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5 Labs Study: Scenarios of U.S. Carbon Reductions Notes and Comments--[GCC (Global Climate Change)] [Binder]

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5 Labs Study:
Scenarios of U.S. Carbon Reductions

Notes and Comments

Joe Aldy
CEA

GCC:

5 Labs Study Notes and Comments

8/22 phone call

David Chien, EIA

will find out ↑ energy consumption w/ flat fuel efficiency

new E/GDP rate

w/ diesel tech - heavily dependent on NO_x catalyst

core tech way to go given PM regs

NO_x + PM - trade-off w/ GHG

distillate tech ↑ NO_x, PM

→ can't meet current emission stds w/ present catalyst

→ diesel hybrid in light duty vehicle

must occur + nee

heavy funding

~50% heavy trucks are independent operators

→ will slow diffusion

will email his comments

fuel prices do rise ~ 10¢/gal

- current tech cost-effective for ↑mpg - these will con
- price↑ brings in more tech.
- path of fuel prices matter, not end + begining prices

lag + price expectations

combining cars + lt. trucks

→ fuel economy has improved, not flat as implied by DOE;

above CAFE floor by 1.2 mpg

dom manufacturers ↑ mpg by 1 since 1990

imports declining in fuel economy

trucks have been ~flat

8/19 mtg - DOE5 presentation

Joe Romm

study should withstand GAO audit

2 peer reviews 1) EPRI, GRI, NAS, UT, Stan, Harv.

2) Al Link - UNC

DeCanio

labs told not to examine policies

looked @ $50/ton bc they were told many supply options become attractive at that price

Climate Technology Strategy - asked of agencies by Pres, Secy

PCAST - Energy R+D Strategy

37% of bldgs can be captured w/ stds

Did I tell you?

Jeff wants to meet w/ the IAT modelers and have them do a set of emissions paths thru 2050 (1990, -10% 1990, Peak 2015, maybe Peak 2025). Jeff said he would like to talk to you about this.

only SGM can do this or G-cubed.

We need to define The policy-space better first

8/15

David Chien, EIA 586-3994 — left msg

Art Andersen, EIA 586-1441 — left msg

Andy Kydes ? phone#

→ can answer that question
assume 1m → ½ quad

ref case: 1.096% ↑ energy

1.063%

2015: 110.87 quads ref case

110.27 quads cons fuel eff

.03% ↓ in energy growth

↳ .87% ~~.01096~~ should be revised baseline

.01096
-.01063
.00033

dom em trading + CAS study

Pencil: conversation w/ Art Andersen 8/15/97

186 cons

17.7 quads constant fuel eff 97-2015

17.1 quads ref

111 quads total

→ .6 quads

300,000 barrels/day

→ .5 → E/GDP disappears in the rounding

VMT ↑ is still big

drives more than fuel economy

9/4 phone conversation w/ Mark Mazer

DOE 5 Labs Study

Δ bears to energy savings

want to keep costs in

→ not a full CBA

will be more careful w/ cost-effectiveness

so will remove some

will address baseline issue

8/12 mtg w/ Treasury

- accel of what would already be adopted ~5 yrs in future

  ↳ what is the time horizon

  get a couple of ex for end of week

  energy use in refrigs over past 20 yrs

  - AHAM data on energy intensity

    Consumer Reports on fridges

  do you really get benes into perpetuity

  - depreciation of knowledge

check literature

Romer

Jaffe

- CRF ↓ 33%-15%

  make equivalence statement, eg = costs of elim corp inc tax for energy eff investments

Joe Roman 8/4

some advice along the way
some as peer review
process not completed – still on-going – hopeful to
finish up this week (week from today)
will release reviewers names when process is complete
– reviewers should see final draft before names
are released
mainly industry, some academics
some just review a specific section
Some review whole report
have sent a letter that reviewers are happy w/ it
will release "draft-final" next week (learning from
IAT process)
→ will accept comments in future if easily incorporated

Marilyn Brown - Oak Ridge Nat'l Lab 8/11

DOE lab study - mostly internal review
6 members of tech review: EPRI
GRI
Monsanto
1 or 2 universities
→ have seen 2 drafts
next draft will be available for widespread review next week
→ some more additional analysis
better cost-savings analysis
better refinement of fuel switching behavior

8/1 DOES Draft

1. BAU

2. Alternative View

3. bldgs - no reference to $25/ton scenario
industry "
trans

> don't know how this is calculated ?

from Howard Gruenspecht

- bldgs + trans would require CAFE, natl bldg codes
- bldgs assumes AC electricity, not use
- no behavioral adaptation = study

1pm Friday - Eric Macris

Copy of DOES presentation package from Bob

15% of total private investment costs = govt costs - now in DOES

- get from Eric

NPV in DOES is to society, not owner

Peg – 10^9 Tonnes = 10^R

1000,000,

DOE Labs Study

lead authors Marilyn Brown 423-576-8152 lm ORNL
Mark Levine 510-486-5238 lm LBNL

buildings Jon Koomey – lead; Levine was co-author – ask him first
[illegible] till Monday

industry Gale Boyd – lead: 630-252-5393 Argonne
- Gale is out of the office until 8/19
- call Joe Roop: 509-372-4245 PNNL
  Joe originally passed me on to Gale – ask him if he can get us the documentation, or who else at Argonne could

transportation Steve Plotkin: 202-488-2403 Argonne – DC office

utilities call your contacts

We want:
1) to know when report will be released
2) documentation: inputs / outputs > baseline, efficiency, high efficiency

preferably on disk (esp. spreadsheet models)

Stan Hadley 423 574-8018
Eric Hirst 423 574-6304

Tradeable Permits – upstream/downstream

5 Labs Study (mid-June draft)

Methodology

Baseline: AEO97 for bldgs, industry
modified AEO97 for transportation + electric

Suite of Technologies: assembled existing info on performance and costs of energy efficient tech
bldgs - database is extensive
trans - database is sufficient
ind - database is partial; analysis relies on historical relations b/t energy use + economic activity + much less on explicit technological opportunities

Scenarios: 1) Baseline / Business As Usual
2) Efficiency - the nation ↑ its emphasis on energy efficiency thru ↑ public + private sector efforts; reduces, but doesn't eliminate, mkt barriers + lags
3) High Efficiency / Low Carbon - focused national R+D effort (↑ fed policies, ↑ state programs, active private sector involvement) → transform mkts plus domestic C permit trading @ $50/ton

Don't Consider: 1) market acceptance: "...we have confined our analysis to technology costs, and have not assessed policies or programs to achieve mkt acceptance." (p. xvi)
2) implementation costs: "Ignoring the implementation costs, this means that the cost of reducing carbon emissions are negative overall." (p. xvi)

Note: "...implementation costs of energy efficiency and the other requirements to achieve rapid and widespread mkt acceptance of technologies will raise the cost of the scenarios, as discussed below." (p. xviii)

Estimate of net costs $\le$ \$10b/yr:

Assumes ≤ 0 net costs of all tech adoption, $\le$ \$6b/yr costs to utilities (\$50/ton permit · 125 mt/yr) and $\le$ \$4b/yr costs to industry + bldgs (\$50/ton · 75 mt/yr)

→ all costs are for permits

Models weren't integrated: ① "The model runs for each of the 3 end-use sectors were not integrated and therefore may overstate the effects of technology penetration. In an integrated modelling effort, fuel prices might fall as consumption declines, resulting in less penetration of energy-conserving technologies." (p. 1-2)

② "While there is considerable variation in the methodologies used to estimate the energy savings and emissions reductions potential of each sector, the 3 sector chapters are consistent in their use of a combination of technology analysis and model-based forecasting, and each sector uses consistent conceptual definitions of scenarios." (p. 1-4) ind appears different than other 2 in intro chp discussion

Efficiency case

- "assumes that natl policy, possibly in combination with exogenous events, leads to an ↑ in the cost-effectiveness and deployment of energy-efficient technologies." (p. 1-5) "cost effective" ≡ "a tech is cost effective if it delivers a good or service at equal or lower life cycle costs relative to current practice" (p. 1-5)

Efficiency assumes ① better tech (incremental effects from R+D thru 2010, revolutionary effects by 2020) ② higher penetration rates - invigorated set of mkt transformation programs that remove or reduce mkt failures which inhibit the use of energy efficient systems

This scenario "also takes into account real-world experience + program implementation constraints which suggest that it is not reasonable to assume that every consumer will purchase the least-cost, high efficiency tech option" (p. 1-6)

High Efficiency: policy announced in 2000 - phased-in thru 2010 (price C ↑ thru 2010) → ① a policy "announcement effect" ② ↑ fed R+D ③ price of C ④ other countries R+D ⑤ Δ in <u>psychology</u>

Methodological Differences Across Sectors

- differences due in part to each sector's modeling approach

ind achieves hi eff by doubling penetration rates

trans postulates a set of tech breakthroughs

Cost-effectiveness by sector: bldgs: 7% disc rate - horizon = operational lifetime

trans: 7% disc rate - horizon = 5 yrs

ind: CRF = 15% (payback < 7 yrs)

"This report does not describe in detail the policies that might be implemented to achieve higher penetrations of energy efficiency technologies." (p. 1-7)

"Additional work will be needed to further refine our analysis of technologies, to improve understanding of what is needed to achieve market penetration of the technologies, and to assess costs and benefits of policies." (p. 1-7)

EXECUTIVE OFFICE OF THE PRESIDENT

COUNCIL OF ECONOMIC ADVISERS
17TH AND PENNSYLVANIA AVENUE, NW
WASHINGTON, DC 20500

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TO: See distribution list

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FROM: Joe Aldy

FAX NUMBER: (202) 395-6853

TEL NUMBER: 395-1455

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EXECUTIVE OFFICE OF THE PRESIDENT
COUNCIL OF ECONOMIC ADVISERS
WASHINGTON, D.C. 20500

SENIOR ECONOMIST

MEMORANDUM

TO: Joe Romm
Acting Assistant Secretary for Energy Efficiency and Renewable Energy

FROM: Randy Lutter and Joe Aldy

DATE: September 4, 1997

RE: Comments on revised executive summary and chapter one of *Scenarios of U.S. Carbon Reductions*

We appreciate the opportunity to review the August 29 draft of the executive summary and chapter one of *Scenarios of U.S. Carbon Reductions*. In this draft, we note that the authors addressed many of our comments made at the August 19 meeting. Since this is a Department of Energy labs report, and not an interagency or CEA report, we do not intend to hold up the report simply because the views presented do not conform in all respects to our own. However, two modifications to chapter one should be made prior to the release of the report.

- First, all references to the "cost-effectiveness" of technologies should be removed and the estimates of costs and benefits in table 1.5 should be deleted. As we noted in our August 22 comments, the report does not appropriately account for all of the costs associated with technology adoption decisions. Without an assessment of the behavioral responses to policies aimed at stimulating technology adoption, the private cost of achieving these emission reductions is unknown. Further, the report insufficiently details the costs of government programs, and does not ascribe any costs to society of standards. Thus, claims of "cost-effectiveness" are premature at best.

  The benefits resulting from energy cost savings do not reflect appropriate energy prices and should not be provided in this table. Since the analyses are not integrated, the energy prices do not reflect declines in demand, resulting decreases in prices, and the behavioral responses of consumers. However, qualitative statements could be included in the text, such as: "The adoption of energy efficient technologies would result in substantial energy cost savings to consumers."

- Second, chapter one should clarify the divergence between the report's BAU case and the Annual Energy Outlook 1997 reference case. We understand that transportation emissions under the BAU reflect a modified assumption about fuel efficiency improvements in the AEO reference case. However, we do not understand the discrepancy in emissions for the buildings and industry sectors between the two reports (see comment 8 in August 22 memorandum). A discussion of the assumptions that resulted in this divergence, or a modification of the projected emissions would be appropriate.

We look forward to receiving your responses to our August 22 memorandum in the near future.

cc: JHF
RL
SR
JA

SCENARIOS OF U.S. CARBON REDUCTIONS

Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond

Prepared by the
Interlaboratory Working Group on
Energy-Efficient and Low-Carbon Technologies

Oak Ridge National Laboratory*
Lawrence Berkeley National Laboratory*
Pacific Northwest National Laboratory
National Renewable Energy Laboratory
Argonne National Laboratory

Prepared for
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

*Coordinating laboratories for this study

Copied

exec sum:
Δed only 2 words
from 8/29/97 version

EXECUTIVE SUMMARY

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States.[1] The study documents in detail how four key sectors of the economy – buildings, transportation, industry, and electric utilities – could respond to directed programs and policies to expand adoption of energy-efficiency and low-carbon technologies, an increase in the relative price of carbon-based fuels by $25 or $50/tonne (e.g., as a result of a cap on domestic carbon emissions and a market for carbon "permits"), and an aggressive program of targeted research and development. Current projections suggest that a carbon emissions reduction of 380 million metric tons per year (MtC/year) is required to stabilize U.S. emissions in 2010 at 1990 levels. BAU

The study, which has been peer-reviewed by industry and academic experts, uses a technology-by-technology assessment as well as an engineering-economic modeling approach. It draws upon a wide variety of technology cost and performance information to assess potential impacts. Analysis of the buildings, industry, and transportation sectors quantifies the impacts of end-use energy-efficiency improvements on carbon emissions. The utility sector analysis estimates the impacts of those improvements on utility carbon emissions, and quantifies additional emissions reductions through conversion of a number of coal power plants to natural gas, dispatching of the utility grid with $25 and $50/tonne carbon permit prices, the accelerated use of biomass cofiring and wind energy, and other low-carbon electricity supply options. Finally, a number of other promising low-carbon technologies are examined to determine their potential for reducing emissions in the end-use sectors, including advanced gas turbines in industry, transportation biofuels, and fuel cells in buildings.

Three overarching conclusions emerge from the analysis of alternative carbon scenarios. First, a vigorous national commitment to develop and deploy energy-efficient and low-carbon technologies has the potential to restrain the growth in U.S. energy consumption and carbon emissions such that levels in 2010 thru policy are close to those in 1997 (for energy) and 1990 (for carbon). We analyze a case in which energy efficiency can reduce carbon emissions by 120 MtC/year by 2010. We analyze a second case, with policies that promote adoption of energy-efficient and low carbon technologies and a $25/tonne carbon permit price, with emission reductions of 230 MtC/year in 2010. Under a $50/tonne carbon permit price and aggresive policies, 2010 emissions could be cut by about 380 MtC/year. The analysis also suggests that substantial additional savings are available if permit prices were to begin to rise above the $50/tonne level.

The second conclusion is that, if feasible ways are found to implement the carbon reductions as described above, all the cases (with reductions varying between 120 and 380 MtC/year by 2010) can produce energy savings that are roughly equal to or exceed costs.[2] The analysis includes only technologies estimated to be cost-effective under 2010 energy prices (with a $25/tonne and $50/tonne carbon permit price for the respective cases); it has not, however, analyzed specific policies to achieve the cases, identified the political feasibility of policies, or described a pathway to achieve the cases.

The third conclusion is that a next generation of energy-efficient and low-carbon technologies promises to enable the continuation of an aggressive pace of carbon reductions over the next quarter century. This report documents a wide array of advanced technology options that could be cost-competitive by the year 2020, assuming a vigorous and sustained program of energy R&D beginning now and extending beyond 2010.

---

[1] The five national laboratories participating in the study were: Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). LBNL and ORNL were the co-leaders of the effort.

[2] Here we count as benefits only the energy savings to the nation. We have not credited reduced CO_2 emissions or other external benefits. Costs include the increased technology cost plus an approximate estimate of the costs of program and policy implementation.

Chapter 1

ANALYSIS RESULTS

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States.[1] The stimulus for this study derives from a growing recognition that any national effort to reduce the growth of greenhouse gas emissions must consider ways of increasing the productivity of energy use. To add greater definition to this view, we quantify the reductions in carbon emissions that can be attained through the improved performance and increased penetration of efficient and low-carbon technologies by the year 2010. We also take a longer-term perspective by characterizing the potential for future research and development to produce further carbon reductions over the next quarter century. As such, this report underscores the value of energy technology research, development, demonstration, and diffusion as a public response to global climate change.

Three overarching conclusions emerge from our analysis of alternative carbon reduction scenarios. First, a vigorous national commitment to develop and deploy cost-effective energy-efficient and low-carbon technologies could reverse the trend toward increasing carbon emissions. Along with utility sector investments, such a commitment could halt the growth in U.S. energy consumption and carbon emissions so that levels in 2010 are close to those in 1997 (for energy) and in 1990 (for carbon). It must be noted that such a vigorous national commitment would have to go far beyond current efforts. Second, if feasible ways are found to implement the carbon reductions, the cases analyzed in the study are judged to yield direct benefits that are roughly equal to or greater than costs. Third, a next generation of energy-efficient and low-carbon technologies promises to enable the continuation of an aggressive pace of carbon reductions over the next quarter century.

1.1 OBJECTIVES OF THE REPORT

The purposes of this study are threefold:

1. To provide a quantitative assessment of the reduction in energy consumption and carbon emissions that could result by the year 2010 from a vigorous national commitment to accelerate the development and deployment of cost-effective energy-efficient and low-carbon technologies;
2. To document the costs and performance of the technologies that underpin a year 2010 scenario in which substantial energy savings and carbon emissions reductions are achieved;
3. To illustrate the potential for energy-efficiency and renewable energy R&D to produce further reductions in energy use and carbon emissions by the year 2020.

1.2 METHODOLOGY

To achieve these objectives, we started with the *Annual Energy Outlook 1997* (AEO97) reference case forecasts for the year 2010 (Energy Information Administration, 1996). After thoroughly reviewing these forecasts on a sector-by-sector basis, and working with EIA staff, we chose to accept the EIA "business-as-usual" (BAU) scenario as is for buildings and industry. We modified some of the assumptions and data to produce a new BAU case – not greatly different from the EIA case – for the transportation and the electric utility sectors.[2]

We then assembled existing information on the performance and costs of technologies to increase energy efficiency or, for selected end-uses, to switch from one fuel to another (e.g., from electricity to natural gas for residential end-uses or from gasoline to biofuels for transportation). For the buildings sector, the technology performance and cost data base are extensive. For transportation, the data base – although less fully developed than for buildings – is sufficient for our purposes. For industry, only partial information on technologies and costs is presently available. As a result, the analysis for industry relies primarily on historical relations between energy use and economic activity and much less on explicit technological opportunities. The industrial analysis also includes some examples of industrial low-carbon technologies. The analysis of low-carbon supply technologies in the electricity sector is based on a review of the literature including detailed technology characterizations prepared by DOE in conjunction with its national laboratories and industry.

Next we created scenarios of increased energy efficiency and lower carbon emissions using the technology data (or, in the industrial sector, historical relations) as key inputs. We chose to run three scenarios other than the BAU case. We have termed the first the "efficiency" (EFF) case. It assumes that the United States increases its emphasis on energy efficiency through enhanced public- and private-sector efforts. The general philosophy of the efficiency case is that it reduces, but does not eliminate, various market barriers and lags to the adoption of cost-effective energy efficiency technology.[3]

The other two cases, dubbed the $25 permit and the $50 permit "high-efficiency/low-carbon" (HE/LC) cases, describe a world in which, as a result of commitments made on a climate treaty or other factors, the nation has embarked on a path to reduce carbon emissions. Both of these cases assume a major effort to reduce carbon emissions through federal policies and programs (including environmental regulatory reform), strengthened state programs, and very active private sector involvement. Both also include a focused national R&D effort to develop and transform markets for low-carbon energy options (e.g., fuel cells for microcogeneration in buildings and advanced turbine systems for combined heat and power in industry). The difference between the two HE/LC cases is in the assumption of a carbon permit price resulting from a domestic trading scheme for carbon emissions with a cap on U.S. emissions (or from equivalent policy measures that increase the price of carbon-based fuels relative to those with less carbon). We assume a domestic permit price of $25 and $50 per tonne of carbon for the two cases. Both of these HE/LC cases include a program of research, development, demonstration and diffusion that is more vigorous than in the efficiency case. In the buildings and industry sectors, the carbon price signal, combined with policies promoting energy efficiency, is believed to trigger most of the additional carbon reductions. In the transportation sector, it is the R&D-driven technology breakthroughs that generate the bulk of the carbon reductions beyond the efficiency case. For the electricity sector, higher prices for carbon-based fuels cause larger shifts from coal to natural gas; for this sector, these same higher relative prices combined with federal and private research, development, and demonstration can bring advanced low-carbon technologies to market.

Although most of the analysis focuses on 2010, we also look beyond this date. Here we describe new technologies, materials, processes, manufacturing methods, and other R&D advances that promise to offer significant energy benefits by the year 2020; for this time period, we make no effort to forecast specific levels of market penetration, energy savings, or carbon reductions. Thus, instead of creating scenarios we describe the technological innovations that could enable the continuation of an aggressive pace of decarbonization well into the next quarter century, if appropriate investments in R&D were made.

1.3 BACKGROUND

The decade of gains in energy productivity achieved by the U.S. following the 1973-74 Arab oil embargo represents a period of economic growth that was decoupled from increases in energy consumption, resulting in substantial economic benefits. Between 1973 and 1986, the nation's consumption of primary energy froze at about 74 quads – while the GNP grew by 35%. Starting in 1986, energy prices began a descent in real terms that has continued to the present. As a result, energy demand grew from 74 quads in 1986 to 91 quads in 1995, and carbon emissions have been increasing at a similar pace.

Despite the growth in energy consumption since 1986, the U.S. economy today remains more energy productive than it was 25 years ago. In 1970, 19.6 thousand Btu of energy were consumed for each (1992) dollar of GDP. By 1995, the energy intensity of the economy had dropped to 13.4 thousand Btu of energy per (1992) dollar of GDP. The U.S. Department of Energy (DOE) estimates that the country is saving $150 to $200 billion annually as a result of these improvements.

Nevertheless, many cost-effective energy-efficient technologies remain underutilized, as discussed in Chapter 2. A host of market barriers account for these lost opportunities. And declining energy R&D expenditures may cause promising technology options to be foregone.

The rationale for government support of energy-efficiency R&D is strong. Much energy-efficiency research is both long-term and high-risk and therefore is not adequately funded by the private sector – despite the possibility of sizable gains in the long run. Furthermore, advances in energy efficiency offer substantial public benefits (such as carbon reductions and improved national security through greater oil independence) that cannot be fully captured in the private marketplace.

The benefits of past public investments in energy-efficiency R&D have been well documented. Between 1978 and 1996, DOE spent approximately $8 billion on energy-efficiency research, development and demonstration (RD&D). Just five of the technologies that were developed or demonstrated with a fraction of this DOE support have resulted in net benefits of $28 billion through 1996. Many other R&D successes have produced technologies yielding substantial energy and cost savings in the market. The DOE RD&D portfolio has also led to significant environmental, health, productivity, and economic competitiveness benefits.

1.4 RESULTS

1.4.1 Prospects for Improved Efficiencies by the Year 2010

Table 1.1 and Figure 1.1 compare the nation's primary energy use in quads for the years 1990 and 1997 (projected) with the results of three scenarios for 2010. (We have included only the high-efficiency/low-carbon case at $50/tonne in the table and figure for simplicity.) The $50/tonne HE/LC case shown below does not reflect the energy impacts of the selected low-carbon technologies described later in this summary (e.g., stationary fuel cells for buildings, advanced turbine systems and biomass gasification in industry) or the supply-side options shown in Table 1.4.

Table 1.1 Primary Energy Use in Quads: 1990-2010

	1990	1997	2010 Business-as-Usual Case	2010 Efficiency Case	2010 High-Efficiency/ Low-Carbon Case ($50/tonne C)
Buildings	29.4	33.7	36.0	34.1	32.0
Industry	32.1	32.6	37.4	35.4	33.6
Transportation	22.6	25.5	32.3	29.2	27.8
Total	84.2	91.8	105.7	98.7	93.4

Source: Energy use estimates for 1990 come from EIA (1996a, Table 2.1, p. 39). Energy use estimates for 1997 come from forecasts conducted for EIA (1996b). Numbers may not add to the totals due to rounding.

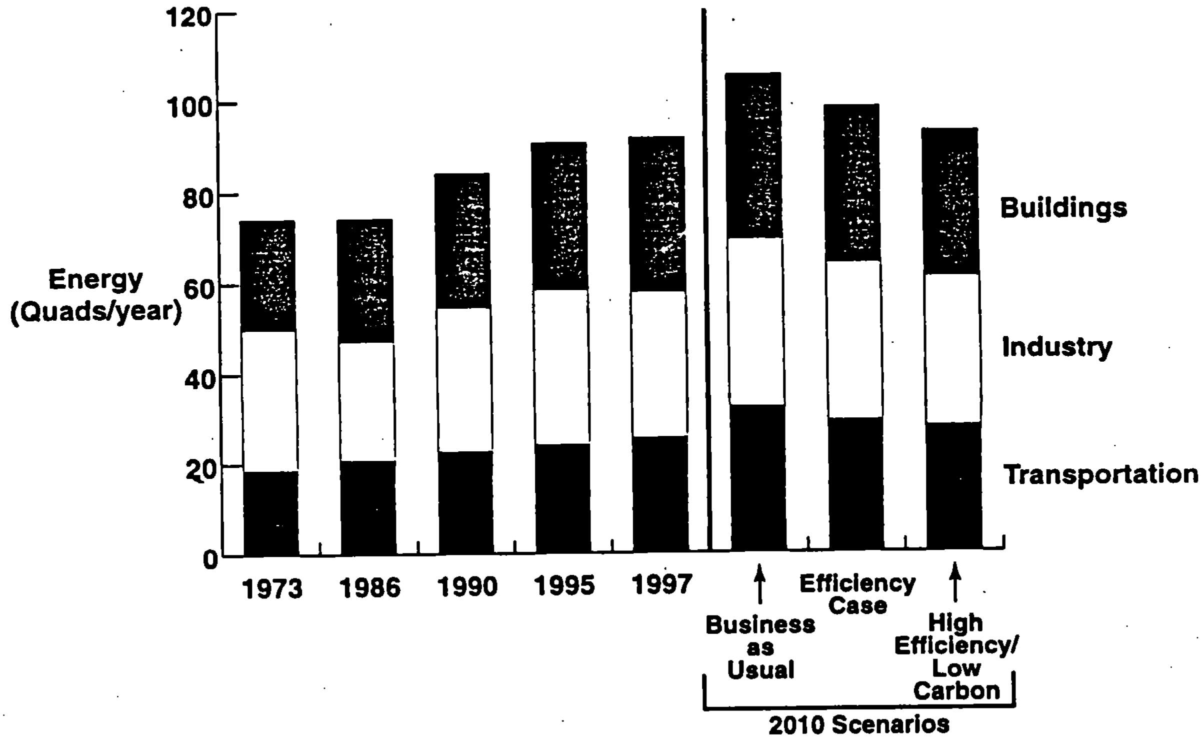
The major observations are as follows:

- In the business-as-usual case, energy use increases by 22 quads (26%) between 1990 and 2010; 8 quads of this increase have occurred during the first seven years of this 20-year period. The fastest growing sector during these initial seven years has been buildings (4.3 quads) followed by transportation (2.9 quads) and industry (0.5 quads). In the BAU case, the fastest growing sector during the remaining 13 years is transportation (6.8 quads). This is followed by industry (4.8 quads) and then buildings (2.3 quads). The rapid projected growth in the energy consumed for transportation is driven by estimates of increased per capita travel and minimal fuel efficiency gains.

- The efficiency scenario cuts the overall growth between 1990 and 2010 from 22 to 15 quads. This is a 17% increase over the level of energy consumption in 1990, down from a 26% increase in the BAU case. Relative to the BAU case, the efficiency scenario for transportation delivers slightly more energy savings (3.1 quads) than do the same scenarios for the industrial (2.0) or buildings (1.9) sectors. Compared with 1997 levels, the smallest increase in energy growth for this case is in buildings (0.4 quads), followed by industry (2.8 quads), and transportation (3.7 quads).

- The high-efficiency/low-carbon scenario with a $50/tonne carbon charge further decreases the overall growth between 1990 and 2010, reducing it from 22 to 9 quads. This is an 11% increase over the level of energy consumption in 1990. Relative to the BAU case, the high-efficiency/low-carbon scenario for buildings, industry, and transportation delivers energy savings ranging from 3.8 to 4.5 quads for each sector. Compared with 1997 levels, the buildings sector is down about 2 quads and industry and transportation are up 1 and 2 quads, respectively.

Figure 1.1 Primary Energy Use in Quads: 1990-2010



Note: The high efficiency/low carbon scenario values represent the $50 per tonne carbon charge.

