Potential Role of Hydrogen In U.S. Energy Mix

Presentation to Hydrogen Technical Advisory Committee

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HTAC Recommendation III.3

"The Posture Plan needs to present a broader vision of how hydrogen fits into the overall energy strategy for the United States, and convey the message that hydrogen will be a key part of the energy mix, which will include an array of advanced technologies using energy derived from fossil, nuclear, and the various renewable resources."

US/DOE Energy Strategy

- US Energy Policy/Strategy (from National Energy Policy, May 2001) includes:
  - Long term, comprehensive approach to energy
  - New, environmentally friendly technologies to increase energy supplies and encourage cleaner, more efficient energy use
  - Full integration of energy, environmental and economic policies
- DOE strategy is technology R&D, aided by policy (EPAct, EISA) aimed at domestically available fuels, energy efficient vehicles and clean, reliable stationary power generation

Role of Hydrogen

- Hydrogen is one component in a portfolio of technologies being developed because of its potential to reduce oil use and CO_2 emissions, to be produced from diverse domestic energy sources, and to be used in highly efficient fuel cells.
- To address the HTAC recommendation, we analyzed market penetration scenarios and determined the potential energy and carbon reduction benefits (not predictions)

Approach and Tools

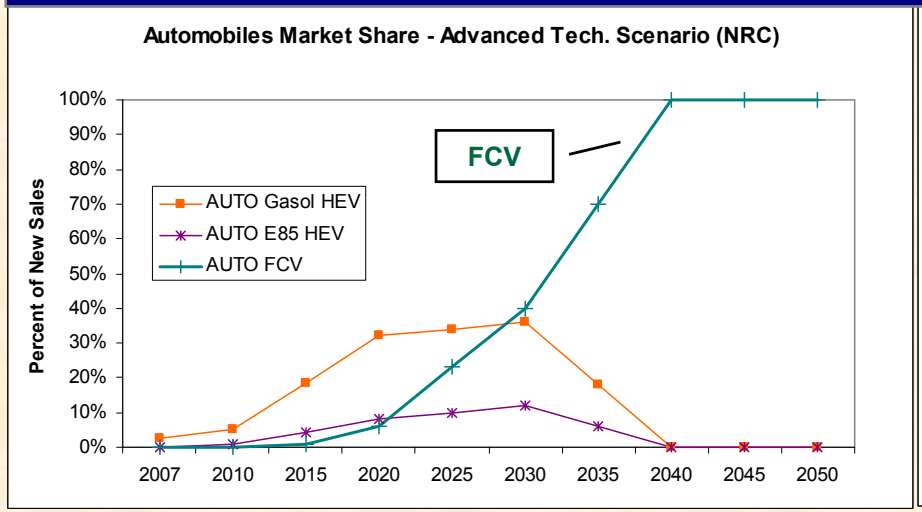
- Argonne National Lab's VISION* Model was used to analyze two transportation scenarios:
  - (a) National Research Council (NRC)'s 2004 scenario for fuel cell vehicles (FCVs)
  - (b) A more moderate FCV penetration scenario based on DOE EERE's ongoing Multi-Path Study
- Analyzed a scenario for stationary fuel cells - combined heat and power, followed by distributed electricity
- The above scenarios were compared to EIA's Reference Case (negligible fuel cell penetration) from their Annual Energy Outlook (AEO 2008)**

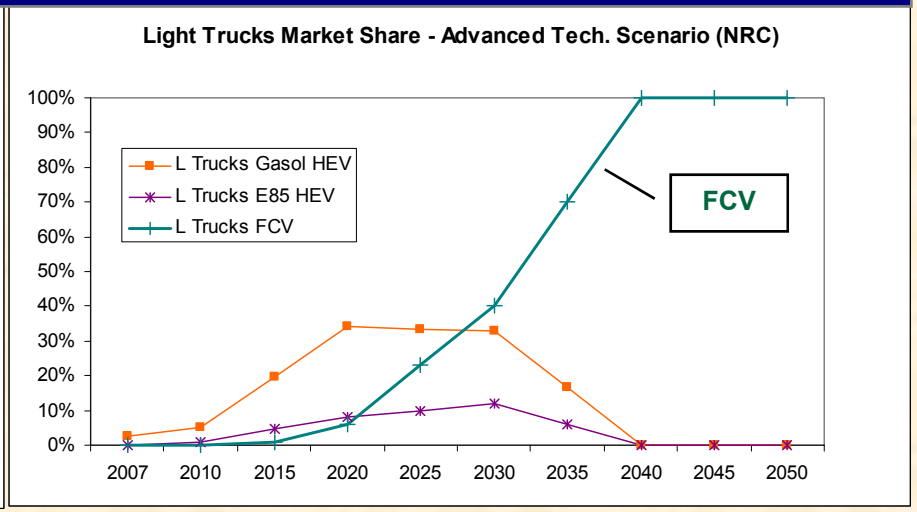
*VISION has been used in studies commissioned by California, USDOE, and others. VISION addresses only the transportation sector.

**EIA's projections do not go past 2030. Extrapolation is based on extending EIA Reference Case trends beyond 2030. For light-duty vehicles, assumed that gasoline hybrid electric vehicles will increase market share to eventually displace all new sales of internal combustion engine (ICE) vehicles by 2050. Assumed continued negligible penetration by stationary fuel cells when extrapolating EIA Case through 2050.

Market Penetration Scenarios of Light Duty Vehicles

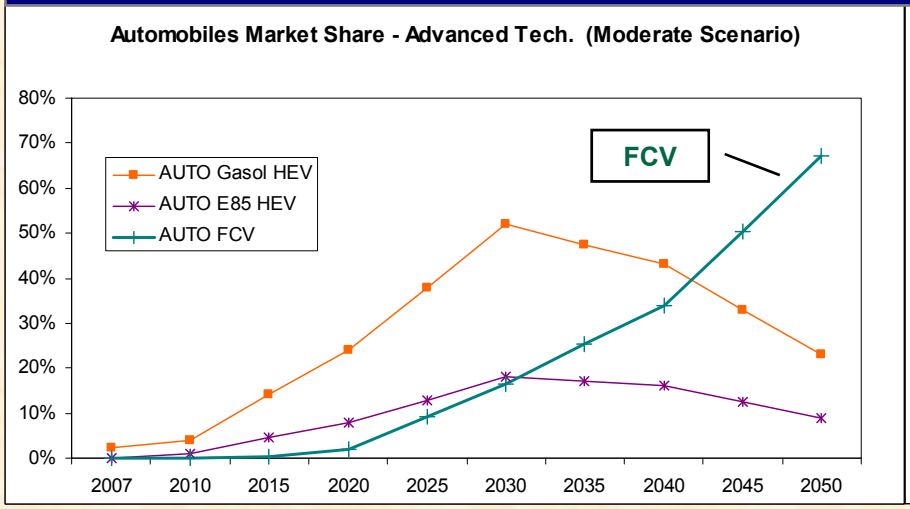
Aggressive Light-Duty Vehicle Penetration Scenario – NRC Case

