Introduction and Classification of IC Engines

A Design Thinking Approach for First-Year Engineering Students

Department of Mechanical Engineering | B.E. Semester I

Academic Year 2025–26

Design Thinking Framework

EMPATHIZE

Understand student background & learning gaps

DEFINE

Set clear learning objectives & outcomes

IDEATE

Explore IC engine concepts creatively

PROTOTYPE

Apply knowledge via diagrams & problems

TEST

Assess understanding & reflect

Empathize: Understanding Student Needs

Who Are Our Learners?

- First-year BE students (17–19 years)
- Diverse pre-university backgrounds (PCM/PCB)
- Limited hands-on exposure to engines
- Strong curiosity about automobiles & machines
- Visual & experiential learners

Key Learning Gaps

- Thermodynamic cycles (theory vs. practice)
- Differentiating SI and CI engines clearly
- Understanding stroke mechanics visually
- Connecting engine types to real applications
- Emissions, efficiency, and modern relevance

Define: Learning Objectives

01

Define & Describe

Explain what an IC engine is and its fundamental working principle

02

Classify Systematically

Categorize IC engines by cycle, fuel, strokes, cooling, and arrangement

03

Compare & Contrast

Distinguish between SI vs CI, 2-stroke vs 4-stroke engines

04

Identify Components

Recognize major engine parts and their functions

05

Analyze Applications

Map engine types to real-world uses in automotive, marine, and power

06

Evaluate Future Trends

Assess challenges, emissions norms, and emerging engine technologies

Presentation Overview

What Is an Internal Combustion Engine?

Definition

An Internal Combustion (IC) engine is a heat engine in which combustion of fuel occurs inside the engine cylinder, converting chemical energy of fuel into mechanical work through expansion of high-temperature, high-pressure gases.

Energy Conversion

Chemical → Thermal → Mechanical energy transformation through combustion

Internal Combustion

Fuel burns inside the working cylinder, unlike external combustion (steam) engines

Reciprocating Motion

Piston moves linearly; crankshaft converts to rotary motion for output

Historical Evolution of IC Engines

1860

Lenoir Engine

First commercial IC engine (gas-fueled, no compression)

1876

Otto Cycle

Nikolaus Otto — first practical 4-stroke spark-ignition engine

1893

Diesel Engine

Rudolf Diesel — compression-ignition engine patented

1908

Ford Model T

Mass production begins — IC engines reach the public

1970s

Emission Controls

Catalytic converters & emission norms introduced

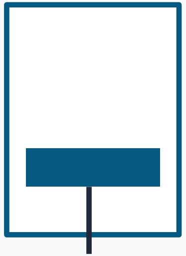
2000s+

Modern Era

GDI, turbocharging, hybrid integration, Euro/BS norms

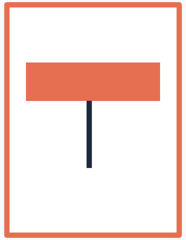
Working Principle of an IC Engine

STROKE 1
INTAKE



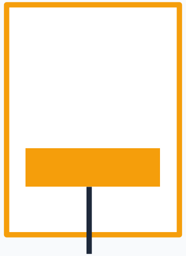
Piston moves down
Inlet valve opens
Air-fuel mixture enters

STROKE 2
COMPRESSION



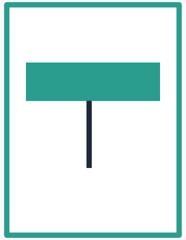
Piston moves up
Both valves closed
Mixture compressed

STROKE 3
POWER



Spark ignites mixture
Hot gases expand
Piston pushed down

STROKE 4
EXHAUST



Piston moves up
Exhaust valve opens
Burnt gases expelled

The 4-stroke cycle completes in two crankshaft revolutions (720°). Only the Power stroke produces work.

