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The Utility of the Toxic Release Inventory (TRI) in Tracking Implementation and Environmental Impact of Industrial Green Chemistry Practices in the United States

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Additional information is available at the end of the chapter

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Abstract

The Toxics Release Inventory is a rich data source with nearly 30 years of reported data from industrial facilities located in the United States. Annually, these facilities report on their chemical waste management practices, including the quantities they release to air, water, and land; treat; combust for energy recovery; or recycle. Facilities are also required to disclose any green chemistry or other pollution prevention practices, and have the option to provide additional details on these practices or on barriers they encounter in implementing such practices. The Toxics Release Inventory (TRI) provides a means by which a facility's or industry sector's implementation of green chemistry practices can be tracked, and the impact that these practices have on environmental performance. This chapter describes analytical options for tracking implementation of green chemistry practices and assessing the environmental impact of such practices. Key TRI data elements are highlighted as well as where to obtain the information.

Keywords: green chemistry, codes, source reduction, toxics, chemicals, TRI, releases, reporting

1. Introduction

Facilities that are subject to the Toxics Release Inventory (TRI) reporting requirements are required to disclose any source reduction practices implemented at their facilities during the year for which they are reporting. Facilities report the newly implemented source reduction practices by choosing one or more predefined codes (W-codes) that correspond to a specific

practice within the eight established TRI source reduction categories (e.g., process modifications, substitution of raw materials).

Over the past 2 decades many facilities have implemented green chemistry practices in their operations that reduce or eliminate the use or generation of TRI-listed chemicals to prevent pollution at its source. In doing so, facilities improve their environmental performance while off-setting the continually rising costs of managing production-related toxic chemical wastes. Beginning with the 2012 TRI reporting year, in recognizing that none of the existing source reduction codes (W-codes) were specific to green chemistry, the U.S. Environmental Protection Agency (EPA) implemented six new codes to align closely with green chemistry practices (e.g., W15, introduced in-line product quality monitoring or other process analysis system and W43, substituted a feedstock or reagent chemical with a different chemical), to enable facilities to disclose adoption of these practices.

This chapter introduces the EPA's TRI program and how the TRI has evolved over the past 30 years into a pollution prevention resource. TRI data specific to source reduction will be described, followed by discussions on how these data can be used to assess industrial progress in implementing green chemistry practices and possible impacts on the reduction of TRI-listed chemical generation and releases to the environment.

2. Toxics Release Inventory (TRI) Program

The TRI program was established by the Emergency Planning and Community Right-to-Know Act (EPCRA) in 1986 [1], and TRI reporting commenced with the 1987 reporting year (first TRI reports due July 1st, 1988), and has continued to the present. The 2015 reporting year marked 29 years of available TRI data, resulting in a rich source of information on TRI-listed chemicals, which now exceeds over 650 discrete chemicals and 30 chemical categories [2].

The Pollution Prevention Act (PPA) of 1990 expanded TRI's authority to collect information beyond release quantities as specified in EPCRA Section 313 to include information specific to source reduction and preferred waste management techniques as described under Section 6607 of the PPA [3]. This change was significant giving the public a broader lens by which to evaluate and track corporate performance in their management of TRI-listed chemicals.

As illustrated in (**Figure 1**), the waste management hierarchy [4], since reporting year 1991, for a given chemical on the TRI list, facilities are *required* to report the quantities of the chemical recycled, used for energy recovery, or treated at the facility or elsewhere in addition to the original reporting requirements on releases emitted directly into the environment or transferred off-site to disposal, treatment, or storage facilities. Optional waste minimization information also transitions to a formal requirement where facilities must report any source reduction activities (e.g., process modifications, substitution of raw materials) newly implemented at the facility during the reporting year.

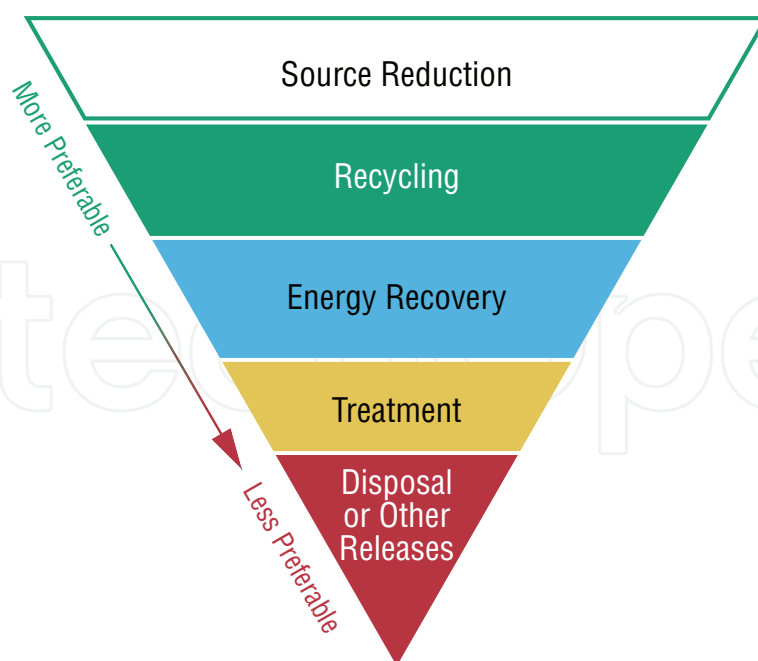


Figure 1. Waste management hierarchy.

For reporting year 2012, the TRI program, cognizant of the advancements in science and initiatives underway at facilities, expanded the codes available to facilities under the source reduction categories to better align with green chemistry practices. The addition of these six new codes is discussed in greater detail in the next section.

During this same time frame, the program made additional enhancements to the reporting form allowing facilities the option to specify barriers that were preventing them from implementing source reduction activities. Previously, facilities only had the opportunity to provide commentary without adequate data fields for tracking purposes.

Of greatest value perhaps to TRI data users are the open text data fields. Facilities (since 1991) can provide additional optional commentary to describe their source reduction activities, other environmental practices, or other activities reported to the TRI program such as reasons for increased releases. This field has the potential to be an important communication mechanism if used by industry. For this reason, the TRI encourages the submittal of optional information, for it not only augments understanding of industrial management, but provides a unique opportunity for facilities to showcase and further extend successful pollution prevention practices.