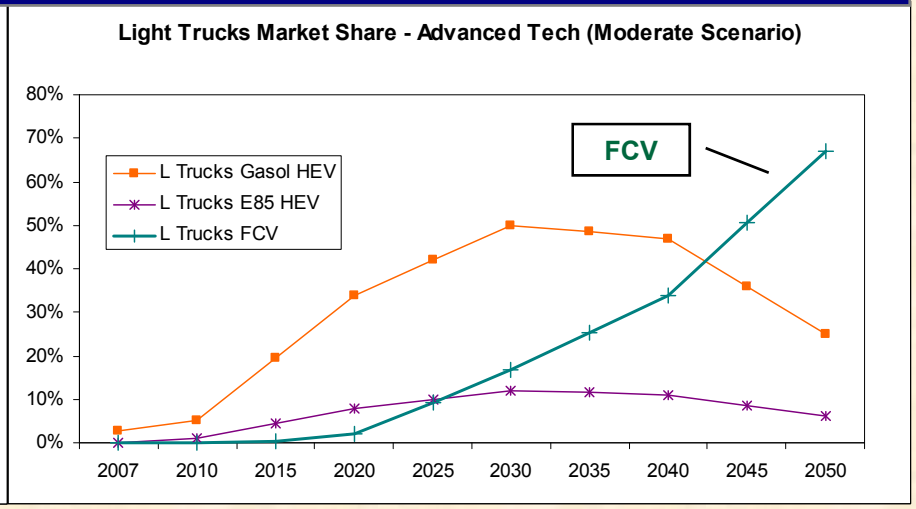




Source: NAS Hydrogen Economy Report

Moderate Light-Duty Vehicle Penetration Scenario





Source: DOE EERE Multi-Path Study

NRC's FCV Scenario vs. Moderate FCV Scenario

- Gasoline HEVs begin entering in 2005, followed by faster ramp-up beginning in 2015 (both scenarios)
- FCVs begin entering in 2015, followed by faster ramp-up beginning in 2025 for both scenarios
  - NRC Scenario is more aggressive with 100% FCV sales in 2050
  - Moderate Scenario achieves ~66% of light-duty market in 2050
- FCV market dominance causes gasoline HEV sales to begin declining in 2025 in NRC Scenario vs. 2031 in Moderate Scenario

Stationary Fuel Cell - Advanced Technology Case (Modified EEA Case)

- Scenario from U.S. Combined Heat and Power Association (2003 EEA Study)*, but assumed that fuel cell will be preferred CHP technology for near through long term
- Simple scale-up of natural gas savings from CHP in the 3 regions (EEA Study) to the entire U.S.
- Assumed penetration for distributed generation of electricity without CHP beginning in 2035 (e.g., backup power)

Energy & Environmental Analysis (EEA) 2003 Study:

- Covers Northeast, TX and CA (use 40% of U.S. natural gas)
- Estimated net reduction in gas use from CHP additions (>50 kW up to 100 MW per site)
- Commercial & industrial sectors (no residential)
- New CHP will displace nearly 7% of central grid capacity
- Power/Heat: 0.67 to 1.1
- Natural gas savings: 4% Northeast, 6% TX, 9% CA

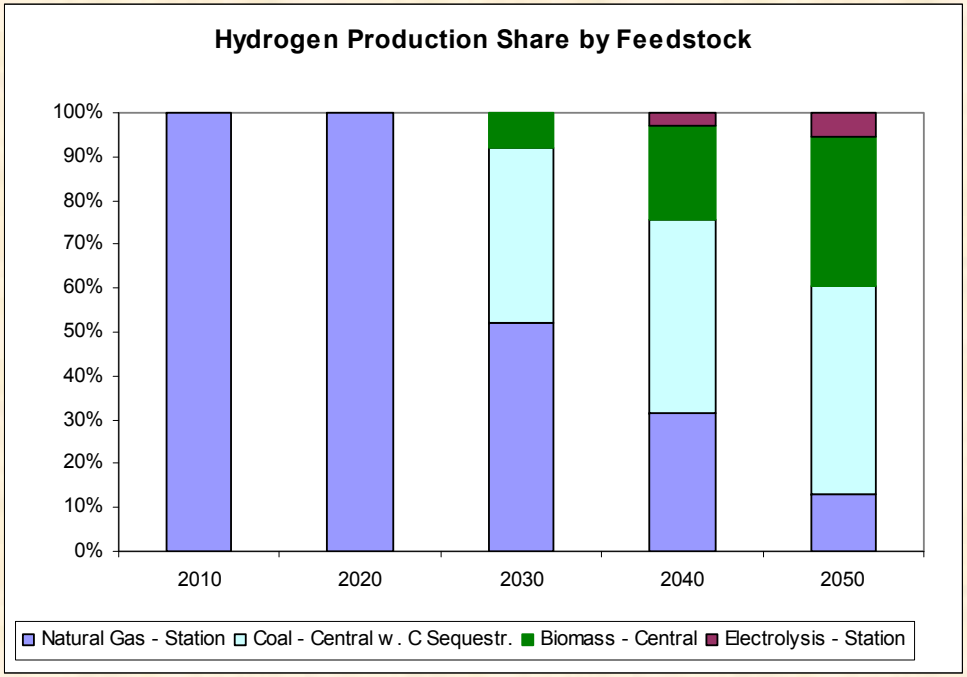
*As a result of a thorough literature review, this scenario was selected on due to the study's sound methodology.

Feedstock & Technology for Hydrogen Production

- Assumed feedstock & technology mix for this scenario is based on relative economics of feedstock/technology pathways

- Greenhouse gas (CO_2, N_2O, CH_4) emissions are from VISION (based on GREET life-cycle results)

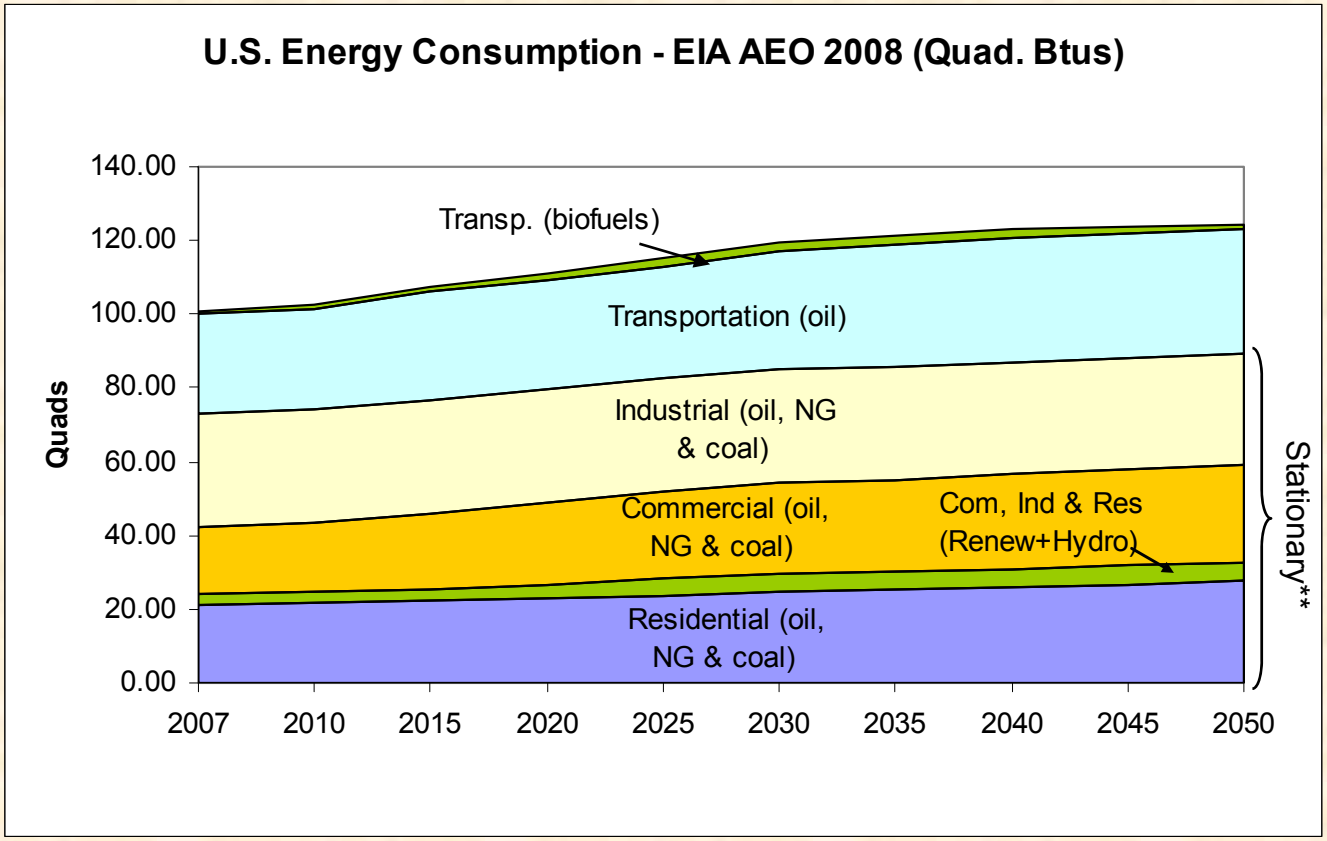
The trend of feedstock mix shown here is consistent with other DOE analyses and the Nation's growing use of renewable resources such as biomass



