Enhancing Industrial Sustainability by Improving Resource Efficiency

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Abstract

With ever increasing energy and raw material costs, coupled with environmental regulations and increasing customer awareness of corporate sustainability efforts, industries are seeking to increase energy and resource efficiency. Over the past decade, the University of Dayton's Industrial Assessment Center (UD-IAC) has developed a systematic methodology and analysis tool to help industry become more energy efficient. The publicly-available Energy Efficiency Guidebook (EEG) is a comprehensive tool that integrates examples and computational resources for improving energy efficiency. This paper describes a parallel effort to improve industrial resource efficiency by developing a methodology for improving resource efficiency and incorporating it into a free publically-available software tool called the Resource Efficiency Guidebook (REG). The methodology focuses on six types of resources: water, raw material, chemical agents, process scrap, packaging waste, and equipment and applies seven principles of resource efficiency to these resources. The result is a prioritized Integrated Resource plus Principles Matrix that guides manufactures through the resource efficiency process. REG combines the Integrated Resource plus Principles Matrix with real-world saving examples and spreadsheet calculators. Case studies with scenario analyses demonstrate the effectiveness of the REG at cost-effectively improving resource efficiency and reducing waste.

Introduction

Great improvements in sustainability can be achieved by applying life-cycle analysis to product design (Graedel and Allenby, 2003; Baumann and Tillman, 2004; Choi et al., 2013). For most products, energy and resource use during the manufacturing stage can be significant. Efforts toward energy and resource savings during the manufacturing stage are often compromised because of the lack of a systematic approach toward identifying and quantifying efficiency opportunities. To address this weakness in regards to energy efficiency, the University of Dayton Industrial Assessment Center (UD-IAC) developed a systematic methodology and analysis tool to improve energy efficiency called the Energy Efficiency Guidebook (EEG) (UD-IAC 2015; Raffio et al., 2013). The EEG is based on the Integrated Systems Plus Principles Approach to industrial energy efficiency that applies six principles of energy efficiency to nine energy systems.

This paper describes an analogous effort to improve the resource efficiency. In this study, the concept of resource covers the raw material, water, chemical agents, equipment, process scraps, and packaging. The principle product is a free publicly-available tool called the Resource Efficiency Guidebook (REG) (UDIAC, 2015). REG encompasses an integrated resource plus principles matrix (IRPM), industrial best practices and resource saving examples with spreadsheet calculators. REG's coherent and easily duplicable spreadsheet calculators help users quantify expected savings and select investment options. This paper discusses: 1) the six categories of industrial resources 2) seven principles of resource efficiency, 3) combining these categories and principles into the Integrated Resource plus Principles Matrix, 4) examples that demonstrate the efficacy of the IRPM, and 5) the composition of the REG.

Integrated Resources plus Principles Matrix

Industrial Resources

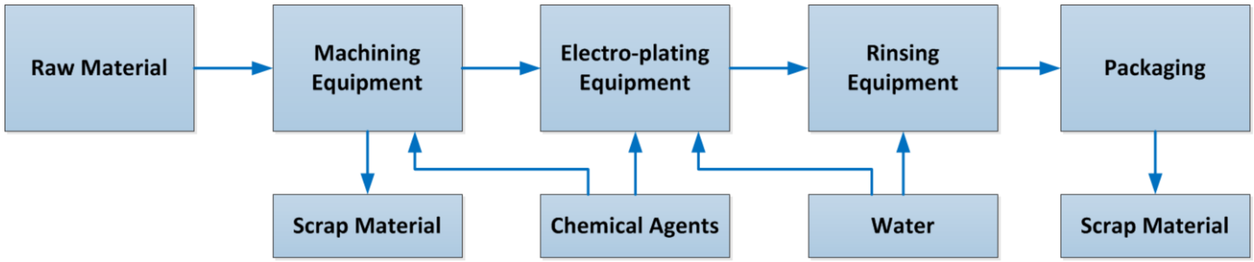
Grouping manufacturing resources into distinct categories simplifies the challenge of improving resource efficiency. Practically all industrial processes use some combination of the following six resources: raw materials, water, chemical agents, equipment, process scraps, and packaging (Table 1). Efficient use of these resources results in cost savings and reduced pollution.

