# EECE3621

# Introduction to Electric Vehicle Technology

# EECE3621: INTRODUCTION TO ELECTRIC VEHICLE TECHNOLOGY

**Unit I: Introduction:**

Air pollution, global warming, petroleum resources, induced costs, and development strategies for future oil supply, Overview of Past, current and future of electric vehicles.

**Unit II: Vehicles' classification:**

Classification of vehicles: Conventional IC engines, electric vehicles, hybrid electric vehicles, plug-in hybrid vehicles, and fuel cell vehicles. Basic principles and operation of electric vehicles.

**Unit III: Configuration and Architecture:**

Configuration of electric vehicles, performance of electric vehicles: traction motor characteristics, requirement of tractive and transmission effort and energy consumption. Architecture of hybrid vehicles: series and parallel

## Unit IV: Basic electric propulsion systems:

*(Elementary treatment only) Principle, operation and performance of DC motors, induction motors, brushless DC motors and switched reluctance motors*

## Unit V: Overview of communication in EVs:

Vehicle to grid communication, vehicle to vehicle communications, and grid to vehicle communication.

# TEXT BOOK(S):

1. Ehsani, M., Gao, Y., Longo, S., & Ebrahimi, K. M. (2018). Modern electric, hybrid electric, and fuel cell vehicles. CRC press.

2. Larminie, James, and John Lowry. Electric vehicle technology explained. John Wiley & Sons, 2012.

- **Theory Component Number of Quizzes: 12 (2 marks each) – best 10: 10*2=20 marks**
- **Summative Assessments (Mids): 3 (10 marks each):3*10=30 marks**
- **Assignments: 2 (10mark each): 2*10=20 marks End semester Exam: 30 marks**

# Timeline of Transport

3,500 BC — 2,000 BC — 1783 AD — 1787 — 1790 — 1801 — 1862

Wheel,

Horses for travel

boats

Steam locomotive

Hot air balloons

1867

1903

1940

1969

First manned Mission to the moon

1981

The first space shuttle

- The development of internal combustion engine vehicles, especially automobiles, is one of the greatest achievements of modern technology.
- Automobiles have made great contributions to the growth of modern society by satisfying many of its needs for mobility in everyday life.
- The rapid development of the automotive industry, unlike that of any other industry, has prompted the progress of human society from a primitive one to a highly developed industrial society.
- The automotive industry and the other industries that serve it constitute the backbone of the word's economy and employ the greatest share of the working population

- The growth of speedy transportation is man's greatest achievement in minimizing distances but at the same time it has also become a cause of ***environmental degradation***.
- In short, we cannot live without transport development, but neither may we be able to cope with its side-effects over the long term.
- Usage of large number of automobiles has caused serious problems for the environment and human life.

# Main Problems are

- **Air pollution**
- **Global warming**
- **petroleum resources depletion**

Research and Development (R&D) concentrated on the development of transportation in terms of

- ✓ **High efficiency**
- ✓ **Clean**
- ✓ **Safe**

Proposed to replace conventional vehicles with

- ❖ **Electric vehicles**
- ❖ **Hybrid electric vehicles**
- ❖ **Fuel cell vehicles**

# AIR POLLUTION

- Transport is a major source of air pollution in developed and in developing countries.

- Ecologists believe that the rapid increase in the number of vehicles on our roads, which has taken place without any real restriction, is fast developing into an environmental crisis.

- ***EXHAUST FUMES*** are the major source of atmospheric pollution by the motor vehicle.

# AIR POLLUTION

- All vehicles depend on the combustion of hydrocarbon fuels to derive the energy necessary for their propulsion.
- Combustion is a reaction between the fuel and the air that releases heat and combustion products.
- The heat is converted to mechanical power by an engine and the combustion products are released into the atmosphere.
- A hydrocarbon is a chemical compound with molecules made up of carbon and hydrogen atoms

https://www.youtube.com/watch?v=xd1alir07q4

# AIR POLLUTION

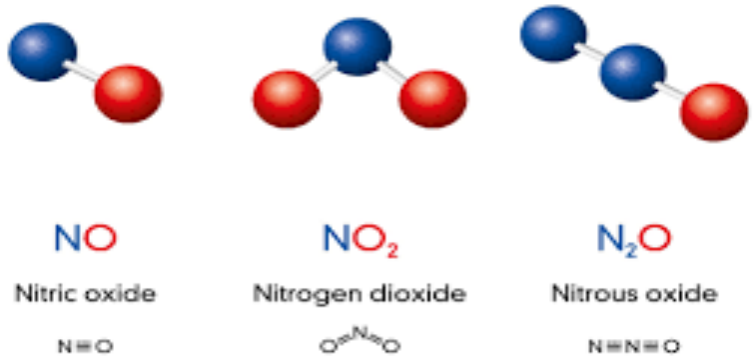
The combustion products contains

- **Nitrogen Oxides (NOx),**
- **Carbon Monoxides (CO),**
- **Unburned Hydrocarbons (HC)**

all of which are poisonous to human health

# Nitrogen Oxides(Nox)

- The reaction between nitrogen in the air and oxygen results NOx
- Nitrogen is an inert gas
- The high temperatures and pressures in engines create favorable conditions for the formation of nitrogen oxides.



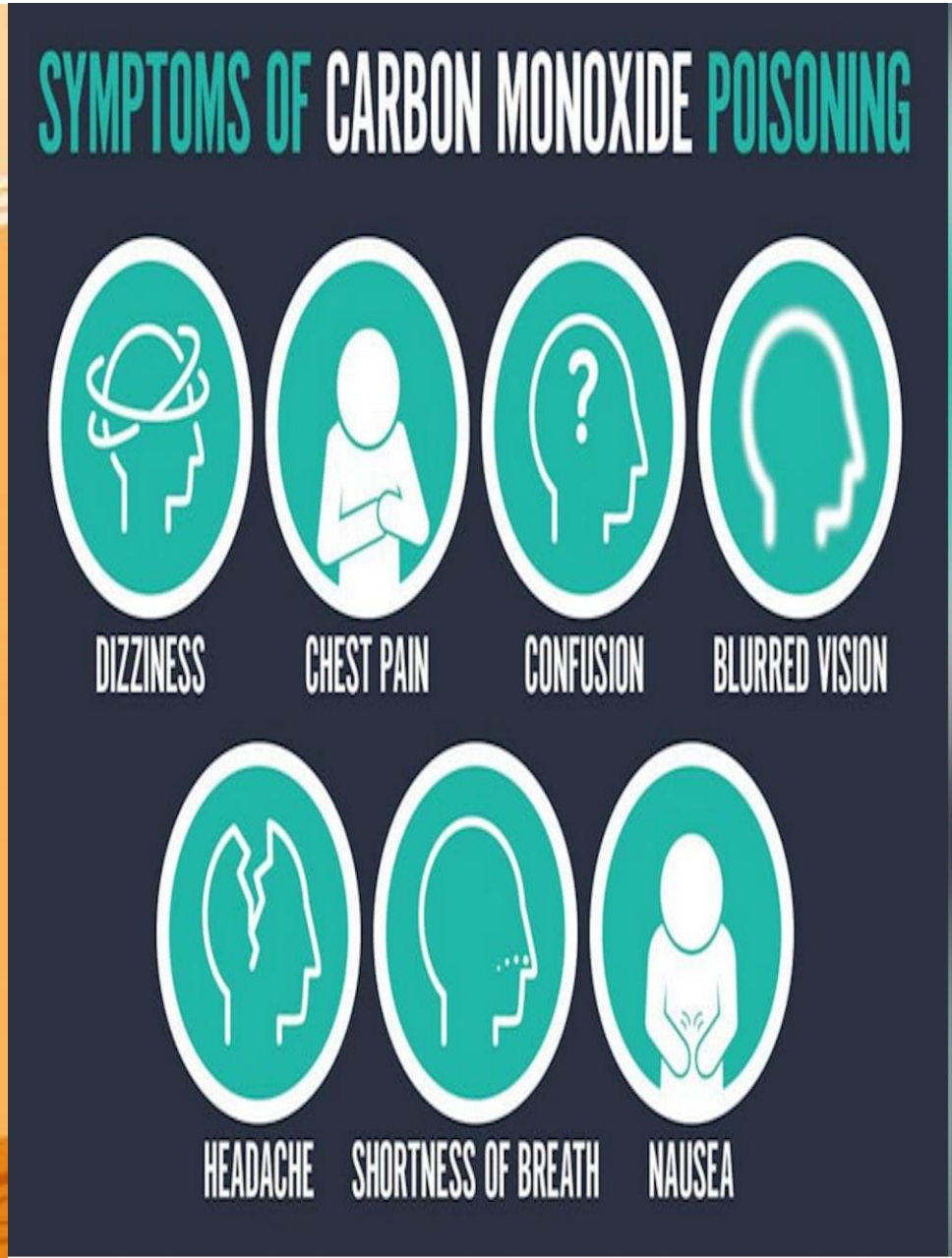
# Nitrogen Oxides(Nox)

- The most commonly found nitrogen oxide is nitric oxide (NO), although small amounts of nitrogen dioxide ($NO_2$) and traces of nitrous oxide ($N_2O$) are also present.
- Once released into the atmosphere, NO reacts with oxygen to form $NO_2$.
- This is later decomposed by the Sun's ultraviolet radiation back to NO and highly reactive oxygen atoms that attack the membranes of living cells.
- It also reacts with atmospheric water to form nitric acid ($HNO_3$), which dilutes in rain known as "acid rain".
- acid rain is responsible for the destruction of forests in industrialized countries.
- https://www.youtube.com/watch?v=dmgLESI4GGU

# Carbon Monoxides(CO)

- Carbon monoxide results from the incomplete combustion of hydrocarbons due to lack of oxygen.
- Once carbon monoxide reaches the blood cells, it fixes to the hemoglobin in place of oxygen.
- Thus, diminishing the quantity of oxygen that reaches the organs and reducing the physical and mental abilities of affected living beings.

