"TRANSBOUNDARY AIR POLLUTION: AN OPPORTUNITY FOR INNOVATION"

by

Robert U. AYRES*

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* Professor of Environmental Economics, Sandoz Chair in Management and the Environment, at INSEAD, Boulevard de Constance, Fontainebleau 77305 Cedex, France.

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TRANSBOUNDARY AIR POLLUTION: AN OPPORTUNITY FOR INNOVATION

Robert U. Ayres
INSEAD
Fontainebleau, France
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Abstract

The paper discusses the problem of transboundary air pollution originating in Eastern Europe as an instance where the "polluter pays principle" (PPP) is neither economically feasible nor socially desirable. In fact, the polluter cannot afford to pay. Whereas PPP would require a wealth transfer from the poorer to the richer, the "victim pays principle" has the disadvantage that, if the wealth transfer is fungible, it creates an *a priori* incentive for the poor country to continue to pollute so as to continue to get paid. This, in turn, creates an incentive for the victim country to finance "end of pipe" treatment technology that can be exported by the victim country. The end result may be to "lock in" unnecessarily polluting forms of industrial activity so as to guarantee continuing markets for the pollution treatment sector in the victim country. On the other hand, there may well be opportunities in poor countries to apply new technologies that are available and "on the shelf" but which have not had the opportunity to become established in the West because they offer only marginal improvements at some financial risk. It is suggested that the risk can be minimized and the benefits maximized by taking an overall systems approach and exploiting economies of integration. An example of an integrated technological approach to the soft-coal based industrial region known as the "black triangle" in eastern Europe is discussed briefly in the Appendix.

Introduction

Transboundary air pollution is a fact of life, especially in Europe. The bulk of it moves from west to east, in the northern hemisphere, since that is the direction of the prevailing winds and the jet streams, along which the weather systems move. However, weather systems are high and low pressure regions around which the wind circulates, typically at speeds faster than the weather pattern itself moves. So, on average, winds from the west are brisker than winds from the east, but over the course of a year, the winds come from all the points of the compass.

Moving air masses, of course, carry airborne pollutants. Eastern Canada suffers from acid rain caused by coal-burning power plants in the midwestern U.S. The Swedes also get acid rain caused by sulfur and nitrogen oxides originating in the U.K. The low countries (Benelux) receive air pollution originating in the Ruhr (and vice versa, of course).

But the transboundary problems within North America and Western Europe are minor in comparison with the transboundary pollution in western Europe caused by uncontrolled emissions in the former Soviet bloc. It is worthwhile to recall that the Chernobyl disaster left a swathe of radioactive fallout over Poland and much of eastern Europe, as far as Sweden (leaving nearby Kiev untouched). Austria and the Danube valley lie under a more or less permanent pall of smog due primarily to the heavy industry of Czechoslovakia and Poland, to the north. Polish and eastern German industry are also the major sources of air pollution in Scandinavia today. Finland receives significant quantities of pollution due to massive and uncontrolled nickel smelting and phosphate rock processing operations in the Karelian peninsula of northern Russia.

Quantitative data is available from the European Monitoring and Evaluation Programme (EMEP) in the case of SO_x and, recently, on NO_x. An input-output table for sulfur emissions and fallout has been prepared for the year 1987 [Newbery 1990]. Details need not be given here but a few interesting numbers are worth citing. Former West Germany received 821 thousand MT (KMT) of sulfur deposition, of which 330 KMT was of domestic origin and 163 KMT originated in the former East Germany, 47 KMT originated in former Czechoslovakia, and 23 KMT came from Poland. On the other hand, West Germany emitted 823 KMT of which 61 KMT went to East Germany, 28 KMT to Czechoslovakia and 47 KMT to Poland. In the case of Austria, detailed allocations are unavailable, but Austria emitted only 75 KMT while receiving 207 KMT in depositions, of which only 9% was of domestic origin. Great Britain exported 9.7 times as much sulfur as it imported. On t he other hand, Norway and Romania imported 5 times as much as they exported, while Austria and Sweden each imported 3 times as much as they exported.

With respect to West Germany, the net flow of sulfur depositions from East Germany was 163-61=102 KMT; from Czechoslovakia the net flow to W.Germany was 47-28=19 KMT; from Poland the net flow was 23-47=-24. Thus, Poland received more from West Germany than it sent. Poland received 790 KMT from domestic sources, 310 KMT from East Germany and 145 KMT from Czechoslovakia. West Germany is a net exporter of sulfur, by a factor of 1.4; East Germany exports 7 times more than it imports from other countries; Czechoslovakia exports 2.8 times as much as it imports; Poland exports 2.1 times what it imports.

At the beginning of May, 1993, a plan prepared by the World Bank and the OECD, called The Environmental Action Program for eastern Europe and the former Soviet Bloc was adapted by a conference of 50 western environment ministers. It is not binding and commits no immediate western funds, except $30 million for studies. However, it constitutes a "game plan" that will probably guide most western donors for the next few years, a least. It puts air pollution first among its list of priorities, stating that emissions of lead, sulfur and soot have already caused serious health problems in some areas.

The program puts particular emphasis on the lignite and sub-bituminous coal burning power plants in the northern Czech Republic and southern Poland, although it explicitly recommends inexpensive solutions like energy conservation, fuel switching and better maintenance, rather than massive investments in flue-gas desulfurization (FGD) technology.

Economic Issues: Who Should Pay Whom?

Transboundary air pollution is a straightforward example of a market failure, or externality, at the national level. Absent any cooperation among countries, transboundary pollution is a given. Then each country has to decide how much to abate its own pollution. The usual rule of thumb is to balance the marginal costs of domestic abatement with the marginal benefits of reduced domestic deposition. Since some countries (like the U.K.) export most of their pollution, while others (like Austria and Switzerland) import most of theirs, the optimal level of reduction for each will be quite different. From available data on sulfur transport and domestic abatement expenditures it is possible to deduce "revealed marginal willingness to pay" for abatement. Using the 1984 EMEP sulfur transport matrix, and assuming constant damage costs per tonne of sulfur deposition (for each country) K-G Mäler calculated an "efficient solution" that would result in an overall reduction in emissions of 39%, but with the allocation of reductions among nations ranging from 10% for France to 86% for Denmark, West Germany and Greece [Mäler 1989, 1990].

A somewhat different result can be obtained by assuming that damages from acid deposition would be mostly to property, in the form of corrosion of metals and stone surfaces, based on prior work by Environmental Resources Ltd [ERL 1983]. This suggests a damage function proportional to GDP per unit area. On this basis, an alternative "efficient solution" has been computed by Newbery, using the 1987 EMEP sulfur transport matrix [Newbery 1990]. The results of the two studies are compared in *Table 1* below. They obviously differ by wide margins. Whereas Mäler's solution called for Yugoslavia to reduce its emissions by 79%, Hungary by 77%, and Czechoslovakia by 75% Newbery's model reduces these to 7%, 9% and 14% respectively. France, on the other hand, goes from 10% to 40%.

