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Preliminary Analysis of Plug-In Hybrid Electric Vehicles (PHEV) Using O^bj^ECTS-MiniCAM

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Pacific Northwest National Laboratory
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Motivation

- Transportation accounts for 33% of US CO_2 Emissions (EIA 2005)
- Transportation is the largest contributing end-use sector to total CO_2 emissions (EIA 2005)
- Light duty vehicles contribute to
  - 60% of total transport CO_2 emissions
  - 80% of passenger transport CO_2 emissions

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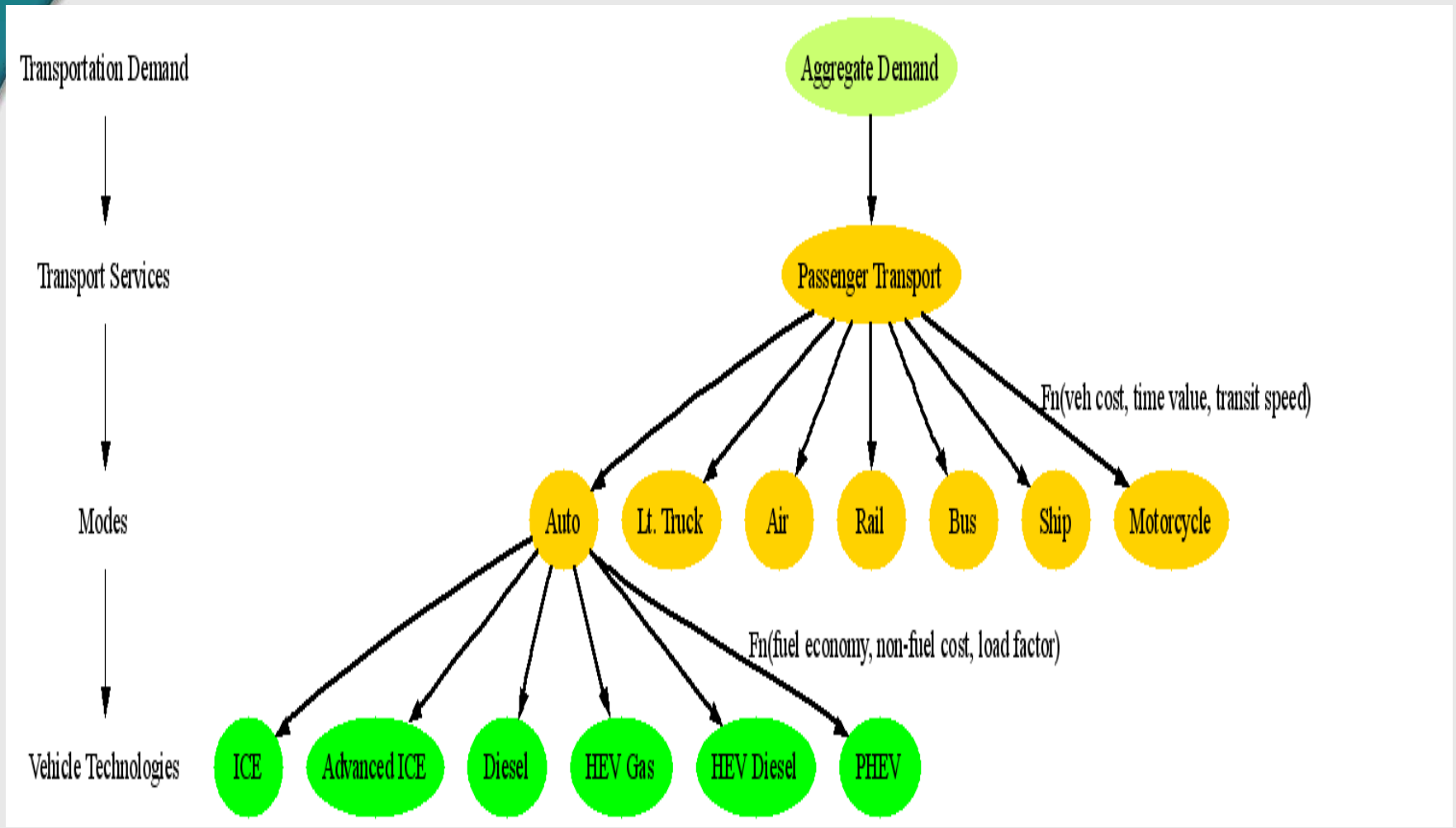
ObjECTS-MiniCAM Transportation



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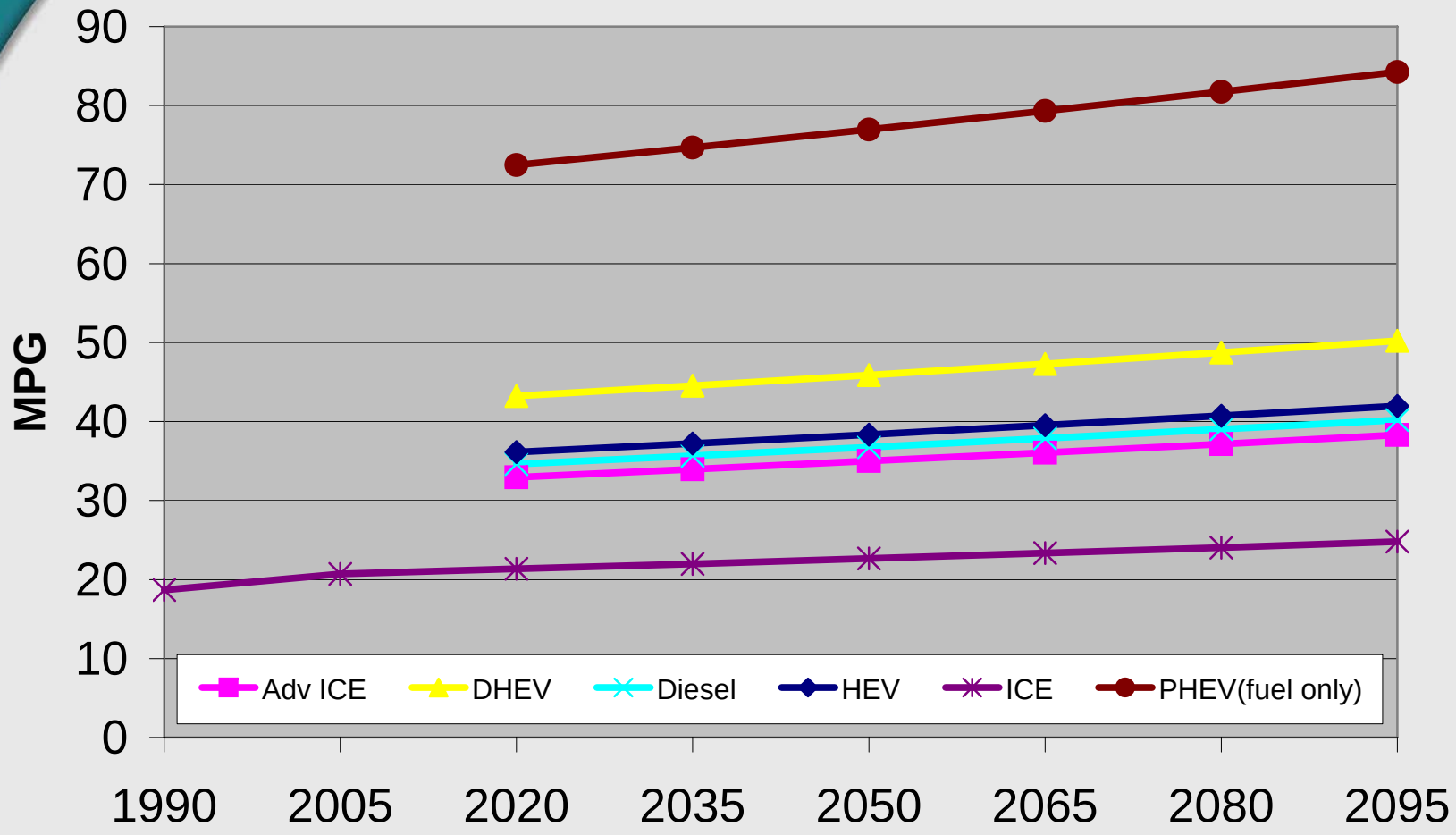
Automobile Fuel Economy



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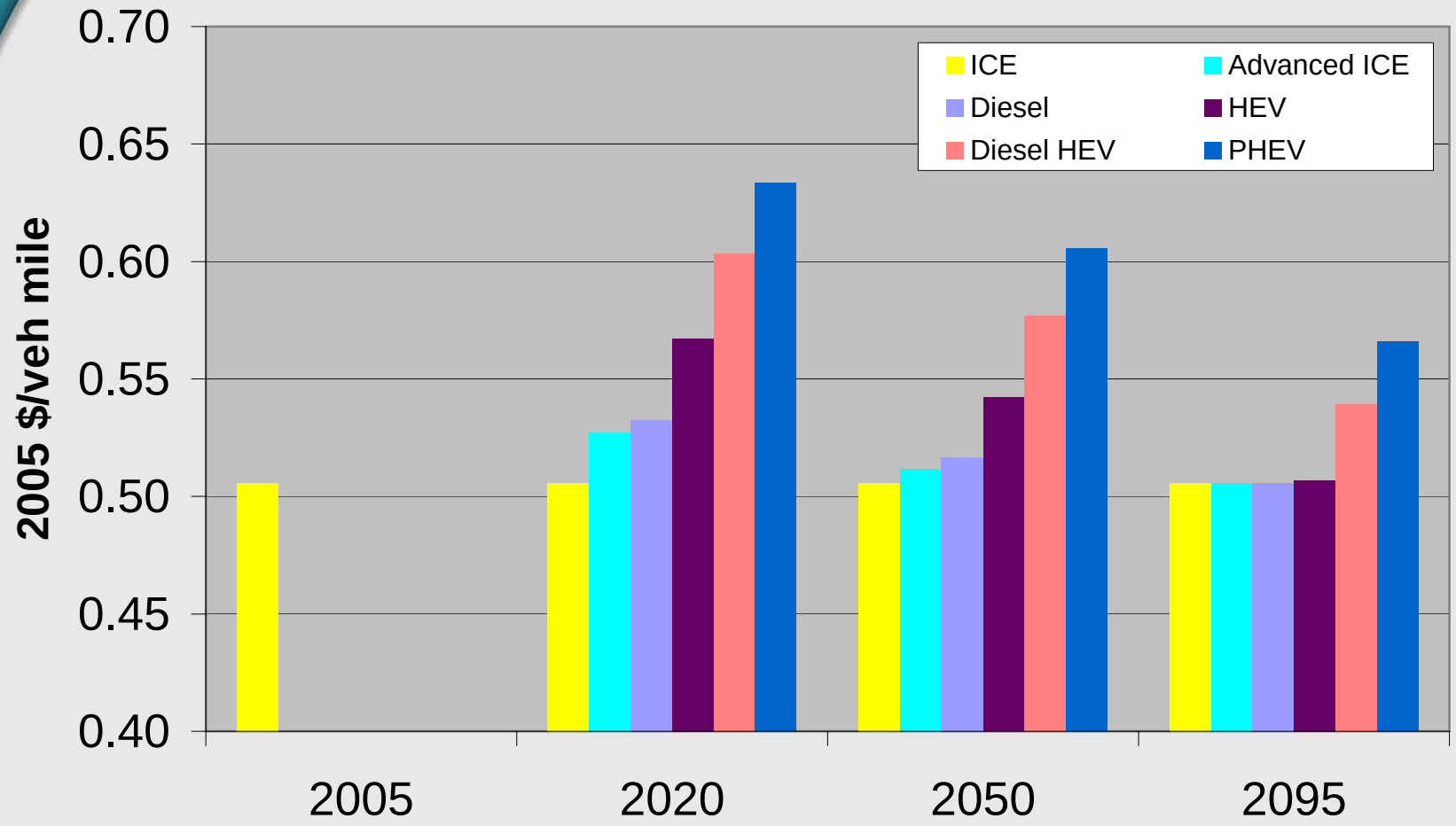
Passenger Vehicle Assumptions: Fuel Economy

Fuel Economy (miles per gallon)	2005	2020	2050	2095
Auto ICE	21	21	23	25
Auto Advanced ICE		33	35	38
Auto HEV		36	38	42
Auto Diesel		35	37	40
Auto Diesel HEV		43	46	50
Auto PHEV		73	77	84
Auto PHEV (electricity KWh/veh-mi)		0.18	0.17	0.16
Lt-Truck ICE	16	17	18	20
Lt-Truck Advanced ICE		26	27	30
Lt-Truck HEV		27	29	31
Lt-Truck Diesel		26	27	30
Lt-Truck Diesel HEV		32	34	37
Lt-Truck PHEV		54	57	63
Lt-Truck PHEV (electricity KWh/veh-mi)		0.23	0.22	0.20

Automobile Non-Fuel Cost (Levelized)



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Scenarios

Part 1	Scenarios	Description
	Base	ICE light-duty vehicles only (auto & truck)
	Base-PHEV	ICE and PHEV light-duty vehicles

Part 2	Base-550	ICE light-duty vehicles with 550 ppmv climate constraint
	Base-PHEV-550	ICE and PHEV light-duty vehicles with 550 ppmv climate constraint

Part 3	Advanced	ICE, advanced ICE, diesel, DHEV, and HEV light-duty vehicles
	Advanced-PHEV	ICE, advanced ICE, diesel, DHEV, HEV, and PHEV light-duty vehicles
	Advanced-550	ICE, advanced ICE, diesel, DHEV, and HEV light-duty vehicles with 550 ppmv climate constraint
	Advanced-PHEV-550	ICE, advanced ICE, diesel, DHEV, HEV, and PHEV light-duty vehicles with 550 ppmv climate constraint

