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Energy Accounting and Renewable Energy Resource Valuation—Proof-of-Concept for the United States

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Pilot Physical and Monetary Energy Flows Account for the U.S.

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1. Introduction

Energy, in its various forms, keeps the economy moving. All economic activity consumes energy; modern economic development has its roots in technological advances that greatly expanded humans' ability to capture, store, and utilize energy. In recent years, debates regarding fossil fuels, nuclear energy, and renewable energy have become central to public discourse and policymaking. Good decision-making hinges on both public and private stakeholders understanding *how* energy flows through the economy and how its use supports industries and households in their economic activity.

Environmental accounting offers a framework to support this understanding, by placing economic activities in the context of their underlying physical processes, such as energy use. In the recent *National Strategy to Develop Statistics for Environmental-Economic Decisions* (*SEED*) both physical and monetary flow accounts for energy are recommended (OSTP, OMB, DOC, 2022). In this paper we present an early-stage pilot combined physical energy flow account (PEFA) and monetary energy flow account (MEFA) for the United States, covering the years from 2017–2022. We discuss challenges encountered and solutions identified in compiling the account, and briefly demonstrate analytical applications. We present summary

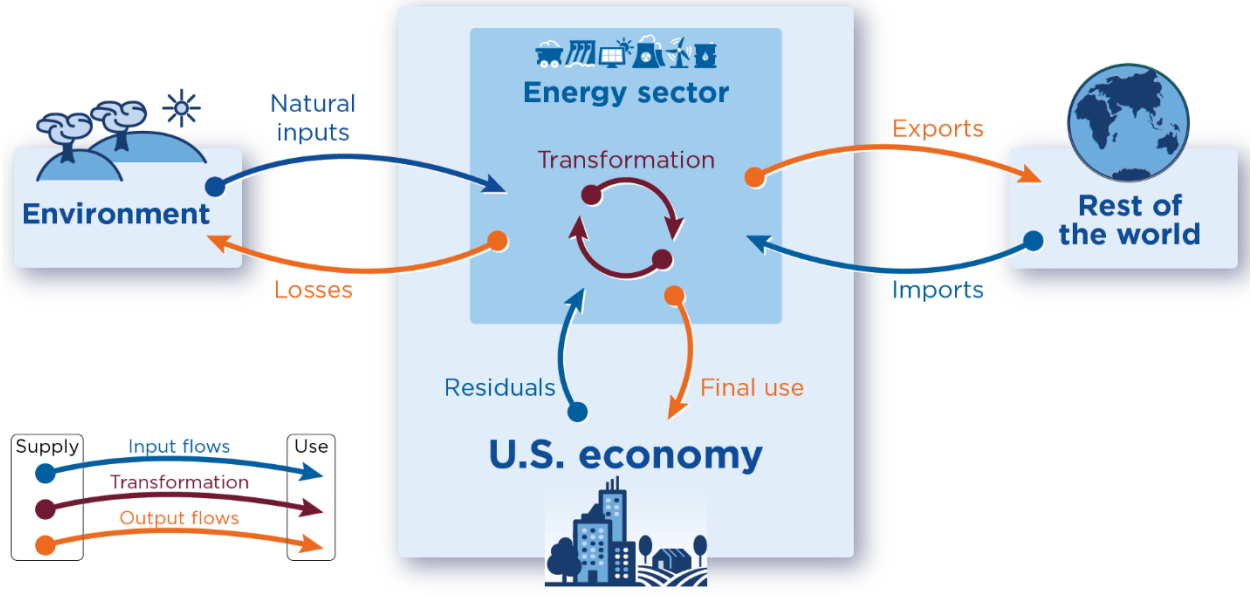

Figure 1. Stylized Diagram of Energy Flows in the U.S. Economy.

supply and use tables for both physical and monetary energy flows in 2022 (more detailed tables for all years are found in an online data appendix) and show the different patterns visible in the energy used for manufacturing, households, and exports over the period of the COVID-19 pandemic and its aftermath.

Figure 1 is an abstracted diagram showing the major categories of energy flows into, within, and out of the economy. Energy may enter the economy from nature (renewable or mineral energy resources), the rest of the world (imports of energy products), or the rest of the domestic economy (waste to be used as fuel). Final users of energy include businesses and households in the domestic economy, exports to the rest of the world, and nature (in the form of extraction, transmission, and distribution losses). A particularly important group of flows is the transformation flows that occur within the energy sector, as energy products are transformed into other energy products; the most prominent examples are electric generation and petroleum refining, with heat generation and ethanol biofuel production also included in this pilot. Figure 1 shows the physical processes to be modeled by the PEFA tables; we hope this relationship is clearly visible in the compiled account.

Following this introduction, section 2 discusses relevant literature and accounting standards, including the *System of Environmental-Economic Accounting* (SEEA), as well as other countries' work on energy accounts. Section 3 discusses the data sources and methods used in compiling the pilot PEFA and MEFA. Section **Error! Reference source not found.** presents summary results and findings, and section 6 concludes with a discussion of further work and recommended refinements to the accounts.

2. Literature and Standards Review

For this combined physical and monetary energy flows account, stakeholders may come from a variety of backgrounds. To set the stage for the rest of this paper, section 2.A reviews the statistical standards that influence the compilation of this account and section 2.B reviews related efforts in the U.S.

A. Statistical Standards

Data quantify reality in numeric form and statistics summarize data into simpler models for understanding. Statistical standards constrain these models so that statistics will be consistent and comparable across the domain of that standard. For example, the Intergovernmental Panel on Climate Change sets the standards used by countries around the world to report their greenhouse gas emissions as required by the Paris Agreement. These standards ensure that countries' reported emissions are consistent and comparable across time and with other countries' reported emissions.

The goal of environmental accounting is to analyze the economy and environment together. Closely related statistical standards must be used, so that the environmental and economic statistics are consistent and comparable with each other. The internationally accepted statistical standards[1] important to the compilation of this pilot energy flows account include the *System of National Accounts* (SNA), for economic accounting; the *System of Environmental-Economic Accounting* (SEEA), for environmental accounting; and *International Recommendations for Energy Statistics* (IRES), for energy balance statistics.

i. System of National Accounts

SNA is the internationally accepted standard for economic accounting, and underlies statistics such as GDP, gross output, and value added. SNA defines the economy of a nation, the agents that make up the economy, and how the goods and services exchanged in the economy are to be valued. The U.S. implementation of SNA, compiled by the Bureau of Economic Analysis (BEA), includes the National Income and Product Accounts (NIPAs) as well as Supply and Use Tables (SUTs) that are important sources of economic data for both the pilot PEFA and MEFA. We discuss here some particularly relevant SNA concepts.

The SNA defines a nation's economy as consisting of all economic agents (households and business establishments) that are *residents* of the nation (SNA 4.1). An agent is considered to reside in a nation if the agent's "[center] of predominant economic interest" is in that nation for a period of at least one year. If a foreign firm owns or leases property to conduct long-term (greater than one year) operations in a nation, those operations are considered to be conducted by a separate economic agent which is a resident of the nation (SNA 4.15c). This definition of the economy contrasts with definitions based on territory (based on economic agents located physically within the national territory) or nationality (based on the legal nationality of agents, which may differ from their residency). In practice, however, for a nation as large as the U.S., residency- and territory-based definitions are very similar, differing primarily with respect to transportation industries, since these are industries which regularly engage in economic activity abroad without necessarily owning or leasing property.

Individual establishments that are engaged in roughly the same type of productive activity are conceptually grouped together into *industries* (SNA 5.46)[2]. A given good or service may be produced by many different industries. For example, electricity may be produced by a nuclear power plant or a widget

[1] All promulgated by the United Nations (UN).

[2] In the U.S. these industries are classified according to the North American Industry Classification System (NAICS) and each establishment's primary industry is self-identified.

factory with solar panels on the roof. As in the case of this hypothetical widget factory with solar panels, an establishment may produce multiple goods or services. Some of these goods and services may be produced for sale in markets, while others may be produced for the establishment's own use. For example, a wholesaler might own and operate a truck to transport goods to purchasers.

Goods and services in the economy are valued, whenever possible, at the price for which they (or similar goods and services) are traded in markets. When such a market price is not available, goods and services are valued at their total cost of production (SNA 6.130). Since energy products are generally traded in markets, valuation is less complicated for this account than for many other environmental accounts.

In addition to the primary series of economic accounts, SNA incorporates flexible satellite accounts (also called thematic or extended accounts) to allow analysis that would be impossible using only the standard accounts. Such accounts may include a subset of the transactions recorded in the main accounts, such as transactions related to outdoor recreation, or may adjust the standard SNA boundaries and definitions, such as to measure nonmarket household production. Both conceptually and as implemented in this pilot, the MEFA is an SNA satellite account of the first type (a subset of transactions already in the economic accounts), akin to existing BEA-compiled satellite accounts.

ii. System of Environmental-Economic Accounting

The *System of Environmental-Economic Accounting* (SEEA) is a companion standard to the SNA, for environmental accounting. A primary purpose of SEEA is comparability between environmental and economic accounts. As much as possible, SEEA uses the same boundaries and definitions as the SNA, including the residency-based definition of the economy and the valuation approaches discussed above. The biggest differences are that SEEA accounts may measure things that lie outside the economy (such as water, waste, or emissions) and that most SEEA accounts measure physical quantities in addition to or instead of monetary quantities. Three broad categories of accounts are included in SEEA: physical flows, environmental activities, and environmental assets.

Physical flow accounts measure the flows of materials or substances important to the relationship between the economy and the environment. Most of these flows, such as extracted minerals, solar/wind energy used to generate electricity, or pollution, cross the environmental-economic boundary. However, some environmentally important flows occurring within the economy are also included, such as electricity

and other energy products. Flows occurring within the environment[3] are specifically excluded (SEEA 3.23). Physical flow accounts may be accompanied with corresponding monetary flows, especially when a large portion of the flows occur within the economy, as is the case with energy flows. The UN Statistics Division has published a manual, *SEEA-Energy*, providing specific guidance on physical and monetary energy flow accounts.

Environmental activity accounts measure the value of goods and services produced within the economy that have the purpose of environmental protection or resource management. Like the MEFA, environmental activity accounts are a strict subset of the SNA economic accounts and could be considered a thematic/satellite account under SNA definitions.