The first resource category is raw material, the basic component of a manufacturing industry that accounts for a significant fraction of the total production cost. The second resource category is water, an increasingly valuable commodity with significant environmental impacts due to collection, transportation, pre-treatment and post-treatment. The third resource category is chemical agents, which typically require special handling and disposal. The fourth resource category is process scrap, which originates as raw material but losses value during the manufacturing process. The fifth resource category is packaging, which requires a separate set of resources and manufacturing processes. The sixth resource category is equipment that accounts for a significant fraction of total production cost and must be purchased, maintained and disposed of over its life cycle. These resource categories are illustrated in a machining and electro-plating process (Figure 1).

Table 1. Resources Categories and Efficiency Opportunities.

Resource	Efficiency Opportunities
Raw Material	Purchasing ancillary materials, Effective reclaim, etc.
Water	Quality, Treatment, Waste reduction, etc.
Chemical Agent	Solvent reduction, Recovery, Pollution reduction, etc.
Process Scrap	Scrap minimization, Reuse, Efficient disposal, etc.
Packaging	Optimal packaging, Use of reusable packaging, etc.
Equipment	Automation, Upgrade, System monitoring, Design, etc.

Figure 1. Electroplating process using all six resource categories.

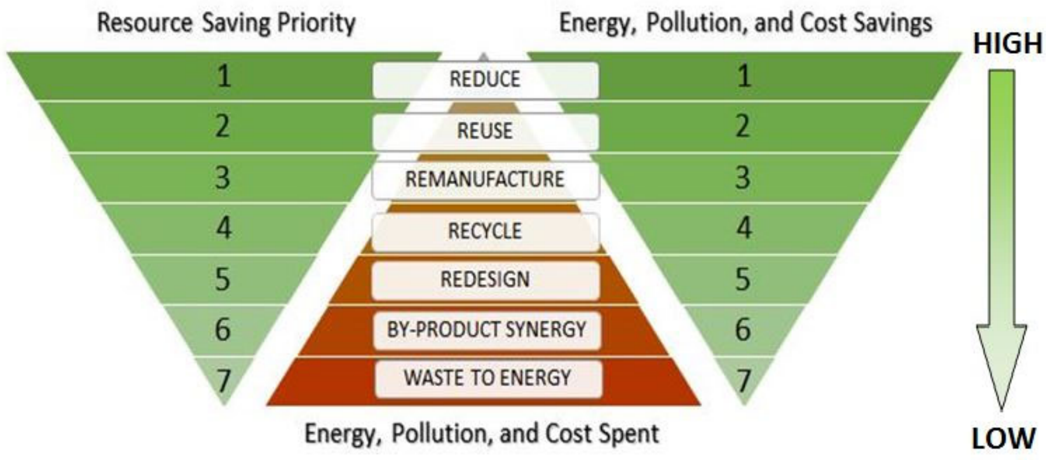


Principles of Resource Efficiency

Seven principles of resource efficiency apply to the six resource categories: reduce, reuse, remanufacture, recycle, redesign, by-product synergy, and waste to energy. These principles are prioritized according to the magnitude of resource saving opportunity. Moreover, the magnitude of resource saving opportunity is also proportional to the energy saving, pollution reduction, and cost saving potential (Figure 2).

For example, "reduce" is prioritized over "reuse" because source reduction eliminates life cycle emissions generated from the extraction of raw materials, transportation to industries, manufacturing of products (Sustainable Ohio, 2010). "Reuse" is prioritized over "remanufacture" since reusing extends resource life and eliminates the need for additional materials, energy, and human effort for remanufacturing. "Remanufacture" has priority over "recycle" since recycling involves more activities such as collecting, shredding, separating, purifying, and shipping recycled materials. As a consequence, recycling entails more financial and environmental burdens than remanufacturing. "Recycle" is prioritized over "redesign" since redesigning each process or whole production system requires significant time and effort (Choi et al., 2013). "Redesign" is prioritized over "by-product synergy (BPS)" because of the time and effort required to locate users for by products. "By-product synergy" is prioritized over "Waste to Energy (WtE)" since resources are completely lost during the energy extraction process. Thus, resource efficiency principles are ranked from the most cost-effective and easy to implement principles to the most demanding to implement in terms of time and effort.

