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Cost-effectiveness of methanol vehicles

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In 1989 President Bush proposed making the use of alternative automotive fuels mandatory in some cities with severe ozone problems. Characterized as a mandate to substitute methanol for gasoline, the proposal launched a debate on the emissions reduction benefits and fuel costs of methanol vehicles. A recently completed study conducted at Resources for the Future suggests that the use of methanol vehicles may be less cost-effective than some other ozone reduction strategies.

The inability of many U.S. cities to attain national ambient air quality standards has prompted policymakers to suggest new, more drastic, controls on certain pollutants. One of these is ozone, the major component of urban smog. It is a particularly difficult pollutant to control because it is not emitted but formed in the air when reactive hydrocarbons (or volatile organic compounds, VOCs) are mixed with nitrogen oxides (NOx) in the presence of sunlight. As a major source of VOCs and NOx—accounting for about 40 percent of VOC emissions and 90 percent of NOx emissions in urban areas—motor vehicles have been targeted in ozone reduction efforts.

Although cars and trucks are considerably cleaner than they were ten or fifteen years ago, some areas of the country still do not achieve national ambient air quality standards. California, for example, has the tightest motor emissions standards and vehicle inspection programs in the country, yet much of the state violates the ozone standard several days a year. (The Los Angeles area violates the standard more than 150 days a year.) Measures that would reduce the number of miles driven—such as a gasoline tax, a second-car tax, an increase in parking fees, mandatory alternate driving days, and a four-day work week (all of which have been proposed for Los Angeles)—may be somewhat effective in reducing VOC and NOx emissions, but whether they could be implemented nationwide is very much an open question.

Thus attention has turned toward cleaner transportation fuels. Last year, for example, the South Coast Air Quality Management District (SCAQMD) recommended that electric vehicles and vehicles that would run on methanol be introduced in the Los Angeles area. President Bush's June 1989 proposal to revise the Clean Air Act included mandatory use of alternative fuels in nine cities with the worst ozone problems. Both houses of Congress have proposed amendments to the Clean Air Act that include alternative fuels provisions for cities with severe ozone problems.

Among the various gasoline substitutes under consideration, methanol, ethanol, natural gas, and propane are the most feasible in the short run; electricity and hydrogen may be possible alternatives in the long run. In addition, the oil industry has recently begun reformulating gasoline, replacing aromatics—the chemicals used to boost octane in gas—with cleaner alcohols such as methanol and ethanol or other additives.

Although it is not the cleanest of the alternative fuels and it is unlikely to be the cheapest, methanol has been the alternative fuel frontrunner. Its appeal results from a combination of factors. First, vehicles that can run either on gasoline or any mixture of gasoline and methanol, such as M85 (a blend of 85 percent methanol and 15 percent gasoline), are currently available. Second, the U.S. Environmental Protection Agency (EPA), in its investigation of alternative fuels, has found methanol to be a clean and relatively inexpensive substitute for gasoline. And third, methanol presents fewer obstacles to use in private automobiles than other alternative fuels. For example, compressed natural gas can only be used in vehicles equipped with a heavy compression tank, and vehicles that use it must be refueled slowly. Ethanol made from corn or other grain products is very costly, although it is marketed at a competitive price because sellers receive a government subsidy. Propane (liquified petroleum gas) is in limited supply.

Some EPA analyses have shown methanol to be a cost-effective way to reduce emissions of volatile organic compounds (VOCs); some oil industry studies show contrary results.

The president's original clean air proposal, characterized as a methanol mandate, generated a heated debate over the characteristics and levels of emissions from methanol vehicles and the cost of methanol fuel relative to gasoline. Some EPA analyses have shown methanol to be a cost-effective way to reduce VOC emissions. Under some scenarios, in fact, the agency predicts that methanol would be even cheaper than gasoline. Some oil industry studies, however, have shown contrary results. They predict that methanol would cost significantly more than gasoline and produce few emissions reduction benefits.

Researchers at Resources for the Future (RFF) recently undertook an independent analysis of the issues surrounding the use of methanol in an effort to estimate its cost-effectiveness. The study involved assessing the likely emissions from methanol vehicles in the years 2000 and 2010 and comparing them with expected emissions from gasoline vehicles in the same years. Impacts on ambient ozone levels in some U.S. cities were also examined, but are not presented here. In addition, the study projected the costs of methanol in 2000 and 2010 and compared them to gasoline price forecasts. The emissions and ozone results were then combined with the cost information to assess the cost-effectiveness of methanol for reducing VOCs and urban ozone in 2000 and 2010.

Emissions analysis

The largest constituent of methanol vehicle emissions is unburned methanol, a relatively benign hydrocarbon compound. While methanol vehicles emit fewer of the less benign, non-methane hydrocarbons—including toxic chemicals such as benzene and 1,3 butadiene, and ozone-forming hydrocarbon compounds—than do gasoline vehicles, they release more formaldehyde emissions, which are toxic and highly reactive in forming ozone. Methanol vehicles also emit nitrogen oxides and carbon monoxide, as do gasoline vehicles.

The RFF study focused only on the potential to form ozone—or the reactivity—of methanol, hydrocarbon, and formaldehyde emissions expected from methanol vehicles after being driven 50,000 miles. The reactivity of these emissions was then compared to that of hydrocarbon and formaldehyde emissions from gasoline vehicles driven 50,000 miles. The study incorporated information supplied in eleven different investigations of gasoline vehicles, flexible-fuel vehicles (FFVs), dedicated M85 vehicles (vehicles designed to run on 85 percent methanol and 15 percent gasoline), and dedicated M100 vehicles (vehicles designed to use 100 percent methanol) conducted by academic researchers, industry, and the government (including the EPA). These investigations considered emissions from late-model gasoline vehicles in general use, late-model methanol vehicles used in government and private sector fleets, and prototypes of both gasoline and methanol vehicles. In addition, a database furnished by the American Petroleum Institute (API) provided further emissions information on methanol fleet vehicles. This database contained information on 55 methanol vehicles of 15 different model types, covering eight model years between 1978 and 1988. In all, RFF researchers examined 471 emissions test results.

Methanol vehicles emit fewer ozone-forming volatile organic compounds than do gasoline vehicles.

RFF's analysis of estimates taken from the investigations by academic researchers, industry, and the government indicated that FFVs operating in the year 2000 would be likely to provide 30 percent lower emissions of reactive hydrocarbons than improved gasoline vehicles (gasoline vehicles meeting slightly tighter emissions standards than today's vehicles). Dedicated M85 vehicles would be likely to provide 50 percent lower emissions in the year 2000. Assuming that today's prototype vehicles would be in use by the year 2010, RFF researchers estimated that, in that year, prototype M100 vehicles would produce 42 percent lower emissions of reactive hydrocarbons than prototype gasoline vehicles.

In contrast to these findings, the API database indicated a smaller reduction

in the emissions of reactive hydrocarbons from current methanol vehicles. The API database showed that both FFVs and M85 vehicles provided only 24 percent lower emissions of reactive hydrocarbons than gasoline vehicles.

RFF researchers identified several reasons why the estimates reported in the API database differed from those obtained from the eleven studies by academic researchers, industry, and the government. First, the API database contains emissions estimates for some older methanol vehicles, as well as more recent models; thus it is likely to be unrepresentative of the emissions reduction potential of new M85 vehicles. Second, emissions estimates from the eleven studies may be based only on methanol vehicles that perform well, resulting in an underestimation of the variability of emissions levels. Third, these studies may underestimate the increase in emissions that occurs as a car is driven more miles.

Table 1. Cost-effectiveness of Methanol Vehicles in the Years 2000 and 2010

	2000[a]		2010[b]
	FFV	M85	M100
Cost difference[c] (1988 $/gallon)	.576	.438	.265
Emissions difference[d] (grams/mile)	.290	.472	.171
Cost-effectiveness[e] (1988 $/ton)	65,660	30,677	51,230

[a]Year 2000 assumptions: crude oil price of $23.76/barrel (in 1988 dollars); methanol plants produce 2,500 metric tons per day (mt/d); 1.7 gallons of M85 provide mileage equivalent of 1 gallon of gasoline in an FFV; 1.63 gallons of M85 provide mileage equivalent of 1 gallon of gasoline in a dedicated M85 vehicle.

[b]Year 2010 assumptions: crude oil price of $35.17/barrel (in 1988 dollars); methanol plants produce 10,000 mt/d; 1.75 gallons of M100 provide mileage equivalent of 1 gallon of gasoline in a dedicated M100 vehicle.

[c]Retail price of methanol, on an energy-equivalent basis, less retail price of gasoline (in 1988 dollars); price includes the additional cost of $300 per FFV for equipment that allows burning of any fuel mixture.