	2020	2030	2050
Fuel Cell Auto MPG	78	89	89
Fuel Cell Auto CO2 -grams/mile	204	132	111
Fuel Cell Light Truck MPG	56	66	66
Fuel Cell Light Truck CO2 -grams/mile	285	188	155
Gasoline Auto MPG	39	40	40
Gasoline Light Truck MPG	28	30	30
Gasoline HEV Auto MPG	52	54	55
Gasoline HEV Light Truck MPG	39	40	41

Results for EIA's Reference Case (Negligible Fuel Cell Penetration)*

- CAFE at 36 mpg in 2020 for light-duty vehicles
- Biofuels mandate is met with ethanol (~90%) and biodiesel (~10%)
- Fossil energy use increases by nearly 14% from 2010 to 2030 and 5% from 2030 to 2050



Notes:

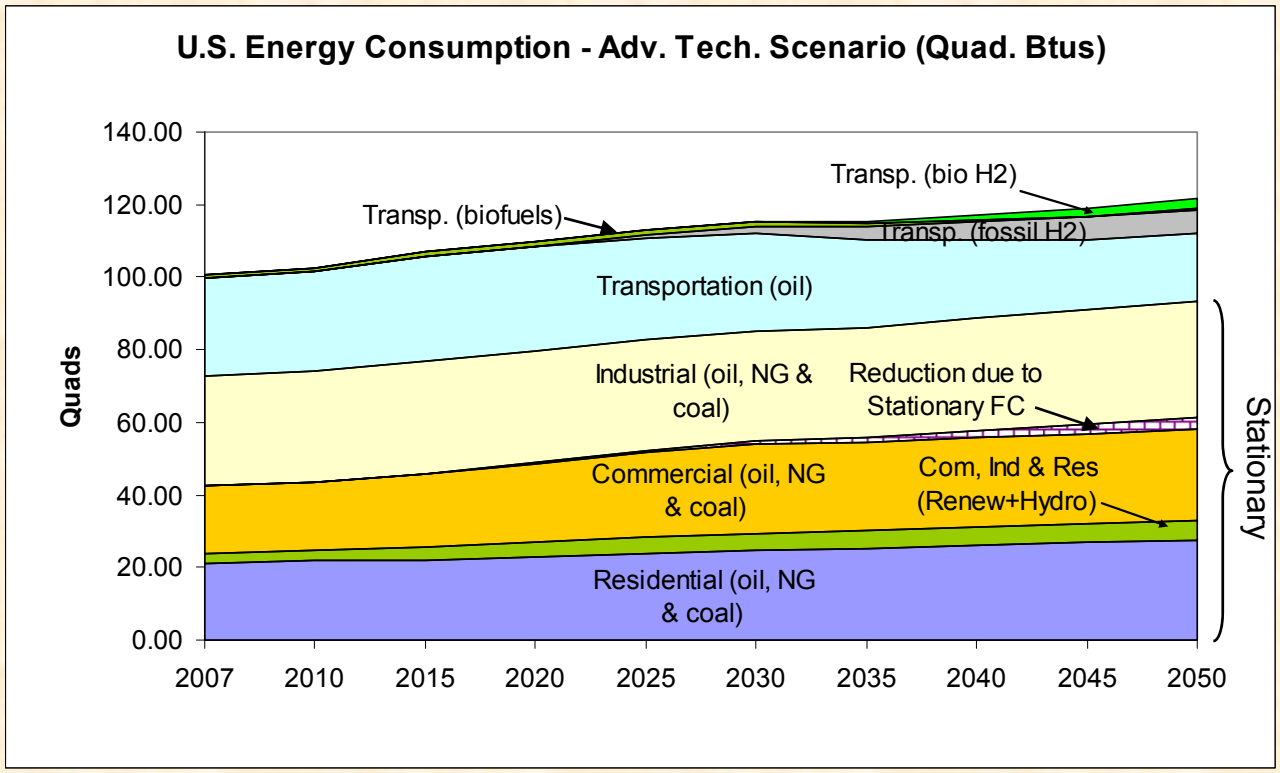
*EIA projections do not go past 2030. Extrapolation is based on extending AEO 2008 trends for the 2020-2030 period through 2050. For vehicles, HEVs will displace all ICE sales by 2050.

**Stationary fuel cell applications are included in this category.

****EIA included energy resources used by power plants in each of the 4 end-use sectors shown, in proportion to each sector's electricity consumption (including transmission losses)*

Advanced Technology Scenario with Aggressive NRC FCV Growth and Modified EEA Stationary FC Case

