DESIGN FOR A TECHNOLOGY ASSESSMENT OF COAL

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The objective of the coal technology assessment is to compare the environmental, social, economic, and institutional consequences that may arise from development of various mixes of coal-based energy technologies to the year 2030. This article presents the assumptions behind the method, the experience from two forums with interested parties, the three scenarios constructed for the study, and the result of one issue analysis, namely the effects of global carbon-dioxide buildup from coal combustion.

As TECHNOLOGY becomes a central social force, so too must its wise management become the quintessential task of our age. Many industrialised societies have become increasingly aware that the good short-term results are now giving way to bad consequences eg pollution, depletion of nonrenewable resources, elimination of cultural diversity, alienation, unemployment. Many of these problems can be traced to the overly simple criteria which guided the technological and economic decisions of the 1950s and the 1960s. Namely, can we do it? Can we sell or market it? Is it safe? The dissonances of today suggest rather clearly that much remained to be understood about both these questions and the answers which have been traditionally provided.

Energy technology is particularly significant because of its long-range consequences. One of the most important challenges facing the USA today is increased coal production and use. There have been a number of important studies conducted on the short-term and medium-term role of coal in energy production. This particular study[1] applies some of the concepts and processes proposed by Arnstein, Christakis, and Wolf.[2]

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A futures-creative approach

The early exponents of technology assessment (TA) emphasised value-free, neutral and objective assessments to be performed by experts using available data, to yield information for a limited number of political actors. Most technology assessments treated technology as an independent variable, which exerts unidirectional impacts on society although such impacts may be unintended, indirect, and delayed. The interdependent relationship between technology and society might be acknowledged, but was not examined explicitly.

The purely rational techno-economic viewpoint did not dominate for long. The policy orientation of technology assessment attracted not only political scientists, long-range social planners, historians, and the like, but also engineers, economists, and systems analysts who had become aware of the pitfalls of the purely rational elements of operations research and cost–benefit analyses.

A diversity of ideas and approaches had been tried in a number of TA projects sponsored by the National Science Foundation. These were discussed in a workshop in 1974. A synopsis of the workshop led to the 'futures-creative' method of technology assessment proposed by Arnstein, Christakis, and Wolf. The principal characteristics of the initial and the emerging philosophies behind technology assessment are shown in Table 1.

TABLE 1. COMPARISON OF INITIAL AND EMERGING APPROACHES TO TECHNOLOGY ASSESSMENT

Contexts	Initial	Emerging
Philosophical	Evaluative	Futures creative
	Elitist assessment	Public participation
	Incremental policy orientation	Metapolicy orientation
	Product and result orientation	Process and balance orientation
	Wholism (bottom up)	Holism (top down)
Epistemological	Value free	Value sensitive
	Restricted to empirical inquiry	Accepting all inquiring systems
	Restricted to scientific knowledge	Admitting intuitive judgment
	Projective (forward-time) causality	Anticipatory (time-reversed) causality
	Empirical verification of truth	Dynamic growth of valid knowledge via falsification/error/feedback
Methodological	Technology as independent variable	Technology and society as interdependent variables
	Quantitative analysis based on data	Combination of qualitative conjectures with quantitative analysis
	Convergent thinking	Successive divergent/convergent thinking
	Theoretical integration	Systemic integration
	Single *ad hoc* project/model	Multiple complementary projects/models
Procedural	Emphasis on intellectual process	Emphasis on social learning process
	Bounding by project staff	Unbounding and bounding jointly by interested parties and project staff
	Aggregated cost–benefit analysis by project staff	Disaggregated cost–benefit analysis jointly by interested parties and project staff
	Policy options suggested for a limited number of political actors	Alternative policy packages analysed by value-oriented procedures for interested parties
	TA as an independent evaluative activity	TA embedded in a futures-creative system for society

The coal technology assessment

The coal technology assessment has recently completed a draft first-year report.[3] The study is focused on two overarching questions:

- Does it matter how much coal the USA uses over the next 50 years (to the year 2030)?
- Given some level of coal-based energy use, how will it matter, from an environmental, social, economic, and institutional standpoint, which particular coal technologies are deployed?

