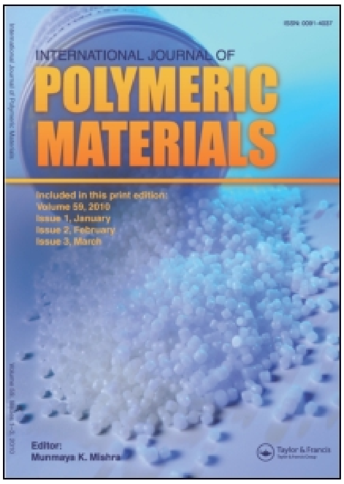

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

Technological Options in the Re-use of Polymers: A Technological Forecast Study

H. P. Schreiber[a]
[a] Department of Chemical Engineering, Ecole Polytechnique, Montreal, Canada

To cite this Article Schreiber, H. P.(1978) 'Technological Options in the Re-use of Polymers: A Technological Forecast Study', International Journal of Polymeric Materials, 6: 3, 197 — 215
To link to this Article: DOI: 10.1080/00914037808077909
URL: http://dx.doi.org/10.1080/00914037808077909

Intern. J. Polymeric Mater., 1978, Vol. 6, pp. 197–215

Printed in Reading, England

Technological Options in the Re-use of Polymers: A Technological Forecast Study

H. P. SCHREIBER

Department of Chemical Engineering, Ecole Polytechnique, Montreal, Canada

(*Received July, 1977*)

Through the use of a Delphi-round of questions posed to individuals concerned with the problem of resource recovery from polymers, an attempt was made to discern the development of alternative technologies for polymer re-use in the period up to the year 2000. Respondents were asked to consider the balance of opportunities and drawbacks for technologies including landfill, incineration, pyrolysis, recycle, UV and biodegradation. Economic, political, societal, ecological and other driving forces for the development or abandonment of technologies were considered. The study, while very limited in scope, showed a significant swing away from entrenched technologies for polymer disposal, notably landfill, and a corresponding growth in the development of pyrolysis and recycle operations. Strong resistance was detected to polymer collection/separation steps required at the end-user stage, coupled with a broadly expressed willingness to use recycled polymers in end uses including packaging and construction. Significant scepticism was expressed on the broad applicabilities of UV or biodegradable plastics, at least in the time-span relevant to this study.

INTRODUCTION

The process of decision-making is vital to the shaping of individual, corporate and global destinies. At no time in history has that process been more complicated than it is today. There are many reasons for this: the unparalleled growth of technology and the subtle, frequently long-delayed consequences of its use, must be counted as one of the more important of these reasons. In this respect the scientist and engineer is directly involved. Classically, his role has been that of an (ideally) detached professional, whose concern is the clarification of the laws of nature and the development of methods for their beneficial application. This simplistic definition no longer applies. The "golden" age of science and engineering has been replaced by one in which the decisions and actions in the technological sector are subject to close scrutiny, and even suspicion, by society at large.[1]

This new accountability arises from the close interdependence between decisions taken in the technological domain, and pressures or considerations arising from the domains of politics, economy, ecology and public opinion. Research, development, and the commitment of manpower and money to a given technical program can therefore be viewed as an aspect of decision-making which responds to, or is accountable to, developments and issues not necessarily technical in nature. The scheme of interdependence, patterned after Bright,[2] is illustrated in Figure 1.

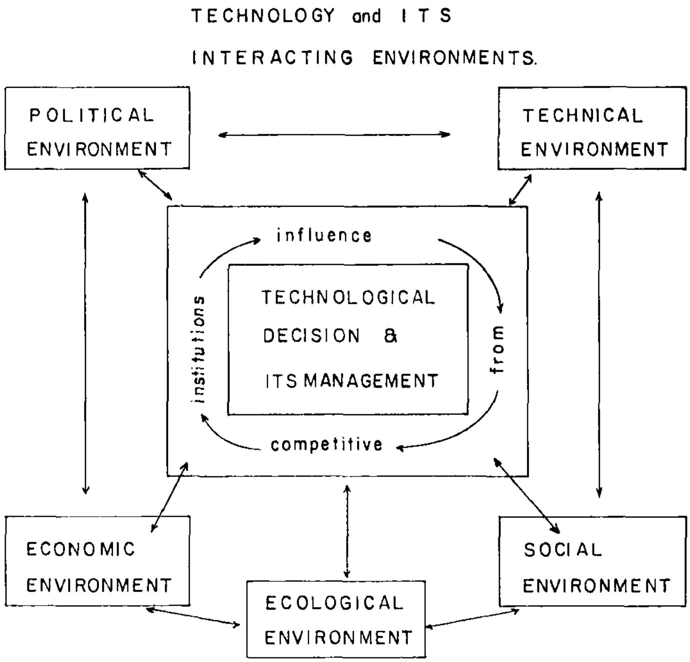

FIGURE 1 Schematic representation of interactions between technology and non-technical environments (After Bright, ref. 2).

The foregoing can also be viewed as a justification for the rapid development of a relatively new para-scientific activity, termed Technological Forecasting (TF). In TF methodologies have been developed whereby the complex cross-impacts defined in Figure 1 may be considered systematically in order to arrive at defensible and useful decisions involving the development, transfer or abandonment of technology. Increasingly used in governmental, industrial and scientific planning, the methodologies of TF have been the subject of much discussion,[2–6] the cited references being only a small representation thereof.