Table 1: Efficient Reductions in Sulfur Emissions (percentage)

Country	*Mäler, 1989*	*Newbery, 1990*
Denmark	86	18
West Germany	86	61
Greece	86	
Romania	83	
UK	81	31
GDR	80	21
Yugoslavia	79	7
Hungary	77	9
Czechoslovakia	75	14
Netherlands	62	65
Belgium	36	69
Italy	33	27
Switzerland	23	44
Spain	14	10
France	10	40

Note: All other countries reduce by less than 50% in Mäler's calculation.
Sources: [Mäler 1989; Newbery 1990]

Given the discrepancies between the two "efficient" non-cooperative solutions, it can be taken for granted that the results are quite sensitive to assumptions about damage, and its relationship to emissions. Evidently there is still room for considerable argument about the most realistic and appropriate assumptions. Nevertheless, it is possible that international cooperation or bargaining might yield a still better joint solution. This possibility is discussed below.

Consider two simplified scenarios. In scenario I, Countries A and B engage in economic activity emitting air pollution in the process. Pollution moves across national boundaries in both directions, but because of prevailing wind patterns country B suffers more pollution from A than vice versa. It therefore bears a disproportionate share of the damage costs. Typical notions of fairness — expressed in the "polluter pays principle", or PPP" — suggest that country A should compensate country B for its excess losses.

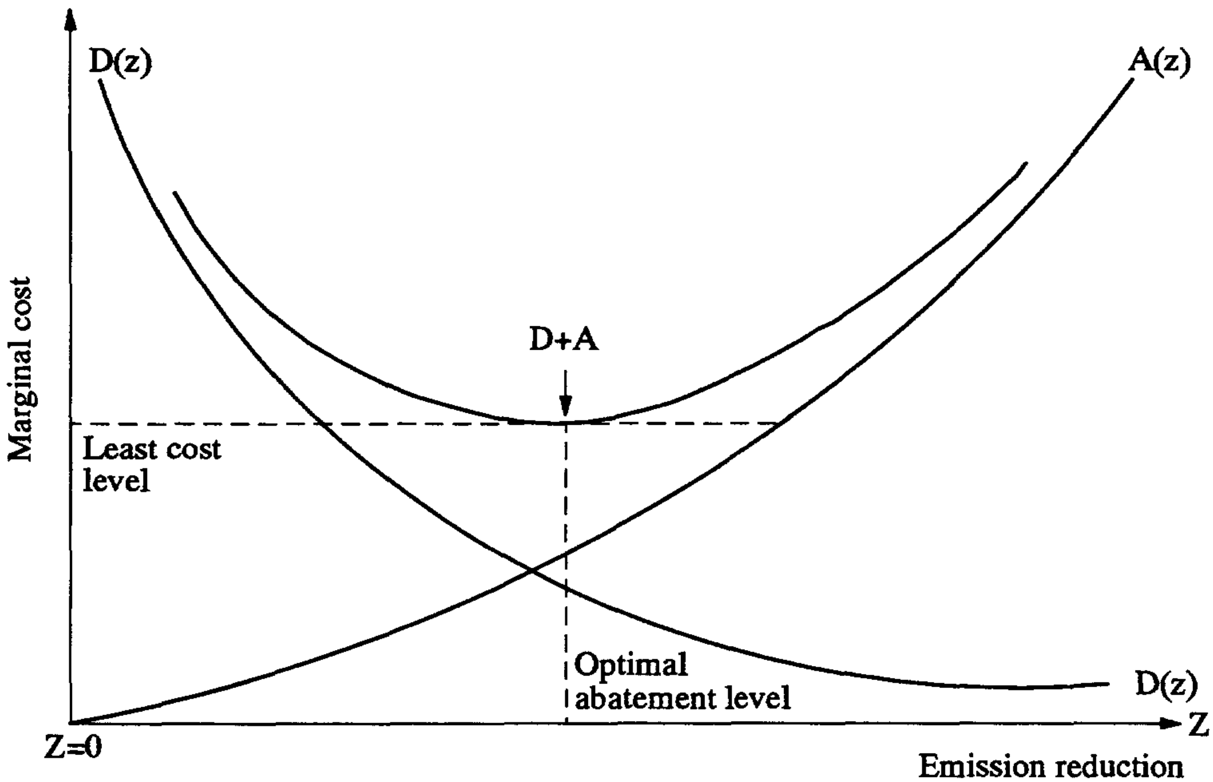

Figure 1: Abatement in Economic Equilibrium
Source: author

Assume a cooperative situation, or one in which some higher authority, such as a world court, capable of adjudicating the issue and enforcing the outcome. The court would presumably require country A to pay country B. This, in turn, would induce country A to factor these compensation payments into its production cost calculations. It would then attempt to find — and very likely succeed in finding — an optimal mode and level of operation that would reduce its transboundary pollution output and therefore its compensation cost, to minimize its total cost. See the idealized scheme in *Figure 1.* This modified mode of production would "internalize" all costs, and would maximize the net social value of total output, not only for A, but for both countries.

In scenario II, there is no cooperation nor any social mechanism to enforce compensation payments. Country A refuses to pay compensation to country B. However, country A may be open to a bargain. Country B may find it cheaper to help country A to reduce its pollution (by changing its more of operation) than suffer the entire cost of transboundary pollution L. (This alternative is sometimes called the "victim pays principle", or VPP). Under these circumstances, assuming Country B knows the cost of pollution abatement in A, B may find that it can reduce its own costs by subsidizing A's pollution abatement effort. If there are only two countries involved, it turns out that the optimum subsidy is the one that also yields the maximum net social output. (This is the famous Coase theorem).

Of course, in scenario II the "polluter pays principle", PPP, is abandoned. The polluter is the one who gets paid by the victim. Yet the victim is still better off than he would have been otherwise, and the polluter is actually much better off. In this case, again, an optimal solution is found (as suggested by ***Figure 1***); only the allocation of costs is different. Both solutions are Pareto optima. But in the global context one can be superior to the other[1]. If country A and country B are equally wealthy (say, Canada and the U.S. or Denmark and Sweden) or if country A is richer, the PPP solution is clearly preferable on equity grounds. It is the solution that would result from creating enforceable property rights for airborne waste acceptance/assimilation permits.

In an ideal world, one could imagine that airborne wastes could be emitted only by entities possessing permits to use the air as a disposal medium. One can also suppose the number of such permits to be limited, and to have been allocated by some rule among all those persons potentially affected by the pollution. Polluters would be forced to buy permits, in proportion to their emissions. The permits (or rights to pollute) would be tradeable. Those who "receive" more pollution (e.g. as fallout) than they generate would sell their excess permits and receive money to compensate them for the damage they suffer. Those who generate more pollution than they accept would have to pay for extra permits. Within the two equally wealthy countries, the creation of tradeable permits amounts to a redistribution of monetary income from the polluters to the "pollutees" within the same countries.

