



## ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

---

# **New Method and Reporting of Uncertainty in LBNL National Energy Modeling System Runs**

Etan Z. Gumerman, Kristina Hamachi LaCommare,  
and Chris Marnay

**Environmental Energy  
Technologies Division**

**October 2002**

This work described in this paper was funded by the Office of the Assistant Secretary of Energy for Energy Efficiency and Renewable Energy, Office of Planning, Budget Formulation, and Analysis of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098



## **Disclaimer**

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.



## **New Method and Reporting of Uncertainty in LBNL National Energy Modeling System Runs**

Prepared for the  
Office of Planning, Budget Formulation, and Analysis  
Assistant Secretary for Energy Efficiency and Renewable Energy  
U.S. Department of Energy

### Principal Authors

Etan Z. Gumerman, Kristina Hamachi LaCommare, and Chris Marnay

Ernest Orlando Lawrence Berkeley National Laboratory  
1 Cyclotron Road, MS 90-4000  
Berkeley CA 94720-8061

October 2002

This work described in this paper was funded by the Office of the Assistant Secretary of Energy for Energy Efficiency and Renewable Energy, Office of Planning, Budget Formulation, and Analysis of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098



## Table of Contents

Acknowledgment .....	v
Acronyms and Abbreviations.....	vii
Abstract .....	ix
1. Introduction.....	1
2. Description and Method .....	7
2.1 Case 0: AL02 case Baseline.....	7
2.1.1 Description .....	7
2.1.2 Method .....	7
2.2 Case 1: Carbon 24% Above 1990 Levels by 2020.....	8
2.2.1 Description .....	8
2.2.2 Method .....	8
2.3 Case 2: Impose a 5¢/kg Carbon Emissions Charge.....	8
2.3.1 Description .....	8
2.3.2 Method .....	8
2.4 Case 3: Multi-Pollutant Limit .....	9
2.4.1 Description .....	9
2.4.2 Method .....	9
2.5 Case 4: High Thermal Generation Cost Forecast.....	9
2.5.1 Description .....	9
2.5.2 Method .....	9
2.6 Case 5: Production Tax Credit Enhancements.....	10
2.6.1 Description .....	10
2.6.2 Method .....	10
2.7 Case 6: 75% Reduction in Distributed Generation Capital Costs.....	10
2.7.1 Description .....	10
2.7.2 Method .....	10
2.8 Case 7: Low Economic Growth Case .....	10
2.8.1 Description .....	10
2.8.2 Method .....	10
2.9 Case 8: High Economic Growth Case.....	11
2.9.1 Description .....	11
2.9.2 Method .....	11
3. Conclusion .....	13





## **List of Figures and Tables**

Figure 1. Total Renewables Capacity .....	5
Figure 2. Total Carbon Emissions (Mt/a) .....	5
Table 1. Results for Year 2020 from Uncertainty Analysis .....	3
Table 2. Example of Brief Description of each Case Provided in Quick Turnaround of Results..	4



## **Acknowledgment**

Our thanks to Susan Holte of the Planning, Budget Formulation, and Analysis office.



## Acronyms and Abbreviations

AEO	Annual Energy Outlook
AL02	combined GPRA case run used as baseline example for this analysis
Btu	British thermal unit
CHP	combined heat and power
DG	distributed generation
DOE	U.S. Department of Energy
ECP	Electricity Capacity Planning module of NEMS
EERE	office of Energy Efficiency and Renewable Energy of DOE
EIA	Energy Information Administration
GPRA	Government Performance and Results Act
GW	$10^9$ (giga)watt
ITC	investment tax credit
MBtu	$10^6$ (million) Btu
MSW	municipal solid waste
Mt	$10^6$ (million) metric tons
NEMS	National Energy Modeling System
NO <sub>x</sub>	nitrogen oxides
O&M	operations and maintenance cost
PBFA	DOE's former office of Planning, Budget Formulation and Analysis
PERI	Princeton Energy Resources International
PTC	production tax credit
PV	photovoltaic
Quad	$10^{15}$ (quadrillion) Btu
SO <sub>2</sub>	sulfur dioxide
TWh	$10^{12}$ (tera)watt hour



