GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Course Title: Electrical and Hybrid Vehicles (GR20A3014)
Following documents are available in Course File.

S.No.	Points	Yes	No
1	Institute and Department Vision and Mission Statements	√	
2	PEO & PO Mapping	√	
3	Academic Calendar	√	
4	Subject Allocation Sheet	√	
5	Class Time Table, Individual Timetable (Single Sheet)	√	
6	Syllabus Copy	√	
7	Course Handout	√	
8	CO-PO Mapping	√	
9	CO-Cognitive Level Mapping	√	
10	Lecture Notes	√	
11	Tutorial Sheets With Solution	√	
12	Soft Copy of Notes/Ppt/Slides	√	
13	Sessional Question Papers and Scheme of Evaluation	√	
14	Best, Average and Weak Answer Scripts for Each Sessional Exam. (Photocopies)	√	
15	Assignment Questions and Solutions	√	
16	Previous Question Papers	√	
17	Result Analysis	√	
18	Feedback From Students	√	
19	CO Attainment for All Mids.	√	
20	Remedial Action.		√

Course Instructor / Course Coordinator **Course Instructor / Course Coordinator)**

DAVU SRINIVASA RAO
Assistant Professor
EEE Department

Vision of the Institute

To be among the best of the institutions for engineers and technologists with attitudes, skills and knowledge and to become an epicentre of creative solutions.

Mission of the Institute

To achieve and impart quality education with an emphasis on practical skills and social relevance

Vision of the Department

To impart technical knowledge and skills required to succeed in life, career and help society to achieve self sufficiency.

Mission of the Department

1. To become an internationally leading department for higher learning.
2. To build upon the culture and values of universal science and contemporary education.
3. To be a center of research and education generating knowledge and technologies which lay groundwork in shaping the future in the fields of electrical and electronics engineering.
4. To develop partnership with industrial, R&D and government agencies and actively participate in conferences, technical and community activities.

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical and Electronics Engineering

This Programme is meant to prepare our students to professionally thrive and to lead.During their progression:

Graduates will be able to

PEO 1: Graduates will have a successful technical or professional careers, including supportive and leadership roles on multidisciplinary teams.

PEO 2: Graduates will be able to acquire, use and develop skills as required for effective professional practices.

PEO 3: Graduates will be able to attain holistic education that is an essential prerequisite for being a responsible member of society.

PEO 4: Graduates will be engaged in life-long learning, to remain abreast in their profession and be leaders in our technologically vibrant society.

Programme Outcomes (B.Tech. – EEE)

At the end of the Programme, a graduate will have the ability to

PO-1: Ability to apply knowledge of mathematics, science, and engineering.

PO-2: Ability to identify, formulate, analyze engineering problems using engineering sciences.

PO-3: Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety..

PO-4: Ability to design and conduct experiments, as well as to analyze and interpret data with valid conclusions.

PO-5: Ability to utilize experimental, statistical and computational methods and tools necessary for modelling engineering activities.

PO-6: Ability to apply reasoning informed by the relative knowledge to evaluate societal, health, safety, legal and cultural issues and tasks applicable to the professional engineering practice.

PO-7: Ability to adapt broad education necessary to understand the impact of engineering solutions and obtain sustainability in a global, economic, environmental, and societal context.

PO-8: Ability to discover ethical principles and bind to professional and ethical responsibility.

PO-9: Ability to function as an individual and in multi-disciplinary teams.

PO-10: Ability to communicate effectively on complex activities in engineering community and society.

PO-11: Ability to develop Project management principles and apply in various disciplinary environments.

PO-12: Recognition of the need for, and an ability to engage in life-long learning

Program Specific Outcomes(PSOs):

PSO-1: Graduates will interpret data and able to analyze digital and analog systems related to electrical and programming them.

PSO-2: Graduates will able to demonstrate, design and model electrical, electronic circuits, power electronics, power systems and electrical machines.

Gokaraju Rangaraju Institute of Engineering and Technology
(Autonomous)
Bachupally, Kukatpally, Hyderabad – 500 090, India

GRIET/DAA/1H/G/22-23 19 July 2022

Academic Calendar
Academic Year 2022-23

III B.Tech. –First Semester

S. No.	EVENT	PERIOD	DURATION
1	Commencement of First Semester class work	08-08-2022	
2	I Spell of Instructions	08-08-2022 to 08-10-2022	9 Weeks
3	I Mid-term Examinations	10-10-2022 to 13-10-2022	3 Days
4	II Spell of Instructions	14-10-2022 to 12-12-2022	9 Weeks
5	II Mid-term Examinations	13-12-2022 to 15-12-2022	3 Days
6	Preparation	16-12-2022 to 22-12-2022	1 Week
7	End Semester Examinations (Theory/ Practical) Regular/ Supplementary	23-12-2022 to 13-01-2023	3 Weeks
8	Commencement of Second Semester, AY 2022-23	16-01-2023	

III B.Tech. – Second Semester

S. No.	EVENT	PERIOD	DURATION
1	Commencement of Second Semester class work	16-01-2023	
2	I Spell of Instructions	16-01-2023 to 16-03-2023	9 Weeks
3	I Mid-term Examinations	17-03-2023 to 20-03-2023	3 Days
4	II Spell of Instructions	21-03-2023 to 29-04-2023	6 Weeks
5	Summer Vacation	01-05-2023 to 20-05-2023	3 Weeks
6	II Spell of Instructions Contd	22-05-2023 to 12-06-2023	3 Weeks
7	II Mid-term Examinations	13-06-2023 to 15-06-2023	3 Days
8	Preparation	16-06-2023 to 22-06-2023	1 Week
9	End Semester Examinations (Theory/ Practical) Regular / Supplementary	23-06-2023 to 15-07-2023	3 Weeks
10	Commencement of IV B.Tech First Semester, AY 2023-24	17-07-2023	

J. Praveen

Gokaraju Rangaraju Institute of Engineering And Technology Griet

Dean Academic Affairs

Copy to Principal, All HoDs, CoE

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY
Department of Electrical and Electronics Engineering

Faculty Work load for the Academic Year 2022-23 / I SEM
Subject Allocation Sheet

S.No.	Faculty	Designation	Faculty ID	YEAR (UG/PG)	Subject Name	No.of Sections	No. of Hours	Total (in Hrs)
2	Dr B Phaneendra Babu	Prof. & HOD	1563	II B.Tech	DCM	1	5	11
				II M.Tech	Dph 1	1	3	
				II M.Tech	DLED	1	3	
3	Dr.D G Padhan	Prof.	1283	III B.Tech	EHV	1	5	11
				I M.Tech	EHV	1	3	
				II M.Tech	IS	1	3	
4	Dr. J. Sridevi	Prof.	516	III B.Tech	PSA	1	6	11
				III B.Tech	PS Lab	1	5	
5	Dr T Suresh Kumar	Prof.	1494	II B.Tech	EMF	1	5	11
				I Mtech	PE Lab	1	3	
				I Mtech	MSPEC	1	3	
6	V.Vijaya Rama Raju	Asso. Prof.	361	II B.Tech	PGT	1	5	11
				II B.Tech	DCM Lab	1	6	
7	P Ravikanth	Asso. Prof.	1178	II B.Tech	PAE	1	5	14
				III B.Tech	NPTEL	1	3	
				IV B.Tech	ED Lab	1	6	
8	A Vinay Kumar	Asso. Prof.	881	IV B.Tech	HVE	2	10	16
				IV B.Tech	PWK	1	3	
				I M.Tech	PQ&FACTS	1	3	

9	Syed Sarfaraz Nawaz	Asso. Prof.	695	Electrical Maintenance Officer				
10	Dr Pakkiraiah B	Asso. Prof.	1593	III B.Tech	PE Lab	1	5	14
				I M.Tech	IPR	1	3	
				III B.Tech	PE Lab	1	6	
11	Dr D Naga Mallesara Rao	Asso. Prof.	1598	IV B.Tech	ED	2	10	16
				IV B.Tech	ED Lab	1	6	
12	Dr P Sri Vidya Devi	Asso. Prof.	931	III B.Tech	MC Lab	1	6	11
				IV B.Tech	PS-III	1	5	
13	Dr D Raveendhra	Asso. Prof.	1604	I M.Tech	MAEM	1	3	11
				I M.Tech	PQ Lab	1	3	
				III B.Tech	MC	1	5	
14	P.Praveen Kumar	Asst. Prof	609	I B.Tech	1 st Year BEE			
15	R. Anil Kumar	Asst. Prof	657	I B.Tech	I st Year BEE			
16	U Vijaya Lakshmi	Asst. Prof	692	II B.Tech	PAE Lab	1	6	15
				III B.Tech	PS Lab	1	6	
				I B.Tech	BEE Lab	1	3	
17	D Karuna Kumar	Asst. Prof	760	II B.Tech	CI	1	2	14
				IV B.Tech	ED Lab	1	6	
				I B.Tech	BEE Lab	2	6	
19	M Naga Sandhya Rani	Asst. Prof	882	III B.Tech	MC Lab	1	6	14
				II B.Tech	BEEE	1	5	
				IV B.Tech	PWK	1	3	
20	G Sandhya Rani	Asst. Prof	888	II B.Tech	ECA	1	5	14

				III B.Tech	PE Lab	1	6	
				IV B.Tech	PWK	1	3	
21	M Rekha	Asst. Prof	933	II B.Tech	DCM Lab	1	6	15
				III B.Tech	PE Lab	1	6	
				I B.Tech	BEE Lab	1	3	
22	V Usha Rani	Asst. Prof	1045	IV B.Tech	ED Lab	1	6	12
				III B.Tech	PS Lab	1	6	
23	P Prashanth Kumar	Asst. Prof	1055	I B.Tech	BEE	1	6	20
				IV B.Tech	PS-III	1	5	
				I B.Tech	BEE Lab	3	9	
24	K Sudha	Asst. Prof	1211	I B.Tech	1 st Year BEE			
25	M Prashanth	Asst. Prof	1279	II B.Tech	PAE Lab	1	6	14
				II B.Tech	VEGC	1	2	
				I B.Tech	BEE Lab	2	6	
26	D Srinivasa Rao	Asst. Prof	1540	IV B.Tech	EHV	2	10	13
				IV B.Tech	PWK	1	3	

Gokaraju Rangaraju Institute of Engineering and Technology

Department of Electrical and Electronics Engineering

GRIET/PRIN/06/G/01/22-23 — **Wef : 08th Jul 2022**

BTech - EEE - A — **III Year - I Semester**

DAY/ HOUR	9:00 - 9:55	9:55- 10:50	10:50 - 11:45	11:45 -12:25	12:25-1:15	1:15 - 2:05	2:05 -2:55
MONDAY	PE	PE	EHV	BREAK	PE Lab (A1)/PS Lab (A2)		
TUESDAY	CC	MC	MC		PSA	PSA	Library
WEDNESDAY	MC	PSA	Mentoring		PS Lab (A1)/MC Lab (A2)		
THURSDAY	PSA	PSA	PE		MC Lab (A1)/PE Lab (A2)		
FRIDAY	EHV	EHV	CC		Library	MC	MC
SATURDAY	CC	PE	PE		Library	EHV	EHV

ROOM NO	
Theory/Tutorial	4402
Lab	PE Lab (4405) MC Lab (4502) PS Lab (4504)
Class Incharge:	G. Sandhya Rani

Subject Code	Subject Name	Faculty Code	Faculty Name
GR20A3012	Power Systems Analysis (PSA)	Dr JSD	Dr J. Sridevi
GR20A3013	Power Electronics (PE)	Dr PB	Dr Pakkiraiah B
GR20A3014	Microprocessors and Microcontrollers (MC)	Dr DR	Dr D Raveendhra
GR20A3015	Electrical and Hybrid Vehicles (EHV)	Dr DGP	Dr D. G. Padhan
	Cloud Computing (CC)	PRK	P. Ravikanth
GR20A3020	Power Systems Lab (PS Lab)	Dr JSD/ VUR/UVL	Dr J. Sridevi/ V. Usharani/ U. Vijayalakshmi
GR20A3021	Power Electronics Lab (PE Lab)	Dr PB/GSR/MRE	Dr. B. Pakkiraiah/G. Sandhya Rani/M Rekha
GR20A3022	Microprocessors and Microcontrollers Lab (MC Lab)	Dr PSVD/MNSR	Dr. P. Srividya Devi/ M. N. Sandhya Rani

Almanac	
1st Spell of Instructions	08-08-2022 to 08-10-2022
1st Mid-term Examinations	10-10-2022 to 13-10-2022
2nd Spell of Instructions	14-10-2022 to 18-12-2022
2nd Mid-term Examinations	09-12-2022 to 13-12-2022
Preparation	14-12-2022 to 20-12-2022
End Semester Examinations (Theory/ Practicals) Regular / Supplementary	21-12-2022 to 10-01-2023
Commencement of Second Semester, A.Y 2022-2023	16-01-2023

Time Table Coordinator **HOD** **DAA**

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY
Department of Electrical and Electronics Engineering

Faculty Name: Dr D G Pradhan							
DAY/ HOUR	**10.20-11.15**	**11.15-12.10**	**12.10-1.05**	**1.05-1.40**	**1.40-2.30**	**2.30 - 3.20**	**3:20 -4.10**
MONDAY			EHV	LUNCH			
TUESDAY							
WEDNESDAY							
THURSDAY							
FRIDAY			EHV				
SATURDAY							EHV

GOKARAJURANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY

ELECTRICAL AND HYBRID VEHICLES
(Professional Elective –I)

Course Code:GR20A3015 **L/T/P/C:3/0/0/3**

III year I semester

COURSE OBJECTIVES

1. Social importance of modern transportation.
2. Demonstrate Vehicle Brake Performance.
3. Analyze power flow control in hybrid drive-train topologies
4. Discuss electric components used in hybrid and electric vehicles.
5. Select the energy storage technology for Hybrid and Electric Vehicles.

COURSE OUTCOMES

1. Summarize the Economic Aspects of EVs compared to ICEs
2. Explain the braking system in EVs and HEVs.
3. Identify various hybrid drive-train topologies
4. Analyze the configuration and control of different motor drives.
5. Interpret the different possible ways of energy storage requirements in Hybrid and Electric Vehicles.

UNITI
ENVIRONMENTAL IMPACT AND HISTORY OF MODERN TRANSPORTATION
Air Pollution and Global Warming, social and environmental importance and Impact of hybrid and electric vehicles, History of Electric Vehicles, History of Hybrid Electric Vehicles, History of Fuel Cell Vehicles.

UNIT II
BRAKING FUNDAMENTALS AND REGENERATIVE BRAKING IN ELECTRIC VEHICLES
General Description of Vehicle Movement, Vehicle Resistance, Dynamic Equation, Tire–Ground Adhesion and Maximum Tractive Effort, Power Train Tractive Effort and Vehicle Speed, Vehicle Power Plant and Transmission Characteristics, Brake Performance.

Braking Energy Consumed in Urban Driving, Importance of Regenerative Braking in Electric and Hybrid Vehicles.

UNIT III
INTRODUCTION TO ELECTRIC AND HYBRID ELECTRIC VEHICLES
Hybrid Electric Drivetrains: Basic concept of hybrid traction, introduction to various hybrid drive-train topologies, power flow control in hybrid drive-train topologies; Introduction to pure EV’s (BEV, FCV).

UNIT IV

ELECTRIC PROPULSION SYSTEMS

Introduction to electric components used in hybrid and electric vehicles, Configuration and control of DC Motor drives, Configuration and control of Induction Motor drives, configuration and control of Permanent Magnet Motor drives, Configuration, and control of Switch Reluctance Motor drives, drive system efficiency.

UNIT V

ENERGY STORAGE REQUIREMENTS IN HYBRID AND ELECTRIC VEHICLES

Introduction to Energy Storage Requirements in Hybrid and Electric Vehicles, Battery based energy storage and its analysis, Fuel Cell based energy storage and its analysis, Super Capacitor based energy storage and its analysis, Flywheel based energy storage and its analysis, Hybridization of different energy storage devices. Sizing the propulsion motor, sizing the power electronics, selecting the energy storage technology, Communications, supporting subsystems.

TEXT BOOKS

1. Mehrdad Ehsani, Yimin Gao, Ali Emadi, “Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals”, CRC Press, 2010.
2. James Larminie, “Electric Vehicle Technology Explained”, John Wiley & Sons, 2003
3. Iqbal Hussain, “Electric & Hybrid Vehicles – Design Fundamentals”, Second Edition, CRC Press, 2011

REFERENCES

1. Hybrid Vehicles and the future of personal transportation, Allen Fuhs, CRC Press, 2011.
2. Vehicle Power Management: Modeling, Control and Optimization, Xi Zhang, Chris Mi, Springer, 2011.

ELECTRIC AND HYBRID VEHICLES(GR20)
Course Handout

S . No.	Unit No.	Date	Topics
UNIT I : Environmental Impact and History of Modern Transportation			
1.	I	8/8/22	Introduction to Electric Vehicles
2.	I	12/8/22	Air Pollution
3.	I	12/8/22	Global Warming
4.	I	13/8/22	Remedies for pollution and global warming
5.	I	13/8/22	social importance
6.	I	22/8/22	Environmental importance
7.	I	26/8/22	Impact of electric vehicles
8.	I	26/8/22	Impact of hybrid vehicles
9.	I	27/8/22	History of Electric Vehicles
10.	I	27/8/22	History of Hybrid Electric Vehicles
11.	I	29/8/22	Introduction to Fuel Cell
12.	I	2/9/22	History of Fuel Cell Vehicles
UNIT II: Braking Fundamentals and Regenerative Braking in Electric Vehicles			
13.	II	2/9/22	General Description of Vehicle Movement
14.	II	3/9/22	Tractive forces and resistive forces
15.	II	3/9/22	Vehicle Resistance
16.	II	5/9/22	Dynamic Equation
17.	II	9/9/22	Numerical problems
18.	II	9/9/22	Tire– Ground Adhesion
19.	II	10/9/22	Maximum Tractive Effort
20.	II	10/9/22	Numerical problems
21.	II	12/9/22	Power Train Tractive Effort

22.	II	16/9/22	Vehicle Speed Expression
23.	II	16/9/22	Vehicle Power Plant Characteristics
24.	II	19/9/22	Transmission Characteristics
25.	II	23/9/22	Brake Performance
26.	II	23/9/22	Numerical problems
27.	II	24/9/22	Braking Energy Consumed in Urban Driving
28.	II	24/9/22	Numerical problems
29.	II	26/9/22	Numerical problems
30.	II	30/9/22	Importance of Regenerative Braking in Electric Vehicles
31.	II	30/9/22	Importance of Regenerative Braking in Hybrid Vehicles
UNIT III: Introduction to Electric and Hybrid Electric Vehicles			
32.	III	1/10/22	Introduction to Hybrid Electric Drivetrains
33.	III	1/10/22	Basic concept of hybrid traction
34.	III	10/10/22	Numerical problems
35.	III	10/10/22	Numerical problems
36.	III	14/10/22	Introduction to various hybrid drive-train topologies
37.	III	14/10/22	Hybrid drive-train topologies
38.	III	15/10/22	Power flow control in hybrid drive-train topologies
39.	III	15/10/22	Power flow control in hybrid drive-train topologies
40.	III	17/10/22	Introduction to pure EV's (BEV)
41.	III	21/10/22	Introduction to pure EV's (FCV)

ELECTRIC AND HYBRID VEHICLES(GR20)
Course Handout

UNIT IV: Electric Propulsion Systems			
42.	IV	21/10/22	Introduction to electric components used in hybrid and electric vehicles
43.	IV	28/10/22	Configuration of DC Motor drives
44.	IV	28/10/22	Control of DC Motor drives
45.	IV	29/10/22	Configuration of Induction Motor drives
46.	IV	29/10/22	Control of Induction Motor drives
47.	IV	31/10/22	Numerical problems
48.	IV	4/11/22	Configuration and control of Permanent Magnet Motor drives
49.	IV	4/11/22	Configuration of Switch Reluctance Motor drives
50.	IV	5/11/22	Control of Switch Reluctance Motor drives
51.	IV	5/11/22	Drive system efficiency
52.	IV	7/11/22	Numerical problems
53.	IV	11/11/22	Numerical problems
UNIT V: Energy Storage Requirements in Hybrid and Electric Vehicles			
54.	V	11/11/22	Introduction to Energy Storage Requirements in Hybrid and Electric Vehicles
55.	V	14/11/22	Energy Storage Requirements in Hybrid and Electric Vehicles
56.	V	18/11/22	Battery based energy storage
57.	V	18/11/22	Battery based energy storage analysis
58.	V	19/11/22	Fuel Cell based energy storage
59.	V	19/11/22	Fuel Cell based energy storage analysis
60.	V	21/11/22	Super Capacitor based energy storage

61.	V	25/11/22	Super Capacitor based energy storage analysis
62.	V	25/11/22	Flywheel based energy storage
63.	V	26/11/22	Flywheel based energy storage analysis
64.	V	26/11/22	Question papers discussion
65.	V	2/12/22	Hybridization of different energy storage devices
66.	V	2/12/22	Hybridization of different energy storage devices
67.	V	3/12/22	Sizing the propulsion motor
68.	V	3/12/22	Sizing the power electronics
69.	V	5/12/22	Selecting the energy storage technology
70.	V	9/12/22	Communications
71.	V	9/12/22	Supporting subsystems

Course Outcomes-Program Outcomes (POs) Relationship Matrix (Relationships are indicated by mark HIGH as "H" and MEDIUM as "M")- COI

		P-Outcomes											
C-Outcomes		1	2	3	4	5	6	7	8	9	10	11	12
	1	M				M			M			M	
	2	M	M		M	M	M	M	H		M	H	H
	3	M				M					M	M	
	4	H	M	M	M	H	M		H	M	M	H	M
	5	M			M	H	M	H	M	M	H	M	M

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY
Department of Electrical and Electronics Engineering

Branch:	Subject Code:	Academic Year:	Regulation:	Year: III
EEE	GR20A3015	2022-23	GR20	Semester: I

ELECTRICAL AND HYBRID VEHICLES (GR20A3015)

L:3 T:0 P:0 C:3

Syllabus

UNIT-I
ENVIRONMENTAL IMPACT AND HISTORY OF MODERN TRANSPORTATION
Air Pollution and Global Warming, social and environmental importance and Impact of hybrid and electric vehicles, History of Electric Vehicles, History of Hybrid Electric Vehicles, History of Fuel Cell Vehicles.

UNIT-II
BRAKING FUNDAMENTALS AND REGENERATIVE BRAKING IN ELECTRIC VEHICLES
General Description of Vehicle Movement, Vehicle Resistance, Dynamic Equation, Tire–Ground Adhesion and Maximum Tractive Effort, Power Train Tractive Effort and Vehicle Speed, Vehicle Power Plant and Transmission Characteristics, Brake Performance.
Braking Energy Consumed in Urban Driving, Importance of Regenerative Braking in Electric and Hybrid Vehicles.

UNIT-III
INTRODUCTION TO ELECTRIC AND HYBRID ELECTRIC VEHICLES
Hybrid Electric Drivetrains: Basic concept of hybrid traction, introduction to various hybrid drive-train topologies, power flow control in hybrid drive-train topologies; Introduction to pure EV's (BEV, FCV).

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Introduction to electric components used in hybrid and electric vehicles, Configuration and control of DC Motor drives, Configuration and control of Induction Motor drives, configuration and control of Permanent Magnet Motor drives, Configuration, and control of Switch Reluctance Motor drives, drive system efficiency.

UNIT-V
ENERGY STORAGE REQUIREMENTS IN HYBRID AND ELECTRIC VEHICLES
Introduction to Energy Storage Requirements in Hybrid and Electric Vehicles, Battery based energy storage and its analysis, FuelCell based energy storage and its analysis, Super Capacitor based energy storage and its analysis, Flywheel based energy storage and its analysis, Hybridization of different energy storage devices. Sizing the propulsion motor, sizing the power electronics, selecting the energy storage technology, Communications, supporting subsystems.

Electric and Hybrid Electric Vehicles

Dr. Dola Gobinda Pradhan

Professor, EEE Department, GRIET

Course Content

UNIT I

ENVIRONMENTAL IMPACT AND HISTORY OF MODERN TRANSPORTATION

Air Pollution and Global Warming, social and environmental importance and Impact of hybrid and electric vehicles, History of Electric Vehicles, History of Hybrid Electric Vehicles, History of Fuel Cell Vehicles.

Development of automobiles

- one of the greatest achievements of modern technology.
- made great contributions to the growth of modern society by satisfying many of its needs for mobility in everyday life
- prompted the progress of human society from a primitive one to a highly developed industrial society
- serve it constitute the backbone of the word's economy and employ the greatest share of the working population

Cons/Difficulties

- large number of automobiles in use around the world has caused and continues to cause serious problems for the environment and human life.

- Air pollution, global warming, and the rapid depletion of the Earth's petroleum resources are now problems of paramount concern.

Remedies

- The research and development activities related to transportation have emphasized the development of high efficiency, clean, and safe transportation.

- Electric vehicles, hybrid electric vehicles, and fuel cell vehicles have been typically proposed to replace conventional vehicles in the near future.

Core Case Study: South Asia's Massive Brown Cloud

- Asian Brown Cloud
- India to Bangladesh to China's Pacific coast
- Pollutants from fires, cars, industry
- Skies permanently gray or brown

Core Case Study: South Asia's Massive Brown Cloud

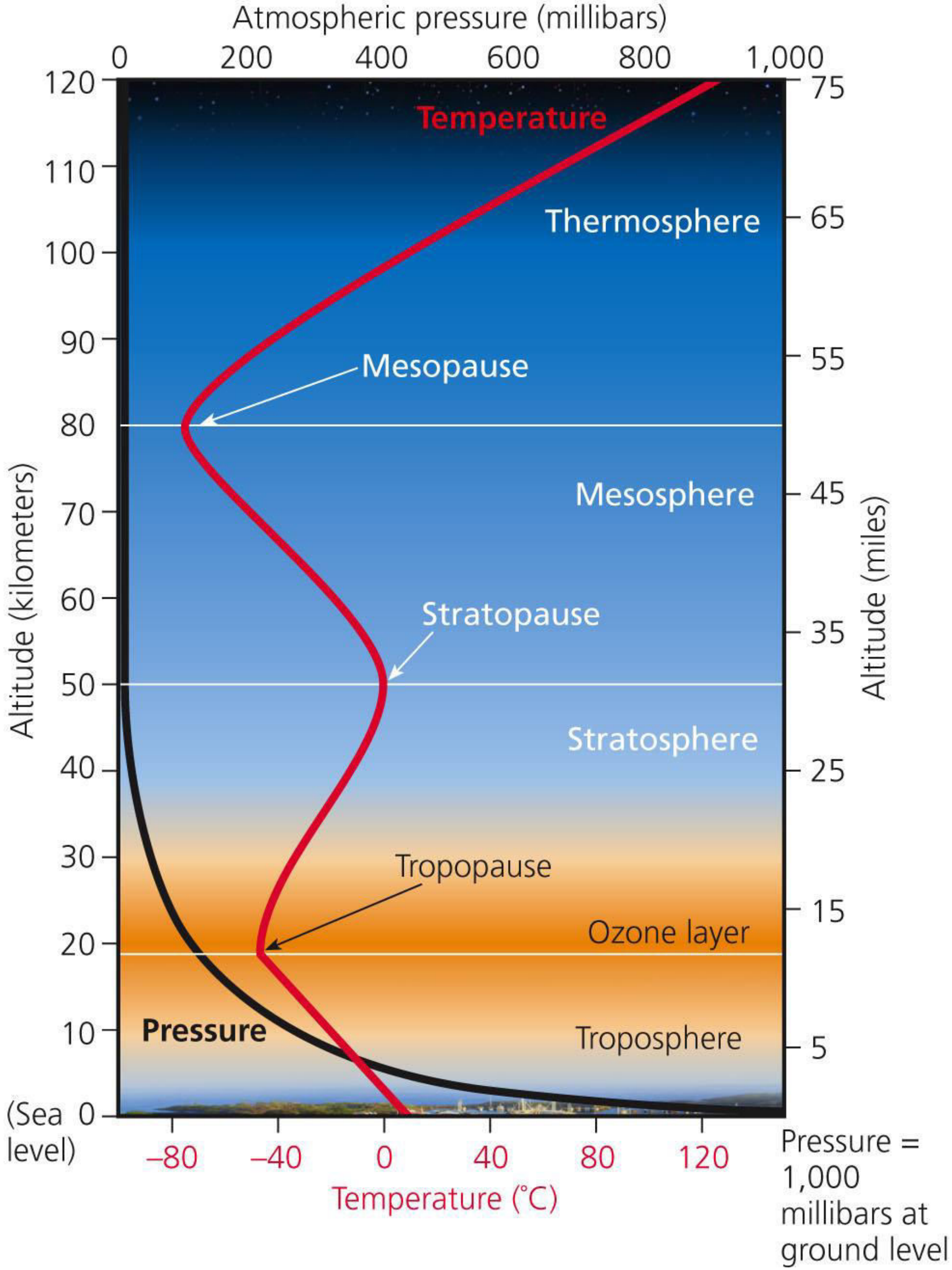
- Changing weather patterns
- 700,000 premature deaths per year
- Has traveled to the west coast of the U.S.
- Made worse by global warming

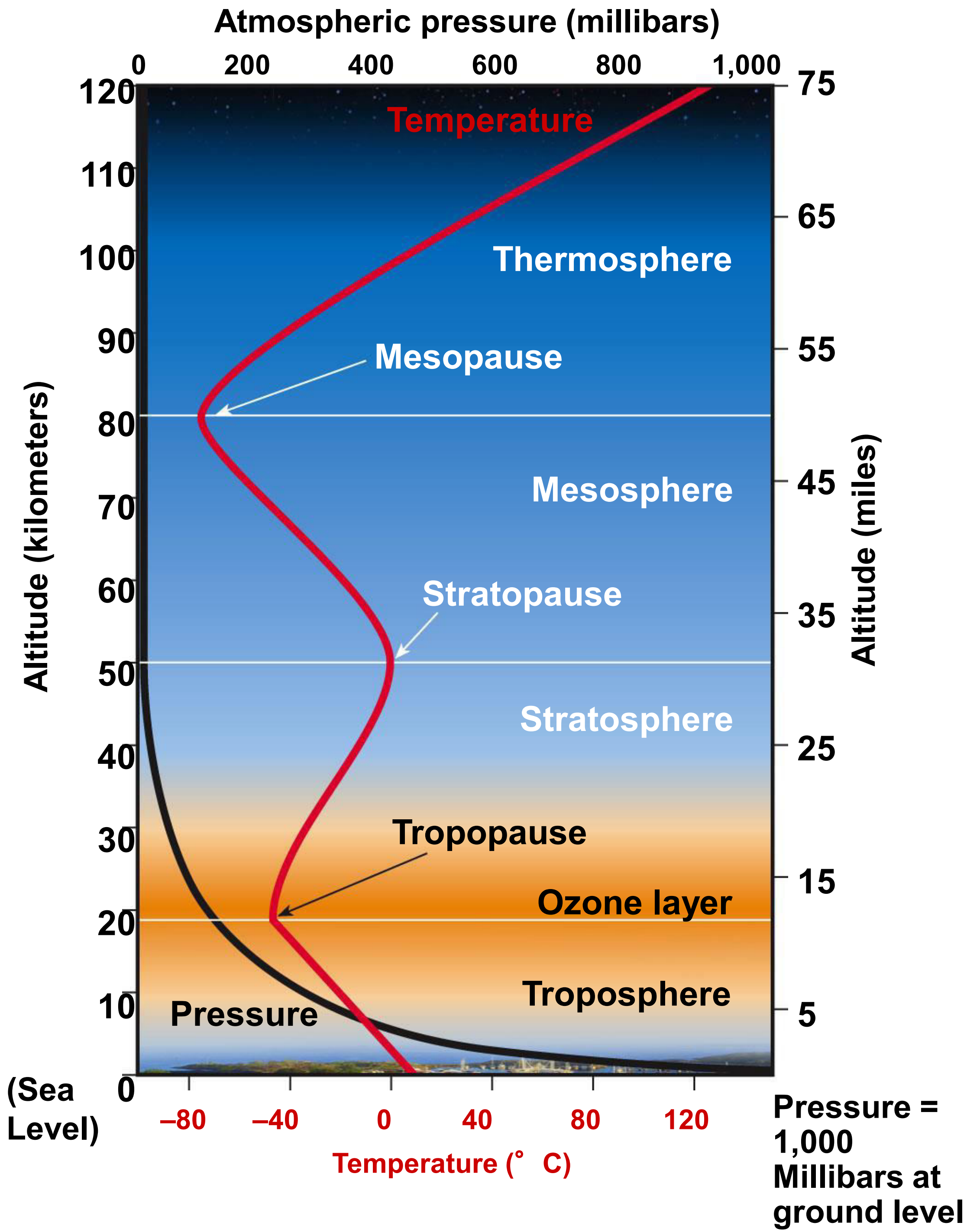
What is the Nature of the Atmosphere?

The two innermost layers of the atmosphere are the troposphere, which supports life, and the stratosphere, which contains the protective ozone layer.

Earth's Atmosphere

- **Troposphere**
  - 5-11 miles above earth's surface
  - 75–80% earth's air mass
  - 78% N_2, 21% O_2
  - Weather and climate
- **Stratosphere**
- **Ozone layer**


Atmospheric pressure (millibars)
0
200
400
600
800
1,000
Altitude (kilometers)
120
110
100
90
80
70
60
50
40
30
20
10
(Sea level) 0
Altitude (miles)
75
65
55
45
35
25
15
5
Temperature
Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Ozone layer
Troposphere
Pressure
–80
–40
0
40
80
120
Temperature (°C)
Pressure = 1,000 millibars at ground level


Atmospheric pressure (millibars)
0
200
400
600
800
1,000
120
110
100
90
80
70
60
50
40
30
20
10
0
(Sea Level)
Altitude (kilometers)
75
65
55
45
35
25
15
5
Altitude (miles)
Temperature
Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Ozone layer
Troposphere
Pressure
–80
–40
0
40
80
120
Temperature (° C)
Pressure = 1,000 Millibars at ground level

What Are the Major Air Pollution Problems?

Three major outdoor air pollution problems are industrial smog from burning coal, photochemical smog from motor vehicle and industrial emissions, and acid deposition from coal burning and motor vehicle exhaust.

What Are the Major Air Pollution Problems?

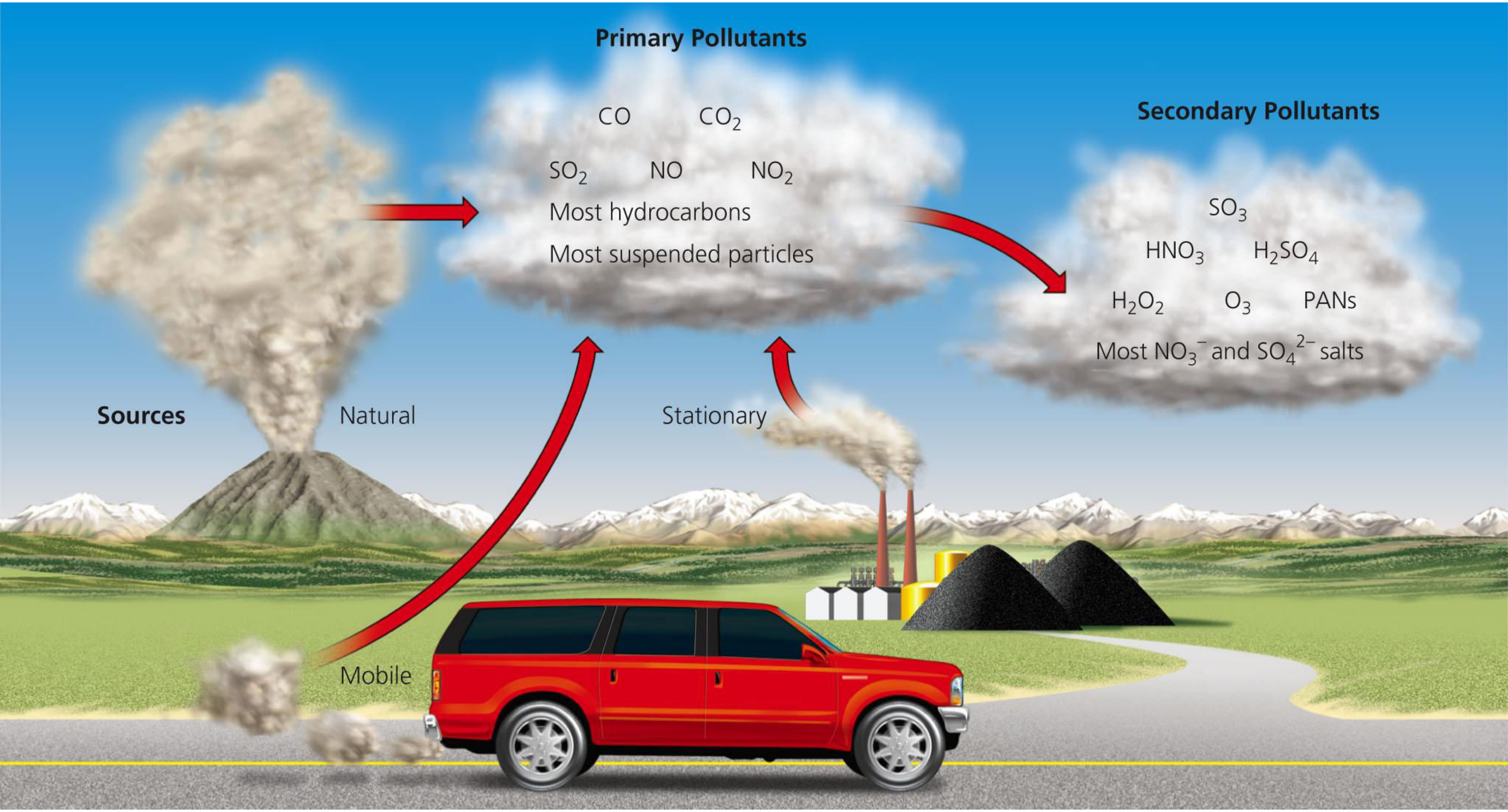
The most threatening indoor air pollutants are smoke and soot from wood and coal fires (mostly in developing countries) and chemicals used in building materials and products.

Outdoor Air Pollution

- What is **air pollution**?
- Stationary and mobile sources
- **Primary pollutants**
- **Secondary pollutants**

Types of Major Air Pollutants

- **Carbon oxides** (CO, CO_2)
- **Nitrogen oxides and nitric acid** (NO, NO_2, HNO_3)
- **Sulfur dioxide and sulfuric acid** (SO_2, H_2SO_4)
- **Particulates** (SPM)
- **Ozone** (O_3)
- **Volatile organic compounds** (VOCs)


Primary Pollutants
CO
CO_2
SO_2
NO
NO_2
Most hydrocarbons
Most suspended particles
Secondary Pollutants
SO_3
HNO_3
H_2SO_4
H_2O_2
O_3
PANs
Most NO_3^- and SO_4^{2-} salts
Sources
Natural
Stationary
Mobile

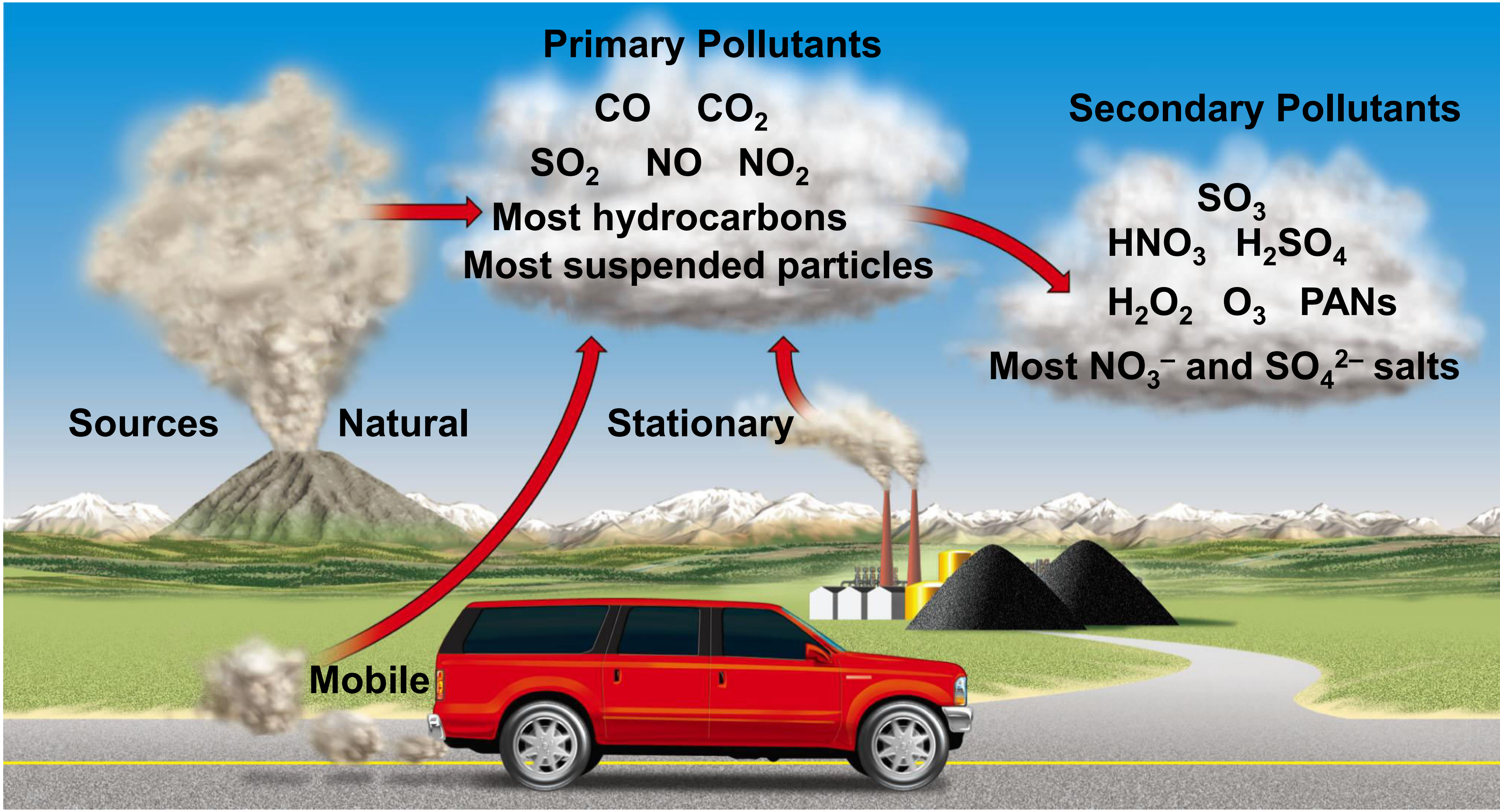

Primary Pollutants
CO CO$_2$
SO$_2$ NO NO$_2$
Most hydrocarbons
Most suspended particles
Secondary Pollutants
SO$_3$
HNO$_3$ H$_2$SO$_4$
H$_2$O$_2$ O$_3$ PANs
Most NO$_3^-$ and SO$_4^{2-}$ salts
Sources
Natural
Stationary
Mobile

Fig. 15-3, p. 371

Industrial Smog

- Burning coal
  - Sulfur dioxide, sulfuric acid, suspended particles
- Developed versus developing countries
  - Air pollution control in the U.S. and Europe
  - China, India, Ukraine

Photochemical Smog

- Photochemical reactions
- **Photochemical smog**
  - Brown-air smog
- Sources
- Health effects
- Urban areas

Natural Factors That Reduce Air Pollution

- Particles heavier than air
- Rain and snow
- Salty sea spray from oceans
- Winds
- Chemical reactions

Natural Factors That Increase Air Pollution

- Urban buildings
- Hills and mountains
- High temperatures
- VOC emissions from certain trees and plants
- Grasshopper effect
- **Temperature inversions**

Acid Deposition

- Sulfur dioxides and nitrogen oxides
- Wet and dry deposition
- Acid rain
- Regional air pollution
  - Midwest coal-burning power plants
  - Prevailing winds

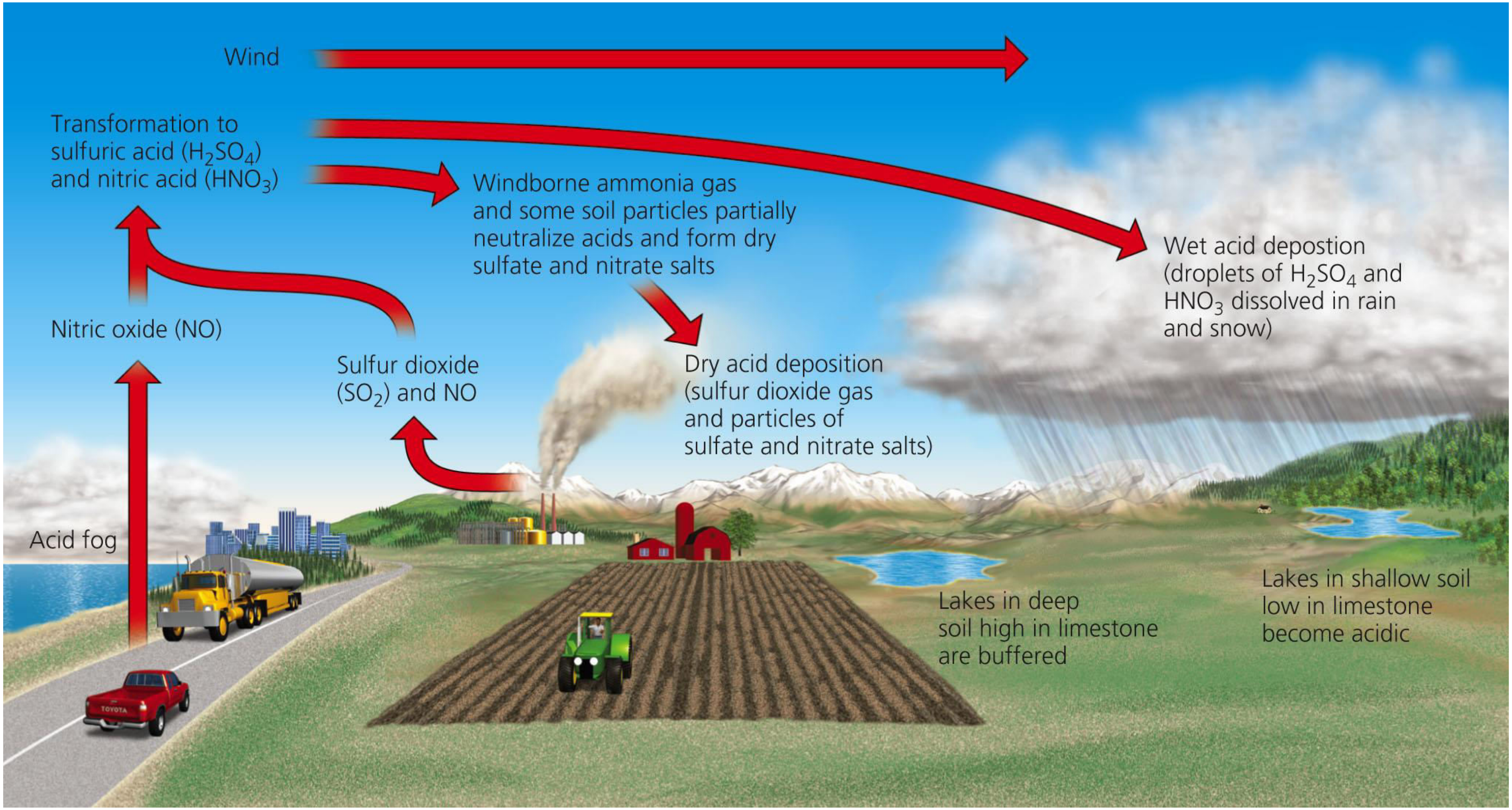

Wind
Transformation to sulfuric acid (H_2SO_4) and nitric acid (HNO_3)
Windborne ammonia gas and some soil particles partially neutralize acids and form dry sulfate and nitrate salts
Wet acid depostion (droplets of H_2SO_4 and HNO_3 dissolved in rain and snow)
Nitric oxide (NO)
Sulfur dioxide (SO_2) and NO
Dry acid deposition (sulfur dioxide gas and particles of sulfate and nitrate salts)
Acid fog
Lakes in deep soil high in limestone are buffered
Lakes in shallow soil low in limestone become acidic

Fig. 15-5, p. 374

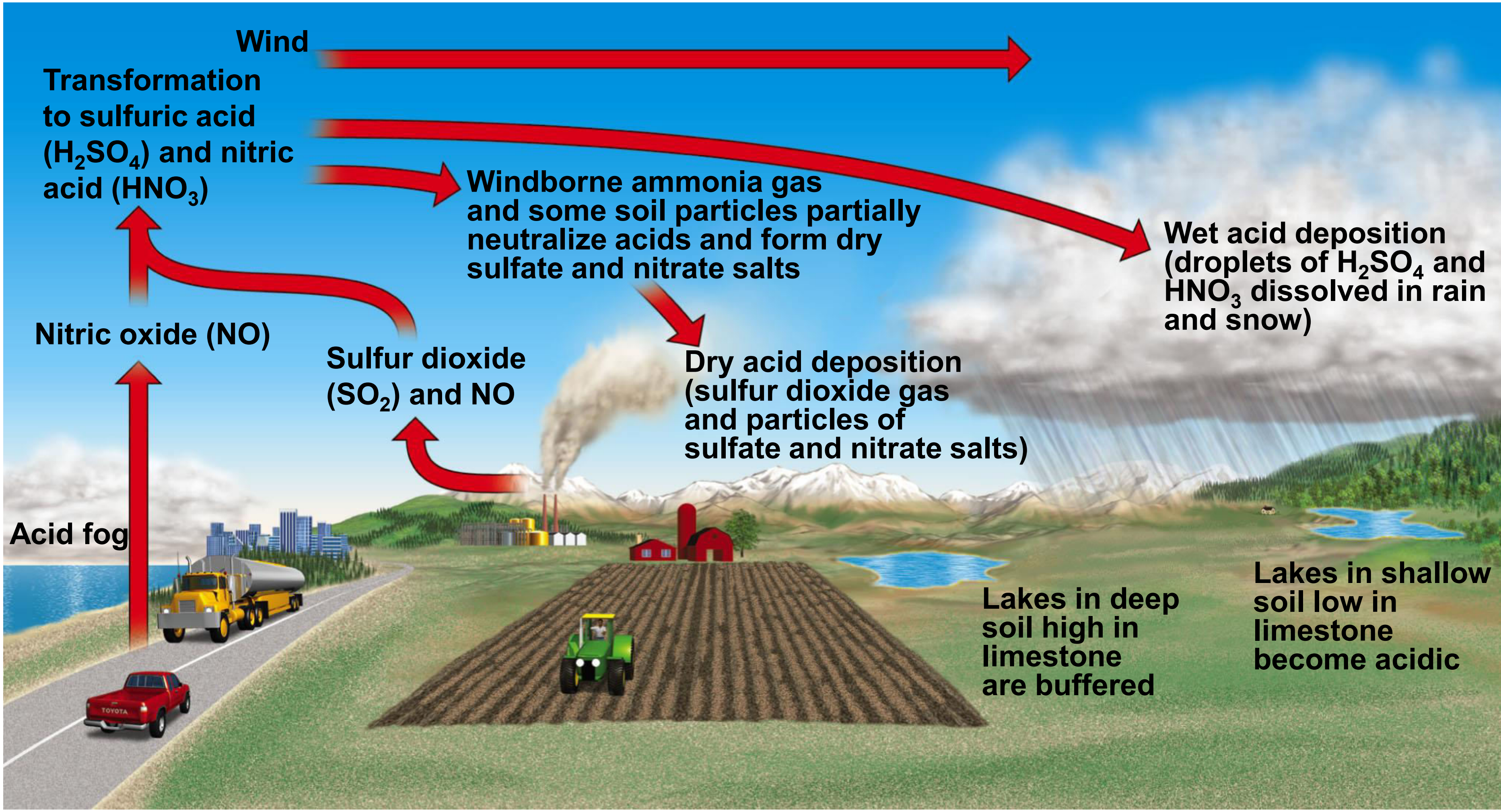

Wind
Transformation to sulfuric acid (H_2SO_4) and nitric acid (HNO_3)
Windborne ammonia gas and some soil particles partially neutralize acids and form dry sulfate and nitrate salts
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Fig. 15-5, p. 374

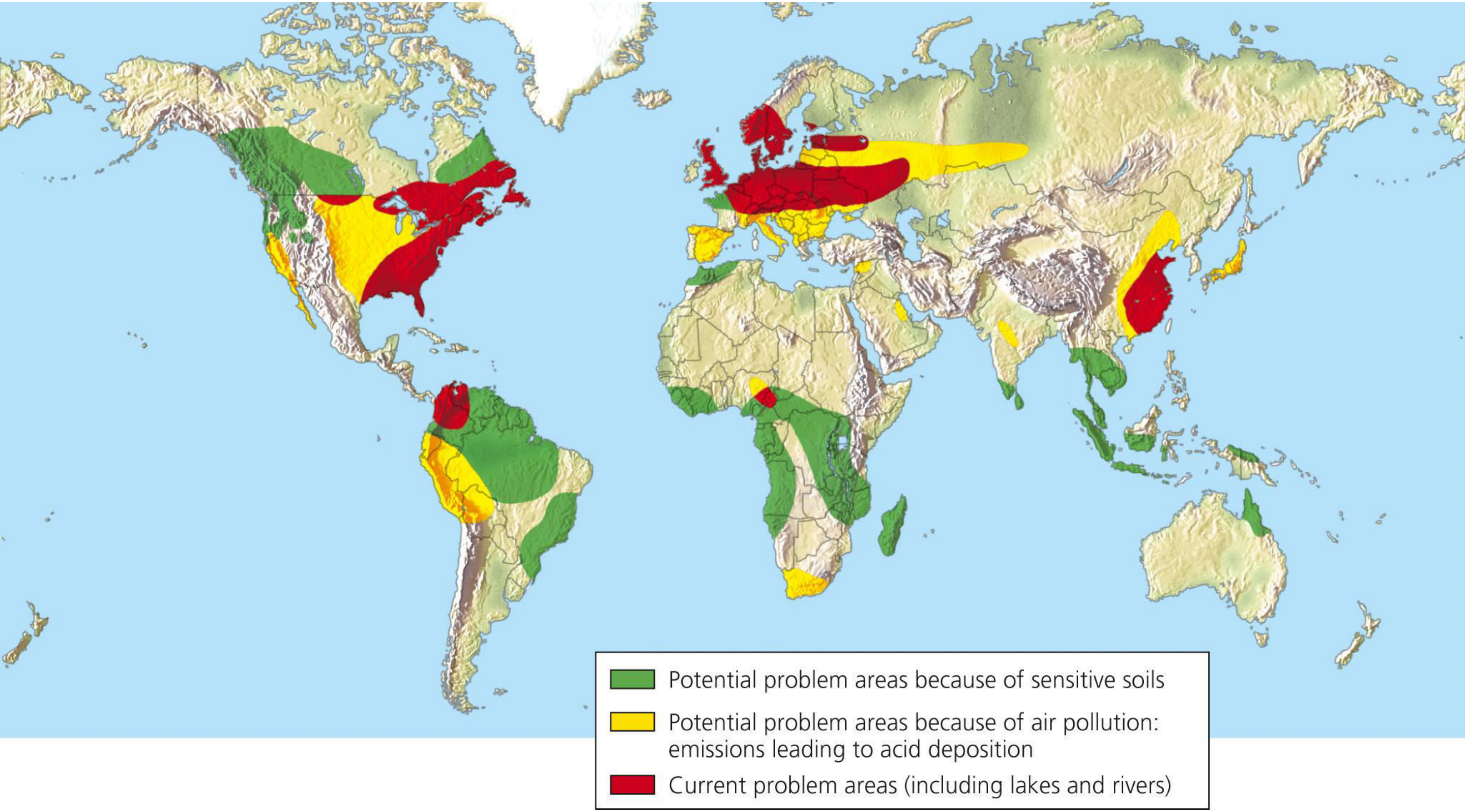

Potential problem areas because of sensitive soils
Potential problem areas because of air pollution: emissions leading to acid deposition
Current problem areas (including lakes and rivers)

Fig. 15-6, p. 375

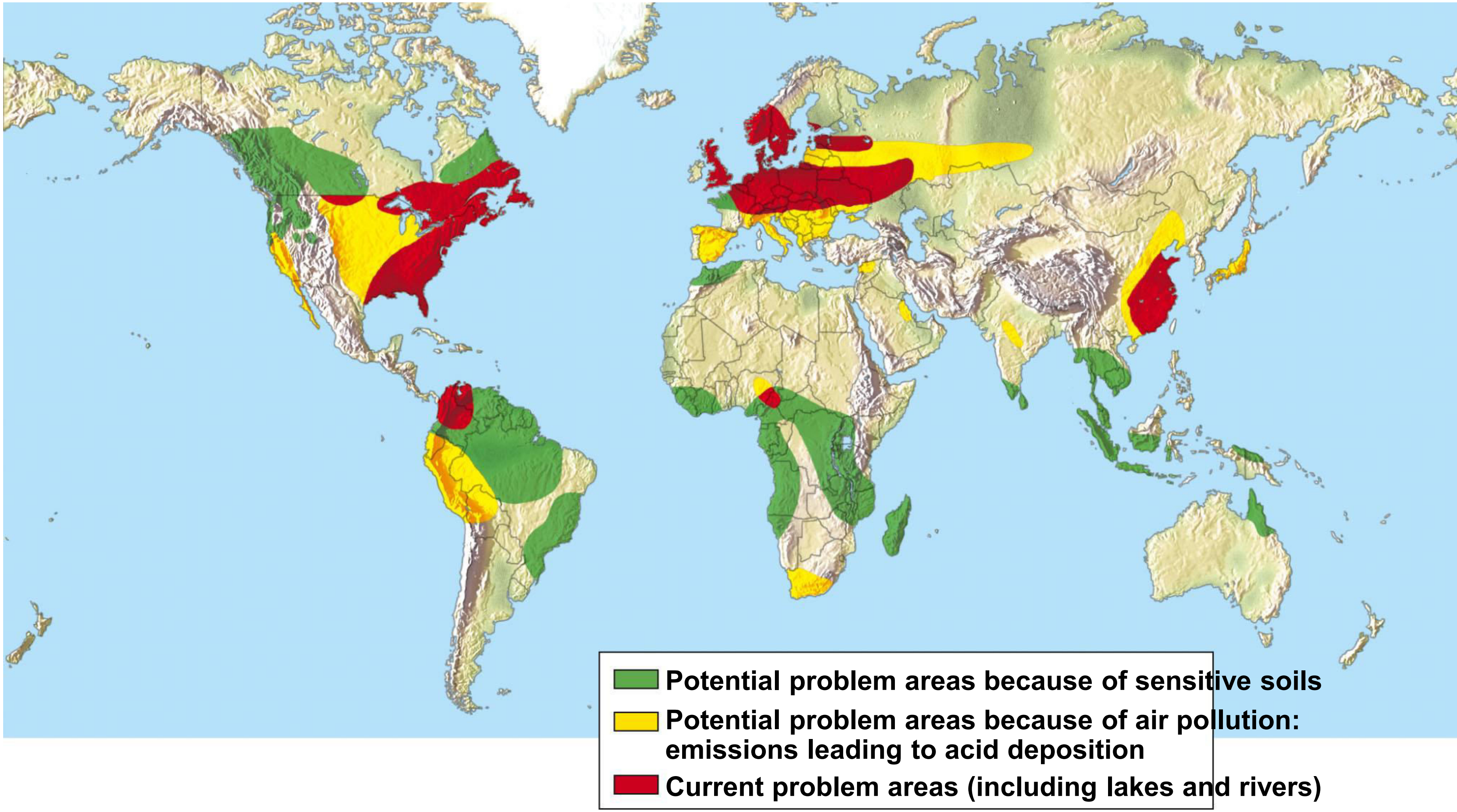

Potential problem areas because of sensitive soils
Potential problem areas because of air pollution: emissions leading to acid deposition
Current problem areas (including lakes and rivers)

Fig. 15-6, p. 375

Harmful Effects of Acid Deposition

- Structural damage
- Respiratory diseases in humans
- Toxic metal leaching
- Kills fish and other aquatic organisms
- Leaches plant nutrients from soil
- Acid clouds and fog at mountaintops