Table 1.2 documents the impact of these projected energy savings in 2010 on carbon emissions in that same year. It also presents the results of the HE/LC scenarios with both $25 and $50 per tonne carbon charges. These scenarios show significant carbon reductions from the combination of greater efficiency improvements and increased use of advanced low-carbon technologies.[4] In these cases, a number of low-carbon technologies have high rates of adoption (e.g., advanced turbine systems and biomass gasification in industry), the utility grid is dispatched to reduce carbon emissions (by using many coal plants for intermediate power and by running more natural gas plants as base load), a set of coal-based power plants are repowered, nuclear plant lifetimes are extended, and key renewable energy technologies are deployed. In all cases, these technologies and measures are estimated to be cost-effective with a differential carbon fee of $50/tonne.

Table 1.2 Carbon Emissions (MtC): 1990-2010

			2010			
	1990	1997	Business-as-Usual (BAU) Case	Efficiency Case	High-Efficiency/ Low-Carbon[a]	
					$25/tonne	$50/tonne
Buildings	460	511	571	546	527	509
Industry	452	482	534	512	488	452
Transportation	432	486	616	543	528	513
Utilities[b]	–	–	–	–	-48	–136
Total (rounded)	1340	1480	1720	1600	1490	1340
Change from 1990		140	380	260	150	0
Change from BAU	–	–	–	-120	-230	-380

[a] This scenario includes the carbon emission reductions resulting from a carbon permit price of $25 or $50/tonne: (1) dispatch of power plants in which natural gas is favored relative to coal, (2) repowering and partial repowering of coal-based power plants to convert to natural gas, and (3) introduction of selected low-carbon technologies to replace conventional ones, primarily in the industrial and utility sectors.

[b] The entries in the last two columns are negative as they correspond to reductions in carbon emissions resulting from the increased use of natural gas and low-carbon technology for electricity generation as a result of the $50/tonne carbon permit price in this scenario.

Table 1.2 presents results for the business as usual and three efficiency and/or low carbon cases in 2010 as point estimates, because they are meant to be scenarios. When we use these scenarios for analysis, in section 1.5, we describe sources of uncertainty and the effects of uncertainty on our understanding of the implications of these cases. For now, we only describe the different cases.

Figures 1.2 and 1.3 complement the above table by illustrating the carbon emissions reductions from each scenario. The major observations are:

- In the BAU case, carbon emissions are forecast to increase by approximately 380 million tonnes.
- The energy-efficiency gains incorporated in the efficiency case cut overall growth between 1990 and 2010 by one-third (from 380 to 260 million tonnes). This represents a carbon increase of 19% above 1990 emissions.
- The HE/LC scenario with $25/tonne carbon charge has the potential to reduce carbon emissions by 230 million tonnes from the BAU case in 2010. The largest part of these carbon reductions are from increased efficiency, but major changes in electricity supply (carbon-based dispatching and repowering) contribute nearly 35 million tonnes, and other low-carbon technology, particularly renewables and advanced turbine systems, produce approximately another 25 million tonnes.
- The HE/LC scenario with $50/tonne carbon charge has the potential to reduce carbon emissions by approximately 380 million tonnes, thereby achieving 1990 carbon emission levels in 2010. Of this 380 million tonne carbon reduction, about 190 million tonnes are from increased energy efficiency, 140 million tonnes results from increases in the use of low-carbon fuels and technologies in the utility sector, and 50 million tonnes results from the use of low-carbon technology in industry and transportation.

Figure 1.2 Reductions in Carbon Emissions from Each Scenario

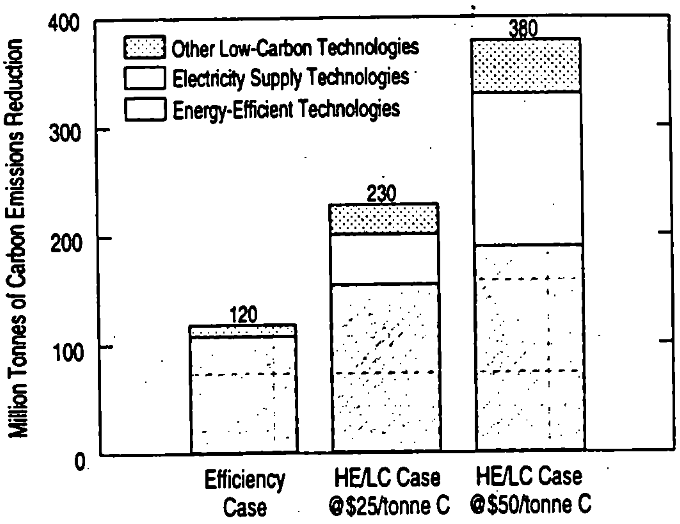
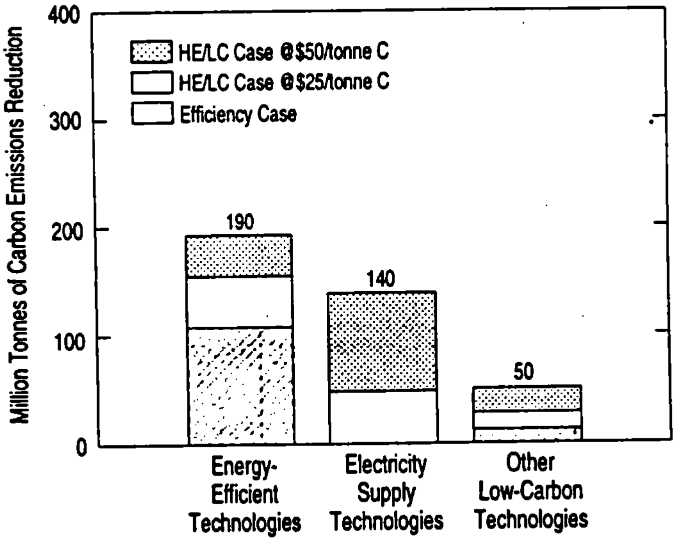


Figure 1.3 Reductions in Carbon Emissions from Each Type of Technology



100 million of the 140 million tonnes of carbon reductions in the utility sector comes from redispatching the utility system (favoring the use of low-carbon fuels) and from repowering coal plants with natural gas. Both are cost-effective with a $50/tonne carbon charge. The remaining 40 million tonnes are from renewables (wind, co-firing coal-based power plants with biofuels, expansion of hydropower capacity), nuclear power plant life extensions, and power plant efficiency improvements.

The remaining 50 million tonnes of carbon reductions in industry and transportation are about equally divided among three sets of fuels/technologies: (1) advanced combustion turbine cogenerators in industry, (2) biomass and black liquor gasification and low-carbon industrial processes, and (3) cellulosic ethanol/gasoline blends for automobiles.

- Approximately 140 MtC of the increase in carbon emissions between 1990 and 2010 will have occurred by the end of 1997; thus, it is useful to look ~~at~~ the 13-year forecast starting with 1997.

The carbon reductions incorporated in the efficiency case cut the overall *growth* in carbon emissions between 1997 and 2010 from 240 million tonnes (as forecast in the BAU case) to 120. The HE/LC scenario with $50/tonne carbon charge *reduces* carbon emissions in 2010 by about 130 million tonnes (compared with the 1997 level).

Table 1.3 provides a comparison of the growth rate in energy and in carbon emissions for the four cases, from 1990 to 2010. For the BAU and efficiency cases, the growth in carbon emissions is slightly more rapid than the increase in energy demand. For the HE/LC cases, carbon emissions decline while energy consumption rises. The carbon reduction reflects the increased deployment of low-carbon fuels and technologies as a consequence of the relative increase in price of carbon-based fuels precipitated by the $50/tonne incentive.

Table 1.3 Average Annual Energy and Carbon Growth Rates, 1997 to 2010, for Four Cases

	Business-As-Usual (BAU)	Efficiency Case	High Efficiency/ Low Carbon Case ($25/tonne)	High Efficiency/ Low Carbon Case ($50/tonne)
Gross Domestic Product (GDP)[a]	1.88%	1.88%	1.88%	1.88%
Energy Demand	1.09%	0.56%	0.34%	0.13%
Carbon Emissions	1.16%	0.60%	0.05%	-0.76%
Energy Consumption Per GDP (E/GDP)	-0.77%	-1.30%	-1.51%	-1.71%
Carbon Emissions Per GDP (C/GDP)[b]	-0.70%	-1.25%	-1.79%	-2.59%

[a] The Gross Domestic Product (GDP) in 1995 was $7251 billion in 1995 dollars. The 1.88% annual growth was assumed to apply to the entire period, 1995-2010 to derive the results above.

[b] The carbon decrease per unit GDP growth for 1990 to 2010 is 0.7%, 1.1%, 1.4% and 1.9% per year for the reference, efficiency, $25/tonne HE/LC, and $50/tonne HE/LC cases, respectively.

It is useful to compare the scenarios in this study to those of other studies. The 1991 report by the Office of Technology Assessment (OTA) titled *Changing by Degrees* (U.S. Congress, 1991) analyzed the potential for energy efficiency to reduce carbon emissions by the year 2015, starting with the base year of 1987. Its "moderate" scenario results in a 15% rise in carbon emissions, from 1300 MtC/year of carbon in 1987 to 1500 MtC/year of carbon in 2015 (compared to a BAU forecast of 1900 MtC/year). Its "tough" scenario results in a 20% to 35% emissions reduction relative to 1987 levels, or emissions levels of 850 to 1000 MtC/year of carbon in 2015. Our efficiency and HE/LC cases ranging from 1.3 to 1.6 billion tonnes of carbon emissions in 2010 are comparable to OTA's "moderate" case and show considerably higher emissions than OTA's "tough" case.

Another benchmark is provided by the 1992 National Academy of Sciences (NAS) report on *Policy Implications of Greenhouse Warming* (National Academy of Sciences, 1992). This study identified a set of energy conservation technologies that had either a positive economic return or that had a cost of less than $2.50 per tonne of carbon. Altogether, NAS concluded that these technologies offer the potential to reduce carbon emissions by 463 million tonnes, with more than half of these reductions arising from cost-effective investments in building energy efficiency. Our efficiency and HE/LC cases suggest the potential for reducing carbon emissions by between 120 and 380 million tonnes by the year 2010. One reason that the NAS estimate is higher is because it is not limited to the 2010 time

frame, but rather characterizes the full potential for carbon reductions. Thus, it did not take into account the replacement rates for equipment and processes, and other factors that prevent the instantaneous, full market penetration of cost-effective energy-efficient and low-carbon technologies.

1.4.2 R&D's Potential for Further Benefits by 2020

If carbon reductions in 2010 and beyond are to be sustained at reasonable cost, vigorous R&D efforts are needed to fill the pipeline of next-generation energy technologies. It is difficult to estimate the carbon savings that will accrue from these technologies; however, our effort to characterize their features suggests that an aggressive pace of carbon reductions over the next quarter century can be sustained, with a sufficient investment in R&D. Our analysis of R&D potential for the year 2020 focuses on opportunities for improved energy-efficiency and renewable energy technologies. The potential long-term contributions of carbon sequestration, advanced coal technologies, and nuclear power may also be significant. However, the treatment of vigorous R&D initiatives to improve these supply options beyond 2010 is beyond the scope of this report.

Renewable energy technologies will likely play a crucial role in limiting carbon emissions over the long term. Low-carbon energy supply options are needed to fuel domestic and international economic development without stimulating further global warming. Although renewable resources account for only 7% of the nation's total energy consumption at present, many believe that they are at the beginning of a long-term growth trajectory. With continuing technological development and cost reductions, renewables could become preferred energy resources some time within the next several decades. Early evidence of this transition is seen in the continuing adoption of renewable power systems, including especially wind farms and biomass power systems, even in the face of low gas-fired power generation costs and considerable uncertainty in today's electric energy sector.

With a vigorous and sustained program of research, development and deployment, biomass, wind, photovoltaics, geothermal, and solar thermal technologies could deliver significant quantities of electricity in 2020, thereby substantially displacing carbon emissions. For example, the use of forestry and agricultural residues in biomass power systems continues to be an attractive power option where those residues exist. The successful development of higher-efficiency biomass gasification systems would make this technology competitive in a wider range of applications, including for power systems using dedicated feed stock supply systems. At the same time, biological and agricultural research on biomass production will lead both to higher biomass yields and better species for energy conversion purposes in the future.

A second area in which a vigorous and sustained R&D effort could spawn a range of key improvements is in wind power systems. Potential improvements include:

- Advanced blade shapes that increase wind power capture while reducing stress loads,
- Elimination of gearboxes through development of direct-drive generators,
- Variable speed turbines, and
- Better resource prediction that will increase the value of wind power to power systems operators.

A third area of renewables development that is at the beginning of a long-term growth path is the use of renewables in buildings. Solar daylighting, passive solar designs, solar water heating, and geothermal heat pumps already are cost-competitive in many applications, but are not yet widely

used. R&D advances could substantially accelerate their market penetration. In addition, building-integrated photovoltaic products will benefit directly from advances in materials research. The ultimate vision is that many buildings will become "net energy generators" through a combination of renewable energy and energy-efficiency technologies.

In the next quarter century, improved energy-efficiency technologies will result from a combination of incremental advances and fundamental breakthroughs. Incremental improvements in all sectors can be achieved by the greater reliance on more precise and reliable sensors and controls or on lower-cost sensors and controls, often integrated into industrial processes, transportation systems, and buildings. Advanced manufacturing technologies, including rapid prototyping and ultraprecision fabrication, also offer broad opportunities for continuous incremental improvements in energy efficiency and renewable energy. Breakthroughs in bioprocessing, separations, superconductivity, catalysts, and materials can have wide-ranging impacts on energy efficiency and carbon emissions by the year 2020. Examples of specific technology opportunities are described in this report, by sector.

Six R&D areas offer great promise to reduce significantly the energy requirements of our nation's buildings in 2020:

- Advanced construction methods and materials,
- Adaptive building envelopes,
- Multi-functional equipment,
- Integrated, advanced lighting systems,
- Improved controls, communications and measurements, and

combined in 8/29/97 draft

- Self-powered buildings.

In addition to the broad application of better process modeling, sensors, and controls in industry, many process/industry-specific opportunities for efficiency gains exist. These are described for each of DOE's targeted industries of the future: pulp and paper, chemicals, petroleum refining, glass, aluminum, iron and steel, and metal casting.

Many of the advanced technologies that have the potential to significantly improve the energy efficiency of transportation need considerable R&D investment before they can become commercially available in the year 2020. For example, to achieve fuel economies in the 60-80 miles per gallon (MPG) range and remain affordable and safe, light-duty vehicles will need:

- Breakthroughs in manufacturing processes for composite materials,
- Large reduction in fuel cell costs and/or cost reductions and performance gains in batteries,
- Ultra-low rolling resistance tires,
- High-efficiency accessories, and
- Highly aerodynamic designs.

Opportunities for R&D to lead to improvements in the energy efficiency of other transportation modes are also described in this report.

In all, the continued adoption of energy efficient and renewable energy technologies and a steady flow of technology improvements from collaborative R&D programs with industry could make such environmentally friendly technology an attractive option for domestic and global energy economies in the future. With strong public-private partnerships to support the necessary R&D and market transformation activities, ample cost-effective energy products and practices will be available in 2020.

1.5 ASSESSMENT OF COSTS, ENERGY SAVINGS, AND SOURCES OF CARBON REDUCTIONS

The business-as-usual scenario projects an increase of 380 MtC/year between 1990 and 2010. In our efficiency scenario, in which the nation actively pursues policies and programs to promote market acceptance of energy efficiency while expanding commitments to research and development, energy-efficient technologies reduce this growth in carbon emissions by 120 MtC/year. Under a carbon cap and trading system, in which permits for carbon sell for either $25 or $50/tonne C, very substantial carbon reductions appear possible. Detailed results for these cases, showing the sources of the carbon reductions, are contained in Table 1.4. (Summaries of these results were presented in Figures 1.2 and 1.3.) Results indicate that, for the $50/tonne HE/LC case, there is a potential to roughly return to 1990 levels of carbon emissions in 2010. About two-thirds of the increase in carbon emissions is eliminated in the case with a $25/tonne carbon charge (Table 1.4).

The estimates in Table 1.4 include ranges for most of the electricity supply options and the other low-carbon technologies. There are no ranges for the efficiency technologies because the models used to estimate their penetration are nonstochastic. When selecting a single estimate for the $50/tonne case, numbers from the low end of the ranges were generally selected in order to be cautious. Because we did not conduct an integrating analysis in which supply options compete against one another, we felt it important to minimize potential overlap by entering the supply options in conservative quantities. Also note that several renewable resources that could play a greater role by 2010 are omitted from Table 1.4; these resources include include photovoltaics, geothermal, solar thermal, and landfill gas.

One should not ascribe too much significance to specific entries in Table 1.4 There are many different technologies, both on the supply and demand side of the energy system, that will compete to achieve carbon reductions in an environment in which policies and economic signals favor such reductions. Thus, for example, Table 4.1 shows advanced turbine systems in industry cutting carbon emissions by 17 MtC/year in 2010, co-firing coal with biomass reducing emissions by the same amount, and other low-carbon supply technologies (wind, nuclear plant extensions, hydropower expansion, and power plant efficiency) contributing 24 MtC/year. The actual choice of technology depends on how the economics of the different systems evolve over time, how the industry to supply technology develops, the nature and speed of deregulation within the utility industry, and numerous other factors that cannot be known today. As such, we do not intend the results in Table 1.4 to be taken as a prediction of one technology over another to achieve carbon reductions. In this instance, we have posited one of many possible mixes of supply technologies. These same comments apply to the demand-side sectors and technologies.

We summarize below the expected technology costs in 2010, as well as the cost of implementing a carbon permit system. While these costs are necessarily uncertain, they are our best estimates and, in our view, as likely to be high as to be low. We note, however, that we have focused our analysis on technology costs, and have not assessed the viability of specific policies or programs to achieve market acceptance. As described below, we do account for program and policy costs in an approximate manner.

Table 1.4 Potential Annual Reductions in Carbon Emissions in 2010, Compared to the Business-As-Usual Forecast for 2010 (MtC)

		High-Efficiency/Low-Carbon Case	
	Efficiency Case	$25/tonne	$50/tonne*
Buildings			
Energy efficiency	25	42	59
Fuel cells		2	3
	25	44	62
Industry			
Energy efficiency	22	36	51
Advanced turbine systems		5	17 (15-26)
Biomass and black liquor gasification, cement clinker replacement, and aluminum technologies		5	14 (13-16)
	22	46	82
Transportation			
Energy efficiency	61	74	87
Ethanol	12	14	16
	73	88	103
Utility Supply Options			
Carbon-ordered dispatching		25	55
Converting coal-based power plants to natural gas		9	40 (25-66)
Co-firing coal with biomass		5	17 (16-24)
Wind		2	7 (6-20)
Extending the life of existing nuclear plants		3	5 (4-7)
Hydropower expansions		2	4 (3-5)
Power plant efficiency		2	8 (7-13)
		48	136
Total (rounded)	**120**	**226**	**383**

*Numbers in parenthesis are ranges, as documented in the text of the report. See Appendix A-1 for a description of the derivation of the results in this table.

Appendix A-2 describes the full set of calculations used to derive the direct costs and benefits of the cases. The costs considered include the incremental technology investment by consumers and businesses, fuel price increases, and the estimated cost of federal, state, and local programs required to achieve the carbon emissions reductions. These constitute the direct costs of the scenarios. The highest of these by far is the incremental investment costs. However, the generally higher first cost of these technologies is counterbalanced by substantially lower operating costs. The benefits considered are limited to the savings in operating (energy) costs from the technology investments.

We have presented the direct and most easily quantified of the costs and benefits, but have not attempted a full benefit-cost calculation. We do not account for indirect effects of policies (e.g., the reallocation of investment dollars to efficiency investments). We do not account for the increased cost of some R&D programs that are needed to achieve the scenario results nor do we count the benefit of reduced carbon and other pollutant emissions. Also, we have not analyzed any possible redistribution of wealth that could arise from a carbon trading system or other policy to increase the price of carbon-based fuel.

Considering only these direct costs and energy-saving benefits of the scenarios, we have analyzed the economics of carbon emissions reductions from two different perspectives in order to establish a credible range of costs. In the first, which we label "optimistic," we evaluate all costs and benefits with a real discount rate that approximates the cost of capital *for efficiency investments* for the different end-use sectors: 7% for buildings, 10% for transportation, and 12.5% for industry.

The lowest discount rate, for buildings, is based on the fact that the money for residential buildings is derived from home mortgages or home improvement loans. The higher rate for industry reflects the fact that energy-efficiency investments have to compete with investments for other projects. These discount rates are not those that describe current market behavior, but rather are reflective of costs of capital if the market did invest in the energy-efficiency measures. For the "optimistic" case, we assume costs for efficiency measures brought about by utility, federal programs, and state programs (e.g., demand-side management programs by utilities, federal market transformation programs) to be 15% of technology costs. We also assume that at least half of the efficiency occurs as a result of federal policies (e.g., standards or carbon permit charges) which add very low direct program costs. Thus, the overall costs of implementation are taken to be about 7% in the "optimistic" case. The electric supply-side technologies are assumed to add an incremental cost of $30/tonne carbon in 2010, based on an average estimate of the incremental costs of the technologies from the appropriate sections of this report.

These programs and policies are not specified in this study, but the broad nature of the actions could include technology R&D partnerships such as the current Partnership for a Next Generation of Vehicles and Industries of the Future; energy efficiency codes and standards; expanded partnerships, technical assistance, and information programs to accelerate the adoption of energy-efficient technologies; incentives through the tax system directed at investments in energy-efficient technology in industry; and a variety of non-federal programs to accelerate market diffusion of energy-efficient and low-carbon technologies.

The second perspective, which we label "pessimistic," assumes that there are hidden costs associated with achieving widespread market acceptance of many of the efficiency and low-carbon technologies, even after the imposition of a carbon charge and the implementation of major policies and programs to promote a low-carbon future. In this perspective, we evaluate costs and benefits at a real discount rate of 15% for buildings and 20% for transportation and industry. Program costs are increased to 30% of the cost of efficiency measures, an estimate that is a high bound compared with federal, state, and utility experience. Overall implementation costs (programs and directed policies) are taken to be 15% of technology investments in this case. Other data and assumptions in this case are the same as for the "optimistic" case.

The results of the economic analysis are presented in Table 1.5. Estimated direct costs are $26-$49 billion per year for the efficiency scenario and $51 to $88 billion per year for the high-efficiency/low-carbon scenario. Estimated savings per year in 2010 are $42 to $51 billion per year in the efficiency case and $70-$88 billion per year for the high-efficiency/low-carbon case. The costs, which are a small portion of annual gross private domestic investment of about $1.4 trillion in 2020, are likely to be more than balanced by savings in energy bills. Thus, net costs to the U.S. economy are estimated to be near or below zero in this time frame.

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Table 1.5 Estimated Costs and Energy Savings of the Efficiency and High-Efficiency/Low-Carbon Scenarios : Optimistic and Pessimistic View Estimates (billions of 1995$, annualized)

	Efficiency Case[a]			High-Efficiency/Low-Carbon Case[b]		
	Costs[d] (billion 1995$)	Energy Savings[c] (billion 1995$)	Carbon[c] Savings MtC	Costs (billion 1995$)	Energy Savings (billion 1995$)	Carbon Savings MtC
Energy Efficiency						
Buildings	7-14	14-17	20-25	14-26	26-33	49-62
Industry	3-5	6-7	18-22	8-13	12-15	66-82
Transportation	16-30	22-27	58-73	23-43	32-40	82-103
Electricity Dispatch	0	0	0	2	0	44-55
Electricity Repowering	0	0	0	2	0	32-40
Other Low-Carbon Techologies	0	0	0	2	0	33-41
Total	**26-49**	**42-51**	**96-120**	**51-88**	**70-88**	**306-383**

[a] Energy efficiency category includes ethanol in transportation.

[b] Energy savings and carbon savings in the HE/LC case are relative to BAU case.

[c] In the "pessimistic" case, we have assumed that only 80% of the carbon savings are achieved, even though the technology and implementation costs are unchanged. The range on carbon savings represents this assumption.

[d] Costs are calculated from differing viewpoints: the "optimistic" case uses discount rates that vary between 7% and 12.5% for the different sectors, as described in the text. For the "pessimistic" case, the discount rates used to annualize costs vary between 15% and 20%. Also in this case, the cost of implementing programs (30%) and an overall package of programs and policies (15%) is taken to be twice that of the "optimistic" case.

The range of estimates in Table 1.5 reflects our attempt to "bound" optimistic and pessimistic assessments. There are clearly other ways in which these bounds could be described, just as there are many scenarios that could have been analyzed. However, we believe that the assumption that 80% of the carbon reductions are achieved at the costs identified, valuation of costs and benefits at discount rates noticeably higher than the likely cost of capital, and doubling the cost of programs and policies from typical experience today is a strong reflection of pessimism in costs for our cases. It is worth noting that if the implementation costs were taken to be much higher than we believe to be reasonable – 50% of investments costs for programs and 25% overall – this would add about $10 billion per year to the costs of the high-efficiency/low-carbon in the pessimistic case.

In addition to these costs, one needs to calculate the impact of the cases on natural gas demand. In all of these cases, natural gas replaces very large quantities of coal. Higher natural gas demand would result in higher natural gas prices, which in turn would increase the cost of substituting natural gas for coal in power production, etc. As it turns out, our scenarios have somewhat reduced gas demand compared with the BAU case (or with AEO97 baseline for 2010, on which the price of natural gas in our work is based). Specifically, demand for natural gas in the HE/LC ($50/tonne) case declines in 2010 by 2 quads compared with the business-as-usual case. This is the result of declines of 0.5 quads for buildings, 1.0 quads for industry, and 0.5 quads for electricity. The latter occurs because of the balance among three factors: increase in gas demand because of the large-scale substitution of natural gas for coal, decrease of gas demand because of the use of many low-carbon technologies that do not use natural gas (wind, nuclear power plant extensions, power plant efficiency upgrades, hydropower expansion, co-firing with biofuels), and the large increase in cogeneration, which reduces demand for natural gas for heating applications.

The sum of the second and third effects are somewhat greater than the first, and thus total natural gas demand associated with electricity generation declines. This will reduce the cost of natural gas, a benefit that we have not included in the analysis.

The $50/tonne carbon charge, while not constituting a direct cost, does represent a potentially large transfer payment. The magnitude of the transfer payment, as well as the losers and winners from the transfers, depends on the nature of policy and its implementation as a cap and trade system or some alternative. The amount of money that could be in play is very large: $50/tonne times 1.3 billion tonnes per year equals $65 billion per year.

In short, while there will surely be winners and losers for these energy-efficiency and low-carbon scenarios, our analysis shows that their net economic costs – under a range of assumptions and alternative methods of cost analysis – are favorable.

The achievability of the cases depends on many factors. In all cases, carbon reductions require the nation to embark on an aggressive set of policies and programs. Such efforts could occur in response to an international agreement on climate change or to other events that result in a national determination to reduce the growth of carbon emissions. In the high-efficiency/low-carbon cases, we assume a vigorous national program of research, development, demonstration, and diffusion, and a trading regime for carbon with a domestic permit price of either $25/tonne or $50/tonne carbon. Without some scheme that provides strong incentives for switching from coal to natural gas, and for deploying other low-carbon technologies, much of the potential for carbon reductions will not be realized.

Government policies and programs that encourage and/or require the adoption of energy-efficiency and low-carbon technologies will be needed, along with incentives for industry to invest more in these technologies. Additional private and public investments are necessary, not only to accelerate the introduction of new technologies into the market before 2010 but also to ensure the availability of technologies for the period after 2010. The transportation and utility sectors are especially dependent on early technological advances to achieve the scenario results in 2010.

There is no assurance that these and other driving forces will cause the scenarios we have described to take place. Our major conclusion is that technology can be deployed to achieve major reductions in carbon emissions by 2010 at low or no net direct costs to the economy. Cost-effective energy efficiency alone can take the nation 30 to 50% of the way to 1990 levels. Two additional utility sector measures can reduce carbon emissions by another 30% at an estimated cost of $50/tonne carbon: carbon-based dispatch and conversion of existing power plants from coal to natural gas.[5] Finally, we identify several additional technologies that can contribute up to 20% of the estimated carbon reductions, also for less than $50/tonne. A next generation of advanced energy-efficiency and renewable energy technologies promises to enable the continuation of an aggressive pace of energy and carbon reductions over the next quarter century.

1.6 REFERENCES

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National Academy of Sciences (NAS). 1992. *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* (Washington, DC: National Academy Press).

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ENDNOTES

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[1] The five national laboratories participating in the study were: Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). LBNL and ORNL were the co-leaders of the effort.

new

[2] The differences between the AEO97 BAU case and ours for 2010 are (1) 1.2 quads higher use of oil in transportation (32.3 instead of 31.1 quads) because auto fuel economy does not increase and (2) lower use of oil for electricity generation (declines from 1.5% of generation to 0.1%) and slightly higher use of natural gas and coal. In all other regards, including price of all fuels and delivered energy, our reference case and the AEO BAU case are essentially identical.

[3] See Section 2.2.3 for a definition of cost-effective energy efficiency technology.