Inasmuch as the technological professions are clearly involved in the interdisciplinary tensions surrounding their activity, an introduction to TF as an aid to decision-making can be regarded as part of the teaching and research activity in engineering schools.[7,8] This paper presents the edited results of a brief TF exercise, employing the Delphi method,[2,3,4] and carried out by a team of students into the question of technological options in the re-use of polymers. It is, therefore, not a technical paper in the accepted sense of the term. Nevertheless, it merits presentation for two reasons:

i) It provides some insights into the attitudes of a cross-section of involved individuals on current and developing technologies in the field of polymer processing and disposal.

ii) It demonstrates one method whereby professional technologists can, at a very early stage of development, become sensitized to complex factors with which they will have to cope throughout their careers.

The team of graduate students involved in the study included:

(Ms.) Bernadette Bertin;
(Ms.) Marie O. Faber;
J. Bertin;
F. Boilot;
J. L. Cambon;
G. Thibault.

This team is principally to be credited for the development of the Delphi questionnaire, and for the time-consuming task of collecting and collating responses. Each of the participants is, in full measure, the co-author of the present report.

OBJECTIVE OF STUDY AND METHODOLOGY

The objective of the TF study was to consider alternative technologies available for the optimum utilization of polymeric materials, to establish trends which will define the technologies of major concern in a 15–25 year future span, and so to help define research programs designed to generate the needed or favored technologies.

The subject of optimum re-use for polymers is an important one. The unprecedented growth in the use of polymers, is such as to place the annual North American consumption by the year 2000 into the range of 70 million tons.[9]

Given the long-term stability of polymers and their widespread use in "throw-away" applications, given the high energy content of polymers, and assuming a persistent increase in the cost of energy resources, it becomes imperative to make optimum use of materials so rich in diminishing and costly commodities. Another view of this aspect is given in Figure 2. Prior to 1973 resin prices diminished according to rationalizable rules, such as those represented by experience curves.[2] The long-term outlook, as illustrated in Figure 2 by U.S. International Trade Commission report data, reflects the rising costs of primary source materials. Clearly, economic considerations will exert increasing demands for the repeated use of polymer stocks.

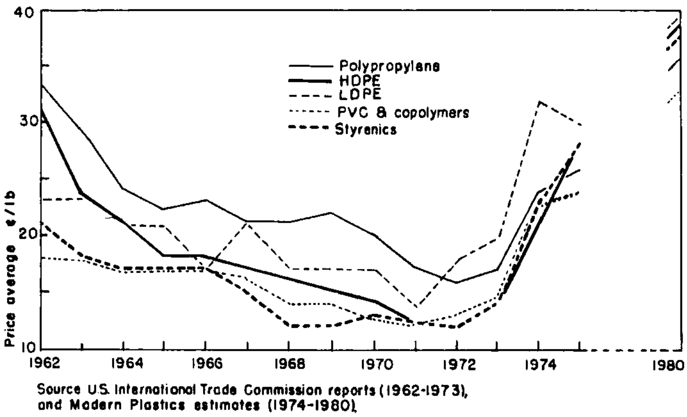

FIGURE 2 Showing forecast price structure to 1980 for commodity polymers.

METHOD OF INQUIRY

A simplified Delphi—or intuitive—TF exercise was conducted in this case. The Delphi method, originally developed by the Rand Corporation, has been widely used to establish longer range technological forecasts. Its strengths and limitations are fully discussed in standard texts on TF methodology.[3,4,5]

Essentially it seeks a consensus of expert opinion on questions critical to the future evolution of concerned organizations. It is subjective, depending both on the quality of questions posed to the respondents, and on the make up of the responding panel. The latter should be representative of as broad a cross-section of concern as possible. Statistical display of responses is used to minimize their inherent subjectivity and, in this case, care was taken not to force extreme opinions towards a "centre-of-the-spectrum" position. Since the respondents worked anonymously and without knowing the identity or opinions of their peers, the results are a valid technological forecast, though clearly subject to all the uncertainties associated with such exercises.[3,4,5]

PANEL OF EXPERTS

For the present study, a total of 28 respondents was selected. The following is the distribution of their concerns:

a)	Manufacturers of Polymer Resins:	5
b)	Converters of Polymers:	7
c)	Industrial and academic technologists in the field of polymer engineering and chemistry:	7
d)	Engineering consultants in materials and environmental controls:	4
e)	Non-technical users of polymers (public domain):	5

Representatives from managerial, sales, manufacturing as well as technical disciplines were included in categories (a)–(d). The sampling is somewhat narrow, a limitation forced by the time-intensiveness of the exercise.

QUESTIONNAIRE

The subject was developed in a total of 34 questions. These sought to identify the major trends in technological approaches to polymer re-use, as well as to establish the principal motivators for the adoption of such technologies. Questions were arranged into "motivator" categories—these including the spheres of economics, politics, society, environment as well as technology, as proposed in Figure 1. For reasons of relevance and space, the discussion to follow selects only a fraction of the questionnaire. Further documentation may be obtained from the author on request.