Figure 2: Resources Savings Priority and its Analogy



Integrated Resources plus Principles Matrix

Table 2 illustrates the application of the resource efficiency principles to the resource categories. The Integrated Resource plus Principles Matrix (IRPM) shown below provides a roadmap to increasing industrial resource efficiency. To apply the IRPM, identify specific resources covered by each of the six resource categories. Next, sequentially apply all seven principles to each resource to identify efficiency opportunities. Application of IRPM provides a comprehensive and repeatable method for identifying resource efficiency opportunities.

Table 2. Integrated Resources plus Principles Matrix

Resources/ Principles	Raw materials	Water	Chemical Agents	Process Scrap	Packaging	Equipment
Reduce						
Reuse						
Remanufacture						
Recycle						
Redesign						
By-product synergy						
Waste to energy						

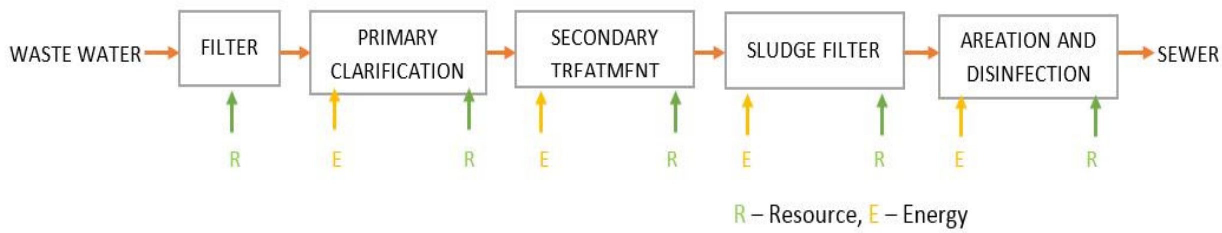
Case Study Examples

Examples of applying resource efficiency principles to the resource categories are discussed below.

Reducing resource waste at source

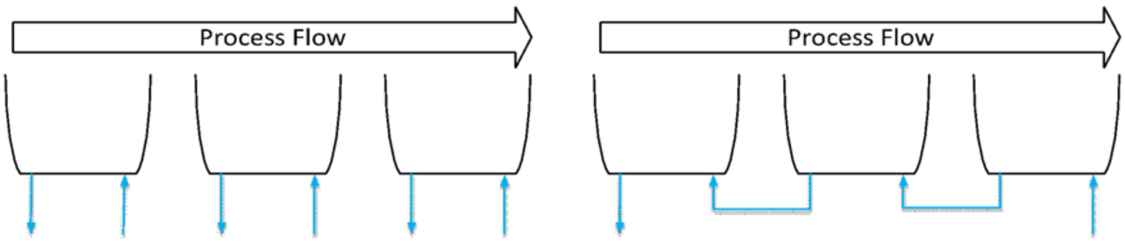
Figure 3 depicts an in-house wastewater treatment process in a manufacturing industry. Reducing waste water at the source would reduce embedded resource and energy consumptions in every process step in Figure 3. This example demonstrates how source reduction saves energy and resources at both in-house and municipal treatment facilities.

Figure 3: Resource and Energy Consumption in an In-House Waste Water Treatment



Another way to reduce energy and resource consumption is to apply the counter-flow concept to the process. Counter-flow processes recycle rinse water from tank to tank in the direction counter to process flow. Counter-flow rinsing uses the cleanest water in the final rinse stage. In the example shown in Figure 4b, counter-flow rinsing would reduce water consumption by a factor of 3.

Figure 4: (a) Single-Flow Rinsing and (b) Counter-Flow Rinsing



(a) (b)

The principle of "reduce" typically provides larger savings at lower implementation costs than other resource efficiency principles. Reducing the generation of waste has ripple effects since it reduces the needs for the secondary treatments and the recovery systems.

