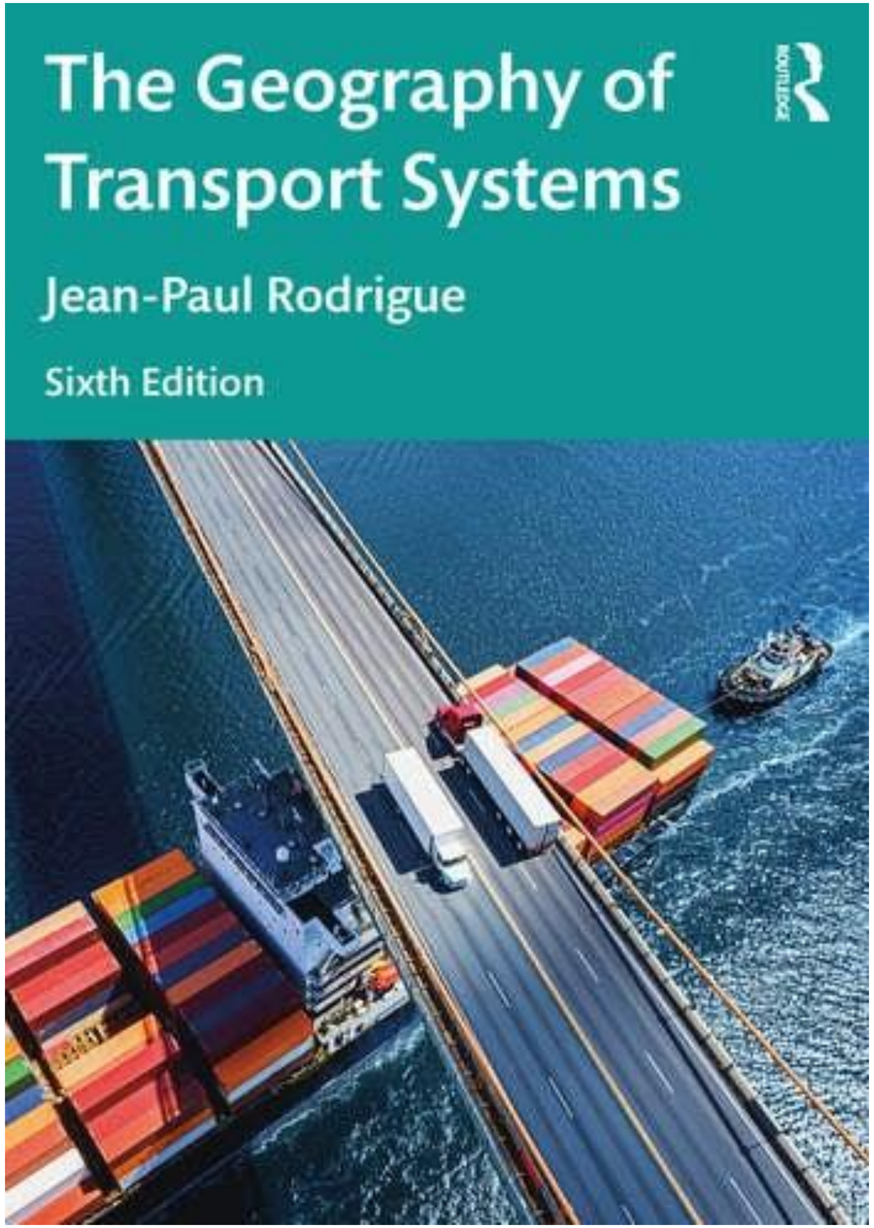

Transport, Energy and Environment

CHAPTER 4

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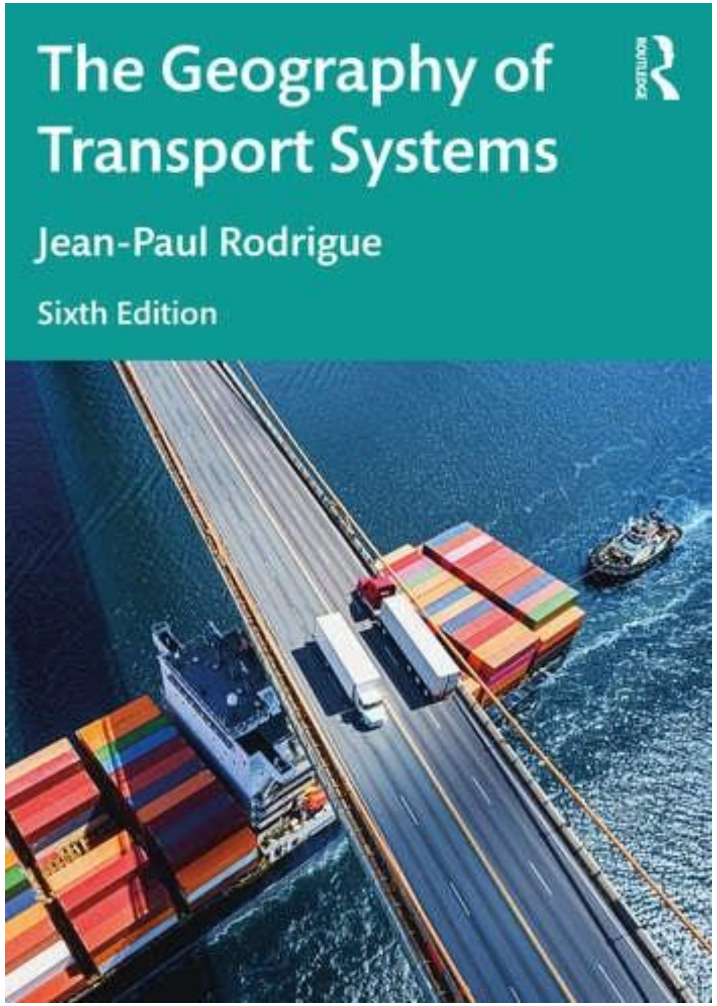

Transportation and Energy

Chapter 4.1

Sources of Energy

ENERGY	NON-RENEWABLE	RENEWABLE	
Chemical **Nuclear** **Gravitational** **Electromagnetic** **Mechanical** **Thermal** **Electrical**	**Chemical** • Fossil fuels (Combustion) **Nuclear** • Uranium (Fission of atoms)	**Chemical** •Hydrogen (Combustion) •Muscular (Oxidization) **Nuclear** • Geothermal (Thermal conversion) • Fusion (Fusion of hydrogen) **Gravitational** • Tidal (Mechanical)	**Indirect Solar** • Biomass (Photosynthesis) • Wind and hydraulic (Mechanical) **Direct Solar** • Photovoltaic cell (Conversion) • Solar thermal (Thermal conversion)

VECTORS: Liquid Fuels | Natural Gas | Electricity | Heat | Hydrogen

USES: Housing | Transportation | Industry | Services

Energy and Work

MODIFICATION OF THE ENVIRONMENT

- Modifying the landscape (agriculture, mining, residential, industry, transportation).
- Construction of infrastructure and buildings.
- Modifying the hydrography (irrigation, water supply, energy).
- Conditioning enclosed structures (temperature and light).

APPROPRIATION AND PROCESSING

- Resources extraction (agricultural products and raw materials).
- Modifying resources (manufacturing).
- Waste disposal (landfills, decontamination and incineration).
- Recycling and re-use.

TRANSPORTATION

- Mobility of freight, people and information.
- Packing, sorting, bundling and unbundling.
- Energy for conveyances.
- Energy for terminals.
- Energy for warehousing and distribution.

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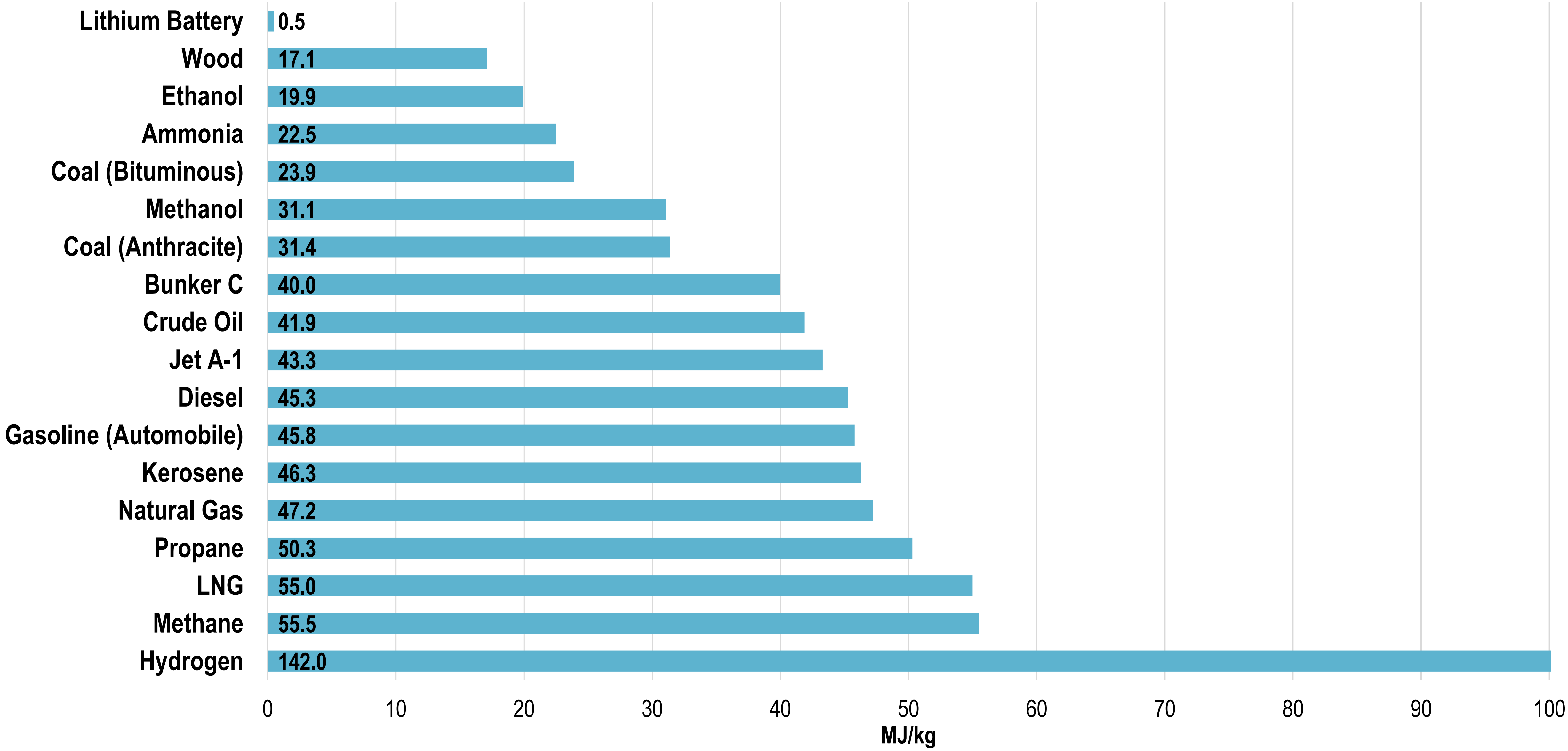
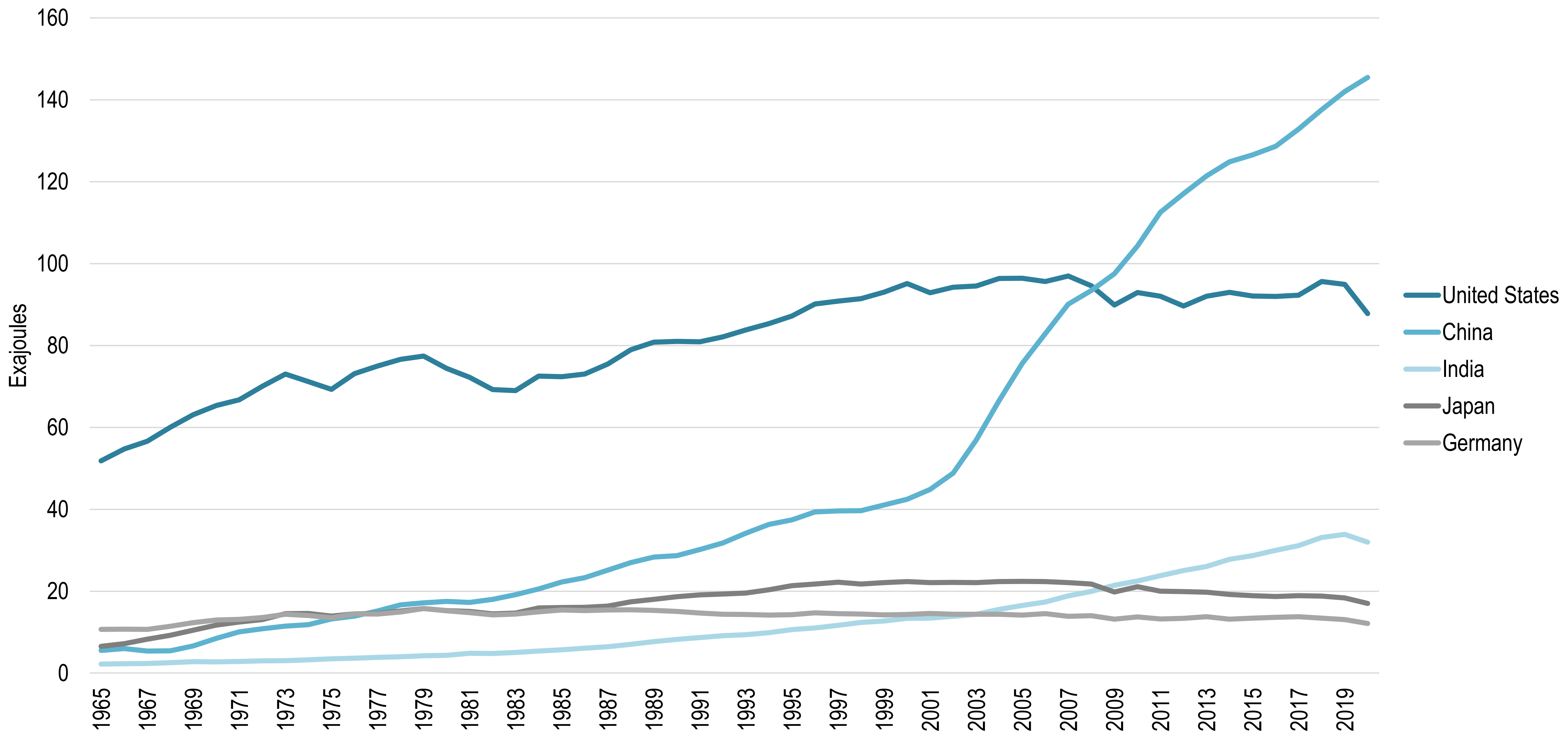
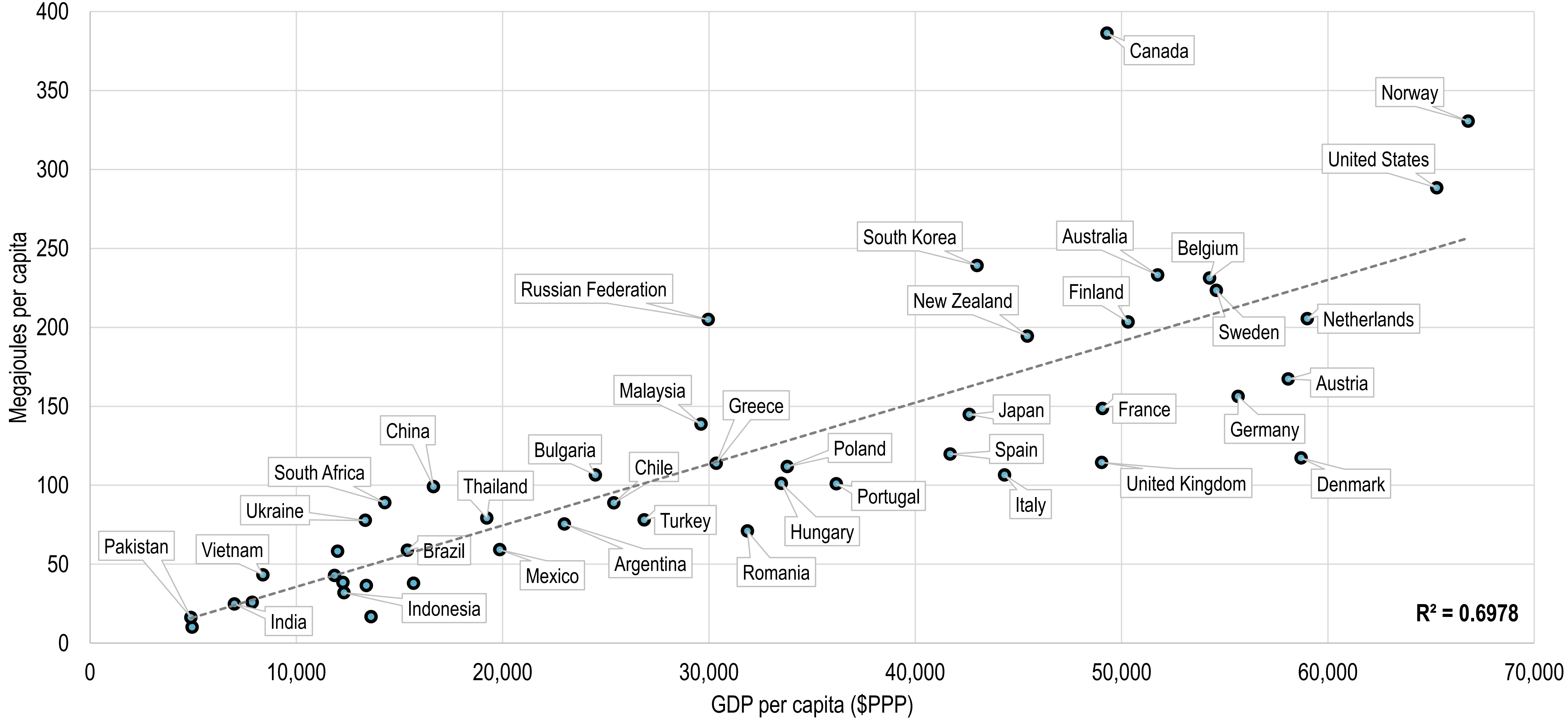
Chemical Energy Content of some Fuels (in MJ/kg)



Primary Energy Consumption, Selected Countries, 1965-2020



Primary Energy Consumption and GPD Per Capita, 2019



Fuels Production Processes

FUEL	SOURCES	PROCESSES
Liquid petroleum fuels (Gasoline, Diesel, Kerosene, Jet fuel, Bunker fuel)	Conventional oil fields (ground and shore-based)	Refining
	Non-conventional sources (tar sands, fracking)	
Liquid synthetic fuels	Natural gas, coal	Gasification
Biodiesel	Oilseed crops	Esterification, hydrogenation
	Biomass from crops or wastes	Gasification
Ethanol	Plant materials (corn, sugar cane)	Saccharification, distillation
	Cellulose	Gasification, pyrolysis
CNG	Natural gas	Gasification
Electricity	Coal, gas, petroleum, nuclear, hydro, solar, wind	Electric generator (source dependent)
Ammonia	Natural gas, hydrogen	Haber-Bosch process
Hydrogen	Natural gas (Grey hydrogen)	Steam reforming, compression
	Electricity (Green/Yellow hydrogen)	Electrolysis
	Biomass (Turquoise hydrogen)	Pyrolysis

Energy Sources Used for Transportation

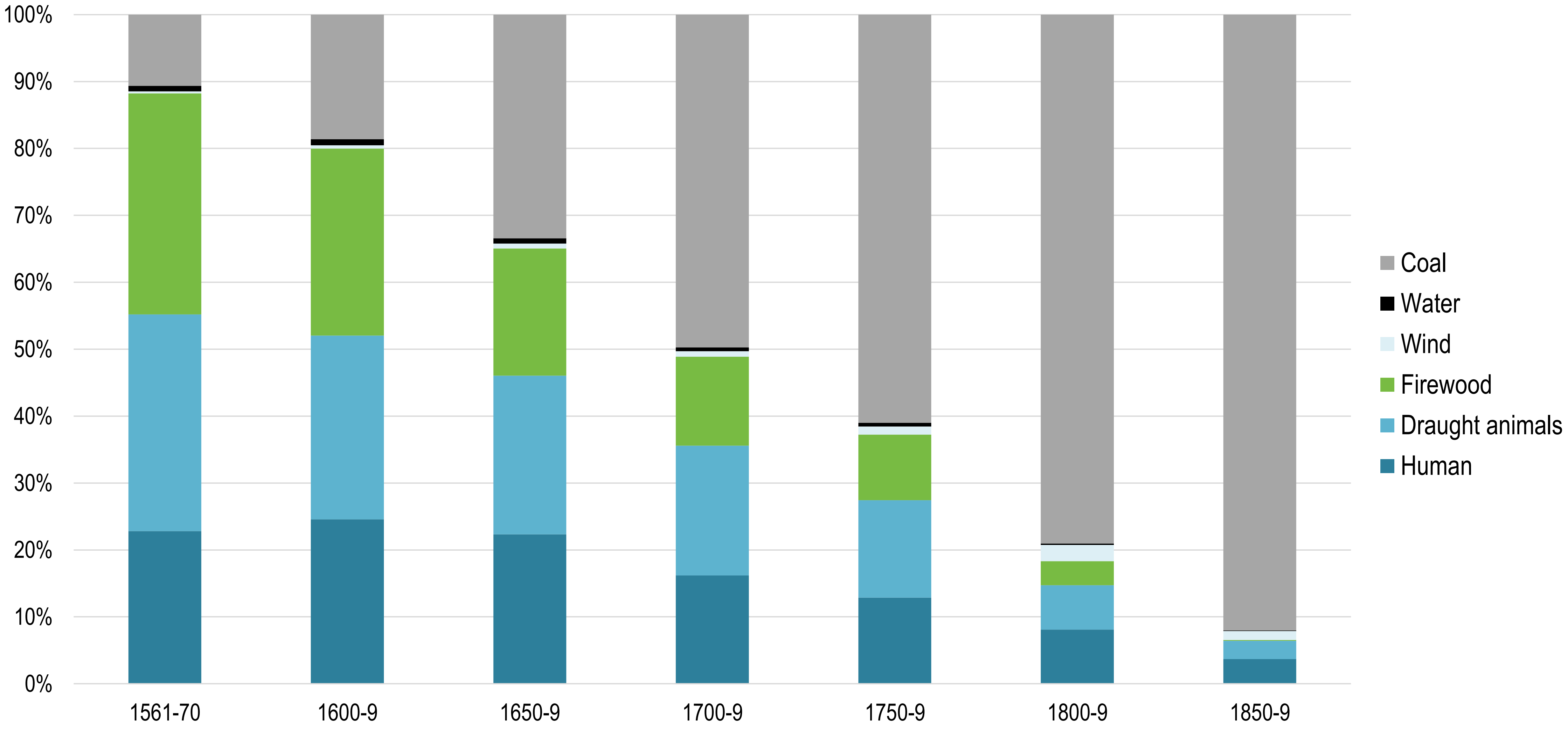
- Muscular
- Wind
- Gravity
- Fossil fuels
- Electricity
- Biofuels

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

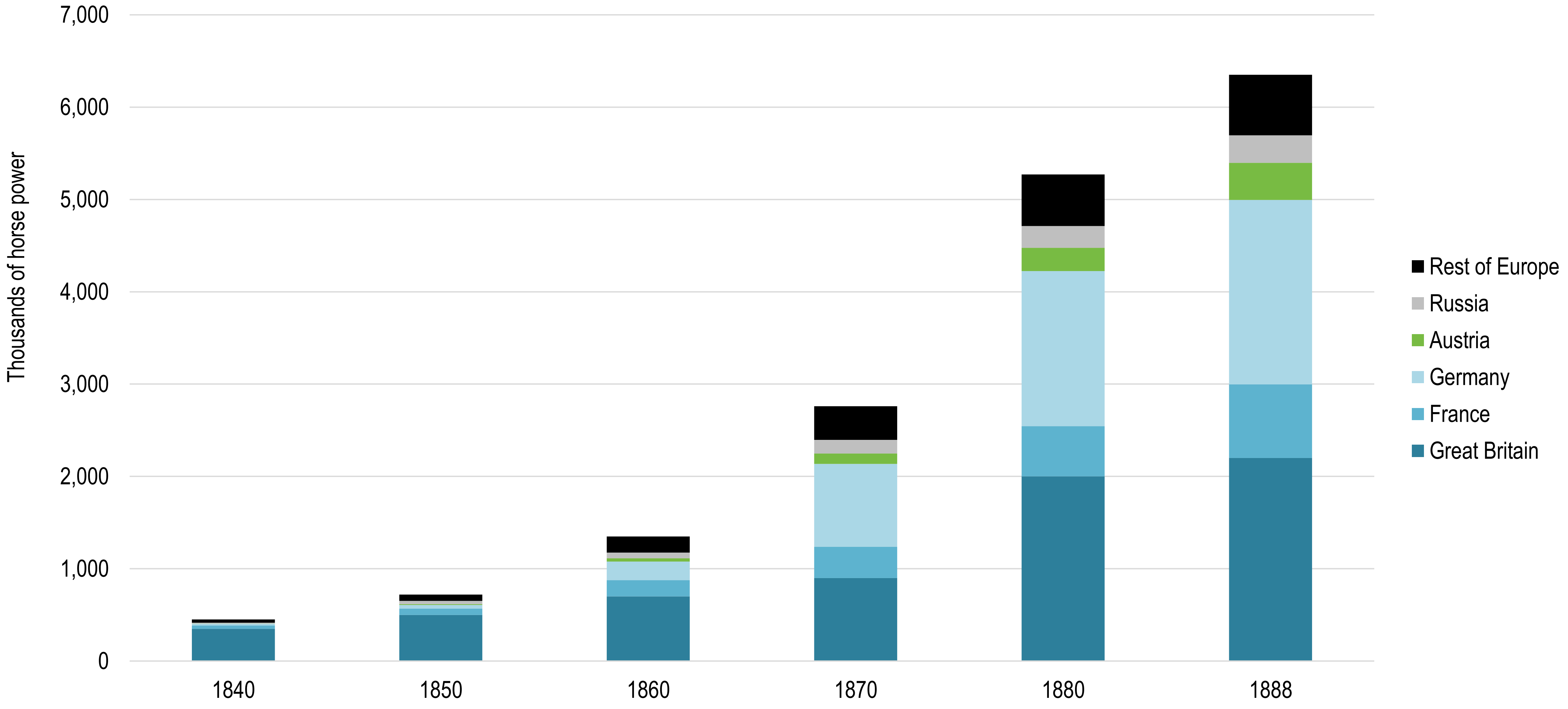
Alternative Sources of Energy for Transportation

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.

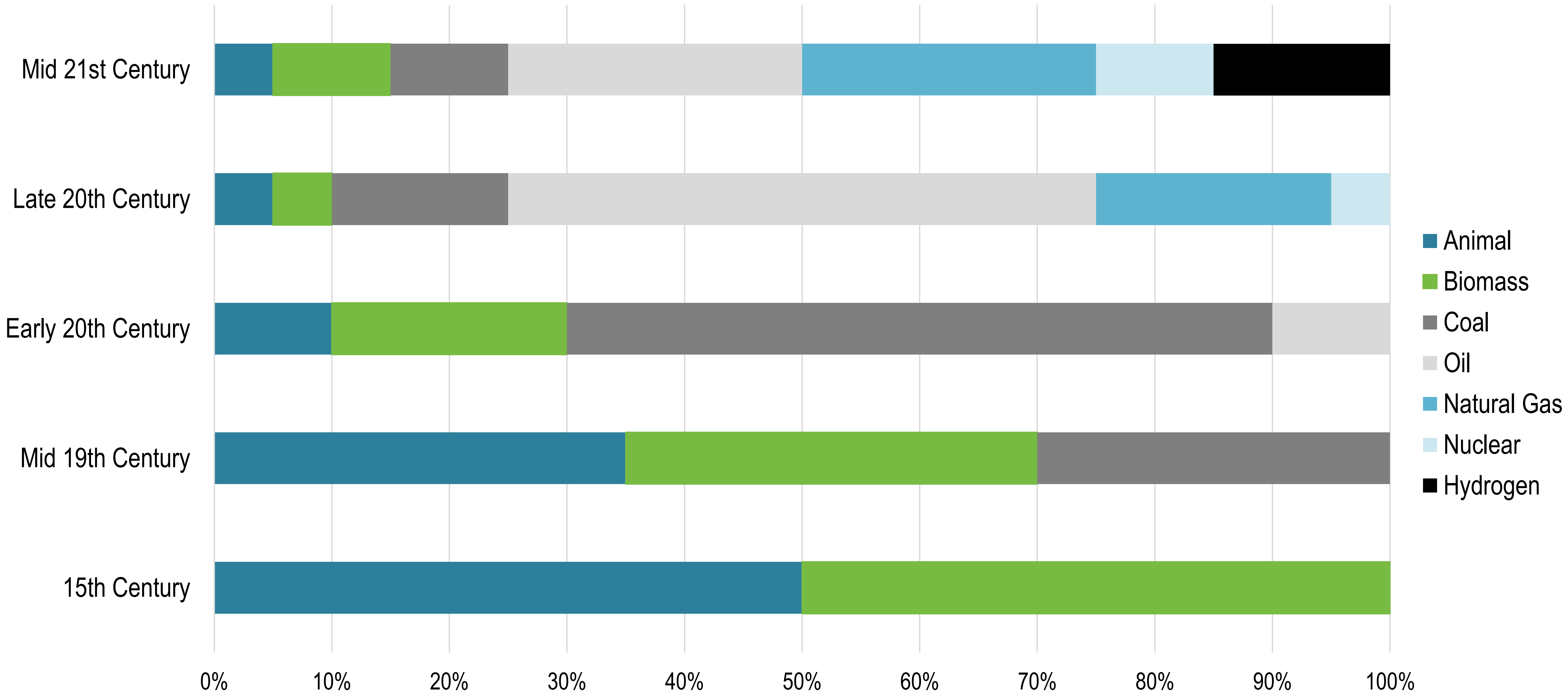
Annual Energy Consumption in England and Wales, 1560s to 1850s (MJ)



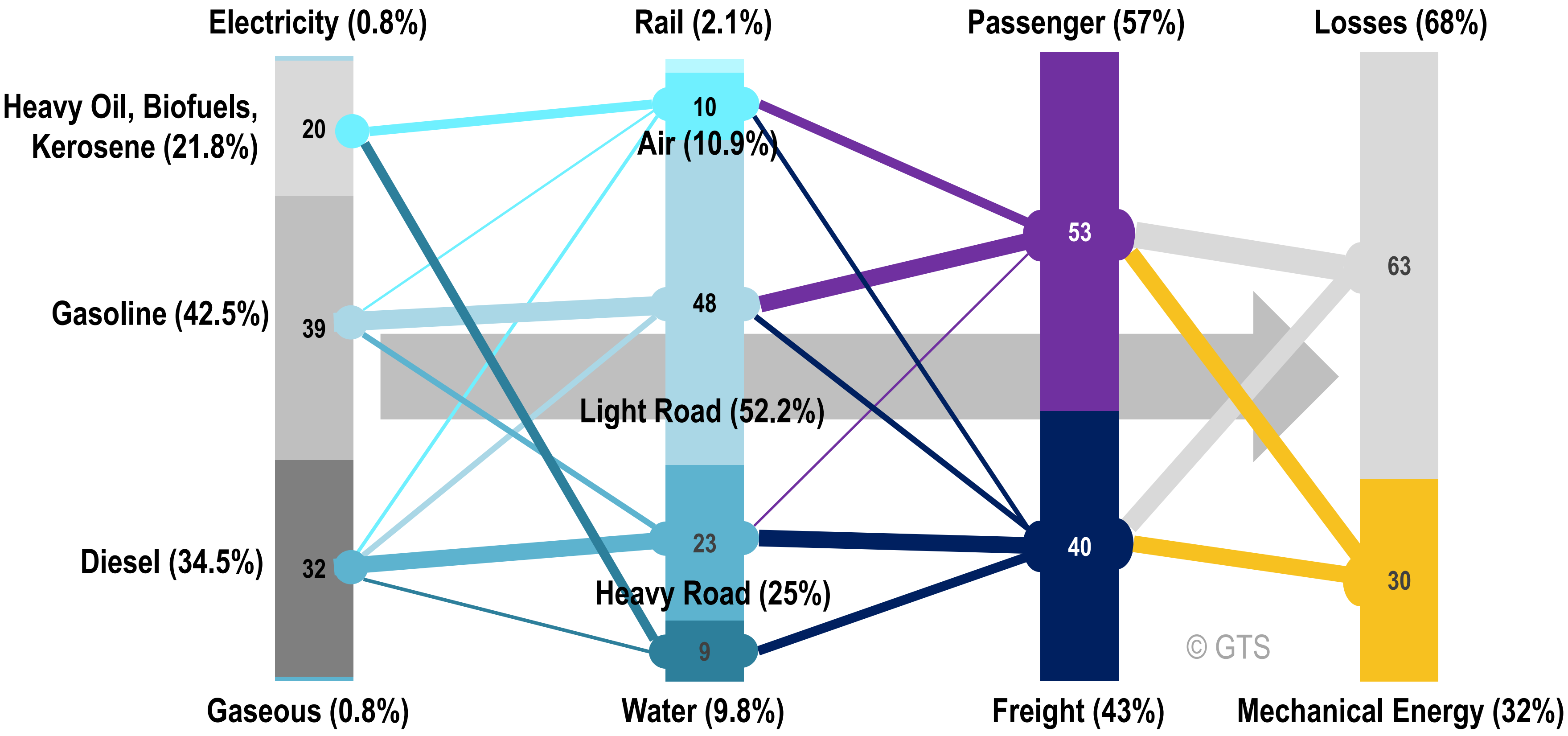
Power Generated by Steam Machines, Europe, 1840-1888



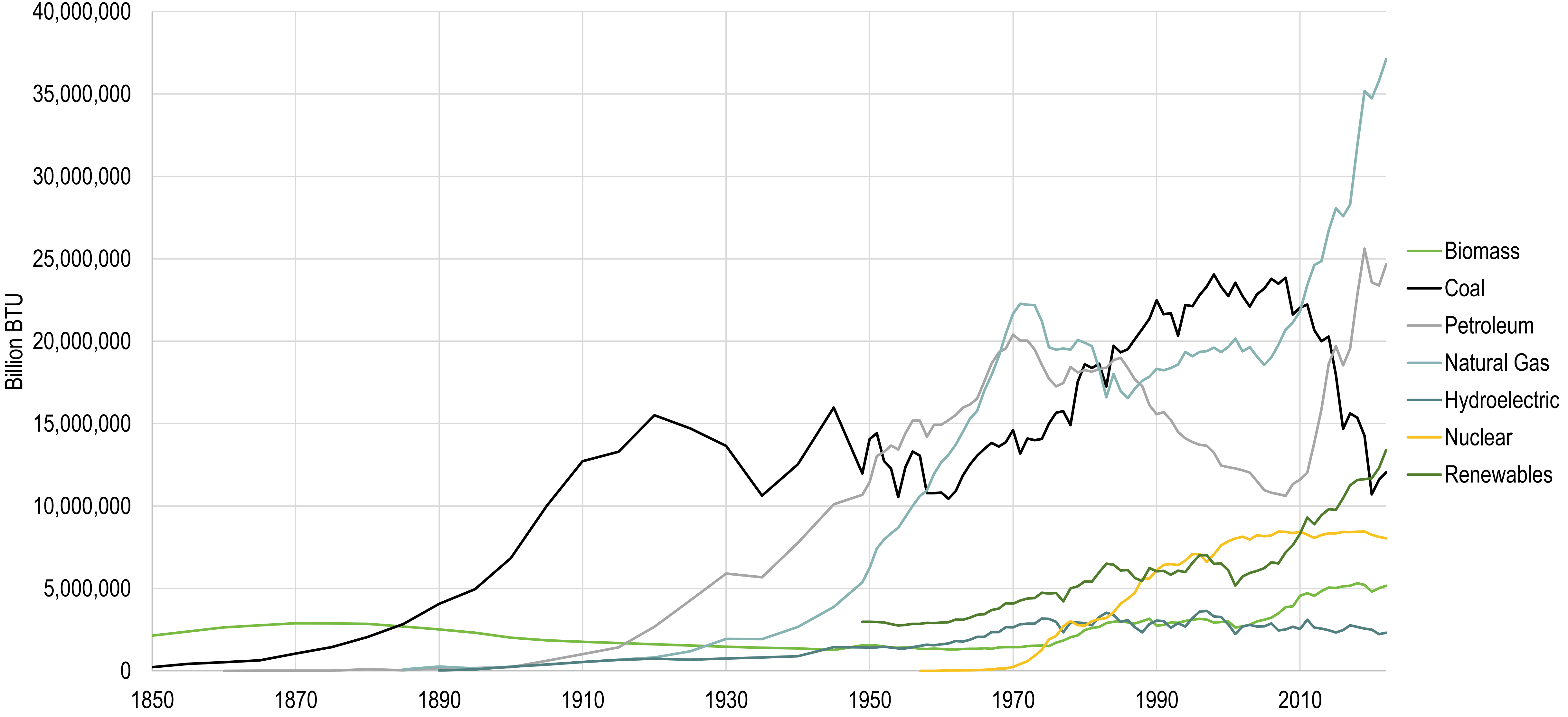
Evolution of Energy Sources



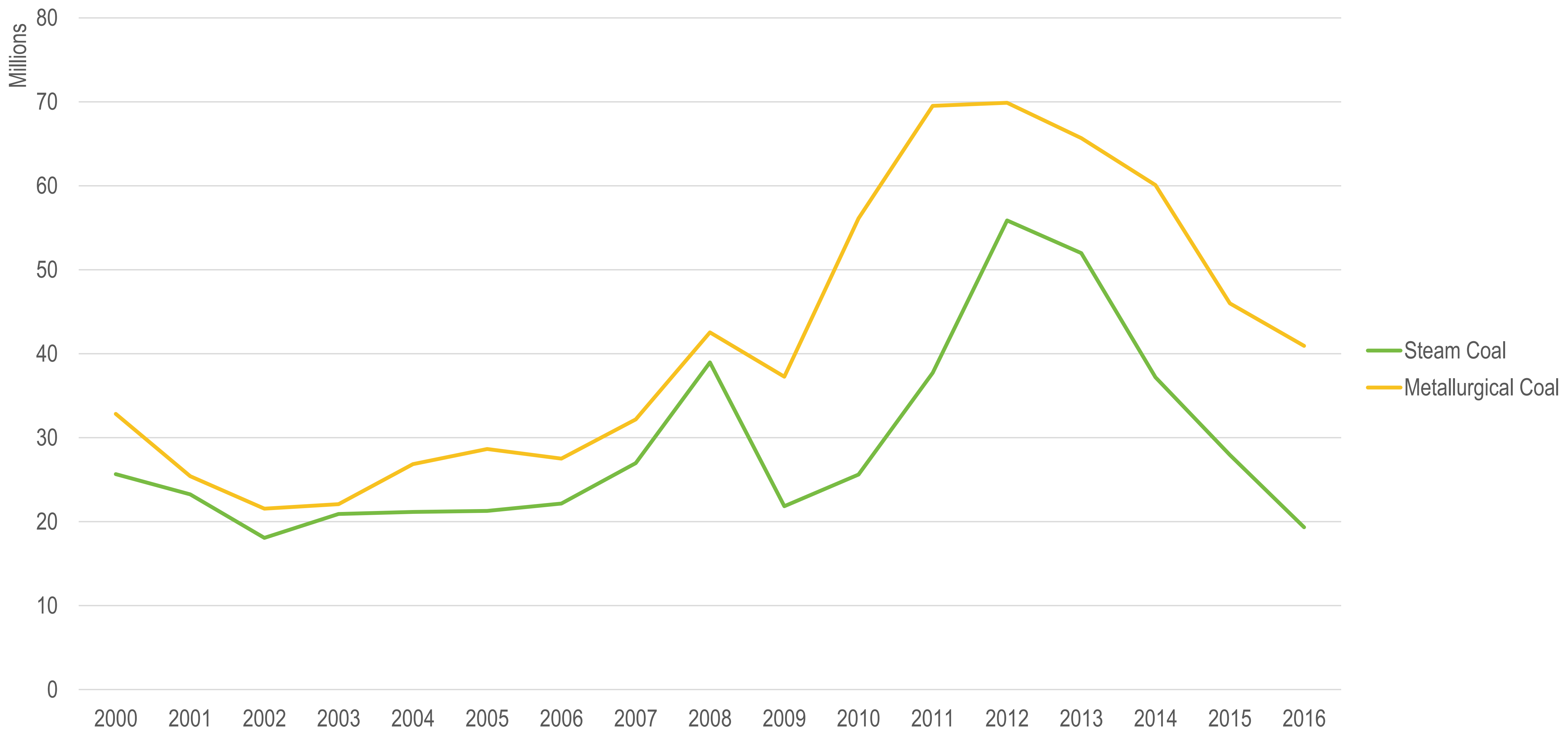
Final Energy Consumption by Fuel Type by Transport Sector (in Exajoules)



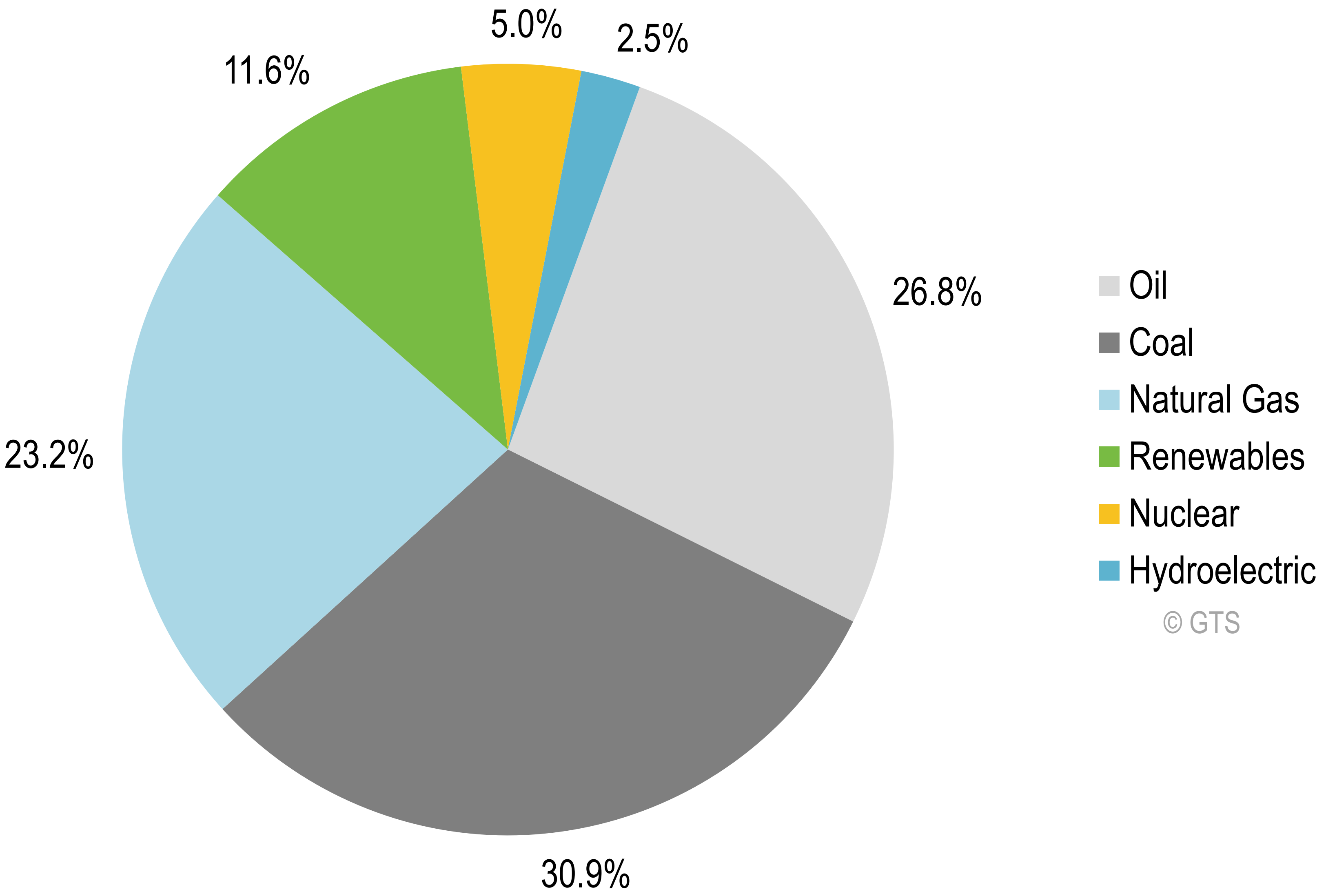
Primary Energy Production by Source, United States, 1850-2022



