Ciências
ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

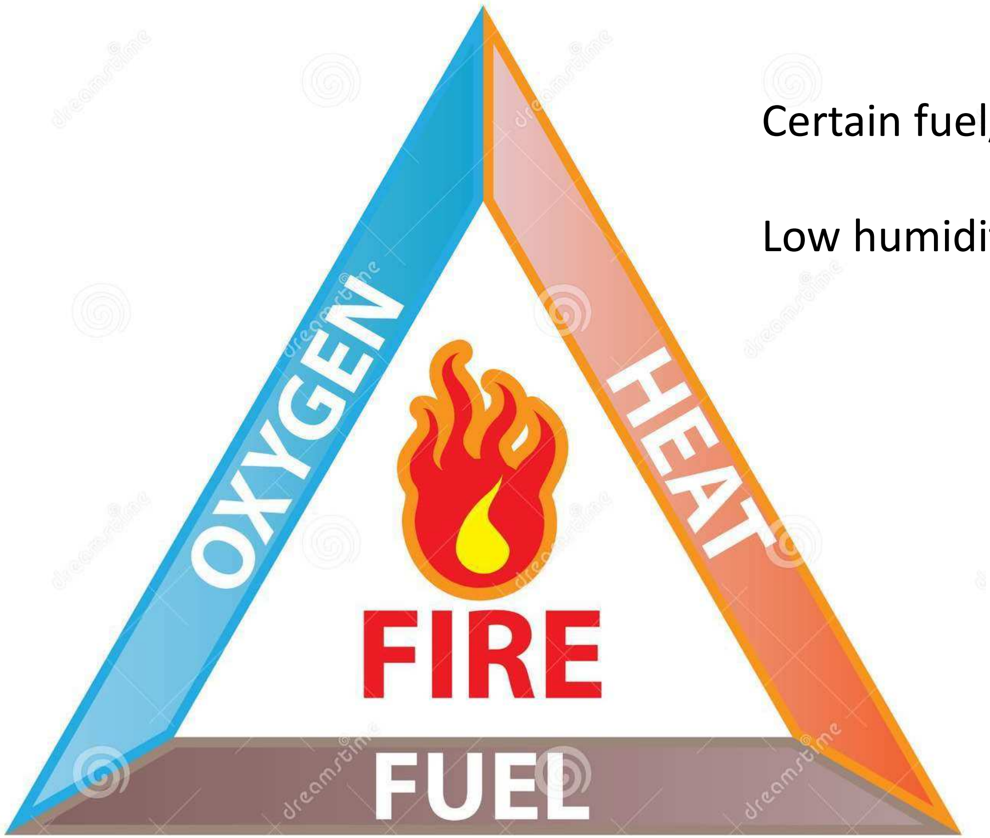
DISCIPLINA MIEEA 2018

Technologies of combustion

Ciências ULisboa

Combustion definition

Combustion is essentially burning, fuels react with oxygen to release energy

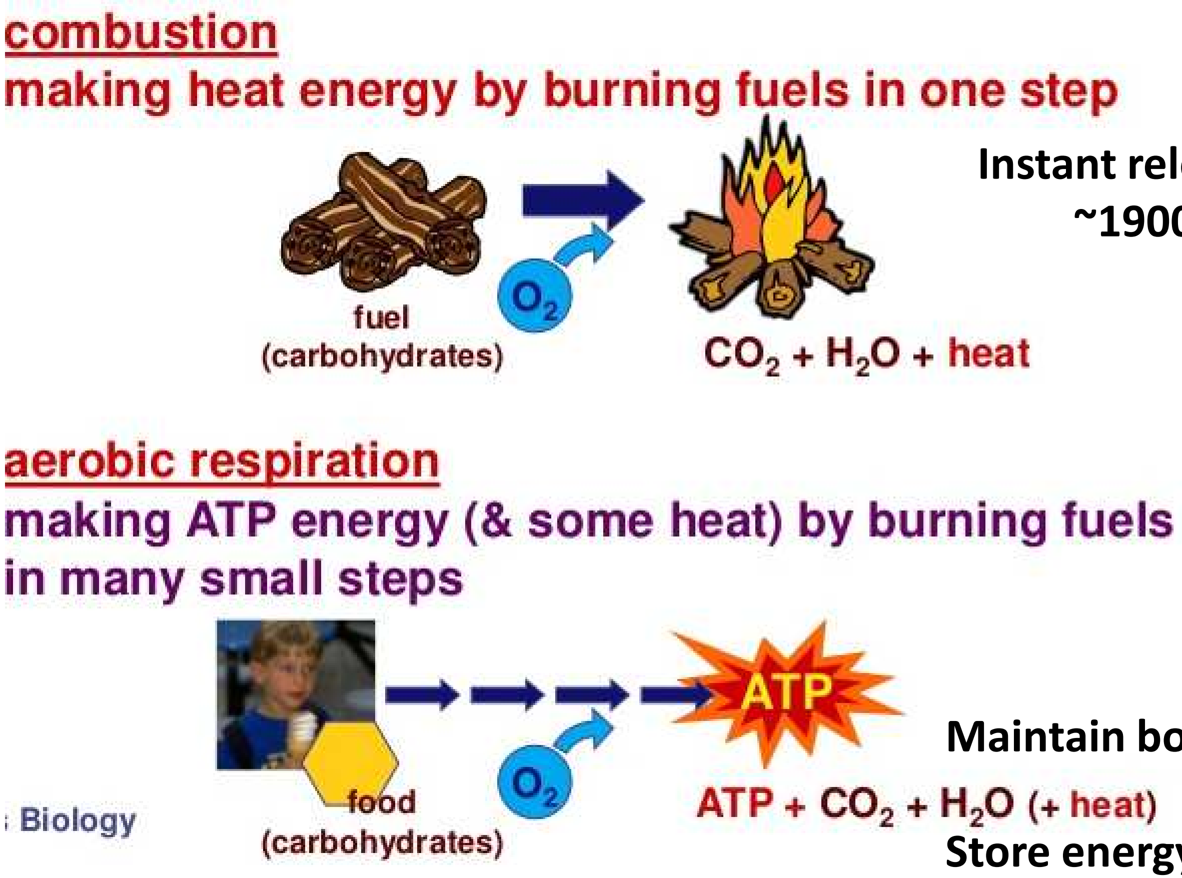


Certain fuel/oxygen ratios

Low humidity

Combustion

Respiration is the chemical reaction in which energy is released from a reaction between Oxygen (O_2) and Glucose ($C_6H_{12}O_6$) Respiration releases energy for cells from glucose