Accordingly, the objectives of the coal technology assessment are to:

- identify coal-related issues;
- compare consequences of the use of coal-based energy technologies;
- explore policy options through the involvement of interested parties; and
- communicate the results.

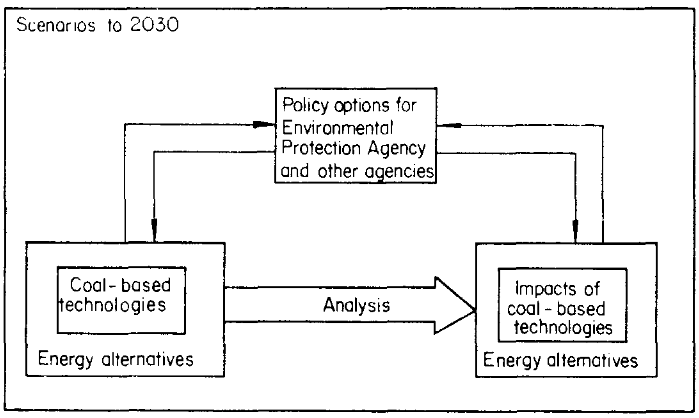

Figure 1. The framework for the coal technology assessment

Figure 1 illustrates the approach used: namely, to embed the analyses in alternative scenarios. The year 2030 has been chosen, because by 2030 coal might replace oil and natural gas as the major fossil fuel in the USA.

The study-team approach was as follows:

- structure scenarios;
- identify issues;
- estimate total energy demand;
- estimate coal-based energy demand;
- select coal-based technology mixes;
- conduct comparative impact analysis;
- evaluate policy options; and
- communicate findings.

These tasks do not necessarily occur sequentially.

The study integrated the three principal aspects of the futures-creative approach throughout:

- the technical analysis based on scientific knowledge and data;
- the policy analysis based on political issues and rationality; and
- the social learning process and the role of the interested parties.

Technical analysis

The technical analysis usually involves expert knowledge, generated by an interdisciplinary team.

For example, in the case of the coal technology assessment, engineering analyses provide detailed data on technology forecasting, the required inputs and outputs of a particular coal-based energy technology (such as fluidised-bed combustion, coal gasification, or coal liquefaction), and the possible effects of configuration changes such as installing environmental controls and minimising water consumption. Environmental impact assessments performed by biologists, chemists, economists, and sociologists are used to estimate the effects of technological configurations on, say, air quality, water quality, and human health. Economic and input–output analyses are performed by economists to generate data on the economic impact of alternative technological choices. Social impact studies provide data on the effects on population distribution, labour markets, work ethics, etc.

Policy analysis

The task of policy analysis is to relate the technical analysis to the decision making of the individuals and groups involved.

A policy-sensitive model for the conduct of the policy analysis has been developed by Ahmad and Christakis:[4]

Identification of the interested parties

The range of the interested parties likely to be affected by the alternative technologies is identified. It is both a function of assumptions about the existing and future forms of the society (eg scenarios) as well as the technical, economic, and sociopolitical nature of the issues being analysed.

Organising the interested-party perceptions

The perceptions of the interested parties are derived (either by interviews, discussion, or a literature survey) in terms of perceived trends, values, and public concerns.

Discussion

Neither the issue-oriented perspectives of the relevant interested parties nor the impact assessments are in themselves adequate for making policy. Policy making requires that the interested parties are familiar with the impact assessments. The outcome of this interaction between the actors' viewpoints and the impact assessments includes both technical and socioeconomic considerations.

Deriving of alternative public preferences

The alternative values of the interested parties and the associated trade-offs as perceived by the interested parties are aggregated in terms of consistent packages of public preferences. The differences and similarities among the separate packages of alternative public preferences provides an indication of the degree of consensus and conflict over alternative technological options.

Exploring policies

Given a set of alternative public preferences and the policy constraints of the organisations responsible for making decisions, a range of feasible policy options are explored. The process, in other words, involves a translation of public preferences into policy options.