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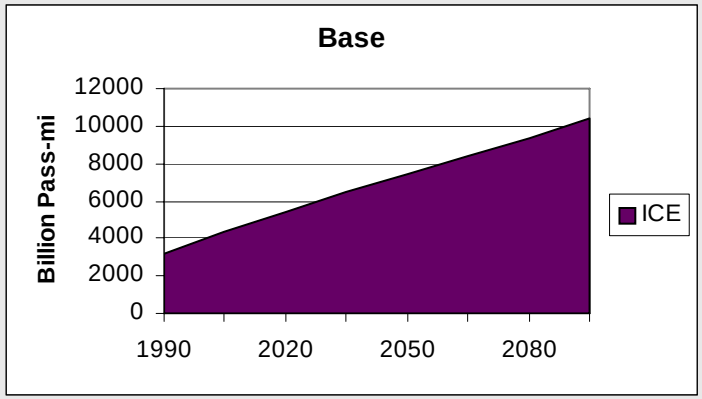
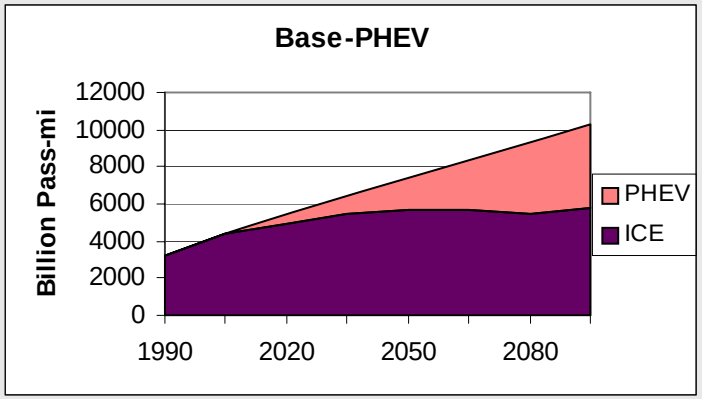
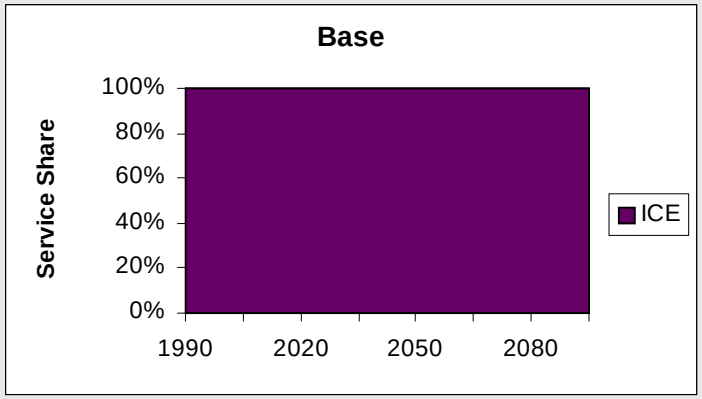
Part 1: PHEV Penetration - No Carbon Price

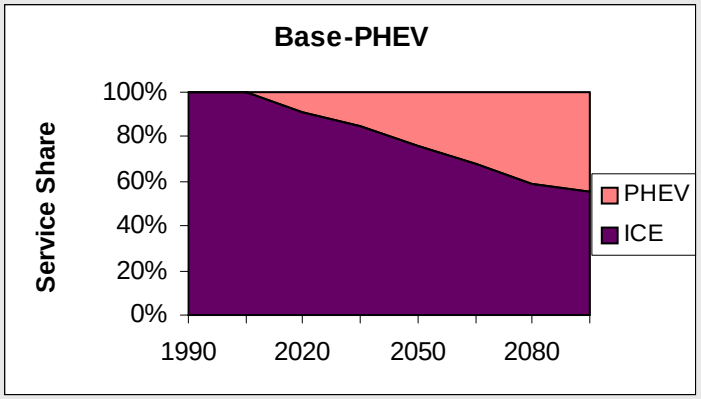
Comparison of Base Case and Base Case with PHEV

US Light Duty Passenger Transport Service (Auto & Truck)

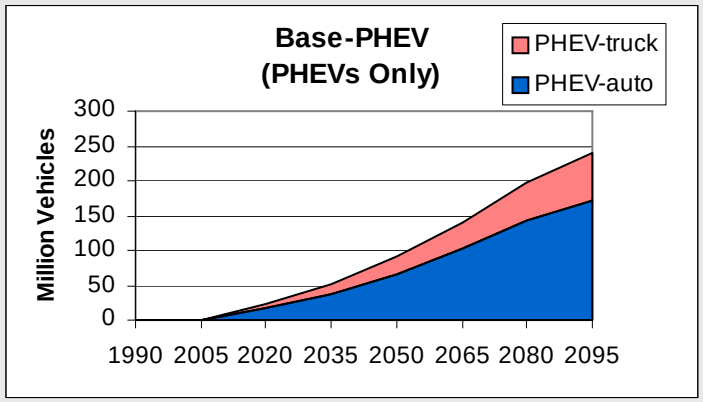


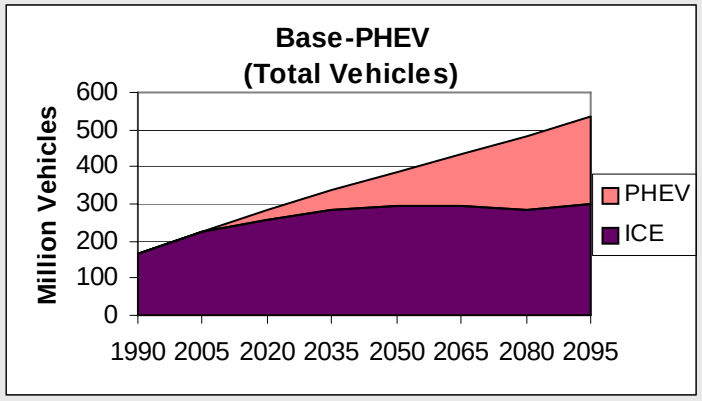






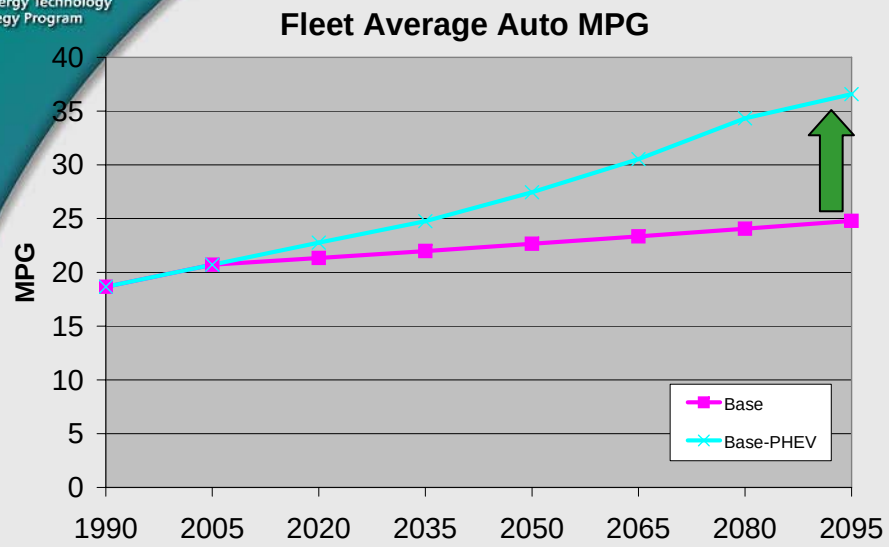
Number of Light Duty Passenger Vehicles in the US (Auto & Truck)

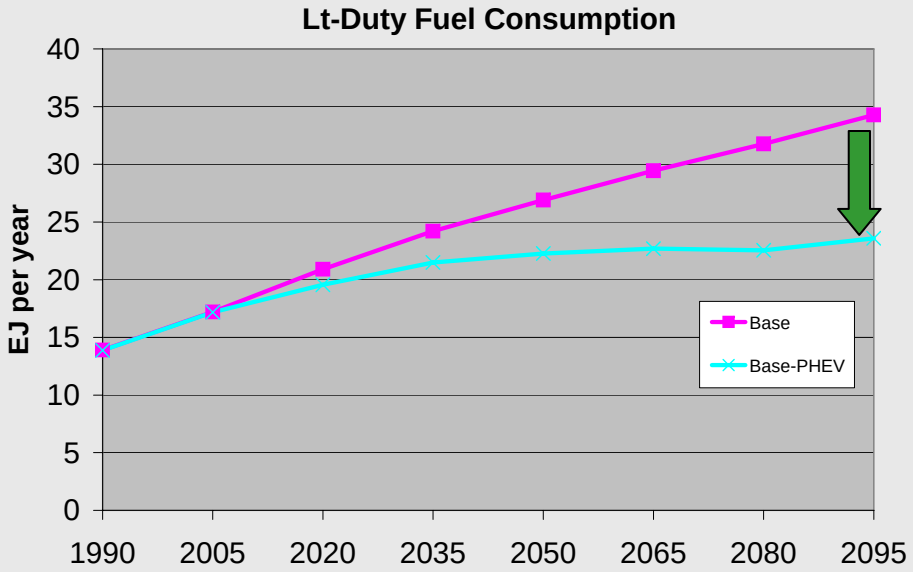




- In 2035: 51 million PHEVs on the road (15% of 336 million Lt-duty vehicles)
- In 2095: 239 million PHEVs on the road (44% of 538 million Lt-duty vehicles)
- Assumptions: 1.6 load factor, 12,000 annual miles per vehicle

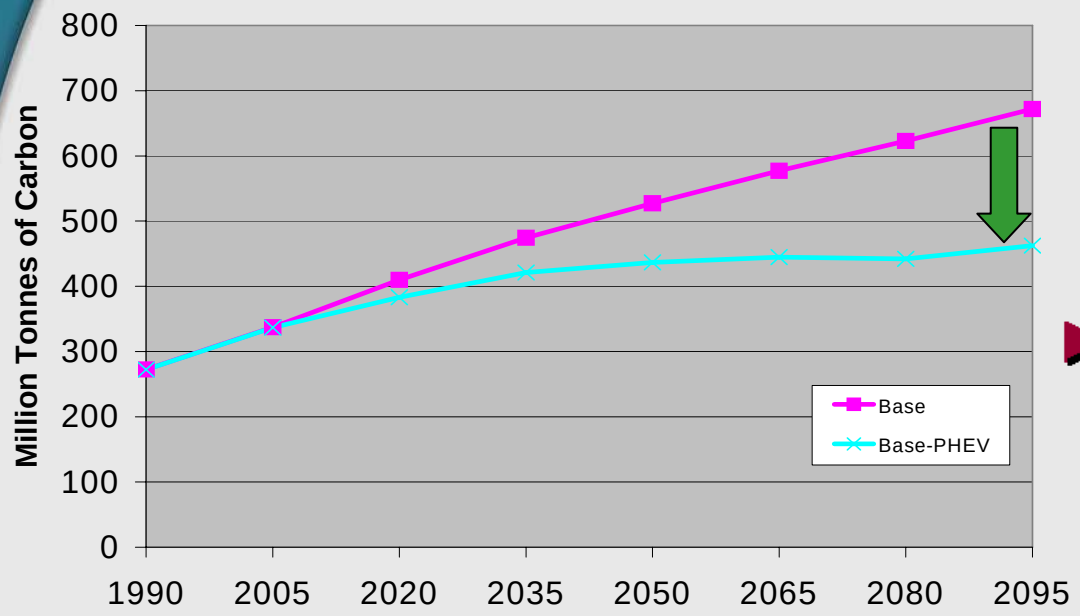
US Fuel Consumption - Light Duty





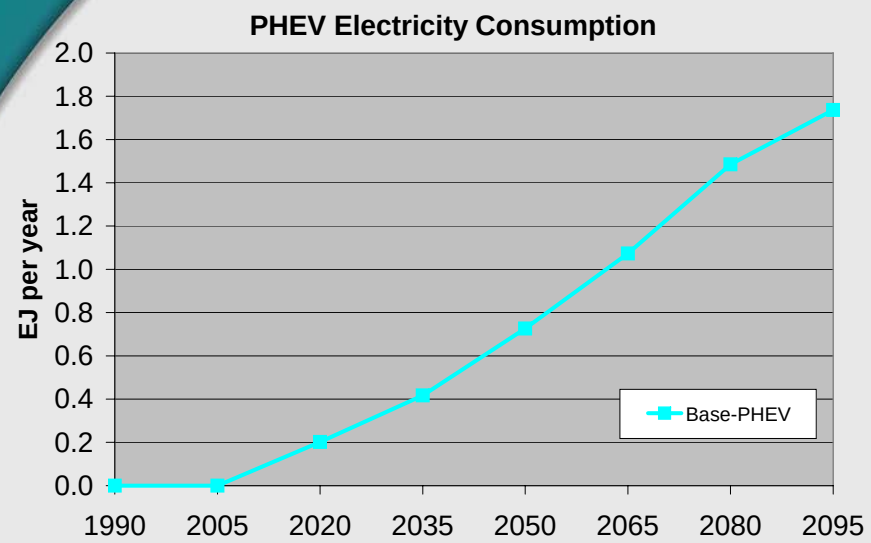
- In 2035: annual gasoline savings of 1.4 million barrels per day from PHEVs (11% savings from Lt-duty total of 12 mbpd without PHEV)
- In 2095: annual gasoline savings of 5.5 million barrels per day from PHEVs (31% savings from Lt-duty total of 18 mbpd without PHEV)

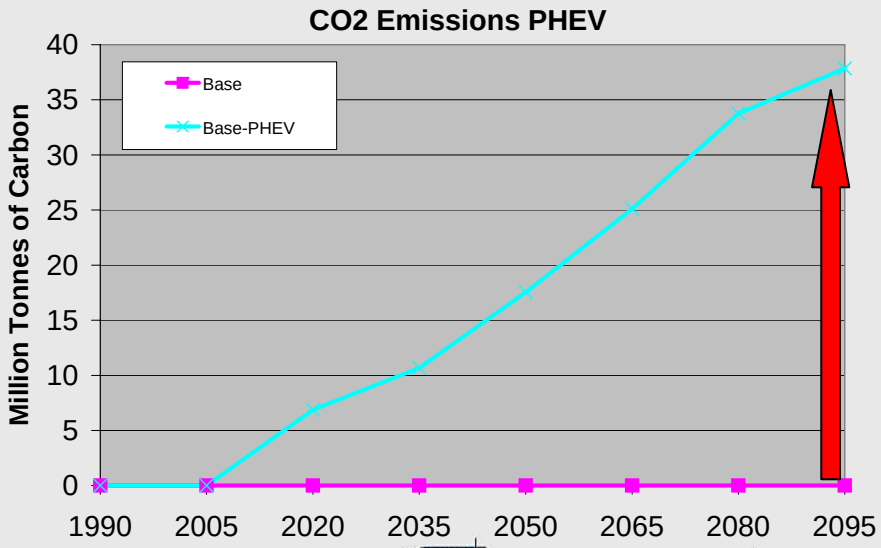
US CO_2 Emissions: From Lt-Duty Vehicle Fuel Consumption



- In 2035: annual net CO_2 emissions reduction of 47 MTC due to PHEVs (9% reduction from Base Case)
- In 2095: annual net CO_2 emissions reduction of 283 MTC due to PHEVs (27% reduction from Base Case)