## **Abstract**

This report describes LBNL's approach for assessing uncertainty in any National Energy Modeling System (NEMS)-related analysis. Based on years of experience using LBNL-NEMS for various analyses, LBNL developed an alternative approach that aims to provide a simple yet comprehensive perspective of how the results behave under a given set of what we believe to be some of the issues important to large-scale energy modeling. This project has established a standard set of eight sensitivity cases that can be run overnight and are highly likely to produce stable and interesting results. The goal was to establish a limited number of interesting sensitivity cases that would routinely produce adjunct results to LBNL-NEMS reporting that will be of value to our readers. These cases will be routinely reported together with future LBNL-NEMS results in the form of a standard output table. As an example, this work uses a Government Performance and Results Act (GPRA) analysis run as the baseline, but the goal is to establish a standardized set of cases that would change little over time and be applicable to other analyses in addition to GPRA. The approach developed here cannot serve as a substitute for a sensitivity analysis tailored to the question at hand, but it can provide a fast review of some areas that have proven to be of interest in the past.





## 1. Introduction

The Lawrence Berkeley National Laboratory (LBNL) has executed and reported to the Department of Energy's (DOE) office of Energy Efficiency and Renewable Energy (EERE) on hundreds of National Energy Modeling System (NEMS) runs over recent years. These runs have been intended for various analysis purposes, although many have been in support of the annual Government Performance and Results Act (GPRA) exercise for the Planning, Budget Formulation and Analysis (PBFA) office. Two related aspects of the LBNL-NEMS analysis process have become somewhat frustrating; interested parties tend to speculate over the possible consequences of a fairly limited number of LBNL-NEMS assumptions; and LBNL-NEMS tends to be quite poorly suited to the execution of numerous parametric runs or uncertainty cases. The inconsistent input formats of the many LBNL-NEMS modules together with the sheer computational time burden involved would make it highly burdensome to prepare and complete a set of numerous relevant exploratory cases relevant to any particular analysis, especially if executing numerous cases and/or combinations of assumptions were involved. Our inability to provide numerous relevant sensitivity runs that fairly cover the range of reasonably credible outcomes establishes a major barrier to providing our reader with a view of the landscape around the target run results.

The purpose of this project is to explore a first cut alternative to producing a comprehensive set of tailored sensitivities to any analysis geared towards the electricity sector. This alternative involves setting up a fixed set of cases in advance that can be run with minimal mechanical intervention and virtually no creative input. The goal then is to establish, based on the authors' experience and judgment, a limited number of interesting sensitivity cases *ex ante* that will routinely produce adjunct results to LBNL-NEMS reporting that will be of value to our readers. Particularly, the results should be comprehensible to the reader without need of careful complex explanation. And of course, these cases should provide answers to a few of the key questions that we know to be the frequent ones asked. The bounds set on the exercise are that the cases must be presented in less than two pages, one of results and a second of supporting explanation, that the necessary runs must complete overnight (i.e. in less than 12 h of clock time), and that they must be stable and robust enough to successfully execute almost all (> 90%) of the time, and finally that the preparation of the runs and the reporting pages must involve no more than an hour or two of total effort.

Given the constraints, it proved quite difficult to define a large number of cases with interesting combinations of assumptions that ran consistently and reliably. In fact, it proved impossible to go beyond a limited set of sensitivity cases, and 8 of these were ultimately chosen. Table 1 shows the results of the exercise. For 12 key indicator results of interest, Table 1 shows the most recent Annual Energy Outlook (AEO) value, the target run value (in this example a recent AL GPRA case), and the equivalent results of the 8 sensitivity cases. The following sections of this memo describe these cases in detail, but since a major objective of this exercise is to produce a minimalist presentation of useful results, the reader is requested to review Table 1 cold at this point. If these results arrived together with a requested LBNL-NEMS run, would it be sufficiently self explanatory to be comprehensible without further review of the case assumptions and/or the general approach? Are the results presented those of most immediate interest and value? Are these results a reasonable first cut compensation for the absence of a carefully

crafted set of sensitivity cases? And most importantly, does this additional page deliver any additional useful interpretation of the results? The example presented is a GPRA LBNL-NEMS run recently completed, but the goal is to establish a standardized set of cases that would change little over time and be applicable to other analyses in addition to GPRA. Although it will not be a standard attachment, Figures 1 and 2, which show total renewables capacity and carbon emissions respectively, are also presented here. The approach developed here cannot serve as a substitute for a sensitivity analysis tailored to the question at hand, but it can provide a fast review of some areas that have proven to be of interest in the past.