# Carbon Monoxides(CO)

# Unburned Hydrocarbons

- Unburned hydrocarbons are a result of the incomplete combustion of hydrocarbons.
- Some of these unburned hydrocarbons may be direct poisons.
- Unburned hydrocarbons are also responsible for smog: the Sun's ultraviolet radiations interact with unburned hydrocarbons and NO in the atmosphere to form ozone and other products.

- Ozone is a molecule formed of three oxygen atoms.
- It is colorless but very dangerous, and poisons as it attacks the membranes of living cells, thus causing them to age prematurely or to die.
- Children, older people, and asthmatic humans suffer greatly from exposure to high ozone concentrations.

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# Other Pollutants

- Impurities in fuels result in the emission of pollutants.
- The major impurity is ***sulfur***, which is mostly found in diesel and jet fuel and in gasoline and natural gas
- The combustion of sulfur with oxygen releases sulfur oxides (SOx).
- Sulfur dioxide (SO2) is the major product of this combustion.
- Upon contact with air, it forms sulfur trioxide, which later reacts with water to form sulfuric acid, a major component of acid rain.

# Other Pollutants

- To improve the performance of engines petroleum companies, add chemical compounds to their fuels.
- Lead was used to improve the knock resistance of gasoline and therefore allow for better engine performance.
- The combustion of this chemical releases lead metal, which is responsible for a neurological disease called “saturnism.”
- The brain is the most sensitive. Symptoms may include **abdominal pain, constipation, headaches, irritability, memory problems, infertility, and tingling in the hands and feet**.
- Usage of lead is now banned in most developed countries, and it has been replaced by other chemicals.

# GLOBAL WARMING

- Global warming is a result of the “greenhouse effect” induced by the presence of carbon dioxide and other gases, such as methane, in the atmosphere.

- These gases trap the Sun’s infrared radiation reflected by the ground, thus retaining the energy in the atmosphere and increasing the temperature.

- An increased Earth temperature results in major ecological damages to its ecosystems and in many natural disasters that affect human populations

# GLOBAL WARMING

- Among the ecological damages induced by global warming, the disappearance of some endangered species is a concern because it destabilizes the natural resources that feed some populations.

- There are also concerns about the migration of some species from warm seas to previously colder northern seas, where they can potentially destroy indigenous species and the economies that live off those species.

- This may be happening in the Mediterranean Sea, where barracudas from the Red Sea have been observed.

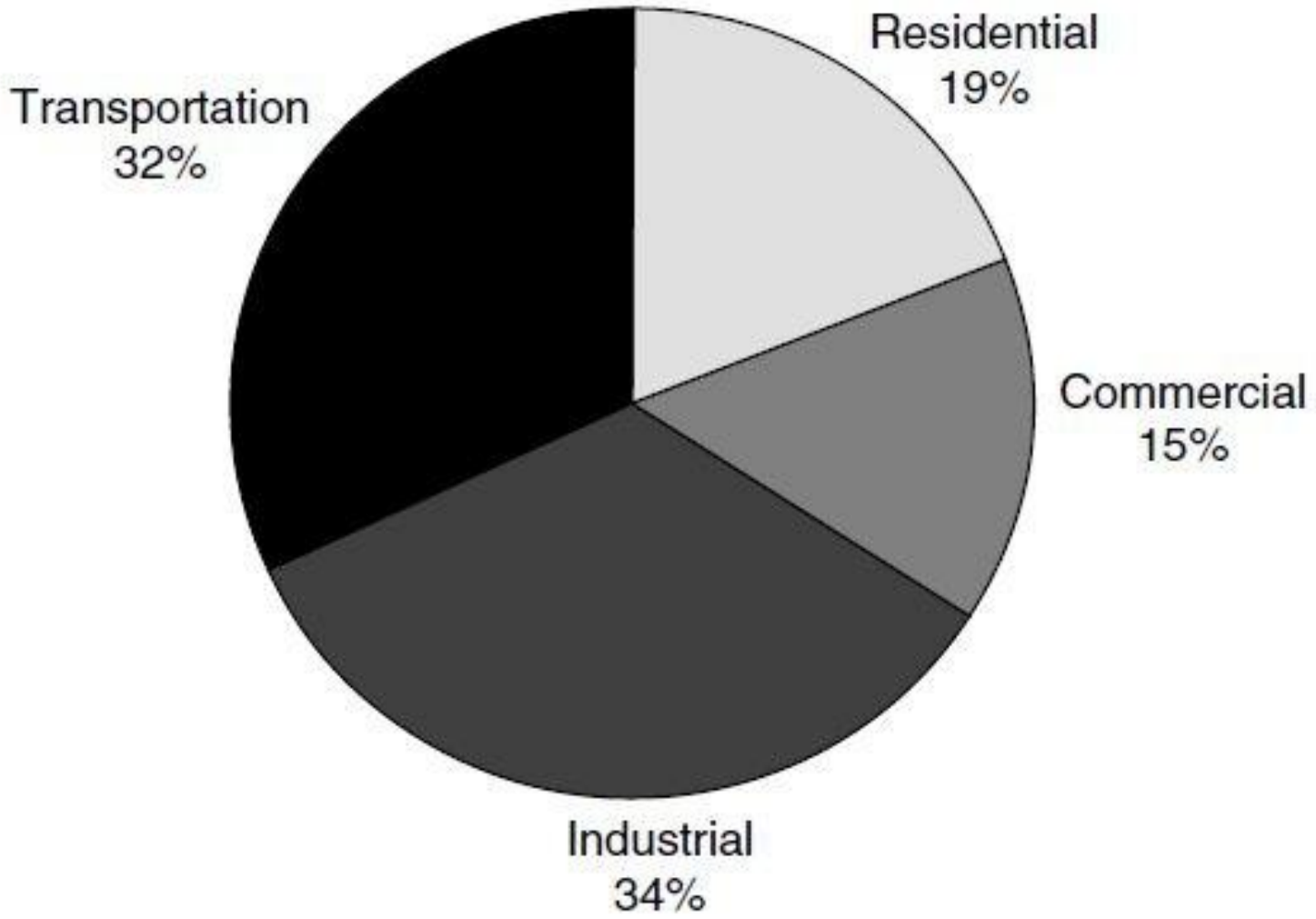
# GLOBAL WARMING

https://www.youtube.com/watch?v=-D_Np-3dVBQ

# GLOBAL WARMING

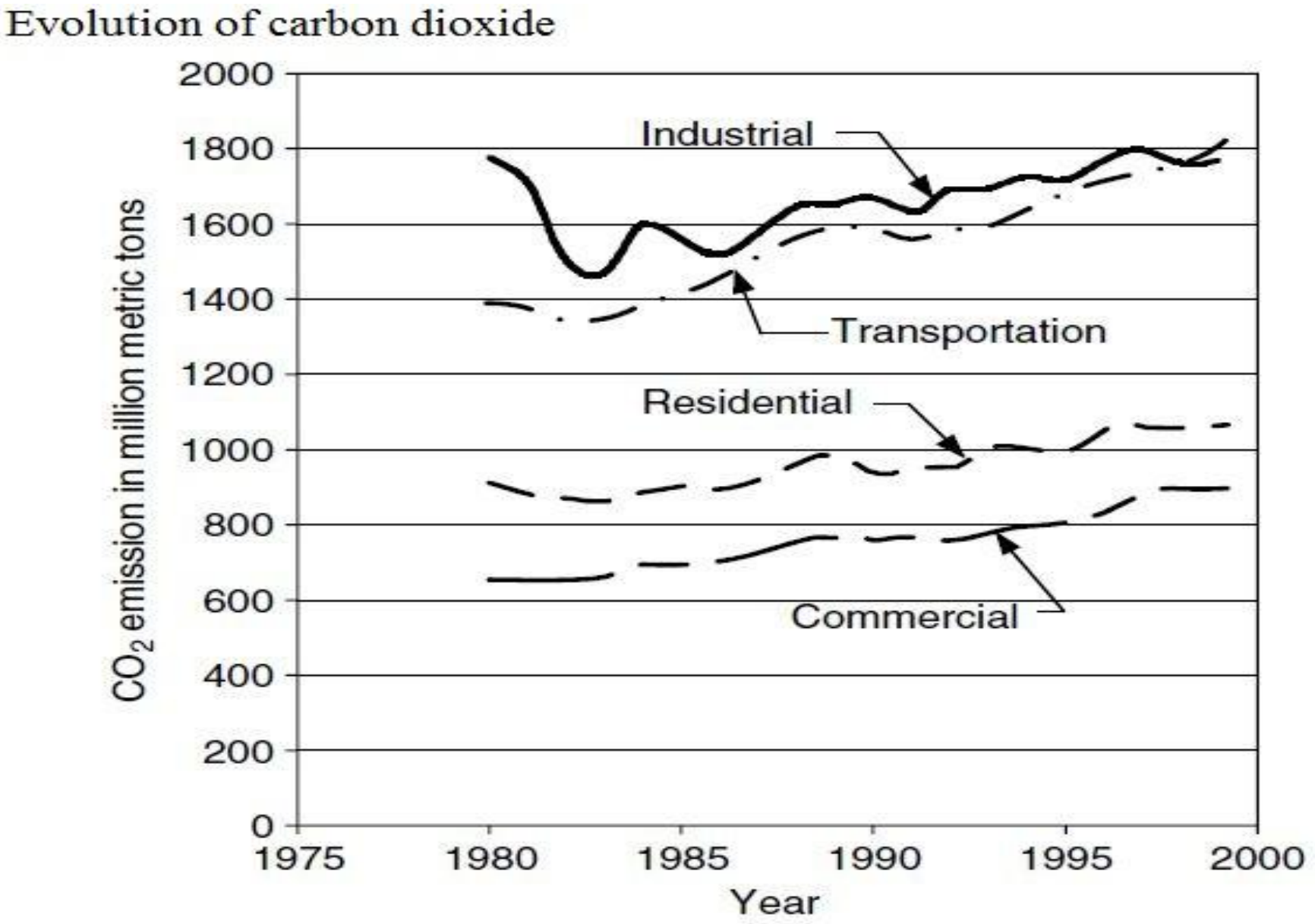
- **Global warming** is the increase in Earth's average temperature due to human activities. It mainly happens because of the buildup of certain gases in the atmosphere, known as **greenhouse gases**, such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$).
- These gases trap heat from the sun that would normally escape back into space, causing the Earth to become warmer over time. This natural process is called the **greenhouse effect**, it is important for life on Earth, but human activities have made it too strong.
- The major cause of global warming is the burning of **fossil fuels** such as coal, oil, and natural gas. These fuels are used for generating electricity, running vehicles, and powering industries. When we burn them, they release large amounts of carbon dioxide into the air.
- Other causes include **deforestation**, which reduces the number of trees that absorb $CO_2$, and certain agricultural practices that release methane.