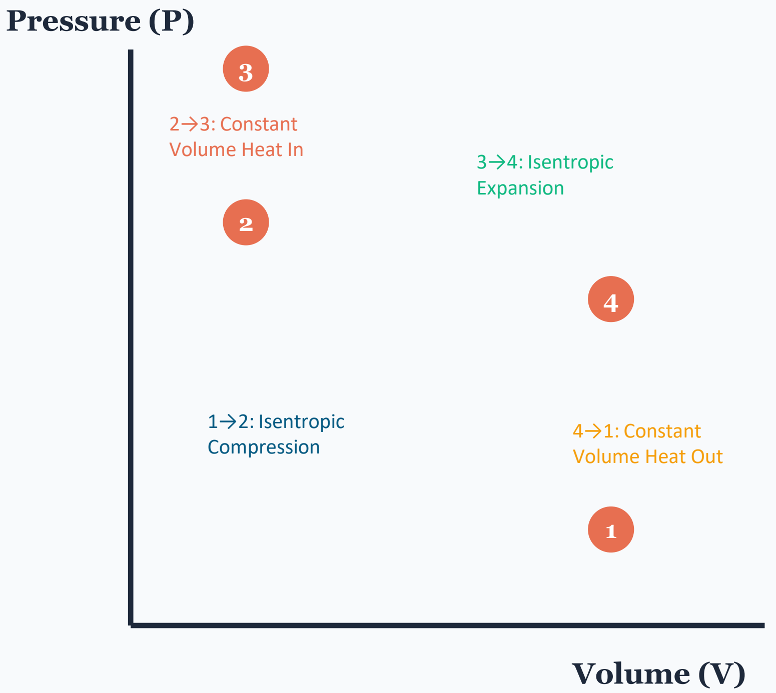
Classification of IC Engines — Overview

Thermodynamic Cycle	Otto (SI) / Diesel (CI) / Dual Cycle
Number of Strokes	2-Stroke / 4-Stroke
Fuel Type	Petrol / Diesel / Gas / Dual-fuel
Cooling System	Air-Cooled / Water-Cooled
Cylinder Arrangement	Inline / V-type / Flat / Radial
Ignition Method	Spark Ignition (SI) / Compression Ignition (CI)

SI Engine vs CI Engine — Detailed Comparison

Parameter	SI Engine (Spark Ignition)	CI Engine (Compression Ignition)
Thermodynamic Cycle	Otto Cycle (constant volume)	Diesel Cycle (constant pressure)
Fuel Used	Petrol (Gasoline)	Diesel
Ignition Method	Spark plug	Self-ignition (compression)
Compression Ratio	6:1 to 12:1	14:1 to 24:1
Thermal Efficiency	25–35%	35–45%
Power-to-Weight Ratio	Higher	Lower
Speed Range	Higher RPM (up to 8000+)	Lower RPM (up to 4500)
Cost	Lower initial cost	Higher initial cost
Fuel Injection	Carburetor / Port / GDI	Fuel injector (direct)
Emissions	More CO and HC	More NOx and PM
Applications	Cars, motorcycles, small engines	Trucks, buses, ships, generators

Otto Cycle — P-V Diagram (SI Engine)



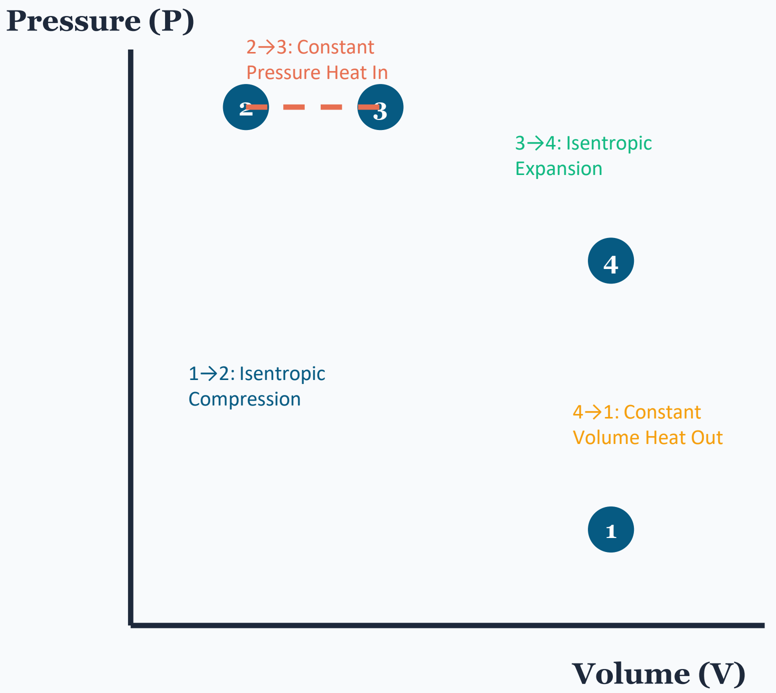
Otto Cycle Processes

- 1→2: Isentropic compression of air-fuel mixture (work input)
- 2→3: Constant volume heat addition (spark ignition, pressure rises rapidly)
- 3→4: Isentropic expansion (power stroke, work output)
- 4→1: Constant volume heat rejection (exhaust blowdown)