[d]Gasoline vehicle emissions at 50,000 miles less methanol vehicle emissions at 50,000 miles; these include exhaust, evaporative, running loss, and refueling emissions of non-methane hydrocarbons (NMHC), methanol, and formaldehyde, which are totaled to adjust for differences in reactivity (the potential to form ozone) in the following manner: NMHC +.19 (methanol), +.22 (formaldehyde).

[e]Cost difference divided by emissions difference (converted to grams per gallon assuming 27.5 miles per gallon); a positive cost-effectiveness estimate means that methanol vehicles have higher costs but lower emissions than gasoline vehicles.

Cost estimates

To estimate the cost of methanol fuel, the RFF study analyzed methanol production costs (capital costs, as well as feedstock and non-feedstock operating costs), transportation costs if the methanol were to be produced overseas, and distribution and marketing costs. Particular attention was paid to the most contentious issue associated with methanol: the feedstock, or raw material, cost. Methanol is most economically produced from a natural gas feedstock, and the largest reserves of natural gas are in countries that currently make very little use of it. This has led some observers to assume that this gas has a zero opportunity cost, and thus is available at the cost only of gathering and transporting it to the methanol plant. RFF researchers believe this to be a flawed assumption. They discovered that the price of this gas is dependent on the prices of alternative energy sources, particularly crude oil, and will become increasingly dependent on those prices in the future. As a result, the RFF study assumed that natural gas used to produce methanol would have a positive and rising opportunity cost.

Some observers assume that natural gas, from which methanol is produced, has a zero opportunity cost; RFF researchers believe this is a flawed assumption.

RFF estimated that, in the year 2000, the price of M85 fuel, if used in dedicated M85 vehicles, would be 44 cents more per gallon than gasoline on an energy-equivalent basis. (Methanol has a lower energy content than gasoline, thus vehicles running on methanol get only about one-half to two-thirds as many miles per gallon. RFF cost estimates are adjusted for this fact.) If used in flexible-fuel vehicles, the price of M85 fuel would be 58 cents more per gallon than gasoline. This is because $300 worth of hardware is needed to equip a flexible-fuel vehicle to burn any fuel mixture and because FFVs are not as fuel-efficient as dedicated methanol vehicles.

In 2010, both methanol and gasoline prices are expected to be higher, but so is the fuel efficiency of methanol vehicles. Thus the difference between the price of M100 fuel (100 percent methanol) and the price of gasoline would be about 27 cents per gallon, on an energy-equivalent basis.

Cost-effectiveness

To estimate the cost-effectiveness of methanol vehicles in the years 2000 and 2010, the RFF study combined emissions reduction and cost estimates to arrive at the dollar cost per ton of emissions reduced (see table 1). According to these

Photo courtesy of the Ford Motor Company

U.S. auto companies have modified regular production models to run on methanol, ethanol, gasoline, or any combination of these fuels.

Many ozone reduction strategies would cost less than $10,000 per ton of VOCs reduced—about one-fifth RFF's estimated cost for reducing VOCs by using methanol vehicles.

calculations, flexible-fuel vehicles would be less cost-effective than dedicated M85 and M100 vehicles. RFF researchers estimated that the replacement of gasoline vehicles by FFVs would likely yield reductions of reactive hydrocarbon emissions at a cost of $66,000 per ton. If dedicated M85 vehicles are operating, emissions reductions would likely be $31,000 per ton. In these scenarios, methanol production plants are as large as the largest existing methanol plants, producing about 2,500 metric tons of methanol per day, and dedicated M85 vehicles are more fuel efficient than their FFV counterparts. The cost-effectiveness estimates above were calculated using the emissions reduction estimates culled from the investigations conducted by academic researchers, industry, and government agencies. If emissions estimates from the API database are used, both FFVs and dedicated M85 vehicles are significantly less cost-effective.

According to the RFF study, in 2010, M100 vehicles would achieve emissions reductions at a likely cost of $51,000 per ton—a figure higher than the estimate for dedicated M85 vehicles in the year 2000. This is the case even though M100 vehicles produce fewer emissions of reactive hydrocarbons than M85 vehicles, and methanol fuel costs are relatively constant between 2000 and 2010. (Although the feedstock costs of methanol rise between 2000 and 2010, capital costs fall because larger methanol plants—which produce fuel more cheaply, on a per gallon basis, than smaller ones—are assumed to be in operation.) The estimated higher cost of emissions reduction from M100 vehicles arises from the assumption that gasoline vehicles would achieve greater emissions reduction in 2010 than in the year 2000.

Comparing alternative strategies

Cost-effectiveness is a relative measure. The only way to evaluate whether the use of methanol vehicles is cost-effective is to compare the costs of that strategy with those of other alternative emissions reduction strategies. Two of the most recent and notable studies that have considered the cost-effectiveness of various VOC reduction strategies were performed by the congressional Office of Technology Assessment (OTA) and by the South Coast Air Quality Management District. Both studies indicate that the cost-effectiveness of various strategies differs enormously. They also note that many options exist for reducing VOC emissions at a cost of less than $10,000 per ton. The OTA identified ten classes of these lower-cost strategies. The agency found that, in the year 2004, VOC emissions could be reduced at a cost of under $6,000 per ton, even in areas of the United States where the ozone standard is violated. The most cost-effective measure OTA cited was reducing gasoline volatility, which reduces evaporative VOC emissions, at a cost of $500 per ton.

In 1989, SCAQMD identified 120 options for the first stage of its multistage plan to make the city of Los Angeles meet national air quality standards. The average cost-effectiveness of 68 mea-

sures proposed was $12,250 per ton of VOCs reduced. Again, lowering fuel volatility was one of the lowest-cost strategies at $4,800 per ton of VOC emissions reduced. (Since California already has a lower fuel volatility limit than the rest of the country, further reductions would presumably be more costly there than in the rest of the United States.) The costs of other measures ranged from $0 for changes in aerospace operations to $467,000 for controls on marine vessel operations. Lowering motor vehicle VOC emissions standards was found to cost $1,600 per ton.

Some of the lower-cost strategies proposed for reducing VOC emissions would not result in compliance with the national ozone standard for many areas of the country.

By these benchmarks, the methanol strategy appears to be a costly one. The RFF cost estimates of $31,000 to $66,000 per ton of VOC emissions reduced are much higher than the cost estimates for the ozone reduction strategies identified by the Office of Technology Assessment and the South Coast Air Quality Management District. One important point should be kept in mind, however. The OTA strategies for reducing VOC emissions would not result in compliance with the national ozone standard for many areas of the country, and the 120 strategies outlined in the first stage of the SCAQMD plan would not enable Los Angeles to achieve national ambient air quality standards. Implementation of very high-cost strategies may be necessary to bring the ozone levels of many cities down to the standards required by the EPA.

Additional considerations

Although RFF estimates show methanol vehicles to be a costly strategy for reducing VOC emissions, might a more optimistic case be made for their cost-effectiveness? The RFF study estimated that the cost per ton of emissions reduced could be as low as $13,000 for M85 vehicles in the year 2000. But reaching this lower number required making two very optimistic assumptions: that M85 vehicles currently in use would achieve the emissions reductions assumed for the best of the prototype methanol vehicles, and that methanol would be produced in plants that are much larger than the largest plants currently in operation.

It is possible that cost-effectiveness could be further improved if methanol vehicles could be manufactured more cheaply than future gasoline vehicles, or if the non-fuel operating costs of methanol vehicles could be lowered below those of gasoline vehicles, or both. At the present time, these events seem unlikely. Future methanol vehicles may be able to run on smaller and thus less expensive engines than gasoline vehicles. On the other hand, M100 vehicles have difficulty starting in cold weather, and the maintenance record for methanol vehicles currently in use has not been good. These two problems can be solved, but at a cost.

Analysis of a number of relatively unexplored ozone reduction strategies are needed.

While reducing the emissions of gasoline vehicles may be costly, there is no presumption that costs would exceed those of reducing emissions of methanol vehicles. Some of the newer gasoline vehicles equipped with on-board diagnostics and "adaptive learning" (a technology that adjusts the fuel-to-air ratio over the driving cycle) already meet the emissions reduction levels that the RFF study assumed for gasoline vehicles in 2010. Thus wider use of current emissions control techniques may go a long way to achieving air quality standards at very little cost.