Reusing resource

After all "reduce" resource saving opportunities are identified, the "reuse" principle should be considered. Reusing resources eliminates additional storage, transportation, and treatment by transforming wastes into useful form. For example, treated wastewater disposed from a process can be utilized for cooling tower make-up water in place of city water. Reusing the treated water eliminates the need for purchasing city water and for disposing the treated wastewater. Table 3 shows results of annual cost and resource savings achieved from an industrial process by reusing water for a cooling tower. In this case, reusing treated wastewater resulted in $89,940 per year water purchase cost and $131,962 per year in sewer cost savings. With a $100,000 implementation cost, 90% of the wastewater can be reused and the simple payback is six months.

Table 3: Annual Savings Reusing Water

Annual Cost and Savings	Resource	Dollars
Water Usage Savings	9,359 ccf	$ 89,940
Sewer Usage Savings	9,359 ccf	$131,962
Total Savings	-	$221,902
Percentage of Water Savings	-	90%
Implementation Cost	-	$100,000
Simple Payback	-	6 months

Figure 5: Cooling Tower

Remanufacturing

Remanufacturing aims to rebuild and return products to the process. Although remanufacturing of certain products, such as engines and heavy industrial parts, is usually performed by a third party contractor, this principle can also be applied to in-house activities. For example, many industries make extensive use of wooden pellets for storage, packaging, and shipping of final products. Rebuilding broken pellets reduces the costs of purchasing new pellets and disposing the broken pellets.

Recycling

Today, about 95% of solid waste generated worldwide is currently sent to landfills (Bingemer and Crutzen, 1987). In many cases, waste disposal costs constitute a significant portion of total production cost. Packaging waste such as cardboard, shrink wrap, and wooden pallets are commonly disposed. Recycling industrial wastes reduces waste disposal costs and landfill tipping fees while generating additional revenue. Equipment such as a baler and a compactor facilitate efficient transportation of waste to third party recyclers. For example, in a garment manufacturing plant, cardboard waste accounted for 12% of the total waste. Annual costs for cardboard transportation and disposal services were $6,189 and $1,514 respectively. Purchasing a baler to compact the volume of the discarded cardboard, made it possible to recycle the cardboard. Recycling the cardboard prevented 39 tonnes of cardboard from being sent to landfills and resulted in annual transportation and disposal cost savings of $4,609 and $1,158 respectively. With a baler purchase cost of $12,900 and annual baler operation cost of $831, the simple payback was 33 months. Table 4 shows the simplified version of the calculations.

Table 4: Annual Savings – Recycling Baled Cardboard

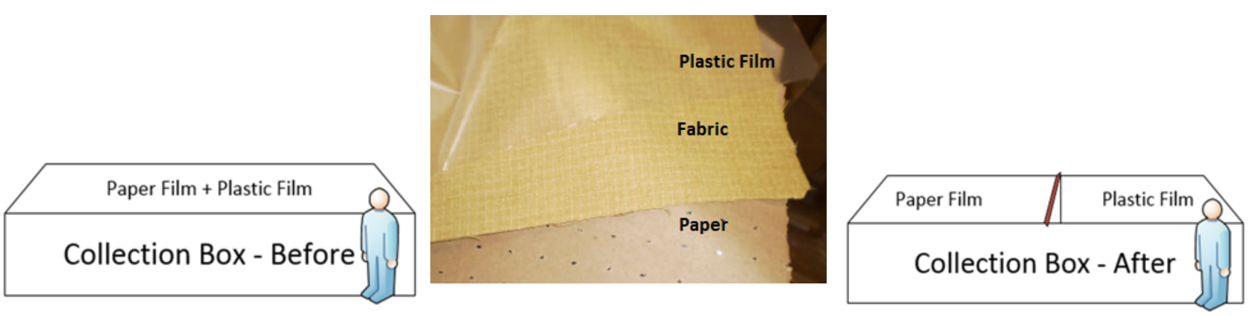
Annual Cost and Savings	Resource	Dollars
Disposal Cost Savings and Transportation Cost Savings	39 tonnes	$2,672
Additional Revenue	-	$3,095
Total Electricity Cost	384 kWh	-$831
Total Savings	-	$4,936
Implementation Cost	-	$12,900
Simple Payback	-	33 months

