Photocatalytic materials and their role in Indoor Air Quality - IAQ

Assist. Prof. Vassilios BINAS

e-mail: vbinas@chem.auth.gr / binasbill@iesl.forth.gr
url: https://www.chem.auth.gr/staff/binas-vasileios/
https://www.iesl.forth.gr/people/binas-vassilios

LIFE VISIONS ONLINE COURSE
Wednesday, 24 January 2024

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

LIFEVISIONS
InnoVative photocatalytIc paintS for healthy envirOnment and eNergy Saving

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Motivation *Climate Change*

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Motivation *Climate Change*

'Can we have two golds?' Our writers' best moments of Tokyo 2020

Sport

The Guardian

For 200 years

Tuesday 10 August 2021

£2.50 | €2.90

From £1.75 for subscribers

▲ A woman shows her distress as an inferno nears her home in Gouves, on the Greek island of Evia. The EU yesterday began a huge operation to tackle fires on the island. **Wildfires in Greece** Page 22→

Global climate crisis: inevitable, unprecedented and irreversible

- Devastating report is 'code red' warning for humanity, UN chief says
- Rapid and drastic cuts to CO_2 emissions needed this decade, warns IPCC
- 'Future is not written and very worst effects still avoidable' – Sharma

Fiona Harvey
Andrew Sparrow

Human activity is changing the Earth's climate in ways "unprecedented" in thousands or hundreds of thousands of years, with some of the changes now inevitable and "irreversible", climate scientists warned the world yesterday.

Within the next two decades, temperatures are likely to rise by more than 1.5C above pre-industrial levels, breaching the ambition of the 2015 Paris climate agreement and bringing widespread devastation and extreme weather. Only rapid and drastic reductions in greenhouse gases in this decade can prevent such climate breakdown, with every fraction of a degree of further heating likely to compound the accelerating effects, according to the Intergovernmental Panel on Climate Change, the world's leading authority on climate science.

The report was given a sombre welcome by world leaders and campaigners, who said the stark findings must force new policy measures as a matter of urgency to shift the global economy to a low-carbon footing. "If ever there was going to be a wake-up call to the world when it comes to climate change, this report is it," said Alok Sharma, the minister who will preside over the Cop26 UN climate summit in Glasgow in November. "But the future is not yet written. The very worst of climate change is still avoidable".

He said the world's biggest emitters of greenhouse gases must produce clear plans to cut carbon output. "What we really need now is for all major emitters to play their part, and the G20 are going to be absolutely key to our 1.5C

Leader comment

'The science is unequivocal. The verdict is clear. There is no more room for manoeuvre, delay or procrastination in dealing with a crisis that is this generation's responsibility to address'

Journal, page 2 →

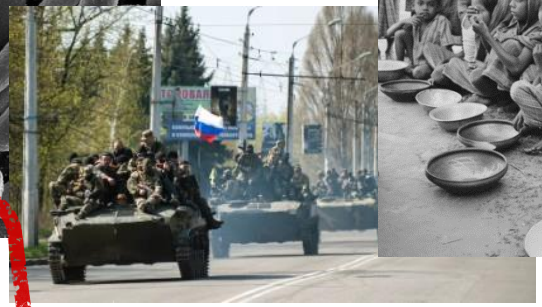
The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Motivation *10 global issues facing the 21st century*











The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Motivation *Let there be light*

PNAS

Photocatalysis and the origin of life: Synthesis of nucleoside bases from formamide on $TiO_2(001)$ single surfaces

S. D. Senanayake and H. Idriss*

Department of Chemistry, University of Auckland, Private Bag 92019, Auckland, New Zealand

Edited by Leslie Orgel, The Salk Institute for Biological Studies, San Diego, CA, and approved November 29, 2005 (received for review July 8, 2005)

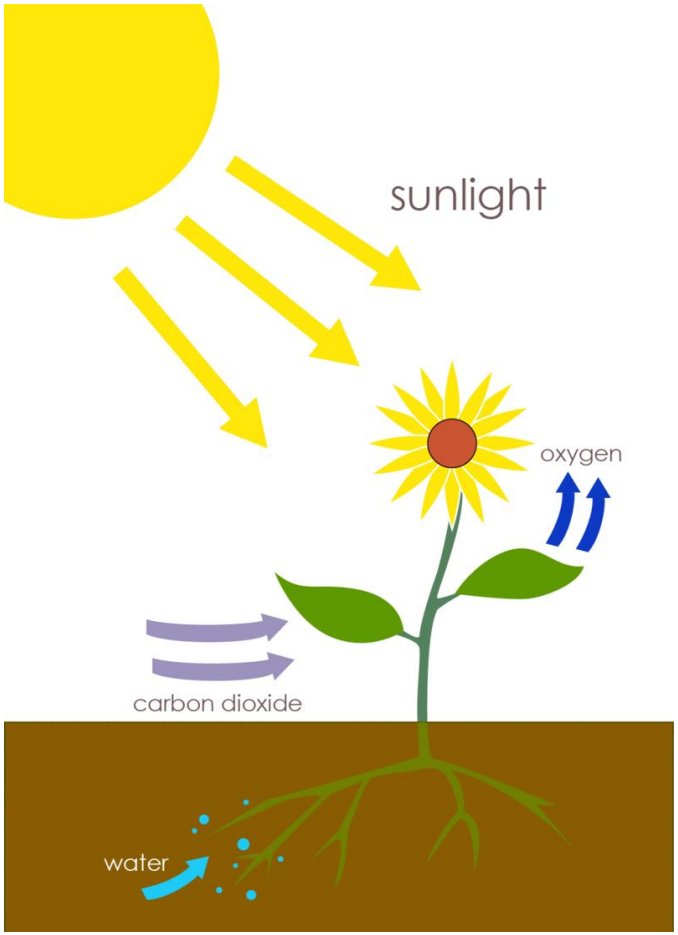
https://www.pnas.org/content/pnas/103/5/1194.full.pdf

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Motivation *Let there be light*

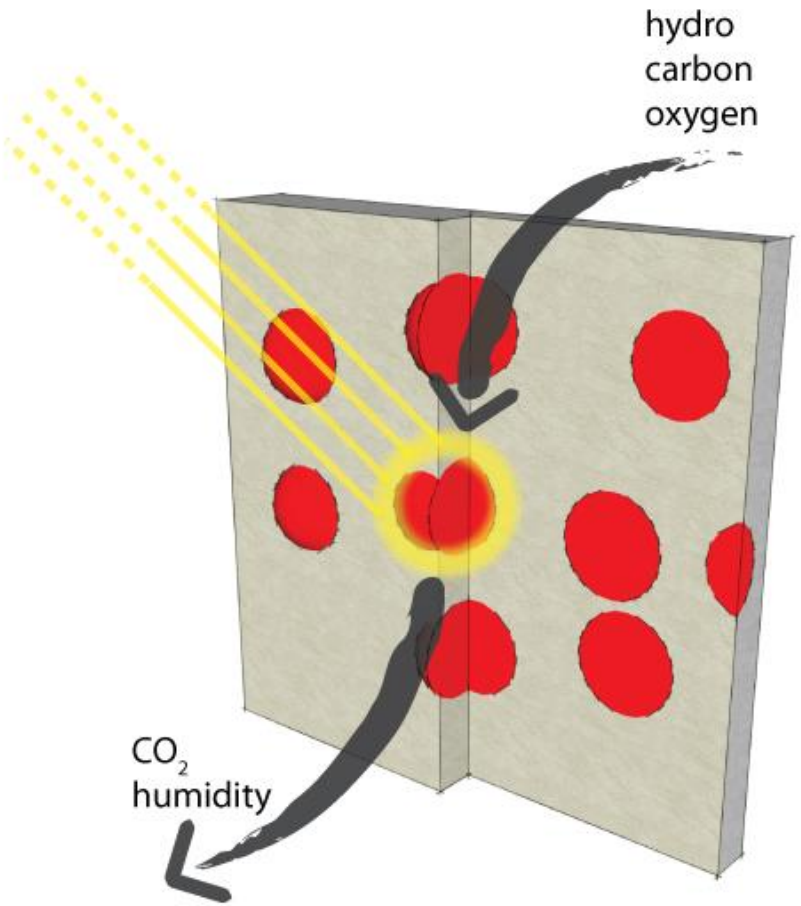
Photosynthesis of Plants

as an example of a Photocatalytic Reaction



By At09kg - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=17219609

Photocatalyst in work

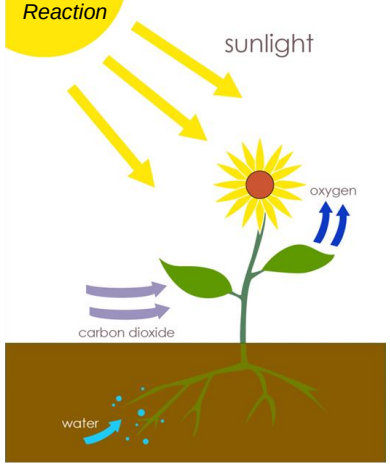


https://www.clear-up.eu/

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

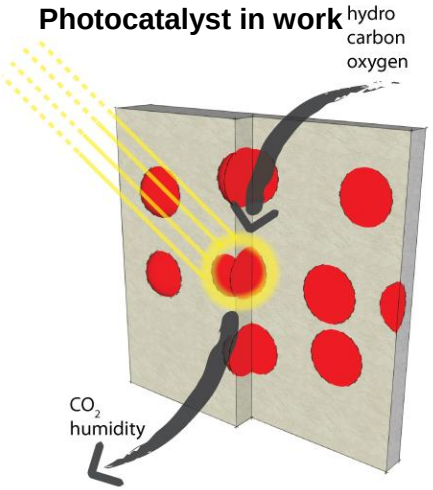
Motivation *Let there be light*

Photosynthesis of Plants
as an example of a Photocatalytic Reaction



By Al09kg - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=17219609

Photocatalyst in work



https://www.clear-up.eu/

nature COMMUNICATIONS

COMMENT

https://doi.org/10.1038/s41467-021-22839-0 OPEN

Photocatalytic air purification mimicking the self-cleaning process of the atmosphere

Fei He[1], Woojung Jeon[1] & Wonyong Choi[1✉]

Photocatalyst Process

$PC_{(heterogeneous\ sensitizer\ such\ as\ TiO_2)} + H_2O(g) + h\nu \rightarrow {}^{o}OH$

