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THE NET ENVIRONMENTAL BENEFITS OF SOLAR ENERGY TECHNOLOGIES

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1. INTRODUCTION

Many factors enter the decision process for national deployment of solar energy technologies: system costs, energy self-sufficiency, labor effects, etc. Important among these are the net environmental effects of displacing nonsolar technologies by solar energy technologies. Quantitatively measuring the environmental effects of emerging and conventional energy technologies is a necessary first step in determining the environmental benefits, or disbenefits, of deploying solar energy technologies. This paper briefly outlines several approaches which have been utilized for quantitating environmental effects in Section 2, and presents the obtained results in Section 3. Section 4 describes the conclusions which can be drawn from results obtained to date.

2. QUANTIFICATION OF ENVIRONMENTAL EFFECTS

Environmental effects of energy technologies include both qualitative and quantitative aspects. Effects, such as changes in local aesthetics due to installation of a wind energy conversion system or reduced visibility from increased coal combustion, are difficult to quantify yet are important in deciding whether an energy conversion facility should or should not be built. Other environmental effects such as emission of air and water pollutants can be quantified rather comprehensively throughout a system's life-cycle; i.e., fabrication of system components, construction of the energy conversion facility, operation, and decommission of the facility. This paper addresses the quantification of the life-cycle air emissions.

Two basic approaches to quantification and projection of air emissions have been used to date at the Solar Energy Research Institute: computer simulation/projection, and direct estimation of first-order emissions, termed process analysis. Within the computer simulation projection approach, two modeling systems have been utilized.

The first is a linear optimization, input-output model developed and housed by Brookhaven National Laboratory (BNL), Upton, NY. The BNL system is a static model which projects 27 environmental pollutants (particulates, sulfur oxides, etc.) to the year 2000. In brief, the BNL model calculates the process-by-process emissions generated for the aggregated solutions to a national economic model, the Brook haven Energy System Optimization Model (BESOM).

An input-output model is also utilized within the second computer simulation projection approach, the Strategic Environmental Assessment System (SEAS). SEAS consists of a series of interconnected models. Important for estimating environmental effects of energy technologies is the submodel termed RESGEN (Residuals Generator). RESGEN converts economic activity by input-output sectors (the aluminum sector, industrial combustion sector, etc.) and national regions to environmental pollutants by sector and region. As with the BNL system, SEAS operates to the year 2000 [1].

Both the BNL and SEAS models have been utilized to estimate national air and water pollutant levels for several future energy scenarios. Scenarios selected are those utilized within the Domestic Policy Review (DPR) [2]. Results (presented in Section 3) were obtained for two scenarios: a base case where solar energy technologies provides 5.3% of national energy supply, and a maximum practical case where solar energy technologies provide 11.3% of national energy supply.

The second basic approach to environmental effects quantification is process analysis. Three steps are employed when estimating environmental effects (expressed as releases of air pollutants) via the process analysis technique. First, material quantities required for construction of the selected energy facilities are collected. Second, emission factors (e.g., pounds of sulfur oxides released per ton of material processed) are tabulated for industries processing the materials required for energy system fabrication. Emission factors are available in several Environmental Protection Agency and related publications [3,4,5]. Emissions of pollutants released from operating the selected energy conversion facilities are also collected, or estimated in the case of many of the solar energy technologies. Third, the emission factors are applied to the material requirements identified in the first step, and the cumulative emissions from operating the facilities are estimated.

3. ENVIRONMENTAL EFFECTS

As previously noted, the BNL and SEAS models were used to estimate the national environmental effects of a low-solar energy and high-solar energy scenario. The results of this exercise are shown in Table 1. The trend in pollutant releases are similar for most pollutant-types: national emissions tend to decrease as deployment of solar energy technologies increase. All pollutant release estimates obtained by the BNL model for the maximum practical scenario decrease relative to the Base Case (lower solar energy deployment) scenario. This is not true for pollutant release estimates obtained from the SEAS model. National levels of particulates increase under the maximum practical scenario. This increase is attributable to release of particulates associated with the high rate of construction of the solar energy conversion facilities. SEAS-derived estimates for releases of carbon monoxide and suspended solids also increase under the maximum practical relative to the Base Case scenario.

Economic activities that contribute most to carbon monoxide releases are iron and steel manufacture and transportation. The high level of carbon monoxide can again be attributed to the high rate of processing and transporting materials necessary to assure construction of enough solar energy systems to meet deployment goals set for the year 2000. National levels of suspended solids under maximum practical solar deployment assumptions are approximately 40% higher than under Base Case deployment assumptions. The deployment of biomass technologies, in particular silvicultural farms, increase significantly within the maximum practical scenario. Accompanying this is an absolute increase in suspended solids carried in runoff from the greater number of silvicultural farms.

It is evident in Table 1 that projected pollutant levels derived from the BNL and SEAS models often differ significantly; this is particularly true in the cases of sulfur oxides, carbon monoxide, and suspended solids. These variations are due to several factors. First, the models themselves differ in their mechanics and in the underlying assumptions (e.g., structure of the major industrial sectors) upon which they are based. Second, system data are entered into the models as dollars spent per sector of the economy, (dollars worth of steel, concrete, labor etc.) per facility of a certain power rating. If the costs of energy systems are not evaluated in the same manner within each modeling approach, different pollutant levels will result. Third, the two models often employ different emission factors for the various industrial sectors (for example, releases of sulfur oxides from coal combustion may not be the same within the two models). Finally, assumptions about future economic trends differ. The BNL model assumes a decrease in overall economic activity in 2000 relative to 1985 due to the higher costs of energy conversion technologies. As a result, national pollutant levels fall for the high-solar energy scenario. The SEAS model does not employ this assumption. Rather, activity (e.g., transportation) increases to meet demands in the maximum practical scenario. As a result, national pollutant levels increase.

Results of the process analysis approach to environmental effects quantification are shown in Table 2. These pollutant estimates were derived on a technology-by-technology basis. Also shown in Table 2 are comparable estimates derived by using the SEAS model. Estimates are for release of particulates during acquisition and processing of

Table 1. POLLUTANT RELEASES FOR FUTURE ENERGY SCENARIOS [1]

DPR[a] Scenario	Base Case, 2000 BNL[b]	SEAS	Maximum Practical, 2000 BNL	SEAS
Pollutant (10^6 tons)				
Particulates	11.2	10.2	9.3(-)[c]	10.8(+)
Sulfur Oxides	11.5	26.3	8.5(-)	23.2(-)
Nitrogen Oxides	26.8	23.3	22.5(-)	21.1(-)
Hydrocarbons	5.7	10.0	5.5(-)	9.7(-)
Carbon Monoxide	15.6	59.9	15.2(-)	60.1(+)
Suspended Solids	0.2	1.9	0.1(-)	2.7(+)

[a]Domestic Policy Review [2].
[b]Results obtained from the Brookhaven National Laboratory (BNL) energy model and from the Strategic Environmental Assessment System (SEAS).
(+) = increase in pollutant relative to that estimated for the Base Case by the same computer model.
(-) = decrease in pollutant relative to that estimated for the Base Case by the same computer model.

Table 2. PARTICULATES RELEASED FROM CONSTRUCTION OF SOLAR ENERGY FACILITIES, 1985

Facility	tons/10^{12}Btu SEAS	Process Analysis
Passive solar heating & cooling	130	93
Active solar heating & cooling	93	25
Process heat provided by		
parabolic trough	66	31
parabolic dish	45	25
Solar thermal central receiver	184	141
Photovoltaics, centralized	82	98
Wind energy conversion system	52	14
Anaerobic digestor	18	11

the raw materials that are necessary to construct enough system types to provide 10^{12}Btu. Similar calculations were performed for releases of sulfur oxides and nitrogen oxides. The process analysis technique produces a first-order estimate of pollutant releases; the SEAS model employs an infinite chain approach to pollutant estimation and, therefore, produces first-order plus secondary, tertiary, etc. emissions. Thus, SEAS pollutant estimates were expected to exceed process analysis estimates. This was the case for particulate releases from all solar energy technologies investigated, except the centralized cadmium sulfide-copper sulfate system type. Approximately 60% of the total process analysis particulate estimate is attributable to bauxite processing and aluminum manufacture. The process analysis emission factor for the aluminum cycle greatly exceeds that employed within the SEAS model (7.80 versus 0.99 pounds particulates per ton aluminum processed). The large process-analysis-derived particulate level for centralized photovoltaics is, therefore, due to the high emission factor for the aluminum cycle. However, in general the process analysis approach yielded environmental pollutant release estimates very similar to those obtained via the modeling approach.

4. CONCLUSIONS

In selecting which of the many energy conversion options will be deployed to meet future energy demands, it is important to consider life-cycle environmental effects. These effects are not readily obtainable from the scenario approach to environmental effects quantification, and are not fully considered in the process analysis results shown in Table 2. A separate set of SEAS-derived pollutant releases were obtained for each of the life-cycle phases: plant construction; fuel acquisition, processing and transport; plant operation; plant maintenance (replacement of broken heliostats, working fluids, etc.); and transmission and distribution of the end product (electricity for all options other than solar heating). Efficiencies for each of the phases were accounted for to assure that 10^{12} Btu are delivered to the consumer. The results of this analysis are shown in Fig. 1, 2, 3.

For each of the environmental pollutants examined, the life-cycle releases from a new coal steam electric plant (which complies with all current and scheduled environmental control regulations) greatly exceeds those from the solar energy options. In all cases, releases of particulates, sulfur oxides, and nitrogen oxides associated with the solar energy options are attributable to facility construction (which includes raw material acquisition and processing) and, to a lesser extent, facility maintenance. All the solar energy options emit no, or few, pollutants during their 20 to 30 years of operation. Thus, the environmental impacts of the solar energy technologies presented in the figures tend to be short-lived and "front-end." By contrast, pollutant releases from the coal-steam electric option are due almost entirely to coal combustion. As a result, effects will continue at a relatively constant level throughout the 30 years of facility operation.

The pollutant quantification results shown in the previous tables and figures indicate that, although the direct effects of construction of the solar energy technologies exceed those of the coal-steam electric option, the solar energy systems have lower life-cycle environmental effects. To fully interpret the environmental significance of these results, research in several areas is required.

There is no accepted method for qualitatively ranking the severity of environmental effects. Present approaches often attempt to translate pollutant levels into human health effect levels in an attempt to measure effects. However, a person-day lost due to illness from exposure to a toxic chemical or air pollutant is not qualitatively equivalent to a person-day lost from an injury such as a broken arm. Present methodologies are not sensitive to these qualitative differences.

Further research is also needed to interpret the ecological and health implications of relative changes in air pollutant levels. For example, what are the long-term environmental benefits of displacing conventional with solar energy systems? Will the environmental effects of the low or nonexistent operational emissions of most of the solar energy options justify the relatively

Figure 1.

Life-Cycle Particulates Emissions

1985

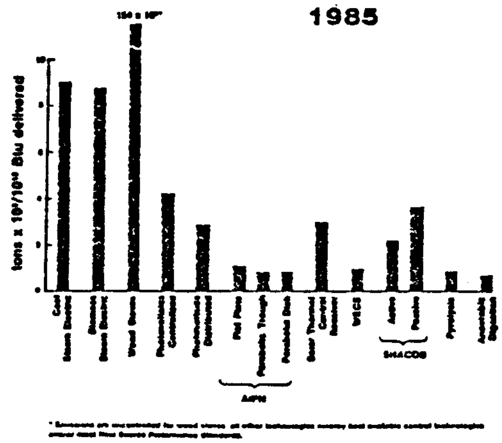


Figure 3.

Life-Cycle Nitrogen Oxides Emissions

1985

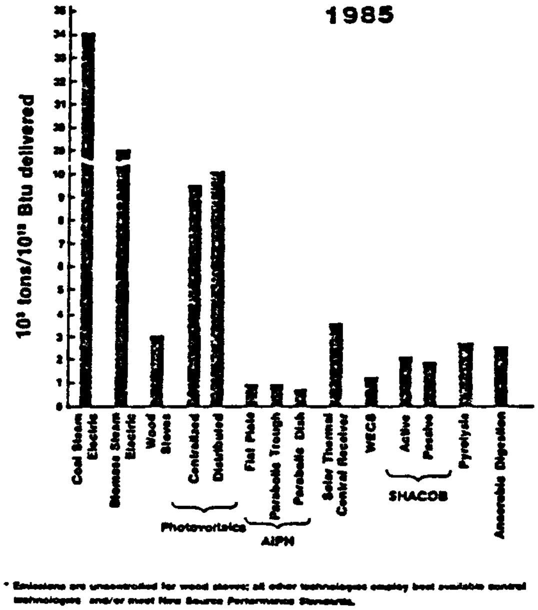
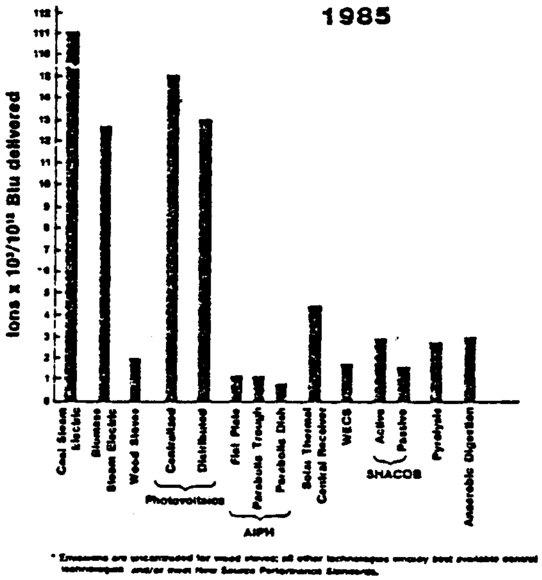


Figure 2.

Life-Cycle Sulfur Oxides Emissions

1985



high effects of construction? Additional information in these areas will allow decision makers to adequately incorporate the long-term environmental effects of an energy conversion option into selecting technologies that will be built to meet future energy needs.

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