HUMANIZING THE DIGITAL EXPERIENCE

TDK Developers Conference 2018

TDK InvenSense EPCOS tronics microsystems Chirp MICRONAS

HUMANIZING THE DIGITAL EXPERIENCE

Gas and Environmental Sensors

Towards Complete Humanized Experience

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TDK Developers Conference
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Santa Clara Marriott

The Complex World of Chemical Sensing

CHEMICAL SENSING

✓ Many gases

CO, CO2, H2, Nox
SO2, H2S
Ethanol, Methane, Ammonia
Formaldehyde, Acetone
Methanol, many other VOC's
…….

✓ Many techniques

Electrochemical
Gravimetric
Optical
Calorimetric
Spectroscopy
Photo-acoustic…….

✓ Many applications

→

Environmental air quality
Indoor air quality
Medical
Automotive
Fire detection
Industrial, Military, Hobby…….

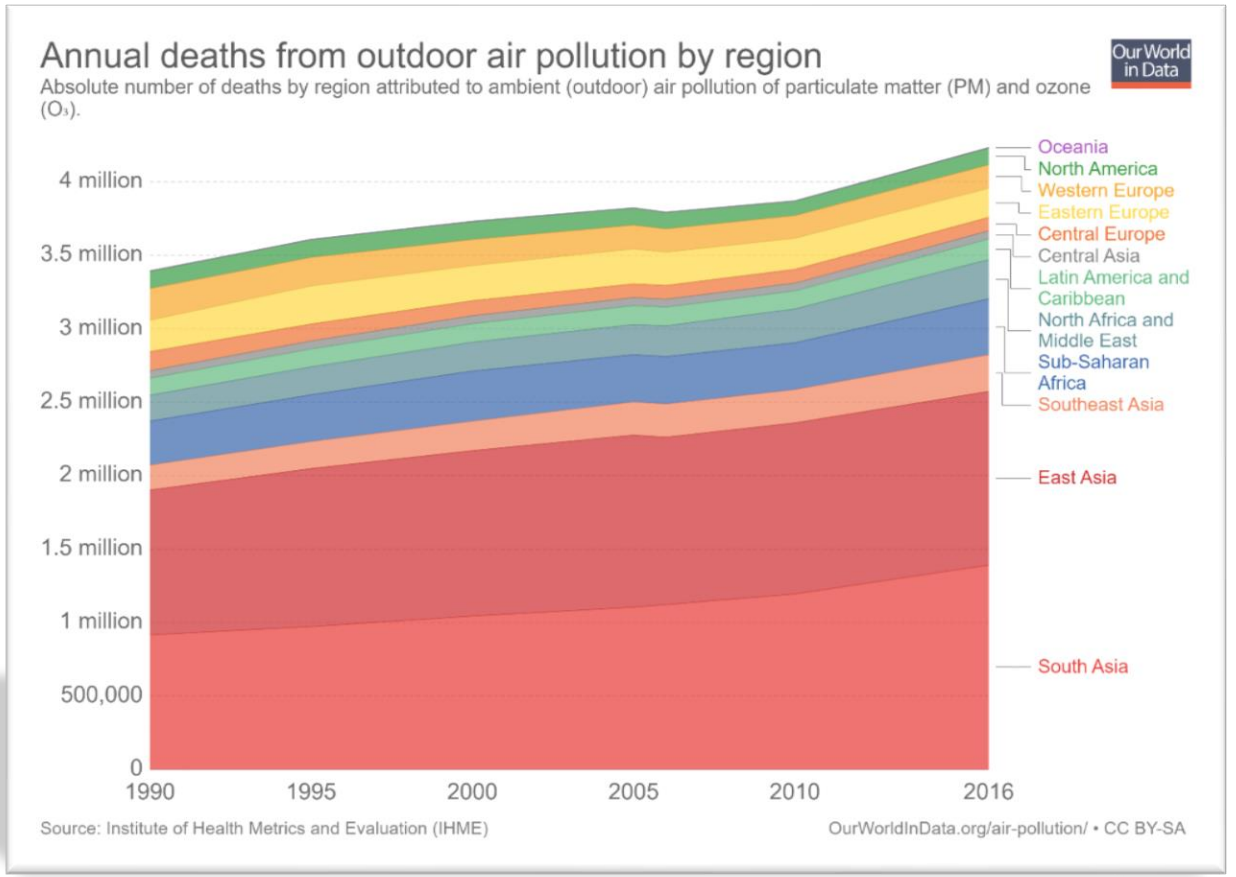
✓ Many platforms

Wearables
Smart speakers
Kitchen appliances
Automotive electronics
Medical devices
Mobile devices…….

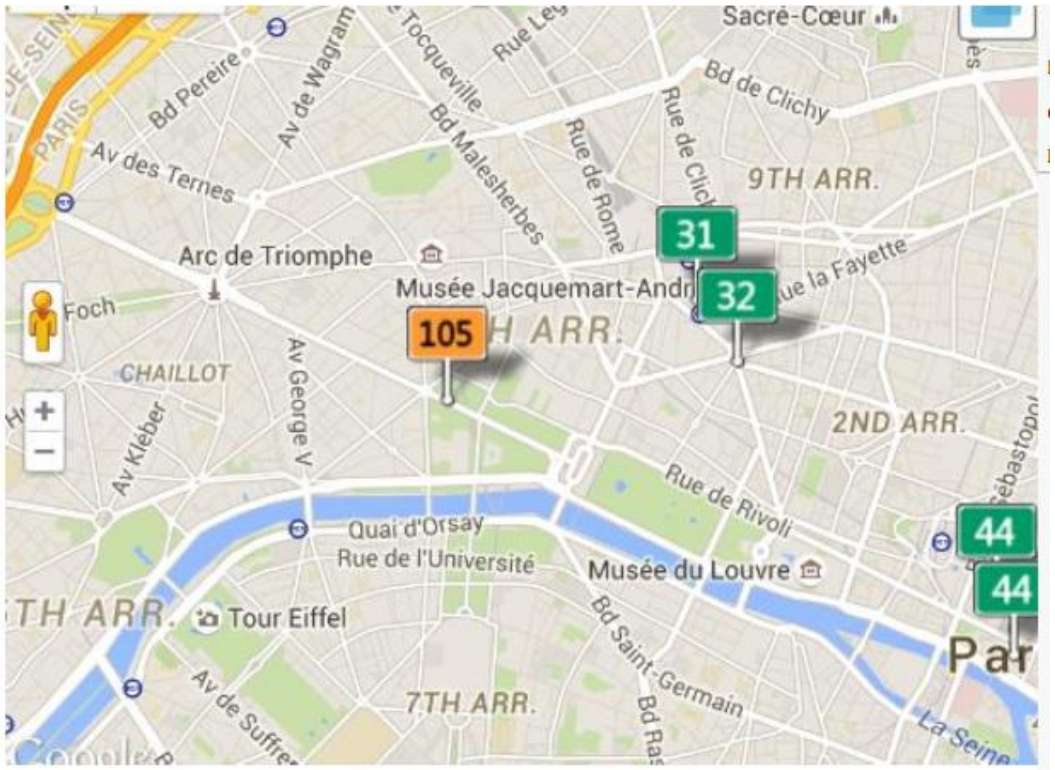
✓ Many $$$

$1.2B SAM

Air Quality is THE Critical Public Health Issue of Our Times



Air Quality is THE Critical Public Health Issue of Our Times



Distance between these two locations < 1 km

(AQI derived from PM10, O_3, NO_2, SO_2, and CO)

