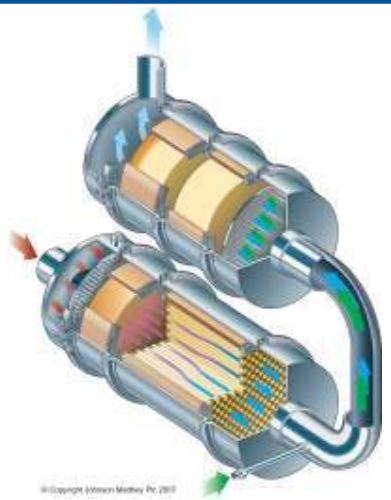
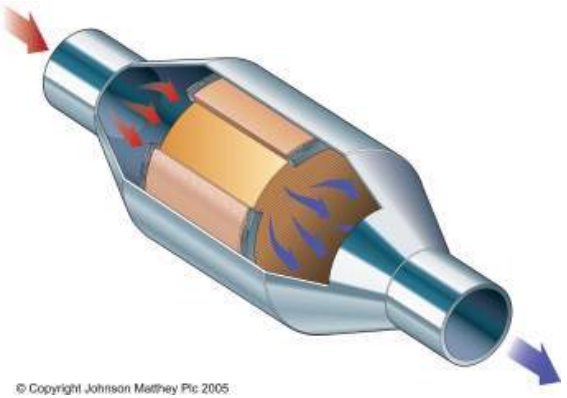
FETE Conference
Cambridge University

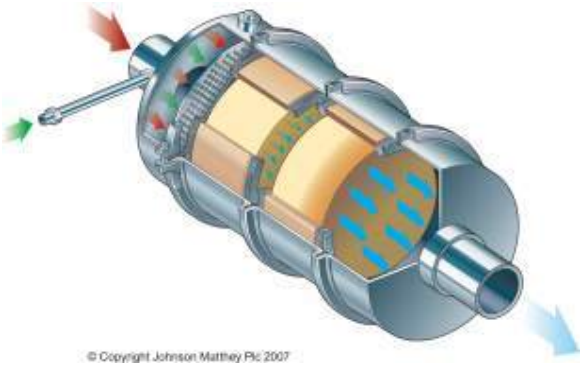
21 July 2011

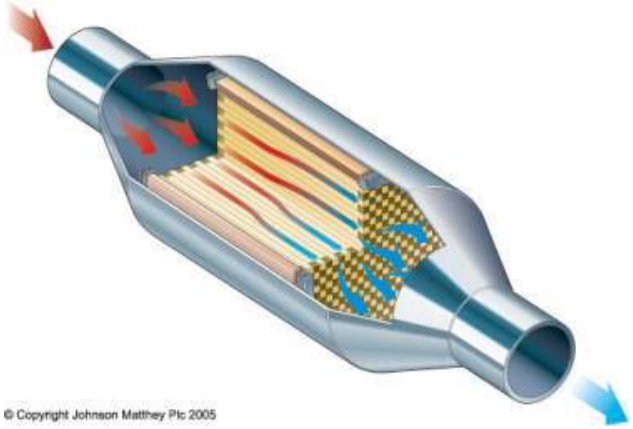
Johnson Matthey
Catalysts

Emission Control Technologies









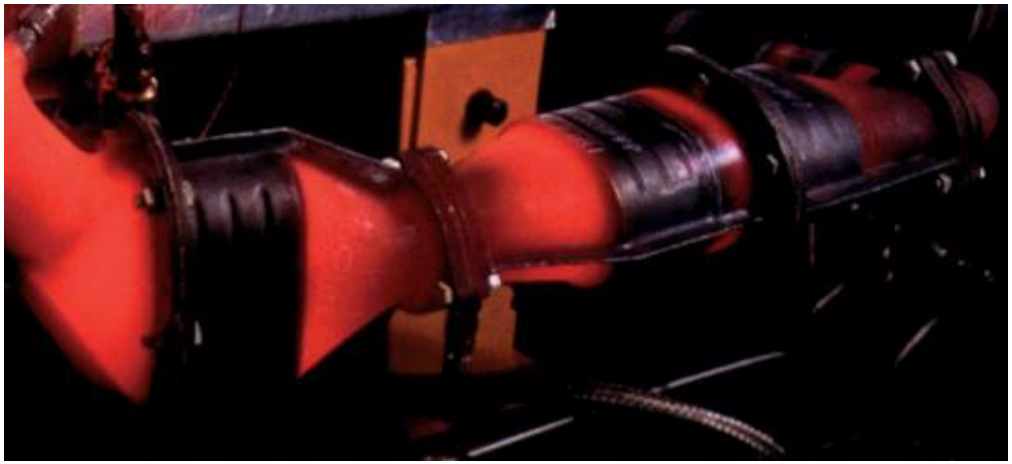
James Wylie
Principal Engineer

EMISSION CONTROL TECHNOLOGIES

OUTLINE

Confidential

- Johnson Matthey
- Vehicle Pollution
- Catalysts For Emissions Reduction
- Working at Johnson Matthey
- Summary



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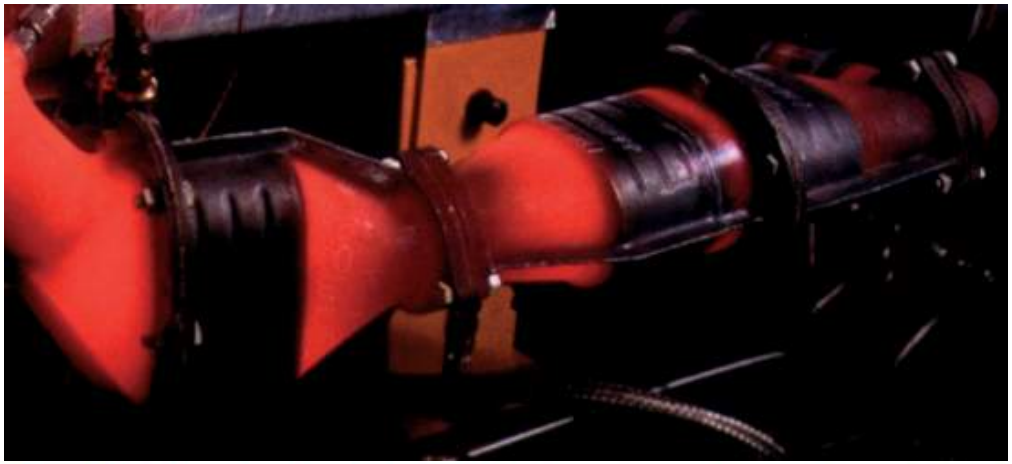


JOHNSON MATTHEY

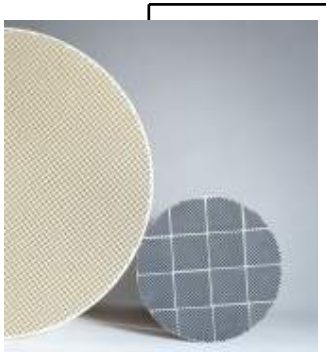
Confidential

- UK FTSE 100 company
- £10 billion turnover for year end March 2011
- 8,500 employees, operating in more than 30 countries
- Leading global market positions in all its major businesses

JOHNSON MATTHEY GROUP STRUCTURE

Confidential

Johnson Matthey Plc



Environmental Technologies Division

- Emission Control Technologies (ECT)
- Process Technologies
- Fuel Cells

Precious Metal Products Division

- Platinum
- Noble Metals
- Catalysts
- Chemicals & Refining
- Colour Technologies

Fine Chemicals Division

- Macfarlan Smith
- Pharmaceutical Materials & Services
- Research Chemicals

Johnson Matthey Emission Control Technologies (ECT)

- Pioneer & world leading manufacturer of catalysts for vehicle exhaust emission control.
  - World's first autocatalyst manufacturing plant 1974
  - Johnson Matthey has supplied one-in-three of all autocatalysts ever sold

- 15 Manufacturing Sites and 9 Technology centres around the world
  - Worldwide, Johnson Matthey has now manufactured over 500 million catalysts and filters

Emission Control Technologies (ECT)

AUTOCATALYST APPLICATIONS

- Passenger cars
  - Gasoline and diesel
- 2/3-wheelers
- HDD On-Road
  - Trucks, Buses etc
- HDD Non-road
  - Mining, construction, agriculture
- Small Utility Engines
  - Handheld
  - Skidoo, Jetski etc
- Also ships, trains, any internal combustion engine…