Self Cleaning mechanism in Earth's atmosphere

O_3 (molecular sensitizer) + $H_2O(g) + h\nu \rightarrow 2{}^{o}OH + O_2$

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

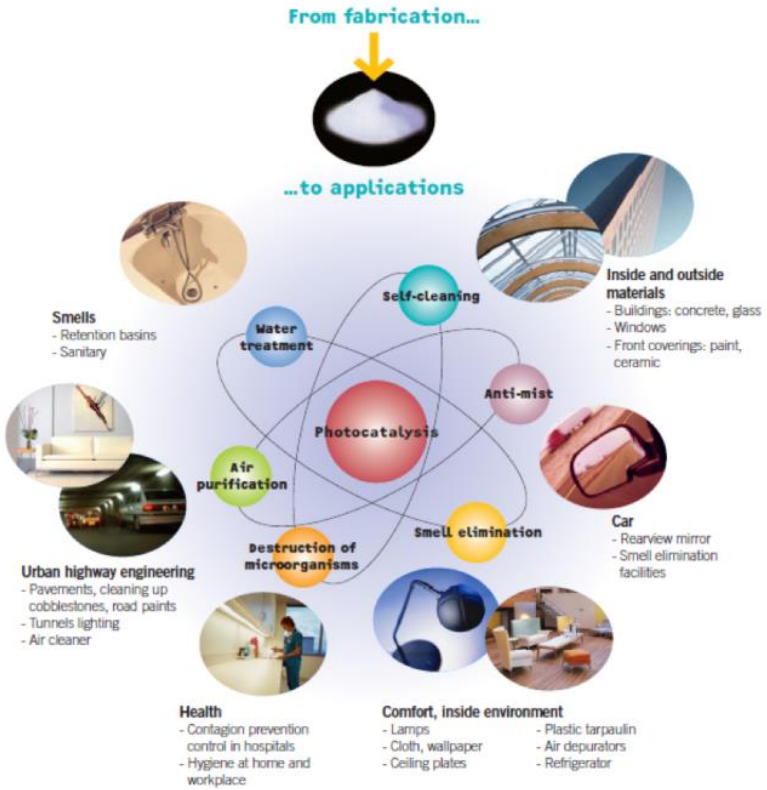
Motivation *Photocatalyst*

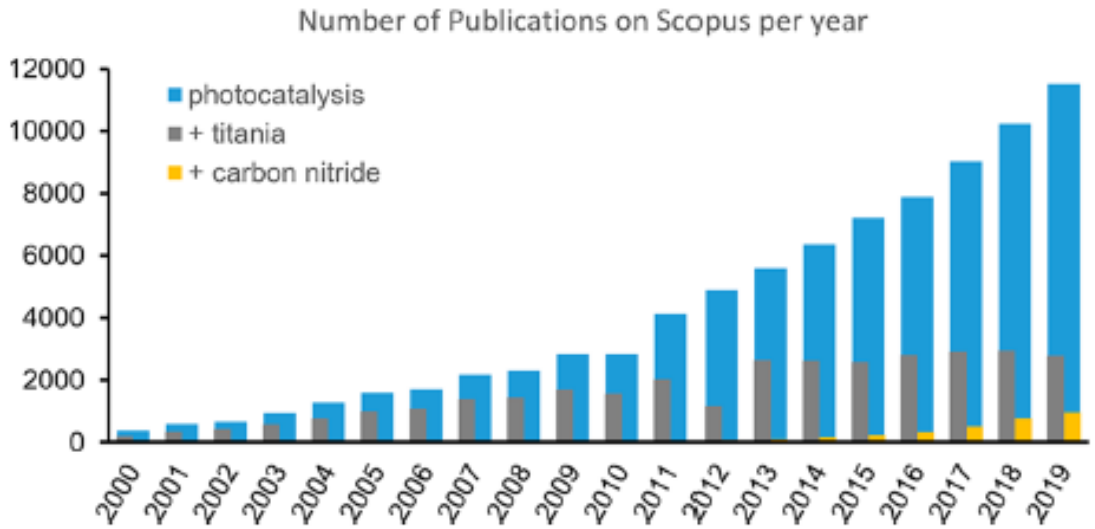
Photo Catalyst

Energy in the form of light

*A **material that induces a reaction** but is not consumed or transformed by it.*

The catalyst remains constantly available.



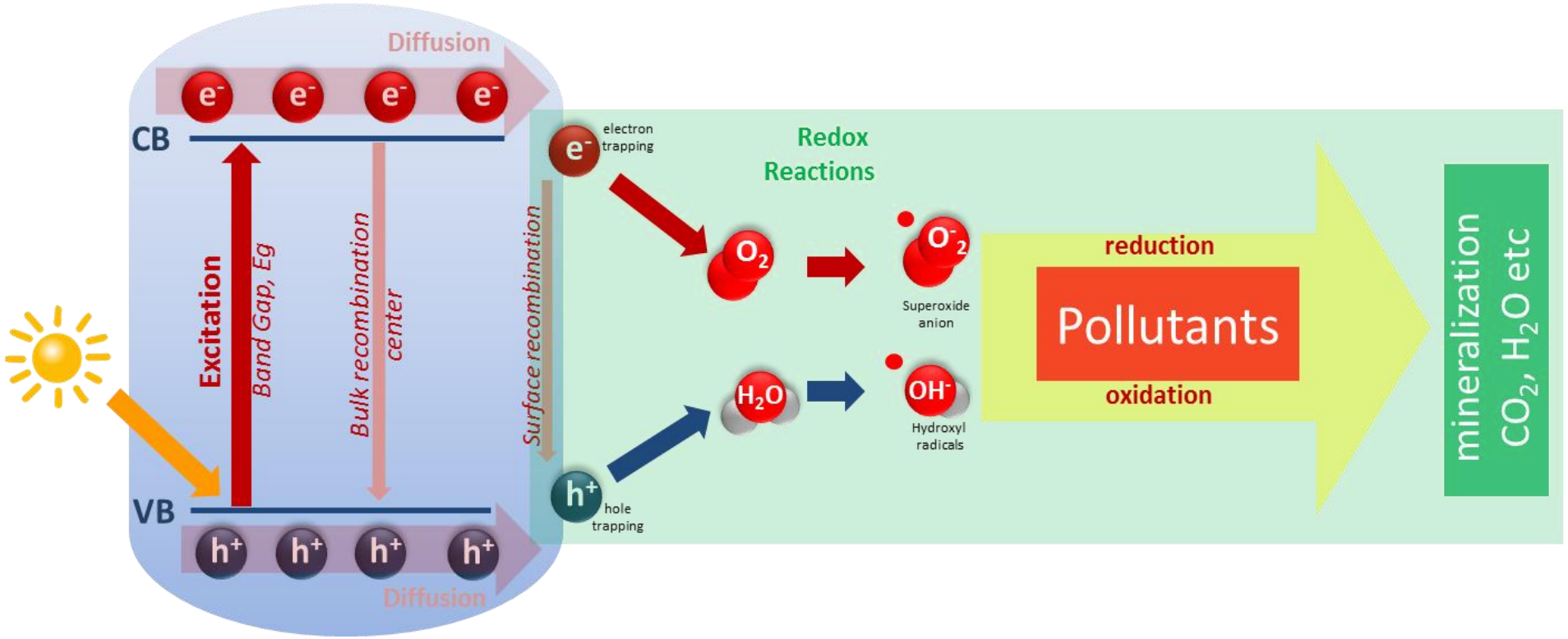


Source: European Federation of Photocatalysis

ACS Catal. 2020, 10, 5493−5501

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Motivation *How it works?*

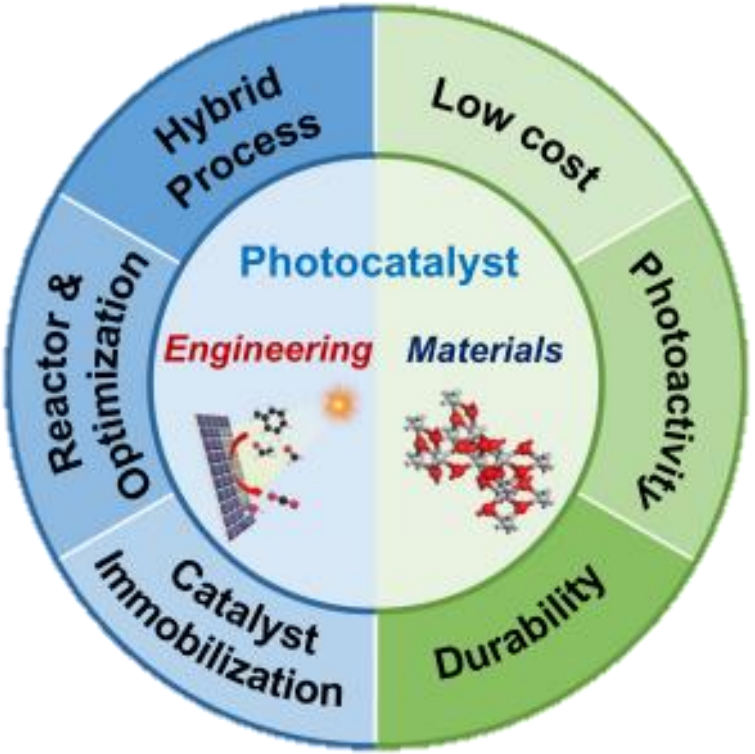


*V. Binas, et all, J Materiomics 3 (**2017**) 3-16*

The project has received funding from the LIFE Programme of
the European Union under GA number LIFE19 ENV/GR/000100

