



**University of
Nottingham**

UK | CHINA | MALAYSIA

Advanced Powertrain Engineering

(former Internal Combustion Engines)

MMME4066

Sustainable transport

Antonino La Rocca

Professor in Applied Thermofluids and Propulsion Systems

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Students should have received an email already about SEAtS and a reminder is scheduled for this week. There is a student comms bank that allows you to see what has been sent here:

https://uniofnottm.sharepoint.com/sites/Student_Engagement/SitePages/SEAtS--Communications-resources...

and there is a checklist for new students on the website here:

<https://www.nottingham.ac.uk/student-services/welcome/get-started/new-starter-checklist.aspx?student...>

In the New starter checklist, under 'prepare your laptop and mobile phone' section, there are instructions how to download the SEAtS app as well as a number of other important apps.



This academic year we have **two hours of in-person learning** scheduled on Tuesday from 11 to 1pm; these sessions will include a more interactive lecture with worked examples and activities to apply what you have learned.

The expectation is that revise and understand the content of the material available on the module Moodle page and lectures on a weekly basis and prior to the lecture on Tuesday afternoon

Moodle page:

Advanced Powertrain Engineering (MMME4066 UNUK) (AUT1 25-26)

Have you enrolled? Currently 61 participants.

Please do so asap, so you won't miss any announcement!



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Typically, each year, one representative from industry delivers one lecture to provide industry perspective on future transport.

This year speaker is

Dr Dave Rogers,
Honorary Fellow of Decarbonised Propulsion & Head of ICE Systems @ Kistler

Other contributors
Dr Andrea Pacino
Research Fellow

MMME 4066 - Advanced Powertrain Engineering

Module convenor: Antonino La Rocca, Professor of Applied Thermofluids and Propulsion Systems

Other academics supporting this module Dr David Rogers, Dr Andrea Pacino

Timetable Week	Teaching Week		Week Commencing	
1				
1	0		22/9/2025	Registration & Induction Week
2	1	Introduction to module Advanced propulsion systems and ICE	29/9/2025	Semester 1
3	2	Performance, efficiency and energy flows	06/10/2025	Semester 1
4	3	In-cylinder pressure measurements and heat release <small>by Dr Dave Rogers, Honorary Fellow of Decarbonised Propulsion & Head of ICE Systems @ Kistler</small>	13/10/2025	Semester 1
5	4	Combustion, heat release and work transfer	20/10/2025	Semester 1
6	5	Cooling circuit & heat transfer	27/10/2025	Semester 1
7	6	Case study – using real engine data from powertrain research centre (no lecture)	03/11/2025	Semester 1
8	7	Lubrication system and friction	10/11/2025	Semester 1
9	8	Alternative fuels for heavy transport. Fuels and fuel delivery	17/11/2025	Semester 1
10	9	Hybrid propulsion	24/11/2025	Semester 1
11	10	Emissions and test regulations	01/12/2025	Semester 1
12	11	Aftertreatment system	08/12/2025	Semester 1
13	Vacation		15/12/2025	Winter Vacation
14	Vacation		22/12/2025	Winter Vacation
15	Vacation		29/12/2025	Winter Vacation
16	Vacation		05/01/2026	Winter Vacation
17	Assessment		12/01/2026	Assessment
18	Assessment		19/01/2026	Assessment



Type	Weight	Requirements
Exam	100%	Closed book exam

Examples of previous exams available on the Moodle site.

Previous exam questions will be solved in the lectures



Notes/Books:

Course notes/exercise sheets provided – bring to every lecture. Supplementary materials will be given as required.

Recommended Core/Supplementary Texts:

- Kelly Senecal, Felix Leach. Racing Toward Zero: The Untold Story of Driving Green
- Heywood, JB, Internal Combustion Engine Fundamentals London: McGraw-Hill (ISBN: 007028637X)
- Ferguson CR and Kirkpatrick AT, Internal Combustion Engines – Applied Thermosciences. 2nd Edition. New York John Wiley & Sons 2001
- Bosch Automotive Handbook 6th ed Robert Bosch GmbH

Youtube

- Ford EcoBoost Engine 2011
- Toyota Dual VVTi Engine Animation 3D
- Garrett VNT turbocharger



An advanced undergraduate module covering fundamental **concepts, principles** and the **applications** of advance propulsion systems and internal combustion engines in the following topics:

- Advanced propulsion systems and ICE
- Performance, efficiency and energy flows
- Power Cell Design & Hybrids
- Combustion, heat release and work transfer
- Lubrication system and friction
- Cooling circuit & heat transfer
- Gas exchange & boosting
- Fuel and fuel delivery
- After-treatment system, emissions and test regulations

Assessments:

Exam – January: Written 2hour examination (100%)



UK-SPEC Learning Outcomes for accredited engineering programmes

Learning Outcomes: On successful completion of this module students will be able to:

Comprehend the fundamental knowledge of design, operation and performance of internal combustion engines and other advanced propulsion systems, developments of technology and practices in the automotive industry (*knowledge and comprehension*)

Apply the fundamental knowledge and understanding at an advanced level to the analysis of internal combustion engine problems (*application*)

Analyse critically standard engine systems, current industry design trends and the developments in internal combustion engine technology (*analysis*)

Formulate appropriate techniques/models to analyse and interpret advanced problems within the context of internal combustion engines (*synthesis*)

Appraise engineering design solutions using an appropriate level of explanation showing evidence of judgement in selection of analysis techniques, given a specification of the required performance attributes of an internal combustion engine or sub-system (*evaluation*)



Be able to find **answers to problems** without needing a support mechanism

- provide you with material to allow you to understand the concepts
- taking you through worked examples
- self-study activities
- self-study example sheets

Long subject to tailpipe pollution limits, transportation sector now faces CO₂ EU regulations, with targets defined for 2025 and 2030 – a function of the need to reduce global carbon emissions to net-zero by 2050

Carbon regulations tightening: In June 2019, the UK became the first major economy to commit and set a legally binding target for net zero carbon (NZC) emissions by 2050

Uncertainly remains on different propulsion solutions. New thermal propulsion technologies, batteries and fuel cells each help address transport air quality and CO₂ ambitions.

Future CO₂ and emission legislation requires electrification of the powertrain.

ICE will still play a major role, but as a modular team player.

Future emission legislation will move towards a “zero impact emission” scenario.

Combustion engines should no longer contribute to pollution of the environment. The electrified powertrain allows optimization potential not used up to now. The electric machine can support in starting, heating up exhaust gas aftertreatment and transient operation.

Sophisticated exhaust gas after treatment allows almost 100% conversion of emissions.

The future electrified powertrain with focus on significantly improved efficiency and minimized emissions.

Roadmaps: heavy-duty sectors like marine and aviation are expected to be reliant on sustainable fuels for decarbonisation, while the light duty sector will be electrified to achieve decarbonisation.



Energy vectors roadmap 2050 for various transportation modes. Innovate UK

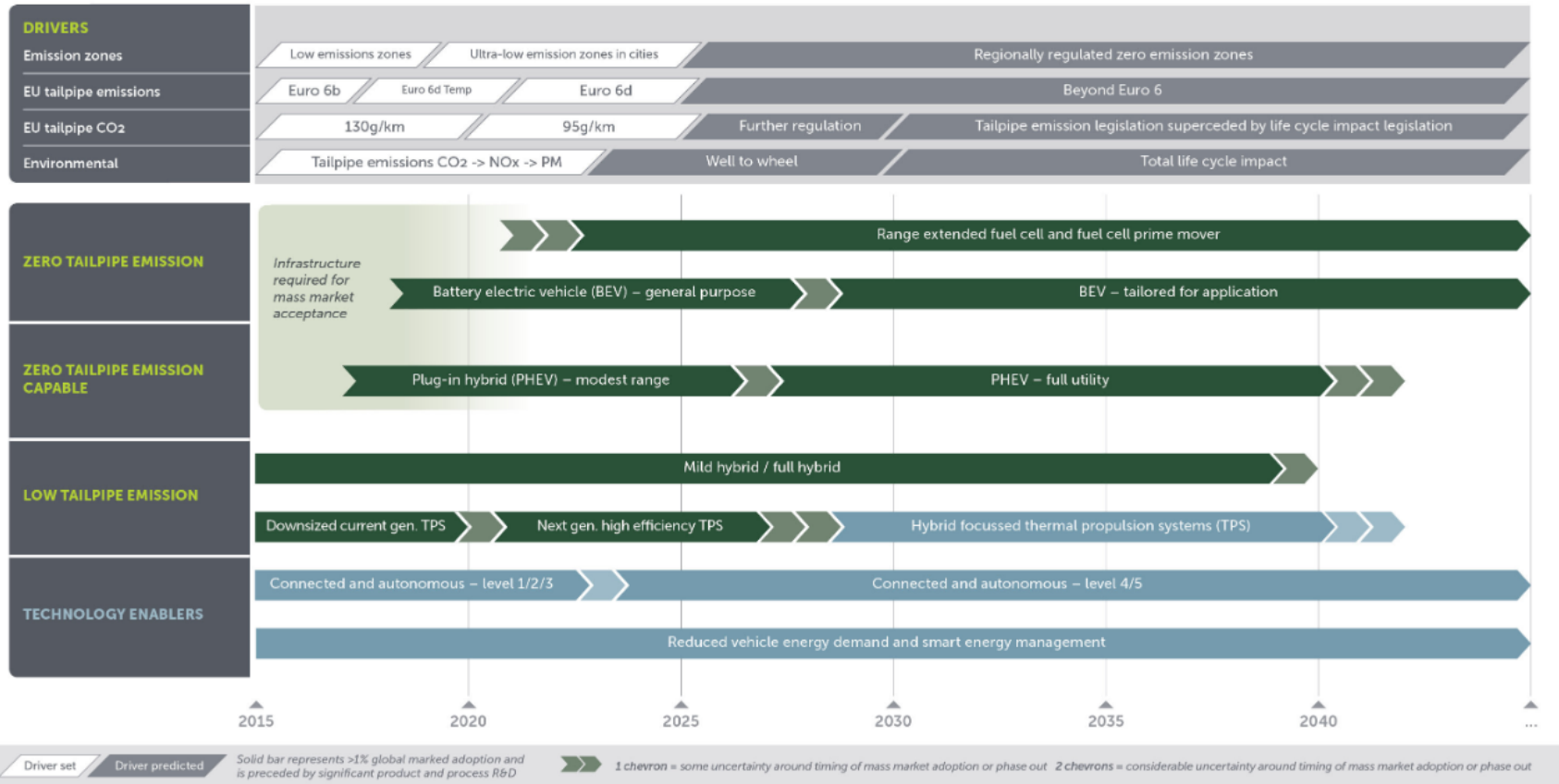
CERTAINTY ■ high ■ med ■ low ■ speculative