- As the Earth warms up, it leads to several serious problems. **Glaciers and polar ice are melting**, causing **sea levels to rise**, which can flood coastal areas.
- **Weather patterns are changing**, leading to more frequent and intense **heatwaves, storms, floods, and droughts**.
- Many **plants and animals** struggle to survive in the changing climate, and some species are at risk of extinction.
- It also affects humans—farming becomes harder, diseases spread more easily, and access to clean water and food may decrease.
- In conclusion, global warming is a major environmental issue caused mainly by human actions. If we don't take steps to reduce greenhouse gas emissions and protect nature, the effects will become more dangerous in the future.
- Solutions include using clean energy like solar and wind, planting more trees, reducing waste, and changing the way we travel and use resources.

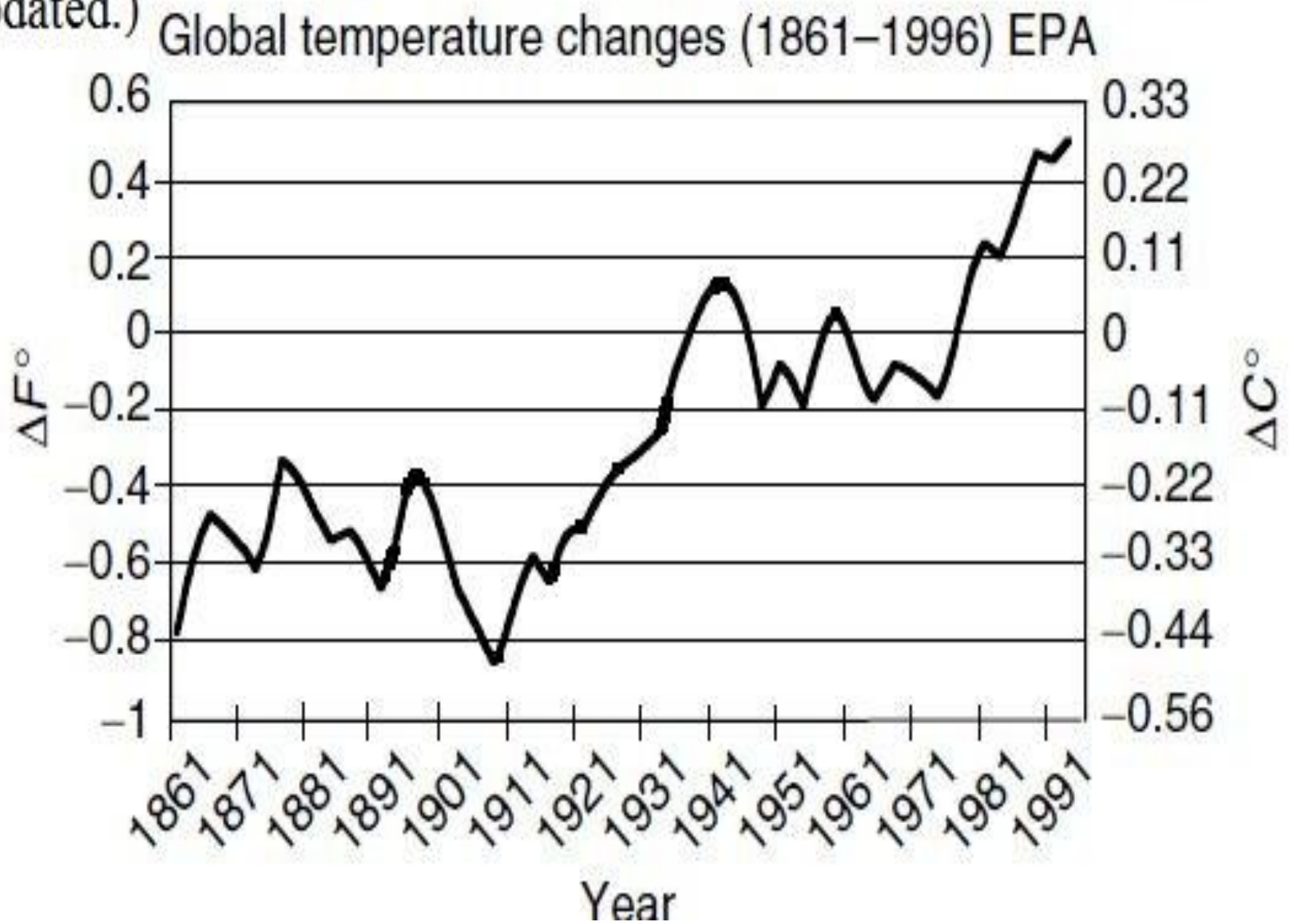



Carbon dioxide emission distribution from 1980 to 1999

# Evolution of Carbon dioxide emission



Global Earth atmospheric temperature. (*Source*: IPCC (1995) updated.)



# PETROLEUM RESOURCES

- The vast majority of fuels used for transportation are liquid fuels originating from petroleum.

- Petroleum is a fossil fuel, resulting from the decomposition of living matters that were imprisoned millions of years in geologically stable layers.

# PETROLEUM RESOURCES

- https://www.youtube.com/watch?v=szNFYED5siY

- https://www.youtube.com/watch?v=8YHsxXEVB1M

# PETROLEUM RESOURCES

- Petroleum is a **fossil fuel** that was formed **millions of years ago** from the remains of tiny plants and animals that lived in the sea.

**Step-by-Step Formation:**

- ***Dead Plants and Animals Sink to the Ocean Floor*** Long ago, tiny sea plants and animals died and sank to the bottom of oceans and seas. They got buried under layers of mud and sand.
- ***Burial Under Pressure and Heat*** Over millions of years, more layers of sand, clay, and rock built up. The pressure and heat from these layers slowly turned the dead plants and animals into a thick, dark liquid – crude oil – and natural gas.
- ***Trapped Under Rock Layers*** The oil and gas moved through porous rocks until they got trapped under non-porous rock layers (called cap rock), forming oil and gas reservoirs.
- ***Drilling and Extraction*** Today, scientists and engineers drill deep wells into the Earth to bring up the crude oil and gas for use.

# PETROLEUM RESOURCES

- The proved reserves are “those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions”
- The Reserves-to-Production(R/P) ratio is **commonly used to estimate how many years' worth of oil a company or a country has**.