Scenario embedding

Technology cannot be assessed without explicitly recognising the social context in which it is deployed and operated. Thus the description of social alternatives is an essential element of technology assessment. When the time horizon is as distant as in this case (50 years away), fundamental changes in social values and institutions can make extrapolations meaningless. On the other hand, there is no reliable way to fully predict the future. Therefore, as a way to explore alternative futures, the coal technology assessment constructed three scenarios.[5]

This means that technology-mix descriptions, impact assessment, and policy analysis will all be scenario dependent. For example, the 'soft' technology mix would make sense only if the assumed social values in a scenario would accept such technologies.[6] The potential health impact of a particular technology mix is also scenario dependent since morbidity and mortality due to pollution depends on, among other factors, demographic distribution patterns. Similarly, whether R and D policy emphasises pollution control will depend on whether the society believes in technological solutions or in changing life styles in order to cope with energy problems.

Scenario construction

For the current study, the scenarios described are relevant to coal-based energy technology but are not 'driven' by it. In spite of the importance of the energy problem, the basic tenets of US society are not expected to be determined by how we try to deal with the energy problem; rather vice versa—the dominant values and institutions will influence how we deal with the energy problem, of which the choice of coal-based energy technology (or technology mixes) is a part.

The above considerations have led us to a methodology of scenario construction which is summarised schematically in Figure 2.[7]

Summary of the three scenarios

Characteristics of each scenario are shown in Figure 3 and Tables 2 and 3.

No one of the scenarios is believed to be more likely than the others. However, the range of future events captured by the three scenarios together spans a future domain with a wide range of viewpoints. Together, the scenarios provide contrasting contexts of coal use and coal technology for the impact assessment and policy analysis phase of the project.

