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• 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**
- Chemical
- Nuclear
- Gravitational
- Electromagnetic
- Mechanical
- Thermal
- Electrical

**NON-RENEWABLE**
- Chemical
  - Fossil fuels (Combustion)
- Nuclear
  - Uranium (Fission of atoms)

**RENEWABLE**
- 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
<table>
<thead>
<tr>
<th>Modification of the Environment</th>
<th>Appropriation and Processing</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making space suitable for human activities (20% of electricity in the US used for AC).</td>
<td>Extraction of resources (agricultural products and raw materials).</td>
<td>Movements of freight, people and information.</td>
</tr>
<tr>
<td>Clearing land for agriculture.</td>
<td>Modifying resources (manufacturing).</td>
<td>Attenuate the spatial inequities in the location of resources by overcoming distance.</td>
</tr>
<tr>
<td>Modifying the hydrography (irrigation).</td>
<td>Disposal of wastes (Piling, decontaminating and burning).</td>
<td>Growing share of transportation in the total energy spent.</td>
</tr>
<tr>
<td>Establishing distribution infrastructures (roads).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constructing and conditioning (temperature and light) enclosed structures.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Fuels Production Processes

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

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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

<table>
<thead>
<tr>
<th>Source</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel</td>
<td>Renewable; biodegradable; domestically produced; improved lubricity in engine; reduced air pollutant emissions.</td>
<td>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.</td>
</tr>
<tr>
<td>Ethanol</td>
<td>Renewable; domestically produced; may reduce harmful air pollutants.</td>
<td>Non-renewable fossil fuels are used in its production; slightly decreases fuel economy.</td>
</tr>
<tr>
<td>Natural gas / propane</td>
<td>Reduced air pollutant emissions.</td>
<td>Non-renewable fossil fuel; reduced driving range; limited availability; larger fuel tanks.</td>
</tr>
<tr>
<td>Electricity</td>
<td>Zero tailpipe emissions; widely available.</td>
<td>High vehicle and battery costs; limited range and performance; electricity production mainly from non-renewable sources.</td>
</tr>
<tr>
<td>Hybrid electric</td>
<td>Increased fuel economy and reduced pollution; good range and performance</td>
<td>Primarily fueled with non-renewable fossil fuels.</td>
</tr>
<tr>
<td>Synthetic fuels</td>
<td>Abundant supply exists.</td>
<td>Significant environmental damages from extraction and processing; high carbon emissions; high production costs.</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Zero tailpipe emissions.</td>
<td>Potential use of fossil fuels to produce; high cost of vehicle.</td>
</tr>
</tbody>
</table>
US Coal Exports in Tons, 2000-2016

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

- Oil: 32%
- Coal: 27%
- Natural Gas: 11%
- Renewables: 5%
- Nuclear: 3%
- Hydroelectric: 22%

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Energy End Uses, 2014

- Transport: 34%
- Manufacturing: 14%
- Residential: 19%
- Services: 27%
- Other (agriculture and mining): 6%
Global Energy Systems Transition, (% of market)

The chart illustrates the transition of global energy systems over time, showing the decline in use of Wood, Coal, Oil, and Natural Gas, and the rise of Hydrogen and Gases. The Y-axis represents the percentage of the market, while the X-axis shows the timeline from 1850 to 2150.

Key points:
- **Wood** declined sharply in the early 20th century.
- **Coal** peaked in the late 19th century and has been in decline since.
- **Oil** saw a significant increase in the 20th century, peaking around 2000.
- **Natural Gas** has been gaining market share, particularly after 2000.
- **Hydrogen** is projected to rise significantly in the future, indicating a shift towards sustainable energy sources.