Instant release

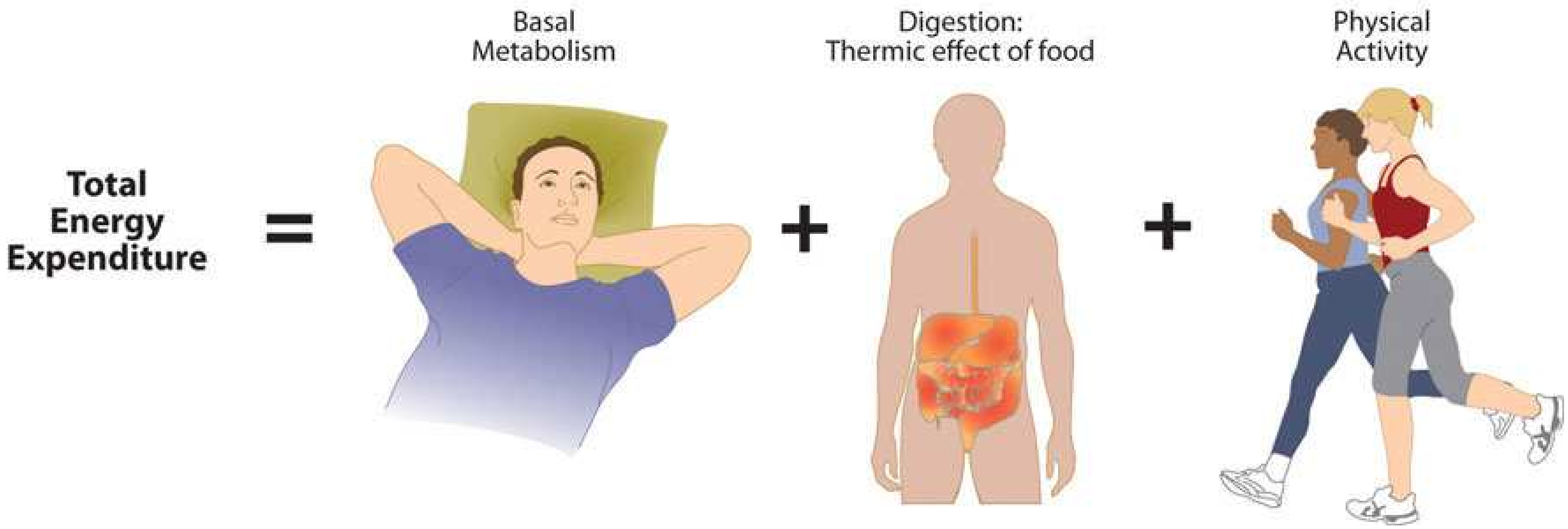
~1900ºC

Maintain body temperature

~37ºC

Store energy

Combustion in biology



Not combustion, but same main emissions **CO_2** and **H_2O**

Combustion in biology

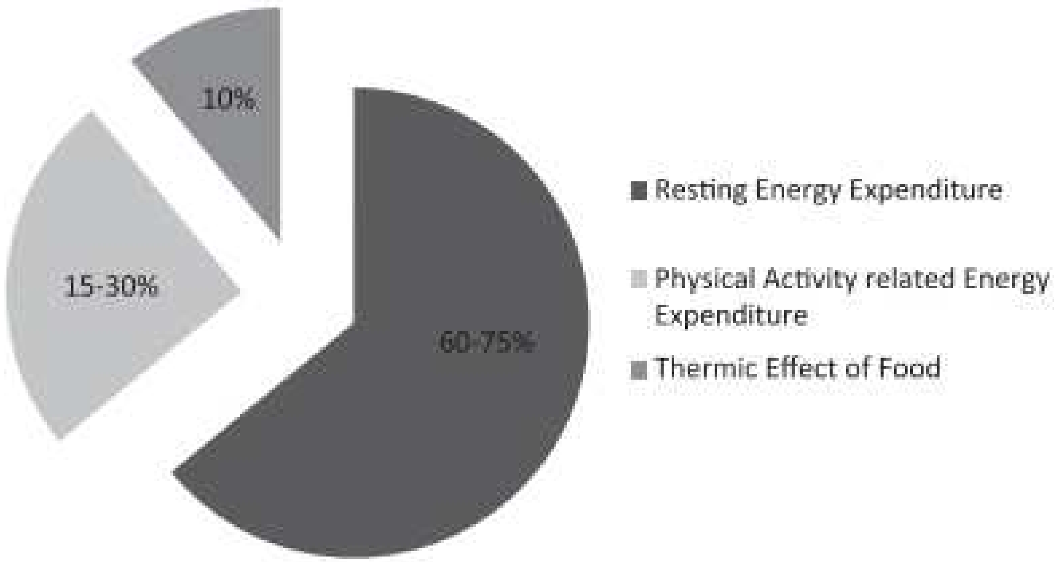


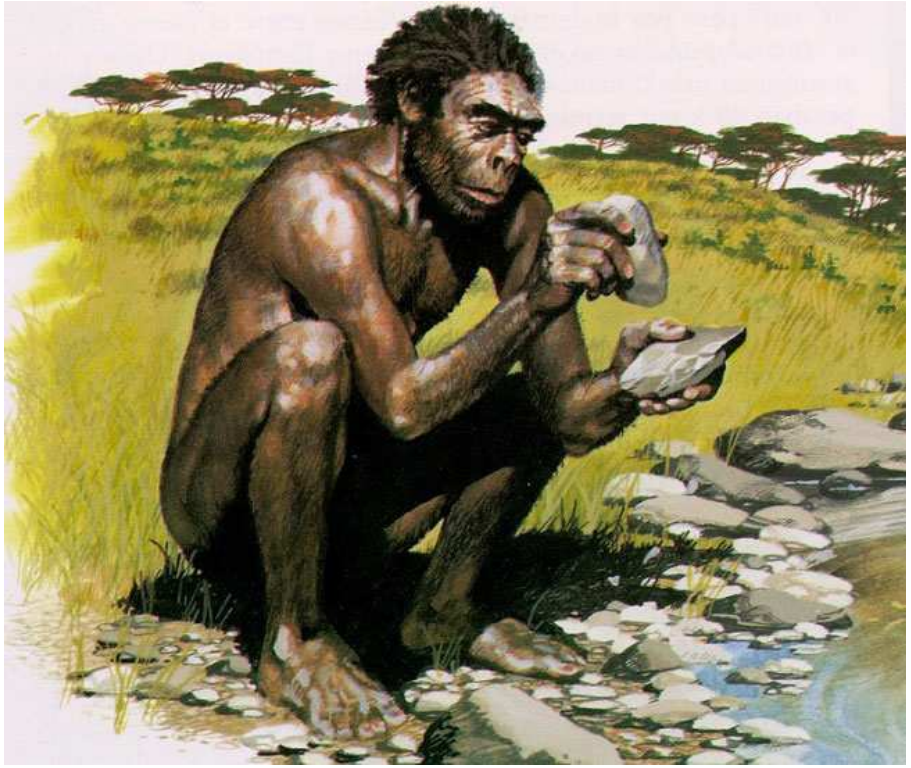
Figure 1. Components of typical total daily energy expenditure. Resting energy expenditure indicates the energy needed to maintain vital life functions during basal and sleeping conditions; physical activity–related energy expenditure, the energy needed to maintain movement demand above that of resting conditions; and thermic effect of food, the energy required for purposes of digestion and the breakdown of food stuff. Modified from McArdle et al.[21]

Combustion history

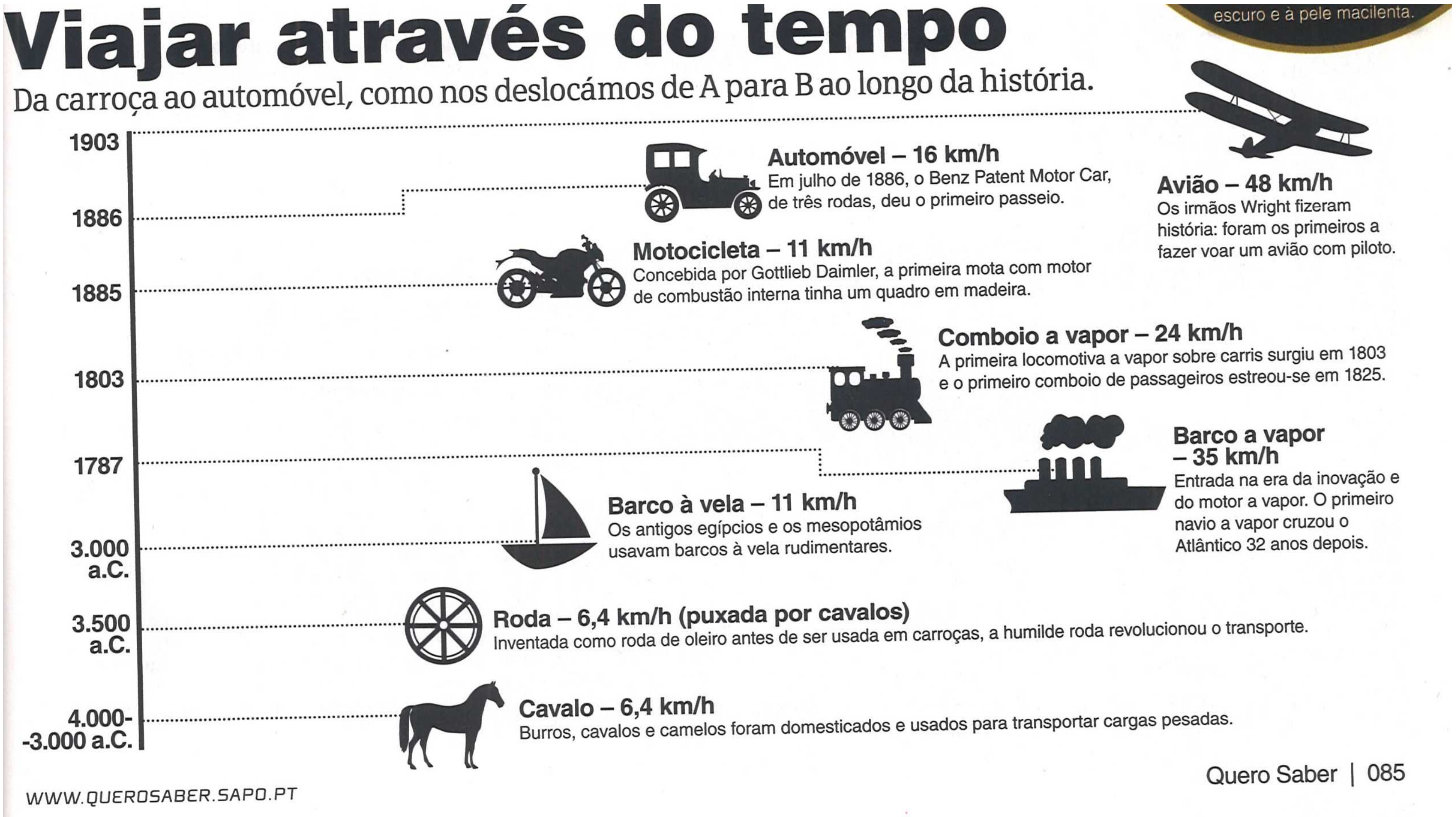
Uncontrolled

Combustion history

Controlled



Combustion in transports



Viajar através do tempo

Da carroça ao automóvel, como nos deslocámos de A para B ao longo da história.

Avião – 48 km/h (1903)
Os irmãos Wright fizeram história: foram os primeiros a fazer voar um avião com piloto.

Automóvel – 16 km/h (1886)
Em julho de 1886, o Benz Patent Motor Car, de três rodas, deu o primeiro passeio.

Motocicleta – 11 km/h (1885)
Concebida por Gottlieb Daimler, a primeira mota com motor de combustão interna tinha um quadro em madeira.

Comboio a vapor – 24 km/h (1803)
A primeira locomotiva a vapor sobre carris surgiu em 1803 e o primeiro comboio de passageiros estreou-se em 1825.

Barco a vapor – 35 km/h (1787)
Entrada na era da inovação e do motor a vapor. O primeiro navio a vapor cruzou o Atlântico 32 anos depois.

Barco à vela – 11 km/h (3.000 a.C.)
Os antigos egípcios e os mesopotâmios usavam barcos à vela rudimentares.

Roda – 6,4 km/h (puxada por cavalos) (3.500 a.C.)
Inventada como roda de oleiro antes de ser usada em carroças, a humilde roda revolucionou o transporte.

Cavalo – 6,4 km/h (4.000-3.000 a.C.)
Burros, cavalos e camelos foram domesticados e usados para transportar cargas pesadas.

WWW.QUEROSABER.SAPO.PT

Quero Saber | 085

Combustion in our lifes

- Transport

Combustion of hydrogen

Combustion of maritime diesel

Combustion of diesel fuel

Combustion of jet fuel

Combustion in our lifes

- Cooking wood; e.g. Africa

Emission to indoor environment

Combustion in our lifes

- Cooking; Thermal comfort

Most emission to outdoor environment

Combustion of natural gas

Combustion of wood/pellets

Combustion in our lifes

- Generation of electricity

Combustion of coal

Combustion of diesel

Combustion of natural gas

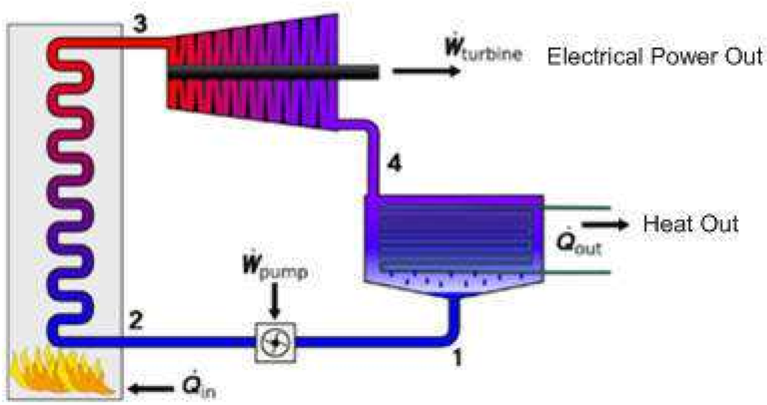
Combustion in our lifes

- Generation of electricity

Combustion of coal

Combustion of biomass

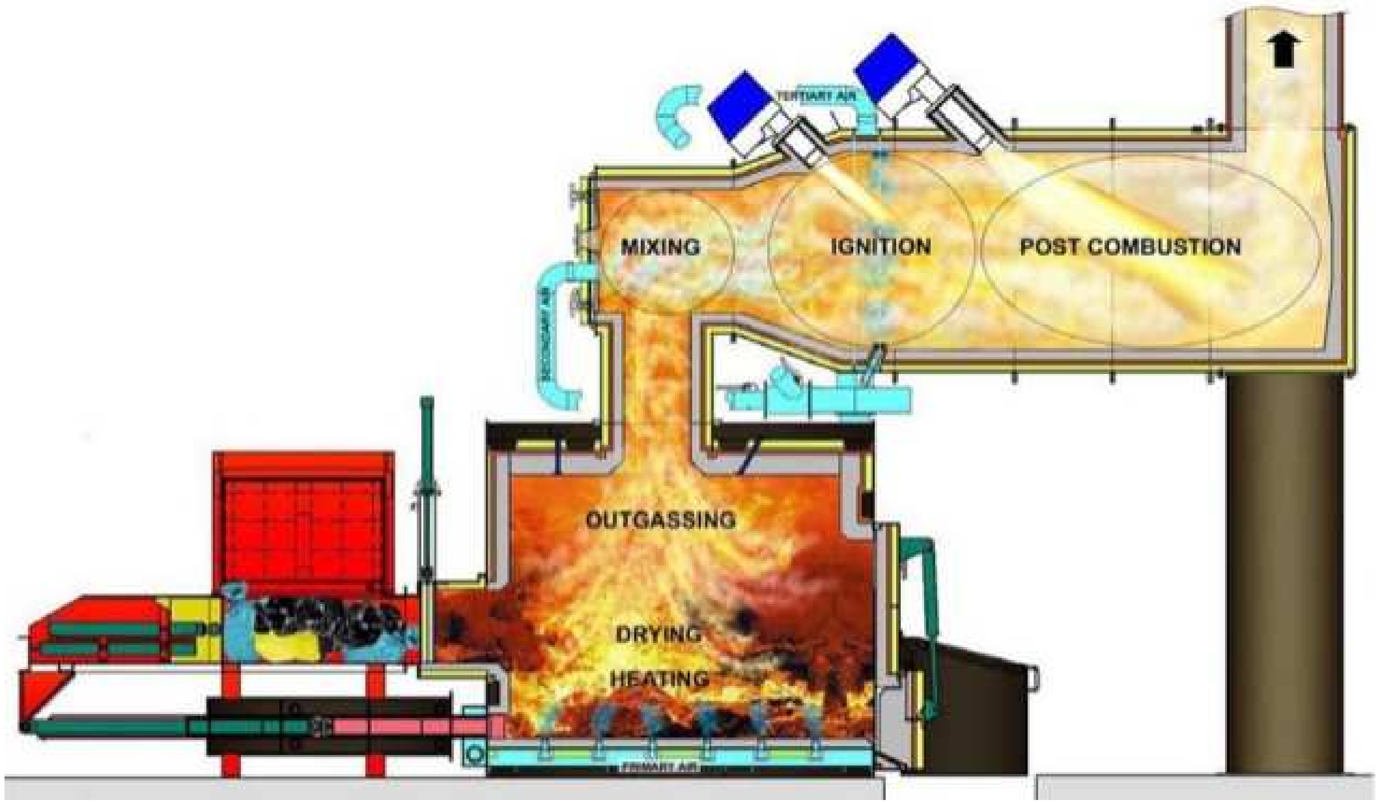
Combustion of natural gas



1. Low Pressure Cool Liquid
2. High Pressure Liquid/Vapor
3. High Pressure Hot Gas
4. Low Pressure Hot Gas

Combustion in our lifes

- Waste disposal/Incineration



Combustion in our lifes

- Waste disposal up to 1000 kg/capita/year

Table 2.1 Key figures—municipal solid waste (kg/capita/year)

Area	*Ref.*	*Waste generation [kg/cap./year]* *Range*	*Mean*	*Annual growth rate*
OECD—total	/2/	263–864	513	1.9%
North America	/2/		826	2.0%
Japan	/2/		394	1.1%
OECD—Europe	/2/		336	1.5%
Europe (32 countries)	/3/	150–624	345	n.a.
8 Asian Capitals	/4/	185–1000	n.a.	n.a.
South and West Asia (cities)	/5/	185–290	n.a.	n.a.
Latin America and the Caribbean	/6/	110–365	n.a.	n.a.

