

The Geography of Transport Systems

FIFTH EDITION

Jean-Paul Rodrigue

Transport, Energy and Environment

CHAPTER 4

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Jean-Paul.Rodrigue@hofstra.edu

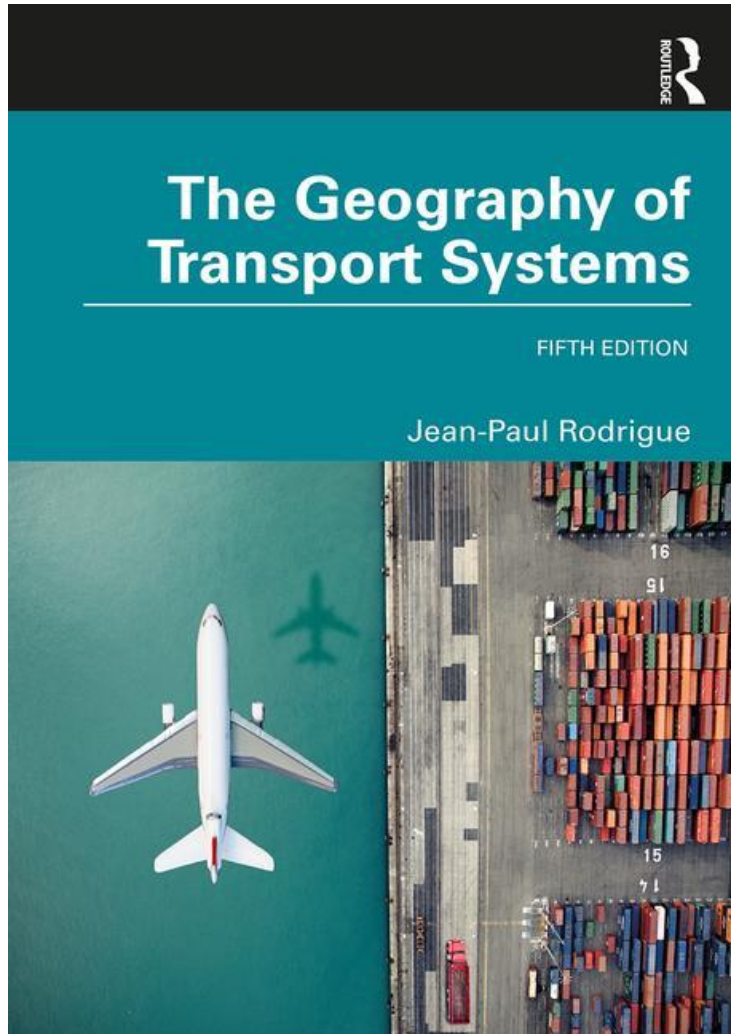
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Table of Contents

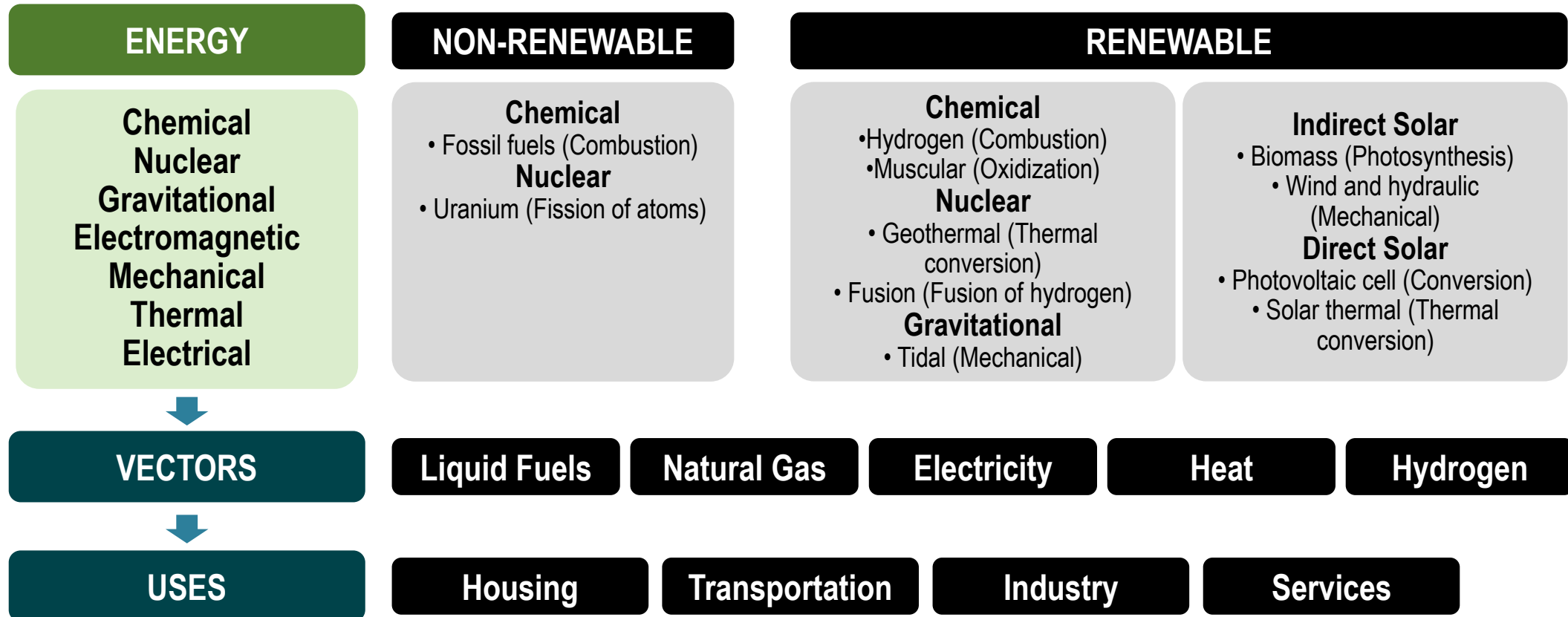
- 4.1 – Transportation and Energy
- 4.2 – Transportation and the Environment
- 4.3 – The Environmental Footprint of Transportation
- 4.4 – Transportation, Sustainability and Decarbonization



Transportation and Energy

Chapter 4.1

Sources of Energy



Energy and Work

Modification of the Environment

- Making space suitable for human activities (20% of electricity in the US used for AC).
- Clearing land for agriculture.
- Modifying the hydrography (irrigation).
- Establishing distribution infrastructures (roads).
- Constructing and conditioning (temperature and light) enclosed structures.

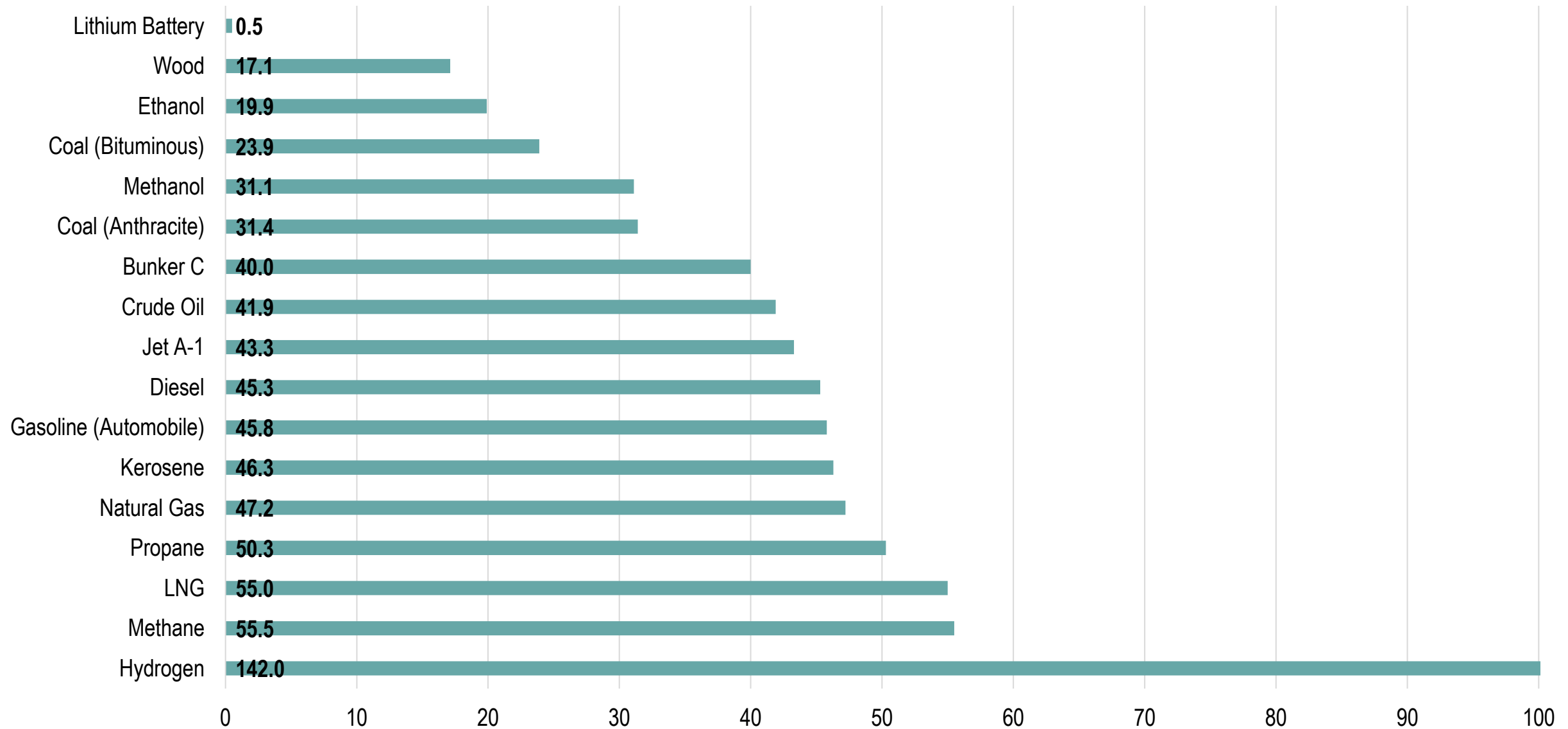
Appropriation and Processing

- Extraction of resources (agricultural products and raw materials).
- Modifying resources (manufacturing).
- Disposal of wastes (Piling, decontaminating and burning).

Transfer

- Movements of freight, people and information.
- Attenuate the spatial inequities in the location of resources by overcoming distance.
- Growing share of transportation in the total energy spent.

Chemical Energy Content of some Fuels (in MJ/kg)



Fuels Production Processes

Fuel	Sources	Process
Liquid petroleum fuels (gasoline, diesel, kerosene, jet fuel, bunker fuel)	Conventional oil fields (ground and shore-based). Non-conventional sources (tar sands)	Refining
Liquid synthetic fuels	Natural gas, coal	Gasification
Biodiesel	Oil seed crops	Esterification, hydrogenation
Ethanol	Grain crops	Saccharification and distillation
	Sugar crops (cane)	Distillation
Advanced biodiesel	Biomass from crops or waste products	Gasification
Compressed natural gas (CNG)	Natural gas	Gasification
Electricity	Coal, gas, petroleum, nuclear, renewables (hydro, wind)	Electric generator (source dependent)
Hydrogen	Natural gas	Reforming, compression
	Electricity	Electrolysis
	Direct production using other sources	High temperature process

Energy Sources Used for Transportation

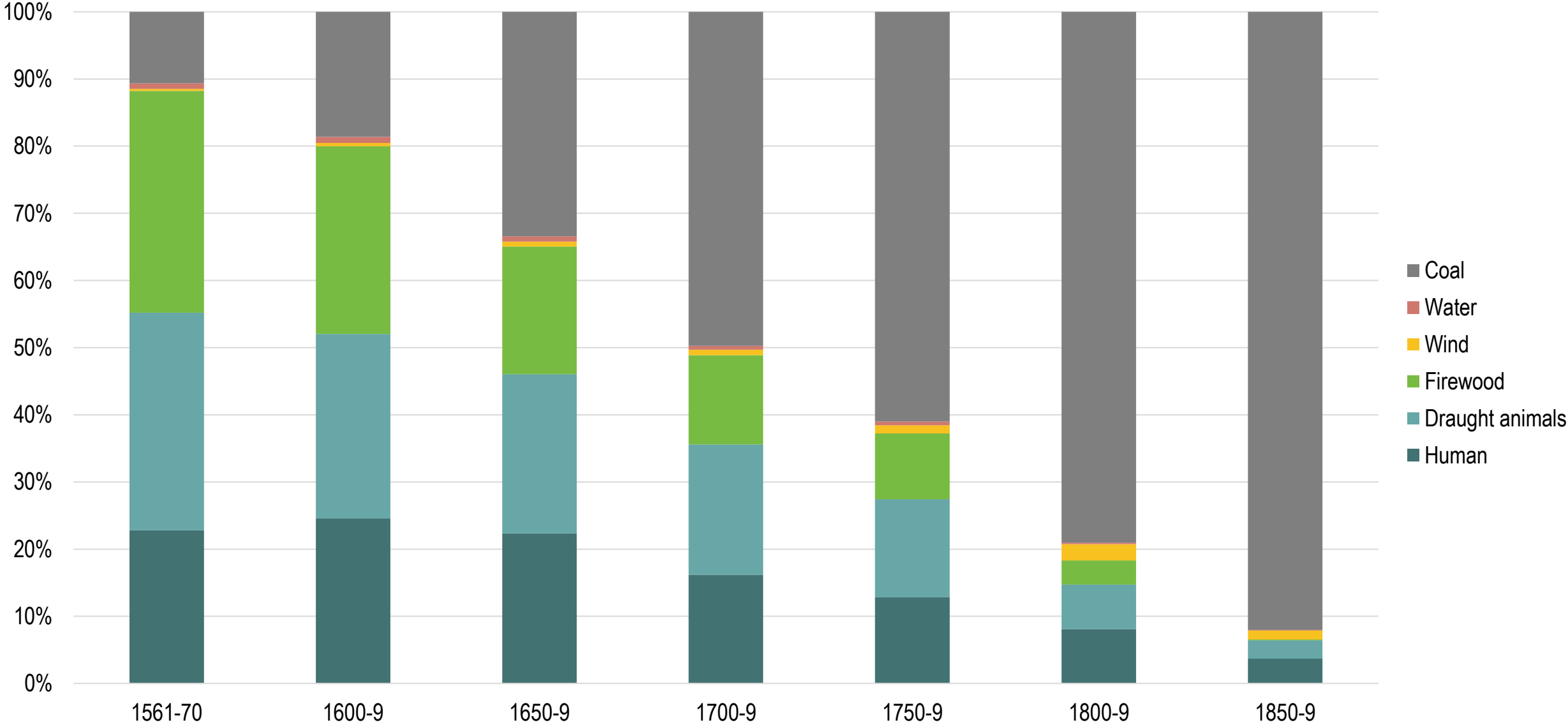
- Muscular
- Wind
- Gravity
- Fossil fuels
- Electricity
- Biofuels

- Engine
 - ICE
 - Steam engine / turbine
 - Electric motor
 - Fuel cells

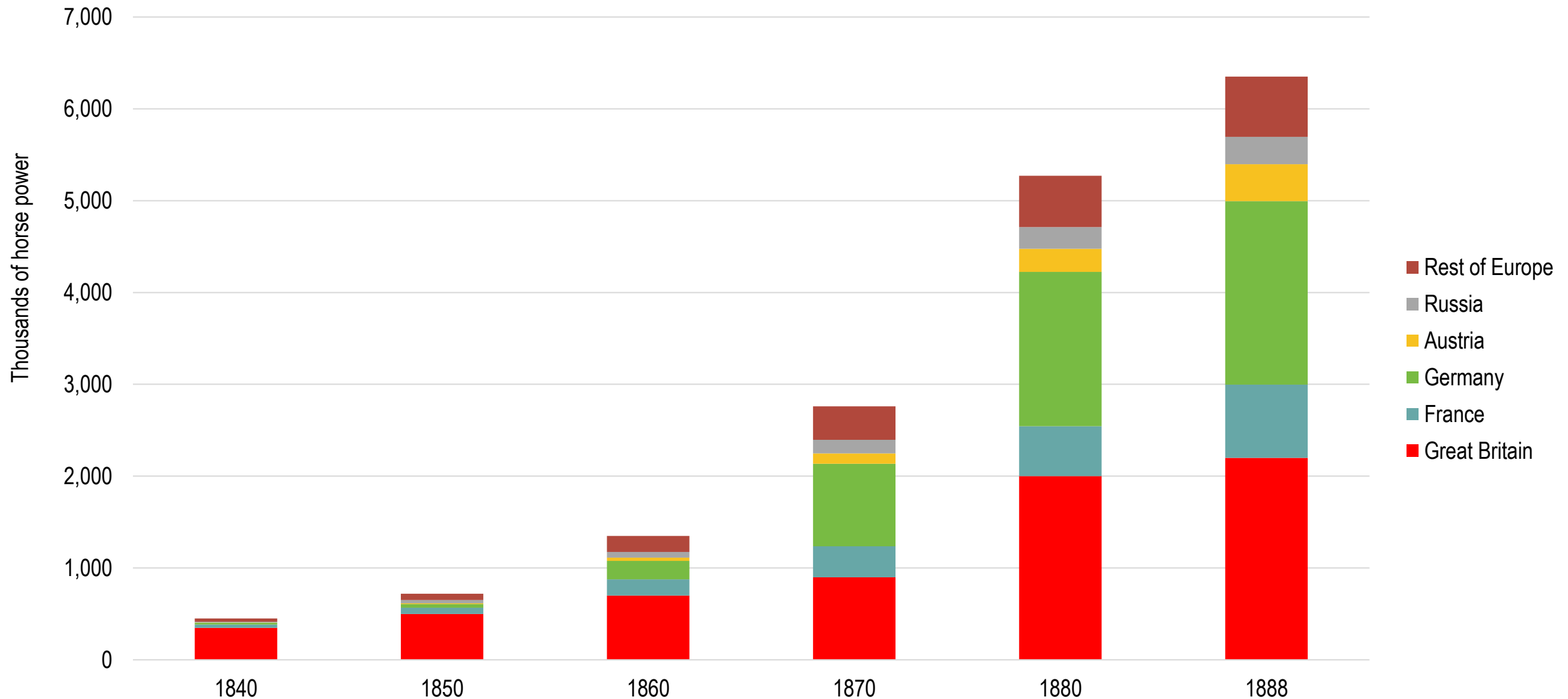
Alternative Sources of Energy for Transportation

Source	Advantages	Drawbacks
Biodiesel	Renewable; biodegradable; domestically produced; improved lubricity in engine; reduced air pollutant emissions.	May congeal at low temperatures; may damage engine components; lower fuel economy; non-renewable fuels are used in production; limited availability; may increase nitrous oxide emissions.
Ethanol	Renewable; domestically produced; may reduce harmful air pollutants.	Non-renewable fossil fuels are used in its production; slightly decreases fuel economy.
Natural gas / propane	Reduced air pollutant emissions.	Non-renewable fossil fuel; reduced driving range; limited availability; larger fuel tanks.
Electricity	Zero tailpipe emissions; widely available.	High vehicle and battery costs; limited range and performance; electricity production mainly from non-renewable sources.
Hybrid electric	Increased fuel economy and reduced pollution; good range and performance	Primarily fueled with non-renewable fossil fuels.
Synthetic fuels	Abundant supply exists.	Significant environmental damages from extraction and processing; high carbon emissions; high production costs.
Hydrogen	Zero tailpipe emissions.	Potential use of fossil fuels to produce; high cost of vehicle.

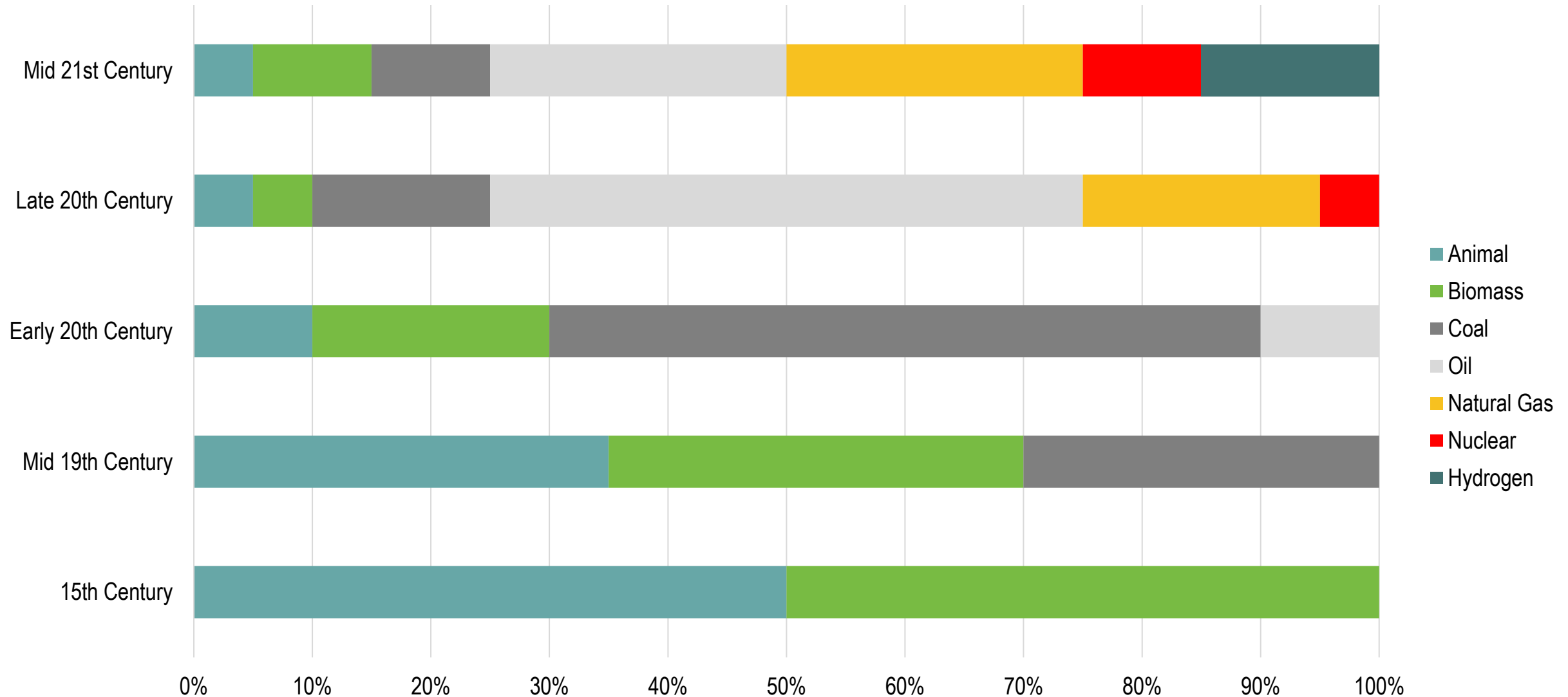
Annual Energy Consumption in England and Wales, 1560s to 1850s (MJ)



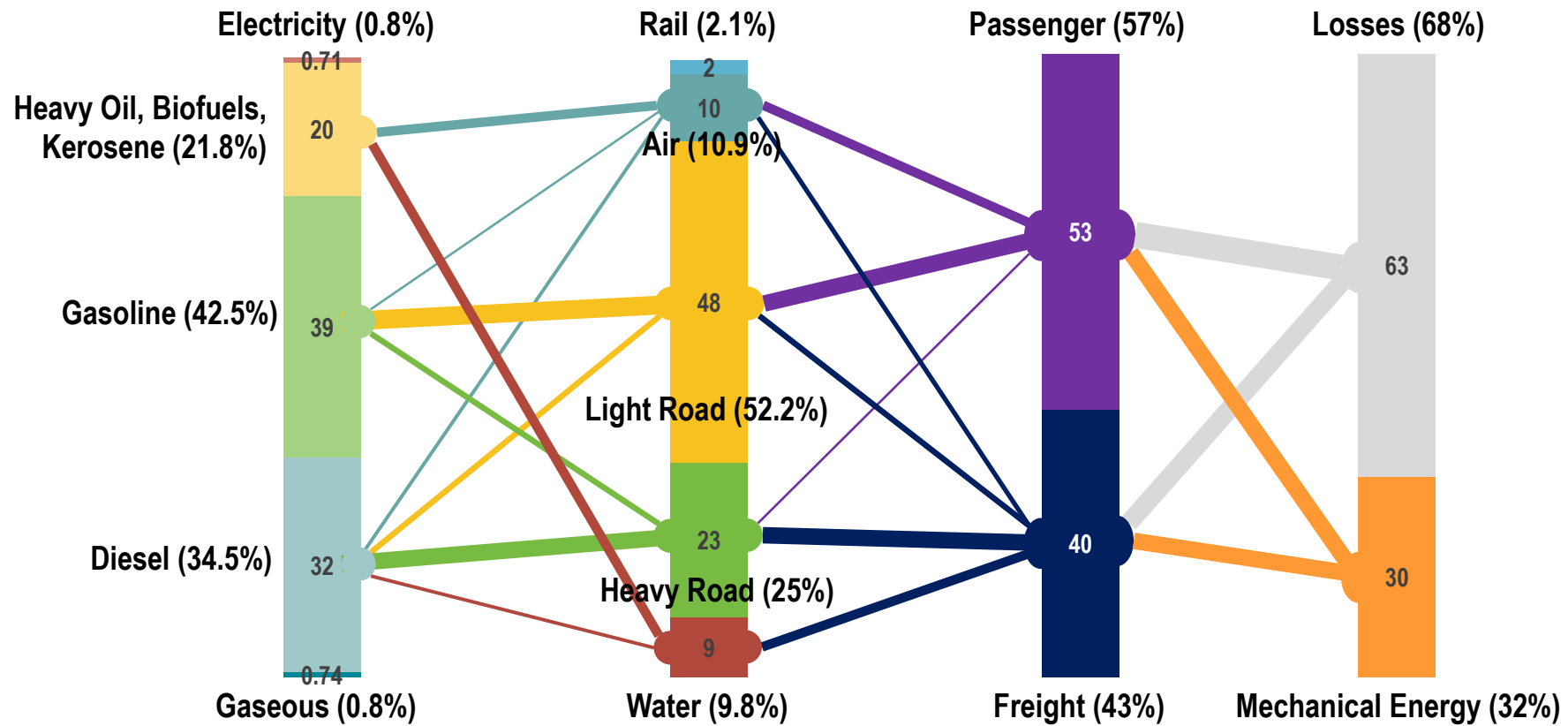
Power Generated by Steam Machines, Europe, 1840-1888



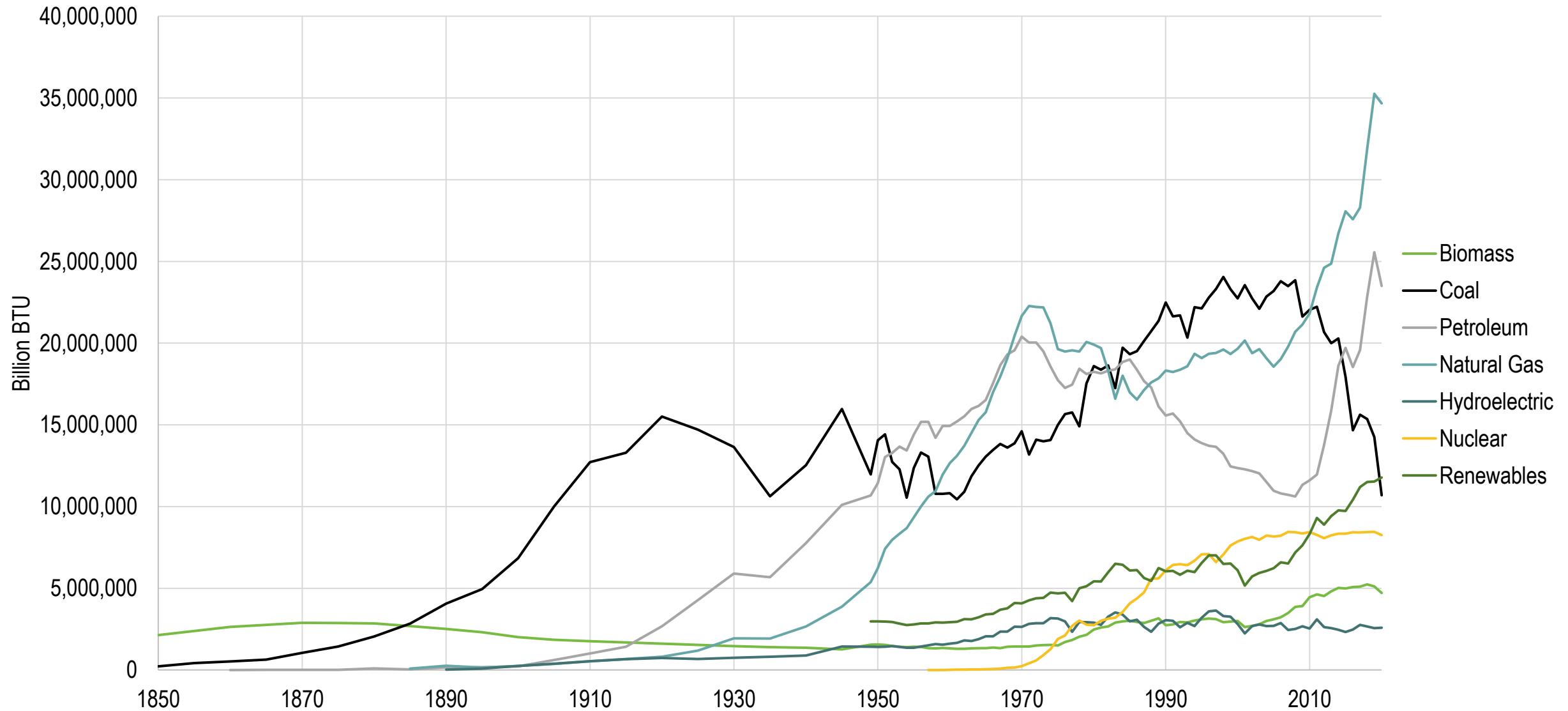
Evolution of Energy Sources



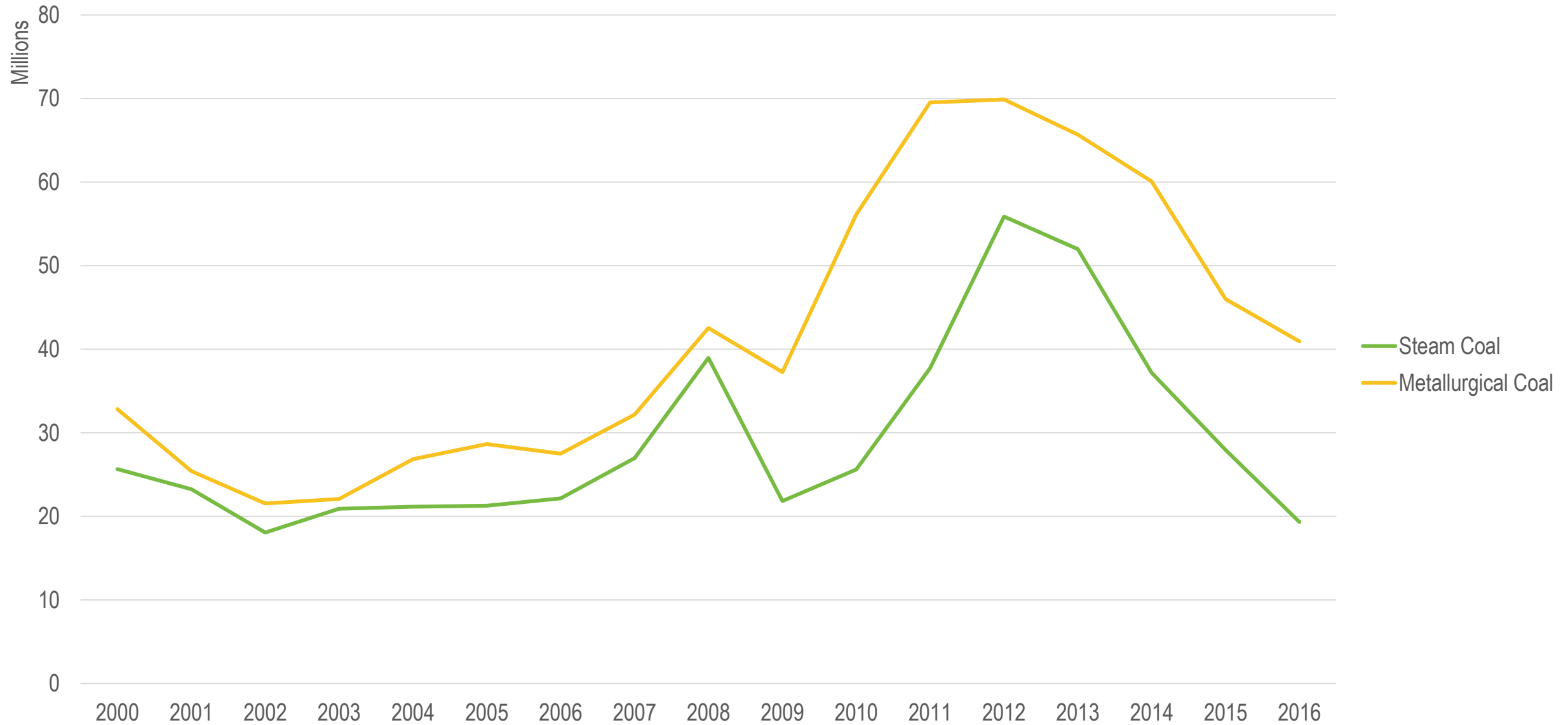
Final Energy Consumption by Fuel Type by Transport Sector (in Exajoules)



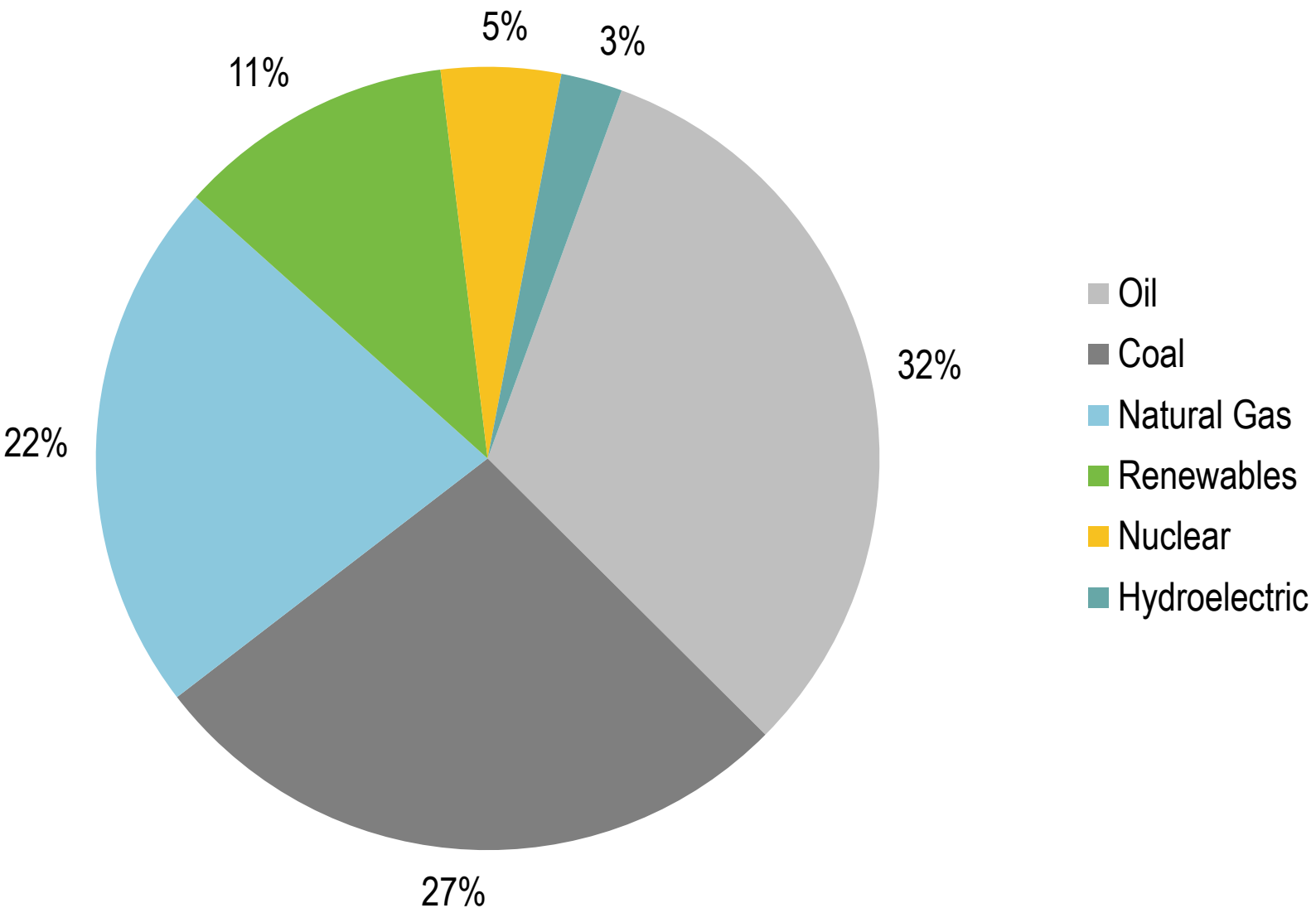
Primary Energy Production by Source, United States, 1850-2020



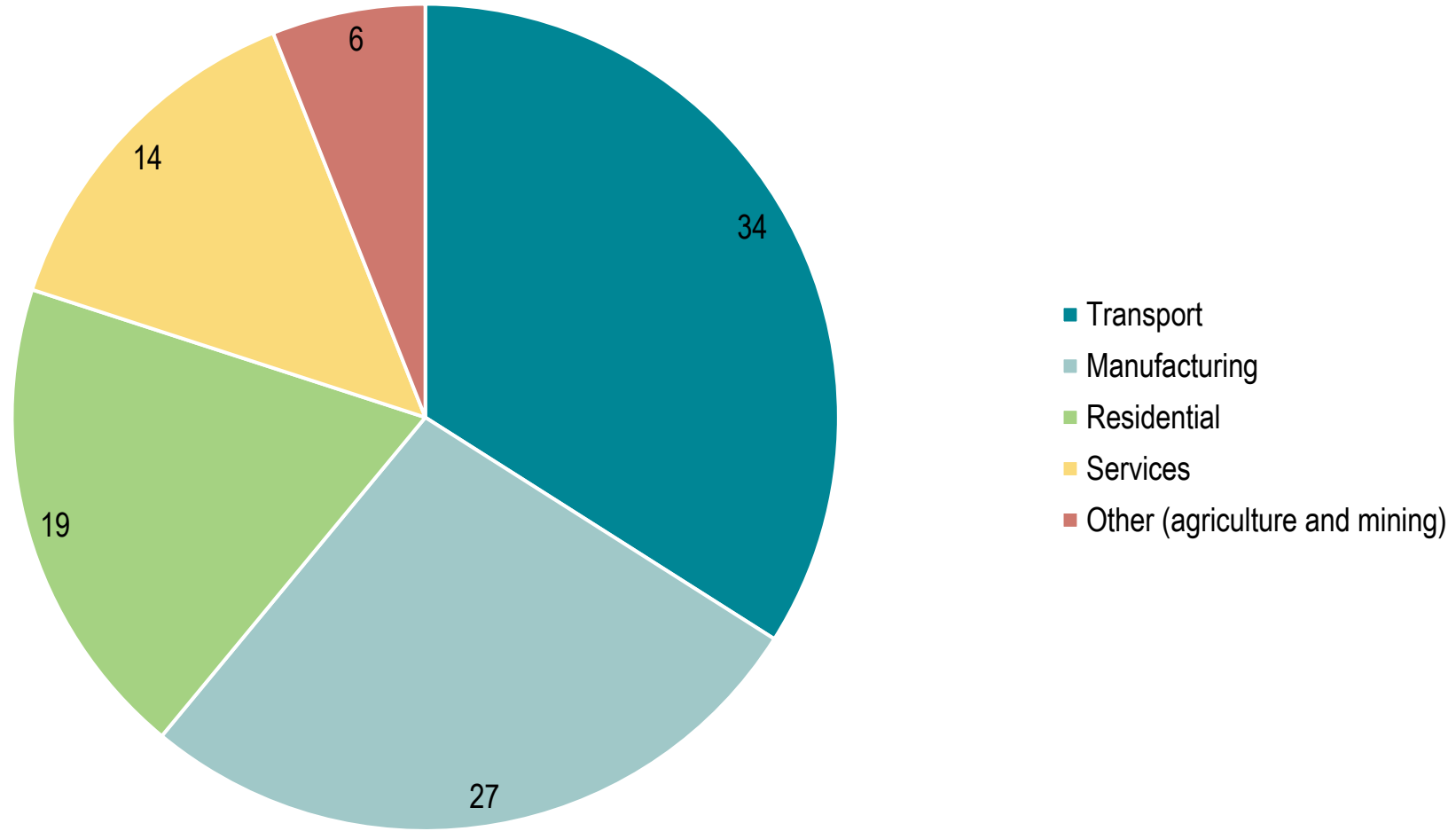
US Coal Exports in Tons, 2000-2016



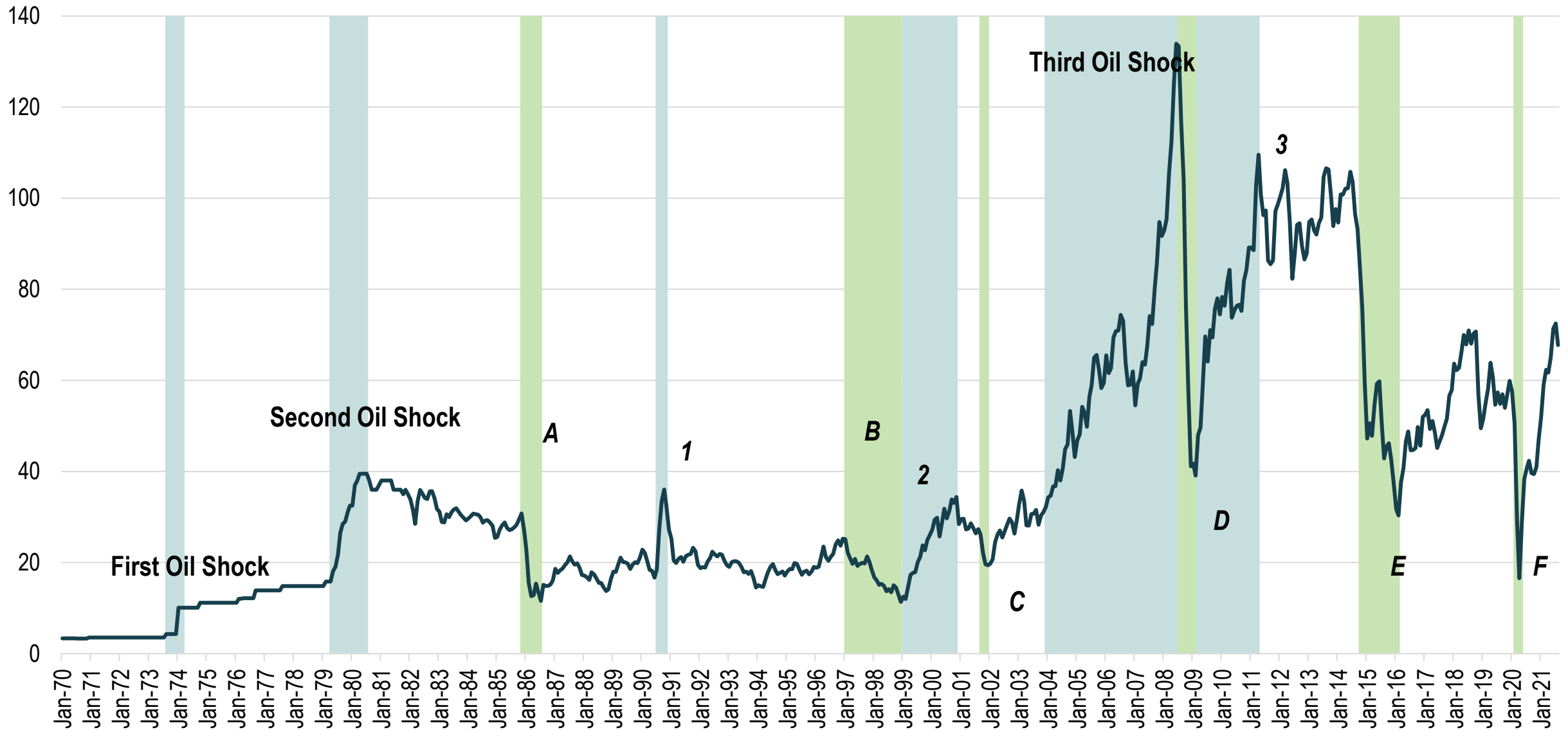
World Energy Production (in Million tons oil equivalent), 2016



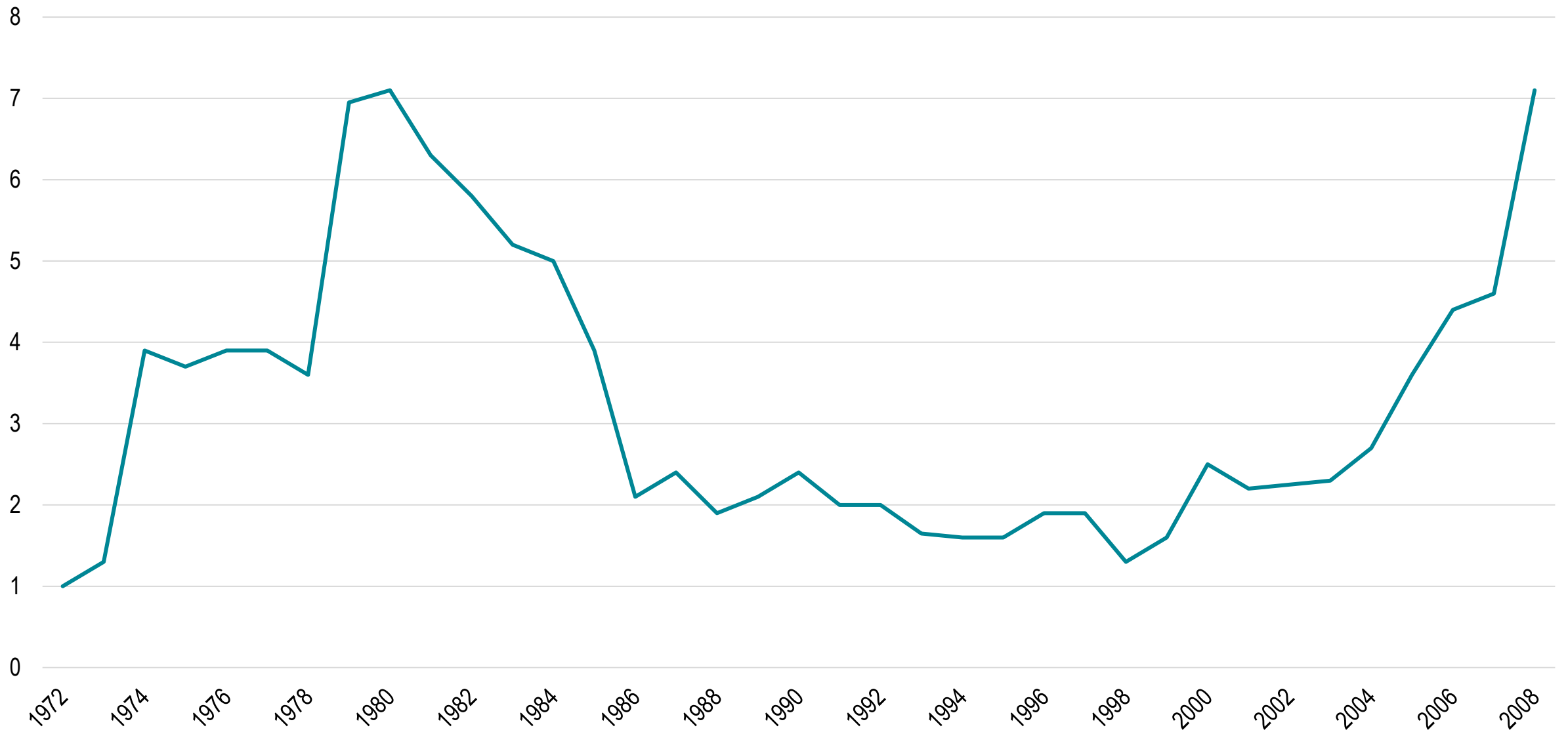
Energy End Uses, 2014



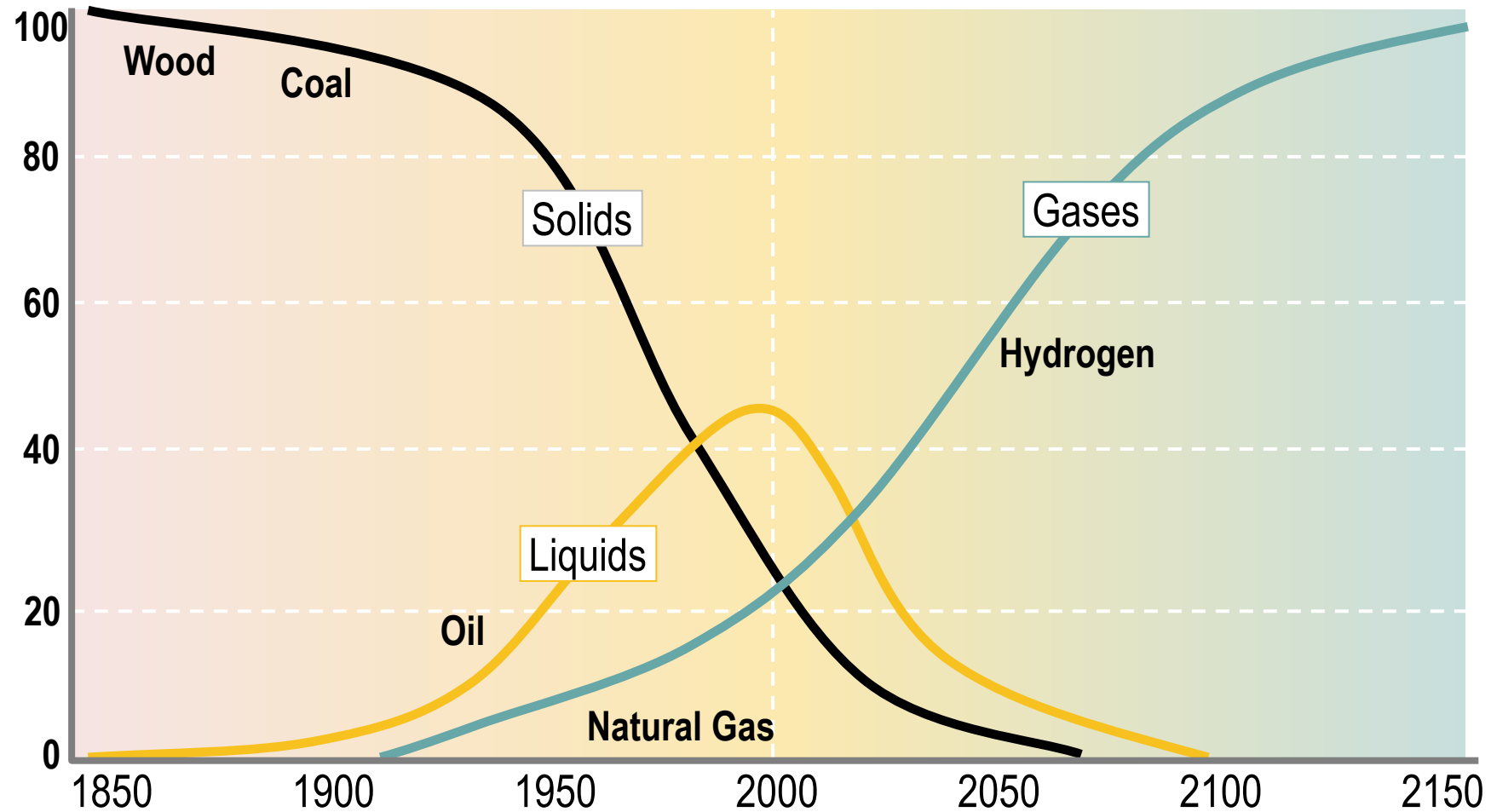
West Texas Intermediate, Monthly Nominal Spot Oil Price (1970-2021)