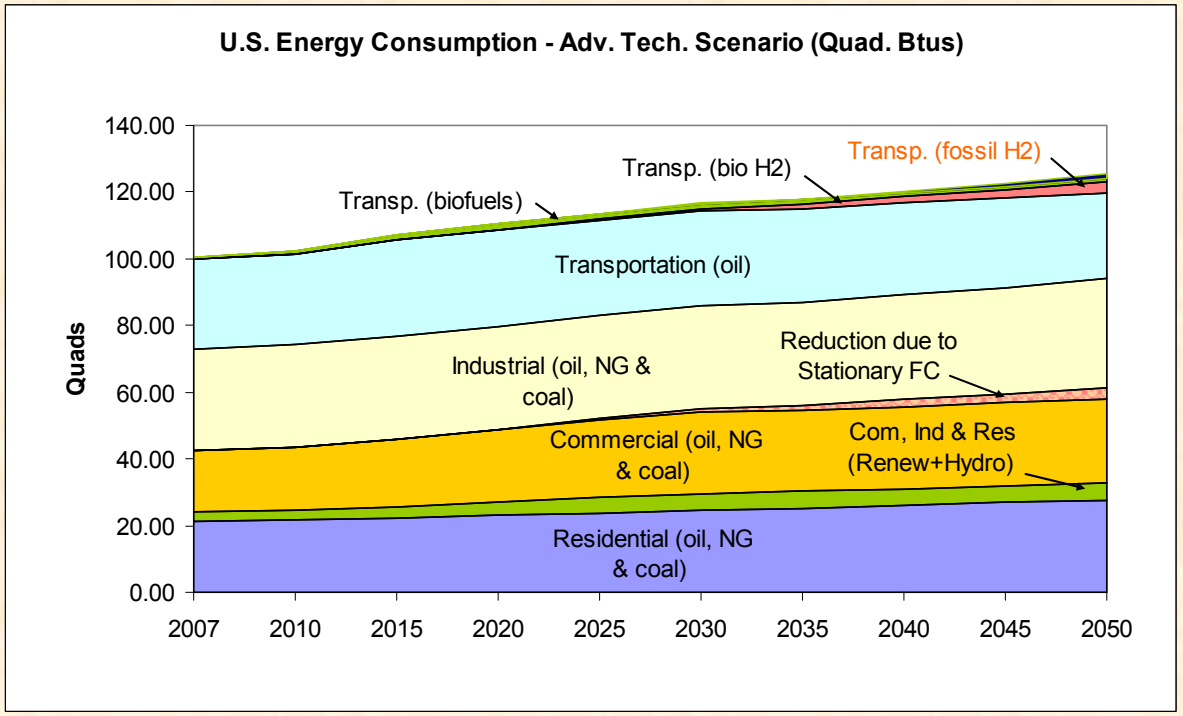
- CAFE at 41 mpg in 2020 based on NRC scenario for HEVs & FCVs
- Same biofuels assumptions as EIA scenario (until H2 production starts using biomass feedstock)
- Fossil energy use increases by nearly 9% from 2010 to 2030
- After 2040, oil is largely for diesel and jet fuel, not for gasoline production



	2030	2050
Gasoline as % of Transportation oil	42%	6%
FCVs as % of Light Duty Vehicles Energy	13%	96%
Fuel Cells as % of Grid Capacity	2%	11%

Advanced Technology Scenario with Moderate FCV Growth* and Modified EEA Stationary FC Case

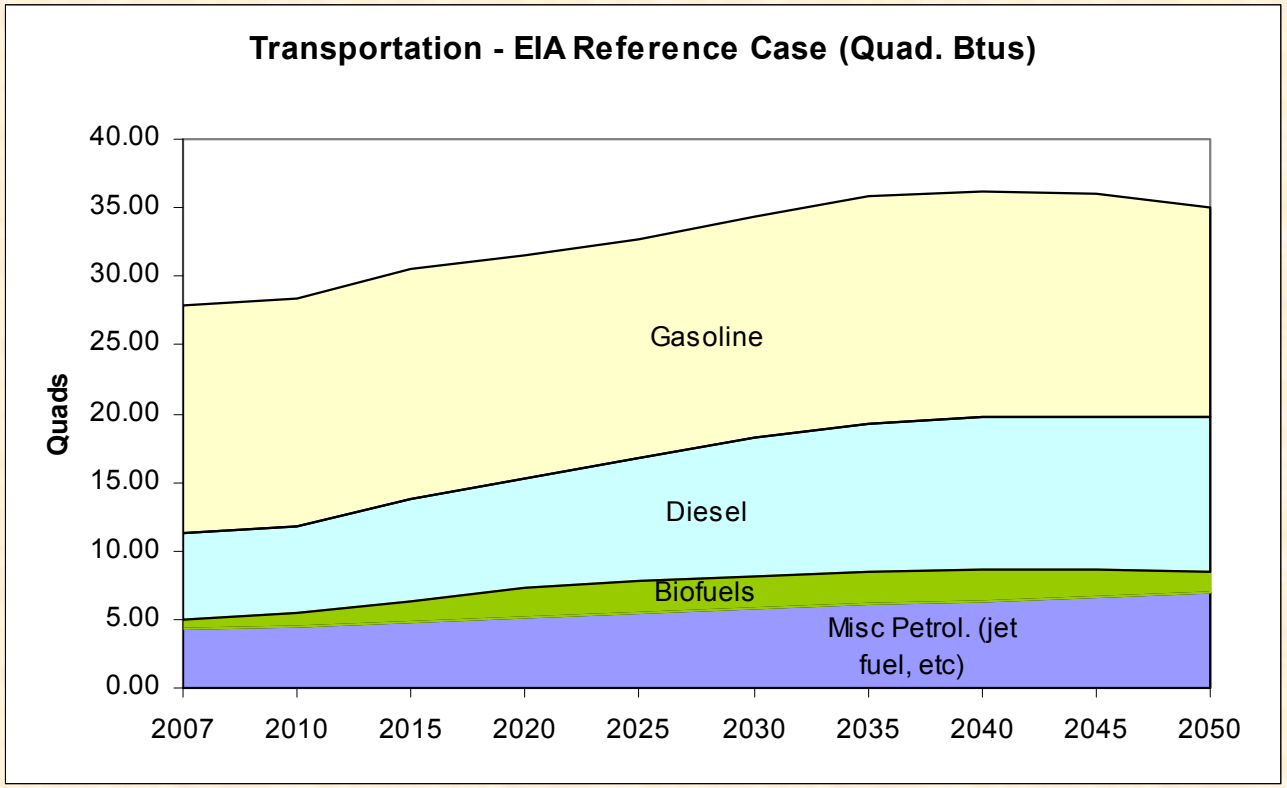
- CAFE at 39 mpg in 2020
- Same biofuels assumptions as previous scenario
- Same stationary fuel cells growth as previous scenario
- Fossil energy use increases by nearly 11% from 2010 to 2030



*FCV growth is bounded by results from ongoing DOE EERE Multi-Path Study

	2030	2050
Gasoline as % of Transportation oil	46%	30%
FCVs as % of Light Duty Vehicles Energy	5%	37%
Fuel Cells as % of Grid Capacity	2%	11%

Transportation – EIA Reference Case (Negligible Fuel Cell Penetration)



- Fossil energy use (primarily oil) increases by 17% between 2010 and 2030, and by nearly 6% between 2030 and 2050
- Basis: updated CAFÉ and Renewable Fuels Standard