Environmental asset accounts are related to ecosystem accounts[4], but measure individual, specific environmental assets such as water or timber, without considering the network of relationships between these assets and other features of their ecosystems.

iii. International Recommendations for Energy Statistics

The *International Recommendations for Energy Statistics* (IRES) are the international standard for energy balance statistics. There are two major differences between IRES-consistent energy balances and SEEA-consistent energy accounts. First, the domain of energy balances is a nation's *territory*, where the domain of an energy account is the nation's *residents*. Second, energy balances are organized around different types of energy use activities or purposes, while energy accounts are organized around the same industries that are found in the economic accounts. Additionally, there are differences in the definition of some terms and in the presentation of the compiled statistics. The U.S. does not currently publish IRES-consistent energy balances.

An important component of IRES is the *Standard International Energy Product Classification* (SIEC). This classification is also used in SEEA-Energy to classify energy products, which constitute most flows in the energy account with the exception of some inputs from nature or the rest of the economy.

B. Related Efforts

i. U.S. Energy Statistics

[3] Trans-boundary pollution flows, formation of secondary pollutants through reactions between primary emitted pollutants, etc.

[4] Covered by *SEEA Ecosystem Accounts*, a (partially accepted) companion standard to SEEA and the SNA.

The Energy Information Administration (EIA) conducts surveys and compiles statistics on energy production and use throughout the U.S. economy. As detailed in section 3.A below, these are the primary data source for the pilot PEFA. Some primary areas in which these statistics diverge from SEEA energy accounting are that they include energy flows that occur within U.S. territory, regardless of the residency of the economic agents involved, and that they are not generally organized by industry[5].

ii. Statistics for Environmental-Economic Decisions

Recognizing the value of statistics on the interaction between the economy and the environment for good decision making, the U.S. Office of Science and Technology Policy (OSTP), Office of Management and Budget (OMB) and Department of Commerce (DOC) have developed a fifteen-year plan, *Statistics for Environmental-Economic Decisions* (SEED), to develop a suite of SEEA-consistent environmental accounts for the U.S. (OSTP, OMB, DOC, 2022). This plan involves many agencies across the federal government, and includes existing pilot accounts for water (Bagstad, et al., 2020), land (Wentland, et al., 2020), environmental goods and services (Fixler, Hass, Highfill, Wentland, & Wentland, 2023), and air emissions (Chambers, 2023). Other pilot accounts, in addition to the pilot energy account described in this paper, are in progress.

The energy account is closely connected to other accounts within the suite of environmental accounts envisioned under SEED, especially the air emissions account. A large portion of the greenhouse gas emissions recorded in the air emissions account result from the burning of fuels for energy, and the energy account provides an important link in the chain that connects industry and household economic activity, through energy requirements, to greenhouse gas emissions. Both the PEFA and MEFA will also be useful in estimating the value of renewable energy flows, the first step in valuing renewable energy assets for ecosystem accounts, and in showing how those flows are attributable to industries and households.

3. PEFA Data and Methods

A. Data

The primary data sources for the pilot PEFA are from EIA: the Monthly Energy Review (MER) and Form 923 survey data on electric generating units (EIA-923). Secondary data sources are needed to disaggregate energy flows reported only at an aggregate level in the primary data sources. These secondary data

[5] With some exceptions; as noted below, EIA publishes some microdata on electric generating units that includes industry (NAICS) codes for the establishments where they are located.

sources include BEA's published SUTs and detailed stock estimates of fixed assets and consumer durable goods, Bureau of Transportation Statistics (BTS) Transportation Satellite Accounts (TSAs) and National Transportation Statistics (NTS) tables, and academic studies.

i. EIA Monthly Energy Review

The MER is one of EIA's flagship statistical products. It is published monthly, as the name suggests, and includes a number of tables with data on energy production, transformation, consumption, and trade within U.S. territory. Source data are drawn from several EIA surveys and models. Historical data are re-estimated when methodological or data source changes are made, so the MER is an internally consistent time series of energy statistics.

MER data are organized by type of energy product (petroleum, electricity, renewable energy, etc.) and are most detailed for the initial stages of energy production: the extraction of petroleum/natural gas or the generation of electricity, for example. Final use of energy is divided into just four "sectors": industrial, commercial, transportation, and residential. Attributing the energy flows reported for these sectors to the industries they consist of is one of the major tasks in compiling the pilot PEFA.

Statistics in the MER are reported in a variety of different units, depending on the energy product in question. These may be units of mass (short tons of coal), volume (cubic feet of natural gas, barrels of petroleum, etc.), or energy/heat content (British thermal units or megawatt-hours)[6]. For accounting purposes, a single energy unit (petajoules for this pilot PEFA) needs to be used, to allow for summing across different types of energy products. Whenever possible, MER data that are already in energy units are used, as energy units are easily converted. Unfortunately, some MER data, particularly on energy transformations such as petroleum refining, are available only in mass or volume units, not energy units. The MER includes a table of heat content factors for converting these mass/volume units to energy units, but the conversion is still not always straightforward, and may be the cause of small discrepancies in the PEFA tables.

ii. EIA Form 923

One of the surveys underlying the MER is EIA's Form 923 survey of electric generating units. EIA also publishes the microdata from this survey, which are used directly in compiling this pilot PEFA. The form 923 microdata are very useful for accounting, as they include every utility-scale generating unit in the U.S.,

[6] EIA uses the gross heat content, or higher heating value, as opposed to the net heat content or lower heating value (more commonly used in Europe) when expressing the energy content of fuels. This carries over into the pilot PEFA.

providing NAICS code, type and quantity of fuel used, energy content of fuel used, and quantity of electricity generated each year. This enables relatively easy accounting for both primary electric generation from renewable sources (solar, wind, etc.) and secondary electric generation (using other energy products such as coal or petroleum to generate electricity).

iii. BEA Benchmark Use Table

BEA's benchmark Use table provides data on expenditures for energy products used as intermediate inputs by industries, or by households. As discussed below, these data are used for attributing energy flows reported in the MER to the industries that make up the reported sector. This attribution relies on the assumption that different industries face similar prices for a given energy product (as otherwise arbitrage would result). BEA publishes a new benchmark Use table every five years; this pilot PEFA uses the 2017 benchmark Use table.

iv. BEA Detailed Fixed Asset and Consumer Durable Goods Tables

BEA publishes detailed estimates of fixed asset stocks, by industry and asset type, together with detailed estimates of consumer durable goods stocks. These data are used for attributing energy flows reported in the MER when there is not a readily associated intermediate input, but there is a type of asset that is closely connected to the energy flow. For example, solar and wind energy generation in the industrial and commercial sectors is attributed using stocks of solar and wind structures from the detailed fixed asset table. Similarly, passenger car and light truck stocks from the detailed consumer durable goods table and detailed fixed asset table are used to attribute energy use by light vehicles across industries and households. These data are available annually.

v. BTS Transportation Satellite Accounts

Transportation activities are a major category of energy use in the economy. While most transportation services are produced by the various transportation industries (air, water, road, rail, and pipeline) a significant percentage, especially in road transportation, are produced by businesses in other industries for their own use. The energy used in producing these "own account" transportation services should be attributed to the industry producing them, not to the transportation industry associated with the mode of transportation. Fortunately, the TSAs are produced annually by the BTS specifically for the purpose of estimating the value of own account transportation services produced by industries. The TSAs are used in the pilot PEFA to attribute energy flows in the transportation sector to the industries that produce these flows, in proportion to their contribution to the total output of transportation services (transportation industry output plus the total value of own account transportation services produced).

vi. BTS National Transportation Statistics

The NTS is one of BTS's flagship statistical reports, containing data on every aspect of the U.S. transportation system, from statistics on road networks, maintenance status, and safety record to environmental impact sand economic performance. For this pilot PEFA, it is the NTS statistics on energy use by mode of transportation that are most valuable. These statistics break down each of the main modes of transportation (air, water, road, etc.) to provide a detailed picture of transportation energy use. For example, air transportation is broken down into certificated air carriers, general aviation using jet fuel, and general aviation using aviation gasoline, and road transportation is broken down by size of vehicle (for highway travel) and fuel type (for mass transit). These data are published annually.

vii. Academic Studies

Geothermal energy may be used to generate electricity, directly as a source of heat for industrial processes, and as a heatsink/source for geothermal heat pumps (the largest use of geothermal energy). Residential us of geothermal energy is assumed to fall into this last category. To understand larger scale, direct (non-heat pump) use of geothermal energy, we use a 2010 academic study (Lund, Gawell, Boyd, & Jennejohn, 2010) that conducted a census of such geothermal energy installations. These installations are classified into one of ten categories, including greenhouse heating, district heating, snow melting, and agricultural drying. For each category, the total installed geothermal capacity and actual energy use are reported as of December 31, 2009.

B. Methods

i. Industry Attribution

Many energy flows in the MER, especially final uses of energy, are attributed to one of a few sectors: industrial, commercial, residential, transportation, or electric power. While the residential and electric power sectors have a mostly straightforward correspondence with BEA industries and institutional sectors (the electric generation industry and households, respectively), the industrial and commercial sectors each consist of many industries, united more by their general energy use profile than by anything else. Attributing these flows to the industries that make up the MER sectors is done proportionally, using other proxy measures of energy use, such as expenditures on energy products or stock of related fixed assets. For example, electricity use by the "Commercial Sector" is attributed to the industries in that sector in

proportion to their expenditures on electricity, as found in the BEA Use table[7]. Identifying appropriate proxy measures is one of the primary tasks in compiling the PEFA and is an area for continued research and refinement.

ii. Residency Adjustments

The primary source data for the pilot PEFA are compiled on a territory basis, meaning that they include energy flows that occur within U.S. territory; the residency of the economic agents involved is not considered. The necessary conceptual adjustment from territory-based statistics to residency-based accounts includes three steps:

1. Reclassify the use of flows to nonresidents on U.S. soil from consumption by industry to exports.
2. Add flows to U.S. residents abroad to the account as a use by the appropriate industry.
3. Add the flows from step 2 into the account on the supply side as imports.

We assume that the residency adjustment is trivial for the household sector due to the size of the U.S. economy relative to the number of non-resident households. We likewise assume that the residency adjustment is negligible for non-transportation industries due to the way that foreign holdings of real property such as land or factories are accounted for under the SNA (see section 2.A.i for details). For transportation industries, however, the residency adjustment may be substantial.