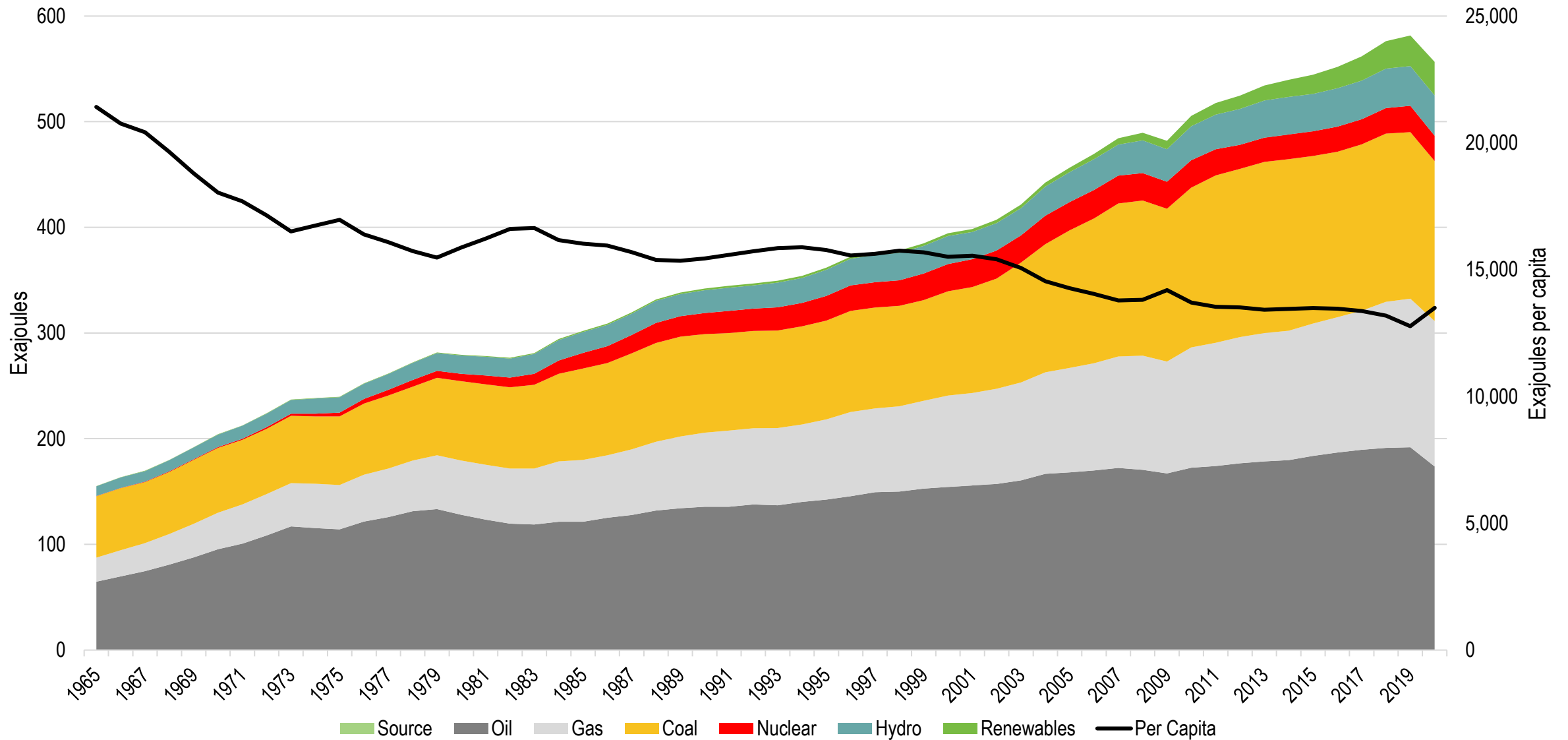
World Oil Expenditures as % of GDP, 1972-2008



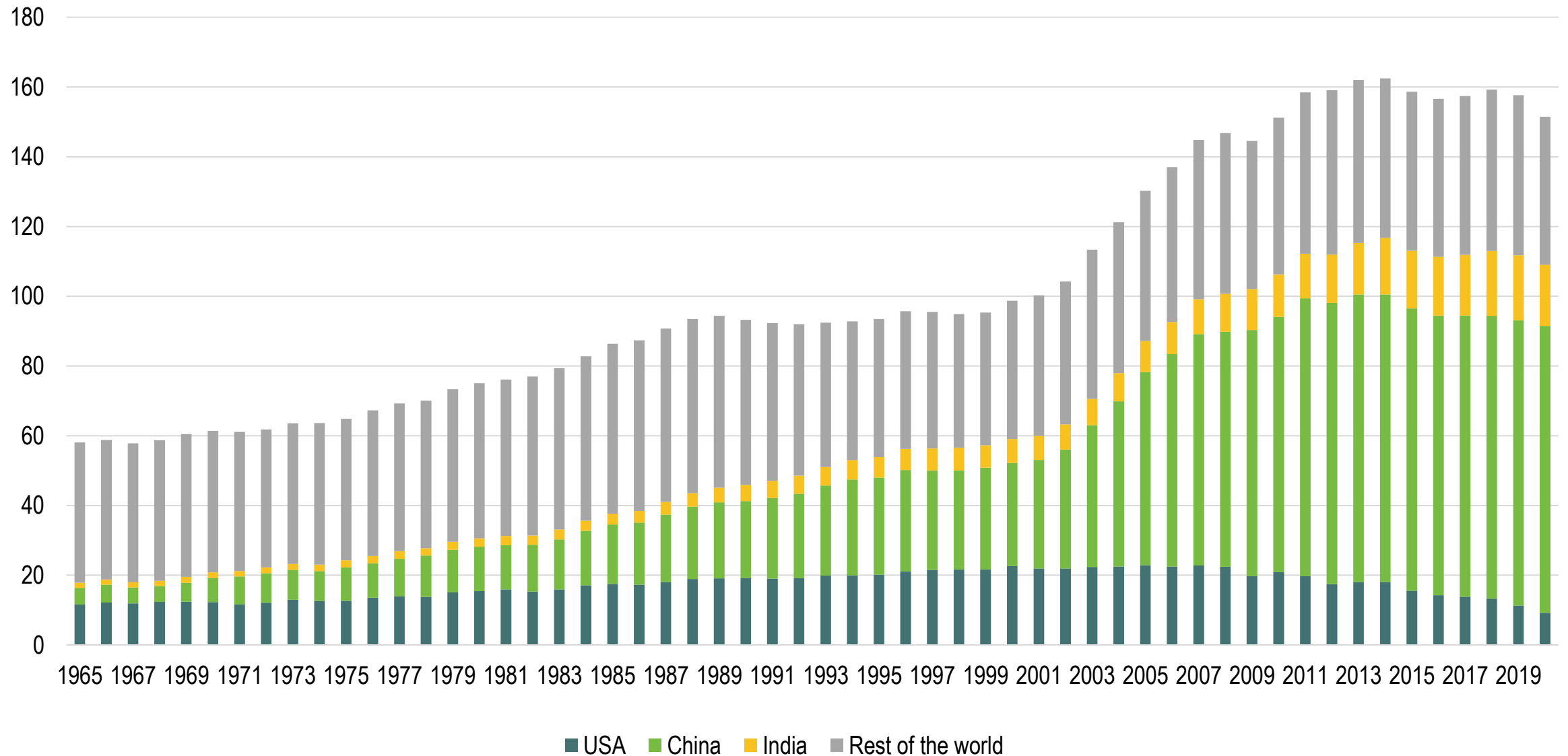
Global Energy Systems Transition, (% of market)



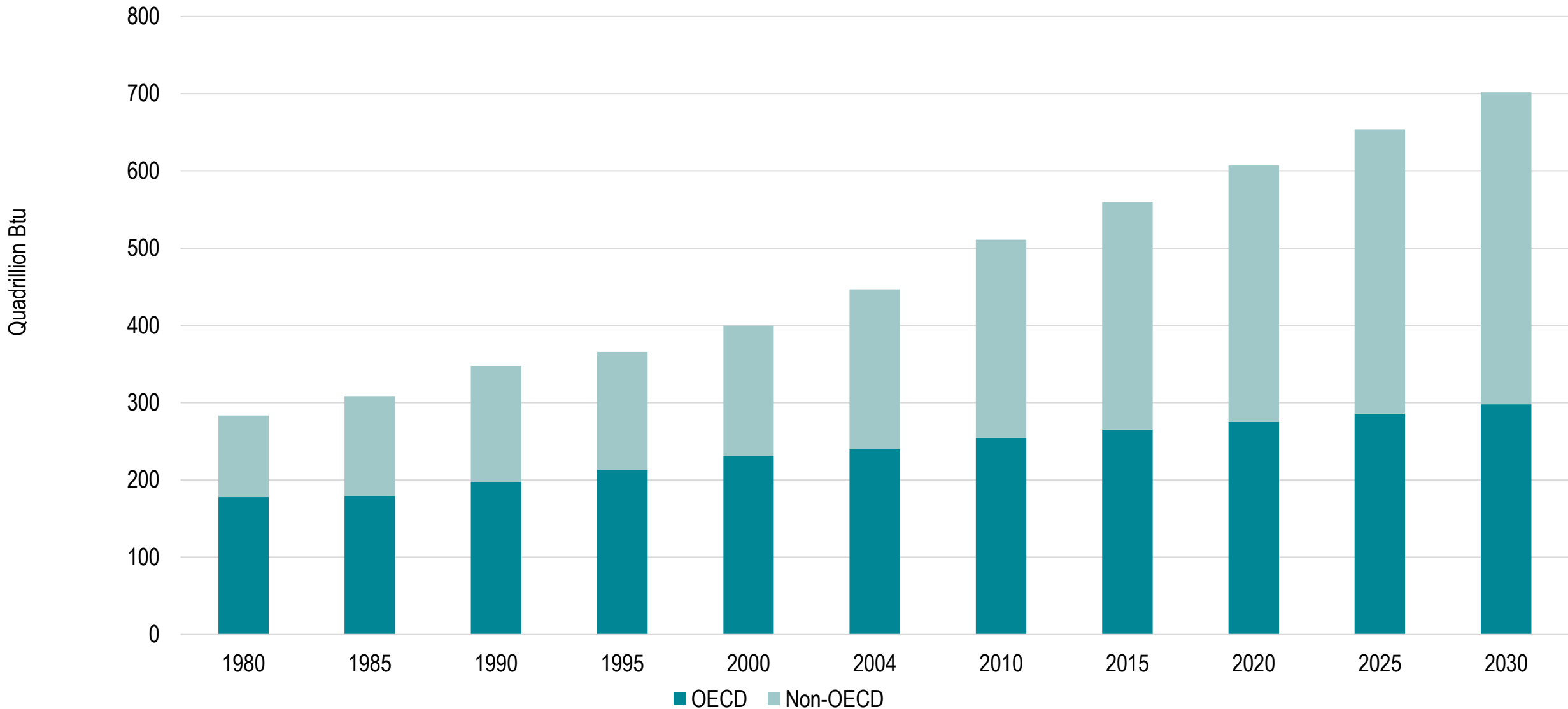
World Energy Consumption, 1965-2020



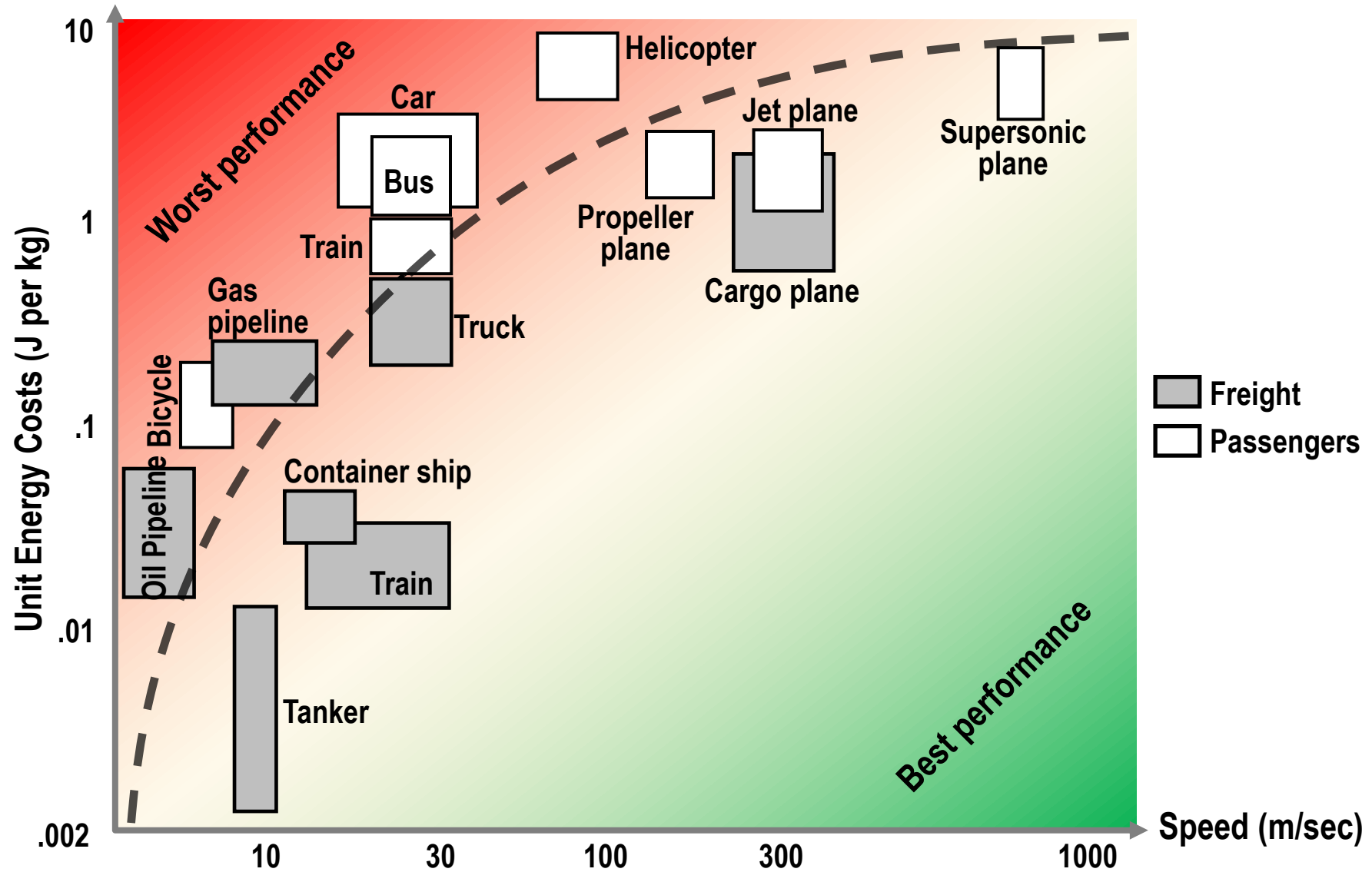
Coal Consumption, 1965-2020 (in Exajoules)



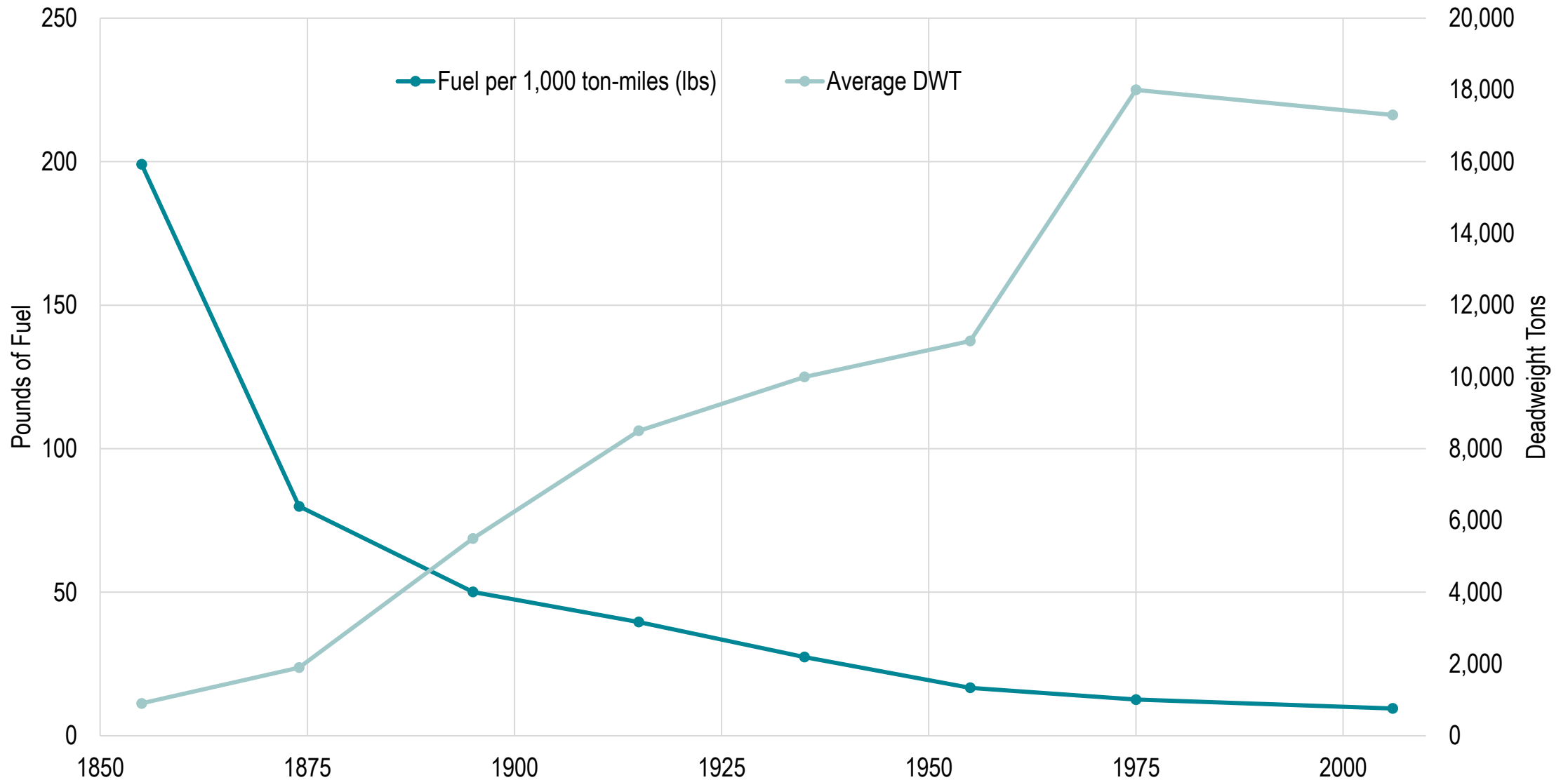
World Marketed Energy Consumption by Region, 1980-2030



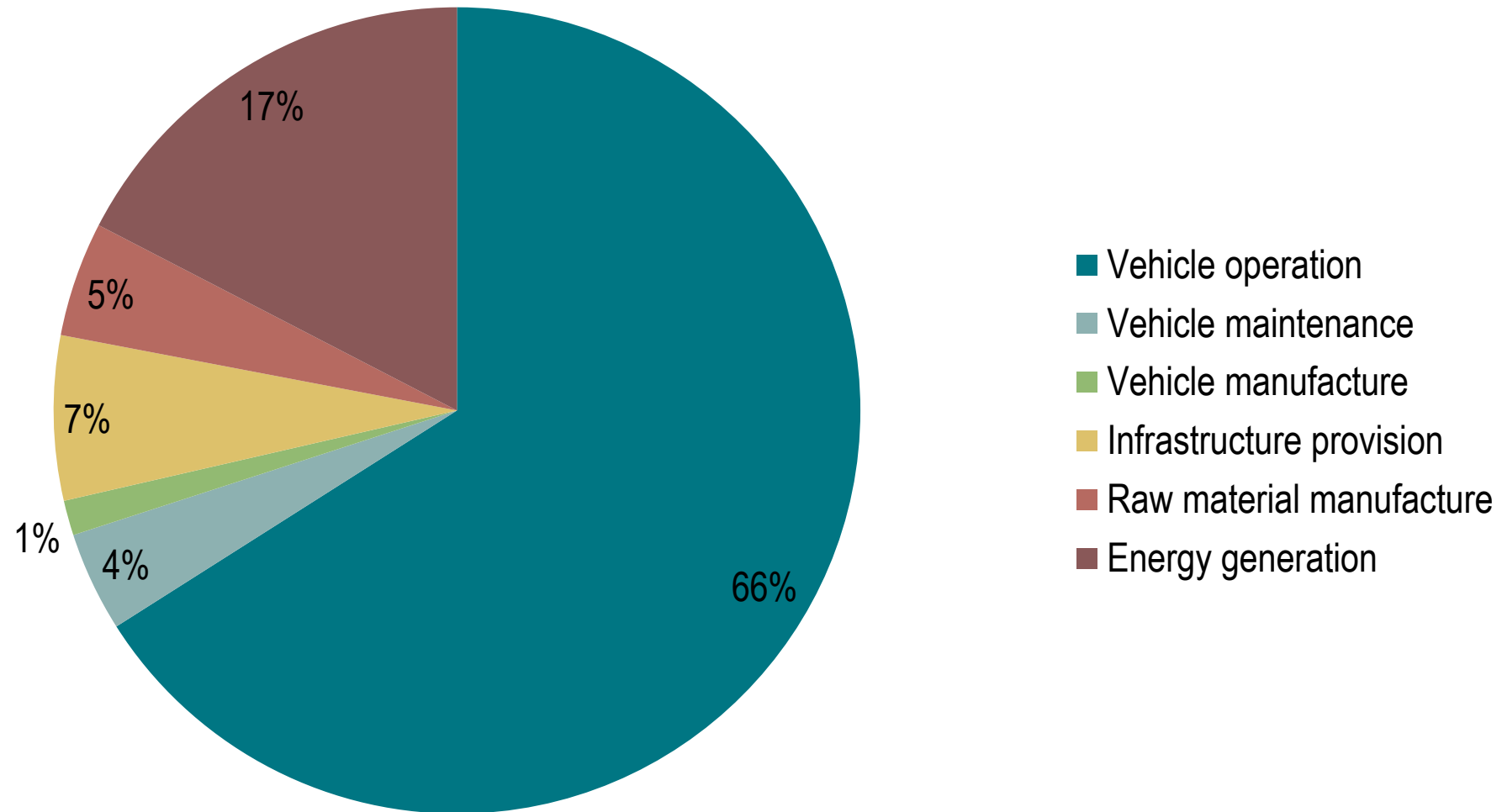
Energy Efficiency by Transportation Mode



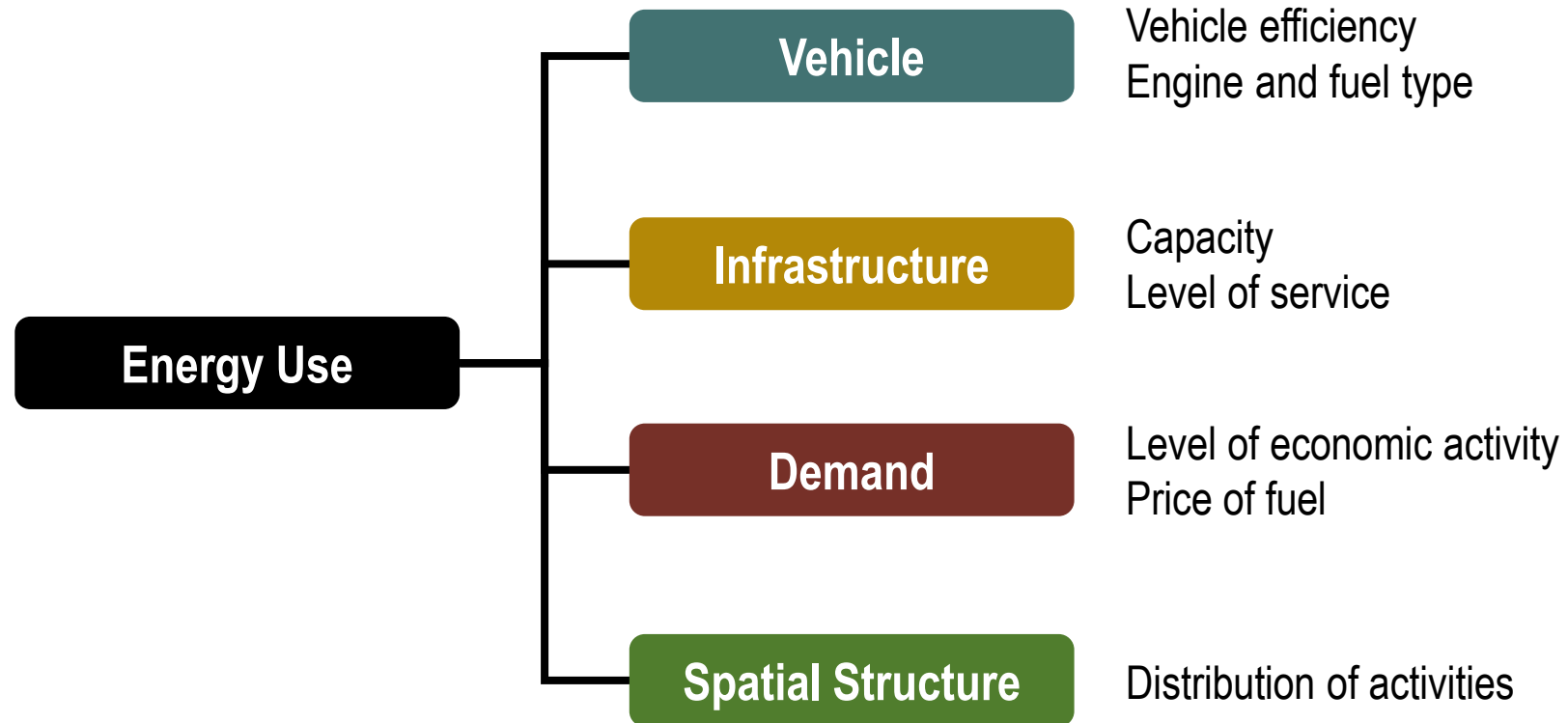
Fuel Consumption for an Average Cargo Ship



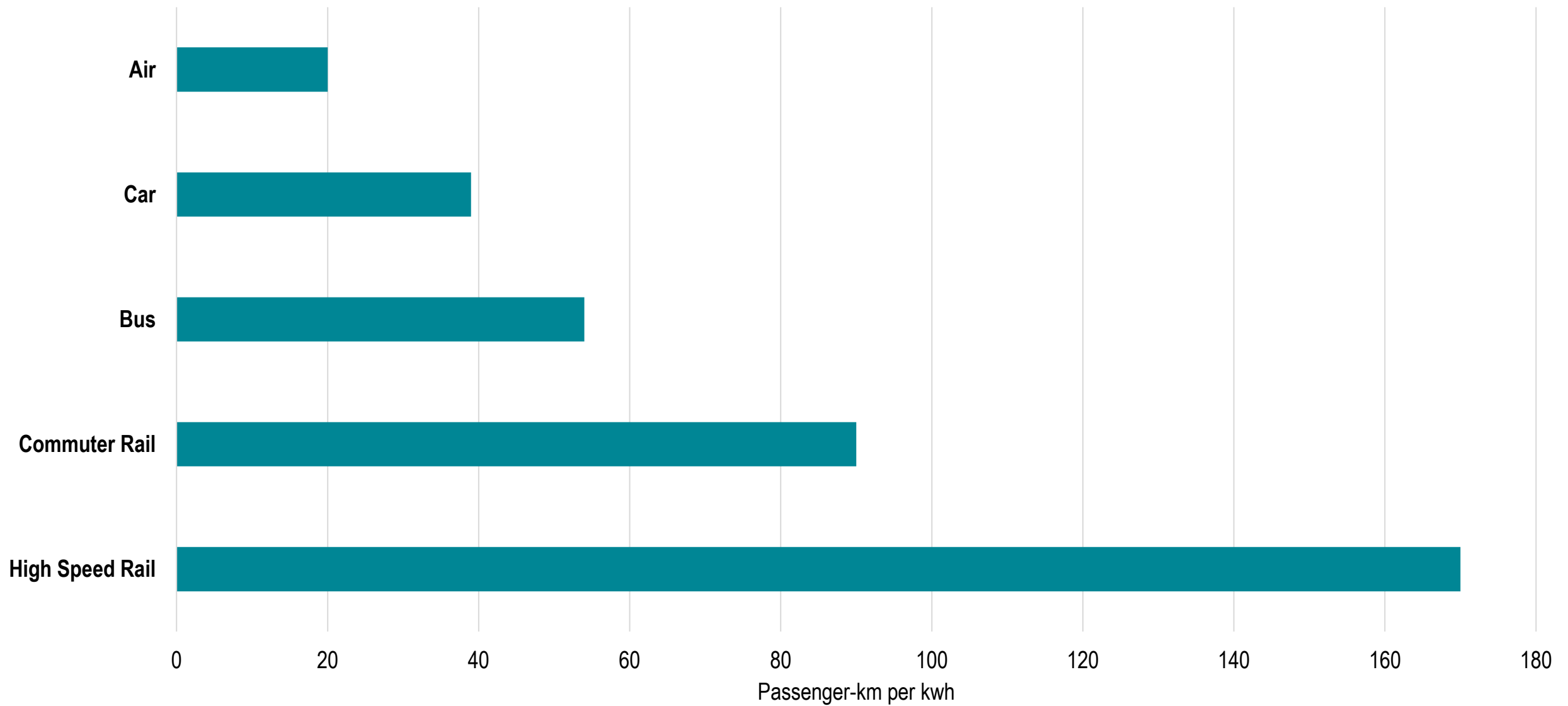
Energy Used by the Road Transportation System



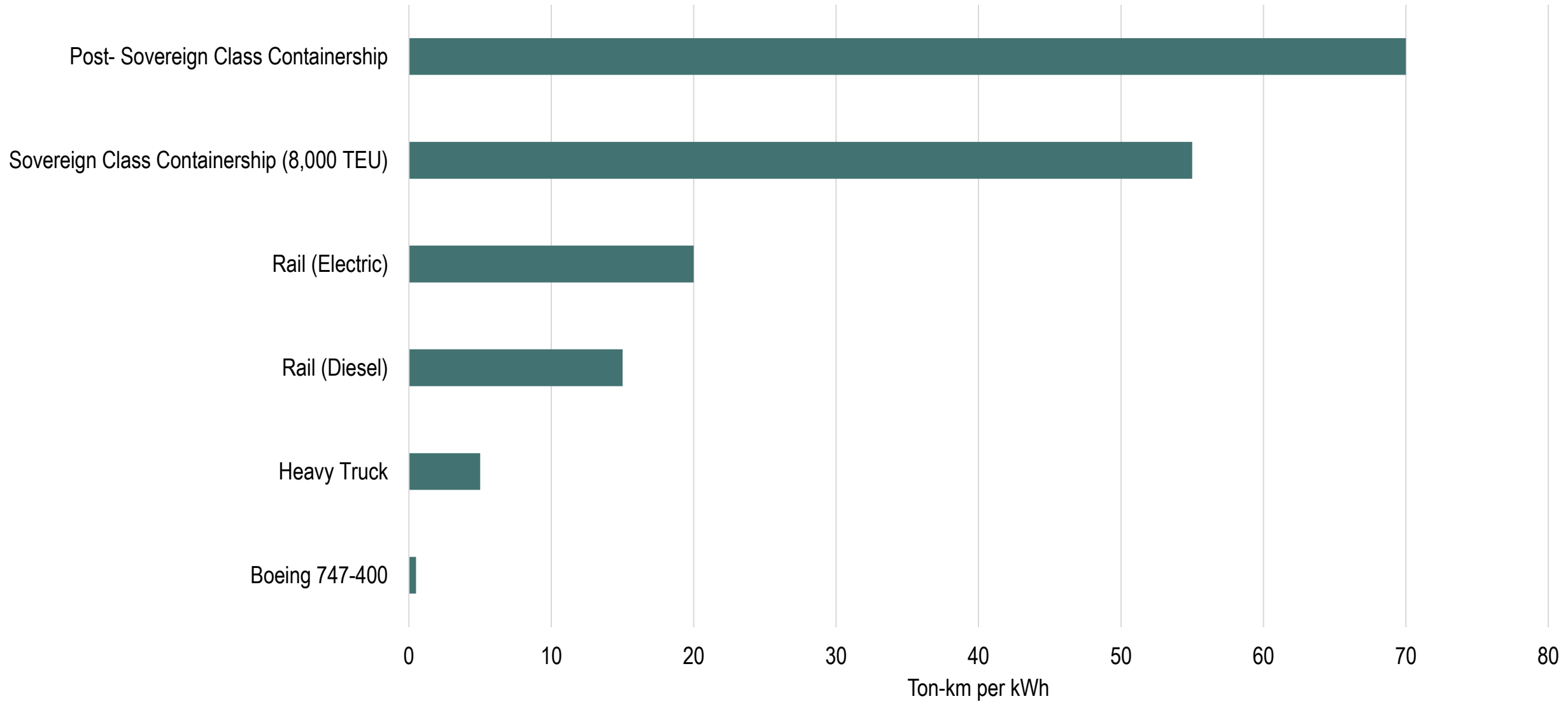
Energy Use Factors by Transportation



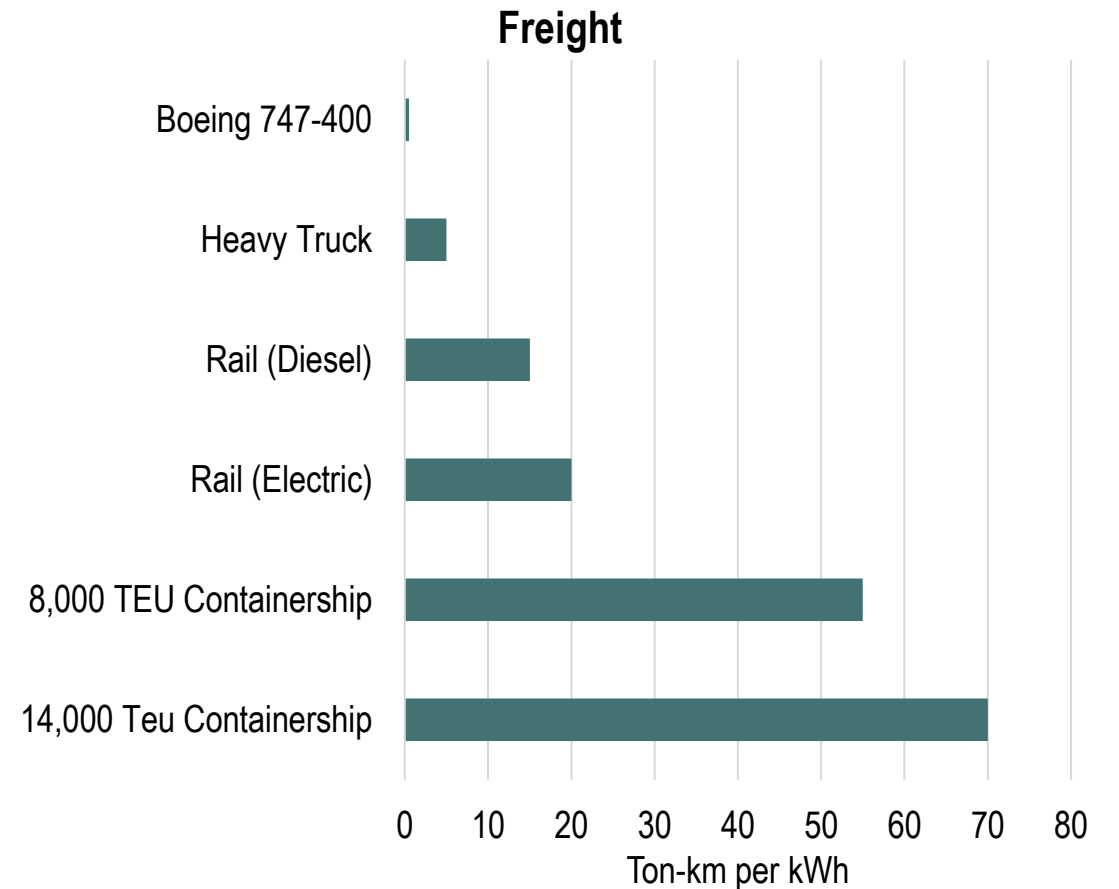
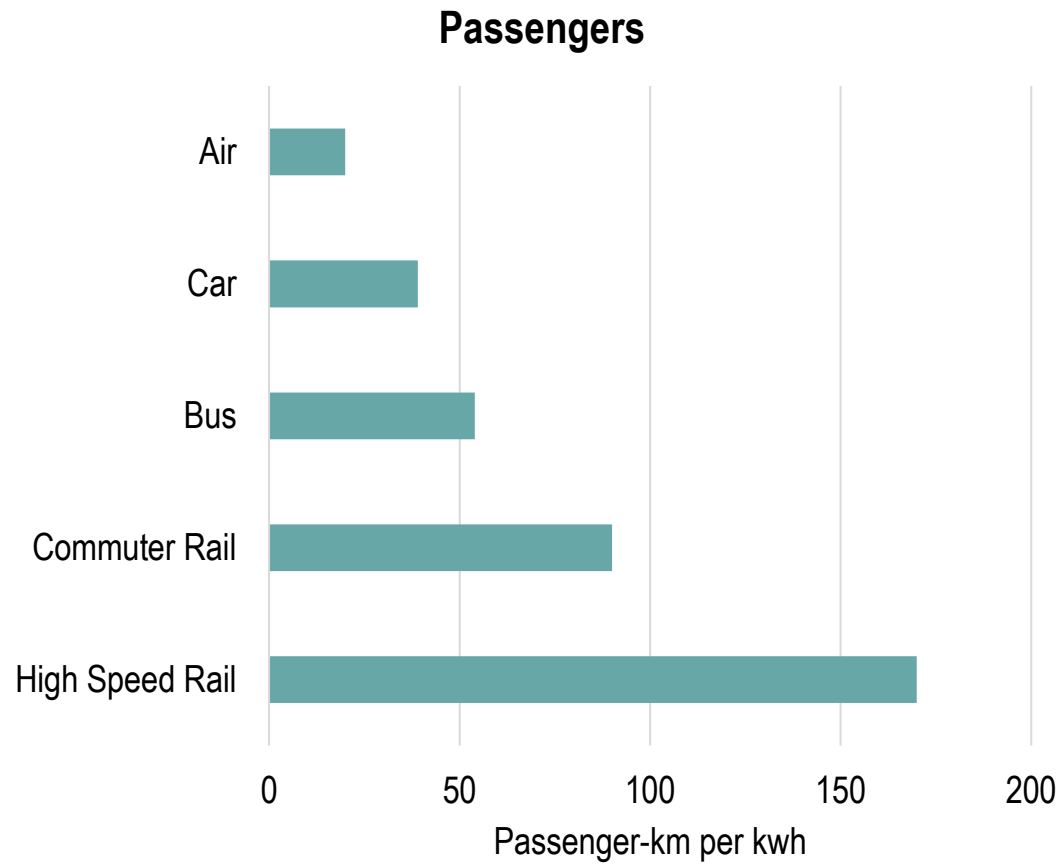
Energy Efficiency of Selected Passenger Modes



Distance Travelled for One Ton of Cargo Using 1 kWh of Energy



Energy Efficiency of Selected Passenger and Freight Modes



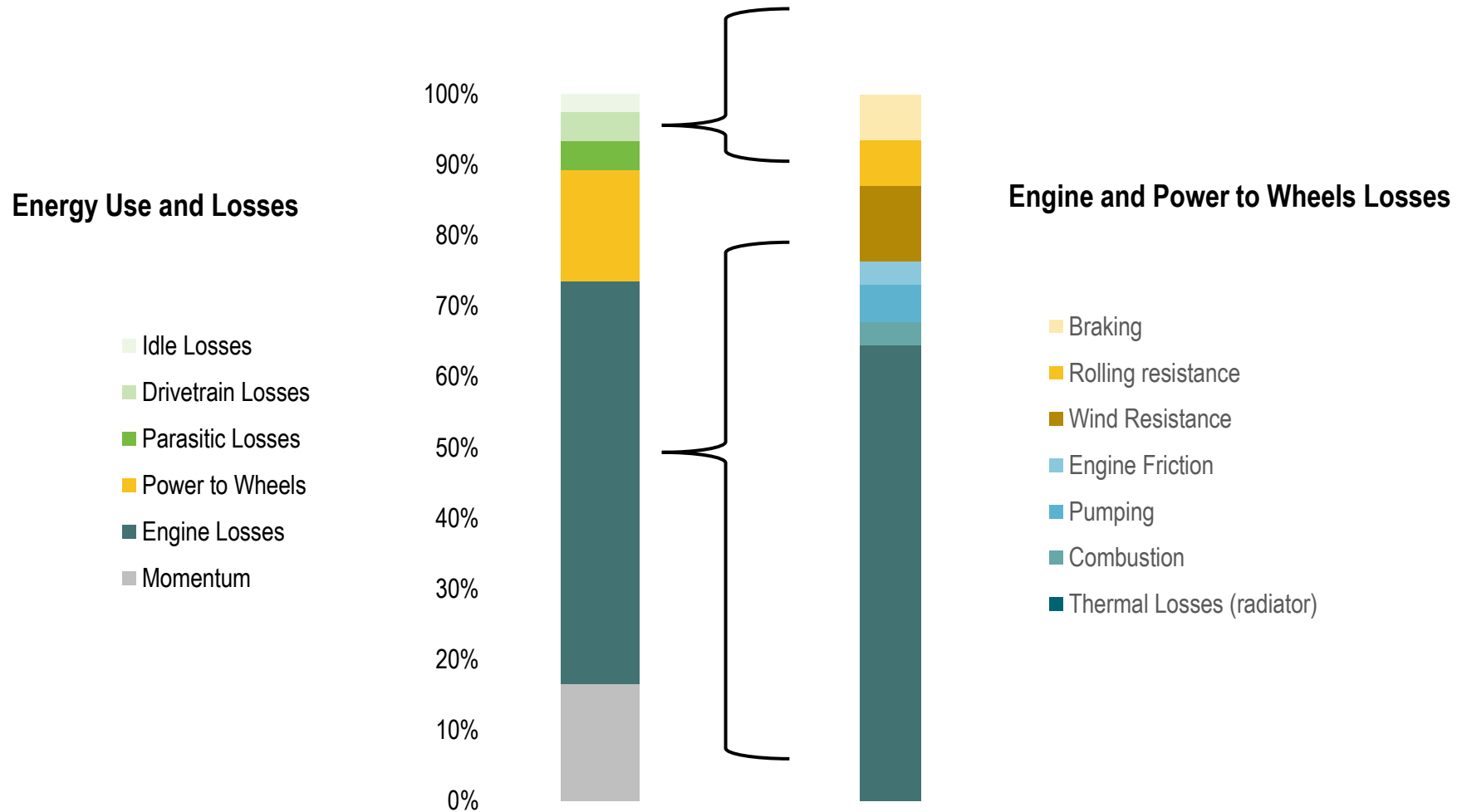
Energy Efficiency of Main Passenger Transportation Modes

Passenger Travel by	Fuel	Rate of fuel use MJ / passenger-km
Personal vehicle (ICE)	Gasoline	2.6
Local bus (ICE)	Diesel	2.8
Electric bus, light rail, subway	Electricity	0.6
Intercity bus (ICE)	Diesel	0.7
Intercity rail (diesel - electric)	Diesel	0.9
Intercity rail (electric)	Electricity	0.2
High-speed rail (electric)	Electricity	0.3
Aircraft (domestic)	Kerosene	2.0

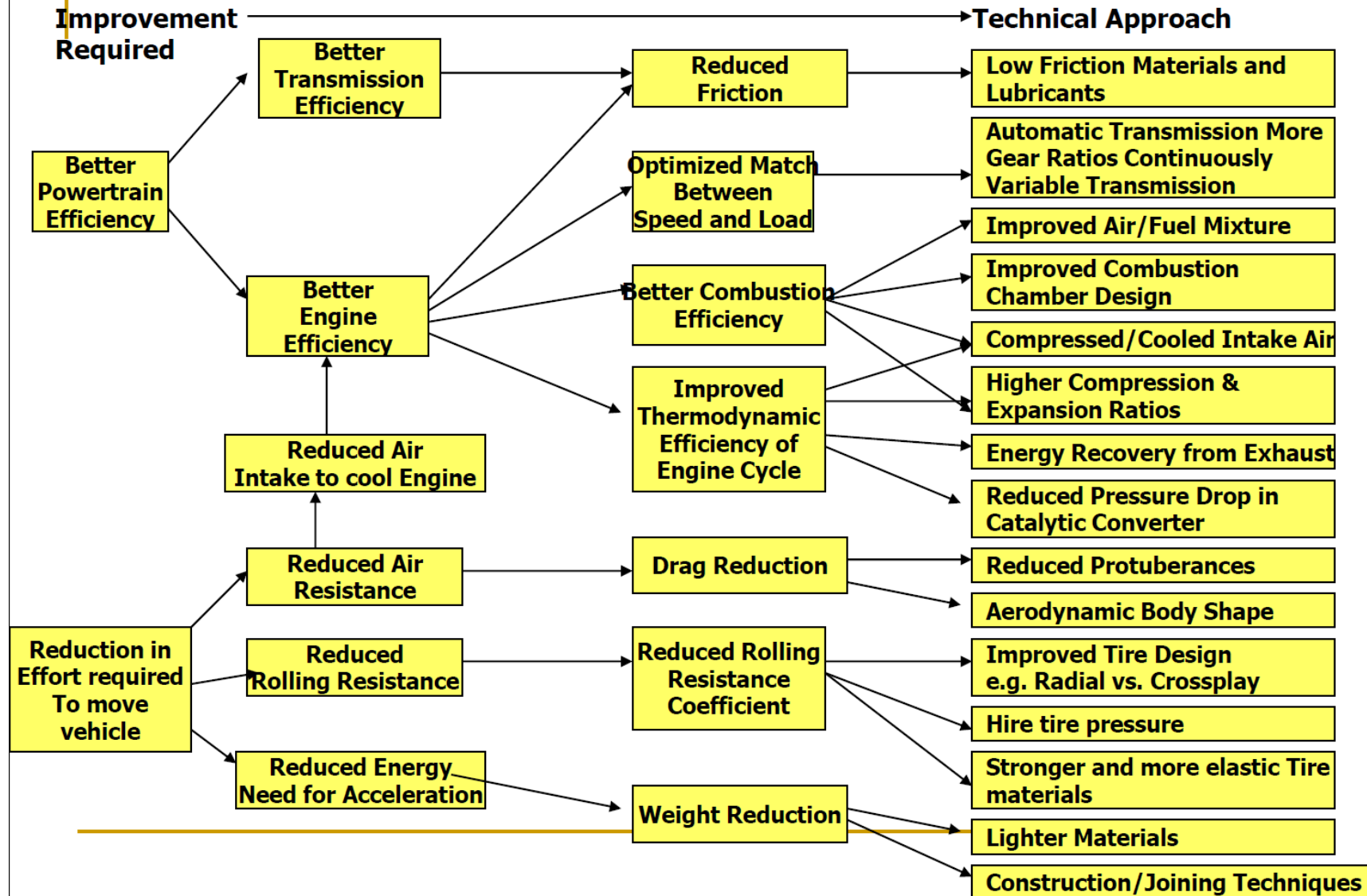
Transportation Fuel Markets

	Marine	Aviation	Road
Type of fuel	Low quality (bunker oil)	High quality (jet fuel)	Medium quality (diesel, gasoline)
Share of energy consumption	2%	6%	90%
Market size (year)	150 M metric tons	190 M metric tons	650 M metric tons
Percentage of operating costs	40%	25%	18-20%