Air Quality is THE Critical Public Health Issue of Our Times

Even Indoors

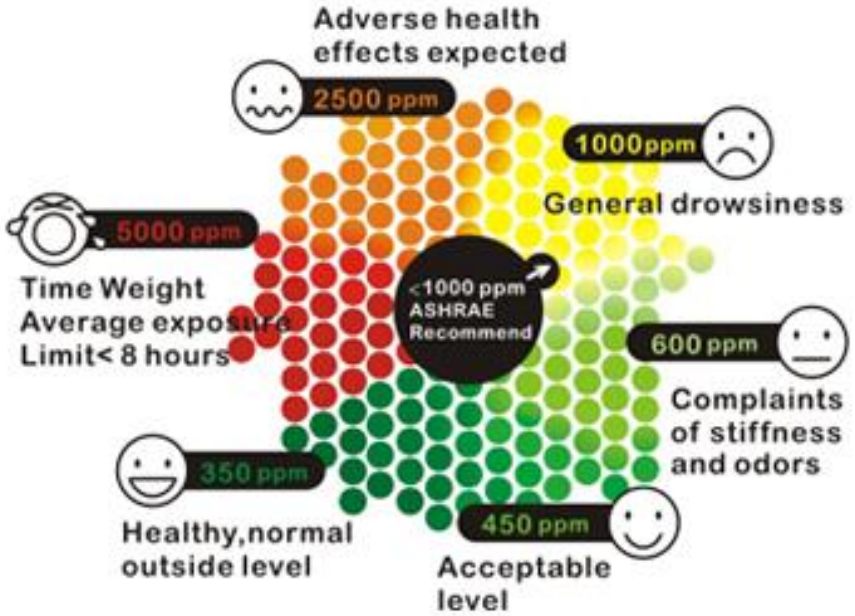
Ratio of "people cost" to "building cost" is 13:1

[source: *https://ehp.niehs.nih.gov/15-10037/*]

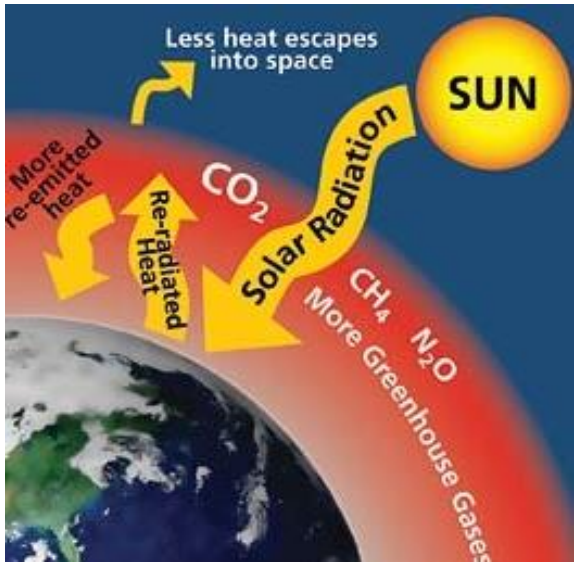
Indoor air quality is a top five environmental risk to public health.
Worst in schools
[source: *EPA*]

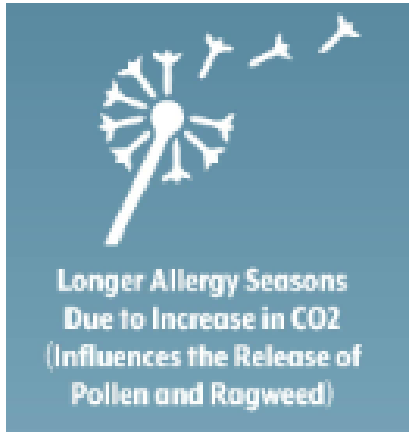
Indoor Pollutant Gases

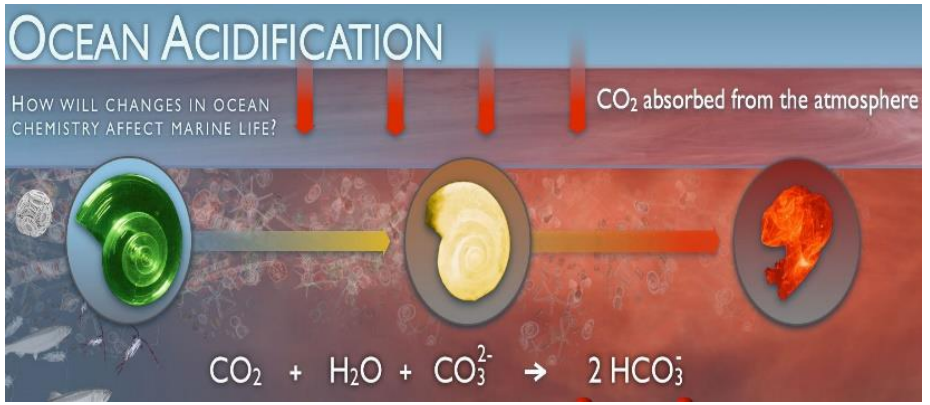
Gas	Emission Sources
Carbon dioxide	Metabolic activity, combustion, garage exhaust, tobacco smoke
Carbon monoxide	Boilers, gas or kerosene heaters, gas stoves, wood stoves, fireplaces, tobacco smoke, garage exhaust, outdoor air
Nitrogen dioxide	Outdoor air, garage exhaust, kerosene and gas space heaters, wood stoves, gas stoves, tobacco smoke
Ozone	Outdoor air, photocopy machines, electrostatic air cleaners



Outdoors or Indoors, CO_2 is a Big Culprit



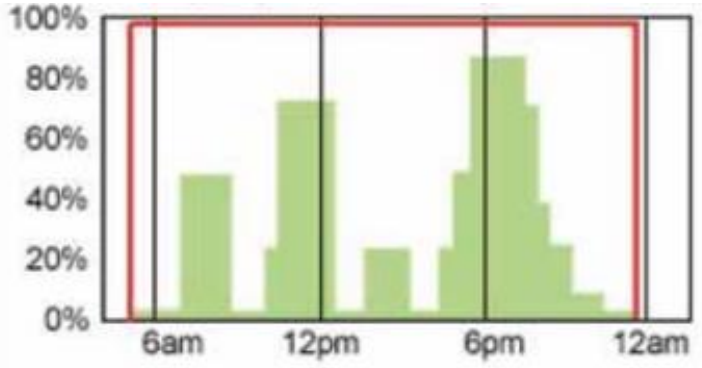




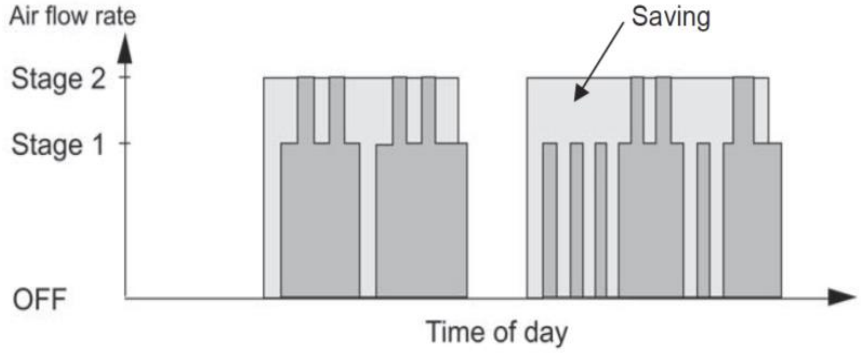
Indoor Air Quality is More Easily Measurable and Actionable

It is not just about quality of life….. it is also about energy savings

Occupancy Pattern in a Typical Store/Gym/Theater



Occupancy Pattern in a Typical Office Building



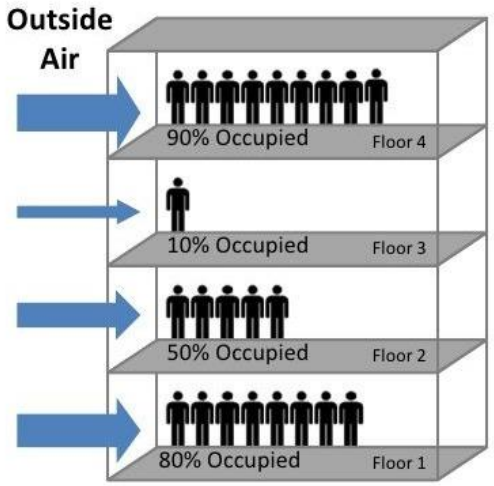
Compared with a system controlled by a time program (blue area), demand-controlled ventilation shows a significant reduction in hours run (area marked in green)