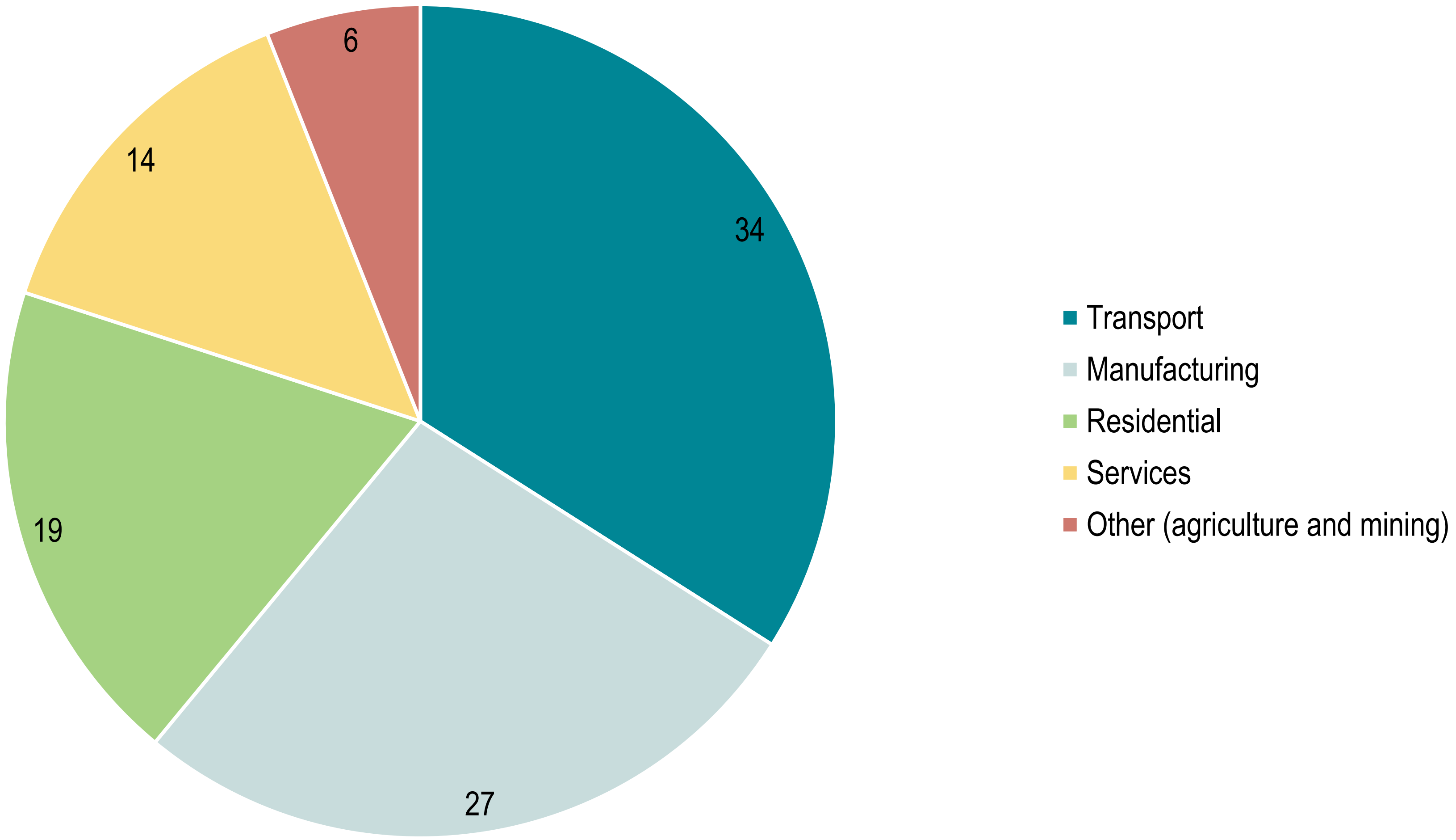
US Coal Exports in Tons, 2000-2016



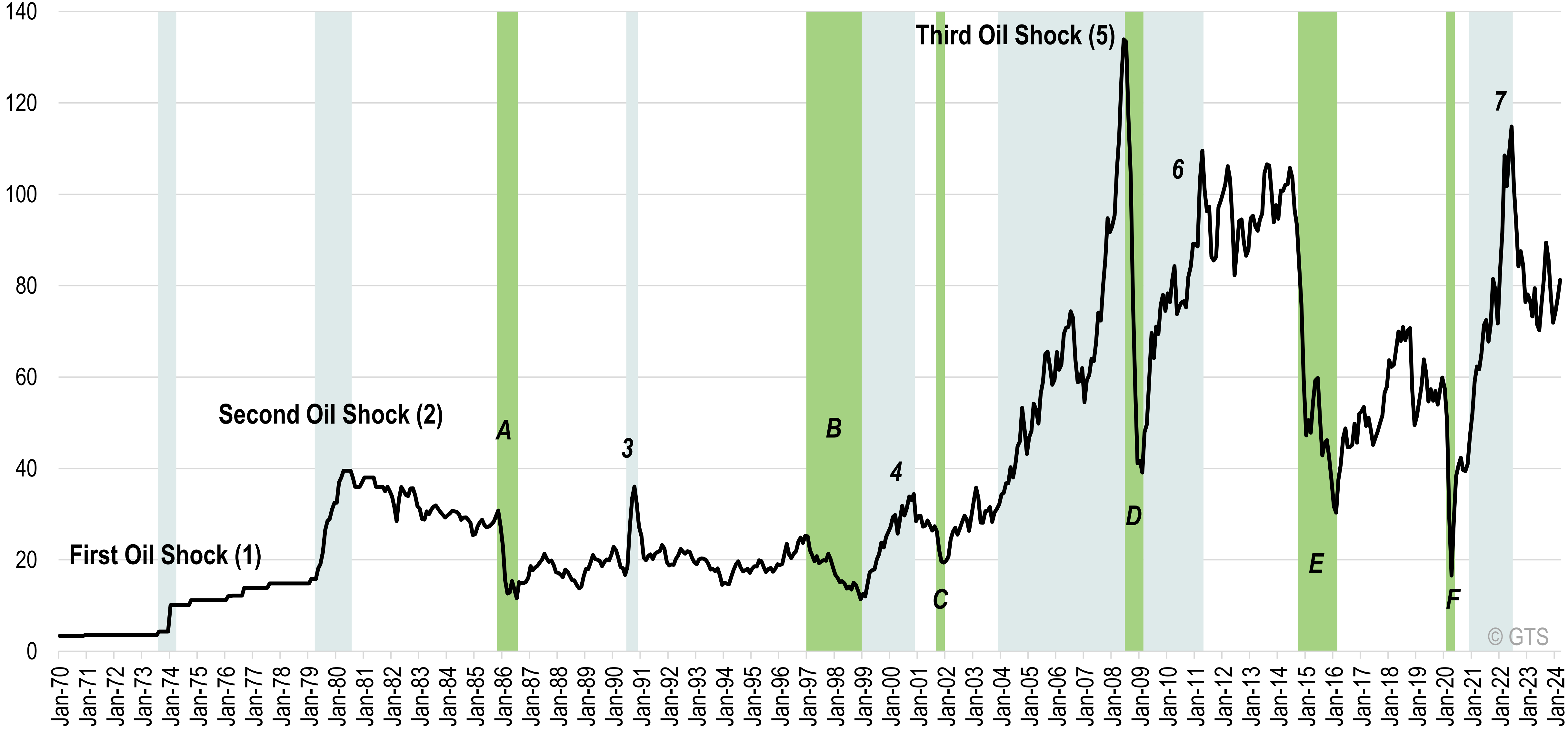
World Energy Production, 2019



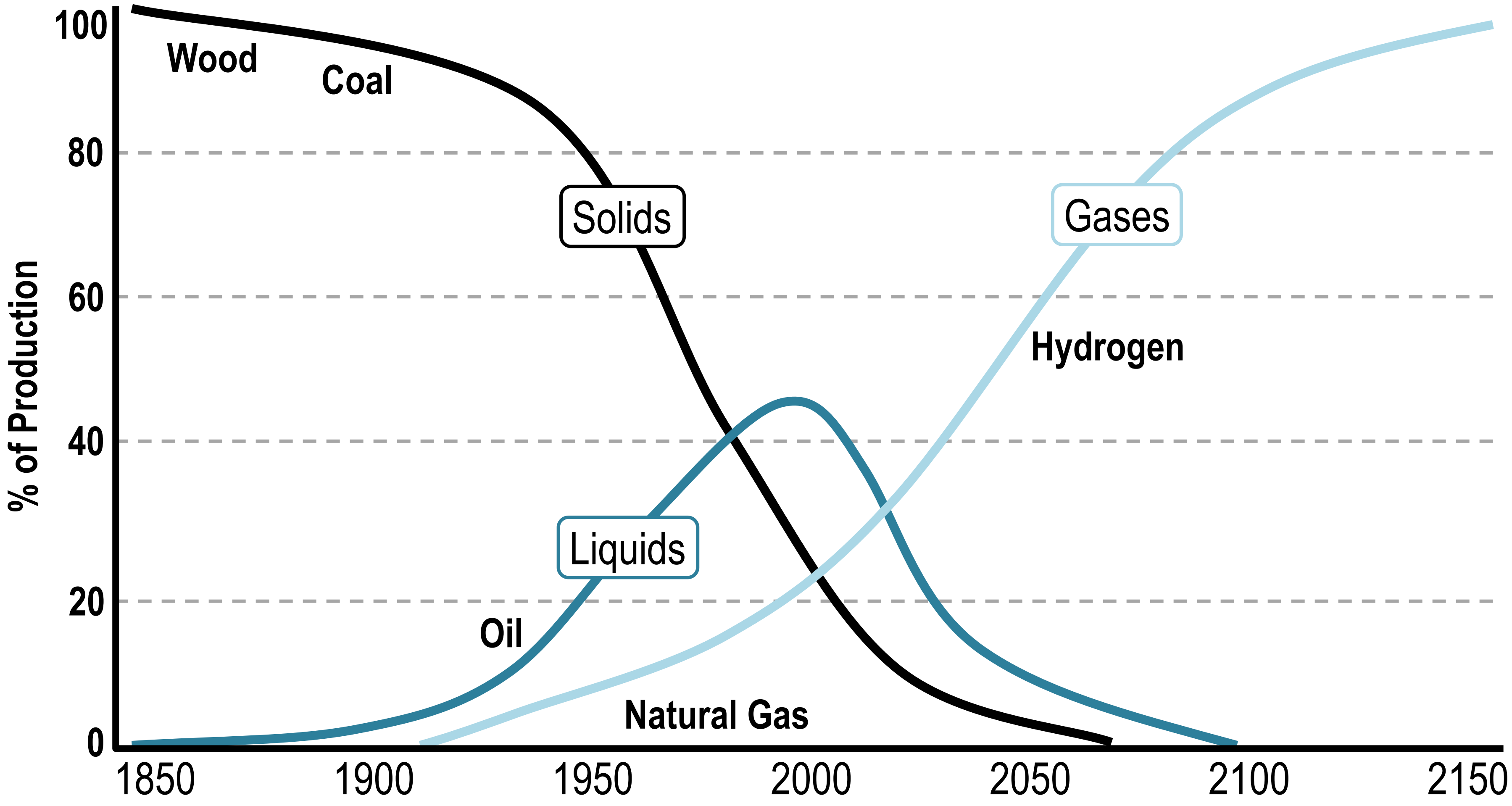
Energy End Uses, 2014



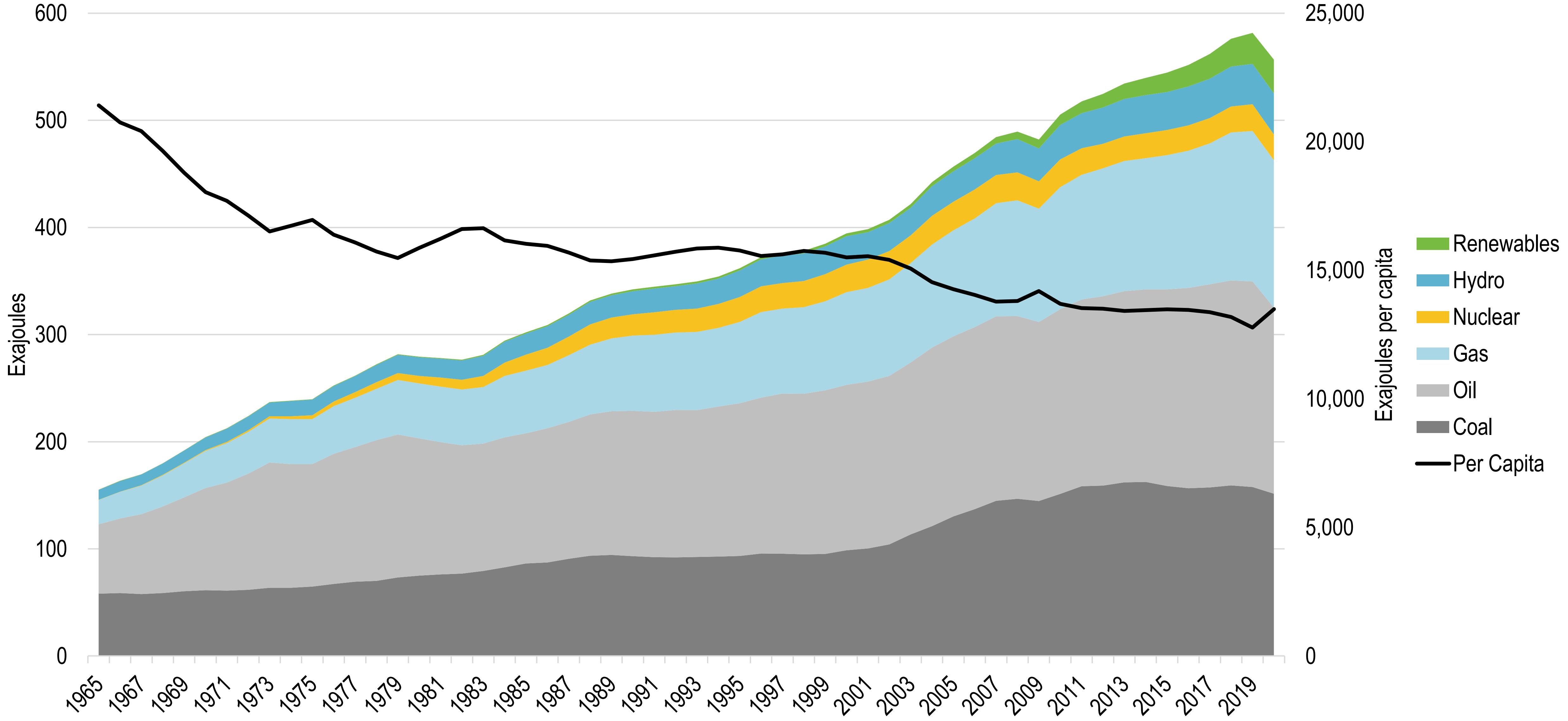
West Texas Intermediate, Monthly Nominal Spot Oil Price (1970-2024)



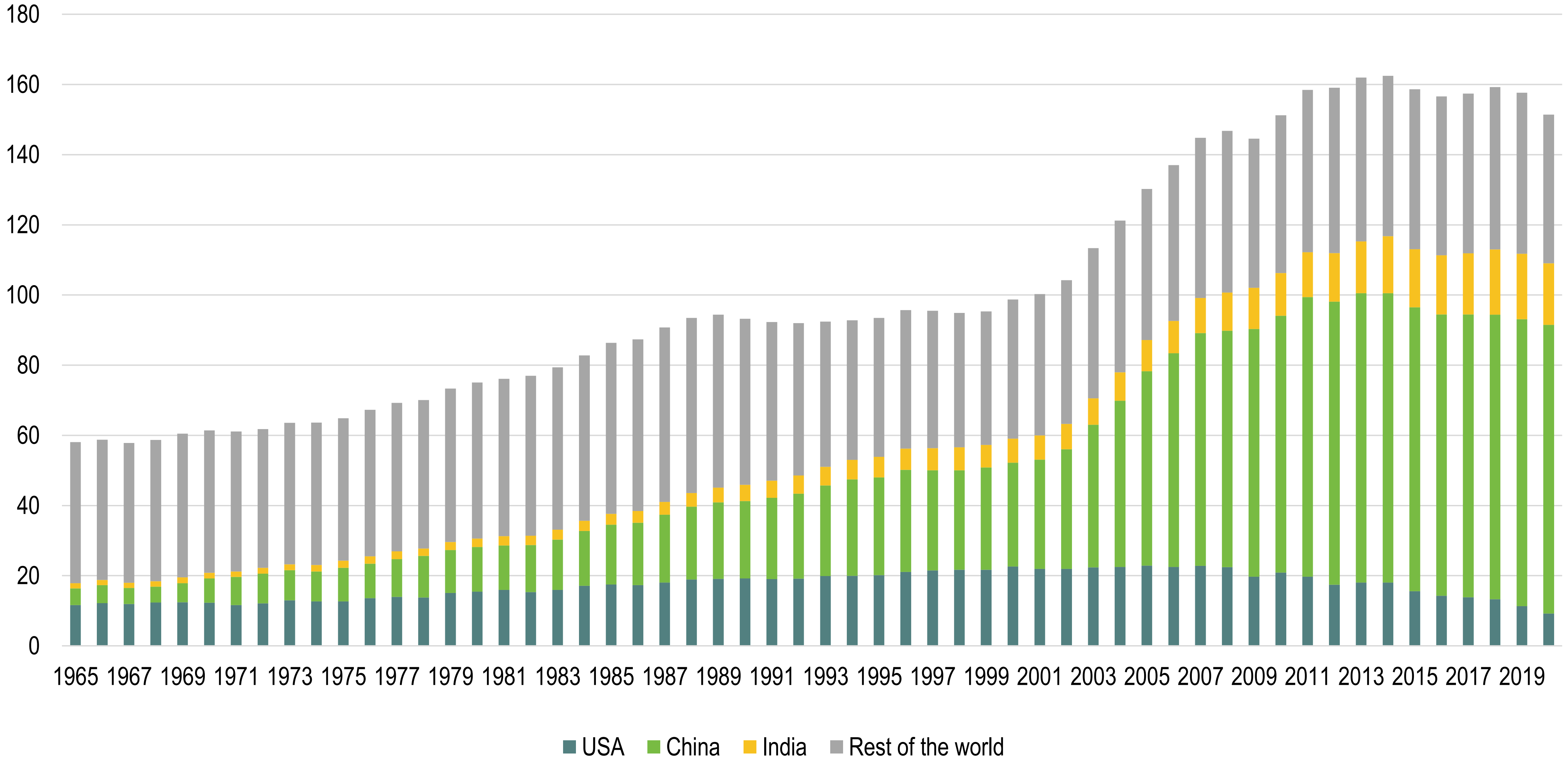
Global Energy Systems Transition



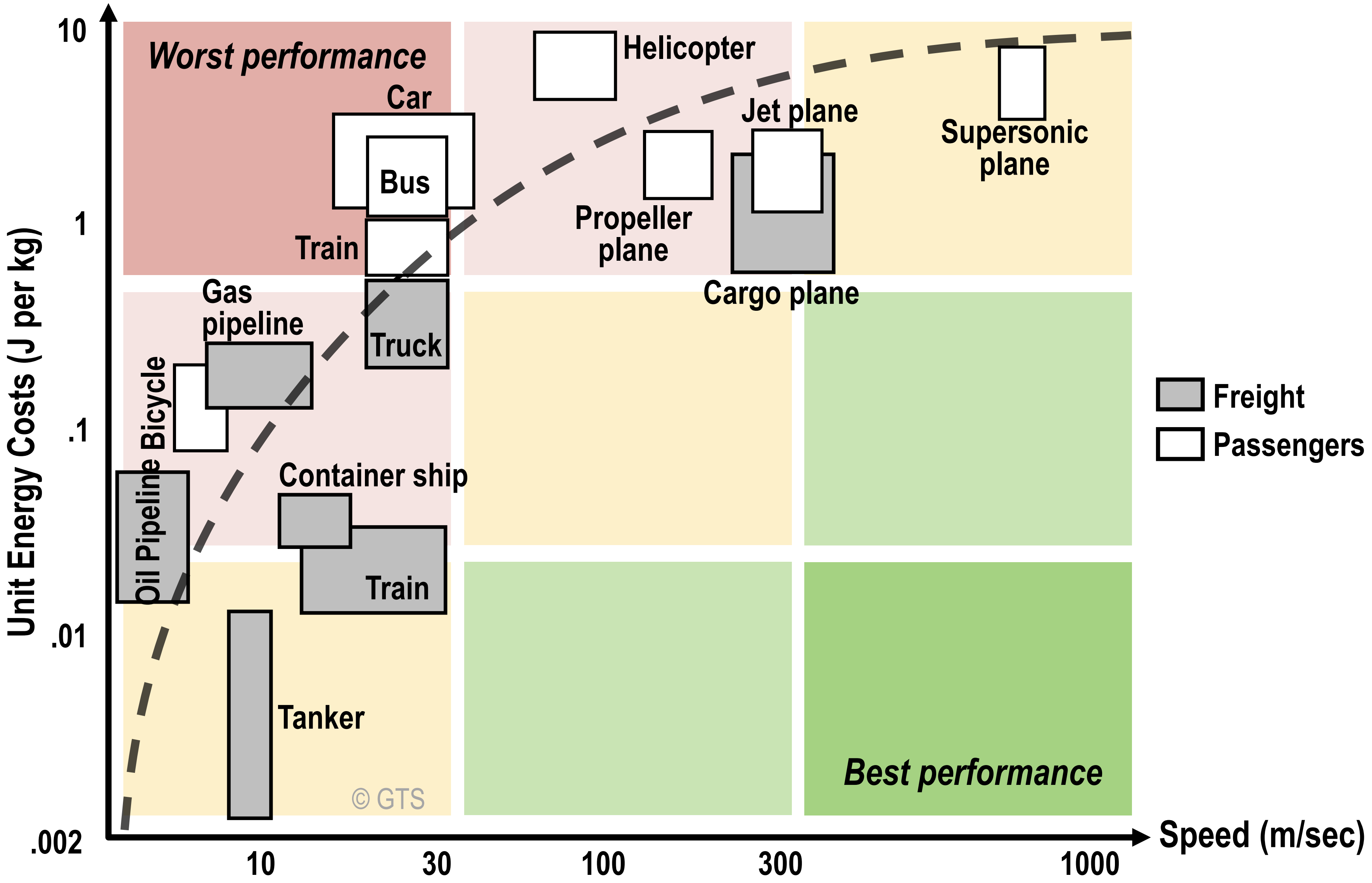
World Energy Consumption, 1965-2020



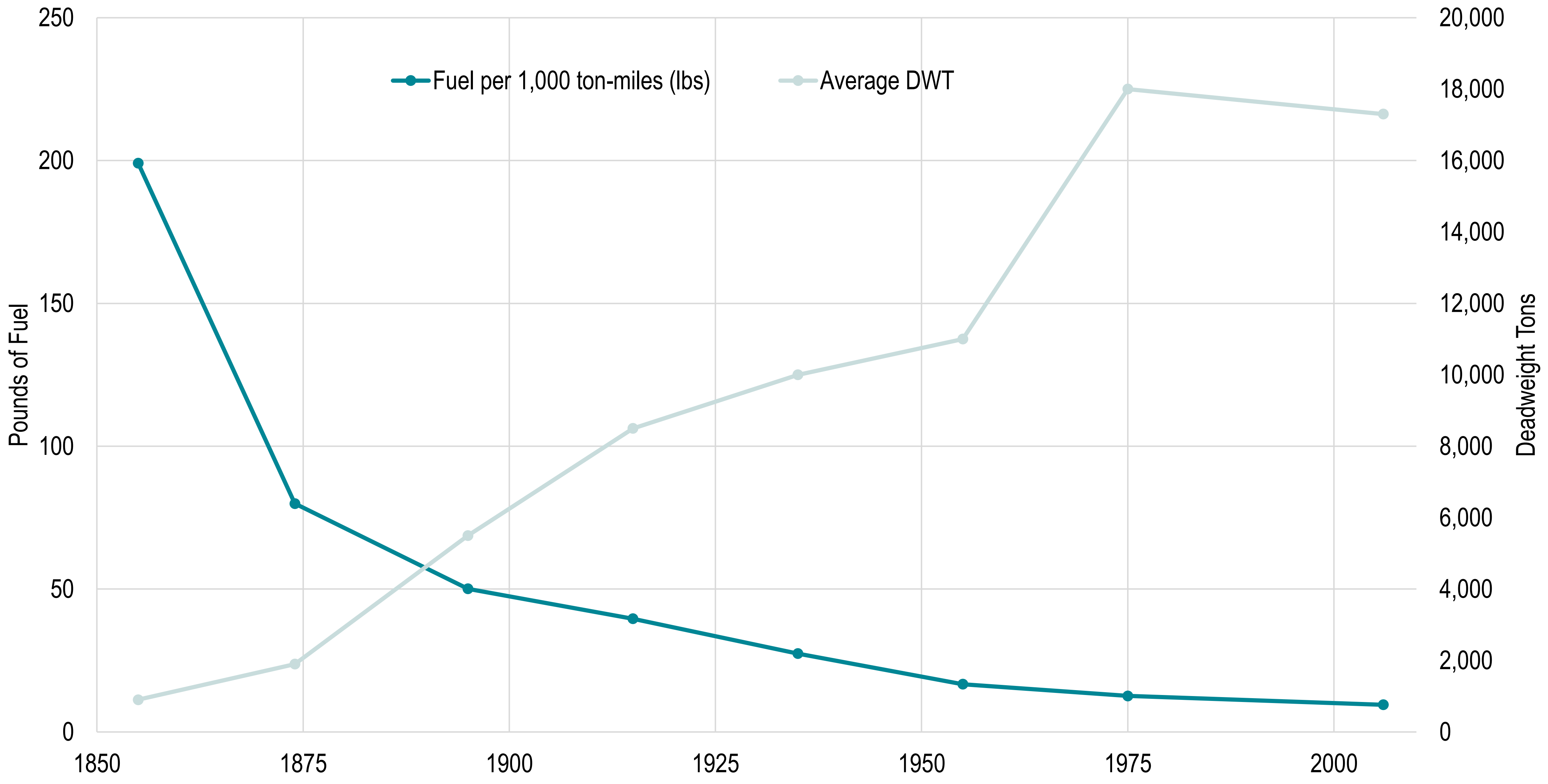
Coal Consumption, 1965-2020 (in Exajoules)



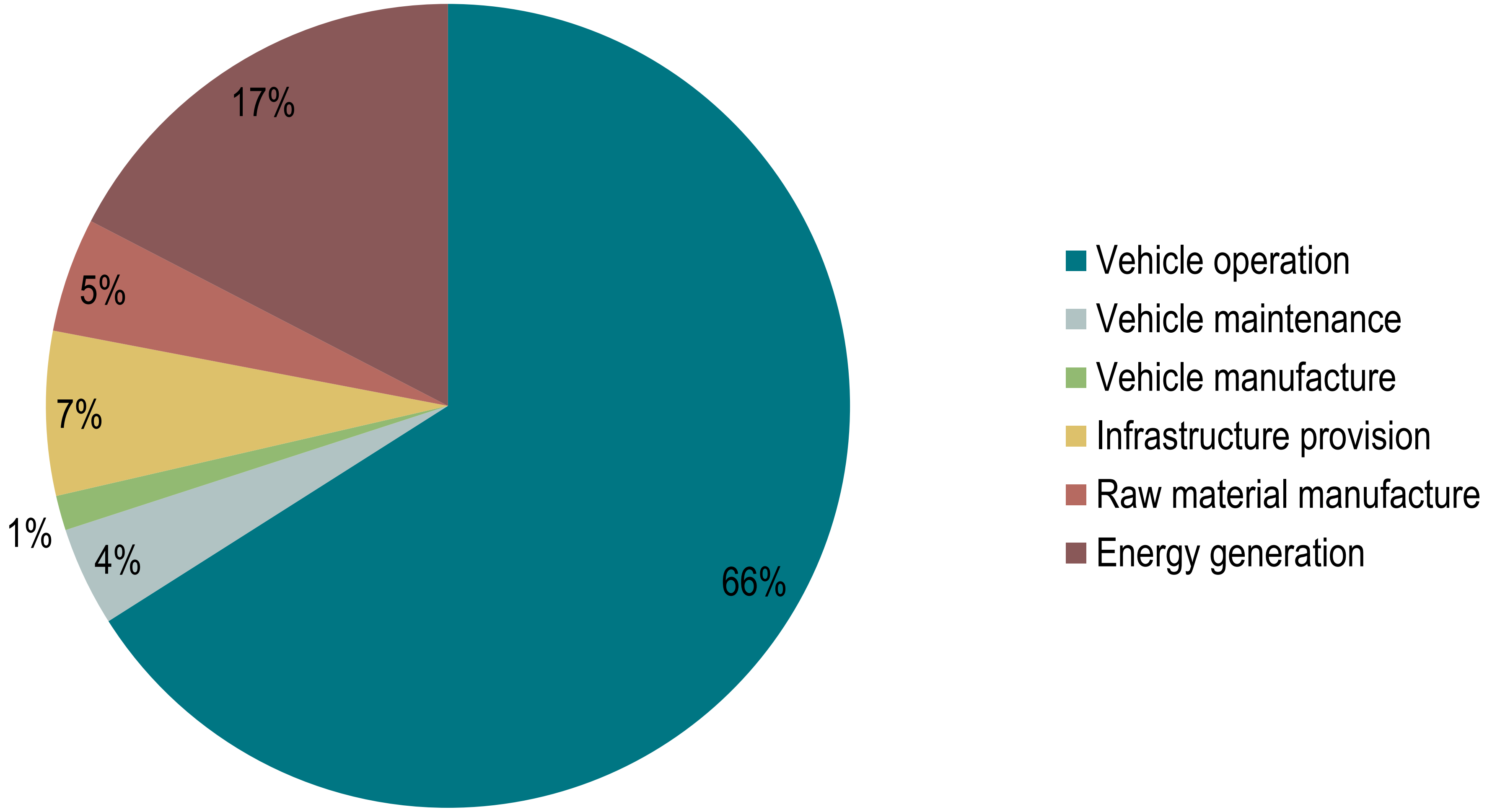
Energy Efficiency by Transportation Mode



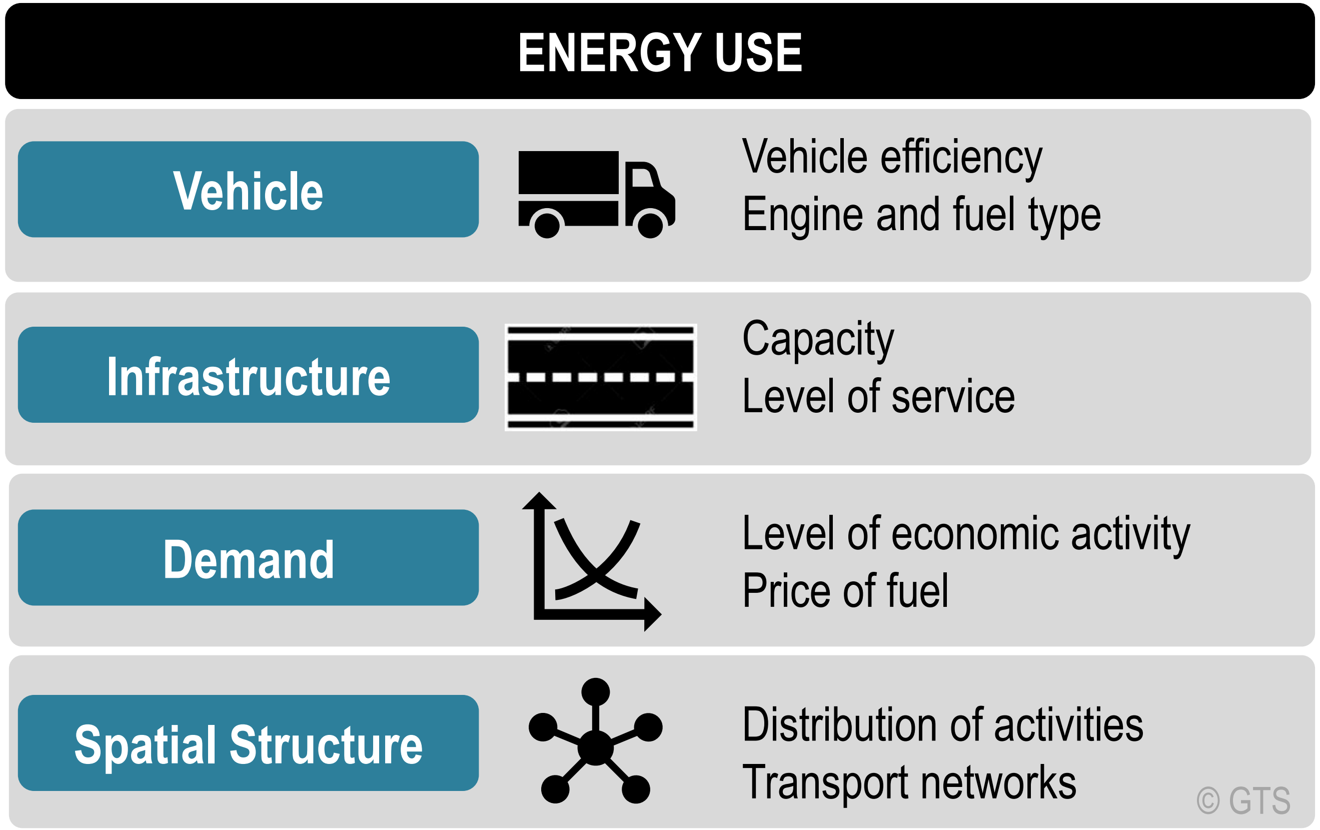
Fuel Consumption for an Average Cargo Ship



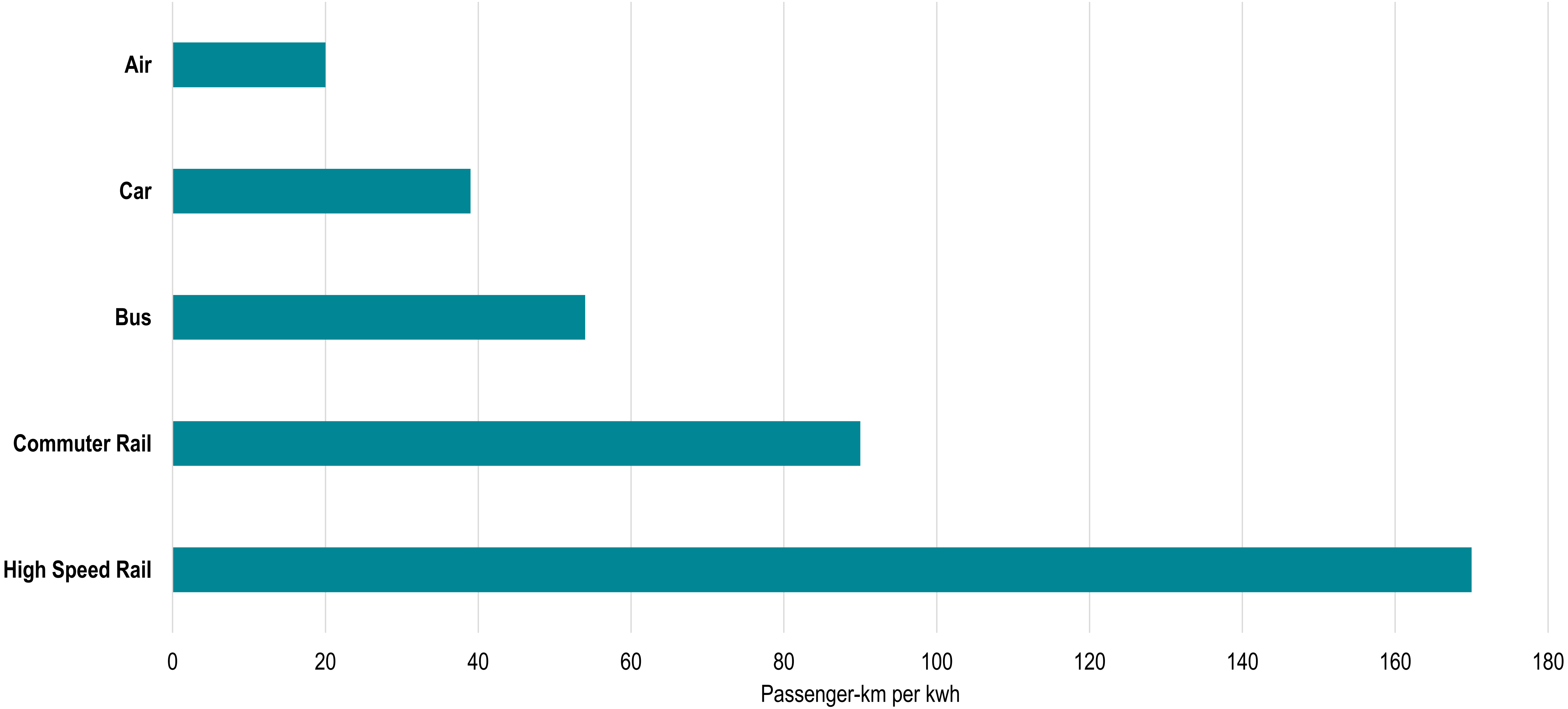
Energy Used by the Road Transportation System



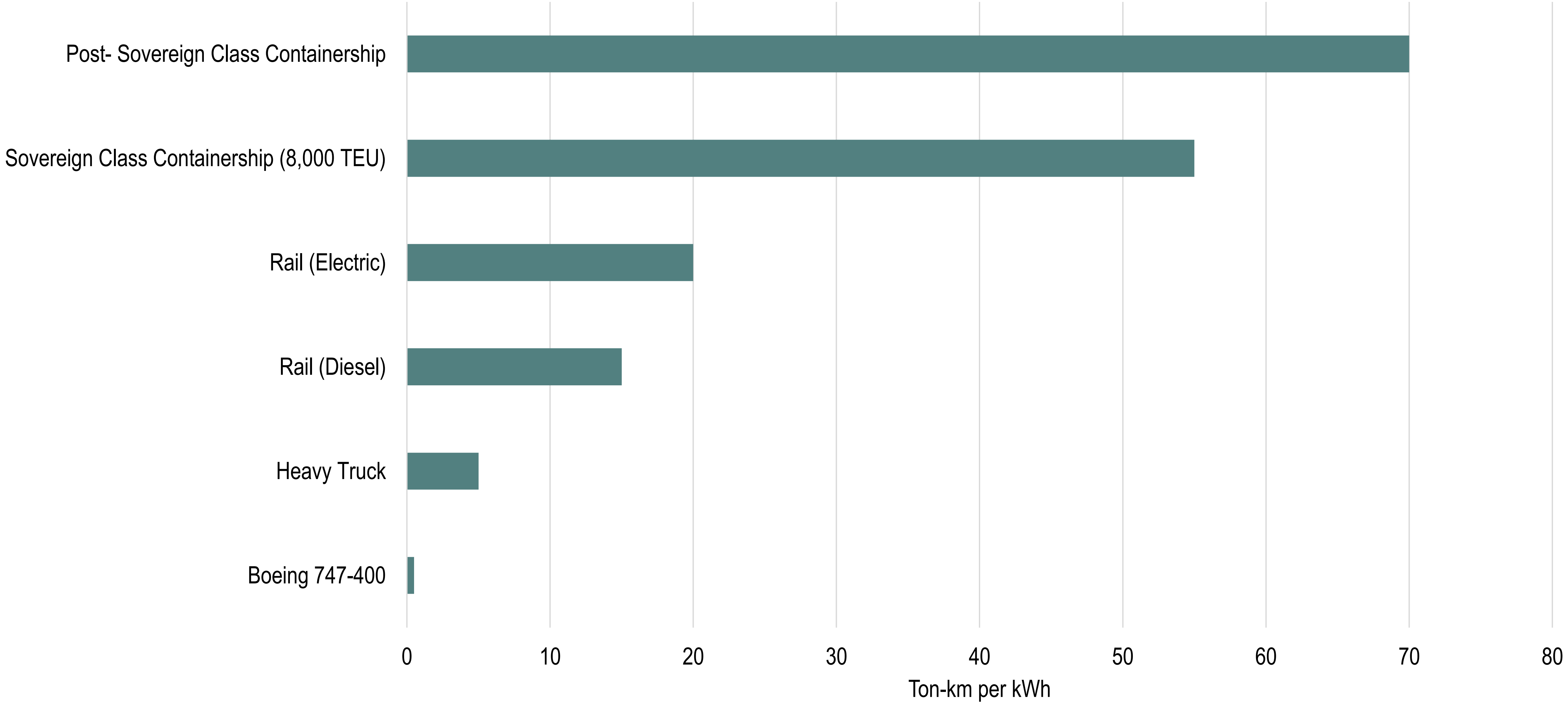
Energy Use Factors by Transportation



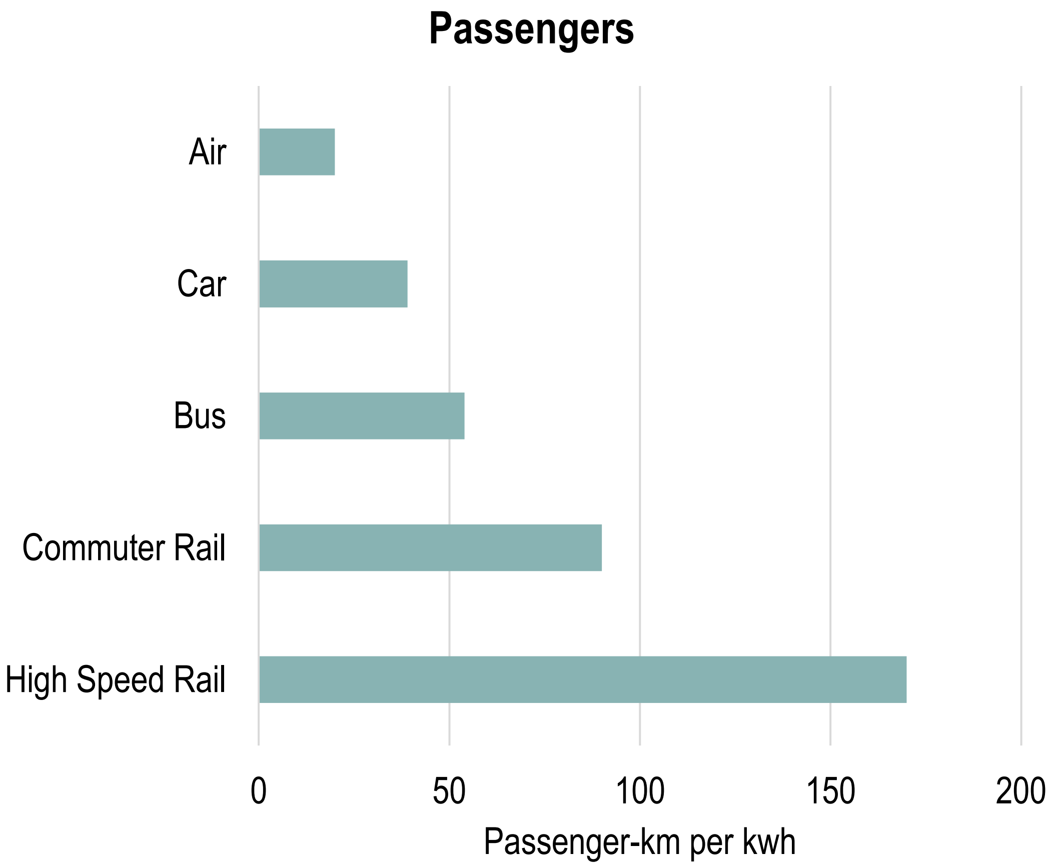
Energy Efficiency of Selected Passenger Modes

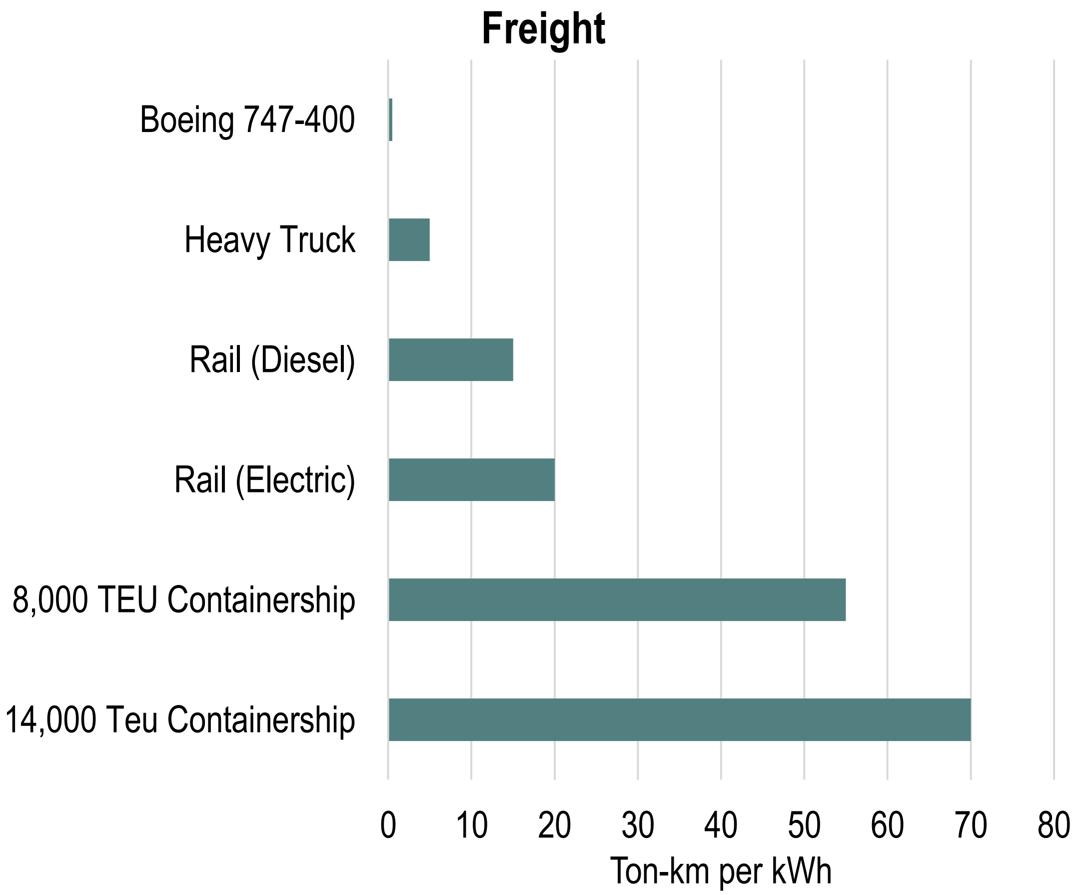


Distance Travelled for One Ton of Cargo Using 1 kWh of Energy



Energy Efficiency of Selected Passenger and Freight Modes





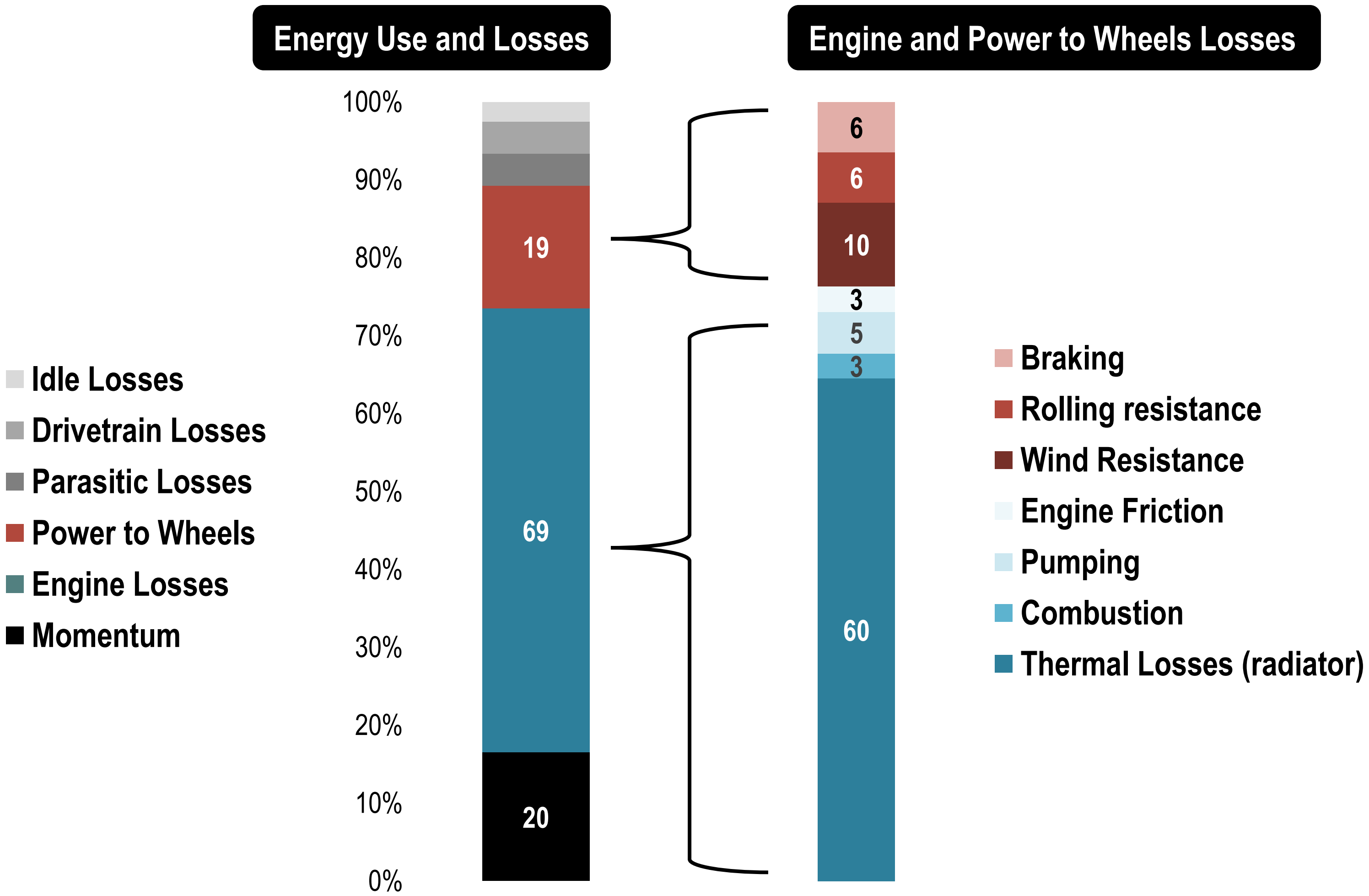
Energy Efficiency of Main Passenger Transportation Modes