Thermal Efficiency:

$\eta = 1 - (1 / r^{(\gamma-1)})$
where r = compression ratio, γ = ratio of specific heats

Diesel Cycle — P-V Diagram (CI Engine)



Diesel Cycle Processes

- 1→2: Isentropic compression of air only (higher ratio than Otto)
- 2→3: Constant pressure heat addition (fuel injected at TDC, burns gradually)
- 3→4: Isentropic expansion (power stroke)
- 4→1: Constant volume heat rejection

Key Difference from Otto:

Heat addition at constant PRESSURE (not volume). Cut-off ratio $\rho = V_3/V_2$ determines efficiency.

2-Stroke vs 4-Stroke Engine Comparison

Parameter	2-Stroke Engine	4-Stroke Engine
Power Strokes per Revolution	1 (every revolution)	1 per 2 revolutions
Weight & Size	Lighter, compact	Heavier, larger
Fuel Efficiency	Lower (fuel-air mixing losses)	Higher (better scavenging)
Lubrication	Oil mixed with fuel	Separate lubrication system
Emissions	Higher (incomplete combustion)	Lower (cleaner burn)
Thermal Stress	Higher (more frequent firing)	Lower
Volumetric Efficiency	Lower (~50-70%)	Higher (~75-90%)
Typical Applications	Mopeds, chainsaws, boats	Cars, trucks, generators

Classification by Fuel Type

Petrol (Gasoline)

Most common SI engine fuel. High volatility, octane rating 87-95 RON. Powers cars, bikes, small engines.

Diesel

Used in CI engines. Higher energy density (38.6 MJ/L vs 34.2 MJ/L for petrol). Powers trucks, buses, ships.

CNG / LPG

Compressed Natural Gas & Liquefied Petroleum Gas. Cleaner combustion, lower emissions, used in city buses and autos.

Biofuels & Ethanol

Ethanol (E10, E20, E85 blends), biodiesel from plant oils. Renewable, lower net carbon emissions.

Cooling Systems & Cylinder Arrangements

Cooling Systems

Air-Cooled

- Fins on cylinder for heat dissipation
- Simpler construction, lighter weight
- Used in motorcycles, small engines, aircraft

Water-Cooled (Liquid)

- Coolant circulates through water jackets
- Radiator dissipates heat, thermostat regulates
- Used in cars, trucks, industrial engines

Cylinder Arrangements

Inline (I)

Cylinders in single row — I4, I6

V-Type

Two banks at angle — V6, V8, V12

Flat/Boxer

Horizontally opposed — Subaru, Porsche

Radial

Cylinders radially around crankshaft — aircraft

Key Engine Components

Component	Function	Material
Cylinder Block	Main body housing cylinders, coolant passages	Cast iron / Aluminum alloy
Piston	Reciprocates inside cylinder, transmits gas force	Aluminum alloy
Connecting Rod	Links piston to crankshaft, converts motion	Forged steel
Crankshaft	Converts reciprocating to rotary motion	Forged carbon steel
Camshaft	Operates inlet & exhaust valves via cam lobes	Chilled cast iron / Steel
Valves	Control gas flow — inlet admits charge, exhaust expels	Alloy steel (Stellite-coated)
Spark Plug / Injector	Initiates combustion (SI: spark; CI: fuel injection)	Ceramic insulator / Steel
Flywheel	Stores rotational energy, smoothens power delivery	Cast iron / Steel

