# Paper/Presentation

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# Technology Scenarios For Achieving Stabilization Of Atmospheric GHG Concentrations: A U.S. Perspective

**Vello A. Kuuskraa[(1)], Phil Dipietro[(2)], Sarah M. Forbes[(3)]**

[(1)]Advanced Resources International, Inc.
4501 Fairfax Drive, Suite 910, Arlington, VA 22203

[(2)]Advanced Resources International, Inc.
401 Wood St., Suite 900, Pittsburgh PA 15222

[(3)]U.S. Department of Energy, National Energy Technology Laboratory (NETL-MGN)
3610 Collins Ferry Road, Morgantown, WV 26507-0880

## Introduction

Greenhouse gas (GHG) emissions from economic activity in the United States were about 7,000 million metric tons in 2004, 12% higher than the 1990 level. The 23% reduction in the GHG intensity from economic activity (to 0.65 kg $CO_2$/MM $GDP in 2004) during these fourteen years was offset by population growth and an increase in the GDP per capita. There was also only modest improvement in the average efficiency of several key energy use areas, including power plants and automobiles[1].

In the most recent forecast by the U.S. Department of Energy, U.S. $CO_2$ emissions from energy in 2030 are projected to be 38% above the 2004 level[2]. One reason for the higher emissions is the expected increases in the prices for crude oil and natural gas ($50/bbl and $5.90/Mcf in 2030), which lead to increased use of coal for power generation and for conversion to liquid fuels. For example, in 2030 coal is projected to account for 57% of power generation in the U.S., up from 51% in 2004. Three other important trends in the forecast are U.S. population growth (0.8% per year through 2030), steady increases in GDP per capita (2.0% per year through 2030), and a continued reduction in the GHG intensity of GDP (1.7% per year through 2030). The CarBen3 model continues these trends through 2050, ending with an expectation of about 12,000 MMt of $CO_2$ emissions in the Reference Case.

This paper begins with a look at expectations for U.S. GHG emissions for the next 50 years. It then examines technology options for reducing emissions to “change the trajectory” to one that is consistent with worldwide efforts to stabilize atmospheric GHG concentrations at 550 ppm. The paper sets forth a combination of policies, actions, and technology performance improvements that achieve the stated GHG emissions goal.

## Methodology

The latest version of the Carbon Sequestration Benefits (CarBen3) model was used to examine technology scenarios that could reduce U.S. GHG emissions in 2050 from about 12,000 MMt $CO_2$ to 4,400 MMt $CO_2$, a target consistent with stabilizing atmospheric GHG concentrations. CarBen3 is a spreadsheet-based model of U.S. GHG emissions that provides a comprehensive look at energy technologies, non-$CO_2$ GHG emissions, and terrestrial off-sets[3].

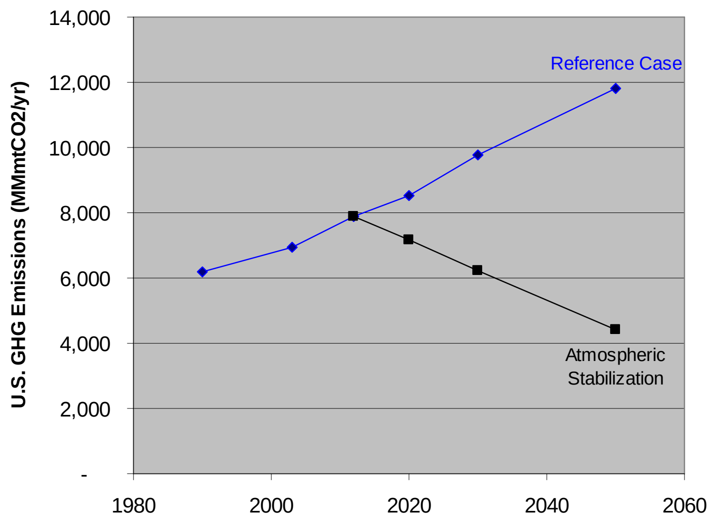
A Reference Case GHG emissions scenario for the United States was developed. The scenario is linked to the DOE/EIA Annual Energy Outlook (AEO) 2006 and incorporates significant technology progress over time. But it does not consider policy incentives to reduce GHG emissions. The reference case was crafted by first setting capacity expansion rates, asset utilization factors, and efficiencies in the sector-level, bottom-up modules to matches the AEO 2006 projections for energy use and $CO_2$ emissions from energy use through 2030. The scenario is then extrapolated to 2050 by extending trends seen between 2020 and 2030. Total GHG emissions were calculated via equation {1}. As a check, a top down estimate of GHG emissions was made based on population growth, economic prosperity, and reductions in the average GHG intensity of economic activity {2}. A reasonably close correlation is found between the two GHG emissions projections.