Solutions

Acid Deposition

Prevention

Reduce coal use

Burn low-sulfur coal

Increase natural gas use

Increase use of renewable energy resources

Remove SO_2 particulates and NO_x from smokestack gases

Remove NO_x from motor vehicular exhaust

Tax emissions of SO_2

Reduce air pollution by improving energy efficiency

Cleanup

Add lime to neutralize acidified lakes

Add phosphate fertilizer to neutralize acidified lakes

Fig. 15-7, p. 376

Solutions

Acid Deposition

Prevention

Reduce coal use

Burn low-sulfur coal

Increase natural gas use

Increase use of renewable energy resources

Remove SO_2 particulates and NO_x from smokestack gases

Remove NO_x from motor vehicular exhaust

Tax emissions of SO_2

Reduce air pollution by improving energy efficiency

Cleanup

Add lime to neutralize acidified lakes

Add phosphate fertilizer to neutralize acidified lakes

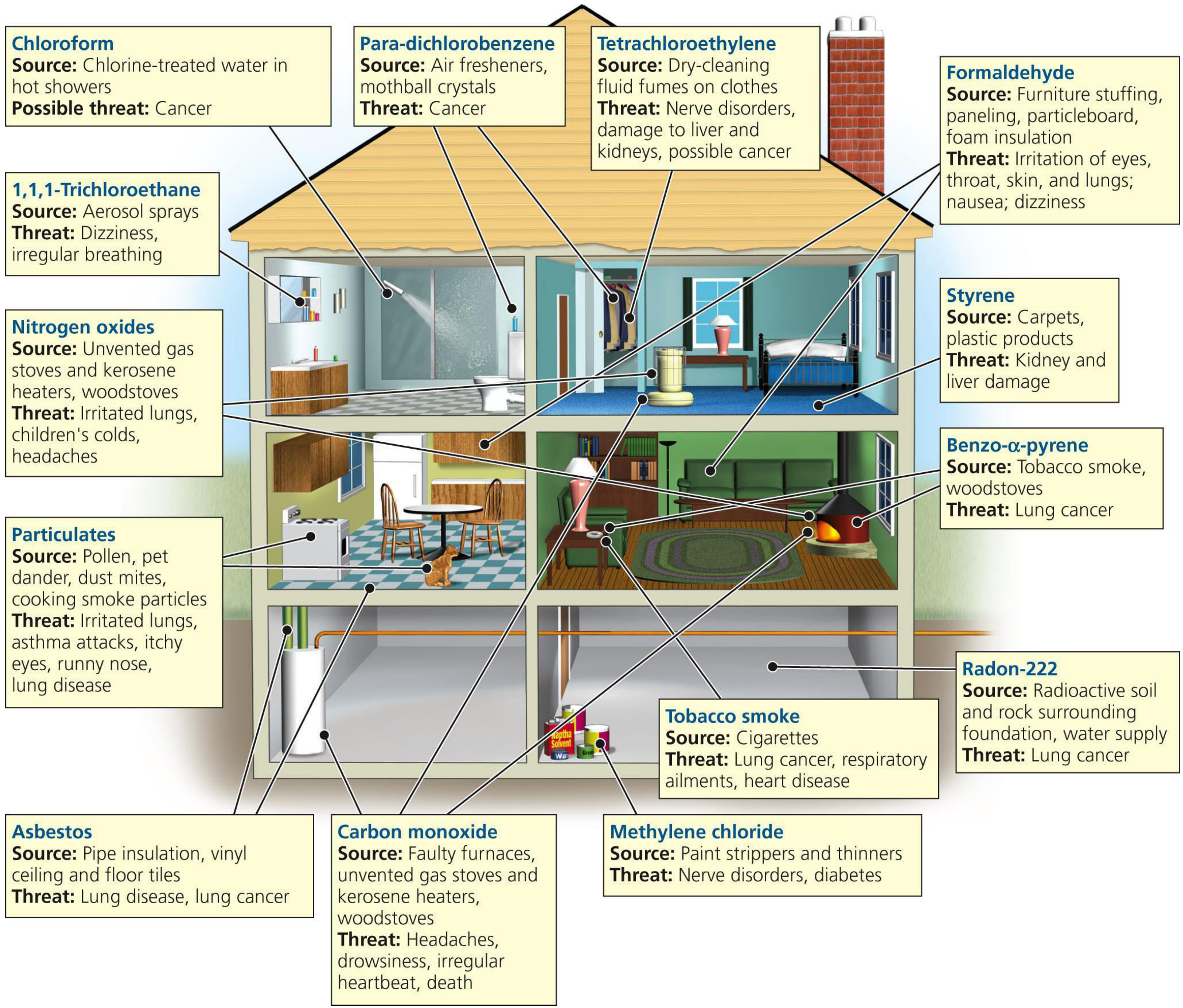
Fig. 15-7, p. 376

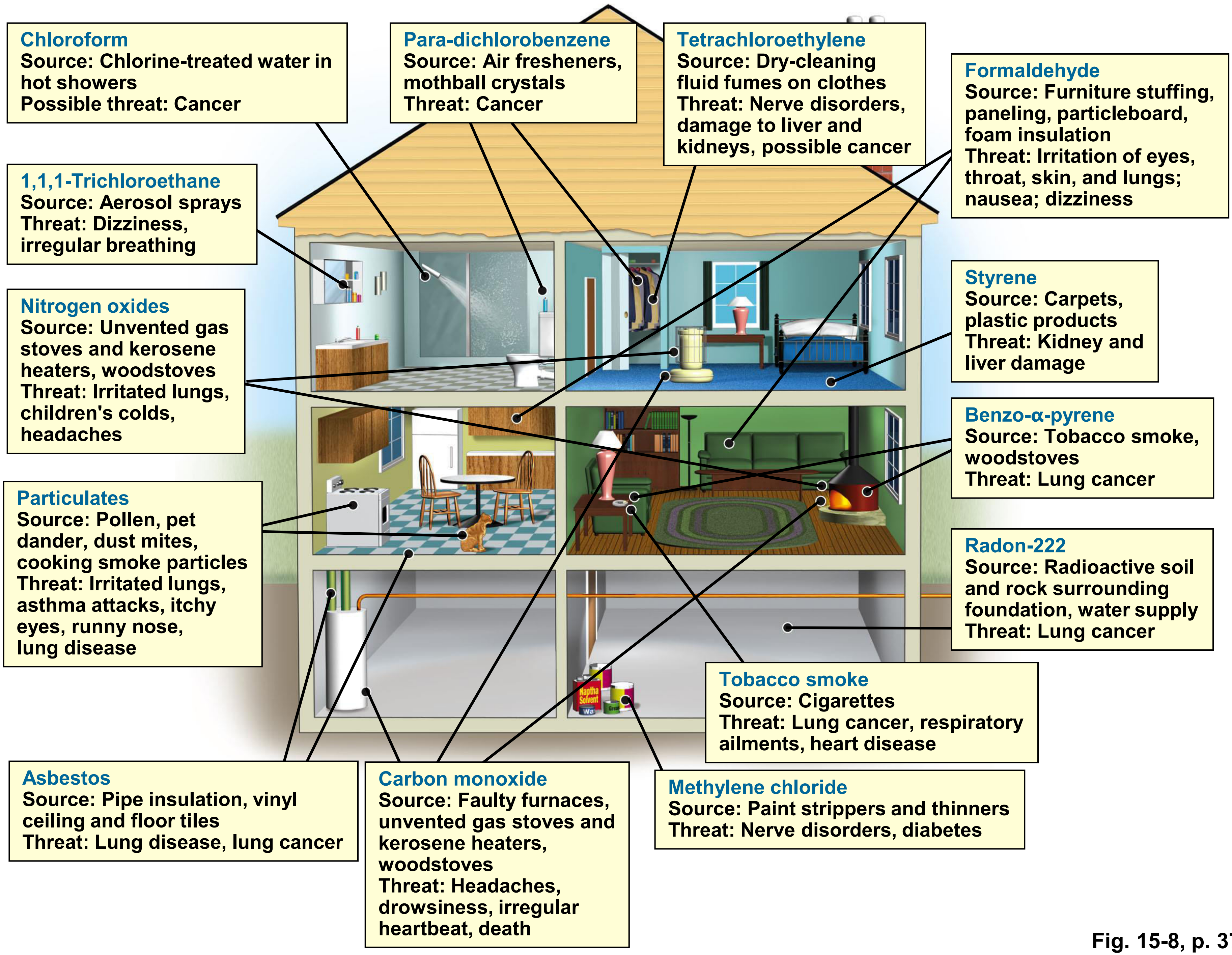
Indoor Air Pollution

- Developing countries
  - Indoor cooking and heating
- Often higher concentration in buildings and cars
- Most time is spent indoors or in cars
- EPA – top cancer risk

Major Indoor Air Pollutants

- Tobacco smoke
- Formaldehyde
- Radioactive radon-222 gas
- Very small particles


Chloroform
Source: Chlorine-treated water in hot showers
Possible threat: Cancer
Para-dichlorobenzene
Source: Air fresheners, mothball crystals
Threat: Cancer
Tetrachloroethylene
Source: Dry-cleaning fluid fumes on clothes
Threat: Nerve disorders, damage to liver and kidneys, possible cancer
Formaldehyde
Source: Furniture stuffing, paneling, particleboard, foam insulation
Threat: Irritation of eyes, throat, skin, and lungs; nausea; dizziness
1,1,1-Trichloroethane
Source: Aerosol sprays
Threat: Dizziness, irregular breathing
Styrene
Source: Carpets, plastic products
Threat: Kidney and liver damage
Nitrogen oxides
Source: Unvented gas stoves and kerosene heaters, woodstoves
Threat: Irritated lungs, children's colds, headaches
Benzo-α-pyrene
Source: Tobacco smoke, woodstoves
Threat: Lung cancer
Particulates
Source: Pollen, pet dander, dust mites, cooking smoke particles
Threat: Irritated lungs, asthma attacks, itchy eyes, runny nose, lung disease
Radon-222
Source: Radioactive soil and rock surrounding foundation, water supply
Threat: Lung cancer
Tobacco smoke
Source: Cigarettes
Threat: Lung cancer, respiratory ailments, heart disease
Asbestos
Source: Pipe insulation, vinyl ceiling and floor tiles
Threat: Lung disease, lung cancer
Carbon monoxide
Source: Faulty furnaces, unvented gas stoves and kerosene heaters, woodstoves
Threat: Headaches, drowsiness, irregular heartbeat, death
Methylene chloride
Source: Paint strippers and thinners
Threat: Nerve disorders, diabetes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Source: Chlorine-treated water in hot showers
Possible threat: Cancer
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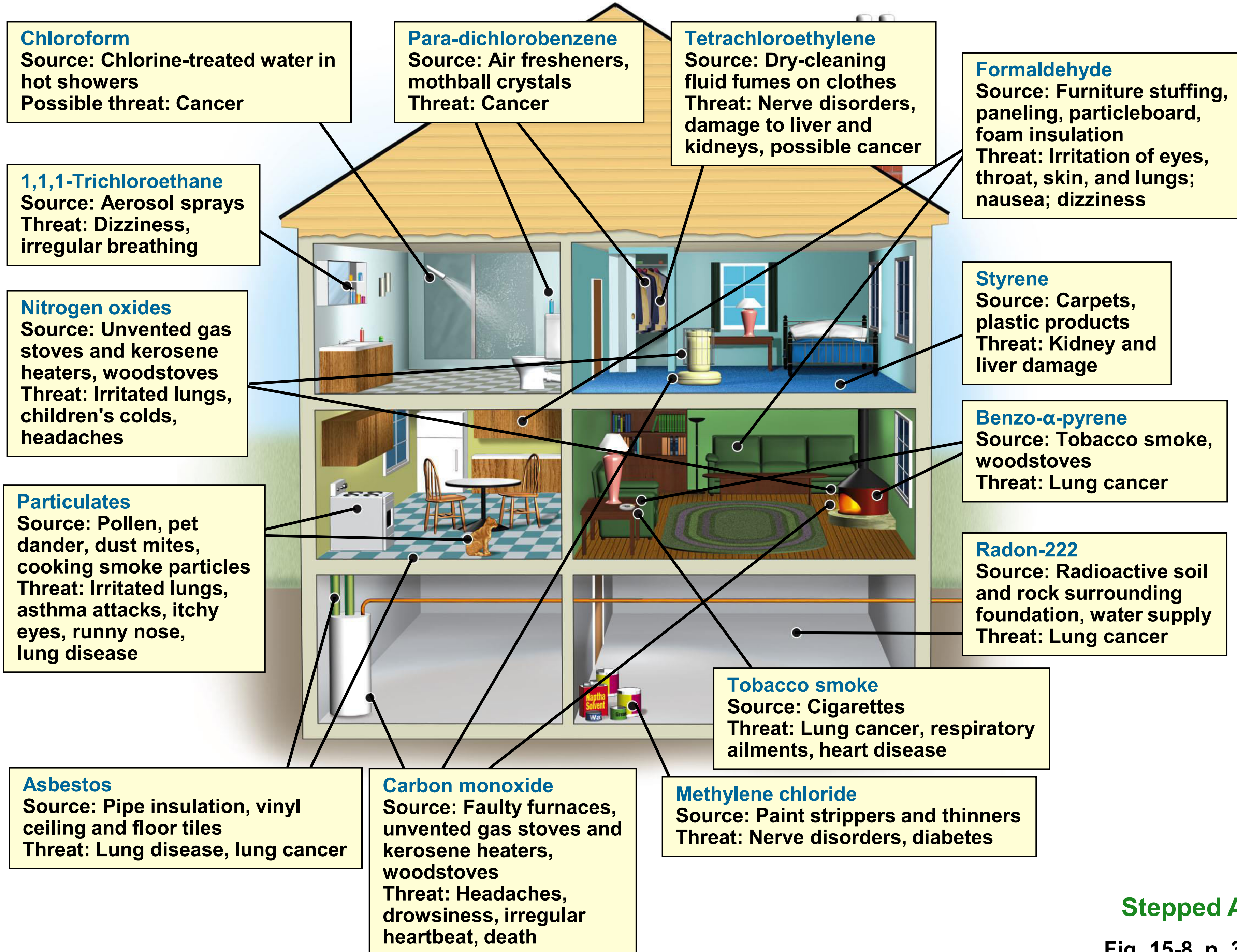
Threat: Headaches, drowsiness, irregular heartbeat, death
Methylene chloride
Source: Paint strippers and thinners
Threat: Nerve disorders, diabetes

Fig. 15-8, p. 377

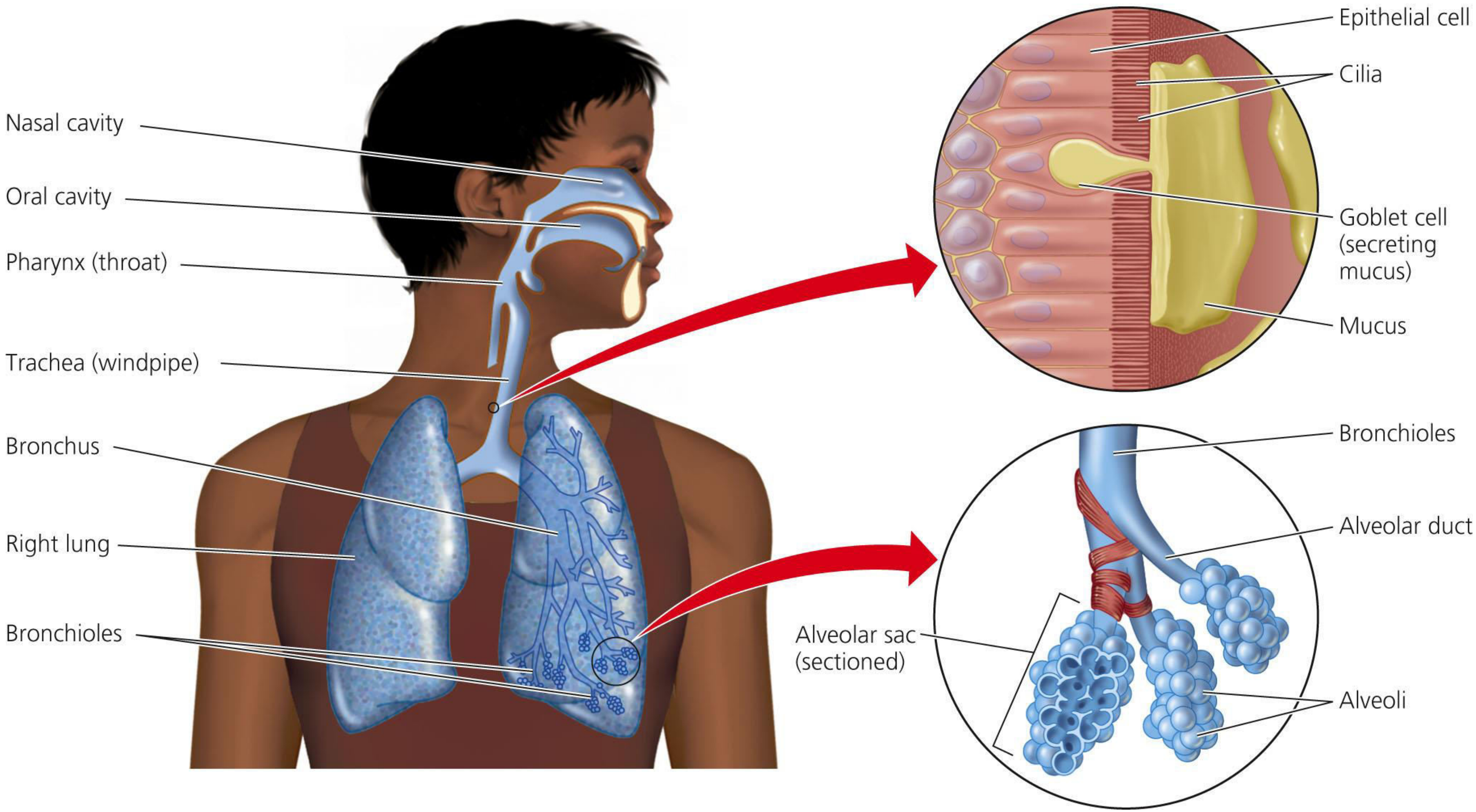


Stepped Art

Fig. 15-8, p. 377

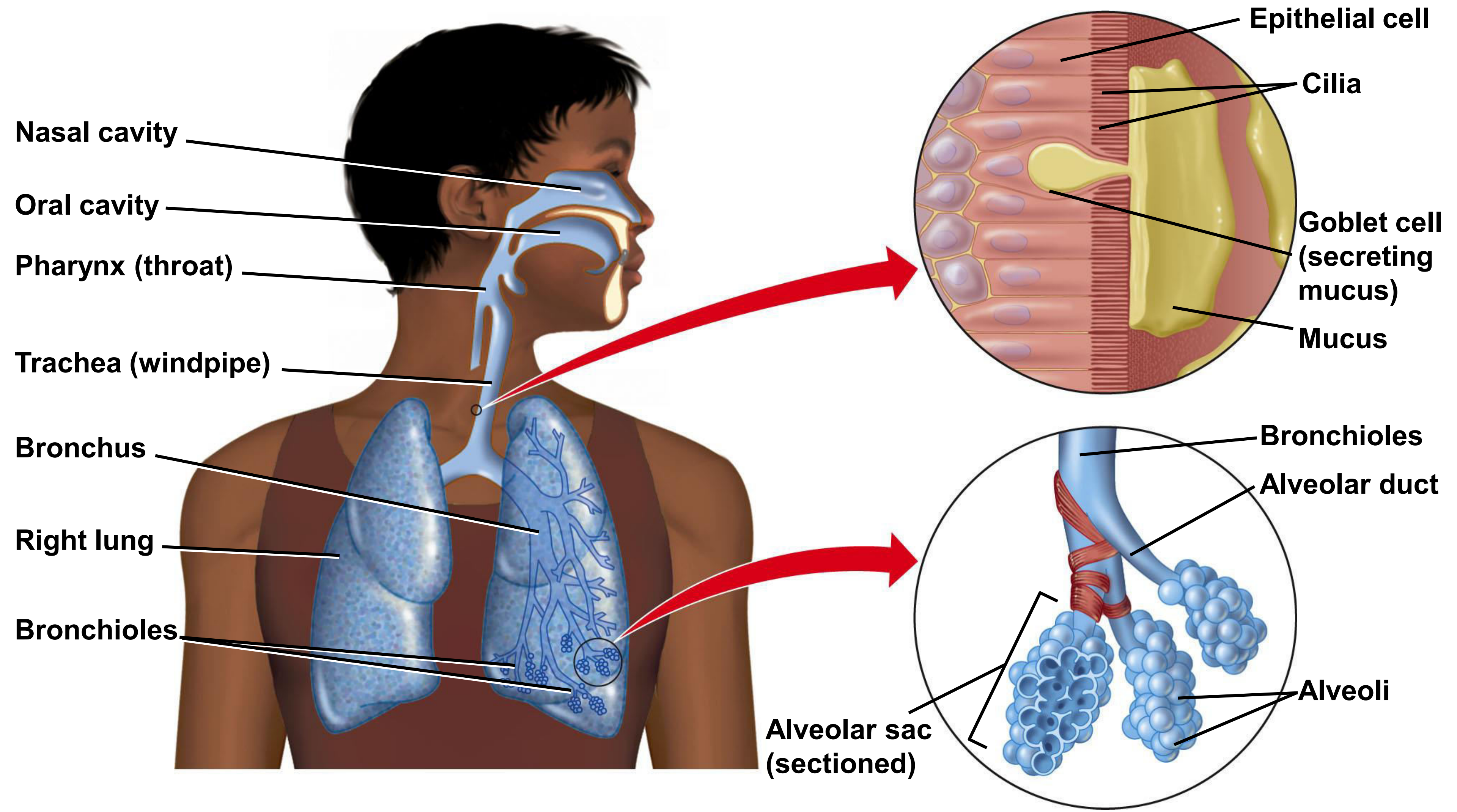
Air Pollution and the Human Respiratory System

- Natural protective system
- Lung cancer, chronic bronchitis, emphysema, asthma
- Premature deaths
- Air pollution kills 2.4 million people prematurely every year



Nasal cavity
Oral cavity
Pharynx (throat)
Trachea (windpipe)
Bronchus
Right lung
Bronchioles
Epithelial cell
Cilia
Goblet cell (secreting mucus)
Mucus
Bronchioles
Alveolar duct
Alveolar sac (sectioned)
Alveoli

Fig. 15-9, p. 378


Nasal cavity
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Pharynx (throat)
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Bronchus
Right lung
Bronchioles
Epithelial cell
Cilia
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Mucus
Bronchioles
Alveolar duct
Alveoli
Alveolar sac (sectioned)

Fig. 15-9, p. 378

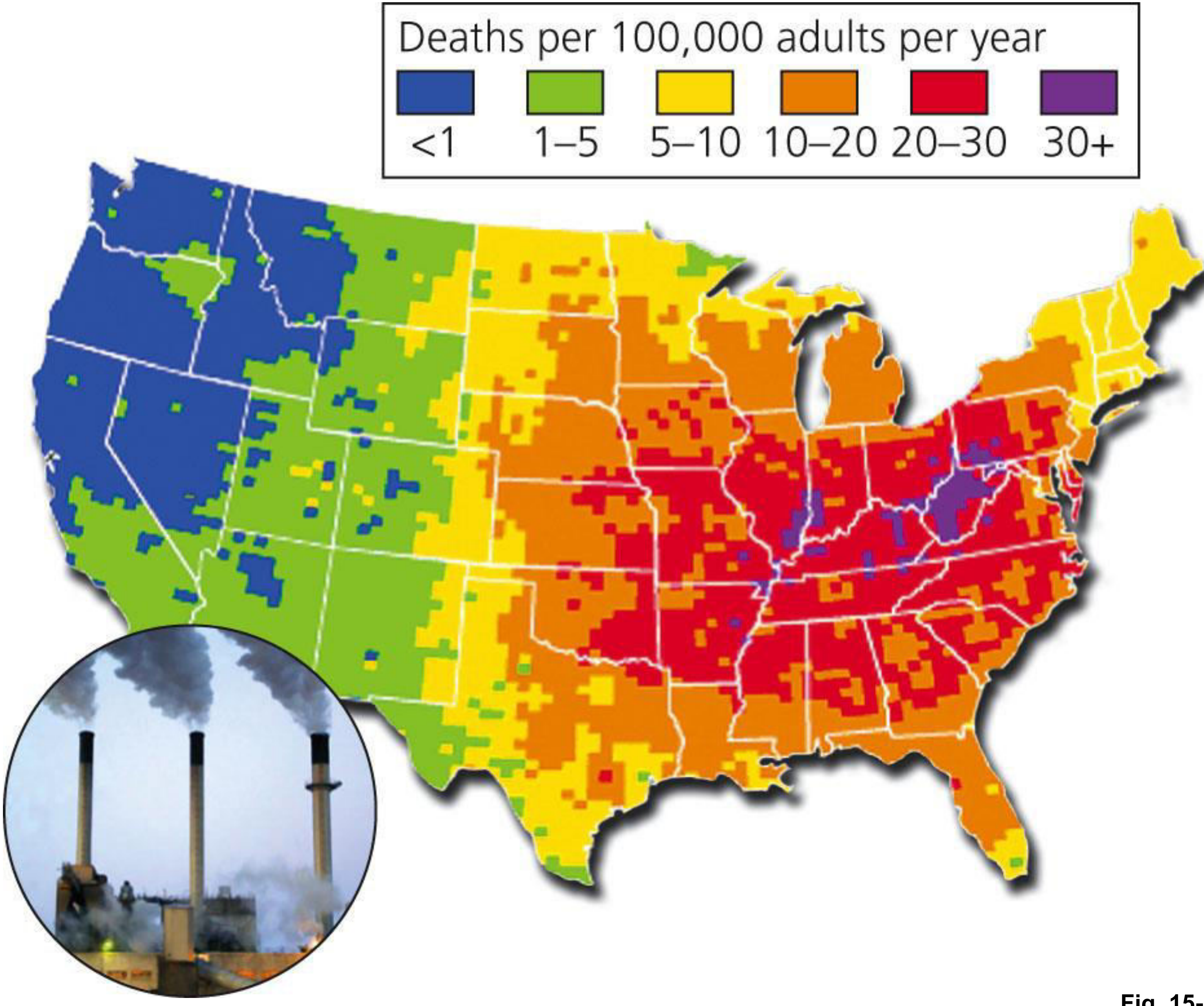

Fig. 15-10, p. 378

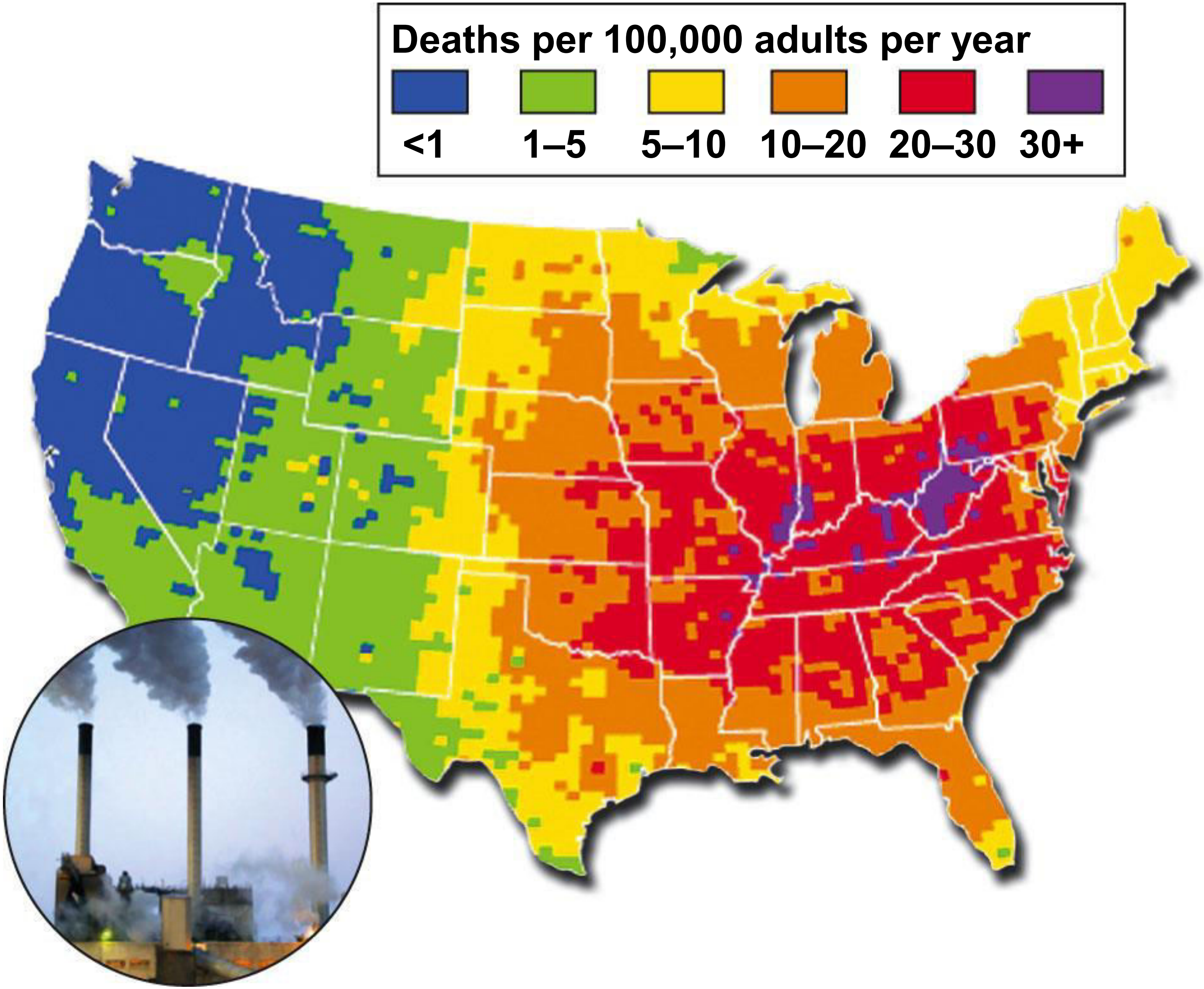

Fig. 15-10, p. 378

Solutions

Stationary Source Air Pollution

Prevention		Dispersion or Cleanup
Burn low-sulfur coal		Disperse emissions above thermal inversion layer with tall smokestacks
Remove sulfur from coal		
Convert coal to a liquid or gaseous fuel		Remove pollutants after combustion
Shift to less polluting energy sources		Tax each unit of pollution produced

Fig. 15-11, p. 380

Solutions

Stationary Source Air Pollution

Prevention

Burn low-sulfur coal

Remove sulfur from coal

Convert coal to a liquid or gaseous fuel

Shift to less polluting energy sources

Dispersion or Cleanup

Disperse emissions above thermal inversion layer with tall smokestacks

Remove pollutants after combustion

Tax each unit of pollution produced

Fig. 15-11, p. 380

Solutions

Motor Vehicle Air Pollution

Prevention		Cleanup
Use mass transit		Require emission control devices
Walk or bike		
Use less polluting fuels		
Improve fuel efficiency		Inspect car exhaust systems twice a year
Get older, polluting cars off the road		
Give large tax write-offs or rebates for buying low-polluting, energy efficient vehicles		Set strict emission standards

Fig. 15-12, p. 381

Solutions

Motor Vehicle Air Pollution

Prevention

Use mass transit

Walk or bike

Use less polluting fuels

Improve fuel efficiency

Get older, polluting cars off the road

Give large tax write-offs or rebates for buying low-polluting, energy efficient vehicles

Cleanup

Require emission control devices

Inspect car exhaust systems twice a year

Set strict emission standards

Fig. 15-12, p. 381

Solutions

Indoor Air Pollution

Prevention

Clean ceiling tiles and line AC ducts to prevent release of mineral fibers

Ban smoking or limit it to well-ventilated areas

Set stricter formaldehyde emissions standards for carpet, furniture, and building materials

Prevent radon infiltration

Use office machines in well-ventilated areas

Use less polluting substitutes for harmful cleaning agents, paints, and other products

Cleanup or Dilution

Use adjustable fresh air vents for work spaces

Increase intake of outside air

Change air more frequently

Circulate a building's air through rooftop greenhouses

Use efficient venting systems for wood-burning stoves

Use exhaust hoods for stoves and appliances burning natural gas

Fig. 15-13, p. 381

Solutions

Indoor Air Pollution

Prevention

Clean ceiling tiles and line AC ducts to prevent release of mineral fibers

Ban smoking or limit it to well-ventilated areas

Set stricter formaldehyde emissions standards for carpet, furniture, and building materials

Prevent radon infiltration

Use office machines in well-ventilated areas

Use less polluting substitutes for harmful cleaning agents, paints, and other products

Cleanup or Dilution

Use adjustable fresh air vents for work spaces

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Change air more frequently

Circulate a building's air through rooftop greenhouses

Use efficient venting systems for wood-burning stoves

Use exhaust hoods for stoves and appliances burning natural gas

Fig. 15-13, p. 381

What Can You Do?

Indoor Air Pollution

- Test for radon and formaldehyde inside your home and take corrective measures as needed
- Do not buy furniture and other products containing formaldehyde
- Remove your shoes before entering your house to reduce inputs of dust, lead, and pesticides
- Test your house or workplace for asbestos fiber levels, and check for any crumbling asbestos materials if it was built before 1980
- Do not store gasoline, solvents, or other volatile hazardous chemicals inside a home or attached garage
- If you smoke, do it outside or in a closed room vented to the outside
- Make sure that wood-burning stoves, fireplaces, and kerosene and gas-burning heaters are properly installed, vented, and maintained
- Install carbon monoxide detectors in all sleeping areas

Fig. 15-14, p. 381

Solutions

Air Pollution

Outdoor

Improve energy efficiency to reduce fossil fuel use

Rely more on lower-polluting natural gas

Rely more on renewable energy (especially solar cells, wind, geothermal and solar-produced hydrogen)

Transfer energy efficiency, renewable energy, and pollution prevention technologies to developing countries

Indoor

Reduce poverty

Distribute cheap and efficient cookstoves or solar cookers to poor families in developing countries

Reduce or ban indoor smoking

Develop simple and cheap tests for indoor pollutants such as particulates, radon, and formaldehyde

Fig. 15-15, p. 382

Solutions

Air Pollution

Outdoor

Improve energy efficiency to reduce fossil fuel use

Rely more on lower-polluting natural gas

Rely more on renewable energy (especially solar cells, wind, geothermal and solar-produced hydrogen)

Transfer energy efficiency, renewable energy, and pollution prevention technologies to developing countries

Indoor

Reduce poverty

Distribute cheap and efficient cookstoves or solar cookers to poor families in developing countries

Reduce or ban indoor smoking

Develop simple and cheap tests for indoor pollutants such as particulates, radon, and formaldehyde

Fig. 15-15, p. 382

How Might the Earth's Climate Change in the Future?

Considerable scientific evidence indicates that emissions of greenhouse gases into the earth's atmosphere from human activities will lead to significant climate change during this century.

Past Climate Changes

- Glacial and interglacial periods
- Global cooling and global warming
- Measurement of past temperature changes
  - Rocks and fossils
  - Ice cores from glaciers
  - Tree rings
  - Historical measurements since 1861

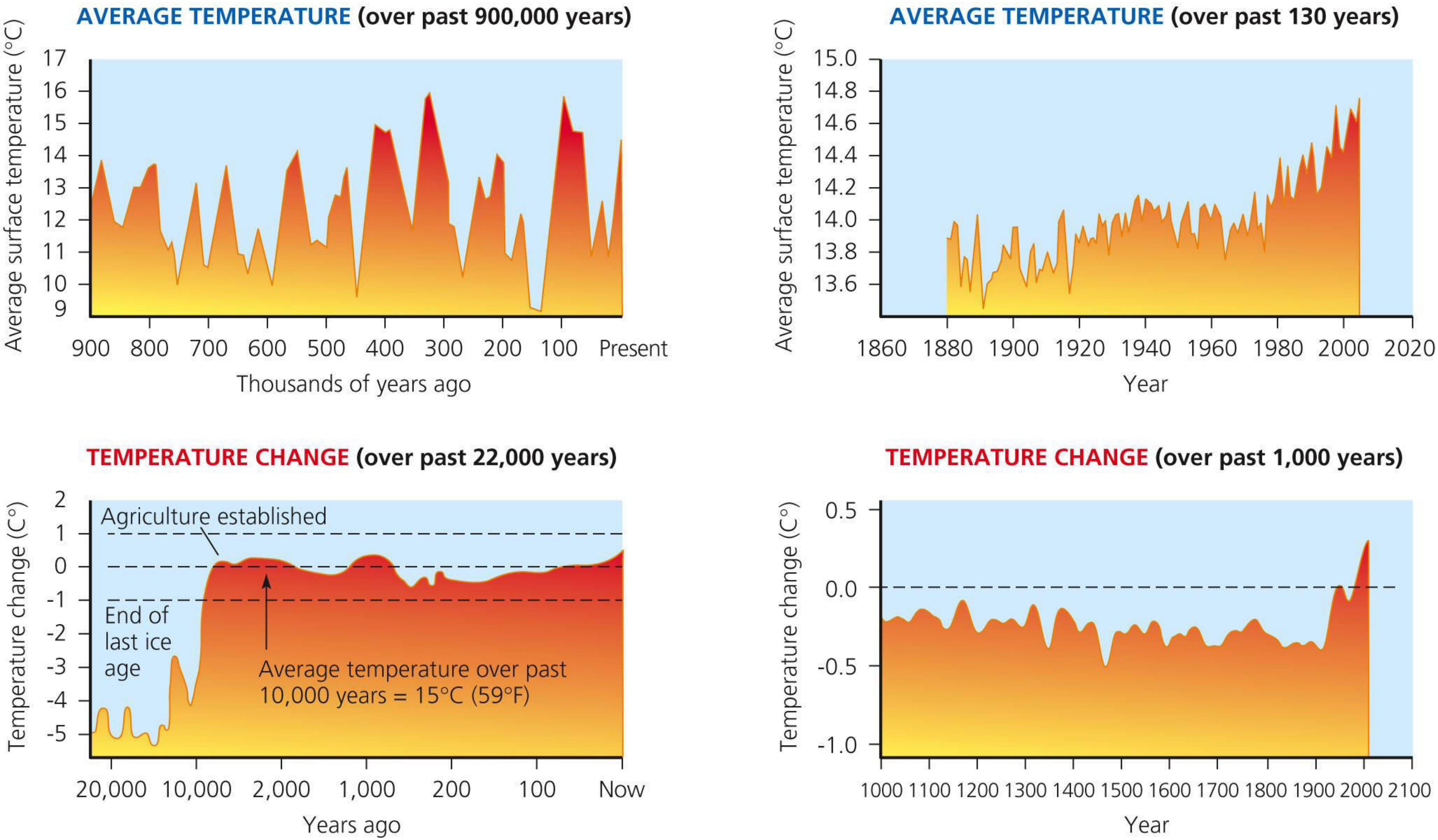
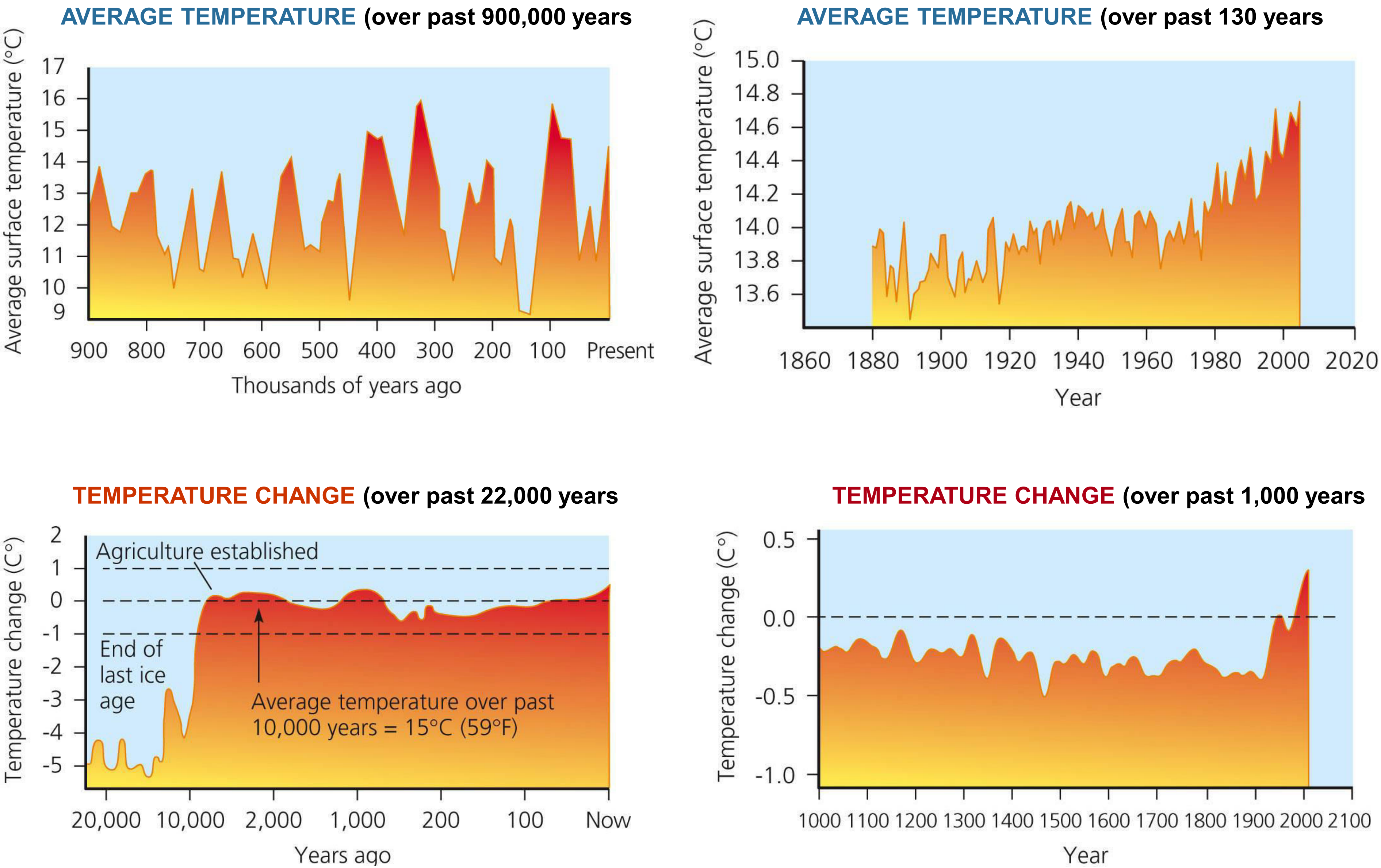


Fig. 15-16, p. 383



Stepped Art

Fig. 15-16, p. 383

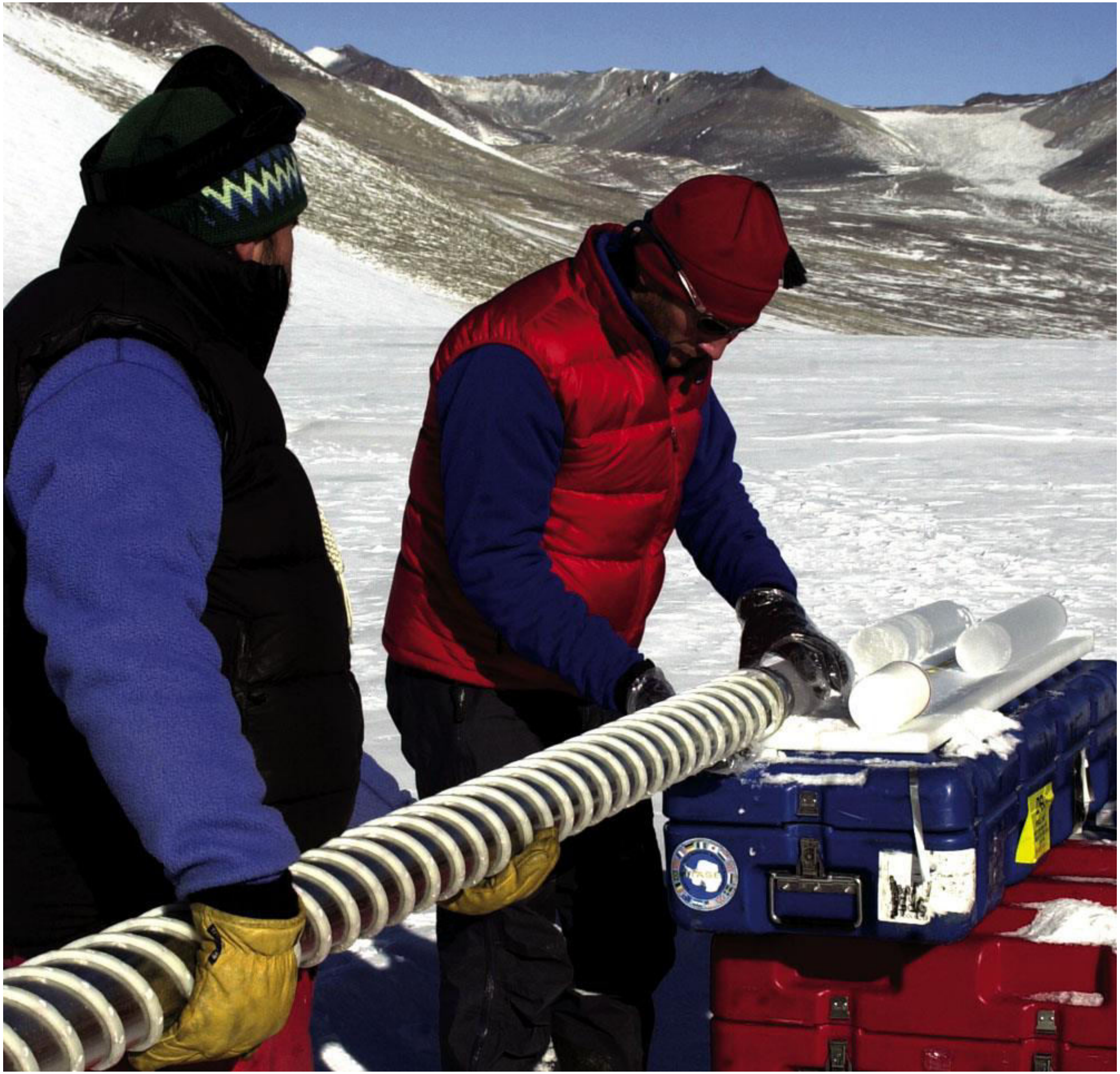


Fig. 15-17, p. 383

The Greenhouse Effect

- Earth's natural greenhouse effect
- Natural greenhouse gases
  - Water vapor (H_2O)
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous Oxide (N_2O)

Evidence to Support Global Warming

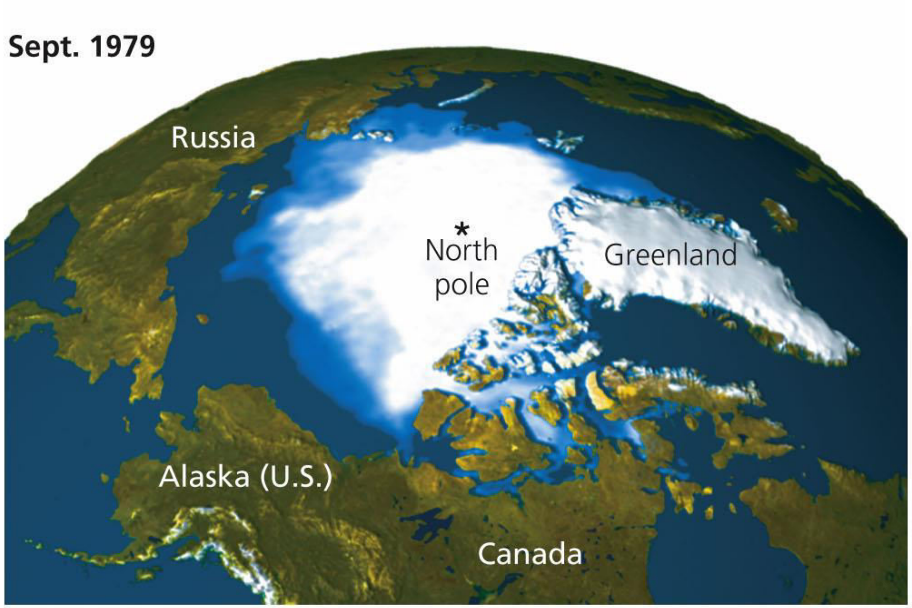
- Intergovernmental Panel on Climate Change
- 2007 IPCC report
- Rise in average global surface temperature
- 10 warmest years on record since 1970

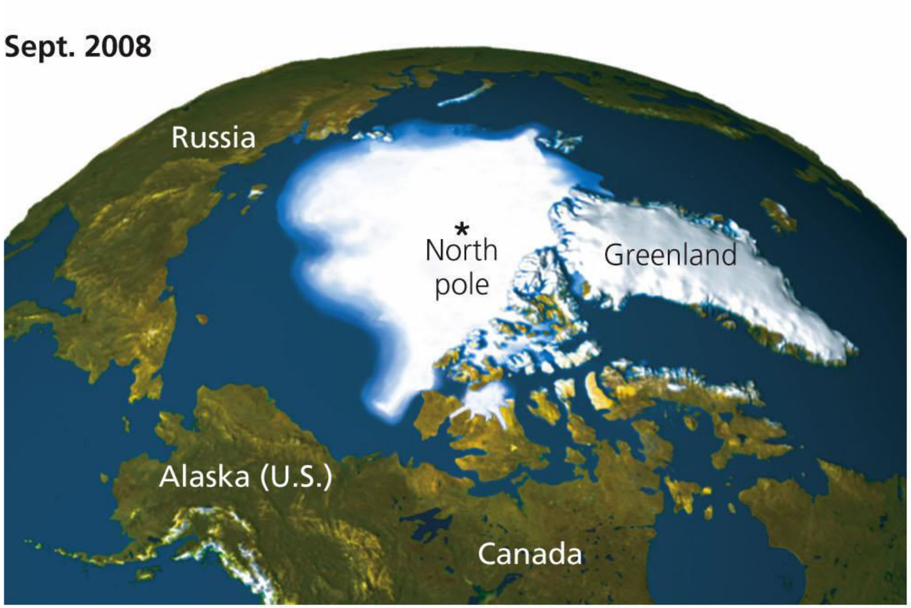
Evidence to Support Global Warming

- Annual greenhouse gas emissions up 70% between 1970 and 2008
- Changes in glaciers, rainfall patterns, hurricanes
- Sea level rise in this century 4–8 inches


Fig. 15-18, p. 384

Fig. 15-18, p. 384


Sept. 1979
Russia
North pole
Greenland
Alaska (U.S.)
Canada


Sept. 2008
Russia
North pole
Greenland
Alaska (U.S.)
Canada

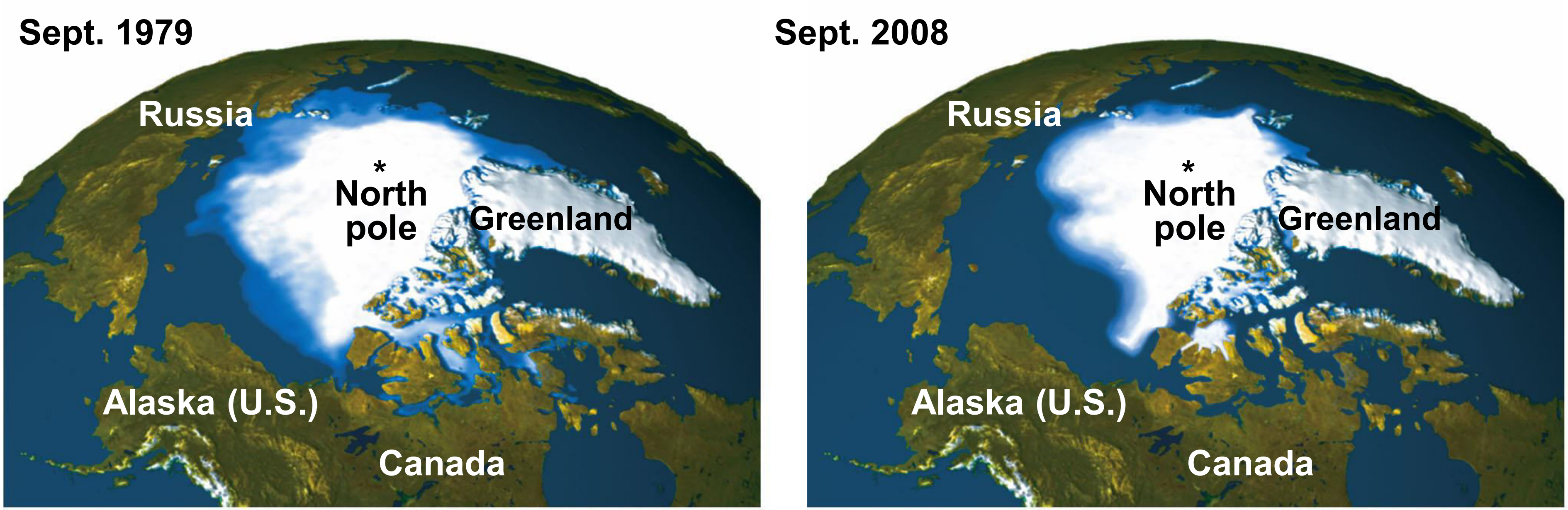
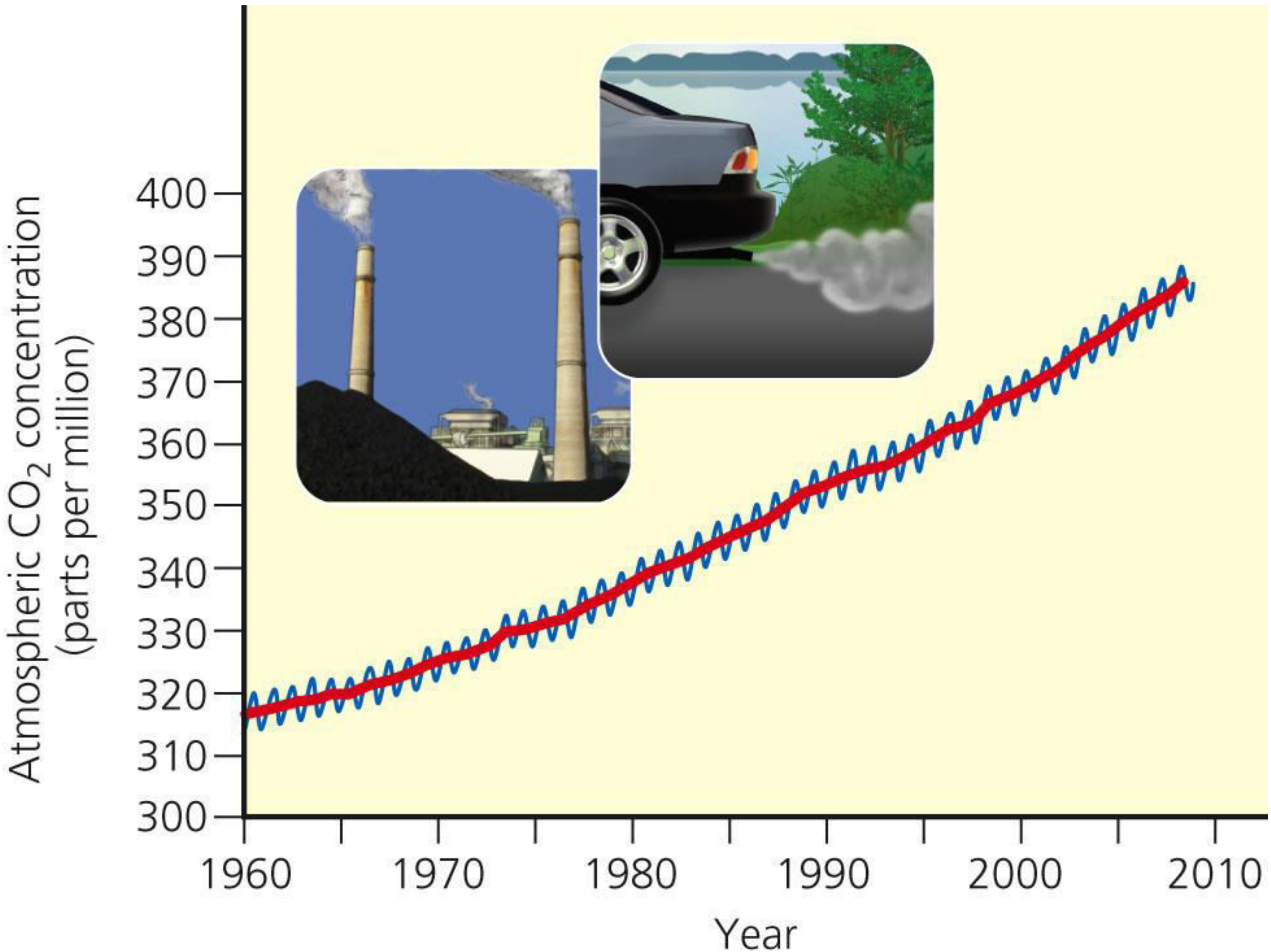


Fig. 15-19, p. 385

CO_2 Is the Major Culprit

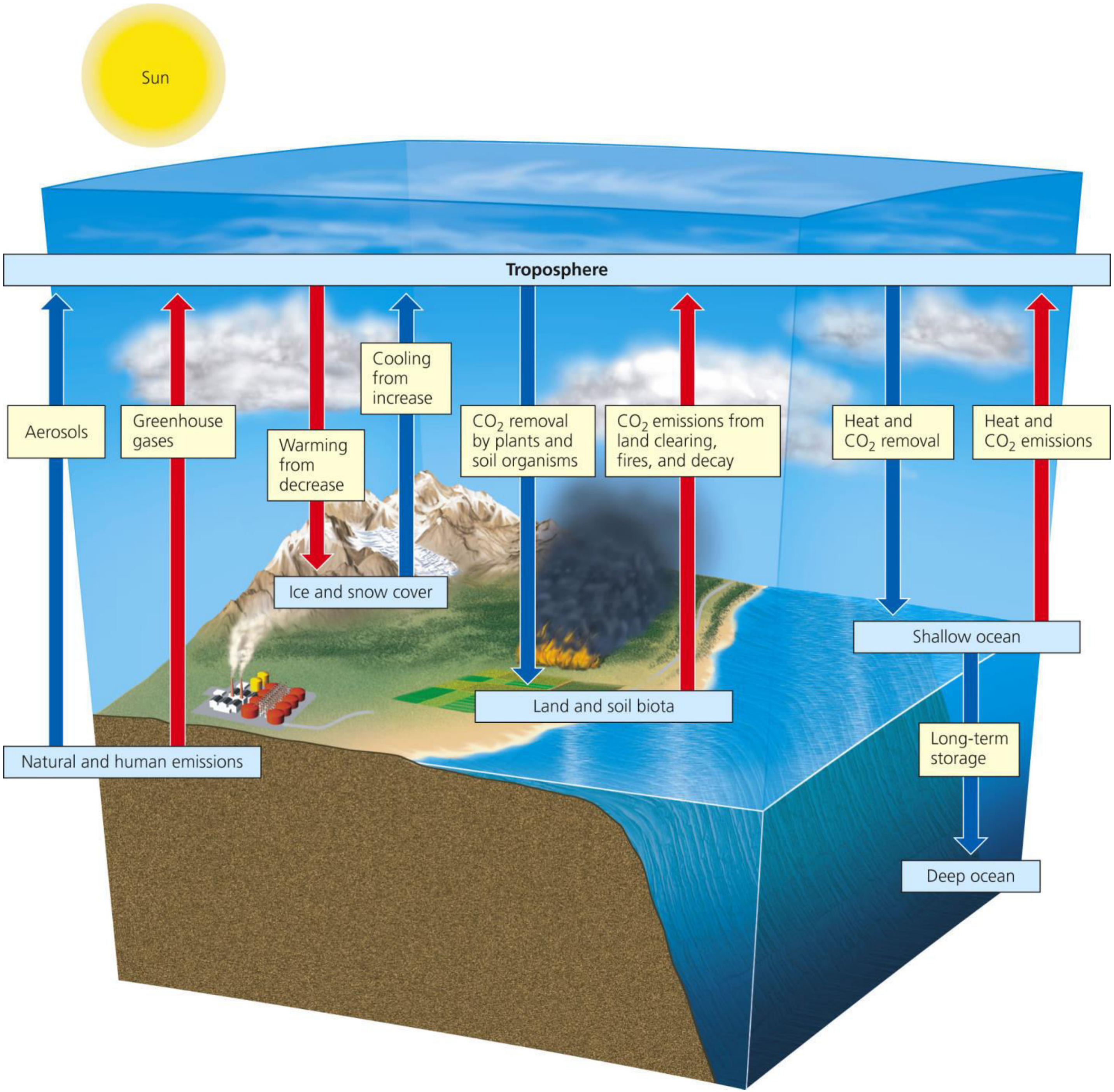
- 1850: 285 ppm
- 2009: 388 ppm
- Over 450 ppm is tipping point
- 350 ppm as intermediate goal



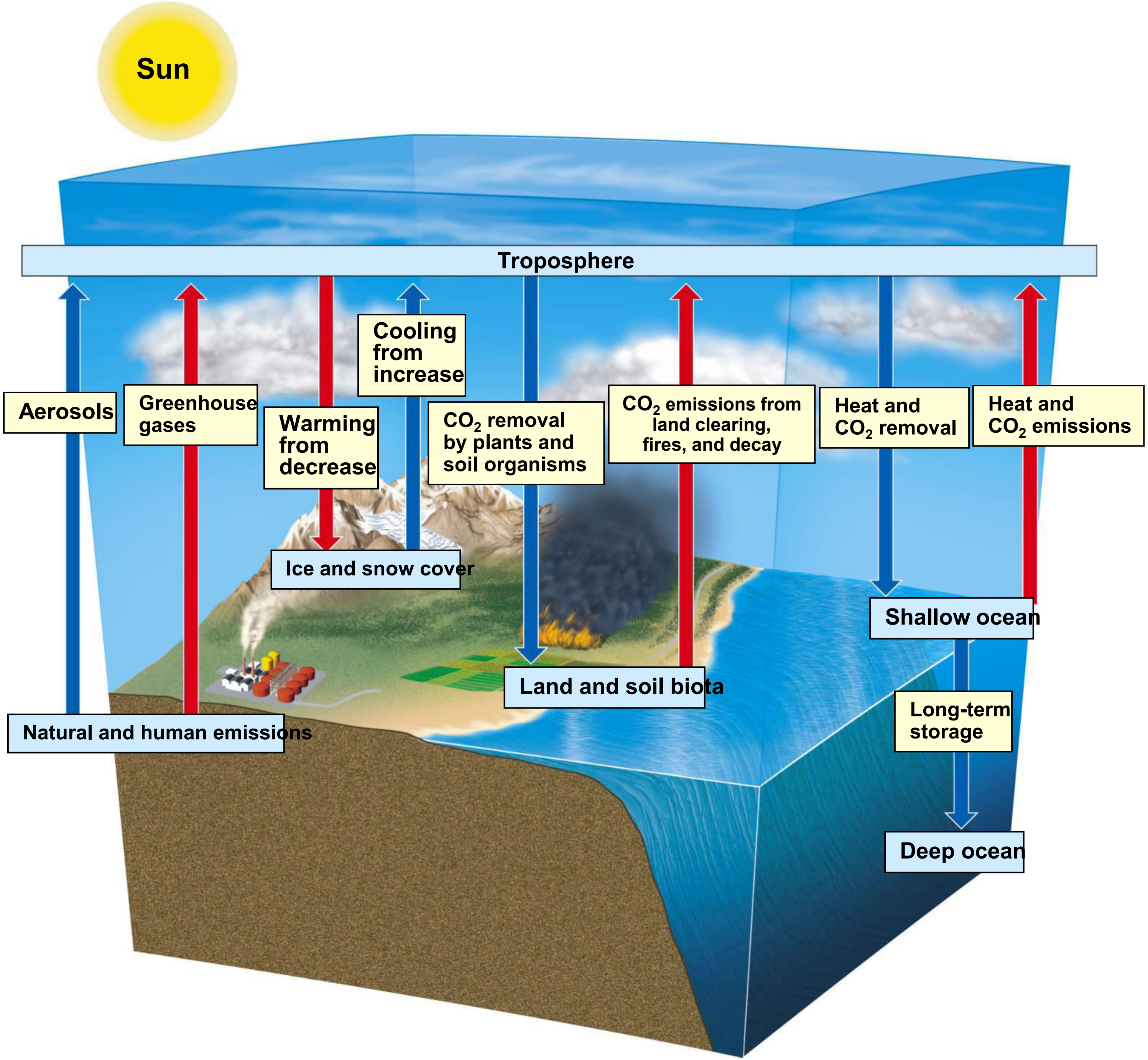
Atmospheric CO_2 concentration (parts per million)
400
390
380
370
360
350
340
330
320
310
300
1960
1970
1980
1990
2000
2010
Year

Science Focus: Scientific Consensus about Future Global Temperature Changes?

