrid think-aloud with retrospective probes was used (Willis, 2005). Respondents were encouraged to think-aloud while they answered the question and were then presented with follow-up retrospective probes. The retrospective probes focused on understanding how the representative of the business comprehended the question, any difficulties retrieving the information (i.e., availability of data in records, which department or person had access to the data), and judgment on what to report on the MECS. (See Figure 2 for an example of probes that focus on comprehension, retrieval and judgment.)

Can you tell me in your own words what this question is asking?

- How does this question compare to **Question 63**?
- What does the term "on-site" mean to you?
- How would you answer this question?
- Would it be easy or difficult to answer it?
- Is this information tracked in your records? If yes, tell me about it. What does it look like?

Figure.2: Example probes used during cognitive testing of the draft MECS questions.

Finally, we must note that the limited geographical scope of the tests, and the fact that these were potential respondents and not existing respondents, may influence the validity of our findings.

3. Findings

The cognitive testing of these seven draft questions specific to the flow of energy through petrochemical plants and asphalt uncovered a range of reporting problems. However, this paper will only focus on the reporting problems that cut across all questions tested.

3.1 Column-Formatting Structure

The decision to develop these seven questions occurred late during the survey-cycle planning process, and as such, financial resources and time were limited in their development. EIA made the decision to use the existing double-column layout of the MECS; petrochemical plants were asked to complete column 1 and asphalt plants were asked to complete column 2 (See Figure 3).

The majority of respondents were confused as to why they were being asked about both petrochemical feedstocks and asphalt. For example, half of the respondents at asphalt plants completed both columns during cognitive testing. As one respondent explained, “We use No. 2 Diesel oil at our plant”, which is why in the respondent’s mind they should complete the petrochemical feedstocks column. However, it became apparent that the No. 2 Diesel was being used not as an energy source to fuel the asphalt plant, but as a lubricant to maintain the machinery at the asphalt plant.

Respondents at petrochemical plants reacted similarly to the draft questions. Upon review, most of these respondents were confused by the columns, although they understood that the columns were asking about petrochemical feedstocks and asphalt separately. These respondents stated that they would not fill in any information in the asphalt columns, but were unsure as to why they were on the same page.

This confusion can be contributed to the double-column format and what Morrison and her colleagues call the “Gestalt Principle of Proximity” (Morrison et al., 2008; Morrison et al., 2010). As explained by Morrison, “Visual elements located closer together are perceived [by respondents] to be a group and more related to one another than elements placed further apart.” As seen in Figure 3, the double-column format grouped unrelated energy sources together, which resulted in an unclear navigational path.

3.2 Misunderstanding the intent of the questions

As the interviews progressed through the cognitive testing protocol, it also became clear that the reason some respondents wanted to complete the columns for both petrochemical feedstocks and asphalt is because they misunderstood the intent of the questions. Likewise, it was misjudged on how the petrochemical and asphalt industries worked. Although it was believed that petrochemical feedstocks and asphalt could be used as a fuel to power these plants, this in fact never happened. When pressed, one respondent asked, “Why would I burn my asphalt to make energy? We call it black gold!”

Because of this misunderstanding, it became clear during some of the interviews that a few respondents believed we were asking about their petrochemical feedstock and asphalt production, and not their use of petrochemical feedstocks or asphalt as fuels. In addition, for those few respondents that understood that we were asking about their fuel usage, they reported their electricity or natural gas usage (which they used as fuel to power their plant), as they did not naturally cognitively map petrochemical feedstocks and asphalt as materials that could be used to power their respective plants.