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

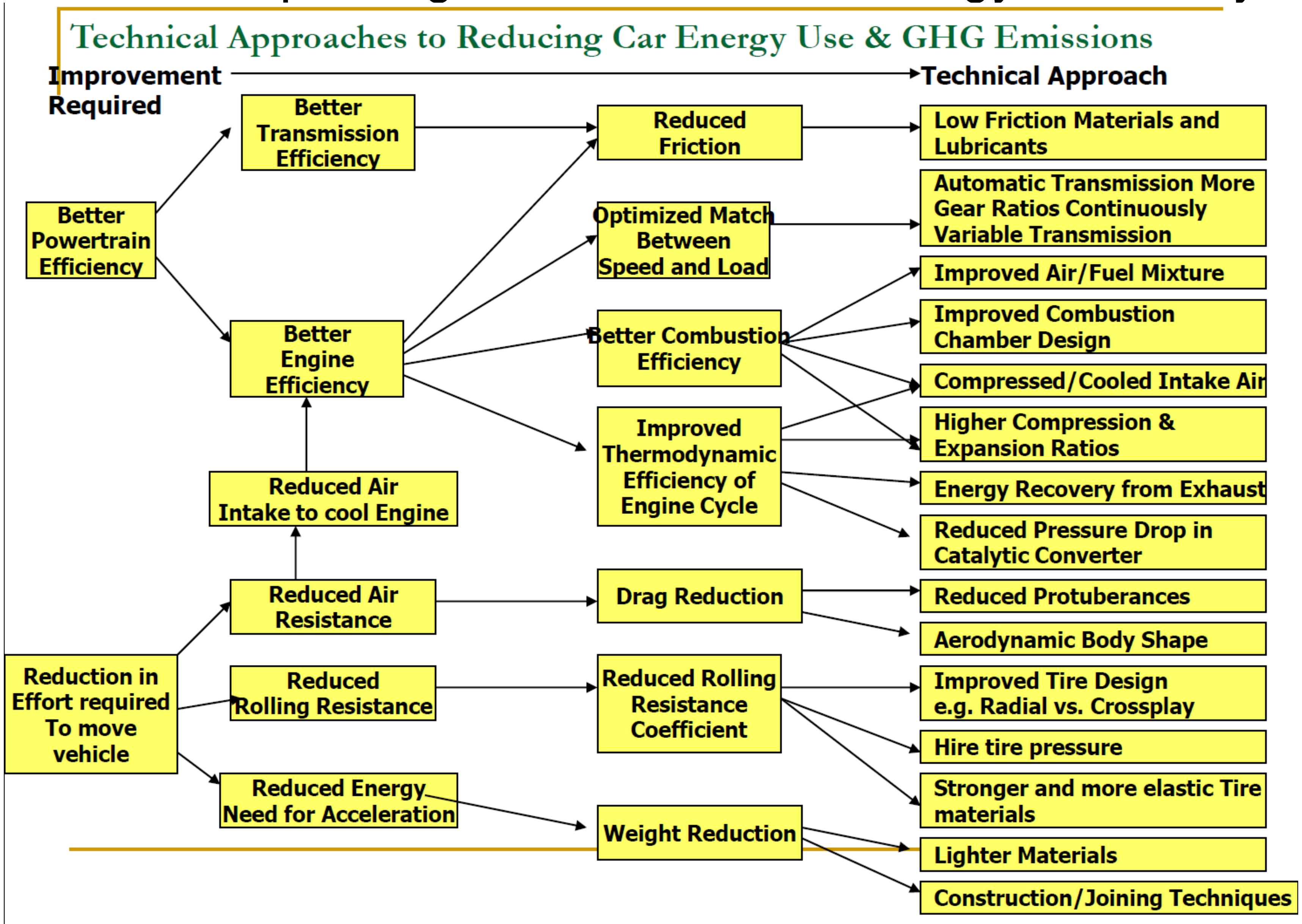
Transportation Fuel Markets

	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%

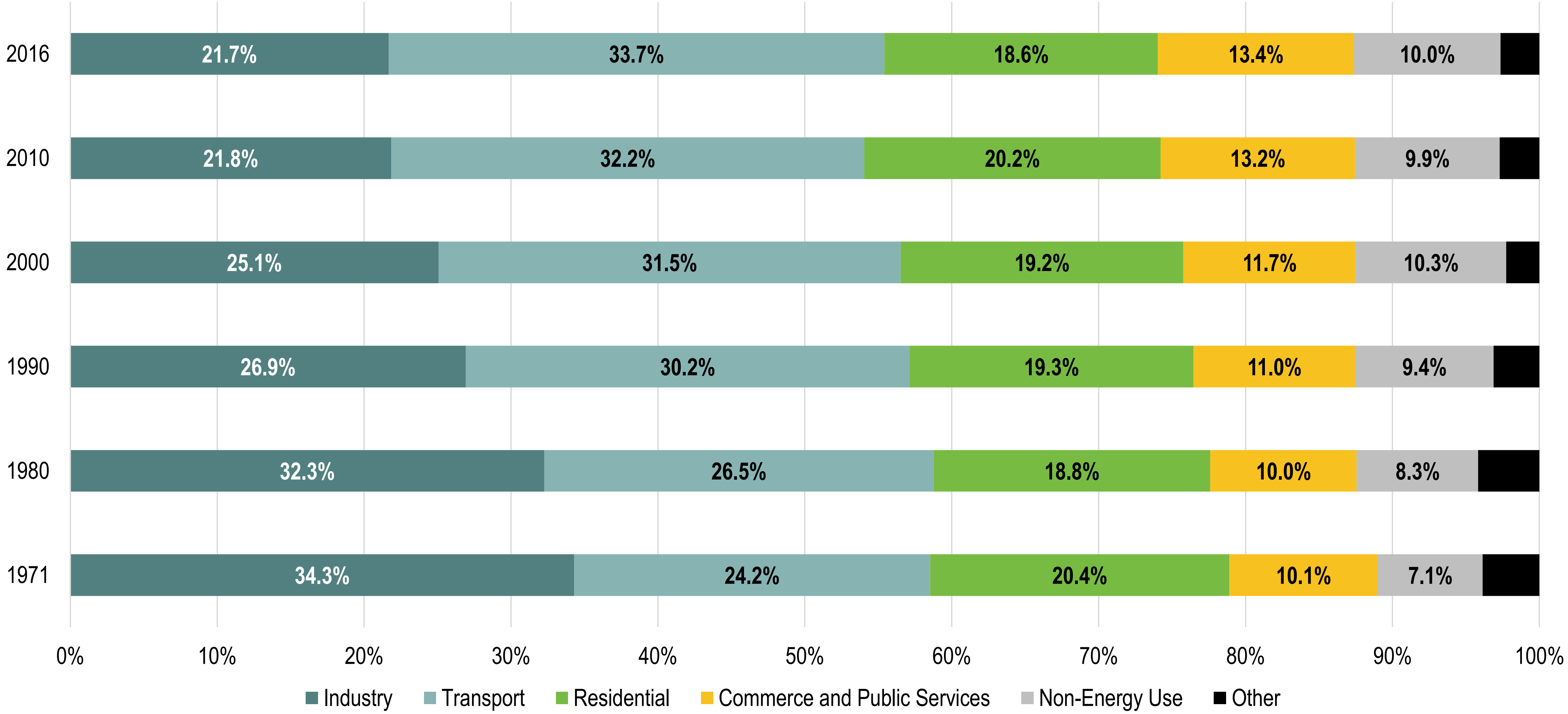
Typical Energy Use for a Car



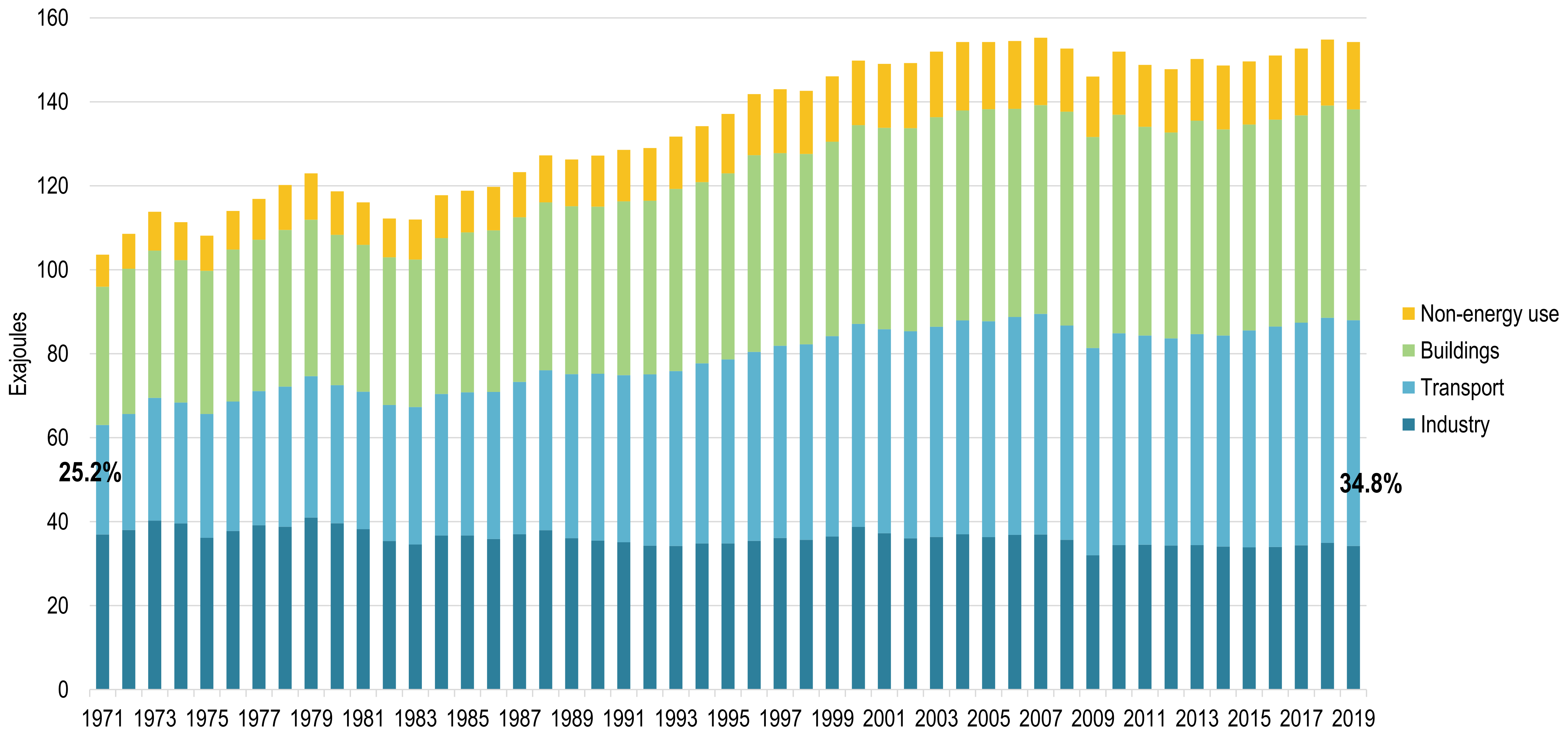
Technical Approaches Improving ICE Automobile Energy Efficiency



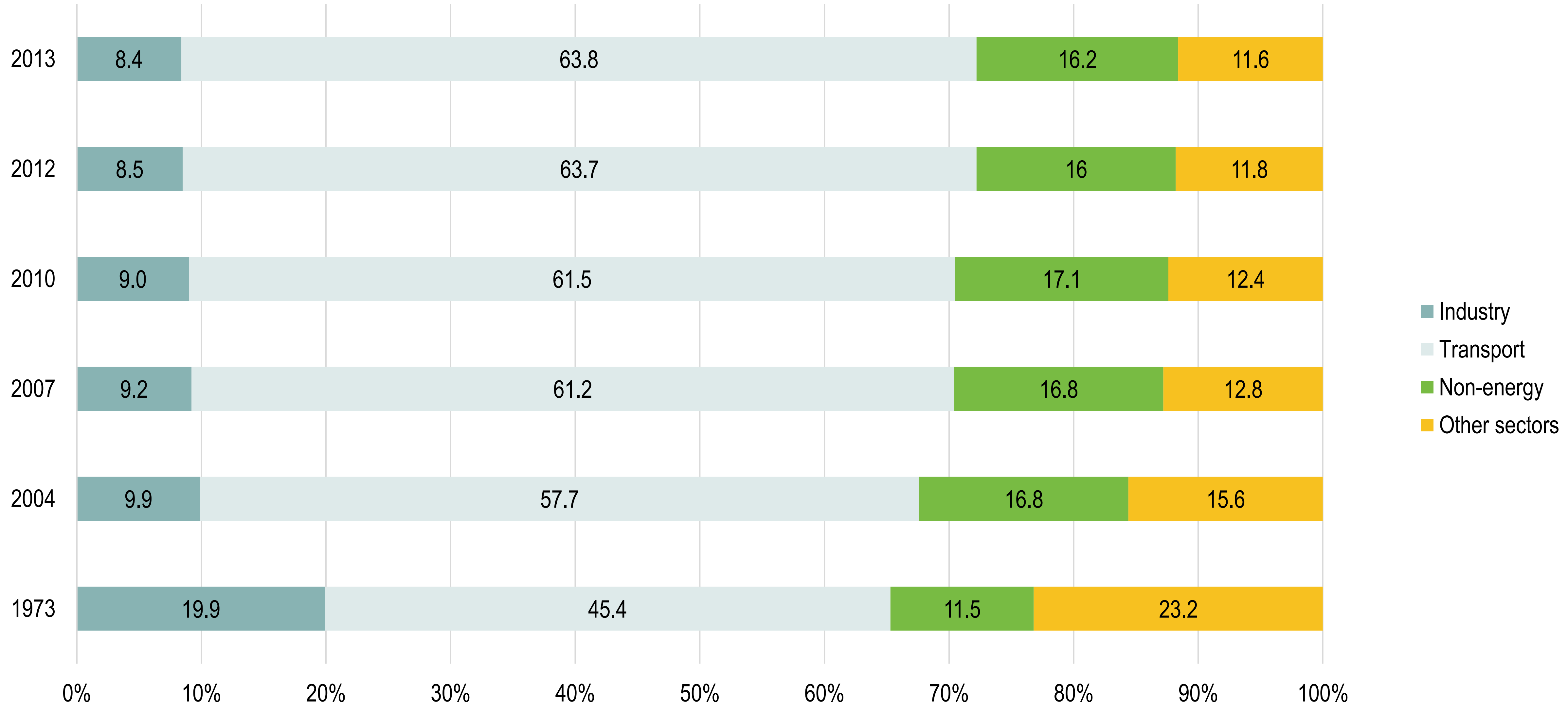
Energy Consumption by Sector, OECD Countries



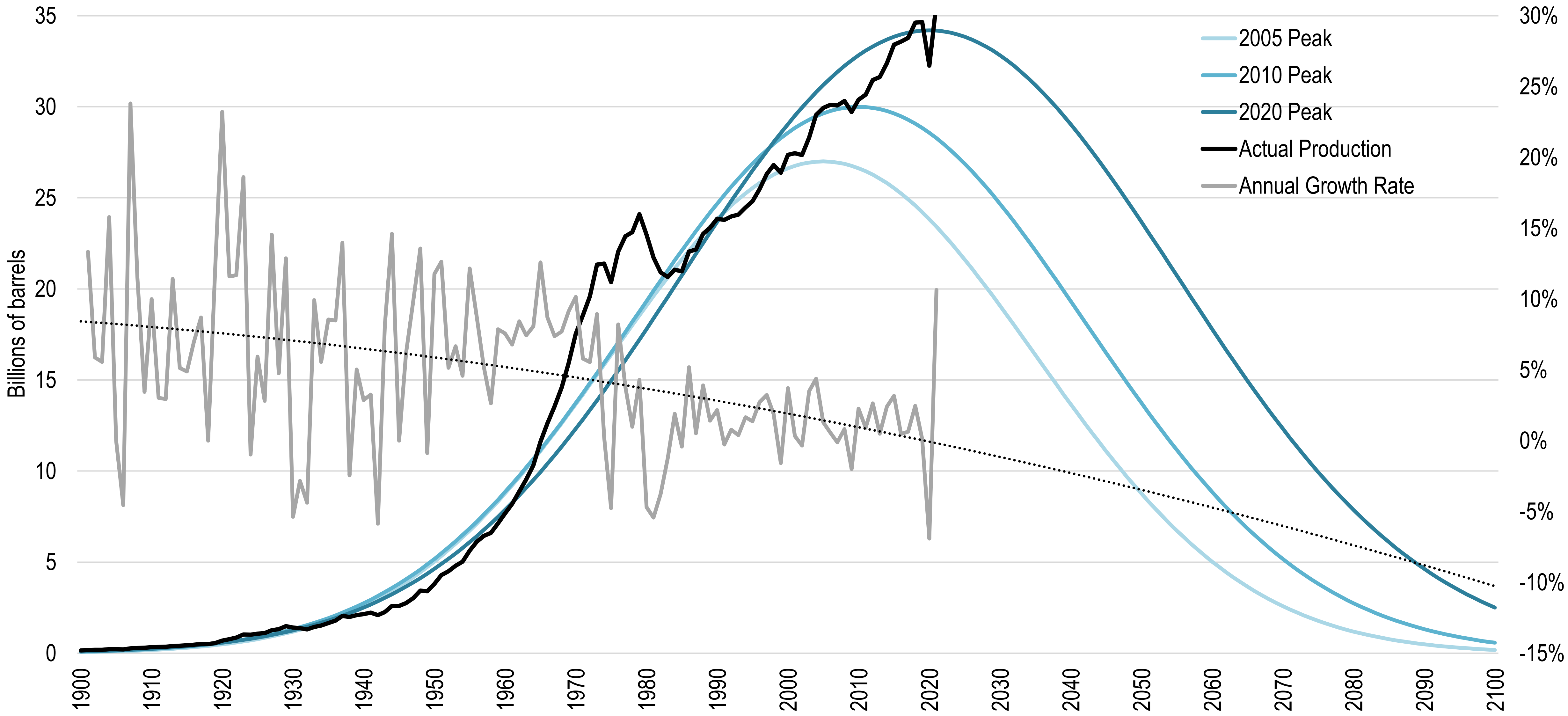
Energy Consumption by Sector, OECD Countries, 1971-2019



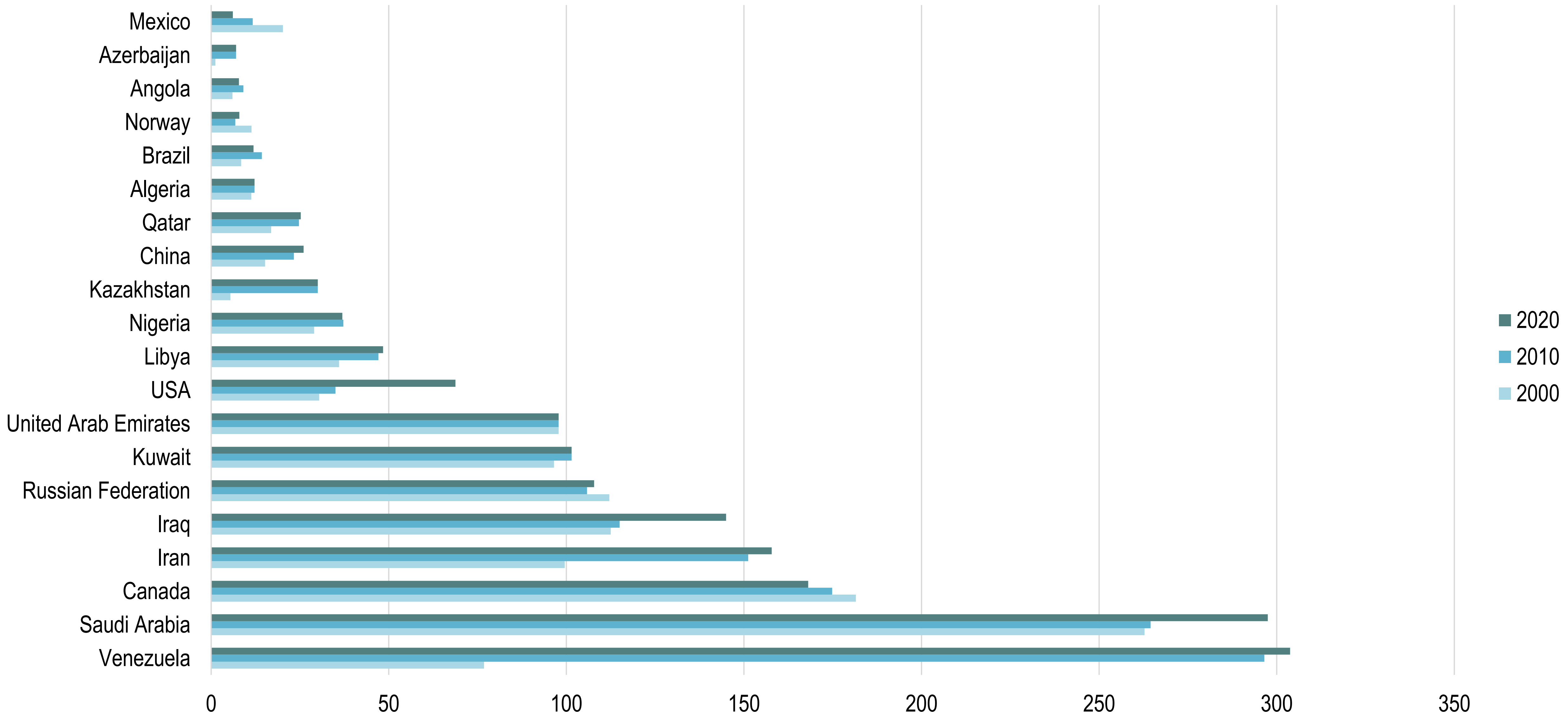
World Oil Energy Consumption by Sector, 1973-2013



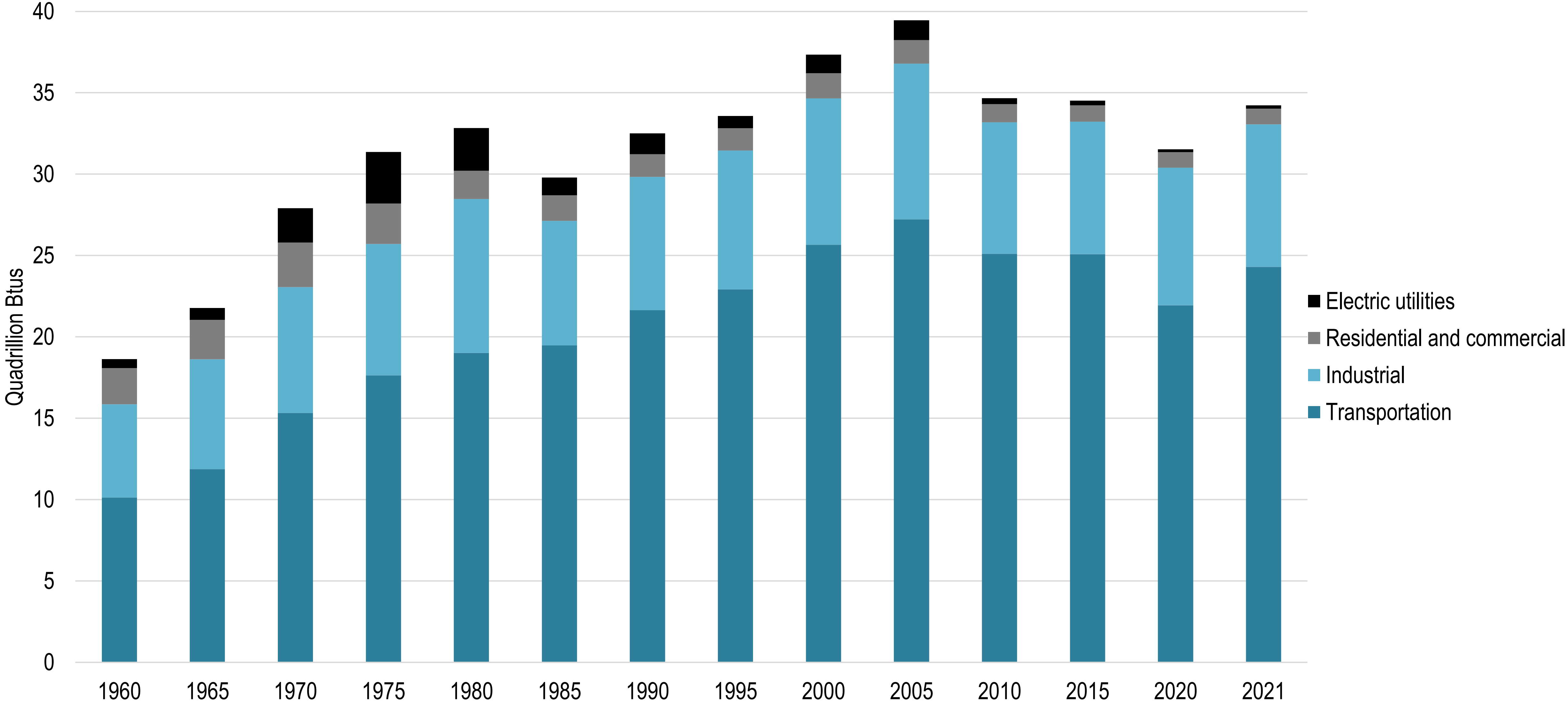
World Annual Oil Production (1900-2021) and Peak Oil (2005-2020)



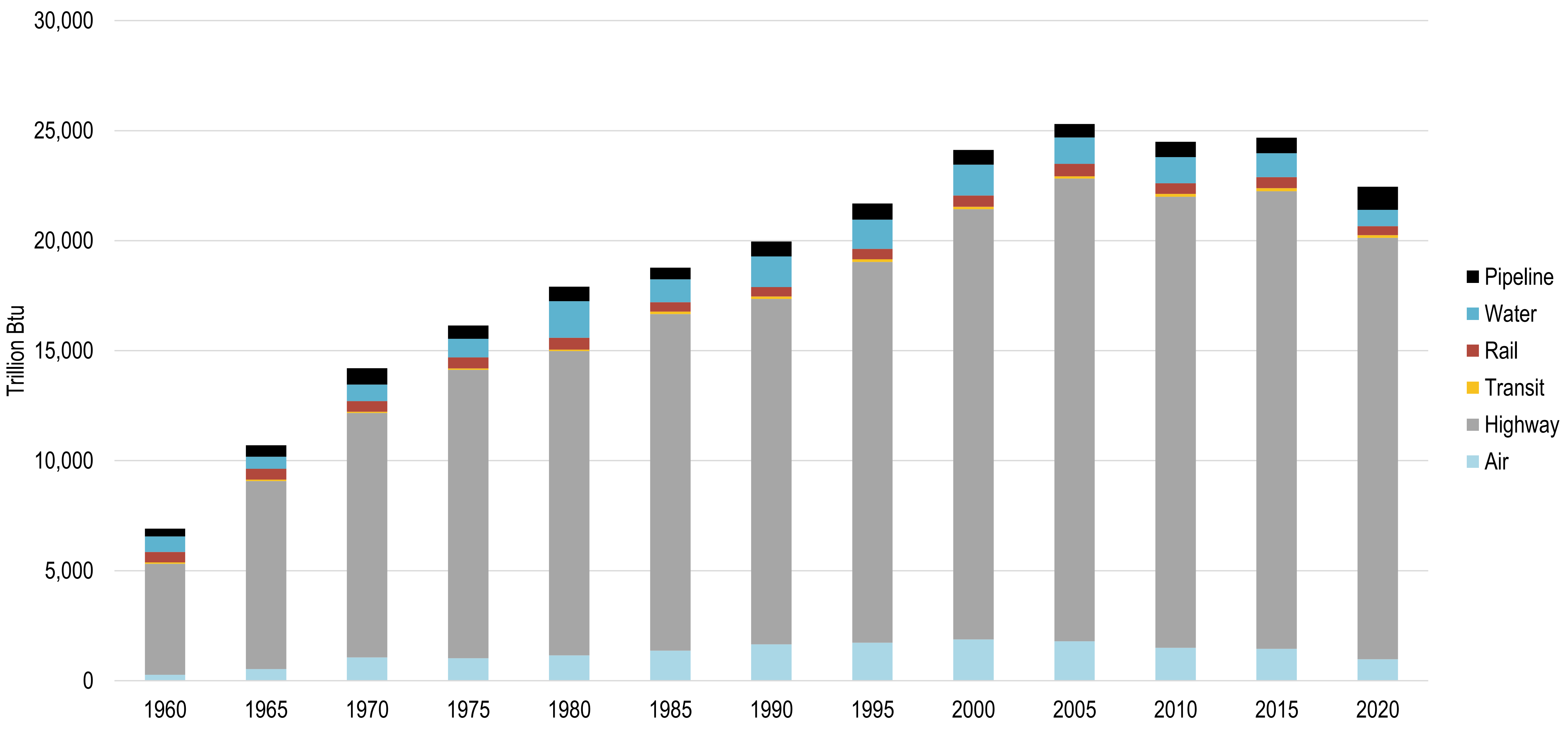
Major Crude Oil Reserves, 2000-2020 (Thousand Million Barrels)



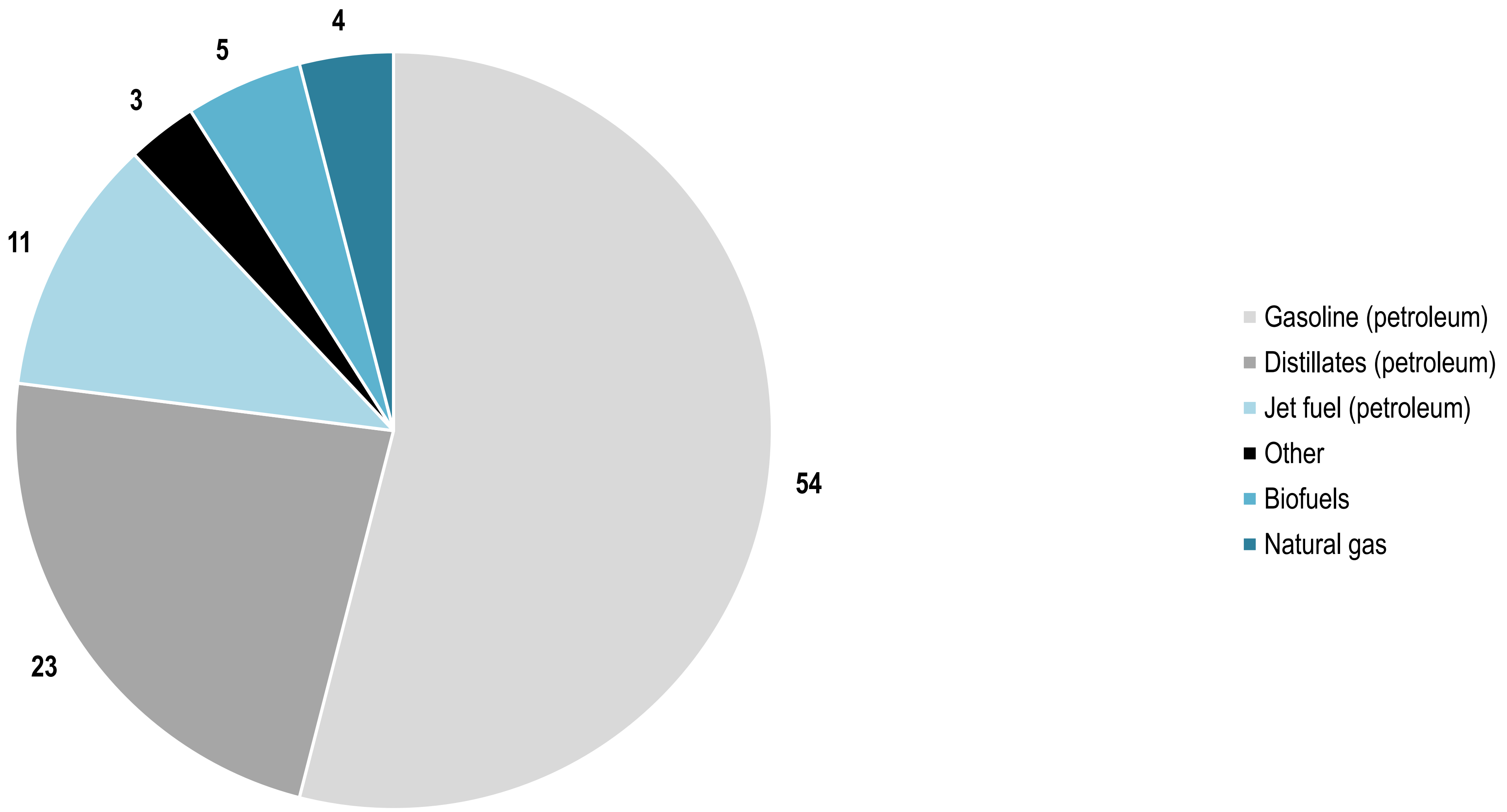
Demand for Refined Petroleum Products by Sector in the United States, 1960-2021



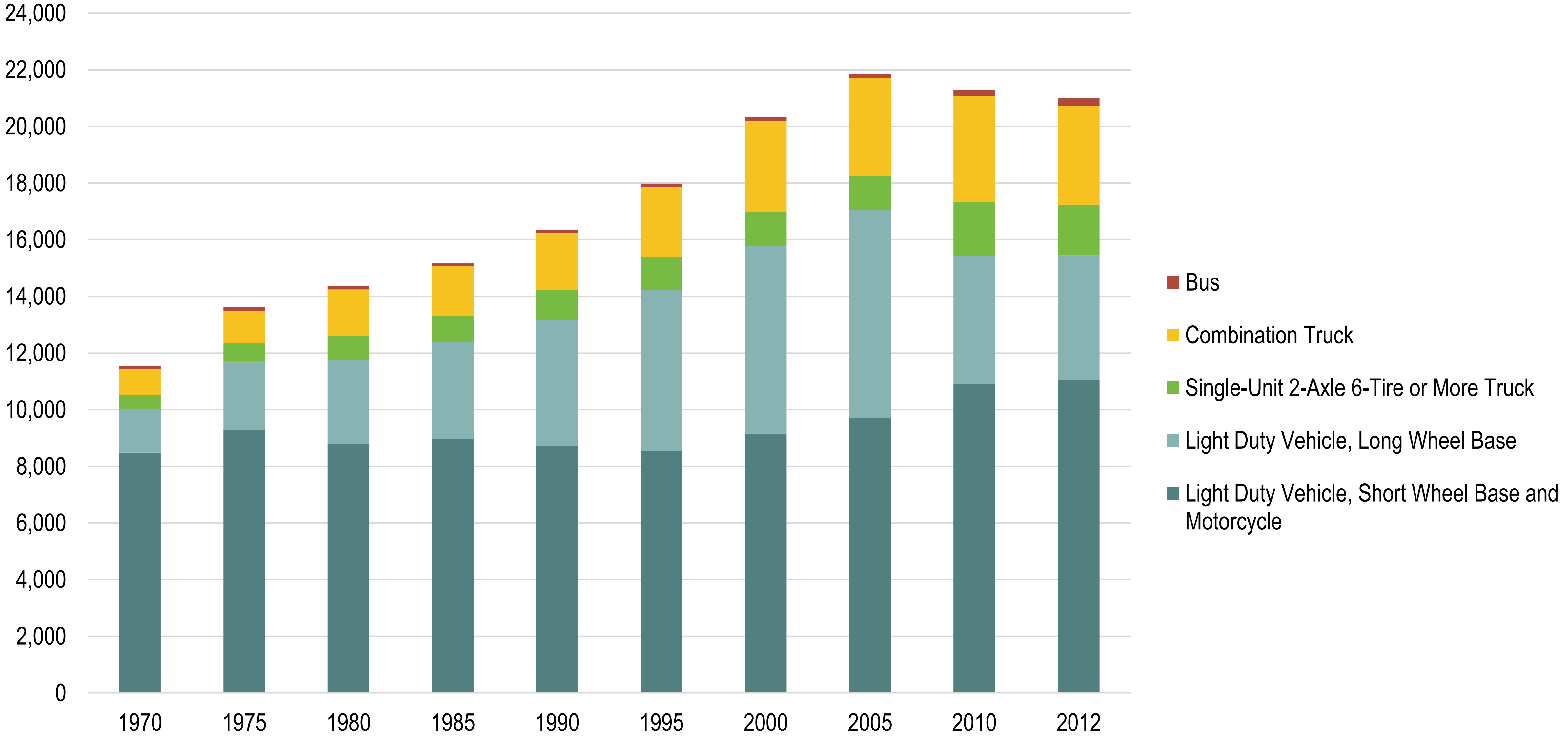
Energy Consumption by Transportation Mode in the United States, 1960-2020



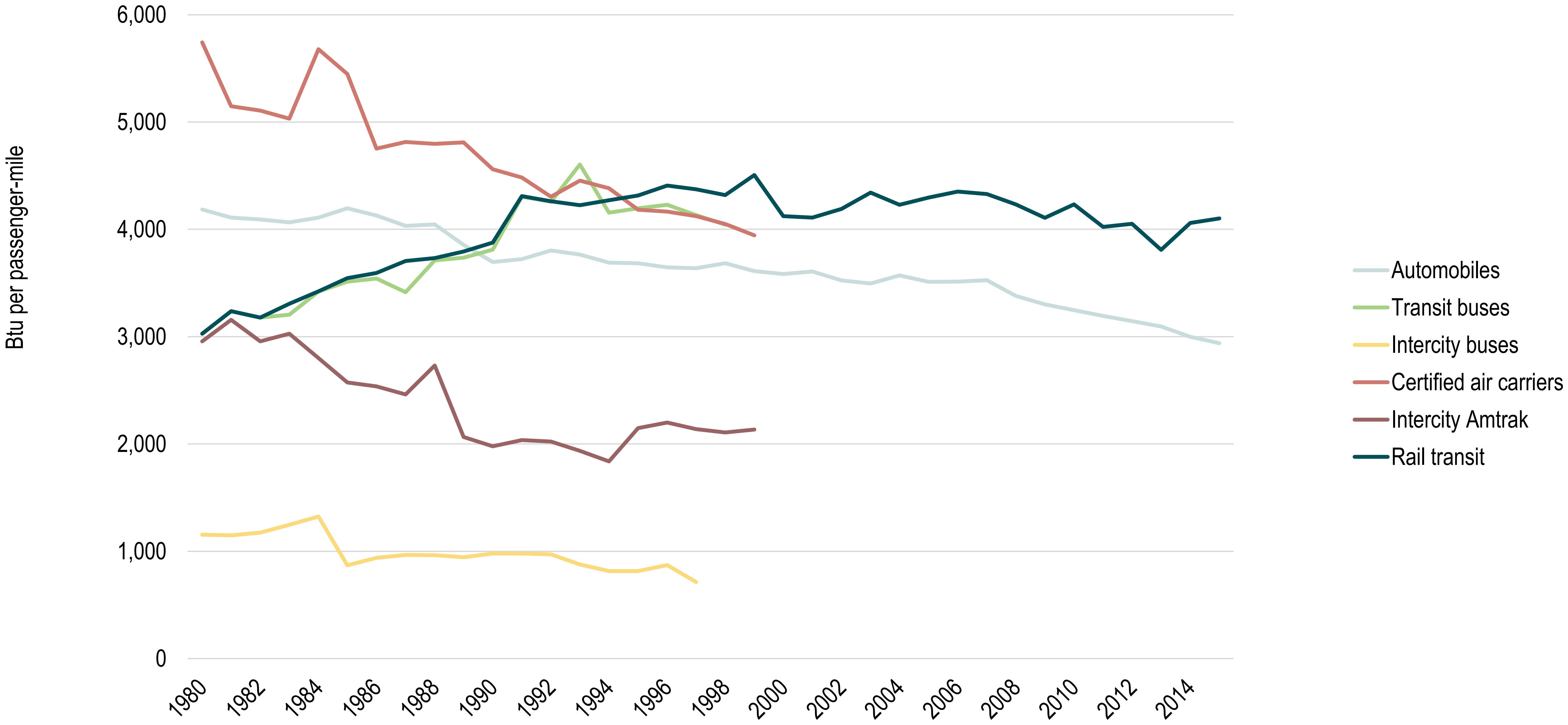
Transportation Energy Sources, United States 2021



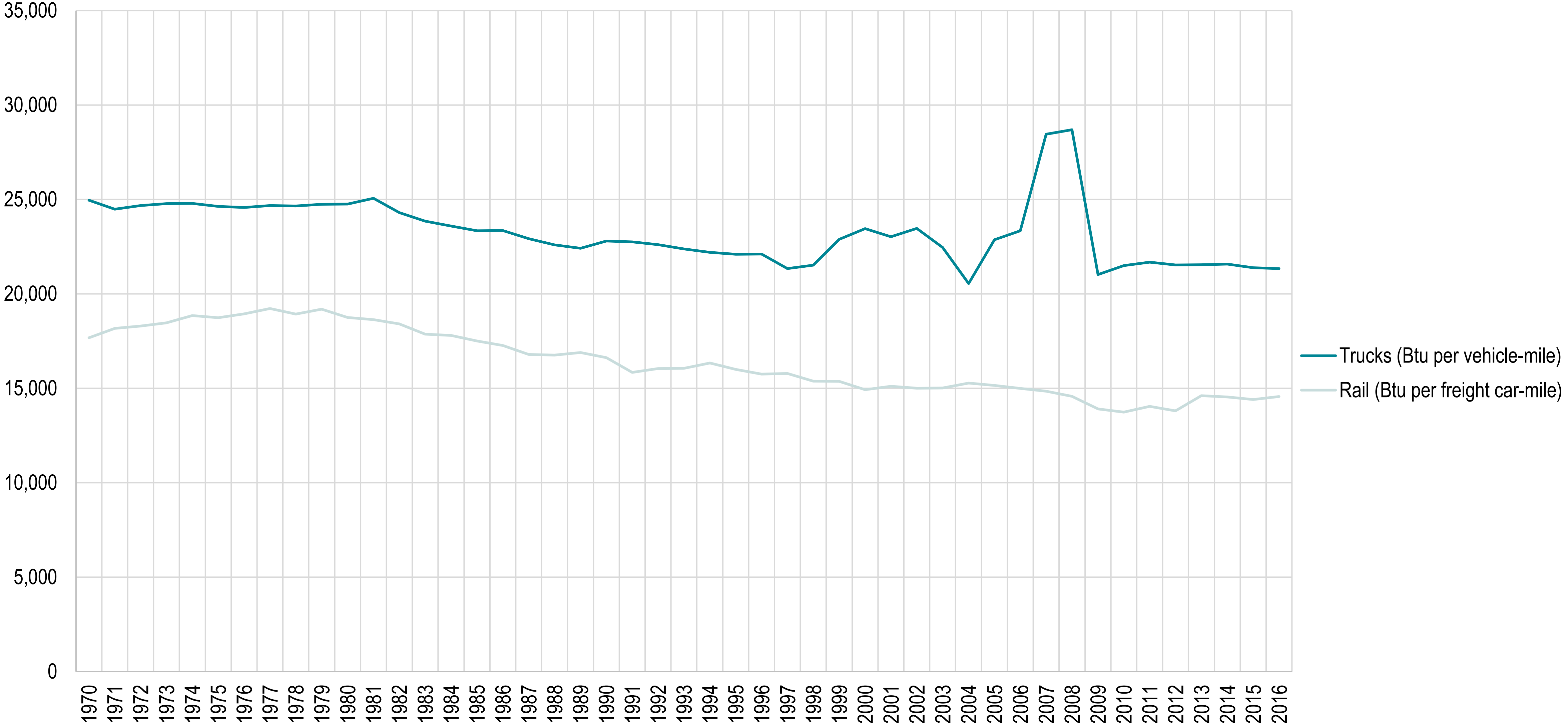
Energy Consumption by Road Transportation in the United States, 1970-2012 (in Trillion BTUs)



