Annual Energy Outlook 2013:
Modeling Updates in the Transportation Sector

John Maples, Patricia Hutchins, Nicholas Chase
Office of Energy Consumption and Efficiency Analysis
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Overview

- Modeling updates made to the *Annual Energy Outlook 2013* Reference case
- Light-duty vehicle technology updates
- Heavy-duty natural gas vehicles
- Preliminary results (Working group presentation for discussion purposes. Do not quote or cite as results are subject to change)

Annual Energy Outlook 2013 Reference case updates

- Light-duty vehicle base year
  - Updated to 2010 for base year vehicle attributes such as price, horsepower, weight, tank size, fuel economy
- Light-duty vehicle technology*
- Light-duty vehicle flex-fuel
  - Updated vehicle choice parameters so that projected sales reflect historical trends
- Light-duty vehicle VMT
  - Historical data updated from Federal Highway Administration and Macroeconomic module
  - Updated VMT model coefficients based on new historical VMT data
- Heavy-duty natural gas vehicles*
- Historical data update from *Annual Energy Review* 2011

Light-duty vehicle technology

Light-duty vehicle technology list update based on latest information

- Primarily drawn from joint EPA/NHTSA Final Rule: 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards

- Additional information taken from:
  - Joint Rulemaking to Establish CAFE and GHG Emissions Standards, MY 2012-2016
  - Average Fuel Economy Standards, Passenger Cars and Light Trucks, MY 2011, Final Regulatory Impact Analysis
  - Assessment of Fuel Economy Technologies for Light-Duty Vehicles, National Academies, 2010
  - Wards Automotive

- We are working with EPA and NHTSA to address differences in cost

Light-duty vehicle technology—the specifics

- Technology list expanded to include 86 technologies
  - **Vehicle:** Mass Reduction I to V; Aerodynamics I and II; Tires I and II; Low Drag Brakes; Secondary Axle Disconnect
  - **Transmission:** 6 speed Manual; 6, 7, and 8 speed Automatic; Dual Clutch Automated Manual; High Efficiency Gearbox; Aggressive Shift Logic I and II; Early Torque Converter Lockup; Continuously Variable Transmission
  - **Accessories/Electrification:** Electric Power Steering; Improved Accessories I and II; 12V Micro Hybrid; Integrated Starter Generator Mild Hybrid
  - **Engine (most by cylinder and cam profile):** Low Friction Lubricants; Engine Friction Reduction I and II; Cylinder Deactivation; Variable Valve Timing (ICP, CCP, DCP); Variable Valve Lift (DVVL, CVVL); Stoichiometric Gasoline Direct Injection; Turbocharging and Downsizing I, II, and III with cooled EGR

Light-duty vehicle technology—the specifics

- Technology update includes attributes and engineering notes:
  - Fuel economy (Final Rule 2017-2025 and Lumped Parameter Model)
  - Cost (derived from Final Rule 2017-2025 and others)
  - Horsepower adjustment
  - Weight adjustment
  - Synergistic fuel economy and supersedes engineering notes
- Base year (2010) market penetration for technologies taken from Wards Automotive and EPA/NHTSA data
- Technology learning similar to Final Rule 2017-2025

Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
Unit Body Construction	125	124	124	124
Mass Reduction I-1.5% reduction	0.08/lb**	0.08/lb	0.08/lb	0.08/lb
Mass Reduction II-3.5% reduction	0.18/lb**	0.18/lb	0.18/lb	0.17/lb
Mass Reduction III-10% reduction	0.52/lb**	0.52/lb	0.51/lb	0.50/lb
Mass Reduction IV-15% reduction	0.78/lb**	0.78/lb	0.77/lb	0.74/lb
Mass Reduction V-20% reduction	0.90/lb**	0.90/lb	0.89/lb	0.86/lb
Aero I-10% Cd reduction	60	54	50	47
Aero II-20% Cd reduction	254	226	213	198
Tires I-10% Crr reduction	7	6	6	5
Tires II-20% Crr reduction	73	73	45	39
Low Drag Brakes	74	74	74	74
Secondary Axle Disconnect	121	108	101	94

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Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
6 Speed Manual	320	285	268	248
Aggressive Shift Logic I	41	36	34	32
Aggressive Shift Logic II	34	34	30	27
Early Torque Converter Lockup	37	33	31	29
High Efficiency Gearbox	251	250	219	201
5 Speed Automatic	130	116	109	101
6 Speed Automatic	338	301	283	263
7 Speed Automatic	502	446	420	390
8 Speed Automatic	667	593	558	518
Dual Clutch Automated Manual	71	63	59	55
CVT	314	279	263	244

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Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
Low Friction Lubricants	4	4	4	4
Engine Friction Reduction I-4 cyl	59	59	59	59
Engine Friction Reduction I-6 cyl	89	88	88	88
Engine Friction Reduction I-8 cyl	118	117	117	117
Engine Friction Reduction II-4 cyl	126	125	125	125
Engine Friction Reduction II-6 cyl	185	184	184	184
Engine Friction Reduction II-8 cyl	244	243	243	243
Cylinder Deactivation-6 cyl	234	208	196	182
Cylinder Deactivation-8 cyl	263	234	220	204

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Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
VVT I-OHC Intake Cam Phasing-4 cyl	55	49	46	43
VVT I-OHC Intake Cam Phasing-6 cyl	111	99	93	86
VVT I-OHC Intake Cam Phasing-8 cyl	111	99	93	86
VVT II-OHV Coupled Cam Phasing-6 cyl	55	49	46	43
VVT II-OHV Coupled Cam Phasing-8 cyl	55	49	46	43
VVT II-OHC Coupled Cam Phasing-4 cyl	55	49	46	43
VVT II-OHC Coupled Cam Phasing-6 cyl	111	99	93	86
VVT II-OHC Coupled Cam Phasing-8 cyl	111	99	93	86
VVT III-OHC Dual Cam Phasing-4 cyl	113	101	95	88
VVT III-OHC Dual Cam Phasing-6 cyl	245	218	205	190
VVT III-OHC Dual Cam Phasing-8 cyl	245	218	205	190

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Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
VVL I-OHV Discrete-6 cyl	282	251	236	219
VVL I-OHV Discrete-8 cyl	404	359	338	314
VVL I-OHC Discrete-4 cyl	195	173	163	151
VVL I-OHC Discrete-6 cyl	282	251	236	219
VVL I-OHC Discrete-8 cyl	404	359	338	314
VVL II-OHV Continuous-6 cyl	1439	1280	1205	1118
VVL II-OHV Continuous-8 cyl	1573	1399	1317	1222
VVL II-OHC Continuous-4 cyl	291	259	244	226
VVL II-OHC Continuous-6 cyl	535	476	448	416
VVL II-OHC Continuous-8 cyl	584	520	489	454
Stoichiometric GDI-4 cyl	331	294	277	257
Stoichiometric GDI-6 cyl	498	443	417	387
Stoichiometric GDI-8 cyl	598	532	501	465

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Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
OHV to DOHC TBDS-I4 (from V6), VVT, VVL, SGDI	1731	1540	1450	1345
OHV to DOHC TBDS I-V6 (from V8), VVT, VVL, SGDI	2623	2334	2198	2038
SOHC to DOHC TBDS I-I4 (from V6), VVT, VVL, SGDI	1035	921	867	804
SOHC to DOHC TBDS I-V6 (from V8), VVT, VVL, SGDI	2009	1787	1683	1561
DOHC TBDS I-I3 (from I4), VVT, VVL, SGDI	1145	1019	959	890
DOHC TBDS I-I4 (from V6), VVT, VVL, SGDI	935	832	783	726
DOHC TBDS I-V6 (from V8), VVT, VVL, SGDI	1915	1704	1604	1488
OHV to DOHC TBDS II-I4 (from V6), VVT, VVL, SGDI	1985	1784	1671	1550
OHV to DOHC TBDS II-V6 (from V8), VVT, VVL, SGDI	3059	2750	2576	2389
SOHC to DOHC TBDS II-I4 (from V6), VVT, VVL, SGDI	1309	1176	1102	1022
SOHC to DOHC TBDS II-V6 (from V8), VVT, VVL, SGDI	2463	2213	2074	1923

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Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
DOHC TBDS II-I3 (from I4), VVT, VVL, SGDI	1414	1271	1191	1105
DOHC TBDS II-I4 (from V6), VVT, VVL, SGDI	1211	1089	1020	946
DOHC TBDS II-V6 (from V8), VVT, VVL, SGDI	2372	2132	1997	1852
OHV to DOHC TBDS III-I4 (from V6), VVT, VVL, SGDI, EGR	2542	2527	2217	2036
OHV to DOHC TBDS III-I4 (from V8), VVT, VVL, SGDI, EGR	2004	1993	1748	1605
SOHC to DOHC TBDS III-I4 (from V6), VVT, VVL, SGDI, EGR	1959	1948	1708	1569
SOHC to DOHC TBDS III-I4 (from V8), VVT, VVL, SGDI, EGR	1727	1717	1506	1383
DOHC TBDS III-I3 (from I4), VVT, VVL, SGDI, EGR	2045	2033	1783	1638
DOHC TBDS III-I4 (from V6), VVT, VVL, SGDI, EGR	1875	1864	1635	1501
DOHC TBDS III-I4 (from V8), VVT, VVL, SGDI, EGR	1629	1620	1421	1304

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Light-duty vehicle technology cost, passenger car (2010 dollars)

Technology	2010 (or first year)	2017	2025	2040
Electric Power Steering	134	119	112	104
Improved Accessories I	109	97	92	85
12V Micro Hybrid w/EPS and IACC	801	510	447	411
Improved Accessories II	161	145	136	126
ISG Mild Hybrid w/EPS and IACC	5239	3334	2953	2698

