Mobile Source Emissions and Climate Change

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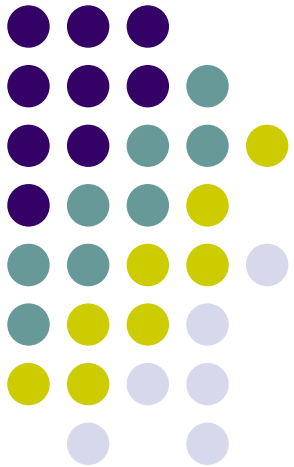
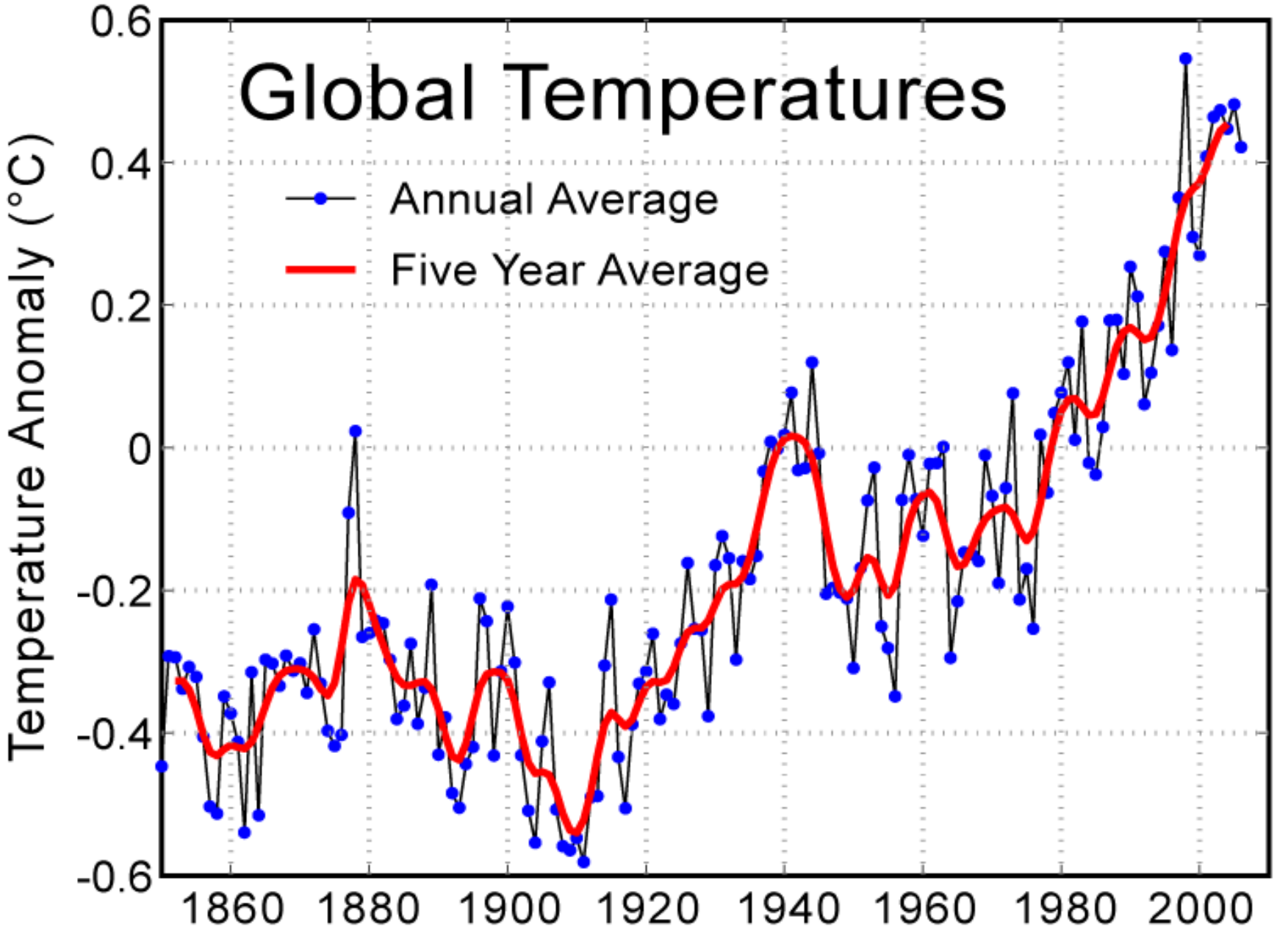
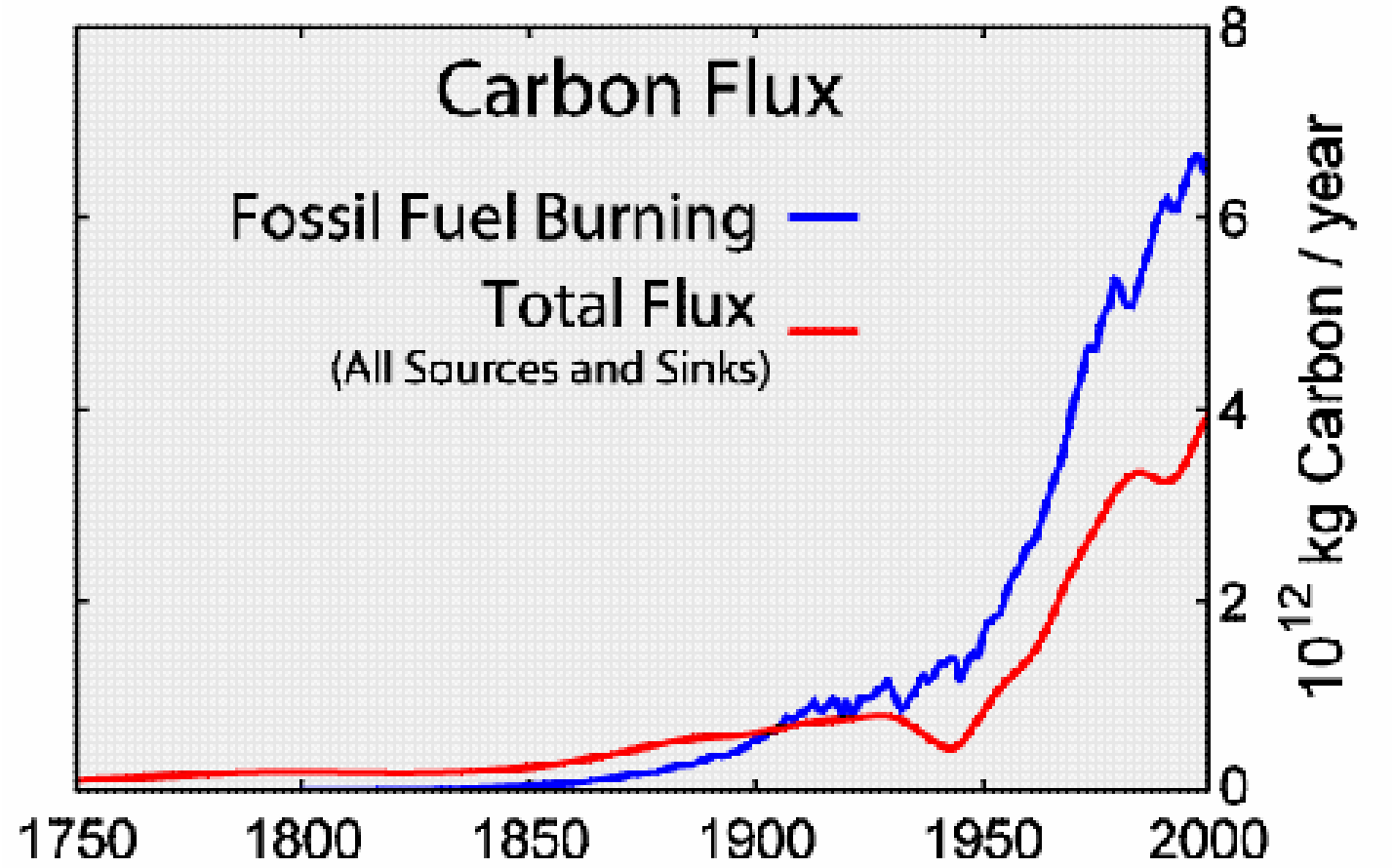
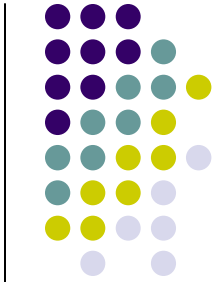


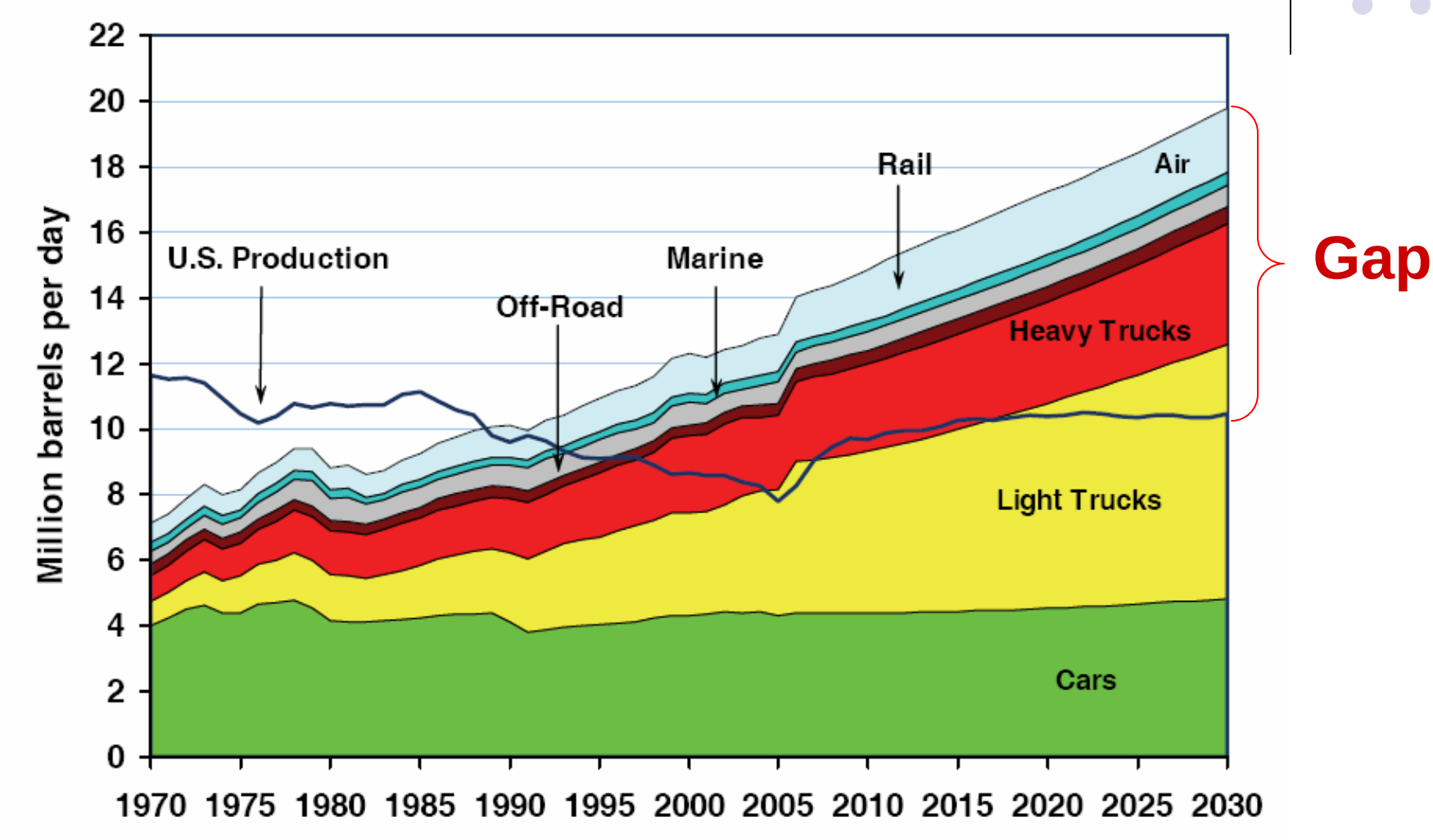

Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1860
1880
1900
1920
1940
1960
1980
2000