Monitoring building occupancy could save 30% of US HVAC energy costs

CO_2 levels are the most reliable indicator of occupancy

The Economics of Demand Control Ventilation HVAC

*Break-even point is not attractive at today's prices**



15 cfm of outside air per person

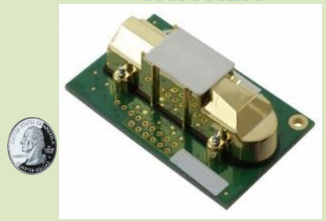
Adjust fresh-air intake based on occupancy

Ventilation demand is determined by CO2 level (ppm)

HVAC Application

Today

TELAIRE SENSIRION VAISALA



Telaire 6613 HVAC grade CO2 sensor

1.75" x 2.25" x 0.6"

$48.5

SIEMENS Honeywell

$150

< $50

HVAC End users – building owners, facility managers

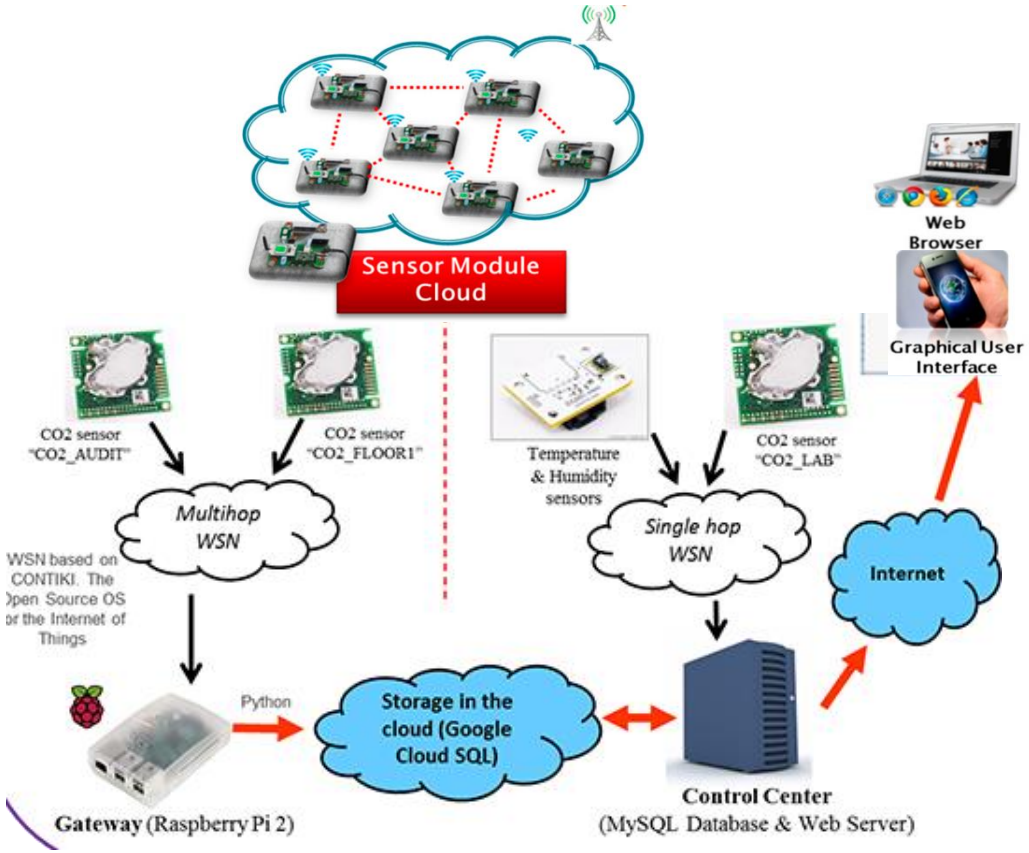
Emerging

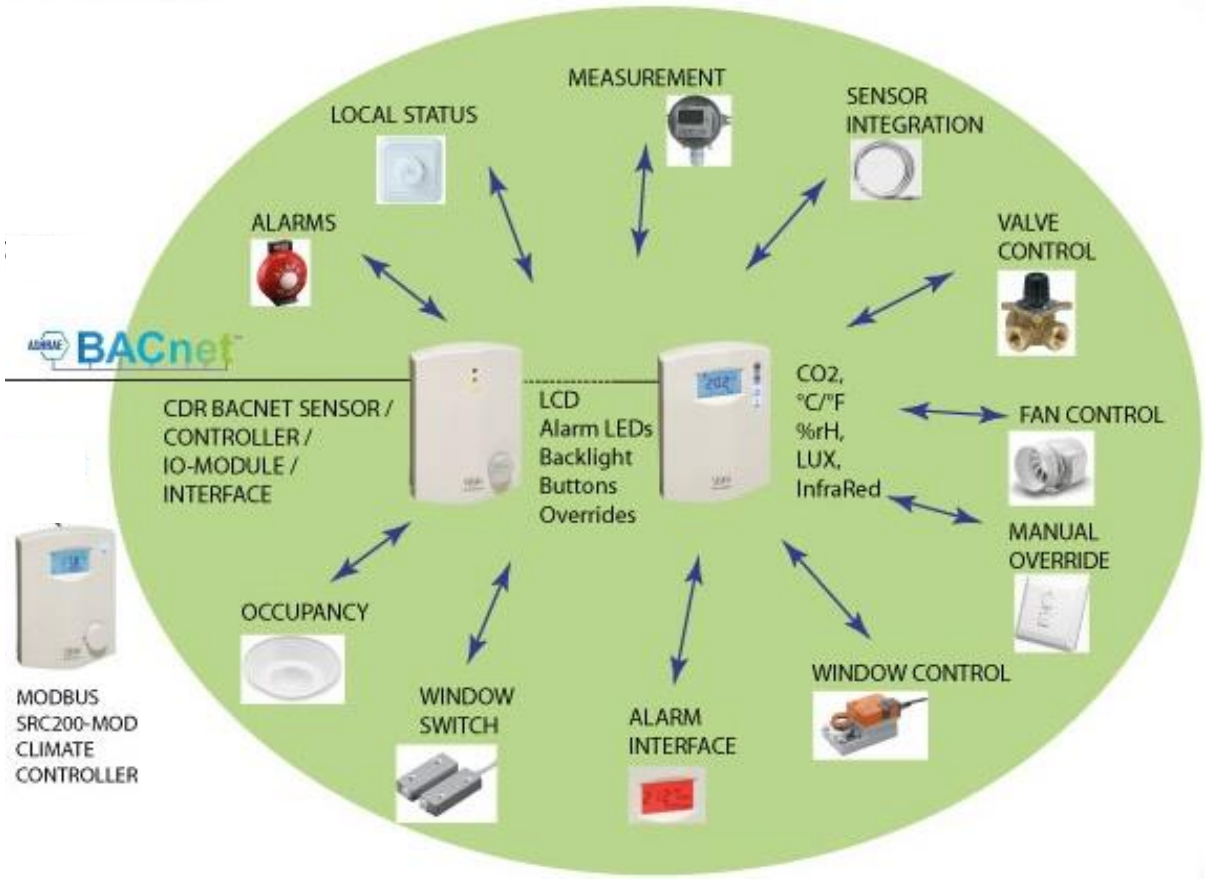
TDK CO2+CO
3x3x1 mm

< $10

**US DoE study published 2015*

Smart Home / Smart Building HVAC Architecture





Courtesy: Syxthsense,

Current CO_2 Sensors are not up to the Job

NDIR

35x16x8mm; 125mW
Typical 1k Price: $60

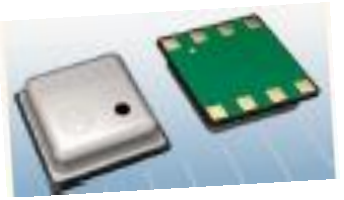
Photo-acoustic

85x40x35mm; >> 100mW
Typical 1k Price: TBD *(Only VOC)*

Electrochemical

10 mm dia x 20 mm high; 400 mW
Typical 1k Price: $30 *(Only VOC)*

MEMS MOX



3x3x1 mm; 30 mW
Typical 1k price: $2 - $5 *(only VOC)*

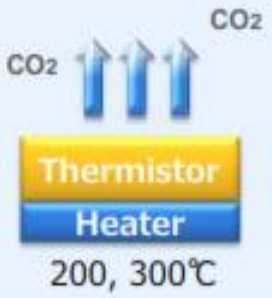
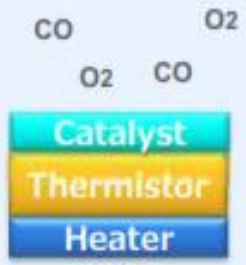
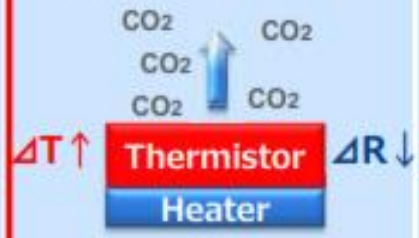
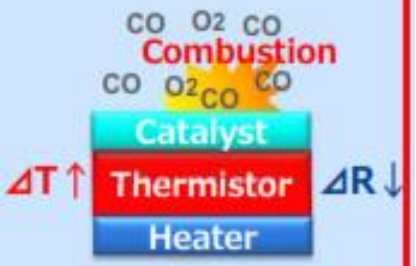
TDK