**Table 1. Results for Year 2020 from Uncertainty Analysis**

Scenario	Renewable Capacity <sup>1</sup> (GW)	Renewable Generation <sup>1</sup> (TWh)	Carbon Emissions (Mt)	NOx Emissions (Mt)	SOx Emissions (Mt)	Electricity Price (\$/MBtu)	Electricity Price (¢/kWh)	Total Generation (TWh)	Total Fuel Consumption (Quads)	Tot. Install. Capacity <sup>2</sup> (GW)	New Capacity (GW)	New Renewables Cap (GW)
AEO2002 Reference Case	21	107	2088	3.8	8.1	19.0	6.5	5430	130.9	1136	374	15
Case 0: AL02 Run5 Baseline	70	330	2052	3.7	8.1	18.7	6.4	5443	132.0	1164	402	64
Case 1: Carbon 24% Above 1990 Levels	125	578	1669	2.0	6.8	30.2	10.3	4992	121.4	1134	411	120
Case 2: 5¢/kg Carbon Emissions Charge	84	453	1939	3.4	8.1	21.7	7.4	5315	129.3	1139	378	77
Case 3: Multi-pollutant Limits	119	553	1674	1.3	2.7	30.0	10.2	4968	121.4	1117	397	114
Case 4: High Thermal Generation Cost Forecast	65	292	1740	1.4	3.7	42.5	14.5	4766	120.8	1059	353	60
Case 5: Production Tax Credit Enhancement	142	623	2011	3.6	8.1	18.4	6.3	5454	132.5	1200	441	136
Case 6: 75% Reduction in DG Capital Costs	71	332	2051	3.7	8.1	18.6	6.3	5448	132.0	1153	392	65
Case 7: Low Economic Growth Case	68	323	2042	3.7	8.1	18.9	6.4	5419	131.5	1154	392	62
Case 8: High Economic Growth Case	72	338	2062	3.7	8.1	18.4	6.3	5462	132.3	1166	405	66

<sup>1</sup>Excludes hydropower

<sup>2</sup>Includes cogeneration

**Table 2. Example of Brief Description of each Case Provided in Quick Turnaround of Results**

<b>Description of Each Case:</b>
<b>AEO2002 Reference Case</b> - This represents EIA's results from the AEO2002 version of NEMS
<b>Case 0 - AL02 Run5 Baseline</b> - The baseline in this example is represented by the AL case, which contains the following changes:
- RA forced builds from run 12. This includes builds as PERI provided for all renewable technologies, except biomass, in which 2017-2020 added 4x what PERI prescribed.
- FX technical fixes from run 1. This includes increased intermittent technology build limit from 12% -> 30%, increase solar thermal capacity credit from 75% -> 100%, extend wind PTC to 2003, turn off project contingency for solar thermal and biomass.
- TC technology characterization changes from run1. This includes no vombens. Other changes include increased CF for wind and solar thermal and PV, extend wind PTC, overwrite wood, solar thermal, PV, and wind capital and fixed O&M costs to match PERI. Changed the geothermal costs and site build constraint from 25MW -> 100MW.
- HP combined heat and power from run 1. Enhancements to natural gas industrial CHP match the same changes as was done in the GPRA FY-03 analysis in 2001.
No biomass CHP changes were made this year b/c the above 2001 target was met with the AEO2002 reference case.
<b>Case 1 - Carbon 24% Above 1990 Levels</b> - Sets a carbon emissions limit to target 1,669 Mt/a by ~2010-2020, or 24% above year 1990 levels.
<b>Case 2 - 5¢/kg Carbon Emissions Charge</b> - Imposes a carbon emissions charge to 5¢/kg by 2014.
<b>Case 3 - Multi-pollutant Limits</b> - Limits are defined for carbon, NOx, and SOx at levels of 1669 Mt/a, 1.8 Mt/a, and 3.1 Mt/a , respectively by 2020.
<b>Case 4: High Thermal Generation Cost Forecast</b> - This case doubles the natural gas and coal price through an imposed carbon tax to the end-use fuel price by 2020.
<b>Case 5 - Production Tax Credit Extension</b> - Modified assumptions include an extension of the wind and biomass PTC's to 2020
<b>Case 6 - 75% Reduction in DG Capital Costs</b> - Represents a 75% reduction in the capital cost of all residential and commercial DG equipment technologies for all years.
<b>Case 7 - Low Economic Growth</b> - This case mimics EIA's Low Economic Growth Scenario. Modified assumptions include lower projected growth rates for population, labor force, and labor productivity relative to the AEO2002 Reference Case.
<b>Case 8 - High Economic Growth</b> - This case mimics EIA's High Economic Growth Scenario. Modified assumptions include higher projected growth rates for population, labor force, and labor productivity relative to the AEO2002 Reference Case.