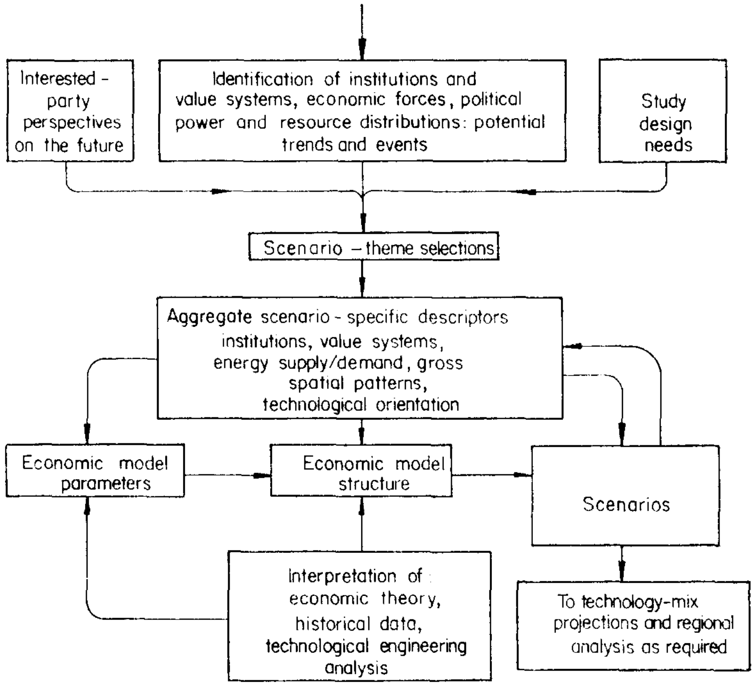

Figure 2. Scenario construction

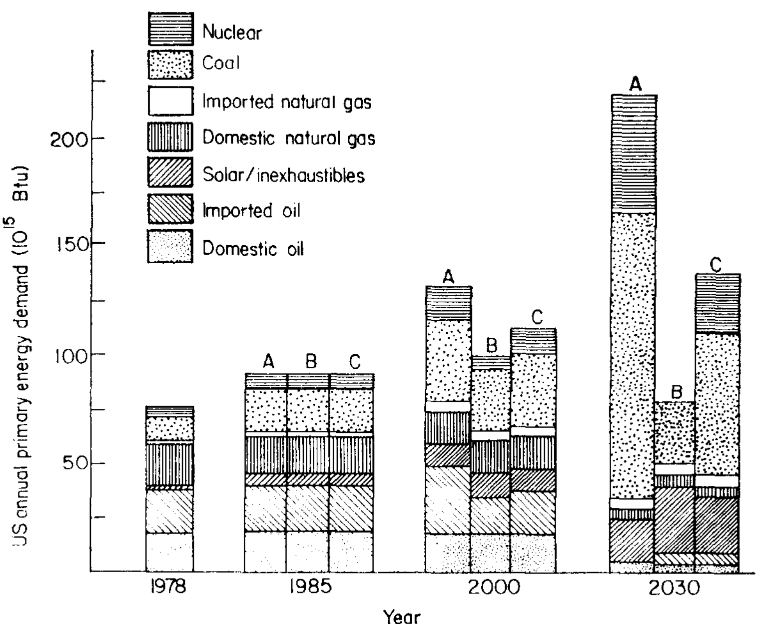

Figure 3. Primary energy demand as projected in the scenarios

TABLE 2. THE THREE SCENARIOS

Scenario A: economic growth

As the US energy problem became more severe during the last quarter of the 20th century, US society turned increasingly to technological solutions. Large technical systems, devised under the auspices of a joint government–industry energy programme (like Project Manhattan), overcame projected energy shortages. Although the market economy was still seen as the way to deal with social issues, decisions were made as the result of government–industry collaboration and governmental pacesetting. Government became the manager of the system in a symbiotic relationship with industry. With the economy functioning like a well-oiled machine, GNP climbed steadily. The level of pursuit of leisure and non-job-related activities such as community service work became the major occupation of many individuals. The average citizen believed that things were going very well.

Scenario B: conservation ethic

As awareness of the economic, the environmental, and the social costs of the continued growth of large-scale, centralised energy-supply systems grew, those who advocated a more energy-efficient and less wasteful life-style increasingly influenced both political decisions and the development of conservation technologies and small-scale, efficient energy systems. By the middle 1990s the idea of a resource-conserving society based on man in harmony with nature was entrenched in many levels of government. Energy conservation practices and the deployment of new energy-conserving technologies were widely supported and implemented. Energy consumption in the USA peaked and began to decrease after the turn of the century. Solar energy became a major energy supplier with many communities approaching energy self-sufficiency. Local and state governments gained more and more power to deal with domestic issues.

Scenario C: business as usual

The USA worked its way through the energy problem as it always had, through considerable conflict and compromise among the various interest groups. Large imports of oil and natural gas and expanded use of coal helped the USA meet domestic demand, with only occasional shortages. Governmental policies varied from time to time to accommodate the fluctuations in both the economy and the political situation. The USA contained a diversity of parochial interests and basic values, with great flexibility and considerable room for individual choice in life-styles. While this diversity and hesitancy to move in any particular direction led to fluctuating economic and investment circumstances, society believed diversity and flexibility were more important than economic efficiency and resolute action. GNP continued to grow steadily, as did the general level of affluence.

TABLE 3. SUMMARY OF US ECONOMIC AND ENERGY TRENDS IN THE SCENARIOS

	1985	2000			2030		
	A, B, C	A	B	C	A	B	C
GNP (thousand million 1975$)	2 300	4 300	3 600	3 700	11 000	7 300	7 700
Average annual growth of GNP (%)	3·7	4·0	3·1	3·3	3·2	2·4	2·5
Energy demand (quads)[a]	91	132	102	110	214	76	135
Average annual growth of energy demand (%)	2·6	2·4	1·0	1·6	1·7	−0·8	0·7
Employment (million full-time equivalents)	110	120	130	130	140	150	150
Capital stock (thousand million 1975$)	5 200	11 400	8 800	8 900	36 100	20 400	21 200
Population (million)	230	260	260	260	300	300	300

Note: [a] 1 quad=10^{15} Btu.

Forum experiences

A public forum on coal-based energy futures was held at Airlie House, Virginia, 5–7 March 1978.[8] The forum had five basic objectives:

- involve interested parties in the study;
- encourage participation during the study and beyond;

- explore long-range social trends and values for the USA, and their interactions;
- identify trends relevant to coal-based energy futures; and
- identify critical problems and issues with respect to the deployment of coal-based energy technologies.

The Airlie House forum initiated the 'social learning' phase.

The technical analyses alone cannot be adequate for policy making. The identification of problems and issues is needed, which should originate from a variety of sources including:

- the interdisciplinary team's technical analysis;
- the interested parties; and
- the interaction of the team with interested parties and policy makers.