Carbon Flux
Fossil Fuel Burning
Total Flux
(All Sources and Sinks)
8
6
4
2
0
1750
1800
1850
1900
1950
2000
10^12 kg Carbon / year



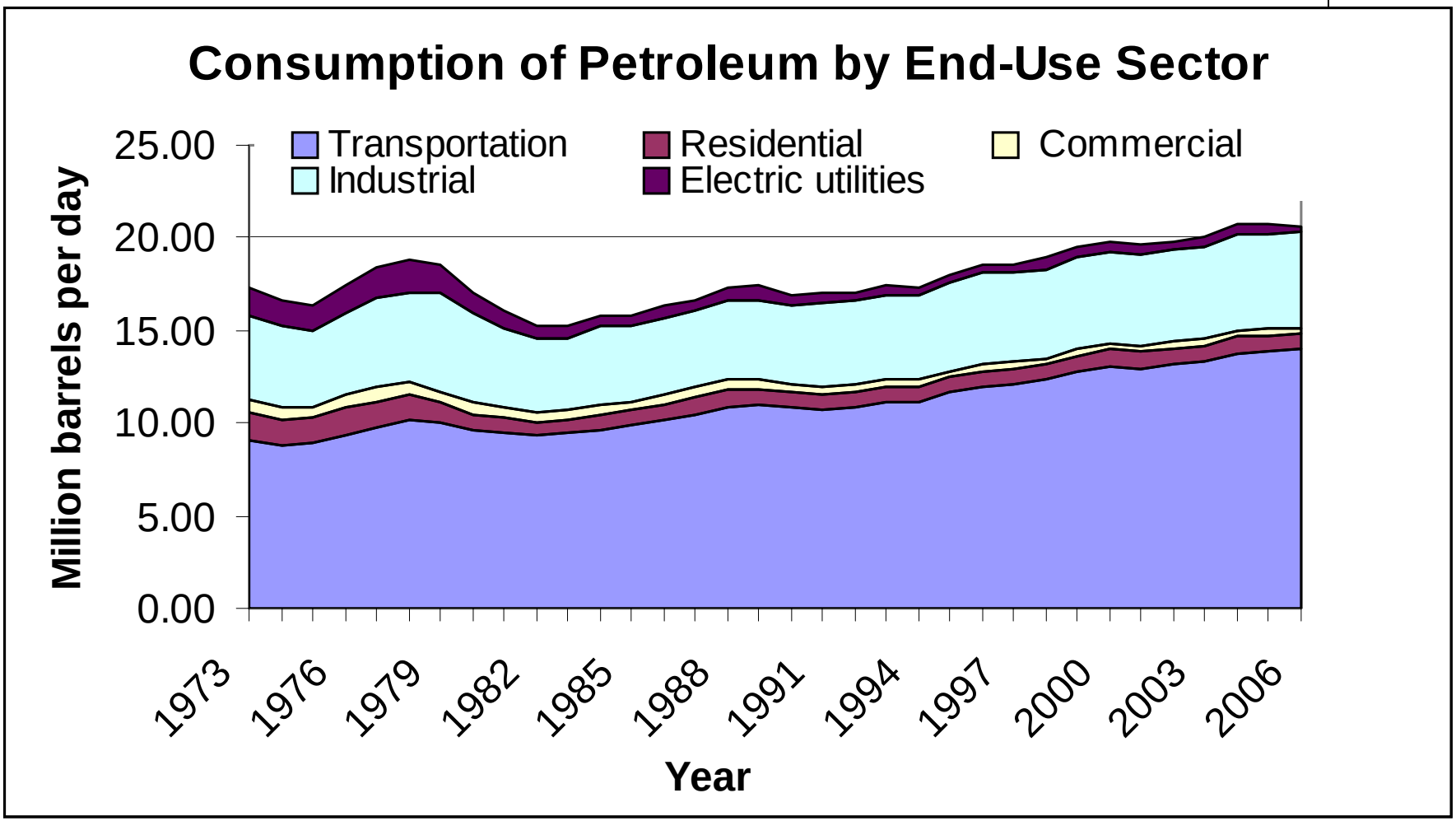
Current Status Quo of Transportation Fuel Consumption, GHGs and Other Pollution

U.S. Transportation Oil Demand



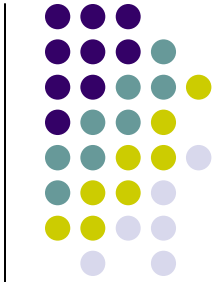
Source: U.S. DOE, *Transportation Energy Data Book*, Edition 26, (2007)

Petroleum Consumption, 1973-2006



Source: U.S. DOE, *Transportation Energy Data Book*, Edition 26, (2007)

U.S. Carbon Emissions from Fossil Energy Consumption

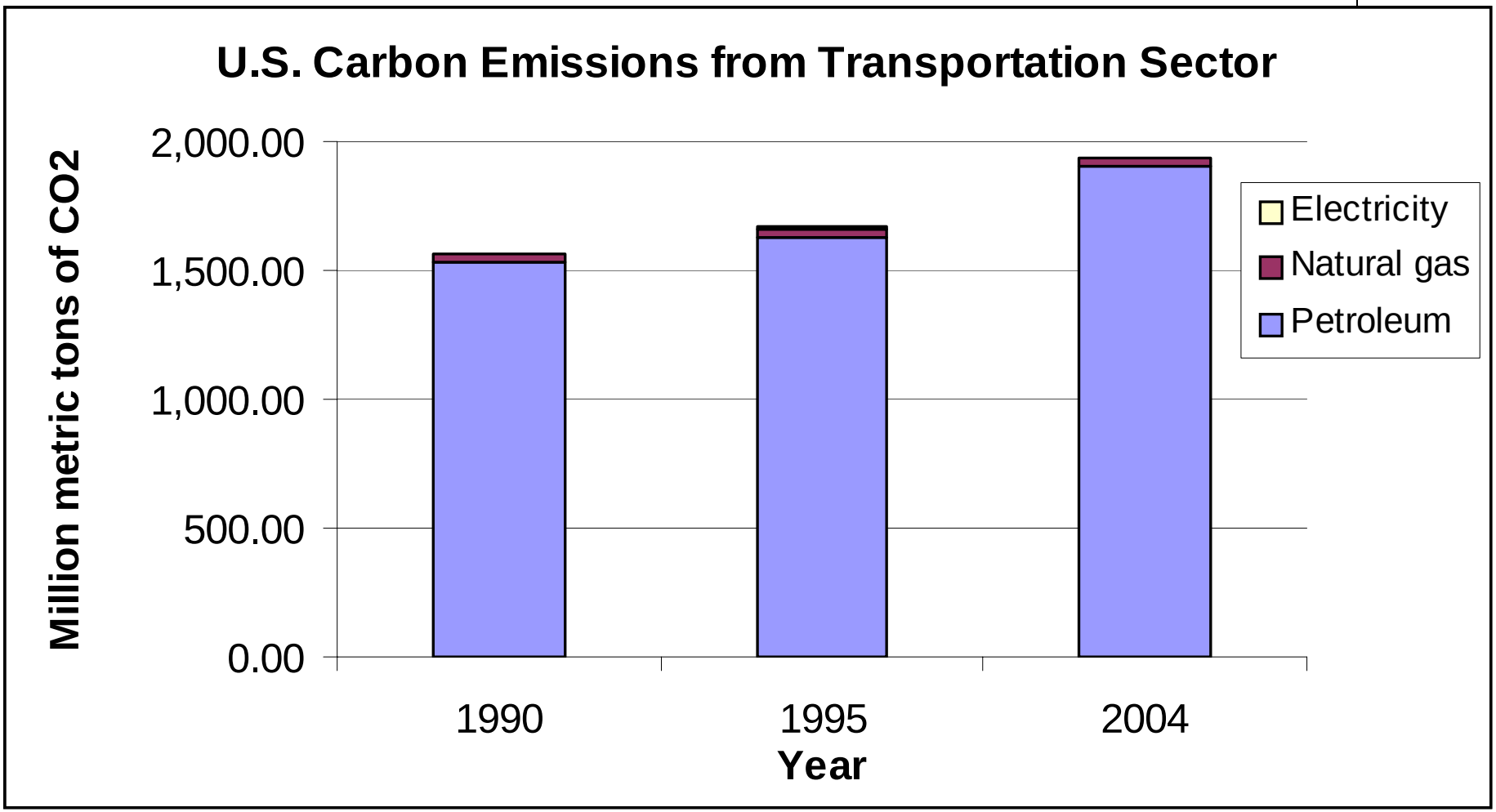


End use sector	2000	2001	2002	2003	2004	2005
Residential	1171.9	1161.1	1186.4	1214.0	1213.9	1253.8
Commercial	1006.4	1014.2	1009.4	1020.3	1034.1	1050.6
Industrial	1778.0	1702.8	1684.7	1688.0	1736.0	1682.3
Transportation	1854.0	1831.7	1871.7	1878.2	1939.2	1958.6
Percentage	31.9%	32.1%	32.5%	32.4%	32.7%	32.9%
All sectors	**5,810.3**	**5,709.8**	**5,752.2**	**5,800.5**	**5,923.2**	**5,945.3**

(in million metric tons of carbon dioxide)

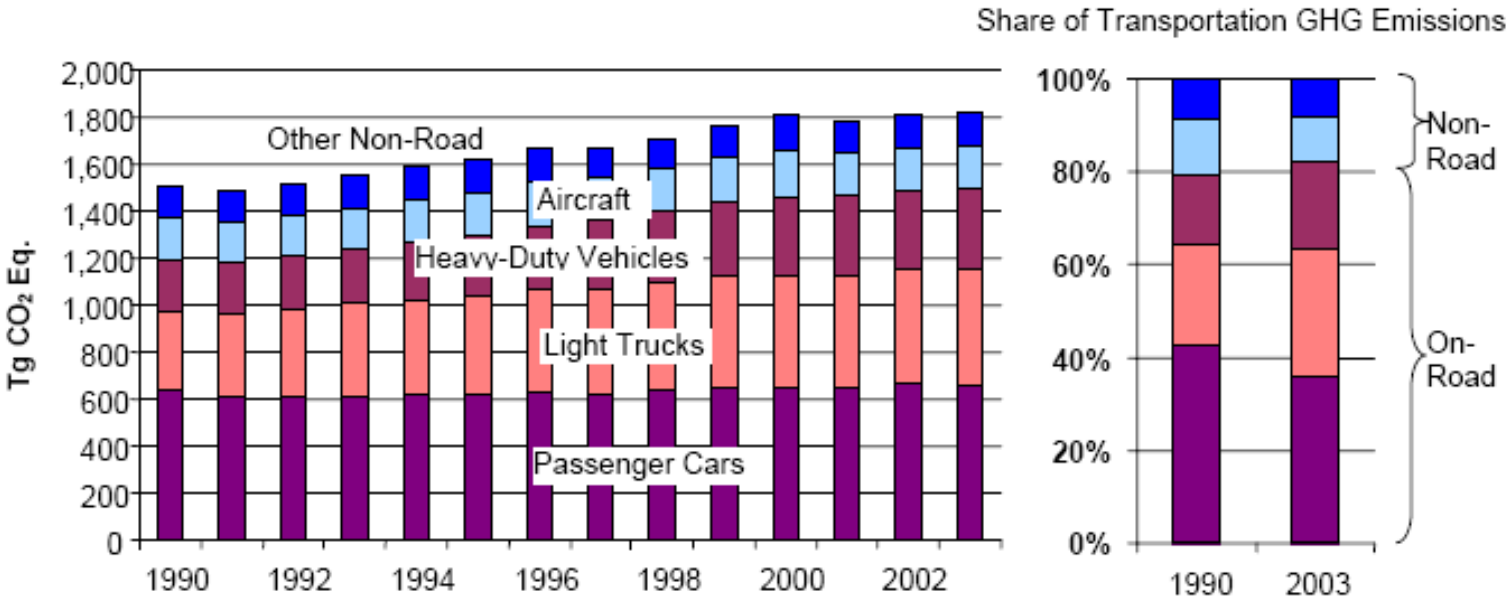
Source: U.S. DOE, 2005

U.S. Carbon Emissions from Transportation Sector, 1990-2004



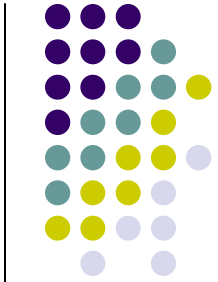
Source: U.S. DOE (2005)

GHGs by Mode of Transportation, 1990-2003



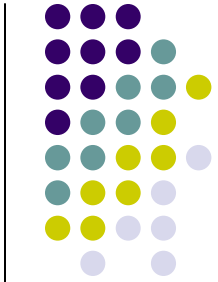
Source: U.S. EPA, 2005

In addition to GHGs,



- Transportation sector produces other harmful pollutants:
  - Criteria pollutants regulated by EPA:
    - Carbon Monoxide (CO)
    - Lead (Pb)
    - Nitrogen Dioxide (NO_2)
    - Particulate Matter (PM_{10} and $PM_{2.5}$)
    - Ozone (O_3)
    - Sulfur dioxide (SO_2)
  - Mobile source air toxics:
    - Six principal MSATs: benzene, formaldehyde, acetaldehyde, diesel particulate matter/diesel exhaust organic gases, acrolein, and 1,3-butadiene.

