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May 1, 2007
New WRI analysis – "**A Snapshot of U.S. Energy Options Today: Climate Change and Energy Security Impacts and Tradeoffs in 2025"**

Dear Climate and Energy Colleague,

World Resources Institute has prepared the attached chart as background material as you review and consider policy options to address the issues of future U.S. energy security and greenhouse gas emissions levels.

The chart, ***A Snapshot of U.S. Energy Options Today: Climate Change and Energy Security Impacts and Tradeoffs in 2025***, compares selected energy technology options U.S. policymakers are considering today and the impacts these technology choices would have on our relative energy security and climate performance in 2025. The full methodology and background material is available at WRI's website (www.wri.org/usenergyoptions).

As you can see in the attached bubble chart, energy technologies in the upper right quadrant have a positive impact on climate change and energy security, while those in the lower left have a negative impact on both. Those in the other quadrants involve tradeoffs. The size of each bubble represents the potential of that technology to meet future energy demand.

Key take-away messages from this review:

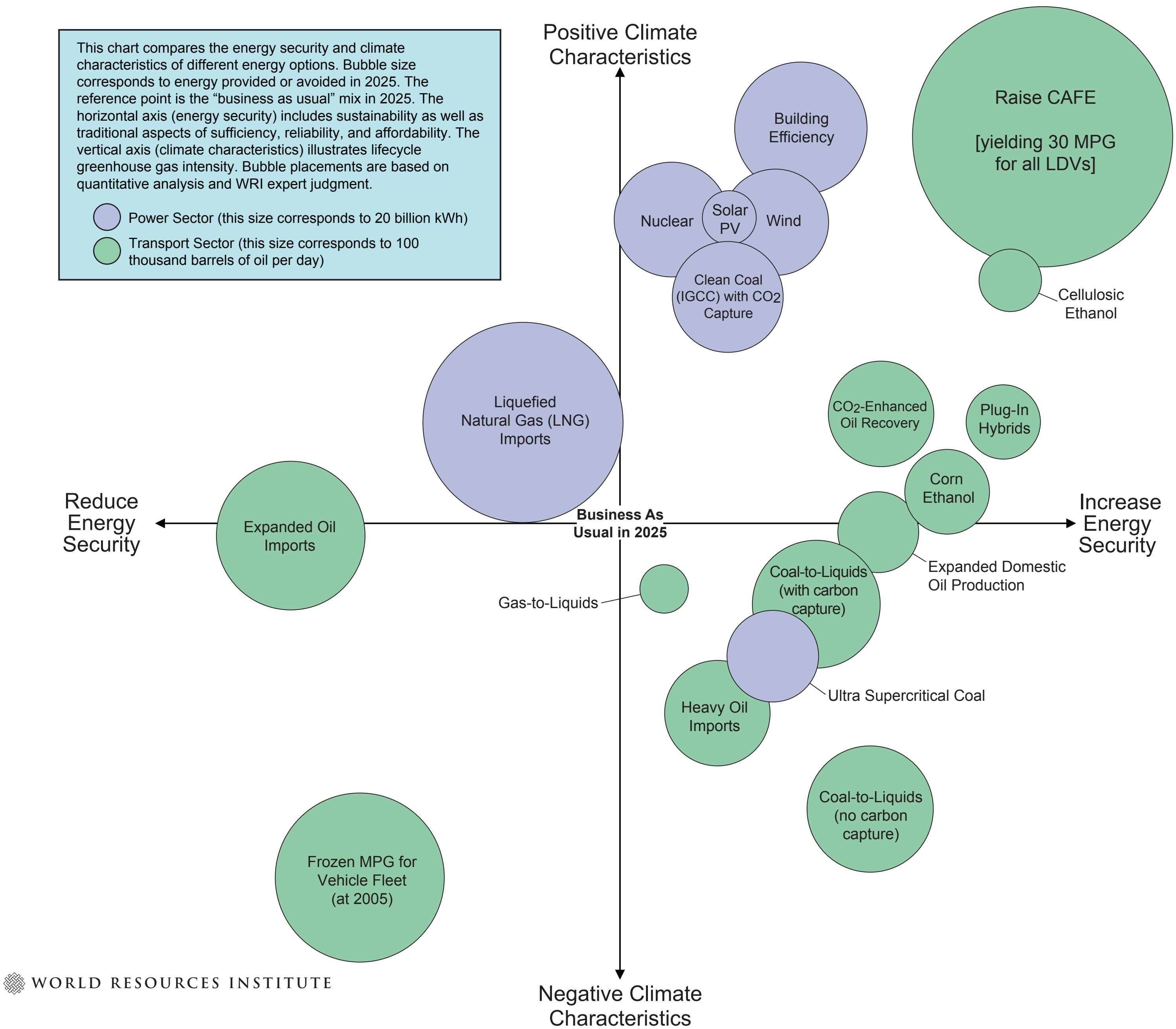
- Increasing fuel efficiency standards has the potential to make the biggest contribution to meeting our energy needs. In addition, this option has very strong positive implications for both energy security and climate.
- While coal-to-liquids can make a small contribution to increase U.S. energy security in this timeframe, pursuing this option would have significant negative impacts to the climate. Even if most of the CO_2 from the conversion process is captured and stored, climate impacts are still negative compared to petroleum.
- Ethanol from corn would deliver significant new energy and increase U.S. energy security, but would deliver relatively small benefits to the climate. This is due to the high energy input required to produce and process corn – and the fact that most of this energy is derived from fossil fuel (in particular, coal). Cellulosic ethanol will likely deliver slightly less energy than corn-based ethanol over this timeframe, but has a greater positive impact on climate change on a life-cycle basis.