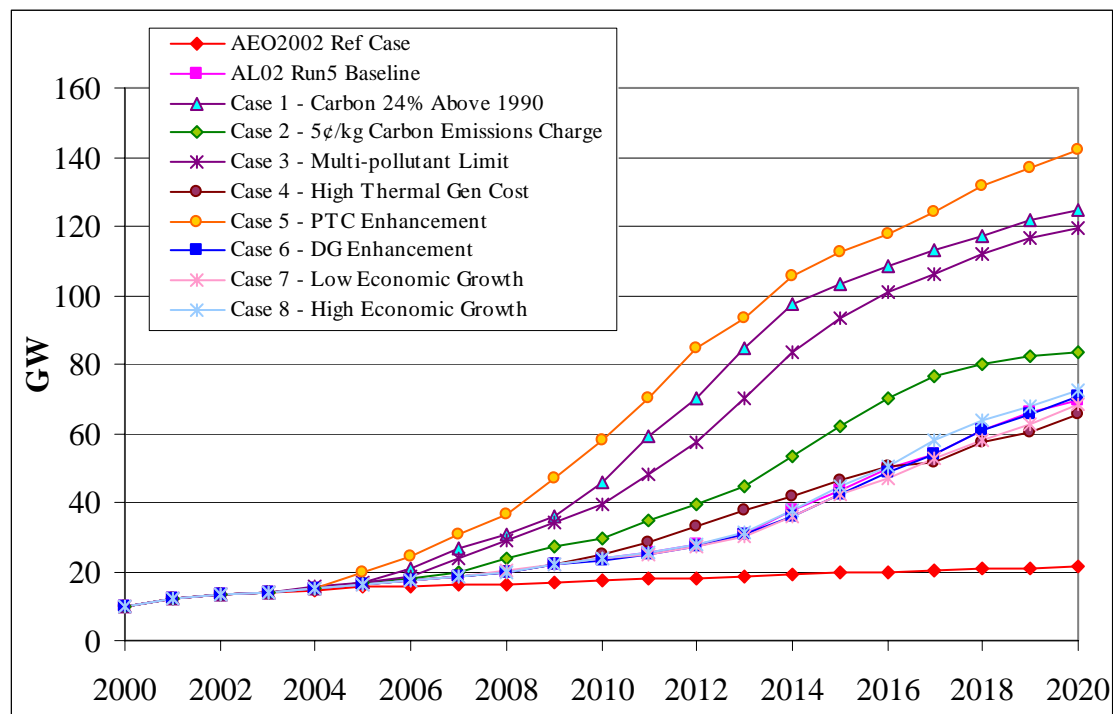


Figure 1. Total Renewables Capacity

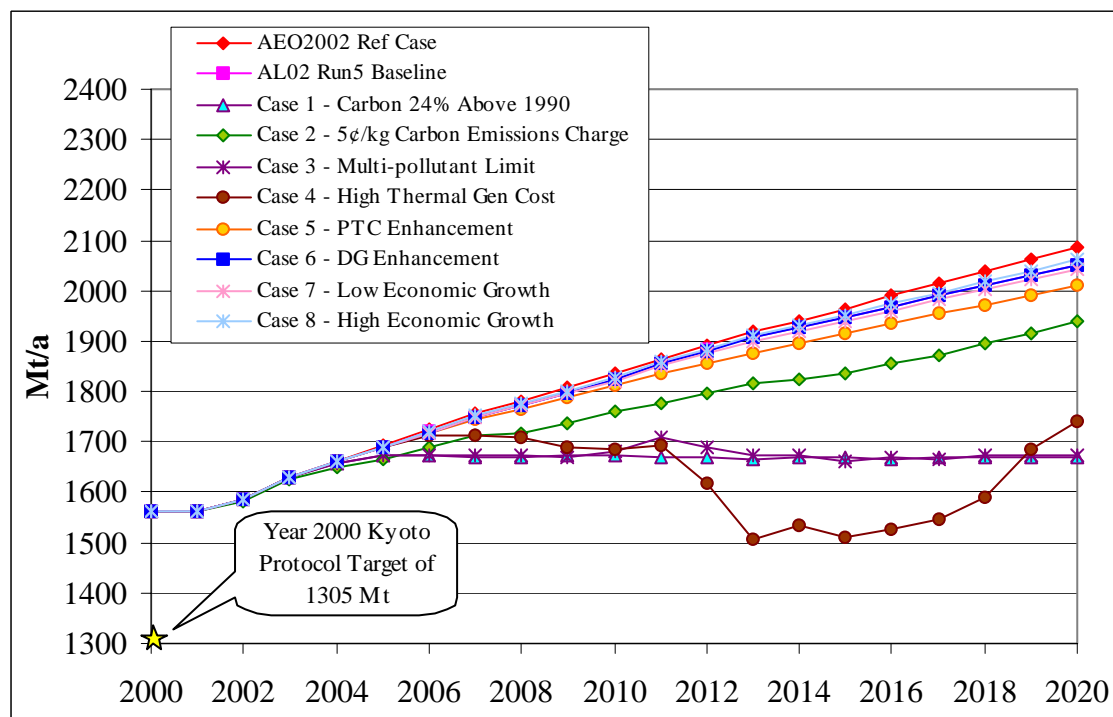


Figure 2. Total Carbon Emissions (Mt/a)



## 2. Description and Method

Numerous input parameters were identified as interesting and ultimately a limited number chosen to include in this uncertainty analysis. The magnitude of each change was selected to be extreme enough to illustrate the likely trend and scale of the effect. Values were not chosen to represent realistic bounds, as LBNL was not trying to define the range for reasonable alternative assumptions. The magnitude of the change in some cases was subjectively chosen to exercise the sensitivity of the selected parameters. The example baseline presented here is the AL02 Run5 case sent to Larry Goldstein *et al.* on 12 July 2002. It is important to note that the choice of baseline is arbitrary and the approach must be robust enough to work with numerous baselines.

The following provides an overview of the baseline and the pre-determined scenarios incorporated in this work along with a detailed description of the method used to perform each scenario. Again, each of the uncertainty runs is performed in conjunction with the AL02 case assumptions to determine the incremental benefits of the specified parameter. Each uncertainty parameter is modified in addition to the assumptions made to the AL case.

### 2.1 Case 0: AL02 case Baseline

#### 2.1.1 Description

The integrated case from our GPRA analysis called the AL02 case serves as the baseline for this study. The AL02 case is a compilation of changes that enhance the potential for renewable energy and combined heat and power through incorporation of various technical fixes to alleviate potential hurdles, through technology characterization enhancements, and through representation of Green Pricing by forced renewable capacity additions. The AL02 run5 was the most current AL02 case as of 15 July 2002 and was selected as the baseline for this work.

#### 2.1.2 Method

The AL02 (run5) case is comprised of the following changes (same as 12 July 2002 results emailed to Larry Goldstein *et al.*):

- Update wind capacity factors in *westech* input file to match PERI's updated TC97
- Hardwired renewable additions (for biomass, geothermal, PV, wind, solar thermal, and MSW) as specified by Jim McVeigh of *Princeton Energy Resources International* (PERI) in his 6 June 2002 spreadsheet sent to Chris Marnay and Kristina LaCommare. Biomass and geothermal forced additions are implemented using a separate input file, consistent with last year's analysis.
- Increased industrial and commercial combined heat and power. This case represents industrial natural gas CHP increases in the range specified by Larry Goldstein in his 4 October 2001 fax to Chris Marnay and Etan Gumerman. The commercial CHP changes were specified by Frances Wood of OnLocation and provided to LBNL on 25 October 2001.
- Update solar thermal and PV capacity factors in *solarin* input file to match PERI's updated TC97
- Modify geothermal capital and fixed O&M costs via *renew.f* source code provided by Frances Wood of OnLocation, Inc. on 20 June 2002

- Turn off the endogenous learning for geothermal through the ECP module (*ucape.f* code change)
- Increase the geothermal site build constraints to 100MW for all years in the *wgesite* input file
- Increase intermittent technology limit to 30% from default of 12%
- Solar thermal capacity credit increase from 75% to 100%
- Overwrite PV, wind, solar thermal, and biomass capital costs and fixed O&M
- Project contingency factor ("UPLRPC") = 1.00 for biomass and solar thermal
- Extend wind production tax credit to plants built from 2001 to 2003 to match the recently legislated extension to 2003 after the official release of the AEO2002.

## **2.2 Case 1: Carbon 24% Above 1990 Levels by 2020**

### **2.2.1 Description**

Case 1 sets a carbon emissions limit of 1,669 Mt/a set constant from 2008 to 2020. Carbon emissions are first limited in 2005, and are gradually reduced to 1669 Mt/a by 2008. This particular value was chosen to be significant but not radical. The Annual Energy Outlook forecasts unrestricted carbon emissions of 2088 Mt/a in 2020. EIA has used 24% above 1990 levels in previous forecasts, e.g. it was the most conservative carbon scenario in the 1998 Kyoto analysis, (EIA report SR/OIAF/98-03(S)).

### **2.2.2 Method**

The same version of the *epmdata* input file that EIA uses for their study is used. The limit in the *epmdata* file is set to 1,669 Mt/a starting in 2008. The *epmcntl* input file is also changed to set up the auction market.

## **2.3 Case 2: Impose a 5¢/kg Carbon Emissions Charge**

### **2.3.1 Description**

Case 2 limits carbon emissions by imposing a carbon emissions charge. The value of \$0.05/kg (year 2000-\$) was chosen as a straightforward amount to use in the input file. This case is different than case 1 in that it makes emitting any and all carbon more expensive. Case 1, on the other hand, assumes a cap and trade system, where the total carbon emissions are limited.

### **2.3.2 Method**

Modifications for this case are made to the *epmdata* input file by increasing the emissions charge to \$0.05/kg by 2014 and holding it steady to 2020. The *epmcntl* input file is also changed to activate a carbon tax.



## 2.4 Case 3: Multi-Pollutant Limit

### 2.4.1 Description

Case 3 sets a cap for two pollutants (SO<sub>2</sub> and NO<sub>x</sub>) and one emission (carbon). The carbon limit is the same as in Case 1, 1,669 Mt/a by 2020. The SO<sub>2</sub> and NO<sub>x</sub> limits are set to the level proposed in the Administration's Clear Skies program, 3.0 Mt/a SO<sub>2</sub> and 1.7 Mt/a NO<sub>x</sub> by 2020.

