CONF-911184--3

THE DESIGN, RESULTS AND FUTURE DEVELOPMENT OF THE NATIONAL ENERGY STRATEGY ENVIRONMENTAL ANALYSIS MODEL (NESEAM)

ANL/CP--74236

DE92 001916

by

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INTRODUCTION

The National Energy Strategy (NES) defines international, commercial, regulatory, and technological policy tools that will substantially diversify U.S. sources of energy supplies, offer more flexibility and efficiency in the way energy is transformed and used, promote economic growth, and ensure a sound environment (1). The entire administration was involved in the process of developing this strategy, from economic direction by the Council of Economic Advisors to estimates of the potential for the tree planting initiative by the Department of Agriculture. The Department of Energy's Office of Policy, Planning, and Analysis had the lead in integrating these inputs and DOE Program Office analyses into a consistent set of policy actions and in presenting a plan to the public.

The Office of Environmental Analysis evaluated environmental effects of energy use projections from a number of modeled policy options. These policy options range from no change in current policy to a high-technology scenario that includes the Clean Air Act Amendments (CAAA) of 1991. Air, land, and water emissions projections were needed to determine the environmental impacts of each scenario. The models used in constructing the NES are FOSSIL2 and the National Energy Strategy Environmental Analysis Model (NESEAM). FOSSIL2 is used to forecast energy demand, NESEAM forecasts pollutant emissions.

FOSSIL2 is a dynamic simulation model developed by Applied Energy Systems (AES) that simulates both energy supply and demand at a national level. FOSSIL2 is written in the Dynamo (2) simulation language which is available to run on both mainframes and PCs. Economic variables are read into FOSSIL2 exogenously from the DRI/McGraw Hill (3) macroeconomic model. The economic forecast, combined with proposed government policy options, drive energy demand. FOSSIL2 forecasts the sources of energy extraction, imports,

Work supported by the U. S. Department of Energy, Deputy Under Secretary for Policy, Planning and Analysis, under contract number W-31-109-Eng-38.

energy demand. FOSSIL2 forecasts the sources of energy extraction, imports, conversion, and end-use demand for five major energy sources: liquids, gases, coal, electricity, and renewables.

NESEAM EXPLANATION

The National Energy Strategy Environmental Analysis Model (NESEAM) accounts for emissions in the five main end-use sectors (electric utility, transportation, residential, commercial, and industrial) as well as emissions resulting from energy extraction and conversion. NESEAM forecasts emissions in five-year increments from 1990 through 2000 and 10 year increments through 2030. The pollutants that the model forecasts are sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2), particulates (TSP), coal ash, biomass ash, water consumption, total suspended solids (TSS), sulfur solids including FGD (SS), oil/grease, petroleum-refining hazardous wastes, coal-cleaning wastes, chromium, and arsenic. The model forecasts these pollutants over all fuel categories: residual oil, distillate oil, natural gas, coal, biomass, nuclear, geothermal, gasoline, diesel, and methanol fuels.

NESEAM is a fuel cycle model that covers all fuels during their respective cycles from extraction and energy production to conversion, energy transportation, and end use. Figure 1 shows the oil fuel cycle flow, as an example, from extraction to end-use consumption. The flow diagram reads from left to right, representing (up to) five stages of activities. Each activity has a name and may also have an associated FOSSIL2 link (in italics) and a share (in parentheses).

The source(s) of primary fuel are shown on the far left of Figure 1 and an arrow leads to the next stage(s). Transportation stages usually have several modes of movement such as trucks, barges, or trains. After the conversion stage (some type of cleaning/purification/refining), a transportation stage takes the delivered fuel to the end uses. Note that in this representation of the fuel cycle, conversion to electricity is an end use. This is done to indicate that no additional emissions arise after that point. In other words, the consequent emissions "end" at that point, while the energy flows may continue. This is a reasonable simplification from the perspective of emission modeling.

The number in parentheses below the name of the activity is a fraction that is applied by NESEAM to some activity in FOSSIL2. For example, in Figure 1, on-shore activity is 90% (0.9) of conventional oil recovery, while off-shore is 10% (0.1). Barge transport is 57% (0.57) of primary oil total transportation, and pipeline is 43% (0.43).

A fuel cycle approach accounts for all energy consumption and emissions associated with final end use of a fuel type. NESEAM projects emissions only from energy-related sources, which limits the completeness of nationwide emission estimates, leaving out significant non-energy emitters such as landfills, and agricultural sources.

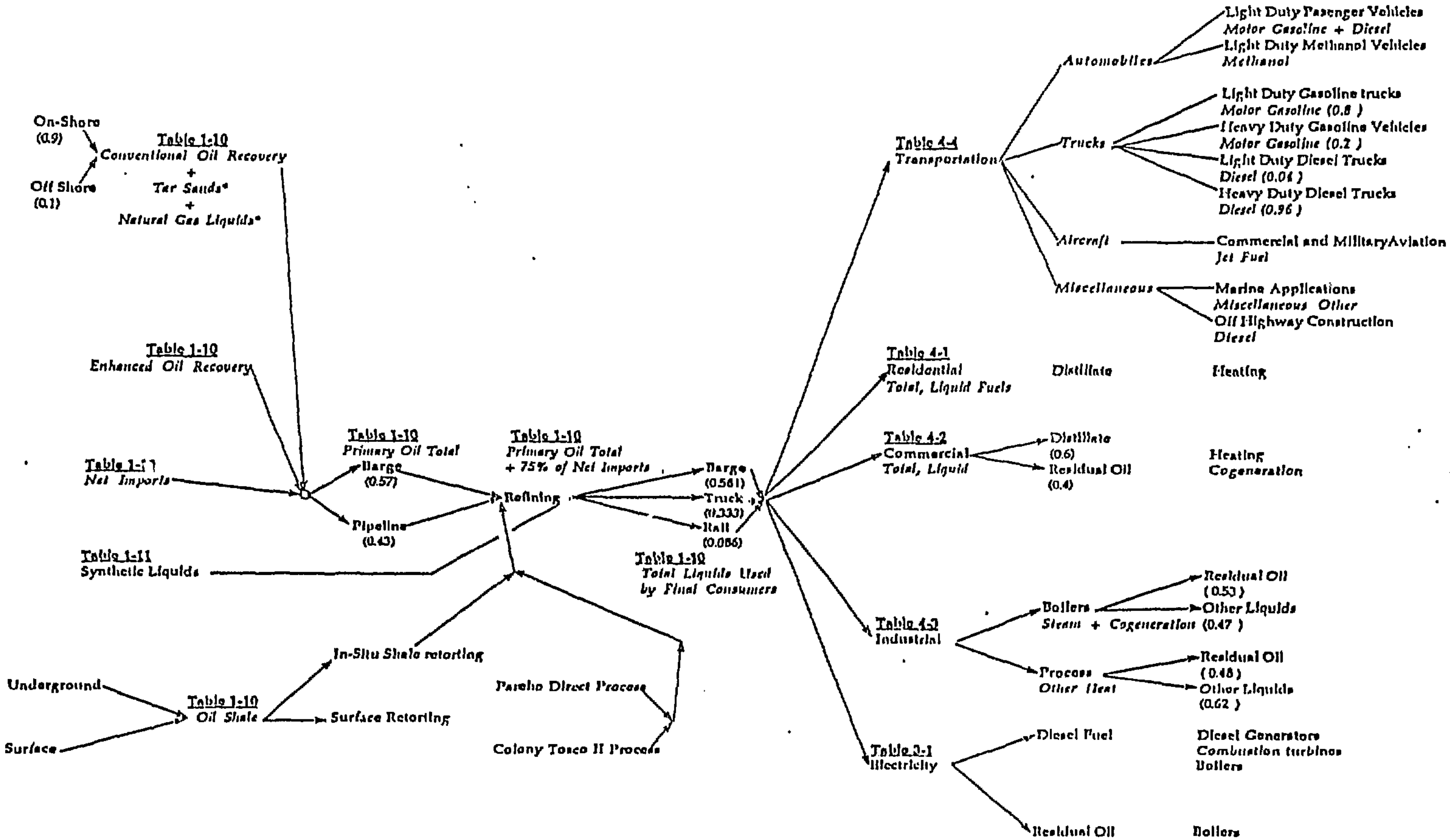

Figure 1: Flow Diagram for Liquid Fuels Linkage between FOSSIL2 and NESEAM

The backbone of NESEAM is the emission coefficients database. These emission coefficients, combined with the energy forecast and energy shares, project emissions. For every activity, pollutant, and year represented in NESEAM there is an associated coefficient that represents the pollutant emissions in pounds per million Btu of input energy, if the activity is end use or electric generation. If the activity is energy production, conversion, or transportation, then the emission coefficient is pounds of pollutant generated in the delivery of a million Btu of energy. For example, gas pipeline compressors often are powered by natural gas. Emission factors for gas pipelines are based on the pounds of pollutant generated by the compressors in terms of the amount of energy through the pipeline, not the amount of energy used by the compressor. In other words, the efficiency of the pipeline, the amount of energy used to deliver some amount of gas to the final consumer, is accounted for in the emission factor.

To provide a forecast of emissions arising from energy end use, a set of national average emission factors were compiled for a variety of sources. For the energy end-use sectors (residential, commercial, industrial, transportation, and electric generation) many of the emission factors were derived from runs of various detailed sectoral emission models. For the extraction and conversion sectors, emission factors are based on engineering coefficients. The sources for these coefficients include the Environmental Protection Agency's AP-42 (4), the Energy Technology Characterization Handbook (5), and other sources. In some cases these coefficients must be modified by the assumptions of the requisite environmental controls that are implied by NSPS regulations.

Environmental emission factors in NESEAM are fuel and sector specific. These emission factors could vary over time because of shifts in fuel quality and environmental regulations not represented by FOSSIL2. Changing regional demographics and mix of activity (e.g., industrial mix or transportation mode changes) can also cause changes in the national average emission factor for any given type of fuel. The emission factors used for energy end use are time-varying emission factors derived from a set of detailed energy and emission models that account for these shifts in the baseline scenario. The utility sector emissions are based on the Argonne Utility Simulation (ARGUS) model (6). Other detailed end-use energy/emission model forecasts for transportation, commercial, residential, and industrial emissions are based on the NAPAP Integrated Model Set (7). The transportation emissions are based on the Transportation Energy/Emission (TEEMS) Model. Commercial and residential emissions are derived from the Commercial and Residential Emissions Simulation System (CRESS). Industrial emissions are derived from the Industrial Combustion Emissions (ICE) and Process Model Projection Technique (PROMPT) models.

The emission factors are derived by running a sectoral energy/emission model and dividing total fuel demand by the corresponding emissions, for each sector, fuel, technology, and year for categories which match FOSSIL2 inputs. Emission factors are calculated for each of the major fuel types used by that sector. This simple approach may be viewed as a weighted average emission factor for each of the disaggregate activities and fuel types represented in the energy/emissions models and with the activity and fuel type weights derived from the detailed model forecast. This process generates a set of emission factors based on a given energy scenario. To the extent that these scenarios are technologically similar these emission factors can be used for alternative energy scenarios. In some cases the NES scenario assumptions are significantly different from those of the scenario used to generate the basic coefficients, such as in the CAAA case.

NESEAM is configured within FOXPRO databases combined with external C language programs and runs on a PC (preferably 486 or 386 compatible). This structure of FOXPRO and C was selected for speed, flexibility in adding model enhancements, portability, and linkages with other models. NESEAM, when set up for a scenario, runs in one minute on a 486 compatible machine. The emission coefficients and energy linkage conform well to a database systems approach. FOXPRO, with its RUSHMORE technology, consistently performs well in speed comparisons. FOXPRO also allows for the integration of C programs and provides a run-time version that can be distributed freely. Also, by using a database system, inputs and outputs from NESEAM can be easily transferred to the other detailed emission models that are used.

When the model is run, a menu system is displayed so the user can select the assumptions to be used. These assumptions include: which FOSSIL2 energy scenario to load, which set of transportation emission coefficients to use, which set of utility emission coefficients to use, and what mile per gallon assumptions to use. NESEAM takes the assumptions for that particular run and inputs them into a database structure that then calculates emissions.

NESEAM COMPARISON AND RESULTS

As part of our quality control process in developing NESEAM, the base year emission estimates for a number of pollutants were compared with estimates from other published reports. Tables 1 and 2 present comparisons between NESEAM estimates and the 1985 NAPAP Inventory and the EPA National Air Quality and Emissions Trends Report for SO_2 and NO_x emissions respectively. Despite differences in the methodology and emitters considered in the studies, the emission estimates are within a few percent of each other.

Figures 2A and 2B show results for the NES Base Case versus the NES Actions Case for SO_2 and NO_x emissions used in the NES analyses. The NES Actions Case include the CAAA as well as alternative fuel vehicles in the transportation sector, a switch to nuclear fuel, and energy conservation. Figures 2A and 2B show the environmental benefits of the NES Actions Case over the Base Case. Both SO_2 and NO_x emissions projections are lower in 2030 than their 1990 level in the NES Actions Case.

TABLE 1 1985 SO_2 Emission Comparisons

	NESEAM	EPA	NAPAP
Utility	15.2	17.0*	15.2
Residential/Commercial	0.6		
Industrial	3.4	3.2	4.9
Transportation	0.7	0.9	
Other	1.0		1.4
Total	20.9	21.1	21.5

* Includes residential and commercial

TABLE 2 1985 NO_x Emission Comparisons

	NESEAM	EPA	NAPAP
Utility	6.1	10.8*	6.1
Residential/Commercial	0.7		0.6
Industrial	2.9		3.1
Transportation	7.9	8.3	8.0
Other	2.7	0.2	0.8
Total	20.3	19.8	18.6

* Includes residential, commercial and industrial

Several individual action cases for NES analyses were used. These cases include: CAAA scenario, industrial research and development, integrated resource planning, and expanded nuclear energy. Figures 3 and 4 show results from these individual action cases as percent differences from the Base Case for SO_2 and NO_x, respectively. In both figures the total effect of the NES Actions Case is shown. Although each action contributes to the NES Actions Case, the actions are not necessarily cumulative. The sum of the individual NES actions may be more than the NES Actions Case because of the diminishing marginal returns to emission reductions. For example, once compliance with the CAAA has made a significant reduction on SO_2 emissions, replacing some of these plants with nuclear units has a smaller impact on emissions than would otherwise have been the case.

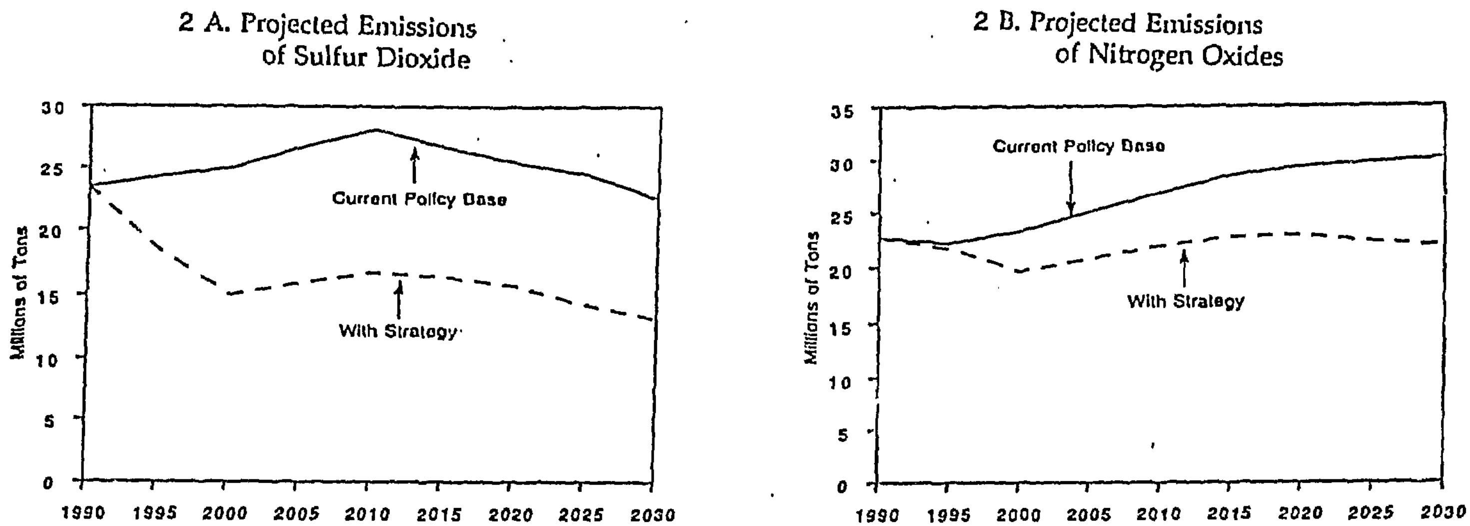

FIGURE 2 Comparison of SO_2 and NO_x Emissions Associated with the NES Actions Case vs. the Current Policy Base Case.

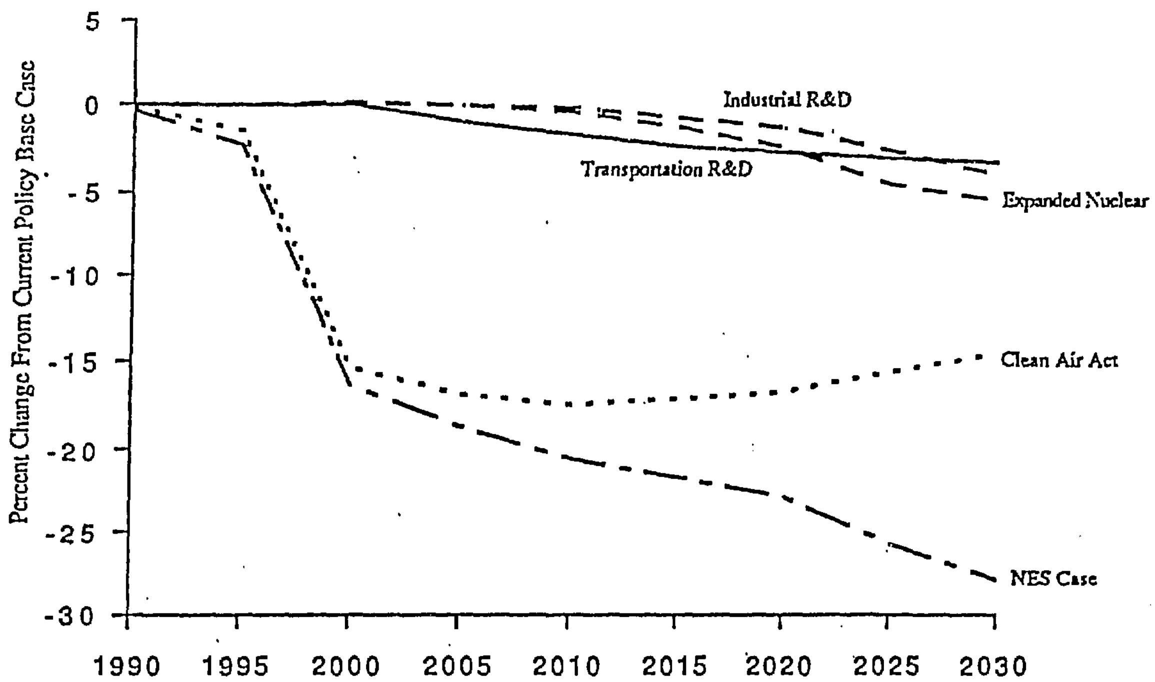

FIGURE 4 NO_x Emissions Associated with Individual NES Action Scenarios

FUTURE NESEAM ENHANCEMENTS

NESEAM will be enhanced in several ways. These enhancements can be broken down into two areas: database development and future legislative applications. The database development includes adding new emission coefficients and pollutants as well as material flows to the model.

Thirteen pollutants were used in the NES analyses. Because of attention to global warming, the global warming potential (GWP) index will be calculated. GWP is an index of several global warming pollutants some of which are not currently modelled in NESEAM. These as well as other emission pollutants will be added in the future. Emission coefficients from advanced technologies such as compressed natural gas and fuel cell vehicles also will be added to NESEAM. Several technologies being examined are still being developed. It is difficult to estimate emission coefficients from these advanced technologies, especially those that are not fully developed.

Another area of database development is stock or capacity related variables. NESEAM currently uses emission coefficients that relate to the flow of energy. Some impacts, such as land use or materials requirements are related to the addition of energy supply capacity, e.g. a power plant or pipeline. Energy production tends to use capital intensive technologies. For those technologies that use large amounts of land or exotic materials, e.g. photovoltaic farms, NESEAM needs to account for these impacts. The material requirements, concrete, steel, land and other "exotic" materials will be added to the database. These coefficients would be denominated in units of energy capacity, rather than energy flows.

In addition to the inclusion of additional emission coefficients, pollutants and material flows to NESEAM, some methodological issues will be re-examined. The transportation sector and the utility sector emission coefficients come directly from detailed emission models, TEEMS and ARGUS respectively. In the transportation sector, projections of emission coefficients from TEEMS are combined with the energy projections from FOSSIL2 in calculating emissions. There are two sets of emission projections from TEEMS: with and without the CAAA. One of the menu screens in NESEAM asks the user which of the two TEEMS runs to select. There are hundreds of FOSSIL2 runs that include the CAAA.

A problem arises when runs include policies that affect the transportation sector. In a FOSSIL2 run including policies that affect vehicle miles travelled would not change the emission coefficients. The emission coefficients would stay constant and the energy projections would increase, which would increase total emissions. Policies that encourage shifts in transportation modes also would not change emission coefficients. If a run included a switch to diesel fuel from gasoline, the emission coefficients for gasoline and diesel would remain constant, but the energy projection would change, which would affect total emissions. Policies in which retirement rate changes or technological changes are made would have an impact on emission coefficients and would need to be adjusted. If a run included using cleaner gasoline and emission coefficients were not adjusted, emissions would be projected to high.

In order for NESEAM to be a more effective policy-making tool, future enhancements should include integrating models for the utility and transportation sectors into NESEAM. By integrating these models into NESEAM, emission coefficients can be adjusted based on changes in policy regulations. However, speed is an important factor in running NESEAM. TEEMS and ARGUS are detailed models that each take one day to run. Simplified versions of TEEMS and ARGUS models will be ported to the PC. Since the emission coefficients are being adjusted and not completely recalculated, complete models do not need to be ported, only select modules from these complete models need to be re-run.

Another methodological issue to be examined is the economic assumptions used. The DRI macroeconomic model is used to project economic conditions out to the year 2030. These economic inputs are used to derive energy consumption in FOSSIL2. Several energy scenarios include restrictions on energy use and emissions limitations. These scenarios result in future shifts in fuel prices based on changes in demand and increased costs from emission compliance strategies. The shift in energy prices will have a direct impact on the economy. In order to include this effect in the DRI forecast, DRI, FOSSIL2, and NESEAM need to iterate together until equilibrium is reached. As FOSSIL2 and NESEAM deviate from the DRI forecast, these changes should be plugged into DRI, re-run the DRI model and then re-run FOSSIL2 and NESEAM. These steps would then be repeated until equilibrium is reached. In order to do this, however, a price elasticity module would have to be developed in NESEAM that calculated these price changes, which could then be fed back into DRI.

The other future direction that NESEAM will take is to provide analysis in future legislative areas. Currently, the NES analysis is performed every other year. The future enhancements to NESEAM mentioned above will aid not only in the 1993 NES but hopefully also in analyzing other areas of environmental interest. The model's flexibility also provides adaptation for modeling future legislation. The proposed Cooper-Synar Bill would put an emissions cap on CO_2. NESEAM can be used to examine the environmental effects of this bill as well as other proposed legislation. As new legislative actions are proposed, these laws and regulations will be modelled by NESEAM.

CONCLUSION

The National Energy Strategy Environmental Model (NESEAM) has been developed to project emissions for the National Energy Strategy (NES). Two scenarios were evaluated for the NES, a Current Policy Base Case and a NES Actions Case. The results from the NES Actions Case project much lower emissions than the Current Policy Base Case.

Future enhancements to NESEAM will focus on fuel cycle analysis, including future technologies and additional pollutants to model. NESEAM's flexibility will allow it to model other future legislative issues.

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