This graph is a representation of the global energy transition, highlighting the shift from traditional solid fuels to cleaner, more sustainable energy sources.
Energy Efficiency by Transportation Mode

![Chart showing energy efficiency by transportation mode. The x-axis represents speed (m/sec) ranging from 10 to 1000, and the y-axis represents unit energy costs (J per kg) ranging from 0.002 to 10. Modes of transportation are categorized by their energy efficiency with symbols for tanker, truck, bus, car, train, cargo plane, jet plane, propeller plane, helicopter, and supersonic plane. The chart indicates that supersonic planes have the highest energy efficiency, followed by cargo planes, and finally, tankers with the lowest efficiency. The chart also shows that energy costs increase with speed for all transportation modes.]
Energy Used by the Road Transportation System

- Vehicle operation: 66%
- Vehicle maintenance: 5%
- Vehicle manufacture: 7%
- Infrastructure provision: 17%
- Raw material manufacture: 1%
- Energy generation: 4%
Energy Use Factors by Transportation

- **Vehicle**
  - Vehicle efficiency
  - Engine and fuel type

- **Infrastructure**
  - Capacity
  - Level of service

- **Demand**
  - Level of economic activity
  - Price of fuel

- **Spatial Structure**
  - Distribution of activities
Distance Travelled for One Ton of Cargo Using 1 kWh of Energy

- Post-Sovereign Class Containership
- Sovereign Class Containership (8,000 TEU)
- Rail (Electric)
- Rail (Diesel)
- Heavy Truck
- Boeing 747-400

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Energy Efficiency of Selected Passenger and Freight Modes

Passengers

- Air
- Car
- Bus
- Commuter Rail
- High Speed Rail

Passenger-km per kwh

Freight

- Boeing 747-400
- Heavy Truck
- Rail (Diesel)
- Rail (Electric)
- 8,000 TEU Containership
- 14,000 TEU Containership

Ton-km per kWh

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# Energy Efficiency of Main Passenger Transportation Modes

<table>
<thead>
<tr>
<th>Passenger Travel by</th>
<th>Fuel</th>
<th>Rate of fuel use MJ / passenger-km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal vehicle (ICE)</td>
<td>Gasoline</td>
<td>2.6</td>
</tr>
<tr>
<td>Local bus (ICE)</td>
<td>Diesel</td>
<td>2.8</td>
</tr>
<tr>
<td>Electric bus, light rail, subway</td>
<td>Electricity</td>
<td>0.6</td>
</tr>
<tr>
<td>Intercity bus (ICE)</td>
<td>Diesel</td>
<td>0.7</td>
</tr>
<tr>
<td>Intercity rail (diesel - electric)</td>
<td>Diesel</td>
<td>0.9</td>
</tr>
<tr>
<td>Intercity rail (electric)</td>
<td>Electricity</td>
<td>0.2</td>
</tr>
<tr>
<td>High-speed rail (electric)</td>
<td>Electricity</td>
<td>0.3</td>
</tr>
<tr>
<td>Aircraft (domestic)</td>
<td>Kerosene</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Marine</td>
<td>Aviation</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td><strong>Type of fuel</strong></td>
<td>Low quality (bunker oil)</td>
<td>High quality (jet fuel)</td>
</tr>
<tr>
<td><strong>Share of energy consumption</strong></td>
<td>2%</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Market size (year)</strong></td>
<td>150 M metric tons</td>
<td>190 M metric tons</td>
</tr>
<tr>
<td><strong>Percentage of operating costs</strong></td>
<td>40%</td>
<td>25%</td>
</tr>
</tbody>
</table>
Technical Approaches to Reducing Car Energy Use & GHG Emissions

Improvement Required

- Better Transmission Efficiency
- Better Powertrain Efficiency
- Better Engine Efficiency
- Reduced Air Intake to cool Engine
- Reduced Air Resistance
- Reduced Rolling Resistance
- Reduced Energy Need for Acceleration
- Weight Reduction

Technical Approach

- Reduced Friction
- Optimized Match Between Speed and Load
- Better Combustion Efficiency
- Improved Thermodynamic Efficiency of Engine Cycle
- Drag Reduction
- Reduced Rolling Resistance Coefficient
- Improved Rolling Resistance Coefficient

Low Friction Materials and Lubricants
Automatic Transmission More Gear Ratios Continuously Variable Transmission
Improved Air/Fuel Mixture
Improved Combustion Chamber Design
Compressed/Cooled Intake Air
Higher Compression & Expansion Ratios
Energy Recovery from Exhaust
Reduced Pressure Drop in Catalytic Converter
Reduced Protuberances
Aerodynamic Body Shape
Improved Tire Design e.g. Radial vs. Crossplay
Hire tire pressure
Stronger and more elastic Tire materials
Lighter Materials
Construction/Joining Techniques
Energy Consumption by Sector, OECD Countries