[4] $50 per tonne of carbon corresponds to 12.5 cents per gallon of gasoline or 0.5 cents per kilowatt-hour for electricity produced from natural gas at 53% efficiency (or 1.3 cents per kilowatt-hour for coal at 34% efficiency). $25 per tonne would cut these gasoline and electricity price increments in half.

[5] The cost curve for repowering is relatively flat; as such, considerable additional reductions are possible at a cost not too different from $50/tonne. The results are highly sensitive to the price differential between coal and natural gas; at a lower (higher) price differential, a higher (lower) permit price of carbon is needed.

Calculate C emissions from oil in electricity generation

POTUS American University speech, 9/9/97
Excerpt on climate change

Next, we must meet a very large environmental challenge in the next three months. We will work toward a worldwide climate change treaty this December in Kyoto that protects the environment even as it promotes global growth by committing the nations that sign on to it to specific, clear guidelines in the reduction of greenhouse gas emissions into the atmosphere. We know -- (applause.) You can clap for that -- that's all right. (Applause.)

Now, there are students here from all over the world, students from all over our country. Many of you have witnessed -- and your families have witnessed -- in your own homes, significant changes in climatic patterns in the last decade, and more extreme climatic develops. It is becoming a part of the common parlance of America, all over the country, to talk about the 500-year flood we had along the Mississippi River. One member of Congress, who happened to be a member of the other party, said to me the other day -- he said, "Mr. President, we've had three 100-year floods in the last five years in my home state." He said, "Does that mean I get to wait 500 years before we have another bad flood?"

Many of you who are studying this issue know that a panel of over 2,500 scientists has concluded that the climate of the Earth is significantly warming in ways that will have not entirely predictable, but almost certainly destructive consequences unless we do something about it.

This is something that will affect people of all incomes, of all backgrounds, from all parts of our country, and, indeed, the whole world. We need the young people of America, particularly the university students who are in a position to study this issue, to make this a gripping national issue. And we also need people who have the confidence in our ability to break new technological and scientific barriers to stand up and say, ***you cannot make me believe that we can't reduce greenhouse gas emissions substantially and still grow the American economy. We could reduce them 20 percent tomorrow with technology that is already available at no cost if we just changed the way we do things.*** (emphasis added)

Now, this will be a very controversial debate. And there will be people who say, President Clinton has spent five years killing himself to revitalize the American economy and now he's going to take it down overnight be committing to reduce greenhouse gas emissions in America. That is not true. But if you let the sea level rise and we flood the southern coast of Florida and we flood the southern coast of Louisiana, and we otherwise disrupt what life in the United States is like over the next 50 years, then your children will pay the price for our neglect. We can grow this economy and do right by the environment. I think you believe that, and I need you to help me convince the American people that it can be done.

Joe Aldy

Office of Economic Policy

Department of the Treasury
Washington, D.C. 20220

FAX

Date: ____________________
Number of pages including cover sheet: _____

	Name	Fax Number	Phone Number
To:	T. J. Glauthier	395-4639	395-4561
	Joe Aldy	395-6853	395-1455
From:	Robert Gillingham	202-622-2633	622-0563

REMARKS: ___ Urgent ___ For your review ___ Reply ASAP ___ Please comment

DEPARTMENT OF THE TREASURY
WASHINGTON, D.C. 20220

September 4, 1997

MEMORANDUM FOR T. J. GLAUTHIER

FROM: Robert Gillingham RG
Jonathan Gruber JG

SUBJECT: 5-Labs Revision

We think this revision is a substantial improvement. Most of our comments are editorial (see attached draft). The major exceptions revolve, not surprizingly, around the treatment of "cost" estimates. We continue to feel that the analysis presents scenarios that *could* be achieved, rather than scenarios that *should* be achieved—regardless of climate benefits—on the basis of cost savings. To address this concern, we recommend (1) eliminating the modifier "cost-effective" when referring to technologies, (2) deleting Table 1.5 and substantially modifying or eliminating the discussion of costs on pp. 15 through 18, and (3) weakening the claim of rough cost/benefit parity in the second overarching conclusion in the executive summary (*e.g.*, recognizing that energy savings are a substantial offset without arguing relative magnitude).

We continue to believe the scenarios are informative primarily in terms of what is technically feasible. We do not believe the paper demonstrates the validity of the criteria used for selecting "cost-effective" technologies. The reasons for this skepticism are outlined in our earlier comments - the underlying model of the costs of technology adoption is not economically rigorous, with limitations that include low discount rates, and in particular extremely low implementation costs.

We view these criteria as one way of selecting technologies that could be adopted; the paper then does a very good job of quantifying the impact of adopting these technologies on energy use and carbon emissions. A possible substitute for Table 1.5 might be a table of reductions in energy consumption valued at today's (or 2010's) prices to quantify the *energy-cost* saving, with the appropriate caveat that it would take a full-blown general-equilibrium analysis (beyond the scope of the paper) to determine what prices would actually obtain. Going further than that, in our opinion, is too ambitious and—for the purposes of this paper—is not critical.

MEMORANDUM

August 29, 1997

TO: T.J. Glauthier (OMB), Jeff Frankel (CEA), Robert Gillingham and Jon Gruber (Treasury), Peter Orszag (NEC)

FROM: Mark D. Levine and Marilyn Brown

RE: Executive Summary and Chapter 1 of the Report "Scenarios of U.S. Carbon Reductions"

CC: Joe Romm, Eric Petersen, Mark Mazur

We are faxing to you a modified version of the Executive Summary and Chapter 1 of the referenced report. In this version, we have attempted to respond to the concerns expressed in the meeting on August 19 while still expressing the major findings of the report.

We have received two sets of comments from you and expect to give you substantive responses to these comments in the near future.

EXECUTIVE SUMMARY

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States.[1] The study documents in detail how four key sectors of the economy – buildings, transportation, industry, and electric utilities – could ~~respond to directed programs and policies to~~ expand adoption of energy-efficiency and low-carbon technologies, an increase in the relative price of carbon-based fuels by $25 or $50/tonne (e.g., as a result of a cap on domestic carbon emissions and a market for carbon "permits"), and ~~an aggressive program of targeted research and development~~. Current projections suggest that a carbon emissions reduction of 380 million metric tons per year (MtC/year) is required to stabilize U.S. emissions in 2010 at 1990 levels.

Partially [illegible] to

do we have more than what was given out?

The study, which has been peer-reviewed by industry and academic experts, uses a technology-by-technology assessment as well as an engineering-economic modeling approach. It draws upon a wide variety of technology cost and performance information to assess potential impacts. Analysis of the buildings, industry, and transportation sectors quantifies the impacts of end-use energy-efficiency improvements on carbon emissions. The utility sector analysis estimates the impacts of those improvements on utility carbon emissions, and quantifies additional emissions reductions through conversion of a number of coal power plants to natural gas, dispatching of the utility grid with $25 and $50/tonne carbon permit prices, the accelerated use of biomass cofiring and wind energy, and other low-carbon electricity supply options. Finally, a number of other promising low-carbon technologies are examined to determine their potential for reducing emissions in the end-use sectors, including advanced gas turbines in industry, transportation biofuels, and fuel cells in buildings.

Three overarching conclusions emerge from the analysis of alternative carbon scenarios. First, based on current projections, it is technically feasible ~~a vigorous national commitment~~ to develop and deploy cost-effective energy-efficient and low-carbon technologies has the potential to restrain the growth in U.S. energy consumption and carbon emissions such that levels in 2010 are close to those in 1997 (for energy) and 1990 (for carbon). We analyze a case in which energy efficiency can reduce carbon emissions by 120 MtC/year by 2010. We analyze a second case, with policies that promote adoption of energy-efficient and low carbon technologies and a $25/tonne carbon permit price, with emission reductions of 230 MtC/year in 2010. Under a $50/tonne carbon permit price and aggresive policies, 2010 emissions could be cut by about 380 MtC/year. The analysis also suggests that substantial additional carbon savings are available if permit prices were to begin to rise above the $50/tonne level.

weaker

The second conclusion is that, if feasible ways are found to implement the carbon reductions as described above, all the cases (with reductions varying between 120 and 380 MtC/year by 2010) can produce direct benefits that are roughly equal to or exceed costs.[2] The analysis includes only technologies estimated to be cost-effective under 2010 energy prices (with a $25/tonne and $50/tonne carbon permit price for the respective cases); it has not, however, analyzed specific policies to achieve the cases, identified the political feasibility of policies, or described a pathway to achieve the cases.

The third conclusion is that a next generation of energy-efficient and low-carbon technologies promises to enable the continuation of an aggressive pace of carbon reductions over the next quarter century. This report documents a wide array of advanced technology options that could be cost-competitive by the year 2020, assuming a vigorous and sustained program of energy R&D beginning now and extending beyond 2010.

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[1] The five national laboratories participating in the study were: Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). LBNL and ORNL were the co-leaders of the effort.

[2] Here we count as benefits only the energy savings to the nation. We have not credited reduced CO_2 emissions or other external benefits. Costs include the increased technology cost plus an approximate estimate of the costs of program and policy implementation.

Chapter 1

ANALYSIS RESULTS

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States.[1] The stimulus for this study derives from a growing recognition that any national effort to reduce the growth of greenhouse gas emissions must consider ways of increasing the productivity of energy use. To add greater definition to this view, we quantify the reductions in carbon emissions that can be attained through the improved performance and increased penetration of efficient and low-carbon technologies by the year 2010. We also take a longer-term perspective by characterizing the potential for future research and development to produce further carbon reductions over the next quarter century. As such, this report underscores the value of energy technology research, development, demonstration, and diffusion ~~as a public response to~~ in mitigating global climate change.

Three overarching conclusions emerge from our analysis of alternative carbon reduction scenarios. First, a vigorous national commitment to develop and deploy ~~cost-effect~~ive energy-efficient and low-carbon technologies could reverse the trend toward increasing carbon emissions. Along with utility sector investments, such a commitment could helt the growth in U.S. energy consumption and carbon emissions so that levels in 2010 are close to those in 1997 (for energy) and in 1990 (for carbon). It must be noted that such a vigorous national commitment would have to go far beyond current efforts. Second, if feasible ways are found to implement the carbon reductions, the cases analyzed in the study are judged to yield direct benefits that ~~are roughly equal to or greater than~~ substantially offset costs. Third, a next generation of energy-efficient and low-carbon technologies promises to enable the continuation of an aggressive pace of carbon reductions over the next quarter century.

1.1 OBJECTIVES OF THE REPORT

The purposes of this study are threefold:

1. To provide a quantitative assessment of the reduction in energy consumption and carbon emissions that could result by the year 2010 from a vigorous national commitment to accelerate the development and deployment of cost-effective energy-efficient and low-carbon technologies;
2. To document the ~~costs and~~ performance of the technologies that underpin a year 2010 scenario in which substantial energy savings and carbon emissions reductions are achieved;
3. To illustrate the potential for energy-efficiency and renewable energy R&D to produce further reductions in energy use and carbon emissions by the year 2020.

1.2 METHODOLOGY

To achieve these objectives, we started with the *Annual Energy Outlook 1997* (AEO97) reference case forecasts for the year 2010 (Energy Information Administration, 1996). After thoroughly reviewing these forecasts on a sector-by-sector basis, and working with EIA staff, we chose to accept the EIA "business-as-usual" (BAU) scenario as is for buildings and industry. We modified some of the assumptions and data to produce a new BAU case – not greatly different from the EIA case – for the transportation and the electric utility sectors.

We then assembled existing information on the performance and costs of technologies to increase energy efficiency or, for selected end-uses, to switch from one fuel to another (e.g., from electricity to natural gas for residential end-uses or from gasoline to biofuels for transportation). For the buildings sector, the technology performance and cost data base are extensive. For transportation, the data base – although less fully developed than for buildings – is sufficient for our purposes. For industry, only partial information on technologies and costs is presently available. As a result, the analysis for industry relies primarily on historical relations between energy use and economic activity and much less on explicit technological opportunities. The industrial analysis also includes some examples of industrial low-carbon technologies. The analysis of low-carbon supply technologies in the electricity sector is based on a review of the literature including detailed technology characterizations prepared by DOE in conjunction with its national laboratories and industry.

Next we created scenarios of increased energy efficiency and lower carbon emissions using the technology data (or, in the industrial sector, historical relations) as key inputs. We chose to run three scenarios other than the BAU case. We have termed the first the "efficiency" (EFF) case. It assumes that the United States increases its emphasis on energy efficiency through enhanced public- and private-sector efforts. The general philosophy of the efficiency case is that it reduces, but does not eliminate, various market barriers and lags to the adoption of cost-effective energy efficiency technology.[2]

The other two cases, dubbed the $25 permit and the $50 permit "high-efficiency/low-carbon" (HE/LC) cases, describe a world in which, as a result of commitments made on a climate treaty or other factors, the nation has embarked on a path to reduce carbon emissions. Both of these cases assume a major effort to reduce carbon emissions through federal policies and programs (including environmental regulatory reform), strengthened state programs, and very active private sector involvement. Both also include a focused national R&D effort to develop and transform markets for low-carbon energy options (e.g., fuel cells for microcogeneration in buildings and advanced turbine systems for combined heat and power in industry). The difference between the two HE/LC cases is in the assumption of a carbon permit price resulting from a domestic trading scheme for carbon emissions with a cap on U.S. emissions (or from equivalent policy measures that increase the price of carbon-based fuels relative to those with less carbon). We assume ~~a~~ domestic permit prices of $25 and $50 per tonne of carbon for the two cases. Both of these HE/LC cases include a program of research, development, demonstration and diffusion that is more vigorous than in the efficiency case. In the buildings and industry sectors, the carbon price signal, combined with policies promoting energy efficiency, is believed to trigger most of the additional carbon reductions. ~~In the~~ transportation sector, ~~it is the R&D driven~~ technology breakthroughs ~~that~~ generate the bulk of the carbon reductions beyond the efficiency case. For the electricity sector, higher prices for carbon-based fuels cause larger shifts from coal to natural gas; for this sector, these same higher relative prices combined with federal and private research, development, and demonstration can bring advanced low-carbon technologies to market.

what type of program?

are related to

Although most of the analysis focuses on 2010, we also look beyond this date. Here we describe new technologies, materials, processes, manufacturing methods, and other R&D advances that promise to offer significant energy benefits by the year 2020; for this time period, we make no effort to forecast specific levels of market penetration, energy savings, or carbon reductions. Thus, instead of creating scenarios we describe the technological innovations that could enable the continuation of an aggressive pace of decarbonization well into the next quarter century, if appropriate investments in R&D were made.

1.3 BACKGROUND

The decade of gains in energy productivity achieved by the U.S. following the 1973-74 Arab oil embargo represents a period of economic growth that was decoupled from increases in energy consumption, resulting in substantial economic benefits. Between 1973 and 1986, the nation's consumption of primary energy froze at about 74 quads – while the GNP grew by 35%. Starting in 1986, energy prices began a descent in real terms that has continued to the present. As a result, energy demand grew from 74 quads in 1986 to 91 quads in 1995, and carbon emissions have been increasing at a similar pace.

Despite the growth in energy consumption since 1986, the U.S. economy has continued to improve its energy productivity. t~~oday remains more energy productive than it was 25 years ago~~. In 1970, 19.6 thousand Btu of energy were consumed for each (1992) dollar of GDP. By 1995, the energy intensity of the economy had dropped to 13.4 thousand Btu of energy per (1992) dollar of GDP. The U.S. Department of Energy (DOE) estimates that the country is saving $150 to $200 billion annually as a result of these improvements.

Nevertheless, many cost-effective energy-efficient technologies remain underutilized, as discussed in Chapter 2. ~~A host of market barriers account for these lost opportunities. And declining energy R&D expenditures may cause promising technology options to be foregone.~~

There are great reasons support energy efficiency R&D

The rationale for government support of energy-efficiency R&D is strong. Much energy-efficiency research is both long-term and high-risk and therefore is not adequately funded by the private sector – despite the possibility of sizable gains in the long run. Furthermore, advances in energy efficiency offer substantial public benefits (such as carbon reductions and improved national security through greater oil independence) that cannot be fully captured in the private marketplace.

The benefits of past public investments in energy-efficiency R&D have been well documented. Between 1978 and 1996, DOE spent approximately $8 billion on energy-efficiency research, development and demonstration (RD&D). Just five of the technologies that were developed or demonstrated with a fraction of this DOE support have resulted in net benefits of $28 billion through 1996. Many other R&D successes have produced technologies yielding substantial energy and cost savings in the market. The DOE RD&D portfolio has also led to significant environmental, health, productivity, and economic competitiveness benefits.

1.4 RESULTS

1.4.1 Prospects for Improved Efficiencies by the Year 2010

Table 1.1 and Figure 1.1 compare the nation's primary energy use in quads for the years 1990 and 1997 (projected) with the results of three scenarios for 2010. (We have included only the high-efficiency/low-carbon case at $50/tonne in the table and figure for simplicity.) The $50/tonne HE/LC case shown below does not reflect the energy impacts of the selected low-carbon technologies described later in this summary (e.g., stationary fuel cells for buildings, advanced turbine systems and biomass gasification in industry) or the supply-side options shown in Table 1.4.

Table 1.1 Primary Energy Use in Quads: 1990-2010

			2010		
	1990	1997	Business-as-Usual Case	Efficiency Case	High-Efficiency/ Low-Carbon Case ($50/tonne C)
Buildings	29.4	33.7	36.0	34.1	32.0
Industry	32.1	32.6	37.4	35.4	33.6
Transportation	22.6	25.5	32.3	29.2	27.8
Total	84.2	91.8	105.7	98.7	93.4

Source: Energy use estimates for 1990 come from EIA (1996a, Table 2.1, p. 39).
Energy use estimates for 1997 come from forecasts conducted for EIA (1996b).
Numbers may not add to the totals due to rounding.

The major observations are as follows:

- In the business-as-usual case, energy use increases by 22 quads (26%) between 1990 and 2010; 8 quads of this increase have occurred during the first seven years of this 20-year period. The fastest growing sector during these initial seven years has been buildings (4.3 quads) followed by transportation (2.9 quads) and industry (0.5 quads). In the BAU case, the fastest growing sector during the remaining 13 years is transportation (6.8 quads). This is followed by industry (4.8 quads) and then buildings (2.3 quads). The rapid projected growth in the energy consumed for transportation is driven by estimates of increased per capita travel and minimal fuel efficiency gains.

- The efficiency scenario cuts the overall growth between 1990 and 2010 from 22 to 15 quads. This is a 17% increase over the level of energy consumption in 1990, down from a 26% increase in the BAU case. Relative to the BAU case, the efficiency scenario for transportation delivers slightly more energy savings (3.1 quads) than do the same scenarios for the industrial (2.0) or buildings (1.9) sectors. Compared with 1997 levels, the smallest increase in energy growth for this case is in buildings (0.4 quads), followed by industry (2.8 quads), and transportation (3.7 quads).

- The high-efficiency/low-carbon scenario with $50/tonne carbon charge further decreases the overall growth between 1990 and 2010, reducing it from 22 to 9 quads. This is an 11% increase over the level of energy consumption in 1990. Relative to the BAU case, the high-efficiency/low-carbon scenario for buildings, industry, and transportation delivers energy savings ranging from 3.8 to 4.5 quads for each sector. Compared with 1997 levels, the buildings sector is down about 2 quads and industry and transportation are up 1 and 2 quads, respectively.

Figure 1.1 Primary Energy Use in Quads: 1990-2010

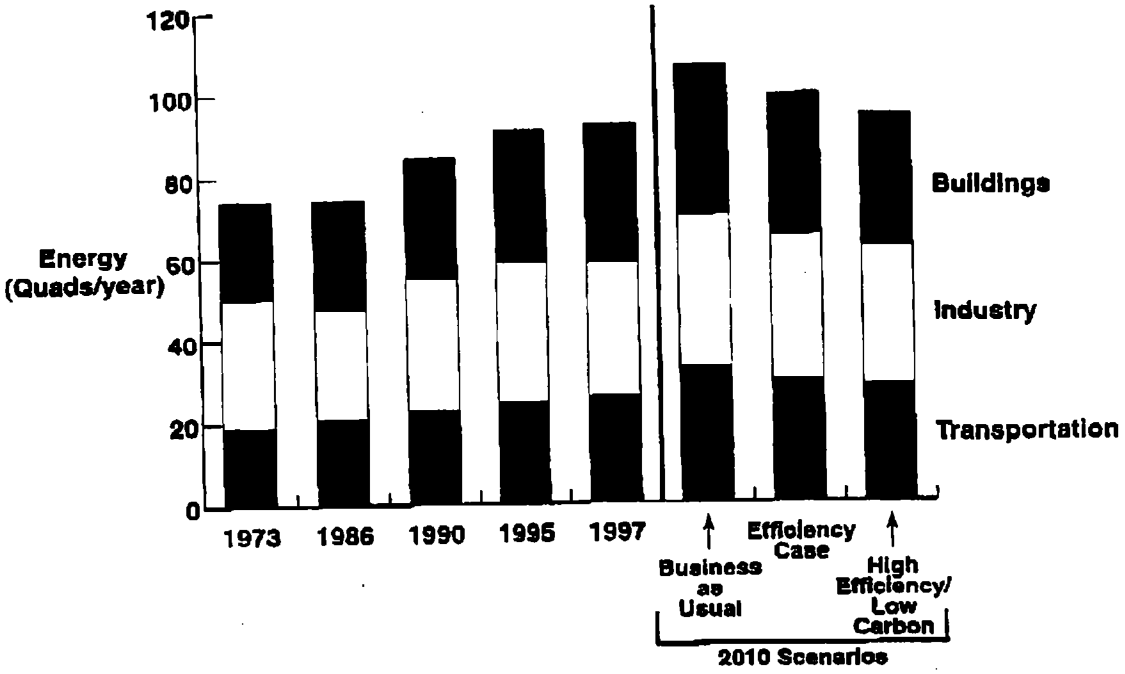


Table 1.2 documents the impact of these projected energy savings in 2010 on carbon emissions in that same year. It also presents the results of the HE/LC scenarios with both $25 and $50 per tonne carbon charges. These scenarios show significant carbon reductions from the combination of greater efficiency improvements and increased use of advanced low-carbon technologies.[3] In these cases, a number of low-carbon technologies have high rates of adoption (e.g., advanced turbine systems and biomass gasification in industry), the utility grid is dispatched to reduce carbon emissions (by using many coal plants for intermediate power and by running more natural gas plants as base load), a set of coal-based power plants are repowered, nuclear plant lifetimes are extended, and key renewable energy technologies are deployed. In all cases, these technologies and measures are estimated to be cost-effective with a differential carbon fee of $50/tonne.

Table 1.2 Carbon Emissions (MtC): 1990-2010

	1990	1997	2010 Business-as-Usual (BAU) Case	2010 Efficiency Case	2010 High-Efficiency/ Low-Carbon[a] $25/tonne	2010 High-Efficiency/ Low-Carbon[a] $50/tonne
Buildings	460	511	571	546	527	509
Industry	452	482	534	512	488	452
Transportation	432	486	616	543	528	513
Utilities[b]	–	–	–	–	-48	–136
Total (rounded)	1340	1480	1720	1600	1490	1340
Change from 1990		140	380	260	150	0
Change from BAU	–	–	–	-120	-230	-380

[a] This scenario includes the carbon emission reductions resulting from a carbon permit price of $25 or $50/tonne: (1) dispatch of power plants in which natural gas is favored relative to coal, (2) repowering and partial repowering of coal-based power plants to convert to natural gas, and (3) introduction of selected low-carbon technologies to replace conventional ones, primarily in the industrial and utility sectors.

[b] The entries in the last two columns are negative as they correspond to reductions in carbon emissions resulting from the increased use of natural gas and low-carbon technology for electricity generation as a result of the $50/tonne carbon permit price in this scenario.

Table 1.2 presents results for the business as usual and three efficiency and/or low carbon cases in 2010 as point estimates, because they are meant to be scenarios. When we use these scenarios for analysis, in section 1.5, we describe sources of uncertainty and the effects of uncertainty on our understanding of the implications of these cases. For now, we only describe the different cases.

Figures 1.2 and 1.3 complement the above table by illustrating the carbon emissions reductions from each scenario. The major observations are:

- In the BAU case, carbon emissions are forecast to increase by approximately 380 million tonnes.
- The energy-efficiency gains incorporated in the efficiency case cut overall growth between 1990 and 2010 by one-third (from 380 to 260 million tonnes). This represents a carbon increase of 19% above 1990 emissions.
- The HE/LC scenario with $25/tonne carbon charge has the potential to reduce carbon emissions by 230 million tonnes from the BAU case in 2010. The largest part of these carbon reductions are from increased efficiency, but major changes in electricity supply (carbon-based dispatching and repowering) contribute nearly 35 million tonnes, and other low-carbon technology, particularly renewables and advanced turbine systems, produce approximately another 25 million tonnes.
- The HE/LC scenario with $50/tonne carbon charge has the potential to reduce carbon emissions by approximately 380 million tonnes, thereby achieving 1990 carbon emission levels in 2010. Of this 380 million tonne carbon reduction, about 190 million tonnes are from increased energy efficiency, 140 million tonnes results from increases in the use of low-carbon fuels and technologies in the utility sector, and 50 million tonnes results from the use of low-carbon technology in industry and transportation.

Figure 1.2 Reductions in Carbon Emissions from Each Scenario

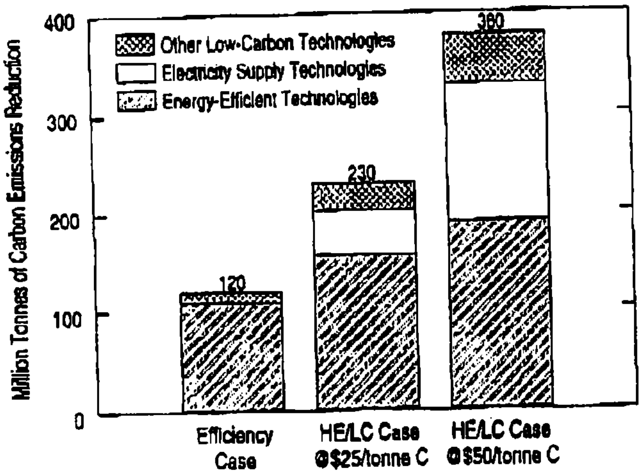
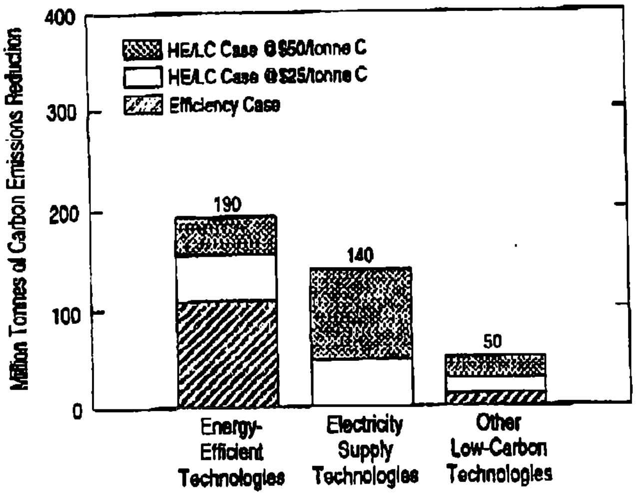


Figure 1.3 Reductions in Carbon Emissions from Each Type of Technology



100 million of the 140 million tonnes of carbon reductions in the utility sector comes from redispatching the utility system (favoring the use of low-carbon fuels) and from repowering coal plants with natural gas. Both are cost-effective with a $50/tonne carbon charge. The remaining 40 million tonnes are from renewables (wind, co-firing coal-based power plants with biofuels, expansion of hydropower capacity), nuclear power plant life extensions, and power plant efficiency improvements.

The remaining 50 million tonnes of carbon reductions in industry and transportation are about equally divided among three sets of fuels/technologies: (1) advanced combustion turbine cogenerators in industry, (2) biomass and black liquor gasification and low-carbon industrial processes, and (3) cellulosic ethanol/gasoline blends for automobiles.

- Approximately 140 MtC of the increase in carbon emissions between 1990 and 2010 will have occurred by the end of 1997; thus, it is useful to look at the 13-year forecast starting with 1997.

The carbon reductions incorporated in the efficiency case cut the overall *growth* in carbon emissions between 1997 and 2010 from 240 million tonnes (as forecast in the BAU case) to 120. The HE/LC scenario with $50/tonne carbon charge *reduces* carbon emissions in 2010 by about 130 million tonnes (compared with the 1997 level).

Table 1.3 provides a comparison of the growth rate in energy and in carbon emissions for the four cases, from 1990 to 2010. For the BAU and efficiency cases, the growth in carbon emissions is slightly more rapid than the increase in energy demand. For the HE/LC cases, carbon emissions decline while energy consumption rises. The carbon reduction reflects the increased deployment of low-carbon fuels and technologies as a consequence of the relative increase in price of carbon-based fuels precipitated by the $50/tonne incentive.