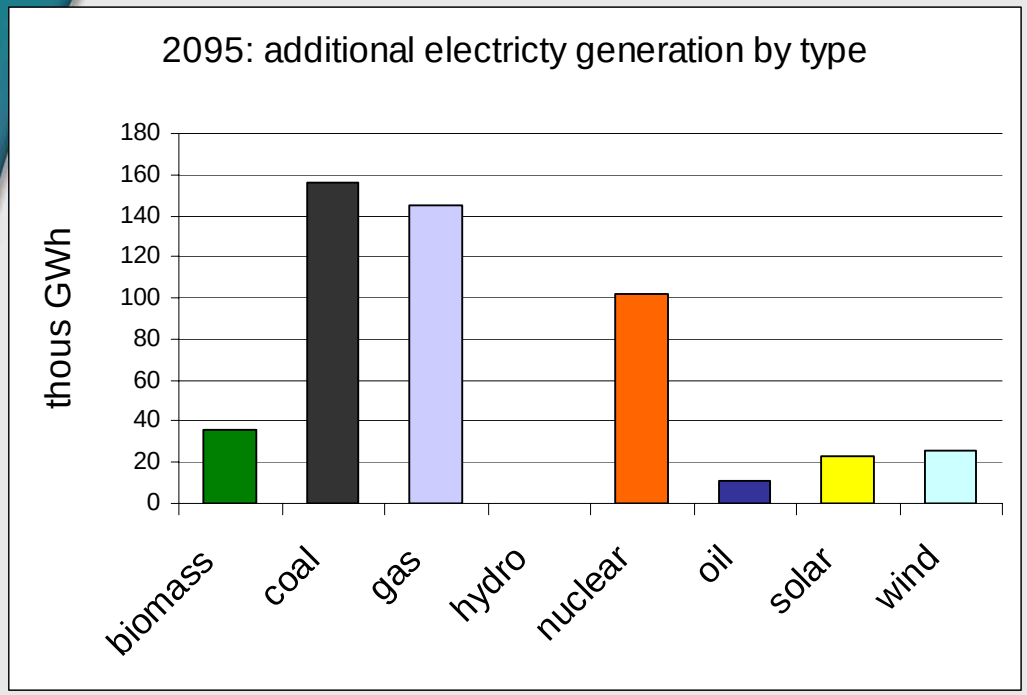
US CO_2 Emissions: From PHEV Electricity Consumption





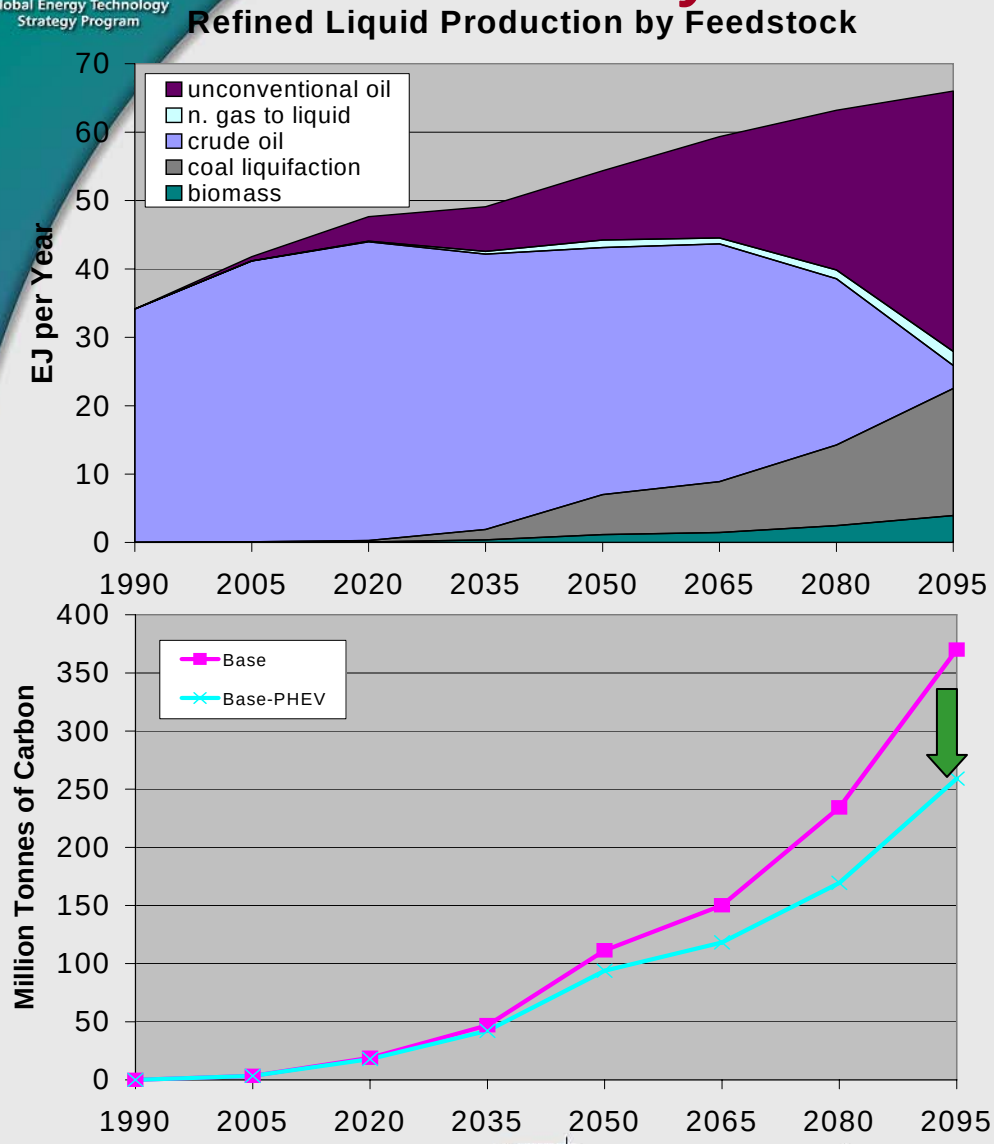
- In 2035: 116 thous. GWh of electricity consumption from PHEVs (2% of 7.7 thou. TWh total electricity).
- In 2035: 11 MTC of CO_2 emissions from PHEV electricity demand.
- In 2095: 482 thous. GWh of electricity consumption from PHEVs (4% of 13 thou. TWh total electricity).
- In 2095: 38 MTC of CO_2 emissions from PHEV electricity demand.
- In 2095: 105 MTC if all additional electricity is from coal.

Sources of Additional Electricity Generation in the US



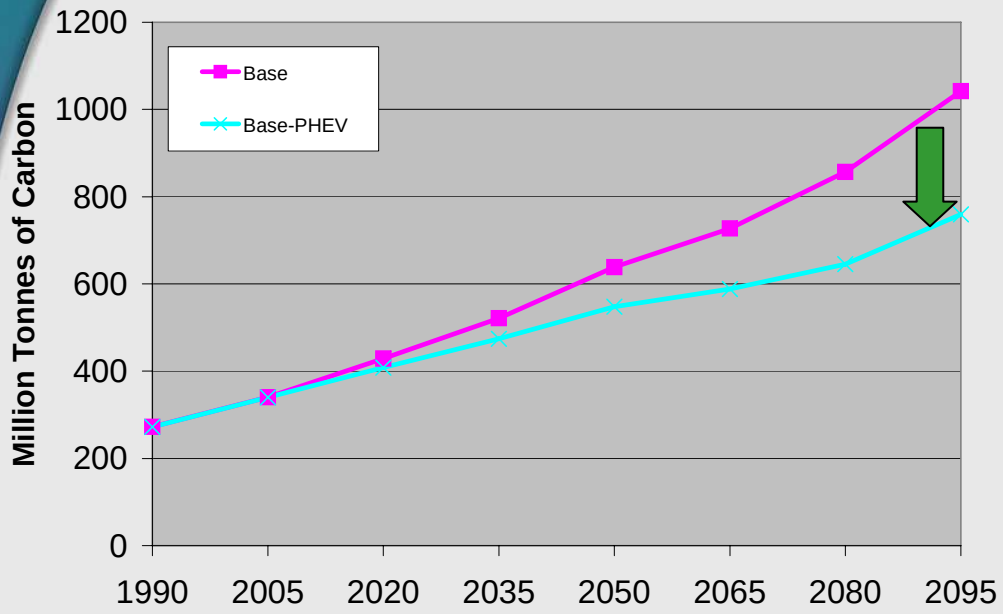
- In 2095: Additional generation of electricity comes primarily from coal, natural gas and nuclear.
- ObjECTS-Minicam does not model peak, intermediate and base load electricity markets or idle capacity.

US CO_2 Emissions: From Refinery for Lt-Duty Vehicle Fuel



- Improved fleet average fuel economy from PHEV penetration has the added benefit of lower refinery CO_2 emissions particularly in the latter half of the century where unconventional oils and coal liquids are in use.
- In 2095: CO_2 emissions reduction of 111 MTC (30% of Base Case refinery emissions).

US CO_2 Emissions - Passenger Light Duty: Sum of Fuel Combustion, Electricity and Refinery Emissions



- In 2035: annual net CO_2 emissions reduction of 47 MTC (169 MT CO_2) due to PHEVs (9% reduction from Base Case).
- In 2095: annual net CO_2 emissions reduction of 283 MTC (1013 MT CO_2) due to PHEVs (27% reduction from Base Case).
- In 2095: annual net CO2 emissions reduction of 215 MTC if all additional electricity demand is from coal.

Conclusions: Part 1 – PHEV Penetration (No Carbon Price)

- In the absence of climate constraints (no carbon price), the penetration of PHEVs for passenger light duty service results in substantial reductions in fuel consumption and CO_2 emissions.
- In 2035 (US Results):
  - 15% PHEV penetration of all vehicles
  - 11% reduction in fuel consumption
  - 9% reduction in net CO_2 emissions from light duty vehicles.
- In 2095 (US Results):
  - 44% PHEV penetration of all vehicles
  - 31% reduction in fuel consumption
  - 27% reduction in net CO_2 emissions from light duty vehicles.
- Additional electricity demand from PHEVs is not large and not a significant source of emissions.
  - Issues: fuel or plant choice for additional electricity generation, availability of excess capacity, and regional demands for electricity

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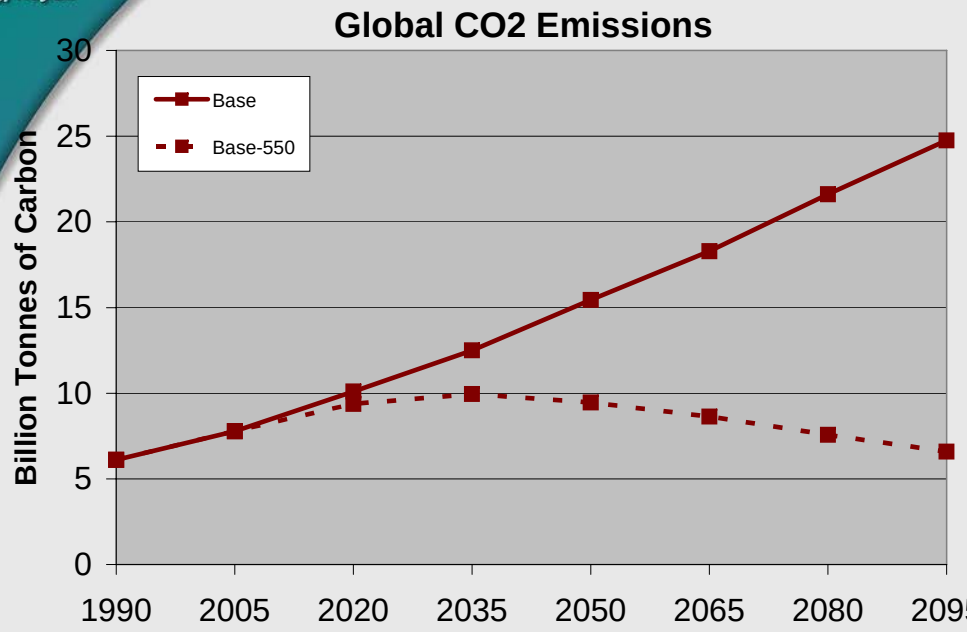
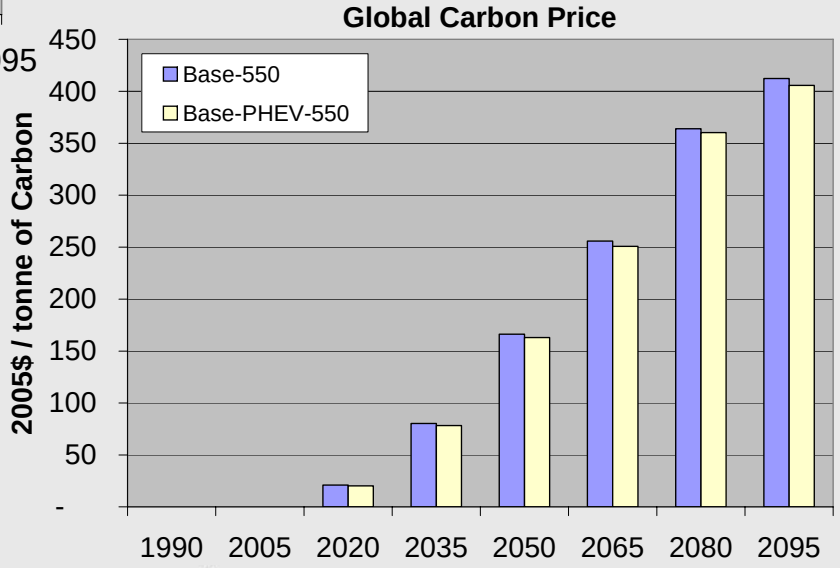
Part 2: PHEV Penetration in a Climate Constrained World

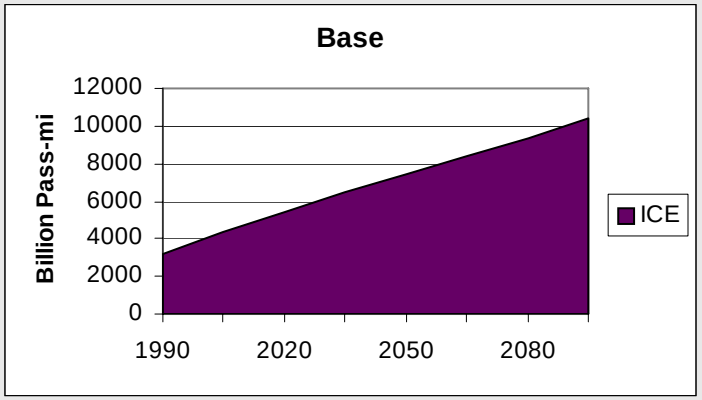
(Comparison of Base Case and Base Case with PHEV and with 550 ppm Constraint)