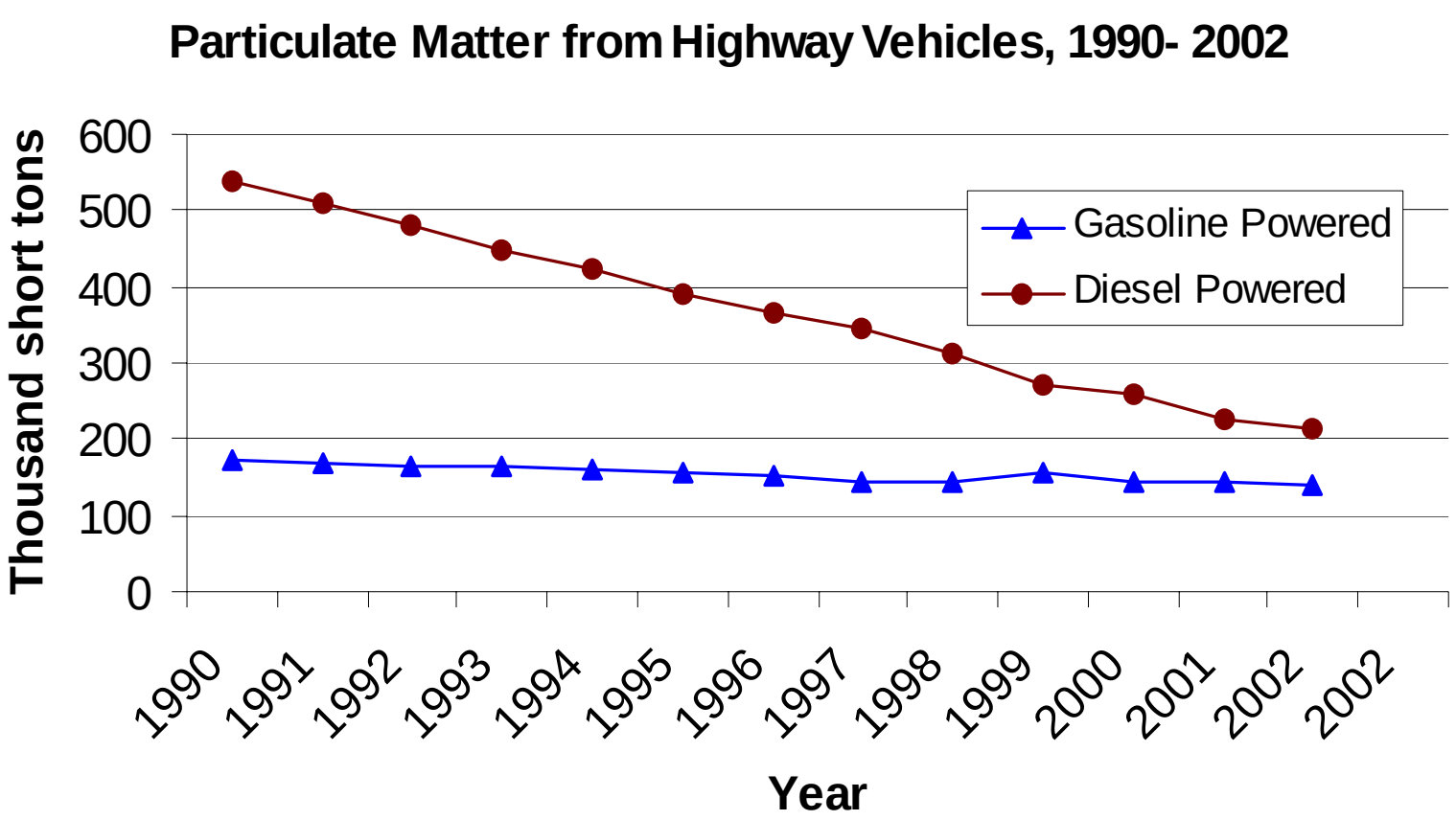
Criteria Pollutant Emissions



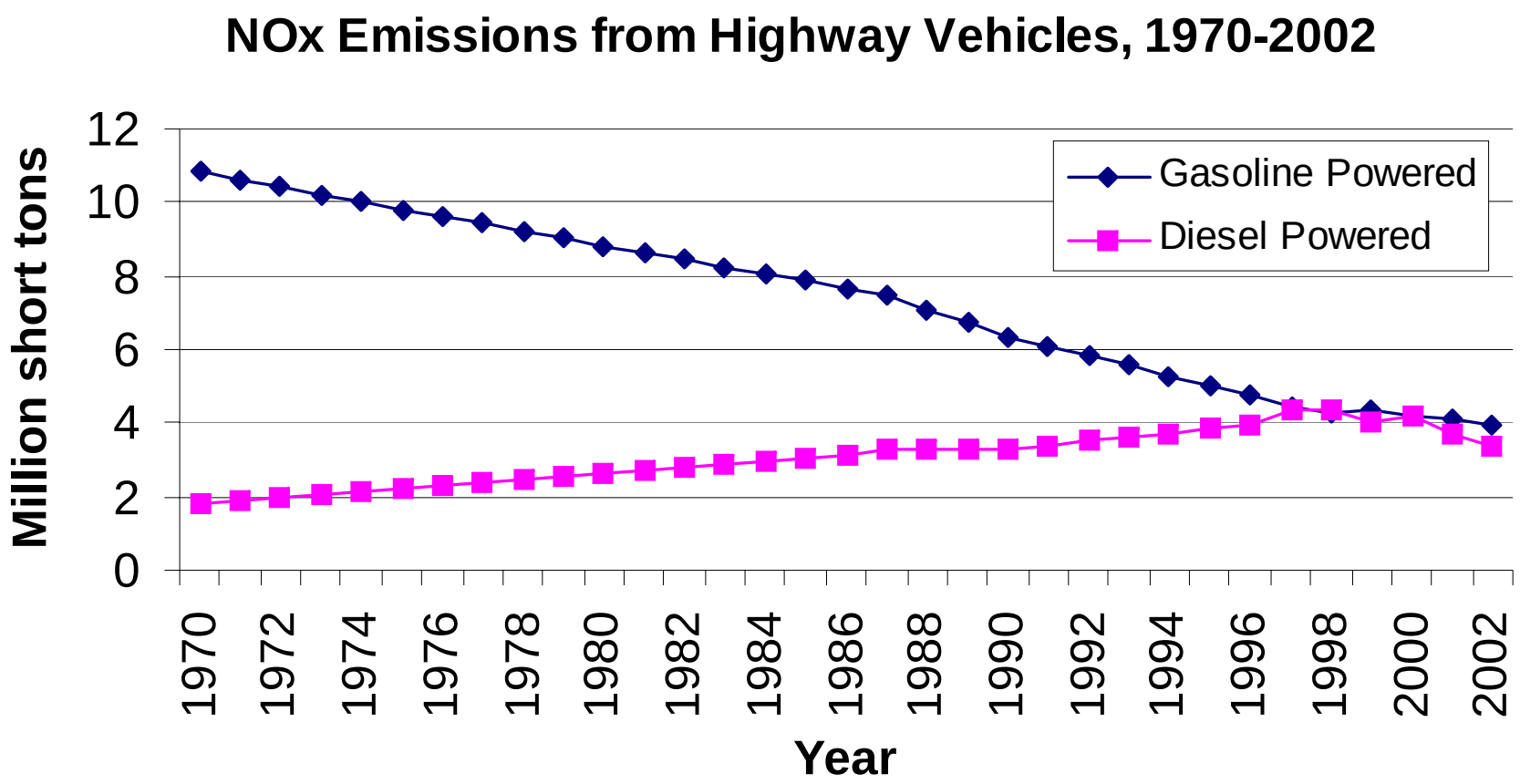
- National inventories of mobile emissions in 2002 (in thousand short tons)
  - CO : 99,502 (82%, 95% in urban)
  - NO_x : 12,405 (56%)
  - VOC : 7,496 (45%)
  - $PM_{2.5}$: 500 (25%)
  - PM_{10} : 534 (20%)
  - SO_2 : 701 (5%)