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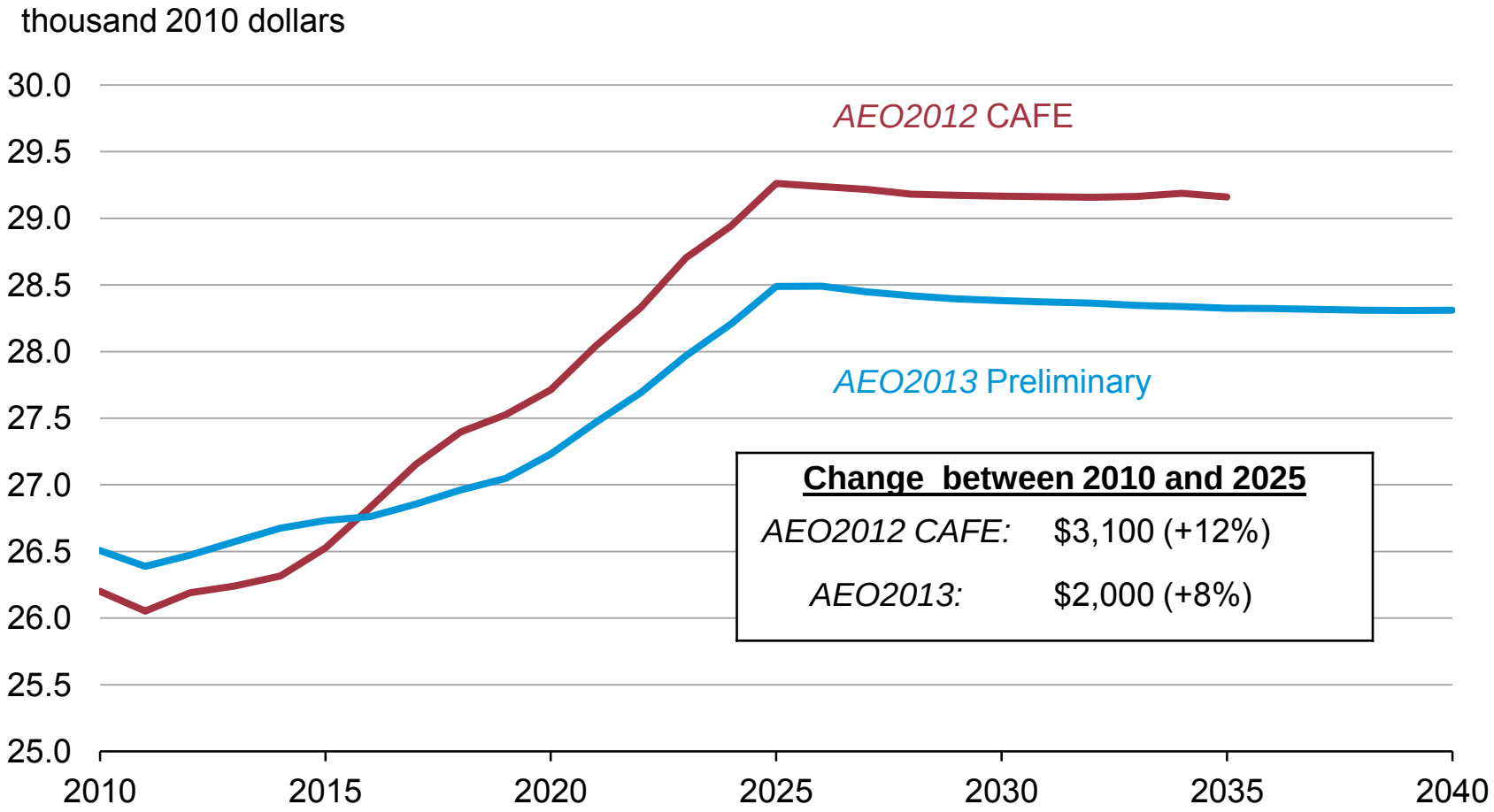
Average lower light-duty vehicle costs lower than *AEO2012* CAFE case due to inclusion of new technology inputs



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Heavy-duty natural gas vehicles

Updated heavy-duty natural gas vehicle fuel economics

- Incremental costs based on engine and tank costs, tank costs based on annual vehicle miles traveled (based on analysis completed for the AEO2012 HD NGV side case)

- New estimates of heavy-duty vehicle VMT distribution based on 2002 VUIS data for new and 2 year old vehicles

Updated heavy-duty natural gas incremental vehicle cost and fuel economics

- Natural gas vehicle incremental cost based on engine and tank cost

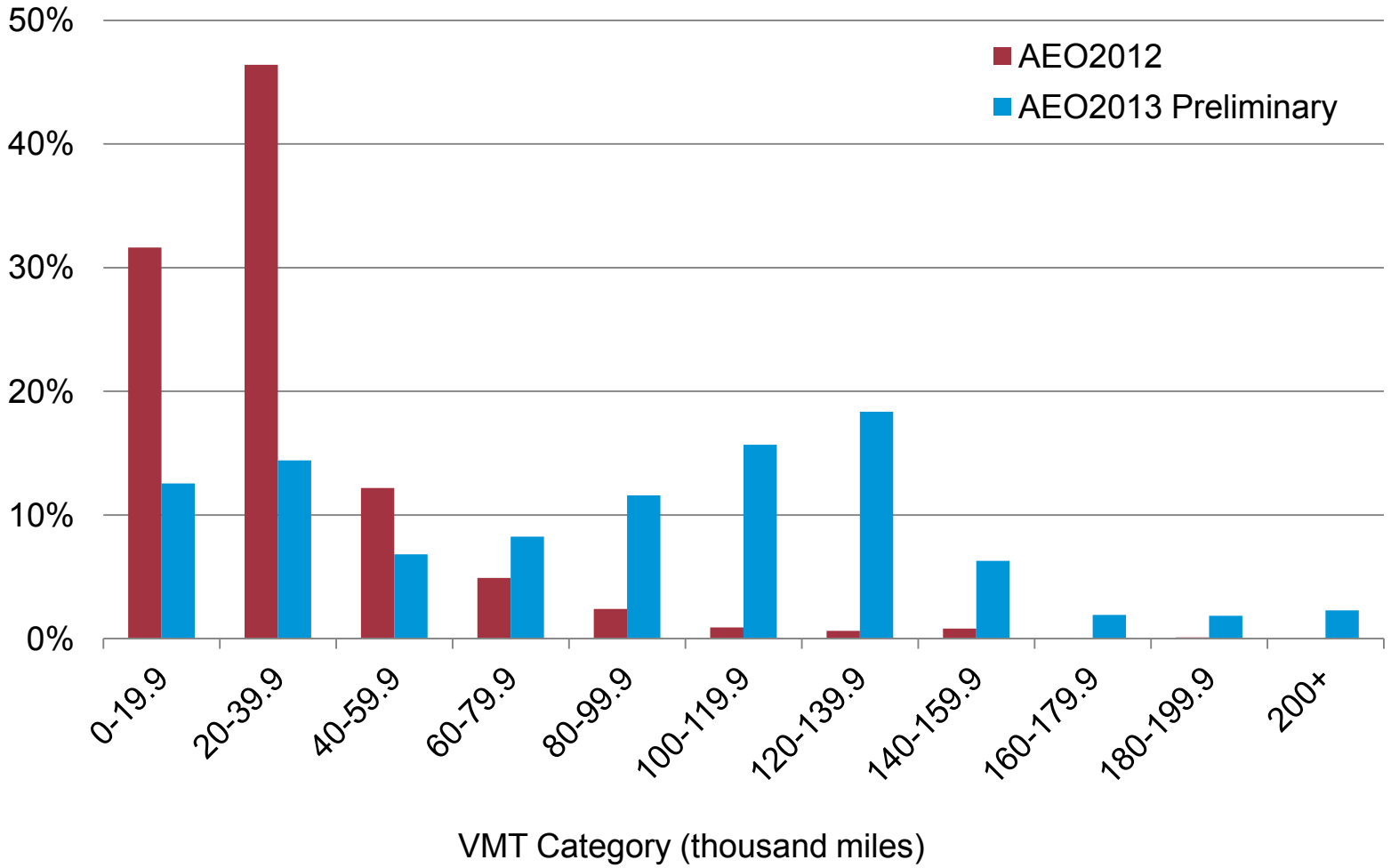
Vehicle Class	Engine/Non-storage tank cost	$/dge tank capacity cost	Fuel type
Class 3	$1,417	$340	CNG
Class 4-6	$19,750	$450	LNG
Class 7-8	$33,875	$475	LNG