DATA ANALYSIS

In common with most Delphi studies, and except where otherwise specified, the present respondents were asked to specify a time in which a proposed event would occur. The time frame was limited to the year 2000 but the option of responding "never" was available in each case. Bar graphs of the number of replies *vs.* time were constructed and then converted to smoothed curves of % response *vs.* time. The latter representations are given here, since they readily allow for the definition of median responses as well as of opinion extremes. Each graph also states a confidence rating, R, defined by

$$R = 100 - \% \text{"Never"}$$

TECHNOLOGICAL OPTIONS

The technologies needed for the effective use and disposal of polymers are in continuing evolution and useful overviews of the technical aspects are readily available.[10] The high level of technological activity notwithstanding, it was assumed here that only those technologies already clearly discernible as economically and technically subject to large-scale development, would play a significant role in the 25 year horizon of this TF study. The rationale for this is the evidence concerning the slow rate at which technology diffuses from the laboratory and pilot stage into commercial use.[2–4] Historically, major innovations appear to take upward of 15–20 years to make a major *commercial* impact, hence leading to the stated decision.

The available or rapidly evolving technologies offered as future options to the panel of respondents, fall into five categories:

1) Sanitary landfill;
2) Incineration;
3) Pyrolysis;
4) Recycle by reprocessing;
5) UV and biodegradation.

No intensive effort was made to up-date the respondents on advances in the areas encompassed by the stated categories. In interviews associated with the completion of the Delphi round, however, some general elaborations were made.

Landfill Low technology response to largely aesthetic, ecological pressures. Does not really constitute useful recycle. No separation of plastic wastes needed. Suitable terrain in which landfill may be undertaken, however, becoming limited in certain areas.[11]

Incineration Modern incineration units used as sources for energy recovery; in mixed municipal wastes, plastics at about 15,000 BTU/lb contribute disproportionately with respect to mixed refuse at about 5,000 BTU/lb.[10] State-of-technology units (e.g. Montreal, Canada, Chicago, Ill. and Paris-Ivry), with capacities in the range 1,500 tons refuse/day capable of producing heating values in the range 2–5 lb steam/lb refuse.

Pyrolysis Destructive distillation of polymers in the absence of oxygen. Wide range of by-products include fuels such as charcoal and cokes, oils and gases with appreciable fuel values, organic acids, waxes for use in polishes, printing inks, mold-release agents, etc. Some indications exist that in pyrolysis of separated plastics, monomers for further polymerization may be produced.

Reprocessing Major upswing in reclaim and re-conversion operations, involves polyolefins, PVC[9–11] and other commodity polymers. Chlorinated polyethylene, intensive mixers (e.g. Reverser—Mitsubishi Petrochemical, Tokyo) and sophisticated extrusion units (e.g. N.R.M. Corporation's 24D system) represent chemical and mechanical means of converting random, often incompatible mixtures, thus avoiding need for separation/classification of wastes.

UV/biodegradability Important guidelines for biodegradability of commodity plastics now being established.[12] At least two systems have been developed[13,14] to render such plastics hypersensitive to UV radiation, thus speed degradation to low molecular weight species.

RESULTS AND DISCUSSION

While the principal goal of the TF study was to specify opinions on technological developments in the area of concern, the strong interdependence between technology and external environments, already discussed here, prompted a parallel inquiry into the motivators for technological development or change. The questions in this Delphi round were therefore grouped according to the environment to which they pertain, and the following presentation adheres to that grouping. In each case the question posed to the panel is stated and this is (usually) followed by the response graph, the confidence rating (R) and a brief discussion.

A. Economic motivators

A.1 The recycle of industrial plant wastes (polymers) is presently limited. Due to economic needs, what percentage of recycled plastics wastes will be in market uses by 1990? Break down the market for recycled wastes into the following categories, stating percentages: thermoplastics; thermosets; fibers; rubber. The response pattern is given in Figure 3a (overall % recycle) and Figure 3b for the breakdown into material categories.

A continuing growth in the marketing of recycled polymer is foreseen, with 25% of all polymers marketed in 1990 containing recycled material. The bulk of recycled material will come from thermoplastics, these accounting for 46% of recycled stocks. By 1990, some 14% of recycled stocks will come from thermosets, 18% from fibers, and rubber stocks account for 22% of the total. Panel members from polymer producing and processing organizations were more pessimistic about the contribution from thermosets and fibers, setting these in the range 5–10%. Accepting projections for polymer production,[9] some 9 MM metric tons of recycled polymer will be marketed in North America by the last decade of the century.