Engine Performance Parameters

Brake Power (BP)
kW

$BP = 2\pi NT / 60$

Actual power output at crankshaft

Indicated Power (IP)
kW

$IP = Pm \times L \times A \times N \times K$

Power developed inside cylinder

Mech. Efficiency (ηm)
%

$\eta m = BP / IP$

Ratio of brake to indicated power

Thermal Efficiency (ηth)
%

$\eta th = BP / (\dot{m}f \times CV)$

Heat converted to useful work

Specific Fuel Consumption
kg/kWh

$SFC = \dot{m}f / BP$

Fuel consumed per unit power

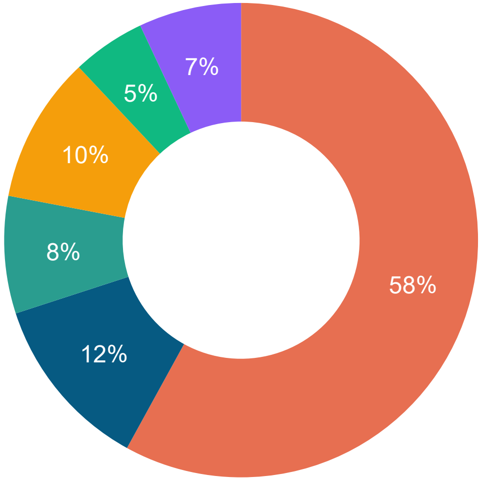
Mean Effective Pressure
bar

$MEP = W_{net} / V_{swept}$

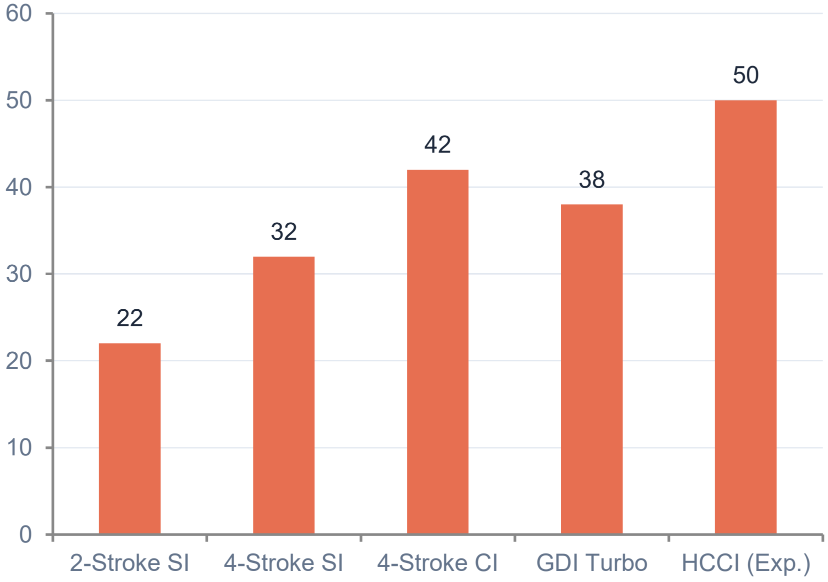
Average pressure during cycle

IC Engine Market & Application Landscape

IC Engine Applications by Sector



Thermal Efficiency Comparison



Sources: IEA World Energy Outlook, SAE International, ARAI data. HCCI = Homogeneous Charge Compression Ignition (experimental)

Real-World Applications of IC Engines

Automotive

Passenger cars, motorcycles, light trucks
Engine types: I4 SI (most common), V6/V8 for performance

Commercial Transport

Heavy trucks, buses, freight logistics
Engine types: 4-stroke CI, turbocharged direct injection

Marine

Ships, boats, submarines
Engine types: Low-speed 2-stroke CI (up to 100,000 HP)

Power Generation

Standby generators, distributed power
Engine types: CI or gas engines, 50 kW to 20 MW

Agriculture

Tractors, harvesters, pump sets
Engine types: 4-stroke CI, rugged and fuel-efficient

Aerospace (Historical)

Piston-engine aircraft, UAVs
Engine types: Flat/radial air-cooled SI engines

Case Study 1: Maruti Suzuki K-Series Engine

Engine Specifications

Type:	4-Stroke, 3-Cylinder, SI (Petrol)
Displacement:	998 cc (K10C DualJet)
Power:	49 kW (67 PS) @ 5500 RPM
Torque:	89 Nm @ 3500 RPM
Fuel System:	Dual Jet, Dual VVT
Compression Ratio:	11.5:1
Emission Norm:	BS-VI compliant
Fuel Efficiency:	~24-28 km/L (ARAI certified)

Design Thinking Analysis

- Empathize: Indian consumers need affordable, fuel-efficient city cars
- Define: Design a compact engine with best-in-class mileage under BS-VI
- Ideate: DualJet technology + Dual VVT for optimal air-fuel mixing
- Prototype: 3-cylinder layout reduces friction, cooled EGR lowers NOx
- Test: ARAI-certified 24-28 km/L; India's best-selling engine family

Key Takeaway: Engine design is driven by market needs — not just engineering.