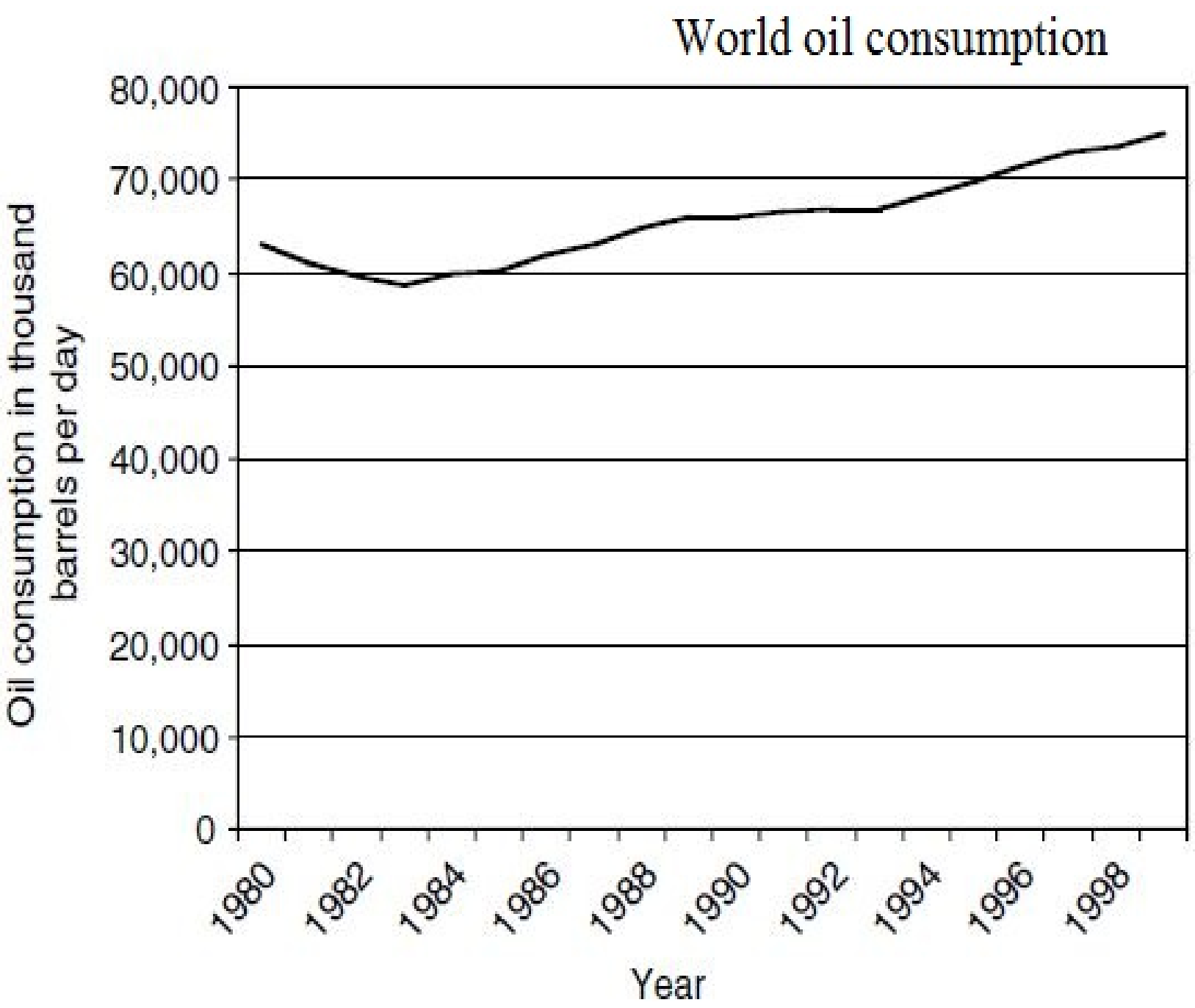
- Although the R/P ratio does not include future discoveries, it is significant.

# Proved Petroleum Reserves in 2000

| Region | Proved Reserves in 2000 in Billion Tons | R/P ratio |
|---|---|---|
| North America | 8.5 | 13.8 |
| South and Central America | 13.6 | 39.1 |
| Europe | 2.5 | 7.7 |
| Africa | 10 | 26.8 |
| Middle East | 92.5 | 83.2 |
| Former USSR | 9.0 | 22.7 |
| Asia Pacific | 6.0 | 15.6 |
| Total world | 142.1 | 39.9 |

# U.S. Geological Survey Estimate of Undiscovered Oil in 2000

| Region | Undiscovered Oil in 2000 in Billion Tons |
|---|---|
| North America | 19.8 |
| South and Central America | 14.3 |
| Europe | 3.0 |
| Sub-Saharan Africa and Antarctica | 9.7 |
| Middle East and North Africa | 31.2 |
| Former USSR | 15.7 |
| Asia Pacific | 4.0 |
| World (potential growth) | 98.3 (91.5) |


World oil consumption
Oil consumption in thousand barrels per day
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year

# INDUCED COSTS

- The rapid and excessive use of fossil fuels leads to several serious problems such as **pollution, global warming, and resource depletion**. The **indirect or induced costs** related to these issues are large and hard to measure. They include **financial losses and human suffering**, such as:

a) **Natural disasters** (like hurricanes and floods),

b) **Crop failures** due to drought,

c) **Property damage**,

d) And **international aid** for affected regions.

- A major issue is that **oil-consuming countries** (like those in **Europe, North America, and Asia-Pacific**) depend heavily on **oil-producing countries**, mainly in the **Middle East**. This **dependency creates political and economic risks**, such as during the oil crises of **1973 and 1977**, or wars like the **Gulf War**. Any disruption in oil supply can slow down economies, spoil goods, halt businesses, and cause major losses.

# INDUCED COSTS

- The problems associated with the combustion of fossil fuels
  - ✓ Pollution
  - ✓ global warming
  - ✓ the probable exhaustion of resources

- Although difficult to estimate, the costs associated with these problems are huge and indirect, and may be financial, human, or both.

# INDUCED COSTS

- Costs associated with global warming are difficult to assess.
- Include the cost of the damages caused by
  - **Natural disasters** (like hurricanes and floods)
  - lost crops due to dryness
  - damaged properties due to floods
  - international aid to relieve the affected populations.

The amount is potentially huge.

# INDUCED COSTS

- consumers must import their oil and depend on the producing countries.
- The dependency of Western economies upon a fluctuating oil supply is potentially expensive.
- Shortage in oil supply causes
  - ✓a serious slowing down of the economy
  - ✓ resulting in damaged delicate goods
  - ✓ lost business opportunities and the eventual impossibility of running businesses.

# INDUCED COSTS

- In searching for a solution to the problems associated with oil consumption, one has to consider those induced costs.
- This is difficult because the cost is not necessarily asserted where it is generated.
- Many of the induced costs cannot be counted in asserting the benefits of an eventual solution.
- The solution to these problems will have to be economically sustainable and commercially viable without government subsidies in order to sustain itself in the long run.
- Nevertheless, it remains clear that any solution to these problems — even if it is only a partial solution — will indeed result in cost savings and will benefit the payers.

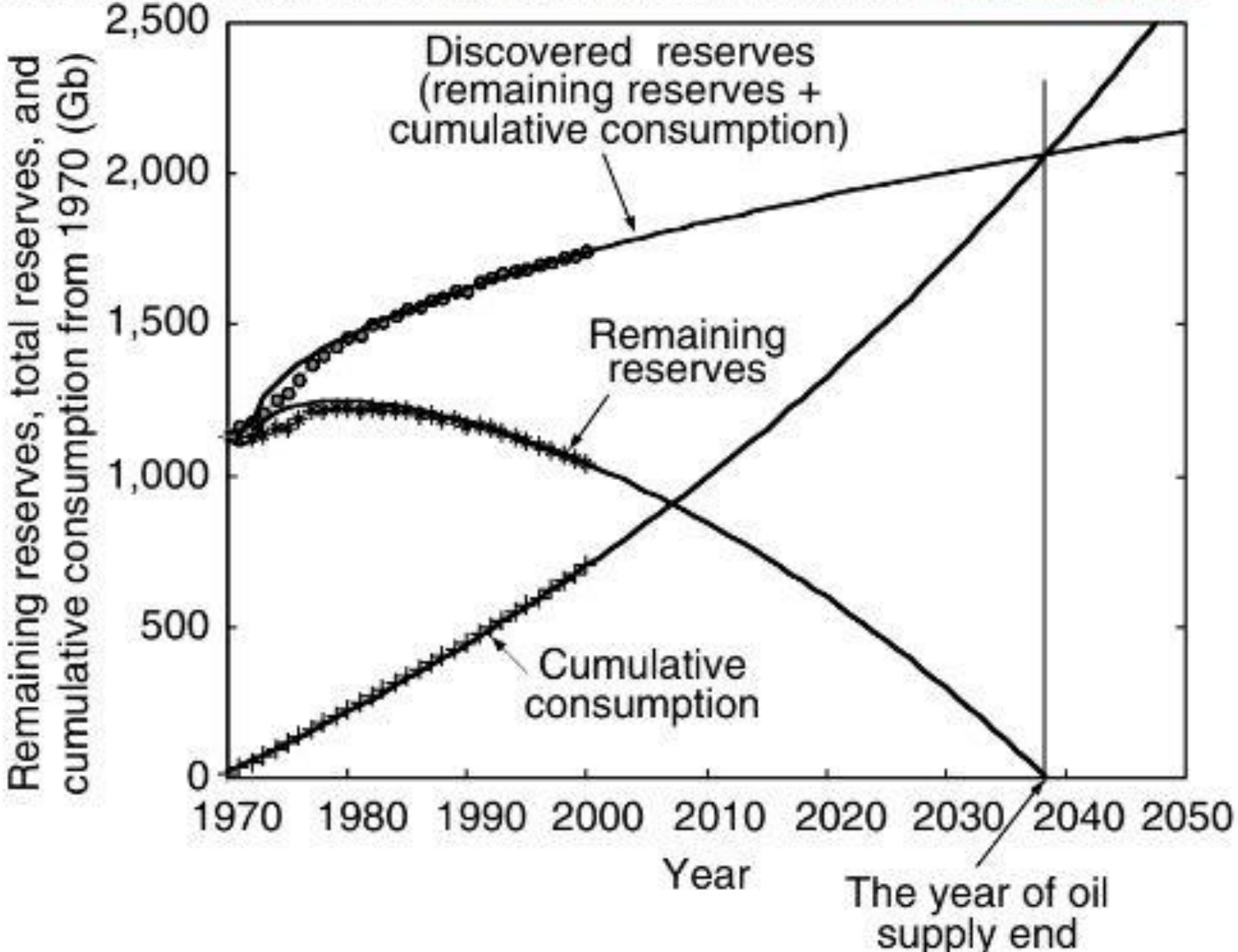
# Development Strategies for future oil supply