The study team developed a five-step approach, by which it could achieve the study objectives in the short time available (two working days), and which looked at trends, values, problems, and issues over two time frames (1978–2000 and 2000–2030):

- Identification of trends.
- Value identification.
- Interactions among trends and values.
- Interactions among trends/values/social sectors.
- Identification of problems/issues.

The participants were put in small groups of nine or ten for the two days of work sessions. Each followed the same general procedures, but the diversity of the groups ensured a variety of outputs.

Some of the issues identified and discussed included:

- Water availability—treatment, quality, allocation.
- Balancing of all values, cost-benefits, and risks—environmental, economic, and social—in the context of energy development.
- Roles and relationships of levels of government, nongovernment agencies, and individuals.
- Socioeconomic effects of increased coal use on communities.
- Trade-offs between known adverse impacts of coal technologies with unknown impacts of alternative energy technologies.

In July 1978, a regional forum was held at Keystone, Colorado to identify issues and policies with respect to coal-based energy development in the Rocky Mountain region.[9,10] The forum results demonstrated a surprising unity despite the diversity of the participants. Each of four working groups agreed that water availability and quality of life have a high priority. Government regulation was identified as a priority by two of the four groups and was an important part of discussions in the other two groups.

Issue development

The choice of issues to be analysed is critical. The approach taken in identifying, ranking, and selecting issues is shown in Figure 4. The study team initially

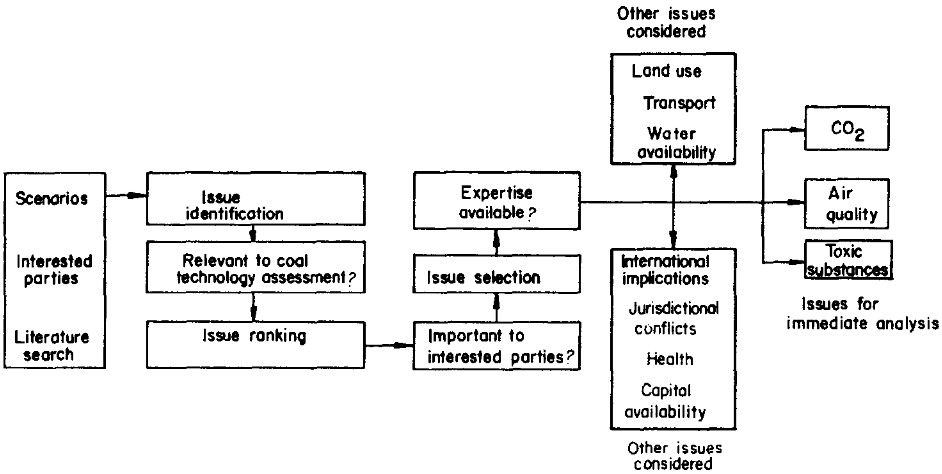

Figure 4. Issue development

compiled a listing of more than 200 issues. Experts helped the research team reduce this to ten key issues:

- Global carbon-dioxide buildup—the effects of release of CO_2 into the atmosphere from coal burning.
- Prevention of significant deterioration in air quality—limits placed on siting, size, and growth rate of coal-related facilities.
- Toxic substances from coal—control of toxic substances from coal use while maintaining balance between environmental and technological requirements.
- Federal/state/local jurisdictional conflicts—the uncertainty and multiplicity of environmental regulations.
- Land use (siting)—the locations and types of coal-based energy facilities.
- Transport—the ability of the national transport system to handle increased coal production.
- Water availability—treatment, quality, aquifer interruption or disruption, allocation among users.
- Capital availability—the constraints on coal development.
- International implications—coal's role in trade and international relations.
- Health—the long-term safety, health, and environmental effects.

Three issues—global carbon-dioxide buildup, prevention of air-quality deterioration, and toxic substances—were chosen for detailed analysis in the first year. The results of one issue analysis, namely global carbon-dioxide buildup, will be described next.

Issue analysis of global carbon-dioxide buildup

A primary factor limiting fossil-fuelled energy production may turn out to be the effects of carbon dioxide release into the atmosphere. As atmospheric CO_2 levels increase, the heat absorbed by CO_2 can be reradiated back to Earth leading to a warming of the atmosphere or the 'greenhouse effect'.