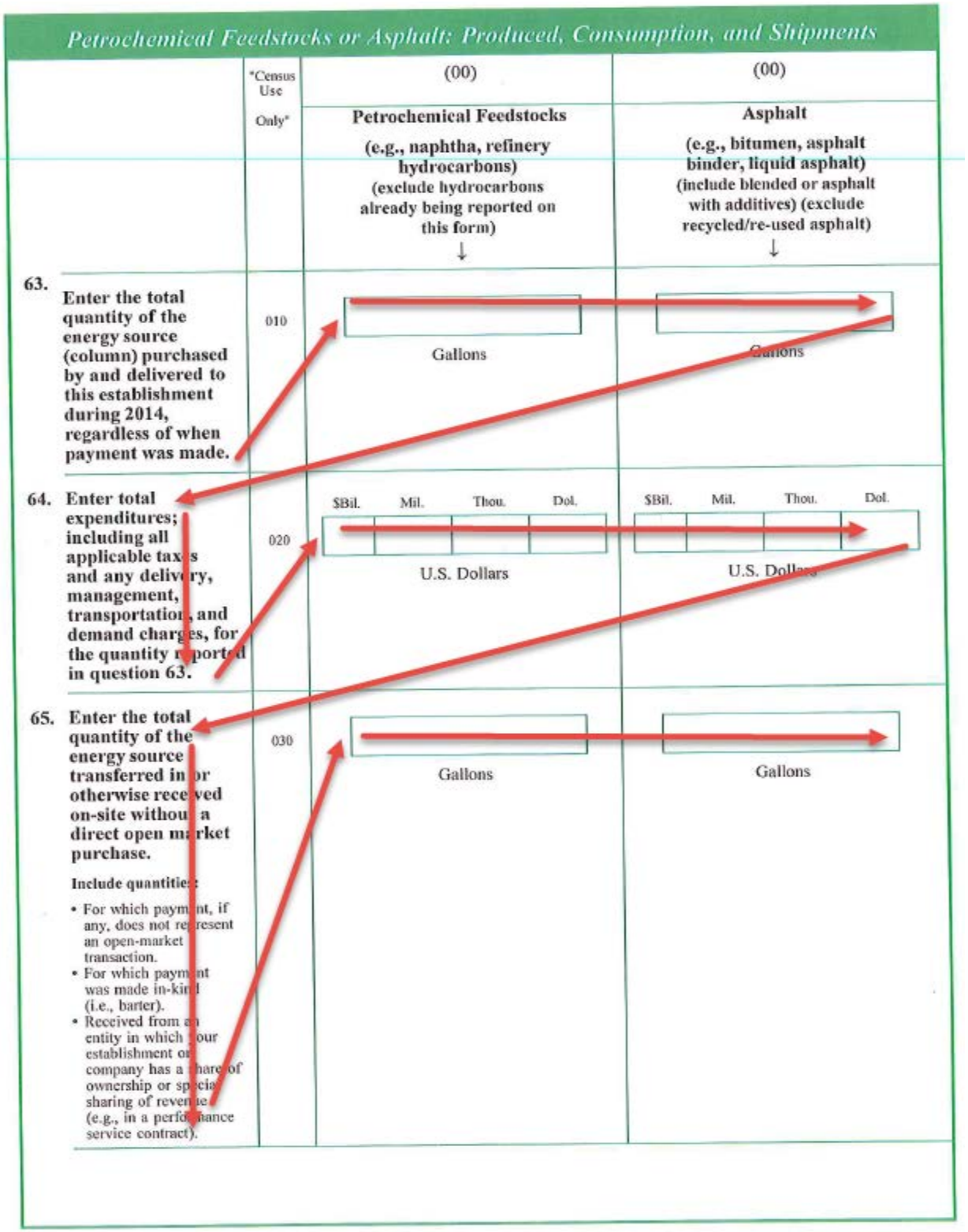
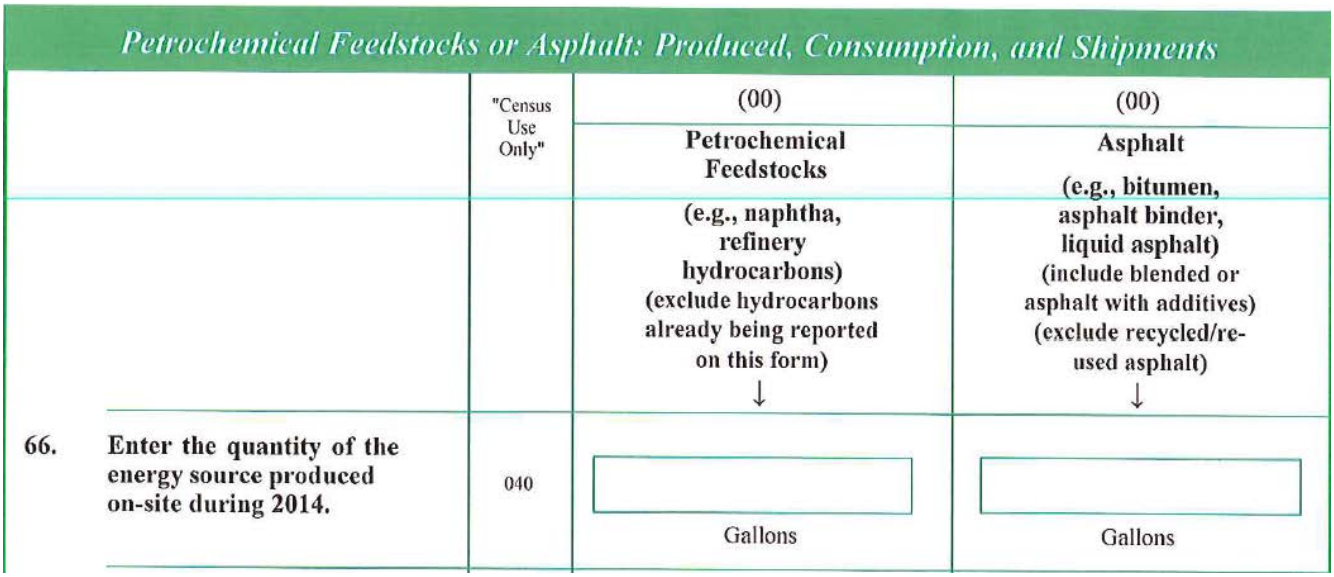