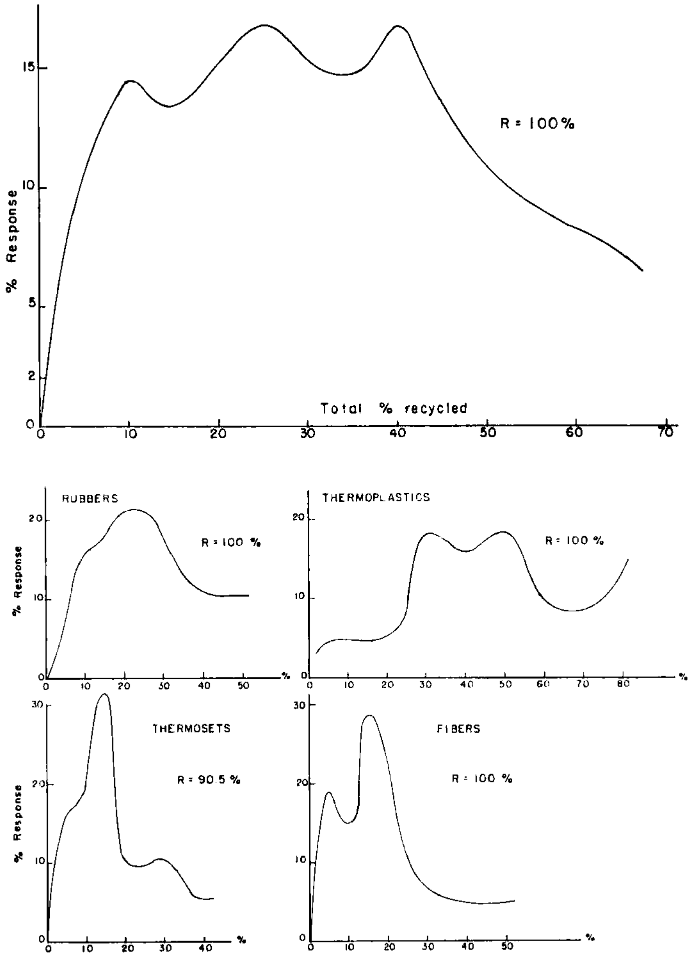

FIGURE 3 (a) Forecast for total % of plastic materials to be recycled by the year 1990. (b) Break-down of above response into contributions from major categories of polymer products.

A.2 Will a continuing crisis in energy costs and availability promote the massive recycling of plastics? If your answer is positive, define a date for the development.

The response pattern in Figure 4 indicates a mean date of 1987 for an energy-motivated upswing in the re-use of polymers. The distribution is rather broad however, with significant peaks in the 1980 and 1990 range. The relatively high *R* value further underscores the importance of the energy motivation to the sampled group.

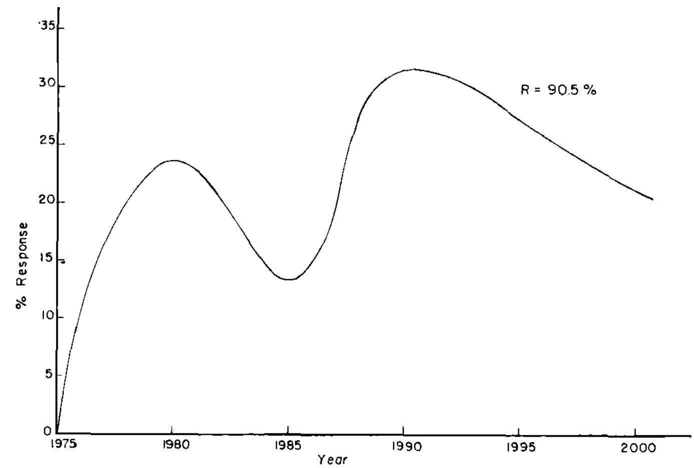

FIGURE 4 Forecasting the period in which plastics recycling will be motivated by energy cost and availability criteria.

A.3 Organized collection and effective separation of plastics wastes may be necessary for an economically viable recycle industry. When do you think will the necessary requisites be taken?

The response pattern in Figure 5 has two important features. The *R* value of 59% indicates strong scepticism on the concept espoused in the question. Over 40% of the respondents either did not believe that organized collection and

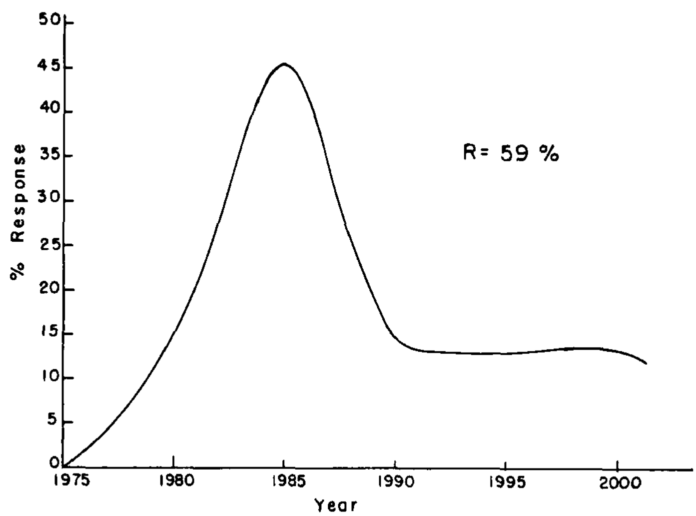

FIGURE 5 When will organized collection and separation of plastic wastes be practised? Note low confidence factor of 59%.

F

separation of plastic wastes is a necessary prerequisite for recycle, or felt unwilling to participate in the organization of an effort needed to create the stated situation. The roughly 60% of respondents agreeing with the basic concept of the question defined 1985 as the most probable date for its realization.

B. Political motivators

A total of eight questions was posed to clarify the role of this important motivator. The following are among the more pertinent points.

B.1 Presently in North America about 5% of primary resources (oil, natural gas . . .) is consumed in the production of petrochemicals. What will that percentage be in 1985, 1990, 1995?