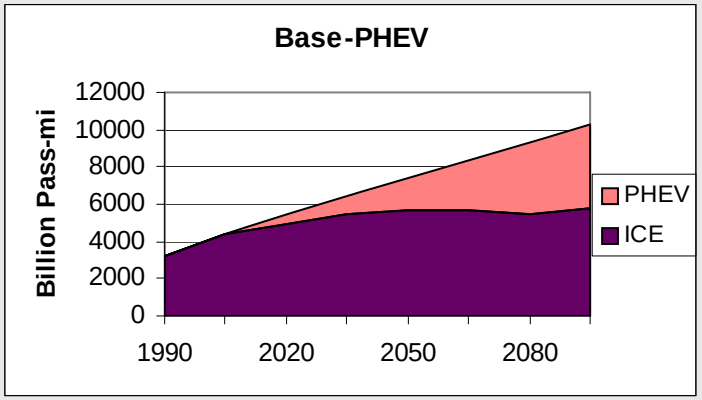
Global CO_2 Emissions and WRE 550 Constraint

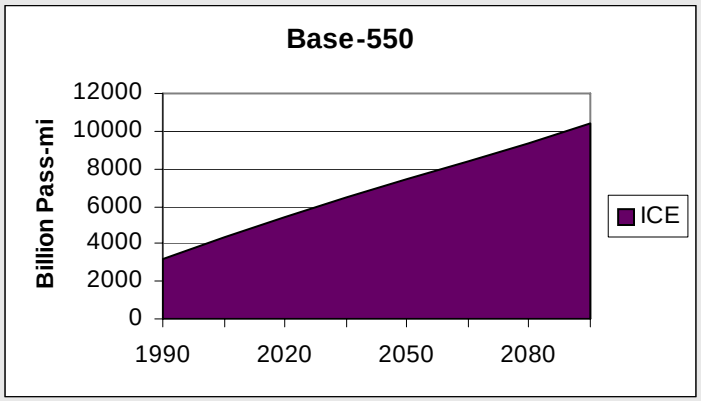


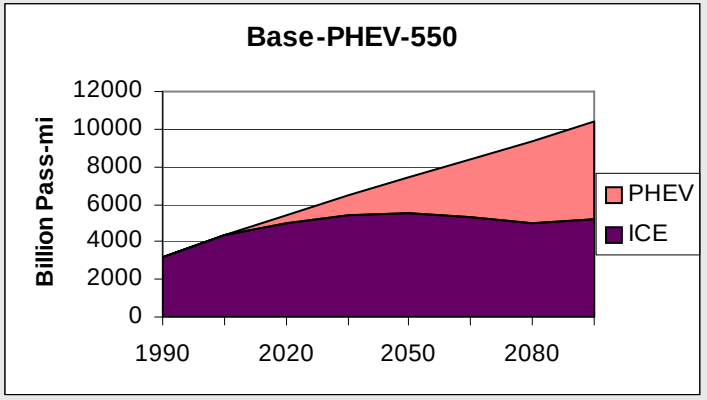


US Light Duty Passenger Transport Service (Auto & Truck)

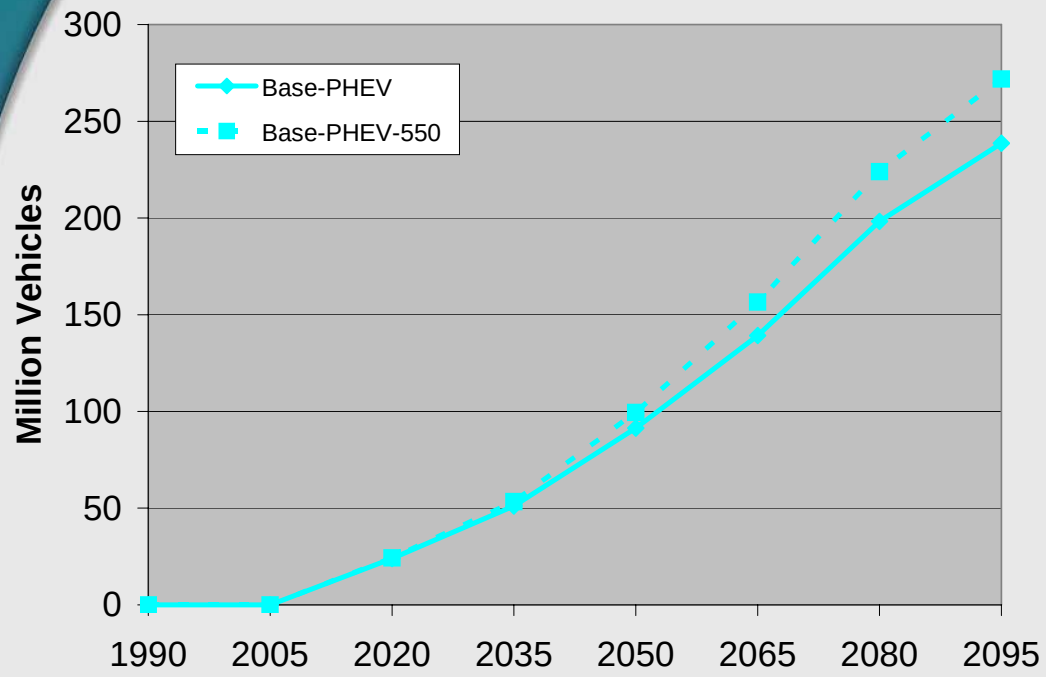






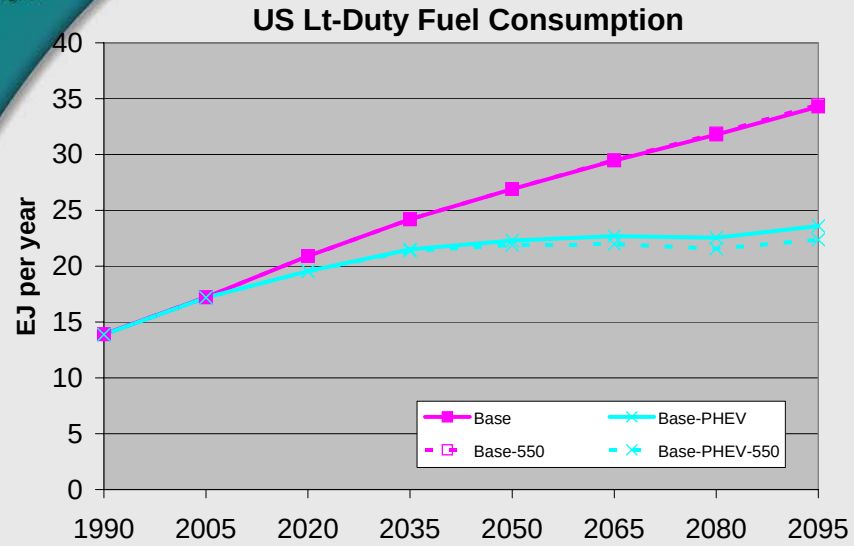


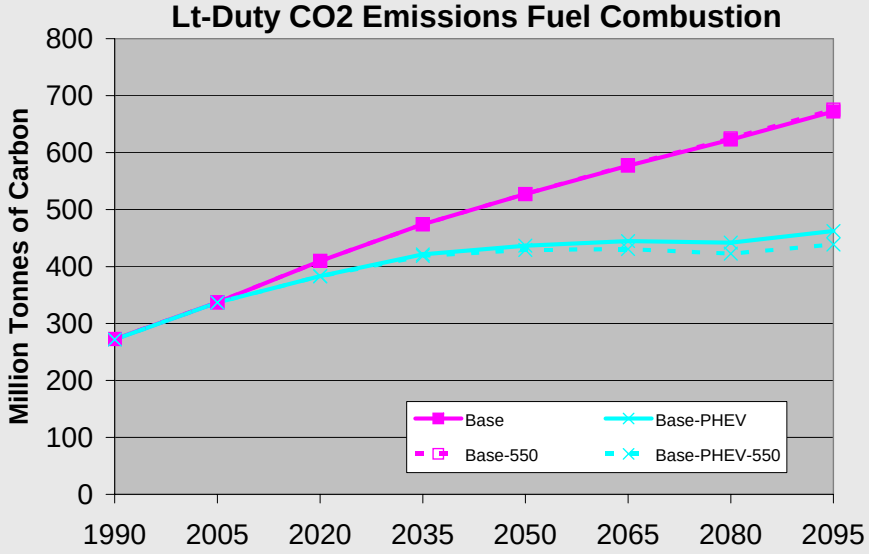
Additions to PHEVs on the Road in the US - 550 ppm Constraint



- In 2035: minimal new PHEV additions as the 550 ppm constraint does not have significant bite in 2035 (additional 2 million PHEV vehicles, 4% more than without constraint).
- In 2095: additional 33 million PHEVs with policy (14% more than without constraint).
- In 2095: 272 million total PHEVs on the road (50% of 542 million total light duty vehicles).

US CO_2 Emissions: From Lt-Duty Vehicle Fuel Consumption

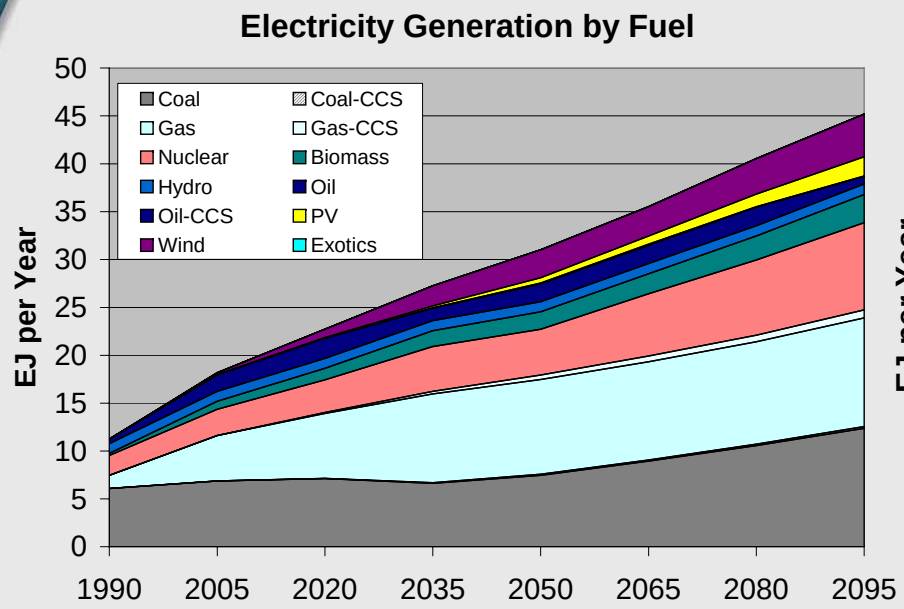




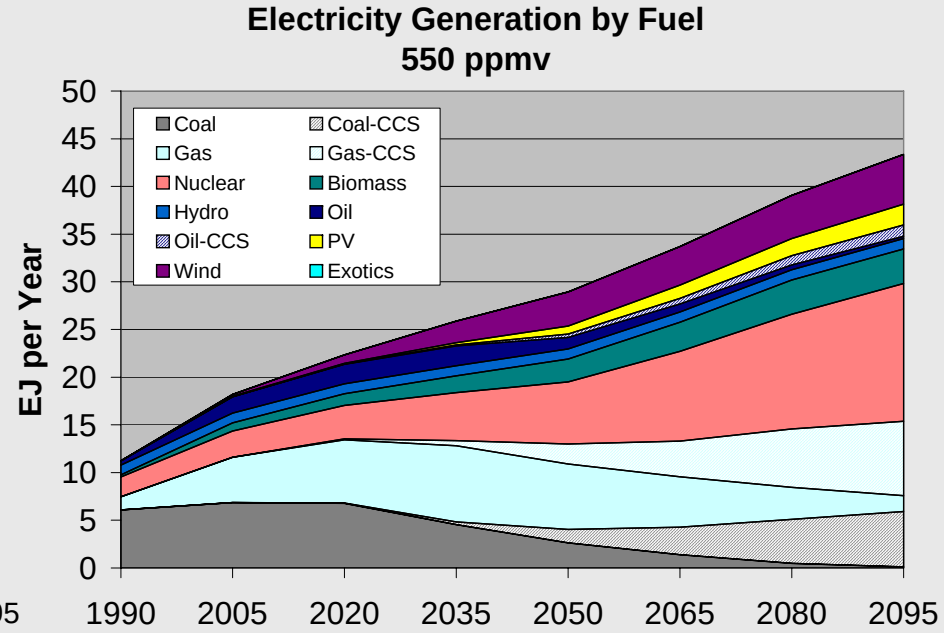
- In 2035: additional annual gasoline savings of 0.04 million barrels per day (total savings 1.44 mbpd).
- In 2095: additional annual gasoline savings of 0.7 million barrels per day (total savings 6.2 mbpd).
- No significant additional CO_2 emissions reduction from vehicle fuel combustion due to the climate constraint.

