# Assessments of Regional and Global Environmental Risks

*Designing Processes for the Effective Use of Science in Decisionmaking*

EDITED BY
Alexander E. Farrell
Jill Jäger

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CHAPTER 11

# *Grounds for Hope*

## Assessing Technological Options to Manage Ozone Depletion

Edward A. Parson

DEBATE OVER GLOBAL environmental issues is typically dominated by questions of the reality, degree, and character of the environmental risk, and the associated scientific evidence and uncertainties. Scientific assessments that seek to advance understanding of these risks are the most frequently undertaken assessments, and they feature most prominently in subsequent policy debates. But these questions of environmental risk address only one side of the judgment required to decide how to respond to a risk. Such judgments must also consider the means available to mitigate the risk and their feasibility, cost, and consequences.

This second type of question, concerning technological options to deal with environmental problems, also depends in diverse ways on scientific and technical expertise and so can usefully be informed by expert assessments. These assessments are typically called "technology assessments" or "option assessments." They can address various questions, ranging from simply identifying potential technological, managerial, or policy options for managing risk, to characterizing a specific option's feasibility, state of development, effectiveness, cost, and other consequences with varying degrees of detail and specificity. Although both types of assessment depend on expert judgments, technical assessments of options differ from scientific assessments of environmental risks in multiple ways. They require different types of expertise, including practical engineering and managerial judgments as well as scientific knowledge and skill. They typically are established by different actors, employ different participation and procedures, address different questions in pursuit of different goals, and face different challenges. They often have more direct implications for action and more direct commercial consequences. They are most appropriately evaluated by different criteria, with technical and political aspects intertwining more closely than is the case in scientific assessments.

In general, the effectiveness of technological option assessments for global environmental issues has been low. One major recent study concluded that they have generally "failed to generate a cumulative body of reliable knowledge concerning alternative responses to global environmental risks" (Clark et al. 2001, *70*),[1] and have had little or no tangible influence on decisions. Even by the more lenient standard of influencing the agenda for decisions, the occasions in which option assessments have either placed or sustained potentially worthy but unpopular options on the agenda—or effected the removal from consideration of options definitively shown to be inferior—have also been rare (Clark et al. 2001, *72*).

This chapter discusses one striking exception to this general pattern: technological option assessments under the international regime to protect the stratospheric ozone layer. While option assessments in the early stages of the ozone issue were as ineffective as option assessments usually are, a series of assessments conducted under the international ozone regime since 1989 has departed sharply from this general pattern, achieving high levels of technical quality, practical utility, and influence that have not been equaled or even approached by any other option-assessment process for any global environmental issue. This case is unique, but it indicates a more general possibility that has not been exploited. Indeed, although technical option assessments have been less frequently undertaken, less frequently effective, and less prominent in policy debate than scientific assessments of environmental risk, this case suggests that they may hold far greater prospect for exercising decisive influence on policy debate and action to manage environmental risks—if the factors contributing to their strong influence in this case can be replicated elsewhere.

## Stratospheric Ozone Policy and Option Assessment, 1974–1985[2]

In 1974 two scientists suggested that various halogenated industrial chemicals, principally the chlorofluorocarbons (CFCs), risked destroying the stratospheric ozone layer that shields life on the earth's surface from harmful solar ultraviolet radiation (Molina and Rowland 1974). The publication of this claim was followed by an intense policy debate, which culminated three years later in decisions in the United States and three other countries to ban the use of CFCs as propellants in aerosol spray cans—constituting slightly more than half of worldwide CFC use at the time. Although it was widely recognized from the outset that the problem's scope was global, and consequently global action was needed to address it, several attempts over 10 years to control ozone-depleting chemicals internationally all ended in failure. One attempt in 1980 to broaden U.S. domestic controls to apply to all CFC uses, rather than to aerosols alone, also failed.

In these early policy debates and their outcomes, assessments of technological responses were sometimes conducted but never influential. They played little role in the decisions to ban CFC aerosols, because questions of the cost and difficulty of reducing aerosol CFCs figured little in policy debates. Rather, the availability, low cost, and relative ease of adopting other ways to package products—either nonaerosol formulations or aerosols using non-CFC propellants—were widely known. A few half-hearted attempts were made to argue that eliminating CFCs in aerosols would be costly or difficult, but in the face of evidence that alternatives were both technically feasible and commercially viable, these objections did not meet minimal standards of credibility.