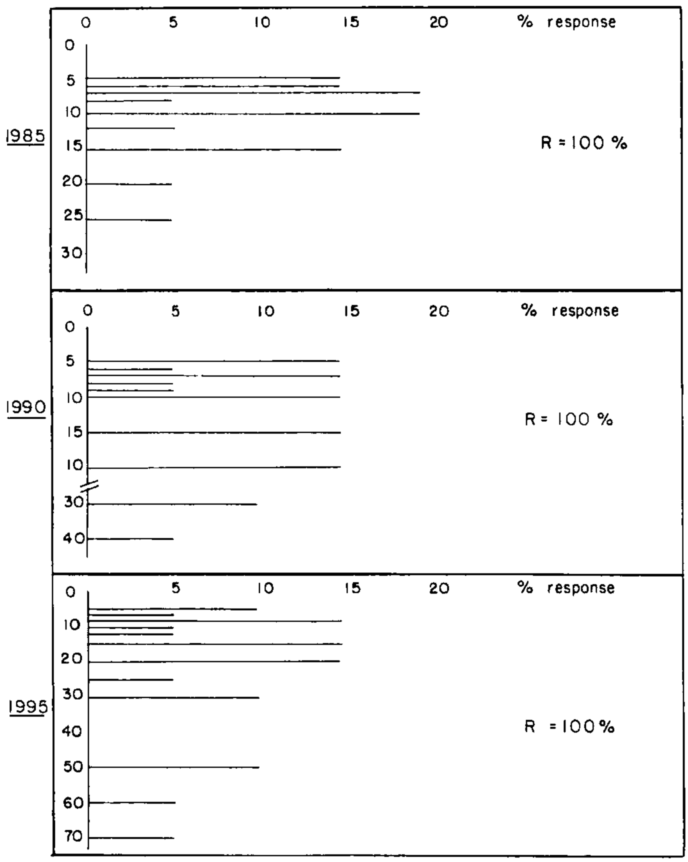

FIGURE 6 Forecasting % of total available energy consumed in the production of polymers by 1985, 1990 and 1995. (1975 level is about 5%).

The response pattern is given in Figure 6. Opinions range from a constant low of 5% to extremes in the 70% range at the end of the century. The means shift systematically upward to 9.5% in 1985, 12.5% (1990) and 16% (1995). It may be inferred that remaining primary resources will be preferentially allocated to the operation of secondary industries in the petrochemical field. The conclusion must be viewed against the make-up of the respondent group which did not include representatives from various levels of government nor from the oil/gas industries.

B.2 Municipal wastes are now being used as fuels in Europe. Will our *laws* encourage the spread of this practice in North America? If so, which governmental level will issue such laws?

The response pattern is given in Figure 7. The *R* value shows that slightly

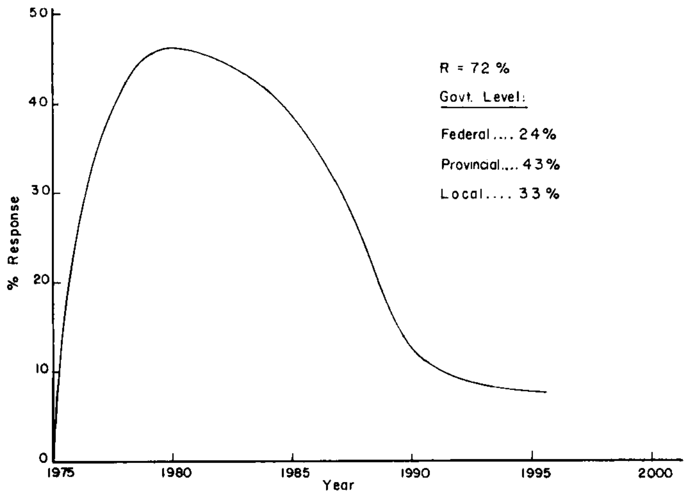

FIGURE 7 Showing trends in law enforcement of energy recovery from plastics wastes, and level of (Canadian) government likely to be involved.

more than 70% of opinion foresees the involvement of government in the recovery of energy values from plastic wastes. The mean date for this occurrence is 1983, but the 1980–1985 corridor is nearly equally weighted (the peak is very broad). Within the 70%-plus, strong involvement is foreseen at provincial (state) and local levels of government, the legislative role of federal bodies being relatively minor in this context. We note that the question posed did not specify which major technology is to be used in energy recovery. Respondents, however, generally assumed that *incineration* would be involved.

B.3 Do you foresee government involvement relating to the production of plastics deemed "unsafe"? (If so, do you foresee the development of substitute polymers in these cases?)

This question was "loaded", in the light of recent adverse publicity on the carcinogenic nature of vinyl chloride *monomer*, and on other suspect components usually associated with PVC technology.

Relating to government restrictions on the production of hazardous polymers, the responses were: 54% yes; 46% no. The "yes" group was large enough to include a significant representation from panelists who were fully aware of the difference between toxicological hazards of monomers versus those of polymers. There was 100% agreement that suitable substitute polymer compositions would be found if (by 1990) the governmental regulations were effected. The response, while intriguing must be viewed in the light of the restricted size and make-up of the responding panel.†

C. Societal motivators

These are often among the most subtle sources for defining the use and development of technology. The following is an illustration of the approach taken.

C.1 Would you agree to use recycled polymers? If yes, in what use category among the following? If no, state reason.

Table I summarizes the opinions derived from the Delphi round. The positive

TABLE I
Attitudes toward use of recycled polymers

Would you use items made of recycled polymer stocks?	
Yes: 90%	
No: 10%	
Product: % positive response	
Packaging	82
Construction mat.	73
Insulation	90
Tires	65
Furniture	80
Shoe bottoms, tops, other clothing	77
Requisites cited for use of recycled stocks (% of sampling)	
Quality standards	62
Safety in use	45
Appearance (aesthetics)	50
Hygienic acceptability	62

†Though it is totally irrelevant to the inquiry, it is interesting to note that within the group of authors of this study there was unanimity on the No position to this question.

response (90 %) demonstrates a broad acceptance of re-used polymers, and the equally uniform response as to use categories indicates that few inhibitions will exist in this respect. The listing of broad areas of concern is mainly of interest in identifying the apparent prerequisites for bringing about the positive consumer attitudes toward the use of recycled polymers. No measurable difference in attitudes was discerned between the technological and non-technological grouping in the panel of respondents.