Source: Cummins/Westport

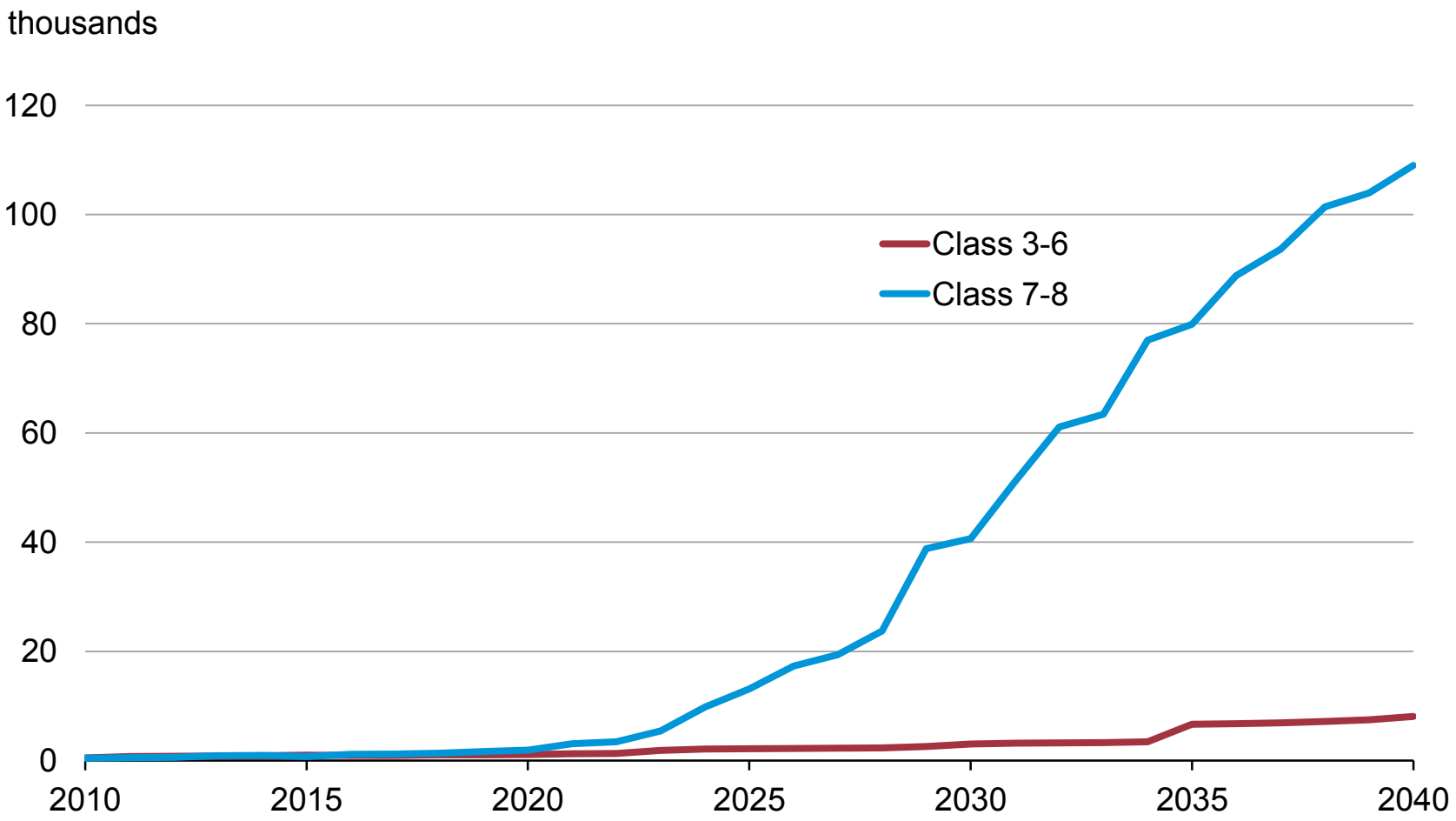
Natural gas vehicle tank sized according to vehicle miles traveled

VMT Group	Annual miles	Vehicle Cost ($)		
		Class 3	Class 4-6	Class 7-8
1	12,554	9,750	34,150	49,075
2	27,855	9,750	34,150	49,075
3	46,021	9,750	40,000	55,250
4	62,276	12,008	44,500	60,000
5	85,000	15,872	54,400	70,450
6	110,000	20,124	60,250	76,625
7	125,000	22,675	69,250	86,125
8	147,500	26,501	69,250	86,125
9	167,500	29,902	69,250	86,125
10	187,500	33,303	69,250	86,125
11	212,500	37,555	69,250	86,125

VMT distribution of fleet operated class 7-8 vehicles



Heavy-duty natural gas vehicle sales



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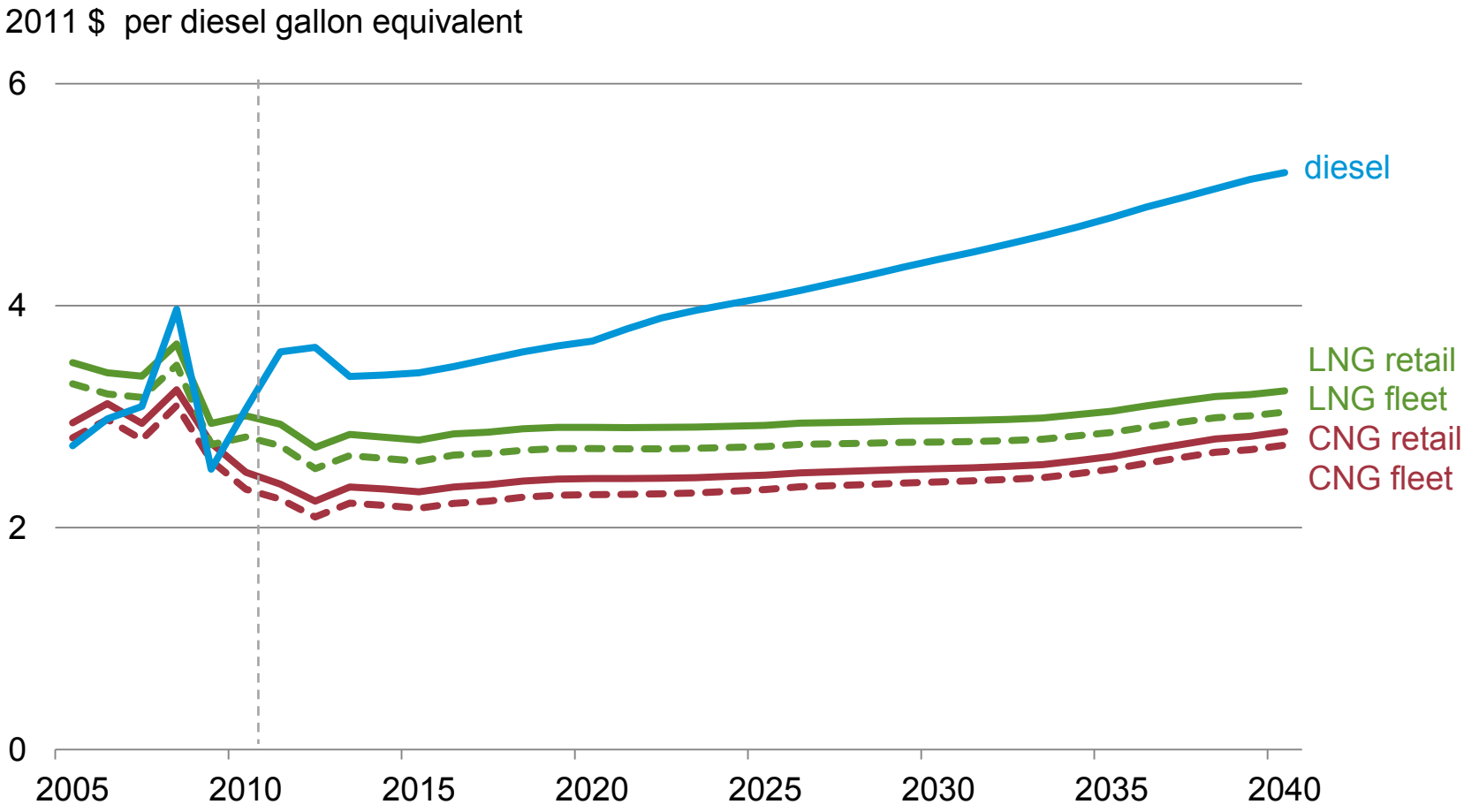
Decision to purchase natural gas based on VIUS 2 years or newer travel distribution

VMT Group	Annual miles (thousand)	Non-fleet			Fleet		
		Class 3	Class 4-6	Class 7-8	Class 3	Class 4-6	Class 7-8
1	0-19.9	69%	40%	15%	84%	52%	13%
2	20-39.9	31%	44%	17%	9%	34%	14%
3	40-59.9	0%	8%	11%	2%	7%	7%
4	60-79.9	0%	3%	12%	5%	4%	8%
5	80-99.9	0%	1%	14%	0%	2%	12%
6	100-119.9	0%	2%	7%	0%	1%	16%
7	120-139.9	0%	0%	13%	0%	0%	18%
8	140-159.9	0%	1%	6%	0%	0%	6%
9	160-179.9	0%	1%	2%	0%	0%	2%
10	180-199.9	0%	0%	1%	0%	0%	2%
11	200+	0%	0%	2%	0%	0%	2%

AEO2013 diesel fuel price increasingly higher than natural gas prices, offering opportunity for heavy-duty natural gas vehicles



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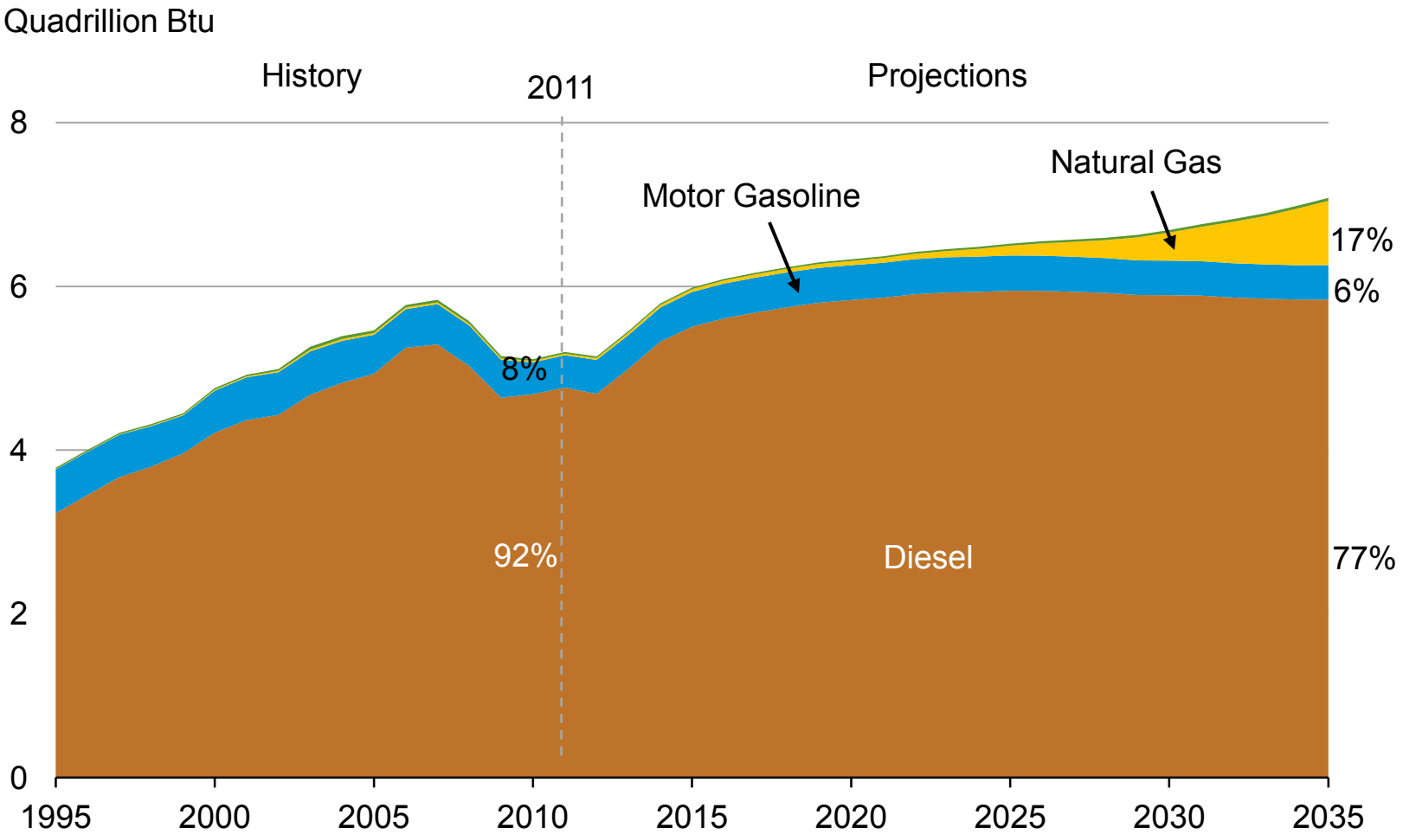
Heavy-duty vehicle natural gas consumption across projection due to difference in natural gas and diesel fuel prices