However, if country A happens to be poor (say, Poland or Mexico) while country B is much wealthier (say, Germany or the U.S.) the VPP principle yields a superior Pareto optimum. As noted, the net social product is the same as in the PPP case, but there is also a flow of wealth from the richer to the poorer. Declining marginal utility guarantees that the gain to A is greater than the loss to B. The major problem with scenario II (VPP) is the practical difficulty of preventing abuse. If A can arrange to be paid for polluting B, what is to prevent it from exploiting the situation? The fact that it also suffers from its own pollution may not be sufficient motivation. For instance, A might decide to shift production away from factories in the interior to factories on the border with B, thus shifting more of its total pollution load to B. Perhaps B can guard against this by narrowly restricting its subsidy to pollution abatement investments in particular plants, e.g. the ones closest to its own border. But money

[1] In more complex general equilibrium cases with many players (countries) the essence of Coase's result is still valid, namely that (absent transaction costs) both PPP and VPP yield Pareto optima. However the two local optima may not yield the same social product, since they involve different wealth distributions. In general, however, VPP yields a higher social product than PPP when the victim is much richer than the polluter.

is fungible and A can still find ways of diverting funds away from their intended use, as long as its interest is not identical to that of B.

Thus, though VPP may theoretically be a superior Pareto optimum in the short run, it is difficult to design a practical system to implement it without risk of serious abuse. Country B (the victim) has a strong motivation to shift to PPP. Failing that, country B would tend — in practice — to be very skeptical of financing higher operating costs in country A or, indeed, any form of assistance except perhaps subsidized equipment sales (thus helping its own manufacturers). This is unquestionably the pattern we currently observe internationally. It has the unfortunate consequence of putting most of the emphasis on "end-of-pipe" abatement technology, whereas the most cost effective opportunities may lie elsewhere.

A key question now arises: is there a way of designing and implementing a pollution abatement program for a poor country based on VPP in the short run, with an automatic evolution (or conversion) into a PPP-based solution in the longer run? It turns out that the answer is 'yes' in principle. The notion of tradeable permits can be applied in this case too. The only difference is in the initial allocation. Suppose the permits were initially allocated, not to citizens (or in proportion to population), but to polluters on a *per unit emissions* basis, throughout both Country A and Country B. (Actually, it would make more sense to do this on a continent wide basis). Suppose, also, that the number of permits created each year for the whole region is fixed by a central authority. Suppose finally that the objective is to reduce regional emissions at the rate of 5% per annum for the indefinite future. The number of permits will therefore also have to be correspondingly reduced by 5% annually.

Firms in poor Country A can abate their emissions by any given amount at lower cost than firms in wealthy Country B. Firms in Country B will offer to buy permits from firms in Country A. Firms in Country A can sell permits to finance the needed abatement, and still have money left over. What is the result? First, there is net abatement within the region as a whole at the rate of 5% annually. Second, there is a net flow of funds from wealthy B to poorer country A. This flow continues, but at a decreasing rate, until A and B reach parity in terms of marginal abatement cost. Thus, the VPP operates on a temporary self-liquidating basis. From that point on, both sides must make annual investments in further pollution abatement as long as the number of permits continues to decline.

New Technology & Economies of Scope

For reasons discussed above, in a VPP situation external assistance to reduce transboundary air pollution (or, for that matter, water pollution) is likely to be limited to contributions of money to buy equipment for 'end-of-pipe' treatment, probably tied to purchases from the donor country. This is not the optimal solution, especially if there are opportunities for reducing pollution at a profit by implementing alternative technologies. Retrofitting existing plants with expensive end-of-pipe treatment equipment will inevitably extent the life of a plant and delay its replacement.

Thus circumstances tend to conspire to bring about a suboptimal allocation of resources in obsolescent technologies, rather than accelerating investment in newer technologies. Looking back at the history of technology, it is clear that similar "lock in" (or "lockout") situations have arisen quite frequently in the past. In other words, the technologies that are actually in existence today are not necessarily the best that could have been chosen, had a free and fully informed choice been possible at every moment in time. A classic example is the standard typewriter keyboard layout (QWERTY). This is significantly inferior to the layout that would be optimal from an ergonomic perspective. It continues to be used because the cost of change outweighs the short term benefits of a change [David 1985].

A fundamental characteristic of some technological systems is that they interact with other systems (or other copies of the same system), either positively and negatively. An example of positive interaction has been called "increasing returns to adoption" [Arthur 1983, 1988]. There are many instances where increasing adoption of one technology tends to be self-reinforcing. For instance, widespread adoption of Ford cars or IBM computers permitted Ford and IBM to provide an effective sales and service network, familiarized many potential new customers with the products and — in the case of IBM — facilitated easy transportation of software from one computer to another. These advantages contributed to the continuing success of the respective companies.

Two close relatives of returns to adoption are "returns to connectivity" and "returns to scope". Simply put, the greater the coverage of the system, the greater its value to users. The most obvious example of increasing returns to connectivity is the telephone. An isolated telephone has no value to anyone. The value of each phone to each of its subscribers increases in direct proportion to the number of other phones to which it is connected. (N.B. as it happens, virtually all telephone subscribers in the world today can be connected to virtually all others, but this need not be the case and was not the case a few years ago). The same thing is true, more or less, of rail networks and road networks.

Standardization, in turn, is an important precondition for connectivity, and thus of adoption. (What would be the use of a rail network in which each line was built with different, incompatible gauges and rolling stock?) The typewriter keyboard is but one instance of the situation where standardization offers major benefits. The proliferation of incompatible computer hardware and software standards today might well account for the fact that computerization has yet to yield measurable economic benefits in terms of increased productivity.

Returns to scope (or "economies of scope") have been discussed primarily in terms of contrast with the more familiar notion of economies of scale, especially in the context of manufacturing [Goldhar & Jelinek 1983]. Exploitation of economies of scale, to the maximum degree, is historically associated with mass production and Taylorism (or Fordism, as it is known in Europe). To exploit economies of scale to the limit it has been necessary to standardize products, on the one hand, and to specialize production machines on the other; it is also logical for mass production firms to discourage technological change, since new models require new production lines [Abernathy 1978]. The long-term potential of computer-integrated manufacturing (CIM) is that it may permit firms to achieve most of the benefits of mass production without the penalty of extreme inflexibility. However this may be, what

CIM offers has been termed "economies of scope", namely the ability to produce a wide variety of different product designs without changing the physical arrangements of the production system.

The above examples have been discussed at some — hopefully not excessive — length to introduce a final example of more direct relevance to the problem of pollution reduction: namely returns to internalization (or closure) of the materials cycle. Dow Chemical Co. has popularized the acronym WRAP, for "waste reduction always pays". This is a slogan to attract the attention of managers and workers, but it contains an element of general truth. Unquestionably, it is desirable to convert waste products into salable by-products. The economic feasibility of this conversion often depends on two factors: (1) the scale of the waste-to-by-product conversion process and (2) the scale of demand (i.e. the size of the *local* market).

