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Waste minimization: The sooner the better

Think about waste early and it may solve itself

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From the conception of any process, waste management should be a fundamental objective. And that objective should be pursued aggressively through process development, engineering, and design, to construction, startup, and operation. It should also be a continuing objective of plant engineers and operators once the unit begins production. We've seen the result when it's otherwise!

The farther away a process is from the beginning of the technology development cycle, the more difficult (and costly) it will be to incorporate a waste minimization step into the process, and the more inertia such a change will have to overcome. The best time to consider waste minimization is when the process is first conceived. The most responsible individual is the original inventor. This reversal of the "Not Invented Here" reaction gives the initial waste minimization challenge to the inventor: the one most interested and capable of meeting it.

In Union Carbide's new technology development program, waste minimization is considered from the time a new process is conceived until the unit begins production (Figure 1). This includes the periods when the original laboratory and pilot scale studies are conducted and the process is conceptually defined, when the process is

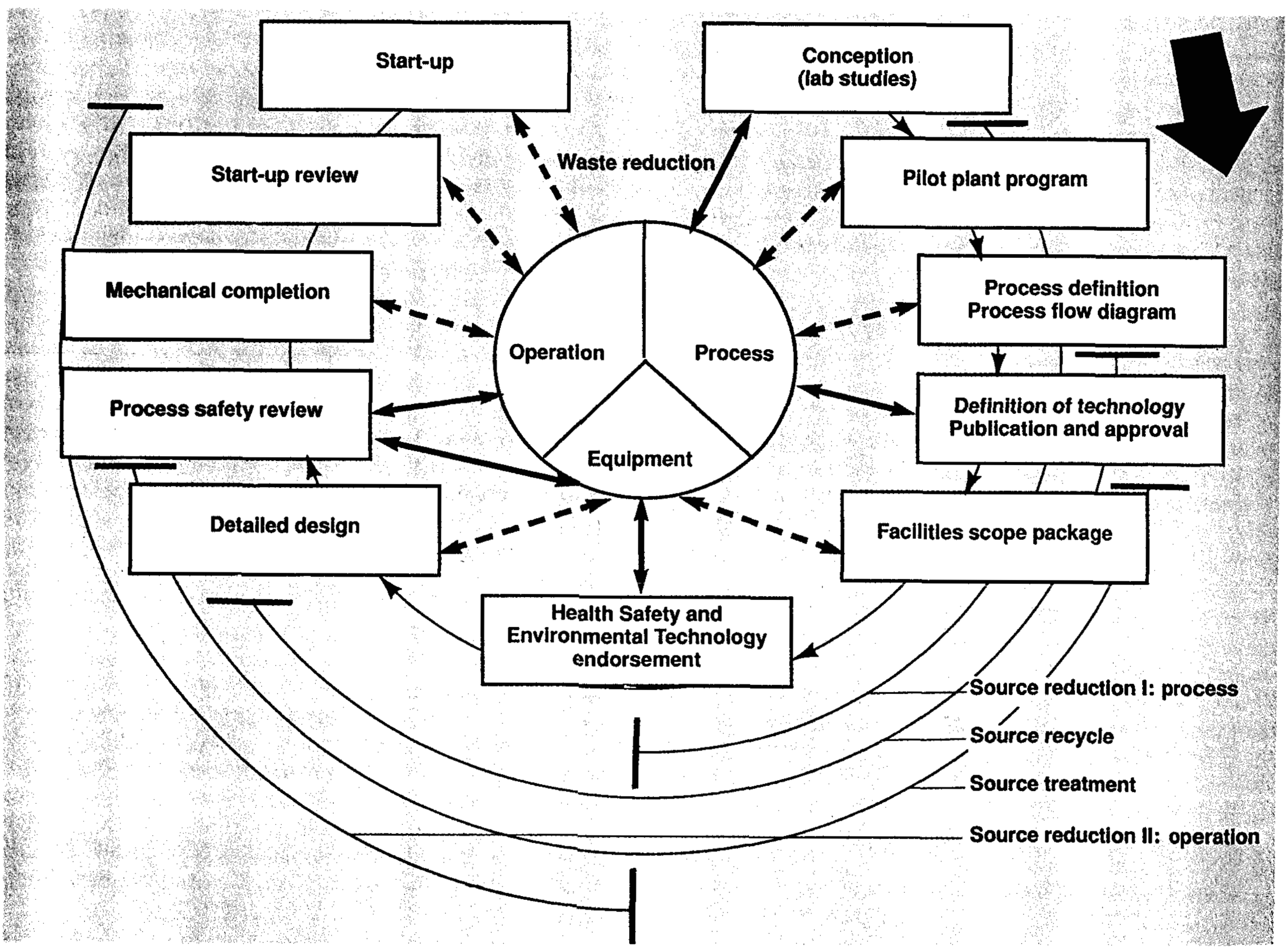

Figure 1. **Waste reduction and new technology development**

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Table 1. **Suitability of waste management options checklist** *(2)*