Energy vectors pathway

Transport modes	Elements	2021 position	By 2025	By 2030	By 2040	By 2050
Air transport	Policy enablers	Early dev of alt. energy vectors	UK SAF mandate implemented	All aircraft certified for 100% SAF	UK SAF industry established	
	Advanced Air Mobility (AAM)		CORSIA mandatory for all UK int flights PIL Strategy 2023	Sufficient SAF for domestic flights		
	Fuel mix [36-41]	>99% kerosene 1% SAF	>99% kerosene 1% SAF	90% kerosene 10% SAF	70% kerosene 20% SAF 10% hydrogen	43% kerosene offset [1][2] 32% SAF (including some PtL) 25% hydrogen for commuter to short-range
	International and domestic		Development of hydrogen powered aviation. Transatlantic flight 100% SAF demonstrator by 2025 Domestic flight 100% SAF demonstrator by 2023	ZE flight demonstrator 2026 All aircraft certified for 100% SAF by 2030	2031 UK domestic aviation 100% SAF	
			At scale SAF plant by 2025	SAF significant increase in production	Zero-E planes enter into service in 2035	Sufficient SAF to meet >30% UK domestic demand [14]
Maritime	International	Marine diesel & heavy fuel oil (HFO) [11]	BEV for short journeys only	All new ships to be ZE capable	Large shift in take up of ZE energy sources from 2030s [2][15]	All zero emission [4]
	Domestic		TRL3-7 hydrogen & ammonia projects [6]	Wind, biofuel, electro-fuel and H2 demonstrators [6]		
	Fuel mix [14]	52% marine diesel [14] 48% heavy & low sulphur fuel oil [14]	52% Marine diesel [14] 48% low sulphur and heavy fuel oil [14]	40% marine diesel [14] 47% low sulphur and heavy fuel oil [14] 4% methanol [14] 3% shore power [14] 4% ammonia [14] 2% hydrogen [14]	18% marine diesel [14] 33% low sulphur and heavy fuel oil [14] 10% methanol [14] 5% shore power [14] 30% ammonia [14] 4% hydrogen [14]	1% marine diesel [14] 0% low sulphur and heavy fuel oil [14] 26% methanol [14] 5% shore power [14] 62% ammonia [14] 4% hydrogen [14]
Micromobility	Policy enablers	Encourage more active travel Provide infrastructure	Develop micro-consolidation hubs	Large-scale urban freight consolidation Electric-powered last-mile delivery		
All modes	E-scooter and e-cargo bike trials ongoing	>99% BEV and active travel modes	100% BEV and active modes			
Rail [7, A2, 25]	Policy enablers	Develop hydrogen and battery solutions	Hydrogen and battery electric trials Manufacture of diesel trains ends	Increased electrification of network Manufacture of ZE trains only	Diesel trains removed by 2035-2040	Wholesale integration with energy system Net zero rail network [22]
	Fuel mix	71% electric 25% diesel [18]	75% electric 29% diesel [18]	80% electric (inc direct electric and electric diesel hybrids) 15% fossils fuels 2% hydrogen 2% battery electric hybrids 1% battery	85% direct electric electric diesel hybrids phased out 5% hydrogen 5% battery electric hybrids 5% battery	
Road [9, 11]	Policy enablers	ICE sales end 2030, hybrids 2035 [19]	ICE de-incentivised	ZEV capability and affordability increased	Shift to ZEV for HGVs [12]	Circular economy for ZEV established
	Cars (2020: 32.9m) [2, 22a, 3, 24, 25]	97.6% ICE [9, 17] 2.1% hybrid [9, 17] 0.3% BEV [9, 17]	84% ICE [9, 23, 24] 7% hybrid [9, 23, 24] 9% BEV [9, 23, 24]	57% ICE [9, 23, 24] 9% hybrid [9, 23, 24] 34% BEV [9, 23, 24]	8% ICE [9, 23, 24] 5% hybrid [9, 23, 24] 87% BEV [9, 23, 24]	100% BEV [9, 23, 24, 25]
	Vans (LCVs) (2020: 4.3m) [23, 24d]	99.8% ICE [9, 18] 0.2% BEV [9, 18]	84% ICE [9, 23b, 24d] 9% BEV [9, 23b, 24d]	57% ICE [9, 23b, 24d] 34% BEV [9, 23b, 24d]	8% ICE [9, 23b, 24d] 87% BEV [9, 23b, 24d]	100% BEV [9, 23b, 24d]
	Motorcycles (2020: 1.4m) [9, 22d]	99.8% ICE [9, 22d] 0.2% BEV [9, 22d]	84% ICE [9, 22d] 9% BEV [9, 22d]	57% ICE [9, 22d] 34% BEV [9, 22d]	8% ICE [9, 22d] 87% BEV [9, 22d]	100% BEV [9, 22d]
	Bus & coaches (2020: 144k) [22c, 22e, 25]	99.6% ICE [9] 0.4% BEV [9]	98% ICE [9, 23c, 23e, 25] 1% BEV [9, 23c, 23e, 25]	85% ICE [9, 23c, 23e, 25] 7% BEV [9, 23c, 23e, 25]	33% ICE [9, 23c, 23e, 25] 33% BEV [9, 23c, 23e, 25]	50% BEV [9, 23c, 23e, 25]
	HGV (2020: 508k) [22d, 24b, 25]	99.9% ICE [9, 21] 0.1% BEV [9, 21]	98% ICE [9, 23d, 24b, 25] 1% BEV [9, 23d, 24b, 25]	85% ICE [9, 23d, 24b, 25] 7% BEV [9, 23d, 24b, 25]	33% ICE [9, 23d, 24b, 25] 33% H2 [9, 23d, 24b, 25]	50% BEV [9, 23d, 24b, 25] 50% H2 [9, 23d, 24b, 25]
			1% H2 [9, 23d, 24b, 25]	7% H2 [9, 23d, 24b, 25]	33% H2 [9, 23d, 24b, 25]	

PRODUCT ROADMAP 2017: PASSENGER CAR

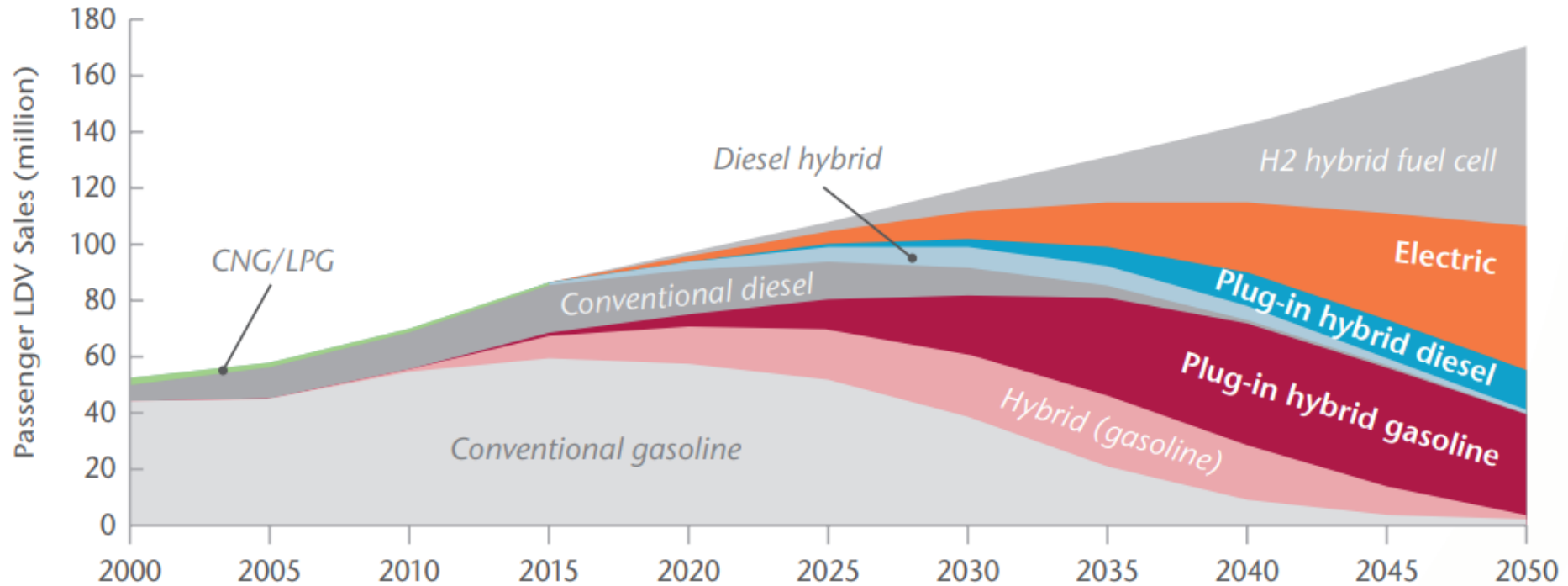
Roadmap developed by the Automotive Council and the Advanced Propulsion Centre



With support of the electric machine, at low load the vehicle will be driven purely electric. At full load the ICE will be supported by the electric machine. Highest torque (e.g. low-end torque) will lose its importance. ICE main operation: “sweet spot”: Area of best efficiency.