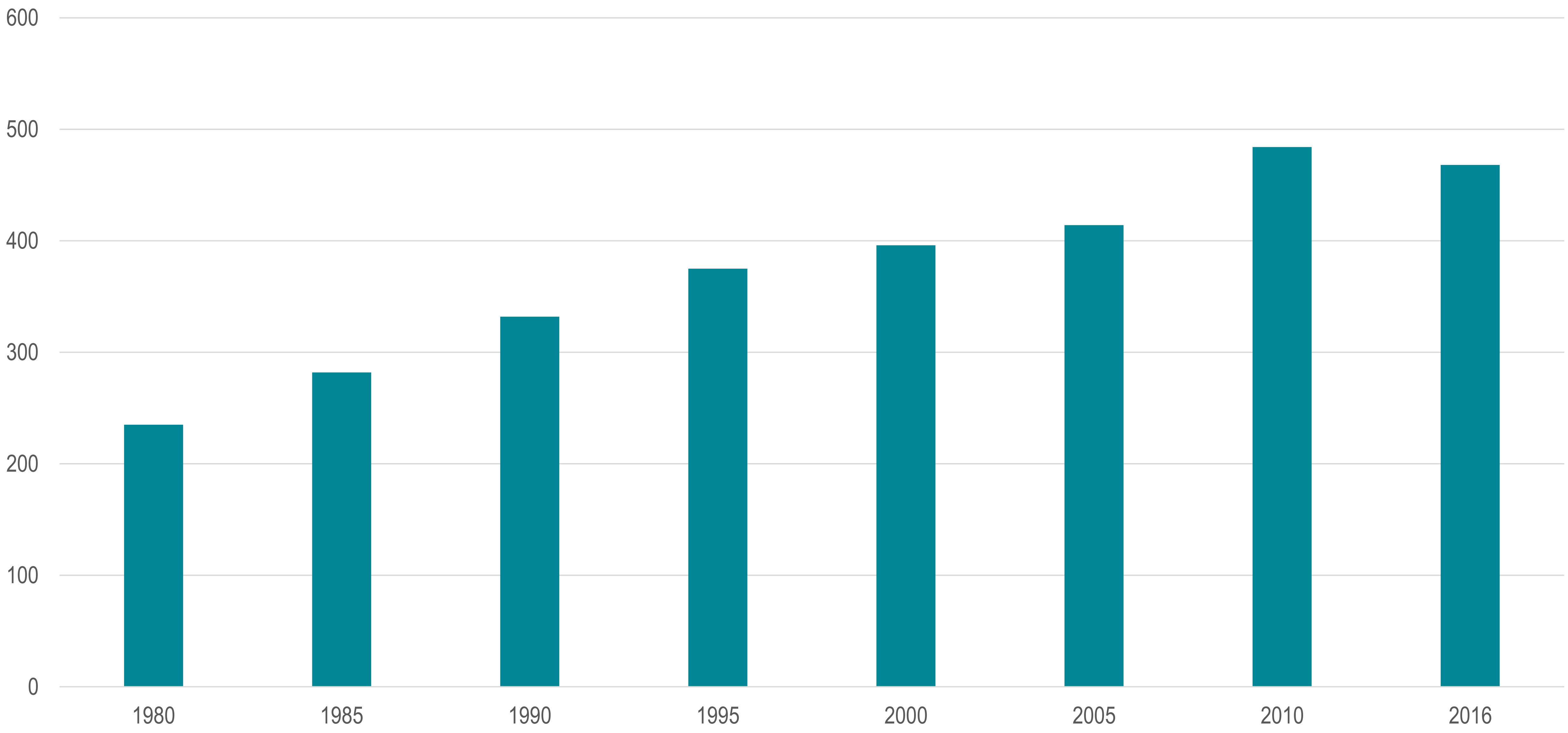
Energy Intensities of Passenger Modes, 1980-2016 (in BTU per passenger-mile)



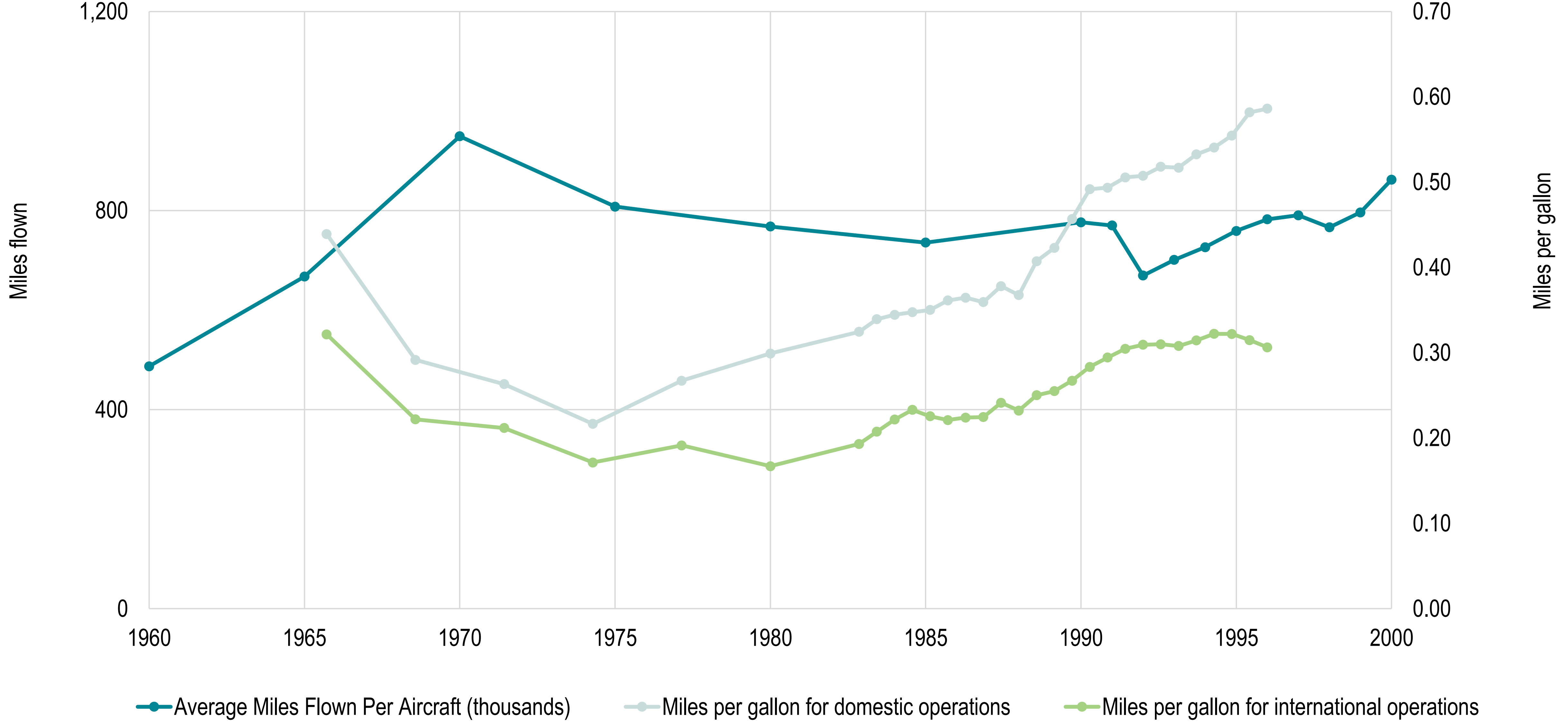
Energy Intensities of Freight Modes, 1970-2016



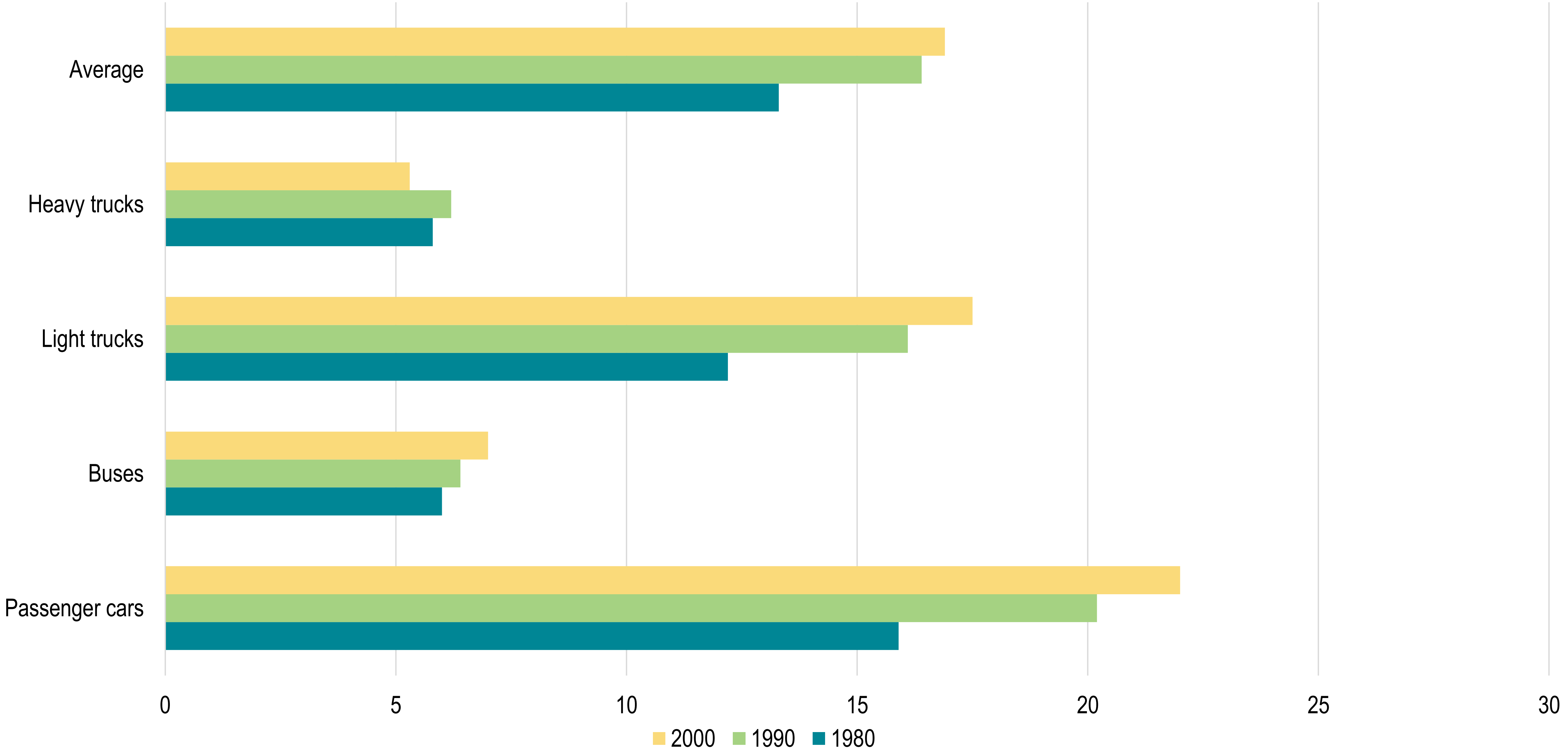
Rail Freight Fuel Efficiency (ton-miles per gallon)



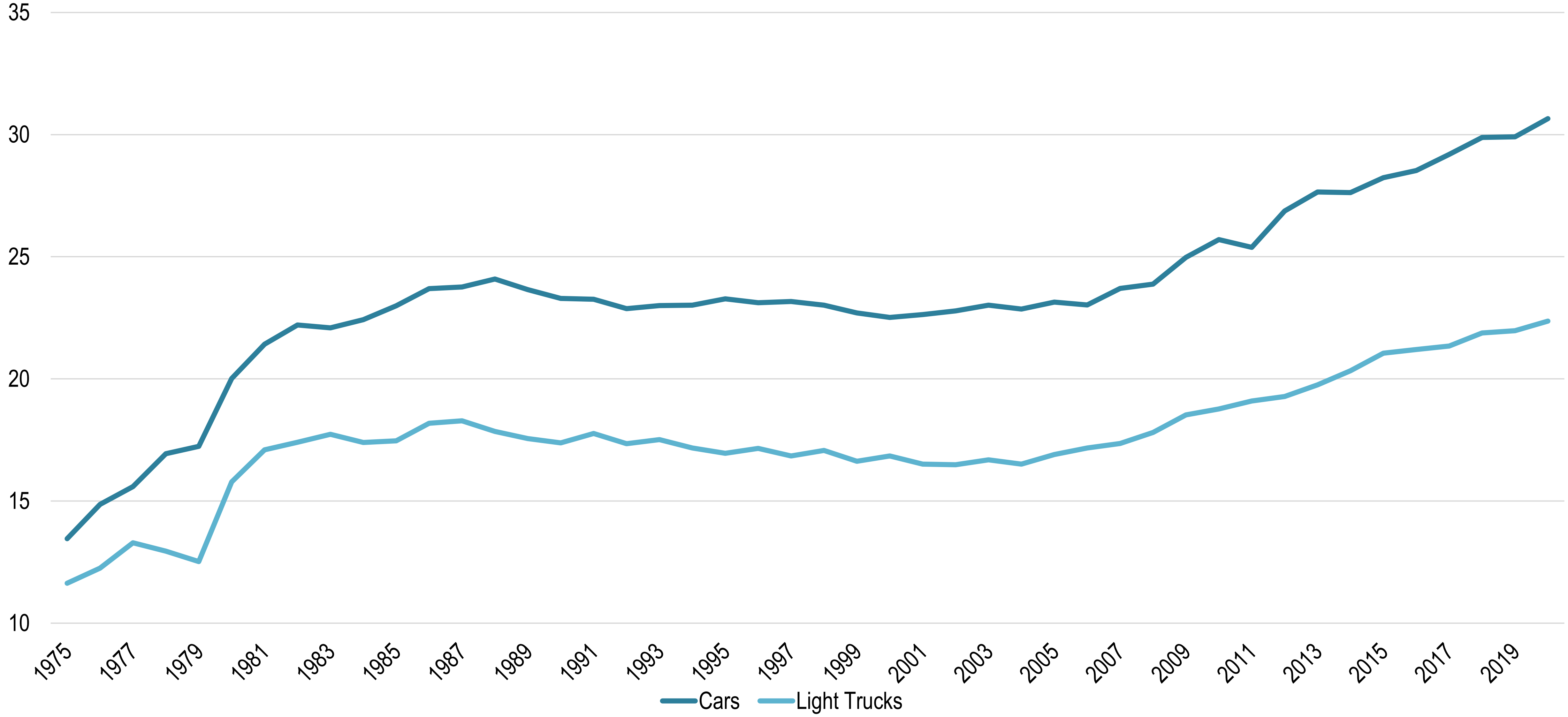
Fuel Consumption and Travel by Certificated Air Carriers in the United States, 1960-2000



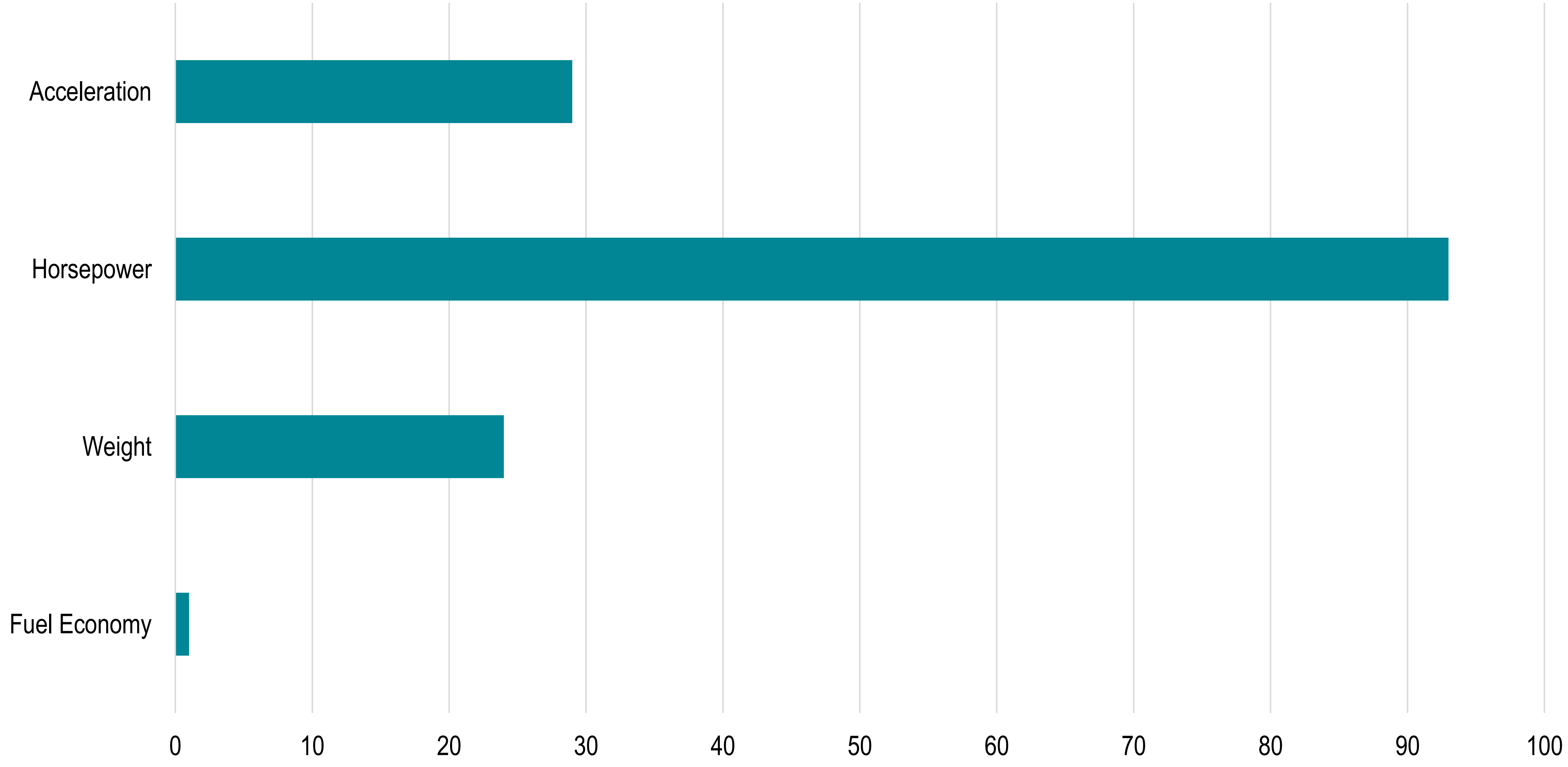
Average Miles per Gallon Traveled by Road Vehicle in the United States, 1980-2000



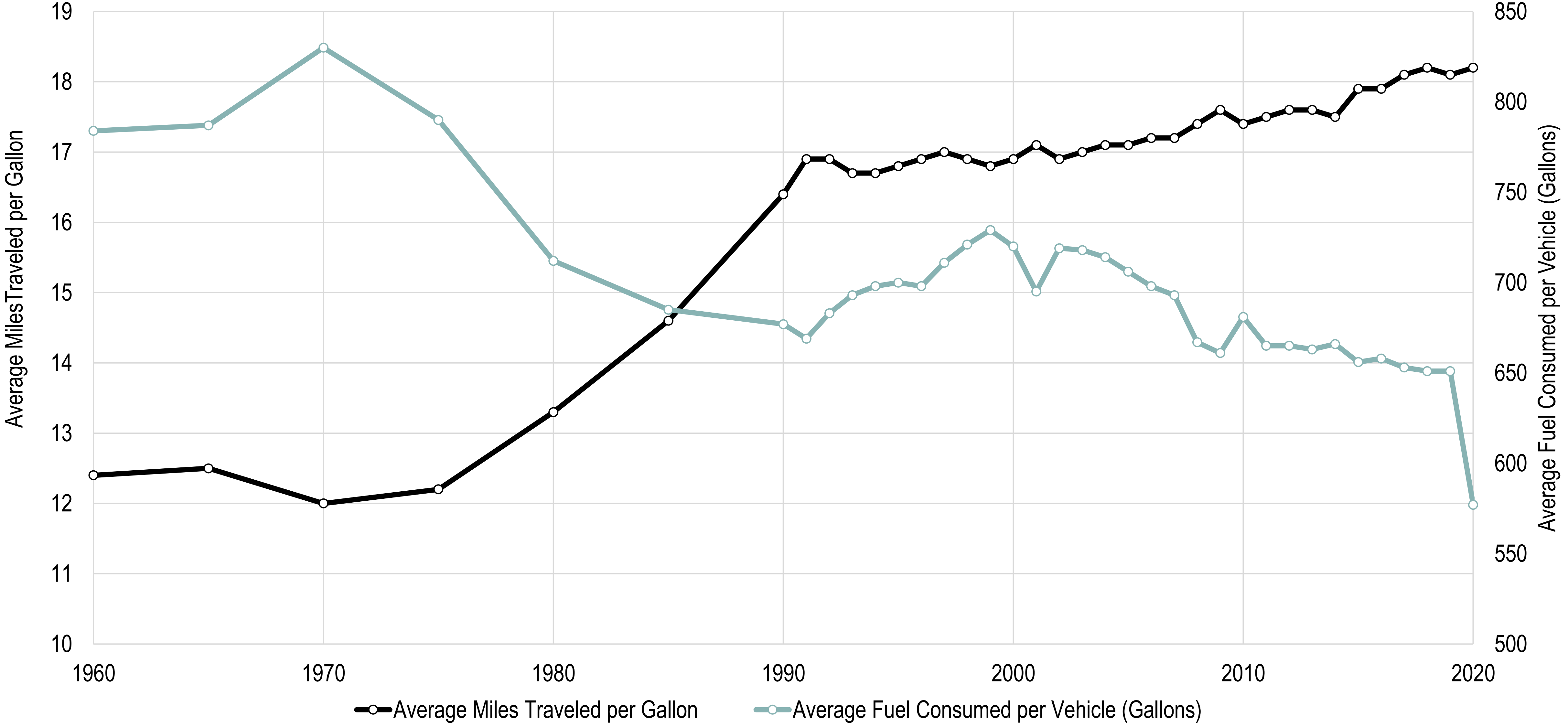
Average Gasoline Consumption for New Vehicles, United States, 1972-2020 (in miles per gallon)



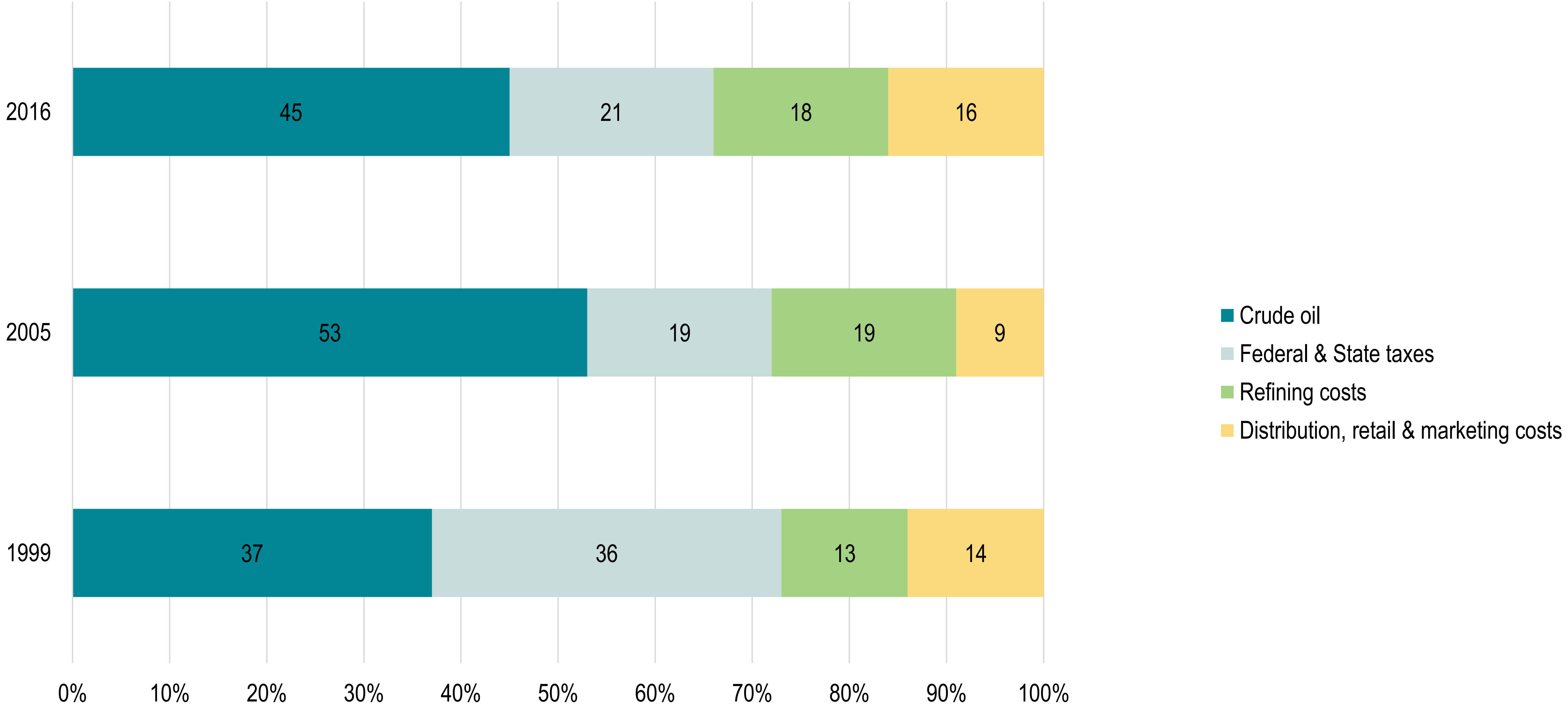
Change in Average Vehicle Characteristics, 1981-2003 (in %)



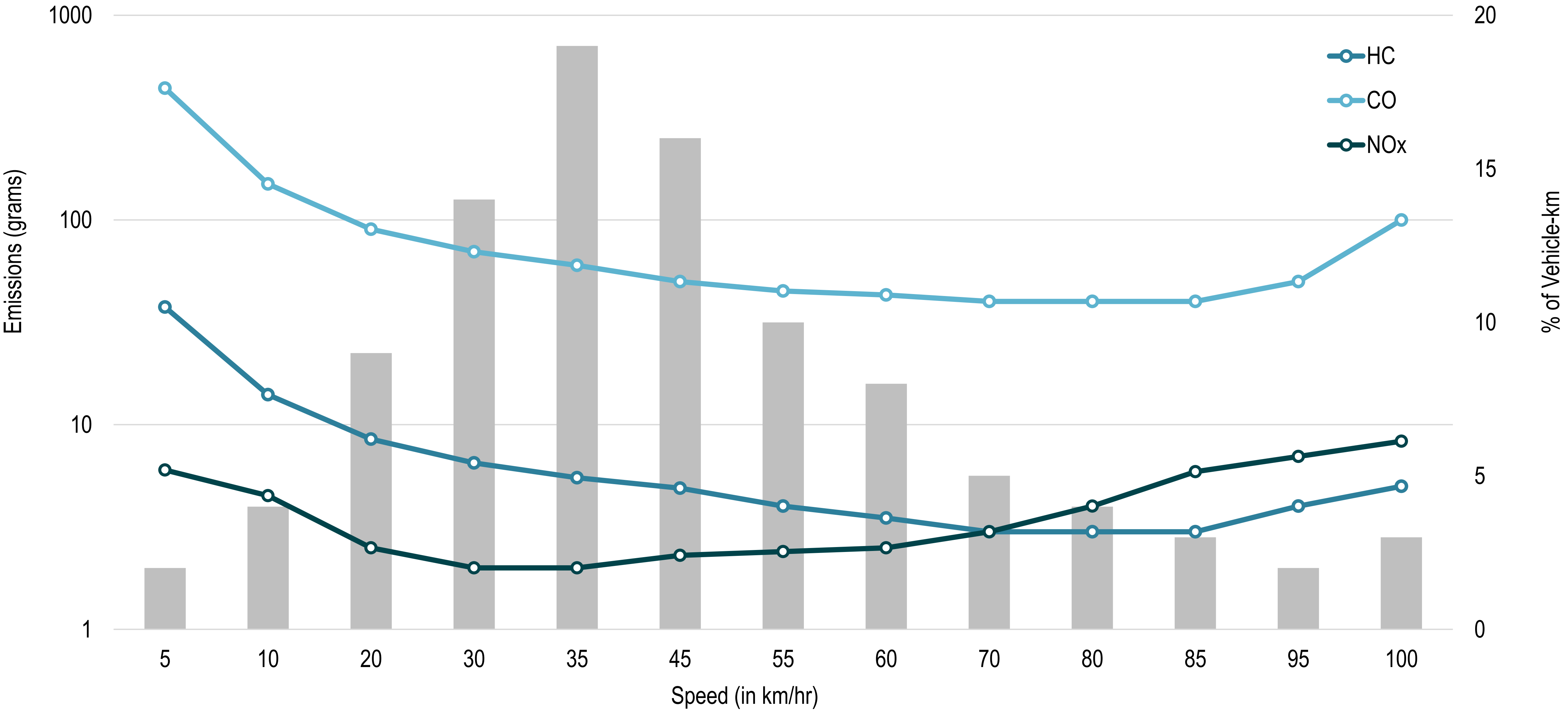
Total Motor Vehicle Fuel Consumption and Travel in the United States, 1960-2020



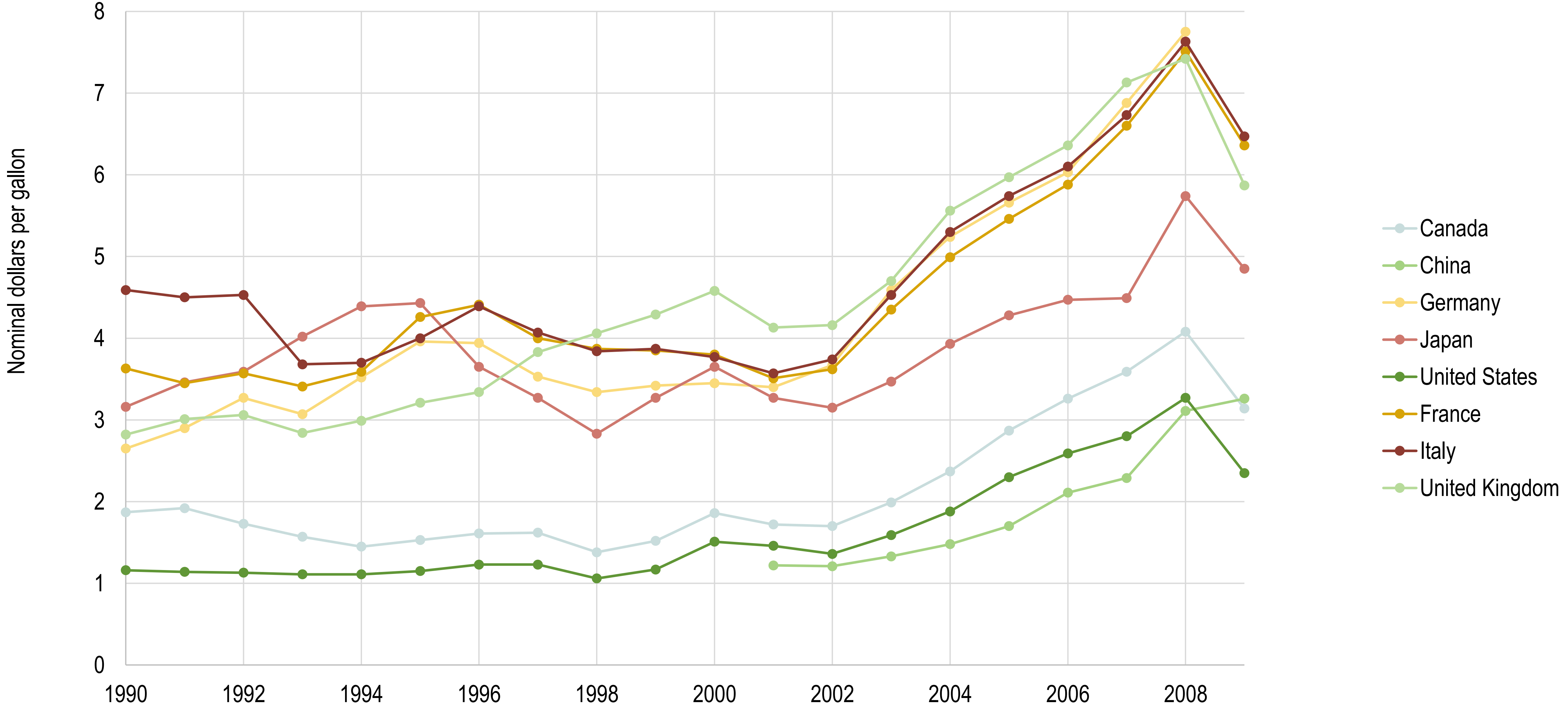
Components of Retail Costs of Gasoline, United States, 1999-2016



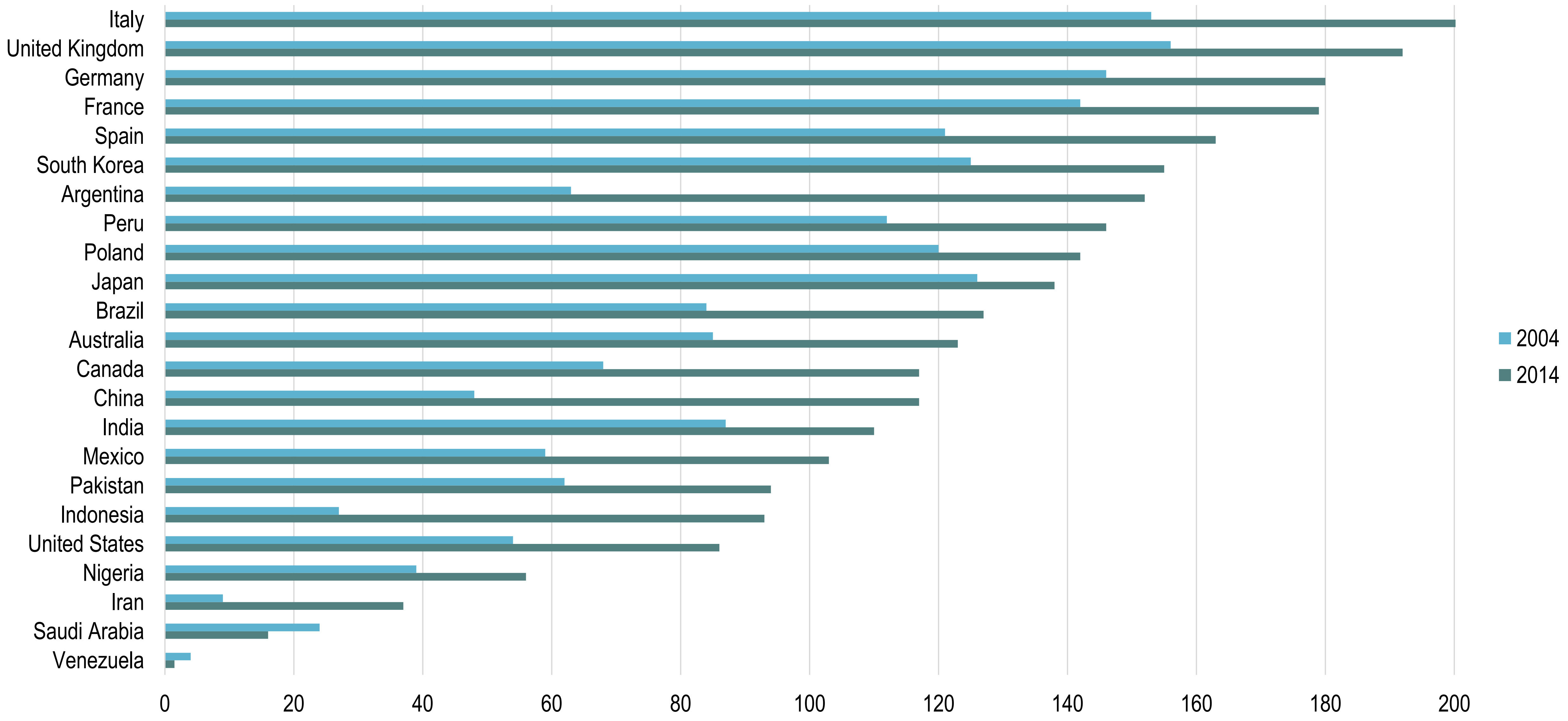
Automobile Emission Factors



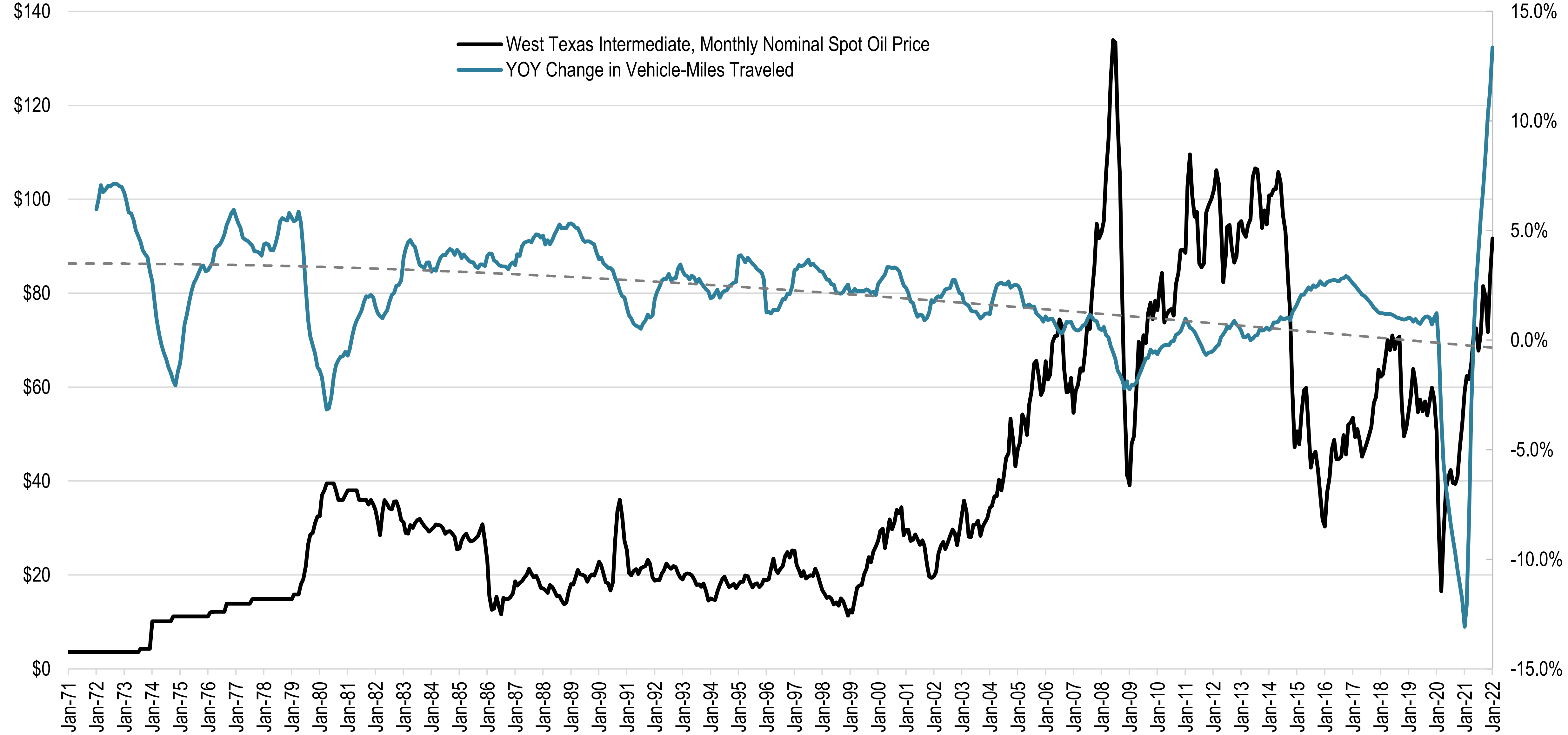
Retail Motor Gasoline Prices, Selected Countries, 1990-2009



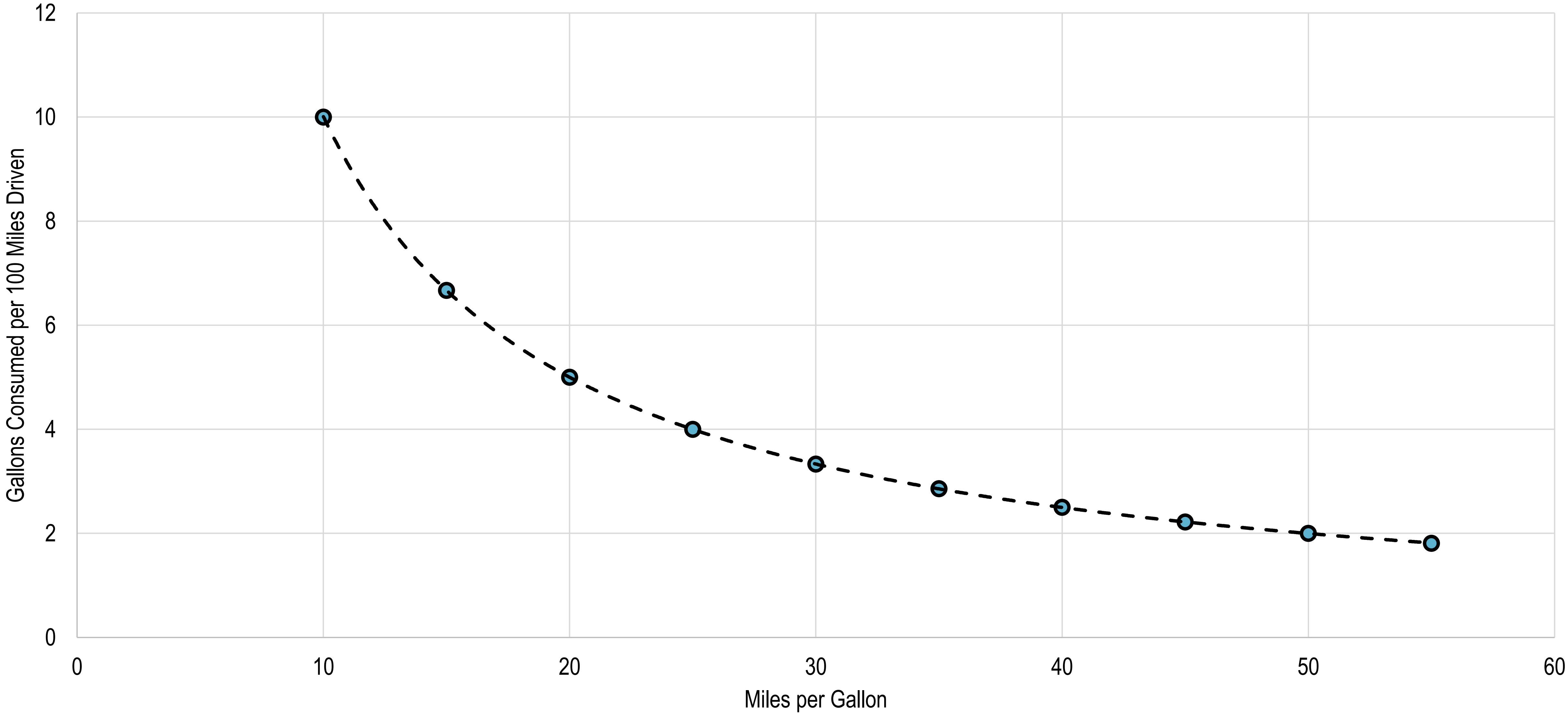
Retail Motor Gasoline Prices (cents per liter), Selected Countries, 2004-2014