Source: EPA, http://www.epa.gov/airtrends/

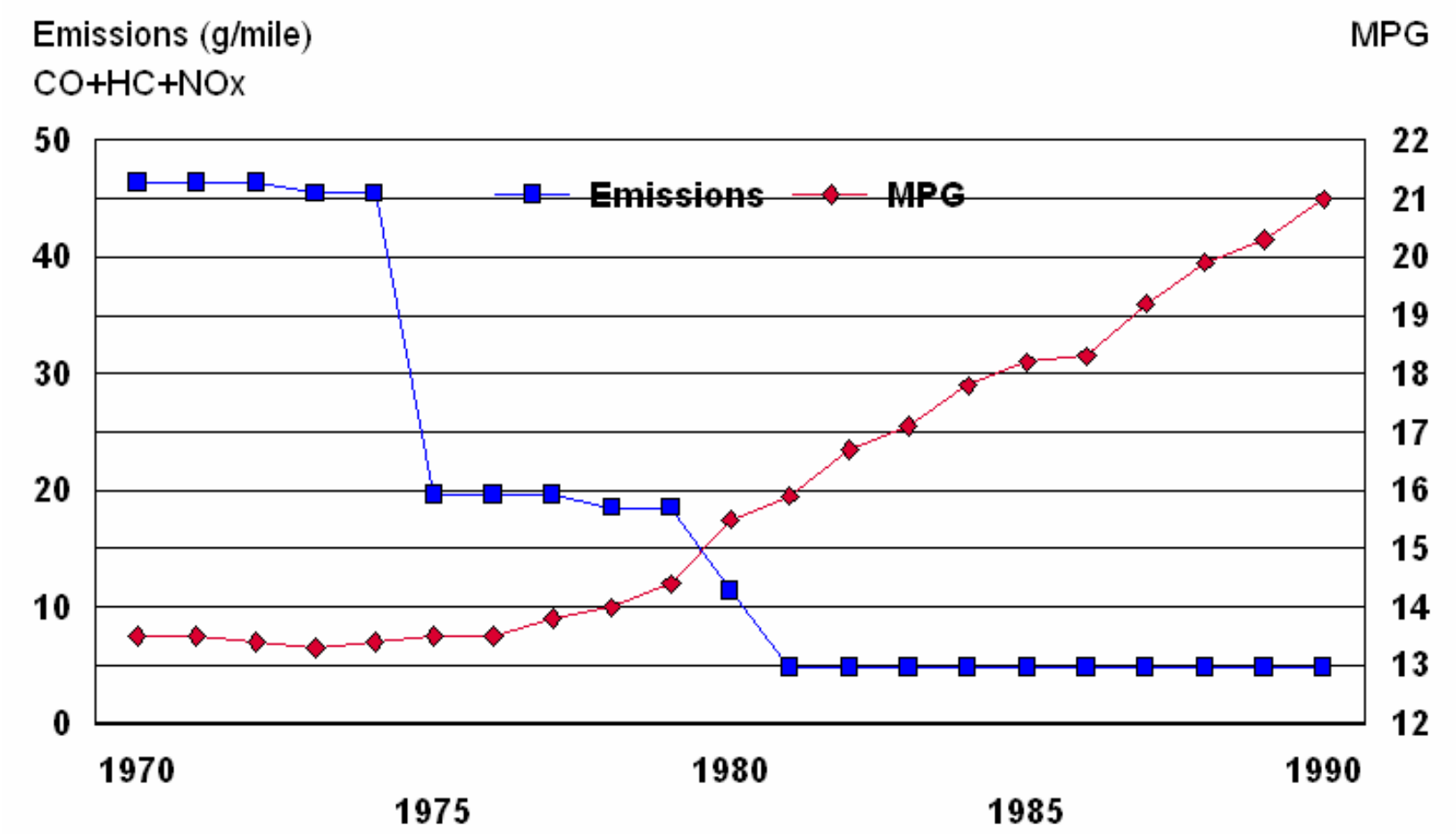
Particulate Matter Emissions



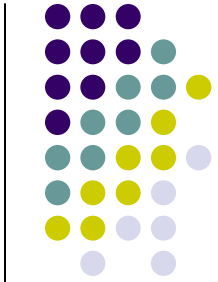
NOx Emissions



Vehicle Technological Improvements and Improved Fuel Economy

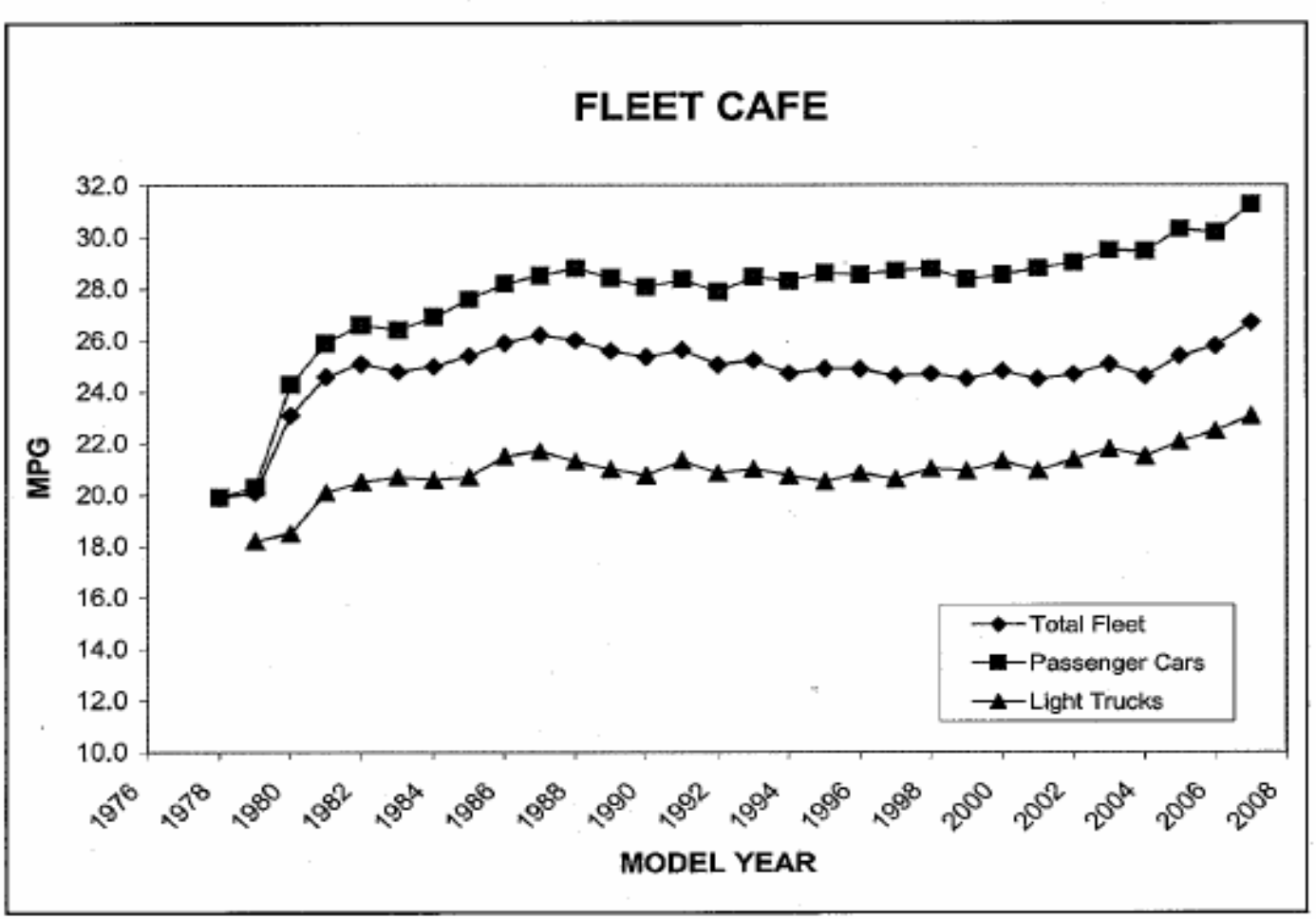


Corporate Average Fuel Economy (CAFE) Standards



- Passenger cars:
  - CAFE standard since 1985: 27.5 miles per gallon (mpg)
  - Sales weighted fuel economy: 29.7 mpg (2006 estimate)
- Light trucks:
  - CAFE standard since 2007: 22.2 mpg
  - Sales weighted fuel economy: 22.3 mpg (2006 estimate)
- Proposed CAFE standards
  - For passenger cars, from the current 27.5 miles per gallon to 35.7 miles per gallon by 2015.
  - For light trucks, from 23.5 miles per gallon in 2010 to 28.6 miles per gallon in 2015.

Fleet Fuel Economy, 1975-2006



Source: USDOT

Emission Standards for NEW Vehicles

- **Tier 2 Standards (1999 rulemaking)** – 77-95% lower light-duty vehicle standards (beginning in 2004)– Same standards for light trucks and cars; gasoline and diesel

Light-duty vehicles

- **Heavy-Duty 2007 Standards (2000 rulemaking)** – Diesel sulfur control (15 ppm maximum, beginning in 2006)– 90% lower heavy-duty gasoline & diesel vehicle standards

Heavy-duty trucks & buses

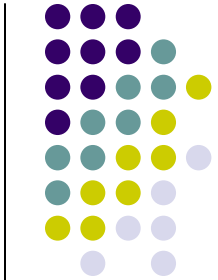
- **Nonroad Tier 4 Standards (2004 rulemaking)** – Diesel sulfur control (2 steps -500 ppm in 2007, 15 ppm in 2010)– 90-95% lower emission standards -based on highway technology

Nonroad machines

Heavy-Duty Engine 2007 Standard Requirements

	2006	2007	2008	2009	2010	2011	2012
PM		**100%** at **0.01** g/hp-hr					
NOx		**50%** at **0.20** g/hp-hr			**100%** at **0.20** g/hp-hr		
Fuel		**80%** at **15 ppm maximum sulfur** (under temporary compliance option)			**100%** at **15 ppm**		

Air Quality Attainment Designation

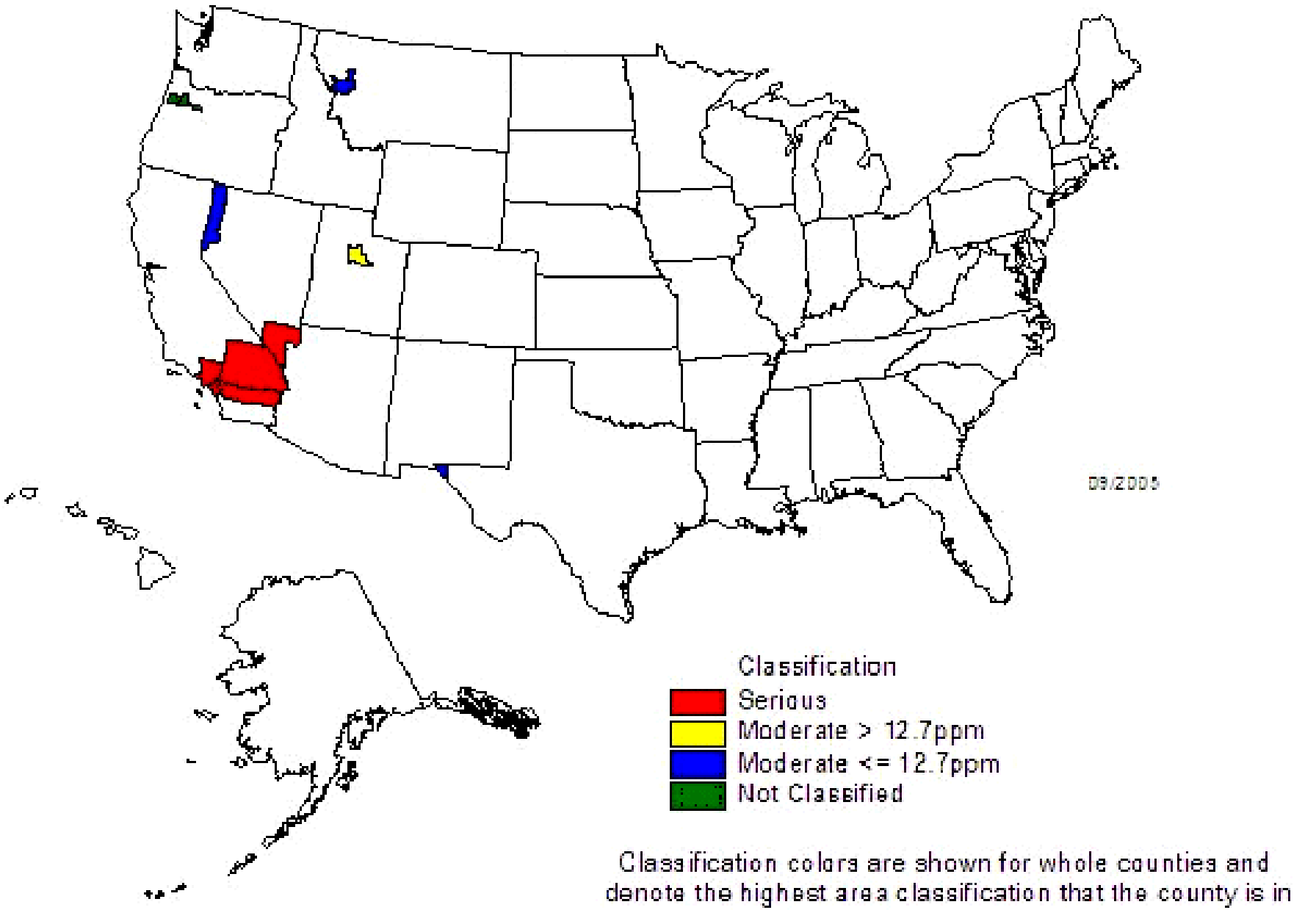


- **1990 Clean Air Act Amendments (CAAA)** define a "nonattainment area" as a locality where air pollution levels persistently exceed NAAQS, or that contributes to ambient air quality in a nearby area that fails to meet standards.
- Designation is done by U.S. Environmental Protection Agency (EPA)
  - Attainment areas
  - Nonattainment areas
  - Maintenance areas