Table 1.3 Average Annual Energy and Carbon Growth Rates, 1997 to 2010, for Four Cases

	Business-As-Usual (BAU)	Efficiency Case	High Efficiency/ Low Carbon Case ($25/tonne)	High Efficiency/ Low Carbon Case ($50/tonne)
Gross Domestic Product (GDP)[a]	1.88%	1.88%	1.88%	1.88%
Energy Demand	1.09%	0.56%	0.34%	0.13%
Carbon Emissions	1.16%	0.60%	0.05%	-0.76%
Energy Consumption Per GDP (E/GDP)	-0.77%	-1.30%	-1.51%	-1.71%
Carbon Emissions Per GDP (C/GDP)[b]	-0.70%	-1.25%	-1.79%	-2.59%

[a] The Gross Domestic Product (GDP) in 1995 was $7251 billion in 1995 dollars. The 1.88% annual growth was assumed to apply to the entire period, 1995-2010 to derive the results above.

[b] The carbon decrease per unit GDP growth for 1990 to 2010 is 0.7%, 1.1%, 1.4% and 1.9% per year for the reference, efficiency, $25/tonne HE/LC, and $50/tonne HE/LC cases, respectively.

It is useful to compare the scenarios in this study to those of other studies. The 1991 report by the Office of Technology Assessment (OTA) titled *Changing by Degrees* (U.S. Congress, 1991) analyzed the potential for energy efficiency to reduce carbon emissions by the year 2015, starting with the base year of 1987. Its "moderate" scenario results in a 15% rise in carbon emissions, from 1300 MtC/year of carbon in 1987 to 1500 MtC/year of carbon in 2015 (compared to a BAU forecast of 1900 MtC/year). Its "tough" scenario results in a 20% to 35% emissions reduction relative to 1987 levels, or emissions levels of 850 to 1000 MtC/year of carbon in 2015. Our efficiency and HE/LC cases ranging from 1.3 to 1.6 billion tonnes of carbon emissions in 2010 are comparable to OTA's "moderate" case and show considerably higher emissions than OTA's "tough" case.

Another benchmark is provided by the 1992 National Academy of Sciences (NAS) report on *Policy Implications of Greenhouse Warming* (National Academy of Sciences, 1992). This study identified a set of energy conservation technologies that had either a positive economic return or that had a cost of less than $2.50 per tonne of carbon. Altogether, NAS concluded that these technologies offer the potential to reduce carbon emissions by 463 million tonnes, with more than half of these reductions arising from cost-effective investments in building energy efficiency. Our efficiency and HE/LC cases suggest the potential for reducing carbon emissions by between 120 and 380 million tonnes by the year 2010. One reason that the NAS estimate is higher is because it is not limited to the 2010 time

frame, but rather characterizes the full potential for carbon reductions. Thus, it did not take into account the replacement rates for equipment and processes, and other factors that prevent the instantaneous, full market penetration of cost-effective energy-efficient and low-carbon technologies.

1.4.2 R&D's Potential for Further Benefits by 2020

If carbon reductions in 2010 and beyond are to be sustained at reasonable cost, vigorous R&D efforts are needed to fill the pipeline of next-generation energy technologies. It is difficult to estimate the carbon savings that will accrue from these technologies; however, our effort to characterize their features suggests that an aggressive pace of carbon reductions over the next quarter century can be sustained, with a sufficient investment in R&D. Our analysis of R&D potential for the year 2020 focuses on opportunities for improved energy-efficiency and renewable energy technologies. The potential long-term contributions of carbon sequestration, advanced coal technologies, and nuclear power may also be significant. However, the treatment of vigorous R&D initiatives to improve these supply options beyond 2010 is beyond the scope of this report.

Renewable energy technologies will likely play a crucial role in limiting carbon emissions over the long term. Low-carbon energy supply options are needed to fuel domestic and international economic development without stimulating further global warming. Although renewable resources account for only 7% of the nation's total energy consumption at present, many believe that they are at the beginning of a long-term growth trajectory. With continuing technological development and cost reductions, renewables could become preferred energy resources some time within the next several decades. Early evidence of this transition is seen in the continuing adoption of renewable power systems, including especially wind farms and biomass power systems, even in the face of low gas-fired power generation costs and considerable uncertainty in today's electric energy sector.

With a vigorous and sustained program of research, development and deployment, biomass, wind, photovoltaics, geothermal, and solar thermal technologies could deliver significant quantities of electricity in 2020, thereby substantially displacing carbon emissions. For example, the use of forestry and agricultural residues in biomass power systems continues to be an attractive power option where those residues exist. The successful development of higher-efficiency biomass gasification systems would make this technology competitive in a wider range of applications, including for power systems using dedicated feed stock supply systems. At the same time, biological and agricultural research on biomass production will lead both to higher biomass yields and better species for energy conversion purposes in the future.

A second area in which a vigorous and sustained R&D effort could spawn a range of key improvements is in wind power systems. Potential improvements include

- Advanced blade shapes that increase wind power capture while reducing stress loads
- Elimination of gearboxes through development of direct-drive generators
- Variable speed turbines, and
- Better resource prediction that will increase the value of wind power to power systems operators.

A third area of renewables development that is at the beginning of a long-term growth path is the use of renewables in buildings. Solar daylighting, passive solar designs, solar water heating, and geothermal heat pumps already are cost-competitive in many applications, but are not yet widely

used. R&D advances could substantially accelerate their market penetration. In addition, building-integrated photovoltaic products will benefit directly from advances in materials research. The ultimate vision is that many buildings will become "net energy generators" through a combination of renewable energy and energy-efficiency technologies.

In the next quarter century, improved energy-efficiency technologies will result from a combination of incremental advances and fundamental breakthroughs. Incremental improvements in all sectors can be achieved by the greater reliance on more precise and reliable sensors and controls or on lower-cost sensors and controls, often integrated into industrial processes, transportation systems, and buildings. Advanced manufacturing technologies, including rapid prototyping and ultraprecision fabrication, also offer broad opportunities for continuous incremental improvements in energy efficiency and renewable energy. Breakthroughs in bioprocessing, separations, superconductivity, catalysts, and materials can have wide-ranging impacts on energy efficiency and carbon emissions by the year 2020. Examples of specific technology opportunities are described in this report, by sector.

Five R&D areas offer great promise to reduce significantly the energy requirements of our nation's buildings in 2020:

- Advanced construction methods and materials
- Adaptive building envelopes
- Multi-functional equipment
- Integrated, advanced lighting systems, controls and communications and
- Self-powered buildings.

In addition to the broad application of better process modeling, sensors, and controls in industry, many process/industry-specific opportunities for efficiency gains exist. These are described for each of DOE's targeted industries of the future: pulp and paper, chemicals, petroleum refining, glass, aluminum, iron and steel, and metal casting.

Many of the advanced technologies that have the potential to significantly improve the energy efficiency of transportation need considerable R&D investment before they can become commercially available in the year 2020. For example, to achieve fuel economies in the 60-80 miles per gallon (MPG) range and remain affordable and safe, light-duty vehicles will need

- Breakthroughs in manufacturing processes for composite materials
- Large reduction in fuel cell costs and/or cost reductions and performance gains in batteries
- Ultra-low rolling resistance tires
- High-efficiency accessories and
- Highly aerodynamic designs.

Opportunities for R&D to lead to improvements in the energy efficiency of other transportation modes are also described in this report.

In all, the continued adoption of energy efficient and renewable energy technologies and a steady flow of technology improvements from collaborative R&D programs with industry could make such environmentally friendly technology an attractive option for domestic and global energy economies in the future. With strong public-private partnerships to support the necessary R&D and market transformation activities, ample cost-effective energy products and practices will be available in 2020.

1.5 ASSESSMENT OF COSTS AND SOURCES OF CARBON REDUCTIONS

The business-as-usual scenario projects an increase of 380 MtC/year between 1990 and 2010. In our efficiency scenario, in which the nation actively pursues policies and programs to promote market acceptance of energy efficiency while expanding commitments to research and development, energy-efficient technologies reduce this growth in carbon emissions by 120 MtC/year. Under a carbon cap and trading system, in which permits for carbon sell for either $25 or $50/tonne C, very substantial carbon reductions appear possible. Detailed results for these cases, showing the sources of the carbon reductions, are contained in Table 1.4. (Summaries of these results were presented in Figures 1.2 and 1.3.) Results indicate that, for the $50/tonne HE/LC case, there is a potential to roughly return to 1990 levels of carbon emissions in 2010. About two-thirds of the increase in carbon emissions is eliminated in the case with a $25/tonne carbon charge (Table 1.4).

The estimates in Table 1.4 include ranges for most of the electricity supply options and the other low-carbon technologies. There are no ranges for the efficiency technologies because the models used to estimate their penetration are nonstochastic. When selecting a single estimate for the $50/tonne case, numbers from the low end of the ranges were generally selected in order to be cautious. Because we did not conduct an integrating analysis in which supply options compete against one another, we felt it important to minimize potential overlap by entering the supply options in conservative quantities. Also note that several renewable resources that could play a greater role by 2010 are omitted from Table 1.4; these resources include include photovoltaics, geothermal, solar thermal, and landfill gas.

One should not ascribe too much significance to specific entries in Table 1.4 There are many different technologies, both on the supply and demand side of the energy system, that will compete to achieve carbon reductions in an environment in which policies and economic signals favor such reductions. Thus, for example, Table 4.1 shows advanced turbine systems in industry cutting carbon emissions by 17 MtC/year in 2010, co-firing coal with biomass reducing emissions by the same amount, and other low-carbon supply technologies (wind, nuclear plant extensions, hydropower expansion, and power plant efficiency) contributing 24 MtC/year. The actual choice of technology depends on how the economics of the different systems evolve over time, how the industry to supply technology develops, the nature and speed of deregulation within the utility industry, and numerous other factors that cannot be known today. As such, we do not intend the results in Table 1.4 to be taken as a prediction of one technology over another to achieve carbon reductions. In this instance, we have posited one of many possible mixes of supply technologies. These same comments apply to the demand-side sectors and technologies.

We summarize below the expected technology costs in 2010, as well as the cost of implementing a carbon permit system. While these costs are necessarily uncertain, they are our best estimates and, in our view, as likely to be high as to be low. We note, however, that we have focused our analysis on technology costs, and have not assessed the viability of specific policies or programs to achieve market acceptance. As described below, we do account for program and policy costs in an approximate manner.

Table 1.4 Potential Annual Reductions in Carbon Emissions in 2010, Compared to the Business-As-Usual Forecast for 2010 (MtC)

		High-Efficiency/Low-Carbon Case	
	Efficiency Case	$25/tonne	$50/tonne*
Buildings			
Energy efficiency	25	42	59
Fuel cells		2	3
	25	44	62
Industry			
Energy efficiency	22	36	51
Advanced turbine systems		5	17 (15-26)
Biomass and black liquor gasification, cement clinker replacement, and aluminum technologies		5	14 (13-16)
	22	46	82
Transportation			
Energy efficiency	61	74	87
Ethanol	12	14	16
	73	88	103
Utility Supply Options			
Carbon-ordered dispatching		25	55
Converting coal-based power plants to natural gas		9	40 (25-66)
Co-firing coal with biomass		5	17 (16-24)
Wind		2	7 (6-20)
Extending the life of existing nuclear plants		3	5 (4-7)
Hydropower expansions		2	4 (3-5)
Power plant efficiency		2	8 (7-13)
		48	136
Total (rounded)	**120**	**226**	**383**

*Numbers in parenthesis are ranges, as documented in the text of the report. See Appendix A-1 for a description of the derivation of the results in this table.

Appendix A-2 describes the full set of calculations used to derive the direct costs and benefits of the cases. The costs considered include the incremental technology investment by consumers and businesses, fuel price increases, and the estimated cost of federal, state, and local programs required to achieve the carbon emissions reductions. These constitute the direct costs of the scenarios. The highest of these by far is the incremental investment costs. However, the generally higher first cost of these technologies is counterbalanced by substantially lower operating costs. The benefits considered are limited to the savings in operating (energy) costs from the technology investments.

Using these factors as the direct costs and benefits of the scenarios, we have analyzed the economics of carbon emissions reductions from two different perspectives in order to establish a credible range of costs. In the first, which we label "optimistic," we evaluate all costs and benefits with a real discount rate that approximates the cost of capital *for efficiency investments* for the different end-use sectors:

- 7% for buildings
- 10% for transportation
- 12.5% for industry.

The lowest discount rate, for buildings, is based on the fact that the money for residential buildings is derived from home mortgages or home improvement loans. The higher rate for industry reflects the fact that energy-efficiency investments have to compete with investments for other projects. These discount rates are not those that describe current market behavior, but rather are reflective of costs of capital if the market did invest in the energy-efficiency measures. For the "optimistic" case, we assume costs for efficiency measures brought about by utility, federal programs, and state programs (e.g., demand-side management programs by utilities, federal market transformation programs) to be 15% of technology costs. We also assume that at least half of the efficiency occurs as a result of federal policies (e.g., standards or carbon permit charges) which add very low direct program costs. Thus, the overall costs of implementation are taken to be about 7% in the "optimistic" case. The electric supply-side technologies are assumed to add an incremental cost of $30/tonne carbon in 2010, based on an average estimate of the incremental costs of the technologies from the appropriate sections of this report.

These programs and policies are not specified in this study, but the broad nature of the actions could include technology R&D partnerships such as the current Partnership for a Next Generation of Vehicles and Industries of the Future; energy efficiency codes and standards; expanded partnerships, technical assistance, and information programs to accelerate the adoption of energy-efficient technologies; incentives through the tax system directed at investments in energy-efficient technology in industry; and a variety of non-federal programs to accelerate market diffusion of energy-efficient and low-carbon technologies.

The second perspective, which we label "pessimistic," assumes that there are hidden costs associated with achieving widespread market acceptance of many of the efficiency and low-carbon technologies, even after the imposition of a carbon charge and the implementation of major policies and programs to promote a low-carbon future. In this perspective, we evaluate costs and benefits at a real discount rate of 15% for buildings and 20% for transportation and industry. Program costs are increased to 30% of the cost of efficiency measures, an estimate that is a high bound compared with federal, state, and utility experience. Overall implementation costs (programs and directed policies) are taken to be 15% of technology investments in this case. Other data and assumptions in this case are the same as for the "optimistic" case.

The results of the economic analysis are presented in Table 1.5. Estimated direct costs are $26-$49 billion per year for the efficiency scenario and $51 to $88 billion per year for the high-efficiency/low-carbon scenario. Estimated savings per year in 2010 are $42 to $51 billion per year in the efficiency case and $70-$88 billion per year for the high-efficiency/low-carbon case. The costs, which are a small portion of annual gross private domestic investment of about $1.4 trillion in 2020, are likely to be more than balanced by savings in energy bills. Thus, net costs to the U.S. economy are near or below zero in this time frame.

Table 1.5 Estimated Costs and Benefits of the Efficiency and High-Efficiency/Low-Carbon Scenarios : Optimistic and Pessimistic View Estimates (billions of 1995$, annualized)

	Efficiency Case[a]			High-Efficiency/Low-Carbon Case[b]		
	Benefits[c] (billion 1995$)	Costs[d] (billion 1995$)	Carbon[c] Savings MtC	Benefits (billion 1995$)	Costs (billion 1995$)	Carbon Savings MtC
Energy Efficiency						
Buildings	14-17	7-14	20-25	26-33	14-26	49-62
Industry	6-7	3-5	18-22	12-15	8-13	66-82
Transportation	22-27	16-30	58-73	32-40	23-43	82-103
Electricity Dispatch	0	0	0	0	2	44-55
Electricity Repowering	0	0	0	0	2	32-40
Other Low-Carbon Techologies	0	0	0	0	2	33-41
Total	**42-51**	**26-49**	**96-120**	**70-88**	**51-88**	**306-383**

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[a] Energy efficiency category includes ethanol in transportation.

[b] Benefits and carbon savings in the HE/LC case are relative to BAU case.

[c] Benefits are calculated as annual energy savings. The scenarios are meant to be point estimates. In the "pessimistic" case, we have assumed that only 80% of the carbon savings are achieved, even though the technology and implementation costs are unchanged. The range on carbon savings represents this assumption.

[d] Costs are calculated from differing viewpoints: the "optimistic" case uses discount rates that vary between 7% and 12.5% for the different sectors, as described in the text. For the "pessimistic" case, the discount rates used to annualize costs vary between 15% and 20%. Also in this case, the cost of implementing programs (30%) and an overall package of programs and policies (15%) is taken to be twice that of the "optimistic" case.

The range of estimates in Table 1.5 reflects our attempt to "bound" optimistic and pessimistic assessments. There are clearly other ways in which these bounds could be described, just as there are many scenarios that could have been analyzed. However, we believe that the assumption that 80% of the carbon reductions are achieved at the costs identified, valuation of costs and benefits at discount rates noticeably higher than the likely cost of capital, and doubling the cost of programs and policies from typical experience today is a strong reflection of pessimism in costs for our cases. It is worth noting that if the implementation costs were taken to be much higher than we believe to be reasonable – 50% of investments costs for programs and 25% overall – this would add about $10 billion per year to the costs of the high-efficiency/low-carbon in the pessimistic case.

In addition to these costs, one needs to calculate the impact of the cases on natural gas demand. In all of these cases, natural gas replaces very large quantities of coal. Higher natural gas demand would result in higher natural gas prices, which in turn would increase the cost of substituting natural gas for coal in power production, etc. As it turns out, our scenarios have somewhat reduced gas demand compared with the BAU case (or with AEO97 baseline for 2010, on which the price of natural gas in our work is based). Specifically, demand for natural gas in the HE/LC ($50/tonne) case declines in 2010 by 2 quads compared with the business-as-usual case. This is the result of declines of 0.5 quads for buildings, 1.0 quads for industry, and 0.5 quads for electricity. The latter occurs because of the balance among three factors:

- Increase in gas demand because of the large-scale substitution of natural gas for coal
- Decrease of gas demand because of the use of many low-carbon technologies that do not use natural gas (wind, nuclear power plant extensions, power plant efficiency upgrades, hydropower expansion, co-firing with biofuels), and

- The large increase in cogeneration, which reduces demand for natural gas for heating applications.

The sum of the second and third effects are somewhat greater than the first, and thus total natural gas demand associated with electricity generation declines. This will reduce the cost of natural gas, a benefit that we have not included in

The $50/tonne carbon charge, while not constituting a direct cost, does represent a potentially large transfer payment. The magnitude of the transfer payment, as well as the losers and winners from the transfers, depends on the nature of policy and its implementation as a cap and trade system or some alternative. The amount of money that could be in play is very large: $50/tonne times 1.3 billion tonnes per year equals $65 billion per year.

In short, while there will surely be winners and losers for these energy-efficiency and low-carbon scenarios, our analysis shows that their net economic costs – under a range of assumptions and alternative methods of cost analysis – are favorable.

The achievability of the cases depends on many factors. In all cases, carbon reductions require the nation to embark on an aggressive set of policies and programs. Such efforts could occur in response to an international agreement on climate change or to other events that result in a national determination to reduce the growth of carbon emissions. In the high-efficiency/low-carbon cases, we assume a vigorous national program of research, development, demonstration, and diffusion, and a trading regime for carbon with a domestic permit price of either $25/tonne or $50/tonne carbon. Without some scheme that provides strong incentives for switching from coal to natural gas, and for deploying other low-carbon technologies, much of the potential for carbon reductions will not be realized.

Government policies and programs that encourage and/or require the adoption of energy-efficiency and low-carbon technologies will be needed, along with incentives for industry to invest more in these technologies. Additional private and public investments are necessary, not only to accelerate the introduction of new technologies into the market before 2010 but also to ensure the availability of technologies for the period after 2010. The transportation and utility sectors are especially dependent on early technological advances to achieve the scenario results in 2010.

There is no assurance that these and other driving forces will cause the scenarios we have described to take place. Our major conclusion is that cost-effective technology can be deployed to achieve major reductions in carbon emissions by 2010. Cost-effective energy efficiency alone can take the nation 30 to 50% of the way to 1990 levels. Two additional utility sector measures can reduce carbon emissions by another 30% at an estimated cost of $50/tonne carbon: carbon-based dispatch and conversion of existing power plants from coal to natural gas.[4] Finally, we identify several additional technologies that can contribute up to 20% of the several carbon reductions, also for less than $50/tonne. A next generation of advanced energy-efficiency and renewable energy technologies promises to enable the continuation of an aggressive pace of energy and carbon reductions over the next quarter century.

1.6 REFERENCES

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ENDNOTES

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[1] The five national laboratories participating in the study were: Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). LBNL and ORNL were the co-leaders of the effort.

[2] See Section 2.2.3 for a definition of cost-effective energy efficiency technology.

[3] $50 per tonne of carbon corresponds to 12.5 cents per gallon of gasoline or 0.5 cents per kilowatt-hour for electricity produced from natural gas at 53% efficiency (or 1.3 cents per kilowatt-hour for coal at 34% efficiency). $25 per tonne would cut these gasoline and electricity price increments in half.

[4] The cost curve for repowering is relatively flat; as such, considerable additional reductions are possible at a cost not too different from $50/tonne. The results are highly sensitive to the price differential between coal and natural gas; at a lower (higher) price differential, a higher (lower) permit price of carbon is needed.

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FAX

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MEMORANDUM

August 29, 1997

TO: T.J. Glauthier (OMB), Jeff Frankel (CEA), Robert Gillingham and Jon Gruber (Treasury), Peter Orszag (NEC)

FROM: Mark D. Levine and Marilyn Brown

RE: Executive Summary and Chapter 1 of the Report "Scenarios of U.S. Carbon Reductions"

CC: Joe Romm, Eric Petersen, Mark Mazur

We are faxing to you a modified version of the Executive Summary and Chapter 1 of the referenced report. In this version, we have attempted to respond to the concerns expressed in the meeting on August 19 while still expressing the major findings of the report.

We have received two sets of comments from you and expect to give you substantive responses to these comments in the near future.

EXECUTIVE SUMMARY

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States.[1] The study documents in detail how four key sectors of the economy – buildings, transportation, industry, and electric utilities – could respond to directed programs and policies to expand adoption of energy-efficiency and low-carbon technologies, an increase in the relative price of carbon-based fuels by $25 or $50/tonne (e.g., as a result of a cap on domestic carbon emissions and a market for carbon "permits"), and an aggressive program of targeted research and development. Current projections suggest that a carbon emissions reduction of 380 million metric tons per year (MtC/year) is required to stabilize U.S. emissions in 2010 at 1990 levels. not based on this study's BAU

The study, which has been peer-reviewed by industry and academic experts, uses a technology-by-technology assessment as well as an engineering-economic modeling approach. It draws upon a wide variety of technology cost and performance information to assess potential impacts. Analysis of the buildings, industry, and transportation sectors quantifies the impacts of end-use energy-efficiency improvements on carbon emissions. The utility sector analysis estimates the impacts of those improvements on utility carbon emissions, and quantifies additional emissions reductions through conversion of a number of coal power plants to natural gas, dispatching of the utility grid with $25 and $50/tonne carbon permit prices, the accelerated use of biomass cofiring and wind energy, and other low-carbon electricity supply options. Finally, a number of other promising low-carbon technologies are examined to determine their potential for reducing emissions in the end-use sectors, including advanced gas turbines in industry, transportation biofuels, and fuel cells in buildings.

thru government policies + programs

Three overarching conclusions emerge from the analysis of alternative carbon scenarios. First, a vigorous national commitment to develop and deploy cost-effective energy-efficient and low-carbon technologies has the potential to restrain the growth in U.S. energy consumption and carbon emissions such that levels in 2010 are close to those in 1997 (for energy) and 1990 (for carbon). We analyze a case in which energy efficiency can reduce carbon emissions by 120 MtC/year by 2010. We analyze a second case, with policies that promote adoption of energy-efficient and low carbon technologies and a $25/tonne carbon permit price, with emission reductions of 230 MtC/year in 2010. Under a $50/tonne carbon permit price and aggresive policies, 2010 emissions could be cut by about 380 MtC/year. The analysis also suggests that substantial additional savings are available if permit prices were to begin to rise above the $50/tonne level.

thru policy

not true

The second conclusion is that, if feasible ways are found to implement the carbon reductions as described above, all the cases (with reductions varying between 120 and 380 MtC/year by 2010) can produce direct benefits that are ~~roughly equal to or~~ exceed costs.[2] The analysis includes only technologies estimated to be cost-effective under 2010 energy prices (with a $25/tonne and $50/tonne carbon permit price for the respective cases); it has not, however, analyzed specific policies to achieve the cases, identified the political feasibility of policies, or described a pathway to achieve the cases.

The third conclusion is that a next generation of energy-efficient and low-carbon technologies promises to enable the continuation of an aggressive pace of carbon reductions over the next quarter century. This report documents a wide array of advanced technology options that could be cost-competitive by the year 2020, assuming a vigorous and sustained program of energy R&D beginning now and extending beyond 2010.

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[1] The five national laboratories participating in the study were: Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). LBNL and ORNL were the co-leaders of the effort.

[2] Here we count as benefits only the energy savings to the nation. We have not credited reduced CO_2 emissions or other external benefits. Costs include the increased technology cost plus an approximate estimate of the costs of program and policy implementation. Explain / ID omitted costs

Chapter 1

ANALYSIS RESULTS

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States.[1] The stimulus for this study derives from a growing recognition that any national effort to reduce the growth of greenhouse gas emissions must consider ways of increasing the productivity of energy use. To add greater definition to this view, we quantify the reductions in carbon emissions that can be attained through the improved performance and increased penetration of efficient and low-carbon technologies by the year 2010. We also take a longer-term perspective by characterizing the potential for future research and development to produce further carbon reductions over the next quarter century. As such, this report underscores the value of energy technology research, development, demonstration, and diffusion as a public response to global climate change.

thru govt policies + programs

Three overarching conclusions emerge from our analysis of alternative carbon reduction scenarios. First, a vigorous national commitment to develop and deploy cost-effective energy-efficient and low-carbon technologies could reverse the trend toward increasing carbon emissions. Along with utility sector investments, such a commitment could helt the growth in U.S. energy consumption and carbon emissions so that levels in 2010 are close to those in 1997 (for energy) and in 1990 (for carbon). It must be noted that such a vigorous national commitment would have to go far beyond current efforts. Second, if feasible ways are found to implement the carbon reductions, the cases analyzed in the study are judged to yield direct benefits that are roughly equal to or greater than costs. Third, a next generation of energy-efficient and low-carbon technologies promises to enable the continuation of an aggressive pace of carbon reductions over the next quarter century.

1.1 OBJECTIVES OF THE REPORT

The purposes of this study are threefold:

1. To provide a quantitative assessment of the reduction in energy consumption and carbon emissions that could result by the year 2010 from a vigorous national commitment to accelerate the development and deployment of cost-effective energy-efficient and low-carbon technologies;

   early documented
   partial

2. To document the costs and performance of the technologies that underpin a year 2010 scenario in which substantial energy savings and carbon emissions reductions are achieved;
3. To illustrate the potential for energy-efficiency and renewable energy R&D to produce further reductions in energy use and carbon emissions by the year 2020.

1.2 METHODOLOGY

To achieve these objectives, we started with the *Annual Energy Outlook 1997* (AEO97) reference case forecasts for the year 2010 (Energy Information Administration, 1996). After thoroughly reviewing these forecasts on a sector-by-sector basis, and working with EIA staff, we chose to accept the EIA "business-as-usual" (BAU) scenario as is for buildings and industry. We modified some of the assumptions and data to produce a new BAU case – not greatly different from the EIA case – for the transportation and the electric utility sectors.

We then assembled existing information on the performance and costs of technologies to increase energy efficiency or, for selected end-uses, to switch from one fuel to another (e.g., from electricity to natural gas for residential end-uses or from gasoline to biofuels for transportation). For the buildings sector, the technology performance and cost data base are extensive. For transportation, the data base – although less fully developed than for buildings – is sufficient for our purposes. For industry, only partial information on technologies and costs is presently available. As a result, the analysis for industry relies primarily on historical relations between energy use and economic activity and much less on explicit technological opportunities. The industrial analysis also includes some examples of industrial low-carbon technologies. The analysis of low-carbon supply technologies in the electricity sector is based on a review of the literature including detailed technology characterizations prepared by DOE in conjunction with its national laboratories and industry.