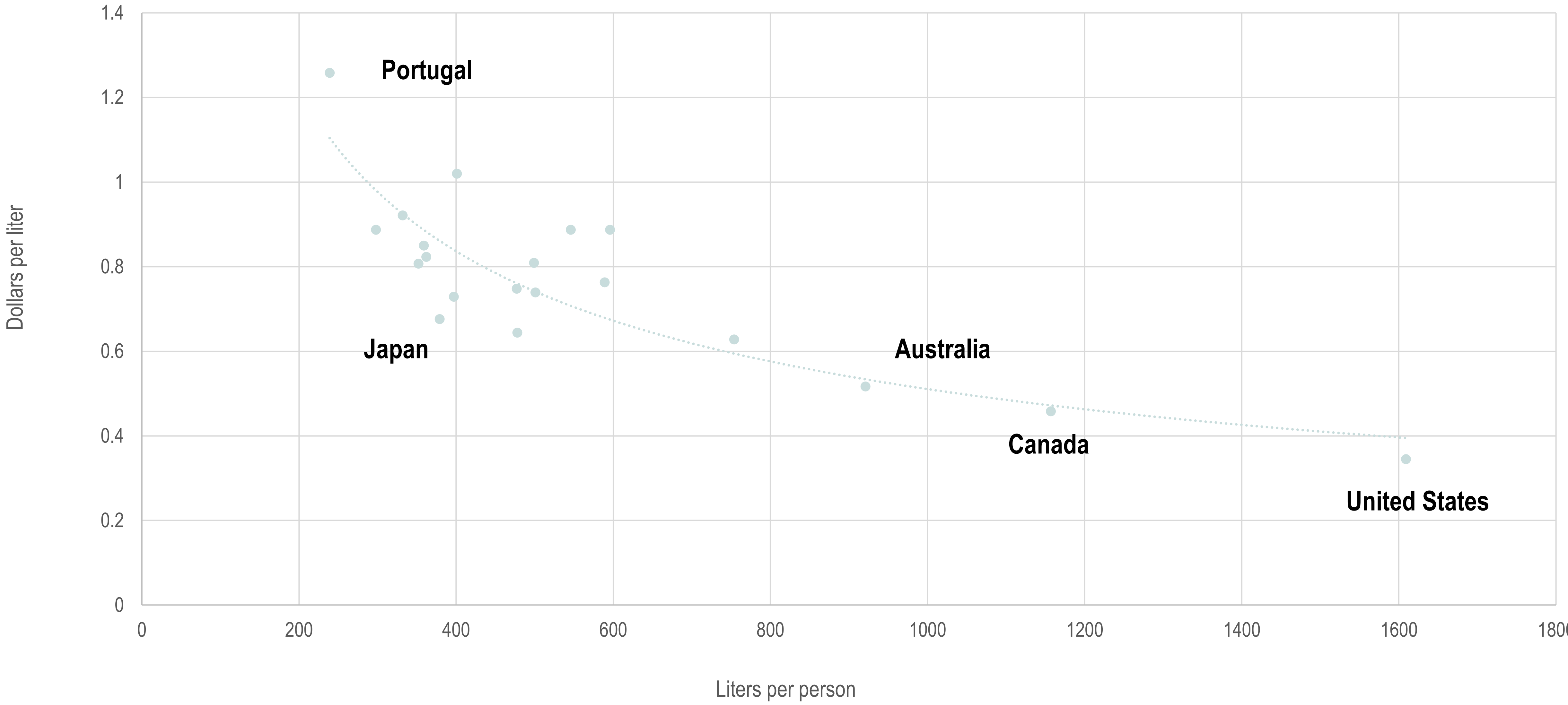
Annual Vehicle-Miles Traveled in the United States, Year-over-Year Changes, 1971-2022



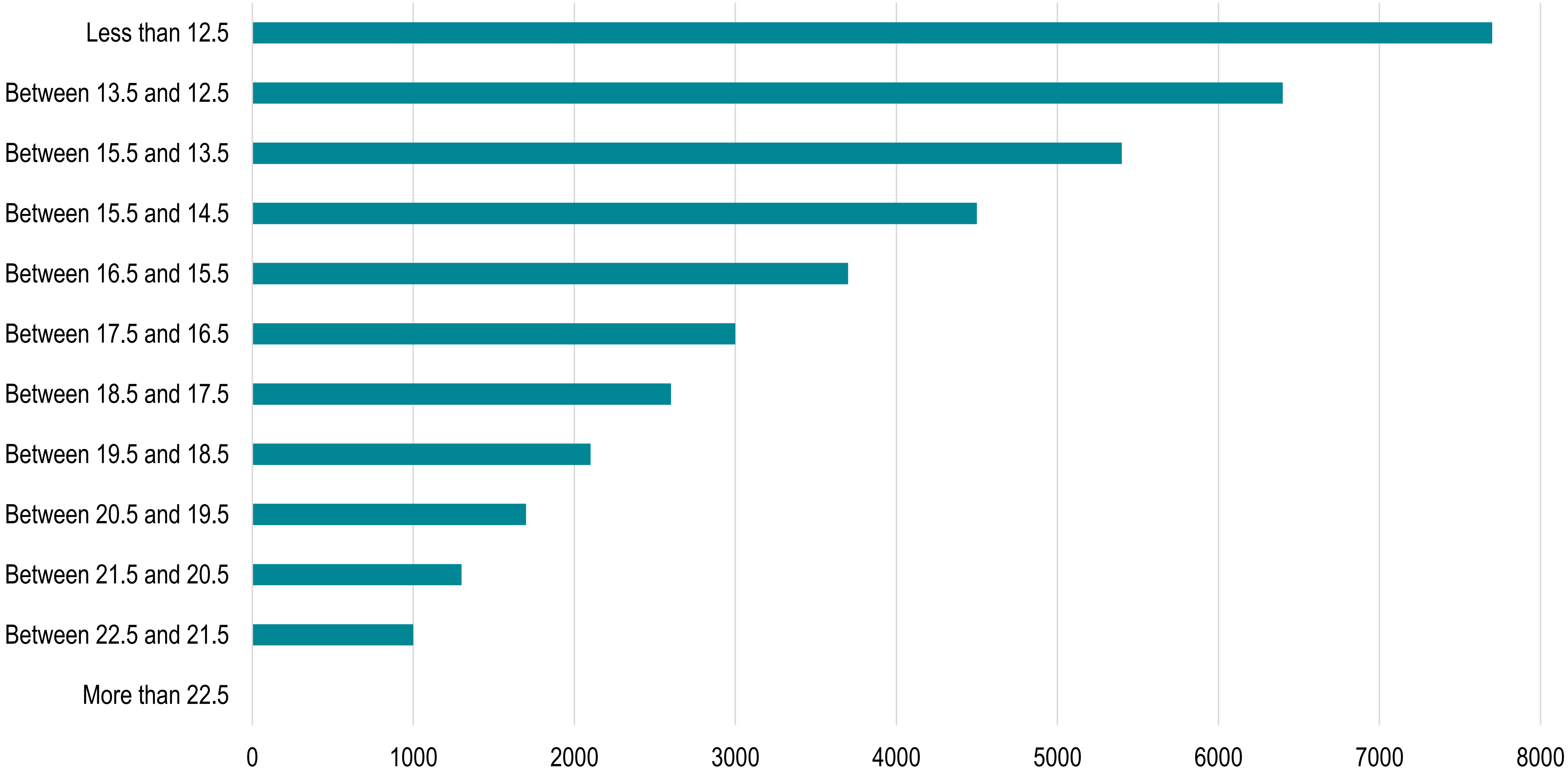
Automobile Fuel Consumption and Fuel Efficiency



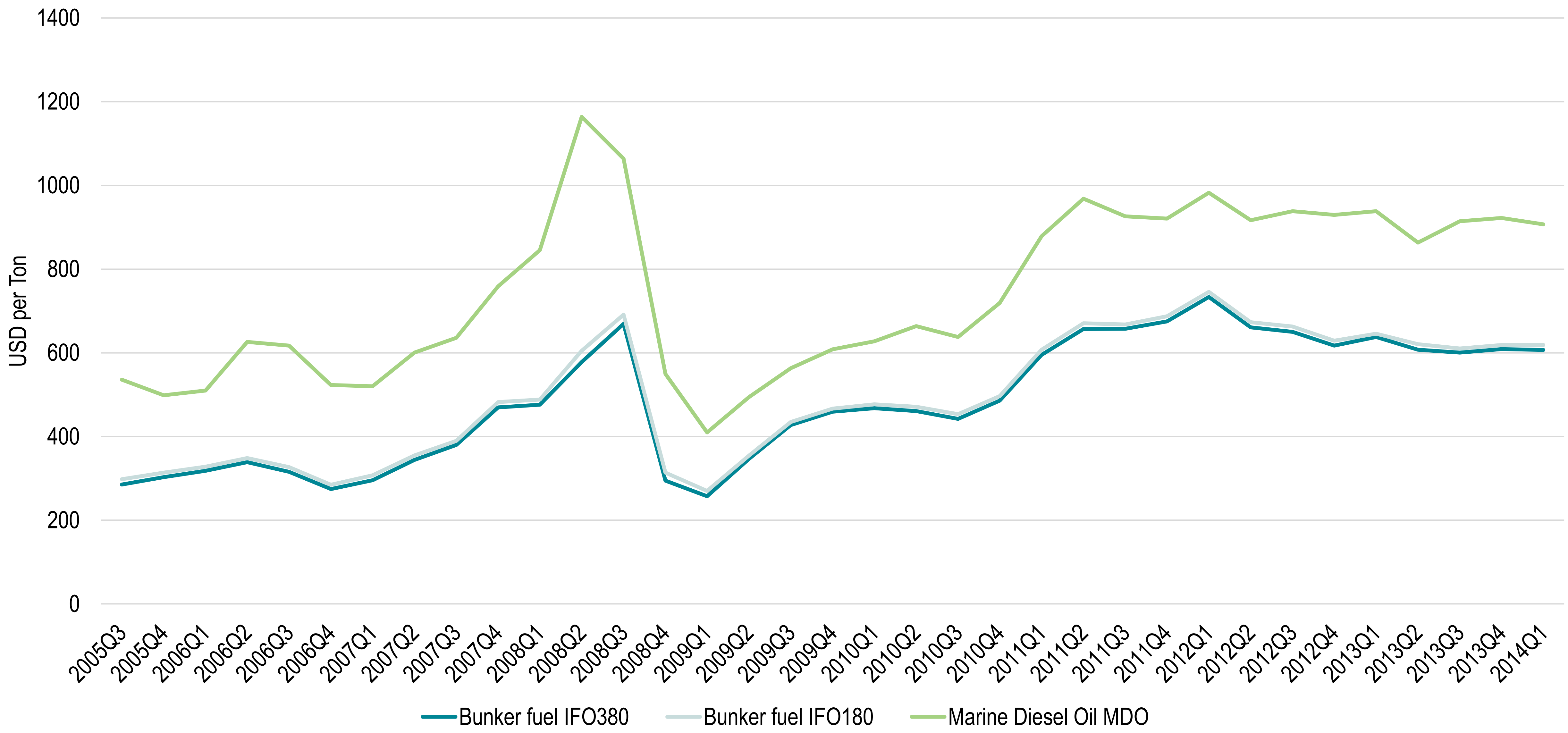
Gasoline Price and Fuel Consumption, Western Industrial Countries, 1994



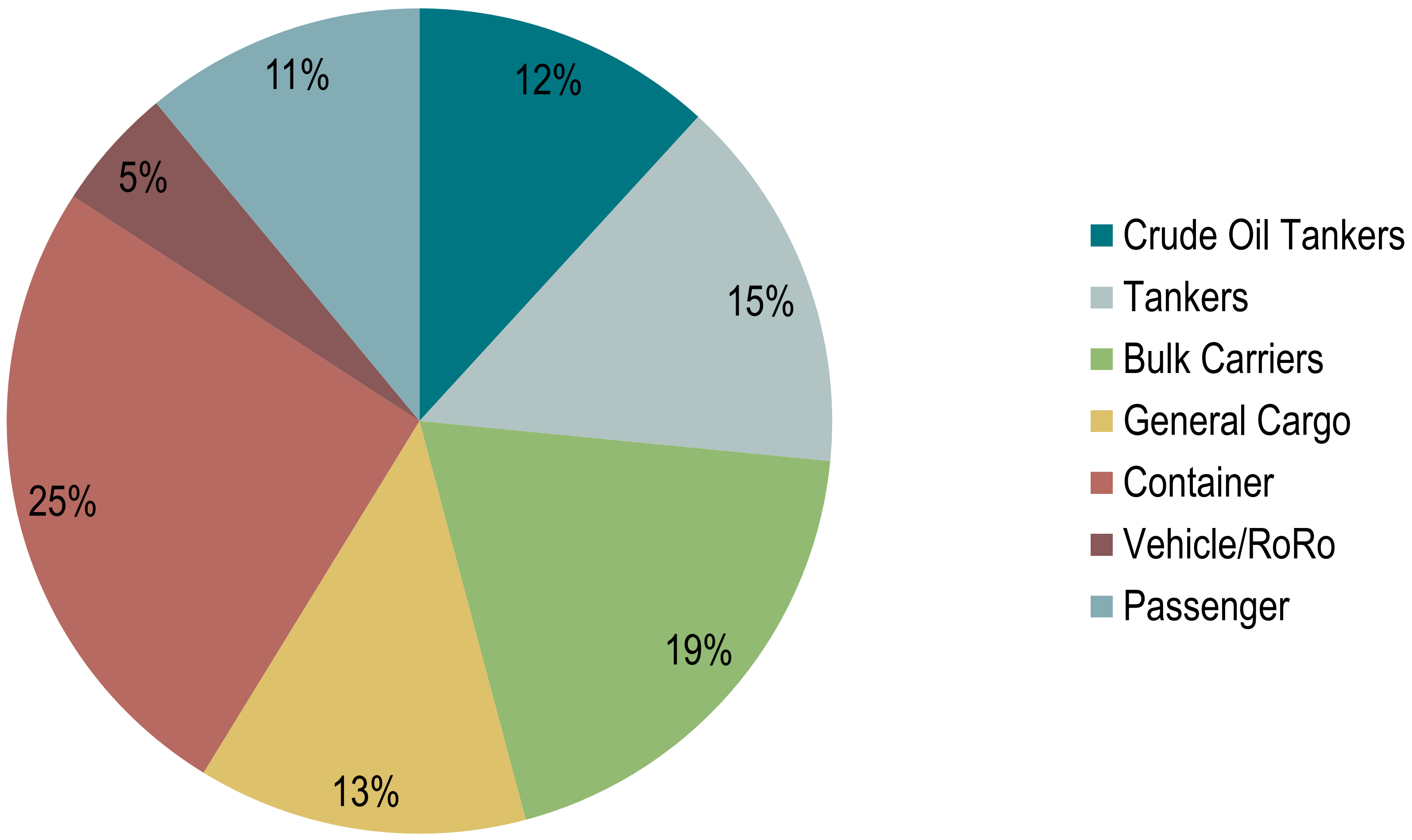
Gas Consumption Tax in the United States, 1999 (in $ per mile per gallon per vehicle)



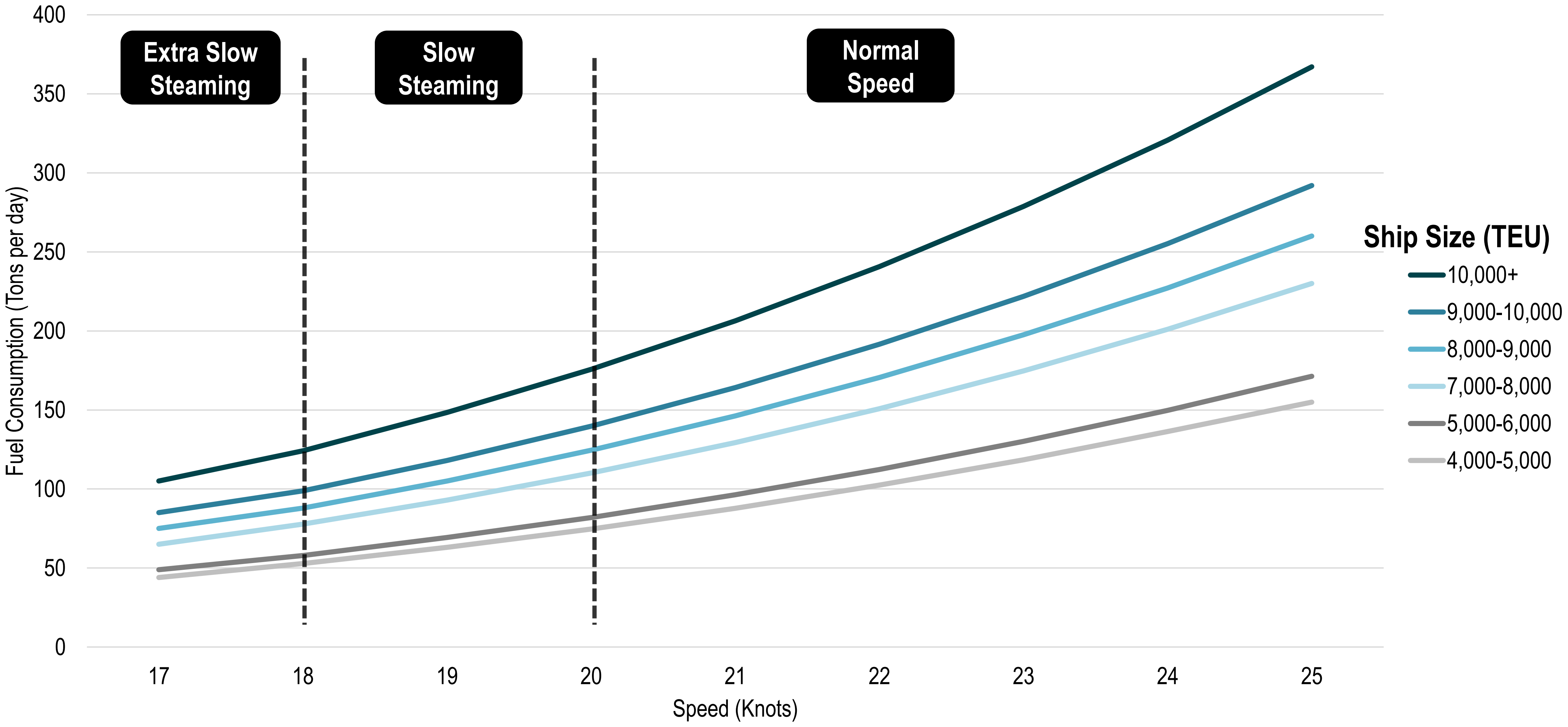
Bunker Fuel Spot Prices, Singapore FOB



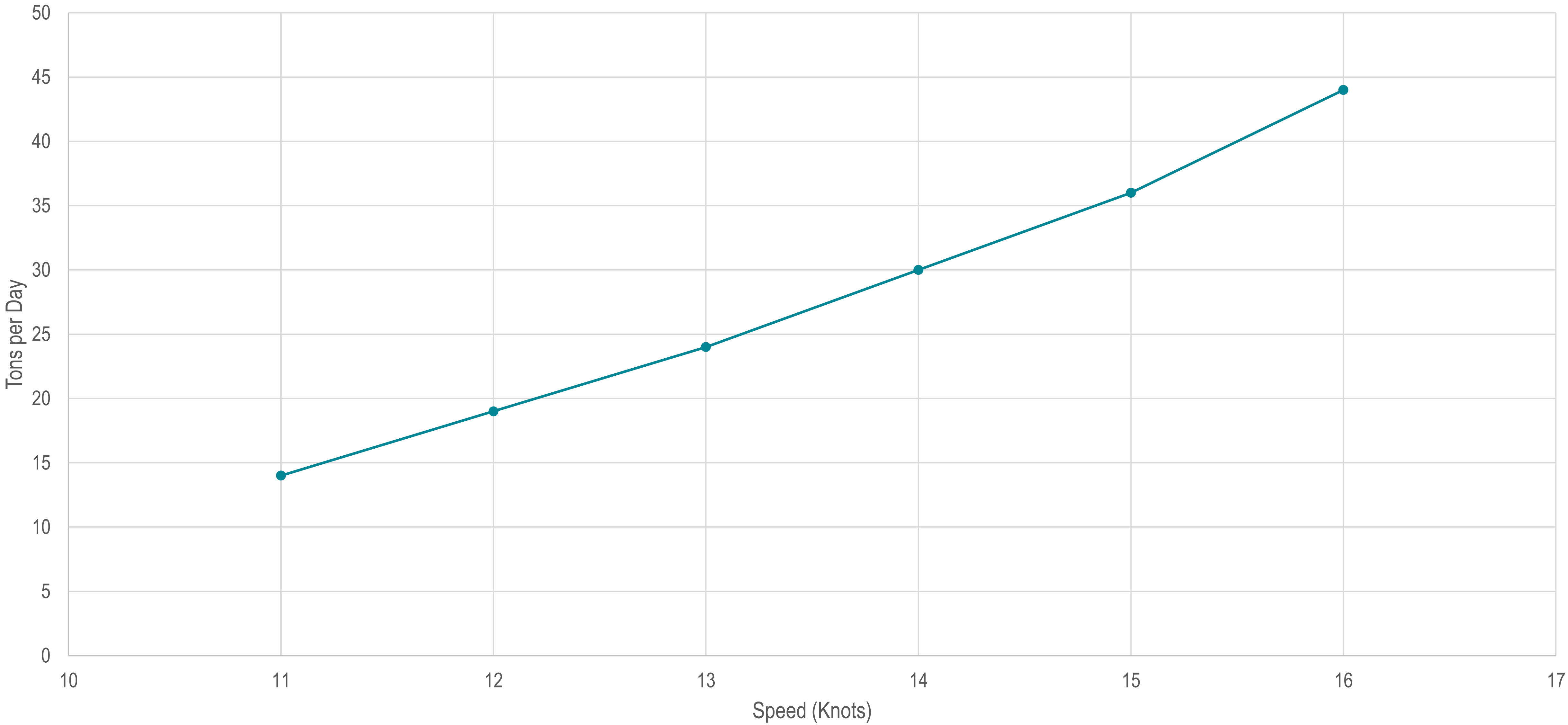
Fuel Consumption by Ship Category, 2007



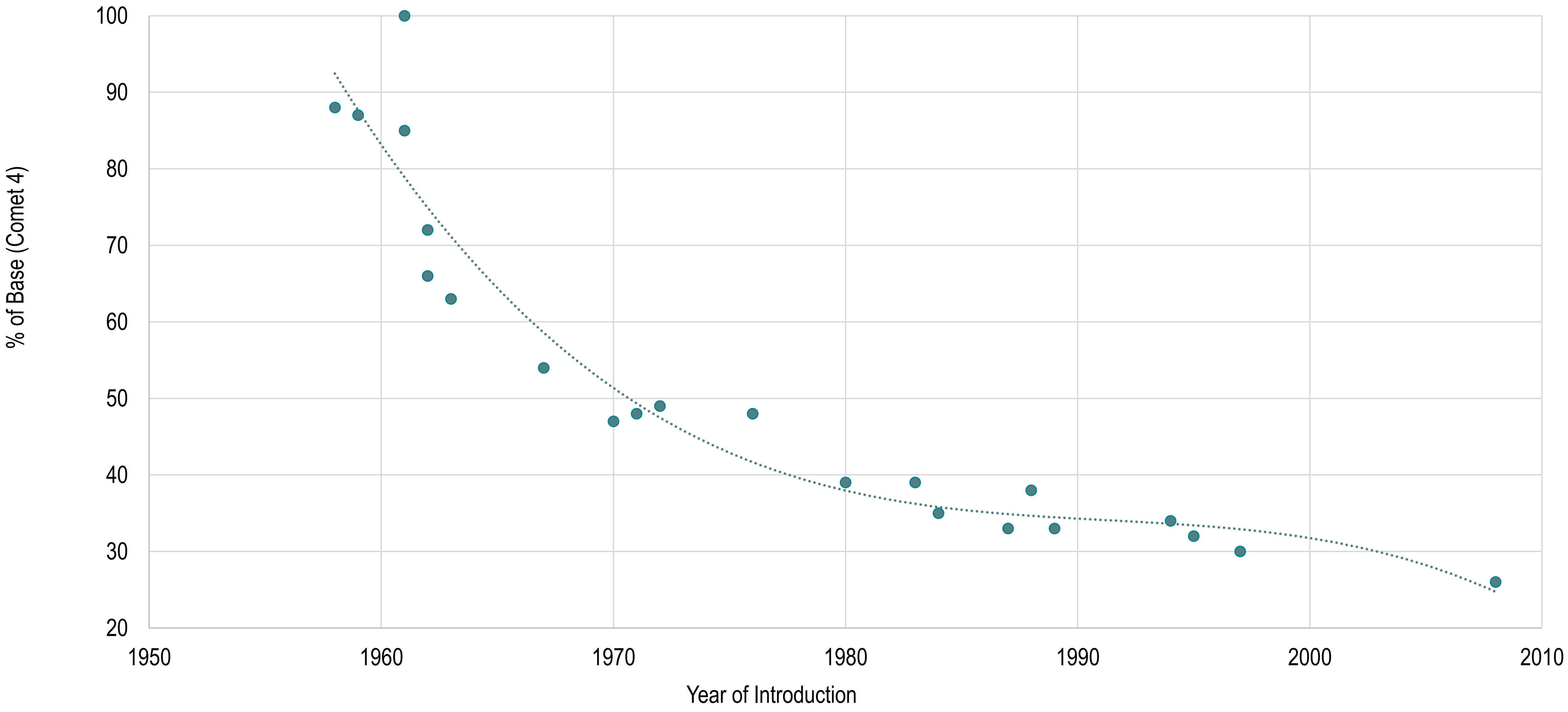
Fuel Consumption by Containership Size and Speed



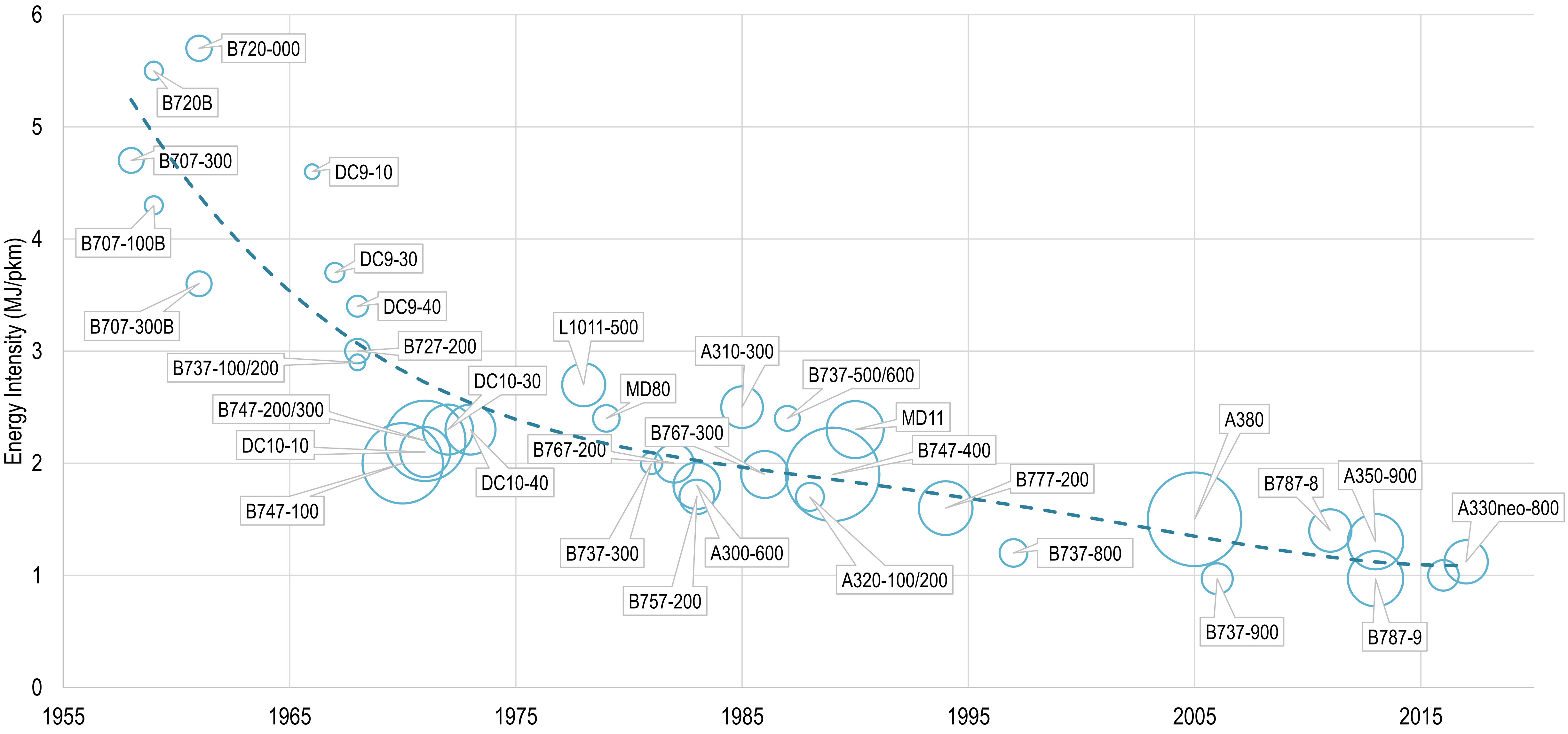
Effects of Speed on Fuel Consumption, Panamax Bulk Carrier



Trend in Aircraft Fuel Efficiency (Fuel burned per Seat)



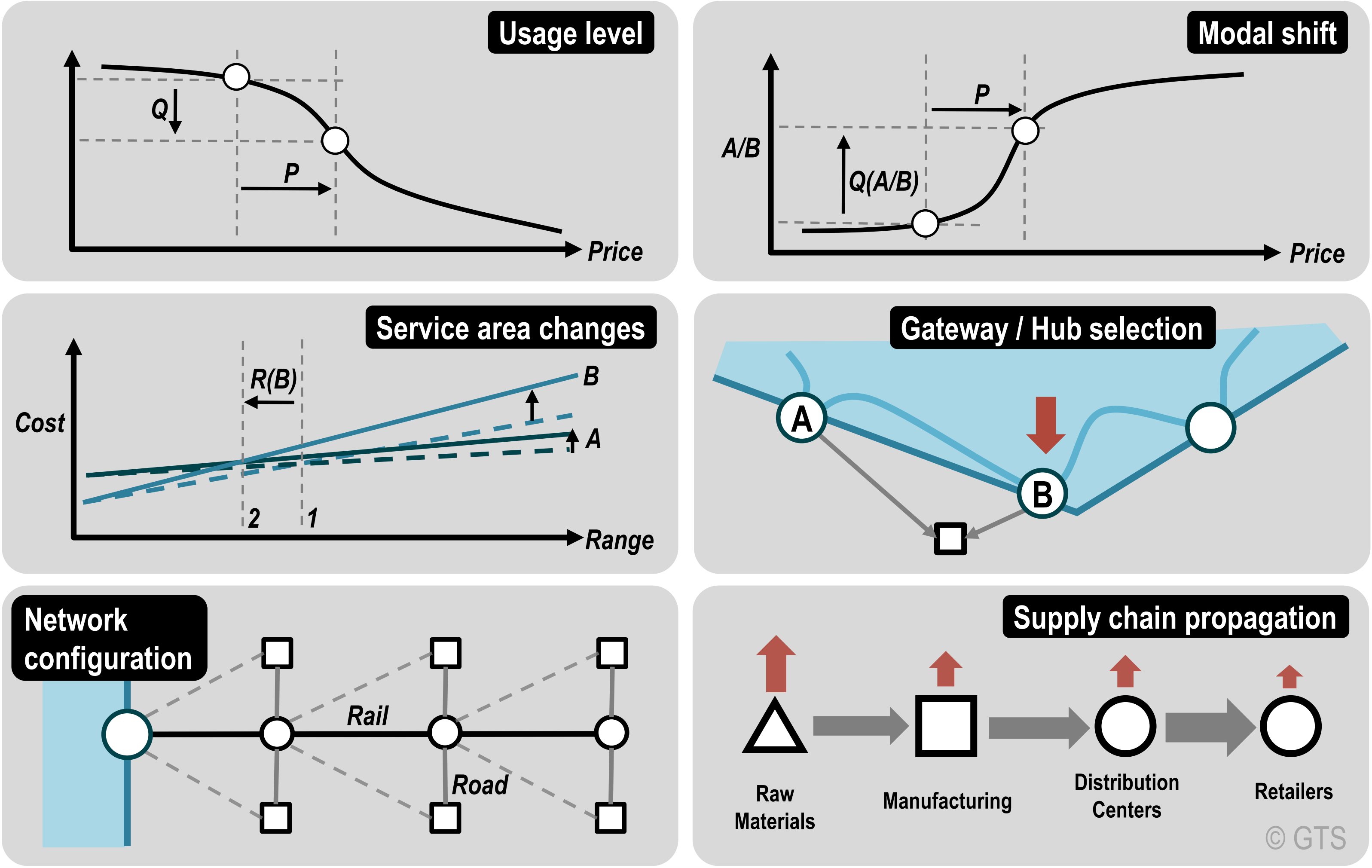
Trends in Fuel Efficiency, Selected Passenger Jet Planes



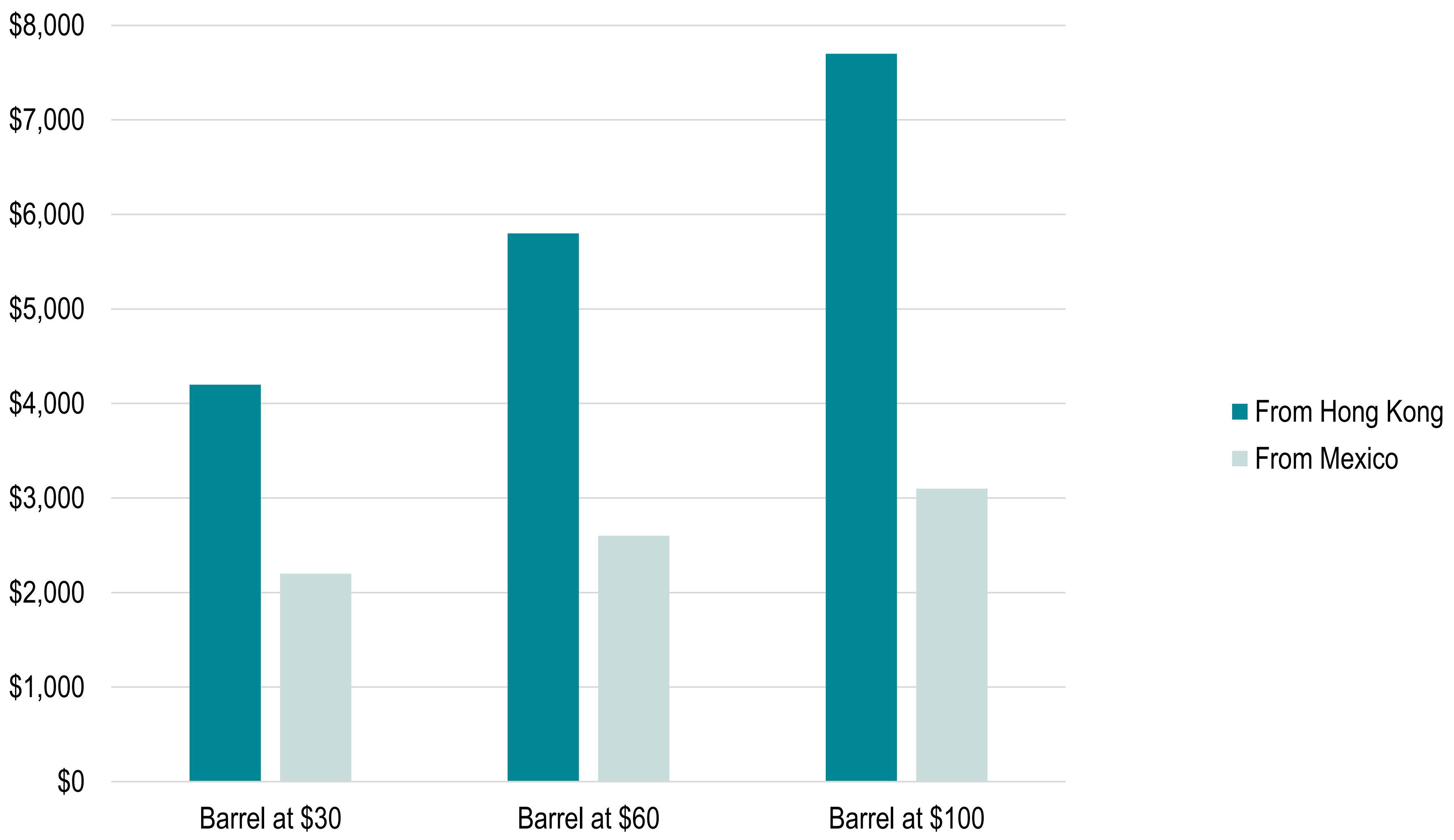
Potential to Reduce Energy Consumption in Air and Maritime Transportation

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%

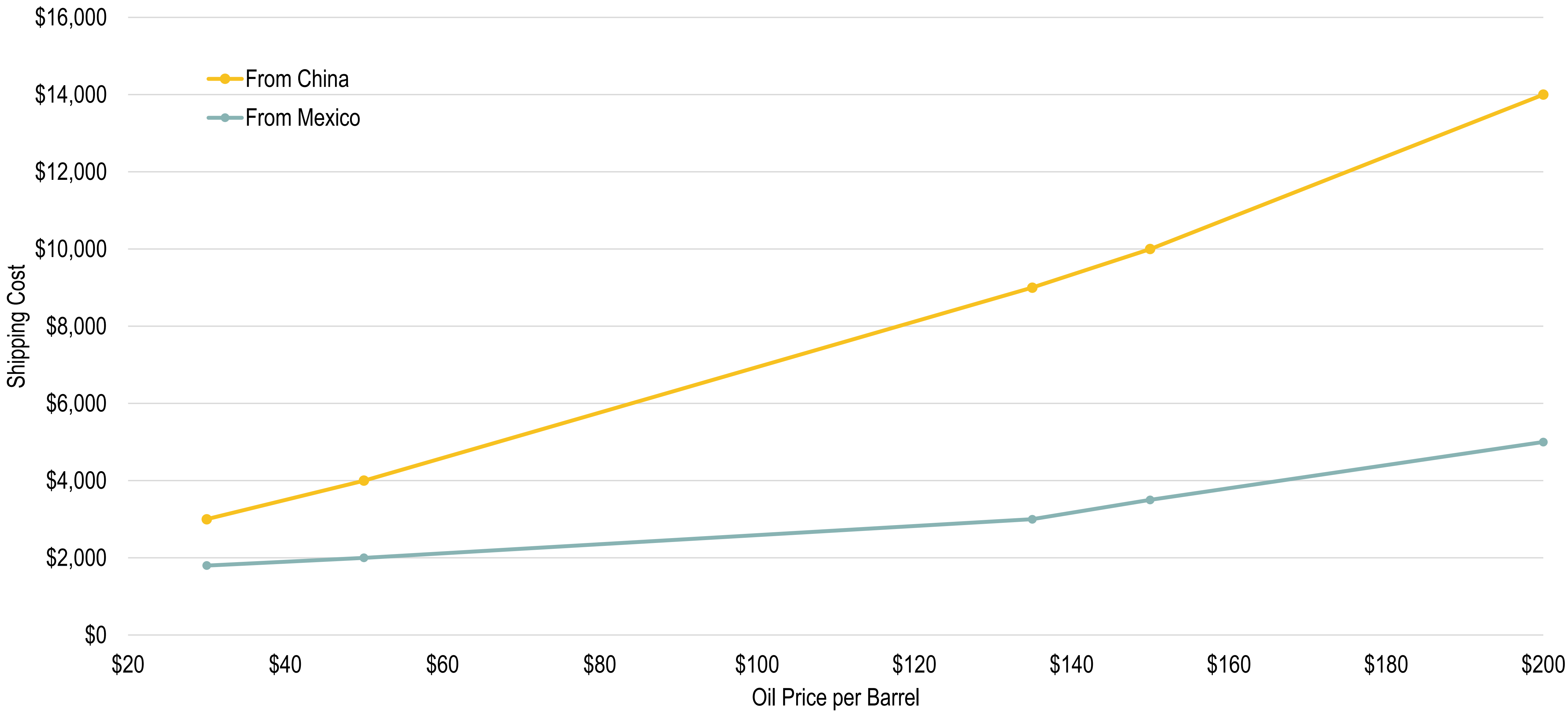
Potential Impacts of High Energy Prices on Transportation

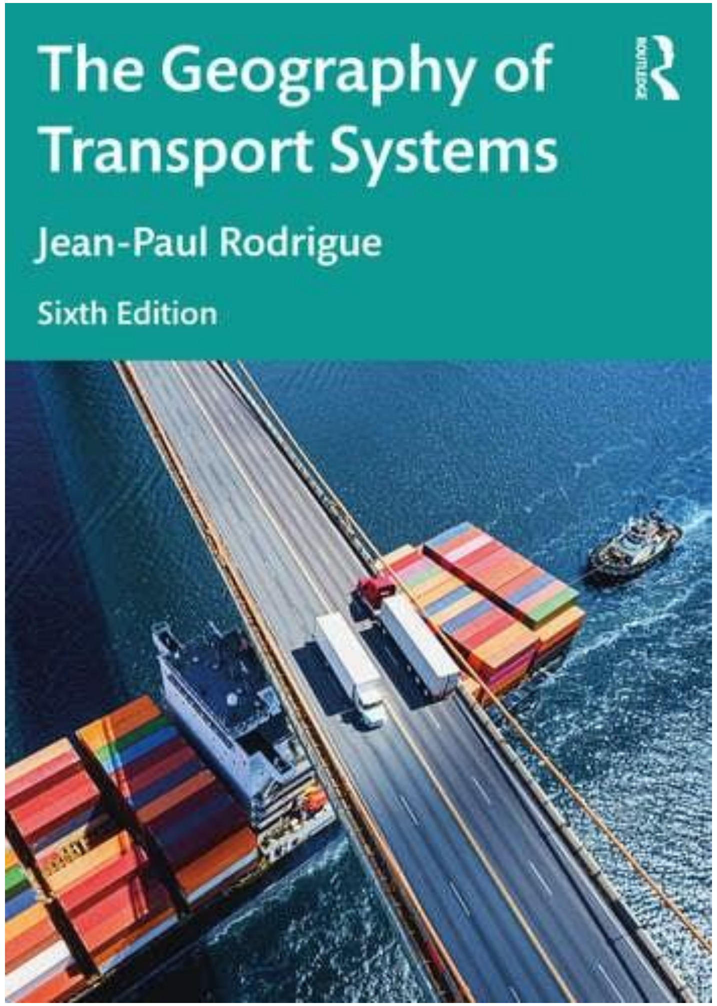


Costs of Shipping a 40 foot Container to New York



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

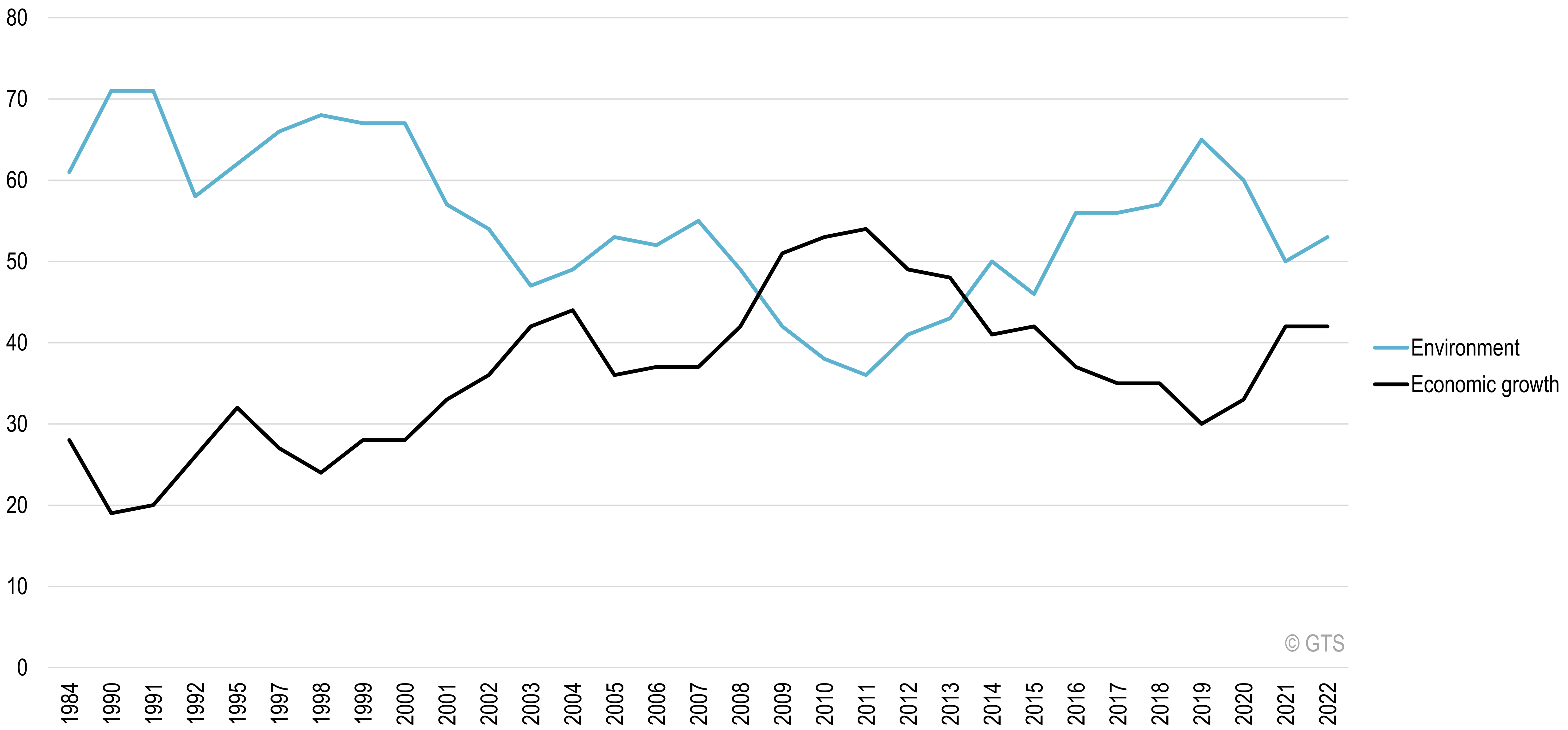




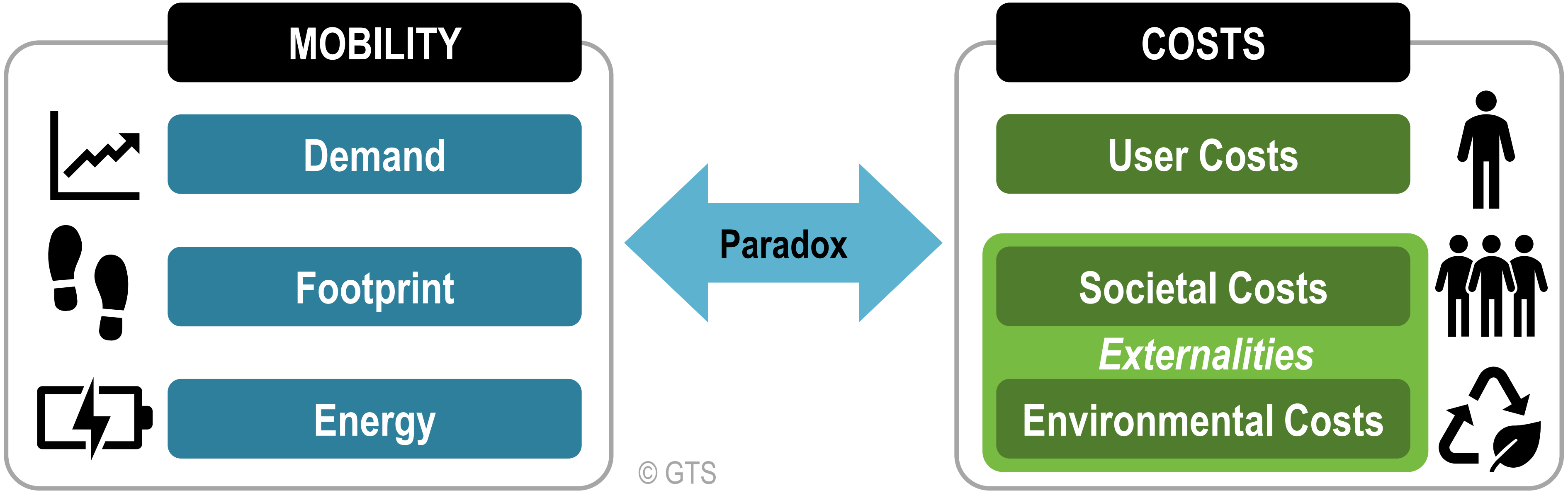
Transportation and the Environment

Chapter 4.2

Public Preferences for Priority between the Economy and the Environment, 1984-2022



The Paradox of Mobility and its Costs



Environmental Costs Hierarchy

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 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
- Costs/benefits related to the subjective perceptions of a firm's stakeholders.
- Difficult to quantify.

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).

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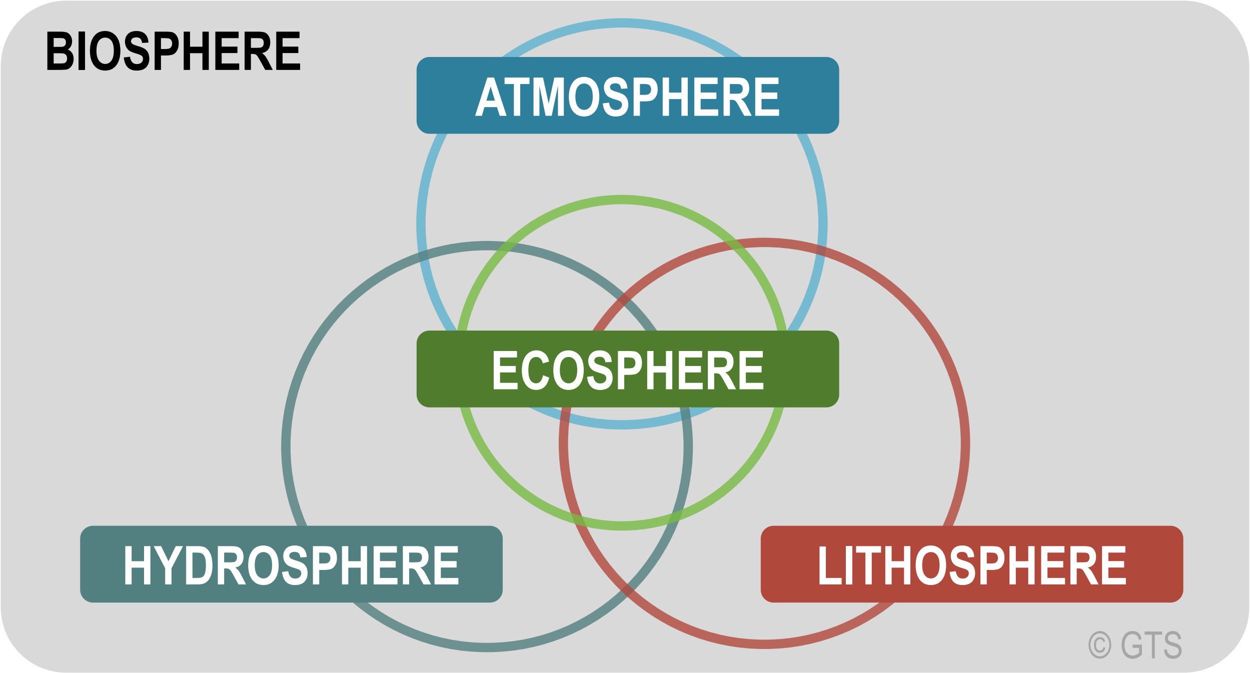
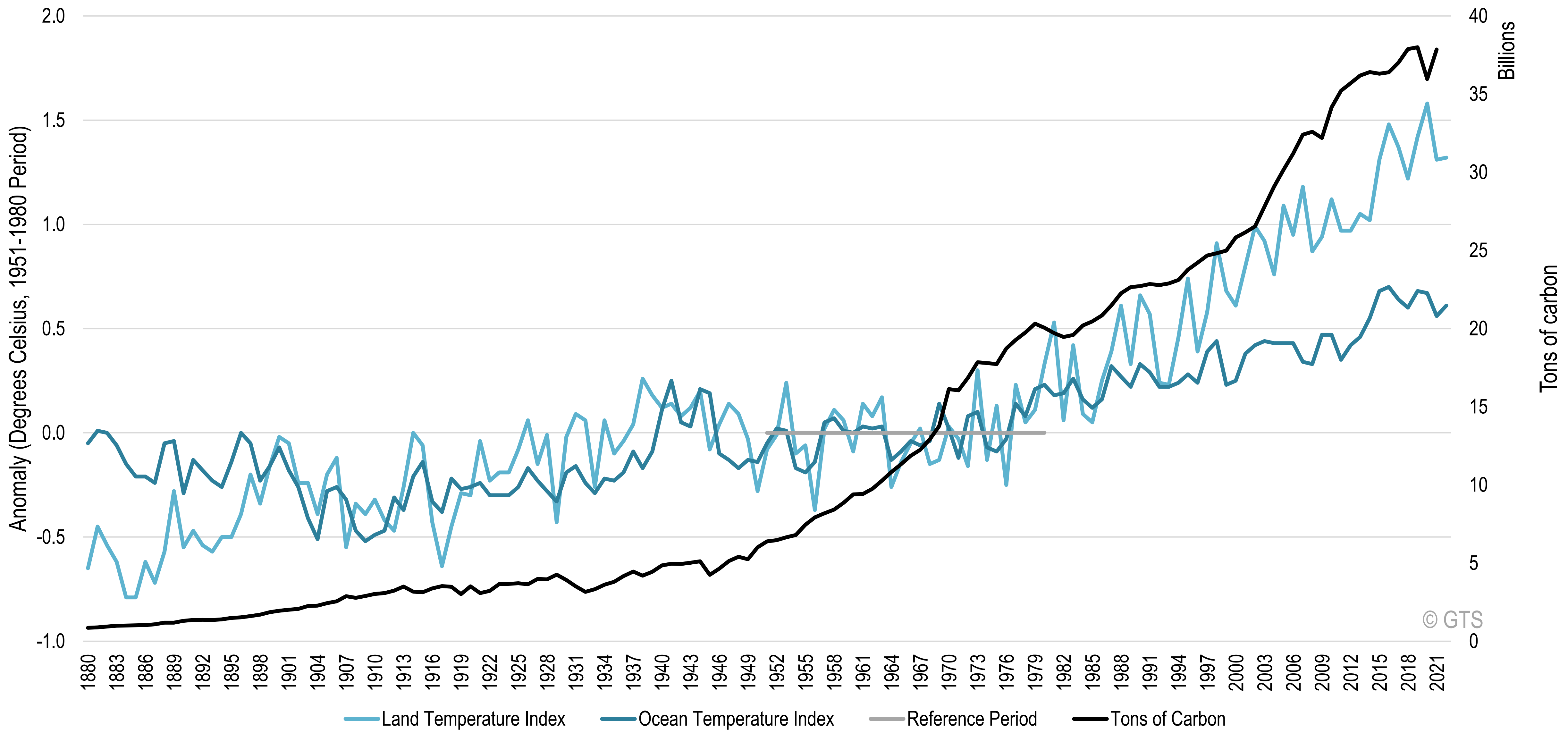
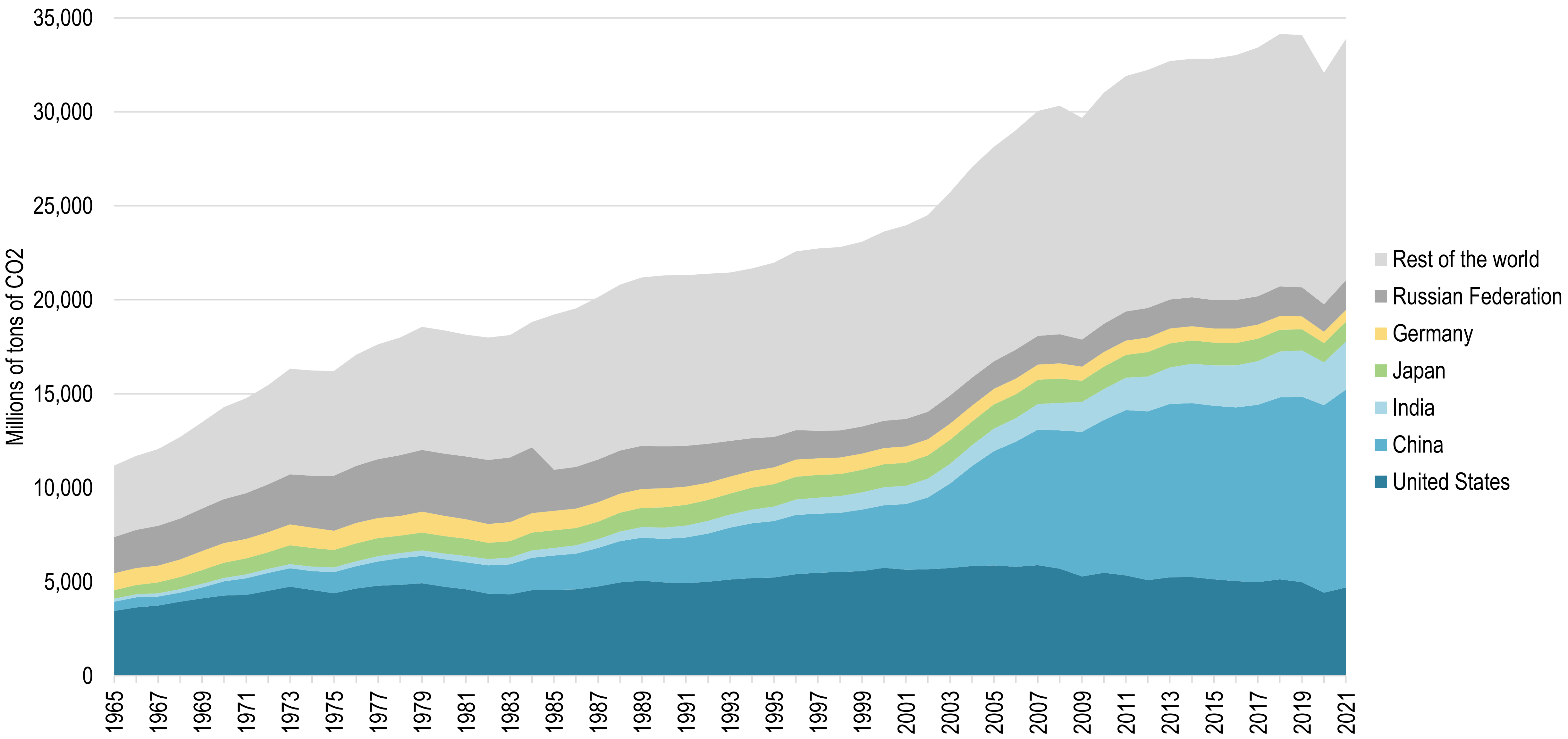
The Environmental System



Average Global Temperature and Carbon Emissions from Fossil Fuel Burning, 1880-2022



Carbon Emissions by Country, 1965-2021



The Environmental Relationships of Transportation Systems

1. ATMOSPHERE

- Large scale diffusion of pollutants.
- Concentration of pollutants because of local conditions (e.g. smog).
- Photochemical reactions caused by ultraviolet rays, notably over ozone, sulfur dioxide and nitrogen dioxide.
- Climate change.
- 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 organisms 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.
- Inhibition of decomposition.
- Loss of the soil flora and fauna.
- Fixation by plants of heavy metals (e.g. lead) and contamination.
- Land footprint.
- Extraction of raw materials like minerals and energy.

4. ECOSPHERE

4.1 AQUATIC ECOSPHERE

- Unforeseen alterations of ecosystems.
- 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.

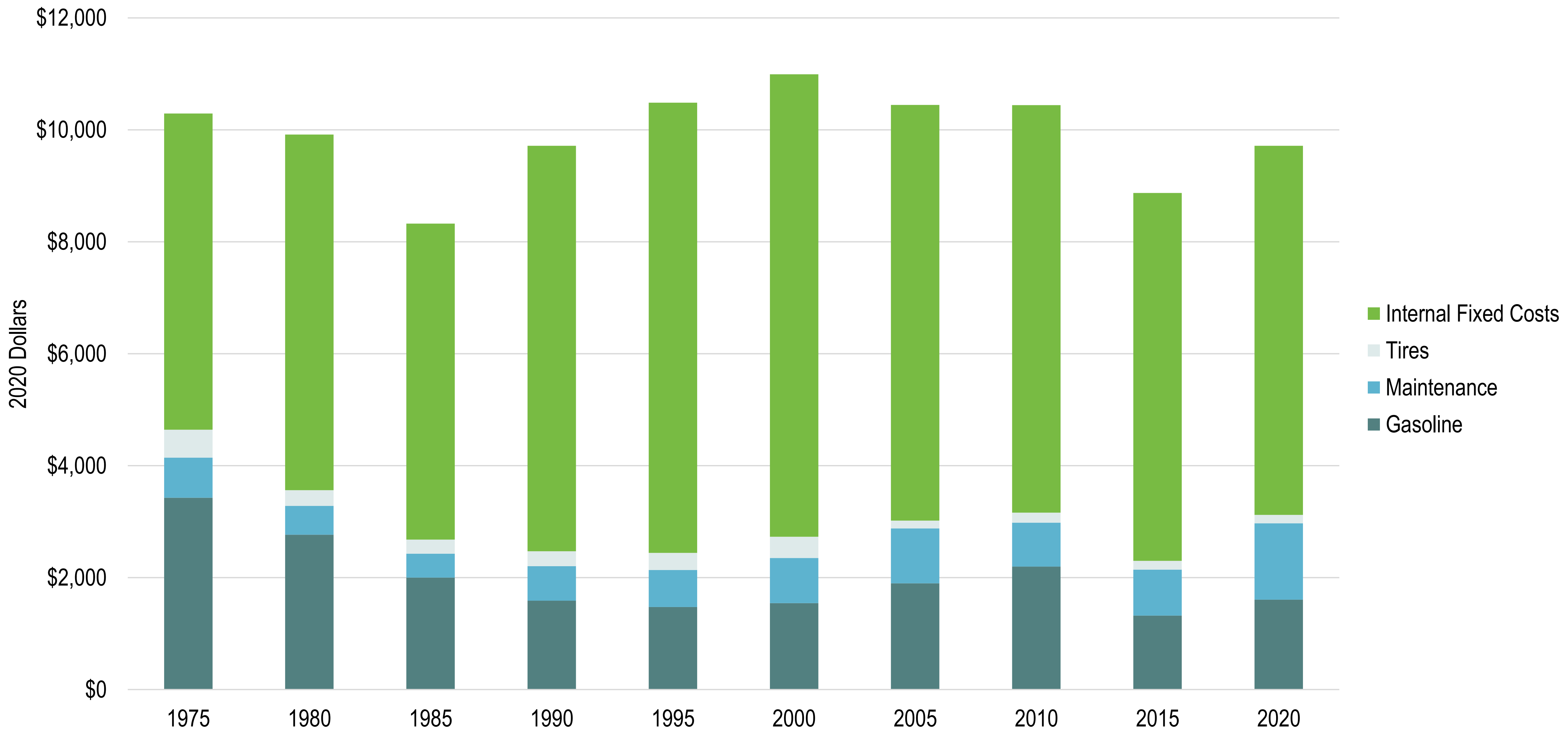
4.2 LAND ECOSPHERE

- Damages over the vegetation modifying:
  - Hydrological cycles.
  - Level of underground water resources.
  - Soil erosion.
  - Air purification capacity of the ecosphere.
  - Food sources (agriculture).
  - Entertainment and tourism.
- Reduction of ecological ranges.
- Reduction of the genetic potential of species.
- Reduction of the food supply and alteration of the food chain.
- Consumption of resources.

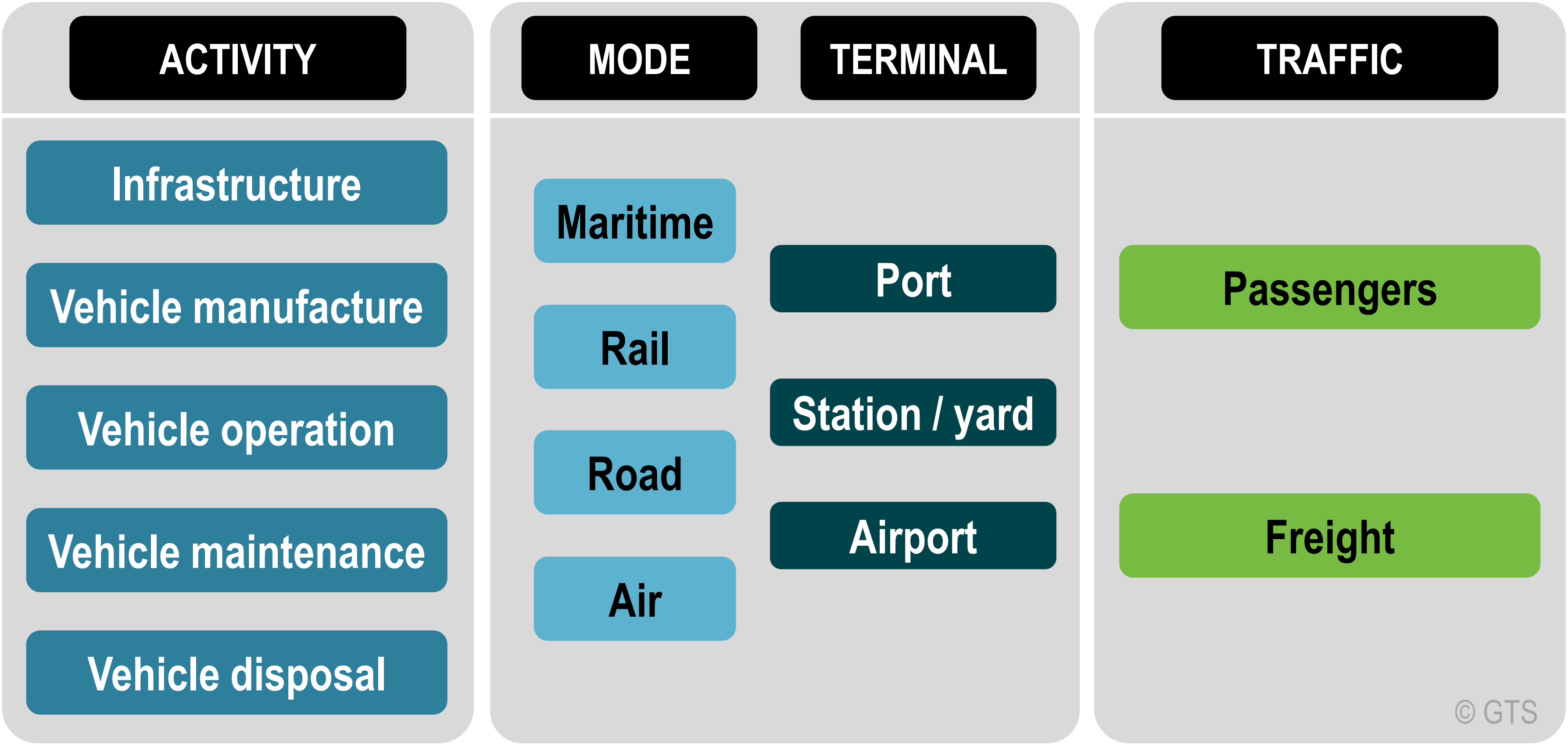
4.3 HUMAN ECOSPHERE

- 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.

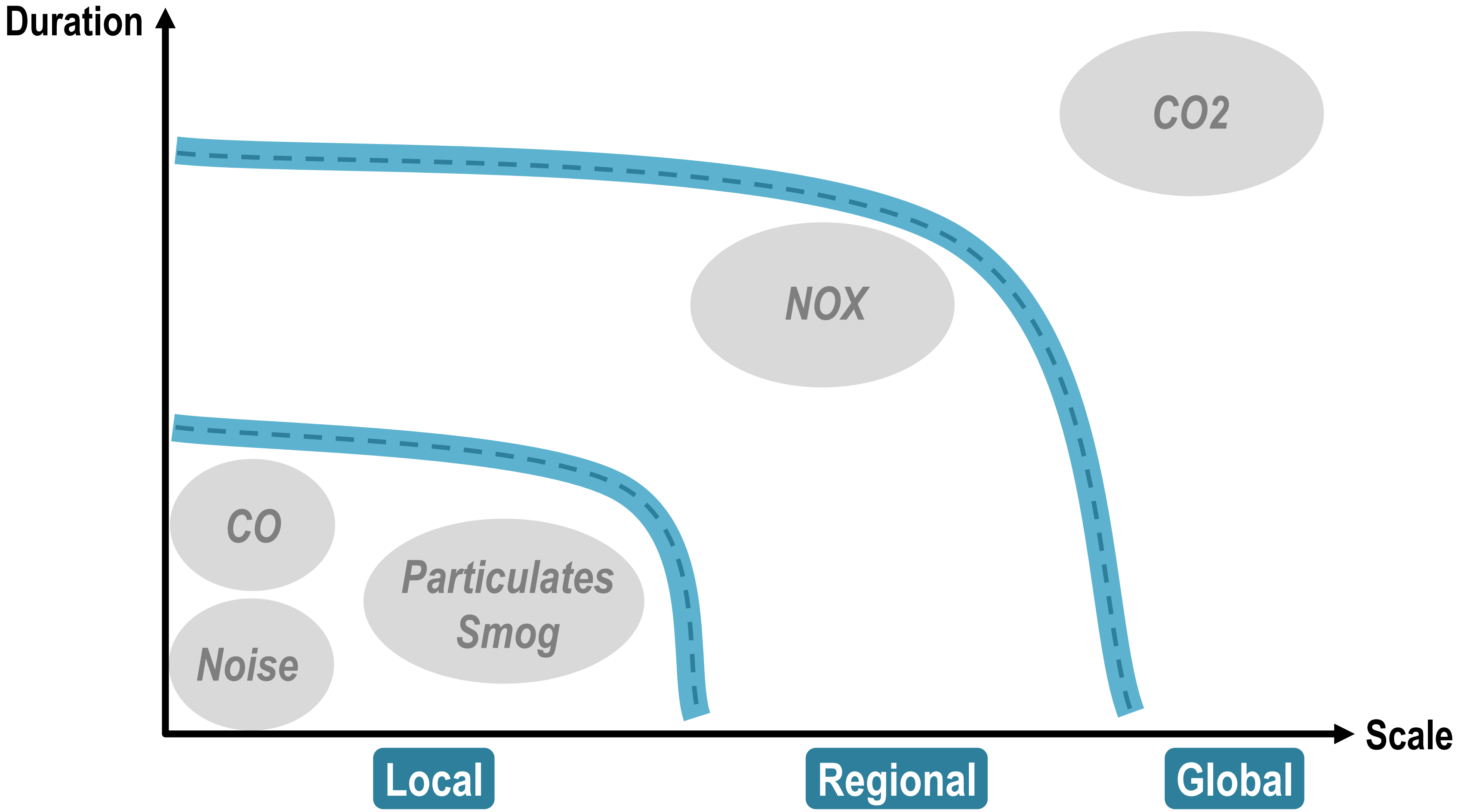
Average Cost of Owning and Operating an Automobile, 1975-2020

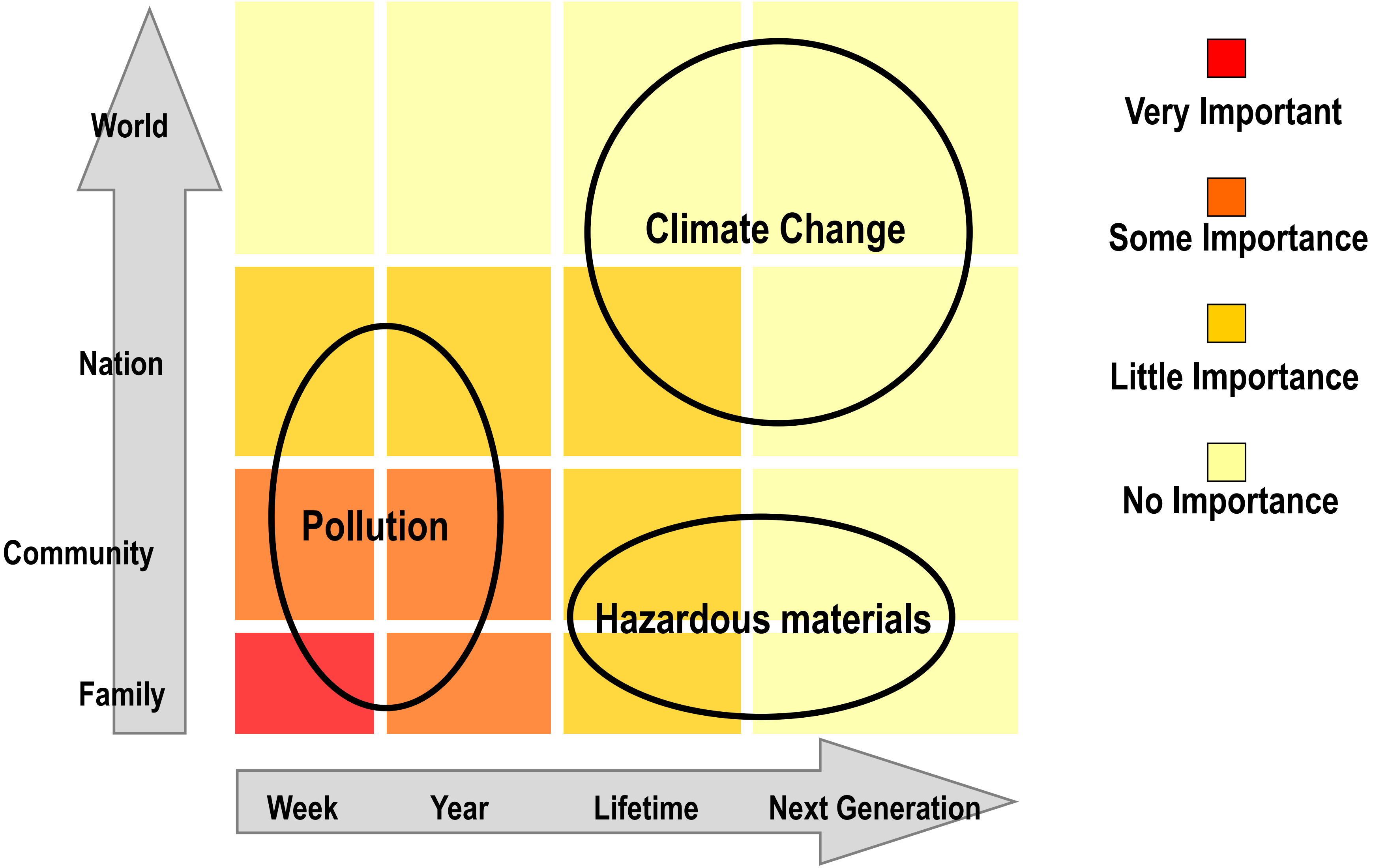


Transportation Activities Affecting the Environment

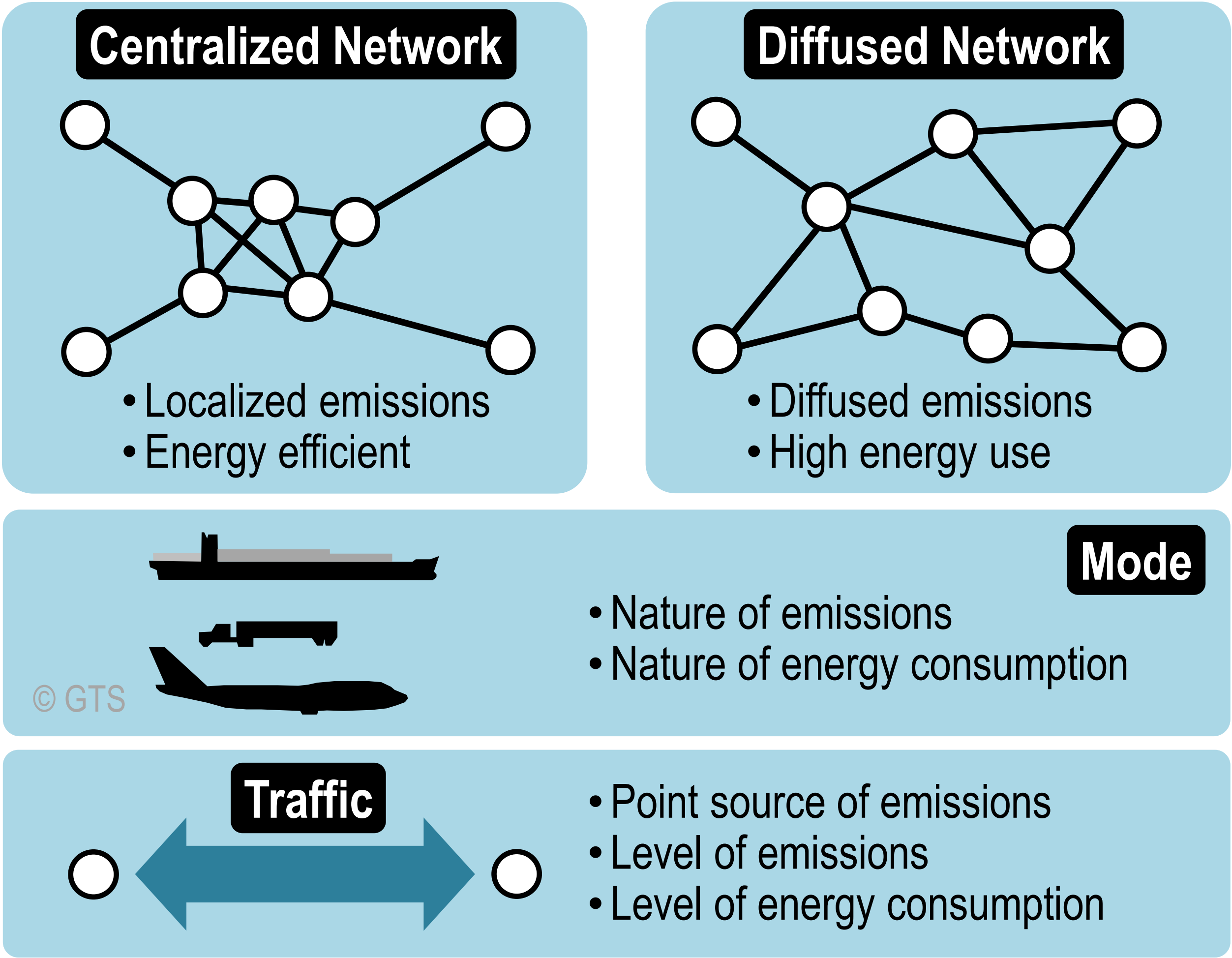


Spatial and Durational Environmental Effects of Selected Environmental Externalities

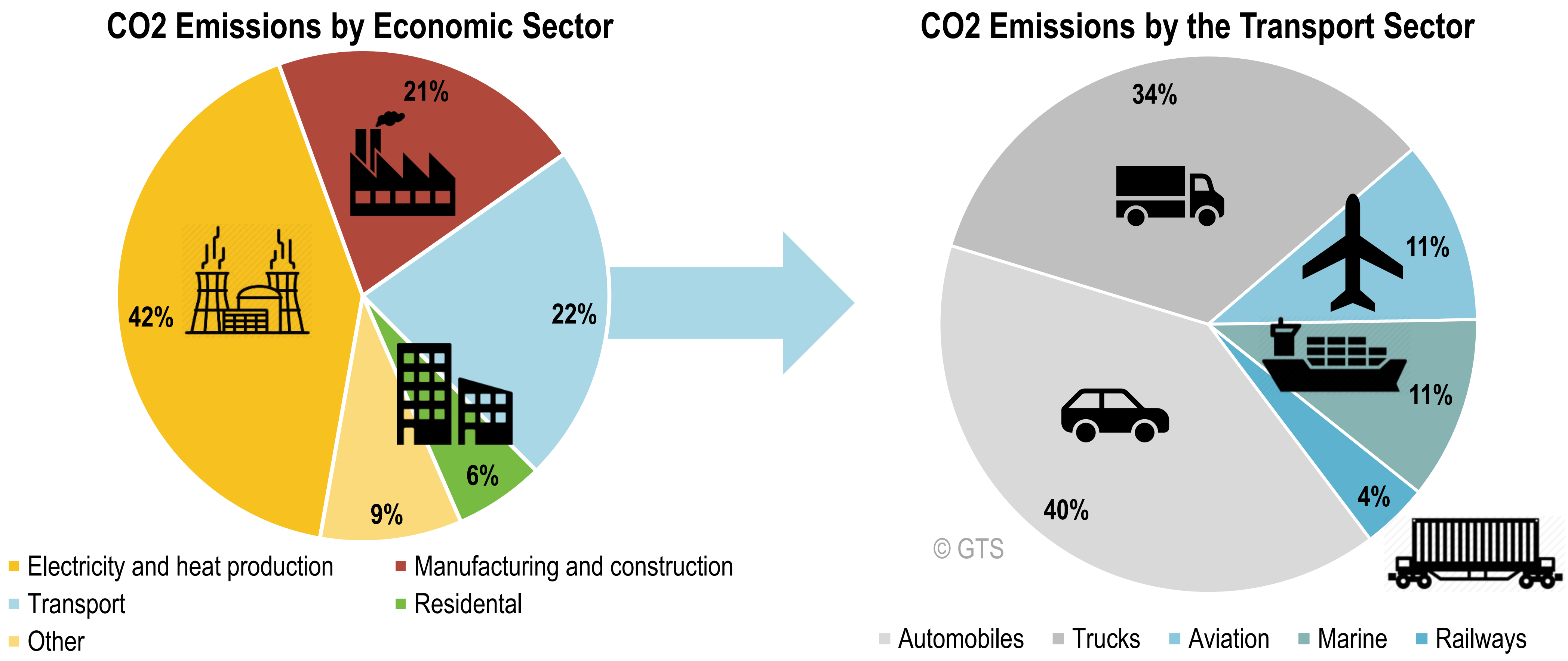



World
Nation
Community
Family
Climate Change
Pollution
Hazardous materials
Week
Year
Lifetime
Next Generation
Very Important
Some Importance
Little Importance
No Importance

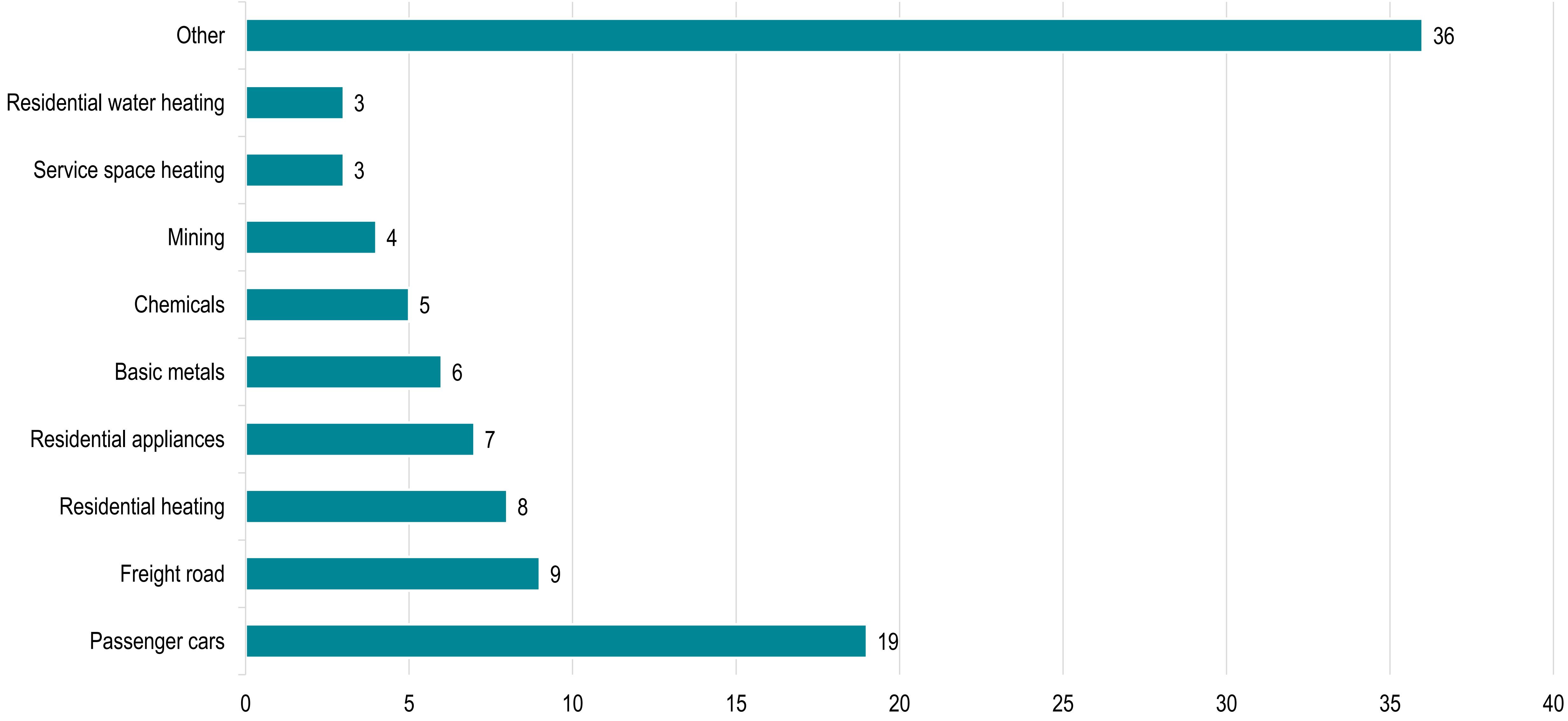
Transportation Systems and the Environment



Global Greenhouse Gas Emissions by the Transportation Sector



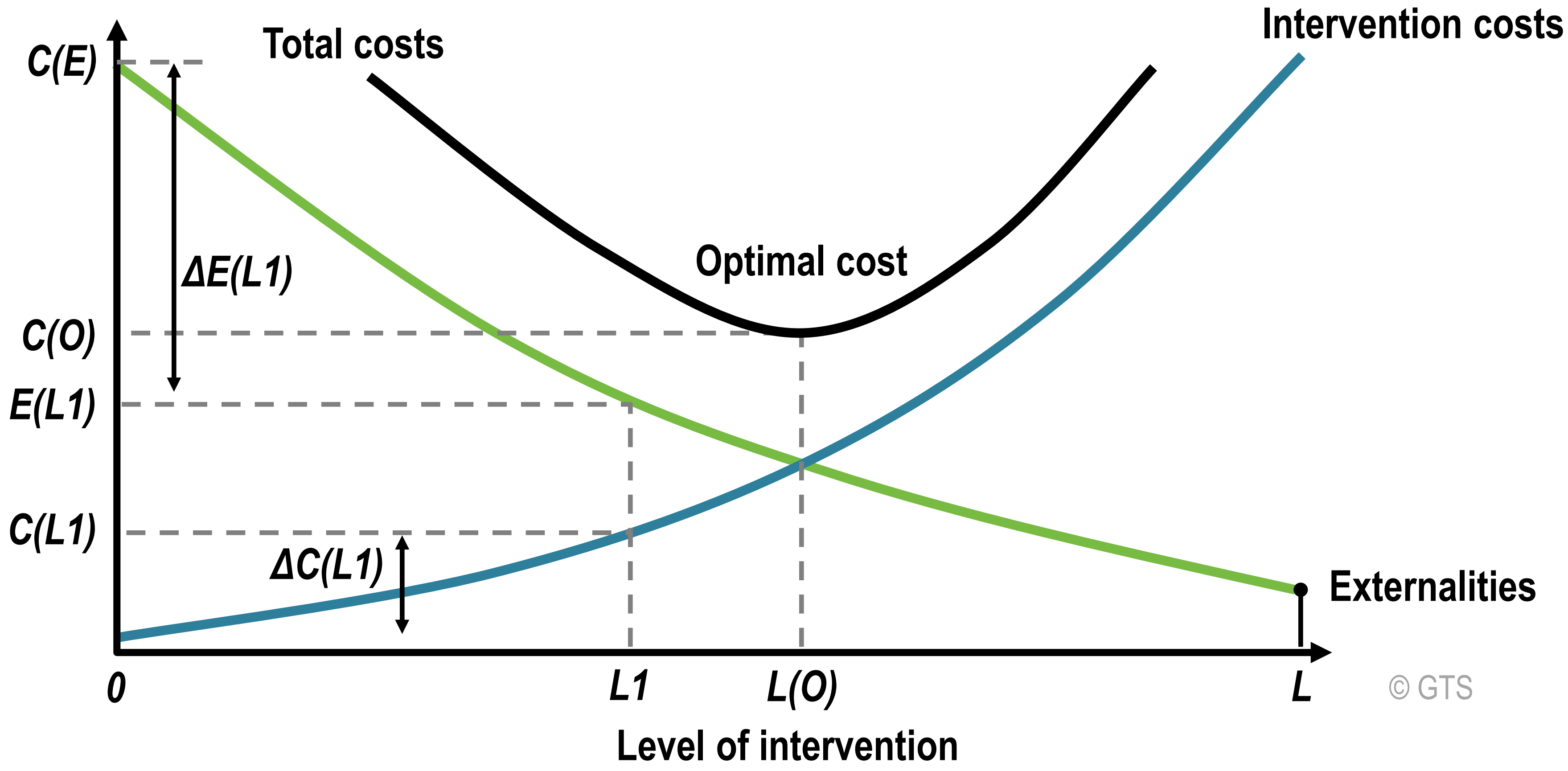
Top 10 CO2 Emitting Sources, 2014 (in % of total emissions)



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

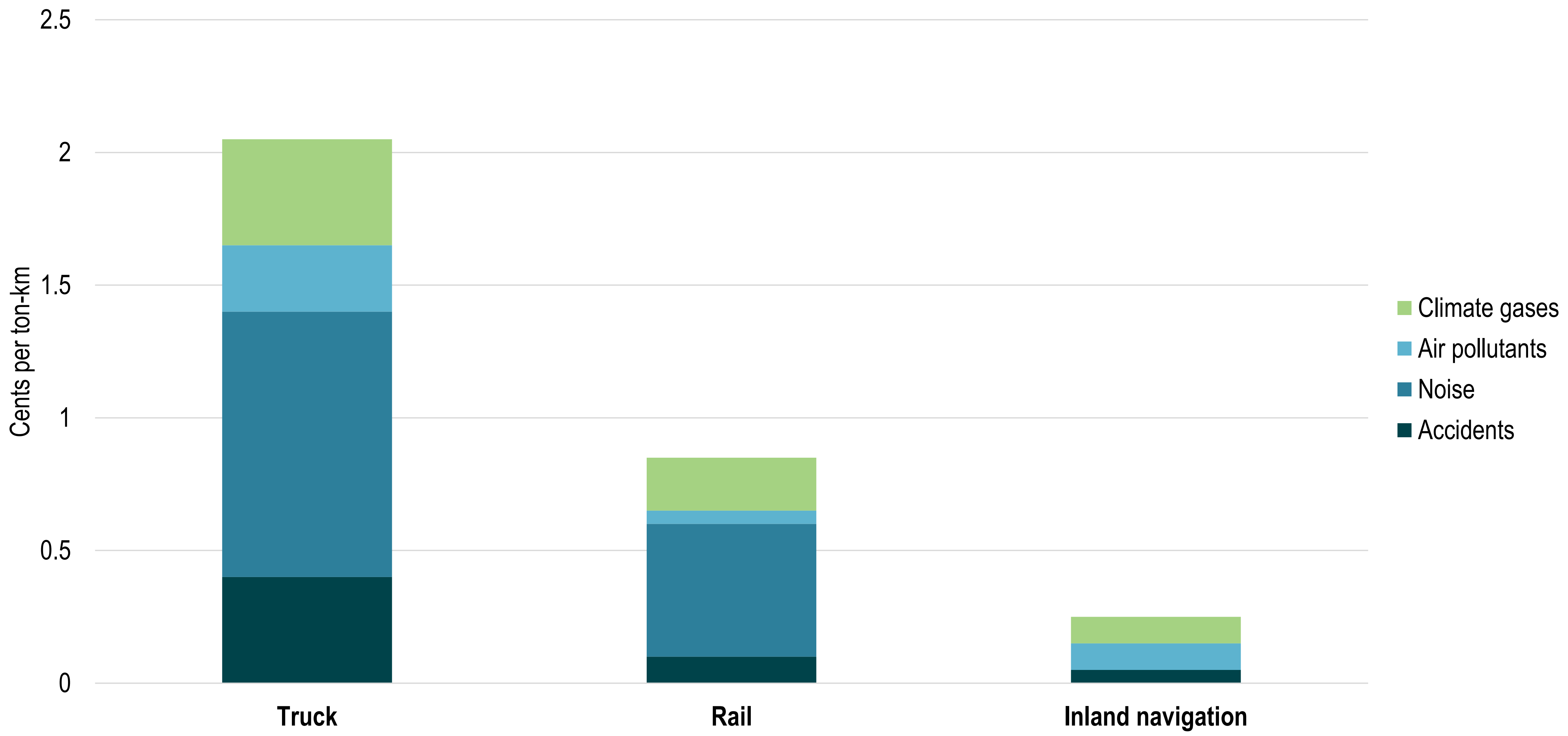
The Concept of Externalities



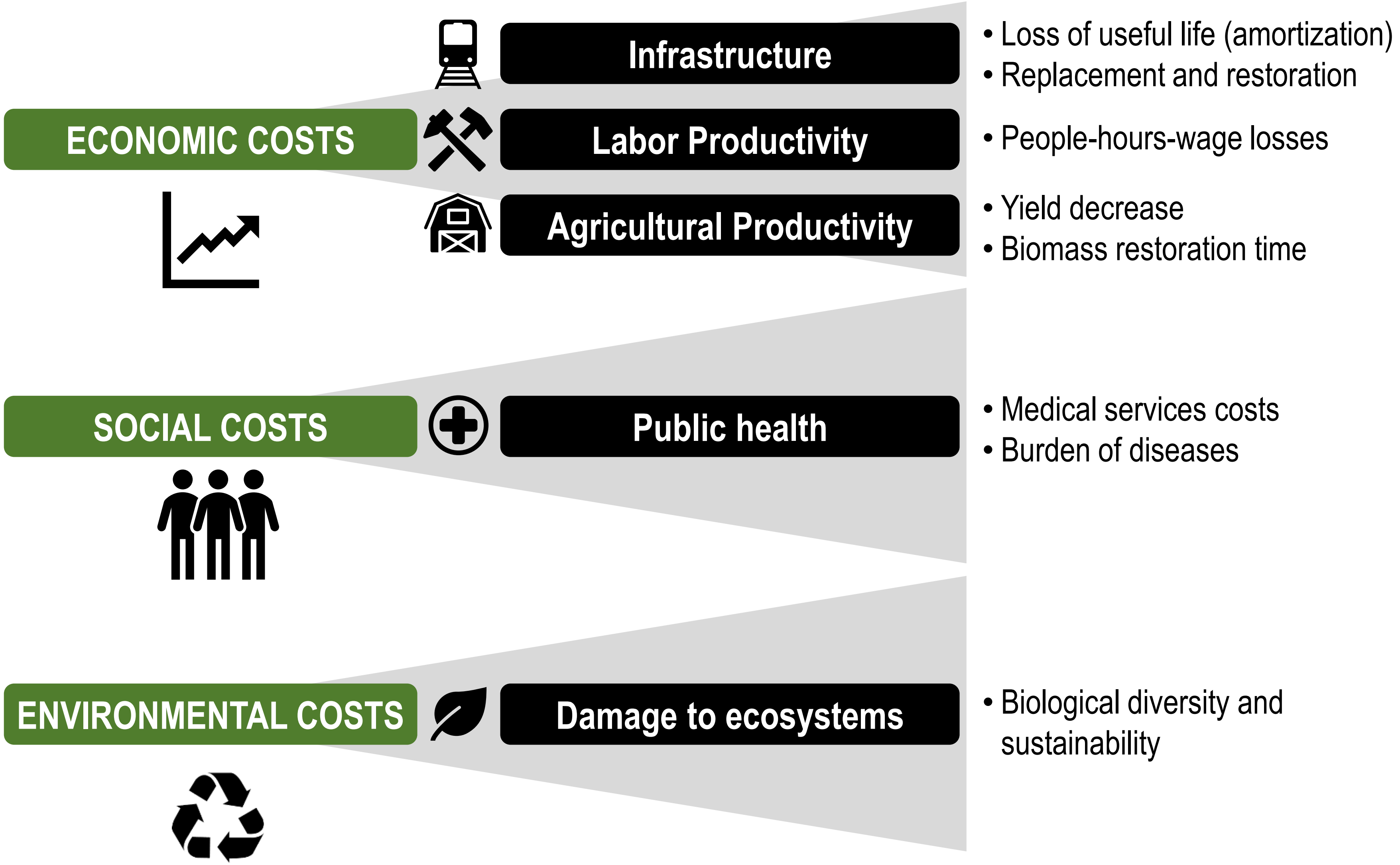
Environmental Externalities Generated by Transportation

Supra and infrastructure; Labor Productivity; Agricultural Productivity	Vehicle emissions; CO_2 (30%), CO (70-90%), SO_2 (5%), NO_x (45-50%), HC/VOC (40-50%), Particulates (25%), O_3 (indirect), Smog (indirect), Acid rain (10-30%), CFCs (20%), Lead (5%)
Commercial fishing; Recreational facilities; Water purification	Air pollution fallouts, Marine vessels discharges and spills, De-icing of infrastructure, Runoffs, Construction and maintenance of infrastructure, Dredging (80%)
Accidents/Spills	Marine vessels spills, Accidental and intentional releases (Hazmat); Road (84%), Rail (12%), Air (3%) and Maritime (1%)
Property values	Vehicle emissions; Road (70%), Rail (10%) and Air (20%)
Public health	Vehicle emissions, During transport
Damage to ecosystems	Vehicle emissions, during transport, Infrastructure

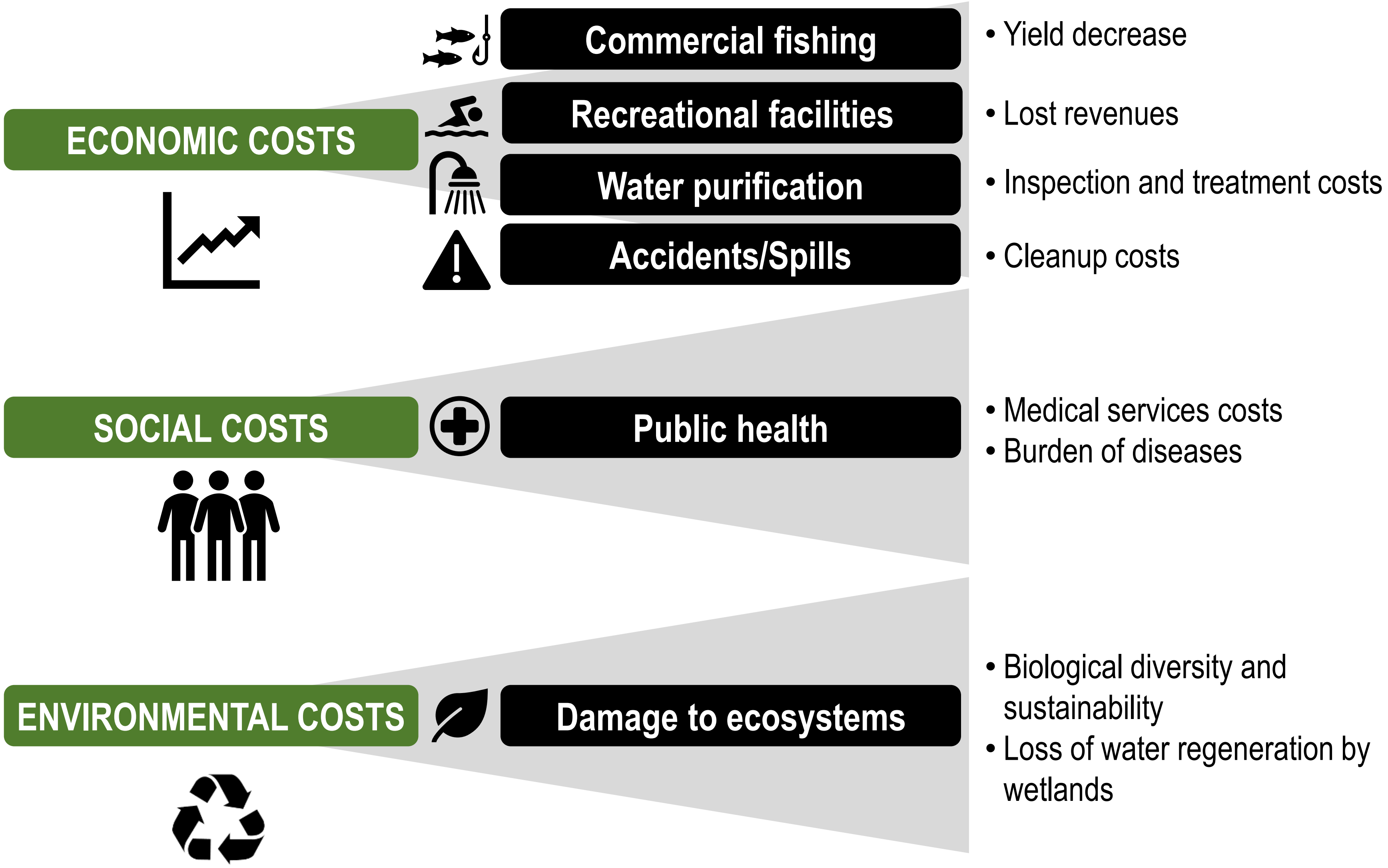
External Costs for Bulk Transportation



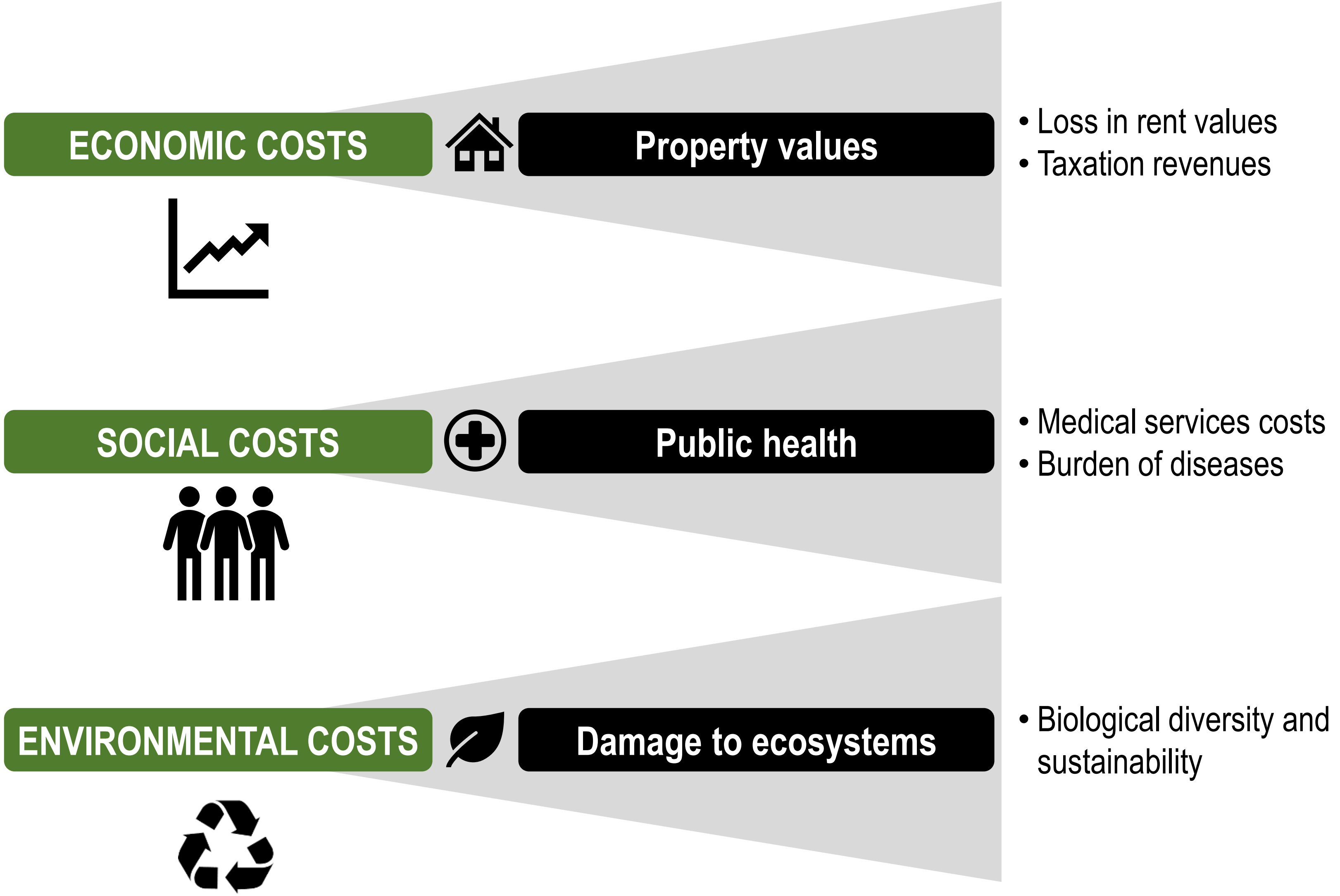
Externalities of Air Pollution



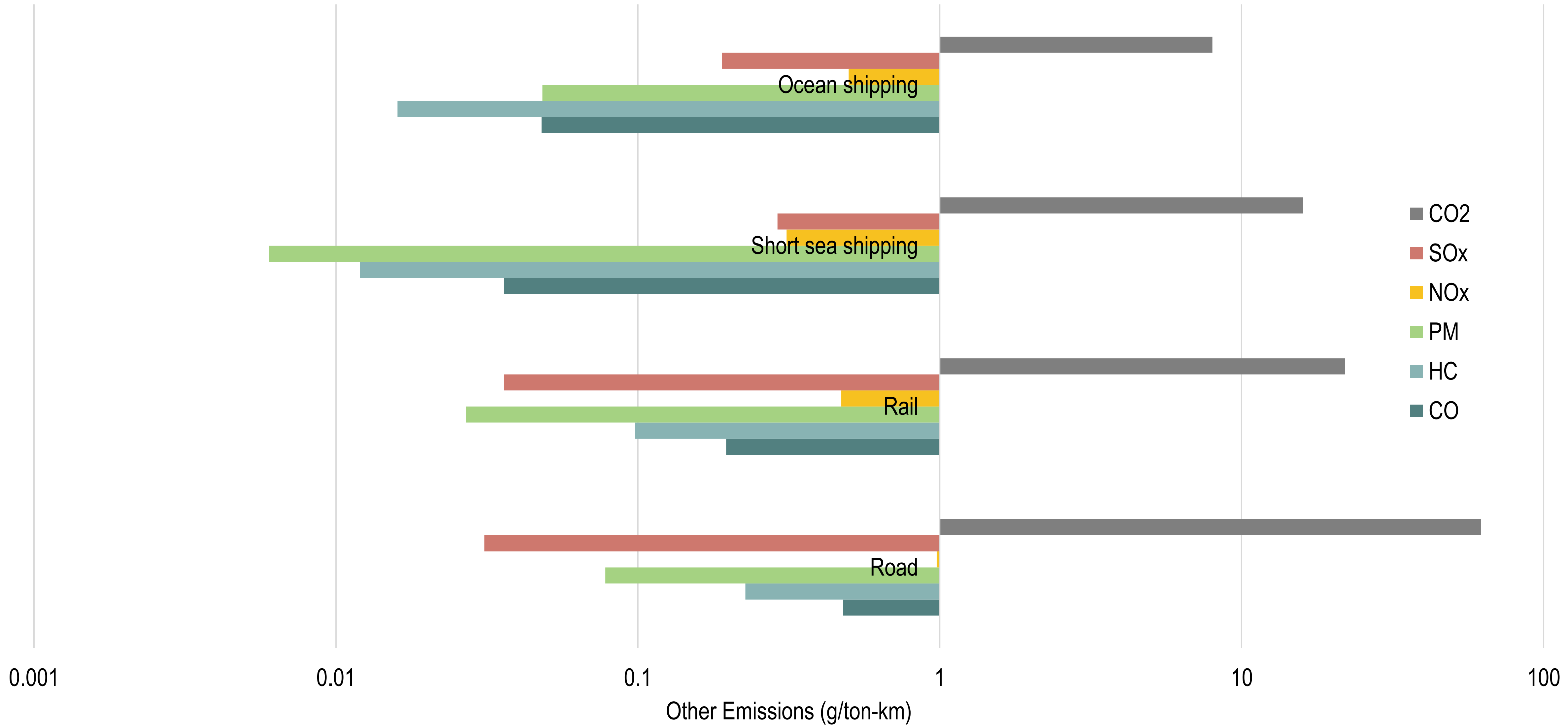
Externalities of Water Pollution



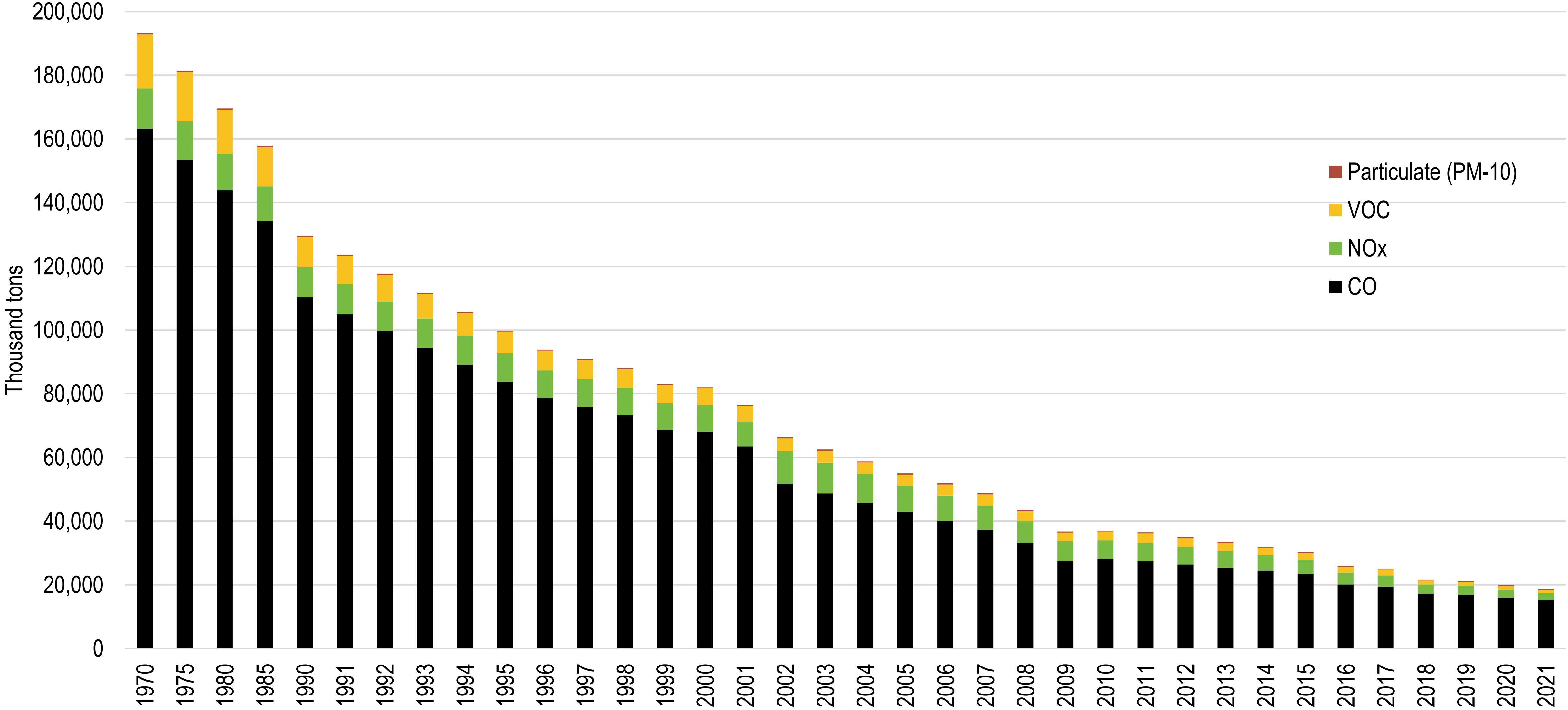
Externalities of Noise Pollution



Emissions from Freight Modes (grams / ton-km)



Estimated Air Pollutants Emitted by Highway Transportation in the United States, 1970-2021



Noise Levels (in decibels)

dB (A)	Source	Level
120	Aircraft at take off	Extremely Loud
110	Car horn	Extremely Loud
100	Subway	Very Loud
90	Truck, motorcycle	Very Loud
80	Busy crossroads	Very Loud
70	Noise level near a motorway	Loud
60	Busy street through open windows	Moderate
50	Light traffic	Moderate
40		Faint
30	Quiet room	Faint
20		Faint
10	Desert	Faint
0	Earing threshold	Faint

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Hazmat Accidents in the United States, 1975-2020

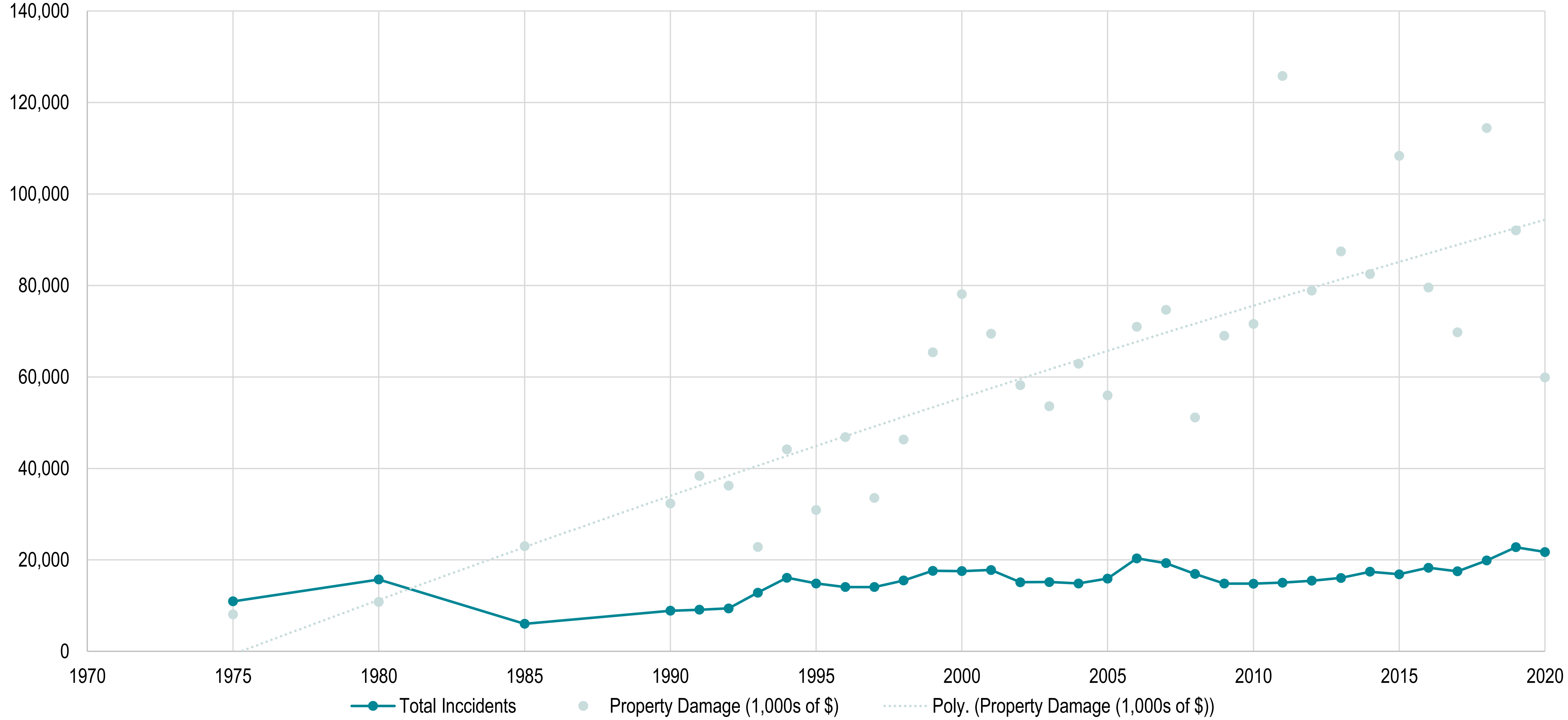
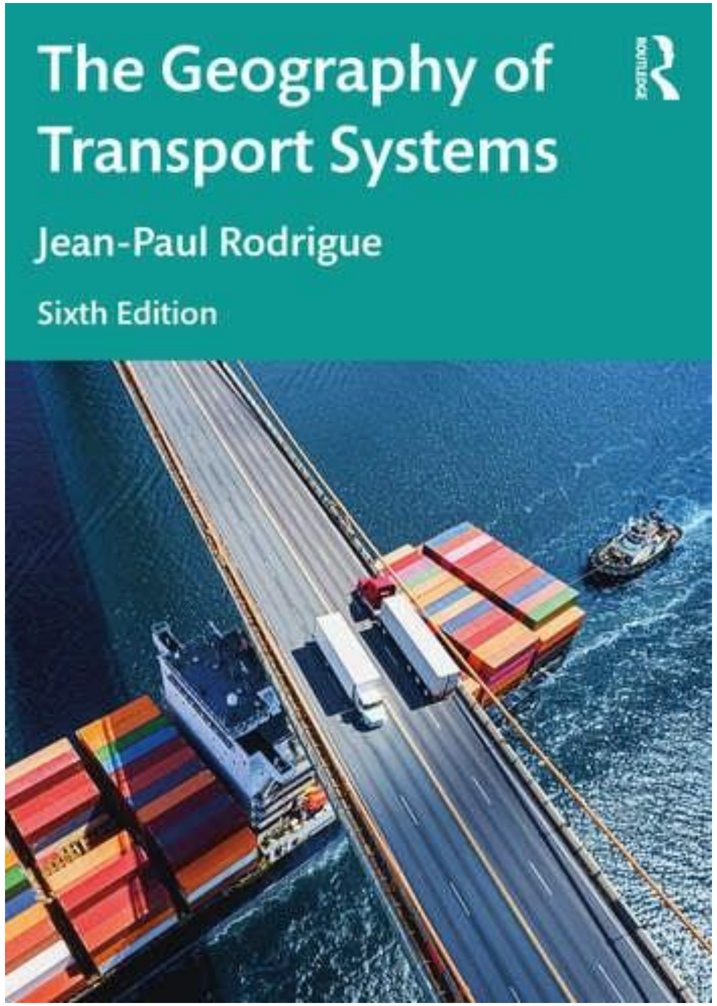


Table 3. Road traffic and networks of social support

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

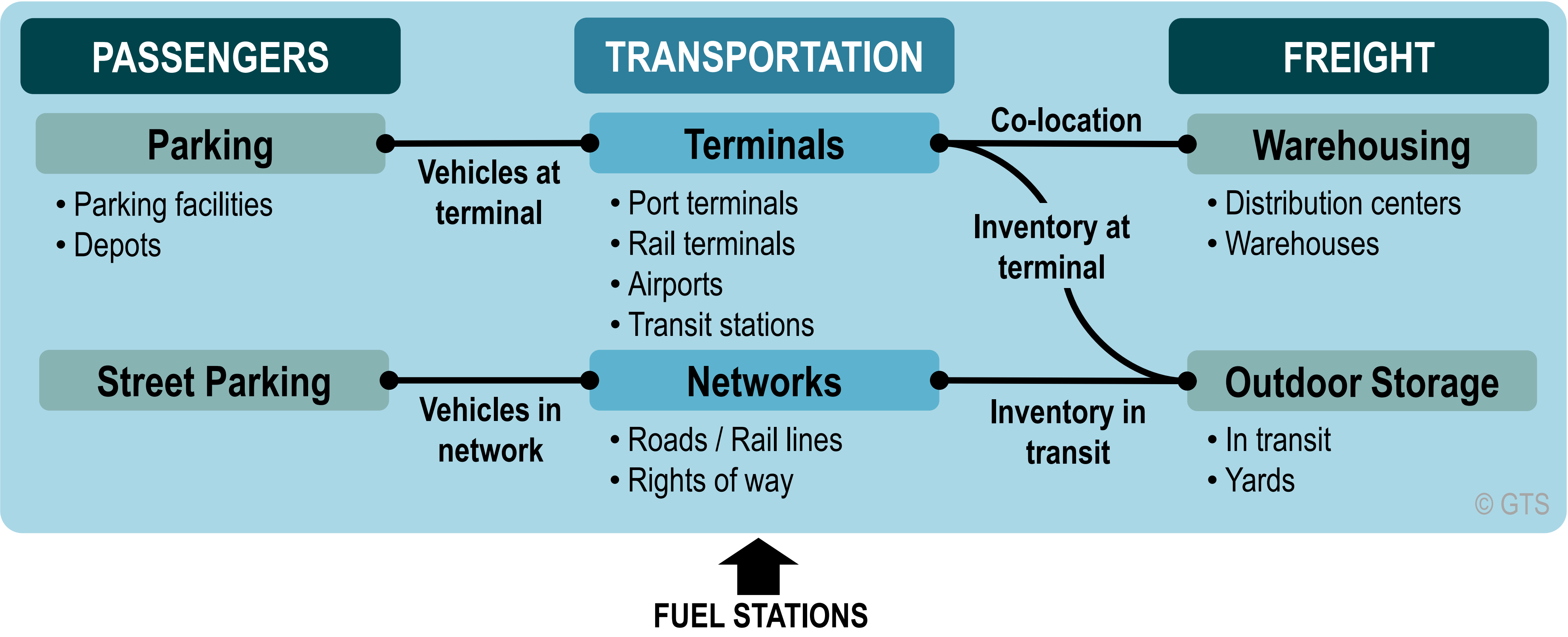
Source: adapted from Appleyard & Lintell *(62)*.



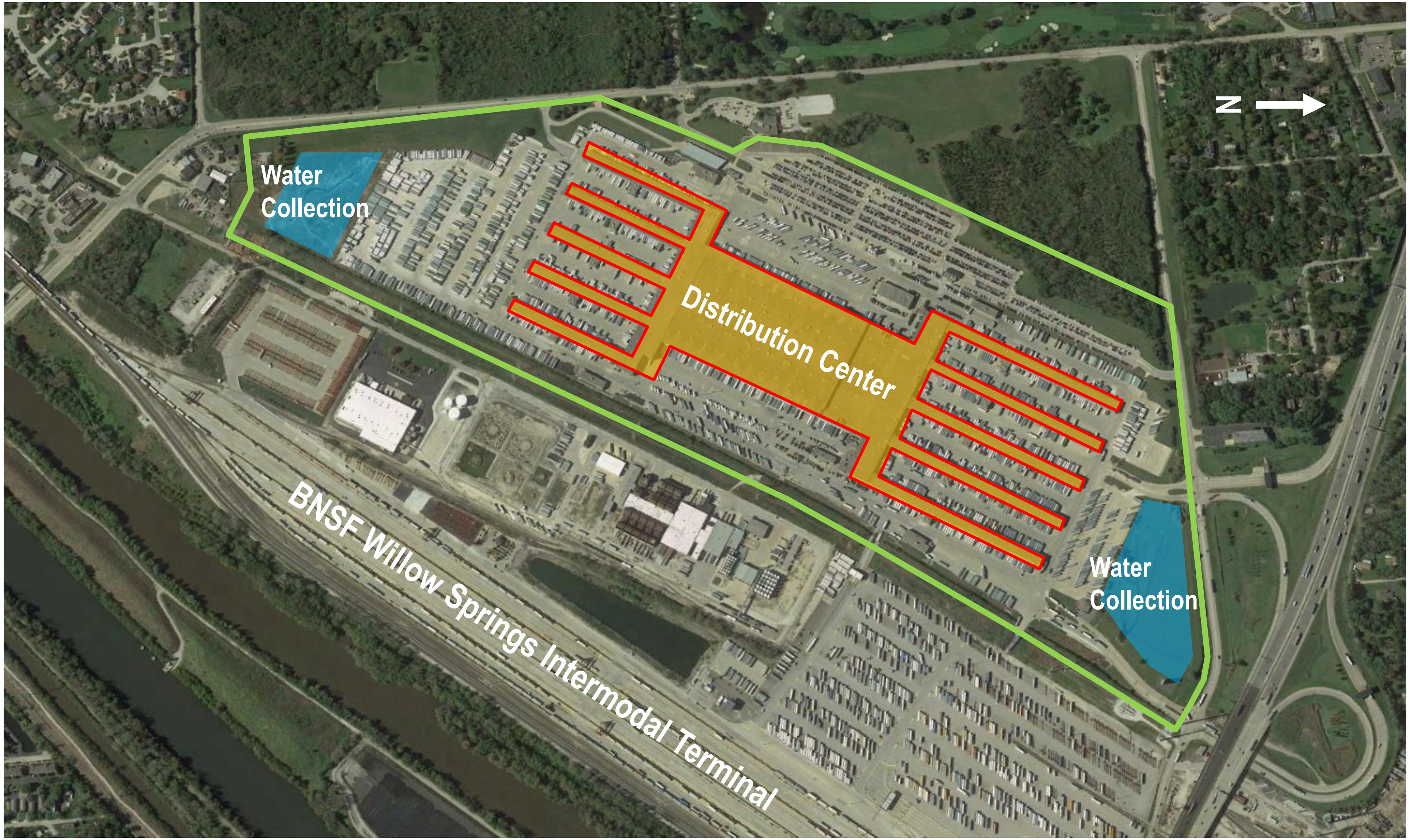
The Environmental Footprint of Transportation

Chapter 4.3

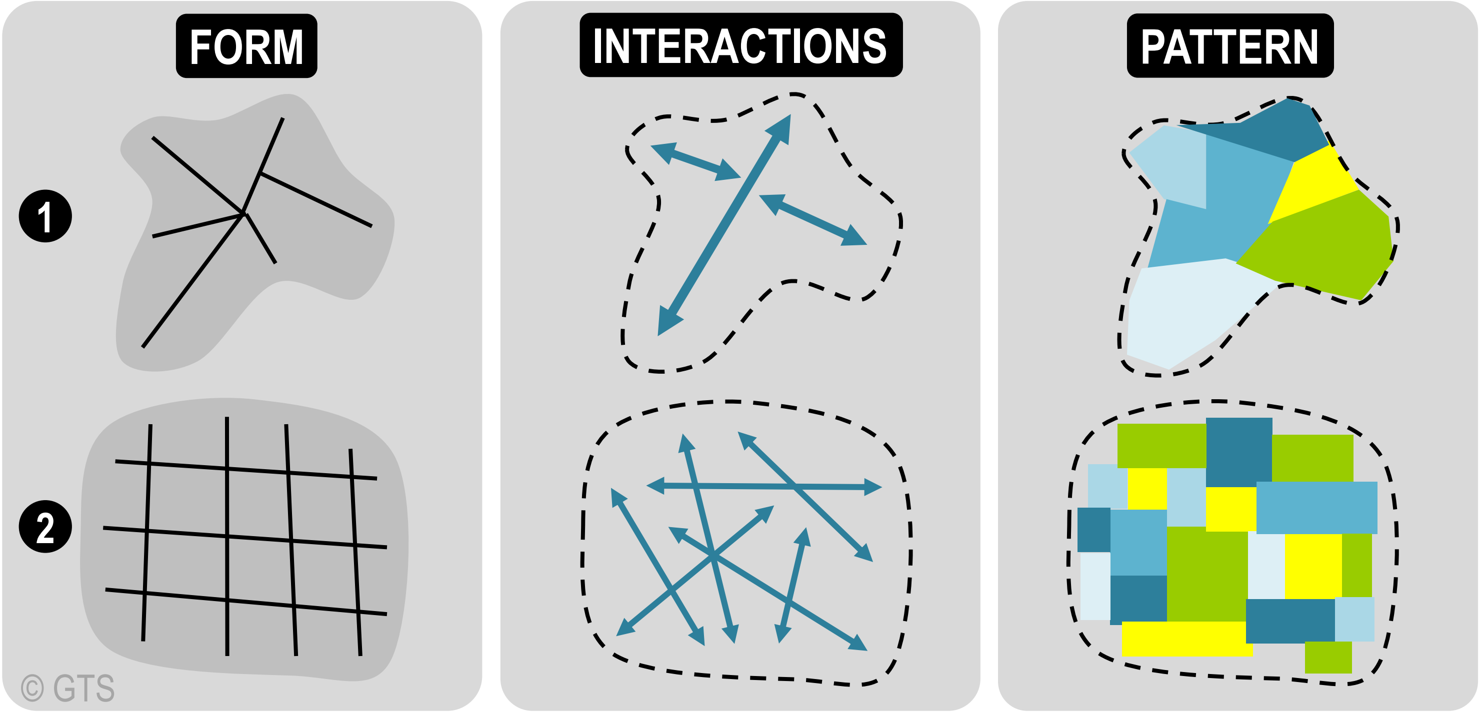
The Footprint of Transportation

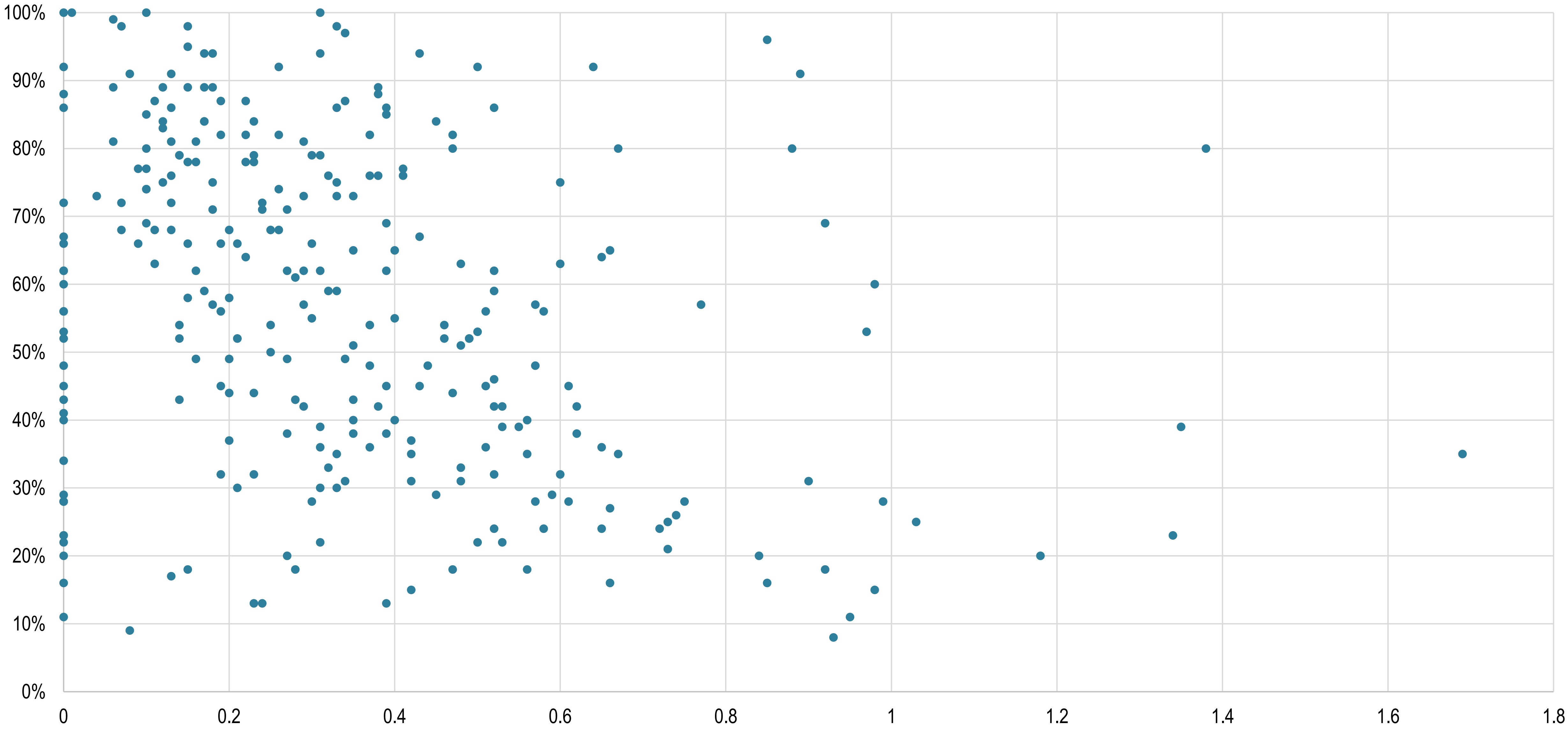


UPS Chicago Area Consolidation Hub

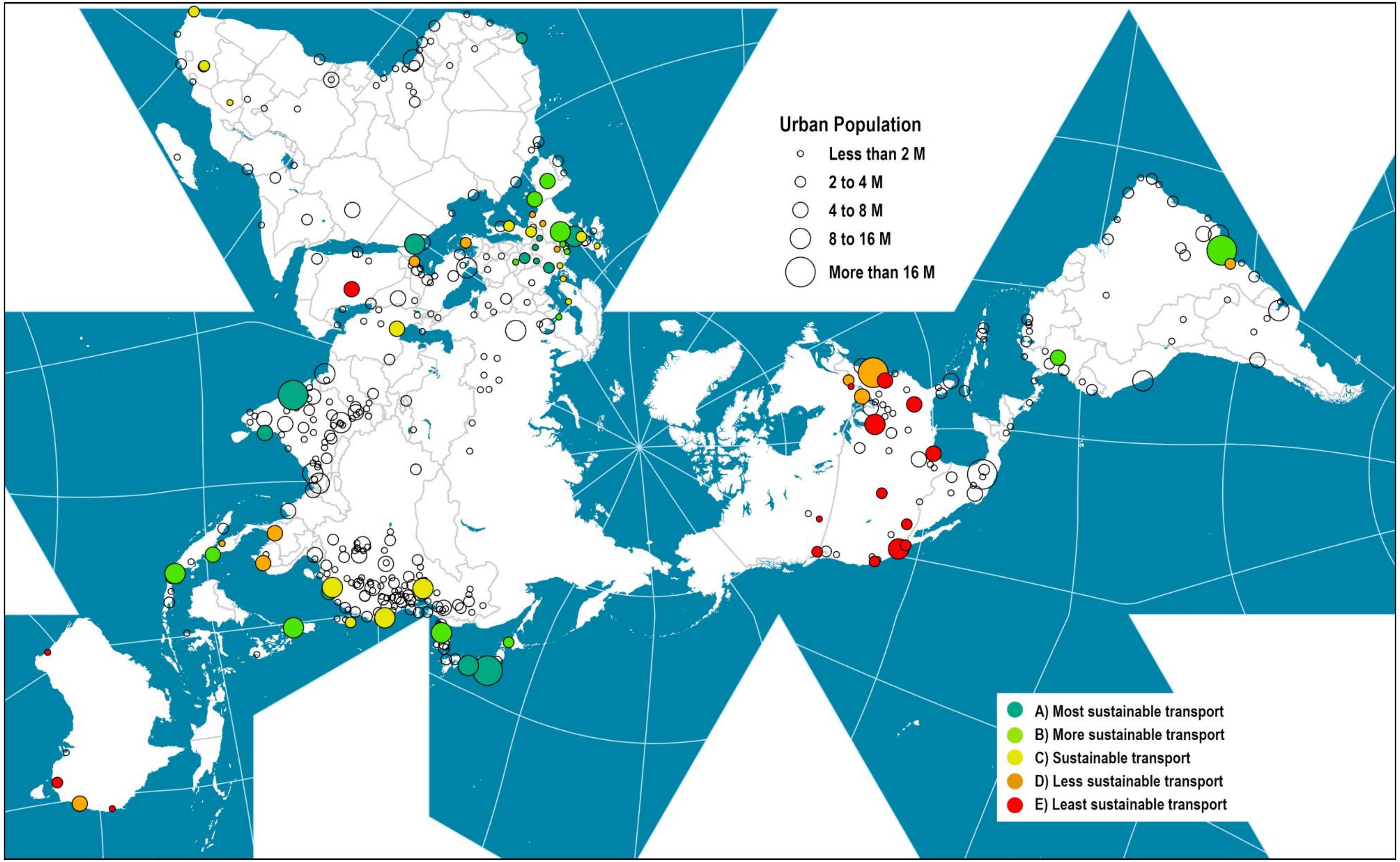


Spatial Form, Pattern and Interaction and the Environmental Impacts of Transportation