$$GHG_{\text{Bottom Up}} = (\text{power + transportation + other energy + non-}CO_2\text{ GHG}) - \text{terrestrial off-sets} \quad \{1\}$$

$$GHG_{\text{Top Down}} = \text{Population} * \text{GDP/population} * \text{GHG/GDP} \quad \{2\}$$

A GHG emissions scenario consistent with atmospheric stabilization at 550 ppm was then crafted. It represents an estimated U.S. share of worldwide anthropogenic GHG emissions under the atmospheric stabilization curves developed by Wigley, Richels, and Edmunds[4]. The target for U.S. emissions in 2050 is approximately 4,400 million metric tons of $CO_2$ equivalent per year. Figure 1 shows the reference case and atmospheric stabilization scenarios. By 2050, the Atmospheric Stabilization Scenario requires a 63% reduction in GHG emissions below the Reference Case and represents a challenging goal.

**Figure 1. The U.S. GHG Emissions Gap Under and Atmospheric Stabilzation Scenario**




Three different GHG emissions reduction scenarios were evaluated for meeting this goal:

- **$E^2$ w/CCS** (Efficient Electricity with Carbon Capture and Storage)
- **$T^2$ w/CCS** (Transformed Transportation with Carbon Capture and Storage)
- **$O^2$ w/CCS** (Other Options with Carbon Capture and Storage

These scenarios use a combination of sector-specific policies, expectations of technology performance and market factors. Each scenario is described below.

**Scenario #1. E² w/CCS** *(Efficient Electricity Sector with Carbon Capture and Storage).* This scenario examines the role of the U.S. electric power sector in achieving stabilization of $CO_2$ concentrations. The average generation efficiency of coal-fired power plants (CFPPs) in the U.S. has been flat at 33% over the past three decades. This is due to a combination of factors including: inexpensive coal which reduces the economic incentive for efficiency improvements, parastic loads from $SO_x$ and $NO_x$ controls which offsets efficiency gains, and the high price of natural gas which as moved many older and less-efficient CFPPs up on the dispatch. In 2003, 31% of the power generation from coal came from power plants built before 1970. In its most recent forecast, the U.S. DOE projects that essentially all of the existing CFPPs will remain in operation through 2030 and that over 150 GW of new CFPP capacity will be built between now and 2030.

In contrast, in the $E^2$ scenario, all the pre-1970 CFPPs are retired by 2030, and all the pre-1990 CFPPs by 2050. These assets are replaced with highly-efficient power plants, Table 1. The efficiencies presented in Table 1 for the $E^2$ case are consistent with sustained research investment technology performance goals set forth by DOE and the Coal Utilization Research Council[5]. $CO_2$ capture and storage is applied to one-third of the coal-fired power plants built between 2013 and 2020, and to all of coal-fired power plants built after 2020. Deployments of nuclear power and non-hydro renewable are also increased, by 50% compared to the Reference Case. The demand for electricity per $ of GDP is decreased by 10% compared to the Reference Case, based on estimated demand elasticity due to increased costs as well as policies that encourage conservation.