In contrast to aerosol CFC uses, questions of technical feasibility and cost were both important and contentious in debates over controls on nonaerosol uses, and several attempts were made to inform these questions and delimit policy conflict by conducting assessments of potential technological and other options to reduce use. These attempts all failed, however.

The most important of these attempts were two assessments commissioned by the U.S. Environmental Protection Agency in 1979 to inform its consideration of comprehensive CFC controls. The assessments were conducted by the Rand Corporation and by a committee of the National Academy of Sciences (NAS). The two efforts were quite similar; indeed, the NAS assessment relied in part on data and analysis from an early draft of the Rand assessment. Both assessments tried to characterize present (at that time) uses of CFCs, to identify potential technological alternatives to reduce use and emissions, and to characterize the extent of feasible reductions. Both reached extremely pessimistic conclusions about the extent to which CFC use could be reduced or substituted with non-CFC alternatives. The Rand study constructed a marginal-cost curve for CFC reductions attainable at various price increments. It concluded that a tax of $1 per pound (a tripling of the market price) would reduce use by only 20 percent, and that reductions beyond 25 percent were technically infeasible "at any price." Conducting a purely technical analysis, the National Academy of Sciences study concluded that the maximum feasible reduction was 50 percent, and that even modest cuts would be highly costly.[3]

The conclusion that large reductions would be costly and difficult does not by itself indicate an inadequate study, although the extremity of both studies' conclusions gives grounds for skepticism. But the failure of these studies is directly evident in the details of their analysis. Both considered an extremely limited set of potential alternatives, which were almost entirely restricted to alternatives previously identified or used and rejected in favor of CFCs. New chemical alternatives being pursued by CFC manufacturers were not considered because their development was not complete. Therefore, the only substitution considered for most uses was a hydrochlorofluorocarbon (HCFC) called HCFC-22. Both studies adopted a presumption that only commercially available alternatives should be considered, that no adjustment of equipment or manufacturing process could be assumed, and that no significant degradation of product performance was acceptable. This approach created a huge bias toward the conclusion that nothing could be done. Although the National Academy of Sciences assessment identified widespread disagreement among technical experts over what reductions were feasible, it did nothing to reduce this disagreement or to explicate its foundations. The failure of these assessments contributed to the failure to enact the seemingly modest and reasonable 1980 U.S. proposal for comprehensive CFC controls,[4] because proponents were unable to make the case that CFC limits were feasible and their cost acceptable. Industry assertions that significant cuts would be difficult, disruptive, and costly met no effective response (DuPont 1980; *International Environment Reporter* 1980, *401*).

While the causes of failure in option assessments in general may be diverse, the causes of failure in these two cases are clearly related to the assessment bodies' inability to make technical judgments that were independent of industry-held information and industry biases. Authoritative technical information about potential alternatives was overwhelmingly held by the CFC manufacturers and a few major user firms. These parties were inclined to doubt that CFC limits were feasible at reasonable cost, and they had no interest in helping officials or independent assessment bodies make the opposite case. The assessment bodies, forced to rely almost entirely on industry sources for technical information about the availability, development status, performance, and costs of alternatives, were in effect asking industry experts how easily their firms could give up CFCs. Unable to develop the knowledge necessary to conduct an independent critical assessment, the assessment bodies adopted a framework and a set of assumptions that strongly biased their conclusions toward the status quo and the interests of the industries producing and using CFCs.

Subsequent attempts to assess prospects for CFC reductions through the mid-1980s, at both national and international levels, foundered on the same obstacles as the two earlier assessments. A brief attempt to assess CFC-reduction options under the Organization for Economic Cooperation and Development, as part of a broad integrated assessment of the ozone issue in 1981, met sharp opposition and was effectively reduced to a reprise of earlier assessments (U.S. EPA 1982; *International Environment Reporter* 1981, *826*; OECD 1981). After international negotiations on the ozone layer were first convened in January 1982, delegations could not agree how—or even whether—to convene technical discussions of CFC alternatives and controls. One existing international assessment body had these questions within its formal mandate, but the group repeatedly refused to address them out of concern that they lacked necessary expertise and that the questions risked politicizing the committee and damaging its scientific credibility (UNEP 1981, 1982). In the only further attempt to assess CFC reduction options prior to 1987, an ostensibly informal international workshop of experts, held in Rome in 1986, precisely mirrored the lines of conflict that prevailed in official international negotiations at the time. Participants could not even agree as to whether the cost of the original U.S. aerosol ban—by that time in effect for seven years—had been low or high (UNEP 1986).