Examining other alternatives

In the final analysis, relatively unexamined approaches to lowering motor vehicle emissions are likely to be more cost-effective than methanol. Other types of alternate fuels, particularly compressed natural gas and reformulated gasoline—the latter is currently being pushed in the debate over the Clean Air Act—may reduce emissions at a lower cost. Advances in catalytic converter technologies, such as an electrically heated catalyst that controls emissions from a car while it is warming up, are expected to cost very little. Early test results show VOC and other emissions at near zero in gasoline and methanol vehicles equipped with such catalysts. Programs to purchase and retire 15 percent of the most polluting cars and trucks could reduce VOC emissions by 30 percent, and programs to help enforce vehicle exhaust standards through the automatic measurement of vehicle emissions at expressway entrances, and subsequent prosecution of violators, might also be cost-effective. Finally, a growing number of atmospheric chemists believe that measures focusing on reducing nitrogen oxides instead of VOCs may be a more productive means of reducing ambient ozone levels in some cities.

Ultimately, comprehensive cost-effectiveness analyses are needed to identify whether the national ambient ozone standard can be met at lower costs than by substituting methanol vehicles for gasoline vehicles. While the results of the RFF study indicate that using methanol vehicles is more costly than other approaches to ozone reduction, a comprehensive analysis of a number of relatively unexplored strategies could suggest more cost-effective ways to meet the ozone standard. ■

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Agricultural protectionism in the industrialized world

Fred H. Sanderson

Domestic farm support policies have resulted in inefficient use of agricultural resources, lost trading opportunities for efficient producers, and distorted international trade flows—all at great expense to national economies. Ironically, the countries that most oppose liberalizing agricultural trade have the most to gain from doing so. Despite resistance to fundamental reform, the latest round of GATT talks offers hope for reducing the costs and adverse effects of protectionist policies.

Agricultural protectionism is not new. In Europe it reaches back to the nineteenth century. With some exceptions, it has grown steadily as a by-product of economic development. In essence, it can be seen as an effort to resist and delay the adjustments required of the agricultural sector to remain competitive with other countries and with other sectors in a rapidly changing economic environment.

Estimates of the costs of agricultural protection to consumers and taxpayers vary, depending mainly on which programs are included in the definition of support to agriculture. According to the Organization for Economic Cooperation and Development (OECD), which uses the most inclusive definition, annual consumer and taxpayer costs almost doubled between 1979-1981 and 1984-1986, from 116 billion European currency units (ECUs) to 219 billion ECUs. (The value of the ECU as a monetary unit is based on the weighted average of currencies of European Community members; debts and credits in the European Monetary System are denominated in ECUs.) Costs declined to 140 billion ECUs unit in 1988, but in the absence of significant changes in protectionist policies, this decline is likely to be temporary.

The massive costs of agricultural support have not brought commensurate benefits to farmers. Less than half of the costs end up as increased income in their hands. Further, most of the benefits go to large commercial farmers who do not need assistance. Even on the large farms, incomes benefit only in the short run. In the long run, high support prices are capitalized in the price of land, driving up production costs for new entrants and for farmers who rent their land.

The persistence and growth of agricultural protectionism has become one of the major challenges to the General Agreement on Tariffs and Trade (GATT). While successive GATT negotiations have succeeded in reducing barriers to trade in industrial products, agriculture has been left behind in the process of trade liberalization. When the latest round of GATT talks was launched in Uruguay, in 1986, governments agreed that domestic policies distorting trade in agricultural products must be brought into the negotiations. Indeed, the United States and other agricultural exporting countries indicated that they might not be able to enlist sufficient domestic support for agreements on other aspects of the negotiations if there was no significant progress on liberalizing agricultural trade. Yet as the Uruguay Round of trade negotiations draws to a close, resistance to fundamental agricultural policy reforms remains strong in Europe, Japan, and North America.

Domestic farm support policies are at the root of international agricultural trade problems.

The basic reason for the difficulties experienced in the trade negotiations is that agricultural trade barriers and export subsidies are rooted in domestic farm support policies that have become firmly entrenched in most industrialized countries. High price guarantees to producers—the prevalent method of farm support—stimulate uneconomic production, which has to be protected against imports or dumped abroad, displacing exports of efficient exporting countries. These countries, in turn, may be led to subsidize their own production, or exports, or both (as has been the case in the United States and Canada). This further depresses world prices and escalates budget costs.

Thus international trade in farm products is shaped by the interaction of national agricultural policies. Trade flows are distorted and destabilized by such policies, and trade becomes a balancing mechanism for policy-determined deficits and surpluses. The results are inefficiencies in the use of the world's agricultural resources; lost trading opportunities for efficient agricultural producers; costly and politically dangerous conflicts between otherwise friendly states; and the erosion of the integrity of the multilateral trading system.

Despite these negative impacts, the trend toward agricultural protectionism has accelerated over the last decade. For the OECD, the level of agricultural protection, in terms of Producer Subsidy Equivalents (PSEs), soared from 28 percent in 1980 to 47 percent in 1986. (PSEs are defined as the net assistance provided through market price supports and government expenditures, expressed as a percentage of total farm receipts.) The level of protection is highest in Japan and in the European Community (EC), but the sharpest increases have occurred in the United States and Canada (see figure 1). Most PSEs declined somewhat after 1986, not because of changes in policy, but because of the recovery in world prices that began in 1987.

Consequences of free trade

The approach of the 1990 round of trade negotiations and a U.S. proposal for total liberalization of agricultural trade have stirred interest in what would happen if the industrialized countries did away with all market-distorting government interventions in agriculture. The available econometric models agree that free trade would increase only modestly the total volume of agricultural trade. It would, however, redistribute production and trade in favor of efficient exporters. It would also tend to raise the international trading prices of commodities now being dumped on world markets. It would be wrong to conclude from this that liberalization serves the interests of only a few traditional agricultural exporting countries, with the EC and Japan footing the bill. This is not the case even if attention is focused narrowly on the farm sectors. Because of present high levels of protection, North American producers, too, would have to accept losses, at least in the short term. Furthermore, if consumer and taxpayer interests are taken into account, all countries would gain, with the EC and Japan reaping the bulk of the benefits.

These "static" welfare gains, due to a more efficient allocation of resources, provide the most obvious economic justification for trade liberalization. Although estimates of the size of this social dividend vary, it probably would have amounted to U.S. $30 billion to $40 billion in 1986 for the OECD countries as a whole. If gains to the nonagricultural sectors are also counted, the total welfare benefits could be over $70 billion. To this should be added the unquantified but probably even more important social dividend that could be expected to accrue from the "dynamic" effects of liberalization, in terms of more rapid economic growth.

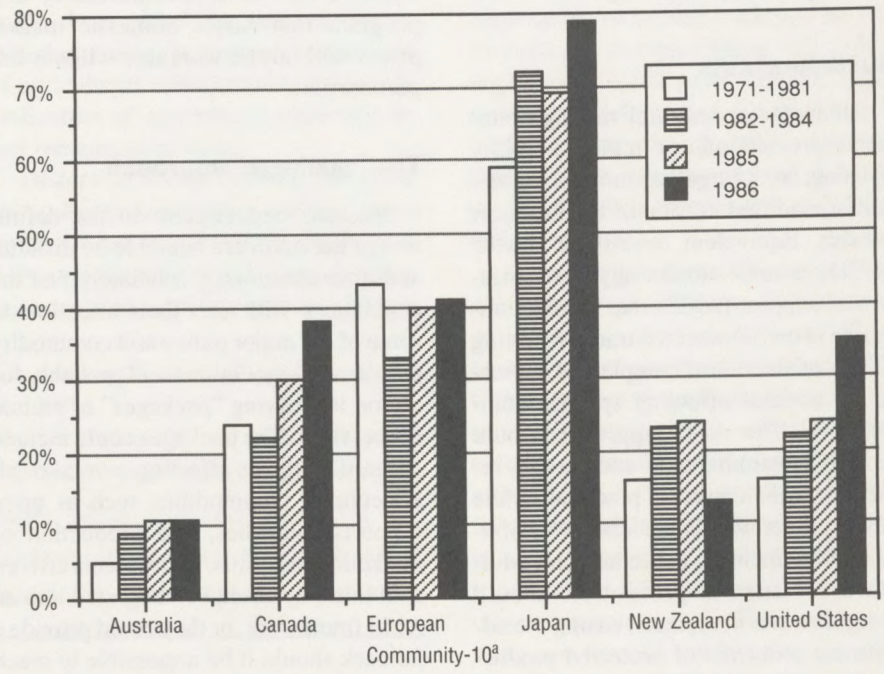
Social dividends accruing from trade liberalization would include more efficient allocation of resources and more rapid economic growth.

This is not to deny that there would be losers from liberalization within each country. In general, producers in highly protected countries would lose when protection was removed. One estimate, based on the hypothetical event that all developed countries had liberalized simultaneously in 1986, puts producer losses in the EC and Japan each at $21 billion and in the United States at $15 billion. Relatively unprotected producers in small exporting countries such as Australia and New Zealand would gain from liberalization. In the long run, per capita farm incomes would tend to recover everywhere because increased competition would accelerate the process of farm consolidation and modernization.