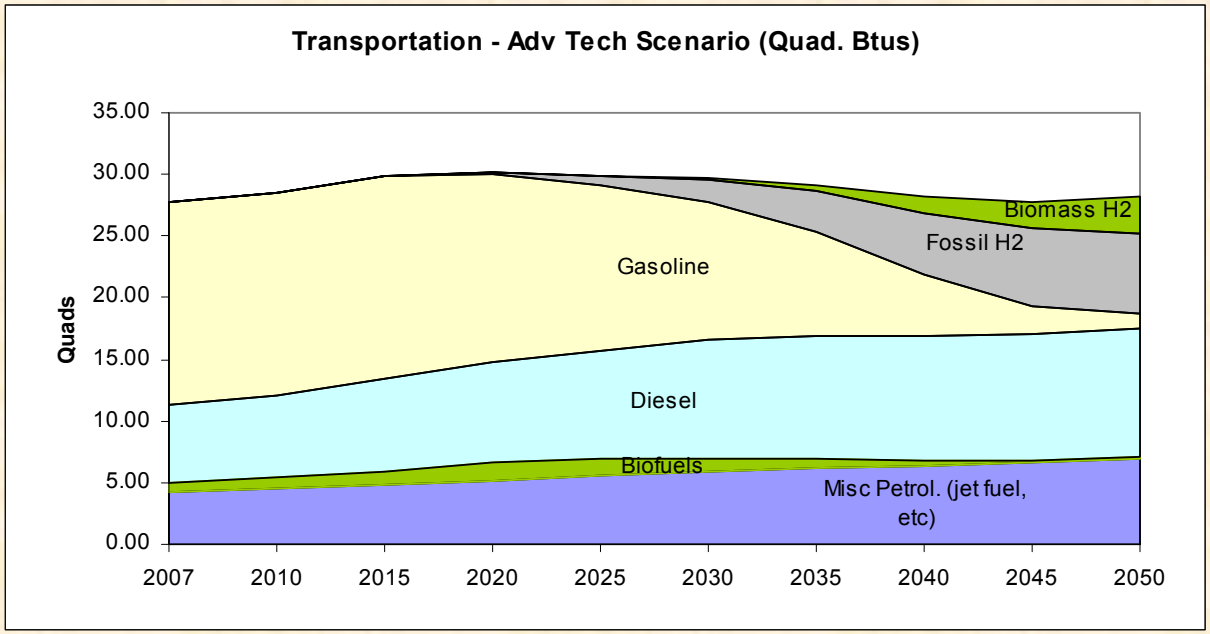
Mbpd Oil-Eqv.	2010	2030	2050
Gasoline	7.7	7.5	7.4
Diesel	3.0	4.8	5.3
Misc. (jet fuel, etc.)	2.1	2.8	3.3
Biofuels	0.5	1.1	0.8

Ethanol (10^9 gallons)
2020 : 22
2040 : 29

2020 CAFE (mpg)
Cars: 40
Light Trucks: 30

2040 CAFE (mpg)
Cars: 45
Light Trucks: 35

Transportation – Advanced Technology Scenario (NRC FCV Growth)



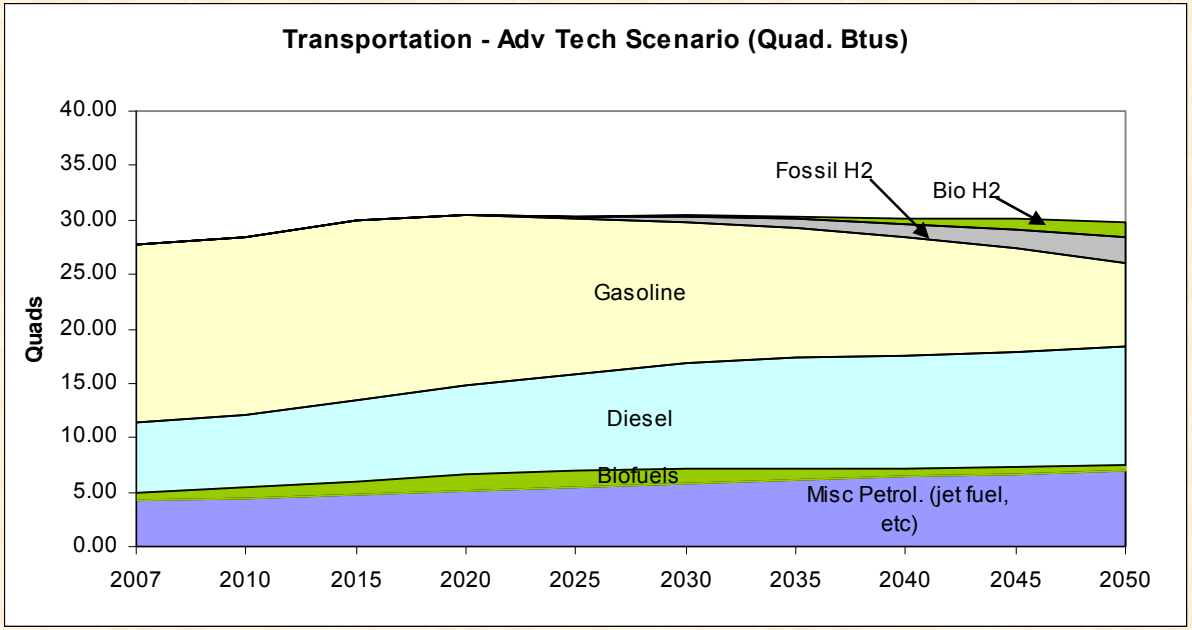
- Fossil energy use increases by 3% between 2010 and 2030, and decreases by nearly 12% between 2030 and 2050
- Transportation oil is nearly 17% less than EIA Case in 2030 and 45% less in 2050
- Basis: MPG and renewable fuels standards similar to previous scenario

Mbpd Oil-Eqv.	2010	2030	2050
Gasoline	7.7	5.3	0.6
Diesel	3.2	4.5	5.0
Misc. (jet fuel, etc.)	2.1	2.8	3.3
Biofuels	0.4	0.5	0.0
Fossil H2	0.0	0.9	3.1
Bio H2	0.0	0.1	1.4

Ethanol - 10^9 gallons per year
2020 20
2040 10
(ICEs & HEVs ramping down causes biofuels reduction)

Note: Residual HEVs will continue to use gasoline past 2040, after phase-out of new HEV sales. Some medium trucks will continue to be gasoline-powered over the entire study period

Transportation – Advanced Technology Scenario (Moderate FCV Growth)



- Fossil energy use increases by 5% between 2010 and 2030, and decreases by 4% between 2030 and 2050
- Transportation oil is 10% less than EIA Case in 2030 and 24% less in 2050
- Basis: MPG and renewable fuels standards similar to previous scenario

Mbpd Oil-Eqv.	2010	2030	2050
Gasoline	7.7	6.2	3.7
Diesel	3.2	4.6	5.1
Misc. (jet fuel, etc.)	2.1	2.8	3.3
Biofuels	0.4	0.6	0.2
Fossil H2	0.0	0.4	1.6
Bio H2	0.0	0.03	0.7