## Establishment of the Ozone Regime and Its Assessment Bodies, 1986–1988

After several years of largely deadlocked negotiations, international management of ozone depletion advanced rapidly between 1986 and 1988, culminating in the signing and entry into force of the Montreal Protocol—the first international agreement with concrete action to protect the ozone layer. This rapid progress was driven by unique factors unrelated to the perceived ease of reducing CFCs. A group of activist officials gained control of the U.S. negotiating agenda and succeeded in sustaining an extreme international negotiating position (CFC reductions by 95 percent) against substantial domestic and international opposition. A shocking report of ozone loss in the Antarctic and claims that global ozone losses could be detected in a satellite record also helped strengthen the activists in their insistence on deep cuts. With a broad international consensus emerging that the appropriate treatment of CFCs was to freeze usage near then-current levels, the activists' persistence was largely responsible for a negotiated agreement to reduce CFCs by half.

Technical assessment of CFC reduction options had little if anything to do with this outcome. In fact, the technical basis for confidence that either 95 or 50 percent cuts were technically achievable at acceptable cost was extremely thin for countries such as the United States that had already eliminated aerosols. An unguarded industry revelation in 1986 had suggested that chemical CFC alternatives could be developed in 5 to 10 years, but serious problems were evident in applying these new chemicals to existing CFC uses (Alliance for Responsible CFC Policy 1986). Uncertainty over the feasibility of these cuts—including significant risks of disruption, premature capital write-off, loss of amenities, and bankruptcies in some usage sectors—was at least as serious as uncertainty over the character of the environmental risk.

But while progress in technical knowledge and technical assessment contributed little to the rapid formation of an international ozone regime, the new regime transformed the subsequent conduct of technical assessment and the significance of technical information. The Montreal Protocol required that parties periodically review the adequacy of the Protocol's control measures in view of advances in knowledge and capability, and it required parties to consider modifying the measures based on advice from expert assessment panels. Although the Protocol's adoption of concrete international CFC controls represented an important first step, these provisions for repeated review and modification of its control measures represented the most central contribution to the ozone-reduction regime's subsequent adaptation and ultimate success.

Panels were initially established in four areas: atmospheric science, ultraviolet effects, technology, and economics. These panels were organized, chairs were identified, and tentative designs and mandates were established at a series of informal consultations between key delegations and United Nations Environment Programme Director Mustafa Tolba, culminating in a series of workshops in The Hague in late 1988 (*International Environment Reporter* 1988, *210*). A series of design decisions made in these initial consultations were decisive for the subsequent effectiveness of the panels. Most importantly, organizational decisions made in the interests of fast work had the effect of substantially reducing the political control over the panels from what was originally envisioned in Protocol negotiations. Rather than authorizing a political body to supervise and integrate the work of four "reporting groups" of independent experts, each of these four groups operated with substantial independence under its chair. The chairs coordinated among themselves to synthesize and publish the four group's work, under minimal oversight by the main political negotiating body. In addition, the organizers of the technology panel made a decisive early choice that the body would rely principally on knowledge and participation from industry experts—although their concern about potential bias or capture is evident from their decision to exclude experts from the CFC producers from the panel, relying instead on experts from user industries and industry associations, as well as government, university, and nongovernmental organization (NGO) experts.[5] This controversial decision, made at the initiative of Mustafa Tolba with the support of several major delegations, reflected negotiators' mistrust of the CFC producers for their long history of obstruction, and it reflected their concern that these firms were too committed to their own chemical alternatives to assess other potential alternatives objectively.