- Temperature as a function of greenhouse gases
- Mathematical models
- Model data and assumptions
- Predictions and model reliability
- Recent warming due to human activities



Sun
Troposphere
Aerosols
Greenhouse gases
Warming from decrease
Cooling from increase
CO_2 removal by plants and soil organisms
CO_2 emissions from land clearing, fires, and decay
Heat and CO_2 removal
Heat and CO_2 emissions
Ice and snow cover
Shallow ocean
Land and soil biota
Long-term storage
Natural and human emissions
Deep ocean



Sun
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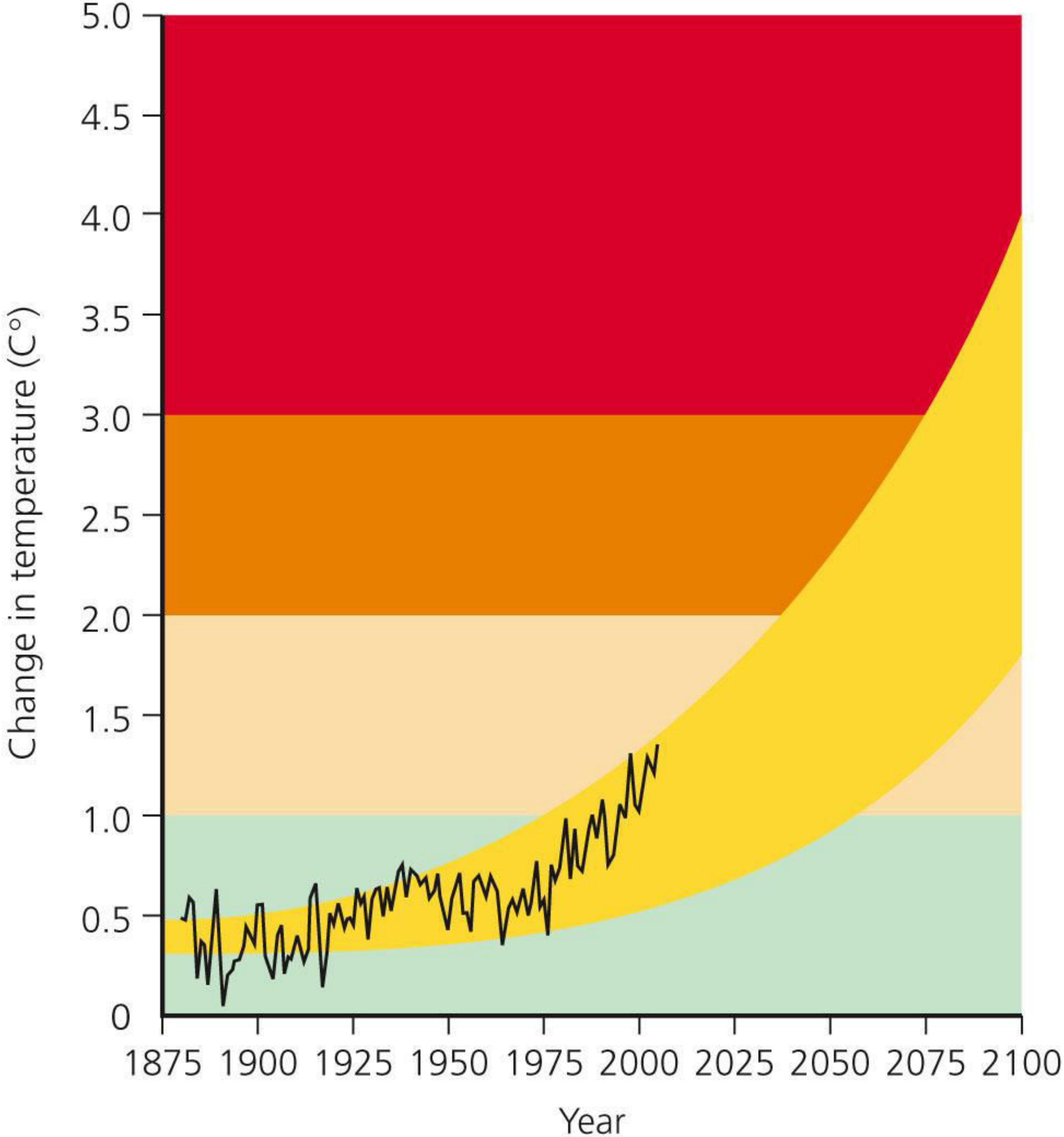

5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Change in temperature (C°)
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100
Year

Fig. 15-B, p. 387

What Role for Oceans in Climate Change?

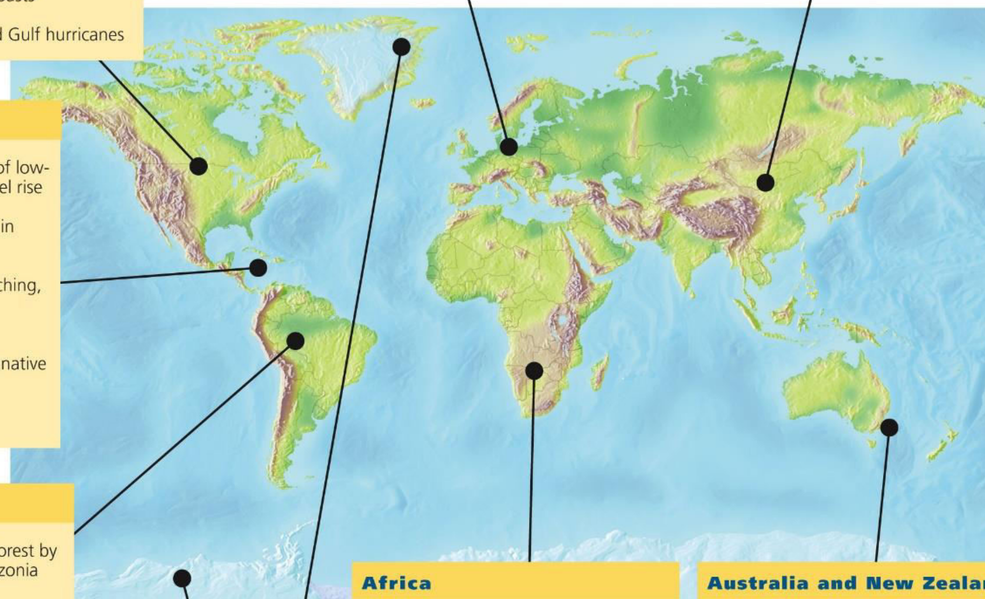
- Absorb CO_2
- CO_2 solubility decreases with increasing temperature
- Upper ocean getting warmer

What Are Some Possible Effects of a Projected Climate Change?

The projected change in the earth's climate during this century could have severe and long-lasting consequences, including increased drought and flooding, rising sea levels, and shifts in locations of agriculture and wildlife habitats.

Potential Severe Consequences

- Rapid projected temperature increase
- 2 Cº inevitable
- 4 Cº possible
- Effects will last for at least 1,000 years



North America

- In the western mountains, decreased snowpack, earlier snowmelt, more winter flooding, and reduced summer water flows
- Increased forest growth and increased forest fires
- Rapid melting of Alaska glaciers
- Increased intensity, duration and number of heat waves in many cities
- Sea-level rises, tidal surges, and flooding along Gulf and Atlantic coasts
- More intense Atlantic and Gulf hurricanes

Europe

- Increased risk of inland flash floods and coastal flooding
- Disappearance of alpine glaciers
- In the south, more health-threatening heat waves and wildfires, reduced forest area, reduced water availability and hydropower potential, reduced crop yields, and reduced summer tourism
- In the central and eastern areas, more heat waves and peatland fires and reduced summer rainfall and forest productivity
- In the north, negative impacts eventually outweigh such initial benefits as reduced heating demand, less severe winters, increased forest area, and increased crop yields and forest growth

Asia

- Increased flooding, rock avalanches and water resource disruptions from melting Himalayan glaciers
- Ongoing risk of hunger in several developing regions because of crop productivity declines combined with rapid population growth and urbanization
- Coastal flooding from rising sea levels

Small Islands

- Severe flooding and loss of low-lying islands from seal-level rise
- Reduced water resources in many places
- Beach erosion, coral bleaching, loss of mangroves, and declining fisheries
- Increased invasion by nonnative species
- Decreased tourism

Latin America

- Replacement of tropical forest by savannah in eastern Amazonia
- Desertification of farmland from increased drought in dry areas
- Melting of glaciers in tropical Andes with reduced water supplies and hydropower generation
- Rice yields may fall but soybean yields may increase

Polar Regions

- Thinning and shrinking of glaciers and ice sheets
- Decreased Arctic summer sea ice
- Decreased permafrost
- Increased agriculture and forest cover in Siberia
- Arctic tundra replaced by forest

Africa

- Decreased water availability by 2020 for 75 million–250 million people
- Loss of arable land, reduced growing seasons and reduced crop yields in some areas
- Decreased fish stocks in large lakes
- Coastal flooding from rising sea levels
- Flooding, drought, spread of disease

Australia and New Zealand

- Intensified water shortages in southern and eastern Australia and parts of New Zealand by 2030
- Increased loss of biodiversity by 2020
- Increased bush fires
- Increased storm severity and frequency in several places
- Coastal flooding from sea-level rise

What Can We Do to Slow Projected Climate Change?

To slow the rate of projected climate change, we can increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

Options to Deal with Climate Change

- Two approaches:
  1. Drastically reduce greenhouse gas emissions
  2. Develop strategies to reduce its harmful effects
- Mix both approaches
- Governments beginning to act

Solutions

Slowing Climate Change

Prevention

Cut fossil fuel use (especially coal)

Shift from coal to natural gas

Improve energy efficiency

Shift to renewable energy resources

Transfer energy efficiency and renewable energy technologies to developing countries

Reduce deforestation

Use more sustainable agriculture and forestry

Limit urban sprawl

Reduce poverty

Slow population growth

Cleanup

Remove CO_2 from smokestack and vehicle emissions

Store (sequester) CO_2 by planting trees

Sequester CO_2 in soil by using no-till cultivation and taking cropland out of production

Sequester CO_2 deep underground (with no leaks allowed)

Sequester CO_2 in the deep ocean (with no leaks allowed)

Repair leaky natural gas pipelines and facilities

Use animal feeds that reduce CH_4 emissions from cows (belching)

Fig. 15-23, p. 393

Solutions

Slowing Climate Change

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Fig. 15-23, p. 393

Reducing the Threat of Climate Change

- Improve energy efficiency to reduce fossil fuel use
- Shift from coal to natural gas
- Improve energy efficiency
- Shift to renewable energy sources

Reducing the Threat of Climate Change

- Transfer appropriate technology to developing countries
- Reduce deforestation
- Sustainable agriculture and forestry
- Reduce poverty
- Slow population growth

Reducing the Threat of Climate Change

- Decrease CO_2 emissions
- Sequester CO_2
  - Plant trees
  - Agriculture
  - Underground
  - Deep ocean
- Repair leaking natural gas lines
- Reduce methane emissions from animals

Science Focus: Is Capturing and Storing CO_2 the Answer?

- Global tree planting
- Restore wetlands
- Plant fast-growing perennials

Science Focus: Is Capturing and Storing CO_2 the Answer?

- Preserve natural forests
- Seed oceans with iron to promote growth of phytoplankton
- Sequester carbon dioxide underground and under the ocean floor

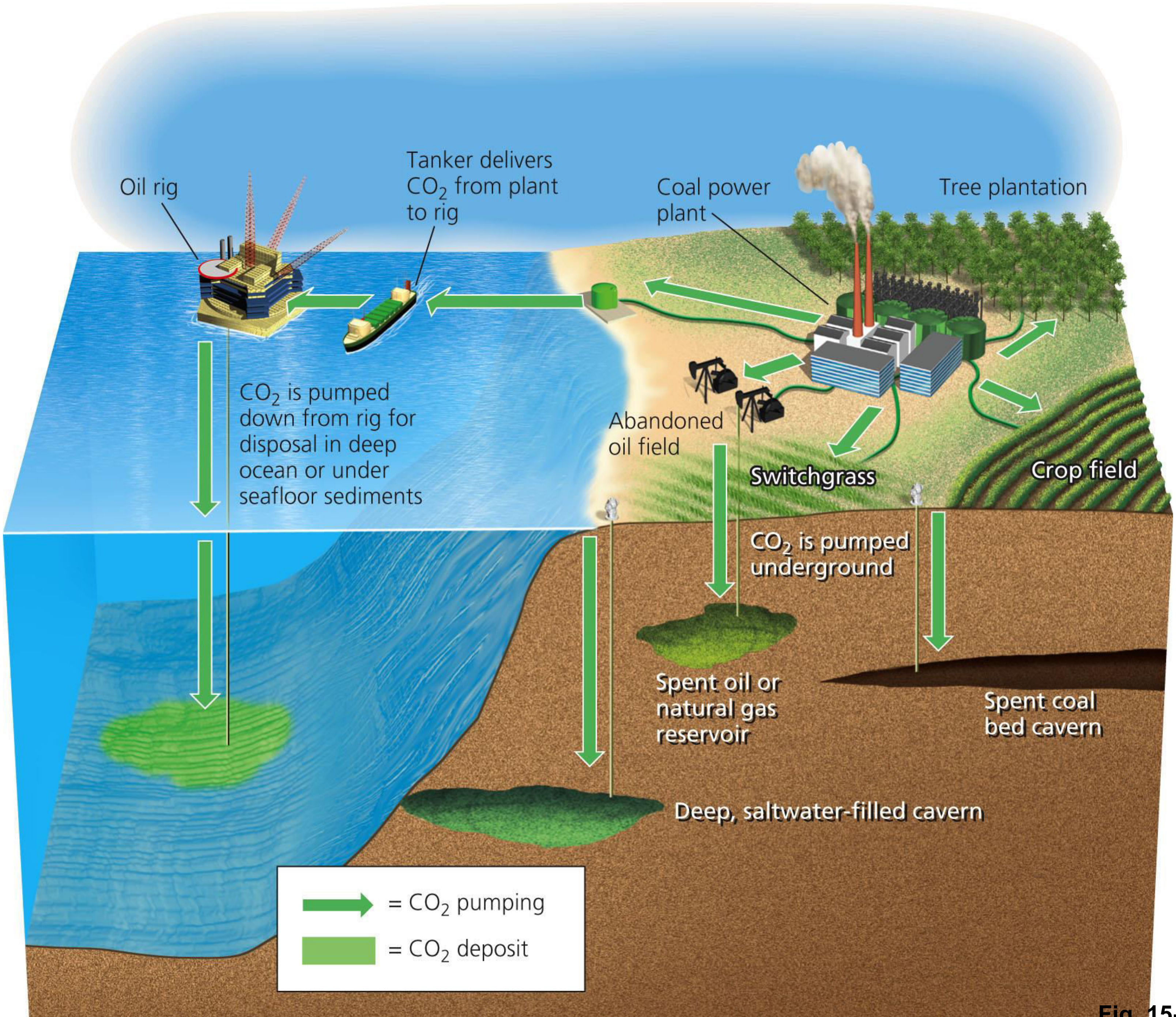
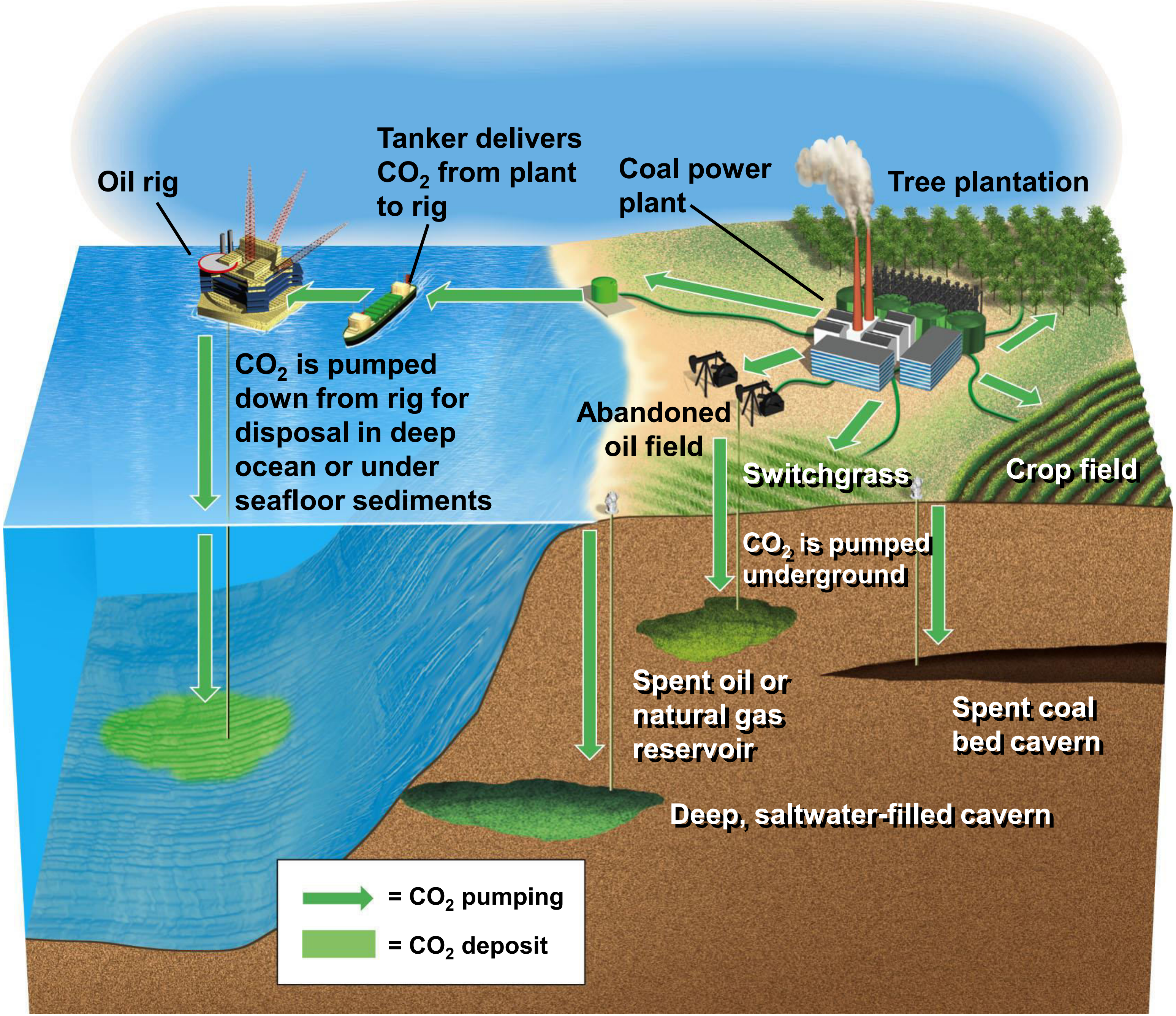

Oil rig
Tanker delivers CO_2 from plant to rig
Coal power plant
Tree plantation
CO_2 is pumped down from rig for disposal in deep ocean or under seafloor sediments
Abandoned oil field
Switchgrass
Crop field
CO_2 is pumped underground
Spent oil or natural gas reservoir
Spent coal bed cavern
Deep, saltwater-filled cavern
= CO_2 pumping
= CO_2 deposit

Fig. 15-C, p. 394



Tanker delivers CO_2 from plant to rig
Oil rig
Coal power plant
Tree plantation
CO_2 is pumped down from rig for disposal in deep ocean or under seafloor sediments
Abandoned oil field
Switchgrass
Crop field
CO_2 is pumped underground
Spent oil or natural gas reservoir
Spent coal bed cavern
Deep, saltwater-filled cavern
= CO_2 pumping
= CO_2 deposit

Fig. 15-C, p. 394

Government Roles in Reducing the Threat of Climate Change

- Regulate carbon dioxide and methane as pollutants
- Carbon taxes
- Cap total CO_2 emissions
- Subsidize energy-efficient technologies
- Technology transfers

Government Roles in Reducing the Threat of Climate Change

- International climate negotiations
- Kyoto Protocol
- Act locally
  - Costa Rica
  - U.S. states
  - Large corporations
  - Colleges and universities

What Can You Do?

Reducing CO_2 Emissions

- Drive a fuel-efficient car, walk, bike, carpool, and use mass transit
- Use energy-efficient windows
- Use energy-efficient appliances and lights
- Heavily insulate your house and seal all air leaks
- Reduce garbage by recycling and reusing more items
- Insulate your hot water heater
- Use compact fluorescent lightbulbs
- Plant trees to shade your house during summer
- Set your water heater no higher than 49 °C (120 °F)
- Wash laundry in warm or cold water
- Use a low-flow showerhead
- Buy products from, or invest in, companies that are trying to reduce their impact on climate

Fig. 15-24, p. 396

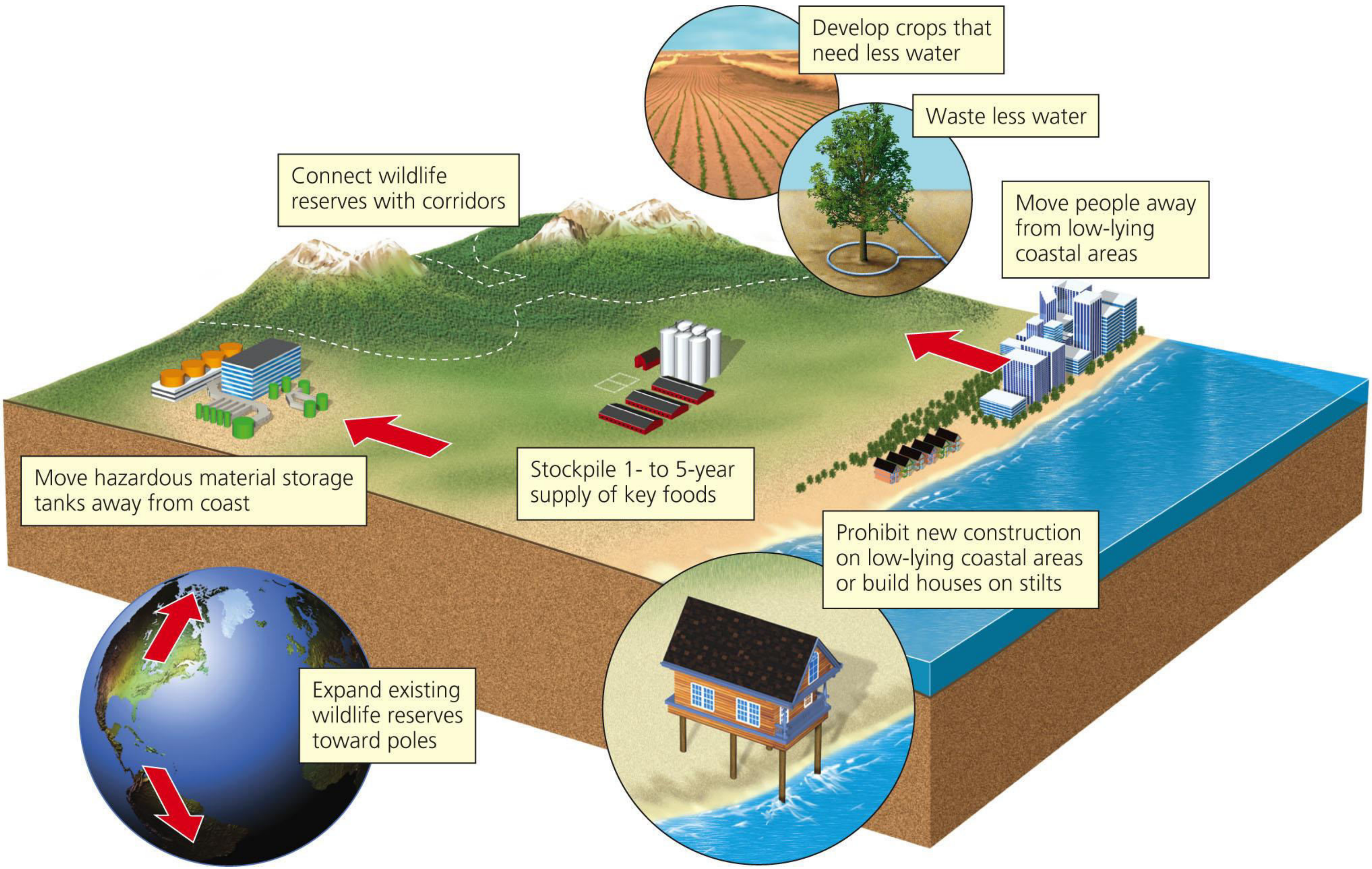


Fig. 15-25, p. 396

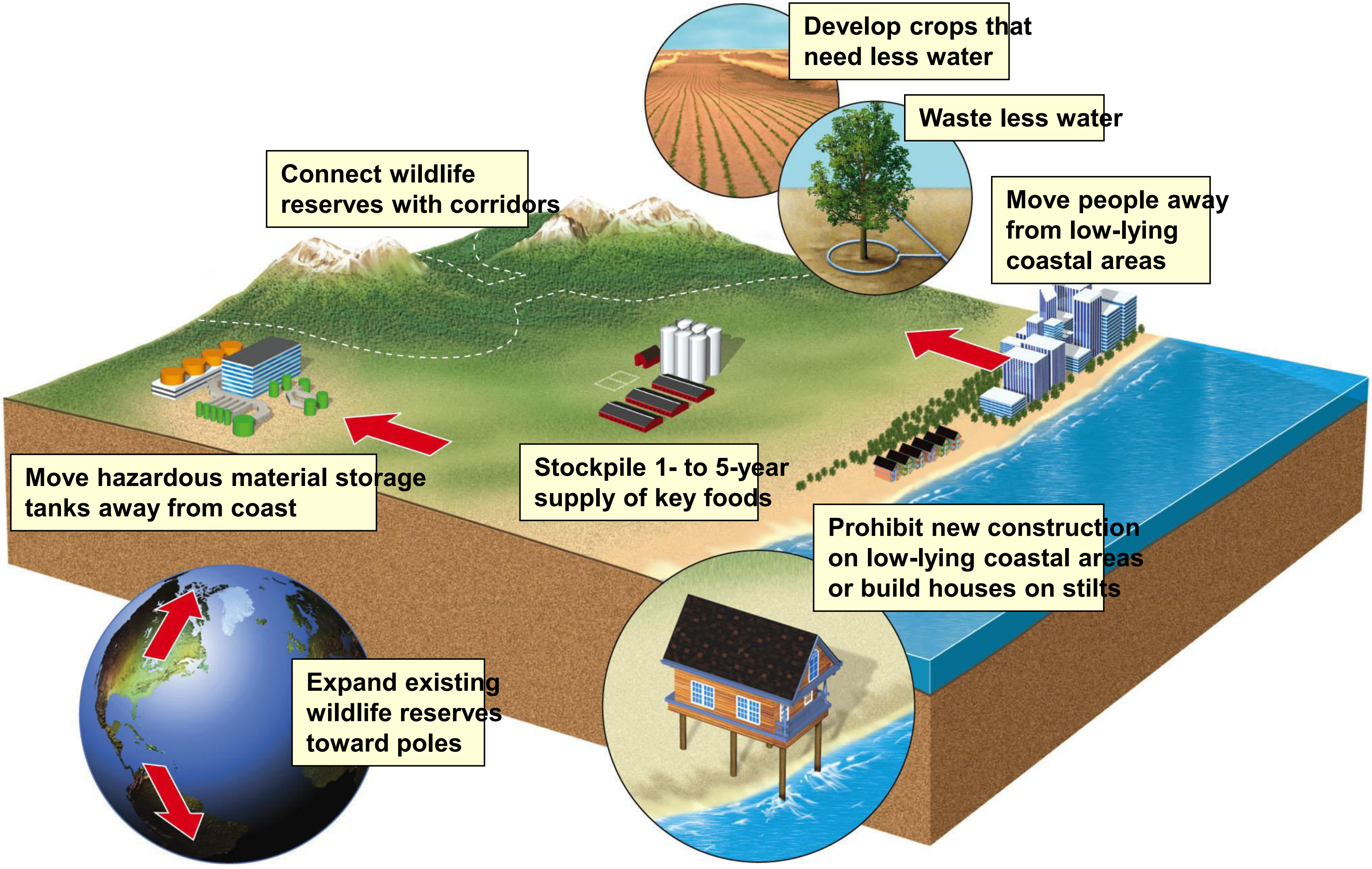


Fig. 15-25, p. 396

How Have We Depleted Ozone in the Stratosphere and What Can We Do about It?

- *Widespread use of certain chemicals has reduced ozone levels in the stratosphere and allowed more harmful ultraviolet radiation to reach the earth's surface.*
- *To reverse ozone depletion, we need to stop producing ozone-depleting chemicals and adhere to the international treaties that ban such chemicals.*

Human Impact on the Ozone Layer

- Location and purpose of the ozone layer
  - Blocks UV-A and UV-B
- Seasonal and long-term depletion of ozone
- Threat to humans, animals, plants
- Causes – chlorofluorocarbons (CFCs)

Individuals Matter: Banning of Chlorofluorocarbons (CFCs)

- Chemists Rowland and Molina –
  - Nobel Prize in 1995
- Called for ban
  - Remain in atmosphere
  - Rise into stratosphere
  - Break down into atoms that accelerate ozone depletion
  - Stay in stratosphere for long periods
- Defended research against big industry

Former Uses of CFCs

- Coolants in air conditioners and refrigerators
- Propellants in aerosol cans
- Cleaning solutions for electronic parts
- Fumigants
- Bubbles in plastic packing foam

Natural Capital Degradation

Effects of Ozone Depletion

Human Health

- Worse sunburns
- More eye cataracts
- More skin cancers
- Immune system suppression

Food and Forests

- Reduced yields for some crops
- Reduced seafood supplies from reduced phytoplankton
- Decreased forest productivity for UV-sensitive tree species

Wildlife

- Increased eye cataracts in some species
- Decreased populations of aquatic species sensitive to UV radiation
- Reduced populations of surface phytoplankton
- Disrupted aquatic food webs from reduced phytoplankton

Air Pollution and Materials

- Increased acid deposition
- Increased photochemical smog
- Degradation of outdoor paints and plastics

Climate Change

- While in troposphere, CFCs act as greenhouse gases

Fig. 15-26, p. 398

What Can You Do?

Reducing Exposure to UV Radiation

- Stay out of the sun, especially between 10 A.M. and 3 P.M.
- Do not use tanning parlors or sunlamps.
- When in the sun, wear protective clothing and sunglasses that protect against UV-A and UV-B radiation.
- Be aware that overcast skies do not protect you.
- Do not expose yourself to the sun if you are taking antibiotics or birth control pills.
- When in the sun, use a sunscreen with a protection factor of at least 15.
- Examine your skin and scalp at least once a month for moles or warts that change in size, shape, or color and sores that keep oozing, bleeding, and crusting over. If you observe any of these signs, consult a doctor immediately.

Fig. 15-27, p. 398

Reversing Ozone Depletion

- Stop producing ozone-depleting chemicals
- Slow recovery
- Montreal Protocol
- Copenhagen Protocol
- International cooperation

Three Big Ideas from This Chapter - #1

All countries need to step up efforts to control and prevent outdoor and indoor air pollution.

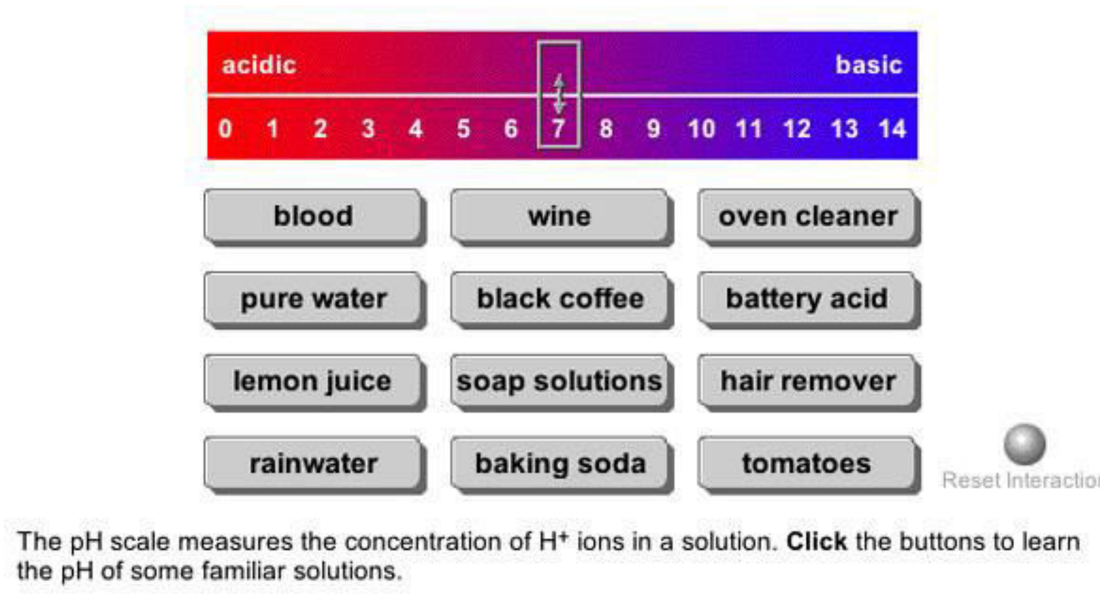
Three Big Ideas from This Chapter - #2

Reducing the possible harmful effects of projected rapid climate change during this century requires emergency action to cut energy waste, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

Three Big Ideas from This Chapter - #3

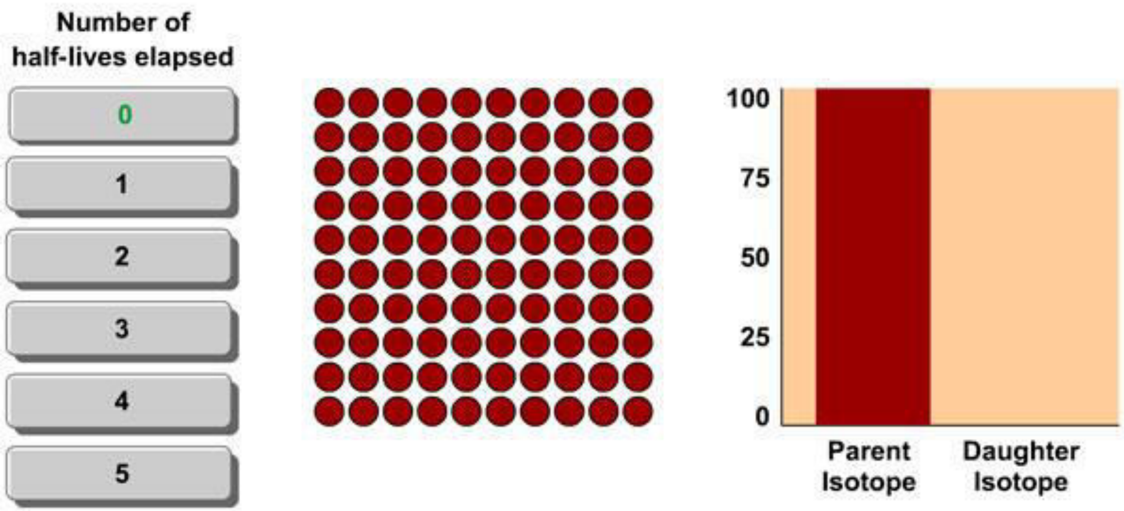
We need to continue phasing out the use of chemicals that have reduced ozone levels in the stratosphere and allowed more harmful ultraviolet radiation to reach the earth's surface.

Animation: pH Scale



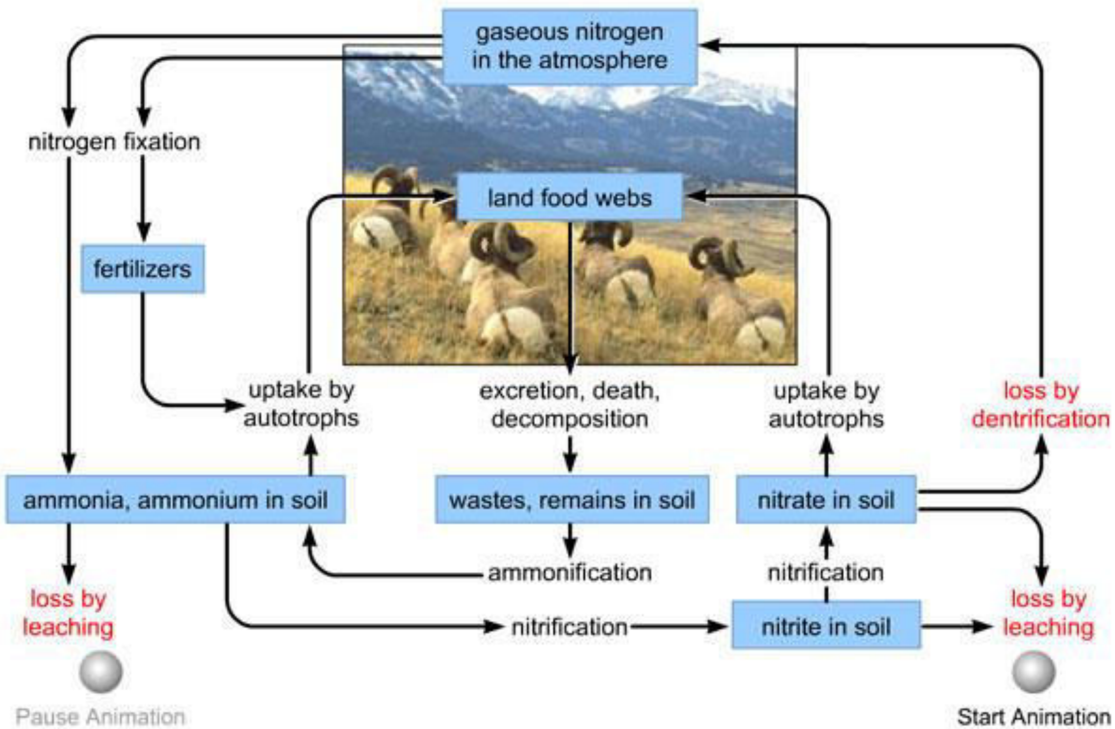
PLAY ANIMATION

Animation: Half-Life



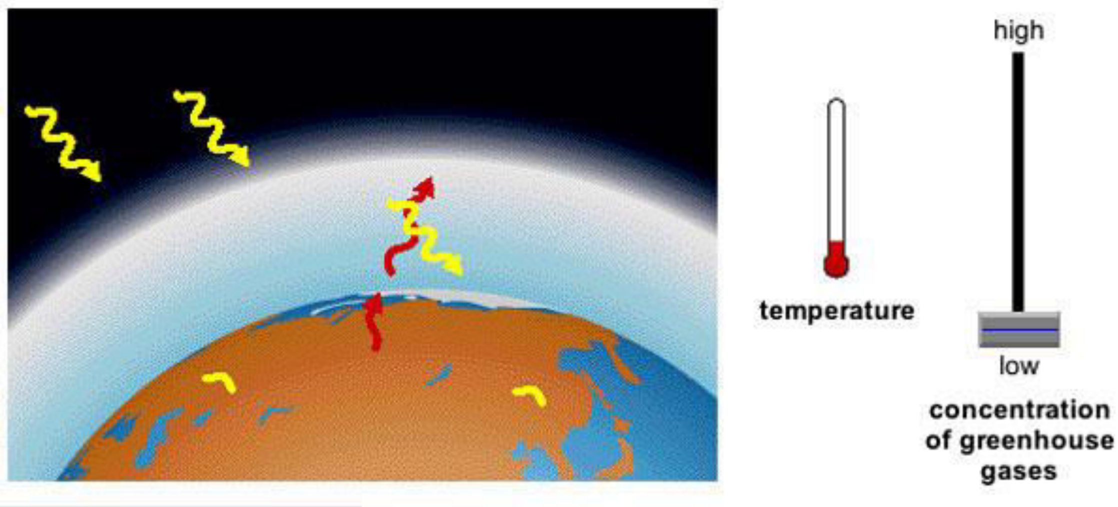
PLAY ANIMATION

Animation: Nitrogen Cycle



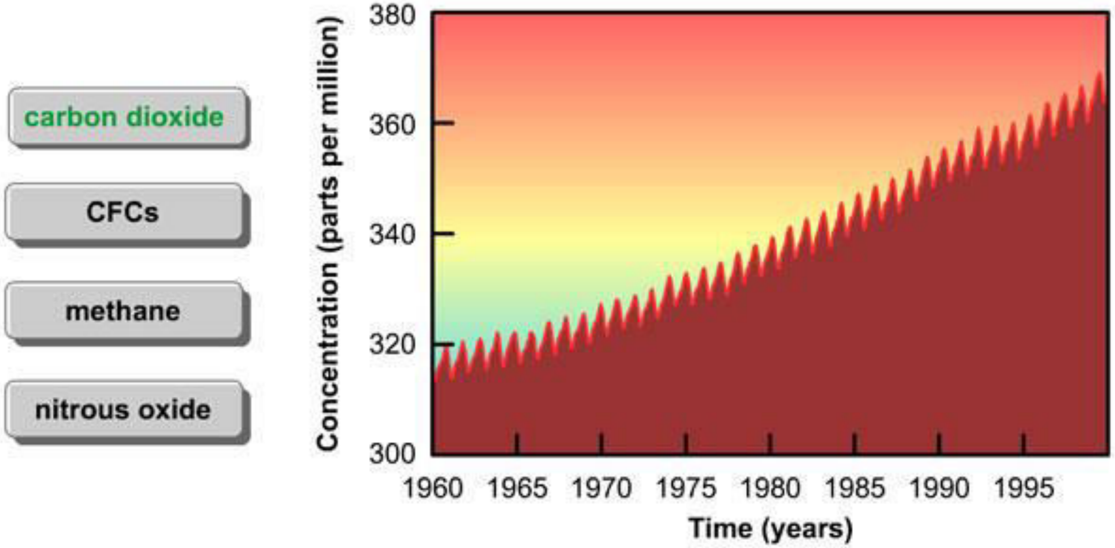
PLAY ANIMATION

Animation: Greenhouse Effect



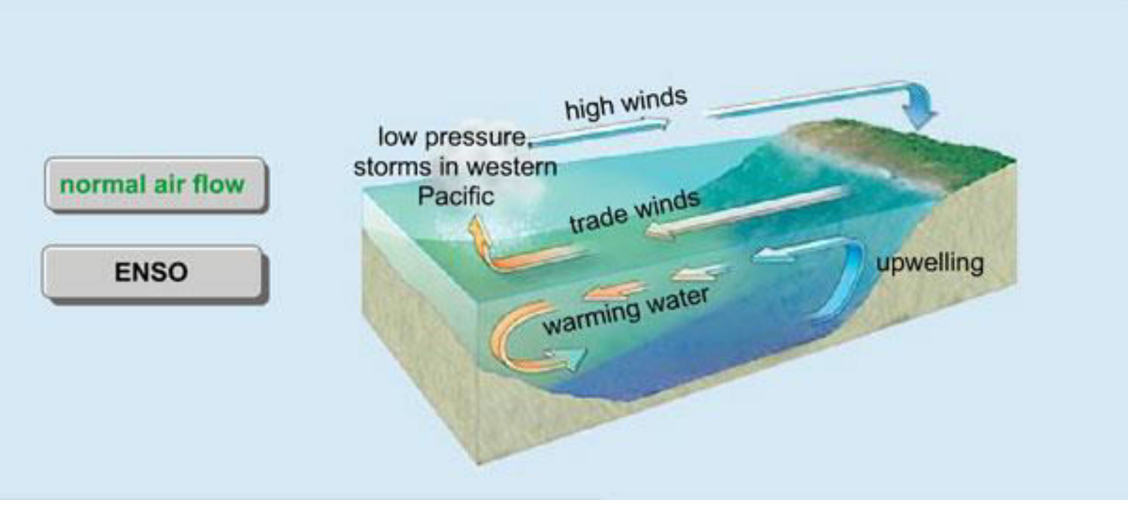
PLAY ANIMATION

Animation: Increasing Greenhouse Gases



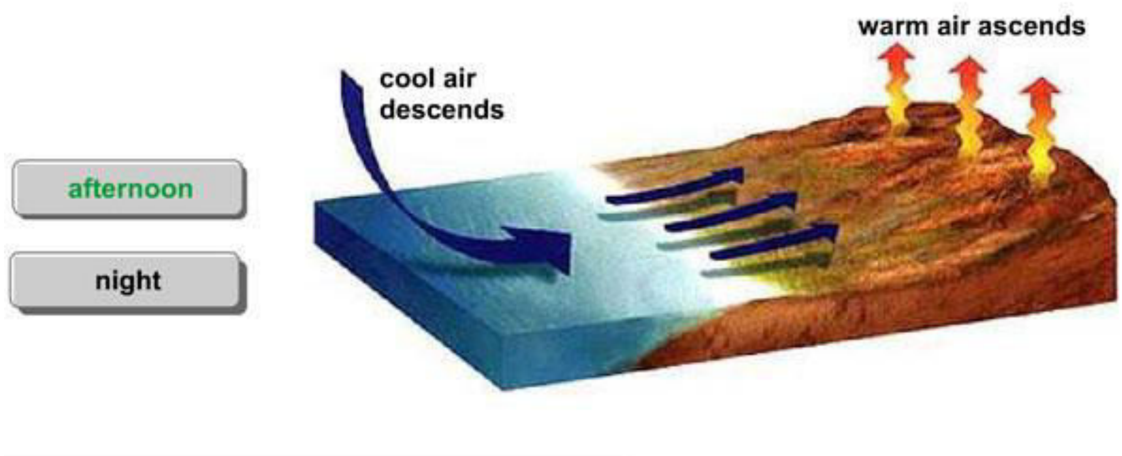
PLAY ANIMATION

Animation: El Nino Southern Oscillation



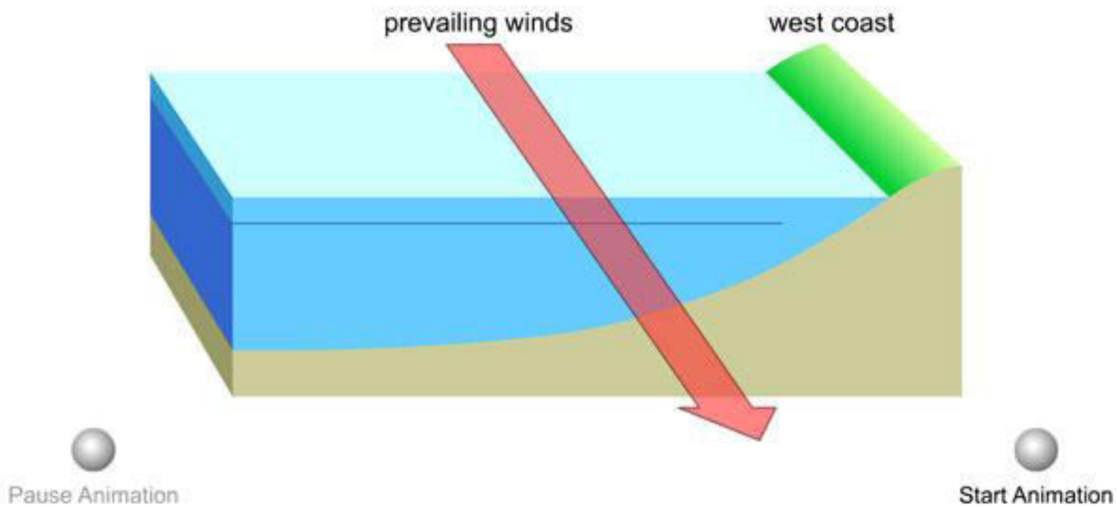
PLAY ANIMATION

Animation: Coastal Breezes



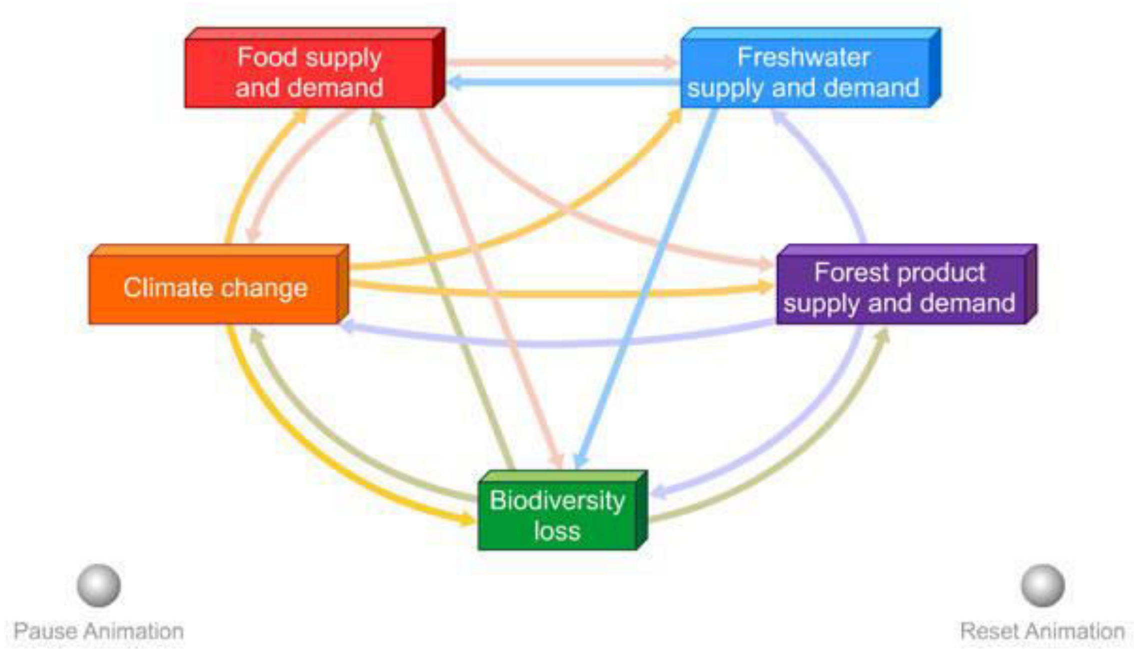
PLAY
ANIMATION

Animation: Upwelling Along Western Coasts



PLAY ANIMATION

Animation: Humans Affect Biodiversity



PLAY ANIMATION

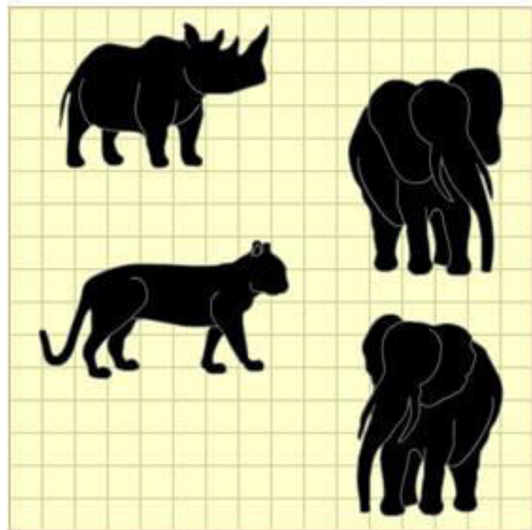
Animation: Habitat Loss and Fragmentation

black rhino

African elephant

Indian tiger

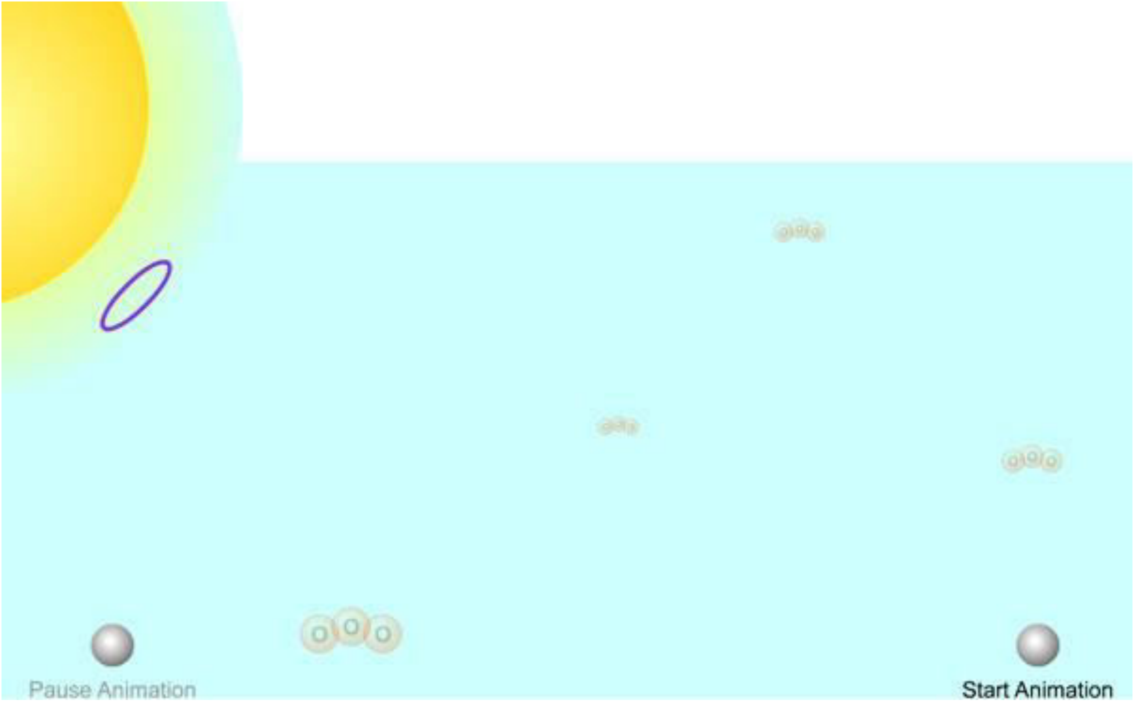
Asian elephant



Reset Animation

PLAY ANIMATION

Animation: How CFCs Destroy Ozone



PLAY ANIMATION

Video: Air Pollution in China

PLAY
VIDEO

Video: Clean Air Act

PLAY
VIDEO

Video: China Computer Waste

PLAY
VIDEO

Video: U.S. Earth Summit

PLAY VIDEO

Video: Melting Ice

PLAY VIDEO

Video: Global Warming

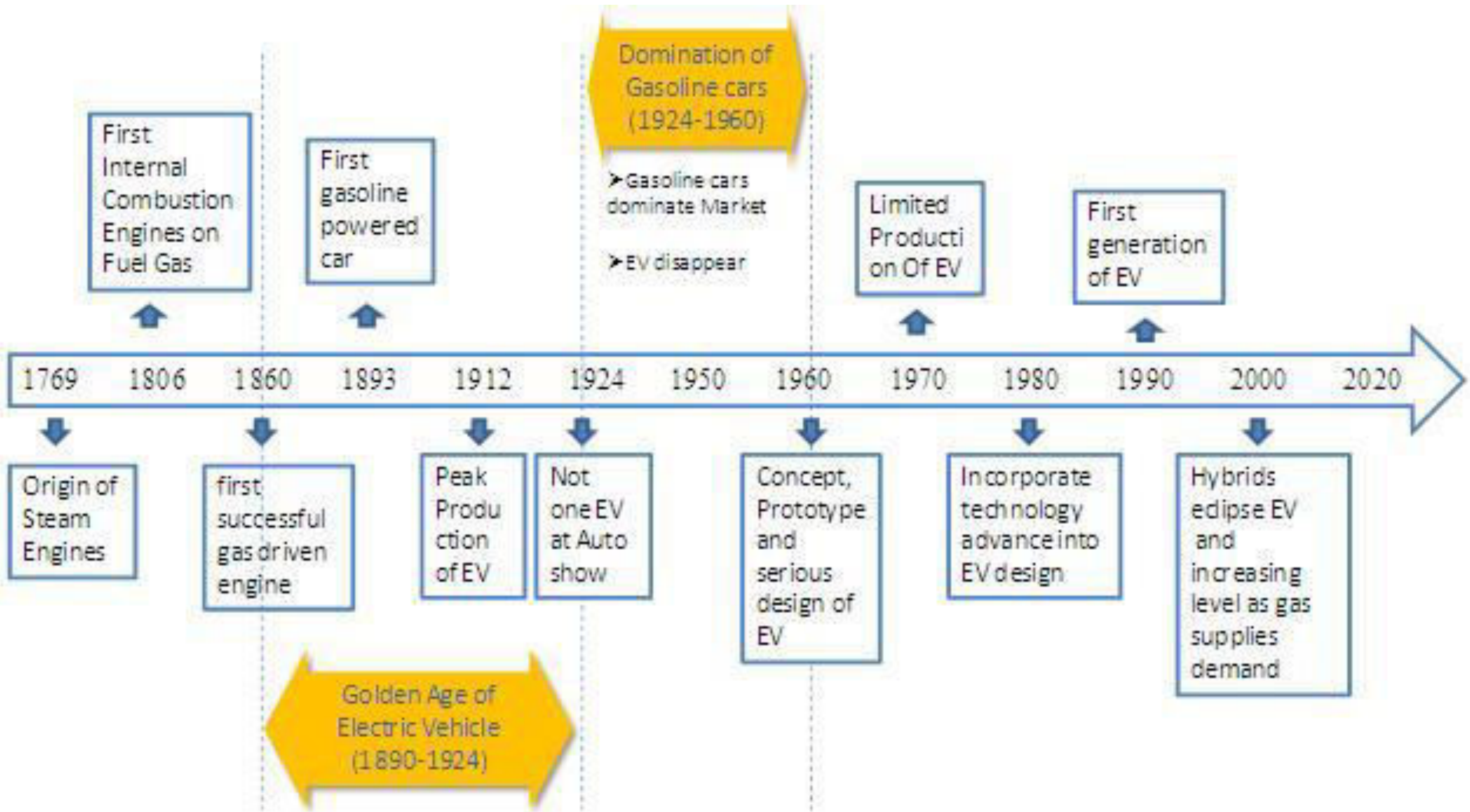
PLAY VIDEO

What is a hybrid?

A hybrid vehicle combines any two power (energy) sources. Possible combinations include diesel/electric, gasoline/fly wheel, and fuel cell (FC)/battery. Typically, one energy source is storage, and the other is conversion of a fuel to energy. The combination of two power sources may support two separate propulsion systems. Thus to be a True hybrid, the vehicle must have at least two modes of propulsion.

- For example, a truck that uses a diesel to drive a generator, which in turn drives several electrical motors for all-wheel drive, is *not a hybrid* . But if the truck has electrical energy storage to provide a second mode, which is electrical assists, then it is a hybrid Vehicle.
- These two power sources may be paired in series, meaning that the gas engine charges the batteries of an electric motor that powers the car, or in parallel, with both mechanisms driving the car directly.

Historical development (root) of Automobiles



Modern Period of Hybrid History

The history of hybrid cars is much longer and more involved than many first imagine. It is, however, in the last ten years or so that we, as consumers, have begun to pay more attention to the hybrid vehicle as a viable alternative to ICE driven cars. Whether looking for a way to save money on spiraling gas costs or in an attempt to help reduce the negative effects on the environment we are buying hybrid cars much more frequently.

1990s

Automakers took a renewed interest in the hybrid, seeking a solution to dwindling energy supplies and environmental concerns and created modern history of hybrid car

1993

In USA, Bill Clinton's administration recognized the urgency for the mass production of cars powered by means other than gasoline. Numerous government agencies, as well as Chrysler, Ford, GM, and USCAR combined forces in the PNGV (Partnership for a New Generation of Vehicles), to create cars using alternative power sources, including the development and improvement of hybrid electric vehicles.

1997

The Audi Duo was the first European hybrid car put into mass production and hybrid production and consumer take up has continued to go from strength to strength over the decades.

2000

Toyota Prius and Honda Insight became the first mass market hybrids to go on sale in the United States, with dozens of models following in the next decade. The Honda Insight and Toyota Prius were two of the first mainstream Hybrid Electric Vehicles and both models remain a popular line.

2005

A hybrid Ford Escape, the SUV, was released in 2005. Toyota and Ford essentially swapped patents with one another, Ford gaining a number of Toyota patents relating to hybrid technology and Toyota, in return, gaining access to Diesel engine patents from Ford.

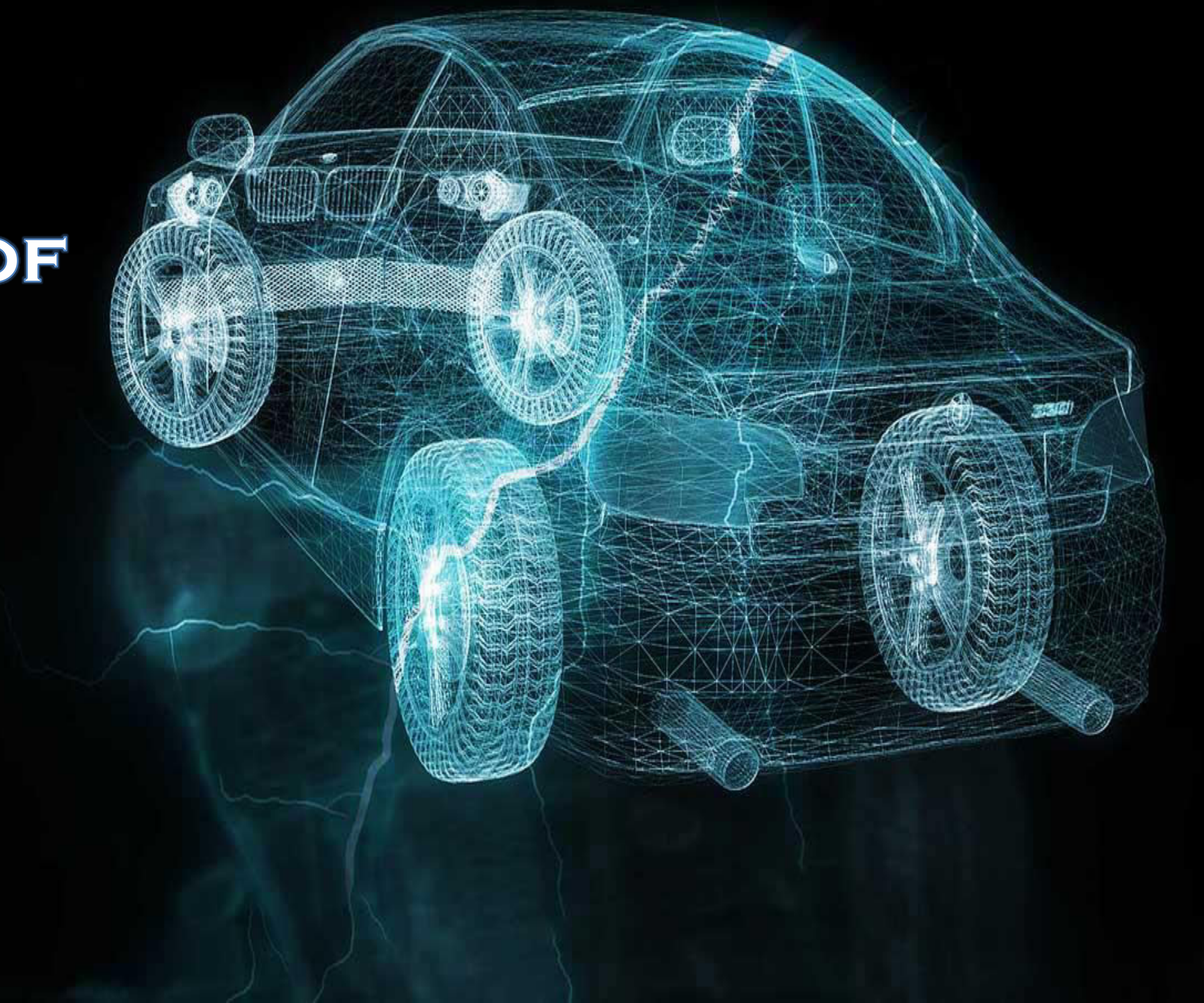
Present of Hybrid Electric vehicle

Toyota is the most prominent of all manufacturers when it comes to hybrid cars. As well as the specialist hybrid range they have produced hybrid versions of many of their existing model lines, including several Lexus (now owned and manufactured by Toyota) vehicles. They have also stated that it is their intention to release a hybrid version of every single model they release in the coming decade. As well as cars and SUVs, there are a select number of hybrid motorcycles, pickups, vans, and other road going vehicles available to the consumer and the list is continually increasing.

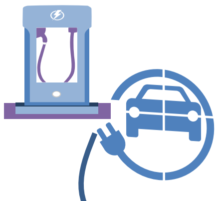
Future of Hybrid electrical vehicle

Since petroleum is limited and will someday run out of supply. In the arbitrary year 2037, an estimated one billion petroleum-fueled vehicles will be on the world's roads. gasoline will become prohibitively expensive. The world need to have solutions for the " ***400 million otherwise useless cars"*** . So year 2037 "gasoline runs out year" means, petroleum will no longer be used for personal mobility. A market may develop for solar-powered EVs of the size of a scooter or golf cart. Since hybrid technology applies to heavy vehicles, hybrid buses and hybrid trains will be more significant.