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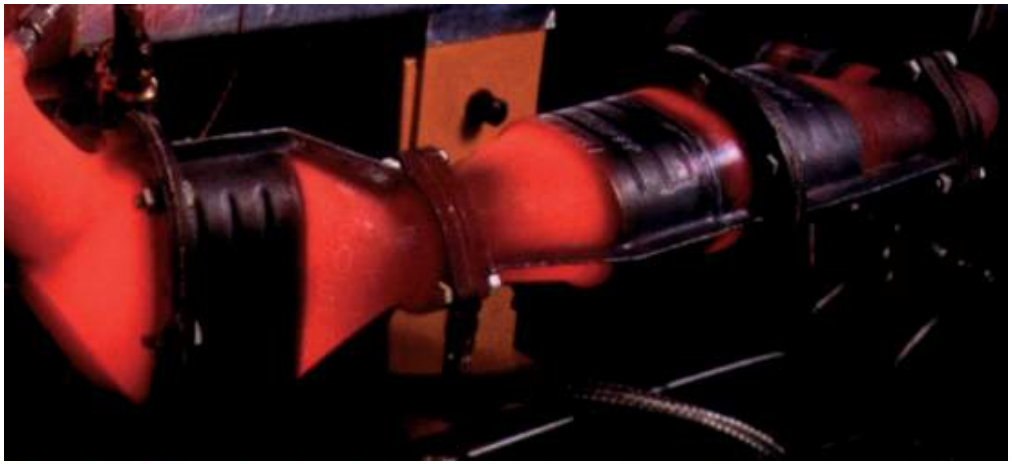
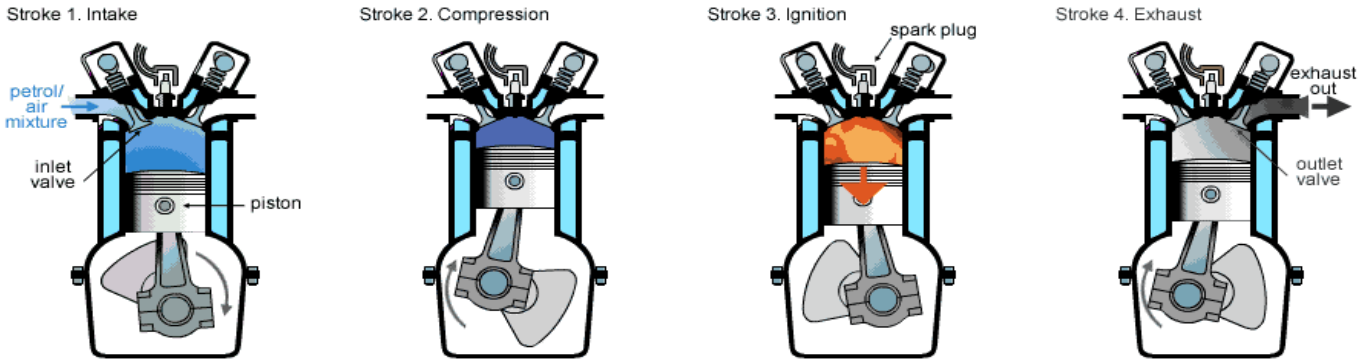
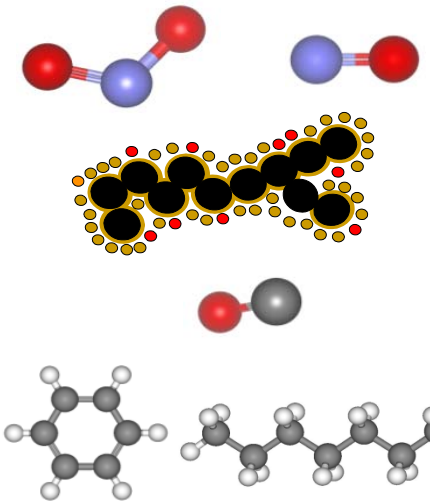


Vehicle Engines Produce Pollutants…

Engine



Emissions

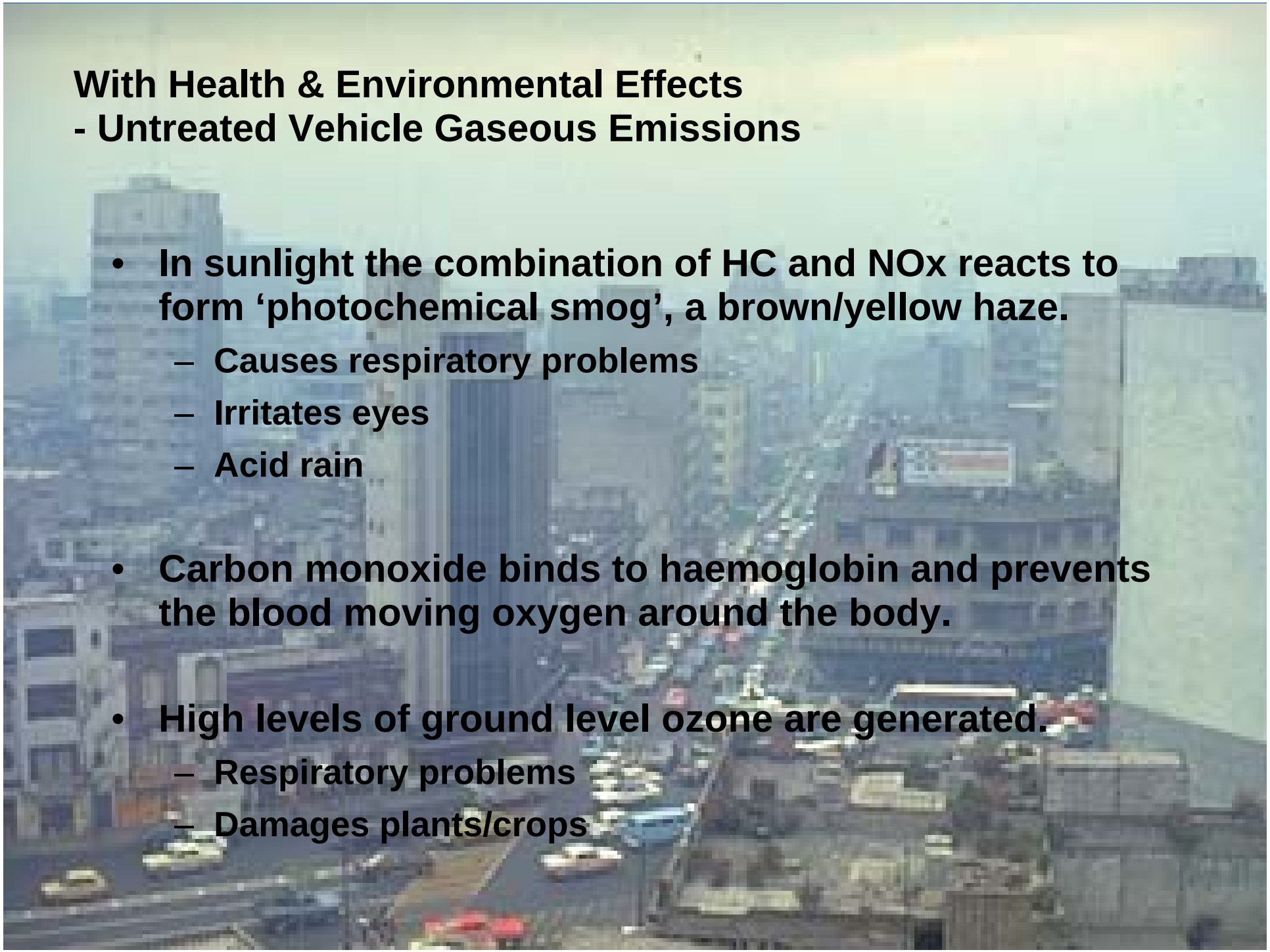


Oxides of Nitrogen (NO_x)

Particulate Matter (PM)

Carbon Monoxide (CO)

Unburnt Hydrocarbons (HC)



With Health & Environmental Effects
- Untreated Vehicle Gaseous Emissions

- In sunlight the combination of HC and NOx reacts to form ‘photochemical smog’, a brown/yellow haze.
  - Causes respiratory problems
  - Irritates eyes
  - Acid rain
- Carbon monoxide binds to haemoglobin and prevents the blood moving oxygen around the body.
- High levels of ground level ozone are generated.
  - Respiratory problems
  - Damages plants/crops

Particulate also a Major Health Concern

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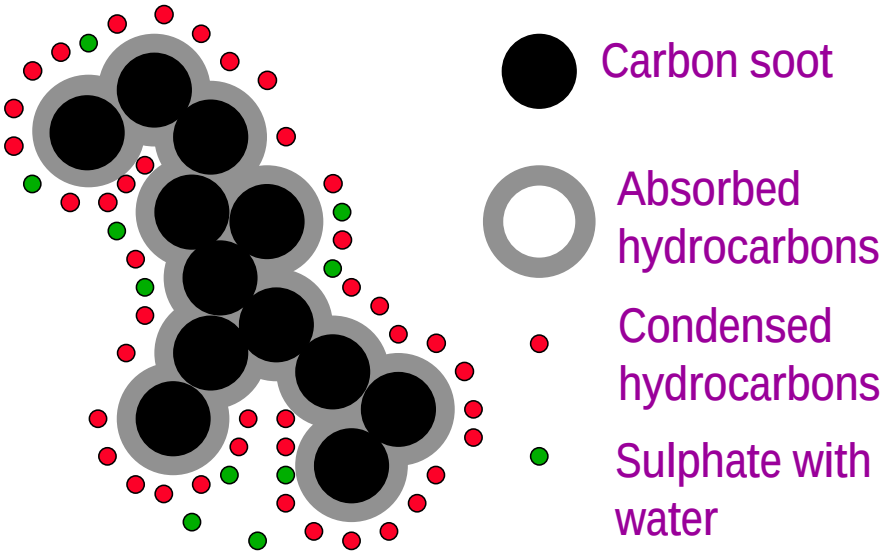
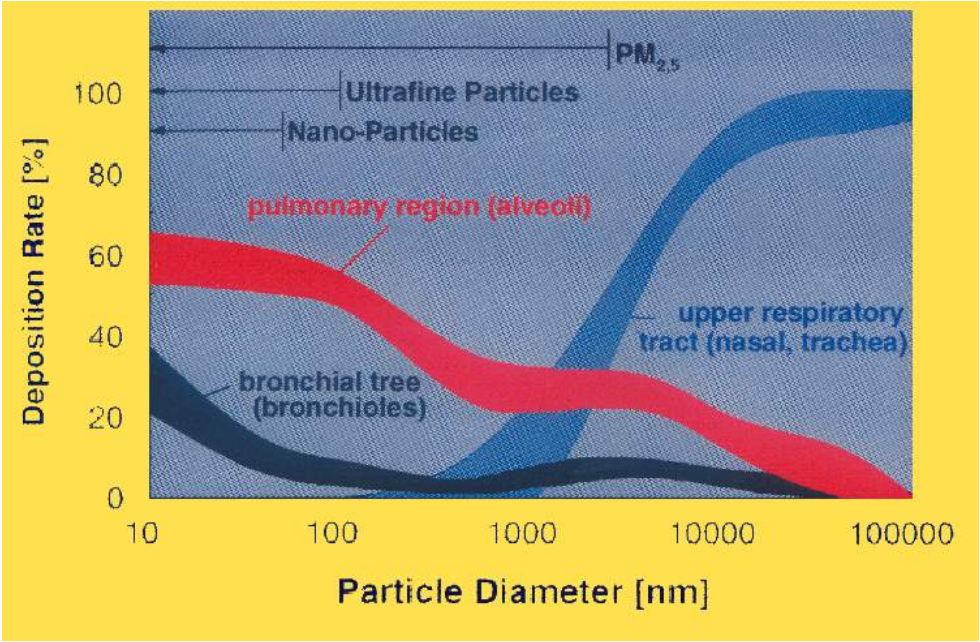
Emphasis on PM10 turns attention to diesel exhaust