Next we created scenarios of increased energy efficiency and lower carbon emissions using the technology data (or, in the industrial sector, historical relations) as key inputs. We chose to run three scenarios other than the BAU case. We have termed the first the "efficiency" (EFF) case. It assumes that the United States increases its emphasis on energy efficiency through enhanced public- and private-sector efforts. The general philosophy of the efficiency case is that it reduces, but does not eliminate, various market barriers and lags to the adoption of cost-effective energy efficiency technology.[2]

The other two cases, dubbed the $25 permit and the $50 permit "high-efficiency/low-carbon" (HE/LC) cases, describe a world in which, as a result of commitments made on a climate treaty or other factors, the nation has embarked on a path to reduce carbon emissions. Both of these cases assume a major effort to reduce carbon emissions through federal policies and programs (including environmental regulatory reform), strengthened state programs, and very active private sector involvement. Both also include a focused national R&D effort to develop and transform markets for low-carbon energy options (e.g., fuel cells for microcogeneration in buildings and advanced turbine systems for combined heat and power in industry). The difference between the two HE/LC cases is in the assumption of a carbon permit price resulting from a domestic trading scheme for carbon emissions with a cap on U.S. emissions (or from equivalent policy measures that increase the price of carbon-based fuels relative to those with less carbon). We assume a domestic permit price of $25 and $50 per tonne of carbon for the two cases. Both of these HE/LC cases include a program of research, development, demonstration and diffusion that is more vigorous than in the efficiency case. In the buildings and industry sectors, the carbon price signal, combined with policies promoting energy efficiency, is believed to trigger most of the additional carbon reductions. In the transportation sector, it is the R&D-driven technology breakthroughs that generate the bulk of the carbon reductions beyond the efficiency case. For the electricity sector, higher prices for carbon-based fuels cause larger shifts from coal to natural gas; for this sector, these same higher relative prices combined with federal and private research, development, and demonstration can bring advanced low-carbon technologies to market.

no detail on $25 case to back this up

Although most of the analysis focuses on 2010, we also look beyond this date. Here we describe new technologies, materials, processes, manufacturing methods, and other R&D advances that promise to offer significant energy benefits by the year 2020; for this time period, we make no effort to forecast specific levels of market penetration, energy savings, or carbon reductions. Thus, instead of creating scenarios we describe the technological innovations that could enable the continuation of an aggressive pace of decarbonization well into the next quarter century, if ~~appropriate~~ investments in R&D were made.

sufficient or extensive

1.3 BACKGROUND

The decade of gains in energy productivity achieved by the U.S. following the 1973-74 Arab oil embargo represents a period of economic growth that was decoupled from increases in energy consumption, resulting in substantial economic benefits. Between 1973 and 1986, the nation's consumption of primary energy froze at about 74 quads – while the GNP grew by 35%. Starting in 1986, energy prices began a descent in real terms that has continued to the present. As a result, energy demand grew from 74 quads in 1986 to 91 quads in 1995, and carbon emissions have been increasing at a similar pace.

Despite the growth in energy consumption since 1986, the U.S. economy today remains more energy productive than it was 25 years ago. In 1970, 19.6 thousand Btu of energy were consumed for each (1992) dollar of GDP. By 1995, the energy intensity of the economy had dropped to 13.4 thousand Btu of energy per (1992) dollar of GDP. The U.S. Department of Energy (DOE) estimates that the country is saving $150 to $200 billion annually as a result of these improvements.

Nevertheless, many cost-effective energy-efficient technologies remain underutilized, as discussed in Chapter 2. A host of market barriers account for these lost opportunities. And declining energy R&D expenditures may cause promising technology options to be foregone. or postponed?

The rationale for government support of energy-efficiency R&D is strong. Much energy-efficiency research is both long-term and high-risk and therefore is not adequately funded by the private sector – despite the possibility of sizable gains in the long run. Furthermore, advances in energy efficiency offer substantial public benefits (such as carbon reductions and improved national security through greater oil independence) that cannot be fully captured in the private marketplace.

The benefits of past public investments in energy-efficiency R&D have been well documented. Between 1978 and 1996, DOE spent approximately $8 billion on energy-efficiency research, development and demonstration (RD&D). Just five of the technologies that were developed or demonstrated with a fraction of this DOE support have resulted in net benefits of $28 billion through 1996. Many other R&D successes have produced technologies yielding substantial energy and cost savings in the market. The DOE RD&D portfolio has also led to significant environmental, health, productivity, and economic competitiveness benefits.

1.4 RESULTS

1.4.1 Prospects for Improved Efficiencies by the Year 2010

Table 1.1 and Figure 1.1 compare the nation's primary energy use in quads for the years 1990 and 1997 (projected) with the results of three scenarios for 2010. (We have included only the high-efficiency/low-carbon case at $50/tonne in the table and figure for simplicity.) The $50/tonne HE/LC case shown below does not reflect the energy impacts of the selected low-carbon technologies described later in this summary (e.g., stationary fuel cells for buildings, advanced turbine systems and biomass gasification in industry) or the supply-side options shown in Table 1.4. ?

should be constant
thru-out – include $25 case

Table 1.1 Primary Energy Use in Quads: 1990-2010

	1990	1997	2010 Business-as-Usual Case	2010 Efficiency Case	2010 High-Efficiency/ Low-Carbon Case ($50/tonne C)
Buildings	29.4	33.7	36.0	34.1	32.0
Industry	32.1	32.6	37.4	35.4	33.6
Transportation	22.6	25.5	32.3	29.2	27.8
Total	84.2	91.8	105.7	98.7	93.4

Source: Energy use estimates for 1990 come from EIA (1996a, Table 2.1, p. 39).
Energy use estimates for 1997 come from forecasts conducted for EIA (1996b).
Numbers may not add to the totals due to rounding.

The major observations are as follows:

- In the business-as-usual case, energy use increases by 22 quads (26%) between 1990 and 2010; 8 quads of this increase have occurred during the first seven years of this 20-year period. The fastest growing sector during these initial seven years has been buildings (4.3 quads) followed by transportation (2.9 quads) and industry (0.5 quads). In the BAU case, the fastest growing sector during the remaining 13 years is transportation (6.8 quads). This is followed by industry (4.8 quads) and then buildings (2.3 quads). The rapid projected growth in the energy consumed for transportation is driven by estimates of increased per capita travel and minimal fuel efficiency gains.

- The efficiency scenario cuts the overall growth between 1990 and 2010 from 22 to 15 quads. This is a 17% increase over the level of energy consumption in 1990, down from a 26% increase in the BAU case. Relative to the BAU case, the efficiency scenario for transportation delivers slightly more energy savings (3.1 quads) than do the same scenarios for the industrial (2.0) or buildings (1.9) sectors. Compared with 1997 levels, the smallest increase in energy growth for this case is in buildings (0.4 quads), followed by industry (2.8 quads), and transportation (3.7 quads).

- The high-efficiency/low-carbon scenario with $50/tonne carbon charge further decreases the overall growth between 1990 and 2010, reducing it from 22 to 9 quads. This is an 11% increase over the level of energy consumption in 1990. Relative to the BAU case, the high-efficiency/low-carbon scenario for buildings, industry, and transportation delivers energy savings ranging from 3.8 to 4.5 quads for each sector. Compared with 1997 levels, the buildings sector is down about 2 quads and industry and transportation are up 1 and 2 quads, respectively.

Figure 1.1 Primary Energy Use in Quads: 1990-2010

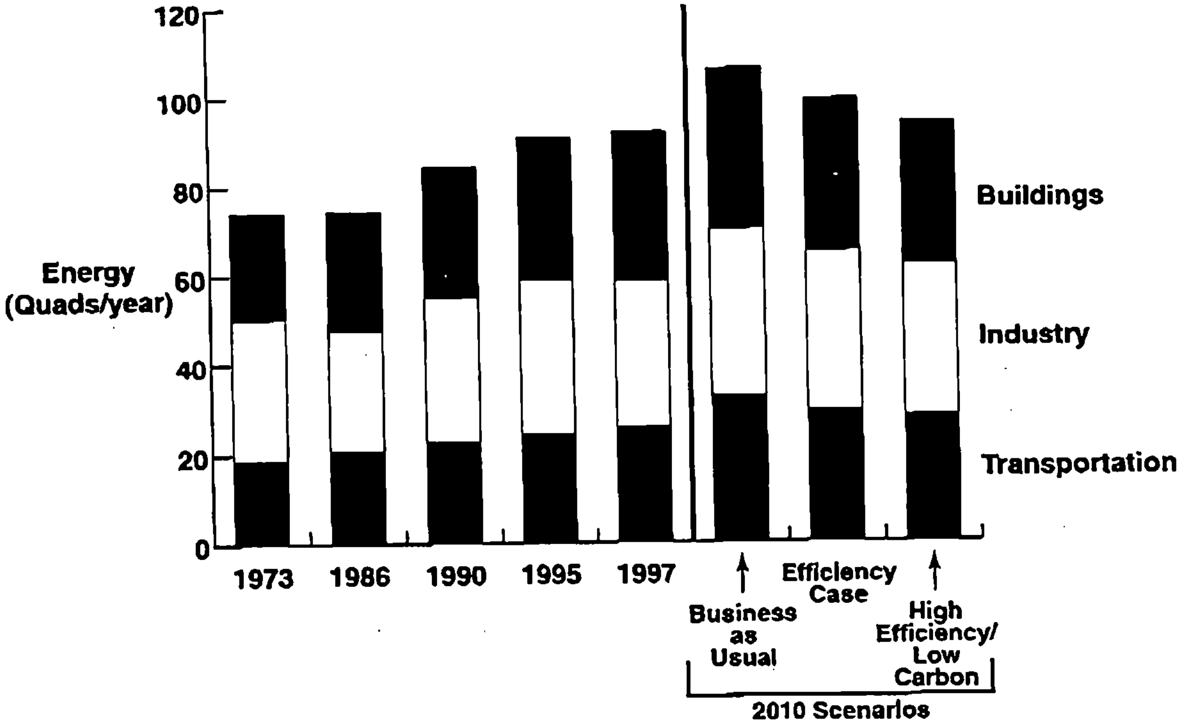


Table 1.2 documents the impact of these projected energy savings in 2010 on carbon emissions in that same year. It also presents the results of the HE/LC scenarios with both $25 and $50 per tonne carbon charges. These scenarios show significant carbon reductions from the combination of greater efficiency improvements and increased use of advanced low-carbon technologies.[3] In these cases, a number of low-carbon technologies have high rates of adoption (e.g., advanced turbine systems and biomass gasification in industry), the utility grid is dispatched to reduce carbon emissions (by using many coal plants for intermediate power and by running more natural gas plants as base load), a set of coal-based power plants are repowered, nuclear plant lifetimes are extended, and key renewable energy technologies are deployed. In all cases, these technologies and measures are estimated to be cost-effective with a differential carbon fee of $50/tonne.

Table 1.2 Carbon Emissions (MtC): 1990-2010

	1990	1997	2010			
			Business-as-Usual (BAU) Case	Efficiency Case	High-Efficiency/ Low-Carbon[a]	
					$25/tonne	$50/tonne
Buildings	460	511	571	546	527	509
Industry	452	482	534	512	488	452
Transportation	432	486	616	543	528	513
Utilities[b]	–	–	–	–	-48	–136
Total (rounded)	1340	1480	1720	1600	1490	1340
Change from 1990		140	380	260	150	0
Change from BAU	–	–	–	-120	-230	-380

[a] This scenario includes the carbon emission reductions resulting from a carbon permit price of $25 or $50/tonne: (1) dispatch of power plants in which natural gas is favored relative to coal, (2) repowering and partial repowering of coal-based power plants to convert to natural gas, and (3) introduction of selected low-carbon technologies to replace conventional ones, primarily in the industrial and utility sectors.

[b] The entries in the last two columns are negative as they correspond to reductions in carbon emissions resulting from the increased use of natural gas and low-carbon technology for electricity generation as a result of the $50/tonne carbon permit price in this scenario.

why don't you define scenario

Table 1.2 presents results for the business as usual and three efficiency/and/or low carbon cases in 2010 as point estimates, because they are meant to be scenarios. When we use these scenarios for analysis, in section 1.5, we describe sources of uncertainty and the effects of uncertainty on our understanding of the implications of these cases. For now, we only describe the different cases.

Figures 1.2 and 1.3 complement the above table by illustrating the carbon emissions reductions from each scenario. The major observations are:

- In the BAU case, carbon emissions are forecast to increase by approximately 380 million tonnes.
- The energy-efficiency gains incorporated in the efficiency case cut overall growth between 1990 and 2010 by one-third (from 380 to 260 million tonnes). This represents a carbon increase of 19% above 1990 emissions.
- The HE/LC scenario with $25/tonne carbon charge has the potential to reduce carbon emissions by 230 million tonnes from the BAU case in 2010. The largest part of these carbon reductions are from increased efficiency, but major changes in electricity supply (carbon-based dispatching and repowering) contribute nearly 35 million tonnes, and other low-carbon technology, particularly renewables and advanced turbine systems, produce approximately another 25 million tonnes.
- The HE/LC scenario with $50/tonne carbon charge has the potential to reduce carbon emissions by approximately 380 million tonnes, thereby achieving 1990 carbon emission levels in 2010. Of this 380 million tonne carbon reduction, about 190 million tonnes are from increased energy efficiency, 140 million tonnes results from increases in the use of low-carbon fuels and technologies in the utility sector, and 50 million tonnes results from the use of low-carbon technology in industry and transportation.

Figure 1.2 Reductions in Carbon Emissions from Each Scenario

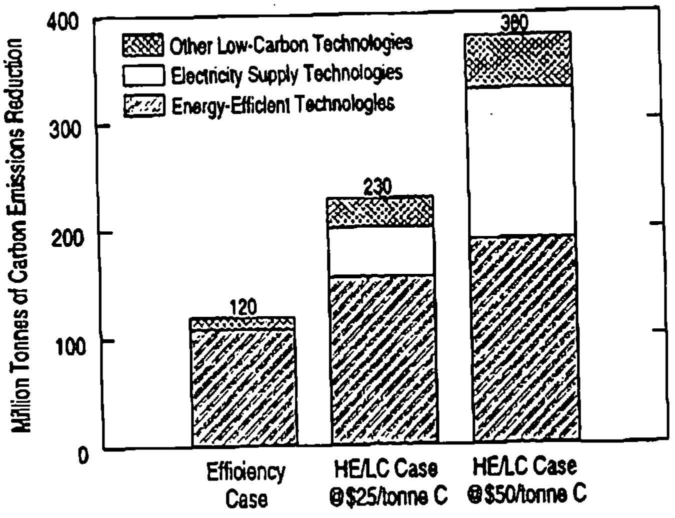
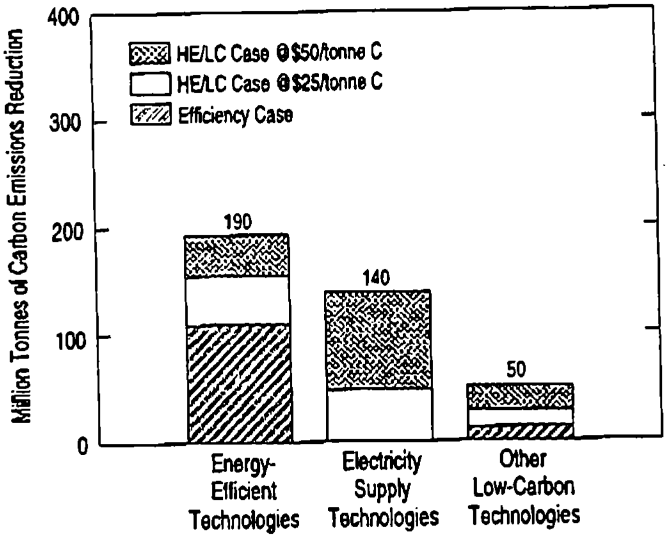


Figure 1.3 Reductions in Carbon Emissions from Each Type of Technology



100 million of the 140 million tonnes of carbon reductions in the utility sector comes from redispatching the utility system (favoring the use of low-carbon fuels) and from repowering coal plants with natural gas. Both are cost-effective with a $50/tonne carbon charge. The remaining 40 million tonnes are from renewables (wind, co-firing coal-based power plants with biofuels, expansion of hydropower capacity), nuclear power plant life extensions, and power plant efficiency improvements.

The remaining 50 million tonnes of carbon reductions in industry and transportation are about equally divided among three sets of fuels/technologies: (1) advanced combustion turbine cogenerators in industry, (2) biomass and black liquor gasification and low-carbon industrial processes, and (3) cellulosic ethanol/gasoline blends for automobiles.

- Approximately 140 MtC of the increase in carbon emissions between 1990 and 2010 will have occurred by the end of 1997; thus, it is useful to look at the 13-year forecast starting with 1997.

The carbon reductions incorporated in the efficiency case cut the overall *growth* in carbon emissions between 1997 and 2010 from 240 million tonnes (as forecast in the BAU case) to 120. The HE/LC scenario with $50/tonne carbon charge *reduces* carbon emissions in 2010 by about 130 million tonnes (compared with the 1997 level).

Table 1.3 provides a comparison of the growth rate in energy and in carbon emissions for the four cases, from 1990 to 2010. For the BAU and efficiency cases, the growth in carbon emissions is slightly more rapid than the increase in energy demand. For the HE/LC cases, carbon emissions decline while energy consumption rises. The carbon reduction reflects the increased deployment of low-carbon fuels and technologies as a consequence of the relative increase in price of carbon-based fuels precipitated by the $50/tonne incentive.

Table 1.3 Average Annual Energy and Carbon Growth Rates, 1997 to 2010, for Four Cases

	Business-As-Usual (BAU)	Efficiency Case	High Efficiency/ Low Carbon Case ($25/tonne)	High Efficiency/ Low Carbon Case ($50/tonne)
Gross Domestic Product (GDP)[a]	1.88%	1.88%	1.88%	1.88%
Energy Demand	1.09%	0.56%	0.34%	0.13%
Carbon Emissions	1.16%	0.60%	0.05%	-0.76%
Energy Consumption Per GDP (E/GDP)	-0.77%	-1.30%	-1.51%	-1.71%
Carbon Emissions Per GDP (C/GDP)[b]	-0.70%	-1.25%	-1.79%	-2.59%

[a] The Gross Domestic Product (GDP) in 1995 was $7251 billion in 1995 dollars. The 1.88% annual growth was assumed to apply to the entire period, 1995-2010 to derive the results above.

[b] The carbon decrease per unit GDP growth for 1990 to 2010 is 0.7%, 1.1%, 1.4% and 1.9% per year for the reference, efficiency, $25/tonne HE/LC, and $50/tonne HE/LC cases, respectively.

It is useful to compare the scenarios in this study to those of other studies. The 1991 report by the Office of Technology Assessment (OTA) titled *Changing by Degrees* (U.S. Congress, 1991) analyzed the potential for energy efficiency to reduce carbon emissions by the year 2015, starting with the base year of 1987. Its "moderate" scenario results in a 15% rise in carbon emissions, from 1300 MtC/year of carbon in 1987 to 1500 MtC/year of carbon in 2015 (compared to a BAU forecast of 1900 MtC/year). Its "tough" scenario results in a 20% to 35% emissions reduction relative to 1987 levels, or emissions levels of 850 to 1000 MtC/year of carbon in 2015. Our efficiency and HE/LC cases ranging from 1.3 to 1.6 billion tonnes of carbon emissions in 2010 are comparable to OTA's "moderate" case and show considerably higher emissions than OTA's "tough" case.

– check AEO97
↓
p.120: ref case (AEO97)
2015: 1800 mmtce

Another benchmark is provided by the 1992 National Academy of Sciences (NAS) report on *Policy Implications of Greenhouse Warming* (National Academy of Sciences, 1992). This study identified a set of energy conservation technologies that had either a positive economic return or that had a cost of less than $2.50 per tonne of carbon. Altogether, NAS concluded that these technologies offer the potential to reduce carbon emissions by 463 million tonnes, with more than half of these reductions arising from cost-effective investments in building energy efficiency. Our efficiency and HE/LC cases suggest the potential for reducing carbon emissions by between 120 and 380 million tonnes by the year 2010. One reason that the NAS estimate is higher is because it is not limited to the 2010 time

frame, but rather characterizes the full potential for carbon reductions. Thus, it did not take into account the replacement rates for equipment and processes, and other factors that prevent the instantaneous, full market penetration of cost-effective energy-efficient and low-carbon technologies.

1.4.2 R&D's Potential for Further Benefits by 2020

If carbon reductions in 2010 and beyond are to be sustained at reasonable cost, vigorous R&D efforts are needed to fill the pipeline of next-generation energy technologies. It is difficult to estimate the carbon savings that will accrue from these technologies; however, our effort to characterize their features suggests that an aggressive pace of carbon reductions over the next quarter century can be sustained, with a sufficient investment in R&D. Our analysis of R&D potential for the year 2020 focuses on opportunities for improved energy-efficiency and renewable energy technologies. The potential long-term contributions of carbon sequestration, advanced coal technologies, and nuclear power may also be significant. However, the treatment of vigorous R&D initiatives to improve these supply options beyond 2010 is beyond the scope of this report.

Renewable energy technologies will likely play a crucial role in limiting carbon emissions over the long term. Low-carbon energy supply options are needed to fuel domestic and international economic development without stimulating further global warming. Although renewable resources account for only 7% of the nation's total energy consumption at present, many believe that they are at the beginning of a long-term growth trajectory. With continuing technological development and cost reductions, renewables could become preferred energy resources some time within the next several decades. Early evidence of this transition is seen in the continuing adoption of renewable power systems, including especially wind farms and biomass power systems, even in the face of low gas-fired power generation costs and considerable uncertainty in today's electric energy sector.

note that
only a fraction
of this 7% likely
[illegible]ance growth
[illegible] any growth 7%
(bulk of 7%
is hydro)

With a vigorous and sustained program of research, development and deployment, biomass, wind, photovoltaics, geothermal, and solar thermal technologies could deliver significant quantities of electricity in 2020, thereby substantially displacing carbon emissions. For example, the use of forestry and agricultural residues in biomass power systems continues to be an attractive power option where those residues exist. The successful development of higher-efficiency biomass gasification systems would make this technology competitive in a wider range of applications, including for power systems using dedicated feed stock supply systems. At the same time, biological and agricultural research on biomass production will lead both to higher biomass yields and better species for energy conversion purposes in the future.

biomass
production
must compete
w/ crop
production

A second area in which a vigorous and sustained R&D effort could spawn a range of key improvements is in wind power systems. Potential improvements include

- Advanced blade shapes that increase wind power capture while reducing stress loads
- Elimination of gearboxes through development of direct-drive generators
- Variable speed turbines, and
- Better resource prediction that will increase the value of wind power to power systems operators.

A third area of renewables development that is at the beginning of a long-term growth path is the use of renewables in buildings. Solar daylighting, passive solar designs, solar water heating, and geothermal heat pumps already are cost-competitive in many applications, but are not yet widely

used. R&D advances could substantially accelerate their market penetration. In addition, building-integrated photovoltaic products will benefit directly from advances in materials research. The ultimate vision is that many buildings will become "net energy generators" through a combination of renewable energy and energy-efficiency technologies.

In the next quarter century, improved energy-efficiency technologies will result from a combination of incremental advances and fundamental breakthroughs. Incremental improvements in all sectors can be achieved by the greater reliance on more precise and reliable sensors and controls or on lower-cost sensors and controls, often integrated into industrial processes, transportation systems, and buildings. Advanced manufacturing technologies, including rapid prototyping and ultraprecision fabrication, also offer broad opportunities for continuous incremental improvements in energy efficiency and renewable energy. Breakthroughs in bioprocessing, separations, superconductivity, catalysts, and materials can have wide-ranging impacts on energy efficiency and carbon emissions by the year 2020. Examples of specific technology opportunities are described in this report, by sector.

doesn't mention the role of consumer demand in these advances

Five R&D areas offer great promise to reduce significantly the energy requirements of our nation's buildings in 2020:

- Advanced construction methods and materials
- Adaptive building envelopes ? Is there a trade-off w/ IAQ
- Multi-functional equipment
- Integrated, advanced lighting systems, controls and communications and
- Self-powered buildings.

In addition to the broad application of better process modeling, sensors, and controls in industry, many process/industry-specific opportunities for efficiency gains exist. These are described for each of DOE's targeted industries of the future: pulp and paper, chemicals, petroleum refining, glass, aluminum, iron and steel, and metal casting.

check these descriptions

Many of the advanced technologies that have the potential to significantly improve the energy efficiency of transportation need considerable R&D investment before they can become commercially available in the year 2020. For example, to achieve fuel economies in the 60-80 miles per gallon (MPG) range and remain affordable and safe, light-duty vehicles will need

- Breakthroughs in manufacturing processes for composite materials
- Large reduction in fuel cell costs and/or cost reductions and performance gains in batteries
- Utra-low rolling resistance tires
- High-efficiency accessories and
- Highly aerodynamic designs.

Opportunities for R&D to lead to improvements in the energy efficiency of other transportation modes are also described in this report.

In all, the continued adoption of energy efficient and renewable energy technologies and a steady flow of technology improvements from collaborative R&D programs with industry could make such environmentally friendly technology an attractive option for domestic and global energy economies in the future. With strong public-private partnerships to support the necessary R&D and market transformation activities, ample cost-effective energy products and practices will be available in 2020.

1.5 ASSESSMENT OF COSTS AND SOURCES OF CARBON REDUCTIONS

This is AEO97 ref case not DOE'S BAU

The business-as-usual scenario projects an increase of 380 MtC/year between 1990 and 2010. In our efficiency scenario, in which the nation actively pursues policies and programs to promote market acceptance of energy efficiency while expanding commitments to research and development, energy-efficient technologies reduce this growth in carbon emissions by 120 MtC/year. Under a carbon cap and trading system, in which permits for carbon sell for either $25 or $50/tonne C, very substantial carbon reductions appear possible. Detailed results for these cases, showing the sources of the carbon reductions, are contained in Table 1.4. (Summaries of these results were presented in Figures 1.2 and 1.3.) Results indicate that, for the $50/tonne HE/LC case, there is a potential to roughly return to 1990 levels of carbon emissions in 2010. About two-thirds of the increase in carbon emissions is eliminated in the case with a $25/tonne carbon charge (Table 1.4).

why always the low [illegible]? 1

The estimates in Table 1.4 include ranges for most of the electricity supply options and the other low-carbon technologies. There are no ranges for the efficiency technologies because the models used to estimate their penetration are nonstochastic. When selecting a single estimate for the $50/tonne case, numbers from the low end of the ranges were generally selected in order to be cautious. Because we did not conduct an integrating analysis in which supply options compete against one another, we felt it important to minimize potential overlap by entering the supply options in conservative quantities. Also note that several renewable resources that could play a greater role by 2010 are omitted from Table 1.4; these resources include include photovoltaics, geothermal, solar thermal, and landfill gas.

being conservative is not a good substitute for doing it right

check on these

with each other? Don't we need an integrated analysis then?

But the virtue of the bottoms up approach that it can give this kind of detail

One should not ascribe too much significance to specific entries in Table 1.4 There are many ~~different~~ technologies, both on the supply and demand side of the energy system, that will compete to achieve carbon reductions in an environment in which policies and economic signals ~~favor such~~ reductions. Thus, for example, Table 4.1 shows advanced turbine systems in industry cutting carbon emissions by 17 MtC/year in 2010, co-firing coal with biomass reducing emissions by the same amount, and other low-carbon supply technologies (wind, nuclear plant extensions, hydropower expansion, and power plant efficiency) contributing 24 MtC/year. The actual choice of technology depends on how the economics of the different systems evolve over time, how the industry to supply technology develops, the nature and speed of deregulation within the utility industry, and numerous other factors that cannot be known today. As such, we do not intend the results in Table 1.4 to be taken as a prediction of one technology over another to achieve carbon reductions. In this instance, we have posited one of many possible mixes of supply technologies. These same comments apply to the demand-side sectors and technologies.

?

why?

We summarize below the expected technology costs in 2010, as well as the cost of ~~implementing~~ a carbon permit system. While these costs are necessarily uncertain, they are our best estimates and, in our view, as likely to be high as to be low. We note, however, that we have ~~focused our~~ analysis on technology costs, and have not assessed the viability of specific policies or programs to achieve market acceptance. As described below, we do account for program and policy costs in an approximate manner.

best or optimistic

Table 1.4 Potential Annual Reductions in Carbon Emissions in 2010, Compared to the Business-As-Usual Forecast for 2010 (MtC)

	Efficiency Case	High-Efficiency/Low-Carbon Case $25/tonne	High-Efficiency/Low-Carbon Case $50/tonne*
Buildings			
Energy efficiency	25	42	59
Fuel cells		2	3
	25	44	62
Industry			
Energy efficiency	22	36	51
Advanced turbine systems		5	17 (15-26)
Biomass and black liquor gasification, cement clinker replacement, and aluminum technologies		5	14 (13-16)
	22	46	82
Transportation			
Energy efficiency	61	74	87
Ethanol	12	14	16
	73	88	103
Utility Supply Options			
Carbon-ordered dispatching		25	55
Converting coal-based power plants to natural gas		9	40 (25-66)
Co-firing coal with biomass		5	17 (16-24)
Wind		2	7 (6-20)
Extending the life of existing nuclear plants		3	5 (4-7)
Hydropower expansions		2	4 (3-5)
Power plant efficiency		2	8 (7-13)
		48	136
Total (rounded)	**120**	**226**	**383**

why don't these have ranges ?