The options graphed here are not drawn from specific pieces of legislation, nor are they part of an energy forecast. Different policy designs would lead to different placement of "bubbles" on the chart as well as influence the size of the bubbles themselves. Attached is basic background on the chart, and in a separate file, some basic technology descriptions. For specific assumptions, go to www.wri.org/usenergyoptions.

With best regards,

Jonathan Pershing
Director, Climate and Energy Program

A Snaphot of Selected U.S. Energy Options Today: Climate Change and Energy Security Impacts and Tradeoffs in 2025



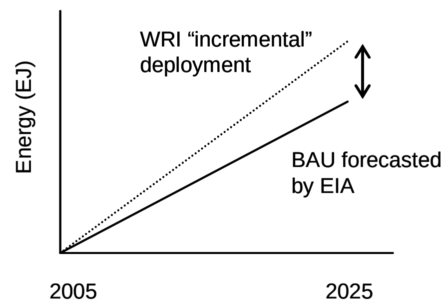
Date: **May 1, 2007**

For specific details on the assumptions underlying the options on this chart, go to http://www.wri.org/usenergyoptions

Discussion and Assumptions for U.S. Energy Options

This chart illustrates the climate and security impacts of selected energy options in the United States in 2025. There are cyclical debates in the U.S. about how to meet future energy needs. We are currently in a period of elevated concern due to a combination of high and unstable oil prices, uncertain supply, geopolitical dynamics, and the growing threat of climate change. Sufficient, reliable and affordable energy is considered the basis of any traditional definition of energy security—but sustainability, geopolitical, and social acceptability issues have become increasingly important in recent dialogues. A country's energy system is not secure, after all, if it consumes water supplies unsustainably, fuels political instability internationally, or results in strong local opposition. This chart allows for comparative analysis of different energy options meant to address energy security and climate change challenges.

Explanation of Chart



The size of each bubble represents one view of how much energy the option could deliver (or offset) in 2025 given a modest policy driver. These values are incremental to the amounts forecasted under existing business as usual scenarios (see figure). Sizes are based on a combination of existing forecasts in the literature and our largely qualitative view of how a moderate policy push would impact penetration of different options. Bubble size is measured as the amount of primary coal (power) or oil (transport) that would be offset by implementing each option. We chose coal and oil as the points of comparison for power and transport, respectively, because they are the current most likely options on the margin. Because energy is measured at the same upstream (primary) point of conversion, bubble sizes for each option can be directly compared. Table 1 lists our assumptions for each option.