84 million motor vehicles sold worldwide annually. What are the options?



International Energy Agency: Achieve a combined EV/PHEV sales share of at least 50% of Light Duty Vehicle sales worldwide by 2050.

RD&D priorities: research, development and demonstration must continue to reduce battery costs and ensure adequate materials supply. More research is also needed on smart grids and the vehicle-grid interface.

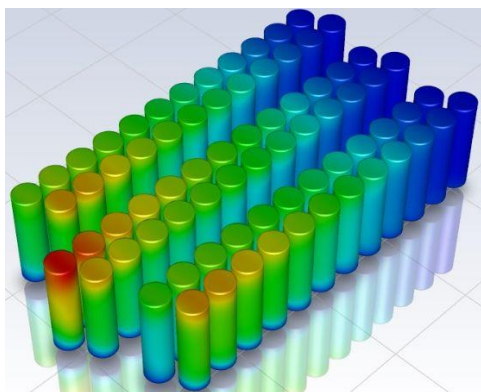


Electrical Energy Storage

Manufacturers are consolidating on a number of cell formats.

Cylindrical, pouch and prismatic are the three main options. A clear winner is difficult to predict as each have unique advantages.

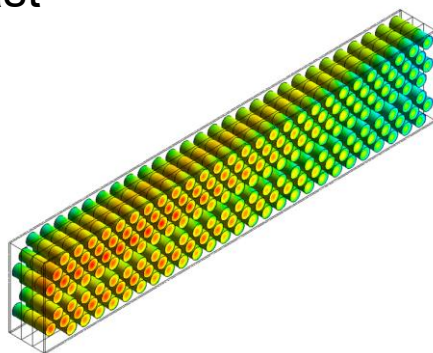
New cell formats optimised for new chemistries are also likely to emerge.



Battery management system software need to improve performance and health.

Improvements to busbars and connectors/contactors will be needed as vehicle architectures adopt higher voltages.

With higher-power applications and fast charging, thermal management becomes more important.



Horizon project new battery design - Just completed



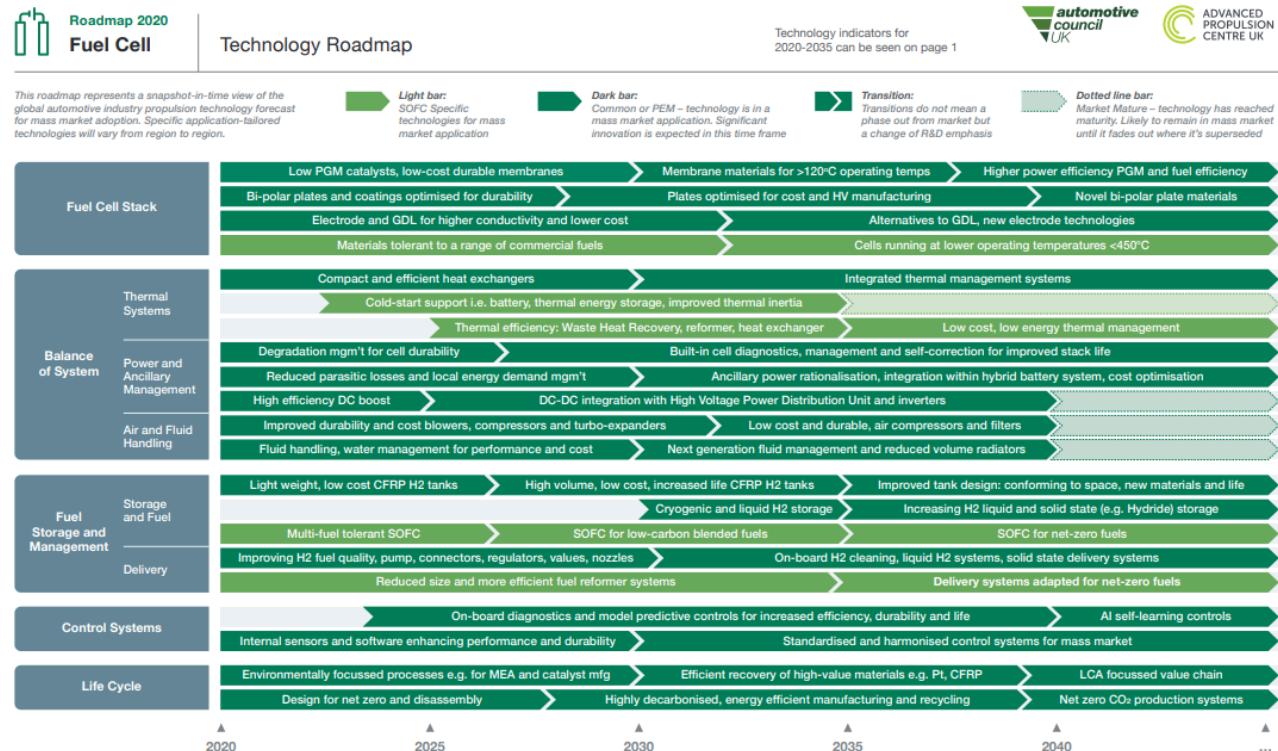
84 million motor vehicles sold worldwide annually. What are the options?

Fuel Cells: Global sales of FCEVs (fuel cell electric vehicles): in 2022, over 20,000 FCEVs were sold globally. In 2023, there were ~14,451 sales (prominent passenger FCEV models. Hyundai Nexa and Toyota Mirai.

FCEVs alternative to battery electric vehicles (BEVs). System efficiency competes with the best-in-class ICE for specific use cases. Two primary fuel cell technologies used in automotive applications: proton-exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC).

However, there are significant challenges to overcome.

The 2020 technology roadmaps have been developed delivering a view of future automotive propulsion targets, technologies and timescales.





John Heywood has recently highlighted three important areas to explore:

An obvious way to reduce energy and emissions is to minimise demand for energy intensive personal mobility (often 1 person per car) as well as freight services.

In the short term more efficient technology needs to be developed, e.g. hybrids new fuels, improved ICE

Last but not least, develop new propulsion technologies that can significantly lower emission (pollutants and GHG) e.g. electricity and hydrogen

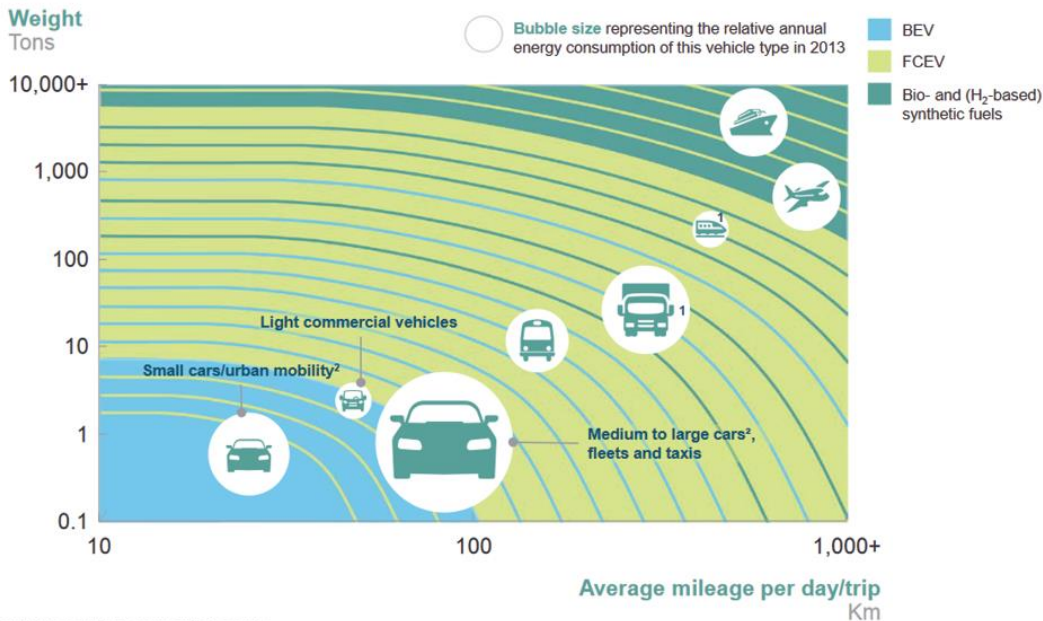


It is not R.I.P. Internal Combustion Engines (ICE) quite yet!