National Ambient Air Quality Standards

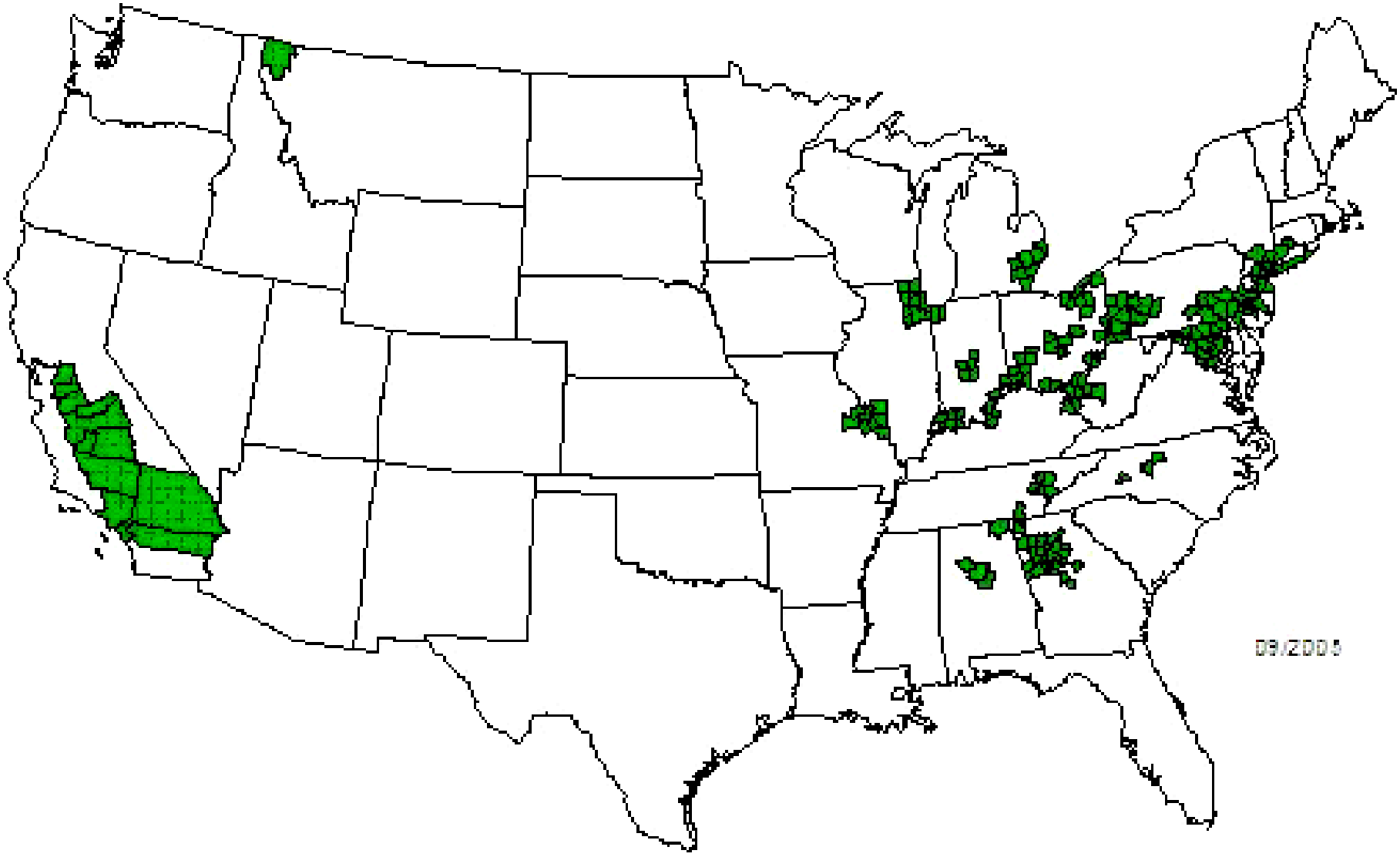
	Primary Standards		Secondary Standards	
Pollutant	**Level**	**Averaging Time**	**Level**	**Averaging Time**
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour	None	
	35 ppm (40 mg/m^3)	1-hour		
Lead	1.5 $\mu g/m^3$	Quarterly Average	Same as Primary	
Nitrogen Dioxide	0.053 ppm (100 $\mu g/m^3$)	Annual (Arithmetic Mean)	Same as Primary	
Particulate Matter (PM_{10})	150 $\mu g/m^3$	24-hour	Same as Primary	
Particulate Matter ($PM_{2.5}$)	15.0 $\mu g/m^3$	Annual (Arithmetic Mean)	Same as Primary	
	35 $\mu g/m^3$	24-hour	Same as Primary	
Ozone	0.075 ppm (2008 std)	8-hour	Same as Primary	
	0.08 ppm (1997 std)	8-hour	Same as Primary	
	0.12 ppm	1-hour (Applies only in limited areas)	Same as Primary	
Sulfur Dioxide	0.03 ppm	Annual (Arithmetic Mean)	0.5 ppm (1300 $\mu g/m^3$)	3-hour
	0.14 ppm	24-hour		

Counties Designated Nonattainment for Carbon Monoxide



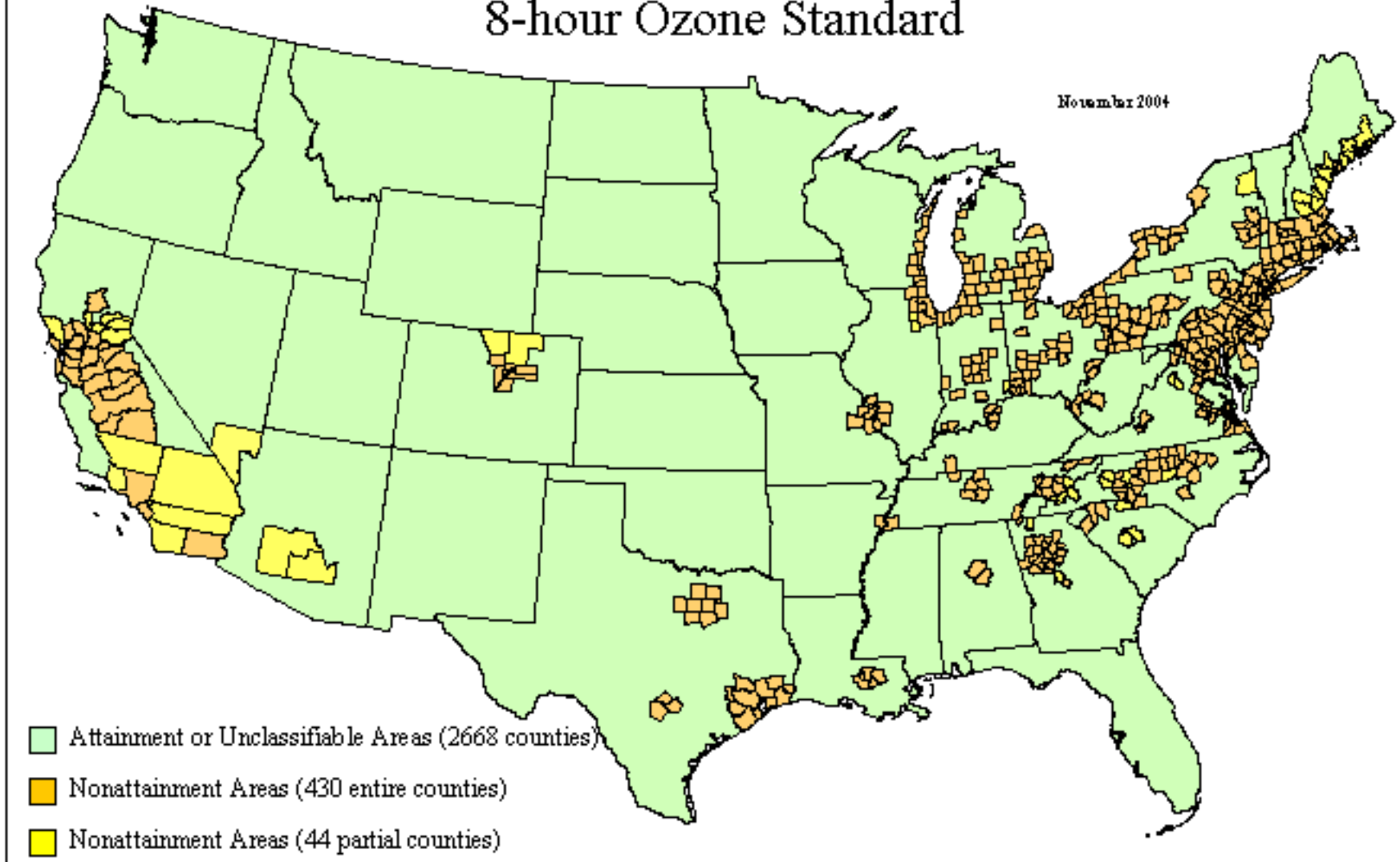
Classification colors are shown for whole counties and denote the highest area classification that the county is in

Counties Designated Nonattainment for PM-2.5

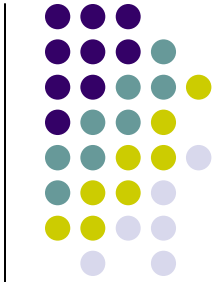


Partial counties are shown as whole counties

Attainment and Nonattainment Areas in the U.S.
8-hour Ozone Standard



Transportation Conformity

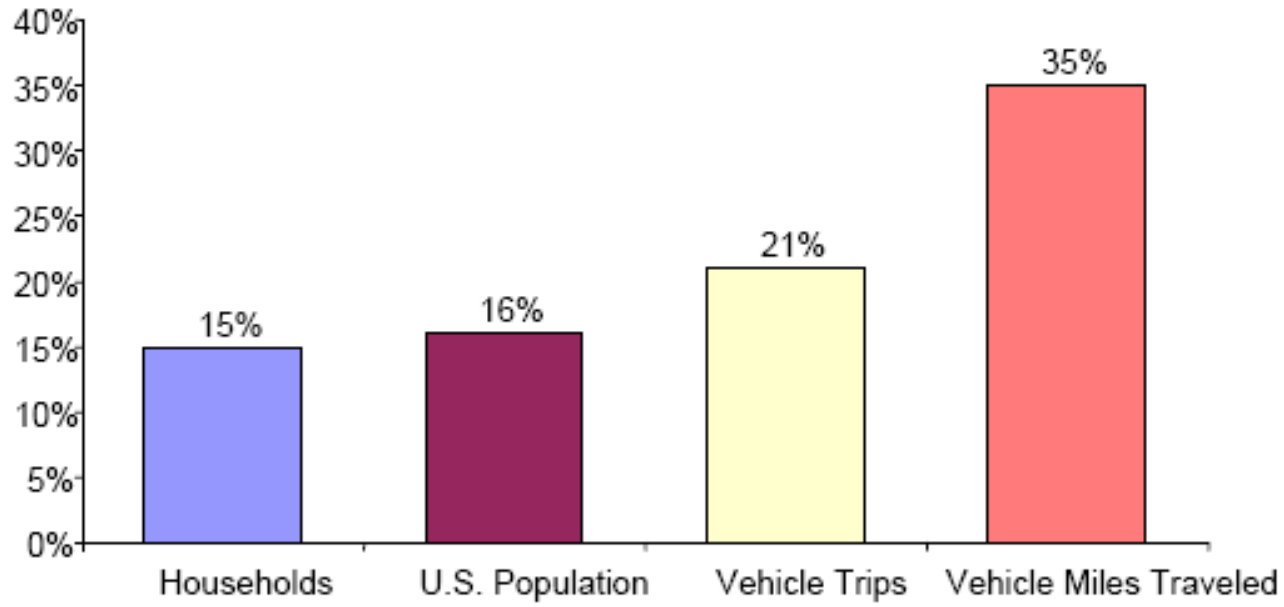


- States with nonattainment areas must draft a plan known as a state implementation plan (SIP) to improve the air quality in nonattainment areas. This regulatory procedure is known as transportation conformity
- Three levels:
  - State level: state implementation plan (SIP) to allocate statewide emissions budgets and outline plans to retain emissions within the budgets
  - County and MPO level: transportation improvement programs (TIP) to demonstrate efforts to reduce transportation emissions
  - Project level: federal or state funded transportation projects must carry out project level environmental impact analysis

Challenge #1:

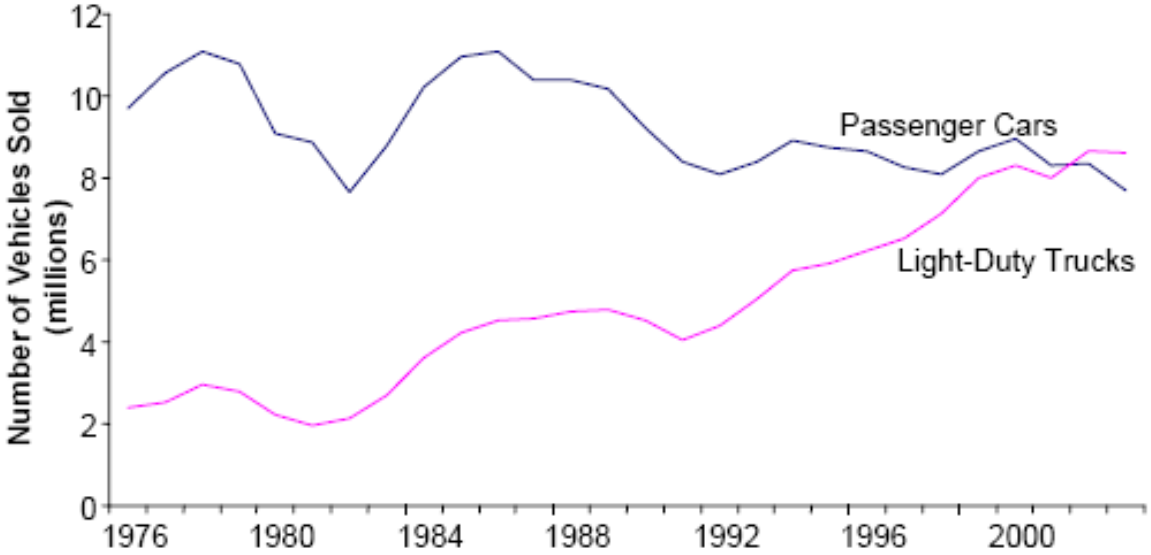
We continue seeing increasing trends in fuel consumption, GHGs and other pollution from transportation sector despite technological advancements, introduction of alternative fuels, and other regulatory efforts.