Combustion in our lifes

- Waste disposal

Table 2.2 Composition of municipal wastes (percentage of wet weight)

% of waste		*Guangzhou, China, 8 districts*		*Manila*	*22 European Countries*	
	Year	*1993*		*1997*	*1990*	
	Ref.	*/7/*		*/9/*	*/3/*	
Fraction		*Range*	*Mean*	*Mean*	*Range*	*Mean*
Food and organic waste		40.1 – 71.2	46.9	45.0	7.2 – 51.9	32.4
Plastics		0.9 – 9.5	4.9	23.1	2 – 15	7.5
Textiles		0.9 – 3.0	2.1	3.5	n.a.	n.a.
Paper & cardboard		1.0 – 4.7	3.1	12.0	8.6 – 44	25.2
Leather & rubber		..	..	1.4	n.a.	n.a.
Wood		..	..	8.0	n.a.	n.a.
Metals		0.2 – 1.7	0.7	4.1	2 – 8	4.7
Glass		0.8 – 3.4	2.2	1.3	2.3 – 12	6.2
Inerts (slag, ash, soil, etc.)		14.0 – 59.2	40.2	0.8	..	..
Others		..	..	0.7	6.6 – 63.4	24.0

Notes: n.a. = Not applicable
.. = Negligible

@http://web.mit.edu/urbanupgrading/urbanenvironment/resources/references/pdfs/MunicipalSWIncin.pdf

Combustion in our lifes

- Waste incineration and energy generation

Osaka, Japan

Outputs	Efficiency	Use
Heat Only	Up to 80-90%[15] thermal efficiency.	Local district heating for buildings (residential, commercial) and or for industrial processes.
Electricity	14%-27%*	Can be supplied to national grid for sale and distribution.
Heat and Power	Dependent on specific demand for heat and power.	Combination of above.

* The lower efficiency performance is more typical of older facilities and it is possible that in the future the efficiency of electricity generation using incineration will increase.

Table 3: Examples of Energy Efficiency for Incineration

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/221036/pb13889-incineration-municipal-waste.pdf

Combustion in our lifes

- Waste incineration and energy generation

Denmark: around **31** Waste-to-Energy plants, with an average capacity of 120,000 t/y; 100% CHP Waste-to-Energy plants -

Netherlands: 12 Waste-to-Energy plants, with an average capacity of 620,000 t/y; 100% CHP Waste-to-Energy plants (2011 data) -

Germany: 71 Waste-to-Energy plants, with an average capacity of 250,000 t/y; 71.8% (= 51/71) of CHP Waste-to-Energy plants -

France: 130 Waste-to-Energy plants with an average capacity of 100,000 t/y 27.7% (= 36/130) of CHP Waste-to-Energy plants;

Italy: 50 Waste-to-Energy plants with an average capacity of 100,000 t/y; 11 (22%) CHP Waste-to-Energy plants: All CHP are among the 29 plants in Northern Italy (none in the 24 plants in Central and Southern Italy). (2010 data, Federambiente) -

Spain: 10 Waste-to-Energy plants with an average capacity of 220,000 t/y; 1 CHP Waste-to-Energy plant; 10% of CHP Waste-to-Energy plants -

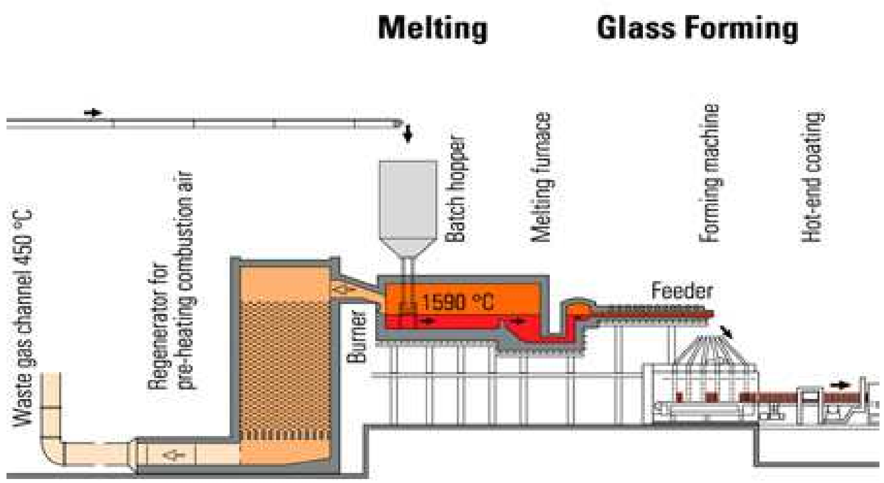
Portugal: 3 Waste-to-Energy plants with an average capacity of 350,000 t/y; 0 (0%) CHP Waste-to-Energy plants (all generating electricity only)

@http://iet.jrc.ec.europa.eu/remea/sites/remea/files/r1_climate_factor_report_final.pdf

Energy recovery Efficiency in Municipal Solid Waste-to-Energy plants in relation to local climate conditions

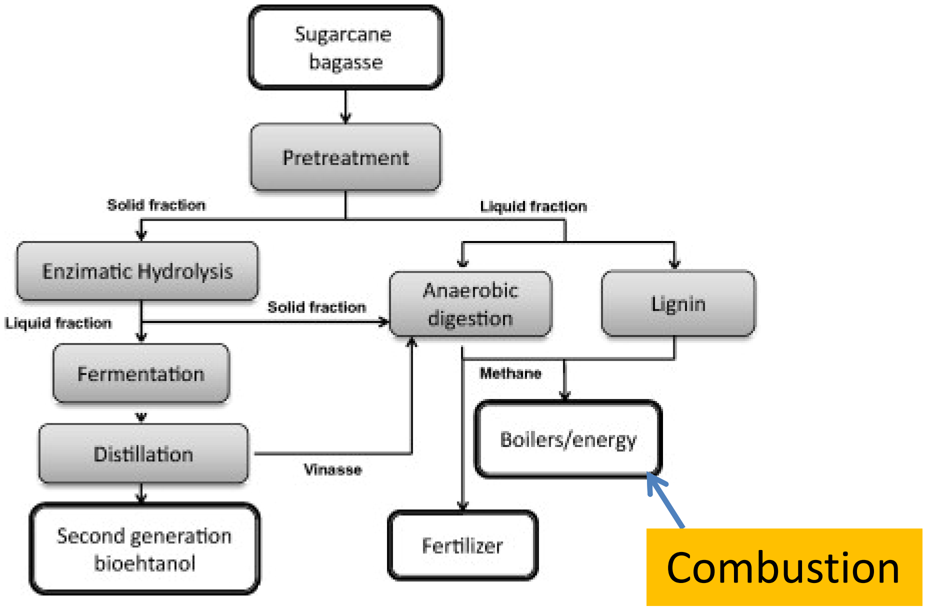
Combustion in our lifes

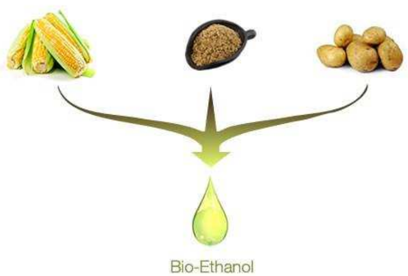
- Product manufacturing

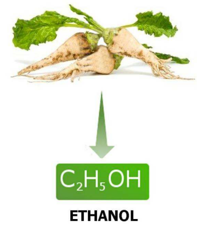


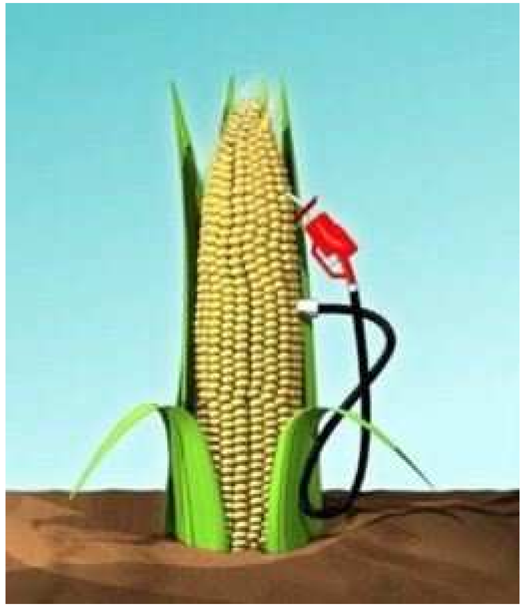
Combustion in our lifes

- Product manufacturing









Combustion in our lifes

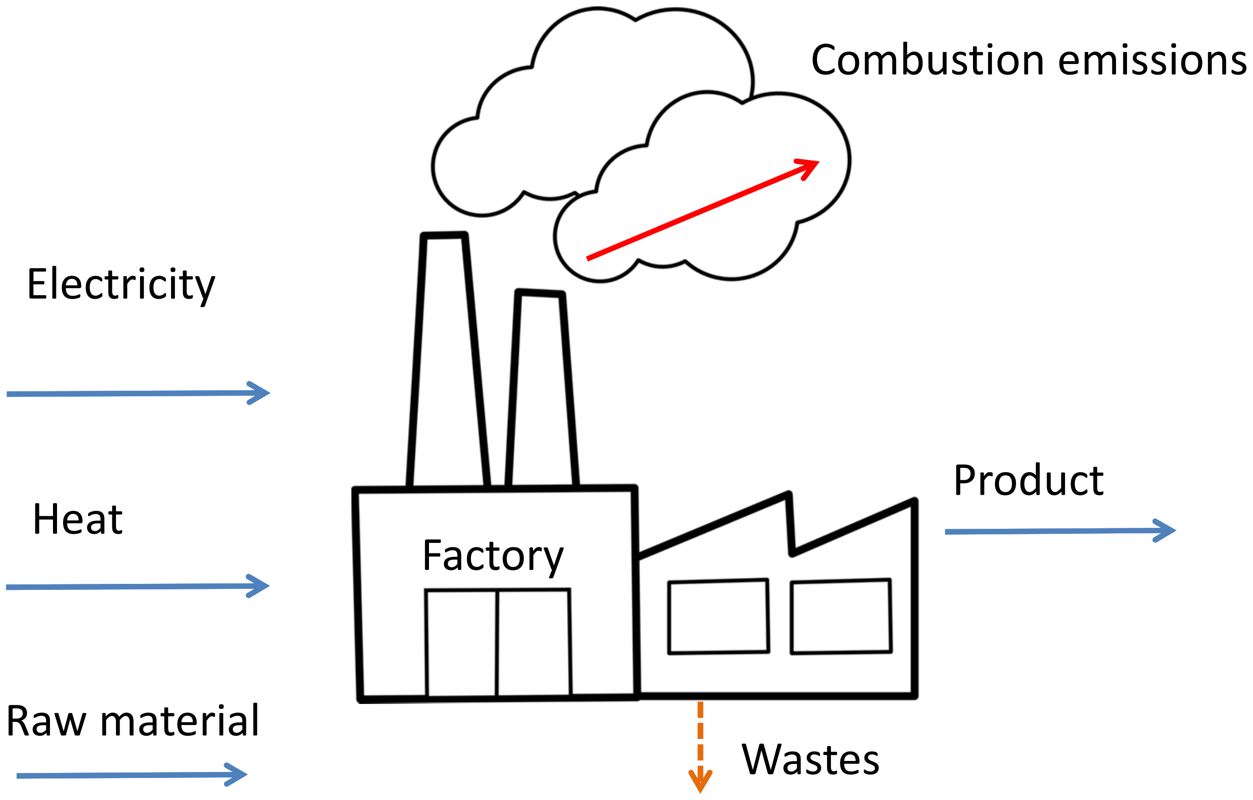
- Product manufacturing

SESEC
Sustainable Energy Saving
for the European Clothing Industry

Energy can either be supplied by direct combustion of gas in the productive machines, or indirectly through production of steam or hot water