- The number of years that the oil resources of the Earth can support our oil supply completely depends on

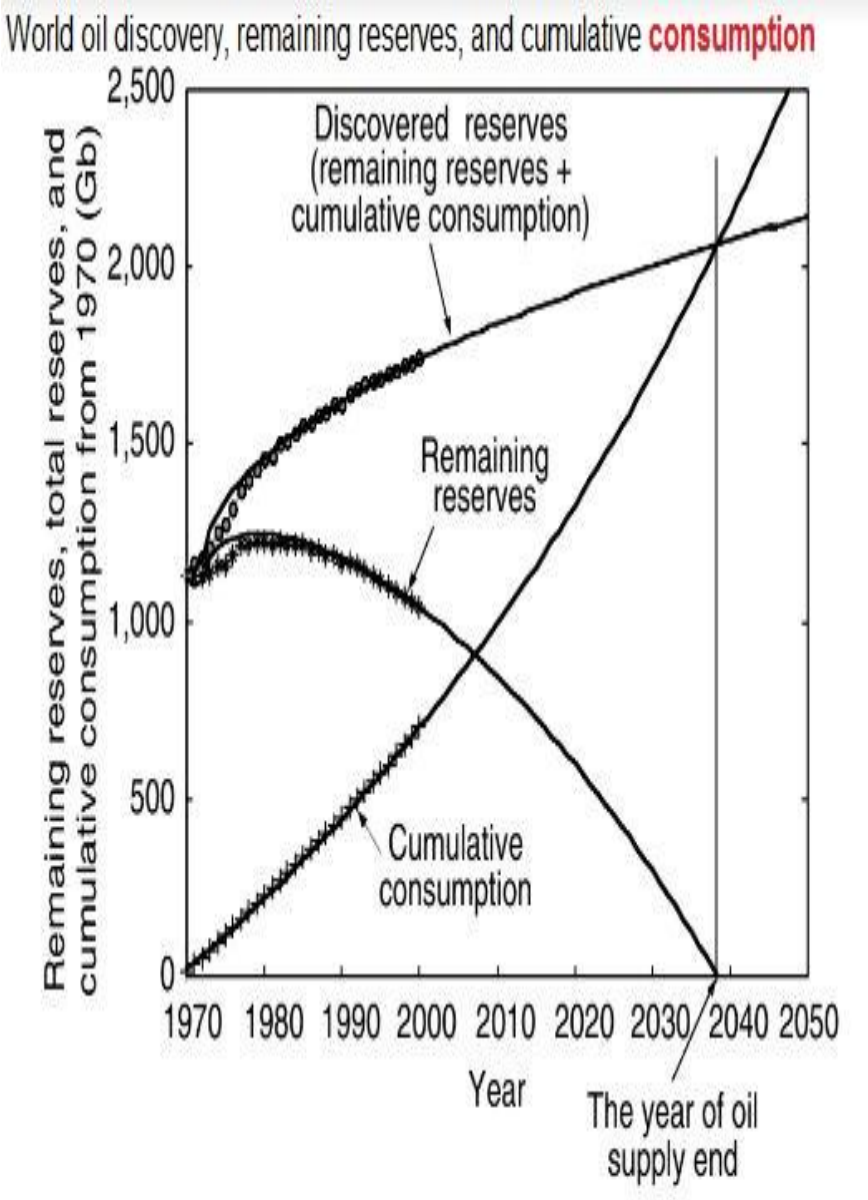
a) **The discovery of new oil reserves**: This means finding new places underground where oil is stored. If we keep discovering new oil fields, we can continue extracting oil for more years. But, according to historical records, **new oil reserves are being discovered at a very slow rate**.

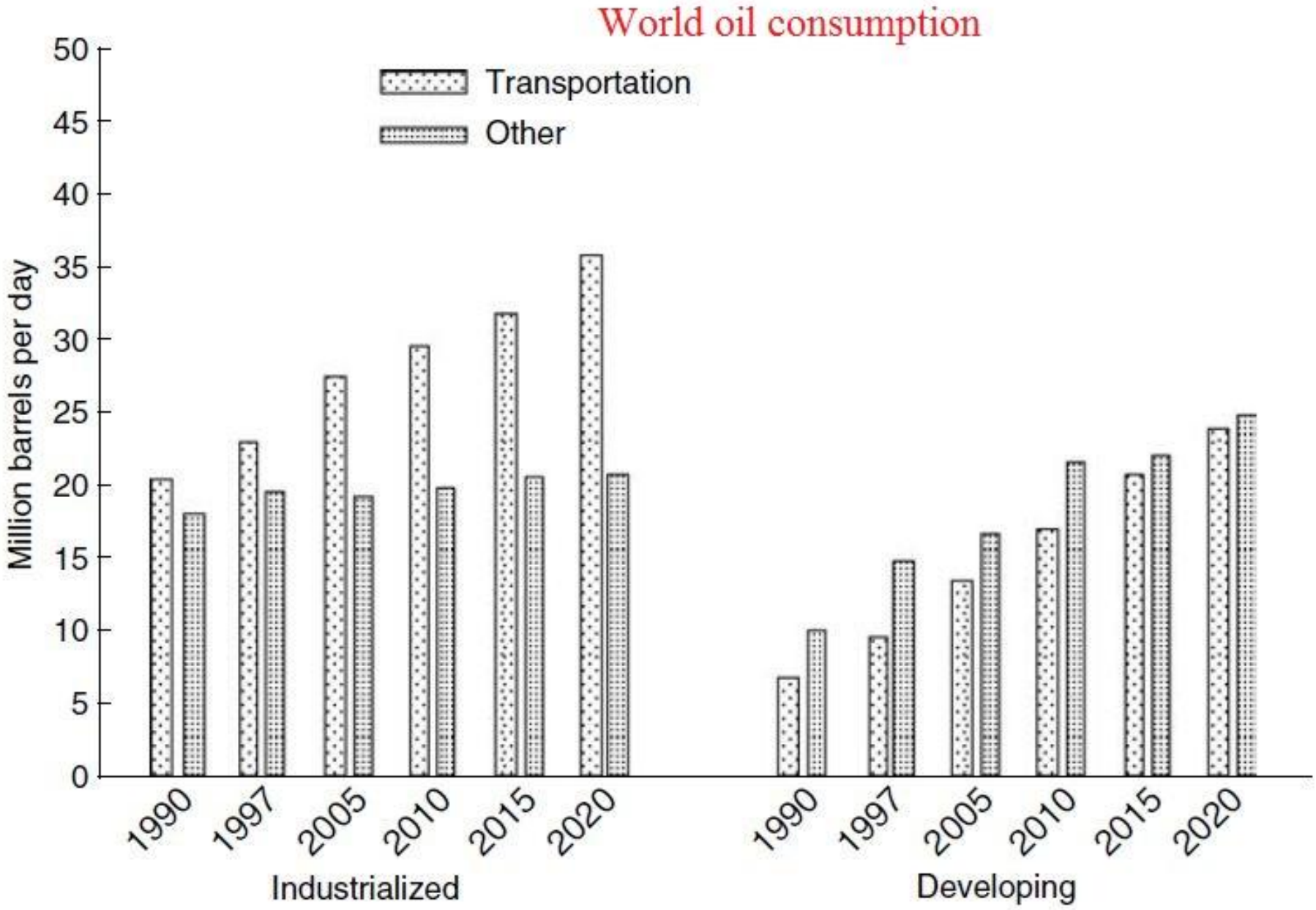
b**) cumulative oil production**: This refers to the total amount of oil we have already taken out and used over the years. As we keep extracting and using more oil, the amount left in the Earth decreases. The **faster we consume oil**, the **less time we have before it runs out**.

World oil discovery, remaining reserves, and cumulative **consumption**



- the consumption shows a high growth rate
- If oil discovery and consumption follow current trends, the world oil resource will be used(completed) by about **2038**.
- It is very difficult to discover new reserves of petroleum under the Earth.
- The cost of exploring new oil fields is becoming higher and higher.
- It is believed that the scenario of the oil supply will not change much if the consumption rate cannot be significantly reduced.