Figure 3: By grouping unrelated energy sources in columns side-by-side, respondents' navigational path went across the page versus going vertically down the columns.

3.3 Use of the term "energy source"

The misunderstanding of the intent of these questions was reinforced by the use of the term "energy source." Throughout the MECS questionnaire, the term "energy source" is used in the question stem to refer to the different types of energy that are asked in the double-column format to different respondents (see Fig. 3). When some respondents saw the term "energy source" in the question stem, they believed we were asking about their energy use of electricity, natural gas, fuel oil, and even solar. As such, they would respond to the questions by pulling out their utility records.

The fundamental problem remained that respondents did not think of petrochemical feedstocks and asphalt as "energy sources." To respondents, these materials were either components of a product or the end-result of production. As a result, a number of respondents answered both the petrochemical feedstocks and asphalt questions thinking that we were asking about their production and not their use of these materials to create energy for their plants. To underscore this fact, when thinking-aloud, some respondents at asphalt plants indicated that they would put the amount of asphalt their plant produced in Question 66, thinking that the question was asking for total production (see Fig.4).



Petrochemical Feedstocks or Asphalt: Produced, Consumption, and Shipments

		"Census Use Only"	(00) Petrochemical Feedstocks (e.g., naphtha, refinery hydrocarbons) (exclude hydrocarbons already being reported on this form) ↓	(00) Asphalt (e.g., bitumen, asphalt binder, liquid asphalt) (include blended or asphalt with additives) (exclude recycled/re-used asphalt) ↓
66.	Enter the quantity of the energy source produced on-site during 2014.	040	Gallons	Gallons

Figure 4: Some respondents reported their production of petrochemical feedstocks and asphalt used in their products versus petrochemical feedstocks and asphalt used to burn as energy to run their plants.

