# Measurement and Management of Particle Emissions from In-Use Diesel Engines - an Australian Perspective

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## 1. The Author

Graduating from the University of Salford, UK in 1969, Peter has held a number of senior engineering and policy positions in both the private and public sectors

Over the past decade, his close involvement with national and international vehicle emissions issues has included

- Two terms as Chair of the ministerial Advisory Committee on Vehicle Emissions and Noise;
- Chair of the Transport Panel of the National Inquiry into Urban Air Pollution;
- Provision of strategic and policy advice and technical services to governments, industry and international agencies on vehicle emission and greenhouse issues;
- The design and development of novel, low-cost technologies for particle emissions measurement;
- Author of numerous papers, publications and comparative studies on vehicle emissions and emission testing technologies.

## 2. Background

Human exposure to respirable fine particles continues to burden communities with huge economic costs and human suffering, throughout the developed and developing world. Despite its wide open spaces and pristine environment, Australia's major cities are faced with exactly the same problems.

Ultra-fine nano-particles emitted from the combustion of carbon-based fuels can readily by-pass the human body's defences and penetrate to the deepest, most sensitive areas of the lung, and even directly into the bloodstream, leading to incidences of cancer, heart disease and a range of respiratory problems.

The situation is not improving. In September 2005 an extensive study undertaken by the World Health Organisation reported that in the European Union alone almost 300,000 people die prematurely every year from exposure to fine particles, with an overall annual cost to the community exceeding US$150 billion.

These findings are staggering and, given that motor vehicles and engine-powered industrial plant are the dominant sources of respirable particle

emissions in many cities, they underline the need to take effective measures to reduce emissions of this dangerous pollutant.

## 3. Australian In-Use Vehicle Particle Emissions

Responding to this serious public health issue, in 1998 the Australian Federal Government initiated a series of projects to:

- review and evaluate existing research into particle emissions from motor vehicles;
- develop drive cycles representative of Australian urban and regional traffic patterns for each vehicle category;
- undertake extensive laboratory testing to quantify and characterise particle and gaseous emissions rates from a representative sample of diesel vehicles operating in Australia;
- develop test procedures and measuring instrumentation suitable for quickly and reliably measuring particle emissions from in-use vehicles;
- conduct a pilot testing program to evaluate capability of the selected test protocols and instrumentation to identify high polluters and validate the effectiveness of subsequent maintenance and repairs.

## 4. Outcomes of the Research

The projects outlined above confirmed that poor maintenance can increase particle emissions from older vehicles by a factor of five or more. Conversely, the highest polluting vehicles are generally capable of delivering the highest particle emission reductions, often for the lowest cost.

It is also important to recognise the potential for modern diesel vehicles, fitted with extremely efficient particle filters, to become very high emitters if the filter suffers thermal or mechanical damage during the life of the vehicle.

It is therefore vitally important that particle emissions from engines of all ages and technology levels are regularly checked, and that the effectiveness of any subsequent emission-related maintenance or repair work is also validated by direct measurement of particle levels.

From a technology standpoint, a key outcome of the Australian research was the confirmation that particle emission levels can be quickly and reliably measured using low-cost, real-time measuring techniques. Laser light-scattering photometry was shown to provide accurate and reliable measurement of particle mass concentration, delivering better than 90% correlation with the traditional laboratory gravimetric filter methods.

## 5. Government Action

Based on the outcomes of its research projects, in 2002 Australia became the first country to introduce national standards for test protocols and particle emission limits for in-use diesel vehicles.

In a comprehensive federal-state approach to tackling the problem, several complementary strategies have been adopted to deliver reductions in motor vehicle particle emissions, including:

- rapid catch-up with European timetables for new vehicle homologation regulations and related fuel quality standards (currently Euro4 and adoption of Euro5 in 2010);
- fuel excise rebates for operators of vehicles meeting specific emission-related criteria;
- preferential selection of “green fleet” compliant operators for major government and commercial transport contracts;
- targeted emission testing programs.

To facilitate wider adoption of in-use tailpipe emission testing, lower capital cost approaches are also being considered to relace or complement the current transient dynamometer and exhaust mass flow measurement - based regime.

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# Why is Vehicle Pollution an Issue ?