High performance advanced materials

for efficient photocatalytic systems



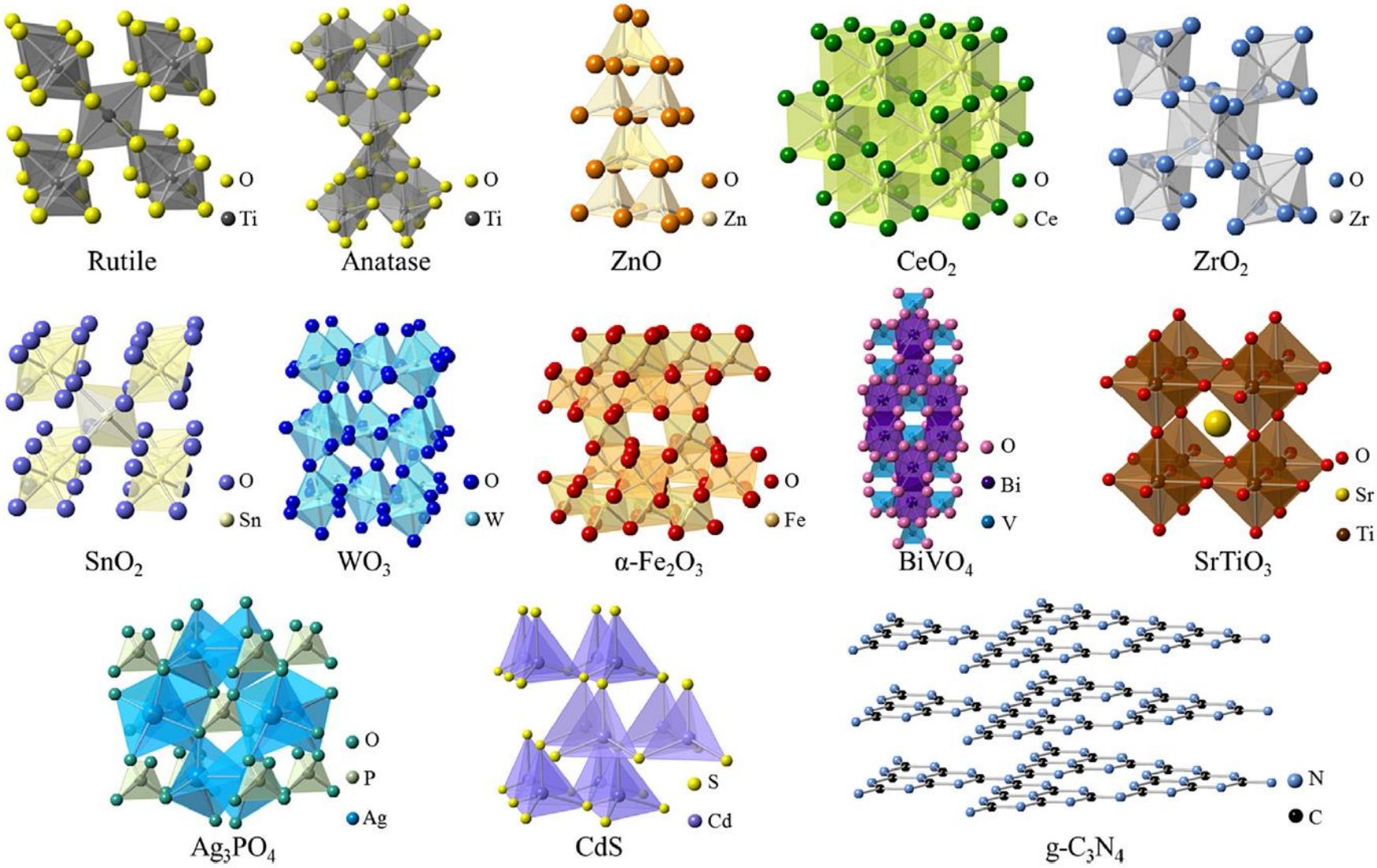
https://doi.org/10.1038/s41467-021-22839-0

FORTH / IESL / TCM
@ *V*assilios *B*inas

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

High Performance Advanced Materials *for efficient photocatalytic systems*

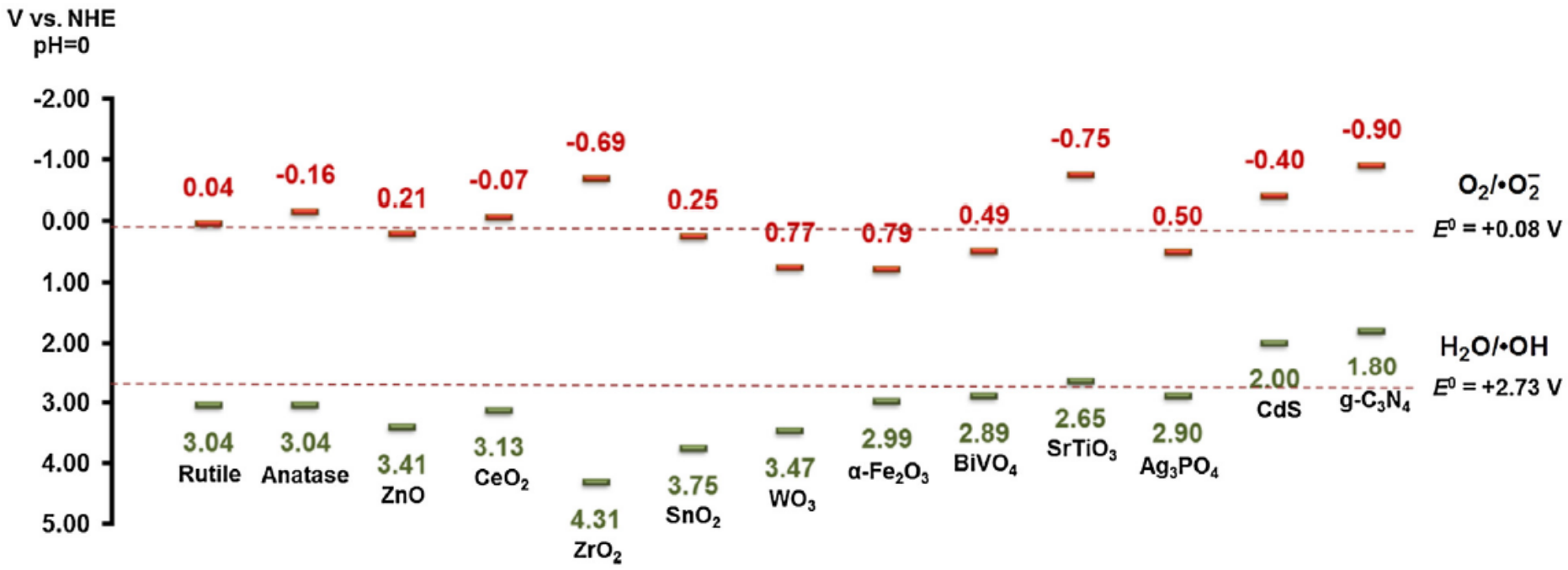
Crystal structures of different photocatalytic materials



H. Ren et al. / Journal of Hazardous Materials 325 (2017) 340–366

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

High Performance Advanced Materials *for efficient photocatalytic systems*

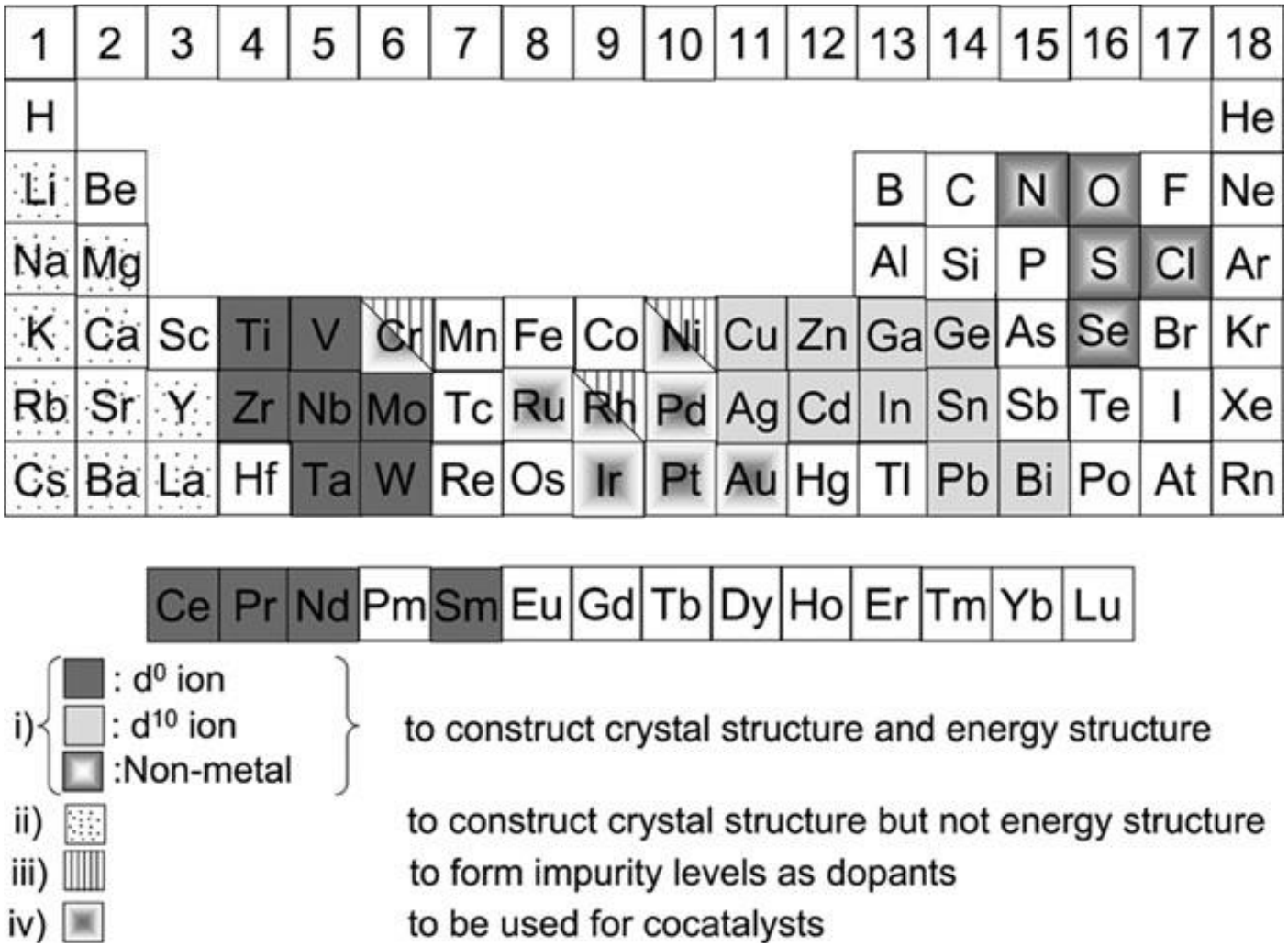


Energy levels of the conduction band minimum (E_{CB}, red) and the valence band maximum (E_{VB}, green) of the photocatalysts indicate the reducing ability of their photogenarated electrons (large negative E_{CB}) and the oxidizing ability of their photogenarated holes (large positive E_{VB})