The principal gainers from agricultural liberalization would be the consumers and taxpayers of the most highly protected countries. Their gains would exceed the losses sustained by producers; thus society as a whole would be better off. The consumer/taxpayer gains could be used to fully compensate producers, with something left over to lighten the burden on the public. Alternatively, producers could be compensated in part.

Realizing agricultural liberalization will be difficult, however. At the GATT talks in Geneva in 1989, negotiators achieved a broad measure of consensus for making agricultural policies more responsive to international market signals, and providing producer support and protection in a less market-distorting manner. Among the proposed approaches for achieving these goals are multilateral cuts in overall levels of internal support and protection; changes in methods of support that would make them less trade-distorting; agreements on specific policies and commodities to implement cuts in overall support; and strengthening of the

Figure 1. Agricultural Producer Subsidy Equivalents (PSEs) in major industrial countries



Note: PSEs are defined as the net assistance provided through market price supports and government expenditures, expressed as a percentage of total farm receipts.

Sources: Organization for Economic Cooperation and Development; U.S. Department of Agriculture.

[a] Belgium, Denmark, France, Greece, Ireland, Italy, Luxembourg, the Netherlands, the United Kingdom, and West Germany.

rules governing international agricultural trade by eliminating exceptions, ambiguities, and loopholes. Each of these entails advantages and disadvantages.

Multilateral cuts

All major agricultural trading countries expressed interest in the possibility of using, as a target or monitoring device, a modified version of the Producer Subsidy Equivalent developed by the OECD, or some similar aggregate measure of support (AMS) that would summarize in one number the trade-distorting effects of the entire complex of protectionist policies affecting specific commodities. The AMS approach would commit governments to comparable reductions in their levels of protection while leaving them with considerable flexibility in implementing the reductions. Multilateral cuts in protection would strengthen world markets, easing the adjustment problems of protected producers. Once agreement was reached by the major agricultural trading countries on target cuts, other countries might find it more difficult to refuse to participate.

However, the technical problems in reducing all trade-distorting government interventions to a common denominator are daunting. Agricultural policies involving identical measures of support can have very different trade effects. For example, supply controls offset to some degree—and may even more than offset—the output-stimulating effects of high support prices. Deficiency payments may distort trade less than market price supports do, because they do not depress domestic consumption. Countries could switch from less trade-distorting to more trade-distorting policies without affecting their AMS.

In general, the categorization of policies as trade-distorting or non-trade distorting will be contentious. Heavily subsidized stabilization and disaster relief programs, large income payments (even if decoupled from current production), lavish adjustment assistance without a firm phase-out schedule, producer cartels (even those that do not produce surpluses for export), and two-price systems (even if they limit price supports to quantities consumed domestically) are all open to challenge because they cause substantially more resources to be retained in agriculture than would otherwise be the case. Furthermore, any program that raises domestic market prices will not be workable without import barriers.

The "package" approach

Because negotiations on the definition of the AMS are bound to be difficult and time-consuming, it is likely that the negotiators will turn their attention to some of the major policy and commodity problems. Negotiations will probably focus on identifying "packages" of mutual concessions. The packages could include domestic policies affecting several or all agricultural commodities such as price supports, subsidies, and production or marketing restraints. Agreements arrived at in this way could be integrated into an AMS framework, or they could provide a fallback should it be impossible to reach agreement on a comprehensive solution.

Without a comprehensive framework, the package approach would sacrifice the political advantages that countries would gain from proceeding together on a broad front. It could encourage governments to drag their feet on sensitive concessions. And it would sacrifice some of the economic advantages of an across-the-board reduction in protection.

Reform proposals generally involve the replacement of output-stimulating producer price supports by production-neutral income payments or by some form of income insurance.

But there are also advantages to the package approach. Governments could offer selective concessions or reforms that they consider most feasible in terms of their domestic politics and available policy tools. Trading partners could focus their requests on policies that are most harmful to them. It would be left to each trading partner to assess the value of any package that might prove to be negotiable so as to ensure a rough equivalence of concessions among countries. Moreover, the package approach would be more compatible with divergent domestic policy orientations. It would not prevent the United States from moving toward greater market orientation, or the European Community from increasing its reliance on supply controls in implementing its international commitments.

Policy reinstrumentation

The current interest in policy reinstrumentation—or the reform of policy instruments—is explained by the political difficulty of withdrawing all assistance to agriculture over a reasonably short period of time. Reform proposals generally involve the replacement of output-stimulating producer price supports by production-neutral income payments or by some form of income insurance. However, almost any farm subsidy, even if decoupled from a farm's current production or not product-specific, will cause more resources to be retained in agriculture than are justified by comparative advantage. Since the degree of trade distortion (which depends not only on the general nature of the programs but also on the level of subsidization and other specific parameters) is difficult to analyze in quantitative terms, a new source of controversy would be introduced into an already difficult negotiating framework.

The analytical and negotiating problems are compounded by proposals that envisage the decoupling of farm subsidy from production only at the margin (that is, affecting only production exceeding a basic quantity that would remain eligible for price support). Nor is it clear that decoupling proposals would be more acceptable than gradual across-the-board reductions in price supports. Farm organizations are generally opposed to types of assistance that would make the nature of the income transfers more obvious and, hence, more vulnerable to budget cuts. Finance ministers, on the other hand, are wary of increased budget costs, particularly in situations where farm support is

now provided by consumers rather than the budget.

Reform of GATT rules

Strengthening GATT rules on agricultural trade is a long-standing objective toward which little progress has been made in the past. Wide differences remain over what can be accomplished. The United States and other traditional agricultural exporting countries favor the elimination of the exemptions provided for agriculture in the GATT. Export subsidies would be prohibited and import quotas, variable levies, "voluntary" export restraint agreements, and other nontariff barriers would be replaced by fixed tariffs that would be reduced simultaneously with the reductions in domestic support. "Tariffication"—as this process is known—would make protection more transparent and more readily negotiable and make domestic markets more responsive to world market conditions. The EC and Japan believe that special provisions must continue to apply to agricultural trade. The EC considers variable levies to be a legitimate means of stabilizing internal markets; Japan has pleaded for exempting basic foodstuffs on the grounds of food security. Short of a radical reform to eliminate all nontariff distortions, an effort could be made to strengthen the present constraints on such measures so as to make them more effective in protecting the existing trade of other countries against adverse effects of domestic support policies.

Prospects for progress

The consensus on principles of agricultural policy reform reached in the OECD and the negotiations begun in the GATT represent the most important attempt ever made to reshape national agricultural policies and to have agricultural trade determined by market forces. Whether radical reductions in the level of agricultural subsidization and the liberalization of agricultural trade will result remains to be seen.

History is on the side of the pessimists. Agricultural protection has proved impervious to past efforts to deal with it. Although the adjustment costs of reducing protection would be attenuated if cuts were made on a phased, balanced, multicountry, and multicommodity basis, the fact is that the incomes and net worth of many protected farmers would fall if programs that transfer income to them were ended. Farmers everywhere are opposed to changes in both the level and the form of the subsidies and protection they enjoy. In addition, agricultural policy reform remains hostage to cycles in world market conditions. After the farm crisis of the first half of the 1980s, markets seemed to come back into balance, supporting the view on both sides of the Atlantic that the present farm programs are working and require only minor modifications. This attitude dims prospects for fundamental policy reforms.

Taxpayers, consumers, and national governments are increasingly disenchanted with the expenses, inequities, and failures of domestic farm support programs.

Optimists find comfort in the fact that taxpayers, consumers, and national governments everywhere are increasingly disenchanted with the budgetary expense, the inequities, the failures, and the perversities of the national farm programs that are the root cause of international agricultural trade problems. Competing demands on national budgets have brought expenditures for farm support under much closer scrutiny.

The European Community, since its transformation from a major importer to a major exporter of agricultural products, can no longer avoid mounting budget costs unless surplus production is brought under control. Japan, acutely aware of its dependence on foreign trade and its vulnerability to foreign retaliation, is relaxing its agricultural protectionism. Trade and budget deficits and falling shares in world agricultural markets have made the United States more determined to secure the benefit of its comparative advantage in agriculture.