For example, low grade sulfuric acid is not worth transporting but it can be valuable if there is a local use for it. Similarly, sulfur dioxide, carbon monoxide and carbon dioxide are both needed for certain chemical synthesis processes, but cannot be economically transported more than a few tens or hundreds of meters. Hydrogen, produced in petroleum refineries, can be shipped but it is much better to use it locally. So called blast-furnace gas can be burned as fuel, but it is not economical to transport very far. There are numerous examples in the chemicals industry, especially. Closing the materials cycle can take the form of creating internal markets (i.e. uses) for low value by-products by upgrading them to standard marketable commodities. This often depends upon returns to scale.

To summarize, there are significant returns to internalization of the materials cycle. The so-called integrated steel mill (including its own ore sintering and smelting stages) is an example. It would not pay to produce pig iron in one location and ship it to another location for conversion to steel, for two reasons: (1) there would be no way to use the heating value of the blast furnace gas and (2) the molten pig iron would cool off *en route* and it would have to be remelted again. Thus energy conservation considerations dictate integration. The same logic holds for petroleum refineries and petro-chemical complexes. In each case there are a number of low value intermediate products that can be utilized beneficially if, and only if, the use is local.

In principle, this logic also applies to some cases where it has not been applied in practice up to now. Major unexploited technological opportunities would change the conventional picture shown in *Figure 1* to a situation more like *Figure 2*, in which there is some room for improvement at zero or even negative cost. A possible illustration of this sort, arising from the existence of economies of integration, may be found in the utilization of coal. A hypothetical case is described sketchily below. It is important to stress that process changes to take advantage of returns to closing the materials cycle are very definitely *not* "end-of-pipe" treatment of wastes.

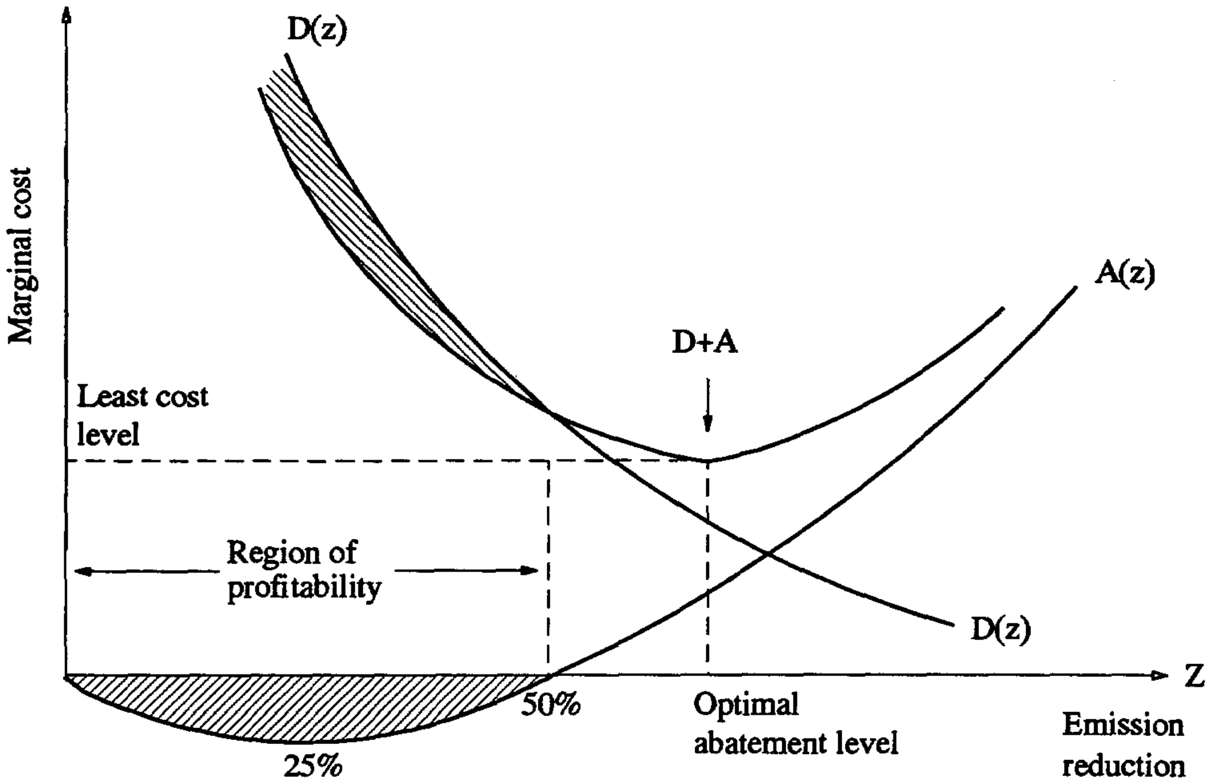

Figure 2: Optimal Abatement in Economic Disequilibrium
Source: author

Implementation Issues[2]

Returning to the specific case of the Black Triangle in eastern Europe, it is reasonable to infer that Poland and the Czech Republic qualify as "Country A", while Germany, Austria and Scandinavia are "Country B". (East Germany meanwhile having been absorbed by West Germany). Country B has already invested a lot in air pollution abatement — to the point where the marginal costs of additional domestic abatement are equal to the marginal benefits thereof. At this point, the most cost-effective way for Country B to reduce air pollution further within its own borders may well be to assist Country A in the east to cut airborne emissions.

As above, we can specify that "pollution" hereafter means sulfur dioxide and particulate emissions from coal combustion. The general strategy proposed is to allocate emission permits to existing large-scale coal consumers throughout Europe on the basis of actual current SO_x and fly ash emissions. (Two types of permits need to be created; one for each pollutant). The

[2]There is also a set of questions concerning optimal negotiating *tactics*. A growing body of literature in mathematical economics treats multi-party negotiations as "games". However, it is not clear what, if any, practical implications this abstruse literature has for real international negotiations at the present time.

target for regional emissions reduction can presumably be set by the EEC in Brussels. Since the eastern countries would be net financial beneficiaries of the scheme for a number of years, and since they also want to join the EEC, their agreement should be *pro forma.* We can also suppose that sufficiently detailed cost studies have been done, so that the most cost-effective "next step" is relatively easy to determine at each point in time.

The first real implementation problem is determination of baselines for permit allocation. This is problematic because current coal and electricity output levels in all of the countries are depressed, but unequally so. Some formula would have to be devised to adjust the allocation to some common basis like 80% capacity utilization. Even so, there will be messy questions with regard to determining actual capacity in the eastern countries.