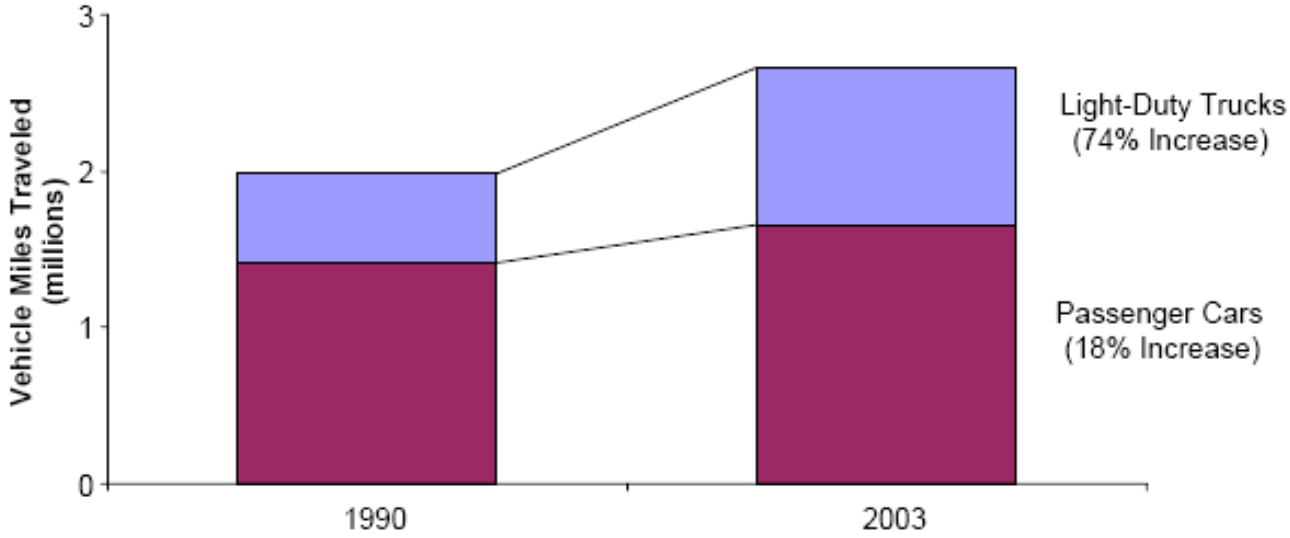
Comparison of Percent Growth of U.S. Population, Households, Vehicle Trips, and Vehicle Miles Traveled by Households, 1990-2001



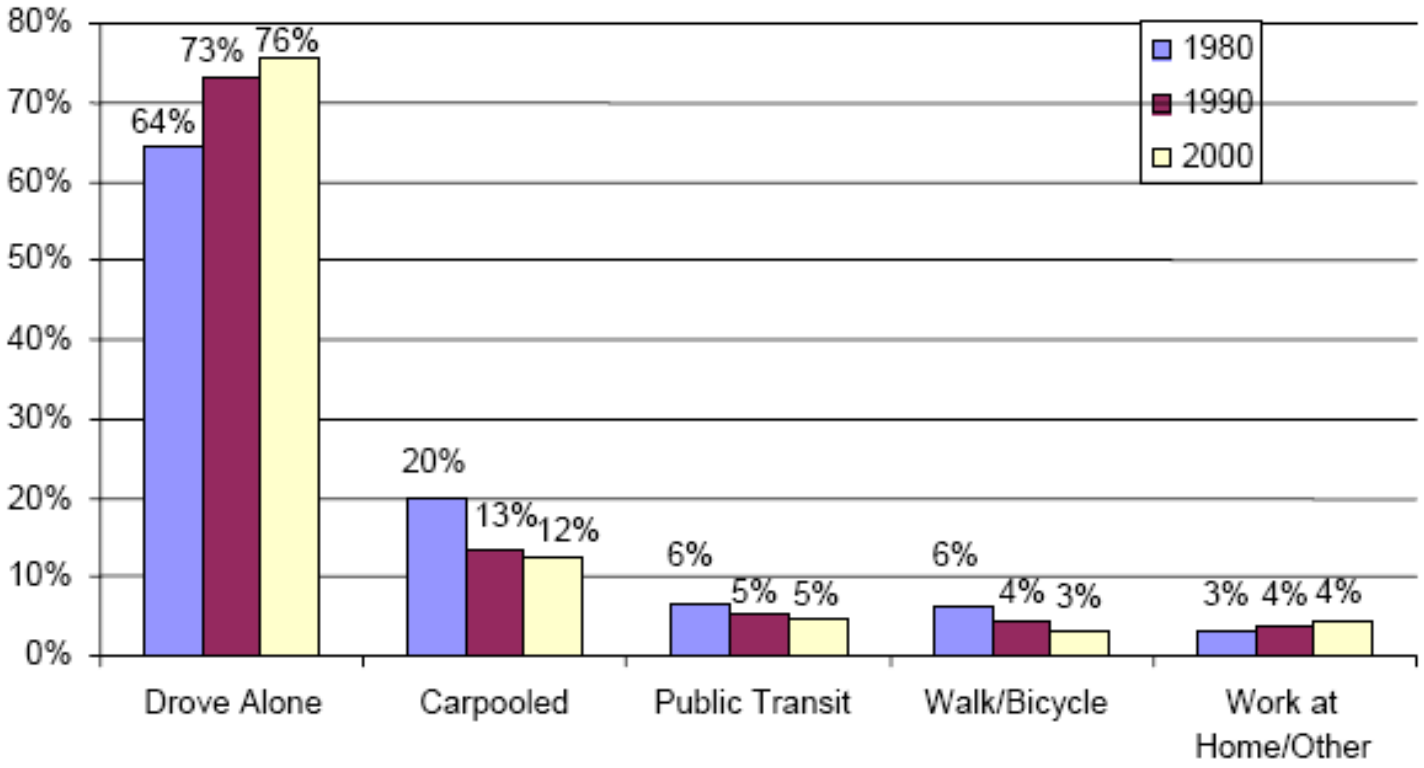
Source: Federal Highway Administration

Number of New LDV Sold, 1976-2003, and VMT Breakdown

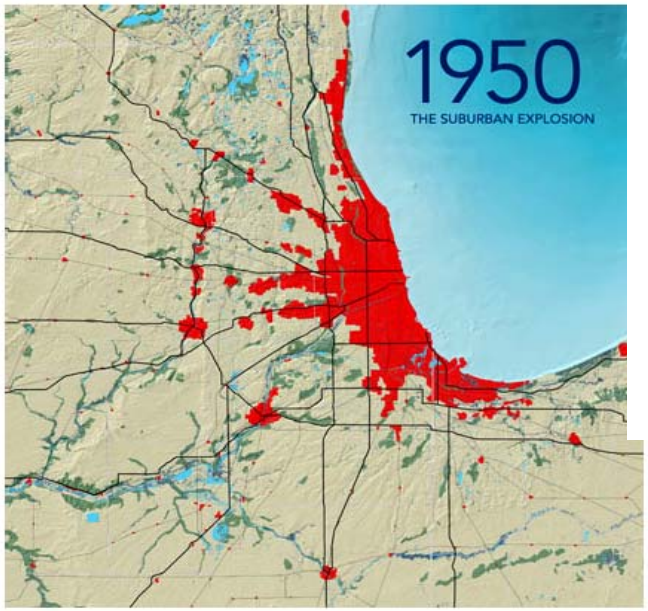




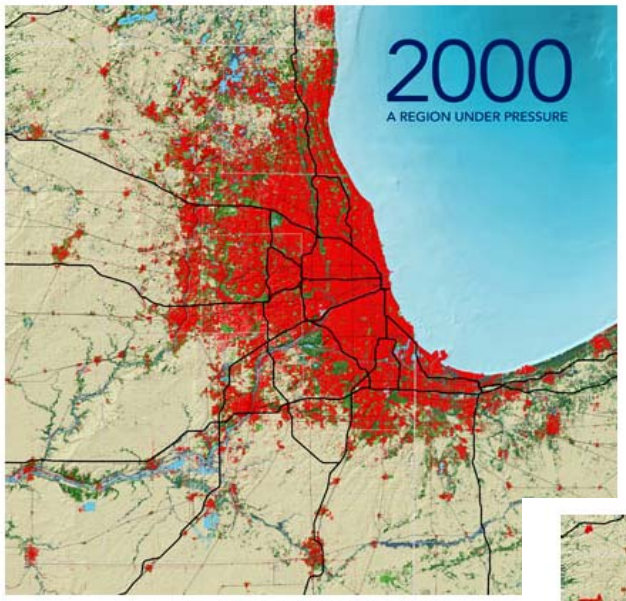
Journey to Work Mode Choice, 1980, 1990 and 2000



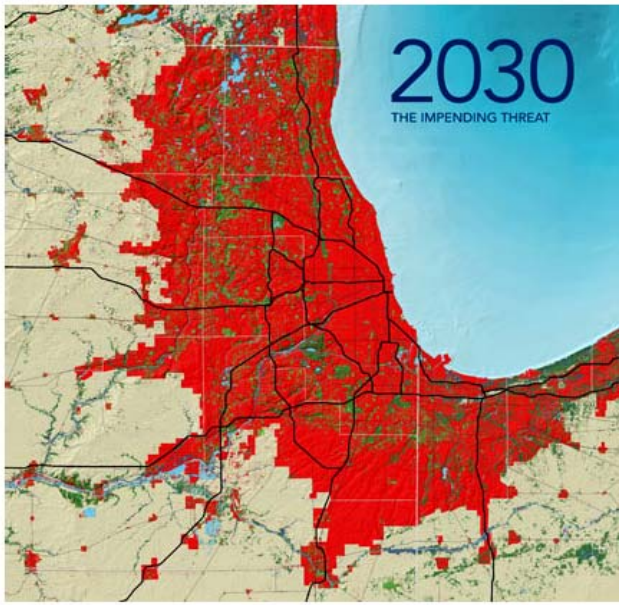
Urban Sprawl Continues



1950: THE EARLY AUTOMOBILE ERA...



