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The Environmental Impact of Pollution Prevention and Other Sustainable Development Strategies Implemented by the Automotive Manufacturing Industry

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CHAPTER MENU

6.1 Introduction

This chapter characterizes chemical release and other waste management quantities as well as pollution prevention activities carried out by the US automotive manufacturing industry over the 2005–2015 time-frame.[1] Analysis of information available from federal databases such as the US Environmental Protection Agency's (EPA's) Toxics Release Inventory (TRI) and industry reports reveals the corresponding environmental impacts, and identifies opportunities for continued progress. Throughout this chapter several terms are used that may not be familiar to the reader. These terms are defined below.

> A **'TRI chemical'** is a chemical that is included on the Toxics Release Inventory (TRI) list of chemicals, as established under Section 313(d)(2) of the *Emergency Planning and Community Right-to-Know Act*. Chemicals included on the TRI list are those that as a result of continuous, or frequently recurring releases are known to cause or can reasonably be anticipated to cause (1) significant adverse acute human health effects at concentration levels reasonably likely to exist beyond facility site boundaries; (2) cancer or teratogenic effects or serious or irreversible reproductive dysfunctions, neurological disorders, heritable genetic mutations, or other chronic health effects; or (3) a significant adverse effect on the

1 At the time of the analysis and writing of this chapter, the 2015 reporting year was the year for which the most recent TRI data were available.

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environment of sufficient seriousness to warrant reporting due to the chemical's toxicity, its toxicity and persistence in the environment, or its toxicity and tendency to bioaccumulate in the environment.

A **'TRI-reported chemical'** refers to chemicals on the TRI list of chemicals for which facilities in the US have submitted reports to the US Environmental Protection Agency (EPA) TRI Program indicating releases to the environment or otherwise managed as waste.

'TRI-reported chemical waste' or **'TRI-reported waste'** refers to the quantity of the TRI chemical(s) contained in waste and reported to EPA by facilities as released to the environment or otherwise managed as waste, such as through recycling, treatment, or combustion for energy recovery.

Beyond TRI-reported chemical waste management, this chapter also reviews data and literature on a range of pollution prevention and sustainability strategies in the industry such as those related to improving energy efficiency and material use. This chapter does not consider, in detail, the environmental impacts from resource extraction or depletion such as water consumption or mining of raw materials.

6.2 Overview of the Automotive Manufacturing Industry

The automotive manufacturing industry, as defined in this chapter, includes three subsectors characterized by the North American Industry Classification System (NAICS) as: Motor Vehicle Manufacturing (NAICS 3361); Motor Vehicle Body and Trailer Manufacturing (NAICS 3362); and Motor Vehicle Parts Manufacturing (NAICS 3363). Facilities in these subsectors do not conduct after-market vehicle repairs and modifications or any other waste-generating processes occurring over a vehicle's lifetime aside from its initial manufacture. However, this chapter considers certain factors that are under manufacturers' control such as fuel economy and recyclability of vehicles at the end of their useful life. Off-road recreational and industrial vehicles are not discussed herein.

6.2.1 History

The US automotive industry was established in the late 1800s with vehicles powered by a variety of energy sources including steam, electricity, gasoline, and even biodiesel, but were too expensive for most households. With pioneers such as Henry Ford and the increased efficiency of new moving assembly lines, production grew rapidly between 1910 and 1920, and vehicles eventually became more accessible and affordable to the general public. Ford Motor Company, General Motors (GM) Company, and Fiat Chrysler Automobiles (previously Chrysler Group) quickly established their dominance and still lead production today. In total, the US is one of the largest auto-producing countries in the world, with about 12 million vehicles produced annually, second only to China with about 25 million vehicles produced annually. By comparison, the countries in the European Union produce about 18 million vehicles per year collectively (OICA 2015).

6.2.2 Production and Economic Trends

In 2015, the automotive manufacturing industry contributed $678 billion (US Bureau of Economic Analysis 2015), or 3.8%, to the US Gross Domestic Product (GDP) and provided approximately 811 000 US jobs (US Census Bureau 2014). From December 2007 through June 2009, production within the US automotive industry slowed due to a global-scale recession. Total US motor vehicle production dropped from 10.7 million vehicles in 2007 to 5.7 million vehicles in 2009. Production

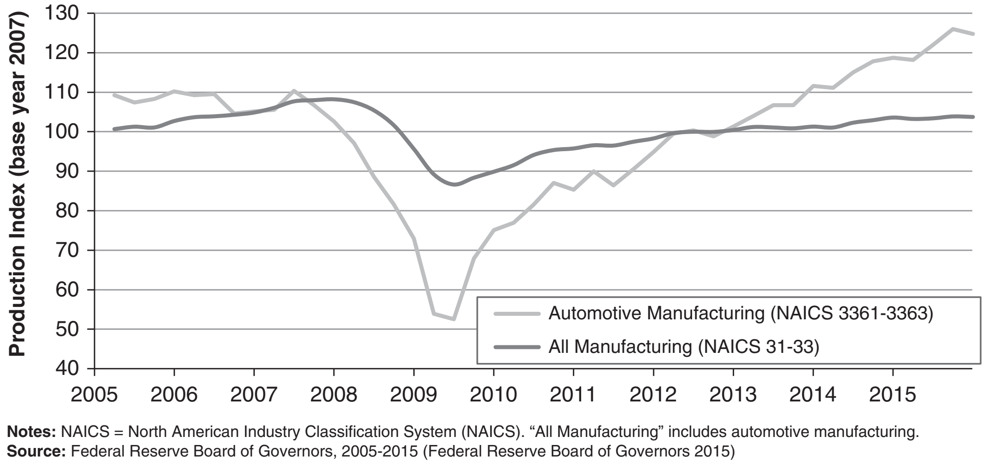

Figure 6.1 Automotive manufacturing production index – seasonally adjusted, 2005–2015. Notes: NAICS, North American Industry Classification System (NAICS). ‘All Manufacturing’ includes automotive manufacturing. Source: Federal Reserve Board of Governors, 2005–2015 (Federal Reserve Board of Governors 2015).

of cars and light, medium, and heavy trucks declined significantly by 2008 and bottomed out in mid-2009. Between 2007 and 2009, the industry lost over a quarter of a million employees, and two of the three largest automakers (GM and Chrysler) filed for bankruptcy (Katz et al. 2013). Over the course of the next several years, the US Treasury Department invested approximately $80 billion dollars in the industry to help it recover (US Department of the Treasury 2015). GM and Chrysler emerged from bankruptcy in June 2009. The industry gradually created 500 000 new jobs, and total production has largely returned to pre-recession levels (US Department of the Treasury 2015, Automotive News 2015) .

The automotive manufacturing production index indicates that this industry was more affected by the 2007–2009 recession than all manufacturing industries in aggregate, as shown in Figure 6.1. Even before 2008, the industry was experiencing declining market shares as well as significant debt, pension, and health care costs. Additionally, due to the declining availability of loans and rising unemployment, consumers were not able to purchase new vehicles, causing sales to drop rapidly in 2008 (Biesbroeck and Sturgeon 2010).

The financial health of the automotive manufacturing industry is strongly influenced by the cost of vehicle production. In fact, raw materials contribute to about half of the total cost to produce a vehicle. Automobiles are primarily composed of steel (47%), iron (8%), plastic (8%), aluminium (7%), and glass (3%), among other materials. Some automakers are shifting towards higher proportions of aluminium to steel to reduce vehicle weight and increase fuel economy (Kallstrom 2015), and presumably production costs.

6.2.3 Key Players

Despite the 2007–2009 economic recession, the US automobile manufacturers – Ford, GM, and Fiat Chrysler – remained the three largest in terms of US car and light truck production between 2005 and 2015. Foreign automakers with manufacturing operations in the United States did not experience as much of a decline in production during the recession and quickly recovered (Automotive News 2015). Specifically, production of cars and light trucks by facilities in the US that are owned and operated by Honda and Toyota (Japanese automakers) increased significantly after the recession, exceeding pre-recession levels (Young 2014).

6.3 Chemicals and Chemical Waste in Automotive Manufacturing

A variety of chemicals are used throughout the automobile manufacturing process, and many must be managed as waste after their useful life. Additionally, pollutants are emitted during automobile operation. Automotive manufacturing facilities can have a significant impact on the quantity and composition of the TRI chemical wastes they generate and manage through selection of chemicals used, their application, and the design of fuel-efficient vehicles.

6.3.1 Emissions from Fuel Combustion

Fossil fuels are the primary sources of energy used to power motor vehicles and automotive manufacturing facilities. Even if fossil fuels are not used at an automotive manufacturing facility, most power their operations with electricity generated from fossil fuels. The processing and combustion of fuels during facility operation generate pollution in the form of releases of TRI chemicals, smog-forming particles, and greenhouse gases (GHGs). The fuel economy (or fuel efficiency) of motor vehicles also influences the quantity of fuel combusted and, therefore, the amount of pollution emitted.

