

Technology Diffusion and Pollution Prevention

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Illinois Sustainable Technology Center

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About this publication

The information in this publication was originally developed as narrative for the Technology Diffusion Topic Hub in 2004. Topic Hubs were web-based guides to peer-reviewed pollution prevention information and expertise on specific subjects. They were developed by centers in the Pollution Prevention Resource Exchange (P2Rx) network, which was funded by U.S. EPA until 2018.

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Background and overview

What is technology diffusion?

Under most circumstances, the success or failure of the widespread adoption of a technology associated with effectively addressing P2 problems is dependent on one or more of the activities summarized below:

- **Technology development** - *For problems that currently do not have satisfactory solutions.* The technical aspects must be developed to a point such that the technology is simple, compatible and rugged enough to be used in real-world applications. Additionally, the technical advantages (economics, materials efficiency, etc.) must be well established. **These activities are performed predominantly by researchers and entrepreneurs.**
- **Technology transfer** - *For solutions that are not readily available on the open market.* The technology must have moved beyond the laboratory testing and demonstration phases. It needs to be marketed to private sector entities willing to commercialize the technology. **These activities are performed primarily by lawyers and business specialists such as venture capitalists.**
- **Technology diffusion** - *For solutions that are commercially available but have not achieved widespread market penetration.* Clients need technology education assistance to create technology awareness and promote understanding of technical principles. Uncertainty issues associated with how to implement the technology must be resolved. This is often accomplished through demonstrations and pilot trials. **These activities are usually performed by sales people, technical assistance providers, and consultants.**

Technology diffusion addresses the broader scope and approach of facilitating change or implementation of technologies that reduce raw material use and waste at industrial facilities, thus achieving pollution prevention (P2). With this approach, change agents combine traditional assistance methods with site-specific information, assistance information, and on-site help with how to implement a particular technology. This includes technology demonstrations and on-site pilot trials. They follow up with evaluations and outcomes, along with recommendations and conclusions about whether the technology achieves the intended goal (reduce waste and save money) for the individual facility.

Prevention is hard to sell

Prevention tends to be difficult to sell because the benefits occur in an unknown distant future and require real behavior change, which reduces comfort and increases complexity. For example, seatbelts were not widely adopted until laws were instituted that required their use, despite the fact that the advantages of seatbelts, in terms of injury prevention, were well documented and publicized.

Additionally, government change agents that actively promote P2 are generally regarded as being very different from or even hostile to the private sector entities they are trying to influence. Businesses do not normally turn to government agencies as sources of innovation.

Three types of knowledge are involved in the decision to adopt or reject an innovation:

- **Awareness knowledge:** Information that an innovation exists
- **How-to knowledge:** Information necessary to use an innovation properly

- **Principles knowledge:** Information dealing with the functioning principles underlying how the innovation works.

Most organizations that are actively trying to promote P2 concentrate on the **awareness knowledge** step, which includes creating fact sheets, case studies, databases, and other information tools, as well as holding workshops and seminars. These methods are generally effective at describing the advantages of various P2 practices and they distribute large amounts of information to many customers at a relatively modest cost.

The change agents that use these methods often become frustrated with their clients for not adopting P2 practices because they believe that awareness information should be adequate to justify adoption. However, they fail to recognize that companies often need assistance with developing sound technical principles and knowledge about how to implement P2 practices. These additional supports are necessary to ensure that the company's uncertainty level about how the practices will work in their specific operation is reduced to a point where adoption will occur.

Additionally, very few regulatory requirements have been instituted that require implementation of P2 practices. Although most potential P2 adopters recognize its value and importance, the choice is still predominantly optional, with little urgency associated with it. Consequently, P2 tends to be pushed aside in favor of more immediate compliance-oriented strategies that are not optional.

An innovation's adoption rate is affected by five basic characteristics:

- **Relative advantage** over the practice that the innovation supersedes
- **Compatibility** with existing values, past experiences, and needs of potential adopters
- **Complexity**, or perceptions regarding how difficult the innovation is to understand and use
- **Observability**, or the degree to which the results of the innovation are visible to others
- **Trialability**, or the degree to which an innovation can be experimented with on a limited basis

P2 innovations tend to have strong relative advantages. However, they are often perceived to be complex and incompatible with existing operations methods. Fortunately, many P2 technologies also exhibit strong observability and trialability characteristics that can be used to effectively address these problems. Technology demonstrations and extended pilot trials can reduce uncertainty associated with the technology's complexity and compatibility.

Existing technical assistance methods for technology diffusion

Most P2 technical assistance providers focus most of their technology-related efforts on education. These practices are great for creating P2 technology awareness and for explaining the technical principles behind the technologies. However, technology education alone does not usually provide the site-specific information required for widespread implementation.

While awareness and understanding are certainly important elements in the decision-making process, clients usually require performance confirmation by opinion leaders before adopting a technology. Using time-tested innovation diffusion principles to promote P2 technology adoption offers motivation to P2 change agents and offers them an approach to acquire additional skills required to improve their effectiveness.

Generally, alternative P2 technologies are applied to manufacturing production and maintenance processes where the opinion of environmental regulators is a motivating change factor. The opinions

of company personnel, trusted vendors, competitors and peers are considered to be most important. Most companies decide whether to adopt or reject an innovation based on a subjective evaluation of the innovation grounded by input from peers who have implemented or at least understand the technology and are perceived to be credible.

The ADOP²T model

Introduction

The Illinois Sustainable Technology Center (ISTC) developed a model for promoting the diffusion of pollution prevention technologies. This model, known as Accelerated Diffusion of Pollution Prevention Technologies, or ADOP²T, is founded on innovation diffusion principles that have been applied to industries as diverse as agriculture and communications. Research conducted on innovation diffusion of P2 technologies has confirmed that these principles apply to P2 as well (Timothy Lindsey, 2000).

How the ADOP²T model works

The process flow diagram in Figure 1 illustrates how the model works. The process begins by working with various stakeholders, including government agencies, trade associations and consultants, to identify the best P2 practices for a particular sector based on its current practices and interests.

Most decisions to adopt or reject an innovation are based on a subjective evaluation of the innovation grounded in input from peers who are perceived to be credible. For this reason, change agents involved in the P2 diffusion effort need to identify industry sector **opinion leaders** that the majority of individual businesses look to for innovation advice.

Some of these opinion leaders can be recruited to serve as **mentors** to companies that have not yet adopted innovative P2 practices. Demonstration sites can be established at the mentor facilities. Technical assistance providers and other stakeholders can then bring individuals from companies that have not yet adopted the best practices to the mentor facilities to view demonstrations of the innovations.

Using opinion leaders to facilitate adoption

Decades of research have shown that innovation diffusion campaigns are more likely to be successful if change agents identify and mobilize opinion leaders. Several states have undertaken P2 diffusion

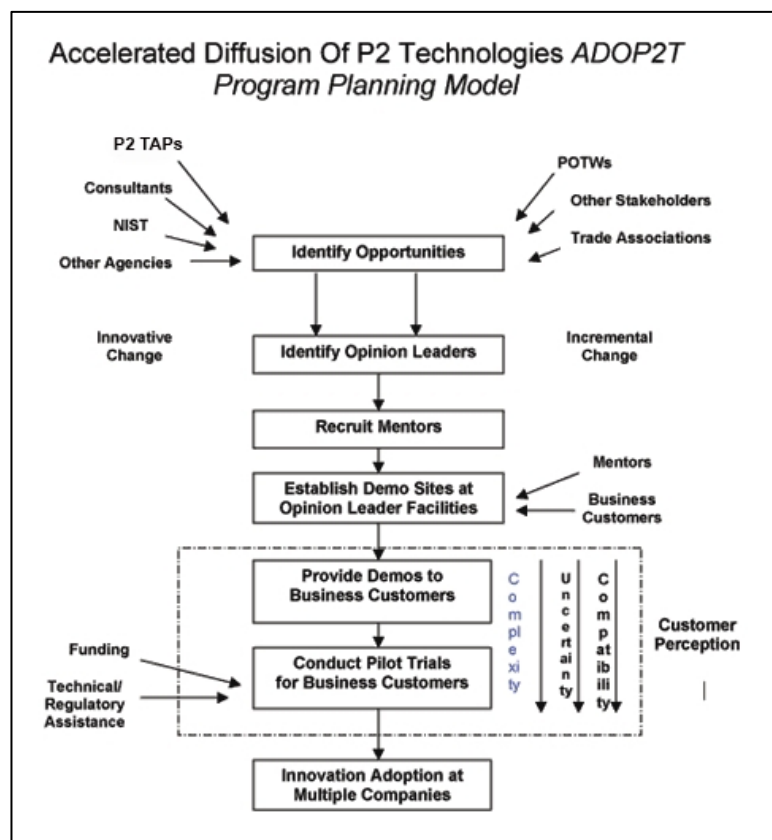


Figure 1: ADOP²T Program Planning Model

sites

campaigns that target opinion leaders (Bartholomew, Lindsey, Sparks, & McKinley, 2008). Some of these projects are described in the State Technology Diffusion Case Studies section of this report.

This approach expedites the overall diffusion process and often reduces the number of clients that change agents need to work with to achieve widespread adoption of alternative practices and technologies that achieve P2. The primary drawback to focusing innovation campaigns on opinion leaders is that it may appear that change agents are providing assistance to organizations that do not appear to need it. Often the organizations that need the innovations the least tend to be the first ones to adopt. Conversely, the organizations that need the assistance the most commonly do not have the resources or the confidence to risk on change, but opinion leaders or the actions of larger entities can motivate them.

Demonstrations and pilot trials

Some companies choose to implement incremental practices based solely on observations of these practices at the mentor facilities. However, **demonstrations and pilot trials** are generally needed in the case of practices that require more extensive process change and/or more sophisticated technology implementation.

Brief (several hours to several days) demonstrations of technologies can help reduce the perceived complexity associated with new technologies and encourage potential adopters to investigate the technology further. However, pilot trials (often lasting several weeks to several months) are frequently required to fully reduce the perceived complexity and resolve site-specific implementation issues. Pilot trials enable the adopters to resolve complexity and compatibility issues and determine if/how they can successfully implement the technology in their specific application. Uncertainty and risk are reduced during the pilot trials to a point where the adopters become comfortable with the anticipated performance, become familiar with how to operate the equipment involved, and proceed with implementation.

Change agents should focus on conducting pilot trials of innovative P2 practices at the facilities of potential adopters with technical and monetary support from the stakeholders. Demonstrations and pilot trials will enable potential adopters to reduce the uncertainty associated with the previously unfamiliar practices. These activities will also help resolve compatibility issues associated with the incorporation of the practices into adopters' existing operations and address the perceived technical complexity of the innovation.

Barriers to implementing and reasons to switch to the ADOP²T model

There are two factors that may prevent technical assistance providers from using the ADOP²T approach to P2 technical assistance.

First, ADOP²T can be labor intensive for technical assistance providers. Many local, state and federal technical assistance programs provide limited services. For example, some technical assistance programs only provide printed and web-based information and telephone and e-mail assistance. Others offer on-site assessments, but may be limited to the amount of assistance they can provide due to manpower restrictions, lack of sufficient change agents working in the field, and/or the depth of knowledge and experience within the organization. In such cases, the technical assistance program

staff should investigate partnerships with other complimentary organizations that can provide additional services within the ADOP²T model.

Second, technology demonstrations and on-site trials require capital investment. Many assistance programs either purchase or lease equipment that the change agents can then take to facilities to perform demonstrations and pilot tests. There are alternative approaches that relieve some of the financial burden placed upon the technical assistance program. For example, the Kentucky Pollution Prevention Center (KPPC) worked with metal finishers by offering to purchase proven P2 technologies for a facility as an applied research project. In return, the metal finisher agreed to reimburse KPPC for the equipment costs if the payback on the technologies occurred within a certain agreed-upon time period (Metcalf, 2004). For a more detailed discussion of this project, see the State Technical Assistance Program Technology Diffusion Case Studies section of this report.

There are several reasons for technical assistance providers to consider using the ADOP²T model. ADOP²T can reduce their uncertainty level with new technologies and processes. Industrial facilities and clients often need assistance with developing sound technical principles and how-to support regarding implementation of P2 practices, in addition to awareness knowledge materials (e.g. fact sheets, case studies).

In addition, few regulations require P2 implementation, which makes the adoption of these technologies voluntary. While many members of industry recognize the value and importance of P2, there is little urgency associated with it. P2 tends to be pushed aside in favor of more immediate compliance-oriented strategies.

Finally, adoption of innovation is traditionally a slow process. The greatest lag time occurs in the early testing and verification stages. Even a successful technology is slow to be adopted until a critical mass of industry opinion leaders has implemented it. At this stage, the technology moves from being innovative and risky to being recognized as standard and accepted. ADOP²T attacks this early stage by creating an industry-driven incubator for demonstration, testing, and adoption of innovative technologies.

Initiating an ADOP²T program

Once a technical assistance program decides to modify its assistance approach, it must identify technologies and processes to learn about and then sell them to industries that would be good candidates for the technology. Below are the steps that organizations can use when starting this process.

- Identify target industries by evaluating the industry demographics (see the Tools for TAPs LibGuide (<http://guides.library.illinois.edu/tools-for-taps>) for relevant data sets).
 - Identify potential P2 technologies that can benefit those industries.
- Identify industry opinion leaders who represent the targeted industrial processes that the technology can benefit.
- Partner with change agents or near-peers (POTW reps, vendors, power utilities, manufacturing extension centers, consultants, chemical management firms and recycling technology services) who can inform the affected industry representatives about these new opportunities and provide credibility to the technology as well as the individuals actually assisting the business with implementation.