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

High Performance Advanced Materials *for efficient photocatalytic systems*

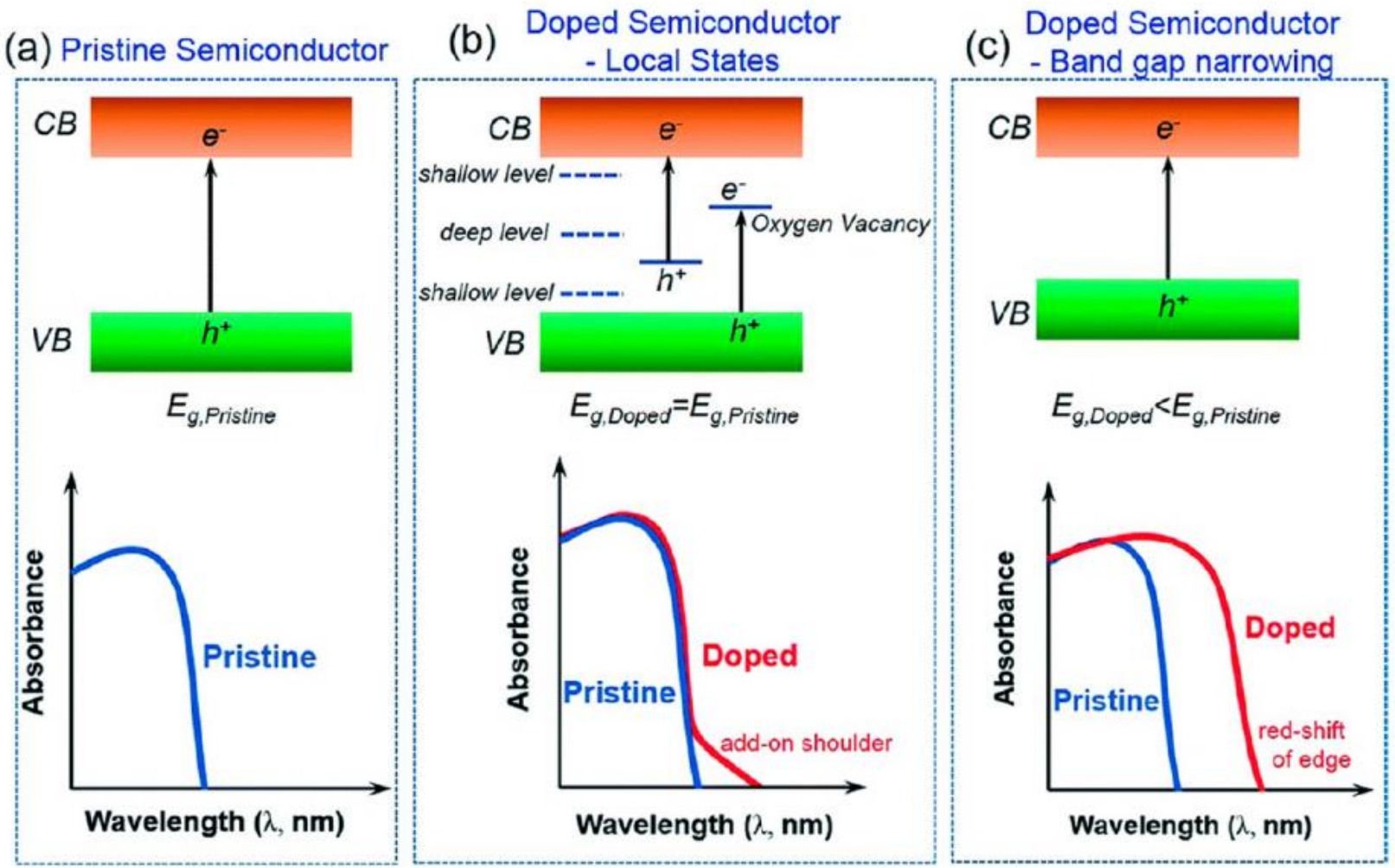
Elements constructing heterogeneous photocatalysts



The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

High Performance Advanced Materials *for efficient photocatalytic systems*

band structure engineered semiconductors



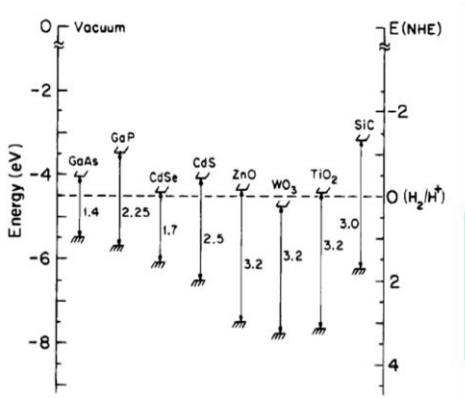
The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

LIFEVISIONS
Innovative photocatalytic paints for healthy environment and allergy Saving

High Performance Advanced Materials *for efficient photocatalytic systems*

Metal Oxide Semiconductors

Band gap of semiconductors



TiO_2

$$TiO_2 \xrightarrow{h\nu} h^+ + e^-$$

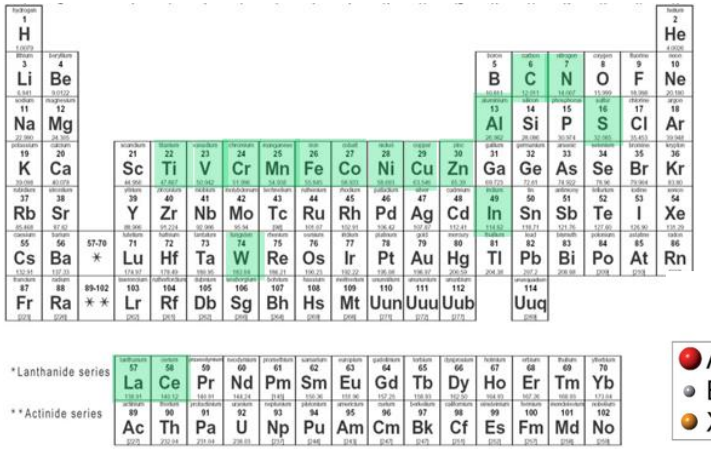
$$h^+ + OH^-_{ads.} \rightarrow OH^*_{ads.}$$

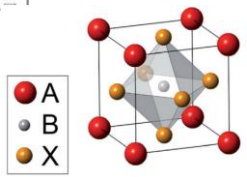
$$e^- + O_2 \rightarrow O_2^*$$

- *low cost*,
- **innoxiousness**,
- **chemical inertness**,
- and **high photocatalytic performance under UV light**

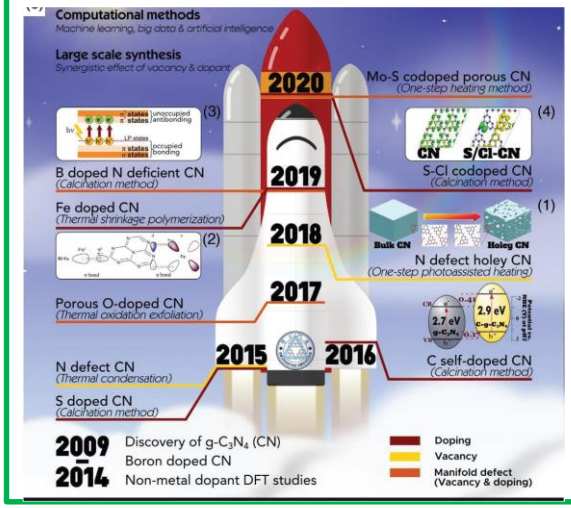
Perovskite and ilmenite type Oxides

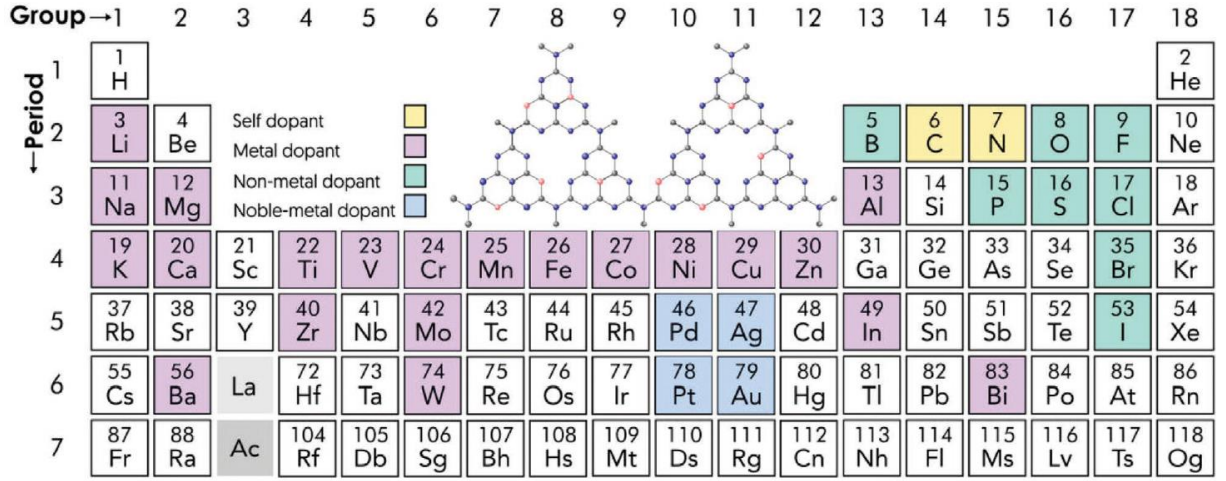
(Titanates, Tungstates, Vanadates etc)





Carbon Nitride g-C_3N_4 Nanosheets / Hybrid materials





FORTH / IESL / TCM
@ *V*assilios *B*inas

LIFE VISIONS ONLINE COURSE
Wednesday, 24 January 2024

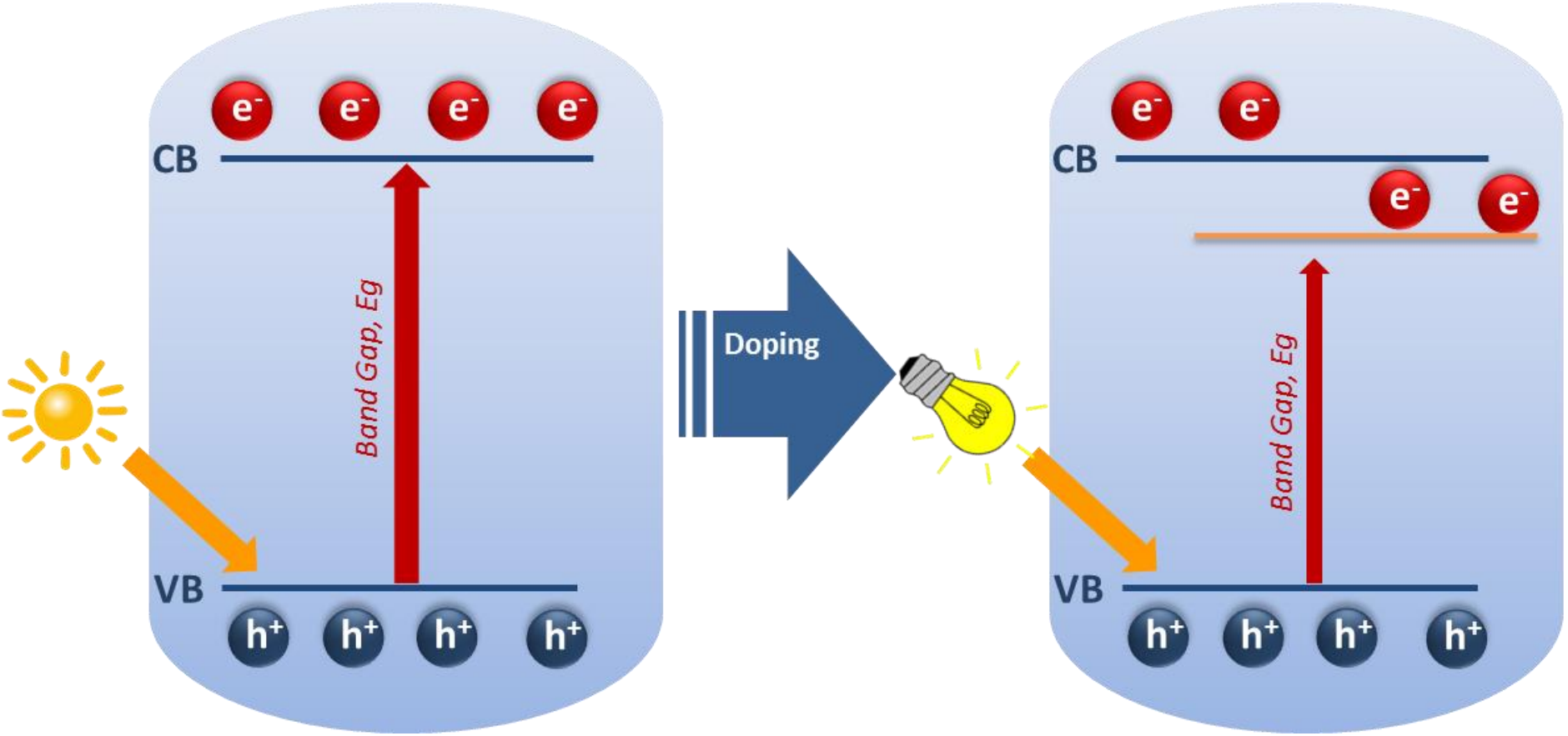
TCMD Transparent Conductive Materials & Devices Group