Table 1. Future Coal-Fired Power Plant Efficiencies

| Power Plant Vintage | Reference Case | $E^2$ scenario |
|---|---|---|
| 2013-2020 | 41% | 45% |
| 2021-2030 | 43% | 55% |
| 2031-2050 | 45% | 60% |

**Scenario #2, T² w/CCS** *(Transformed Transportation fleet and fuels infrastructure with Carbon Capture and Storage).* The average mileage efficiency for passenger vehicles increased only from 15.4 to 17.0 miles per gallon between 1990 and 2004. Improvements in engine efficiency have been offset by increased vehicle weight and increased auxiliary load. In the $T^2$ scenario, we assume a CAFÉ-like standard that moves the average LDV efficiency closer to what is technologically achievable. The opportunities in the transportation sector are enhanced by the fact that the automobile capital stock turns over relatively quickly, and newer cars are driven more than older ones. In any given year, 80% of the LDV miles traveled come from cars that are less than five years old. We also estimate a 10% reduction in vehicle miles traveled per GDP based on higher fuel costs. We also assume increased use of ethanol and hydrogen based on a projected sustained increase in the cost of crude oil. The future ethanol and hydrogen manufacturing facilities are assumed to be constructed with $CO_2$ capture and storage.

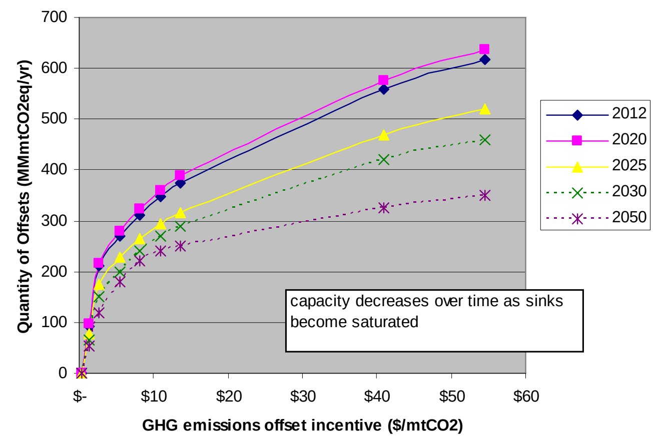
Table 2. Average Light Duty Vehicle Fleet Average Mile per Gallon

| | Reference Case | $E^2$ scenario |
|---|---|---|
| 2020 | 21.4 | 25 |
| 2030 | 22.5 | 35 |
| 2050 | 24.7 | 50 |

**Scenario #3. O[2] w/CCS** *(Other Options with Carbon Capture and Storage).* This scenario examines GHG emissions reductions via (1) terrestrial offsets, (2) abatement of non-$CO_2$ GHG emissions, (3) $CO_2$ capture from industrial vents, and (4) efficiency improvements in the residential, commercial, and industrial sectors. As a group, these are often discussed as the "no-regrets" options that everyone agrees should be pursued.

Figure 2 presents a supply curve for terrestrial offsets. It was developed by USDA and used by DOE in its assessment of the McCain Lieberman Act[6]. The supply of terrestrial offsets initially increases (between 2004 and 2012) as market penetration limits are relieved. Post-2020 the supply of these offsets shrinks as the sinks become saturated. CarBen3 has terrestrial offset supply curves for 2030 and 2050 based on the trends expected through 2020. The assumed incentive price for terrestrial sequestration is \$10 per ton of CO2 in 2012, increasing \$40 per ton in 2050. [As a comparison, the May 2006 price for $CO_2$ emissions reduction was 4.55 \$/t$CO_2$ on the CCX and 17.13 \$/t$CO_2$]