**Vehicle Pollution makes people SICK**

**Vehicle Pollution KILLS people**

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# Australian Motor Vehicle PM Management - History

## New Diesel Vehicles

- Pre-1995: Nil - smoke opacity only
- 1995-97: Phase-in of Euro1
- 2002-03: Phase-in of Euro3
- 2006-08: Phase-in of Euro4
- 20010-11: Phase-in of Euro5

## In-Use Diesel Vehicles

- 1997: National Air Pollution Inquiry recommends action
- 1998-01: Research and Pilot Projects
- 2002: National standards and PM limits for in-use testing
- 2003-08: Establishment of federal/state programs and pilots, including economic and voluntary strategies

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# In-Use Test Evaluation/Development Program - Outline

- **Performed in two testing phases, plus several desktop studies.**
- **First phase comprised:**
  - **intensive 80 vehicle laboratory program which compared all potential tests against reference CUEDC cycle**
  - **measured PM (filter, TEOM, APS, SMPS, Laser Photometry) plus all regulated gases, CO2 and smoke opacity on all tests where practical to do so**
  - **also PM size distribution analysis and high interest air toxics to maximise value of laboratory time**
- **Second phase was a 700 vehicle pilot program**
  - **I/M grade instrumentation, mass flow measurement and mobile dynamometers, using the preferred short test (DT80)**
  - **included maintenance /repair and re-test of around 120 vehicles to establish program effectiveness profile.**

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# Elements of an Effective In-Use Emissions Test

- **Must identify vehicles that emit excessive levels of pollutants during normal on-road driving.**
- **Must reliably determine emission levels of ALL pollutants of concern**
- **Must be practical and cost-effective**

**Unfortunately, reality is sometimes a compromise !**

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# Setting a Reference

- **Potential short test performance needs to be measured against real-world driving**

- **Composite Urban Emissions Drive Cycle (CUEDC) was developed to provide this**
  - **aggressive, contemporary speeds & accelerations**
  - **includes most significant traffic conditions**
  - **based on instrumented vehicle research**

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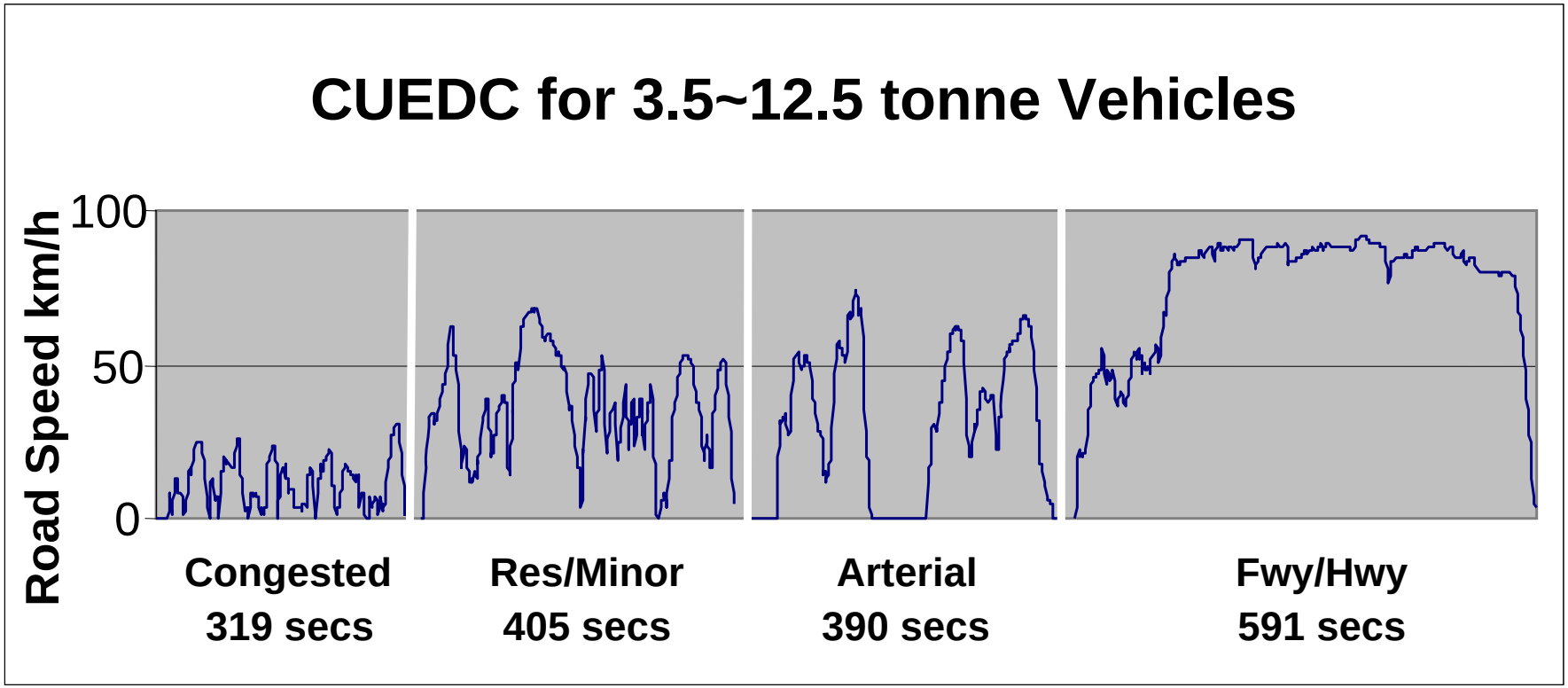
# Composite Urban Emissions Drive Cycle (CUEDC)