Ethanol - 10^9 gallons per year

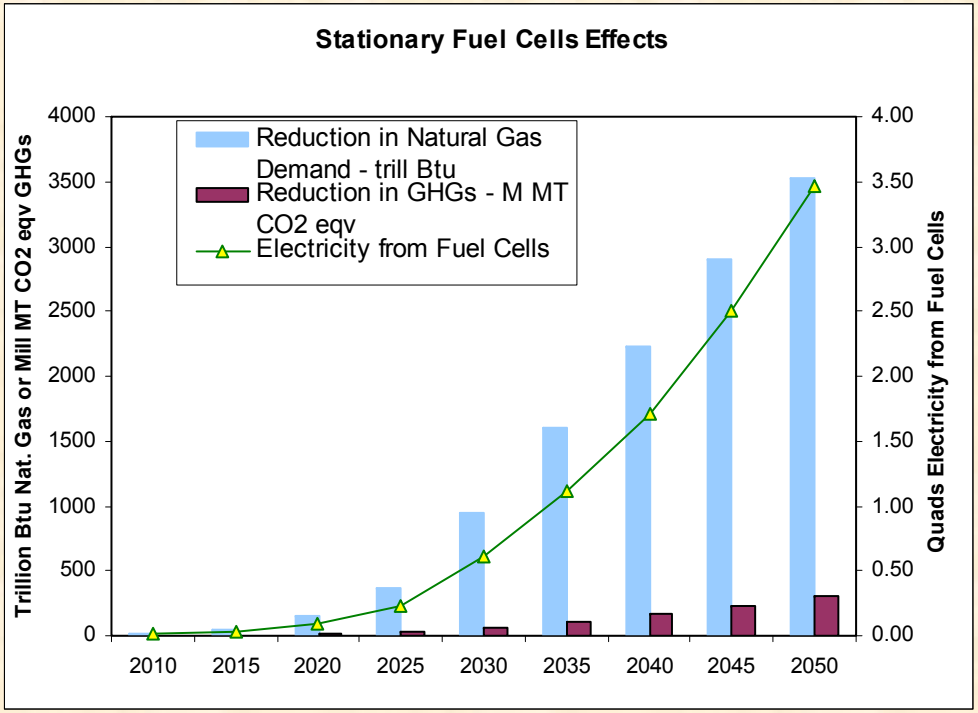
2020 20

2040 19.5

Stationary Fuel Cell Scenario

- **Stationary market penetration could grow to 2% of the electrical grid by 2030 and to 11% by 2050**
  - ❖ **Primary penetration in industrial and commercial sectors**

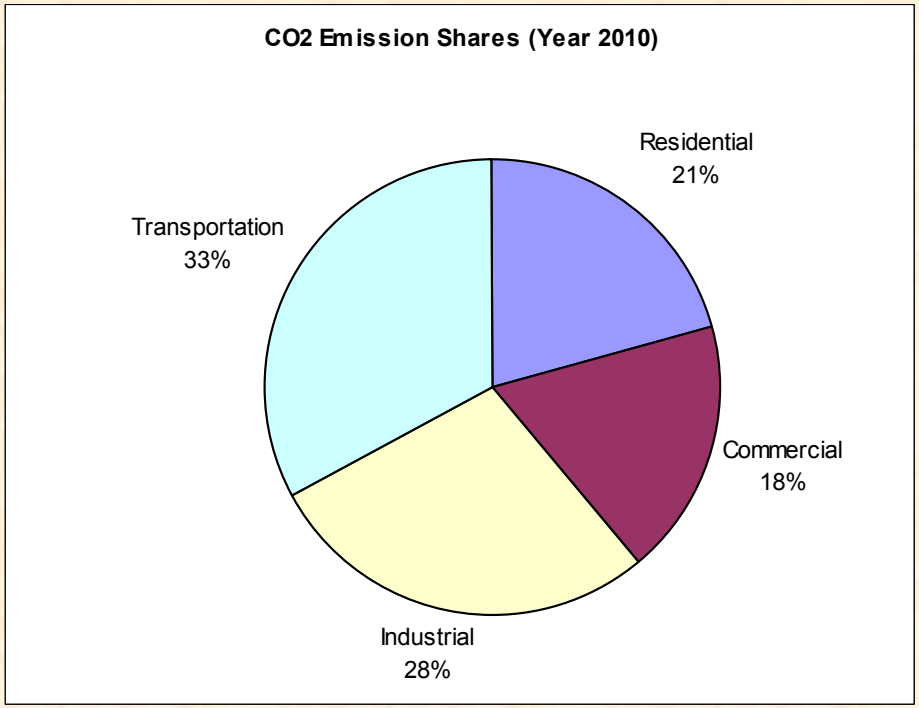
- **Natural gas will be primary fuel for stationary applications, except for industrial facilities located near renewable energy sources (biogas, landfill gas, etc.)**



- Assumed natural gas fuel cells for CHP and, after 2035, for both CHP and non-CHP distributed generation

	2030	2050
Fraction of Grid	2%	11%
Gwe	25	145

CO_2 Emissions (source: EIA - AEO 2008)

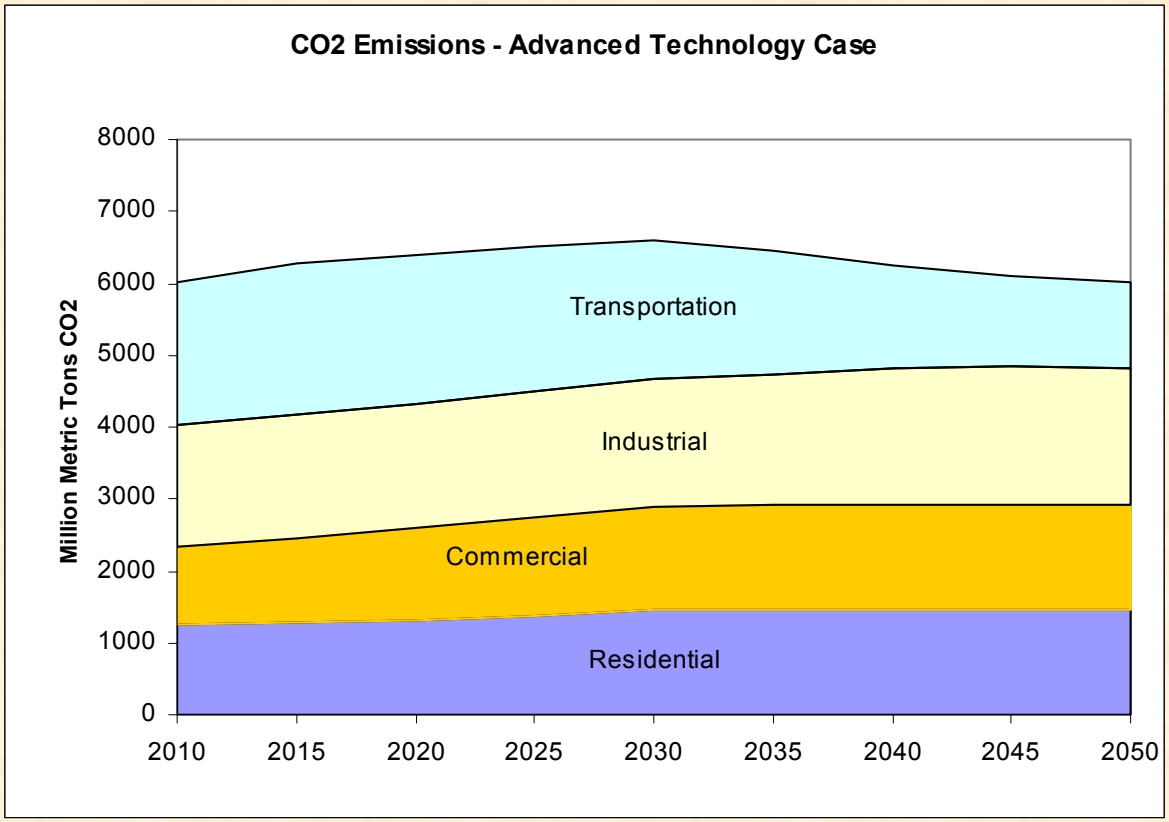


Million MT CO_2 in 2010	
Residential	1259
Commercial	1079
Industrial	1693
Transportation	1980
Total	**6011**

The transportation sector is the largest CO_2 emitting source

The electricity sector's emissions are included within each end-use sector shown, in proportion to the electricity used by each sector