US Electricity Generation Penetration of CCS and Nuclear

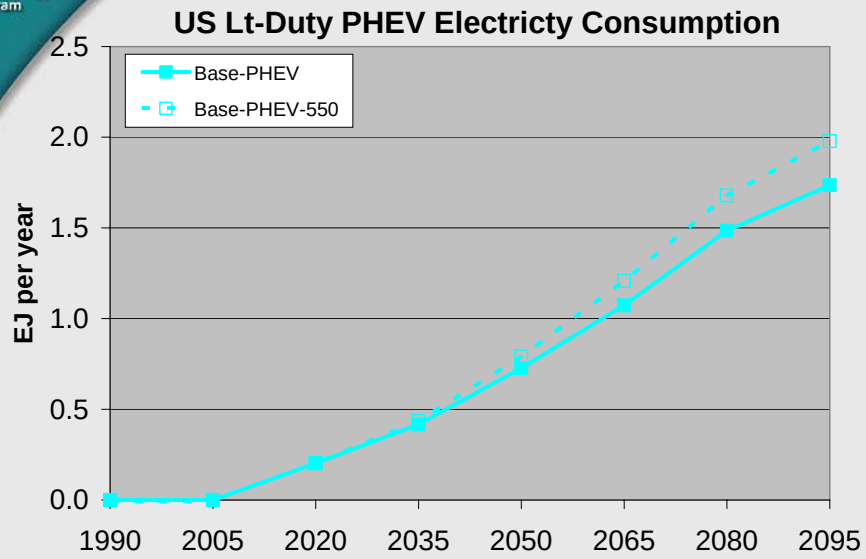
Base

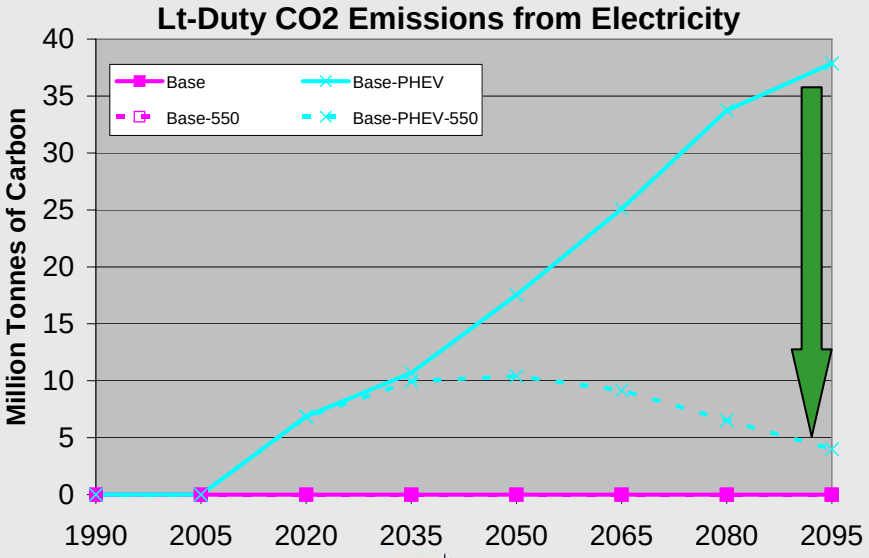


Base-550



US CO_2 Emissions: From PHEV Electricity Consumption

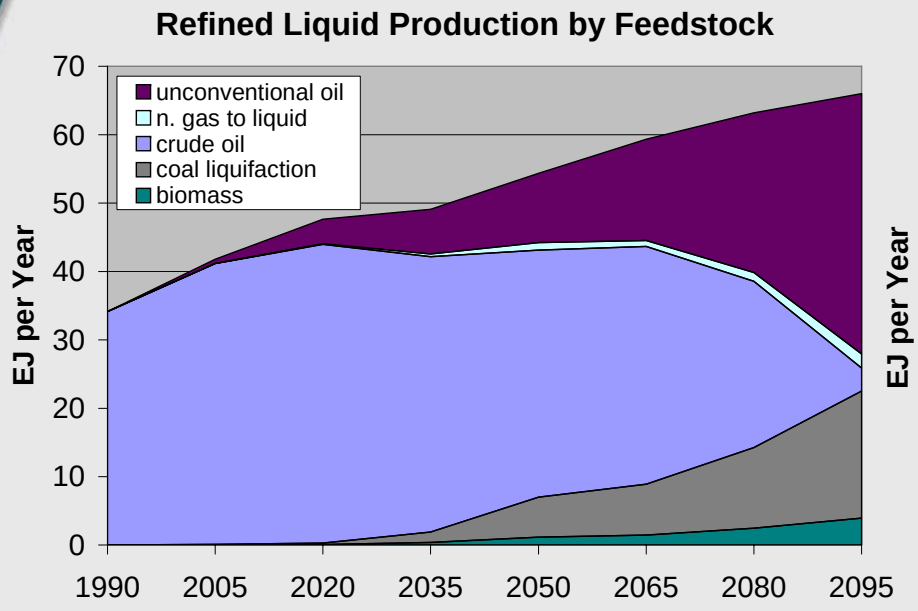




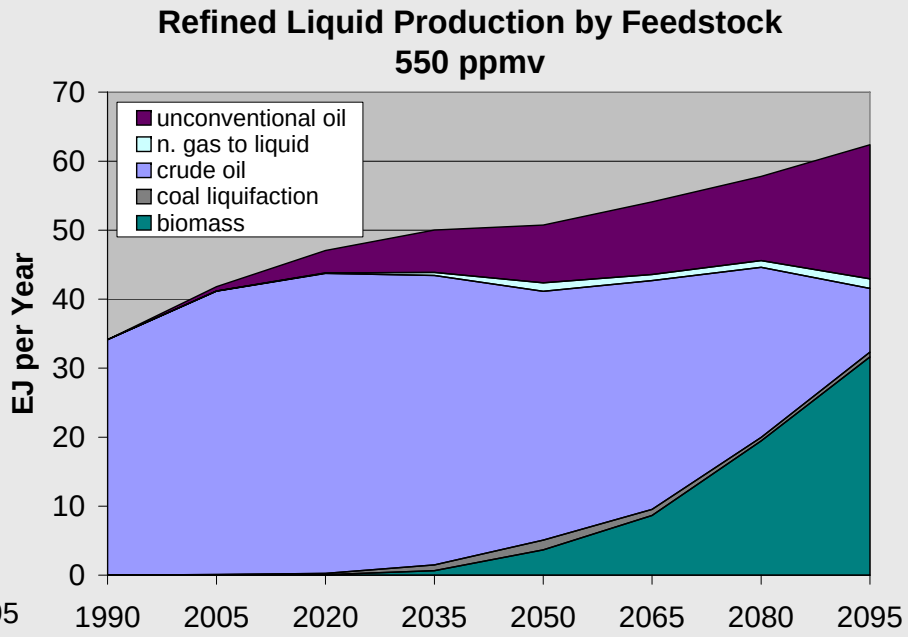
- In 2035: 121 thous. GWh of electricity consumption from PHEVs (4% more than without climate constraint).
- In 2095: 550 thous. GWh of electricity consumption from PHEVs (14% more than without climate constraint, 4.6% of 12 thou. TWh total electricity).
- While more electricity is consumed with PHEVs and climate constraint, CO_2 emissions from the electricity sector are significantly lower with the carbon price.
- In 2095: CO_2 emissions are 89% less relative to case without the carbon price.

US Refined Liquid Fuel Production
Penetration of Biomass Based Fuels

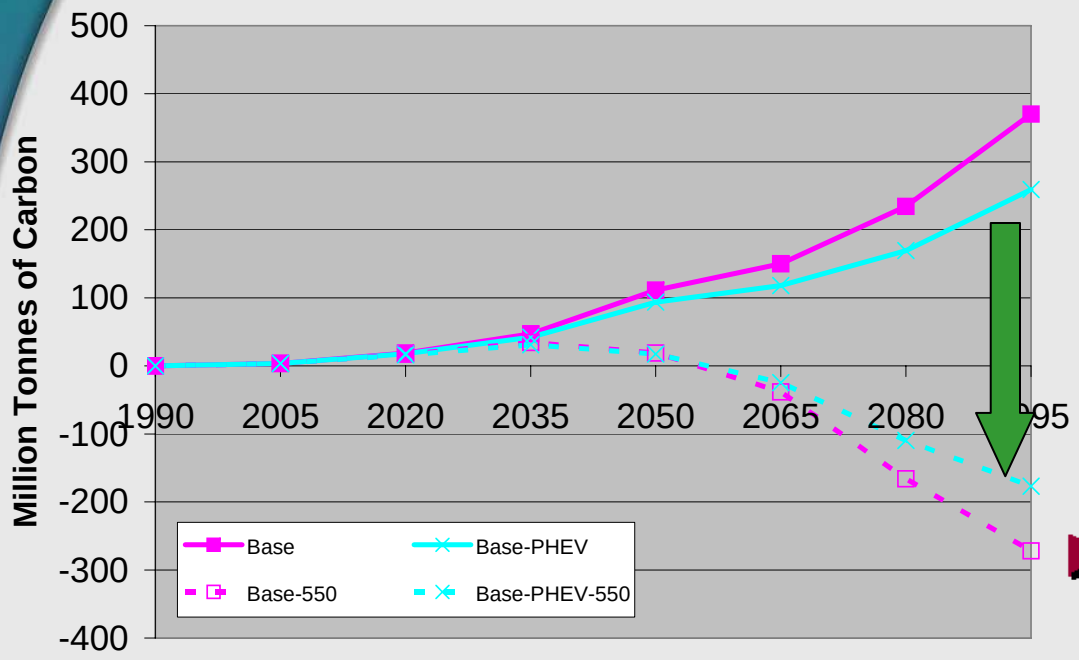
Base



Base-550

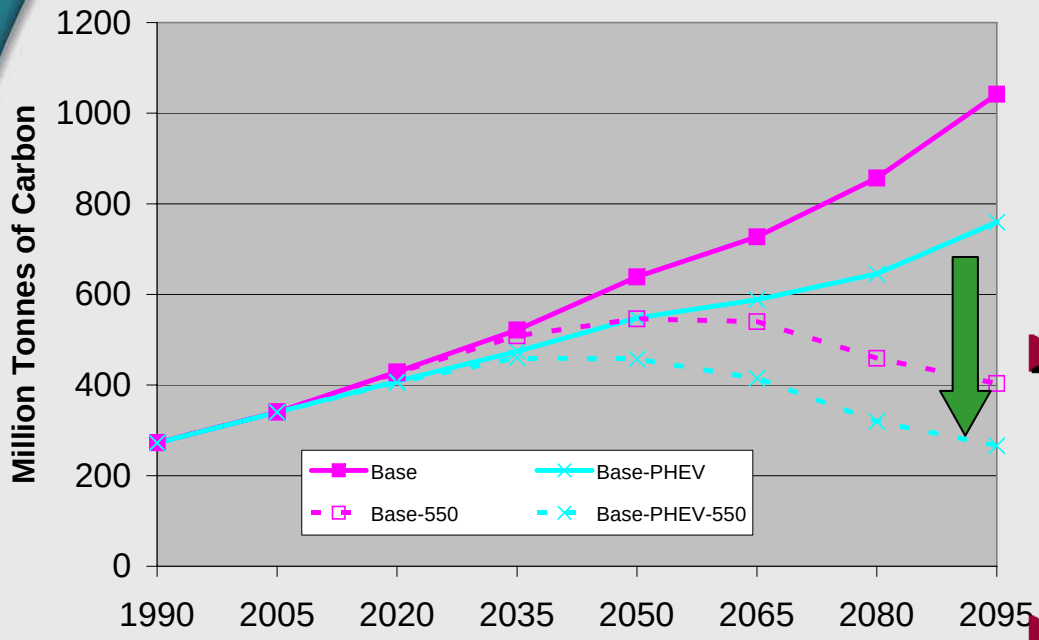


US CO_2 Emissions: From Refinery for Lt-Duty Vehicle Fuel



- While nearly the same amount of fuel is consumed with PHEVs and a climate constraint, CO_2 emissions from refineries are significantly lower with the carbon price.
- In 2095: CO_2 emissions credit (negative offset) of 177 MTC due to climate constraint and biomass fuels.

US CO_2 Emissions - Passenger Light Duty: Sum of Fuel Combustion, Electricity and Refinery Emissions



- Although the total number of PHEVs on the road is not significantly greater under the climate constraint, net CO_2 emissions from Lt-duty vehicles are significantly lower.
- In 2095: additional 494 MTC CO_2 emissions reduction with PHEVs and climate constraint.
- In 2095: 74% reduction from Base Case (without PHEVs and climate constraint).

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Conclusions: Part 2 – PHEV Penetration in a Climate Constrained World

- A carbon price that raises vehicle fuel cost is not a strong leverage on the penetration of PHEVs (relative cost of fuel is small compared to the total service cost).
- In a climate constrained world, carbon is taken out of electricity and refined fuel production.
- Advanced vehicle technologies or low carbon or carbon neutral fuels (and electricity) are alternative means for CO_2 emissions reduction from transportation.
- A comprehensive approach that includes advanced vehicle technologies and economy-wide carbon constraints are the most effective for reducing transportation CO_2 emissions.
- Future studies: land-use emissions, net emissions from bio-fuel production, and carbon capture technologies for refineries.

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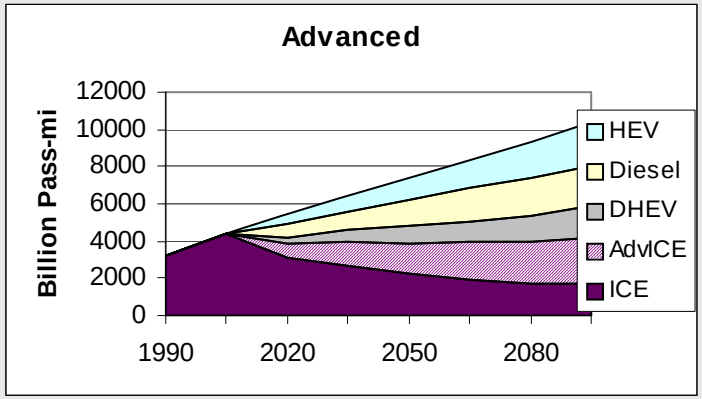
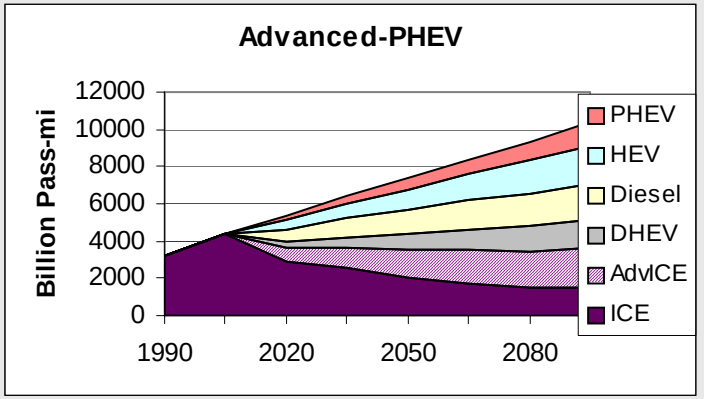
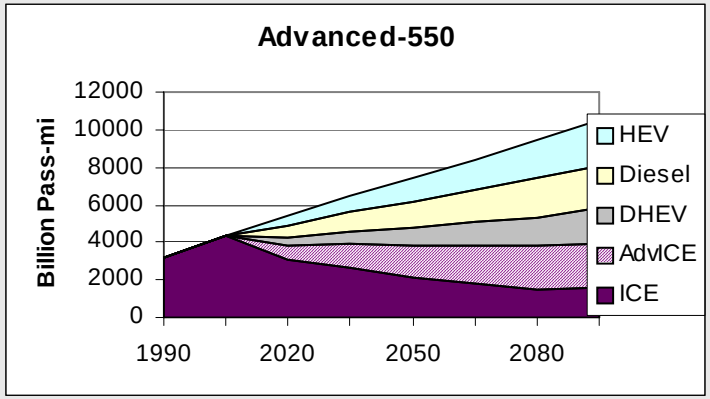
Part 3: Vehicle Technology Competition