FORTH FOUNDATION FOR RESEARCH AND TECHNOLOGY – HELLAS INSTITUTE OF ELECTRONIC STRUCTURE AND LASER

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

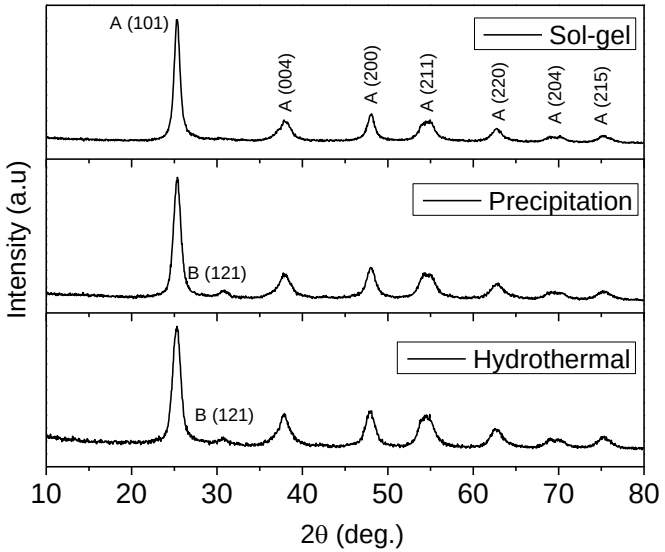
High Performance Advanced Materials *for efficient photocatalytic systems*

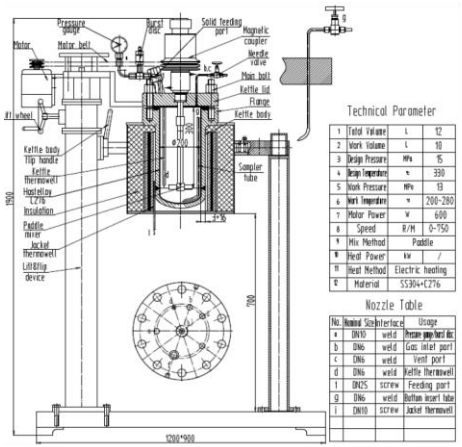
Strategy Enhancement of Efficiency



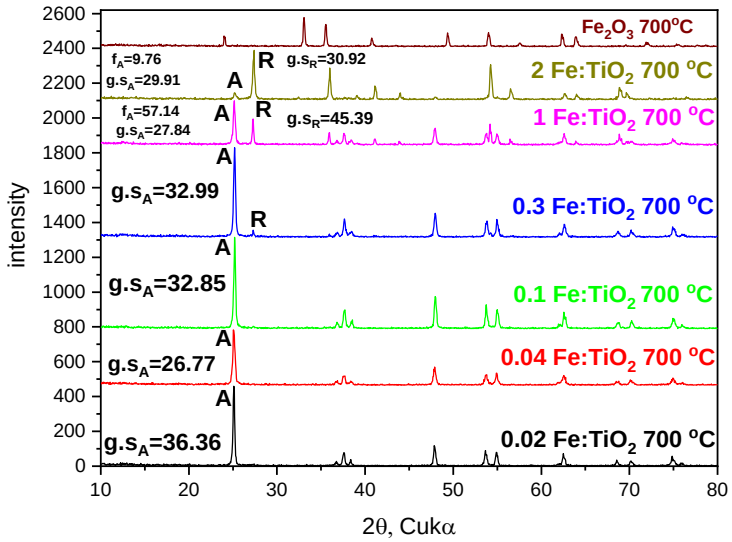
The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

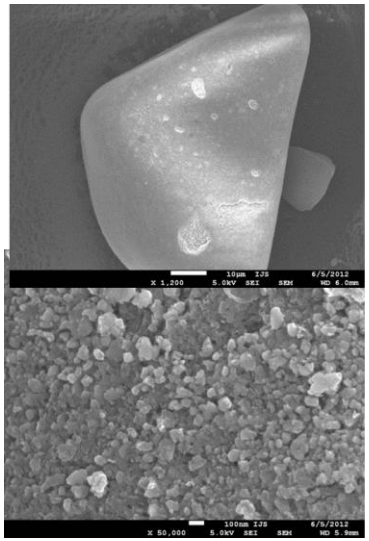
High Performance Advanced Materials *for efficient photocatalytic systems*

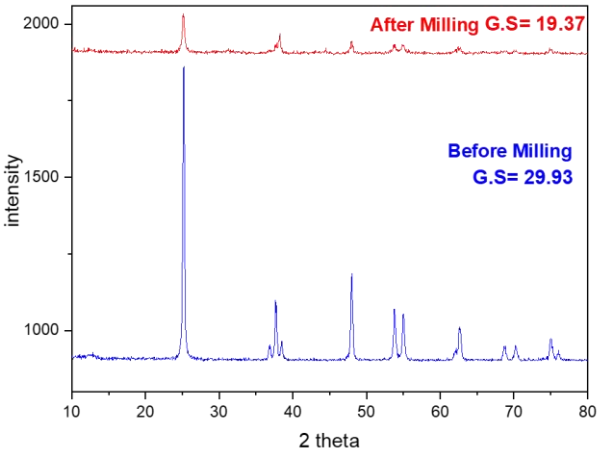




Fe doped TiO_2







The project has received funding from the LIFE Programme of
the European Union under GA number LIFE19 ENV/GR/000100

LIFEVISIONS
Innovative photocatalytic paint5 for healthy environment and allergy Saving

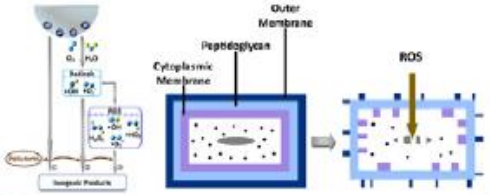
High Performance Advanced Materials *for efficient photocatalytic systems*

*V. Binas, et all, J Materiomics 3 (**2017**) 3-16*

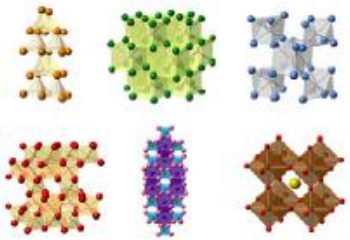
Chapter 15

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

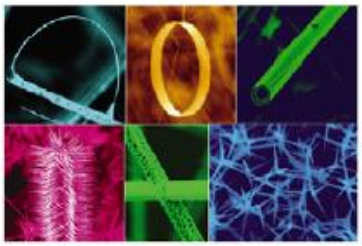
Improve Air Quality



Photocatalyst Types

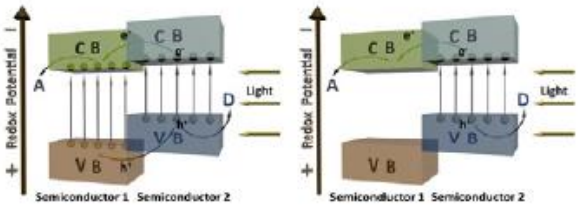


Photocatalyst Synthesis



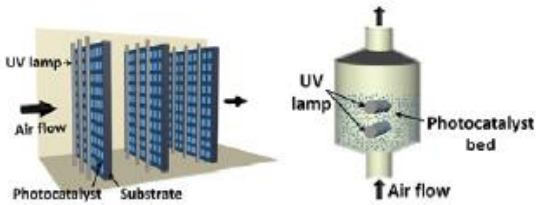
Photocatalytic Air Purification

Design Strategies



Outlook

Purification Systems



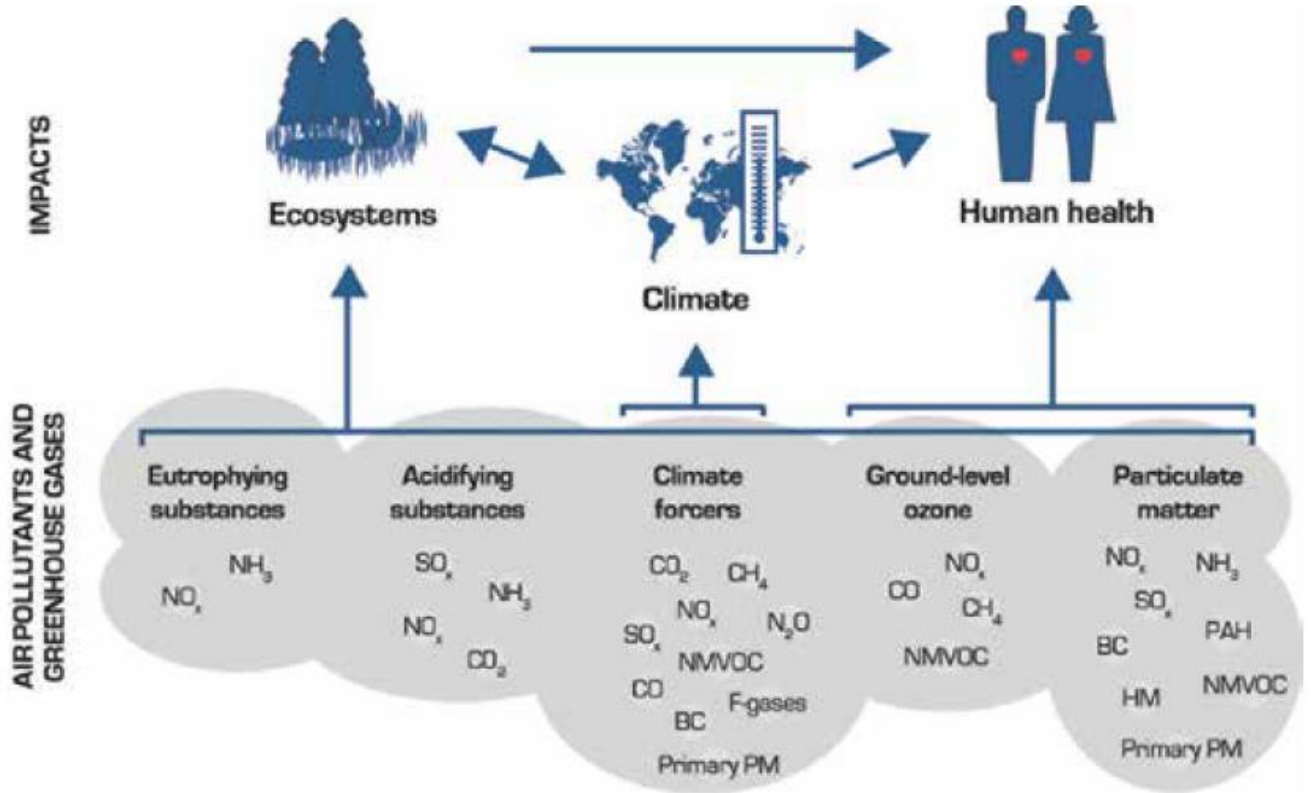
The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Poor Air Quality: *A social Problem*