*Numbers in parenthesis are ranges, as documented in the text of the report. See Appendix A-1 for a description of the derivation of the results in this table.

Appendix A-2 describes the full set of calculations used to derive the direct costs and benefits of the cases. The ~~costs considered~~ include the incremental technology investment by consumers and businesses, fuel price increases, and the estimated cost of federal, state, and local programs required to achieve the carbon emissions reductions. These constitute the direct costs of the scenarios. The highest of these by far is the incremental investment costs. However, the generally higher first cost of these technologies is counterbalanced by substantially lower operating costs. The benefits considered are limited to the savings in operating (energy) costs from the technology investments.

does it? Text does not read as such — sector chapters; Calculations don't reflect price increases

Using these factors as the direct costs and benefits of the scenarios, we have analyzed the economics of carbon emissions reductions from two different perspectives in order to establish a credible range of costs. In the first, which we label "optimistic," we evaluate all costs and benefits with a real discount rate that approximates the cost of capital *for efficiency investments* for the different end-use sectors:

this is not true

- 7% for buildings
- 10% for transportation
- 12.5% for industry.

are these real

The lowest discount rate, for buildings, is based on the fact that the money for residential buildings is derived from home mortgages or home improvement loans. The higher rate for industry reflects the fact that energy-efficiency investments have to compete with investments for other projects. These discount rates are not those that describe current market behavior, but rather are reflective of costs of capital if the market did invest in the energy-efficiency measures. For the "optimistic" case, we assume costs for efficiency measures brought about by utility, federal programs, and state programs (e.g., demand-side management programs by utilities, federal market transformation programs) to be 15% of technology costs. We also assume that at least half of the efficiency occurs as a result of federal policies (e.g., standards or carbon permit charges) which add very low direct program costs. Thus, the overall costs of implementation are taken to be about 7% in the "optimistic" case. The electric supply-side technologies are assumed to add an incremental cost of $30/tonne carbon in 2010, based on an average estimate of the incremental costs of the technologies from the appropriate sections of this report.

1/2 of reductions f(stds)

These programs and policies are not specified in this study, but the broad nature of the actions could include technology R&D partnerships such as the current Partnership for a Next Generation of Vehicles and Industries of the Future; energy efficiency codes and standards; expanded partnerships, technical assistance, and information programs to accelerate the adoption of energy-efficient technologies; incentives through the tax system directed at investments in energy-efficient technology in industry; and a variety of non-federal programs to accelerate market diffusion of energy-efficient and low-carbon technologies.

this appears to be realistic, not pessimistic

The second perspective, which we label "pessimistic," assumes that there are hidden costs associated with achieving widespread market acceptance of many of the efficiency and low-carbon technologies, even after the imposition of a carbon charge and the implementation of major policies and programs to promote a low-carbon future. In this perspective, we evaluate costs and benefits at a real discount rate of 15% for buildings and 20% for transportation and industry. Program costs are increased to 30% of the cost of efficiency measures, an estimate that is a high bound compared with federal, state, and utility experience. Overall implementation costs (programs and directed policies) are taken to be 15% of technology investments in this case. Other data and assumptions in this case are the same as for the "optimistic" case.

reference this experience

net savings

The results of the economic analysis are presented in Table 1.5. Estimated direct costs are $26-$49 billion per year for the efficiency scenario and $51 to $88 billion per year for the high-efficiency/low-carbon scenario. Estimated savings per year in 2010 are $42 to $51 billion per year in the efficiency case and $70-$88 billion per year for the high-efficiency/low-carbon case. The costs, which are a small portion of annual gross private domestic investment of about $1.4 trillion in 2020, are likely to be more than balanced by savings in energy bills. Thus, net costs to the U.S. economy are near or below zero in this time frame.

Table 1.5 Estimated Costs and Benefits of the Efficiency and High-Efficiency/Low-Carbon Scenarios : Optimistic and Pessimistic View Estimates (billions of 1995$, annualized)

	Efficiency Case[a]			High-Efficiency/Low-Carbon Case[b]		
	Benefits[c] (billion 1995$)	Costs[d] (billion 1995$)	Carbon[c] Savings MtC	Benefits (billion 1995$)	Costs (billion 1995$)	Carbon Savings MtC
Energy Efficiency						
Buildings	14-17	7-14	20-25	26-33	14-26	49-62
Industry	6-7	3-5	18-22	12-15	8-13	66-82
Transportation	22-27	16-30	58-73	32-40	23-43	82-103
Electricity Dispatch	0	0	0	0	2	44-55
Electricity Repowering	0	0	0	0	2	32-40
Other Low-Carbon Techologies	0	0	0	0	2	33-41
Total	**42-51**	**26-49**	**96-120**	**70-88**	**51-88**	**306-383**

Compare w/ 8/1 draft

---

[a] Energy efficiency category includes ethanol in transportation.

[b] Benefits and carbon savings in the HE/LC case are relative to BAU case.

[c] Benefits are calculated as annual energy savings. The scenarios are meant to be point estimates. In the "pessimistic" case, we have assumed that only 80% of the carbon savings are achieved, even though the technology and implementation costs are unchanged. The range on carbon savings represents this assumption.

[d] Costs are calculated from differing viewpoints: the "optimistic" case uses discount rates that vary between 7% and 12.5% for the different sectors, as described in the text. For the "pessimistic" case, the discount rates used to annualize costs vary between 15% and 20%. Also in this case, the cost of implementing programs (30%) and an overall package of programs and policies (15%) is taken to be twice that of the "optimistic" case.

The range of estimates in Table 1.5 reflects our attempt to "bound" optimistic and pessimistic assessments. There are clearly other ways in which these bounds could be described, just as there are many scenarios that could have been analyzed. However, we believe that the assumption that 80% of the carbon reductions are achieved at the costs identified, valuation of costs and benefits at discount rates noticeably higher than the likely cost of capital, and doubling the cost of programs and policies from typical experience today is a strong reflection of pessimism in costs for our cases. It is worth noting that if the implementation costs were taken to be much higher than we believe to be reasonable – 50% of investments costs for programs and 25% overall – this would add about $10 billion per year to the costs of the high-efficiency/low-carbon in the pessimistic case.

In addition to these costs, one needs to calculate the impact of the cases on natural gas demand. In all of these cases, natural gas replaces very large quantities of coal. Higher natural gas demand would result in higher natural gas prices, which in turn would increase the cost of substituting natural gas for coal in power production, etc. As it turns out, our scenarios have somewhat reduced gas demand compared with the BAU case (or with AEO97 baseline for 2010, on which the price of natural gas in our work is based). Specifically, demand for natural gas in the HE/LC ($50/tonne) case declines in 2010 by 2 quads compared with the business-as-usual case. This is the result of declines of 0.5 quads for buildings, 1.0 quads for industry, and 0.5 quads for electricity. The latter occurs because of the balance among three factors:

- Increase in gas demand because of the large-scale substitution of natural gas for coal
- Decrease of gas demand because of the use of many low-carbon technologies that do not use natural gas (wind, nuclear power plant extensions, power plant efficiency upgrades, hydropower expansion, co-firing with biofuels), and

- The large increase in cogeneration, which reduces demand for natural gas for heating applications.

The sum of the second and third effects are somewhat greater than the first, and thus total natural gas demand associated with electricity generation declines. This will reduce the cost of natural gas, a benefit that we have not included in ?

The $50/tonne carbon charge, while not constituting a direct cost, does represent a potentially large transfer payment. The magnitude of the transfer payment, as well as the losers and winners from the transfers, depends on the nature of policy and its implementation as a cap and trade system or some alternative. The amount of money that could be in play is very large: $50/tonne times 1.3 billion tonnes per year equals $65 billion per year.

In short, while there will surely be winners and losers for these energy-efficiency and low-carbon scenarios, our analysis shows that their net economic costs – under a range of assumptions and alternative methods of cost analysis – are favorable.

The achievability of the cases depends on many factors. In all cases, carbon reductions require the nation to embark on an aggressive set of policies and programs. Such efforts could occur in response to an international agreement on climate change or to other events that result in a national determination to reduce the growth of carbon emissions. In the high-efficiency/low-carbon cases, we assume a vigorous national program of research, development, demonstration, and diffusion, and a trading regime for carbon with a domestic permit price of either $25/tonne or $50/tonne carbon. Without some scheme that provides strong incentives for switching from coal to natural gas, and for deploying other low-carbon technologies, much of the potential for carbon reductions will not be realized.

Government policies and programs that encourage and/or require the adoption of energy-efficiency and low-carbon technologies will be needed, along with incentives for industry to invest more in these technologies. Additional private and public investments are necessary, not only to accelerate the introduction of new technologies into the market before 2010 but also to ensure the availability of technologies for the period after 2010. The transportation and utility sectors are especially dependent on early technological advances to achieve the scenario results in 2010.

There is no assurance that these and other driving forces will cause the scenarios we have described to take place. Our major conclusion is that cost-effective technology can be deployed to achieve major reductions in carbon emissions by 2010. Cost-effective energy efficiency alone can take the nation 30 to 50% of the way to 1990 levels. Two additional utility sector measures can reduce carbon emissions by another 30% at an estimated cost of $50/tonne carbon: carbon-based dispatch and conversion of existing power plants from coal to natural gas.[4] Finally, we identify several additional technologies that can contribute up to 20% of the several carbon reductions, also for less than $50/tonne. A next generation of advanced energy-efficiency and renewable energy technologies promises to enable the continuation of an aggressive pace of energy and carbon reductions over the next quarter century.

1.6 REFERENCES

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ENDNOTES

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[1] The five national laboratories participating in the study were: Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). LBNL and ORNL were the co-leaders of the effort.

[2] See Section 2.2.3 for a definition of cost-effective energy efficiency technology.

[3] $50 per tonne of carbon corresponds to 12.5 cents per gallon of gasoline or 0.5 cents per kilowatt-hour for electricity produced from natural gas at 53% efficiency (or 1.3 cents per kilowatt-hour for coal at 34% efficiency). $25 per tonne would cut these gasoline and electricity price increments in half.

[4] The cost curve for repowering is relatively flat; as such, considerable additional reductions are possible at a cost not too different from $50/tonne. The results are highly sensitive to the price differential between coal and natural gas; at a lower (higher) price differential, a higher (lower) permit price of carbon is needed.

cc: JA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
AIR AND RADIATION

FAX MEMORANDUM: 3 Total Pages

TO: Joe Romm, Acting Assistant Secretary
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

CC: Eric Petersen, DOE/EE
Mark Levine, LBL
Marilyn Brown, ORNL
T.J. Glauthier, OMB
Jeffrey Frankel, CEA
Jonathan Gruber, Treasury

FROM: Skip Laitner

SUBJECT: Comments on the National Lab Study

DATE: August 28, 1997

Please note the attached memo from David Doniger, et al.
Many thanks!

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MEMORANDUM

OFFICE OF
AIR AND RADIATION

TO: Joe Romm, Acting Assistant Secretary
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

FROM: Skip Laitner, EPA/OAP
Julie Gorte, EPA/OPPE
Jim Turnure, EPA/OPPE

THROUGH: David Doniger, EPA/OAR

SUBJECT: Comments on the National Lab Study

DATE: August 28, 1997

This memo outlines a number of EPA suggestions to provide a stronger economic context for the findings contained in the National Lab Study, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond.* As it stands, the combined efforts of DOE and its National Laboratories deserve consideration at the highest levels. In the interest of improving the final work product, however, our comments for improvements follow.

(1) What the Report Provides: The report provides an excellent reference for policy makers to help them understand the role of technology in reducing overall carbon emissions within the United States. In particular, the scenarios of potential carbon reductions offer a useful benchmark to gauge the impact of different investment decisions on overall carbon emissions. The technology costs, energy bill savings, and emission reductions identified for each of the scenarios and end-use sectors fall within the range of documented estimates with which we are familiar.

(2) What the Report Doesn't Provide: Although the report provides a reasonable analysis of the direct costs and benefits of the scenarios, it does not provide any estimate of the indirect or secondary costs and benefits. This point needs to be made early in the presentation. For example, the report does not include specific estimates of the R&D costs needed to stimulate the development of new technology. Neither does it provide estimates of the program costs which may be needed to accelerate the diffusion of both existing and new technology that can help reduce carbon emissions. At the same time, however, the report does not provide estimates of the benefits from reduced emissions of criteria air pollutants or larger productivity gains made possible by energy-efficient and low-carbon technologies. Again, it would be helpful to state clearly and early what economic costs and benefits are included and which ones are not included.

(3) Magnitude of Investment: We believe it is worth noting that in the period 1998 through 2010, the AEO97 forecast indicates the United States will generate a total investment of $17.2 trillion (in 1992 dollars). If the Lab Study numbers are right, the roughly $400 billion investment is less than 3 percent of the total investment otherwise anticipated by AEO97. In other words, we are talking about diverting only 2 to3 percent of the typical investment pattern away from less-efficient and more carbon-intensive technologies into a more productive mix of technologies.

(4) The Economic Costs: A separate analysis based upon the results of the Lab Study suggests that stabilizing to 1990 emission levels by 2010 would require a cumulative investment of $400 billion in the period 1998 through 2010 (based upon 1995 dollars). It further suggests that energy bill savings will be on the order of $700 billion over that same period of time (also in 1995 dollars). The analysis further suggests that the economic costs (i.e., non-investment expenditures such as R&D and program costs) are on the order of 7 percent of the technology investment. This implies, by definition, that the economic costs are about 4 percent of the cumulative energy bill savings. This number appears to be a reasonable estimate drawn from the literature. However, it would be useful to provide a range of dollar estimates rather than a mere percentage of the technology investment costs. Our own estimate suggests that this would be on the order of $20-25 billion. We e-mailed to you previously the outline of a suggested methodology that documents how we derived this estimate.

(5) An Integrated Analysis: The individual scenarios are essentially a series of bottom-up analyses with little or no economic feedbacks that reflect either price or income effects. This is hardly a fatal flaw since these second order impacts will not likely affect the overall result of the Lab Study. Still, it would be helpful to understand the influence of such effects on the study results. For that reason, we suggest that DOE continue the work that EPA began with LBL last fall, using the NEMS model to evaluate the impact of the Lab Study scenarios. As the early information from the Lab study became available, we asked LBL to integrate it into the NEMS framework. The preliminary results are encouraging. That work should be immediately completed since it will help tell a more complete story. (Note: EPA has completed a similar macroeconomic analysis using Argonne's AMIGA model which, unlike NEMS, is a CGE model. The results there, are encouraging as well.)

Cc:
Eric Petersen, DOE/EE
Mark Levine, LBL
Marilyn Brown, ORNL
T.J. Glauthier, OMB
Jeffrey Frankel, CEA
Jonathan Gruber, Treasury

cc: JA

BERKELEY LAB
ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

FAX

Date:	August 26, 1997	**Total Pages:**	2
To:	See Distribution	**Fax No.:**	See Distribution
Location:			
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Subject:	Memorandum		

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ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY | ONE CYCLOTRON ROAD | BERKELEY, CA 94720

MEMORANDUM

To: T.J. Glauthier (OMB), Jeff Frankel (CEA), Jon Gruber and Robert Gillingham (Treasury), and Peter Orszag (NEC)

From: Mark D. Levine (LBNL) and Marilyn Brown (ORNL)

Date: August 26, 1997

Subject: Response to the Economic Review of the Draft Report "Scenarios of U.S. Carbon Reductions, 2010"

The purpose of this memo is to note the ways in which we intend to respond to the review that was conducted in the multiagency meeting (EPA, CEA, Commerce, DOE, NEC, OMB, OSTP, Treasury) on August 19.

First, we noted the concern that the report, as written, could be picked up and misunderstood or misrepresented by the press. In particular, as Jeff Frankel articulated, there might be a sense that the carbon reduction scenarios could be achieved easily, and that it would only be necessary to check some box for policies to go into place to bring it about.

We also noted two related concerns: first, that the results were presented as scenarios with point estimates rather than ranges. Second, we note the belief that was stated that the economic analysis was incomplete, and that the study may have not included costs associated with achieving the carbon reductions.

We agree with the first concern. We do not believe that the results we obtained mean that achieving 1990 carbon emission levels in 2010 is either easy to do or even reasonably achieveable in the policy environment in which we now find ourselves. We do believe that, if policies were put in place and effectively implemented, the net cost of the scenario could be low or even negative. But that depends (among other things) on the ability to reach concensus in Congress and the White House on a number of matters.

Regarding the presentation of point estimates of both carbon reductions and costs: we agree that these point estimates can easily lead the reader to assume the these results are known much better than they are. It is a feature of scenario analysis that one often "pretends" certainty for a given scenario, in order to illustrate simply the consequences of a set of assumptions. One then deals with the uncertainty through (1) sensitivity analyses to the scenarios or (2) offering different scenarios. However, we are sensitive to the concern that leaving the results as they are will increase the likelihood of misinterpretation by the press and others.

Finally, regarding the comments on the economics: in our view, we have done a great deal of work on the microeconomic costs of bringing energy efficiency and low carbon technologies into the market. We will respond more fully on this when we respond to the memo from Robert Gillingham and Jonathan Gruber to T.J. Glauthier of August 21 entitled "Comments on the 5-labs Study." Nonetheless, we do agree that there is more uncertaintly in the economic analysis than the reader might believe reading the report, and we will strive to make that clear in the next version.

In conclusion, we intend to respond to the comments in the meeting by modifying the executive summary and chapter 1, Analysis Results, by either eliminating point estimates or presenting sensitivity analyses and in other ways (more and better caveats) to try to avoid misunderstandings of our results. We will also respond to the written comments separately, thus permitting a more in-depth exploration of the other issues that were raised about the study.

David.Chien @ eia.doe.gov
08/25/97 02:07:00 PM

Record Type: Record

To: joseph e. aldy

cc:

Subject: Inter-lab report and AEO97 energy/gdp ratios w/constant MPG

Dear Joseph Aldi of the Council of Economic Advisers:

I have included my two rounds of comments on the inter-lab report. Also, listed below is the information you requested on the calculation for the energy increase in fuel consumption in the transportation sector by holding new vehicle fuel economy constant from 1995 on (620 tril BTU difference in 2010). Accompanying the results are also calculations for the energy/gdp ratio for the transportation sector for 1995 and 2010 for both the reference case and the constant MPG case, as well as the growth rates associated with both cases.

	1995	Ref. Case 2010	Constant MPG 2010
Trans. Energy	24.36Quads	31.4 Q	32.03 Q
GDP(bil $87)	5677	9200	9200
Energy/GDP	4.29E-3	3.41E-3	3.48E-3
Energy/GDP Annual Growth		-1.5%/yr.	-1.39%/yr.

Inter-lab Report comments

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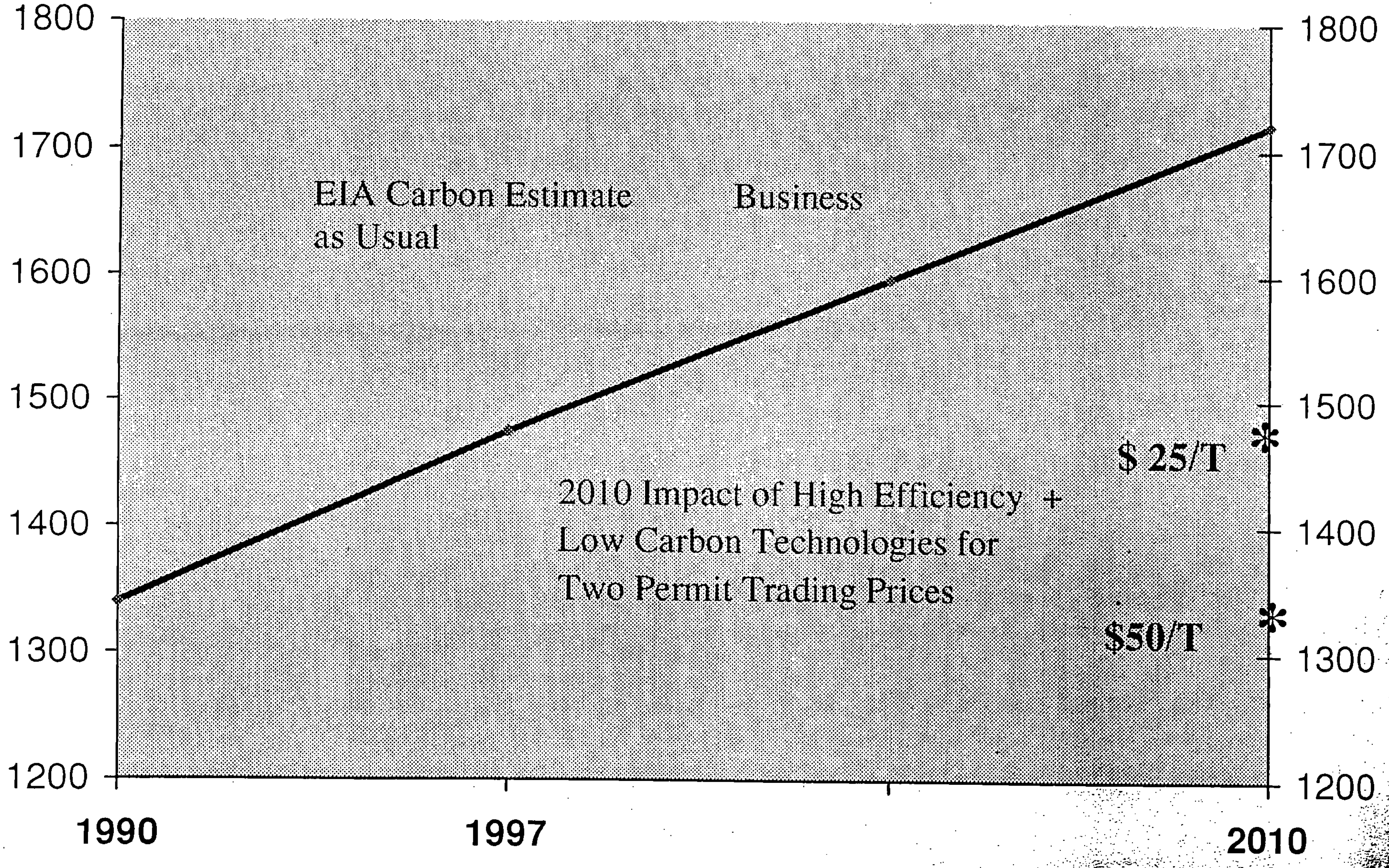
The Five Lab Study

- Five National Labs Assess Potential of Energy Technologies to Reduce Carbon Emissions
  - **LABS: Lawrence Berkeley, Oak Ridge, Argonne, Renewable Energy, Pacific Northwest**
  - Externally Peer Reviewed: U.Tenn, Monsanto, EPRI, GRI, Harvard, NAS, Stanford (Huntington), UNC (Link), and UCSB (DeCanio)

- Assumes
  - Expanded Technology Strategy (R&D and Diffusion)
  - Carbon Dioxide has a price and is traded

Lab Study Results

US Carbon Emissions in MMTCE



Low-Carbon Technologies

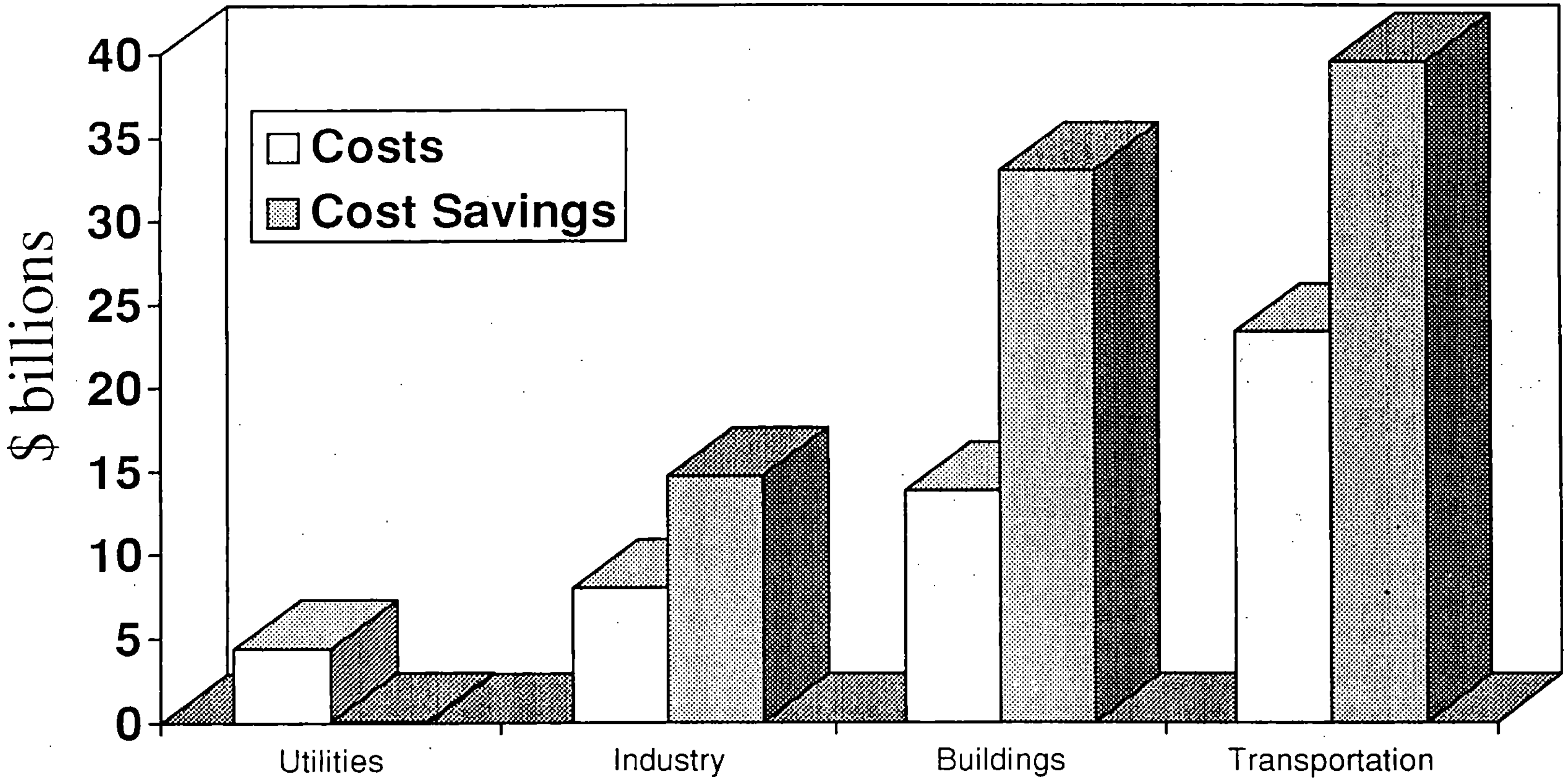
Technology	Cost to Generate *cents/kWh	Incremental Cost $/ton Carbon	Carbon Reduction Potential (MMT)	
• Utilities				
– Carbon Dispatch	--	$30	**55**	
– Gas Repowering	2.5 - 3.2	$30	**40**	(24-83+)
– Biomass co-firing	2.7 - 3.2	$38	**17**	(16-24+)
– Wind	2.5 - 3.5	$42	**7**	(6-20+)
– Other	--	$25	**9**	(7-12)
• Industry				
– Advanced Turbine	2.5 - 3.5	$40	**17**	(15-26)
– Industry Specific	--	$40	**14**	(13-16)
• Buildings				
– Fuel Cell	5.0 - 6.0	$30	**3**	
• Transportation				
– Non-corn Ethanol	--	--	**16**	
Total (rounded)			**180**	(160-250)

*Average costs as of 2005

Energy Efficient Technologies

Technology	Carbon Reduction Potential (MMT)	
• Utilities		
– Generation Efficiency	**8**	(7-13)
• Industry		
– R&D and Diffusion	**51**	
• Buildings		
– Standards and Diffusion	**59**	
• Transportation		
– Passenger Cars	**28**	
– Light Trucks	**28**	
– Heavy Trucks	**14**	
– Aircraft	**14**	
Total (rounded)	**200**	

Business and Consumer Annual Costs and Cost Savings in 2010



APPENDIX A-2

KEY OPPORTUNITIES FOR CARBON SAVINGS FROM END-USE EFFICIENCY IMPROVEMENTS

Each of the three end-use efficiency chapters (Chapters 3-5) assessed the magnitude of carbon savings that could be achieved by the year 2010 from specific submarkets, energy end-uses, and technologies. These key opportunities are summarized in the following table. The table includes those submarkets and end-uses that were estimated to offer the potential for at least 2 MtC of savings by the year 2020. Tables A-2.2 to A-2.4 list some of the key technologies.