History of Electric Vehicles



History of Electric Vehicles



1837

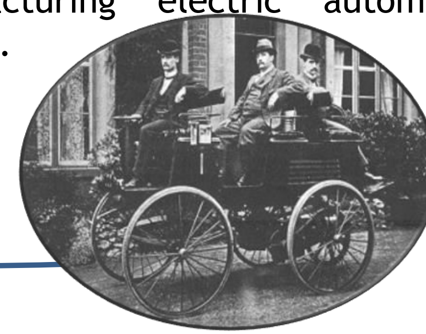
Electric car begin their long history in Aberdeen, Scotland through inventor Robert Davidson. Later in 1841, he built a bigger electric train car.

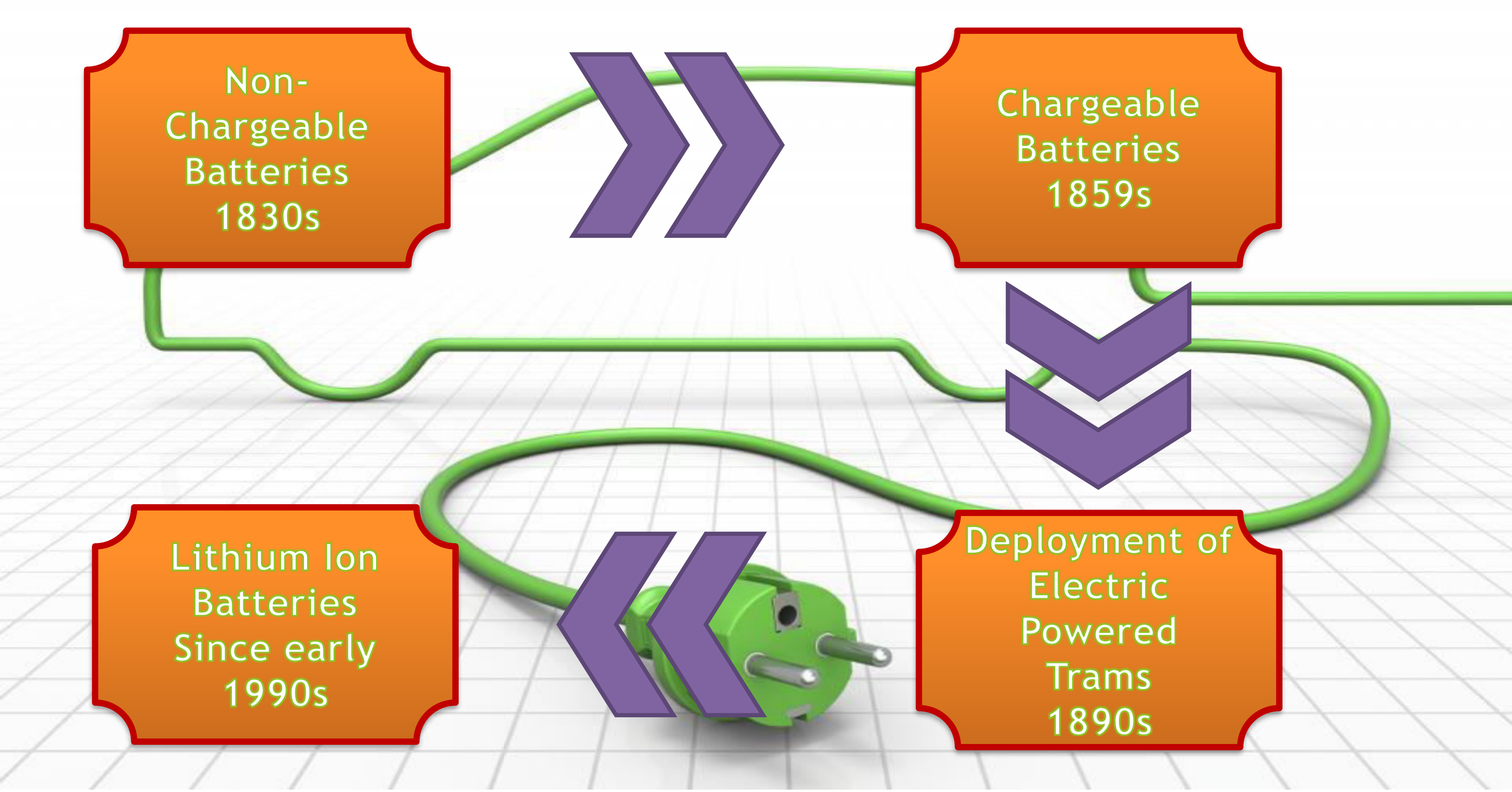
1884

After more than 40 years, inventor Thomas Parker creates the first manufacturing electric automobile in London.

1890

The first electric car was produced in Lowa, U.S.A by William Morrison. The car is little more than an electrified wagon. This six-seater has a top speed of 14 mph.





Non-Chargeable Batteries 1830s
Chargeable Batteries 1859s
Deployment of Electric Powered Trams 1890s
Lithium Ion Batteries Since early 1990s

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 golf courses, etc.

In fact, basic study shows that electric vehicles will never be able to challenge liquid fueled vehicles even with the optimistic value of battery energy capacity.

In recent years, advanced vehicle technology research has turned to hybrid electric vehicles as well as fuel cell vehicles.

History of Hybrid Electric Vehicles

The concept of a hybrid electric vehicle is almost as old as the automobile itself.

The primary purpose, however, was not so much to lower the fuel consumption but rather to assist the ICE to provide an acceptable level of performance.

In the early days, ICE engineering was less advanced than electric motor engineering.

The first hybrid vehicles reported were shown at the Paris Salon of 1899. These were built by the Pieper establishments of Liège, Belgium and by the Vendovelli and Priestly Electric Carriage Company, France.

The Pieper vehicle was a parallel hybrid with a small air-cooled gasoline engine assisted by an electric motor and lead–acid batteries.

It is reported that the batteries were charged by the engine when the vehicle coasted or was at a standstill. When the driving power required was greater than the engine rating, the electric motor provided additional power. In addition to being one of the two first hybrid vehicles, and being the first parallel hybrid vehicle, the Pieper was undoubtedly the first electric starter.

The other hybrid vehicle introduced at the Paris Salon of 1899 was the first series hybrid electric vehicle and was derived from a pure electric vehicle commercially built by the French firm Vendovelli and Priestly. This vehicle was a tricycle, with the two rear wheels powered by independent motors. An additional 3/4 hp gasoline engine coupled to a 1.1 kW generator was mounted on a trailer and could be towed behind the vehicle to extend its range by recharging the batteries. *In the French case, the hybrid design was used to extend the range of an electric vehicle, and not to supply additional power to a weak ICE.*

Frenchman, H. Krieger, built series hybrid vehicle in 1902. His design used two independent DC motors driving the front wheels. They drew their energy from 44 lead–acid cells that were recharged by a 4.5 hp alcohol spark-ignited engine coupled to a shunt DC generator. Another, Frenchman Camille Jenatzy presented the second vehicle a parallel hybrid vehicle at the Paris Salon of 1903. This vehicle combined a 6 hp gasoline engine with a 14 hp electric machine that could either charge the batteries from the engine or assist them later.

Other hybrid vehicles, both of the parallel and series type, were built during a period ranging from 1899 until 1914. Although electric braking has been used in these early designs, there is no mention of regenerative braking. It is likely that most, possibly even all, designs used dynamic braking by short circuiting or by placing a resistance in the armature of the traction motors. The Lohner-Porsche vehicle of 1903 is a typical example of this approach.

Early hybrid vehicles were built in order to assist the weak ICEs of that time or to improve the range of electric vehicles. They made use of the basic electric technologies that were then available. In spite of the great creativity that presided in their design, these early hybrid vehicles could no longer compete with the greatly improved gasoline engines that came into use after World War I. The gasoline engine made tremendous improvements in terms of power density, the engines became smaller and more efficient, and there was no longer a need to assist them with electric motors. The supplementary cost of having an electric motor and the hazards associated with the – acid batteries were key factors in the disappearance of hybrid vehicles from the market after World War I.

THANK YOU

Electric and Hybrid Electric Vehicles

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Course Content

UNIT II

BRAKING FUNDAMENTALS AND REGENERATIVE BRAKING IN ELECTRIC VEHICLES

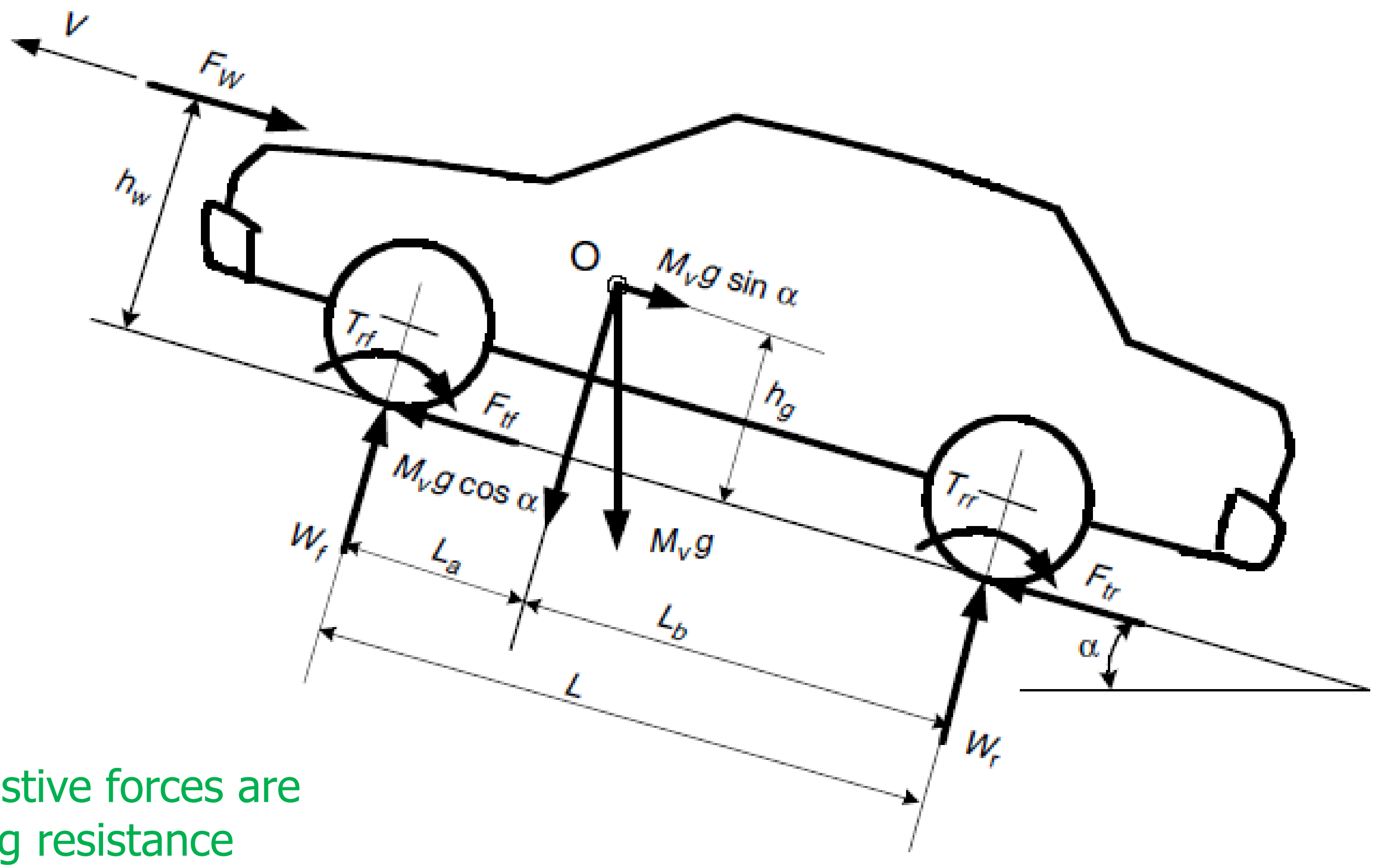
General Description of Vehicle Movement, Vehicle Resistance, Dynamic Equation, Tire–Ground Adhesion and Maximum Tractive Effort, Power Train Tractive Effort and Vehicle Speed, Vehicle Power Plant and Transmission Characteristics, Brake Performance.

Braking Energy Consumed in Urban Driving, Importance of Regenerative Braking in Electric and Hybrid Vehicles.

General Description of Vehicle Movement

- The vehicle motion can be completely determined by analysing the forces acting on it in the direction of motion.
- The tractive force (**F_t**) in the contact area between the tires of the driven wheels and the road surface propels the vehicle forward.
- The tractive force (**F_t**) is produced by the power plant and transferred to the driving wheels via the transmission and the final drive.
- When the vehicle moves, it encounters a resistive force that tries to retard its motion.

Forces acting on a vehicle going uphill



The resistive forces are

- Rolling resistance
- Aerodynamic drag
- Uphill resistance

The typical values of the rolling resistance coefficient (**f_r**) are given in following **Table**

Table 1: Reference values for the rolling resistance coefficient (f_r)

Conditions	Rolling resistance coefficient (f_r)
Car tire on smooth tarmac road	0.01
Car tire on concrete road	0.011
Car tire on a rolled gravel road	0.02
Tar macadam road	0.025
Unpaved road	0.05
Bad earth tracks	0.16
Loose sand	0.15-0.3
Truck tire on concrete or asphalt road	0.006-0.01
Wheel on iron rail	0.001-0.002

Based on experimental results, many empirical formulas have been proposed for calculating the rolling resistance on a hard surface. For example, the rolling resistance coefficient of a passenger car on a concrete road may be calculated as:

$$f_r = f_0 + f_s \left(\frac{V}{100} \right)^{2.5}$$

where

$V = vehicle\ speed\ [km/h]$

In vehicle performance calculation, it is sufficient to consider the rolling resistance coefficient as a linear function of speed. For most common range of inflation pressure, the following equation can be used for a passenger car on a concrete road

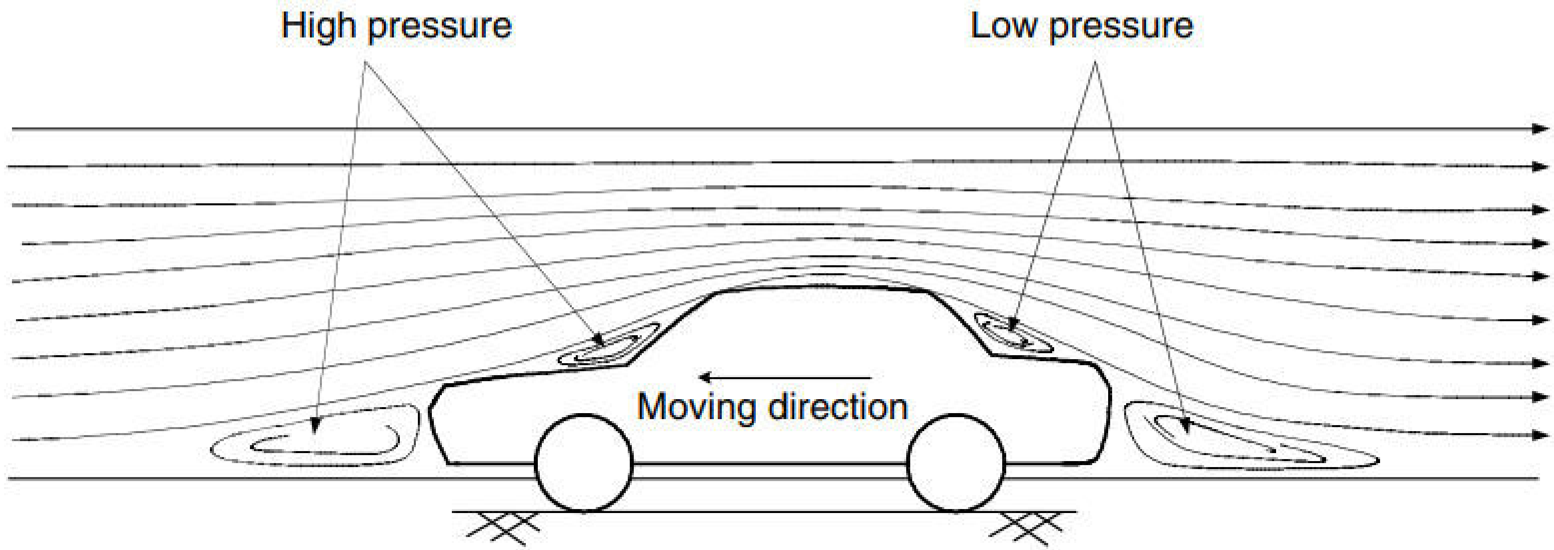
$$f_r = 0.01\left(1 + \frac{V}{160}\right)$$

where

V = *vehicle speed* [km/h]

The above Equation can predict the values of $\mathbf{f_r}$ with acceptable accuracy for speed upto 128km/h.

Aerodynamic Drag



A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is known as aerodynamic drag. The main causes of aerodynamic drag are:

- shape drag
- skin friction

To determine the maximum tractive effort, that the tire ground contact can support, the normal loads on the front and rear axles have to be determined. By summing the moments of all the forces about point **R** (centre of the tire-ground area), the normal load on the front axle $\mathbf{W_f}$ can be determined as

$$W_f = \frac{MgL_b \cos(\alpha) - \left(T_{rf} + T_{rr} + F_w h_w + Mgh_g \sin(\alpha) + Mh_g \frac{dV}{dt} \right)}{L}$$

Similarly, the normal load acting on the rear axel can be expressed as

$$W_r = \frac{MgL_a \cos(\alpha) - \left(T_{rf} + T_{rr} + F_w h_w + Mgh_g \sin(\alpha) + Mh_g \frac{dV}{dt} \right)}{L}$$

In case of passenger cars, the height of the centre of application of aerodynamoic resistance (**h_w**) is assumed to be near the height of centre of gravity of the vehicle (**h_g**).

$$W_f = \frac{L_b}{L} Mg\cos(\alpha) - \frac{h_g}{L}\left(F_w + F_g + Mgf_r \frac{r_{dyn}}{h_g}\cos(\alpha) + M\frac{dV}{dt}\right)$$

$$W_r = \frac{L_a}{L} Mg\cos(\alpha) - \frac{h_g}{L}\left(F_w + F_g + Mgf_r \frac{r_{dyn}}{h_g}\cos(\alpha) + M\frac{dV}{dt}\right)$$

By simplification, we get

$$W_r = \frac{L_a}{L} Mg\cos(\alpha) - \frac{h_g}{L}\left(F_t - F_r\left(1 - \frac{r_{dyn}}{h_g}\right)\right)$$

$$W_r = \frac{L_a}{L} Mg\cos(\alpha) + \frac{h_g}{L}\left(F_t - F_r\left(1 - \frac{r_{dyn}}{h_g}\right)\right)$$

The first term on the right hand side of the above **equation** is the static load on the front and the rear axles when the vehicle is at rest on level ground. The second term is the dynamic component of the normal load.

The maximum tarctive effort (**F$_{tmax}$**)) that the tire-ground contact can support is described by the product of the normal load and the coefficient of road adhesion (**m**). For the front wheel driven vehicle, **F$_{tmax}$** is given by

$$F_{tmax} = \mu W_f = \mu\left[\frac{L_b}{L} Mg\cos(\alpha) - \frac{h_g}{L}\left(F_{tmax} - F_r\left(1 - \frac{r_{dyn}}{h_g}\right)\right)\right]$$

$$F_{tmax} = \frac{\mu Mg\cos(\alpha)\left[L_b + f_r\left(h_g - r_{dyn}\right)\right]/L}{1 + \mu h_g / L}$$

For the rear wheel driven vehicle, $\mathbf{F_{tmax}}$ is given by

$$F_{tmax} = \mu W_r = \mu \left[\frac{L_b}{L} Mg\cos(\alpha) + \frac{h_g}{L} \left(F_{tmax} - F_r \left(1 - \frac{r_{dyn}}{h_g} \right) \right) \right]$$

$$F_{tmax} = \frac{\mu Mg\cos(\alpha)\left[L_a - f_r \left(h_g - r_{dyn} \right) \right] / L}{1 - \mu h_g / L}$$

Table 3: Coefficient of road adhesion

Road speed [km/h]	**Coefficient of road adhesion for dry roads**	**Coefficient of road adhesion for wetroads**
50	0.85	0.65
90	0.8	0.6
130	0.75	0.55

Adhesion, Dynamic wheel radius and slip

When the tractive effort of a vehicle exceeds the maximum tractive effort limit imposed by the adhesive capability between the tyre and ground, the driven wheels will spin on the ground. The adhesive capability between the tyre and the ground is the main limitation of the vehicle performance especially when the vehicle is driven on wet, icy, snow covered or soft soil roads.

The maximum tractive effort on the driven wheels, transferred from the power plant through the transmission should not exceed the maximum values given by above **equations**. Otherwise, the driven wheels will spin on the ground, leading to vehicle instability. The slip between the tyres and the surface can be described as:

$$\text{drive slip } S_T = \frac{\omega_R r_{dyn} - V}{\omega_R r_{dyn}}$$

where

ω_R = angular speed of the tyre $[rad/s]$

The dynamic wheel radius (**r_{dyn}**) is calculated from the distance travelled per revolution of the wheel, rolling without slip. The dynamic wheel radius is calculated from a distance travelled at 60km/h. The increasing tyre slip at higher speeds roughly offsets the increase in **r_{dyn}**.

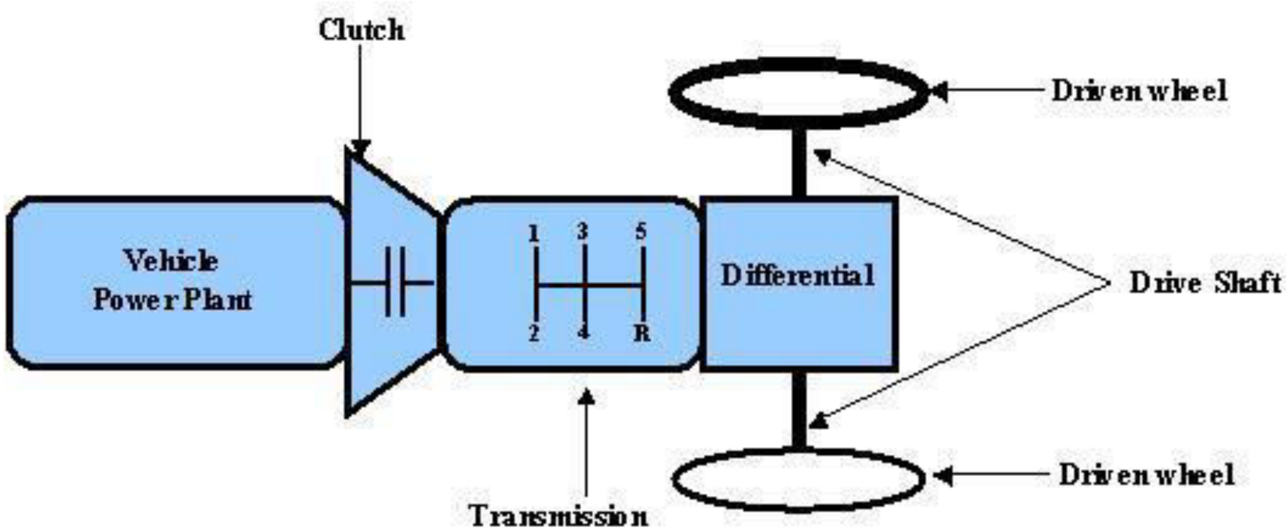
Table 4: Dynamic wheel radius of common tyre sizes

Tyre Size	Rolling Circumference [m]	Rdyn [m]	Tyre Size	Rolling Circumference [m]	Rdyn [m]
Passenger cars			**Passenger cars**		
135 R 13	1.67	0.266	205/65 R15	1.975	0.314
145 R 13	1.725	0.275	195/60 R15	1.875	0.298
155 R 13	1.765	0.281	205/60 R 15	1.91	0.304
145/70 R 13	1.64	0.261	**Light commercial vehicles**		
155/70 R13	1.68	0.267	185 R 14	1.985	0.316
165/70 R 13	1.73	0.275	215 R 14	2.1	0.334
175/70 R 13	1.77	0.282	205 R 14	2.037	0.324
175 R 14	1.935	0.308	195/75 R 16	2.152	0.343
185 R 14	1.985	0.316	205/75 R 16	2.2	0.35
195/70 R 14	1.94	0.309	**Trucks and buses**		
185/65 R 14	1.82	0.29	12 R 22.5	3.302	0.526
185/60 R 14	1.765	0.281	315/80 R 22.5	3.295	0.524
195/60 R 14	1.8	0.286	295/80 R 22.5	3.215	0.512
195/70 R 15	2	0.318	215/75 R 17.5	2.376	0.378
185/65 R15	1.895	0.302	275/70 R 22.5	2.95	0.47
195/65 R15	1.935	0.308	305/70 R 19.5	2.805	0.446

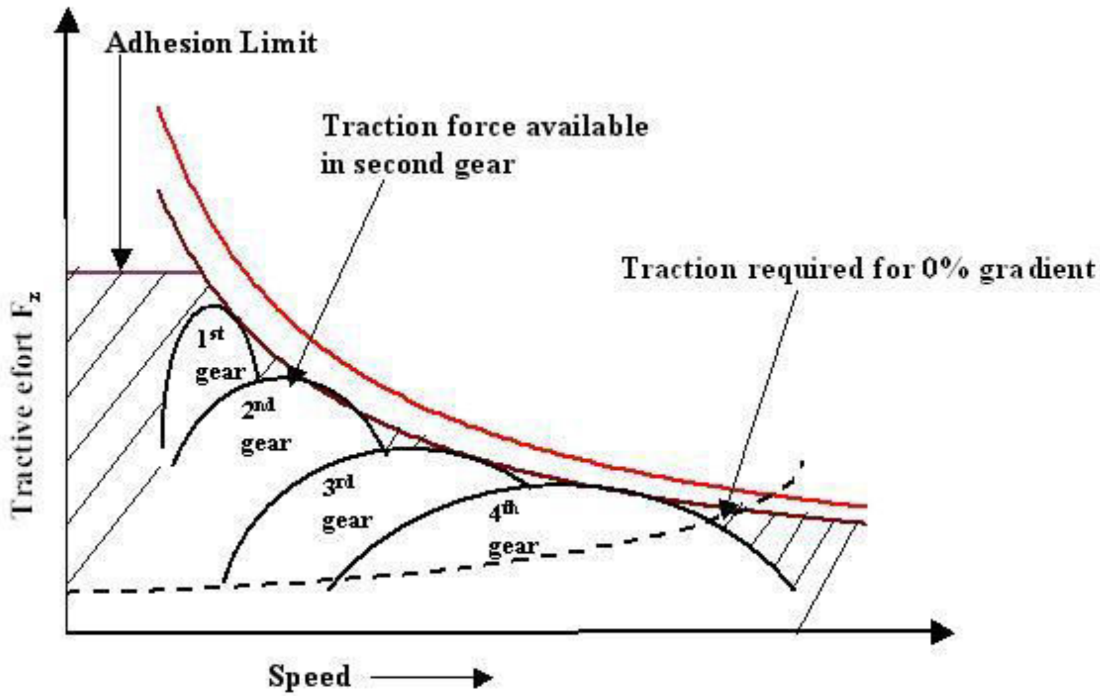
Drive train Configuration

An automotive drive train is shown in **Figure**. It consists of:

- a power plant
- a clutch in a manual transmission or a torque converter in automatic transmission
- a gear box
- final drive
- differential shaft
- driven wheels



Traction force vs. speed map of an internal combustion engine with gearbox



In order to utilize the shaded area, shown in previous **Figure** , additional output converter is required. The output converter must convert the characteristics of the combustion engine in such a way that it approximates as closely as possible to the ideal ***traction hyperbola*** (See **Figure**).

The proportion of the shaded area, i.e. the proportion of impossible driving states, is significantly smaller when an output converter is used. Thus, the power potential of the engine is better utilized. The **Figure** shows how increasing the number of gears gives a better approximation of the ***effective traction hyperbola***.

Power train tractive effort and vehicle speed

After having dealt with the configuration of the drivetrain, this section deals with the ***tractive effort*** . The torque transmitted from the power plant to the driven wheels ($\mathbf{T_w}$) is given by:

$$T_w = i_g i_o \eta_t T_p$$

where

i_g = gear ratio of the transmission

i_o = gear ratio of the fianl drive

η_t = efficiency of the driveline from the power plant to the driven wheels

T_p = torque output from the power plant $[Nm]$

The tractive effort on the driven wheels is expressed as

$$F_t = \frac{T_w}{r_{dyn}}$$

where

r_{dyn} = dynamic radius of the tyre [m]

$$F_t = \frac{T_p i_g i_o \eta_t}{r_{dyn}}$$

The total mechanical efficiency of the transmission between the engine output shaft and driven wheels is the product of the efficiencies of all the components of the drive train.

The rotating speed of the driven wheel is given by

$$N_w = \frac{N_p}{i_g i_o} \ [rpm]$$

where

N_p = *rottational speed of the transmission* $[rpm]$

The rotatational speed $\mathbf{N_p}$ of the transmission is equal to the engine speed in the vehicle with a manual transmission and the turbine speed of a torque converter in the vehicle with an automatic transmission. The ***translation speed of the wheel*** (***vehicle speed***) is expressed as

$$V = \frac{\pi N_w r_{dyn}}{30} \ [m/s]$$

By substituting the value of $\mathbf{N_w}$, the ***vehicle speed*** can be expressed as

$$V = \frac{\pi N_p r_{dyn}}{30 i_g i_o} \ [m/s]$$

Vehicle performance

The performance of a vehicle is determined by the following factors:

- maximum cruising speed
- gradeability
- acceleration

Maximum Cruising Speed

The maximum speed of a vehicle is defined as the constant cruising speed that the vehicle can achieve with full power plant load on a flat road. The maximum speed of a vehicle is determined by the equilibrium between the tractive effort of the vehicle and the resistance and maximum speed of the power plant and gear ratios of the transmission.

This equilibrium is:

$$\frac{T_p i_g i_0 \eta_t}{r_{dyn}} = Mgf_r \cos(\alpha) + \frac{1}{2}\rho_a C_D A_f V^2$$

where

i_g = *gear ratio of the transmission*

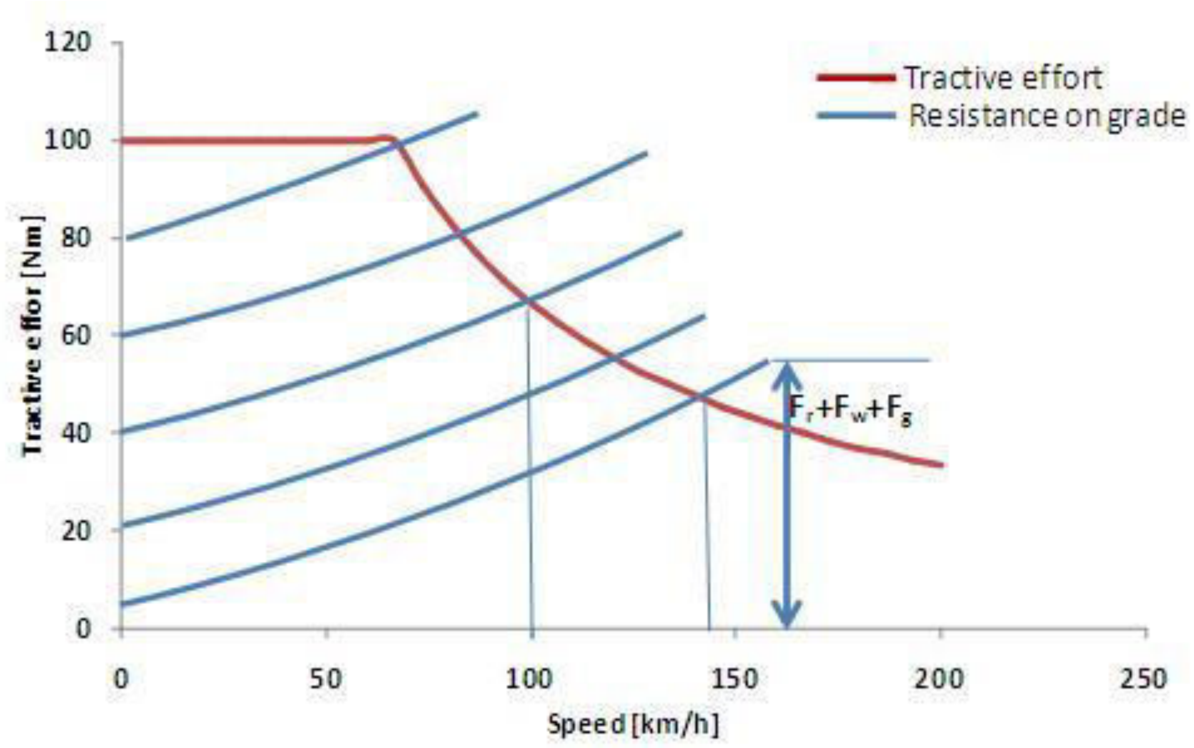
i_0 = *gear ratio of the final drive*

η_t = *efficiency of the driveline from the power plant to the driven wheels*

T_p = *torque output of the power plant* [Nm]

equation *shows that the vehicle reaches its maximum speed when the tractive effort, represented by the left hand side term, equals the resistance, represented by the right hand side.*

Tractive effort of an electric motor powered vehicle with a single speed transmission and its resistance



The intersection of the tractive effort curve and the resistance curve is the maximum speed of the vehicle.

For some vehicles, no intersection exists between the tractive effort curve and the resistance curve, because of a large power plant. In such a case the maximum speed of the vehicle is determined by the maximum speed of the power plant. This maximum speed is given by

$$V_{\max} = \frac{\pi n_{p\max} r_{dyn}}{30 i_0 i_{g\min}}$$

where

$i_{g\min}$ = minimum gear ratio of the transmission

i_0 = gear ratio of the final drive

$n_{p\max}$ = maximum speed of the power plant (motor or engine) [rpm]

T_p = torque output of the power plant [Nm]

r_{dyn} = dynamic radius of the tyre [m]

Gradeability

- Gradeability is defined as the grade angle that the vehicle can negotiate at a certain constant speed. For heavy commercial vehicles the gradeability is usually defined as the maximum grade angle that the vehicle can overcome in the whole speed range.
- When the vehicle is driving on a road with relatively small grade and constant speed, the tractive effort and resistance equilibrium can be expressed as

$$\frac{T_p i_0 i_g \eta_t}{r_{dyn}} = Mgf_r + \frac{1}{2}\rho_a C_D A_f V^2 + Mgi$$

$$i = \frac{T_p i_0 i_g \eta_t / r_{dyn} - Mg f_r - 1/2 \rho_a C_D A_f V^2}{Mg} = d - f_r$$

$$d = \frac{T_p i_0 i_g \eta_t / r_{dyn} - 1/2 \rho_a C_D A_f V^2}{Mg}$$

The factor **d** is called the performance factor.

When the vehicle drives on a road with a large grade, the gradeability of the vehicle can be calculated as

$$\sin(\alpha) = \frac{d - f_r^2 \sqrt{1 - d^2 + f_r^2}}{1 + f_r^2}$$

Acceleration Performance

The acceleration of a vehicle is defined by its acceleration time and distance covered from zero speed to a certain high speed on a level ground. The acceleration of the vehicle can be expressed as

$$a = \frac{dV}{dt} = \frac{F_t - F_f - F_w}{M\delta} = \frac{T_p i_0 i_g \eta_t / r_{dyn} - Mgf_r - 1/2 \rho_a C_D A_f V^2}{M\delta} = \frac{g}{\delta}(d - f_r)$$

where δ is the rotational inertia factor taking into account the equivalent mass increase due to the angular moments of the rotating components. This mass factor can be written as

$$\delta = 1 + \frac{I_w}{Mr_{dyn}^2} + \frac{i_0^2 i_g^2 I_p}{Mr^2}$$

I_w = total angular inertial moment of the wheels

I_p = total angular inertial moment of the rotating components associated with the power plant

To determine the value of δ, it is necessary to determine the values of the mass moments of inertia of all the rotating parts. In case the mass moments of inertia are not available then, the rotational factor (δ) can be approximated as:

$$\delta = 1 + \delta_1 + \delta_2 i^2 i_0^2$$

$$\delta_1 \approx 0.04$$

$$\delta_2 \approx 0.0025$$

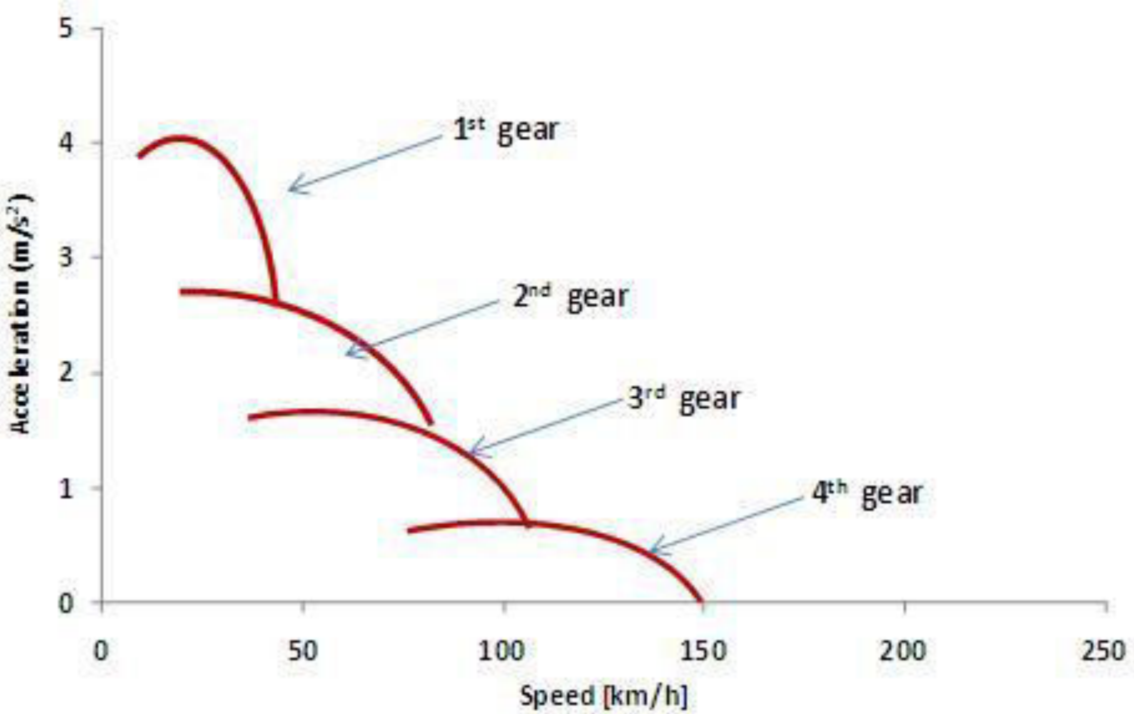


Fig: Acceleration rate of a petrol engine powered vehicle with four gears

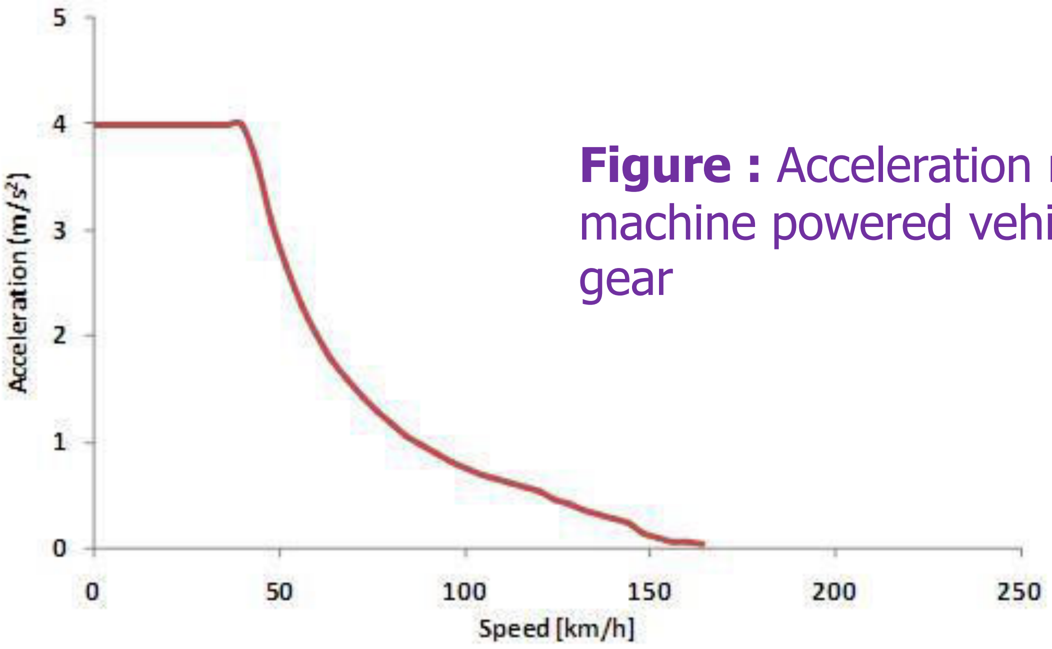
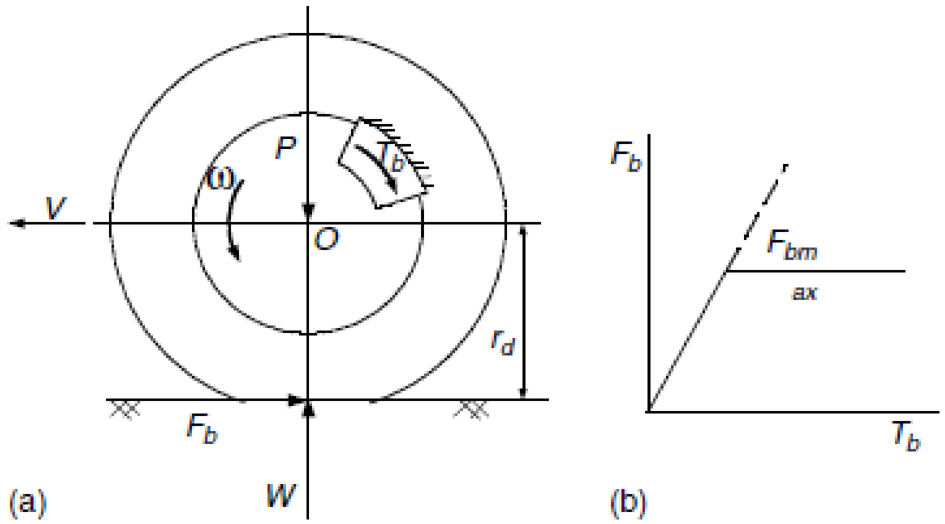


Figure : Acceleration rate of an electric machine powered vehicle with a single gear

Braking Performance

- The braking performance of a vehicle is undoubtedly one of the most important characteristics that affect vehicle safety. In urban driving, a significant amount of energy is consumed in braking.
- In recent years, more and more electric drives have been involved in vehicle traction, such as electric vehicles, hybrid electric vehicles, and fuel cell-powered vehicles.
- The electrification of the vehicle drive train makes it feasible to recover some of the energy lost in braking.
- This technology is usually referred to as regenerative braking.
- A well-designed regenerative braking system not only improves vehicle efficiency but also potentially improves braking performance.
- In this section, a method of approach to the analysis of braking performance will be presented, which aims to help the designing of regenerative braking systems.

Braking Force



The brake pad is pressed against the brake plate, thus developing a frictional torque on the brake plate. This braking torque results in a braking force in the tire–ground contact area. It is just this braking force that tries to stop the vehicle.

The braking force can be expressed as

$$F_b = \frac{T_b}{r_d}.$$

The braking force increases with an increase in braking torque. However, when the braking force reaches the maximum braking force that the tire–ground adhesion can support, it will not increase further, although the braking torque may still increase as shown in Figure (b). This maximum braking force limited by the adhesive capability can be expressed as

$$F_{b\max} = \mu_b W,$$

where μ_b is the adhesive coefficient of the tire–ground contact.

Braking Distribution on Front and Rear Axles

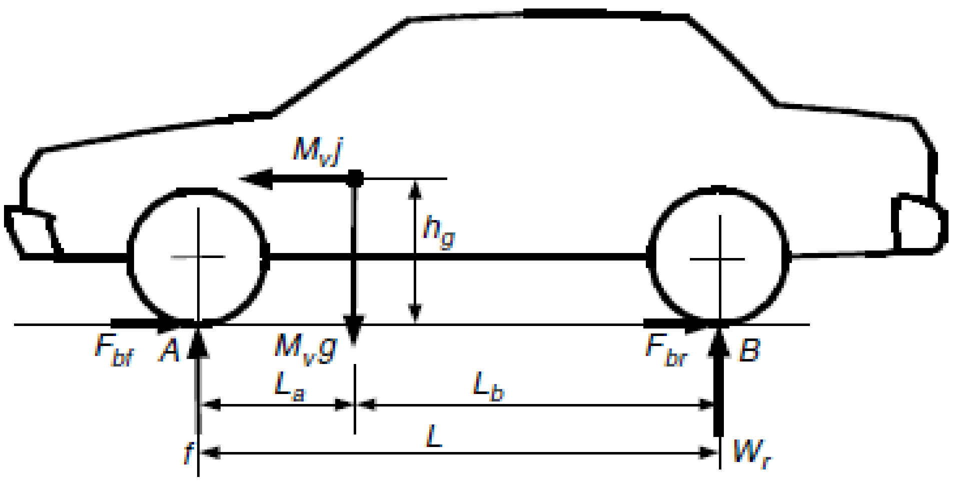


FIGURE:
Force acting on a vehicle during braking on a flat road

Rolling resistance and aerodynamic drag are ignored in this figure, because they are quite small compared to the braking forces. j is the deceleration of the vehicle during braking, which can be easily expressed as

$$j = \frac{F_{bf} + F_{br}}{M_v},$$

where F_{bf} and F_{br} are the braking forces acting on front and rear wheels, respectively.

The maximum braking force is limited by the tire–ground adhesion and is proportional to the normal load acting on the tire. Thus, the actual braking force developed by the brake torque should also be proportional to the normal load so that both the front and the rear wheels obtain their maximum braking force at the same time.

During braking, there is load transfer from the rear axle to the front axle.

By considering the equilibrium of moments about the front and rear tire–ground contact points A and B, the normal loads on the front and rear axles, *Wf* and *Wr*, can be expressed as

$$W_f = \frac{M_v g}{L}\left(L_b + h_g \frac{j}{g}\right)$$

and

$$W_r = \frac{M_v g}{L}\left(L_a - h_g \frac{j}{g}\right),$$

where j is the deceleration of the vehicle.

The braking forces of the front and rear axle should be proportional to their normal load, respectively; thus, one obtains

$$\frac{F_{bf}}{F_{br}} = \frac{W_f}{W_r} = \frac{L_b + h_g j/g}{L_a - h_g j/g}.$$

The ideal braking force distribution curve (simply, *I* curve) is a nonlinear hyperbolic curve. If it is desired for the front and rear wheels to lock up at the same time on any road, the braking force on the front and rear axle must closely follow this curve.

Electric and Hybrid Electric Vehicles

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Course Content

UNIT III

INTRODUCTION TO ELECTRIC AND HYBRID ELECTRIC VEHICLES

Hybrid Electric Drivetrains: Basic concept of hybrid traction, introduction to various hybrid drive-train topologies, power flow control in hybrid drive-train topologies; Introduction to pure EV's (BEY, FCV).

Hybrid Electric Vehicle (HEV)

- ***Hybrid vehicle*** refers to a vehicle with at least two sources of power.
- A ***hybrid-electric vehicle*** indicates that ***one source of power*** is provided by an ***electric motor***. The ***other source of motive power*** can come from a number of different technologies, but is typically provided by an ***internal combustion engine*** designed to run on either gasoline or diesel fuel.

An HEV is a vehicle in which propulsion energy is available from two or more types of energy sources and at least one of them can deliver electrical energy .

Based on this general definition, there are many types of HEVs, such as:

- the gasoline ICE and battery
- diesel ICE and battery
- battery and FC
- battery and capacitor
- battery and flywheel
- battery and battery hybrids.

Most commonly, the propulsion force in HEV is provided by a combination of electric motor and an ICE. The electric motor is used to improve the energy efficiency (improves fuel consumption) and vehicular emissions while the ICE provides extended range capability.

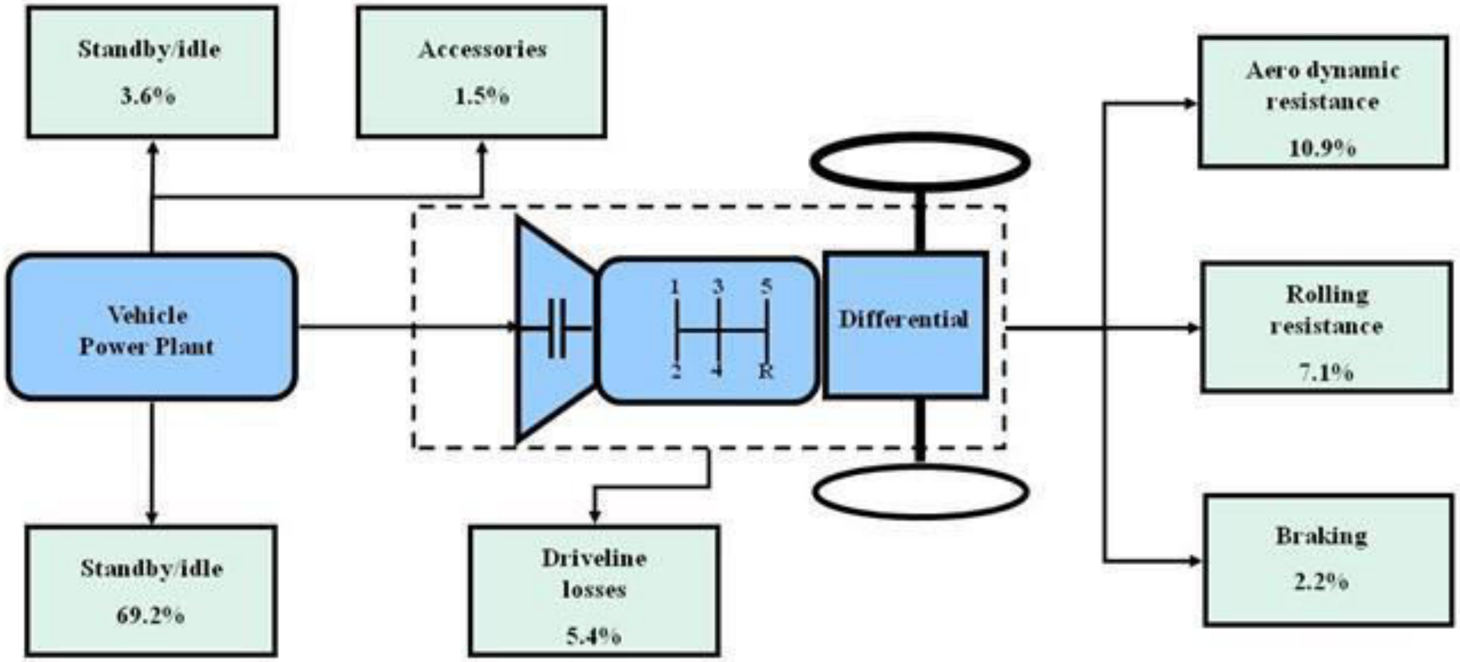


Fig: Translation of fuel energy into work in a vehicle

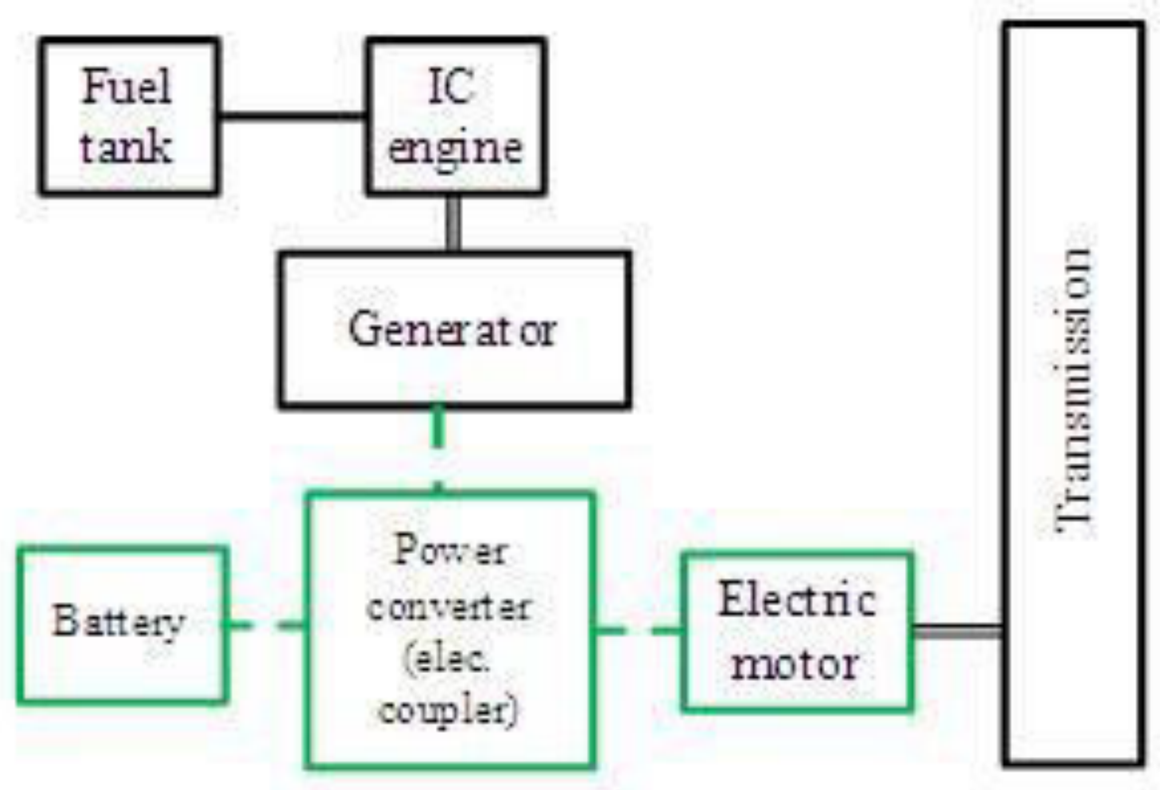


Figure a: Series hybrid

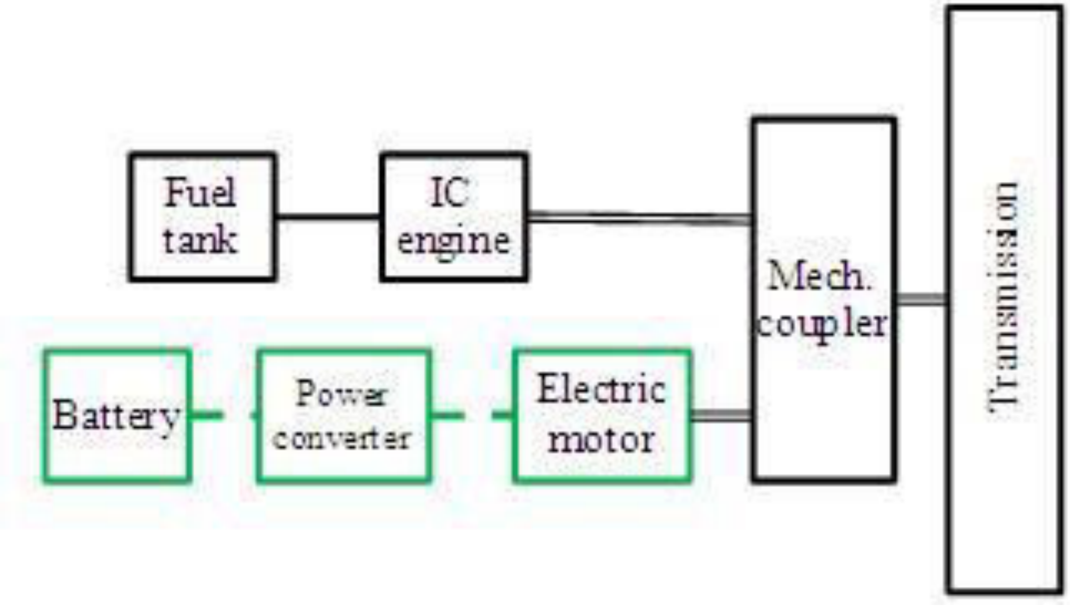


Figure c: Parallel hybrid

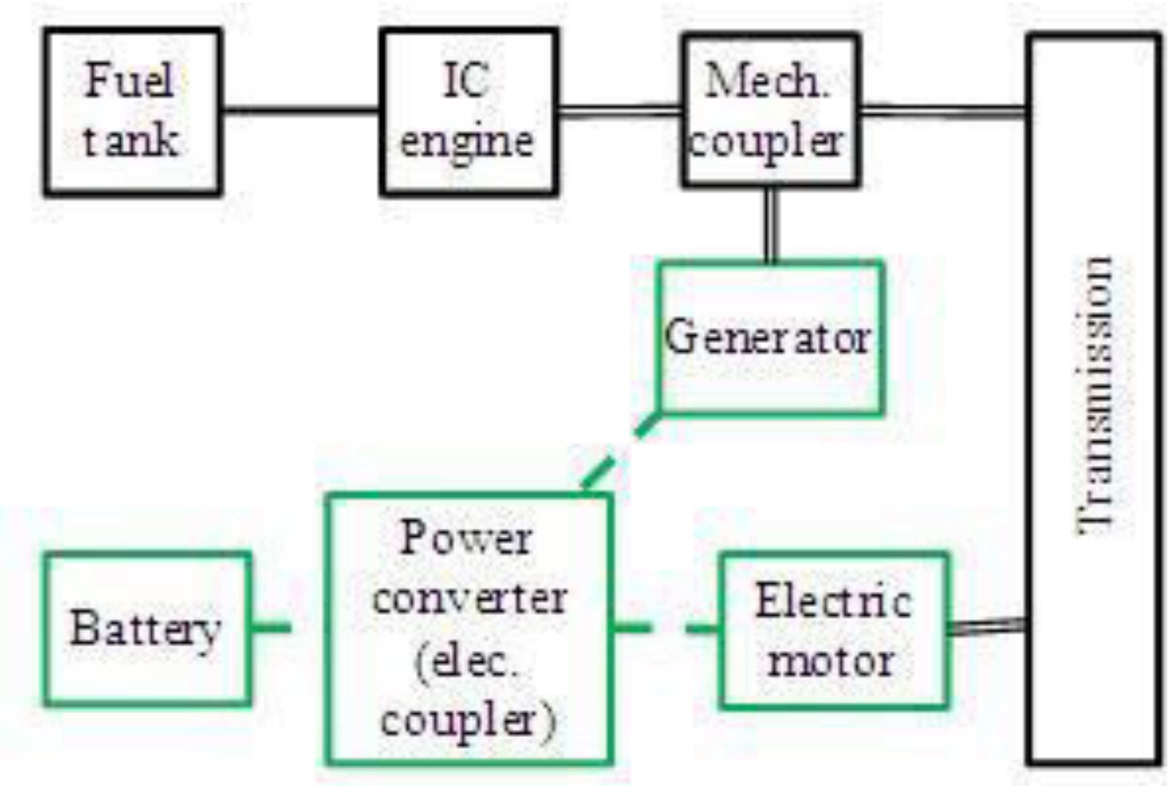


Figure b: Series-Parallel hybrid

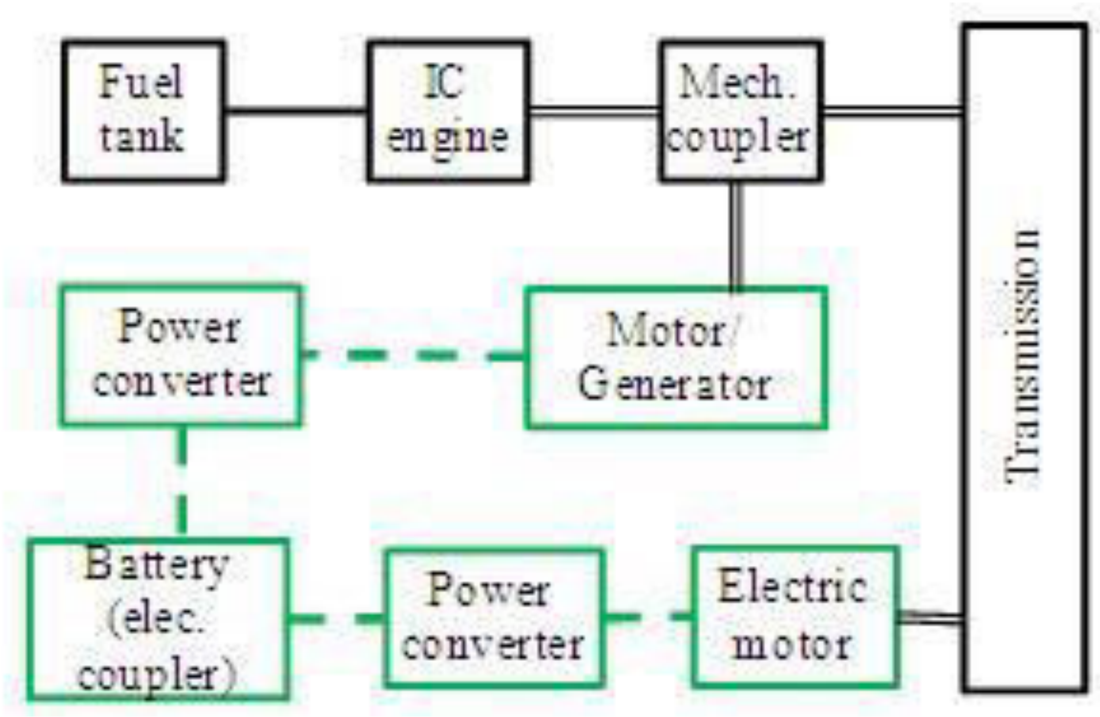


Figure d: Complex hybrid

Series Hybrid System

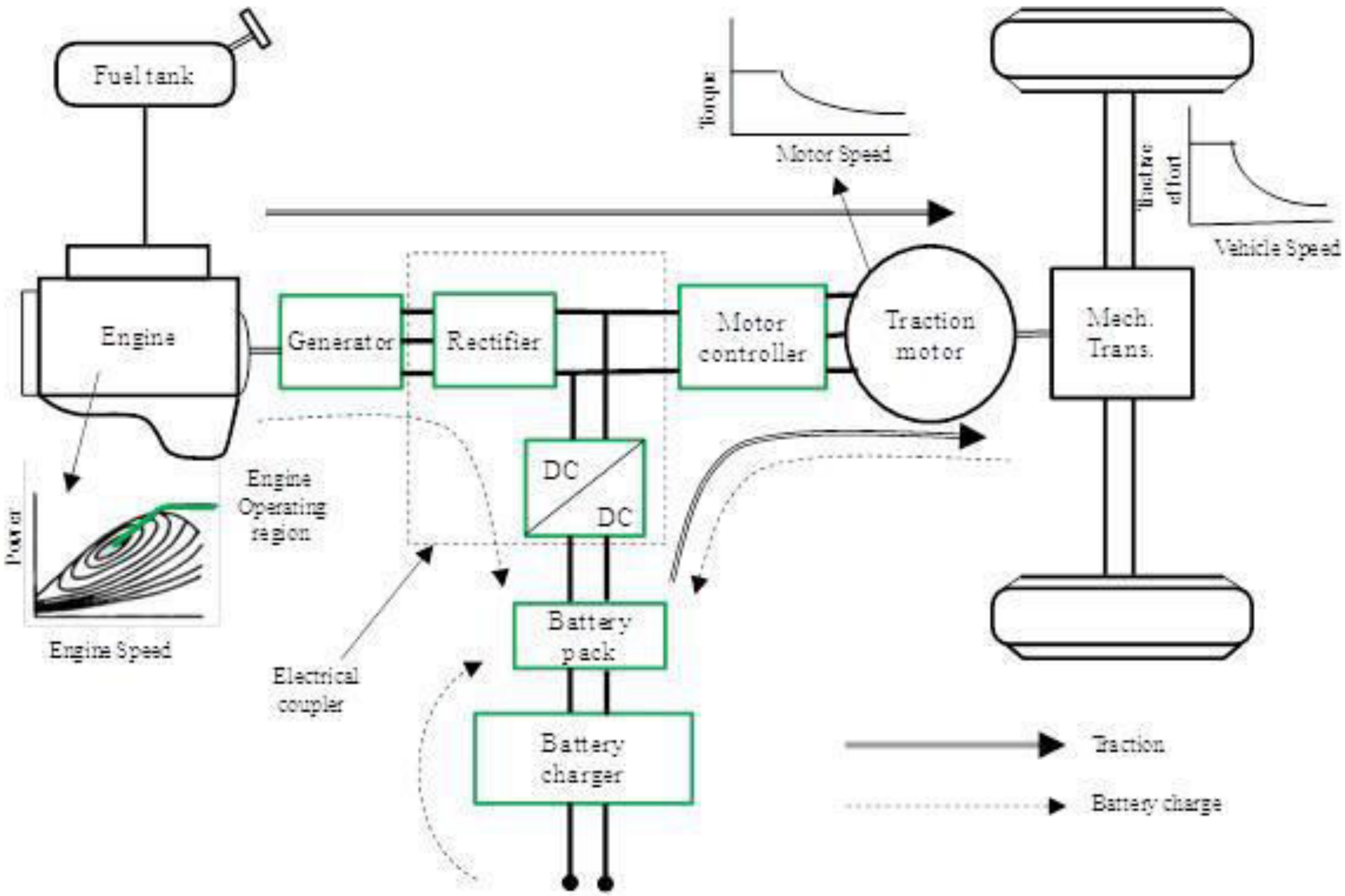


Figure : Detailed Configuration of Series Hybrid Vehicle

Power Flow Control

Due to the variations in HEV configurations, different power control strategies are necessary to regulate the power flow to or from different components. All the control strategies aim satisfy the following goals:

- maximum fuel efficiency
- minimum emissions
- minimum system costs
- good driving performance

The design of power control strategies for HEVs involves different considerations such as:

- ***Optimal ICE operating point:*** The optimal operating point on the torque-speed plane of the ICE can be based on maximization of fuel economy, the minimization of emissions or a compromise between fuel economy and emissions.
- ***Optimal ICE operating line:*** In case the ICE needs to deliver different power demands, the corresponding optimal operating points constitute an optimal operating line.
- ***Safe battery voltage:*** The battery voltage may be significantly altered during discharging, generator charging or regenerative charging. This battery voltage should not exceed the maximum voltage limit nor should it fall below the minimum voltage limit.