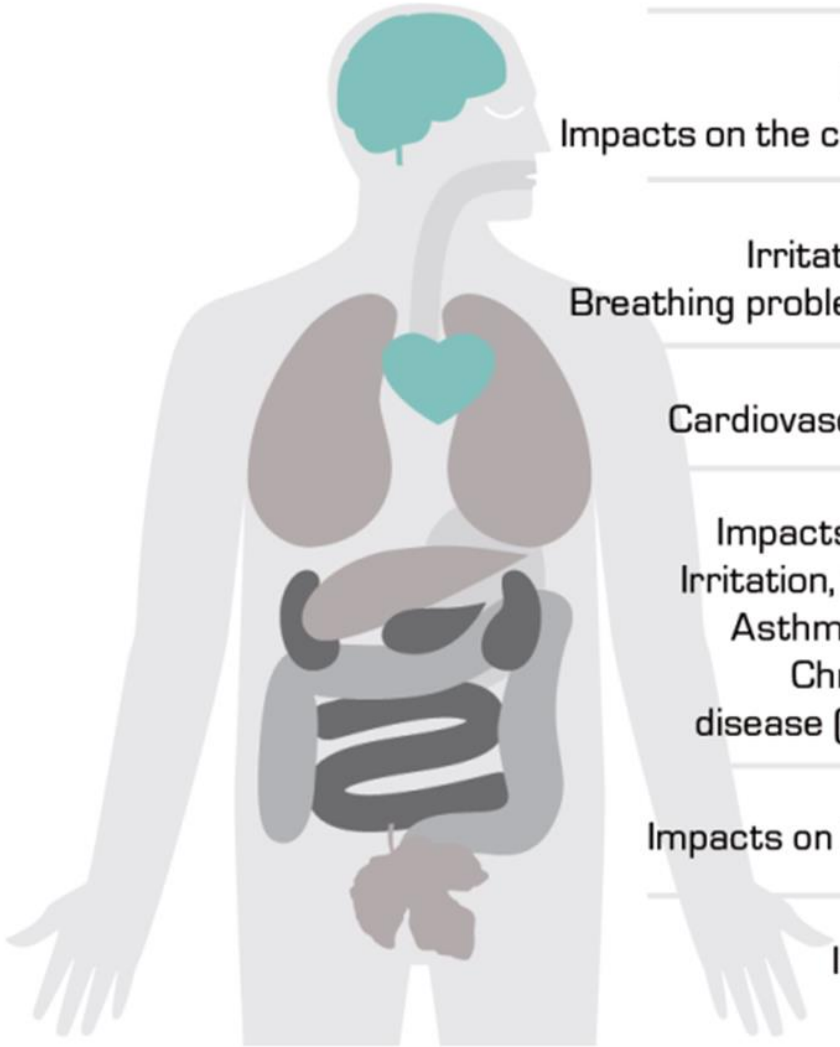




Source: EEA.

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Air Quality: *Health impacts of air pollution*



Headache and anxiety (SO_2)
Impacts on the central nervous system (PM)

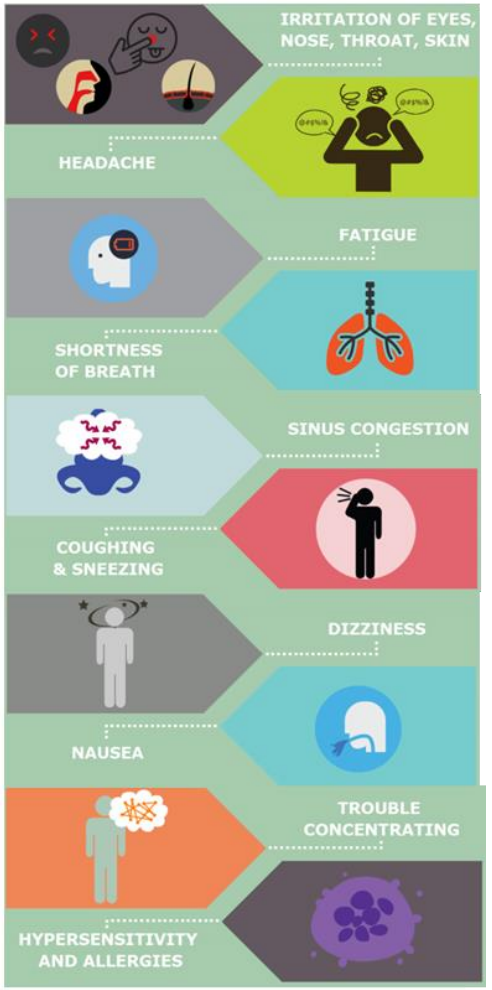
Irritation of eyes, nose and throat
Breathing problems (O_3, PM, NO_2, SO_2, BaP)

Cardiovascular diseases (PM, O_3, SO_2)

Impacts on the respiratory system:
Irritation, inflammation and infections
Asthma and reduced lung function
Chronic obstructive pulmonary disease (PM) Lung cancer (PM, BaP)

Impacts on liver, spleen and blood (NO_2)

Impacts on the reproductive system (PM)



European Environment Agency

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Air Quality: *Health impacts of air pollution*

400 000 premature deaths in the EU every year are linked to air pollution

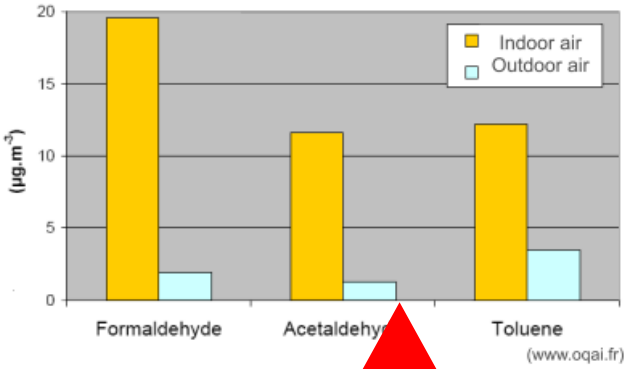
Air pollution costs over **€4 billion in healthcare** and **€16 billion in lost workdays**

About **130 cities** across Europe do not meet EU air quality standards

72 % of Europeans want **public action** to improve air quality

€4

Particulate matter and nitrogen dioxide are the main urban pollutant and are **very harmful** to **human health**



Did you know?

one of every three students in Europe has asthma or allergies

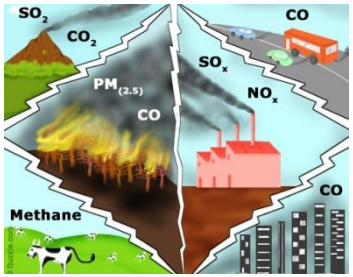
primary and secondary schools in the EU
71 million of students
4.8 million of teachers
800 hours / year
1/3 of the day

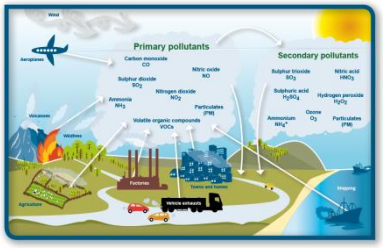
20% of the total population

FORTH / IESL / TCM
@ *V*assilios *B*inas

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Air Quality: *Outdoor and Indoor Environment*





Outdoor Pollution

Adverse Effects on Humans, Environment and Ecosystem

Man-Made | Natural Sources

Urban and Industrial Areas Air Pollutants:

Sulfur Oxides (SOx), Nitrogen Oxides (NOx), Carbon Oxide (CO)

Volatile Organic Compounds (VOC): **Benzene**, **Toluene**, **Xylene**

Indoor Pollution

Major Issue for Humans' Health

People Spent ~90 % of their Time Indoor

Air-Toxic Sources at Public Buildings, Working Places and Houses

Perfumes, Detergents, Paints, Laquers, Varnishes, Wall Boards

Most Abundant Indoor Air-Toxics

Aldehydes (HCHO, **CH_3CHO**), **Benzene**, **Toluene**, **Xylene**

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Air Quality: *Degradation of Nitrous Oxides*

$$TiO_2 \xrightarrow{hv} (TiO_2)^* \longrightarrow h^+ + e^-$$

$$h^+ + H_2O \longrightarrow OH^\bullet + H^+$$

$$H^+ + e^- + O_2 \longrightarrow HO_2^\bullet$$

$$2HO_2^- \longrightarrow H_2O_2 + O_2$$

$$2e^- + O_2 + 2H^+ \longrightarrow H_2O_2$$

$$2h^+ + 2H_2O \longrightarrow H_2O_2 + 2H^+$$

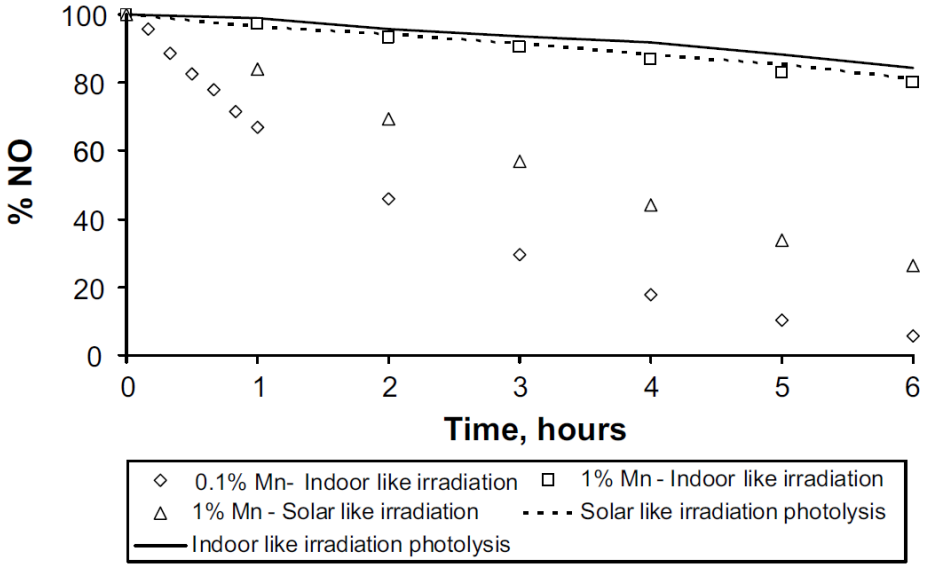
$$NO + HO_2 \longrightarrow NO_2 + OH^-$$