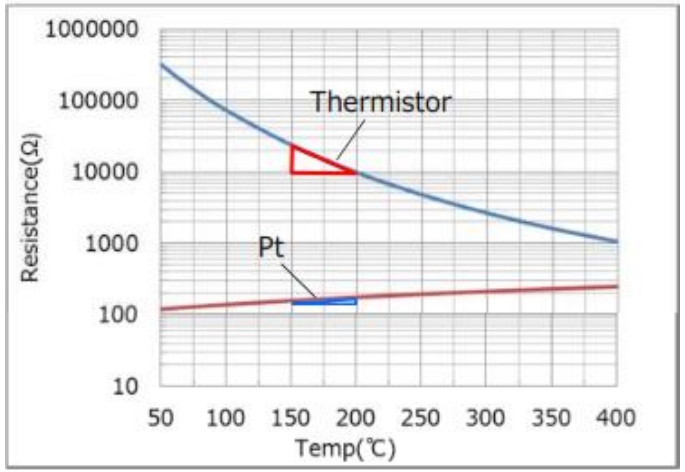
$CO + CO_2$ sensor
Target: 3x3x1 mm; ~0.5 mW

- *TDK offers the only non-optical direct CO_2 detector*
- *TDK offers the only price-competitive direct CO_2 detector*

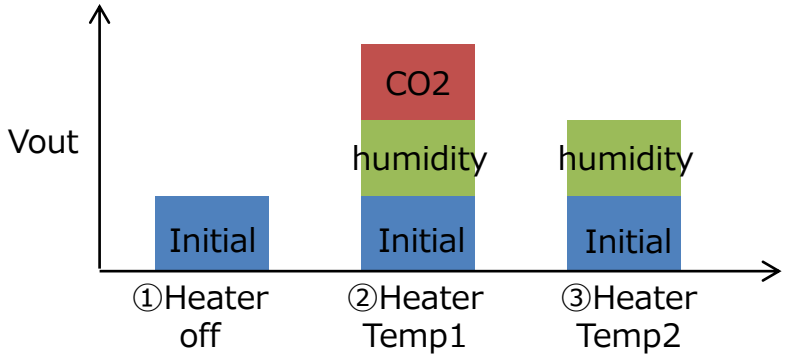
TDK's CO/CO_2 Sensing Technology

- CO_2 gas sensor : Thermal conductivity type
- CO gas sensor : Catalytic combustion type

Target	CO_2	CO
Method	Thermal conductivity	Catalytic combustion
Gas concentration **Low**	 200, 300℃	 200℃
Gas concentration **High**	Thermal conductivity →Low 	

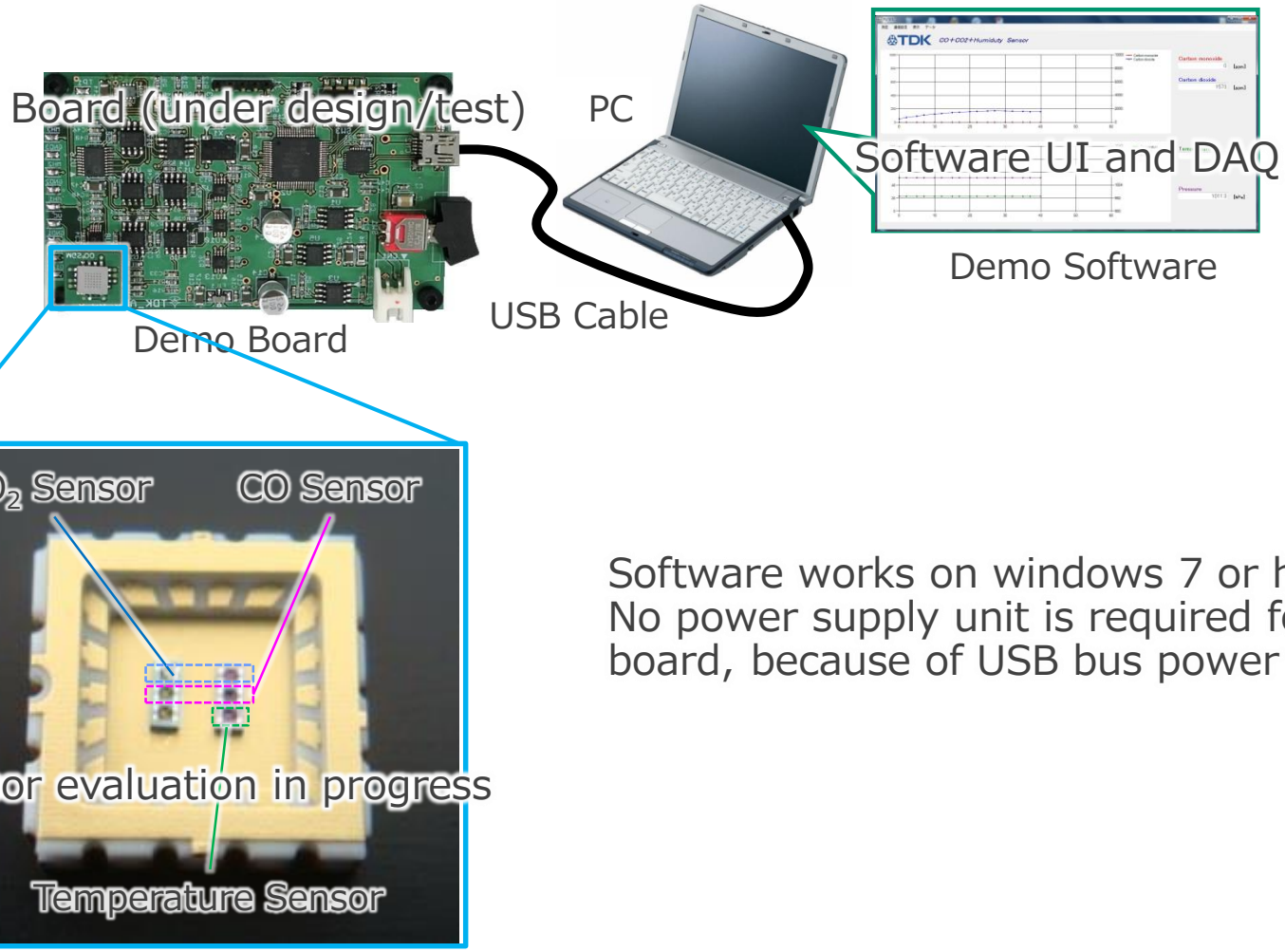


Resistance change >> that of Pt
Sensitivity is higher by ~ 10x



② - ③ = CO_2

TDK CO_2 Sensor Demo Board



Software works on windows 7 or higher.
No power supply unit is required for the board, because of USB bus power from PC.