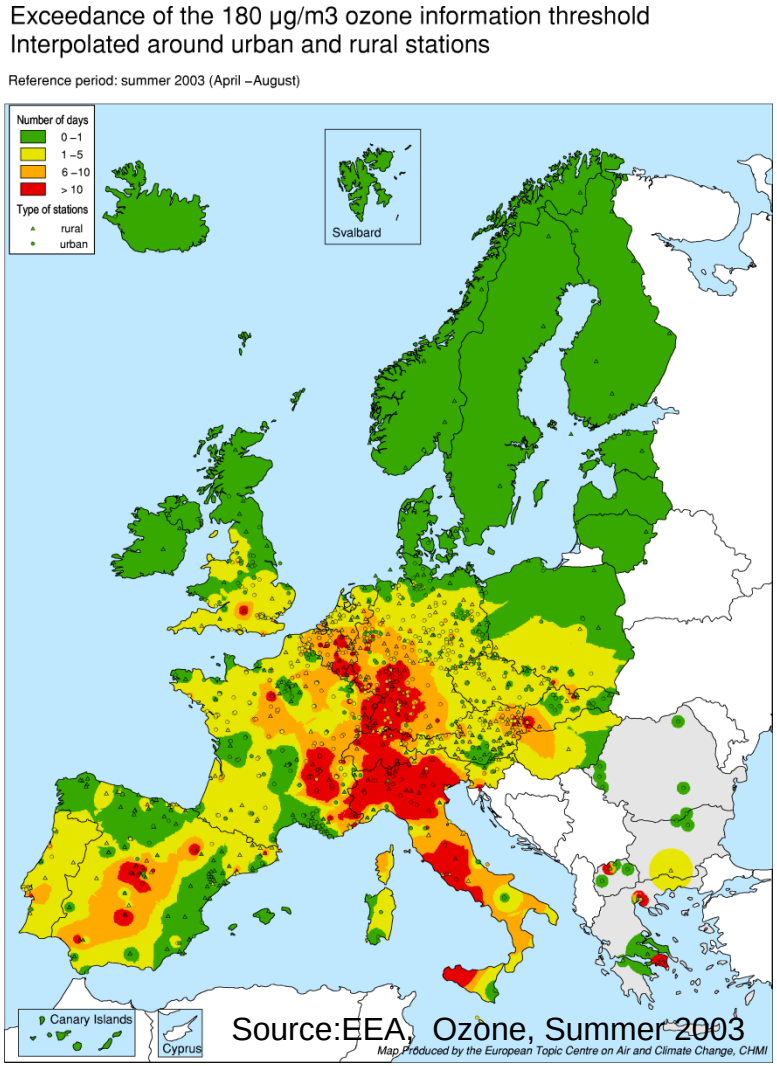


Epidemiological studies highlight risks from PM10. Medical experts believe that diesel particulate matter bypasses the lungs defence mechanisms, aggravating lung and heart conditions. Hydrocarbons are a cancer risk.



European Air Quality still needs to be improved

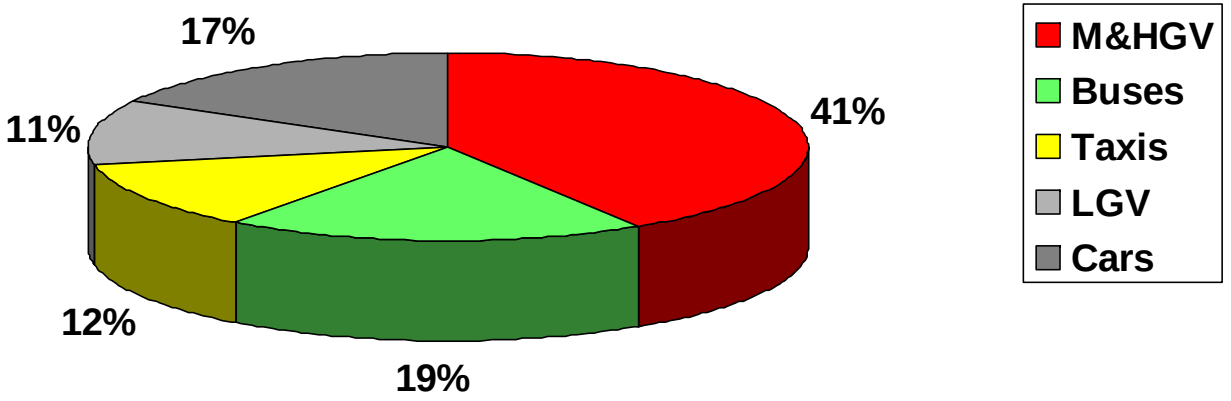
- Urban
  - Particulate
    - “Soot”
  - NO_2
    - Oxides of nitrogen
    - “NOx”
  - Ozone
    - Sunlight + hydrocarbon + NOx
  - Hence legislation, driving tougher emissions limits



Local Air Quality Remains a Problem

Air quality modelling shows that PM_{10} and NO_2 air quality standards will be exceeded in London and other city centres

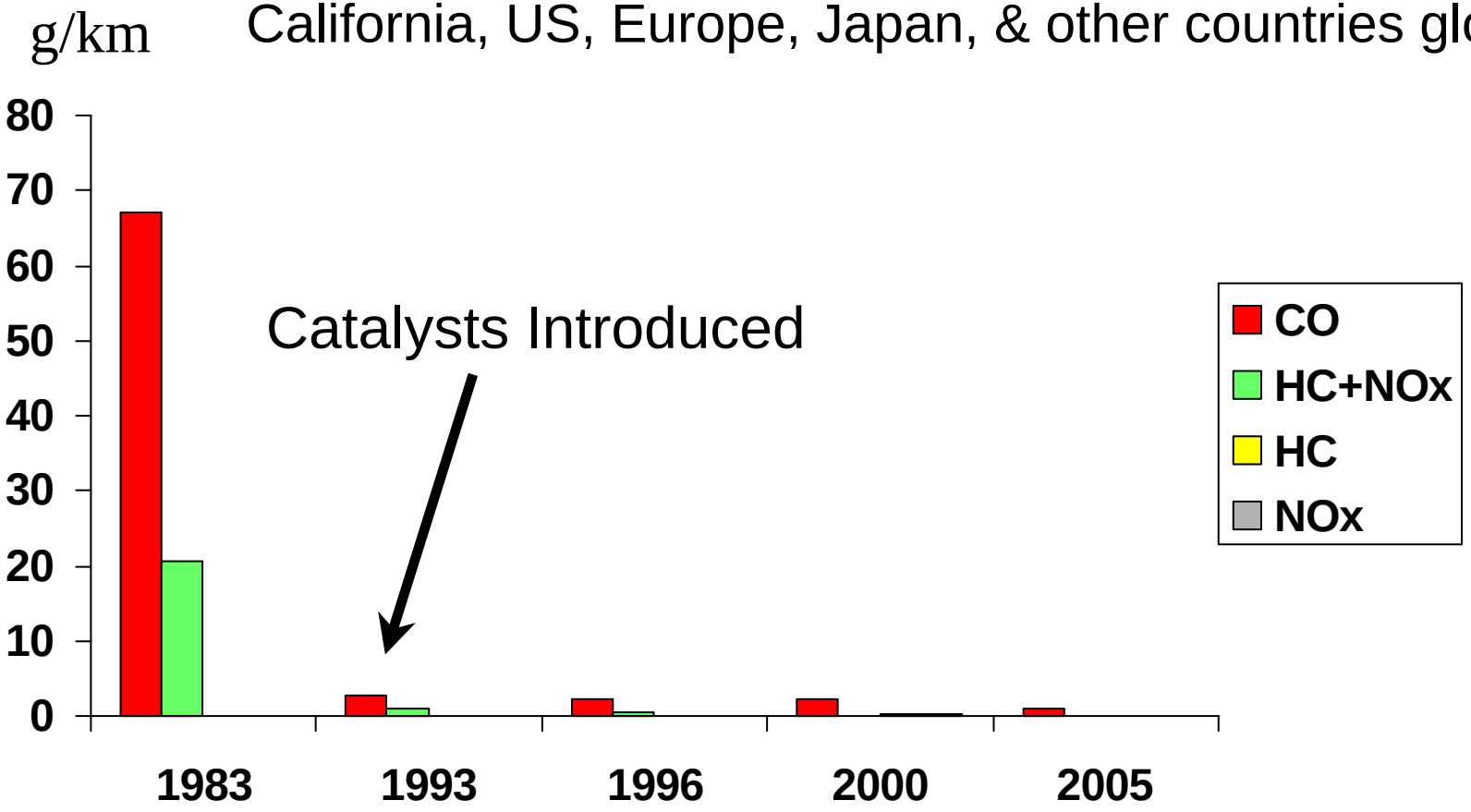
Studies highlight the significance of HGV and Buses for city centre PM_{10}