ICE will carry on being at the centre of propulsion systems for future road transport.

Why and how? – Development focused on sustainability (Full life-cycle)

Why is ICE still so popular: Attributes such low cost, high power density, proven durability, and fuel use flexibility with established fuel networks coupled with a wide range of electrification options



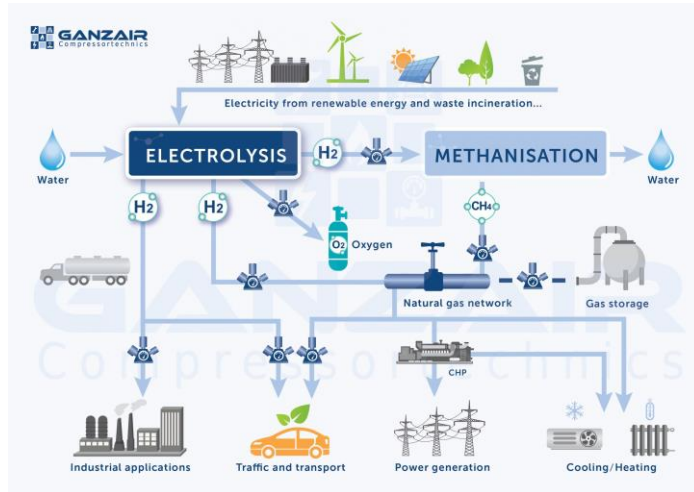
Energy source for transport modes

To get to the 2050 target chart shows which energy vector and powertrain dominate.

¹ Battery-hydrogen hybrid to ensure sufficient power
² Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand
 Source: Toyota, Hyundai, Daimler



The next generation of heavy-duty ICE products will deliver increased sustainability via thermal efficiency gains and renewable fuel types.



Future fuels includes increasing bio content and developing new e-fuels which make use of excess renewable electricity. (synthetic methane (with a manageable transition via natural gas) and green hydrogen from electrolysis).

Sustainability of vehicles due to their Green House Gas (GHG) impact, must be based on product life-cycle assessment (include the contribution from vehicle and fuel production and vehicle disposal as well as the vehicle use phase).



Motor vehicles account for about 20% of global CO₂ emissions from energy and 75% of transportation-specific emissions.

The UK Government announced last year that it will end the sale of new petrol and diesel cars and vans by 2030 and is due to launch a consultation on the phase out of new diesel heavy goods vehicles (HGVs).



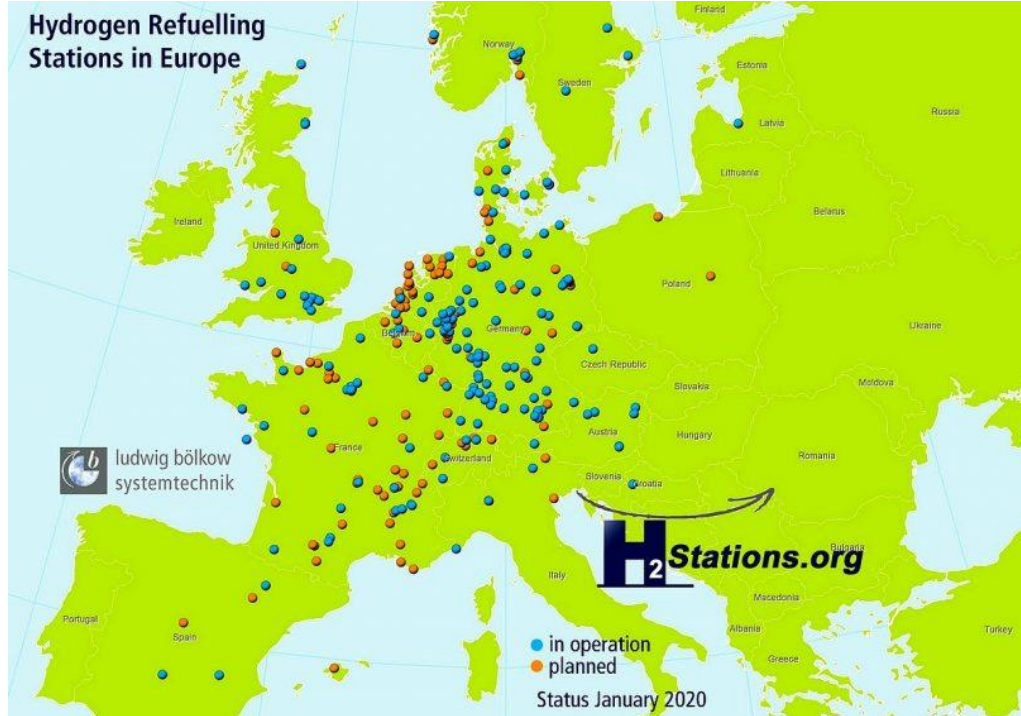
Electrification is less established within other transport sectors such as heavy-duty long haul where requirements continue to favour non-hybrid ICE solutions.

Iveco, Daimler and Volvo have joined forces with energy companies Shell and OMV to form H2Accelerate. They say hydrogen will be an essential fuel for the complete decarbonisation of the truck sector.



Pathway to energy and emission reductions

Europe had 177 hydrogen stations at the end of the year



Tesla 2020 Supercharger map



Hydrogen stations vs Supercharging very different

Infrastructure needs to build up

15,000 total Superchargers worldwide.



Considerable of interest in H₂

16 national hydrogen roadmaps publicly released
\$70 Bn government funding announced



H₂ production is not new:

(reforming or gasification)

50% produced from Natural gas (grey H₂)

45% from coal or oil

(electrolysis)

5% from renewables (green H₂)

Blue hydrogen: the carbon generated from steam reforming is captured and stored underground through industrial carbon capture and storage (CSS).



MariNH₃

Clean, green ammonia engines for maritime

A five-year research programme investigating the potential of green ammonia to fuel & decarbonise the commercial shipping industry led by A Cairns @ UoN

Investigating the potential of green ammonia to fuel and decarbonise commercial shipping



Fuel	Volumetric Energy Density (approx.)	Storage State
Hydrogen (H ₂)	~0.0108 MJ/L (gas at 1 atm, 15°C) ~8.5 MJ/L (as liquid H ₂) ~5.6 MJ/L (at 700 bar compressed gas)	Gas, Liquid
Ammonia (NH ₃)	~11.5 MJ/L (liquid at 20°C, ~10 bar)	Liquid

Ammonia (NH₃) has excellent potential to play a significant role as a sustainable future fuel in both retrofitted and advanced engines.



There are challenges to overcome such as the NO_x emissions

Can help pushing the infrastructure while fuel cells achieve a reasonable level of development

Certainly, there is a strong drive to make H₂ ICE efficient and low-emission as it can be part of the indefinite transport future.



ICE part of propulsion systems for future road transport

HD, off-road, marine will most likely continue to use CI engine

H₂, NH₃ and e-fuels will play a role to support zero emission in future transport systems

H₂ infrastructure needs to build up



Following the VW “dieseldgate” scandal the diesel engine has fall out of favour.

Where do you see the Diesel engine being exploited in the near future and why/how?

Please find a recent journal paper that support your answer.



What are these?

#1:

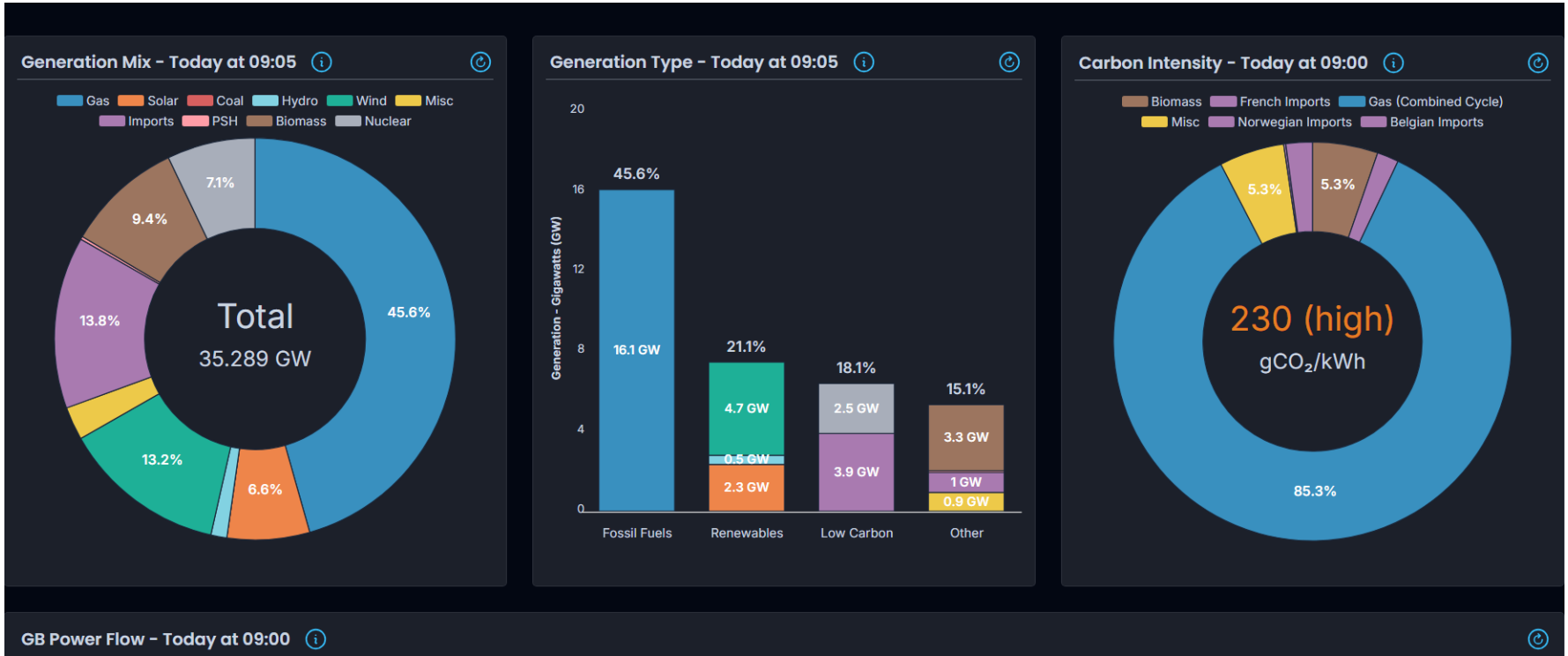


#2:



#1: engine type? Why?