Technical
- Is technology available and usable without modification?
- What major equipment modifications are needed?
- Are there major waste modification or pretreatment needs?

Environmental
- How will waste be reduced in volume or hazard?
- Will secondary releases, now or in the future, result in new air, water, or solid waste pollution problems?
- Could the technology result in any new worker safety problems?

Regulatory
- Will the technology result in wastes of less regulatory concern?
- Can permits realistically be obtained in a reasonable time frame for the technology?
- Will additional regulations be imposed that could result in additional air, water, or solid waste controls?

Public acceptance
- Will the use of the technology to reduce the waste at the proposed location be acceptable to the citizens (or political groups) affected by the operation?

Economic
- What is the cost compared with other technologies?

developed, when the final technology is defined, when the process unit is designed and engineering specifications prepared, and when the unit is constructed and started up.

The emphasis at each stage of a new technology development program varies. After the process is conceived and laboratory- and pilot-scale studies are initiated to define the process, the emphasis is on the process itself. Once the process is defined and the facility is being scoped and designed, the emphasis moves to the equipment needed for the process. With the completion of the engineering design and purchase of the necessary equipment, the emphasis moves to the successful installation and operation of the process. Each of these stages of new technology development focuses on a different aspect of the process; each needs a different approach to waste minimization.

Conception of technology

Source reduction opportunities are most effectively considered after exploratory researchers define a desired product and during the early stages of process development (conception, laboratory studies, pilot-scale studies). A key aspect of the waste minimization program at this time is to develop an appropriate mass balance around the process. This mass balance needs to be as comprehensive as possible, including the fate of trace contaminants in raw materials, degradation products, catalysts, sorbents, and cleaning solvents. After assessing the wastes that would be coming from the process, the following checklist is completed for each waste stream (*2*):

- How is the waste generated?
- Why is the waste generated?
- Is it hazardous?
- How can its volume or quantity be reduced?
- How much will it cost to reduce its volume and toxicity?
- Is it economically practicable to reduce its volume and toxicity?

The goal of the researcher should be a process that gives minimal nonusable by-product formation. Thus, source reduction would be emphasized at this stage of the operation (though source recycle might also be considered). The modifications recommended during this stage include: improved controls, minimizing water or solvent use, waste stream segregation or concentration, change of reactants, optimized reaction conditions, improved catalyst, internal recycle, and avoidance of contact between water and organics.

Definition of technology

Continued consideration of opportunities for waste reduction during process development and definition is vital to a successful waste minimization program. A significant milepost in the development process occurs at Union Carbide when the Definition of Technology (DOT) document is prepared. The DOT document is prepared by the research and engineering team developing the process, for review by project management for business viability, and by the Heath, Safety, and Environmental Technology (HSET) department for potential concerns. During development and review of the DOT, a more extensive examination of additional waste reduction and waste management issues can take place. In particular, the development and review of the DOT Health, Safety, and Environmental Affairs section (HS & EA) will:

Identify critical data and technology necessary for the design and operation of a safe, health-conscious, and environmentally sound facility;

Collect the available critical data and **document** the resolution of any HS & EA critical issues that can be resolved at the DOT stage; and

Develop action plans for obtaining any unavailable critical data or resolving any outstanding critical issues.

This stage in the development process occurs, however, when most of the options for reducing waste through process or raw material changes have already been considered, and serves as a formal review of these activities. Reducing waste at this stage will involve changes in process configuration, equipment selection and specification, waste recycle, waste treatment at the source, and waste management.

A critical question is asked of the researcher in preparing the DOT documentation:

As a result of a waste minimization opportunities review process, have process wastes, waste streams, or gaseous emissions been eliminated, recycled, or treated to reduce toxicity? If so, summarize these streams and the waste reduction practice initiated.