Table A-2.1. Key Opportunities for Carbon Savings From End-Use Efficiency Improvements

Submarkets and Technologies with >2 MtC Estimated Reductions in 2010:	Carbon Reductions Estimated by High Efficiency/Low Carbon Case (in MtC)
Buildings	
Miscellaneous electric uses: residential	15.9
Miscellaneous electric uses: commercial	8.5
Commercial lighting	6.6
Commercial electric space conditioning	5.4
Residential lighting	4.4
Commercial gas space conditioning	3.3
Residential electric space conditioning	3.1
Electric water heating	2.9
Gas water heating	2.7
Refrigerators/freezers	2.3
Industry	
Heavy manufacturing industries:	16.1
Petroleum	4.3
Bulk chemicals	4.1
Pulp and paper	2.6
Iron and steel	2.6
Light manufacturing	24.0
Non-manufacturing	10.8
Transportation	
Light-duty vehicles	73.3
Freight trucks	14.1
Air transport	13.9
Freight rail	2.5

Table A-2.2. Illustrative Energy-Efficiency Buildings Technologies

Residential Building End-Uses

- Miscellaneous electricity (efficient motors, variable speed drives)
- Lighting (halogen IR lamps, compact fluorescent lamps, motion sensors)
- Electric water heating (standby loss reduction, horizontal axis clothes washer, heat pump water heater – post 2000)
- Electric cooling (more/improved insulation, spectrally-selective glazings, variable speed compressors, white roofs, reduced infiltration)
- Electric space heating (more/improved insulation, reduced infiltration, low-E argon glazings, superwindows, improved compressors)
- Electric clothes dryers (heat pump clothes dryers at very low penetration)
- Refrigeration (improved insulation, improved compressors)
- Gas water heating (standby loss reduction, horizontal axis clothes washer)
- Gas space heating (more/improved insulation, reduced infiltration, low-E argon glazings, superwindows, condensing furnaces)
- Electric cooking (improved insulation)
- Freezers (more/improved insulation, improved compressors)
- Oil space heating (low-E argon glazings, superwindows, improved insulation, reduced infiltration, condensing furnaces)

Commercial Building End-Uses

- Miscellaneous electricity (variable speed drives, efficient motors, smart redesign)
- Lighting (electronic ballasts, motion sensors, halogen IR lamps, compact fluorescent lamps)
- Electric cooling (system controls, variable speed compressors, switching systems, white roofs)
- Gas space heating (condensing furnaces, fuel cells, system controls)
- Ventilation (variable speed drives, system controls)
- Refrigeration (improved insulation, better compressors)
- Miscellaneous gas (smart redesign, eliminate pilot lights)
- Electric space heating (switch to heat pump, system controls)
- Gas water heating (standby loss reduction, improved burners, flow
- controls)
- Electric water heating (standby loss reduction, flow controls)
- Oil space heating (condensing furnaces, system controls)

Table A-2.3. Illustrative High-Efficiency/Low-Carbon Industrial Technologies

Fuel Switching
- Advanced turbine systems for industrial cogeneration applications
- Integrated gasification combined cycle technologies for the forest products industry

Motors
- Proper load matching
- Variable speed drives

Pulp/Paper
- Impulse drying
- Multiport cylinder drying
- On-machine sensors

Chemicals
- Pinch analytic techniques
- Advanced distillation control techniques

Petroleum Refining
- Utility system improvements
- Process/equipment modifications

Glass
- Oxy-fuel process
- Advanced burner technology
- Glass batch/cullet preheater technology

Aluminum
- New aluminum production cell
- Materials recycling
- Improve furnace efficiency
- Titanium diboride cathodes

Iron/Steel
- Direct smelting/direct reduction
- Scrap preheating
- Hot connection
- Process controls

Metal Casting
- Computer-aided casting design
- Optimized coreless induction melting

Cement
- Cement clinker replacement

Table A-2.4. Key Transportation Technologies Based on the High-Efficiency/Low-Carbon Scenario

Light-Duty Vehicles
- Direct-injection stratified charge (DISC) gasoline engine
- Turbocharged direct-injection clean diesel engine (TDI diesel)
- Hybrid vehicles (gasoline and diesel)
- Gasoline fuel cell vehicle
- Materials substitution, advanced drag reduction, engine friction and pumping loss reductions, and transmission improvements
- Cellulosic ethanol as a blending component with gasoline

Truck Freight
- LE-55 diesel engine
- Turbocompound diesel engine
- Improved tires
- Advanced drag reduction
- Electronic controls

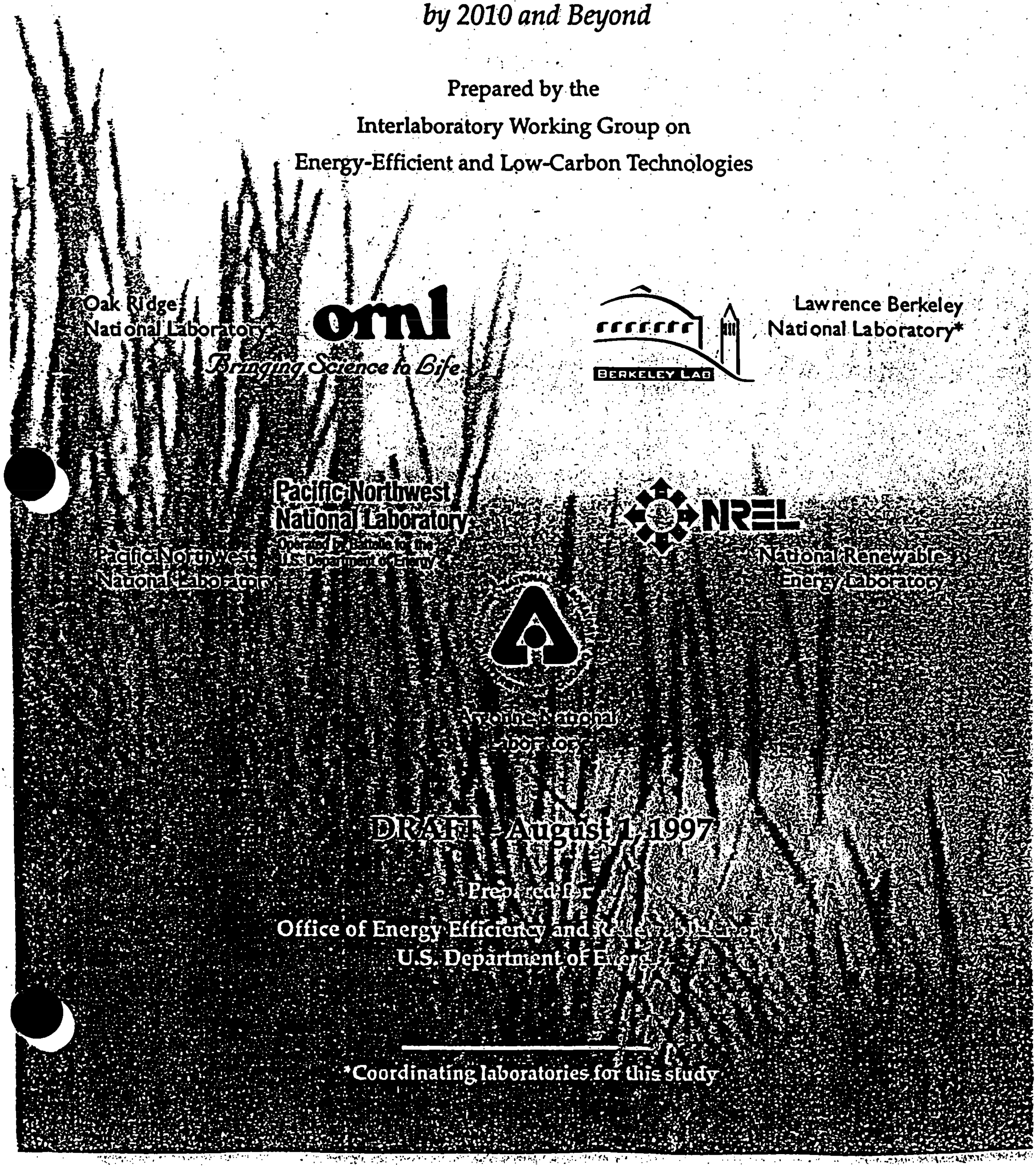
Rail
- Flywheels
- Alternative fuels
- Fuel cells
- Operational efficiency improvements

Air
- Ultra-high bypass turbofans
- Material improvements
- Aerodynamic drag reduction
- Propfans
- Laminar flow control

SCENARIOS OF U.S. CARBON REDUCTIONS

Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond

Prepared by the
Interlaboratory Working Group on
Energy-Efficient and Low-Carbon Technologies



Oak Ridge
National Laboratory*

Lawrence Berkeley
National Laboratory*

Pacific Northwest
National Laboratory

National Renewable
Energy Laboratory

Argonne National
Laboratory

DRAFT - August 1, 1997

Prepared for
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

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*Coordinating laboratories for this study

EXECUTIVE SUMMARY

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States.[1] The study documents in detail how four key sectors of the economy – buildings, transportation, industry, and electric utilities – could respond to directed policies to expand adoption of energy-efficiency and low-carbon technologies, an increase in the relative price of carbon-based fuels by $25 or $50/tonne (e.g., as a result of a cap on domestic carbon emissions and a market for carbon "permits"), and an aggressive program of research, development, and deployment of clean technologies. Current projections suggest that a carbon emissions reduction of 380 million metric tons (MtC) is required to stabilize U.S. emissions in 2010 at 1990 levels.

The study, which has been peer-reviewed by industry and academic experts, uses a technology-by-technology assessment as well as an engineering-economic modeling approach. It draws upon a wide variety of technology cost and performance information to assess potential impacts. Analysis of the buildings, industry, and transportation sectors quantifies the impacts of end-use energy-efficiency improvements on carbon emissions. The utility sector analysis estimates the impacts of those improvements on utility carbon emissions, and quantifies additional emissions reductions through conversion of a number of coal power plants to natural gas, dispatching of the utility grid with $25 and $50/tonne carbon permit prices, the accelerated use of biomass cofiring and wind energy, and other low-carbon electricity supply options. Finally, a number of other promising low-carbon technologies are examined to determine their potential for reducing emissions in the end-use sectors, including advanced gas turbines in industry, transportation biofuels, and fuel cells in buildings.

Three overarching conclusions emerge from the analysis of alternative carbon scenarios. First, a vigorous national commitment to develop and deploy cost-effective energy-efficient and low-carbon technologies has the potential to restrain the growth in U.S. energy consumption and carbon emissions such that levels in 2010 are close to those in 1997 (for energy) and 1990 (for carbon). We analyze a case in which energy efficiency alone can reduce carbon emissions by 120 MtC by 2010. Under more aggressive assumptions motivated in part by a $25/tonne carbon permit price, a combination of energy-efficient and low-carbon technologies can reduce 2010 emissions by a total of 230 MtC. Under a $50/tonne carbon permit price, technology investments reduce 2010 emissions by about 380 MtC. The analysis also suggests that substantial additional savings are available if permit prices were to begin to rise above the $50/tonne level.

The second conclusion is that, if feasible ways are found to implement the carbon reductions as described above, all the cases (with reductions varying between 120 and 380 MtC/year by 2010) can produce benefits that exceed costs, counting as benefits only the energy savings to the nation. We estimate net benefits of $6 to $38 billion per year in 2010. Such net benefits, not generally observed in macroeconomic models requiring structural change in the economy to accommodate reductions in carbon emissions, result from the application of cost-saving energy technologies at the sectoral level.

The third conclusion is that a next generation of energy-efficient and low-carbon technologies promises to enable the continuation of an aggressive pace of cost-effective carbon reductions over the next quarter century. This report documents a wide array of advanced technology options that could be cost-competitive by the year 2020, assuming a vigorous and sustained program of energy R&D beginning now and extending beyond 2010.

---

[1] The five national laboratories participating in the study were: Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). LBNL and ORNL were the co-leaders of the effort.

ACKNOWLEDGMENTS

Funding for this report was provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE). Overall guidance and advice on the report was provided by Joe Romm, Eric Petersen, and Art Rosenfeld. Other EERE staff members provided input and feedback on individual chapters, including Bill Raup and and John Ryan (Office of Building Technologies, State and Community Programs), Lou Divone and Jim Quinn (Office of Industrial Technologies), Phil Patterson (Office of Transportation Technologies), and Joe Galdo (Office of Utility Technologies).

Staff at Lawrence Berkeley National Laboratory (LBNL) and Oak Ridge National Laboratory (ORNL) put enormous efforts into producing this report, especially as contributions came from many different places. We gratefully acknowledge Barbara Maximovich, Leslie Shown, Sam Webster, and Nathan Martin (LBNL) and Tonia Edwards and Kathi Vaughan (ORNL) for word processing (BM and TE), copy editing (LS and NM), and cleanup of figures (KV and SW).

The completion of this study was guided by a committee of experts from industry, universities, and utility research organizations. The committee was chaired by Bill Fulkerson (University of Tennessee) and included: Morton H. Blatt (Electric Power Research Institute), Daniel E. Steinmeyer (Monsanto Chemical Company), Robert A. Frosch (Kennedy School, Harvard University), Douglas C. Bauer (National Academy of Sciences), Hillard G. Huntington (Energy Modeling Forum, Stanford University) and Thomas Roose (Gas Research Institute).

This report benefited from the contributions and assistance of numerous experts on energy efficiency and electricity production. The authors would like to acknowledge contributors by chapter:

Chapter 1 (Summary): Jonathan Koomey.

Chapter 3 (Buildings): George Courville, Mike MacDonald, Jeff Muhs, John Tomlinson, Jim Van Coevering, Robert Wendt (ORNL); Steve Selkowitz, Joe Huang and Steve Johnson (LBNL).

Chapter 4 (Industry): Jim Chang, Hann Huang, Zhuoxiong Mao, John Molburg, Ken Natesan, Leslie Nieves, and Mike Petrick (ANL), Scott L. Freeman, Gary B. Josephson, and Mark J. Niefer (PNNL), Wayne Hayden (ORNL), Keith Davidson and Bill Major (OnSite Energy, Inc.), and Nancy Margolis (Energetics, Inc.).

Chapter 5 (Transportation): K. G. Duleep (Energy and Environmental Analysis, Inc.).

Chapter 7 (Electricity Supply Technologies): Helena Chum, David Kline, and Ralph Overend (NREL), Jack Siegel (Energy Resources International, Inc.), Claud Pugh and Mike Sale (ORNL). Ronald Wolk contributed to Appendix G-1 and Ronald Fisher contributed to Appendix G-4.

Staff members of DOE's Energy Information Administration (EIA) participated in the planning process for this report, provided advice and assistance with the modelling described in the report, and offered insightful comments on previous drafts. Leading this group were Mary Hutzler, Andy Kydes, and Barry Cohen. Sector-specific assistance and feedback was provided by EIA's Erin Boedecker and John Cymbalsky (buildings), Crawford Honeycutt (industry), David Chien and Mark Friedman (transportation), and Art Holland and Dave Schoeberlein (electricity).

Table of Contents

Chapter 1

Chapter 2

Chapter 3

Chapter 5

Chapter 7

Chapter 5

Chapter 6

Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

the EIA "business-as-usual" (BAU) scenario as is for buildings and industry and to modify some of the assumptions and data to produce a new BAU case – not greatly different from the EIA case – for the transportation and the electric utility sectors.

We then assembled existing information on the performance and costs of technologies to increase energy efficiency or, for selected end-uses, to switch from one fuel to another (e.g., from electricity to natural gas for residential end-uses or from gasoline to biofuels for transportation). For the buildings sector, the technology performance and cost data base are extensive. For transportation, the data base – although less fully developed than for buildings – is sufficient for our purposes. For industry, only partial information on technologies and costs is presently available. As a result, the analysis for industry relies primarily on historical relations between energy use and economic activity and much less on explicit technological opportunities. The industrial analysis also includes some examples of industrial low-carbon technologies. The analysis of low-carbon supply technologies in the electricity sector is based on a review of the literature including detailed technology characterizations prepared by DOE in conjunction with its national laboratories and industry.

Next we created scenarios of increased energy efficiency and lower carbon emissions using the technology data (or, in the industrial sector, historical relations) as a key input. We chose to run three scenarios other than the BAU case. We have termed the first the "efficiency" (EFF) case. It assumes that the United States increases its emphasis on energy efficiency through enhanced public- and private-sector efforts. The general philosophy of the efficiency case is that it reduces, but does not eliminate, various market barriers and lags to the adoption of cost-effective energy-efficient technology.

The other two cases, dubbed the "high-efficiency/low-carbon" (HE/LC) cases, describe a world in which, as a result of commitments made on a climate treaty or other factors, the nation has embarked on a path to reduce carbon emissions. These two cases assume a major effort to reduce carbon emissions through federal policies and programs (including environmental regulatory reform), strengthened state programs, and very active private sector involvement. They include a focused national R&D effort to develop and transform markets for low-carbon energy options (e.g., fuel cells for microcogeneration in buildings and advanced turbine systems for combined heat and power in industry). The difference between the two HE/LC cases is in the assumption of a carbon permit price resulting from a domestic trading scheme for carbon emissions with a cap on U.S. emissions (or from equivalent policy measures that increase the price of carbon-based fuels relative to those with less carbon). We assume a domestic permit price of $25 and $50 per tonne of carbon for the two cases. Both of these HE/LC cases include a program of research, development, demonstration and diffusion that is more vigorous than in the efficiency case. In some sectors (buildings and industry), the carbon price signal, combined with policies promoting energy efficiency, is believed to trigger the bulk of the additional carbon reductions portrayed in the HE/LC cases. In the transportation sector, it is the R&D-driven technology breakthroughs that generate the bulk of the carbon reductions beyond the efficiency case. For the electricity sector, higher prices for carbon-based fuels cause larger shifts from coal to natural gas; for this sector, these same higher relative prices combined with federal and private research, development, and demonstration can bring advanced low-carbon technologies to market.

Although the work focuses on 2010, we also look beyond this date. Here we describe new technologies, materials, processes, manufacturing methods, and other R&D advances that promise to offer significant energy benefits by the year 2020; for this time period, we make no effort to forecast specific levels of market penetration, energy savings, or carbon reductions. Thus, instead of creating scenarios we describe the technological innovations that could enable the continuation of an aggressive pace of decarbonization well into the next quarter century, if appropriate investments in R&D were made.

carbon reductions incorporated in the efficiency case cut the overall growth in carbon emissions between 1997 and 2010 from 240 million tonnes (as forecast in the BAU case) to 120. The HE/LC scenario with $50/tonne carbon charge reduces carbon emissions in 2010 by about 130 million tonnes (compared with the 1997 level).

1.4 RESULTS

1.4.1 Prospects for Improved Efficiencies by the Year 2010

Table 1.1 and Figure 1.1 compare the nation's primary energy use in quads for the years 1990 and 1997 (projected) with the results of the three scenarios for 2010. (We have included only the high-efficiency/low-carbon case at $50/tonne in the table and figure for simplicity.) In addition, the HE/LC case shown below does not reflect the energy impacts of the selected low-carbon technologies described later in this summary (e.g., stationary fuel cells for buildings, advanced turbine systems and biomass gasification in industry) or the supply-side options shown in Table 1.4.

Table 1.1 Primary Energy Use in Quads: 1990-2010

			2010		
	1990	1997	Business-as-Usual Case	Efficiency Case	High-Efficiency/Low-Carbon Case ($50/tonne C)
Buildings	29.4	33.7	36.0	34.1	32.0
Industry	32.1	32.6	37.4	35.4	33.6
Transportation	22.6	25.5	32.3	29.2	27.8
Total	84.2	91.8	105.7	98.7	93.4

Source: Energy use estimates for 1990 come from EIA (1996a, Table 2.1, p. 39).
Energy use estimates for 1997 come from forecasts conducted for EIA (1996b).
Numbers may not add to the totals due to rounding.

The major observations are as follows:

- In the business-as-usual case, energy use increases by 22 quads (26%) between 1990 and 2010; 8 quads of this increase have occurred during the first seven years of this 20-year period. The fastest growing sector during these initial seven years has been buildings (4.3 quads) followed by transportation (2.9 quads) and industry (0.5 quads). In the BAU case, the fastest growing sector during the remaining 13 years is transportation (6.8 quads). This is followed by industry (4.8 quads) and then buildings (2.3 quads). The rapid projected growth in the energy consumed for transportation is driven by estimates of increased per capita travel and minimal fuel efficiency gains.

- The efficiency scenario cuts the overall growth between 1990 and 2010 from 22 to 15 quads. This is a 17% increase over the level of energy consumption in 1990, down from a 26% increase in the BAU case. Relative to the BAU case, the efficiency scenario for transportation delivers slightly more energy savings (3.1 quads) than do the same scenarios for the industrial (2.0) or buildings (1.9) sectors. Compared with 1997 levels, the smallest increase in energy growth for this case is in buildings (0.4 quads), followed by industry (2.8 quads), and transportation (3.7 quads).

Table 1.2 Carbon Emissions (MtC): 1990-2010

Same as June

			2010				
	1990	1997	Business-as-Usual (BAU) Case	Efficiency Case	High-Efficiency/Low-Carbon[a]		different than hi eff w/o low C
					$25/tonne	$50/tonne	
Buildings	460	511	571	546	527	509	lower
Industry	452	482	534	512	488	452	lower
Transportation	432	486	616	543	528	513	same
Utilities[b]	–	–	–	–	-48	–136	higher
Total (rounded)	1340	1480	1720	1600	1490	1340	
Change from 1990		140	380	260	150	0	
Change from BAU	–	–	–	-120	-230	-380	

[a] This scenario includes the carbon emission reductions resulting from a carbon permit price of $25 or $50/tonne: (1) dispatch of power plants in which natural gas is favored relative to coal, (2) repowering and partial repowering of coal-based power plants to convert to natural gas, and (3) introduction of selected low-carbon technologies to replace conventional ones, primarily in the industrial and utility sectors.

[b] The entries in the last two columns are negative as they correspond to reductions in carbon emissions resulting from the increased use of natural gas in power plants as a result of the $50/tonne carbon permit price in this scenario.

Figures 1.2 and 1.3 complement the above table by illustrating the carbon emissions reductions from each scenario. The major observations are:

- In the BAU case, carbon emissions are forecast to increase by approximately 380 million tonnes.
- The energy-efficiency gains incorporated in the efficiency case cut overall growth between 1990 and 2010 by one-third (from 380 to 260 million tonnes). This represents a carbon increase of 19% above 1990 emissions.
- The HE/LC scenario with $25/tonne carbon charge has the potential to reduce carbon emissions by 230 million tonnes from the BAU case in 2010. The largest part of these carbon reductions are from increased efficiency, but major changes in electricity supply (carbon-based dispatching and repowering) contribute nearly 35 million tonnes, and other low-carbon technology, particularly renewables and advanced turbine systems, produce approximately another 25 million tonnes.
- The HE/LC scenario with $50/tonne carbon charge has the potential to reduce carbon emissions by approximately 380 million tonnes, thereby achieving 1990 carbon emission levels in 2010. Of this 380 million tonne carbon reduction, about 190 million tonnes are from increased energy efficiency, 140 million tonnes results from increases in the use of low-carbon fuels and technologies in the utility sector, and 50 million tonnes results from the use of low-carbon technology in industry and transportation.

100 million of the 140 million tonnes of carbon reductions in the utility sector comes from redispatching the utility system (favoring the use of low-carbon fuels) and from repowering coal plants with natural gas. Both are cost-effective with a $50/tonne carbon charge. The remaining 40 million tonnes are from renewables (wind, co-firing coal-based power plants with

Table 1.3 provides a comparison of the growth rate in energy and in carbon emissions for the four cases, from 1990 to 2010. For the BAU and efficiency cases, the growth in carbon emissions is slightly more rapid than the increase in energy demand. For the HE/LC cases, carbon emissions decline while energy consumption rises. The carbon reduction reflects the increased deployment of low-carbon fuels and technologies as a consequence of the relative increase in price of carbon-based fuels precipitated by the $50/tonne incentive.

Table 1.3 Average Annual Energy and Carbon Growth Rates, 1997 to 2010, for Four Cases

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	Business-As-Usual (BAU)	Efficiency Case	High Efficiency/ Low Carbon Case ($25/tonne)	High Efficiency/ Low Carbon Case ($50/tonne)
Gross Domestic Product (GDP)[a]	1.88%	1.88%	1.88%	1.88%
Energy Demand	1.09%	0.56%	0.34%	0.13%
Carbon Emissions	1.16%	0.60%	0.05%	-0.76%
Energy Consumption Per GDP (E/GDP)	-0.77%	-1.30%	-1.51%	-1.71%
Carbon Emissions Per GDP (C/GDP)[b]	-0.70%	-1.25%	-1.79%	-2.59%

[a] The Gross Domestic Product in 1995 was $6,739 billion chained 1992 dollars.

[b] The carbon decrease per unit GDP growth for 1990 to 2010 is 0.7%, 1.1%, 1.4% and 1.9% per year for the reference, efficiency, $25/tonne HE/LC, and $50/tonne HE/LC cases, respectively.

It is useful to compare the scenarios in this study to those of other studies. The 1991 report by the Office of Technology Assessment (OTA) titled *Changing by Degrees* (U.S. Congress, 1991) analyzed the potential for energy efficiency to reduce carbon emissions by the year 2015, starting with the base year of 1987. Its "moderate" scenario results in a 15% rise in carbon emissions, from 1300 MtC/year of carbon in 1987 to 1500 MtC/year of carbon in 2015 (compared to a BAU forecast of 1900 MtC/year). Its "tough" scenario results in a 20% to 35% emissions reduction relative to 1987 levels, or emissions levels of 850 to 1000 MtC/year of carbon in 2015. Our efficiency and HE/LC cases ranging from 1.3 to 1.6 billion tonnes of carbon emissions in 2010 are comparable to OTA's "moderate" case and show considerably higher emissions than OTA's "tough" case.

Another benchmark is provided by the 1992 National Academy of Sciences (NAS) report on *Policy Implications of Greenhouse Warming* (National Academy of Sciences, 1992). This study identified a set of energy conservation technologies that had either a positive economic return or that had a cost of less than $2.50 per tonne of carbon. Altogether, NAS concluded that these technologies offer the potential to reduce carbon emissions by 463 million tonnes, with more than half of these reductions arising from cost-effective investments in building energy efficiency. Our efficiency and HE/LC cases suggest the potential for reducing carbon emissions by between 120 and 380 million tonnes by the year 2010. One reason that the NAS estimate is higher is because it is not limited to the 2010 time frame, but rather characterizes the full potential for carbon reductions. Thus, it did not take into account the replacement rates for equipment and processes, and other factors that prevent the instantaneous, full market penetration of cost-effective energy-efficient and low-carbon technologies.

efficiency and renewable energy. Breakthroughs in bioprocessing, separations, superconductivity, catalysts, and materials can have wide-ranging impacts on energy efficiency and carbon emissions by the year 2020. Examples of specific technology opportunities are described in this report, by sector.

Six R&D areas are forecast to offer great promise to reduce significantly the energy requirements of our nation's buildings in 2020: advanced construction methods and materials; adaptive building envelopes; multi-functional equipment; integrated, advanced lighting systems, controls and communications; and self-powered buildings.

In addition to the broad application of better process modeling, sensors, and controls in industry, many process/industry-specific opportunities for efficiency gains exist. These are described for each of DOE's targeted industries of the future: pulp and paper, chemicals, petroleum refining, glass, aluminum, iron and steel, and metal casting.

Many of the advanced technologies that have the potential to significantly improve the energy efficiency of transportation after 2010 need considerable R&D investment before they can become commercially available in the year 2020. For example, to achieve fuel economies in the 60-80 miles per gallon (MPG) range and remain affordable and safe, light-duty vehicles will need breakthroughs in manufacturing processes for composite materials; large reduction in fuel cell costs and/or cost reductions and performance gains in batteries; ultra-low rolling resistance tires; high-efficiency accessories; and highly aerodynamic designs. Opportunities for R&D to lead to improvements in the energy efficiency of other transportation modes are also described.

In all, the continued adoption of energy efficient and renewable energy technologies and a steady flow of technology improvements from collaborative R&D programs with industry could make such environmentally friendly technology an attractive option for domestic and global energy economies in the future. With strong public-private partnerships to support the necessary R&D and market transformation activities, ample cost-effective energy products and practices will be available in 2020.

1.5 ASSESSMENT OF COSTS AND SOURCES OF CARBON REDUCTIONS

The business-as-usual scenario projects an increase of 380 MtC/year between 1990 and 2010. In our efficiency scenario, in which the nation actively pursues policies and programs to promote market acceptance of energy efficiency while expanding commitments to research and development, energy-efficient technologies reduce this growth in carbon emissions by 120 MtC/year. Under a carbon cap and trading system, in which permits for carbon sell for $25 and $50/tonne C for the two cases considered, very substantial carbon reductions appear possible. Detailed results for these cases, showing the sources of the carbon reductions, are contained in Table 1.4. (Summaries of these results were presented in Figures 1.2 and 1.3.) Results indicate that, for the HE/LC case, there is a potential to roughly return to 1990 levels of carbon emissions in 2010 at a cost of approximately $50/tonne carbon. About two-thirds of the increase in carbon emissions is eliminated in the case with $25/tonne carbon charge.