4. Discussion

The cognitive testing for these seven draft questions specific to the flow of energy through petrochemical plants and asphalt plants found three reporting problems, or sources of measurement error, that cut across all questions tested. First, the double-column formatting compelled some respondents to report for both petrochemical feedstocks and asphalt, when respondents should only report for their specific energy. Second, some respondents misunderstood the intent of the questions and reported production or fuel use of other energy types (i.e., mainly electricity and natural gas), when they should have reported for the use of petrochemical feedstocks and asphalt at their plant. Third, that the use of the term "energy source" in the question stem fed into this confusion that the questions were asking about the fuel use of other energy

types (i.e., mainly electricity and natural gas). This was further complicated by the fact that none of the respondents that participated in cognitive testing burned petrochemical feedstocks and asphalt as fuel.

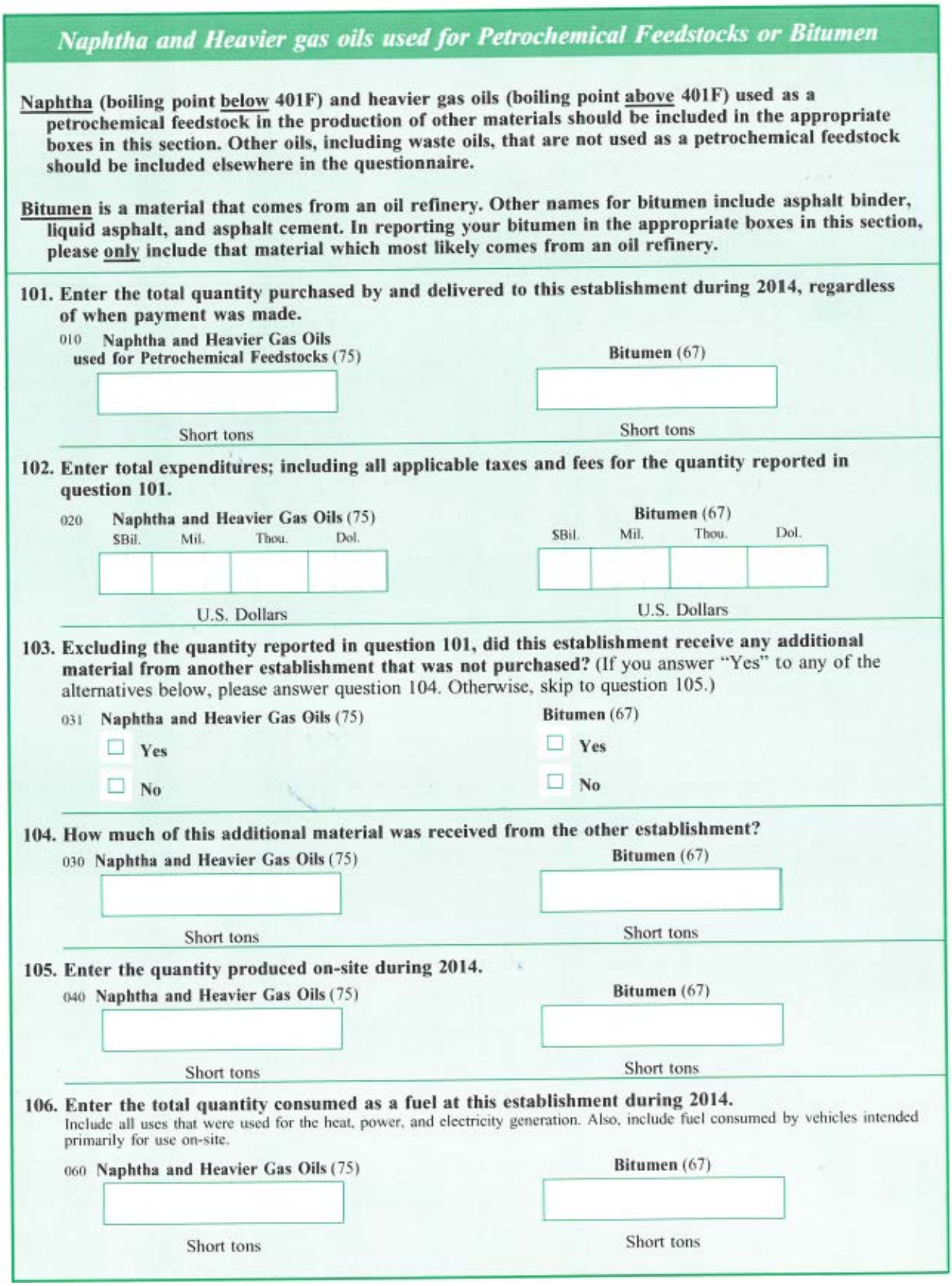
To address these findings, we first recommended that since cognitive testing found that respondents do not burn petrochemical feedstocks and asphalt as fuel for their plants, EIA should reconsider if this data should even be collected. However, the decision was made to collect this information regardless of the finding in an attempt to improve the EIA's manufacturing energy use model.