The vertical axis illustrates climate characteristics, taking into account lifecycle greenhouse gas emissions for each option. The horizontal axis is a measure of the energy security characteristics of each option. While the vertical position of each bubble is relatively objective, horizontal placements are more subjective and open to discussion. Bubble location is the authors' assessment of the energy security and climate attributes for each option. We do not claim these placements as the only answer.

The chart is divided into four quadrants. Options in the top right quadrant have both positive climate and energy security characteristics. Increasing vehicle corporate average fuel economy (CAFE) standards, for example, directly offsets the need to import petroleum while also reducing CO_2 emissions. Options that fall in the bottom right quadrant have positive energy security but negative climate traits. Using coal-to-liquids (CTL) technology, for example, may allow reduced oil imports, but the additional CO_2 emissions resulting from the conversion of coal to liquid fuel are approximately 85% higher than standard petroleum use (without carbon dioxide capture and sequestration, CCS).

Options in the top left quadrant have positive climate but negative energy security characteristics. For example, expanding imports of liquefied natural gas (LNG) may expose the country to greater risks of potential imported fuel supply disruption, but this fuel is less carbon-intensive than the forecasted power sector mix in 2025. Finally, options in the bottom left quadrant, such as expanded reliance on imported oil or an effective "freeze" in actual vehicle fleet mileage, have both negative energy security and climate implications.

Increases or decreases in CO_2 from the business as usual (BAU) status quo were estimated for each option and included in Table 1. For the power sector, the BAU is the mix of energy sources forecasted (by U.S. DOE EIA) to provide this power (coal, nuclear, natural gas, etc.) in 2025. For the transport sector, the BAU is the forecasted mix of energy sources in this sector (mostly petroleum) in 2025.

The chart represents one of many possible energy snapshots of the future and is meant to encourage discussion. It is not an energy forecast and does not include feedback effects. Assumptions used in sizing and locating each bubble are described on the following pages.

Deployment Assumptions

WRI surveyed a wide range of reports, forecasts, and expert opinions to arrive at estimates of the potential deployment for each option under a moderate policy driver in 2025. Drivers could include broad measures, such as a greenhouse gas cap and trade system, or specific targets like a renewable portfolio standard or tax credits for nuclear power. To compare options against one another, we estimate the primary coal (power sector) or oil (transport sector) in EJ that could be offset by implementing each option. Related studies and forecasts are also provided as additional points of comparison.

Table 1. Assumptions Underlying the Amount of Energy Provided or Avoided from Each Option

Energy Option	Energy (EJ)	CO_2 (MMT)	WRI Assumptions, Compared to Business as Usual (BAU) in 2025	Other Studies/Forecasts
Electric Power Sector				
Nuclear	1.3	-80	Additional 20 GW of nuclear capacity (5-10 plants).	• EIA reports nuclear capacity of about 100 GW in 2005. • EIA forecasts 9 GW unplanned additions by 2025 in the reference case, 24 GW of new capacity in the high price case, and 27 GW of new capacity in the high growth case. • The U.S. Nuclear Regulatory Commission (NRC) is expecting 22 applications over the next two years, for at least 32 new reactors.
Clean Coal (IGCC) with CCS	1.1	-40	Additional 15 GW of integrated gasification combined-cycle (IGCC) plants with carbon capture & storage (15-60 plants). Assumes 20% energy penalty and 90% capture efficiency.	• EIA forecasts 67 GW of power from IGCC by 2030 in the reference case scenario, assuming no carbon regulation. • NETL reports that over the next 10 years, 159 coal based electricity plants (96 GW) are expected to come into service, 32 of which are proposed to be built using IGCC, roughly 10 GW capacity.
Imported LNG	3.7	-35	Additional 40 BCM (1.4 trillion cubic feet) of imported LNG, fueling 48 GW of additional combined-cycle plants.	• EIA reports net imports at 0.6 trillion cubic feet (tcf) in 2005. • EIA forecasts 4.5 tcf of net LNG imports in the reference case for 2030, 5.7 tcf in the high growth case, and 7.5 tcf in the low price case.
Wind	1.2	-70	Additional 50 GW capacity from wind farms.	• EIA reports wind farm capacity of 9.6 GW in 2005, and forecasts a total of 18 GW capacity by 2025 in their reference scenario. • The American Wind Energy Association (AWEA) estimates that 6% of U.S. electricity could be supplied by wind in 2020 under an aggressive growth strategy. This would equate to 330 billion kWh in 2025, or 123 GW total capacity.