- **Note:** Trade organizations and vendors can be an asset, but in some cases they may perceive a P2 technology as a threat and may attempt to influence facilities in their decisions to adopt the technology permanently. This is an obstacle the change agent must be prepared to address. Ideally, individuals can be approached directly to provide process information and to answer any questions or concerns they may have. In reality, there will be some instances where the vendor cannot be convinced and may successfully sway a facility to terminate further interest in a P2 project.
- Form focus groups composed of smaller operations. Local trade or business organizations can be used to form these focus groups.
- Change agents must identify the individual(s) within the organization who are familiar with the processes, are respected among their peers, and are the type of person(s) who can communicate with both the production level and the upper management levels in the organization.
 - Once this individual is identified it is imperative to determine whether or not he or she is willing to champion the suggested change before going forward. Once a candidate for pollution prevention assistance has been identified, the organization and the individuals within the organization must change for the pollution prevention technology to diffuse into the organization.
- Change agents must also identify powerful individuals, preferably with a high office in the organization, such as the company president, owner or division chief at facilities that are receiving assistance. The level of the individual who supports change within the company will significantly impact the adoption of the less polluting technologies.
 - These individuals should be carefully informed about the potential benefits of implementing the pilot study and the final adoption of the technology so that they support and endorse the program. This support needs to be observed by other affected employees who may otherwise permit the project to wither and die.
- Connecting technology developers with end users who are trying to solve real-world problems is often one of the most important aspects of facilitating effective technology diffusion. Accelerated technology diffusion goes beyond technical journal articles, sales ads and conference presentations.
- Results of developmental and applied research can be used to document the principles of the technology. An understanding of the technical principles associated with a technology (how it works, what impacts it will have on waste generation and costs) is necessary for a decision maker to be interested in investigating it further. This information can, in turn, be used to facilitate the development of a demonstration site at a mentor facility.

State technical assistance program technology diffusion case studies

Illinois

Metal finishing

This project was a partnership between a state government agency, the Illinois Sustainable Technology Center (ISTC), a POTW (the Metropolitan Water Reclamation District of Greater Chicago), and the Chicago Metal Finishers Institute (CMFI) (Lindsey, 2013).

Since 2000, ISTC has used the ADOP²T model to substantially improve the diffusion of innovative P2 practices within this sector. ISTC identified opinion leaders within the sector and recruited them to participate in the project as mentors.

Twelve companies volunteered to participate. A wide variety of electroplating and other metal finishing operations were included in this group.

The shops agreed to be mentor facilities to promote the P2 technology to other shops. ISTC convened a focus group to determine their specific pollution prevention technology needs and interests. Attendees identified many technologies and pollution prevention needs. Some needed technology development. Others needed technology transfer/verification before pilot testing was warranted. However, several technologies were identified for pilot testing.

With these mentor facilities, ISTC project engineers developed and executed 51 pilot trials of eleven innovative P2 processes and technologies at the 12 mentor facilities. Results as of July 2003 are shown in Table 1.

In order to match technologies with facilities, project team members conducted P2 assessments of the operations. They visited each shop to determine the variety and extent of its metal finishing and waste management operations.

The shops were also studied to determine their rates of water usage, wastewater treatment practices, cleaning chemical usage, and interest levels regarding participation in specific technology evaluation projects. The results of the assessments were used to develop scopes of work and to identify test sites for pilot trials of innovative technologies.

Printed wiring board

The printed wiring board (PWB) sector in Illinois has come under increasing regulatory scrutiny due to metals in their effluent. P2 technologies show potential to reduce pollutant discharges. Specific P2 and

Technology	Pilots	Implemented	Rejected	Evaluating
Conductivity controls	4	3	0	1
Reverse osmosis	3	0	0	3
Ultrafiltration	15	12	1	2
Bath filtration	2	2	0	0
Barrel design	1	1	0	0
Water reduction	9	8	0	1
Electroless nickel	1	0	0	1
Acid reclamation	3	0	3	0
Evaporation	2	0	2	0
Microbial cleaners	1	0	0	1
Energy efficiency	10	7	0	3
TOTALS	51	33	6	12

best management practices (including water conservation) that can help reduce wastewater discharges and waste generation at PWB sources include:

- minimizing drag-out between process baths
- using countercurrent rinsing
- managing rinses with flow control devices
- extending bath life using advanced filtration technologies
- pre-treating spent baths
- controlling bath makeup

Unfortunately, P2 continues to diffuse relatively slowly across the PWB sector due to concerns about potential negative impacts on product quality. Typically there is little question that the candidate technologies will reduce process waste and save money. But issues of compatibility and complexity (how they fit into the overall production process) are of great enough concern that the technologies are not adopted.

In cooperation with the Chicagoland Circuit Board Association (CCBA), ISTC began testing the ADOP²T model within the Illinois PWB sector. They held meetings with opinion leaders in the PWB industry to identify P2 opportunities. ISTC and CCBA project engineers carried out several demonstration and pilot trial projects of innovative P2 processes and technologies in various mentor shops.

As of 2003, ISTC worked with three POTWs to provide technical assistance to the PWB facilities identified as having problems with their discharge. The project team assisted twelve PWB facilities. This included conducting assessments of their operations to determine the extent of their pollution prevention and waste management practices and their rates of water usage, cleaning chemical usage, and interest levels regarding participation in specific technology evaluation projects.

In 2003, the team initiated two reverse osmosis projects to recycle wastewater and two conductivity control projects to reduce water usage. They also evaluated an ultrafiltration project to recycle rinse water.

Kentucky

In 2001, the Kentucky Pollution Prevention Center (KPPC) initiated a technology diffusion project based on ISTC's successful ADOP²T model (Metcalf, 2004). KPPC technical staff visited the ISTC facility to view firsthand how the model was developed and operates. KPPC's program, called the Kentucky Metal Finishing Initiative (KMFI), targeted the metal finishing sector. The concept was simple. KPPC offered to purchase proven P2 technologies for a facility as an applied research project. The metal finisher, in return, would agree to reimburse KPPC for these costs if the payback was within a certain agreed-upon time period.

To promote the initiative, KPPC (serving in the role as a stakeholder) met with the American Electroplaters and Surface Finishers (AESF) Bluegrass Chapter, the state trade association for the metal finishing industry. To further promote KMFI, KPPC offered two one-day workshops on "Pollution Prevention for Metal Finishers" in Bowling Green and Lexington, Kentucky.

KPPC's marketing efforts eventually attracted seven Kentucky metal finishers interested in KMFI. Of these, one facility agreed to participate in the program. KPPC technical personnel conducted a P2 assessment at the facility and identified P2 opportunities and cost savings. KPPC subsequently developed a proposal to purchase a totalizer and three conductivity meters for one of the automated

plating lines. An agreement was reached whereby the facility reimbursed KPPC for the equipment costs (total of \$4,835) if payback was achieved within 12 months.

In four months, the facility saved \$6,112, including \$4,495 in reduced water and sewer charges (487,744 gallons/year) and \$1,617 in reduced wastewater treatment chemical usage (996 gallons/year). In addition to the water, sewer and chemical savings, the metal finisher experienced other benefits including:

- No quality concerns related to the changes in the rinsing stages and no decrease in work volume.
- The facility maintains a sand filter for wastewater polishing. This filter requires periodic back flushing for cleaning daily. Back flushing has been reduced by 60% due to lower water usage; labor and process efficiency savings have also been recognized.
- Plant water pressure increased which provides more consistency in water flow to other plating lines.

The results of this project illustrate that issues of compatibility and complexity were critical to successful adoption. In this case, companies were first approached with some technologies for consideration.

Reasons why more companies did not participate need to be determined. One factor may be that the technologies proposed were not the ones of greatest interest to these companies. In some cases the company may rent or purchase the technologies from a vendor. One or more vendors (e.g., equipment and chemical suppliers) may need to actively participate.

Minnesota

In 2003, the Minnesota Technical Assistance Program (MnTAP) initiated the early stages of the technology diffusion process in two industry areas: fiberglass reinforced plastics (FRP) and painting/coating (McComas & Cook, 2004).

The success of this FRP Demo Days and previous Paint Expos prompted MnTAP to begin plans for a 5th Annual Paint and Powder Coating Expo in September 2002.

Pollution prevention technologies had been identified the previous year at the Coating 2001 Conference, and included quick color change powder, electrostatic liquid spray, and UV curing. MnTAP was active on the board of the Minnesota Chapter of the Chemical Coaters Association International (CCAI). They used that group (comprised of vendors and applicators) as the opinion leader group.

While planning for the Paint Expo, vendors and companies were recruited as mentors. Since there were no installations in Minnesota of the three to four technologies, MnTAP believed a Paint Expo where vendors could demonstrate the technologies would be the best way to reach the greatest number of people.

The Paint Expo was held October 2002, with 400 attendees, vendors and speakers. The Expo featured 50 exhibits/demos and 15 technical seminars. MNTAP continues to work with mentor companies and vendors to provide demonstrations to business customers and conduct pilots at companies, toward eventual adoption of the technology.

Table 2: MnTAP Technology Diffusion Work Conducted		
ADOP²T Model Step	Painting and Coating Sector	Fiberglass Fiber Reinforced Plastics Sector
Identify P2 technologies and best practices	Quick color change powder, Electrostatic liquid spray (coating conference / staff knowledge)	Closed mold, non-atomized spray (FRP Conference / staff knowledge)
Identify opinion leaders	Chemical Coaters Association (CCA)	Vendors / Composite Fabricators Association (CFA)
Recruit members	Vendors and companies	Vendors & Phoenix / Consultant
Establish demonstration sites	Paint and Powder Coatings Expo	FRP Demo Days
Provide demos to business customers		
Conduct pilots at companies		
Technology adoption		

Regional technology diffusion efforts

Illinois, Minnesota, and Kentucky collaborated on a multi-state technology diffusion initiative funded by the US Environmental Protection Agency from January 2004 through December 2005. Results of the project were reported in the *Journal of Cleaner Production*. Below is a summary of the findings from the article.

The three state programs involved in this project are generally pleased with the process and results obtained, but some difficulties were encountered during the process. In limited cases, companies in the targeted sector did not feel comfortable sharing information with competitors. At focus group meetings, narrowing down broad categories of solutions into actionable technologies or solutions was sometimes difficult. Another challenge was identifying technologies that are likely to diffuse well in a sector. Another difficulty encountered during some focus group meetings was the decision-making authority of the attendees. In smaller companies, owners or top managers were in attendance making recruiting of mentors easier. Larger companies would often send technical personnel or lower level managers who did not have the authority to open their facilities to demonstrations. Identifying and targeting people with decision-making authority appears to be a critical part of the process.

Three key objectives were accomplished in this multi-state initiative. First, participating state programs built expertise in key technologies for critical industrial sectors. Second, the participating state programs established partnerships within industry, and with each other, to share capabilities and resources. Third, decision-makers at the federal level obtained information needed to develop a comprehensive national pollution prevention technology diffusion system.

The ADOP²T model has proven to be a useful way to improve the rate of implementation for pollution prevention technologies.

(Bartholomew et al., 2008).

Definitions

Accelerated Diffusion of Pollution Prevention Technologies (ADOP²T)	A model for technology diffusion developed by the Illinois Sustainable Technology Center (ISTC).
Awareness knowledge	Information that an innovation exists.
Change agent	Individuals who assist companies with pollution prevention, environmental compliance and manufacturing assistance. This may include technical assistance providers from university programs, state pollution prevention agencies, NIST manufacturing extension agents, consultants, and vendors.
Complexity	Perceptions about how difficult an innovation is to understand and use.
How-to knowledge	Information necessary to use an innovation properly.
Observability	The degree to which an innovation can be experimented with on a limited basis.
Pollution prevention (P2) benefits	The amount of pollution avoided from the generation of regulated and non-regulated waste, adoption of alternative materials that are less polluting, minimization of raw materials used or consumed in a process, including water. Also includes reduction of energy use and labor inputs.
Principles knowledge	Information dealing with the functioning principles underlying how an innovation works.
Stakeholder	A company or organization that may benefit from assistance to implement P2 technologies.
Technology development	The process of creating technological solutions to problems that currently do not have satisfactory solutions. The technical aspects must be developed so that the technology is simple, compatible and rugged enough to be used in real-world applications. Additionally, the technical advantages (economics, materials efficiency, etc.) must be well established. These activities are performed predominantly by researchers and entrepreneurs.
Technology diffusion	The process of facilitating change or implementation of technologies/solutions that are commercially available, but have not yet achieved widespread market penetration.
Technology transfer	The process of getting new technologies/solutions to be readily available on the open market.

Works cited

Bartholomew, K. M., Lindsey, T. C., Sparks, J. O., & McKinley, D. (2008). Multi-state initiative to enhance pollution prevention technology diffusion using the ADOP2T model. *Journal of Cleaner Production*, 16(6), 686–692. <https://doi.org/10.1016/j.jclepro.2007.02.019>

Lindsey, Tim. (2013). *ADOP²T for the Metal Finishing Industry*. Champaign, IL: Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/2008>

Lindsey, Timothy. (2000). Key Factors for Promoting Pollution Prevention Technology Adoption. *Pollution Prevention Review*, 10(1), 1–12.

McComas, C. A., & Cook, R. J. (2004). Pollution prevention technology diffusion in Minnesota: Fiber reinforced plastics and coating industries. *Proceedings of the Air and Waste Management Association's Annual Meeting and Exhibition*, 4615–4624.

Metcalf, C. (2004). Pollution prevention Technology Diffusion Initiative (TDI) for Kentucky. *Proceedings of the Air and Waste Management Association's Annual Meeting and Exhibition*, 4603–4613.

Annotated bibliography

This section includes journal articles, books, reports, and case studies related to diffusion of pollution prevention technologies.

