EPA Analysis of the Transportation Sector

Greenhouse Gas and Oil Reduction Scenarios

February 10, 2010

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Framing and Assumptions

Analysis Request

JOHN KERRY
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COMMITTEES:
COMMERCE, SCIENCE AND TRANSPORTATION
FINANCE
FOREIGN RELATIONS
SMALL BUSINESS

United States Senate
WASHINGTON, DC 20510-2102

September 9, 2009

The Honorable Lisa Jackson
USEPA Headquarters
Ariel Rios Building
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Dear Administrator Jackson:

I am writing to respectfully request additional information in the Environmental Protection Agency's (EPA) modeling of H.R.2454, the American Clean Energy and Security Act of 2009.

Thank you for the excellent work the EPA has done to model the greenhouse gas reductions and oil savings associated with H.R.2454. However, the analysis does not account for additional reductions that could potentially be achieved with additional, complementary transportation policies. I respectfully request that you provide information on the greenhouse gas emission reductions and oil savings that could be achieved from a variety of transportation policies, including more aggressive fuel economy standards and policies to address vehicle miles traveled.

Thank you for your consideration of this request. If you have any questions or concerns, please do not hesitate to contact Kathleen Frangione on my staff at 202-228-3227.

Sincerely,

John F. Kerry

Interpretation of Request

- The letter from Senator Kerry requested information on "additional reductions that could potentially be achieved with additional, complementary transportation policies," in the context of previous analyses of an economy-wide cap.
  - The examples given in the request—"more aggressive fuel economy standards and policies to address vehicle miles traveled"—would, under an economy-wide cap that includes transportation fuels, provide additional transportation-specific reductions, but would not provide any reductions that are additional to those required by an economy-wide cap.
    - Given the examples cited, we interpreted the request as asking what additional emission reductions could be achieved directly from the transportation sector if effective transportation-specific drivers were in place.
    - Costs for the transportation sector scenarios have not been considered in this analysis.
  - Any approaches that specifically reduced transportation greenhouse gases (GHGs) would reduce the emission requirements needed from other sectors (e.g., electricity) under the cap, but would have no net effect on economy-wide emissions.
    - Additional modeling to integrate these results with an economy-wide cap, taking relative costs into consideration, is not part of this analysis.
    - Large oil savings resulting from these policies may also act to promote greater international GHG leakage, because a large drop in domestic oil consumption could lower the world oil price, stimulating demand elsewhere.
- We considered this request to be a broad scoping exercise of potential tailpipe GHG reductions and oil savings in the US transportation sector, using technologies and travel efficiency measures that are known and considered to be technologically feasible. Therefore, this analysis focuses on vehicle tailpipe emissions and fuel consumption based on:
  - Technology advancements for new vehicles and equipment across these subsectors,
  - Potential improvements to the existing fleet where technologies are readily available but not yet fully utilized,
  - Improvements in travel efficiency and operational measures, and finally,
  - Shifts from liquid fuels to electricity
    - Renewable fuels are in the baseline through the Renewable Fuel Standard and so are not further addressed.
- We did not assess the relative costs of the reductions, nor did we compare the relative merits of the various policy approaches that could be used to achieve them.

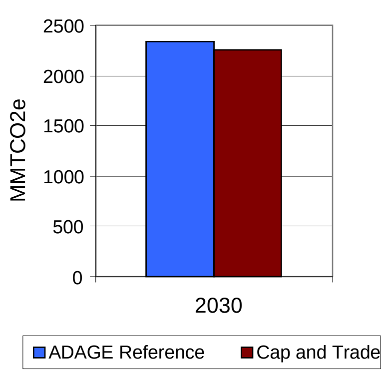
Potential Policy and Market Drivers

- The types of polices that could potentially be used to achieve transportation sector reductions include (but are not limited to):
  - Vehicles, engines, and equipment
    - GHG standards
    - R&D funding
    - Manufacturer and start-up funding/tax incentives for production facility retooling/capital costs
    - Requirements or incentives to retrofit existing fleets with low-GHG technologies (e.g., enhanced aerodynamics)
    - Accelerated fleet turnover programs, such as Cash for Clunkers
    - Programs that incentivize low-GHG purchases, such as feebates or tax incentives
    - Low-interest loans to fund capital investments in more efficient trucks and equipment
  - Fuels
    - Renewable fuels polices such as Renewable Fuels Standard and/or Low Carbon Fuel Standard
    - Requirements to offset increases in GHGs from petroleum-based fuels (e.g., to address tar sands)
    - Border tax adjustments for imports of higher-GHG fuels
  - Public funding for transportation infrastructure
    - Funding for development of the infrastructure needed to fuel electric or hydrogen vehicles
    - Funding for mass transit, compact development, traffic management
    - Infrastructure support for mode-shifting freight from truck to rail or barge
  - Enhancements to current planning process
    - Better integrated land-use, transportation, and environmental planning at the state/local level
  - Information programs to address imperfect information concerns
    - Provide confidence in fuel savings from technologies and operational strategies
    - Connect broader shipper and carrier community to maximize efficiency in system-wide operations
    - Support ridesharing, eco-driving techniques, idle reduction
  - Taxes on Carbon, Fuel, Vehicle Miles Traveled (VMT)
  - Cap-and-Trade
- This analysis does not consider the policy or market choices that would be needed to generate certain GHG outcomes, which is a valuable but complex analysis. Instead, it focuses more narrowly on the GHG reductions that could be derived directly from the transportation sector if effective drivers were in place. We make no assessment of the relative merits, costs, or impacts of various approaches.

Comparison of Transportation Measures with Economy-Wide Cap

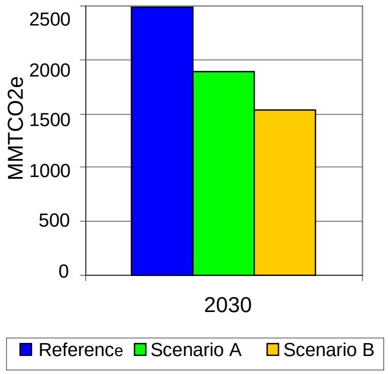
- Under recently proposed economy-wide caps, transportation is projected to achieve reductions of 80 million metric tons of CO2-equivalent (MMTCO2e) in 2030, a reduction of about 3.5% from the 2030 reference case.
- Although transportation is currently responsible for 28% of GHG emissions in the US, it is projected to produce only about 5% of the covered sector GHG reductions under these caps.
  - This is because the increase in gasoline prices that results from the carbon price ($0.25 in 2030) is not projected to be sufficient to substantially change consumer or manufacturer behavior. This is particularly true given that transportation is heavily reliant on petroleum-based fuels and alternative transportation choices are not readily available.
- H.R. 2454 (Waxman-Markey) and S. 1733 (Kerry-Boxer), which are currently pending in Congress, contain both cap and trade provisions and complementary transportation-related policies to reduce GHG emissions. EPA analysis of the cap and trade portions of those bills reveal negligible differences between the two bills with respect to their effect on transportation sector emissions. EPA has not modeled the GHG emissions reductions that would result from many of the transportation-related policies included in the legislation. Enactment of the transportation-related policies in the bills would achieve greater emissions reductions from the transportation sector than the cap alone.

- This analysis portrays transportation-specific scenarios, which are modeled here separately from a cap.
  - These scenarios explore technologically feasible GHG reductions that are available to the transportation sector but are not driven by today's market conditions.
- The analysis looks at two scenarios—A and B—which are described throughout this briefing. This analysis suggests that such reductions in the U.S. transportation sector could be on the order of 600-1000 MMTCO2e in 2030, or 26-40% below the 2030 reference case.
- The implication of transportation policies reducing capped emissions is that overall reductions under the cap would remain the same, but some of the reductions would shift from other sectors to transportation.



Transportation emissions in the cap analyses consist of the ADAGE model transportation category and residential category (which is primarily made up of personal automobile use). ADAGE does not explicitly model new developments in transportation technologies—these reductions occur in the model due to the price changes resulting from the imposition of the upstream cap on emissions from the petroleum sector.

EPA has not evaluated how the overall costs of these two approaches to reducing greenhouse gases compare.



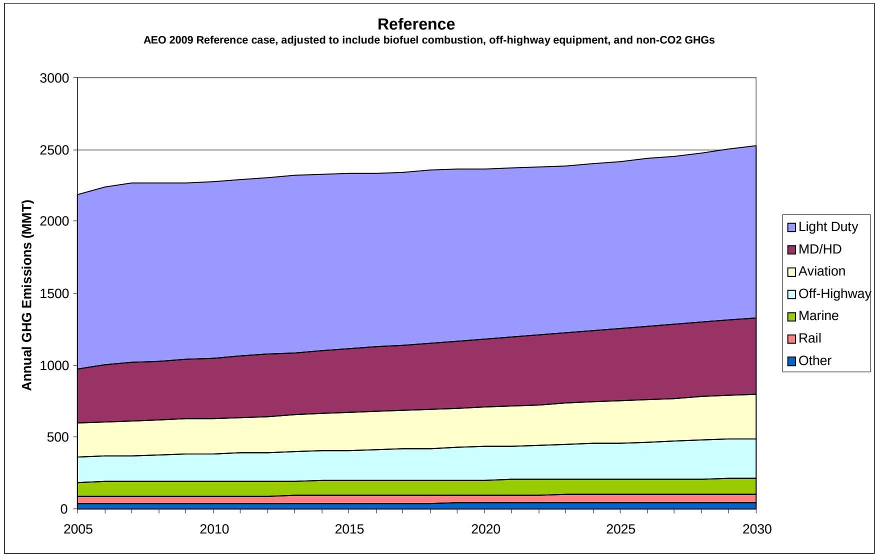
This analysis has a somewhat higher reference 2030 emissions than the cap analyses because it includes tailpipe emissions from biofuels (which are assumed to be zero under the cap). Biofuel consumption for all scenarios is assumed to remain at levels consistent with the volumes required under the Renewable Fuel Standard.

Scenarios and Results by Subsector

Reference Case

EIA's Annual Energy Outlook AEO 2009 (March release) reference case is used as the baseline in this analysis to ensure consistency with other analyses. AEO 2009 assumes the following:

- AEO 2009 covers light-duty vehicles (cars and light trucks), commercial light trucks (8,501-10,000 lbs gross vehicle weight), freight trucks (>10,000 lbs gross vehicle weight), freight and passenger aircraft, rail, freight shipping (waterborne), and miscellaneous transport such as mass transit.
- AEO 2009 assumes EISA fuel economy levels for light duty vehicles plus improvements in vehicles and engines due to fuel price effects.
  - Fuel economy standard assumptions in AEO 2009 for new light-duty vehicles:
    - Through model year 2010: reflect current law
    - Model years 2011 through 2015: reflect DOT/NHTSA's proposed Corporate Average Fuel Economy (CAFÉ) standards
    - Model years 2016 through 2020: reflect the Energy Independence and Security Act of 2007 (EISA) requirements--new light vehicles achieve 35 mpg by model year 2020
    - 2021-2030: assumes new light duty vehicles exceed these projected requirements due to fuel price effects, reaching 38 mpg by 2030.
    - Note that the recent EPA/NHTSA Joint Light Duty rulemaking proposal reaches 35 mpg by 2016. Because the AEO 2009 release predated the proposed rule, this incremental improvement beyond EISA in the 2017-2020 timeframe is not reflected in the baseline. The early release of AEO 2010 does model the joint rulemaking more precisely and will be used in future analyses.
  - For other transportation subsectors, assumptions about fuel-efficiency vary, but are generally based on analysis of the availability of fuel-saving technologies, future fuel prices, and/or historic rates of efficiency improvements
- For all sectors, AEO 2009 assumes increases in transportation activity. These increases offset some or all of the GHG reductions from adoption of fuel-saving strategies.



- AEO 2009 projections in some cases assume that the markets adopt fuel efficiency to a greater degree than has been reflected historically, in the absence of policy drivers. Thus, AEO projections may incorporate some GHG reductions in the reference case that are more appropriately assigned to the scenarios. Nevertheless, since the AEO reference case is widely utilized as a base case for analyses, we use it here, with the following adjustments:
  - Emissions from the off-highway subsector—such as farm, construction, and mining equipment--is not included under transportation in AEO.   Since emissions from this subsector have historically been addressed through mobile source requirements under the Clean Air Act, they are included in this analysis. Baseline projections come from the EPA NONROAD model, and amount to 257 MMTCO2e in 2030.
  - Biofuels are counted as zero tailpipe GHG emissions by AEO.   Because this analysis focuses on tailpipe emissions, we include them here, at volumes required by the Renewable Fuel Standard. This amounts to 227 MMTCO2e annually, included in the baseline as well as in the scenarios. (Indirect emissions from biofuel production are not included.)
  - We adjusted for other GHGs–primarily N20 and a small amount of methane—by increasing the tons of CO2 derived from fuel consumption values by about 3%, or about 70 mmt.
- The AEO 2010 Early Release has a number of differences from AEO 2009; these changes work in both directions with respect to projected fuel consumption and GHG emissions. Specifically, the 2010 early release projects higher mpg levels for light duty than does AEO 2009, along with higher rates of activity for highway and aviation. The activity levels for rail and marine are projected to be somewhat lower. The combination of these effects would be expected to have only a minor impact on the results this analysis.