Power Flow Control in Series Hybrid

In the series hybrid system there are four operating modes based on the power flow:

Mode 1: During startup (**Figure a**), normal driving or acceleration of the series HEV, both the ICE and battery deliver electric energy to the power converter which then drives the electric motor and hence the wheels via transmission.

Mode 2: At light load (**Figure b**), the ICE output is greater than that required to drive the wheels. Hence, a fraction of the generated electrical energy is used to charge the battery. The charging of the batter takes place till the battery capacity reaches a proper level.

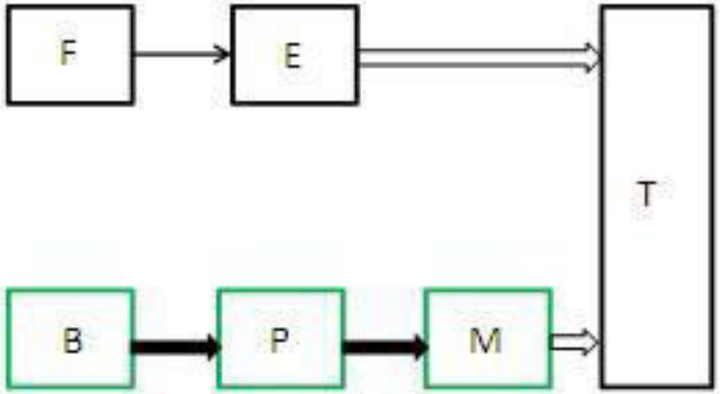


Figure 2a: Mode 1, start up

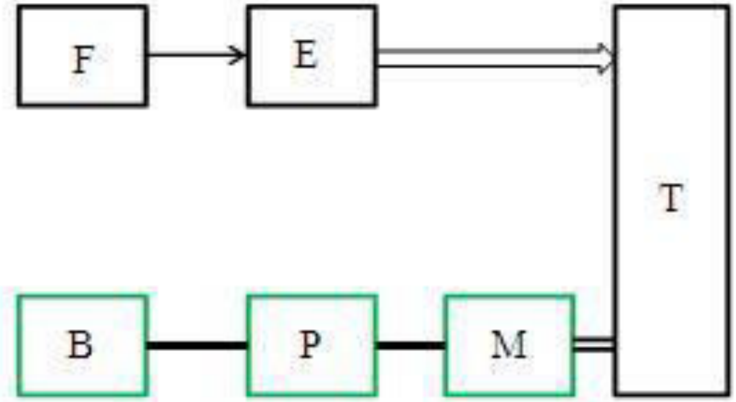


Figure 2b: Mode 2, normal driving

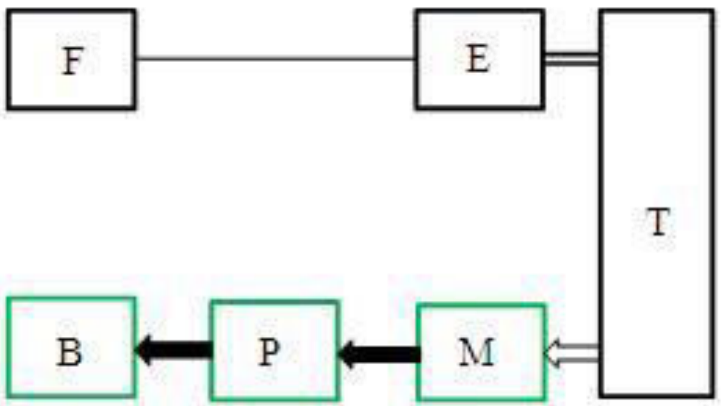


Figure 2c: Mode 3, braking or deceleration

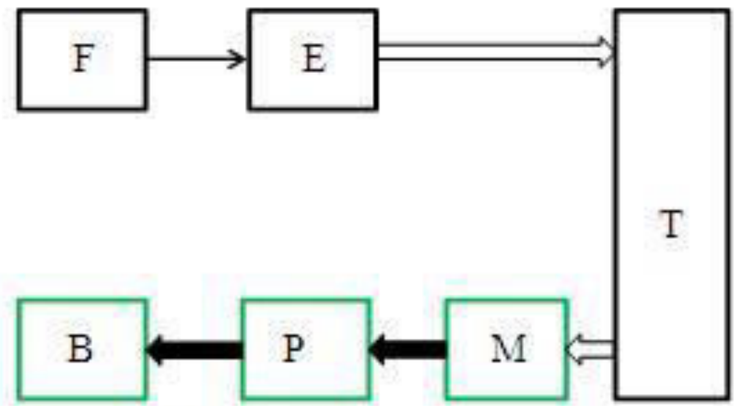


Figure 2d: Mode 4, light load

B:Battery
E: ICE
F: Fuel tank

G: Generator
M: Motor
P: Power Converter

Electrical link
Hydraulic link
Mechanical link

T: Transmission (including brakes, clutches and gears)

Power Flow Control Series-Parallel Hybrid

The series-parallel hybrid system involves the features of series and parallel hybrid systems. Hence, a number of operation modes are feasible. Therefore, these hybrid systems are classified into two categories: **the ICE dominated** and the **EM dominated** .

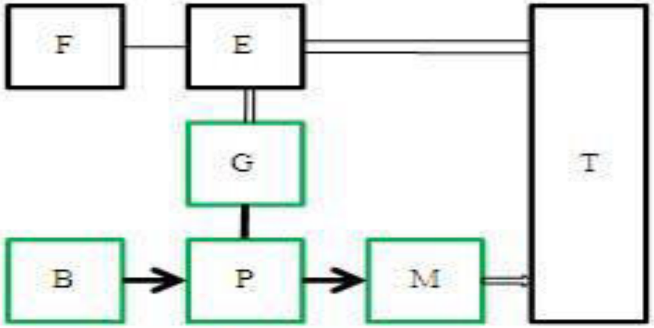


Figure 3a: Mode 1, start up

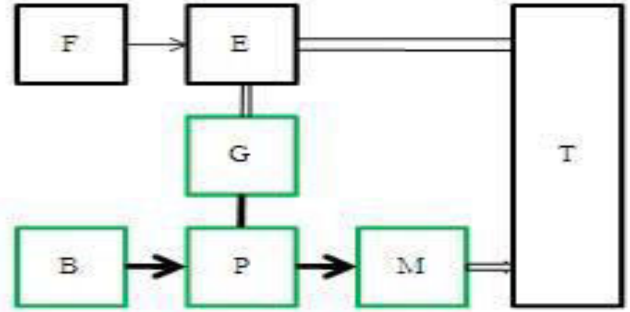


Figure 3b: Mode 2, acceleration

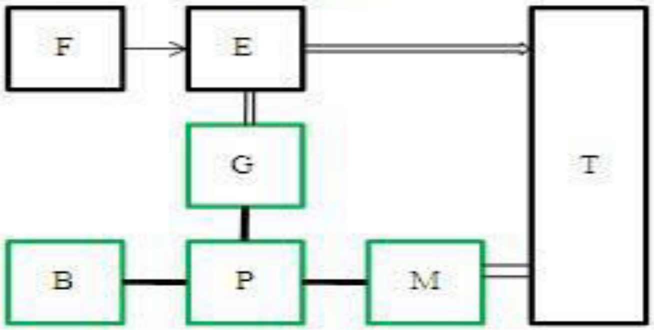


Figure 3c: Mode 3, normal drive

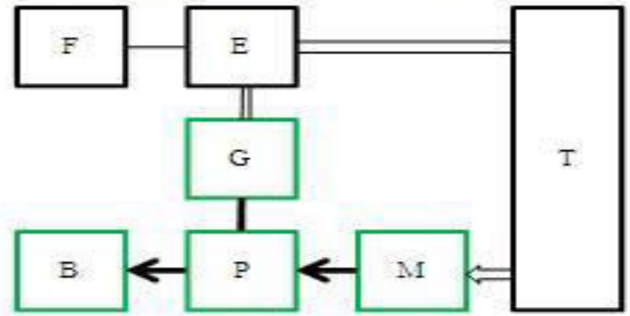


Figure 3d: Mode 4, braking or deceleration

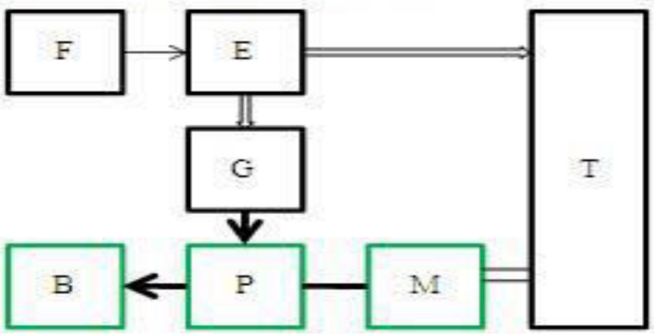


Figure 3e: Mode 5, battery charging during driving

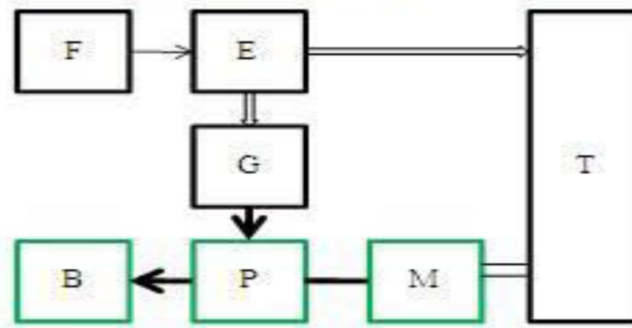


Figure 3f: Mode 6, battery charging during standstill

B : Battery
E : ICE
F : Fuel Tank
G : Generator
M : Motor
P : Power Converter
T : Transmission(including brakes, clutches and gears)

Electrical link
Hydraulic link
Mechanical link

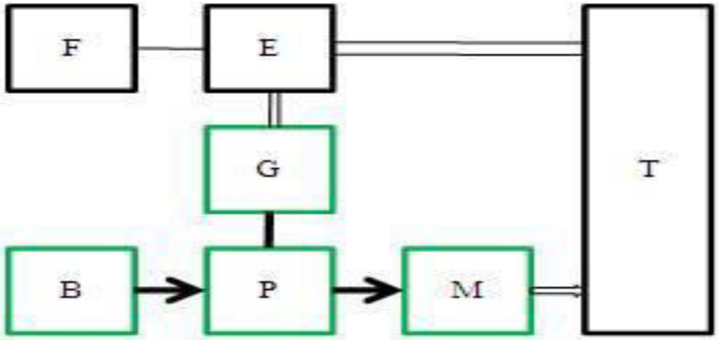


Figure 4a: Mode 1, start up

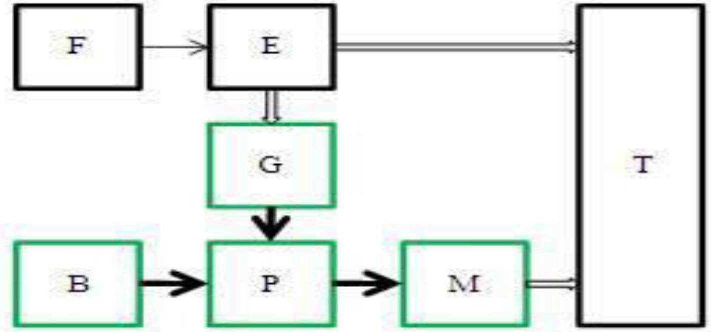


Figure 4b: Mode 2, acceleration

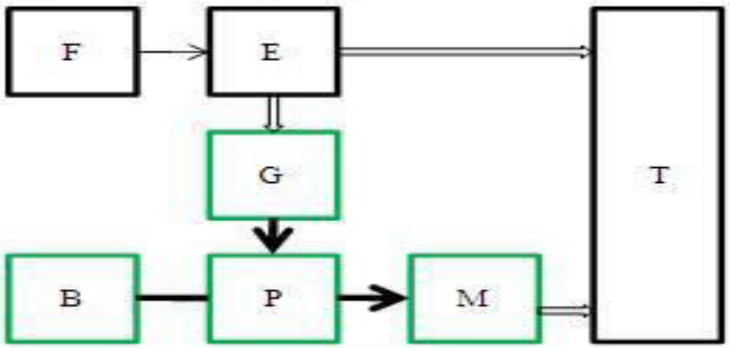


Figure4c: Mode 3, normal drive

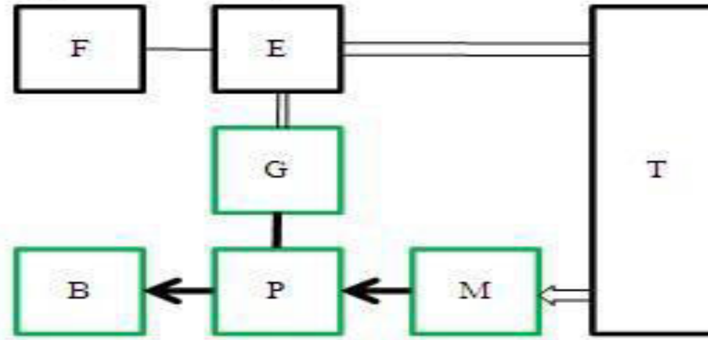


Figure 4d: Mode 4, braking or deceleration

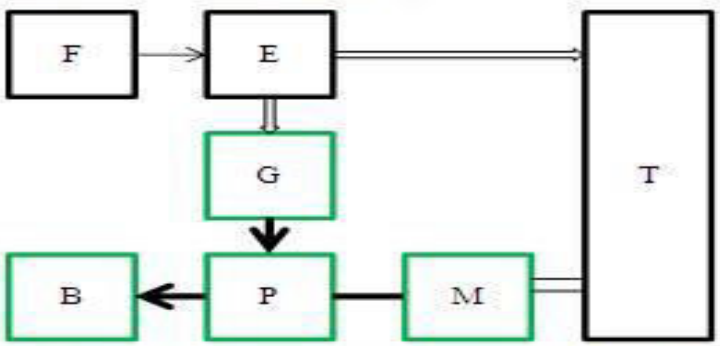


Figure 4e: Mode 5, battery charging during driving

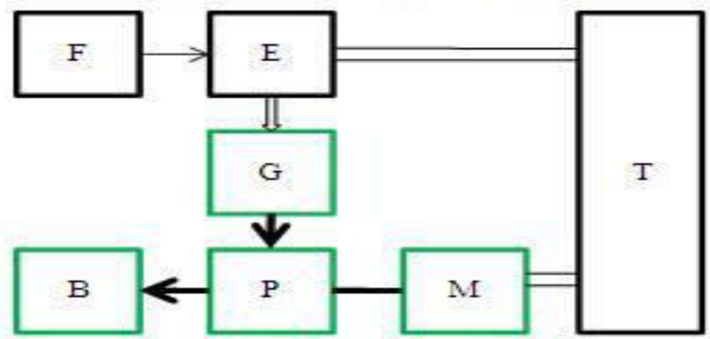


Figure 4f: Mode 6, battery charging during standstill

B : Battery
E : ICE
F : Fuel Tank
G : Generator
M : Motor
P : Power Converter
T : Transmission(including brakes, clutches and gears)

Electrical link
Hydraulic link
Mechanical link

Power Flow Control Complex Hybrid Control

The complex hybrid vehicle configurations are of two types:

- Front hybrid and rear electric
- Front electric and rear hybrid

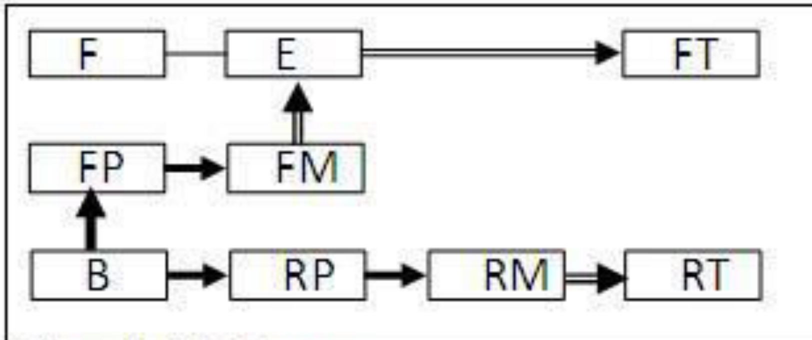


Figure 5a: Mode 1, startup

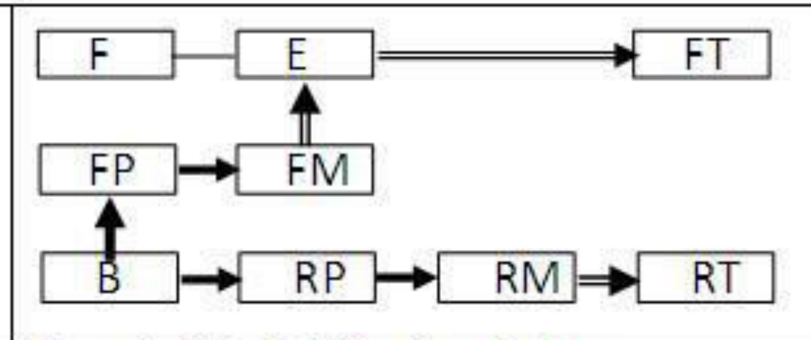


Figure 5b: Mode 2, full throttle acceleration

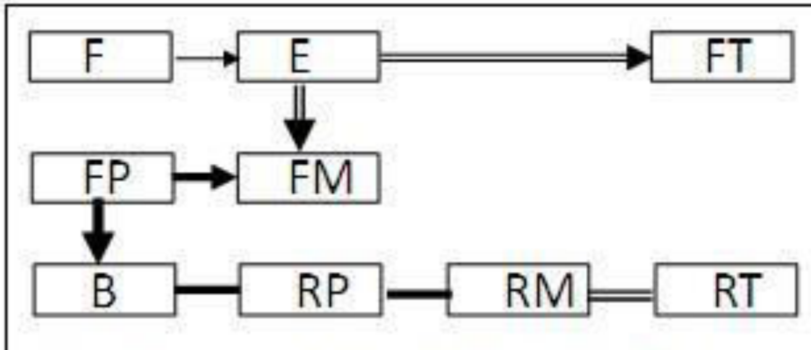


Figure 5c: Mode 3, vehicle propel and battery charging

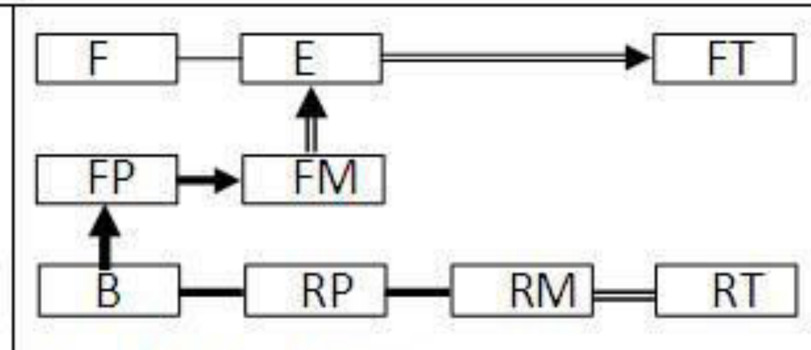


Figure 5d: Mode 4, light load

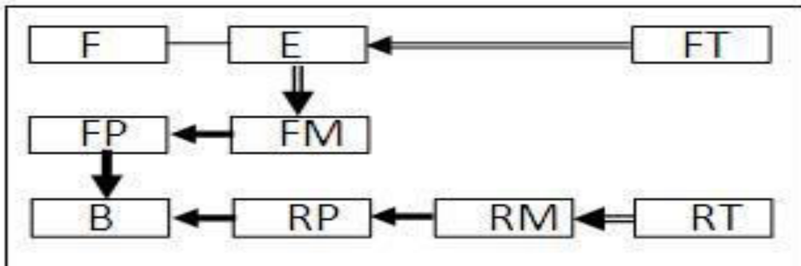


Figure 5e: Mode 5, braking or decelration

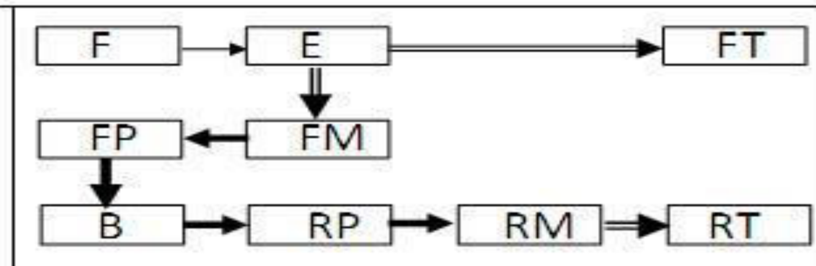


Figure 5f: Mode 1, axil balancing

B:Battery FM: Front motor FP: Front power converter FT: Front axel transmission E: ICE F: Fuel tank
RM: Rear motor RP: Rear power converter RT: Rear axel transmission

Electrical link
Hydraulic link
Mechanical link

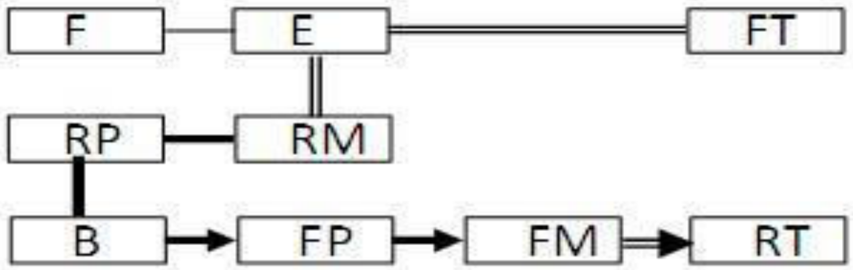


Figure 6a: Mode 1, startup

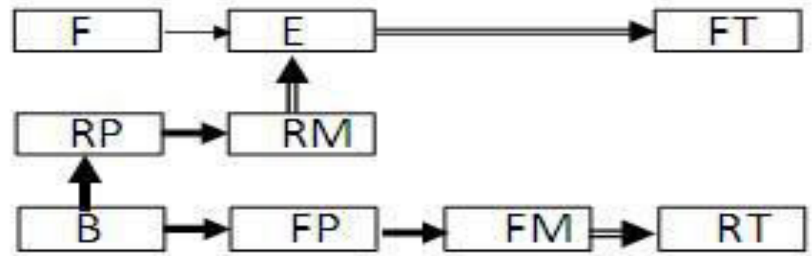


Figure 6b: Mode 2, full throttle acceleration

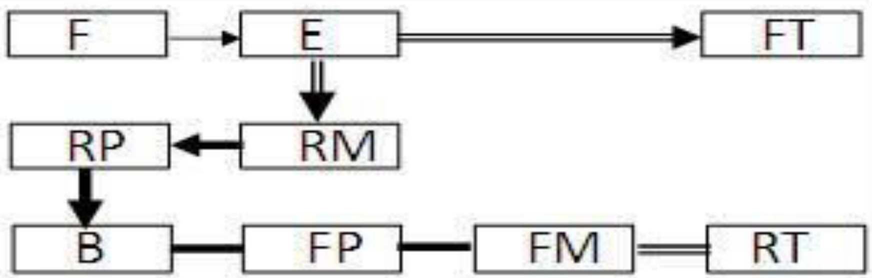


Figure 6c: Mode 3, vehicle propel and battery charging

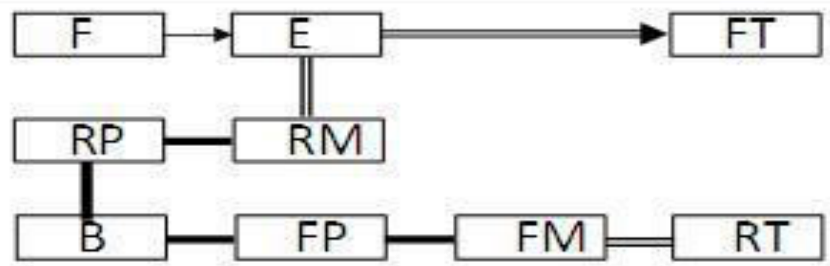


Figure 6d: Mode 4, light load

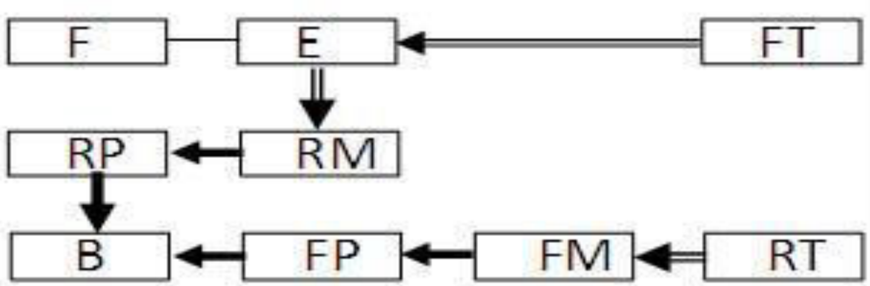


Figure 6e: Mode 5, braking or decelration

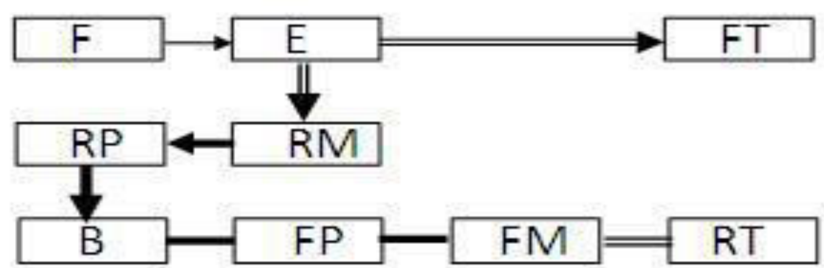


Figure 6f: Mode 1, axil balancing

B:Battery RM: Rear motor FP: Front power converter FT: Front axel transmission E: ICE F: Fuel tank
RM: Rear motor RP: Rear power converter RT: Rear axel transmission

Electrical link
Hydraulic link
Mechanical link

In Figures 6a-f all the six modes of operation of front electric and rear hybrid are shown.

Electric and Hybrid Electric Vehicles

Dr. Dola Gobinda Pradhan
Professor, EEE Department, GRIET

UNIT IV: Electric Propulsion Systems

Introduction to electric components used in hybrid and electric vehicles, Configuration and control of DC Motor drives, Configuration and control of Induction Motor drives, configuration and control of Permanent Magnet Motor drives, Configuration and control of Switch Reluctance Motor drives, drive system efficiency.

Electric Vehicle (EV) Configurations

Compared to HEV, the configuration of EV is flexible. The reasons for this flexibility are:

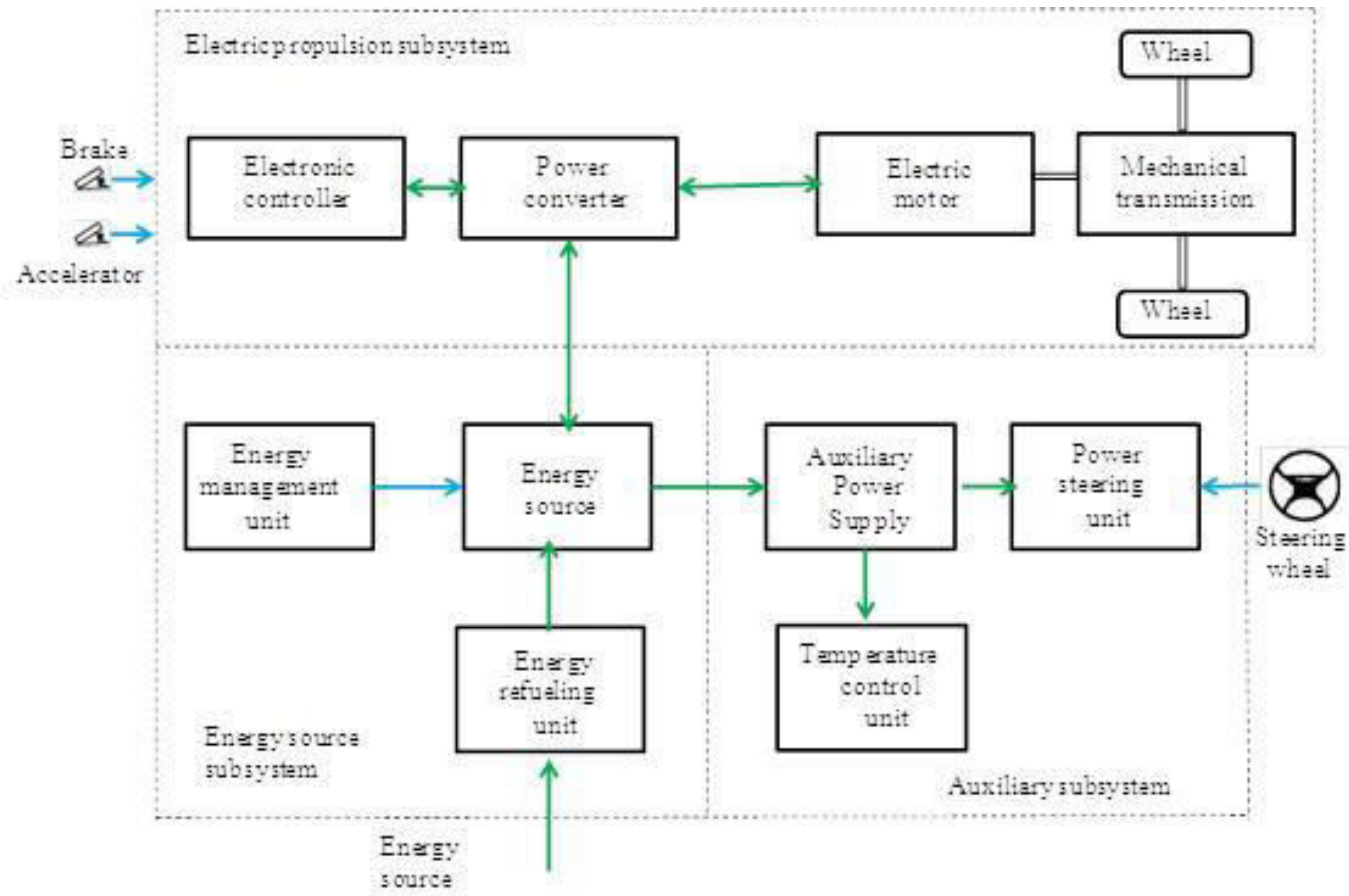
- The energy flow in EV is mainly via flexible electrical wires rather than bolted flanges or rigid shafts. Hence, distributed subsystems in the EV are really achievable.

- The EVs allow different propulsion arrangements such as independent four wheel and in wheel drives.

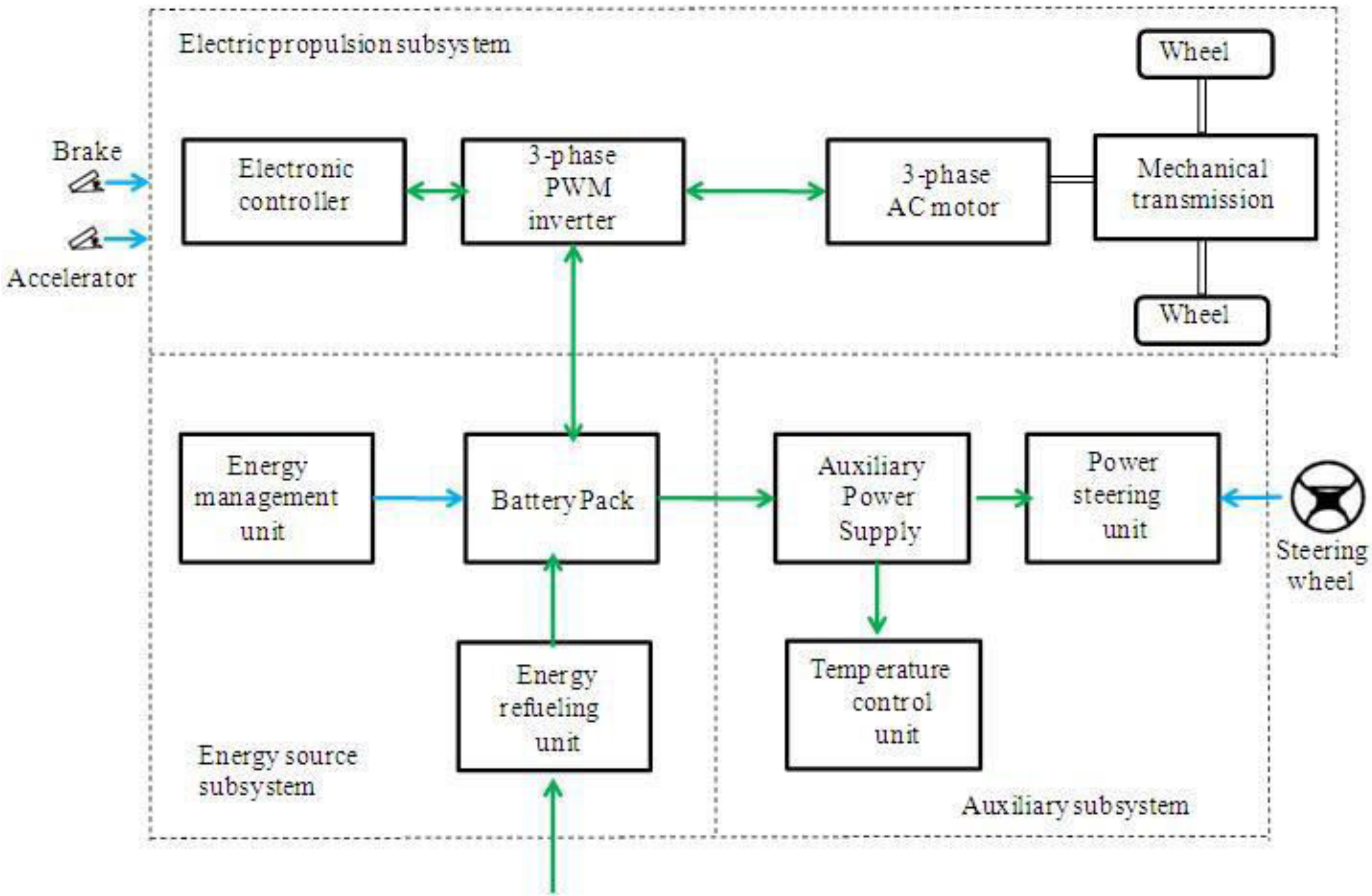
The EV has three major subsystems:

- Electric propulsion
- Energy source
- Auxiliary system

General Configuration of a Electric Vehicle



Typical Configuration of a Electric Vehicle



Electric Vehicle (EV) Drivetrain Alternatives Based on Drivetrain Configuration

There are many possible EV configurations due the variations in electric propulsion and energy sources. Based on these variations, six alternatives are possible as shown in **Figure 3**. These six alternatives are

EV configuration with clutch, gearbox and differential

EV configuration without clutch and gearbox

EV configuration with clutch, gearbox and differential

EV configuration with two EM

EV configuration with in wheel motor and mechanical gear

EV configuration with in wheel motor and no mechanical gear

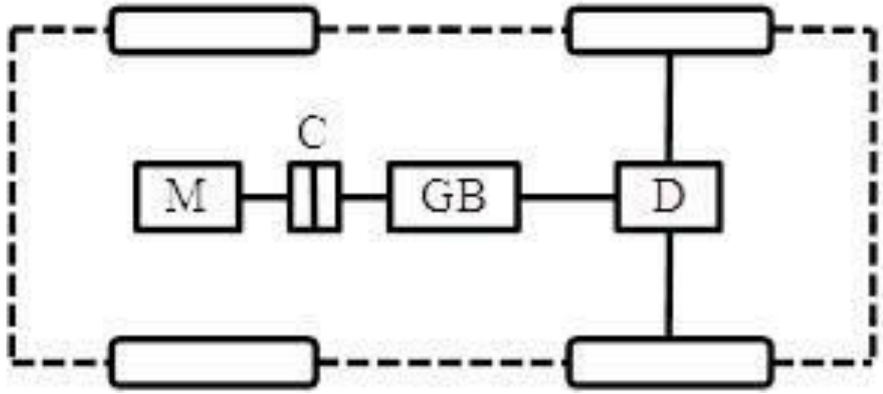


Figure 3a: EV configuration with clutch, gearbox and differential

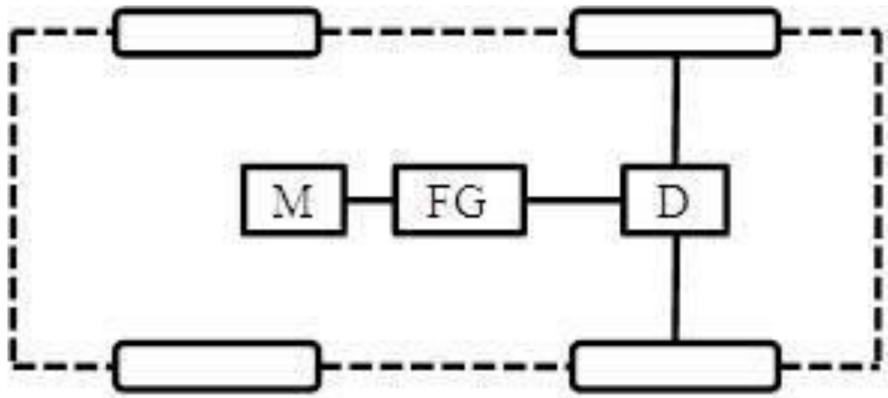


Figure 3b: EV configuration without clutch and gearbox

C: Clutch
D: Differential
FG: Fixedgearing
GB: Gearbox
EM: Electricmotor

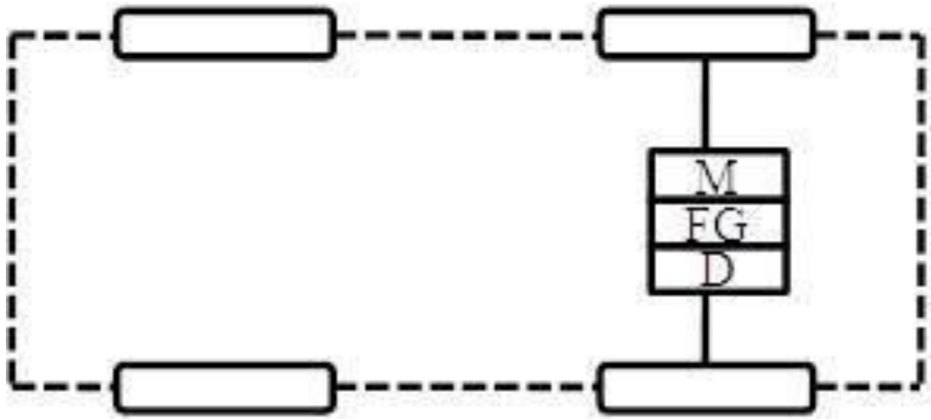


Figure 3c: EV configuration with clutch, gearbox and differential

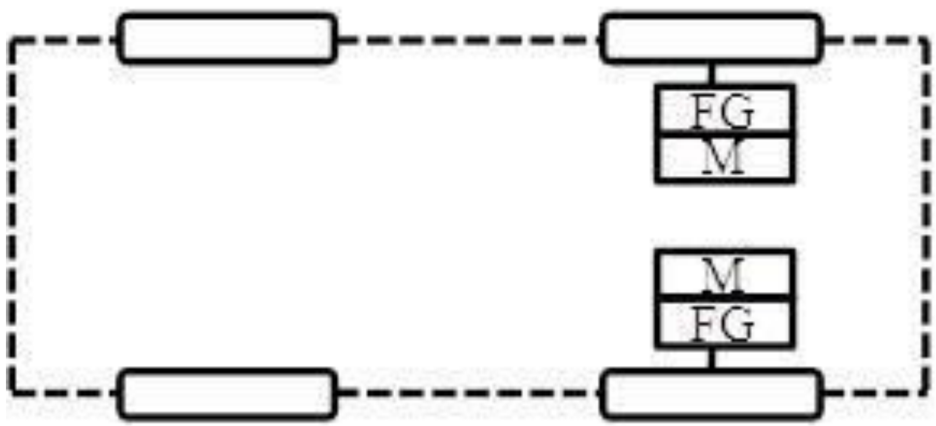


Figure 3d: EV configuration with two EM

C: Clutch
D: Differential
FG: Fixedgearing
GB: Gearbox
EM: Electricmotor

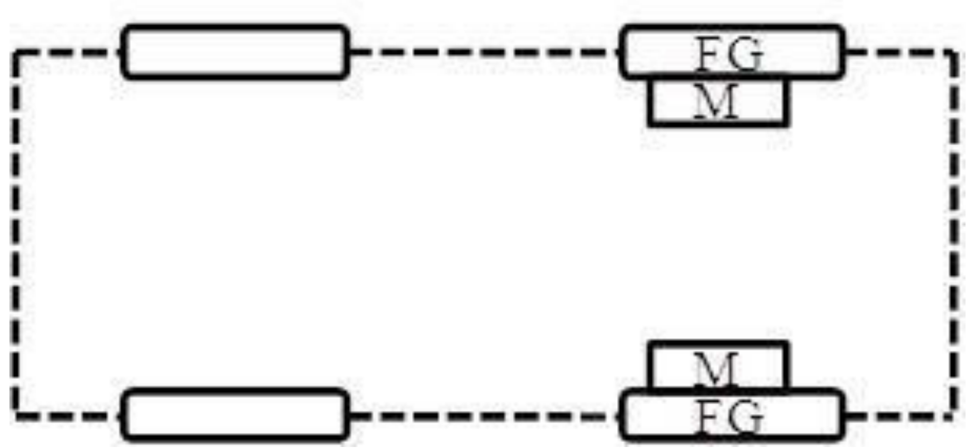


Figure 3e: EV configuration with in wheel motor and mechanical gear

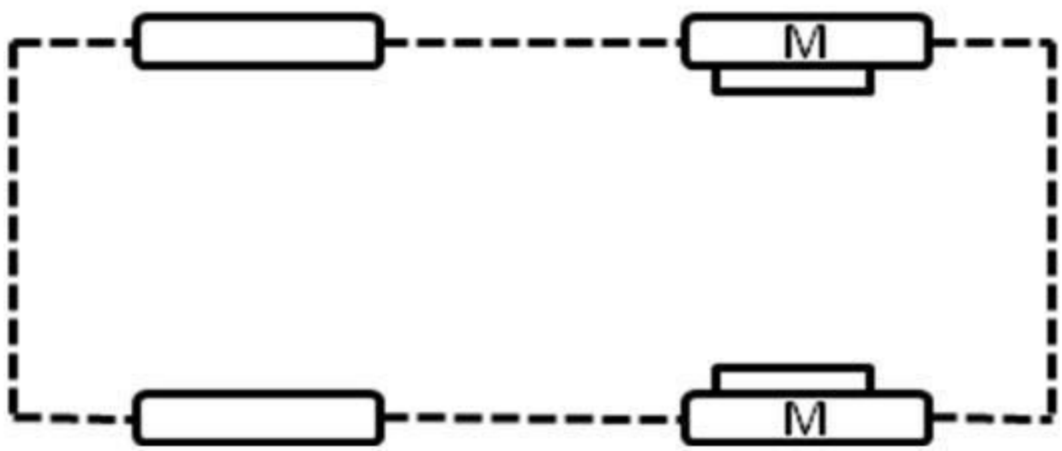
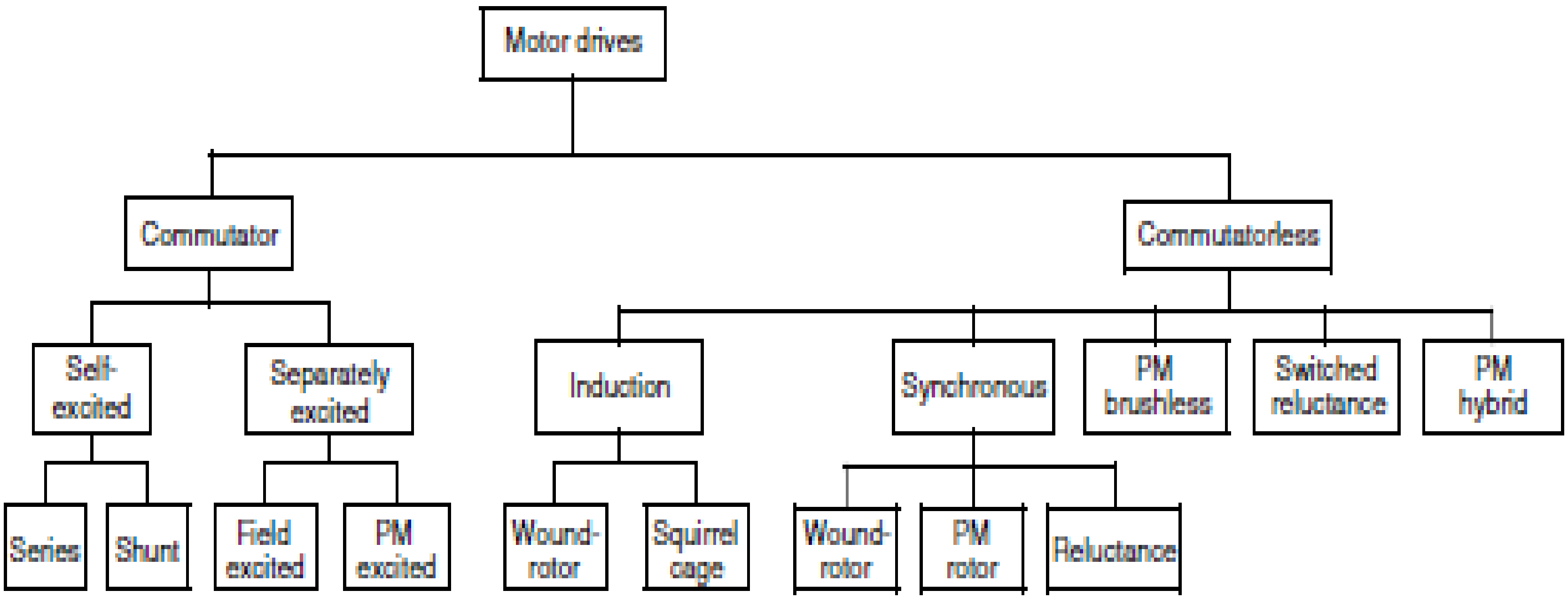


Figure 3f: EV configuration with in wheel motor and no mechanical gear

C: Clutch
D: Differential
FG: Fixedgearing

GB: Gearbox
EM: Electricmotor



Motor drives
Commutator
Commutatorless
Self-excited
Separately excited
Induction
Synchronous
PM brushless
Switched reluctance
PM hybrid
Series
Shunt
Field excited
PM excited
Wound-rotor
Squirrel cage
Wound-rotor
PM rotor
Reluctance

DC Series Motor

High starting torque capability of the DC Series motor makes it a suitable option for traction application.

It was the most widely used motor for traction application in the early 1900s.

The advantages of this motor are easy speed control and it can also withstand a sudden increase in load.

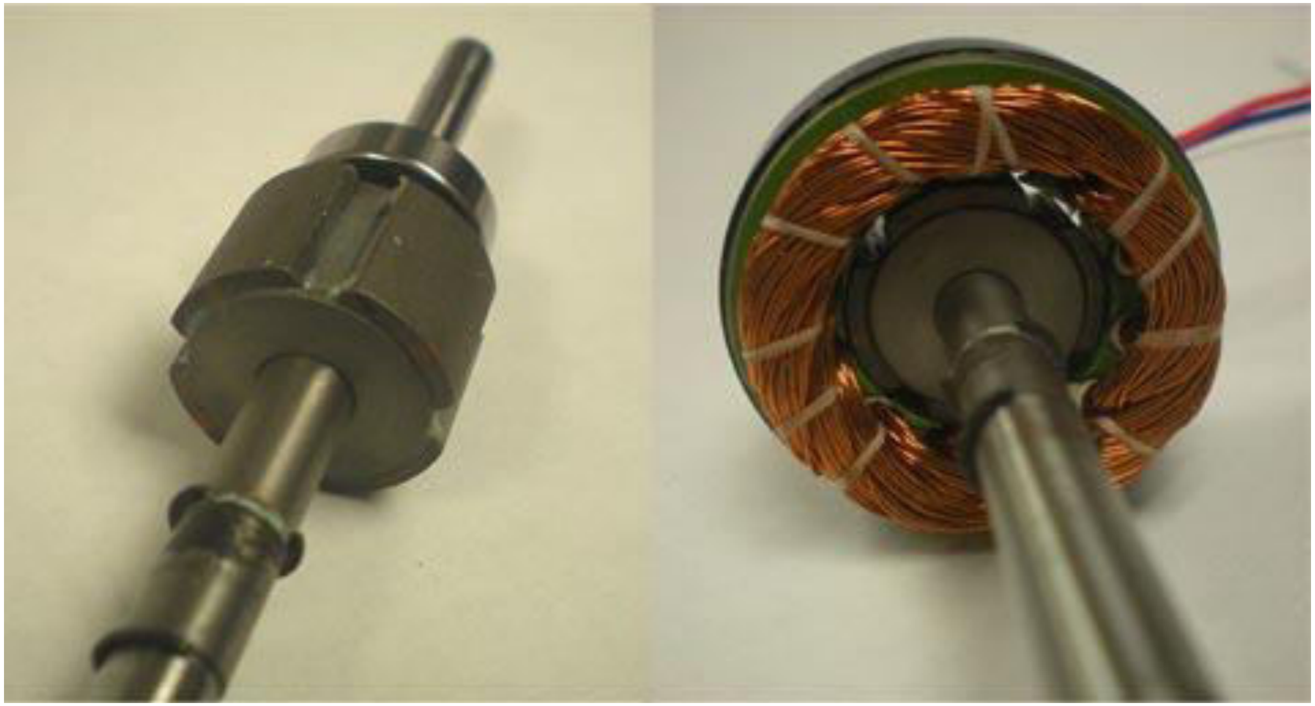
The main drawback of DC series motor is high maintenance due to brushes and commutators.

Brushless DC Motors

Motors who do not adopt the use of brushes for commutation.

However, how the motor gets powered and how motion is achieved without brushes is the main aspect in this motors.

The armature which in the case of the brushed motor, rotates within the stator, is stationary in brushless motors and the permanent magnet, which in brushed motors is fixed, serves as the rotor in a brushless motor.



Stator for brushless DC motors is made up of coils while its rotor (to which the motor shaft is attached) is made up of a permanent magnet.

Commutation algorithms for Brushless DC motors can be divided into two;
Sensor-based and senseless commutation.

In sensor-based commutation, sensors (e.g hall sensor) are placed along the poles of the motor to provide feedback to the control circuitry to help it estimate rotor position. There are three popular algorithms employed for sensor-based commutation;

- Trapezoidal commutation
- Sinusoidal commutation
- Vector (or field-oriented) control.

Each of these control algorithm has its pros and cons and the algorithms can be implemented in different ways depending on the software and the design of the electronics hardware to make necessary changes.

In sensorless commutation on the other hand, instead of sensors being placed within the motors, the control circuitry is designed to measure the back EMF to estimate rotor position. This algorithm performs well and is at a reduced cost as the cost of the hall sensors is eliminated but its implementation is a lot more complex compared to the sensor based algorithms.

Permanent Magnet Synchronous Motor (PMSM)

- **similar to BLDC motor which has permanent magnets on the rotor**
- Similar to BLDC motors these motors also have traction characteristics like high power density and high efficiency.
- The difference is that PMSM has sinusoidal back EMF whereas BLDC has trapezoidal back

- Permanent Magnet Synchronous motors are available for higher power ratings.
- PMSM is the best choice for high performance applications like cars, buses.

Despite the high cost, PMSM is providing stiff competition to induction motors due to increased efficiency than the latter.

PMSM is also costlier than BLDC motors.

Most of the automotive manufacturers use PMSM motors for their hybrid and electric vehicles.

For example, Toyota Prius, Chevrolet Bolt EV, Ford Focus Electric, zero motorcycles S/SR, Nissan Leaf, Hinda Accord, BMW i3, etc use PMSM motor for propulsion.

Three Phase Induction Motors

The induction motors do not have a high starting toque like DC series motors under fixed voltage and fixed frequency operation. But this characteristic can be altered by using various control techniques like FOC or v/f methods.

By using these control methods, the maximum torque is made available at the starting of the motor which is suitable for traction application.

Squirrel cage induction motors have a long life due to less maintenance. Induction motors can be designed up to an efficiency of 92-95%.

Drawback of an induction motor is that it requires complex inverter circuit and control of the motor is difficult**.**

Merit: Adjusting the value of B in induction motors is easy when compared to permanent magnet motors. It is because in Induction motors the value of B can be adjusted by varying the voltage and frequency (V/f) based on torque requirements. This helps in reducing the losses which in turn improves the efficiency.

Induction motors are the preferred choice for performance oriented electric vehicles due to its cheap cost. The other advantage is that it can withstand rugged environmental conditions.

Switched Reluctance Motors (SRM)

Switched Reluctance Motors is a category of variable reluctance motor with double saliency. Switched Reluctance motors are simple in construction and robust. The rotor of the SRM is a piece of laminated steel with no windings or permanent magnets on it. This makes the inertia of the rotor less which helps in high acceleration.

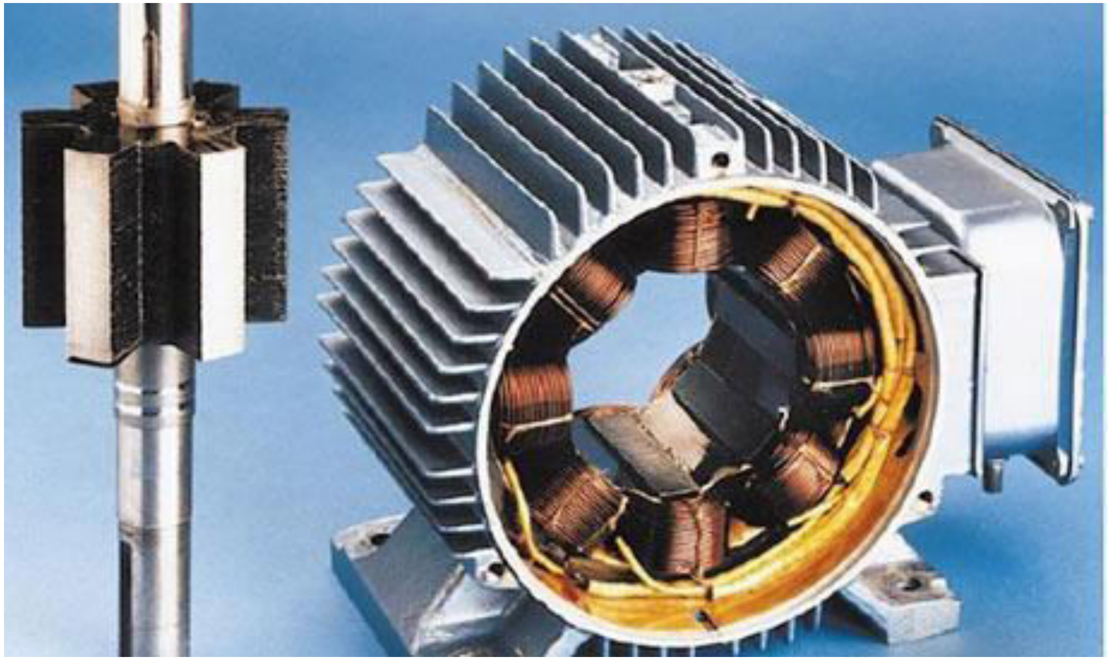
The robust nature of SRM makes it suitable for the high speed application. SRM also offers high power density which are some required characteristics of Electric Vehicles. Since the heat generated is mostly confined to the stator, it is easier to cool the motor.

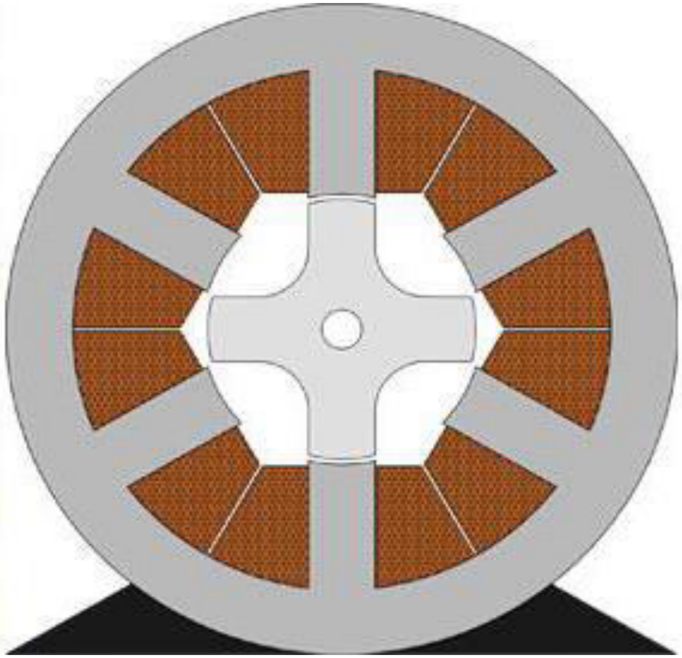
Drawback of the SRM is

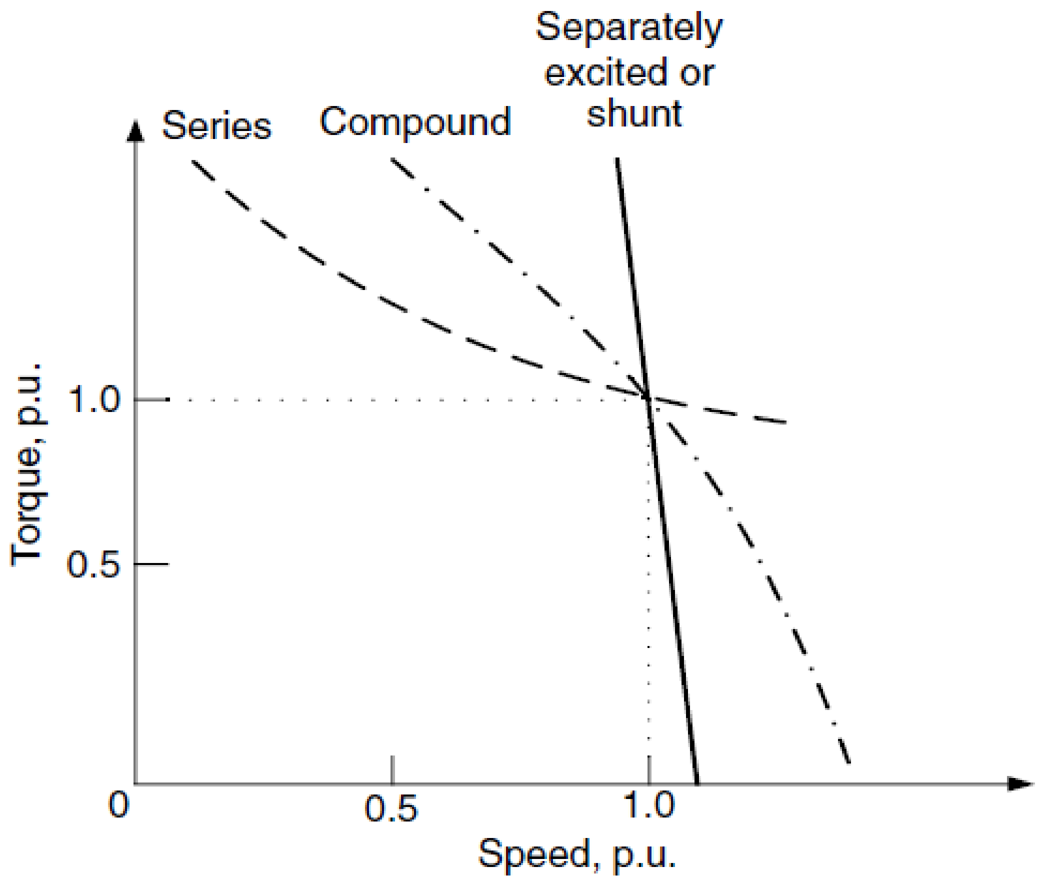
 Complexity in control and increase in the switching circuit**.**
It also has some noise issues.