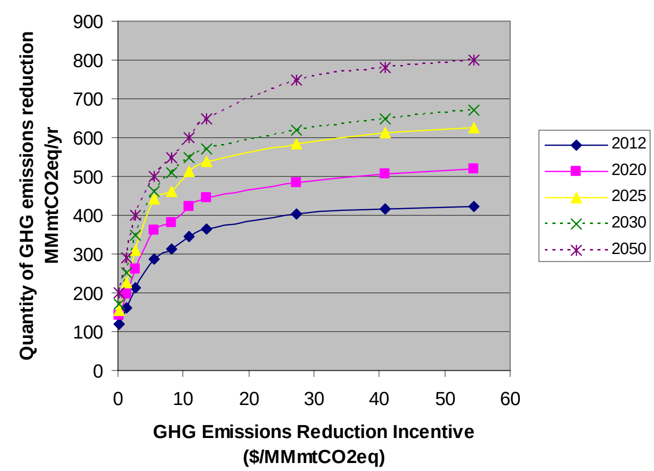
**Figure 2. U.S. Terrestrial Sequestration Supply Curve**




Source; EIA analysis of S.139

Figure 3 presents a supply curve for non-$CO_2$ GHG emissions abatement in the U.S. It was developed by U.S. EPA and used by DOE in its assessment of the McCain Lieberman Act. The supply for non-$CO_2$ abatement increases over the analysis period as the overall level of Reference Case Non-$CO_2$ emission increases with economic activity. The assumed incentive price for non-$CO_2$ abatement is \$10 per ton of $CO_2$ in 2012, increasing \$40 per ton in 2050.

**Figure 3. Non-CO2 GHG emissions Reduction Supply Curve**




CarBen3 estimates that $CO_2$ emissions from industrial vents (e.g., natural gas processing, cement manufacture, ammonia production) will increase with economic growth from 110 million metric tons $CO_2$ in 2004 to 260 million metric tons in 2050. The model estimate that the great bulk of these high $CO_2$ concentration vents are captured in 2050 in response to incentives of \$40/MMmt$CO_2$ plus market based revenues from sale of this high concentration $CO_2$ into the $CO_2$-EOR market. In 2050 $CO_2$ emissions from residential, commercial, and industrial sources are estimated to decrease by 22% below the Reference Case due to efficiency improvements.

## Potential GHG Emission Reductions

Table 3 shows the expected levels of GHG emission reductions for each of the three scenarios ($E^2$, $T^2$, and $O^2$ w/CCS) as well as for the "Combined Portfolio" scenario that aggregates the gains from the three scenarios. A combined portfolio meets the atmospheric stabilization scenario goal.

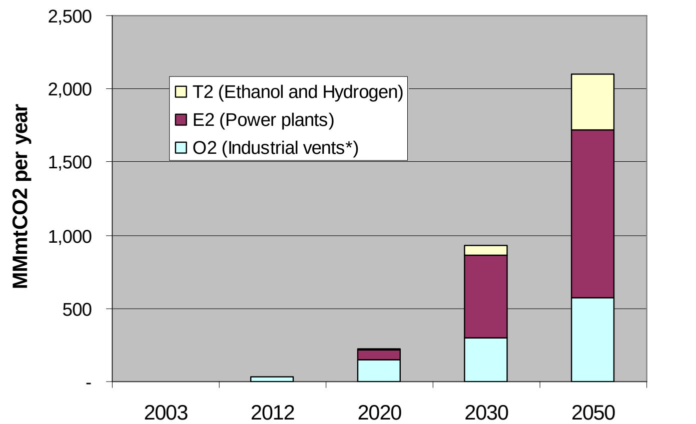
**Table 3. U.S. GHG Emissions and Reductions from the Reference Case, MMmt$CO_2$ eq/yr**

| | 2003 | 2012 | 2020 | 2030 | 2050 |
|---|---|---|---|---|---|
| U.S. GHG Emissions Reference Case Scenario | 6,931 | 7,896 | 8,545 | 9,782 | 11,825 |
| $E^2$ (Electricity Scenario) (Reductions below Reference Case) | | (235) | (497) | (1,447) | (2,626) |
| $T^2$ (Transportation Scenario) (Reductions below Reference Case) | | - | (259) | (745) | (2,017) |
| $O^2$ (Other options Scenario) (Reductions below Reference Case) | | (668) | (1,008) | (1,349) | (2,782) |
| Combined Portfolio Scenario (Reductions below Reference Case) | | (903) | (1,764) | (3,541) | (7,425) |
| Total U.S. GHG Emissions under the Combined Portfolio Scenario | | 6,993 | 6,781 | 6,241 | 4,400 |

## $CO_2$ Capture and Storage

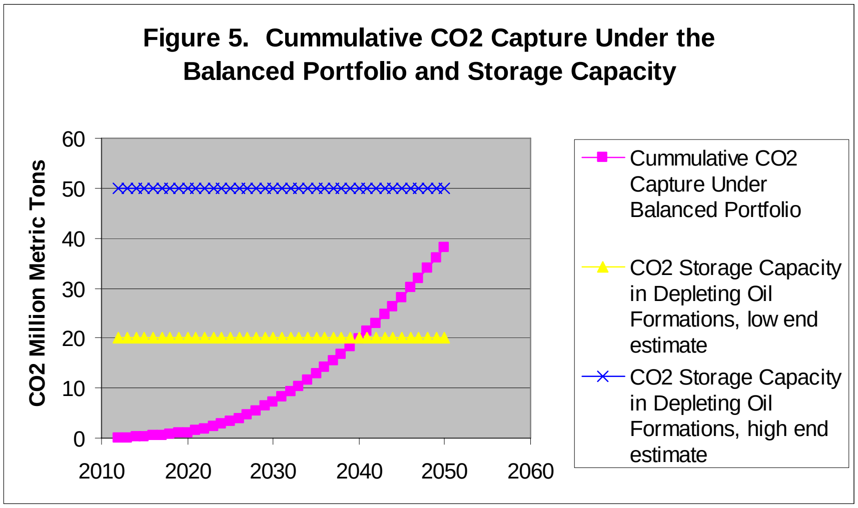
$CO_2$ capture and storage plays a key role in meeting the atmospheric stabilization goal, providing roughly 25% of the total GHG emissions reduction under the "Combined Portfolio" scenario. Figure 4 shows the amount of $CO_2$ captured and stored under the $E^2$, $T^2$, and $O^2$ scenarios. In general terms, $CO_2$ vents provide early opportunities for $CO_2$ capture, and the power sector dominates toward the end of the analysis period. $CO_2$ captured from upstream processing of transportation fuels make a significant contribution by 2050.

**Figure 4. CO2 Captured Under the U.S. Atmospheric Stabilization Scenario**




*Industrial vents include natural gas processing, steam reforming, cement mfr, and coal-derived liquids

Figure 5 shows that geologic formations underlying the contiguous United States have adequate capacity to accommodate the level of $CO_2$ capture projected under the "Combined Portfolio" scenario. By 2050, the cumulative amount of $CO_2$ captured and sequestered is 33 billion mt $CO_2$. The aggregate $CO_2$ storage capacity in depleting oil formations in the contiguous United States is estimated to be between 20 and 50 billion mt $CO_2$[7]. The low end of the CO2 storage capacity estimate is based on current industry enhanced oil recovery practices, and the high end estimate is based on vertical flooding, utilization of the residual oil zone, and other advanced approaches for storing $CO_2$ in depleted oil fields.




## Conclusions

A comprehensive set of actions to reduce $CO_2$ and other GHG emissions can achieve a GHG emissions trajectory over the next 50 years that is consistent with atmospheric stabilization at 550 ppm. This can be accomplished within reasonable rates of capital stock turnover and with supportable expectations for future technology performance.

$CO_2$ capture and storage provides roughly 25% of total GHG emissions reduction under the CarBen3 atmospheric stabilization scenario. The use of $CO_2$ sequestration is integral to re-powering the existing fleet of coal-fired power plants and helping transition the transportation sector to lower carbon fuels. The levels of $CO_2$ captured under the atmospheric stabilization scenario can be safely stored in depleted oil fields.

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