The transportation sector is the primary user of petroleum, consuming 49% of the oil used in the world in 1997

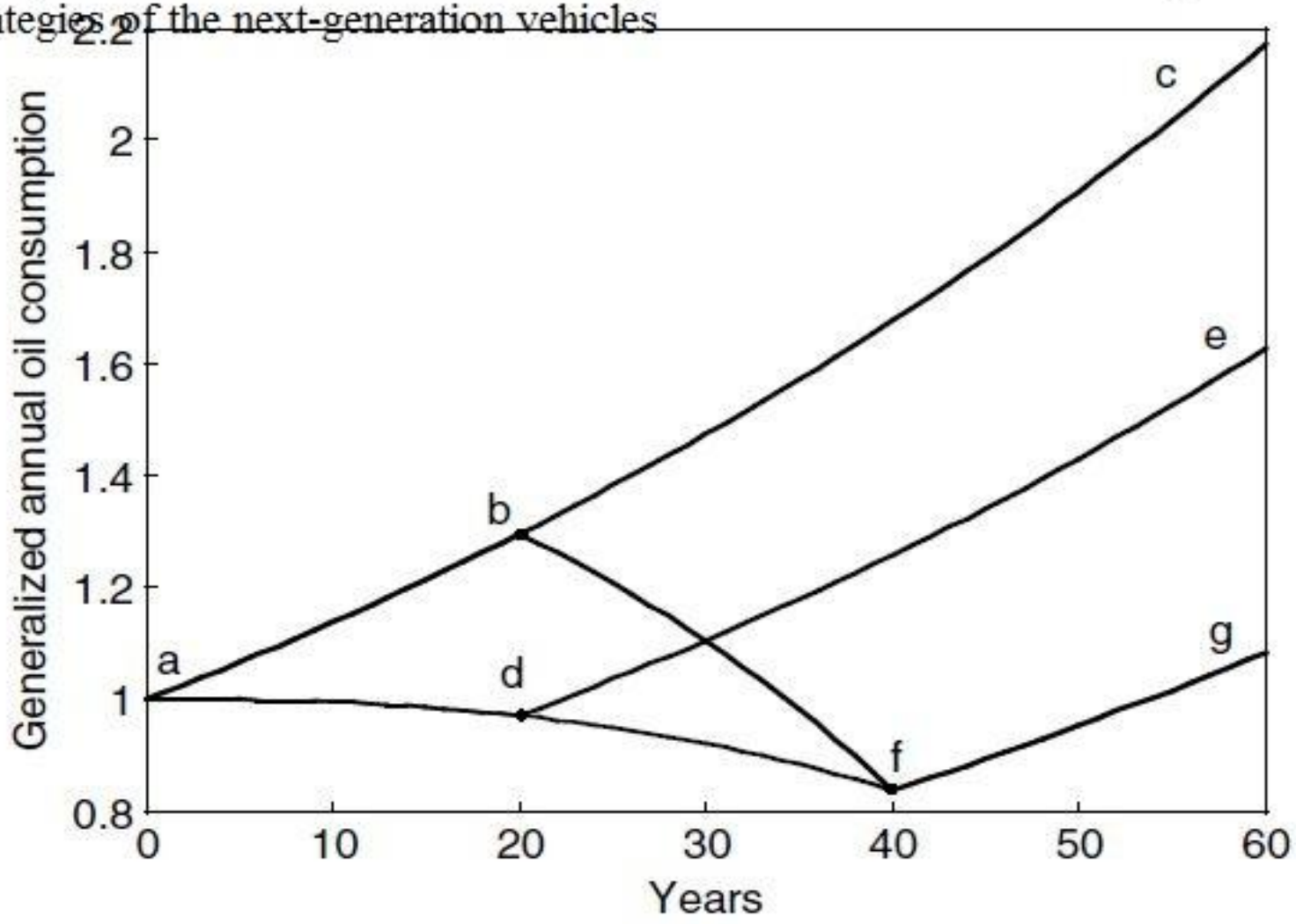
- Most of the gains in worldwide oil use occur in the transportation sector.
- Of the total increase 11.4 million barrels per day projected for industrialized countries from 1997 to 2020, 10.7 million barrels per day are attributed to the transportation sector.
- In the developing world, however, unlike in industrialized countries, oil use for purposes other than transportation is projected to contribute 42% of the total increase in petroleum consumption.
- Improving the fuel economy of vehicles has a crucial impact on oil supply.
- So far, the most promising technologies are hybrid electric vehicles and fuel cell vehicles.

- Hybrid vehicles, using current internal combustion engines (ICEs) as their primary power source and batteries/electric motors as the peaking power source, have a much higher operation efficiency than those powered by ICEs alone.

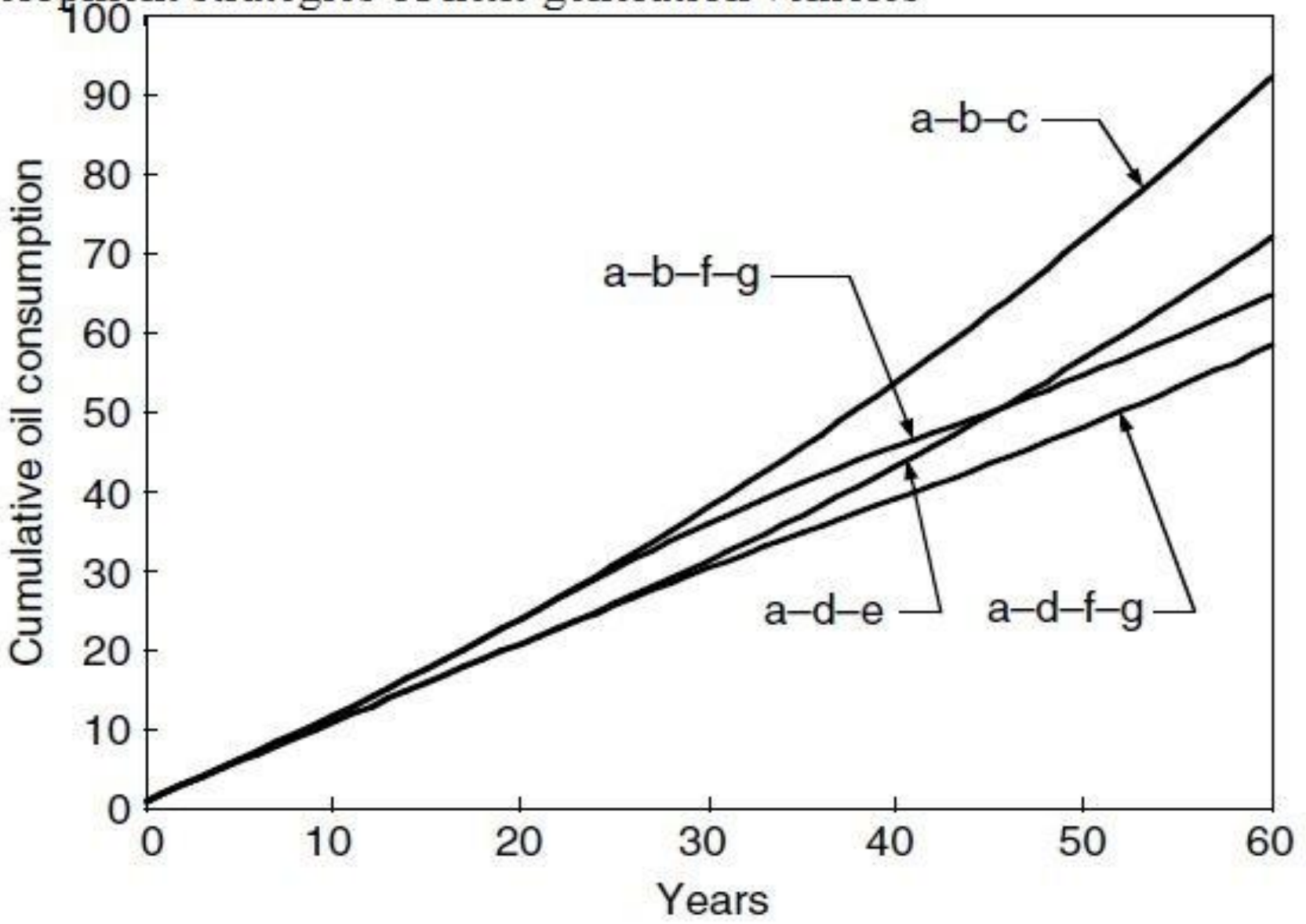
- The hardware and software of this technology are almost ready for industrial manufacturing.

- On the other hand, fuel cell vehicles, which are potentially more efficient and cleaner than hybrid electric vehicles, are still in the laboratory stage and it will take a long time to overcome technical hurdles for commercialization.

Comparison of the annual fuel consumption between different development strategies of the next-generation vehicles

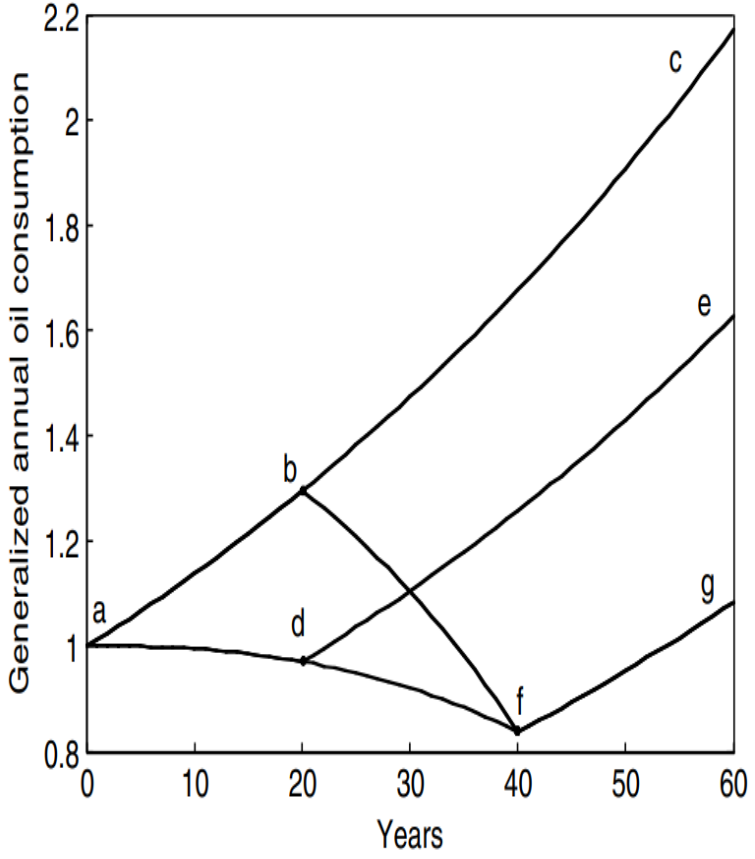


Comparison of the cumulative fuel consumption between different development strategies of next-generation vehicles