Journal articles

Andersen, S. O., Corona, J., & Mosler, C. (2000). Case study 17: CFC (ODS) solvent phaseout in Mexican electronic industries. *Methodological and Technological Issues in Technology Transfer*, 415–416.

This industrial sector case study exemplifies the Mexican government's leadership and technology cooperation by multinational companies to set in place the technology know-how and information necessary to rapidly eliminate CFC solvents used in the Mexican electronic manufacturing industry. The CFCs were phased out under the Montreal Protocol by using HFCs, which are regulated under the Kyoto Protocol. HFCs have much lower GWP as compared to CFCs. The lesson learned from this technology transfer may be useful for similar transfer under the Climate Change Convention.

Axsen, J., & Kurani, K. S. (2014). Social influence and proenvironmental behavior: The reflexive layers of influence framework. *Environment and Planning B: Planning and Design*, 41(5), 847–862. <https://doi.org/10.1068/b38101>

Social influence can be an important factor in the adoption of pro-environmental behaviors and technologies. Processes of social influence can be varied and complex yet are often represented or discussed in a simplified, aggregated manner. To facilitate more nuanced study of social influence, we draw from a literature review and empirical observation to propose a conceptual behavioral framework that integrates three processes of interpersonal influence; we call this the reflexive layers of influence (RLI) framework. RLI proposes three generally successive and iterative 'layers' of the consumer's relation to a new technology (or practice): awareness, assessment, and alignment with self-concept. These layers are antecedents to, and potentially consequences of, adoption and use of proenvironmental technology. Social influence follows different processes at each layer. Awareness is influenced by the diffusion of simple, functional information. The consumer forms an assessment, at least in part, through translating the technology's attributes into specific benefits (or disbenefits). Through reflexivity, the translated assessment of the technology is framed in terms of maintaining, developing, or altering self-concept according to perceptions of others' behaviors and values. We illustrate RLI through application to three case studies of households participating in a multiweek trial of a plugin hybrid electric vehicle—demonstrating that the consumer's self-concept, perceptions, and behavior can change substantially according to the social processes represented by RLI. We conclude with policy implications and discuss future hypotheses and priorities for research

Bartholomew, K. M., Lindsey, T. C., Sparks, J. O., & McKinley, D. (2008). Multi-state initiative to enhance pollution prevention technology diffusion using the ADOP²T model. *Journal of Cleaner Production*, 16(6), 686–692. <https://doi.org/10.1016/j.jclepro.2007.02.019>

Accelerated Diffusion of Pollution Prevention Technologies (ADOP²T) is a stepwise model designed to improve the implementation rate of pollution prevention technologies. It focuses on reducing the uncertainty associated with new technologies by providing demonstrations and "how-to" knowledge through pilot testing. Three university-based technical assistance programs collaborated to promote implementation of pollution prevention technologies using the ADOP²T model. This paper briefly

describes the model, and discusses the experiences, observations, and results obtained by the technical assistance programs that used the model

Benn, S., Teo, S. T., & Martin, A. (2015). Employee participation and engagement in working for the environment. *Personnel Review*, 44(4), 492–510. <https://doi.org/10.1108/PR-10-2013-0179>

Purpose – The purpose of this paper is to explore the role of specific human resource management (HRM) practices in the implementation of environmental initiatives in terms of their impact on employee attitudes to the organization and to its environmental programme.

Design/methodology/approach – The study used a mixed method approach comprising a survey of 675 employees and 16 semi-structured interviews undertaken across two organizations. Findings – Survey data, analysed using path analysis, showed that participation in environmental initiatives is directly associated with higher levels of employee engagement with the organization, higher rating of their organization’s environmental performance, and lower intention to quit. The qualitative study supports the quantitative data, also highlighting other aspects of environmental initiatives that may affect employee attitudes. Research limitations/implications – Future study should either collect longitudinal data or rely on data collected from two waves of data collection. Objective performance data should also be collected in order to better understand the causal effect of HRM on environmental performance. Practical implications – Our findings have implications for the business case for sustainability, providing some evidence that implementing environmental initiatives with HRM support may not only motivate staff around environmental programmes but may provide wider benefits for organizations in terms of overall job satisfaction and employee retention. Social implications – Successful implementation of environmental management initiatives have both organizational and employee level outcomes. Employees who were more aligned with their organizational environmental objectives were found to be more engaged and less likely to quit. Originality/value – This study provided both quantitative and qualitative empirical evidence to support the importance of integrating the HRM function into the implementation of environmental initiatives.

Bierma, T.J., & Waterstraat, F. L. (1999). Cleaner production from chemical suppliers: Understanding shared savings contracts. *Journal of Cleaner Production*, 7(2), 145–158.

The “chemical chaos” experienced by many companies today can be linked, in part, to chemical supply strategies that have not kept pace with changes in the business environment. The traditional chemical supply relationship has incentives that promote waste and expand the “hidden” cost of chemicals. “Shared Savings”, an innovative alternative to traditional chemical supply relationships, has proved effective in reducing both waste and the overall costs of chemical use. Supplier revenue is linked to chemical performance, rather than chemical supply, harnessing the resources of the supplier to ensure and improve chemical performance. Five manufacturing plants, with over 35 years of combined experience with Shared Savings, are profiled.

Bierma, T.J., & Waterstraat, F. L. (2006). “Standards” as a service marketing tool: Framework and application. *Services Marketing Quarterly*, 27(4), 49–72. https://doi.org/10.1300/J396v27n04_04

Standards have the potential to be a significant tool in the marketing of services, just as they have been in the marketing of products. Ranging from regulatory to voluntary, product-based to producer-based, standards can increase the competitive position of a product by reducing customer uncertainty. However, the lack of a framework for understanding and designing standards has limited their application in service industries. Examination of existing standards suggests a framework of five key dimensions. Through the example of chemical management services (CMS) we show how this can be

done, resulting in three options for the CMS industry. Using this framework as a guide, other service industries can determine if a standard would provide significant competitive advantage and, if so, design the optimal standard for their market conditions.

Bierma, T.J., & Waterstraat, F. L. (2008). Marketing P2-CP to business—Past, present, and possible future. *Journal of Cleaner Production*, 16(6), 693–703. <https://doi.org/10.1016/j.jclepro.2007.02.020>

For over a decade, organizations involved in promoting pollution prevention/cleaner production (P2-CP) to businesses have been asking business managers to change the way they think. But perhaps the greatest adoption of P2-CP will occur when organizations take advantage of the way business managers already think, using strategies of business-to-business (B2B) marketing. In this paper, we trace the evolution of P2-CP promotion from an Educational Strategy, through a Diffusion Strategy, and finally to the B2B Strategy. We argue that P2-CP adoption can be significantly increased if organizations apply the techniques of companies that make their living from selling innovations to businesses and use the B2B markets to bring P2-CP innovations to businesses.

Bierma, T.J., Waterstraat, F. L., Kimmel, G., & Nowak Jr., P. (1997). If it sells soap it can help sell innovations: A useful lesson from marketing. *Journal of Extension*, 35(5), 24–33.

Promoting innovations is an act of marketing. Carefully conceived marketing plans can greatly enhance success. Understanding that different market segments have different product and information needs is a basic concept in commercial marketing. “Innovativeness” and “Stage in the adoption process” are two useful ways of segmenting a market. The Innovativeness-Stages Matrix, combined with an understanding of the different needs of market segments, provides a powerful tool for focusing marketing efforts without extensive marketing research or resources.

Blackman, A. (1997). *The Economics of Technology Diffusion: Implications for Greenhouse Gas Mitigation in Developing Countries* (No. RFF Climate Issues Brief #5). Washington, DC : Resources for the Future. <https://media.rff.org/documents/RFF-CCIB-05.pdf>

In this paper Alan Blackman reviews the current state of knowledge on diffusion of new technologies. He describes seven types of policy options that are available to influence the speed of climate-friendly technology diffusion in developing countries.

Cetindamar, D. (2003). The diffusion of environmental technologies: The case of the Turkish fertiliser industry. *International Journal of Technology Management*, 26(1), 68–87. <https://doi.org/10.1504/IJTM.2003.003145>

This paper aims to analyse the diffusion of environmental technologies. By studying the Turkish fertiliser industry as a case, we exemplify how a system is built around environmental technology applications and what factors are active in its diffusion. Our results show that regulations and public pressures are the main determinants in the diffusion of environmental technologies, indicating the importance of the institutional infrastructure, namely the interplay among firms, governmental and non-governmental organisations.

Chudnovsky, D., & Lopez, A. (2003). Diffusion of environmentally friendly technologies by multinational corporations in developing countries. *International Journal of Technology Management & Sustainable Development*, 2(1), 5–18. <https://doi.org/10.1386/ijtm.2.1.5/0>

Multinational corporations (MNCs) can be an important source of environmentally friendly technologies for developing countries since their affiliates are often more advanced than local firms in

the adoption of modern environmental technologies and management practices. This does not mean, however, that MNC affiliates in developing countries invariably employ the same standards, technologies and management approaches adopted by their parent companies or by affiliates operating in developed countries. The contribution of MNC affiliates to sustainable development depends on the quality of their operation and the characteristics of the host countries where they operate. The former is conditioned by such factors as the nature of the sectors where MNCs direct their investments, the kind of assets brought by MNCs, and the role played by the affiliates within the MNC global network. The latter is mainly about the availability of skills, the state of domestic technological infrastructure, the competitiveness of local suppliers, the nature of national environmental regulations and the extent to which these regulations are enforced. We note the need for more robust empirical studies on the environmental role of MNCs to guide policy aimed at enhancing the effectiveness of foreign direct investment (FDI) initiatives in promoting sustainable development.

Comin, D., & Hobijn. (2008). *An Exploration of Technology Diffusion* (No. HBS Working Paper 08-093). Cambridge, MA : Harvard Business School. <http://www.hbs.edu/research/pdf/08-093.pdf>

How long are technology adoption lags? Can cross-country differences in technology adoption lags account for a significant fraction of cross-country GDP disparities? Diego Comin of Harvard Business School and Bart Hobijn of the Federal Reserve Bank of New York develop a new benchmark to understand the diffusion process of individual technologies and the consequences that this has for aggregate growth.

Cordano, M., Marshall, R. S., & Silverman, M. (2010). How do small and medium enterprises Go “Green”? A study of environmental management programs in the U.S. wine industry. *Journal of Business Ethics*, 92(3), 463–478. <https://doi.org/10.1007/s10551-009-0168-z>

In industries populated by small and medium enterprises, managers’ good intentions frequently incur barriers to superior environmental performance (Tilley, Bus Strategy Environ 8:238-248, 1999). During the period when the U. S. wine industry was beginning to promote voluntary adoption of sound environmental practices, we examined managers’ attitudes, norms, and perceptions of stakeholder pressures to assess their intentions to implement environmental management programs (EMP). We found that managers within the simple structures of these small and medium firms are responsive to attitudes, norms, and pressures from internal stakeholders and that voluntarily established EMP increased the success of firms’ implementation of energy conservation and recycling practices. Applications of our findings to future research on small and medium enterprises as well as direct practical applications of our results are discussed.

del Río González, P. (2005). Analysing the factors influencing clean technology adoption: A study of the Spanish pulp and paper industry. *Business Strategy and the Environment*, 14(1), 20–37. <https://doi.org/10.1002/bse.426>

Technological change has a relevant role to play in the transition towards a sustainable industry. However, slow diffusion of clean technologies can be observed in OECD countries. The analysis of the determinants and barriers to clean technology adoption should be a main goal of economists and social scientists. This paper shows that three sets of interrelated factors prevent but also stimulate the widespread adoption and diffusion of clean technology: these are factors external and internal to the firm, conditions of the potential adopters and characteristics of the environmental technology. These factors are included in the so-called “triangular model”, which is further applied to the analysis of clean

technology adoption in the pulp and paper industry in Spain. The empirical study shows that clean technology adoption decisions are the result of an interaction between these factors, often involving contradictory signals for the potential adopter. The paper closes with some public policy recommendations for the effective and efficient promotion of clean technology diffusion.

Dhanorkar, S. S., Siemsen, E., & Linderman, K. W. (2018). Promoting change from the outside: Directing managerial attention in the implementation of environmental improvements. *Management Science*, 64(6), 2535–2556. <https://doi.org/10.1287/mnsc.2017.2748>

Regulatory agencies, auditing firms, and supply chain partners externally promote change in firms. To this end, they commonly employ two different and somewhat contradictory intervention approaches. One approach uses punitive tactics to coerce firms to change, while the other approach uses supportive tactics to encourage change. Using the context of government agencies promoting environmental improvements in firms, we examine whether such punitive (e.g., regulatory inspections with possible sanctions) and supportive (e.g., environmental assistance, improvement recommendations) tactics can be administered in a complementary manner. Using a unique and novel longitudinal data set collected from two state-level environmental agencies in Minnesota, we analyze over 1,000 supportive environmental improvement (EI) projects in combination with intermittent (but currently uncoordinated) punitive tactics. One key finding from our research is that the timing, severity, and relatedness of punitive tactics is critical for directing managerial attention and thus improving the efficacy of supportive tactics (i.e., EI implementation). Contingent on their timing, inspections can increase EI implementation rates by up to 60% but can also reduce implementation rates by up to 50% compared with EIs in facilities that do not experience inspections. Classifying regulatory inspections as (1) either clean or adverse and (2) either related or unrelated allows us to further explain the influence of such punitive tactics on EI implementation. Finally, we provide evidence for a positive effect of successful EI implementation on long-term environmental compliance.