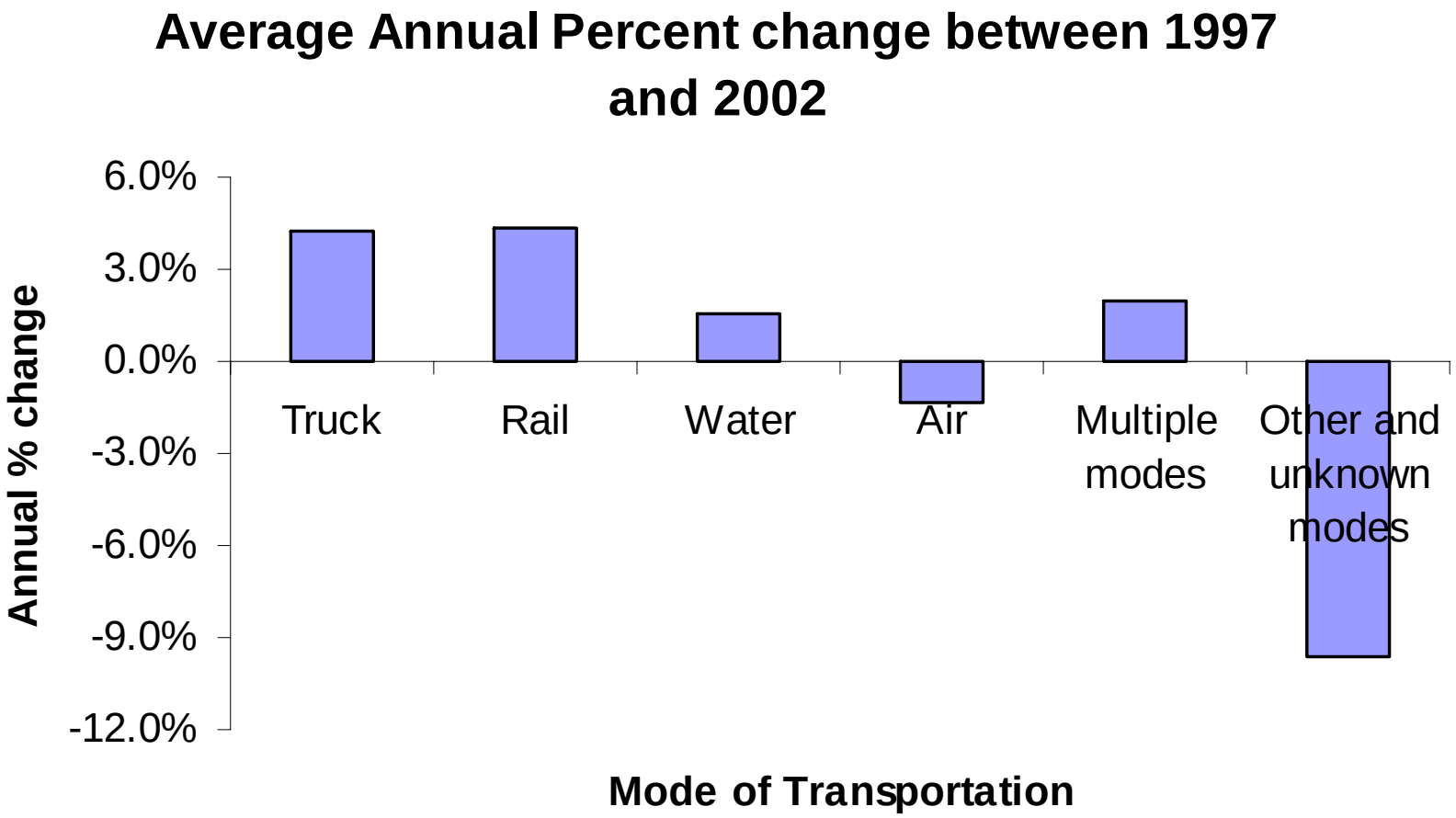
2000: LOW DENSITY DEVELOPMENT...



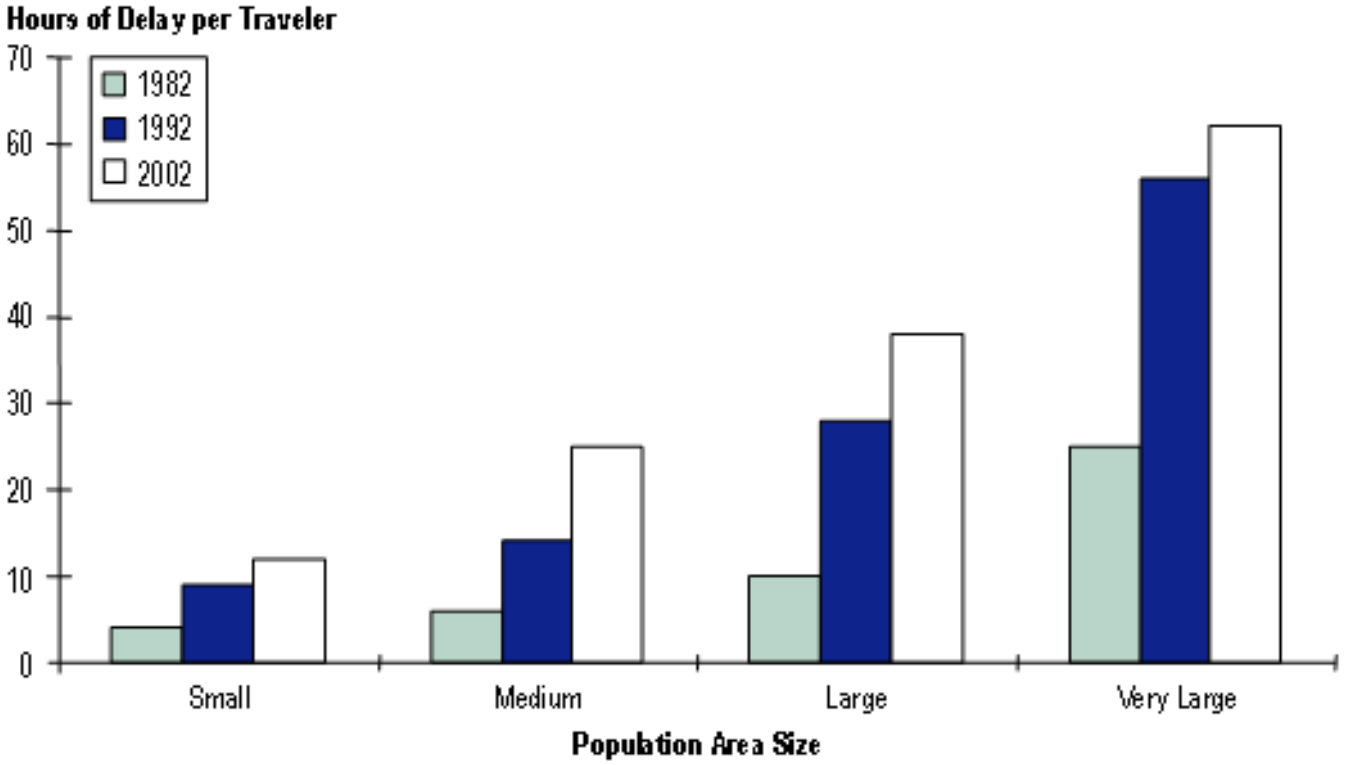
2030: BUSINESS AS USUAL—OR SOMETHING BETTER?...

Source: T. Evans and C. Wheelan, 2005

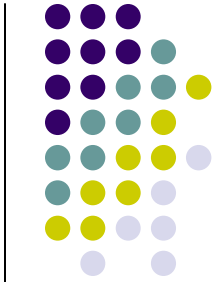
Comparison of Freight Miles Traveled, 1997 and 2002



Congestion Growth in U.S. Cities



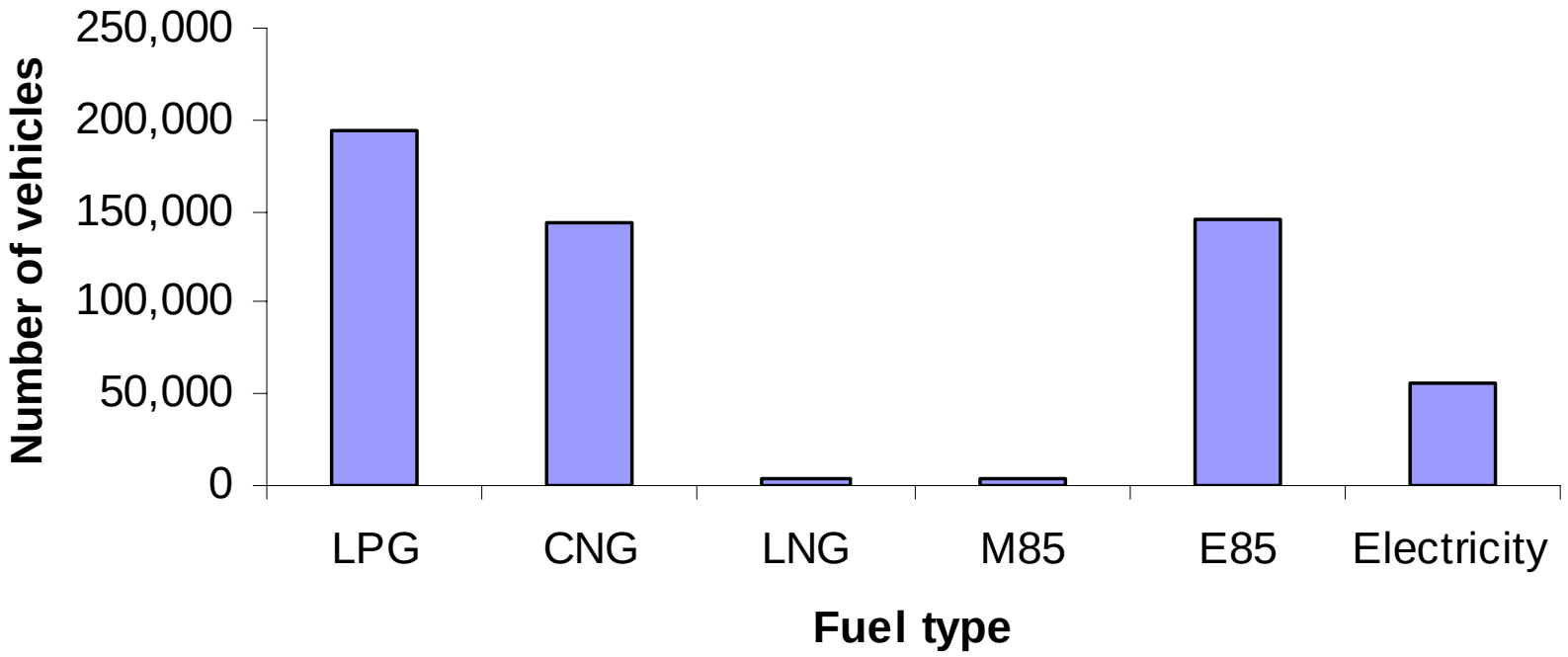
Source: Federal Highway Administration



Challenge #2:

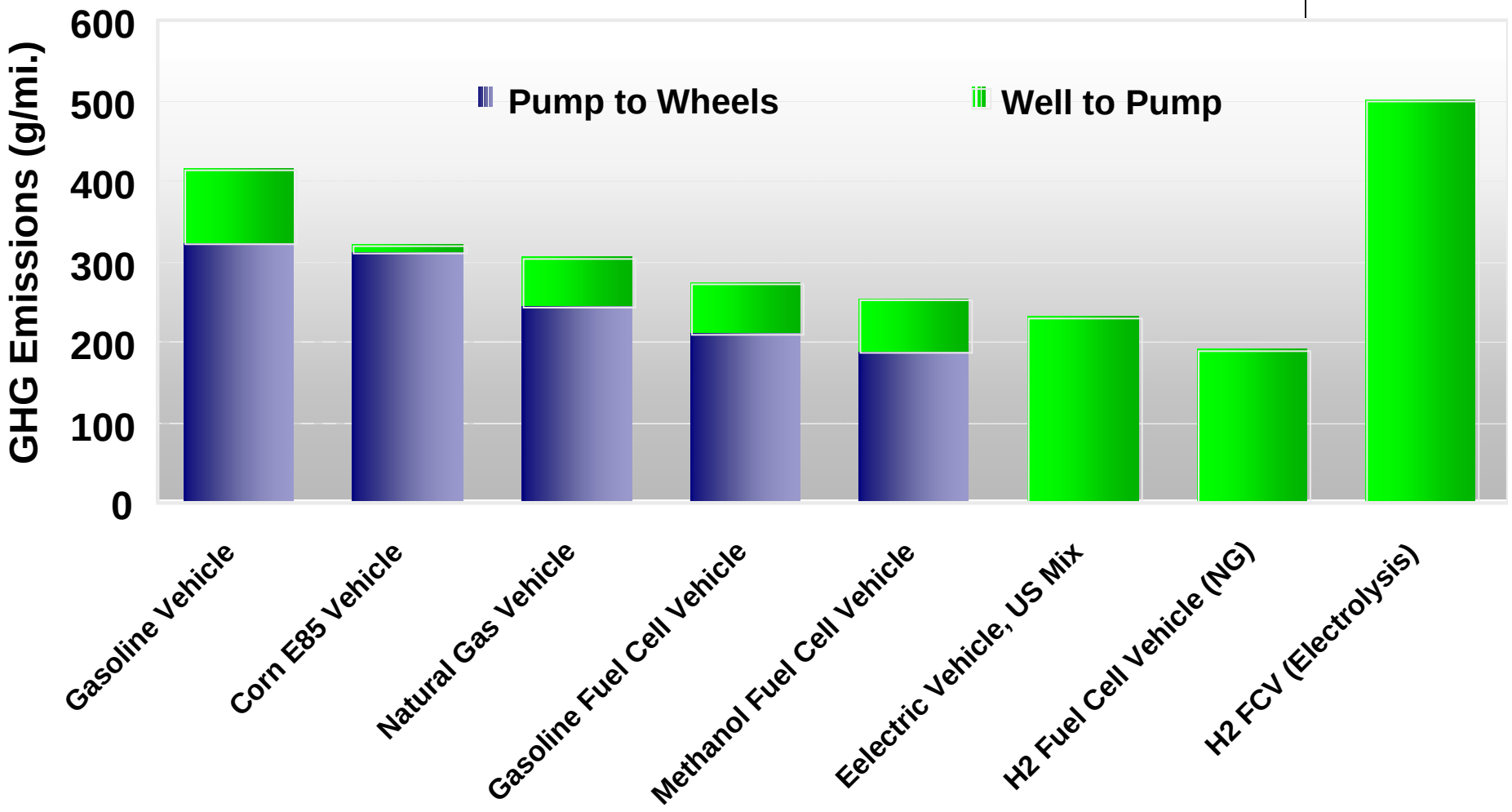
Are renewable alternative fuels the solution? Think again.