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Energy Option	Energy (EJ)	CO_2 (MMT)	WRI Assumptions, Compared to Business as Usual (BAU) in 2025	Other Studies/Forecasts
Building Efficiency	1.7	-100	Savings of 1.6 QBtu from an additional 20% increase in the efficiency of building electricity use.	• A study by ACEEE estimates that the median achievable potential across a number of state studies was 24% for electricity, which could be achieved at an average of 1.2% per year. They suggest a total potential of lowering national energy use through energy efficiency by 33% in 2020. • ACEEE also reports that a DOE study estimated that increasing energy efficiency throughout the economy could cut national energy use by about 20% in 2020. • EIA forecasts that the residential and commercial sectors will need 7.8 QBtu of additional generation between now and 2025.
Solar Photovoltaics	0.3	-15	Additional 16 GW capacity from solar photovoltaics, which assumes an annual growth rate of 25% through 2025.	• EIA reports 2005 capacity at roughly 0.21 GW producing 2,700 GWh of electricity. • EIA forecasts 2025 capacity at roughly 1.53 GW producing 3100 GWh of electricity. Annual growth rate for solar PVs is 23% in the electric power sector and 11% in all other sectors (where the most of the current capacity is). • A study by NREL (PV Roadmap) proposes a goal of attaining a 25% annual growth rate for PVs to 2020.
Ultra-Supercritical Coal	0.8	+25	Additional 15 GW of ultra-supercritical pulverized coal (PC) plants achieving 45% efficiency (HHV). (15-30 new plants).	• EIA forecasts 35 GW of new supercritical pulverized coal (PC) plants 2020, and 79 GW by 2030 in the reference scenario. • NETL reports that in the next 10 years, 159 new coal based plants are expected to come online. Of these new plants 14 are expected to use supercritical PC and 4 to use ultra-supercritical PC combustion technology for their operations, with a total capacity of approximately 16 GW.

Energy Option	Energy (EJ)	CO_2 (MMT)	WRI Assumptions, Compared to Business as Usual (BAU) in 2025	Other Studies/Forecasts
Transport Sector				
Raise CAFE (30 MPG LDV fleet average)	6.3	-410	Savings of 3.1 million barrels per day (mb/d) or 48 billion gallons (bgal) from an increase in CAFE or similar measure that results in an average achieved fuel economy of 30 MPG for light duty vehicles (versus about 20 MPG today). Light duty vehicles include passenger cars and light trucks under 8,500 lbs. EIA forecasts that the MPG for LDVs will increase from 19.6 in 2005 to 21.8 in 2025 in the reference scenario. EIA forecasts vehicle miles traveled (VMT) at 3.8 trillion in 2025. If that LDV fleet averages 30 MPG instead of 21.8 MPG, this savings would result.	• CAFE currently is set at 27.5 MPG for new cars, though the average achieved fuel economy for the LDV fleet is roughly 20 MPG (EIA). • The Ten in Ten Fuel Economy Act (S.357) introduced by Senator Feinstein (D-CA) would require new cars and light trucks to get 35 MPG in 2019. The Union of Concerned Scientists estimates that this would save 2.3 mb/d or 35 bgal of gasoline in 2027. • The Fuel Economy Reform Act (S.767) introduced by Senator Obama (D-IL) would push for an increase in CAFE of roughly 4% per year beginning in 2013. The sponsors of a similar bill submitted in 2006 estimated that it will save a cumulative total of 549 bgal by 2028.
Expanded Oil Imports	2.0	+5	Additional 1.0 mb/d (15 bgal) of additional oil imports, roughly an 8% increase in imports.	• EIA reports 22.1 QBtu (23 EJ) of crude oil imports in 2005. They forecast annual imports at 28.6 QBtu (30.2 EJ) in the reference scenario, 33.2 QBtu (35 EJ) in the high economic growth case.
CTL	1.5	+85	Additional 0.75 mb/d (11 bgal) from "coal-to-liquids" (CTL). Assumes 85% more carbon intensive than petroleum.	• EIA assumed 0.9 QBtu for the reference case in 2030, 3.5 QBtu in high price case. This is a difference of about 2.7 EJ, or 20 bgal.
CTL with CCS	1.5	+25	Additional 0.75 mb/d (11 bgal) from "coal-to-liquids" (CTL). Assumes 85% more carbon intensive than petroleum and 70% of process emissions sequestered.	• EIA assumed 0.9 QBtu of traditional CTL (no CCS) for the reference case in 2030, 3.5 QBtu in high price case. This is a difference of about 2.7 EJ, or 20 bgal.
GTL	0.2	+5	Additional 0.1 mb/d (1.5 bgal) from "gas-to-liquids" (GTL). Assumes 25% more carbon intensive than petroleum.	• EIA assumed no production in the reference case in 2030, 0.15 QBtu in high price case, a difference of about 0.16 EJ, or 1.2 bgal.