- **2016**
  - Industry: 21.7%
  - Transport: 33.7%
  - Residential: 18.6%
  - Commerce and Public Services: 13.4%
  - Non-Energy Use: 10.0%
  - Other: 2.0%

- **2010**
  - Industry: 21.8%
  - Transport: 32.2%
  - Residential: 20.2%
  - Commerce and Public Services: 13.2%
  - Non-Energy Use: 9.9%
  - Other: 2.1%

- **2000**
  - Industry: 25.1%
  - Transport: 31.5%
  - Residential: 19.2%
  - Commerce and Public Services: 11.7%
  - Non-Energy Use: 10.3%
  - Other: 2.1%

- **1990**
  - Industry: 26.9%
  - Transport: 30.2%
  - Residential: 19.3%
  - Commerce and Public Services: 11.0%
  - Non-Energy Use: 9.4%
  - Other: 2.2%

- **1980**
  - Industry: 32.3%
  - Transport: 26.5%
  - Residential: 18.8%
  - Commerce and Public Services: 10.0%
  - Non-Energy Use: 8.3%
  - Other: 2.1%

- **1971**
  - Industry: 34.3%
  - Transport: 24.2%
  - Residential: 20.4%
  - Commerce and Public Services: 10.1%
  - Non-Energy Use: 7.1%
  - Other: 2.0%

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World Annual Oil Production (1900-2020) and Peak Oil (2005-2020)
Major Crude Oil Reserves, 2000-2018 (Thousand Million Barrels)

- Venezuela: 303.3
- Saudi Arabia: 297.7
- Canada: 167.8
- Iran: 155.6
- Iraq: 147.2
- Libya: 106.2
- United Arab Emirates: 97.8
- Russia: 101.5
- Kazakhstan: 61.2
- Nigeria: 48.4
- Kuwait: 37.5
- Algeria: 25.2
- China: 25.9
- Angola: 12.2
- Brazil: 13.4
- Norway: 8.6
- Mexico: 7.7

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

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

- Passenger cars
- Buses
- Light trucks
- Heavy trucks

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Average Gasoline Consumption for New Vehicles, United States, 1972-2014 (in miles per gallon)
Change in Average Vehicle Characteristics, 1981-2003 (in %)

- Acceleration
- Horsepower
- Weight
- Fuel Economy
Automobile Emission Factors

Emissions (grams) vs. % of Vehicle-km

- HC
- CO
- NOx

Speed (in km/hr)

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

West Texas Intermediate, Monthly Nominal Spot Oil Price
YOY Change in Vehicle-Miles Traveled

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Gasoline Price and Fuel Consumption, Western Industrial Countries, 1994
Gas Consumption Tax in the United States, 1999 (in $ per mile per gallon per vehicle)
Fuel Consumption by Ship Category, 2007

- Crude Oil Tankers: 15%
- Tankers: 12%
- Bulk Carriers: 11%
- General Cargo: 19%
- Container: 25%
- Vehicle/RoRo: 13%
- Passenger: 5%
## Potential to Reduce Energy Consumption in Air and Maritime Transportation

<table>
<thead>
<tr>
<th>Sector</th>
<th>Category</th>
<th>Measure</th>
<th>Potential Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aviation</td>
<td>Operations</td>
<td>Advanced communications, navigation and surveillance (CNS) and air traffic management (ATM)</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Airframe Design and Propulsion</td>
<td>More efficient turbofan engines, Unducted fan engines, Advanced lightweight materials, Improved aerodynamics, New airframe designs</td>
<td>30%</td>
</tr>
<tr>
<td>Marine</td>
<td>Operations</td>
<td>Speed reduction, Optimized routing, Reduced port time</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>Ship Design and Propulsion</td>
<td>Novel hull coatings and propellers, Fuel efficiency optimization, Combined cycle operation, Multiple engines</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>Alternative Fuels and Power</td>
<td>Marine diesel oil (MDO), Liquefied natural gas (LNG), Wind power sails</td>
<td>40%</td>
</tr>
</tbody>
</table>
Potential Impacts of High Energy Prices on Transportation