#2: engine type? Why?



You are purchasing a so-called “Zero Emission Vehicle”. Charging this vehicle may require activation of fossil fuel power plants often located where the residents cannot afford electric vehicles. Please drive less so that they might also see the benefits of reduced emissions in their communities. But do not drive so little that you never pay back the high production CO₂ from creating the battery pack. Oh boy, this is complicated.



Last year 1-10-2024



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Introduction & Design Features, Functions and Layout

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Design Features, Functions and Layout

Summary

1. Definition of internal combustion engines
2. 2035 Engines Scenario and recent developments
3. Design Features, Functions and Layout
4. Components in internal combustion engines

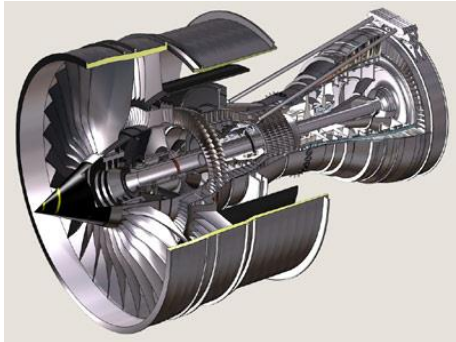
Definition of ICE

A **heat engine** that converts chemical energy in fuels into mechanical power, in which the heat source is the combustible mixture/burned products that also serves as the working fluid. (1st Year Thermodynamics!!!)



An **internal combustion engine** is one in which the combustion occurs within the engine itself,

An **external combustion engine** is one where combustion occurs outside the engine system, and heat transfers is via a heat exchanger.



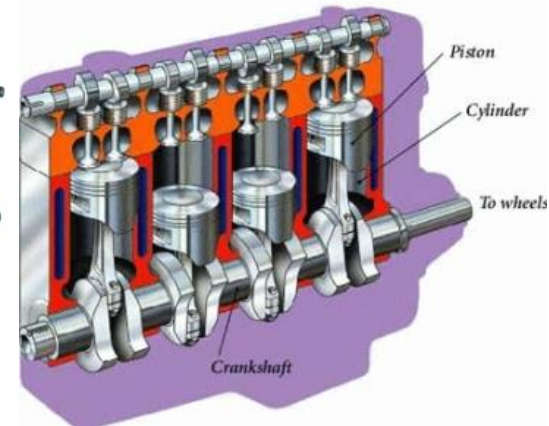
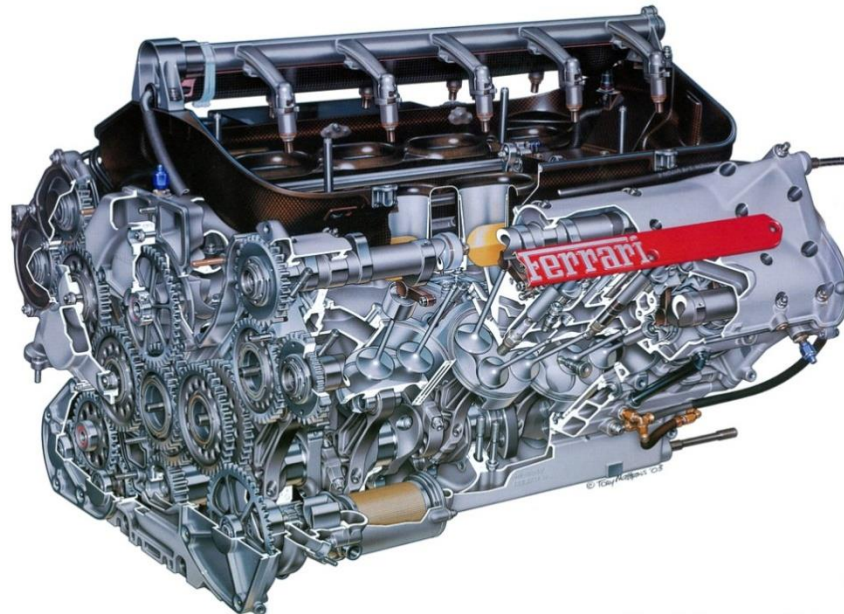
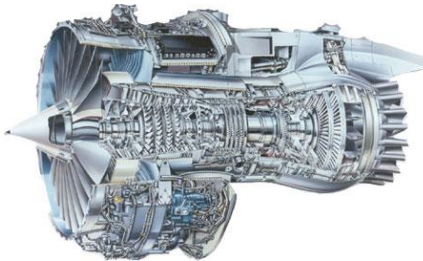
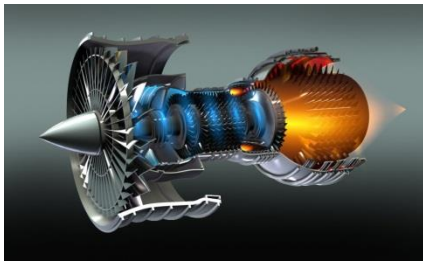
Internal Combustion Engines

ECE: Steam power plant, Solar power plant, Nuclear power plant

ICE: Reciprocating piston engine, Rotary engine, Gas turbine, Jet engine

Internal Combustion engines

- Produce work by pushing on a reciprocating piston or turbine blades that drives a rotating shaft.
- Creates a high-momentum fluid that is used directly as propulsive force

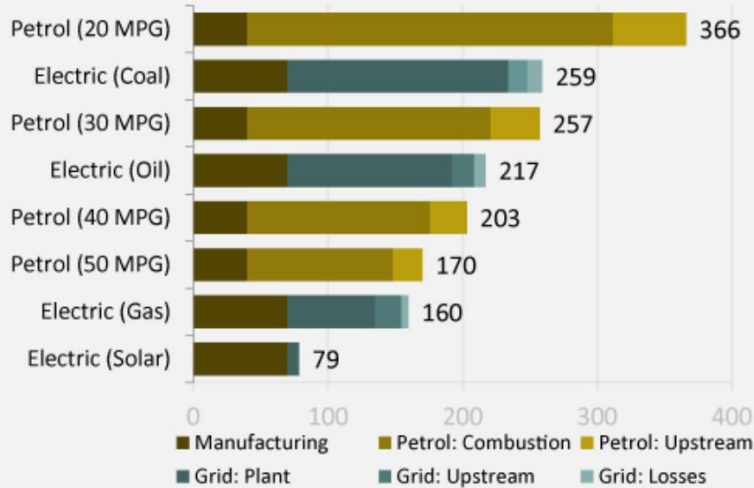


MM4ICE focuses on powertrain designs for automotive applications

Have You Made The Right Module Choice?



Petrol vs Electric Vehicle Emissions (g CO₂e/km)



Notes: Electric vehicle emissions based on Nissan Leaf combined rating of 29 kWh/100 mi. Petrol combustion and upstream based on conventional oil extraction.
 Source: DEFRA (emission factors), EPA (ratings), IPCC shrinkthatfootprint.com

A dramatic shift towards electrified vehicles over a short period is unlikely albeit European market will need to progressively and significantly increase the proportion of electrified powertrain vehicles.

Mild hybrids with clean gasoline ICE are foreseen to be popular in small and medium sized cars

Heavy duty long haul will still be reliant on diesel, so will heavier commuter cars

Why ICE is so ubiquitous

There are around 29M cars in the UK

Hard to beat liquid-fueled internal combustion engines for:

- Power/weight & power/volume of engine
- Energy/weight & energy/volume of liquid hydrocarbon fuels
- Distribution & handling convenience of liquids hydrocarbon fuels

What are the concerns?

CO₂ emissions

Fuel economy

Oil price/scarcity

Noxious emissions

What are the alternatives?

Public transport (what sort?)

More efficient conventional vehicles

Different vehicle concepts:

- Plug-in, All electric
- Fuel cell

More efficient conventional vehicles

Background to what's happening in the automotive industry

Sustainability and CO₂

Automotive i.c. engines and sustainability is a 'hot' topic as the result of concerns over climate change, the role of CO₂ in this, and the contribution of the transport sector.