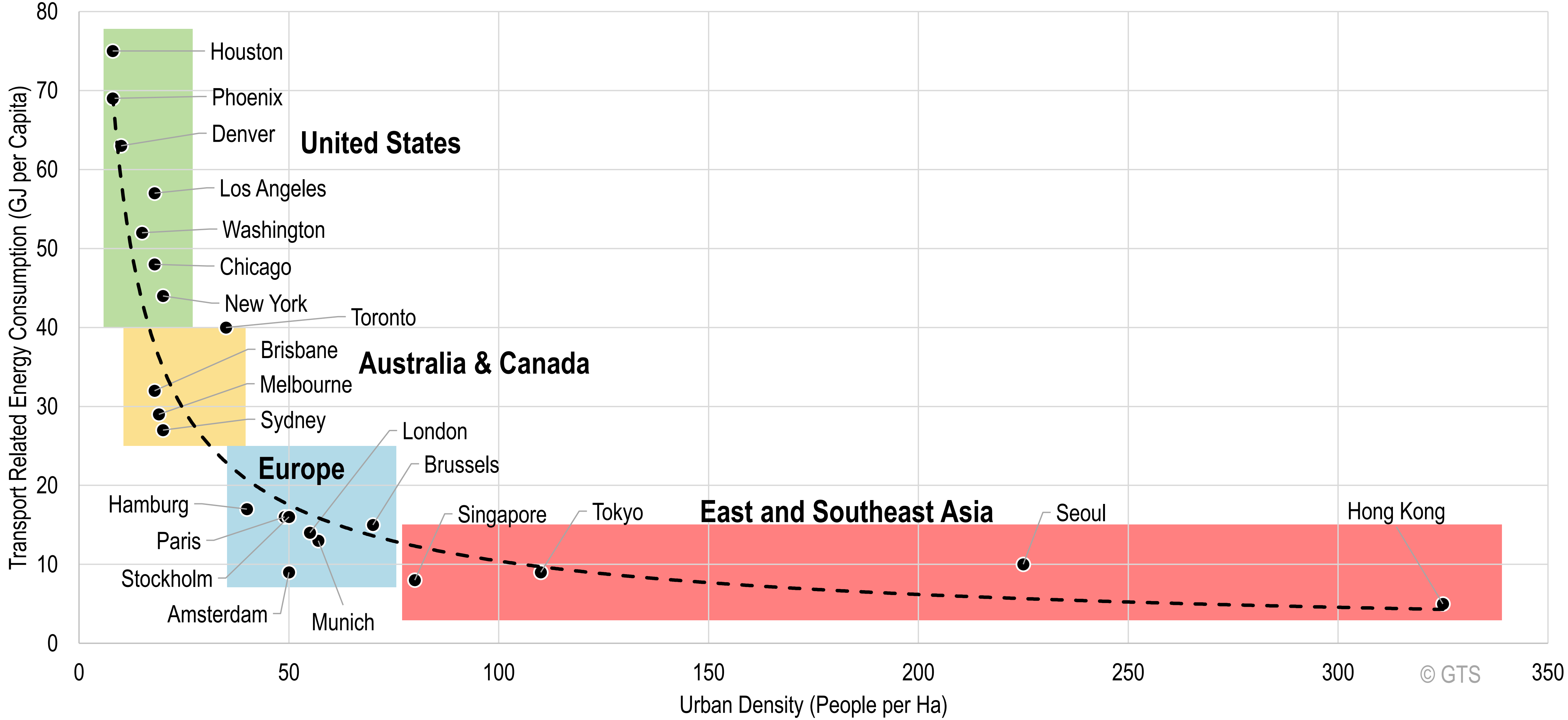



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

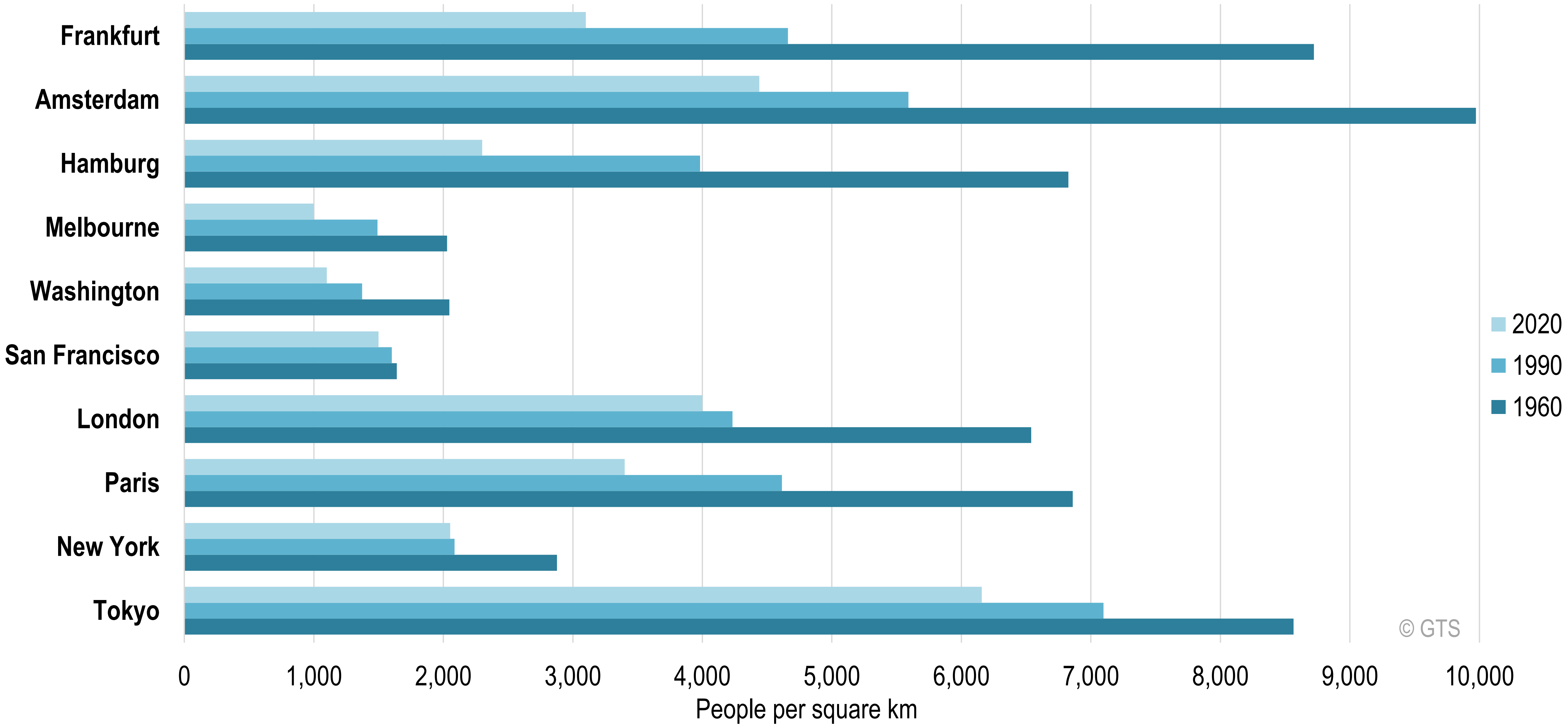
Sustainable Urban Passenger Travel, Selected Cities



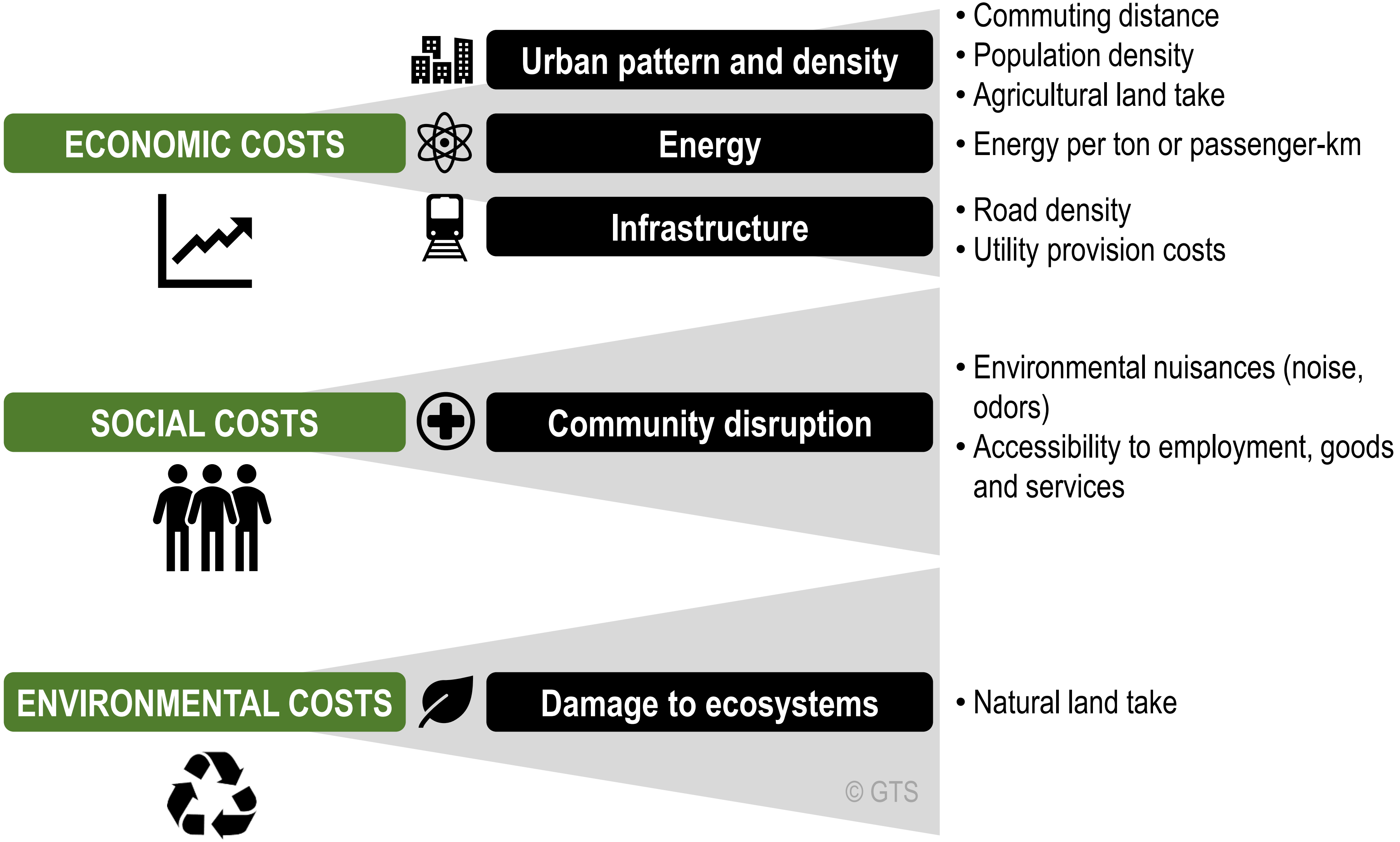
Transport Energy Consumption and Density in Major Metropolitan Areas, 1990

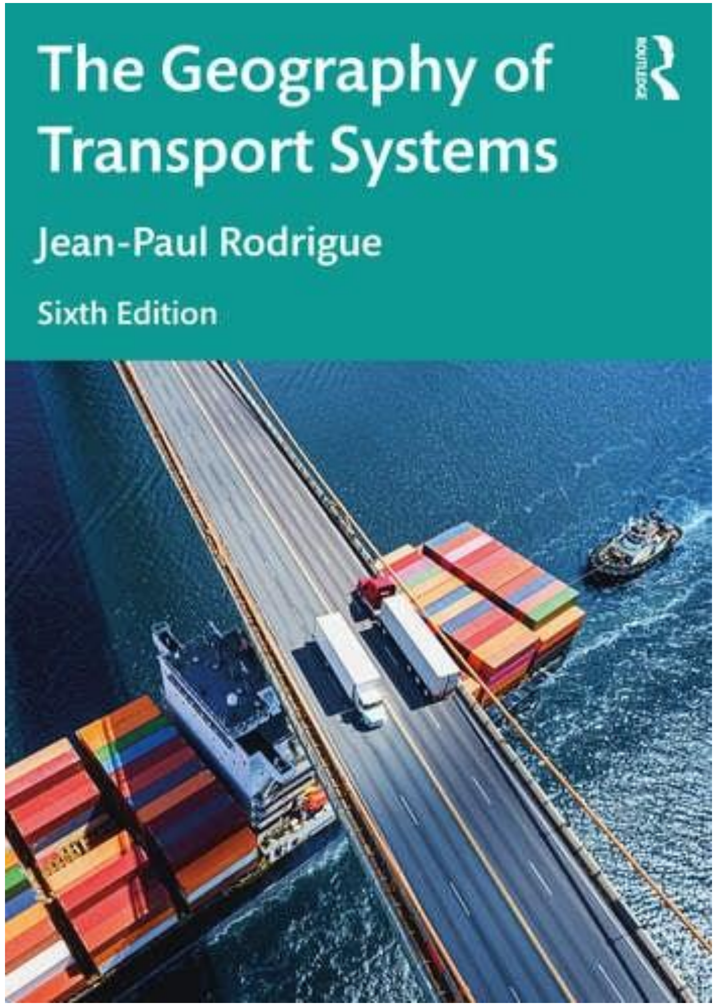


Population Density, Selected Cities, 1960-2020



Environmental Externalities of Land Use

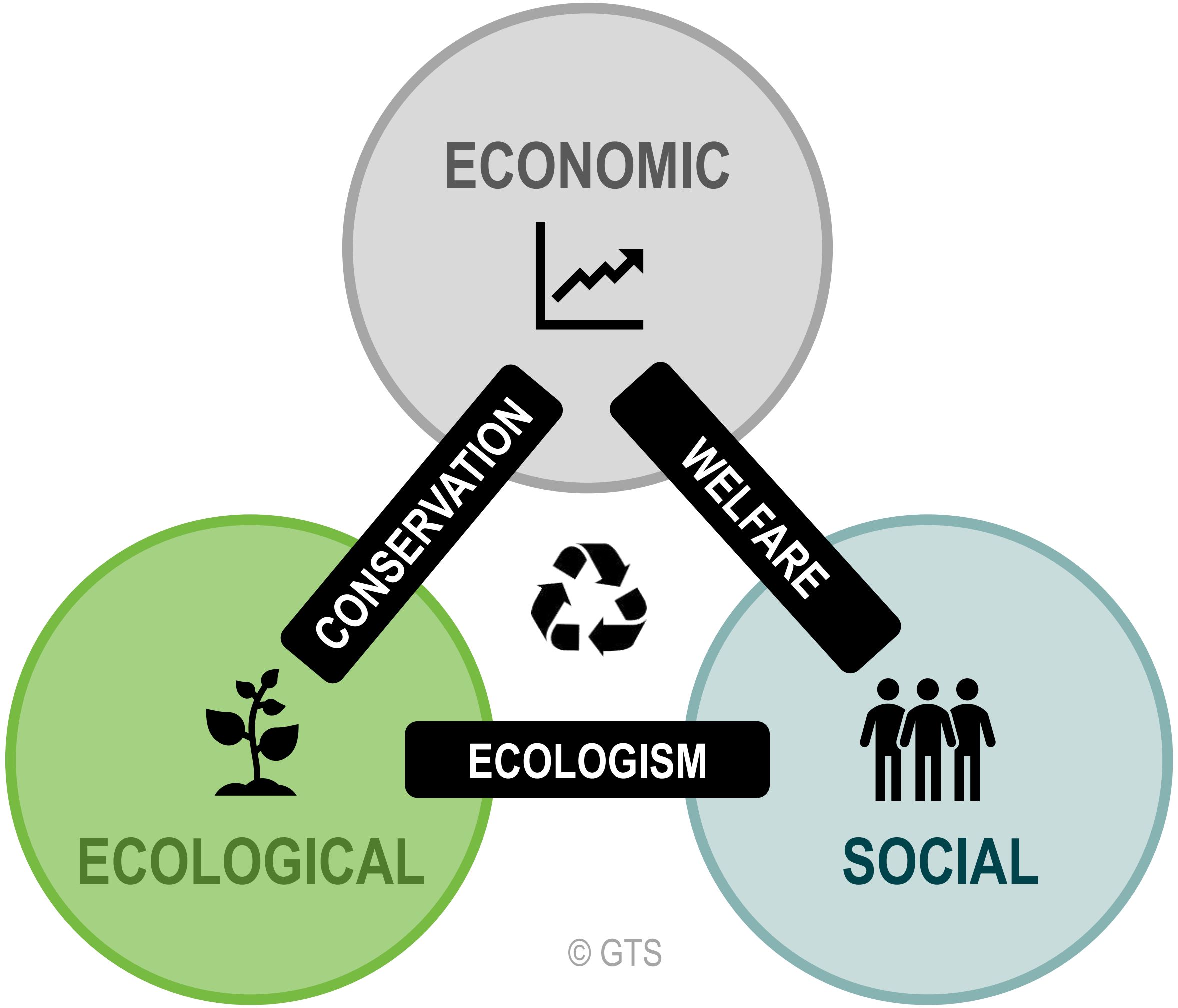




Transportation, Sustainability and Decarbonization

Chapter 4.4

Global Sustainability



Sustainable Development Goals

SUSTAINABLE DEVELOPMENT

SOCIETY

- Welfare
- Equal opportunity
- Social cohesion
- International relations
- Maintenance of human capital

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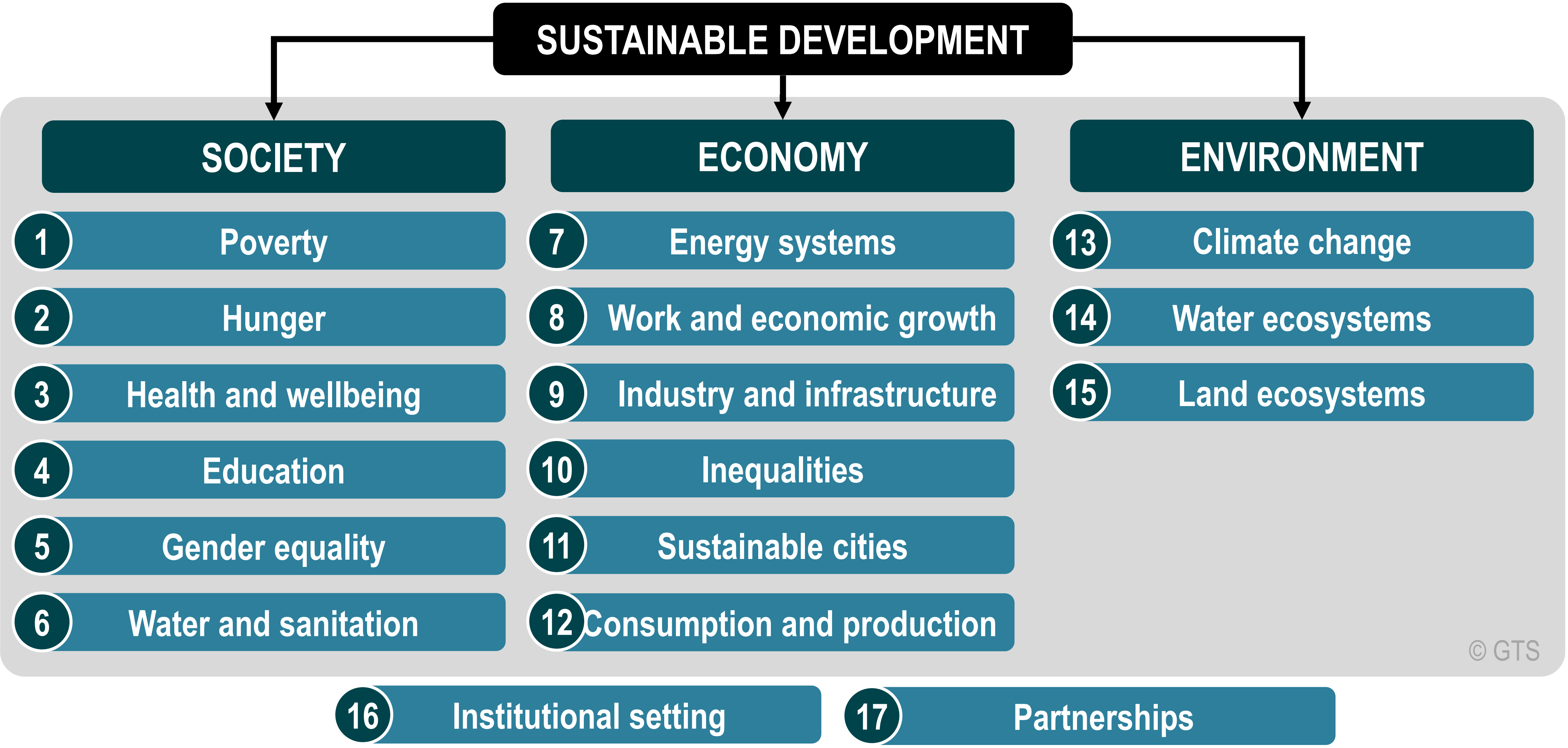
ECONOMY

- Economic growth
- Efficiency and competitiveness
- Flexibility and stability
- Production / consumption
- Employment
- International trade

ENVIRONMENT

- Consumption of resources
- Materials and wastes
- Risks
- Rate of change
- Natural and cultural landscape

Sustainable Development Goals



Environmental, Social and Governance Criteria

GOVERNANCE	PLANET	PEOPLE	PROSPERITY
Governing purpose	Climate change	Dignity and equality	Employment and wealth
Quality of governing body	Nature loss	Health and well-being	Innovation
Stakeholder engagement	Freshwater availability	Skills for the future	Community and social
Ethical behavior			
Risk and opportunity			

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Issues with ESG

EFFECTIVENESS

- Reflective of sustainability?
- Unclear benefits.
- Ideological judgment of value.

FOCUS LOSS

- Diversion of capital and effort.
- Virtue signaling.
- Limited value.

LEGITIMACY

- Ideological capture of rating agencies.
- Overreach in internal corporate decisions.

REPORTING

- Burden of resources for data collection.
- Ticking boxes.
- Results difficult to compare.

VISION

- Divert attention towards compliance.
- Overlook real opportunities.

COMPETITION

- Tool to avoid competition and new entrants.

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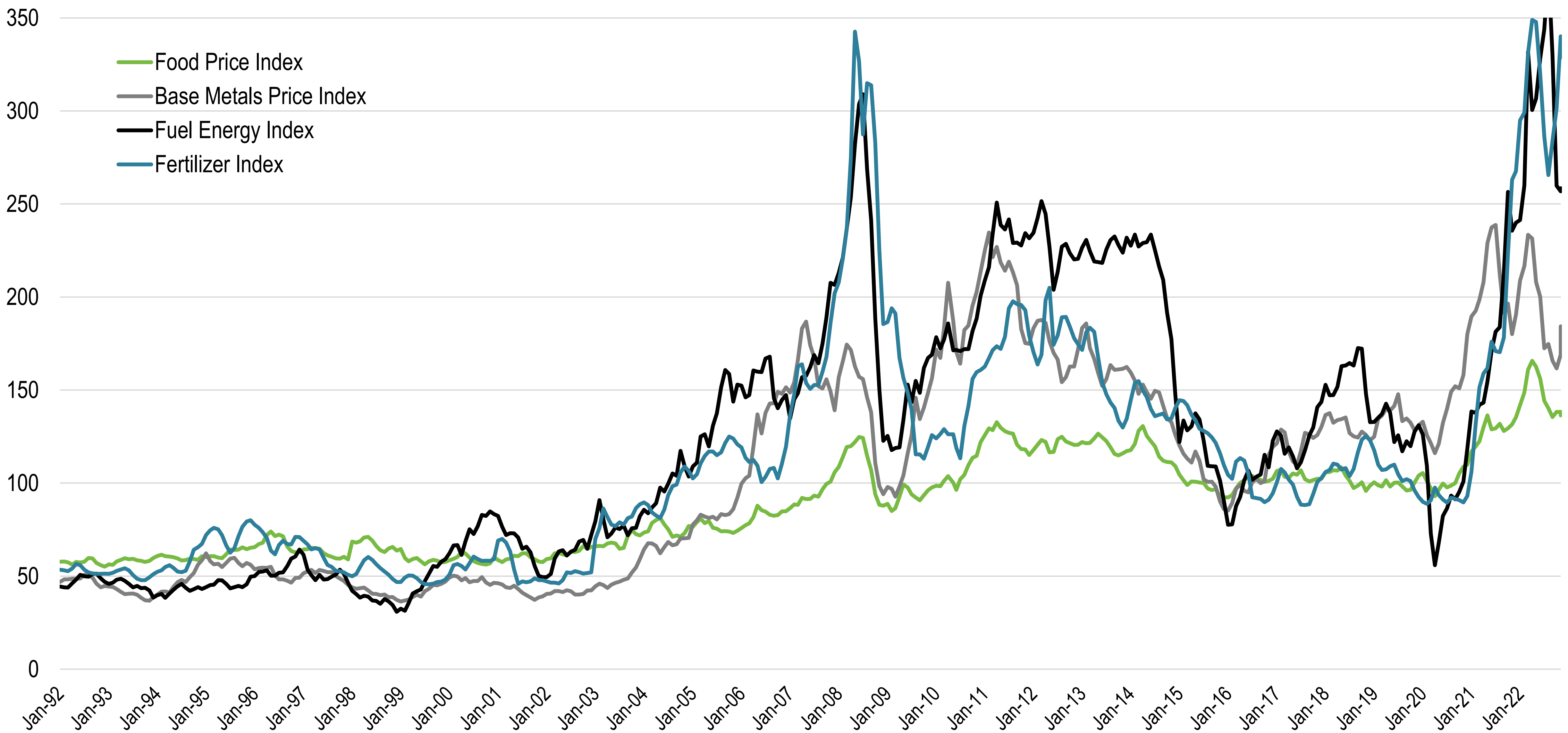
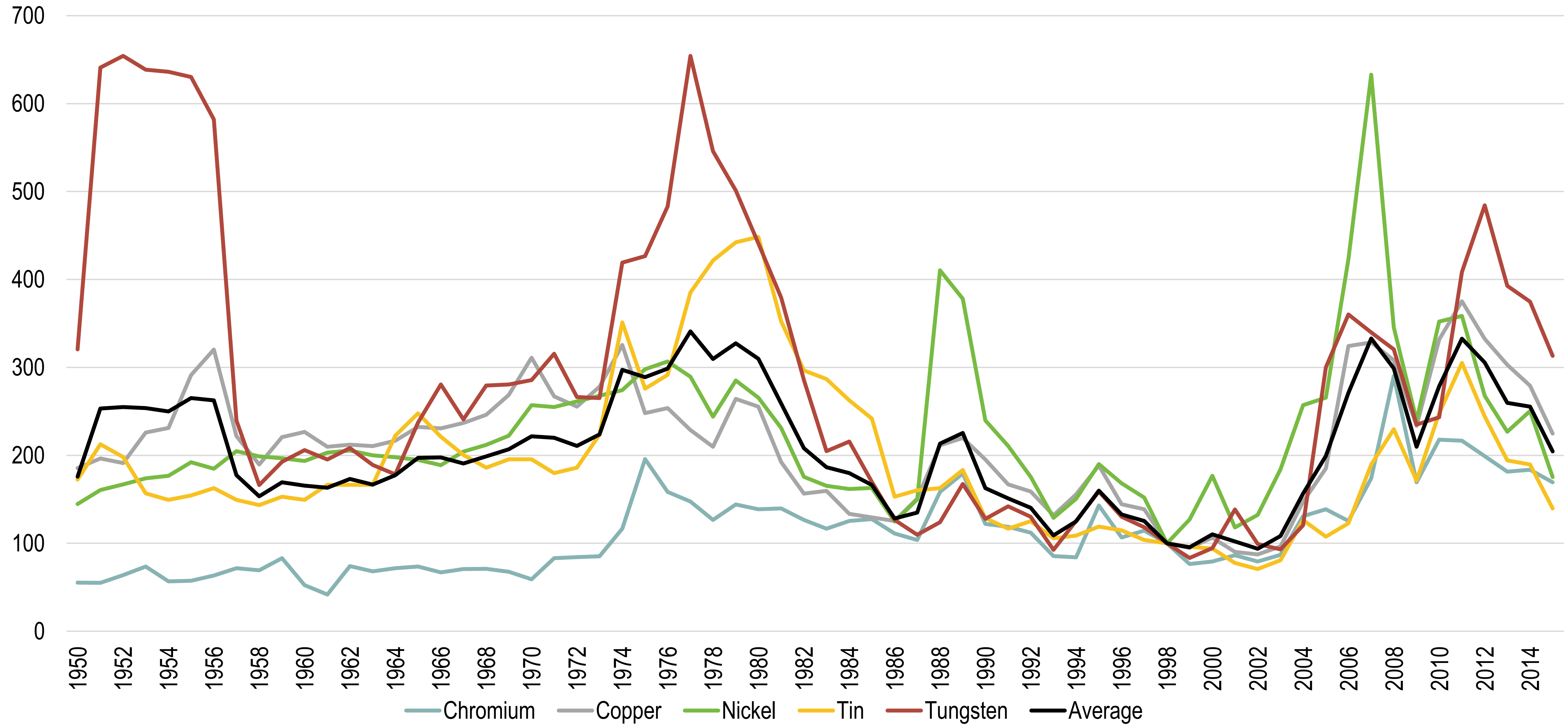
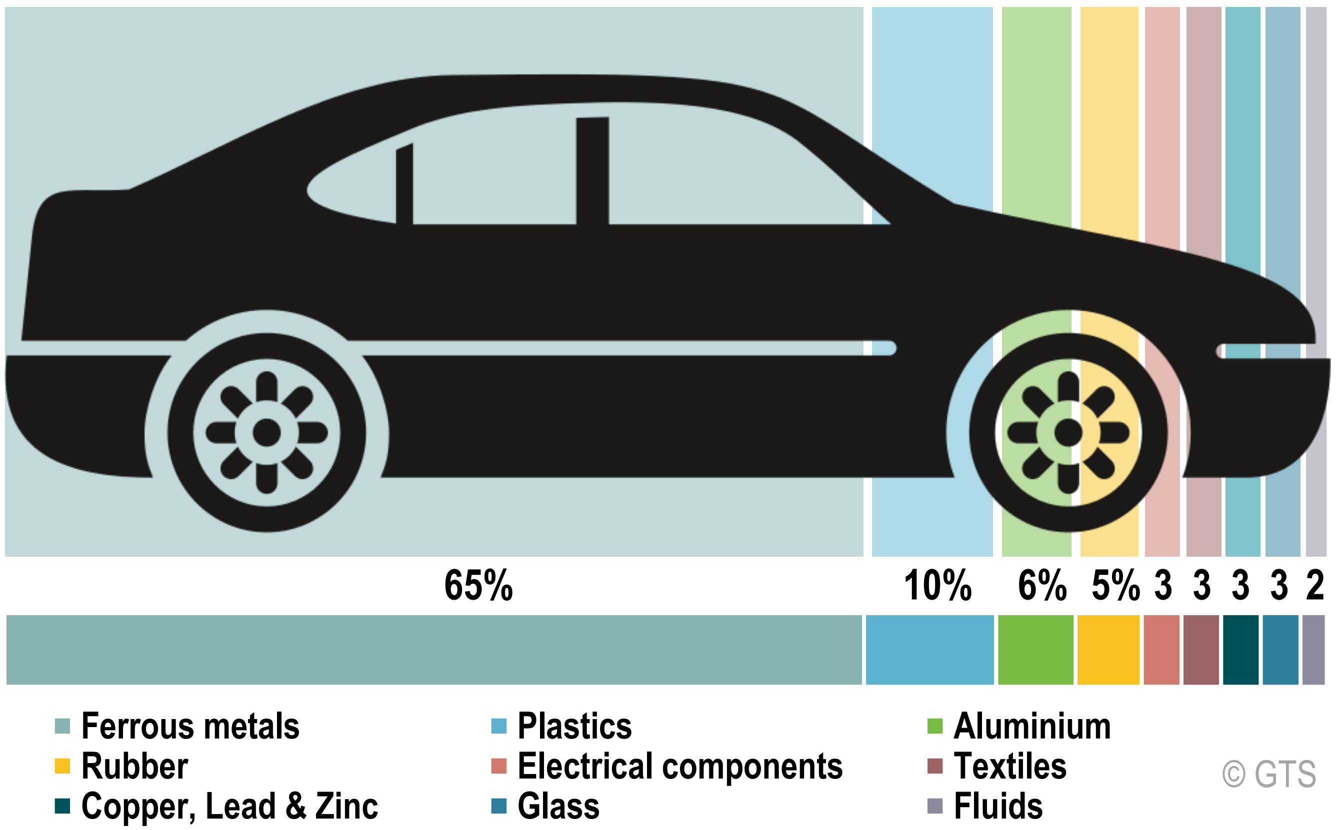
Main Commodity Price Indexes, 1992-2022 (2016=100)



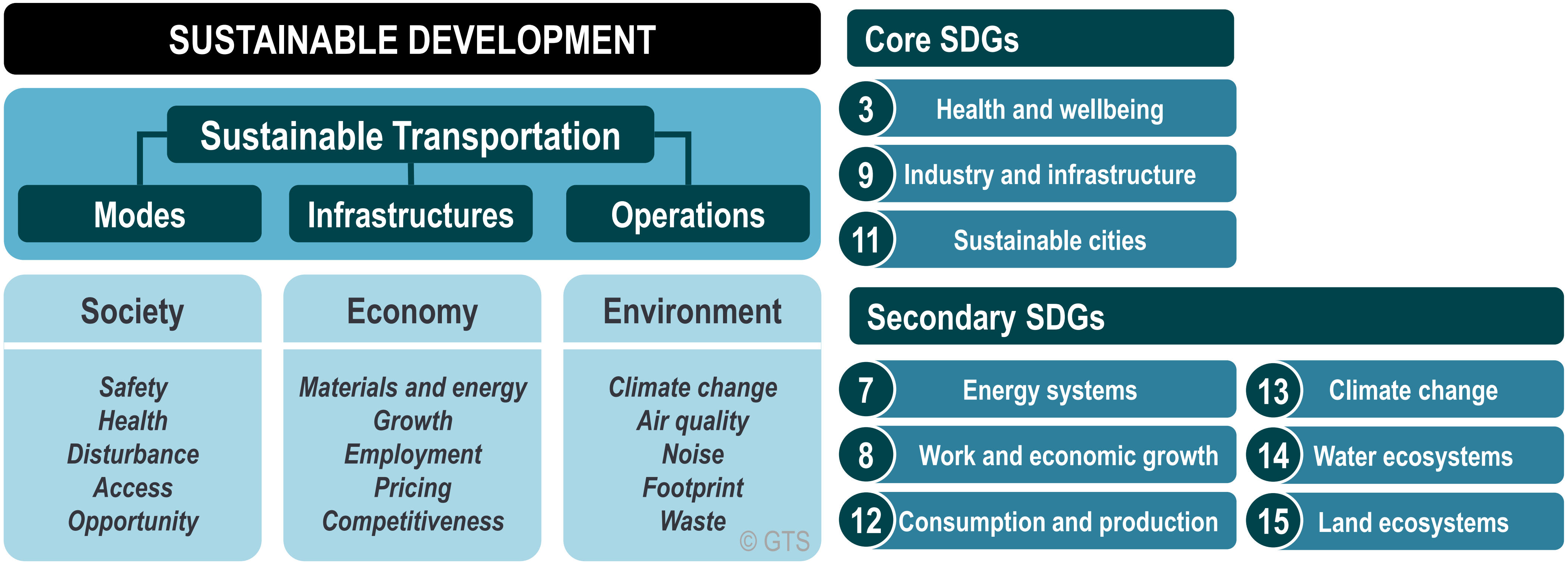
Inflation-Adjusted Price of some Commodities, 1950-2015 (1998=100)



Main Material Components of a Car



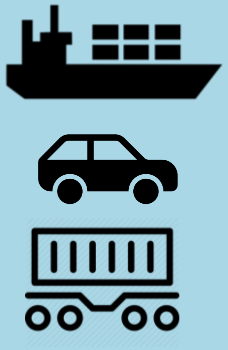
Sustainable Transportation



Sustainability Dimensions in the Transport Industry

Modes

- Manufacturing and disposal



- Water quality
- Air quality
- Noise and odors
- Waste management
- Energy consumption
- Hazardous materials

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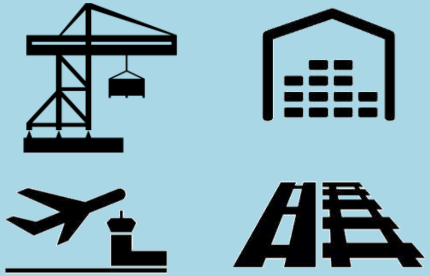
Infrastructures

- Site construction
- Greenfield and brownfield sites



Economic and Social Outcomes of Sustainable Transportation

EQUITY	EFFICIENCY	SAFETY	GREEN
• Access by identity groups (income, age, disability, gender) • Access to employment and opportunities • Access to goods and services • Reduction of transport barriers	• Access to global markets • Improved efficiency in the use of resources • Reduced footprint • Reducing the energy intensity of economic sectors • Increased trade • Regional integration	• Reduction of fatalities and injuries • Reduced risks of vulnerable groups (pedestrians, cyclists, elderly, children) • Reduction of social costs (health, productivity)	• Decarbonization • Better air quality • Lower noise pollution • Resilience to environmental disruptions • Preservation of ecosystems • Reduction of health costs related to the environment

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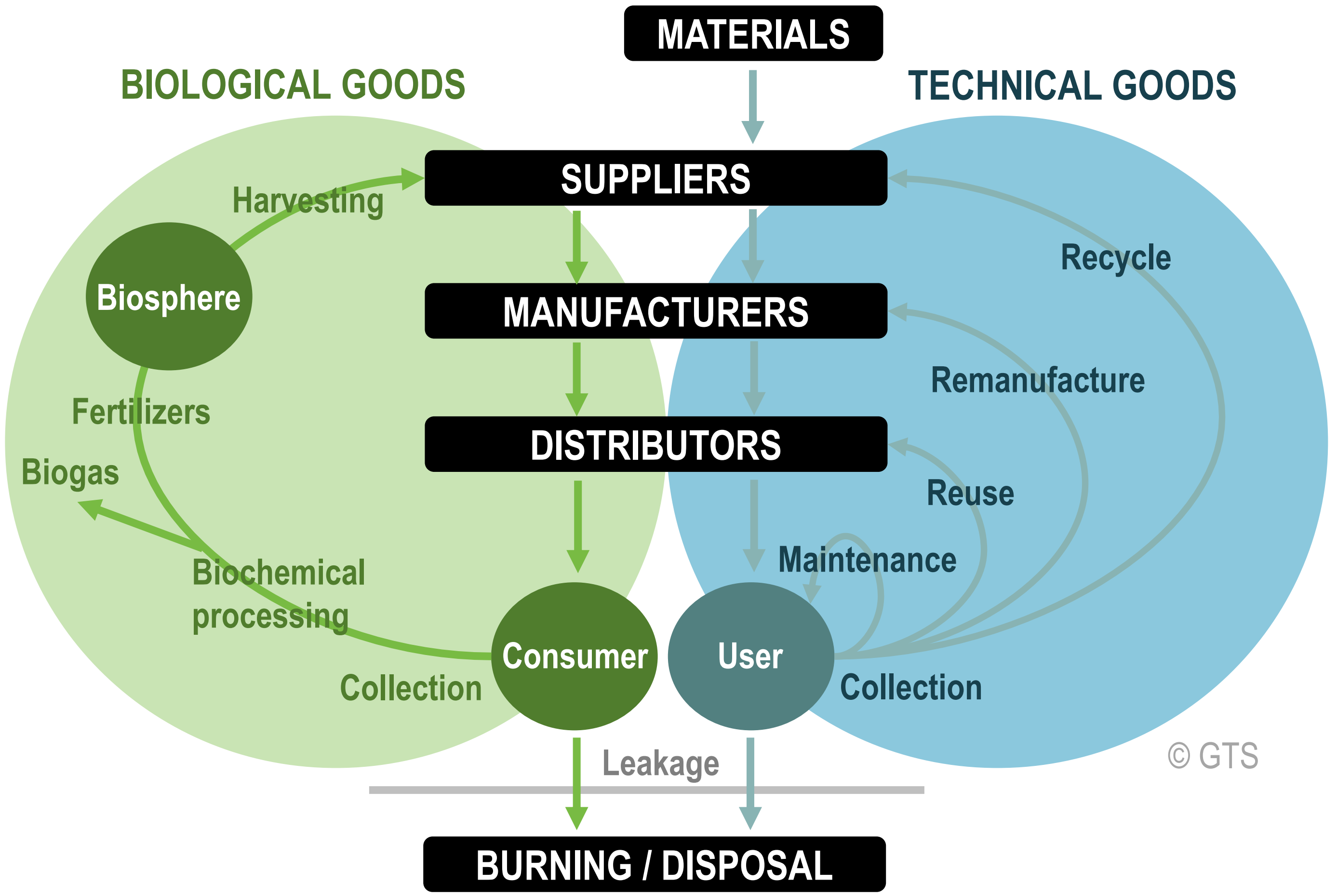
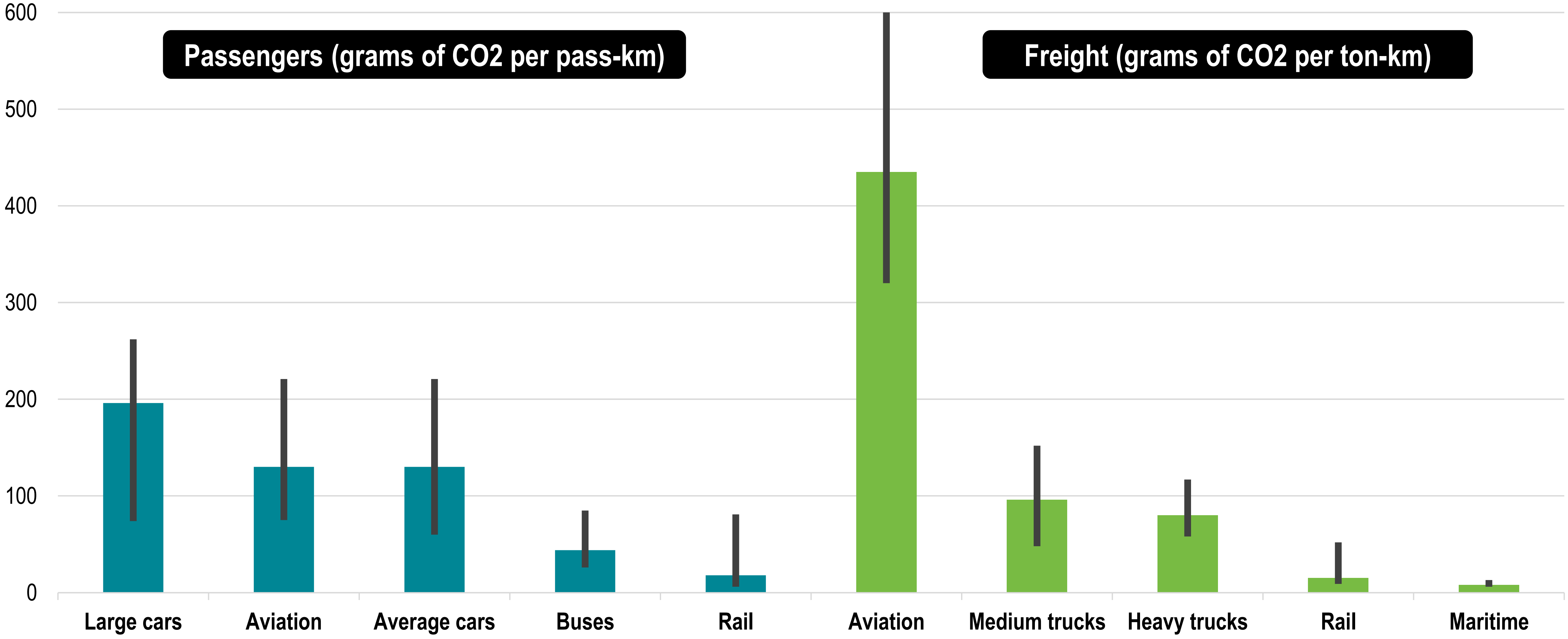
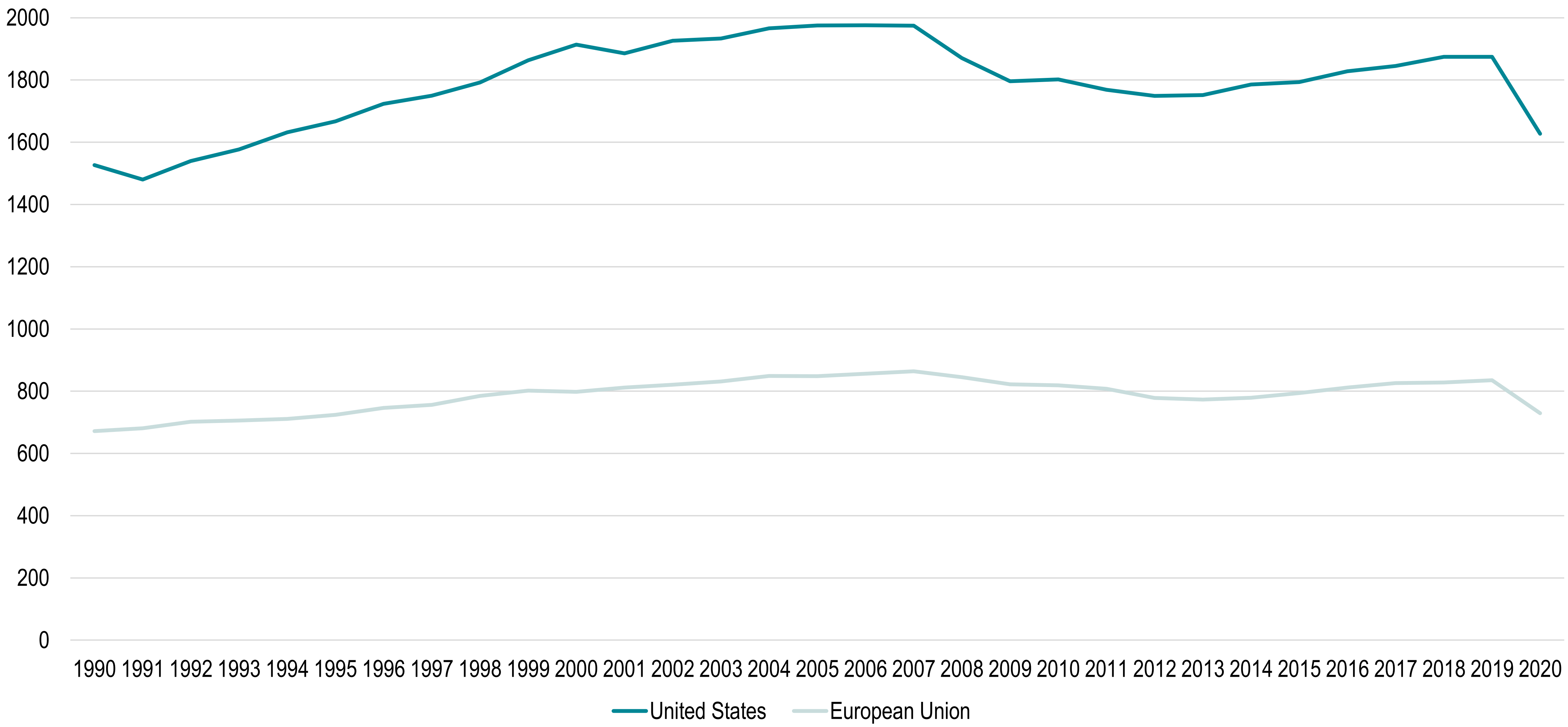
The Circular Economy and Supply Chains



Average CO2 Emissions by Passenger and Freight Transport Mode



Greenhouse Gas Emissions from Transport



General Indicators of Urban Sustainability

URBAN SUSTAINABILITY

- Water, materials and waste
- Energy and air quality
- Transportation and telecommunications
- Land, green spaces and biodiversity
- Livability

The Decarbonization of Transportation

Infrastructure | **Conveyances and Equipment** | **Management and Operations**

Procurement

Rail corridors (passengers & freight)
Public transit systems
Inland waterways
Rail electrification

Intelligent transport systems (digitalization)

Park and ride
Walking and cycling facilities
Shore-based power
Alternative fuel infrastructure

Electric vehicles
Terminal automation

Congestion pricing
Fuel/carbon pricing
Tolls
Vehicle / fuel taxes
Differentiated terminal pricing

Parking regulation
Speed controls
Traffic management
High occupancy vehicles
Vehicle bans
Fuel and energy efficiency standards

Freight platforms
Ride-sharing
Mobility as a service

Economic
Infrastructure
Regulatory
Innovation/IT

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Global Electric Vehicles Sales, 2010-2022