A comprehensive understanding of the automotive manufacturing industry's environmental impacts includes consideration of the industry's GHG emissions. GHG emissions are typically measured in million metric tons of carbon dioxide equivalent (MMT CO_2-eq) and include direct emissions of carbon dioxide, methane, and nitrous oxide. Direct GHG emissions associated with the industry can be grouped into two sources: automobile manufacturing and automobile operation.

6.3.1.1 Automobile Manufacturing GHG Emissions

The manufacture of automobiles generates GHG emissions from the stationary combustion of fuels to power manufacturing operations. Regulated facilities meeting certain thresholds are required to report their GHG emissions to EPA's Greenhouse Gas Reporting Program (GHGRP).[2] Figure 6.2 presents the annual direct GHG emissions from automotive manufacturing facilities that also reported to TRI from 2010 to 2015. Total direct GHG emissions have fluctuated over the years, but GHG emissions reported for 2010 are essentially equal to GHG emissions reported for 2015. Indirect emissions associated with the use of electricity are not captured here.

6.3.1.2 Automobile Operation GHG Emissions

The operation of motor vehicles generates GHG emissions through fuel combustion. Emissions from this activity can be studied by analysing the EPA Inventory of Greenhouse Gas Emissions and Sinks[3] for the *transportation sector*, which includes 'the movement of people and goods by cars, trucks, trains, ships, aeroplanes, and other vehicles' and does not include emissions from manufacturing (US EPA 2017b). Transportation sector GHG emissions are shown in Table 6.1 by vehicle type (US EPA 2017a). Overall, GHG emissions in 2015 increased by 20% since 1990 but decreased by 12% since 2005, despite a slight increase in vehicle-miles travelled (US Department of

2 For more information on EPA's GHGRP, please visit https://www.epa.gov/ghgreporting.

3 For more information on EPA's Inventory of Greenhouse Gas Emissions and Sinks, please visit https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

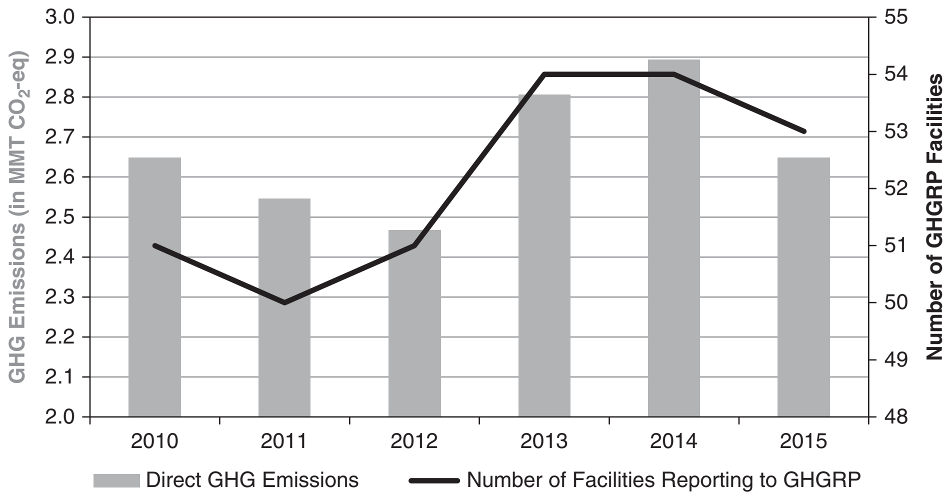

Figure 6.2 Direct GHG emissions from automotive manufacturing facilities, 2010–2015. Source: US EPA Greenhouse Gas Reporting Program 2010–2015 (US EPA 2015b).

Table 6.1 GHG emissions from automobile operation in the United States (MMT CO_2-eq).

Vehicle type	1990[a)]	2005	2010	2011	2012	2013	2014	2015	% change 2005–2015
Passenger cars	657	709	784	774	768	763	763	744	5%
Light-duty trucks	336	552	349	332	326	323	338	302	−45%
Medium- and heavy-duty trucks	231	409	400	398	398	405	415	412	1%
Buses and motorcycles	10	14	20	20	22	22	23	23	64%
Total	1234	1684	1552	1525	1514	1513	1539	1481	−12%

a) Year 1990 is included as a common baseline for assessing trends in GHG emissions. Data were not available for all years.

Source: US EPA Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2015 (US EPA 2017a)

Transportation 2014). GHG emissions from passenger cars increased by 5% from 2005 to 2015 due to a slight increase in market share. However, GHG emissions from light-duty trucks decreased by 45%. This general trend is due to the improved fuel economy and declining market share of new light-duty trucks (US EPA 2017a). Fuel economy is discussed further in Section 6.4.1.9.

6.3.2 TRI-Reported Chemical Waste Management

The automotive manufacturing industry, as defined by facilities classified in NAICS 3361, 3362, or 3363, covers the assembly of automobiles and the manufacture of parts, vehicle bodies, and trailers.

Inputs		Outputs
Metalworking fluids, metals	Casting, Forging, & Stamping	Metal filings, chips, spent fluids
Chemicals, solvents, water	Metal Parts Cleaning & Coating	Spent chemical baths, oils, spills, wastewater
Plastic pellets, cleaning solvents	Plastic Parts Molding	Excess plastic bits, spent solvents
Treatment chemicals, water, facility waste streams	Waste Water Treatment	Treated effluent, sludge
Water, samples, chemicals, rags, solvents, lubricants	Assembly, Testing, & Cleanup	Waste solvent/oils/grease, discarded samples
Paints, organic solvents, water	Body Painting	VOCs, spent paints and solvents
Soldering metals	Vehicle Assembly & Welding	Excess soldering material
Auto bodies and parts	End-of-Life	Auto shredder residue, scrap metals, engine oils, gasoline, batteries, plastics

Figure 6.3 Automobile manufacturing process: material inputs and outputs. Source: Adapted from the International Labour Organization Encyclopaedia of Occupational Health and Safety, 4th Edition (McCann 2012).

Manufacturing practices include 'metal bending, forming, welding, machining, and assembling metal or plastic parts into components and finished products' (US Department of Labor 2012). These operations generate scrap metal that is either recycled or released to air, land, and water (such as in the form of metal dust). Other chemical-intensive practices include the application of surface coatings, paints, and adhesives to vehicle frames, bodies, and other components. For example, painting alone requires pretreatment, a rust prevention layer, sealer, primer-surfacer, and top coats with chemical products containing metals, organic solvents, resins, and pigments (Akufuah et al. 2016, Fettis 1995). Figure 6.3 shows a schematic of common automotive manufacturing practices that generate chemical wastes reportable to the TRI.

6.3.2.1 US EPA Toxics Release Inventory

EPA's TRI Program publicly tracks quantities of chemicals included on the TRI chemical list that are released on-site to air, water, and land, transferred off-site to other facilities, or otherwise managed as waste by facilities throughout the United States, as specified under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) and Section 6607 of Pollution Prevention Act (PPA). TRI data are reported by facilities subject to the TRI reporting requirements, and reported to EPA's TRI Program, state, and tribal governments (US EPA 2016). The TRI reporting requirements include facilities that (i) are classified by a TRI-covered industry NAICS code, (ii) have the equivalent of 10 or more full-time employees, and (iii) manufacture or process more than 25 000 pounds, or otherwise use more than 10 000 pounds of a TRI chemical within a calendar year. Thresholds for TRI chemicals that are designated as persistent and bioaccumulative, are lower – as low as 0.1 g for dioxin – due to their potentially greater threat to human and environmental health. Currently, the TRI list of chemicals includes almost 600 individually-listed chemicals, and more than 30 chemical categories.

Facilities in a regulated sector, that meet the employment threshold, and exceed any of the activity thresholds discussed above within a given calendar year are required to report quantities of the TRI chemicals that they released on-site to air, land, or water; recycled, combusted for energy recovery, treated on-site, or transferred off-site to other facilities or locations for treatment, recycling, storage, or disposal. Releases to air include stack and fugitive emissions. Releases to land include, for example, disposal in landfills and injection into underground wells. Releases to water include discharges into rivers, streams, or other bodies of water. In addition, for a given chemical for which reporting is required, a facility is also required to disclose any source reduction practices (e.g. process modifications, substitution of raw materials) implemented at a facility for the chemical during the reporting year.

Facilities are required to submit a TRI reporting form by July 1 of the following year for each chemical for which an applicable reporting threshold was exceeded. Each year, EPA's TRI Program receives approximately 80 000 reporting forms from approximately 20 000 facilities. Since not all facilities meet the reporting thresholds, the TRI database does not contain information on all the quantities of TRI chemicals released to the environment or otherwise managed as waste. EPA makes all reported information available to the public through various data tools maintained by EPA.

