

# Towards Purer Air:

A review of the latest evidence of the effectiveness of photocatalytic materials and treatments in tackling local air pollution





# Contents

<b>Foreword</b> .....	4
<b>Introduction</b> .....	5
<b>The need to tackle NO<sub>x</sub></b> .....	5
<b>Use of TiO<sub>2</sub></b> .....	6
<b>AQEG study</b> .....	6
<b>EIC-commissioned research</b> .....	7
<b>Side products</b> .....	8
<b>Cost-benefit analysis</b> .....	9
<b>Conclusion and recommendations</b> .....	10

## **Annex 1: Titanium dioxide-based coatings for the abatement of nitrogen oxides in air** – A report by Imperial College London

I. Aims.....	11
II. Introduction .....	11
III. Field trials.....	24
IV. Modelling .....	33
V. Conclusions.....	36
References .....	39
Abbreviations.....	44
Appendix.....	45

## **Annex 2: Economic assessment of photocatalytic treatment** – A report by Temple Group

Introduction .....	46
Methodology .....	47
Economic Assessment of Photocatalytic Coatings .....	48
Conclusions .....	50
Endnotes.....	50

# Foreword



Air pollution is one of the most challenging, and insidious, public health issues of our time. High urban concentrations of particulate matter and nitrogen oxides are estimated to be responsible for tens of thousands of premature deaths. The young and the old are especially vulnerable.

There is a wide agreement that air pollution must be reduced, but comprehensive solutions are elusive. Electric vehicles, for example, clearly have a role to play, but still create particulate matter through brake and tyre wear.

EIC represents the businesses which are working to solve environmental problems, including air pollution. Our member companies are innovative and include both technology manufacturers and expert consultancies. As an organisation we believe that there is no single solution to air pollution, but that a range of technologies and approaches will be needed, with an evidence-based assessment of the costs and strengths and weaknesses of each technology essential to decide what combination of measures will lower dangerous air pollution levels quickly and affordably.

This report is one of a number of reports we have published on the policies and technologies of air pollution. It focuses on the potential of photocatalytic treatments (PCT's) to reduce ambient levels of nitrogen oxides. If effective, such treatments could be applied to road surfaces and buildings in the most polluted urban streets. They would not be enough by themselves, but could be used as a relatively cheap and unobtrusive way to add to other efforts.

Studies have shown that photocatalytic treatments do work in laboratory conditions, something noted by the Government's Air Quality Expert Group. Can we ensure that this pollution reduction effect could be replicated at scale in the real world? AQEG thought not, pointing to a selection of field trials which had mixed results. Their report did recognise the value of further work, and given the need to leave no stone unturned in searching for solutions to air pollution, we decided to commission further research from Imperial College London to understand the implications of all available studies and trials in this field in as much depth as possible. We also commissioned EIC member consultancy Temple Group to undertake a new cost benefit analysis on the use of PCTs.

The conclusions of this research are set out in this report and give cause for optimism. We hope that the work will stimulate further debate over the value of conducting a number of large scale field trials to provide hard evidence of the role PCTs could play in cleaning up the polluted air we all breathe.

My thanks to Imperial College and to Temple Group for their detailed and thorough work.

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**Executive Director**  
**EIC**

# Introduction

This report contains an assessment of the most up-to-date evidence for the effectiveness of photocatalytic treatments (PCTs) on reducing nitrogen oxides. It summarises the results of two studies commissioned by the Environmental Industries Commission – the first by Imperial College London, which examined all the available published evidence from both laboratory studies and field trials, and develops a model of the likely impact of PCTs on a typical street canyon, and the second by environmental consultancy Temple Group, who has used the work by Imperial and additional analysis to calculate cost benefit analyses for a plausible scenario of PCT deployment. Both studies are included as Annexes to this report.

The report also includes recommendations from EIC for policymakers.

## The need to tackle NO<sub>x</sub>

Nitrogen oxides, and especially nitrogen dioxide, are harmful pollutants released when fossil fuels are burned. For public health reasons, the EU has set legal limits on NO<sub>2</sub> concentrations, which many UK towns and cities regularly exceed. The public health cost of these levels of NO<sub>2</sub> is estimated to be tens of thousands of premature deaths. There is a broad political and scientific consensus that levels of NO<sub>2</sub> in urban areas must be reduced as quickly as possible for public health reasons, and this is also a legal requirement under EU law.

There is currently an active debate over the policies and technologies that will reduce NO<sub>2</sub> levels in the most effective manner. Practicality, cost and speed of deployment are all key issues.

Most options being considered are either behaviour change options (reduced car use, switching off vehicle engines when stationary), or designed to cut out pollution at source (eg DPF/SCR exhaust treatments, low emissions fuels, or zero emission vehicles such as electric cars).