For all remaining process wastes, waste streams, and gaseous emissions, summarize alternatives for reduction, recycling, or treatment considered.

A summary of possible waste reduction options is provided to the researcher to serve as a starting point for assessing opportunities. These are listed under the general categories of process changes, recycle, treatment at the source, and administrative controls.

The researcher and review team are asked to use a detailed checklist (Table 1), adapted from reference 3, to assess the applicability of these waste reduction options. Clearly, the proper completion of this checklist requires the interaction of individuals knowledgeable

PROCESS: __________
DIVISION: __________
LOCATION: __________

FORM G-1

SUBMITTED BY: __________
DATE: __________

ENVIRONMENTAL DATA - WASTE REDUCTION DESCRIPTION

WASTE STREAM MINIMIZED	TOTAL DISCHARGE RATE	COMPOSITION	WASTE MINIMIZATION APPROACH CONSIDERED	REASON FOR REJECTION	WASTE MINIMIZATION APPROACH USED	ANTICIPATED CHANGE
GASEOUS						
AQUEOUS						
RESIDUES, SOLIDS, SLUDGE						

Figure 2.
The waste reduction description form

PROCESS: __________
DIVISION: __________
LOCATION: __________

FORM G-2

SUBMITTED BY: __________
DATE: __________

ENVIRONMENTAL DATA - WASTE STREAM DESCRIPTION

WASTE NAME	NORMAL OR ABNORMAL	CONTINUOUS OR INTERMITTENT?	TOTAL DISCHARGE RATE	COMPOSITION	PROBLEM CHEMICAL LIST?	RCRA HAZARDOUS WASTE?	PLANNED DISPOSAL TECHNIQUE	LBS WASTE PER LB PRODUCT*
GASEOUS								
AQUEOUS								
RESIDUES, SOLIDS, SLUDGES								

Figure 3.
The waste stream description form

Table 2. **Waste minimization areas considered during the DOT review**

Minimizing method	Number considered	Number adopted
Process changes	48	31
Recycling	59	27
Source treatment	8	9
Administrative controls	17	13
Total	132	80

Table 3. **Alternatives for waste reduction**

Process changes	Changes in operating procedures
	Changes in process control
	Substitution of chemicals
	Better quality materials
Recycling	In-process recycling
	Regeneration and reuse
	Use as a fuel
	Sale
Administrative changes	Minimize washdown
	Reduce cleaning frequency
	Longer turnaround periods
	Improved spill control

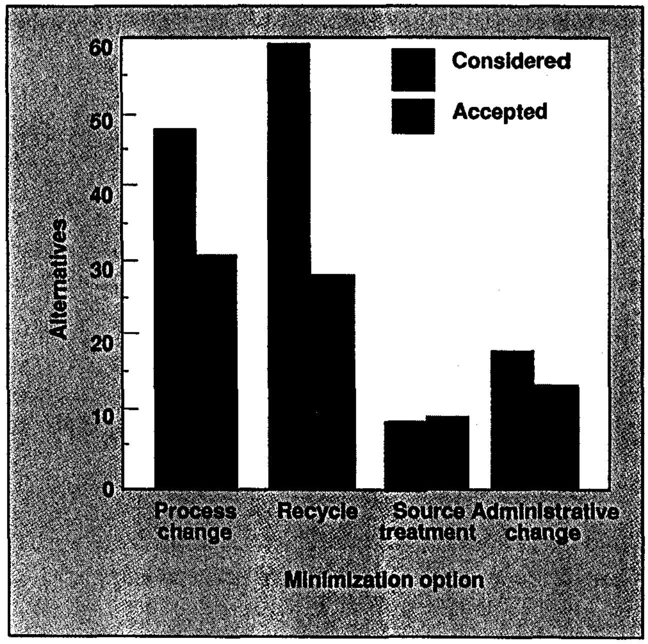


Figure 4. **Waste minimization alternatives**

about the process, waste reduction technology, and environmental regulations. Hence, the development of the Waste Minimization Opportunities Review team.

In addition, two forms are completed by the researcher prior to the DOT review (Figures 2 and 3), to document waste reduction considerations that have been incorporated into the proposed process configuration and to lead the DOT review team to consider additional waste minimization opportunities. Readers are encouraged to use an enlarging duplicating machine to copy these forms for their own use.

How has the process worked?