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# Candidate Short Tests

- **Candidate short tests for Australian diesel program were in three categories:**
  - **Unloaded: Free Acceleration (SAE J1667)**
  - **Steady State Loaded: D550, Lug-Down, 2-Speed**
  - **Transient Loaded: DT80, AC5080**
- **Project included measurement of PM, smoke opacity, NOx and other regulated gases**
  - **Results of each candidate test were correlated against CUEDC results for same vehicle.**

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# Evaluation Program Outcomes (1)

- **Real-time measurement of PM mass concentration was a key target for the program**

- **Laser light-scattering photometry (LLSP) proved capable of delivering reliable, repeatable measurements of PM concentration**

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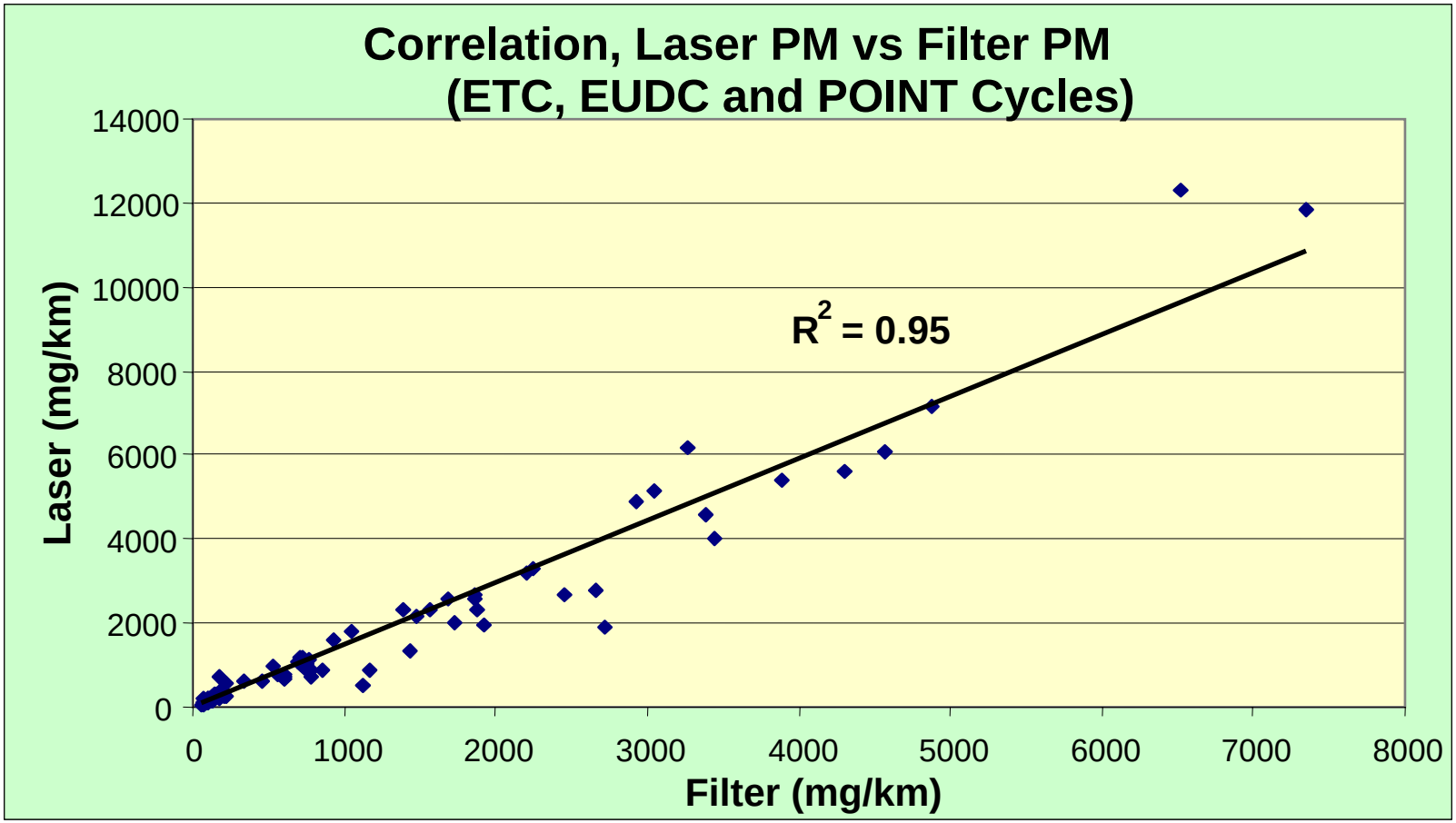
# Comparing Filter and LLSP Results