Combustion in our lifes

- Product manufacturing



Ciências ULisboa

Combustion in our life

- Product manufacturing

robots welding in an automobile factory (automotive, manufacturing, automation)

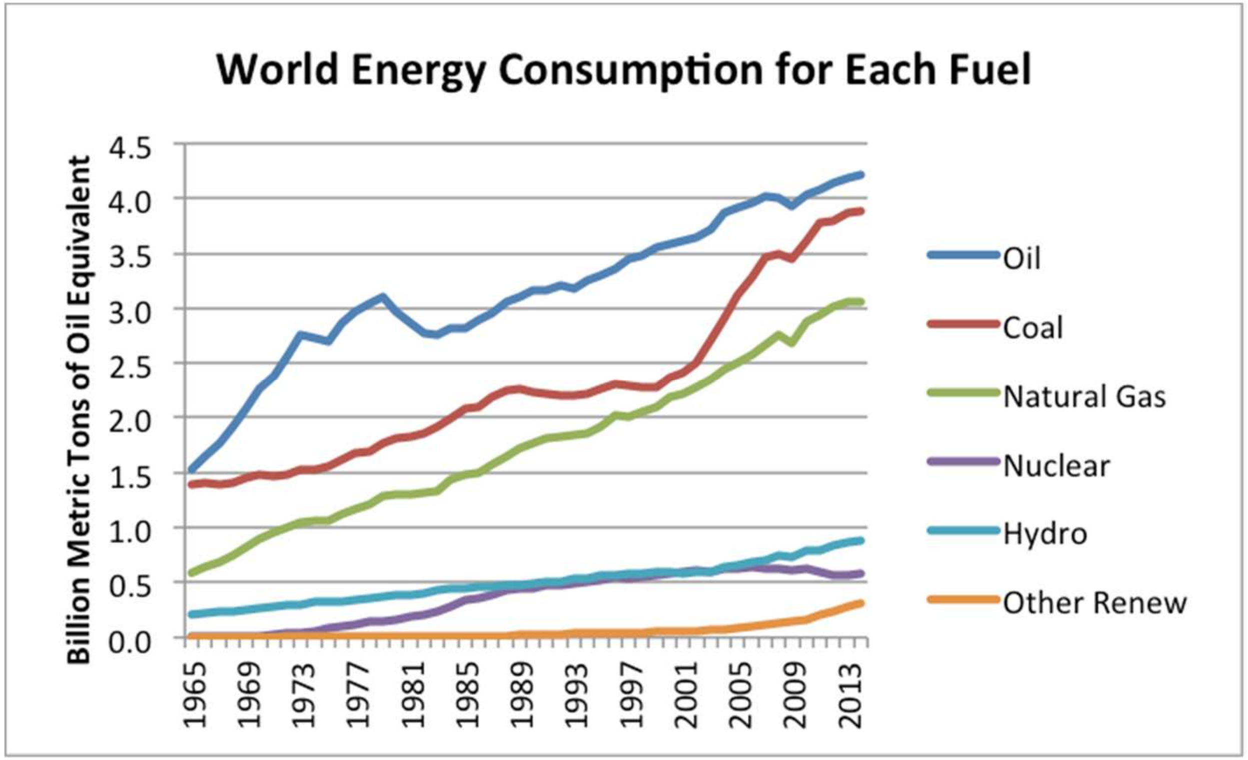
Combustion

Combustion in our lifes/uncontrolled

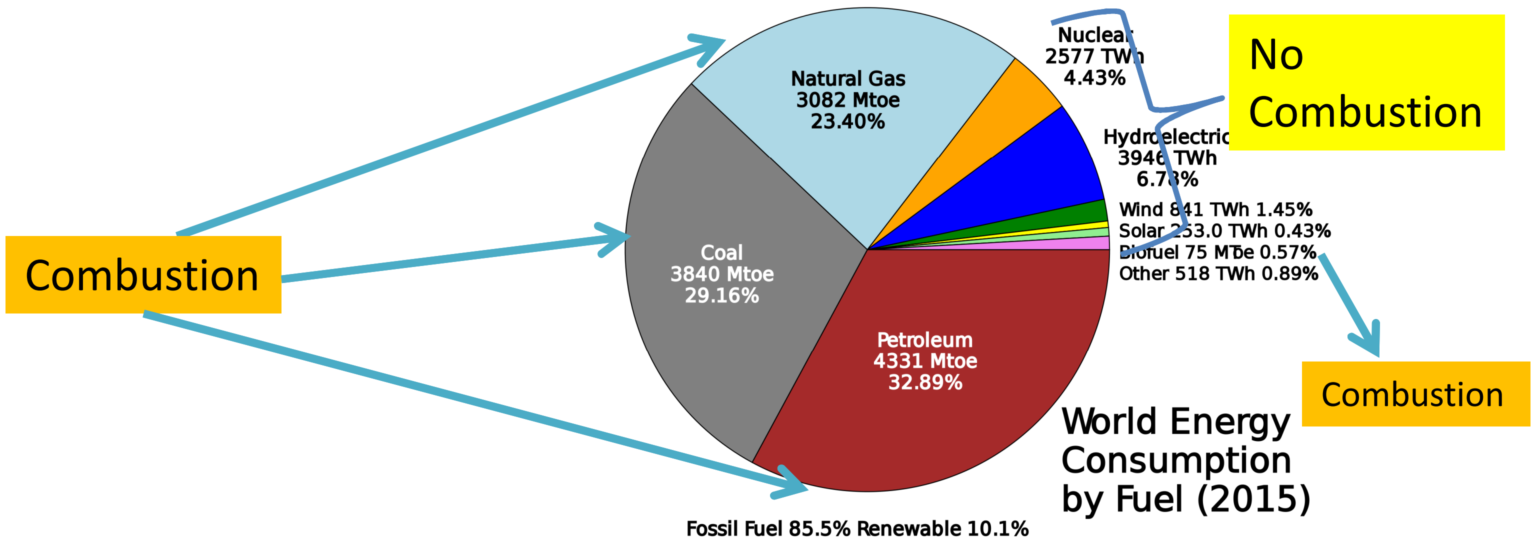
Combustion in our life/uncontrolled

Combustion in our lifes

Combustion use in the world

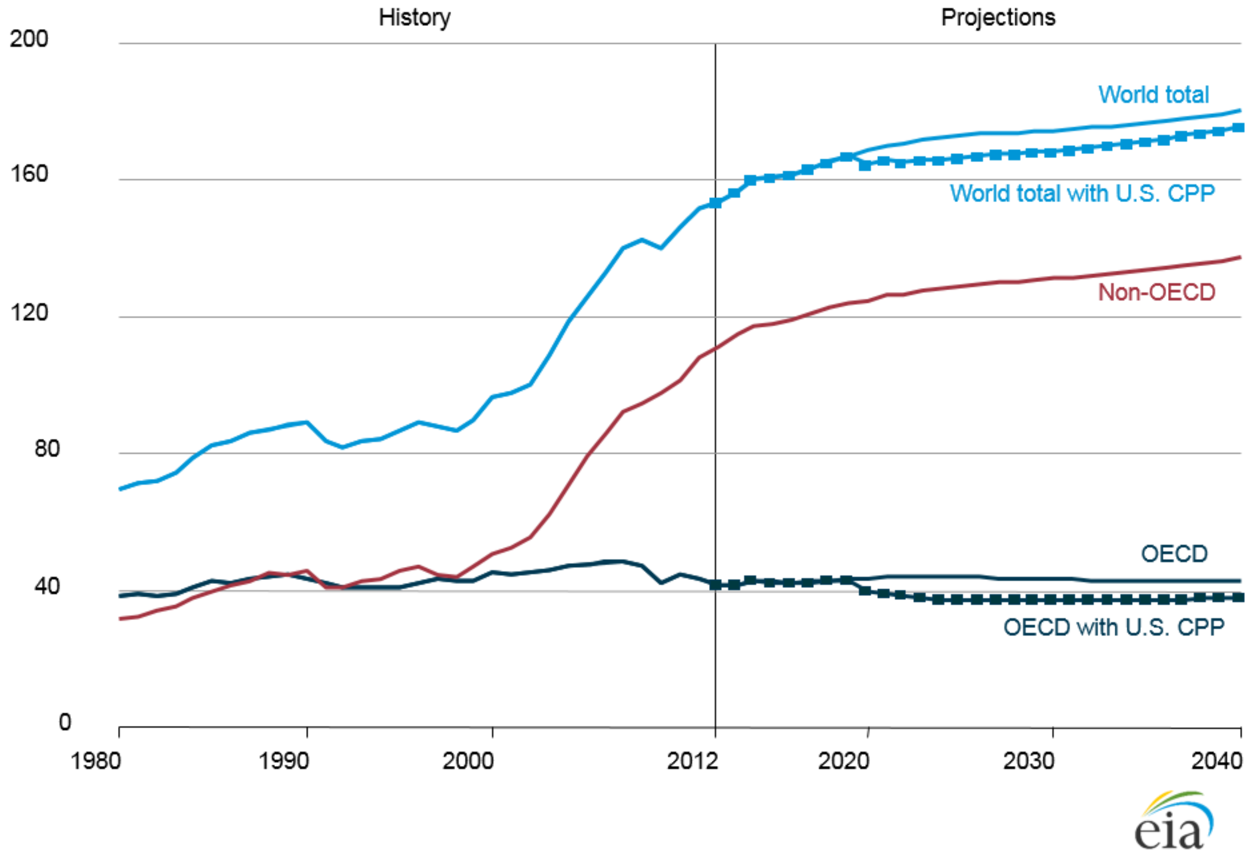


Combustion use in the world



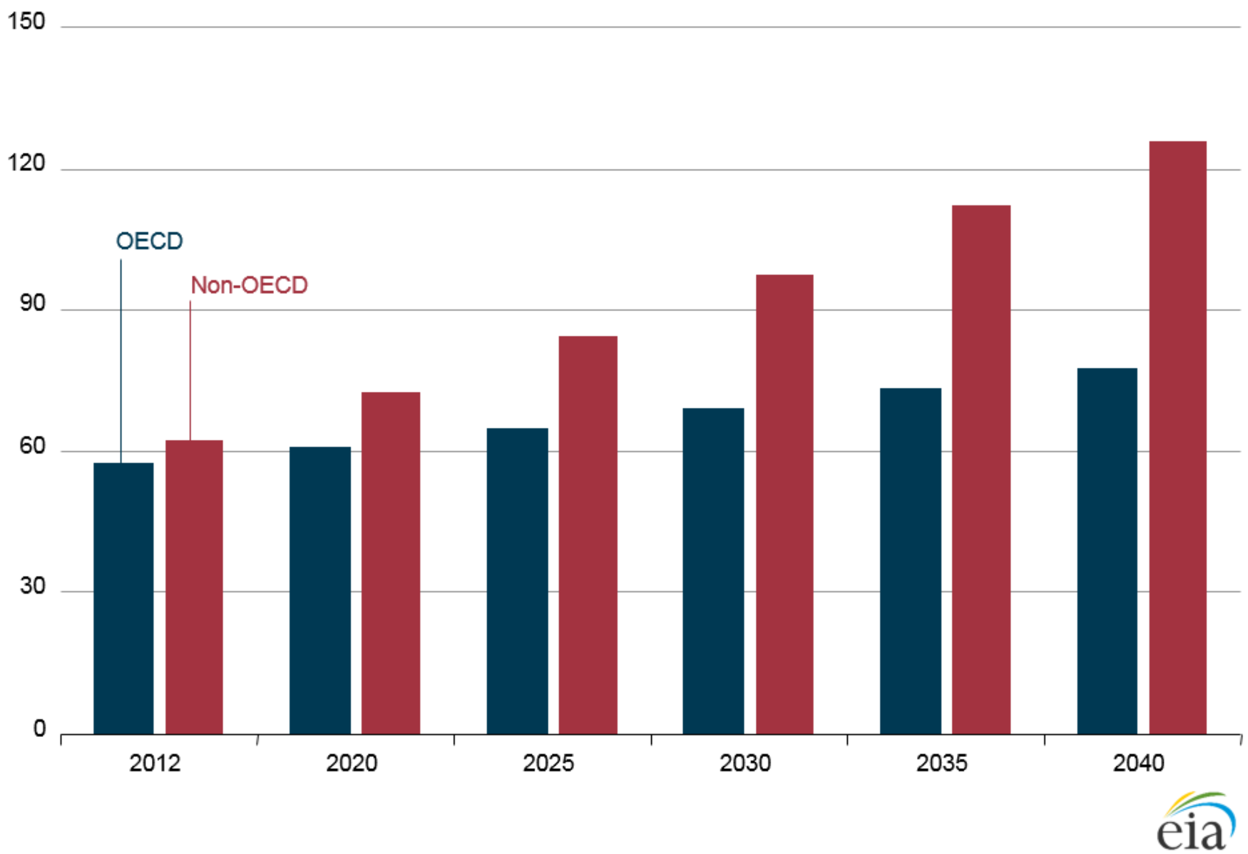
Combustion use in the world

Figure 4-1. World coal consumption by region, 1980–2040
quadrillion Btu

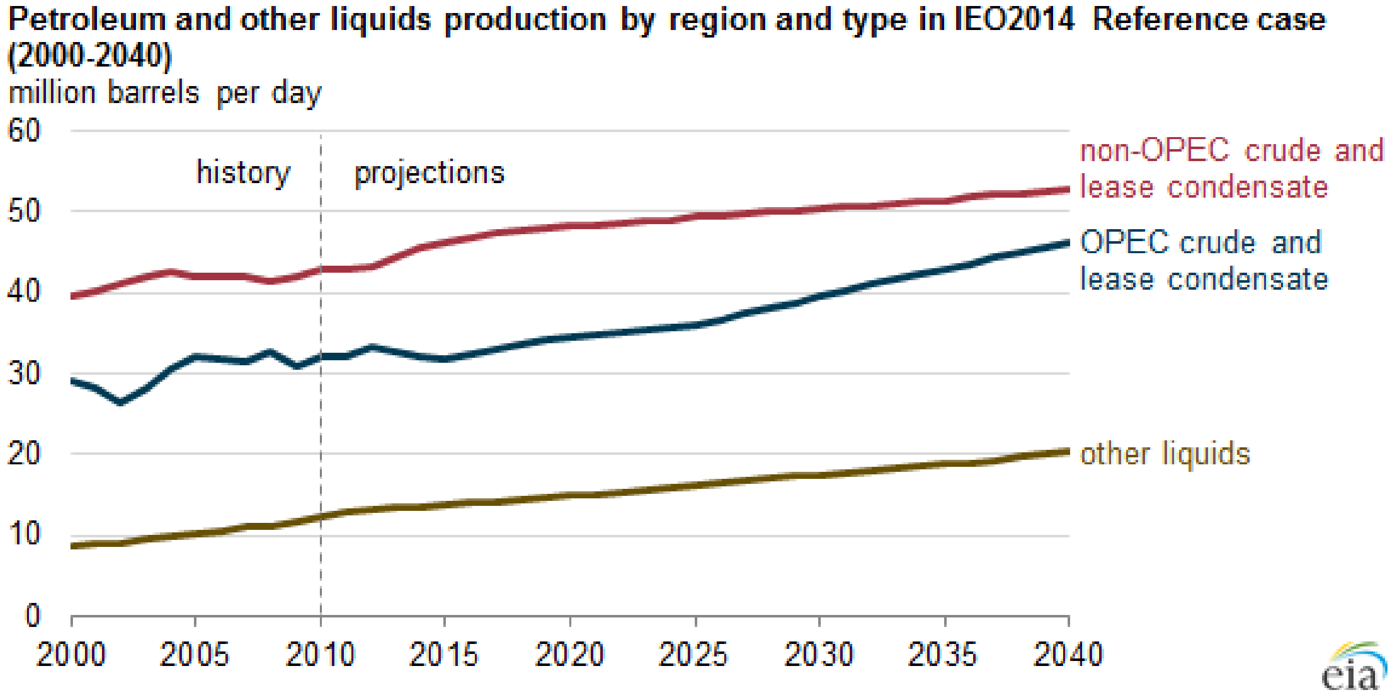


Combustion in the world

Figure 3-1. World natural gas consumption, 2012–40
trillion cubic feet



Combustion in the world



Combustion problem

1 toe = 41.868 GJ or 11.63 MWh

the amount of energy released by burning one tonne of crude oil