6.3.2.2 Trends in TRI-Reported Chemical Waste Management

From 2005 to 2015, 1485 unique automotive manufacturing facilities reported to EPA's TRI Program. Automotive facilities reporting to TRI are located primarily in Michigan, Indiana, Ohio, Kentucky, Tennessee, Alabama, and neighbouring states. For 2015, 825 facilities reported, which is a 23% decrease from the 1072 facilities that reported for 2005.[4] The number of TRI forms filed by the automotive manufacturing industry also decreased over the same period from 3959 to 2911 (26% decrease). TRI forms filed for 33 metals and metal compound categories accounted for roughly half of all forms submitted. Other chemicals for which TRI forms were commonly submitted by automotive manufacturing facilities include toluene, xylenes, diisocyanates, and ethylene glycol.

A summary of the automotive manufacturing sector's TRI reporting is included in Table 6.2 and is discussed in more detail throughout this section of the chapter.

For TRI reporting, waste managed includes all chemical waste managed through recycling, energy recovery, treatment, and release except catastrophic or one-time releases. Between 2005 and 2015, total waste managed from automotive manufacturing decreased by 11%. Releases alone decreased by 50% over this time period.

Automotive industry subsectors follow similar trends in quantities of waste managed and released. However, motor vehicle manufacturing has experienced the largest percentage decrease in waste managed with a 28% reduction from 2005 to 2015 compared to a 13% reduction for body and trailer manufacturing and a 1% increase for parts manufacturing. There is also variability in chemicals reported between subsectors. For example, parts manufacturing tends to use more metals while automobile manufacturing tends to use more solvents. Since metals make up much of the final products, it may not be feasible for parts manufacturers to significantly reduce the quantities used.

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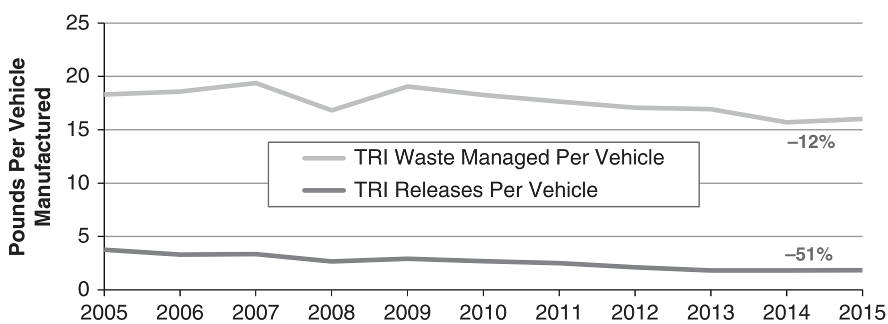
4 The possibility that some of this reduction in facilities reporting may be attributed to outsourcing is discussed in Section 6.3.2.5.

Table 6.2 TRI reporting overview for automotive manufacturing, 2015.

Sector	Number of facilities	Facilities reporting source reduction	Waste managed[a)]		Releases	
			Million pounds	% of sector total	Million pounds	% of sector total
Motor vehicle manufacturing (NAICS 3361)	76	11	61.3	31.7%	11.7	53.0%
Motor vehicle body and trailer manufacturing (NAICS 3362)	169	16	13.8	7.1%	2.3	10.5%
Motor vehicle parts manufacturing (NAICS 3363)	580	83	118.2	61.2%	8.1	36.5%
Total	825	110	193.3	100%	22.1	100%

a) Managed waste quantities include release quantities.
Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017

Figure 6.4 presents TRI data on releases and waste managed quantities reported by the automotive manufacturing industry normalized by production volume. As mentioned previously, quantities of chemical waste managed include chemical release quantities. In Figure 6.4, release quantities per vehicle are shown separately from the other waste management quantities. Although production has increased significantly since 2009, releases have remained relatively steady, resulting in significant reductions in TRI-reported releases and waste managed per vehicle. It is important to note that this calculation is only a proxy for the quantities of TRI chemicals used and released because motor vehicle parts manufactured in a given year may not be assembled in that same year. Additionally, parts used in the US automotive industry can be imported into the United States and not all facilities that manufacture parts meet the TRI reporting criteria.



Note: 1) Quantities per vehicle are calculated by dividing annual releases and waste managed from all subsectors by U.S. production. 2) Managed waste quantities include release quantities.
Sources: U.S. EPA Toxics Release Inventory-2015 National Analysis Dataset, Retrieved January 2017; Federal Reserve Board of Governors, 2005–2015

Figure 6.4 Releases and waste managed quantities per motor vehicle produced, 2005–2015. Note: (i) Quantities per vehicle are calculated by dividing annual releases and waste managed from all subsectors by US production. (ii) Managed waste quantities include release quantities. Sources: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017; Federal Reserve Board of Governors, 2005–2015.

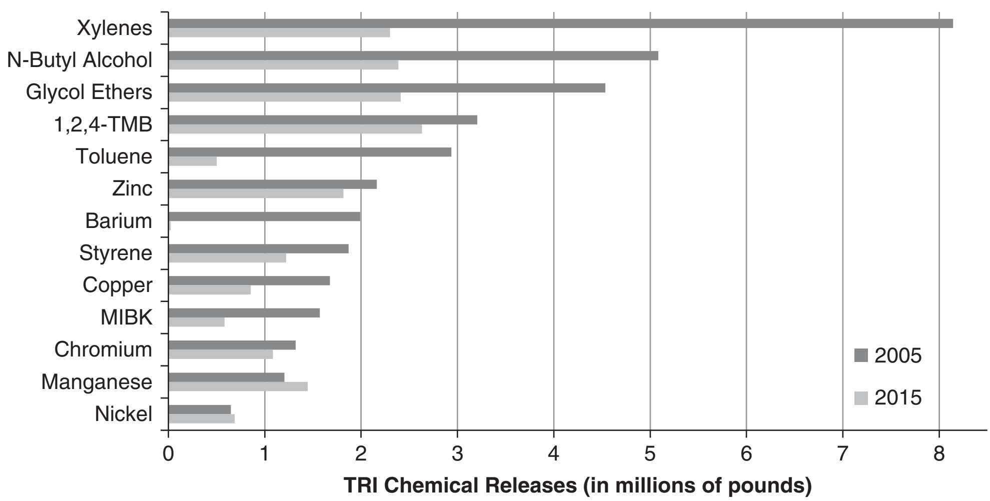
6.3.2.3 Waste Management Methods

Recycling is the primary waste management method the automotive manufacturing industry uses to manage chemical waste reported to TRI. The proportion of TRI-reported waste that was recycled increased from 64% to 76% between 2005 and 2015. Recycling is applied mostly to metals and metal compounds, specifically to manganese, copper, chromium, zinc, nickel, and the respective compounds of these metals. Recycling is applied to a lesser extent to organic solvents, specifically xylenes, 1,2,4-trimethylbenzene, n-butyl alcohol, and glycol ethers. For these chemicals, treatment and release to the environment are the more commonly applied waste management practices.

6.3.2.4 Trends in Releases

Air releases make up the largest portion of the automotive manufacturing industry's TRI-reported releases due to the use of volatile compounds in paints and other coatings formulations. Although metals and metal compounds account for about 65% of the quantities managed as waste, organic solvents are released into the environment in greater quantities, as reported to EPA's TRI Program by facilities in the automotive manufacturing industry.

Figure 6.5 compares the 10 chemicals released in the largest quantities in both 2005 and 2015, and shows that the following eight chemicals have remained at the top of the list over this period: xylenes, glycol ethers, n-butyl alcohol, 1,2,4-trimethylbenzene (1,2,4-TMB), methyl isobutyl ketone (MIBK), styrene, zinc, and copper. It is clear from Figure 6.5 that, with the exception of manganese and nickel (and nickel compounds), releases of these chemicals have decreased dramatically from 2005 to 2015.



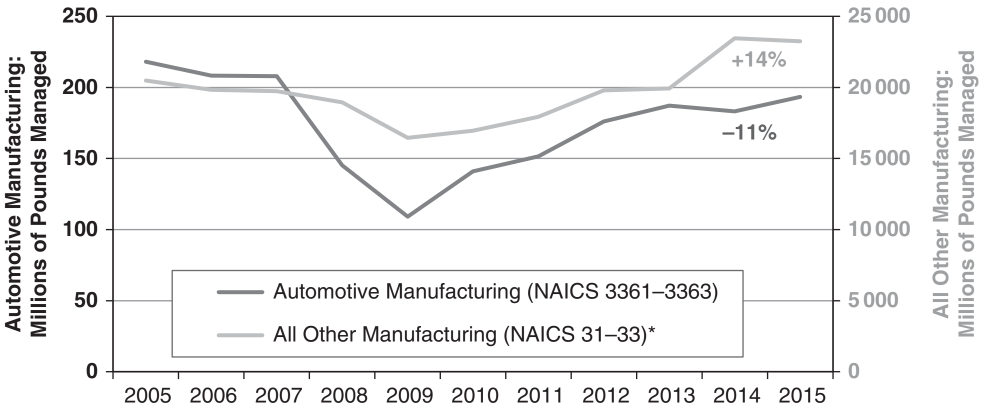
Notes:(1) Metals are grouped with their respective metal compounds. The quantities represent only the mass quantities of the metals, and do not include non-metal portions of metal compounds. (2) Chemicals are included according to the top 10 chemicals released in the largest quantities in 2005 and 2015, with both years having eight of the same chemicals. (3) TMB = Trimethylbenzene, MIBK = Methyl Isobutyl Ketone.

Source: U.S. EPA Toxics Release Inventory-2015 National Analysis Dataset, Retrieved January 2017

Figure 6.5 TRI chemicals released in the largest quantities from automotive manufacturing facilities during 2005 and 2015. Notes: (i) Metals are grouped with their respective metal compounds. The quantities represent only the mass quantities of the metals, and do not include non-metal portions of metal compounds. (ii) Chemicals are included according to the top 10 chemicals released in the largest quantities in 2005 and 2015, with both years having eight of the same chemicals. (iii) TMB, Trimethylbenzene; MIBK, Methyl Isobutyl Ketone. Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017.

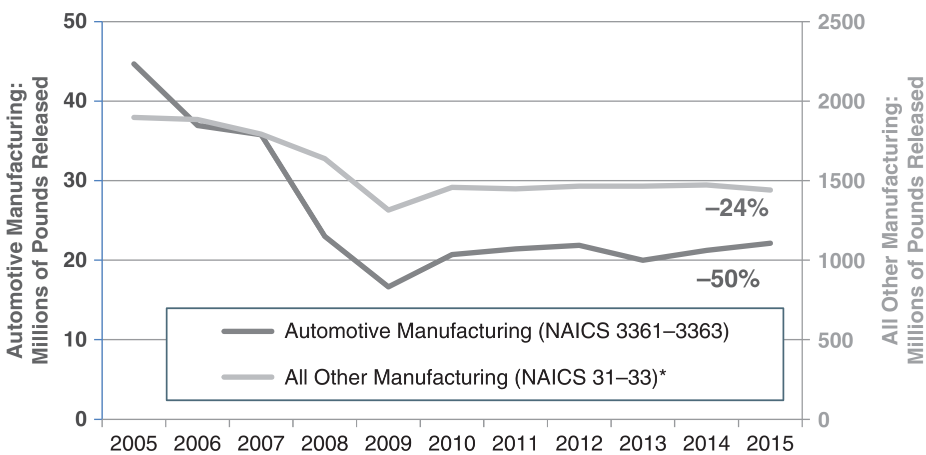
6.3.2.5 Automotive Manufacturing vs. All Other Manufacturing Sectors

Quantities of TRI chemical waste managed reported by facilities over the 2005–2015 time frame decreased by 11% in the automotive manufacturing industry, but increased by 14% in all other manufacturing industries, as shown in Figure 6.6. Similarly, during the same period, quantities of TRI chemicals released into the environment by the automotive manufacturing industry decreased by 50%, and by 24% in all other manufacturing industries, as shown in Figure 6.7. Although overall waste managed quantities among all manufacturing industries have essentially returned to pre-recession levels, release quantities have remained low. Possible explanations



Note: *Excludes the Automotive Manufacturing Industry (NAICS 3361–3363).
Source: U.S. EPA Toxics Release Inventory-2015 National Analysis Dataset, Retrieved January 2017

Figure 6.6 TRI waste managed by automotive manufacturing vs. all other manufacturing, 2005–2015. Note: *Excludes the Automotive Manufacturing Industry (NAICS 3361–3363). Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017.



Note: *Excludes the Automotive Manufacturing Industry (NAICS 3361–3363).
Source: U.S. EPA Toxics Release Inventory–2015 National Analysis Dataset, Retrieved January 2017

Figure 6.7 TRI releases from automotive manufacturing vs. all other manufacturing, 2005–2015. Note: *Excludes the Automotive Manufacturing Industry (NAICS 3361–3363). Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017.

include implementation of preferred waste management practices, outsourcing of processes with significant releases, or changes in chemical composition of the materials used. As noted in Section 6.2.2, total US vehicle production and the automotive manufacturing production index have largely recovered from the 2007 to 2009 recession, indicating that decreased production is not the reason for the reduction in releases. An earlier analysis by the TRI Program also concluded that outsourcing was not the primary driving factor (US EPA 2017c). It therefore appears that the automotive manufacturing industry emerged from the recession with more efficient waste management programs that reduce wastes and releases of TRI chemicals into the environment.

6.4 Pollution Prevention in Automotive Manufacturing

6.4.1 Sustainability Trends in Automotive Manufacturing

This section discusses the activities, innovative research, and developments that have contributed to the automotive manufacturing industry's progress in environmental sustainability. These methods and technologies are compared to source reduction activities reported to TRI to assess their effectiveness and to provide insights as to where additional activities could be implemented.

Pollution prevention is an essential component of sustainable manufacturing practices. In the United States the PPA of 1990 established a national policy that 'pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner'. This hierarchy is illustrated in Figure 6.8. While not specifically mentioned in the PPA of 1990, energy recovery is a preferred practice over treatment and disposal, and hence, is included in the hierarchy illustrated in Figure 6.8.

As established by the PPA, source reduction 'is more desirable than waste management or pollution control. Source reduction refers to practices that reduce hazardous substances from being released into the environment prior to recycling, treatment, or disposal. These practices

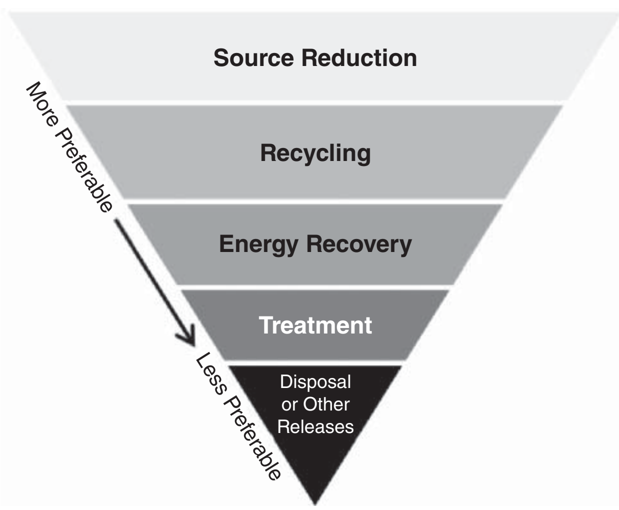


Figure 6.8 Waste management hierarchy. Source: TRI P2 Webpage {US EPA, n.d. #52}.

include equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control' (Pollution Prevention Act 1990).

Along with source reduction, further sustainability gains are achieved by implementing preferred waste management practices such as recycling and treatment. Pollution prevention and improved waste management practices have been applied throughout the manufacturing life cycle of automobiles as follows:

- *Process and technology modifications* implemented to reduce energy consumption and the amount of raw materials used;
- *Safer, environmentally friendly alternative materials* substituted throughout the manufacturing process;
- *Recycling of metals and solvents* to reduce environmental impacts after the useful life of a material or product; and
- *Fuel economy improvements* contribute to reducing the industry's environmental impacts by manufacturing vehicles that are more fuel efficient.

6.4.1.1 Corporate Sustainability Reports

Corporate sustainability reports provide an overview of sustainability goals, efforts, and accomplishments for some of the largest automotive manufacturers. Water use, energy use, and waste generated from vehicle manufacturing may also be included in these reports. Companies often report recognition in Leadership in Energy and Environmental Design (LEED), ENERGY STAR building labels, and other sustainability awards. Additionally, they provide specific examples of sustainability progress such as General Motors' 122 landfill-free facilities (General Motor Company 2014); Ford's first automotive application of cellulose-reinforced plastic to replace fibreglass (Ford Motor Company 2014); and the Toyota Prius' ranking for highest fuel efficiency in the compact, midsize, and midsize station wagon classes (Toyota Motor Corporation 2014).

6.4.1.2 Eco-Efficiency

In a study of industry-wide environmental sustainability, manufacturing sectors were ranked by *eco-efficiency score*, a measure of environmental performance against economic output (Egilmez 2013). The score accounted for GHG emissions, energy use, hazardous waste, TRI releases, and water use. Motor vehicle manufacturing (NAICS 3361) ranked among the highest with an *eco-efficiency score* of 100%.[5]

However, when automotive manufacturing and its supply chain (including extraction and processing of raw materials) are compared, the industry's upstream supply chain is responsible for 92.8% of TRI releases and 60.8% of hazardous waste generation. In other words, the production of materials used by the industry generates significantly more pollution than automobile production alone. Some of the highest contributing supply chain sectors include other basic organic chemical manufacturing, iron and steel mills, power generation and supply, and paint and coating manufacturing (Egilmez 2013).

The motor vehicle parts, body, and trailer manufacturing industry (NAICS 3362 and 3363) received an *eco-efficiency score* of 69%. In order to become 100% eco-efficient, the industry would need to 'reduce GHG emissions by 35%, energy use by 31%, hazardous waste by 37%, toxic releases by 38%, and water withdrawals by 32%' (Egilmez 2013, p. 97).

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5 Eco-efficiency scores are a comparison of environmental impacts and economic output relative to other manufacturing sectors. A score of 100% does not mean that the industry cannot improve its eco-efficiency.

6.4.1.3 Process and Technology Modifications

Process and technology modifications have the potential to reduce chemical inputs and wastes at all stages of production. The use of metalworking fluids, solvents, lubricants, paints, and other chemicals throughout production result in chemical wastes such as metal filings, spent chemical baths, and emissions of volatile organic compounds (VOCs). Source reduction practices, waste treatment, and recycling can all help to reduce releases of TRI chemicals.

Energy Efficiency Improving energy efficiency in the automotive production process reduces the quantities of fuels burned and thereby reduces the quantities of TRI chemicals formed as byproducts and released to the environment. If energy is generated by combustion of fossil fuels on-site at a facility, and energy efficiency improvements are implemented, the corresponding reductions in the releases of TRI chemicals produced will likely be reflected in the facility's TRI reporting. Most automobile manufacturers have had programs in place for many years to improve the efficiency of material and energy use throughout production. Companies are incentivized by cost savings that they can pass on to consumers (Orsato and Wells 2007).

Government programs also incentivize improvements. For example, the automotive industry collaborated with EPA's ENERGY STAR Program[6] in 2005 to develop an energy performance indicator tool to recognize energy-efficient automobile assembly plants (Boyd 2005). ENERGY STAR certification is awarded to plants ranking in the lowest 25% by energy use per vehicle manufactured. In 2014, 10 facilities received certifications. ENERGY STAR determined that paint booths used the most energy (30–50% of a plant's energy consumption), followed by heating/ventilating/air conditioning, lighting, compressed air, welding, material handling, metal forming, and other processes. Automotive assembly plants reported energy efficiency improvements for all of these processes (US EPA 2015a). ENERGY STAR also produced a report containing recommendations for energy efficiency measures for the automotive assembly industry; providing detailed technical direction, associated cost savings, and payback times. Some automotive-specific recommendations include adopting technologies in infrared and ultraviolet (UV) paint curing, powder-based paints, ultrafiltration/reverse osmosis for wastewater cleaning, energy-efficient welding, and hydroforming (Galitsky and Worrell 2008). Major US automobile manufacturers have also reported advancements in energy efficiency and set future energy consumption goals in their corporate sustainability reports. For example, Ford has reduced the energy consumed per vehicle produced by 9% from 2014 to 2015 and aimed to reduce this amount by 25% from 2011 to 2016 (Ford Motor Company 2016). Similarly, GM has set a goal for a 25% reduction in energy consumption at its US facilities by 2018. In addition to reducing fossil fuel combustion, some companies seek out cleaner sources of energy. GM has invested in more than 100 MW of renewable energy including solar power, landfill gas, hydro-electric power, and waste-to-energy (General Motor Company 2016).

Process Improvements In order to help facilities realize the many possible process improvement options, the US Department of Energy Advanced Manufacturing Office[7] sponsored the development of a process modelling framework to help manufacturers select processes that decrease waste without compromising quality. Some examples of design efficiency can include decreasing cutting fluid, scrap, and overall energy loss (Marusich 2013). This type of research has direct applications in the motor vehicle manufacturing industry, as it helps optimize production time, energy consumption, and use of 'raw materials while assuring quality, performance, and costs' (Marusich 2013).

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6 For more information on EPA's ENERGY STAR Program, please visit https://www.energystar.gov.

7 For more information on the Department of Energy's Advanced Manufacturing Office, please visit http://energy.gov/eere/amo/advanced-manufacturing-office.

6.4.1.4 Safer, Environmentally Friendly Alternative Materials

The automotive manufacturing industry uses a wide variety of chemicals, many of which are TRI chemicals, throughout the production process including chemicals used in paints, adhesives, coatings, and resins. Research continues to advance the knowledge and availability of safer alternatives for the ingredients used to develop materials including alternatives to metals used in the manufacture of vehicle components.

Alternative Paints and Coatings Before new technologies can be fully developed and deployed by the industry, they must first be recognized as viable and cost-effective alternatives. EPA sponsors the Presidential Green Chemistry Challenge every year to promote the environmental and economic benefits of innovative green chemistry research. Winning technologies developed and used for automobile manufacturing have included (US EPA 2014):

- a UV-curable paint primer by BASF Corporation that significantly decreases VOCs compared to existing primers, eliminates use of diisocyanates, and, therewith, eliminates landfill waste,
- a bio-based oil by the Proctor & Gamble Company and the Cook Composites and Polymers Company to replace petroleum-based solvents in alkyd paints that reduces the amount of solvent required by 50% and reduces VOC and ozone emissions, and
- water-based refinish coatings by PPG Industries, Inc. to reduce metal sludge and VOC emissions.

Despite the health and safety advantages of less toxic materials, other environmental criteria need to be considered. For example, a concern for water-based paints is the requirement for significantly more air conditioning and ventilation needed to dry the paints. Further investigation is needed to ensure that this energy requirement does not undermine the overall environmental benefits of water-based paints (Kanellos 2009). Alternatively, the use of powder-based coatings has experienced rapid growth in the automotive industry in recent years. These coatings completely eliminate the use of solvent because they are applied in powder form and then cured with heat or light (Acmite 2011).

Bio-Based Materials Bio-based materials have long been used to make a variety of vehicle components. Natural fibres from bananas, jute, sisal, and flax are used to reinforce resins and plastics such as those used in door panelling. Cotton, hemp, coir, and ramie have been used to create carpets and insulating mats for vehicle interiors (Center for Automotive Research 2012). These materials are renewable and biodegradable, and can be less toxic than petrochemical-derived plastics (Institute for Local Self-Reliance 1997). Examples include:

- *Interior components*. The plastics research group at Ford is leading research on use of soy-based foams in seat cushions, plant material byproducts to reinforce plastics vehicle storage bins, electrical harnesses, and armrests (Briddell 2015). The Ford team is also investigating the use of other byproducts including shredded currency, tomato skins, and hemp fibres to manufacture vehicle interior components.
- *Mechanical vehicle components*. In terms of core vehicle components such as engines and vehicle bodies, bio-based materials may not provide the durability needed. However, Goodyear has developed bio-based isoprene to replace a petroleum-derived ingredient in synthetic rubber for tyres, and Daimler produces air filter systems made from bio-based polyamide (Andresen et al. 2012). Additionally, the Ford Motor Company is developing brake lines and fuel tubes made from bio-based polyamides (Lee 2013).

Table 6.3 summarizes examples of bio-based materials and other alternatives used in automotive manufacturing.

Table 6.3 Examples of alternatives for vehicle components.

Component	Alternative materials
Paints and coatings	• UV-curable paint primers to reduce energy use and VOC emissions • Bio-based oil to replace petroleum-based solvents in alkyd paints • Water-based coatings to replace petroleum based solvents
Plastics, resins, and adhesives	• Biodegradable plant based resins for vehicle interiors • Plastics reinforced with plant byproducts (corn/rice husks, coconut fibres, and wheat straw) • Tree-based cellulose to replace fibreglass in armrests • Natural fibres from bananas, jute, sisal, and flax are used to reinforce resins and plastics such as those used in door panelling • Use of plant lignin in adhesives and polymer additives
Interior surfaces and cushioning	• Soy-based foams for seat cushions • Use of cotton, hemp, coir, and ramie to create carpets and insulating mats • Recycled clothing used in sound insulation materials
Metals	• Replacement of steel with aluminium or magnesium to produce lighter, more fuel-efficient vehicles

Sources: Institute for Local Self-Reliance 1997; Lee 2013; Briddell 2015; and Ford Motor Company 2014

Greater industry use of these alternative materials has significant potential to reduce TRI-reported chemical waste quantities because the alternatives can completely replace use of certain TRI chemicals or materials that contain TRI chemicals with safer alternatives that serve the same purpose, sometimes more effectively. (Section 6.4.2 discusses how innovations in paints, coatings, and other materials have contributed to reducing the generation of TRI chemical wastes from solvents and metals such as copper, zinc, and lead.)

6.4.1.5 Recycling of Metals and Solvents

While the automotive manufacturing industry has made progress in changing production practices to reduce the quantity of scrap metal generated, recycling of scrap metal continues to play a crucial role in achieving sustainability, both during the manufacturing process and at the end of the vehicle life. The automotive recycling industry reports over $32 billion in annual sales (Automotive Recyclers Association 2015). Approximately 95% of vehicles are recycled, and 86% of materials from those vehicles are recycled, reused, or used for energy recovery (Duranceau and Sawyer-Beaulieu 2011, US EPA 2013).

6.4.1.6 Metal Scrap and Waste

Most vehicle bodies and mechanical components are constructed from metals. Metal stamping, moulding, and machining results in large quantities of scrap metal. In addition, metals are used in coatings, brake pads, catalytic converters, and electronics. As discussed earlier, TRI-reported metal wastes from automotive manufacturing are often recycled at rates above 90%. Some of the most commonly recycled metals (and their metal compounds) include copper, manganese, chromium, zinc, nickel, and lead.

6.4.1.7 Fluids and Solvents

Solvent recycling, which started occurring in automotive manufacturing in the 1980s, applies mainly to paint solvents. Some waste management companies now provide full solvent recycling services to manufacturing facilities. These companies partner with facilities to install recycling equipment free of charge; facilities only pay the discounted costs of the recovered chemicals and save money on disposal costs. Some recycled paint thinners include methyl ethyl ketone, acetone, naphtha, xylene, and toluene (CleanPlanet 2015). As of this analysis, most of the TRI-reported solvent recycling that occurs is done off-site.

6.4.1.8 End-of-Life Vehicles (ELVs)

After a vehicle's useful life, some parts can be reused in other vehicles including engines, transmissions, doors, and bumpers. Starters, alternators, and water pumps can be remanufactured, while batteries, catalytic converters, tyres, and plastics can be recycled into new products via shredding, magnetic separation, metal smelting, and other methods. By avoiding the mining and processing of virgin materials, the current use of recycled copper, aluminium, and steel results in approximately 5600 pounds of GHG reductions per vehicle (Automotive Recyclers Association 2015).

In addition, the Automotive Recyclers Association estimates reuse or recycling of '100.8 million gallons of gasoline and diesel fuel, 24 million gallons of motor oil, 8 million gallons of engine coolant, 4.5 million gallons of windshield washer fluid, 96% of all lead acid batteries' from end-of-life vehicles (ELVs) every year (Automotive Recyclers Association 2015).

6.4.1.9 Fuel Economy

The fuel economy of motor vehicles is a measure of how efficiently fuel is being used and therefore has a direct influence on the quantity of GHG emissions. Fuel economy is measured in miles per gallon (MPG) for gasoline and diesel powered vehicles. A miles per gallon equivalent (MPGe) can also be calculated for electric vehicles by associating the electricity required per vehicle with the quantity of fossil fuel needed for electricity generation. FuelEconomy.gov, the US government's official website on fuel economy information for most gas-powered, electric, and hybrid vehicles sold in the United States, combines highway and urban fuel economy to calculate a final MPGe value. A strong drive for fuel economy improvements has been the Corporate Average Fuel Economy standards, which require manufacturers to maintain a certain average fuel economy across their fleet of new vehicles each year. Automotive manufacturers have improved their vehicles' fuel economy through engine modifications or other features including:

- regenerative braking to charge hybrid electric vehicle batteries;
- hybrid electric and combustion propulsion systems;
- continuous variable transmission to allow engines to run at their most efficient rotations per minute;
- smaller engines that rely on turbo systems for power; and
- use of lighter materials and reduction of air resistance.

Figure 6.9 shows average fuel economy across all models by vehicle type in 2014 (US Department of Energy 2015). Electric vehicles have the highest MPGe, while vehicles running on conventional gasoline or compressed natural gas have the lowest MPGe. Although electric vehicles, plug-in hybrid electric vehicles, and hybrid vehicles have traditionally had very low production volumes, they have become more commercialized in recent years (Automotive News 2015).

6.4.2 Pollution Prevention Activities Reported to TRI

As discussed in Section 6.3.2, the quantities of TRI chemicals reported by the automotive manufacturing sector as released to the environment or otherwise managed as waste decreased significantly between 2005 and 2015. This section identifies the chemicals targeted for pollution prevention and

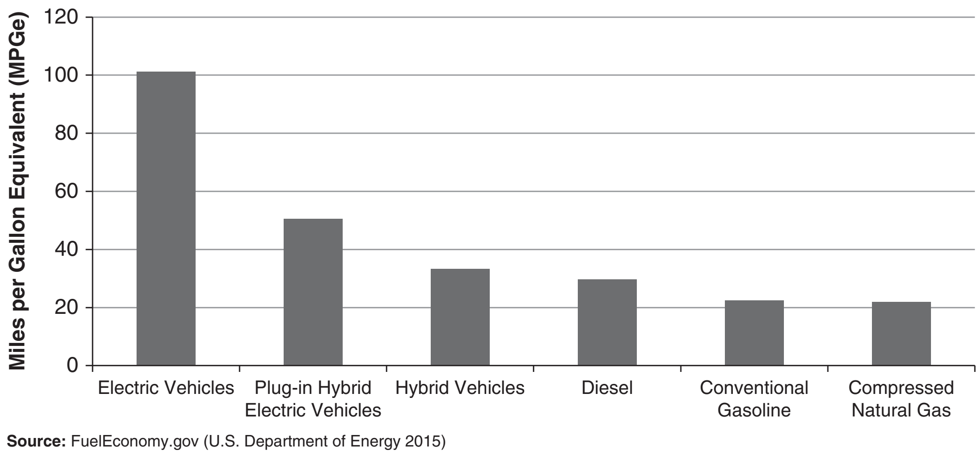


Figure 6.9 Average fuel economy across vehicle models by vehicle type in 2014. Source: FuelEconomy.gov (US Department of Energy 2015).

the types of pollution prevention activities implemented. Additionally, the automotive manufacturing industry's progress towards reducing TRI chemical waste managed and released is described.

Facilities subject to the TRI reporting requirements, such as those within the automotive manufacturing industry, are required to report any source reduction practices (e.g. process modifications, substitution of raw materials) that were implemented at the facility during the year for the chemical for which they are reporting. TRI Reporting Form R contains specific fields for these required data elements. In Section 8.10 of the TRI Form R, for example, facilities select source reduction activities[8] from a list of coded processes or improvements (all source reduction activity codes are grouped into the eight categories listed in Figure 6.10). In addition, facilities have the option to provide additional text to describe their source reduction activities in Section 8.11 of Form R. It is a unique opportunity for manufacturers to share their achievements in pollution prevention with other automotive facilities, users of TRI data, and the public. For reporting year 2015, 23% of automotive manufacturing facilities included text in Section 8.11 of their Form R reports.

For the 2015 reporting year, 110 facilities in the automotive manufacturing industry reported 285 source reduction activity codes for 63 chemicals and chemical categories. This represents approximately 13% of the 825 automotive manufacturing facilities that reported to EPA's TRI Program for the 2015 reporting year. 'Good operating practices' was the most commonly reported source reduction category as shown in Figure 6.10. 'Process modifications' and 'raw material modifications' were also frequently reported.

Within the eight source reduction categories listed in Figure 6.10, there are nearly 50 specific, predefined source reduction activities that facilities can select. Six of these are specific to 'green chemistry' (US EPA 2016). These green chemistry-specific source reduction codes were added to the list of source reduction codes beginning with the 2012 reporting year. From 2012 to 2015 auto manufacturing facilities have reported these codes 105 times (mostly by facilities that manufacture parts, i.e. facilities classified in NAICS 3363). The most frequently reported green chemistry source reduction activities are:

8 The terms 'source reduction' and 'pollution prevention' are used interchangeably here. In this chapter, the term 'source reduction' is used in order to be consistent with TRI reporting terminology.

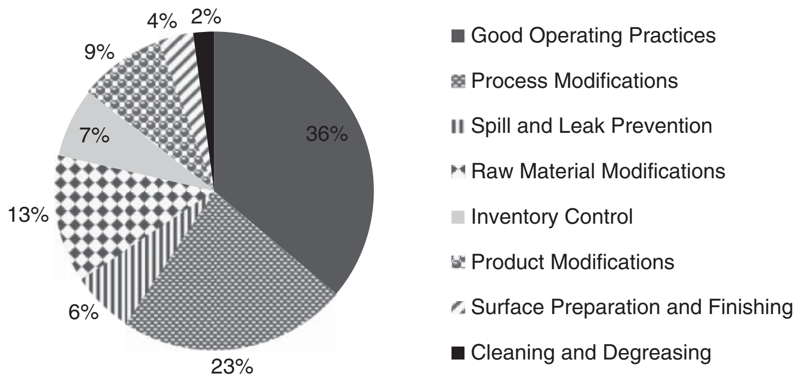


Figure 6.10 Source reduction activities reported by automotive manufacturing facilities for 2015. Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017.