Westminster Study, city centre PM10

Development of Passenger Car Legislation - Europe as an example

Vehicle emissions reduction driven by legislation in California, US, Europe, Japan, & other countries globally



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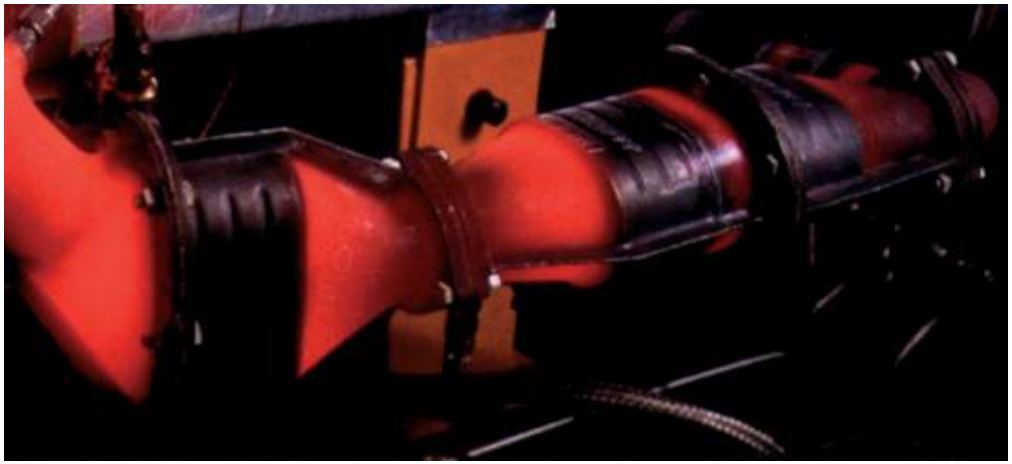
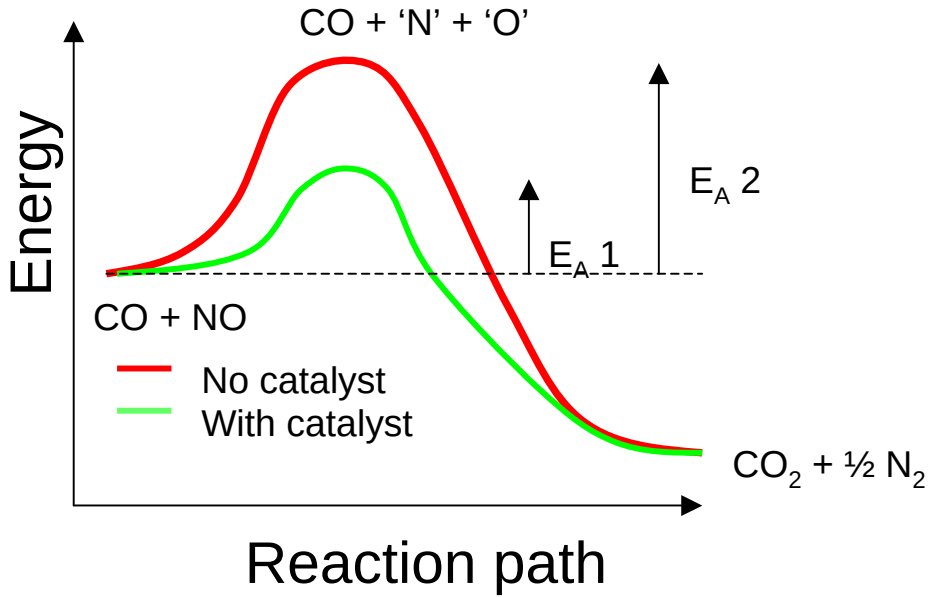


Catalysts do not perform miracles: the reactions they perform have to be “allowed” chemically.

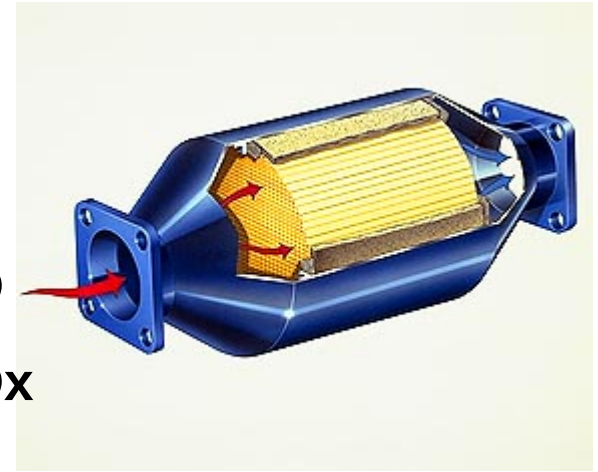
- Catalysts accelerate the rate of “allowed” reactions: the kinetics of the reaction are speeded up
- Catalyst is designed to speed up desired reactions and not undesired ones: selectivity
- The gas molecules land on the surface and find “sites” where they are activated and reactions occur
- Once a reaction has happened they return to the gas phase, leaving the catalyst ready to do the process again



Reaction rate $\propto 1/(\exp(E_A/T)$

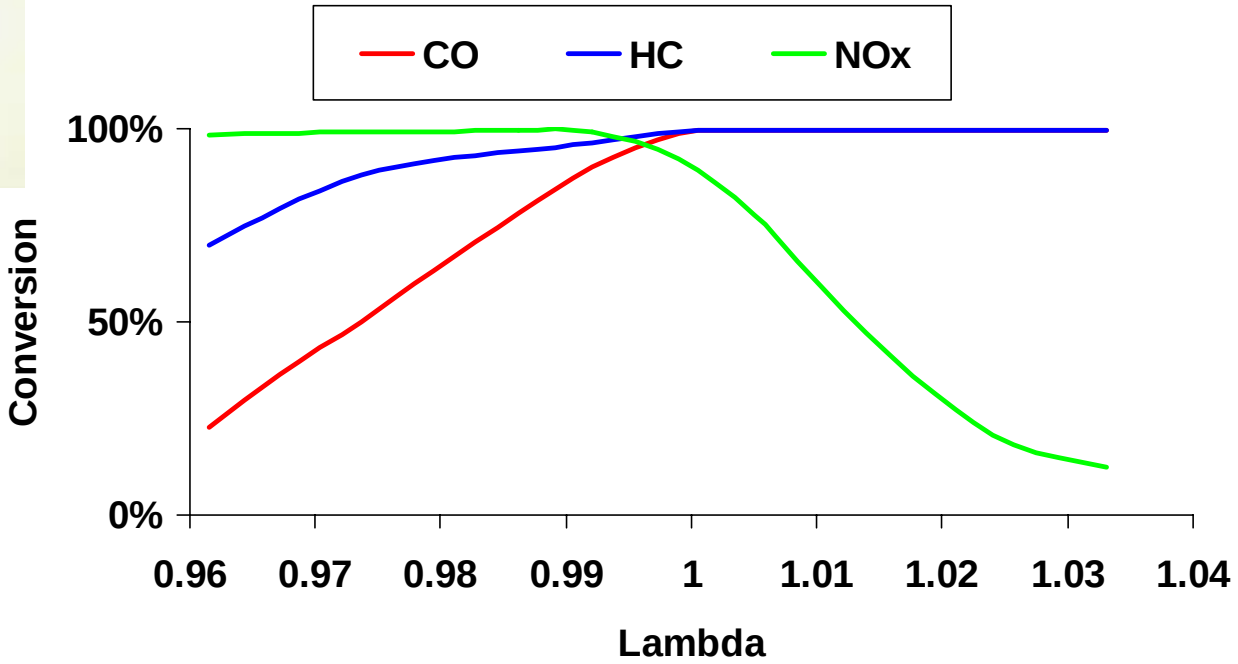
GASOLINE ENGINE: THREE-WAY CATALYST

- Needs The Correct Gas Mix To Work Effectively
- Lean Burn Engines Require Additional After-treatment



For gasoline cars, autocatalysts promote both oxidation and reduction of pollutants

Operation at lambda = 1 offers control of all three gaseous pollutants



Careful control of the air-fuel ratio is required

Pt, Pd to promote oxidation reactions. Rh for reduction

DIESEL ENGINE exhaust is very different to gasoline
HC/CO OXIDATION TECHNOLOGY - DOC

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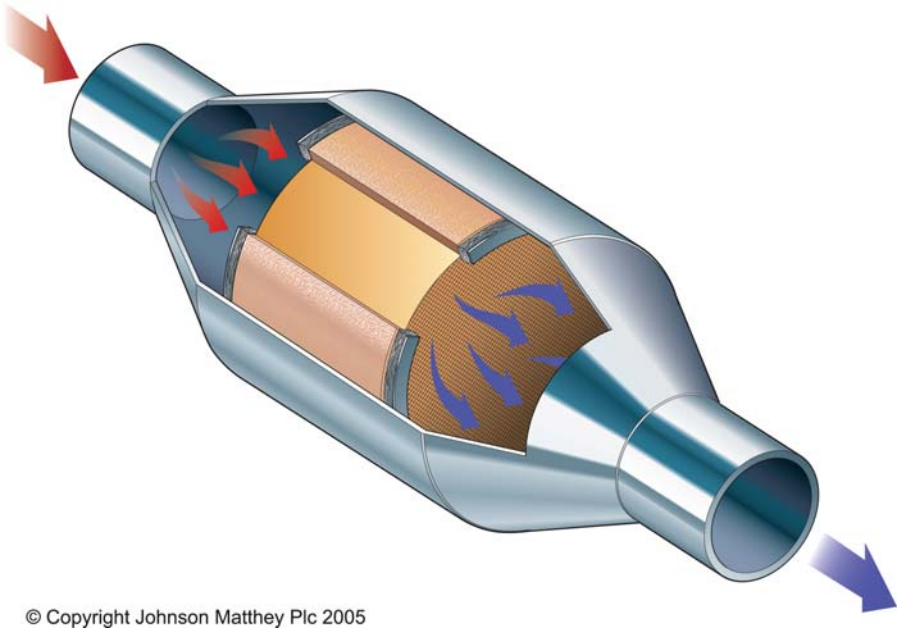
- Diesel is very lean (oxygen rich) so oxidation reactions occur easily
  - But NOx reduction is much harder