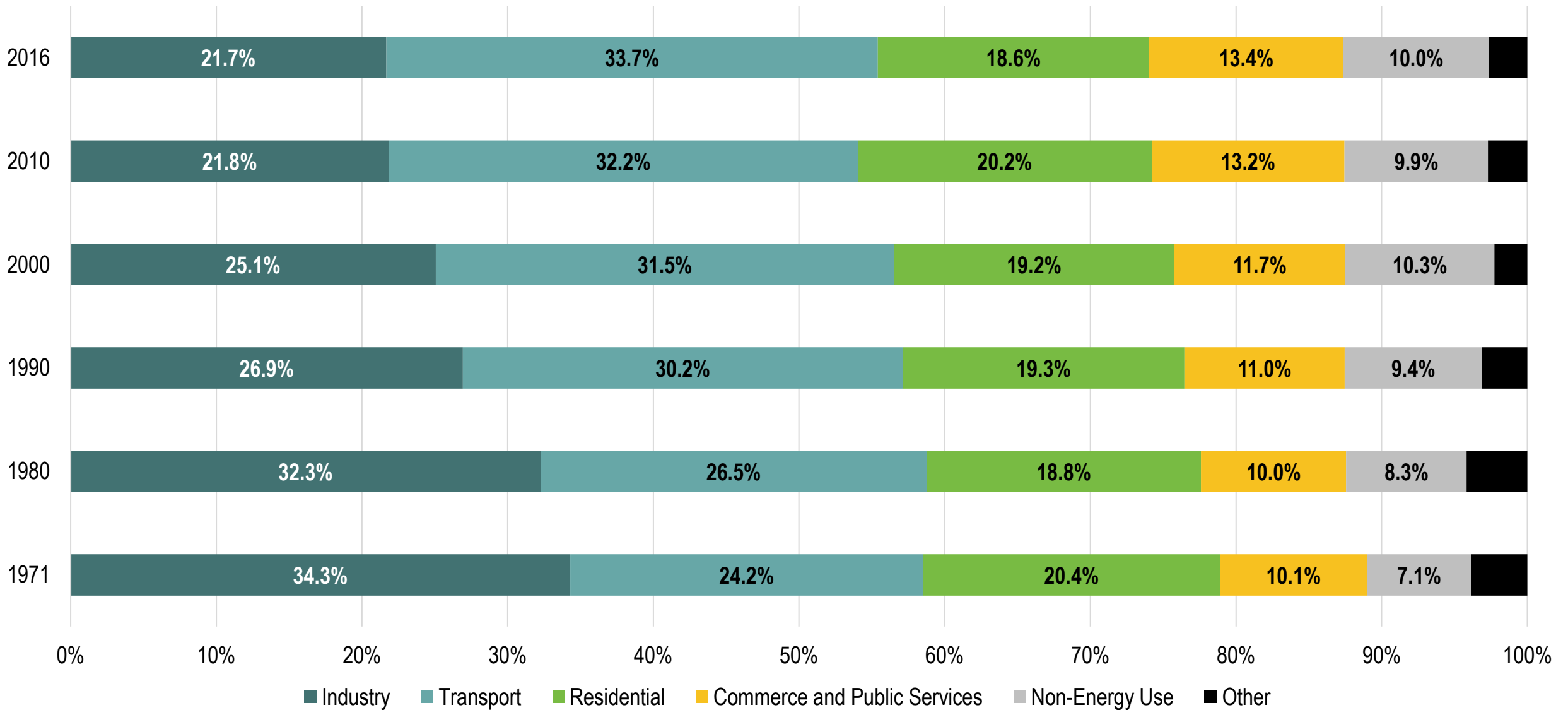
Typical Energy Use for a Car



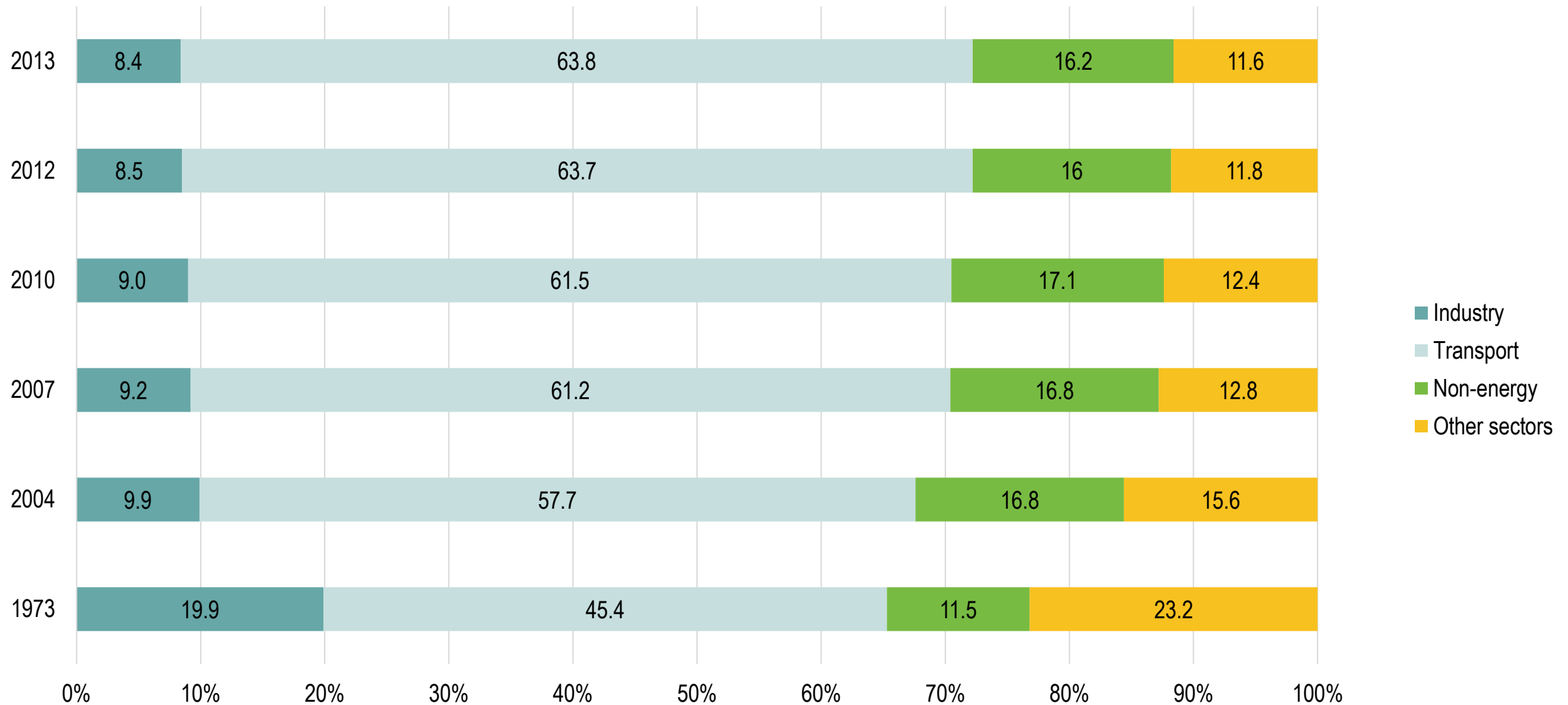
Technical Approaches to Reducing Car Energy Use & GHG Emissions



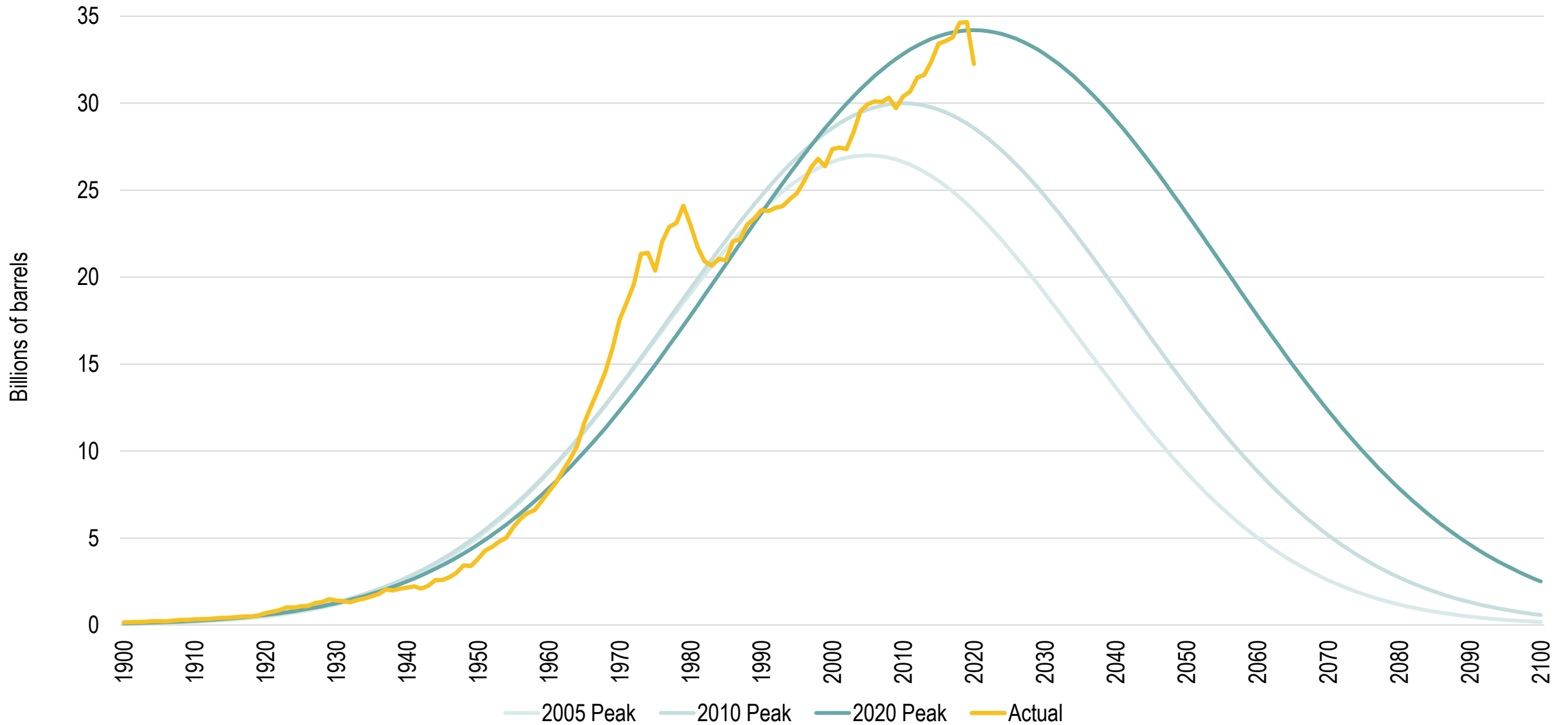
Energy Consumption by Sector, OECD Countries



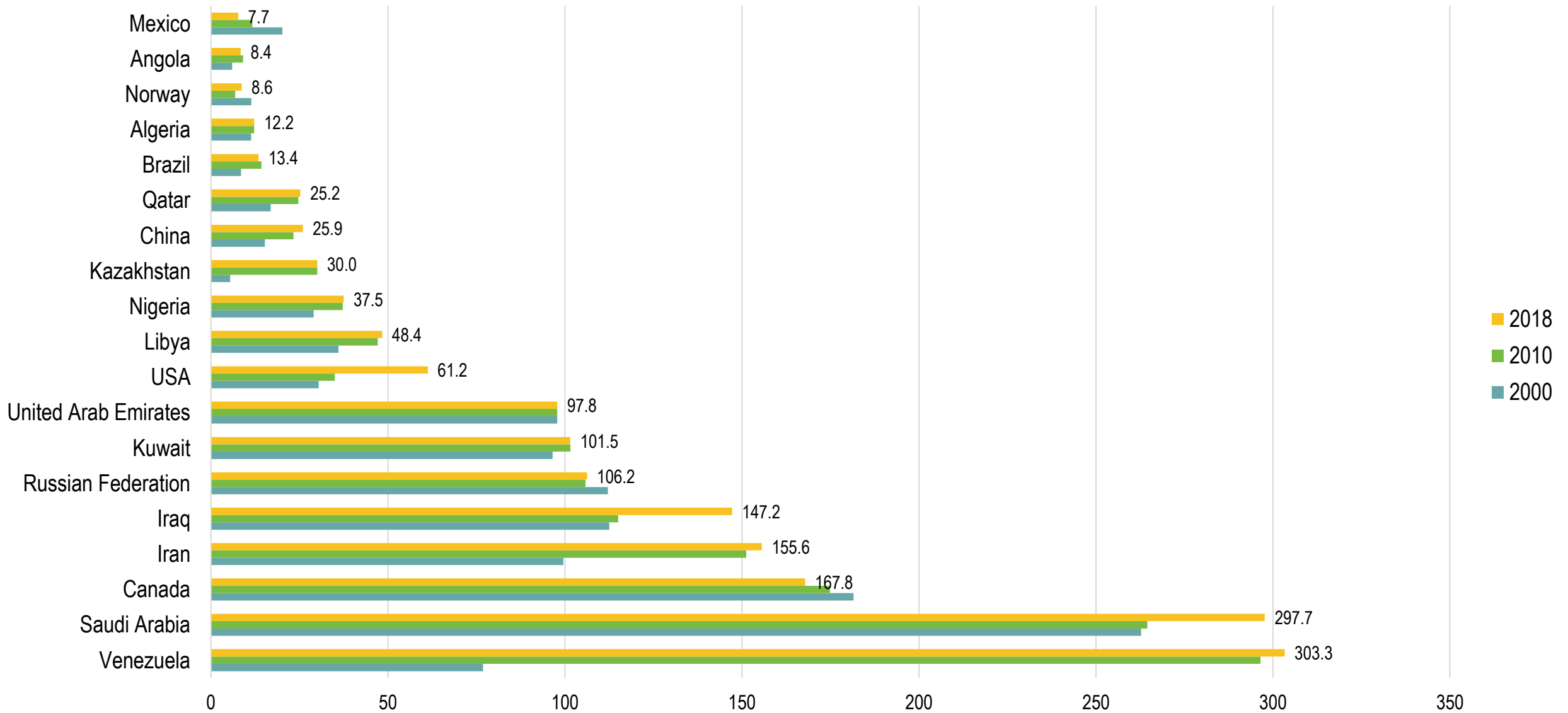
World Oil Energy Consumption by Sector, 1973-2013



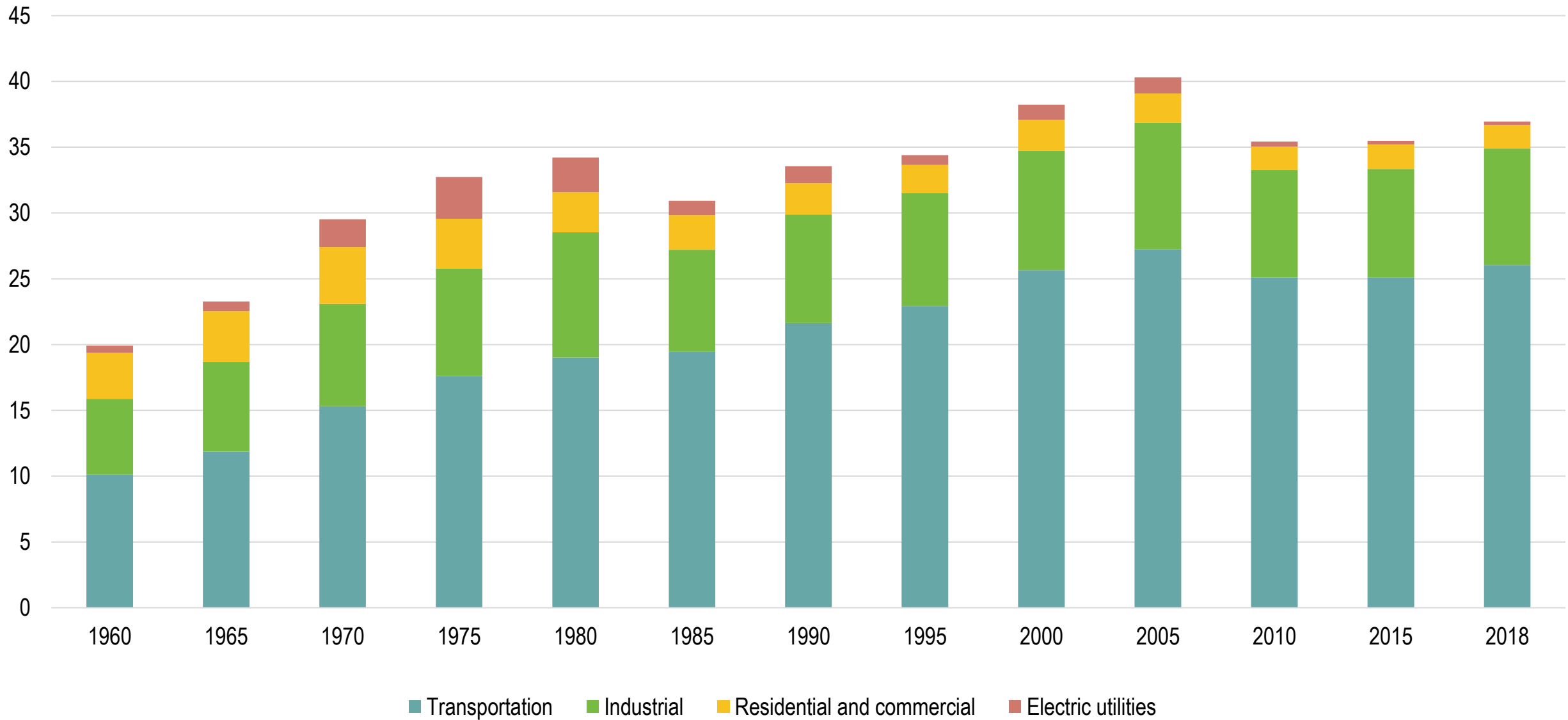
World Annual Oil Production (1900-2020) and Peak Oil (2005-2020)



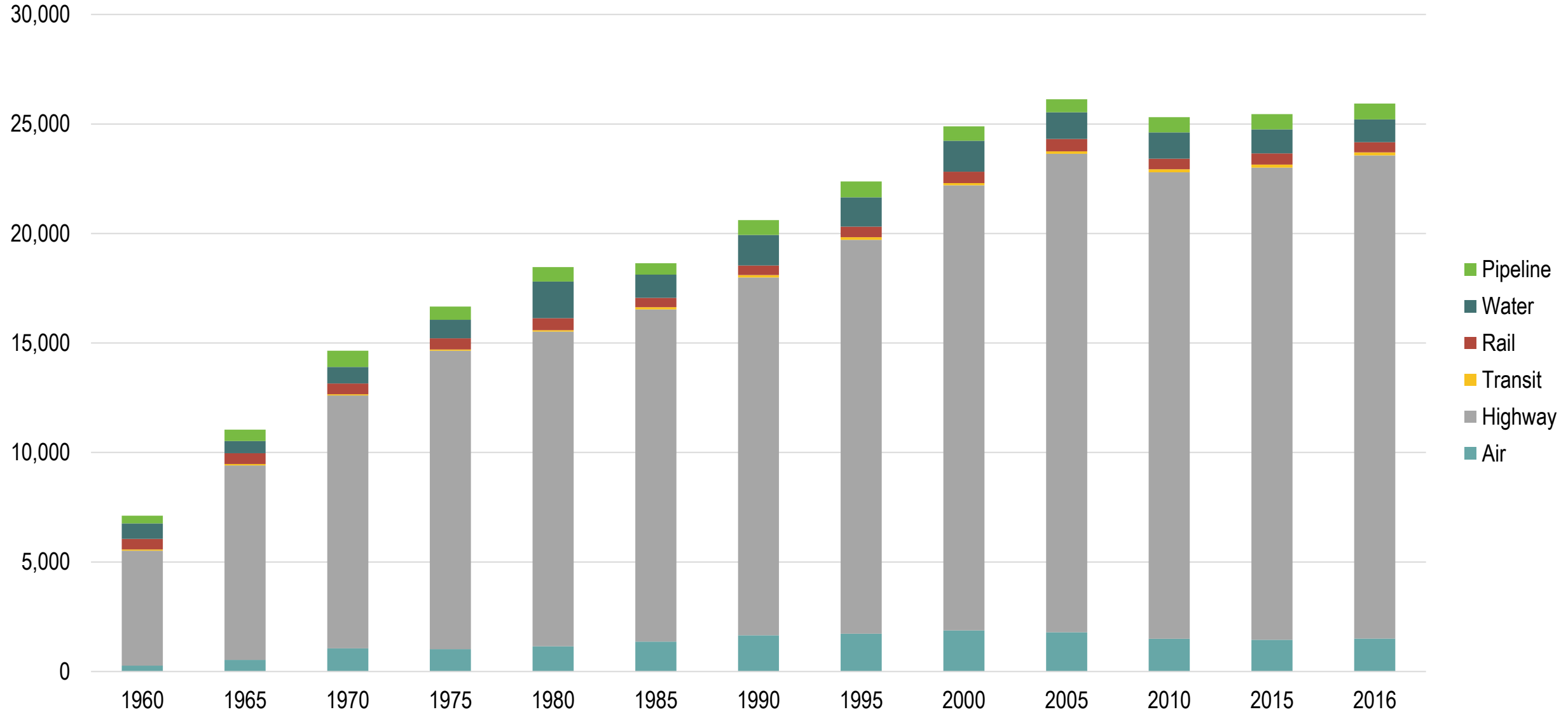
Major Crude Oil Reserves, 2000-2018 (Thousand Million Barrels)



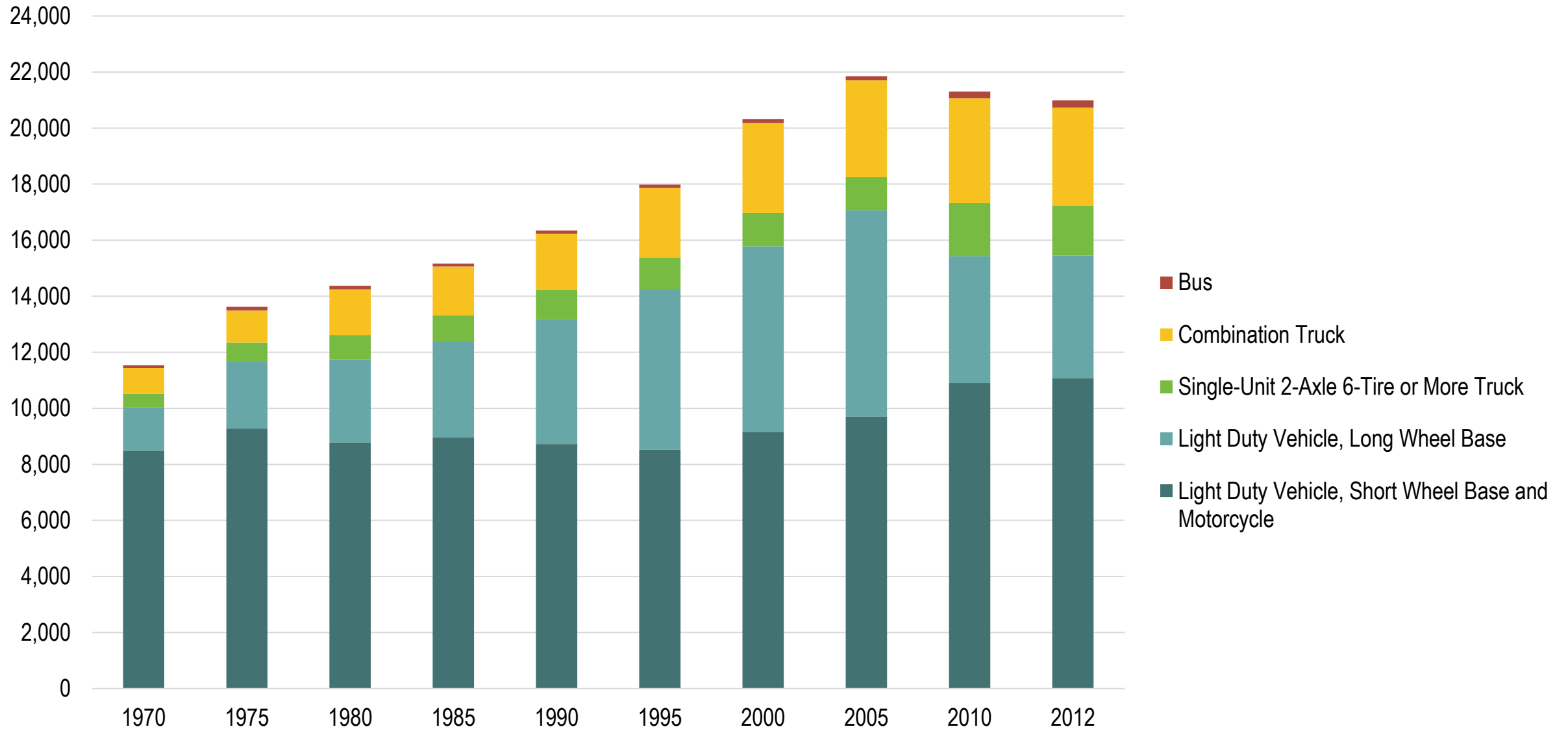
Demand for Refined Petroleum Products by Sector in the United States, 1960-2018 (in Quadrillion BTUs)



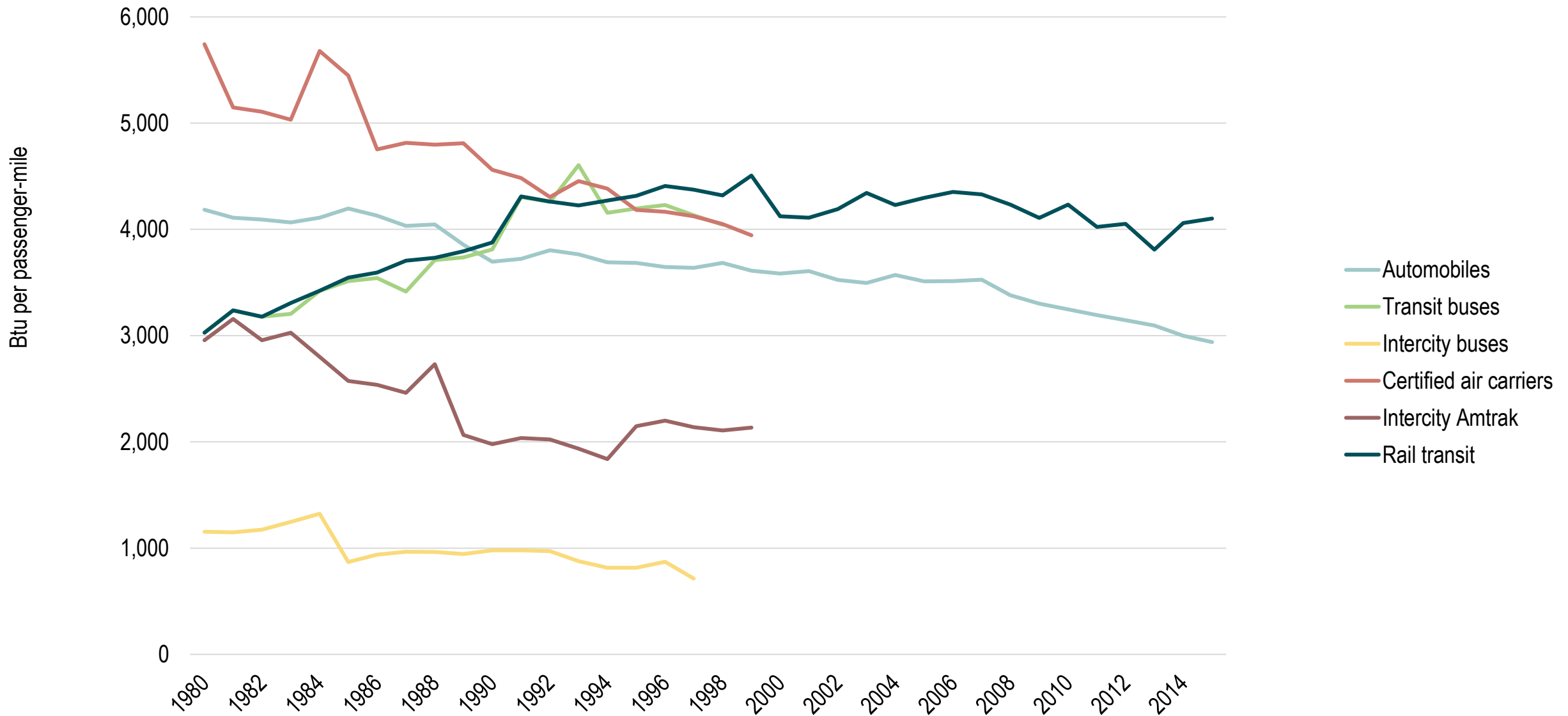
Energy Consumption by Transportation Mode in the United States, 1960-2016 (in Trillion BTUs)



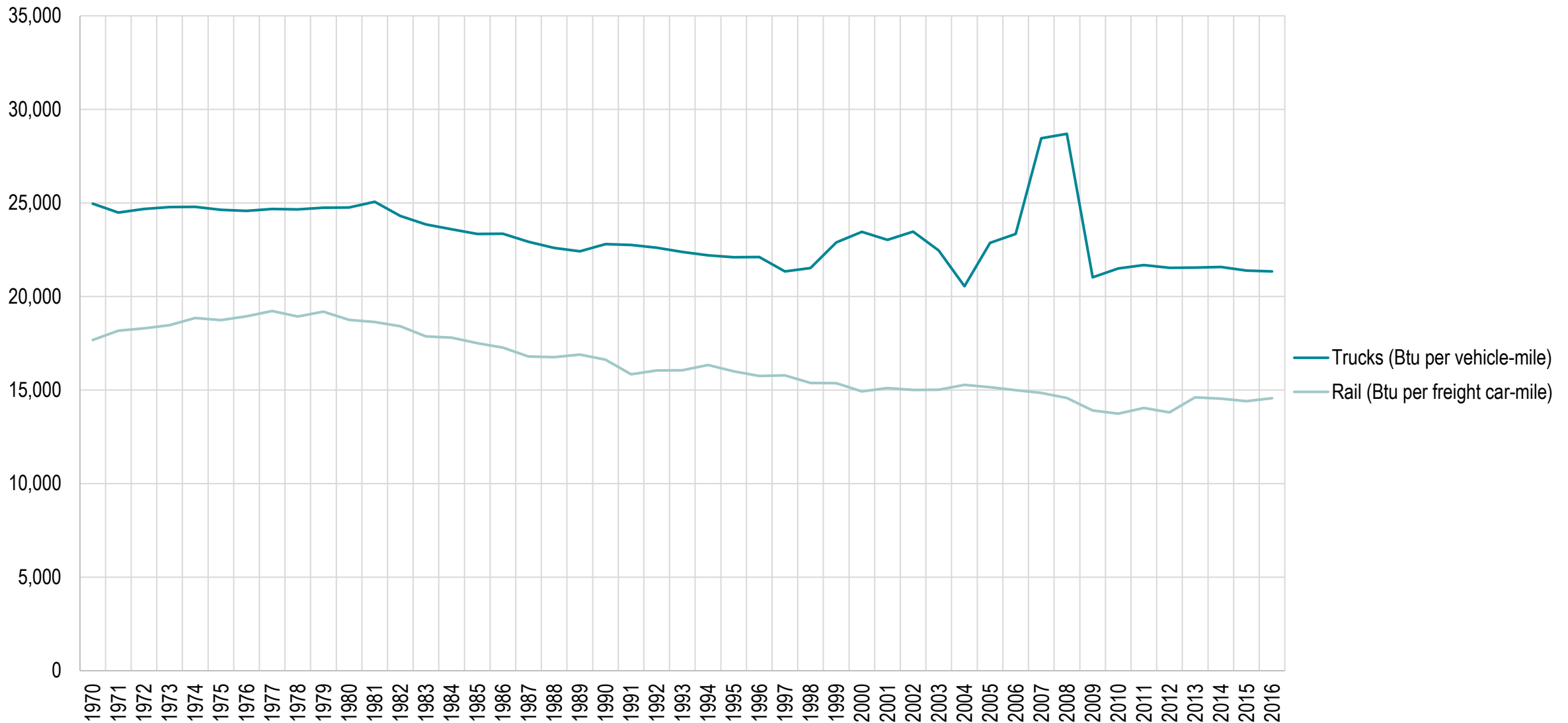
Energy Consumption by Road Transportation in the United States, 1970-2012 (in Trillion BTUs)



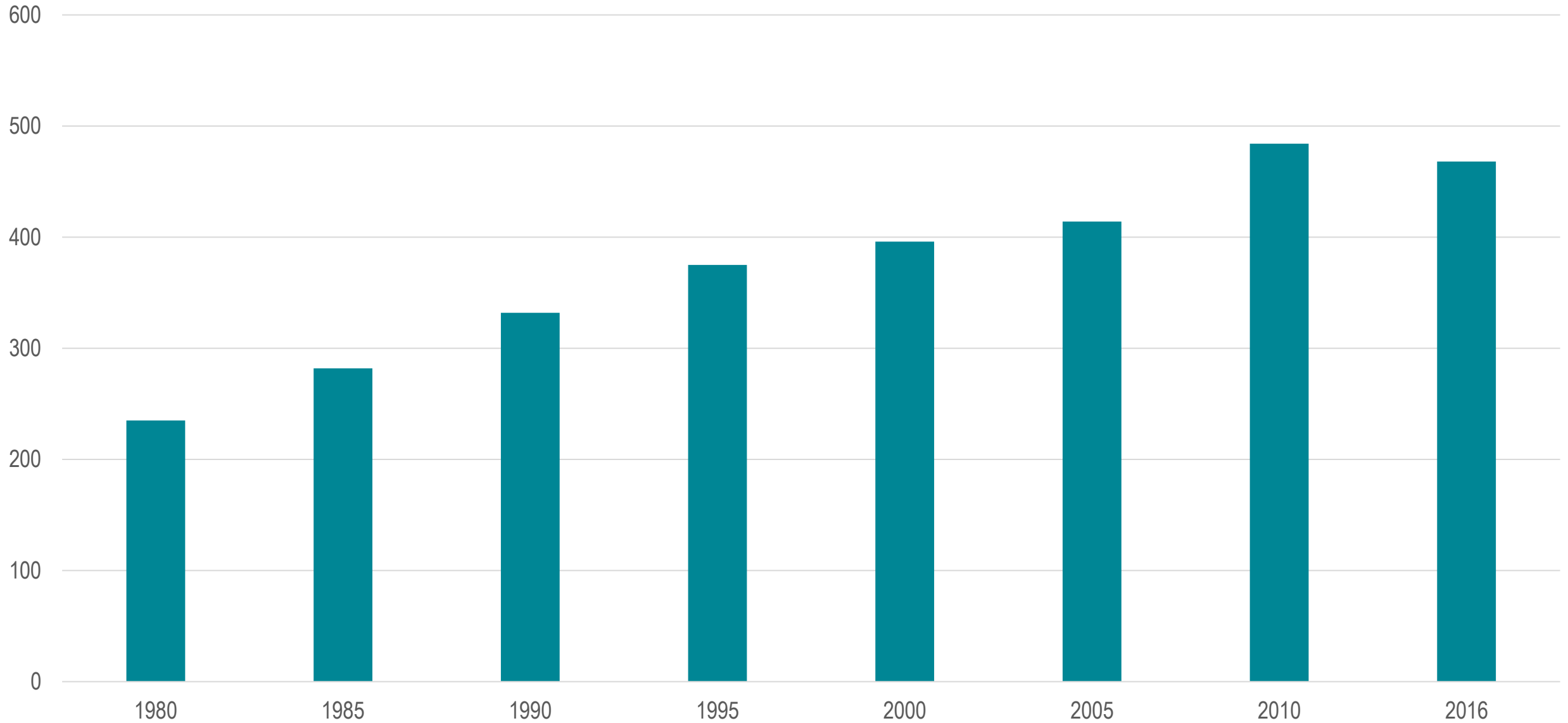
Energy Intensities of Passenger Modes, 1980-2016 (in BTU per passenger-mile)



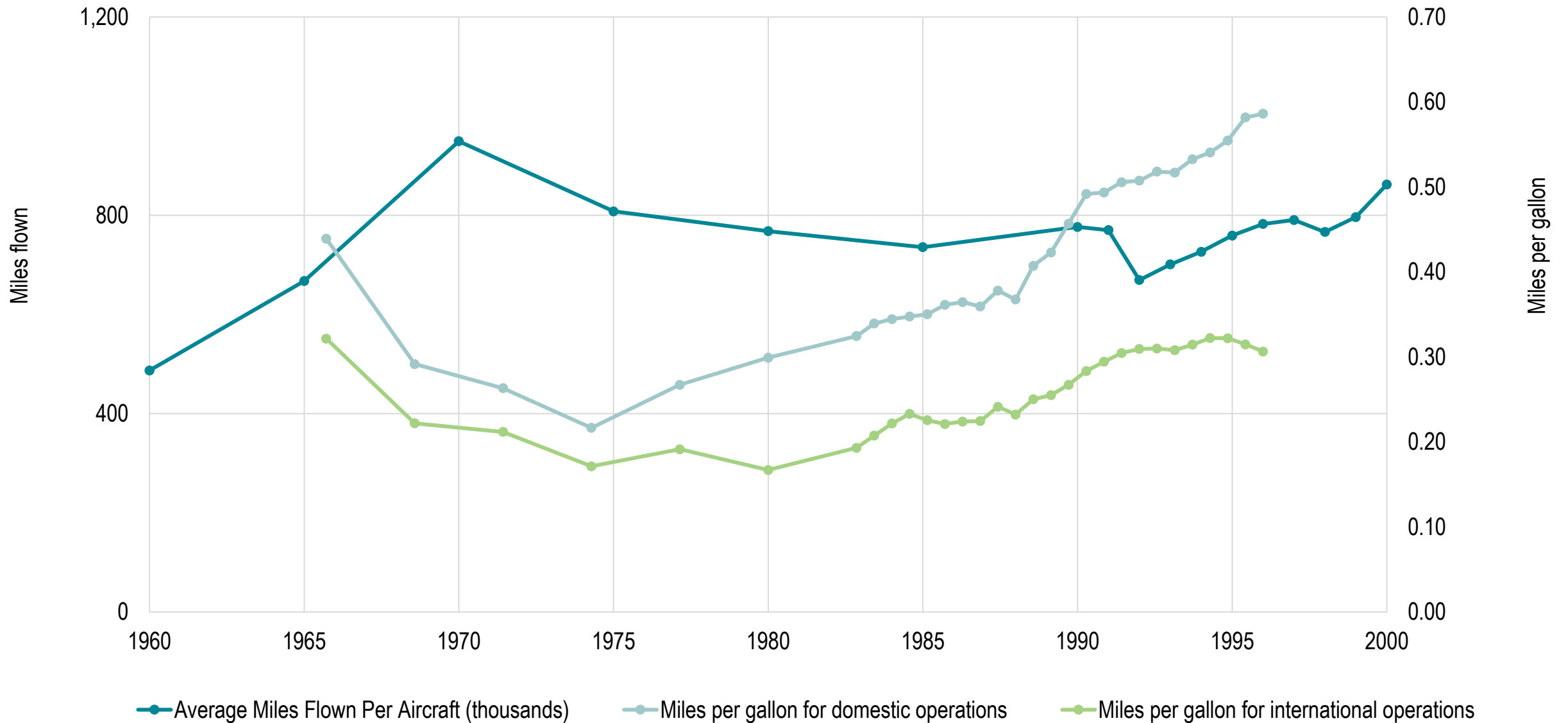
Energy Intensities of Freight Modes, 1970-2016



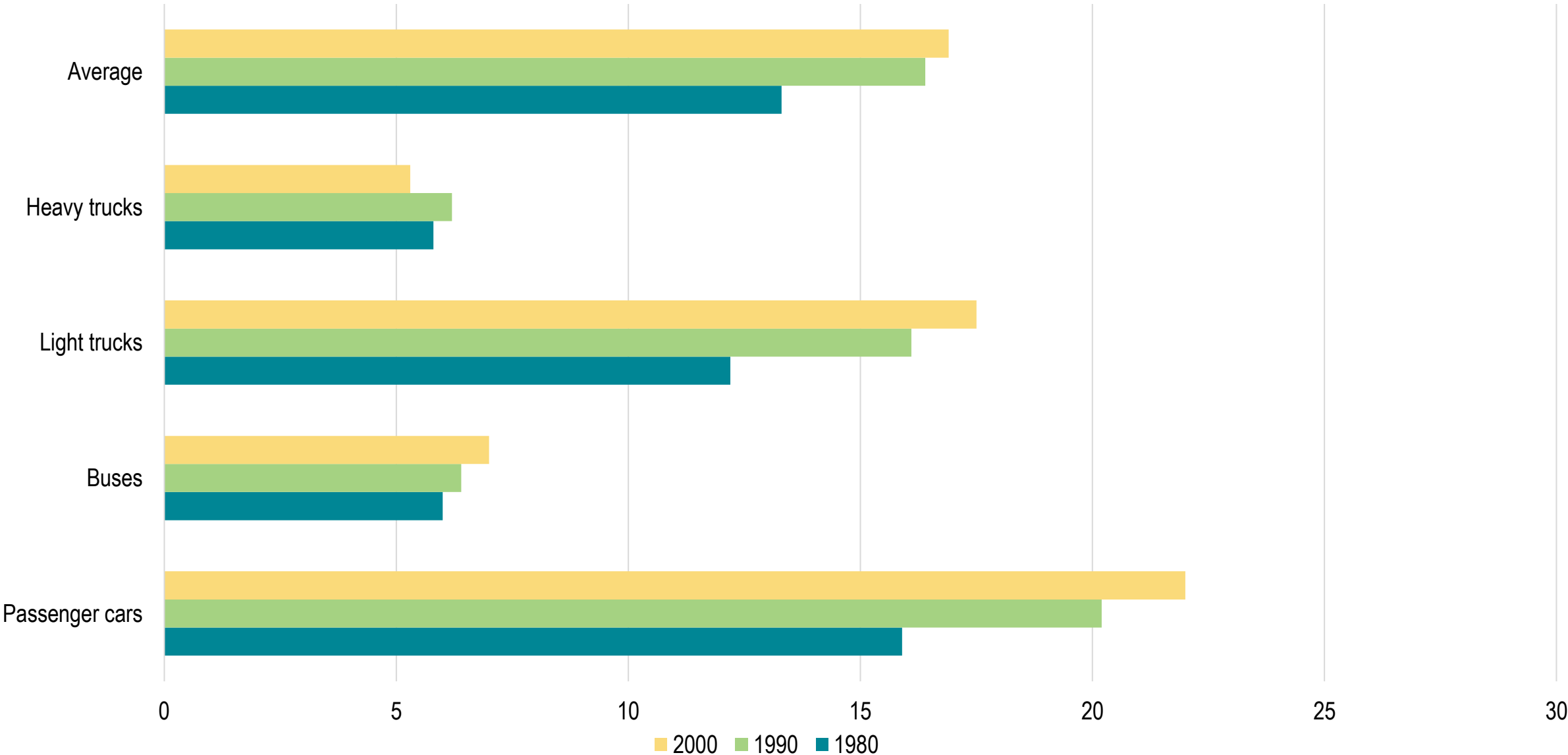
Rail Freight Fuel Efficiency (ton-miles per gallon)



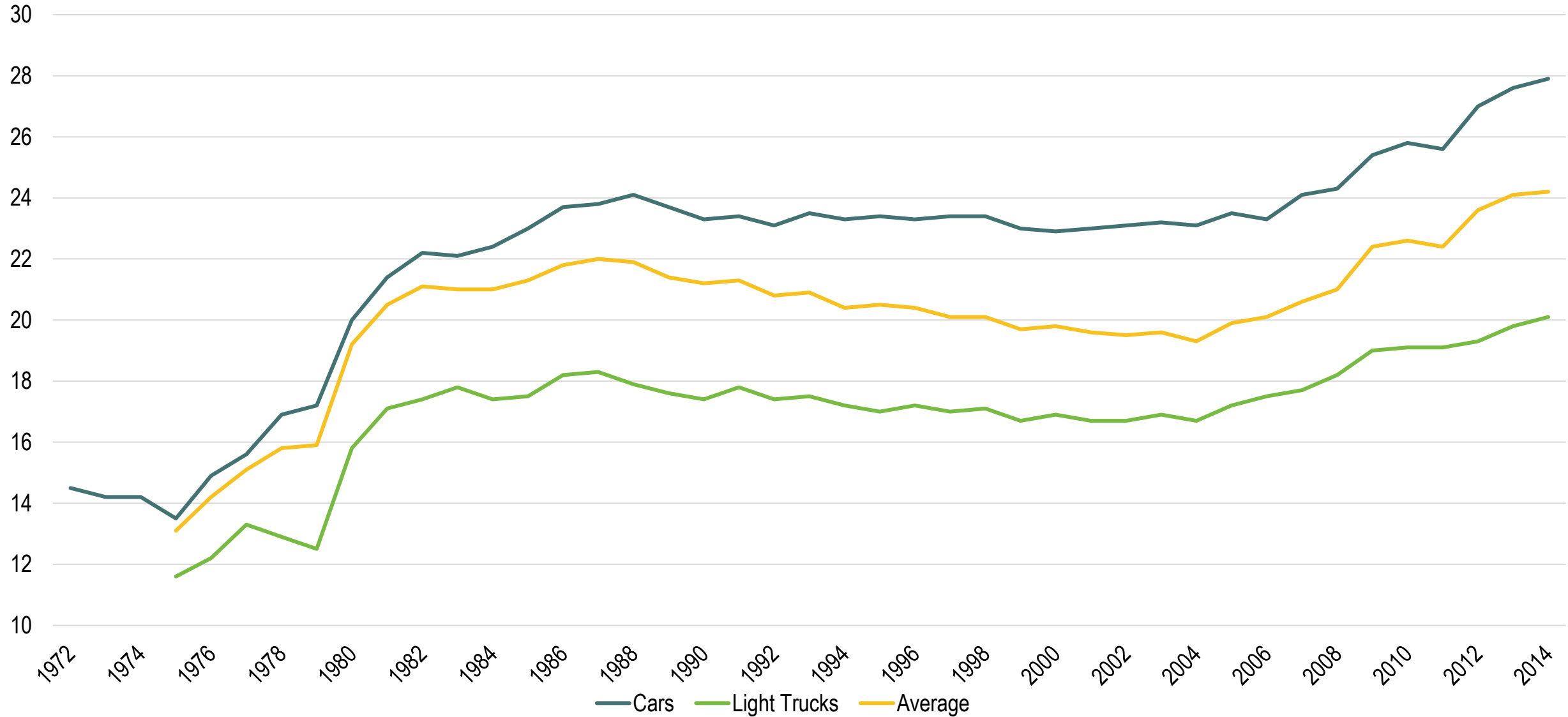
Fuel Consumption and Travel by Certificated Air Carriers in the United States, 1960-2000