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Annual Energy Outlook 2013
Reference case preliminary results

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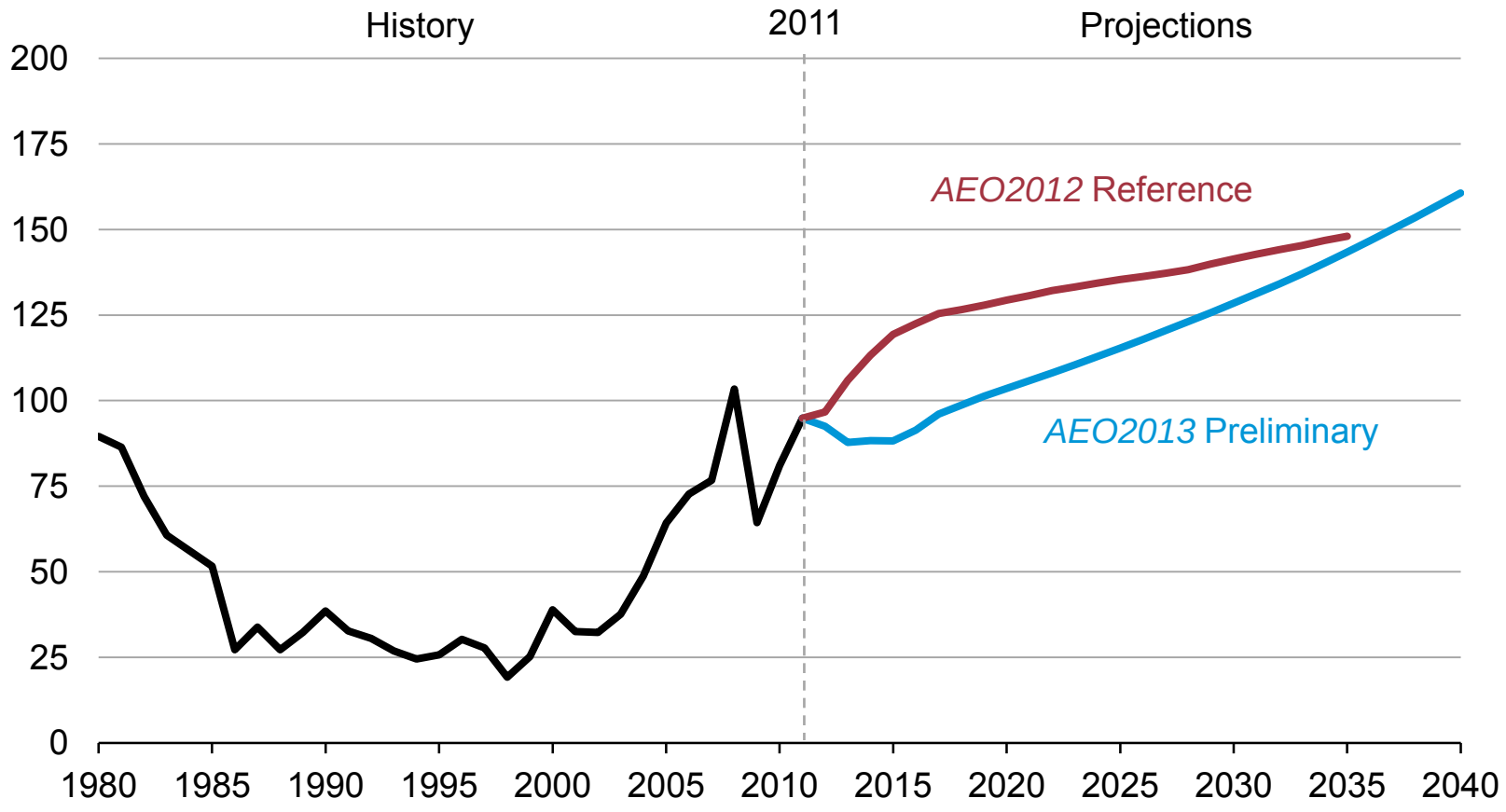
Oil price lower than *AEO2012*, rises steadily over projection period

annual average price
real 2011 $ per barrel



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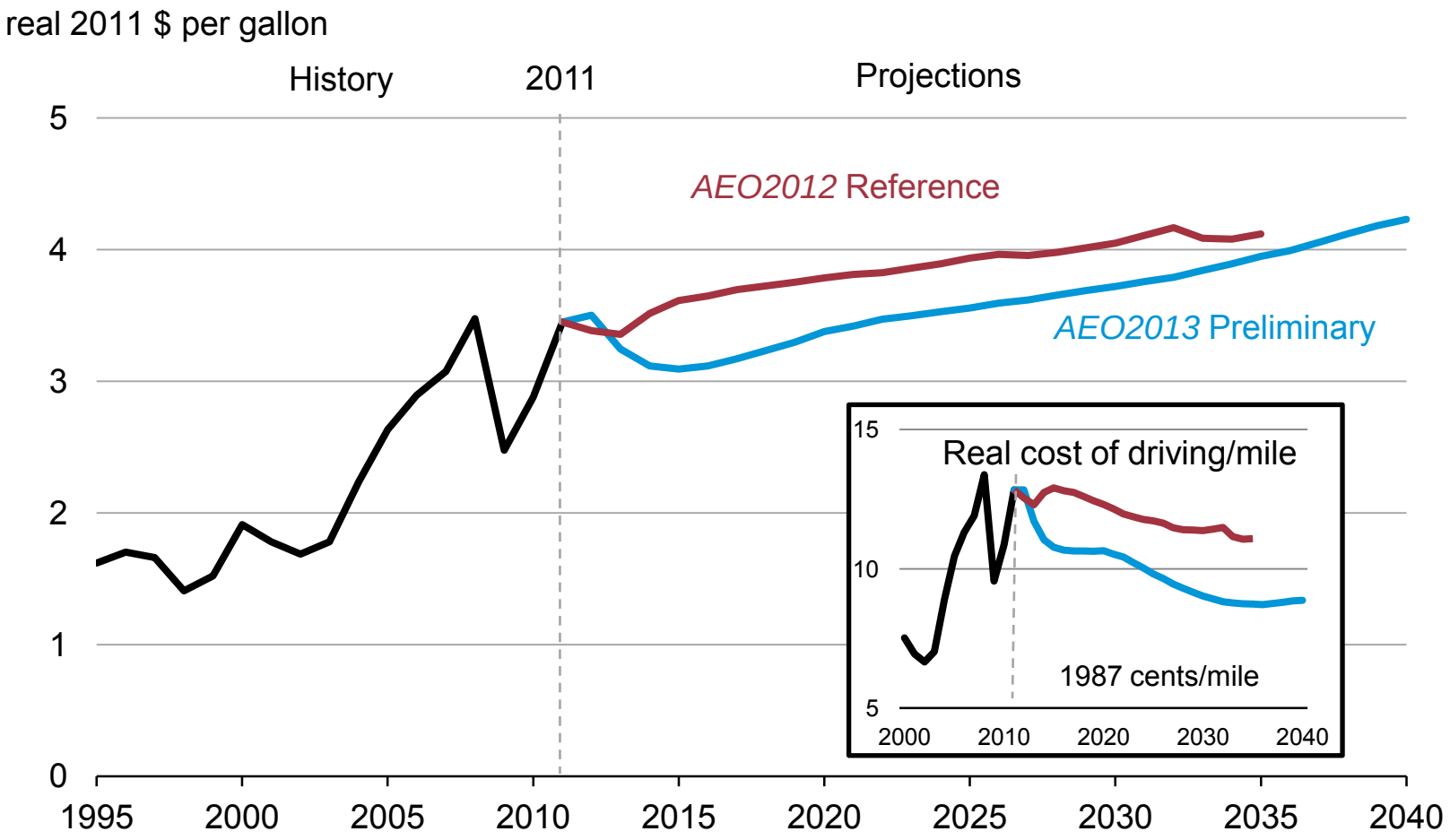
Motor gasoline price lower than *AEO2012*, rises steadily over projection, real cost of driving declining