Scenario Overview

- This analysis provides potential GHG and energy demand reductions from two scenarios for each transportation subsector.
- This analysis is focused on vehicle energy consumption and tailpipe emissions.
  - It does not take into consideration upstream impacts of fuel production and distribution (petroleum, biofuels, nor electricity), nor does it consider vehicle manufacturing and disposal impacts.
- Scenarios are based on technical and operational approaches that are considered to be feasible in the 2015-2030 timeframe by expert analysts under relatively optimal conditions.
  - This analysis does not assess the relative merits or costs of the policy or market drivers themselves.
- We looked at two scenarios, A and B. Scenarios A and B can be loosely considered to be somewhat aggressive and very aggressive, respectively. They do not reflect the entire range of possible outcomes, but rather, a set of outcomes that could occur, based on technical feasibility, if effective policy or market drivers were in place.
- These scenarios assume annual improvements in GHG rates greater than historical norms, which tend to reflect periods of static policy and market conditions.
- Current levels of vehicle utility and transportation opportunities are assumed to be maintained, which implies that reductions in fuel consumption derive entirely from the use of improved technologies and operational strategies, rather than from reducing vehicle utility or transportation options.
- Throughout this analysis, the illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards. The scenarios represent a set of reductions that could occur depending on the strength of regulatory and market drivers.

Analytical Limitations and Caveats

- The EPA GHG transportation models do not formally represent uncertainty. Alternative scenarios have been included to provide a range of values and to show the impact of different assumptions. However, this range should not be interpreted as a confidence interval or as representing upper and lower bounds for what is technologically possible.
  - Modeling was done primarily using EPA's Advanced Transportation Limited Analysis Spreadsheet (ATLAS). This in-house EPA tool is a GHG emissions and energy consumption accounting spreadsheet model for the transportation sector.
- Additional factors such as potential adverse or favorable impacts on safety, consumer welfare, or travel time are not taken into consideration.
- These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards.
- All rates of improvement are expressed as annual, compound rates of GHG reduction for ease of comparison. Actual modeling is more complex.
- Costs
  - Costs of different strategies were not assessed on a relative basis.
  - Macro-economic effects were not considered.
  - Capital costs, such as those entailed by converting to more fuel-efficient fleets or upgrading infrastructure, were not assessed.
- The baseline does not reflect improvements in transportation efficiency and technology adoption included by higher allowance prices in an economy-wide cap-and-trade program such as H.R. 2454 or S. 1733.
- Assumes a light duty vehicle miles traveled rebound effect of 10% in the United States due to decreased fuel costs per mile from improved vehicle efficiency. This analysis does not take into account any rebound in global demand due to decreased prices of petroleum.

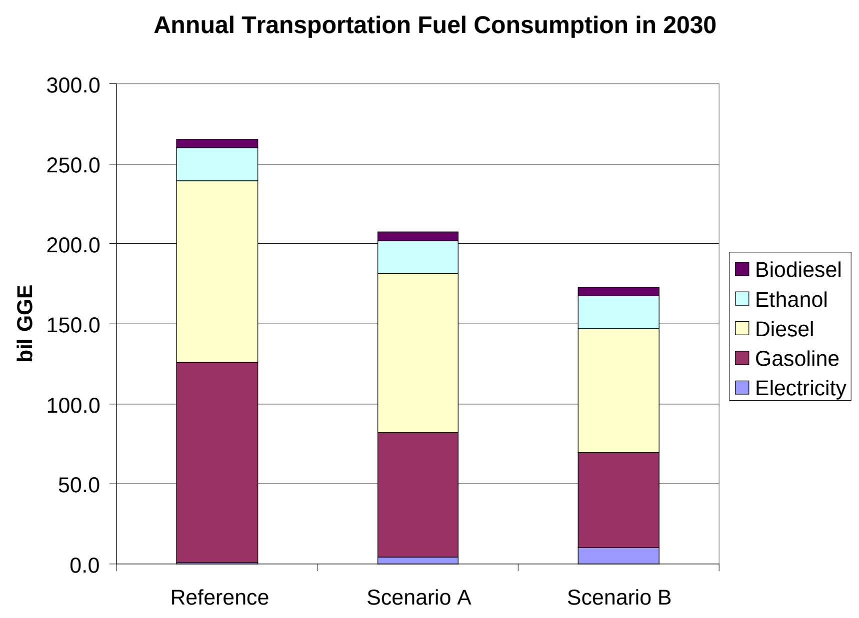
Transportation Fuels

Fuel Assumptions and Resulting Usage

- Because this analysis focuses on the emissions from combustion of fuels for transportation, the upstream effects of fuel production are not incorporated.
- Renewable fuels could have upstream implications; however, they are included in the baseline through the Renewable Fuel Standard and so are not further addressed.
- Increased use of non-traditional petroleum feedstocks could also have upstream implications which are not addressed in this analysis. AEO assumes increased penetration of both Canadian oil sands and Venezuelan heavy crude, although their upstream emissions are not accounted for.
- Decreases in energy demand under the scenarios are reflected as reductions in petroleum consumption (gasoline and diesel). Biofuel consumption for all scenarios is assumed to remain at levels consistent with the volumes required under the Renewable Fuel Standard.
- This analysis does not include indirect impacts resulting from petroleum rebound/leakage in other sectors of the U.S. and world economy due to a decrease in petroleum demand and price under these scenarios.
- Powerplant emissions from this increase in electrification of transportation are assumed to be addressed by electricity sector policies. Nevertheless, quantification of their potential magnitude in 2030 is provided on the next slide. These upstream increases (and concurrent reductions in petroleum production emissions) are not included in the overall analysis, which is focused on tailpipe emissions.

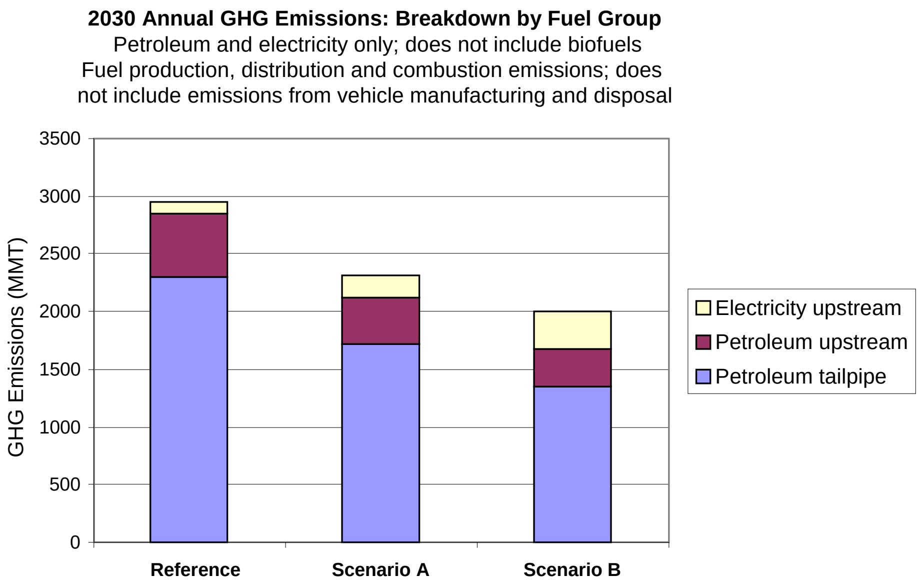
The remainder of this briefing analyzes two technologically feasible scenarios to reduce GHGs from U.S. transportation. The scenarios focus on technology advancement and travel efficiency measures that would create an overall decrease in demand for transportation fuels, as well as shift some demand to electricity-powered transportation.

This graph illustrates the resulting fuel usage under these scenarios. GGE = gallons of gasoline equivalent on an energy basis.



Electrification of Transportation

- The scenarios assume a significant increase in electrification of transportation (primarily light duty, off-highway and rail), which could result in an increase in upstream emissions due to increased electricity generation (absent an economy-wide cap).
  - Light Duty: Vehicles capable of running off grid electricity some or all of the time reach 14% of the light duty vehicle population for scenario A and 21% for scenario B in 2030.
    - Of these, about 1/3 are electric vehicles (EVs) and 2/3 are plug-in hybrid electric vehicles (PHEVs) in scenario A. For scenario B, 2/3 are EVs and 1/3 are PHEVs. EVs are operated fully on grid electricity, while PHEVs are assumed to run half of their miles on electricity.
    - These vehicles are assumed to ramp into the fleet starting in 2015, with new vehicle sales reaching 17-19% PHEVs and 13%-30% EVs in 2030.
    - Fleet average electricity demand for electric-powered light duty operation is assumed to be 250 Watt-hour/mile in 2030. Vehicle charging efficiency combined with transmission and distribution losses assumed to be 79%.
  - Off-Highway: 5% reduction in GHG emission rates by 2030 in scenario A, and 15% in scenario B
    - Scenario A electrification primarily by increased use of electric lawn-care and portable equipment, as well as equipment such as forklifts and excavators
    - Scenario B additionally assumes some electrification of equipment for farming (e.g., tractors) and jobsite use (e.g., welders and pumps)
  - Rail: Electrification of total rail fleet assumed to reach 10% of baseline rail energy demand in 2030.
    - Electrification of rail is assumed to ramp in from base levels in 2020 through 2029.
    - Electricity demand assumes 1 gallon of gasoline-equivalent (GGE) of electricity replaces every 2 GGE fuel saved via electrification relative to baseline, since locomotives use electricity more efficiently than petroleum.
      - GGE = gallons of gasoline equivalent, or the energy-equivalent of a gallon of gasoline
- Under these assumptions for electrification, the increase in nationwide electricity demand relative to AEO projected 2030 electricity demand is 3% for scenario A and 7% for scenario B.
- Of the total vehicle tailpipe GHG emission reductions from electrification, 82% are from light duty, 15% from off-highway, and 3% from rail for scenario B.
- These upstream impacts of electrification of transportation are not included in the overall analysis, which focuses on tailpipe emissions.



Assuming current national average electric utility GHG emission rates, utilities would see an annual 2030 increase of 92 MMTCO2e for scenario A and 235 MMTCO2e for scenario B. Concurrent reductions in petroleum demand would decrease GHG emissions from petroleum production, offsetting most or all of the emission increases from electricity production. The net upstream impacts (from increased electricity production and decreased petroleum production) would be a decrease of 49 MMTCO2e in scenario A and an increase of 4 MMTCO2e in scenario B. Reductions in tailpipe emissions under the scenarios would more than offset any increases in upstream electricity GHGs.

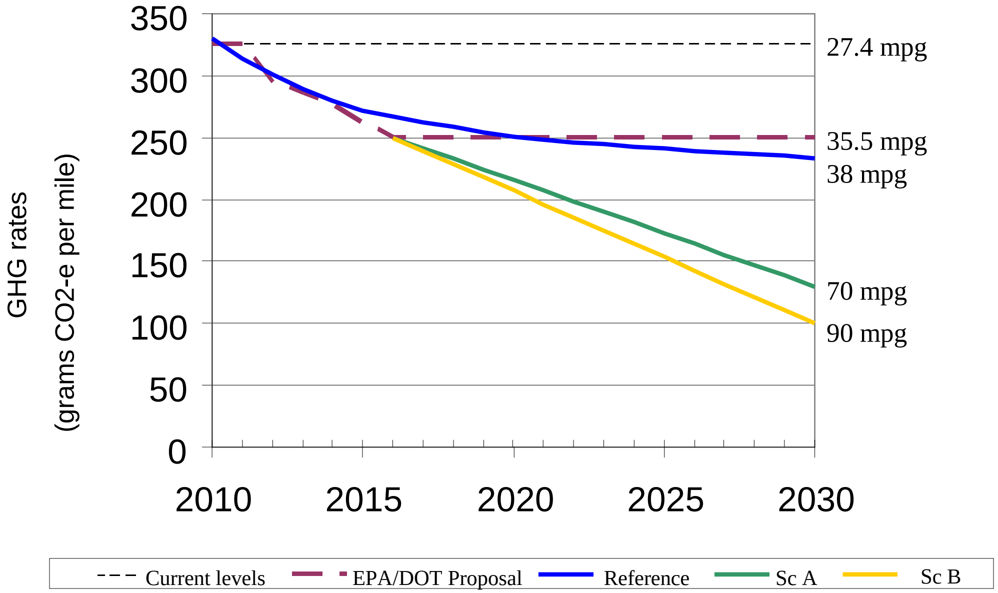
This does not take into account rebound in demand due to decreased prices in world petroleum, nor does it consider impacts of vehicle manufacturing and disposal.

Roadway

Light Duty

Light Duty Technology Scenarios

- Light duty includes passenger and small commercial vehicles (cars, minivans, vans, SUVs, crossovers, pick-ups).
- Scenario A
  - New vehicles achieve 130 grams GHGs per mile—about 70 mpg—by 2030
- Scenario B
  - New vehicles achieve 100 grams per mile—about 90 mpg—by 2030
- Context
  - The mpg rates implied by these scenarios are not as stringent as they may initially sound, for two reasons:
    - Electric vehicles are counted in this tailpipe analysis as consuming zero fuel; therefore, a few electric vehicles can go a long way in reducing fleet average tailpipe GHGs.
    - Miles per gallon is not linear with fuel consumption or GHG emission rates. The result is that apparently large increases in mpg are actually caused by much smaller relative decreases in fuel consumption. For example, a 100% increase in fuel economy—of, say, 35 to 70 mpg--equates to reducing fuel consumption by 50%.

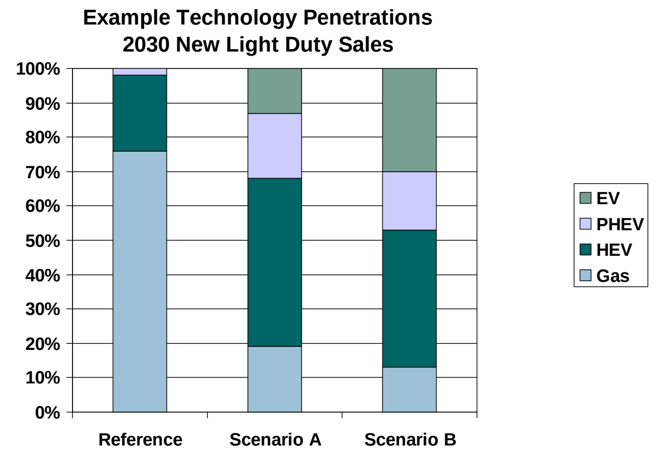


Light duty GHG and mpg values are based on fuel economy tests; actual on-road GHG rates will be higher and actual mpg will be lower

- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA's best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards. The scenarios represent a range of technologically feasible reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes are not assessed. This tailpipe analysis does not take into account upstream nor disposal emissions nor does it consider additional factors such as economic impacts, safety, consumer choice, or travel time.