With that decision made, we then focused on improving the draft questions. First, we recommended removing the double-column question format in the paper questionnaire and asking the petrochemical feedstocks and asphalt questions separately using a single-column format. We suggested that the petrochemical feedstocks and asphalt columns be more explicit and read, "bitumen received from the supplier for energy use" or something similar that is specific to the intent of the questions. Finally, concerning the term "energy source" in the question stem, we recommended using the specific energy type (i.e., napthas or bitumen) to assuage any confusion respondents may have in interpreting the intent of the question. In summary, we wanted to remove formatting obstacles and provide clearer language to make the intent of these questions more apparent.

However, faced with resource, technology, and time constraints, EIA and the Census Bureau were only able to make slight modifications to the double-column formatting of the paper questionnaire (see Figure 5). The double-column formatting was replaced with a single-column format with two response options underneath. However, the burden was still on the respondent to respond to the energy source only relevant to their plant. To be more explicit in our data request, the "petrochemical feedstocks" column label was replaced with "naptha and heavier gas oils used for petrochemical feedstocks." Likewise, "asphalt" was replaced with "bitumen" in order to downplay a term that was more frequently associated with production. Finally, we removed the term "energy source" from the question stem to assuage confusion associated with other energy types that may be used as a fuel.

In the MECS electronic questionnaire, a screener question was used to ask which energy types the plant used as a fuel in calendar year 2014. The intent was that by having a screener question, respondents would only see the energy types applicable to them and as such, reduce misreporting. Because we felt like there would be reduced measurement error in the MECS electronic form, EIA and the Census Bureau adopted a web first approach. Specifically, we decided to direct respondents to the web instrument in the initial survey letter. The paper questionnaire was only sent out for nonresponse follow-up.

These overall findings contribute to the broader questionnaire design literature and specifically to those related to business surveys. Our research has shown that survey methodologists, when designing surveys, should create a clear navigational path for respondents in the form of a single-column format. Furthermore, our findings illustrate that designers of survey questions should be explicit in their survey requests to assuage the chance of respondents misinterpreting what is being requested. Finally, qualitative research such as early-stage scoping should be started early in the survey lifecycle so that the data requests closely match how respondents think of constructs, which can only lead to reduced measurement error and reduced cognitive burden for the respondent.



Naphtha and Heavier gas oils used for Petrochemical Feedstocks or Bitumen

Naphtha (boiling point below 401F) and heavier gas oils (boiling point above 401F) used as a petrochemical feedstock in the production of other materials should be included in the appropriate boxes in this section. Other oils, including waste oils, that are not used as a petrochemical feedstock should be included elsewhere in the questionnaire.

Bitumen is a material that comes from an oil refinery. Other names for bitumen include asphalt binder, liquid asphalt, and asphalt cement. In reporting your bitumen in the appropriate boxes in this section, please only include that material which most likely comes from an oil refinery.