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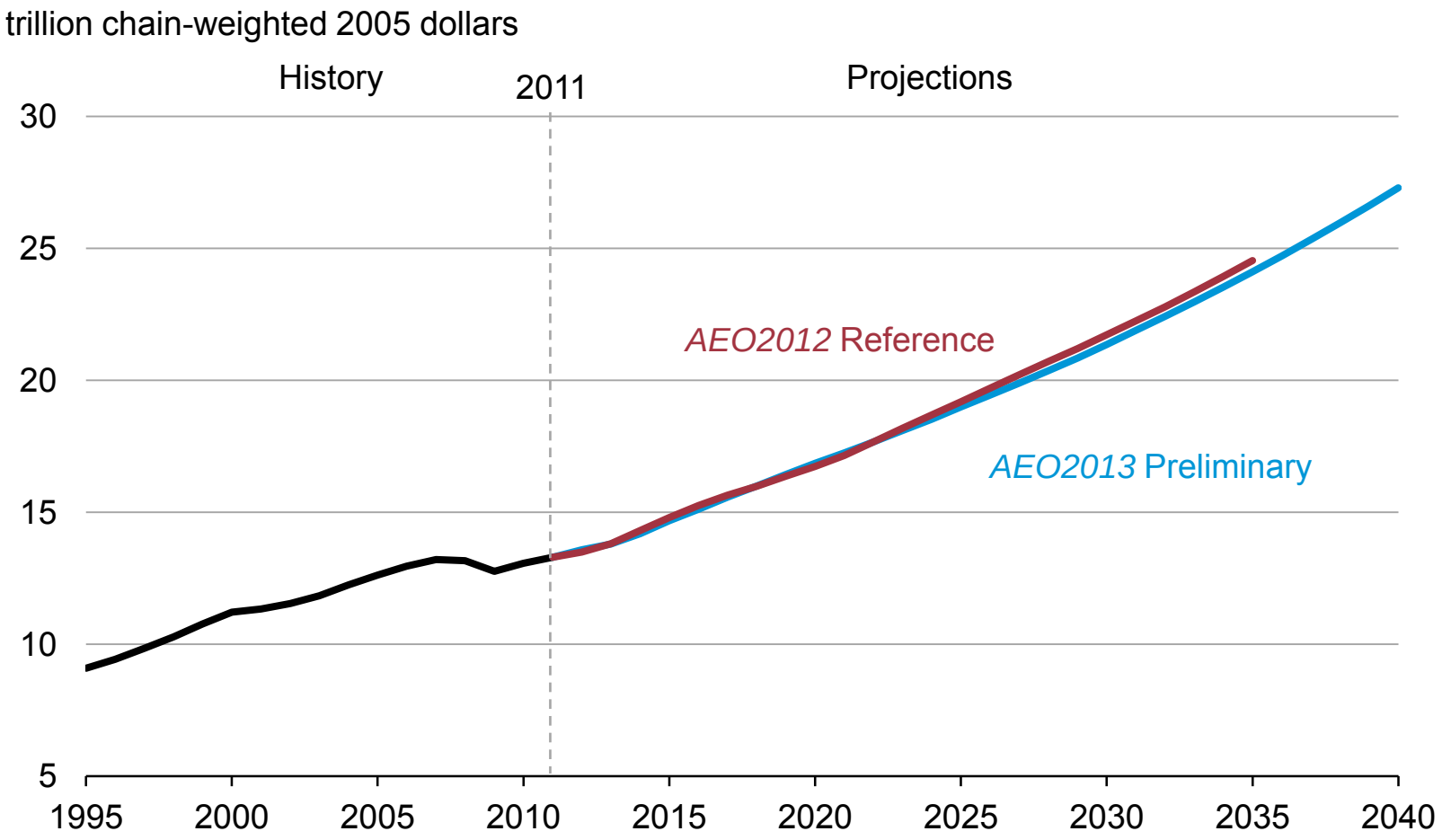
GDP slightly lower across projection compared to *AEO2012*



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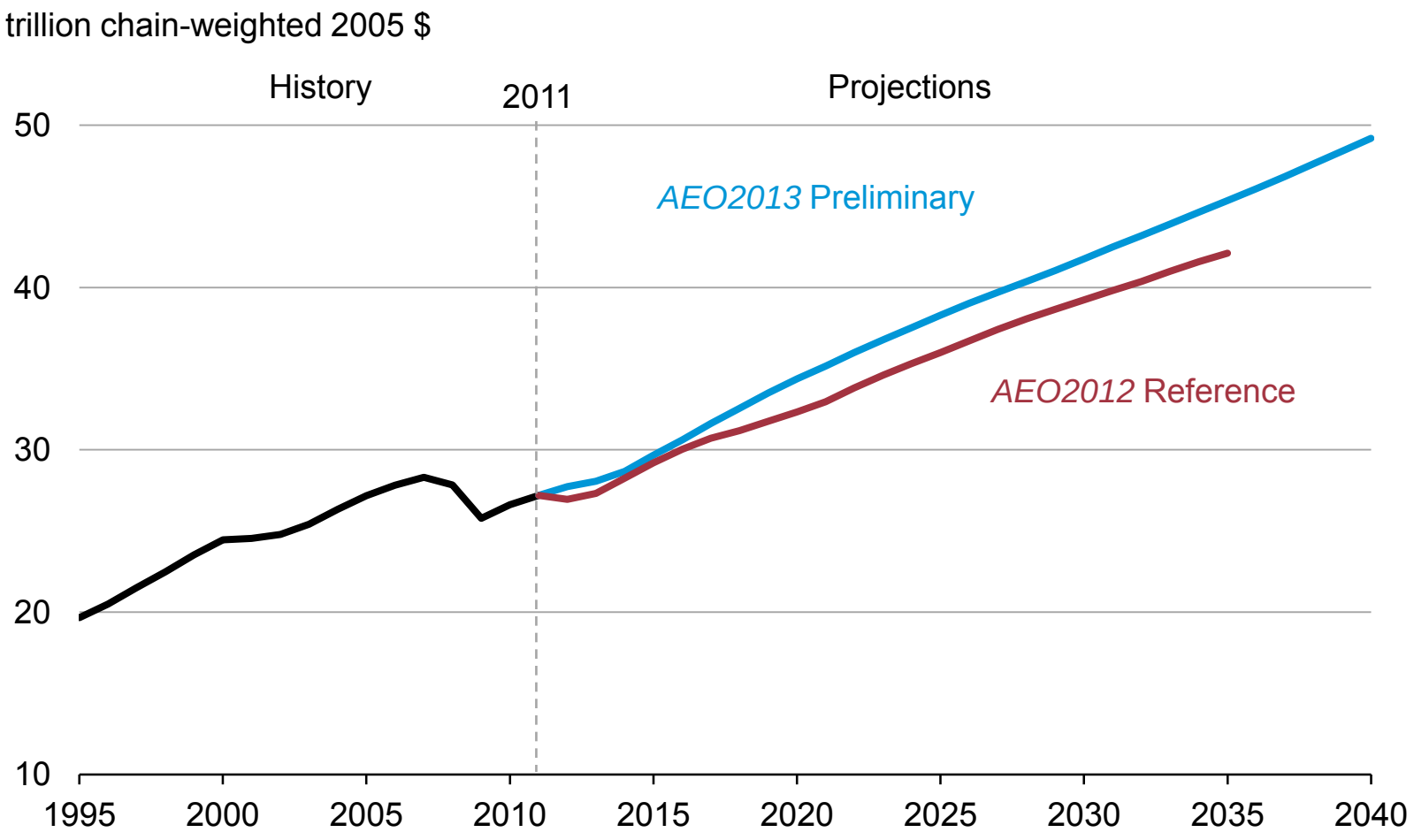
Total value of industrial shipments is higher across projection relative to *AEO2012*



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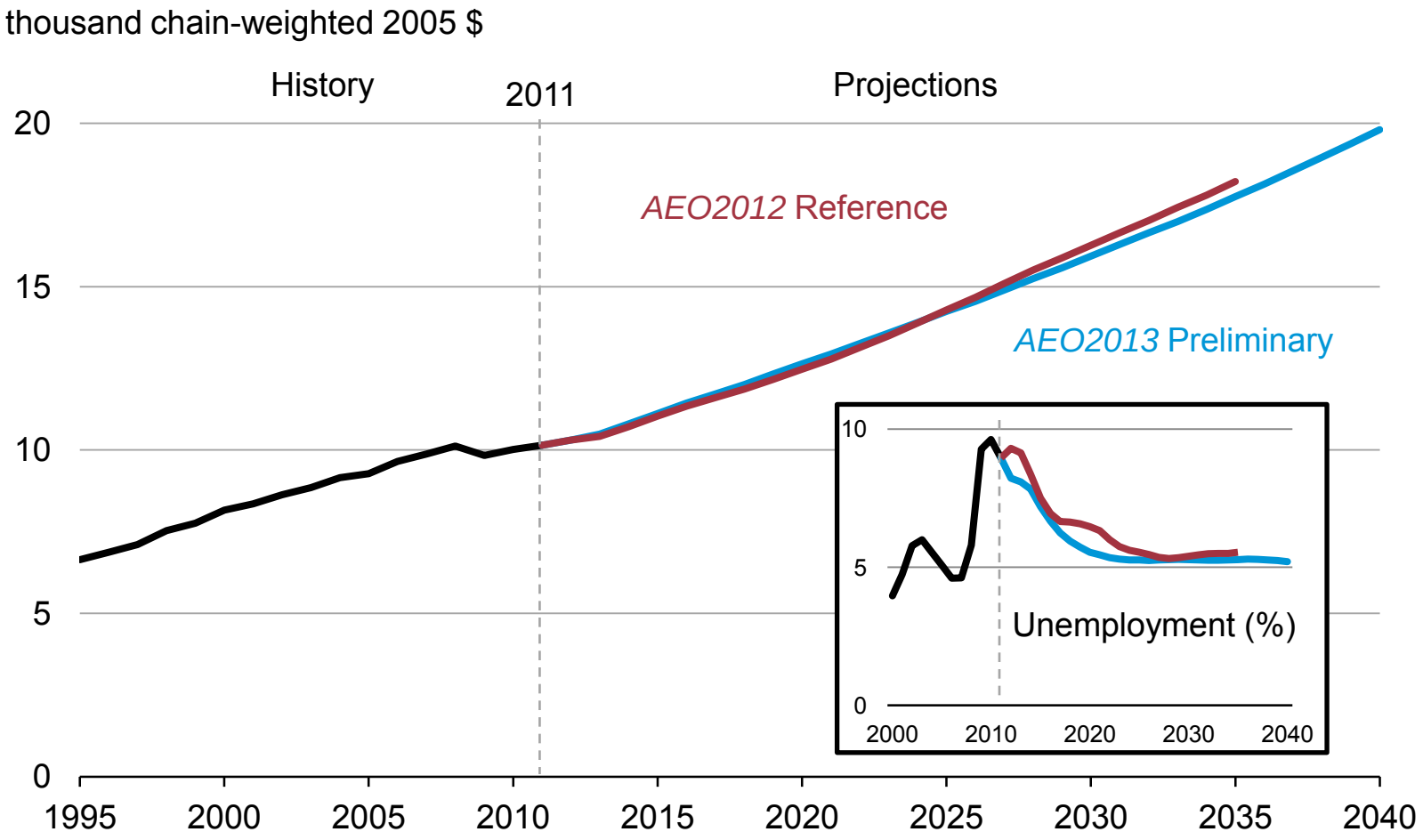
Real disposable personal income slightly lower than AEO2012 across projection period; unemployment is lower