Usage level

Price

P

Q

Modal shift

Price

A/B

Q(A/B)

Usage level

Cost

Range

B

R(B)

A

1

2

Service area changes

Gateway / Hub selection

Network configuration

Supply chain propagation

Raw Materials

Manufacturing

Distribution Centers

Retailers

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Transportation and the Environment

Chapter 4.2
The Paradox of Mobility and its Costs

Mobility
- Demand
- Footprint
- Energy

Costs
- User Costs
- Societal Costs
  - Externalities
- Environmental Costs

Paradox
## Environmental Costs Hierarchy

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

 BIOSPHERE

 ATMOSPHERE

 ECOSPHERE

 HYDROSPHERE

 LITHOSPHERE
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

- External cost: 32%
- Internal fixed costs: 24%
- Internal variable costs: 44%
Average Cost of Owning and Operating an Automobile, 1975-2018
Transportation Activities Affecting the Environment

<table>
<thead>
<tr>
<th>Activity</th>
<th>Mode</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>Maritime</td>
<td>Passengers</td>
</tr>
<tr>
<td>Vehicle manufacture</td>
<td>Rail</td>
<td>Freight</td>
</tr>
<tr>
<td>Vehicle operation</td>
<td>Road</td>
<td></td>
</tr>
<tr>
<td>Vehicle maintenance</td>
<td>Air</td>
<td></td>
</tr>
<tr>
<td>Vehicle disposal / recycling</td>
<td>Station/yard</td>
<td></td>
</tr>
</tbody>
</table>
Spatial and Durational Environmental Effects of Selected Environmental Externalities

- **Space**
- **Duration**
- **Noise**
- **Lead**
- **Particulates**
- **NOX**
- **CO2**

**Categories**:
- Local
- Regional
- Global
Localized emissions
Energy efficient

Diffused emissions
High energy use

Nature of emissions
Nature of energy consumption

Point source of emissions
Level of emissions
Level of energy consumption

Traffic
Mode

Centralized Network
Diffused Network
World CO2 Emission by Economic Sector, 2011

- Electricity and heat production: 42%
- Manufacturing and Construction: 21%
- Transport: 22%
- Residential: 9%
- Other: 6%

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Global Greenhouse Gas Emissions by the Transportation Sector

**CO2 Emissions by Economic Sector**

- Electricity and heat production: 42%
- Manufacturing and Construction: 21%
- Transport: 22%
- Residential: 9%
- Other: 6%

**CO2 Emissions by the Transport Sector**

- Automobiles: 40%
- Trucks: 11%
- Aviation: 11%
- Marine: 11%
- Railways: 4%
Top 10 CO2 Emitting Sources, 2014 (in % of total emissions)

- Passenger cars: 19%
- Freight road: 9%
- Residential heating: 8%
- Residential appliances: 7%
- Basic metals: 6%
- Chemicals: 5%
- Mining: 4%
- Service space heating: 3%
- Residential water heating: 3%
- Other: 36%
## Major Oil Spills Since 1967

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

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The Concept of Externalities

![Graph showing the concept of externalities]

- **Level of intervention**
- **Total costs**
- **Intervention costs**
- **Optimal cost**
- **Externalities**

### Key Points
- The graph illustrates the relationship between the level of intervention and total costs, as well as intervention costs, to find the optimal level of intervention.