2.1. Evolution of the TRI reporting form

Facilities have had the option to report on pollution prevention activities since the start of the TRI program. For the first 4 years (1987–1990) of the program, prior to implementation of the additional TRI reporting requirements established under the PPA, facilities could voluntarily

provide information on waste minimization (pollution prevention) through the selection of one of eight codes shown in **Table 1** that best described their activities. Facilities could also indicate the effect of these activities on the quantities released by providing a waste minimization index helping to distinguish between business activities and minimization efforts. However, this optional data collected in Section 8 of the TRI form was highly underreported. Note that recycling was included within this category and later separated [5].

Code	Description	Example
M1	Recycling/reuse on-site	Solvent recovery still; vapor recovery systems; reuse of materials in a process
M2	Recycling/reuse off-site	Commercial recycler; toll recycling; at an off-site company-owned facility
M3	Equipment/technology modifications	Change from solvent to mechanical stripping; modify spray systems to reduce overspray losses; install floating roofs to reduce tank emissions; install float guards to prevent tank overflow
M4	Process procedure modifications	Change production schedule to minimize equipment and feedstock change-overs; improved control of operating conditions; segregation of wastes to permit recycling
M5	Reformulation/redesign of product	Change in product specifications; modify design or composition; reduce or modify packaging
M6	Substitution of raw materials	Change or eliminate additives; substitute water-based for solvent-based coating materials, cleaners, and pigments; increase purity of raw materials
M7	Improved housekeeping, training, inventory control	After maintenance frequency; institute leak detection program; improved inventory control; institute training program on waste minimization
M8	Other waste minimization technique	Elimination of process; discontinuation of product

Table 1. Pre-PPA codes, waste minimization codes.

Recognizing the importance of this information as a possible way to address chemical wastes and operations at industrial facilities, regulators significantly expanded Section 8 of the TRI reporting form (Form R) and made mandatory the reporting of pollution prevention (P2) activities as of reporting year 1991. Source reduction activities implemented during a year would be reported through the selection of the appropriate code(s) indicating the type of actions taken to reduce chemical waste: disposed of or released, treated, used for energy recovery, or recycled. Facilities could select from the 43 codes listed in **Table 2** that correspond to eight source reduction categories [6].

The expanded Section 8 of the TRI Form R also includes other reporting requirements specified by the PPA on quantities of chemical waste managed as waste (which includes recycled, burned for energy recovery, treated, or released). This section often represents a summary of more detailed information presented in other sections, such as releases in Sections 5 and 6 or on-site treatment methods and efficiencies in Section 7. Beyond the additional report data elements, following the PPA, the reporting form was reorganized and condensed into two parts, combining previous Parts II and III into the current Part II on Chemical Information.

Source reduction category	Source reduction code	Source reduction description
Good operating practices	W13	Improved maintenance scheduling, record keeping, or procedures
	W14	Changed production schedule to minimize equipment and feedstock changeovers
	W19	Other changes made in operating practices
Inventory control	W21	Instituted procedures to ensure that materials do not stay in inventory beyond shelf-life
	W22	Began to test outdated material — continue to use if still effective
	W23	Eliminated shelf-life requirements for stable materials
	W24	Instituted better labeling procedures
	W25	Instituted clearinghouse to exchange materials that would otherwise be discarded
	W29	Other changes made in inventory control
Spill and leak prevention	W31	Improved storage or stacking procedures
	W32	Improved procedures for loading, unloading, and transfer operations
	W33	Installed overflow alarms or automatic shutoff valves
	W35	Installed vapor recovery systems
	W36	Implemented inspection or monitoring program of potential spill or leak sources
	W39	Other changes made in spill and leak prevention
Raw material modifications	W41	Increased purity of raw materials
	W42	Substituted raw materials
	W49	Other raw material modifications made
Process modifications	W51	Instituted re-circulation within a process
	W52	Modified equipment, layout, or piping
	W53	Used a different process catalyst
	W54	Instituted better controls on operating bulk containers to minimize discarding of empty containers
	W55	Changed from small volume containers to bulk containers to minimize discarding of empty containers
	W58	Other process modifications made

Source reduction category	Source reduction code	Source reduction description
Cleaning and degreasing	W59	Modified stripping/cleaning equipment
	W60	Changed to mechanical stripping/cleaning devices (from solvents or other materials)
	W61	Changed to aqueous cleaners (from solvents or other materials)
	W63	Modified containment procedures for cleaning units
	W64	Improved draining procedures
	W65	Redesigned parts racks to reduce drag out
	W66	Modified or installed rinse systems
	W67	Improved rinse equipment design
	W68	Improved rinse equipment operation
	W71	Other cleaning and degreasing modifications made
Surface preparation and finishing	W72	Modified spray systems or equipment
	W73	Substituted coating materials used
	W74	Improved application techniques
	W75	Changed from spray to other system
	W78	Other surface preparation and finishing modifications made
Product modifications	W81	Changed product specifications
	W82	Modified design or composition of product
	W83	Modified packaging
	W89	Other product modifications made

Table 2. Post-PPA codes, source reduction codes.

Since 1991, the TRI Form R has been fine-tuned with smaller improvements for clarification purposes and to reduce reporting burdens. The gradual transition from 2006 to 2014 from paper form reporting to an electronic-only system, with the exception of those facilities claiming trade secret information also helped greatly with data quality and increased reporting of optional descriptive information. Moreover, significant to pollution prevention and green chemistry are the additions for the 2012 reporting year [7]. The 2012 update allows for the tracking of green chemistry activities as well as better tracking of barriers to source reduction. As explained in the introduction, six green chemistry source reduction codes were added expanding the total number of source reduction codes to 49. Noticing that facilities were providing commentary on obstacles, the TRI Program also developed eight codes that enable facilities to disclose (voluntarily) the most common barriers to source reduction implementation. These additional codes are listed in **Table 3**.

Green chemistry code	Green chemistry code description	Barrier code	Barrier code description
W15	Introduced in-line product quality monitoring or other process analysis system	B1	Insufficient capital to install new source reduction equipment or implement new source reduction activities/initiatives
W43	Substituted a feedstock or reagent chemical with a different chemical	B2	Require technical information on pollution prevention techniques applicable to specific production processes
W50	Optimized reaction conditions or otherwise increased efficiency of synthesis	B3	Concern that product quality may decline as a result of source reduction
W56	Reduced or eliminated use of an organic solvent	B4	Source reduction activities were implemented but were unsuccessful
W57	Used biotechnology in manufacturing process	B5	Specific regulatory/permit burdens
W84	Developed a new chemical product to replace a previous chemical product	B6	Pollution prevention previously implemented-additional reduction does not appear technically or economically feasible
		B7	No known substitutes or alternative technologies
		B8	Other barriers

Table 3. Green chemistry and barrier codes added in 2012.