TDK CO_2 Sensor Demo Videos

Air Quality Depends on Many Other Gases

- Indoor
  - Radon, NO_2, Particulates, Biologicals
  - Volatile Organic Compounds (VOC's)
    - Formaldehyde (CH_2O)
    - WHO recommends 80 ppb as safe; >100 ppb as "actionable"



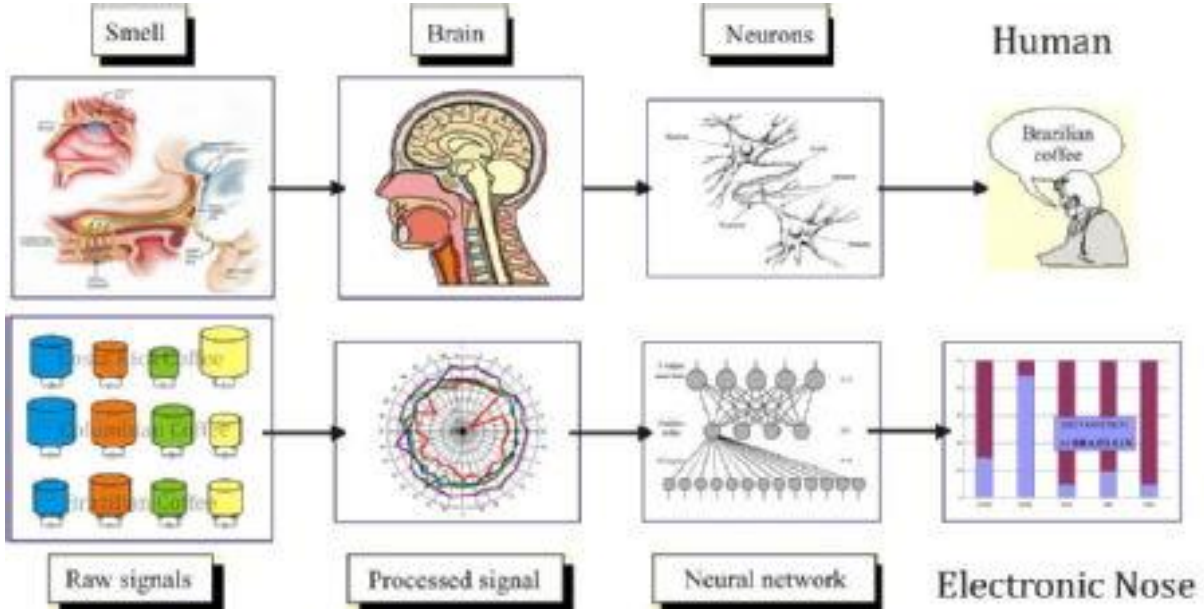

- Outdoors
  - Particulates, Ozone, CO, NOx, VOC's…..

Temperature °C ± 1°	Relative Humidity % ± 5%	Formaldehyde Concentration ppm
30	70	0.36
25	70	0.29
30	50	0.26
30	30	0.23
25	50	0.17
25	30	0.14
20	70	0.12
20	50	0.09
20	30	0.07

Efficient and cost-effective VOC sensing is an unmet need

The Real Challenge in Real World is Odor Detection

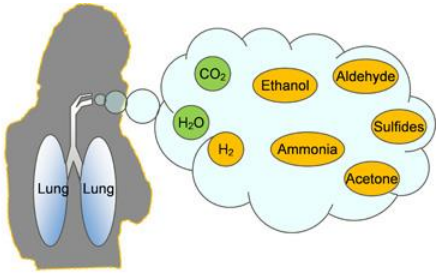
Applications of Odor Detection



Environmental Monitors

Airport/Train Station Security

Food Freshness



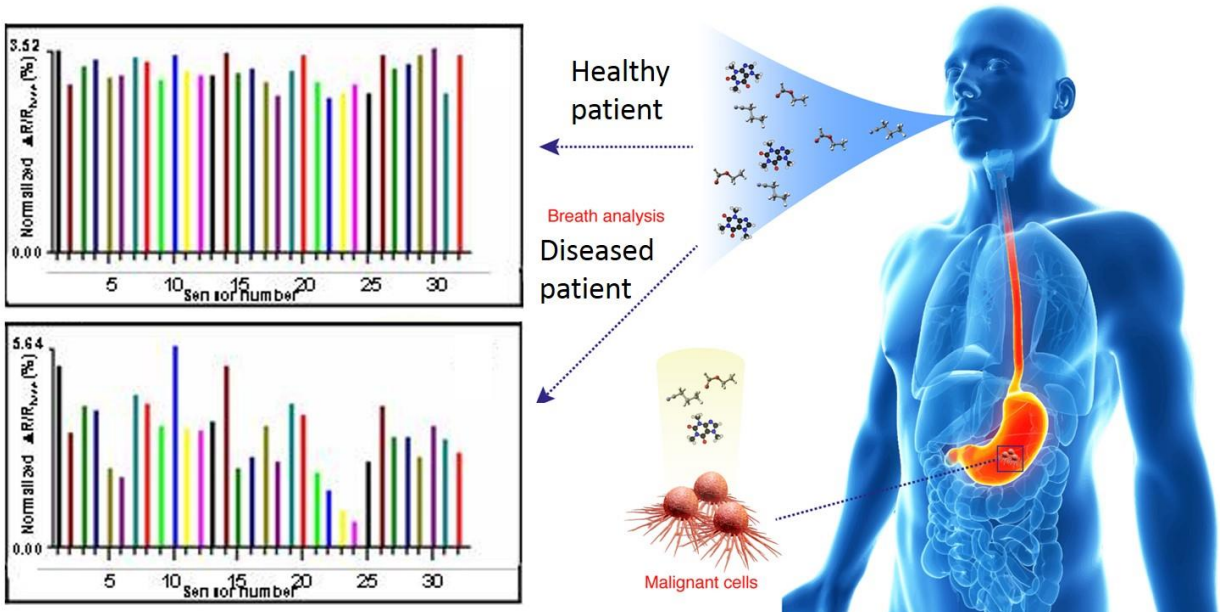
Medical Analysis

Medical Applications for Gas Sensing Abound

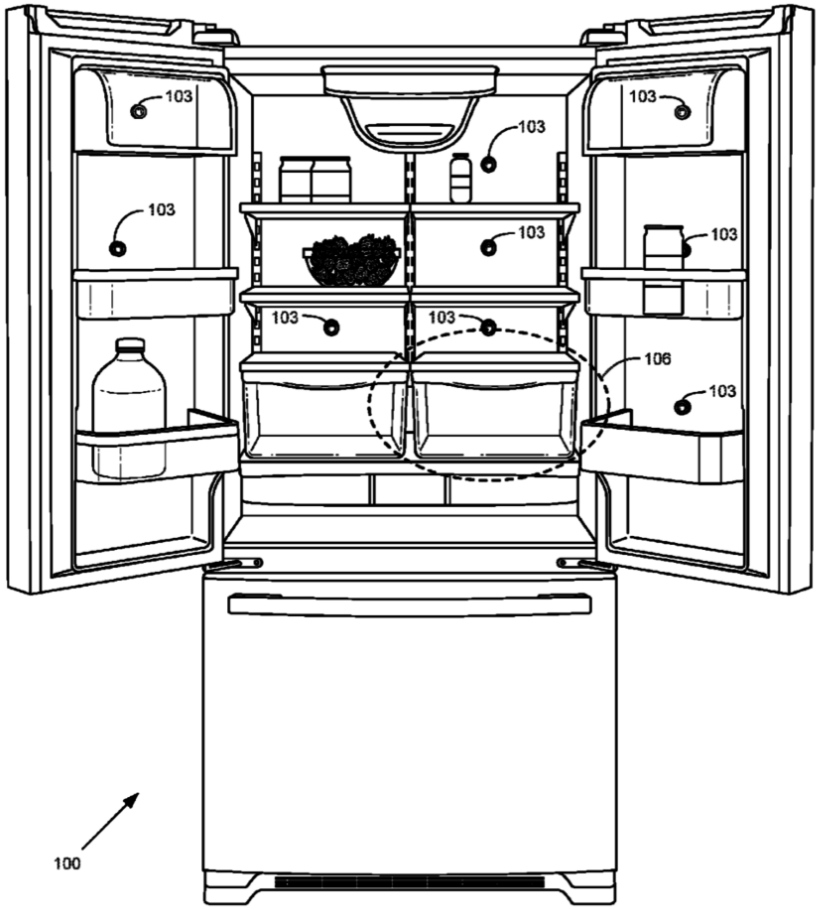
Human breath typically contains ~200 VOC's