Dupuy, D. (1997). Technological change and environmental policy: The diffusion of environmental technology. *Growth and Change*, 28(1), 49–66. <https://doi.org/10.1111/j.1468-2257.1997.tb00916.x>

As concern for environmental protection is growing within all sectors of society, industrial firms are being forced to become more accountable for their actions. Government policies, in the form of environmental standards, have been designed to reduce the level of toxic pollutants being discharged by firms. In order to comply with these standards, firms must either change the nature of their production processes or employ technologies that reduce the level of effluent being discharged. This paper investigates the role of environmental policy in driving firms to adopt pollution control technologies. The policy addressed is the Province of Ontario's Municipal Industrial Strategy for Abatement (MISA) which seeks to compel firms to reduce discharges of industrial effluent through the application of the "Best Available Technology Economically Achievable." The impact of this policy instrument on the adoption of pollution control technology in the Ontario organic chemical industry is examined. The analysis is based on interviews with firms in the chemical industry which reveal that environmental policy has played a central role in inducing firms to adopt pollution control technologies. The paper draws on literature about technology diffusion, especially the relationship between suppliers and users of technology, and examines the process through which environmental technology is transferred to regulated firms. The relationship between the suppliers and users of technology is strong, especially between the large multinational users and smaller independent domestic technology suppliers.

Fadly, D., & Fontes, F. (2019). Geographical proximity and renewable energy diffusion: An empirical approach. *Energy Policy*, 129, 422–435. <https://doi.org/10.1016/j.enpol.2019.02.034>

In an era where achieving both economic growth and environmental sustainability is paramount, the role of technology diffusion remains an important one. Recent literature explores the link between geographical proximity and the adoption and diffusion of climate change adaptation policies. However, it has generally focused on a restricted set of developed countries and focused on the diffusion of policy instrument rather than the outcome of the policies. In this paper, we argue that domestic intensity of adoption of renewable energy technologies is likely to be affected by the adoption pattern in neighbouring countries. Additionally, this effect is likely to be stronger when important trade partners are intensive adopters of renewable energies. To test these hypotheses, we construct an index that captures a distance-weighted measure of intensity of renewable energies in other countries and apply a fixed effects framework to a panel of up to 116 countries over the (1980–2012) period. Our results confirm the existence of a geographic spill-over effect on the intensity of adoption of renewable energy technologies. Moreover, this effect is stronger when intensive adopters of renewable energies are also important trading partners, highlighting the relevance of trade channel as a potential catalyst of the diffusion of renewable energies across countries.

Garay, L., Font, X., & Pereira-Moliner, J. (2017). Understanding sustainability behaviour: The relationship between information acquisition, proactivity and performance. *Tourism Management*, 60, 418–429. <https://doi.org/10.1016/j.tourman.2016.12.017>

We use the concept of absorptive capacity to better understand the relationship between sustainability information acquisition, proactivity and performance. A quantitative analysis of a survey of 408 tourism enterprises in Catalonia (Spain) shows that: i) growth-oriented motivations are related to communication with industry-related sources, and to individual and informal channels, while lifestyle motivations are related to communication with other stakeholders; ii) sustainability implementation is related to communication with other stakeholders, to the use of collective and formal channels, and to the perceived usefulness of information; and iii) sustainability performance is related to the introduction of environmental and economic practices, to the use of both industry and broader sources of information, and to the perceived usefulness of information. We suggest that sustainability training and education may be more successful in achieving behaviour change when they are adapted to the absorptive capacity and learning styles of their target audiences.

Girod, B., Mayer, S., & Nägele, F. (2017). Economic versus belief-based models: Shedding light on the adoption of novel green technologies. *Energy Policy*, 101, 415–426. <https://doi.org/10.1016/j.enpol.2016.09.065>

Understanding the determinants for the adoption of novel green consumer technologies is important to effectively foster their diffusion. Energy and environmental science literature often takes an approach based on economic variables such as objectively measurable household and technology characteristics. Increasingly, also subjective variables based on personal belief are considered. On the basis of a survey about the intention to adopt an exemplary novel green consumer technology (intelligent thermostats), we contribute to the clarification of the explanatory power of these two approaches. We first compare the economic model to the belief-based model and second, investigate how beliefs about the green technology are influenced by personal environmental norms and innovativeness. Our evaluation shows that the belief-based model explains considerably higher variance in the intention to adopt. Thereby the perceived hedonic satisfaction, usefulness, habit and

facilitating conditions reveal as key determinants. Moreover, environmental norms show lower impact than personal innovativeness. In the discussion we consolidate these findings and point to the risk of omitted variable bias when selectively including belief-based variables in adoption models. Our findings suggest that policies can effectively accelerate the early market diffusion of green consumer technologies by incentivizing retailers to introduce and market such technologies.

Howarth, R., & Fredericks, J. (2012). Sustainable SME practice: A reflection on supply-chain environmental management intervention. *Management of Environmental Quality: An International Journal*, 23(6), 673–685. <https://doi.org/10.1108/14777831211262945>

Purpose: This article aims to consider different interpretation(s) of small to medium-sized enterprise (SME)-environment behaviour and the potential implications for intervention and change in theory and practice. **Design/methodology/approach:** The article is primarily a reflection on a supply-chain environmental management project and the specific and wider SME literature(s). **Findings:** The proposal is that if/when embracing the internal SME dimension and sense-making processes it is possible to conceive/describe a landscape of SME-environment intervention and change. Recognition of this landscape is of use to interventionists involved with the facilitation of change(s) and may support improvements in the quality of outcome(s). **Research limitations/implications:** The implication of the work is that there is a need to more effectively and appropriately consider the internal SME dimension and sense-making processes when investigating and describing SME-environment behaviour and interventions based on such descriptions. **Practical implications:** The work will be of interest to interventionists, those who sponsor their work or develop policy and intervention(s) in this area. **Originality/value:** This article identifies some of the impacts and implications for change that lead from the consideration of the internal SME dimension and related sense-making processes; a dimension surfaced in the case project work but not fully engaged in that work or the SME-environment and related literature.

Intarakumnerd, P., & Goto, A. (2016). *Technology and Innovation Policies for Small and Medium-Sized Enterprises in East Asia* (No. ADBI Working Paper No. 578). Tokyo : University of Tokyo. <https://www.ssrn.com/abstract=2812432>

Policies for stimulating technological development and innovation in small and medium-sized enterprises can be divided into three groups. Supply-side policies aim at increasing firms' incentives to invest in innovation by reducing costs. Demand-side policies are public actions to induce innovation and/or speed up the diffusion of innovation. Systemic policies focus on strengthening interactive learning between actors in innovation systems. Policies can be implemented through various instruments comprising tax incentives, grants or direct subsidies, low-interest loans, and the government's direct equity participation. These instruments have pros and cons. The experiences of four late-industrializing East Asian economies — Taipei, China; Singapore; Malaysia; and Thailand — provide key lessons. Firms at different levels of technological and innovative capability need different policy instruments. The more successful economies have a higher level of flexibility and policy coordination and learning. The amount, duration, and continuity of government supporting schemes are crucial. Policy makers must have a deep understanding of what constitutes innovations and innovation systems, and how they evolve over time. Innovation financing policies require other corresponding policy initiatives to make them successful. Lastly, institutional factors do shape the choices and effective implementation of these policies.

Islam, M. S., Tseng, M.-L., & Karia, N. (2019). Assessment of corporate culture in sustainability performance using a hierarchical framework and interdependence relations. *Journal of Cleaner Production*, 217, 676–690. <https://doi.org/10.1016/j.jclepro.2019.01.259>

There is a gap in the extant literature on what corporate cultural attributes drives toward corporate sustainability performance. This study investigates corporate culture attributes that are conducive for sustainability and forms these attributes as a measurement tool for assessing corporate sustainability performance using linguistic preferences. Most of the prior assessment frameworks use composite attributes which cannot handle subjective perceptions, however, sustainability issues are multi-dimensional and requires subjective judgements and linguistic preferences. Additionally, corporate sustainability performance is highly dependent on cultural aspect. Therefore, this study forms a measurement structure using cultural attributes to evaluate corporate sustainability performance. This study integrates the fuzzy synthetic evaluation and a decision-making trial and evaluation laboratory (DEMATEL) approach to address the interdependence relation among attributes in a hierarchical structure. The proposed framework is tested to show the reliability and validity. The proposed framework is able to identify over all sustainability performance as well as is able to draw specific managerial implications. The result reveals that overall corporate sustainability performance is low, and a poorer performance is found with regard to social responsibility. The study contributes in the literature by presenting a hierarchical assessment framework for understanding corporate sustainability performance.

Kim, Y. J., & Brown, M. (2019). Impact of domestic energy-efficiency policies on foreign innovation: The case of lighting technologies. *Energy Policy*, 128, 539–552. <https://doi.org/10.1016/j.enpol.2019.01.032>

Fostering the global development of low-carbon technology is crucial to mitigating greenhouse gas emissions. This paper analyzes the effect of energy-efficiency policies on lighting patenting between 1992 and 2007, using data for 19 OECD countries. We examine levels of energy-efficiency RD&D expenditures (representing a technology-push approach) and the stringency of energy-efficiency performance standards (representing a demand-pull approach). We find strong correlational evidence that both domestic demand-pull and technology-push policies positively affect domestic lighting patenting. We also provide strong correlational evidence that the demand-pull policy positively affects foreign lighting patenting; however, the technology-push policy does not. These findings suggest that demand-pull policies can help to transform international markets for low-carbon technology innovation, and they underscore the importance of the often-overlooked international dimension of domestic energy-efficiency policies. To the extent that our findings are generalizable, our research suggests that governance processes that strengthen energy performance standards and steady investment in RD&D could spur energy innovation in industrialized nations across the world.

Klewitz, J., & Hansen, E. G. (2014). Sustainability-oriented innovation of SMEs: A systematic review. *Journal of Cleaner Production*, 65, 57–75. <https://doi.org/10.1016/j.jclepro.2013.07.017>

Since the Brundtland report in 1987 a wide debate has emerged on eco-innovation (e.g. eco-design, cleaner production) and sustainability-oriented innovations (SOIs), that is, the integration of ecological and social aspects into products, processes, and organizational structures. While prior research has often dealt with SOIs in large firms, the last decade has begun to generate broad knowledge on the specificities of SOIs in small and medium sized enterprises (SMEs) as they are increasingly recognized as central contributors to sustainable development. However, this knowledge is scattered across

different disciplines, research communities, and journals. Therefore, this paper analyzes the heterogeneous picture research has drawn within the past 20 years with a focus on the innovation practices including different types of SOIs and strategic sustainability behaviors of SMEs through an interdisciplinary, systematic review in a time frame between 1987 and 2010. By consulting major research databases we have analyzed 84 key journal articles bibliographically and thematically. We find that first SME strategic sustainability behavior ranges from resistant, reactive, anticipatory, and innovation-based to sustainability-rooted. Second, we identify innovation practices at the product, process, and organizational level. Third, our results show that research is still strong on eco-innovation rather than on innovation from a triple bottom line perspective (economic, social, and environmental dimension), that is, SOIs of SMEs. Our main theoretical contribution is the development of an integrated framework on SOIs of SMEs where we delineate how distinct strategic sustainability behaviors can explain contingencies in types of innovation practices. Furthermore, for the more proactive SME behaviors we argue that they possess higher capabilities for more radical SOIs with the innovation process itself changing. Therefore, we propose that interaction with external actors (e.g. customers, authorities, research institutes) can ultimately increase the innovative capacity of SMEs for SOIs. Finally, we identify major research gaps with regard to radical SOIs, streamlined innovation methods, the role of SMEs in industry transformation and in sustainable supply chains, as well as a need for a stronger theoretical debate on SOIs of SMEs. © 2013 Elsevier Ltd. All rights reserved.

Knight, H., Megicks, P., Agarwal, S., & Leenders, M. A. A. M. (2018). Firm resources and the development of environmental sustainability among small and medium-sized enterprises: Evidence from the Australian wine industry. *Business Strategy and the Environment*, 28(1), 25–39.

<https://doi.org/10.1002/bse.2178>

Scholars and industry professionals want clarification of the specific firm resources that influence the adoption and development of environmentally sustainable strategies. This paper, set in the context of the Australian wine industry, explores different firm resources that are beneficial for environmentally sustainable development and examines the role of management attitudes and norms in moderating this relationship. It establishes which resources small and medium-sized enterprises (SMEs) should invest in to be more successful in following environmental principles. The findings of a survey of the owner-managers of Australian wine-producing SMEs are reported, and partial least squares structural equation modelling is utilized to analyze the data. Results clearly indicate that successful firms that manage their resources more effectively influence the application of environmental behaviour, with one distinct resource significantly influencing the disclosure of such behaviour. A moderating effect is established which supports the notion that pro-environmental decision-making in SMEs is heavily influenced by the attitudes and norms held by management.

Koefoed, M., & Buckley, C. (2008). Clean technology transfer: A case study from the South African metal finishing industry, 2000-2005. *JOURNAL OF CLEANER PRODUCTION*, 16(1), S78–S84.

<https://doi.org/10.1016/j.jclepro.2007.10.023>

The article describes the uptake of cleaner technology to the metal finishing sector in South Africa. Cultural determinants in uptake process are emphasized and strategies to foster uptake are presented: regulatory instruments, communication, training, cleaner technology assessments and subsidy. Results from the period 2000-2005 comprise: more than 12 full-scale demonstration plants were built with best available cleaner technology (BAT) with a payback time of 1.8 years; design and testing of a cleaner production apprentice education programme; set-up of 3 industrial associations, which have merged into a commercial sustainable nationwide association. A regional environmental authority has

developed capabilities for stimulating cleaner technology diffusion and sharpened its regulatory instruments meeting international level.

Lindsey, T. C. (1998a). Diffusion of P2 innovations. *P2: Pollution Prevention Review*, 8(1), 1–14.
[https://doi.org/10.1002/\(SICI\)1520-6815\(199824\)8:1<1::AID-PPR1>3.0.CO;2-R](https://doi.org/10.1002/(SICI)1520-6815(199824)8:1<1::AID-PPR1>3.0.CO;2-R)

P2 innovations seem to be diffusing at a disappointingly slow rate. This article examines the reasons why and suggests how the pace could be stepped up.