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# Evaluation Program Outcomes (2)

- **Maintenance of diesel vehicles can deliver very large PM emission reductions**
  - **PM reductions up to 80% are achievable from effective maintenance and repair**
  - **solution is often very simple, such as air filter replacement**
  - **most of the available PM reductions are delivered by the top 25% polluters.**

**Long-term durability and failure modes of advanced exhaust after treatments are not yet fully understood**

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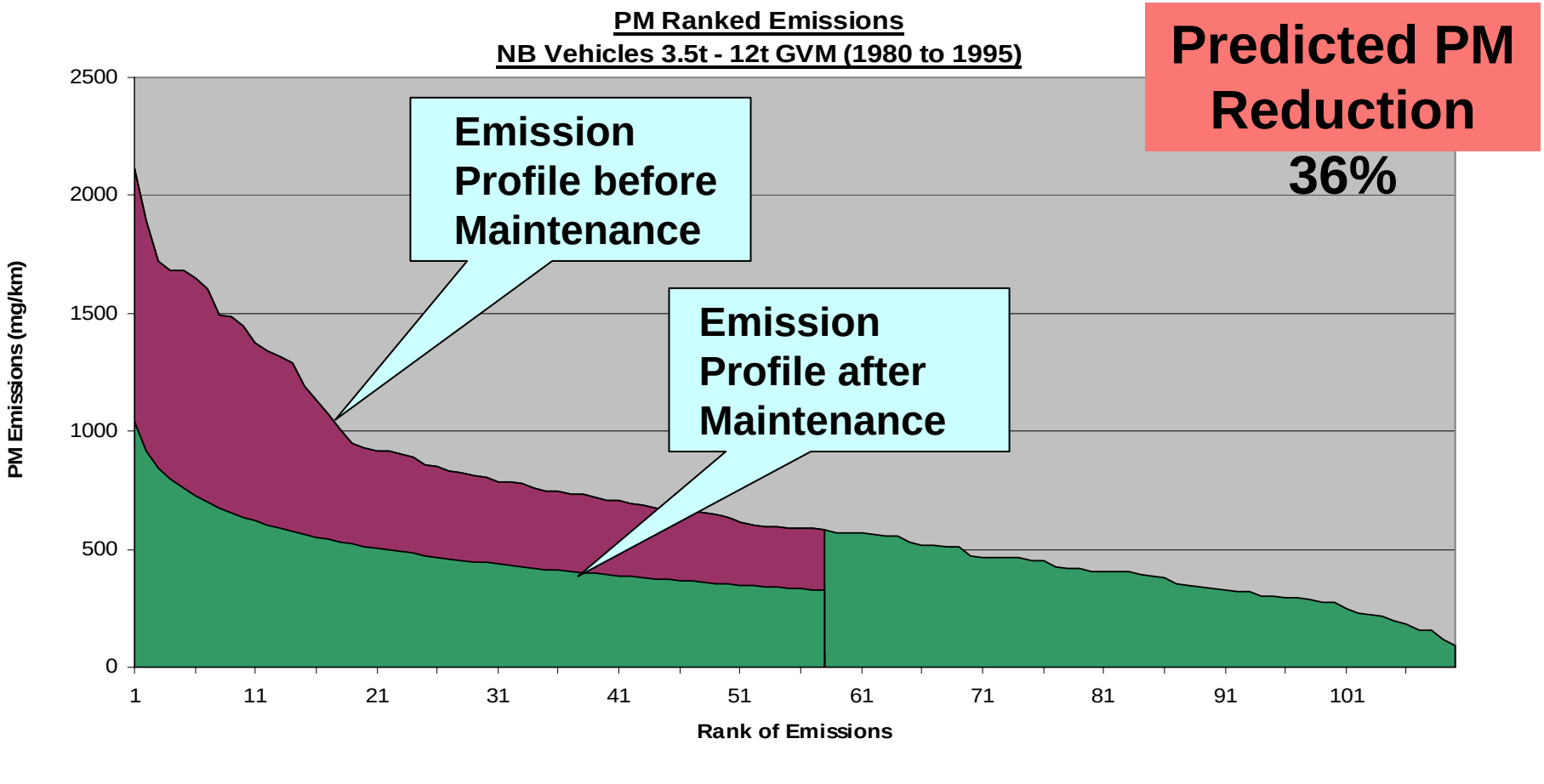
# PM Reductions from Maintenance