In the final analysis, the integrity of the multilateral trading system must be an overriding concern. Both the European heads of government and the U.S. Congress have given notice that even the status quo may be in jeopardy if the agricultural negotiations fail to produce significant results. Beyond this, another failure to address the problems of agricultural trade would undoubtedly contribute to the spread of protectionism in other economic sectors. The fateful consequence for the world economy and polity is perhaps the best hope for progress in agricultural trade and policy reform. ■

Fred H. Sanderson is a senior fellow at the National Center for Food and Agricultural Policy at RFF. This article is exerpted from his introduction to Agricultural Protectionism in the Industrialized World, *published in July 1990 by RFF.*

A correction

In Hans H. Landsberg's article, "Two decades of energy policy" (*Resources* no. 99, Spring 1990), it was erroneously stated that efficiency standards for household appliances never became law. Though such standards were first called for in a 1975 law, specific standards were not mandated by Congress until 1987.

Emissions trading in the electric utility industry

Alan J. Krupnick, Douglas R. Bohi, and Dallas Burtraw

Emissions trading as a means of controlling sulfur dioxide emissions appears inevitable as Congress prepares to enact legislation providing for a revised Clean Air Act. But will this kind of market-driven program work in an industry as highly regulated as that of electric utilities? At stake is not the degree of environmental protection achieved, but the cost of achieving it.

In the annals of air pollution control policy, 1990 will be remembered as a watershed year for the use of economic incentives to reduce the cost of meeting pollution control goals. In this year, Congress agreed to institute a major economic incentive program under the Clean Air Act to control acid rain caused by emissions from electric utilities. The proposed emissions trading program promises drastic cuts in sulfur dioxide (SO_2) emissions at far lower cost than the costs projected for other types of regulatory programs. What is more, emissions trading provides the most polluting utilities with a way of sharing their high costs of cleanup with less polluting utilities—a feature that was useful in reducing opposition to steep emissions reductions from Midwestern utilities, which are forced to make the deepest cuts in emissions. Whether the promise of this program is realized depends on how well the details of the emissions trading are crafted, a task made difficult because the electric utility industry is already regulated in many ways.

Simply, the idea behind any emissions trading program is to fix the amount of emissions reductions that are desired in total, to allocate emissions reduction responsibilities to each emissions source, and to authorize any sources that discharge less emissions than legally permitted to sell emissions "allowances" to sources that discharge more than permitted. The costs to society of attaining the desired emissions reductions is minimized, in theory, because those plants that can control emissions most cheaply will find it in their interest to reduce their emissions below their standard and to sell their allowances for the emissions that are controlled in excess of that required by law. Buyers of allowances will be those higher-cost plants that find it is cheaper to purchase allowances than to control their emissions.

Cost-effectiveness is not the only benefit of emissions trading. Trading of allowances also provides a more flexible mechanism for accommodating the addition of new sources of emissions than a command-and-control system does. New plants wishing to begin operations enter the allowance market as buyers in competition with existing plants. These newcomers will bid up the price of allowances to encourage existing plants to further reduce their emissions. This is because under any system with a fixed level of total emissions, newcomers can only obtain allowances from tighter controls on or retirements of existing plants. In contrast to arbitrary emissions allocations under a command-and-control system, a market for allowances encourages voluntary compliance with a tighter emissions standard and allows greater flexibility in making room for newcomers.

A market for allowances encourages voluntary compliance with a tighter emissions standard.

An additional advantage of an emissions trading system is the enhanced incentive to find more efficient methods of controlling emissions. Since emission allowances are valuable property rights, firms will be encouraged to search for and develop more cost-effective ways of reducing emissions in order to make allowances available for sale. Thus improvements in emissions control technology are expected by-products of emissions trading.

While a final clean air bill has yet to emerge from Congress, the broadest provisions of the SO_2 trading proposal seem certain to become law. In order to reduce SO_2 emissions by around 10 million tons annually, or to 50 percent of 1980 emissions levels, probably by the year 2001, existing electricity generation units (boilers) burning fossil fuel would be endowed with specified amounts of annual SO_2 allowances consistent with the overall SO_2 reduction goal. Emissions would have to be less than or equal to allowances held, and the Environmental Protection Agency (EPA) would levy heavy fines for emissions exceeding allowances. Excess allowances would be held for future use or traded among units of the same utility, to other electric utilities, or to new generators of electricity, which do not receive allowances. A portion of the initial allocation of emissions allowances would be set aside for purchase as a safety precaution should the market price of allowances rise too high.

Potential pitfalls

Whether the potential benefits of an SO_2 trading program are realized depends on how the program is implemented in the special circumstances of the electric utility industry. Since the industry is subject to economic regulation by state and federal authorities—which control prices, the disposition of assets, and the earnings of shareholders, among other things—it is possible that the opportunities offered by emissions trading will not lead to the kind of responses from electric utilities that would otherwise be expected from profit-making firms. For example,

the incentive to purchase allowances may be distorted by regulations governing the types of expenses for which plants earn or do not earn a rate of return. (Plants earn a return on the capital costs they incur but not on the fuel they use.) If the cost of emissions control equipment is added to the asset base on which a rate of return is earned, while the cost of allowances is treated as an operating expense, then plants will be encouraged to add control equipment even when the cost exceeds that of purchasing pollution allowances. Unless these costs are treated symmetrically, the demand for emission allowances may be smaller than that which is cost-effective.

On the supply side of the allowance market, the incentive to overcontrol emissions to generate surplus allowances for sale may be diluted by regulations that limit the property rights of utilities. If a plant has limited rights to hold allowances for future use (as when allowances expire if not used within a certain time), or if the revenues from the sale of allowances accrue entirely to ratepayers and are not shared with shareholders, then the supply of allowances in the market will likely be less than the cost-effective amount. Owners of plants with lower control costs would not be encouraged to reduce emissions as much as they otherwise would. For the same reasons, incentives to develop improvements in control technology would be weaker, and the cost of reducing emissions would not decline as swiftly over time, as they would in a well-functioning market.

Economic regulation of the industry could dilute incentives for electric utilities to buy and sell allowances.

If there is a reduction in the incentives to buy and sell allowances, there will be fewer trades, the price of allowances will be subject to greater volatility, and the market will be more susceptible to influence by the actions of individual buyers and sellers. Any emission control plan that places an upper limit on the total volume of allowances that would be available to all current and future sources arouses a concern that allowances would become increasingly scarce and expensive over time—that is, their price would rapidly increase, posing a barrier to the entry of new generation plants. Uncertainty about the price and availability of allowances could make it difficult for new generators to arrange financing, particularly for those plants being developed by independent generating companies that have no captive markets and that must compete with established utilities. Further, regulators expecting rapid allowance price increases would treat allowances as a scarce resource that would restrain electricity supply and future economic growth. Therefore they would attempt to block the sale of allowances by utilities under their jurisdiction.

It is possible that the market for allowances could be controlled by individual participants where trades were few. In particular, a utility may have an incentive to inflate the price of allowances when its shareholders can obtain capital gains. Ironically, granting the utility a property right in the allowances is necessary to make the market work efficiently, even though this property right provides an incentive to earn capital gains by withholding supply from the market.

Apart from any gains that may be earned from the sale of allowances, utilities have an unambiguous incentive to limit competition in their markets for electricity. The exercise of power in the allowance market could be aimed at reducing competition in power markets. This strategy would be difficult to implement, however, because of the broad areas in which trades might occur. A bias in favor of selling allowances to utilities rather than to independent power pro-

Photo courtesy of the University of Vermont, Botany Department

Emissions from electric utilities as far away as the Midwest cause acid rains that kill spruce trees in the Camel's Hump forest in Vermont.

ducers will not effectively limit competition since many utilities also own subsidiaries that compete in wholesale power markets.

A more subtle bias may work against independent power producers, however. Even within an active market, the time and expense of arranging a transaction in allowances is greater for new—and particularly for independent—generators that must compete with existing utilities in wholesale power markets. The latter enjoy the option of transferring emissions allowances from existing to new generating units. Utilities also might favor selling their excess allowances to their own subsidiaries over any other potential buyer since the earnings of subsidiaries are less regulated than those of the parent company. If this preference is exercised, independent generators would face a competitive disadvantage relative to utility-owned generators. In the worst case, this could derail the deregulation of the utility industry that has evolved over the last few years.

Making trading work

In spite of this impressive list of potential problems, there is reason to believe that emissions trading in the electric utility industry can deliver cost-effective SO_2 emissions reduction. This optimism is based, in part, on the fact that the proposed SO_2 trading law incorporates the essential features of a well-functioning tradable emissions permit system. By endowing polluters with tradable emissions allowances, such a system reduces political resistance to the SO_2 cleanup through implied cost-sharing. In response to the major disadvantage of allowance endowment—that it creates too much uncertainty about the price and availability of allowances for new generators, particularly those that are not owned by a utility—the proposed law has set aside allowances for purchase, at either fixed price or auction, by new generators. Finally, by legislating the right to trade and bank allowances (subject to regulations set by the EPA), companies are granted maximum flexibility in how they meet the SO_2 emissions limits.