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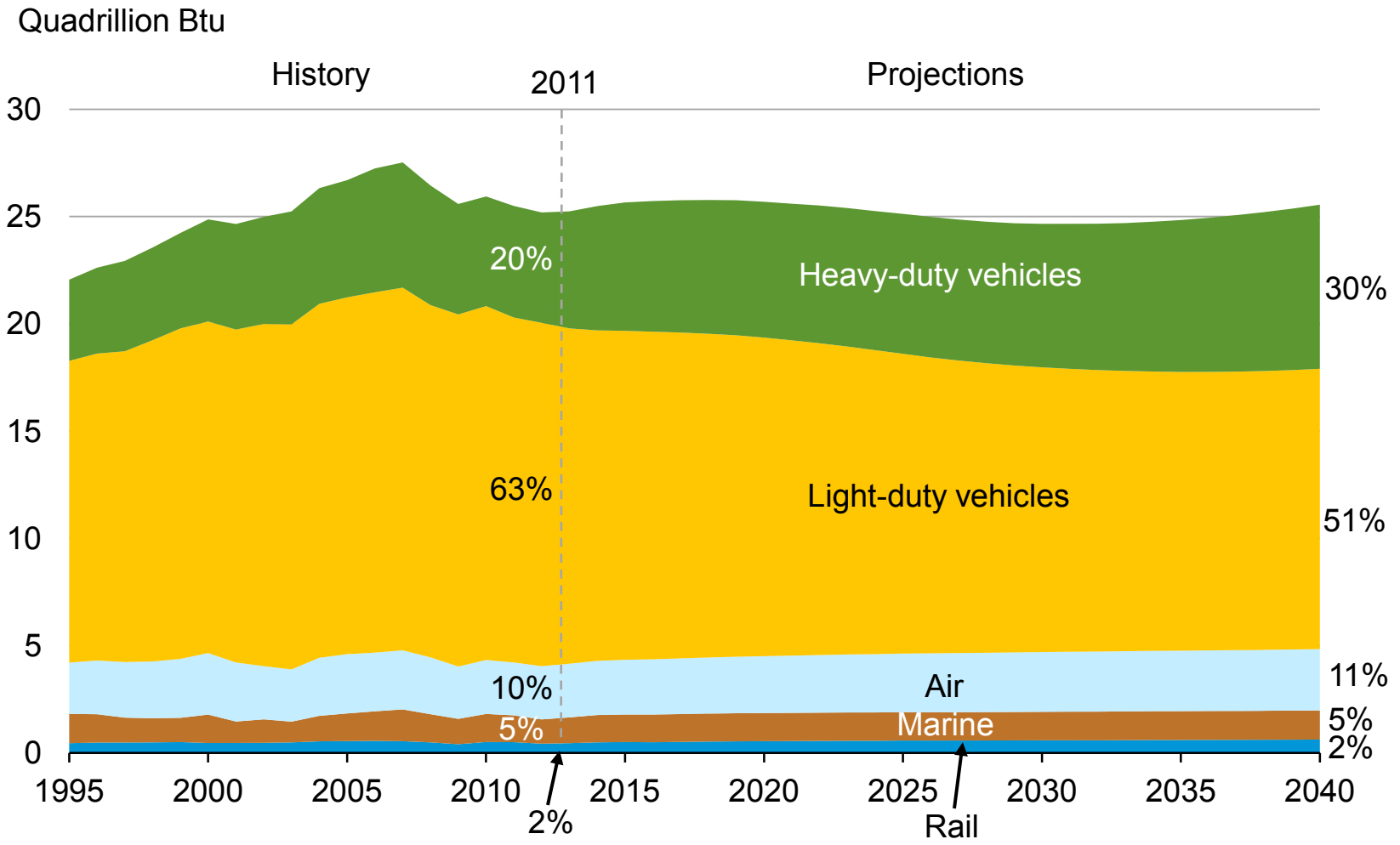
Transportation energy remains flat across projection, with light-duty demand declining and heavy-duty demand growing



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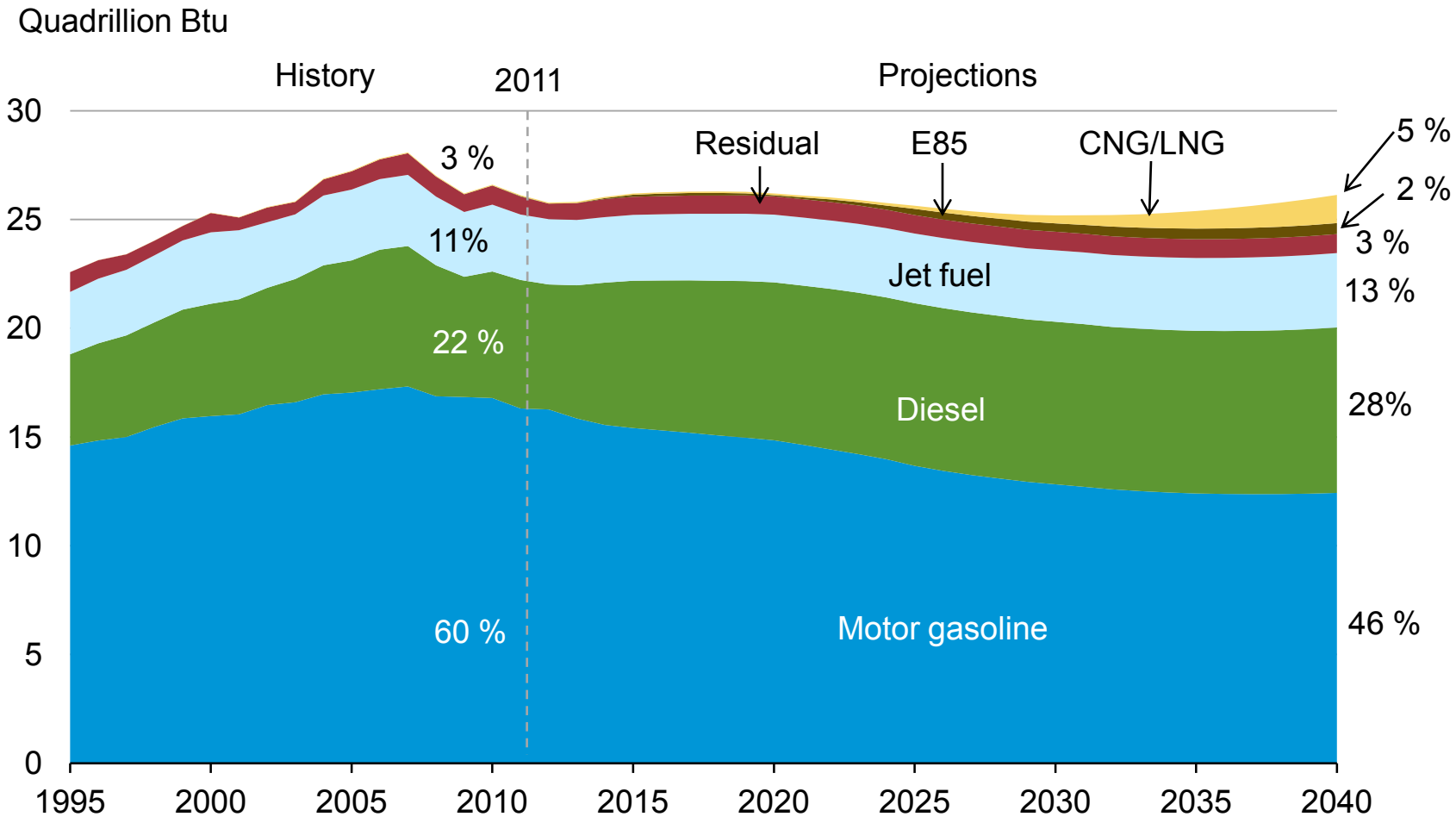
Transportation delivered energy consumption by fuel shows declining motor gasoline demand