101. Enter the total quantity purchased by and delivered to this establishment during 2014, regardless of when payment was made.

010 **Naphtha and Heavier Gas Oils used for Petrochemical Feedstocks** (75)

Short tons

Bitumen (67)

Short tons

102. Enter total expenditures; including all applicable taxes and fees for the quantity reported in question 101.

020 **Naphtha and Heavier Gas Oils** (75)

$Bil. Mil. Thou. Dol.

U.S. Dollars

Bitumen (67)

$Bil. Mil. Thou. Dol.

U.S. Dollars

103. Excluding the quantity reported in question 101, did this establishment receive any additional material from another establishment that was not purchased? (If you answer "Yes" to any of the alternatives below, please answer question 104. Otherwise, skip to question 105.)

031 **Naphtha and Heavier Gas Oils** (75)

☐ **Yes**

☐ **No**

Bitumen (67)

☐ **Yes**

☐ **No**

104. How much of this additional material was received from the other establishment?

030 **Naphtha and Heavier Gas Oils** (75)

Short tons

Bitumen (67)

Short tons

105. Enter the quantity produced on-site during 2014.

040 **Naphtha and Heavier Gas Oils** (75)

Short tons

Bitumen (67)

Short tons

106. Enter the total quantity consumed as a fuel at this establishment during 2014.

Include all uses that were used for the heat, power, and electricity generation. Also, include fuel consumed by vehicles intended primarily for use on-site.

060 **Naphtha and Heavier Gas Oils** (75)

Short tons

Bitumen (67)

Short tons

Figure 5: Revised MECS questions incorporating results from cognitive testing.

5. Future Research

EIA made the decision to collect all petrochemical feedstocks and asphalt data from the petrochemical and asphalt plants rather than continue to include them as part of the non-energy source shipment estimate from the petroleum refineries. It was assumed that the collection of data using these seven draft questions specific to the flow of energy through petrochemical plants and asphalt plants would yield more accurate data than estimating it through the EIA-810 data. However, is this assumption valid? Our next step in the research is to look at the quality of the data received from respondents, including response data and paradata, to get a sense of potential measurement error. We will also work with EIA's estimation model staff to see if the collected data improves the accuracy of the energy use model. This will be done by reviewing the collected data against historical estimates. In addition, we will compare the collected data to the shipment data reported on the EIA-810.

At the writing of this paper, the 2014 MECS is currently in data collection. As such, it is too early to tell if there is item nonresponse with these new questions by the companies with the North American Industry Classification System (NAICS) codes that should be completing them (i.e., petrochemical plants and asphalt plants). However, it is our expectation that certain plants, with certain NAICS codes, should be completing these new questions. If they are not, what does that mean? Does it corroborate our finding that these respondents do not think of petrochemical feedstocks and asphalt as an energy source? Did these respondents not check petrochemical feedstocks and asphalt as energy types listed in the screener questions of the electronic survey?

In addition to item nonresponse, these new questions could have an impact on the survey's overall response rates. The 2014 MECS is not complete in its data collection, but thus far, the cumulative response rate for the 2014 MECS is slightly lower (2%), but on par, with the cumulative response rate for the 2010 MECS. However, there are many variables, in addition to these new questions, that could be influencing that slightly lower response rate. First, for the 2010 survey, we conducted a pre-mailing to the respondents, which we did not do for the 2014 MECS cycle. Second, the timing of the 2010 mailing was one month earlier than the 2014 mailing. For the MECS data collection in 2018, we would like to embed experiments to see what factors are influencing the survey's overall response rates. This includes experiments that may explore the impact of these new questions on the survey's overall response rates.

Even though there are lingering questions about the validity of the data collected from these seven questions, EIA's estimation model staff are more confident in the collected data than in the estimates that were previously used. As a result, in the long-term EIA's estimation model staff may want to switch the classification of asphalt in the energy use model and instead, put it under manufacturing. The result will be a better alignment of the overall energy use model with how the petrochemical and asphalt industries use energy.

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