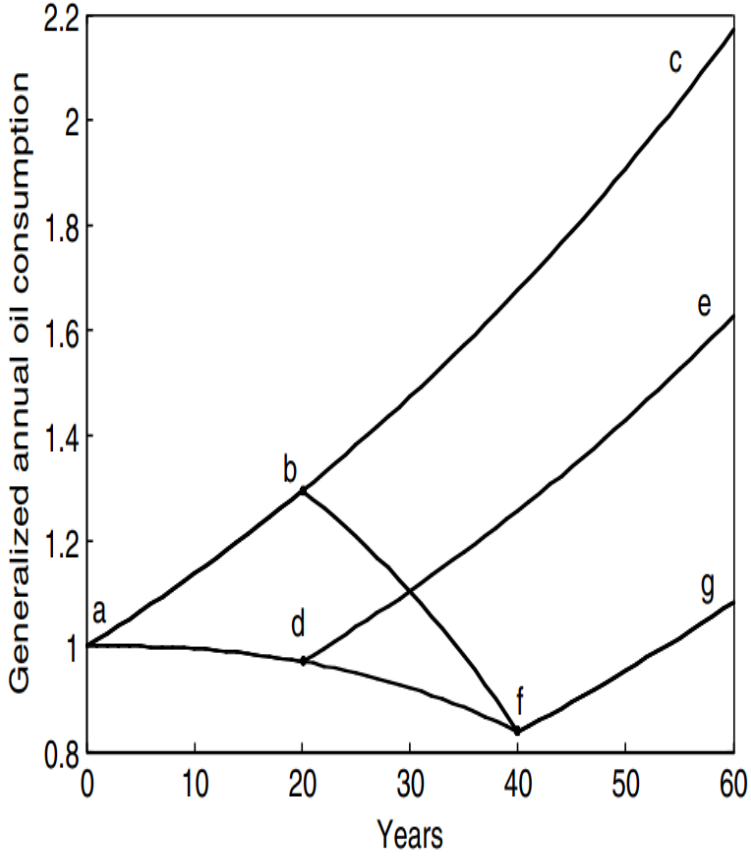


- Curve a–b–c represents the annual fuel consumption trend of current vehicles, which is assumed to have a 1.3% annual growth rate

- Curve a–d–e represents a development hybrid vehicles during the first 20 years - hybrid vehicle is 25% more efficient than a current conventional vehicle



- Curve a–b–f–g represents a strategy in which, in the first 20 years, fuel cell vehicles are in a developing stage while current conventional vehicles are still on the market



# Development Strategies for future oil supply

- Fuel cell vehicles should not rely on oil products because of the difficulty of future oil supply 45 years later.
- The best development strategy of next-generation transportation would be to commercialize hybrid electric vehicles immediately and, at the same time, do the best to commercialize nonpetroleum fuel cell vehicles as soon as possible

# History of Electric Vehicles

- The first electric vehicle was built by Frenchman Gustave Trouvé in 1881.
- It was a tricycle powered by a 0.1 hp DC motor fed by lead–acid batteries.
- The whole vehicle and its driver weighed approximately 160 kg.
- A vehicle similar to this was built in 1883 by two British professors

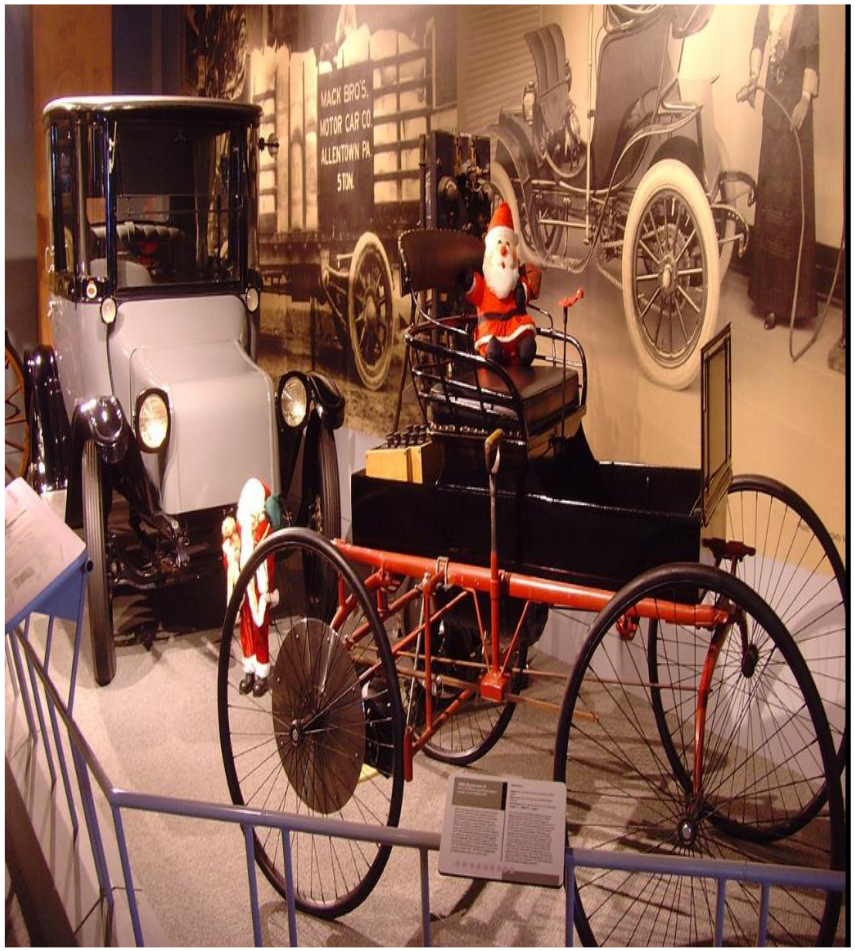
# History of Electric Vehicles

- Gustave Trouvé


https://www.thisismoney.co.uk/money/cars/article-9512103/We-test-replica-Gustave-Trouves-1881-rechargeable-electric-vehicle.html

# History of Electric Vehicles

- The first commercial electric vehicle was Morris and Salom's ***Electrobat***.
- This vehicle was operated as a taxi in New York City by a company created by its inventors.
- The Electrobat proved to be more profitable than horse cabs despite a higher purchase price (around $3000 vs. $1200).
- It could be used for three shifts of **4 h with 90-min recharging periods in between.**
- It was powered by two 1.5 hp motors that allowed a maximum speed of 32 km/h and a 40-km range.



# History of Electric Vehicles

The first vehicle ever to reach 100 km/h. It was "***La Jamais Contente***" built by Frenchman Camille Jenatzy.


# History of Electric Vehicles

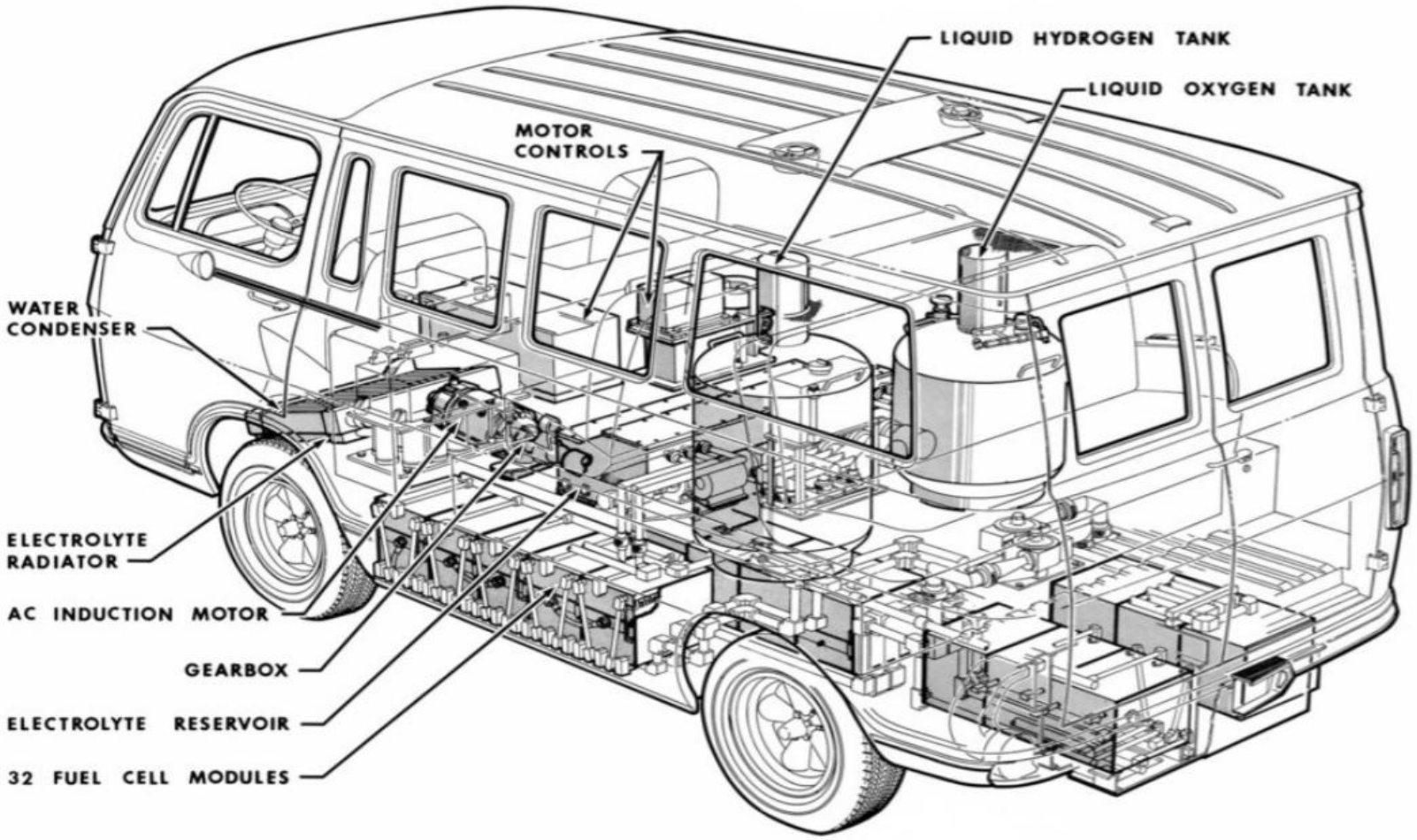
- As gasoline automobiles became more powerful, more flexible, and, above all, easier to handle, electric vehicles started to disappear.
- Their high cost did not help, but it is their limited driving range and performance that really impaired them vs. their gasoline counterparts.
- The last commercially significant electric vehicles were released around 1905.
- During nearly 60 years, the only electric vehicles sold were common golf carts and delivery vehicles.