Gas (Normal level)	Disease
Acetone *(480 ppb)*	Diabetes
Ammonia *(830 ppb)*	Kidney malfunction
Isoprene *(110 ppb)*	Cholesterol
Methylated Hydrocarbons	Breast cancer
Sulfur compounds	Liver disease
Toluene	Lung cancer
Nitrous Oxide (NO) *(40 ppb)*	Asthma
H_2S *(100 ppb)*	Helitosis (bad breath)
Ethanol *(200 ppb)*	Alcohol
Ethane	Inflammatory diseases
Methanol *(470 ppb)*	Liver Cirrhosis

Breath gas profile analysis is a strong disease indicator



VOC Sensing is a Ubiquitous Need



Home Products / IAQ

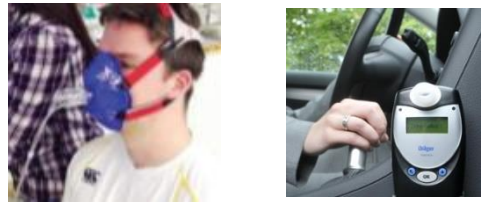
Formaldehyde, Methane, Other VOC's

Kitchen Products

Several VOC's

Environmental

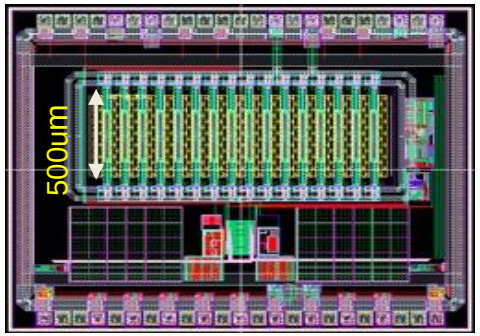
O3, VOC's (Benzene, Toluene, Xylene, etc.)



Medical

Multiple VOC's (ex. Benzene, Acetone, Ethanol)

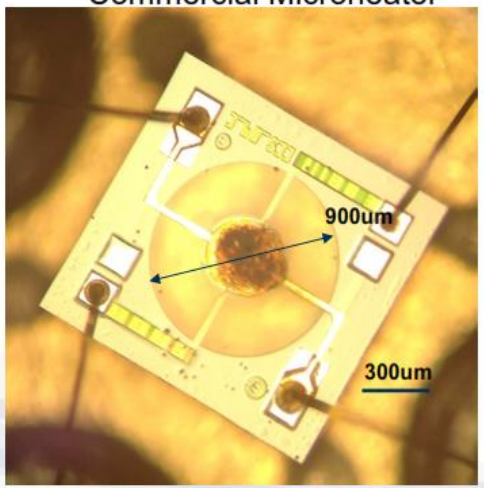
TDK's MEMS Multipixel Sensor



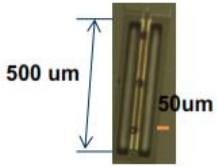
16 Pixel array

- Upto 16 independently addressable microheater bridges
- Full function ASIC: 4mm x 1 mm
- Target platform for VOC's
- Nanoparticle ink

Commercial Microheater



InvenSense Microheater



InvenSense Platform utilizes Ultra-small microheaters to enable multi-pixel sensing in small form factor

Integrated CMOS limits anneal temperature for metal-oxides

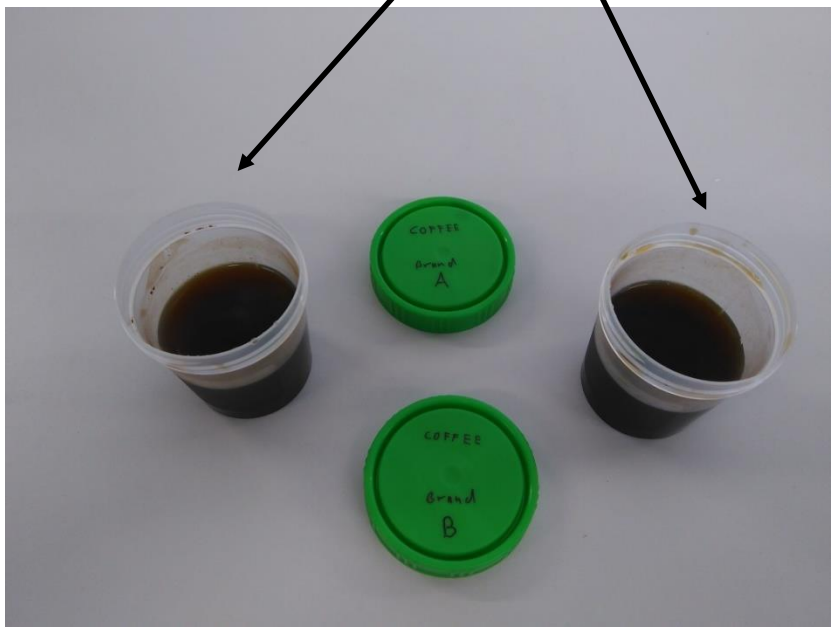
20x better response time and 1.5x better sensitivity

Gases currently targeted: Ethanol, Methane, Acetone, H_2S, O_2

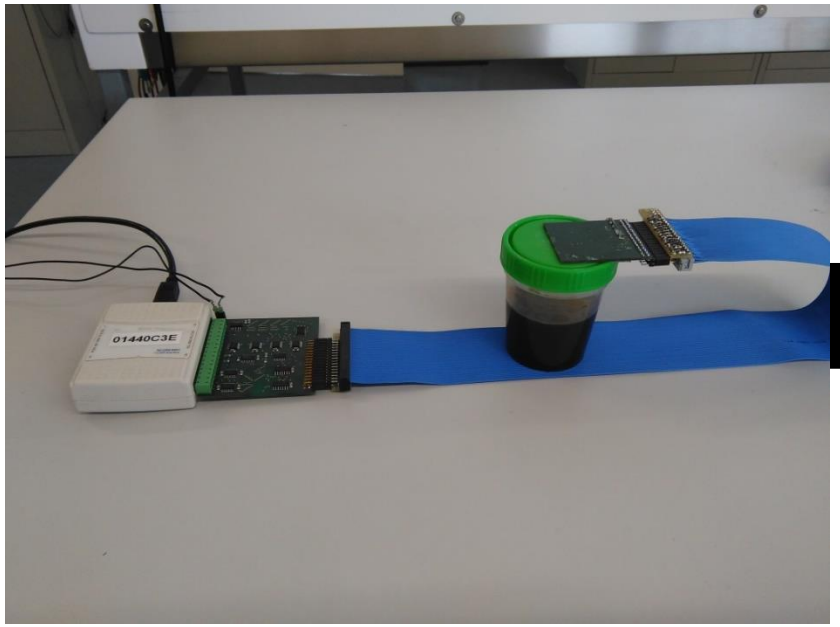
Applications of Odor Detection: Material Classification

Separate different brands of coffee

Is it Brand A or B ?



Check with neuronal network



Brand A

Brand B

Odor Detection Demo Video

The Complex World of Chemical Sensing

CHEMICAL SENSING

✓ Many gases

CO, CO2, H2, Nox
SO2, H2S
Ethanol, Methane, Ammonia
Formaldehyde, Acetone
Methanol, many other VOC's
…….

✓ Many techniques

Electrochemical
Gravimetric
Optical
Calorimetric
Spectroscopy
Photo-acoustic…….