Figure 6: Baler

Redesign

Redesign is a modification of the production process to improve resource efficiency. For example, consider a laser fabric cutting operation that results in a 10% scrap rate. The operation requires both paper and plastic films for support materials as shown in Figure 7b. After cutting, these support materials are collected in a box and disposed as shown in Figure 7a. Separating the mixed plastic film and paper from the collection box is laborious. Redesigning the process to create a partition in the collection box eliminates mixed scrap so the plastic film and paper can be separately recycled as shown in Figure 7c. Separating and recycling these materials reduces landfill, transportation and disposal costs.

Figure 7: a) Collection Box before Redesign, b) 3 layers of materials, and c) Box after Redesign



(a) (b) (c)

By-product synergy (BPS)

The BPS resource efficiency principle turns one industry's waste into another industry's resource. The practice converts industrial waste into profit by matching waste streams with users. Applied broadly, BPS develops into a network of potential users for waste streams. For example, in Ohio, a BPS network reduced landfill waste by 30,000 tonnes per year and resulted in 230,000 tonnes of CO_2 reduction per year for a $3.5 million per year cost savings (Sustainable Ohio, 2010).

The savings for individual manufacturers are also significant. For example, a manufacturer disposes 12 tonnes of Medium Density Fiber (MDF) every month. MDF is similar to wood saw dust and can be easily pelletized. Pelletizing MDF reduced disposal costs and made it possible to sell the MDF pellets to a customer. In this case, applying the BPS principle generated annual disposal savings and additional revenue of $7,000 and $6,300 respectively. The implementation cost of the pelletizer was $6,000 and the annual operation cost was $185, resulting in a simple payback of 6 months. Table 5 depicts simplified version of calculation.

Table 5: Annual Savings - Pelletizing MDF

Annual Cost and Savings	Resource	Dollars
MDF Disposal Savings	84 tonnes	$7,000
Additional Revenue	-	$6,300
Additional Cost	-	$185
Total Savings	-	$13,115
Implementation Cost	-	$6,000
Simple Payback	-	6 months

Figure 8: MDF Pellets

Waste to Energy (WtE)

Waste-to-energy is the principle of generating electricity and/or heat from the incineration of waste. It encompasses both thermal and non-thermal techniques in converting non-recyclable resources to an energy source (U.S.EPA, 2014). For example, a saw dust burner is a small scale application of the WtE principle. Installing a saw dust burner in the MDF plant in the previous example, eliminates 60 tonnes per year of MDF landfill waste resulting in $5,000 per year in annual cost savings. In addition, it saves $5,914 per year in natural gas expenses. With $40,000 implementation cost, the simple payback is 43 months. Table 6 shows a simplified version of the calculation.

Table 6: Annual Savings – Burning MDF

Annual Cost and Savings	Resource	Dollars
MDF Disposal Savings	60 tonnes	$5,000
Natural Gas Savings	-	$5,914
Total Savings	-	$10,914
Implementation Cost	-	$40,000
Simple Payback	-	43 months

Figure 9: Saw Dust Burner

Resource Efficiency Guidebook (REG)

The IRPM, examples such as those listed above, and spreadsheet calculators have been combined into a tool called the Resource Efficiency Guidebook (REG). The goal of the tool is offer setting a systematic strategy and tool set for effective resource management. REG is a free, publicly-available and regularly-updated Excel based tool. Figure 10 shows the main menu of REG; each icon represents a resource and links to best practices and examples.