Air Transportation

The air transportation industry may be divided into two categories: certificated commercial carriers and general aviation. These are defined according to which part of Federal Aviation Administration rules their operation is licensed under. Roughly, general aviation corresponds to civilian, non-commercial flight, while an air carrier certificate under 14 CFR 135 (small commercial carriers) or 14 CFR 121 (large commercial carriers) is required for commercial operations (charging to carry passengers or freight). For this reason, we assume that for-hire air transportation is carried out by certificated carriers, while own-account air transportation is carried out under general aviation licenses[8]. We also assume that all international air transportation operations are carried out by certificated air carriers[9]. BTS collects and publishes data

[7] This attribution implicitly assumes that all industries face the same price for electricity.

[8] In the 2019 NTS table 4.6 certificated carriers are responsible for 87% of air transportation fuel use, while in the 2019 TSAs for-hire air transportation is responsible for 85% of air transportation output.

[9] We have not identified a good data source to evaluate this assumption or to estimate the appropriate residency adjustment for general aviation.

specifically on fuel consumption by large U.S. carriers for both domestic and international operations. Since these data line up directly with the residency basis required for the PEFA, we use them in place of the NTS data on fuel use by certificated carriers, which is restricted to domestic operations only. This takes care of step 2 (recording flows to U.S. residents abroad as use by the appropriate industry). Adding the international operations portion of these energy flows to the PEFA supply table under imports takes care of step 3. We are still working on identifying an appropriate data source for step 1, reassigning flows to foreign residents in U.S. territory from industry consumption to exports.

Water Transportation

For water transportation, the residency adjustment is most relevant in the case of marine shipping. Lacking data on fuel *consumption* by U.S. marine carriers (like BTS publishes for air carriers), we use unpublished BEA data on fuel *expenditures* by foreign carriers in the U.S. and U.S. carriers abroad. We divide these expenditures by the world average price of bunker fuel[10] to obtain an estimate of the flows of energy to foreign residents (exports, step 1) and to U.S. residents (use by industries, step 2, and supply via imports, step 3) needed for the residency adjustment.

Truck Transportation

We have not been able to identify and acquire data on fuel consumption, fuel expenditures, or vehicle use for U.S. trucks operating abroad (Canada and Mexico) or foreign (Canadian or Mexican) trucks operating in the U.S. Consequently, we do not make a residency adjustment in the pilot PEFA for truck transportation, leaving it as an area for future research.

Rail and Pipeline Transportation

Because rail and pipeline operators own (or have long-term leases) on the land and fixed assets that make up the railroad or pipeline[11], we consider all operations in the rest of the world to be conducted by foreign residents (either foreign businesses or foreign affiliates of U.S. multinational enterprises) and similarly consider all operations in U.S. territory to be conducted by U.S. residents (either U.S. businesses or U.S. affiliates of foreign multinational enterprises). Therefore, by definition no residency adjustment is needed for these industries.

[10] Obtained from ShipandBunker.com.

[11] See section 2.A.i for a discussion of the relevant SEEA principles.

4. MEFA Data and Methods

A. Data

The primary data source for the pilot MEFA is detailed unpublished data from BEA's supply and use tables (SUTs) for 2017-2022. These SUT data decompose industry output for the entire US economy into more than 5,300 distinct product categories. The fine product-level detail of these data provide insight into the internal workings of the US economy by detailing the contribution of specific industries and commodities to gross output and value added.

B. Methods

To construct the pilot MEFA, we identify and isolate the production of, and spending on, energy products that are already present in the SUTs. These pilot estimates are akin to other BEA thematic satellite accounts that isolate production of a specialized area of the economy, such as the digital economy, the outdoor recreation economy, and the space economy. Satellite accounts are particularly useful to understand economic activity that is not easily identifiable under the standard NAICS industry classification or for activity that is spread across multiple NAICS industries. BEA's satellite accounts typically do not include full supply and use tables, however, so these pilot energy account estimates go a step further by showing this additional detail.

The products included in the monetary energy SUTs are listed by SEEA category in Appendix Table 1. We also indicate in the table whether or not the product is considered an energy product. We used the SEEA Energy manual (United Nations Statistics Division, 2019) as a guide to decide which product categories to include. Product categories that included both energy and non-energy products were excluded from the pilot estimates. These categories included sewage treatment facilities and government sewerage systems (partial overlap with SIEC waste category) and manufacturing of wood chips and reconstituted wood products (partial overlap with SIEC biofuels category). Excluding these categories means we are undercounting the supply and use of energy products, though we do not believe these products represent a significant portion of the total.

Due to the composition of the internal SUT data, taxes could not easily be uncoupled from the industry supply and use values. Therefore, our tables differ slightly from the SEEA tables in that taxes are included with basic prices in the supply table and with intermediate consumption in the use table. Future improvements to these pilot estimates could separate out taxes to better align with the SEEA tables.

5. Results

A. PEFA

Full physical flow SUTs are under development for the PEFA, and the current iteration is included in the data appendix. We believe this iteration covers nearly everything the pilot PEFA should cover (with exceptions noted below), but the reader will quickly observe that these SUTs are not quite balanced (that is, supply does not equal use). This is a crucial area of ongoing work; other areas for refinement are discussed in section 6. We present some preliminary results and statistics derived from the current iteration of the physical SUTs.

Table 1 is a subset of the physical Supply table for 2022 showing primary energy inputs to the U.S. energy sector from nature, the rest of the world, or the rest of the U.S. economy. Table 2 shows final uses, including losses from electric generation, transmissions, and distribution (under "Energy Residuals").

Table 1. Physical Primary Inputs of Energy to the U.S. Economy, 2022

Energy Product	Nature	Imports	Residuals	Total	Percentage
Biofuels	4,065	77	0	**4,141**	*3.3%*
Geothermal energy	125			**125**	*0.1%*
Hydroelectric energy	917			**917**	*0.7%*
Solar energy	807			**807**	*0.6%*
Wind energy	1,563			**1,563**	*1.2%*
Coal	12,706	145		**12,850**	*10.1%*
Natural gas	39,733	3,270		**43,003**	*33.9%*
Oil	34,237	19,906		**54,143**	*42.7%*
Nuclear and other	8,504	0		**8,504**	*6.7%*
Electricity		205		**205**	*0.2%*
Waste		0	435	**435**	*0.3%*
Total	**102,657**	**23,602**	**435**	**126,694**	***100%***
Percentage	*81.0%*	*18.6%*	*0.3%*	***100%***	

Notes: units are petajoules (PJ). Components may not sum to totals due to rounding. Dark grey cells are zero by definition.

The PEFA shows trends in energy use by households and industries. As an example, figure 2 shows how final use of energy evolved over the period of 2017–2022 for households, manufacturing, and exports. As the figure shows, they responded differently to the shocks associated with the COVID-19 pandemic and

its aftermath. Showing how trends and responses to shocks differ (or don't) across industries is one of the key contributions of the PEFA.

Table 2. Physical Final use of Energy in the U.S. Economy, 2022

Energy Product	Industries	Households	Exports	Nature	Total	Percentage
Biofuels	2,624	446	293		**3,362**	*2.8%*
Geothermal energy	0	42			**42**	*0.0%*
Solar energy	0	211			**211**	*0.2%*
Coal	1,056	0	2,268		**3,325**	*2.7%*
Natural gas	16,572	5,423	7,349		**29,343**	*24.2%*
Oil	23,038	13,164	19,265		**55,468**	*45.7%*
Electricity	8,790	5,433	57		**15,017**	*12.4%*
Heat	1,670	0	0		**1,670**	*1.4%*
Energy Residuals				13,613	**13,613**	*11.2%*
Total	**53,750**	**24,718**	**29,233**	**13,613**	**121,314**	***100%***
Percentage	*44.3%*	*20.4%*	*24.1%*	*11.2%*	***100%***	

Notes: units are petajoules (PJ). Components may not sum to totals due to rounding. Dark grey cells are zero by definition.

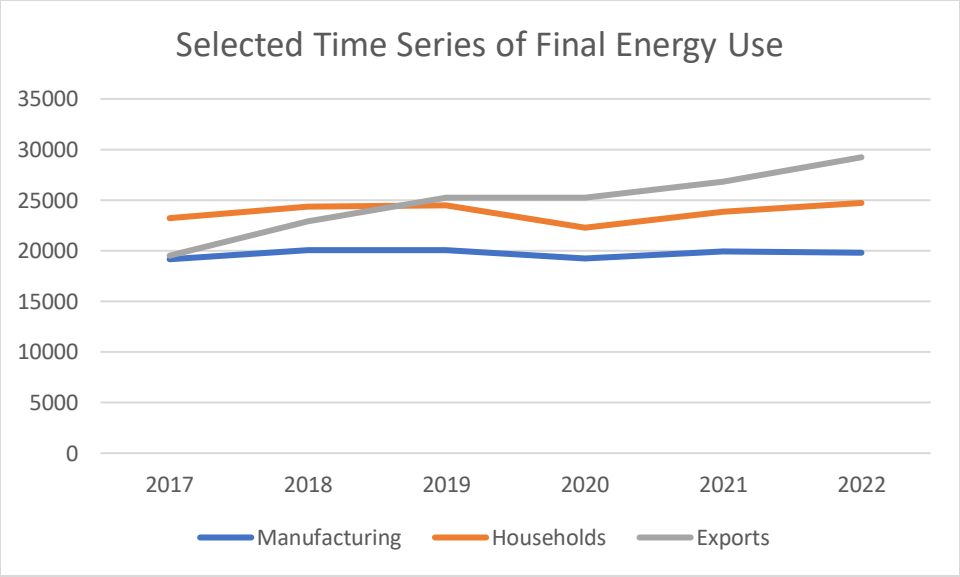

Figure 2. Selected Time Series of Final Energy Use. Units are in petajoules (PJ).