The next implementation issue is more fundamental. It is how to create a viable exchange market for the permits. The analogy with stock markets is appealing but misleading, since only a small number of large enterprises would be buying and selling. Opportunities for manipulation by unscrupulous insiders are almost inevitable. How should such a limited market be regulated, and by who? How would prices be determined? How can the weaker players be protected against conspiracies among the stronger players? Most important of all, how can the players in the market be convinced that cheating (i.e. emitting without a permit) is not possible?

This last point is fundamental. The market players will be firms, not individuals. Unless cheating firms are virtually certain to be caught, and unless the penalty for cheating is high enough to be an effective deterrent to the responsible manager (but not high enough to drive the firm into bankruptcy) there will be no viable market for permits, because no firm will be willing to buy. The viability of the market depends on very accurate monitoring of emissions, and on very strict enforcement of limits. Who, then, will be the enforcers? What sort of legal process will be required? What kinds of evidence will be needed to prove a case? Who will be the judge and jury? What happens, incidentally, if the offender is a nationalized company? (At present, most utilities in Europe are public enterprises). All of these questions need to be addressed in detail in the implementing legislation.

Concluding Comments

A final issue that arises from the various considerations discussed above is whether there is conceivably a role for private enterprise, not just is a seller of end-of-pipe pollution control equipment, but also as an investor in potentially profitable new technologies? In short, is there a possible "no regrets" strategy that is in danger of being overlooked? The conventional view of pollution reduction presumes that environmental benefits can only be achieved at the expense of economic growth, due to the need for economically unproductive investments in waste treatment technology. If end-of-pipe treatment is the only option, the conventional view is realistic.

Yet, the existence of returns to scale, returns to adoption, returns to connectivity and returns to closure of the materials cycle strongly suggest that the conventional view is much too simplistic. The fact that sub-optimal technologies can be (and have been) "locked in" has already been mentioned. It also follows that potentially better technologies may have been "locked out". If so, it is possible that there are "win-win" strategies that offer both environmental and economic benefits in the same package. A case can be made for the viability of such strategies.

To explore this idea in concrete terms, consider the Black Triangle as an industrial ecosystem based on coal. The core of the hypothetical system (described in the Appendix) is a set of relatively new processes to create salable products and economic value from coal ash and sulfur. A spectrum of products, from elemental sulfur and/or synthetic gypsum to alumina (or aluminum) and ferrosilicon would be produced. The various possible components are indicated in *Figure 3*, although both simpler and more complex variants can easily be constructed.

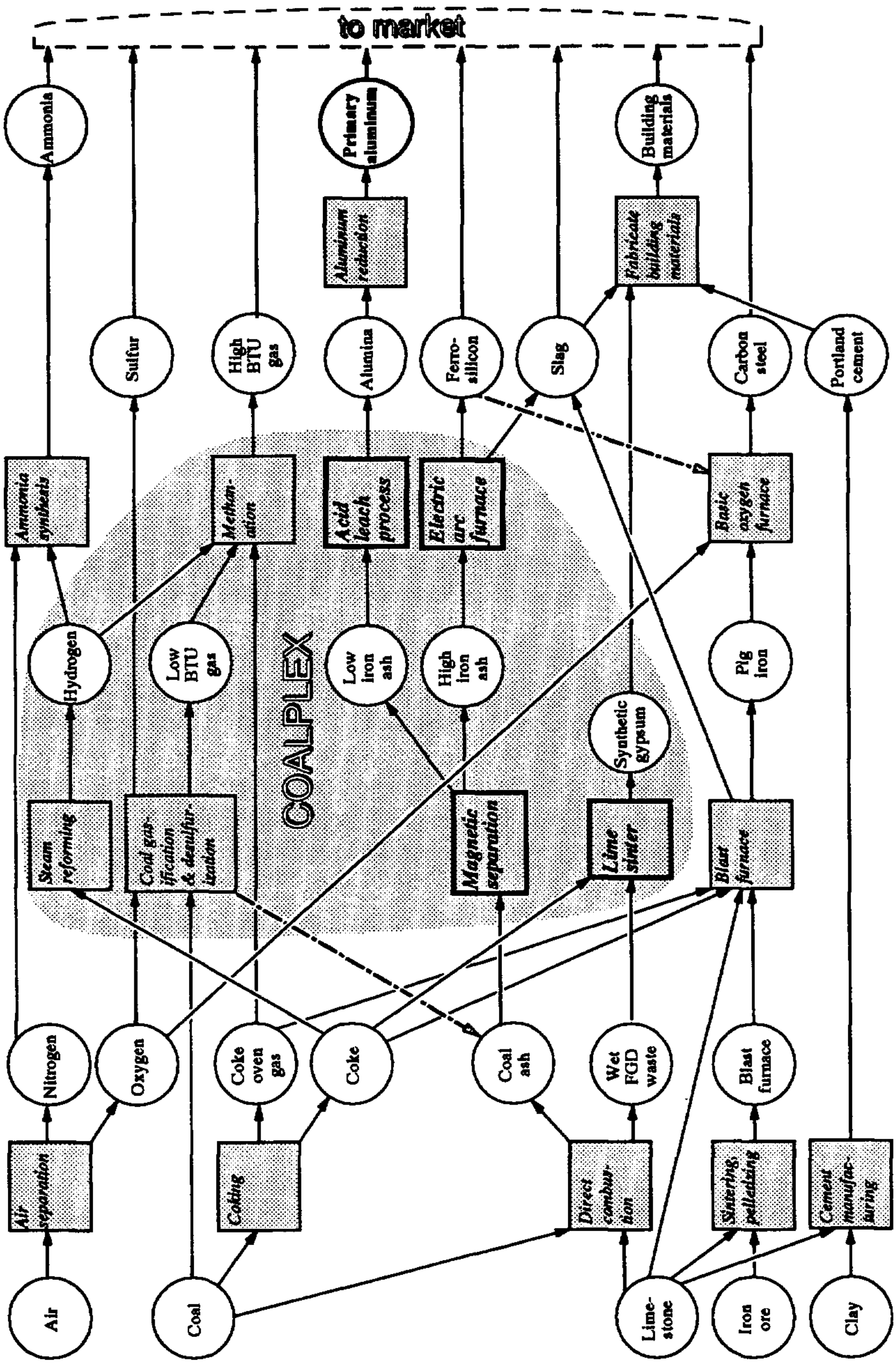

Figure 3: Hypothetical Process-Product Flows for Coal-Plex
Source: author

Appendix A: An Integrated Technology; Coal-Plex

The environmental problems in the Black Triangle are essentially entirely attributable to the use of brown coal. Nothing short of shutting down the mines and the electric power plants — hence the industry — could eliminate the pollution problems in a short time. Lacking alternative sources of employment and export earnings, this is not an option. Over a longer period — by the second half of the next century — the use of coal may have to be sharply cut back or phased out altogether, for environmental reasons. But, realistically, the interim solution must be coal-based. Since the use of coal itself cannot be eliminated, its major pollutants — at least sulfur and ash — must be captured and disposed of safely.