D. Ecological motivators

The ecology motive is illustrated by three question/response pairs.

D.1 Do you consider plastics to be pollutants? If so, state the nature of pollution hazard.

Responses are given in Table II. A very high percentage of respondents consider plastics as environmental pollutants. While all respondents from group (e) replied positively, the number of positive responses from groups (a)–(d) was also high (69 %). This suggests that a clear majority of opinion in the technically and economically involved groups also considers (disposed) plastics as a pollutant. The inquiry leaves no doubt that the pollution hazard here is aesthetic or visual. Once again the toxicity rating may have been occasioned by recent publicity concerning the toxicological effects of various monomers.

TABLE II
The plastics pollution relationship (ecologic motivation)

Are plastics environmental pollutants?	
Yes:	82%
No:	18%
Main reason for pollution hazard	
Permanence (non-degradability)	45%
Aesthetics	42%
Toxicity	13%

D.2 Because of ecological considerations, disposable plastic containers, packaging, etc. will have to be made of degradable plastics (UV—or bio) by the year . . . .

This question followed logically upon the preceding, and elicited the result shown in Figure 8. The broad plateau in the range 1978–1990 has a median date of 1983, but this is to be viewed in the light of the 62 % confidence index. That is, a significant minority of opinion (38 %) replied "never" to this question.

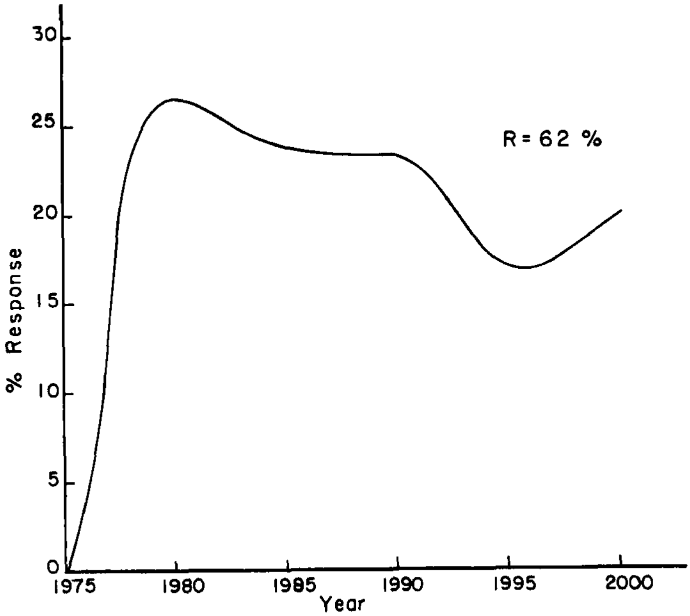

FIGURE 8 Disposable plastics will be made of UV or biodegradable plastics. % of positive responses *vs.* year in which event will occur; 38% of respondents replied "never".

The situation is therefore similar to that given for question *A.3* (Figure 5). Within the majority grouping, a fairly rapid penetration of technology was indicated, the general tendency being to favor already established methods[14,15] for conferring UV-degradability to polymers.

D.3 Do you consider ecological motives, as opposed to economic or technological ones, to be sufficient in themselves to stimulate the effective re-use of polymers?

The response pattern: 20% yes; 80% no, appears to be self-explanatory.

E. Technological motivators

The major single objective of the present study, to which the preceding sets allude, is embodied by the first of the technological questions.

E.1 Consider the alternative technologies for polymer re-use and evaluate their status in 1985, 1990 and 1995, according to the following code:

Code	*Technological State*
1	In experimental (laboratory) stage
2	Pilot plant-scale use
3	Industrial production (use) beginning
4	Full-scale industrial activity
5	Technology is obsolescent

The situation in 1976 was given as a guide:

Process	*Rating*
Landfill	4
Incineration	3–4
Pyrolysis	2
Recycling	2–3
UV-degradation	2
Biodegradation	1

Figure 9 represents the results of this inquiry. The R index for each segment is 100%. The conclusions to be drawn from Figure 9 include:

—*Landfill*, while continuing to be used extensively in the medium term (largely for reasons of simplicity and economy) will become increasingly obsolete as a method for disposal in the 1990's.

—Energy recovery via *incineration* will be practised increasingly on full industrial scales throughout the remainder of this century, though a tendency to phase-out this methodology is discerned in the long term.

—*Pyrolysis* and *recycle re-use* are the major growth technologies for the forthcoming 25 years. Both of these would appear to merit major efforts in R & D; their economic, ecological and public acceptability is high.

—Lower though significant growth rates are foreseen for *UV* and *biodegradation*. The former displays an appreciable "obsolescence" index beyond 1990; this is related to objections to degrade polymers and thus loose the values inherent in them. There is wide-spread scepticism on the feasibility of using bacterial processes on the scale of index 4.

E-2 Technology will allow the complete recovery of *industrial wastes*:
Thermoplastics by . . .
Thermosets by . . .
Composite materials by . . .