B. MEFA

Tables 3 and 4 show total supply and use of energy products at purchasers' prices for 2022; full MEFA SUTs are in the data appendix. Total supply and use of energy products grew from $2.0 trillion in 2017 to $3.3 trillion in 2022 (7.3% of total US gross output in 2022). Oil products represented the largest SEEA category for all 6 years, averaging 40.3% of total supply and use. Trade and transport margins represented 27.9% of the total supply of oil products in 2022 at purchasers' prices, the highest share of all categories and 12 percentage points higher than the average share for all categories (15.9%). In terms of use, nearly half (49.0%) of oil products were used as intermediate inputs to other products in 2022. Electricity represented the second largest SEEA category over the study period, averaging 21.1% of total supply and use between 2017 and 2022, followed closely by the oil extracted category (17.8%). The oil products, electricity, and oil extracted categories combined represented 79.9% of the total supply and use of energy products in 2022.

Table 3. Monetary Supply of Energy Products by SEEA Category, 2022

SEEA Category	Imports	Total supply at basic prices + taxes	Trade and transport margins	Total supply at purchasers' prices	Share of total supply	Average share of total supply, 2017-2022
Coal	$648	$41,823	$15,457	**$57,280**	2%	2%
Coal products	$38	$3,391	$288	**$3,680**	0%	0%
Natural gas (distributed)	.	$143,091	$0	**$143,091**	4%	4%
Natural gas (extracted)	$17,718	$172,292	$43,215	**$215,507**	6%	5%
Oil extracted (e.g., conventional crude oil)	$201,969	$606,939	$56,174	**$663,113**	20%	18%
Oil supporting activities	$1,391	$78,089	$0	**$78,089**	2%	3%
Oil (oil products)	$91,886	$1,007,588	$389,161	**$1,396,750**	42%	40%
Biofuels	$1,148	$19,900	$3,498	**$23,398**	1%	1%
Electricity	$2,486	$612,338	$53	**$612,391**	18%	21%
Electricity Distribution	$2,187	$39,212	$0	**$39,212**	1%	1%
Heat	.	$1,049	$0	**$1,049**	0%	0%
Non-energy uses of energy products	$11,835	$86,183	$22,358	**$108,541**	3%	4%
Pipeline transportation (non-margin and international freight)	.	$667	$0	**$667**	0%	0%
Annual total	**$331,306**	**$2,812,563**	**$530,206**	**$3,342,769**	**100%**	**100%**

Note: dollars in millions.

Table 4. Monetary Use of Energy Products by SEEA Category, 2022

SEEA Category	Total intermediate consumption	Total private consumption and other	Total use	Share of total use	Average share of total use, 2017-2022
Coal	$38,123	$19,157	**$57,280**	*2%*	*2%*
Coal products	$2,915	$765	**$3,680**	*0%*	*0%*
Natural gas (distributed)	$63,440	$79,652	**$143,091**	*4%*	*4%*
Natural gas (extracted)	$149,917	$65,591	**$215,507**	*6%*	*5%*
Oil extracted (e.g., conventional crude oil)	$531,888	$131,225	**$663,113**	*20%*	*18%*
Oil supporting activities	$18,695	$59,394	**$78,089**	*2%*	*3%*
Oil (oil products)	$683,997	$712,752	**$1,396,750**	*42%*	*40%*
Biofuels	$22,010	$1,388	**$23,398**	*1%*	*1%*
Electricity	$387,897	$224,494	**$612,391**	*18%*	*21%*
Electricity Distribution	$25,406	$13,806	**$39,212**	*1%*	*1%*
Heat	$1,018	$31	**$1,049**	*0%*	*0%*
Non-energy uses of energy products	$88,581	$19,960	**$108,541**	*3%*	*4%*
Pipeline transportation (non-margin and international freight)	$381	$286	**$667**	*0%*	*0%*
Annual total	**$2,014,267**	**$1,328,502**	**$3,342,769**	***100%***	***100%***

Note: dollars in millions and in purchasers' prices.

The full MEFA SUTs in the data appendix show the vast majority of energy products were supplied by three industry categories: manufacturing; electricity, gas, steam, and AC supply; and mining and quarrying. Manufacturing represented 32.1% of total supply at basic prices[12] on average between 2017 and 2022, followed by electricity, gas, steam, and AC supply (27.5%) and mining and quarrying (23.8%). The manufacturing industry was the largest supplier of oil products by far, producing more than 90% of supply annually at basic prices. Use of energy by industries was concentrated in the manufacturing industry and "other" industries which represented 40.7% and 36.9% of use in 2022, respectively.

[12] Includes taxes

6. Further Work and Refinements

As discussed above, the pilot PEFA tables are still under development. A fundamental accounting identity is that supply should equal use. Balancing the PEFA tables, so that this identity holds, is still needed. Additionally, some elements that should conceptually be included in the PEFA are still missing from the tables presented here:

- The residency adjustment for truck transportation.
- A portion of the residency adjustment for air transportation; specifically, reclassifying energy flows to non-residents from industry consumption to exports.
- Stock changes, such as additions to or withdrawals from fuel reserves.
- Separating imported and domestically produced uranium for nuclear fuel.

While the MEFA tables are more well-developed, a potential refinement in future estimates would be to provide more industry detail in both the supply and use tables. While these additions are outside of the scope of these pilot estimates, they are technically feasible with additional time and resources.

Avenues for future research using the PEFA and MEFA include estimating the value of renewable energy flows and renewable energy assets and developing combined presentations using energy account statistics together with air emissions and ecosystem account statistics to provide further detail on energy's important role in linking together economic activity and the environment.

Appendix

Appendix Table 1. Products included in the Monetary Flow Accounts for Energy

Product Description	Energy Product
Biofuels	
Fuel ethanol (fuel-grade ethyl alcohol), ethyl alcohol, manufactured by the wet mill process	
Hardwood charcoal and charcoal briquets, including blends with lignite or other materials	
Fatty acids (produced for sale as such)	
Coal	
Anthracite mining inventory change	y
Anthracite	y
Bituminous Coal and Lignite Mining Other Miscellaneous Receipts	y
Bituminous Coal and Lignite Mining Inventory Change	y
Bituminous coal and lignite	y
Coal mining services	
Coal mining services, nsk	
Support Activities for Coal Mining Other Miscellaneous Receipts	
Support Activities for Coal Mining Inventory Change	
Coal products	
Coke oven products, coke (excluding screenings and breeze)	y
Coke oven products, screenings and breeze	y
Coke oven products, other (including tar derivatives, ammonia, light oil derivations, and coke oven gas)	y
Coke oven and blast furnace products, not made in steel mills, nsk	y
Electricity	
Uranium-radium-vanadium ore mining inventory change	
Uranium-radium-vanadium ore	
Electric power generation	y
Electric Bulk Power Transmission and Control	y
Electric power distribution	y
Bonneville power administration	y
Southeastern power administration	y
Southwestern power administration	y
Tennessee valley authority	y
Western area power administration	y
Electricity distribution	
Electricity power marketing and brokering	
Heat	
Steam and air-conditioning supply	y
Natural gas (distributed)	
Natural gas distribution	y
Natural gas power marketing and brokering	
Natural gas (extracted)	
Natural gas	y
Natural gas extraction other miscellaneous receipts	y
Natural gas, nsk	y

Non-energy uses of energy products	
Asphalt	y
Petroleum waxes	y
Lubricating oils and greases, nsk	y
Lubricating oils (including hydraulic fluids, quenching & cutting oils, etc.)	y
Lubricating greases, not made in a refinery	y
Petroleum lubricating oil and grease manufacturing Other Miscellaneous Receipts	y
Petroleum lubricating oil and grease manufacturing Inventory Change	y
Aromatics (benzene, toluene, xylene, etc.), for use as a chemical raw material, made in petrochemical plants	
Aromatics (benzene, toluene, xylene, etc.), for other uses, made in petrochemical plants	
Aromatics (benzene, toluene, xylene, etc.), for use as a chemical raw material, made in petrochemical plants, nsk	
Oil (oil products)	
Aviation gasoline (except jet fuel), including finished base stocks & blending agents	y
Motor gasoline, including finished base stocks & blending agents	y
Gasoline, including finished base stocks & blending agents	y
Jet fuel	y
Kerosene, except jet fuel	y
Light fuel oils	y
Petroleum refineries Other Miscellaneous Receipts	y
Heavy fuel oils, including grades no. 5,6, heavy diesel-type	y
Petroleum refineries Inventory Change	y
Unfinished oils and lubricating oil base stock	y
Liquefied refinery gases, for uses other than chemical raw material	y
Petrolatum	y
Petroleum coke	y
Road oil	y
Still gas	y
Special petroleum napthas	y
Other finished petroleum products, made in a refinery	y
Other finished petroleum products, including waxes, nsk	y
Refined petroleum products, nsk	y
Coke oven products, crude tar	y
Coke oven products, crude light oil	y
Calcined petroleum coke, not made in a refinery	y
All other petroleum and coal products, including packaged fuel & fuel briquettes	y
All other petroleum & coal products, except coke oven products, nsk	y
All other petroleum and coal products manufacturing Other Miscellaneous Receipts	y
All other petroleum and coal products manufacturing Inventory Change	y
All other petroleum & coal products manufacturing, nsk	y
Liquefied refinery gases (aliphatics), for use as a chemical raw material, made in petrochemical plants	y
Petrochemical manufacturing Other Miscellaneous Receipts	
Petrochemical manufacturing Inventory Change	
Petrochemical manufacturing, nsk, total	
Oil extracted (e.g., conventional crude oil)	
Crude petroleum, including lease condens. (vols. Corrected to 60 deg. F) shipped	y

Crude petroleum other miscellaneous receipts	y
Crude Petroleum and Natural Gas Extraction Inventory Change	y
Crude petroleum, nsk	y
Natural gas liquids	y
Natural gas liquid extraction inventory change	y
Drilling, spudding, or tailing oil, gas, dry, or service wells - construction	
Drilling Oil and Gas Other Miscellaneous Receipts	
Drilling oil and gas wells Inventory Change	
Oil supporting activities (e.g., conventional crude oil)	
Oil and gas field exploration services	
All other oil and gas field services - construction	
Support Activities for Oil and Gas Operations Other Miscellaneous Receipts	
Support Activities for Oil and Gas Operations Inventory Change	
Oil and gas repair and maintenance	
Pipeline transportation (non-margin and int'l freight)	
Crude petroleum pipelines-non-margin	y
International freight, crude petroleum Pipeline	y
Natural gas pipelines - non-margin	y
International freight, natural gas pipeline	y
International freight, refined petroleum pipeline	y

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Pilot Physical and Monetary Energy Flows Account for the U.S.