- Key Oxidation reactions over a DOC:

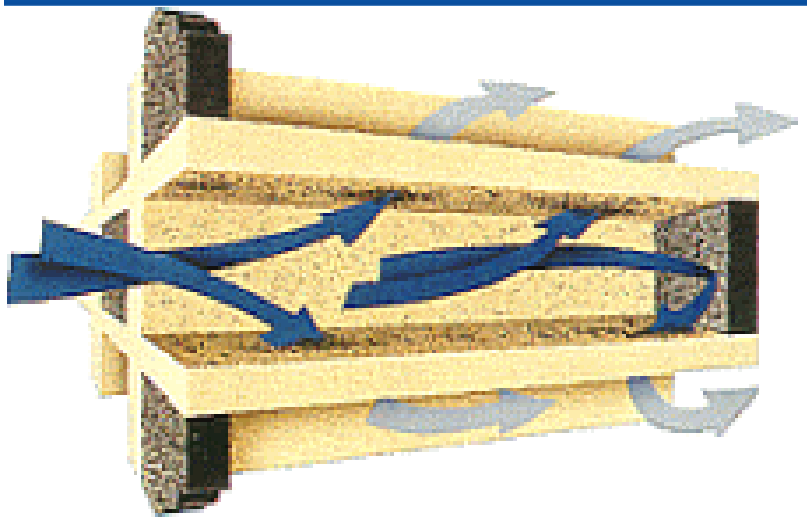


$CO + ½ O_2 \rightarrow CO_2$

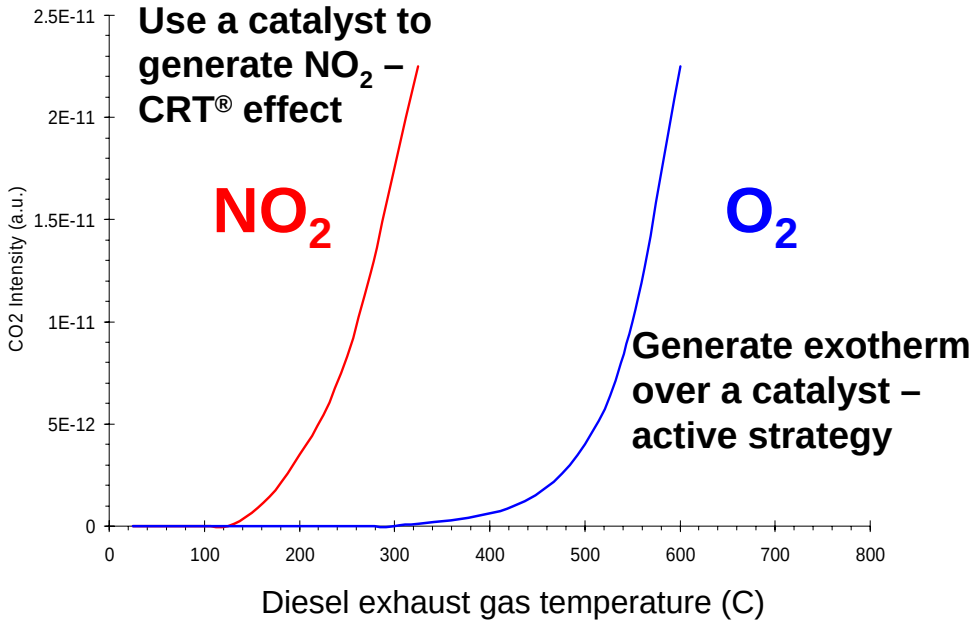
$HC + O_2 \rightarrow CO_2 + H_2O$

$NO + ½ O_2 \rightarrow NO_2$

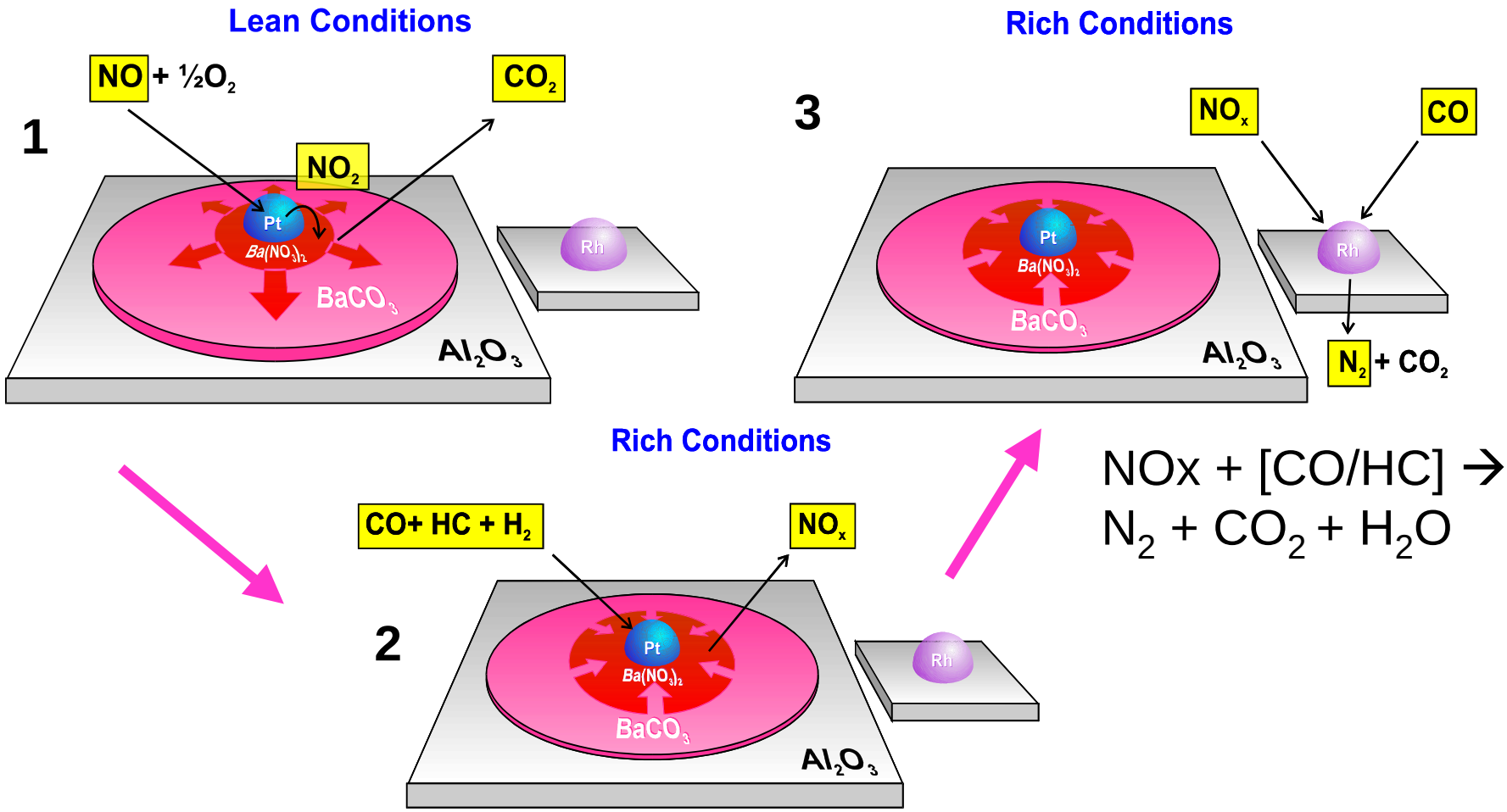
DIESEL ENGINE exhaust is more sooty than gasoline
SOOT - DIESEL CATALYSED SOOT FILTERS



Catalysed soot filter used to remove soot from exhaust
- Passive and / or active regeneration to remove soot



DIESEL NOx REDUCTION – Challenging in lean environment
NOx Trap Technology is one option, with NOx storage when lean, with periodic reduction using rich regeneration conditions



NOx + [CO/HC] → $N_2 + CO_2 + H_2O$

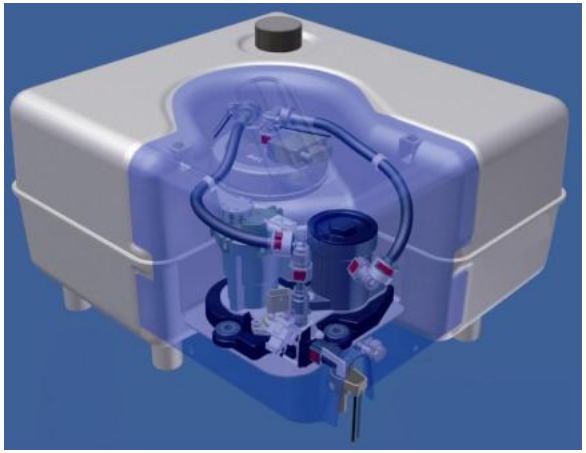
Engine operated in mode to give excess CO/HC/H_2

DIESEL NOx REDUCTION – Challenging in lean environment

SCR Technology is another option, with NOx reduction using NH_3 as reducing agent under continuously lean conditions

Confidential

Urea dosing system



(Source AECC)

Urea injector, mixing device and SCR catalyst

(Source AECC)

Different reductant sources can be used; common option is dosing of urea from on-board tank, to form NH_3 gas in exhaust system

$$(NH_2)_2CO \rightarrow HNCO + NH_3$$

$$HNCO + H_2O \rightarrow CO_2 + NH_3$$

$$2NH_3 + NO + NO_2 \rightarrow 2N_2 + 3H_2O$$

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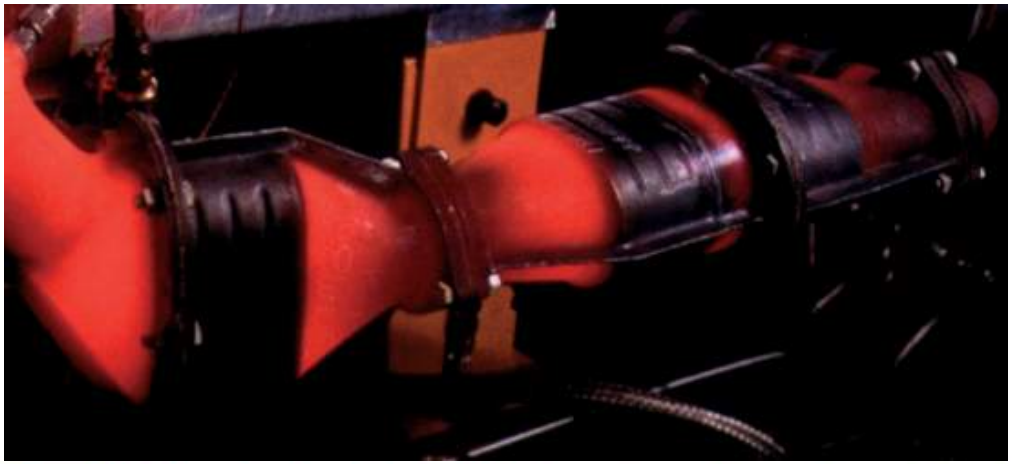


ECT European Technology, Royston

STRUCTURE

- Product Development
  - Teams of chemists and engineers developing & testing catalysts for gasoline and diesel for hundreds of applications
- Process Development
  - Teams of chemists and engineers overseeing catalyst lifecycle from development to production
- Analytical and QC
  - Post mortem, material screening, production quality
- Catalyst Test Laboratories
  - Teams of engineers providing & running facilities for evaluation of catalysts - engines, vehicles, synthetic gas /soot rig testing

ECT European Technology, Royston

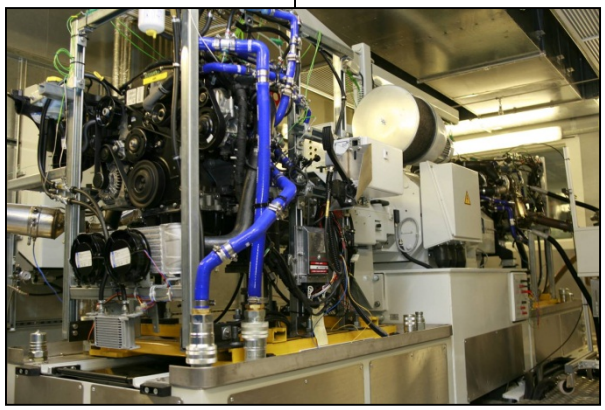
CATALYST TEST LABORATORY STRUCTURE

Confidential

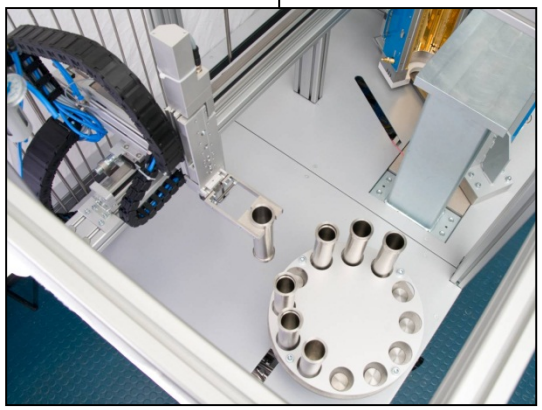
Royston

Catalyst Test Laboratories

Vehicle Testing



Engine Testing



Synthetic Testing

Exhaust Composition and Emissions Drive Cycles

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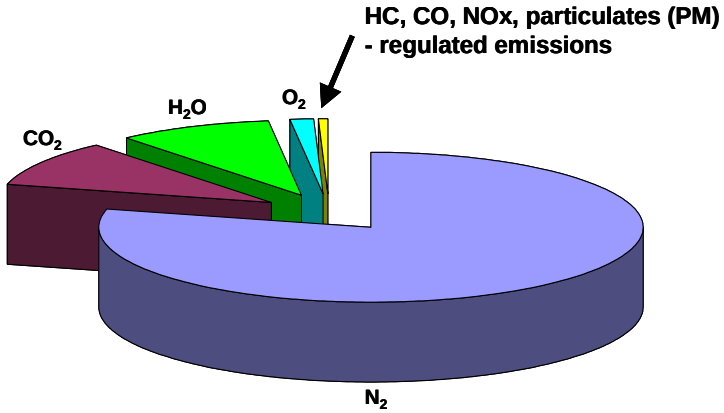
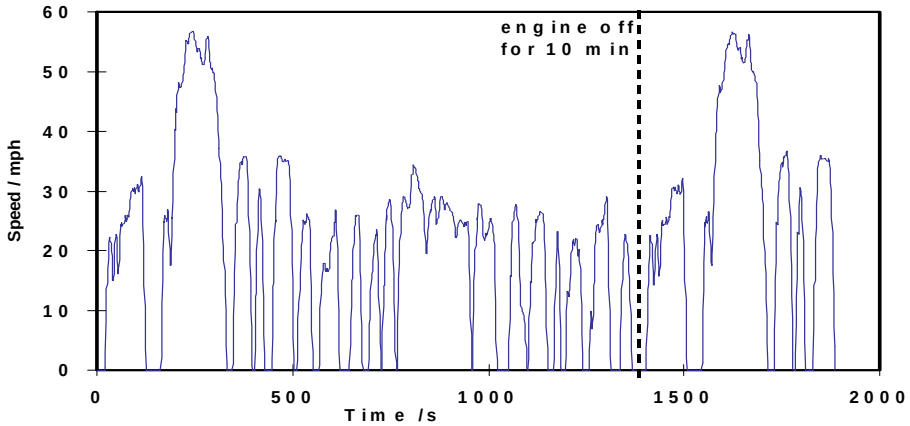


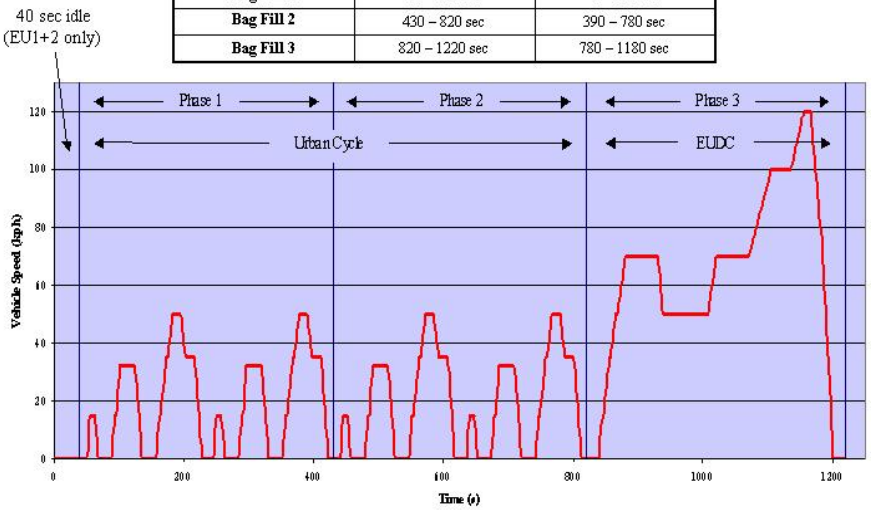
…. the regulated emissions are a small fraction of the total

The US EPA 75 Drive Cycle

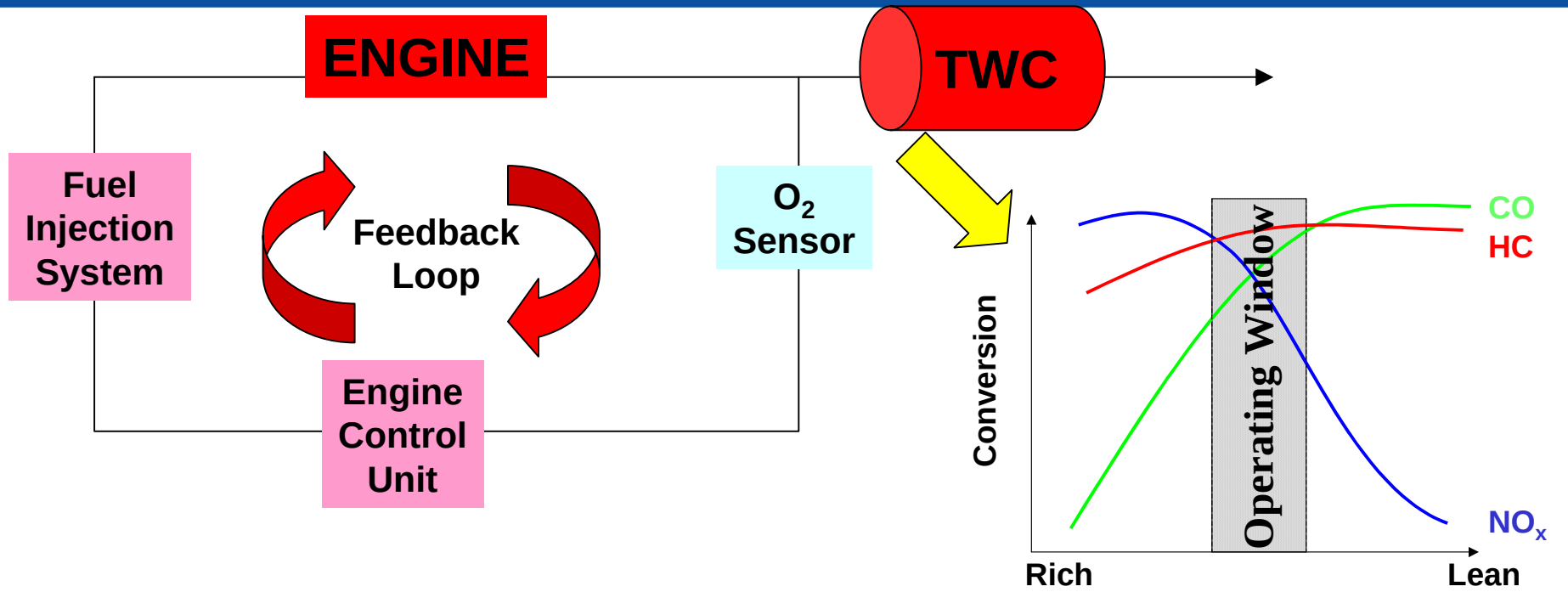


The European MVEG Drive Cycle

	EURO 1+2	EURO 3+4
Maximum Speed	120 kph	
Duration	1220 sec	1180 sec
Distance	11.007 km	
Bag Fill 1	40 – 430 sec	0 – 390 sec
Bag Fill 2	430 – 820 sec	390 – 780 sec
Bag Fill 3	820 – 1220 sec	780 – 1180 sec

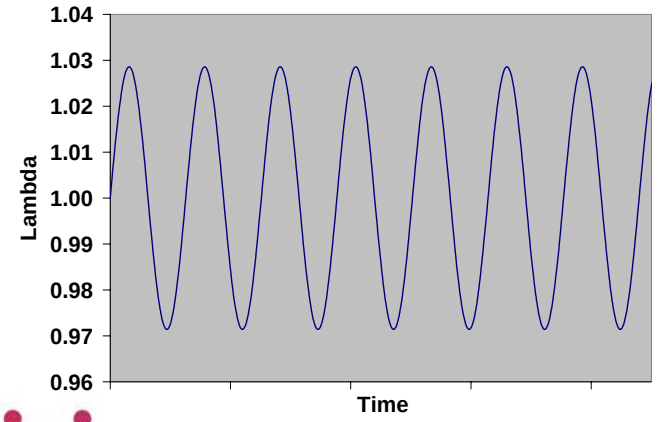


A GASOLINE EMISSIONS CONTROL SYSTEM
- Closed-loop Control



Air-fuel ratio adjusted every second or so

AFR kept to within 2-3% of lambda 1.00



Accelerated Catalyst Ageing

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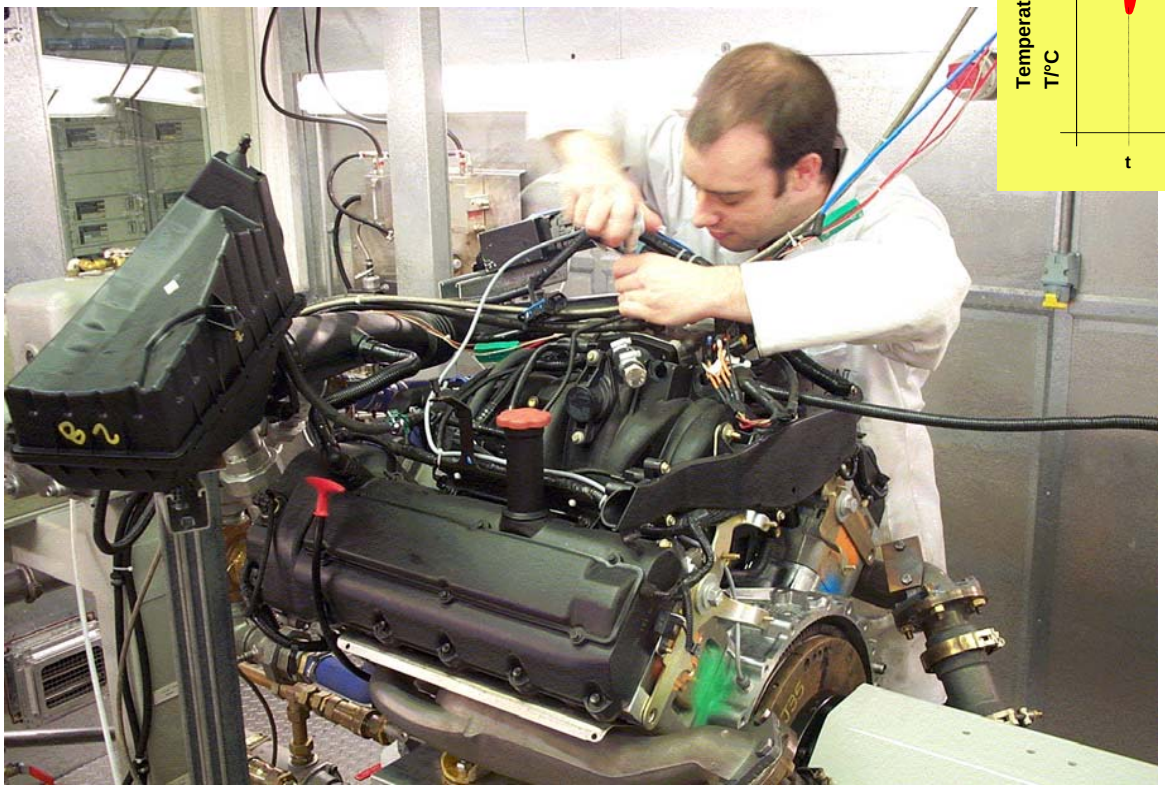

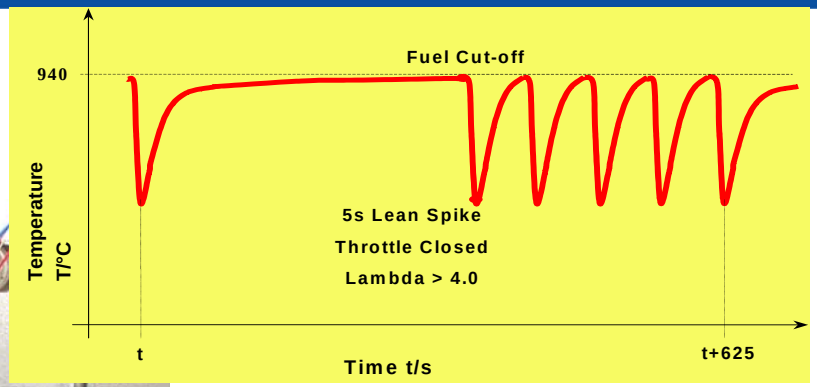

Catalyst Evaluation

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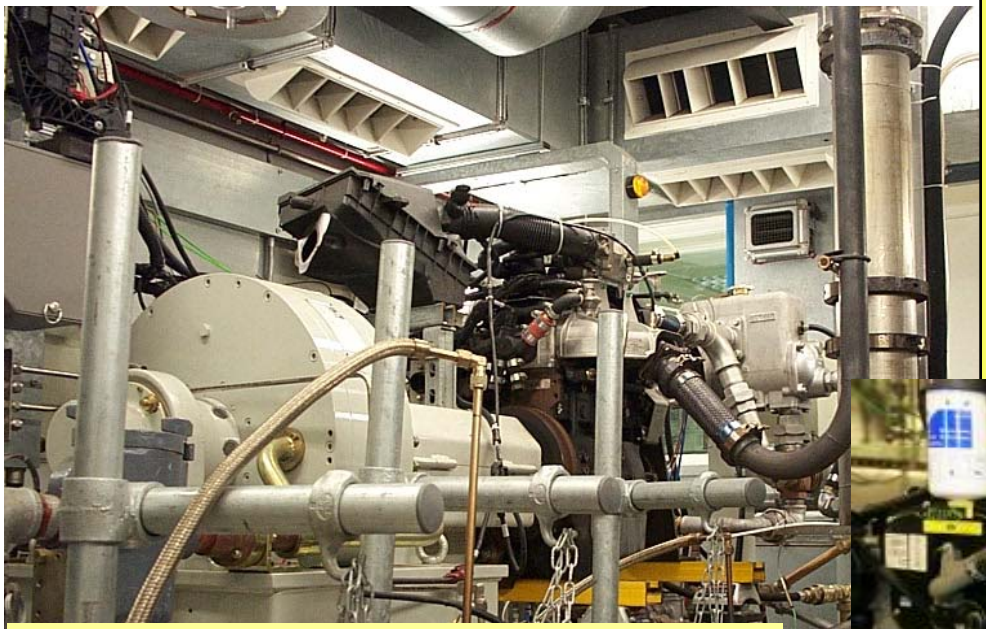

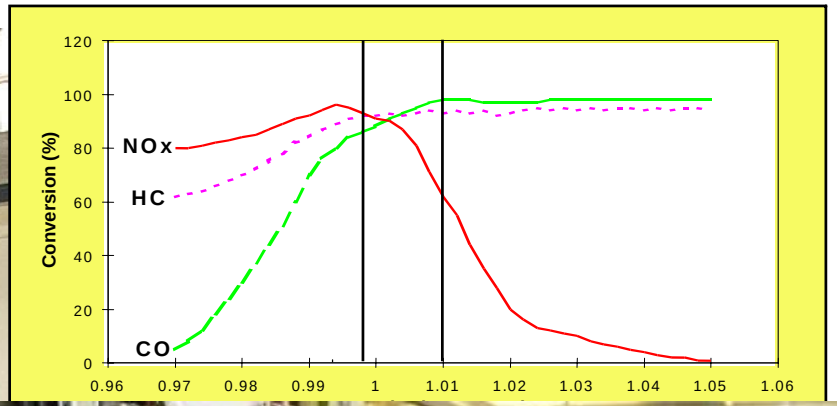

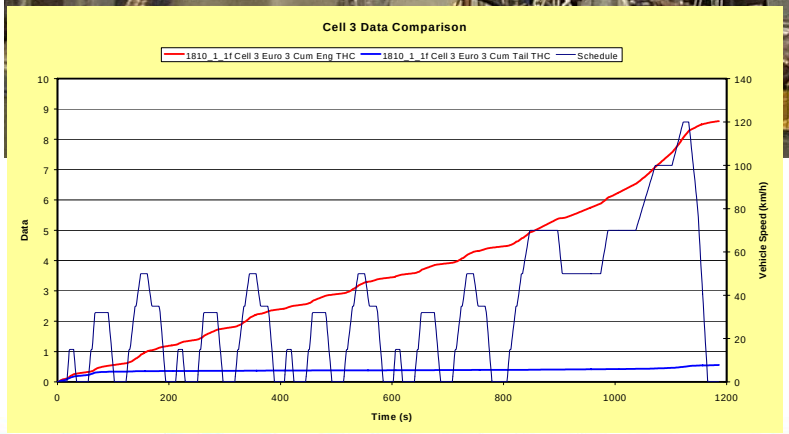

Vehicle Emissions Testing

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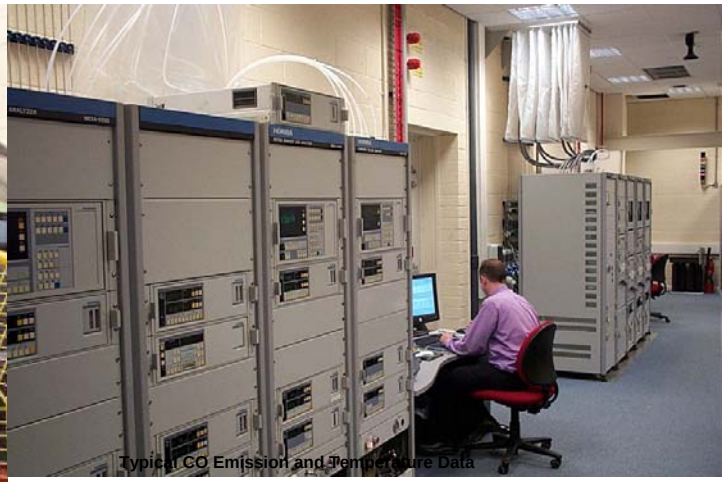
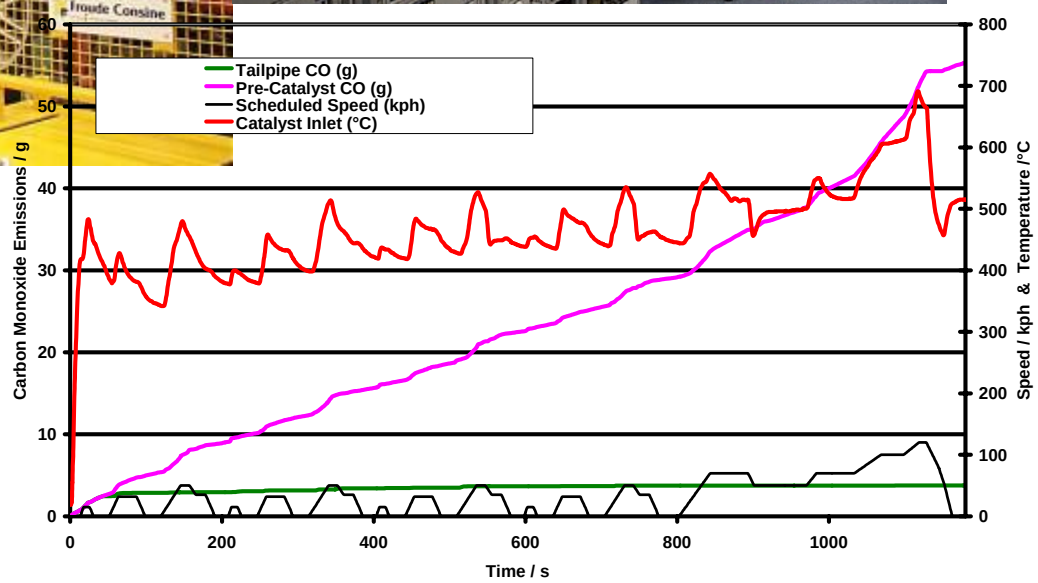




Motorcycle Testing

Confidential

On-Vehicle Durability Testing

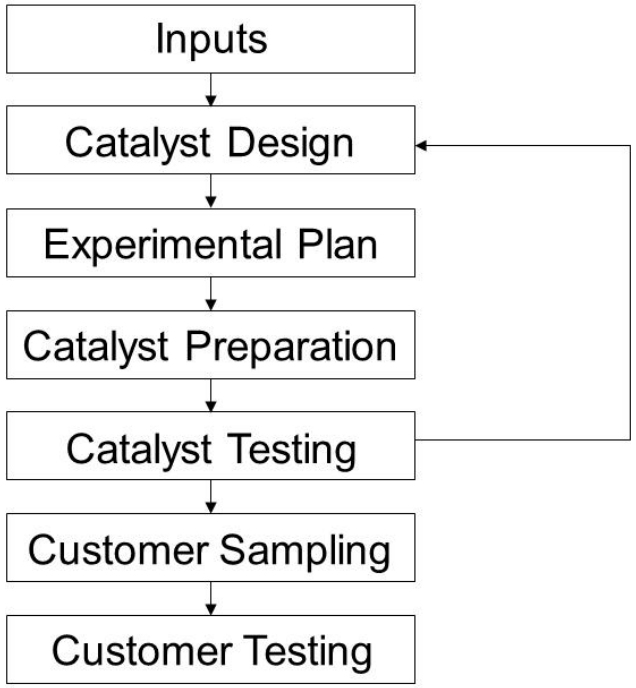
Confidential

Emissions measurement

- Driven by legislation and environmental demands
- Established techniques to measure regulated emissions
- New developments:
  - PM counting and size
  - NOx speciation – N_2O
    NO
    NO_2
    NH_3
  - SOx speciation - SO_2
    H_2S
    COS
  - Unregulated hydrocarbons – aldehydes, PAHs etc.

The Technology Department - people

- Chemists
- Material Scientists
- Computer Modellers
- Chemical, Mechanical and Automotive Engineers
- Technicians/apprentices



- Develop Products
- Technical Marketing and Liaison
- Supply Prototype Samples
- Scale-up to Production

Personal Characteristics

- Close customer contact is the key to JM success
- Keeping pace with customer requirements, legislation demands, raw material cost and availability, production capability and competitor pressure
- ‘Can do’ attitude, capable of working flexibly at all levels
  - Chemists/Engineers/Technicians working closely together
- Tenacity, pragmatic approach, good interpersonal skills
- Safety conscious and striving for improved sustainability both within the company and through improved products

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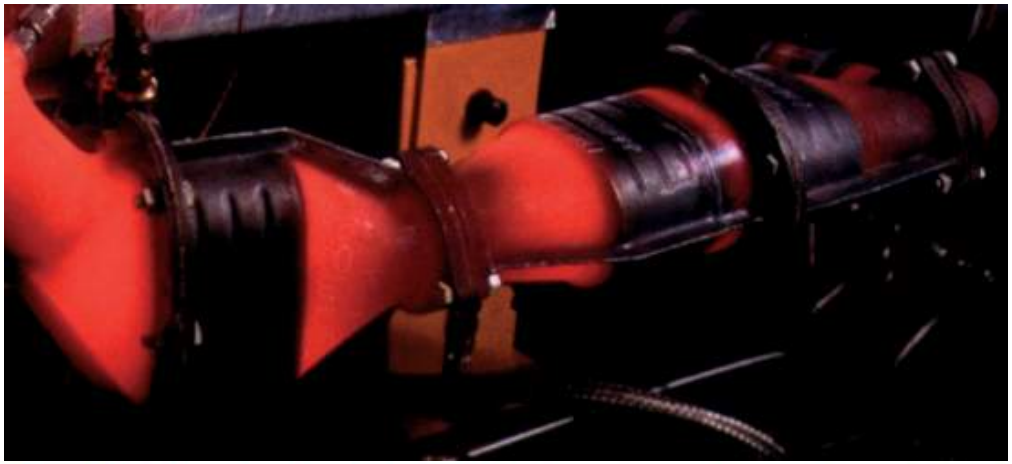

Johnson Matthey ECT

SUMMARY

- Teams of chemists and engineers developing and evaluating catalysts from concept to production
- Business is won or lost as a consequence of product development
- Direct customer contact in all areas
- Exciting, competitive environment at the forefront of technology
- The outcome of research and is clear to see (smog banished, urban health improved)