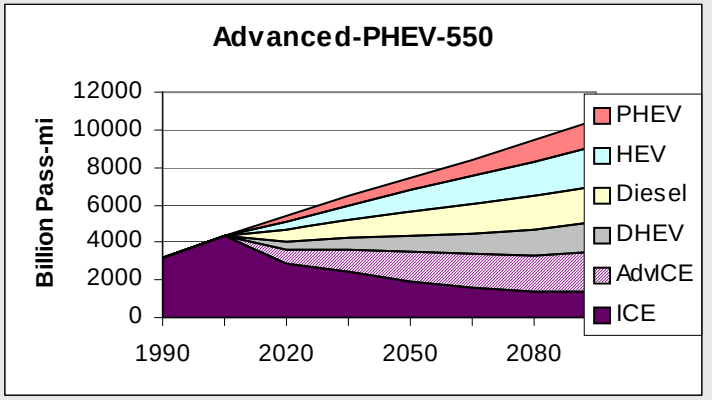
(Comparison of Advanced Case and Advanced Case with PHEV - With and Without Climate Constraint)

US Light Duty Passenger Transport Service

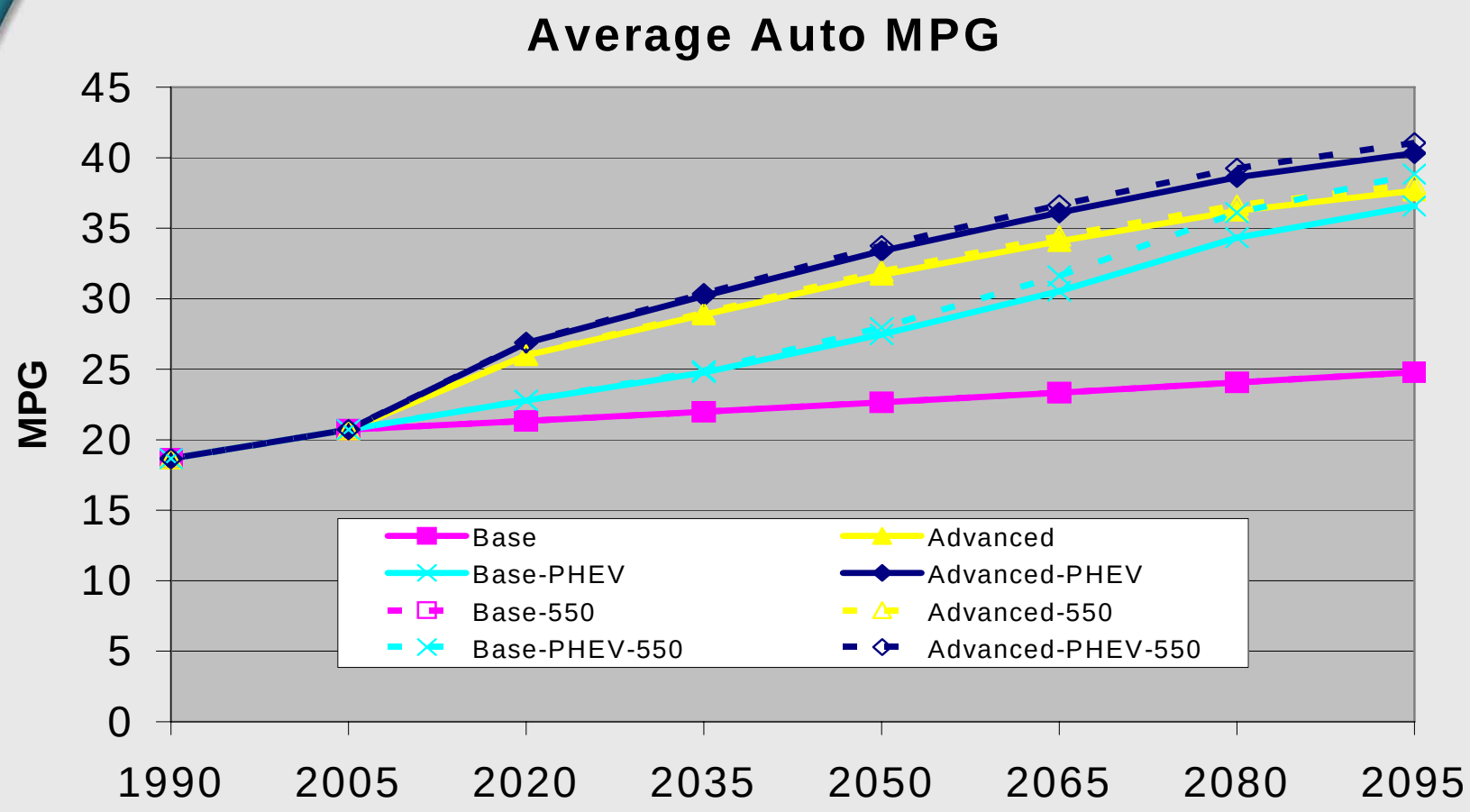




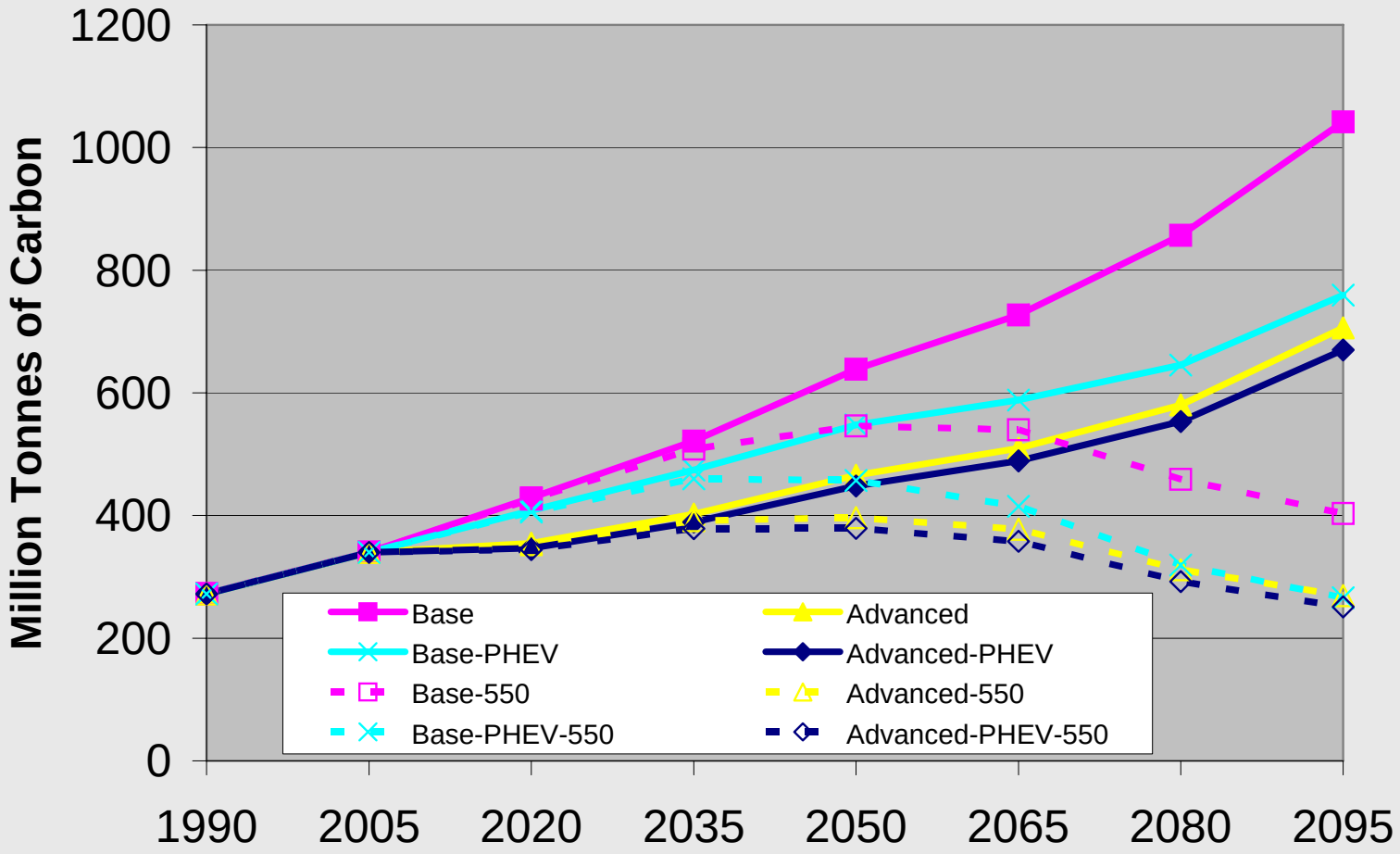




US Fleet Average Automobile Fuel Economy



US CO_2 Emissions - Passenger Light Duty: Sum of Fuel Combustion, Electricity and Refinery Emissions



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Conclusions: Part 3 – Vehicle Technology Competition

- Total fleet average fuel economy is the key determinant of transportation fuel consumption and CO_2 emissions reduction.
- Greater penetration of lower cost but second best alternative vehicle technologies could result in higher fleet average fuel economy then the single best alone.
- Availability of the suite of advanced vehicle technologies (with climate constraint), however, resulted in the greatest cumulative reduction in fuel consumption and CO_2 emissions from passenger light duty transport.

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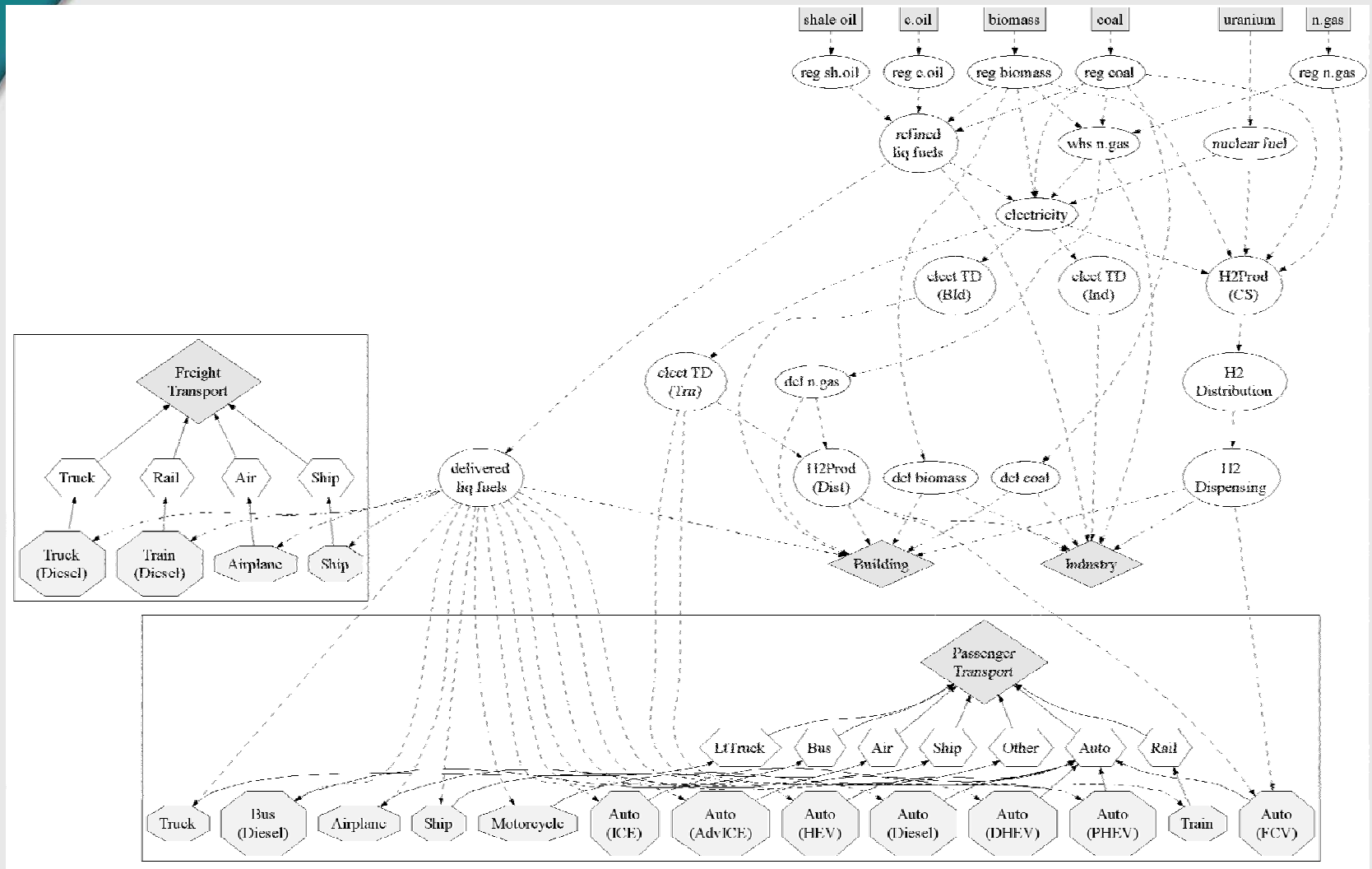
ObjECTS-MiniCAM Transportation



GTSP
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Modeling Transportation

- **Many different vehicle technologies and modes.**
- **Two transport services, passenger and freight.**
- **Modeled simply.**

Vehicle Service $$P_{veh} = [(P_{fuel} / Eff_{veh}) + P_{non-fuel,veh}] / LF_{veh}$$