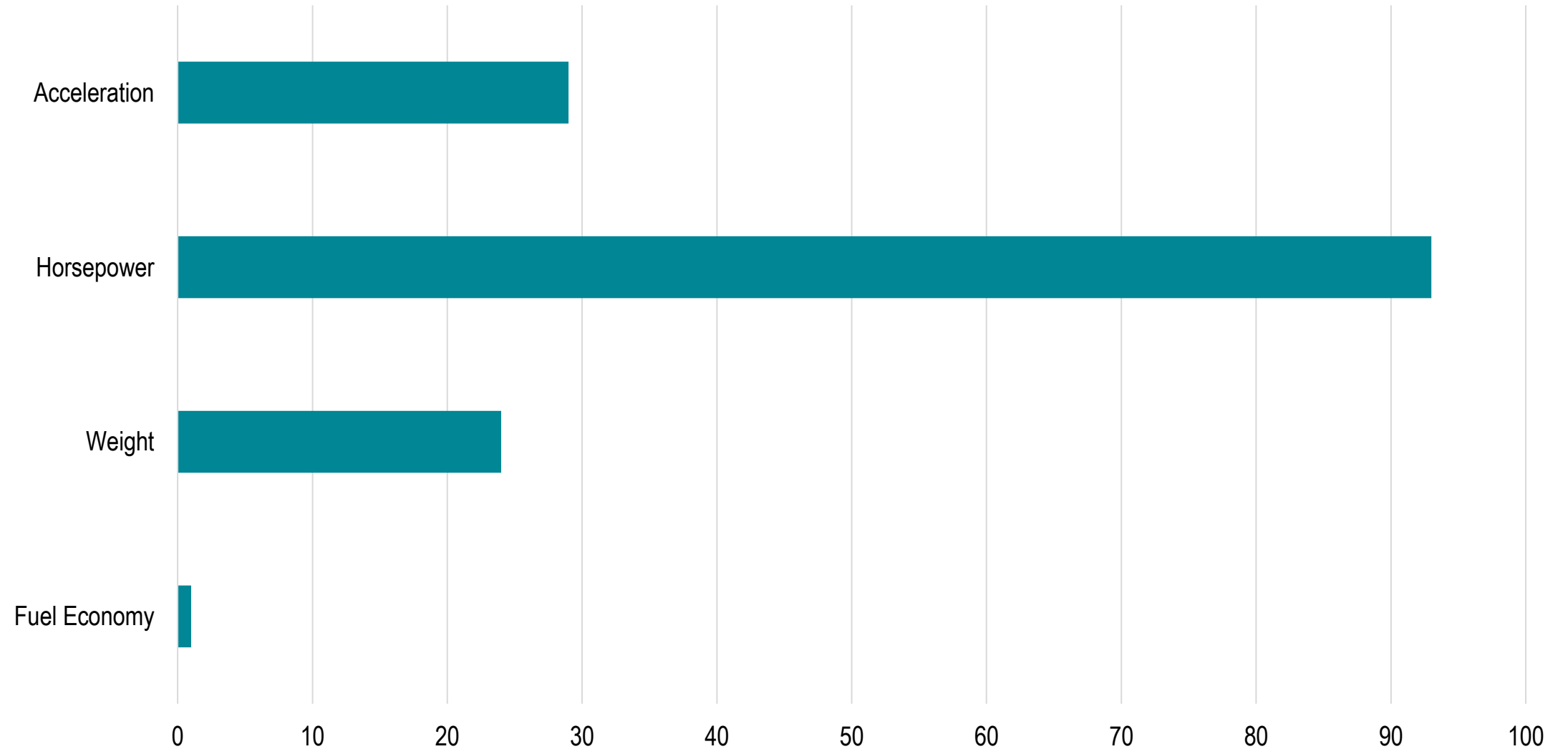
Average Miles per Gallon Traveled by Road Vehicle in the United States, 1980-2000



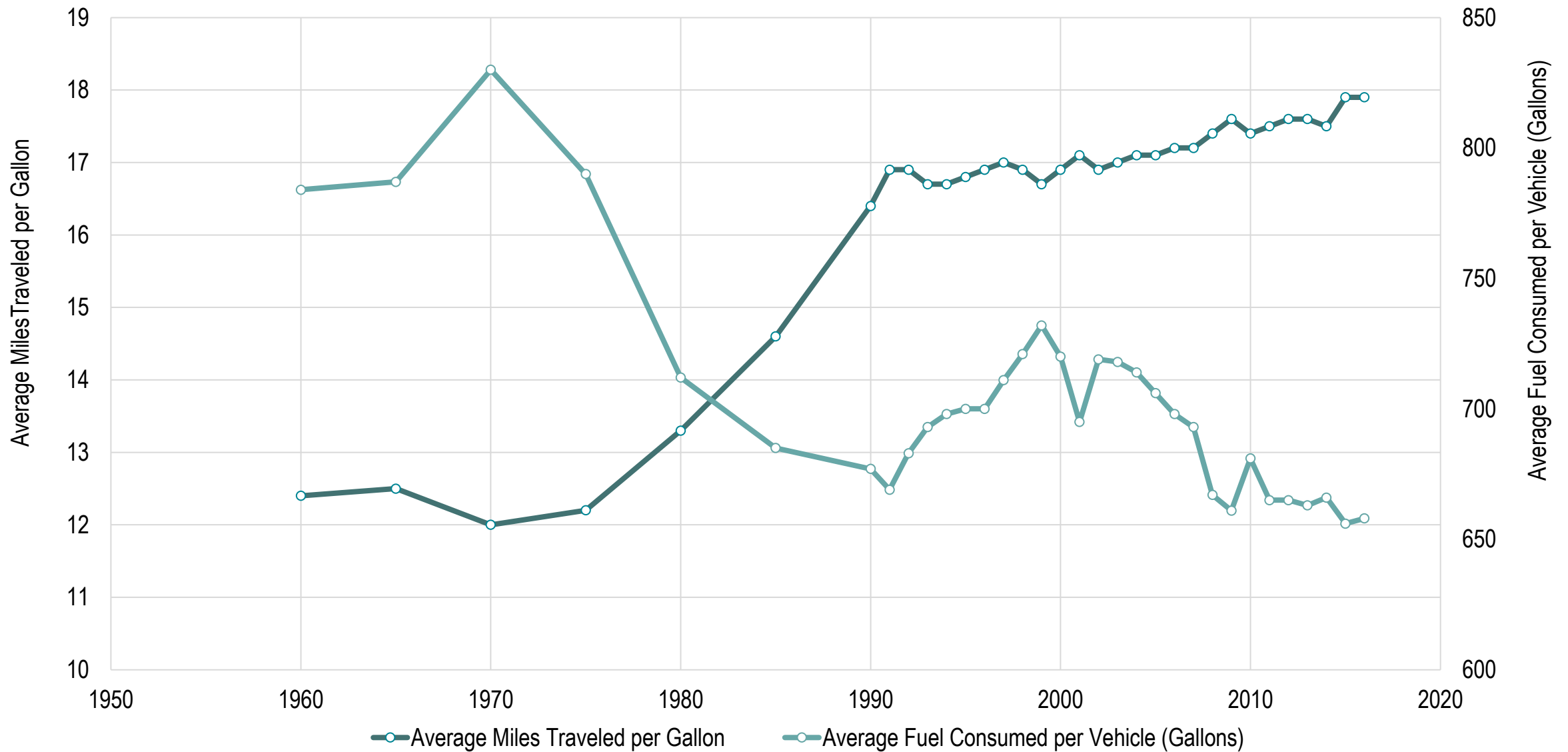
Average Gasoline Consumption for New Vehicles, United States, 1972-2014 (in miles per gallon)



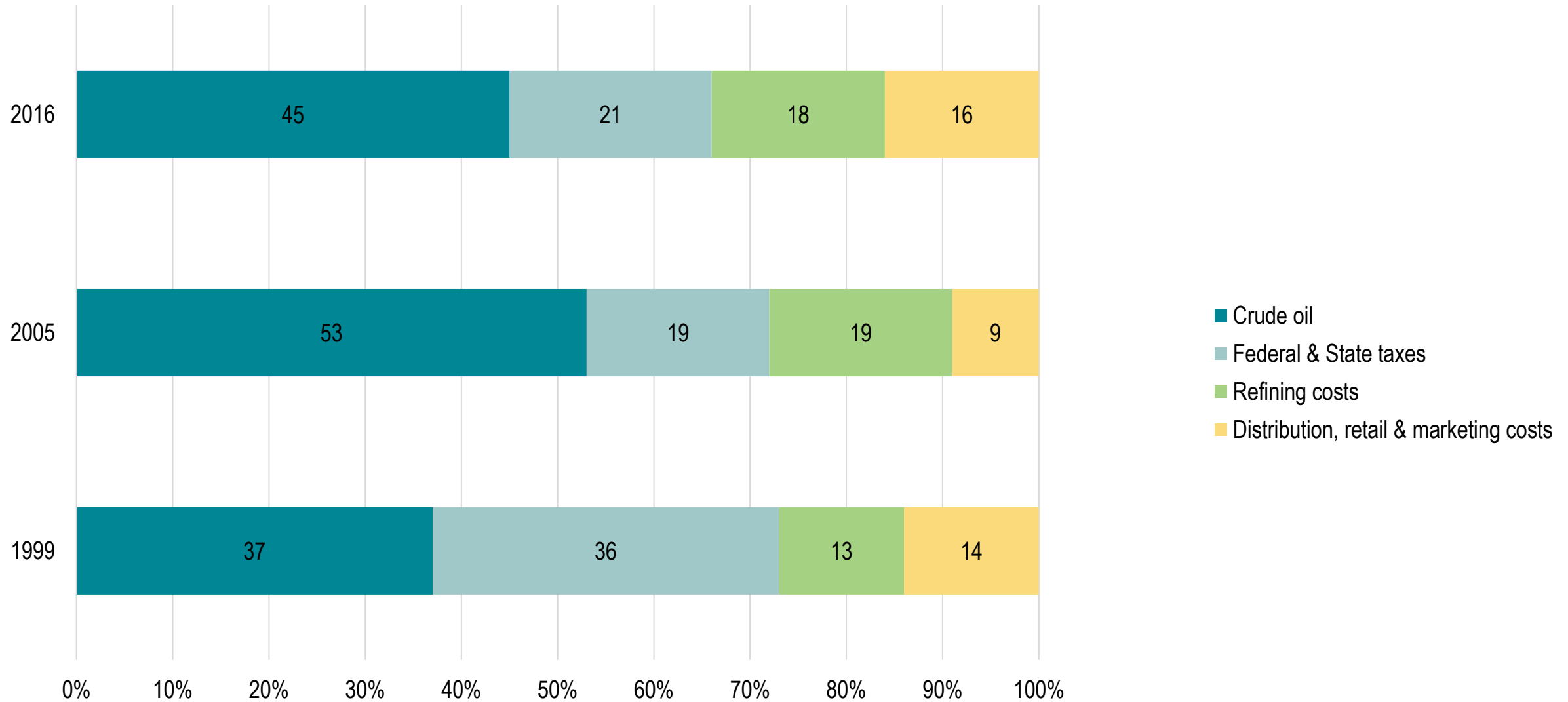
Change in Average Vehicle Characteristics, 1981-2003 (in %)



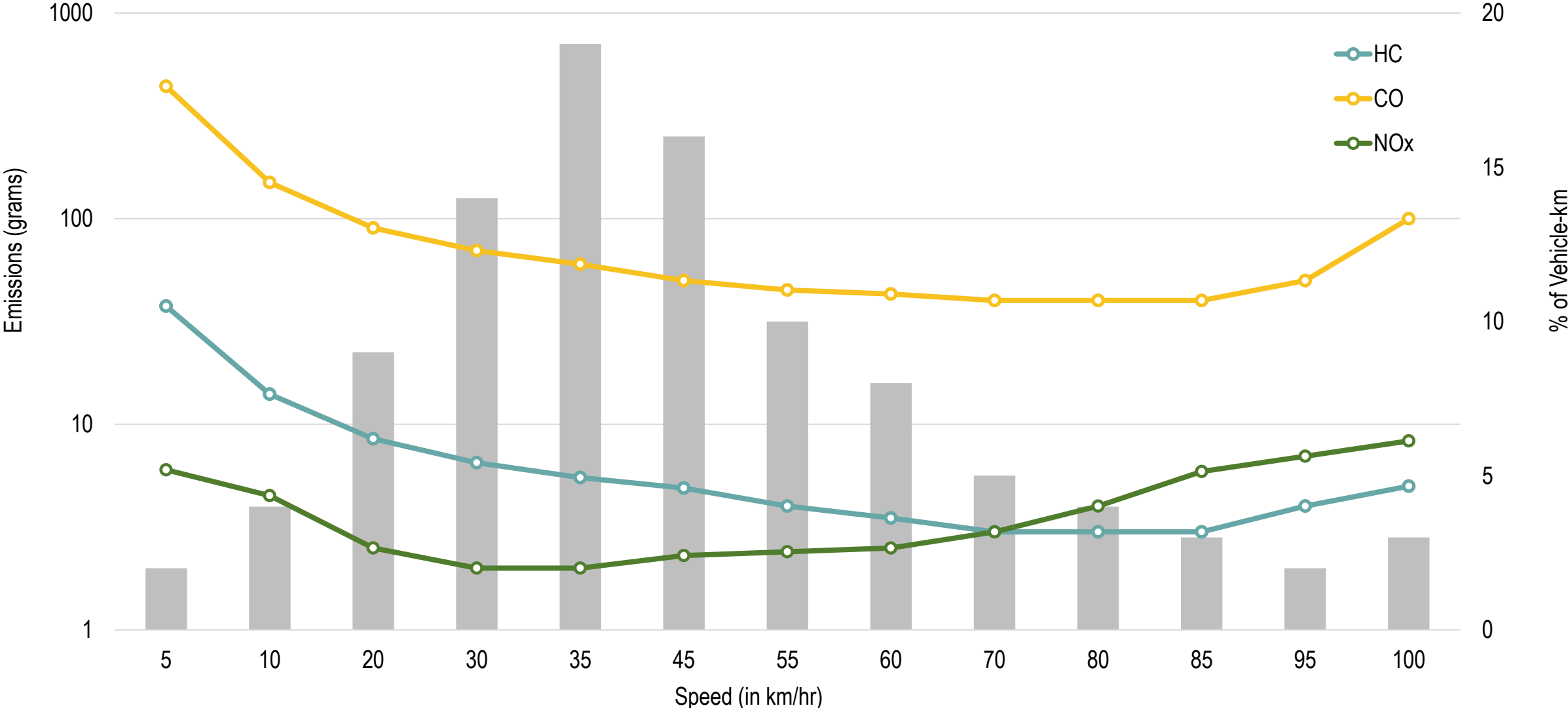
Total Motor Vehicle Fuel Consumption and Travel in the United States, 1960-2016



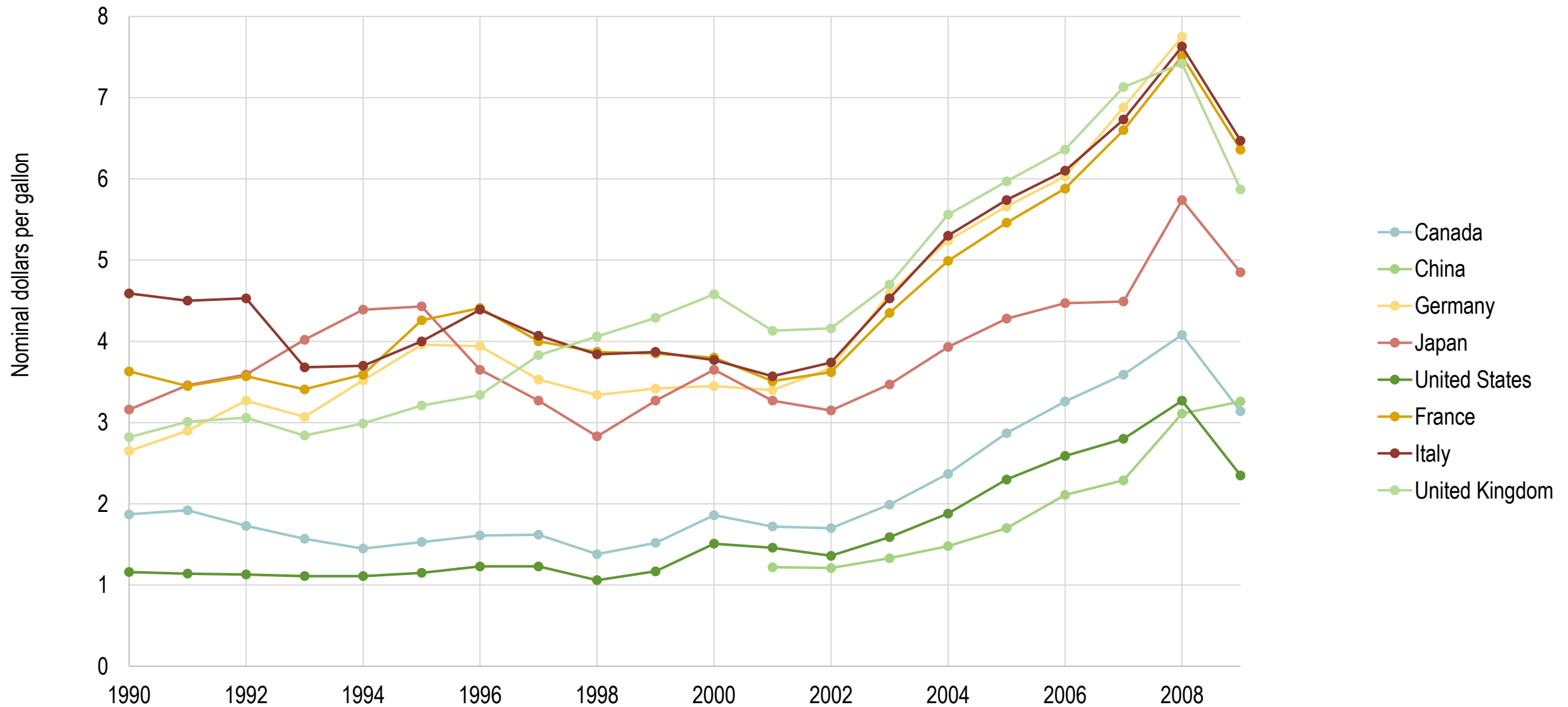
Components of Retail Costs of Gasoline, United States, 1999-2016



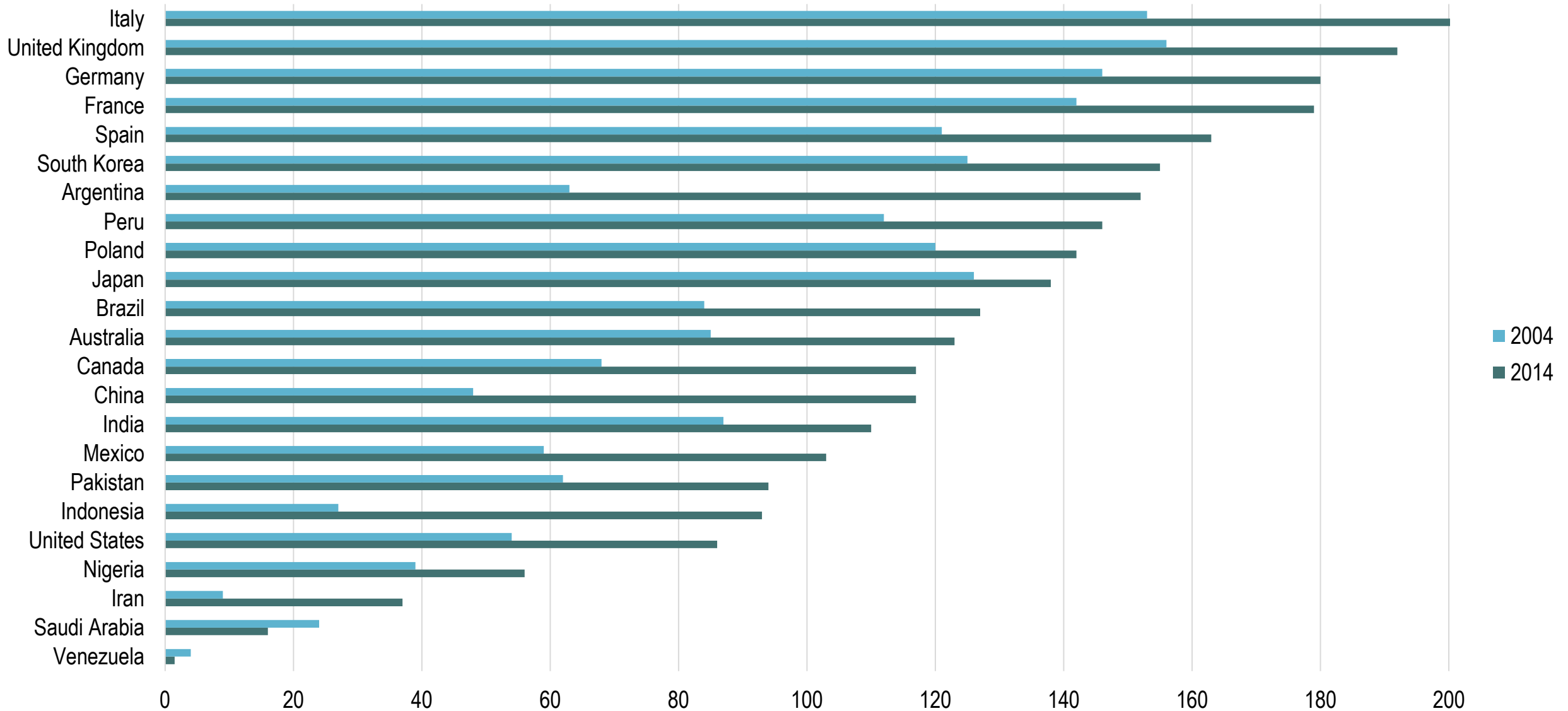
Automobile Emission Factors



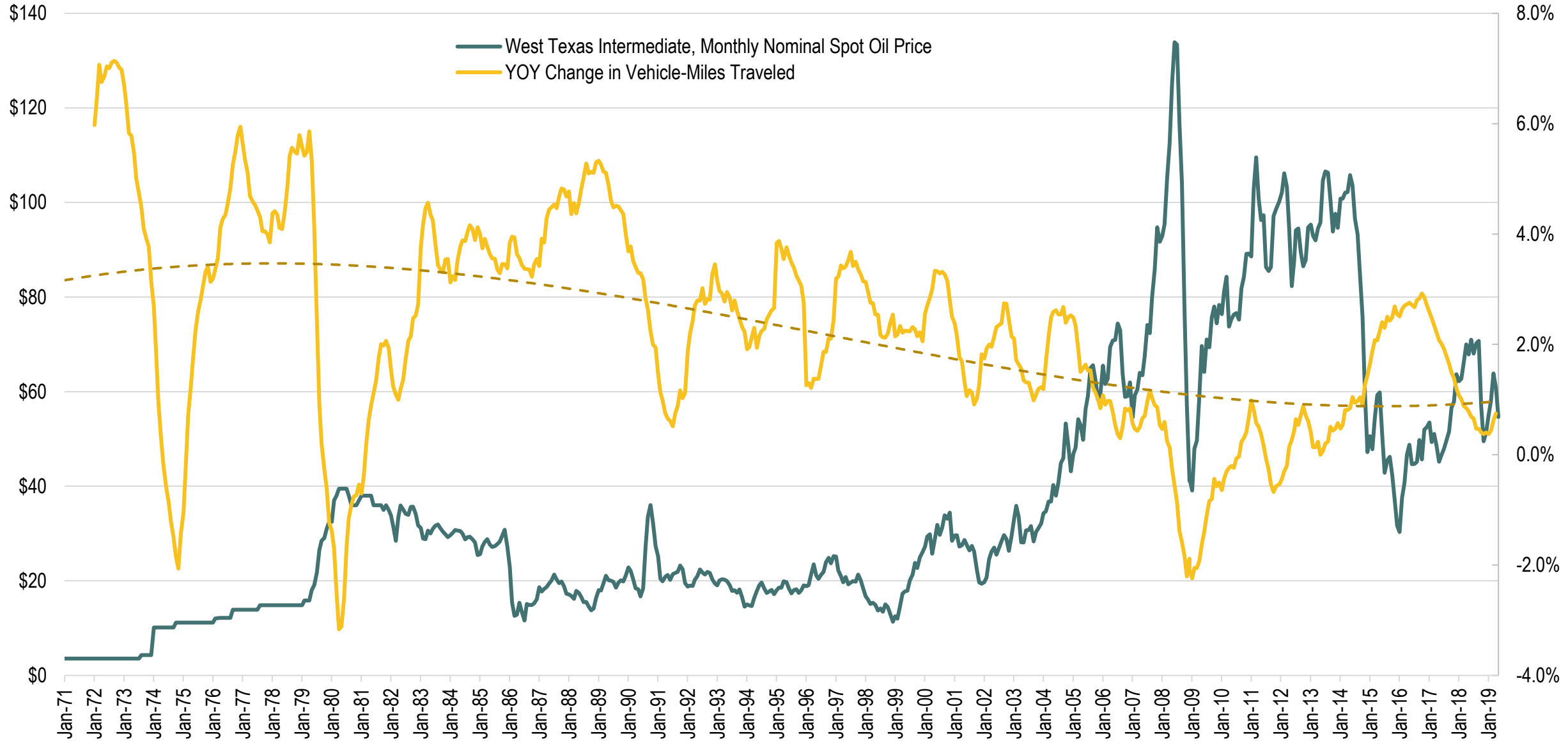
Retail Motor Gasoline Prices, Selected Countries, 1990-2009



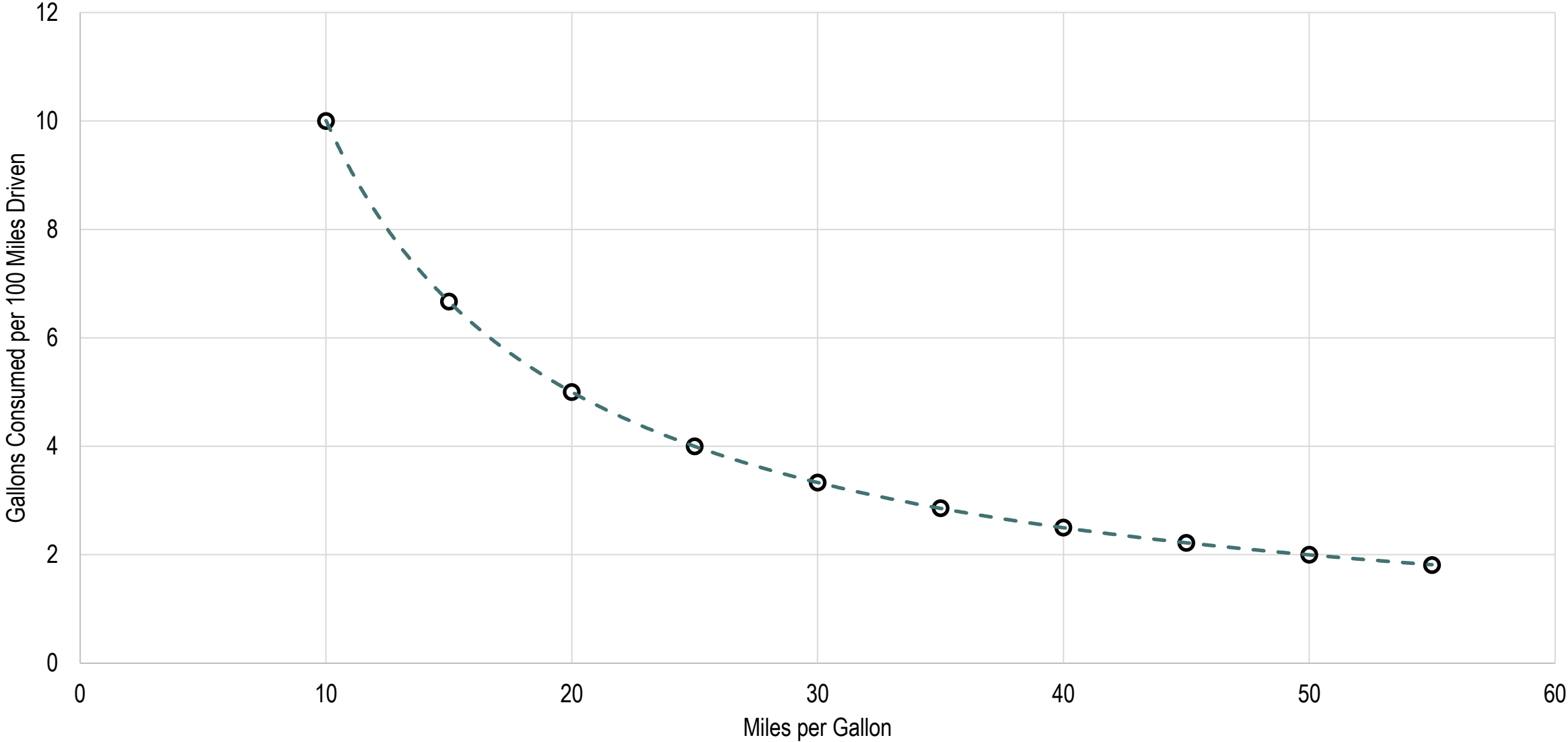
Retail Motor Gasoline Prices (cents per liter), Selected Countries, 2004-2014



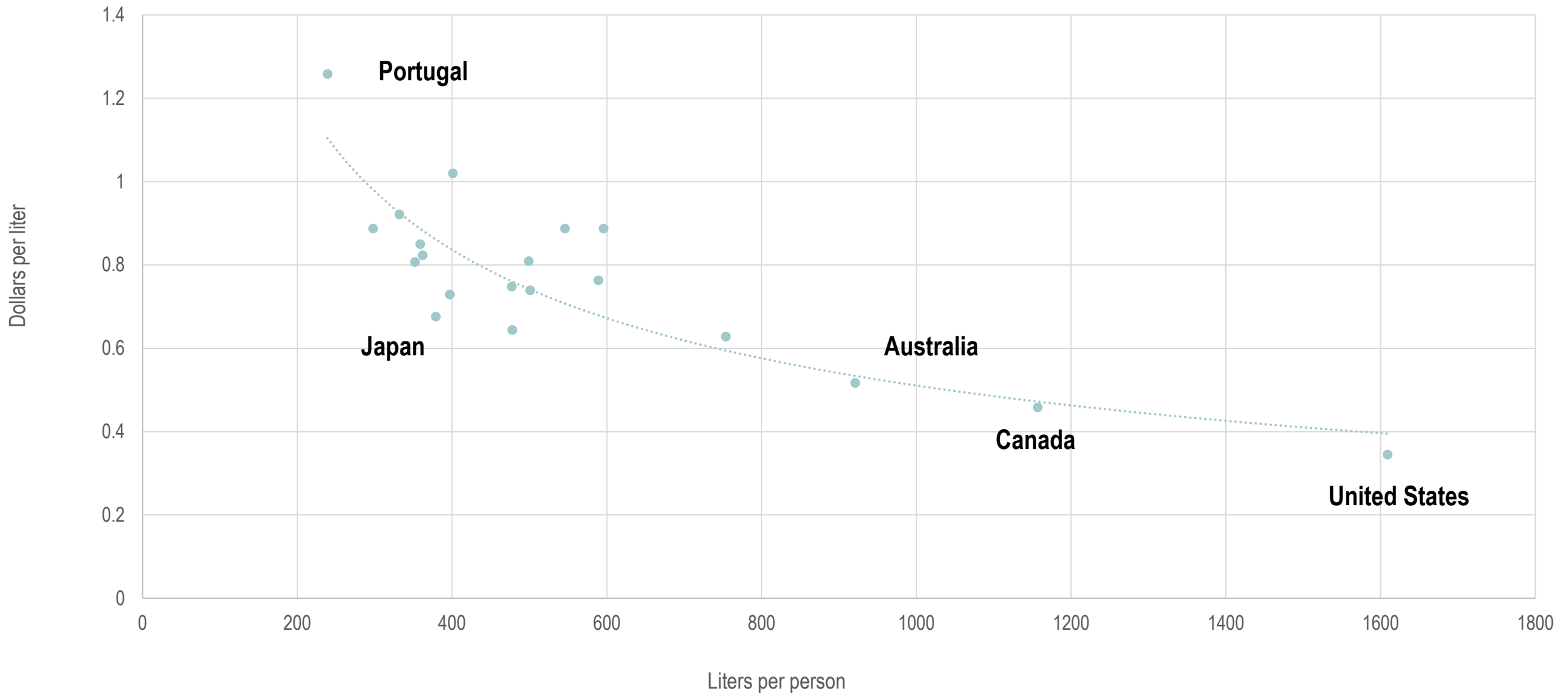
Annual Vehicle-Miles Traveled in the United States, Year-over-Year Changes, 1971-2019



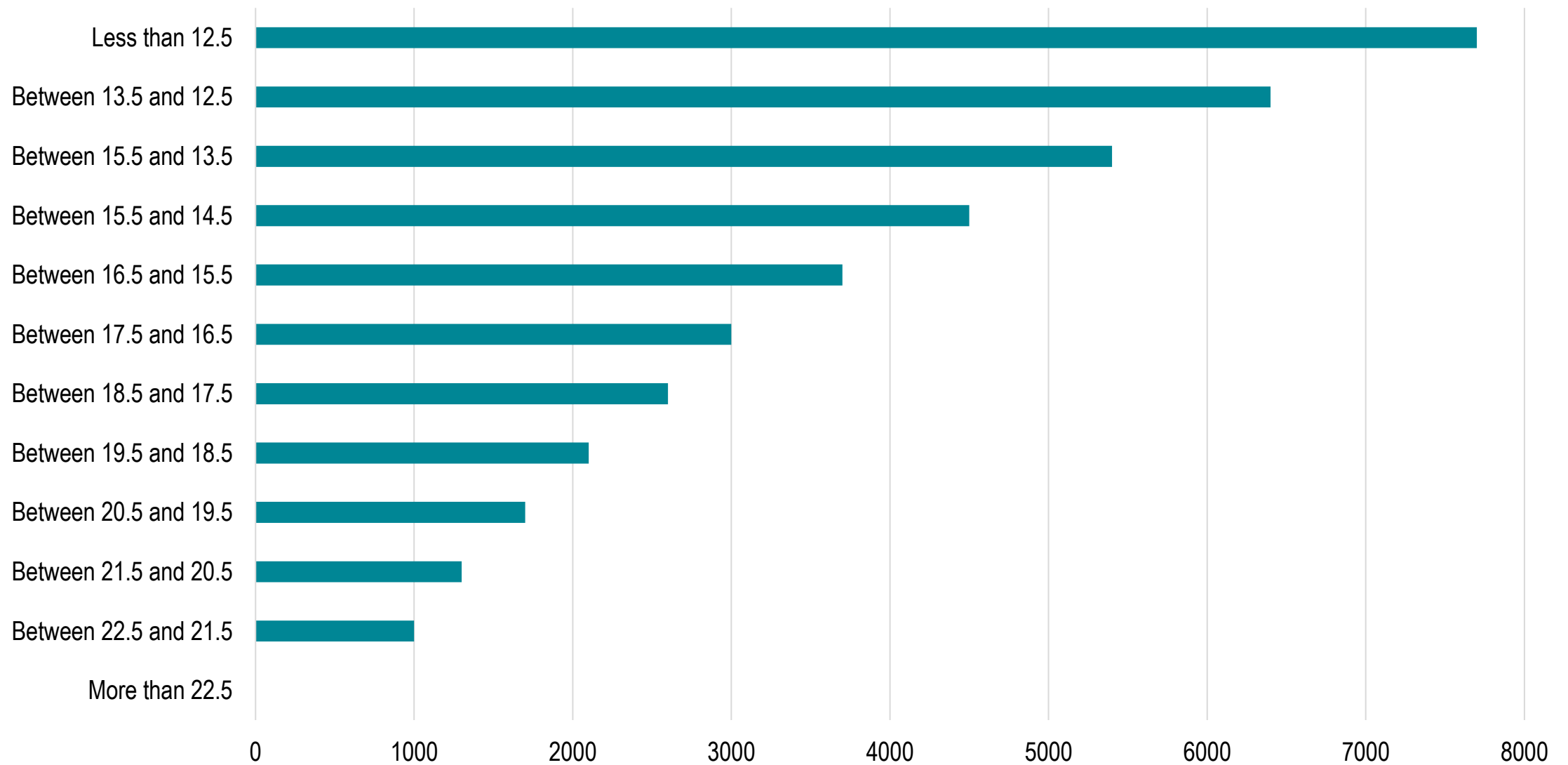
Automobile Fuel Consumption and Fuel Efficiency



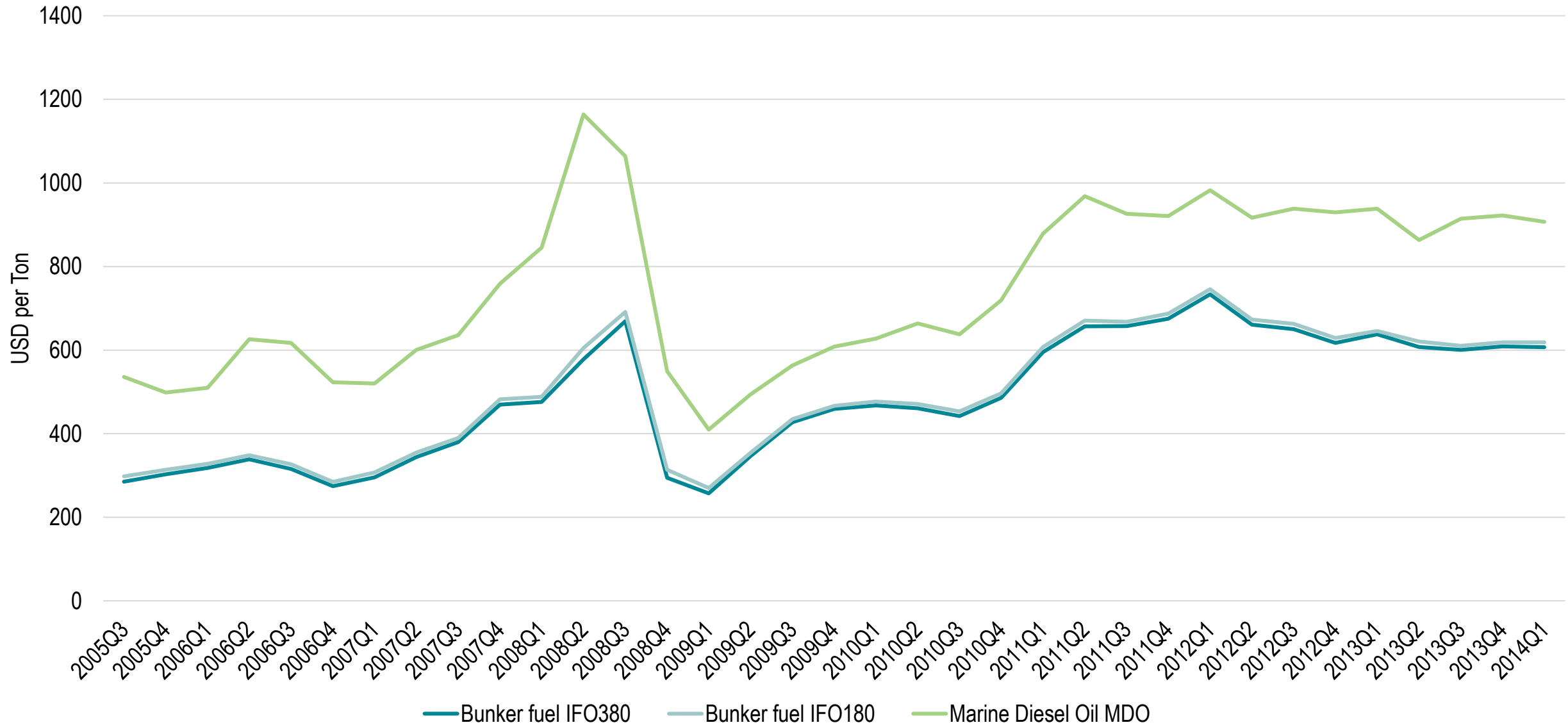
Gasoline Price and Fuel Consumption, Western Industrial Countries, 1994



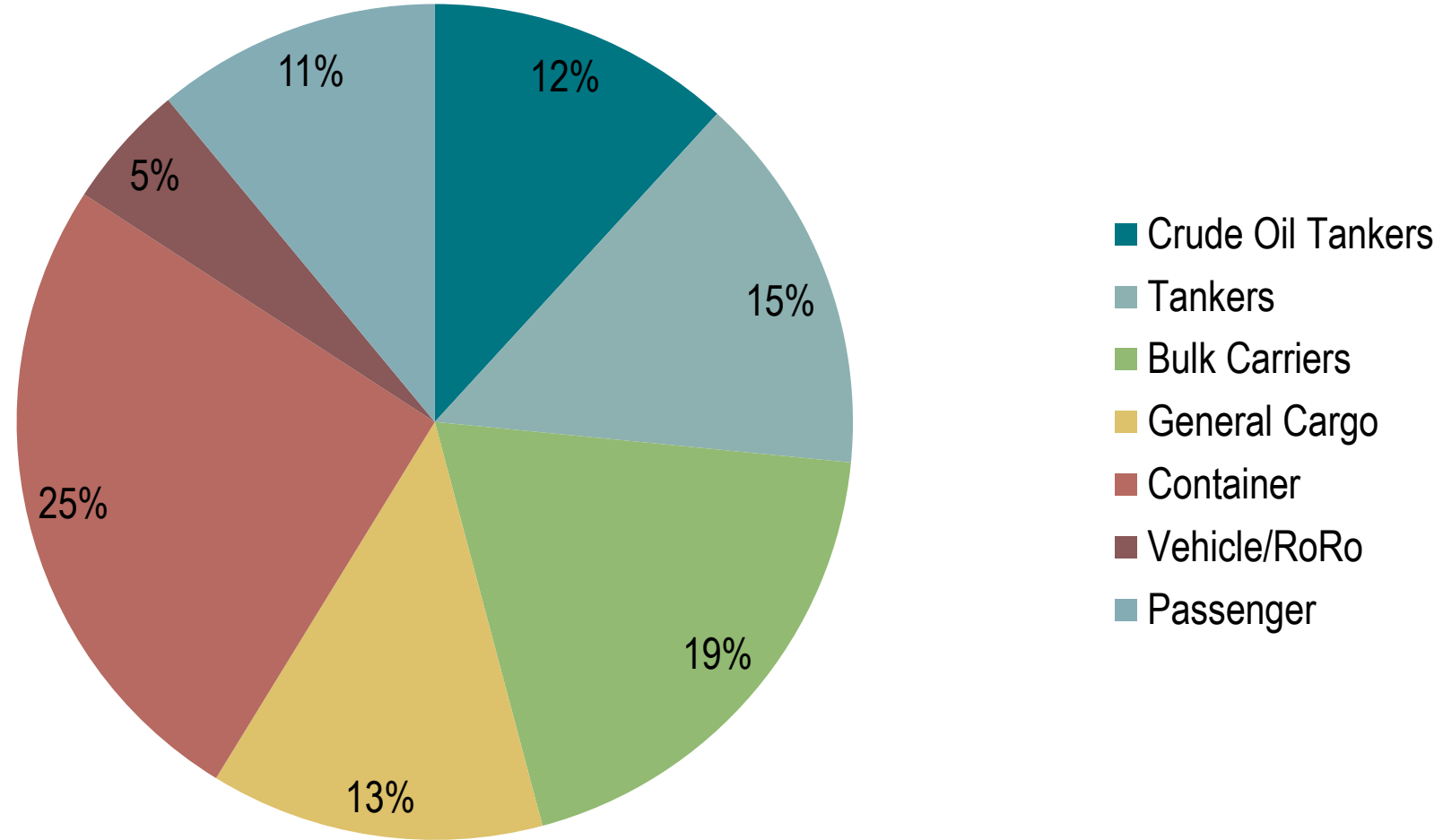
Gas Consumption Tax in the United States, 1999 (in \$ per mile per gallon per vehicle)



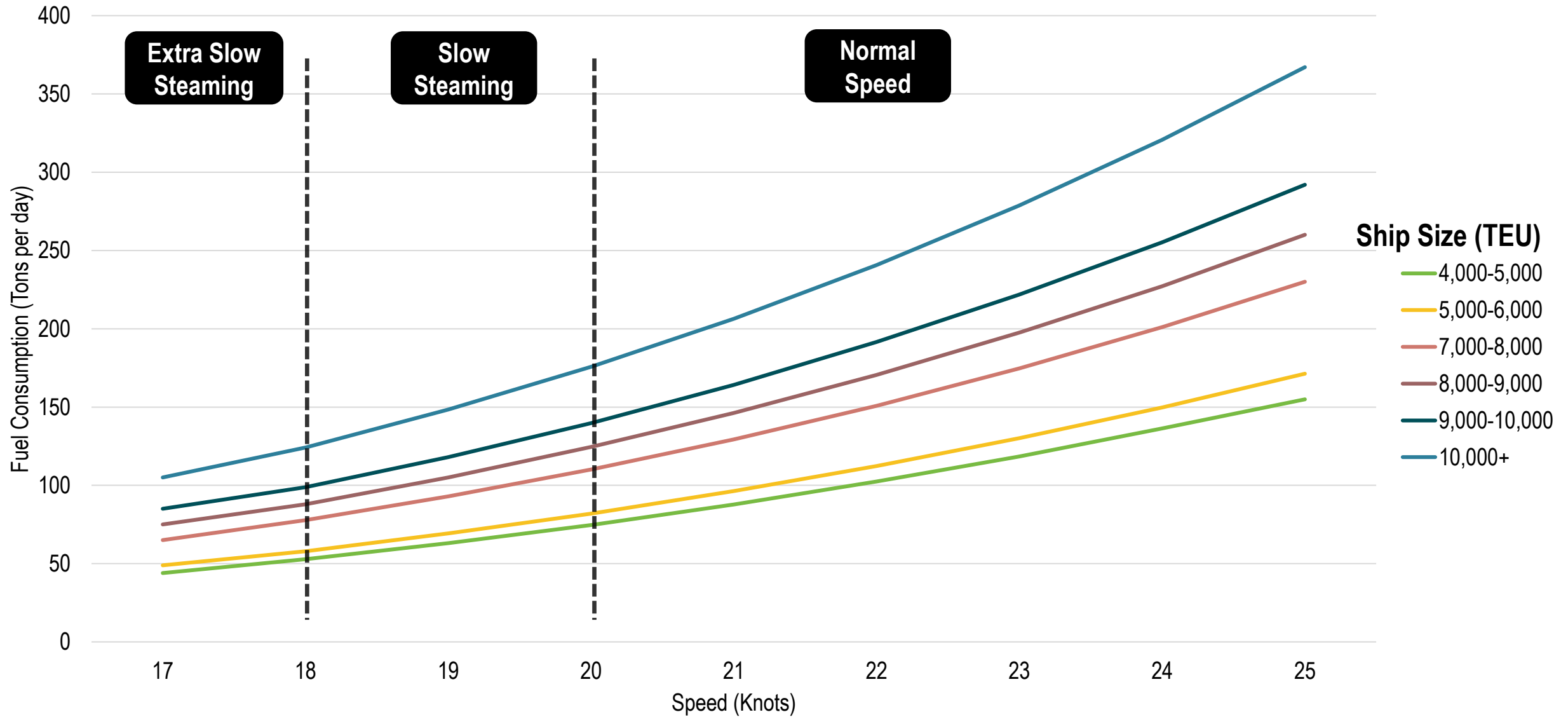
Bunker Fuel Spot Prices, Singapore FOB



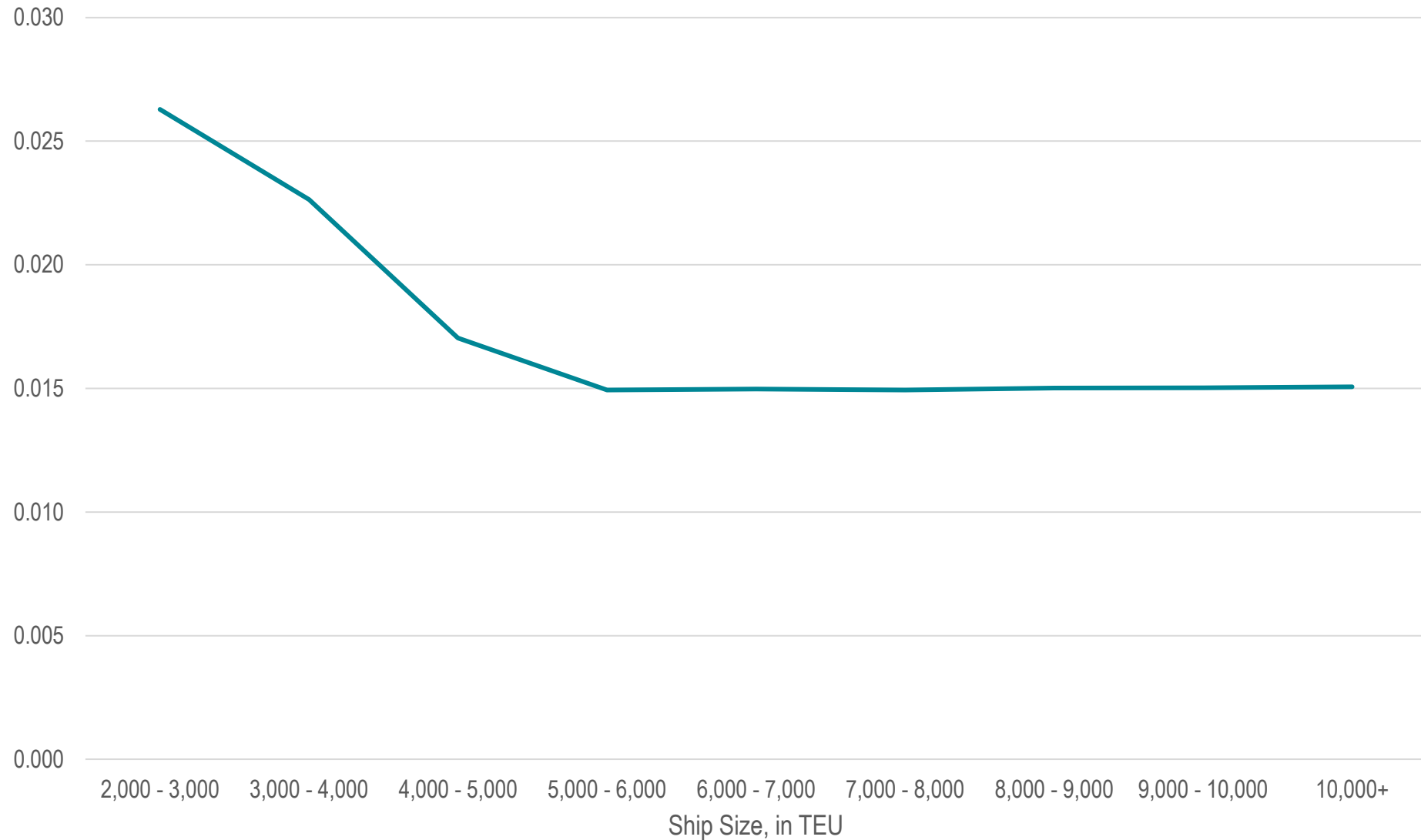
Fuel Consumption by Ship Category, 2007



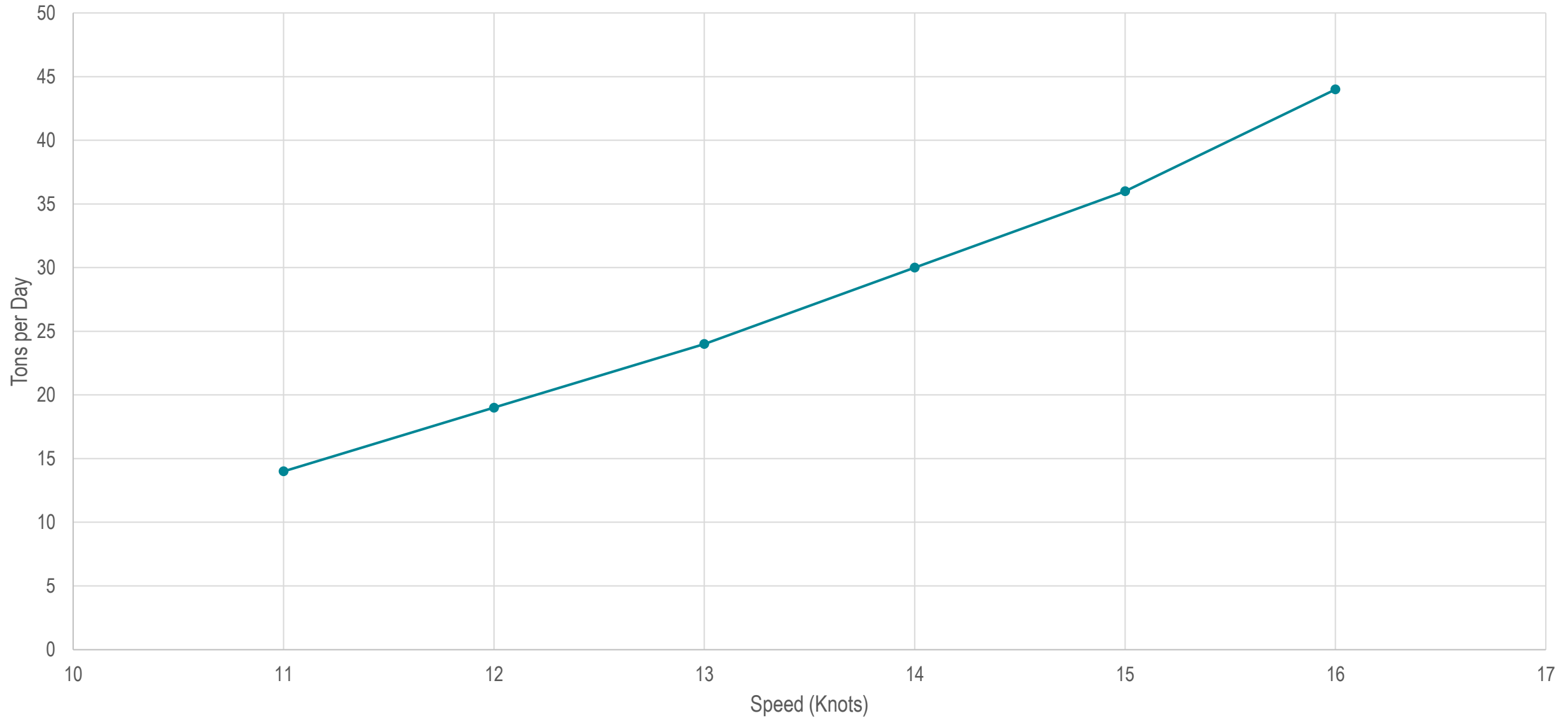
Fuel Consumption by Containership Size and Speed