Conventional fuels – diesel and gasoline – are high carbon (around 86% carbon, 14% hydrogen), high energy density (~42 MJ/kg) fossil fuels derived from oil

Approximately 3.15 kg CO₂/kg of fuel. CO₂ is a 'bad' Greenhouse gas; and burning diesel and gasoline produces lots of it

European Commission set an average CO₂ targets of

- 95g/km for new cars sold in 2020

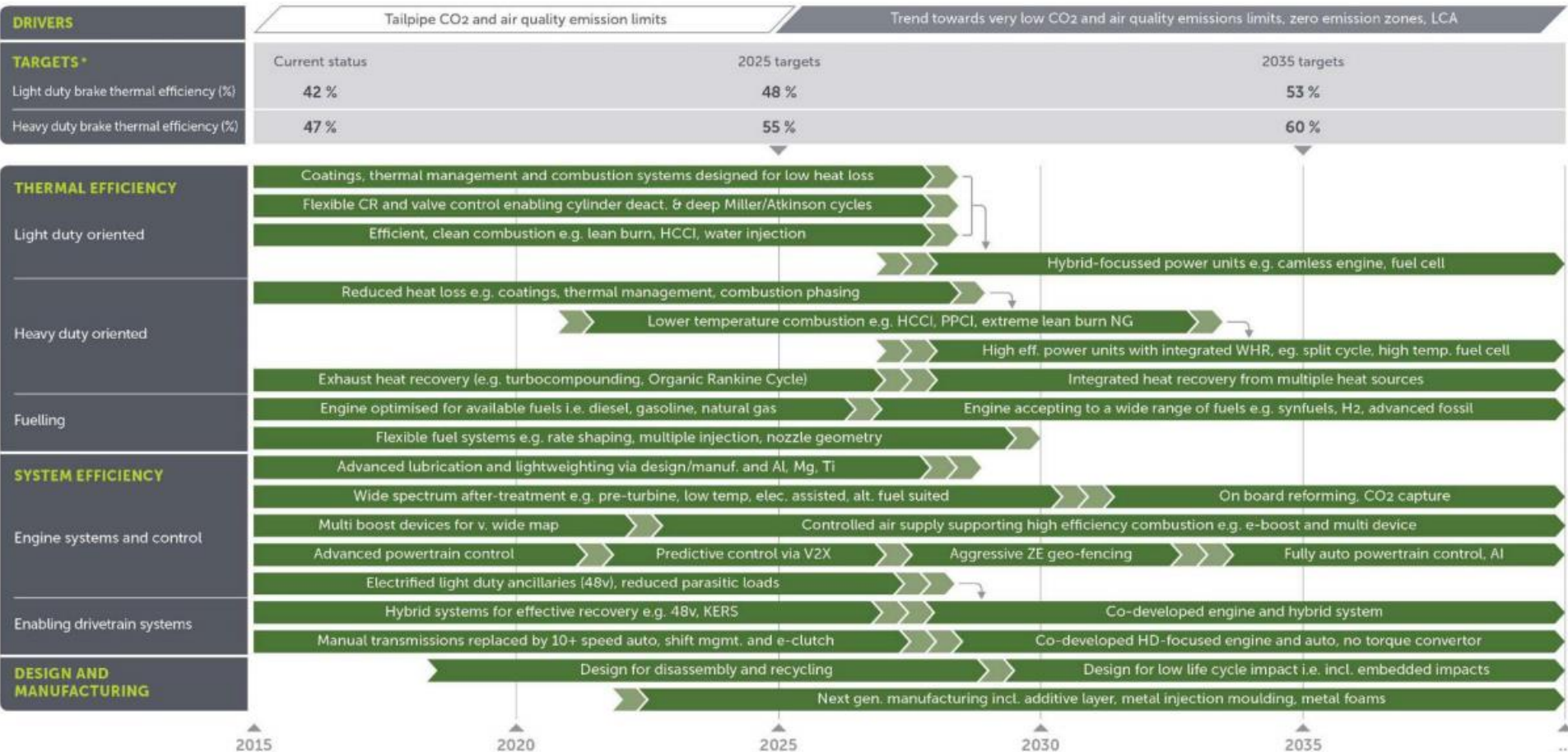
Fuel consumption:

2020 target equated to approx 4.1 l/100 km of petrol or 3.6 l/100 km of diesel.

Mapping out the automotive future

TECHNOLOGY ROADMAP 2017: THERMAL PROPULSION SYSTEMS

Roadmap developed by the Automotive Council and the Advanced Propulsion Centre



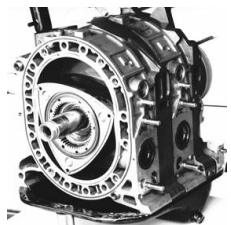
* Values reflect midpoint peak efficiency between diesel and gasoline efficiency (current difference ~5%)

1 chevron = some uncertainty around timing of mass market adoption or phase out 2 chevrons = considerable uncertainty around timing of mass market adoption or phase out

Design Features, Functions and Layout

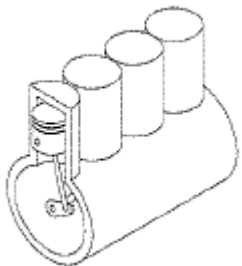
Engine types

Basic engine design



Rotary engine
(Wankel engine
in Mazda models)

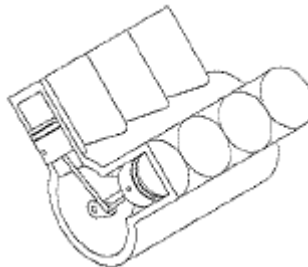
Reciprocating engine



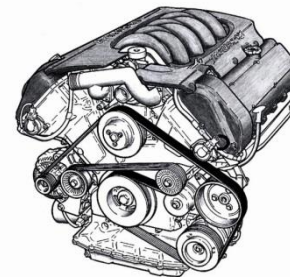
In-line (Straight)



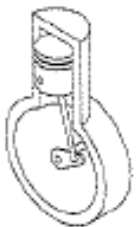
Peugeot 407



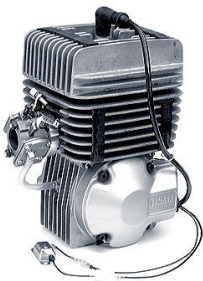
V-type



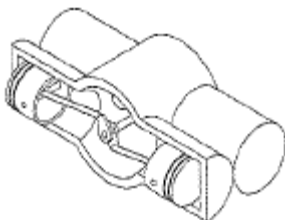
Jaguar 4litre V8



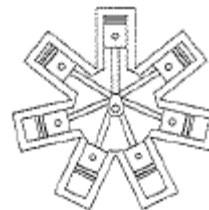
Single
cylinder



Yamaha



Opposed cylinder - Porsche 911



Radial



Aero engine

What do they look like?



Subaru Boxer Engine, 6 cylinder, 3.6l; 256 hp@ 6000rev/min; 247 lb-ft @4800rev/min



2007 Toyota DISI V6, 3.5 l

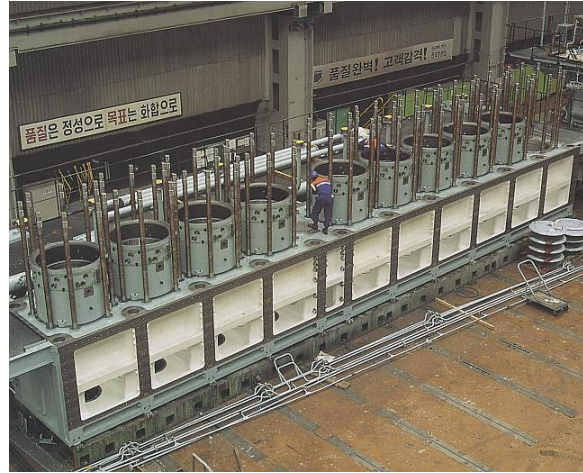
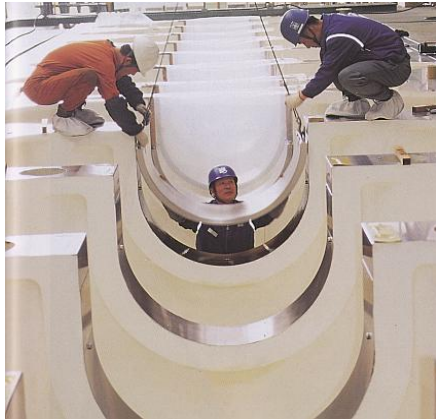


Pistons, connecting rods, camshafts, crankshaft, camshaft belt drive off crankshaft

Largest & Smallest ICE

Wartsila-Sulzer RTA96-C turbocharged two-stroke diesel
(Application: large container ships)