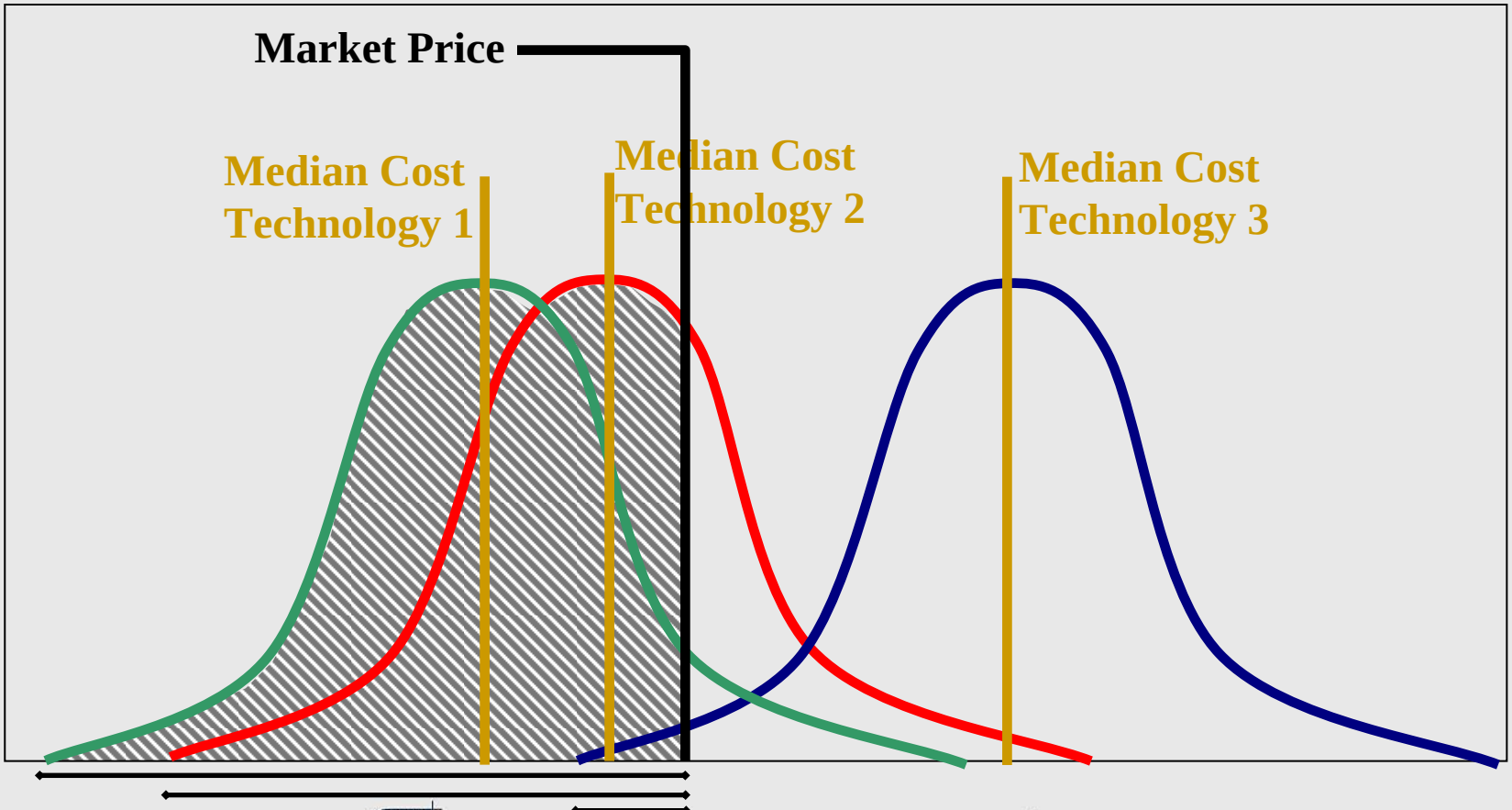
Modal Service $$P_{mode} = \sum_{i}^{N} s_i P_{veh,i} + W / T_{mode}$$

Passenger Service $$P_{pass} = \sum_{j}^{M} s_j P_{mode,j}$$

Aggregate Demand $$D_{pass} = C_o \cdot P_{pass}^{-\alpha} \cdot I_{cap}^{\beta} \cdot Pop$$

Technology Competition

A Probabilistic Approach



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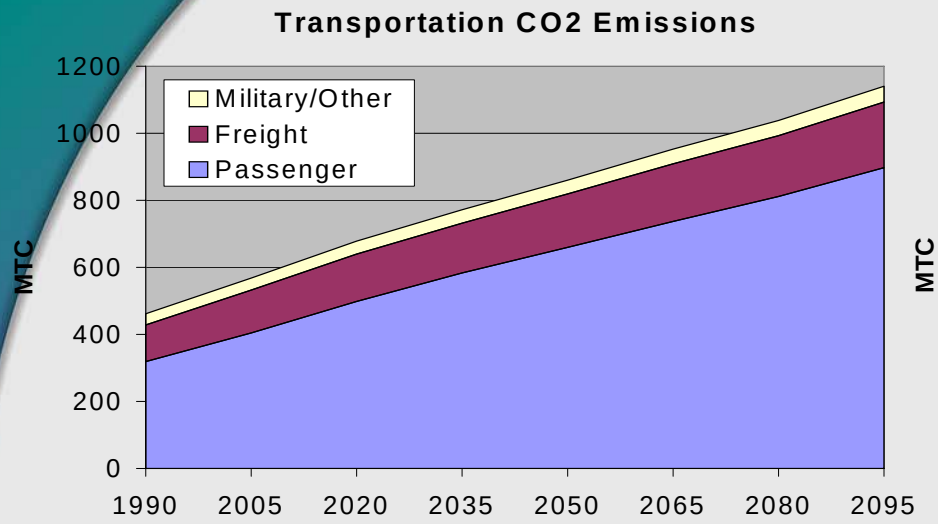
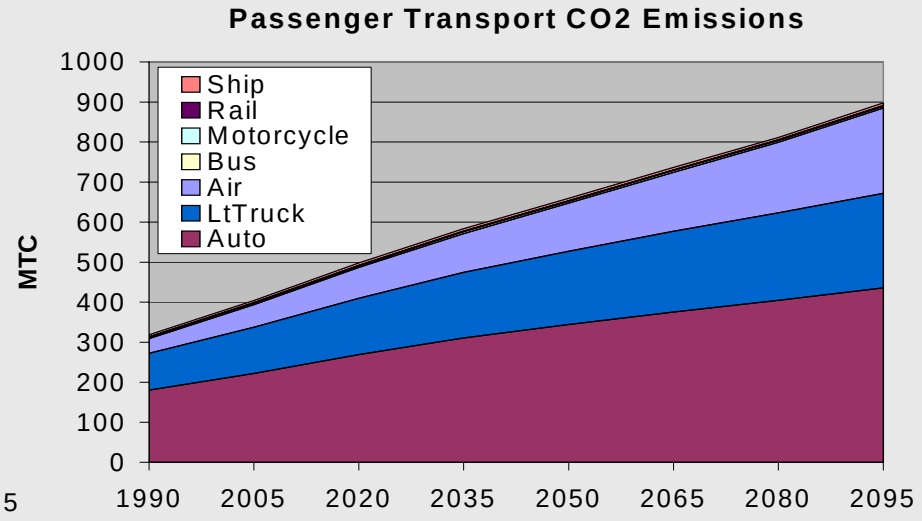
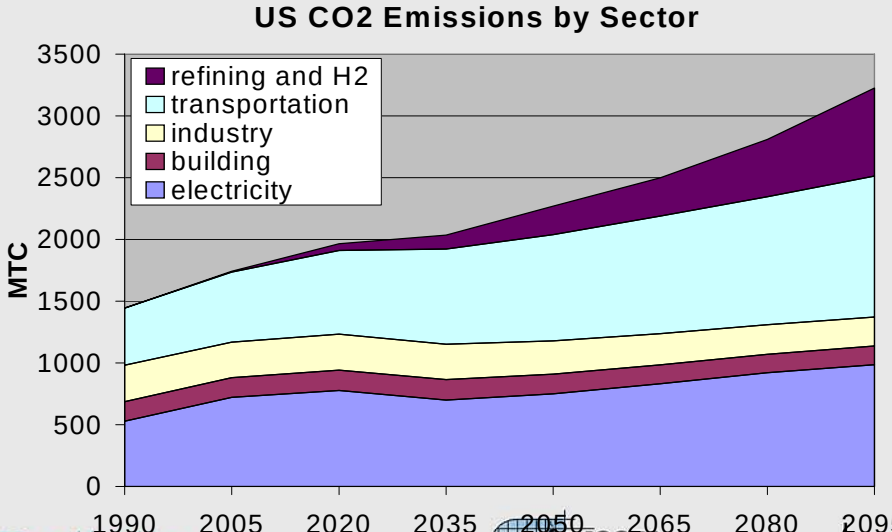
Passenger Vehicle Assumptions: Non-Fuel Costs

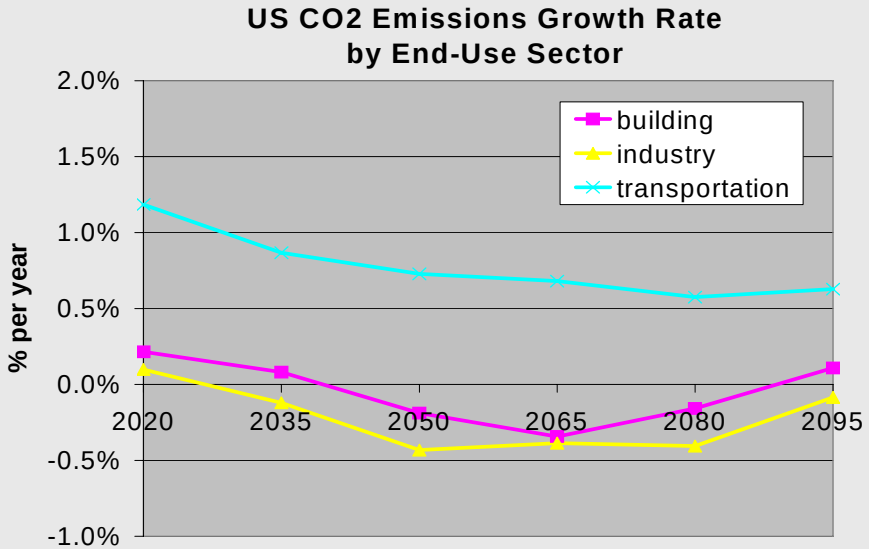
Non-fuel Cost (2005 US$ per vehicle-mile)	2005	2020	2050	2095
Auto ICE	0.51	0.51	0.51	0.51
Auto Advanced ICE		0.53	0.51	0.51
Auto HEV		0.57	0.54	0.51
Auto Diesel		0.53	0.52	0.51
Auto Diesel HEV		0.60	0.58	0.54
Auto PHEV		0.63	0.61	0.57
Lt-Truck ICE	0.53	0.53	0.53	0.53
Lt-Truck Advanced ICE		0.57	0.55	0.53
Lt-Truck HEV		0.62	0.59	0.55
Lt-Truck Diesel		0.61	0.60	0.57
Lt-Truck Diesel HEV		0.67	0.64	0.60
Lt-Truck PHEV		0.70	0.67	0.63