✓ Many applications

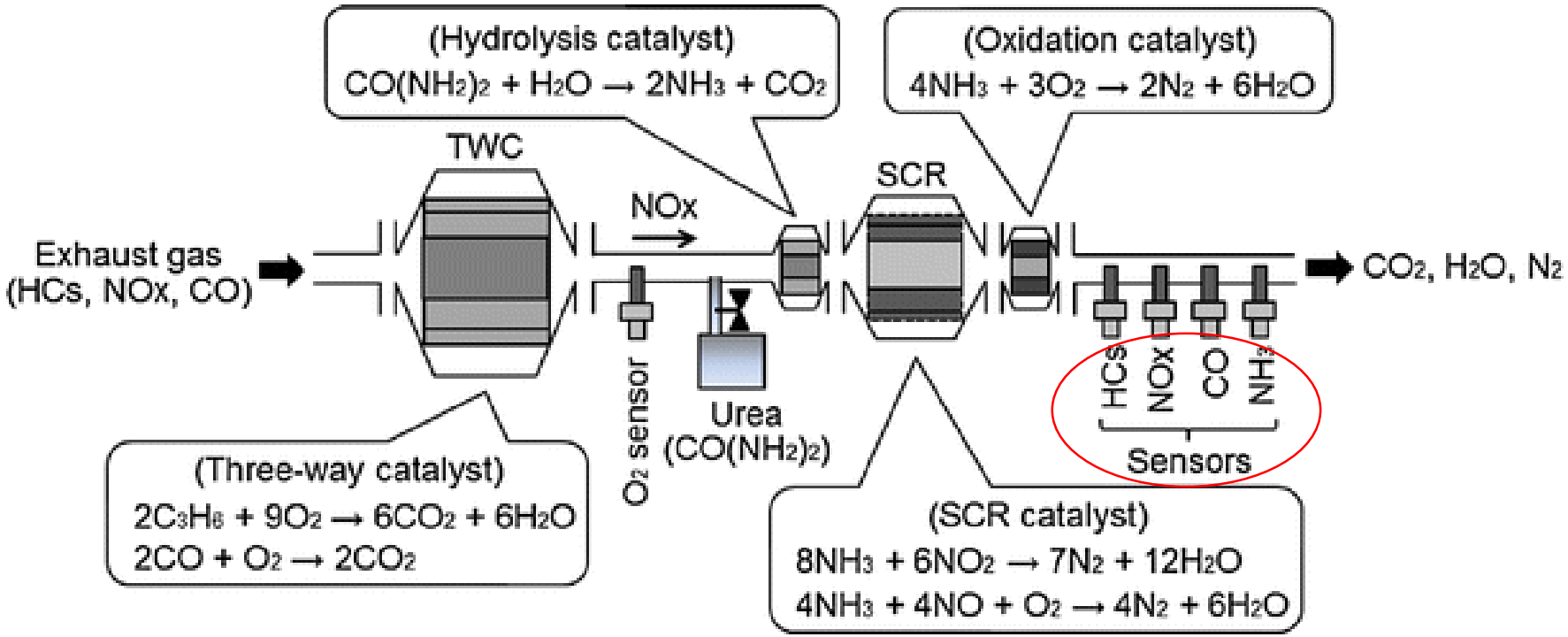
Environmental air quality
Indoor air quality
Medical
Automotive
Fire detection
Industrial, Military, Hobby……..