2.2. TRI data elements

For analytical purposes to track the implementation and impact of green chemistry practices, five overarching data elements are important. Background on source reduction has already been provided and to a lesser extent on optional pollution prevention (P2) text. These first two elements along with production information help understand the quantitative values (waste managed and releases) reported for TRI-listed chemicals. These elements are:

- **Optional P2 Text**, which includes narratives on P2-related activities and provide greater context for understanding source reduction activities, other environmental management practices, as well as barriers to source reduction implementation at the facility (reported in TRI Form R Section 8.11).
- **Source Reduction**, which includes newly implemented activities that reduce or eliminate the generation of pollutants (reported in TRI Form R Section 8.10). Source reduction practices include for example process modifications and substitution of raw materials.
- **Production Ratio (PR) or Activity Index (AI)**, which specifies the level of increase or decrease from the previous year, of the production process or other activity in which the toxic chemical is manufactured, processed or otherwise used (reported in TRI Form R Section 8.9). This number is usually around 1.0. For example, a production ratio or activity index of 1.5 indicates about a 50% increase in production from the prior year associated with, for example, the use of the chemical, while a value of 0.3 indicates about a 70% decrease in production associated with the chemical.

- **Waste Managed**, which includes all quantities of waste that are recycled, used for energy recovery, treated, or released whether on-site or transferred off-site (reported in TRI Form R Sections 8.1 through 8.7). Waste managed tracks production-related waste only and does not include quantities associated with accidental or remedial one-time events.
- **Releases**, which includes all quantities disposed of or otherwise released to the environment through all release mechanisms to all media, whether on-site or transferred off-site to a publically owned treatment works (POTWs) or other facility for disposal, treatment, or storage (reported in TRI Form R Sections 5 and 6). Release quantities track both production and non-production related releases. 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.

2.3. TRI data reporting and access

Before delving into analytical methodologies, it's important to understand the segment of industrial activity that TRI covers. TRI represents a slice of industrial activity. The inventory collects information from larger industrial facilities that meet the TRI reporting criteria for the employee threshold, the chemical manufacture, processing or otherwise use threshold, and operate within an industry covered sector. Specifically, facilities are subject to reporting if they (1) have ten or more full-time employees, (2) are in a TRI-covered industry NAICS code such as the manufacturing sector and other sectors (e.g., electric utilities, metal mining, and hazardous waste management) or are federal facilities, and (3) manufacture or process more than 25,000 lb., or otherwise uses more than 10,000 lb. of a TRI-listed chemical within a calendar year. Thresholds for persistent bioaccumulative toxic (PBT) chemicals are lower – as low as 0.1 g for dioxin – due to their potentially greater threat to human and environmental health.

Facilities subject to the TRI reporting requirements report annually by July 1st of each year to EPA's TRI Program, and state and tribal governments [8]. Each year, EPA's TRI Program receives approximately 80,000 form reports from approximately 20,000 facilities [9]. Form reports are chemical and chemical category specific and facilities that exceed the thresholds discussed above for a specific calendar year are required to report on the data elements outlined above as well as others.

EPA makes this information available and readily accessible to the public through various data tools, maintained by EPA's TRI Program. Various access options are discussed later in the chapter.

2.4. Analytical considerations and methodologies

In order to conduct sound analysis of green chemistry activities reported to the TRI Program, certain considerations are key for tailoring the research. Three considerations are outlined below using the data that can be derived from the TRI dataset.

Tracking a set of facilities: Analysis of the reported quantities for waste managed and released in the year the source reduction activity was reported may not lead to any significant insight as implementation of an action may not result in immediate effects. Therefore, instead of gathering data for the specific years associated with green chemistry codes, set analyses

are recommended. For example, to fully understand the potential impact of green chemistry practices it is important to track the set of facilities that reported green chemistry for specific chemicals over a broad time frame. Gathering pre-source reduction quantities as well as post-source reduction quantities would give some insight as to the impact of the change.

Production levels: Consideration should also be given to production information and whether the facility is operating within normal ranges and not below or above for the time span being considered. The reported production ratio or activity index help understand the quantitative values reported and assess whether changes (increases or decreases) are due to shifts in production levels or attributable to other factors such as the implementation of new source reduction activities. Increasing or stable production coupled with decreasing releases is a positive indicator of effective pollution prevention practices.

Focus on subgroups: To more profoundly understand the magnitude of the impact, segmenting the data by industry (e.g., specific industry sector or subsector) can inform on overall activities undertaken by similar businesses. Facilities reporting to the TRI can specify up to six North American Industrial Classification System (NAICS) codes with one as the primary NAICS code, corresponding to their primary business activity. More in-depth analysis using industry-chemical combinations may also be advantageous to more accurately assess green chemistry impacts of certain chemicals or types of chemicals. Geographic analysis as an additional layer to the industry studies or as a separate subgroup option may provide some insight on local policies or clustering of mutually-beneficial resources.

The TRI dataset, while very comprehensive as a multi-media inventory of releases and other waste management information, should not be studied in isolation. Consideration of TRI in conjunction with other data sources will allow for more holistic assessment of green chemistry impacts in light of other confounding factors. For example, external factors such as outsourcing (transferring manufacturing and production operations to facilities in other countries) and the state of the economy should also be evaluated. A study published in 2015 considering this same topic of assessing the implementation and effectiveness of green chemistry in industrial manufacture of chemicals, but focused on TRI and pharmaceutical manufacturers, describes how these external factors can be considered [10]. Another valuable resource that discusses more general details on limitations of the TRI data is EPA's document on *Factors to Consider when using TRI Data* [11].

3. Tracking implementation of source reduction and green chemistry in the US

3.1. Source reduction

According to the Pollution Prevention Act of 1990, source reduction is any practice that:

"reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants."