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1. Introduction

Energy, in its various forms, keeps the economy moving. All economic activity consumes energy; modern economic development has its roots in technological advances that greatly expanded humans' ability to capture, store, and utilize energy. In recent years, debates regarding fossil fuels, nuclear energy, and renewable energy have become central to public discourse and policymaking. Good decision-making hinges on both public and private stakeholders understanding *how* energy flows through the economy and how its use supports industries and households in their economic activity.

Environmental accounting offers a framework to support this understanding, by placing economic activities in the context of their underlying physical processes, such as energy use. In the recent *National Strategy to Develop Statistics for Environmental-Economic Decisions* (*SEED*) both physical and monetary flow accounts for energy are recommended (OSTP, OMB, DOC, 2022). In this paper we present an early-stage pilot combined physical energy flow account (PEFA) and monetary energy flow account (MEFA) for the United States, covering the years from 2017–2022. We discuss challenges encountered and solutions identified in compiling the account, and briefly demonstrate analytical applications. We present summary

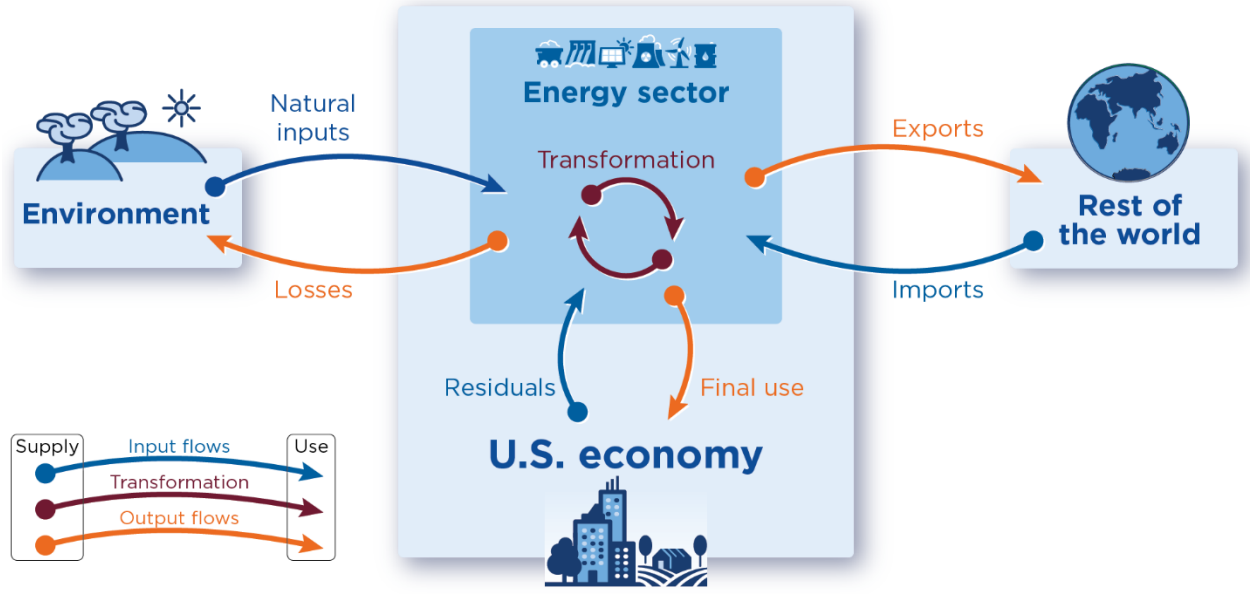

Figure 1. Stylized Diagram of Energy Flows in the U.S. Economy.

supply and use tables for both physical and monetary energy flows in 2022 (more detailed tables for all years are found in an online data appendix) and show the different patterns visible in the energy used for manufacturing, households, and exports over the period of the COVID-19 pandemic and its aftermath.

Figure 1 is an abstracted diagram showing the major categories of energy flows into, within, and out of the economy. Energy may enter the economy from nature (renewable or mineral energy resources), the rest of the world (imports of energy products), or the rest of the domestic economy (waste to be used as fuel). Final users of energy include businesses and households in the domestic economy, exports to the rest of the world, and nature (in the form of extraction, transmission, and distribution losses). A particularly important group of flows is the transformation flows that occur within the energy sector, as energy products are transformed into other energy products; the most prominent examples are electric generation and petroleum refining, with heat generation and ethanol biofuel production also included in this pilot. Figure 1 shows the physical processes to be modeled by the PEFA tables; we hope this relationship is clearly visible in the compiled account.

Following this introduction, section 2 discusses relevant literature and accounting standards, including the *System of Environmental-Economic Accounting* (SEEA), as well as other countries' work on energy accounts. Section 3 discusses the data sources and methods used in compiling the pilot PEFA and MEFA. Section **Error! Reference source not found.** presents summary results and findings, and section 6 concludes with a discussion of further work and recommended refinements to the accounts.

2. Literature and Standards Review

For this combined physical and monetary energy flows account, stakeholders may come from a variety of backgrounds. To set the stage for the rest of this paper, section 2.A reviews the statistical standards that influence the compilation of this account and section 2.B reviews related efforts in the U.S.

A. Statistical Standards

Data quantify reality in numeric form and statistics summarize data into simpler models for understanding. Statistical standards constrain these models so that statistics will be consistent and comparable across the domain of that standard. For example, the Intergovernmental Panel on Climate Change sets the standards used by countries around the world to report their greenhouse gas emissions as required by the Paris Agreement. These standards ensure that countries' reported emissions are consistent and comparable across time and with other countries' reported emissions.

The goal of environmental accounting is to analyze the economy and environment together. Closely related statistical standards must be used, so that the environmental and economic statistics are consistent and comparable with each other. The internationally accepted statistical standards[1] important to the compilation of this pilot energy flows account include the *System of National Accounts* (SNA), for economic accounting; the *System of Environmental-Economic Accounting* (SEEA), for environmental accounting; and *International Recommendations for Energy Statistics* (IRES), for energy balance statistics.

i. System of National Accounts

SNA is the internationally accepted standard for economic accounting, and underlies statistics such as GDP, gross output, and value added. SNA defines the economy of a nation, the agents that make up the economy, and how the goods and services exchanged in the economy are to be valued. The U.S. implementation of SNA, compiled by the Bureau of Economic Analysis (BEA), includes the National Income and Product Accounts (NIPAs) as well as Supply and Use Tables (SUTs) that are important sources of economic data for both the pilot PEFA and MEFA. We discuss here some particularly relevant SNA concepts.

The SNA defines a nation's economy as consisting of all economic agents (households and business establishments) that are *residents* of the nation (SNA 4.1). An agent is considered to reside in a nation if the agent's "[center] of predominant economic interest" is in that nation for a period of at least one year. If a foreign firm owns or leases property to conduct long-term (greater than one year) operations in a nation, those operations are considered to be conducted by a separate economic agent which is a resident of the nation (SNA 4.15c). This definition of the economy contrasts with definitions based on territory (based on economic agents located physically within the national territory) or nationality (based on the legal nationality of agents, which may differ from their residency). In practice, however, for a nation as large as the U.S., residency- and territory-based definitions are very similar, differing primarily with respect to transportation industries, since these are industries which regularly engage in economic activity abroad without necessarily owning or leasing property.

Individual establishments that are engaged in roughly the same type of productive activity are conceptually grouped together into *industries* (SNA 5.46)[2]. A given good or service may be produced by many different industries. For example, electricity may be produced by a nuclear power plant or a widget

[1] All promulgated by the United Nations (UN).

[2] In the U.S. these industries are classified according to the North American Industry Classification System (NAICS) and each establishment's primary industry is self-identified.

factory with solar panels on the roof. As in the case of this hypothetical widget factory with solar panels, an establishment may produce multiple goods or services. Some of these goods and services may be produced for sale in markets, while others may be produced for the establishment's own use. For example, a wholesaler might own and operate a truck to transport goods to purchasers.

Goods and services in the economy are valued, whenever possible, at the price for which they (or similar goods and services) are traded in markets. When such a market price is not available, goods and services are valued at their total cost of production (SNA 6.130). Since energy products are generally traded in markets, valuation is less complicated for this account than for many other environmental accounts.

In addition to the primary series of economic accounts, SNA incorporates flexible satellite accounts (also called thematic or extended accounts) to allow analysis that would be impossible using only the standard accounts. Such accounts may include a subset of the transactions recorded in the main accounts, such as transactions related to outdoor recreation, or may adjust the standard SNA boundaries and definitions, such as to measure nonmarket household production. Both conceptually and as implemented in this pilot, the MEFA is an SNA satellite account of the first type (a subset of transactions already in the economic accounts), akin to existing BEA-compiled satellite accounts.

ii. System of Environmental-Economic Accounting

The *System of Environmental-Economic Accounting* (SEEA) is a companion standard to the SNA, for environmental accounting. A primary purpose of SEEA is comparability between environmental and economic accounts. As much as possible, SEEA uses the same boundaries and definitions as the SNA, including the residency-based definition of the economy and the valuation approaches discussed above. The biggest differences are that SEEA accounts may measure things that lie outside the economy (such as water, waste, or emissions) and that most SEEA accounts measure physical quantities in addition to or instead of monetary quantities. Three broad categories of accounts are included in SEEA: physical flows, environmental activities, and environmental assets.

Physical flow accounts measure the flows of materials or substances important to the relationship between the economy and the environment. Most of these flows, such as extracted minerals, solar/wind energy used to generate electricity, or pollution, cross the environmental-economic boundary. However, some environmentally important flows occurring within the economy are also included, such as electricity

and other energy products. Flows occurring within the environment[3] are specifically excluded (SEEA 3.23). Physical flow accounts may be accompanied with corresponding monetary flows, especially when a large portion of the flows occur within the economy, as is the case with energy flows. The UN Statistics Division has published a manual, *SEEA-Energy*, providing specific guidance on physical and monetary energy flow accounts.

Environmental activity accounts measure the value of goods and services produced within the economy that have the purpose of environmental protection or resource management. Like the MEFA, environmental activity accounts are a strict subset of the SNA economic accounts and could be considered a thematic/satellite account under SNA definitions.