Combustion problem

Why do we have emissions???

$$C_nH_m + S + N_2 + O_2 \rightarrow CO_2 + H_2O + N_2 + O_2 + NO_x + CO + SO_x + Soot + UHC$$

- Fuel: C_nH_m
- Air: $N_2 + O_2$
- Products of ideal combustion: $CO_2 + H_2O + N_2 + O_2$
- Products of non-ideal combustion: $NO_x + CO + SO_x + Soot + UHC$

NO_x: Affects ozone (O_3) concentration
CO_2: Absorbs outgoing infrared radiation
CO: Toxic
Soot: Visible

Combustion problem

1 toe = 41.868 GJ or 11.63 MWh

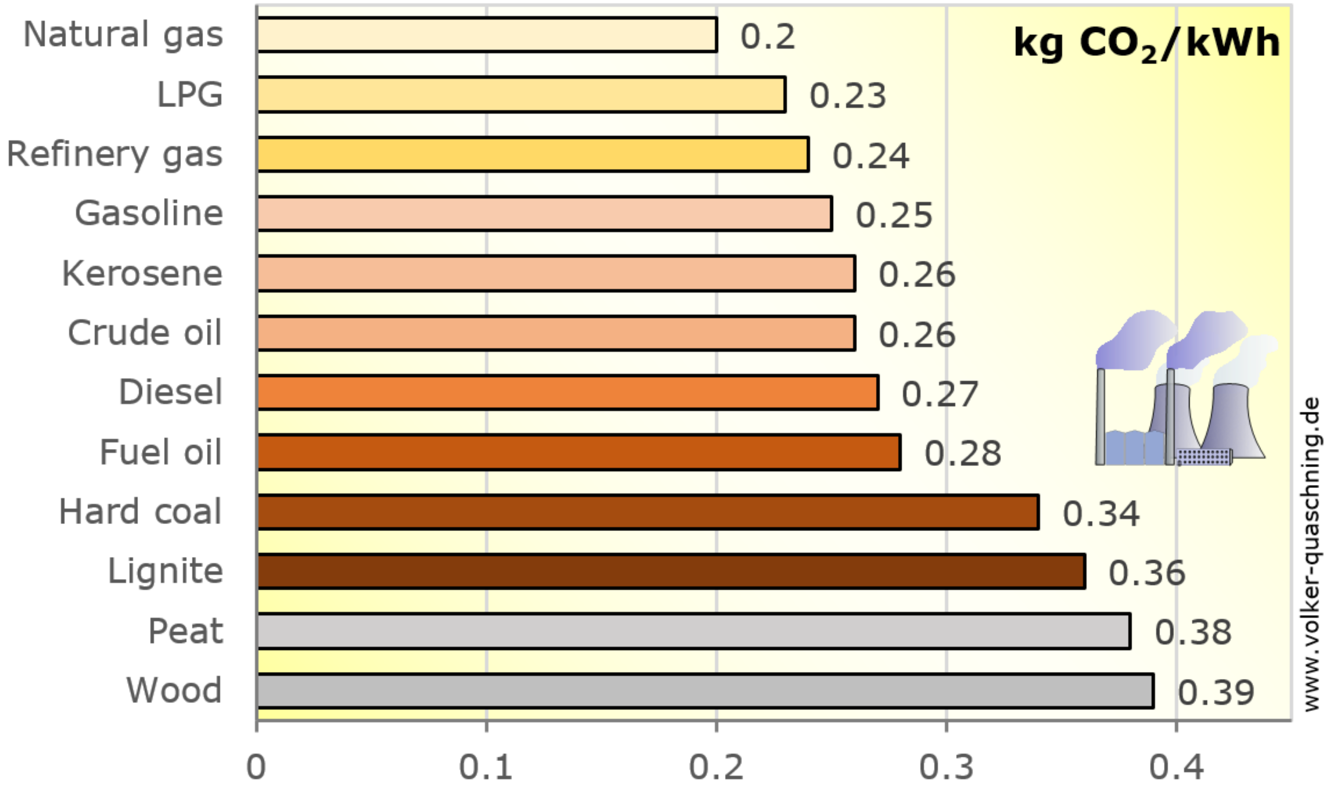
the amount of energy released by burning one tonne of crude oil

1 toe ~ 2.5 tCO_2

Table 1.3 Typical pollutants of concern from selected sources

Source	Pollutants: Unburned Hydrocarbons	Oxides of Nitrogen	Carbon Monoxide	Sulfur Oxides	Particulate Matter
Spark-ignition engines	+	+	+	−	−
Diesel engines	+	+	+	−	+
Gas-turbine engines	+	+	+	−	+
Coal-burning utility boilers	−	+	−	+	+
Gas-burning appliances	−	+	+	−	−