Light Duty Technology Scenario Selection

- Both scenarios A and B are based on technologies that are considered to be feasible in the 2017-2030 timeframe by EPA experts based on no more than one technological breakthrough. (e.g., electric vehicles but not fuel cells)
  - Gasoline vehicles
    - Primarily made up of the next generation of vehicles based off of the conventional gasoline vehicles that dominate the US market today
    - A small number of conventional gasoline vehicles assumed to remain in the market
  - Hybrid electric vehicles (HEVs)
    - Currently account for 2-3% of US sales
    - One high-volume model—the Prius—with about 150,000 sales per year
  - Plug-in hybrid electric vehicles (PHEVs)
    - No OEM models in the market today
    - Most automakers developing prototypes
    - GM introducing Volt in late 2010, also Toyota and others
  - Electric vehicles (EVs)
    - No OEM models in the market today
    - Several offerings in the early and mid-1990s
    - Many automakers developing prototypes and likely to enter US market in 2011-2013 timeframe: Nissan, Ford, Mitsubishi, BMW, etc.
  - Automotive Air Conditioning
    - For the above technologies, automotive A/C efficiency improvements of 7 g/mile are assumed toward the 100 and 130 g/mi levels
    - Another 14 g/mile from reducing automotive air conditioner HFC leakage is assumed to occur beyond the 100 and 130 g/mi levels; these reductions are reflected in the total GHG levels in this analysis
- 10% domestic VMT rebound effect assumed
- Technology costs were not considered in selecting the scenarios.



Illustrated are example technology penetrations to achieve the scenario levels. However, many other technology combinations could achieve the same levels. There are no specific enabling technologies that are required for the scenario levels to be achieved.

Many of these technologies are not in full use today, even though many of them would pay back in fuel savings within the first few years of vehicle ownership. This is consistent with the energy paradox observed with other consumer products, in which consumers appear to routinely undervalue a wide range of investments in energy conservation. Some possible explanations for the paradox include: consumers who put little weight on the future, the difficulty in calculating expected fuel savings, uncertain fuel savings contrasted with certain and immediate increased costs, and loss aversion.

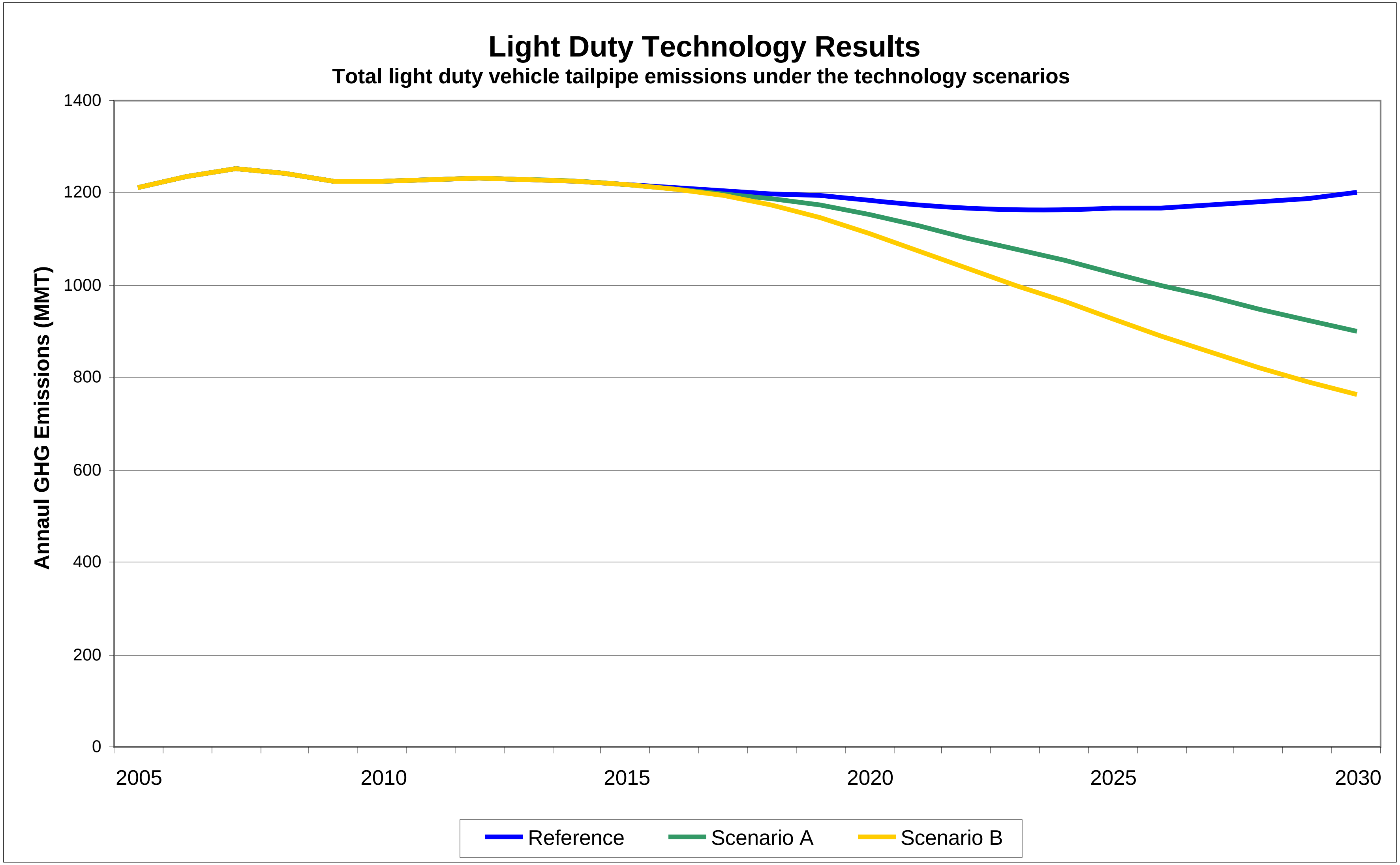
Light Duty Technology Assumptions

- Scenario A
  - 5% annual improvement in GHG emission rates through 2030
    - Continues the rate of annual improvement in the Joint EPA/NHTSA National Program for Model Years 2012-2016
  - Underlying assumptions
    - GHG improvements per vehicle type and technology examples described on next slide
    - A variety of vehicle types and technology advancements could combine to achieve these levels of improvement. There are no specific enabling technologies that are required for the scenario levels to be achieved.
    - Technology continues to improve at current rates
      - Historically 2-4% per year when adjusted to account for vehicle performance and weight
      - Battery innovation at present pace is higher than the rate of technology innovation in general
    - Current levels of household vehicle utility assumed to be maintained—such as range, towing capacity, interior space, performance
      - For instance, small “city cars” not needed to achieve these levels
      - However, some future improvements in vehicle utility may be foregone to achieve these levels
    - Technologies applied only where they make engineering and technical sense
    - Technologies limited in their rates of application to preserve current household vehicle utility
      - For instance, EVs are assumed to capture market share primarily as second or third car in multi-car households, where the first or second car would be used for longer trips and/or heavier hauling applications
- Scenario B
  - 5% annual improvement in GHG emission rates though 2016
  - 6% annual improvement in GHG emission rates from 2017 through 2030
      - Fuel economy increased at about a 7% per year compound rate from 1975-1982 after EPCA required the initial implementation of CAFE; average vehicle weight and horsepower dropped significantly
      - However, there are key differences between 1975-1982 and today
        - EPCA did not allow sufficient leadtime for major technology innovation—here, we would be allowing many years leadtime
        - After decades of low oil prices and little incentive for innovation, there was little technology on the shelf—today, much technology has been under development and is ready or nearly ready to go
  - Underlying assumptions
    - A variety of vehicle types and technology advancements could combine to achieve these levels of improvement. There are no specific enabling technologies that are required for the scenario levels to be achieved.
    - Assumes greater availability of the more advanced technologies than under Scenario A
    - Battery innovations accelerate from present pace
    - Current levels of individual vehicle utility assumed to be maintained as in Scenario A
    - The mix of vehicles would shift toward more EVs, as illustrated on the preceding slide
    - Technologies applied to somewhat broader range of uses, although still limited overall
      - For instance, EVs allowed in mainstream applications, but liquid-fueled vehicles still assumed to be needed for applications such as heavy towing

Light Duty Technology Projected Advancements

Technology	GHG Tailpipe Reduction from 2011 Baseline Vehicle	GHG Tailpipe Reduction from 2030 Baseline Vehicle	2030 New Vehicle Fuel Economy (CAFE)	Example Technology Improvements	
Gasoline	21%	7% increase	36 mpg	Engines -downsized/turbo -cylinder deactivation -stop-start -direct injection -HCCI	Transmissions Weight Reduction -advanced materials -component design Aerodynamics Tires
Next Generation Hybrid Electric Vehicle (HEV)	53%	36%	60 mpg	Most of the above Motors Power electronics	Li-ion batteries -3x power density -2x energy density -wider state of charge
Next Generation Plug-In Hybrid Electric Vehicle (PHEV) (40 mile electric range)	81%	74%	74 mpg when operated on gasoline only	Most of the above Note: PHEV fuel economy on gasoline is assumed to be greater than that of a conventional hybrid because the larger battery in the PHEV allows for more recovery of regenerative braking energy and provides more opportunities for the engine to operate more efficiently.	
Next Generation Electric Vehicle (EV) (150 mile range)	100%	100%	N/A	Most of the above	Ground-up redesign

Note: The 2030 gasoline vehicle in this analysis is less efficient than the 2030 baseline vehicle because the AEO 2030 baseline includes hybrids (22% of new sales). The gasoline vehicle category in this analysis include conventional and advanced gasoline vehicles, but not hybrids.
The mpg values in this table do not account for air conditioner efficiency improvements, as these are not reflected in CAFE testing and compliance.


Light Duty Technology Results
Total light duty vehicle tailpipe emissions under the technology scenarios
Annaul GHG Emissions (MMT)
1400
1200
1000
800
600
400
200
0
2005
2010
2015
2020
2025
2030
Reference
Scenario A
Scenario B

Light Duty Travel Efficiency Scenarios

- In addition to technology advancements, GHG reductions can be obtained from the transportation sector through a set of measures that together are often referred to as "travel efficiency." These measures impact the transportation choices that people make, affecting such key variables as vehicle operation, vehicle miles travelled, and mode of transportation.

- The following slides illustrate these reductions, which were modeled by layering them on top of the reductions from vehicle technology:

  - Scenario A: Increasing application of strategies, reaching 12% annual reduction from light duty GHG emissions by 2030 after applying scenario A technologies, assuming AEO 2009 VMT projections
    - 4.7% from speed limit reductions and urban parking restrictions
    - 2.3% from pricing (e.g., parking taxes, congestion pricing)
    - 1.8% from intelligent transportation and eco-driving
    - 1.7% from land use and SmartGrowth
    - 1.0% from HOV/vanpool/carpool/commute strategies
    - 0.1% from public transportation strategies

  - Scenario B: Increasing application of technologies, reaching 16% reduction from total light duty GHG emissions by 2030 after applying scenario B technologies, assuming AEO 2009 VMT projections
    - 5.0% from speed limit reductions and urban parking restrictions
    - 3.1% from intelligent transportation and eco-driving
    - 3.0% from land use and SmartGrowth
    - 2.9% from pricing (e.g., parking taxes, congestion pricing)
    - 2.3% from HOV/vanpool/carpool/commute strategies
    - 0.1% from public transportation strategies

- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA's best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for targets. The scenarios represent a range of feasible reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes are not assessed. This tailpipe analysis does not take into account upstream nor disposal emissions nor does it consider additional factors such as economic impacts, safety, or travel time.

Light Duty Travel Efficiency Scenario Selection

- EPA relied on analysis from the *Moving Cooler*[1] report to estimate potential levels of emissions reductions from light-duty travel efficiency.
  - *Moving Cooler* included six different bundles of strategies to reflect different potential groups of strategies that could be implemented.
  - For the purposes of EPA's analysis, we chose the "Low Cost" bundle because we believed that it represented the best combination of strategies based on cost, likelihood of success, and accuracy of the research results.
    - This bundle included strategies like smart growth/transit, commuter strategies, system operations (e.g., eco-driving, ramp metering), pricing (e.g., parking taxes, congestion pricing, intercity tolls), speed limit restrictions, and multimodal freight strategies. Note that this bundle, as opposed to other bundles in Moving Cooler, did not include a VMT tax or cap-and-trade assumptions.
    - We removed the percent reductions associated with multimodal freight strategies since these do not apply to the light-duty sector.
  - *Moving Cooler* made assumptions about the geographic scope for which each strategy could be implemented, with certain strategies like transit being dependent on greater populations, while other strategies like speed limit restrictions could be implemented in both urban and rural areas. Adjustments were also made to operational and commuter strategies to account for induced demand impacts.
  - Scenarios A and B represent aggressive and maximum deployment, respectively, of the “Low Cost” bundle of strategies in *Moving Cooler*.
- Possible reasons the market has not fully implemented existing light duty travel efficiency strategies include:
  - Imperfect information has been a market barrier to their adoption.
    - For example, many local governments are just becoming aware of the substantial financial savings and GHG reductions from more compact development in terms of road construction/maintenance, water/sewage facilities, and delivery of fire and safety services.
    - The public is generally not aware and realtors do not communicate the substantial fuel savings from living in more compact, transit-oriented developments.
  - Mixed-use development projects can also be more difficult to implement because of complex financing, local government permitting delays, and uncertainties about legal liability.