Case Study 2: Toyota Hybrid Synergy Drive

System Architecture

1.8L Atkinson Cycle Engine → Power Split Device (CVT) → Electric Motor/Generator → Battery Pack (NiMH) → Wheels (Drive)

41%
Thermal Efficiency (Atkinson Cycle)

~23 km/L
Fuel Economy (ARAI, Prius)

50M+
Hybrids Sold Globally (Toyota)

90%
Lower NOx vs Conventional

Key Lesson: The Atkinson cycle (longer expansion than compression) achieves higher thermal efficiency than the standard Otto cycle. Toyota's Hybrid Synergy Drive demonstrates how IC engines evolve — not by being replaced, but by being intelligently integrated with electric powertrains.

Challenges: Emissions & Environmental Impact

Pollutant	Source	Health / Environmental Impact	Control Technology
CO	Incomplete combustion (SI)	Toxic, reduces O_2 in blood	Catalytic converter
HC	Unburnt fuel (SI > CI)	Smog, carcinogenic	Catalytic converter, EGR
NOx	High-temp combustion (CI > SI)	Acid rain, respiratory harm	SCR, EGR, lean NOx trap
PM / Soot	Diesel combustion	Lung disease, visibility loss	DPF (Diesel Particulate Filter)
CO_2	All combustion	Greenhouse effect, climate change	Efficiency improvement, alt fuels

Emission Norms Progression (India & EU)

- BS-III (2005) → BS-IV (2010) → BS-VI (2020): India skipped BS-V entirely
- Euro 7 (proposed 2025): Even stricter limits on real-driving emissions (RDE)
- BS-VI reduced PM limits by ~80% and NOx by ~70% compared to BS-IV for diesel vehicles

Future Trends in IC Engine Technology

Hybrid Powertrains

IC + electric motor integration. Mild hybrid (48V), full hybrid, plug-in hybrid (PHEV) configurations becoming mainstream.

Hydrogen IC Engines

Direct hydrogen combustion in modified IC engines. Near-zero CO_2. Toyota, BMW actively researching H_2 ICE.

Advanced Combustion

HCCI, RCCI, GCI technologies combine SI and CI principles for 50%+ efficiency with low emissions.

E-Fuels & Biofuels

Synthetic carbon-neutral fuels (e-gasoline, e-diesel). India's E20 ethanol blending target by 2025-26.

Variable Compression

Infiniti VC-Turbo: world's first production variable compression engine. CR adjusts 8:1 to 14:1 dynamically.

Digital Twin & AI

AI-powered engine management. Digital twins for predictive maintenance. Machine learning for combustion optimization.

Ideate: Student Design Challenge

CHALLENGE

"Design a conceptual IC engine for a rural Indian application (water pump, mini tractor, or generator). Consider fuel availability, cost, maintenance simplicity, and emission targets. Which engine type and configuration would you choose, and why?"

1

Brainstorm

List 3-5 engine configurations suitable for the chosen application

2

Evaluate

Score each option on efficiency, cost, fuel type, and emissions

3

Select & Justify

Choose the best option and write a 100-word justification

4

Sketch

Draw a labeled schematic of your chosen engine layout

Prototype & Test: Assessment Activities

Quick Quiz (5 min)

10 MCQs covering: SI vs CI differences, 4-stroke cycle order, compression ratios, fuel types, component identification. Use Kahoot or Mentimeter for live engagement.

Diagram Labeling (10 min)

Students receive an unlabeled cross-section diagram of a 4-stroke engine. Task: Label all major components (piston, crankshaft, valves, spark plug, etc.) and indicate stroke directions.

Peer Discussion (10 min)

Groups of 4 debate: 'Which is better for India's future — diesel or electric?' Students must use evidence from the lecture to support arguments.