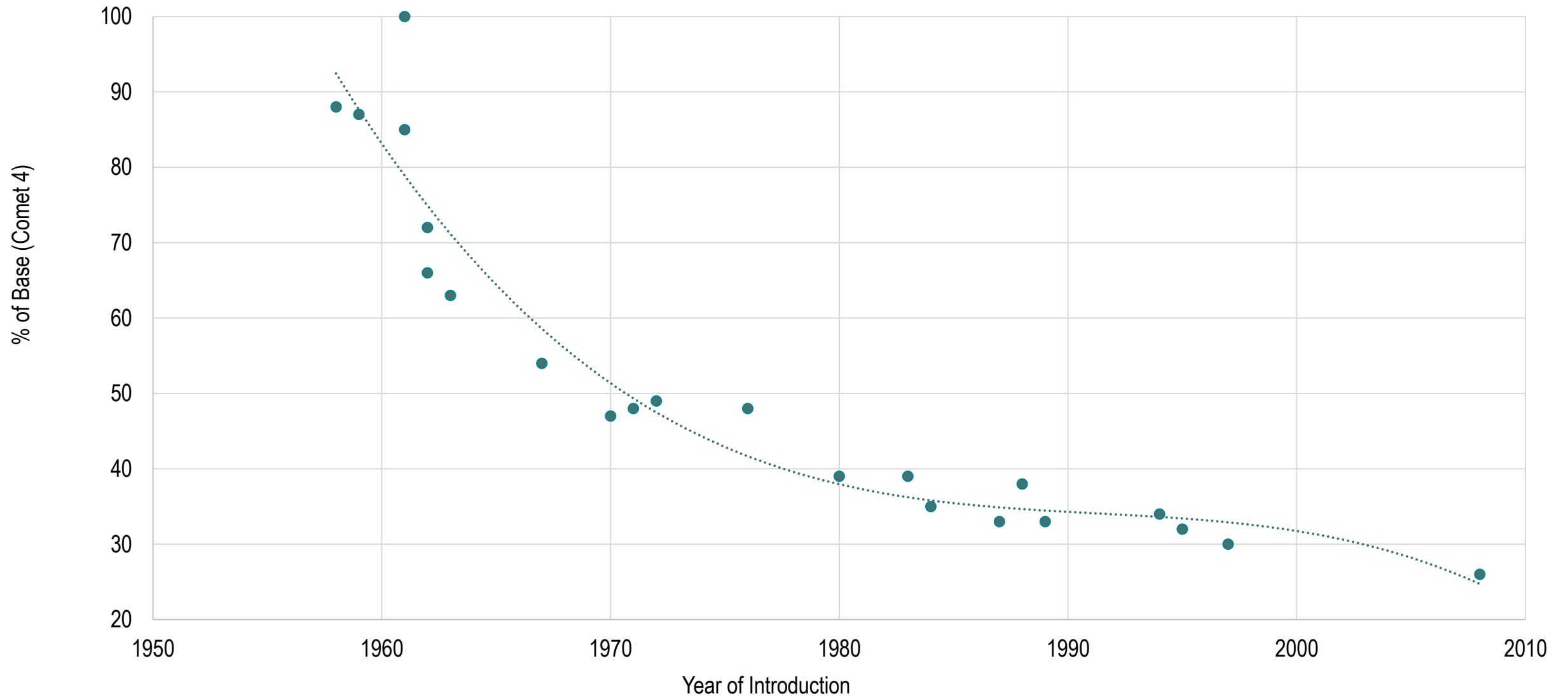
Fuel Consumption at 20 knots in Tons per TEU per Day by Containership Size



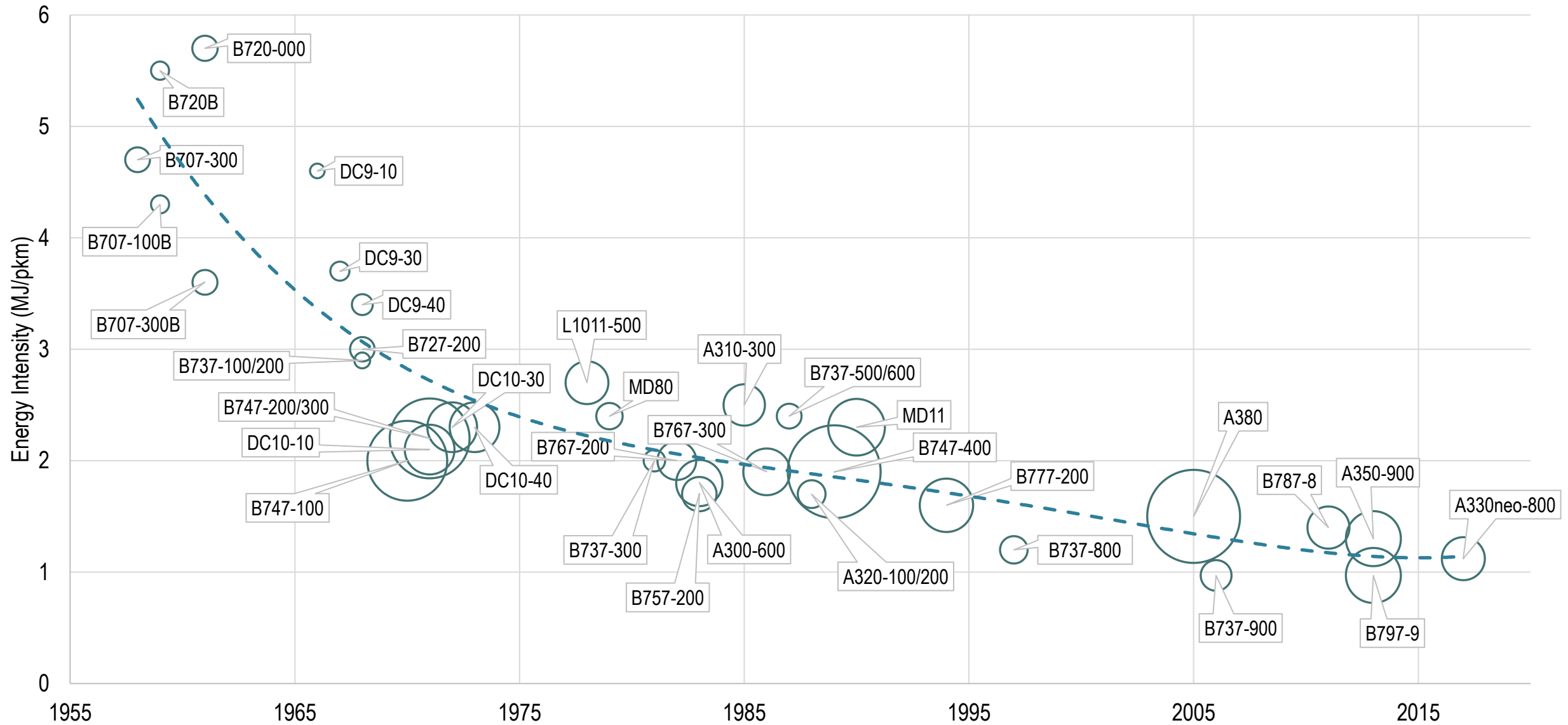
Effects of Speed on Fuel Consumption, Panamax Bulk Carrier



Trend in Aircraft Fuel Efficiency (Fuel burned per Seat)



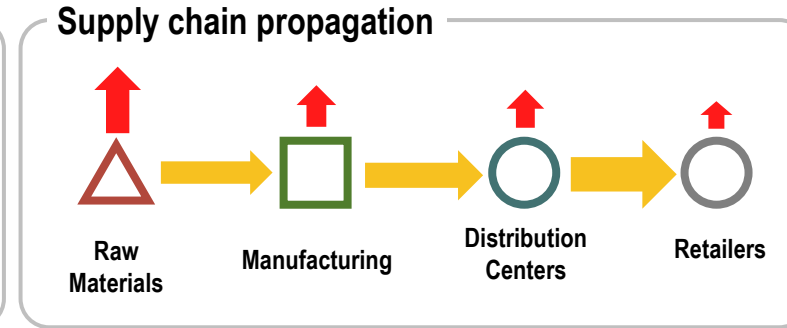
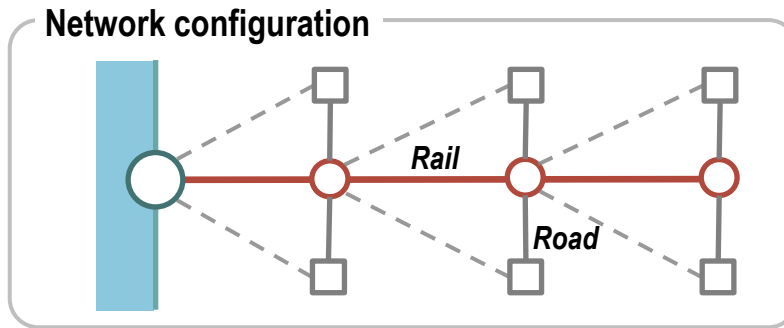
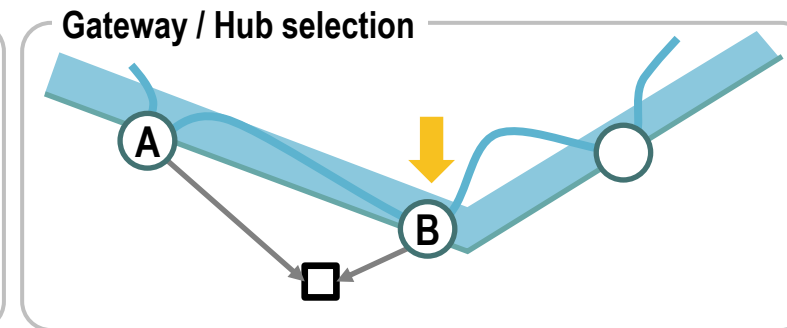
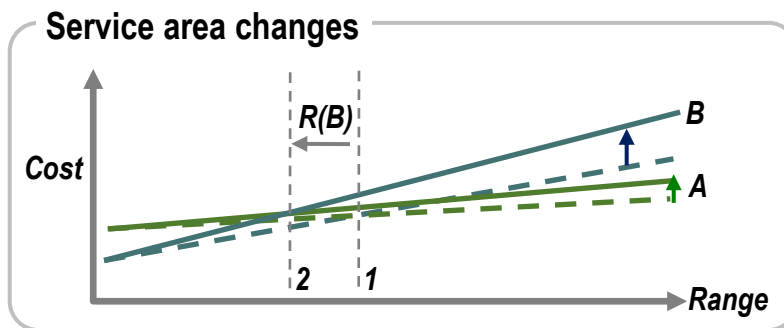
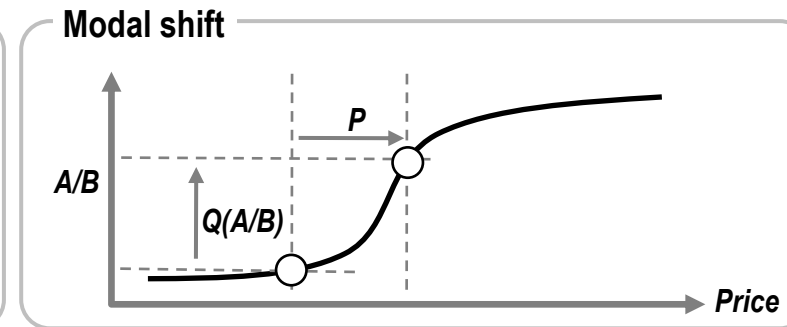
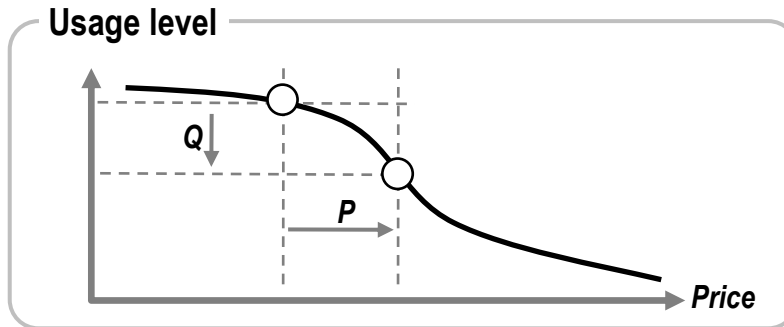
Trends in Fuel Efficiency, Selected Passenger Jet Planes



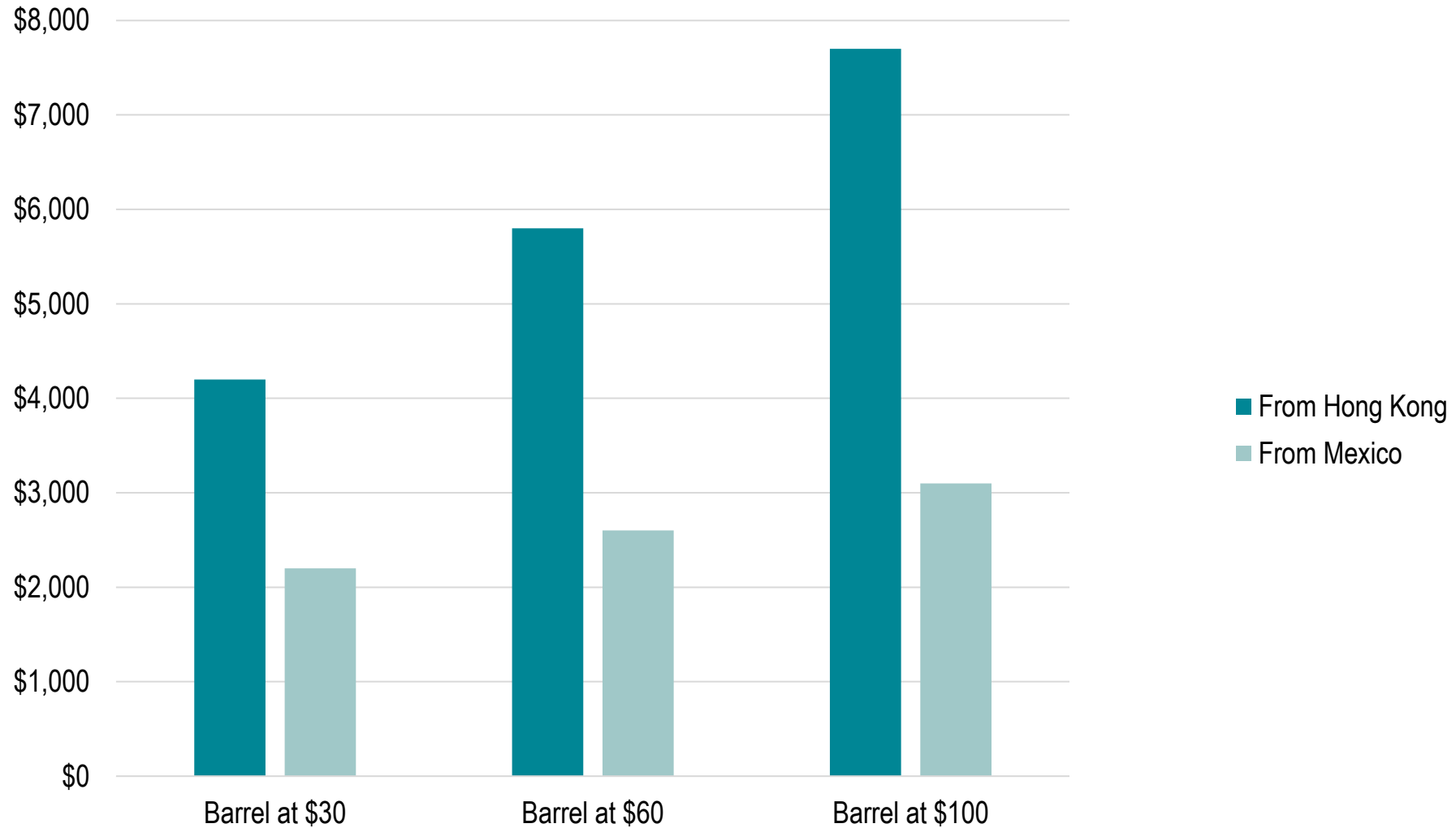
Potential to Reduce Energy Consumption in Air and Maritime Transportation

Sector	Category	Measure	Potential Improvements
Aviation	Operations	Advanced communications, navigation and surveillance (CNS) and air traffic management (ATM)	5%
	Airframe Design and Propulsion	More efficient turbofan engines, Unducted fan engines, Advanced lightweight materials, Improved aerodynamics, New airframe designs	30%
	Alternative Fuels	Medium term: Biofuels; Long term: Biofuels, Hydrogen	25%
Marine	Operations	Speed reduction, Optimized routing, Reduced port time	45%
	Ship Design and Propulsion	Novel hull coatings and propellers, Fuel efficiency optimization, Combined cycle operation, Multiple engines	35%
	Alternative Fuels and Power	Marine diesel oil (MDO), Liquefied natural gas (LNG), Wind power sails	40%

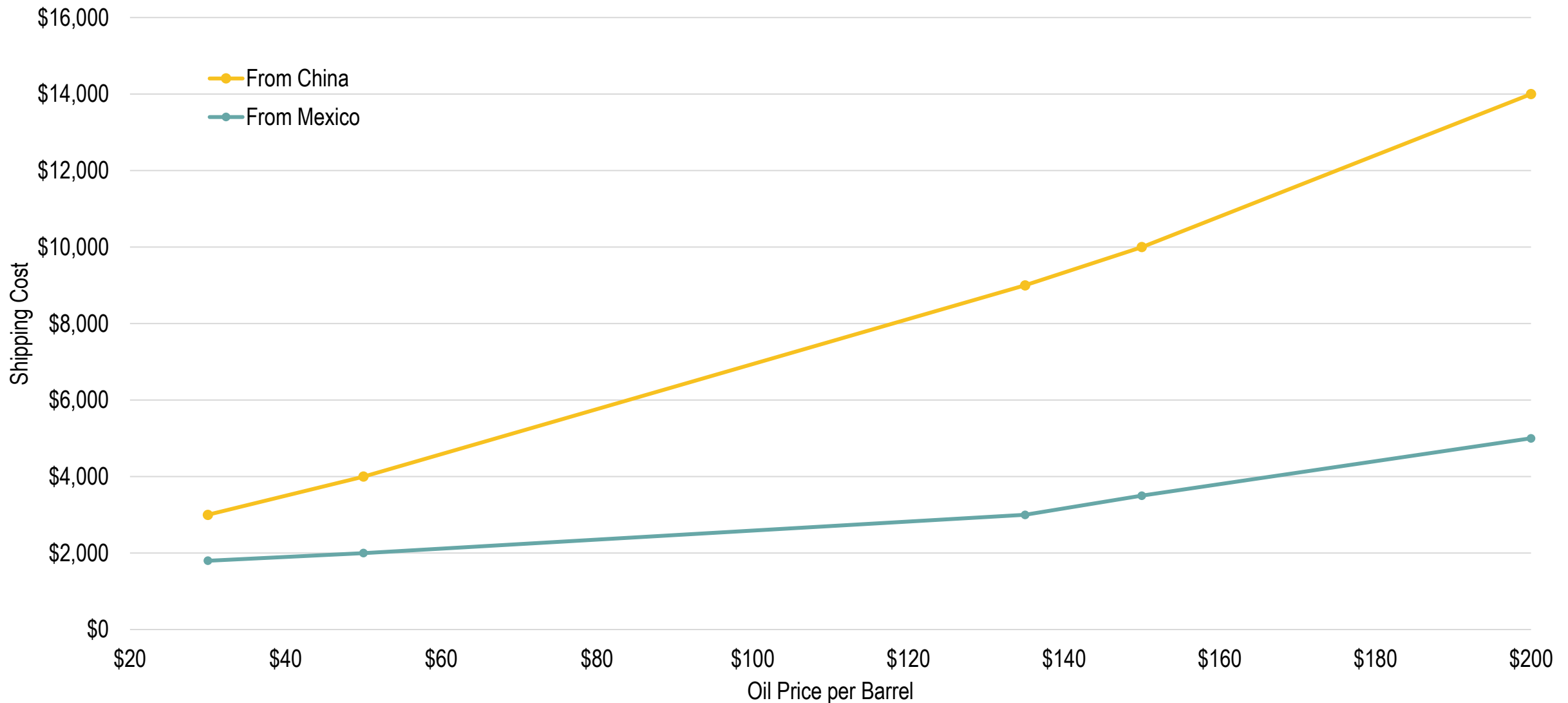
Potential Impacts of High Energy Prices on Transportation

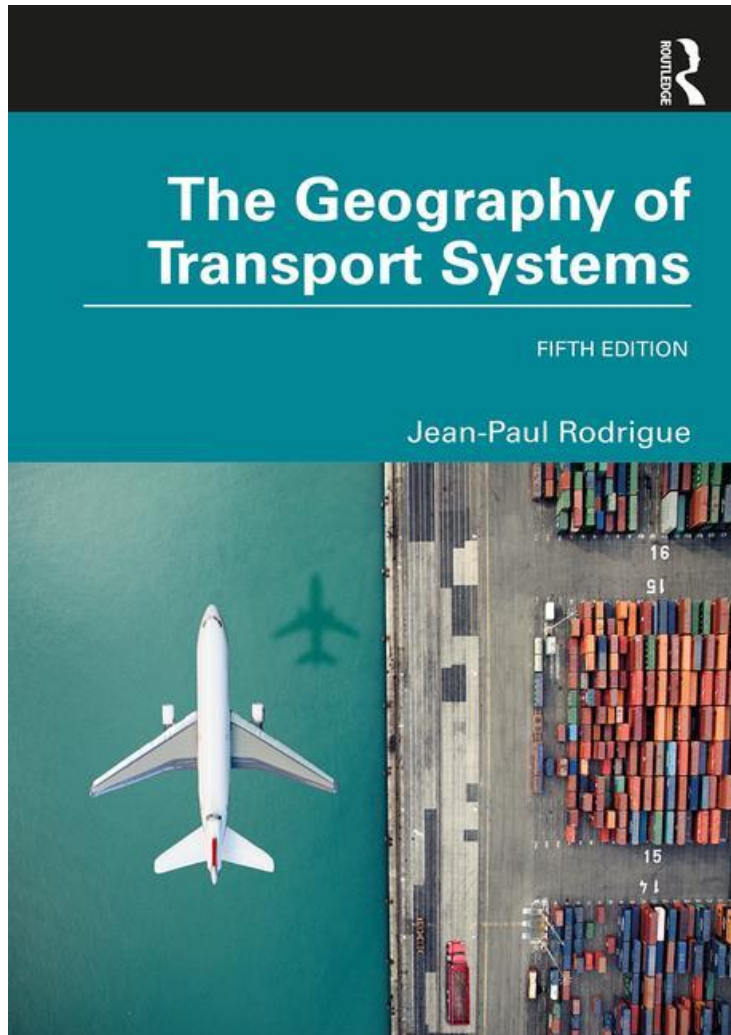


Costs of Shipping a 40 foot Container to New York



Costs of Shipping a 40-foot Container to the American East Coast

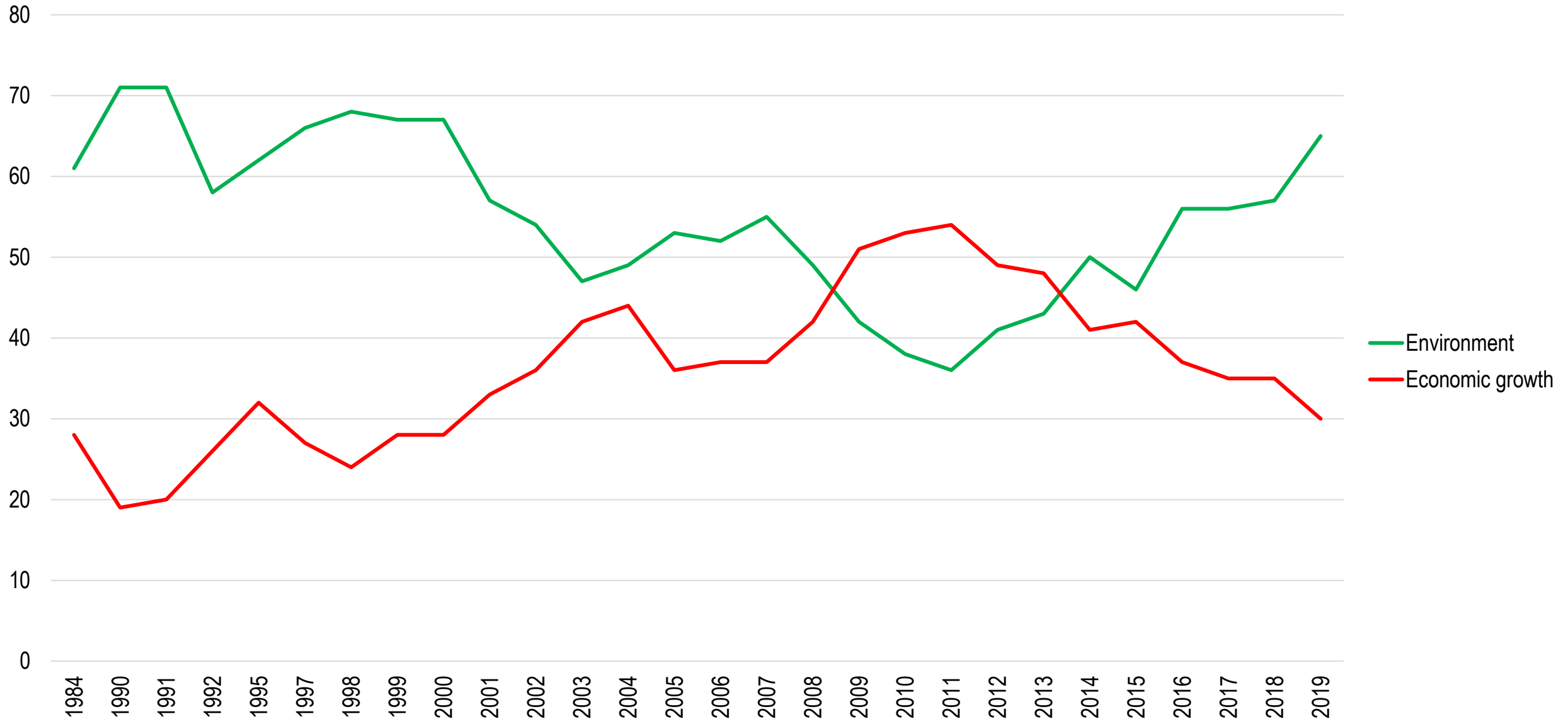




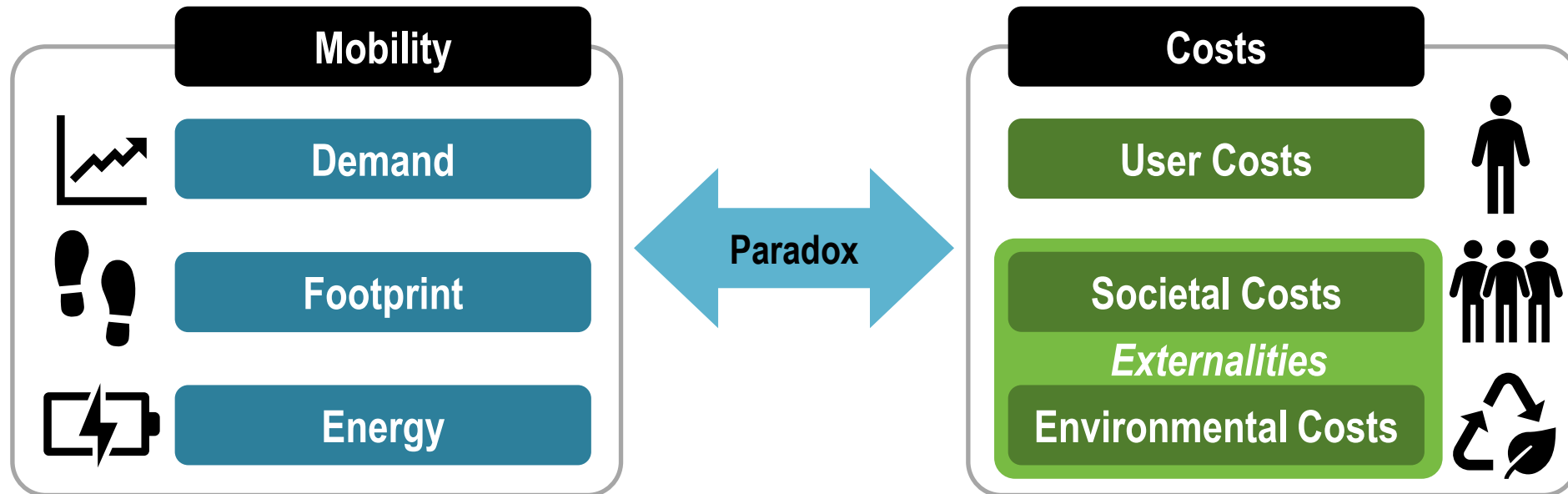
Transportation and the Environment

Chapter 4.2

Public Preferences for Priority between the Economy and the Environment, 1984-2019



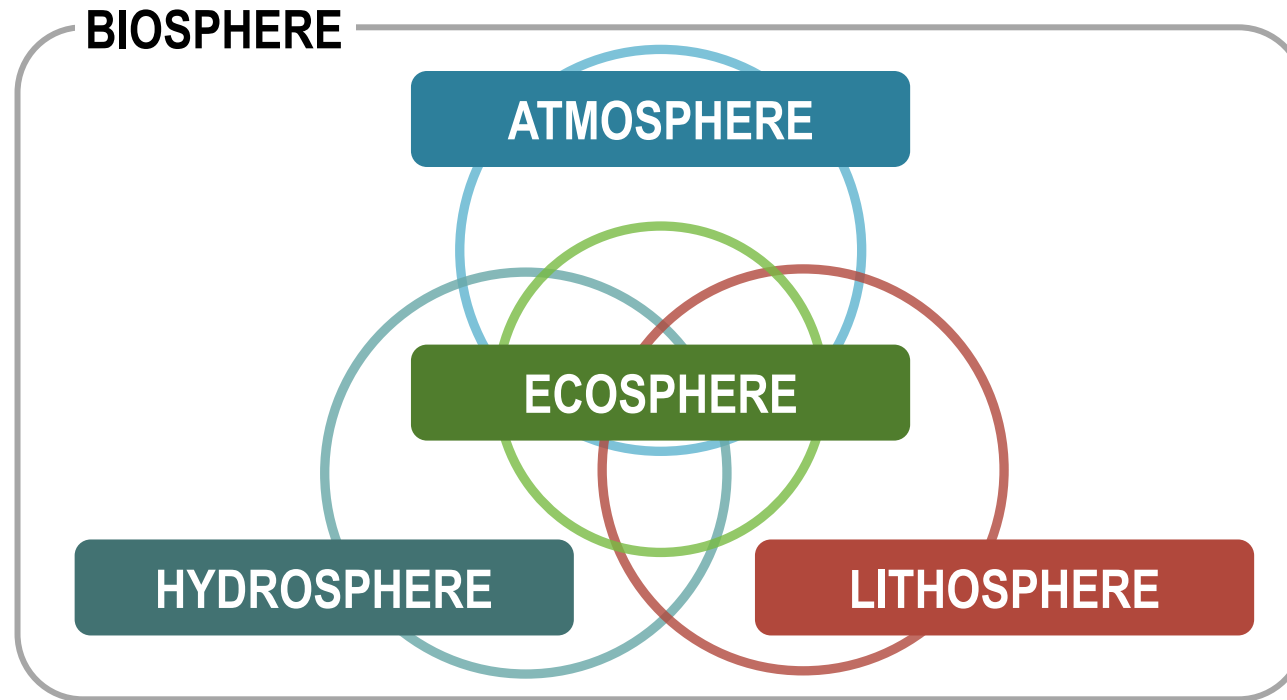
The Paradox of Mobility and its Costs



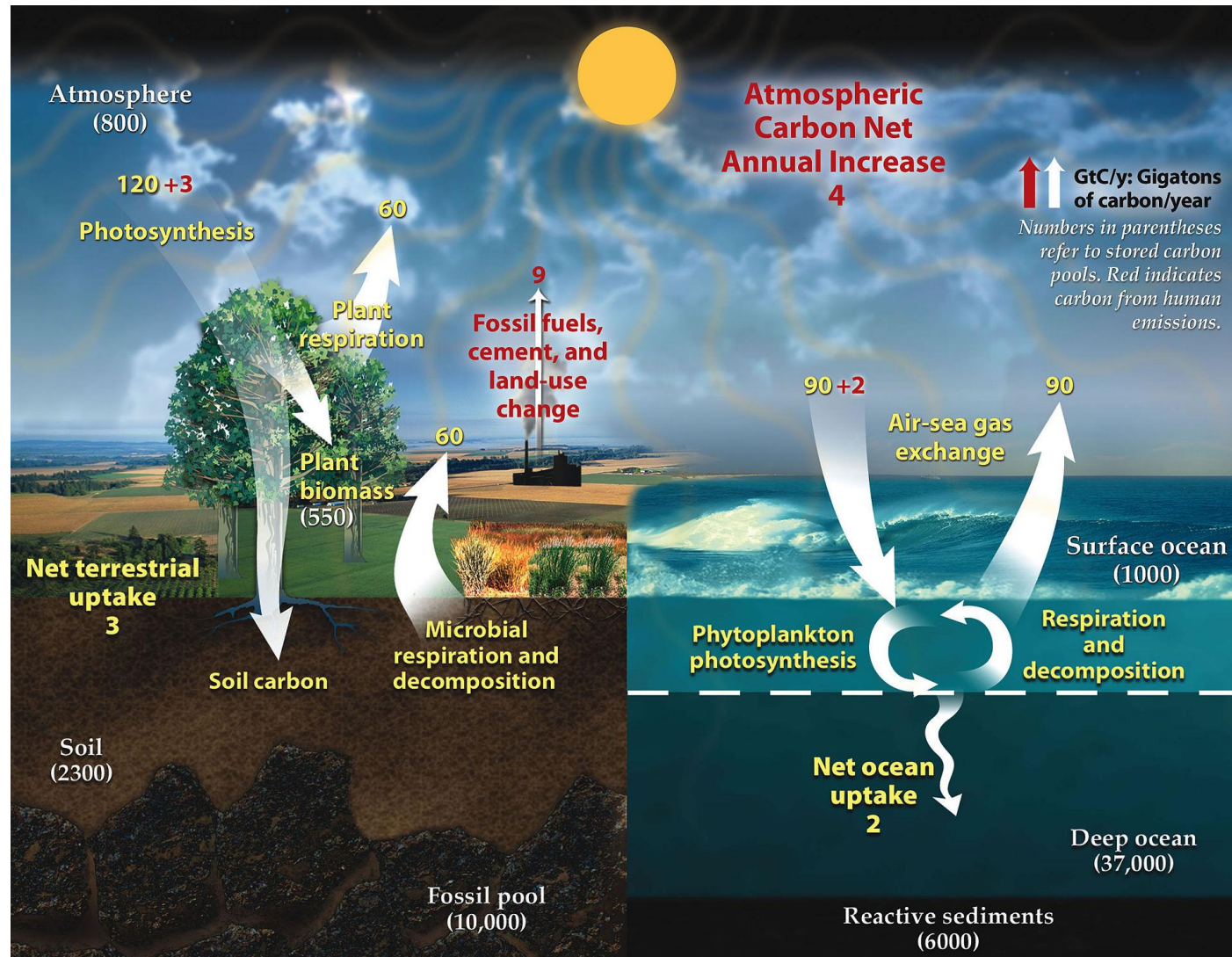
Environmental Costs Hierarchy

Cost Type	Implications
Internal	Material, labor, other expenses, and revenues that are commonly allocated to a product or process. Can easily be quantified (internalized).
Compliance	Expenses incurred by and benefits to the firm that are not related to products or processes. Mostly concern compliance to regulations.
Contingent	Potential liability or benefit that depends on the occurrence of a future event. Assessed as a risk.
Image / Relationship	Costs/benefits related to the subjective perceptions of a firm's stakeholders.
External	Costs/benefits of a company's impacts upon the environment and society that do not directly accrue to the business. Difficult to quantify (externalized).

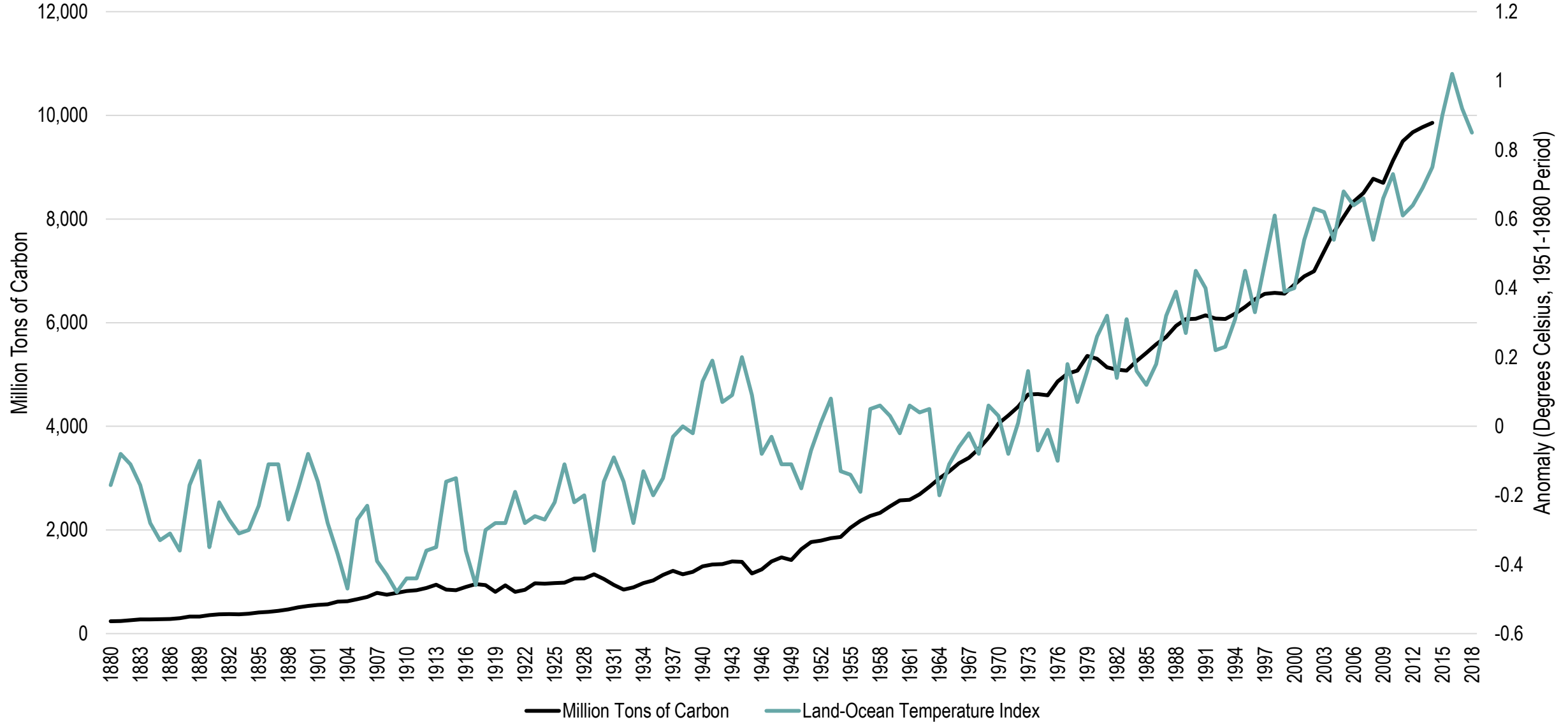
The Environmental System



The Carbon Cycle



Average Global Temperature and World Carbon Emissions From Fossil Fuel Burning, (in millions of tons) 1880-2018



The Environmental Impacts of Transportation

1. ATMOSPHERE

- Large scale diffusion of pollutants.
- High growth on a short-term basis of the concentration of pollutants because of local conditions (e.g. smog).
- Photochemical reactions caused by ultraviolet rays, notably over ozone, sulfur dioxide and nitrogen dioxide.
- Climatic changes (global warming).
- Acid rain.
- Synergetic effects when pollutants are combined (e.g. smog and greenhouse gases).

2. HYDROSPHERE

- Diffusion of pollutants in a dissolved or colloidal state.
- Acidification and loss of neutralizing potential of ground and underground water.
- Drops of pH following snow melting (aquatic organism are particularly vulnerable).
- Growth in the solubility of several metals because of acidification.
- Additions of organic compounds, aluminum, manganese, calcium, magnesium and potassium by runoffs.
- Contamination of ground and underground water by nitrates.

3. LITHOSPHERE

- Acid depositions.
- Liberation of toxic metallic ions (aluminum, cadmium, etc.) through acidification.
- Loss of nutrients, notably calcium and magnesium.
- Inhibition of the mineralization of nitrogen.
- Modifications in the compositions and the depth of decomposition gradient.
- Inhibition of decomposition.
- Loss of the soil flora and fauna.
- Fixation by plants of heavy metals (e.g. lead) and contamination.
- Removal and consumption of land.
- Extraction of raw materials like mineral products and energy.

4. ECOSPHERE

4.1 AQUATIC ECOSPHERE

- Alteration of ecosystems in unforeseeable ways.
- Disappearance of vulnerable species and proliferation of tolerant ones.
- Reduction of bacterial treatment of organic matter by nitrification.
- Reduction of available nutrients to aquatic species.
- Reproductive impediments.

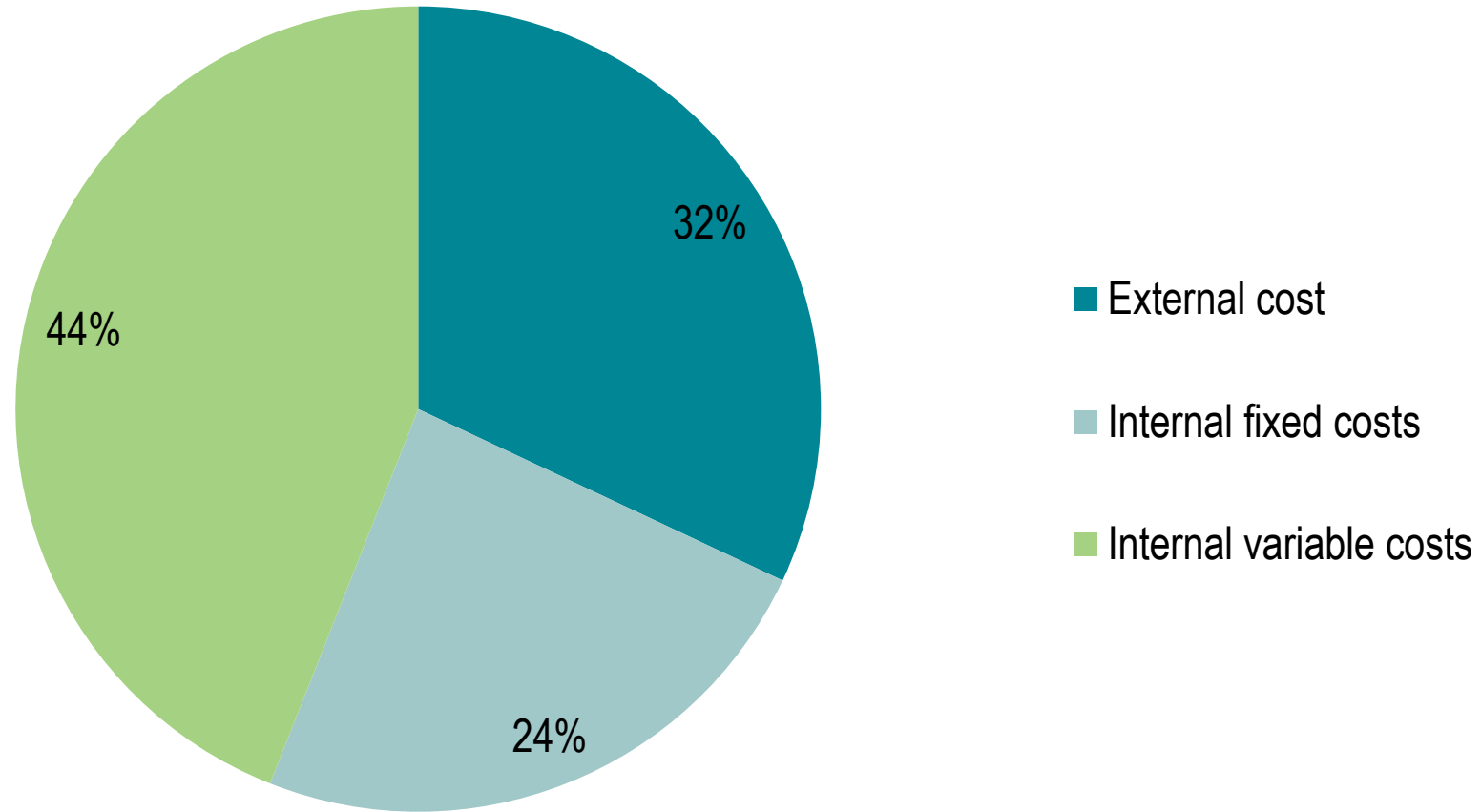
4.2 LAND ECOSPHERE

- Damages over the vegetation modifying:
 - hydric cycles.
 - the level of underground water resources.
 - soil erosion.
 - air purification capacity of the ecosphere.
 - food sources (agriculture).
 - entertainment and tourism.
- Reduction of the vital space.
- Reduction of the genetic potential of species.
- Reduction of the food supply and alteration of the food chain.
- Consumption of resources.