The estimates in Table 1.4 include ranges for most of the electricity supply options and the other low-carbon technologies. There are no ranges for the efficiency technologies because the models used to estimate their penetration are nonstochastic. When selecting a single estimate for the $50/tonne case, numbers from the low end of the ranges were generally selected in order to be cautious. Because we did not conduct an integrating analysis in which supply options compete against one another, we felt it important to minimize potential overlap by entering the supply options in conservative

We have analyzed the economics of carbon emissions reductions from two different perspectives. In the first, which we label "best estimate," we evaluate all costs and benefits with a real discount rate that approximates the cost of capital *for efficiency investments* for the different end-use sectors: 7% for buildings, 10% for transportation, and 12.5% for industry. The lowest cost, for buildings, is based on the fact that the money for residential buildings is derived from home mortgages or home improvement loans. The higher cost for industry reflects the fact that energy-efficiency investments have to compete with investments for other projects. These discount rates are not those that describe current market behavior, but rather are reflective of costs of capital if the market did invest in the energy-efficiency measures. One could argue that a lower discount rate should be used for the "best estimate" case – namely, a social discount rate which might be between 3 and 7% real – but we have made a more conservative assumption on discount rates. For the "best estimate" case, we assume costs for efficiency measures brought about by utility, federal programs, and state programs (e.g., demand-side management programs by utilities, federal market transformation programs) to be 15% of technology costs. We also assume that at least half of the efficiency occurs as a result of federal policies (e.g., standards or carbon permit charges) which add very little direct program costs. The electric supply-side technologies are assumed to add an incremental cost of $30/tonne carbon in 2010, based on an average estimate of the incremental costs of the technologies from the appropriate sections of this report.

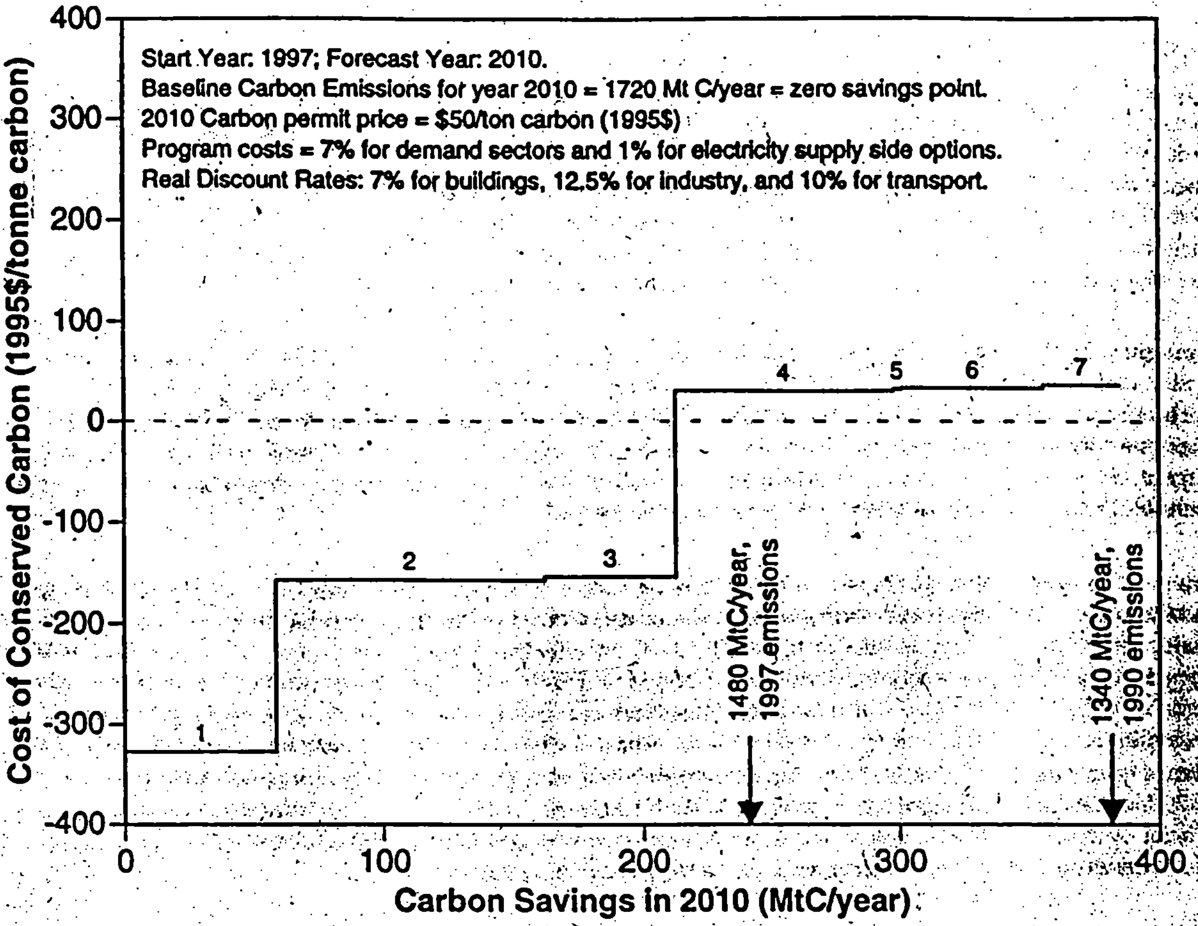
The second perspective, which we label "alternative view," assumes that there are hidden costs associated with achieving widespread market acceptance of many of the efficiency and low-carbon technologies, even after the imposition of a carbon charge and the implementation of major policies and programs to promote a low-carbon future. In this perspective, we evaluate costs and benefits at a real discount rate of 15% for buildings and 20% for transportation and industry. Program costs are increased to 15% of the cost of efficiency measures. Other data and assumptions in this case are the same as for the "best estimate" case.

The results of the economic analysis are presented in Table 1.5. We show results for two of our scenarios (efficiency case and HE/LC at $50/tonne carbon) and for both the "best estimate" and "alternative view" perspectives. Also, we have grouped the results into just four categories of energy technologies. For more detail, both on the results and methodology, the reader is referred to Appendix A-2.

The "best estimate" for the efficiency scenario shows annual net benefits of $26 billion in 2010 ($26 billion in costs and $52 billion in benefits). This value reflects the fact that, even after accounting for energy-efficiency investment, the annual energy savings (without including the benefits of reduced carbon emissions) are $26 billion greater than the required investment. The "best estimate" for the HE/LC scenario with $50/tonne carbon charge produces an annual net benefit of $38 billion in 2010 ($50 billion in costs and $87 billion in benefits).

The "alternative view" shows annual net direct benefits for the efficiency scenario of $7 billion in 2010 ($45 billion in costs and $52 billion in benefits). For the HE/LC ($50/tonne carbon) scenario, the "alternative view" indicates annual net benefits of $6 billion in 2010 ($81 billion in costs and $87 billion in benefits).

Figure 1.4 Cost of Carbon Savings in 2010, High Efficiency/Low Carbon Case (Best Estimate)



	Annual Savings		Annual Costs
1. Buildings Efficiency	$19.3B	4. Electric Repowering/Other	$2.6B
2. Transport Efficiency	$16.2B	5. Fuel Cells in Commercial Bldgs.	$0.1B
3. Industry Efficiency	$7.9B	6. Electricity Dispatch	$1.8B
		7. Industry Other	$1.1B
Total Savings	$43.4B	Total Costs	$5.6B

Total Annual Net Savings (Items 1 through 7) = $38 B/year

The $50/tonne carbon charge, while not constituting a direct cost, does represent a potentially large transfer payment. The magnitude of the transfer payment, as well as the losers and winners from the transfers, depends on the nature of policy and its implementation as a cap and trade system or some alternative. The amount of money that could be in play is very large: $50/tonne times 1.3 billion tonnes per year equals annual revenues of $65 billion.

In short, while there will surely be winners and losers ~~for these~~ energy-efficiency and low-carbon scenarios, our analysis shows that their net economic costs – under a range of assumptions and alternative methods of cost analysis – are favorable: from ~~$6 billion~~ to $38 billion per year in 2010.

[2] $50 per tonne of carbon corresponds to 12.5 cents per gallon of gasoline or 0.5 cents per kilowatt-hour for electricity produced from natural gas at 53% efficiency (or 1.3 cents per kilowatt-hour for coal at 34% efficiency). $25 per tonne would cut these gasoline and electricity price increments in half.

[3] The cost curve for repowering is relatively flat; as such, considerable additional reductions are possible at a cost not too different from $50/tonne. The results are highly sensitive to the price differential between coal and natural gas; at a lower (higher) price differential, a higher (lower) permit price of carbon is needed.

The report focuses on energy-efficiency and renewable energy R&D. The coverage of additional selected low-carbon end-use and electricity supply options was based in large measure on their perceived potential to contribute significantly to stabilizing carbon emissions by 2010 at their 1990 level, which is one possible national target under discussion.

2.2 METHODOLOGY

2.2.1 Overview

To achieve these objectives, we started with the *Annual Energy Outlook 1997* (AEO97) reference case forecasts for the year 2010 (Energy Information Administration, 1996). After thoroughly reviewing these forecasts on a sector-by-sector basis, and working with EIA staff, we chose to accept the EIA "business-as-usual" (BAU) scenario as is for buildings and industry and to modify some of the assumptions and data and produce a new BAU case – not greatly different from the EIA case – for the transportation and the electric utility sectors.

We then assembled existing information on the performance and costs of technologies to increase energy efficiency or, for selected end-uses, to switch from one fuel to another (e.g., from electricity to natural gas for residential end-uses or from gasoline to biofuels for transportation). For the buildings sector, the technology performance and cost data base are extensive. For transportation, the data base – although less fully developed than for buildings – is sufficient for our purposes. For industry, only partial information on technologies and costs is presently available. As a result, the analysis for industry relies primarily on historical relations between energy use and economic activity and much less on explicit technological opportunities. The industrial analysis also includes some examples of industrial low-carbon technologies. The analysis of low-carbon supply technologies in the electricity sector is based on a review of the literature including detailed technology characterizations prepared by DOE in conjunction with its national laboratories and industry.

Next we created scenarios of increased energy efficiency and lower-carbon emissions using the technology data (or, in the industrial sector, historical relations) as a key input. We chose to run three scenarios other than the BAU case. We have termed the first the "efficiency" case. It assumes that the United States increases its emphasis on energy efficiency through enhanced public- and private-sector efforts. The general philosophy of the efficiency case is that it reduces, but does not eliminate, various market barriers and lags to the adoption of cost-effective energy-efficient technology.

The other two cases, dubbed the "high efficiency/low carbon" (HE/LC) cases, describe a world in which, as a result of commitments made on a climate treaty or other factors, the nation has embarked on a path to reduce carbon emissions. They assume a major effort to reduce carbon emissions through federal policies and programs (including environmental regulatory reform), strengthened state programs, and very active private sector involvement. They include a focused national R&D effort to develop and transform markets for low-carbon energy options (e.g., fuel cells for microcogeneration in buildings and advanced turbine systems for combined heat and power in industry). The difference between the two HE/LC cases is in the assumption of a carbon permit price resulting from a domestic trading scheme for carbon emissions with a cap on U.S. emissions (or from equivalent policy measures that increase the price of carbon-based fuels relative to those with less carbon). We assume a domestic permit price of $25 and $50 per tonne of carbon for the two cases. Both of these HE/LC cases include a program of research, development, demonstration and diffusion that is more vigorous than in the efficiency case. In some sectors (buildings and industry), the carbon price signal, combined with policies promoting energy efficiency, is believed to trigger the bulk of the additional carbon reductions portrayed in the HE/LC cases. In the transportation sector, it is

The scenarios for each sector also use the AEO97 energy price forecasts. World oil prices are assumed to rise from $17 per barrel in 1995 to $20.4 per barrel (in 1995$) in 2010. In AEO97, natural gas prices in the industrial, electricity, and transportation sectors increase throughout the forecast period; natural gas prices for the residential and commercial sectors decrease significantly. Between 1995 and 2010, the average price of electricity is projected to decline by 0.6% a year as a result of competition among electricity suppliers. Electricity prices are forecast to decrease the most for industrial customers and the least for residential customers.

Such macroeconomic and fuel price assumptions strongly influence the rate of penetration of energy-efficient technologies in each sector. Further details regarding these assumptions can be found in EIA (1996c).

Frozen Efficiency Baseline. This case, which is analyzed only for the buildings sector, assumes that energy-consuming equipment and systems existing in the year 1997 remain at the same efficiency until they are retired. This equipment and these systems retire over the 1997-2010 period at a rate based on standard equipment lifetimes. It assumes that all new equipment employed after 1997 remains at the efficiency of new devices in the year 1997. The frozen efficiency baseline provides an upper bound to likely energy demand (under the economic assumptions applied to all the cases), because it ignores all forces leading to higher efficiency of new equipment in the business-as-usual case. It also ignores any retrofits that might take place if there were economic reasons for early retirement of equipment.

This case is presented primarily for heuristic reasons: it describes an easily-understood case in which technology does not change. This is useful for exploring the impacts of technology change. Also, the case is not necessarily divorced from reality: in the era of low energy prices preceding the oil embargo of 1973-74, the energy efficiency of many household, transportation, and industrial technologies changed very little.

Business-as-Usual Case. The business-as-usual (BAU) case represents the best estimate of future energy use given current trends in service demand, stock turnover, and natural progress in the efficiency of new equipment. It assumes that R&D and implementation programs at DOE and EPA continue at more or less current levels, without a significant influx of new funding. It captures likely changes in efficiencies of new equipment over the analysis period. It also allows for some early retirement of equipment where cost savings from new energy-efficient products are high relative to purchase and installation costs, as in some industrial motor and drive systems and commercial lighting retrofits.

To create this scenario, the buildings and industry sectors adopted the AEO97 reference case as their BAU cases. For the transportation sector, we modified AEO97 somewhat. Specifically, the AEO97 reference case forecasts that the efficiency of passenger cars will increase from 27.5 MPG in 1997 to 31.5 MPG in 2010. We believe such improvements are unlikely in the absence of increases in real gasoline prices and hence our BAU case for transportation leaves the MPG performance of light-duty vehicles in 2010 unchanged from 1997 performance.

Efficiency Case. The efficiency case describes the potential for cost-effective, energy-efficient technologies to penetrate the market by the year 2010, given an invigorated public- and private-sector effort to promote energy efficiency through enhanced R&D and market transformation activities. This case assumes that national policy, possibly in combination with exogenous events, leads to an increase in the cost-effectiveness and deployment of energy-efficient technologies. Cost-effectiveness is improved because R&D, in combination with increased deployment efforts, result in declining capital costs. We do not specify the policies or exogenous events that could precipitate

- The actual increases over time in the permit price of carbon (which we model as averaging either $25 or $50 per tonne for much of this period);
- Increased federal effort to accelerate R&D and diffusion of low-carbon technologies;
- The development and introduction by other countries of advanced low-carbon technologies; and
- The change in consumer preferences and behavior that would result from an international treaty and national commitment to stabilize greenhouse gases, much like changes in consumer behavior in the aftermath of the oil embargo of 1973-74.

In summary, this scenario for 2010 describes a combination of better technology, "readier" markets, and a price of carbon that results in a significantly increased willingness to manufacture, purchase, and use low-carbon technologies.

2.2.4 Methodological Differences Across Sectors

The operational definitions used to model these scenarios for the individual end-use sectors reflect the above conceptual definitions, but are nevertheless distinct (Table 2.1). These differences are due partly to the modeling approaches used for each sector. They also reflect the authors' sense of what could "drive" significant increases in energy efficiency in each sector. For instance, to achieve a high-efficiency/low-carbon scenario, the transportation analysis postulates a set of technology breakthroughs. The industrial analysis, on the other hand, achieves its high-efficiency/low-carbon scenario by doubling market penetration rates and assuming that energy-efficiency decisions are treated as strategic investments with correspondingly lower hurdle rates.

The sectors also differ in the way that life-cycle costs and benefits are calculated to determine the cost-effectiveness of technologies in their efficiency scenarios.

- The buildings sector employs a 7% real discount rate to value the stream of benefits accruing from an investment. These benefits accumulate throughout the specific operational lifetimes assumed for individual technologies. The efficiency case assumes market penetration of about one-third of the technologies that are cost-effective at a 7% real discount but not adopted in the business-as-usual case. The HE/LC case doubles this penetration.
- The industrial sector assumes a capital recovery factor (CRF) of 15%, rather than 33% (which is the BAU assumption). Thus, to be considered cost-effective in this sector, an investment must pay back in no more than approximately seven years.
- The transportation sector uses a 7% discount rate, but it is applied only to the first five years of operation, even though the expected lifetime of a vehicle may be much longer. This five-year period is meant to reflect the realities of purchase behavior in this sector, and results in decisions that are based on considerably less than the full life-cycle of benefits.

2.2.5 What the Study Does Not Do

This report does not describe the policies that might be implemented to achieve higher penetrations of energy-efficient and low-carbon technologies. (Reviews of a wide range of possible policy options can be found in several recent publications, including OTA (1991), NAS (1992), and DOE (1996b)). Rather, this report highlights the potential performance and impacts of technological developments and transformed markets. The existence of cost-effective technologies is a prerequisite for public policies to work. Without the technologies, policies to reduce greenhouse gas emissions will be very costly. Indeed, this analysis suggests that carbon stabilization could produce net benefits if the nation invests significantly in cost-effective energy-efficiency and low-carbon technologies.

Thus, we believe it is critical to understand the availability of technologies, their performance, and their costs for as many end-uses of energy as possible. Armed with this knowledge, discussion of policies becomes much more meaningful. Without it, such discussion is less likely to lead to good decisions. Thus, we choose to focus this report on the more narrow topic of technologies in the belief that doing a credible job in this area will ultimately further the policy dialogue.

A second reason for focusing on technologies is our belief that the role of R&D on energy-efficient and low-carbon technologies as a means to deal with climate change and other environmental impacts has been inadequately recognized. If effective energy technologies are not developed, then the cost of reducing greenhouse gas emissions (and other environmental impacts of energy) will be very high.

As in the AEO97 reference case, each of the scenarios is completed at the national level. Thus, regional variations in population and economic activity are not considered, nor are regional differences in fuel price, weather, or air quality and environmental conditions that might create regional niche markets for particular technologies. As a result, our analyses have undoubtedly overlooked the possible development of regional markets for advanced energy technologies. A valuable next step would be to conduct analyses at a finer geographic scale to produce national estimates that reflect such regional variations.

2.3 OVERVIEW OF THE REPORT

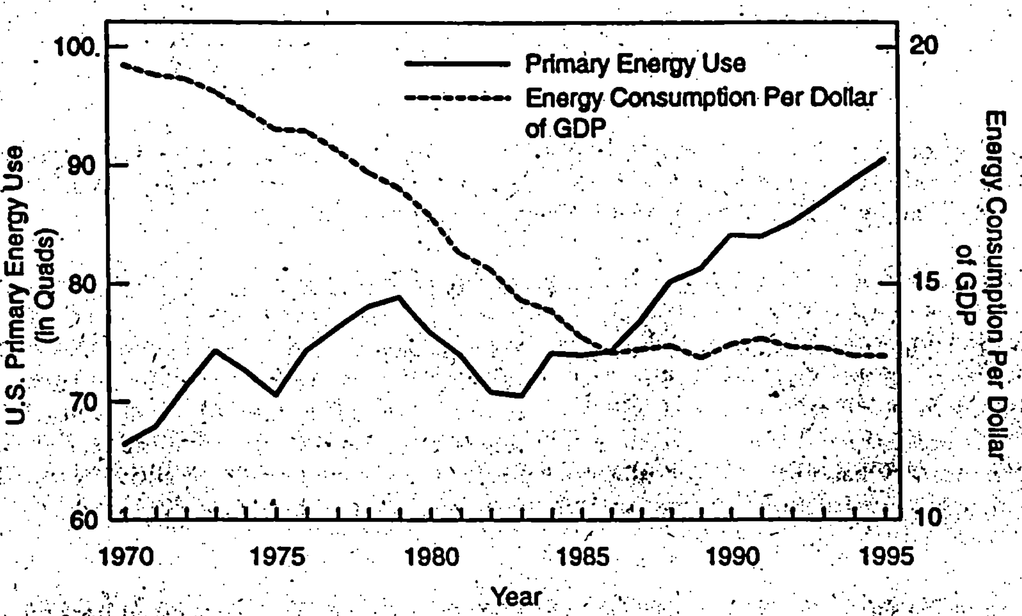
The rest of Chapter 2 sets the stage for the remainder of this report. It describes historical energy and carbon trends, both at the national level and by sector, as a backdrop for assessing energy consumption and carbon emission forecasts. It also discusses the government's role in energy R&D, including the rationale for government support and some evidence of past energy-efficiency technology successes that benefited from government sponsorship.

Chapters 3 through 5 address each of the major energy end-use sectors: buildings (Chapter 3), industry (Chapter 4), and transportation (Chapter 5). Four tasks are completed for each sector:

1. Energy scenarios with and without a strong efficiency push, focusing on the year 2010, and including comparisons with the AEO97 projections from the National Energy Modeling System;
2. Documentation of the cost and performance assumptions for individual energy-efficient and low-carbon technologies;
3. Development of three scenarios (business-as-usual, efficiency, and high-efficiency/low-carbon cases) for the year 2010 and an explanation of how the scenarios were developed, and

to 13.4 thousand Btu of energy per dollar of GDP (1992$) (EIA, 1996a, p. 17). DOE estimates that the country is saving $150 to $200 billion annually as a result of these improvements.

Figure 2.1 Energy Consumption Per Dollar of Gross Domestic Product: 1973-1995



Starting in 1986, energy prices began their descent in real terms that has continued to the present. As a result, energy demand grew from 74 quads in 1986 to 91 quads in 1995, and it continues to increase. One of the major lessons of the period since 1973 is that the economy will and can respond to energy price changes. In addition to prices, other factors are also important and can slow the decline in conservation activity that otherwise would be expected with declining energy prices. Federal policies, as well as federal, state, and utility programs and consumer preferences for energy-efficient appliances, houses, and cars can increase the purchase and use of energy-efficient products. Technological developments can improve the energy efficiency, reduce the carbon emissions, and often improve the performance of the product. Demand for energy-efficient products and low-carbon energy technologies is also strengthened by factors such as environmental concerns.

2.4.2 Sectoral Trends

Each end-use sector functions differently in the U.S. energy marketplace. One of the reasons for these differences is the differing market structure for delivering new technologies and products in each sector. Residential and commercial building technology is shaped by thousands of building contractors and architectural and engineering firms, whereas transportation technology is in the hands of a few manufacturers.

The principal causes of energy inefficiencies in manufacturing and transportation are not the same as the causes of inefficiencies in homes and office buildings, although there are some similarities (Hirst and Brown, 1990). For example, in the manufacturing sector, energy-efficiency investments are hindered by a preference for investments that increase output compared with investments that reduce operating costs. The cost and relative difficulty of obtaining reliable information often prevents energy-efficient features of buildings from being capitalized into real estate prices. This is

Over the entire period from 1973 to 1997, energy use increased in buildings from 24.1 to 33.7 quads (40%); in industry, from 31.5 to 32.6 quads (3.5%); and in transportation, from 18.6 to 25.5 quads (37%). As shown in Table 2.3, the growth in buildings and transportation has been relatively steady, at less than 1% per year from 1973 to 1986, and between 1.3 and 2.9% per year from 1986 to 1997. Growth in energy demand in industry has been much more volatile during the period, showing substantial declines during the period of rising prices (a negative 1.3% annual growth for the 13 years of increasing energy prices), an increase of 2.7% per year from 1986 to 1995, and a 2.9% per year decline from 1995 to 1997.

Table 2.3 Historical Energy Growth Rates: 1973-1997

	AAGR 1973-97	AAGR 1973-86	AAGR 1986-90	AAGR 1990-95	AAGR 1995-1997
Buildings	1.41%	0.85%	2.25%	1.77%	2.46%
Industry	0.14%	-1.31%	4.81%	1.45%	-2.87%
Transportation	1.32%	0.86%	2.10%	1.29%	2.86%
Total	0.89%	0.0%	3.18%	1.48%	0.66%

AAGR = Average Annual Growth Rate

The growth of carbon emissions during the period roughly follows that of energy demand growth. Table 2.4 shows estimated carbon emissions from 1973 to 1997. Like energy, carbon emissions were flat between 1973 and 1986. The increase in the fraction of coal in the final mix from 17.5% in 1973 to 23.2% in 1986 was offset by the increasing fraction of primary energy from nuclear power, from 0.1% in 1973 to 6.0% in 1986. From 1986 to 1997, carbon emissions grew more slowly than energy consumption. This was a result of an increase in the share of natural gas from 22.5% in 1987 to 25.4% in 1997 and in electricity from nuclear power from 4.5% to 7.2%, combined with a small decrease in coal (23.3% to 22.5%) and a larger decrease in petroleum (43.3% to 39.7%).

Table 2.4 Carbon Emissions from Fossil Energy Consumption: 1973 to 1997

	1973	1986	1990	1995	1997
Carbon emissions from energy in MtC	1260	1240	1344	1424	1480
	1973-97	**1973-86**	**1986-90**	**1990-95**	**1995-97**
Average annual growth rates (AAGR) for carbon emissions	0.67	–0.12%	2.03%	1.16%	1.95%

Sources: Carbon emissions estimates for 1990 are from EIA (1996b, Table 6, p. 16), and for 1995 are from EIA [illegible] (1996b, Table A19, p. 120). Carbon emission estimates for 1973 and 1986 were derived using factors for carbon [illegible] emissions from combustion of oil, natural gas, and coal for 1990. For 1997, they are from the end-use sector analyses described in Chapters 3 through 5 of this report.

results of the R&D. This is characteristic, for instance, of much defense and crime prevention research.

Based on these three justifications, the rationale for government support of energy-efficiency and low-carbon technology R&D is strong. Much of this research is both long-term and high-risk and therefore cannot be afforded by private companies despite the possibility of substantial gains in the long run. Examples include high temperature superconductivity, fuel cell vehicles, and building materials with switchable thermal and optical properties. Advances in energy research also offer substantial public benefits that cannot be fully captured by private entities. Specifically, energy-efficiency and low-carbon resources improve energy security by reducing the nation's reliance on foreign sources of oil; they lead to reductions in waste streams; and they reduce greenhouse gas emissions, which contribute to global warming. Finally, it is possible that governments will in the future become the principal purchaser of greenhouse gas reductions as the result of future international agreements. In this case, the third rationale for federal sponsorship of energy R&D will also apply.

Industry's R&D priorities are shifting away from basic and applied research and toward near-term product development and process enhancements. Business spending on applied research has dropped to 15% of overall company R&D spending, while basic research has dropped to just 2%. In addition, corporate investments in energy R&D, in particular, are down significantly (DOE, 1996a, p. 2).

Great potential exists for public-private R&D partnerships to produce scientific breakthroughs and incremental technology enhancements that will produce new and improved products for the marketplace. U.S. industry spends more than $100 billion per year on all types of R&D. The top 20 R&D-performing companies all have R&D budgets exceeding $1 billion per year. These expenditures dwarf the U.S. government's energy-related R&D appropriations. If climate mitigation policies reoriented even a tiny fraction of this private-sector expenditure and capability, it could have an enormous impact. One way to reorient private-sector R&D is through industry-government R&D partnerships that involve joint technology roadmapping, collaborative priorities for the development of advanced energy-efficient and low-carbon technologies, and cost-shared R&D.

2.5.2 Past R&D Successes

Some indication of the cost-effectiveness of energy-efficiency R&D can be gleaned from the experiences to date of DOE's Office of Energy Efficiency and Renewable Energy. From fiscal year 1978 through fiscal year 1994, DOE spent a total of about $8 billion on energy-efficiency R&D and related deployment programs. Estimates of the benefits of several dozen projects supported by this funding were published in DOE/SEAB (1995). In response to a detailed review of these estimates by the General Accounting Office in 1995/96, DOE has revised and updated the estimated benefits accruing from five technologies that were developed with DOE support. Altogether, these five technologies alone have resulted in net benefits (i.e., the value of energy saved minus annualized cost premiums for better equipment) of approximately $28 billion (1996$) and annual emissions reductions of 16 MtC equivalent (Table 2.5).

Thus, the value of the energy saved by these five technologies, alone, far exceeds the cost to the taxpayers of DOE's entire energy-efficiency R&D budget over the past two decades. Additional case studies and benefits are documented in Geller and McGaraghan (1996) and DOE/SEAB (1995).

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