Reflection Journal

One-paragraph reflection: 'What surprised me most about IC engines today, and how does this connect to something I see in daily life?'

Key Takeaways

1. IC engines convert chemical energy of fuel to mechanical work through controlled combustion inside the cylinder
2. Classification spans multiple criteria: cycle type (Otto/Diesel), strokes (2/4), fuel (petrol/diesel/gas), cooling (air/water), arrangement (inline/V/flat/radial)
3. SI engines (Otto cycle): spark-ignited, lower CR, higher RPM — ideal for light vehicles
4. CI engines (Diesel cycle): compression-ignited, higher CR, better efficiency — ideal for heavy-duty
5. Modern IC engines are evolving: hybrid integration, advanced combustion, alternative fuels, digital optimization
6. Design Thinking teaches us to approach engineering problems with empathy, creativity, and iterative testing

References & Recommended Resources

Textbooks & Standards

[1] Heywood, J.B. (2018). Internal Combustion Engine Fundamentals, 2nd Ed., McGraw-Hill.

[2] Ganesan, V. (2021). Internal Combustion Engines, 5th Ed., McGraw-Hill Education (India).

[3] Mathur, M.L. & Sharma, R.P. (2014). A Course in Internal Combustion Engines, Dhanpat Rai & Co.

[4] Pulkrabek, W.W. (2004). Engineering Fundamentals of the Internal Combustion Engine, 2nd Ed., Pearson.

[5] Rajput, R.K. (2020). Internal Combustion Engines, Laxmi Publications.

[6] SAE International Standards (J1349, J2723) — Engine performance testing methods.

[7] Bureau of Indian Standards: IS 14599 (Emission norms), IS 10000 (IC Engine testing).

Online Resources & Data Sources

- IEA World Energy Outlook — https://www.iea.org/reports/world-energy-outlook
- ARAI (Automotive Research Association of India) — https://www.araiindia.com
- NPTEL IC Engines Course — https://nptel.ac.in (free video lectures)

Appendix A: Detailed Diagram Descriptions

Fig. 1:	**4-Stroke Cycle Schematic**	Four-panel diagram showing piston position, valve states, and gas flow for each stroke. TDC/BDC marked. Arrows indicate piston direction.
Fig. 2:	**Otto Cycle P-V & T-S**	Dual diagrams: P-V showing processes 1-2-3-4 with isentropic curves; T-S showing entropy changes. Constant volume lines marked.
Fig. 3:	**Diesel Cycle P-V & T-S**	Similar to Otto but with constant pressure heat addition (horizontal top line in P-V). Cut-off ratio labeled.
Fig. 4:	**Engine Cross-Section**	Labeled sectional view: cylinder block, piston, rings, connecting rod, crankshaft, camshaft, valves, intake/exhaust manifolds, spark plug/injector.
Fig. 5:	**Cylinder Arrangement Types**	Top-view schematics of Inline-4, V-6, Flat-4, and Radial-7 showing cylinder bank angles and firing order.
Fig. 6:	**Hybrid Powertrain Layout**	Block diagram: IC engine → Power split device → Motor/Generator → Battery → Wheels with energy flow arrows.

Appendix B: Data Tables & Verified Sources

Typical Engine Specifications Across Applications

Application	Type	Disp.	Power	Efficiency
Motorcycle (150 cc)	4-Stroke SI	150 cc	~12 kW	~25%
Passenger Car (I4)	4-Stroke SI	1.5 L	~85 kW	~30-35%
Diesel Truck (I6)	4-Stroke CI	7-12 L	~250 kW	~40-43%
Marine (2-Stroke CI)	2-Stroke CI	~25,000 L	~50 MW	~50%
Generator Set (CI)	4-Stroke CI	5-20 L	50-500 kW	~38-42%
Hybrid Car (Atkinson)	4-Stroke SI	1.8 L	~72 kW	~40-41%

Data Verification Notes

- Efficiency values are approximate peak brake thermal efficiencies from SAE papers and manufacturer data
- Marine engine data based on MAN B&W and Wärtsilä published specifications
- Hybrid data based on Toyota THS-II system (4th generation Prius)
- For latest verified data: consult ARAI, SAE Digital Library, and manufacturer technical papers

Thank You

"The engine of education powers the future of engineering."

Questions & Discussion Welcome