Merit:

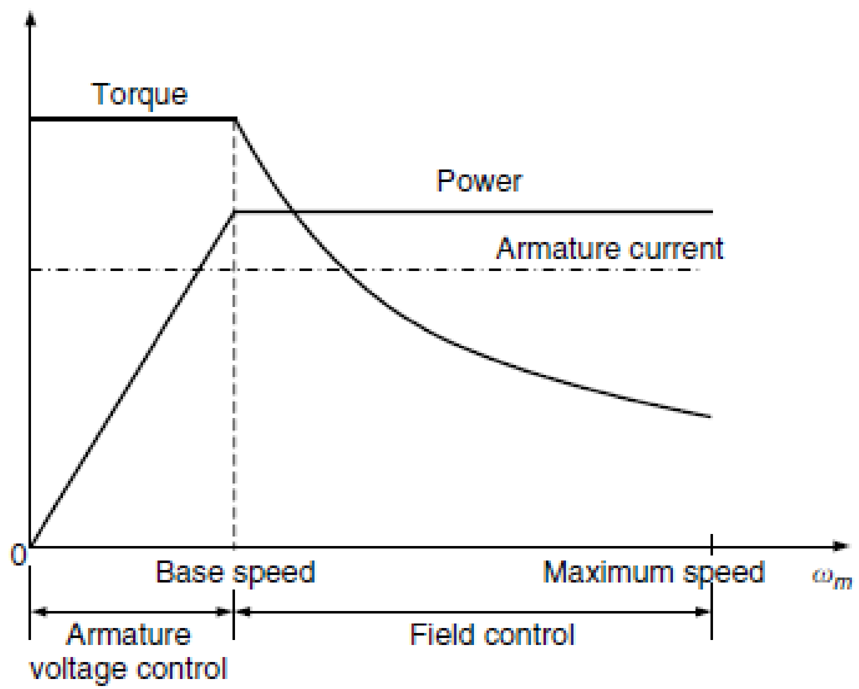
Once SRM enters the commercial market, it can replace the PMSM and Induction motors in the future.






Separately
excited or
shunt
Series
Compound
Torque, p.u.
1.0
0.5
0
0.5
1.0
Speed, p.u.

Combined Armature Voltage and Field Control

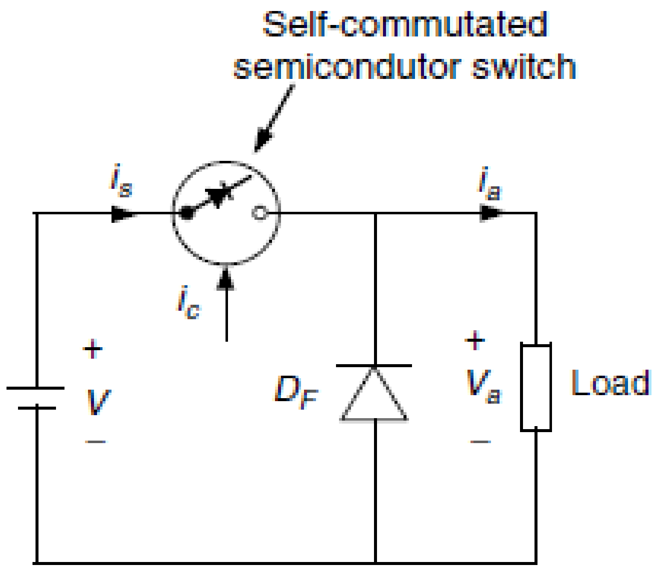


In EV and HEV applications, the most desirable speed–torque characteristic is to have a constant torque below a certain speed (base speed), with the torque dropping parabolically with the increase of speed (constant power) in the range above the base speed,

- In the range of lower than base speed, the armature current and field are set at their rated values, producing the rated torque.
- From equations , it is clear that the armature voltage must be increased proportionally with the increase of the speed.
- At the base speed, the armature voltage reaches its rated value (equal to the source voltage) and cannot be increased further.
- In order to further increase the speed, the field must be weakened with the increase of the speed, and then the back EMF *E* and armature current must be maintained constant.
- The torque produced drops parabolically with the increase in the speed and the output power remains constant

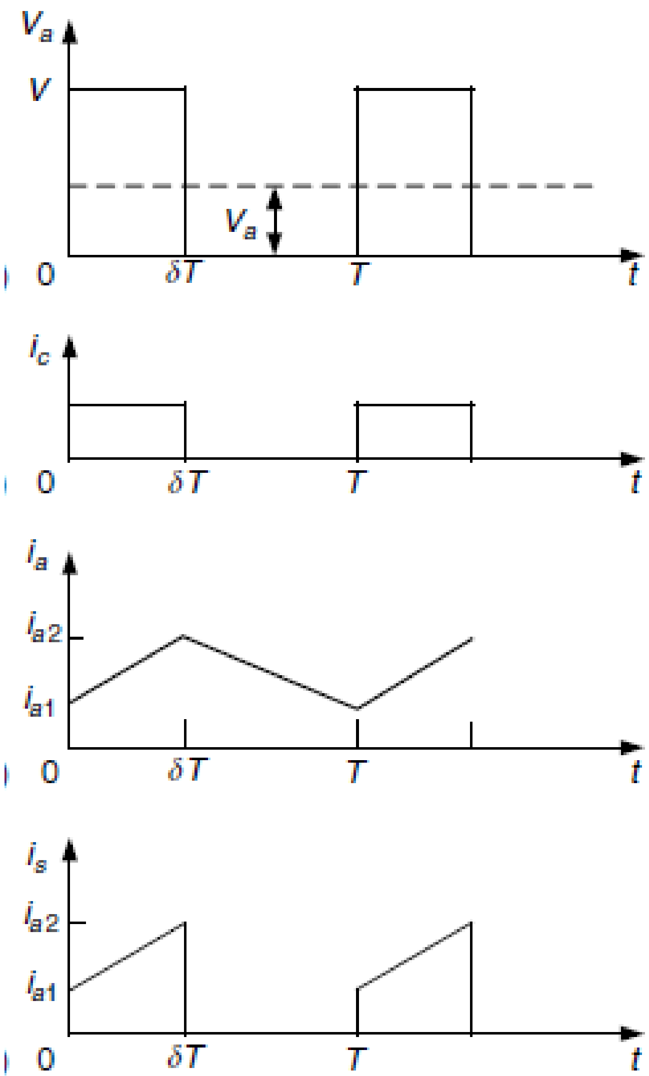
Chopper Control of DC Motors

- Choppers are used for the control of DC motors because of a number of advantages such as high efficiency, flexibility in control, light weight, small size, quick response, and regeneration down to very low speeds.
- Presently, the separately excited DC motors are usually used in traction, due to the control flexibility of armature voltage and field.
- For a DC motor control in open-loop and closed-loop configurations, the chopper offers a number of advantages due to its high operation frequency.



basic chopper circuit

$$V_a = \frac{1}{T}\int_0^T v_a\,dt = \frac{1}{T}\int_0^{\delta T} V\,dt = \delta t.$$



waveforms

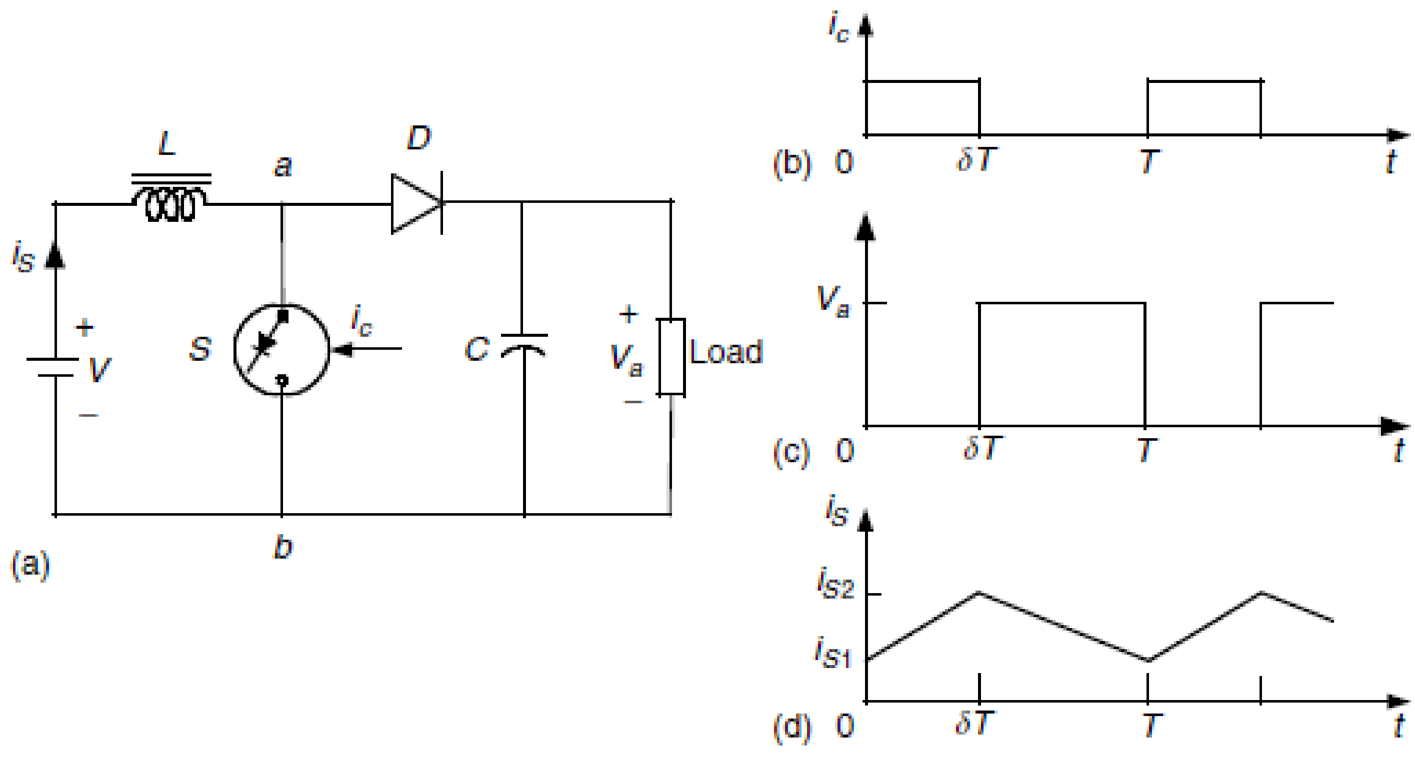
The control technologies can be divided into the following categories:

1. Time ratio control (TRC).
2. Current limit control (CLC).

In TRC, also known as pulse width control, the ratio of on time to chopper period is controlled. The TRC can be further divided as follows:

1. Constant frequency TRC: The chopper period T is kept fixed and the on period of the switch is varied to control the duty ratio δ.

2. Varied frequency TRC: Here, δ is varied either by keeping t_{on} constant and varying T or by varying both t_{on} and T.

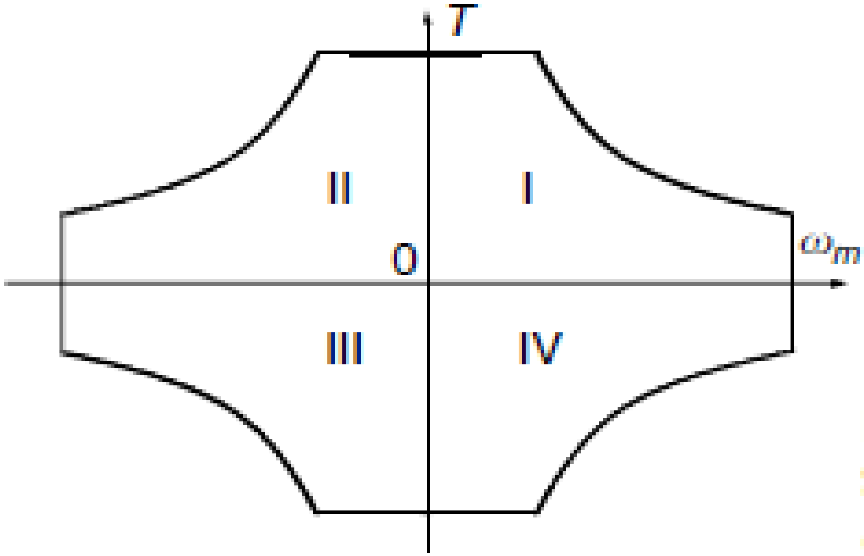


Principle of operation of a step-up (or class B) chopper: (a) basic chopper circuit; (b) to (d) waveforms

$$V_{ab} = \frac{1}{T}\int_0^T v_{ab}\,dt = V_a(1-\delta).$$

$$V = V_a(1-\delta) \text{ or } V_a = \frac{V}{1-\delta}.$$

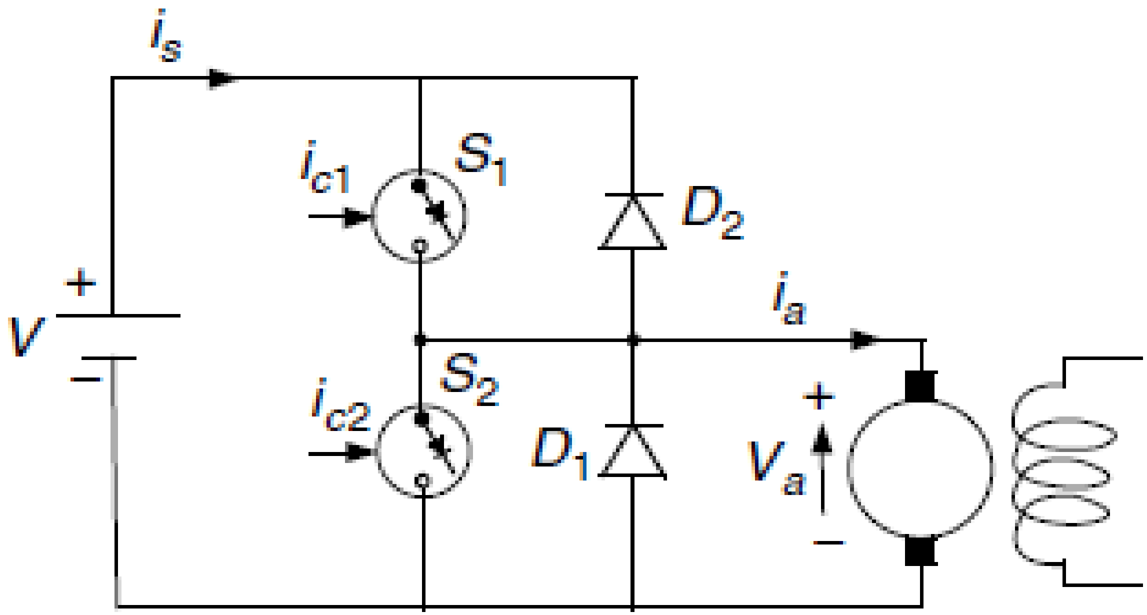
Multiquadrant Control of Chopper-Fed DC Motor Drives

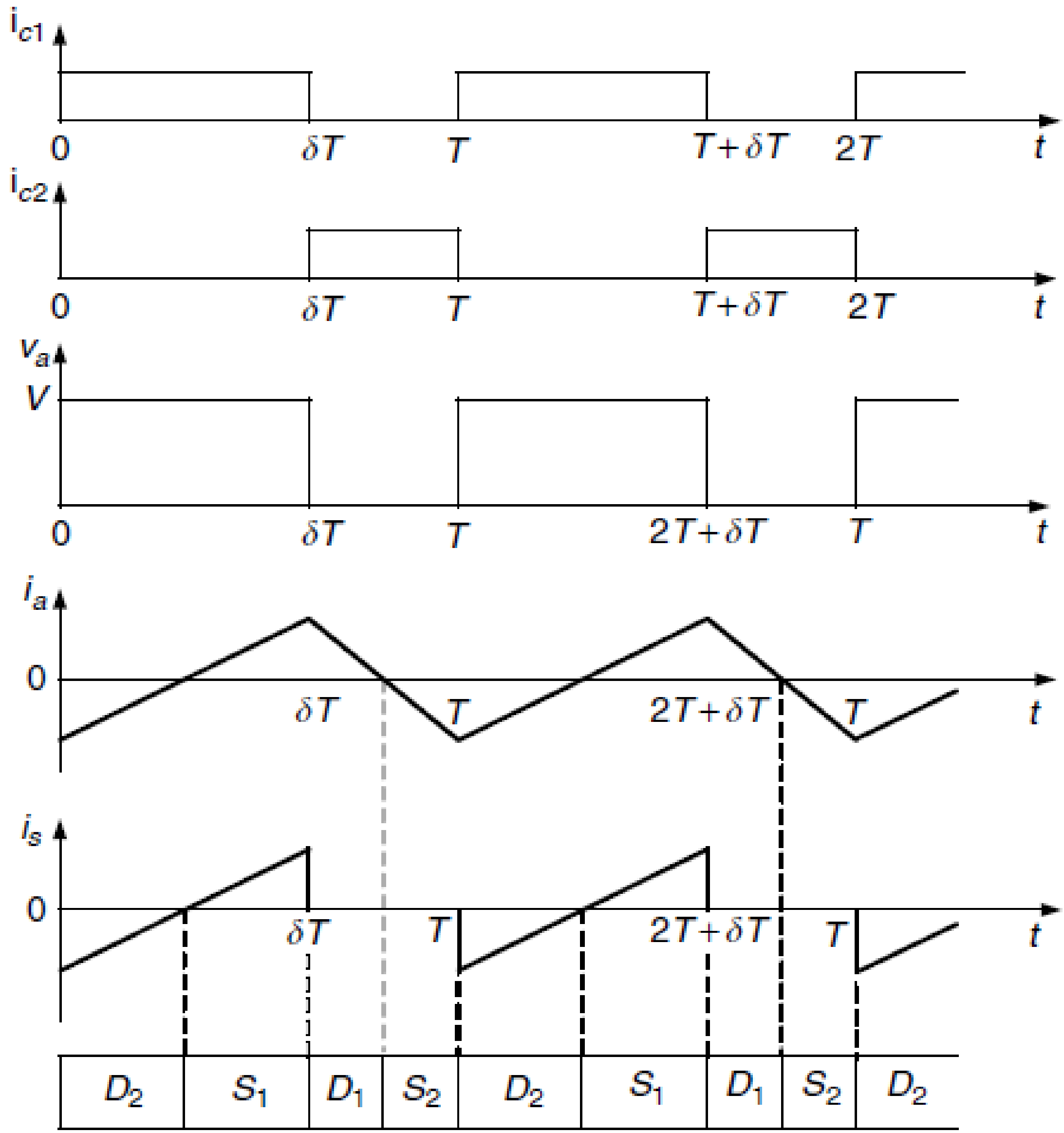


The application of DC motors on EVs and HEVs requires the motors to operate in multiquadrants, including forward motoring, forward braking, backward motoring, and backward braking

For vehicles with reverse mechanical gears, two-quadrant operation (forward motoring and forward braking, or quadrant I and quadrant IV) is required. However, for vehicles without reverse mechanical gears, four-quadrant operation is needed.

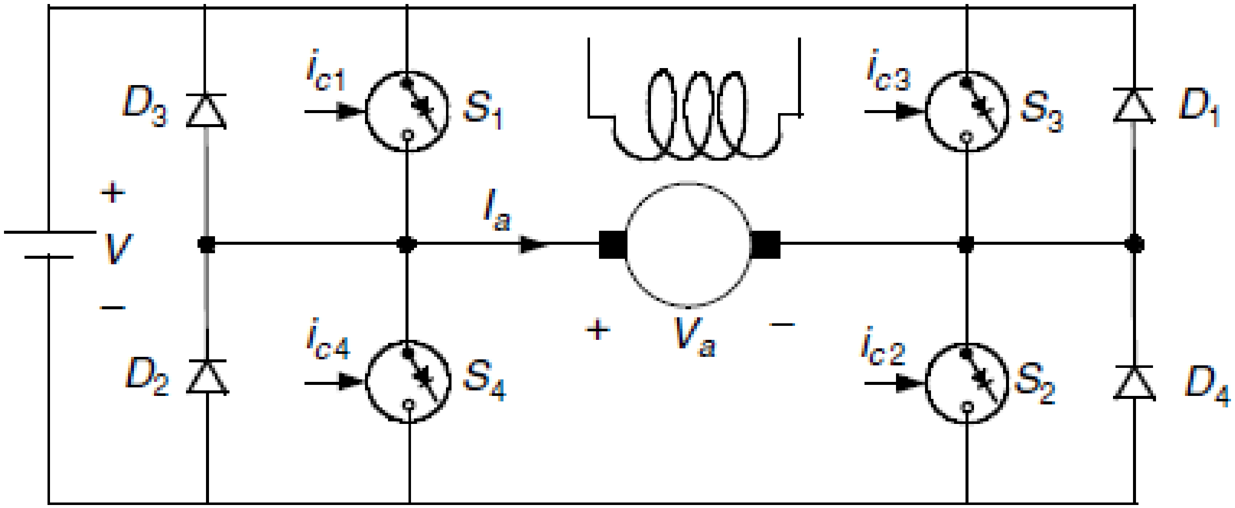
Class C Two-Quadrant Chopper





i_{c1}
0
δT
T
$T+\delta T$
$2T$
t
i_{c2}
0
δT
T
$T+\delta T$
$2T$
t
v_a
V
0
δT
T
$2T+\delta T$
T
t
i_a
0
δT
T
$2T+\delta T$
T
t
i_s
0
δT
T
$2T+\delta T$
T
t
D_2
S_1
D_1
S_2
D_2
S_1
D_1
S_2
D_2

Four-Quadrant Operation



Permanent Magnetic Brush-Less DC Motor Drives

A permanent magnet motor drive can be potentially designed with high power density, high speed, and high operation efficiency.

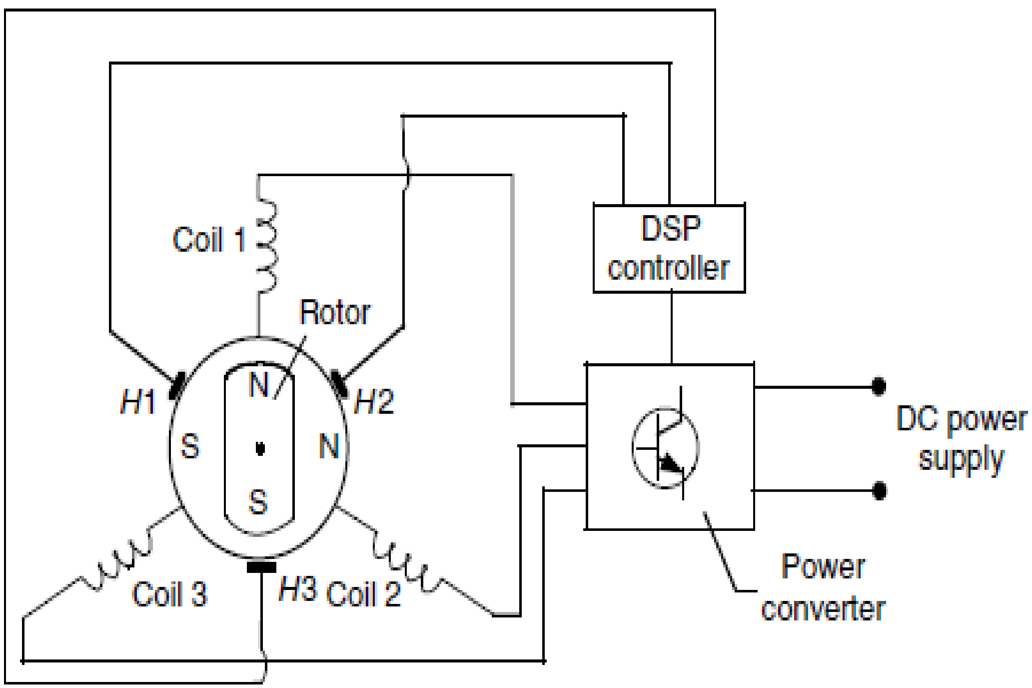
The major advantages of BLDC motor include:

High efficiency: BLDC motors are the most efficient of all electric motors. This is due to the use of permanent magnets for the excitation, which consume no power. The absence of a mechanical commutator and brushes means low mechanical friction losses and therefore higher efficiency.

Compactness: The recent introduction of high-energy density magnets (rare-earth magnets) has allowed achieving very high flux densities in the BLDC motor. This makes it possible to achieve accordingly high torques, which in turns allows making the motor small and light.

Ease of control: The BLDC motor can be controlled as easily as a DC motor because the control variables are easily accessible and constant throughout the operation of the motor.

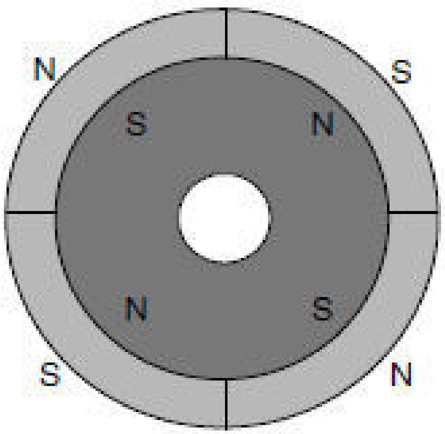
Basic Principles of BLDC Motor Drives



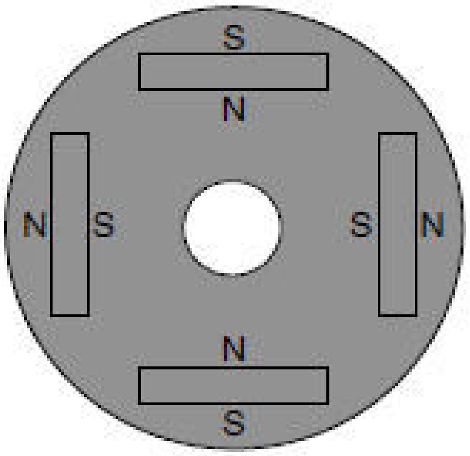
A BDLC motor drive consists mainly of the brush-less DC machine, a DSPbased controller, and a power electronics-based power converter, as shown in Figure. Position sensors *H*1, *H*2, and *H*3 sense the position of the machine rotor. The rotor position information is fed to the DSP-based controller, which, in turn, supplies gating signals to the power converter by turning on and turning off the proper stator pole windings of the machine.

In this way, the torque and speed of the machines are controlled.

BLDC Machine Construction and Classification



surface-mounted PM rotor



interior-mounted PM rotor

Each permanent magnet is mounted on the surface of the rotor. It is easy to build, and specially skewed poles are easily magnetized on this surface-mounted type to minimize cogging torque. But there is a possibility that it will fly apart during high-speed operations.

Each permanent magnet is mounted inside the rotor. It is not as common as the surface-mounted type but it is a good candidate for high-speed operations.

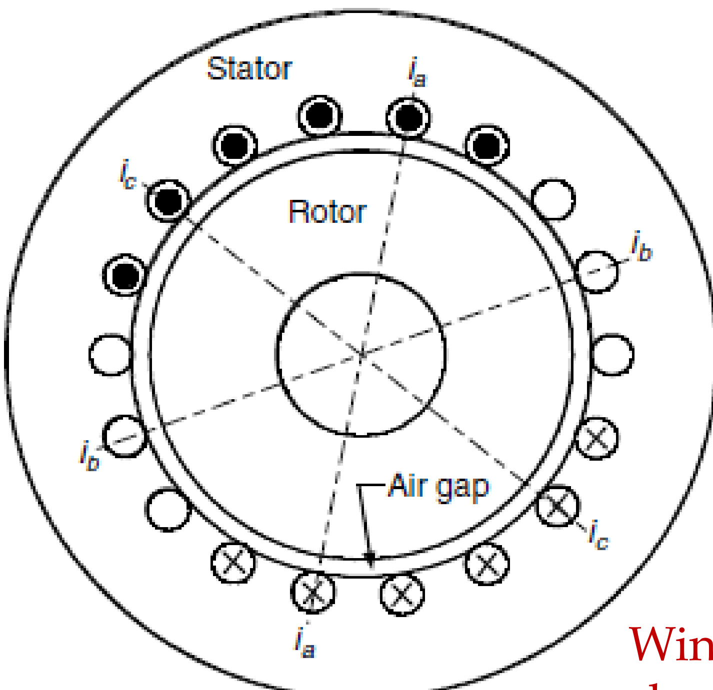
In the case of the stator windings, there are two major classes of BLDC motor drives, both of which can be characterized by the shapes of their respective back EMF waveforms: trapezoidal and sinusoidal.

The trapezoidal-shaped back EMF BLDC motor is designed to develop trapezoidal back EMF waveforms.

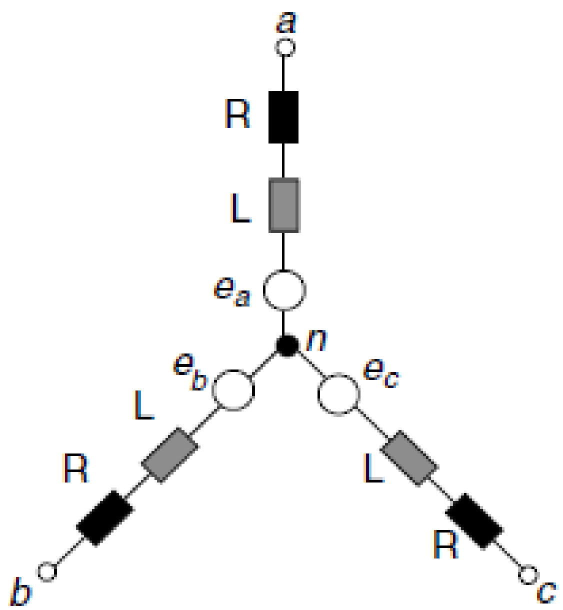
It has the following ideal characteristics:

1. Rectangular distribution of magnet flux in the air gap
2. Rectangular current waveform
3. Concentrated stator windings.

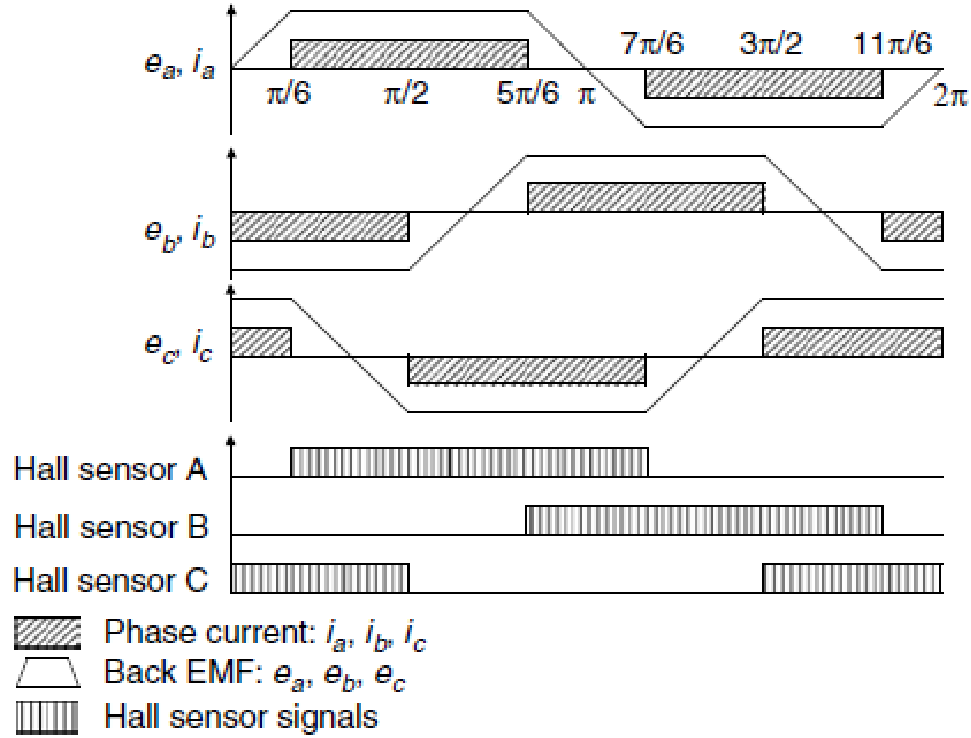
Excitation waveforms take the form of quasisquare current waveforms with two 60º electrical intervals of zero current excitation per cycle. The nature of the excitation waveforms for trapezoidal back EMF permits some important system simplifications compared to sinusoidal back EMF machines. In particular, the resolution requirements for the rotor position sensor are much lower since only six commutation instants are necessary per electrical cycle. Figure shows the winding configuration of the trapezoidal-shaped back EMF BLDC mac



Winding configuration of the trapezoidal-shaped back EMF BLDC



Three-phase equivalent circuit



back EMFs, currents, and Hall sensor signals of a BLDC motor

Excitation waveforms take the form of quasisquare current waveforms with two 60º electrical intervals of zero current excitation per cycle. The nature of the excitation waveforms for trapezoidal back EMF permits some important system simplifications compared to sinusoidal back EMF machines. In particular, the resolution requirements for the rotor position sensor are much lower since only six commutation instants are necessary per electrical cycle.

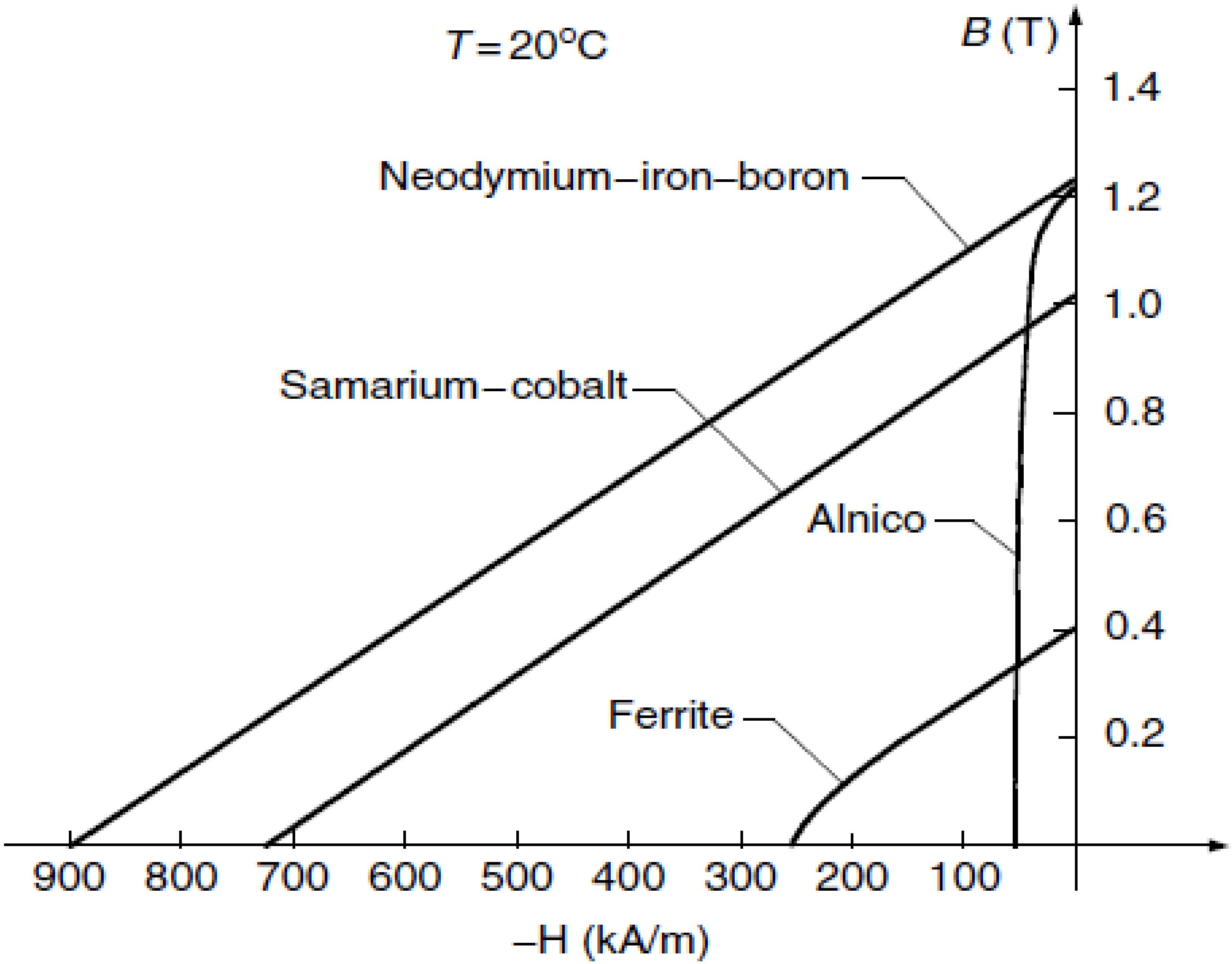
Figure shows an equivalent circuit and (b) shows trapezoidal back EMF, current profiles, and Hall sensor signals of the three-phase BLDC motor drive. The voltages seen in this figure, *ea*, *eb*, and *ec*, are the line-to-neutral back EMF voltages, the result of the permanent-magnet flux crossing the air gap in a radial direction and cutting the coils of the stator at a rate proportional to the rotor speed.

The coils of the stator are positioned in the standard three-phase full-pitch, concentrated arrangement, and thus the phase trapezoidal back EMF waveforms are displaced by 120º electrical degrees. The current pulse generation is a “120º on and 60º off” type, meaning each phase current is flowing for two thirds of an electrical 360º period, 120º positively and 120º negatively. To drive the motor with maximum and constant torque/ampere, it is desired that the line current pulses be synchronized with the line-neutral back EMF voltages of the particular phase.

Properties of PM Materials

There are three classes of permanent magnet materials currently used for electric motors:

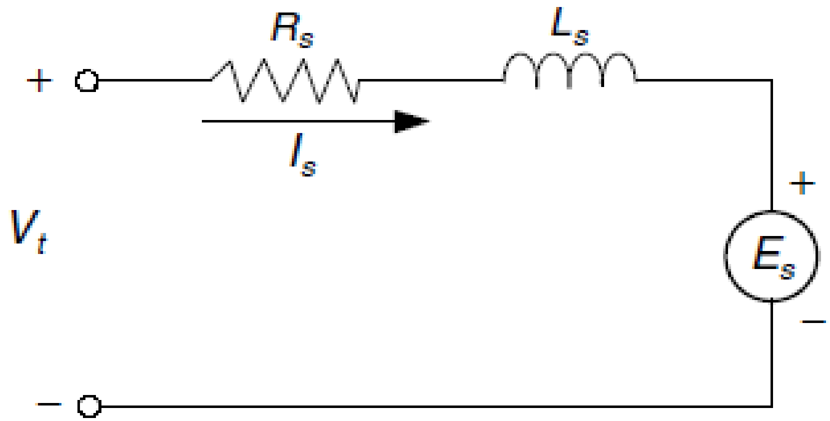
1. Alnicos (Al, Ni, Co, Fe)
2. Ceramics (ferrites), for example, barium ferrets $BaO6Fe_2O_3$ and strontium ferrite $SrO6Fe_2O_3$
3. Rare-earth materials, that is, samarium–cobalt SmCO and neodymium–iron–boron NdFeB.



T = 20°C
B (T)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Neodymium–iron–boron
Samarium–cobalt
Alnico
Ferrite
900
800
700
600
500
400
300
200
100
–H (kA/m)

Alnico

The main advantages of Alnico are its high magnetic remanent flux density and low-temperature coefficients. The temperature coefficient of its remanent magnetic flux density *Br*, or remanence, is 0.02%/ºC and the maximum service temperature is 520ºC. These advantages allow quite a high airgap flux density and high operating temperature. Unfortunately, coercive force is very low and the demagnetization curve is extremely nonlinear. Therefore, it is very easy not only to magnetize but also to demagnetize Alnico. Alnico magnets have been used in motors having ratings in the range of a few watts to 150 kW.



Simplified equivalent circuit of BLDC motor

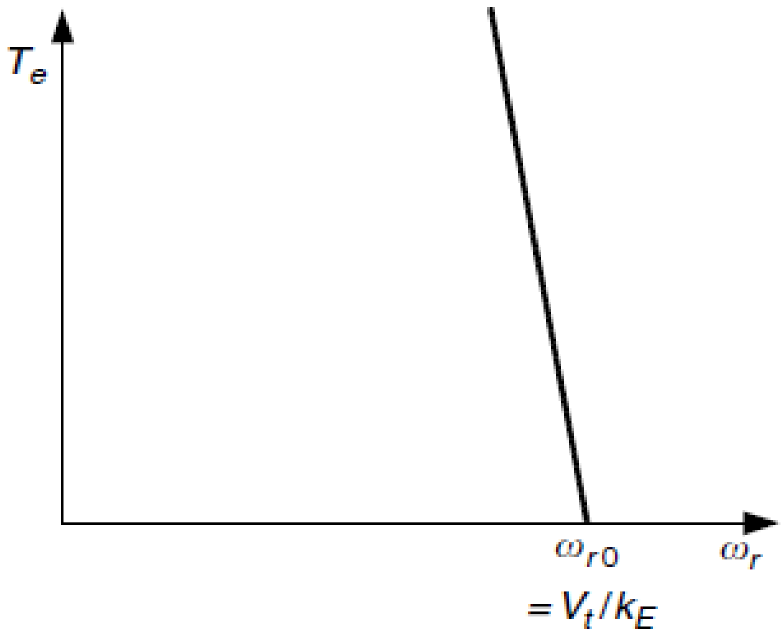
$$V_t = R_s I_s + L_s \frac{dI_s}{dt} + E_s,$$

$$E_s = k_E \omega_r,$$

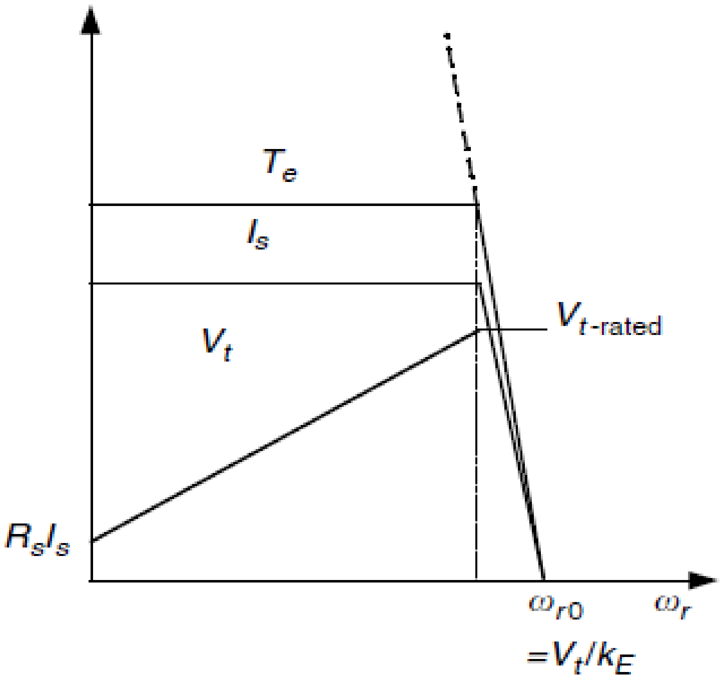
$$T_e = k_T I_s,$$

$$T_e = T_L + J \frac{d\omega_r}{dt} + B\omega_r,$$

$$T_e = \frac{(V_t - k_E \omega_r) k_T}{R_s}.$$



Speed–torque curve at steady state with constant voltage



Speed–torque curve at steady state with variable voltage supply

Laplace forms as

$$V_t(s) = E_s(s) + (R_s + \mathrm{s}L_s)I_s(s),$$

$$E_s(s) = k_E\omega_r(s),$$

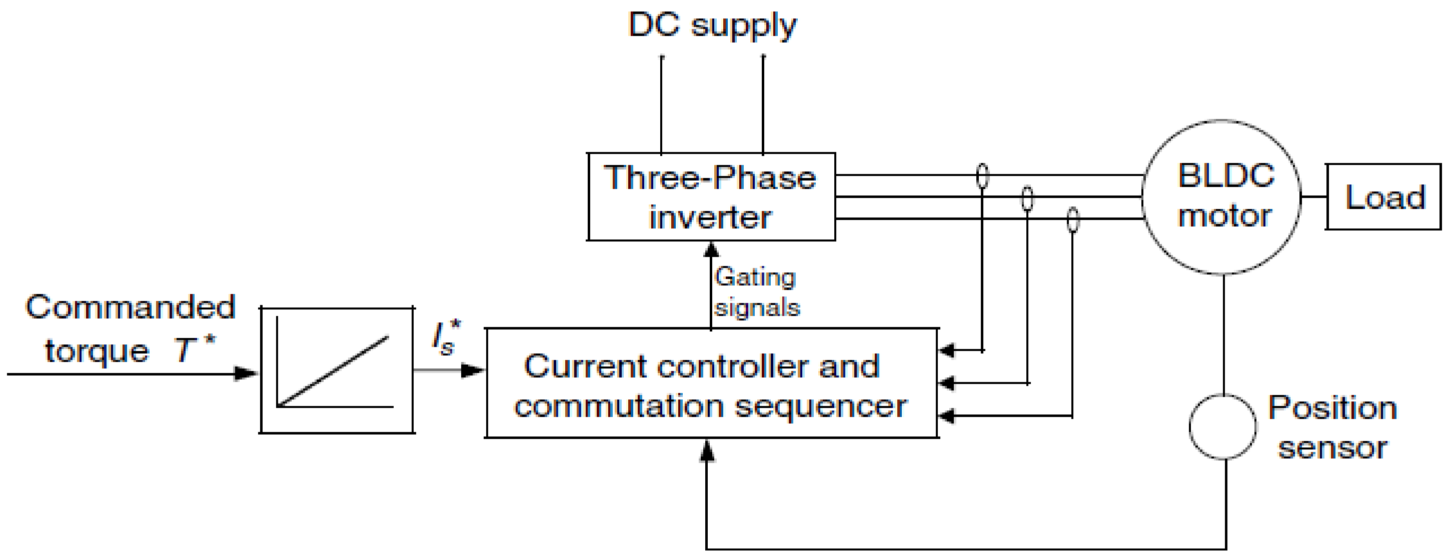
$$T_e(s) = k_T I_s(s),$$

$$T_e(s) = T_L(s) + (B + sJ)\omega_r(s).$$

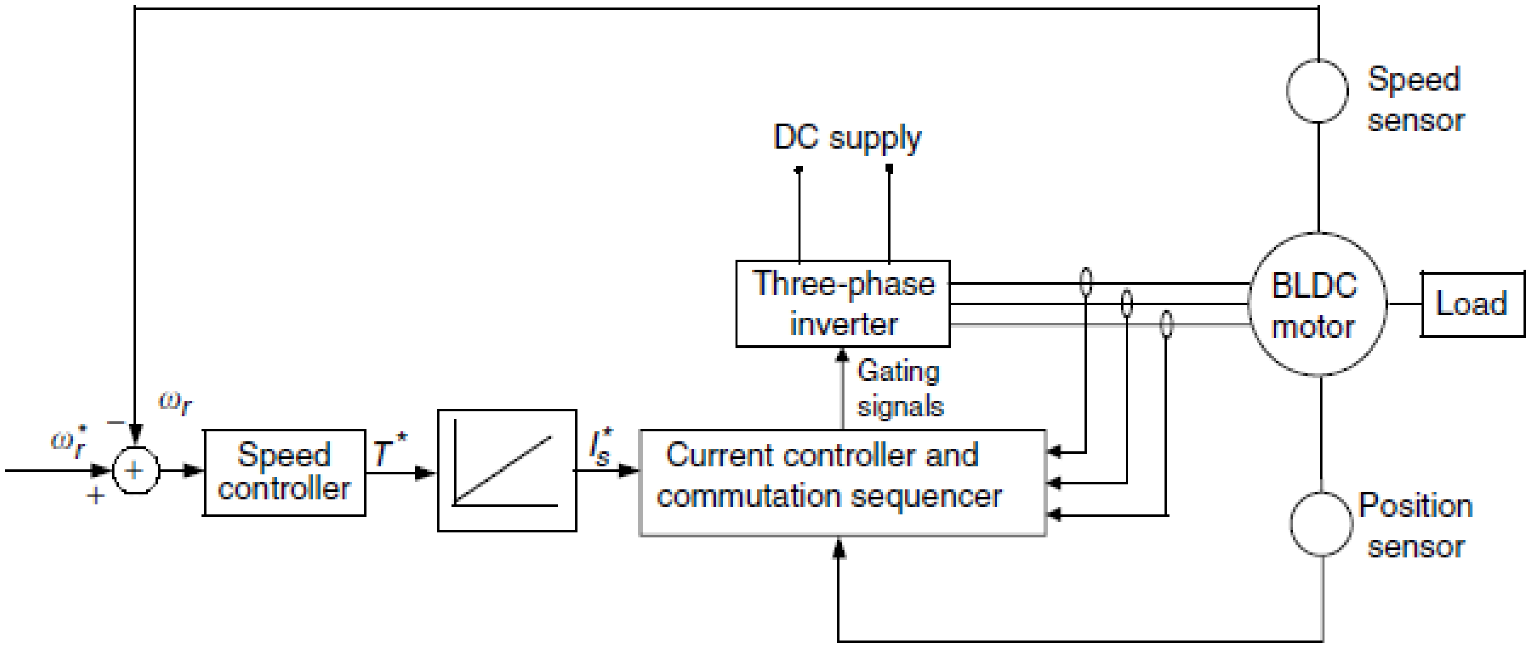
Thus, the transfer function of the BLDC motor drive system is

$$\omega_r(s) = \frac{k_T}{(R_s + sL_s)(sJ + B) + k_T k_E} V_t(s) - \frac{R_s + sL_s}{(R_s + sL_s)(sJ + B) + k_T k_E} T_L(s)$$

Control of BLDC Motor Drives



Block diagram of the torque control of the BLDC motor



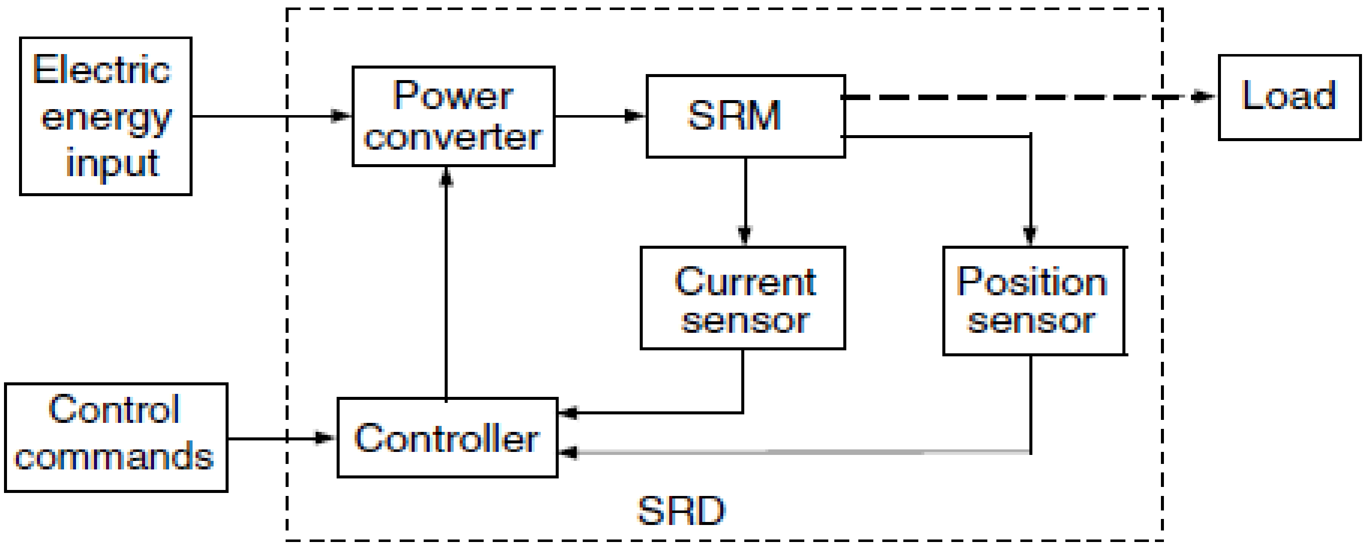
Block diagram of the speed control of the BLDC motor

Switched Reluctance Motor Drives

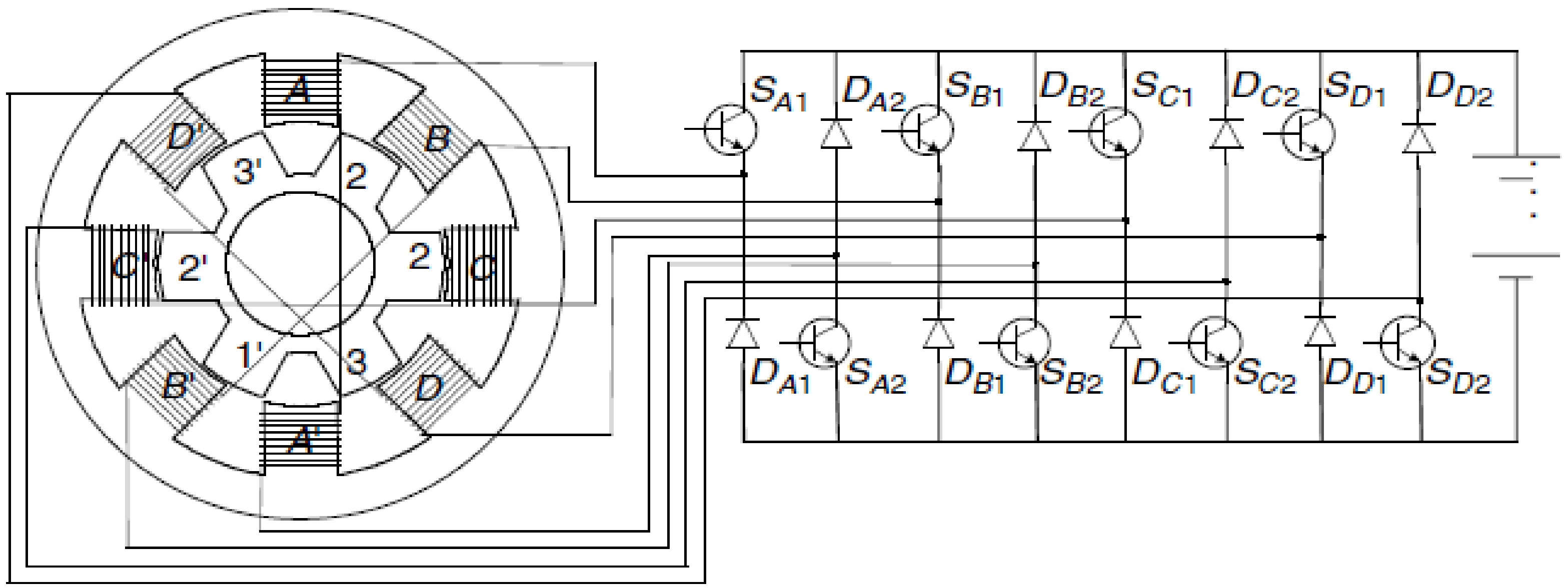
The switched reluctance motor (SRM) drive is considered to be an attractive candidate for variable speed motor drives due to its low cost, rugged structure, reliable converter topology, high efficiency over a wide speed range, and simplicity in control.

These drives are suitable for EVs, electric traction applications, automotive applications, aircraft starter/generator systems, mining drives, washing machines, door actuators, etc

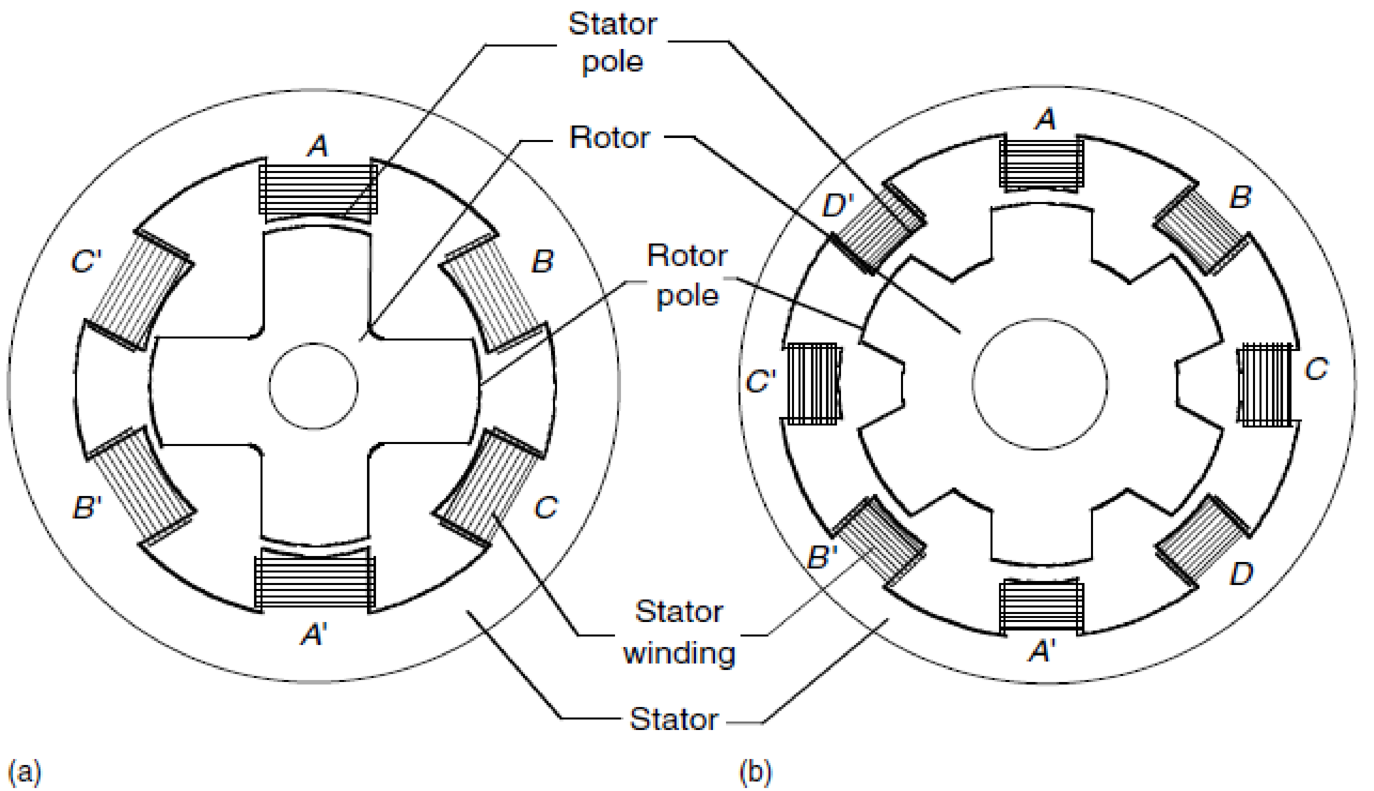
Basic Magnetic Structure of SRM



SRM drive system



SRM and its power supply



Cross-section of common SRM configurations: (a) a 6/4 SRM and (b) a 8/6 SRM

The SRM has salient poles on both the stator and rotor. It has concentrated windings on the stator and no winding or PM on the rotor. There are several configurations for SRM depending on the number and size of the rotor and stator poles. The configurations of the 8/6 and 6/4 SRM, which are more common, are shown in Figure

Due to its double saliency structure, the reluctance of the flux path for a phase winding varies with the rotor position. Also, since the SRM is commonly designed for high degree saturation at high phase current, the reluctance of the flux path also varies with the phase current. As a result, the stator flux linkage, phase bulk inductance, and phase incremental inductance all vary with the rotor position and phase current.