# History of Electric Vehicles

- In 1945, three researchers at Bell Laboratories invented a device that was meant to revolutionize the world of electronics and electricity: the transistor.
- It quickly replaced vacuum tubes for signal electronics and soon the thyristor was invented, which allowed switching high currents at high voltages.
- This made it possible to regulate the power fed to an electric motor without the very inefficient rheostats, and allowed the running of AC motors at variable frequency.
- In 1966, General Motors (GM) built the ***Electrovan***, which was propelled by induction motors that were fed by inverters built with thyristors.

# History of Electric Vehicles

**world's first hydrogen fuel cell vehicle**, developed by GM in **1966**



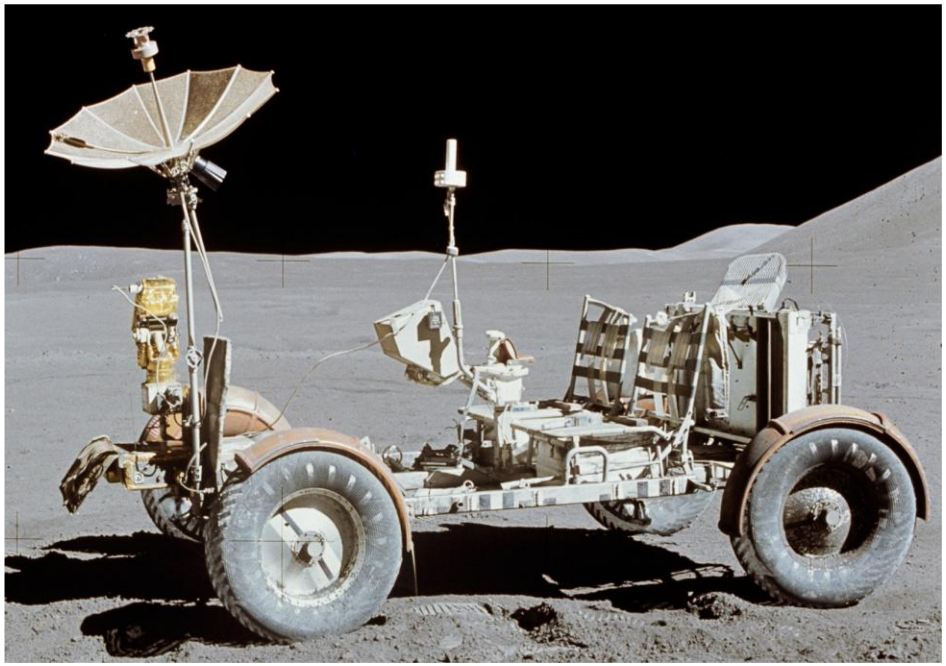

CUTAWAY VIEW OF GENERAL MOTORS ELECTROVAN

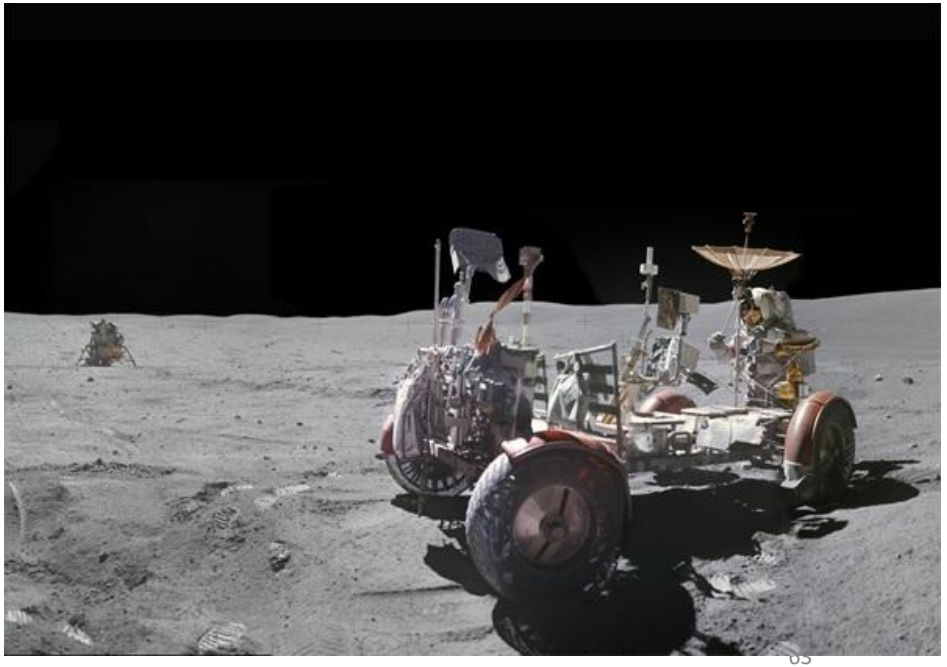
# Key Components & Their Functions

| Component | Function |
|---|---|
| **Liquid Hydrogen Tank** | Stores hydrogen ($H_2$) fuel in cryogenic form. |
| **Liquid Oxygen Tank** | Stores oxygen ($O_2$), also cryogenically. |
| **32 Fuel Cell Modules** | The core system that combines hydrogen and oxygen electrochemically to generate electricity and water. |
| **Electrolyte Reservoir** | Supplies and maintains the electrolyte needed for the fuel cell reaction. |
| **Electrolyte Radiator** | Cools down the system by dissipating heat generated during the reaction. |
| **Water Condenser** | Collects water vapor, which is the only emission of the fuel cell reaction. |
| **AC Induction Motor** | Converts the electricity generated into mechanical motion to drive the wheels. |
| **Gearbox** | Transmits power from the motor to the wheels efficiently. |
| **Motor Controls** | Regulates power delivery, acceleration, and system operation. |

# History of Electric Vehicles

- The most significant electric vehicle of that era was the Lunar Roving Vehicle, which the Apollo astronauts used on the Moon.
- The vehicle itself weighed 209 kg and could carry a payload of 490 kg. The range was around 65 km.
- The design of this extraterrestrial vehicle, however, has very little significance down on Earth.
- The absence of air and the lower gravity on the Moon, and the low speed made it easier for engineers to reach an extended range with limited technology.





# History of Electric Vehicles

- During the 1960s and 1970s, concerns about the environment triggered some research on electric vehicles.
- However, despite advances in battery technology and power electronics, their range and performance were still obstacles.
- The modern electric vehicle era culminated during the 1980s and early 1990s with the release of a few realistic vehicles by firms such as GM with the EV1 and PSA with the 106 Electric.
- Although these vehicles represented a real achievement, especially when compared with early realizations, it became clear during the early 1990s that electric automobiles could never compete with gasoline automobiles for range and performance.

# History of Electric Vehicles

- **The reason is that in batteries the energy is stored in the metal of electrodes, which weigh far more than gasoline for the same energy content.**
- The automotive industry abandoned the electric vehicle to conduct research on hybrid electric vehicles.
- After a few years of development, these are far closer to the assembly line for mass production than electric vehicles have ever been.

# History of Electric Vehicles

- In the context of the development of the **electric vehicle, it is battery technology that is the weakest,** blocking the way of electric vehicles to market.
- Great effort and investment have been put into battery research, with the intention of improving performance to meet the electric vehicle's requirement.
- Unfortunately, progress has been very limited. Performance is far behind the requirement, especially energy storage capacity per unit weight and volume.
- This poor energy storage capability of batteries limits electric vehicles only to some specific applications, such as at airports and railroad stations, on mail delivery routes, and on golfcourses, etc.
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# History of Electric Vehicles

- Perhaps the biggest change in electric vehicles in the last few years has been the development of the **lithium battery**, which has a reasonable specific energy and a more reasonable charge time than previous batteries.
- **higher energy density, longer lifespan, and reduced weight.**
- This has ultimately led to a series of commercial vehicles such as the Tesla sports car .
- More recently manufacturers such as Nissan, Mitsubishi and Renault are producing in quantity commercial electric vehicles such as the Nisan Leaf and the Mitsubishi MiEV.

- https://www.budgetdirect.com.au/blog/influential-evs-an-illustrated-history-of-electric-car-design.html