A further approach, complementary to the others, is to remove NO<sub>x</sub> from the atmosphere in the most polluted areas. One way to do this is to apply photocatalytic treatments to surfaces in areas of high NO<sub>x</sub> pollution.



## Use of TiO<sub>2</sub>

Titanium dioxide (TiO<sub>2</sub>) is the naturally occurring oxide of titanium. It is used in a wide range of pigment related applications (e.g. as a white pigment in paint, a UV blocker in sunscreen, a food colorant etc). TiO<sub>2</sub> is also a powerful photocatalyst, and can speed up the natural, but slow oxidation of organic matter in the presence of light and water.

Specialist photoactive TiO<sub>2</sub> is already used in a wide range of photocatalytic products, including self-cleaning windows (Pilkington NSG - Activ™, Saint-Gobain - Bioclean, PPG - Sunclean), self-cleaning tiles (TOTO - Hydrotect) and air purification devices (Hoover, electriQ, De'Longhi, Green UV etc). The current global market for photocatalytic compositions was \$1.5 billion in 2014, and is forecast to grow at a compound annual growth rate of 12.6% over the next five years.

Photoactive TiO<sub>2</sub> is already being used in photocatalytic coatings for the abatement of NO<sub>x</sub> in polluted air (Boysen Paints, Keimfarben, Sto Climisan, PPG and others). The core of this idea is to incorporate photoactive TiO<sub>2</sub> onto the surface of building materials, where under the action of UV light present in natural sunlight, ambient NO<sub>x</sub> gases will be oxidised into benign compounds. Various products have been examined; including photocatalytic concretes, paints and asphalts. In addition to oxidising NO<sub>x</sub> gases in air, these coatings can also oxidise sulphurous oxides, ammonia and VOCs into benign compounds (Guerrini, 2012).

Because of the global concern over air pollution in urban areas, there has been significant interest in the potential of photocatalytic treatments. Laboratory studies have been conducted as well as field trials in numerous places.

## AQEG study

In 2016, the UK Government's Air Quality Expert Group produced a review of a number of these studies and trials [Paints and Surfaces for the Removal of Nitrogen Oxides - UK Air Quality Expert Group, 2016]. The AQEG report recognised that 'Under laboratory conditions photocatalytic surfaces have been shown to effectively reduce concentrations of NO<sub>x</sub>.'

The report then looked at a selection of field trials and concluded that they showed mixed results. AQEG then made a set of assumptions about the way that the airflow would interact with the PCT surface coating, and modelled the effectiveness of a PCT coating on reducing NO<sub>x</sub> pollution in a typical London environment. The review concluded that the build up of NO<sub>x</sub> in the London atmosphere would be six times greater than the removal capacity of the PCT coating, and that PCT treatments would have limited effect.

The AQEG report also pointed out that some studies had shown evidence of potential generation of harmful by-products during the photocatalytic reaction.

## EIC-commissioned research

AQEG recognised that there are many uncertainties in assessing and modelling the effect of photocatalytic treatments, commenting that ‘it is uncertain what magnitude of reduction in concentration might be expected under real conditions e.g. in urban streets due to the complex way in which the atmosphere interacts with surfaces.’

Given the theoretical potential of photocatalytic treatments to be a low cost, unobtrusive option to help tackle air pollution, EIC decided it was worth doing further analysis and in Autumn 2017 commissioned Imperial College London to undertake a thorough analysis of all available evidence including the most recently published. The full report from Imperial College is in Annex 1.

The Imperial College report examined both laboratory studies and field trials, for both photocatalytic concrete products, photocatalytic paints and treatments. The research was able to cover a much wider range of field trials than the AQEG report was able to (see table)

**Table 1: Trials covered in AQEG and Imperial College reports**

Trials covered by AQEG report	Trials covered by Imperial College report
Paris – 2004	Paris – 2004
	Antwerp – 2004
	Tower Hamlets – 2005
	Rome - 2007
Camden – 2007	Camden – 2007
Hengelo – 2008	Hengelo – 2008
	Manila – 2009
	Louisiana – 2011
	Wijnegem - 2011
Brussels – 2011	Brussels – 2011
Copenhagen - 2012	Copenhagen – 2012
	The Hague - 2013

Imperial College noted that in two large scale trials not covered in the AQEG report, Rome - 2007 (9,000 m<sup>2</sup> coating) and Manila (6,000 m<sup>2</sup> coating) ‘showed significant decreases in NO<sub>2</sub> in the surrounding air’. Imperial College also noted that several of the trials considered by AQEG to be “not comprehensive and unreliable” did actually demonstrate viable reductions in pollution level.

The Imperial College research then modelled a scenario where photocatalytic paint and a road coating were used in a representative London street canyon (the urban architecture in which the impact of photocatalytic treatment would be most effective and where it would make sense to target any deployment of PCTs – they would not be appropriate for all urban areas). Pp 33-36 in Annex 1 set out the full details of the scenario and the modelling.