Lindsey, T. C. (1998b). *Promoting the Adoption of Pollution Prevention Innovations with the Assistance of Publicly Owned Treatment Works* (Thesis, University of Illinois at Urbana-Champaign).
Retrieved from <http://hdl.handle.net/2142/79569>

The thesis explains key factors and events that influenced the various adoption/rejection decisions regarding this technology. Additionally, the efforts of the State P2 change agents to promote the technology are evaluated along with the impacts of involving change agent aides (publicly owned treatment works). The thesis also provides a model of how this concept could be applied to other planning disciplines and specifically defines how the model could be applied for the facilitation of P2 adoption on a national level.

Lindsey, T. C. (1999). Accelerated Diffusion of Pollution Prevention Technologies (ADOP²T). *Pollution Prevention Review*, 9(2), 33–37.

Accelerated Diffusion of Pollution Prevention Technologies or ADOP²T offers an innovative and practical approach to speeding up the adoption of pollution prevention technologies.

Lindsey, Timothy. (2000). Key Factors for Promoting Pollution Prevention Technology Adoption. *Pollution Prevention Review*, 10(1), 1–12.

This article discusses the results of projects undertaken by the Illinois Waste Management and Research Center (WMRC), to determine what types of technical assistance can be provided to industry to expedite the diffusion of proven innovative P2 technologies.

Marshall, R. S., Akoorie, M. E. M., Hamann, R., & Sinha, P. (2010). Environmental practices in the wine industry: An empirical application of the theory of reasoned action and stakeholder theory in the United States and New Zealand. *Journal of World Business*, 45(4), 405–414.
<https://doi.org/10.1016/j.jwb.2009.08.009>

Industry transformation related to environmental stewardship has received significant scholarly attention over the past decade. However, limited theoretical and empirical work examines the motivations for improving environmental performance in an industry in different countries. In this paper, we develop a set of hypotheses, based in the theory of reasoned action and stakeholder theory, regarding drivers of the adoption of environmental practices in the wine industries of New Zealand and the United States. We test our hypotheses using data from survey questionnaires collected in each country. Our findings suggest that subjective norms and internal stakeholder pressures are common drivers of the adoption of environmental practices in these two countries. However, managerial attitudes and external stakeholder pressures are not significant drivers. We also find that managerial attitudes and export dependence are stronger determinants of environmental practice adoption in New Zealand compared to the U.S.

McComas, C. A., & Cook, R. J. (2004). Pollution prevention technology diffusion in Minnesota: Fiber reinforced plastics and coating industries. *Proceedings of the Air and Waste Management Association's Annual Meeting and Exhibition*, 4615–4624.

The work Minnesota Technical Assistance Program (MnTAP) conducted by fiber reinforced plastics (FRP) industry to reduce styrene emissions, using the technology diffusion model was discussed. MnTAP was able to document 108,400 pounds in styrene reductions from three shops, 17.7 tons of FRP scrap generation avoided that would have gone to landfills, and savings to companies of \$119,150 due to more efficient use of raw materials and avoided landfill costs. Technology diffusion approaches allowed technologies to be adopted more effectively and at a faster rate. The technologies helped the shop owners to overcome the barriers that arise from uncertainties about quality, cost, and operator training.

Metcalf, C. (2004). Pollution prevention Technology Diffusion Initiative (TDI) for Kentucky. *Proceedings of the Air and Waste Management Association's Annual Meeting and Exhibition*, 4603–4613.

There are few business opportunities that have no downside. But, that is exactly what the Kentucky Pollution Prevention Center (KPPC) at the University of Louisville is offering. KPPC will recommend innovative pollution prevention (P2) approaches and technologies for participating organizations and provide “creative” financial assistance to pay for the capital expenditure. This innovative program is all part of KPPC’s P2 Technology Diffusion Initiative (TDI) for Kentucky to promote and improve the diffusion of P2 technologies. KPPC is demonstrating that the cost savings from P2 approaches and technologies can be significant. With this program, KPPC initially conducts a P2 assessment of the facility’s operations. After the assessment, KPPC provides a P2 report documenting the P2 opportunities with estimated cost savings and payback for the facility’s operations. If the facility agrees to implement any of these P2 opportunities, KPPC and the company then work together to install the equipment at the facility. After the pilot trial is completed, KPPC determines final cost savings and a special effort is made to document barriers addressed. This paper will discuss one successful pilot trial with a small metal finishing company (45 employees) installing conductivity meters on (3) rinsing stages to reduce the amount of rinse water usage. The pilot trial enabled the company to resolve complexity and compatibility issues and determine how they could successfully implement the P2 technology in their specific application. The project was such a success that rinsing controls have been installed on a second plating line and water usage has been reduced by 300,000 gallons annually with savings of \$40,000 including reduced treatment chemical usage and sludge disposal costs.

Mickwitz, P., Hyvättinen, H., & Kivimaa, P. (2008). The role of policy instruments in the innovation and diffusion of environmentally friendlier technologies: Popular claims versus case study experiences. *Journal of Cleaner Production*, 16(1 SUPPL. 1), S162–S170.

<https://doi.org/10.1016/j.jclepro.2007.10.012>

Moving towards sustainability will require that new environmentally friendlier technologies are developed and widely adopted. Policy instruments that promote eco-efficiency are therefore necessary. Some claims frequently made in the literature on the relationship between policy instruments and technological development are examined. The claims concern regulations, environmental taxation and funding of research and development. The claims are explored on the basis of empirical evidence from two sectors: the pulp and paper industry and the marine engine industry. Little support was found for some of the claims, in some cases even contradictory findings,

and for some claims the findings differed between the sectors and even within a sector, depending on the issue.

Miyamoto, M., & Takeuchi, K. (2019). Climate agreement and technology diffusion: Impact of the Kyoto Protocol on international patent applications for renewable energy technologies. *Energy Policy*, 1331–1338. <https://doi.org/10.1016/j.enpol.2019.02.053>

This study examines the Kyoto Protocol's impact on the international diffusion of renewable energy technologies including solar and wind energy. Using patent application data of 133 countries from 1990 to 2013 and a difference-in-difference approach, we find that the Kyoto Protocol increased international patent applications from the countries with emission targets. The effect appeared over many years during the period studied, particularly for solar energy technology. When we focus on countries with more stringent targets, the effect of the Kyoto Protocol is even stronger. For these countries, the Protocol's impact on the numbers of applications for international patent persisted strongly, even for wind energy technology. Moreover, we find a similar effect for the international patent applications filed in four developing countries that are large emitters of greenhouse gases: Brazil, China, India, and Mexico. These results suggest that the Kyoto Protocol stimulated international patenting activities from countries that are committed to stringent targets for climate mitigation. Our results endorse the importance of climate change agreements for international diffusion of technology.

Montalvo, C. (2008). General wisdom concerning the factors affecting the adoption of cleaner technologies: A survey 1990-2007. *Journal of Cleaner Production*, 16(1 SUPPL. 1), S7–S13. <https://doi.org/10.1016/j.jclepro.2007.10.002>

Cleaner technologies (CT) have recently received much attention in diverse media and policy agendas. This comes out of the clear role they play in environmental protection and sustainability and the large potential to contribute to economic growth and competitiveness. The realization of both potentials depends on the level diffusion and exploitation achieved, today very low. This article presents a selective survey of papers that today represent the general wisdom concerning the factors affecting adoption as a primary condition to diffusion and exploitation of CT. The paper helps to clarify the challenges facing diffusion modelers and policy makers when dealing with policy design, assessing the levels of diffusion achieved as well as the factors affecting diffusion of a particular technology. The paper ends outlining further research need in the field.

Montalvo, C., & Kemp, R. (2008). Cleaner technology diffusion: Case studies, modeling and policy. *Journal of Cleaner Production*, 16(1 SUPPL. 1), S1–S6. <https://doi.org/10.1016/j.jclepro.2006.06.005>

The development and application of cleaner technologies (environmental technologies) offer multiple benefits for the adopter: reduced emissions, less waste and cost savings from reduced resource use and savings on waste costs. The question here is: if cleaner technologies offer such great benefits why they are diffusing so slowly across the economy? This special issue is about answering this question by presenting a collection of contributions that lay down a good foundation for students, scholars, practitioners and policy makers interested in making sustainable development more than a metaphor. The contributions range from surveys of literature identifying gaps and directions in the field, cleaner technology diffusion case studies, advances in diffusion modeling and diffusion policy issues and recommendations. In general the set of papers present an overview of the advances in the field of cleaner technologies diffusion research.

Neri, A., Cagno, E., Di Sebastiano, G., & Trianni, A. (2018). Industrial sustainability: Modelling drivers and mechanisms with barriers. *Journal of Cleaner Production*, 194, 452–472.
<https://doi.org/10.1016/j.jclepro.2018.05.140>

Sustainability's relevance is constantly increasing among industrial decision makers, policy-makers and scholars. To improve sustainability performance, firms must adopt industrial sustainability measures. These have been proven to positively impact on overall firm's performance, but their rate of adoption is still low, and barriers to their adoption need to be properly tackled by drivers. This work is based on a review of literature on drivers to sustainability and to the areas of occupational health and safety, eco efficiency, and energy efficiency, and contributes to industrial sustainability research presenting a novel framework of drivers. The framework comprehends a model of drivers and a model of mechanisms: the former encompasses previous literature contributions and aims to characterize drivers for the adoption of measures in all areas of industrial sustainability; the latter aims to evaluate if a driver may tackle specific barrier or boost the action of another driver. We conducted a preliminary validation of the framework in nine Italian manufacturing firms. Regarding model of drivers, capacity to represent, usefulness and ease of use were evaluated; concerning model of mechanisms usefulness and ease of use were evaluated. Results seem to be sound with an overall positive evaluation of the framework by all the interviewees. Model of drivers was appreciated for its structure and completeness, and for its ability to enhance knowledge and awareness; model of mechanisms was considered useful for properly foster the adoption of a measure within the firm. The framework could be useful for industrial decision makers and policy-makers to better direct resources and efforts to foster the adoption of industrial sustainability measures.

Parker, C. M., Redmond, J., & Simpson, M. (2009). A review of interventions to encourage SMEs to make environmental improvements. *Environment and Planning C: Government and Policy*, 27(2), 279–301. <https://doi.org/10.1068/c0859b>

Small and medium-sized enterprises (SMEs) are an important part of the world economy but they are thought to be responsible for around 60% of all carbon dioxide emissions and 70% of all pollution. SMEs often have major problems with limited resources, limited knowledge, and limited technical capabilities to deal with their own negative environmental impact. SMEs exhibit widely differing characteristics and commitment where environmental issues are concerned. Yet under these conditions they are all expected to engage in environmental improvement. Interventions that encourage environmental improvement are often polarised between regulation and legislation at one extreme and voluntary environmental agreement at the other. It is clear that a holistic mixture of interventions is necessary to achieve maximum engagement and environmental improvement by all SMEs. In this paper we categorise the different levels of environmental commitment observed in SMEs and develop a selection or "toolkit" of intervention strategies that might be deployed within each category of SME.

Raar, J. (2015). SMEs, environmental management and global warming: A fusion of influencing factors? *Journal of Small Business and Enterprise Development*, 22(3), 528–548.
<https://doi.org/10.1108/JSBED-10-2013-0157>

Purpose – Stakeholder theory provided the broad theoretical lens to explore environmental issues in small and medium enterprises (SMEs). The diversity in issues examined ranged from concern for immediate stakeholders, their industry group and the influence of global warming on their business activities, to the type of environmental information included within their internal information systems.

The paper aims to discuss these issues. Design/methodology/approach – A mailed survey was used to obtain data from SMEs operating in Australia. The focus was primarily directed to medium size firms. Findings – The findings indicate that SMEs were aware that their stakeholders, particularly their employees and customers were concerned with environmental issues. The respondent SMEs were also aware that global warming would influence their activities, for example, the design of their projects, occupational, health and safety, labour contracts and customer relations. Overall, the findings suggest that any tailored approach to regulate or self-regulate environmental management in SMEs, be industry and stakeholder driven. Research limitations/implications – The limitations of this research are primarily those applicable to the survey method, SME response rates, and the geographical location covered by the survey. The focus of this study is primarily medium size firms, rather than micro small business. Originality/value – This study gains insights into some of the practical aspects of environmental management in SMEs and in so doing adds to the growing body of literature in this under researched area. ©Emerald Group Publishing Limited.

Redmond, J., & Walker, B. (2011). Environmental education and small business environmental activity. *Australian Journal of Environmental Education*, 27(2), 238–248.

<https://doi.org/10.1375/ajee.27.2.238>

Environmental education is seen as a key driver of small business environmental management, yet little is known about the activities small business owner-managers are undertaking to reduce their environmental impact or in what areas they may need education. Therefore, research that can identify environmental management activities being undertaken in small businesses may provide potential targets for education. As intention to behave in a particular way is often predicated on some sort of planning, extending the research questions to ascertain if planning is occurring and its impact on environmental behaviour in small businesses is also seen as critical. The results revealed that, overall, the level of environmental activity in small business was low and that less than a quarter had an environmental plan. In addition, reducing greenhouse gas emissions and purchasing green energy are not areas of engagement for most small businesses and are recommended as potential targets for education.