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<table>
<thead>
<tr>
<th>Category</th>
<th>Environmental Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supra and infrastructure</td>
<td>Vehicle emissions; CO2 (30%), CO (70-90%), SO2 (5%), NOx (45-50%),</td>
</tr>
<tr>
<td></td>
<td>HC/VOC (40-50%), Particulates (25%), O3 (indirect), Smog (indirect), Acid rain</td>
</tr>
<tr>
<td></td>
<td>(10-30%), CFCs (20%), Lead (30%)</td>
</tr>
<tr>
<td>Labor Productivity</td>
<td>Air pollution fallouts, Marine vessels discharges and spills, De-icing of infrastructure, Runoffs, Construction and maintenance of infrastructure, Dredging (80%)</td>
</tr>
<tr>
<td>Agricultural Productivity</td>
<td>Marine vessels spills, Accidental and intentional releases (Hazmat); Road (84%), Rail (12%), Air (3%) and Maritime (1%)</td>
</tr>
<tr>
<td>Commercial fishing</td>
<td>Vehicle emissions; Road (70%), Rail (10%) and Air (20%)</td>
</tr>
<tr>
<td>Recreational facilities</td>
<td>Vehicle emissions, During transport</td>
</tr>
<tr>
<td>Water purification</td>
<td>Vehicle emissions, during transport, Infrastructure</td>
</tr>
<tr>
<td>Accidents/Spills</td>
<td></td>
</tr>
<tr>
<td>Property values</td>
<td></td>
</tr>
<tr>
<td>Public health</td>
<td></td>
</tr>
<tr>
<td>Damage to ecosystems</td>
<td></td>
</tr>
</tbody>
</table>
Externalities of Air Pollution

Economic Costs
- Infrastructure
- Labor Productivity
- Agricultural Productivity

Social Costs
- Public health
- People-hours-wage losses
- Medical services costs
- Burden of diseases

Environmental Costs
- Damage to ecosystems
- Yield decrease
- Biomass restoration time
- Loss of useful life (amortization)
- Replacement and restoration
- Biological diversity and sustainability
Externalities of Water Pollution

**Economic Costs**
- Commercial fishing
  - Yield decrease
- Recreational facilities
  - Lost revenues
- Water purification
  - Inspection and treatment costs
- Accidents/Spills
  - Cleanup costs

**Social Costs**
- Public health
  - Medical services costs
  - Burden of diseases

**Environmental Costs**
- Damage to ecosystems
  - Biological diversity and sustainability
  - Loss of water regeneration by wetlands
Externalities of Noise Pollution

**Economic Costs**
- Property values
  - Loss in rent values
  - Taxation revenues

**Social Costs**
- Public health
  - Medical services costs
  - Burden of diseases

**Environmental Costs**
- Damage to ecosystems
  - Biological diversity and sustainability
Emissions from Freight Modes (grams / ton-km)

- **Road**
- **Rail**
- **Short sea shipping**
- **Ocean shipping**

**Other Emissions (g/ton-km):**
- **CO2**
- **SOx**
- **NOx**
- **PM**
- **HC**
- **CO**
Estimated Air Pollutants Emitted by Highway Transportation in the United States, 1970-2019

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Noise Levels (in decibels)

- **Extremely Loud**: 120 dB (A) - Aircraft at take off
- **Very Loud**: 110 dB (A) - Car horn
- **Loud**: 100 dB (A) - Subway
- **Moderate**: 90 dB (A) - Truck, motorcycle
- **Faint**: 80 dB (A) - Busy crossroads
- **Quiet room**: 70 dB (A) - Noise level near a motorway
- **Busy street through open windows**: 60 dB (A)
- **Light traffic**: 50 dB (A)
- **Desert**: 40 dB (A)
- **Ear ing threshold**: 30 dB (A)
Hazmat Accidents in the United States, 1975-2005

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### Table 3. Road traffic and networks of social support

<table>
<thead>
<tr>
<th>Traffic levels</th>
<th>Contacts living on the same street</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Friends</td>
</tr>
<tr>
<td>Light traffic (200 vehicles at peak hour)</td>
<td>3.0</td>
</tr>
<tr>
<td>Moderate traffic (600 vehicles at peak hour)</td>
<td>1.3</td>
</tr>
<tr>
<td>Heavy traffic (1000 vehicles at peak hour)</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Source: adapted from Applecard & Listel (1:2)
The Environmental Footprint of Transportation

Chapter 4.3
Current and Potential Car Fleet in India and China

- China: 250 (Vehicle Fleet Size for Industrialized Vehicle Ownership Level) vs. 640 (Size of Vehicle Fleet (2018))
- India: 29 (Size of Vehicle Fleet (2018)) vs. 513

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Land Footprint for Freight Distribution