A number of considerations warrant a closer look at atmospheric levels of CO_2 from fossil-fuel combustion:

- Atmospheric CO_2 levels have increased from an estimated 290 ppm (parts per million by volume) before the industrial revolution to 330 ppm today (new estimates may lower the 290 ppm figure to about 270 ppm—indicating a faster rate of buildup).[11]
- Approximately half of the fossil-fuel CO_2 released each year remains in the atmosphere.
- Atmospheric CO_2 concentrations may peak as much as 50 years after the peak of fossil-fuel use.
- The end of the mesozoic era saw the demise of the dinosaur: it may have resulted from global warming in CO_2-induced 'greenhouse' conditions.[12]

Atmospheric CO_2 levels are increasing. Yet there is a great deal of uncertainty over the balance of sources to sinks to sources again that comprise the global carbon cycle. This uncertainty extends to the relative role of fossil-fuel combustion in atmospheric CO_2 levels. However, in the absence of counterbalancing trends (such as the beginning of an ice age, an increase in airborne particles to screen out sunlight, or yet-to-be-identified mechanisms of CO_2 uptake), a doubling of atmospheric CO_2 concentrations would lead to temperature increases in the order of 2·5° C.[13] Increases would be greatest towards the Earth's poles. Increases approaching 1–2° C are felt to be great enough to bring about significant changes in climate, particularly in some regions. Climatic changes, in turn, could cause agricultural zones to shift, arid and semiarid regions to expand, polar ice to melt, precipitation to increase, and wind patterns to shift. Postulated outcomes of such changes range over persistent fluctuations in global food supply, disruption of world economic systems, alternations in power balances among nations, and inability to use fossil-fuel resources.[14]

Approach

Because of the uncertainty and controversy surrounding the CO_2 issue, no attempt was made to embark upon in-depth research on CO_2 effects *per se*. Instead, the state of CO_2 research, obtained from knowledgeable consultants as well as the literature, was applied to answer questions relevant to the coal technology assessment. The study team emphasised the following guidelines:

Range analysis. A reasonable range for the key variables in the CO_2 issue was determined by first taking a set of consistently pessimistic assumptions (CO_2 will have grave consequences soon) and then a set of consistently optimistic assumptions (CO_2 might never become a problem).

Scenario dependence. The analysis was based on data derived from national scenarios A and B and linked to global scenarios from the literature for high and low fossil-fuel use.

Contingency planning. Because of the high degree of uncertainty in CO_2 effects, contingency planning is probably the most prudent action to be taken in the foreseeable future. The basic elements in contingency plans were explored to determine how effective these plans can be, and when they should and can be implemented.

Social learning. In the face of the uncertainty of CO_2 effects, there is a lot to be learned—not only by scientists engaged in CO_2-effects research, but also by policy makers and the global community. The need and the criteria for success in such learning with the interested parties were explored.

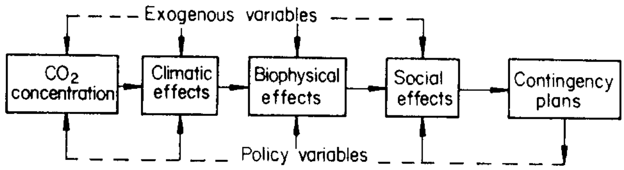

Figure 5. Issue analysis

While numerous variables are included in Figure 5, only the key variables listed in Table 4 were considered in the analysis. The uncertainties in the first two blocks were made explicit by range analysis. Outputs from the third and fourth blocks were considered only where effects were severe enough to justify contingency planning actions.

TABLE 4. KEY VARIABLES IN THE CO_2 ANALYSIS

	Output variables	**Exogenous variables**	**Policy variables**
CO_2 concentration	Average atmospheric CO_2 concentration	Coal-use levels Other fossil-fuel use Land use	Coal-technology mix CO_2-control technology
Climatic effects	Average global temperature rise		
Biophysical effects	Agricultural productivity Water-level rises		
Social effects	Mass famine International power shifts		Foreign policy implications

Results

The results of the analysis are based on data in the literature and judgements and calculations made by the project staff and consultants. A high fuel-use projection and a low fuel-use projection (corresponding roughly to scenarios A and B), were chosen from the literature for long-term total projections of energy use. In neither projection would the US coal contribution to the world CO_2 release exceed 10% in the years 2000 and 2030.