## Technology Assessment under the Protocol, 1989–1999

The Montreal Protocol's technology panel, along with the other assessment panels, has conducted four full assessments since it was initially established—to advise renegotiations of the Protocol in 1990, 1992, 1995, and 1999. Although many aspects of the panel's operations have adjusted over time to meet the evolving needs of the Protocol, certain core elements of its organization and the questions it has addressed have remained constant. From the outset, the technology panel has repeatedly addressed central questions of what reductions in ozone-depleting chemicals are feasible in particular uses and sectors, and by what time. Feasibility has been defined, following initial guidance from the parties, as "the possibility to provide substitutes or alternative processes without substantially affecting properties, performance or reliability of goods and services from a technical and environmental point of view" (UNEP 1989b). Although the definition of feasibility was modified after 1990 to include economic as well as technical feasibility, the extent of feasible reductions has remained a single estimate, defined without explicit reference to the cost of alternatives (UNEP 1989c, *9*). The panel has addressed these questions by critically examining specific alternatives available and under development, including new production technologies, process changes, changes in product characteristics, and changes in management practices. To answer the questions of feasibility, the panel has relied on working groups assembling the focused knowledge of 15 to 50 experts, principally via a set of Technical Options Committees (TOCs). The committees examine alternatives for each major usage sector, such as refrigeration, foams, and solvents. Although participating experts have consistently included individuals from universities and governments (and government officials have provided leadership and administration), most participating experts have been from private industry, principally from user firms, engineering and consulting firms, and industry associations. Parties to the Montreal Protocol nominate experts to participate, but in practice the chairs of the technology panel and its TOCs have exercised substantial control over participation.[6] They have used this authority to identify expert and energetic people committed to solving problems, with sufficiently wide representation from affected industries in each usage sector to produce high-quality and credible results.

The first decisive phase of the panel's work took place in 1989, when it advised the 1989–1990 negotiations to revise the Protocol. In this round, only the central questions of the degree of feasible reductions in each sector were considered. The conclusions were shocking, in that they stated that at least 95 percent of CFC and halon consumption could be eliminated by 2000. The separate reports of each TOC provided backup, elaboration, and qualifications for this aggregate conclusion, and they illustrated the different degrees of difficulty identified in each sector. At one extreme, the reports found that aerosols could be eliminated immediately except for a few small medical uses; at the other, some long-lived refrigeration equipment would require continued servicing with CFCs to the end of its life, accounting for the few percent of CFC use that the panel judged might be needed beyond 2000. Only the halon TOC failed to reach complete consensus, with the committee splitting over the feasibility of further reductions beyond the 60 percent cuts they agreed were available from reducing nonessential uses and better managing existing stocks (Mauzerall 1990; UNEP 1989a, *3*; UNEP 1989b, *iv*).

This technology panel report, together with that of the atmospheric-science panel, strongly conditioned the negotiations to revise the Protocol in 1989 and 1990. Even before negotiations resumed, these results had prompted many governments and industry actors to endorse strengthening the Protocol to essentially eliminate the original five CFCs by 2000, while several had proposed even earlier phase-outs. The panels did not, however, eliminate all disagreement, but rather channeled discussion into second-order matters such as the precise dates of phase-outs, interim reduction schedules, and the need for a continued small CFC stock for servicing existing equipment. Even on the question of extending controls to new ozone-depleting chemicals, particularly the solvent methyl chloroform—a controversial point, which brought new industry actors into the negotiations, and on which the panel's work had been more hasty and less well-grounded than for other sectors—the panel's judgment of feasible reductions prevailed over contrary claims by industry, and it was subsequently shown to have been correct by the reductions actually achieved (ENDS 1989; UNEP 1989b, *v*).

After the striking success of its first assessment, the technology panel was reorganized in 1991 to absorb the economics assessment panel—whose work in 1989 had been unsuccessful, in large part because it was divorced from technology—to form the new Technology and Economics Assessment Panel (TEAP). In the next major assessment, conducted to support negotiations for further Protocol revisions in 1992, TEAP once again addressed the central questions of what further reductions in ozone-depleting chemicals were feasible—now with experts from CFC manufacturers participating, and with broadened participation of developing-country experts. In addition, TEAP addressed other specific questions at parties' requests, including the earliest possible date to eliminate methyl chloroform, the likely need and availability of ozone-depleting chemicals for developing countries, and the extent to which eliminating CFCs would require use of HCFCs—transitional chemicals marketed as CFC alternatives that also depleted ozone, but by only a few percent to 15 percent as much as CFCs. As in 1989, the panel reached strong conclusions about the feasibility of further reductions. Noting that progress in reducing ozone-depleting chemicals had been more rapid than anticipated two years earlier, they concluded that substantial further tightening of targets was feasible, eliminating virtually all CFCs, halons, and carbon tetrachloride by 1995 to 1997, and methyl chloroform by 1995 to 2000. Achieving the accelerated phase-outs would also depend on several conditions being met, including increased short-term use of HCFCs (UNEP 1991).

This assessment also saw the panel begin to address operational questions of the management of the ozone regime, reminding parties of concrete steps they would need to take to accomplish phase-outs by 1997. In addition, following the 1990 decision to eliminate halons with an exemption for essential uses, parties delegated to TEAP the task of evaluating proposed essential uses. With no specific guidance from the parties, TEAP and the halon TOC developed criteria to define essential uses. On that basis, they expressed a "qualified opinion" that all essential uses could be supplied until at least 2000 by redeploying existing stocks, and they recommended that parties reject all essential-use applications, subject to periodic re-assessment. Although this conclusion was carefully expressed in purely advisory terms, parties' deference to the panel's findings and subsequent similar decisions represented a substantial delegation of operational responsibility for managing the regime to TEAP.

Through 1991 and 1992, Protocol negotiators experienced substantial conflict in three areas: the relationship between developing-country commitments and associated financial assistance; how sharply to restrict HCFCs in view of their transitional character; and whether to extend controls to methyl bromide, a major agricultural pesticide, on the basis of new suggestions that it was an important contributor to ozone depletion. On each of these issues, parties attempted to limit political conflict by seeking related technical information from TEAP. In carefully worded instructions, TEAP was asked to study the implications of advancing all phase-outs, with specific reference to developing countries; to identify specific uses in which a rapid CFC phase-out required HCFCs and a feasible timetable to eliminate them; and to review uses and alternatives for methyl bromide. Parties' responses to the answers TEAP provided to these questions were mixed. TEAP's conclusion that HCFCs could be reduced but remained essential for eliminating CFCs in some uses was attacked by some delegations, but it provided the basis for negotiating only limited HCFC restrictions. TEAP's conclusion that a substantial advance of cuts in developing countries was feasible with proper financial support did not support any concrete decisions, however, in the face of strong disagreement over how much financial support to provide.

After the 1992 Protocol revisions, the tasks delegated to TEAP continued to expand, and its work was more closely integrated with parties' negotiations. TEAP once again assessed the extent of feasible opportunities for further reductions in ozone-depleting chemicals, now with specific charges to assess alternatives to HCFCs in the uses most dependent on them (refrigeration and insulating foams) and to conduct the first full-scale assessment of alternatives to methyl bromide (UNEP 1991, 1994). In addition, TEAP conducted further essential-use evaluations for all controlled chemicals, presenting recommendations that were implemented by the parties with only small modifications despite substantial political controversy; recommended a strategy for managing the stock of halons; assessed the feasibility of implementing a particularly expansive provision in the Protocol's trade restrictions; and evaluated technologies for recovering and recycling ozone-depleting chemicals. As in 1992, parties repeatedly asked TEAP to address additional questions related to points of particularly sharp conflict in negotiations, some of them new and some of them reconsiderations or elaborations of questions already addressed.

In a series of reports presented through 1994 and 1995, TEAP largely re-affirmed its conclusions of 1992: Further reductions in HCFCs were judged feasible, although these remained necessary for some applications. Accelerating developing-country phase-outs was feasible, but only with adequate financial support and timely implementation of sponsored projects. In addition, a newly established 65-member TOC conducted the first full assessment of methyl bromide, concluding that at least 90 percent of use could be eliminated. Industry representatives, including some who served on the TOC, sharply attacked this conclusion. They claimed that only much smaller reductions, perhaps as little as a few percent, were feasible. By this time, TEAP's influence over policy negotiations was coming to be widely recognized; delegations responded by beginning to oppose proposals to pose questions to TEAP, while TEAP began declining or avoiding parties' questions when they judged them not sufficiently technical that they could provide a helpful resolution. In these negotiations, TEAP's conclusions on the continuing need for HCFCs helped resist calls for rapid cuts, but north–south political disagreement prevented delegates from acting on the large reduction opportunities identified for methyl bromide.

Following the 1995 negotiations, the operations of TEAP and the tasks assigned to it continued to evolve. After the panel estimated the level of funding required for continuing phase-out programs in developing countries, parties implemented its recommended level in the fund re-authorization decision of 1996 (ENDS 1996, *36*). As phase-outs of ozone-depleting chemicals in industrialized countries approached, industrialized-country firms became less willing to bear the substantial costs of participating, while developing-country needs for technical assessment increased as their targets approached. In response to these changes, TEAP was reorganized to reduce the number of separate bodies, increase participation of developing-country experts, and increase reliance on ad hoc teams to address questions requiring highly specific expertise. This reorganization provided the opportunity as well to re-constitute the methyl bromide TOC in order to reduce participation by those with commercial stakes in methyl bromide but who offered no alternatives. In its next assessment, this newly reconstituted methyl bromide body reported that it could not find a crop that needed methyl bromide and increased its estimated feasible near-term reduction to more than 95 percent. With the assessment body moving in this direction, the promoters of methyl bromide increasingly operated directly through political channels outside the technology assessment process. Delegations finally broke their deadlock on methyl bromide in 1997 and agreed to a worldwide phase-out, although with certain crudely defined and potentially large exemptions (UNEP 1997).

In sum, the striking success of the Montreal Protocol's technology assessment process over its 10 years of operation is evident in the huge number of specific technical judgments it provided, which were with few exceptions persuasive, technically supported, consensual, and found to be accurate or moderately conservative when tested by subsequent events. The success is also evident in the substantial influence TEAP exercised over parties' decisions, even while carefully avoiding usurping their authority. TEAP's strong, specific, carefully delimited statements of feasible reductions have been disputed by policy actors on very few occasions, even when they have not translated into parties' decisions. The TEAP process itself spurred many innovations and succeeded in keeping top industry expertise engaged through the 10-year process of moving to full phase-outs. One measure of their approval of TEAP's performance is that parties repeatedly asked them to take on new and expanded jobs, even delegating significant de facto operational responsibility in the case of the essential-use process.

## Explaining the Success

Before the enactment of the 1987 Montreal Protocol, technological knowledge about the feasibility, performance, and cost of potential chemical alternatives to CFCs was held nearly exclusively by the CFC manufacturers. These firms could withhold technical knowledge about alternatives from other actors, and could also control how much knowledge they themselves possessed, because it was their choice how far to pursue the development of alternatives. These firms had no interest in helping the proponents of CFC controls make them do something costly, risky, and inconvenient, and they successfully promoted an environment of widespread pessimism about the viability of alternatives. Other policy actors had no equivalently authoritative technical information and therefore could not rebut claims by the CFC manufacturers to demonstrate that significant reductions were technically feasible. Unable to effectively engage industry expertise, the few attempts to conduct independent assessments of CFC alternatives either echoed the pessimistic public stance of industry, or could not be undertaken at all. The result was a low-confidence equilibrium, in which the actors who wanted CFC controls could not make the case that they were technically feasible, while those with the best knowledge of technical feasibility would not reveal it. Sustaining the widespread belief that CFC alternatives were infeasible or unacceptably costly counts as a great strategic success of industry organizations through the early 1980s.

The shock of the 50 percent cuts enacted in the Montreal Protocol, together with growing alarm through 1988 over the severity of the ozone-depletion risk and widespread calls to eliminate CFCs entirely, began a sharp shift from the prior low-confidence equilibrium to a high-confidence equilibrium that generated rapid, continuous progress in the identification and implementation of new approaches to reducing ozone-depleting chemicals. These initial shifts transformed the business environment for firms producing and using ozone-depleting chemicals, suggesting that the 50 percent cuts of 1987 would soon be tightened and possibly extended to other chemicals. For producers, the looming targets imposed grave risks but also carried potential opportunities for the largest and most technically sophisticated producers, because restrictions on CFCs appeared likely to create commercial opportunities in new alternative chemicals. For CFC users, however, agreed and threatened targets posed only risks, whether through losing technologies on which they depended or through requiring them to commit to costlier chemical alternatives of uncertain availability, performance, and regulatory acceptability. This prospect set off a headlong rush to reduce dependence on the threatened chemicals, which various government and industry bodies sought to support by promoting open sharing, exchange, and critical examination of potential alternatives—accelerating further the CFC manufacturers' loss of their former control over technical information about alternatives.

TEAP and its sectoral subbodies played critical roles in promoting innovation and linking it to the evolving negotiations of Protocol targets. These bodies succeeded by exploiting two fundamental differences between technology assessments and scientific assessments. First, technology assessments can to a significant degree change the conditions of technological feasibility on which they are reporting by advancing present technical skill, solving problems, and identifying and removing barriers to product and process development. Second, in accomplishing these tasks, technology assessments are able to jointly provide public and private benefits—the public benefits for which they are established, and the private benefits to participating individuals and their employers that are sufficient to motivate the level of participation and effort the assessment needs to succeed.

Although so many prior attempts at technology assessment had failed, TEAP succeeded by motivating top industry experts to participate and provide their best and most honest efforts and judgments—with little regard for the policy positions or immediate commercial interests of their employers. TEAP organizers were able to accomplish this by exploiting the crisis user firms faced from looming CFC controls and their resultant need to reduce their reliance on ozone-depleting chemicals as rapidly as possible. TEAP's panels offered user firms unique opportunities to solve the technical problems of achieving such rapid reductions by bringing together critical masses of the most respected experts in each sector, both from user firms and from firms developing diverse alternative technologies. The processes of critically examining and evaluating technical alternatives and solving application problems provided a highly rewarding professional challenge and the best chance to reduce the business risk imposed by CFC reductions, thereby increasing both individuals' interest in participating and their firms' willingness to send them. The same activities of gathering data, deliberating, and solving problems that served the needs of participating firms also served the panel's purpose of giving the parties high-quality technical advice on the extent of feasible reductions.

Moreover, the same activities provided still further benefits to the ozone-reduction regime, which were not among TEAP's official responsibilities but were among its most important contributions. Experts' work on the panels advanced the margin of feasible reductions, not just to meet existing regulatory targets but beyond them. After each assessment round, the aggregate effect of the problems solved and the alternatives identified and refined was to reveal opportunities to reduce use beyond existing targets. With industry's vigorous response to the environmental and regulatory challenge almost always bringing them ahead of existing regulatory obligations, and with further reduction opportunities repeatedly identified, repeated further tightening of the requirements was possible. Moreover, as the panel's work proceeded and further opportunities were identified, individual participants increasingly worked to confirm the accuracy of the assessment and spread information about the opportunities it identified among their industry peers, helping to advance the reductions actually achieved.

The Protocol's technology assessment process achieved its success by tying together the provision of public benefits to the ozone regime and private benefits to participating individuals and firms. Participants were attracted by the need to solve their own problems of reducing ozone-depleting chemicals, by prospective opportunities to market alternative technologies and associated services and information (including the expertise gained from participating on the panel), and by the professional challenge, satisfaction, and prestige the process offered (Kuijpers et al. 1998, *172*). In pursuing these private benefits through the assessment process, participants also provided the public benefits of good advice to the parties as to the extent of feasible reductions, and identification of additional opportunities to reduce still more.

In certain key respects, this contribution was achieved by reversing the order of activities in canonical policy choice. Rational policy choice is conventionally viewed as involving the assessment of risks, impacts, and responses prior to deliberations over control measures. But in this case, an initial regulatory target was adopted with little confidence that it could be met at reasonable cost. This fairly stringent target, and the risk of more to come, then set in motion the subsequent processes of technological development, assessment, and strengthening of control measures. In these dynamic processes of adaptation lie some of the most important insights to be drawn from the ozone regime. The problem of ozone depletion was not solved by the 1987 Protocol, but (to the extent that it has been solved) by the subsequent adaptation, refinement, and expansion of the regime.

The technology assessment process for ozone reduction has not succeeded in everything, of course. The assessment process has been most contentious and least effective on those occasions when the greatest individual competitive advantages were at stake in the outcome (Kuijpers et al. 1998, *170*). The assessments have also overreached on a few occasions, particularly on occasions when parties were considering broadening controls to include new chemicals involving new firms. Each time such an expansion was considered, the usual means of eliciting industry input in assessments was unavailable. As long as the relevant firms thought they could block controls, their preferred strategy was to obstruct technology assessments and claim that significant reductions were not feasible, as for CFCs before 1987. Absent the serious engagement of industry experts in these cases, the assessment panel's judgments were weakly founded, contested, and at heightened risk of error. More recently, TEAP's effectiveness has increasingly been challenged by parties' responses to its effectiveness, as they have asked it to answer questions that embed too much policy to be resolved by technical deliberations or tried to assert greater control over specific aspects of the assessment process and conclusions as they have seen its influence grow.

## Applying the Lessons

The successful adaptation of the Montreal Protocol was principally driven by interactions between regulatory targets, technology assessment, and industry response that promoted a rapid process of innovation to reduce the use of ozone-depleting chemicals. Although no similar system has yet developed on any other issue, many aspects of its operation are likely to be applicable to other issues, if the required conditions are in place.

Setting this interaction in motion depended on the initial regulatory targets and the risk of more to come. The targets posed a strong enough threat and opportunity to elicit strong efforts to reduce controlled substances by targeted industry sectors and to develop new alternatives by potential market entrants. In addition, the regulations required a system for technology assessment to facilitate and channel these efforts, thus exploiting the effect of the target to harness private interests to public purposes. The technology assessment system effectively engaged the energetic, honest efforts of top industry experts by linking their private interests in solving their existing and anticipated reduction problems or by profiting from alternatives, to the public interests of informing and advancing the regime's control measures. The effective operation of this system depended on many practical design details, such as structuring working groups by specific industries—participants' problems were similar enough that they could all benefit from the common effort.

The strategy of coupling private and public benefits also carried the risk of capture by particular participants' interests. While the existence of regulatory targets diminished this risk by posing immediate priority challenges to participants, organizers also sought to defend against it through the organization and operations of the panel's working bodies. Most importantly, participation in work groups was balanced to include advocates of multiple alternatives and a broad range of material interests. In addition, the stature and closely overlapping expertise of the participants promoted a critical, nondeferential working environment in which implausible or weakly supported claims were vigorously questioned. In most cases, these factors sufficed to ensure the technical quality and perceived impartiality of the proceedings. Achieving this did, however, depend on specific interests of individual participants (e.g., shifting competitive advantages due to the body's evaluation of a proprietary technology) being less prominent than their shared interests in solving common technical problems. The process was least effective when these conditions could not be met.

The prospects for designing similarly structured assessment bodies on other issues appear promising, as long as the necessary conditions are met (e.g., that the relevant technological problems and the expertise most needed to solve them are sufficiently widely shared within some industry subsectors). The Montreal Protocol's model of technical assessment has already been applied once to technical assessment for climate change, for the high global warming potential gases that are implicated in both the ozone and climate issues, with promising results. This collaboration, however, has also highlighted several broad limitations that are necessary costs of this assessment strategy. The ozone assessments have consistently declined to estimate costs quantitatively or even to specify clearly what they mean by economic, as opposed to technical, feasibility. While these omissions have drawn strong criticism, they have conferred clear advantages on the assessments, and TEAP leaders argue that quantitative cost estimates are of little value in a context of rapid technical change and moving regulatory targets. Such estimates would also be vulnerable to attack for their methods and details, as the present opaque process of evaluating options and adding up feasible potential is not. A second limitation of the process is that it cannot be transparent, because it relies on closed deliberations to allow participating experts to make independent judgments, without regard for the positions of their employers. Such secret deliberations are unproblematic if they are overwhelmingly technical in content, but they can represent significant loss of accountability if they move into trade-offs over political and social values. Finally, the process has no provision for independent review comparable to scientific peer review. Rather, it relies on the participating experts and panel leadership to police each other's work both for technical quality and for bias. The lack of transparency and outside review distinguishes this technology assessment process sharply from that conducted for climate change under the Intergovernmental Panel on Climate Change, and it has led to substantial tensions when the two bodies have collaborated. The risks of the Montreal Protocol's technology assessment approach are many, but it may still represent the best review attainable, if—as the Protocol's process assumed—the best technical information is privately held and likely to be unknown to independent reviewers.

## Notes

1. This study looked at dozens of separate option assessments in a cross-national and international context.

2. This historical summary of policy and assessments for stratospheric ozone is drawn principally from Parson (2003).

3. The maximum price considered was $2 per pound, a six-fold increase over the market price. An update of this analysis two years later increased the maximum technically feasible reduction to one-third (Palmer et al. 1980, 14; Mooz et al. 1982).

4. The proposed regulation also included two important innovations: the first proposal for a tradable-permit system and the first proposal for joint control of multiple chemicals according to a common metric of their environmental harm (*International Environment Reporter* 3:8, August 13, 1980, 337; Shapiro and Warhit 1983).

5. The major user industries included manufacturers of cooling equipment, foam products, aerosol products, and fire extinguishing equipment, as well as diverse large-scale users of halogenated solvents, particularly in the electronics, computer, and aerospace industries.

6. Although parties nominate individual expert participants, the chairs may—and sometimes do—reject nominees they judge to be unqualified. The chairs can also find parties willing to nominate experts upon their request (Parson 2003).

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