Combustion problem



Specific Carbon Dioxide Emissions of Various Fuels

Combustion problem

Transports, local emissions

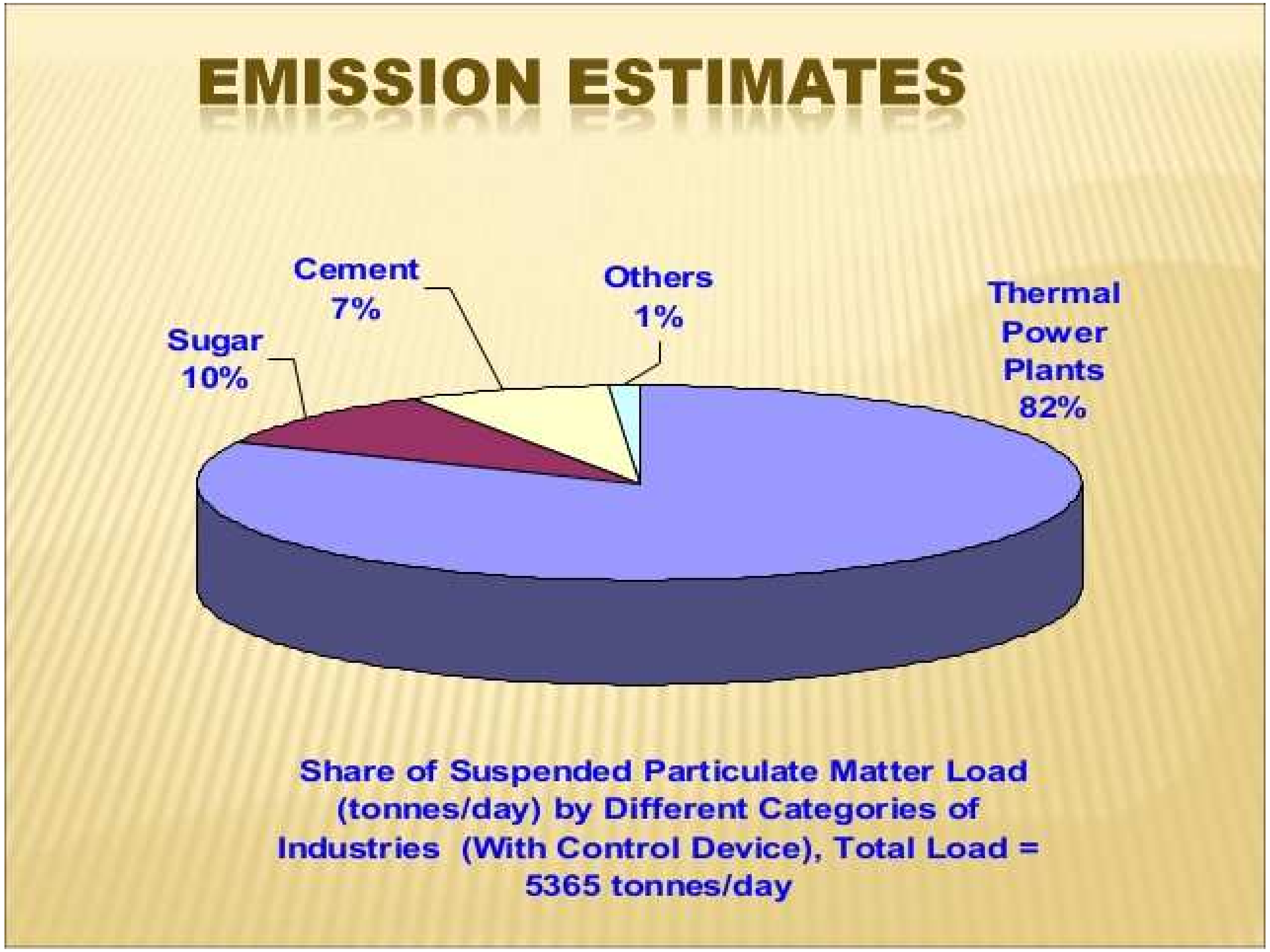
LOCAL AIR QUALITY EMISSIONS (EUROPE)

					NON-TRANSPORT	
NOx	32.9%	0.9%	19.1%	4.5%	NOx	42.6%
CO	26.6%	0.2%	2.3%	0.7%	CO	70.2%
SOx	0.1%	0.0%	20.9%	0.5%	SOx	78.5%
VOLATILE ORGANIC COMPOUNDS	15.4%	0.14%	2.52%	0.40%	VOLATILE ORGANIC COMPOUNDS	81.54%
FINE PARTICLES (PM2.5)	14.2%	0.4%	11.4%	0.6%	FINE PARTICLES (PM2.5)	73.4%

In % of total emissions | source: European Environment Agency, 2013

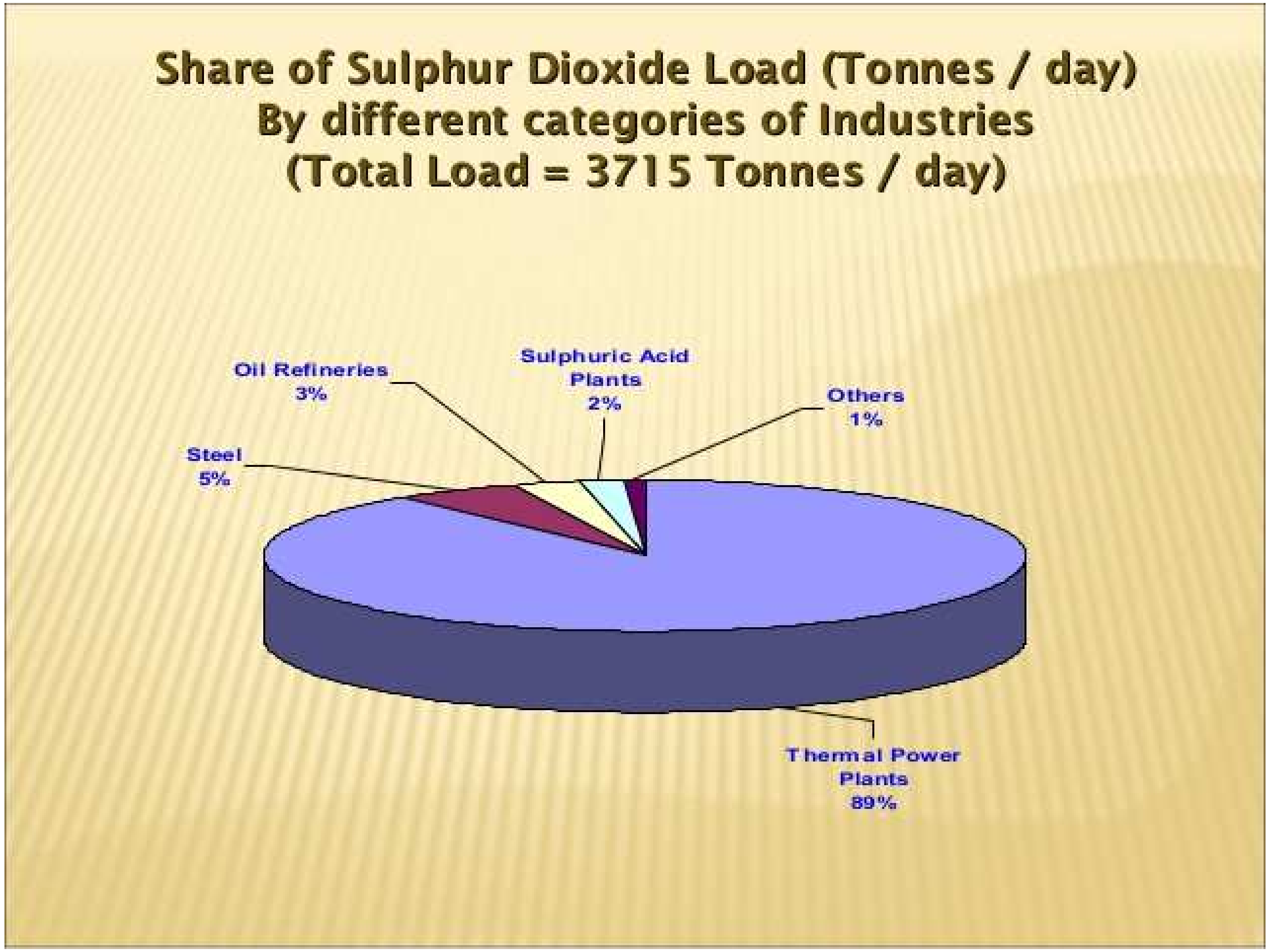
THANKS TO IMPROVEMENTS IN AIRCRAFT TECHNOLOGY, THE IMPACT OF AIRCRAFT EMISSIONS ON LOCAL AIR QUALITY IS RELATIVELY LOW COMPARED TO OTHER SOURCES.