Pollution can be reduced at its source by a wide variety of techniques, prior to end-of-pipe pollution controls or recycling, such as by changing the product, materials, or processes that generate pollution in the first place. Because of the potential advantages of these preventative approaches, the U.S. EPA took steps to encourage industrial facilities to engage in source reduction. On their part, industrial facilities have engaged in substantial pollution prevention efforts, by carrying out 447,000 unique source reduction activities between 1991 and 2015 (as reported to the EPA's TRI Program).¹ **Figure 2** shows that many facilities (about 107,000) conducted these source reduction projects over the past 25 years [12].

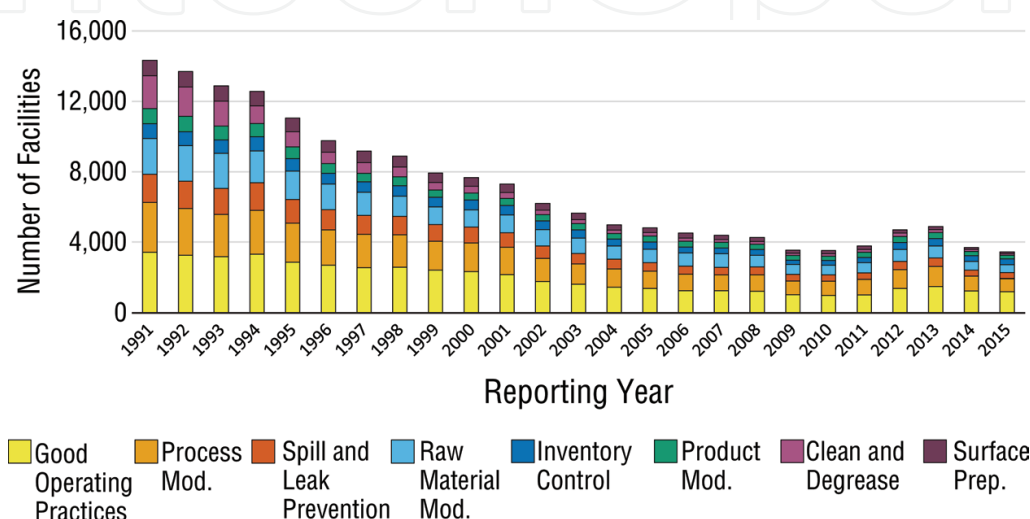


Figure 2. Facilities with source reduction projects.

Based on the eight source reduction categories tracked, the trend graph above shows that the most reported source reduction category is good operating practices. Source reduction data reported for 2015 (**Figure 3**) show that good operating practices represents 40% followed by the process modifications category at 21%. The two least reported categories are surface preparation and finishing as well as cleaning and degreasing.

3.2. Green chemistry

According to the U.S. EPA, “Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal” [13].

There are many benefits to implementing green chemistry that are inextricably linked to its preventative premise. These include improved economy and business, environment, and human health conditions.

¹The results have been updated from previously published results (Ranson et al. [16]) to include the 2013 to 2015 TRI data.

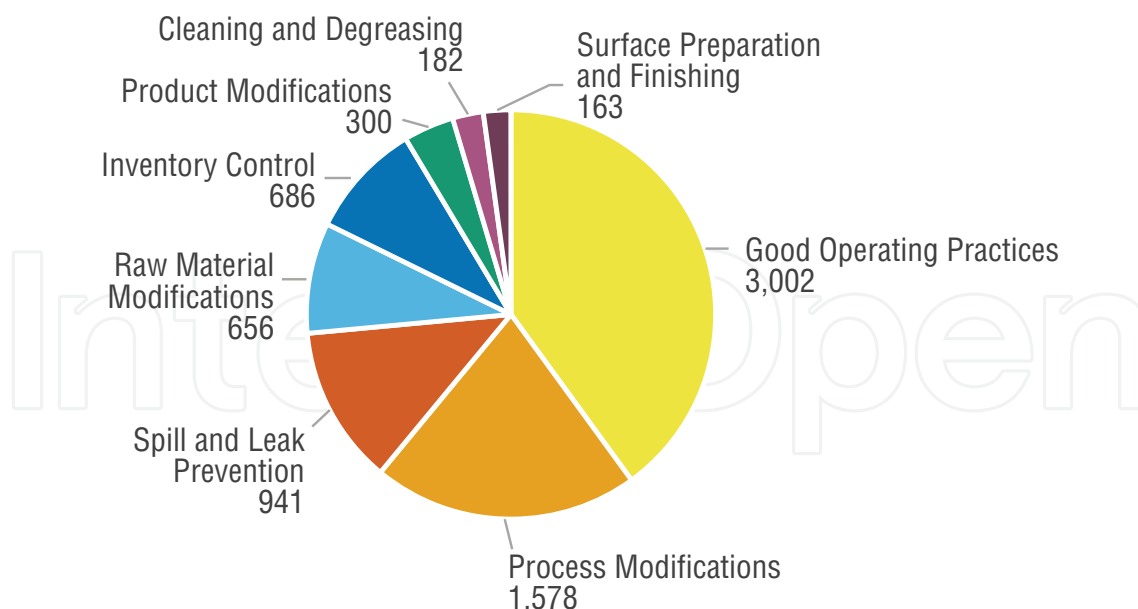


Figure 3. Number of source reduction activities.

Economy and business benefit from reduced waste generation, eliminating costly remediation in the event of accidental releases, hazardous waste disposal, and end-of-the-pipe treatments. Implementing green chemistry saves money by offsetting the costs associated with managing toxic or hazardous chemical waste. In terms of the chemicals, it reduces the need and demand for the manufacture of TRI-listed chemicals while incentivizing the creation of less toxic or non-toxic chemicals, improving competitiveness of chemical manufacturers and their customers. Use of green chemistry and associated safer-product labeling (e.g. Safer Choice labeling) [14] may also lead to increased consumer sales (by earnings).

The environment benefits from reduced emissions of TRI-listed chemicals or other hazardous substances, signifying less chemical disruptions to ecosystems. Through green chemistry, the environment would benefit from reductions in emissions of toxics to air, water, and land such as reduced use of landfills, especially hazardous waste landfills. Plants and animals also suffer less harm from reductions in hazardous chemicals entering the environment.

Human health also benefits from cleaner environmental conditions. Cleaner air resulting from reductions in hazardous chemicals released to air leads to reduced respiratory disease and other illnesses. Similarly, cleaner water resulting from reductions in hazardous chemicals released to water lead to cleaner drinking and recreational water. Application of green chemistry results in safer consumer products that enter the market and are available for purchase, thereby increasing the safety of consumers and society in general. These products may be new, replacements for less safe products (e.g., certain pesticides, cleaning products), or designed to be manufactured efficiently and with less accompanying waste (e.g., drugs). This preventive practice also benefits the workers in the chemical industry resulting in increased safety through less use of toxic materials, reduced potential for exposure and accidents (e.g., fires or explosions), and reduced need for personal protective equipment.