Environmental asset accounts are related to ecosystem accounts[4], but measure individual, specific environmental assets such as water or timber, without considering the network of relationships between these assets and other features of their ecosystems.

iii. International Recommendations for Energy Statistics

The *International Recommendations for Energy Statistics* (IRES) are the international standard for energy balance statistics. There are two major differences between IRES-consistent energy balances and SEEA-consistent energy accounts. First, the domain of energy balances is a nation's *territory*, where the domain of an energy account is the nation's *residents*. Second, energy balances are organized around different types of energy use activities or purposes, while energy accounts are organized around the same industries that are found in the economic accounts. Additionally, there are differences in the definition of some terms and in the presentation of the compiled statistics. The U.S. does not currently publish IRES-consistent energy balances.

An important component of IRES is the *Standard International Energy Product Classification* (SIEC). This classification is also used in SEEA-Energy to classify energy products, which constitute most flows in the energy account with the exception of some inputs from nature or the rest of the economy.

B. Related Efforts

i. U.S. Energy Statistics

[3] Trans-boundary pollution flows, formation of secondary pollutants through reactions between primary emitted pollutants, etc.

[4] Covered by *SEEA Ecosystem Accounts*, a (partially accepted) companion standard to SEEA and the SNA.

The Energy Information Administration (EIA) conducts surveys and compiles statistics on energy production and use throughout the U.S. economy. As detailed in section 3.A below, these are the primary data source for the pilot PEFA. Some primary areas in which these statistics diverge from SEEA energy accounting are that they include energy flows that occur within U.S. territory, regardless of the residency of the economic agents involved, and that they are not generally organized by industry[5].

ii. Statistics for Environmental-Economic Decisions

Recognizing the value of statistics on the interaction between the economy and the environment for good decision making, the U.S. Office of Science and Technology Policy (OSTP), Office of Management and Budget (OMB) and Department of Commerce (DOC) have developed a fifteen-year plan, *Statistics for Environmental-Economic Decisions* (SEED), to develop a suite of SEEA-consistent environmental accounts for the U.S. (OSTP, OMB, DOC, 2022). This plan involves many agencies across the federal government, and includes existing pilot accounts for water (Bagstad, et al., 2020), land (Wentland, et al., 2020), environmental goods and services (Fixler, Hass, Highfill, Wentland, & Wentland, 2023), and air emissions (Chambers, 2023). Other pilot accounts, in addition to the pilot energy account described in this paper, are in progress.

The energy account is closely connected to other accounts within the suite of environmental accounts envisioned under SEED, especially the air emissions account. A large portion of the greenhouse gas emissions recorded in the air emissions account result from the burning of fuels for energy, and the energy account provides an important link in the chain that connects industry and household economic activity, through energy requirements, to greenhouse gas emissions. Both the PEFA and MEFA will also be useful in estimating the value of renewable energy flows, the first step in valuing renewable energy assets for ecosystem accounts, and in showing how those flows are attributable to industries and households.

3. PEFA Data and Methods

A. Data

The primary data sources for the pilot PEFA are from EIA: the Monthly Energy Review (MER) and Form 923 survey data on electric generating units (EIA-923). Secondary data sources are needed to disaggregate energy flows reported only at an aggregate level in the primary data sources. These secondary data

[5] With some exceptions; as noted below, EIA publishes some microdata on electric generating units that includes industry (NAICS) codes for the establishments where they are located.

sources include BEA's published SUTs and detailed stock estimates of fixed assets and consumer durable goods, Bureau of Transportation Statistics (BTS) Transportation Satellite Accounts (TSAs) and National Transportation Statistics (NTS) tables, and academic studies.

i. EIA Monthly Energy Review

The MER is one of EIA's flagship statistical products. It is published monthly, as the name suggests, and includes a number of tables with data on energy production, transformation, consumption, and trade within U.S. territory. Source data are drawn from several EIA surveys and models. Historical data are re-estimated when methodological or data source changes are made, so the MER is an internally consistent time series of energy statistics.

MER data are organized by type of energy product (petroleum, electricity, renewable energy, etc.) and are most detailed for the initial stages of energy production: the extraction of petroleum/natural gas or the generation of electricity, for example. Final use of energy is divided into just four "sectors": industrial, commercial, transportation, and residential. Attributing the energy flows reported for these sectors to the industries they consist of is one of the major tasks in compiling the pilot PEFA.

Statistics in the MER are reported in a variety of different units, depending on the energy product in question. These may be units of mass (short tons of coal), volume (cubic feet of natural gas, barrels of petroleum, etc.), or energy/heat content (British thermal units or megawatt-hours)[6]. For accounting purposes, a single energy unit (petajoules for this pilot PEFA) needs to be used, to allow for summing across different types of energy products. Whenever possible, MER data that are already in energy units are used, as energy units are easily converted. Unfortunately, some MER data, particularly on energy transformations such as petroleum refining, are available only in mass or volume units, not energy units. The MER includes a table of heat content factors for converting these mass/volume units to energy units, but the conversion is still not always straightforward, and may be the cause of small discrepancies in the PEFA tables.

ii. EIA Form 923

One of the surveys underlying the MER is EIA's Form 923 survey of electric generating units. EIA also publishes the microdata from this survey, which are used directly in compiling this pilot PEFA. The form 923 microdata are very useful for accounting, as they include every utility-scale generating unit in the U.S.,

[6] EIA uses the gross heat content, or higher heating value, as opposed to the net heat content or lower heating value (more commonly used in Europe) when expressing the energy content of fuels. This carries over into the pilot PEFA.

providing NAICS code, type and quantity of fuel used, energy content of fuel used, and quantity of electricity generated each year. This enables relatively easy accounting for both primary electric generation from renewable sources (solar, wind, etc.) and secondary electric generation (using other energy products such as coal or petroleum to generate electricity).

iii. BEA Benchmark Use Table

BEA's benchmark Use table provides data on expenditures for energy products used as intermediate inputs by industries, or by households. As discussed below, these data are used for attributing energy flows reported in the MER to the industries that make up the reported sector. This attribution relies on the assumption that different industries face similar prices for a given energy product (as otherwise arbitrage would result). BEA publishes a new benchmark Use table every five years; this pilot PEFA uses the 2017 benchmark Use table.

iv. BEA Detailed Fixed Asset and Consumer Durable Goods Tables

BEA publishes detailed estimates of fixed asset stocks, by industry and asset type, together with detailed estimates of consumer durable goods stocks. These data are used for attributing energy flows reported in the MER when there is not a readily associated intermediate input, but there is a type of asset that is closely connected to the energy flow. For example, solar and wind energy generation in the industrial and commercial sectors is attributed using stocks of solar and wind structures from the detailed fixed asset table. Similarly, passenger car and light truck stocks from the detailed consumer durable goods table and detailed fixed asset table are used to attribute energy use by light vehicles across industries and households. These data are available annually.

v. BTS Transportation Satellite Accounts

Transportation activities are a major category of energy use in the economy. While most transportation services are produced by the various transportation industries (air, water, road, rail, and pipeline) a significant percentage, especially in road transportation, are produced by businesses in other industries for their own use. The energy used in producing these "own account" transportation services should be attributed to the industry producing them, not to the transportation industry associated with the mode of transportation. Fortunately, the TSAs are produced annually by the BTS specifically for the purpose of estimating the value of own account transportation services produced by industries. The TSAs are used in the pilot PEFA to attribute energy flows in the transportation sector to the industries that produce these flows, in proportion to their contribution to the total output of transportation services (transportation industry output plus the total value of own account transportation services produced).

vi. BTS National Transportation Statistics

The NTS is one of BTS's flagship statistical reports, containing data on every aspect of the U.S. transportation system, from statistics on road networks, maintenance status, and safety record to environmental impact sand economic performance. For this pilot PEFA, it is the NTS statistics on energy use by mode of transportation that are most valuable. These statistics break down each of the main modes of transportation (air, water, road, etc.) to provide a detailed picture of transportation energy use. For example, air transportation is broken down into certificated air carriers, general aviation using jet fuel, and general aviation using aviation gasoline, and road transportation is broken down by size of vehicle (for highway travel) and fuel type (for mass transit). These data are published annually.

vii. Academic Studies

Geothermal energy may be used to generate electricity, directly as a source of heat for industrial processes, and as a heatsink/source for geothermal heat pumps (the largest use of geothermal energy). Residential us of geothermal energy is assumed to fall into this last category. To understand larger scale, direct (non-heat pump) use of geothermal energy, we use a 2010 academic study (Lund, Gawell, Boyd, & Jennejohn, 2010) that conducted a census of such geothermal energy installations. These installations are classified into one of ten categories, including greenhouse heating, district heating, snow melting, and agricultural drying. For each category, the total installed geothermal capacity and actual energy use are reported as of December 31, 2009.

B. Methods

i. Industry Attribution

Many energy flows in the MER, especially final uses of energy, are attributed to one of a few sectors: industrial, commercial, residential, transportation, or electric power. While the residential and electric power sectors have a mostly straightforward correspondence with BEA industries and institutional sectors (the electric generation industry and households, respectively), the industrial and commercial sectors each consist of many industries, united more by their general energy use profile than by anything else. Attributing these flows to the industries that make up the MER sectors is done proportionally, using other proxy measures of energy use, such as expenditures on energy products or stock of related fixed assets. For example, electricity use by the "Commercial Sector" is attributed to the industries in that sector in

proportion to their expenditures on electricity, as found in the BEA Use table[7]. Identifying appropriate proxy measures is one of the primary tasks in compiling the PEFA and is an area for continued research and refinement.

ii. Residency Adjustments

The primary source data for the pilot PEFA are compiled on a territory basis, meaning that they include energy flows that occur within U.S. territory; the residency of the economic agents involved is not considered. The necessary conceptual adjustment from territory-based statistics to residency-based accounts includes three steps:

1. Reclassify the use of flows to nonresidents on U.S. soil from consumption by industry to exports.
2. Add flows to U.S. residents abroad to the account as a use by the appropriate industry.
3. Add the flows from step 2 into the account on the supply side as imports.

We assume that the residency adjustment is trivial for the household sector due to the size of the U.S. economy relative to the number of non-resident households. We likewise assume that the residency adjustment is negligible for non-transportation industries due to the way that foreign holdings of real property such as land or factories are accounted for under the SNA (see section 2.A.i for details). For transportation industries, however, the residency adjustment may be substantial.