Energy Option	Energy (EJ)	CO_2 (MMT)	WRI Assumptions, Compared to Business as Usual (BAU) in 2025	Other Studies/Forecasts
Corn Ethanol	0.7	-7	Additional 0.5 mb/d (8 bgal). Assume better technology and additional land used for corn can expand yield to 20 bgal. Assumes that corn ethanol reduces CO_2 emissions by 15% compared to petroleum, and has a 30% lower energy density.	• EIA reports ethanol consumption in 2005 at about 4 bgal, and forecasts about 12 bgal in 2025. • EPAct 2005 mandates 7.5 bgal of renewable fuels by 2012. • In his 2007 State of the Union Address, President Bush called for 35 bgal of "renewable and alternative fuels" in 2017. • Senators Lugar (R-IN) and Harkin (D-IA) introduced the Biofuels Security Act in May 2006, which would set a renewable fuels standard of 30 bgal per year by 2020 and 60 bgal by 2030. • A study by Alex Farrell *et al* finds that corn ethanol reduces GHG emissions by 13% compared to petroleum (*Science*, January 2006).
Cellulosic Ethanol	0.4	-20	Additional 0.3 mb/d (5 bgal). Assumes lower costs for cellulosic ethanol and higher oil prices. Assumes that cellulosic ethanol reduces CO_2 emissions by 80% compared to petroleum.	• EIA forecasts roughly 5 bgal of cellulosic ethanol produced in 2025 under a scenario of lower capital and operating costs and high energy prices. • The National Commission on Energy Policy estimates that the U.S. could produce 2.2-4.1 mb/d (34 to 63 bgal) of cellulosic ethanol by 2025.
Heavy Oil Imports	1.0	+35	Additional 0.5 mb/d (8 bgal) from heavy oil imports from primarily Canada and Venezuela. Assumes 50% more carbon intensive than traditional petroleum.	• EIA forecasts that the U.S. will increase annual imports of unconventional oil from Canada and Mexico from 1.1 to 3.3 mb/d (17 to 50 bgal) by 2025. • Wood MacKenzie forecast that Canada will increase oil sands production from 1 to 4 mb/d (15 to 60 bgal) by 2020.
CO_2 EOR with CCS	1.0	-25	Additional 0.5 mb/d (8 bgal) from "enhanced oil recovery" production from domestic sources using carbon dioxide as a stimulant.	• DOE reports that about 3 bgal was produced by CO_2 EOR in 2004, and that total potential for all types of EOR in the U.S. is 210 billion barrels. • A DOE/NETL analysis forecasts that CO_2 EOR oil production could quadruple by 2020 with CO_2 incentives.
Expanded Domestic Oil Production	0.6	<5	Additional 0.3 mb/d (5 bgal) production from domestic oil and natural gas sources previously considered "off-limits".	• EIA forecasts that removing drilling restrictions from the outer continental shelf of the lower 48 states would yield 0.2 mb/d or roughly 3 bgal. • EIA forecasts that if technology advances in the oil industry occur more rapidly than expected, domestic crude oil production could increase 0.3 mb/d in 2030.