Combustion problem



PM10;PM2.5

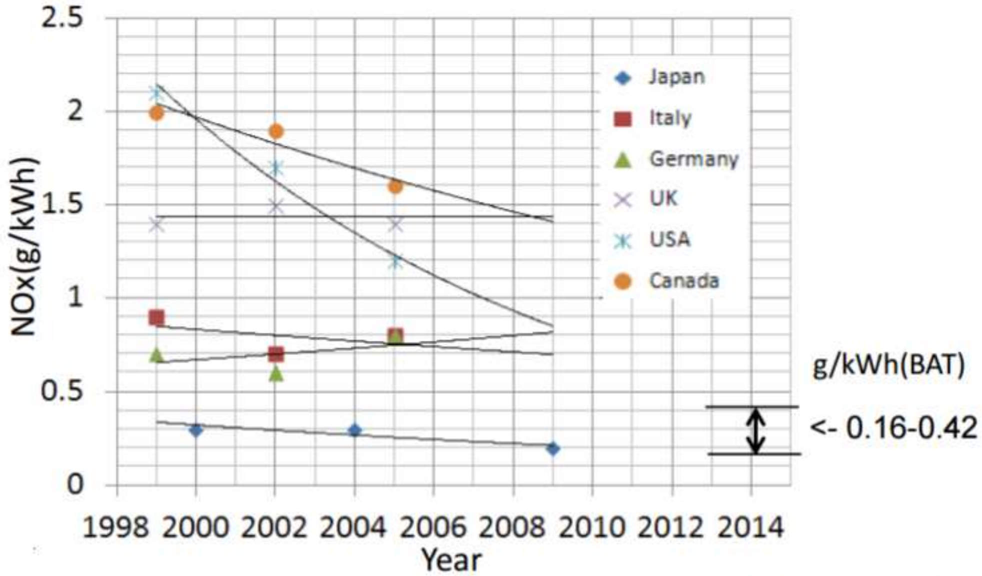
Combustion problem



SO_2

Combustion problem

Figure: Trend of average NOx emission from thermal power plants



Source: Federation of Electric Power Companies,INFOBASE2010

BAT :Best Available Technology

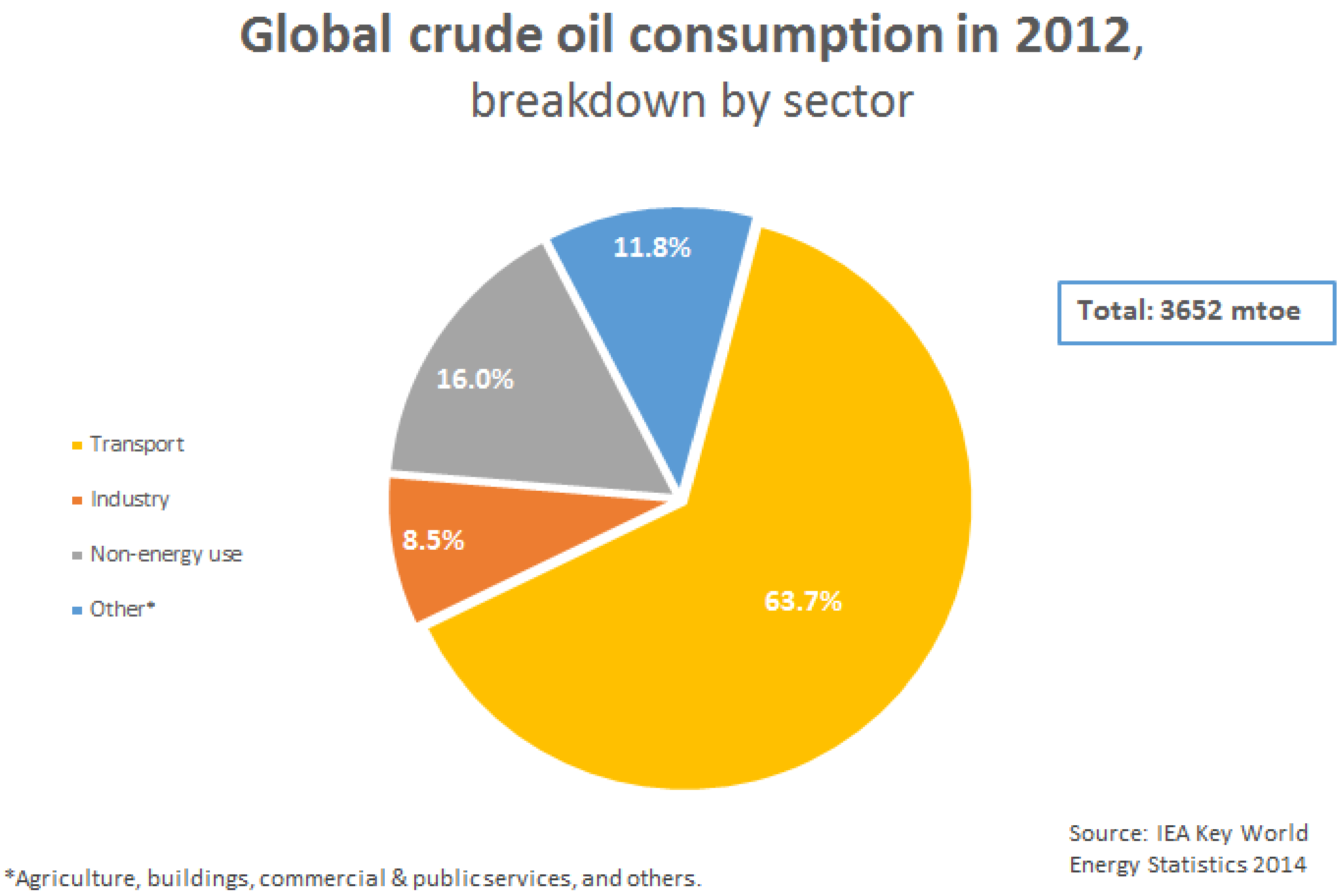
NO_2, NO

Typically called

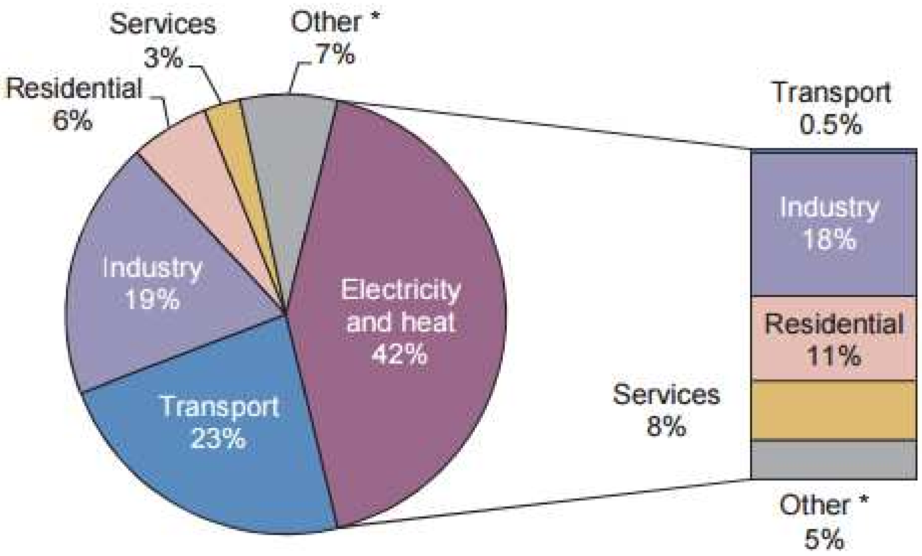
NOx

2 ordens de grandeza abaixo do CO_2

Combustion in the world



Combustion in the world



Note: Also shows allocation of electricity and heat to end-use sectors.

* Other includes agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

World CO_2 emissions by sector in 2013 Note: Also shows allocation of electricity and heat to end-use sectors. * Other includes agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

Future goals

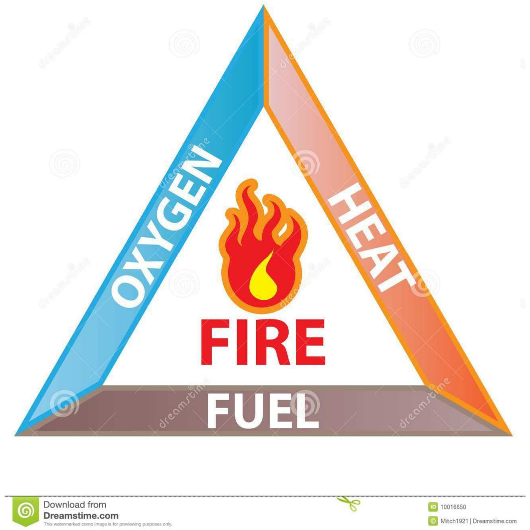
- Increase efficiency
- Reduce emissions

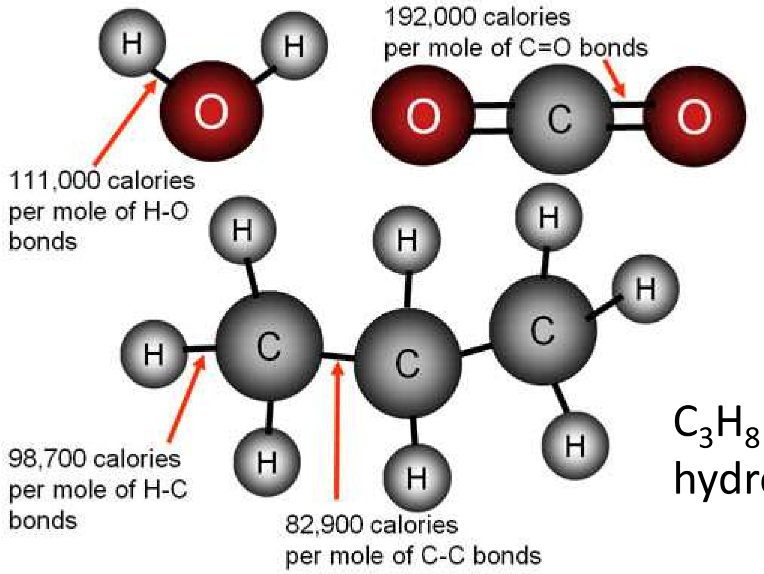
Avoid combustion in some sectors, e.g., transport

Combustion definition

Combustion is essentially burning, fuels react with oxygen to release energy (heat or both light and heat)

Combustion transforms energy stored in chemical bonds to heat that can be utilized in a variety of ways





C_3H_8
hydrocarbon

Thermochemistry

$$fuel + oxidizer \rightarrow products$$

Generic hydrocarbon

$C_xH_yO_z$

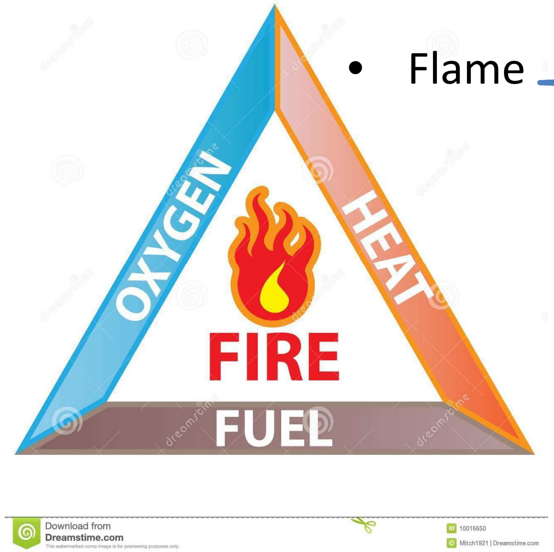
O_2 or air

CO_2, H_2O and N_2

Air composition

21% O2 and 79% N2 (by volume)

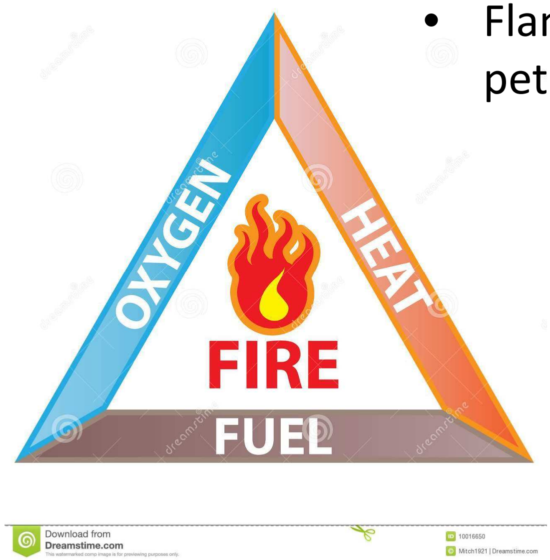
Flame types



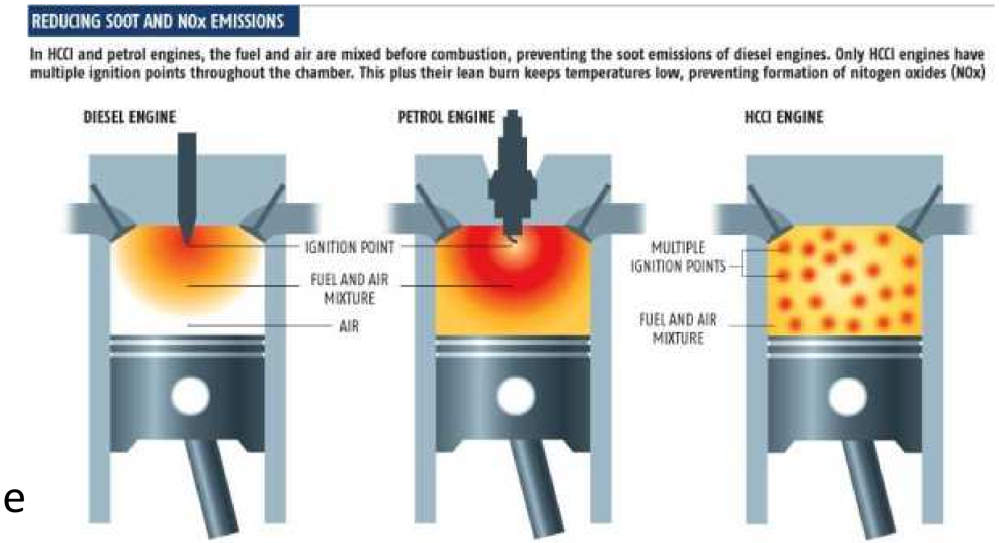
- Flame
  - Premixed
    - Fuel and oxidizer are mixed at the molecular level prior to the occurrence of any significant chemical reaction
  - Nonpremixed (difusion)
    - Laminar
    - Turbulent
- Nonflame

Ciências ULisboa

Combustion modes



- Flame e.g. petrol engine

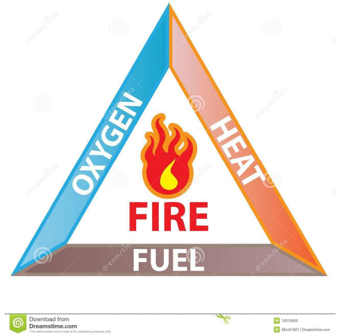


- Nonflame

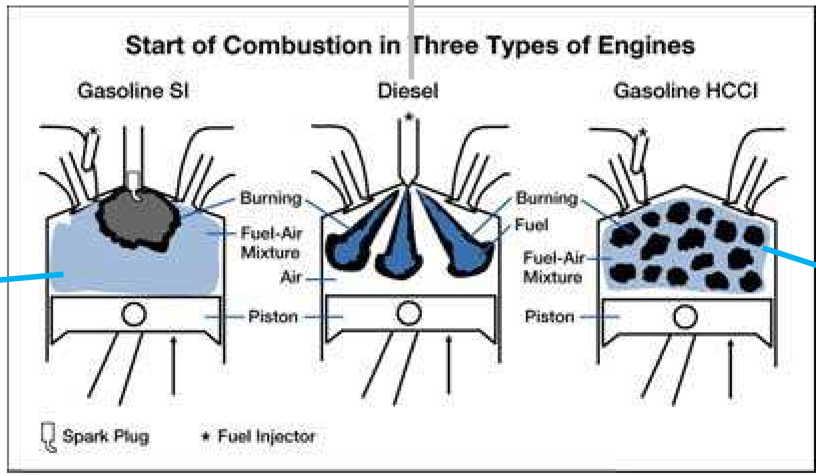
e.g. Diesel engine **autoignition** or homogeneous charge compression by high pressure