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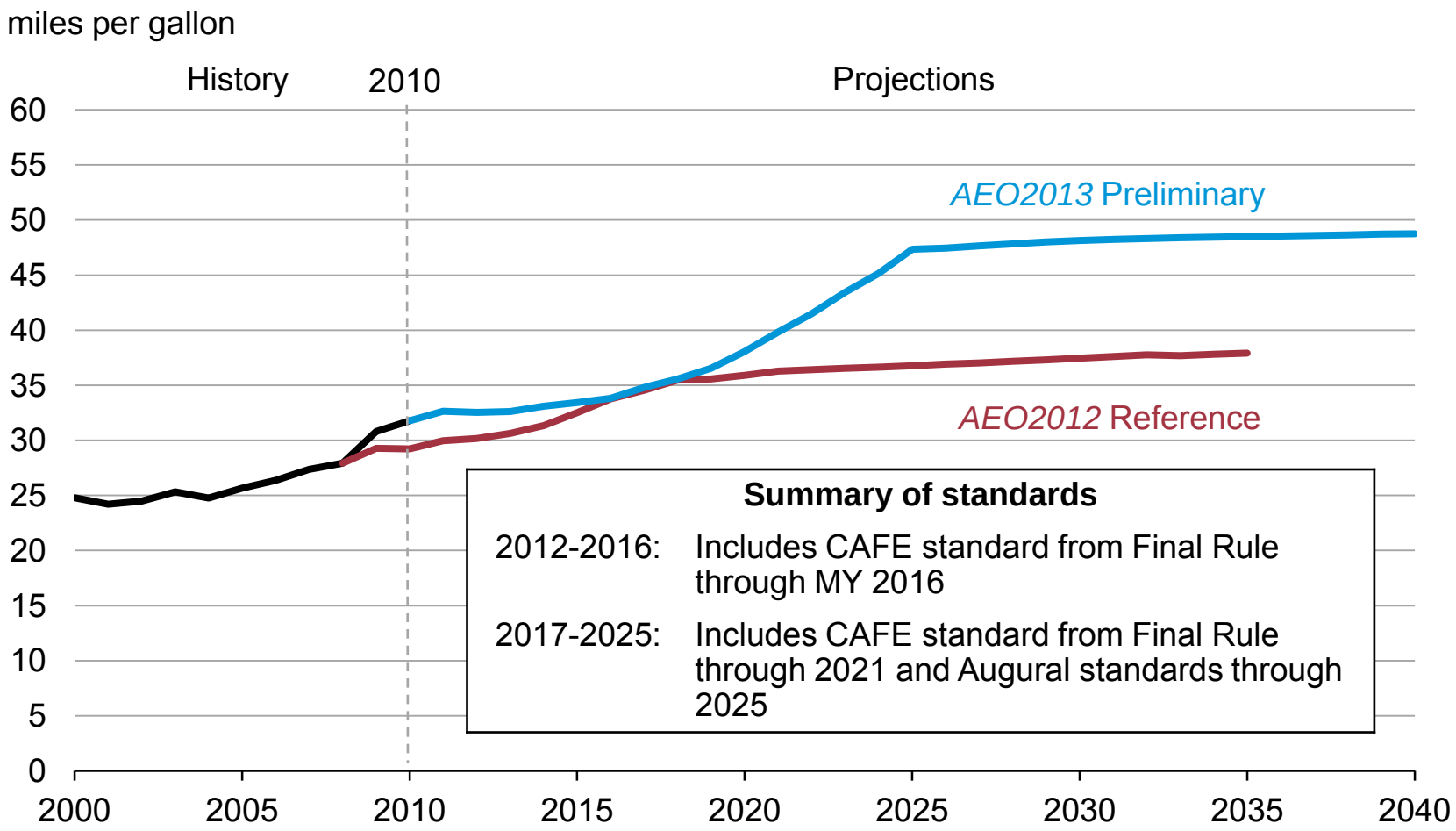
New light-duty vehicle fuel economy reaches almost 49 mpg by 2040, higher than *AEO2013* due to recently enacted standards



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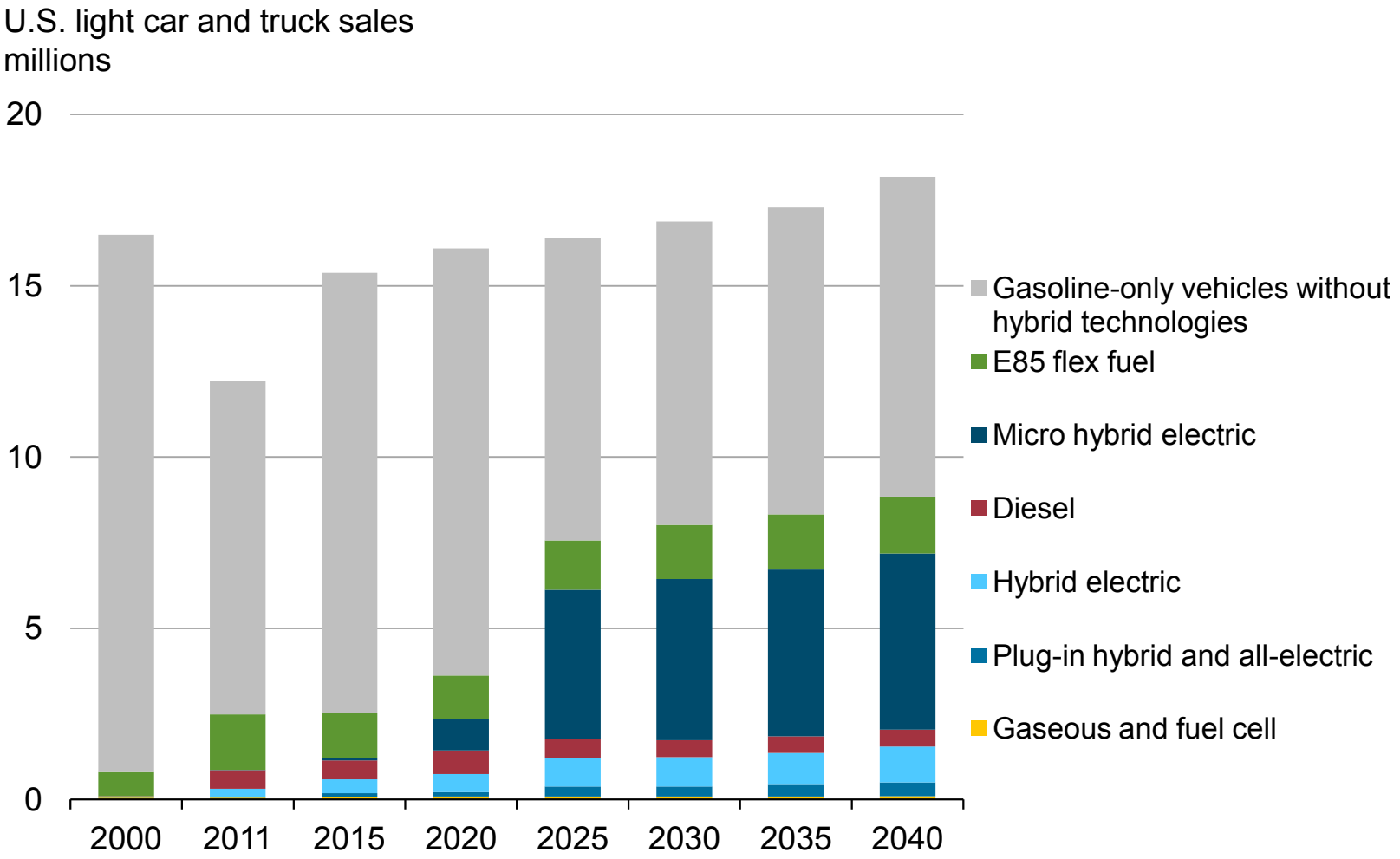
Gasoline micro hybrid vehicles grow as a share of new sales, conventional gasoline remains largest share



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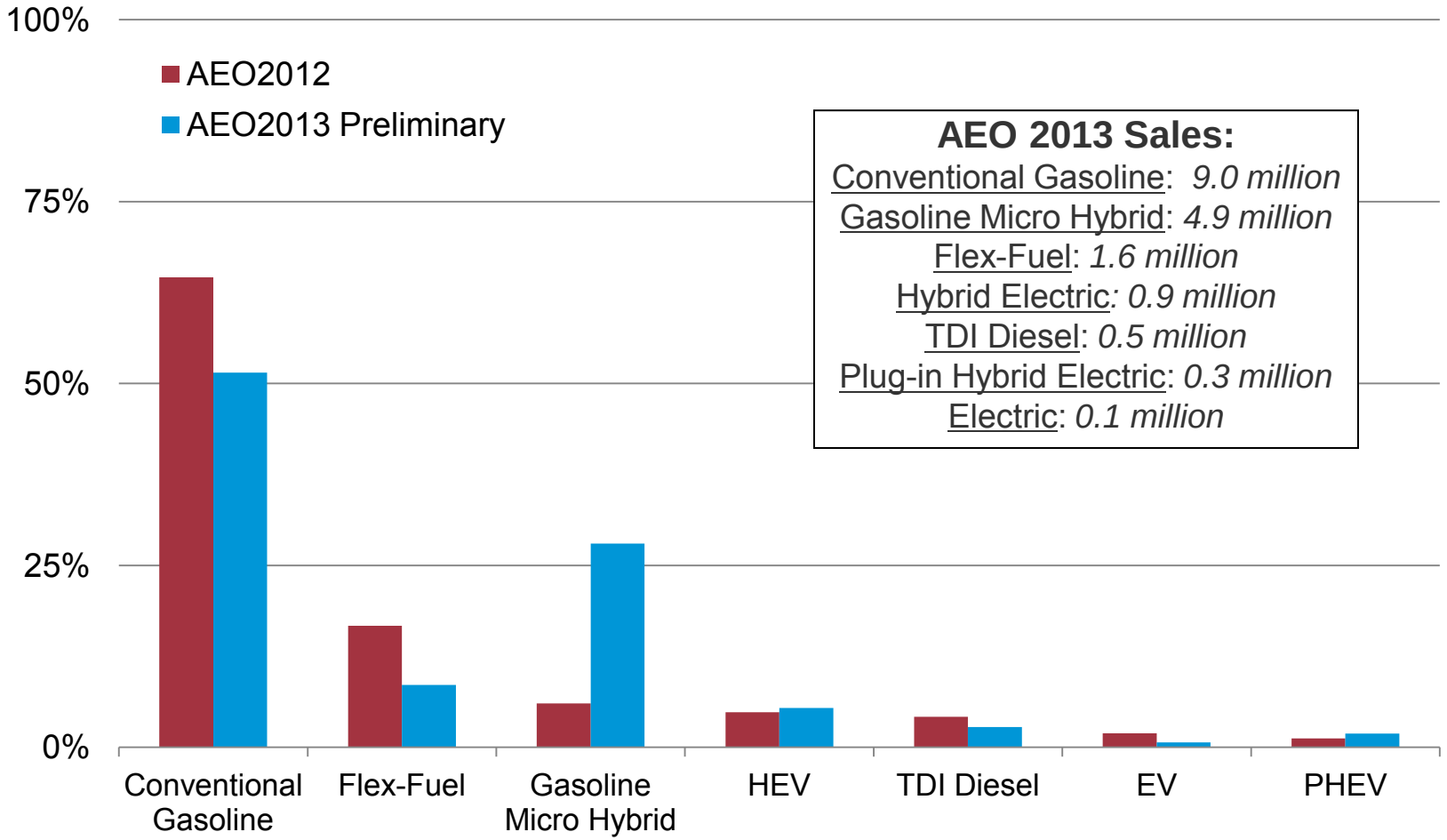
Sales shares of new light-duty vehicles in 2035, in two cases