Alternative Fuel Vehicles in Use, 2004



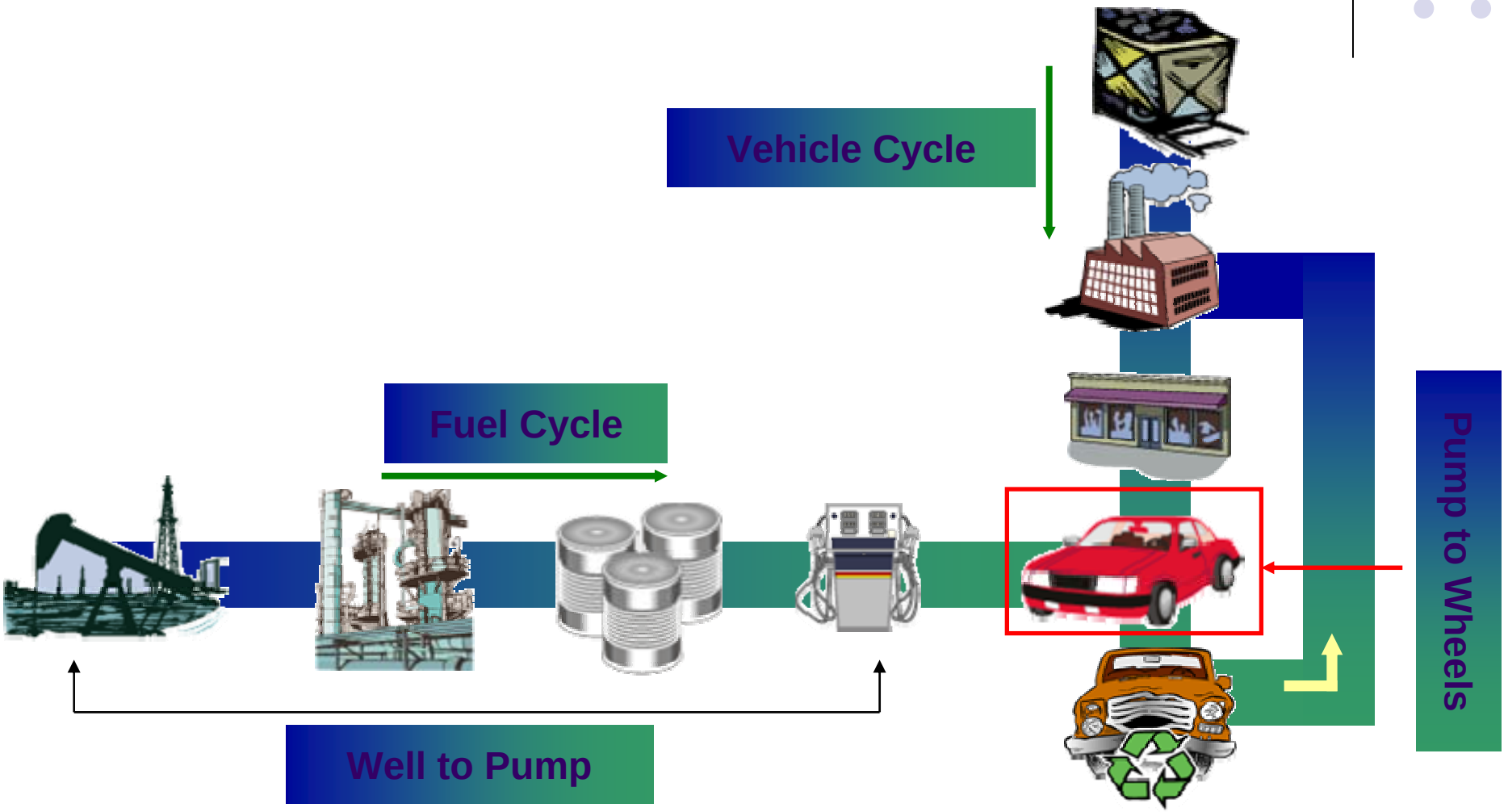
Source: U.S. DOE, 2004

GHGs During Vehicle Operation Stage (Pump to Wheels) – An Illustrative Example



Source: Wang, M. (2006)

Well-to-Wheels (WTW) Analysis: Petroleum-Based Fuels



Life-cycle Analysis

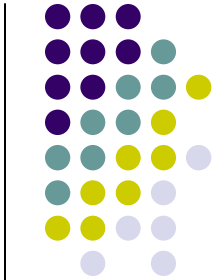
- Well-to-wheels is a life-cycle analysis of the fuel cycle.

- In life-cycle energy analysis, there are three stages
  - Production: “Pathways”
    - raw materials (or feedstocks)
    - Production procedure/technology
  - Distribution:
    - Transportation means
  - End use/consumption
    - Vehicle type/age/technology/operations etc.

Well-to-Pump

Pump-to-Wheels

Take biofuel as an example



- Key issues associated with the WTP stage
  - Nitrogen cycle and N2O conversion of nitrogen fertilizer
    - Energy use in nitrogen fertilizer production
    - Natural gas vs. coal as feedstock
    - Background vs. N fertilizer-induced N2O emissions in fields
  - Farming
    - Crop and biomass yields
    - Energy and chemical inputs
  - Land use changes and resulted CO2 and CH4 emissions

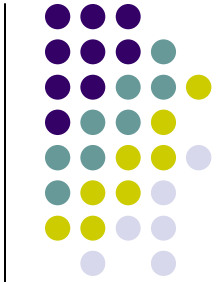
Biofuel-Induced Land Use Change at Global Scale

Change in Land Use by Biofuel Production of 13.4 Billion Gallons in the U.S. and 7.2 Billion Gallons in the EU in 2010

Aggregated Land Use Change (%)	USA	Canada	EU	Brazil	All Others
Coarse Grains	11.2	11.7	0.5	3.7	4.7
Other Grains	-13.5	-2.4	-12.9	-7.8	0.1
Oilseeds	-6.2	13.9	21.4	12.4	5.4
Sugarcane	-5.8	-3.5	-6.1	1.7	-0.9
Livestock	-6.8	-3.8	-6.3	-5.0	-0.9
Forestry	-11.6	-11.1	-16.1	-11.1	-4.3
Other Agri Goods	-6.4	-3.7	-7.1	-5.8	-0.9

From Birur et al. of Purdue University

Summary Remarks

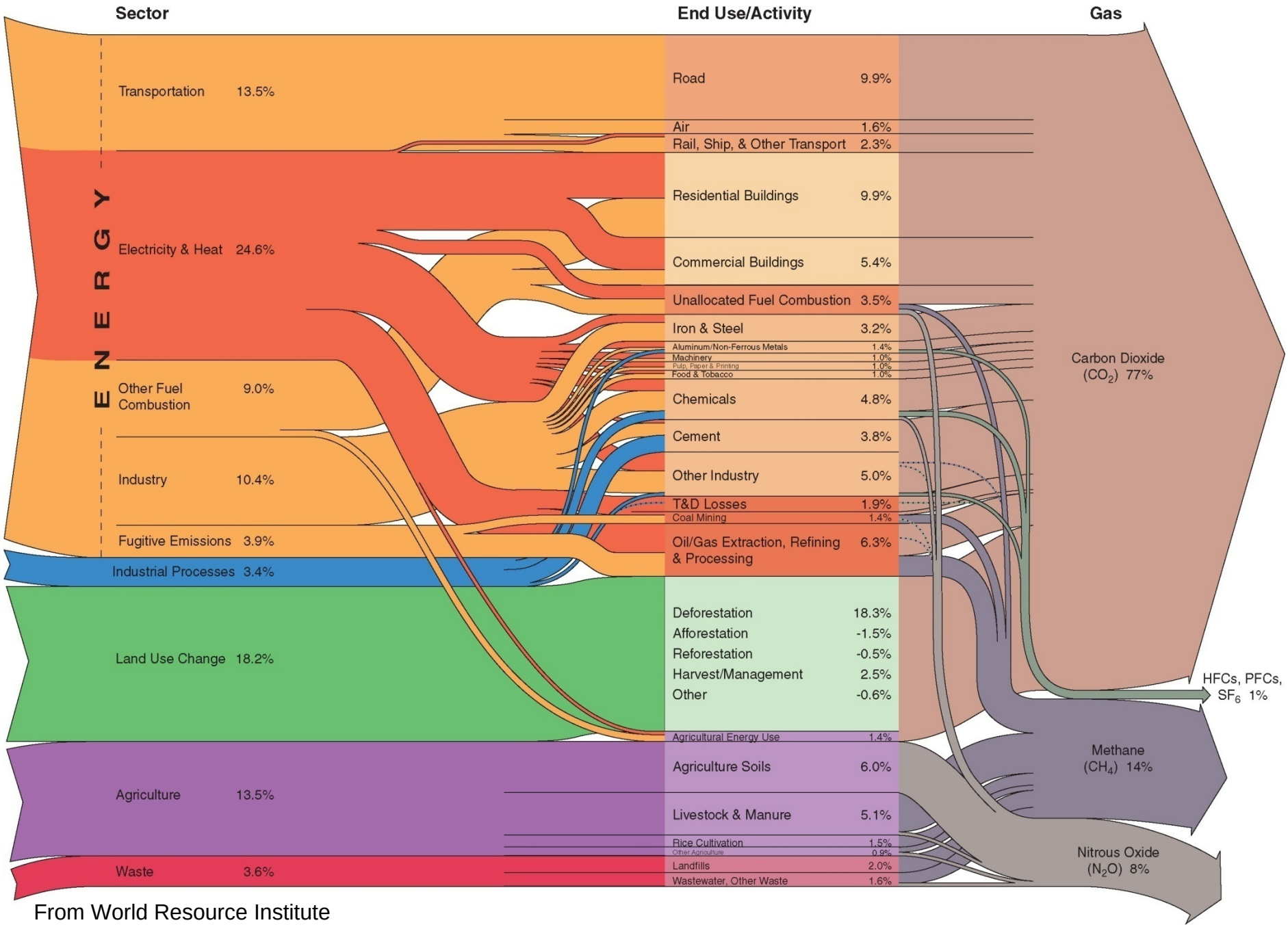


- Transportation is a major contributor to total energy consumption, fossil fuel consumption, GHG emissions and other pollution
- And the trends continue to grow (most of them) despite advanced vehicle technology and regulatory efforts.
- Transportation demand and travel behavior:
  - VMT growth
  - Mode choice
  - Fleet composition shift
  - Freight transportation growth
  - Congestion level
- Urban Sprawl and land use change

Summary Remarks (cont'd)

- Advanced vehicle/fuel technologies could significantly reduce energy use and GHG emissions
- But we need to look at the Life cycles of different fuels to gain a complete picture of the energy flow and GHGs from alternative fules.

Global Greenhouse Gas Emission Flows



From World Resource Institute