Environmental Studies
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Controlling pollution: Tropospheric ozone

This Factsheet looks at the problems governments face when trying to reduce local, national and international pollution.

Definitions

Ozone
A gas, composed of three oxygen atoms. A natural constituent of both the stratosphere and troposphere.

Stratospheric ozone
Produced following the photolysis of molecular oxygen. The 'ozone layer' acts as a protective layer, filtering out dangerous UV radiation from the sun.

Tropospheric or Ground-level ozone
A dangerous pollutant generated when primary pollutant gases such as NO_x and VOC react in the presence of sunlight.

Peak ozone concentrations
The highest short-term concentrations that are reached during hot,sunny days when there are very high concentrations of the primary pollutants.

Hemispheric background ozone
The remaining concentration once the emissions of man-made primary pollutants from within a region are switched off. Made up of ozone produced from natural sources plus the ozone that has been imported into a region via global air circulation.

Ozone is a secondary pollutant

Tropospheric ozone isn't emitted directly by humans – it is a secondary pollutant i.e. it is formed when primary pollutants interact.

These primary pollutants include non-methane volatile organic compounds (nmVOC), carbon monoxide (CO), oxides of nitrogen (NO_x), and methane (CH_4) that interact to produce ozone in sunny conditions. Because these primary pollutants must form before tropospheric ozone forms, they are sometimes called **ozone precursors**.

In the exam, you need to know this equation:

$$NO_x + CO + HC \xrightarrow[\text{Reaction with } O_2]{\text{UV from Sun}} O_3$$

NO_x = oxides of nitrogen
CO = carbon monoxide
HC = hydrocarbons
UV = ultraviolet radiation
O_3 = ozone

Ozone and its precursors are **transboundary pollutants** – they can travel across continents via weather systems and jet streams e.g. ozone formed in Asia and Europe contributes to ozone concentrations in the US. This is why tackling tropospheric ozone will take coordinated international efforts.

Tropospheric ozone is a serious threat to human health and food production, contributes to smog formation and is a powerful greenhouse gas.

Sources of ozone precursors

NO_x, CO, CH_4, and nmVOC are emitted from a wide of both natural and man-made sources (Table 1)

Table 1 Sources of ozone precursors

Ozone precursor	Source	
	Natural	Man-made
NO_x	Bacterial activity in soil Volcanic activity Lightning	Fossil fuel combustion in transport and power stations
CO	Methane oxidation Plant synthesis Oceans Wildfires	Deforestation Savannah burning Burning of agricultural waste Transport emissions
CH_4	Wetlands	Coal mining Coal and gas Industry Landfill Ruminants Rice growing Biomass burning
nmVOC	Terrestrial plants emit a wide range of nm VOC e.g. isoprene	Combustion processes Extraction and production of fossil fuels Industrial solvent use

Looking at both the natural and man-made sources of ozone precursors, it is clear why ozone pollution is likely to increase as human population increases; demand for agricultural land will increase, so more forests and savannahs will be burned; accelerating urbanization in LEDCs will increase demand for energy for industry and transport, so more fossil fuels will be burned.

The relative contribution of natural and man-made sources also causes problems….

True or false? (answers at the end of the Factsheet

Statement	True	False
Most carbon monoxide in the atmosphere is generated from transport emissions		
Most methane in the atmosphere is generated by human activity		
The greatest sources of nmVOCs are transport and industrial use of solvents		

Predicting ozone pollution

Why do scientists need to try to predict future ozone levels? So that effective legislation and technology can be put in place now so that the worst effects of that potential pollution are avoided.

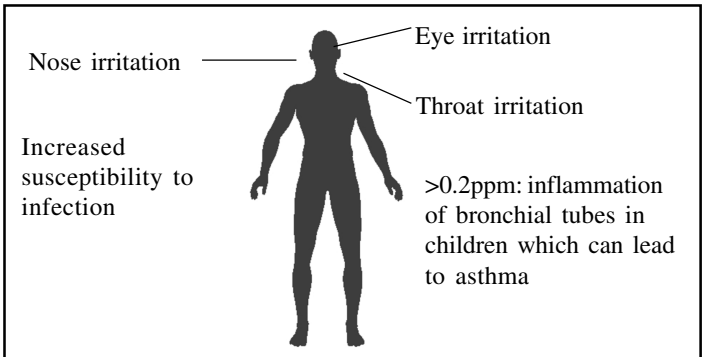
But predicting ozone levels e.g. in 2050 isn't easy. One source of uncertainty is climate change. Climate change is expected to change the relative importance of natural and man-made sources of ozone precursors.

Emissions of those precursors from vegetation, soil and lightning are all affected by sunlight, temperature, humidity and rainfall – all of which may change as a result of climate change.

Effects of tropospheric ozone

In addition to chemical sinks in the atmosphere, ozone is deposited at the Earth's surface onto soils, vegetation and water. This is the pathway that leads to crops and other vegetation being damaged. During drought conditions, when deposition is reduced, tropospheric ozone concentrations rise significantly.

Effect on people



Susceptible people begin to show signs of harm at typical (ambient) concentrations (around 35 ppb)

In Europe it is estimated that contributes to 21,400 premature deaths annually

Effects on vegetation

- The US Dept of Agriculture reports: "tropospheric ozone causes more damage to plants than all other air pollutants combined".
- > 40 ppb = vegetation damage, although this is dependent on species and environmental conditions
- Reduced tree growth & carbon sequestration
- Reduced crop yield
- Reduced nutrient composition of wheat, rice and soya
- Changes to species composition of plant communities

Ozone in a busy city

Motor vehicles are a major source of the precusrsors
On a sunny day, ozone levels will be low first thing, before rush hour.

As the morning goes on, more and more vehicles release the precursors, it gets warmer, UV rays get stronger and O_3 levels rise.

The background level in the UK is 35-40ppb but on hot, sunny days, peaks can reach 100ppb.

Thus: if you are going to try to be healthy e.g. jog, in an unhealthy place e.g. a city, do it first thing in the morning

Controlling tropospheric ozone

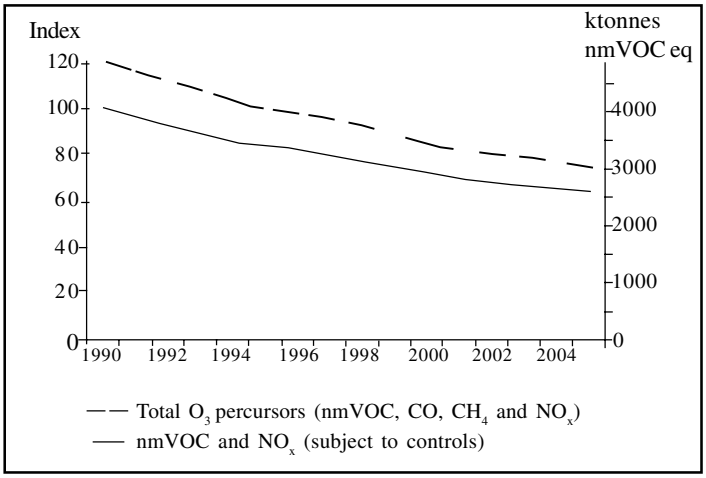
Since the 1970s the EU has:

- Set regulatory limits on emissions ozone of precursors
- Agreed guidelines to alert vulnerable members of the population and polluting industries when ozone concentrations exceed levels that may seriously harm human health

The only attempt to address the long-distant transport of ozone or its precursors is the Gothenburg Protocol which provides a regional approach to ozone and other pollutants with which it may interact.

Recent research suggests that the Protocol has successfully led to reduced emissions of the ozone precursors in Europe (Fig.1).

Fig 1. Emissions of ozone precursors in Europe



Scientists estimate that the hemispheric background ozone concentration in many areas has doubled between 1900 and 1980 and has risen by 6% per decade since then. This is thought to have already significantly reduced food production In the Northern Hemisphere mid-latitudes, where the majority of global population and food production occurs.

The problem for politicians

Elected politicians don't want to do things that will make them so unpopular their government will lose the next election. In the UK, millions of jobs stem directly or indirectly from aviation (e.g. tourism) and shipping e.g. importing food, timber, coal etc). This means that these industries have often escaped pollution regulation..

Although land-based emissions of NO_x have been reduced in many countries, emissions from international aviation and shipping are rapidly increasing. Global passenger air travel, for example, is expected to grow by 5% per year between 2000 and 2020.

In Europe, NO_x emissions from shipping are currently estimated to be one-third of land-based NO_x emissions, but are expected to exceed these sources by 2020.

Exam Hint:- *In the exam you are likely to be asked to state two harmful effects of ozone on living organisms and to define terms such as secondary pollutant and transboundary pollutant.*

Table 2. Controlling tropospheric ozone precursors

Precursor	Reducing emissions
NO_x	Reducing the peak combustion temperature in power station or vehicles will decrease NO emissions Flue gas denitrification in power stations - ammonia or urea is injected and this converts NO into N_2 Catalytic converters reduce NO to N_2 and oxidise HCs to carbon dioxide and water
CO	
HCs	More careful use of solvents in industry Vapour-recovery on petrol pump nozzles

Conclusion

On a global scale, despite 40 years of controls in North America, Japan and Europe, tropospheric ozone remains a serious air pollution problem.

Some pollution policies have successfully reduced emissions of ozone precursors, especially NO_x and VOC (Table 2.), and this has resulted in short-term peak ozone concentrations falling.

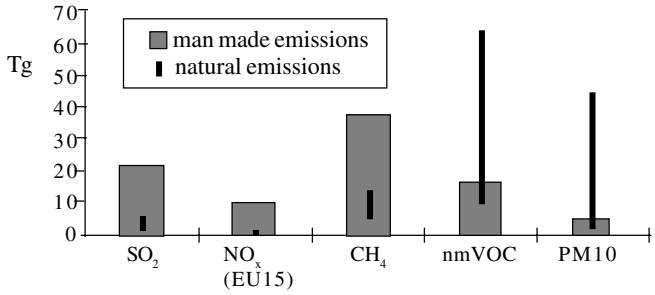
At the same time, however, the hemispheric background concentration has been increasing by about 2 ppb per decade since 1980 in the mid-latitude Northern Hemisphere. This increase in background ozone is not fully understood, but is thought to be due mainly to emission increases in other Northern Hemisphere countries and increases in emissions from poorly regulated sectors such as international shipping and aviation.

Scientists and governments have begun to realize that efforts to reduce the impacts of ozone on human health and the environment must target background as well as peak ozone. This requires measures to reduce ozone at the hemispheric /global scales as well as regional / local scales.

True/false? Answers All false.

The greatest source of CO is the natural oxidation of methane.
Humans only contribute between 10-15% of the CO in the atmosphere
Natural emissions of methane dwarf man-made emissions (Note: it is extremely difficult to estimate natural emissions. For example, lightning is a natural source of NO_x – but man-made climate change is increasing lightning events, so is the extra NO_x generated natural or man-made?)
Natural emissions of nmVOCs dwarf man-made emissions.

Fig 3. Natural and man-made emissions in Europe (EU-15 only for NO_x)



Source: Friedrich,R Atmospheric Environment 43 (2009) 1377–1379

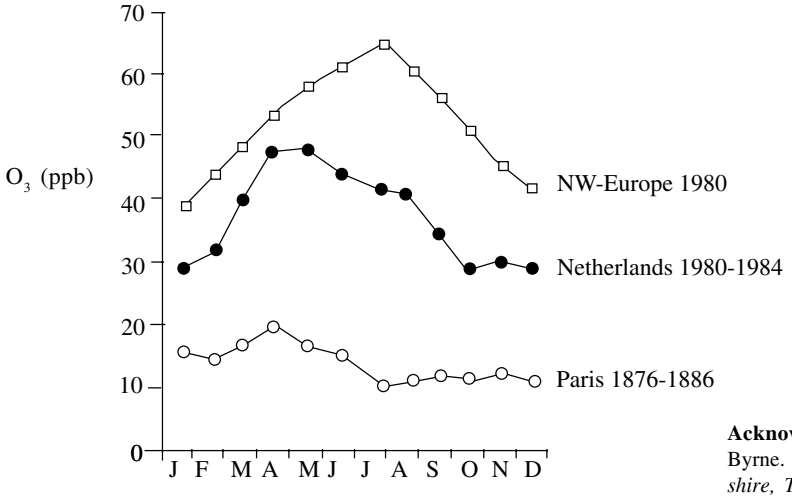
Practice Questions

1. The table shows the number of days per year during which UK government health standards for ground-level ozone were exceeded in five areas. The maximum acceptable level is 50 parts per billion measured as a mean over an eight-hour period.

	Area				
	Rochester	East Anglia	Exeter	N. Scotland	Leicester
No. days exceeded	44	33	20	19	19

(a) (i) Calculate the mean number of days on which the acceptable level was exceeded (1)
(ii) What effect does measuring the pollution as a mean over an eight hour period have on the data?(1)

The graph shows average monthly ozone concentrations at monitoring stations in Europe



(b) Summarise the data (2)

Markscheme

1. (a) (i) 135/5 = 27 days;
(ii) It makes the data more reliable;
(b) Monthly ozone concentrations have increased over the period;
Peak concentrations are occurring later in the year;

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