### 2.4.2 Method

The carbon limit includes the same changes to the *epmdata* and *epmcntl* files used for Case 1. The SO<sub>2</sub> and NO<sub>x</sub> levels are set according to the goals of the Administration's Clear skies program as follows:

- SO<sub>2</sub> emissions limited to 4.5 Mt/a by 2010
- SO<sub>2</sub> emissions limited to 3.0 Mt/a by 2018
- NO<sub>x</sub> emissions limited to 2.1 Mt/a by 2008
- NO<sub>x</sub> emissions limited to 1.7 Mt/a by 2018

## 2.5 Case 4: High Thermal Generation Cost Forecast

### 2.5.1 Description

Case 4 forces an increase in the natural gas and coal prices by applying a fuel-specific end-use carbon tax. The natural-gas price ramps up over time beginning in 2005 to produce a doubling of the AEO2002 reference case by 2020. Coal prices were then increased to the point where average electricity prices to all users are doubled beyond any effect from the natural gas increase. Another interesting case would have been to just impose a high natural gas price scenario, however previous experience with imposing increased natural gas prices in LBNL-NEMS resulted in little impacts elsewhere.

### 2.5.2 Method

Because coal and natural gas prices are endogenously calculated within the NEMS model, LBNL had to increase these fuel prices indirectly. To do this, a carbon tax is applied to the end-use coal and natural gas price via the *epm.f* code. This tax is applied to all sectors – residential, commercial, transportation, industrial, and electric generation. The natural gas price is modified to approximately double within each sector by 2020, while the coal prices have variable taxes subsequently applied in order to redouble the electricity price. These modifications will have slightly different effects when combined with the other AL changes in addition to the reference case, but the doubling was targeted to the reference case version, without the presence of AL changes.

## **2.6 Case 5: Production Tax Credit Enhancements**

### **2.6.1 Description**

Case 5 extends the production tax credit for wind and biomass to 2020 from the default expiration year of 2001. Although the PTC is typically only extended for 2-5 years at a time, its likely continued renewal makes a 2020 year time horizon both convenient and credible. The PTC is also doubled in magnitude.

### **2.6.2 Method**

The wind and biomass production tax credits are extended to 2020 from the default sunset year of 2001 via the *ecpdat* input file. The magnitude of the tax credit is doubled from 1.2 ¢/kWh to 2.4 ¢/kWh (in 1987-\$) to capture the sensitivity of both tax credit time horizon and the magnitude of the subsidy in the same *ecpdat* input file.

## **2.7 Case 6: 75% Reduction in Distributed Generation Capital Costs**

### **2.7.1 Description**

Case 6 reduces all distributed generation technology capital costs by 75% from the AEO2002 assumptions. The reduced costs apply to all the residential and commercial DG technologies considered in LBNL-NEMS.

### **2.7.2 Method**

This reduction is applied to all forecasted years via the *rgentk* and *kgentk* residential and commercial DG input files, respectively.

## **2.8 Case 7: Low Economic Growth Case**

### **2.8.1 Description**

Case 7 incorporates the AEO2002 low economic growth assumptions. Under this lower economic growth scenario, gross domestic product grows at an average rate of 2.4% per year versus the 3.0% per year in the AEO2002 reference case.

### **2.8.2 Method**

This case involved switching out a series of input and code files to account for lower rates of population, labor force, labor productivity, leading to lower inflation and interest rates. Paul Kondis of EIA provided the files needed to run this case. These files include the *restart*, *impcurv*, *basppmm2*, *basemmo*, and *baxppmm2*.

## **2.9 Case 8: High Economic Growth Case**

### **2.9.1 Description**

Case 8 incorporates the AEO2002 high economic growth assumptions. Under this accelerated economic growth scenario, gross domestic product grows at an average rate of 3.4% per year versus the 3.0% in the AEO2002 reference case.

### **2.9.2 Method**

This case involved switching out the same series of input and code files as for Case 7.



### **3. Conclusion**

LBNL set out to establish a standard manageable method for introducing some uncertainty into typical, LBNL-NEMS runs completed for GPRA and other analyses. Ultimately, a set of eight sensitivity cases was chosen to show uncertainty. These cases were carefully selected such that they can be run overnight with a high probability of reliably producing results, and such that complete results can be presented in a single table. This standard table will be produced together with all future LBNL-NEMS runs.