US Transportation CO_2 Emissions Base Case









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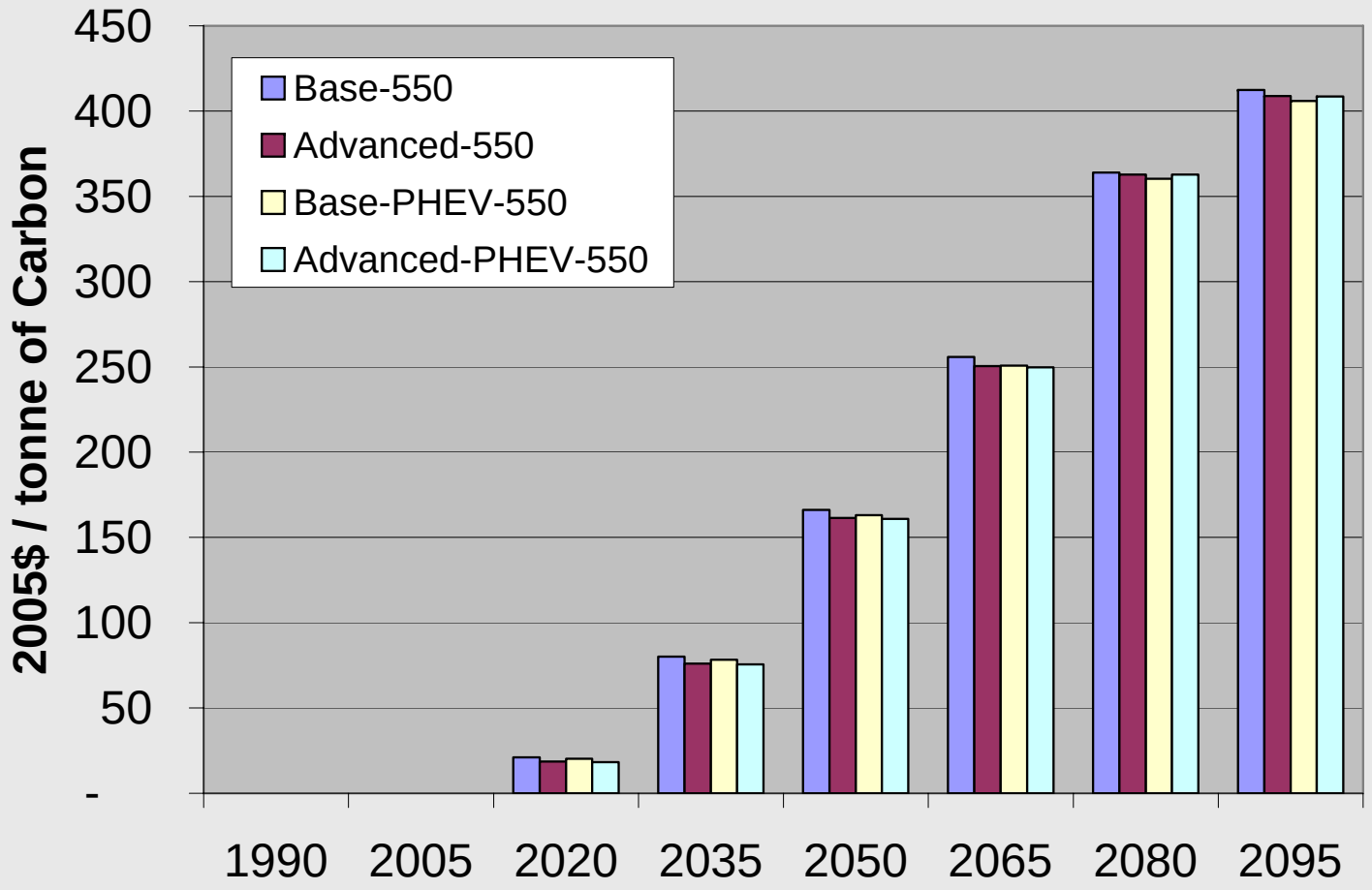
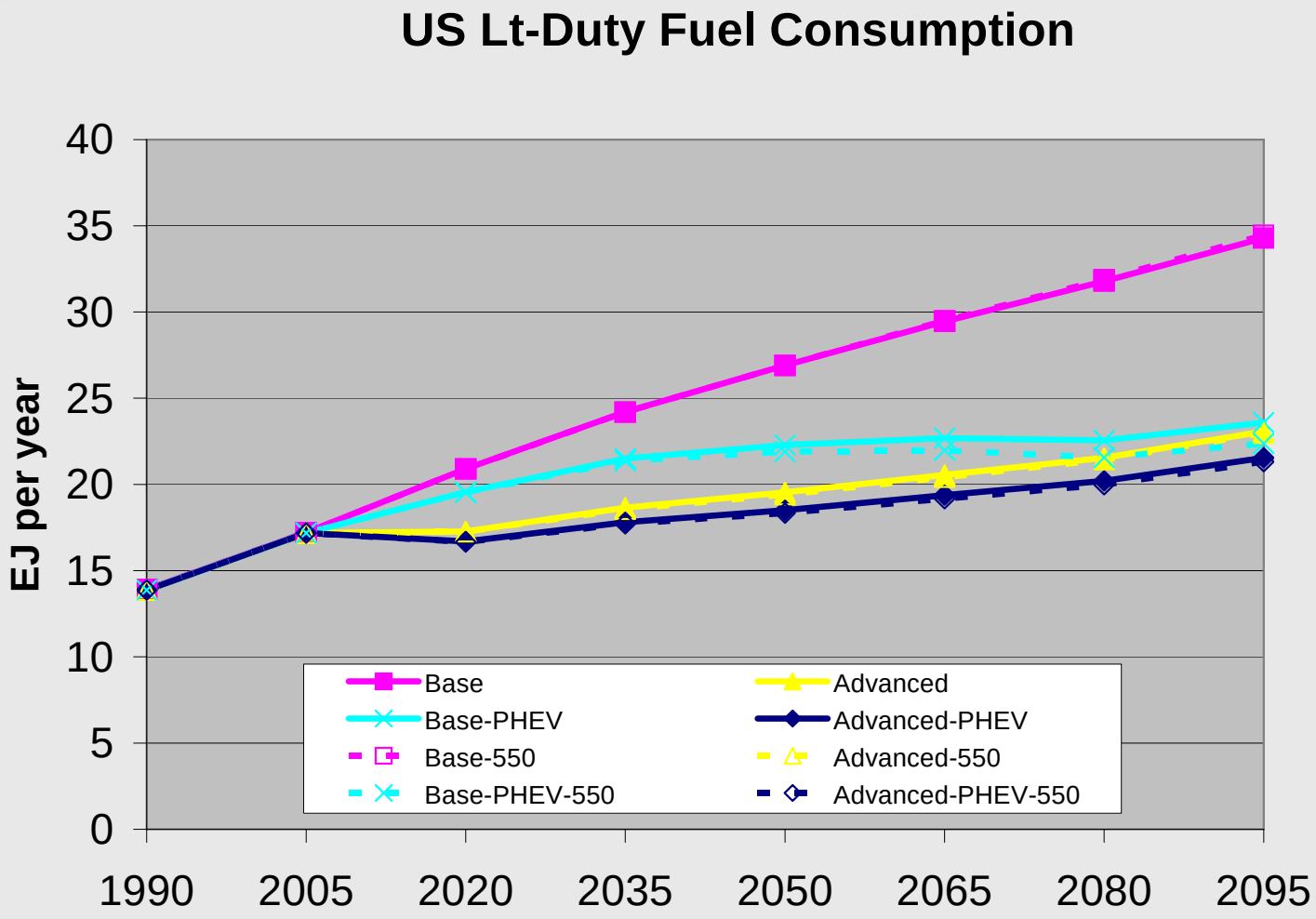
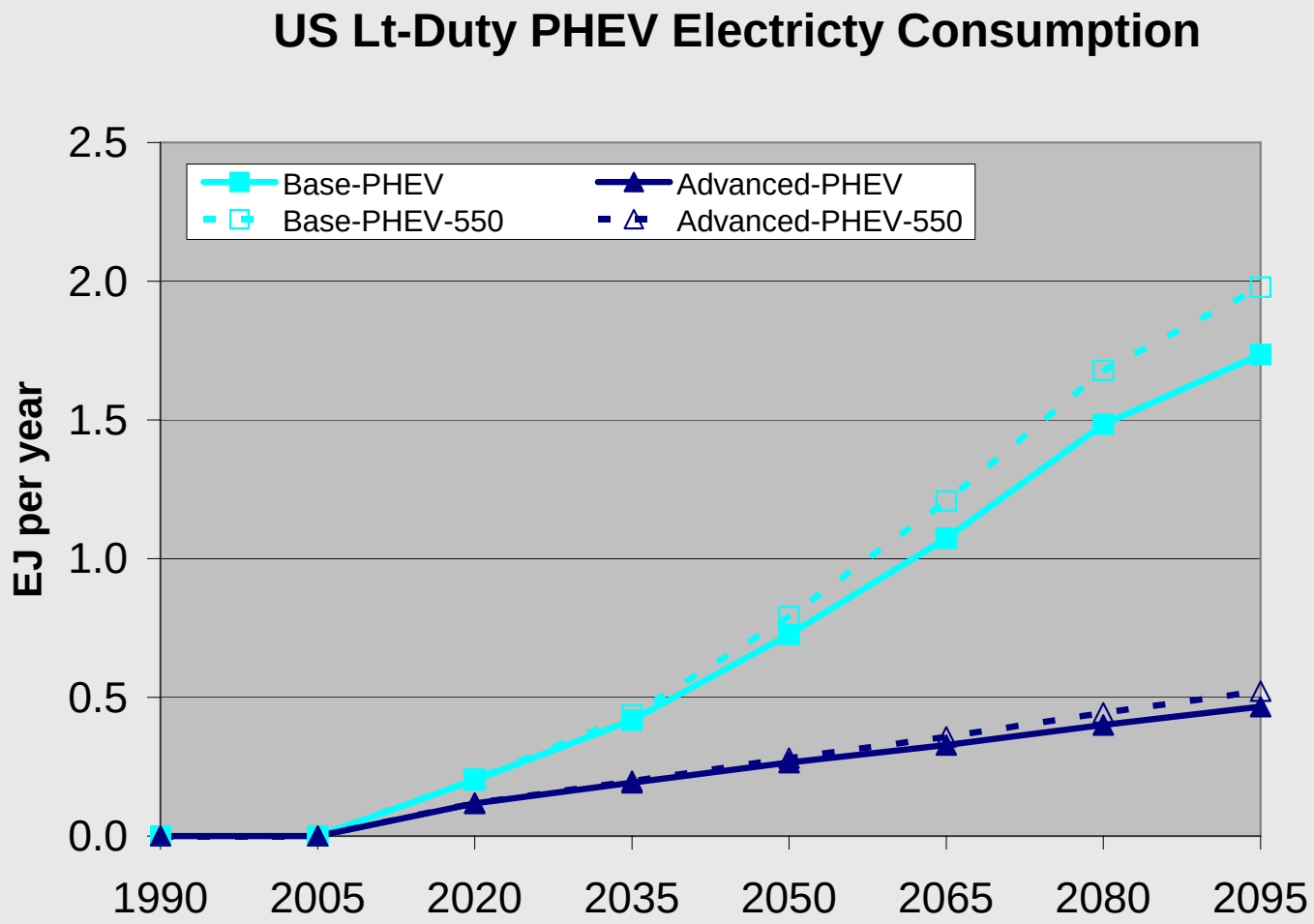
Global Carbon Price



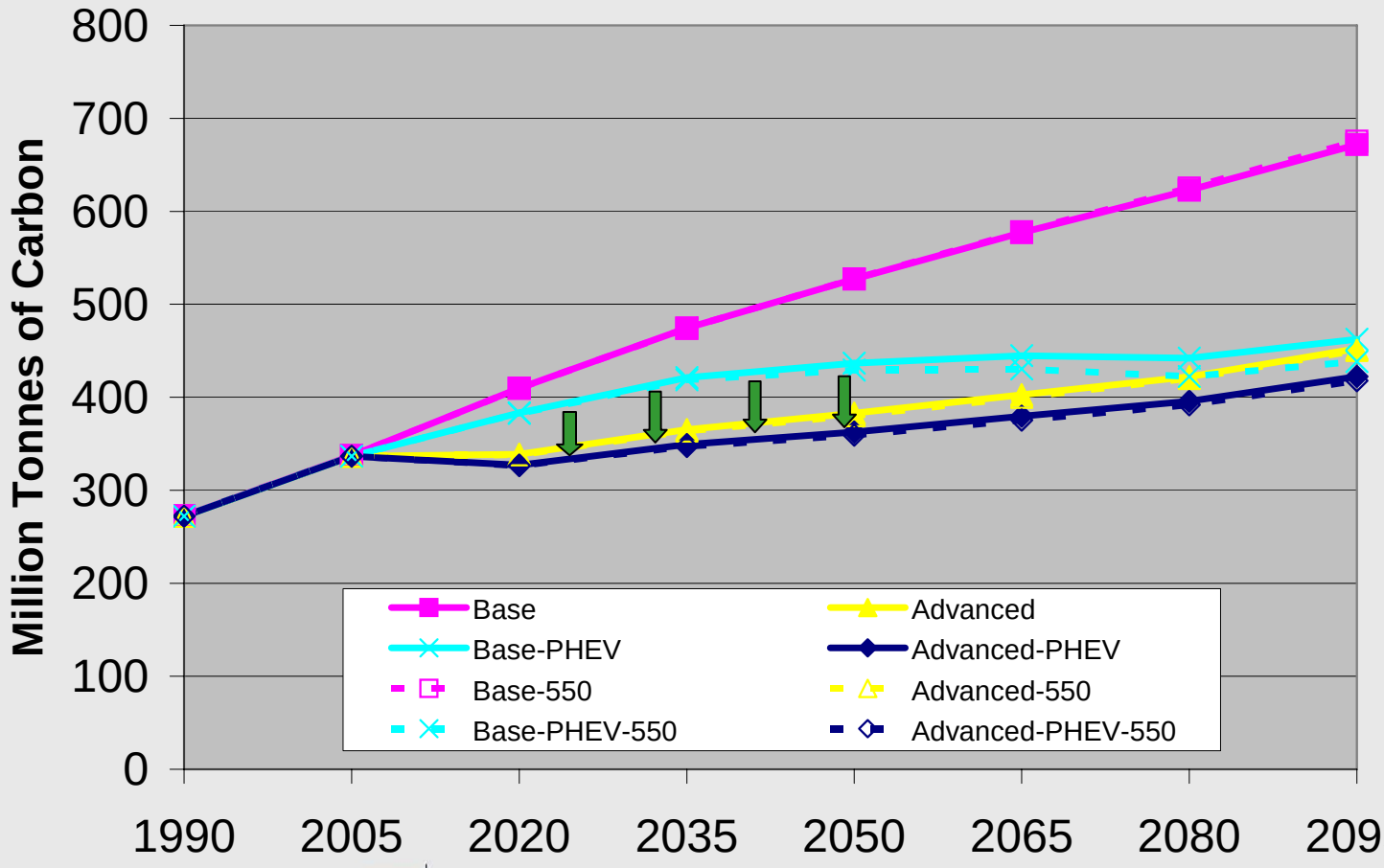
US Refined Fuel Consumption



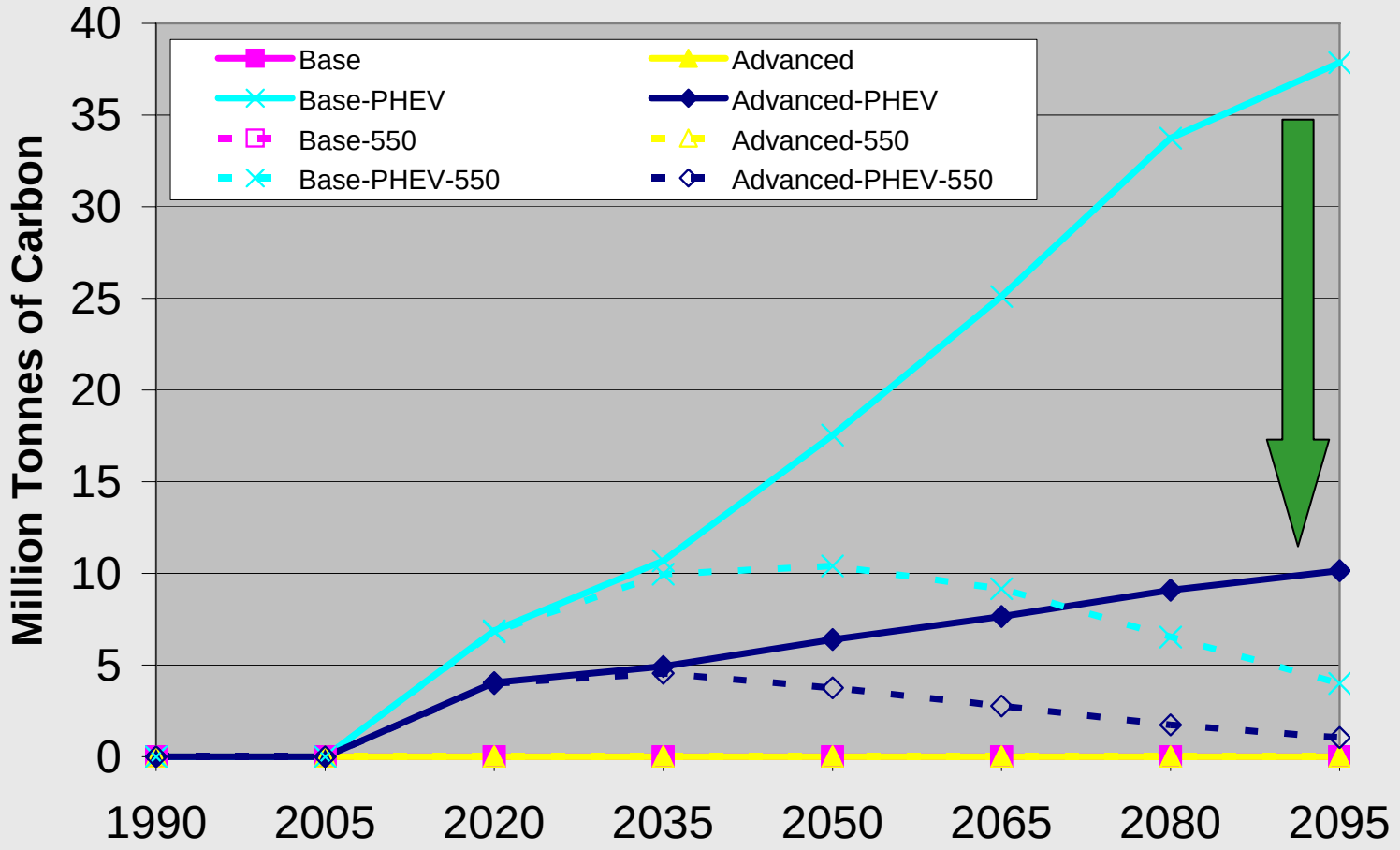
US Electricity Consumption



US CO_2 Emissions: From Lt-Duty Vehicle Fuel Consumption



US CO_2 Emissions: From PHEV Electricity Consumption



US CO_2 Emissions: From Refinery for Lt-Duty Vehicle Fuel