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WRI REPORT

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MATERIAL FLOWS IN THE UNITED STATES

A Physical Accounting of the U.S. Industrial Economy

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FOREWORD

There is no end to the debate about the direction and condition of the U.S. economy. Is it growing fast enough? Which sectors are taking off, and which are in decline? Recently, economic dialogue has expanded to encompass urgent, new questions about human-induced climate change. How will climate change affect the economy? What shifts can we anticipate in the energy sector—including introduction of new, carbon-neutral energy sources as well as accelerating technological innovation in the efficiency of energy use—and how will this evolution affect economic growth and environmental quality?

In general, U.S. decision-makers enjoy access to some of the best economic information and analysis in the world, including detailed measurements of economic activity, employment, and changes in the productivity of labor and capital. These statistics and indicators drive policy and move markets. Regrettably, our conventional economic accounts are not so effective when it comes to providing adequate information on the long-term costs to society of environmental degradation.

Official U.S. economic accounts do not systematically track the movement of materials and energy into and out of our economy—from extraction to manufacturing, product use (and reuse or recycling), and eventual disposal. This failure makes it more difficult to gauge the full economic costs and benefits (including associated environmental consequences) of the energy and materials used to provide goods and services. And as a result, public policies and private actions are based on an incomplete, perhaps seriously misguided, understanding of the true costs of production.

With this report *Material Flows in the United States: A Physical Accounting of the U.S. Industrial Economy*, WRI is releasing the third in a series of studies that explore the development of measurements that can document the flow of materials through the national economy. This information can be used to monitor progress and shape policies toward a more efficient economy—one that will be built on new forms of energy, on technological and economic innovations, and on an accounting system that includes the full spectrum of production costs.

The current report follows on our 1997 study *Resource Flows: The Material Basis of Industrial Economies*, which set out the basic concepts and accounting procedures to measure the physical flows of materials. In a subsequent study, *The Weight of Nations*, released in 2000, we compared U.S. material flows with those of other advanced countries, including Austria, Germany, Japan, and the Netherlands.

This new report, *Material Flows in the United States*, provides detailed data on trends in material flows in four key sectors of the U.S. economy: metal and minerals, nonrenewable organic materials (including fossil fuels), agriculture, and forestry. It looks at 169 primary-level raw materials for which data are available and which are the building blocks of the U.S. economy. Among these 169 materials are toxic substances—such as arsenic, cadmium, lead, mercury, and others—whose flow we trace into the economy and back out to the environment, revealing in the process the strengths and weaknesses in our national regulatory policies and procedures.

So, where do we stand? How do we use these accounts and indicators to assess progress (or the lack of it) toward sustainability?

Those who follow the ebb and flow of the business cycle, when assessing economic conditions and policies, speak in terms of leading, coincident, and lagging indicators. In the case of material flows, our leading indicator is the amount of materials consumed to produce a dollar of GDP. According to the findings of this study, this figure declined by 31 percent over the 25-year study period (1975 to 2000), reflecting more efficient use of fossil fuels, metals and minerals, and renewable resources.

However, the trend in per capita consumption of material (a coincident indicator) is increasing, with a rise of some 23 percent over the study period. If the U.S. economy were solidly on a path to sustainability, this indicator would be declining.

Meanwhile, total consumption of materials (a lagging indicator) grew 57 percent over the study period, to 6.5 billion metric tons in 2000. If the United States had been a sustainable economy during this period, we would have avoided the creation of 25 billion tons of waste (and its subsequent disposal into our air and water and onto our land).

These numbers carry important messages for meeting one of the most significant challenges of our time: to create an economy that uses materials more efficiently and that is much less damaging to the environment.

An accounting system of material flows is feasible as this report shows and provides a useful, even essential, tool for charting the course to a more sustainable economy.

The time has come for the U.S. government to embrace the development of material flows accounting on a regular basis, report the data and indicators to the public, and make the information widely available. The United States needs, and deserves to have, official accounts that capture material flows, and their environmental consequences, as well as they do financial flows.

JONATHAN LASH
President, World Resources Institute

EXECUTIVE SUMMARY

Economists and policymakers often look to a country's gross domestic product (GDP) when measuring its economic health. However, GDP and other standard economic indicators measure only the dollar value of goods and services without specifically considering the non-dollar cost of the physical movement of materials associated with industrial development.

Experts in the field of industrial ecology have quantified the movement of raw materials and processed goods through national economies using a system known as material flows analysis (MFA). MFA has already shown, in a broad sense, how natural resources are extracted, used, and discarded, providing important insight into the links between economic growth, population growth, and materials use. When more developed, MFA will give a more accurate account of the time cost of industrial development. The results will lead to improved policy in a variety of fields, including environmental protection, trade, national security, and technology development.

This report is the third in a series of material flows analyses conducted by the World Resources Institute (WRI). In 1995, WRI partnered with five international organizations to develop the first systematic method for tracing the extraction, processing, production, use, recycling, and disposal of all major commodities in a nation's economy. Two reports have already been published: *Resource Flows: The Material Basis of Industrial Economies* (1997) and *The Weight of Nations: Material Outflows from Industrial Economies* (2000). This, the third report, focuses on the United States and accounts of material flows from 1975 to 2000. It presents the accounts in aggregate and by economic sector, examines specific flows of environmental or economic importance, and recommends next steps for institutionalization of these accounts at the national level.

The full details of the study, including technical notes, sources, and a database of material flows accounts for the United States can be accessed online at http://materials.wri.org.

FINDINGS

Focusing on just the United States has permitted a significant expansion of the materials included and of the dimensions analyzed, leading to a greater depth of analysis across materials, economic sectors, and end uses. Results indicate the following trends in material consumption, efficiency, and outputs:

1. Consumption. In absolute terms, total material consumption increased from 1975 to 2000 by 57 percent to 6.5 billion metric tons in 2000. Per capita consumption increased by 23 percent. (See Figure 1.) The majority of growth can be explained by an 83 percent increase in built infrastructure.

Measurements by the U.S. Census Bureau support this finding: from 1975 to 2000, the Bureau reported a national increase of 52 percent in the number of housing units and a greater intensity of material use per housing unit.[1] Significant increases were also measured in the use of nonrenewable organic materials, specifically fossil fuel consumption for both transportation and electricity generation.

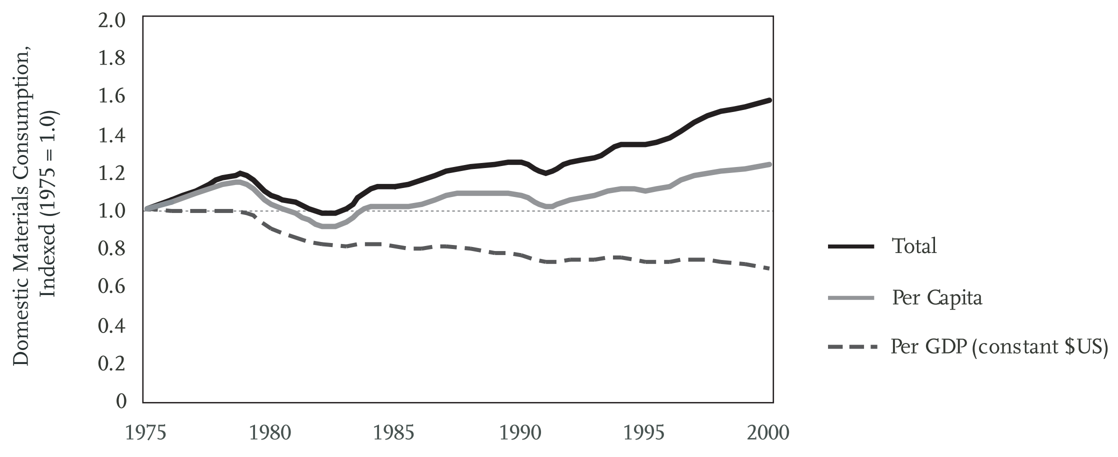
Domestic materials consumption of all materials in the industrial sector of the United States from 1975 to 2000 shows an increase in total and per capita consumption but a decrease in consumption per GDP. Consumption levels from 1975 were set to 1.0 to permit a comparison of trends over time.

2. Material Efficiency. While both total and per capita consumption of materials increased between 1975 and 2000, consumption declined relative to GDP by 31 percent. (See Figure 1.) This gain in efficiency is attributable to a general dematerialization in the U.S. economy: 84 percent of the absolute growth in GDP during the study period was in the services sector.[2]

3. Material Outputs. Nearly 2.7 billion metric tons of material were returned to the environment as waste (outputs) in 2000. Total outputs have increased by 26 percent since 1975, and the most environmentally harmful outputs—synthetic and persistent organic chemicals, radioactive compounds, and heavy metals—have increased by 24 percent to 16 million metric tons. While many policies to control point-source and industrial pollution levels have curbed hazardous releases into the environment, toxic releases from diffuse sources such as imported consumer electronics have increased. Figure 2 shows that more than 60 percent of the cadmium consumed in 2000 was contained in imported batteries. Only 32 percent of all cadmium was recycled in 2000.[3]

4. International Comparisons. Per capita material consumption in the United States is more than 50 percent higher than the average of 15 European Union countries. This difference could be due either to the presence of more extensive extractive industries (e.g., mining and forestry) in the United

FIGURE 1 | U.S. MATERIALS USE (DIRECT MATERIAL CONSUMPTION), 1975–2000



Source: WRI Material Flows Database 2005.

States or to differences in consumption, housing, transportation, and infrastructure development patterns between the EU and the United States. Despite small methodological differences in material flows accounting, consumption values for the United States can generally be compared to those computed for the European Union. However, because of the differences in national economies mentioned above, the comparisons must be interpreted with care.

RECOMMENDATIONS

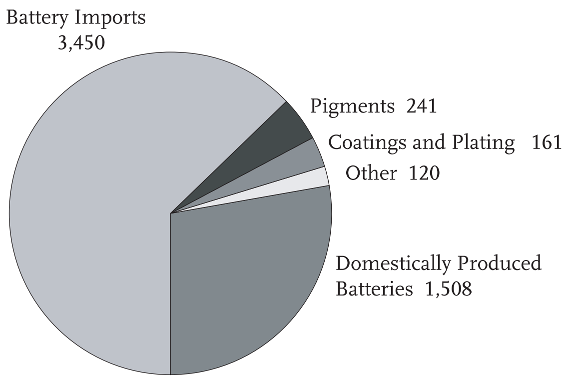
A well established system of national material accounts could enable more effective policymaking in both the public and private sectors. Until now, however, material analyses have been conducted sporadically, with limited resources, and principally through the work of nongovernmental organizations. Making MFA effective will require funds for both data collection and policy analysis across a number of government agencies; partnerships with international MFA consortia, private industry, academia, and NGOs; and the establishment of a central organization—a Center for Material Flows—to manage the collection, analysis, and dissemination of material flows accounts in the United States.

Establishing viable material accounts in the United States will require both institutional and analytical improvements. To create a practical analytical framework for MFA, WRI has joined the National Resource Council's Committee on Materials Flow Accounting in recommending that the federal government establish a Center for Material Flows in collaboration with nongovernmental organizations and the private sector.[4] WRI also recommends the following actions:

1. Establish a robust materials accounting framework. A more systematic and vigorous methodology needs to be established to fully capture the physical and chemical changes observed in materials across time and space. While the accounts presented in this report are detailed enough to allow for tentative recommendations about materials (e.g., cadmium metal) and industries (e.g., construction), the current MFA accounting methodology is not yet adequately developed to account for variations in a material's residence time in the economy, chemical transformations, or fabrications of finished goods with components from many different sectors. In addition, accounts must allow geospatial analysis and evaluation of the intensity of materials across economic sectors in order to provide policy-relevant information.

2. Expand and synthesize core data across the life cycle of a material. While the latest study of material flows accounts features more detailed information from a broader range of sources than previous studies, significant data gaps remain. Current accounts do not contain any specific information

FIGURE 2 | CADMIUM USE IN THE UNITED STATES, 2000 (metric tons)



Source: WRI Material Flows Database 2005; NYAS 2003.

"Other" releases of cadmium are from plastic stabilizers, coal combustion emissions, and alloys.

about the production and use of organic and inorganic chemicals, plastics, and synthetic fibers. The materials in most imported finished goods cannot be measured, including electronic devices that contain heavy metals and other materials that are hazardous to human health and the environment. Data on wastes released to the environment in the United States are still largely nonexistent.

To fill these data gaps, the federal government can engage local and national agencies as well as the private sector to compile the data necessary for complete material flows accounts. The centralization of statistical functions across different organizations—particularly through increased coordination among U.S. government agencies such as the Environmental Protection Agency, the U.S. Geological Survey, the Forest Service, and the U.S. Department of Agriculture—will allow the full value of both new and existing data to be better captured for use in policymaking.