A range of potential outcomes bounded on the high side by consistently pessimistic assumptions and on the low side by consistently optimistic assumptions was applied to the projected figures. Assumptions relate to the sources, sinks, and rates of exchange in the carbon cycle, projections of CO_2 releases from fossil-fuel combustion, and the relationship between atmospheric CO_2 and average temperature rise. Results are shown in Figure 6 as they relate to temperature changes.

The conclusion may be drawn that *only* under conditions of low consumption *and* optimistic assumptions will global buildup from CO_2 be a trivial consideration. In the other cases, CO_2 from fossil-fuel combustion could be devastating. In this sense, CO_2 may be considered a potential pollutant, and the logical

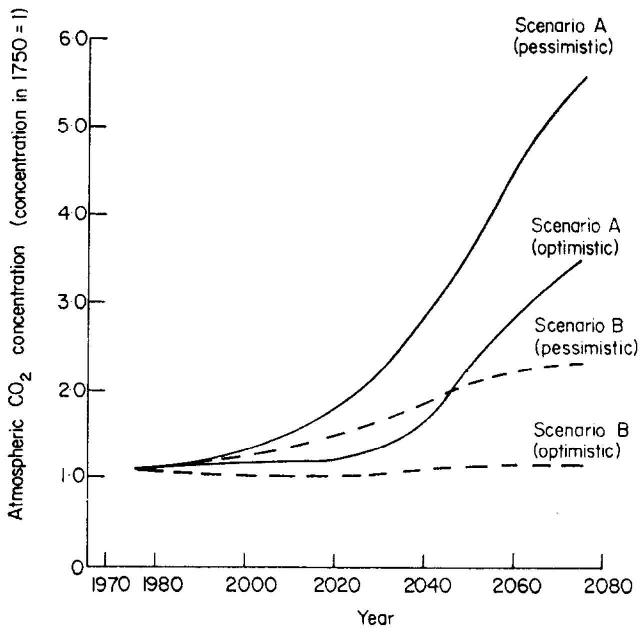

Figure 6. The range of atmospheric CO_2 levels in the two scenarios

question is whether there are coal-based energy technologies or control technologies that decrease the release of carbon dioxide.

There are considerable differences between the amounts of CO_2 released from different trajectories when the combined efficiencies of the mining, transportation, energy transmission, and conversion facilities are taken into account. Increased process efficiencies alone will not be sufficient to limit CO_2 releases should they prove as significant as the three upper cases on Figure 6 indicate. Thus control technology, if applicable, may be required. Review of the literature and consultation with experts indicate six key control points:

- 100% CO_2 scrubbing at plant stacks could reduce conversion facility efficiencies from about 37% to 30%.
- Use of the cryogenic process for CO_2 capture represents a net energy loss.
- Storage of CO_2 in depleted oil fields would be sufficient for less than 20% of current global release of CO_2 per year.
- The deep ocean is the most attractive disposal site for CO_2 due to its enormous capacity and the fact that the ocean is a natural permanent sink for CO_2 in the form of carbonates.
- Reforestation, fertilisation of forests, and use of bacterial action have been suggested for CO_2 conversion but do not appear promising.
- Energy requirements for CO_2 conversion in nuclear reactors would favour the nuclear capacity for energy production directly over conversion.

Based upon the analysis and a number of assumptions, alternative calculations were made to determine the reduction in global CO_2 levels for the worst case with application of control. The conclusion was that if the CO_2 effect is indeed a problem, by the time most people in the world are convinced of that fact, there may not be enough time to apply control technology to avoid possible dire consequences of excessive CO_2 in the global atmosphere.

Notes and references

1. The 30-month study is being conducted by an interdisciplinary team from Battelle Columbus Laboratories and University of Michigan, under the sponsorship of the US Environmental Protection Agency's integrated technology assessment programmes. For a detailed description of the method see K. Chen *et al*, "An integrated approach to coal-based energy technology assessment in the United States and the international implications", *IEEE Transactions on Systems, Man, and Cybernetics*, volume SMC-8, number 12, pages 822–829, November 1978.
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