[1]Cambridge Systematics, Inc. (2009). *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions.* Urban Land Institute: Washington, D.C.

Light Duty Travel Efficiency Scenario Assumptions

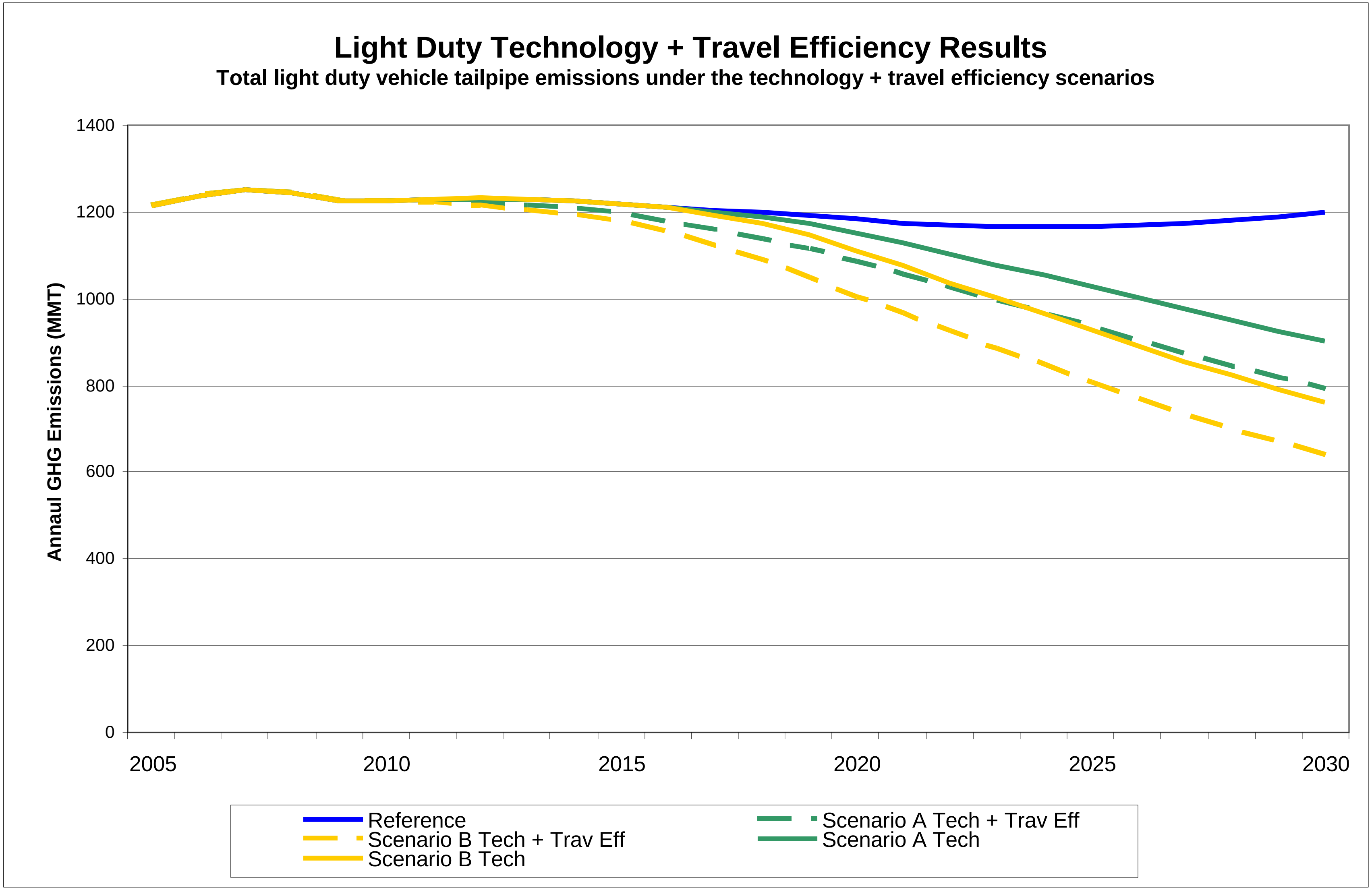
- To avoid the potential double-counting that could occur from simply adding the estimated percent emission reductions from the different strategies together, *Moving Cooler* used a multiplicative approach for most strategies. In certain other cases, it was appropriate to capture the synergistic effects among strategies, like transit and compact development.

- In order to aggregate the percent reductions from different strategies, a number of different models were used in *Moving Cooler* including FHWA's HERS model, and the EPA COMMUTER and Smart Growth Index models.
  - The HERS model was developed by the Federal Highway Administration to examine the relationship between investment levels and the condition and performance of the Nation's highway system. FHWA uses the model to estimate future investment required to either maintain or improve the Nation's highway system. FHWA provides this information to the U.S. Congress on a biennial basis. See http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.cfm for more information.
  - The COMMUTER model is an EPA assessment tool that provides estimates on how commuter benefits can impact nitrogen oxide, particulate matter and air toxic emissions, and fuel use and costs. See http://www.epa.gov/oms/stateresources/policy/pag_transp.htm#cp for more information.
  - The Smart Growth Index is an EPA model for community planners to simulate alternative land-use and transportation scenarios and evaluating their outcomes using indicators of environmental performance. See http://www.epa.gov/dced/pdf/Final_screen.pdf for more information.

- Percent reduction estimates for individual strategies were based on a literature review conducted by Cambridge Systematics, overseen by the Moving Cooler Steering Committee, which included EPA, FHWA, FTA, and a number of non-governmental organizations. Independent peer reviews were also conducted by outside experts.

- Percent reduction estimates in Moving Cooler are, in turn, supported by independent, published studies:
  - Transit and Smart Growth Planning can reduce VMT by 10% to 14% by 2050 (Urban Land Institute, 2008).
  - Commuter Benefits like subsidies for transit passes and carpools can reduce local VMT by 10% to 11% (EPA study for TRB, 2006),
  - Congestion Pricing can reduce local VMT by approximately 10%. ~$7 per day congestion fees in London have reduced CO_2 emissions by 19%. (Beevers et al., *Atmospheric Environment*, 2006)
  - Pay-As-You-Drive Insurance could incentivize people to drive 8% fewer miles nationwide (Bordoff, J., *Brookings Institute*, 2008).

- To calculate cumulative and annual emission reductions, EPA applied the total percent reductions in each scenario to the new emissions levels projected under the Light Duty Technology scenarios.

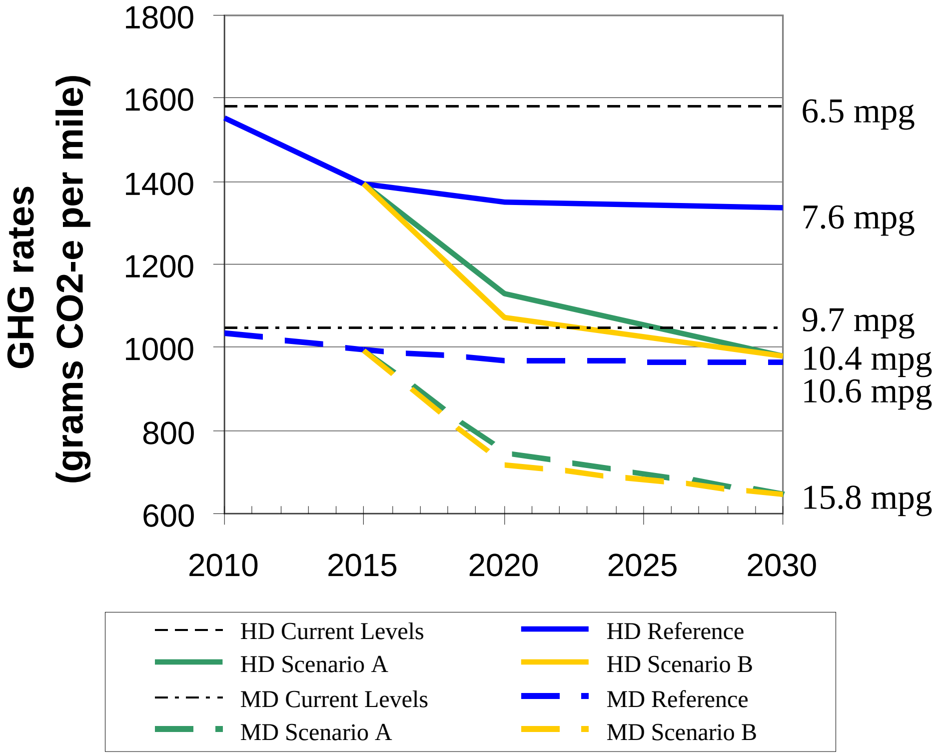

Light Duty Technology + Travel Efficiency Results
Total light duty vehicle tailpipe emissions under the technology + travel efficiency scenarios
Annaul GHG Emissions (MMT)
1400
1200
1000
800
600
400
200
0
2005
2010
2015
2020
2025
2030
Reference
Scenario B Tech + Trav Eff
Scenario B Tech
Scenario A Tech + Trav Eff
Scenario A Tech

Roadway

Medium and Heavy Duty

Medium and Heavy Duty Technology Scenarios

- The Heavy Duty subsector consists of Medium and Heavy Duty trucks primarily used for commercial purposes.
  - This large and varied category covers uses such as refuse haulers, urban delivery trucks, large pickups, and long-distance tractor-trailers.
- Scenario A:
  - Annual reductions in GHG rates of 4.9% from 2015 through 2020 and 1.5% through 2030.
- Scenario B:
  - Annual reductions in GHG rates of 5.6% from 2015 through 2020 and 1% through 2030.
  - Also assumes tire and trailer retrofits for existing fleet



Medium Duty and Heavy Duty mpg values are expressed as diesel-equivalent

- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA's best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards. The scenarios represent a range of technologically feasible reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes are not assessed. This tailpipe analysis does not take into account upstream nor disposal emissions nor does it consider additional factors such as economic impacts, safety, consumer choice, or travel time.

Medium and Heavy Duty Technology Scenario Selection

- The technologies that were included in the analysis are those that are currently available or under development and are expected to pay back over the lifetime of the vehicle under AEO 2009 fuel price projections.
  - Through the 21st Century Truck program, the SmartWay Transport program, and a number of public-private initiatives (e.g., the Hybrid Truck Users Forum), a generally accepted menu of technologies to reduce the carbon intensity of heavy-duty trucks and trailers has been developed.
  - As a general rule, only technologies that would be expected to pay back to the vehicle owner over the lifetime of the technology are considered in this menu.
    - Technical solutions to reduce CO2 but not fuel consumption (such as mobile carbon capture) are not reflected in this menu of technologies as they provide no direct mechanism to offset the upfront technology cost.
  - Applied engineering judgment to determine when each technology would be ready for application in new vehicles (not the existing fleet)
    - Reflecting the uncertainty in precisely the year in which discrete technology improvements can be introduced to all vehicles, EPA converted its best estimates of those technology steps into an annual percent improvement for projections beyond 2020.
  - Limited the technology penetration rate based on our estimates of the fraction of vehicles that would be expected to benefit from the application of technology
    - For example, while hybrid truck systems are projected to be highly beneficial for medium duty applications (such as refuse trucks, utility trucks, urban buses, and urban pick up and delivery vehicles), they are not expected to provide significant benefits for heavy duty line haul tractor trailer operations.
    - Therefore, EPA limited the fraction of new vehicles that would be expected to use hybrid drivetrains to 50 percent of new medium duty (not heavy duty) trucks by 2030.
  - This analysis does not claim that this payback would actually occur and does not account for the benefits of any payback ; rather, an expectation that payback was likely was used as the criterion for inclusion of any particular technology.
  - We expect these technologies to be available with no degradation in performance, although the market may forego performance increases in lieu of GHG reductions
- Many of these technologies are not used today, even though the business case would suggest that money-saving technologies would be in full use. Potential reasons why the market has not fully adopted some of these technologies include:
  - Owner-operator disconnect: The owner of the truck or trailer is often not the entity that does the shipping and pays for the fuel; the truck-trailer owner optimizes for price point, longevity, and maintenance costs, not for fuel efficiency or lifetime cost.
  - Conservative mindset regarding new technologies: Uncertainty about their long-term performance; truck buyers typically purchase only those technologies that can pay back in 18-24 months; engine and truck OEM have thus internalized this rule of thumb as a gateway for any technology they bring to market.
  - Capital investment limitations: Often funneled into additional equipment in the hopes of generating additional revenue.
  - Imperfect information: Lack of good information about the actual effects of new technologies on fuel consumption, and uncertainty about the future price of fuel.