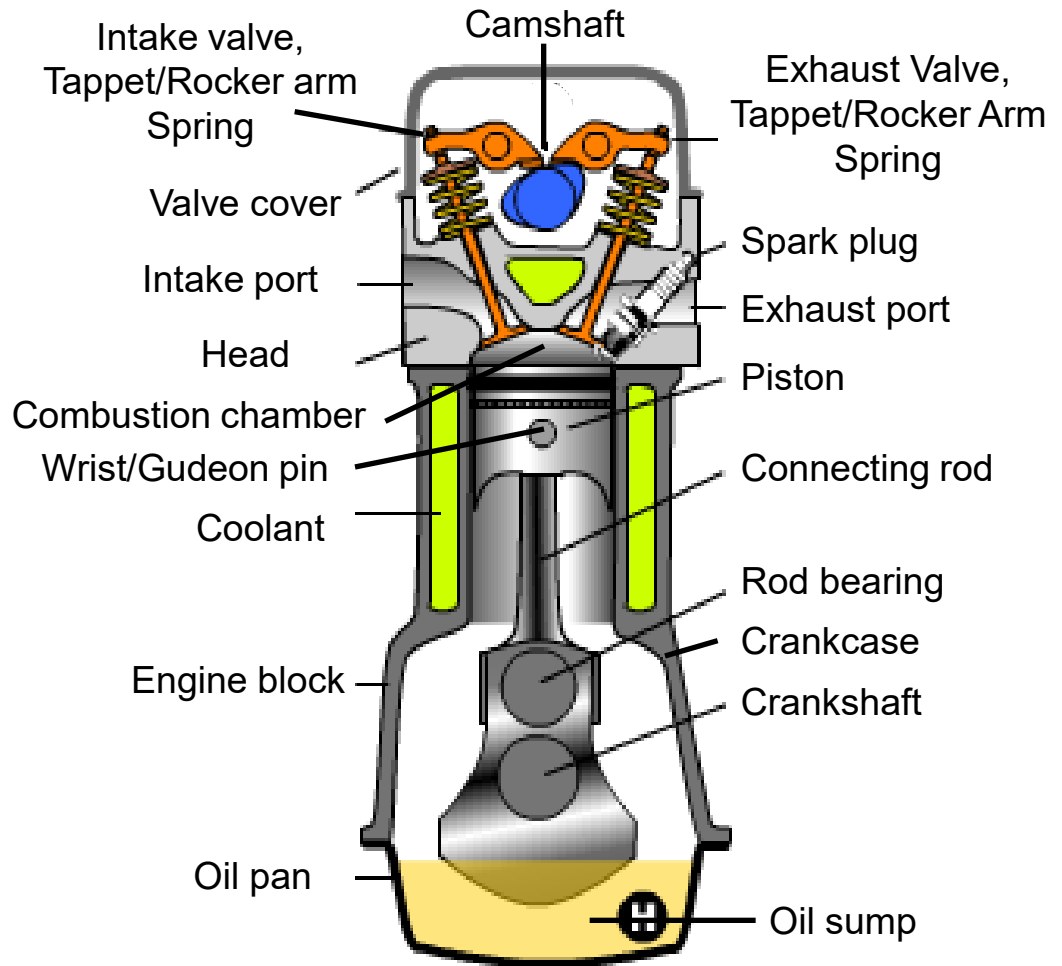
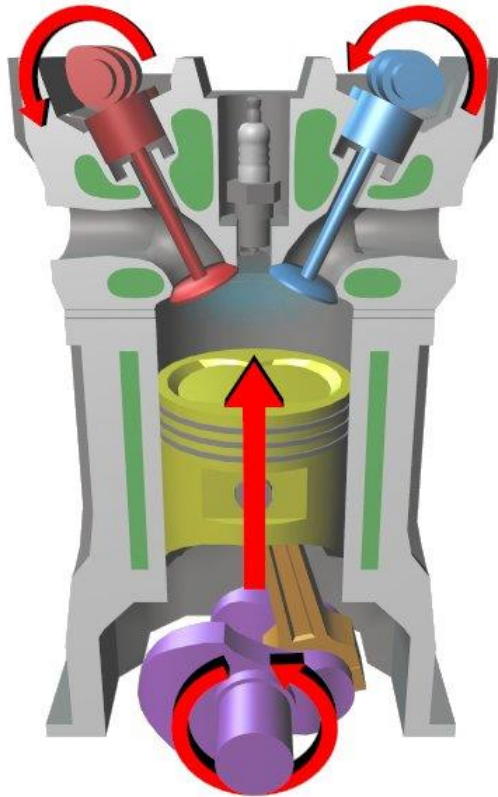
Cylinder bore: 1m, Stroke: 2.5m; 14 cylinder version; Weight: 2300 tons; Length:
27m; Height: 13m; Max. power: 80,568 kW @ 102 rpm;
Max. torque: 7,603,850 Nm @ 102 rpm;
BMEP: 18.5 atm.



Application:	Model airplanes
Weight:	0.49 oz. = 13.9 g
Bore:	0.237" = 6.02 mm
Stroke:	0.226" = 5.74 mm
Displacement:	0.00997 in ³ (0.163 cm ³)
Speed:	30,000 rpm
Power:	3 watts
BMEP:	0.36 atm (low!)



Engine components



Classification of ICEs

Method of ignition : Spark ignition (SI); Compression ignition (CI)

Working cycle: 4-stroke cycle; 2-stroke cycle

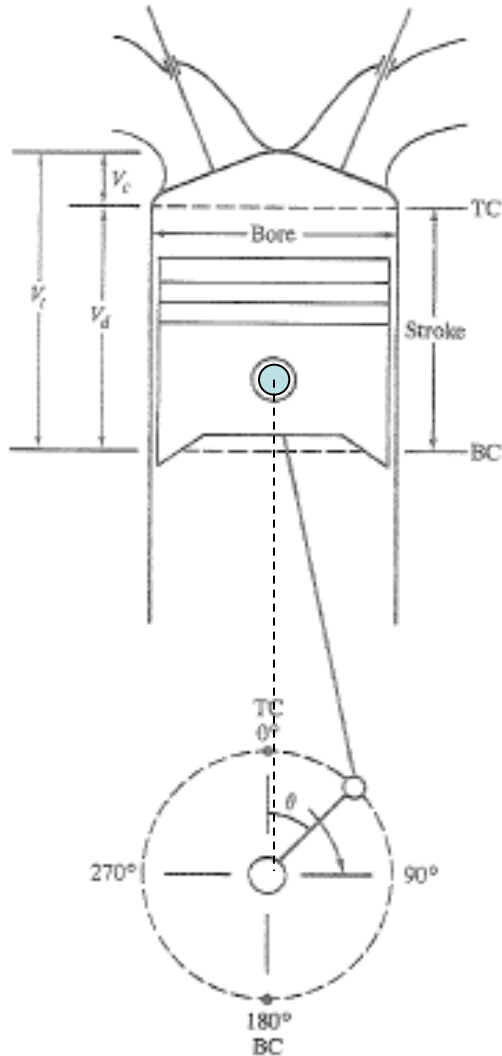
Air intake process: Naturally aspirated; supercharged; turbocharged;

Method of cooling: Air cooled; Liquid cooled/water cooled; Uncooled (besides natural convection and radiation)

Combustion chamber design: Open chamber (disc, wedge, hemisphere, bowl-in-piston); Divided chamber (swirl chamber, prechamber)

Method of load control: Throttling of fuel and air flow together to maintain mixture composition; Control of fuel flow alone; Combination of both

Geometrical properties of reciprocating engines



Top-Dead-Center (TDC)

Piston comes to rest at furthest point away from crankshaft, when cylinder volume is minimum

Bottom-Dead-Center (BDC)

Piston comes to rest at closest point from crankshaft when cylinder volume is maximum

Bore, B

Diameter of the cylinder

Stroke, L

Distance travelled by piston from one extreme end to the other (TDC to BDC)

Clearance volume, V_c

Minimum cylinder volume

Spark Ignition (SI) engine

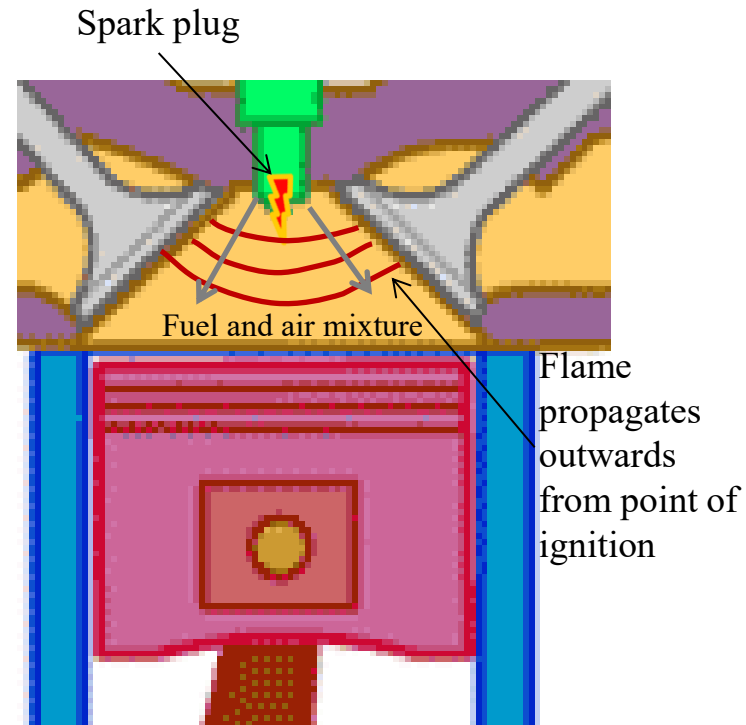
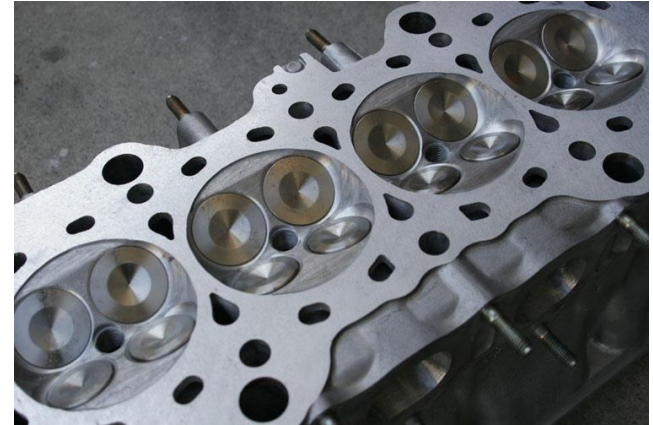
Combustion chamber: typically pent-roof