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## Evaluation Program Outcomes (3)

- **Analysis recommended adoption of DT80 test for Australia**
  - duration 3~4 minutes
  - contains idle, acceleration and cruise modes
  - good correlation with complex CUEDC cycle
- **DT80 test includes second-by-second measurement of PM, NOx, smoke opacity, velocity, power and exhaust mass flow**
  - CH4 and CO2 also measured for greenhouse gas performance certification testing

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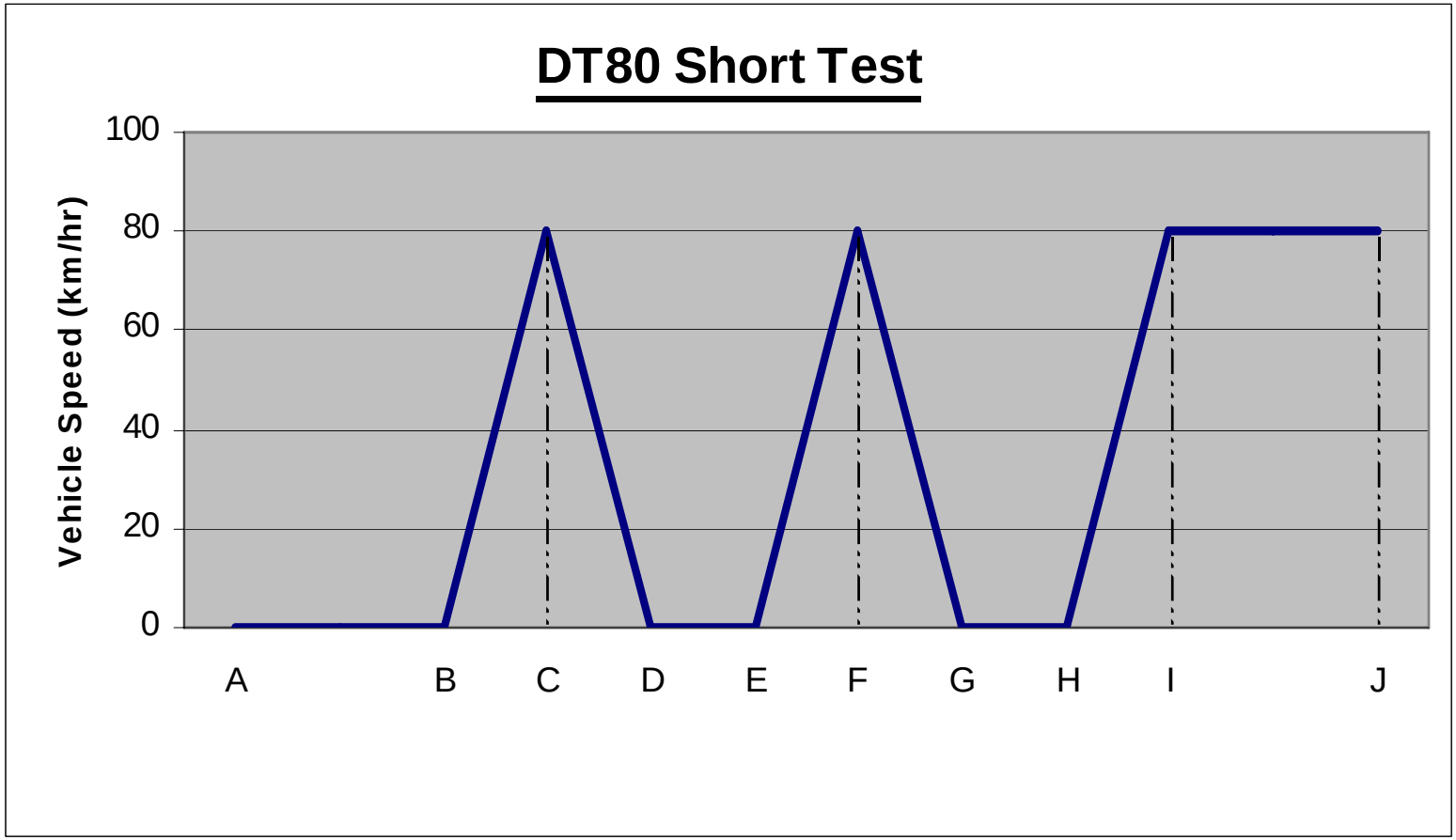
# DT80 Test