Medium and Heavy Duty Technology Assumptions

- Scenario A:
  - Assumes technologies that are expected to be developed for the 21st Century Truck (EPA/DOT/DOE).
  - Assumes annual 4.9% reduction in GHG emission rates for new vehicles and engines in 2015 through 2020, and then a 1.5% annual reduction through 2030.
  - Key technologies:
    - Aerodynamics: basic cab, enhanced cab, pneumatic blowing, roof fairings, fuel tank fairings, aerodynamic mirrors and bumpers, trailer gap reduction, trailer side skirts
    - Tires: low rolling resistance, single wide
    - Powertrain: diesel engine improvements through advanced EGR, emissions optimization, valve timing, injection optimization; turbocompounding; reduced friction transmission and driveline; vehicle speed limiters; APUs for idle reduction
    - Hybrid: limited in penetration; systems will be optimized for a range of applications (from overnight auxiliary power supply to urban braking recovery) according to expected driving cycles.
    - Weight reduction via material substitution

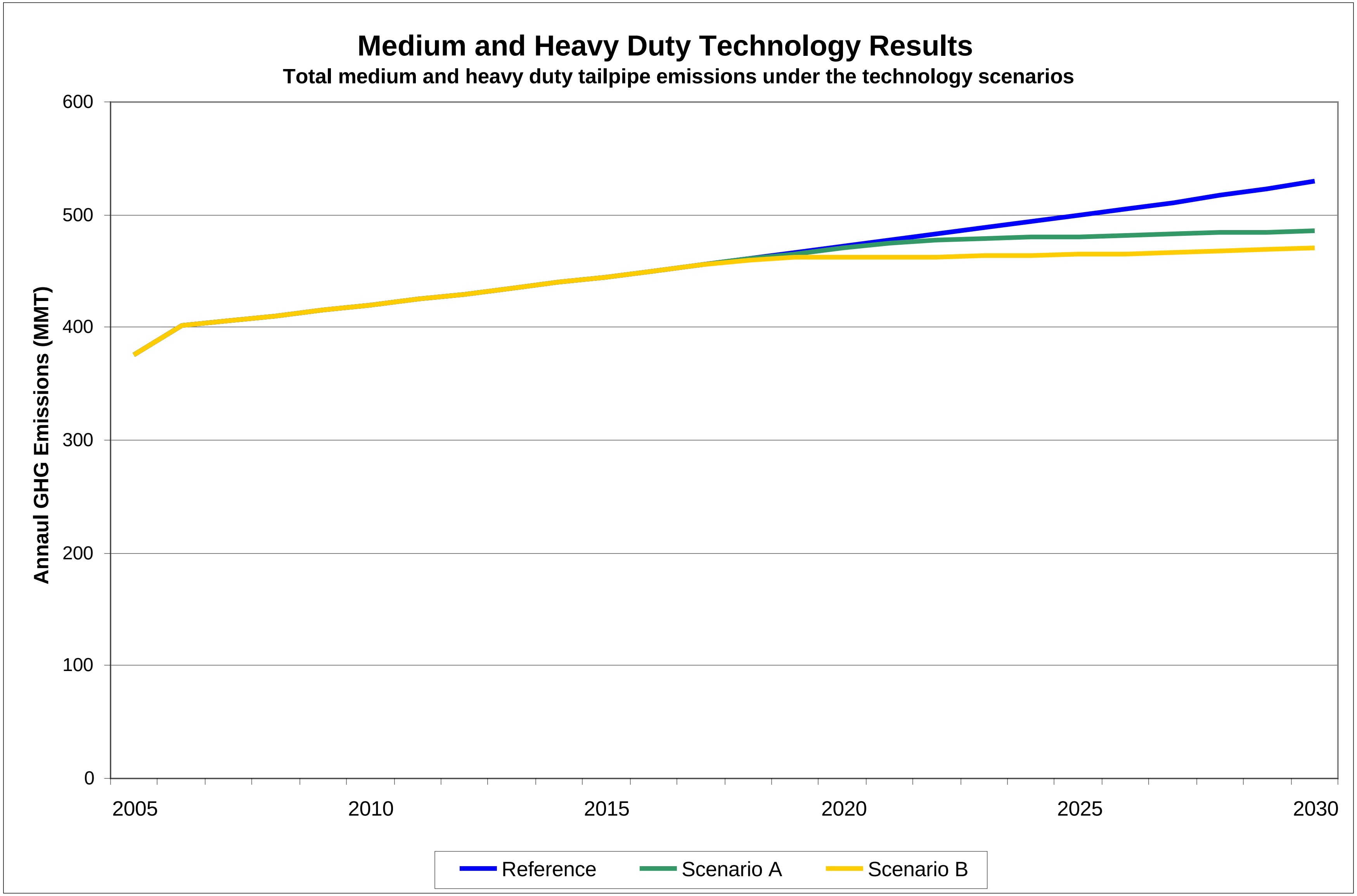
- Scenario B:
  - Assumes 21st Century Truck technologies with continual development of technologies for new trucks, plus retrofits of existing fleet.
  - For new trucks, assumes an annual 5.6% reduction in GHG emission rates for new vehicles and engines in 2015 through 2020, and then a 1% annual reduction through 2030.
  - Assumes the same key technologies as in scenario A, but with earlier introduction and faster penetration rates.
  - Also assumes retrofits of existing fleet:
    - Replacement tires—low rolling resistance
      - 1% efficiency gain per truck
      - Assumes replacement tires on 50% of existing fleet in 2015 and 100% of existing fleet by 2020
    - Retrofit trailers with SmartWay technologies
      - 10% improvement in GHG performance relative to a standard trailer
      - Applies only to trucks with box trailers
      - Assumes 10% of existing box trailers have received the retrofit in 2015, 60% by 2020, and 100% by 2030

Medium and Heavy Duty Technology Assumptions

Scenarios A and B utilize all technologies at their maximum feasible levels by 2030. Scenario A sees a slower rate of application in the early years. Technology penetration rates limited to those uses that would be expected to benefit from the application of technology.

		GHG Improvement	
		Medium Duty	**Heavy Duty**
2015 (reduction from average 2010 vehicle)			
	Aerodynamics	6%	7%
	Low Rolling Resistance Tires	3%	6%
	Engine	5%	4%
2020 (reduction from average 2015 vehicle)			
	Advanced Aerodynamics	2%	3%
	Advanced Engine	8%	8%
	Transmission	2%	2%
	Weight Reduction	3%	0%
	Hybrids	7%	0%
	Vehicle Speed Limiters	0%	3%
	Auxiliary Power Units	0%	4%
2030 (reduction from average 2020 vehicle)			
	Advanced Engine	2%	
	Hybrids	11%	5%
	Pneumatic Blowing	0%	2%
	Weight Reduction	0%	3%

The reductions presented in this analysis represent those that could be brought about by a mix of existing authority as well as new legislative authority and funding. This analysis makes no distinction between these pathways nor does it reflect a regulatory plan or budget proposal.



Medium and Heavy Duty Travel Efficiency Scenarios

- As with light duty, there is an array of travel efficiency measures that can achieve substantial GHG reductions beyond those available through technology advancements.
- The following slides illustrate these improvements in travel efficiency, layered on top of the illustrated technology reductions:
  - Scenario A: Increasing application of strategies, reaching 6% annual reduction in medium and heavy duty GHGs by 2030 after applying scenario A technologies, assuming AEO 2009 VMT projections
    - 0.8% from idle reduction
      - Linear phase-in starting 2010
      - Reflects eliminating 50% of remaining truck episodic idle fuel consumption
    - 5% from improved driver performance
      - Linear phase-in starting 2010
      - Strategies to improve driver performance include intelligent cruise control technology, improved acceleration and shifting techniques, speed management, proper tire inflation, and traffic avoidance.
  - Scenario B: Increasing application of strategies, reaching 21% annual reduction in medium and heavy duty GHGs by 2030 after applying scenario B technologies, assuming AEO 2009 VMT projections
    - 1.4% from idle reduction
      - Linear phase-in starting 2010 (same as Scenario A)
      - Reflects maximum feasible episodic idle reduction
    - 5% from improved driver performance
      - Same as scenario A
    - 2% from higher-capacity trucks (2% only from HD; 0% in MD sector)
      - Linear phase-in starting 2015
      - Assumed 17% GHG reduction for 50% of combination trucks with van trailers.
    - 5% from better loading, packaging, routing, and “empty mile” reduction
      - Linear phase-in starting 2015
    - 10% from intermodal shifts (5% to rail, 5% to marine)
      - Linear phase-in starting 2015
      - Represents ~4% increase in rail ton-miles and ~12% increase in domestic waterborne ton-miles projected for 2030 in AEO 2009
        - Assumes ratio of ton-miles/truck/yr to VMT/truck/yr will remain constant. Ratio based on BTS and AEO data for 2006.
- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA’s best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for targets. The scenarios represent a range of feasible reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes are not assessed. This tailpipe analysis does not take into account upstream nor disposal emissions nor does it consider additional factors such as economic impacts, safety, or travel time.

Medium and Heavy Duty Travel Efficiency Scenario Selection

- Scenarios are based on aggressive applications of technology and operational strategies that EPA currently promotes in the SmartWay Transport program (i.e. they are commercially viable in 2009).
  - Attempted to include estimates for all strategies with potentially large GHG impacts
  - Application of strategies limited to appropriate segments of the trucking sector, taking into account existing rates of adoption.
    - For example, assumed that all long-duration idling would be addressed by 2030 with new vehicle technologies, but some levels of episodic idling would remain from trucks outside of long-haul sector.
  - Scenario A reflects implementation of two on-the-shelf strategies that do not require major infrastructure investments or changes to business practices – idle reduction (50% of remaining idle fuel consumption) and improved driver performance.
  - Scenario B is more aggressive and reflects maximum adoption of idle reduction strategies and assumes higher truck capacity, improved shipper operations (less packaging, better routing, etc.), and a significant shift from trucking to lower-carbon modes (rail and marine).

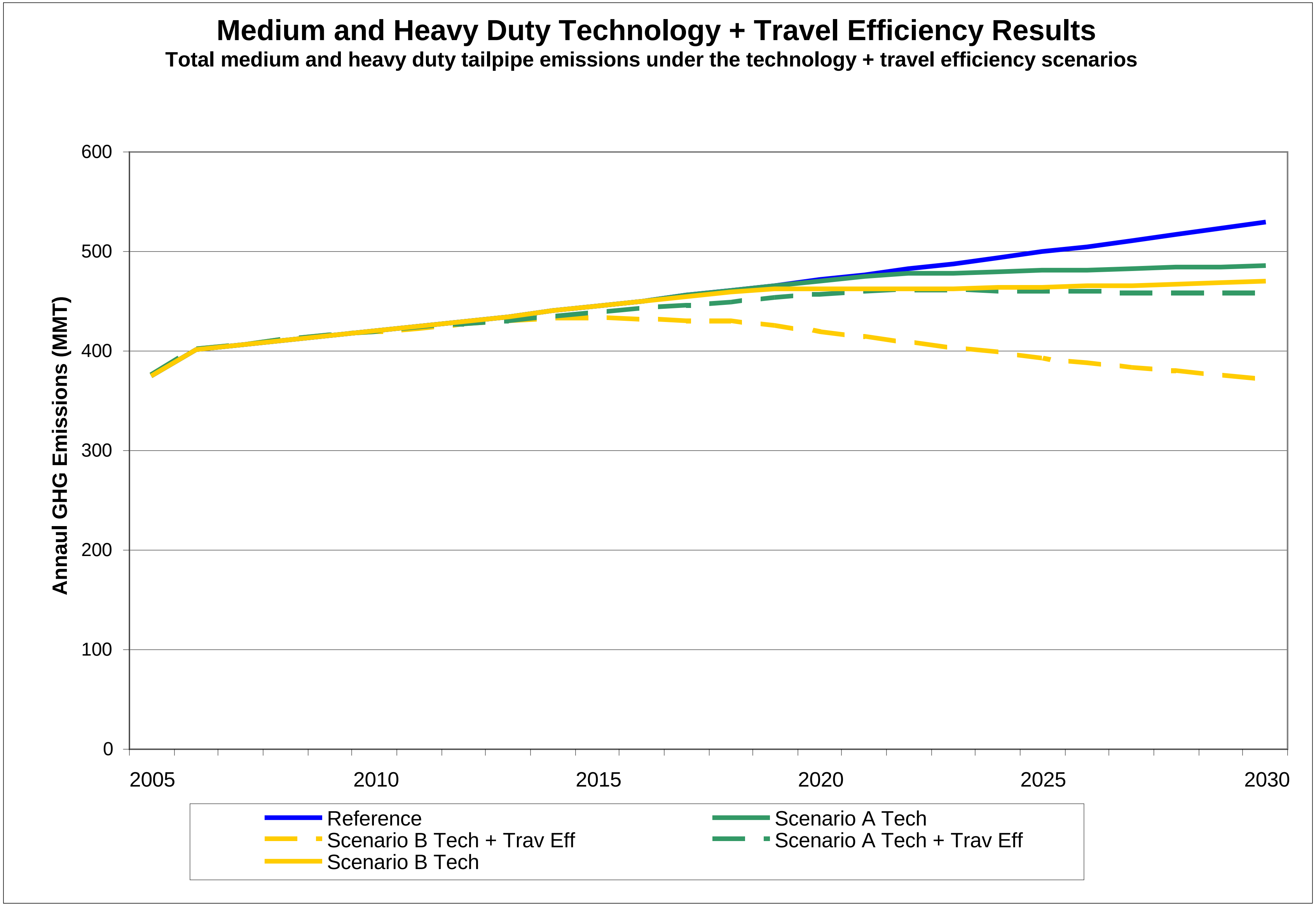
- Potential reasons why the market has not fully adopted some of these strategies include:
  - Imperfect information: Freight industry lacks awareness of and clear, reliable information on technologies and operational strategies.
  - Network inefficiencies: Individual shippers (freight suppliers) and carriers (freight movers) may not optimize routing for the entire system (e.g., neighboring shippers may not work together to fill a truckload, and carriers may not work with shippers at both the origin and destination of a certain truckload resulting in "empty miles").
  - Misplaced incentives (i.e., incentives do not accrue to the stakeholder with the direct ability to save fuel): Sometimes the owner of the truck is not the entity that does the shipping and pays for the fuel. In other cases, shippers are only charged for the ton-miles of freight carried and therefore may not directly benefit from helping carriers minimize back-hauling or repositioning miles, which are often "empty miles".
  - Institutional/organizational barriers or decisions influenced by customs/norms: Transportation costs do not always represent a large share of total costs for shippers; as a result, these companies may under-invest in human and financial resources necessary to indentify and implement fuel-saving measures, even when cost-effective. Truck owner-operators traditionally only invest in projects with less than 18-24 month payback.
  - Lack of capital: truck owner-operators often face high costs of capital.
  - Public goods/collective action issues: leading to an under-investment in new infrastructure.

Medium and Heavy Duty Travel Efficiency Scenario Assumptions

- To avoid the potential double-counting that could occur from simply adding the estimated percent emissions reduction from different strategies together, we used a multiplicative approach.