Reiche, D. (2013). Climate policies in the U.S. at the stakeholder level: A case study of the National Football League. *Energy Policy*, 60, 775–784. <https://doi.org/10.1016/j.enpol.2013.05.039>

This article analyzes how stakeholders are able to influence climate policy-making in the U.S.; emphasis is placed upon the most popular sports league in the United States, the National Football League (NFL). An empirical analysis of the 32 NFL franchises identifies pioneering clubs that have introduced ambitious green programs that include the utilization of renewable energies, the adoption of energy efficiency measures and carbon offsetting policies, as well as the facilitation of public transport and electric cars. Apart from environmental concerns, this paper identifies several drivers for pioneering actions: economic motives, pressure exerted by the local environment, public relations, and political incentives such as the promotion from the federal government's stimulus package. Finally, this article investigates the role that state actors, such as the Environmental Protection Agency, and non-state actors, such as the Natural Resources Defense Council, play in the innovation and diffusion processes of environmental programs in the NFL.

Rohracher, H. (2003). The role of users in the social shaping of environmental technologies. *Innovation*, 16(2), 177–192. <https://doi.org/10.1080/13511610304516>

A better understanding of the role of end-users in processes of technology innovation and diffusion could help to develop a broader range of policy instruments fostering the development of environmentally friendly and politically desirable technologies and products. Such insights could help to improve conditions for a more conscious, reflexive and inclusive learning process between designers, intermediaries and users in product-creation processes. This article builds on an empirical investigation of two technologies that may enhance the environmental performance of buildings: balanced ventilation systems with heat recovery and “smart home” technologies. Both technologies are in an early phase of diffusion, but are still in a process of change and adaptation. The interaction of users, producers and intermediary actors is of crucial importance for the learning processes taking place at this stage. The paper will focus on three levels of product development where the actions and expectations of diverse actors meet: extending actor networks, appropriating technologies by users and translating discourses and visions into technical practice. An improvement of these interactions and learning processes could have a high potential to better adapt technologies to the needs and practices of diverse groups of users.

Rothenberg, S., & Becker, M. (2004). Technical Assistance Programs and the Diffusion of Environmental Technologies in the Printing Industry: The Case of SMEs. *Business & Society*, 43(4), 366–397. <https://doi.org/10.1177/0007650304268801>

The goal of this article is to better understand the diffusion of environmentally preferable manufacturing technology (as distinct from pollution control technology) in small- and medium-sized firms (SMEs) and the influence of technical assistance programs on the diffusion of these technologies. The authors draw their insights from the printing industry, a sector where small firms predominate. They find that smaller firms lag slightly in the adoption of environmental technologies. With regard to technical assistance, they find that printers identify suppliers and other industry sources as more useful than government in providing information that leads to active exploration of new environmental technologies. In addition, in comparison to larger firms, smaller firms reported to be less familiar with government-sponsored programs and perceived some of the programs to be less useful. They point to several ways in which regulatory agencies are experimenting to make government sponsored programs more effective.

Roy, M.-J., Berger-Douce, S., & Audet, J. (2008). The environmental commitment in SMEs: The influence of resources, skills and knowledge. *Journal of Small Business and Entrepreneurship*, 21(1), 75–93. <https://doi.org/10.1080/08276331.2008.10593414>

This article presents the conclusions of an empirical study bearing on the factors that may contribute to environmental commitment among small and medium-sized enterprises (SMEs). The data obtained from a sample of 136 small manufacturing businesses in Quebec have led to various statistical analyses aiming to verify whether these businesses’ resources, skills and intelligence activities show a positive correlation with environmental commitment. In particular, our results confirm that the SBs that show superior environmental commitment are larger and possess skills related to innovation and to quality management systems. The results also suggest that these SBs emphasize intelligence activities, especially regarding suppliers, industrial associations, and government agencies.

Roy, M.-J., & Thérin, F. (2008). Knowledge acquisition and environmental commitment in SMEs. *Corporate Social Responsibility and Environmental Management*, 15(5), 249–259.
<https://doi.org/10.1002/csr.145>

This article presents the results of an empirical study that investigated the relationship between a firm's knowledge acquisition activities and its environmental commitment. The study focuses on both regular knowledge acquisition activities and those specific to environmental issues. Statistical analyses of the data obtained from a sample of 136 Canadian manufacturing small and medium enterprises (SMEs) were conducted. Study results first revealed that regular knowledge acquisition activities and those specific to environmental issues are positively related to environmental commitment. Results also suggest that SMEs use different knowledge sources when acquiring environmental knowledge and that trade associations and suppliers play a significant role in this process

Shapira, P., & Rosenfeld, S. (1996). *An Overview of Technology Diffusion Policies and Programs to Enhance the Technological Absorptive Capabilities of Small and Medium Enterprises*. Atlanta, GA : Georgia Institute of Technology. <http://www.prism.gatech.edu/~jy5/pubs/oecdtech.htm>

Throughout the developed industrial economies (and increasingly in developing industrial countries), there has been a great increase in recent years in policy and programmatic initiatives to promote the diffusion of technology. The effective deployment of technology has been associated with industrial competitiveness, productivity and efficiency, economic development, business growth, business flexibility, quality, the maintenance of high-wage jobs, and the support of further rounds of innovation. Attention has been paid not only to specific policy measures that might accelerate technology diffusion and tighten links between technology developers and users, but also to the creation and nurturing of supportive systems and infrastructures for technology diffusion. In following sections, the paper considers the meaning of technology diffusion and how technology diffusion measures can be classified. This is followed by a discussion of specific policies which aim to increase the technological absorptive capacities of firms, especially small and mid-sized enterprises. A review of technology diffusion approaches in selected OECD countries is then presented, again with an emphasis on measures for small and mid-sized firms.

Trianni, A., Cagno, E., & Neri, A. (2017). Modelling barriers to the adoption of industrial sustainability measures. *Journal of Cleaner Production*, 168, 1482–1504.
<https://doi.org/10.1016/j.jclepro.2017.07.244>

Sustainability is constantly gaining relevance among industrial decision makers, policy makers and scholars. In order to be sustainable, firms need to implement industrial sustainability measures, however there are many barriers to doing this. This work is based on a review of literature on barriers to the areas of occupational health and safety, eco efficiency, energy efficiency and to sustainability, and contributes to industrial sustainability research by presenting a novel, integrated theoretical model of barriers to the implementation of sustainability measures. The model encompasses previous literature review contributions and is intended to characterize and evaluate barriers to the adoption of industrial sustainability measures in all its areas. We have conducted a preliminary validation of the model investigating eight northern Italian manufacturing firms, looking at its ability to represent barriers to sustainability, usefulness and ease of use. We conducted semi-structured interviews to people responsible of the different areas of industrial sustainability, complemented by questionnaires and secondary materials. Results show a positive overall judgment of the model by all the interviewees. Moreover, the model was able to be applied to issues deriving from different

perspectives and different areas of industrial sustainability. The findings can help firms and policy makers overcome barriers and they also provide insight into the different perspectives on the adoption of industrial sustainability measures than can be used to promote their adoption.

Vermeulen, W. J. V., & Witjes, S. (2016). On addressing the dual and embedded nature of business and the route towards corporate sustainability. *Journal of Cleaner Production*, 112, 2822–2832.
<https://doi.org/10.1016/j.jclepro.2015.09.132>

This article argues for greater attention to be paid to the dual and embedded nature of business. We propose that a more inclusive systemic perspective is needed for the challenge of speeding up the application of “inclusive” corporate sustainability. The key question is how an on-going upward dynamic of transformative learning cycles can be achieved in practice. The current practice of implementing sustainability management systems, identifying key performance indicators, reporting on sustainability policies and outcomes has a strong focus on the physical dynamics in companies and (in the good cases) in their value chain. In many cases the three dimensions of issues, time and place are only addressed partially. We argue that the academic community needs to pay greater retro- and prospective attention to the social intervention dynamics, introducing checks on the assumed effects of social interventions. In order to achieve a more balanced and inclusive corporate sustainability we need to link levels of the achievement of corporate sustainability goals more strongly with (self-) assessment of the social dynamics in firms and their societal system.

Weerts, K., Vermeulen, W., & Witjes, S. (2018). On corporate sustainability integration research: Analysing corporate leaders’ experiences and academic learnings from an organisational culture perspective. *Journal of Cleaner Production*, 203, 1201–1215.
<https://doi.org/10.1016/j.jclepro.2018.07.173>

Addressing corporate impacts on the sustainability of society entails a dynamic capability and management of organisational change. Although the integration of Corporate Sustainability into the corporate culture involves both the physical and social dynamics of business activities, scientific research has been mostly focusing on interventions in the physical dynamics. This article focuses on interventions in the social dynamics, by analysing literature from environmental sciences on optimising social interventions aiming for the integration of Corporate Sustainability into the corporate culture on the one hand and literature written by successful Corporate Sustainability change agents from industry on the other hand. We use the three perspectives of organisational culture change by Martin (1992) to compare the analysis of scientific and practical literature. By reflecting upon practical and theoretical advances, this research identified practical grounded learnings on Corporate Sustainability integration contributing to both society and science that give input for improvements of research on the integration of Corporate Sustainability. We conclude that where Corporate Sustainability scholars tend to focus on one specific Corporate Sustainability integration approach, the change agents intuitively apply what is best in their specific situations, resulting in a mix of approaches. Consequently, the combative attitude of scholars is not very fruitful. Moreover, all three perspectives on changing organisational culture could be seen in both scientific as well as practical literature as developmental stages of the transformation process. Consequently, including the time dimension in Corporate Sustainability integration research enables a longitudinal analysis to capture social interventions. We, therefore, stress the need for more longitudinal transdisciplinary research approaches aimed at enhanced understanding of how culture at different organisational levels may affect the success of the integration of Corporate Sustainability into the corporate culture.

Witjes, S., & Lozano, R. (2016). Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models. *Resources, Conservation and Recycling*, 112, 37–44. <https://doi.org/10.1016/j.resconrec.2016.04.015>

Sustainability aims at addressing environmental and socio-economic issues in the long term. In general, the literature on sustainability has focused mainly on the environmental issues, whereas, more recently, a Circular Economy has been proposed as one of the latest concepts for addressing both the environmental and socio-economic issues. A Circular Economy aims at transforming waste into resources and on bridging production and consumption activities; however, there is still limited research focusing on these aspects. This paper addresses the link between procurement and supply practices, and proposes changing from a traditional public procurement process, based on product-selling business models, to a more service-oriented system. The paper proposes a framework to include technical and non-technical specifications of product/service combinations that improve resource usage efficiency through recovery. The framework also considers socio-cultural specifications and physical and social proximity between the stakeholders in the procurement process. The framework is based on collaboration, which is a vital link between the public procurement process and the development of more sustainable business models, where the experience gained in the collaboration process serves as the bases for suppliers and procurers in improving their contribution to CE, whilst at the same time securing economic benefits for both parties. Although, in this process, the specification setting may take longer, the relationships between procurer and supplier tend to be longer lasting and stronger. This research shows that collaboration between procurers and suppliers throughout the procurement process can lead to reductions in raw material utilisation and waste generation, whilst promoting the development of new, more sustainable, business models.

Zhang, L., Xue, L., & Zhou, Y. (2019). How do low-carbon policies promote green diffusion among alliance-based firms in China? An evolutionary-game model of complex networks. *Journal of Cleaner Production*, 210, 518–529. <https://doi.org/10.1016/j.jclepro.2018.11.028>

China has launched a series of low-carbon policies that promote the diffusion of green technologies, in order to advance what is now the world's largest manufacturing area toward more sustainable and environmentally friendly practices. Specifically, alliances between manufacturers (as one of the policy initiatives) have been set up to expedite technology diffusion. What are the patterns of technology diffusion in the alliance, and what are the effects of low carbon policy on the diffusion of technology in the alliance? Using game-based theory, this paper builds an evolutionary game model of technology diffusion between enterprises in the context of a complex network. In particular, it simulates the effects of a carbon trading market, environmental taxes, and innovation subsidies, on green technology diffusion of manufacturing firms in a BA scale-free network (Barabási–Albert model) in China. The results show that various levels of policy-implementation (especially the market-based policies) lead to different rates of diffusion. This study provides insights on green diffusion policies and the effectiveness of their implementation in inter-firm alliances.

Zhang, P., Duan, N., Dan, Z., Luo, J., Shi, F., & Wang, H. (2018). Impact of Different Factors on the Pollution-Reduction and Resource-Saving Effects of Cleaner Production. *ACS Sustainable Chemistry and Engineering*, 6(7), 9480–9487. <https://doi.org/10.1021/acssuschemeng.8b02052>

Cleaner production (CP) is one of the most important tools to propel sustainable development. This research investigates the influences of pollutant and resource type, industry sector, time, and region on CP implementation, and understanding these influences is conducive to further CP implementation.

More than 241 CP cases in China were selected as the data source, and the reduction rate (rr) of pollutant generation or resource consumption was used to quantify the pollution-reduction and resource-saving effects of CP. Time and region cannot affect CP spontaneously. However, the positive attitude of the regional government is instrumental to CP promotion. Statistical inferences indicate that rr is significantly influenced by the pollutant and resource type, and industry. Because of the adoption of suitable technologies, the rr of heavy metals is higher than that of resources and pollutants. The rr of resources was found to be lower than that of pollutants. However, because of the cost reduction caused by resource saving, relevant cleaner technologies were more easily adopted by enterprises. The significant impact of industry was caused by the different resources and pollutants of different industries. CP should be implemented on the basis of the specific resource and environmental issues that the industry confronts.

Books and reports

Berg, D. R., Kerr, R. L., Fleischer, S., Gorsen, M., & Harris, E. (1993). *Transforming Environmental Permitting and Compliance Policies to Promote Pollution Prevention: Removing Barriers and Providing Incentives to Foster Technology Innovation, Economic Productivity, and Environmental Protection*. Washington, DC : The Agency.