https://www.youtube.com/watch?v=9nCr3h0-eV8

Flame types



Nonflame combustion
Nonpremixed (difusion) flame

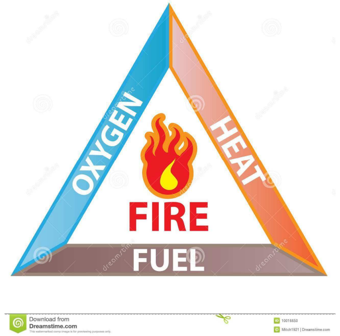


Flame combustion
Premixed flame

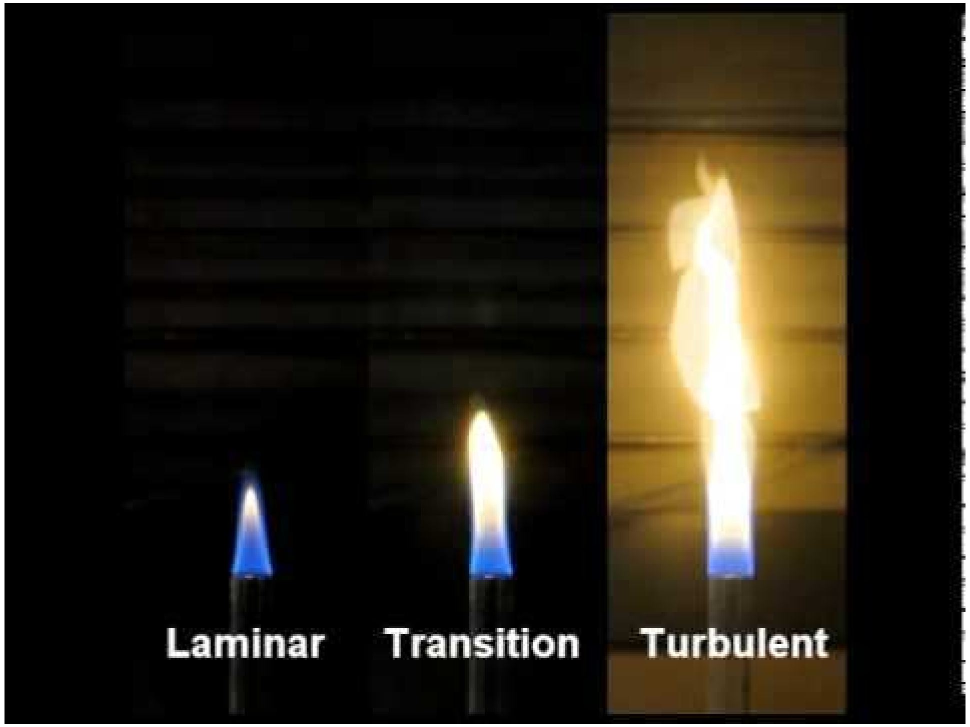
Nonflame combustion
Premixed flame

Internal

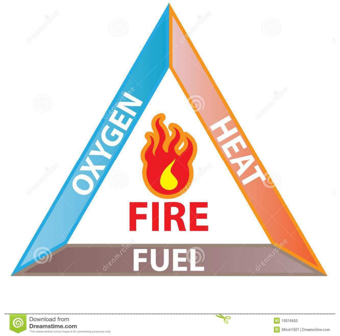
Flame types



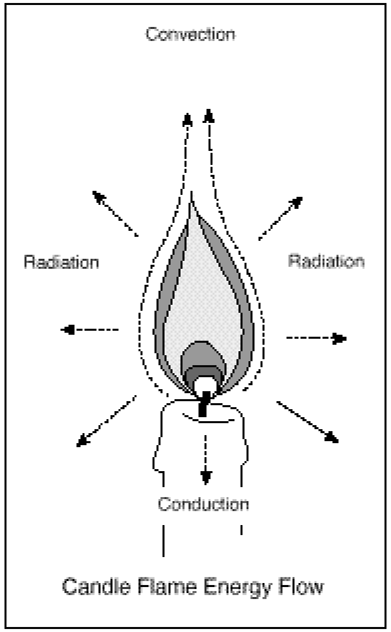
External combustion

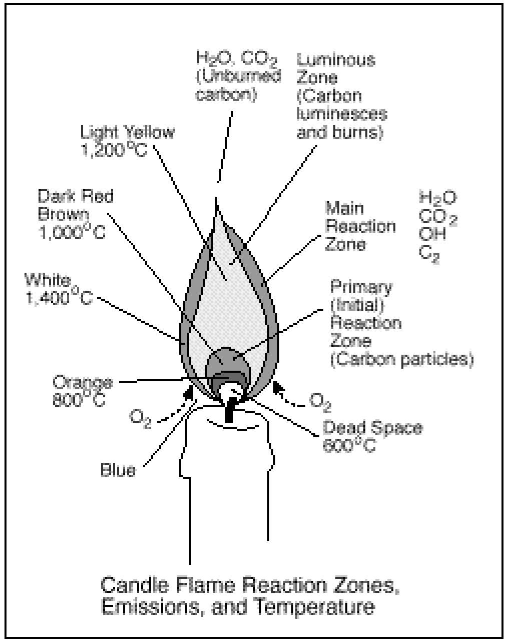


Flame types



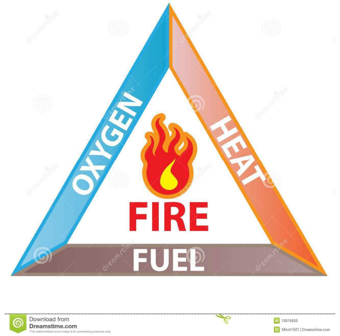
Candle
Fuel: wax
Oxidizer: air
Reaction zone between wax vapours and air (difusion flame)





Candle flame diagrams adapted from "The Science of Flames" poster, National Energy Foundation, Salt Lake City, UT.

Flame types

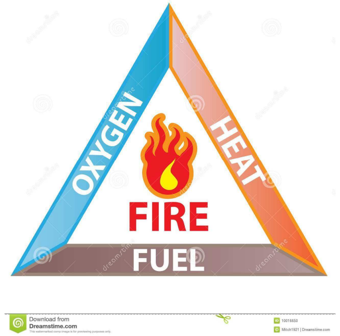


Gravity

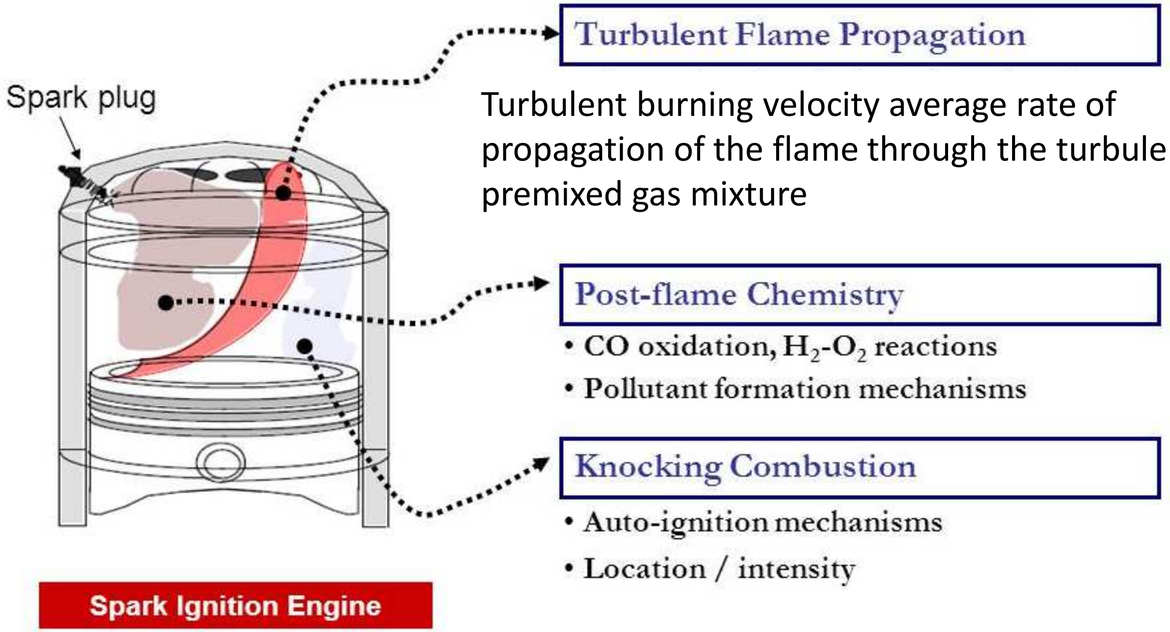
No gravity

You get a blue gas flame when you have enough oxygen for complete combustion

Flame types



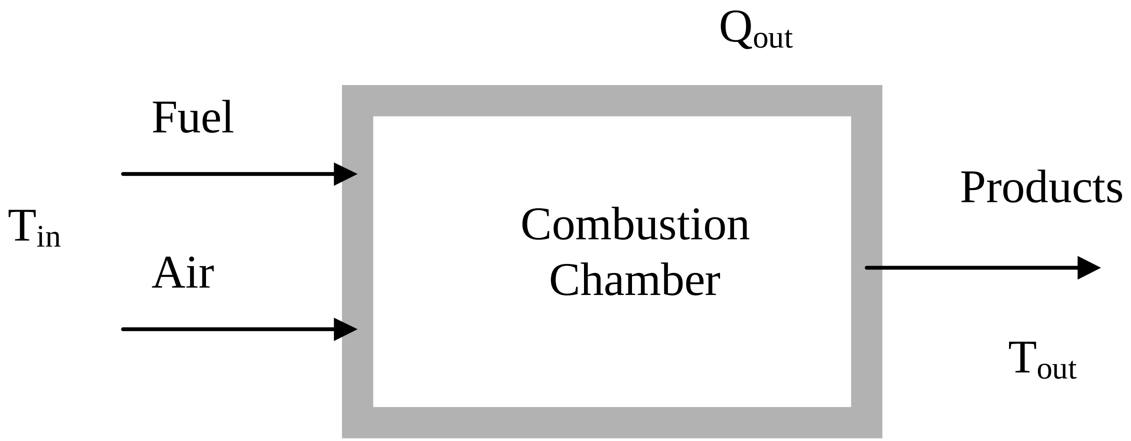
Spark ignition engine
Fuel: gasoline, ethanol, GPL or natural gas
Oxidizer: air
Reaction zone between premixture and air (premixed flame)



Turbulent burning velocity average rate of propagation of the flame through the turbulent premixed gas mixture

Thermochemistry

$$fuel + oxidizer \rightarrow products$$



Thermochemistry

$$fuel + oxidizer \rightarrow products$$

Air composition

21% O2 and 79% N2 (by volume)

$$C_xH_yO_z + n(0.21O_2 + 0.79N_2) \rightarrow xCO_2 + y/2H_2O + 0.79 * nN_2$$

$\lambda = \frac{\frac{A}{F}}{\left(\frac{A}{F}\right)_S}$ excess air coefficient

- λ<1 No sufficient air; fuel is not completely burned
- λ=1 Exact amount air, fuel is completely burned
- λ>1 Excess air; fuel is completely burned

$\phi = \frac{1}{\lambda}$ equivalence ratio

$e(\%) = \frac{\frac{A}{F} - \left(\frac{A}{F}\right)_S}{\left(\frac{A}{F}\right)_S} * 100\% = \frac{1-\phi}{\phi}$ = excess air in %

Thermochemistry

$$\underbrace{fuel + oxidizer}_{\text{Reactants}} \rightarrow products$$

Air composition

21% O2 and 79% N2 (by volume)

$$C_xH_yO_z + n(O_2 + 3.76N_2) \rightarrow xCO_2 + y/2H_2O + 0.79 * nN_2$$

Right amount of oxidizer to burn all fuel?

1) Determine n,

2n+z=2x+y/2 ⇔ n=x+y/4-z/2

2) Determine mass air/mass fuel $(A/F)_s$ this is the stoichiometric air fuel ratio

$$\frac{mass\ air}{mass\ fuel} = \frac{n * (M_{O2} + 3.76M_{N2})}{Mfu} = \frac{(x + \frac{y}{4} - z/2) * (M_{O2} + 3.76M_{N2})}{Mfu}$$

Thermochemistry

P#1 Consider the combustion of CH_4 in air, determine:

a) The stoichiometric ratio;

b) Molar fractions of combustion products with 15% excess air.

Thermochemistry

P#2 A combustion chamber burns propane, C_3H_8 with excess air. Dry analysis (excluding water) of combustion products was: 2%O_2, 12.4% CO_2 and 85.6% N_2. Determine:

a) The excess air.
b) The coefficient of air excess.
c) The equivalence ratio.

Thanks

Ciências
ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa