THE TECHNOLOGY GROUP ANALYSIS

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INTRODUCTION

Of the 14 models participating in the EMF 12 exercise, three agreed to participate in an exercise analyzing the sector- and service-specific fuel switches and efficiency improvements that lead to carbon reductions. Fossil2, Gemini, and Markal contain enough technology specific detail to allow such analysis. A list of the major technologies included in each of the three models is included as an appendix. The analysis was confined to results for the United States over the next few decades.

The goal of the exercise was to, first, describe the source of the emissions reductions and then explain the differences among the model forecasts. We were able to accomplish the first goal, i.e., describe the differences in the source of reductions among models. We were able to explain some, but not all, of these differences.

CASES ANALYZED

The modelers agreed to investigate carbon reductions achieved under two scenarios: 1) emissions stabilization by 2000 and 2) 20 percent reduction, compared to 1990 levels, by 2010. The discussion is limited to analysis of the 20 percent reduction scenario. Two sectors were examined in detail: 1) residential sector and 2) electric utilities. Energy inputs and outputs were provided by service and/or fuel through 2030 (2020 for Markal).

CARBON REDUCTIONS: WHERE DO THEY COME FROM?

Figures 1 and 2 display emissions by sector for 1990 and 2020. In addition to estimates of emissions in 2020 under the reference case and the 20 percent reduction scenario, the figure shows emissions under a hypothetical "fixed emission rate" scenario.[1] In this scenario, emissions are estimated assuming the mix of fuels used in 1990 along with each model's 2020 forecast of residential homes; commercial floor space; personal vehicle miles, air miles, and freight miles travelled; and GNP as a surrogate for industrial activity. For example, total carbon emissions in Fossil2's reference case increase to about 50 percent above 1990 levels by 2020. However, Fossil2 emissions would have increased by about 75 percent above 1990 levels if the fuel mix and technology efficiencies had remained at 1990 levels.

Note that even though GNP growth assumptions are quite similar among the three models, the forecasts for activity levels in each sector vary from model to model. Growth in carbon emitting activities is fastest in Fossil2, again, increasing by 76 percent by 2020. Growth is somewhat slower in Markal (67 percent increase above 1990 levels by 2020) and slowest in Gemini (61 percent increase.)

Figure 3 displays carbon reductions by sector, first, due to changes in fuel mix and energy efficiency between the fixed emission rate scenario and the reference scenario (left bar) and second, reductions between the reference scenario and the 20 percent reduction scenario (right bar). Note that in each of the three models, between one third and one half of the reductions come from the industrial sector, with substantial reductions occurring in both the reference case and the control case.

Figure 4 displays carbon reductions by generic type of reduction. We have partitioned emissions reductions into five categories. These include reductions due to:

Figure 1

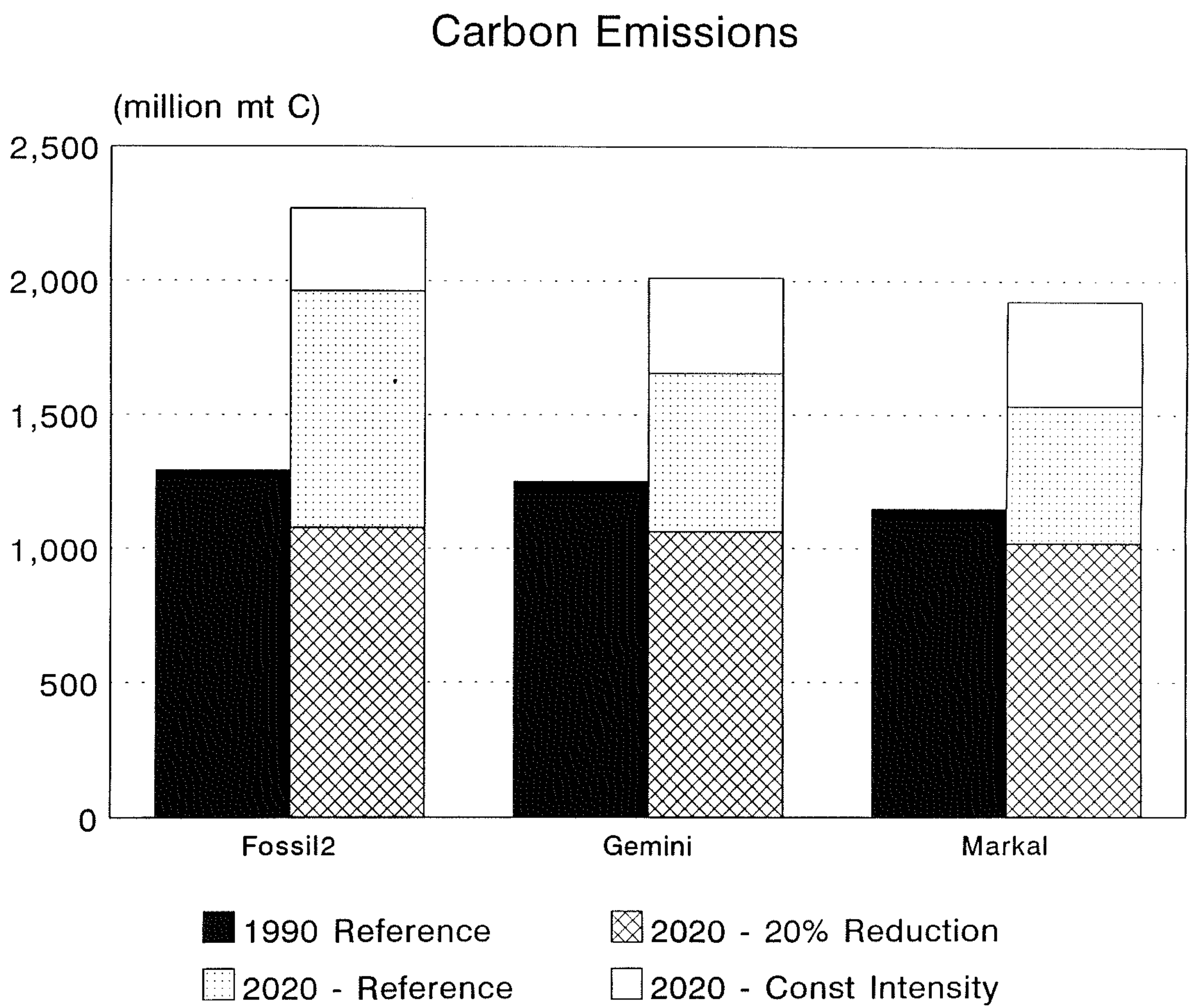

Carbon Emissions
(million mt C)
2,500
2,000
1,500
1,000
500
0
Fossil2
Gemini
Markal
1990 Reference
2020 - 20% Reduction
2020 - Reference
2020 - Const Intensity

Figure 2

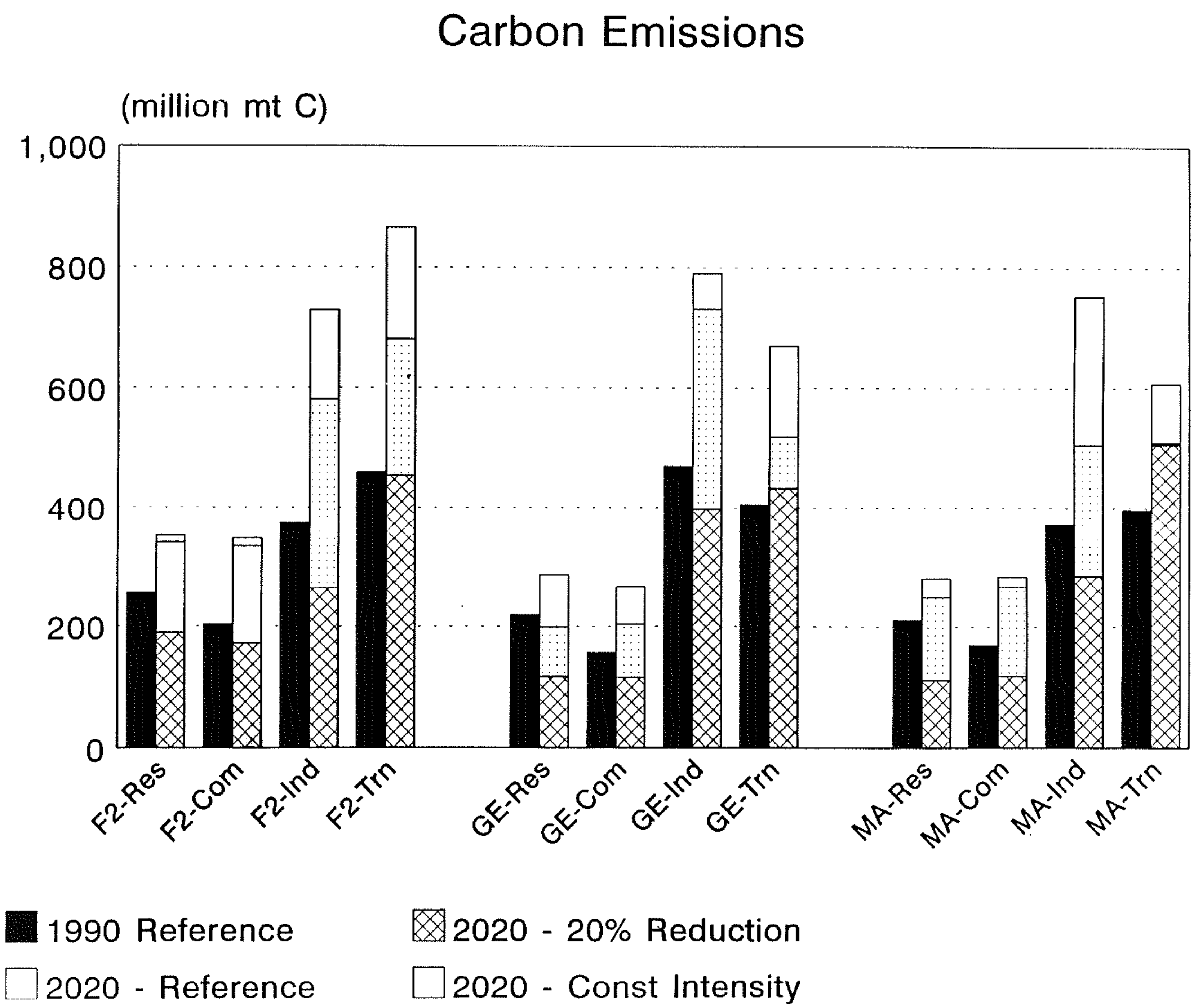

Carbon Emissions
(million mt C)
1,000
800
600
400
200
0
F2-Res
F2-Com
F2-Ind
F2-Trn
GE-Res
GE-Com
GE-Ind
GE-Trn
MA-Res
MA-Com
MA-Ind
MA-Trn
1990 Reference
2020 - 20% Reduction
2020 - Reference
2020 - Const Intensity

Figure 3

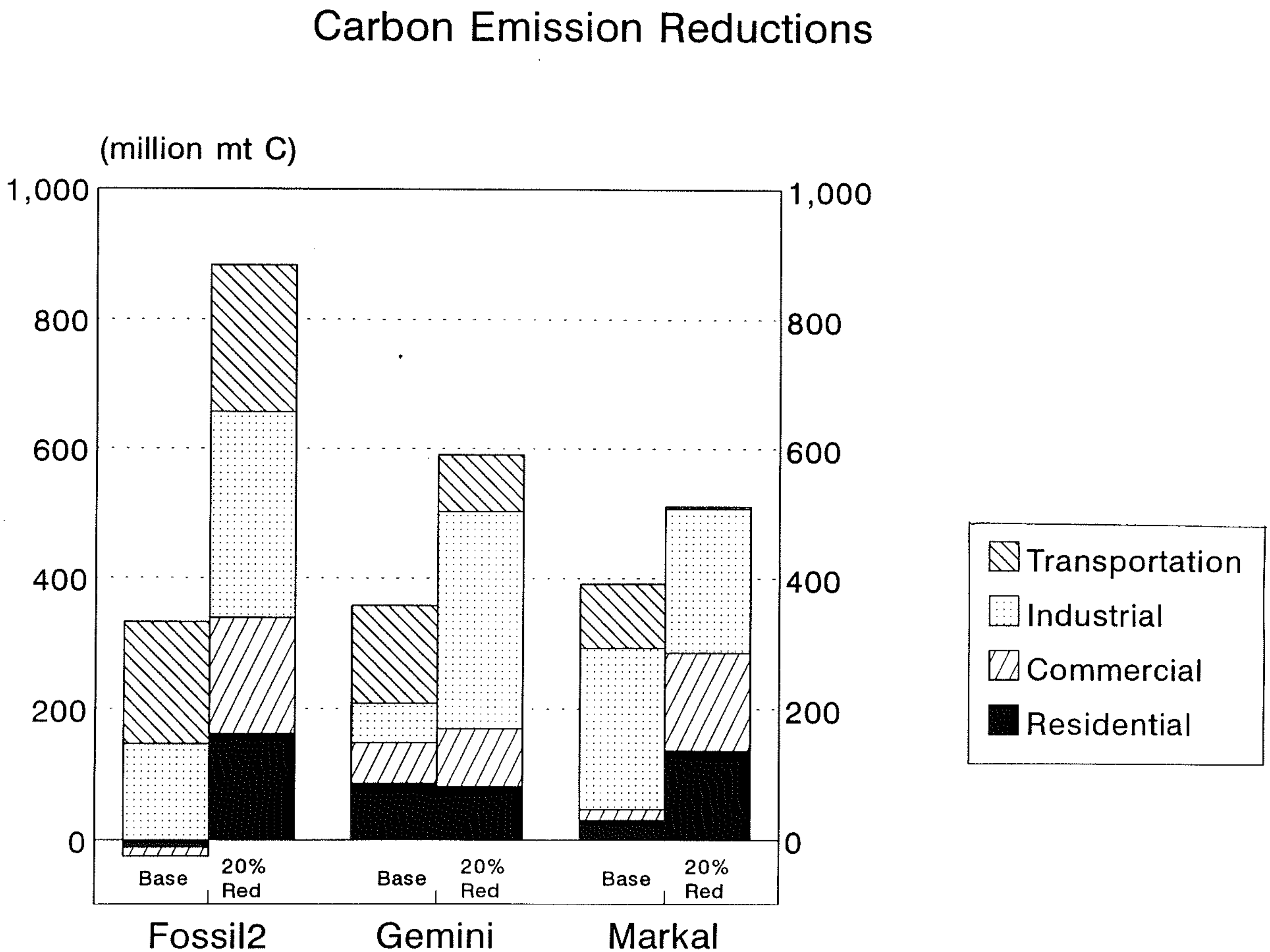
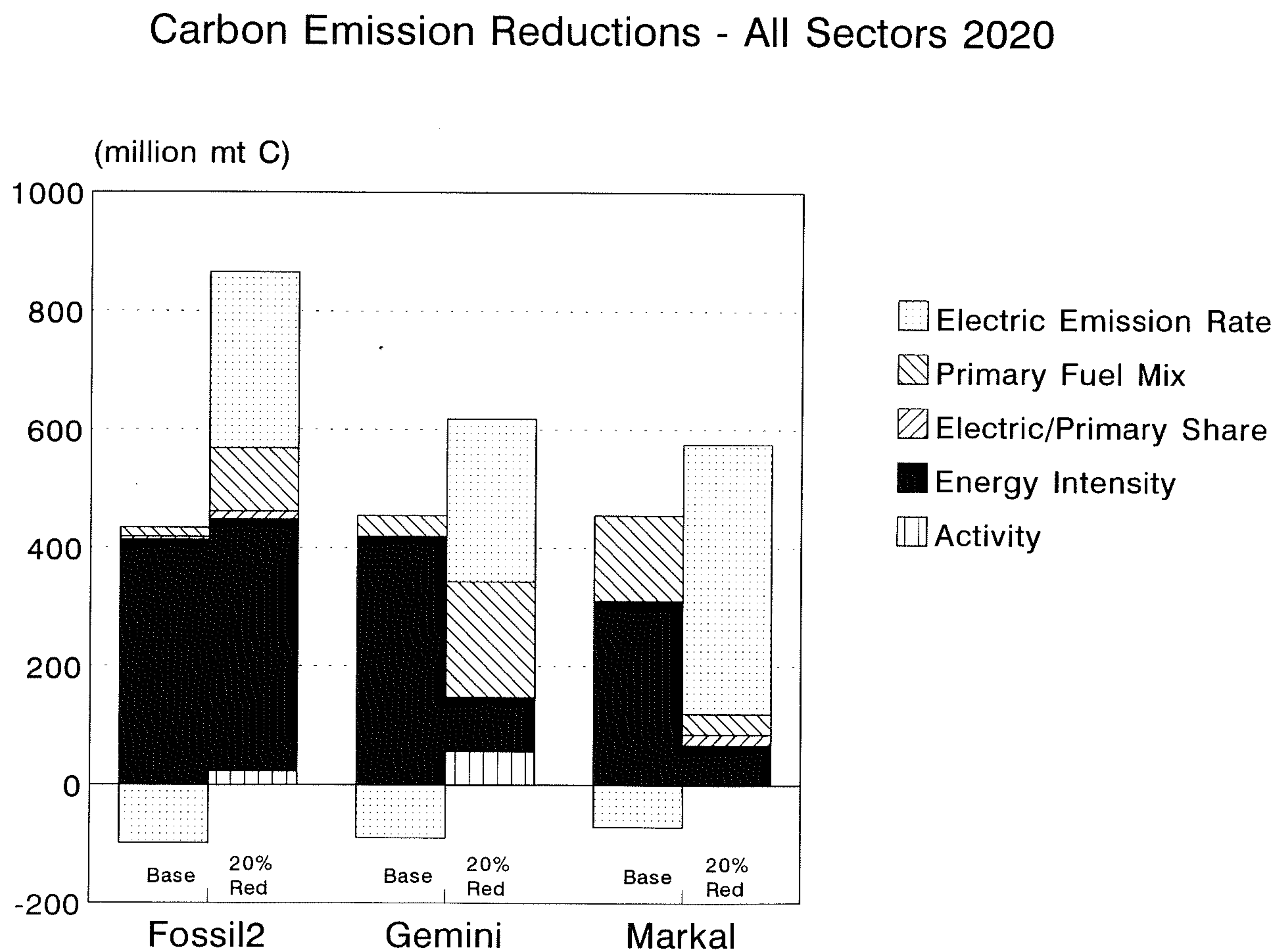

Carbon Emission Reductions
(million mt C)
1,000
800
600
400
200
0
Base
20% Red
Fossil2
Gemini
Markal
Transportation
Industrial
Commercial
Residential

Figure 4



Carbon Emission Reductions - All Sectors 2020
(million mt C)
1000
800
600
400
200
0
-200
Base
20% Red
Fossil2
Gemini
Markal
Electric Emission Rate
Primary Fuel Mix
Electric/Primary Share
Energy Intensity
Activity

1. changes in the average electricity emission rate due to the fuel mix used to generate electricity and the efficiency of the technology;

2. changes in the mix of primary fuels consumed by end users, for example, from switching from oil to natural gas;

3. changes in the mix of electricity versus primary fuels consumed by end users;

4. changes in energy intensity, i.e. energy per unit of activity, primarily due to changes in efficiency; and

5. changes in activity, for example, a drop in VMT due to higher gasoline taxes. (Activity changes are presented for the 20 percent reduction scenario only.)

In all of the models there is a decline in emissions between the hypothetical fixed emission rate scenario and the reference case in 2020. The reductions are primarily due to lowered energy intensity (either efficiency improvements or a change in the mix of services within each sector)[2]. These are partially offset by a higher carbon emission rate by electric utilities.

Change in energy intensity is a major source of reductions achieved under the control scenario, as well. In Fossil2, improvements in energy intensity are responsible for about 70 percent of the reductions between the hypothetical fixed emission rate scenario and the 20 percent reduction scenario[3]. In Gemini, intensity changes are responsible for about half the carbon reductions by 2020, and in Markal, changes in energy intensity achieve about 40 percent of the total. Note that in the latter two models, most of the intensity improvements occur in the reference case. Additional taxes under the control scenario more strongly induce changes in the mix of fuels used to generate electricity and the mix of primary fuels purchased by end users. In Fossil2, additional taxes continue to spur intensity improvements in addition to inducing changes in the fuel mix used by utilities and end users.

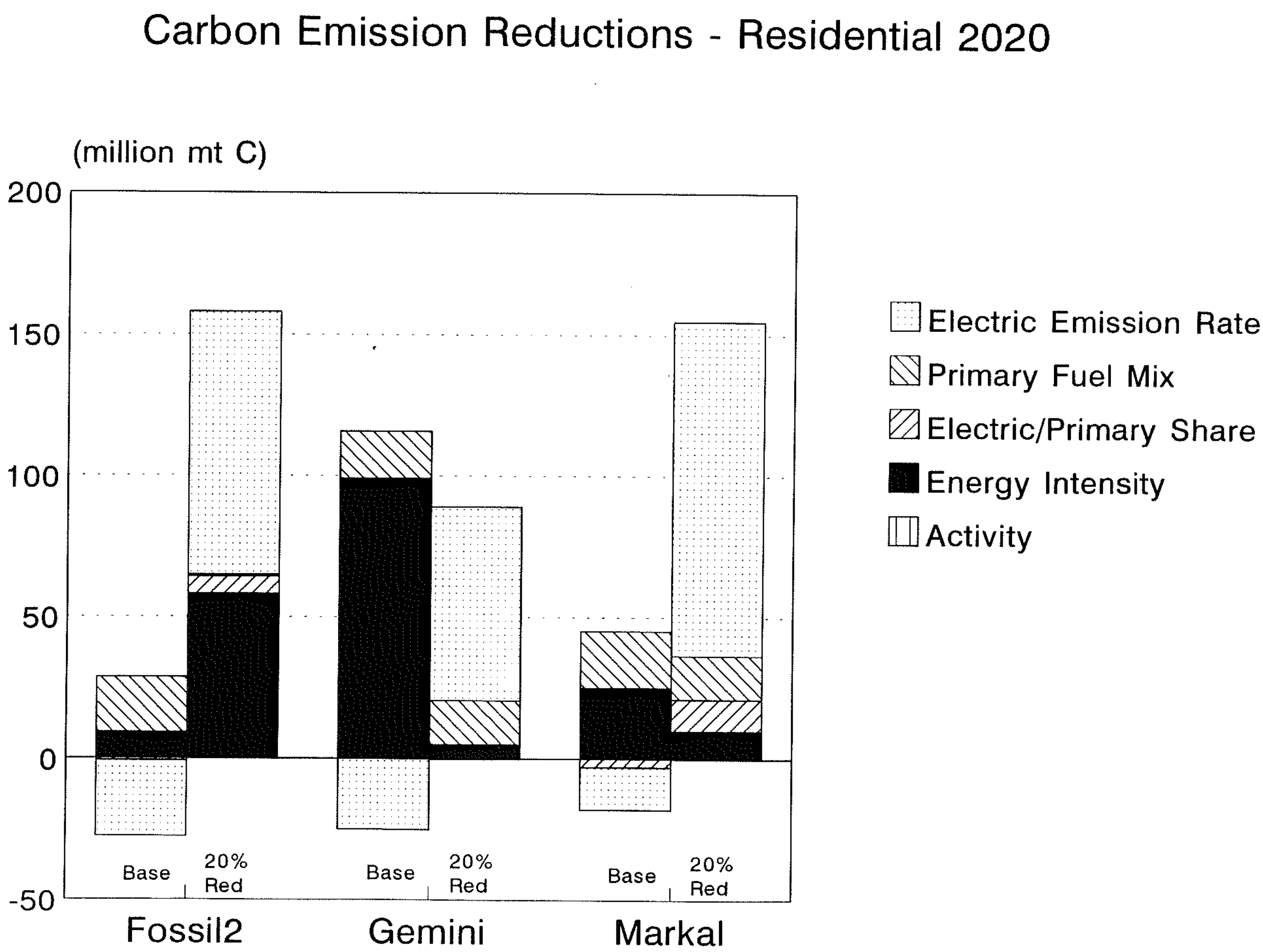
Changes in activity levels between the reference case and the control scenario are quite modest and thus have a small effect on emissions. Nearly all of this occurs in the transportation sector. Note that Markal does not allow activity changes as a control option.

Figures 5 through 8 display carbon reductions by the categories listed above separately for each sector. Within the residential and commercial sectors (figures 5 and 6) in both Fossil2 and Gemini, lowered energy intensity is the single largest source of carbon reductions between the hypothetical fixed emission rate scenario and the 20 percent reduction scenario. Reductions due to changes in fuel mix to generate electricity are of slightly smaller magnitude. Note, however, that in Gemini, most of the efficiency improvements occur in the reference case, whereas in Fossil2, the reverse is true. In Markal, most of the carbon reductions in these two sectors are due to changes in the fuel mix used to generate electricity.

Figure 7 displays the sources of reductions within the industrial sector. In both Fossil2 and Markal, these come primarily from lowered intensity, followed by changes in electricity generation. In Gemini, change in intensity is also the single largest source, followed closely by a change in the mix of primary fuel (primarily a shift to noncarbon fuels). In all three models, about half to three quarters (or more) of the reductions due to lowered intensity are found in the reference case.

In the transportation sector (figure 8) the single largest source of reductions in all of the models is improved efficiency. Lowered activity (in Gemini) and use of alternative fuels (in Fossil2) achieve additional reductions. Fossil2 is the only one of the three models that forecasts major additional efficiency improvements beyond the base case in the 20 percent reduction scenario. Note once again that Markal does not include changes in activity (i.e., lowered VMT) as an option.

Figure 5



Carbon Emission Reductions - Residential 2020
(million mt C)
200
150
100
50
0
-50
Base
20% Red
Fossil2
Gemini
Markal
Electric Emission Rate
Primary Fuel Mix
Electric/Primary Share
Energy Intensity
Activity

Figure 6

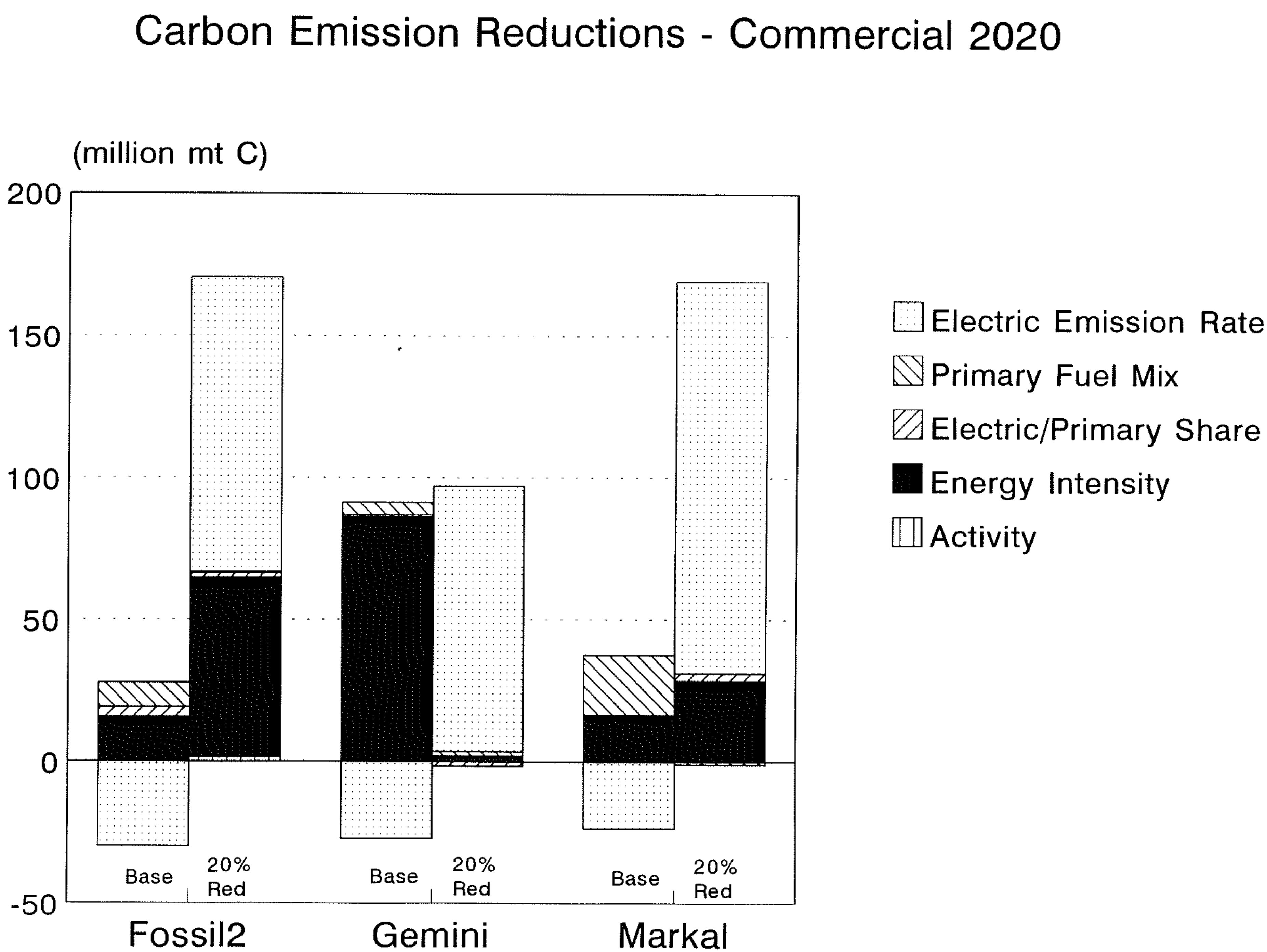

Carbon Emission Reductions - Commercial 2020
(million mt C)
200
150
100
50
0
-50
Base
20% Red
Base
20% Red
Base
20% Red
Fossil2
Gemini
Markal
Electric Emission Rate
Primary Fuel Mix
Electric/Primary Share
Energy Intensity
Activity

Figure 7

Carbon Emission Reductions - Industrial 2020

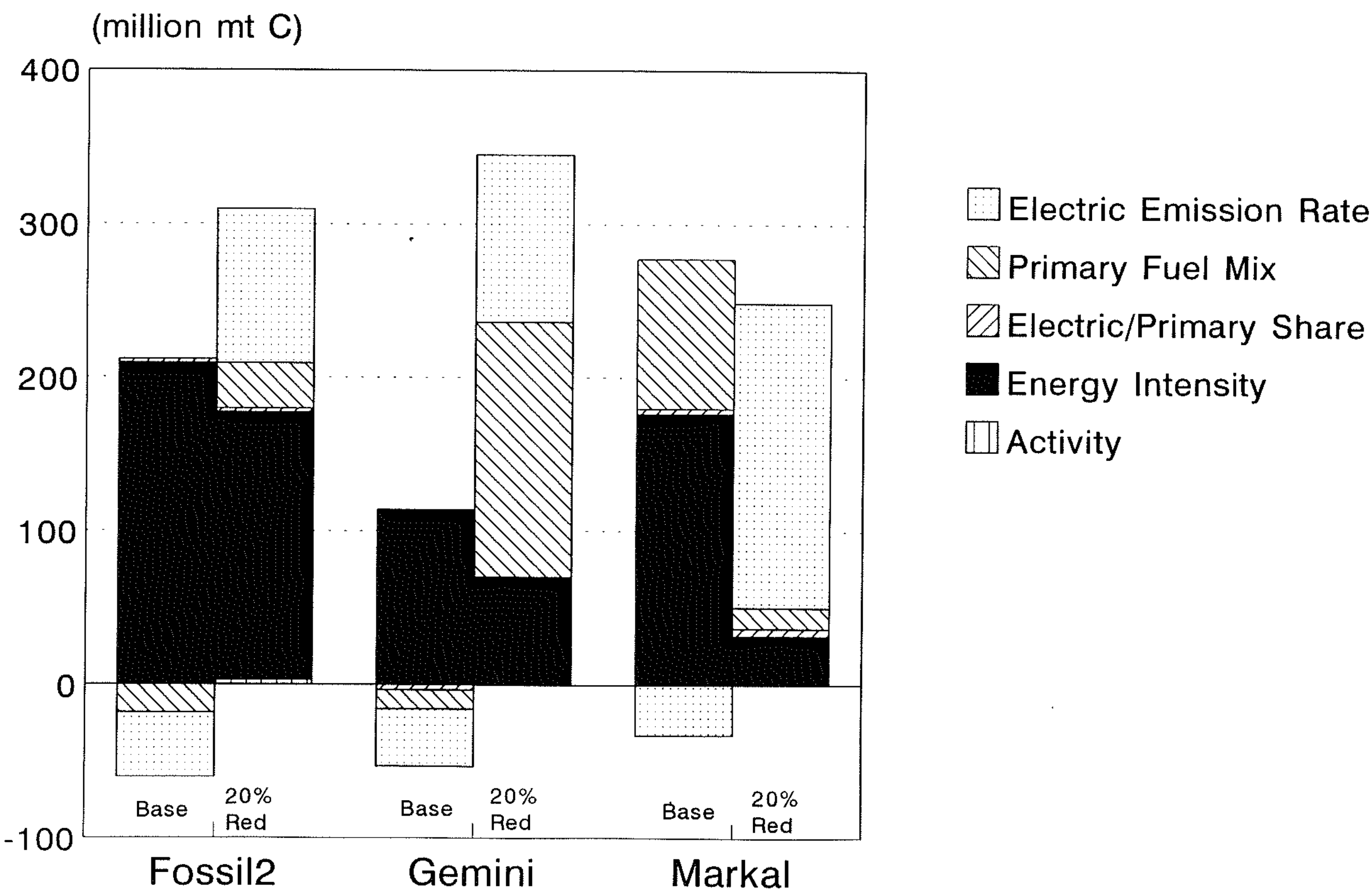
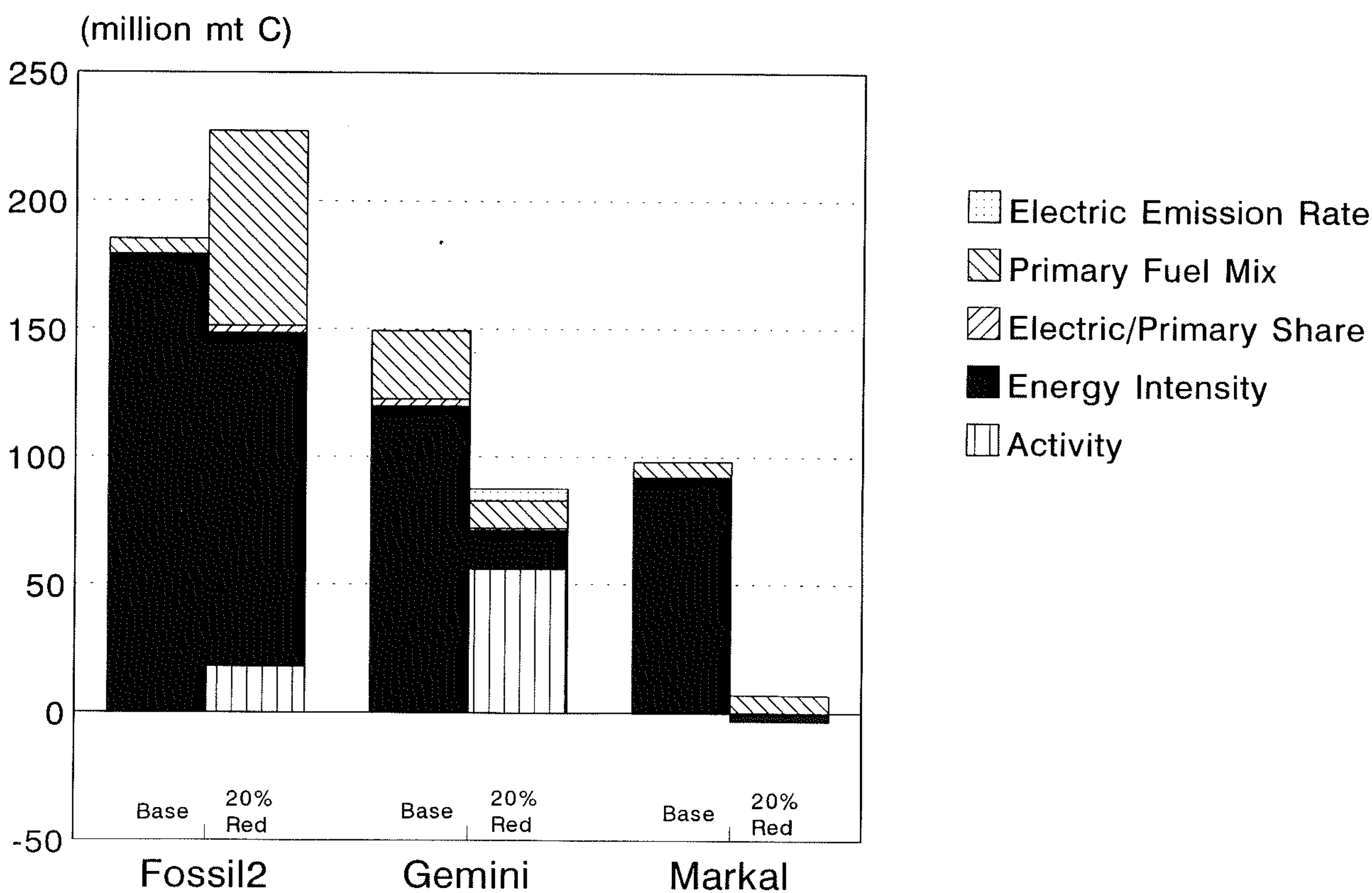


Figure 8

Carbon Emission Reductions - Transportation 2020



A CLOSER LOOK AT EMISSIONS REDUCTIONS FROM CHANGES IN ELECTRICITY GENERATION AND USE

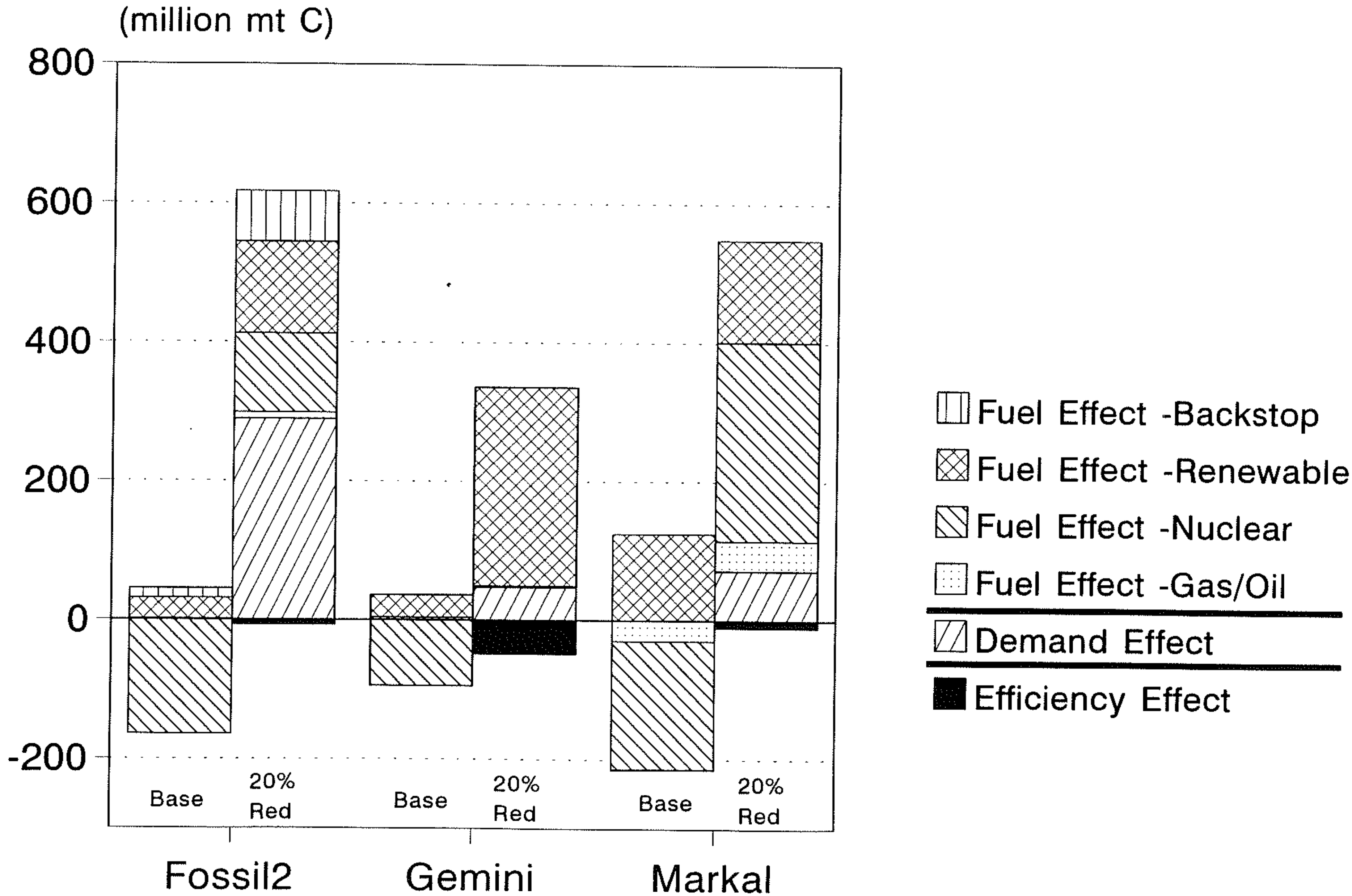
We partitioned emissions reductions from changes in electricity generation and use into six categories: 1) through 4), reductions due to increased use of lower carbon fuels (natural gas, nuclear, renewables, and the "backstop" technology) in the utility sector, 5) reductions due to lowered demand for electricity, and 6) increases due to changes in overall efficiency of electricity generation.[4] Once again, Figure 9 displays changes in emissions between the hypothetical fixed emission rate scenario and the reference case in 2020, and reductions from the reference scenario to the 20 percent reduction scenario.

Unlike the other sectors, emissions under the reference case are higher than under a hypothetical 1990 fixed emission rate scenario. Nuclear plants retire and utilization drops. Some of this is replaced with electricity generated from renewable sources, but most is replaced by coal.

Under the control scenario, we once again see the differences in the importance of efficiency improvements mentioned earlier. Fossil2 gets nearly half of its electricity-related carbon reduction from the demand side. Because Gemini and Markal reflect much less potential for efficiency improvements beyond that included in the base case, both get less than 20 percent of their electricity-related reductions from the demand side.

Note the striking difference in the fuels responsible for emissions reductions among the three models: In Gemini, most of the reductions come from increased use of renewable sources; in Markal, most of the reductions come from increased use of nuclear. Fossil2 falls between the two other models, with slightly more from renewables than nuclear[5], and some from the generic "backstop" technology.[6]

Figure 9
Carbon Emission Reductions - Electricity Generation 2020



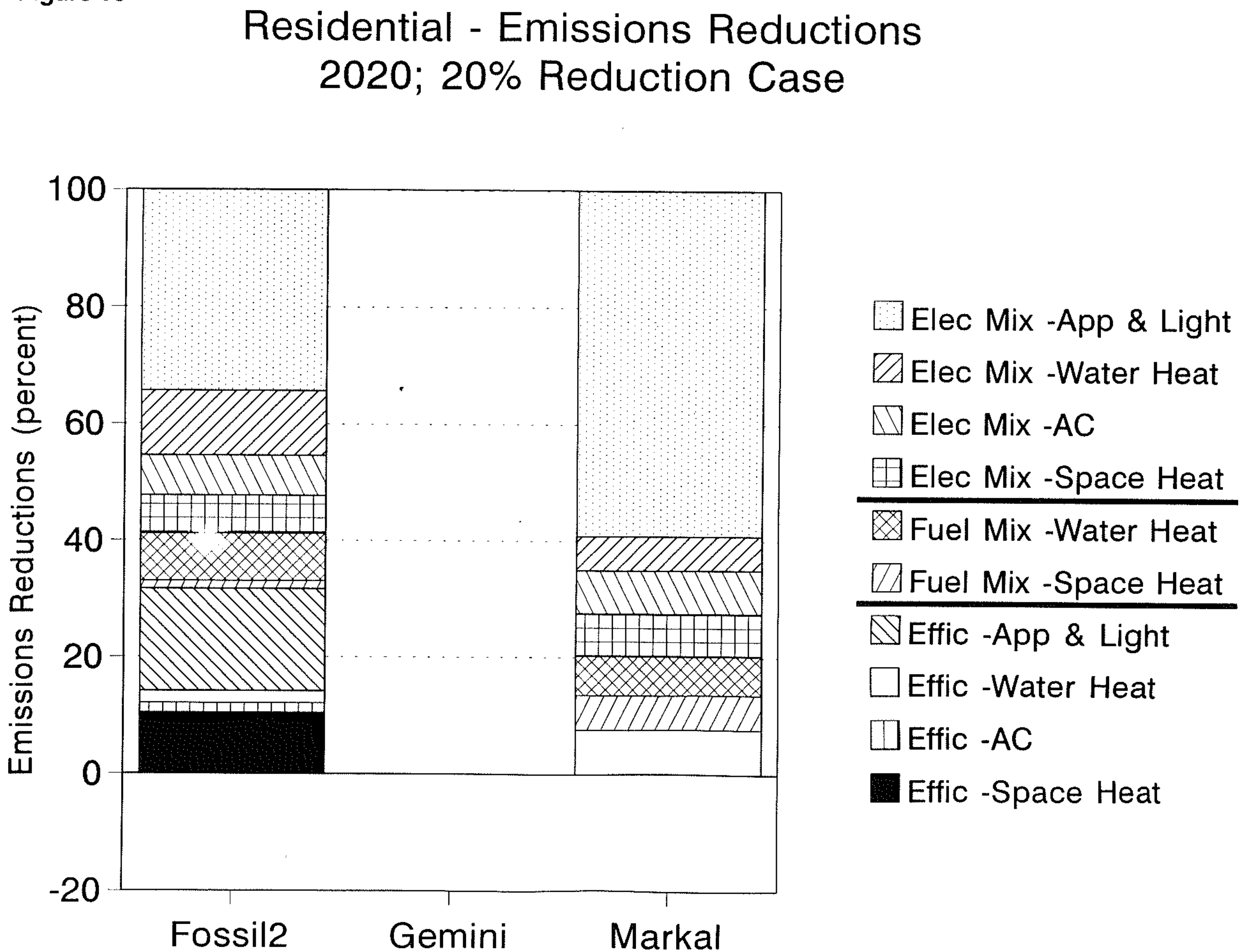
Note that the last category, generation efficiency changes, results in modest emissions increases as compared to the reference scenario. This is because fewer new fossil-fuel fired plants are built, hence the efficiency of the industry is more heavily influenced by plants built prior to the imposition of a carbon tax.

A CLOSER LOOK AT EMISSIONS REDUCTIONS FROM CHANGES IN THE RESIDENTIAL SECTOR

Two models provided detailed information on fuel consumption in residential buildings: Fossil2 and Markal. Energy inputs and service demands were collected by primary fuel and electricity for the following energy services: space heat, air conditioning, water heating, and appliances and lighting. Reductions were partitioned into 1) those due to changes in the fuel mix used to generate electricity, 2) reductions due to increased efficiency of equipment, and 3) changes due to the mix of primary fuels within the residential sector.

As might be anticipated from the earlier discussion, the largest share of emissions reductions in the residential sector comes from fuel mix changes "upstream" by electric utilities. Figure 10 illustrates this for reductions between the reference scenario and the 20 percent reduction scenario. About 60 percent of the reductions in Fossil2 and 80 percent of the reductions in Markal come from changes in utility fuel mix (labeled "Elec Mix" in the figure). In Fossil2, the bulk of the remaining reductions comes from efficiency improvements in appliances, lighting, and space heating and fuel switching in water heating. In Markal, additional reductions come from efficiency improvements and fuel switching in water heating and fuel switching from oil to natural gas for space heating.

Figure 10



Residential - Emissions Reductions
2020; 20% Reduction Case
Emissions Reductions (percent)
100
80
60
40
20
0
-20
Fossil2
Gemini
Markal
Elec Mix -App & Light
Elec Mix -Water Heat
Elec Mix -AC
Elec Mix -Space Heat
Fuel Mix -Water Heat
Fuel Mix -Space Heat
Effic -App & Light
Effic -Water Heat
Effic -AC
Effic -Space Heat

COMPARISON TO A "BOTTOMS UP" ANALYSIS

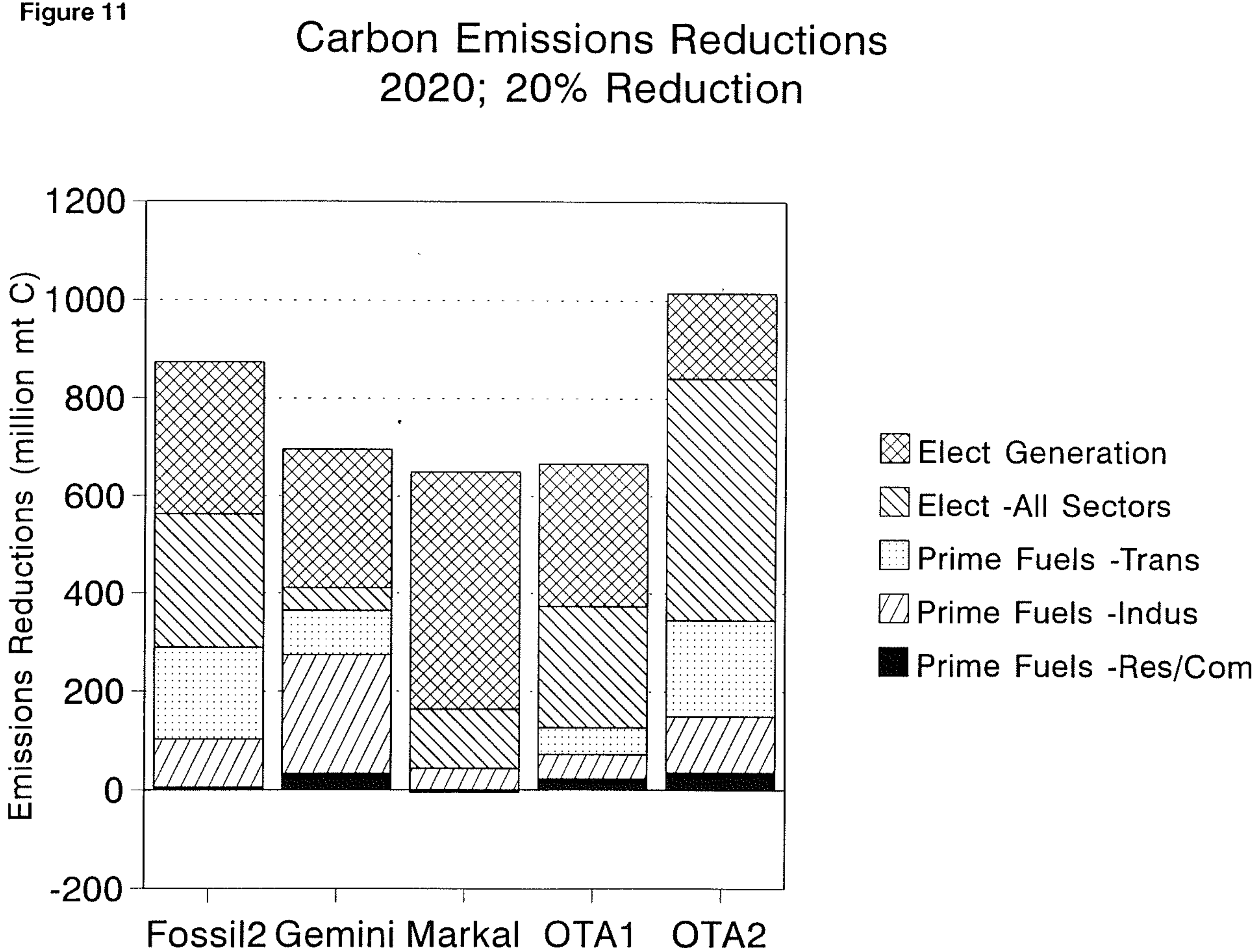
In a recent study, "Changing by Degrees: Steps to Reduce Greenhouse Gas Emissions"[7], the Office of Technology Assessment (OTA) analyzed the potential for carbon emissions reductions following a "bottoms up" approach (i.e., technology-by-technology analysis). Figures 11 and 12 present a comparison of the sources of emissions reductions between the reference case and the 20 percent reduction scenario for the three models discussed above, to two OTA scenarios that bracket the 20 percent target (for 2015, the last year of the OTA analysis). The scenario labelled OTA1 includes aggressive electricity supply-side changes and more moderate demand-side reductions (affecting both primary fuels and electricity). The scenario labeled OTA2 includes aggressive measures on both the demand and supply side, lowering carbon emissions to about 30 percent below 1990 levels by 2015.

The OTA results are closest to the aggregate results for Fossil2. One major difference is apparent, however: the OTA scenarios, while achieving the bulk of their reductions from changes in electricity generation and use, get a greater proportion from demand side reductions (i.e., efficiency improvements) than from changes in fuel mix. When compared to reductions achieved by both Gemini and Markal, the "bottoms-up" approach used in the OTA analysis achieves several times more reductions through efficiency improvements among electricity consuming technologies.

DISCUSSION

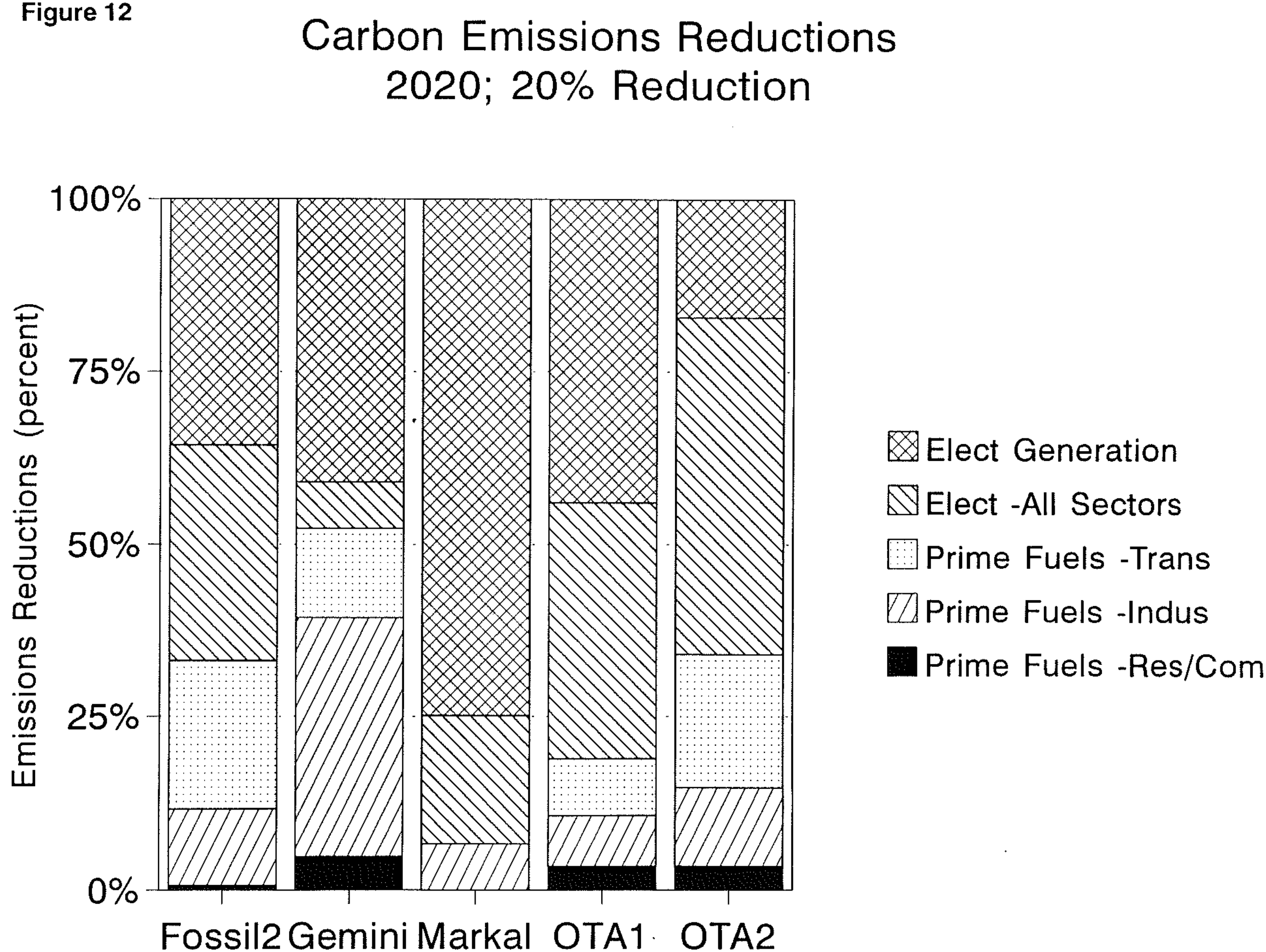
Unfortunately, time did not permit a detailed comparison of the costs and efficiencies of the many demand and supply side technologies included in the three models -- both to each other and to the bottoms-up studies that did not participate in EMF 12. It is thus difficult to

Figure 11



OTA data for 2015

Figure 12



OTA data for 2015

determine the precise reason for the differing response among the models. A few factors appear most important, however.

First, though the assumed GNP growth rates are the same for all models, the growth in carbon emitting activities under the base case is not. Fossil2 has the highest growth rates, followed by Markal and then Gemini. The greater the growth in carbon emitting activities (for example, vehicle miles traveled) the more difficult it is to lower emissions. Transportation is the sector with the largest differences in activity forecasts among the models.

These activity differences are at least part of the reason why the carbon tax needed to achieve the same emissions target -- 20 percent below 1990 levels -- varies among the models. Fossil2 requires the highest tax, about \$500/ton, followed by Markal at about \$200/ton and Gemini at about \$110 per ton.

A second reason for the different model responses is, of course, differing assumptions of relative prices among fuels and the costs of more efficient technologies. Some of the differences in the assumed costs of more efficient technologies are reflected in the base case: overall carbon intensity (emissions per unit of end-use activity) of the 2020 reference case as compared to 1990 drops the least in Fossil2 (14 percent by 2020), followed by Gemini (18 percent) and Markal (20 percent).

The source of reductions, again a function of relative prices, varies among models, too. In Fossil2, improvements in energy intensity are responsible for about 70 percent of the reductions between the hypothetical fixed emission rate scenario and the 20 percent reduction scenario. In Gemini, intensity changes are responsible for about half the carbon reductions by 2020, and in Markal, changes in energy intensity achieve about 40 percent of the total. Markal's greater reliance on fuel switching is probably due to the fact that it is the only one of the three models that chooses new nuclear power plants to meet increased demand for electricity. Gemini appears more bullish on the potential for renewable electric generating technologies, which leads to substantial fuel switching. Fossil2 is clearly more pessimistic about the opportunities for fuel switching than the other models. (Even at the higher carbon tax it achieves less reductions through fuel switching.) However, it is unclear whether Fossil2 actually includes greater potential for carbon reductions from efficiency improvements than the other two models or whether the model is just forced to choose higher cost efficiency improvements to achieve the required reductions.

There are differences in the cost and performance of lower carbon technologies in each of the sectors that should be examined further. For example, Fossil2 has identified considerable potential for reductions from the transportation sector, Gemini from industry, and Markal from electric utilities. Further work may allow specification of an improved set of technology assumptions that would be beneficial to all of the models. The next Energy Modeling Forum (EMF 13) will explore part of this question in greater detail by further examining the potential for cost-effective energy efficiency improvements over the next few decades.

ENDNOTES

1. In each category in figures 1 and 2, the left bar represents 1990 emissions. The right bar displays three scenarios of 2020 emissions. For each scenario, emissions are represented by the height of the correspondingly labeled section (plus the height of the sections below it.)

2. Note that intensity is calculated on a primary fuels basis, that is, the energy used to generate electricity, rather than the quantity of electricity used by the end user, is used in the calculation.

3. To estimate changes in emissions between the hypothetical fixed emission rate scenario and the control case, add the reductions shown in both the left and right bars in the figures.

4. Emissions reductions were partitioned among the six categories using a simple shift-share technique. Emissions were calculated first under the reference scenario and then with changes in fuel mix, demand, and efficiency made one at a time, e.g. the control scenario electricity demand with fuel mix and efficiency held to the values under the reference scenario.

5. In Fossil2, the increased use of nuclear power is from life extensions of existing nuclear plants, rather than from new ones.

6. Data for the stabilization scenario were available from Fossil2 and Gemini. The pattern of reductions within the utility sector is quite similar under both scenarios in Gemini. In Fossil2, however, there is a heavier reliance on renewables and the "backstop" technology under the 20 percent reduction scenario than under the stabilization case. Electricity related reductions under the stabilization scenario are due primarily to demand side reductions, then increased use of nuclear, and finally use of renewable sources.

7. U.S. Congress, Office of Technology Assessment, Changing By Degrees: Steps to Reduce Greenhouse Gases, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991).