Figure 10: Resource Efficiency Guidebook

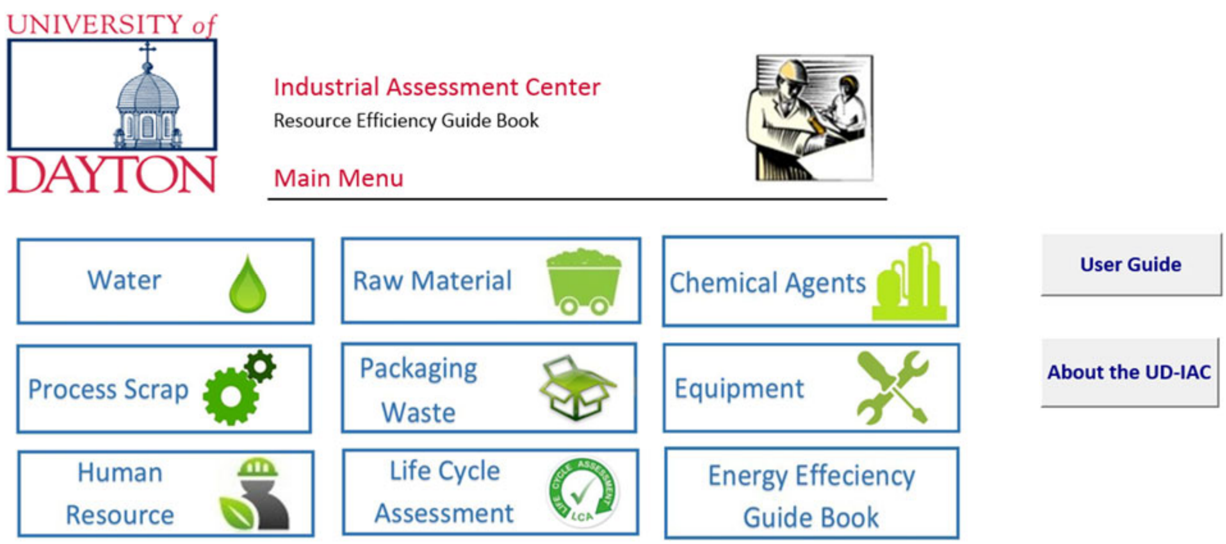
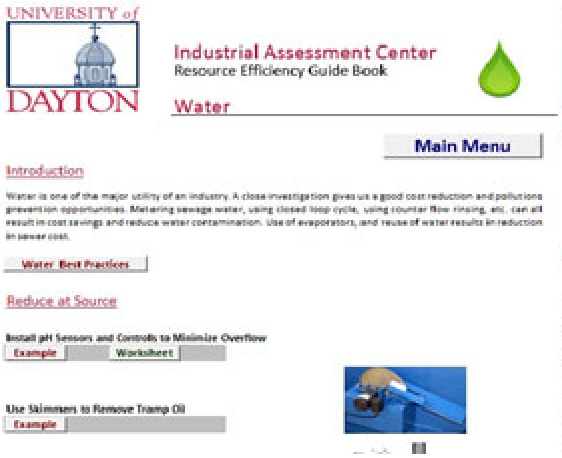
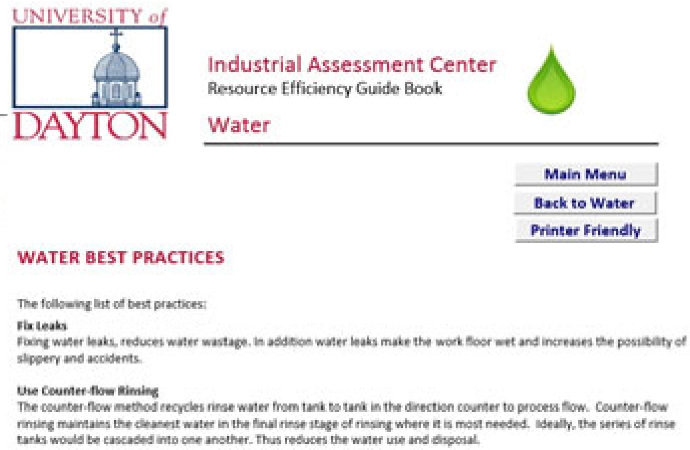


Figure 11a shows the water resource page, which includes example recommendations such as install pH sensor, use skimmer to prevent tramp oil. Figure 11b shows the water best practices page, which includes best practices such as fix leaks and counter-flow rinsing.

Figure 11: (a) Water resource page (b) Water resource best-practice page



(a)



(b)

Streamlined LCA

Each resource category encompasses resource acquisition, transportation, use and disposal phases. For example in the water resource category, pumping water to the plant is the acquisition phase, piping the water to different areas within the plant is the transportation phase, the use of water in a process is the use phase, and the discharge of waste water to the sewer is the disposal phase. Likewise, in the raw material category, metal bars are acquired, transported to the plant, fabricated into products in the use phase, and the metal scraps are disposed to the recyclers. In each stage, energy and materials are consumed and the certain forms of wastes are generated (Kirkeby et al., 2007). Reverse flows of resources occur through activities such as reuse, remanufacturing, and recycling at the end-of-life stages to close material loops as discussed in this paper. Life Cycle Assessment (LCA) provides a holistic view of industrial energy consumption, resource consumption, and environmental emissions. However, perform a complete LCA is often challenging and time consuming. The REG includes a streamlined LCA to capture the impact of resource consumption and product use. The streamlined LCA will perform a tailored life cycle assessment with fixed system boundary, industry specific life cycle inventory (LCI) data, and geographically specific emission data.

Conclusion

This paper discussed the development of an Integrated Resources plus Principles Matrix (IRPM) that offers a comprehensive and systematic way of improving manufacturing resource efficiency. When incorporated into the Resource Efficiency Guidebook (REG), it serves as an effective tool for identifying and quantifying sustainable manufacturing opportunities. Thus far, we have used the IRPM on 22 industrial energy/resource audits and have recommended projects that would result in 1 million dollars per year of savings with an average payback of 6 months. We use future audits to update the REG with new innovative industrial resource efficiency examples.

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References

Baumann, H. and A.M. Tillman, The Hitch Hiker's Guide to LCA-An Orientation in Life Cycle Assessment Methodology and Application. 2004, Lund, Sweden: Student Literature.

Bingemer, H. G and Crutzen, P. J. 1987. "The Production of Methane from Solid Wastes". *Journal of Geophysical Research*, 92, 2182–2187.

Choi, J.-K., and V.M. Fthenakis. 2014. "Crystalline Silicon Photovoltaic Recycling Planning: Macro and Micro Perspectives". *Journal of Cleaner Production 66,* 443-449.

Choi, J.-K., J.K. Kissock, and K. Hallinan. 2013. "Beyond Industrial Energy Assessments: The Life Cycle Design Perspective". In *Proceedings of the ACEEE Summer Study 2013 on Energy Efficiency in Industry*, 4-1 ~ 4-11 Niagara Falls, NY: ACEEE.

Graedel, T.E. and B.R. Allenby, Industrial Ecology. 2 ed. 2003: Prentice-Hall.

Kirkeby, J.T., H. Birgisdottir, G. S. Bhander, M. Hauschild, and T. H. Christensen. 2007 "Modelling of Environmental Impacts of Solid Waste Landfilling within the Life-Cycle Analysis Program EASEWASTE". *Waste Management. 27(7)* 961–970.

Sustainable-Ohio, User Information, 2010; Available from: http://www.sustainable-ohio.org/index.php?option=com_content&view=frontpage&Itemid=10.

Raffio, T., H. Zhang, B. Abels and J.K. Kissock. 2013 "Integrated Systems plus Principles Approach to Industrial Energy Efficiency". In *Proceedings of the ACEEE Summer Study 2013 on Energy Efficiency in Industry*, 1-1 ~ 1-12 Niagara Falls, NY: ACEEE.

UD-IAC (University of Dayton Industrial Assessment Center) last accessed on 2015, "Energy Efficiency Guidebook", https://www.udayton.edu/engineering/centers/industrial_assessment/index.php.

U.S.EPA (U.S. Environmental Protection Agency) 2014, Energy Recovery from Waste: Municipal Solid Waste. Available from: http://www.epa.gov/waste/nonhaz/municipal/wte/.