Trading and banking of allowances would permit companies to have maximum flexibility in how they meet SO_2 emissions limits.

A second reason for optimism about the success of emissions trading is a prediction that allowance prices will rise—if they rise at all—more slowly than the rate of interest. If this prediction is correct, it makes sense to sell allowances today even if they will be needed in the future for expansion of capacity. Allowances that are not immediately needed for compliance would be offered for sale as soon as possible, while prospective buyers of allowances would put off their purchases as long as possible in response to the declining real value of allowances. Under these conditions, new generators would not be overly concerned about being locked or priced out of the market, and even state regulators would find less reason to be concerned about the need to hold allowances for future economic growth. Consequently, this optimistic view of the future would lead to a more active market in allowances today.

Whether this optimistic view prevails will depend, in large part, on the availability of clean coal technologies that are economically competitive and on the willingness of utilities to aggressively adopt them. Newer technologies such as fluidized bed combustion and integrated coal gasification and combined cycle units, which permit the removal of 95 to 98 percent of the sulfur content of coal burned, may be economically superior to traditional pulverized coal technologies over a wide range of assumptions about input costs and operating performance. However, because they are newer, clean coal technologies offer less certainty about construction costs, operating costs, and operating performance than do traditional technologies. Thus the newer technologies will be adopted more rapidly if regulators allow a higher than normal return on investment in them, at least until a track record is established.

A third reason for optimism about the SO_2 trading program comes from a recently completed analysis of state regulatory behavior conducted at Resources for the Future. According to RFF's findings, regulators can and will support the SO_2 trading program if they are not forced to follow specific practices with regard to allowance transactions. Moreover, Congress, the EPA, and the Federal Energy Regulatory Commission (FERC) can take actions to encourage state regulators' voluntary compliance with the program. By providing clear language concerning the benefits of allowance trading and the steps required to develop efficient markets, they can help regulators to justify their decisions under the program and to reduce uncertainty within the electric industry about the nature of the property right being created and the rules for engaging in transaction. In particular, the language of legislative history and congressional and conference committee reports on SO_2 trading can make it clear that allowances should be "bubbled" (traded between units owned by the same utility), banked, and leased without restrictions.

If the emissions trading market fails, flexibility in accommodating new emissions sources would be lost.

The FERC can play a key role in establishing precedent for the treatment of allowances by state regulators by giving blanket approval to interstate trades once compliance plans are filed and approved. This will encourage state regulators to do the same. Further, the FERC can establish accounting practices to clearly define the allowance property right, allow the sharing of capital gains, and permit the cost of allowances to enter the rate base. In doing so, the commission will have to take cognizance of the generally higher rate of return required for risky investments in both allowances and clean coal technologies.

The EPA can also establish and maintain a data reporting and dissemination

program for conveying information about allowance trades to all interested parties. This information would improve the efficiency of the market and would reveal the value of allowances. The gains to ratepayers from creating and selling allowances will be clear to state administrators and state regulators, whose support is critical to the success of the program.

The prospects for a successful SO_2 emissions trading program in the electric utility industry are good. However, even if emissions allowance trading does not work, the result will be the same environmental protection that would have been achieved using a command-and-control approach. If the allowance market fails, each individual state or utility system must internally achieve compliance with the emission standard as if there were no option of achieving offsets from outside the system or state. The cost of meeting the standard by existing emissions sources would be higher if trading fails, but no higher than that prevailing if a command-and-control approach were applied to individual systems or states at the start. In addition, while trades between utilities may be few if expectations are for rapidly rising prices, cost-reducing trades between plants owned by the same utility are quite likely, irrespective of the future course of allowance prices. Flexibility in accommodating new emissions sources would also be lost if the market fails, but again the problem would be no greater than that which would occur if a command-and-control system was used initially.

In implementing the SO_2 trading program, the one danger that economic and environmental regulators must guard against—and the one that set-aside allowances for purchase by new generators addresses—is placing the emerging independent power segment of the industry at a disadvantage during the initial transition period when trading proves to be a success or a failure. Despite this danger, the downside risk of the emissions trading program is low, and the potential gain in lower environmental protection costs is large. ■

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The question of climate as a natural resource

William E. Easterling III

As one of the elements constituting the earth's natural endowments, climate not only provides critical life support services but economic goods and services. When some uses of the atmosphere adversely affect delivery of those goods and services, climate resources, like other resources, can become scarce. Along with the need to adapt to climate change, this consideration suggests that technology may provide partial substitutes and complements to climate resources. Indeed, technical and institutional innovations may be needed to avoid long-term climate resource scarcity.

Natural resources can be defined as the elements that make up the earth's natural endowments. Broadly conceived, they are energy, matter, and aesthetics, all of which have the potential to yield services that are valued by society. They include not only material assets such as mineral ores, soils, and water, but environmental assets such as wildlife and clean air and aesthetic ones such as a visually pleasing landscape.

Climate can also be considered a natural resource. A composite of all states of the atmosphere such as mean temperatures and precipitation, as well as meteorological events such as heat and cold waves and storms, climate provides a wide range of services to man and the biosphere. The atmosphere and its motions provide a vehicle for the delivery and removal of energy and matter. Cloudiness and turbidity affect the quantity and quality of solar radiation received by the earth. Winds sweep carbon dioxide to plants, making photosynthesis possible; they also disperse industrial wastes away from smokestacks. Wind and wind-driven ocean currents transport heat from warm equatorial regions poleward to regions that otherwise would be much colder. Winds and currents bring colder air and water to the tropics. Water vapor from the ocean surface is transported over land and deposited as precipitation. These are examples of the enormous capacity of the atmosphere to provide resource services.

In addition to rendering these critical life support services, climate contributes to a number of economic goods and services. The economic importance of climate is readily apparent in agricultural production. Under a given cropping system, a climate that provides adequate solar radiation, rainfall, and warmth is necessary if farming is to succeed. When deliveries of these "climatic inputs" are curtailed, as in prolonged cloudy or cloudless periods, crop productivity diminishes and so, often, do profits.

Despite the many services climate renders, there are some difficulties in conceiving of it as a natural resource. Climate is so thoroughly involved in determining the quality and quantity of other natural resources such as energy and water that its distinction as a natural resource is obscured. It is not as easy to

Photo courtesy of the National Oceanic and Atmospheric Administration

The atmosphere and its motions provide a vehicle for the delivery and removal of energy and matter.

value the goods and services provided by climate as those of some other natural resources. The atmosphere, and hence climate, is a common property resource—that is, it is freely accessible to all. Since it is not exclusively owned by any individual or group, it cannot readily be valued and, therefore, priced. Consequently, it cannot be as easily managed as those resources for which clear and enforceable property rights have been established. Moreover, unlike most natural resources, climate cannot be depleted in quantity. As it relates to climate, quantity can be defined as the capacity of climate to transport matter and energy; and the quality of climate can be viewed as the efficiency of a given quantity of climate in providing services such as snowfall for recreation or rainfall to fill reservoirs. The quality of climate can be reduced or enhanced at a particular location, but the quantity of climate is, for all practical purposes, always constant or fixed.

Use of the atmosphere as a sink for residual production wastes can adversely affect the delivery of climatic goods and services.

Can climate become "scarce"?

What makes a resource scarce is the difficulty—and therefore the costliness—of obtaining the services, or uses, of it. If a resource does not become scarce, there is no significant economic problem in allocating that resource. But are climatic goods, as resources, consumed in ways that lead to problems of resource scarcity?

To be sure, most uses of climate resources such as rainfall for crops, solar radiation for space and water heating, and wind power for electrical generation, do not diminish the availablity of those resources. Even climate fluctuations such as droughts, heat waves, or severe storms, which disrupt the normal flow of climate resources, pose few long-term problems as long as the fluctuations are expected and plans are made for adapting to their occurrence. For example, large water storage projects are sized and managed according to the historical probability of droughts or floods of critical magnitude that would occur during the lifetime of the project. That is, they are designed to absorb the effects of a relatively severe climatic fluctuation without a disruption in water distribution to end users.

On the other hand, some uses of climate resources can adversely affect deliveries of climatic goods and services. The use of the atmosphere as a sink for residual wastes from production processes is one example. Industrial emissions of carbon dioxide, oxides of sulphur and nitrogen, methane, chlorofluorocarbons, and particulate matter can eventually alter the quality of climate. Oxides of sulfur and nitrogen emitted into the atmosphere are precursors to airborne acids, which can make rainfall acidic enough to potentially harm the environment. Particulate matter from urban sources enhances the formation of clouds, which may cause rainfall in regions downwind to increase in amount and intensity. The emission of carbon dioxide, methane, and other radiatively-active trace gases strengthens the greenhouse effect. A stronger greenhouse effect could cause a gradual rise in the temperature of the lower layers of the earth's atmosphere and a cooling of the upper layers of the atmosphere. The persistence of this phenomenon could lead to global warming. Thus alteration of the quality of climate—at least when that quality is diminished—can be interpreted as a disruption in deliveries of climatic goods and services.