Figure 10 represents the three sets of replies. A very high level of confidence places the full re-use of industrial scrap in thermoplastics into the 1980–1990 range, with the median set at 1987. A 1985 peak is displayed for composite materials but at a lower confidence level, while the thermoset median of 1988 is to be viewed against the background of a 41% "never" response.

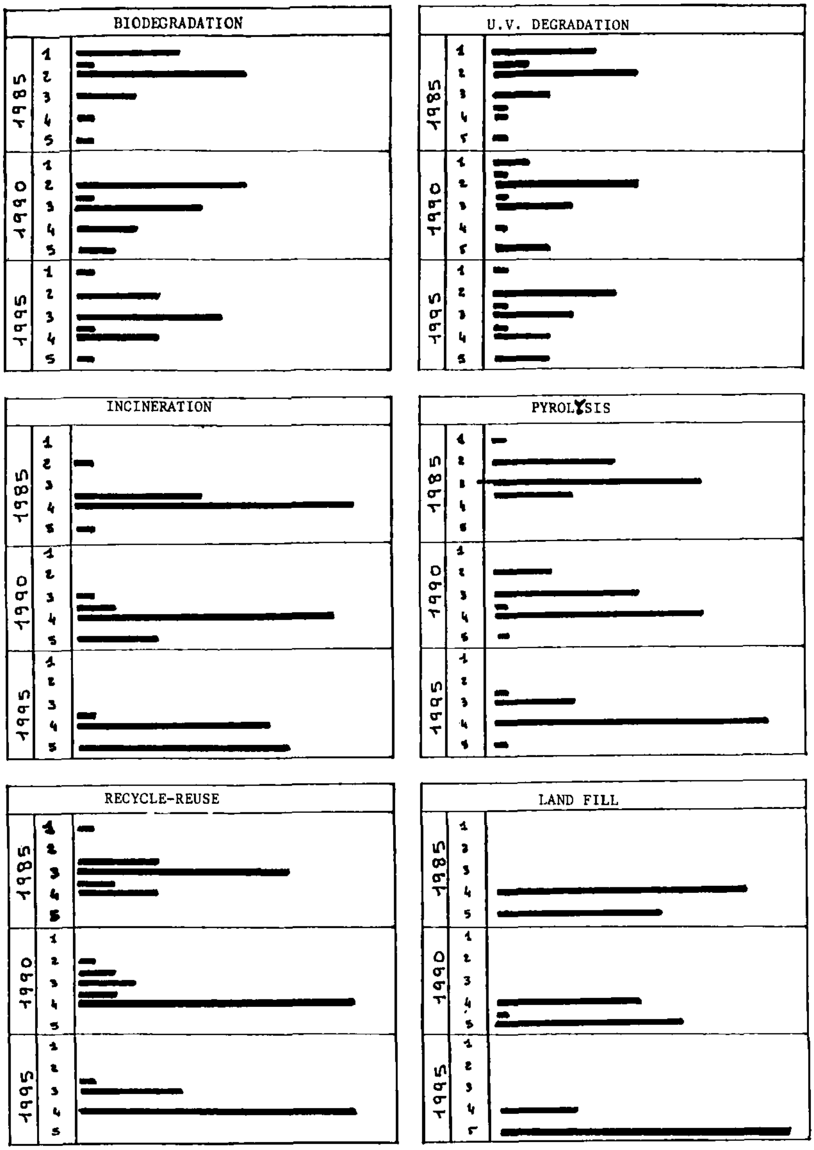

FIGURE 9 Showing the predicted evolution, to 1995, of competing technologies for polymer re-use/removal. See text for explanation of code numbers 1–5.

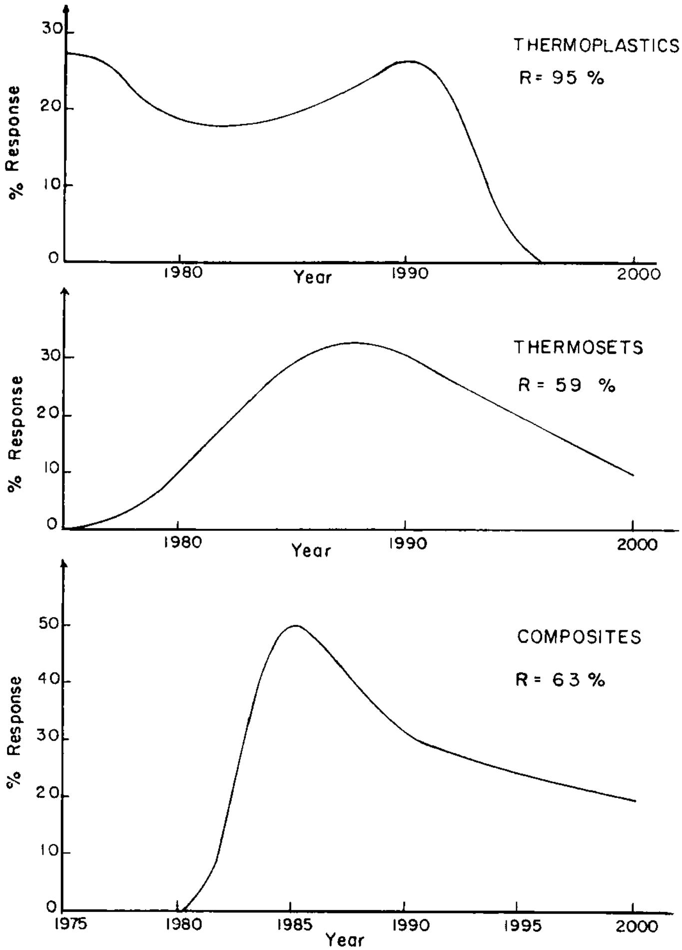

FIGURE 10 Response to: Technology will allow complete recovery of industrial wastes by . . . . Note break-down into product categories.