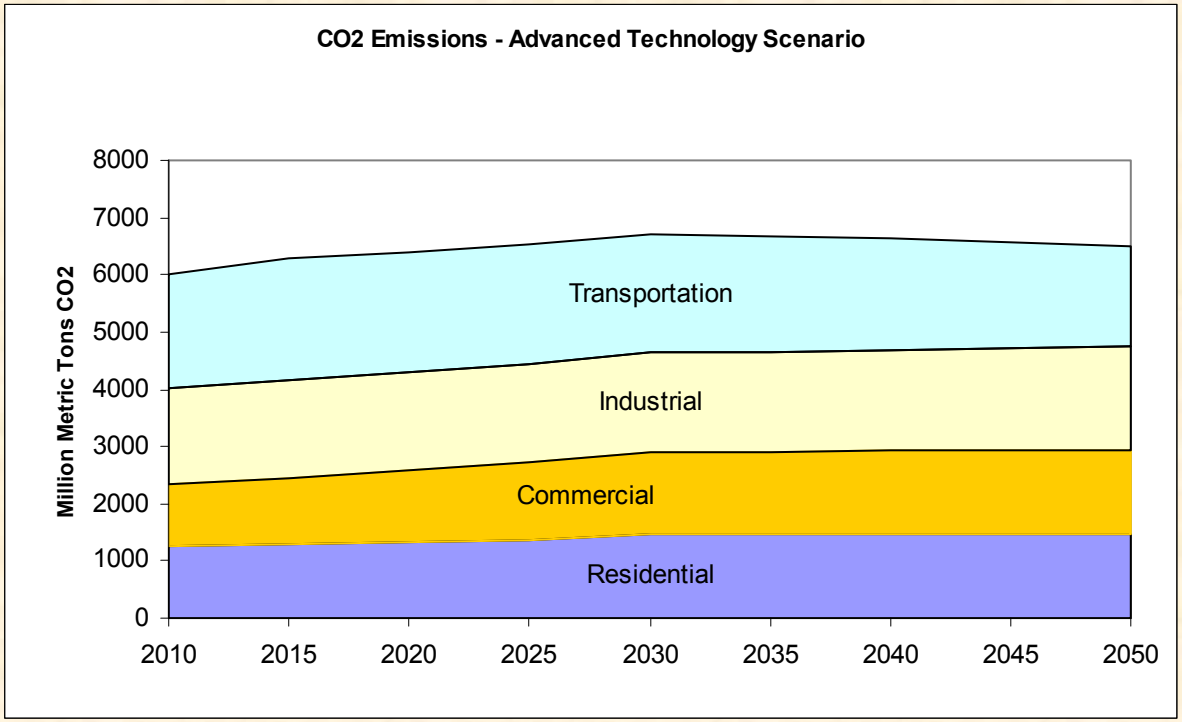
CO_2 Emissions: Aggressive NRC Advanced Technology Scenario



NRC scenario results in significant reduction of CO_2 emissions beginning in 2030 for the transportation sector (relative to the EIA Case)

CO2 Emissions in M MT	2010	2030	2050
Advanced Technology Scenario	6122	6741	6092
EIA Reference Case	6126	7250	7451
Reduction due to Fuel Cells		509	1360

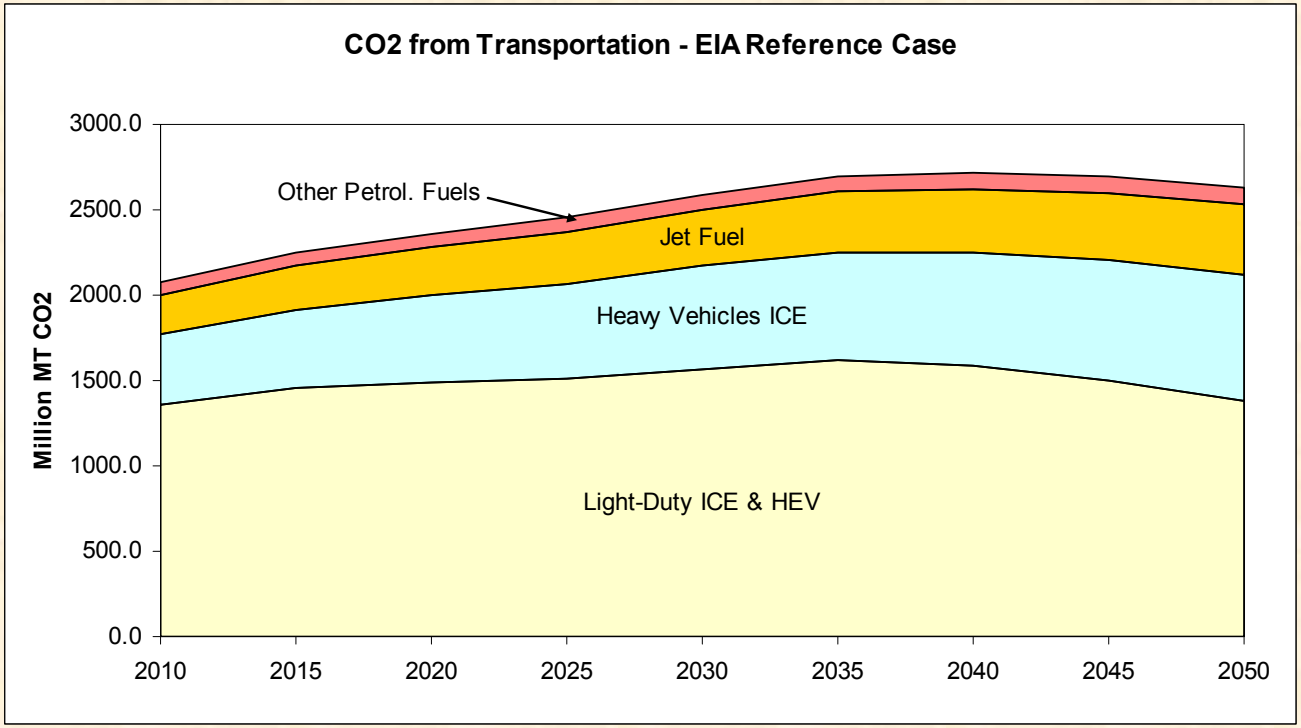
CO_2 Emissions: Moderate Advanced Technology Scenario



Scenario results in more moderate reduction of CO_2 emissions beginning in 2030 for the transportation sector (relative to the EIA Case)

CO2 Emissions in M MT	2010	2030	2050
Advanced Technology Scenario	6124	6899	6702
EIA Reference Case	6126	7250	7451
Reduction due to Fuel Cells		351	749