- quality monitoring or analysis systems for products or processes involving manganese, nickel, and chromium;
- optimizations of reactions using ammonia and other various chemicals; and
- the reduction of use of solvents such as xylenes and other organic solvents.

Figure 6.11 shows how the total number of reported source reduction activities changed from 2005 through 2015. The decline from 2007 to 2009 corresponds to an overall decrease in TRI

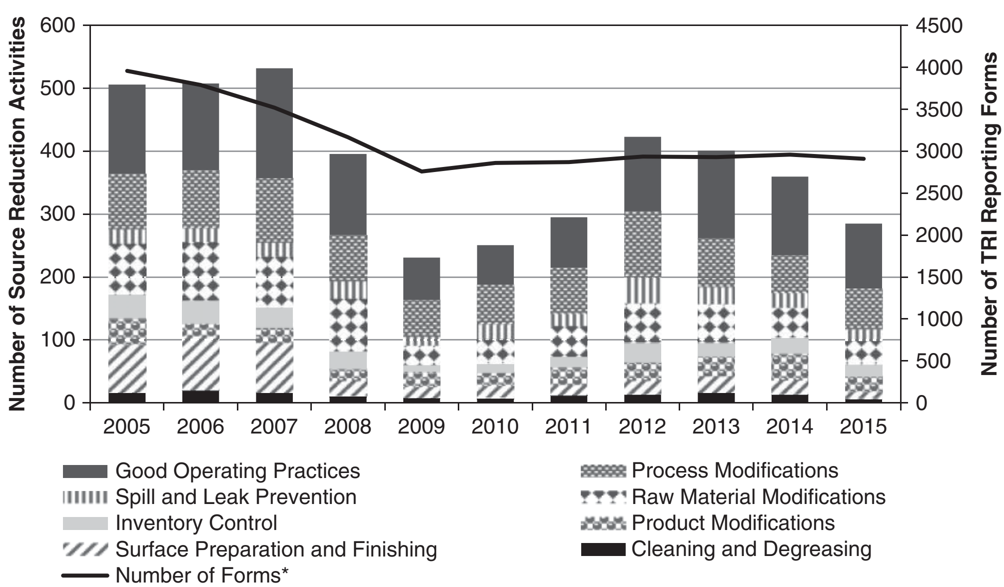


Figure 6.11 Source reduction activities reported by automotive manufacturing facilities, 2005–2015. Note: *Total number of forms reported by the automotive manufacturing industry. Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017.

reporting due to reduced production during the economic recession. Since 2005, the percentage of facilities with source reduction and the distribution of source reduction types have remained fairly constant except for ‘surface preparation and finishing’, which has decreased in recent years. In the mid-2000s, solvent waste had already been significantly minimized by the use of water-based paints and improved spraying techniques. Following this change, facilities may have shifted their efforts towards other areas of source reduction.

Observations from the TRI data regarding source reduction activities for chemicals with the largest decreases in waste managed include:

Metals tend to undergo more ‘raw material modifications’ because they are primarily used in alloys for vehicle bodies and parts. For example, many ‘raw material modifications’ were implemented for materials containing lead and lead compounds. This was likely due to reductions in the use of lead solder, which was reported in explanatory text in Section 8.11 of Form R by several facilities. Non-metals and organic solvents tend to undergo more ‘surface preparation and finishing’ modifications, as they are primarily used in paints and coatings. The use of organic solvent-based paints and coatings has declined significantly over the past decade due to their replacement with powder and water-based paints. This has led to a decline in releases for some of the most common organic solvents, such as xylenes, toluene, and glycol ethers.

6.4.2.1 Examples of Source Reduction Activities Reported to TRI

Facilities subject to the TRI reporting requirements have the option of describing their source reduction activities in explanatory text; Table 6.4 provides examples of this text for reported chemicals showing the greatest decreases in waste managed between 2005 and 2015. Notable activities include the reduction of metals in brake pad friction formulations, paints, and solders as well as leak prevention and solvent substitutions. In many cases source reduction activities can be associated with specific regulatory drivers; for example, state-imposed limits on the copper content of brake pad formulations.

6.4.2.2 TRI Pollution Prevention Analysis – Effectiveness of Source Reduction Activities

A published study estimated how source reduction activities affect quantities of TRI chemical releases reported by facilities that are subject to the TRI reporting requirements (Ranson et al. 2015). The study used a common economics research technique known as a ‘differences-in-differences’ analysis. This method estimates how releases of a TRI chemical from a facility change in the years before and after implementing a source reduction project by comparing trends in releases of TRI chemicals targeted by source reduction against trends in releases of chemicals not targeted for source reduction. This comparison helps to control for other factors that affect releases, such as changes in production, economic conditions, and environmental regulations.

Applying this technique to the automotive manufacturing industry showed that the *average* source reduction project in the automotive manufacturing industry resulted in a 12–26% decrease in facility-level TRI releases of the targeted chemical. ‘Surface preparation and finishing’ and ‘raw material modifications’ were found to be the most effective types of source reduction with average decreases in releases of 26% and 24%, respectively. Between 1991 and 2014, source reduction may have reduced cumulative automotive manufacturing releases reported to EPA’s TRI Program by 300–700 million pounds (17–34%), as calculated by the difference between actual releases and simulated releases with no source reduction.

6.4.2.3 Barriers to Source Reduction

Facilities can voluntarily report barriers they face in implementing source reduction activities in Section 8.11 of Form R. These explanatory text data can be used to identify the challenges that

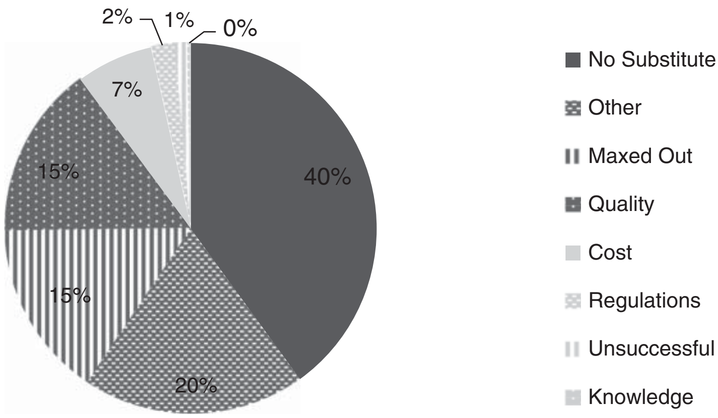
Table 6.4 Example descriptions of source reduction activities reported by automotive manufacturing facilities for TRI chemicals with the greatest decrease in waste managed from 2005 through 2015.

Source reduction type	Example source reduction activity
Good operating practices	*Xylenes*. 'Facility reduced Defects Per Unit (DPU) in paint areas resulting in a paint consumption reduction (i.e. spraying less paint for repair work). This reduces usage, emissions, and waste disposal of chemicals in paint (Xylene)'.
	Zinc and zinc compounds. 'looking into reduced copper formulas for brake pads, which will reduce the amount of brass in some blocks, which will decrease the amount of brass used, thus reducing copper, lead, and zinc'.
	Methyl isobutyl ketone. 'Production to line-up like colour trucks so there is less colour changing resulting in a reduction in flush solvent used (flush solvent and paint contains MIBK). Facility reduced Defects Per Unit (DPU) in paint areas resulting in a paint consumption reduction (i.e. spraying less paint for repair work)'.
Process modifications	*n-butyl alcohol*. 'Using a reformulated cleaning solvent that has replaced the n-Butyl alcohol component with other solvent components that are not TRI listed substances'.
Spill and leak prevention	*Toluene*. 'Improved solvent leak detection (virgin and return lines) through use of a new photoionization detector'.
Raw material modifications	*Lead and lead compounds*. 'Lead solder use is decreasing dramatically. Approximately 25% of all soldering is leaded now. Expect this number to continue to decrease moving forward'.
Inventory control	*Toluene*. 'Vendor substituted less hazardous solvents to reduce VOC and HAPs; also, evaluated existing warehouse and disposed of outdated materials. Implemented new procedures to limit storage of rejected or unused products'.
Product modifications	*Copper and copper compounds*. 'Product formulation has been modified to reduce the amount of copper used. This formulation management method will continue to reduce the amount of copper used in brake pad friction formulations over the next few years'.
Surface preparation and finishing	*Glycol ether*. 'Replaced water-based paints with 2k urethane solvent-based [paints] that are HAP-free'.
	Ethylbenzene. 'Have gone to water based coatings as a standard'.
	Barium and barium compounds. 'Substituted coating material December 2009 to a barium free material'.
Cleaning and degreasing	*Copper and copper compounds*. 'Facility personnel reviewed parts washing processes and installed filtering units that increased the life of wash waters; thus reducing the need for changeovers and reducing the amount of wastewaters generated'.

Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017.

facilities face in implementing source reduction. As of reporting year 2014, the TRI reporting form allows facilities to select from a list of barrier codes.

For the 2015 reporting year, 345 barriers were reported by the automotive manufacturing industry. Of these entries, the most commonly reported barrier category was 'no known substitutes or alternative technologies' (abbreviated as 'no substitute'). This barrier may have a variety of causes including a lack of awareness of substitutes, stringent material specifications, or product testing requirements. Barriers in this category were primarily reported for metals and metal compounds, including chromium, copper, lead, and manganese, which are present in raw materials. The second most commonly reported barrier category was 'concern that product quality may decline as a result of source reduction' ('quality'), and the third most commonly reported



Source: U.S. EPA Toxics Release Inventory-2015 National Analysis Dataset, Retrieved January 2017

Figure 6.12 Barriers to source reduction reported by automotive manufacturing facilities for 2015. Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017.

barrier, 'pollution prevention previously implemented – additional reduction does not appear technically or economically feasible' ('maxed out'), was reported by facilities that have already implemented source reduction activities to the maximum extent possible as shown in Figure 6.12. Specific examples from each category are provided in Table 6.5.

Barrier categories reveal some challenges to source reduction; however, for some chemicals there is no evidence that source reduction was attempted. Table 6.6 lists 10 of the 34 chemicals for which no source reduction activities were reported to EPA's TRI Program between 2005 and 2015, in order of descending quantity of waste managed. Several of these are metals that are present in raw materials and cannot be substituted easily. For example, aluminium oxide is used to give automotive paints their reflective properties. Moving forward, these chemicals should be considered for further pollution prevention efforts.

6.5 Perspectives

Useful perspectives can be inferred from the analysis presented here, and a summary overview of the situation today yields powerful insights for the future of global pollution prevention practice, as follows.

6.5.1 Summary

The US automotive manufacturing industry is a key sector of the American economy with many pollution prevention practices already implemented and with many opportunities for continued progress. Analysis of this sector using data from the TRI shows that:

- The most released chemicals have remained largely the same since 2005. The top chemicals released are organic solvents such as xylenes, n-butyl alcohol, and glycol ethers, which are primarily used in paints, coatings, and cleaners.
- Other chemicals released in large quantities include metals such as zinc, barium, and copper, which are used as components of vehicle parts and in paints and coatings.

Table 6.5 Example descriptions of barriers to source reduction reported to TRI by automotive manufacturing facilities.

Barrier category	Example
No substitute	'The TRI chemicals this facility reports are present as an article component of the steel. The end uses of the products determine the content of the TRI chemicals present in the steel. Therefore, the site cannot opt to reduce or substitute the TRI chemicals present in the steel'.
Quality	'Working with raw material manufacturers to encourage development of materials containing less styrene when possible. Must balance product quality, strength, and other requirements with new materials'.
Maxed out	'Ethylene Glycol based antifreeze are already reused on-site for testing after being put through a filtration unit. Pollution prevention previously implemented as we have switched over as many processes as we could to Propylene Glycol (molding machines). Additional reduction does not appear technically feasible, as we must use Ethylene Glycol for testing radiators and heater cores that use Ethylene Glycol antifreezes'.
Cost	'We have looked at and continue to look at other resins that are classified as more "green," but the costs associated with using them in our process at this point are prohibitive'.
Customer demand	'Customer dictates what camshaft materials are made out of. Manganese compounds are in the lobes we receive for assembling and grinding for the customer'.
Unsuccessful	'Different type of spray nozzles [sic] were tested to reduce over spray from our paint processes. The new type of nozzles [sic] did reduce over spray but the paint thickness was reduced. With the reduced paint thickness our parts would not meet the customer requirements. We were unable to use the nozzles as hoped'.
Regulations	'Ammonia is used in Selective Catalytic Reduction to reduce nitrogen oxide emissions generated during the combustion of natural gas. This emission control equipment/process is required by the local air district'.
Knowledge	'Require technical information on pollution prevention techniques applicable to specific production processes'.

Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017

Although US automobile production fell rapidly in the years of the economic recession, the industry has largely recovered, and production has returned to near pre-recession levels. TRI data reflects this fluctuation with a drop in waste managed quantities between 2005 and 2009 and a subsequent increase back to pre-recession levels. However, the quantity of chemicals released to the environment decreased by half due to the many efforts by the automotive industry to use chemicals more efficiently and utilize new technologies and materials. Examples of these sustainable opportunities include:

- eliminating material from the start such as the use of solder that contains lead or reducing the use of copper in brake pads;
- transitioning to UV-curable paints provides manufacturers with low-energy coating options, and water- or bio-based paints greatly reduces the use of organic solvents waste;
- substituting for bio-based materials considered safer, biodegradable alternatives like the use of plant-based materials in vehicle interiors and coatings or bio-based alternatives for more functional vehicle components such as tyres and tubing; and
- recycling of manufacturing materials and end-of-life vehicles at high rates mitigates TRI chemical releases and supplies automakers with recycled materials.

Table 6.6 Top 10 chemicals for which the largest quantities of waste managed and no source reduction activities were reported by automotive manufacturing facilities from 2005 to 2015.

Rank	Chemical	Production-related waste managed (in pounds), 2005–2015
1	Aluminium oxide (fibrous forms)	13 142 042
2	Polychlorinated alkanes	801 478
3	Sodium dimethyldithiocarbamate	519 596
4	N,N-Dimethylformamide	308 856
5	1,1-Dichloro-1-Fluoroethane	282 866
6	Chlorine	195 305
7	3-Iodo-2-Propynyl butylcarbamate	175 374
8	Chlorine dioxide	163 726
9	Vanadium and vanadium compounds	116 868
10	Cyanide compounds	108 177

Note: (i) 24 other chemicals reported by the automotive industry had no source reduction reported. (ii) The top 10 chemicals were chosen based on the highest aggregate TRI chemical waste managed over the period of 2005–2015.
Source: US EPA Toxics Release Inventory – 2015 National Analysis Dataset, Retrieved January 2017

Many of these efforts are reflected in the TRI reporting of source reduction activities, and these actions implemented by the automotive manufacturing industry have reduced releases of a targeted chemical by 12–24% on average, with 'surface preparation and finishing' and 'raw material modifications' categories being the most effective types. For the entire industry, the analysis shows an estimated reduction of 300–700 million pounds of TRI-reported releases from 1990 to 2014 due to source reduction efforts.

6.5.2 Potential Pollution Prevention Opportunities

Further reductions in the automotive manufacturing industry's TRI-reported releases, human health impacts and environmental impacts may require coordinated efforts and research from numerous stakeholders. Since the automotive manufacturing industry's upstream supply chain, including other basic organic chemical manufacturing, iron and steel mills, power generation and supply, and paint and coating manufacturing contribute more to quantities of TRI-reported releases than the industry itself (Egilmez 2013), the supply chain should be further examined to identify where impacts can be reduced. Additional research is also warranted regarding barriers to source reduction options especially those that limit the economic viability of alternatives. Information reported to TRI indicates that the top barriers relate to a lack of known alternatives and the perception that additional reduction is not technically or economically feasible.

TRI can be used as a platform to share the effective pollution prevention methods across the automotive industry that have been successfully employed within a parent company or on a facility level. Communication between EPA and industry will facilitate transitions to alternative materials and processes, and perhaps EPA can inform and incentivize academic research through government grants or by recognizing products that reduce pollution. Quantities of TRI chemical releases, source reduction activities, and barriers to pollution prevention, as reported to TRI, can be communicated back to the industry with insights on what pollution prevention measures have been most effective. EPA's TRI Program has implemented such outreach through the TRI Pollution Prevention

Search Tool,[9] the TRI Pollution Prevention Spotlights,[10] and through this chapter. Moving forward, EPA can continue to expand on these types of outreach efforts to share and promote successful pollution prevention activities throughout the industry.

Disclaimer

The views, statements, opinions, and conclusions expressed in this chapter are entirely those of the authors, and do not necessarily reflect those of the United States EPA, the Eastern Research Group, or Abt Associates Incorporated, nor does mention of any chemical substance, commercial product, or company constitute an endorsement by these organizations.

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9 For more information on the TRI Pollution Prevention Search Tool, please visit https://www3.epa.gov/enviro/facts/tri/p2.html.

10 For more information on the TRI Pollution Prevention Spotlights, please visit https://www.epa.gov/toxics-release-inventory-tri-program/tri-p2-spotlight-series-0.

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