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# Normalising for Vehicle Mass

- **However, absolute emission levels do not tell the full story**
  - It is useful to link PM emission levels with power (g/kWh)
  - in city driving aerodynamic loads are generally small relative to mass (inertia) loads
  - dividing measured emissions rate (g/km) by vehicle test mass (tonnes), gives a result (g/km.t) which correlates more closely with g/kWh.

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# Australian HD Vehicle Standard 147A

## Note: Extracts only - see Regulation for full text

(b) the vehicle must not emit particles at a rate (measured in grams of particles emitted per kilometre travelled per tonne of the vehicle's test mass) greater than that specified for the vehicle according to its GVM rating and age in the following table:

| Vehicle's GVM rating (t) | Rate of particle emission (g/km/t) | |
|---|---|---|
| | *Vehicle manufactured in December 1995 or earlier* | *Vehicle manufactured in January 1996 or later* |
| not greater than 3.5 | 0.23 | 0.23 |
| more than 3.5 but not greater than 12 | 0.23 | 0.15 |
| more than 12 but not greater than 25 | 0.08 | 0.05 |
| more than 25 | 0.07 | 0.03; |

**Schedule 1** **DT80 transient test procedure for testing of diesel-fuelled vehicle exhaust emissions**

(rule 147A)

1 Secure the vehicle on the dynamometer.

2 Set the dynamometer to simulate the correct load and inertia for the vehicle.

3 Start sampling.

4 Idle for 60 seconds.

5 Accelerate rapidly to 80 km/hr under simulated inertia using wide open throttle, making gear changes as required for smooth acceleration.

6 Decelerate by removing all pressure from the accelerator pedal, disengaging the gears and gently applying brakes to bring the vehicle to a standstill.

7 Idle for 10 seconds.

*Road Transport Reform (Vehicle Standards) Amendment Regulations 2001 (No. )* 2001,

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# Australian In-Use Diesel Programs

- **Initial focus is on targeted and incentive-based strategies, rather than mandatory periodic testing for all vehicles:**
  - fuel tax rebates
  - audited maintenance
  - on-road monitoring
- **Extensive communication, partnership and education have paid dividends**
  - strong voluntary uptake by many larger fleets
- **DT80 testing is principally used for determination of eligibility for incentive programs**
  - targeted test programs now being considered

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# Fuel Tax Rebate

- **Federal tax on diesel fuel is 37cents per litre.**
  - **operators of on-road diesel vehicles >4.5t GVM can claim a rebate of 50% of this tax**

- **At least one of four specified emission-related criteria must be met for eligibility:**
  - **modern technology engine (incl. retrofits)**
  - **operator's vehicle maintenance system is audited and formally accredited**
  - **vehicles are maintained under a prescribed regime**
  - **valid emission test certificate (DT80 test).**

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Greyed out eligibility criteria are meaningless and should be removed (author's personal opinion).