Given these benefits, it is not surprising to see industry advances in green chemistry. In 2012, the TRI program added six green chemistry source reduction codes to better track these ongoing activities and their possible improvements. These codes are captured within 4 of the 8 categories and are listed in (Table 4) along with guidance provided to reporters for increased data quality [15].

Source reduction categories	Green chemistry codes	Guidance in TRI reporting forms
Good operating practices	W15: Introduced in-line product quality monitoring or other process analysis system	Select code W15 if the introduction of such a system led to a reduction in the amount of the EPCRA Section 313 chemical generated as waste.
Raw material modifications	W43: Substituted a feedstock or reagent chemical with a different chemical	<p>Select code W43 if the EPCRA Section 313 chemical was a feedstock or reagent chemical and you replaced it (in whole or in part) with a different chemical.</p> <ul style="list-style-type: none"> For raw material substitutions not at the level of the individual chemical (e.g., the substitution of natural gas for coal), select instead W42 <i>Substituted raw materials</i>. If use of a feedstock or reagent chemical was reduced or eliminated because of a change in the final product, select instead one of the codes listed under <i>Product Modifications</i>.
Process modifications	<p>W50: Optimized reaction conditions or otherwise increased efficiency of synthesis</p> <p>W56: Reduced or eliminated use of an organic solvent</p> <p>W57: Used biotechnology in manufacturing process</p>	<p>Select code W50 if the amount of the EPCRA Section 313 chemical generated as waste was reduced by increasing the overall efficiency of the synthesis.</p> <ul style="list-style-type: none"> If efficiency of syntheses was improved by using of a different catalyst, select instead W53 <i>Used a different process catalyst</i>. <p>Select code W56 if the EPCRA Section 313 chemical was used as a solvent in the process and the process was modified such that the EPCRA Section 313 chemical was either replaced or no longer used in as large a quantity.</p> <p>Select code W57 if the use of biotechnology in the process reduced or eliminated the use of the TRI chemical.</p>
Production modifications	W84: Developed a new chemical product to replace a previous chemical product	Select code W84 if the EPCRA Section 313 chemical had been produced at the facility but was replaced it (in whole or in part) with the production of a different chemical or chemicals.

Table 4. Green chemistry codes and reporting guidance.

3.2.1. Tracking green chemistry by year and code

From 2012 to 2015, TRI reporting rates by year and code show that of the 37,117 total source reduction activities reported, 1756 (5.1%) were reported as green chemistry (i.e., reported on a Form R using one of the six green chemistry codes). The vast majority were reported as W15 or W50 as shown in **Figure 4**. These relatively high reporting rates indicate that facilities are seizing opportunities for increased monitoring and efficiencies. Whereas a minimum number of facilities reported W57, demonstrating limited implementation of biotechnology in manufacturing processes.

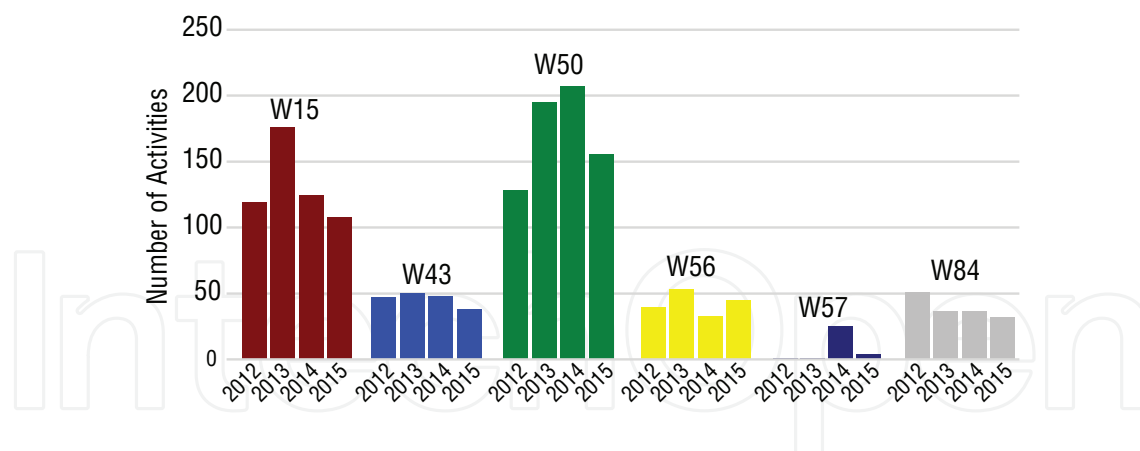


Figure 4. Green chemistry by year and code.

3.2.2. Tracking green chemistry by industry sector

On an industry sector level, implementation of green chemistry and total source reduction activities reported from 2012 to 2015 is visible for the top six sectors shown in **Figure 5**. The chemical manufacturing industry makes up the greatest percentage of all green chemistry reporting and constitutes a greater percentage of green chemistry reporting than of total source reduction reporting for the sector (35% vs. 29%). Both metrics are consistent with Fabricated Metal Product Manufacturing in second place, respectively at 13 and 12%. Differences in industry reporting are notable at the third level and beyond with the following observations:

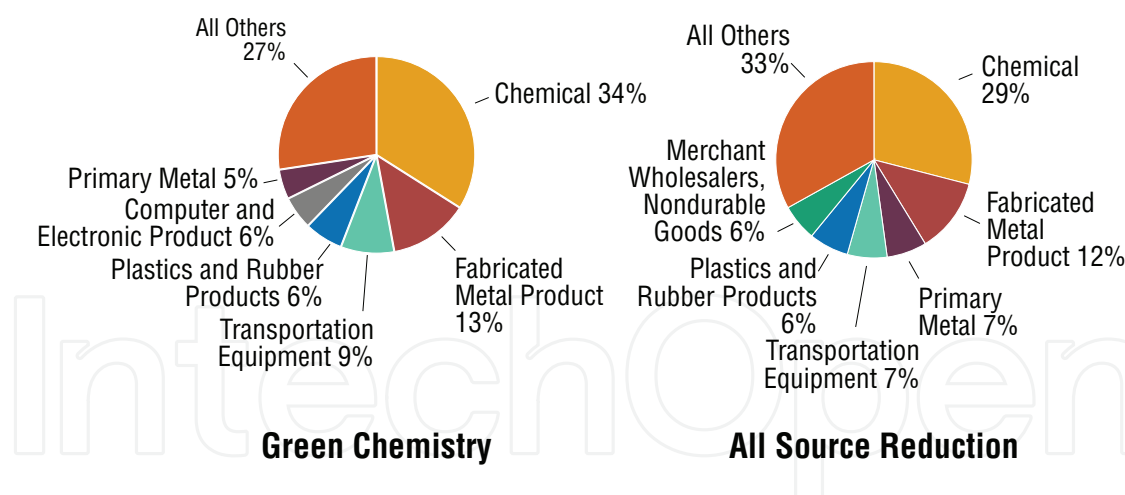


Figure 5. Green chemistry versus total source reduction by sector, 2012–2015.

- The Primary Metal Manufacturing dropping from 7% for all source reduction activities to nearly 5% for only green chemistry. A possible reason for this may be that the nature of the business may not be as amenable to green chemistry as it is in the chemical manufacturing industries.
- The Transportation Equipment Manufacturing sector covers the Automotive Manufacturing sector (NAICS 3361-3363) and as expected given recent advances, the majority (70%) of green chemistry reporting is from the auto sector. Overall, the transportation sector represents a larger share of green chemistry reporting compared to total source reduction reporting (9% vs. 7%).

- The Merchants and Wholesalers sector, while actively implementing source reduction activities and within the top six, is almost nil for ranking based on green chemistry with 0.2% representing three activities during the 4-year time period.
- The Computer and Electronic Product Manufacturing sector, while not delineated in the source reduction pie chart, falls in seventh position representing 5% of the “all others” category. This indicates that the computer manufacturing sector implemented a consistent share of green chemistry activities to source reduction activities.

How does reporting of green chemistry implementation compare to all TRI reporting? Tracking the implementation of green chemistry in the context of all TRI reports is important because it provides a lens as to sectors more amenable to green chemistry practices and where collaborative efforts may be more readily established. High TRI reporting rates from sectors that do not report green chemistry practices are likely indicators that such sectors face source reduction obstacles. Barriers are discussed in more detail later in the chapter. The pie charts in **Figure 6** show that three of the six sectors fall within the top ranking for both green chemistry and overall TRI reporting. Other sectors such as Petroleum and Coal Products Manufacturing and Utilities, while high in number of TRI forms submitted to TRI, do not report many source reduction activities or specific green chemistry practices for TRI-listed chemicals.

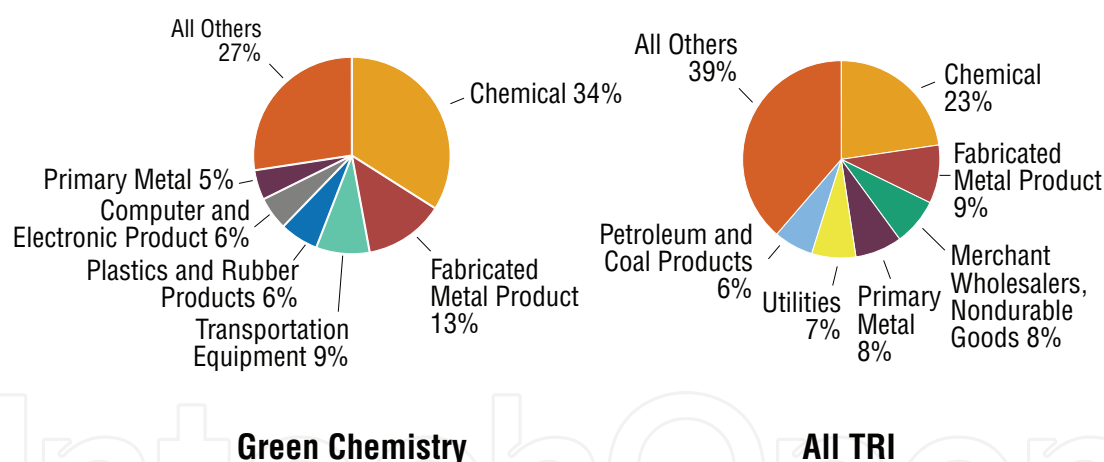


Figure 6. Green chemistry versus TRI reporting by sector, 2012–2015.

More in-depth analysis by NAICS code is recommended to help delineate more precisely green chemistry implementation by facilities within specific subsectors of a given industrial sector and their environmental impact. For example, the case study involving TRI and Pharmaceutical Manufacturers to assess the implementation and effectiveness of green chemistry practices focused on facilities classified in NAICS codes 325411 (Medicinal and Botanical Manufacturing) and 325412 (Pharmaceutical Preparation Manufacturing) [10]. This sector represents 16.5% of the chemical manufacturing sector or about 6% of all industry sectors that reported green chemistry practices to TRI from 2012 to 2015.

Case Study Focus: The study examined TRI data submitted for reporting years 2002 through 2011 and, hence did not include consideration of the green chemistry codes since the codes were implemented for reporting year 2012. Nonetheless, the analyses show that over the 2002–2011 timeframe the quantities of TRI chemicals reported annually by pharmaceutical manufacturing facilities to EPA’s TRI Program as released to the environment or otherwise managed as waste declined steadily and by more than 60%. The downward trend was largely driven by reductions in the quantities reported for organic solvents. Five solvents (methanol, dichloromethane, toluene, dimethylformamide and acetonitrile) accounted for three-quarters of the declining trend in production-related waste managed, which includes environmental releases. Overall, the reductions in reported quantities are sector-wide, and it appears that factors such as outsourcing, production levels, regulations, shifts to other waste management practices, or larger pharmaceutical firms did not precipitate the decline. The authors concluded from their analyses and the extensive evidence in the literature of green chemistry advances within the pharma sector that implementation of green chemistry practices is a major contributing factor to the large reductions [10].

3.2.3. Tracking green chemistry by chemical

Green chemistry implementation can also be tracked on a chemical level. Industrial facilities reported green chemistry activities to reduce the generation of waste of the following chemicals. **Figure 7** shows the top 8 chemicals based on total green chemistry reporting from 2012 to 2015 and delineates the individual green chemistry codes selected. The majority of green chemistry codes were reported for methanol, toluene, copper, and ammonia, representing 21%. With the chemical manufacturing industry ranking first and the published solvent reduction advancements, TRI data confirm industries’ efforts to implement projects to reduce methanol and toluene, the top two most reported chemicals [10]. The top W-codes selected were W50, optimized reaction conditions, followed by W15, in-line product quality monitoring.