Energy Option	Energy (EJ)	CO_2 (MMT)	WRI Assumptions, Compared to Business as Usual (BAU) in 2025	Other Studies/Forecasts
Frozen MPG	2.6	+170	Assumes a policy weakening CAFÉ is adopted, resulting in no increases in vehicle efficiency from today's levels (~20 MPG). Additional 1.3 mb/d (20 bgal) of fuel is required.	• EIA forecasts travel by LDVs to increase 45% from 2005 to 2025, and average vehicle efficiency to increase from 19.6 to 21.8 MPG. This bubble assumes that the vehicle-miles traveled and the efficiency remain unchanged from today.
PHEVs	0.5	-15	Additional 0.3 mb/d (4 bgal) oil offset by 6 million vehicles. 30,000 PHEVs on the road in 2009, 40% annual growth rate yields about 6 million vehicles in 2025. Assumes that 50% of the needed power requires addition power plant operation (and the remaining 50% would be "free" from off-peak generation that occurs anyway).	• A study by NREL estimates that a high level of market penetration by PHEVs could be obtained with advances in technology, reductions in costs, high oil prices, policies to promote energy security, and carbon constraints. In this high case, they forecast 80 million PHEVs on the road by 2025. PHEVs introduced in 2008 and achieve a 50% market share of the light-duty vehicle stock by 2050. • A study by EPRI assess the potential impacts of 25 million PHEVs in 2025 and 70 million in 2050.

Notes:

- Energy (EJ) values for the power sector options are equivalent to what would have otherwise been consumed by coal power plants to generate an equivalent amount of electricity (1 EJ or exajoule equals 10^18 joules).
- Energy values for the transport options are equivalent to the amount of petroleum that would have been consumed.
- CO_2 (MMT) are the estimated reductions (-) or increases (+) from each policy option in million metric tons of CO_2.
- A gigawatt (GW) is one billion watts of electric generating capacity, roughly equivalent to that of a typical large power plant.
- The U.S. currently consumes roughly 21 million barrels of crude and petroleum products per day (315 bgal), about 65 percent of which is imported.

General assumptions for power sector options:

- Coal consumed in the electric power sector has an energy content of approximately 23 MJ per mt.
- Capacity factors of 85% for nuclear, 75% for coal and natural gas, 30% for wind.
- Efficiency factors in 2025 of 41% for subcritical pulverized coal, 45% for ultra supercritical pulverized coal, and 61% for natural gas combined-cycle plants.
- A 1 GW coal plant emits about 5.6 million metric tons of CO_2 ($MMTCO_2$) per year.
- The electric power sector will emit an average of 530 metric tons of CO_2 per GWh produced in 2025 (EIA).

General assumptions for transport sector options:

- Fuel consumed in the transport sector (primarily motor gasoline and diesel) has an energy content of 5.7 MJ per barrel.
- 12.5 bgal of ethanol is roughly equivalent to 1 EJ.
- One mb/d is equivalent to 15.3 bgal per year.
- The transport sector will emit an average of 65 $MMTCO_2$ per EJ consumed in 2025 (EIA).

Energy Security Assessment

Each option was assessed based on an expanded definition of energy security, which includes elements of sufficiency, reliability, affordability, sustainability, socially acceptance, and geopolitically factors. Most options in the transport sector offset imports of foreign oil, and thus have relatively higher energy security benefits.