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# Clean Fleet (NSW)

- **New South Wales "Clean Fleet" initiative is a voluntary audited maintenance program, designed to improve air quality by reducing vehicle emissions.**

- **Operators must demonstrate:**
  - **Use of clean (low sulphur) fuel**
  - **Engine and fuel settings all to manufacturer specifications**
  - **Documented maintenance schedules**
  - **Establish emission-related fault identification and repair procedures.**
- **Now being required under many bus and freight contracts with government and big business.**

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# Other Initiatives

- **DPF and DOC retrofit – state rebates most of cost but many fleets now fitting them voluntarily.**
- **Mechanic training courses (technical college and interactive computer-based).**
- **Smoky Vehicles must be repaired and retested (DT80 test) to validate repairs.**
- **On-board measuring systems (PM, NOx, opacity, speed, power, exhaust mass flow) are being evaluated**

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# Mobile Emission Testing - Queensland

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# Diesel Program Review (April 2007)

- **Joint federal/state government review to assess current system effectiveness and to consider future directions**
- **Key Findings / Recommendations:**
  - **laser PM measurement confirmed reliable and practical**
  - **explore feasibility of shorter/cheaper emission test**
  - **increase stringency of DT80 test pass/fail limits**
  - **explore feasibility of “briefcase” on-board systems**
  - **expand programs to include periodic testing**
- **Unfortunately no recommendations were made for more stringent diesel excise tax rebate eligibility criteria.**

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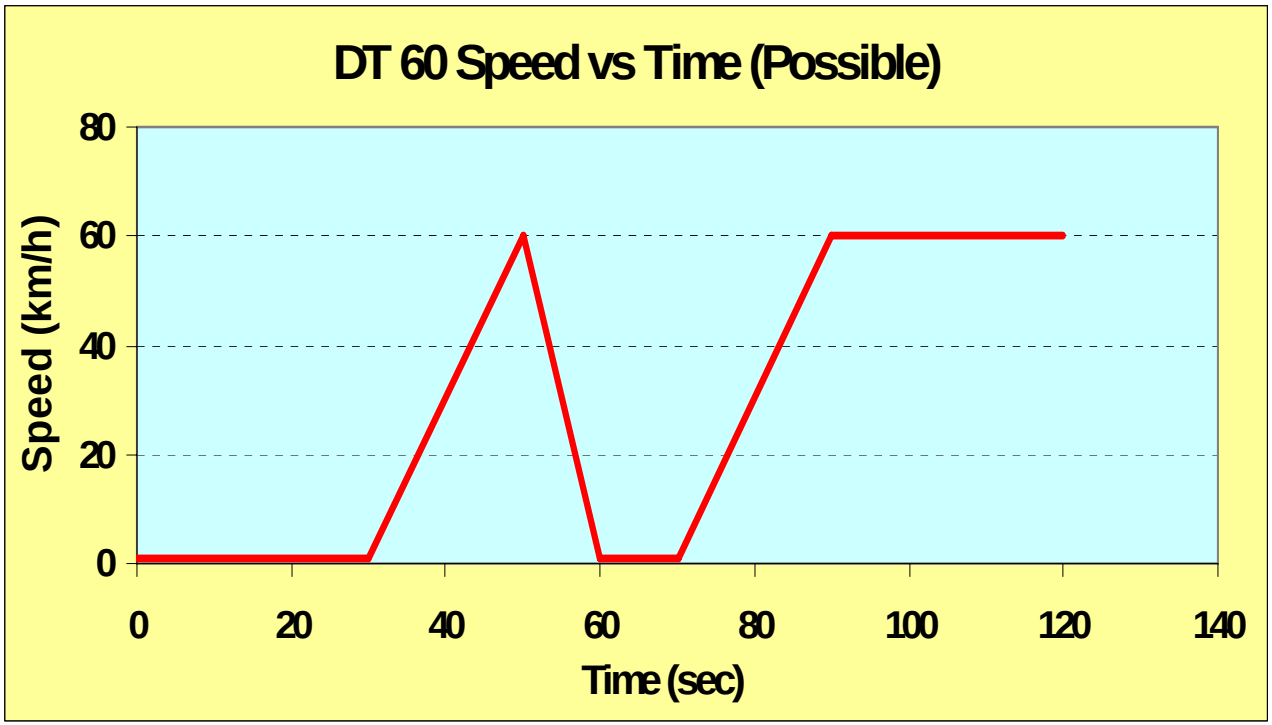
# Some Options (1)