Homogeneous combustion

- Air/fuel premixed outside the cylinder (except DISI)
- Spark ignites the mixture
- Combustion rate is controlled by the flame propagation
- Intake throttle to regulate quantity of charge (quantity controlled)
- Compression ratio typically 10:1 (avoid charge starting to burn too early)

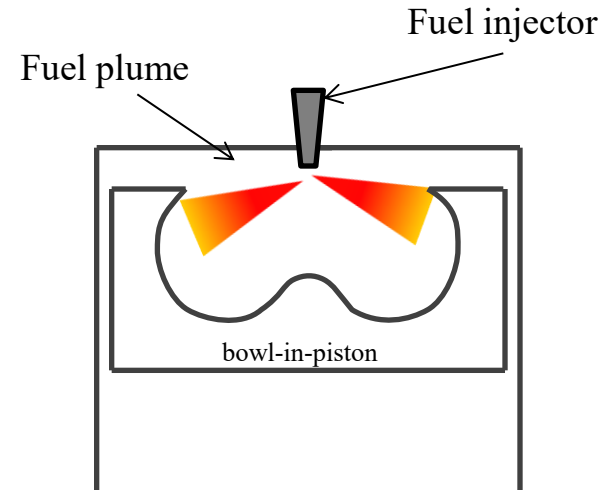
Work output

- Quantity governed – quantity of air and fuel regulated
- AFR is constant at stoichiometric value (14.7) for most conditions



Compression Ignition (CI) engine

Combustion chamber: bowl-in-piston



Heterogeneous combustion

- Fuel injected late in the compression stroke
- Auto ignition occurs due to high compression temperature/pressure
- Rate of fuel and air mixing controls the combustion rate

Work output

- Quality governed - fuel injected regulated to change work output; air not regulated
- AFR changes over time

Operations of a 4-stroke SI engine

Induction/Intake



Piston travels downwards; Intake valves open
Partial vacuum (low pressure) inside cylinder
Mixture of air and fine mist of fuel is delivered by carburetor or an injection system into intake port
Atmospheric pressure pushes fuel / air mixture into cylinder
Engine does work on working fluid

Compression



Intake valves close; Piston travels upwards
Mixture is compressed to high pressure and temperature
Near the end of the stroke as piston approaches TDC, ignition occurs
Engine does work on working fluid

Expansion/Power



Combustion propagates; Mixture composition changes; Pressure and temperature increase
High pressure created forces piston downward, producing work output
At the end of expansion, pressure and temperature drop
Working fluid does work on engine

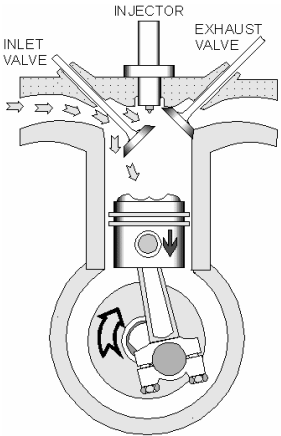
Exhaust



Exhaust valves open near BDC; Piston travels upwards
Pressure differential pushes exhaust gases out of cylinder
At the end of the stroke, exhaust valves close
Engine does work on working fluid

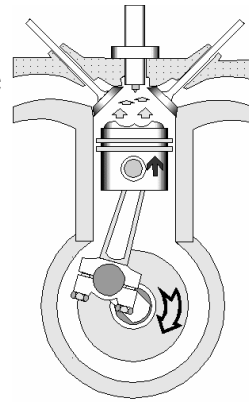
Operations of a 4-stroke CI engine

Induction/Intake



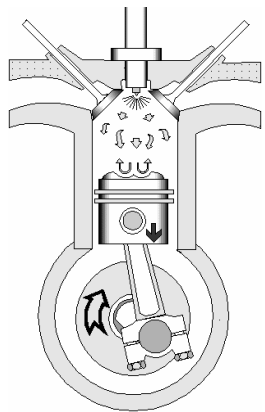
Piston travels downwards; Intake valves open
Partial vacuum (low pressure) inside cylinder
Atmospheric pressure pushes air into cylinder
Engine does work on working fluid

Compression



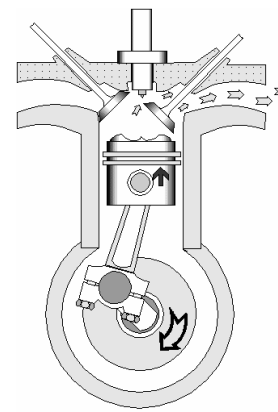
Intake valves close; Piston travels upwards
Air compressed to higher pressure and temperature than in SI (due to higher CR)
Near the end of the stroke as piston approaches TDC, fuel injected directly into combustion chamber
Fuel vapourisation due to hot air entrainment and atomisation; Autoignition occurs
Engine does work on working fluid

Expansion/Power



Combustion fully developed by TDC at constant pressure until fuel injection ceased
Mixture composition changes; Pressure and temperature increase
High pressure created forces piston downward, producing work output
Pressure/temperature drop at the end of expansion
Working fluid does work on engine

Exhaust

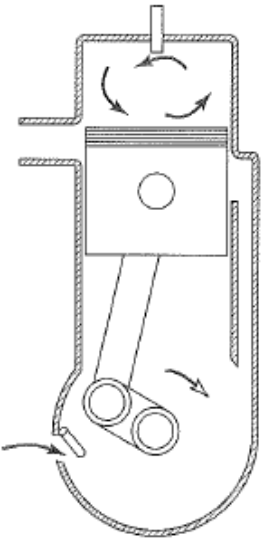


Exhaust valves open near BDC; Piston travels upwards
Pressure differential pushes exhaust gases out of cylinder
At the end of the stroke, exhaust valves close
Engine does work on working fluid

Operations of a 2-stroke SI engine

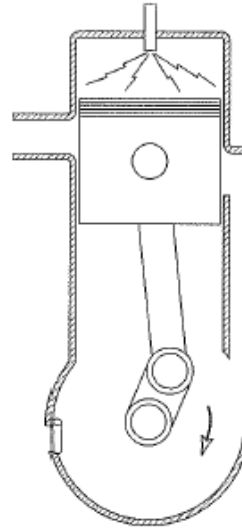
Compression 1

As piston travels upwards, transfer port closes followed by exhaust port
Trapped charge is compressed to higher pressure and temperature
Underside of piston is drawing in an air-fuel mixture into the crankcase through a spring-loaded non-return inlet valve.



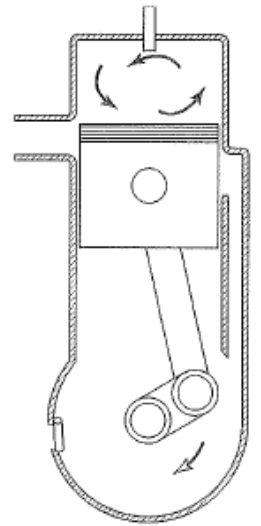
Compression 2

Spark ignition occurs near TDC at the end of the compression stroke
Combustion at almost constant volume near TDC



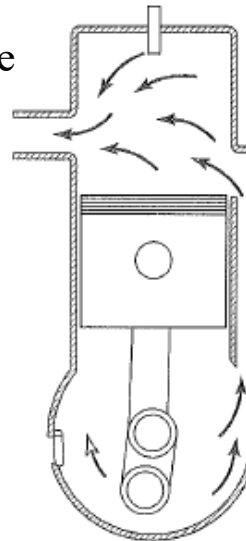
Expansion 1

Combustion at almost constant volume near TDC
Mixture composition changes;
Pressure and temperature increase
High pressure created forces piston downward, producing work output
Fuel-air mixture in crankcase compressed by downward motion of piston



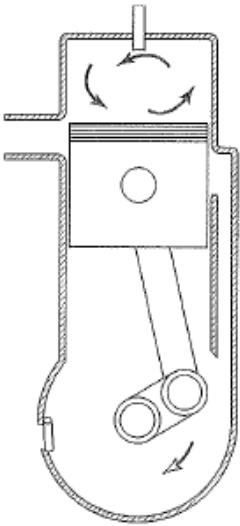
Expansion 2

Near the end of power stroke, exhaust port uncovered and exhaust blowdown occurs
At BDC, transfer port uncovered and compressed charge expands into cylinder
Some remaining exhaust gases are displaced by this fresh charge – flow mechanism called ‘loop scavenging’



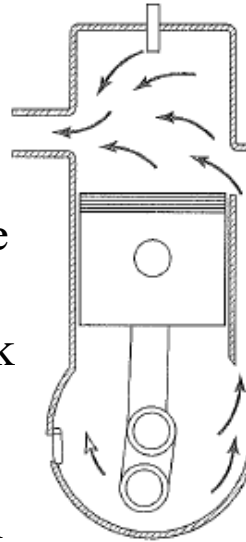
Operations of a 2-stroke SI engine

Expansion 1



Combustion at almost constant volume near TDC
Mixture composition changes;
Pressure and temperature increase
High pressure created forces piston downward, producing work output
Fuel-air mixture in crankcase compressed by downward motion of piston

Expansion 2



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