3. Incorporate material flows analysis into environmental and economic decisionmaking. Because material flows accounts track the movement of goods into and out of the economy, they can be used as early warning indicators of potential threats to human health and undesirable changes in natural resources. With a more detailed database on materials use and consumption, policymakers can track materials of environmental concern and act to stem their release into the environment.

1

INTRODUCTION TO MATERIAL FLOWS

In the past decade, experts in the field of industrial ecology have quantified the movement of raw materials and processed goods through national economies, providing insight into the links between economic growth, population growth, and materials use. These flows are measured and reported using a system known as material flows analysis (MFA). Because MFA provides information on the potential environmental impacts associated with industrial development, it offers an analytical framework for considering ways to meet society's social and economic needs while preserving the natural resource base upon which all life depends.

Researchers working at the World Resources Institute (WRI) have been engaged in preparing and analyzing material flows accounts since 1995. A network of five international organizations, including WRI, developed the first systematic method for tracing the extraction, processing, production, use, recycling, and disposal of all major commodities in a nation's economy. Preliminary national material flows accounts for Germany, Japan, the Netherlands, and the United States were published in 1997 in *Resource Flows: The Material Basis of Industrial Economies.*[5] Updated accounts for these four countries plus Austria were published in 2000 in *The Weight of Nations: Material Outflows from Industrial Economies.*[6]

This, the third report, provides material flows accounts for the United States from 1975 to 2000. Focusing on one country has permitted a significant expansion in the dimensions of the material flows analyzed and a greater depth of analysis across commodities, sectors, and end uses. The study compiled a set of inputs and outputs for 169 individual commodities, using these data to develop aggregated indicators of material flows for the United States. (For a list of these 169 commodities, see Appendix 2.) Indicators were created for four economic sectors of origin: agriculture, forestry, minerals and metals, and nonrenewable organic materials (mainly fossil fuels). The data used in this study were derived primarily from official government statistics on materials use. In some cases these data were supplemented by industry and other sources. (See Sources.)

The full details of this study include technical notes, sources, a database of U.S. material flows accounts, and a report, *Material Flows Accounts: A Tool For Making Environmental Policy*. All can be accessed online at <http://materials.wri.org>.

MFA DEFINITIONS

MFA begins with examining data on the resources that are extracted from the environment in the form of commodities. In this study, commodities refer to primary-level raw materials and manufactured products, such as plywood for construction or iron ore for automobile manufacture. These are direct inputs into the economy. The total mass of material inputs from both domestic extraction and imports are combined across all sectors to form an aggregate indicator measured at a national scale, Direct Material Input (DMI). Material inputs that are not exported to other countries are consumed in the United States. The Direct Material Consumption (DMC) indicator is calculated as DMI minus exports.

The extraction and processing of inputs often results in additional materials that are not purchased or consumed as finished goods in the economy, such as earth moved for mineral extraction or wastes emitted from manufacturing processes. In MFA, these are known as hidden flows. Hidden flows include mining overburden, erosion, earth moving, gangue (the unusable portion of mineral ore that typically is discarded as waste by mining operations), residues from logging and crop harvests, and manufacturing losses in all sectors. Some hidden flows associated with erosion and infrastructure development could not be categorized in any of the four primary sectors studied but are still included in the aggregate MFA indicators.

Many hidden flows associated with extraction and processing are not directly measured. Some can be derived from production and import data based on technical estimates; for example, overburden from iron ore extraction is estimated to be 2.3 times the production of usable ore. Other hidden flows, such as manufacturing wastes, are assumed to equal the mass of material not accounted for in the finished goods. For example, manufacturing waste from a chicken processing plant is calculated as the live weight of chickens slaughtered less the mass actually sold as food and animal feed. All hidden flows generated in this country and abroad for imports (foreign hidden flows) are added to DMI to produce an indicator called Total Material Requirement (TMR), the sum of all flows associated with material inputs.

BOX 1

SUMMARY OF TERMS USED IN MATERIAL FLOWS ACCOUNTING

Total Material Requirement (TMR): The sum of all raw materials (inputs) required to produce commodities in an economy. TMR includes raw materials extracted domestically, imports of raw materials, and the mass of all hidden flows generated in securing those inputs. Hidden flows generated in other countries (foreign hidden flows) are included in this analysis, but they are typically omitted when comparing material flows among countries.

Direct Material Input (DMI): Sum of all inputs that enter the economy. Equivalent to TMR less hidden flows generated during extraction and processing.

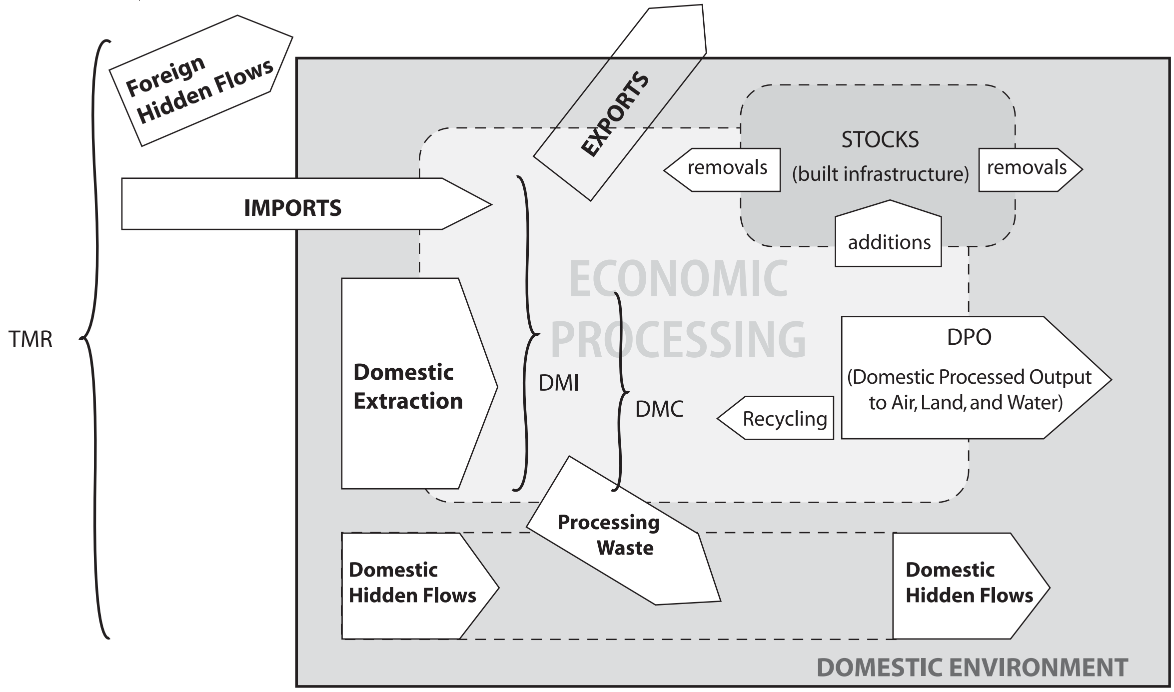
Direct Material Consumption (DMC): Total materials consumed in the domestic economy. Equivalent to DMI less exports of processed materials.

Net Additions to Stock (NAS): The mass of physical infrastructure added to an economy's stock minus the mass of used materials removed from stock. Items removed from stock include construction materials that are reclaimed or discarded when buildings are dismantled.

Domestic Processed Output (DPO): Materials that are consumed in the domestic economy and subsequently flow to the domestic environment. Additions to stock, recycled materials, and hidden flows are not included here.

Hidden Flows: Materials that are mobilized or produced in the domestic and/or foreign environment but are not purchased as finished goods or consumed in the economy. Hidden flows occur during the extraction, processing, manufacturing, and use of materials. All hidden flow inputs become hidden flow outputs.

FIGURE 3 | A SCHEMATIC OF AGGREGATE MFA INDICATORS



Total Material Requirement	TMR = Domestic Extraction + Imports + Domestic Hidden Flows + Foreign Hidden Flows
Direct Material Input	DMI = Domestic Extraction + Imports + Recovered (Recycled) Material
Direct Material Consumption	DMC = DMI - Exports
Domestic Processed Output	DPO = DMC - Net Additions to Stock - Recycled Material

Source: WRI MFA Project (see http://materials.wri.org).

Just as materials flow into the economy, they flow from the economy back into the environment as they are used. These flows are called outputs. Outputs can include emissions to air from fuel combustion, material loads in wastewater, household wastes deposited in landfills, and dissipated flows such as fertilizer and road salt that are dispersed on land. Additions to stock (defined below) and recycled materials are not included in output flows.[7] The sum of all output flows that enter the waste stream in a given year is expressed as Domestic Processed Output (DPO).

Some materials do not exit the economy rapidly but accumulate in the form of buildings and other infrastructure. They are called stocks. Net Additions to Stock (NAS) measures stocks entering infrastructure in a given year minus stocks removed. In this report, any material that is in use for more than 30 years before it is recycled or discarded is classified as an addition to stock.[8]

BOX 2 | **CATEGORIES OF MATERIAL OUTPUTS**

Mode of First Release (M)

M0 Added to built infrastructure (NAS).

M1 Contained on land as solids (e.g., in landfills or as overburden).

M2 Contained on land as liquids or partial solids (e.g., tailings ponds, impoundments).

M3 Dispersed on land as solids or liquids (e.g., fertilizers, pesticides).

M4 Discharged into water as solids or liquids (e.g., soil erosion, sewage effluent, deep well injections).

M5 Discharged into air from point sources as gasses or particulates (e.g., power plant emissions).

M6 Dispersed in the air from diffuse sources as gasses or particulates (e.g., auto emissions, spray paints).

M7 Flows that take many paths or cannot be classified.

Please refer to Appendix 1 for a more complete explanation of these categories.

Source: WRI MFA Project.

Quality of Release (Q)

Q1 Biodegradable organic materials (includes most agriculture, forest, and fishery products).

Q2 Materials which break down physically without significant chemical interaction or harm to human health and the environment (e.g. stone, sand).

Q3 Chemically active (e.g., salt), or biologically hazardous materials (e.g., asbestos) that have not been chemically altered.

Q4 Chemically altered materials (e.g., fuel emissions, fertilizers, industrial chemicals).

Q5 Heavy metals, synthetic and persistent chemical compounds, and radioactive materials.

Velocity of Release (V)

V1 Materials that exit within 2 years after entry (e.g., food, packaging, petroleum used as fuel).

V2 Durable goods that are consumed for more than 2 but less than 30 years (e.g., automobiles).

V3 Net additions to stock, typically in use for more than 30 years (highways, buildings).

METHODOLOGICAL LIMITATIONS

The current MFA methodology assumes that materials are either recycled or discarded as waste in the same year they were initially consumed. This oversimplifies the actual situation. A number of durable goods are consumed for more than 1 year but less than 30 years (e.g., automobiles, computers, refrigerators). However, since durable goods only represent 6 percent of material consumption by weight, this assumption should not distort the accuracy of the aggregate accounts in any critical way.

All flows are measured by weight in metric tons. Water flows and oxygen emissions from combustion were excluded from the aggregated accounts. However, some mass of water and oxygen is embodied in agriculture and forestry raw materials. This mass is included in material consumption (DMC) but not in outputs (DPO).

At the present time, imports of finished goods are not accounted for in material flows analysis since these items are typically recorded by customs offices in dollar terms without specific measures of material content. In dollar terms, however, imports of goods quadrupled over the study period, accounting for 13 percent of GDP in 2000,[9] meaning that there are possibly large quantities of environmentally and economically important materials flowing into the United States without being monitored.

The definitions and methodologies incorporated in these accounts differ slightly from the international practices established by Eurostat (Statistical Office of the European Communities) in 2002. The Eurostat methodology records flows only when they enter or leave the economy, removing some of the accounting difficulties and potential inconsistencies possible in the U.S. accounts, which currently track flows through extraction, manufacturing, use, and post-use phases.[10] Nonetheless, material input and consumption values for the United States are generally comparable to those produced by the European Union.[11] This suggests that standardized practices are evolving, permitting meaningful analysis across countries. Because the structure of national economies differs, comparisons must be interpreted with care.

CHARACTERIZING OUTPUTS

Not all material outputs are equal in their potential environmental impact. To take that into consideration in MFA, outputs are rated along three characteristics, based on the use to which a flow is put while a part of the industrial economy. (See Box 2 for category definitions.)

The first category is the mode of first release (M). Some materials become a permanent part of the built infrastructure, such as steel used for building construction. Others may end up contained in landfills for long periods of time, and some materials such as automobile emissions immediately disperse into the environment from many sources.