## Why a DT60?:

- Faster – test time halved
- Less tyre and dynamometer heating
- Better customer acceptance

**Other Options:**

1. **Measure only raw PM, NOx concentration plus Opacity (equivalent to ASM)**
2. **Free Acceleration (stationary) PM only**

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# New Technology Provides PM Measurement in a Workshop Package

**Using laser light scattering technology and high-speed data processing, real-time particle measurement is now a practical option for test lanes and diesel workshops**


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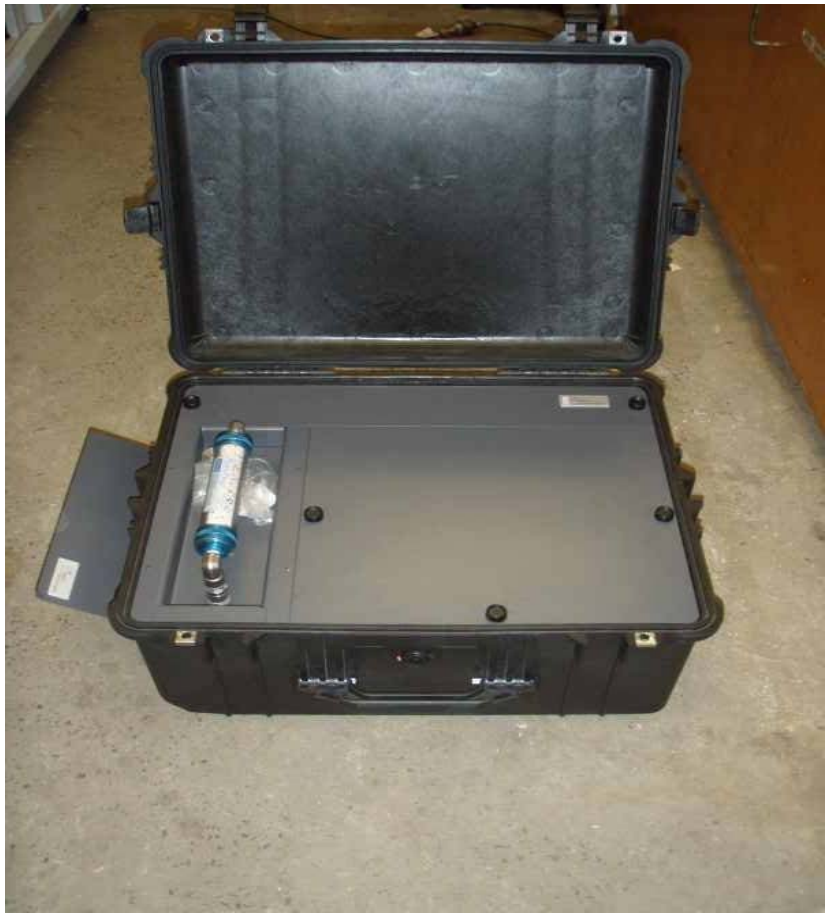
# Prototype “Briefcase” System



**Measures real-time mass emissions (PM, NOx in g/sec and g/km plus opacity) from vehicle in motion**

**Travels on passenger seat, probe connected to exhaust**

**Communicates with laptop via wireless for data capture, analysis and reporting**

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## Summary

- **Strategies to encourage better diesel vehicle maintenance can deliver very significant PM emission reductions**
- **The reliability of the test procedure and instrumentation are critical to reliably identifying high polluters**
- **Instrumentation to quickly and reliably measure PM concentration is now available**
- **When effectively managed, economic and voluntary PM reduction strategies can be very effective alongside traditional periodic testing programs.**

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