✓ Many $$$

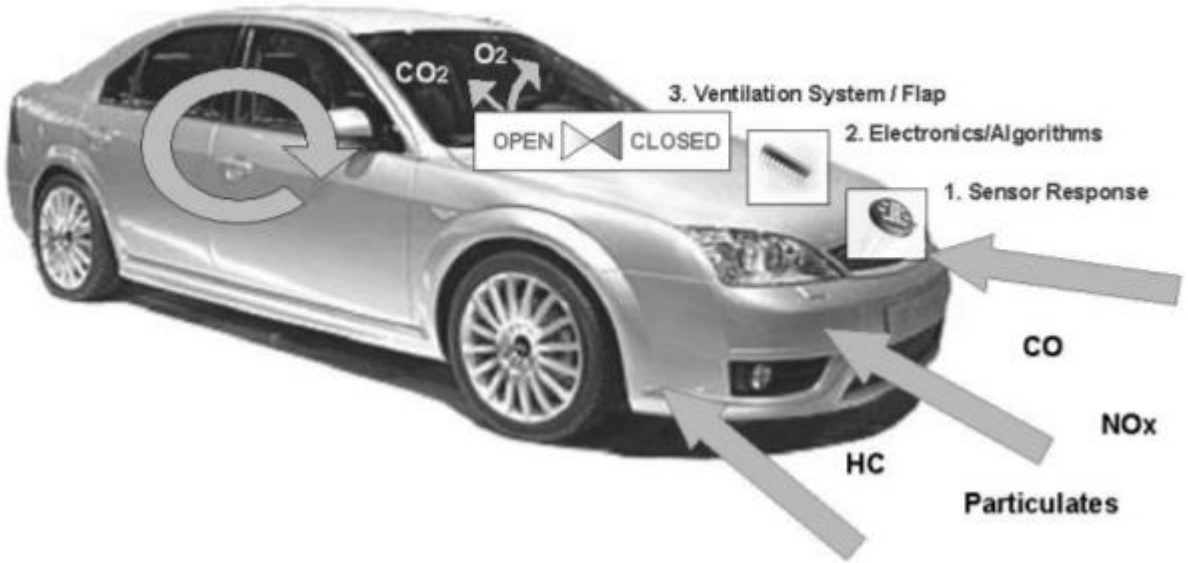
$1.2B SAM

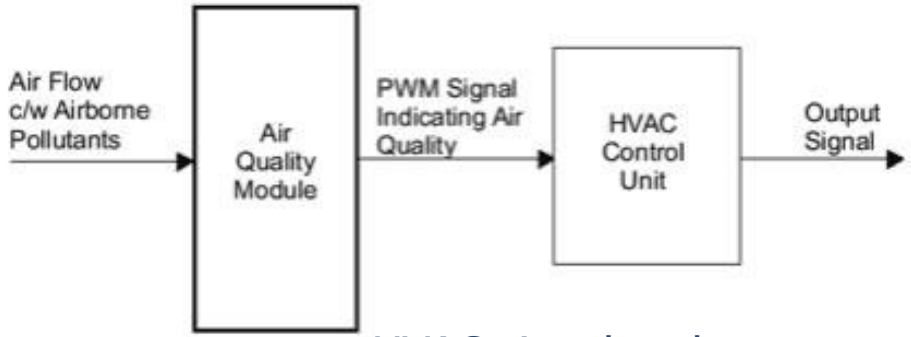
Gas Sensing in Automobiles

Exhaust gas sensing and ignition control are the most common applications



Automotive AQM

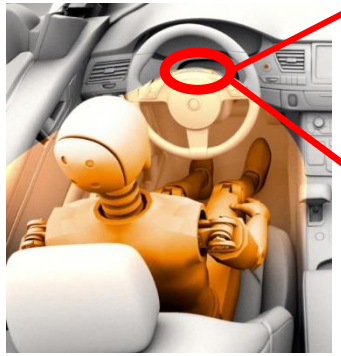


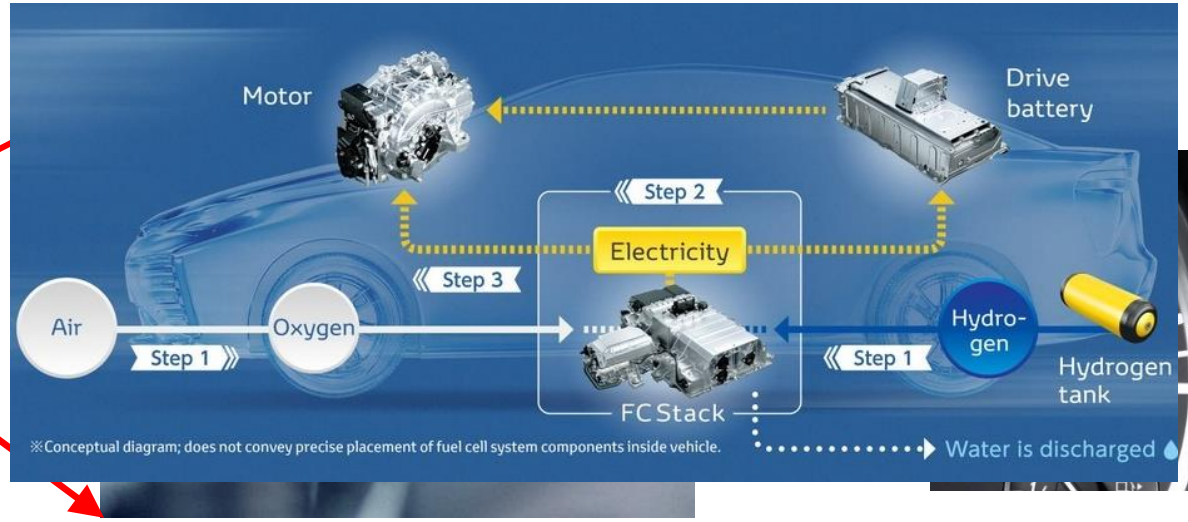


HVAC signal path

Gas Modules	*Range*	*Minimum Detection Limit*
Ozone O_3 (GSS)	0-0.15 ppm	0.001 ppm
Ozone O_3 (GSS)	0-0.5 ppm	0.001 ppm
Nitrogen Dioxide NO_2 (GSS)	0-0.2 ppm	0.001 ppm
Nitrogen Oxides NO_x (GSS)	0-0.5 ppm	0.001 ppm
Carbon Monoxide CO (GSE)	0-25 ppm	<0.04 ppm
Carbon Dioxide CO_2 (NDIR)	0-2000 ppm	<10 ppm
Hydrogen Sulphide H_2S (GSE)	0-10 ppm	<0.03 ppm
Sulphur Dioxide SO_2 (GSE)	0-10 ppm	<0.03 ppm
Volatile Organic Compounds (PID)	0-20 ppm	0.01 ppm
Non-methane Hydrocarbon (GSS)	0-25 ppm	<0.1 ppm
Volatile Organic Compounds (GSS)	0-25 ppm	<0.1 ppm
Particle Monitor (nephelometer)	*Sizes* PM_1 $PM_{2.5}$ *or* PM_{10}	*Range* 0-2000 $\mu g/m^3$
Particle Profiler (OPC)	*Sizes* PM_1 $PM_{2.5}$ *and* PM_{10}	*Range* 0-500 $\mu g/m^3$

Emerging Gas Sensing Needs in Automobiles





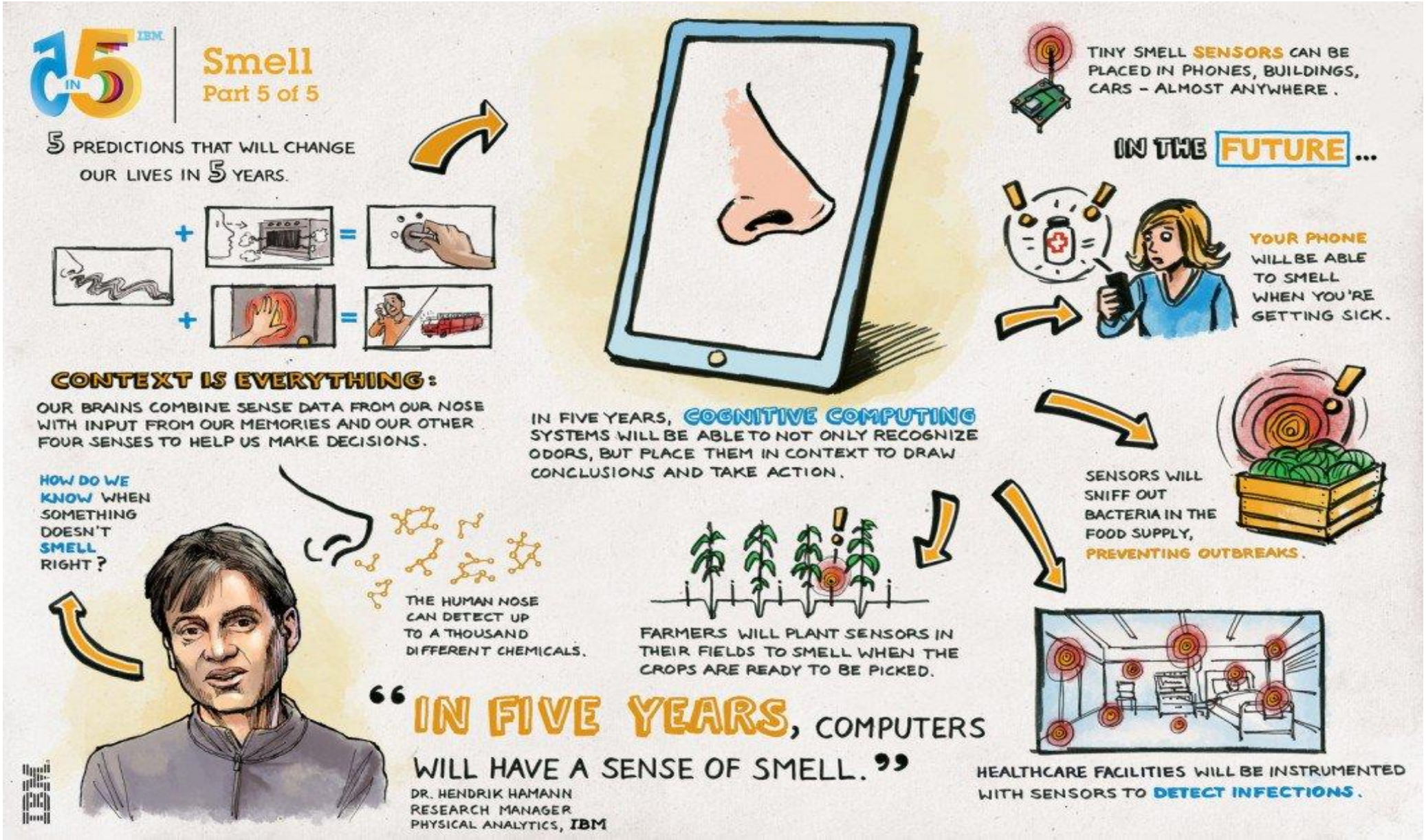
Passive Drunk Driver Detection

Drowsiness Detection / IAQ

dadss
Driver Alcohol Detection System for Safety

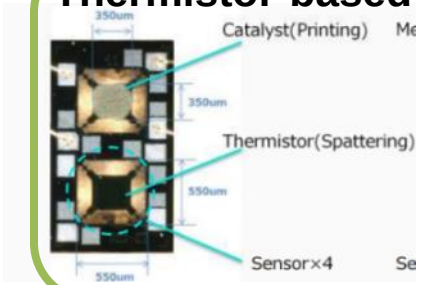
UBER

Summary: Gas Sensing Will be Ubiquitous



TDK: Expertise in Gas Sensing Materials, Electronics, and Algorithms

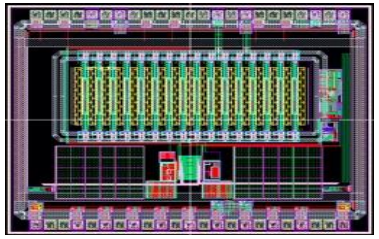
Thermistor-based Platform for CO/CO_2



Heater with TDK unique material

- Significantly smaller and lower power than competition
  - 1.8 mm^2 die, 0.2mW (prototype)
- Sensitivity: CO: ±20ppm, CO_2: ±200 ppm
- Fast response time

MOx Multipixel Platform for VOC's



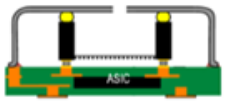
16 Pixel array

- 16 independently addressable pixels
- Nanoparticle ink Formulas
- Full function ASIC: 4mm x 1 mm
- Machine learning Algos -- improved selectivity
- VOC sensor in development

Wide Array of P, T, H Sensors

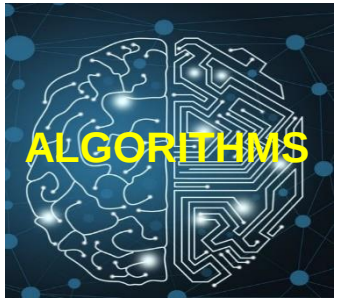
- Integrated PTH
- Stand alone P, T
- High volume, low cost
- Automotive grade

Advanced Packaging



TDK Packaging

- High Vol mic and press. products similar to gas
- Low cost
- SESUB



TDK's solutions are unique and agnostic to end platforms!

Thank You!