- EPA based the percent reduction estimates on literature reviews and internal analyses of SmartWay program strategies. Examples of emission reduction potential:
  - Strategies are available to reduce episodic idling by up to 80% (EPA internal analysis).
  - Driver training and monitoring programs can result in 5-20% fuel savings (Ang-Olson, J., *Journal for the TRB*, 2002).
  - Rocky Mountain Double and triple trailers can reduce emissions by 17-21% compared to 53-foot box trailers (NESCAUM, 2009).
  - An 8% reduction in product packaging can reduce GHG emissions from long-haul trucks by almost 25% (SmartWay Partner case study).
  - Minimizing empty mileage for one truck by just one percent can reduce CO_2 emissions by over 1 metric ton annually (EPA technical bulletin on *Improved Freight Logistics*, 2004).
  - Using more rail and marine vessels in place of trucks can, in certain areas, reduce CO_2 emissions by up to 90% (national modal average emissions based on AEO, 2009 and BTS, 2008).
  - 3.5% of 2020 truck tonnage could be shifted to rail with aggressive infrastructure investments (ASHTO's *Freight-Rail Bottom Line Report*).

- To calculate cumulative and annual emission reductions, EPA applied the total percent reductions in each scenario to the new emissions levels projected under the heavy duty technology scenarios.


Medium and Heavy Duty Technology + Travel Efficiency Results
Total medium and heavy duty tailpipe emissions under the technology + travel efficiency scenarios
Annaul GHG Emissions (MMT)
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
Reference
Scenario B Tech + Trav Eff
Scenario B Tech
Scenario A Tech
Scenario A Tech + Trav Eff

Nonroad
Aviation

Aviation Scenarios

- For the nonroad subsectors, each scenario includes improvements in technology and operational measures. Improvements are assumed only where reasonable for the application.

- Scenario A: 1.2 % average annual improvement in fleet-wide GHG emission rates 2015-2030 (1.8% for new aircraft and engines; 0.7% for fleet-wide operational improvements). These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 20% from engine improvements (geared turbofans, compressor optimization at low-speed), phasing in 2015-2029
  - 5% from airframe weight and drag reductions (laminar flow technology, lighter weight materials), phasing in 2015-2029
  - 10% from operational measures (improved ground operations and air traffic management), phasing in 2015-2029

- Scenario B: 2.2 % average annual improvement in fleet-wide GHG emission rate 2015-2030 (2.3% for new aircraft and engines; 1.4% for fleet-wide operational improvements). These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 20% from engine improvements (geared turbofans, compressor optimization at low-speed) phasing in 2015-2029
  - 10-20% from airframe weight and drag reductions (laminar flow technology, lighter weight materials, blended wing), phasing in 2015-2029
  - 20% from operational measures (improved ground operations and air traffic management) phasing in 2015-2029

- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA's best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards. The scenarios represent a range of technological and operational reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes, and associated costs, are not assessed.

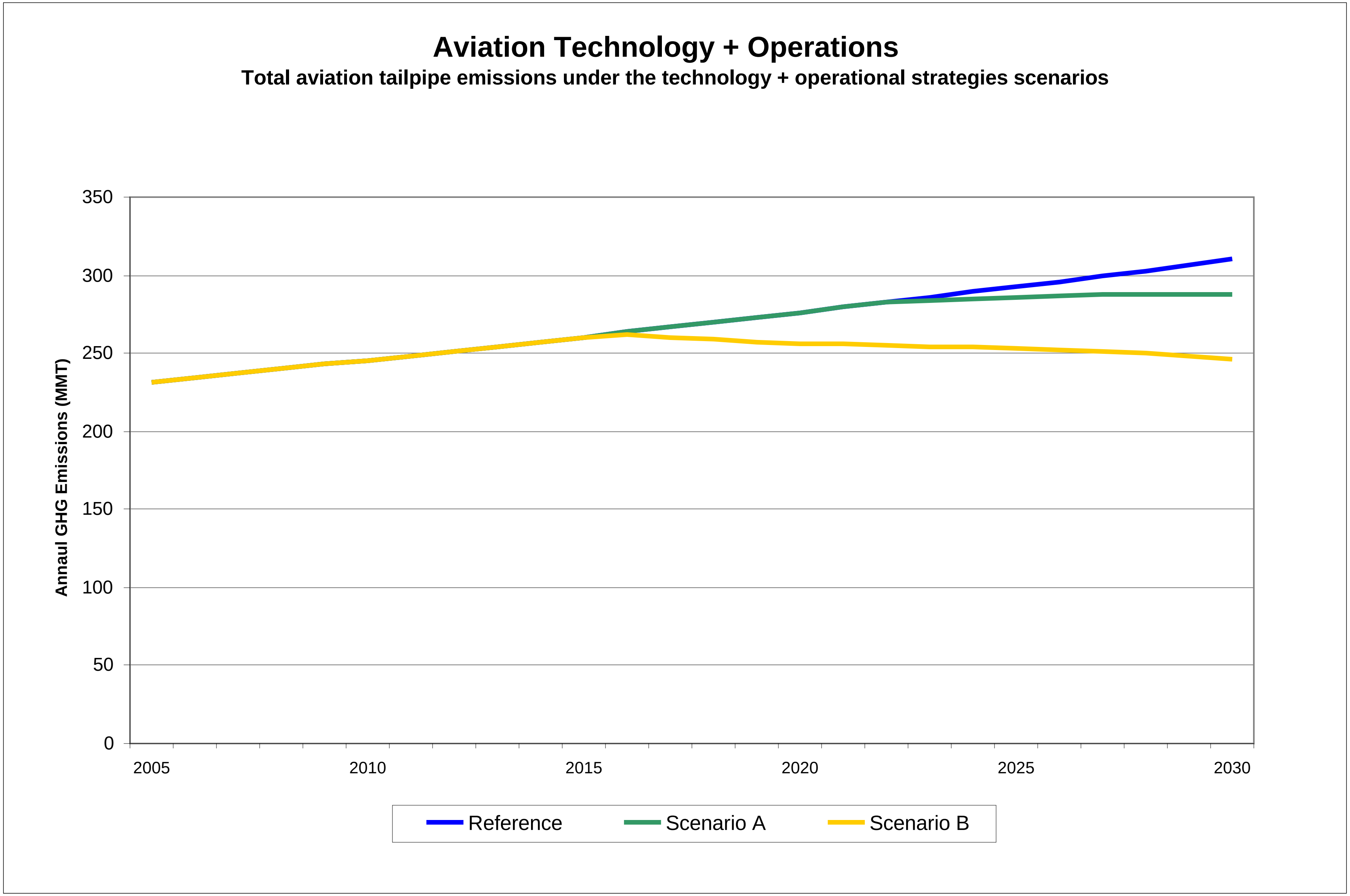
- FAA believes that the levels of operational improvement used in this analysis are optimistic and suggests the following:
  - Scenario A: 0.17% for annual fleet-wide operational improvements, resulting in 2.5% cumulative improvements over 15 years from operational measures.
  - Scenario B: 0.4% for annual fleet-wide operational improvements, resulting in 6% cumulative improvements over 15 years from operational measures.
  - Adopting these levels would impact the analysis by decreasing the annual reductions in 2030 by 20-40 MMT.

Aviation Scenario Selection

- Historically, the fuel efficiency of aviation has improved 2-3% per year on average.
- Based on EPA expertise, engineering judgment suggests that additional opportunities for improvement exist in aviation in the areas of engine efficiency, airframe weight and aerodynamics, and logistical operations and air traffic management.
- The values chosen are derived from and consistent with industry submittals to the Group on International Aviation and Climate Change of the International Civil Aviation Organization (ICAO).
- The aircraft improvements described below are assumed to be applied only to new aircraft/engines. Operational improvements are applied to the entire fleet.

- Scenario A:
  - Steady penetration into the fleet of improved engine efficiency over 15 years through advanced engine technologies such as geared turbofan technology and compressor optimization for lower speeds.
  - Modest penetration of airframes made of lighter materials and utilizing technology to reduce aerodynamic drag.
  - Modest increase in the use of operational measures/improved air traffic management.

- Scenario B:
  - More rapid penetration into the fleet of the engine efficiency improvements considered in Scenario A.
  - More rapid penetration of airframe weight and drag reduction technologies and the entrance into the fleet of the blended wing body.
  - Quicker utilization of operational measures/improved air traffic management.



Note that utilizing the more modest operational improvements suggested by the FAA would increase scenario A by about 20 MMT and scenario B by about 40 MMT in 2030*.*

Nonroad
Rail

Rail Scenarios

- Rail includes freight and passenger rail, both heavy and light.

- Scenario A: 1.0 % average annual improvement in fleet-wide GHG emission rates 2015-2030 (2.2% for new locomotives and engines; 0.3 % for fleet-wide operational improvements). These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 10% from engine efficiency improvements (reduced friction, advanced combustion technologies), phasing in 2015-2029
  - 15% from hybrid locomotives, phasing in 2015-2029
  - 5% from railcar improvements (track lubrication, improved bearings and brakes), phasing in 2015-2019
  - 5% from operational measures (optimized logistics, double-stacking), phasing in 2015-2019

- Scenario B: 2.1 % average annual improvement in fleet-wide GHG emission rates 2015-2030 (2.4% for new locomotives and engines; 1.0 % for fleetwide operational improvements). These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 10% from engine efficiency improvements (reduced friction, advanced combustion technologies), phasing in 2015-2016
  - 15% from grid-capable hybrid locomotives, phasing in 2015-2016
  - 10% from targeted rail segment electrification, phasing in 2020-2029
  - 15% from railcar improvements and operational measures (track lubrication, improved bearings and brakes, optimized logistics, increased double-stacking) phasing in 2015-2029
  - Intermodal: 5% of baseline truck freight activity shifted to rail by 2030. Economic impacts of such a shift are not considered.

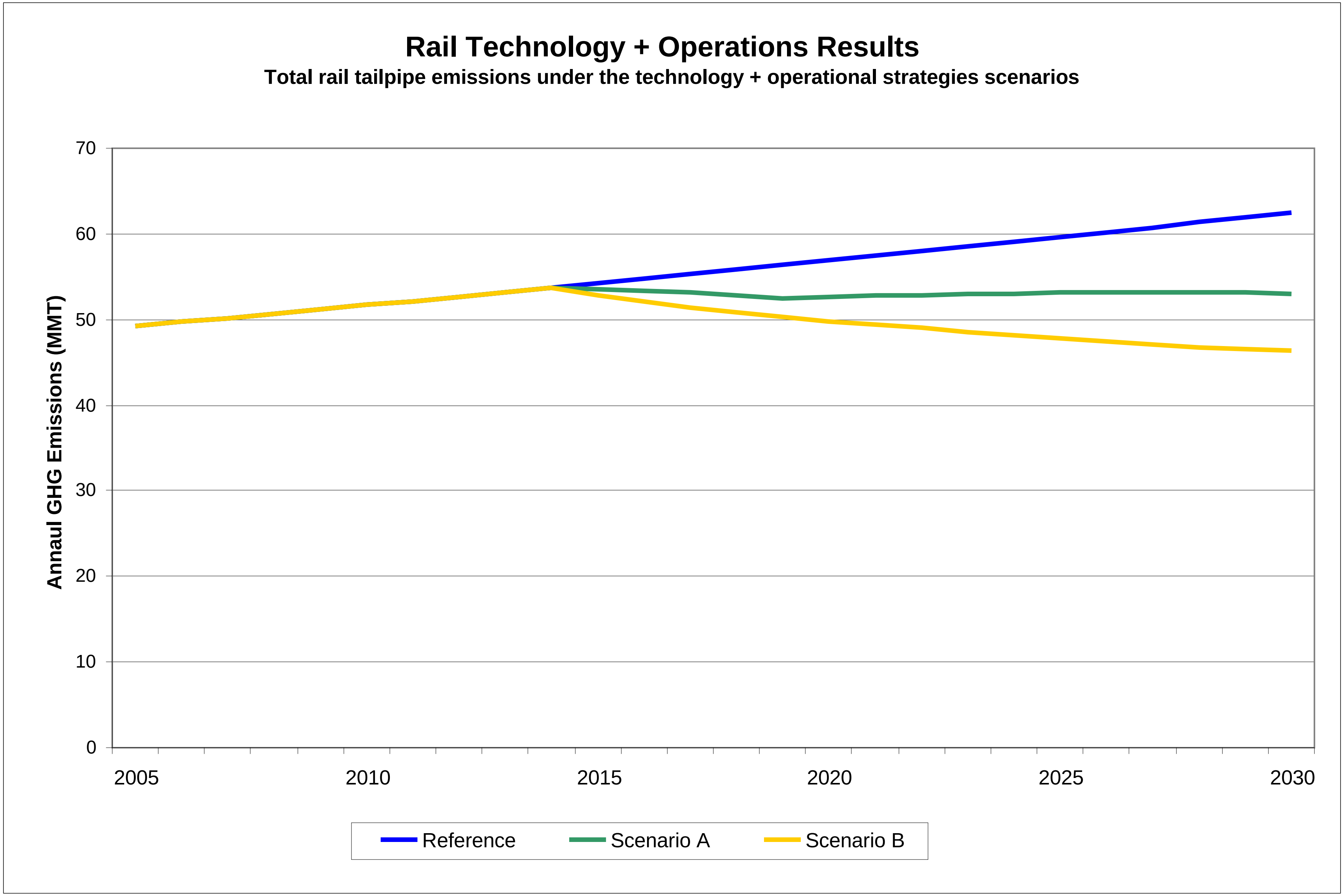
- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA's best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards. The scenarios represent a range of technological and operational reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes, and associated costs, are not assessed.