Table 2. Energy Security Implications of Each Option

Energy Option	Discussion
Electric Power Sector	
Nuclear	*Positive:* Very low air emissions, especially CO_2; high availability; diversifies fuel supply. *Negative:* expensive; low social acceptability; waste disposal barriers; potential terrorist target.
Clean Coal (IGCC) with CCS	*Positive:* Coal is sufficient, reliable and affordable as currently priced. IGCC largely overcomes criteria pollution concerns. *Negative:* IGCC with CCS is expensive and social acceptability is uncertain; need for new CO_2 transport infrastructure and safety regulations at storage sites.
Imported LNG	*Positive:* Relatively clean burning; combined-cycle plants quick to build. Significant new supplies coming on-stream around the globe. *Negative:* increases exposure to global uncertainty; relatively expensive; import terminals and tankers are potential security threats.
Wind	*Positive:* Constant fuel costs; clean; diversifies energy supply; high national social acceptability. *Negative:* power generation not always available (capacity factor of roughly 30%); some local opposition (NIMBY); currently depends on production tax credit.
Building Efficiency	*Positive:* Sufficient, reliable, affordable, sustainable, and socially acceptable. *Negative:* does not offset oil imports; mixed political support.
Solar PV	*Positive:* Constant fuel costs; clean; diversifies energy supply; high national social acceptability. *Negative:* power generation not always available (capacity factor of roughly 20%); currently relies on tax subsidies.
Ultra Supercritical Coal	*Positive:* Coal is sufficient and reliable; ultra-supercritical is relatively efficient, and becoming more commonly used in Europe and Asia; *Negative:* relatively expensive and polluting; somewhat tarnished perception in the U.S. from historical experience.
Transport Sector	
Raise CAFE (30 MPG LDV fleet average)	*Positive:* Offsets oil imports from and wealth transfer to unstable nations; cumulative impacts build throughout fleet turnover; affordable. *Negative:* Mixed political traction.
Expanded Oil Imports	*Positive:* Still relatively affordable compared to alternative fuels. *Negative:* Increases reliance on uncertain global system; wealth transfer to other nations; postpones inevitable transition to a less-petroleum-intensive future.
CTL	*Positive:* Offsets oil imports from unstable nations. Coal is sufficient. *Negative:* expensive; significant climate and sustainability concerns.
CTL with CCS	*Positive:* Offsets oil imports from unstable nations. Coal is sufficient. *Negative:* expensive; significant climate and sustainability concerns; social acceptability of CCS is uncertain; need for new CO_2 transport infrastructure and safety regulations at storage sites.
GTL	*Positive:* Offsets oil imports. *Negative:* increases reliance on natural gas, much of which is from the same regions; relatively energy intensive; energy penalty.

Energy Option	Discussion
Corn Ethanol	*Positive:* Offsets oil imports; diversifies energy supply. *Negative:* Decreased food security, limited land availability, increased fertilizer and water use; energy intensive process.
Cellulosic Ethanol	*Positive:* Offsets oil imports; can be grown in many regions without impacting food production, fertilizer and water use; and auxiliary energy requirements. *Negative:* Not yet commercial.
Heavy Oil Imports	*Positive:* Offsets oil imports from unstable nations if imported from Canada; sufficient, reliable. *Negative:* currently expensive; energy intensive; serious sustainability issues.
CO_2 EOR with Carbon Sequestration	*Positive:* Offsets oil imports; allows otherwise-unlikely domestic oil production; can make good use of otherwise-polluting CO_2. *Negative:* currently limited in application; CO_2 transport infrastructure needed; concern about additionality.
Expanded Domestic Oil Production	*Positive:* Offsets oil imports; reduces wealth transfer. *Negative:* Low social acceptability; remaining resources are limited and relatively expensive to access.
Frozen MPG	*Positive:* May favor domestic carmakers. *Negative:* Increases oil imports and wealth transfer to other nations, increases need to expand domestic oil production, postpones inevitable transition to a less-petroleum-intensive future.
PHEVs	*Positive:* Offsets oil imports; affordable fuel; can be low-carbon alternative if grid has low carbon mix; can capture otherwise lost energy in off-peak generation. *Negative:* Batteries expensive and not yet commercial; can have little climate benefit if grid is largely coal-based.

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