But even if deliveries of climate resources are altered by the use of the atmosphere as a waste dump, is there a long-term problem of climate resource scarcity? In *Scarcity and Growth Reconsidered* (1980), the economist Joseph E. Stiglitz proposes a set of criteria that sheds light on this question. He suggests that one fundamental concern with regard to common property resources is whether, with a growing population, a sustained per capita level of resource consumption can be maintained. In the case of climate resources, this concern might be interpreted as the likelihood of maintaining per capita consumption of climatic goods and services not only in the face of a growing population but under conditions of long-term shifts in the reliability of those goods and services. That likelihood depends, in part, on the degree to which

technical progress, in general, can complement climate resources and lead to the development of production inputs that can be substituted for climatic inputs if existing climate resources are or become less effective, or less reliable, or both.

Substitutes and complements

In general, inputs that are required for the production of a good or service are considered substitutes for one another when a decrease in the price of one input (for example, fertile cropland) leads to a decrease in the demand for a quantity of the other (for example, fertilizer). Thus if the price of fertile cropland were to fall, a farmer might maintain constant output levels by putting more cropland into production and using less fertilizer, which would now be a relatively more expensive input than land.

Production inputs are complements to one another when a decrease in the price of one input (say, iron ore for steel production) leads to an increase in the demand for a quantity of another (say, coal for producing coke, an ingredient of steel). Thus iron ore is not a substitute for coal, but fluctuations in its price affect the level at which coal is exploited for coke.

The concepts of substitution and complementarity can be applied to climate resources. While it is pointless to look for complete substitutes for climate resources—apart from the occurrence of some unimaginable or highly improbable geophysical calamity, it can be assumed that some form of climate will always exist—partial substitutes can be realized through the application of technical advances that offset deficiencies in existing climate resource services. For example, meteorological research has improved the timeliness and accuracy of short-term weather forecasts to the point that they can be reliably used in the making of certain climate-sensitive economic decisions. Weather forecasts provide information that allows farmers to choose between alternative courses of action that would either reduce the negative effects or take advantage of the positive effects of weather variations. Technological advances have made possible the substitution of irrigation water for rainwater, making farming more productive.

Other research has led to the development of complements to existing climate resources by making the harvesting of the energy and material resources embodied in climate more efficient. Research on alternative energy sources has shown how to capture the energies of the sun and wind and put them to work to complement conventional forms of energy. As solar and wind collection technologies become cheaper and more efficient, they could increase the demand for solar and wind resources, which have not been economically feasible thus far.

Agricultural research has led to the development of strains of crops that are tolerant of climatic stresses such as drought, severe cold, and extreme heat. In examining the expansion of the zone in which hard red winter wheat is grown across steep thermal and moisture gradients in the North American Great Plains, Norman J. Rosenberg, a researcher at Resources for the Future, has found that the expansion was aided by the development of temperature-hardy wheat strains and the development and application of tillage practices that conserve moisture. Before cold-hardy wheat strains were developed, virtually no hard red winter wheat was grown within a few hundred miles of its current northern limit in southern Canada. This is the kind of technical progress that increases the productivity of the existing climate resource.

Partial climate substitutes can be realized through technical advances that offset deficiencies in climate resource services.

Another way of increasing the productivity of climate resources is by reducing society's vulnerability to the vagaries of climate. Droughts, severe storms, and heat and cold waves continue to cause economic hardship, environmental damage, and human suffering, especially in less developed countries that may lack the human and material resources to deal with climatic hazards. It is important to identify activities that are both directly and indirectly vulnerable to climate fluctuations. Ongoing research is aimed at describing and quantifying the risks of climatic hazards includes retrospective regional assessments of the frequencies and magnitudes of droughts, hail storms, tornadoes, early and late frosts, and other climatic extremes.

Future use of climate resources

It would be unwise to assume that the productivity of climate resources in the coming decades will be the same as it is today. Even if the current climatic regime persists—and it may not—a wide range of technical innovations could make climate resources more productive. Agricultural research is likely to produce new crop varieties, through conventional procedures and biotechnology, that are better adapted to regional climatic conditions. Improvements in irrigation efficiency are likely. Depending on the direction of future energy prices, solar photovoltaics, a technology for converting solar energy directly into electrical current, could be a major method of generating electricity. Should economical solar energy lead to cheaper electricity, desalinization of sea water could provide water that might open deserts for a variety of uses. The ability to predict climate itself is expected to improve through the development of faster computers and better representation of the physical properties of the atmosphere in climate models.

But there may be a dark side to the future use of climate resources. The possibility of global warming in the coming decades may bring pressure on the research establishment to develop technical and institutional innovations that are apace with or in advance of the changing climate in order to prevent the degradation of usable climate resources in some regions. To be effective in responding to climate change, technical and institutional progress must follow two paths. The first can be called adaptive response, and would include efforts to change production processes in ways that minimize the costs of deleterious changes in climate or, conversely, maximize the benefits of positive changes in climate. An example of adaptive response would be the devel-

opment of crop varieties that are better able to utilize the higher carbon dioxide concentrations that would accompany greenhouse warming than do current varieties.

Technical and institutional innovations apace with or in advance of changes in climate could mitigate the degradation of usable climate resources.

Institutions can facilitate adaptive responses to climate change. Pierre R. Crosson of Resources for the Future has argued that the international food research institutions making up the Consultative Group for International Agricultural Research could serve as a model for organizing future agricultural research aimed at adapting to climate change. Another adaptive institutional response to greenhouse warming would be to make reductions in trade barriers that would allow countries disadvantaged by climate change to have easier access to food and fiber from advantaged countries.

The second path important to technical and institutional progress can be called mitigative response. This would include efforts to slow the rate of climate change to the point that degradation of usable climate resources is curtailed or lessened enough so that adaptive measures are not overwhelmed. The reduction of greenhouse gas emissions is one obvious strategy, though it would be difficult to implement because of its high costs to national economies. Another mitigative strategy, however, would serve to increase the productivity of current and future climate resources; this is the planting of forests to sequester carbon (helping to abate greenhouse warming) and to produce fuel wood (making wider use of the potential of existing climate resources to produce biomass). The costs of this strategy are unknown.

In conclusion, climate resources, like other resources, can become scarce in the sense that expected delivery of the energy and mass needed is not made. Normal fluctuations in the existing climate that produce droughts, severe storms, and other climate hazards do not necessarily point to a long-term problem of climate resource scarcity. Rather, they point to the continuing need to better adapt climate-sensitive economic activities to the normal variability in climate. However, in the future, if climate warming continues unabated and population and economic growth place mounting pressures on climate-dependent resources, then appropriate technical and institutional innovations will be necessary if we are to avoid a long-term problem of climate resource scarcity.

Population and economic growth, as well as climate warming, could result in a long-term problem of climate scarcity.

Climate is a natural resource that can change in such a way that it is no longer productive to those who are dependent on it. The result may be per capita decreases in the beneficial use of climatic services. Recognition of problems created by overconsumption of common property resources such as public grazing lands, groundwater, and fish and wildlife leads to a demand for resource management. Why should climate resources be treated any differently? ■