The solution we seek, then, is one in which these pollutants can be converted to salable by-products and sold to other users in the region to replace raw material imports. In other words, we propose to treat the region as an integrated system, in which the success of the parts depends on the success of the whole as much as *vice versa*. An important feature of the concept is that technologies will be selected in order to minimize costs for the system as a whole, not for individual units within it. Mechanisms for accomplishing this are discussed later.

From a technological perspective, the plan we propose has two phases. The first phase is to eliminate the direct use of coal as a domestic furnace fuel, and possibly also as a fuel for electric power production. The obvious alternative to coal is gas. Thus, the central element of Phase I would be the building of a gas distribution system for the cities and towns of the region, supplemented by a butane/propane distribution system for the rural regions.

There are two possibilities here: (i) diversion of existing natural gas (available by existing pipeline from Russia, but exclusively reserved hitherto for the use of large industries under the communist regime) or/and (ii) construction of coal-gasification facilities. We consider only the latter possibility hereafter. The choice here is between a high BTU fuel produced by a sophisticated high-tech coal hydrogenation system, or a low BTU fuel ("town gas") made by some variant of the old established steam-reforming process. Economically speaking, the advantage of the high BTU gas is that it takes less volume and therefore requires smaller pipes, which will be less expensive to install. However, most of the cost of the gas distribution system is construction, not pipe. Steel in the region is particularly cheap, at present, so it might make sense to use the low BTU gas, at least during the first decade or so.[3] This strategy would have the further benefit of facilitating later expansion of the gas capacity of the gas distribution system by gradually increasing the BTU content of the fuel.

It should be noted, in this context, that some high BTU processes (such as Hydrogasification) begin, essentially, with a low BTU gasification stage. Subsequently, the gas is methanated to bring it up to "pipeline quality". However, there is really no good reason why the two stages need to be implemented from the start. A second stage could be added after some years to accommodate higher demand without reconstructing the gas distribution system.

[3]Also, it should be noted that a variant of the water gas process uses pure oxygen rather than air, so the fuel contains no inert nitrogen. The nitrogen from the air separation plants can be used in ammonia synthesis plants.

It is also possible that the large steel manufacturing enterprises in the region could be upgraded in efficiency so as to release surplus quantities of either coke-oven gas, or blast furnace gas, or both. The former can be used for domestic purposes, while the latter is suitable for use in coal gasification or electric power plants. Later, it is possible that the use of gas as a domestic fuel could be reduced by using efficient forms of electric heating (e.g. heat pumps) in suitable locations.

Evidently, building a gas generation and distribution system would provide a large domestic demand for steel pipe, at least during the construction phase. While such a project would be very costly, it is something that must done in the coming years regardless of whether or not the rest of the plan is carried out. As noted above, the only real optimization problem concerns the optimum BTU-content of the gas and the consequent size of the pipes.[4]

Over the next two decades, then, coal burning would gradually be restricted to large industrial establishments and some of the larger electric utilities, where flue gas desulfurization (FGD), cyclones, bag-houses and electrostatic precipitators (ESP's) are technologically and economically feasible.

Table A-1: Composition of Fly Ash

Constituent	*Weight (percent)*	*Standard deviation (percent)*
SiO_2	45.6	4.8
Al_2O_3	21.9	5.4
Fe_2O_3	17.4	4.7
CaO	3.8	1.8
SO_3	2.5	3.7
K_2O	1.6	0.7
MgO	1.0	0.2
TiO_2	0.9	0.5
Na_2O	0.7	0.6
P_2O_5	0.3	0.1

Source: [Roy *et al* 1979]

The second phase of the plan, which could begin well before the first phase is completed, would be to develop new industries based on the use of (i) coal ash as an industrial feedstock. *Table A-1* shows the average composition of bituminous coal ash in the U.S. Ash composition should not vary significantly in other locations, although the ash content of the coal varies enormously. A further objective would be to extract and utilize (ii) sulfur or (iii) synthetic gypsum. The essence of our plan is to use *new* technologies that have been developed and tested (in many cases, in pilot plants) but never before implemented on a large scale elsewhere. The risk of setbacks, unexpectedly high costs, or even outright failure due to unanticipated technical problems cannot be denied. However, by judicious selection of

[4]It would be economical, incidentally, to lay optical fiber cables at the same time as the pipelines.

technologies, together with shrewd project organization (with heavy emphasis on innovative solutions to problems as they arise) we think these risks can be minimized.

Technological possibilities that need to be investigated in detail include the following:

- The use of coal ash as a partial substitute for Portland cement in concrete. This possibility is fairly well-known in the industry. It would only require minor changes in building industry practice. Governments could dramatically accelerate the use of fly ash as a pozzolanic material by simply imposing minimum fly ash percentages for concrete used in various applications.

- Recovery of elemental sulfur from FGD [Kelly & Dickerman 198?]. This is very straightforward in a hydrogasification plant, since the sulfur combines initially with hydrogen to form H_2S, which is easily reduced to elemental sulfur buy the Claus process. It is less easy in an oxidizing environment, where the most useful product that can be extracted is probably a low-grade sulfuric acid.

Table A-2: Composition of Sample Fly Ash and Fractions Obtained by Magnetic Separation

	Chemical Composition, Weight Percent				
		Dry Separation		*Wet Separation*	
Constituent	*Whole Fly Ash 100 parts*	*Magnetics 23.6 parts*	*Non-Magnetics 76.4 parts*	*Magnetics 26.1 parts*	*Non-Magnetics 73.9 parts*
SiO_2	42.36	20.31	47.89	20.83	53.0
Al_2O_3	17.91	10.21	20.04	9.95	22.83
Fe_2O_3	19.29	60.08	6.56	65.00	5.24
CaO	4.49	1.87	4.88	13.20	5.82
MgO	0.71	0.40	0.76	0.42	0.99
Na_2O	0.35	0.18	0.35	0.14	0.31
K_2O	1.72	0.81	1.85	0.71	1.91
SO_3	2.13	0.79	2.04	c	c
LOD[a]	0.58	0.13	0.45	0.12	0.56
LOI[b]	10.39	2.13	12.40	1.70	8.46

Source: [Chou *et al* 1978]
a. LOD is loss on drying at 110°C
b. LOI is loss on ignition from 110-800°C
c. Not detected

- Synthetic gypsum for use in plaster-boards and building materials can be produced from wet FGD wastes from coal-burning plants. One viable approach seems to be the so-called lime-sinter process [Motley & Cosgrove 1978], although there are several variants. At least one such plant is already operational, on an experimental basis, in the Czech Republic, using German technology.

- Use of coal ash as a source of iron ore (magnetite). See *Table A-2*. Magnetic separation is quite straightforward, and has been demonstrated in several places [Nowak 1978; Roy *et al* 1979]. The hematite content of the magnetic fraction ranges between 60% and 70%. The magnetic fraction itself varied between one fourth and one third. Assuming an ash content of 10% and annual consumption of 100 million MT, the iron "ore" content of the ash would be of the order of 3% or 3 million MT. While this could not displace all of the virgin iron ore needed in the steel industry of the region, it is not insignificant.