Union Carbide's Waste Minimization Opportunities Review was initiated in the fall of 1987 and about 30 new processes have passed through this review. New technology for which DOTs were reviewed included those representing modifications to existing units, addition of new operations to existing units, installation of existing operations at different plants, and development of entirely new processes.

Of these 30 Definition of Technology documents, 25 completed the Waste Minimization Opportunities Review and 132 different waste minimization opportunities were considered. Eighty waste minimization alternatives were selected for inclusion in the final technology for the process, with 17 (21%) utilized on the gaseous waste streams, 27 (33%) applied to the aqueous waste streams, and 36 (46%) adopted for the solid waste streams or residues.

Fugitive emissions and spills were not explicitly included in this summary of waste streams, as fugitive emissions control and spill prevention are addressed in all new processes through administrative and regulatory programs, and through special equipment designs for units handling chemicals of special concern.

The methods chosen

The waste minimization options that were proposed and adopted during the DOT review process were revealing. Of the four general categories used to summarize the waste minimization options, the overall distribution of alternatives considered and adopted is shown in Table 2, while Table 3 shows the possible options for each alternative. Waste minimization through either process changes or recycling accounted for 82% of the alternatives proposed, and 73% of the alternatives adopted (Figure 4).

Solid wastes. The majority of the proposed recycling-related alternatives applied to the solid waste streams, yet only 13 of these alternatives were eventually adopted (Figure 5a). On the other hand, 19 of the 24 alternatives for the solid waste streams which focused on changes to the process were eventually adopted. It appears that while recycling of a solid waste, residue, or sludge may be appealing when selecting alternatives, the best approaches are directed at process changes that assure that less of these wastes are generated in the first place.

Aqueous wastes. Only half of the process changes proposed to reduce aqueous wastes were adopted, compared with 75% of the recycling alternatives, 91% of

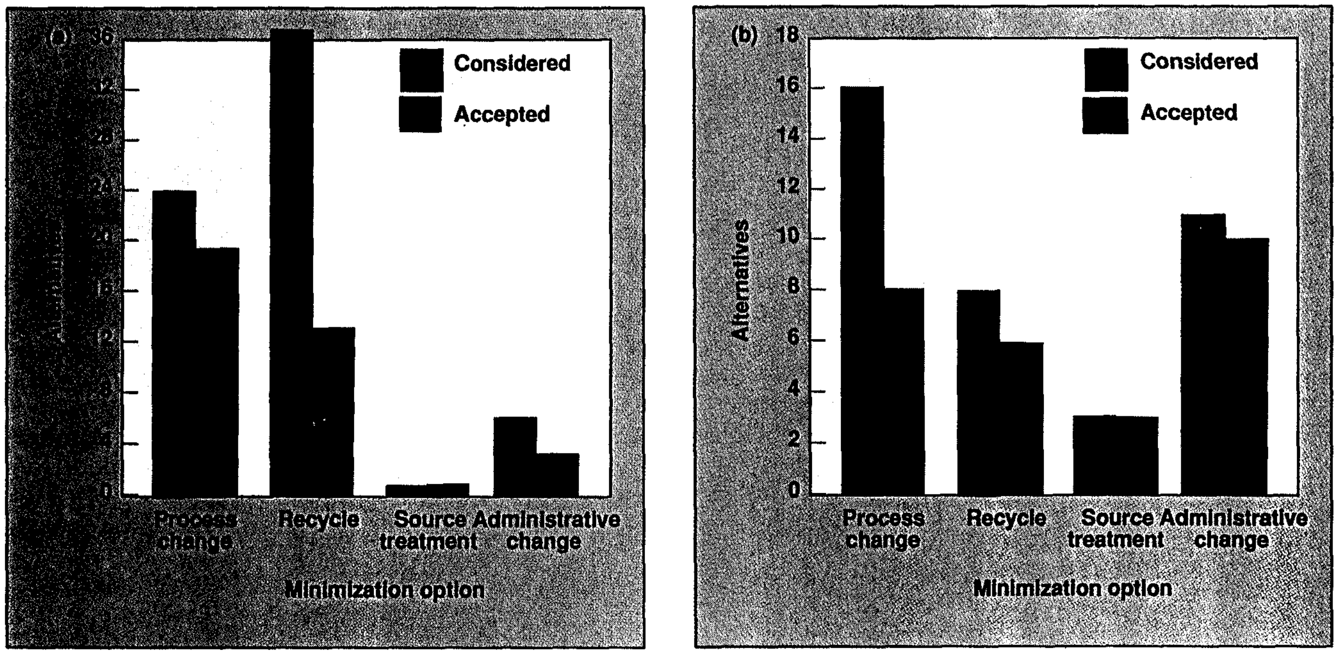


***Figure 5.* Options for minimization of (a) solid wastes,** **(b) aqueous wastes,**

the administrative control alternatives, and all of the source treatment alternatives (Figure 5b). Administrative control alternatives, shown in Table 3, were ideally suited to aqueous waste streams and readily applied during the DOT review process.