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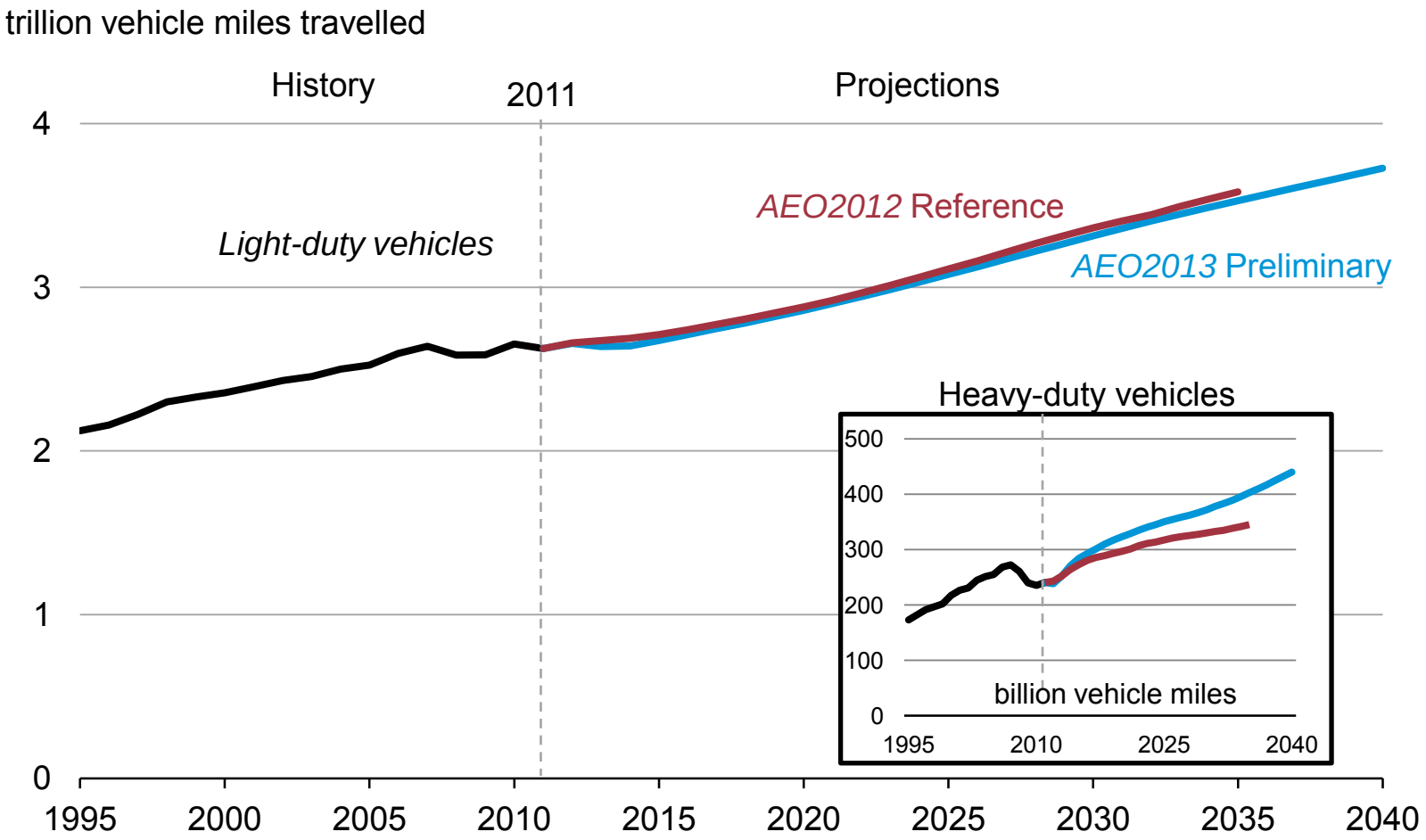
Light-duty vehicle miles traveled lower, heavy-duty vehicle travel higher than *AEO2012*



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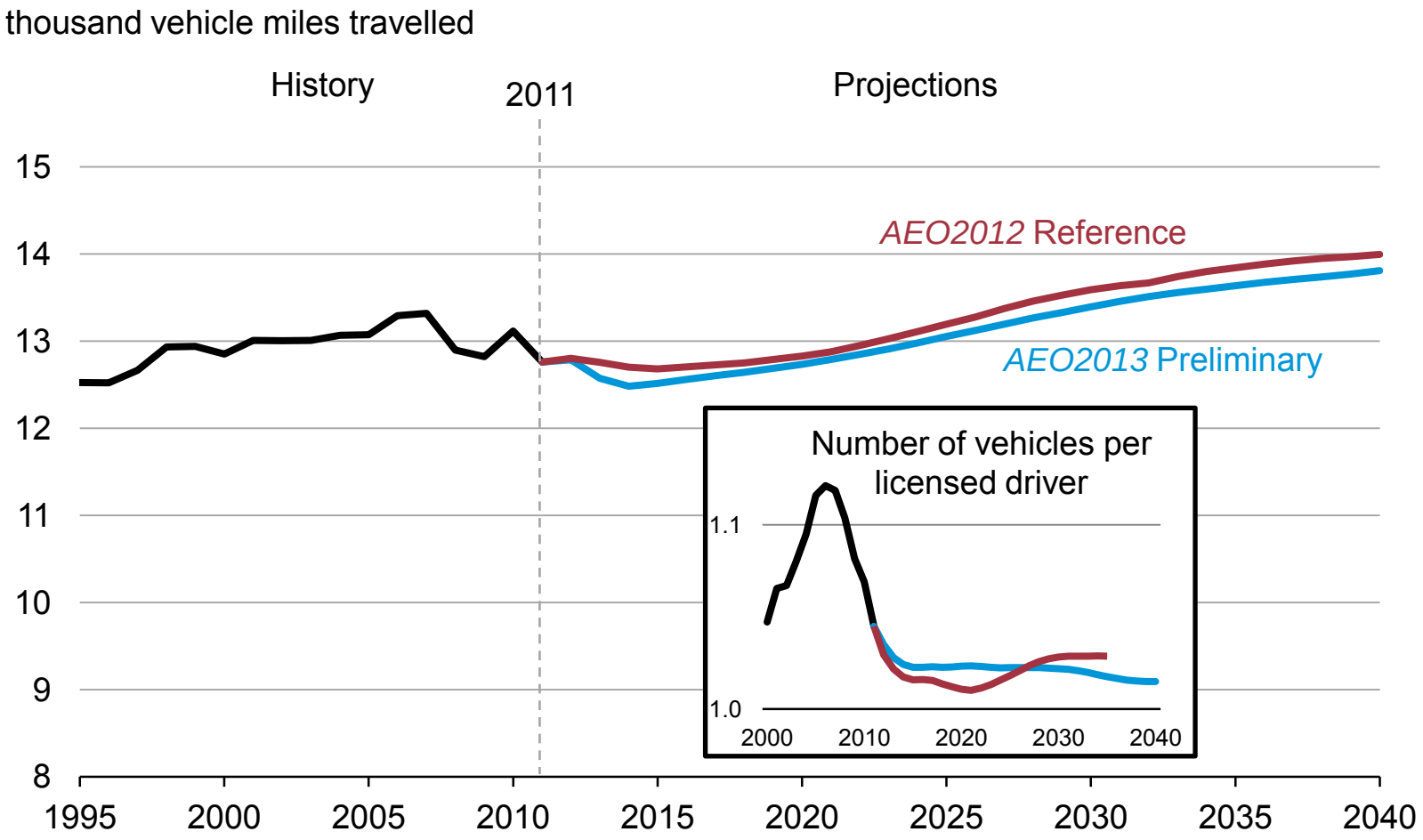
Light-duty vehicle miles traveled per licensed driver increases across projection; lower than *AEO2012*



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A look ahead: future modeling updates

- Light-duty vehicle battery electric vehicles (HEVs, PHEVs, EVs)
  - BatPaC model developed by Argonne National Lab
  - Battery Ownership Model (BOM) developed by NREL
  - Develop battery and non-battery systems cost modeling depending on power/energy ratio specific to different vehicle configurations and range
- Further study and update to heavy-duty vehicle technology attributes and penetration and heavy-duty vehicle market
- Inclusion of natural gas as a fuel option for rail and inclusion of stock model for locomotives

Questions/Feedback

John Maples
(202)-586-1757 john.maples@eia.gov

Patricia Hutchins
(202)-586-1029 patricia.hutchins@eia.gov

Nicholas Chase
(202)-586-8851 nicholas.chase@eia.gov