<https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=4000012Q.txt>

The Technology Innovation and Economics (TIE) Committee, a standing committee of EPA's National Advisory Council for Environmental Policy and Technology (NACEPT), has concluded that major changes are needed in federal and state permitting and compliance programs to encourage adoption of practical pollution prevention approaches to environmental protection. The Committee recommends seven major areas for improvement, including: (1) Redesigning permit procedures to encourage regulated facilities to expand multi-media and pollution prevention environmental improvement efforts; (2) Accelerating development and use of innovative pollution prevention technologies and techniques through special permitting and review procedures during RD&D and commercialization phases; (3) Developing and expanding federal and state pollution prevention enforcement initiative; (4) Supporting state initiatives in pollution prevention facility planning; (5) Expanding pollution prevention-related training, educational and technology diffusion efforts to better reach managers in all sectors of the economy; (6) Altering personnel reward systems to encourage EPA staff to champion pollution prevention; (7) Expanding and publicizing the system of national awards honoring outstanding pollution prevention research, training and technology implementation.

Berg, D. R., Vaughn, R., Altschuler, M., & Richardson, C. (1992). *Improving Technology Diffusion for Environmental Protection: Report and Recommendations of the Technology Innovation and Economics Committee*. Washington, DC : The Agency.

<https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=400003Q4.txt>

The Technology Innovation and Economics (TIE) Committee, a standing committee of EPA's National Advisory Council for Environmental Policy and Technology (NACEPT), has concluded that the environmental regulatory system could expand environmental progress and improve economic competitiveness if processes that diffuse environmentally beneficial technologies are used to effectively complement regulations. In the report, the Committee analyzes several critical policy issues affecting EPA's essential diffusion roles and makes five major policy recommendations, including: making technology diffusion a major supporting mission for EPA; building a stronger partnership with technology diffusion providers and users; making diffusion and incentives the emphasis of EPA's

pollution prevention programs; expanding support for the international diffusion of environmental technologies to help meet U.S. environmental and competitiveness objectives; increasing the support of diffusion provided by EPA's environmental technology research programs.

Lindsey, Tim. (2018). *Headwinds of Opportunity: A Compass for Sustainable Innovation*. London: Routledge.

Offers strategic guidance regarding how to make all types of organizations function more sustainably while improving their competitiveness. It approaches sustainability as an innovation and applies technology diffusion principles to drive change.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York: Free Press.
<http://www.worldcat.org/oclc/856602496>

Everett M. Rogers provides a revision of the theoretical framework and the research evidence supporting this model of diffusion and introduces new concepts and theoretical viewpoints.

U.S. Environmental Protection Agency - New England. (1999). *Pilot of the Pollution Prevention Technology Application Analysis Template Utilizing Acid Recovery System*. Boston, MA : The Agency.
<https://www.mass.gov/files/documents/2016/08/xc/zero-discharge-assessment.pdf>

The purpose of the technology application analysis template is to assist potential users in evaluating the applicability of innovative pollution prevention technology. This technology application analysis characterizes the main features of the Acid Recovery System manufactured by Zero Discharge Technologies, which recovers acids from various metal plating operations.

U.S. Environmental Protection Agency. (1992). *Improving Technology Diffusion for Environmental Protection: Report and Recommendations of the Technology Innovation and Economics Committee*. Washington, DC : The Agency. <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=400003Q4.txt>

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Case studies

Babcock, L., DeWahl, K., Gage, M., Domski, M., Vanyo, J., Paulson, J., & Hanlon, P. (2017, May). *Material Substitution Workshop: Safer Products That Work: Cleaners and Degreasers for Industrial Maintenance and Auto Repair: State/Community Hazardous Material Source Reduction*. Presented at the 2017 Triple Regional Pollution Prevention Roundtable, Minneapolis, MN. Retrieved from <http://hdl.handle.net/2142/102174>

Presentation details Minnesota Technical Assistance Program's safer chemicals work with auto repair shops and the City of Minneapolis Green Business Cost Share Program. Presented as Day 2 materials substitution workshop at the 2017 Triple Regional Pollution Prevention Roundtable.

Barnes, K. (2013). *Acid Recycling Technology*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/1998>

This fact sheet describes acid recovery technology through diffusion dialysis. Also includes a case study involving a pilot project using diffusion dialysis at Gerlin, Inc., a manufacturer of stainless steel fittings and flanges in Carol Stream, IL.

Bierma, Thomas J., & Marsch, D. (2008). *Materials and Energy Efficiency in SMEs*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/9478>

Efficiency performance contracts (EPCs) for small and medium enterprises (SMEs) are a market based approach that rewards suppliers for improving efficiency and reducing waste in SME operations through pollution prevention and energy efficiency (P2E2) innovations. They are similar to programs such as chemical management services, energy savings performance contracts, and resource management contracts that have been successfully used in larger enterprises. However, they are unique in that they combine a variety of “spends,” such as tooling, chemicals, paint, and energy, in order to achieve sufficient economies of scale. In a pilot project combining tooling and metalworking fluid spends, the SME realized a 40% reduction in tooling costs while improving process efficiency and reducing tooling waste. Evidence suggests that similar EPC programs could successfully bring P2E2 innovations to many SMEs while simultaneously reducing costs and increasing profitability. However, significant barriers exist and EPC programs are unlikely to be adopted on a widespread basis without efforts by government or non-profit organizations to overcome these barriers. Most importantly, many suppliers are not willing to form the alliances necessary to make EPCs successful, particularly in the area of energy efficiency. Several steps to overcome these barriers are recommended.

Bierma, Thomas J., & Waterstraat, F. L. (1995). *Overcoming Barriers to Pollution Prevention in Small Businesses: Applications in the Metal Parts Fabrication Industry*. Champaign, IL : Illinois Waste Management and Research Center. <http://hdl.handle.net/2142/1946>

The purpose of this research was to answer two fundamental questions: Why is business adopting pollution prevention (P2) so slowly despite the financial and environmental benefits of P2 and the extensive promotion efforts of federal, state and local government?; What strategies could be used to significantly accelerate the adoption of P2 by business? The researchers employed telephone and personal interviews to study small businesses in metal parts fabricating (MPF) industry in the state of Illinois. The researchers found that the business conditions are very good for P2 diffusion, but the diffusion is limited. MPF managers are demanding manufacturing innovations, but they are not seeking P2 innovations. Current formal and informal industry communication channels are not promoting P2, while government efforts to promote P2 are having limited effect.

Bierma, Thomas J., & Waterstraat, F. L. (2001). *Chemical Management: Overcoming Barriers to Diffusion*. Champaign, IL : Illinois Waste Management and Research Center. <http://hdl.handle.net/2142/2269>

Chemical management services (CMS) is an innovative alternative to traditional chemical supply, resulting in lower chemical costs and reduced chemical waste. However, we estimate that only 3%-6% of applicable companies have adopted CMS. This report identifies the most significant barriers to diffusion and provides a “Top 10” list of recommendations for strengthening and expanding the CMS industry. These 10 priority activities were derived from a comparison of the CMS and chemical industries (Part 1 of this report), and from an evaluation of the factors governing market demand for CMS (Part 2). The “Top 10” list represents broad initiatives for CMS growth; specific marketing

activities must be developed by CMS suppliers, industry associations, and other organizations, such as WMRC, that seek to accelerate diffusion of CMS.

Boser, R., Bierma, T. J., & El-Gafy, M. (2010). *Overcoming Barriers to P2 and Recycling for Construction Waste*. Champaign, IL : Illinois Sustainable Technology Center.

<http://hdl.handle.net/2142/15438>

Estimates of construction and demolition (C&D) waste entering landfills range from 20 to 33% of the total waste stream volume. Although waste estimates are difficult to verify, it is clear that, even at the low end of this estimate range, there is significant potential for diverting C&D materials from landfills. A study by the California Environmental Protection Agency (2006) found that new residential construction comprised about 10% of the C&D waste stream. Although much of the construction waste that currently and typically goes to landfill can be recovered, effective waste management in the residential construction industry remains an elusive goal. Guided by the ADOP2T model (Lindsey, 1998, 1999) for diffusion of innovation, this research project worked toward accelerating the adoption of waste minimization and pollution prevention (P2)/recycling practices by Illinois home builders. Major phases of the study included: establishing partnerships with home builders in two Illinois counties; identifying and quantifying typical waste streams from residential construction; identifying priority waste materials for P2/recycling, local best management practices, and barriers to P2/recycling faced by home builders; implementing P2/recycling demonstration projects in two counties; developing case study fact sheets to document the procedures and results; and disseminating the results of the demonstration projects.

Boyle, M. (2013). *Copper Reduction in QMA's Wastewater Using TMT*. Champaign, IL : Illinois Sustainable Technology Center <http://hdl.handle.net/2142/45268>

QMA, Inc. is located in Elk Grove Village, IL. The company makes printed wiring boards (PWBs) and employs about 40 people. QMA wanted to reduce the cost of disposing of its wastewater which was being hauled off site. The company also wanted to improve the safety of its workers by eliminating 3,000 gallons of highly acidic wastewater, which had to be stored in the plant while awaiting disposal. QMA company officials attended a workshop presented by ISTC for the printed wiring board sector and asked ISTC for assistance.

Brown, J. (2013a). *Achieving Zero Process Water Discharge at Ace Plating Company: Ace Plating Part III*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/2005>

Ace Plating Company is a small Chicago job shop offering a variety of decorative electroplating finishes including various types of brass, nickel, bronze and copper. In 1993, Ace Plating used about five million gallons of water annually and discharged 176 pounds of metal to the sewer. In light of new discharge fees and what appeared to be ever-changing environmental regulations, Ace Plating sought assistance from the Illinois Sustainable Technology Center (ISTC) to seek ways to reduce disposal costs and minimize environmental liability. Beginning in 1995, the management at Ace used ISTC's assistance to launch an aggressive effort to use environmentally responsible processes and procedures in all of its business operations.

Brown, J. (2013b). *Conductivity Control System Technology*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/2001>

As part of the Accelerated Diffusion of Pollution Prevention Technologies (ADOP2T) program, staff engineers worked with API Industries, Inc. to install and monitor electrodeless conductivity control systems

Brown, J. (2013c). *Electrocoagulation Technology: Ace Plating Part II*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/45267>

Electrocoagulation is a process of applying a direct or alternating current and voltage of varying strength to electrodes in contact with water. In theory, this contact causes the suspended and/or dissolved solids in that water to form into a floc or precipitate of sufficient size that it can be rapidly removed from the liquid by filtration. Electrocoagulation technology vendors promote the ability of this method to reduce water usage and the amount of metals discharged to the sewer.

Electrocoagulation vendors claim the process removes 75-99% of metals and 90-99% of suspended solids while reducing BOD and COD by 50-75%. Sometimes the process is also marketed as having the ability to reduce the amount of inorganic salts in the water being treated. These claims were based primarily on laboratory data only. The vendors also stated that this process not only improved water quality over other technologies, but did so with lower costs. Reportedly, electrocoagulation would eliminate adding expensive chemicals to the wastewater and would subsequently generate less solid waste, thus saving on disposal costs. The Illinois Sustainable Technology Center (ISTC) investigated the electrocoagulation process to determine its effectiveness. If this technology could be proven to be as effective in actual process applications as reported in lab studies, it would be a valuable tool for cost-effective water recycling and reuse. ISTC worked with Ace Plating, an electroplater in the Chicago area that agreed to host a series of tests. ISTC engineers had previously worked with Ace to reduce their water usage, dragout, and metals discharged to the sewer (details about this project are available in ISTC publication TN13-066). The pollution prevention goal was to recycle the process rinse waters and eventually achieve zero process water discharge to the sewer. Equipment from two separate vendors was tested.

Chicago Metal Finishers Institute. (2002). *Effect of Barrel Design on Dragout Rate*. Champaign, IL : Illinois Sustainable Technology Center. <https://www.ideals.illinois.edu/handle/2142/2272>

New barrels for electroplating have been developed and manufacturers of some of these newer designs have claimed significant improvements in drag-out losses by their new barrels. Since water consumption and waste generation are directly tied to dragout rate from processing solutions, it is clear that there is a need to produce a method of evaluating such barrels, so that the user minimizes pollution. This study, funded by The Illinois Waste Management Research Center (WMRC) produced a benchmark test to compare drag-out rates of plating barrels. The study used this test to compare two size ranges of plating barrels, small and large. For small barrels (6" x 12"), testing showed that a reduction in dragout rate, as high as 48%, may be achieved. For large barrels (16" x 36"), testing showed that a reduction as high as 44% may be obtained. A survey was conducted to determine the relative durability of the barrels under study. The survey indicated that some of the barrels that produce lower levels of dragout (those using fine mesh) may unfortunately provide less service life, but other low dragout rate barrels offered service life that is similar to traditional barrels.

Illinois Sustainable Technology Center. (1999). *Analytical evaluation of ultrafiltration for reduction of oily wastewater: A technology demonstration project performed at B-Line Systems, Inc., Highland, Illinois.* Champaign, IL : The Center. <http://hdl.handle.net/2142/98446>

On February 10, 1999, a technology demonstration project was conducted at 8-Line Systems, Inc. The project successfully demonstrated the use of membrane filtration to separate chemicals in solution, in this case - oil and water.

Illinois Sustainable Technology Center. (2013a). *Coolant Recycling and Waste Water Reduction Alternatives for the Aluminum Disc Polishing Industry.* Champaign, IL : The Center. <http://hdl.handle.net/2142/2017>

A manufacturer of aluminum discs used for the production of CD-ROMs and other computer peripherals was discharging a high biological oxygen demand (BOD) effluent at a rate of 35,000 gallons/day. This waste was consuming approximately 20% of the local POTWs wastewater treatment capacity. Preliminary process assessment indicated an opportunity to greatly reduce chemical usage through recycling and reuse of machine coolant, alkaline cleaner and rinse water.

Illinois Sustainable Technology Center. (2013b). *Membrane Filtration Technology.* Champaign, IL : The Center. <http://hdl.handle.net/2142/2018>

This fact sheet describes membrane filtration technology and provides three case studies in which ISTC helped Illinois companies with membrane filtration applications.

Illinois Sustainable Technology Center. (2013c). *Nitric Acid Pickling Bath Recovery.* Champaign, IL : The Center. <http://hdl.handle.net/2142/1996>

Gerlin Inc. located in Carol Stream, IL manufactures stainless steel pipe fittings and flanges. As part of Gerlin's process, stainless steel parts undergo a pickling bath step to provide the parts the required surface quality. ISTC engineers developed a pilot project using diffusion dialysis acid recovery technology to assist Gerlin. This fact sheet describes the benefits Gerlin experienced as the result of this project and the factors involved in the company's decision to implement the technology.

Illinois Sustainable Technology Center. (2013d). *Recycling of Cleaning Solution at the Ford Stamping Plant.* Champaign, IL : The Center. <http://hdl.handle.net/2142/2014>

Describes an ultrafiltration pilot project conducted by ISTC engineers at Ford's Chicago Heights, IL stamping plant. Ultrafiltration was used to remove contaminants from aqueous solutions used for cleaning floors and dies at the plant so that these solutions could be reused.

Illinois Sustainable Technology Center. (2013e). *Reducing Water and Metal Discharges at Ace Plating Company.* Champaign, IL : The Center. <http://hdl.handle.net/2142/1993>

Ace Plating Company is a small Chicago job shop offering a variety of decorative electroplating finishes including types of brass, nickel, bronze and copper. This case study describes how WMRC engineers worked with Ace to reduce their water usage, dragout, and metals discharged to the sewer. The effect of implementing P2 was clearly seen on the company's bottom line. The cost of implementing full countercurrent rinsing was recouped in about six months.

Illinois Sustainable Technology Center. (2013f). *Roller Mill Coolant Recovery*. Champaign, IL : The Center. <http://hdl.handle.net/2142/1997>

Describes a pilot project at B-Line Systems, Inc., a manufacturer of metal support systems used in electrical and mechanical systems for conduit, process piping, wiring and other equipment. Implementation of membrane filtration technology in B-Line's roller mill operations and their press operations was expected to save the company approximately \$46,000 per year, with an expected payback on the project of less than seven months.

Illinois Sustainable Technology Center. (2013). *Automotive Plant Reduces Cleaner Usage*. Champaign, IL : The Center. <http://hdl.handle.net/2142/2000>

This case study describes a pilot project at Eagle Wings Industries, Inc. (EWI), an automotive parts original equipment manufacturer located in Rantoul, IL. EWI discharged more than 26,000 gallons of alkaline waste to its water treatment plant each year, in addition to the loss of 8,000 gallons of cleaning chemicals.

Lindsey, T. C. (1997). *Evaluation of Ultrafiltration for In-Process Recycling of Cleaning Solution at Ford's Chicago Stamping Plant*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/1994>

This project was conducted to evaluate the technical and economic potential for ultrafiltration to recycle aqueous cleaning solutions used at the Ford Stamping Plant.

Lindsey, T. C., & Montemurro, T. (1994). *Oil Waste Reduction and Recycling Pilot Test*. Champaign, IL Hazardous Waste Research and Information Center: <http://hdl.handle.net/2142/103786>

Triad Engineering under the direction of the Illinois Hazardous Waste Research and Information Center (HWRIC) conducted a study comparing ultrafiltration and vapor recompression recovery technologies on the water soluble die lubricant (die lube) waste produced at the OMC Waukegan facility. Water soluble die lube waste disposal represents an annual disposal expense of approximately 123,000 dollars. A side-by-side comparison of ultrafiltration technology and vapor recompression technology was conducted for a period of 25 days. This period of time was considered adequate to evaluate both technologies' ability to perform under normal production conditions. The permeate quality from the ultrafiltration system was generally somewhat poorer than the condensate from the vapor recompression system. However, field trials utilizing both permeate and condensate from the systems indicated they could be used in the water soluble die lube make up process. Biological growth and sulfide odors would be a problem with both systems. The capital costs and operation and maintenance costs of the ultrafiltration system are slightly lower than the vapor recompression system for this application. A single sample was also collected and evaluated using atmospheric evaporation. The capital costs and operating costs for an atmospheric evaporation system are higher than either the ultrafiltration or the vapor recompression system, primarily due to the addition of a condenser system to recover distillate. The payback period for the ultrafiltration system would be 1.19 years with an annual savings after payback of 90,275 dollars per year. The payback period for the vapor recompression system would be 1.48 years with an annual savings after payback of 77,900 dollars per year. The estimated payback period for the atmospheric evaporator system would be 1.51 years with an annual savings after payback of 56,200 dollars per year.

Lindsey, T. C., Ocker, A. G., Miller, G. D., & Miller, M. C. (1994). *Evaluation of Ultrafiltration to Recover Aqueous Iron Phosphating/Degreasing Bath*. Champaign, IL : Hazardous Waste Research and Information Center. <http://hdl.handle.net/2142/2031>

Pollution prevention efforts targeted the hazardous waste generated from a 5000-gallon iron phosphating/degreasing bath used by a metal fabricator to clean and precondition steel parts for painting. With extended use, the buildup of emulsified oil in the bath reduced cleaning and phosphating efficiency. Dragout of oil from the bath into the rinse water also pushed oil and grease levels in the effluent over the allowable limit. When oil in the bath began to sacrifice product quality and effluent levels edged closer to the maximum allowable limit, all 5000 gallons were dumped and replaced. Periodic dumping, about three times each year, resulted in at least 15,000 gallons per year of hazardous waste. Several waste minimization alternatives were considered, and ultrafiltration was selected as the most promising technology to recover and reuse the bath and to reduce the total amount of hazardous waste generated. Ultrafiltration has proven successful in similar industrial applications with alkaline cleaning solutions, but the application of new membrane filtration technology to this acidic, corrosive, high temperature bath was an innovative approach to pollution prevention. This project was carried out in four stages: (1) initial assessment of the problem and evaluation of alternatives, (2) bench-scale screening of ultrafiltration membrane candidates, (3) pilot-scale study at the Illinois Hazardous Waste Research and Information Center (HWRIC), and (4) full-scale implementation and testing onsite at the company's facility. Full-scale testing integrated the new waste reduction scheme into the facility's production process by applying ultrafiltration directly to the 5000-gallon iron phosphating/degreasing bath. Ultrafiltration successfully removed oil contamination from the bath and returned clean process solution back to the original 5000-gallon tank. Ultrafiltration concentrated the hazardous component down to 10 gallons of oily waste and reduced hazardous waste generation 99.8%. The concentration of oil in the bath was substantially reduced and maintained at acceptable operating levels. Permeate flux rates exhibited excellent performance and were high enough to compete with the constant input of oil from the production line. A significant portion of the unused phosphating agents were also conserved although some surfactant was lost. Product quality tests revealed that quality achieved during the full-scale ultrafiltration study was good for the facility's application. The estimated payback period associated with implementing ultrafiltration was only 6.9 months. Results of this study were used to justify installing a permanent ultrafiltration system and operating practices that would improve product quality.

Lindsey, Tim. (2013a). *ADOP2T for Metal Forming and Machining Sectors*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/2007>

The Illinois Sustainable Technology Center (ISTC) has developed a technical assistance program to improve adoption of pollution prevention technologies in the metal forming and machining sectors. The Accelerated Diffusion of Pollution Prevention Technologies Program (ADOP2T) is a process of identifying best practices and executing brief demonstrations and extended pilot trials of pollution prevention practices and technologies in actual industrial facilities. These pilot trials will provide the site specific information required to influence companies' decisions to adopt these technologies where economically and technically feasible.

Lindsey, Tim. (2013b). *ADOP2T for the Metal Finishing Industry*. Champaign, IL : Illinois Sustainable Technology Center. <http://hdl.handle.net/2142/2008>

The Illinois Sustainable Technology Center (ISTC) has developed a technical assistance program to improve adoption of pollution prevention technologies in the metal finishing industry. The Accelerated Diffusion of Pollution Prevention Technologies Program (ADOP2T) is a process of identifying best practices and executing brief demonstrations and extended pilot trials of pollution prevention practices and technologies in actual metal finishing facilities. These pilot trials will provide the site specific information required to influence companies' decisions to adopt these technologies where economically and technically feasible.

Marsch, D., & Springman, M. (2013). *Shedding Light on Water: Reducing Lighting and Water Costs at Highland Machine -- A Metal Fabricator*. Champaign, IL : Illinois Sustainable Technology Center. <https://hdl.handle.net/2142/2015>

The University of Illinois Sustainable Technology Center (ISTC) worked with Highland Machine, a metal fabricator, to assess potential savings through analysis of lighting and water use.

Michigan Department of Environmental Quality. (1999). *The Bohning Company, Ltd.: A RETAP Success Story*. Lansing, MI : The Department. https://www.michigan.gov/documents/deq/deq-ead-p2-retap-bohning_279151_7.pdf

This case study describes the efforts of the Bohning Company, to reduce, reuse and recycle following an assessment by a team from the Michigan DEQ's Retired Engineer Technical Assistance Program (RETAP). Bohning sells many products ranging from archery and golf equipment to Christmas tree colorant.

Minnesota Technical Assistance Program (MnTAP). (2001a). *Controlled Spraying and Laser Touch in the Fiber Reinforced Plastics Industry*. Minneapolis, MN : MnTAP. http://www.mntap.umn.edu/wp-admin/admin-ajax.php?juwpfisadmin=false&action=wpfd&task=file.download&wpfd_category_id=166&wpfd_file_id=11859&token=2e91d5e714aff14f87d21aa1d48eaef1&preview=1

This case study describes the testing of Laser Touch controlled spraying technology at Fiberglass Fabricators, in Le Center, Minnesota by an intern from MnTAP. Controlled spraying significantly reduces styrene emissions from open mold fiber reinforced application processes, benefiting plant personnel, the manufacturing operation and natural environment by increasing materials transfer efficiency

Minnesota Technical Assistance Program (MnTAP). (2001b). *Pollution Prevention Assistance Tools for the Fiber Reinforced Plastics and Boat Manufacturing Industries*. Minneapolis, MN : MnTAP. <https://p2infohouse.org/ref/26/25282.htm>

MnTAP and SBAP assisted fiberglass shops with implementation of pollution prevention strategies that will help the industry meet or go beyond regulatory thresholds for compliance with OSHA and the CAA.

Minnesota Technical Assistance Program (MnTAP). (2007a). *Fiber Reinforced Plastics Shop Complies With New Air Permit Regulations*. Minneapolis, MN : MnTAP. http://www.mntap.umn.edu/wp-admin/admin-ajax.php?juwppfisadmin=false&action=wpfd&task=file.download&wpfd_category_id=166&wpfd_file_id=11860&token=2e91d5e714aff14f87d21aa1d48eaef1&preview=1

Sunrise Fiberglass Company replaced spray equipment with nonatomized equipment in open mold process. Low styrene resin replaced traditional resin. The company reduced its styrene emissions by 43 percent, meeting the requirements of its new air permit without lost production time or excess capital costs.

Minnesota Technical Assistance Program (MnTAP). (2007b). *Fiber Reinforced Plastics Shop Implements Light RTM to Produce Parts*. Minneapolis, MN : MnTAP. http://www.mntap.umn.edu/wp-admin/admin-ajax.php?juwppfisadmin=false&action=wpfd&task=file.download&wpfd_category_id=166&wpfd_file_id=11861&token=2e91d5e714aff14f87d21aa1d48eaef1&preview=1

This case study describes the pollution prevention efforts of Phoenix Industries in Crookston, MN. Phoenix Industries converted 60% of molded part production to closed molding and light Resin Transfer Molding (RTM) is used for a quarter of this closed molding. Payback on the new equipment was less than two years, and these efforts resulted in reduced styrene emissions, cleaner production and better material efficiency.

Minnesota Technical Assistance Program (MnTAP). (2007c). *Fiberglass Fabricators Upgrades Open Mold Processing Equipment*. Minneapolis, MN : MnTAP. http://www.mntap.umn.edu/wp-admin/admin-ajax.php?juwppfisadmin=false&action=wpfd&task=file.download&wpfd_category_id=166&wpfd_file_id=13203&token=2e91d5e714aff14f87d21aa1d48eaef1&preview=1

This FRP shop adopted nonatomized equipment to replace spray equipment in open mold process and added raw material monitoring equipment to reduce styrene emissions by 50,400 pounds annually.

Ronda, R. (2000). *Reducing Chemical Waste through Distillation*. Champaign, IL : The Center. <http://hdl.handle.net/2142/2002>

This case study highlights pollution prevention efforts at Alexian Brothers Medical Center, located in the Chicago suburb of Elk Grove Village. Hospital officials were interested in recycling ethanol and xylene laboratory waste solvents. They hoped to reduce or eliminate disposal cost, reduce cost and usage of new chemicals and control inventory in the laboratory.

Ryberg, A. (2000). *Wenger Corporation Saves Money*. Minneapolis, MN : MnTAP. <http://www.mntap.umn.edu/industries/facility/paint/resources/wenger/>

Wenger Corporation supplies equipment and technology for music education and performing arts. Wenger coats nearly 800 different parts with dimensions that range from a few inches to 10 feet. Wenger needed to fine tune its new powder coating system. The automatic spray system was not performing as anticipated and used more powder than projected. Manual touchup and the number of reject parts was higher than Wenger expected. The company wanted to reduce powder use and the cost of waste by 25 percent. A MnTAP intern reviewed the programming and set up of the automatic spray guns. He investigated other improvements to the painting system as well.