Gaseous wastes. For gaseous wastes, 52% of the alternatives proposed focused on recycling (Figure 5c), with the remainder addressing source treatment or changes to the process. Sometimes the option combined one or more of these alternatives. Administrative controls to reduce fugitive emissions will be adopted for all new processes, but such changes to reduce a gaseous process emission do not appear to be warranted. Unlike what was seen for solid wastes, recycling of gaseous wastes is a viable and preferred alternative for a good number of these operations.

Modifying the process for a copolymer unit

We wanted to put into operation a copolymer unit that would produce, utilizing various combinations of two different monomers and different process conditions, a variety of polymeric materials for which a market was already available. The review procedure allowed us to modify the process significantly to minimize the waste from it.

We identified three wastes during the review process that resulted from the steam stripping of residual monomer from product. A wastewater stream came from the condensed steam and monomer and an air stream came from the uncondensed vapors. There was a third solid-waste problem that could occur under inappropriate operating conditions. The air stream was small relative to the liquid stream and could be adequately controlled, but the wastewater stream needed more study and analysis.

We also identified an environmental release problem. All wastewater streams at this complex are sent to a wastewater treatment facility where the organic compounds are destroyed in a biological treatment system. During the waste stream review process, we estimated (from predictive models for the facility) that before entering the biological treatment system, about 20% of both monomer A and monomer B could volatilize to the atmosphere during transport and preliminary treatment. Although no regulations then applied to this volatilization problem, the site management concluded that the potential air emissions of these monomers would be unacceptable in the polymer operation.

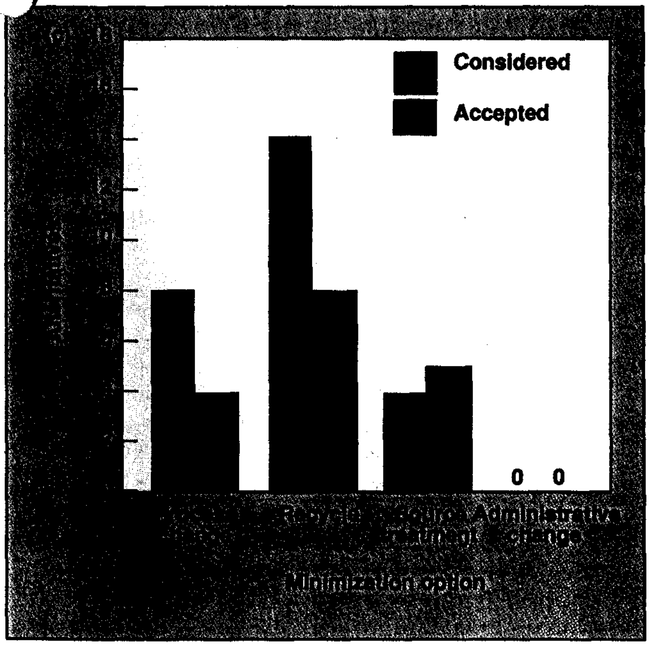
The multidisciplinary team

The team formed to develop the waste minimization program consisted of representatives of the R&D, Engineering, and Environmental departments at the research center where the process was being developed, and Operating and Environmental department representatives from the site where the process was going to be installed.

The initial activities of this team were to:

- Determine the source of the wastewater stream;
- Develop a list of approaches that might be used to eliminate the problem;
- Review the problem with the suppliers of the two monomers and solicit their aid in developing solutions; and
- Anticipate future regulatory trends that might affect the viability of any particular option.

After this review was completed, each option was



and (c) gaseous wastes

studied using these criteria: waste minimization potential, technical feasibility, time, cost, and uncertainties. The options were grouped into three categories corresponding to source reduction, recycle, and source treatment.

Source reduction. The catalyst used to initiate the polymeric reaction in this process results in a by-product solid that sublimes in the operation. To avoid buildup of this solid in the strippers (the third "solid" waste stream that could appear), all lines are kept hot until the solid is condensed by the direct injection of steam between jet stages. It is this solid that requires the use of a large amount of steam in the operation, and hence produces the wastewater being discharged. If an initiator were used that did not produce a problematic solid, a monomer stripping approach without steam could allow much of the monomer to be directly condensed and recycled into the process.

Other initiators had been considered during development of this process, and although the one selected had the best overall product yield, some others, which had good but lower yields, did not produce the problematic solid by-product. Therefore, the choice of a different initiator might eliminate all three of the waste streams for this process.

Preliminary data on the other initiators were available. But questions of yield, by-product formation, performance of the product, and safety of the alternatives remained unresolved. These questions could not be resolved without much more testing and this option was not selected. But a program to consider the options is being incorporated into the continued research for this area.

Recycle. Monomer A, a low-volatility compound that is only slightly soluble in water, could be separated from the concentrated wastewater at the source by installing a decanter at the unit. The recovered monomer could be recycled back into the process. This option was readily accepted and preliminary assessments are that a substantial amount of monomer A may be recovered in this operation. But, because of other impurities in the decanted liquid (including monomer B), we need to determine how much of this stream can be recycled and how much additional treatment may be necessary. As these options are being reviewed, a portion of the recovered monomer that is not recycled into the process can be used as fuel at the plant site.

An existing (but unused) monomer recovery column at the plant site could be used to strip both monomers from the condensate stream before it is discharged to the wastewater treatment system, but this column was no longer being used because of fouling problems. Substantial study of fouling inhibitors would be needed before this option would be acceptable.

Source treatment. The recycle option discussed above was accepted for monomer A. The supplier of monomer B suggested reacting it with a reagent at elevated temperatures to form a nonvolatile by-product, then discharging the wastewater to the treatment facility. This required that a reaction system with a heat exchanger be installed at the process unit, and the optimum reaction conditions be evaluated. Although this option would not actually reduce the waste leaving the process unit, it would eliminate entry of the monomer or any by-products into the environment. After evaluating the cost of this option, and determining that the reaction kinetics would favor a rapid conversion of the monomer, it was selected for use in the process.

Two options that focused not on the process in the polymer production area, but on the process in the wastewater treatment facility, were also considered. One option proposed modification of the wastewater treatment facility to eliminate the contact between the air and wastewater and thus minimize the volatilization potential. The second option proposed to pump the wastewater directly into the biological treatment system, and hence bypass the air emission points in the operation. However, neither of these approaches could assure the reduction achieved with the accepted options, nor could they guarantee that the treatment system could handle the direct discharge of a waste stream during an upset. In addition, either or both of these options might be inconsistent with future regulatory developments.

What we learned

Two successive waste minimization options were selected to remove the two monomers from the wastewater stream: monomer A was recovered, monomer B was removed through treatment at the source. Our preference would have been to eliminate the generation of the waste containing the monomers at the source, but time constraints made that impossible. That sort of process change to eliminate the generation of waste streams must be considered as the process is conceived, and is seldom viable as a retrofit. However, the researchers involved in this study will include such considerations early in their next development studies.

The process works

The Definition of Technology (DOT) review is an excellent way to incorporate waste minimization into the early stages of the process development cycle. The Waste Minimization Opportunities Review team found additional waste minimization opportunities for every program passing through the review. Equally important, the review served to train process researchers developing the DOT documents, as well as the review team members, on the significance of waste minimization as a long-term objective of Union Carbide in all areas. Once a researcher has participated in a DOT review, waste minimization lessons learned can be applied as a new process is developed.

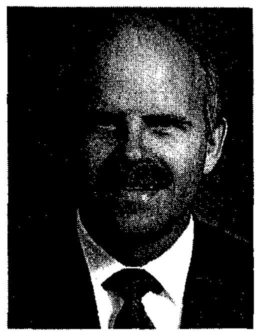
However, what we've described here is only part of the answer to the waste minimization problem. Fundamental changes to the technology can best be addressed during the initial conception of technology. As researchers learn to think of reducing waste from the start of any developing process, industry will be able to make significant progress in reducing the waste it generates.

References

(1) Ward, H. C. *Union Carbide's Progress in Reducing Waste Generation;* Paper #89-78.4, presented at the 1989 Annual Meeting of the Air and Waste Management Association, June 26, 1989, Anaheim, California.

(2) Moran, P. J. "Rohm and Haas Survey Results" In *Waste Reduction: The Untold Story;* Proceedings of Waste Reduction Conference; Tufts University: Woods Hole, Mass., 1985.

(3) Geiser, K. "Critical Elements of a Waste Reduction Plan" In *Hazardous and Solid Waste Minimization;* Government Institutes: Washington, D. C., Feb. 19–20, 1986.



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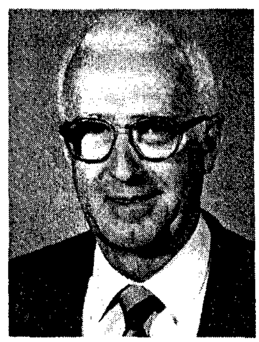

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And there is the unspoken possibility that Saddam Hussein will do real damage to Kuwait's oil fields and take the country's production off the market for an indefinite period. Questioned about that possibility, Sheikh Ali Khalifa Al-Sabah, Kuwait's Minister of Finance, said, "There are some things we will not discuss. That is one of them."

But talk to knowledgeable oilmen, and there is real fear that if Iraq blows Kuwait's wellheads, the wait for that oil could be years. There would be two significant delays. The first would come in putting out the fires. Kuwait's fields are under huge gas pressure, and the resultant firestorm from the destruction of 1500 wells would be enormous. Says Martin Kelly, a snubber for the Houston-based oil well firefighting specialist Boots & Coots: "There is the good possibility that because of the well spacing, wells that were put out could reignite. So we just don't know how long it would take."

Robert Rasor, a consulting engineer with a Houston-based reservoir specialist, Miller & Lents Ltd., says the real problems begin once the fires go out. The availability of drilling rigs, tubing, and new wellheads would be a first hurdle, followed by the availability of manpower. Says Rasor: "If you look at the time it has taken to develop Kuwait, you know you can't replace it in even two years." Marilyn Wilson, a vice-president at Gray Engineering, describes the nightmare this way: "In Kuwait, it would probably take five or six years to get the fields back on line. If we bombed Iraq, then of course we would be looking at $40 oil for the rest of my lifetime."

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SUMMARY FOR Berglund, 1990

3.d Global, integrated view of manufacturing: Berglund, 1990: HE STATES THAT A graphic depiction of globalization of P2 concepts in figure 1 integrates the ideas of source reduction, recycling, etc, and also presents the relationship of process development from conception through lab, pilot plant, and commercialization. The further along in the development the process is, the more difficult and costly are P2 efforts to implement. Waste reduction can be formalized by the use of standardized evaluation protocol and forms. Interdisciplinary team reviews are advocated to determine sources, identify alternatives, work with raw material suppliers and evaluate options in terms of future regulatory factors.:MY COMMENTS Figure 1 may be useful in a modified form. This same subject is referred to also in Smith, 1994 (CHMR draft document) under sections 3.1 and 4.1. The forms on page 742 of the reference are useful. In a general way, this is good information.

3.j Process alternatives: Berglund, 1990: HE STATES THAT Mass balance is an important tool, including the fate of trace impurities in raw materials, in evaluating conceptual process options at the lab and pilot plant stage. Several important questions to ask are: How is waste generated?, Why is it generated?, Is it Hazardous?, How to reduce volume or toxicity?, What are the economics of reduction?: MY COMMENTS This is useful.

3.a Design stage planning for processes and products: Berglund, 1990: HE STATES THAT Criteria for technology selection are presented in Table 1, including technical, environmental, economic and political.: MY COMMENTS Table I may be useful in modified form.

3 General PP Techniques: Berglund, 1990: HE STATES THAT Table 3 gives some P2 alternatives.: MY COMMENTS The information in Table 3, when expanded and integrated with similar tables in other references, may be useful.

1.d Types of Waste: Berglund, 1990: HE STATES THAT A study of 30 P2 projects at Union Carbide (a manufacturer of textile chemicals) showed that 21% related to gaseous waste, 33% to wastewater and 46% to solid waste. Fugitive emissions and spills are also recognized as important. Waste reduction by recycling generally is most prevalent for solid waste (my comment: due to its ease of capture). Process modifications were more prevalent for water. About 60% of proposed process modifications and about 80% of administrative changes in this study were actually adopted commercially.: MY COMMENTS This is useful introductory information for sections 1.d.i-iv.