- Ferro-silicon is another possible product. Fly ash can be smelted in an electric arc furnace (even without magnetic separation) to produce ferro-silicon [Morton 1978]. All of the aluminum remains in the slag. See *Table A-3*. Thus, in effect, this process would recover the iron and about half of the silicon in a very marketable form, while upgrading the slag as a potential aluminum source.

Table A-3: Composition of Products; Fly Ash without Magnetic Separation

Ferro Silicon		*Slag*	
Iron	61.00%	Aluminum oxide	35.00%
Silicon	33.00%	Silica	26.40%
Chromium	1.89%	Calcium oxide	11.68%
Carbon	1.88%	Magnesium oxide	10.63%
Vanadium	1.07%	Iron oxide	7.80%
Magnesium	0.09%	Sulfur	2.17%
Copper	0.04%	Chromic oxide	0.50%
Sulfur	0.01%	Copper	0.08%
Phosphorus & other trace elements	1.02%	Phosphorus	0.03%
		Vanadium & other trace elements	5.71%
	100.00%		100.00%

Source: [Morton 1978]

- Use of iron-free coal ash, or slag, as a source of alumina (Al_2O_3) in place of bauxite. The U.S. Bureau of Mines studied at least 18 alternative processes for extracting alumina from clay or anorthosite in the early 1970's [Peters & Johnson 1974]. None appeared competitive with the Bayer process, at the time (*Table A-4*). However, fly ash is a more attractive raw material than clay, since the most energy-intensive step in clay processing is dehydration, and this is unnecessary when fly ash is the starting material [e.g. Yun *et al* 1980]. Also, the magnetic fraction has some value. Based on 1981 prices several processes appeared to be promising (*Table A-5*). Later, the Electric Power Research Institute (EPRI) studied several processes in detail. One, hydrochloric acid leach, appeared to be quite

Table A-4: Summary of Published Bureau of Mines Estimates of Alumina Process Costs (1973 basis)

Raw Material *Bureau of Mines Reference # Input* *Process*	*Energy (Utility) Cost $ per ton Al_2O_3*	*Total Operating Cost $ per ton Al_2O_3*	*Fixed Capital Cost 1000 tpd Plant (million $)*
Clay (cost, $1/ton)			
RI6431 Nitric Acid ($83/ton)	32.04	93.47	110
RI6133 Hydrochloric Acid; isopropyl ether extraction	31.76	98.94	116
gas precipitation	59.76	135.80	156
gas precipitation - isopropyl ether extraction	98.65	187.67	195
caustic purification	24.74	13.53	143
sinter purification	35.45	121.76	151
RI5997 Sulfurous Acid; caustic purification	27.33	103.23	130
RI6229 Sulfuric Acid; electrolytic iron removal	50.59	133.84	152
chemical iron removal	51.34	131.89	135
ethanol purification	58.35	136.97	126
RI7758 Sulfurous Acid/Sulfuric Acid	92.14	142.67	97
RI6290 Potassium Alum	40.48	148.17	166
RI6573 Ammonium Alum; ammonium bisulfate leaching	82.06	187.40	243
ammonium sulfate baking	62.89	168.18	224
RI6927 Lime-Soda Sinter; dry-grinding option	34.55	13.12	104
wet-grinding option	32.19	104.88	96
RI7299 Lime Sinter; double leach	44.23	122.77	122
single leach	59.33	138.60	124
Anorthosite (costs: anorthosite, $2.50/ton; limestone, $1/ton)			
RI7068 Lime-Soda Sinter; dry-grinding option	33.94	111.15	110
wet-grinding option	38.49	111.26	101
Bauxite (cost, $8/ton)			
RI6730 Bayer process	10.48	63.15	67

Source: [Peters & Johnson 1974]

Table A-5: Estimated Annual Operating Costs for Baseline & 4 Processes Using Fly Ash to Produce 1000 TPD of Alumina (1980 $)

Item	*HNO_3-Ion Exchange*		*Hcl-Ion Exchange*		*Hcl-Isopropyl Ether*		*Potassium Alum*		*Bayer Process*	
	Annual Cost $1000	*$ Cost per ton of Alumina*	*Annual Cost $1000*	*$ Cost per ton of Alumina*	*Annual Cost $1000*	*$ Cost per ton of Alumina*	*Annual Cost $1000*	*$ Cost per ton of Alumina*	*Annual Cost $1000*	*$ Cost per ton of Alumina*
Direct Cost	17210	49.17	18677	53.36	17874	51.07	20566	58.76	15799	45.14
raw materials cost	4250	12.14	7002	20.01	4834	13.81	1022	2.92	8402	24.01
utilities cost	6848	19.57	5374	15.36	6105	17.44	9242	26.41	3668	10.48
direct labor	2045	5.84	1550	4.43	1507	4.31	2745	7.84	1819	5.20
plant maintenance	2376	6.79	2985	8.53	3476	9.93	4679	13.37	1660	4.74
payroll overhead	1215	3.47	1169	3.34	1257	3.59	1943	5.55	-	-
operating supplies	475	1.36	597	1.71	695	1.99	936	2.67	249	0.71
Indirect Cost	1769	5.05	1814	5.18	1993	5.69	2969	8.48	1739	4.97
Fixed Cost	23484	67.10	26851	76.72	27007	77.16	33905	96.87	22104	63.15
taxes	644	1.84	909	2.60	1020	2.91	1481	4.23	634	1.81
insurance	644	1.84	909	2.60	1020	2.91	1481	4.23	634	1.81
depreciation	3218	9.19	4543	12.98	5100	14.57	7407	21.16	3298	9.42
Credit for Fe_2O_3	-5250	-15.00	-5612	-16.04	-5623	-16.07	-5560	-15.89	-	-
Net Operating Cost	18234	52.10	21239	60.68	21384	61.10	28345	80.99	22104	63.15

Source: [Ayres & Steger 1981]

economically favorable in comparison with the Bayer process. See *Figure A-1.* EPRI estimated a return on investment of 40% p.a. for an industrial scale unit [Canon *et al* 1981].