Rail Scenario Selection

- Industry estimates show a 2% annual improvement in rail efficiency (in gallons of fuel per ton-mile) over the past two decades.
- Based on EPA expertise, engineering judgment suggests that additional opportunities for advancement exist in this sector, in the areas of engine and locomotive efficiency, railcar friction, braking, aerodynamics, and train management and operations.
- The locomotive improvements discussed below are assumed to be applied only to new locomotives, though some could be applied to remanufactured locomotives as well.

- Scenario A:
  - Gradual locomotive engine efficiency improvement over 15 years through reducing internal friction and improvements in air and fuel management.
  - Adoption of electric or hydraulic hybrid locomotives in line-haul and switch applications, phased into the new locomotive market over 15 years. At least one manufacturer is currently developing a line-haul hybrid with fuel savings of up to 15%.
  - Modest penetration of railcar improvements known to be feasible or already in limited use, such as track lubrication, low-friction/low-torque bearings, and aerodynamic shrouds.
  - Modest increased penetration of efficiency-improving operational measures, such as double-stacking and GPS-assisted dispatch optimization for locomotives and railcars.

- Scenario B:
  - More rapid introduction of the engine efficiency improvements considered in Scenario A.
  - Increased penetration of railcar improvements under consideration in the rail industry, including electronically-controlled pneumatic brakes.
  - Rapid adoption over 2015-2016 of hybrid electric locomotives with capability for future connection to grid electricity. The rapid phase-in would help ensure a fleet of grid-capable locomotives ready for future electrification.
  - Electrification over 10 years of targeted rail segments that allow hybrid locomotives to take grid power (and to give some back on downhill grades). Rail segments with high-traffic or high-elevation changes could be targeted.
  - Increased penetration of efficiency-improving operational measures.
  - 5% of truck freight activity shifted to rail


Rail Technology + Operations Results
Total rail tailpipe emissions under the technology + operational strategies scenarios
Annaul GHG Emissions (MMT)
70
60
50
40
30
20
10
0
2005
2010
2015
2020
2025
2030
Reference
Scenario A
Scenario B

Nonroad
Marine

Marine Scenarios

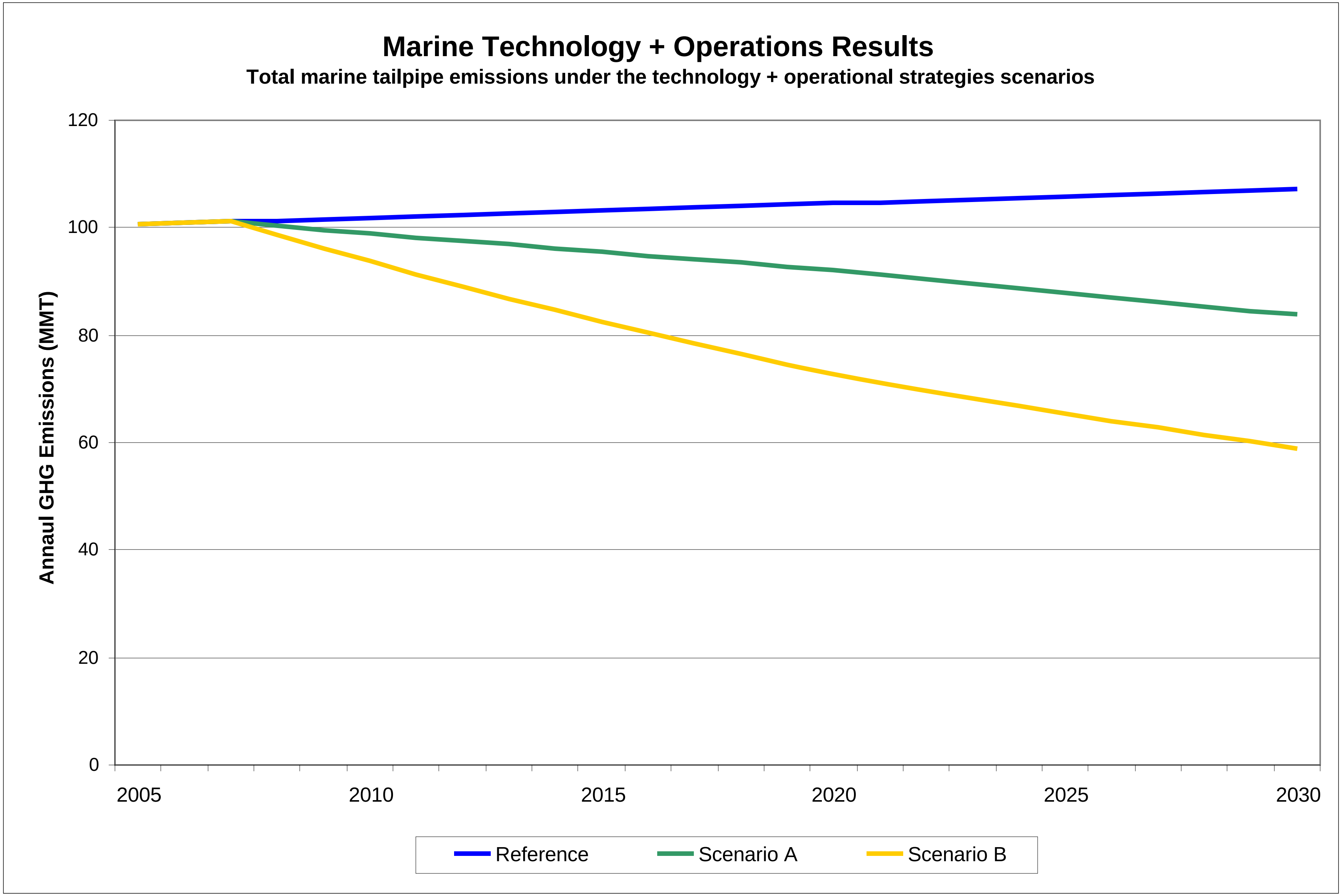
- Marine includes domestic recreational boating and commercial waterborne shipping as well as international bunker fuels.
- Scenario A: 1.1% average annual improvement in fleet-wide GHG emission rates 2007-2030. These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 5% efficiency improvement from technology retrofits on existing ships
  - 10% from technology or design concepts for both new ships and retrofits
  - 10% from operational improvements for all ships
- Scenario B: 2.6% average annual improvement in fleet-wide GHG emission rates 2007-2030. These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 25% from technology retrofits on existing ships
  - 50% from technology or design concepts for both new ships and with retrofits
  - Up to 50% operational improvements for all ships
  - Intermodal: 5% of baseline truck freight activity shifted to marine by 2030
- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA's best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards. The scenarios represent a range of technological and operational reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes, and associated costs, are not assessed.

Marine Scenario Selection

- The maritime industry is diverse with different ship types, capacity or size, travel routes and design speed. Some technology improvements available to a specific ship may not be compatible with certain operational measures, which was taken into account by limiting their application in the analysis.
- Scenario A:
  - Would require existing ship efficiencies that are only modestly improved beyond business as usual, incorporating minimal feasible equipment upgrades and operational measures.
- Scenario B:
  - Would require existing ship efficiencies that are nearly at the technological and operational limit of feasibility. The technologies that were included in the analysis are those that are currently available or feasible for specific ships.
- Potential reasons that many of these technologies are not in full use today may include:
  - Existing ship efficiency: Maritime industry is already a relatively efficient method per ton-mile freight, but significant potential exists to improve efficiency of existing ships through technologies as well as operational improvements
  - Owner-operator disconnect: The owner of the ship is often not the entity that does the shipping and pays for the fuel
  - Conservative mindset regarding new technologies: Uncertainty about their long-term performance and required maintenance
  - Incomplete information: Lack of good information about the actual effects of new technologies on fuel consumption on specific ship types and routes, and uncertainty about the future price of fuel

Marine Technologies and Operational Improvements

- Technology retrofits on existing ships
  - Engine system optimization (waste heat, engine technologies)
  - Speed reductions
  - Air lubrication or bubblers
  - Reduced ballast
  - Hull friction – optimized openings and increased maintenance
  - Propeller design optimization, polishing and maintenance
  - Wind and solar power
  - Engine system optimization (waste heat, engine technologies)
- Technology or design concepts for new ships combined with retrofits
  - Larger capacity with efficiency of scale
  - Hull and superstructure design
  - Power and propulsion hybrid systems
  - Low carbon fuels
- Operational improvements for all ships
  - Fleet management and logistics
  - Voyage optimization and weather routing
  - Energy management
  - Trim optimization


Marine Technology + Operations Results
Total marine tailpipe emissions under the technology + operational strategies scenarios
Annaul GHG Emissions (MMT)
120
100
80
60
40
20
0
2005
2010
2015
2020
2025
2030
Reference
Scenario A
Scenario B

Nonroad
Off-Highway

Off-Highway Scenarios

- Off-highway is a large and varied category covering engines and equipment used for purposes such as agriculture (e.g. tractors and combines), construction (e.g., cranes and bulldozers), lawn and garden, and mining.

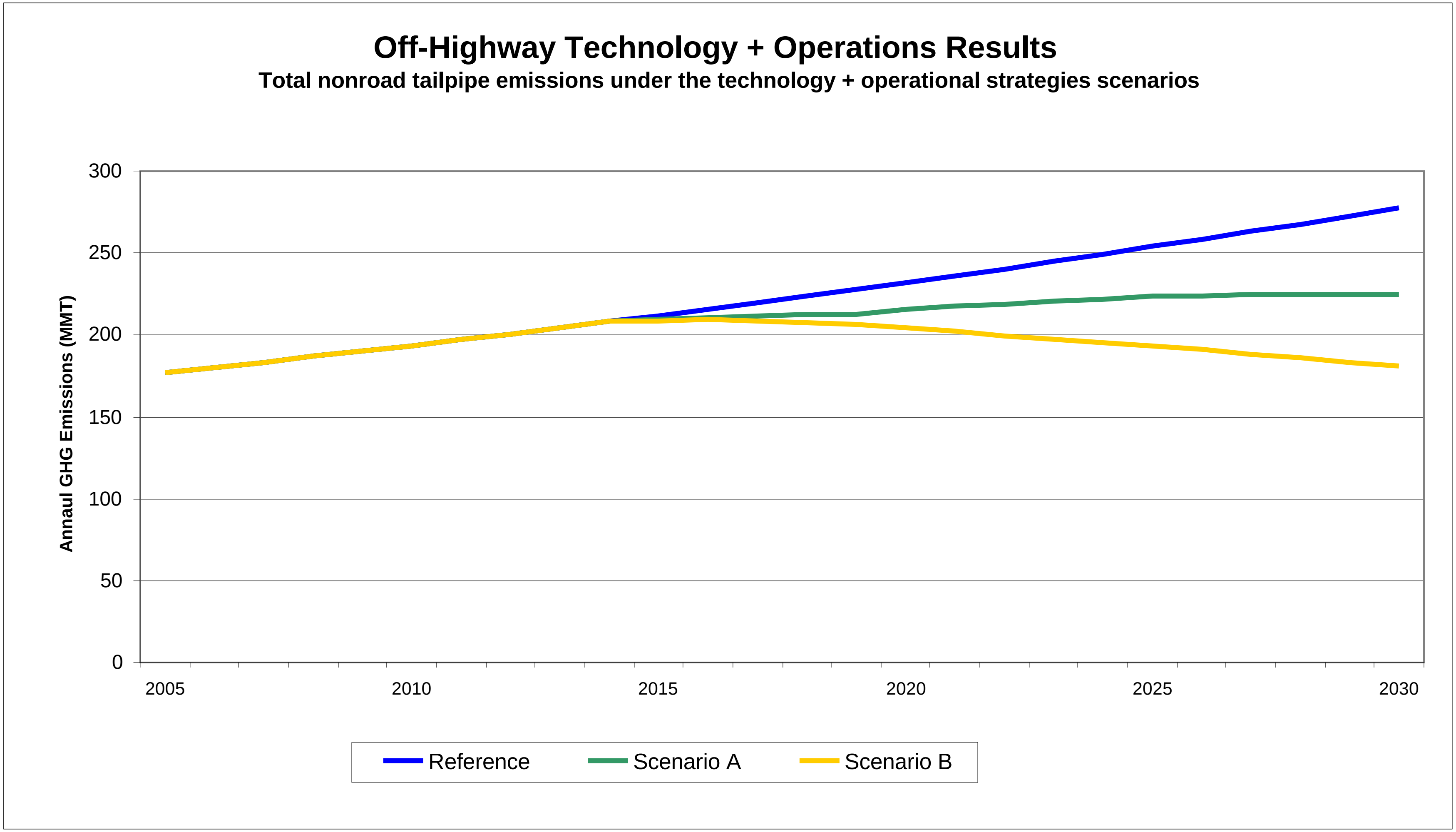
- Scenario A: 1.3 % average annual improvement in fleet-wide GHG emission rates 2015-2030 (1.8% for new equipment and engines; 0.2% for fleet-wide operational improvements). These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 15% from engine efficiency improvements (reduced friction, advanced fuel and intake air management, 4-stroke engines) by 2030
  - 10% from electric and hydraulic hybrid equipment by 2030
  - 5% from increased electrification of lawncare and portable equipment by 2030
  - 5% from operational measures by 2020

- Scenario B: 2.6 % average annual improvement in fleet-wide GHG emission rates 2015-2030 (2.4% for new equipment and engines; 1.1% for fleet-wide operational improvements). These annual improvements result from the following measures, expressed as total improvements in GHG rates by 2030 relative to the baseline:
  - 20% from engine and equipment efficiency improvements (reduced friction, advanced fuel and intake air management, 4-stroke engines, hybrids, implement efficiency improvements) by 2030
  - 15% from increased equipment electrification by 2020
  - 15% from operational measures by 2030

- EPA acknowledges that there may be differences of opinion regarding achievable levels; however, these levels represent EPA's best technical judgment at this time. These illustrative example scenarios do not imply that EPA considers these to be the appropriate levels or dates for standards. The scenarios represent a range of technological and operational reductions that could occur depending on the strength of regulatory and market drivers; the drivers that would be necessary to effect these changes, and associated costs, are not assessed.