- **Transportation**
  - Terminals
    - Port terminals
    - Rail terminals
    - Airports
  - Networks
    - Roads / Rail lines
    - Rights of way

- **Storage**
  - Warehousing
    - Distribution centers
    - Warehouses
  - Outdoor Storage
    - In transit
    - Parking

Energy Supply

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UPS Chicago Area Consolidation Hub
Spatial Form, Pattern and Interaction and the Environmental Impacts of Transportation
Sustainable Urban Passenger Travel, Selected Cities

Urban Population
- Less than 2 M
- 2 to 4 M
- 4 to 8 M
- 8 to 16 M
- More than 16 M

A) Most sustainable transport
B) More sustainable transport
C) Sustainable transport
D) Less sustainable transport
E) Least sustainable transport
Environmental Externalities of Land Use

**Economic Costs**
- Urban pattern and density
- Energy
- Infrastructure

**Social Costs**
- Community disruption

**Environmental Costs**
- Damage to ecosystems

- Commuting distance
- Population density
- Agricultural land take
- Energy per ton or passenger-km
- Road density
- Utility provision costs
- Environmental nuisances (noise, odors)
- Accessibility to employment, goods and services
- Natural land take
Sustainable Development

Society
- Welfare
- Equal opportunity
- Social cohesion
- International solidarity
- Maintenance of human capital

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

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Economic and Social Outcomes of Sustainable Transportation

**EQUITY**
- Equity of access across income groups, gender, age, disability status, and geographical location—thus, leaving "no one behind"
- Improved access to jobs and productive opportunities
- Improved access to markets and basic services as health and education
- Reduction of transport barriers for groups such as women and girls

**EFFICIENCY**
- Better and faster access to world markets
- More efficient use of resources (including energy, technology, space, institutions and regulations)
- Decoupling of GDP growth and energy consumption for transport
- Increase in global trade
- Regional integration
- Simplified border crossings

**SAFETY**
- Reduction of fatality, injury, and crash rates across all modes of transport
- Reduced risks for vulnerable groups, such as pedestrians, bicyclists, and children
- Reduction of social costs of transport related (such as health costs and forgone productivity)

**GREEN**
- Curbing the increase of global temperatures due to GHG emissions
- Better quality of air and lower noise pollution
- Resilience to climate disasters
- Preservation of Ecosystems
- Reduction of health costs associated with poor air quality and noise levels

Source: Own elaboration
The Circular Economy and Supply Chains

Suppliers → Manufacturers → Distributors → Consumer → User

Materials → Technical Goods

Biological Goods → Harvesting → Fertilizers → Biogas → Biochemical processing → Collection

Biogas → Biochemical processing

Biosphere

Collection → Biochemical processing

Leakage → Burning / Disposal

Recycle → Remanufacture → Reuse → Maintenance → Collection

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Sustainability Dimensions in the Transport Industry

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

- Infrastructures
  - Site construction
  - Greenfield and brownfield sites

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Average CO2 Emissions by Passenger and Freight Transport Mode

Passengers (grams of CO2 per pass-km)
- Large cars: 200
- Aviation: 400
- Average cars: 150
- Buses: 100
- Rail: 50
- Aviation: 600
- Medium trucks: 150
- Heavy trucks: 150
- Rail: 50
- Maritime: 5

Freight (grams of CO2 per ton-km)
- Large cars: 10
- Aviation: 400
- Average cars: 10
- Buses: 5
- Rail: 10
- Aviation: 600
- Medium trucks: 15
- Heavy trucks: 15
- Rail: 5
- Maritime: 5

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Environmental Management System for Port and Maritime Transport

Environmental conditions

Port legislation

Port operations

Assessment:
- Risks
- Impacts
- Responsibilities

Problem identification

Selection of a management system

Strategies of commercial maritime carriers

Selection of performance indicators for sustainable port system

Production of an environmental management information system

Selection of performance indicators for sustainable maritime shipping

Implementation of an environmental management program

Policy statement for environmental management of ports and maritime transport
## Clean Air Action Plan, Ports of Los Angeles and Long Beach

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

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

**Infrastructure**
- 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

**Conveyances and Equipment**
- Electric vehicles
- Terminal automation

**Management and Operations**
- 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

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