The phase voltage equation of the SRM is given by

$$V_j = Ri_j + \frac{d}{dt}\sum_{k=1}^{m}\lambda_{jk}$$

where m is the total number of phases, V_j is the applied voltage to phase j, i_j is the current in phase j, R is the winding resistance per phase, λ_{jk} is the flux linkage of phase j due to the current of phase k, and t is the time. The phase flux linkage, λ_{jk}, is given by

$$\lambda_{jk} = L_{jk}(i_{k,\theta},\theta)i_k$$

where L_{jk} is the mutual inductance between phase k and phase j. Mutual inductance between phases is usually small compared to the bulk inductance and is neglected in equations.

$$V_j = Ri_j + \frac{d}{dt}\sum_{k=1}^{m}\lambda_{jk} = Ri_j + \sum_{k=1}^{m}\left\{\frac{\partial\lambda_{jk}}{\partial i_k}\frac{di_k}{dt} + \frac{\partial\lambda_{jk}}{\partial\theta}\frac{d\theta}{dt}\right\}$$

$$= Ri_j + \sum_{k=1}^{m}\left\{\frac{\partial(L_{jk}i_k)}{\partial i_k}\frac{di_k}{dt} + \frac{\partial(L_{jk}i_k)}{\partial\theta}\omega\right\}$$

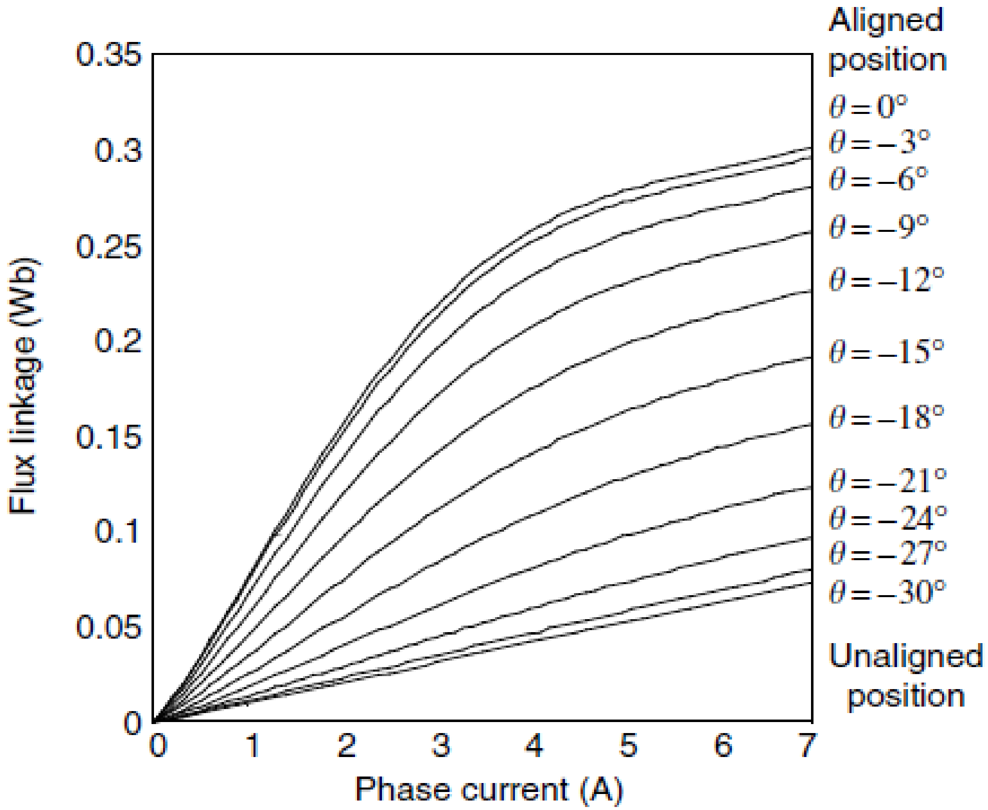
$$= Ri_j + \sum_{k=1}^{m}\left\{\left(L_{jk} + i_k\frac{\partial L_{jk}}{\partial i_k}\right)\frac{di_k}{dt} + i_k\frac{\partial L_{jk}}{\partial\theta}\omega\right\}.$$

When only one phase is energized in the operation, the above equation can be written as

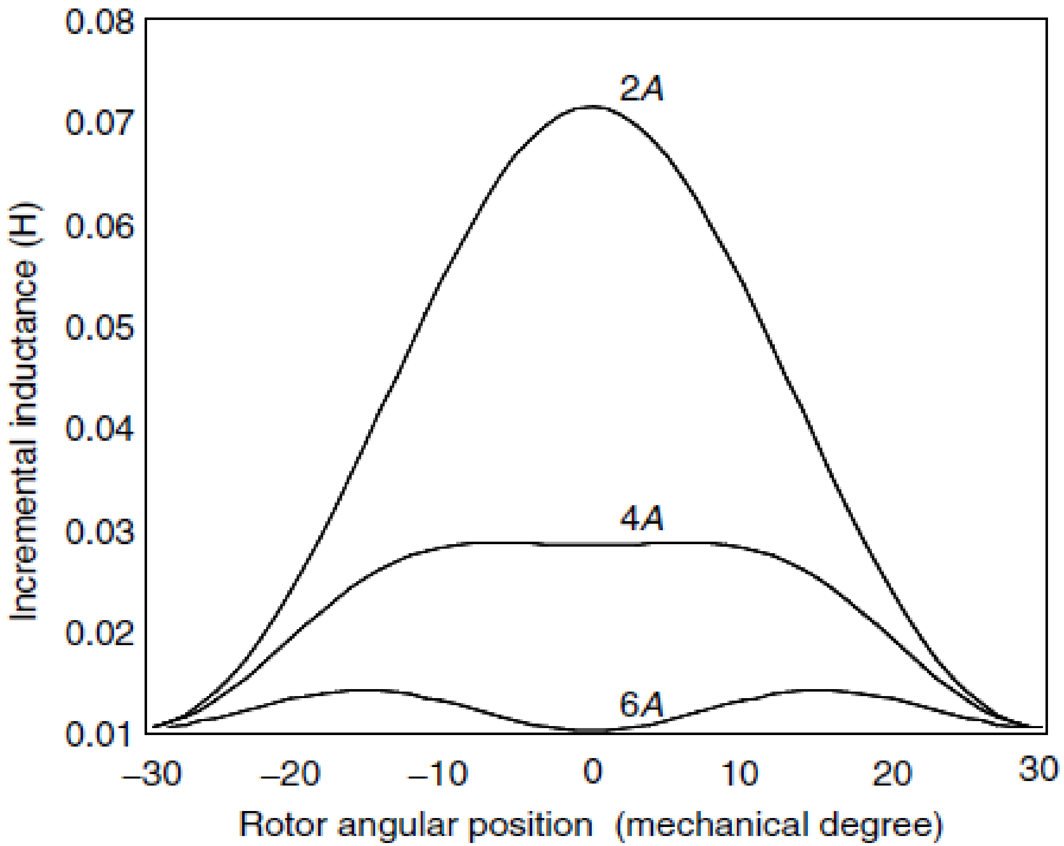
$$V_j = Ri_j + \left(L_{jj} + i_j\frac{\partial L_{jj}}{\partial i_j}\right)\frac{di_j}{dt} + i_j\frac{\partial L_{jj}}{\partial\theta}\omega.$$

Torque Production in SRM

Torque in SRM is produced by the tendency of the rotor to get into alignment with the excited stator poles. The analytical expression of the torque can be derived using the derivative of the coenergy against the rotor position at a given current.



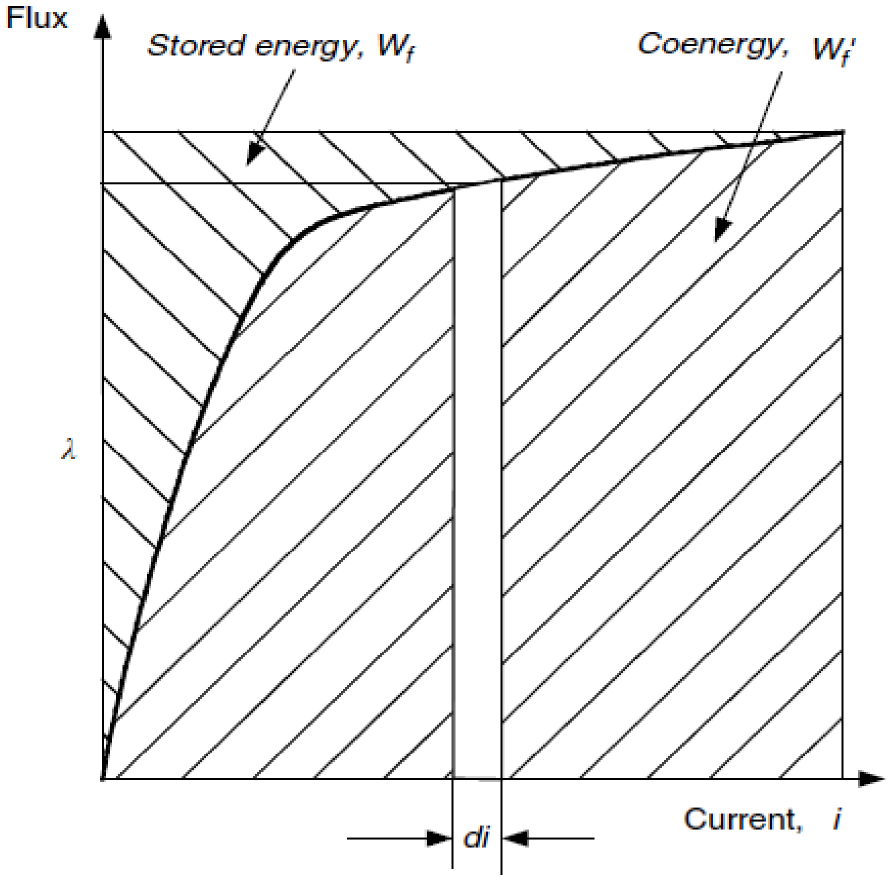
Variation of phase flux linkage with rotor position and phase current



Variation of phase incremental inductance with rotor position and phase current for a typical 8/6 SRM

Coenergy can be found from the definite integral:

$$W'_f = \int_0^i \lambda \, di.$$



Stored field energy and coenergy

The torque produced by one phase coil at any rotor position is given by

$$T = \left[\frac{\partial W'_f}{\partial \theta} \right]_{i=constant}$$

In the case of flux being linear with current, for example, in an unsaturated field, the magnetization curve in Figure would be a straight line and the co-energy would be equal to the stored field energy.

The instantaneous torque can be given as

$$T = \frac{1}{2} i^2 \frac{dL(\theta)}{d\theta}$$

where L is the unsaturated phase bulk inductance. In the case of a saturated phase, the torque cannot be calculated by a simple algebra equation; instead, an integral equation such as

$$T = \int_0^i \frac{\partial L(\theta, i)}{\partial \theta} i \, di$$

The output torque of an SRM is the summation of torque of all the phases

$$T_m = \sum_{i=1}^{N} T(i, \theta)$$

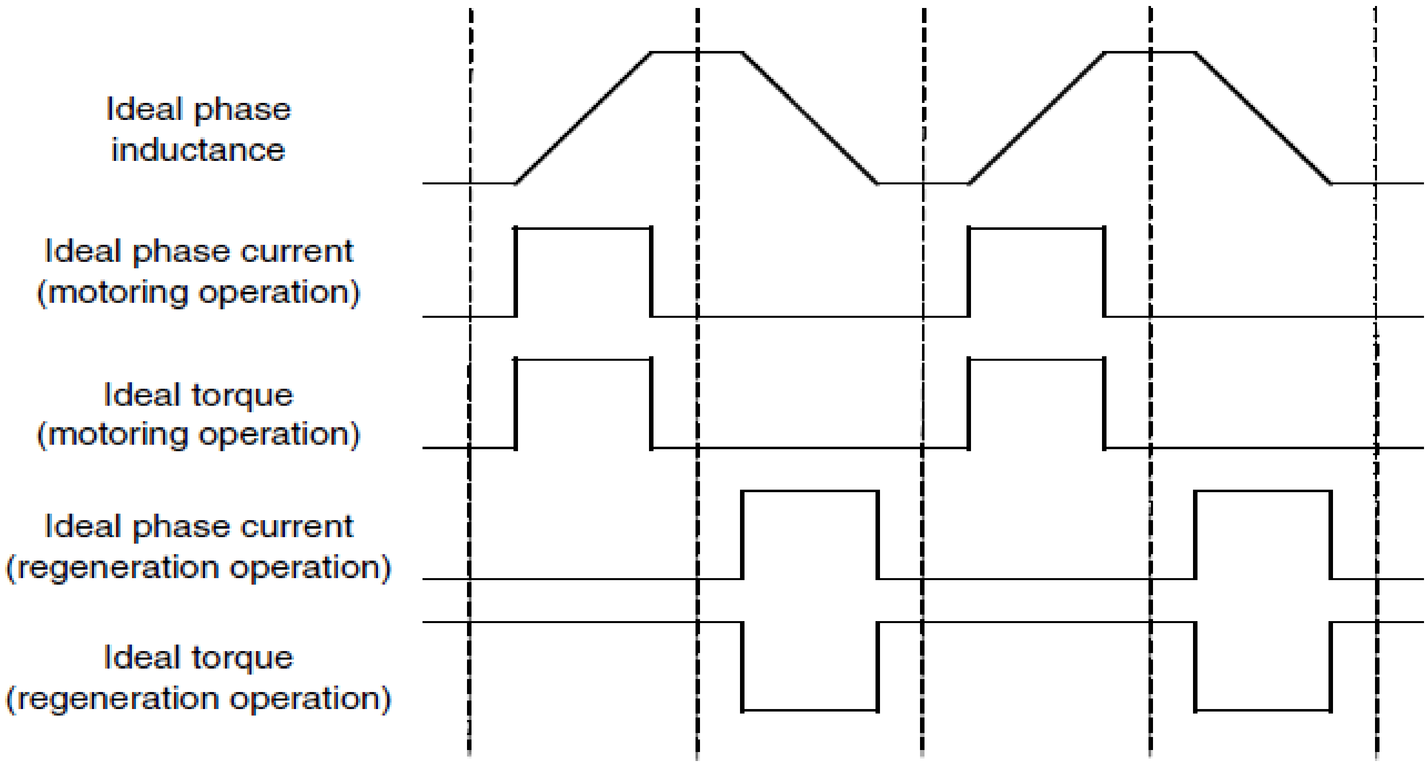
where T_m and N are the output torque and phase number of motor. The relation between the motor torque and mechanical load is usually given by

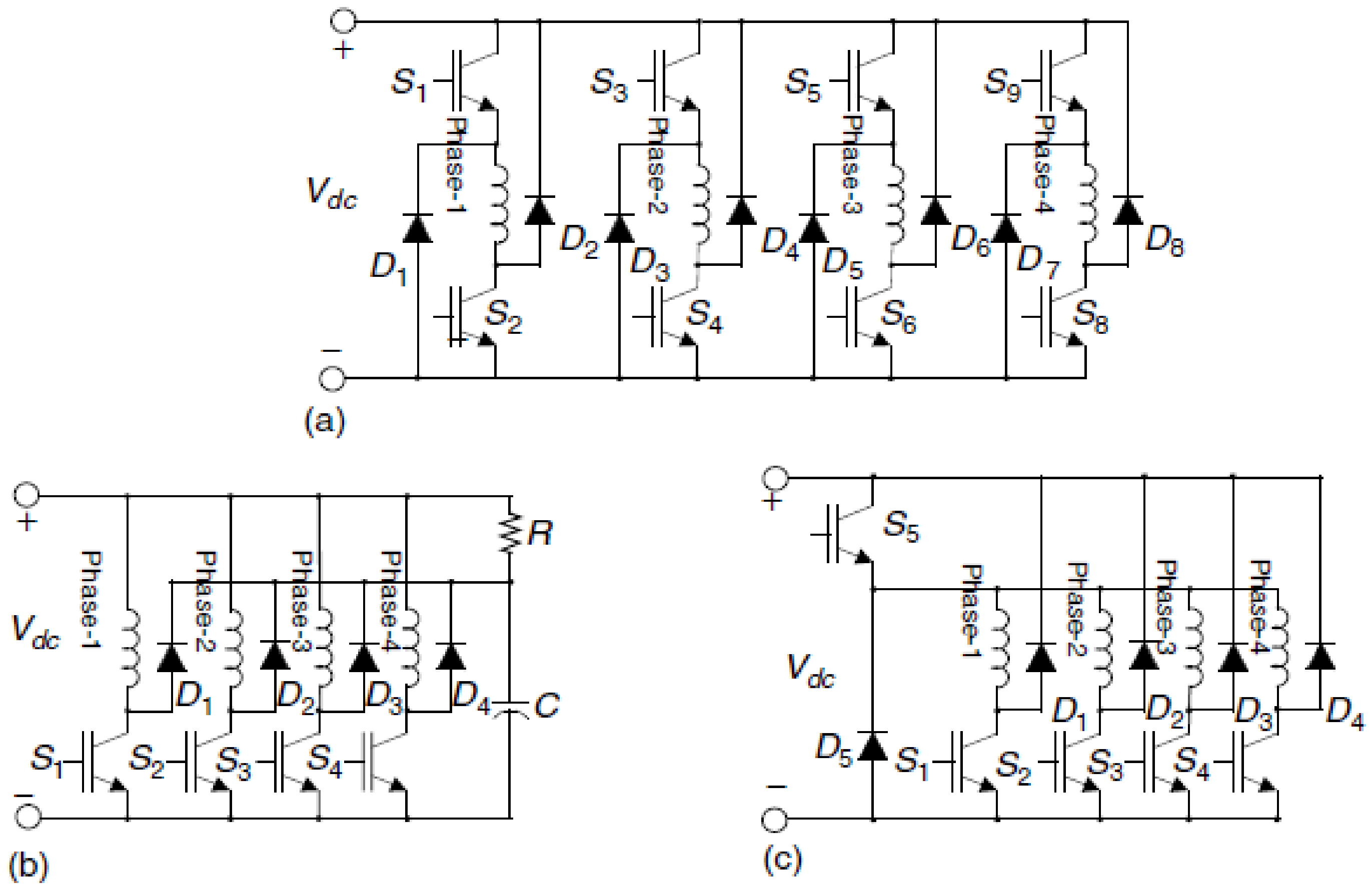
$$T_m - T_l = J\frac{d\omega}{dt} + B\omega$$

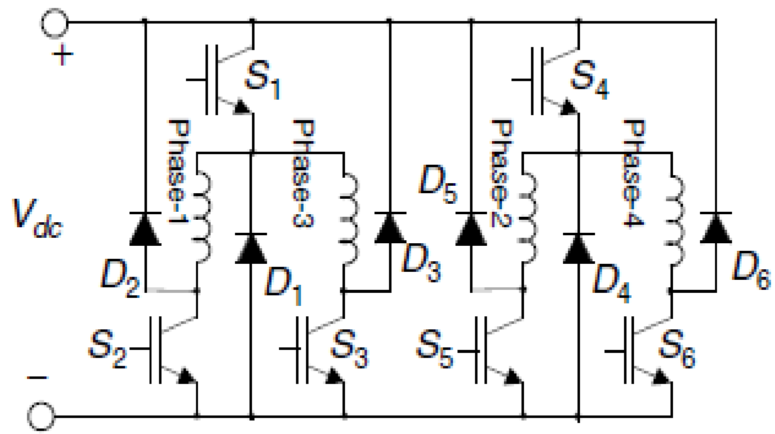
where J, B, and T_l are the moment of inertia, viscous friction, and load torque, respectively. The relation between position and speed is given by

$$\omega = \frac{d\theta}{dt}$$

SRM Drive Converter

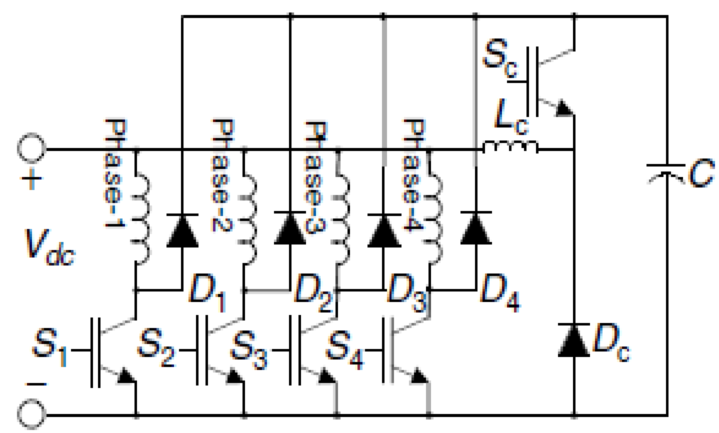



+
−
Vdc
S1
S2
S3
S4
S5
S6
S8
S9
D1
D2
D3
D4
D5
D6
D7
D8
Phase-1
Phase-2
Phase-3
Phase-4
(a)
R
C
(b)
(c)



+
S1
S4
Phase-1
Phase-3
Phase-2
Phase-4
D5
Vdc
D2
D1
D3
D4
D6
S2
S3
S5
S6
–

(d)



Sc
Lc
C
+
Phase-1
Phase-2
Phase-3
Phase-4
Vdc
D1
D2
D3
D4
Dc
S1
S2
S3
S4
–

(e)

Electric and Hybrid Electric Vehicles

Dr. Dola Gobinda Pradhan
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UNIT V: ENERGY STORAGE REQUIREMENTS IN HYBRID AND ELECTRIC VEHICLES

Introduction to Energy Storage Requirements in Hybrid and Electric Vehicles, Battery based energy storage and its analysis, Fuel Cell based energy storage and its analysis, Super Capacitor based energy storage and its analysis, Flywheel based energy storage and its analysis, Hybridization of different energy storage devices. Sizing the propulsion motor, sizing the power electronics, selecting the energy storage technology, Communications, supporting subsystems.

Energy storages

The devices that store energy, deliver energy outside (discharge), and accept energy from outside (charge).

These energy storages, mainly include chemical batteries, ultracapacitors or supercapacitors, and ultrahigh-speed flywheels.

There are a number of requirements for energy storage applied in an automotive application, such as specific energy, specific power, efficiency, maintenance requirement, management, cost, environmental adaptation and friendliness, and safety.

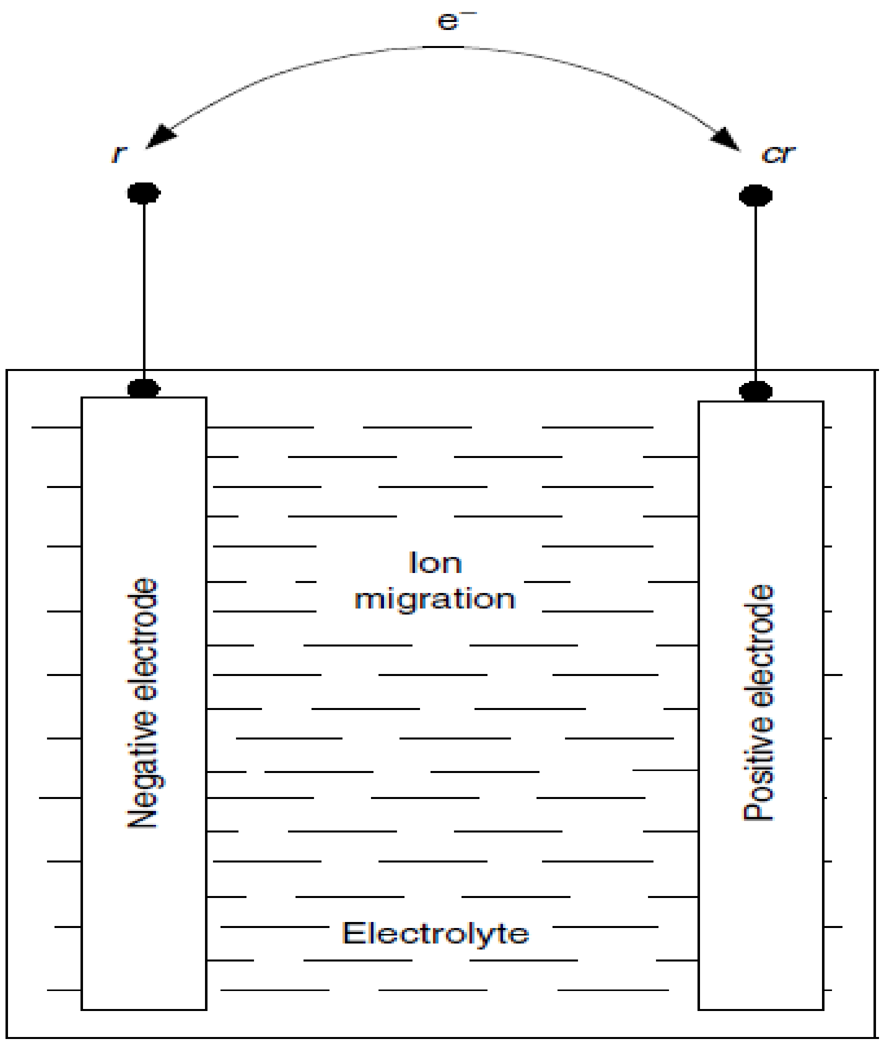
Electrochemical Batteries

- Electrochemical batteries, more commonly referred to as "batteries,"

- electrochemical devices that convert electrical energy into potential chemical energy during charging, and convert chemical energy into electric energy during discharging.

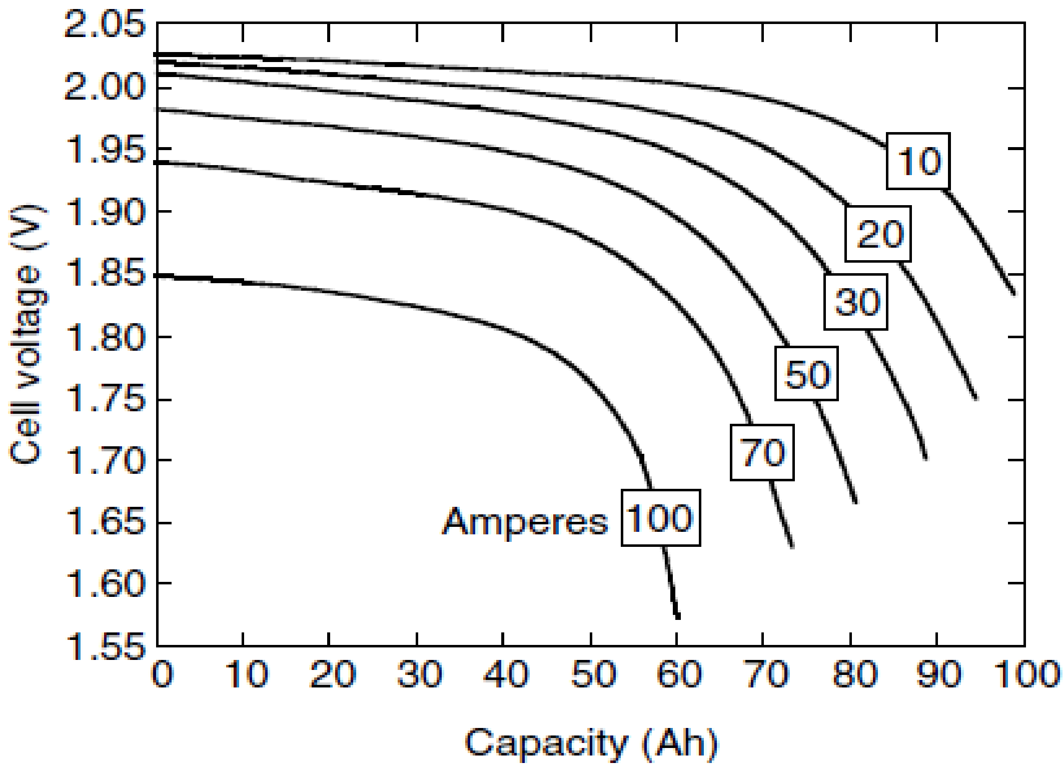
- A "battery" is composed of several cells stacked together. A cell is an independent and complete unit that possesses all the electrochemical properties.

- Basically, a battery cell consists of three primary elements: two electrodes (positive and negative) immersed into an electrolyte as shown in Figure



A typical electrochemical battery cell

Generally, the capacity will become smaller with a large discharge current rate, as shown in Figure. Battery manufacturers usually specify a battery with a number of amp-hours along with a current rate. For example, a battery labeled 100 Ah at C5 rate has a 100 amp-hour capacity at 5 hours discharge rate (discharging current=100/5=20 A).



Discharge characteristics of a lead-acid battery

State-of-charge (SOC)

SOC is defined as the ratio of the remaining capacity to the fully charged capacity.

A fully charged battery has an SOC of 100% and a fully discharged battery has an SOC of 0%.

The change in SOC in a time interval, *dt*, with discharging or charging current *i* may be expressed as

$$\Delta SOC = \frac{i\,dt}{Q(i)}$$

where *Q(i)* is amp-hour capacity of the battery at current rate *i*. For discharging, *i* is positive, and for charging, *i* is negative. Thus, the SOC of the battery can be expressed as

$$SOC = SOC_0 - \int \frac{i\,dt}{Q(i)}$$

where SOC_0 is the initial value of the SOC

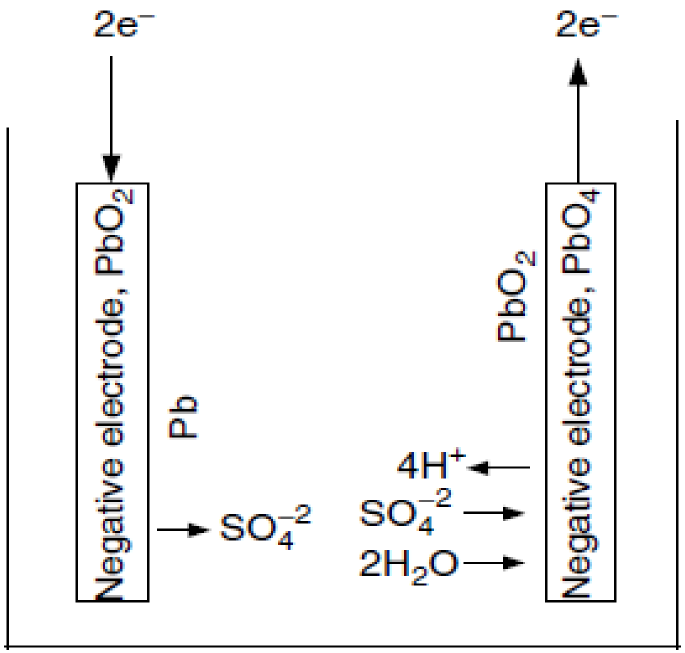
For EVs and HEVs, the energy capacity is considered to be more important than the coulometric capacity (Ahs), because it is directly associated with the vehicle operation.

The energy delivered from the battery can be expressed as

$$EC = \int_0^t V(i, SOC)\, i(t)\, dt$$

where *V(i, SOC)* is the voltage at the battery terminals, which is a function of the battery current and SOC.

During charging, the reactions on the anode and cathode are reversed as shown in Figure 10.4(b) that can be expressed by:



(b) Charging

anode: $$PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$$

and

cathode: $$PbSO_4 + 2H_2O \rightarrow PbO_2 + 4H^+ + SO_4^{2-} + 2e^-$$

The overall reaction in a lead-acid battery cell can be expressed as

overall: $$Pb + PbO_2 + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2PbSO_4 + 2H_2O.$$

The lead-acid battery has a cell voltage of about 2.03 V at standard condition, which is affected by the concentration of the electrolyte.

Thermodynamic Voltage

The thermodynamic voltage of a battery cell is closely associated with the energy released and the number of electrons transferred in the reaction.

The energy released by the battery cell reaction is given by the change in Gibbs free energy, Δ*G*, usually expressed in per mole quantities.

The change in Gibbs free energy in a chemical reaction can be expressed as

$$\Delta G = \sum_{\text{Products}} G_i - \sum_{\text{Reactants}} G_j$$

where G_i and G_j are the free energy in species *i* of products and species *j* of reactants. In a reversible process, Δ*G* is completely converted into electric energy, that is,

$$\Delta G = -nFV_r,$$

where *n* is the number of electrons transferred in the reaction, $F = 96{,}495$ is the Faraday constant in coulombs per mole, and V_r is the reversible voltage of the cell. At standard condition (25°C temperature and 1 atm pressure), the open circuit (reversible) voltage of a battery cell can be expressed as

Specific Energy

Specific energy is defined as the energy capacity per unit battery weight (Wh/kg).
The theoretical specific energy is the maximum energy that can be generated per unit total mass of the cell reactant.

The energy in a battery cell can be expressed by the Gibbs free energy ΔG. With respect to theoretical specific energy, only the effective weights (molecular weight of reactants and products) are involved; then

Energy Storages

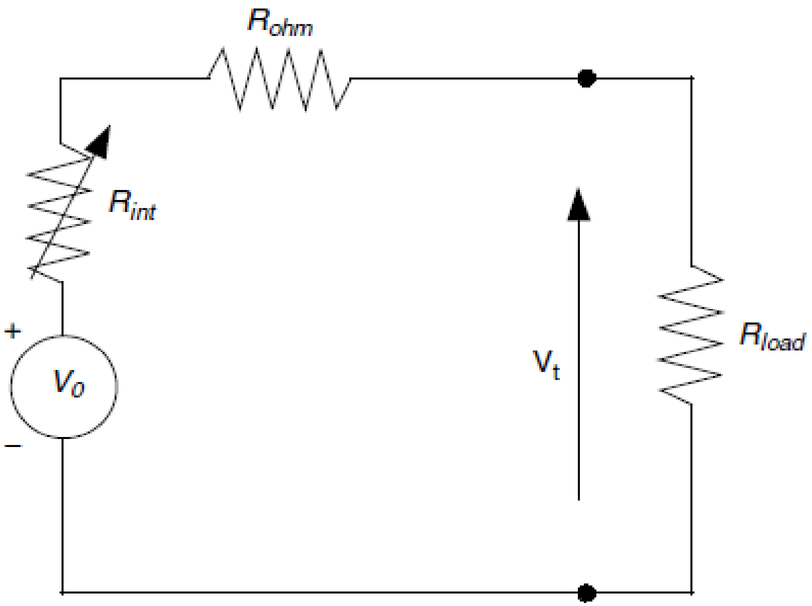
$$E_{spe,theo} = -\frac{\Delta G}{3.6\sum M_i} = \frac{nFV_r}{3.6\sum M_i}(\text{Wh/kg})$$

Specific Power

Specific power is defined as the maximum power of per unit battery weight that the battery can produce in a short period.

Specific power is important in the reduction of battery weight, especially in high power demand applications, such as HEVs.

The specific power of a chemical battery depends mostly on the battery's internal resistance. With the battery model as shown in Figure , the maximum power that the battery can supply to the load is



$$P_{peak} = \frac{V_0^2}{4(R_c + R_{int})}$$

Battery circuit model

where R_{ohm} is the conductor resistance (ohmic resistance) and R_{int} is the internal resistance caused by chemical reaction.

Internal resistance, R_{int}, represents the voltage drop, ΔV, which is associated with the battery current. The voltage drop ΔV, termed overpotential in battery terminology, includes two components: one is caused by reaction activity ΔV_A, and the other by electrolyte concentration ΔV_C. General expressions of ΔV_A and ΔV_C are[2]

$$\Delta V_A = a + b \log I$$

and

$$\Delta V_C = -\frac{RT}{nF} \ln\left(1 - \frac{I}{I_L}\right),$$

where a and b are constants, R is the gas constant, 8.314 J/K mol, T is the absolute temperature, n is the number of electrons transferred in the reaction, F is the Faraday constant — 96,495 ampere-seconds per mole — and I_L is the limit current. Accurate determination of battery resistance or voltage drop by analysis is difficult and is usually obtained by measurement.[1] The voltage drop increases with increasing discharging current, decreasing the stored energy in it (refer to Figure 10.3).

Energy Efficiency

The energy or power losses during battery discharging and charging appear in the form of voltage loss.

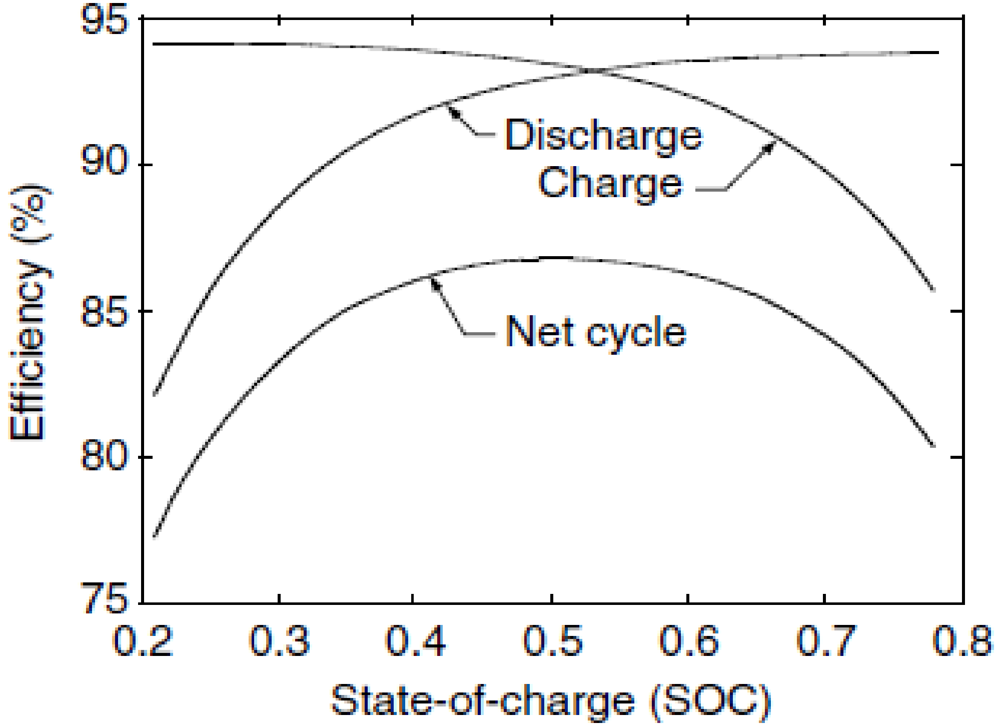
Thus, the efficiency of the battery during discharging and charging can be defined at any operating point as the ratio of the cell operating voltage to the thermodynamic voltage, that is:

during discharging: $$\eta = \frac{V}{V_0}$$

and

during charging: $$\eta = \frac{V_0}{V}.$$

The terminal voltage, as a function of battery current and energy stored in it or SOC, is lower in discharging and higher in charging than the electrical potential produced by a chemical reaction.



Typical battery charge and discharge efficiency

- The battery has a high discharging efficiency with high SOC and a high charging efficiency with low SOC.
- The net cycle efficiency has a maximum in the middle range of the SOC.
- Therefore, the battery operation control unit of an HEV should control the battery SOC in its middle range so as to enhance the operating efficiency and depress the temperature rise caused by energy loss.
- High temperature would damage the battery.

FUEL CELLS

- A fuel cell is an electrochemical device that produces electricity by means of a chemical reaction, much like a battery.

- The major difference between batteries and fuel cells is that the latter can produce electricity as long as fuel is supplied

- Batteries produce electricity from stored chemical energy and, hence, require frequent recharging.

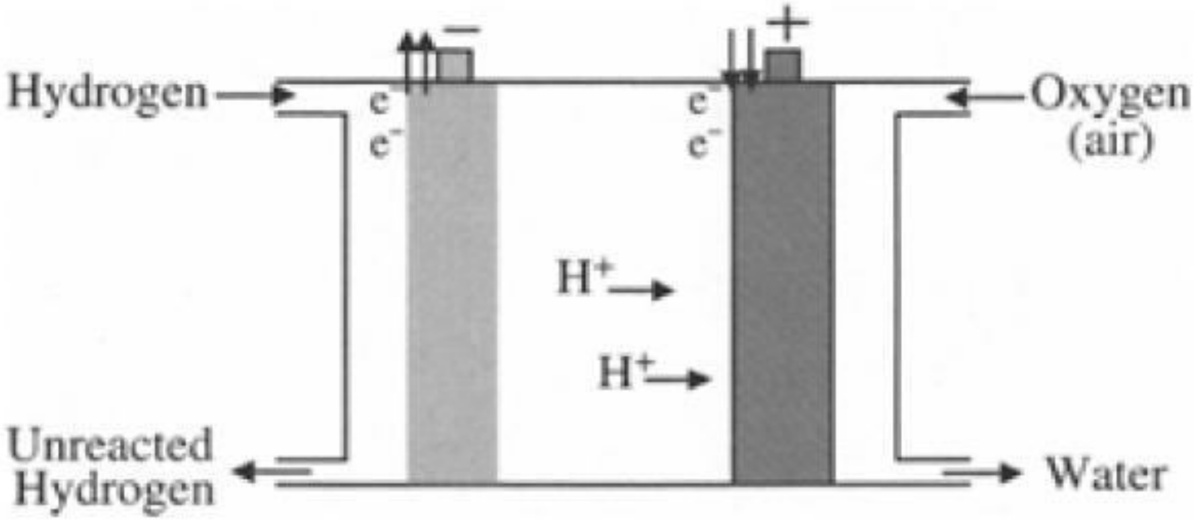


FIGURE Basic fuel cell structure

The basic structure of a fuel cell consists of an anode and a cathode, similar to a battery.

The fuel supplied to the cell is hydrogen and oxygen.

The concept of fuel cell is the opposite of electrolysis of water, where hydrogen and oxygen are combined to form electricity and water.

FUEL CELL CHARACTERISTICS

fuel cells operate isothermally, meaning that all free energy in a fuel cell chemical reaction should convert into electrical energy.

The hydrogen "fuel" in the fuel cell does not burn as in IC engines, bypassing the thermal to mechanical conversion.

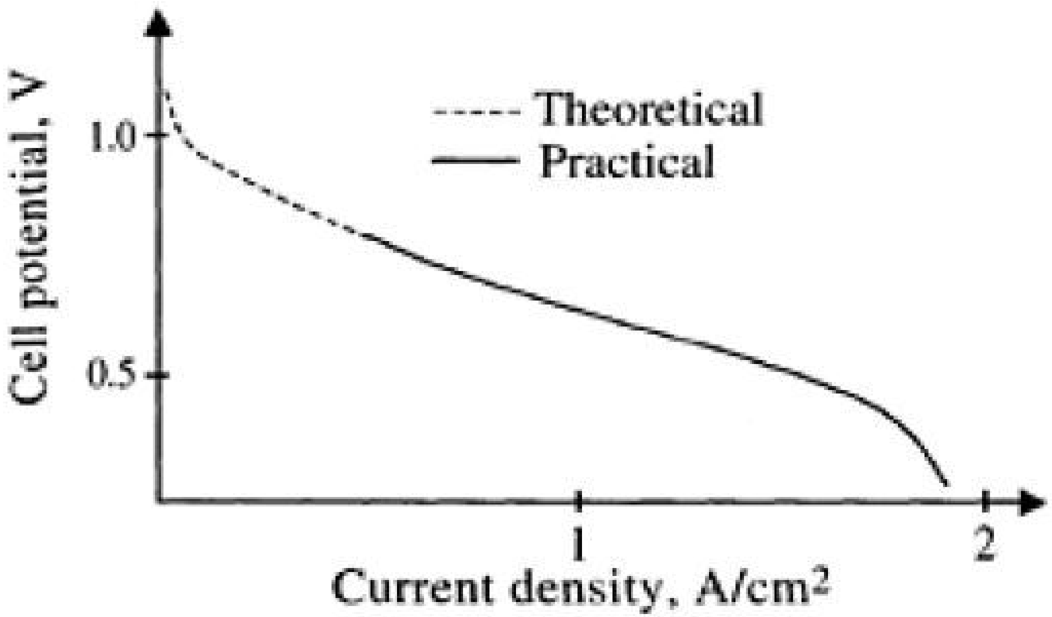


FIGURE Voltage-current relationship of a hydrogen/oxygen cell

The linear region where the reduction in cell potential is due to ohmic losses is where a practical fuel cell operates.

The resistive components in the cell limit the practical achievable efficiency of a fuel cell.

The working voltage of the cell falls with an increasing current drain, knowledge that is important in designing fuel-cell-powered EVs and hybrid vehicles.

Because cell potential is small, several cells are stacked in series to achieve the desired voltage.

The major advantage of fuel cells is lower sensitivity to scaling, which means that fuel cells in the kW range have similar overall system efficiencies up to the MW range.

FUEL CELL TYPES

The six major types of fuel cells are as follows:

- Alkaline **Fuel Cell (AFC)**
- **Proton Exchange Membrane (PEM)**
- **Direct Methanol Fuel Cell (DMFC)**
- **Phosphoric Acid Fuel Cell (PAFC)**
- **Molten Carbonate Fuel Cell (MCFC)**
- **Solid Oxide Fuel Cell (SOFC)**

Solid Oxide Fuel Cell (SOFC, ITSOFC)

Solid oxide fuel cells (SOFCs) use a solid ionic conductor as the electrolyte rather than a solution or a polymer, which reduces corrosion problems.

However, to achieve adequate ionic conductivity in such a ceramic, the system must operate at very high temperatures.

The original designs, using yttria-stabilized zirconia as the electrolyte, required temperatures as high as 1000°C to operate, but the search for
materials capable of serving as the electrolyte at lower temperatures resulted in the "intermediate temperature solid oxide fuel cell" (ITSOFC).

This fuel cell has high electrical efficiency of 50 to 60%, and residual heat can also be used for cogeneration.

Although not a good choice for vehicle applications, it is at present the best option for stationary power generation.

SUPER CAPACITORS AND ULTRA CAPACITORS

Capacitors are devices that store energy by the separation of equal positive and negative electrostatic charges.

The basic structure of a capacitor consists of two conductors, known as plates, separated by a dielectric, which is an insulator.

The power densities of conventional capacitors are extremely high (~10^{12} W/m^3), but the energy density is very low (~50 Wh/m^3).

These conventional capacitors are commonly known as “electrolytic capacitors.” They are widely used in electrical circuits as intermediate energy storage elements for time constants that are of a completely different domain and are of much smaller order compared to the energy storage devices that are to serve as the primary energy sources for EVs.

The capacitors are described in terms of capacitance, which is directly proportional to the dielectric constant of the insulating material and inversely proportional to the space between the two conducting plates.

The capacitance is measured by the ratio of the magnitude of the charge between either plate and the potential difference between them *($C=q/V$)*.

Supercapacitors and ultracapacitors are derivatives of conventional capacitors, where energy density has been increased at the expense of power density to make the devices function more like a battery.

Power density and energy density of supercapacitors and ultracapacitors are of the order of 10^6W/m3 and 10^4 Wh/m3, respectively.

Energy density is much lower compared to those of batteries (~5 to 25×10^4 Wh/m3), but the discharge times are much faster (110 s compared to ~5×10^3 s of batteries), and the cycle life is much more (~10^5 compared to 100 to 1000 of batteries).

FLYWHEELS

The flywheel is the kind of energy supply unit that stores energy in mechanical form.

Flywheels store kinetic energy within a rotating wheel-like rotor or disk made of composite materials.

Flywheels have a long history of usage in automobiles, being routinely used in all of today's IC engines to store energy and smooth the power delivered by abrupt pulses of the engine.

However, the amount of energy storage required in flywheels of IC engines is small and is limited by the need of the vehicle to accelerate rapidly.

The flywheel is currently being looked into for use in a number of different capacities.

Flywheels can be used in HEVs with a standard IC engine as a power assist device.

Alternatively, flywheels can be used to replace chemical batteries in EVs to serve as the primary energy source or could be used in conjunction with batteries.

However, technological breakthroughs in increasing the specific energy of flywheels are necessary before they can be considered as the energy source for EVs and HEVs.

The flywheels of today are quite complex, large, and heavy. Safety is also a concern with flywheels.

The flywheel design objective is to maximize energy density. The energy *U* stored in the flywheel is given by

$$U = \frac{1}{2} J\omega^2$$

where *J* is the polar moment of inertia, and is the angular velocity. Energy storage is increased by spinning at higher velocities without increasing the inertia, which is directly proportional to mass.

Increasing angular velocity , in turn, increases centrifugal stress, which must not exceed failure stress with a given factor of safety. Stored energy per unit mass can be expressed as follows:

$$\frac{U}{m} = k\frac{\sigma}{\rho}$$

where *k* is a constant depending on the geometry, s is the tensile strength, and is the density of the material.

Therefore, the material to be used in a flywheel must be lightweight with high tensile strength, conditions that are satisfied by composite materials.

Flywheels have several advantages as an energy source, the most important of which is the high specific power.

Theoretically, specific power of fly wheels has been shown to be of the order of 5 to 10 kW/kg, with a specific power of 2 kW/kg being easily achievable without exceeding safe working
stresses.

Other performance features that make flywheels attractive can be attributed to their mechanical nature.

Flywheels are not affected by temperature extremes.

Ultracapacitors

Because of the frequent stop/go operation of EVs and HEVs, the discharging and charging profile of the energy storage is highly varied.

The average power required from the energy storage is much lower than the peak power of relatively short duration required for acceleration and hill climbing.

The ratio of the peak power to the average power can be over 10:1

Features of Ultracapacitors

- The ultracapacitor is characterized by much higher specific power, but much lower specific energy compared to the chemical batteries.
- Its specific energy is in the range of a few watt-hours per kilogram.
- Its specific power can reach up to 3 kW/kg, much higher than any type of battery.

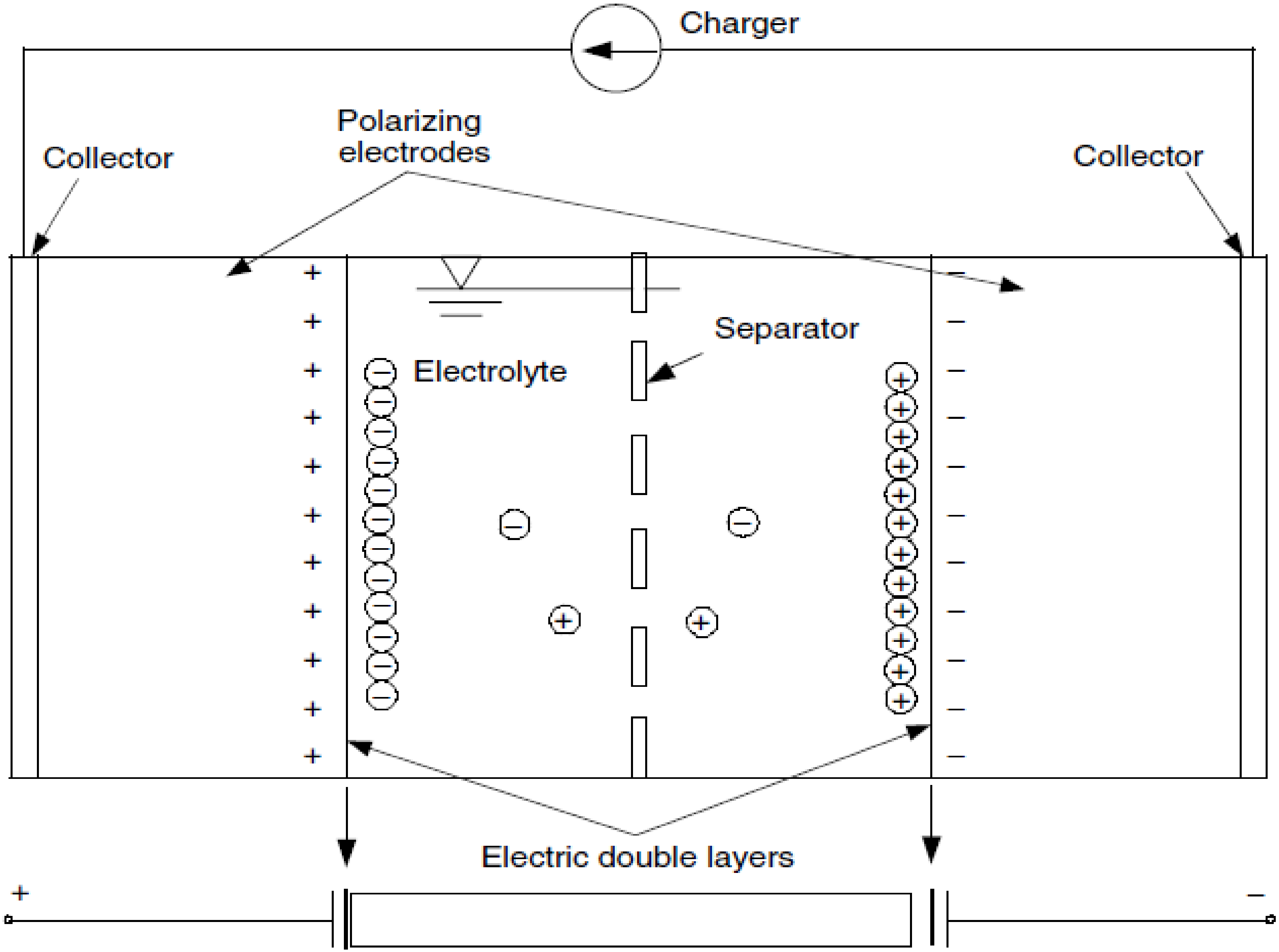


FIGURE 10.8
Basic principles of a typical electric double-layer capacitor

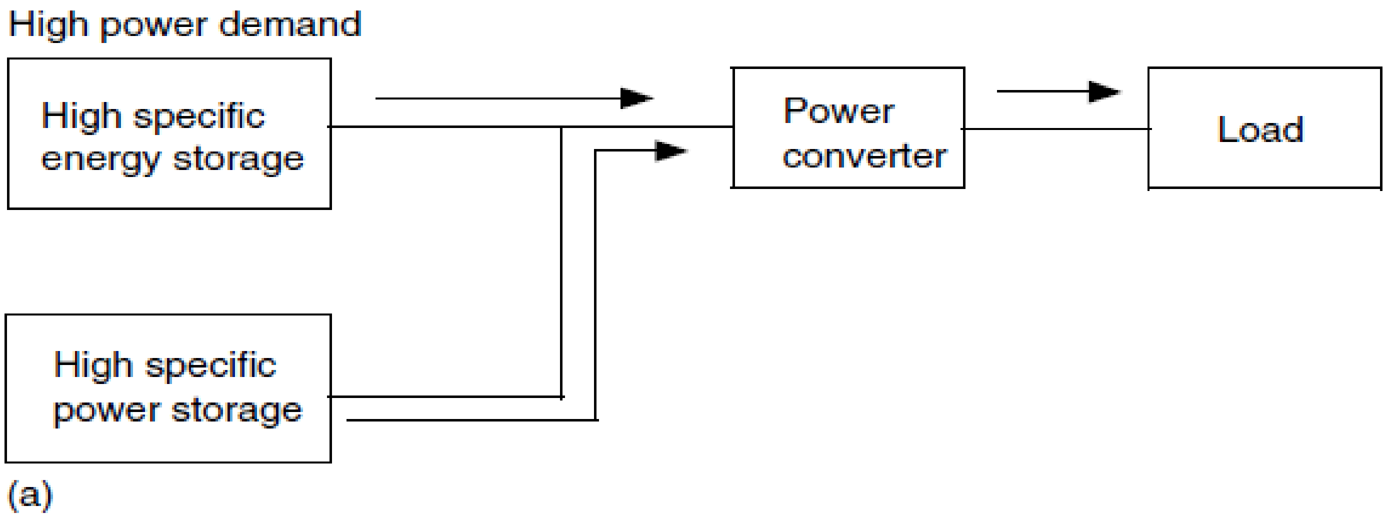
- Below the decomposition voltage, while the current does not flow, an "electric double layer" then occurs at the boundary of electrode and electrolyte. The electrons are charged across the double layer and for a capacitor.
- An electrical double layer works as an insulator only below the decomposing voltage. The stored energy, *Ecap*, is expressed as

$$E_{cap} = \frac{1}{2} C V^2,$$

where C is the capacitance in Faraday and V is the usable voltage in volt.

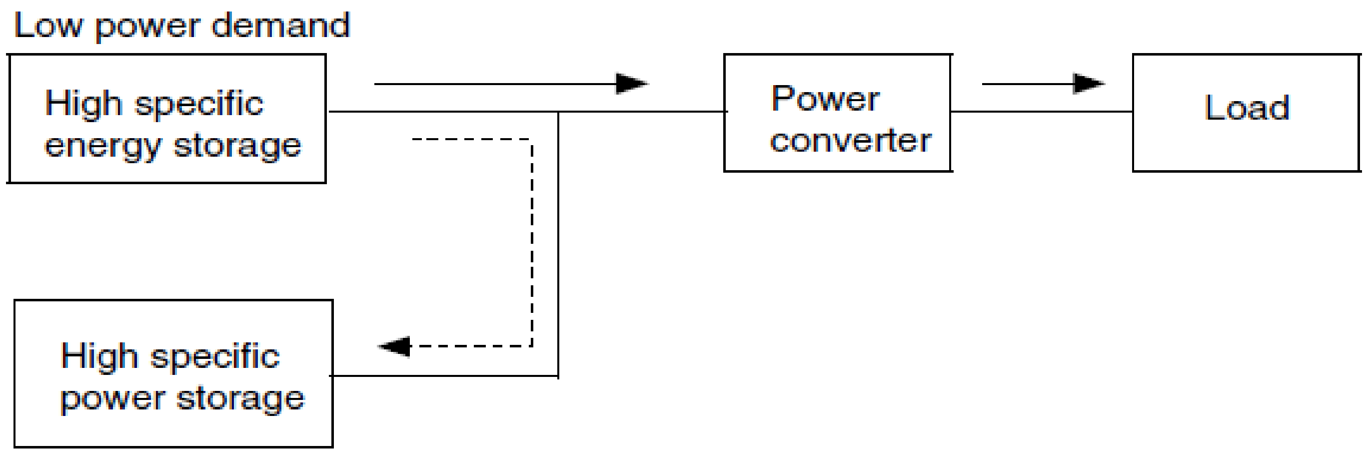
This equation indicates that the higher rated voltage V is desirable for larger energy density capacitors. Up to now, capacitors' rated voltage with an aqueous electrolyte has been about 0.9 V per cell, and 2.3 to 3.3 V for each cell with a nonaqueous electrolyte.

Basically, the hybridized energy storage consists of two basic energy storages: one with high specific energy and the other with high specific power. The basic operation of this system is illustrated in Figure



In high power demand operations, such as acceleration and hill climbing, both basic energy storages deliver their power to the load as shown in Figure (a).

In low power demand operation, such as constant speed cruising operations, the high specific energy storage will deliver its power to the load and charge the high specific power storage to recover its charge lost during high power demand operation, as shown in Figure (b)



(b)

In regenerative braking operations, the peak power will be absorbed by the high specific power storage, and only a limited part is absorbed by the high specific energy storage.

In this way, the whole system would be much smaller in weight and size than if any one of them alone was the energy storage.

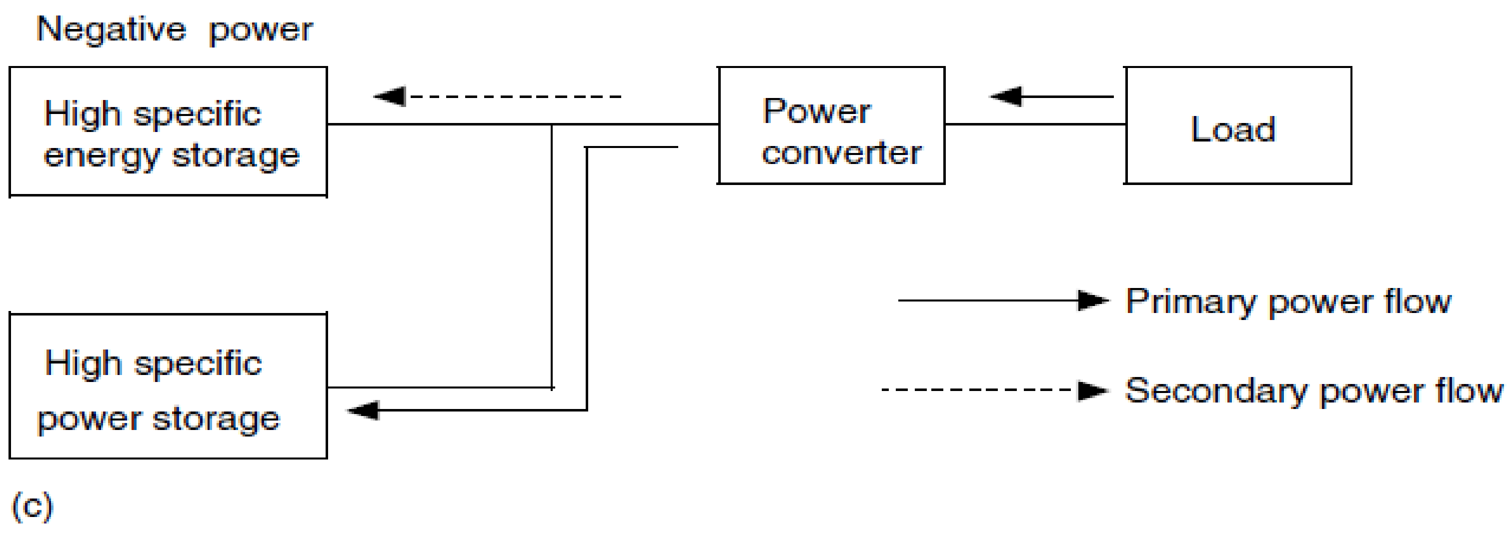


FIGURE Concept of a hybrid energy storage operation

There is a third natural mode region for high motor speeds, where the torque falls rapidly, being inversely proportional to the square of the speed.

The natural characteristic region can be an important part of the overall torque-speed curve of certain motors that can be used to reduce the power rating of the motor.

However, in most cases, the vehicle's maximum speed is considered to be at the end of the constant power region.

Note that the curves in Figure show the envelope, i.e., the operating torque and speed limits in different regions.

The electric motor can operate at any point within the envelope through the feed from a power electronics based motor drive component.

The salient feature of wide-operating speed range characteristics of an electric motor makes it possible to eliminate multiple gear ratios and the clutch in EV and other applications.

A single gear ratio transmission is sufficient for linking the electric motor with the driveshaft.

Electric motors with extended constant power region characteristics are what is needed to minimize the gear size in EVs.

CODE: GR20A3015 **GR 20** **SET-4**

III B.Tech I Semester Regular Examinations, December/January 2022/23

ELECTRICAL AND HYBRID VEHICLES

PART – A

Q.1 (a) The average Internal Combustion Engine has a fuel efficiency of only 40% – with 60% lost via heat and friction. As a result, ICEs consume far more energy travelling the same distance as an EV. EVs are well known for running smoothly and silently. Using an electric engine instead of an exhaust system, they naturally operate with less noise pollution and have smoother acceleration and deceleration. Compared to petrol and diesel, refuelling a car with electricity is more cost effective.

(b) Hybrid electric vehicles available in the Indian market: Toyota Innova Hycross, Maruti Suzuki Grand Vitara, Toyota Vellfire, Toyota Camry, Porsche Cayenne, Honda City Hybrid eHEV, Porsche Panamera, Lexus RX etc.

(c) The advantages of regenerative braking are the following.

- This braking system will increase the vehicle's fuel economy.
- It permits for conventional brakes based on friction.
- It extends the battery charge.

(d) A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is known as aerodynamic drag. The main causes of aerodynamic drag are shape drag and skin friction.

(e)

Battery cell	Fuel cell
They store energy in the form of chemical energy	They cannot store energy. Fuel cell converts chemical energy to electrical energy.
Reactants are inside the cell itself.	Reactants for chemical reaction are supplied continuously.
Chemical reaction products remain inside the cell itself	Chemical reaction products are removed from the cell
Rechargeable	Not rechargeable
Less efficiency	High efficiency
It consists of limited amount of fuel and oxidant and these reactants diminish with time	Needs a continuous supply of fuel and oxygen from an external source
Supply energy for a limited period of time	Supply energy for a long period of time
Less expensive	They are expensive
Example : lithium ion batteries	Example : hydrogen-oxygen fuel cell

(f) The various smart hybrid topologies are listed below

- Series configuration
- Parallel configuration
- Series-parallel configuration
- Complex configuration

(g) Working Principle of PM Brushless DC motor

BLDC motor works on the principle similar to that of a Brushed DC motor. The Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. In the BLDC motor, the current carrying conductor is stationary and the permanent magnet is moving. When the stator coils get a supply from source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.

(h) EVs range can be increased in the following ways

- Drive Smoothly
- Slow Down
- Maximize Regenerative Braking
- Go Easy On The Heat
- Be Cool With The Ac
- Tend To Tires
- Travel Light
- Keep It Slick

- Plan A More-Efficient Route
- Time Your Charge

(i) Hydrogen fuel cells (HFCs) produce no harmful emissions, eliminating the costs associated with handling and storing toxic materials like battery acid or diesel fuel. In fact, when fueled with pure hydrogen, the only by-products are heat and water, making our products a zero-emission, sustainable power source.

(j) Automaker working in fuel cell based EVs: Honda Clarity Fuel Cell, the Hyundai Nexo SUV, Toyota Mirai and BMW are leading the automotive industry focusing extensively on hydrogen passenger cars.

PART – B

Q.2 (a) Undesirable emissions in internal combustion engines are of major concern because of their negative impact on air quality, human health, and global warming. Therefore, there is a concerted effort by most governments to control them. Undesirable emissions include unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). In this chapter, we present the U.S. and European emissions standards, both for gasoline and diesel operated engines, and strategies to control the undesirable emissions. The role of engine design, vehicle operating variables, fuel quality, and emission control devices in minimizing the above-listed pollutants are also detailed in this chapter. "Emissions" is a collective term that is used to describe the undesired gases and particles which are released into the air or emitted by various sources, Its amount and the type change with a change in the industrial activity, technology, and a number of other factors, such as air pollution regulations and emissions controls. The U.S. Environmental Protection Agency (EPA) is primarily concerned with emissions that are or can be harmful to the public at large. EPA considers carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), paniculate matter (PM), and sulfur dioxide (SO_2) as the pollutants of primary concern, called the *Criteria Pollutants*. These pollutants originate from the following four types of sources. 1. Point sources, which include facilities such as factories and electric power plants. 2. Mobile sources, which include cars and trucks but also lawn mowers, airplanes, and anything else that moves and releases pollutants into the air. 3. Biogenic sources, which include trees and vegetation, gas seeps, and microbial activity. 4. Area sources, which consist of smaller stationary sources such as dry cleaners and degreasing operations.