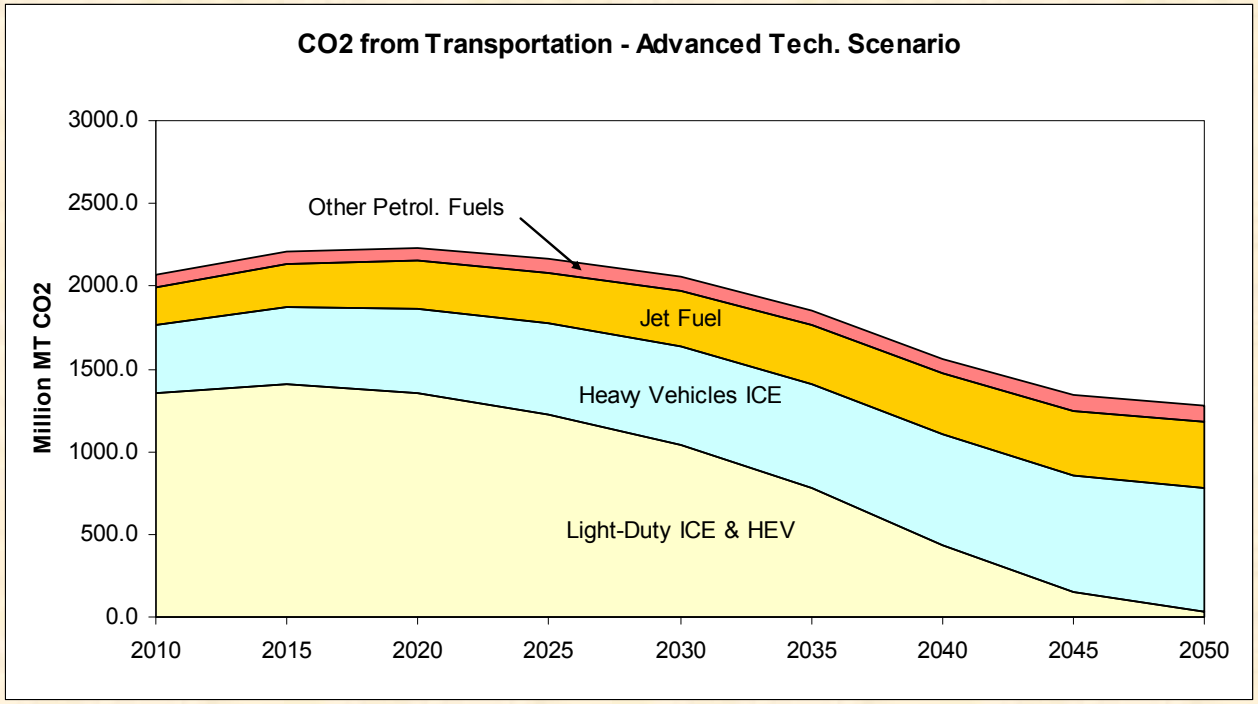
Transportation CO_2 Emissions – EIA Reference Case



By 2030, light-duty vehicles continue to emit significant CO_2 since fuel cell vehicles do not penetrate in the EIA Reference Case

CO2 Emissions in M MT	2010	2030	2050
Light-Duty ICE	1356	1569	1381
Heavy Vehicles ICE	414	602	742
Jet Fuel	233	334	407
Other Petrol. Fuels	72	86	101
Total - Transportation	2075	2591	2631

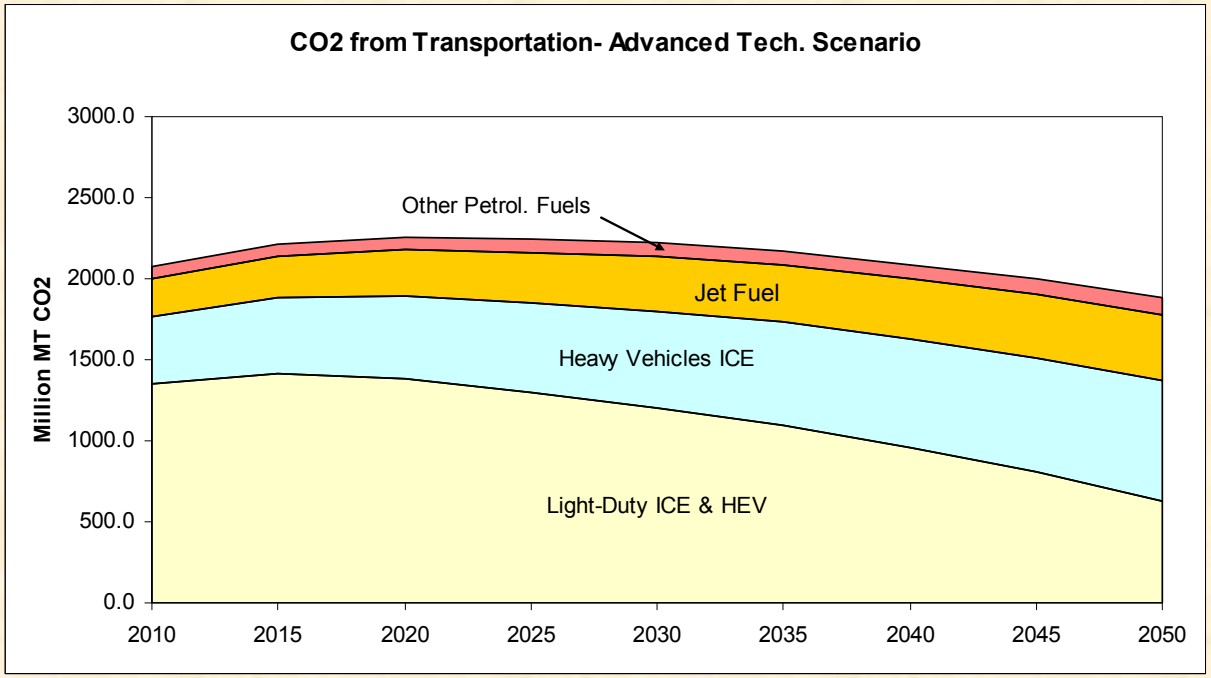
Transportation CO_2: Aggressive Advanced Technology Scenario (NRC)



NRC scenario results in significant decrease in light-duty vehicles' CO_2 by 2030

CO2 Emissions in M MT	2010	2030	2050
Light-Duty ICE	1349	1035	33
Light-Duty FCVs	0	0	0
Heavy Vehicles ICE	414	602	742
Jet Fuel	233	334	407
Other Petrol. Fuels	72	86	101
Total - Transportation	2068	2057	1283

Transportation CO_2: Moderate Advanced Technology Scenario



Fuel Cell scenario results in a decrease in light-duty vehicle CO_2, but total transportation CO_2 continues to increase through 2030

	2010	2030	2050
Light-Duty ICE & HEV	1351	1201	631
Light-Duty FCVs	0	0	0
Heavy Vehicles ICE	414	602	742
Jet Fuel	233	334	407
Other Petrol. Fuels	72	86	101
Total - Transportation	2070	2223	1881

Conclusions

Transportation Sector

- Relative to the Transportation Sector of the EIA Case, aggressive deployment of FCVs can reduce gasoline use by 30% in 2030 and by over 90% in 2050
  - Gasoline reduction for the Moderate Scenario is 18% in 2030 and 50% in 2050

- The overall transportation oil demand, including diesel and jet fuel, is reduced by 17% in 2030 and 45% in 2050 for the aggressive scenario
  - Oil reduction for the Moderate Scenario is 10% in 2030 and 24% in 2050

Stationary Sector

- Stationary fuel cells can potentially expand to over 10% of projected U.S. grid capacity by 2050 and account for a 2% reduction in CO_2 in 2030 and 8% reduction in CO_2 by 2050 relative to the EIA Reference Case for the 2 most impacted sectors (commercial and industrial)

Overall Energy Mix (Transportation, Commercial, Residential and Industrial Sectors)

- For the overall energy mix (Transportation, Commercial, Residential and Industrial Sectors), fuel cell vehicles and stationary fuel cells would reduce CO_2 emissions by 7% in 2030 and 18% in 2050 for the aggressive scenario relative to the EIA Reference Case
  - In the Moderate Scenario the CO_2 would be reduced by 5% in 2030 and 10% in 2050

- For the overall energy mix, stationary fuel cells would cause a 1% reduction in CO_2 emissions for both scenarios in 2030 and 3% in 2050