Air Transportation

The air transportation industry may be divided into two categories: certificated commercial carriers and general aviation. These are defined according to which part of Federal Aviation Administration rules their operation is licensed under. Roughly, general aviation corresponds to civilian, non-commercial flight, while an air carrier certificate under 14 CFR 135 (small commercial carriers) or 14 CFR 121 (large commercial carriers) is required for commercial operations (charging to carry passengers or freight). For this reason, we assume that for-hire air transportation is carried out by certificated carriers, while own-account air transportation is carried out under general aviation licenses[8]. We also assume that all international air transportation operations are carried out by certificated air carriers[9]. BTS collects and publishes data

[7] This attribution implicitly assumes that all industries face the same price for electricity.

[8] In the 2019 NTS table 4.6 certificated carriers are responsible for 87% of air transportation fuel use, while in the 2019 TSAs for-hire air transportation is responsible for 85% of air transportation output.

[9] We have not identified a good data source to evaluate this assumption or to estimate the appropriate residency adjustment for general aviation.

specifically on fuel consumption by large U.S. carriers for both domestic and international operations. Since these data line up directly with the residency basis required for the PEFA, we use them in place of the NTS data on fuel use by certificated carriers, which is restricted to domestic operations only. This takes care of step 2 (recording flows to U.S. residents abroad as use by the appropriate industry). Adding the international operations portion of these energy flows to the PEFA supply table under imports takes care of step 3. We are still working on identifying an appropriate data source for step 1, reassigning flows to foreign residents in U.S. territory from industry consumption to exports.

Water Transportation

For water transportation, the residency adjustment is most relevant in the case of marine shipping. Lacking data on fuel *consumption* by U.S. marine carriers (like BTS publishes for air carriers), we use unpublished BEA data on fuel *expenditures* by foreign carriers in the U.S. and U.S. carriers abroad. We divide these expenditures by the world average price of bunker fuel[10] to obtain an estimate of the flows of energy to foreign residents (exports, step 1) and to U.S. residents (use by industries, step 2, and supply via imports, step 3) needed for the residency adjustment.

Truck Transportation

We have not been able to identify and acquire data on fuel consumption, fuel expenditures, or vehicle use for U.S. trucks operating abroad (Canada and Mexico) or foreign (Canadian or Mexican) trucks operating in the U.S. Consequently, we do not make a residency adjustment in the pilot PEFA for truck transportation, leaving it as an area for future research.

Rail and Pipeline Transportation

Because rail and pipeline operators own (or have long-term leases) on the land and fixed assets that make up the railroad or pipeline[11], we consider all operations in the rest of the world to be conducted by foreign residents (either foreign businesses or foreign affiliates of U.S. multinational enterprises) and similarly consider all operations in U.S. territory to be conducted by U.S. residents (either U.S. businesses or U.S. affiliates of foreign multinational enterprises). Therefore, by definition no residency adjustment is needed for these industries.

[10] Obtained from ShipandBunker.com.

[11] See section 2.A.i for a discussion of the relevant SEEA principles.

4. MEFA Data and Methods

A. Data

The primary data source for the pilot MEFA is detailed unpublished data from BEA's supply and use tables (SUTs) for 2017-2022. These SUT data decompose industry output for the entire US economy into more than 5,300 distinct product categories. The fine product-level detail of these data provide insight into the internal workings of the US economy by detailing the contribution of specific industries and commodities to gross output and value added.

B. Methods

To construct the pilot MEFA, we identify and isolate the production of, and spending on, energy products that are already present in the SUTs. These pilot estimates are akin to other BEA thematic satellite accounts that isolate production of a specialized area of the economy, such as the digital economy, the outdoor recreation economy, and the space economy. Satellite accounts are particularly useful to understand economic activity that is not easily identifiable under the standard NAICS industry classification or for activity that is spread across multiple NAICS industries. BEA's satellite accounts typically do not include full supply and use tables, however, so these pilot energy account estimates go a step further by showing this additional detail.

The products included in the monetary energy SUTs are listed by SEEA category in Appendix Table 1. We also indicate in the table whether or not the product is considered an energy product. We used the SEEA Energy manual (United Nations Statistics Division, 2019) as a guide to decide which product categories to include. Product categories that included both energy and non-energy products were excluded from the pilot estimates. These categories included sewage treatment facilities and government sewerage systems (partial overlap with SIEC waste category) and manufacturing of wood chips and reconstituted wood products (partial overlap with SIEC biofuels category). Excluding these categories means we are undercounting the supply and use of energy products, though we do not believe these products represent a significant portion of the total.

Due to the composition of the internal SUT data, taxes could not easily be uncoupled from the industry supply and use values. Therefore, our tables differ slightly from the SEEA tables in that taxes are included with basic prices in the supply table and with intermediate consumption in the use table. Future improvements to these pilot estimates could separate out taxes to better align with the SEEA tables.

5. Results

A. PEFA

Full physical flow SUTs are under development for the PEFA, and the current iteration is included in the data appendix. We believe this iteration covers nearly everything the pilot PEFA should cover (with exceptions noted below), but the reader will quickly observe that these SUTs are not quite balanced (that is, supply does not equal use). This is a crucial area of ongoing work; other areas for refinement are discussed in section 6. We present some preliminary results and statistics derived from the current iteration of the physical SUTs.

Table 1 is a subset of the physical Supply table for 2022 showing primary energy inputs to the U.S. energy sector from nature, the rest of the world, or the rest of the U.S. economy. Table 2 shows final uses, including losses from electric generation, transmissions, and distribution (under "Energy Residuals").

Table 1. Physical Primary Inputs of Energy to the U.S. Economy, 2022

Energy Product	Nature	Imports	Residuals	Total	Percentage
Biofuels	4,065	77	0	**4,141**	*3.3%*
Geothermal energy	125			**125**	*0.1%*
Hydroelectric energy	917			**917**	*0.7%*
Solar energy	807			**807**	*0.6%*
Wind energy	1,563			**1,563**	*1.2%*
Coal	12,706	145		**12,850**	*10.1%*
Natural gas	39,733	3,270		**43,003**	*33.9%*
Oil	34,237	19,906		**54,143**	*42.7%*
Nuclear and other	8,504	0		**8,504**	*6.7%*
Electricity		205		**205**	*0.2%*
Waste		0	435	**435**	*0.3%*
Total	**102,657**	**23,602**	**435**	**126,694**	***100%***
Percentage	*81.0%*	*18.6%*	*0.3%*	***100%***	

Notes: units are petajoules (PJ). Components may not sum to totals due to rounding. Dark grey cells are zero by definition.

The PEFA shows trends in energy use by households and industries. As an example, figure 2 shows how final use of energy evolved over the period of 2017–2022 for households, manufacturing, and exports. As the figure shows, they responded differently to the shocks associated with the COVID-19 pandemic and

its aftermath. Showing how trends and responses to shocks differ (or don't) across industries is one of the key contributions of the PEFA.

Table 2. Physical Final use of Energy in the U.S. Economy, 2022

Energy Product	Industries	Households	Exports	Nature	Total	Percentage
Biofuels	2,624	446	293		**3,362**	*2.8%*
Geothermal energy	0	42			**42**	*0.0%*
Solar energy	0	211			**211**	*0.2%*
Coal	1,056	0	2,268		**3,325**	*2.7%*
Natural gas	16,572	5,423	7,349		**29,343**	*24.2%*
Oil	23,038	13,164	19,265		**55,468**	*45.7%*
Electricity	8,790	5,433	57		**15,017**	*12.4%*
Heat	1,670	0	0		**1,670**	*1.4%*
Energy Residuals				13,613	**13,613**	*11.2%*
Total	**53,750**	**24,718**	**29,233**	**13,613**	**121,314**	***100%***
Percentage	*44.3%*	*20.4%*	*24.1%*	*11.2%*	***100%***	

Notes: units are petajoules (PJ). Components may not sum to totals due to rounding. Dark grey cells are zero by definition.

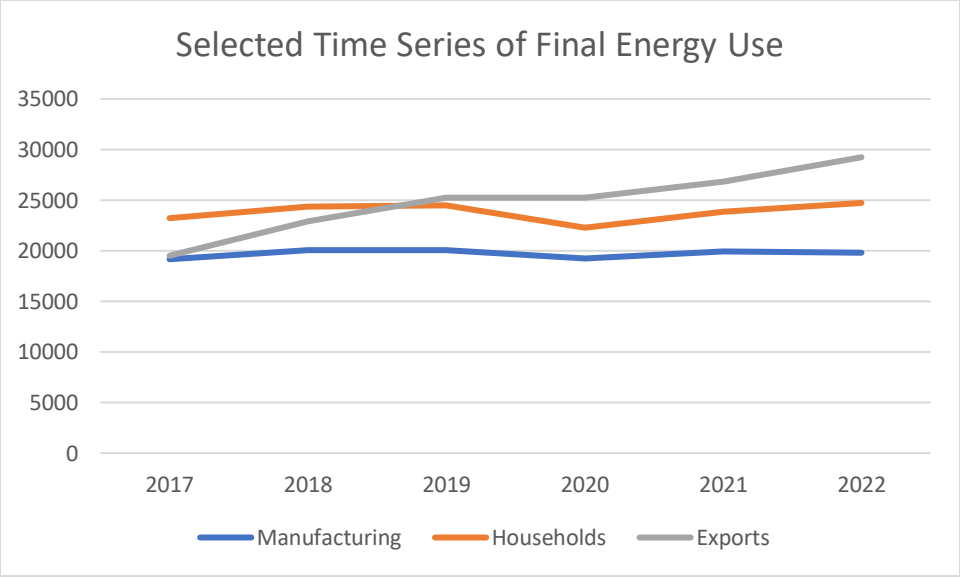

Figure 2. Selected Time Series of Final Energy Use. Units are in petajoules (PJ).