(b) Electrification is widely considered an attractive solution for reducing the oil dependency and environmental impact of road transportation. Many countries have been establishing increasingly stringent and ambitious targets in support of transport electrification. While transport electrification alone would not contribute to climate change mitigation, it is interesting to note that switching to electrified road transport under the sustainable shared socioeconomic pathways permitted an optimistic outlook for a low-carbon transition, even in the absence of a decarbonized power sector. Another interesting finding was that the stringent penetration of electric vehicles can reduce the mitigation cost generated by the 2 °C climate stabilization target, implying a positive impact for transport policies on the economic system. With technological innovations such as electrified road transport, climate change mitigation does not have to occur at the expense of economic growth. Because a transport electrification policy closely interacts with energy and economic systems, transport planners, economists, and energy policymakers need to work together to propose policy schemes that consider a cross-sectoral balance for a green sustainable future. Transportation is a growing source of the global greenhouse gas emissions that are driving climate change, accounting for 23% of energy-related carbon dioxide emissions worldwide in 2019 and 29% of all greenhouse gas emissions in the U.S.

Q.3 (a)

Specifications	**Hybrid Vehicles**	**Electric Vehicles**
Power/Fuel Source	Electricity and Fossil Fuel (Petrol and Diesel)	Electricity Through Battery Pack (DC)
Engine	Internal Combustion Engine (ICE) and Electric Motor(s)	Electric Motor(s)
Fuel Efficiency	Combination of ICE and Battery Range	Depends on Battery Range
Emission Levels	Higher Compared to Electric Cars	Lower Compared to ICE and Hybrid Cars
Price Range	Similar to Conventional ICE Cars	High
Charging	Not Needed	Needed

(b)

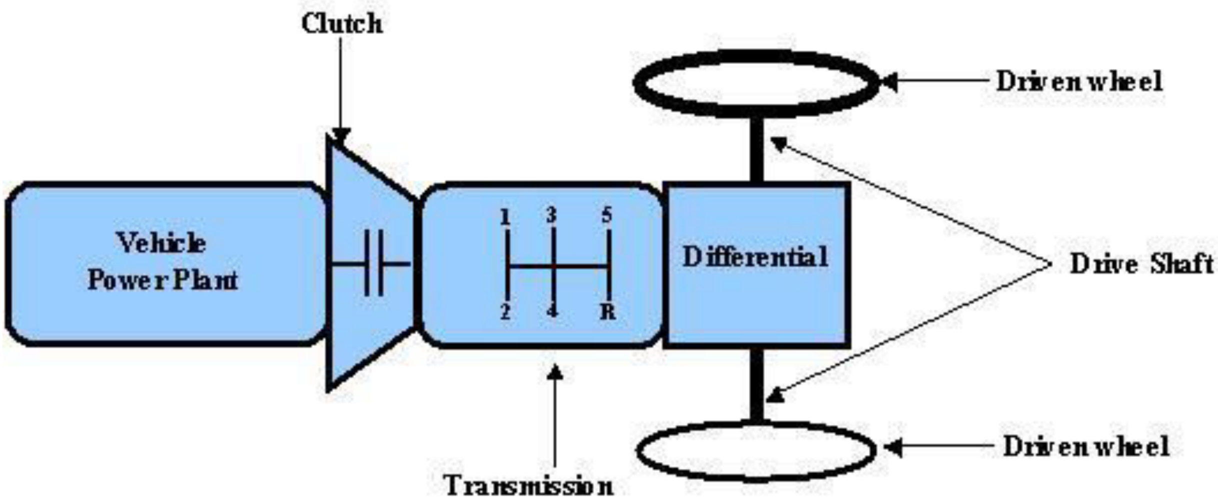
Six Technology Innovations in Electric Vehicle Charging

- Smart EV Charging
- Self-Healing Algorithms for EV Charging Management
- Vehicle-to-X (V2X)

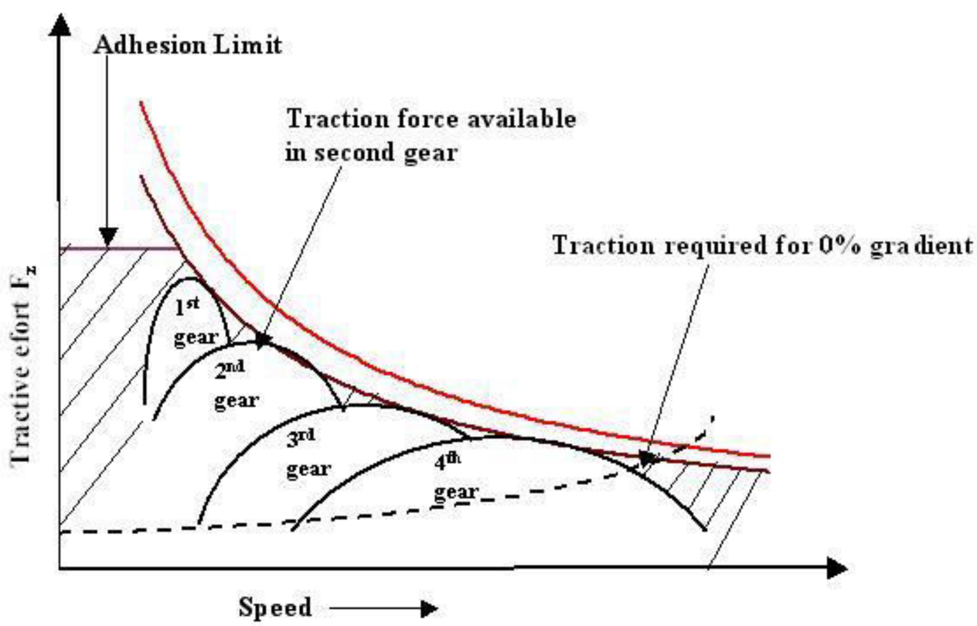
- EV Battery Technology
- Megawatt Charging System for Big Trucks
- Smart Battery Management

Q.4

General lay out of a EV: It consists of a power plant, a clutch in a manual transmission or a torque converter in automatic transmission, a gear box, final drive, differential shaft and driven wheels



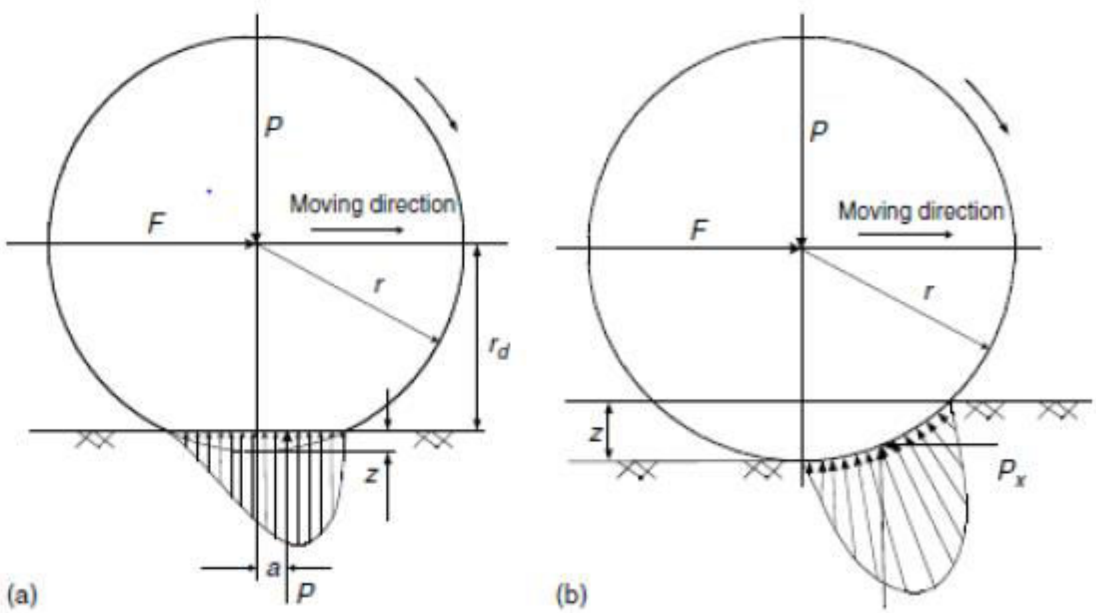
Transmission characteristics:



Q.5

Rolling Resistance

The rolling resistance of tires on hard surfaces is primarily caused by hysteresis in the tire materials.

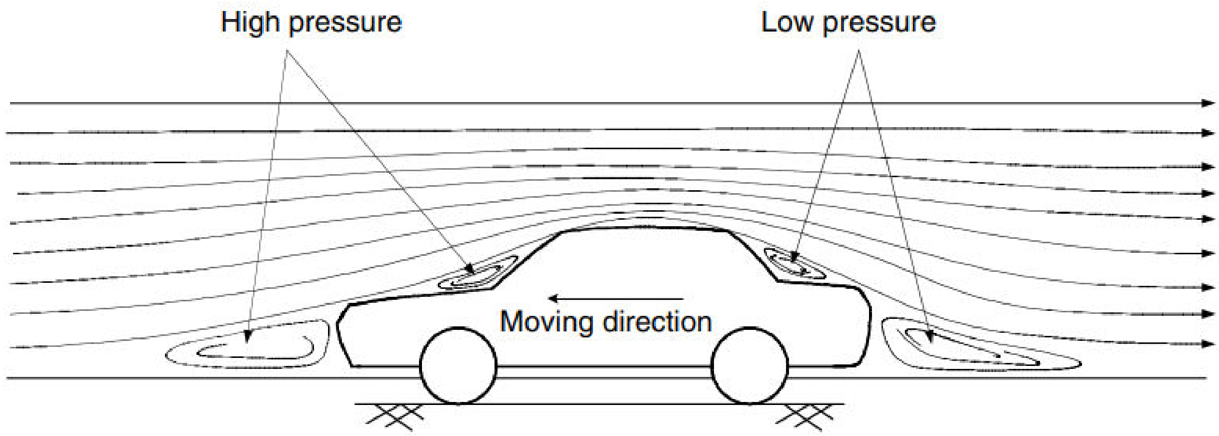


This is due to the deflection of the carcass while the tire is rolling. The hysteresis causes an asymmetric distribution of ground reaction forces. The pressure in the leading half of the contact area is larger than that in the trailing half, as shown in Figure (a). This phenomenon results in the ground reaction force shifting forward. This forwardly shifted ground reaction force, with the normal load acting on the wheel center, Creates a moment that opposes the rolling of the wheel. On soft surfaces, the rolling resistance is primarily caused by deformation of the ground surface as shown in Figure (b). The ground reaction force almost completely Shifts to the leading half.

Aerodynamic Drag

A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is known as aerodynamic drag. The main causes of aerodynamic drag are:

- shape drag
- skin friction



Shape drag

The shape drag is due to the shape of the vehicle. The forward motion of the vehicle pushes the air in front of it. However, the air cannot instantaneously move out of the way and its pressure is thus increased. This results in high air pressure in the front of the vehicle. The air behind the vehicle cannot instantaneously fill the space left by the forward motion of the vehicle. This creates a zone of low air pressure. Hence, the motion of the vehicle creates two zones of pressure. The high pressure zone in the front of the vehicle opposes its movement by pushing. On the other hand, the low pressure zone developed at the rear of the vehicle opposes its motion by pulling it backwards.

Skin friction

The air close to the skin of the vehicle moves almost at the speed of the vehicle while the air away from the vehicle remains still. Between these two layers (the air layer moving at the vehicle speed and the static layer) the molecules move at a wide range of speeds. The difference in speed between two air molecules produces friction. This friction results in the second component of aerodynamic drag and it is known as skin friction.

Q.6 Power Flow Control in Hybrid Drive Train Topologies:

- Power Flow Control in Series Hybrid
- Power Flow Control in Parallel Hybrid
- Power Flow Control Series-Parallel Hybrid
- Power Flow Control Complex Hybrid Control

Power Flow Control in Series Hybrid

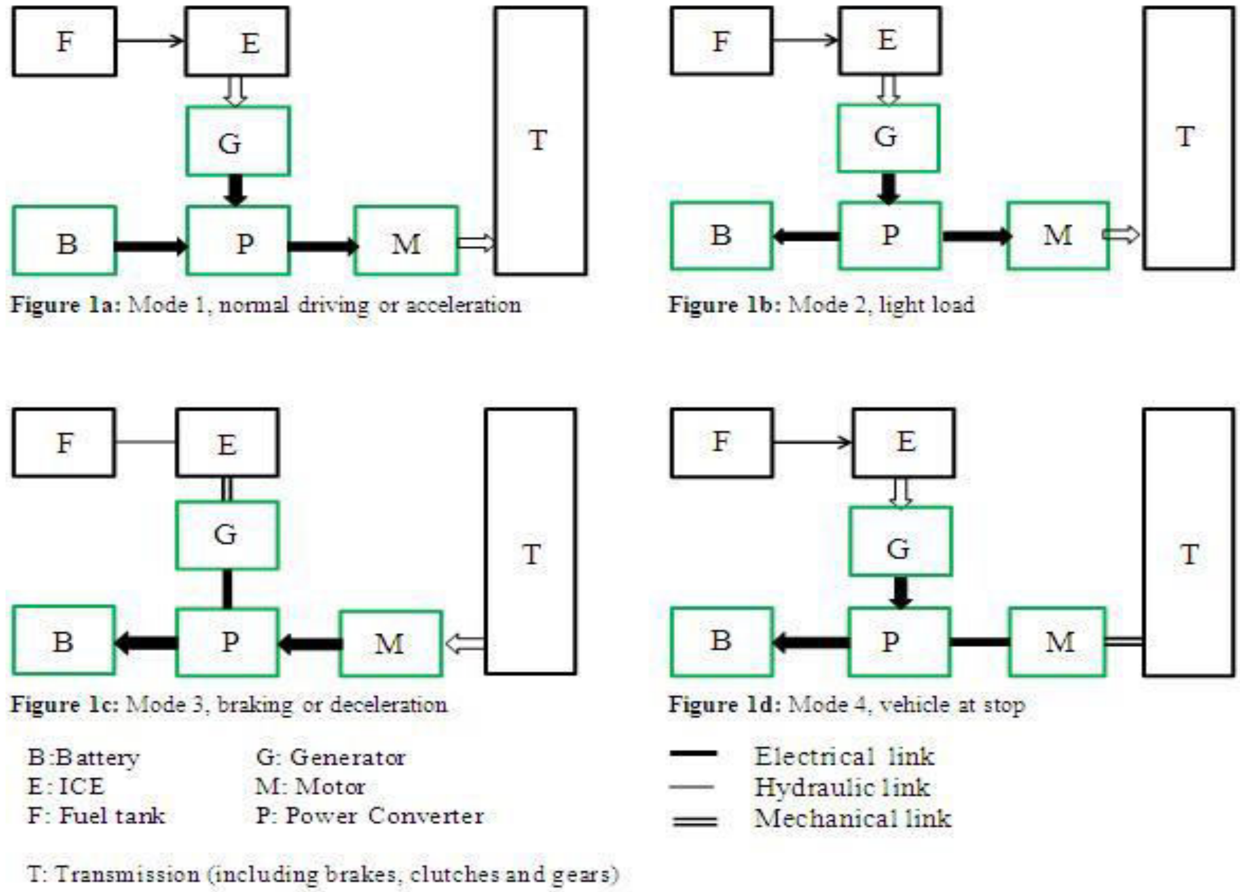


Figure 1a: Mode 1, normal driving or acceleration

Figure 1b: Mode 2, light load

Figure 1c: Mode 3, braking or deceleration

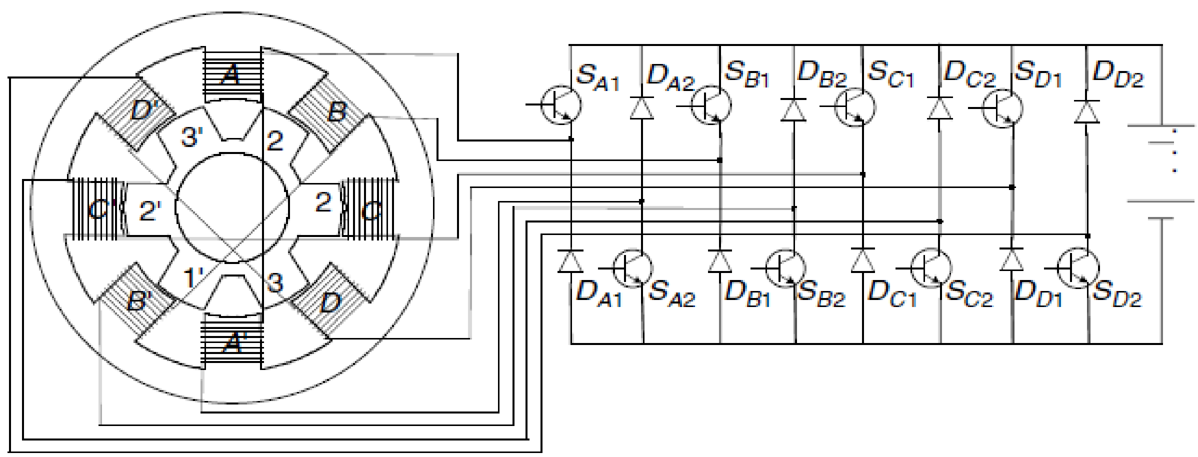
Figure 1d: Mode 4, vehicle at stop

Q.7 A fuel cell is an electrochemical device that continuously generates electricity without the need for any intermediate energy conversion. Hydrogen fuel cells work like batteries, but they do not need any recharging as they produce electricity if there is a supply of H2 and O2 as fuels. A fuel cell is made up of a negative electrode (anode), and a positive electrode (cathode) sandwiched around an electrolyte. Hydrogen is fed to the anode, and the air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, the electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and electrons to produce water and heat.

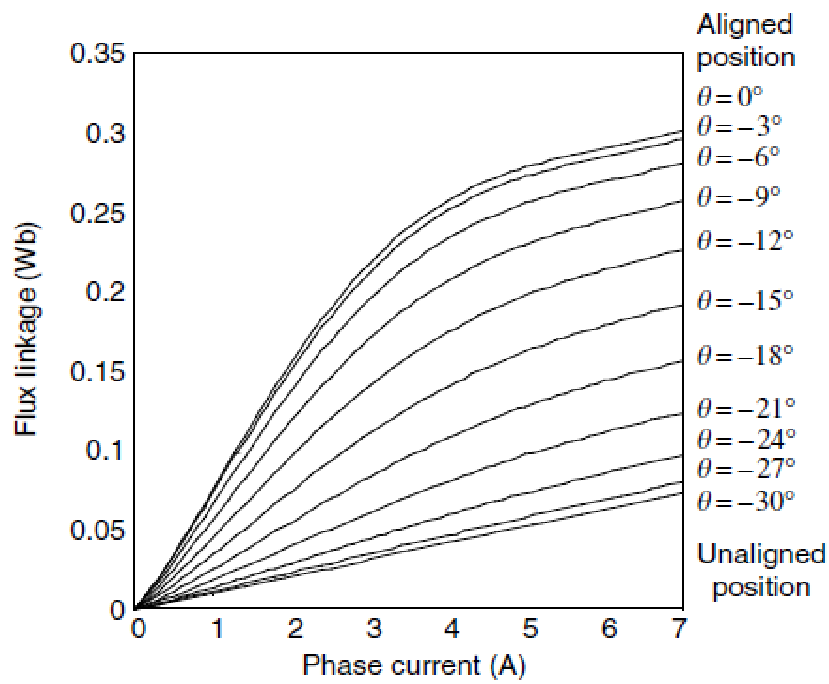
The expectation from the market is to have safe, green, sustainable, and reliable automobiles with minimal or no wait time for refuelling/recharging like ICE vehicles. However, the current technology is not adequate to cater to these needs. The challenges include a lack of adequate infrastructure (Refuelling stations), Hydrogen produced from fossil fuels which nullifies the effort to move to greener mobility and would require huge investments to produce green hydrogen through renewable resources. Also, the quantity of hydrogen currently produced is less as it is currently being produced only for industrial purposes and would require additional funds to increase the production to cater to demands from the automobile sector.

Q.8 Configuration and control of Switched Reluctance Motor

The SRM has a simple, rugged, and low-cost structure. It has no PM or winding on the rotor. This structure not only reduces the cost of the SRM but also offers high-speed operation capability for this motor. Unlike the induction and PM machines, the SRM is capable of high-speed operation without the concern of mechanical failures that result from the high-level centrifugal force.
In addition, the inverter of the SRM drive has a reliable topology. The stator windings are connected in series with the upper and lower switches of the inverter. This topology can prevent the shoot-through fault that exists in the induction and permanent motor drive inverter.



The SRM has salient poles on both the stator and rotor. It has concentrated windings on the stator and no winding or PM on the rotor. There are several configurations for SRM depending on the number and size of the rotor and stator poles.
Due to its double saliency structure, the reluctance of the flux path for a phase winding varies with the rotor position. Also, since the SRM is commonly designed for high degree saturation at high phase current, the reluctance of the flux path also varies with the phase current. As a result, the stator flux linkage, phase bulk inductance, and phase incremental inductance all vary with the rotor position and phase current.

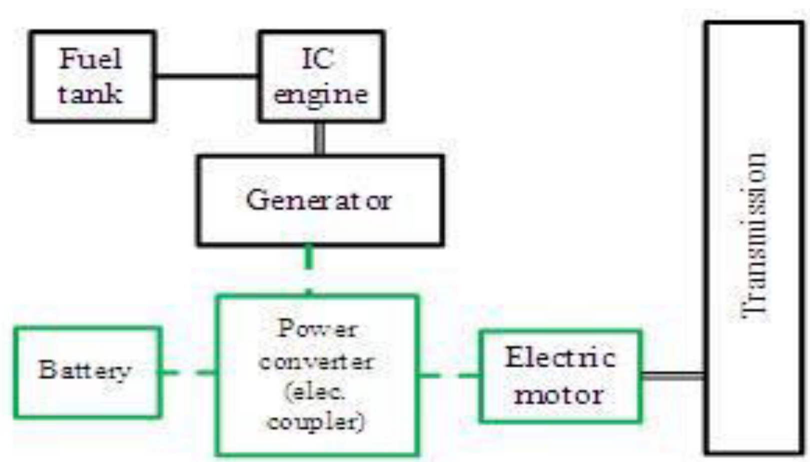


Torque in SRM is produced by the tendency of the rotor to get into alignment with the excited stator poles. The analytical expression of the torque can be derived using the derivative of the co-energy against the rotor position at a given current.

Q.9 The hybrid drive train concept can be implemented by different configurations as follows:

- Series configuration
- Parallel configuration
- Series-parallel configuration
- Complex configuration

Series Hybrid Electric Drive Train

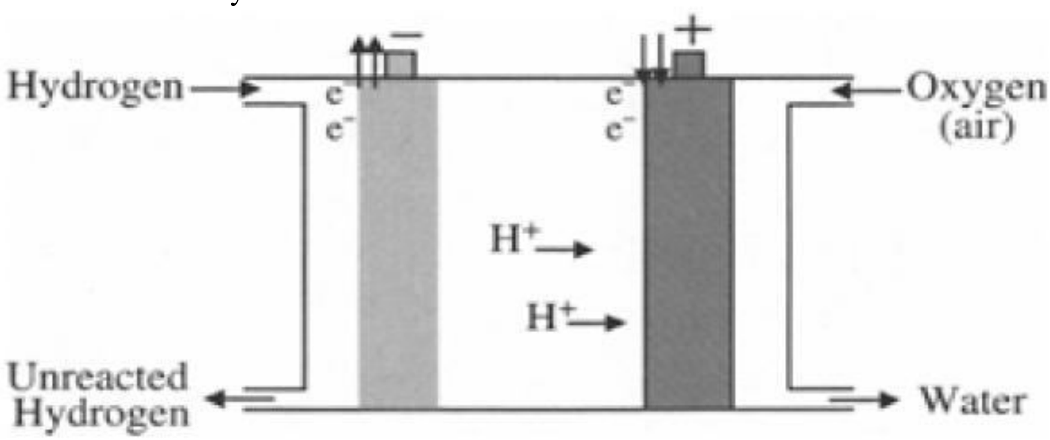


In case of series hybrid system, the mechanical output is first converted into electricity using a generator. The converted electricity either charges the battery or can bypass the battery to propel the wheels via the motor and mechanical transmission. Conceptually, it is an ICE assisted Electric Vehicle (EV).

Q.10 (a)

There are a number of requirements for energy storage applied in an automotive application, such as specific energy, specific power, efficiency, maintenance management, cost, environmental adaptation and friendliness, and safety. For allocation on an EV, specific energy is the first consideration since it limits the vehicle range. On the other hand, for HEV applications specific energy becomes less important and specific power is the first consideration, because all the energy is from the energy source (engine or fuel cell) and sufficient power is needed to ensure vehicle performance, particularly during acceleration, hill climbing, and regenerative braking.

(b) A fuel cell is an electrochemical device that produces electricity by means of a chemical reaction, much like a battery.



The major difference between batteries and fuel cells is that the latter can produce electricity as long as fuel is supplied. Batteries produce electricity from stored chemical energy and, hence, require frequent recharging.

The basic structure of a fuel cell consists of an anode and a cathode, similar to a battery. The fuel supplied to the cell is hydrogen and oxygen. The concept of fuel cell is the opposite of electrolysis of water, where hydrogen and oxygen are combined to form electricity and water.

The chemical reaction taking place in a fuel cell is as follows:

$$\text{Anode: } H_2 \rightarrow 2H^+ + 2e^-$$

$$\text{Cathode: } 2e^- + 2\mathrm{H}^+ + \frac{1}{2}(\mathrm{O}_2) \rightarrow \mathrm{H_2O}$$

$$\text{Cell: } \mathrm{H}_2 + \frac{1}{2}\mathrm{O}_2 \rightarrow \mathrm{H_2O}$$

Q.11

With the development of energy storage technology, the main energy storage technology can be divided into the following categories. According to the classification of technology, it is divided into four categories: Physical storage (such as pumped storage, compressed air energy storage, flywheel energy storage, etc.), chemical energy storage (such as sodium sulfur batteries, flow batteries, lead-acid batteries, nickel-cadmium batteries, supercapacitor, etc.), Energy Storage (superconducting magnetic energy storage, etc.) and the phase change energy storage (ice storage, etc.).

Large-capacity, high-density, high-efficiency, low-cost and long service life of the storage energy technology is undoubtedly the most ideal, but so far there is not a kind of energy storage technology can satisfy these conditions simultaneously. Therefore, it is necessary for all storage technology choice suitable application field, namely the right selection of energy storage. Under normal circumstances, when the selection of energy storage system, the economy, security and stability, and the capacity of the energy storage system should be considered. It can be predicted that the future power grid will be presented with a situation of energy storage, and the largest proportion of clean energy, fossil energy is used as auxiliary. The rational allocation of the load control system, and complemented by high-performance power electronic devices, flexible transmission, distributed power supply, demand response, efficient control of the new clean energy development model systems and other advanced technologies.

CODE: GR20A3015	GR 20	SET - 4

III B.Tech I Semester Regular Examinations, December/January 2022/23

ELECTRICAL AND HYBRID VEHICLES

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

Instructions:

1. Question paper comprises of **Part-A** and **Part-B**
2. **Part-A** (for 20 marks) must be answered at one place in the answer book.
3. **Part-B** (for 50 marks) consists of **five questions with internal choice,** answer all questions.
4. **CO** means Course Outcomes. **BL** means Blooms Taxonomy Levels.

PART – A

(Answer ALL questions. All questions carry equal marks)

10 * 2 = 20 Marks

1. a.	How are EVs better than ICE vehicles	**[2]**	CO1	BL1
b.	Mention few hybrid electric vehicles available in the Indian market.	**[2]**	CO1	BL2
c.	Mention the merits of regenerative braking	**[2]**	CO2	BL1
d.	Define Aerodynamic drag.	**[2]**	CO2	BL2
e.	Differentiate between battery and fuel cell based EVs.	**[2]**	CO3	BL1
f.	Mention various smart hybrid topologies.	**[2]**	CO3	BL2
g.	Write the principle of PMBLDC motor.	**[2]**	CO4	BL1
h.	How can we increase the range of EVs?	**[2]**	CO4	BL2
i.	What is the advantage of fuel cell in EVs?	**[2]**	CO5	BL1
j.	Mention the automaker working in fuel cell based EVs.	**[2]**	CO5	BL2

PART – B

(Answer ALL questions. All questions carry equal marks)

5 * 10 = 50 Marks

2.	**(a)** Enumerate the carbon emissions of IC engines and the associated environmental effects **(b)** Demonstrate the role of electrifying the transportation system to reduce global warming.	**[10]**	CO1	BL2
	OR			
3.	**(a)** Give a detailed comparative analysis between pure electric and hybrid electric vehicles. **(b)** Elaborate the recent developments in EV and EHV.	**[10]**	CO1	BL3

4.	Draw a general lay out of a EV and discuss the transmission characteristics.	**[10]**	CO2	BL2
	OR			
5.	Explain rolling resistance and aerodynamic drag in vehicles.	**[10]**	CO2	BL2
6.	Explain in detail the power flow control in hybrid drive-train topologies	**[10]**	CO3	BL2
	OR			
7.	Enumerate the battery and fuel cell vehicles. Write the future possibilities.	**[10]**	CO3	BL3
8.	Discuss the configuration and control of Switched reluctance motor	**[10]**	CO4	BL3
	OR			
9.	Enlist the different architectures of hybrid electric drive train and explain the series hybrid electric drive train	**[10]**	CO4	BL3
10.	**(a)** Enumerate the Energy Storage Requirements in Hybrid and Electric Vehicles. **(b)** Describe the Fuel Cell based energy storage and its analysis.	**[10]**	CO5	BL3
	OR			
11.	Enumerate the selection of the energy storage technology, Communications and supporting subsystems.	**[10]**	CO5	BL2

*****

GR 20

ELECTRIC AND HYBRID VEHICLES
ASSIGNMENT

Unit-I	
1.	compare the difference of energy sources used in EVs and EHVs .?
2.	Write the Role of electrifying the transportation system to reduce gobal warming
Unit-II	
3.	Explain about Rolling Resistance and Aerodynamic Drag?
4.	Draw the layout of a ev and discuss the characteristics.
Unit-III	
5.	Illustrate the power flow control in hybrid electric drive train
6.	Explain the battery and fuel cell?
Unit-IV	
7.	Draw and explain the block diagram of switched reluctance motor drive system
8.	Explain the working Principle of PM Brushless DC moto
Unit-V	
9.	Distinguish between Super capacitor based energy storage and Fuel cell based energy storage
10.	Briefly explain about different energy storage systems used in EVs?

*****

ELECTRIC AND HYBRID VEHICLES

ASSIGNMENT

Unit-I

1. compare the difference of energy sources used in EVs and EHVs .?

Specifications	**Hybrid Vehicles**	**Electric Vehicles**
Power/Fuel Source	Electricity and Fossil Fuel (Petrol and Diesel)	Electricity Through Battery Pack (DC)
Engine	Internal Combustion Engine (ICE) and Electric Motor(s)	Electric Motor(s)
Fuel Efficiency	Combination of ICE and Battery Range	Depends on Battery Range
Emission Levels	Higher Compared to Electric Cars	Lower Compared to ICE and Hybrid Cars
Price Range	Similar to Conventional ICE Cars	High
Charging	Not Needed	Needed

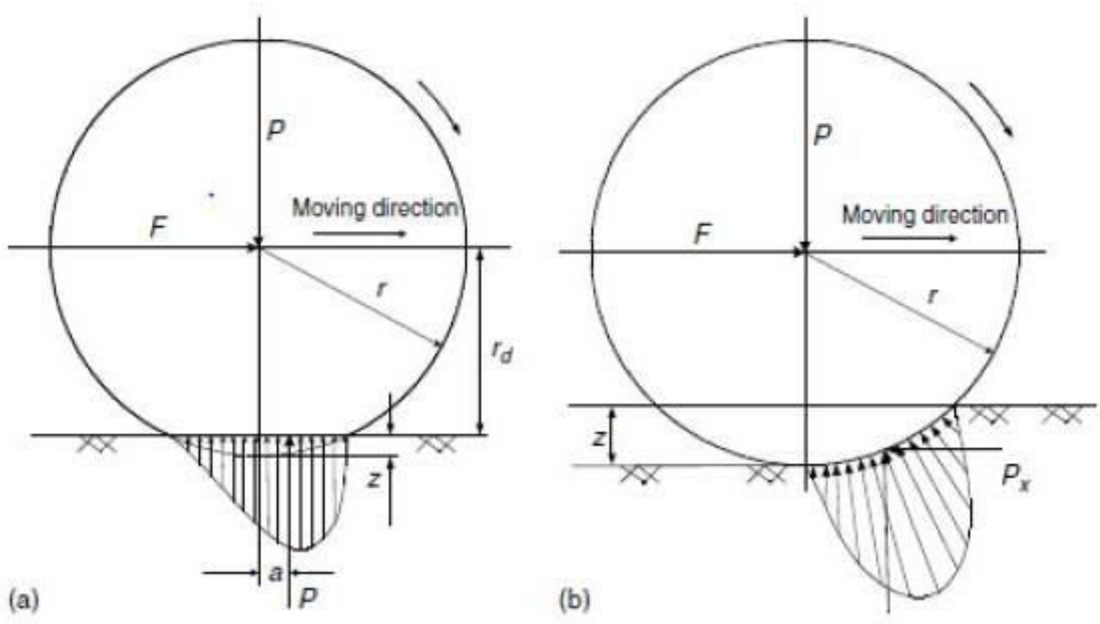
2. Write the Role of electrifying the transportation system to reduce gobal wariming.

Electrification is widely considered an attractive solution for reducing the oil dependency and environmental impact of road transportation. Many countries have been establishing increasingly stringent and ambitious targets in support of transport electrification. While transport electrification alone would not contribute to climate change mitigation, it is interesting to note that switching to electrified road transport under the sustainable shared socioeconomic pathways permitted an optimistic outlook for a low-carbon transition, even in the absence of a decarbonized power sector. Another interesting finding was that the stringent penetration of electric vehicles can reduce the mitigation cost generated by the 2 °C climate stabilization target, implying a positive impact for transport policies on the economic system. With technological innovations such as electrified road transport, climate change mitigation does not have to occur at the expense of economic growth. Because a transport electrification policy closely interacts with energy and economic systems, transport planners, economists, and energy policymakers need to work together to propose policy schemes that consider a cross-sectoral balance for a green sustainable future. Transportation is a growing source of the global greenhouse gas emissions that are driving climate change, accounting for 23% of energy-related carbon dioxide emissions worldwide in 2019 and 29% of all greenhouse gas emissions in the U.S.

Unit-II

3. Expalin about Rolling Resistance and Aerodynamic Drag?

The rolling resistance of tires on hard surfaces is primarily caused by hysteresis in the tire materials.

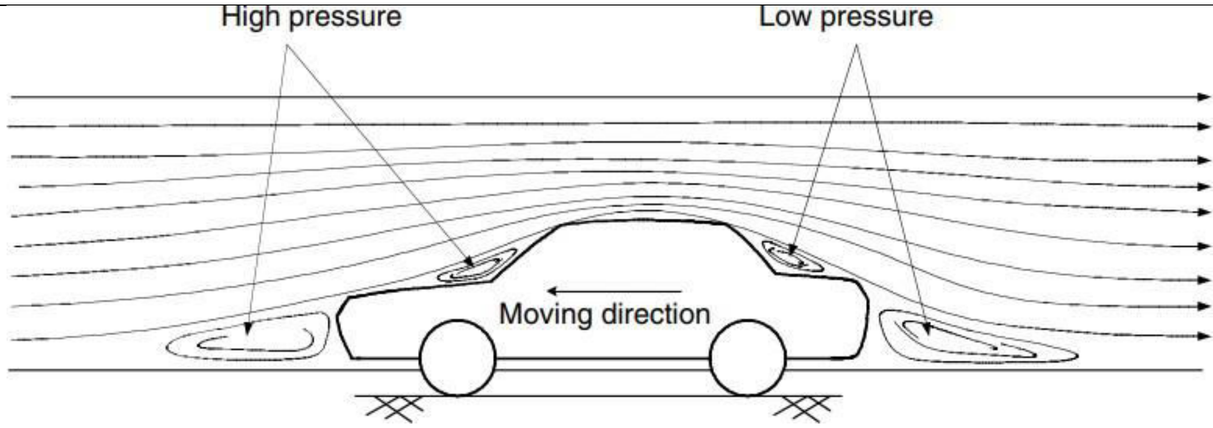


This is due to the deflection of the carcass while the tire is rolling. The hysteresis causes an asymmetric distribution of ground reaction forces. The pressure in the leading half of the contact area is larger than that in the trailing half, as shown in Figure (a). This phenomenon results in theground reaction force shifting forward. This forwardly shifted ground reaction force, with the normal load acting on the wheel center, Creates a moment that opposes the rolling of the wheel. On soft surfaces, the rolling resistance is primarily caused by deformation of the ground surface as shown in Figure (b). The ground reaction force almost completely Shifts to the leading half.

Aerodynamic Drag

A vehicle traveling at a particular speed in air encounters a force resisting its motion. This forceis known as aerodynamic drag. The main causes of aerodynamic drag are:

- shape drag
- skin friction



Shape drag

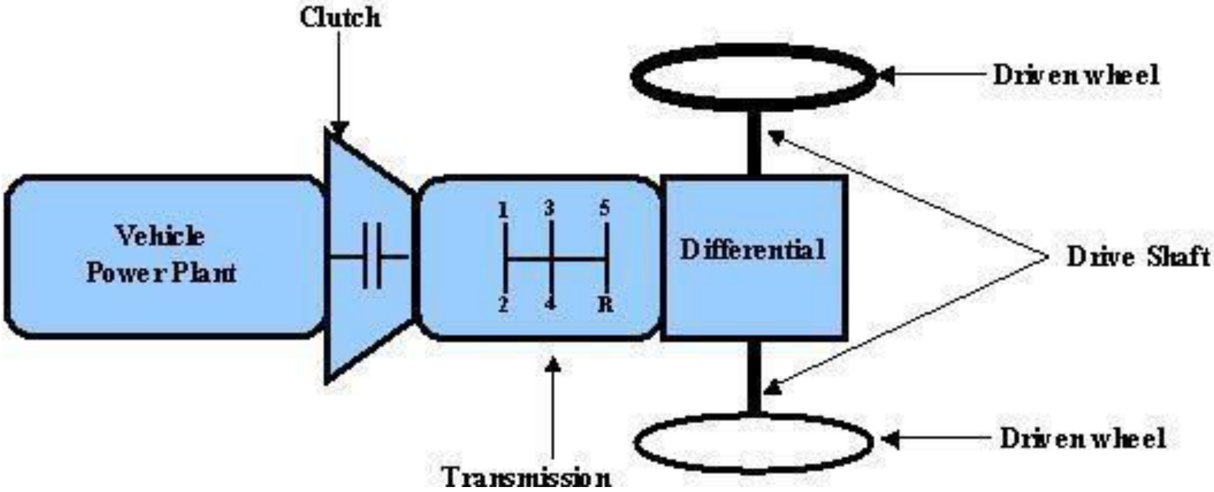
The shape drag is due to the shape of the vehicle. The forward motion of the vehicle pushes the air in front of it. However, the air cannot instantaneously move out of the way and its pressure is thus increased. This results in high air pressure in the front of the vehicle. The air behind the vehicle cannot instantaneously fill the space left by the forward motion of the vehicle. This creates a zone of low air pressure. Hence, the motion of the vehicle creates two zones of pressure. The high pressure zone in the front of the vehicle opposes its movement by pushing.On the other hand, the low pressure zone developed at the rear of the vehicle opposes its motion by pulling it backwards.

Skin friction

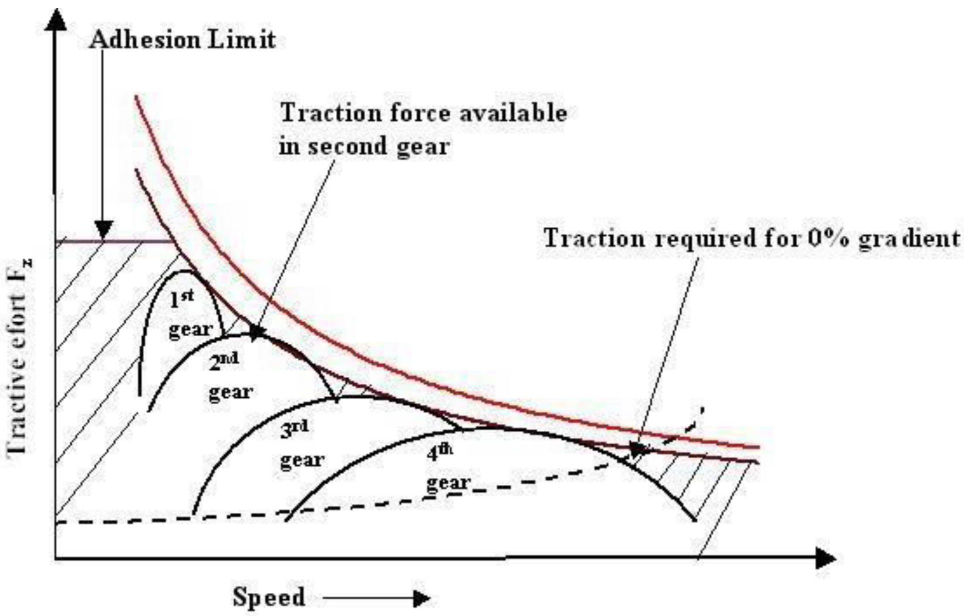
The air close to the skin of the vehicle moves almost at the speed of the vehicle while the air away from the vehicle remains still. Between these two layers (the air layer moving at the vehicle speed and the static layer) the molecules move at a wide range of speeds. The difference in speed between two air molecules produces friction. This friction results in the second component of aerodynamic drag and it is known as skin friction.

4. **Draw the layout of a ev and discuss the characteristics.**

General lay out of a EV: It consists of a power plant, a clutch in a manual transmission or a torque converter in automatic transmission, a gear box, final drive, differential shaft and driven wheels



Transmission characteristics:



Unit-III

5. Illustrate the power flow control in hybrid electric drive train.

Power Flow Control in Series Hybrid

- Power Flow Control in Parallel Hybrid
- Power Flow Control Series-Parallel Hybrid
- Power Flow Control Complex Hybrid Control

Power Flow Control in Series Hybrid

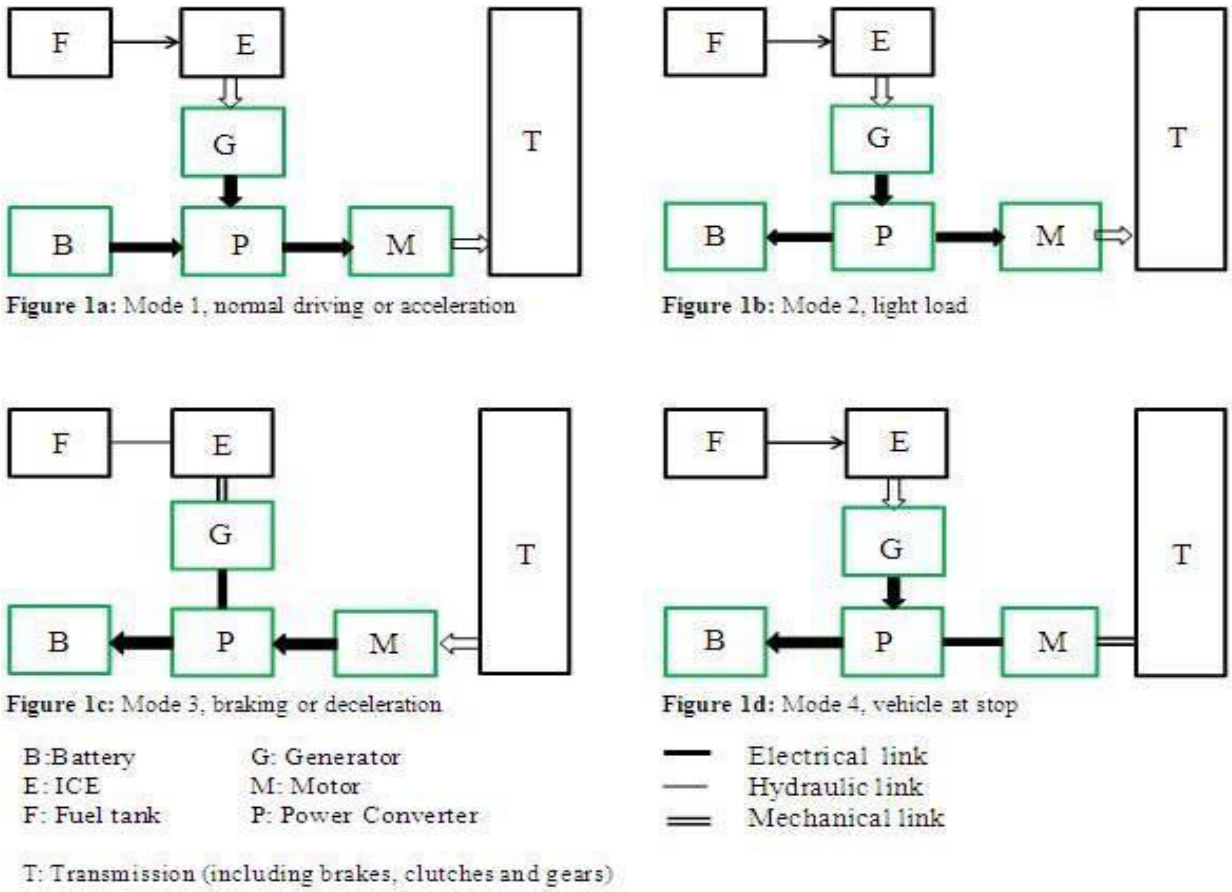


Figure 1a: Mode 1, normal driving or acceleration

Figure 1b: Mode 2, light load

Figure 1c: Mode 3, braking or deceleration

Figure 1d: Mode 4, vehicle at stop

6. **. Explain the battery and fuel cell?**

A fuel cell is an electrochemical device that continuously generates electricity without the need for any intermediate energy conversion. Hydrogen fuel cells work like batteries, but they donot need any recharging as they produce electricity if there is a supply of H2 and O2 as fuels. A fuel cell is made up of a negative electrode (anode), and a positive electrode (cathode) sandwiched around an electrolyte. Hydrogen is fed to the anode, and the air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, the electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and electrons to produce water and heat.

The expectation from the market is to have safe, green, sustainable, and reliable automobiles with minimal or no wait time for refuelling/recharging like ICE vehicles. However, the current technology is not adequate to cater to these needs. The challenges include a lack of adequate infrastructure (Refuelling stations), Hydrogen produced from fossil fuels which

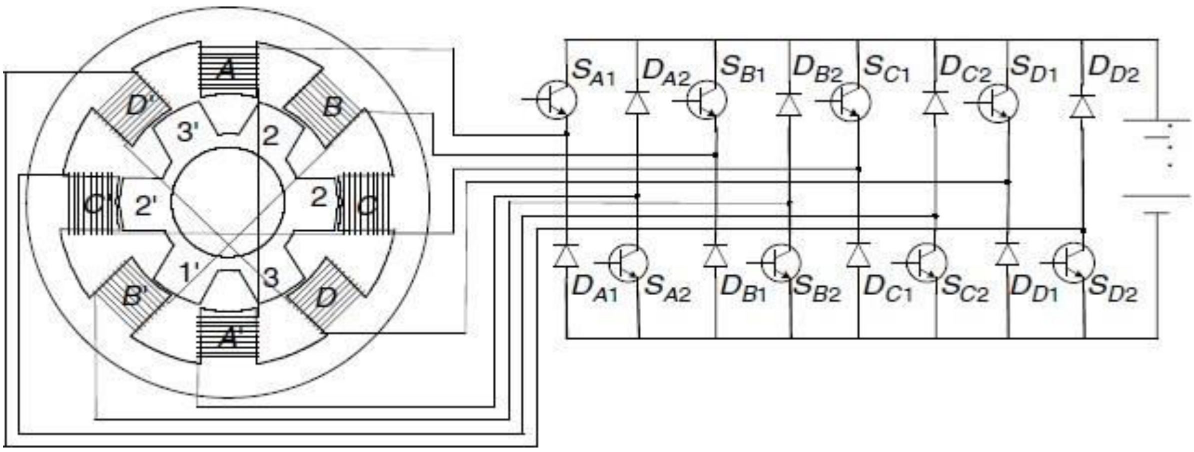
nullifies the effort to move to greener mobility and would require huge investments to produce green hydrogen through renewable resources. Also, the quantity of hydrogen currently produced is less as it is currently being produced only for industrial purposes and would require additional funds to increase the production to cater to demands from the automobile sector.

Unit-IV

7. Draw and explain the block diagram of switched reluctance motor drive system

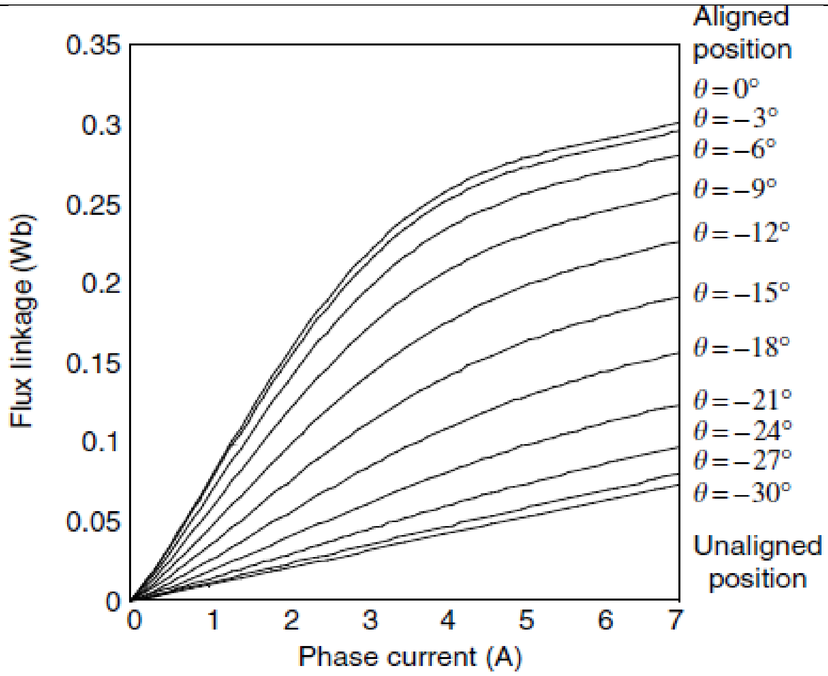
The SRM has a simple, rugged, and low-cost structure. It has no PM or winding on the rotor. This structure not only reduces the cost of the SRM but also offers high-speed operation capability for this motor. Unlike the induction and PM machines, the SRM is capable of high- speed operation without the concern of mechanical failures that result from the high-levelcentrifugal force.

In addition, the inverter of the SRM drive has a reliable topology. The stator windings are connected in series with the upper and lower switches of the inverter. This topology can prevent the shoot-through fault that exists in the induction and permanent motor drive inverter.



The SRM has salient poles on both the stator and rotor. It has concentrated windings on the stator and no winding or PM on the rotor. There are several configurations for SRM depending on the number and size of the rotor and stator poles.

Due to its double saliency structure, the reluctance of the flux path for a phase winding varies with the rotor position. Also, since the SRM is commonly designed for high degree saturation at high phase current, the reluctance of the flux path also varies with the phase current. As a result, the stator flux linkage, phase bulk inductance, and phase incremental inductance all vary with therotor position and phase current.



Torque in SRM is produced by the tendency of the rotor to get into alignment with the excited stator poles. The analytical expression of the torque can be derived using the derivative of the co-energy against the rotor position at a given current.

8. **Explain the working Principle of PM Brushless DC motor**

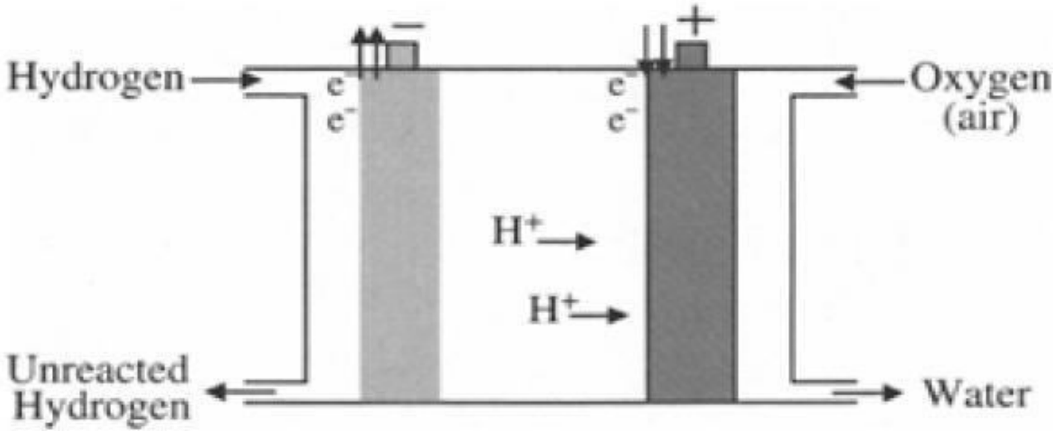
BLDC motor works on the principle similar to that of a Brushed DC motor. The Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences aforce. As a consequence of reaction force, the magnet will experience an equal and opposite force.In the BLDC motor, the current carrying conductor is stationary and the permanent magnet is moving. When the stator coils get a supply from source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes togenerate an AC voltage waveform with trapezoidal shape. Due to the force of interaction betweenelectromagnet stator and permanent magnet rotor, the rotor continues to rotate.

Unit-V

9. **Distinguish between Super capacitor based energy storage and Fuel cell based energy storage**

There are a number of requirements for energy storage applied in an automotive application, such as specific energy, specific power, efficiency, maintenance management, cost, environmental adaptation and friendliness, and safety. For allocation on an EV, specific energy is the first consideration since it limits the vehicle range. On the other hand, for HEV applications specific energy becomes less important and specific power is the first consideration, because all the energy is from the energy source (engine or fuel cell) and sufficient power is needed toensure vehicle performance, particularly during acceleration, hill climbing, and regenerative braking.

(b) A fuel cell is an electrochemical device that produces electricity by means of a chemical reaction, much like a battery.



The major difference between batteries and fuel cells is that the latter can produce electricity as long as fuel is supplied. Batteries produce electricity from stored chemical energy and, hence, require frequent recharging.

The basic structure of a fuel cell consists of an anode and a cathode, similar to a battery. The fuel supplied to the cell is hydrogen and oxygen. The concept of fuel cell is the opposite of electrolysis of water, where hydrogen and oxygen are combined to form electricity and water.

The chemical reaction taking place in a fuel cell is as follows:

$$\text{Anode: } H_2 \rightarrow 2H^+ + 2e^-$$

$$\text{Cathode: } 2e^- + 2H^+ + \frac{1}{2}(O_2) \rightarrow H_2O$$

$$\text{Cell: } H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

10. Briefly explain about different energy storage systems used in EVs?

With the development of energy storage technology, the main energy storage technology

can be divided into the following categories. According to the classification of technology, it is divided into four categories: Physical storage (such as pumped storage, compressed air energy storage, flywheel energy storage, etc.), chemical energy storage (such as sodium sulfur batteries, flow batteries, lead-acid batteries, nickel-cadmium batteries, supercapacitor, etc.), Energy Storage (superconducting magnetic energy storage, etc.) and the phase change energy storage (ice storage, etc.).Large-capacity, high-density, high-efficiency, low-cost and long service life of the storage energy technology is undoubtedly the most ideal, but so far there is not a kind of

	energy storage technology can satisfy these conditions simultaneously. Therefore, it is necessary for all storage technology choice suitable application field, namely the right selection of energy storage.Under normal circumstances, when the selection of energy storage system, the economy, securityand stability, and the capacity of the energy storage system should be considered. It can be predicted that the future power grid will be presented with a situation of energy storage, and the largest proportion of clean energy, fossil energy is used as auxiliary. The rational allocation ofthe load control system, and complemented by high-performance power electronic devices, flexible transmission, distributed power supply, demand response, efficient control of the new clean energy development model systems and other advanced technologies.

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CODE: GR20D3015 | GR 20 | SET - 1

III B.Tech I Semester Regular Examinations, December 2022
ELECTRIC AND HYBRID VEHICLES
(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

< **Note:** Type the questions in the given format only, Times New Roman font , size 12 >

Instructions:

1. Question paper comprises of **Part-A** and **Part-B**
2. **Part-A** (for 20 marks) must be answered at one place in the answer book.
3. **Part-B** (for 50 marks) consists of **five questions with internal choice,** answer all questions.

PART – A

(Answer ALL questions. All questions carry equal marks)

10 * 2 = 20 Marks

1. a.	Why electric vehicles are called Zero Emission vehicles?	**[2]**	**CO1**	**BL2**
b.	What is global worming?	**[2]**	**CO1**	**BL1**
c.	Define Aerodynamic drag.	**[2]**	**CO2**	**BL1**
d.	What is grading resistance?	**[2]**	**CO2**	**BL2**
e.	State four different types of rotors used in PM Machines.	**[2]**	**CO3**	**BL1**
f.	Compare Series and Parallel Hybrid Drive train topologies?	**[2]**	**CO3**	**BL2**
g.	Compare between PMSM and BLDC motors.	**[2]**	**CO4**	**BL2**
h.	State the advantages and disadvantages of SRM?	**[2]**	**CO4**	**BL1**
i.	What are the advantages of Super Capacitor based energy storage?	**[2]**	**CO5**	**BL2**
j.	What is Hybridization of energy storage devices?	**[2]**	**CO5**	**BL2**

PART – B

(Answer ALL questions. All questions carry equal marks)

5 * 10 = 50 Marks

2.	What are the major air pollution problems? What are the impacts on environment?	**[10]**	**CO1**	**BL2**
	OR			
3.	Explain the Historical development of Hybrid Electric Vehicles.	**[10]**	**CO1**	**BL2**
4.	Derive the expression for dynamic equation of electric vehicle?	**[10]**	**CO2**	**BL3**
	OR			
5.	Compute Forces due to drag, rolling resistance and gradient for the following vehicles assuming ρ = 1.2 (kg/m3) and θ = 8°. For the three vehicles given in the table 1, find Aerodynamic drag at velocity v1 and v2; also find rolling resistance	**[10]**	**CO2**	**BL4**

	at two velocities.			

Vehicle	GVW (kg)	C_D	Area (m2)	μ	V1 (km/h)	V2 (km/h)	Tyre Radius (m)
3-wheeler	600	0.45	1.6	0.015	30	80	0.2
4-wheeler	1500	0.3	**2.5**	0.015	30	80	0.3

6.	With the help of block diagrams, discuss in detail the different configurations of HEV drive train.	**[10]**	**CO3**	**BL2**
	OR			
7.	What is power flow control? Explain various operating modes of ICE dominated system.	**[10]**	**CO3**	**BL3**
8.	Draw the Speed-Torque characteristics of DC motor drives. Explain the four-quadrant chopper control of dc motor drives.	**[10]**	**CO4**	**BL3**
	OR			
9.	What is Electric Propulsion System? Explain the Configuration of Electric Vehicle with block diagrams.	**[10]**	**CO4**	**BL2**
10.	What are factors affecting the performance of batteries used in EVs? Explain Each factor in detail.	**[10]**	**CO5**	**BL2**
	OR			
11.	Explain fuel cell and flywheel as energy source elements in electric and hybrid electric vehicle.	**[10]**	**CO5**	**BL2**

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Gokaraju Rangaraju Institute of Engineering & Technology

III B.Tech I Sem (EEE) Result Analysis

Academic Year: 2022-23 Total No. of Students Registered: 65

Course	Total No. of Students appeared	Total No. of Students Passed	No. of Students Failed	Count of Students with Grade Point					
				GP (10)	GP (9)	GP (8)	GP (7)	GP (6)	GP (5)
PSA	65	50	15	00	00	12	10	14	14
PE	65	50	15	00	02	06	12	19	11
MPMC	65	47	18	00	01	09	08	12	17
EHV	65	60	05	00	05	14	20	15	06
PS-I Lab	65	63	02	10	19	07	03	13	11
PE Lab	65	64	01	22	11	15	10	06	00
MPMC Lab	65	64	01	07	11	21	16	08	01
Cloud Computing (MOOCs)									

Arrears Position – III year / I Semester

No.of students	All Pass	One Arrear	Two Arrears	Three Arrears	More than three arrears	Over all % of pass
65	38	11	09	03	04	58.46 %

Performance overall Class Three Toppers

ROLL NO.	NAME	SGPA
20241A0235	RAMINENI VYSHNAVI	8.53
21245A0201 21245A0206	JAKINAPALLI CHANDHANA VEMULA SATYANARAYANA	8.43
20241A0248 20241A0257 21245A0205	UMMIDISETTY NIHARIKA SUSANI NEHA SANATHANA JAHNAVI	8.28

Class coordinator **HOD,EEE**

III B.Tech - I Sem (EEE)

SECTION	Courses	PSA	PE	MPMC	EHV	PS Lab	PE Lab	MPMC Lab	Cloud Computing (moocs)
	Course codes	GR20A3012	GR20A3012	GR20A3012	GR20A3012	GR20A3012	GR20A3012	GR20A3012	GR20A3012
A	TOTAL	65	65	65	65	65	65	65	
	PASS	50	50	47	60	63	64	64	
	PASS(%)	76.92%	76.92%	72.30%	92.30%	96.92%	98.46%	98.46%	
	FACULTY NAME	Dr J Sridevi	Dr Pakkiraiah B	Dr D Raveendra	Dr D G Padhan	Dr J Sridevi / V Usha Rani/ U Vijaya Lakshmi	Dr Pakkiraiah B/ G Sandhya Rani	Dr P Srividya Devi/ M N Sandhya Rani	P Ravikanth
	FACULTY ID	516	1593	1604	1283	516/1045/692	1593/888	931/882	1178

Dr Phaneendra Babu B

Class coordinator **HOD,EEE**

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGGY
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STUDENT FEEDBACK

Faculty : **DOLA. GOBINDA PADHAN**

Subject : Electrical And Hybrid Vehicles (B.Tech, III/IV B.Tech I Semester, EEE Sec-A)

Academic Year : 2022 - 2023

Phase : Phase-3

Sl.No	Question	Excellent	Good	Average	Poor	Q.Wise Total	Q.Wise %
1	Preparation and delivery of the lessons by the teacher	16	38	2	2	184	79.00
2	Subject Knowledge	17	38	1	2	186	80.00
3	Clarity in Communication	17	35	4	2	183	79.00
4	Using Modern Teaching Aids of ICT	16	36	2	4	180	78.00
5	Creating interest on the course in the class	19	36	1	2	188	81.00
6	Maintaining discipline in the class	16	36	4	2	182	78.00
7	Encouraging and clearing doubts in the class	17	36	2	3	183	79.00
8	Punctuality	17	37	2	2	185	80.00
9	Accessibility of the teacher	15	38	3	2	182	78.00
10	Overall grading of the teacher	17	38	0	3	185	80.00
	Total	167	368	21	24		
	Total Points	**668**	**1104**	**42**	**24**	**1838**	**79.00**

No.Of Students Posted	**58**
Total Percentage Awarded to The Faculty	**79.00**
Grade of Faculty	**Good**

***Excellent (4) : >=90 % *Good (3) : >=75 & <90%**
***Average (2) : >=60 & <75 % *Poor (1) : Below 60 %**

Formula: Total Obtained Points/(Max Points(i.Excellent-4) * No.Of.Students * NoOfQuestions)