Off-Highway Scenario Selection

- The off-highway equipment sector is extremely diverse, with applications ranging from handheld gasoline string trimmers to large diesel mine trucks.
- The opportunities for GHG reductions are therefore quite varied, but most applications have opportunities In general areas– engine efficiency improvements, equipment redesign to increase overall efficiency, and changes to operating practices.
- In many off-highway applications fuel economy has not historically been a major focus, and so large opportunities exist.
- For the same reason, however, historical rates of improvement occur indirectly as a consequence of technology migration from the highway engine sector and adoption of time-saving innovations. Those technologies typically improve at rates of 2-4% per year.
- The engine and equipment improvements discussed here are for new sales, not retrofitted to the existing fleet.
- Scenario A considers:
  - An evolutionary (~1%/yr) engine efficiency improvement over 15 years through reducing engine friction, migration of electronically-enabled highway engine technologies for air and fuel management, and additional changeover of 2-stroke gasoline engines to 4-stroke technology. This rate of improvement is on the low end of historical annual improvement for engine technologies in general.
  - Introduction of electric and hydraulic hybrid machines in key applications, especially those involving repetitive tasks with potential energy recovery, such as excavators (horizontal swing motion) and forklifts (vertical lift/lower motion). Li-ion batteries developed for highway vehicles will find use in these applications.
  - Increased use of plug-in electric lawncare machines, both cord-type and rechargeable battery-type, using Li-ion batteries developed for highway use.
  - Modest rates of further adoption of energy-saving work practices and products, such as no-till farming, slow-growth grasses and natural landscaping, and LED portable lighting.
- Scenario B considers:
  - A wider penetration of the Scenario A engine and hybrid technologies, plus improvements in the design of farm and construction implements that reduce energy use, continuing a decades-old trend.
  - Replacement of some diesel, gasoline, and LPG equipment with electrics, using a mix of 3 modes– batteries that charge at night (e.g., farm tractors on farmsteads with wind turbines), batteries swapped out as needed (e.g., at jobsite central charging stations), and increased jobsite electrification for corded welders, pumps, etc.
  - Increased adoption of energy-saving work practices and products (same annual rate as scenario A, sustained over 10 additional years).


Off-Highway Technology + Operations Results
Total nonroad tailpipe emissions under the technology + operational strategies scenarios
Annaul GHG Emissions (MMT)
300
250
200
150
100
50
0
2005
2010
2015
2020
2025
2030
Reference
Scenario A
Scenario B

Transportation Sector Results

Transportation Sector Results—Annual

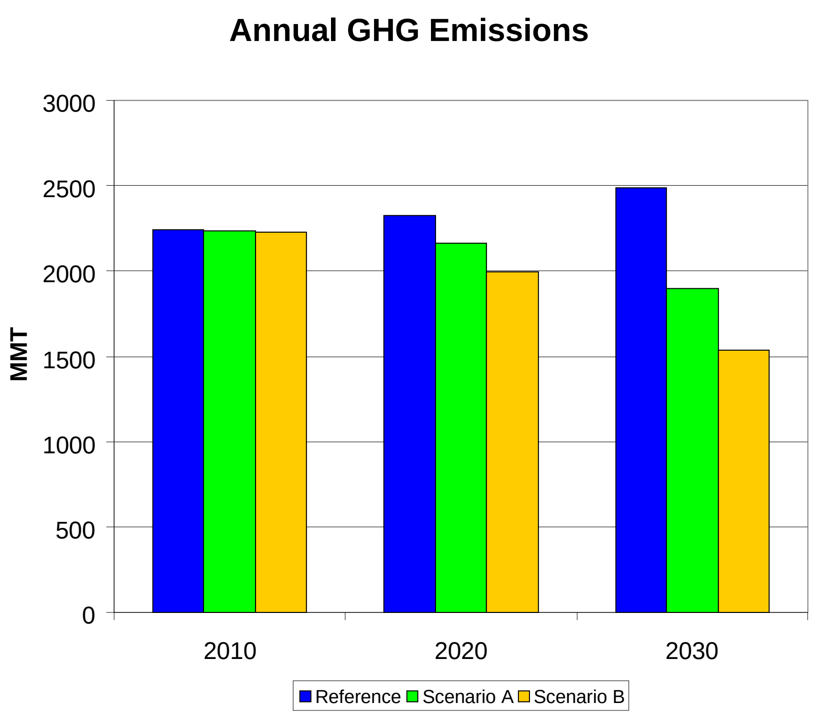
The illustrated scenarios would result in the following annual reductions in 2030 relative to the AEO 2009 reference case for 2030.

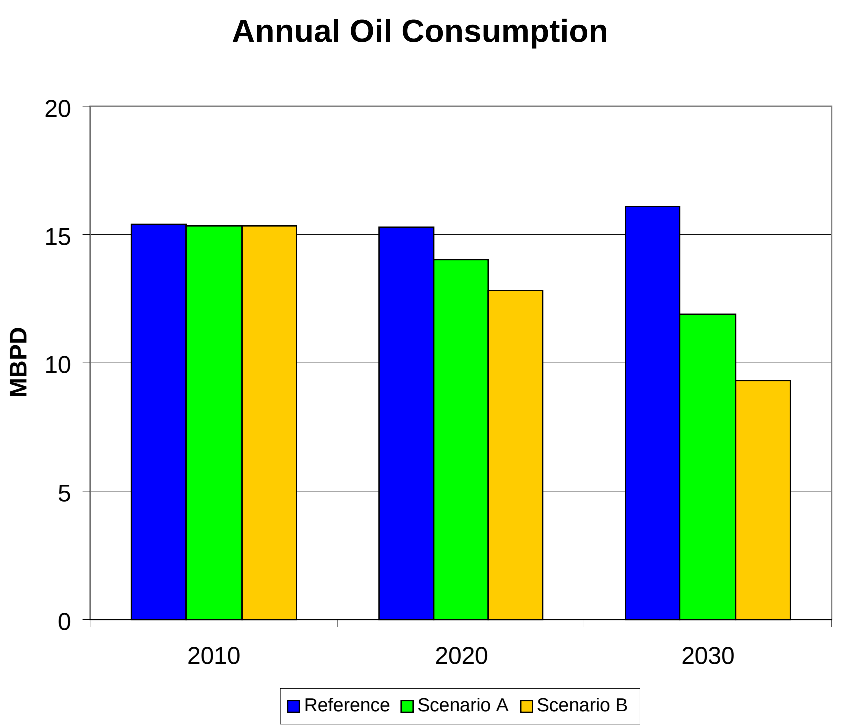
	Reference		Scenario A				Scenario B			
	GHG Emissions	Oil Consumption	GHG Reduction	Oil Savings	GHG Reduction	Oil Reduction	GHG Reduction	Oil Savings	GHG Reduction	Oil Reduction
	MMT	MBPD	MMT	MBPD	% of subsector		MMT	MBPD	% of subsector	
Light Duty	1200	7.4	346	2.1	29%	29%	485	3.1	40%	42%
Heavy Duty	529	3.6	43	0.3	8%	9%	59	0.4	11%	12%
Nonroad	758	5.1	109	0.8	14%	15%	226	1.6	30%	32%
LD + HD Travel Efficiency	n/a	n/a	139	1.0	8%	9%	224	1.6	13%	14%
Total	**2487**	**16.1**	**637**	**4.2**	**26%**	**26%**	**994**	**6.7**	**40%**	**42%**

Recall that the results presented here and on subsequent pages do not account for rebound effects except for in light duty; the greenhouse gas emissions associated with increased electrification nor other upstream fuel effects; the effects of vehicle manufacturing and disposal; the possible rebound in world petroleum demand due to lower petroleum prices; the costs of different strategies nor other economic effects; potential effects on safety, travel time, or consumer choice implications. Rather, they are an accounting of the reductions at the vehicle tailpipe that could occur if known technology and operational improvement opportunities were realized.

Transportation Sector Results--Annual

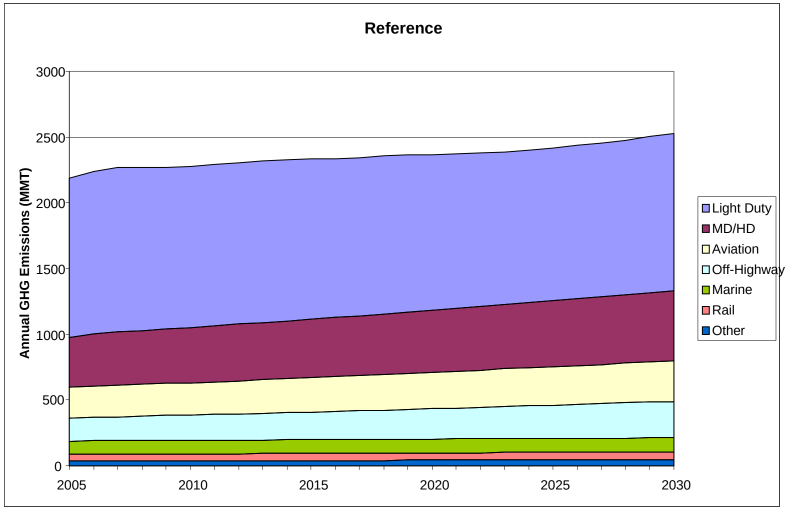
These charts show the total annual GHG emissions and oil consumption for the transportation fleet for the two scenarios relative to the reference case.

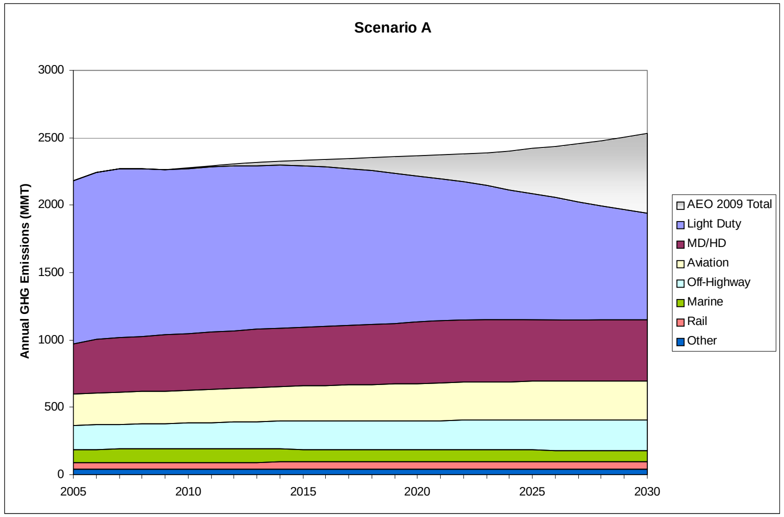


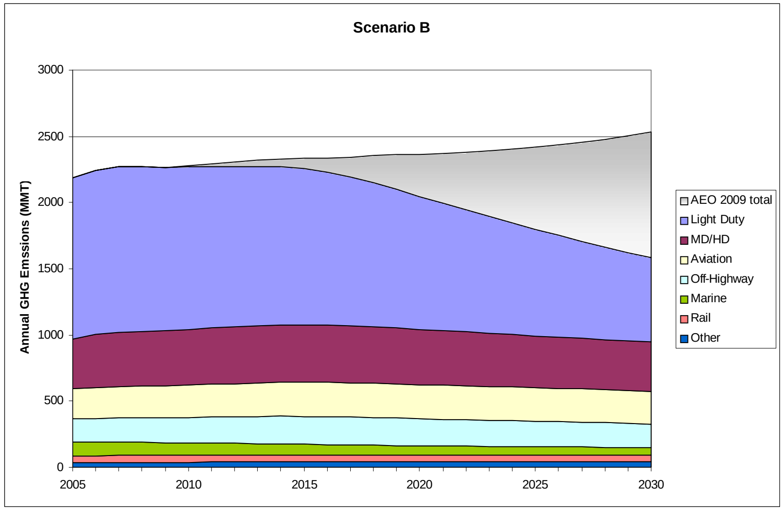


Transportation Sector Results--Annual

These graphs illustrate the total annual GHG emissions for the transportation fleet from 2005 to 2030 for the reference case and two scenarios.







Transportation Sector Results—Lifetime Cumulative

This table shows the cumulative vehicle lifetime GHG and oil savings for the two scenarios for vehicles and equipment sold between 2012 and 2030, including increasingly effective technologies on new vehicles and equipment and reductions from highway travel efficiency measures, operational strategies, and retrofits of the existing truck fleet.

	Reference Case		Scenario A 2012-2030 MY Cumulative Lifetime				Scenario B 2012-2030 MY Cumulative Lifetime			
	GHG Emissions	Oil Consumption	GHG Reduction	Oil Savings	GHG Reduction	Oil Reduction	GHG Reduction	Oil Savings	GHG Reduction	Oil Reduction
	MMT	Bbbl	MMT	Bbbl	% of subsector		MMT	Bbbl	% of subsector	
Light Duty	20000	53	3700	8.9	19%	17%	5400	14	27%	26%
Heavy Duty	11000	30	1900	5.2	17%	17%	2000	5.4	18%	18%
Nonroad	13000	32	1400	3.4	11%	11%	2600	6.4	20%	20%
Travel Efficiency	n/a		1200	3.2	4%	4%	2100	5.5	7%	7%
Total	**44000**	**110**	**8200**	**21**	**19%**	**19%**	**12000**	**31**	**27%**	**28%**

The illustrated scenarios would result in the following cumulative vehicle lifetime savings through model year 2030 relative to the AEO 2009 Reference Case:

- 8,200-12,000 MMT of GHGs—a 19-27% reduction in cumulative lifetime emissions
- 21-31 billion barrels of oil—a 19-28% reduction in cumulative lifetime oil consumption