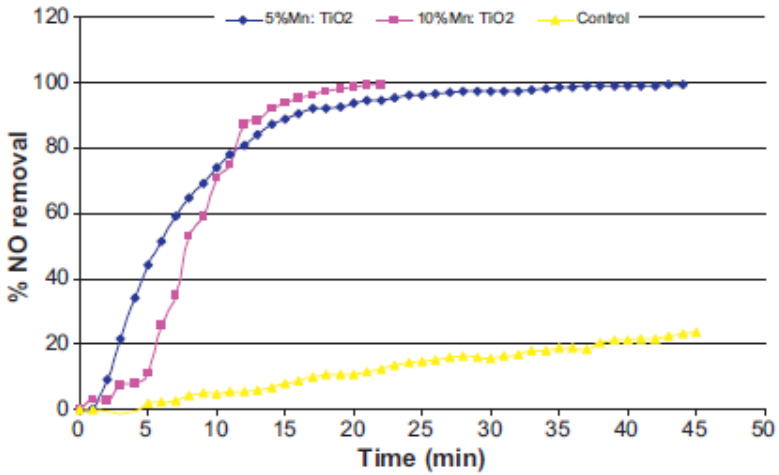
$$NO_2 + NO + H_2O \longrightarrow 2HONO$$

$$NO_2 + OH^- \longrightarrow HNO_3$$

$$NO + OH^- \longrightarrow HNO_2 \longrightarrow H^+ + NO_2^-$$

$$HNO_2 + OH^- \longrightarrow NO_2 + H_2O$$





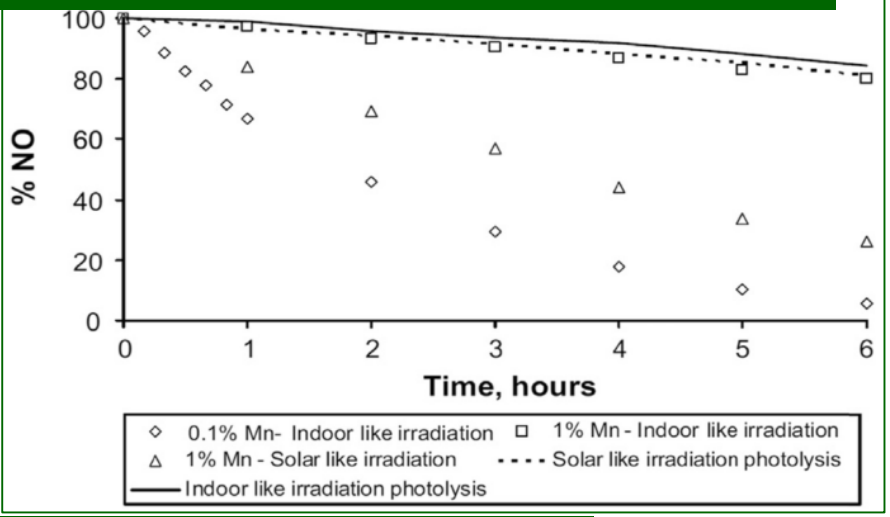
*Binas V., Applied Catalysis B: Environmental 113-114, (2012) 79-86

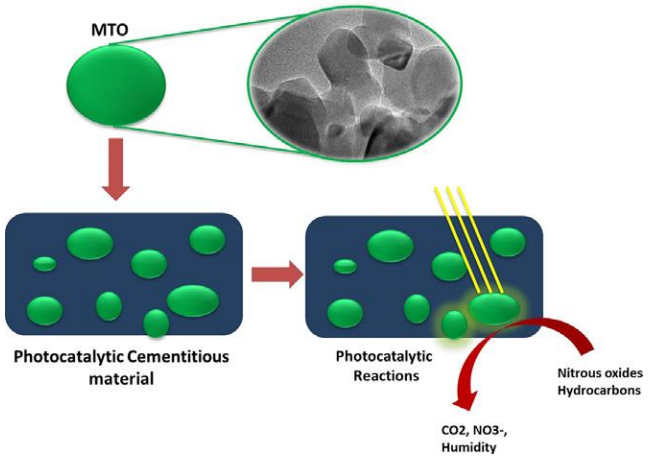
Binas V., Journal of Photochemistry and Photobiology A: Chem 222 (2011) 304

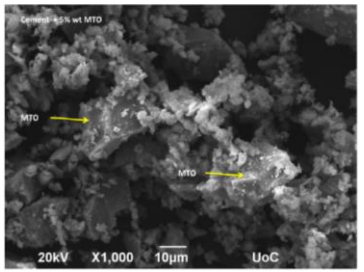
The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

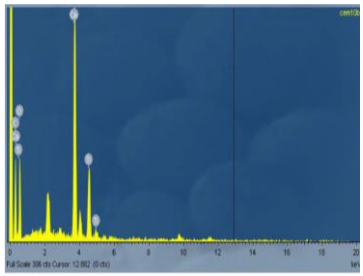
Air Quality: *Effect of Building Matrix*

Photochemical degradation of NO

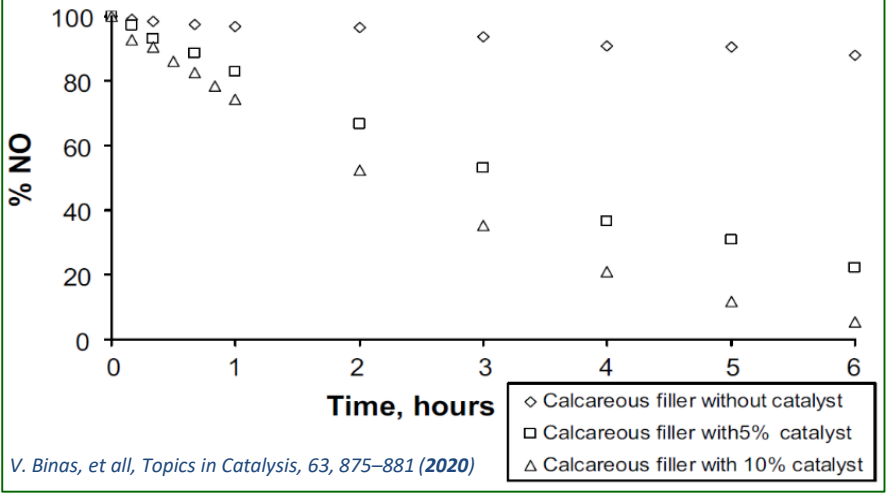






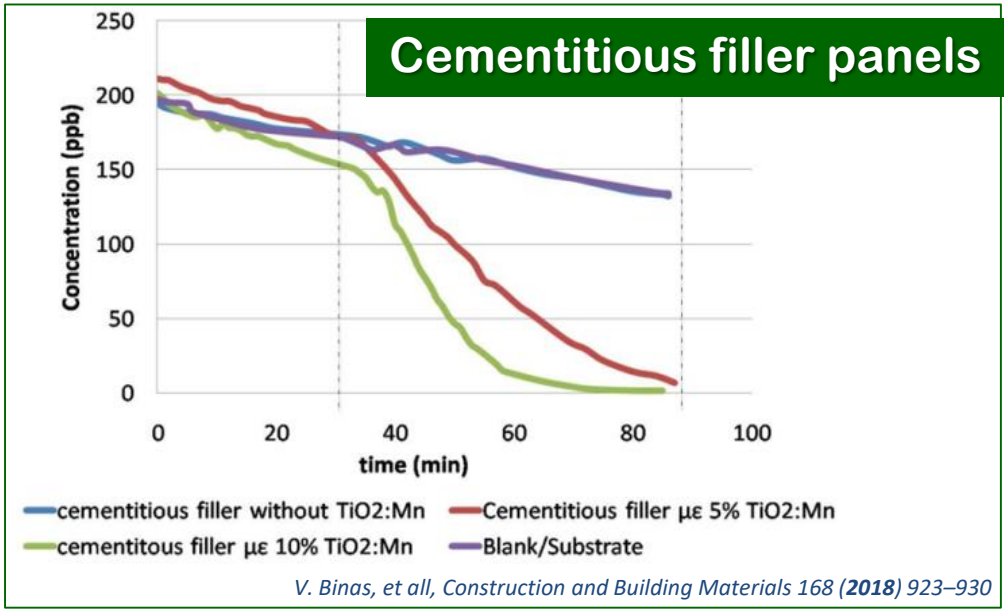


Calcareous filler panels



*V. Binas, et all, Topics in Catalysis, 63, 875–881 (**2020**)*

Cementitious filler panels



*V. Binas, et all, Construction and Building Materials 168 (**2018**) 923–930*

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Large Scale projects: *Greek Army Medical Centre*

Μνημόνιο Συνεργασίας (Memorandum of Understanding)
μεταξύ 691 ΒΕΒ - ΙΤΕ

ΜΝΗΜΟΝΙΟ ΣΥΝΕΡΓΑΣΙΑΣ
MEMORANDUM OF UNDERSTANDING
(MOU)

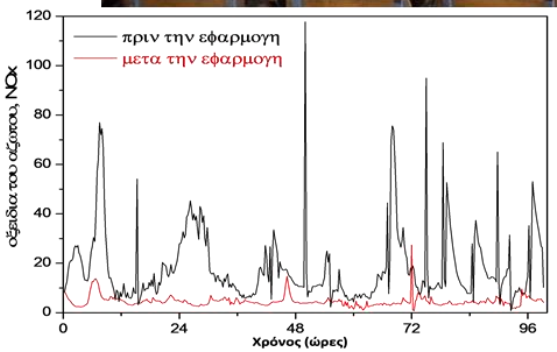
Μελέτη πιλοτικής εφαρμογής καινοτόμου επιχρίσματος για την βελτίωση της ποιότητας του αέρα και της υγιεινής σε εσωτερικούς χώρους (ιατρεία)