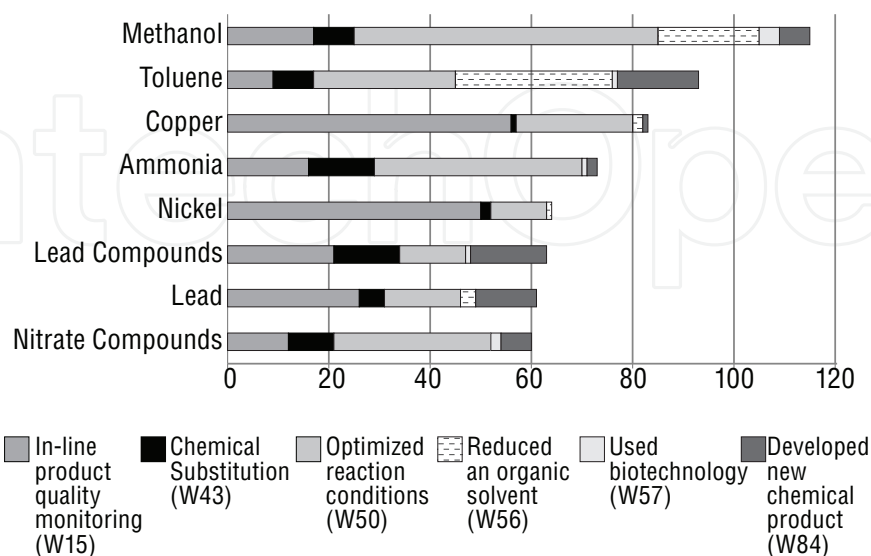


Figure 7. Green chemistry by chemical.

3.3. Assessing impact of industrial green chemistry practices

In practice, implementing source reduction activities aims to improve environmental performance, and as TRI-listed chemicals are eliminated or reduced in processes, facilities consequently reduce associated costs with managing production-related waste of those chemicals. However, what do the data indicate? Do the data confirm that implementation of green chemistry techniques results in reduced waste management and release quantities?

Based on a previous statistical analysis using the “differences-in-differences” methodology, all implemented source reduction is not equal, meaning all activities do not equally decrease the quantities of chemical waste managed. The study, which considered a wide range of TRI data from 1987 to 2012, shows that there is considerable variation in how the implementation of different source reduction activities affects releases. For example, good operating practices, which is the category corresponding to green chemistry code W15, has only a small effect (roughly -4%). In contrast, source reduction activities focused on raw material modifications, which contains green chemistry code W53, shows a large decrease in releases of -20%. Similarly, product modifications, including W84 shows a -13% decrease. The other green chemistry codes fall under the process modifications category, which has shown moderate decreases of -5% [16]. One can infer from this study that to quantify the effectiveness of source reduction, different green chemistry practices would result in different environmental impacts.

This study also shows that impacts may be experienced up to 5 years following the implementation of a source reduction project. Conducting a similar type of analysis focused on green chemistry practices, especially now that codes are available to clearly track any associated projects would serve as a good case study to verify the overall results. However, additional data is needed to apply this methodology and conduct a robust statistical analysis to observe the long-term impact of green chemistry practices. Within 3–5 years from the time of this writing, sufficient data will be available to evaluate the effectiveness of those activities implemented from 2012 to 2015. As mentioned previously, tracking the same set of facilities over time will ensure visibility of any impacts associated with green chemistry approaches.

3.3.1. *Impact of green chemistry on waste managed quantities*

Analysis of the green chemistry practices implemented during 2012 and the impact these practices had on the quantities of TRI chemical waste managed is presented below. To account for at least one factor that could influence changes in the quantities of chemical waste managed, the analysis normalizes based on reported production values. Considering only those facilities that reported green chemistry codes for 2012 and reported production ratios within the normal range (greater than 0.2 and less than 3) and consistently for all years in the time span, the normalized production-related waste managed trend in **Figure 8** shows 7 years of data with 3 years prior to 2012 and 3 years after 2012. The decrease in waste managed during 2012 indicates that green chemistry actions implemented during that year could have contributed to the observed reduction. Investigation into the release quantities for 2013 and 2014 indicates that two facilities are primarily responsible for increases in releases and treatment.

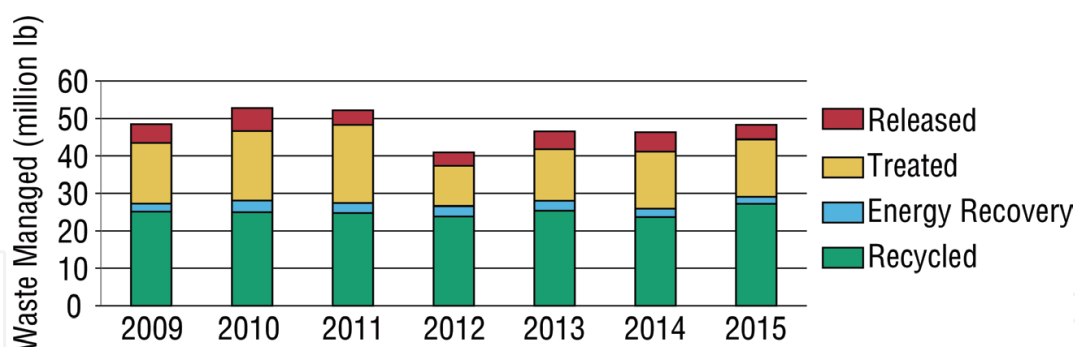


Figure 8. Production normalized waste managed, 2009–2015.

BASF CORP-SAVANNAH OPERATIONS, TRIFID 31404KTLST1800E, NAICS 327992: Ground or Treated Mineral and Earth Manufacturing. Facility reported green chemistry code, W50, for nitrate compounds for 2012. The 3 years following show highest releases for 2014, with 2,860,000 pounds (55% of total releases) discharged to water.

ARKEMA INC CLEAR LAKE, TRIFID 77507DWCHM952BB, NAICS 325110: Petrochemical Manufacturing. Facility reported green chemistry code, W50, for two chemicals: butyl acrylate and n-butyl alcohol for 2012. The years following show the highest treatment quantities of butyl acrylate for 2013 with 3,848,260 pounds, 28% of the total treated waste. For n-butyl alcohol, 1,732,045 pounds were treated during 2014, representing 11% of total treated waste during the year.

The formula used to calculate the normalized trend is as follows. It is applied to all year-facility-chemical combinations to obtain a normalized production value for each. Year 2009, as the first year in the series, is set as the base year equal to 1.

P = absolute production

PR = production ratio (provided by facility. relative to previous year.)

PI = production index relative to 2009

W = absolute waste quantity

PNW = production normalized waste quantity

General formulas:

$$PI_{year\ x} = PI_{year\ x-1} * PR_{year\ x} \quad (1)$$

$$PNW_{year\ X} = \frac{W_{year\ X}}{PI_{year\ X}} = \frac{W_{year\ X}}{PI_{year\ X-1} * PR_{year\ X-1}} \quad (2)$$

Example 1:

$$PI_{2009} = 1$$

$$PNW_{2009} = W_{2009}$$

Example 2:

$$PI_{2010} = PI_{2009} * PR_{2010} = PR_{2010}$$

$$PNW2010 = W2010/PI2010 = W2010/PR2010$$

Example 3:

$$PI_{2011} = PI_{2010} * PR_{2011} = PR_{2009} * PR_{2010} * PR_{2011}$$

$$PNW2011 = W2011/PI2011 = W2011/(PR_{2010} * PR_{2011})$$

A more direct analysis of the data without consideration of production indicates implementation of green chemistry practices as favorable to lowering waste management quantities. Comparing the 2012 subset of facilities that reported green chemistry codes to all other facilities that reported to the TRI Program for the same year, shows that facilities reporting green chemistry have a larger decrease in their waste managed compared to all facilities. Out of 249 facilities that reported implementation of a green chemistry practice during 2012, 59.2% of those facilities decreased their waste from 2011 to 2015. While 47.6% of facilities that did not report implementation of a green chemistry practice during 2012 decreased their waste from 2011 to 2015.

Assessing impact is both a beneficial exercise and a difficult one because facilities do not directly report the extent to which green chemistry impacts production-related waste managed. However, the optional text that facilities may include in their reports does provide additional insight as to the specific practices implemented and their success. As an example, Cathay Industries USA Inc., in Valparaiso, Indiana in the Chemicals Manufacturing sector, Synthetic Dye and Pigment Manufacturing (NAICS 325130), reported green chemistry code, W50, "Optimized reaction conditions or otherwise increased efficiency of synthesis" for both 2012 and 2013 for ammonia. Normalized production waste management trends of ammonia show decreases in those years, and continued low levels in 2014–2015. Additionally, Cathay Industries noted "Improved measurement and control of reactant / reaction" in the source reduction optional text field for the Form R filed for reporting year 2013 [17]. This additional context could be useful for encouraging similar best practices at other facilities.

More focused analysis by industry sector or green chemistry code would provide more insightful findings as well as more accurate estimates of impact. Analysis of waste managed quantities help to track the overall performance of the facility and more granular analysis of each of the waste management methods, particularly the releases portion, which would inform on progress toward reducing the emission of toxic chemicals to environmental media.

4. Accessing TRI green chemistry data

Over the time span of the TRI program various tools for accessing and analyzing TRI data have been developed comprising the TRI tool suite available today. Depending on data user objectives, some tools are better suited for certain purposes than others. Three resources are described below and summarized in **Table 5**.

TRI data resources	Description
TRI Pollution Prevention Search Tool	Easiest method to explore and access P2 related information by facility and conduct comparisons on an industry scale
TRI National Analysis Supporting Data File "Additional P2 Data" Download	Pre-formatted downloadable P2 data file for a specific reporting year
TRI Customized Search Tool	Most robust tool for ad-hoc querying of all TRI reported data fields

Table 5. TRI data resources to access green chemistry data.

In the realm of pollution prevention data, the best way to explore all available P2 information is through **TRI's Pollution Prevention Search Tool** [18]. A user can easily query for all information reported for a specific year or can further limit to a specific chemical or industry. The results table shows the source reductions codes reported along with any optional text. The P2 text filter box can be adjusted to display all comments. This data can then be downloaded and more easily filtered to show only those facilities that reported green chemistry. The P2 tool is also a great way to explore the data on a facility level or to compare to other industries. For general instructions on how to conduct an industry analysis using the P2 tool, see the How-to Guidance [19].

For downloading a comprehensive set of P2 data per reporting year, the **TRI National Analysis supporting data files** are a good resource. Refer to the file "Additional P2 Data" [20]. A quick link is available from TRI's P2 webpage [4] or can be obtained directly from the National Analysis Download Report tab. The Excel workbook packages the P2 data used for EPA's interpretation of the data for the given year's National Analysis report. It is a well-organized workbook with P2 data presented over several tabs including a dedicated tab on 8.10 entries (source reduction codes reported). These codes can be filtered to those specific to green chemistry.

The most robust option to download all possible data fields associated with all facilities that reported green chemistry is **TRI's Customized Search Tool** [21]. This tool provides access to all publicly available TRI reported fields and can be tailored to your data needs. The most comprehensive table is the "flat" view (v_tri_form_r_ez) and can be selected along with other tables.

5. Conclusion

This chapter describes the utility of the TRI as a useful tool for measuring the impact of green chemistry practices on reducing releases and other waste management quantities of chemicals reportable to the TRI Program, and assessing progress toward sustainability goals. As discussed, the TRI is uniquely well-suited for assessing the progress made by specific industry sectors or specific facilities therein in implementing green chemistry practices. Green chemistry codes as a new data field will become richer with time allowing for more comprehensive analysis of impact. Three to four more years of data will be especially valuable for trend analysis and longer-term assessment of effectiveness. The TRI will continue to be an excellent source for gauging progress toward sustainability as well as for promoting possible alternatives to the manufacture, processing, or use of TRI-listed chemicals.

Disclaimer

This chapter was prepared by Sandra D. Gaona of the United States Environmental Protection Agency. The contents of this chapter do not necessarily reflect the views, rules or policies of the United States Environmental Protection Agency, nor does mention of any chemical substance necessarily constitute Agency endorsement or recommendation for use. In addition, mention of any companies does not necessarily constitute Agency endorsement.

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