B. MEFA

Tables 3 and 4 show total supply and use of energy products at purchasers' prices for 2022; full MEFA SUTs are in the data appendix. Total supply and use of energy products grew from $2.0 trillion in 2017 to $3.3 trillion in 2022 (7.3% of total US gross output in 2022). Oil products represented the largest SEEA category for all 6 years, averaging 40.3% of total supply and use. Trade and transport margins represented 27.9% of the total supply of oil products in 2022 at purchasers' prices, the highest share of all categories and 12 percentage points higher than the average share for all categories (15.9%). In terms of use, nearly half (49.0%) of oil products were used as intermediate inputs to other products in 2022. Electricity represented the second largest SEEA category over the study period, averaging 21.1% of total supply and use between 2017 and 2022, followed closely by the oil extracted category (17.8%). The oil products, electricity, and oil extracted categories combined represented 79.9% of the total supply and use of energy products in 2022.

Table 3. Monetary Supply of Energy Products by SEEA Category, 2022

SEEA Category	Imports	Total supply at basic prices + taxes	Trade and transport margins	Total supply at purchasers' prices	Share of total supply	Average share of total supply, 2017-2022
Coal	$648	$41,823	$15,457	**$57,280**	2%	2%
Coal products	$38	$3,391	$288	**$3,680**	0%	0%
Natural gas (distributed)	.	$143,091	$0	**$143,091**	4%	4%
Natural gas (extracted)	$17,718	$172,292	$43,215	**$215,507**	6%	5%
Oil extracted (e.g., conventional crude oil)	$201,969	$606,939	$56,174	**$663,113**	20%	18%
Oil supporting activities	$1,391	$78,089	$0	**$78,089**	2%	3%
Oil (oil products)	$91,886	$1,007,588	$389,161	**$1,396,750**	42%	40%
Biofuels	$1,148	$19,900	$3,498	**$23,398**	1%	1%
Electricity	$2,486	$612,338	$53	**$612,391**	18%	21%
Electricity Distribution	$2,187	$39,212	$0	**$39,212**	1%	1%
Heat	.	$1,049	$0	**$1,049**	0%	0%
Non-energy uses of energy products	$11,835	$86,183	$22,358	**$108,541**	3%	4%
Pipeline transportation (non-margin and international freight)	.	$667	$0	**$667**	0%	0%
Annual total	**$331,306**	**$2,812,563**	**$530,206**	**$3,342,769**	**100%**	**100%**

Note: dollars in millions.

Table 4. Monetary Use of Energy Products by SEEA Category, 2022

SEEA Category	Total intermediate consumption	Total private consumption and other	Total use	Share of total use	Average share of total use, 2017-2022
Coal	$38,123	$19,157	**$57,280**	*2%*	*2%*
Coal products	$2,915	$765	**$3,680**	*0%*	*0%*
Natural gas (distributed)	$63,440	$79,652	**$143,091**	*4%*	*4%*
Natural gas (extracted)	$149,917	$65,591	**$215,507**	*6%*	*5%*
Oil extracted (e.g., conventional crude oil)	$531,888	$131,225	**$663,113**	*20%*	*18%*
Oil supporting activities	$18,695	$59,394	**$78,089**	*2%*	*3%*
Oil (oil products)	$683,997	$712,752	**$1,396,750**	*42%*	*40%*
Biofuels	$22,010	$1,388	**$23,398**	*1%*	*1%*
Electricity	$387,897	$224,494	**$612,391**	*18%*	*21%*
Electricity Distribution	$25,406	$13,806	**$39,212**	*1%*	*1%*
Heat	$1,018	$31	**$1,049**	*0%*	*0%*
Non-energy uses of energy products	$88,581	$19,960	**$108,541**	*3%*	*4%*
Pipeline transportation (non-margin and international freight)	$381	$286	**$667**	*0%*	*0%*
Annual total	**$2,014,267**	**$1,328,502**	**$3,342,769**	***100%***	***100%***

Note: dollars in millions and in purchasers' prices.

The full MEFA SUTs in the data appendix show the vast majority of energy products were supplied by three industry categories: manufacturing; electricity, gas, steam, and AC supply; and mining and quarrying. Manufacturing represented 32.1% of total supply at basic prices[12] on average between 2017 and 2022, followed by electricity, gas, steam, and AC supply (27.5%) and mining and quarrying (23.8%). The manufacturing industry was the largest supplier of oil products by far, producing more than 90% of supply annually at basic prices. Use of energy by industries was concentrated in the manufacturing industry and "other" industries which represented 40.7% and 36.9% of use in 2022, respectively.

[12] Includes taxes

6. Further Work and Refinements

As discussed above, the pilot PEFA tables are still under development. A fundamental accounting identity is that supply should equal use. Balancing the PEFA tables, so that this identity holds, is still needed. Additionally, some elements that should conceptually be included in the PEFA are still missing from the tables presented here:

- The residency adjustment for truck transportation.
- A portion of the residency adjustment for air transportation; specifically, reclassifying energy flows to non-residents from industry consumption to exports.
- Stock changes, such as additions to or withdrawals from fuel reserves.
- Separating imported and domestically produced uranium for nuclear fuel.

While the MEFA tables are more well-developed, a potential refinement in future estimates would be to provide more industry detail in both the supply and use tables. While these additions are outside of the scope of these pilot estimates, they are technically feasible with additional time and resources.

Avenues for future research using the PEFA and MEFA include estimating the value of renewable energy flows and renewable energy assets and developing combined presentations using energy account statistics together with air emissions and ecosystem account statistics to provide further detail on energy's important role in linking together economic activity and the environment.

Appendix

Appendix Table 1. Products included in the Monetary Flow Accounts for Energy

Product Description	Energy Product
Biofuels	
Fuel ethanol (fuel-grade ethyl alcohol), ethyl alcohol, manufactured by the wet mill process	
Hardwood charcoal and charcoal briquets, including blends with lignite or other materials	
Fatty acids (produced for sale as such)	
Coal	
Anthracite mining inventory change	y
Anthracite	y
Bituminous Coal and Lignite Mining Other Miscellaneous Receipts	y
Bituminous Coal and Lignite Mining Inventory Change	y
Bituminous coal and lignite	y
Coal mining services	
Coal mining services, nsk	
Support Activities for Coal Mining Other Miscellaneous Receipts	
Support Activities for Coal Mining Inventory Change	
Coal products	
Coke oven products, coke (excluding screenings and breeze)	y
Coke oven products, screenings and breeze	y
Coke oven products, other (including tar derivatives, ammonia, light oil derivations, and coke oven gas)	y
Coke oven and blast furnace products, not made in steel mills, nsk	y
Electricity	
Uranium-radium-vanadium ore mining inventory change	
Uranium-radium-vanadium ore	
Electric power generation	y
Electric Bulk Power Transmission and Control	y
Electric power distribution	y
Bonneville power administration	y
Southeastern power administration	y
Southwestern power administration	y
Tennessee valley authority	y
Western area power administration	y
Electricity distribution	
Electricity power marketing and brokering	
Heat	
Steam and air-conditioning supply	y
Natural gas (distributed)	
Natural gas distribution	y
Natural gas power marketing and brokering	
Natural gas (extracted)	
Natural gas	y
Natural gas extraction other miscellaneous receipts	y
Natural gas, nsk	y

Non-energy uses of energy products	
Asphalt	y
Petroleum waxes	y
Lubricating oils and greases, nsk	y
Lubricating oils (including hydraulic fluids, quenching & cutting oils, etc.)	y
Lubricating greases, not made in a refinery	y
Petroleum lubricating oil and grease manufacturing Other Miscellaneous Receipts	y
Petroleum lubricating oil and grease manufacturing Inventory Change	y
Aromatics (benzene, toluene, xylene, etc.), for use as a chemical raw material, made in petrochemical plants	
Aromatics (benzene, toluene, xylene, etc.), for other uses, made in petrochemical plants	
Aromatics (benzene, toluene, xylene, etc.), for use as a chemical raw material, made in petrochemical plants, nsk	
Oil (oil products)	
Aviation gasoline (except jet fuel), including finished base stocks & blending agents	y
Motor gasoline, including finished base stocks & blending agents	y
Gasoline, including finished base stocks & blending agents	y
Jet fuel	y
Kerosene, except jet fuel	y
Light fuel oils	y
Petroleum refineries Other Miscellaneous Receipts	y
Heavy fuel oils, including grades no. 5,6, heavy diesel-type	y
Petroleum refineries Inventory Change	y
Unfinished oils and lubricating oil base stock	y
Liquefied refinery gases, for uses other than chemical raw material	y
Petrolatum	y
Petroleum coke	y
Road oil	y
Still gas	y
Special petroleum napthas	y
Other finished petroleum products, made in a refinery	y
Other finished petroleum products, including waxes, nsk	y
Refined petroleum products, nsk	y
Coke oven products, crude tar	y
Coke oven products, crude light oil	y
Calcined petroleum coke, not made in a refinery	y
All other petroleum and coal products, including packaged fuel & fuel briquettes	y
All other petroleum & coal products, except coke oven products, nsk	y
All other petroleum and coal products manufacturing Other Miscellaneous Receipts	y
All other petroleum and coal products manufacturing Inventory Change	y
All other petroleum & coal products manufacturing, nsk	y
Liquefied refinery gases (aliphatics), for use as a chemical raw material, made in petrochemical plants	y
Petrochemical manufacturing Other Miscellaneous Receipts	
Petrochemical manufacturing Inventory Change	
Petrochemical manufacturing, nsk, total	
Oil extracted (e.g., conventional crude oil)	
Crude petroleum, including lease condens. (vols. Corrected to 60 deg. F) shipped	y

Crude petroleum other miscellaneous receipts	y
Crude Petroleum and Natural Gas Extraction Inventory Change	y
Crude petroleum, nsk	y
Natural gas liquids	y
Natural gas liquid extraction inventory change	y
Drilling, spudding, or tailing oil, gas, dry, or service wells - construction	
Drilling Oil and Gas Other Miscellaneous Receipts	
Drilling oil and gas wells Inventory Change	
Oil supporting activities (e.g., conventional crude oil)	
Oil and gas field exploration services	
All other oil and gas field services - construction	
Support Activities for Oil and Gas Operations Other Miscellaneous Receipts	
Support Activities for Oil and Gas Operations Inventory Change	
Oil and gas repair and maintenance	
Pipeline transportation (non-margin and int'l freight)	
Crude petroleum pipelines-non-margin	y
International freight, crude petroleum Pipeline	y
Natural gas pipelines - non-margin	y
International freight, natural gas pipeline	y
International freight, refined petroleum pipeline	y

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