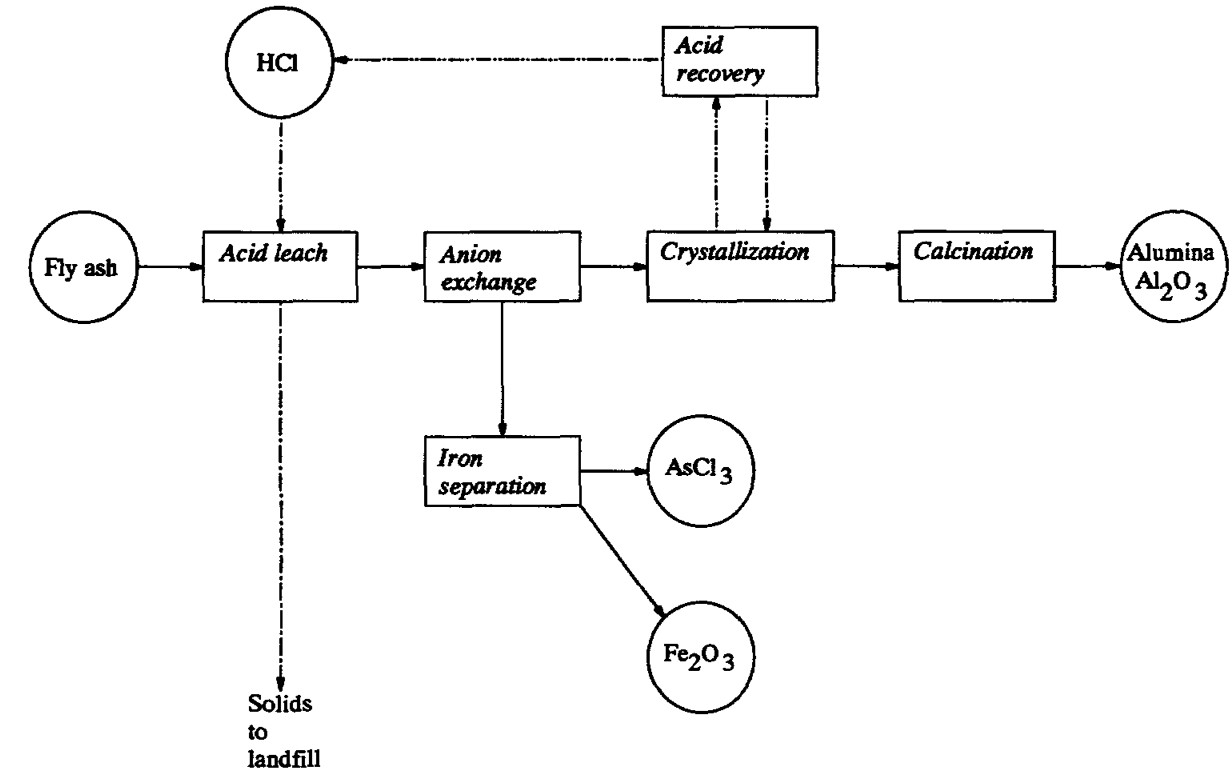

Figure A-1: Hydrochloric Acid Leach Process
Source: author

- Recovery of primary aluminum by chemical means, not requiring electrolysis. At least one such process (the Toth process) received considerable attention in the early 1970's [Business Week 24-2-73] though it was never adopted by the aluminum industry.

The fact that these technologies have not been commercialized, in most cases, does not imply that the processes in question are faulty, though they are untested. It can be laid to the fact that the relevant industries — notably electric power and primary aluminum — are generally mature, slow growing (or non-growing), oligopolistic, and extremely risk averse.

A somewhat more speculative (hence longer range) possibility is electrolytic separation of fly ash (plus slag from the smelting of iron) into all of its metallic components. Conceptually the problem is fairly simple, and closely analogous to the current Hall process for aluminum reduction[5]. The fly ash would first be dissolved in molten cryolite (Na_3AlF_6) at a temperature of 970 degrees C. Iron, silicon and aluminum oxides can be reduced electrolytically, in a sequence of three bipolar cells at different voltages. Iron is extracted first at 1 volt; silicon follows at 1.8 volts. Finally, aluminum is extracted at 2.2 volts. An inert anode (not carbon, as in the Hall cell) would be used. Cells of this type have been under development for a number of years, for eventual use in the aluminum industry itself.

Calcium, magnesium, sodium and potassium oxides actually react by ion-exchange with the cryolite, exchanging their oxygen for fluorine from the aluminum, and yielding the corresponding fluorides plus alumina. These contaminants gradually build up over time, and the cryolite must be purged and recycled at intervals. The product of this step is an alloy of the four light metals (Ca-Mg-Na-K) that can be used as a reductant. The fluorine gas is recycled back to the cryolite as AlF_3).

From an economic point of view, the key to success is physical integration. It is essential for the Coal-Plex to assure reliable availability of the ash and its intermediate products, on the one hand, and reliable utilization on the other hand. In the absence of existing established markets for intermediates (like high/low iron ash) the entire complex of related activities must be designed and operated *as a unit*. Under normal conditions, private firms from different industries would specialize in each of the component elements of the system. Electric and gas utilities want to sell electricity, not sulfur or ash; certainly not alumina or ferro-silicon. Yet the viability of each component of the system depends on by-product credits.

For this reason, and others, a holding company structure is almost imperative. The holding company would have to be a regulated monopoly (analogous to EDF in France) with exclusive rights to produce electricity and syngas for consumer use from coal. It must have the exclusive right to build (or contract to be built) a gas pipeline distribution system. It would also need to be given a strong mandate to remove at least 95% of sulfur and 99% of fly ash from the air, within 20 years, and to convert both the sulfur and the ash in the coal into useful products, ranging from building materials to metals.

In exchange, the Coal-Plex holding company must have rights to sell stocks and bonds, to negotiate binding contracts with other firms, to allow investors to repatriate profits, and so on. It should be exempt from anti-trust or similar restrictions on cooperation among the member enterprises. It must be given blanket rights to undertake, or subcontract, any necessary construction in the area. It should be given "fast track" approval of necessary licenses, zoning permits, labor contracts and any other regulatory hurdles. The Coal-Plex company also needs insurance before it can hope to raise money in private financial markets.

Given the technological uncertainties of innovating untested technologies the Coal-Plex company should be given some relief with regard to other business risks. It should have the statutory right to insist on no-strike contracts with labor unions for at least ten years. A

[5] The idea is primarily due to Noel Jarrett, of ALCOA Research Center. It was conceived as a way to extract metals from lunar soil [Jarrett *et al* 1980].

further condition would be credible government guarantees of repatriation of profits by foreign investors. Finally, it might be important to revamp any applicable standards on building materials to encourage the introduction of new combinations utilizing some of the residues of the other processes.

A final topic of importance is the extent to which western governments, especially in neighboring states, might be persuaded that outright grants-in-aid to support industrial restructuring in the Black Triangle, along the lines suggested above, would be in their own best interests. This would be so if it could be shown that such an investment would be more cost-effective than bearing the long-term health care costs associated with trans-boundary air pollution, not to mention additional marginal expenditures on pollution control or abatement within their own national territories. In particular, western Germany and Austria would very probably benefit considerably by contributing financially to "greening" the Black Triangle. They might be more likely to do so, if it could also be shown that a small public sector investment would catalyze a larger private sector investment.

In this context, it seems worth mentioning that the most effective use of western public sector funds might well be to reduce the financial risk of the private investors. This could be done in a variety of ways, from direct subsidies of interest rates to private borrowers to the creation of special insurance funds to reduce the financial risk of technological difficulties.

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