To supplement questions on the problems involved in collecting and sorting plastic wastes, a set of questions was posed exploring alternatives to this need. The following example illustrates the approach.

E-3 The need to separate plastic wastes will be eliminated or greatly reduced by the use of stabilizers or suitable mechanical mixers for the recycle of plastics by the year . . . .

The response pattern of Figure 11 gives a median of 1988 with a confidence

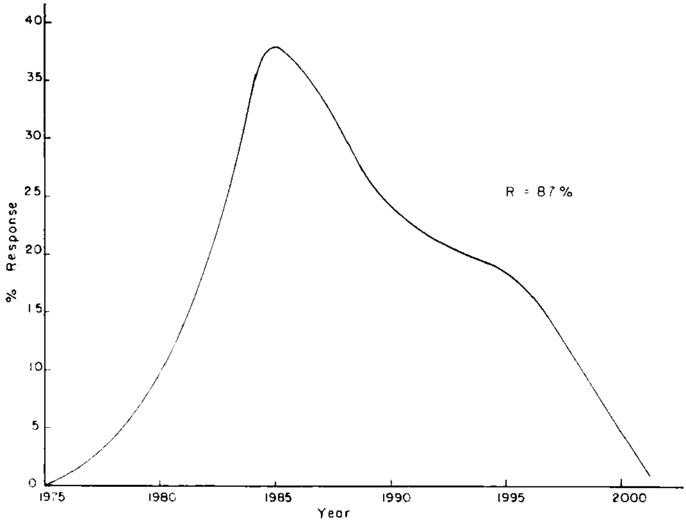

FIGURE 11 Forecasting the use of chemical or mechanical means for effective recycling of plastics as an alternative to separating plastic wastes.

rating of 87%. The response is internally consistent with the pattern displayed in Figure 5, and in questions not presented in this summary. It indicates a preference for the development of technology which will obviate the sociological as well as technical problems involved in the separation of various categories of polymer wastes.

CONCLUSION

The Delphi round, excerpted here, indicated broad support for the view that economic, social and ecological pressures will combine to motivate an efficient value use (recovery) in commodity polymers. Current landfill methods for disposing of polymer wastes are becoming obsolescent, with incineration and related recovery of energy values coming into large-scale operation. Strong growth rates are forecast for pyrolysis and recycle, and for the production of chemical and mechanical methods to make recycle feasible without the need to separate components of plastic wastes. Full re-use of thermoplastics is forecast, and lower but significant reprocessing of thermoplastics and rubbers is also foreseen in forthcoming technological developments. More limited use is foreseen for UV-sensitive or biodegradable plastics, the latter, however, facing appreciable consumer resistance.

Acknowledgements

We are grateful to the respondents of the present study for the time and effort devoted to it. The financial assistance of a Consortium of industrial and governmental organizations within the Province of Quebec (Canada) is gratefully acknowledged.

References

1. S. C. Florman, *The Existential Pleasures of Engineering*, St. Martin's Press, New York (1976).
2. J. R. Bright, *A Brief Introduction to Technology Forecasting*, The Permaquid Press, Austin, Texas. Chapters 1 and 6 (1972).
3. J. R. Bright and M. E. F. Schoeman, *A Guide to Practical Technological Forecasting*, Prentice-Hall Inc., Englewood Cliffs, N.J. (1973).
4. R. U. Ayres, *Technological Forecasting and Long-Range Planning*, McGraw-Hill Book Co., New York, N.Y. (1969).
5. M. J. Cetron, *Technological Forecasting—A Practical Approach*, Gordon and Breach Science Publishers, New York (1969).
6. J. P. Martino, *Technological Forecasting for Decision Making*, American Elsevier Publishing Co., New York, N.Y. (1972).
7. H. P. Schreiber, *Chem. Eng. Education* **9**, 184 (1975).
8. R. D. Deanin and C. C. Kourdocelakos, Proceedings 33rd Annual Conference, S.P.E., Atlanta, Ga., Vol. 33, 169 (1975).
9. C. O. Port, *Modern Plastics* **51**, 38 (1974).
10. *Recycling Plastics, A Survey and Assessment of Research and Technology*, International Research and Technology Corp., Society of Plastics Industry, 250 Park Ave., New York (1973).
11. R. S. Hayter, in Montreal Gazette, Aug. 29 (1974), p. 42.
12. J. E. Potts, R. A. Clendinning and W. B. Ackart, Paper presented at 1972 National Meeting, The American Institute of Chemical Engineers, St. Louis, Mo., May 24 (1972).
13. J. E. Guillet, *Polymers with Controlled Lifetimes*. In Polymers and Ecological Problems, J. E. Guillet, Ed. Plenum Press, New York (1973).
14. G. Scott, *Delayed Action Photo-Activator for the Degradation of Packaging Polymers*. In Polymers and Ecological Problems, J. E. Guillet, Ed. Plenum Press, New York (1973).