Δρ. Βασίλειος Μπίνας Τχης (ΥΠ) Βασίλειος Σιαπέρας

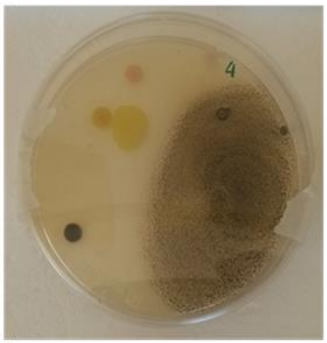
ΑΠΟΡΡΗΤΟ

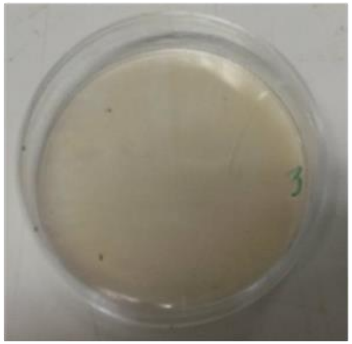
FORTH
FOUNDATION FOR RESEARCH AND TECHNOLOGY – HELLAS
INSTITUTE OF ELECTRONIC STRUCTURE AND LASER

Ηράκλειο
Οκτώβριος 2017



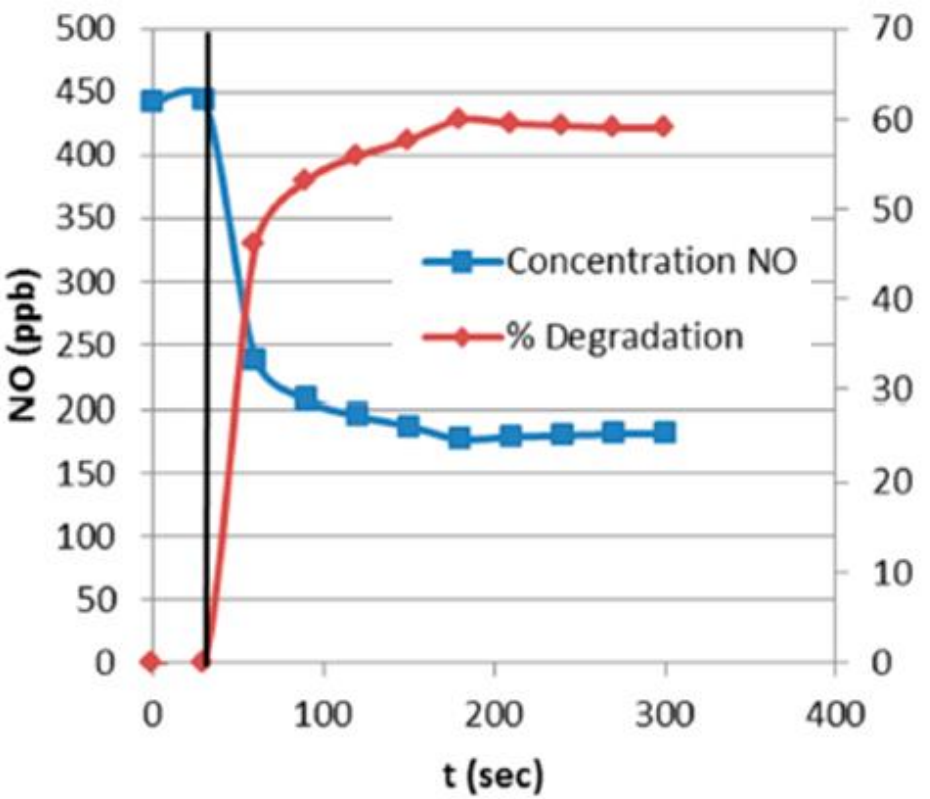
Before After

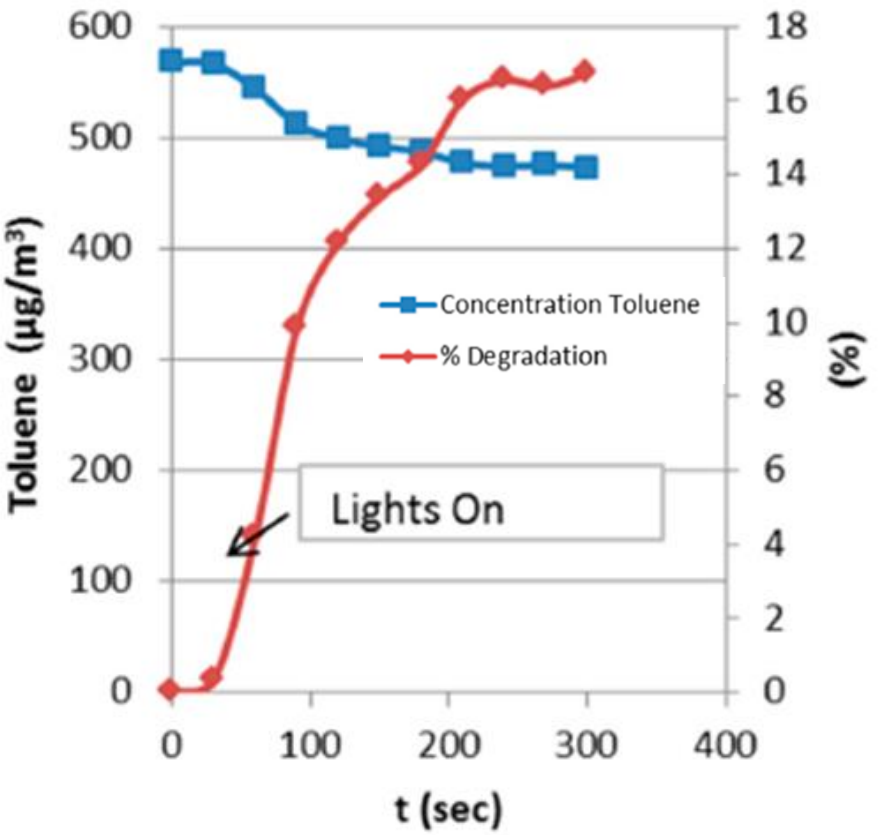




The project has received funding from the LIFE Programme of
the European Union under GA number LIFE19 ENV/GR/000100

Large Scale projects: *Greek Army Medical Centre after 1 year*

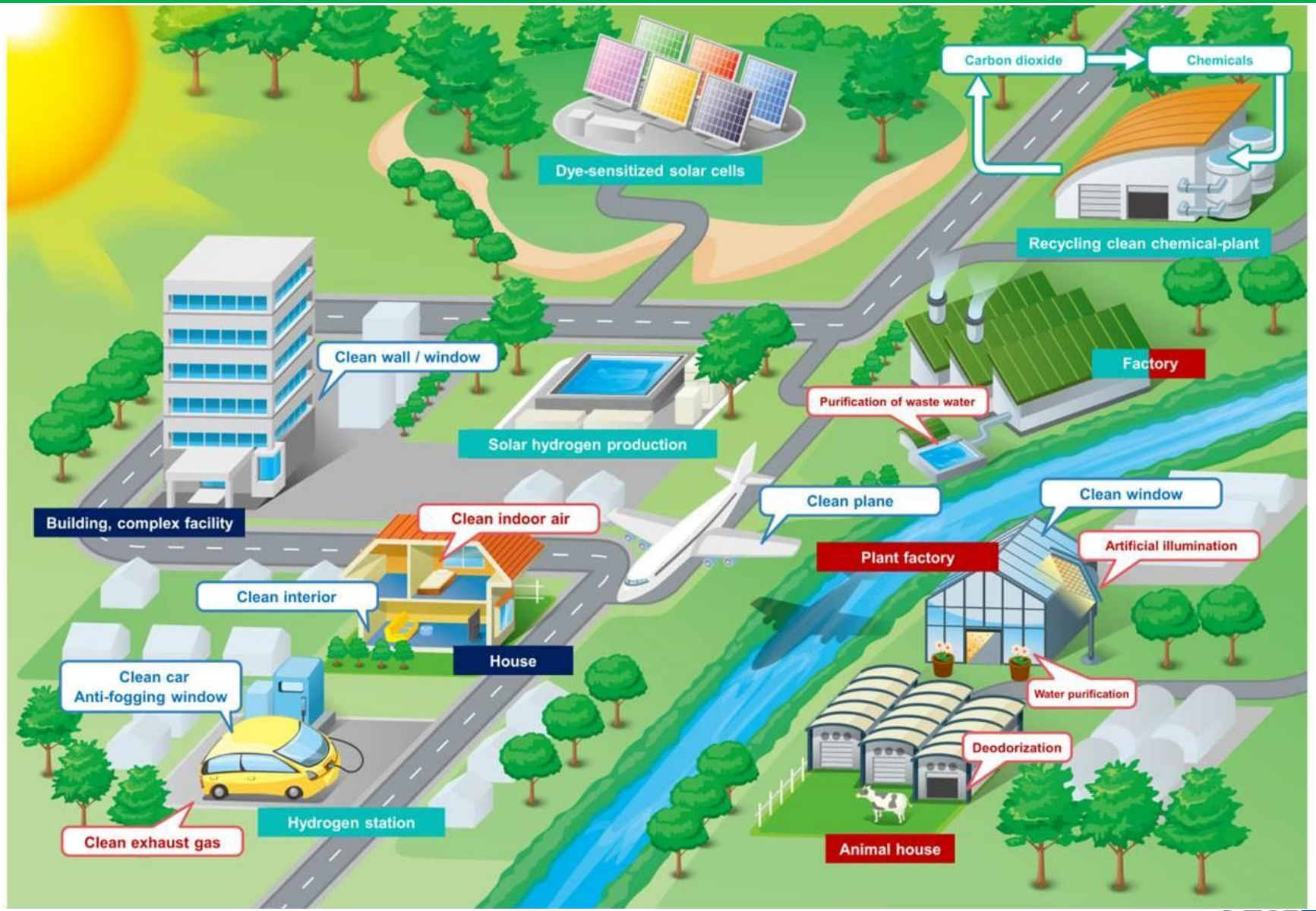




V. Binas, et al, Appl. Sci. ***2019****, 9(22), 4837*

The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

Life VISIONS city



The project has received funding from the LIFE Programme of the European Union under GA number LIFE19 ENV/GR/000100

LIFEVISIONS
InnoVative photocatalytic paintS for healthy envirOnment and eNergy Saving

http://lifevisions.gr/

LIFE VISIONS Facebook page

The project Facebook page is available as LifeVisions. (@LifeVisionsGR)

LIFE VISIONS Twitter account

The project Twitter account is available as LifeVisionsGR, (@gr_visions)

TCMD
Transparent Conductive Materials & Devices Group

FORTH
FOUNDATION FOR RESEARCH AND TECHNOLOGY – HELLAS
INSTITUTE OF ELECTRONIC STRUCTURE AND LASER