The second categorization is quality (Q). Some flows are biodegradable or break down physically in the environment while others are chemically processed or create a potential hazard to the environment. The Q designation enables the isolation of potentially hazardous materials in national material flows accounts. This ability is particularly important as many of the materials that are most toxic to the environment and human health—mercury and arsenic, for example—are consumed in much smaller quantities on a national scale than some relatively benign materials such as sand and gravel, which dominate the aggregated accounts.

The third category is velocity (V). Materials that are retained and used in the economy for long periods decrease the need for extraction of natural resources. Such flows (greater than 30 years for this study) are considered additions to the stock of built infrastructure.

Within these definitions, characterizing a flow of materials is, to a degree, subjective. At their current level of complexity, these preliminary national accounts provide an indication of the potential impact of industrial development on the environment, rather than a definitive linkage between a given flow and its subsequent environmental effects. By disaggregating data on material flows according to industrial sector and characterizing flows according to their mode of first release, this analysis constitutes an important first step in understanding the nature and extent of environmental change due to material flows. However, directly linking individual flows to subsequent environmental impacts would require large amounts of highly specific information (on the characteristics of the flow; when, where, and how the flow was released; and the nature of the systems in which the flow was released), and is thus beyond the scope of this analysis.

2

AGGREGATED INDICATORS OF MATERIAL FLOWS

To understand how U.S. materials use has changed, this study compared the indicators of domestic material inputs and outputs to Gross Domestic Product (GDP) and population over the years 1975 to 2000. The results are consistent with those in the 1997 and 2000 MFA studies. Highlights are summarized below.

SUMMARY INDICATORS OF MATERIAL FLOWS

When all sectors and commodities are combined, the material flows accounts allow for an analysis of aggregated trends. The indicators synthesize information across a variety of disciplines, allowing professionals in the environmental, health, economics, law, and government sectors to communicate in a common language and set national targets for materials use. Table 1 summarizes the aggregated material flows in 2000 for the United States. (More detailed results by sector are available in Appendix 3: National Indicators by Weight and Sector and in Appendix 4: Per Capita Indicators by Sector.)

The MFA summary indicators—DMC, DPO, NAS, and hidden flows—show the path of materials as they move through the U.S. economy. In absolute

TABLE 1 | MATERIAL FLOWS ACCOUNTS FOR THE UNITED STATES, 2000

	TOTAL		PER CAPITA		PER GDP (constant dollars)	
	million metric tons	% change since 1975	metric tons per person	% change since 1975	metric tons per million $GDP	% change since 1975
Materials Consumption (DMC)	6,515	57.0	23.7	23.2	723.2	-30.8
Processed Outputs (DPO)	2,673	26.2	9.8	0.0	296.7	-44.4
Additions to Stock (NAS)	2,888	82.8	10.5	43.4	320.6	-19.5
Hidden Flows	18,462	-8.6	67.0	-28.3	2,634.8	-54.8

Source: WRI Material Flows Database 2005.

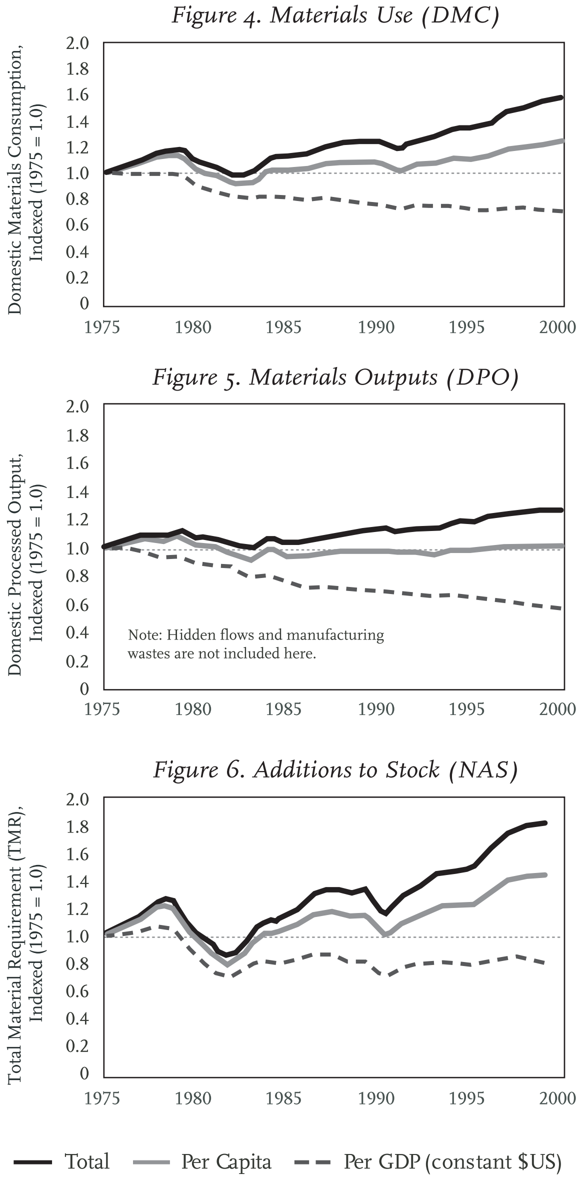
terms, material consumption (DMC) increased over the study period by 57 percent to 6.5 billion metric tons in 2000. Nearly 2.7 billion metric tons of this material were returned to the environment as waste (DPO).

The majority of the increase in consumption can be explained by an 83 percent increase in built infrastructure (NAS) over the study period. This trend corresponds with a national increase of 52 percent in the number of housing units and an apparent increasing intensity of materials use per housing unit.[12] (See Table 5: Housing and Construction Materials in the United States on page 25.) Significant increases were also observed in nonrenewable organic materials, specifically in fossil fuel consumption for both transportation and electricity generation. Hidden flows decreased by 9 percent in absolute terms between 1975 and 2000 due to decreases in erosion, dredging, and highway construction.

Figures 4, 5, and 6 illustrate the trends in materials consumption (DMC), outputs (DPO), and stocks (NAS) over the study period of 1975-2000. In each figure, values are indexed with 1975 set at 1.0, allowing a comparison of changes over time.

Consumption of materials increased much more rapidly than population growth during the same period. Figure 4 shows that the intensity of materials use per capita has grown rapidly, particularly from 1995 to 2000. While the U.S. population grew by 27.5 percent in the 25-year study period, domestic material consumption grew at more than twice the rate of population growth to a level of almost 23 metric tons per person. Because population growth is projected to continue, albeit at a slower pace, the absolute growth in the mobilization and use of resources for construction is expected to increase.[13] During the 25-year study period, material outputs (DPO) kept pace with population growth, while additions to stock (NAS) increased.

TRENDS IN U.S. MATERIAL FLOWS, 1975–2000



Source: WRI Material Flows Database 2005.

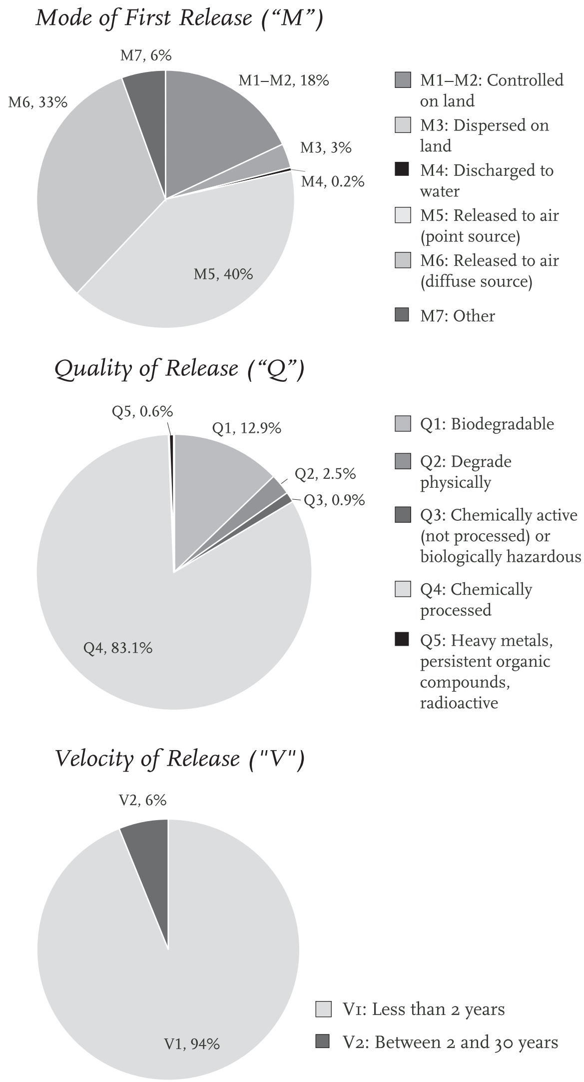
Material consumption (DMC) and outputs (DPO) declined relative to GDP by 31 and 44 percent, respectively, between 1975 and 2000. (See Figures 4 and 5.) While some decoupling of economic growth and materials use has occurred in the United States, increases in extraction and waste in absolute terms over the study period point to rising environmental stress in both the United States and in countries that provide goods for U.S. consumption. A more careful examination of extraction and waste (output) trends could be both environmentally and economically beneficial, revealing opportunities for improved materials efficiency.

The results of the current study were compared with the results obtained in *Resource Flows* (WRI 1997) and *The Weight of Nations* (WRI 2000). Although additional commodity flows were incorporated in the current analysis, and some alternate data sources and methods were employed, the inputs and outputs reported here do not deviate by more than 5 percent from the values reported for the same years in WRI's previous studies.

CHARACTERIZING OUTPUTS

Economic expansion and population growth have fueled an increase in material outputs that includes a number of potentially hazardous and environmentally harmful substances. Domestic processed output (DPO) increased at roughly the same pace as the population to nearly 2.7 billion tons in 2000, with the most growth occurring in the minerals, metals, and nonrenewable organic materials sectors. Characterizing flows in 2000 by type (Q) indicates that more than 80 percent underwent chemical processing, or transformation, at one stage or another of their life cycles. (See Figure 7.) The largest growth, however, was observed in chemically active flows (Q3), which more than doubled to 24 million metric tons over the study period.

FIGURE 7 CHARACTERIZATION OF MATERIAL OUTPUTS TO THE ENVIRONMENT, 2000
(Total releases in 2000: 2672 million metric tons)



Source: WRI Material Flows Database 2005.

Releases to the atmosphere, from both point and diffuse sources, accounted for about three quarters of total outputs to the environment in 2000. The dominance of flows dispersed into the air as a mode of first release is due primarily to emissions associated with energy consumption, which is growing in both absolute and per capita terms. A principal contributor of outputs to the atmosphere is coal-fired electricity plants, which released some 1.9 billion tons of carbon dioxide in 2000. This one category of source was responsible for nearly half of the total increase in outputs to the atmosphere across all sectors over the study period. The emission of carbon dioxide and other greenhouse gasses associated with fossil fuel combustion has been linked with potentially harmful changes in the global climate.[14]

Flows dispersed on land increased by more than 150 percent between 1975 and 2000 as a result of increases in the use of sand and salt to de-ice roads, synthetic rubber for the manufacture of vehicle tires, and nitrogen for fertilizers. These flows still accounted for only 3 percent of all outputs, however.

Outputs discharged directly into water consisted mainly of soaps, detergents, and water treatment chemicals. While this mode of first release represents only a tiny fraction (0.2 percent) of total outputs, some underreporting is likely. No attempt was made to characterize hidden flows that might result in discharges directly into water, such as tailings from metals and minerals extraction. In addition, many flows that are initially discharged to air or dispersed on land travel into water bodies.

COMPARISON WITH EUROPEAN UNION ACCOUNTS

Materials consumption in the United States totaled some 23.6 metric tons per capita in 2000, more than 50 percent higher than consumption in the European Union, averaged across 15 EU countries.[15](See Table 2.) Among the 15 countries, all but two (Finland and Ireland) had lower levels of per capita materials consumption than the United States.

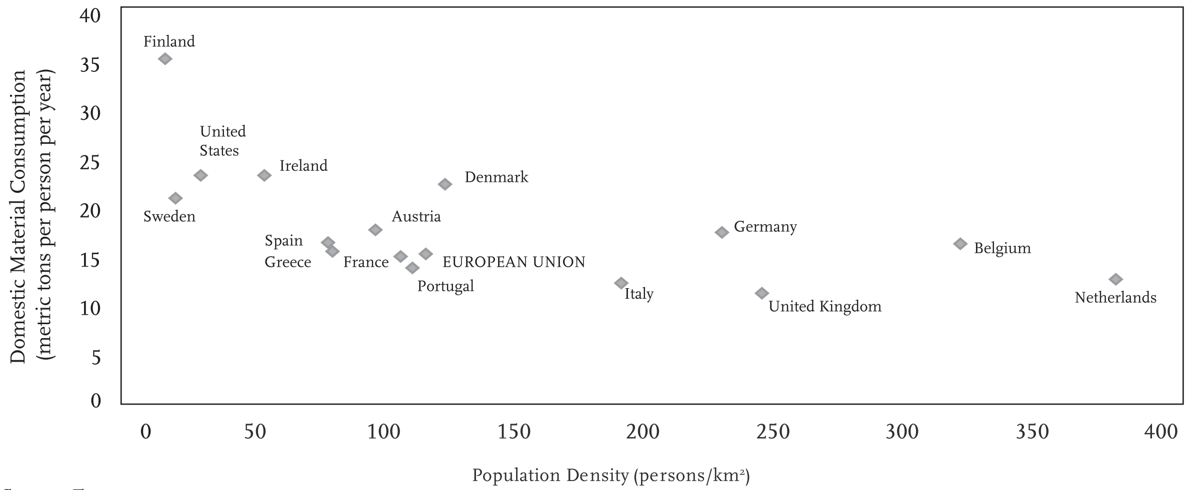
TABLE 2 PER CAPITA MATERIALS CONSUMPTION IN THE EUROPEAN UNION AND THE UNITED STATES, 2000

	Metric Tons Per Person	Percent Change Since 1980
Finland	35.6	-1.0
Ireland	23.6	12.0
United States	23.6	20.7
Denmark	22.7	1.0
Sweden	21.3	-10.0
Austria	18.1	-5.0
Germany	17.8	-13.0
Spain	16.7	39.0
Belgium and Luxemburg	16.6	-4.0
Greece	15.9	35.0
EU-15 AVERAGE	15.6	-3.0
France	15.3	-12.0
Portugal	14.2	32.0
Netherlands	13.0	-17.0
Italy	12.6	-2.0
United Kingdom	11.6	-7.0

Sources: European Commission 2002; WRI Material Flows Database 2005.

Moreover, the rate of growth in U.S. consumption also diverged sharply from trends in the EU. While per capita consumption in the United States grew by almost 21 percent from 1980 to 2000, consumption in the EU (averaged across 15 countries) declined by some 3 percent. Within the 15 countries, only three—Greece, Portugal, and Spain—experienced more rapid increases in consumption than the United States.[16]

FIGURE 8 | POPULATION DENSITY AND MATERIAL CONSUMPTION IN THE UNITED STATES AND EUROPE, 2000



Source: Eurostat 2002.

Note that these three countries produced much lower GDP per capita than other countries in the region ($13,000 per year on average in 2000, versus an average of $21,000 for the EU-15 overall).[17]

The comparatively higher levels of per capita material consumption and growth in the United States than in the EU could be attributable to several factors. Divergence among countries in per capita material flows could be a result of fundamental variations in geography, resource availability, and population density, as well as differences in lifestyle and consumer preferences (size and density of housing, recycling habits, use of individual versus public modes of transportation, etc.).

As shown in Figure 8, per capita materials consumption tends to decline as population density rises.[18] Typically, infrastructure, such as transportation systems and public and commercial buildings, is more efficiently utilized, from a materials perspective, in smaller, more densely populated countries. In contrast, less densely populated countries require great investments per capita in roads and transportation.

In addition, large, sparsely populated countries tend to have significant resource extraction industries. Much of the materials consumptions in Finland and the United States can be attributed to forestry and mining as well as infrastructure development. Meanwhile, more densely populated countries, such as Belgium, the Netherlands, and the United Kingdom, typically import many materials rather than extracting them locally, and these upstream flows are not accounted for in estimates of domestic consumption.

From a policy perspective, certain countries in Europe have chosen to establish higher standards for material use, re-use, and recycling, and as a result, their domestic material consumption is lower.

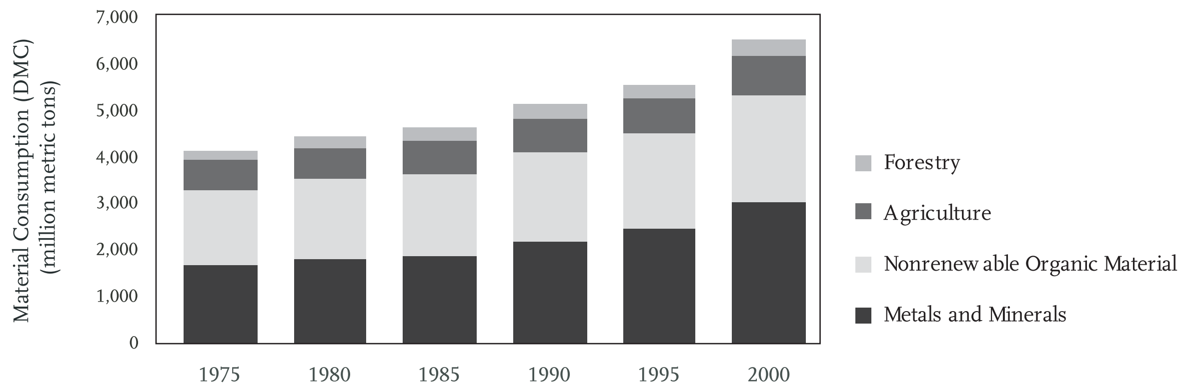
3

MATERIAL FLOWS BY SECTOR OF ORIGIN

In 2004, the OECD Council on Material Flows and Resource Productivity recommended that member states "promote the development and use of material flow analysis and derived indicators at macro and micro levels."[19] The preliminary accounts discussed in this report enable analysis at both of these levels simultaneously. The aggregated MFA indicators presented in Chapter 2—similar to those developed previously for the United States, Japan, and the European Union—provide a broad context for policy decisions at the macro level. The following discussion disaggregates the U.S. accounts by sector of origin, source material, and end use.

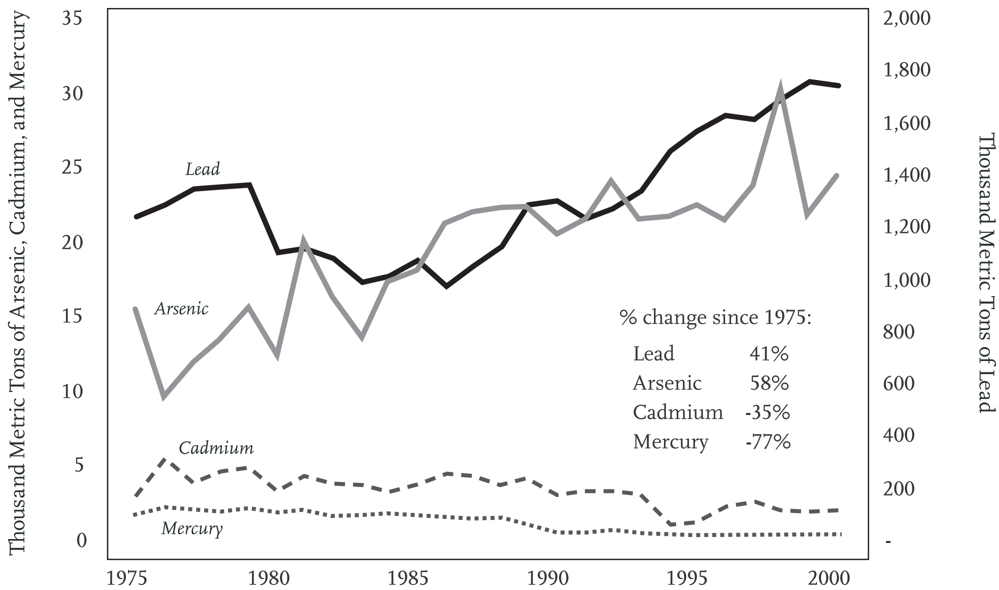
The data collected in this study were classified based on a material's origin in one of four sectors: forestry, agriculture, non-renewable organic materials (mostly fossil fuels), and metals and minerals. As shown in Figure 9, metals and minerals make up the greatest share of materials consumption, increasing from 41 to 47 percent of total materials consumption (DMC) in the study period. Nonrenewable organic materials (mainly fossil fuels) were second.

FIGURE 9 | MATERIALS CONSUMPTION IN THE UNITED STATES BY SECTOR OF ORIGIN, 1975–2000



Source: WRI Material Flows Database 2005.

FIGURE 10 | HEAVY METALS USE IN THE UNITED STATES, 1975–2000



Source: WRI Material Flows Database 2005.
Notes: Amounts shown here reflect "reported use" figures published by the U.S. Geological Survey for individual metals. Cadmium contained in imported batteries and air emissions of mercury from coal combustion are not included here.

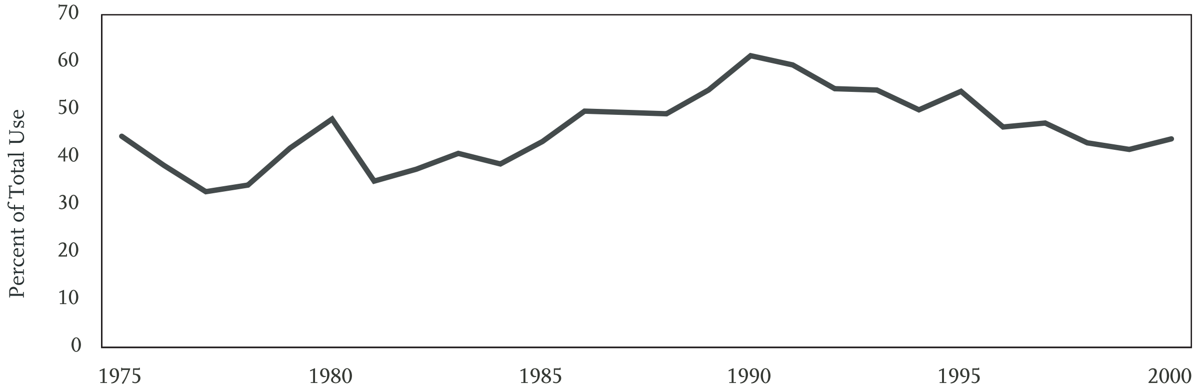
The following analysis examines trends in materials use by sector in order to address the following questions: What are the broad trends in sectoral resource flows? Which commodities and end uses are driving these trends? Where can reduction, re-use, and substitution improve resource efficiency? What are the most important opportunities for further research and policy dialogue?

METALS AND MINERALS

Metals and minerals consumption (DMC) increased by 79 percent between 1975 and 2000. Construction flows, composed mainly of crushed stone, sand, and gravel, accounted for more than 80 percent of metals and minerals use. The construction and high-tech sectors experienced the largest growth in metals and minerals use: 92 percent and 372 percent, respectively.

Heavy metals are of particular concern as their release into the environment, even in small quantities, can result in long-term negative impacts on humans and animals. Arsenic, cadmium, lead, and mercury are among the most toxic materials included in the material flows database developed for this study. While cadmium and mercury consumption declined, arsenic and lead consumption increased nearly 60 percent and 40 percent respectively between 1975 and 2000. (See Figure 10.)

FIGURE 11 | METALS RECYCLING IN THE UNITED STATES AS A PERCENTAGE OF TOTAL USE, 1975–2000



Source: WRI Material Flows Database 2005.

Increases in arsenic use were mainly due to the inclusion of copper chromium arsenate (CCA) as a wood preservative. Since 2004, however, arsenic use has dramatically declined. MFA studies of arsenic were partially responsible for this success in protecting both the environment and human health. Cooperation between the EPA and wood manufacturers produced guidelines that severely restrict the use of CCA in treated wood.[20]

Lead consumption initially declined as its use as a gasoline additive was phased out, but a rise in the number of motor vehicles resulted in increased consumption of lead for automotive batteries. More than 90 percent of all lead is recycled.[21] However, lead released into the environment—estimated at 560,000 tons in 2000—can cause brain and kidney damage in humans, and lead ions that form in surface waters are particularly toxic to marine life.

Generally, recycling presents an opportunity to “close the loop” on the materials cycle by decreasing both the extraction of materials for use and the need for their disposal post-use. Figure 11 shows the trends in metal recycling rates over the study period. Historically, fluctuations in recycling rates have mirrored fluctuations in the commodity prices that drive demand for both new and recycled metals. More recently, however, foreign recycling of U.S.-generated scrap metal (not included in Figure 11) has replaced much domestic recycling. For example, China produces more copper from scrap than any other country in the world, obtaining the majority of its raw material from the United States.[22]

For some heavy metals, recycling trends are influenced by environmental concerns. For example, less than 20 percent of all mercury was recycled in 1975. By 2000, federal regulations had drastically reduced the amount of mercury in use by stipulating complete recovery of mercury from industrial processes such as chlorine and caustic soda manufacture and phasing out mercury’s use in nonessential applications such as paint and thermometers.[23] However, several hundred tons of mercury still enter the environment from coal combustion and discarded waste materials such as fluorescent lamps and computers.

TABLE 3 | TRENDS IN NONRENEWABLE ORGANIC MATERIAL USE (DMC), 1975–2000

Economic Sector (and selected fuel types)	Total Use (thousand metric tons) 1975	2000	Percent change
I. Residential Heating and Cooking *	160,212	137,086	-14
II. Electricity Generation	508,052	1,030,019	103
coal	*368,387*	*894,573*	*143*
natural gas	*64,233*	*105,907*	*65*
III. Industrial Uses	327,174	326,113	0
IV. Commercial Uses	87,515	85,656	-2
V. Transportation	394,344	587,745	49
jet fuel	*44,705*	*77,957*	*74*
motor gasoline	*278,639*	*359,039*	*29*
distillate fuel oil	*48,810*	*122,374*	*151*
VI. Other (Nonfuel Uses)	120,819	149,339	*24*
TOTAL FROM ALL SECTORS	1,598,116	2,315,958	*45*

* Heating and cooking powered by electricity are classified under *II. Electricity Generation* and are not included in *I. Residential Heating and Cooking*.

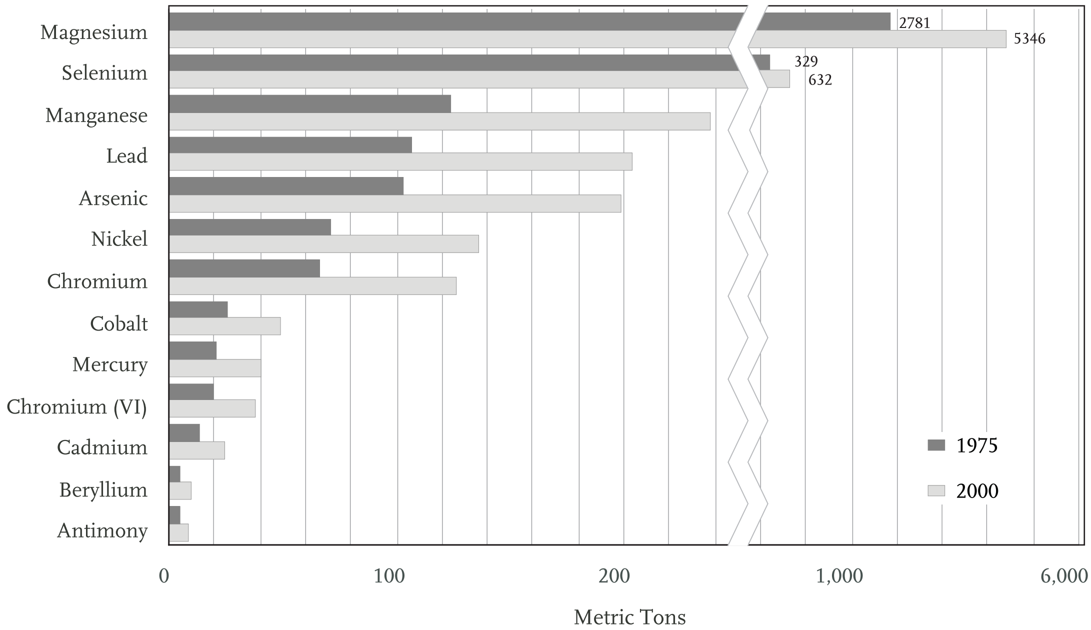
Source: WRI Material Flows Database 2005.

In the future, MFA in the metals and minerals sector would be strengthened by a closer examination of both reclaimed stocks and imported goods. Better accounting of materials that exist as part of and are reclaimed from built infrastructure (stocks) can improve resource efficiency and facilitate the environmental remediation of previously developed lands that are now brownfields. More precise analyses of imported materials would allow policymakers to better manage the unknown quantities of potentially toxic metals and minerals entering the United States in automobiles, electronics, and other goods. For example, more than 50 percent of cadmium use is unaccounted for in the current MFA for the United States because it enters the economy through battery imports.

NONRENEWABLE ORGANIC MATERIALS

Nonrenewable organic materials consist primarily of fossil fuel resources such as coal, natural gas, and petroleum. From 1975 to 2000, annual consumption of nonrenewable organic materials increased by 45 percent, faster than population growth (27 percent) but less rapidly than growth in GDP (127 percent). Electricity generation per capita increased by 60 percent over the study period,[24] driving much of the increase in material flows in this sector. For example, consumption of coal for electricity generation increased by 500 million metric tons, while natural gas consumption for electricity increased by 40 million metric tons. (See Table 3.)

FIGURE 12 | COAL COMBUSTION BY-PRODUCTS, 1995 AND 2000



Source: WRI Material Flows Database 2005.

Fuel consumption in the transportation sector increased nearly 50 percent over the study period. (See Table 3.) Motor gasoline consumption increased by 29 percent as the improved fuel efficiency realized in the first decade of the study period was eclipsed by a growth in total transport volume and a doubling of the market share of vans, pickups, and sport utility vehicles in new vehicle sales.[25] Increases in diesel fuel (distillate fuel oil) consumption can be partially explained by an 84 percent increase in freight traffic carried by trucks between 1975 and 2000.[26]

Use of plastics and synthetic fibers grew by 239 percent over the study period to about 38 million tons in 2000. Only 5 percent of this material, derived from nonrenewable organic resources, was recycled in 2000.[27]

Coal combustion can result in the incidental release of metal by-products such as arsenic, cobalt, lead, mercury, and nickel. The release of such metals and minerals into the air doubled during the study period. (See Figure 12.) While their combined mass is still much smaller than the quantities of metal released on land and in water, these dissipative flows disperse easily into the environment. Even trace amounts can harm human health and ecosystems.

In 2005, the EPA took preliminary actions to limit these flows by proposing a cap-and-trade emissions scheme to regulate mercury emissions from power plants.[28] More sophisticated material flows accounts could help to track the future trends in mercury emissions to evaluate the efficacy of the new regulations.

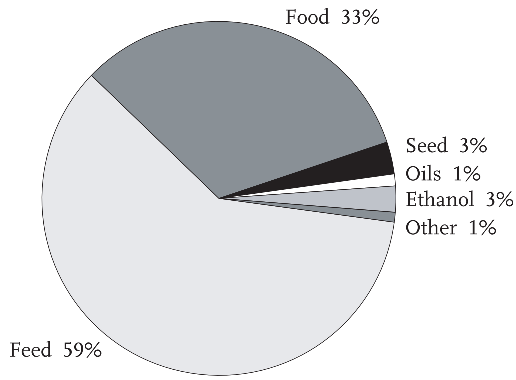
AGRICULTURE

Agricultural flows (DMC) increased by 30 percent in absolute terms between 1975 and 2000, the lowest growth rate of any primary sector. (See Appendix 3.) Most agricultural products (92 percent) are classified as food or animal feed. (See Figure 13.) These flows increased by 66 percent and 16 percent, respectively, over the study period, while material outputs (e.g., manure) from livestock remained fairly constant.

Food consumption outpaced population growth in all categories, with the largest increases observed in sweeteners (130 percent) and grains (75 percent). These results come from both increased caloric intake and an increase in food waste. Consumption of all meat and fish increased slightly faster than population growth, and chicken consumption doubled in the study period. Since animal husbandry practices have changed to produce more rapid weight gain, a shorter lifespan, and lower mortality among livestock, material outputs in this sector remained constant even as meat consumption increased. Outputs from agriculture are still significant, however. The sector produced 250 million tons of manure (dry weight) and consumed 470 million tons of feed to produce 105 million tons of animal products (meat and dairy) for human consumption.

Other agricultural flows with relatively small masses do not affect aggregate accounts but indicate important trends. A more-than-sevenfold increase occurred in the use of grains to produce ethanol for use in automotive fuels. Pesticide consumption remained constant as crop production increased by 25 percent,

FIGURE 13 | AGRICULTURAL CONSUMPTION CLASSIFIED BY END USE, 2000

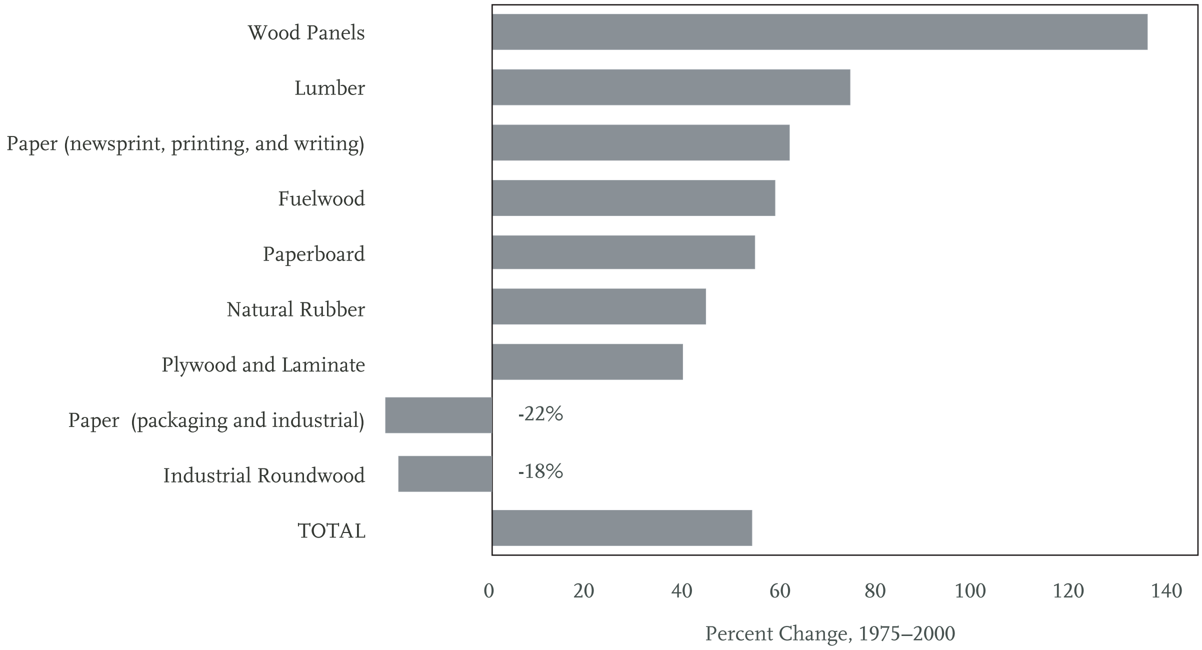


Source: WRI Material Flows Database 2005.

although more detailed analysis would be required to determine specific conclusions or projections from these trends.

The preliminary accounts presented above could be expanded to more specifically address key environmental and economic issues in the agricultural sector: imports and export trends, links to energy flows (specifically energy intensity of agricultural production), geographic intensification of production, and levels of nonpoint source pollution by watershed. In addition, human respiration, animal respiration, and methane emissions from animals and composting were not included in the calculation of outputs; potential improvements to the accounts would enhance the connection between MFA and existing data on biological cycles.

FIGURE 14 | CHANGE IN FORESTRY PRODUCTS USE (DMC) BY TYPE, 1975 TO 2000



Source: WRI Material Flows Database 2005.
Industrial Roundwood comprises all woodproducts not used for paper, fuel, or wood panels.

FORESTRY

Forestry flows were disaggregated into categories reflecting construction, paper products, and fuel wood. Currently each of these uses consumes about 100 million tons of wood per year. Overall, consumption of forestry products grew by 53 percent, almost twice the rate of population growth, but many specific uses exceeded that rate. (See Figure 14.)

Despite the transition to electronic forms of communication during the study period, paper and paperboard consumption increased more than 50 percent from 1975 to 2000, indicating that the use of computers has not converted the United States into a "paperless" economy. This trend is global. Worldwide, paper and paperboard consumption increased by 150 percent in absolute terms during the study period, with two-thirds of this increase occurring in high-income countries.[29] The use of forest products for packaging decreased as plastic was substituted for paper in many applications.

Wood panel and lumber consumption grew by more than 130 percent and 70 percent, respectively. These products are used mostly for construction. The use of natural rubber for automotive and truck tires increased by 44 percent, but this was considerably less than the nearly threefold increase in the use of synthetic rubber for the same purpose.

TABLE 4 | HIDDEN FLOWS AND THEIR SOURCES

Sector	Hidden Flows, 2000 (million metric tons)	Percent Change Since 1975	Sources
Minerals and Metals	3,630	72	Overburden and mining wastes, processing waste from metals fabrication and recycling, chemical waste from manufacture of chlorine, abrasives, lime, etc.
Nonrenewable Organic Materials	5,864	-23	Coal overburden, gas flaring wastes, chemical wastes from synthetics manufacture
Forestry	381	-5	Logging and lumber residue, manufacturing wastes
Agriculture	714	39	Crop residue, food processing wastes, gas emissions from fermentation
Infrastructure Development	6,292	-21	Dredging, construction, erosion (includes erosion from agriculture)
TOTAL	16,882	-10	Includes all domestic and foreign hidden flows with the exception of foreign infrastructure development flows.

Source: WRI Material Flows Database 2005.

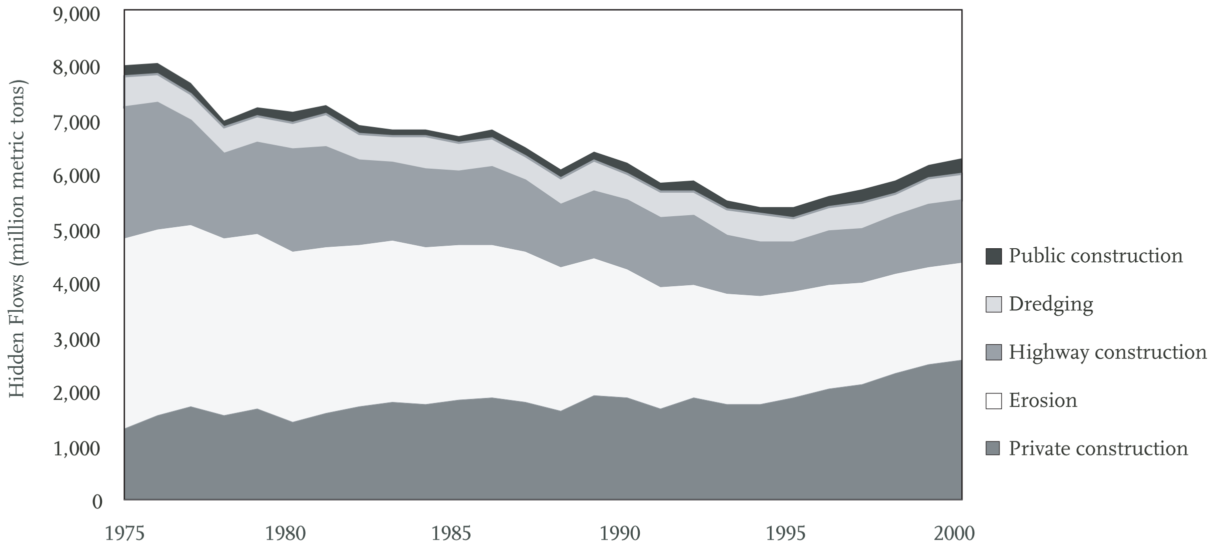
HIDDEN FLOWS

Domestic and foreign hidden flows are incorporated into the U.S. material flows accounts to create a more realistic measure of the physical mobilization of resources and waste required to produce finished goods for consumption. These hidden flows are categorized by the four primary sectors discussed previously and include infrastructure development activities—construction, housing development, road building, and dredging—that are not accounted for in the primary materials sectors. Table 4 shows hidden flows by commodity sector and their most common sources.

Even though hidden flows are rarely captured or measured in traditional economic accounts, they can have effects on both the environment and the economy. Earth moving as a result of industrial activities, such as mining and agriculture, can cause potentially destructive alterations of natural habitat. Manufacturing wastes are not assigned an economic value until the costs from pollution and waste disposal are considered.

Nearly one-half of all hidden flows result from infrastructure development. While flows in this category decreased by 10 percent on average between 1975 and 2000, some subcategories increased. (See Figure 15.) Public and private construction flows grew by 31 and 94 percent, respectively. Conversely, material flows associated with highway construction decreased markedly from the high levels required for the expansion of the interstate system in the early 1970s. Between 1975 and 2000, road mileage in the United States increased by only 2.6 percent, with most construction attributed to upgrades and modification of existing highways.

FIGURE 15 | INFRASTRUCTURE DEVELOPMENT FLOWS, 1975–2000



Source: WRI Material Flows Database 2005.

4

SPECIAL APPLICATIONS OF MATERIAL FLOWS ANALYSIS

It is difficult to identify the specific material flows associated with the consumption of many finished goods. However, MFA estimates for the United States identify broad categories of use for specific source commodities and therefore allow researchers to analyze trends in materials consumption. Two product categories in particular are experiencing rapid growth: housing and electronic goods.

HOUSING AND PUBLIC CONSTRUCTION

In 1975, the median size of a new home in the United States was 1535 square feet; less than 1 percent of these homes contained three or more baths. In 2000, the median size of new homes rose to 2057 square feet, and 20 percent of all homes contained three or more baths.[30] The total number of housing units in the United States increased by 52 percent from 1975 to 2000, nearly twice as fast as population growth.[31] Concurrent with this increase, the material flows associated with housing grew by 91 percent (see Table 5), indicating that the intensity of materials used per housing unit has risen substantially. The use of clay, primarily in the production of tiles and sanitary ware, nearly quadrupled, reflecting the U.S. consumer's growing preference for multiple bathrooms.

In response to the environmental impacts of increased residential construction, the U.S. Green Building Council is developing Leadership in Energy and Environmental Design (LEED) standards for residential housing to complement the commercial guidelines that are already in place. To become LEED-certified, homes must meet certain standards for energy and water efficiency, the sustainability of source materials, and housing size and density.[32]

ELECTRONICS AND COMPUTERS

From 1983 to 2000, sales of consumer electronic devices rose from $14.1 billion to $97 billion, a sevenfold increase.[33] Many of these devices have batteries containing cadmium, which poses a threat to the environment and human health if it is released into air or water, especially as a result of incineration. Although cadmium consumption appears to have declined from 3,000 to 2,000 metric tons per year during the study period, this outcome does not take into account over 2,500 metric tons of cadmium contained in imported batteries in 2000,[34] which are not included in the original U.S. Geological Survey statistics. Indeed, an examination of cadmium flows using additional data indicates that nearly two-thirds of cadmium consumption can be attributed to battery imports. (See Figure 16.)

Concern about the potential release of cadmium from batteries in landfills was the stimulus for state laws controlling its disposal,[35] followed in 1996 by

TABLE 5 | HOUSING AND CONSTRUCTION MATERIALS IN THE UNITED STATES, 1975–2000

Material	Used for:	Consumption in 2000 (thousand metric tons)	% change since 1975
Asbestos	Roofing products	9	-72
Aluminum	Construction	1,113	27
Gypsum	Gypsum products	27,400	201
Clay, ball	Floor and wall tiles	331	373
Clay, ball	Sanitary ware	274	372
Titanium dioxide	Paint, varnishes, and lacquers	575	93
Lumber	Construction	68,227	76
Plywood & Laminated Veneer Lumber (LVL)	Construction	9,010	19
Wood Panels	Construction (estimated 80% of total)	13,942	133
Lumber	Other	10,698	53
Plywood & Laminated Veneer Lumber (LVL)	Other	3,897	128
Wood Panels	Other (estimated 20% of total)	3,486	133
TOTAL		**138,962**	**91**
Total population (millions)		**275.3**	**28**
Total housing units (thousands)		**115,905**	**46**

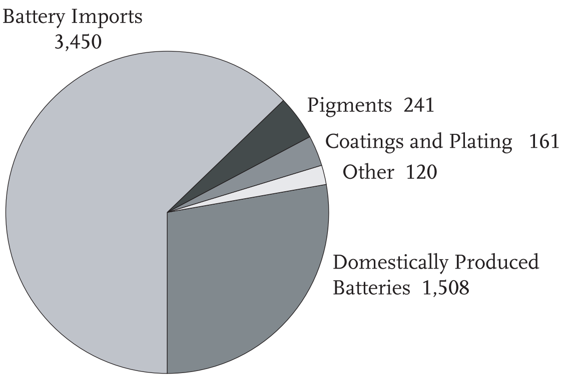
Source: WRI Material Flows Database 2005.

federal legislation requiring that batteries used in small electronic devices be labeled and made easy to remove.[36] Disposing of batteries containing cadmium is already a challenge, and it is likely to become even more so. Understanding and responding to the magnitude of the cadmium disposal problem will require more accurate accounting of battery imports as well as imports of finished goods containing cadmium batteries.

Sales of televisions and computers accounted for more than one-half of the growth in consumer electronic devices.[37] As a result of frequent computer upgrades and electronic innovations, these devices are generally replaced rather than repaired. Data on the average life of televisions are not available, but new computers often become obsolete in five years or less, at which point they may be discarded, recycled, or stockpiled. More than 160 million computers were in use in the United States in 2000, enough to occupy nine million cubic meters of landfill space, the equivalent of a football field stacked 2½ kilometers high with computer waste.[38]

Although the volume of computer-related waste represents only about 1 percent of municipal waste,[39] electronic devices contain heavy metals and other hazardous materials that may be harmful to the environment and to human health if deposited in landfills or improperly recycled. In 2000, only 10 percent of consumer electronics were recycled.[40] Although recycling is recognized as an environmentally

FIGURE 16 | CADMIUM USE IN THE UNITED STATES, 2000 (metric tons)



Source: WRI Material Flows Database 2005; NYAS 2003.

"Other" releases of cadmium are from plastic stabilizers, coal combustion emissions, and alloys.

responsible method of handling most material waste, the processing of electronic waste, or e-waste, can lead to environmental and human health risks. Most e-waste destined for recycling is sent to Asia, particularly China, where it is disassembled by low-skilled, low-wage workers wearing minimal, if any, protective gear. High-value metals, such as gold, silver, and palladium are recovered, while the remainder of the waste may be incinerated in the open air or dumped in streams, in open fields, and along riverbanks. Under these circumstances, unrecovered heavy metals and other non-valuable hazardous substances contained in computers and televisions are likely to contaminate groundwater and aquatic resources.[41]

Public concern for the export of e-waste to developing countries, supported by a number of international nongovernmental organizations, led the EPA's Office of Solid Waste to publish guidelines for the management of "end-of-life" electronics in 2004.[42] The EPA's recommendations for voluntary action have been criticized as insufficient. The United States remains the only industrialized country in the world that has no legislation governing the export of hazardous waste to developing countries and has not ratified the Basel Convention, an international agreement to regulate the flow of hazardous substances across national boundaries.[43]

5

RECOMMENDATIONS

Until now, material flows analyses have been conducted sporadically, with limited resources, and principally through the work of nongovernmental organizations.

Groups in the United States and internationally have called for increases in funding, partnerships, and institutional capacity to establish a complete set of material flows accounts. A study on material flows accounting commissioned in 2003 by the National Research Council (NRC) also recommended that "an independent organization, comprised of interdisciplinary experts, be created and funded through a formal process" to further the development and use of material flows analyses.[44]

In 2003, the Organisation for Economic Co-operation and Development (OECD) began a three-year project to help member countries better understand and implement MFA. Progress to date in the 30 OECD member states has varied. Several countries have established official material flows accounts and set finite targets for materials use. Other OECD countries have not yet developed any accounts at all. While the United States has established preliminary accounts, no specific plans are in place for systematic collection and analysis of national material flows data.

NEXT STEPS FOR IMPROVING MATERIAL FLOWS ACCOUNTS

Full realization of the benefits of MFA will require funds for both data collection and policy analysis across a number of government agencies; partnerships with international MFA consortia, private industry, academia, and NGOs; and the establishment of a central organization—a Center for Material Flows—to manage the collection, analysis, and dissemination of material flows accounts in the United States.

To further the development of material flows accounting, WRI recommends the following actions:

1. ***Establish a systematic and practical framework for material flows accounting.***

   Recent revisions to the U.S. material flows accounts have expanded to more completely describe all stages in the life cycles of materials. Still, a more systematic and robust methodology needs to be established to fully capture the physical and chemical changes observed in materials across time and space. Two existing analytical frameworks—the input-output tables associated with economic accounts and the life-cycle assessments utilized in the field of industrial ecology—are already guiding the evolution of more sophisticated accounts in Europe and may be useful in the United States as well.

The analytical framework for MFA needs to be detailed enough to capture useful information without introducing an unnecessarily burdensome level of complexity. The accounts presented in this report are more detailed than those attempted thus far in European Union countries and Japan. However, the current MFA methodology is not yet adequately developed to account for variations in a material's residence time in the economy, chemical transformations, or fabrications of finished goods with components drawn from many different sectors.

A more systematic accounting methodology will also allow evaluation of the intensity of material flows in economic sectors. This type of analysis is already taking place in some industries. Several major chemicals, metals, and recycling companies currently do track their product materials with MFA.[45] In 2002, a global coalition of activist groups concerned with the impacts of mining on ecosystems and communities called on governments to promote MFA as a way of identifying opportunities for more efficient use of energy and materials in the mining sector.[46]

To date, nearly all material flows analyses have been conducted at a national scale. However, regional and local consumption patterns are most relevant for citizens concerned with the impacts that these materials may have on their neighborhoods and their families. As the National Research Council recommends in their 2003 report,[47] accounts must enable geospatial analysis in order to provide policy-relevant information. A material flows study by the New York Academy of Sciences in the New York/New Jersey Harbor demonstrated the utility of this approach by engaging stakeholders in government, private industry, and the research community to reduce contaminant emissions and health risks.

To create a robust and practical analytical framework for MFA, WRI joins the National Resource Council's Committee on Materials Flow Accounting in recommending that the federal government establish a Center for Material Flows in collaboration with nongovernmental organizations and the private sector. The center would manage the development of MFA methodological guidelines that are applicable to the United States and compatible with international accounts. It would also produce information and analyses of U.S. material flows in coordination with government agencies, academic researchers, and the private sector and produce annual reports on major materials.

2. ***Expand and synthesize core data across the life-cycles of materials.***

While this study of material flows accounts features more detailed information from a broader range of sources than previous studies, significant data gaps remain. Current accounts do not contain any specific information about the production and use of organic and inorganic chemicals or the large flows associated with the production, use, and disposal of plastics and synthetic fibers. Data on pesticides such as pendimethalin or trifluralin are reported erratically, based on isolated studies, with estimates from different government agencies varying by more than 100 percent. The materials in most imported finished goods cannot be measured, including electronic devices that contain heavy metals and other materials that are hazardous to human health and the environment.

Data on wastes released to the environment in the United States are still largely nonexistent. Isolated surveys of municipal solid waste are reported by the Environmental Protection Agency, as are outputs of hazardous materials through the Toxic Resources Inventory and other mechanisms. However, commercial waste, liquid waste, and comprehensive municipal waste are not tracked on a national scale. As a result, substantial errors are introduced into current material flows accounts by estimates of waste based solely on production data.

To fill these data gaps, the federal government can engage local and national agencies as well as the private sector to compile the data necessary for complete material flows accounts. Government agencies may require additional budget and technical support to periodically provide these data to a centralized organization, such as a Center for Material Flows. The coordination of statistical functions across different organizations will allow the full value of both new and existing data to be more fully realized.

3. ***Incorporate material flows analysis into environmental and economic decisionmaking.***

Improvements in assessment methodologies and core data sets will allow policymakers to incorporate MFA into environment, trade, national security, and natural resources management policies. Because material flows accounts track the trends in materials in and out of the economy, they can be used as early warning indicators of potentially serious impacts on human health and undesirable changes in natural resources. With a detailed database on materials use and consumption, policymakers can track materials of environmental concern and act to stem their release into the environment.

In the past, MFA has not directly addressed the environmental impacts of the extraction and release of materials. However, identifying the most environmentally deleterious patterns is required if policymakers are to make informed decisions encouraging more responsible use of natural resources.

Most previous assessments relating materials use to environmental impacts have been largely anecdotal, and MFA does not include an overall measurement of environmental health. Direct correlations between material consumption and its corresponding impact on the environment are possible with some materials, such as CO_2 and chlorofluorocarbons (CFCs). Further work linking impacts and material consumption is required to address such policy-relevant questions as: What consumption patterns are the most environmentally destructive? Where could substitutions or policy interventions be the most effective to ensure that material consumption does not negatively affect human or environmental health?

To date, material flows accounts have received limited support from government agencies. The Environmental Protection Agency has funded three preliminary studies in the past decade, and a number of other agencies—U.S. Geological Survey, the Forest Service, U.S. Department of Agriculture, and the Census Bureau—have provided data and expertise to the effort. Without a larger mandate, these agencies are unable to contribute more time and money to establishing systematic, regularly updated accounts.

While there is still no federal mandate or funding to establish a Center for Material Flows, the U.S. House of Representatives has recognized the need for improved data and comprehensive analysis in the minerals and metals sector. In September 2006, the House of Representative's Committee on Resources introduced the Resource Origin & Commodity Knowledge (ROCK) Act, which would establish a Mineral Commodity Information Administration responsible for "acquiring and analyzing data related to the origin and uses of domestic and international mineral commodities." The ROCK Act represents a promising first step in establishing centralized data collection and analysis of materials use in the United States.[48]

Economic accounts and social indicators have aided policymaking in both the public and private sectors for many decades, yet the resources that support economic and social well-being are typically measured in isolation from each other—if they are measured at all. The holistic approach of material flows accounting provides a critical link in understanding the physical implications of the extraction, fabrication, use, and disposal of roughly 20 billion tons of material each year in the United States. Only with proper measurement can the United States manage the diverse physical resources that support the livelihoods of the entire population.

NOTES

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APPENDIX 1

CHARACTERIZING MATERIAL FLOWS

In MFA, the outputs that flow into the environment are characterized by their use while a part of the industrial economy. Their role generally indicates how, when, where, and in what condition they will be released. To take into account the variety among flows, each flow is characterized by mode of first release (M), quality (Q), and velocity from input to output (V). Within these three categories are many sub-categories that describe the outputs more fully and therefore support an analysis of their impact on the environment. See *The Weight of Nations,* p.117, Box A1, for more information.

MODE OF RELEASE (M)

The spatial dimension over which a flow impacts the environment is related to its dispersion and freedom of movement. A first approximation of this can be inferred from the mode in which the flow exits the economy, the physical state of the output flow (gaseous, liquid, or solid), and the degree to which the output flow is, or can be, controlled. It is fortunate that the available information on material life cycles for most major flows permitted a reasonable judgment about these two factors, especially at the point where the flow first enters the environment.

Changes in form and mobility do occur subsequent to first entry. Flows dispersed on land as solids may later be dissolved and end up in water systems; those released to air may end up on the land. It is acknowledged that identifying all the possible pathways subsequent to first release is necessary for a complete assessment of potential impacts. However, this is normally an extremely complicated, site-dependent analysis, much beyond the first level categorizations undertaken for this study. It should also be noted that no attempt was made to provide information on the specific sites of output flows. The following mode of release categories are used in the spreadsheets:

M0) Flows that become a "permanent" part of the built infrastructure and do not exit the economy during the period under consideration (that is, 30 years).

M1) Flows contained or controlled on land as solids (landfills, overburden).

M2) Flows contained on land as liquids or partial solids (tailings ponds, impoundments).

Since both M1 and M2 are controlled in essentially the same manner, it may be possible to combine them.

M3) Flows dispersed directly onto land in a solid, partial solid, or liquid form (fertilizers, pesticides, and fungicides).

M4) Flows discharged into water systems in a solid, partial solid, or liquid form (dredge spoil, soil erosion, sewage effluent, and deep well injection). While it could be argued that deep well injection is a controlled release more appropriate to category M1, the degree of containment in the geologic structure can be uncertain.

M5) Flows discharged into air from point sources in a gaseous or particulate form (power plant and industrial source stack emissions).

M6) Flows discharged into air from diffuse sources in a gaseous or particulate form (auto emissions, household heating plants, spray paints).

M7) Flows that take many paths, or no clearly defined path, or which are not classifiable.

While it was considered useful to differentiate between point and diffuse sources, it is acknowledged that the spatial domain affected by multiple point sources may, in some cases, be the same as that for diffuse sources.

QUALITY OF RELEASE (Q)

A quality descriptor should provide some information on whether the environment can assimilate a flow and whether it is biologically harmful. Only flows that are biodegradable, or are a consequence of our human physiology, can potentially be assimilated in anything short of thousands of years. A descriptor should also identify flows that are similar to geologic processes that operate over relatively short time frames. Erosion, beach formation and removal, and siltation of rivers are continuous natural processes that physically transform and move material, and are observable in a human time frame. Some flows in our economy, such as road building, are similar to these.

Assigning flows to quality categories is potentially more contentious than mode of first release, but it is necessary if we are to begin sorting out flows in a useful way. It should be noted that quality categories should not be treated as hierarchical. All flows cause environmental change, and none can automatically be considered innocuous. As an example, while biodegradable manure can be a useful soil supplement, too much in one place can be a significant problem, as recently witnessed at some large-scale pig and poultry farms. Similarly, just because a flow replicates a geologic process does not mean it is benign. The filling of a wetland, or the building of a road through a critical ecosystem can have major impacts. The following categories are used in the spreadsheets:

Q1) Flows that are biodegradable (agriculture, forest, and fishery products).

Q2) Flows that replicate rapid continuous geologic processes (particle size reduction and movement only).

Q3) Flows that have not been chemically processed but are chemically active (salt) or biologically hazardous (asbestos).

Q4) Flows that have undergone chemical processing. These may or may not be chemically active (fuel emissions, fertilizers, industrial chemicals, certain mineral processing wastes).

Q5) Flows that are heavy metals, synthetic and persistent chemical compounds, or radioactive.

VELOCITY OF RELEASE (V)

The velocity of a flow—or its converse, the residence time in the human economy—is an important variable that can be related to potential impacts on the environment. Some flows, such as overburden removal, enter and exit almost simultaneously. Others, such as the aluminum used in beverage containers that are not recycled, may have a service life of weeks. Concrete and steel used in construction projects may remain in the economy for 100 years. While the impact a flow has on the environment is not, on a per unit basis, directly related to its velocity, the quantity released, or disposed of in a given period of time, certainly is. Recapture by recycling, remanufacture, or reuse increases residence time and reduces the quantity released per unit of service obtained. The available information allowed the velocity of a flow to be reasonably estimated according to four broad categories as shown below:

V1) Flows that exit within 2 years after entry (food, fertilizer, packaging, petroleum used as fuel).

V2) Flows that exit after from 3 to 30 years in the economy (durable consumer goods, automobiles). It would be useful if V2 could be further divided into 3–10, and 10–30 year categories, but it is not clear that the available data permits this distinction to be made.

V3) Flows that stay in the economy for more than 30 years and are additions to the stock of built infrastructure (highways, buildings).

V4) One item, construction and demolition waste withdrawn from the stock of built infrastructure, was placed in this category.

APPENDIX 2

COMMODITIES INCLUDED IN MATERIAL FLOWS ACCOUNTS

Selection of the individual commodity flows for analysis was based on the availability of sufficient detailed data for the time periods investigated. Specific references for each flow in the database are shown on data sheets on the MFA website, available at <http://materials.wri.org>.

APPENDIX 2 COMMODITIES INCLUDED IN MATERIAL FLOWS ACCOUNTS

Metals and Minerals

1. Abrasives (Manufactured)
2. Aluminum
3. Antimony
4. Arsenic
5. Asbestos
6. Barite
7. Beryllium
8. Bismuth
9. Boron
10. Bromine
11. Cadmium
12. Caustic Soda
13. Cement
14. Cesium
15. Chlorine
16. Chromium
17. Clay, ball
18. Clay, bentonite
19. Clay, common
20. Clay, fire clay
21. Clay, fullers earth
22. Clay, kaolin
23. Clay, totals
24. Cobalt
25. Columbium
26. Copper
27. Crushed stone
28. Diamonds, industrial
29. Diatomite
30. Feldspar
31. Fluorspar
32. Gallium
33. Garnet
34. Germanium
35. Gold
36. Graphite
37. Gypsum
38. Hafnium
39. Helium
40. Indium
41. Iodine
42. Iron & Steel
43. Iron & Steel Slag
44. Iron ore
45. Kyanite and related minerals
46. Lead
47. Lime
48. Lithium
49. Magnesium compounds
50. Magnesium metal
51. Manganese
52. Mercury
53. Mica, natural sheet
54. Mica, scrap and flake
55. Molybdenum
56. Nickel
57. Nickel
58. Nitrogen
59. Peat
60. Perlite
61. Phosphate rock
62. Phosphoric acid
63. Potash
64. Pumice & pumicite
65. Quartz crystal, industrial
66. Rare earths
67. Rhenium
68. Rubidium
69. Salt
70. Sand & Gravel construction
71. Sand & Gravel industrial
72. Scandium
73. Selenium
74. Silicon
75. Silver
76. Soda ash
77. Sodium sulfate
78. Stone, dimension
79. Strontium
80. Sulfur
81. Talc & Pyrophyllite
82. Tantalum
83. Tellurium
84. Thallium
85. Thorium
86. Tin
87. Titanium concentrates
88. Titanium dioxide
89. Titanium sponge metal
90. Tungsten
91. Vanadium
92. Vermiculite
93. Yttrium
94. Zinc
95. Zirconium

APPENDIX 2 (*continued*)

Agriculture

96. Barley
97. Beans
98. Beef
99. Byproducts of animal processing
100. Cattle live
101. Chicken live
102. Chicken meat
103. Citrus fruit
104. Corn
105. Cotton
106. Cottonseed
107. Eggs
108. Fishery Products
109. Hay
110. Lamb and mutton meat
111. Live pigs
112. Live turkeys
113. Milk & Milk Products
114. Millet
115. Mushrooms
116. Non-citrus fruit
117. Oats
118. Peanuts
119. Pork
120. Potatoes
121. Rice
122. Rye
123. Sorghum
124. Soybeans
125. Sugar Beets
126. Sugar Cane
127. Sunflowers
128. Tobacco
129. Tree Nuts
130. Turkey meat
131. Veggies
132. Wheat
133. Wool
134. Cattle manure
135. Hog manure
136. Poultry manure
137. Turkey manure
138. Human bio-solids

Nonrenewable organic material

139. Asphalt & Road Oil
140. Butane
141. Coal
142. Coal Combustion products
143. Coke
144. Distillate Fuel Oil
145. Ethane
146. Jet Fuel
147. Kerosene
148. Lubricants
149. Motor Gasoline
150. Natural gas (Methane)
151. Other Petroleum Products
152. Petroleum Coke
153. Propane
154. Residual Fuel Oil
155. Total plastic and synthetic fibers
156. Synthetic rubber

Forestry

157. Fuelwood
158. Lumber
159. Other Industrial Roundwood
160. Paper & Board
161. Plywood & Laminated Veneer Lumber (LVL)
162. Rubber (crude natural)
163. Wood Panels

Earth moving and infrastructure

164. Sheet and rill
165. Wind erosion
166. Dredging
167. Highway construction
168. Private construction
169. Public construction

APPENDIX 3

NATIONAL INDICATORS BY WEIGHT AND SECTOR, 1975–2000

The categories of national indicators used in this study were developed in earlier, cooperative international studies that have been published by the World Resources Institute in *Resource Flows: The Material Basis of Industrial Economies* (1997) and *The Weight of Nations: Material Outflows from Industrial Economies* (2000). This set of indicators, showing inputs, consumption, and outputs in an industrial economy, have been agreed upon in the international community and adopted by Eurostat and the OECD.

The database for this project contains specific data for input, consumption, and output flows associated with each commodity on the commodity list. These individual data were aggregated into commodity groups and then summed to create indicators for the entire nation. The aggregated data are presented in absolute amounts in this appendix. All data are in thousand metric tons.

APPENDIX 3 NATIONAL INDICATORS BY WEIGHT AND SECTOR, 1975–2000 *(in thousand metric tons)*

	1975	1980	1985	1990	1995	2000	Percent increase
Agriculture							
DMC	653,678	655,063	700,060	725,559	749,989	856,542	31.0
DMI	766,931	810,761	810,098	846,851	902,733	1,004,950	31.0
TMR	1,279,128	1,366,322	1,507,001	1,487,743	1,498,617	1,719,260	34.4
DPO V1	288,185	265,762	271,601	269,145	295,992	300,329	4.2
DPO (V1+V2)	290,475	269,002	275,512	271,403	299,957	303,788	4.6
NAS	-	-	-	-	-	-	
TDO	801,518	823,478	970,340	907,819	887,631	1,009,113	25.9
Forestry							
DMC	197,364	241,366	287,044	297,161	285,478	315,607	59.9
DMI	215,819	267,752	310,017	329,995	321,846	353,208	63.7
TMR	615,535	655,407	666,093	662,265	641,205	734,240	19.3
DPO V1	69,767	85,326	97,307	95,840	85,221	95,012	36.2
DPO (V1+V2)	101,085	118,545	135,897	140,451	121,190	128,805	27.4
NAS	54,531	66,727	82,089	85,939	90,497	95,728	75.5
TDO	493,925	498,274	479,637	463,716	428,955	495,417	0.3
Metals and Minerals							
DMC	1,702,261	1,813,803	1,885,287	2,209,795	2,467,001	3,046,494	79.0
DMI	1,728,674	1,843,241	1,908,384	2,257,407	2,517,147	3,090,193	78.8
TMR	3,836,103	4,009,051	3,826,294	5,188,337	5,841,633	6,720,285	75.2

APPENDIX 3 *(continued)*

	1975	1980	1985	1990	1995	2000	Percent increase
***Metals and Minerals** (continued)*							
DPO V1	115,846	136,873	126,772	166,060	179,554	178,366	54.0
DPO (V1+V2)	173,539	193,197	186,223	199,510	220,542	246,028	41.8
NAS	1,497,970	1,585,191	1,666,021	1,965,260	2,199,041	2,754,950	83.9
TDO	1,625,416	1,693,534	1,491,508	2,586,913	2,878,561	2,807,877	72.7
Nonrenewable Organic Material							
DMC	1,595,821	1,748,675	1,765,244	1,907,851	2,048,054	2,296,460	43.9
DMI	1,668,081	1,861,596	1,890,572	2,049,106	2,181,199	2,406,300	44.3
TMR	9,364,833	8,964,647	8,500,409	8,942,157	8,059,587	8,270,270	-11.7
DPO V1	1,529,415	1,651,258	1,561,137	1,742,508	1,817,774	1,945,117	27.2
DPO (V1+V2)	1,553,056	1,682,827	1,593,900	1,777,947	1,858,954	1,994,132	28.4
NAS	27,203	29,181	31,159	33,137	35,116	37,094	36.4
TDO	9,249,808	8,785,879	8,203,737	8,670,999	7,737,342	7,858,102	-15.0
National Totals							
DMC	4,149,124	4,458,907	4,637,635	5,140,365	5,550,522	6,515,103	57.0
DMI	4,379,504	4,783,350	4,919,071	5,483,359	5,922,926	6,854,651	56.5
TMR	15,095,599	14,995,427	14,499,796	16,280,502	16,041,042	17,444,056	15.6
TMR*	23,115,368	22,136,388	21,224,703	22,480,565	21,424,011	23,735,652	2.7
DPO V1	2,003,213	2,139,219	2,056,817	2,273,553	2,378,541	2,518,824	25.7
DPO (V1+V2)	2,118,156	2,263,571	2,191,533	2,389,311	2,500,643	2,672,753	26.2
NAS	1,579,704	1,681,099	1,779,269	2,084,336	2,324,654	2,887,772	82.8
TDO	12,170,667	11,801,165	11,145,222	12,629,446	11,932,489	12,170,508	0.0
TDO*	20,190,436	18,942,126	17,870,129	18,829,509	17,315,458	18,462,104	-8.6

* *These indicators include the earth moving and infrastructure hidden flows shown below.*
Earth Moving & Infrastructure Hidden Domestic Flows (excluded above, except as noted)

	1975	1980	1985	1990	1995	2000	Percent increase
Erosion							
Sheet and rill	2,000,000	1,720,000	1,534,800	1,303,600	1,101,900	1,010,025	-49.5
Wind erosion	1,500,000	1,420,714	1,339,800	1,074,560	855,400	795,500	-47.0
Dredging							
Dredging (Soil disposed on land)	279,813	255,750	259,875	239,250	224,242	247,706	-11.5
Dredging (Soil disposed in water)	279,813	255,750	259,875	239,250	224,242	247,706	-11.5
Earth moving							
Highway construction	2,427,274	1,891,250	1,376,932	1,253,717	916,810	1,152,751	-52.5
Private construction	1,326,750	1,424,459	1,821,776	1,893,396	1,871,946	2,568,187	93.6
Public construction	206,119	173,038	131,849	196,290	188,429	269,720	30.9
Total	8,019,769	7,140,961	6,724,907	6,200,063	5,382,969	6,291,596	-21.5

APPENDIX 4

NATIONAL INDICATORS PER CAPITA BY SECTOR, 1975–2000

The categories of national indicators used in this study were developed in earlier, cooperative international studies that have been published by the World Resources Institute in *Resource Flows: The Material Basis of Industrial Economies* (1997) and *The Weight of Nations: Material Outflows from Industrial Economies* (2000). This set of indicators, showing inputs, consumption, and outputs in an industrial economy, have been agreed upon in the international community and adopted by Eurostat and the OECD.

The database for this project contains specific data for input, consumption, and output flows associated with each commodity shown on the commodity list. These individual data were aggregated into commodity groups and then summed to create indicators for the entire nation. The aggregated data are presented in this appendix on a per capita basis, a form that permits comparisons among countries, regions, states, and any other comparable groups. Data are in metric tons per person.

APPENDIX 4 PER CAPITA NATIONAL INDICATORS BY SECTOR, 1975–2000 ***(in metric tons per capita)***

	1975	1980	1985	1990	1995	2000	Percent increase
Total US population/1000	215,973	227,726	238,466	249,973	263,082	275,372	27.50
GDP (million 1995 dollars)	3,969,200	4,771,900	5,563,500	6,520,500	7,338,400	9,008,507	126.96
Agriculture							
DMC	3.03	2.88	2.94	2.90	2.85	3.11	2.8
DMI	3.55	3.56	3.40	3.39	3.43	3.65	2.8
TMR	5.92	6.00	6.32	5.95	5.70	6.24	5.4
DPO V1	1.33	1.17	1.14	1.08	1.13	1.09	-18.3
DPO (V1+V2)	1.34	1.18	1.16	1.09	1.14	1.10	-18.0
NAS	0.00	0.00	0.00	0.00	0.00	0.00	
TDO	3.71	3.62	4.07	3.63	3.37	3.66	-1.3
Forestry							
DMC	0.91	1.06	1.20	1.19	1.09	1.15	25.4
DMI	1.00	1.18	1.30	1.32	1.22	1.28	28.4
TMR	2.85	2.88	2.79	2.65	2.44	2.67	-6.4
DPO V1	0.32	0.37	0.41	0.38	0.32	0.35	6.8
DPO (V1+V2)	0.47	0.52	0.57	0.56	0.46	0.47	-0.1
NAS	0.25	0.29	0.34	0.34	0.34	0.35	37.7
TDO	2.29	2.19	2.01	1.86	1.63	1.80	-21.3

APPENDIX 4 PER CAPITA NATIONAL INDICATORS BY SECTOR, 1975–2000 *(in metric tons per capita)*

	1975	1980	1985	1990	1995	2000	Percent increase
Metals and Minerals							
DMC	7.88	7.96	7.91	8.84	9.38	11.06	40.4
DMI	8.00	8.09	8.00	9.03	9.57	11.22	40.2
TMR	17.76	17.60	16.05	20.76	22.20	24.40	37.4
DPO V1	0.54	0.60	0.53	0.66	0.68	0.65	20.8
DPO (V1+V2)	0.80	0.85	0.78	0.80	0.84	0.89	11.2
NAS	6.94	6.96	6.99	7.86	8.36	10.00	44.2
TDO	7.53	7.44	6.25	10.35	10.94	10.20	35.5
Nonrenewable Organic Material							
DMC	7.39	7.68	7.40	7.63	7.78	8.34	12.9
DMI	7.72	8.17	7.93	8.20	8.29	8.74	13.1
TMR	43.36	39.37	35.65	35.77	30.64	30.03	-30.7
DPO V1	7.08	7.25	6.55	6.97	6.91	7.06	-0.3
DPO (V1+V2)	7.19	7.39	6.68	7.11	7.07	7.24	0.7
NAS	0.13	0.13	0.13	0.13	0.13	0.13	6.9
TDO	42.83	38.58	34.40	34.69	29.41	28.54	-33.4
National Totals							
DMC	19.21	19.58	19.45	20.56	21.10	23.66	23.2
DMI	20.28	21.00	20.63	21.94	22.51	24.89	22.8
TMR	69.90	65.85	60.80	65.13	60.97	63.35	-9.4
TMR *	107.03	97.21	89.01	89.93	81.43	86.19	-19.5
DPO V1	9.28	9.40	8.63	9.10	9.05	9.15	-1.4
DPO (V1+V2)	9.81	9.99	9.26	9.63	9.58	9.80	0.0
NAS	7.31	7.38	7.46	8.34	8.84	10.49	43.4
TDO	56.35	51.82	46.74	50.52	45.36	44.20	-21.6
TDO*	93.49	83.18	74.94	75.33	65.82	67.04	-28.3
** These indicators include the Earth Moving and Infrastructure hidden flows shown below*							
Earth Moving & Infrastructure, hidden domestic flows (excluded above, except as noted)							
Total erosion	16.21	13.79	12.05	9.51	7.44	6.56	-59.5
Total dredging	2.59	2.25	2.18	1.91	1.70	1.80	-30.6
Highways construction	11.24	8.30	5.77	5.02	3.48	4.19	-62.8
Total public and private construction	7.10	7.01	8.19	8.36	7.83	10.31	45.2
Total	37.13	31.36	28.20	24.80	20.46	22.85	-38.5

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