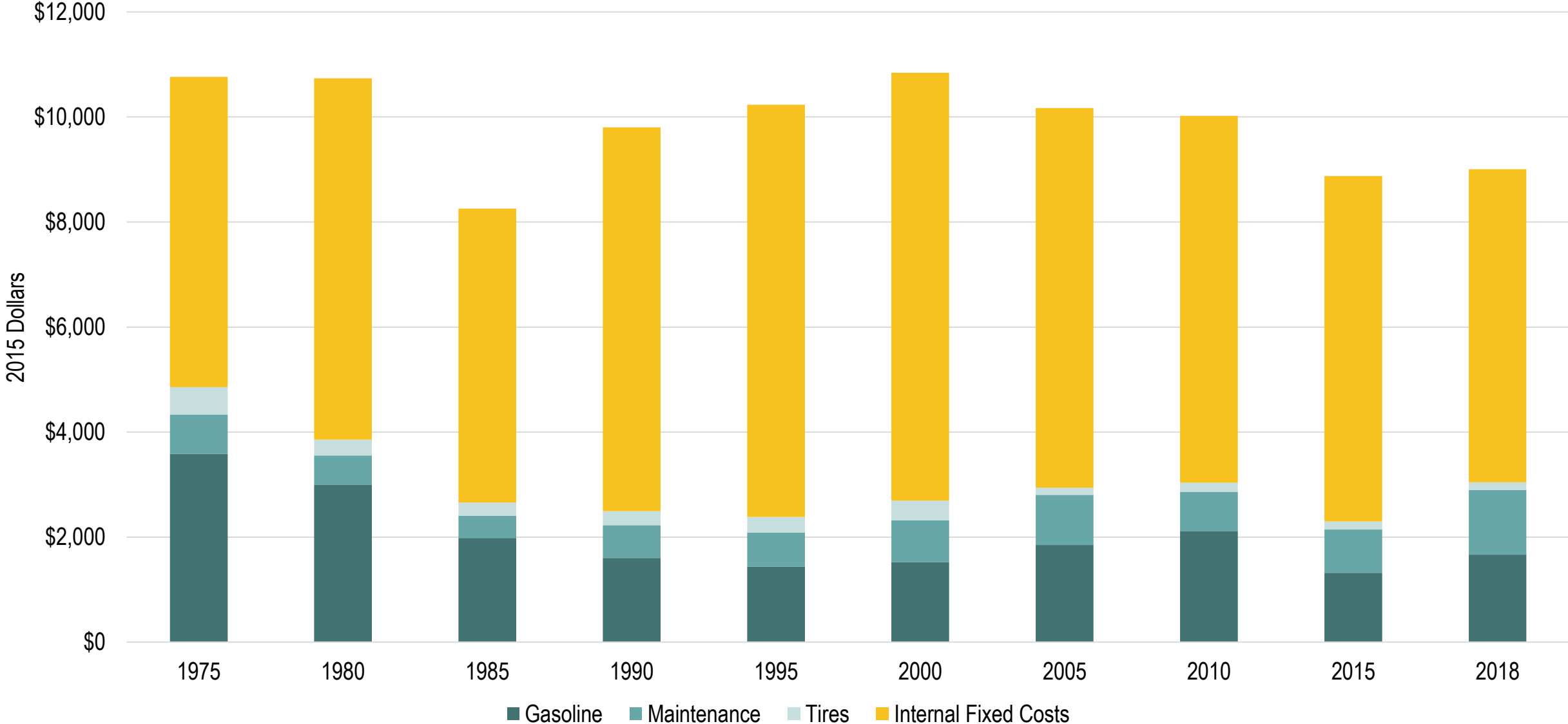
4.3 HUMAN ECOSPHERE

- Odors.
- Noise.
- Cardiovascular and respiratory problems.
- Susceptibility to infection.
- Drops in life expectancy.
- Injuries, incapacity, hospitalization, death.
- Damage to structures:
 - Loss of useful life. (amortization)
 - loss of property values.
 - corrosion of metal structures (bronze, steel, etc.).
 - destruction of historical and cultural monuments.

Estimated Automobile Costs, 2005

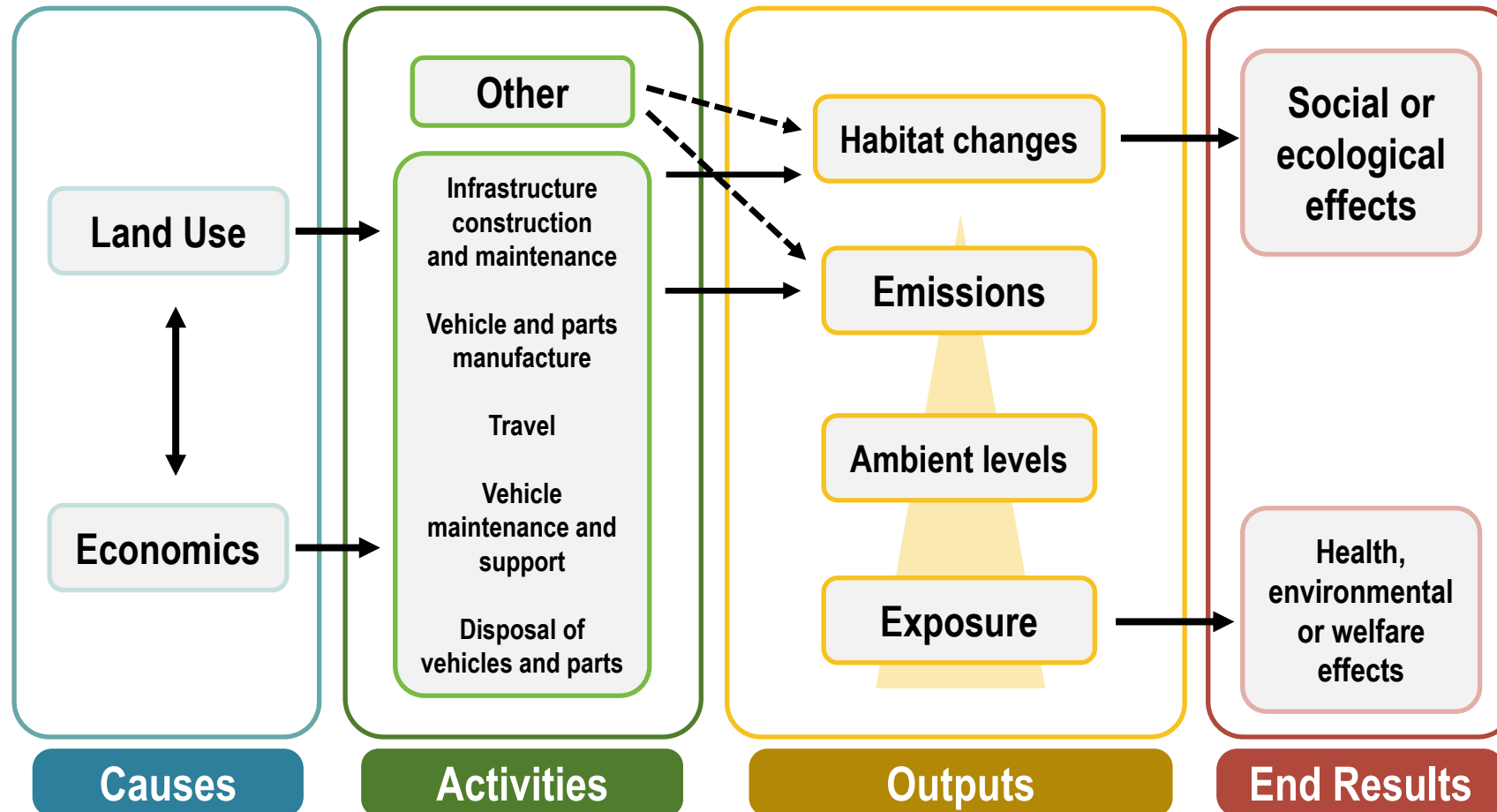


Average Cost of Owning and Operating an Automobile, 1975-2018

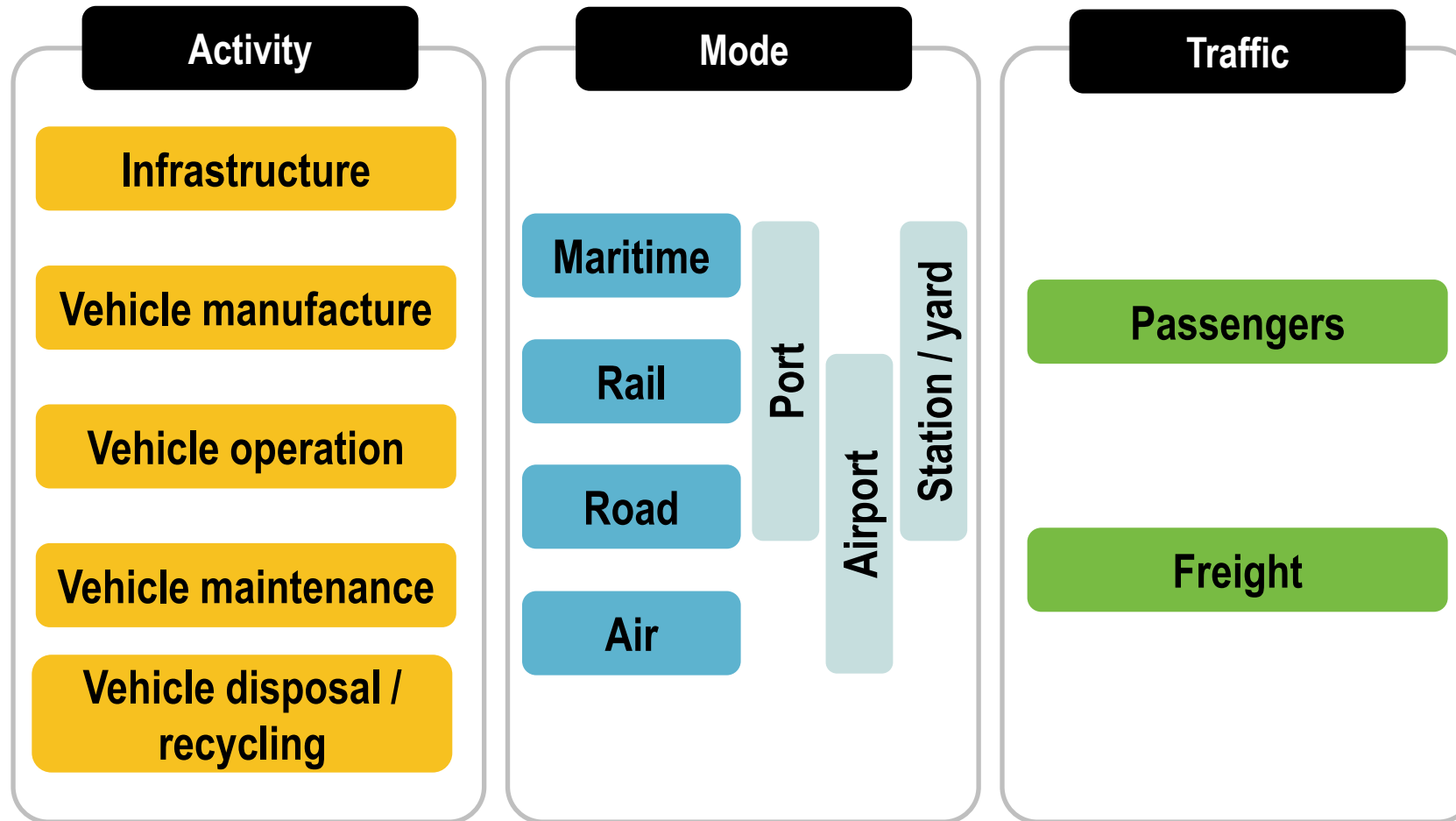


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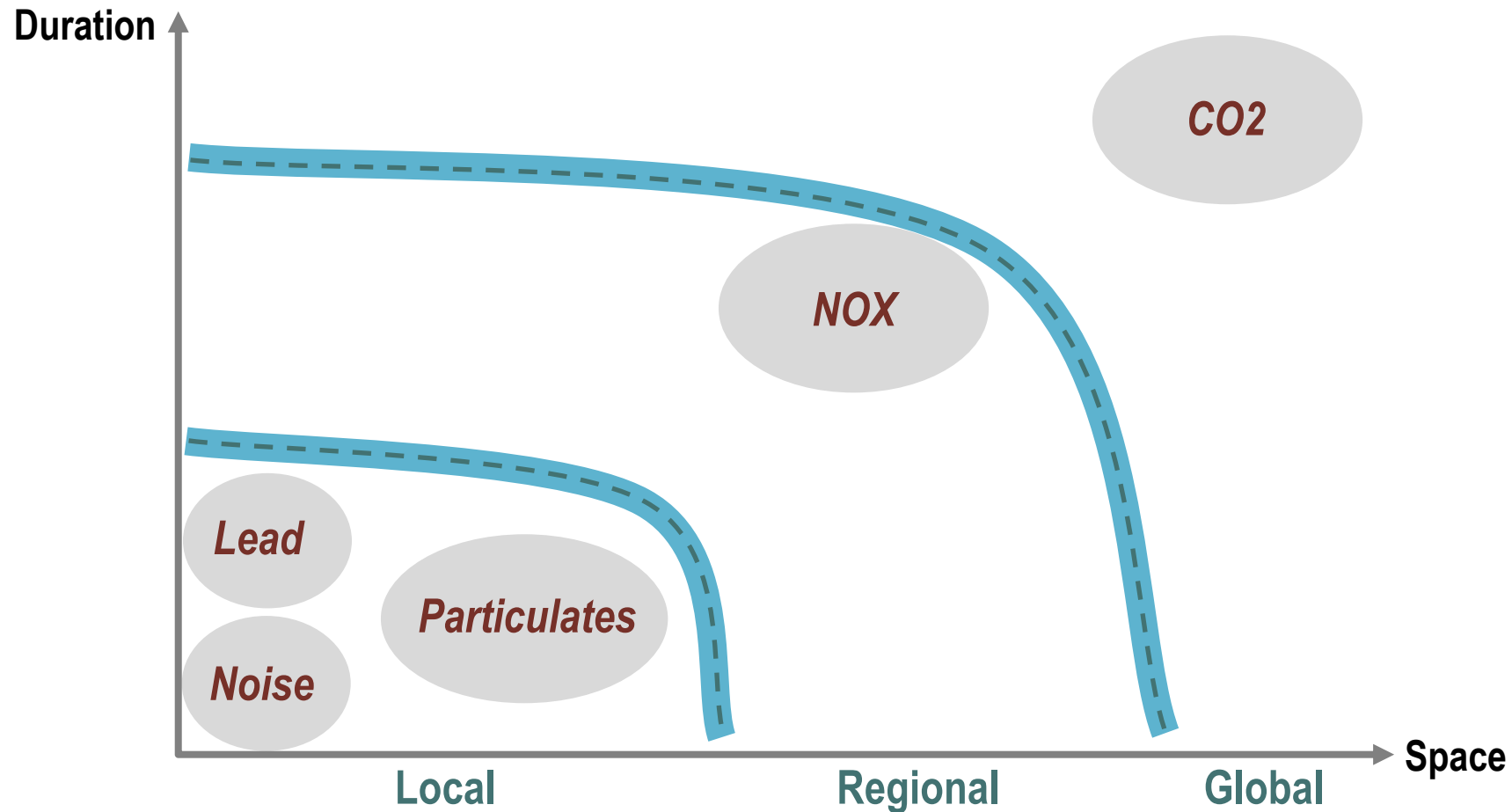
Environmental Dimensions of Transportation

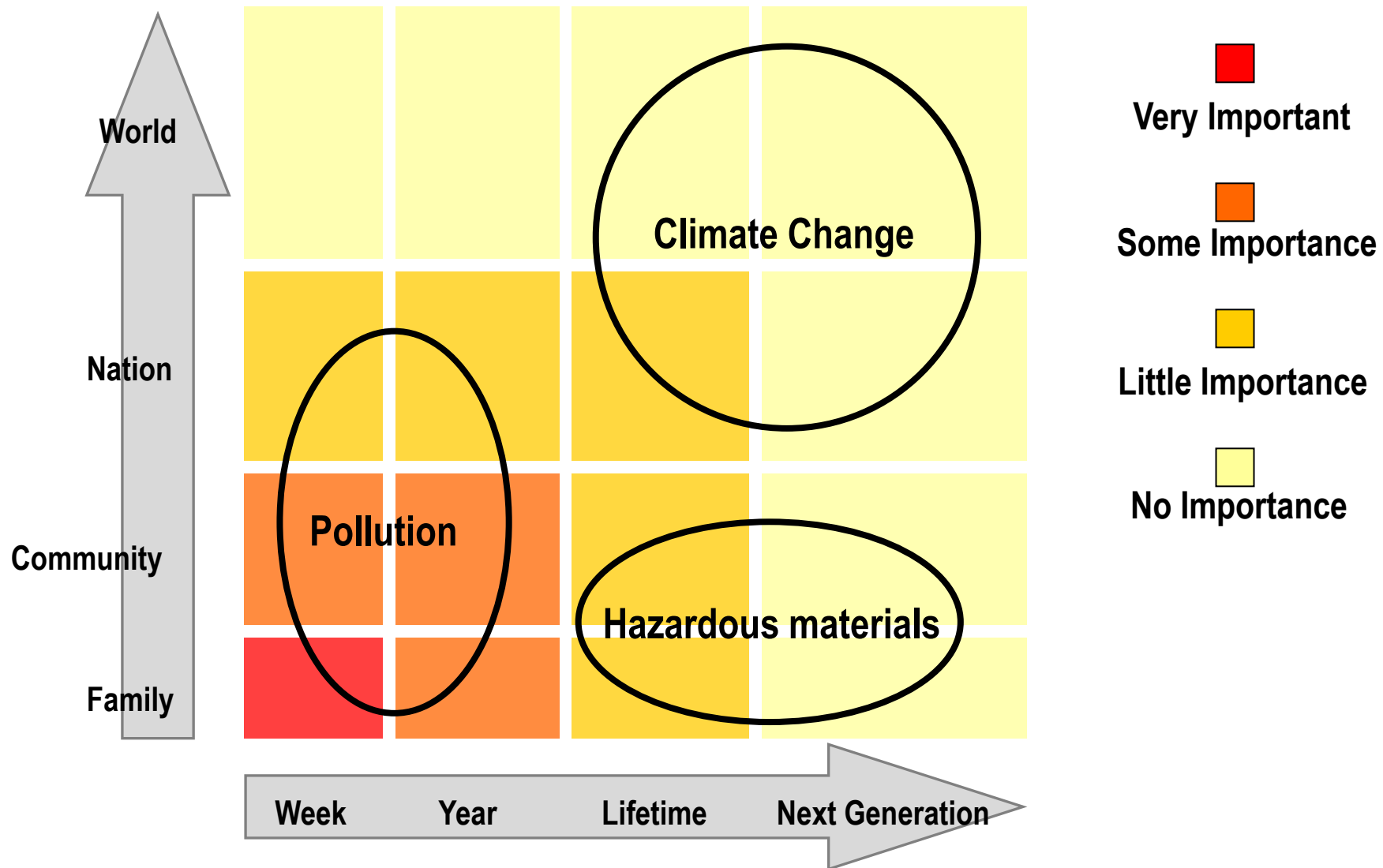


Transportation Activities Affecting the Environment

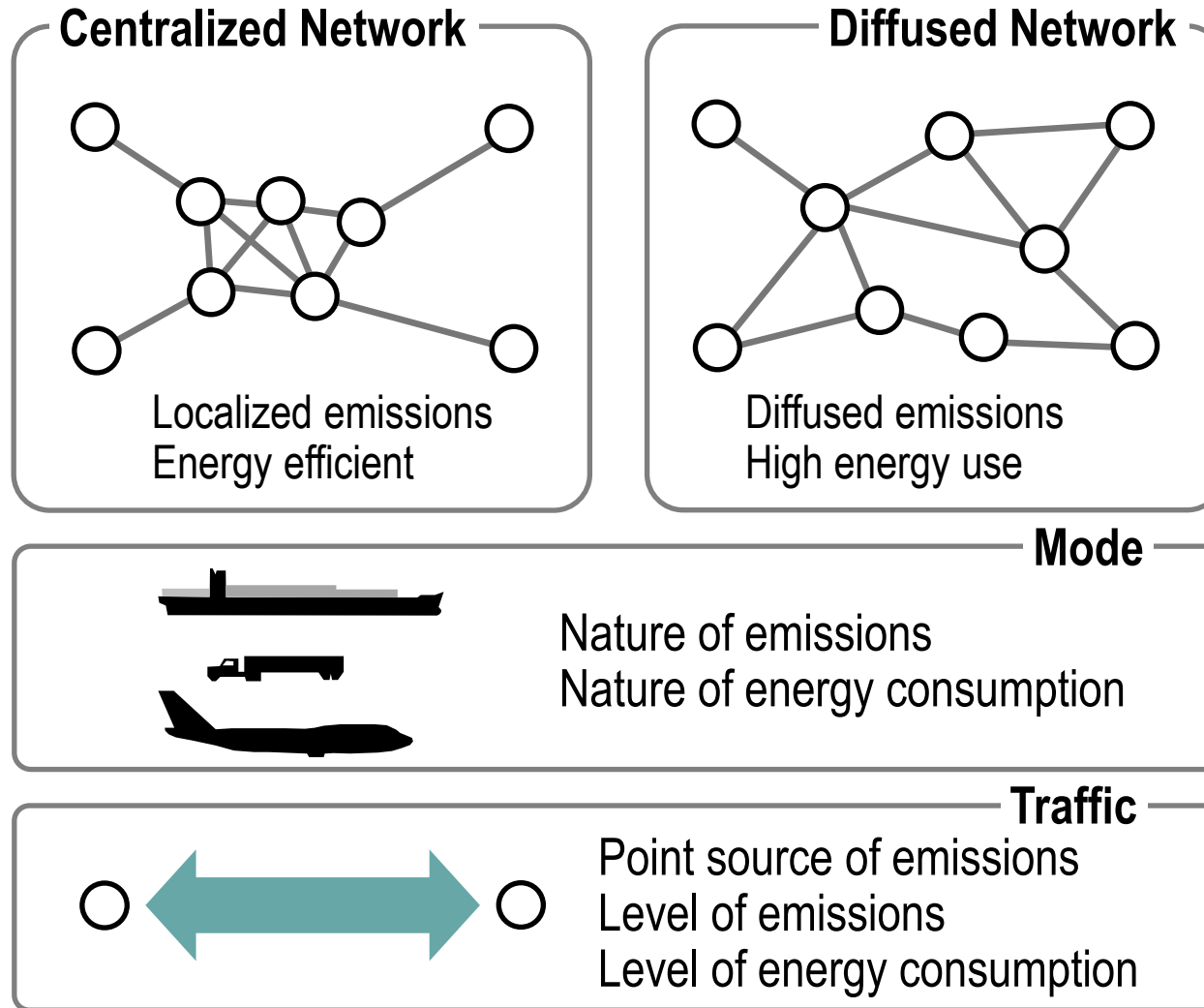


Spatial and Durational Environmental Effects of Selected Environmental Externalities

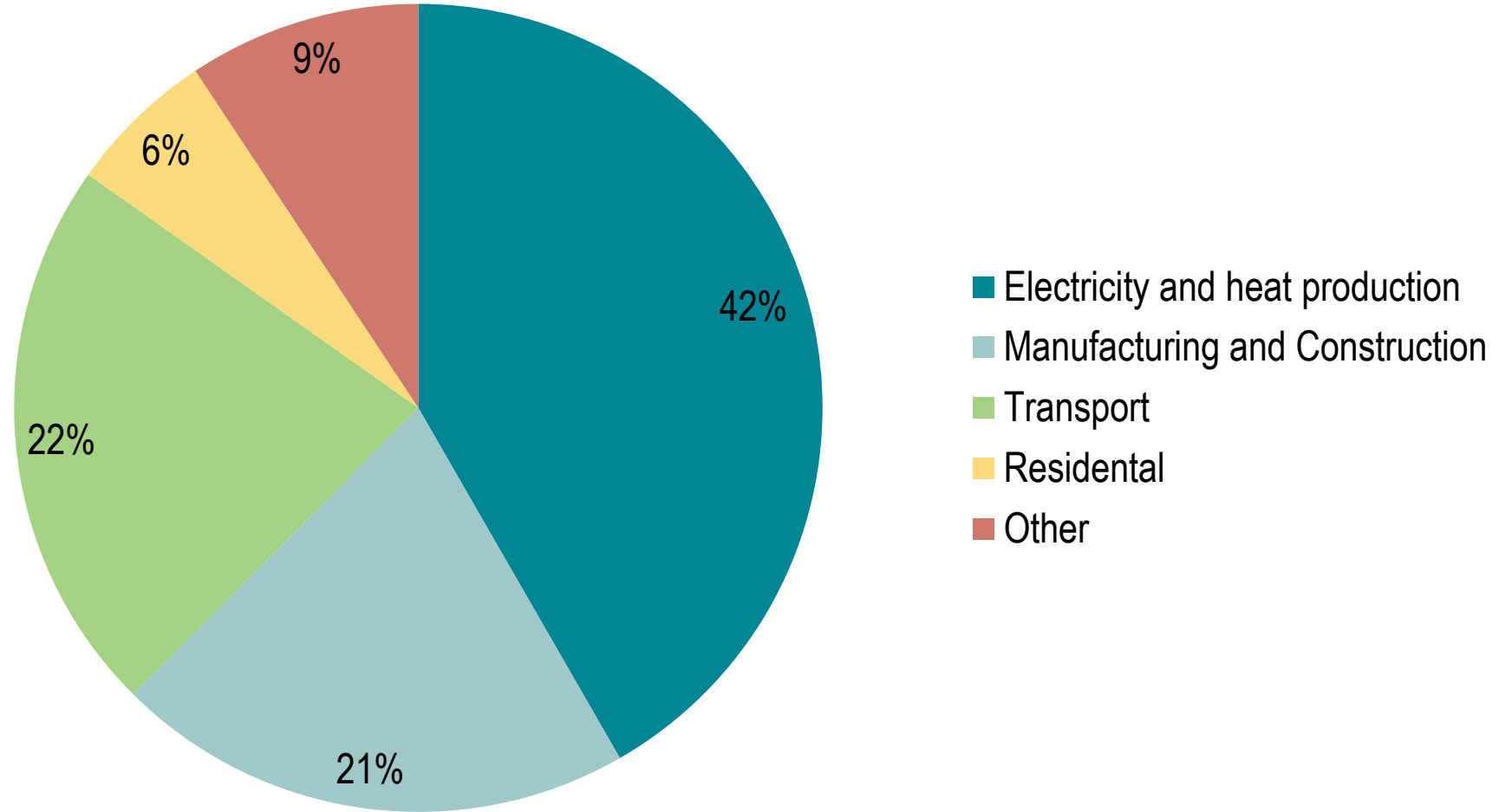




Transportation Systems and the Environment

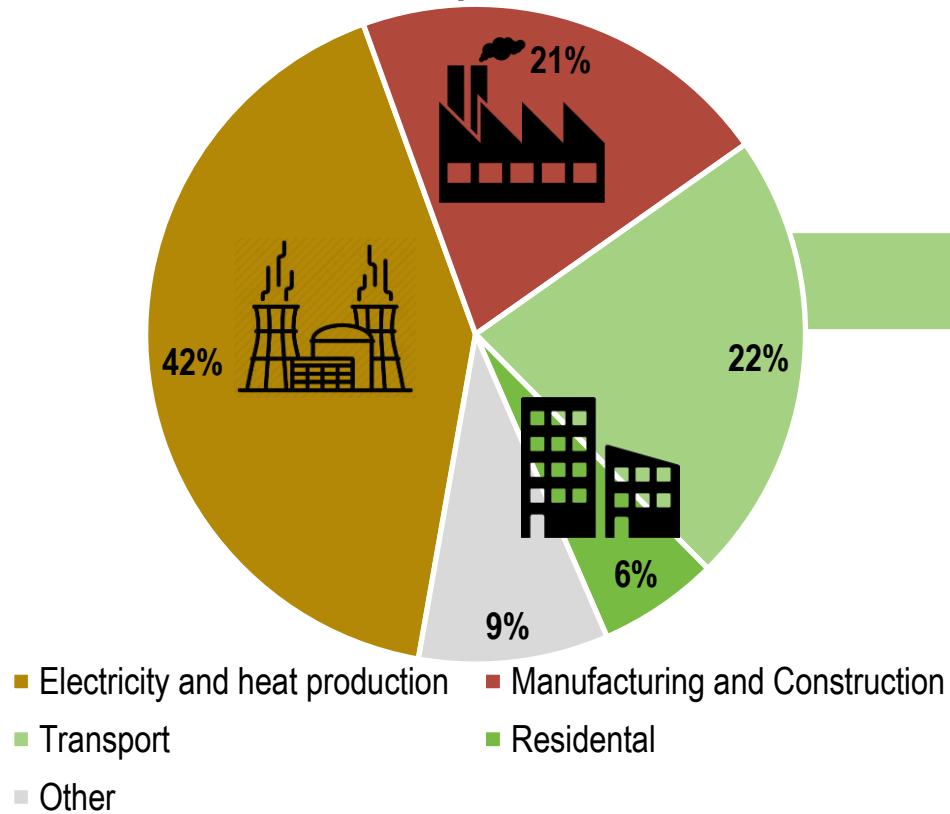


World CO2 Emission by Economic Sector, 2011

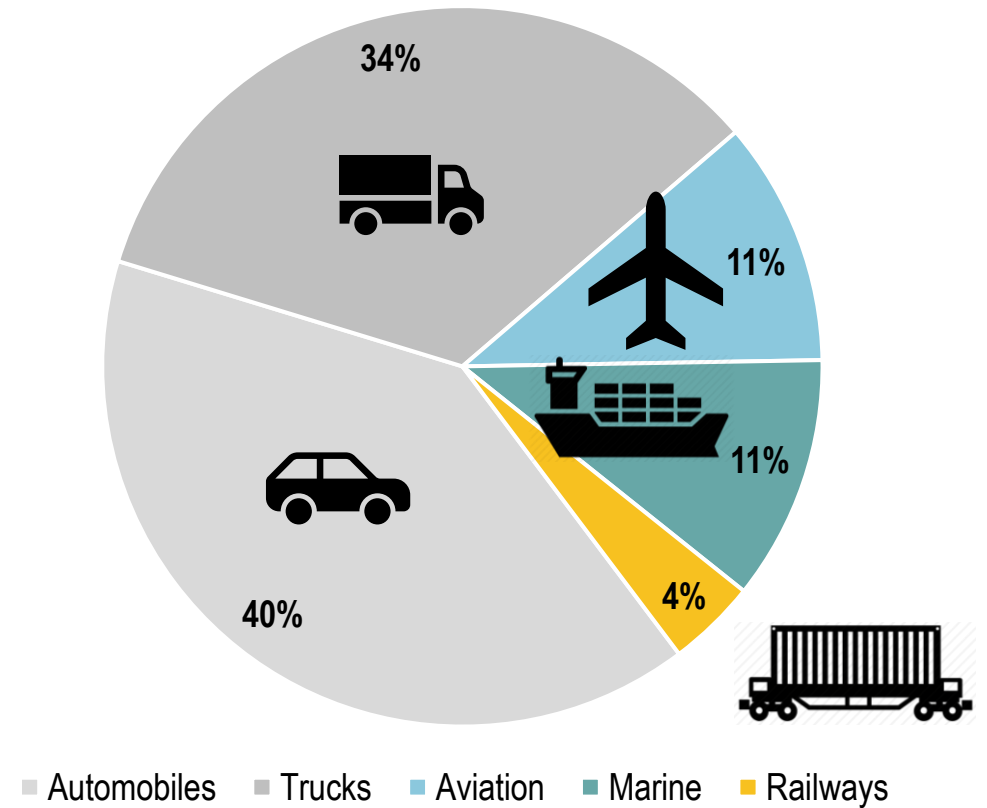


Global Greenhouse Gas Emissions by the Transportation Sector

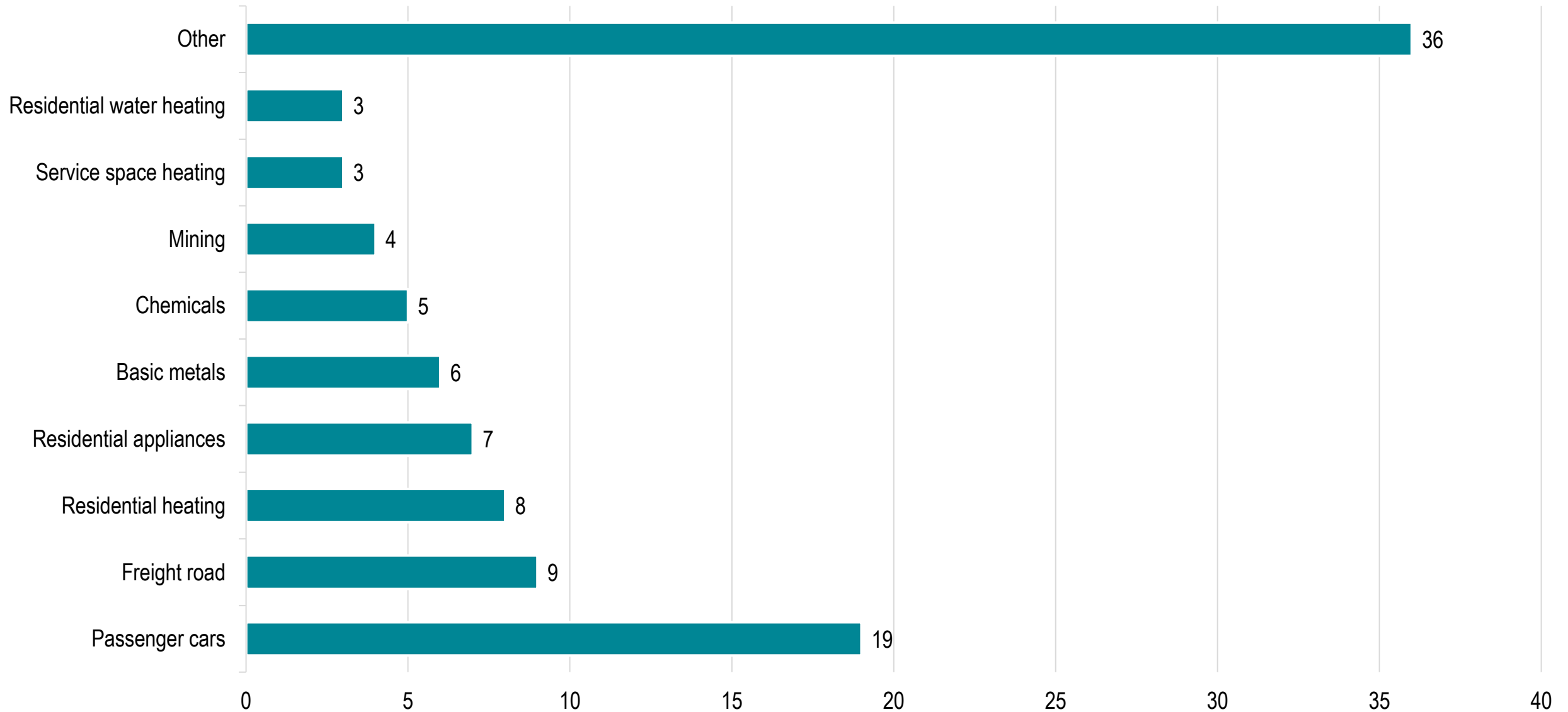
CO2 Emissions by Economic Sector



CO2 Emissions by the Transport Sector



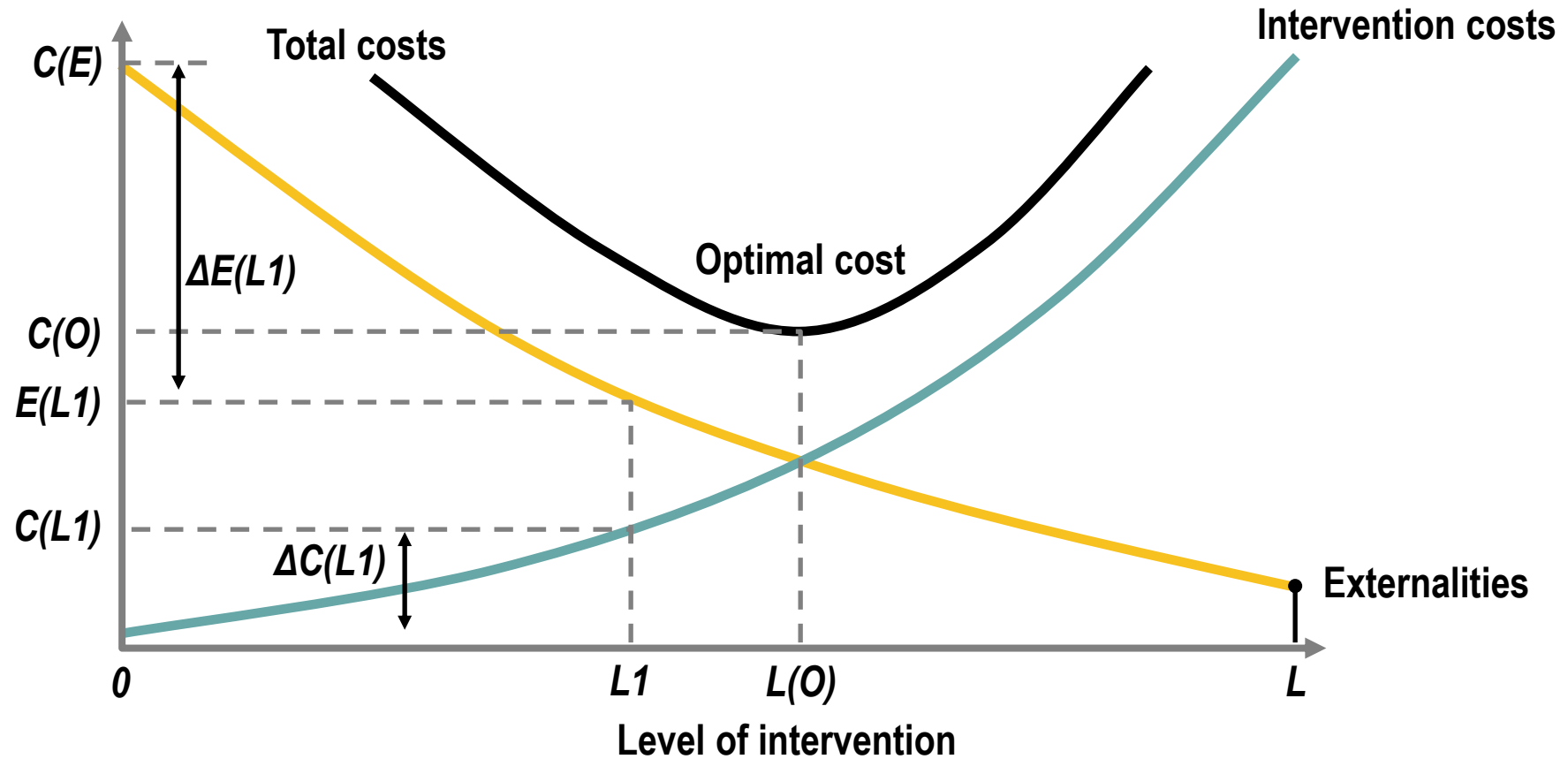
Top 10 CO2 Emitting Sources, 2014 (in % of total emissions)



Major Oil Spills Since 1967

Ship name	Year	Location	Spill Size (tons)
Atlantic Empress	1979	Off Tobago, West Indies	287,000
ABT Summer	1991	700 nautical miles off Angola	260,000
Castillo de Bellver	1983	Off Saldanha Bay, South Africa	252,000
Amoco Cadiz	1978	Off Brittany, France	223,000
Haven	1991	Genoa, Italy	144,000
Odyssey	1988	700 nautical miles off Nova Scotia, Canada	132,000
Torrey Canyon	1967	Scilly Isles, UK	119,000
Sea Star	1972	Gulf of Oman	115,000
Irenes Serenade	1980	Navarino Bay, Greece	100,000
Urquiola	1976	La Coruna, Spain	100,000
Hawaiian Patriot	1977	300 nautical miles off Honolulu	95,000
Independenta	1979	Bosporus, Turkey	95,000
Jakob Maersk	1975	Oporto, Portugal	88,000
Braer	1993	Shetland Islands, UK	85,000
Khark 5	1989	120 nautical miles off Atlantic coast of Morocco	80,000
Aegean Sea	1992	La Coruna, Spain	74,000
Sea Empress	1996	Milford Haven, UK	72,000
Katina P	1992	Off Maputo, Mozambique	72,000
Nova	1985	Off Kharg Island, Gulf of Iran	70,000
Prestige	2002	Off Galicia, Spain	63,000
Exxon Valdez	1989	Prince William Sound, Alaska, USA	37,000

The Concept of Externalities



Environmental Externalities of Transportation



Supra and infrastructure



Labor Productivity



Agricultural Productivity



Commercial fishing



Recreational facilities



Water purification



Accidents/Spills



Property values



Public health



Damage to ecosystems

Vehicle emissions; CO2 (30%), CO (70-90%), SO2 (5%), NOx (45-50%), HC/VOC (40-50%), Particulates (25%), O3 (indirect), Smog (indirect), Acid rain (10-30%), CFCs (20%), Lead (30%)

Air pollution fallouts, Marine vessels discharges and spills, De-icing of infrastructure, Runoffs, Construction and maintenance of infrastructure, Dredging (80%)

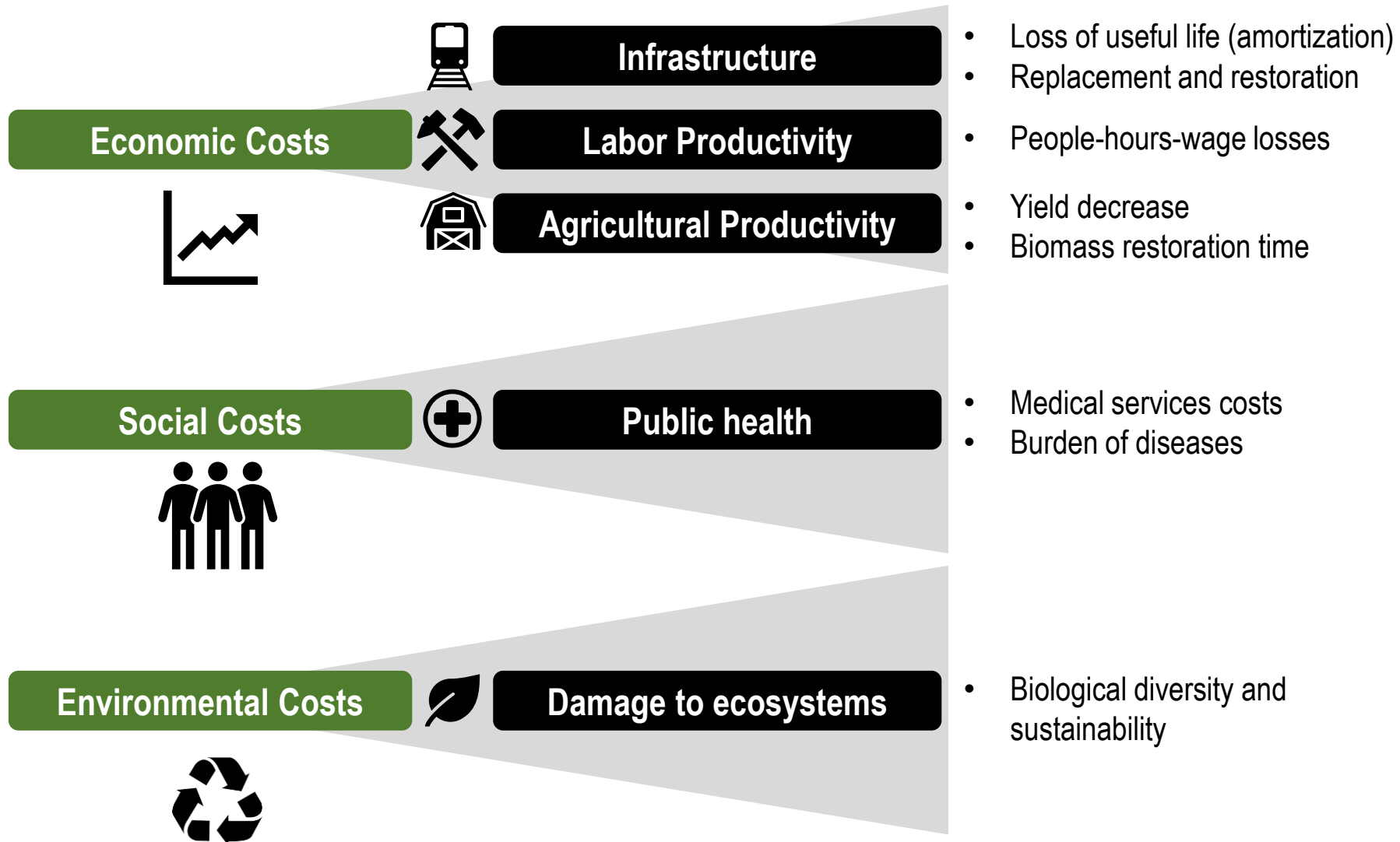
Marine vessels spills, Accidental and intentional releases (Hazmat); Road (84%), Rail (12%), Air (3%) and Maritime (1%)

Vehicle emissions; Road (70%), Rail (10%) and Air (20%)

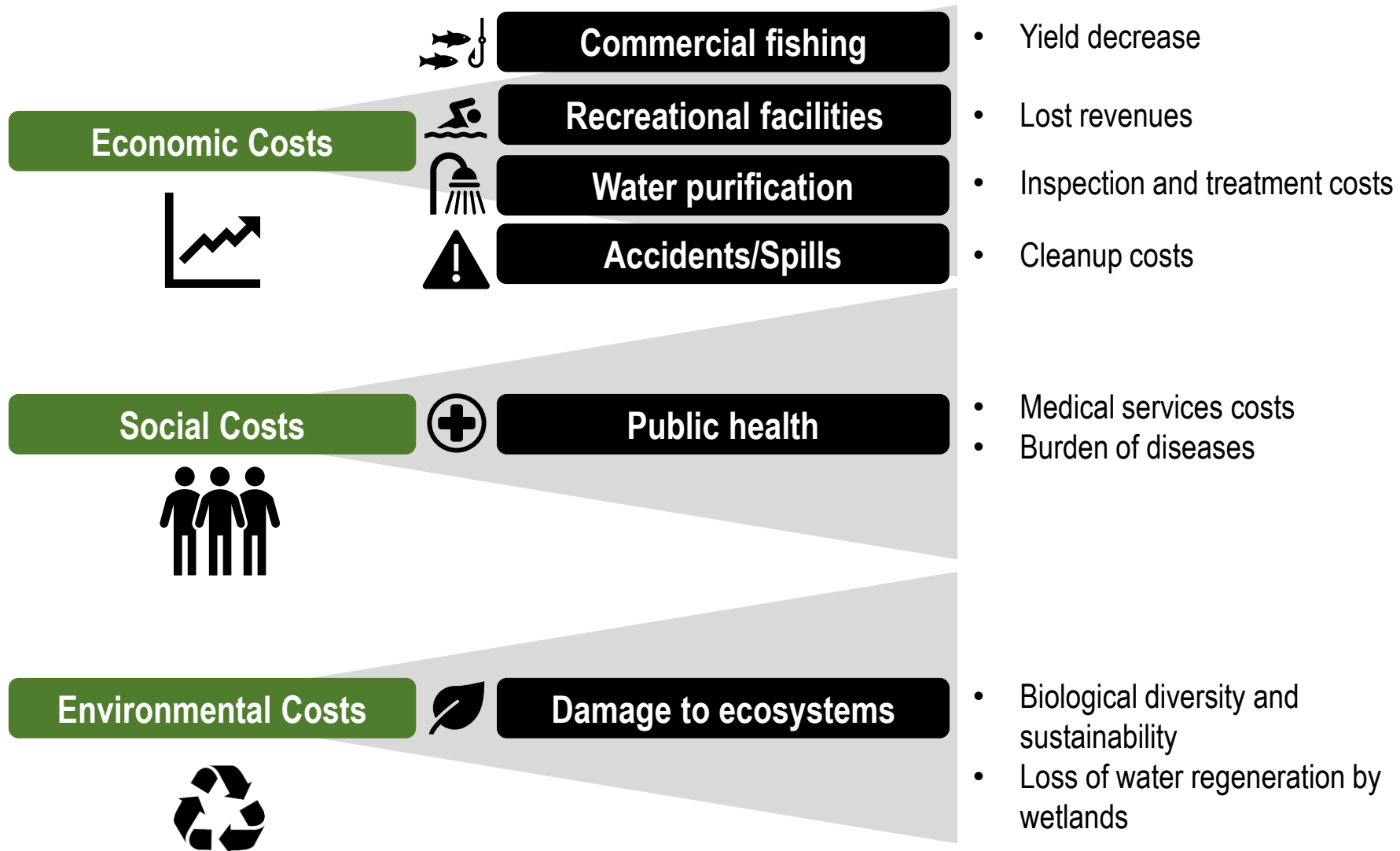
Vehicle emissions, During transport

Vehicle emissions, during transport, Infrastructure

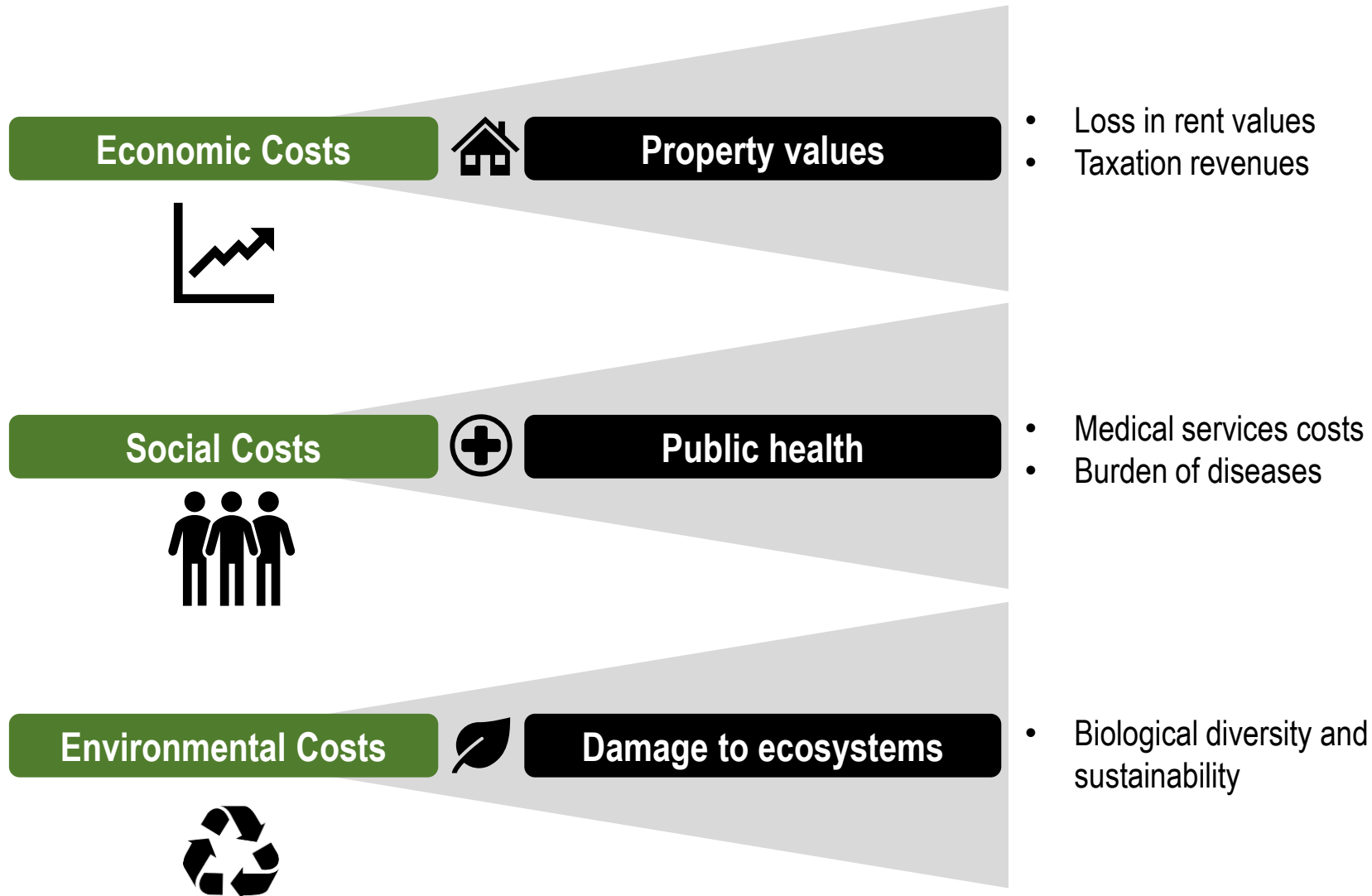
Externalities of Air Pollution



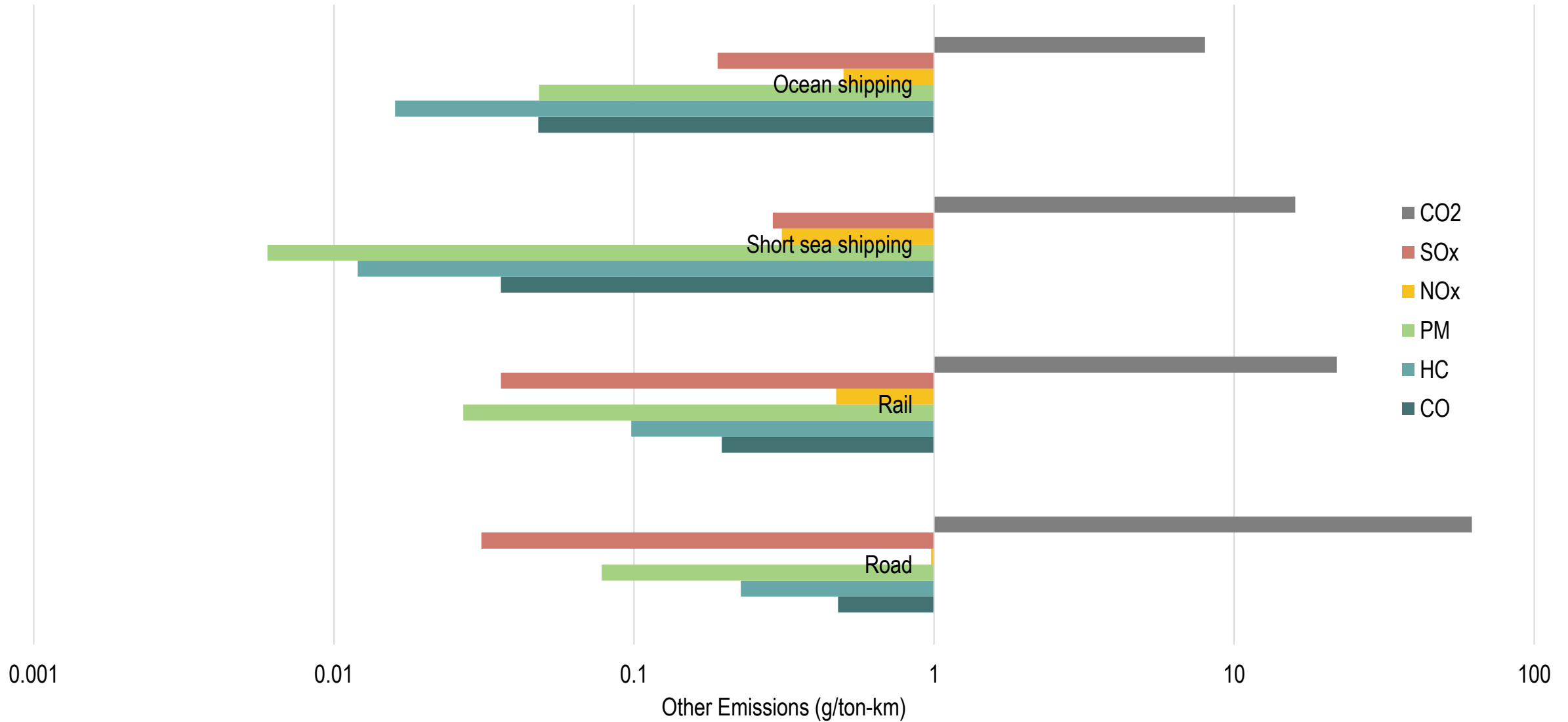
Externalities of Water Pollution



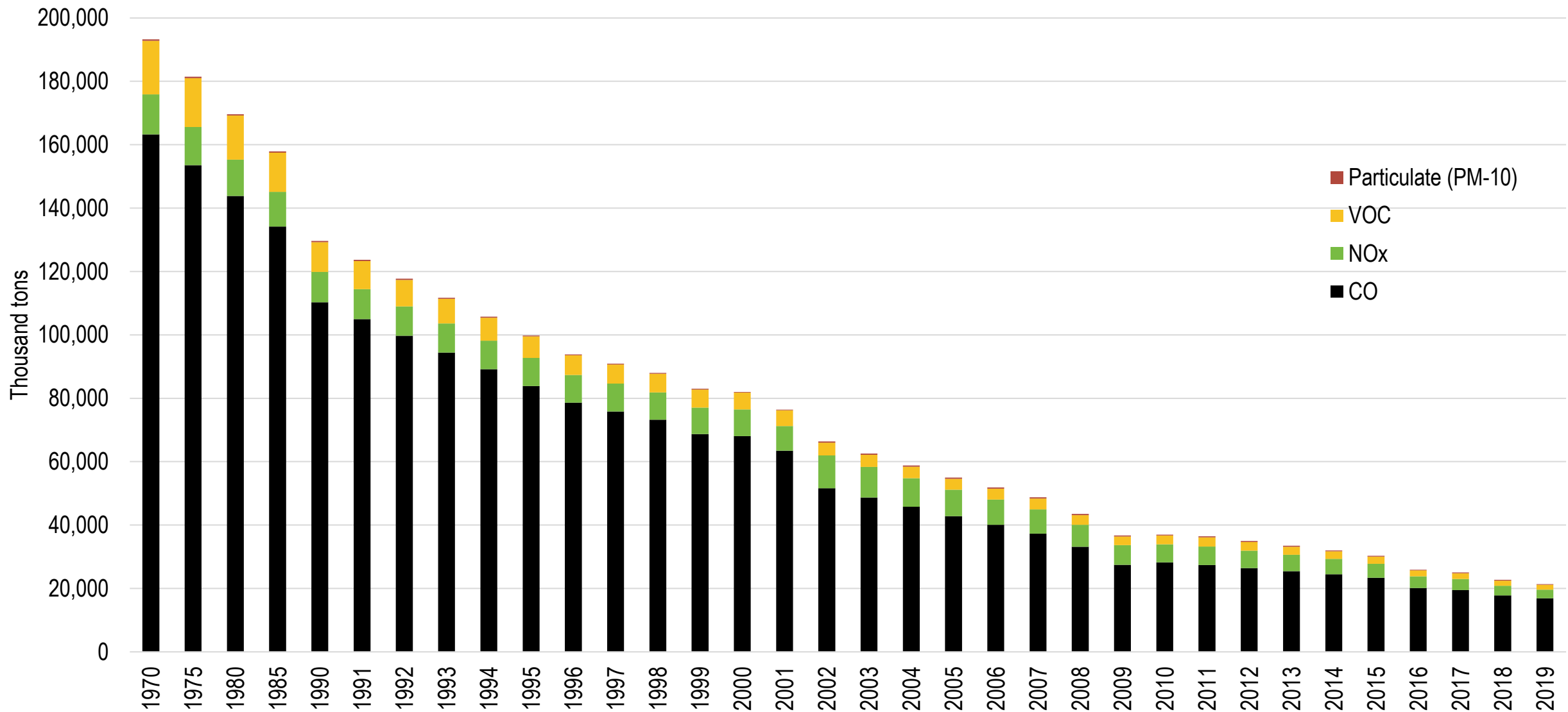
Externalities of Noise Pollution



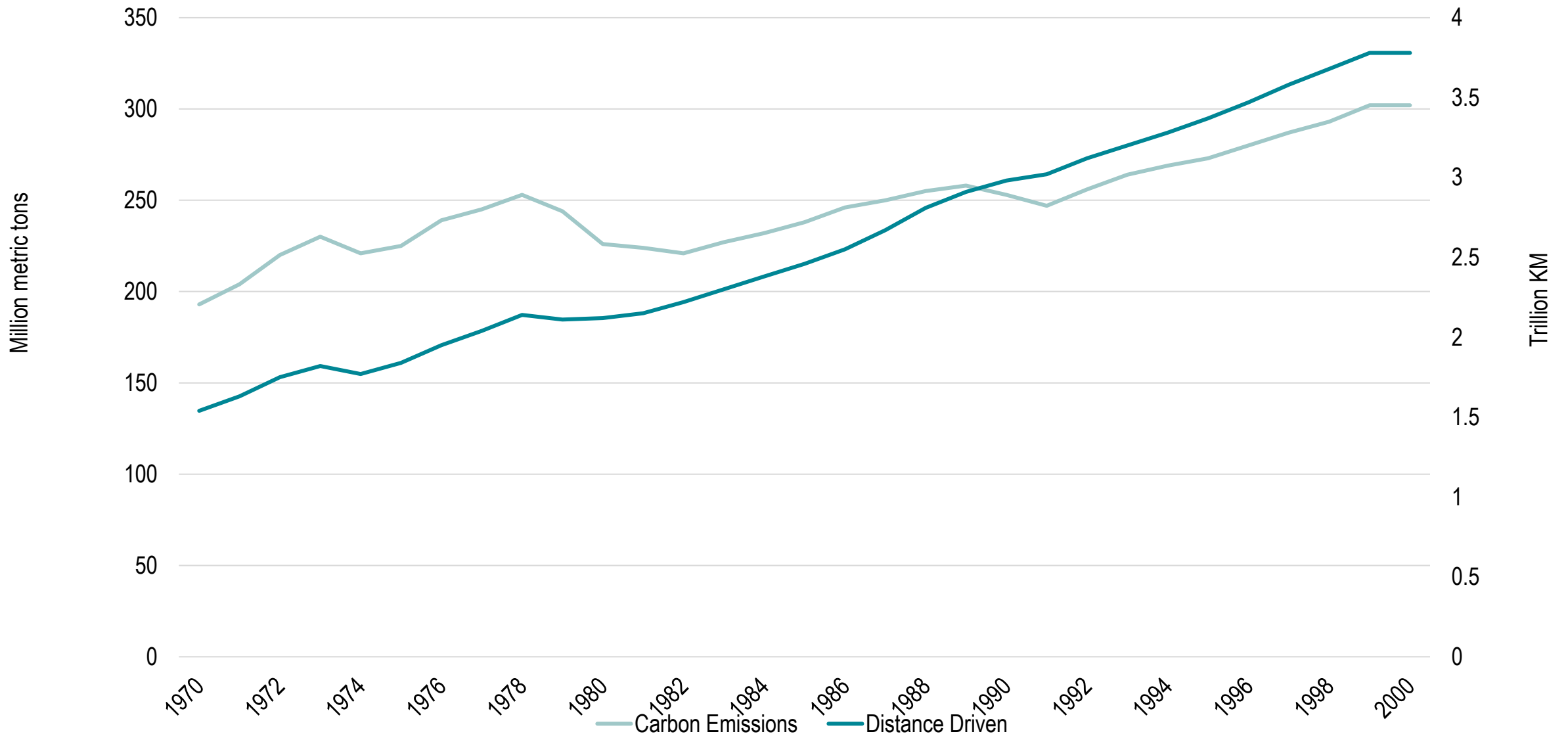
Emissions from Freight Modes (grams / ton-km)



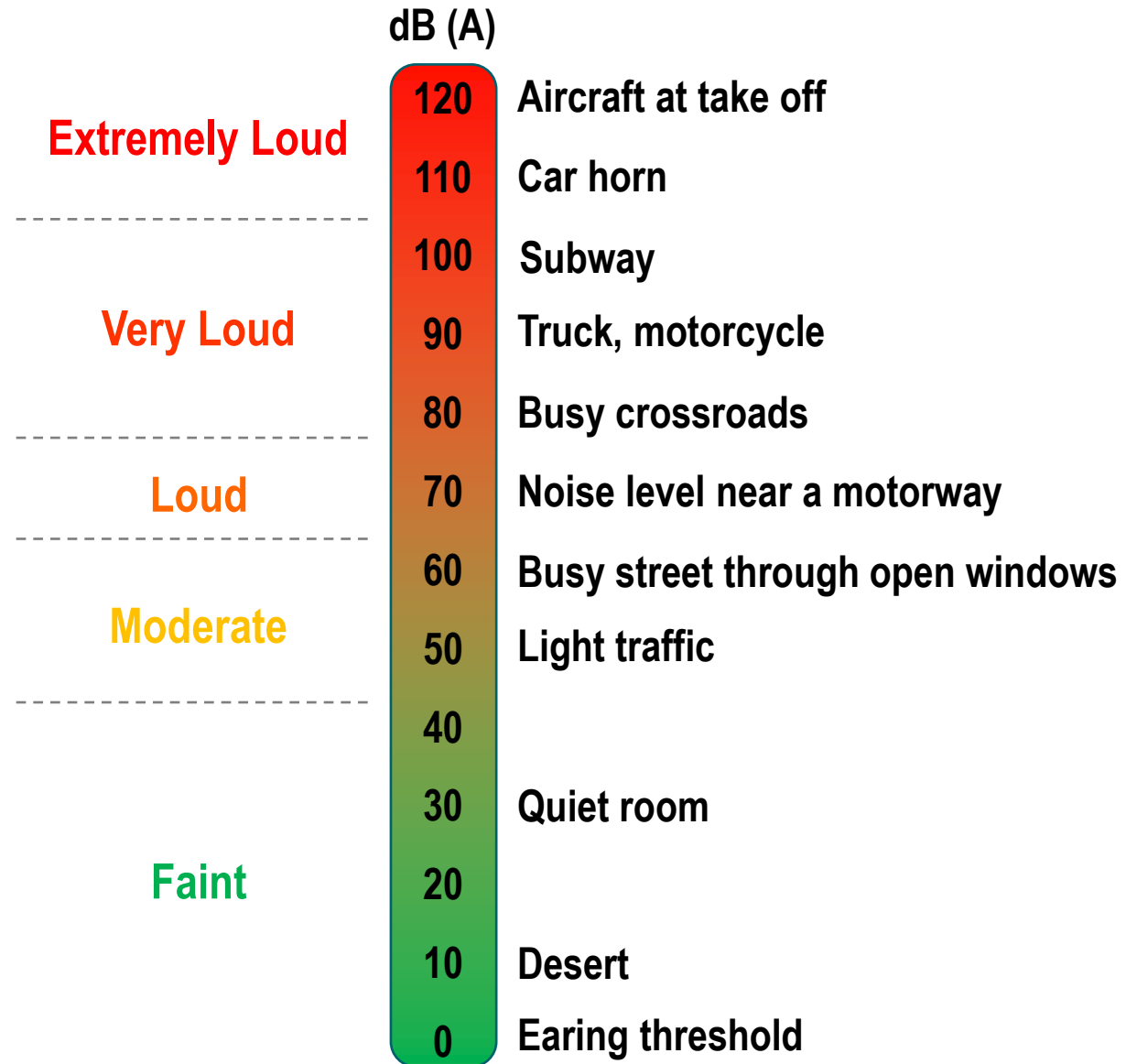
Estimated Air Pollutants Emitted by Highway Transportation in the United States, 1970-2019



Distance Driven and Carbon Emissions, U.S. Automobile Fleet, 1970-2000



Noise Levels (in decibels)



Hazmat Accidents in the United States, 1975-2005

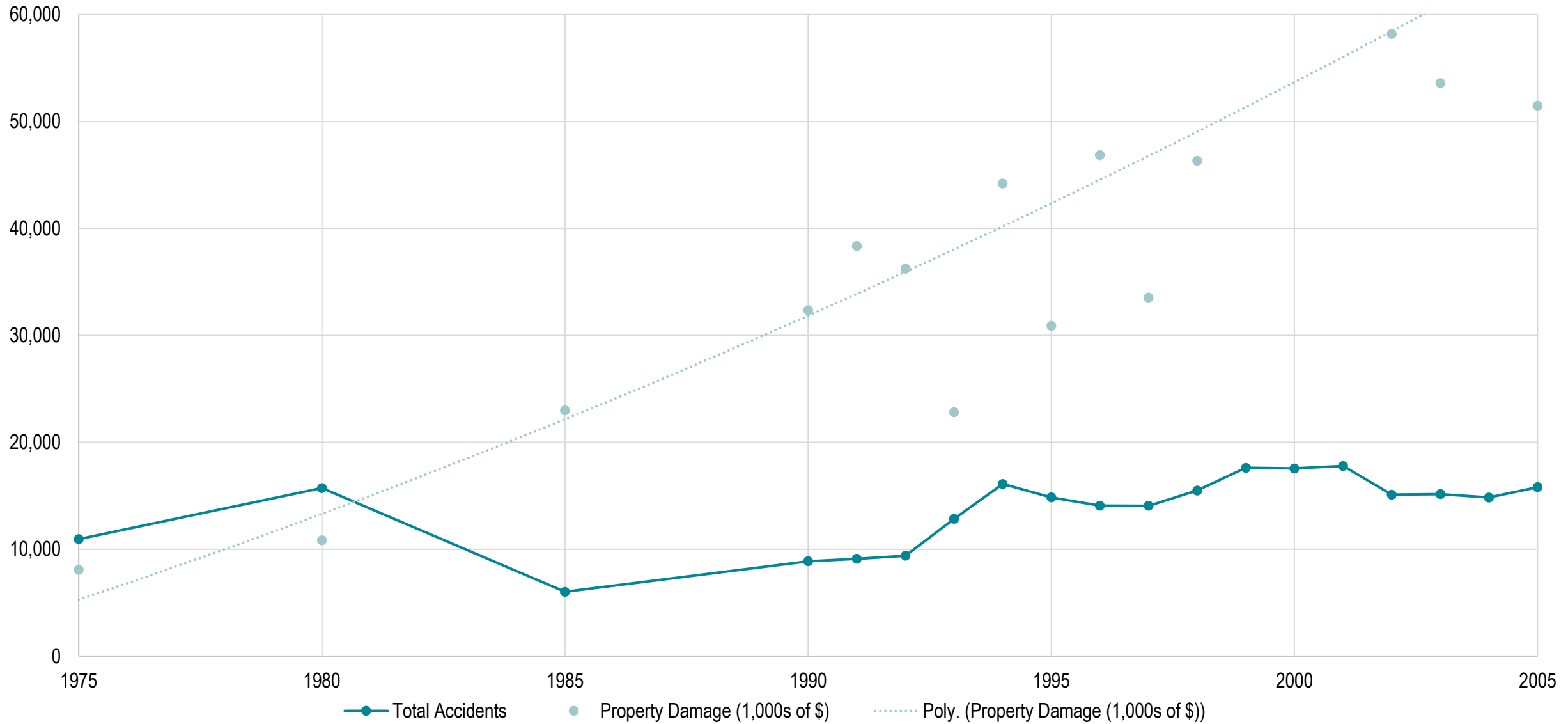
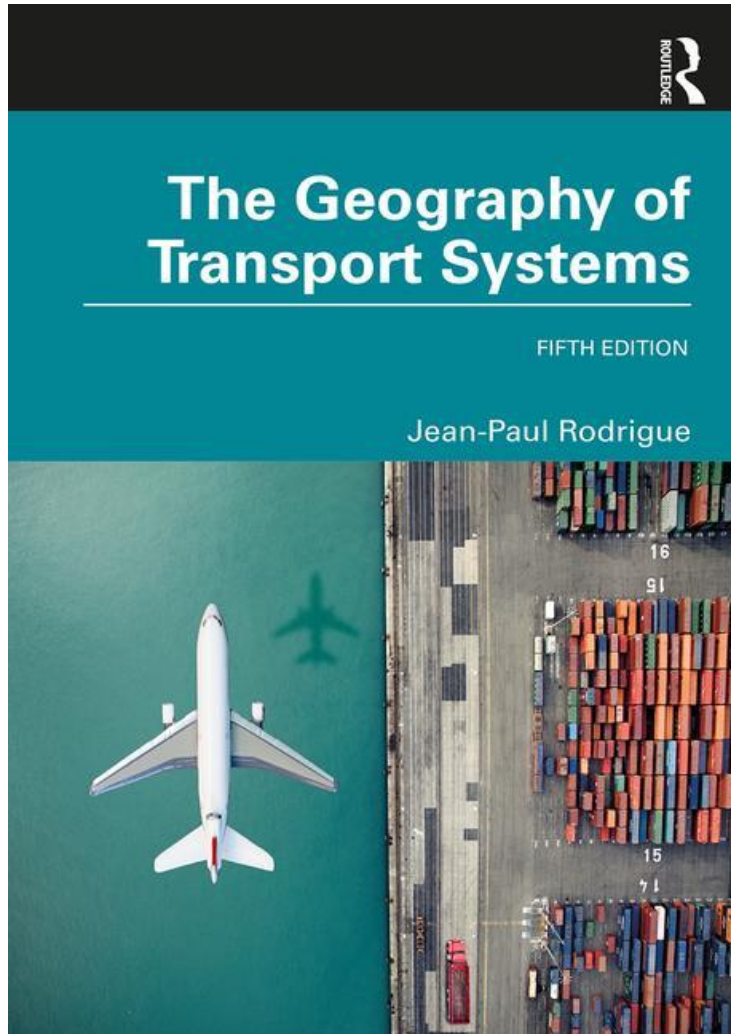


Table 3. Road traffic and networks of social support

Traffic levels	Contacts living on the same street	
	Friends	Acquaintances
Light traffic (200 vehicles at peak hour)	3.0	6.3
Moderate traffic (550 vehicles at peak hour)	1.3	4.1
Heavy traffic (1900 vehicles at peak hour)	0.9	3.1

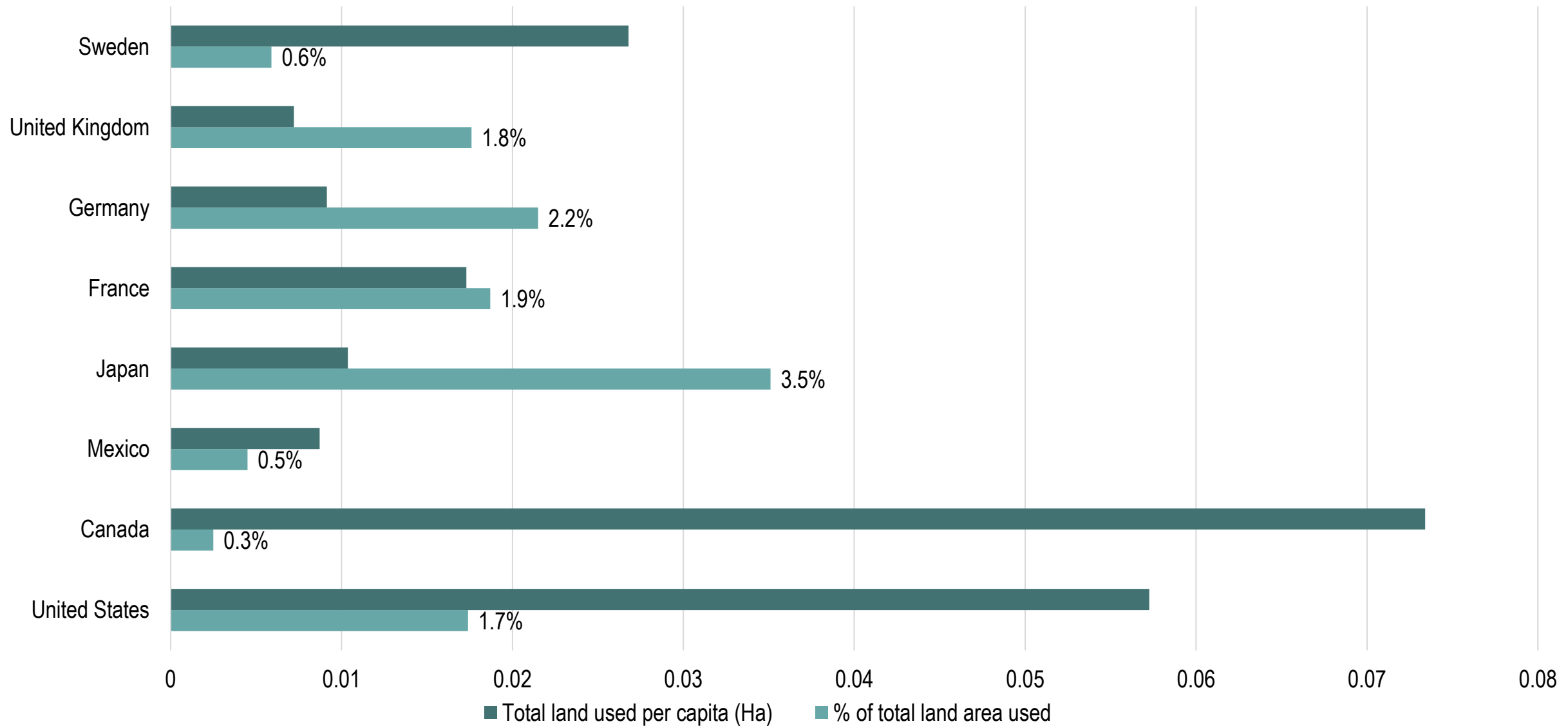
Source: adapted from Appleyard & Lintell (62).



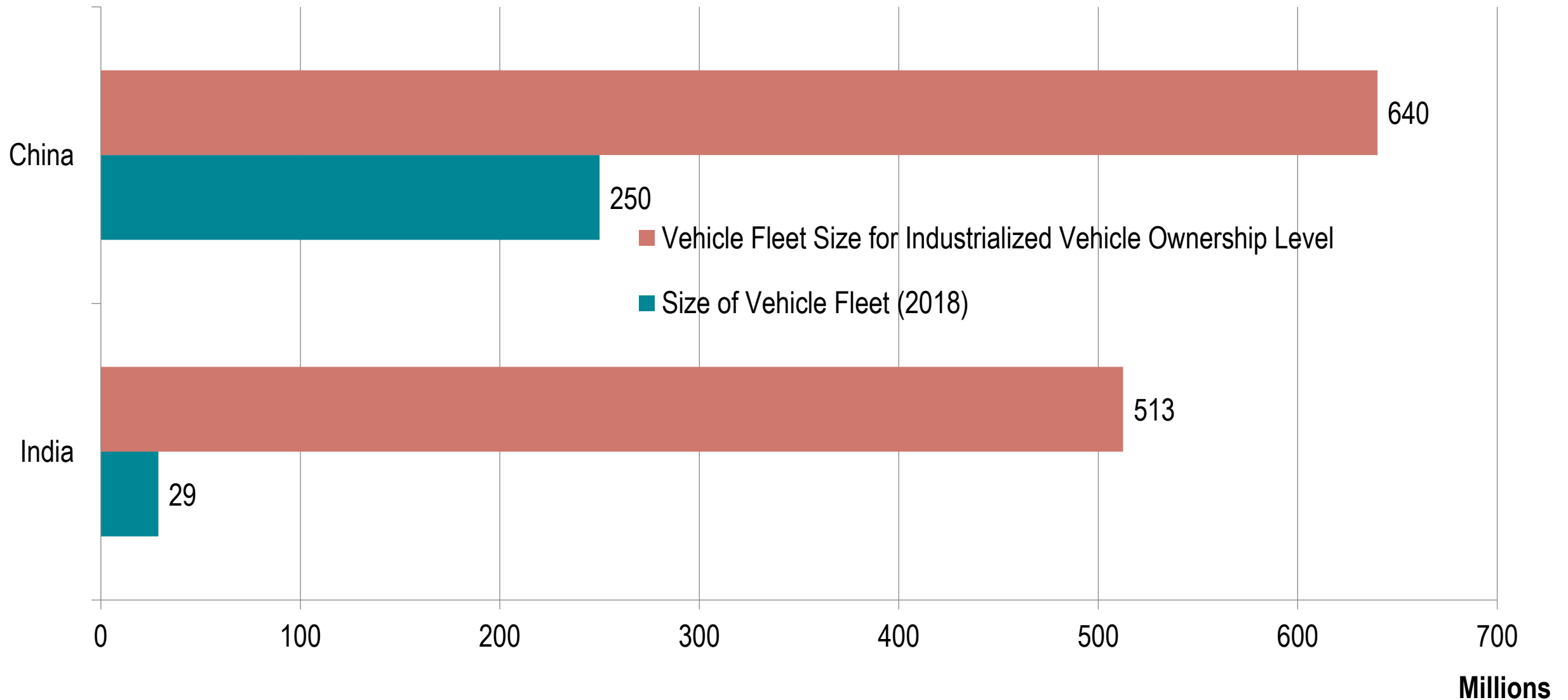
The Environmental Footprint of Transportation

Chapter 4.3

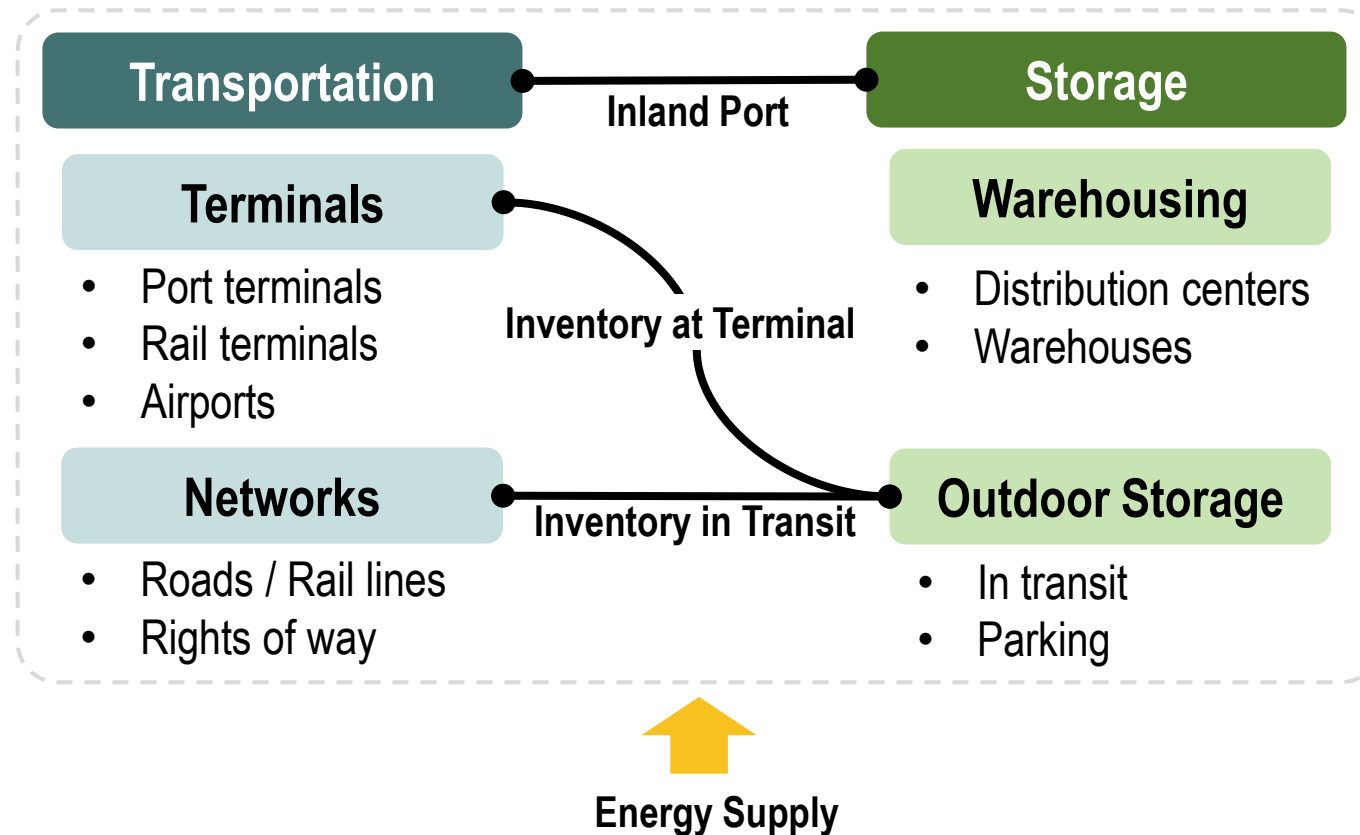
Land Area Consumed by Roads and Parking Facilities in Selected Countries, 1999



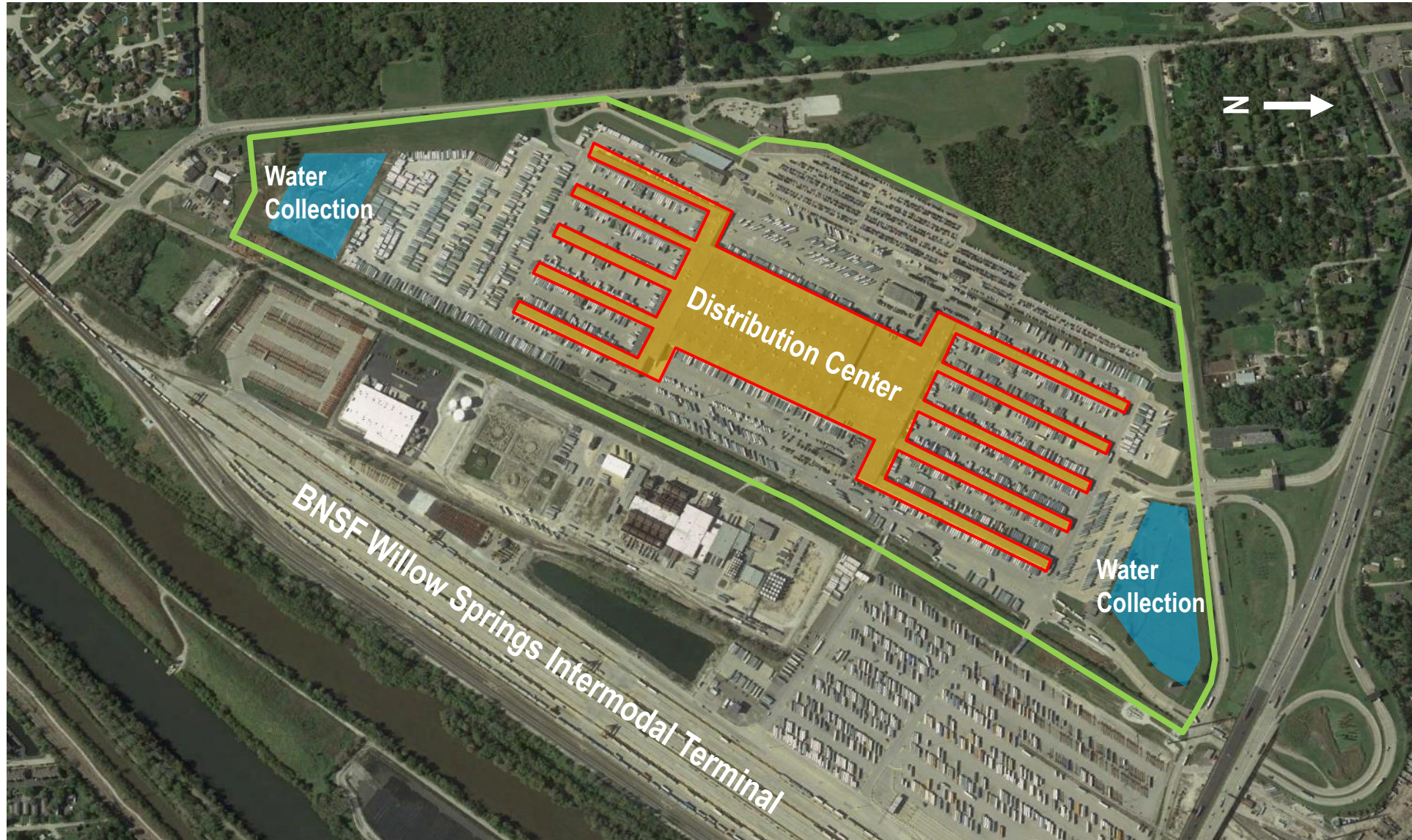
Current and Potential Car Fleet in India and China



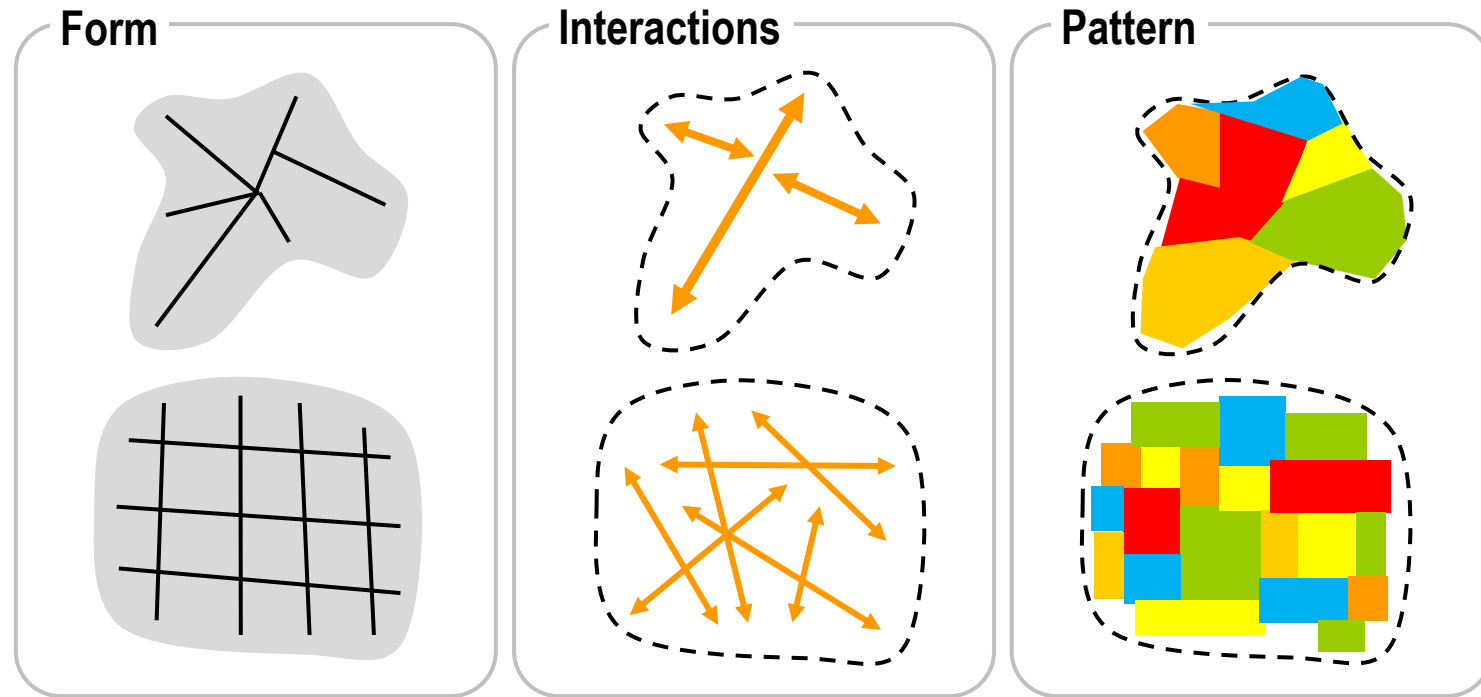
Land Footprint for Freight Distribution



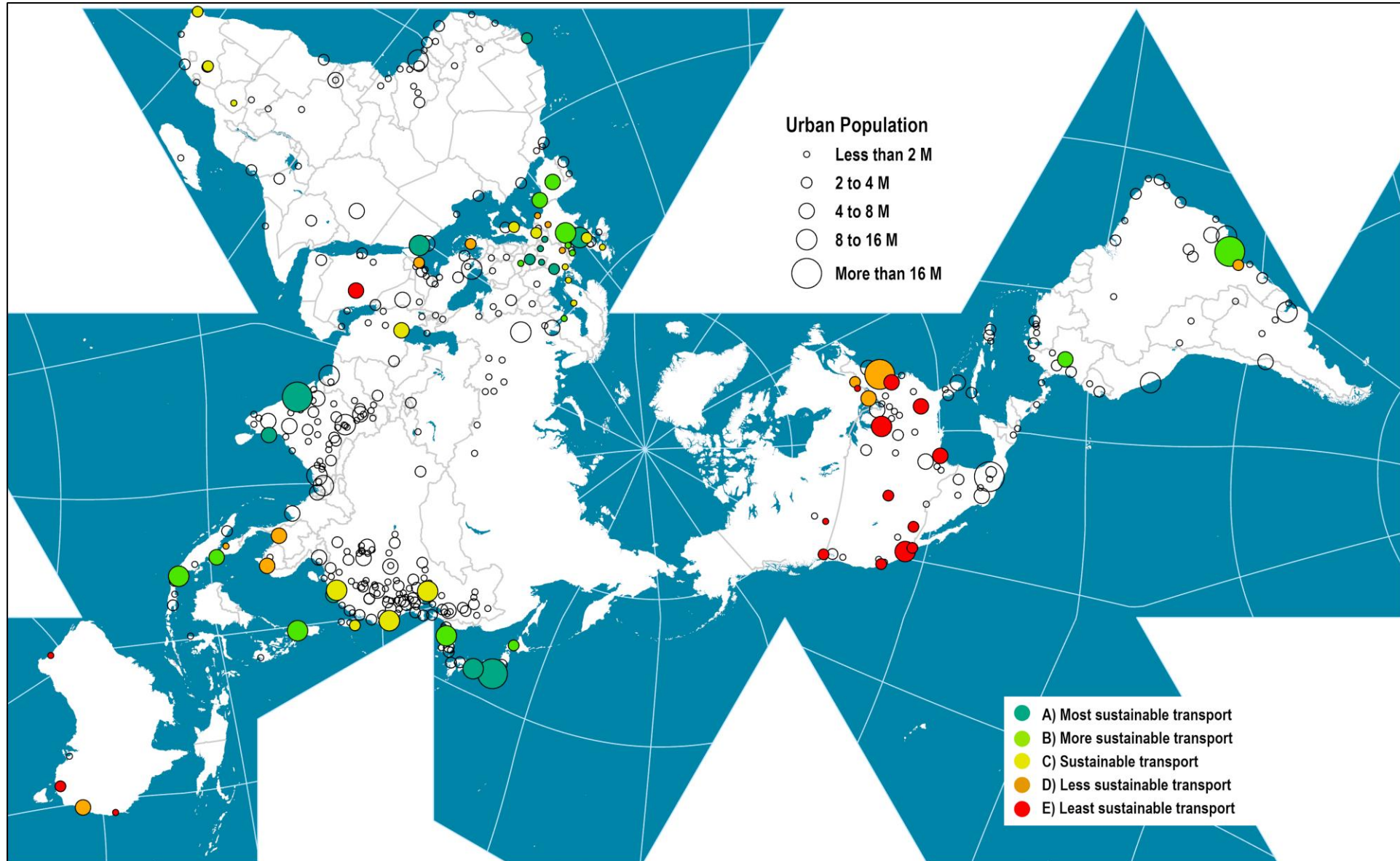
UPS Chicago Area Consolidation Hub



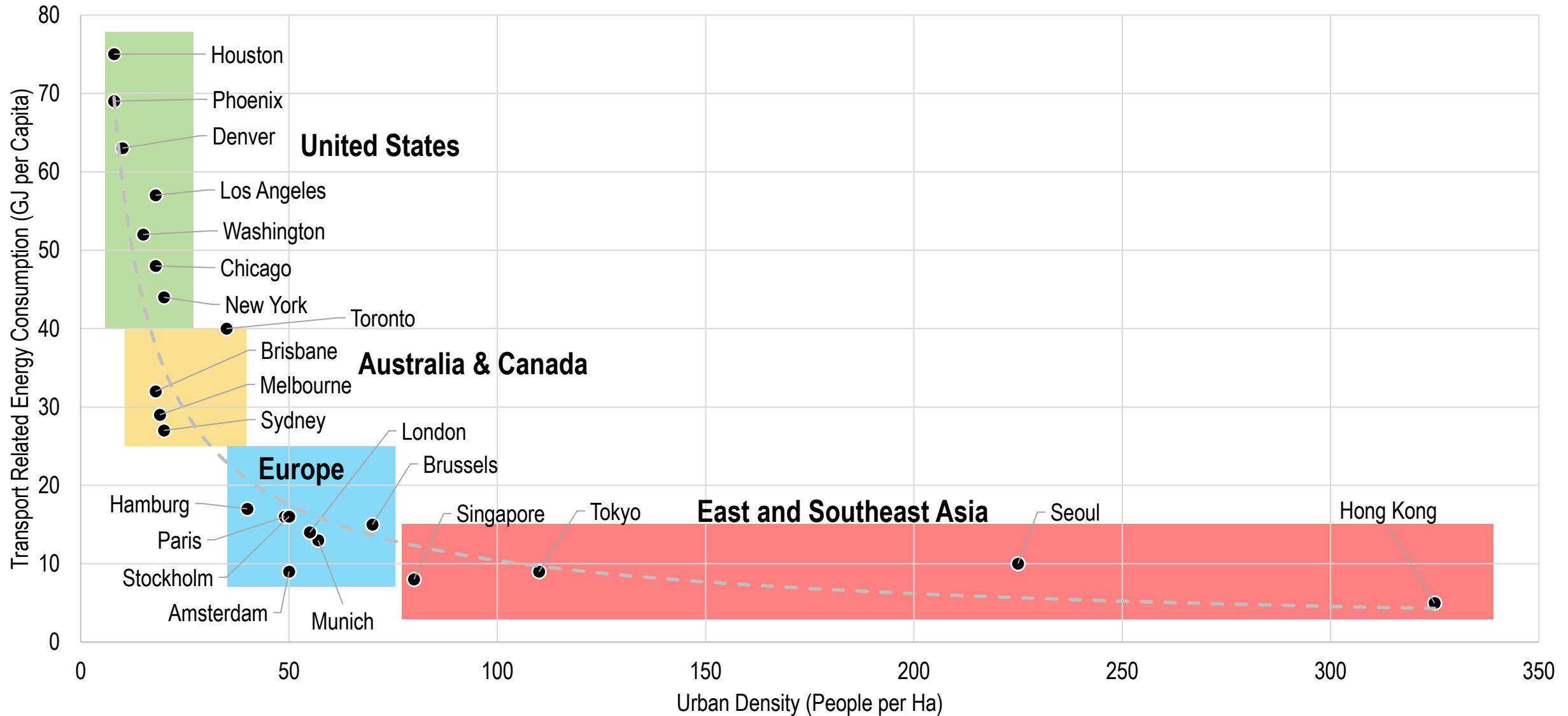
Spatial Form, Pattern and Interaction and the Environmental Impacts of Transportation



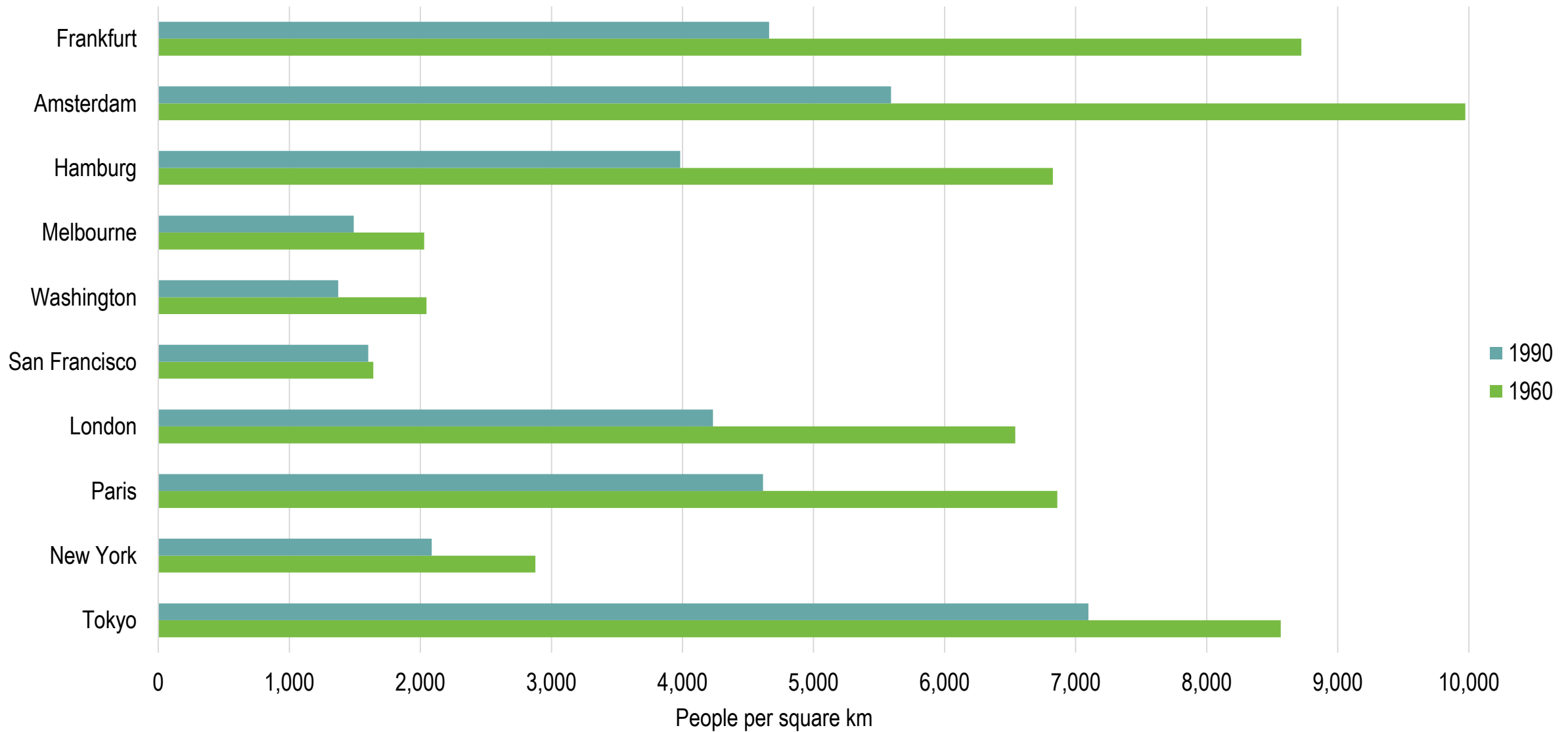
Sustainable Urban Passenger Travel, Selected Cities



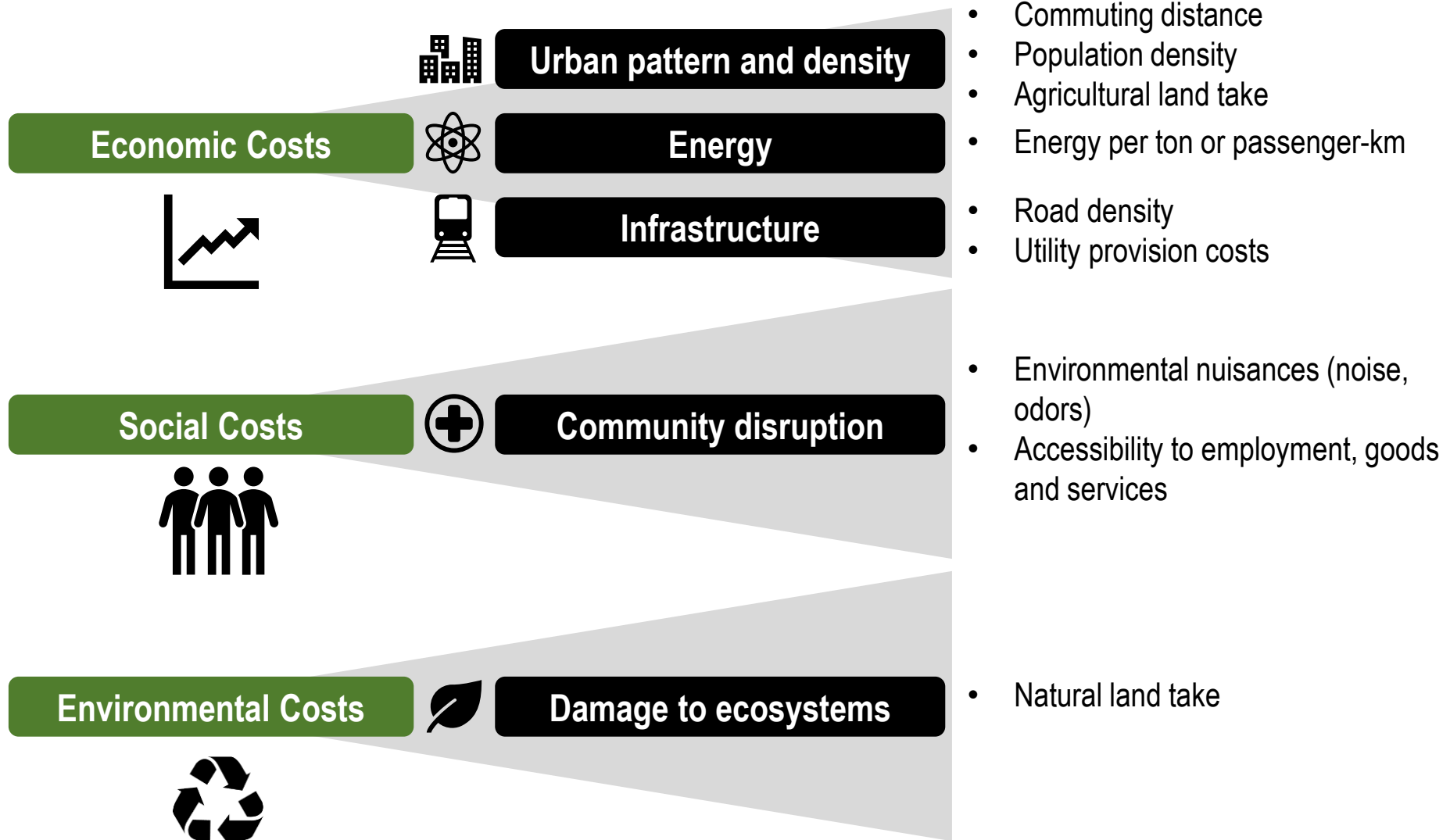
Transport Energy Consumption and Density in Major Metropolitan Areas, 1990

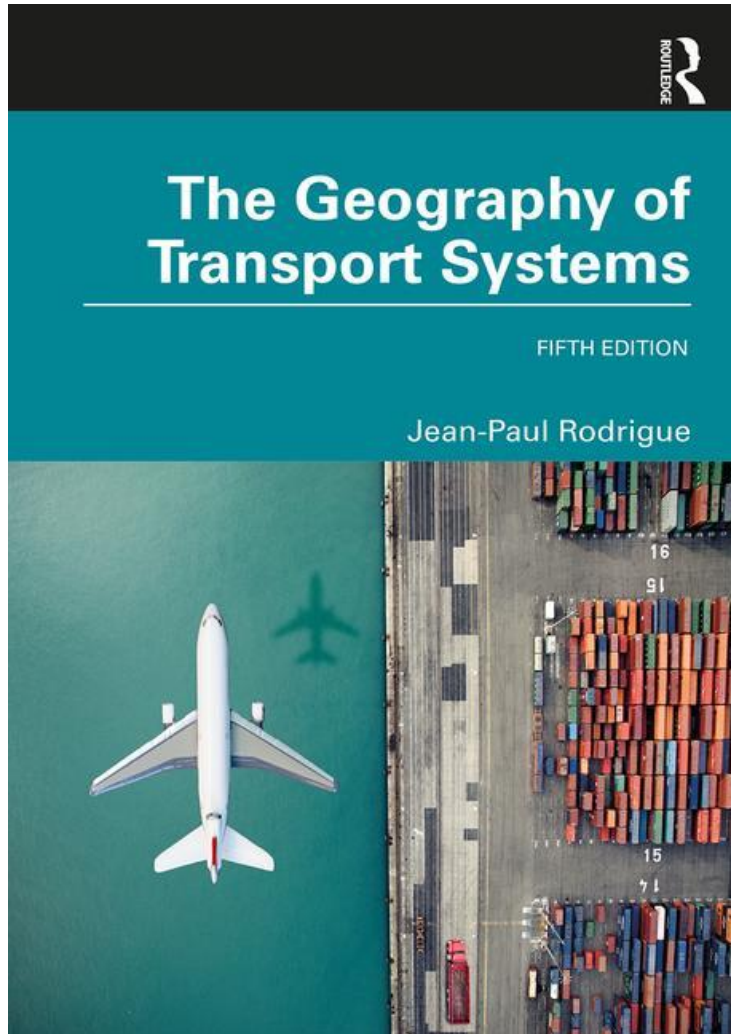


Population Density, Selected Cities, 1960-1990



Environmental Externalities of Land Use

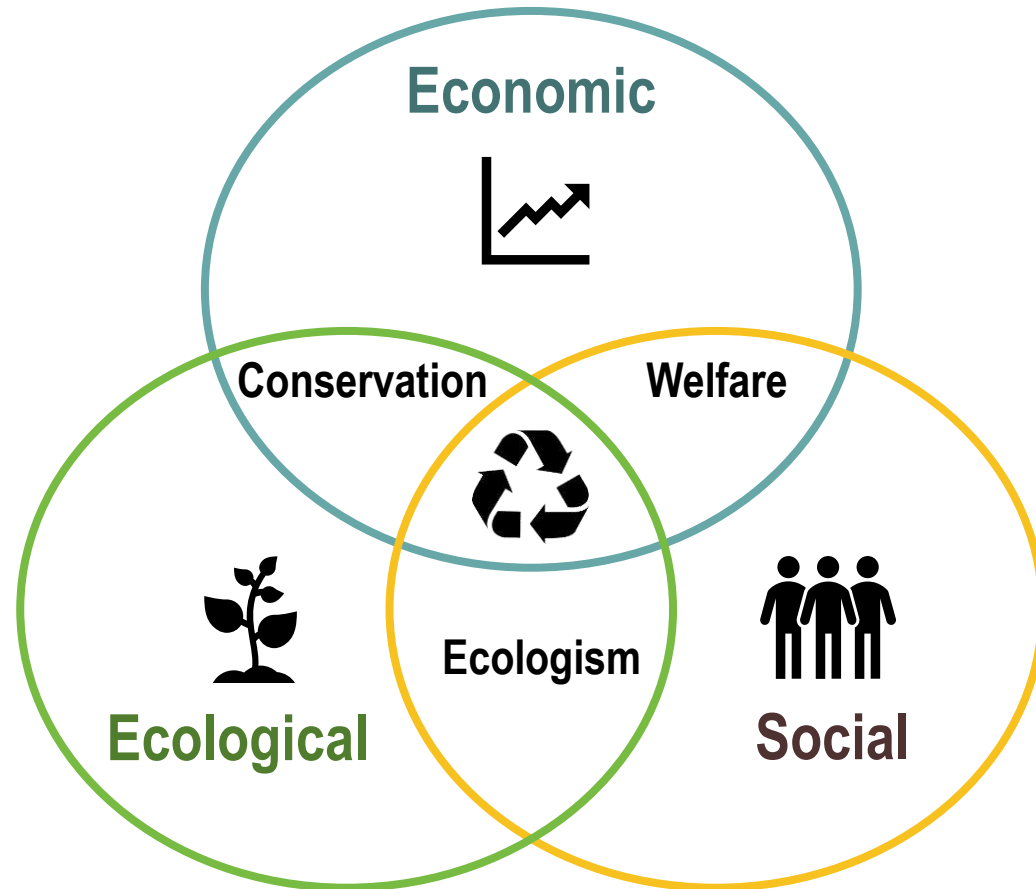




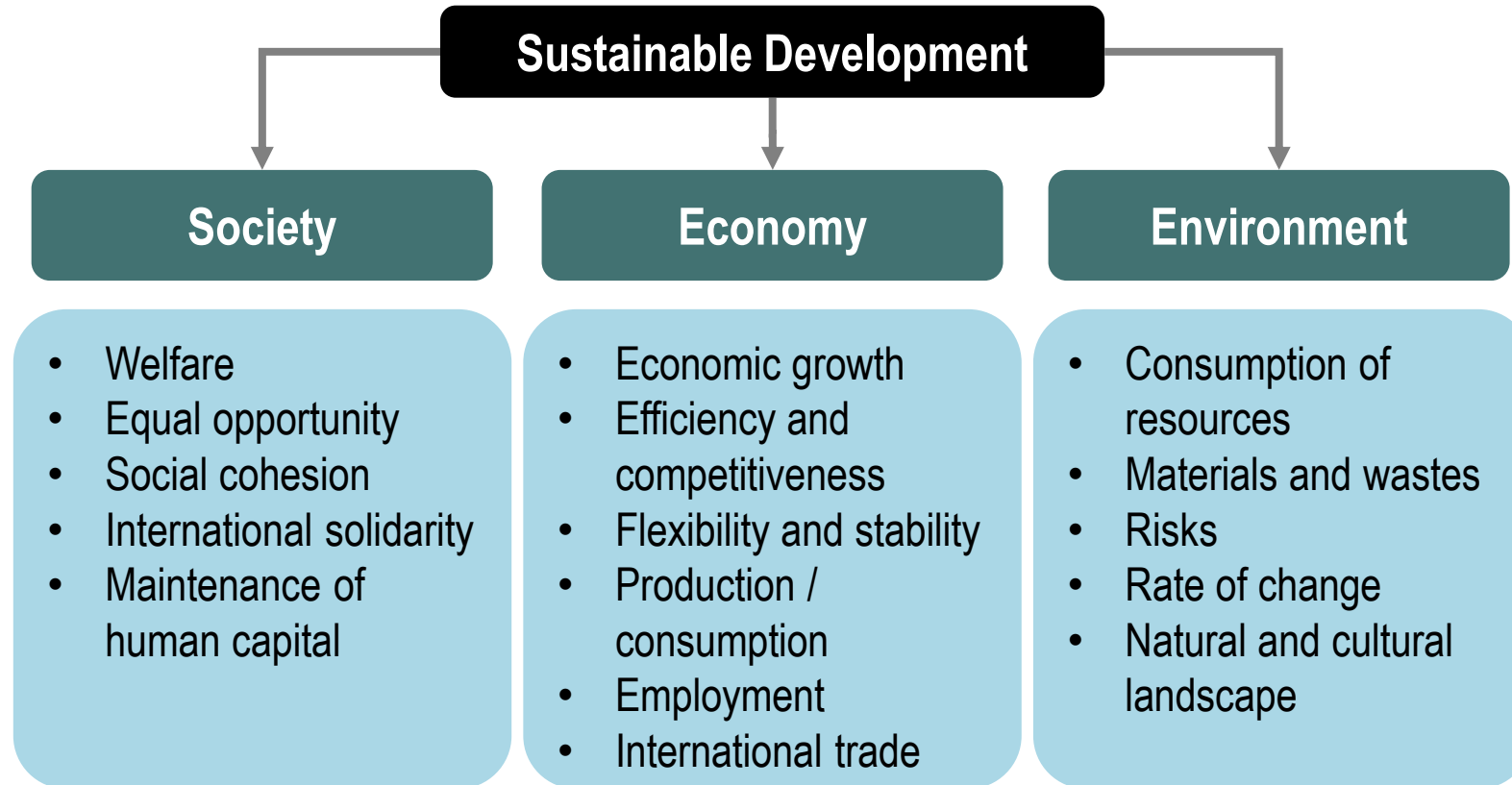
Transportation, Sustainability and Decarbonization

Chapter 4.4

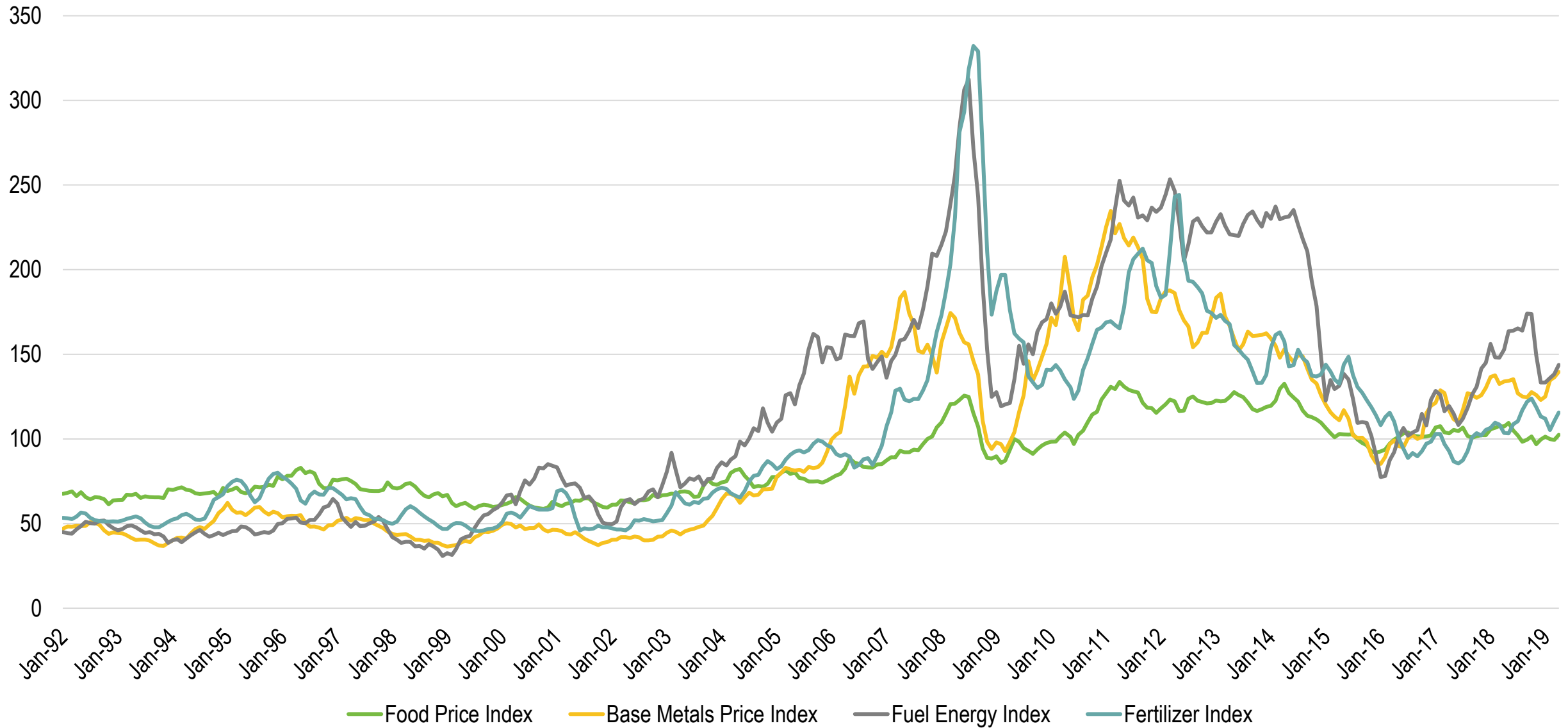
Global Sustainability



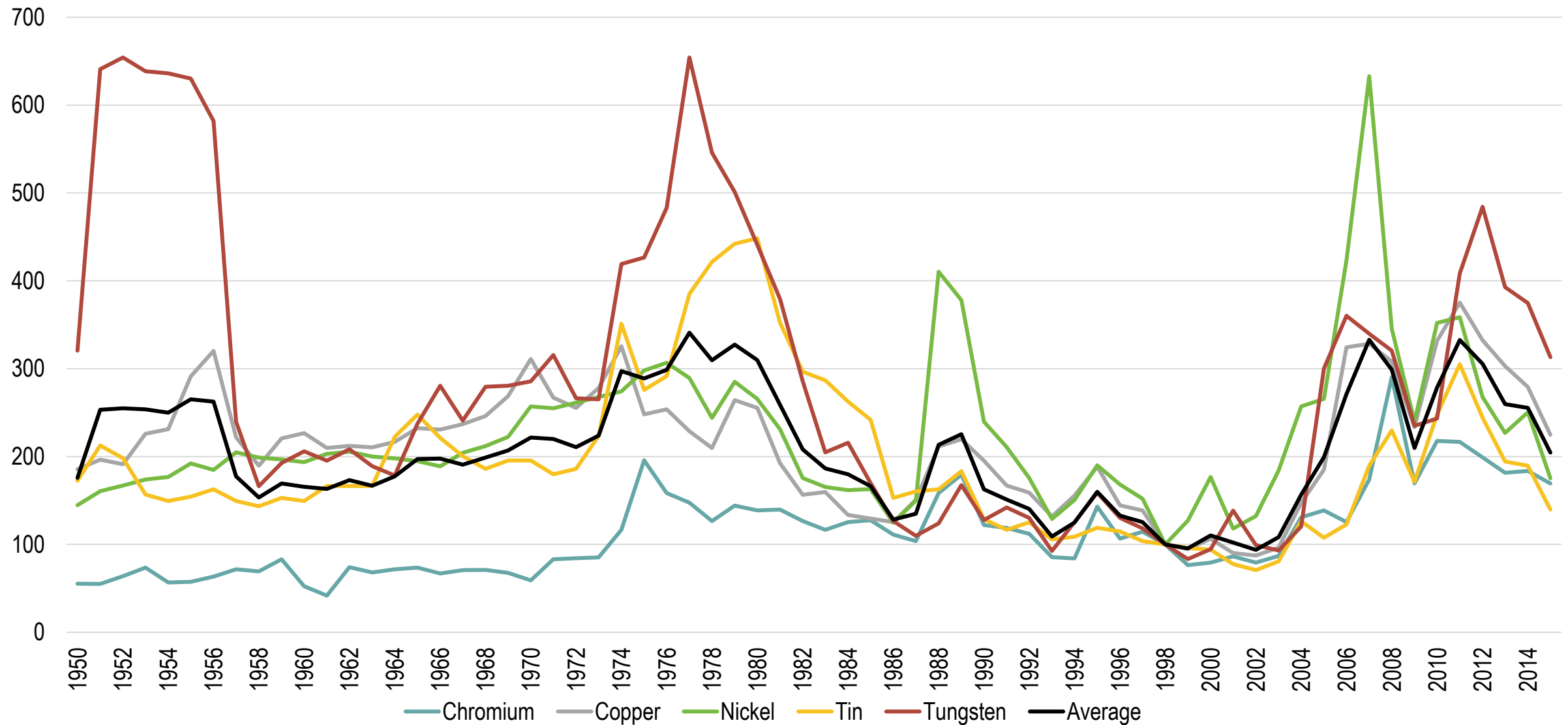
Sustainable Development



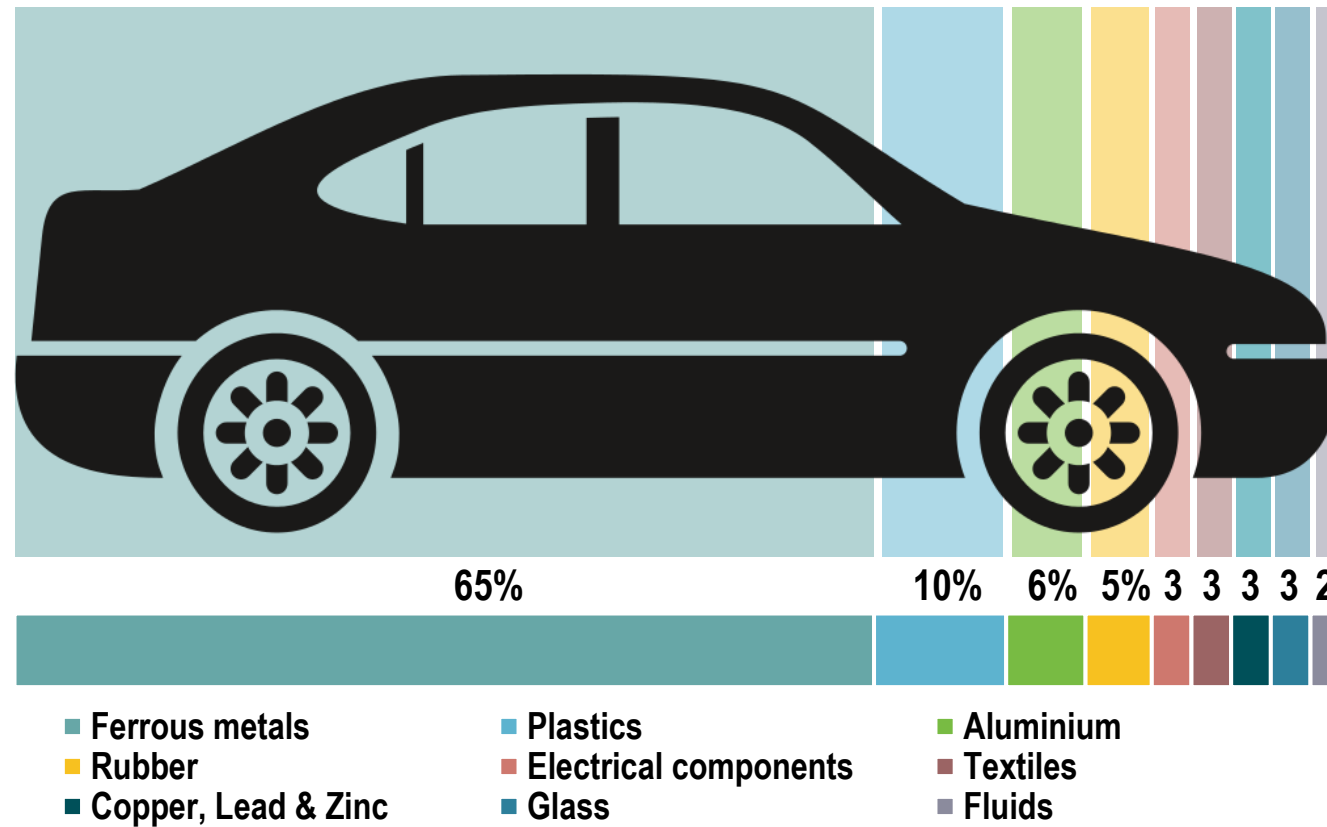
Main Commodity Price Indexes, 1992-2019 (2016=100)



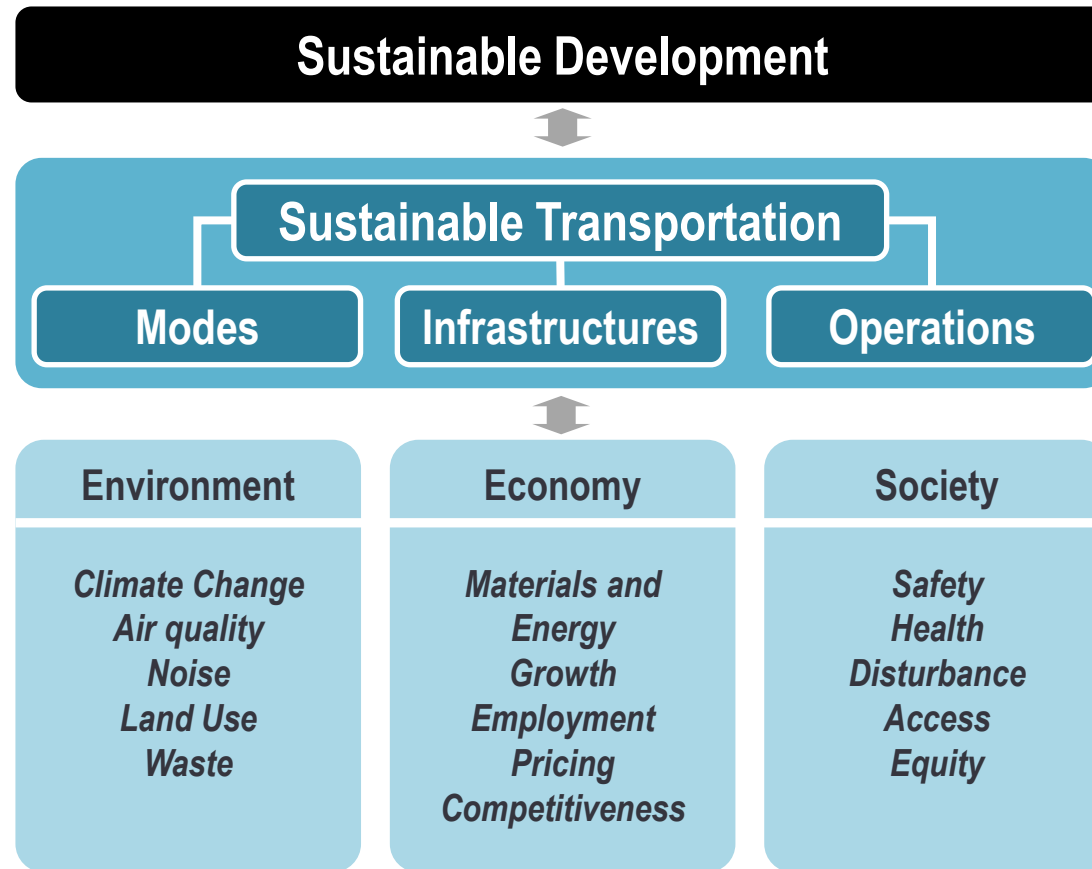
Inflation-Adjusted Price of some Commodities, 1950-2015 (1998=100)



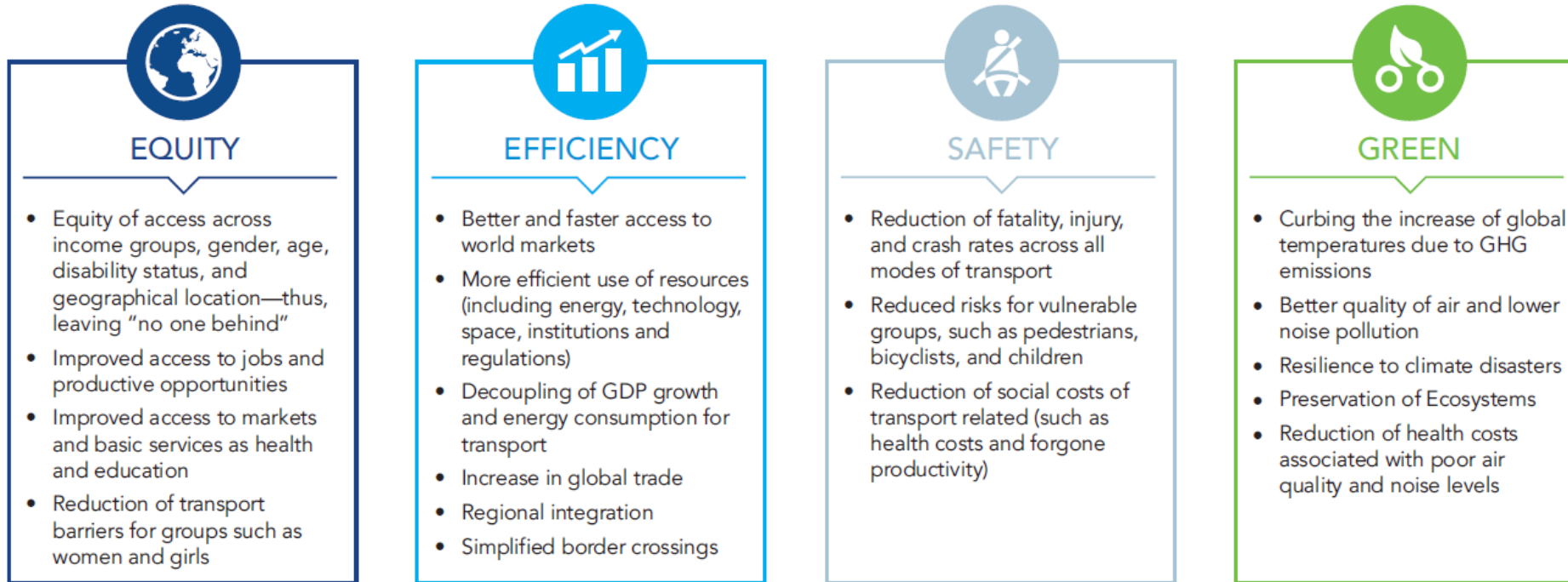
Main Material Components of a Car



Sustainable Transportation

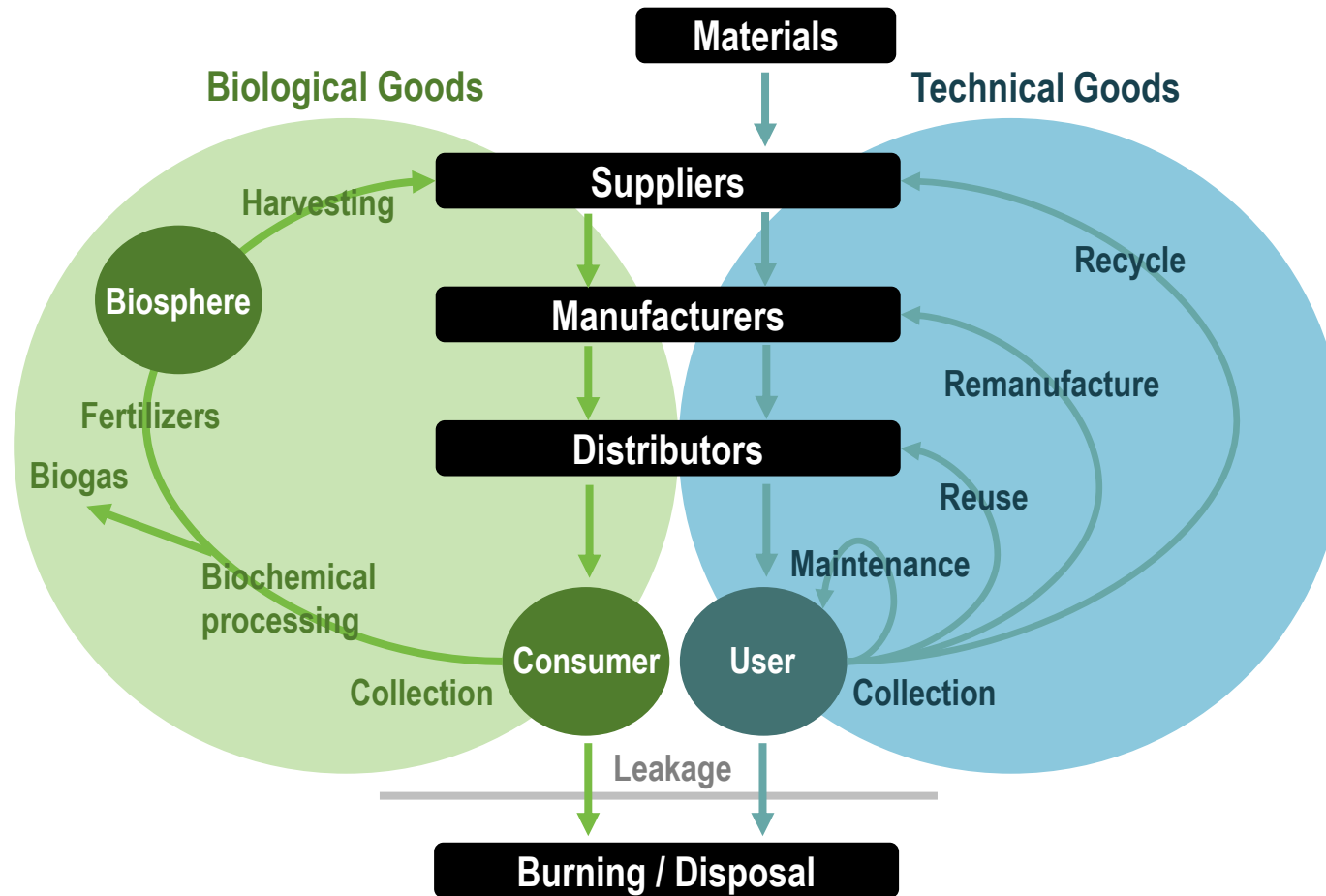


Economic and Social Outcomes of Sustainable Transportation

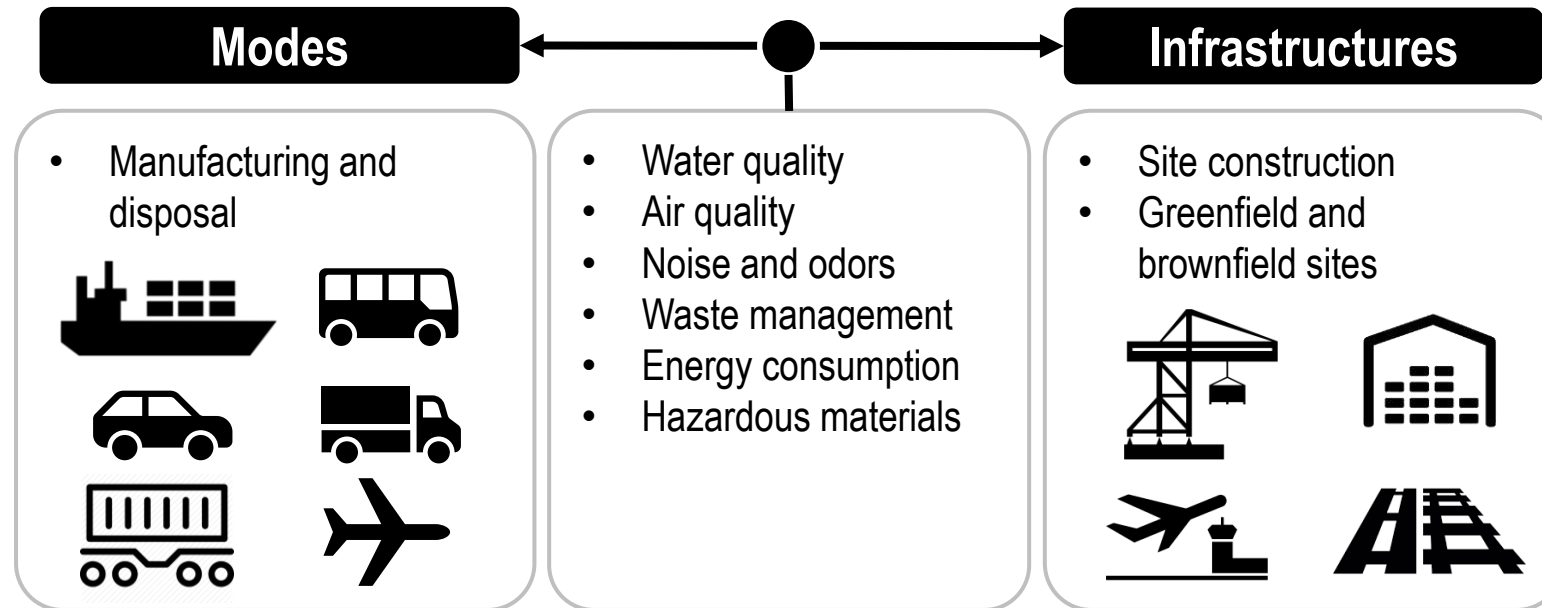


Source: Own elaboration

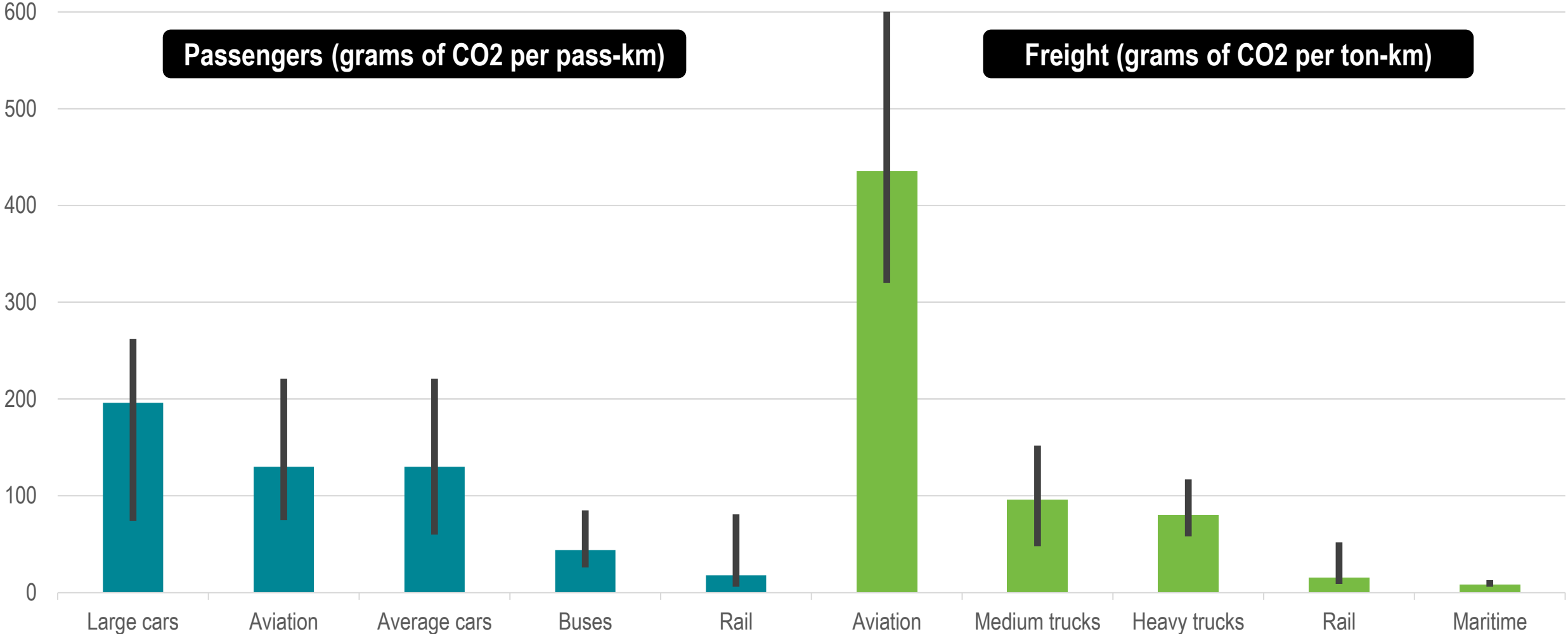
The Circular Economy and Supply Chains



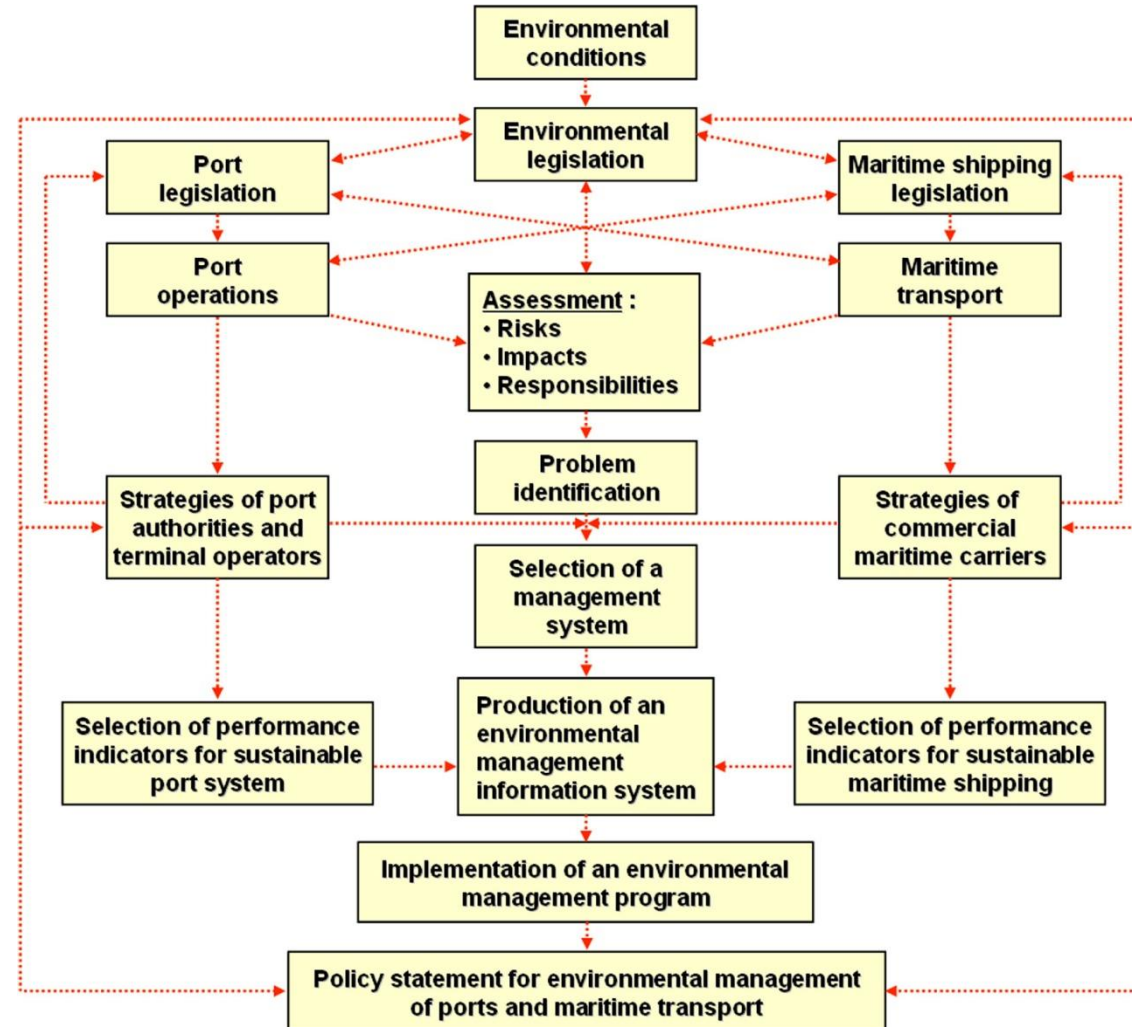
Sustainability Dimensions in the Transport Industry



Average CO2 Emissions by Passenger and Freight Transport Mode



Environmental Management System for Port and Maritime Transport



Clean Air Action Plan, Ports of Los Angeles and Long Beach

Mode	Control Measures	CAAP cost (\$M)	Comments
Heavy duty diesel trucks (HDV)	All trucks meet 2007 EPA standards by 2011 Alternative fuel station	\$1,808	Clean Truck Program: licensed trucking companies, employee drivers, costs to be paid by state bonds, ports, fees on cargo owners
Ocean going vessels (OGV)	Vessel speed reduction Electric shore power Auxiliary engine fuel standards Main engine fuel standards Engine emissions control devices	202	Incentives for VSR, cleaner fuels; ports pay for shore power
Cargo handling equipment (CHE)	Cleanest available technologies All CHE meet 2007 EPA standards by 2010	0	Accelerated equipment replacement by terminal operators
Harbor craft	Gradual shift to highest EPA standards	0	Retrofits, engine replacements
Railroad	Switch engine replacement for local rail line Increased emissions control on Class 1 railroads Cleanest available technology for new rail yards	21	Switch engine replacement part of existing agreement; Class 1 RR compliance by 2011; no new rail yards developed
Other	Technology Advancement Program Infrastructure and operational efficiency Administrative costs	36	TAP for development of clean vehicle technology
Total		\$2,067	

General Indicators of Urban Sustainability



The Decarbonization of Transportation