The conclusions are in the Table below, showing NO<sub>x</sub> reductions of 4 to 11% and NO reductions of 11 to 28% depending on seasonal conditions.

**Table 2: NO<sub>x</sub> Reductions from photocatalytic treatment under different scenarios**

Scenario	Season	Activity (mg.m <sup>-2</sup> .s <sup>-1</sup> )		NO <sub>x</sub> reductions in moving volume of gas (2,400 m <sup>3</sup> )	
		NO	NO <sub>2</sub>	NO	NO <sub>2</sub>
(i)	Summer	3.3	0.93	18.3 mg, 11.0%	5.2 mg, 4.4%
	Winter	5.9	1.12	32.8 mg, 11.1%	6.2 mg, 4.3%
(ii)	Summer	3.3	0.93	45.8 mg, 27.5%	12.9 mg, 11.0%
	Winter	5.9	1.12	81.8 mg, 27.7%	15.6 mg, 10.8%

These results are much higher than the AQEG modelling, which predicted NO<sub>x</sub> reductions of only 0.7%. This difference is explained by:

- The Imperial College modelling used experimentally derived, published deposition velocities based on work by Engel and Bahnemann et al (2015). The values from Engel's study are an order of magnitude higher than the deposition values estimated in the AQEG modelling exercises. There is no experimental or technical justification for the AQEG estimate for deposition velocity of a photocatalytic surface in their report.

Modelling has inherent uncertainties, however it should be noted that the NO<sub>x</sub> reduction rates in the Imperial College model were comparable to the reductions observed in the large scale Rome and Manila trials and other modelling studies which have been carried out.

## Side products

A concern raised about the future deployment of PCTs is the formation of potentially harmful side products such as nitrous acid, (often referred to as HONO), and formaldehyde during reaction of NO<sub>2</sub> on TiO<sub>2</sub> paints. The AQEG report raised this risk. The Imperial College study notes that 'Some studies have shown that HONO levels increase (a harmful respiratory irritant) during the reaction of NO<sub>2</sub> on TiO<sub>2</sub>-based paints (Gandolfo et al., 2015), whereas some studies show the contrary (Laufs et al., 2010).'

Work by Bahnemann et al. (2014) indicates that if a photocatalyst is powerful enough to degrade NO<sub>x</sub> into intermediate forms, these forms are readily and rapidly converted fully to harmless nitrate by oxidation.

# Cost-benefit analysis

Given the range of technology options available to tackle air pollution, it makes sense to prioritise those which have the best cost-benefit ratio. In 2015, EIC commissioned Temple Group to undertake a cost benefit analysis of five technologies, including PCTs, under certain scenarios. For this new report, EIC asked Temple Group to update the modelling for the PCT scenario using the analysis from the Imperial College work, and Temple Group's own updated analysis of the cost of applying and maintaining PCTs. Full details of Temple Group's methodology can be found in their report which forms Annex 2 of this report. The conclusions were that the NPV costs would be as follows:

**Table 3 Net Present Value (NPV) cost of photocatalytic treatment per tonne of NO<sub>x</sub> abated**

Scenario	Data	Units
Low cost scenario to 2020	23,530	£/teNO <sub>x</sub>
Mid cost scenario to 2020	40,523	£/teNO <sub>x</sub>
High cost scenario to 2020	73,203	£/teNO <sub>x</sub>
Low cost scenario to 2030	18,729	£/teNO <sub>x</sub>
Mid cost scenario to 2030	32,255	£/teNO <sub>x</sub>
High cost scenario to 2030	58,267	£/teNO <sub>x</sub>

For comparison, the equivalent costs per tonne for an electric vehicle roll out scenario (as calculated in 2015) were in the order of £1m/tonne of NO<sub>x</sub> abated.



## Conclusion and recommendations

This report is intended to be an evidence-based contribution to the ongoing debate about technology options for tackling air pollution generally, and the potential role of PCTs specifically. Given the thoroughness of the Imperial College research, it seems that the AQEG conclusions were too pessimistic in their assessment of PCTs. Given the inherent uncertainties in modelling, further large scale trials under controlled conditions would be the best way to resolve this. The Temple analysis confirms that if the NO<sub>x</sub> reductions shown in the Imperial modelling were borne out in practice, PCTs would be a highly cost-effective tool in tackling air pollution. The risks of harmful by-products can be analysed further in these trials to ensure that the conditions under which they may form can be fully predicted and avoided.

In light of these conclusions, EIC recommends that:

- The forthcoming Defra Air Quality Strategy includes an assessment of the potential role of PCTs
- Funding from the new Clean Air Fund is made available for a number of controlled large scale trials in selected high-pollution areas and that for investigations into potential by-product formation are made.
- AQEG releases an update to its 2016 report acknowledging the additional findings of the Imperial College research.