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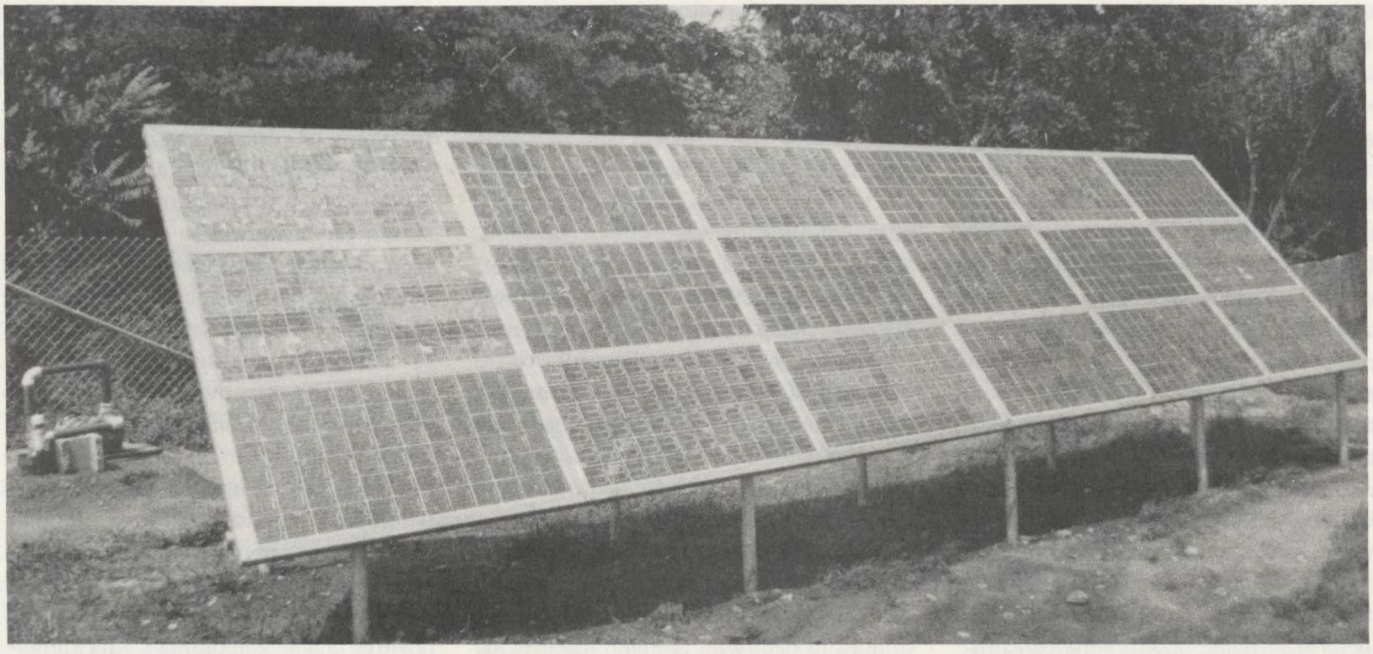


Photo courtesy of the Solarex Corporation

Depending on the direction of future energy prices, solar photo voltaics could be a major method of generating electricity.

RFF awards $100,000 in grants

Resources for the Future has awarded $100,000 in research grants to individuals at four universities and one college. The awards were made through the RFF Small Grants Program, which provides financial support to researchers at universities and other nonprofit institutions in the United States and abroad to study issues related to the environment, natural resources, and energy.

This year RFF awarded grants to the following individuals for research on the subjects indicated:

- William N. Evans, assistant professor of economics at the University of Maryland (College Park): Does Enforcement of Environmental Regulations Provide General Deterrence?
- William H. Kaempfer, assistant professor of economics at the University of Colorado (Boulder): Assessing the Effectiveness of International Economic Sanctions Over Transnational Externalities.
- Vernon L. Smith, director and Regent's Professor of Economics at the University of Arizona (Tucson): Chaos and the Bioeconomics of Fishing.
- Robert N. Stavins, assistant professor of public policy at Harvard University: Wetland Losses and Willingness to Pay for Fishing Opportunities.
- Tom H. Tietenberg, professor of economics at Colby College: Judicial Approaches to Environmental Policy. ■

RFF develops new program

Agriculture, Environment, and Food Safety is the newest program to emerge from the National Center for Food and Agricultural Policy at Resources for the Future. According to program director Katherine H. Reichelderfer, it is designed to examine and evaluate the tradeoffs that become necessary as Americans demand not only an abundant and affordable food supply but greater food safety and environmental quality, which are sometimes adversely affected by agricultural activities.

The program combines the knowledge of scholars skilled in analyzing agricultural and food policy issues with the expertise of economists working in environmental and natural resource fields. Such a coordinated research effort will result in the design and assessment of policy options that take into account the complex interactions among agricultural, environmental, and food safety interests.

According to Reichelderfer, balancing these interests will not be easy. "Currently, many agricultural policies exacerbate environmental problems. Yet ill-considered policies aimed at environmental protection could reduce agricultural productivity and undermine U.S. trade competitiveness. Similarly, policies that reduce the adverse effects of agricultural production could increase or decrease actual or perceived risks to human health posed by agricultural activities. RFF's new program will help decision makers assess the likely consequences of various policy approaches." ■

New publications director appointed

Richard J. Getrich joined Resources for the Future in July as the new director of publications. He was director of book marketing and a senior editor at the American Enterprise Institute for a number of years. More recently, Getrich developed and managed the publishing program at the National Association for Foreign Student Affairs as the association's director of publications. ■

NCFAP resident fellowships awarded

The National Center for Food and Agricultural Policy at Resources for the Future has appointed two resident fellows for 1990-1991. During her tenure at the National Center, Ardith L. Maney, a political scientist at Iowa State University, will investigate the influence of consumer interest groups on public policy. William F. Hyde, an agricultural economist at the Environmental Research Service of the U.S. Department of Agriculture, will examine the linkages between tropical deforestation and agriculture. He will also analyze U.S. forestry policy as it relates to land availability for agriculture. Each year, the National Center offers resident fellowships of up to twelve months to scholars from universities, government, and the private sector for the pursuit of innovative policy analyses. ■

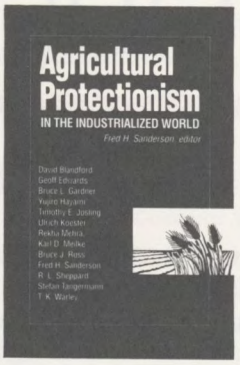
Franklin H. Williams, 1918-1990

Franklin H. Williams, a past member of the board of directors at Resources for the Future, died on May 20. A former United States representative to the United Nations Economic and Social Council and ambassador to Ghana, Williams served on the RFF board from 1979 to 1987. In 1983 he was appointed chairman of the newly formed Development Strategy Committee, which assists in the planning of RFF's outreach and fundraising programs.

A lawyer, educator, and government official, Williams was active in civil rights causes. He helped organize the Peace Corps in 1961, and in 1968, following his ambassadorship in Ghana, he was chosen to head a new urban center at Columbia University. From 1970 until his death, Williams served as president of the Phelps-Stokes Fund, a foundation dedicated to advancing opportunities for American minority groups and Africans. ■

New book

Agricultural Protectionism in the Industrialized World,
edited by Fred H. Sanderson



This book analyzes the close relationship between the domestic and international agricultural policies of the major industrial countries. Sanderson and his coauthors assess these policies and their implications for international trade and for the current round of negotiations in the General Agreement on Tariffs and Trade (GATT). They examine not only who pays the costs of these policies, but also who benefits and what the benefits might be of eliminating or reducing protectionist programs.

Volume contributors note the increasingly complex and often mutually inconsistent instruments of farm support. These—along with inefficient resource use, the dumping of surpluses caused by artificial incentives to production, and protectionist measures taken by governments to offset the protectionism of other countries—account for the large and growing gap between costs to consumers and taxpayers on the one hand and benefits to producers on the other. By reforming present farm support systems, one author points out, a substantial dividend would accrue to the industrialized societies. As regards the current GATT negotiations, others conclude that while there is a broad consensus favoring agricultural policy reforms and greater liberalization of agricultural trade, procedural and substantive agreements to this end will be difficult to achieve. Thus the best hope for progress in agricultural trade and policy reform might be the recognition by European heads of government and the U.S. Congress that failure to address the problems of agricultural trade would risk the spread of protectionism.

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In addition, RFF has received five foundation grants. The U.S.-Japan Foundation awarded RFF a two-year grant in support of research and policy studies concerning international agreement on carbon dioxide containment strategies, a project undertaken in conjunction with the Atlantic Council of the United States and several Japanese research institutes. The G. Unger Vetlesen Foundation awarded a grant to the Climate Resources Program in the Energy and Natural Resources Division. The National Center for Food and Agricultural Policy received a grant from the W. K. Kellogg Foundation. The Rockefeller Foundation awarded a grant to support the work of the International Policy Council at RFF. And the William and Flora Hewlett Foundation awarded RFF a two-year grant. ■

NCFAP announces new council members

The National Center for Food and Agricultural Policy at Resources for the Future has appointed six new members to its advisory council. The six are William T. Boehm, vice president of grocery procurement for The Kroger Company; William W. Erwin, a former U.S. assistant secretary of agriculture; Edgar E. Fehnel, vice president of animal health at Elanco Products Company; Maureen K. Hinkle, director of agricultural policy at the National Audubon Society; George H. Hoffman, vice president of purchasing at Burger King Corporation; and Richard E. Lyng, former U.S. secretary of agriculture and a senior research fellow at Harvard Business School. They join Robert L. Thompson (council chairman), L. L. Boger, Orville L. Freeman, Dale E. Hathaway, Alex F. McCalla, Dean E. McKee, and Douglas P. Wheeler. ■

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